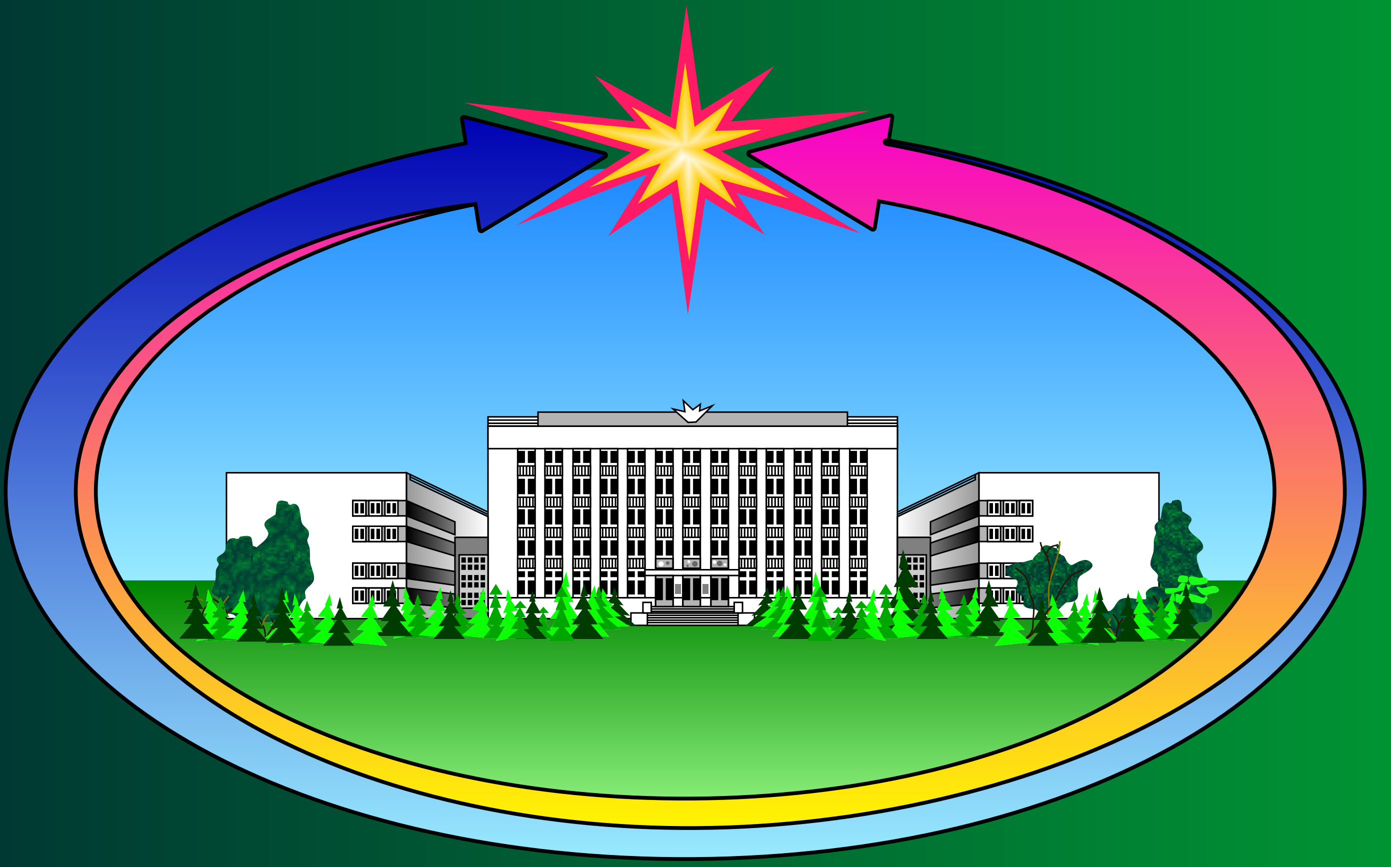
Russian Academy of Sciences
Lenin Order Siberian Branch

BUDKER INSTITUTE OF NUCLEAR PHYSICS



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Introduction

The Institute of Nuclear Physics SB RAS was founded in May, 1958 in accordance with the resolution of the USSR Council of Ministers on the basis of the Laboratory of New Methods of Acceleration (headed by G.I.Budker) of the Institute of Atomic Energy headed by I.V.Kurchatov.

Since 1977, the Director of the Institute is academician A.N.Skrinsky.

At present, BINP SB RAS is the largest academic institute of the country (about 2700 employees). The research staff of the Institute (407 scientific researchers) comprises 10 academicians and corresponding members of the Russian Academy of Sciences, 56 Doctors of science and 156 Candidates of science. A large Experimental Workshop (about 1000 employees) with a high level of technical and technological equipment is a characteristic feature of BINP.

The Institute carries out an active work on training of highly-skilled scientific, technical and engineering personnel. BINP is a head institute for seven sub-departments of the Physics department of Novosibirsk State University (NSU) and Department of Applied Physics of Novosibirsk State Technical University (NSTU) with a total number of about 200 students. About 40 students receive postgraduate training at BINP, NSU and NSTU.

The Institute is one of the world leading centers in several important fields of the high energy and accelerator physics, physics of plasma and controlled thermonuclear fusion. Large-scale experiments in elementary-particle physics at the electron-positron colliders and a unique complex of open plasma traps are carried out at BINP; modern accelerators, intensive sources of a synchrotron radiation and free electron lasers are developed at the Institute. In the majority of its research fields, the Institute is unique in Russia.

The BINP main achievements in the science and technology are the following:

In the field of elementary particles and nuclear physics:

- pioneering works on the development of the colliding beam technique, which at present, is the main method in high energy physics:
  - □ first experiments with electron-electron interactions, simultaneously with Princeton -Stanford works, (1965),
  - □ the world's first experiments with the electron-positron interactions, (1967),
  - □ the world's first observation of the double bremmstrahlung process , (1967),
  - □ pioneering works on two-photon physics, (1970);
- a study of characteristics of the vector mesons at the VEPP-2, VEPP-2M and VEPP-4 electron-positron colliders, (since 1967);
- discovery of a multiple production of hadrons in the electron-positron annihilation, (1970);
- precise measurement of the contribution of vacuum hadron polarization into the value of the muon anomalous magnetic momentum for one of the most sensitive tests of the Standard model, which was carried out jointly with the Brookhaven National Laboratory, (1984 - 2005);
- development of the resonance depolarization technique for the precise measurement of the elementary particle masses, achievement of the record value of the mass measurement accuracy for *k-, p-, ω-,Φ -, ψ-* mesons and γ- mesons, (1975-2004);
- discovery of the parity violation effects in the atomic transitions; corroboration of the

unified theory of electroweak interaction, (1978);

• development of the experimental technique with the internal super thin targets at the storage rings (since 1967) and a study of the electromagnetic structure of a deuteron in polarization experiments (since 1984);

• development of the technique for producing intense fluxes of the high energy tagged gamma-quanta based on the use of the Compton backscattering (1980-1982); experimental observation of the photon splitting in the nucleus Coulomb field , (1997);

• development of new techniques for detecting high-energy charged and neutral particles and of unique detectors for colliders (OLYA, KMD-1, MD-1, KMD-2, ND, SND, KEDR), (since 1974);

• development of x-ray detectors for medical purposes and production of the x-ray detector-based Low Dose Digital Radiographic Device with a super low dose of the patient's irradiation for people screening "SibScan" (since 1981).

In the field of theoretical physics:

• development of the resonant theory of dynamic chaos and pseudochaos in classic and quantum mechanics (since 1959);

• first calculation of a charge renormalization in the Yang-Mills theory, (1969);

• development of the QCD sum rule technique (1979 - 1984);

• prediction of a large magnification of the parity violation effects in neutron resonances of heavy nuclei (1980 - 1985);

• construction of a theory of hard exclusive reactions in QCD (1977 -1984);

• development of an operator approach to the quantum electrodynamics in external fields (1974 - 1976);

• development of the quantum electrodynamics in periodical structures including that in a laser wave (1972 - 1997);

• development of a theory of radiation effects for high energy charged particles and photons passing through the oriented monocrystals (since 1978);

• derivation of the evolution equation in QCD for the parton energy distribution (BFKL-equation)(1975 - 1997);

• perediction of the coherency effect at the gluon irradiation in QCD and a study of its influence on hadron distributions (1981 - 1982).

In the field of accelerator physics and technology:

• a successful long-term experience in the work on the development of storage rings and colliders;

• the invention, development and experimental realization of the "electron cooling" technique for heavy particle beams (1965-1990), which is presently used in high energy physics laboratories all over the world; supply by the efficient "coolers" of heavy ion storage rings in Germany, China, and CERN (1965- 2005),

• invention and development of new types of RF powerful generators (Gyrocon, relativistic klystron, and Magnicon) (since 1967);

• proposal of the linear electron-positron colliding beam method aimed at attaining super high energies (1968), presentation of the physically elaborated project (1978);

• development of the strong-field magnetic optics components (X-lenses, lithium lenses), which are presently used in various laboratories (since 1962);

• invention and experimental test of the charge-exchange injection method that is presently used at all large proton accelerators,(1960-1964);

• theoretical and experimental studies on obtaining the polarized beams and spin dynamics in the storage rings and colliders; the conceptual development and creation of highly efficient spin rotators and “Siberian snakes” for a number of accelerator complexes, (1966 - 1995);

• theoretical and experimental studies of the stochastic instability and “collision effects” limiting the collider luminosity (since 1966);

• development of the physical concept of the new generation of electron-positron colliders with a very high luminosity, the so-called electron-positron factories (since 1987);

• the proposal and development of the method of ionization-cooling of muons for creation of the muon colliders and neutrino factories, (1969 -1981 - 2002);

• development and creation of the low-energy powerful electron accelerators for various technological applications including environment protection, such as ELV-12 with 500 kW power and 1 MeV energy and ILU-10 with the power of up to 50 kW and the energy of 5 MeV (since 1963);

• proposal and realization of the accelerator-recuperator scheme for the free electron lasers of high efficiency - (1979 - 2003).

In the field of plasma physics and thermonuclear fusion:

• invention (1954) and implementation (1959) of a “classic” open magnetic trap (magnetic mirror) for hot plasma confinement;

• invention and development of new schemes of open traps: a multimirror, rotating-plasma, ambipolar, gasdynamic traps; experimental realization of the multimirror confinement of plasma with sub-thermonuclear parameters at the GOL-3 trap; experimental realization of stabilization of MHD instabilities in the axially-symmetric gasdynamic trap at the GDT facility (since 1971);

• discovery of the collisionless shock waves in plasma, (1961);

• development of a plasma heating technique by relativistic electron beams , (since 1971);

• development of the high-intensity surface-plasma sources of negative ions, which are now widely spread in the world, (1969 - 1981);

• proposal and development of the concept of a powerful thermonuclear source of neutrons for the material science on the basis of the open trap (since 1987);

• theoretical prediction of the Langmuir collapse (1972), experimental discovery of the strong Langmuir turbulence and Langmuir wave collapse in the magnetic field, (1989 - 1997);

• development of a series of the unique precise powerful sources of hydrogen atoms for a study of a high-temperature plasma for a number of large facilities, (since 1997).

In the field of synchrotron radiation and free electron lasers:

• the use of synchrotron radiation of the BINP storage rings for various scientific and technological purposes and creation of the Siberian Center of Synchrotron Radiation on the basis of the VEPP-2M, VEPP-3, VEPP-4 storage rings (since 1973);

• theoretical and experimental studies of particle radiation in periodic structures (undulators, wigglers, crystals), since 1972;

• development and construction of the dedicated SR sources, (since 1983);

• development and construction of the one- and two-coordinate detectors for experiments with synchrotron radiation, (since 1975);

• invention and development of the optical klystron (1977), obtainment of radiation generation ranging from the infrared to ultraviolet spectrum (since 1980);

• development and construction of a powerful free electron laser (for the photochemical studies, technological purposes and energy transfer from the Earth to a satellite) on the basis of the most promising scheme using the microtron-recuperator; obtainment of a powerful (400 W) laser radiation in the terahertz range, (since 1987);

• development of a series of superconducting magnetic devices with strong fields for the SR sources and electron storage rings (wigglers and bending magnets with a field of up to 10 T, solenoids with a field of up to 13 T), since 1996.

The Institute's unique installations and equipment provide a basis of an infrastructure for a wide spectrum of the interdisciplinary scientific and scientific-technological research performed in four Centers established at the Institute: the Siberian Center of Synchrotron Radiation, the Center of Photochemical Research, the Center of Cenozoic geochronology, the Center of electron-beam technologies. Annually, hundreds of organizations make use of the possibilities of the Centers.

BINP SB RAS applied works are entirely based on the results of the fundamental studies of the Institute and are focused on the following main areas:

- Industrial high-power electron accelerators used for modification of polymers, industrial and domestic waste treatment, production of fine-metal nanopowders, silica, oxides, carbides and nitrides of metals, radiation treatment of foodstuffs, sterilization of medical equipment, disposable tools and clothes, and for other technological applications.
- Low-dose digital radiographic devices of a scanning type with a super low dose of the patient's irradiation for medicine and security systems.
- Development of nuclear medicine installations for proton, ion and boron-neutron capture therapy of malignant neoplasms.
- Installations for electron-beam welding.
- Dedicated radiographical equipment.

During last 20 years, BINP SB RAS actively used possibilities of financing the fundamental and applied works at the expense of the funds gained from execution of contracts. BINP develops, manufactures and delivers a wide spectrum of science-based and high-technology products to the customers in the countries of Europe, Asia, North and South America (more than 20 countries), and Russia, totally, for more than half-billion roubles annually. With the use of these funds, the VEPP-4 accelerating complex with the unique detector KEDR was completed and put into operation, new large modern unique installations - the VEPP-2000 electron-positron collider, the free-electron laser, a new injection complex for maintenance of the existing and future BINP installations - were developed and built. During entire post-soviet period, a continuous work of the BINP installations and the corresponding infrastructure was supported with these funds.

BINP is notable for a wide long-term international collaboration with the majority of the large foreign and international centers. A vivid example of such collaboration is participation of BINP in the largest modern international project– the creation of the Large Hadron Collider in the European Center of Nuclear Research (CERN, Geneva). Within this cooperation, BINP has developed, manufactured and delivered to CERN the unique hi-tech equipment worth more than 100 million Swiss francs. Besides, participation in the projects of B-factories in the USA and Japan, in the implementation of large European projects such as the synchrotron radiation source PETRA-III and the X-ray free-electron laser (DESY, Hamburg), the heavy-ion acceleration complex (GSI, Darmstadt) and a number of others can be noted among the examples of international collaboration.

BINP plays a key role in a number of large Russian projects, such as: the Synchrotron Radiation Center in SRC "Kurchatov Institute", the Synchrotron Radiation Source TSC in Zelenograd, the neutron source for JINR in Dubna, the dedicated radiographic equipment for Federal State Unitary Enterprise "RFNC-VNIITF" in Snezhinsk.

The Institute takes an active part in formation of an innovative national economy. One of vivid examples of this process is a co-development with ICG SB RAS and Joint-Stock Company "Siberian centre of pharmacology and biotechnology" of the unique technique of electron beam immobilization of biomolecules on the inert support, which is used for a batch production of the first-ever peroral thrombolytic "Trombovazim".

The Institute is deeply integrated into the works of the Russian Academy of Sciences and the Siberian Branch of the Russian Academy of Sciences, carrying out 20 projects under the programs of the Presidium and the branches of the Russian Academy of Sciences, 16 interdisciplinary integration projects and 8 joint projects of SB RAS with the institutes of regional branches of the Russian Academy of Sciences, national academies of sciences of Ukraine, Belarus and the RPC, two projects of SB RAS – as the co-executor; five state contracts under FTP "Research and design in the priority areas of the development of Russian scientific-technological complex for 2007 - 2012" (unique stands and installations, the centers of collective using); 12 state contracts under FCP "Scientific and scientific-pedagogical personal of innovative Russia" for 2009 - 2013; fifty projects of the Russian Foundation for Basic Research.

Annually the Institute's scientists represent about 200 reports at international and Russian conferences, publish about 500 papers in leading Russian and foreign scientific magazines, issue monographs and tutorials. According to the data published in the review "Bibliometric parameters of Russian science and Russian Academy of Sciences" (the RAS Bulletin, June, 2009, vol. 79, № 6), the quantity of references to the BINP works for 1997-2007, taken into account in authoritative international database ESI, is 28267. According to the review data, this value is the maximum result among all institutes of Russian Academy of Sciences. Four scientists of the Institute became prize-winners of the special prize of Elsevier publishing house as the most quoted authors in the post-Soviet area in the field of natural sciences.

The best works of 2009 recognized by the BINP Scientific Council are as follows:

In the field of **an elementary-particle physics and fundamental interactions:**

1. The measurement of the product of electron width of J/ψ-meson by the relative probability of its decay to the electron-positron pair and muon pair in the experiment with the KEDR detector at VEPP-4M with the best world's accuracy:

$$\Gamma_{ee} * B(J/\psi \rightarrow e+e-) = (0.3323 \pm 0.0064 \pm 0.0048) \text{ keV } (2,4\%)$$
$$\Gamma_{ee} * B(J/\psi \rightarrow \mu+\mu-) = (0.3318 \pm 0.0052 \pm 0.0063) \text{ keV } (2,4\ \%)$$

2. The measurement of cross-section of the process: $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$ in the range of energy from 0.75-1.0 GeV (at energy 2E <0.92 GeV – for the first time) in the experiment with the SND detector at VEPP-2M. A rare decay $\rho^0 \rightarrow \pi^+\pi^-\pi^0\pi^0$ having relative probability 1.6×10^{-5} is discovered.

3. The measurement of neutral D-meson mass: M_{D0} = (1865.30 ± 0.33 ± 0.23) MeV in the experiment with the KEDR detector at VEPP-4M. The result obtained has a measurement accuracy comparable with the average world accuracy.

4. The calculation of Coulomb corrections for the process of production of electron-positron pairs at collision of relativistic nuclei in the approximation next after the main one on parameter $L = \ln \gamma_A\gamma_B$. Considerable suppression of the pairs production due to the contribution to events cross-section, when pairs are produced with the energy of a few electron masses in the rest frame of one of the nuclei is discovered. The gained results provide a natural explanation of the experimental results obtained in CERN at SPS accelerator.

5. The precise measurement of cross-section of the process $e^+e^- \rightarrow \mu^+\mu^-$ in the energy range from 1.04-1.38 GeV in the experiment with the SND detector at VEPP-2M. For the first time, for this energy, the value of fine structure constant is determined experimentally: $1/\alpha(s)=134.1\pm1.3$, confirming the growth of constant α (s) in the Standard model in the given energy range.

In the field of **plasma physics:**

6. The experiments at the GOL-3 multimirror trap have shown that at plasma heating by a powerful relativistic electron beam with the diameter reduced from 4 down to 1 cm, the efficiency of beam collective relaxation in plasma reaches the value of ~50 %. In beam cross-section plasma warms up to subthermonuclear temperatures at conservation of energy confinement time; substantial increase of plasma transverse losses is not observed. The given result is important for the choice of the parameters of a multimirror thermonuclear reactor.

In the field of **physics and technique of charged-particle accelerators, SR sources and FEL:**

7. Creation of high-voltage electron cooling system at 400 MeV/nucleon energy for Institute of Modern Physics in Lanzhou (China).

8. Joint creation, together with EB-TECH (South Korea), of the unique mobile electron accelerator on the basis of ELV accelerator intended for the solution of operative ecological problems. Successful tests of the accelerator have been performed in South Korea.

9. Creation of the wiggler system for PETRA III SR source in the DESY laboratory (Hamburg), which allowed obtainment of a record phase volume of a beam with 1 nm-rad emittance.

10. Development, manufacturing and successful introduction of modern domestic power-generating units for electron-beam welding installations at the leading enterprises of defence complex of Russia.

11. The obtainment of induced radiation generation mode at the second stage of Novosibirsk Free Electron Laser (FEL). The average radiation power (0,5 kW) of Novosibirsk FEL is ten times higher than that of all other sources of a coherent radiation in their ranges of wavelengths (40 – 80 and 110 – 240 microns).

Six BINP scientific teams headed by academicians Skrinsky, Barkov, Kruglyakov and Kulipanov, the corresponding member of the Russian Academy of Sciences Dikansky and professor Onuchin have the status of leading scientific schools awarded by the Grant Council under the President of the Russian Federation. Four teams of young scientists of the Institute are prize-winners of the Council as young Doctors and young Candidates of sciences.

Three young scientists of the Institute became prize-winners of the personal prize and the grant of the Administration of Novosibirsk region for young scientists for scientific achievements in the field of fundamental and applied research. Five young scientists of the Institute became prize-winners of the sixth All-Russian competition of youth research projects in the field of energetics «Youth Energy-2009», medals of Russian Academy of Sciences for young scientists in the competition of 2009 in the field of nuclear physics are awarded to three scientific researchers of the Institute .

In 2009 three Councils with the right of accepting Doctor and Candidate theses continued their work at the Institute. 3 Doctor and 9 Candidate theses were defended at 12 sessions .

55 excursions at the BINP installations with the total number of visitors – 1306 have been organized for schoolchildren, students, teachers of schools and high schools, employees of other organizations and visitors of the Institute; 9 lectures have been read in Novosibirsk schools.

1

PHYSICS
OF
ELEMENTARY PARTICLES

1.1 CMD-3 Detector

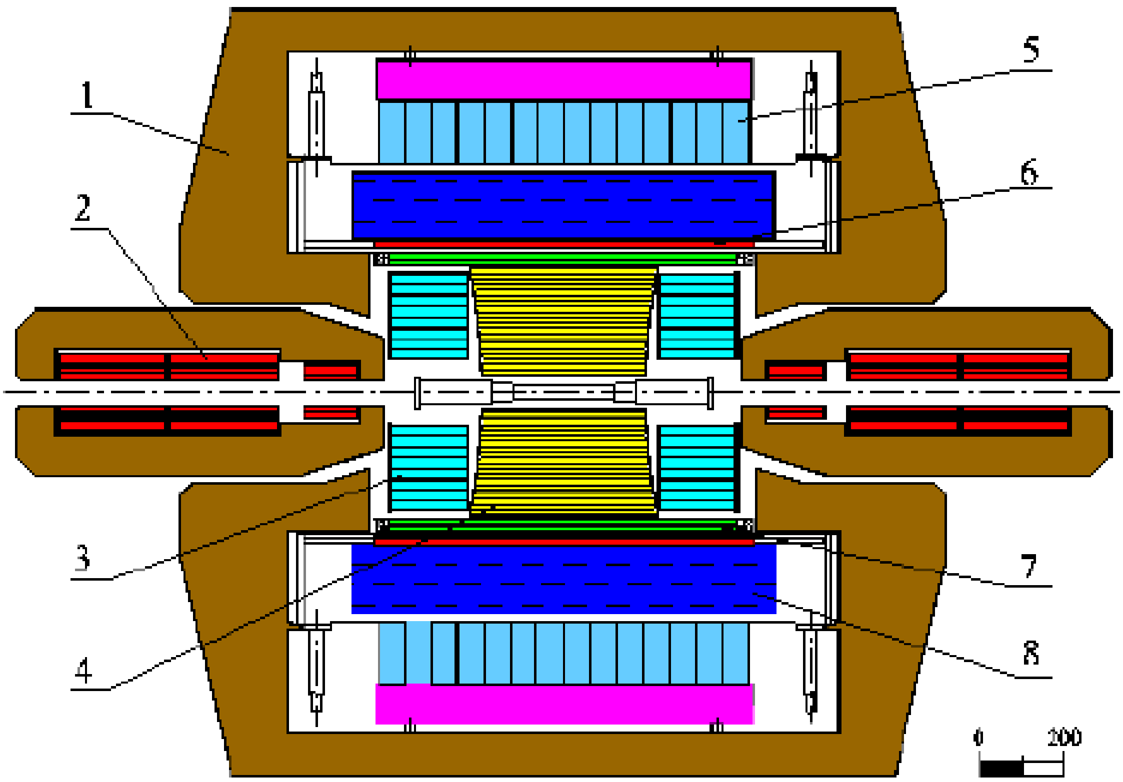


Fig. 1: CMD-3 Detector. 1 — magnet yoke; 2 — VEPP-2000 superconducting solenoids; 3 — endcap BGO electromagnetic calorimeter; 4 — drift chamber; 5 — barrel CsI electromagnetic calorimeter; 6 — CMD-3 superconducting solenoid; 7 — Z-chamber; 8 — barrel LXe electromagnetic calorimeter.

Schematic longitudinal cross section of the CMD-3 detector is shown in Figure 1.

Main areas of work in 2009 were assemblage of the detector systems in the VEPP-2000 storage ring hall and testing of their operation with cosmic-ray particles.

After setting the magnetic field operating value of 1.35 T in the superconducting solenoid, measurements of its homogeneity in the volume occupied by the drift chamber were carried out. The time of powering the solenoid with an operating current does not exceed 10 hours, and the consumption of liquid helium in a stable mode is 4 liters per an hour. In April-May the drift chamber was installed into the detector, the system forming its gas mix was put into operation, digitizing electronics and system of a high-voltage feed system were installed. Simultaneously with the drift chamber, the Z-chamber intended for formation of the trigger and for precise measurement of the coordinates of charged particles tracks along the beam axis was installed into the detector. To this period, the basic work on development and manufacturing of electronics components, which provide the production of trigger signals at registration of charged particles has been finished.

Timely completion of this complex of works allowed carrying out a total complex testing of a coordinate section of the detector with cosmic-ray particles, during which the resolutions of certain systems corresponding the design parameters and stand testing were obtained. After these tests the vacuum section made of a 0.5-mm thick aluminium was installed and the focusing solenoids of the storage ring were moved; this, ultimately, has allowed the installation of the detector on the VEPP-2000 storage ring. After this, blocks of crystals of the endcap calorimeter and endcap iron of the magnet yoke have been installed at the detector.

The data acquisition software, processing and simulation system was substantially developed. The procedures of event construction reading the information out of the new electronics devices and the crates of the KLYUKVA standard (Z-chamber and strip LXe calorimeter) are written and tested. Work on writing the set of programs of events visualization and the experiment status including the information from VEPP and certain systems of the detector for controlling of the quality of the recorded information is being finished.

At the same time, there is still a considerable amount of works on the completion of tuning and installation of certain components of electronics, on the development of the experiment software and upgrading of the computing and network equipment, which provides the reliability of the detector operation and timely data analysis.

Besides, in 2009, the analysis of the experiment with the CMD-2 detector on measuring φ(1020) meson lepton width at the joint analysis of four basic channels of decay of this particle was carried out. The following value of Γ_{ee} was obtained:

$\Gamma_{ee} = (1.233 \pm 0.004 \pm 0.019)$ keV

The obtained measurement is the most precise up-to-date measurement. Publication based on the results of this work is being prepared.

1.2 The SND detector

1.2.1 SND upgrade for experiments at VEPP-2000 and results of the first experiments

At December 15, 2008 SND tracking sistem was installed at the VEPP-2000 interaction interval. In January - February 2009 the tracking system was connected to the recording electronics. In March - April 2009, a series of test runs were performed with the SND detector at VEPP-2000 collider in the φ-meson resonance region (Fig. 1).

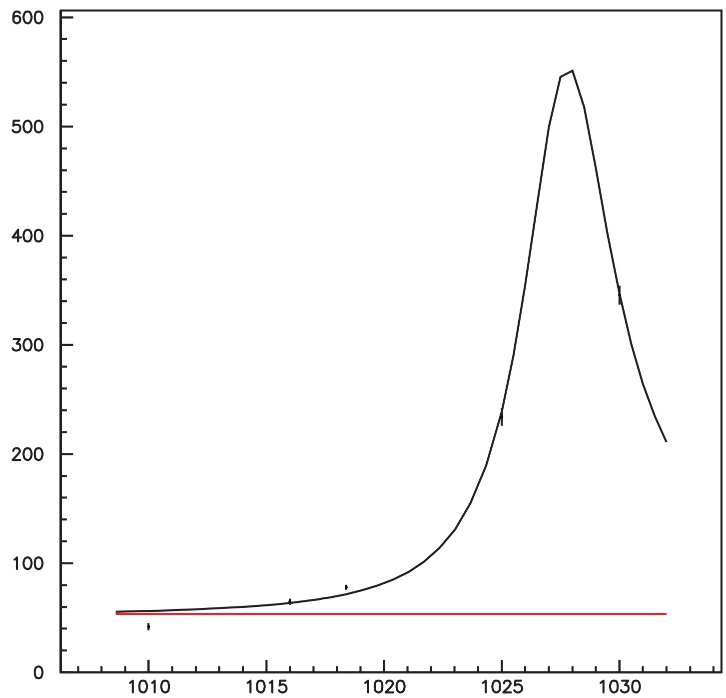


Fig. 1: The dependence of the visible cross section of hadron production on the beam energy.

In total, approximately one million events were recorded. In general, when dealing with beams of VEPP-2000, the tracking system showed a satisfactory perfomance.

In April-June and October-December, experiments were conducted on registration of cosmic ray particles in order to test electronics channels of the tracking system. The triggering scheme used with the coincidence of signals from the aerogel counters, the tracking system and the muon system, with a time resolution of the triggering signal $\sigma_t \approx 2$ ns, made it possible to calibrate the dependence of the coordinates in the r-φ plane on the drift time and define the coordinate resolution of the tracking system $\sigma(r\text{-}\varphi)$, which turned out to be 80 microns at the minimum.

In 2009, a program of generator calibration also has been developed for the drift chamber (DC) cathode strips electronics, displacements of the ends of the DC wires along the z axis were measured, a comparison of the simulated energy deposition in the drift chamber with the experimental data was performed using events of the elastic e^+e^- scattering. The simulation takes into account fluctuations of primary ionization, the drift of the ionization and its diffusion during the drifting, gas amplification and the response of the electronics. The experimental spectra are consistent with the simulated ones.

In the spring of 2009, the aerogel Cherenkov counters system with the refractive index n=1.13 was installed at the SND detector. The efficiency of the system was tested using events with the cosmic ray particles. For this goal, experimental runs were conducted with recording of events taking place only under simultaneous triggering of aerogel, tracking and muon systems. Recorded events were used as for calibration of the tracking system in the r-φ projection, as for study of the response of the aerogel counter. For this latter goal, particles were selected using the tracking system which should fire the aerogel counter. Preliminary results on the time resolution of the counter is shown in Fig. 2. The figure shows the difference between the firing times of the second and seventh counters of the system.

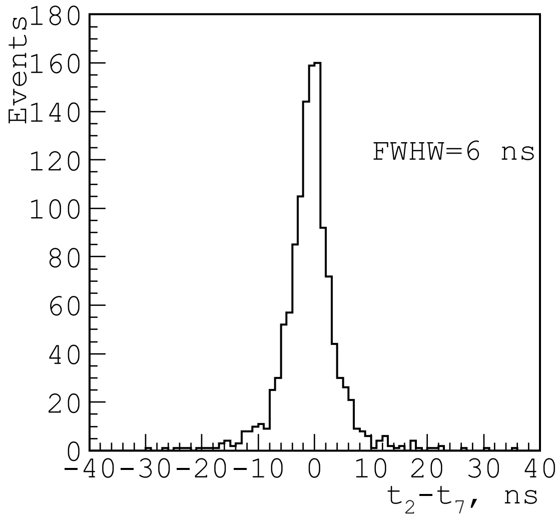


Fig. 2: Time resolution of the SND aerogel counter.

At present, 98% counters of the SND calorimeter are working efficiently. The calorimeter was calibrated by using cosmic muons. Comparison of the calibration results with the similar results in 1996 shows that the average signal in the first and second layers of the calorimeter has not changed, while in the third layer it has decreased approximately by 1.5 times. This change of the signal magnitude is related to the replacement of the photodetectors, vacuum phototriods (VPTs), in the third layer. New devices have a lower product of the quantum yield and the gain compared with the previous ones. On the other hand, the new VPTs do not show any significant decrease of signal over time, which for the old equipment was about 3% per month. The mean change of calibration coefficients for one month in all three layers was not more than 1%. Comparison of the spectra of energy deposition in the calorimeter by electrons and photons with an energy of about 500 MeV with the those obtained in 1996 have showed the stability of the calorimeter parameters.

Observed problems in the calorimeter are related to faulty vacuum phototriods, as well as to the breakdown of charge sensitive preamplifiers. Last complete maintenance of the calorimeter was performed in 2004. To perform full-fledged experiments, one should undertake the replacement of the defective VPTs and preamplifiers in every 2-3 years. The calorimeter electronics was designed and constructed almost 20 years ago. It is stil suitable for new experiments at VEPP-2000, but the element base is outdated and a replacement of faulty components is a time-consuming procedure.

Based on the many years experience with the calorimeter, proposals were formulated for the new electronics which are currently under development at the level of a prototype.

In 2009, the endcap part of the muon system was installed in the detector and connected to the electronics of the SND data acquisition system. Efficiency of the barrel part of the system was tested in experimental runs with cosmic ray particles and VEPP-2000 beams. At present, the endcap part checks are being performed using the nominal detector electronics and the standard software for data collection.

In preparation for the experiment to measure the neutron electromagnetic form factor, tests were performed of the 24-channel 12-bit flash-ADC developed by sector 3-12 staff members (headed by V.M.Aulchenko) for measuring the anti-neutron time-of-flight through the SND calorimeter. Currently, preparations are under way to measure the time resolution of the SND NaI(Tl) calorimeter scintillation counter with a new flash-ADC using cosmic muons.

An accuracy of the anti-neutron interactions simulation in GEANT4 has been investigated. It was established that the implicit annihilation cross section of antineutrons in GEANT4 was significantly overestimated compared with the existing experimental data. The necessary corrections were made in the total annihilation cross section in the simulation program.

Electronics of all subsystems of the SND detector are equipped and ready to use. A gradual modernization of the outdated equipment is under way. In 2009, the preamplifiers of the tracking system were replaced.

In 2009, work was continued on the development of the Data Acquisition System (DAS) software of the SND detector.

- Readout of the new detector subsystems using TP electronic plates was realized (scintillation counters of the muon system and the Cherenkov counters of the aerogel system), Yes/No register readout was realized for the external system.
- A new version of the T2A project with suppression of the not fired channels came into operation.
- PA24 electronic plates calibration was added at the begining of the data collection.
- Storage of the counting-rates of scalers into the files was implemented, a database store was organized for them.
- Work was done to integrate into the DAS software the loading of the first-level trigger configuration files.
- The development of the human-machine interface of the DAS was continued.
- Full-fledged integral test of the DAS was performed during the month of test runs at VEPP-2000.
- Possible causes of readout failures at high loads of the electronics were identified and workarounds were found to confront them.

The results of the test and operational runs were used to fix various errors in DAS and improve the efficiency of the system.

Progress in the field of the «offline» software includes:

- Optimized algorithm for discarding the false hits in the reconstruction of tracks in the drift chamber.
- Implemented integration of elements of the detector into the object «particle». The algorithm is realized, the object is refined, interface with the task is realized.
- Realized algorithm for the drift chamber time calibration which takes into account drift time dependence on the flight-angle of the particle.
- A number of critical changes in the SUMO environment (management of the processing modules), a new release of the SND software.
- Reconstruction system brought into the standardized form with basic blocking errors fixed.
- A realized generator ‘‘4π’’ based on the multihadron events generators package.
- An infrastructure for clustering algorithm for cathode strips hits.
- Work in progress on the modeling of the cathode strips.

1.2.2 VEPP-2M data analysis

Analysis was continued of the data of experiments conducted with the SND detector at VEPP-2M in the period from 1995 to 2000.

An article was published devoted to the study of the process $e^+e^- \to \mu^+\mu^-$ in the experiments with SND at VEPP-2M. Cross section of this process was measured in the energy range $\sqrt{s}$ =980, 1040 ÷ 1380 MeV. The event numbers of the process $e^+e^- \to \mu^+\mu^-$ were normalized to the integrated luminosity measured using $e^+e^-\to e^+e^-$ and $e^+e^-\to\gamma\gamma$ processes. The accuracy of the cross section measurement was 1.6% in the first case and 1.8% the second case. The ratio of the measured cross section to the theoretically predicted value is 1.006±0.007±0.016 and 1.005 ±0.007±0.018 in the first and second cases respectively. Using results of the measurements, the electromagnetic running coupling constant α in the energy region $\sqrt{s}$ = 1040÷1380 MeV was obtained $\langle 1/\alpha \rangle$ = 134.1 ±0.5 ±1.2 (Fig.3). In addition, the cross section of the process $e^+e^- \to e^+e^-$ was determined for scattering angles $30° < \theta_{e\pm} < 150°$ with the systematic error of 1.1%. At that the number of events of the process $e^+e^- \to e^+e^-$ were normalized to the number of events of the process $e^+e^- \to \gamma\gamma$. The ratio of the measured cross section to the theoretically calculated value is 0.999±0.002±0.011.

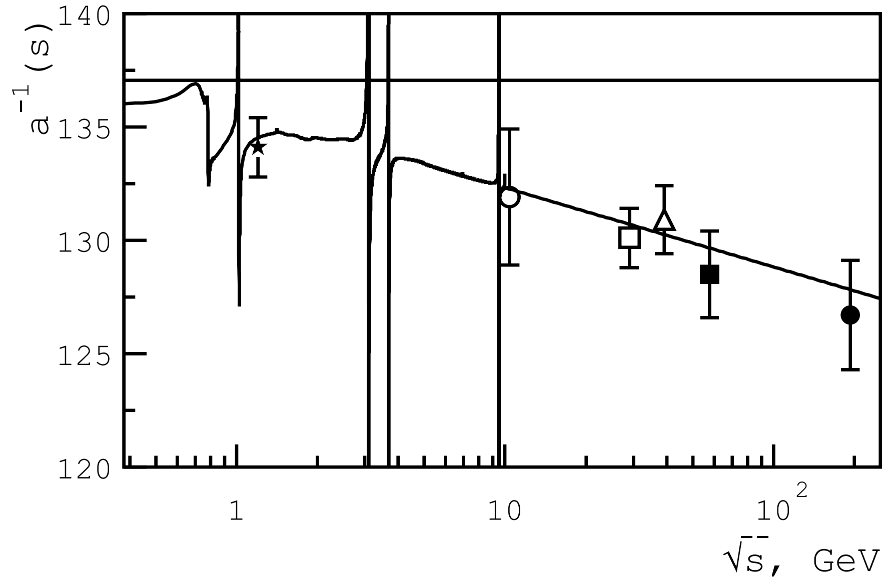


Fig. 3: The values of $\alpha(s)^{-1}$ obtained using results of various experiments. The following results are shown: SND (★), TOPAZ (■) and OPAL (●). Other points were calculated from the results of experiments performed at the colliders DORIS (○), PEP (□) and PETRA (△). The horizontal line shows the value of $1/\alpha^{(0)}$, the curve corresponds to the theoretical calculation of $\alpha(s)^{-1}$.

In the experiment with SND detector at VEPP-2M, the cross section of the process $e^+e^-\to \pi^+\pi^-\pi^0\pi^0$ was measured in the energy range up to 1 GeV (Fig. 4). In the energy ragion 920<$\sqrt{s}$<980MeV, the measurement has the best precision in the world. For energies $\sqrt{s}$ < 920 MeV, this cross section was measured for the first time. The probability of the decay $\rho \to \pi^+\pi^-\pi^0\pi^0$ was determined for the first time with the result $Br(\rho \to \pi^+\pi^-\pi^0\pi^0) = (1.60 \pm 0.74 \pm 0.18)\cdot 10^{-5}$. The upper limit on the decay $\omega \to \pi^+\pi^-\pi^0\pi^0$ was lowered by two orders of magnitude compared with the previous measurements. The new upper limit is $Br(\omega \to \pi^+\pi^-\pi^0\pi^0) < 2 \cdot 10^{-4}$ at the 90% level of confidence.

The paper has been submitted for publication devoted to the search of the process $e^+e^-\to K^+K^-\pi^0$ in the energy range from 1.2 to 1.38 GeV.

Analysis is near completion for the following processes: $e^+e^-\to e^+e^-\gamma\gamma$, $e^+e^-\to\eta\pi^+\pi^-(\eta\to 2\gamma)$, $e^+e^- \to K^\pm K_S\pi^\pm(K_S\to\pi^+\pi^-)$.

Work is continued on the analysis of the following processes:
$e^+e^-\to\pi^0\gamma$, $e^+e^-\to\pi^+\pi^-(2E > 1\ \text{GeV})$, $e^+e^-\to\pi^+\pi^-\pi^+\pi^-$, $e^+e^-\to\pi^+\pi^-\gamma$.

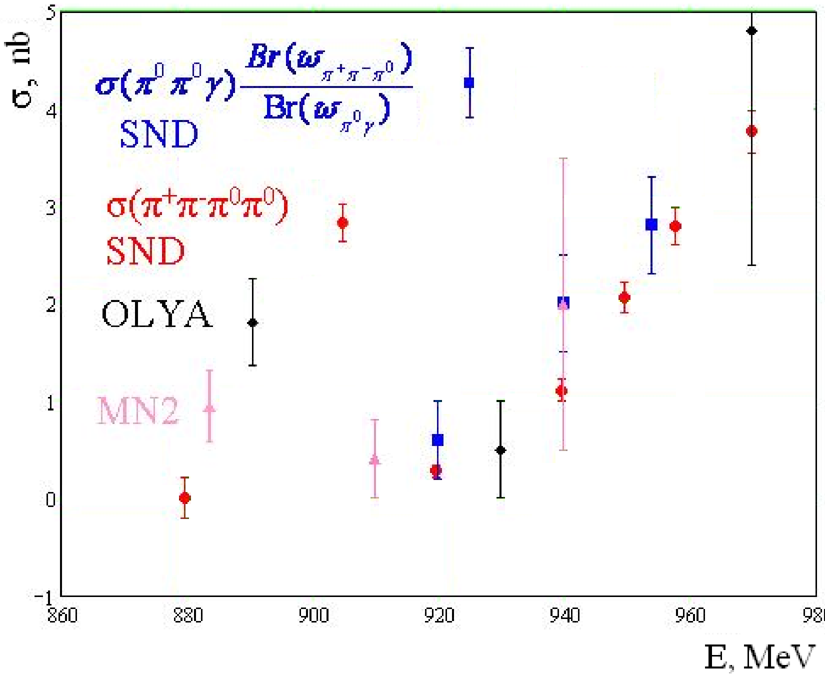


Fig. 4: The cross section of the reaction $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$, SND results - (●), MN2 - (△), OLYA - (♦),(■) - the cross section of the process $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ multiplied by the ratio of the relevant decay probabilities.

1.2.3 Participation in international projects

In 2009, the BABAR collaboration published and prepared for publication about 50 papers. With the direct participation of BINP physicists, data analysis was performed in three directions: measurement of the e^+e^- to hadrons cross sections by the radiative return method, the study of the two-photon physics with the registration of scattered electrons and the measurement of the CKM matrix element $|V_{ub}|$.

Using the technique of radiative return, in 2009 the cross section of the process $e^+e^- \to \pi^+\pi^-$ was measured for energies from the reaction threshold up to 3 GeV. Currently this is the most accurate and complete measurement of the e^+e^- annihilation cross section into two pions. The systematic error in the cross section determination in the ρ(770) resonance region is less than 0.5%. From these data, the contribution of the $e^+e^- \to \pi^+\pi^-$ process into the anomalous magnetic moment of the muon was calculated:

$\alpha_\mu^{\pi\pi} = (514.1 \pm 3.8) \times 10^{-10}$,

which has an accuracy comparable to the accuracy of the combined all previous data, obtained in e^+e^- collisions $(503.5 \pm 3.5) \times 10^{-10}$. The difference between these two values is about two standard deviations.

Results were published on the measurement of the transition form factor of the process $\gamma^* \to \gamma\pi^0$ in the region of squared transfered momentum Q^2 from 2 to 40 GeV^2. The form factor was measured in the two-photon reaction $e^+e^- \to e^+e^-\pi^0$ when one of the final electrons was scattered at the large angle. The results obtained were unexpected: for $Q^2 > 10$ GeV^2 the measured form factor exceeds the asymptotic limit, predicted in the framework of QCD. This result contradicted to the most theoretical models available at that time. The work rised a great interest among theoreticians. At present it already has 30 citations.

In 2009, the collaboration was continued between BINP and IHEP of the Chinese Academy of Sciences in the design and development of a energy calibration system based on the Compton backscattering for the Beijing c-τ factory (BEPC-II). In BINP, laser-to-vacuum insertion system was designed, manufactured and tested which ensures entering of the laser beam into the BEPC-II collider vacuum chamber. The energy measurement system includes two devices - one for the electron and the other for the positron rings. The device consists from a vacuum chamber with the window made from GaAs to enter the laser beam, and a mobile copper mirror, water cooled inside the chamber. Chambers were transported to Beijing and mounted at BEPC-II. The pressure of residual gas after chambers pumping was $1.3 \cdot 10^{-10}$ Torr.

The photon detector is made of high-purity germanium (HPGe). Tests and inspections of the HPGe detector were held at the BINP collider VEPP-4M. The beam energy was measured using Compton backscattering registered by the HPGe detector and also by the resonance depolarization method. The results coincided with an accuracy of $3 \cdot 10^{-3}$ %. After tests, the detector was delivered to IHEP. The system for collecting and processing data from the germanium detector was developed, debugged and tested. Thus, the creation of the energy calibration system is practically completed.

1.2.4 Developments in experimental methodics

In 2009, work was continued on the development of X-ray detectors. During the past year, two OD-3M detectors were build, tested and delivered to customers: Boreskov Institute of Catalysis SB RAS and Institute of Solid State Chemistry and Mechanochemistry SB RAS. Currently two new OD-3M detectors are under construction, as well as some elements are being prepaired for one more detector.

Given the experience of applying the method of Compton backscattering at the VEPP-4M collider and the creation of similar system for BEPC-II, a similar project was offered for VEPP-2000. The expected relative accuracy of the beam energy measurement in the project is less than 10^{-4}. Such precision is required for precision measurements of the e^+e^- annihilation cross section into hadrons. The photon-electron interaction region is proposed to place in a straight section with zero dispersion in which the VEPP-2000 resonator is situated.

The main advantage of the Compton backscattering method compaired to the others lies in the fact that the direct measurement of the beam energy takes place continuously during the data taking over the whole VEPP-2000 energy range, thereby providing the continuous control over the collider operation.

In 2009, the SND group published nine papers, two papers were presented at the international conference ``From φ to ψ'', held in October 2009 in Beijing (China), three were reported at the scientific session of the Nuclear Physics Division of Russian Academy of Sciences. The laboratory has five grants with the total amount of about 2.5 million rubles.

In the work participated:

G.N. Abramov, E.G. Avdeeva, P.M. Astigeevich, M.N. Achasov, V.M. Aulchenko, A.Yu. Barnyakov, K.I. Beloborodov, A.V. Berdyugin, V.E. Blinov, A.G. Bogdanchikov, A.A. Botov, D.A. Bukin, A.V. Vasiljev, V.M. Vesenev, E.P. Volkova, V.B. Golubev, T.V. Dimova, V.P. Druzhinin, L.V. Kardapoltsev, D.P. Kovrizhin, A.A. Korol, S.V. Koshuba, E.A. Kravchenko, A.Yu. Kulpin, K.A. Martin, A.E. Obrazovsky, A.P. Onuchin, E.V. Pakhtusova, V.M. Popov, S.I. Serednyakov, Z.K. Silagadze, A.A. Sirotkin, K.Yu. Skovpen, I.K. Surin, A.I. Tekutev, Yu.A. Tikhonov, Yu.V. Usov, P.V. Filatov, A.G. Kharlamov, Yu.M. Shatunov, D.A. Shtol, A.N. Shukaev.

1.3 Detector KEDR

The KEDR is the universal magnetic detector working on e^+e^- collider VEPP-4M in the energy region from 3 to 11 GeV in the center of mass system.

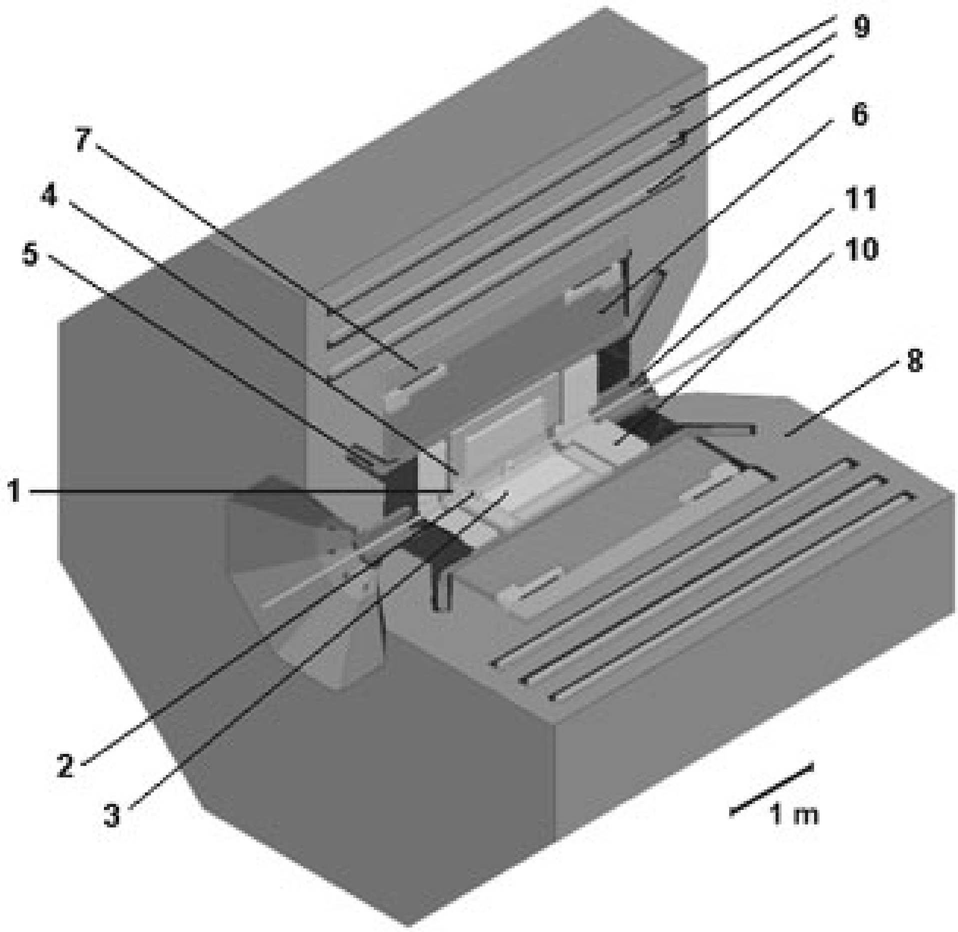


Fig. 1: The KEDR detector. 1 - vacuum chamber of the collider, 2 - vertex detector, 3 - drift chamber, 4 - aerogel Cherenkov counters, 5 - time of flight counters, 6 - liquid krypton barrel electromagnetic calorimeter, 7 - superconducting solenoid, 8 - magnet yoke, 9 - muon chambers, 10 - end cap electromagnetic calorimeter based on CsI crystals, 11 - compensating solenoid.

The KEDR detector includes the following main systems: vertex detector, drift chamber, aerogel threshold Cherenkov counters, time of flight counters, liquid krypton barrel electromagnetic calorimeter, end cap electromagnetic calorimeter based on CsI crystals, superconducting solenoid, magnet yoke, muon chambers, system of detection of scattered electrons for study of γγ physics, and luminosity monitor. The main parameters of the KEDR detector are shown in table 1. In detail, the detector is described in the Annual Report 2008.

Unique feature of experiments with the KEDR detector is a possibility of precision measurement of beams energy. Two methods are used for this: a resonant depolarization method and a Compton backscattering method. It makes possible, despite a moderate luminosity of the VEPP-4M collider, to obtain important physical results, some of them are the best in the world.

Table 1: The main parameters of the KEDR detector

System name	Parameters of system	
Vertex detector	Spatial resolution	250 μm
Drift chamber	Spatial resolution	100 μm
Aerogel Cherenov counters	π/K separation in momentum interval	0.6 - 1.5 GeV/c
Time of flight scintillation counterg	Solid angle Time of flight resolution π/K separation at 2σ up to momentum	95 % of 4π 320 – 350 680 MeV/c
Barrel LKr calorimeter	Polar angle Energy resolution at 1.5 GeV	38°- 142° 3 %
End cap CsI calorimeter	Angle to beam axis Energy resolution at 1.5 GeV	6°- 38° 3 %
Muon system	Solid angle Spatial resolution Thickness in nuclear lengths	67 % 4π 40 mm 6 - 7
Scattered electrons detection system	Range of mass of γγ system Resolution in mass of γγ system	0.14 - 4 GeV 5 - 20 MeV
Luminosity monitor	Process detected by the monitor Relative accuracy Absolute accuracy	$e^+e^- \rightarrow e^+e^-\gamma$ 3 - 4 % 5 %
Trigger	2 charged particles, $P_\perp$ 2-3 neutr. particles, energy of one	> 50 MeV/c > 500 MeV
Cryogenic system	27 tons LKr at temperature 120°K Main field of detector	 0.6 - 1.8 T

1.4 Results of work of the KEDR detector at the VEPP-4M collider in 2009

In season of 2009 the KEDR detector continued collection of statistics at the VEPP-4M collider in the low energy region 2E=1.85 - 3.1 GeV, with the main aim of the search for narrow resonances and the measurement of R. The integrated luminosity about 0.28 pb^{-1} was collected. In the past year, as in 2007 and 2008, due to lack of financing, experiment with the KEDR detector at the VEPP-4M collider was shorten: 2.5 months instead of eight.

In 2009 the analysis of the collected earlier statistics as well as the new data was continued. The most important new physical results are:

- Integrated luminosity at J/ψ was increased up to 1.5 pb^{-1} (about 6 millions decays).

- Scanning of the energy region 2E=1.85-3.1 GeV was performed and limit for electron widths of narrow resonances was 3 times lowered.

- A new result for $\Gamma_{ee} \times B_{ee}$ and $\Gamma_{ee} \times B_{\mu\mu}$ for J/ψ decays with the best in the world accuracy was obtained.

- Analysis of experiment on measurement of masses of charged and neutral D mesons was finished. Mass of charged D meson was measured with the best in the world accuracy.

- New result of measurement of mass and width of ψ(3770) was obtained. Mass has been measured with the best in the world accuracy, its value noticeably depends on account of interference of resonance with $D-\overline{D}$ non-resonant background.

- A preliminary result on B(J/ψ → $\gamma\eta_c$) was obtained with accuracy, comparable with accuracy of this branching in the Particle Data Group (PDG) tables of elementary particles.

Results of experiments with the detector KEDR on the VEPP-4M collider were presented in a number of reports at the international and all-Russia conferences and workshops. The reports completely based on results from the detector are:
- The report on Europhysics Conference on High Energy Physics (EPC2009), 2009, Krakow.
- 3 reports on Sixth International Workshop on e^+e^- collisions from φ to ψ (PHIPSI09), 2009, Beijing.
- 6 reports on Physics Branch of Physical Sciences Department of Russian Academy of Sciences Conference, 2009, (ITEP).

In 2009 experiments with the KEDR detector were supported by eight grants of the RFBR.

Results of experiments with the KEDR detector were published in 2009 in articles [15, 143, 75-79], preprints [5, 46-48], reported at conferences [337-349] .

Further last results of experiments with the KEDR detector on VEPP-4M collider are described in more detail.

1.4.1 Measurement of $\Gamma_{ee} \times B_{ee(\mu\mu)}$ of J/ψ meson

In 2009 an analycis of experimental data for precision measurement of quantities $\Gamma_{ee}\times B_{ee}$ and $\Gamma_{ee} \times B_{\mu\mu}$, where $B_{ee} = \Gamma_{ee}/\Gamma$, $B_{\mu\mu} = \Gamma_{\mu\mu}/\Gamma$ was continued. As result, the accuracy was still improved compared with that published in the Annual report 2008. The analysis is based on the same integrated luminosity 0.22 pb^{-1}, collected during the scan of the J/ψ resonance.

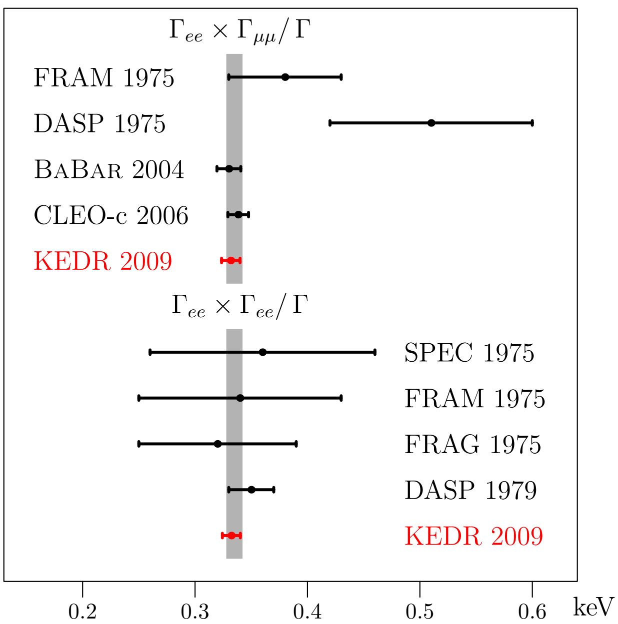


Fig. 2: Products of electronic width of J/ψ meson and its decay probability to e^+e^- and $\mu^+\mu^-$.

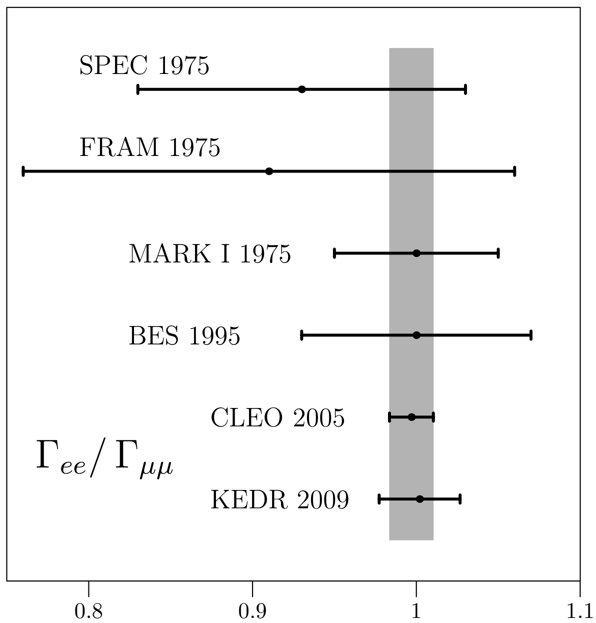


Fig. 3: Ratio $\Gamma_{ee}/\Gamma_{\mu\mu}$ in different experiments for J/ψ meson.

Earlier, the best accuracy of 6 % in the measurement of value $\Gamma_{ee} \times B_{ee}$ was achieved in the experiment DASP in 1979. The value $\Gamma_{ee} \times B_{\mu\mu} = (0.335 \pm 0.007)$ keV, given in the PDG tables has accuracy 2.1 %. It is based on recent measurements of detectors BaBar and CLEO-c by a method of radiative return.

Result of measurement of the KEDR detector

$$\Gamma_{ee} \times B_{ee} = (0.3323 \pm 0.0064 \pm 0.0048)\ \text{keV},$$

$$\Gamma_{ee} \times B_{\mu\mu} = (0.3318 \pm 0.0052 \pm 0.0063)\ \text{keV},$$

has the best in the world accuracy (about 2.4%).

In the season 2007-2008 the integrated luminosity in J/ψ area was increased up to 1.8 pb^{-1}. As result, we expect that statistical error will be decreased down to 1% and accuracy of $\Gamma_{ee}\times \Gamma_{ll} / \Gamma$ measurement will be further improved.

Comparison with results of other experiments is presented in Fig.2. The vertical strip corresponds uncertainty of the table value of $\Gamma_{ee} \times B_{\mu\mu}$.

Independent measurement of values $\Gamma_{ee} \times B_{ee}$ and $\Gamma_{ee} \times B_{\mu\mu}$ in the experiment allows to test the performance of e- μ universality - basic principle of Standard model, which claims the equality of these values. Their ratio in the experiment with the detector KEDR is equal to

$$\Gamma_{ee}/\Gamma_{\mu\mu} = 1.002 \pm 0.021 \pm 0.013\ .$$

Comparison of the ratio $\Gamma_{ee}/\Gamma_{\mu\mu}$ in different experiments is shown in Fig. 3. Average value of this ratio in the PDG tables (vertical strip in Fig. 3) now is determined by the measurement of the CLEO detector. The result of the detector KEDR has only a little worse accuracy than the result of the CLEO.

Measurement of $\Gamma_{ee}\times B_{ee}$ and $\Gamma_{ee}\times B_{\mu\mu}$ was reported on PHIPSI09 in Beijing, an article written on its basis will be published in Physics Letters B.

The experiment on measurement $\Gamma_{ee}\times B_{ee}$ and $\Gamma_{ee}\times B_{\mu\mu}$ for J/ψ resonance with the best in the world accuracy was recognized by the Scientific council as the best work of the Institute in physics of elementary particles in 2009.

1.4.2 Measurement of D mesons masses

Neutral and charged D mesons are lightest of charmed particles. The exact knowledge of their masses is important, because it is a point of readout for spectroscopy of exited states containing c-quarks. This measurement is also necessary for understanding of a nature of the recently opened narrow sate X (3872), with a mass close to the production threshold of D^0-D^{*0} pair. The long time the accuracy of the measurement of D mesons masses in the PDG tables was 0.5 MeV. In 2007 the CLEO-c collaboration has analyzed $D^0 \to K_S\varphi$ decay and published the result of measurement of D^0 meson mass with accuracy 0.18 MeV, which determines accuracy of this mass in the last PDG tables.

In experiment with the KEDR detector with the purpose of measurement of neutral and charged D mesons masses on integrated luminosity 0.9 pb^{-1} the decay of $\psi\,(3770) \to D\overline{D}$ was analysed. In 2009 the following values of masses were obtained:

$$M_{D^0} = (1865.30 \pm 0.33 \pm 0.23)\ \ \text{MeV},$$

$$M_{D^+} = (1869.53 \pm 0.49 \pm 0.20)\ \ \text{MeV}. \qquad (1)$$

In comparison with the result of 2008 the systematic error is appreciably reduced. The value of D^0 meson mass coincides with the more exact measurement of CLEO-c, obtained with the other method, and the measurement of value of $D^{\pm}$ meson mass is the most exact direct measurement.

Result of the KEDR detector on measurement of D^0 and $D^{\pm}$ mesons masses is in the good agreement with the results of other experiments and with the average values of masses in the PDG tables (fig.4 and fig.5). The vertical strip corresponds to uncertainty of average value of mass in the tables.

The result of experiment on measurement of D^0 and $D^{\pm}$ masses was reported on EPC09 and PHIPSI09, the article will be published in Physics Letters B.

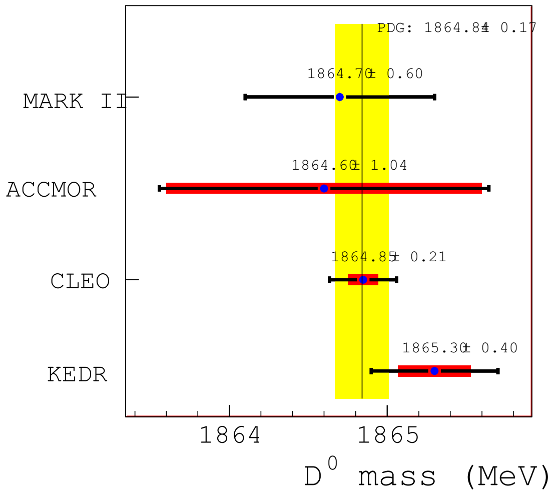


Fig. 4: Mass of D^0 meson.

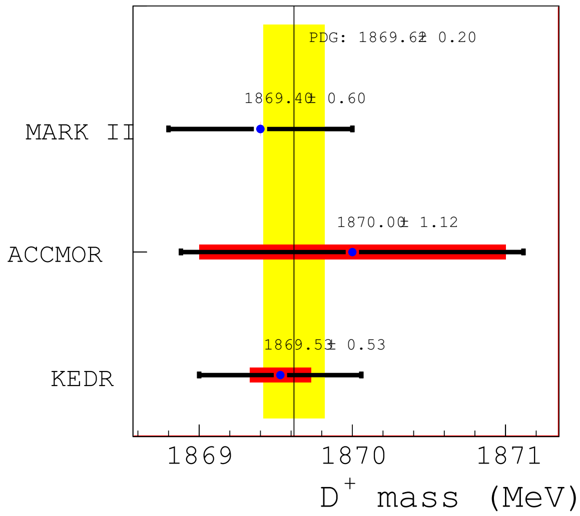


Fig. 5: Mass of $D^{\pm}$ meson.

1.4.3 Measurement of mass and full width of ψ(3770) meson

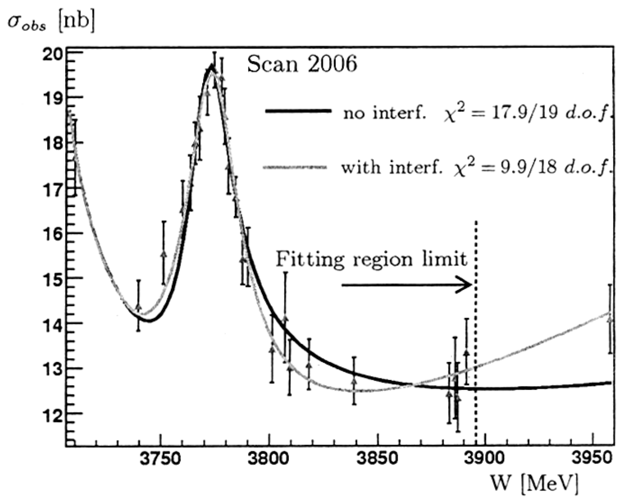


Fig. 6: Observed cross section in the area of ψ(3770).

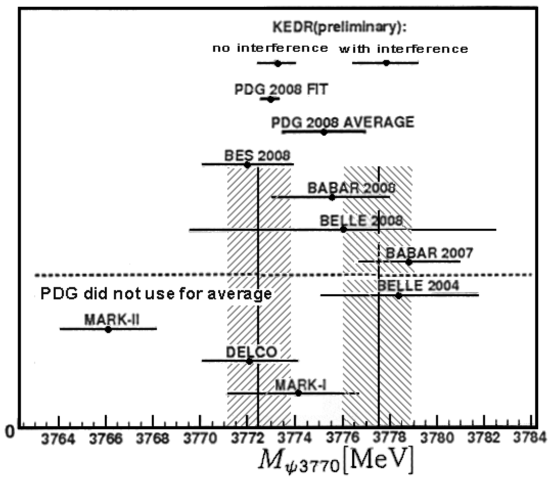


Fig. 7: Mass of ψ(3770).

Though the resonance ψ(3770) was discovered thirty years ago, results of measurement of its mass in various experiments differ rather strong, and there is no clearness with its theoretical description.

For measurement of ψ(3770) parameters during 2004 and 2006 three scans of the wide area from ψ' till 3.95 GeV with the KEDR detector were carried out with the total integrated luminosity $\int L\,dt \approx 2.4\ pb^{-1}$.

The standard method of data processing does not take into account the interference of the resonance decay products with the nonresonant $D\overline{D}$ continuum. Last years a part of experiments take into account such interference.

The fitting of the KEDR data (scanning 2006 with the largest statistics) by two mentioned methods is shown in Fig. 6. In the first case (black line) the following parameters of the resonance are obtained:

- M = (3773.2 ± 0.5 ± 0.6) MeV,
- Γ_{tot} = (23.9 ± 2.2 ± 1.1) MeV,
- Γ_{ee} = (294 ± 22 ± 30) eV.

With the account of the interference the parameferg ore:

- M = (3777.8 ± 1.1 ± 0.7) MeV,
- Γ_{tot} = (28.2 ± 3.1 ± 2.4) MeV,
- Γ_{ee} = (312 ± 31 ± 30) eV.

Taking the interference into account significantly improves the fit quality and increases the ψ(3770) mass by 4.6 MeV.

In Fig. 7 the data of measurements of the ψ(3770) mass in different experiments by the two methods are collected. The result of the KEDR is obtained on all statistics and has the best accuracy. All data are shared into 2 groups. The left group of the data (including PDG) is received by a standard method, right - with the account of interference. The left vertical strip - result of averaging of ψ(3770) mass, received in all experiments without the account of interference, width of a strip corresponds to ±1 standard error. The right vertical strip refers to the data with the account of the interference. One can see, that difference of the average values of mass is about 5 MeV and exceeds 2 standard errors.

This result was reported on PHIPSI09.

1.4.4 Measurement of decay branching J/ψ in $\gamma\eta_c$

Interest to the measurement of probability of the radiative decay $J/\psi \to \gamma\eta_c$ is caused by the appreciable difference of the experimental data with theoretical calculations using the potential models of quarks interactions and the QCD sum rules.

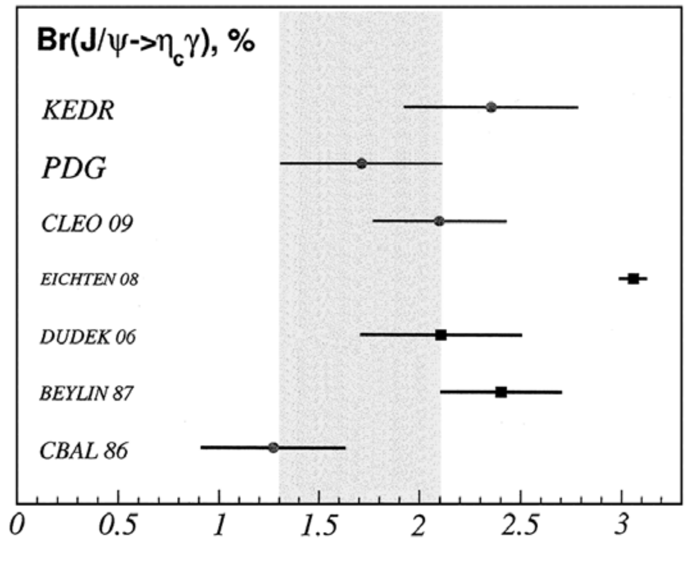


Fig. 8: Prabability of decay $J/\psi \to \gamma\eta_c$.

Until recently table value of this branching was based on one direct measurement in the inclusive photon spectrum, performed by the Crystal Ball detector: $B(J/\psi \rightarrow \gamma\eta_c) = (1.3 \pm 0.4)$ %. This branching is twice smaller, than that follows from theoretical calculations (B =2.5-3 %).

In 2008, the BaBar detector has published measurement of value B in exclusive decays B = (0.8±0.2) %. In 2009, the CLEO detector has received B = (1.98±0.09±0.30) % also in exclusive decays. The experimental data for B value badly coincide among themselves and, except for the CLEO result, with the theory. Therefore additional, independent measurement of probability of this decay, preferably in inclusive spectrum of photons, could give understanding of the reason of this divergence.

The analysis of the KEDR detector data is based on integrated luminosity 1.5 pb^{-1}, collected by the detector in the J/ψ peak. The calculated number of produced J/ψ equals $(5.9\pm0.3) \cdot 10^6$. The following preliminary results of B, and also $M(\eta_c)$ and $\Gamma(\eta_c)$ measurement in inclusive photon spectrum are obtained

$$B\,(J/\psi \rightarrow \gamma\, \eta_c) = (2.34 \pm 0.43)\%,$$

$$M\,(\eta_c) = (2979.4 \pm 2.4)\ \text{MeV},$$

$$\Gamma(\eta_c) = (27.8 \pm 6.1)\ \text{MeV}.$$

Comparison of measurement of B with results of other experiments is shown in Fig. 8. The vertical strip corresponds to uncertainty of the table value of probability of decay $J/\psi \rightarrow \gamma\, \eta_c$.

This result was reported on PHIPSI09.

1.4.5 Search for narrow resonances

Search for narrow resonances in the e^+e^- annihilation represents doubtless interest and can bring discoveries, similar to the recent observation of a narrow resonance X(3872) with the width about 3 MeV.

This experiment with the KEDR detector at the VEPP-4M collider was carried out in the beginning of 2009 , the shown results are still preliminary. The scan was begun above J/ψ down to 2E=1.85 GeV. The search for narrow resonances has been done, automatically reducing an energy in the centre of mass system approximately on $2\sigma_w$(1.4-1.9 MeV) after collection of the required integrated luminosity. The integrated luminosity varied from 0.3 nb^{-1} in the top part of the energy interval till 0.12 nb^{-1} in the bottom. Data collected in every point were analyzed in real time. If after preliminary collection the number of the candidate events exceeded some threshold, integrated luminosity was doubled. It allows to improve sensitivity of the experiment.

Complete integrated luminosity is equal to 0.28 pb^{-1}. The luminosity during data collection was measured with the process of bremsstrahlung, and during the analysis - with the process of Bhabha-scattering. The beam energy was measured with the help of Compton backscattering.

The result of the measurement of the KEDR detector - a product of the electron width of a resonance X on branching of its decay to hadrons is shown in Fig. 9. In the interval 2E=1.85 - 3.1 GeV the limit is lowered more than in 3 times in comparison with the result of the ADONE experiment (500 eV):

$$\Gamma_{ee} \times B_{X \rightarrow hadr} < 150\ \text{eV},\ 90\%\ \text{CL}.$$

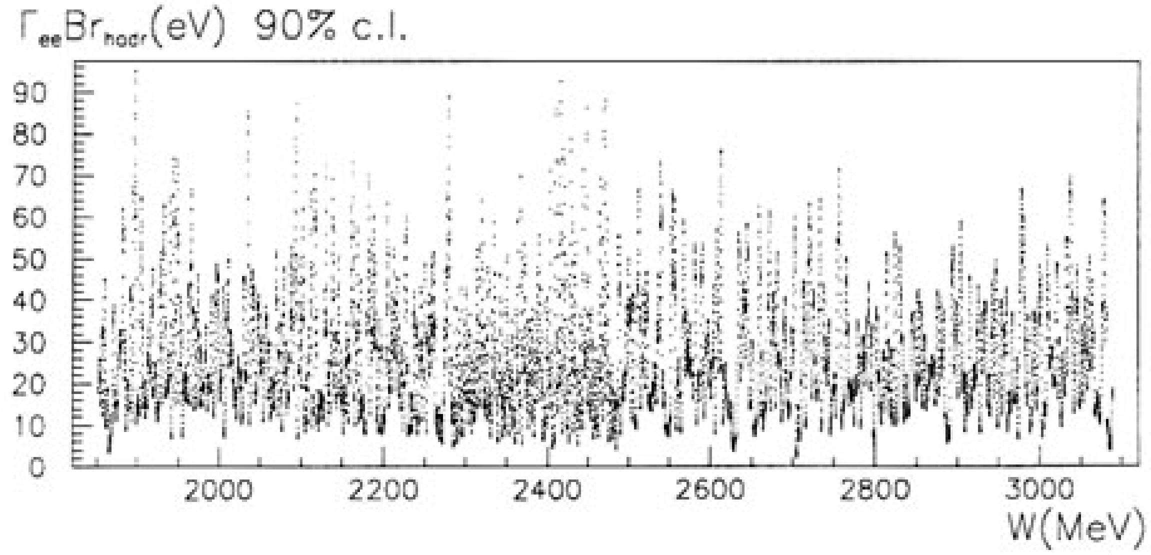


Fig. 9: Search for narrow resonances.

This result was reported on PHIPSI09.

1.5 Detectors for HEP

In 2009, as in the previous year, main efforts in the sphere of KEDR detector electronics were concentrated on the maintenance of functioning of numerous electronic systems of the detector and reduced, mainly, to current repairs.

Also the possibility of using digitizing electronics of the drift chamber in a multihit mode was studied. The set of new electronics for drift tubes is produced and is being tested.

In 2009 a certain progress on the works connected with the system of scattered electrons of the KEDR detector and its integration into the detector's system of data acquisition was attained. The current basic problems are connected with the software failures.

Works on upgrading the electronics of various systems of the SND detector are finished. In 2009 a new Primary Trigger Interface (PTI) of the calorimeter was installed.

The module of a prototype of Flash ADC for the calorimeter electronics is produced. The work on stage-by-stage upgrading of the detector internal electronics (preamplifiers and cross-boards) was started. New preamplifiers of signals from wires and strips are produced and installed for the detector drift chamber.

For the CMD-3 detector calorimeters, manufacturing and tuning of the complete set of the digitizing electronics boards (~90pcs) is finished.

1.6 X-ray detectors

In 2009 the experiments on studying the dynamics of explosions and measurement of sample parameters at SR channel with the use of one-coordinate detector DIMEX-1 with 256 channels were in progress.

Testing of the new DIMEX-3 detector with 512 channels in the case of a more convenient design is finished. In this detector, the electronics printed-circuit board of with the strip structure for the detector is used. The new software providing a more convenient interface for control, processing and representation of the experiment results is written. Further experiments with this detector are planned.

In 2009 the works on manufacturing the case of the detector for the SR experiments on wide-angular scattering were continued. In OD-4, instead of the wire structure as, for example, in OD-3, the multistage gas electron multiplier (GEM) is used; this gives the possibility, along with a high gas amplification (over 10000), to construct the detector in the form of an arch with an arbitrary angular aperture.

Within the frames of modernization of the OD-3–series detectors in order to increase their reliability and improve the parameters, the one-coordinate X-ray detector of the next generation - OD-3M - has been developed. The first detector of this type was produced under the contract with KCSR in 2008. In 2009, two OD-3M detectors were manufactured and delivered to the customers (ICSS and MC SB RAS and IC SB RAS).

1.7 Other works

Within the frame of the international projects, active participation in the works related to the upgrade of the BELLE detector data acquisition system (KEK, Japan) was continued. The first prototypes of new electronics for the calorimeter barrel part based on crystals CsI(Tl) are produced and are being tested after the correction. At the end of 2009, the samples of a new electronics in VME standard – shaper and collector - were produced in South Korea by our design and delivered to KEK (Japan), where they are currently being tested.

The list of publications: [40], [131], [39].

1. 8 Micro-Pattern Gaseous Detectors (MPGDs)

Development of the detectors based on Gas Electron Multipliers (GEMs) was continued in 2009. The work was conducted in several directions :

1) Development of cryogenic two-phase avalanche detectors based on GEMs.

2) Upgrade of the tagging system in the KEDR experiment.

3) Development of the low-pressure gas detector on the basis of thick GEMs for identification of ions at the AMS installation.

4) Participation in RD51 collaboration at CERN for the development of Micro-Pattern Gaseous Detectors (MPGDs).

5) Participation in R&D for TPC of International Linear Collider

1) The main purpose of the project is the development of the techniques of neutrino and dark matter registration and medical imaging through the creation of specialized devices on the basis of Gas Electron Multipliers (GEM), which operate in dense noble gases at cryogenic temperatures in an electron-avalanching mode. The broad variety of application fields listed above is based on the unique property of GEM detectors to operate with high amplification in noble gases at cryogenic temperatures in the gaseous and two-phase modes. The GEM-based cryogenic avalanche detectors can be used for registration of coherent neutrino-nucleus scattering using two-phase Ar and Xe, solar neutrino detection using two-phase or pressured He and Ne, dark matter searches using two-phase Ar and Xe and in Positron Emission Tomography (PET) using two-phase Xe.

In 2009 the study on electron emission was carried out in the two-phase Ar detector and its mixture with N_2, namely on the dependence of characteristics of fast and slow component of emission on the electric field. Simultaneously, fast and slow components were observed for the first time: see Fig. 1. It was found that in pure Ar, a slow component dominates up to the field of 2 kV/cm; and at addition of N_2 to Ar, a slow component disappears changing into a fast component (Fig. 1). The phenomenon model has been built.

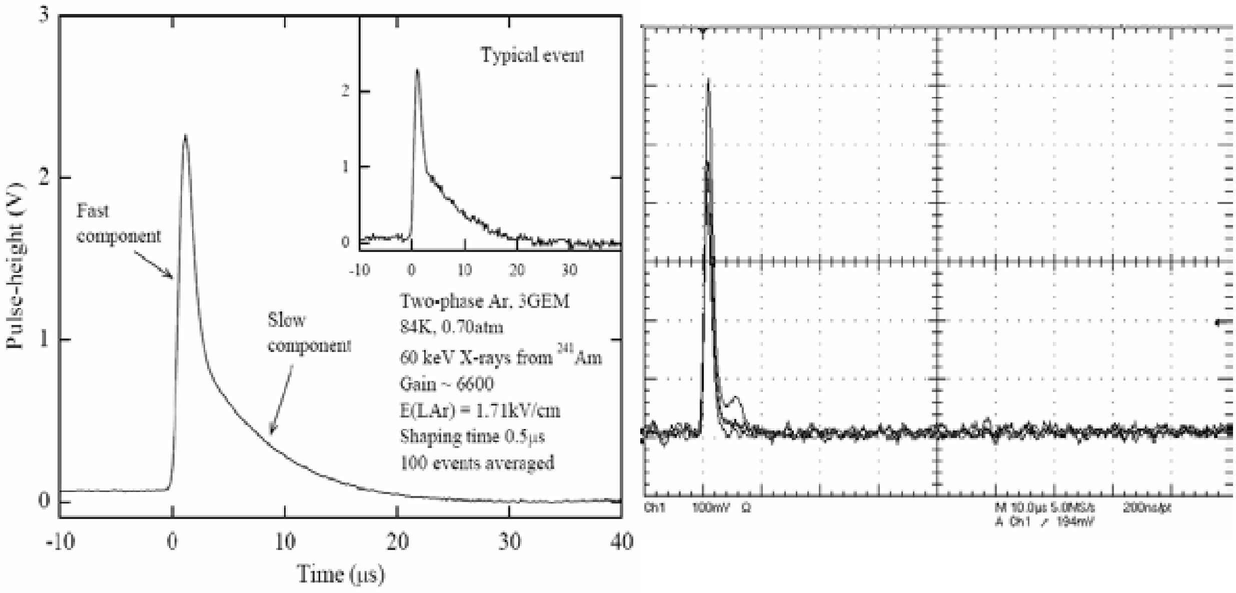


Fig. 1. The left drawing: a signal in the two-phase Ar avalanche detector on the basis of GEM at the emission field of 1.7 kV/cm; both fast and slow component of electron emission are observed. The right drawing: a signal in the two-phase Ar avalanche detector with a nitrogen admixture (1.5 %); only fast component of emission is observed.

In 2009 the work with the cryostat with a 2-litre chamber was finished and the works at the new installation having the cryostat with a 9-litre chamber were started. A two-cascade thick GEM was installed in this chamber for the work with a two-phase argon and xenon. The results are summavized up below.

Cryogenic tests of a new installation for the work with two-phase Xe and Ar were carried out. The cryogenics worked successfully with Xe. However, a number of drawbacks have been revealed: high-voltage connectors did not withstand the necessary voltage, and the cooling for the operation with two-phase Ar was insufficient. Nevertheless, preliminary results of the operation of thick GEMs in Xe at cryogenic temperatures have been obtained at the installation.

In autumn 2009, a considerable modernization of the installation was performed. High-voltage connectors were completely replaced with the new connectors produced in the laboratory. An additional cooling system was installed into the cryogenic chamber for work with two-phase Ar; dead zones at the bottom of the chamber were reduced; the GEM-assembly mounting was improved.

The studies in GEM reading out by means of silicon photo multipliers (SiPM) both in a gas and in a two-phase modes were started at the modernized installation. These studies are conducted in cooperation with the group of D.Yu.Akimov (ITEP). The studies of cryogenic avalanche detectors will be continued in 2010.

2) The system of tagged electrons is a substantial part of the KEDR experiment; it allows detecting the electrons scattered from the colliding point at small angles. These electrons characterize photon-photon interaction; and their detection and the measurement of their momentum are important physics task.

To obtain the ultimate momentum resolution of scattered electrons and to improve signal/background separation, each of 8 system stations is supplied with the detector based on triple-GEM with two-coordinate readout. These detectors allow measurement of the coordinate in the beam orbit plane with ~ a 0.1 mm resolution. In the perpendicular direction the spatial resolution will be ~ 0.25 mm in the region of ±1cm near the orbit and about ~1 mm far away from the orbit plane. To obtain the required parameters a special structure of the readout plane has been developed with the variable angle of stereo-strips. Detector dimensions vary from 125*100 mm^2 to 250*100 mm^2 depending on the station type.

During 2009 the tuning of the system together with the KEDR detector was carried out. Joint measurements with the available coordinate stations on the basis of the drifted tubes have been performed and showed that the results of the measurements gained by means of the GEM-based detectors correlate with the results from the coordinate stations on the basis of the drifted tubes. During 2009-2010 it is planned to include finally the GEM-based detectors into the KEDR data acquisition system and to start collecting statistics.

3) In 2009 the stand for conducting the measurements with the GEM-based low-pressure chamber was constructed. The signal from alpha-particles in isobutane has been registered at the pressure of several torr.

4) The MPGD group of Budker Institute is the member of the RD51 international collaboration at CERN on the development of MPGDs that was established in 2008. In 2009 the group has continued its participation in the activity of this collaboration.

5) In 2009 the participation of the MPGDs-group members in the development of TPC for International Linear Collider (ILC) was in progress. At present the cascade GEM is considered a most probable candidate as the TPC face registering detector.

The following employees participated in the work:
V.M.Aulchenko, A.E.Bondar, A.F.Buzulutskov, A.A.Grebenjuk (lab. 2), V.V. Zhulanov, R.G.Snopkov, A.V.Sokolov, Yu.A.Tikhonov, A.V.Chegodaev, L.I.Shehtman.

1. 9 Participation in the ATLAS experiment on the Large Hadron Collider (LHC)

The group of BINP SB RAS physicists and engineers have participated in the ATLAS collaboration on Large Hadron Collider (LHC) of the European Center of Nuclear Research (CERN) since 1995. The group has made an essential contribution to the construction of the ATLAS face electromagnetic calorimeter with a liquid argon at all the stages since designing. The suggested version of the face calorimeter design (simpler and more reliable in comparison with the initial one) has allowed a substantial reduction of the calorimeter cost, gave the possibility to simplify its manufacturing and to improve physical characteristics that has been confirmed during tests of the calorimeter modules at the extracted beams. Also for compensation of the particle energy loss in the cryostat substance (and the degradation of the energy resolution connected with it), a special minidetector (presampler, see Fig.1) has been suggested and successfully implemented (with BINP resources only).

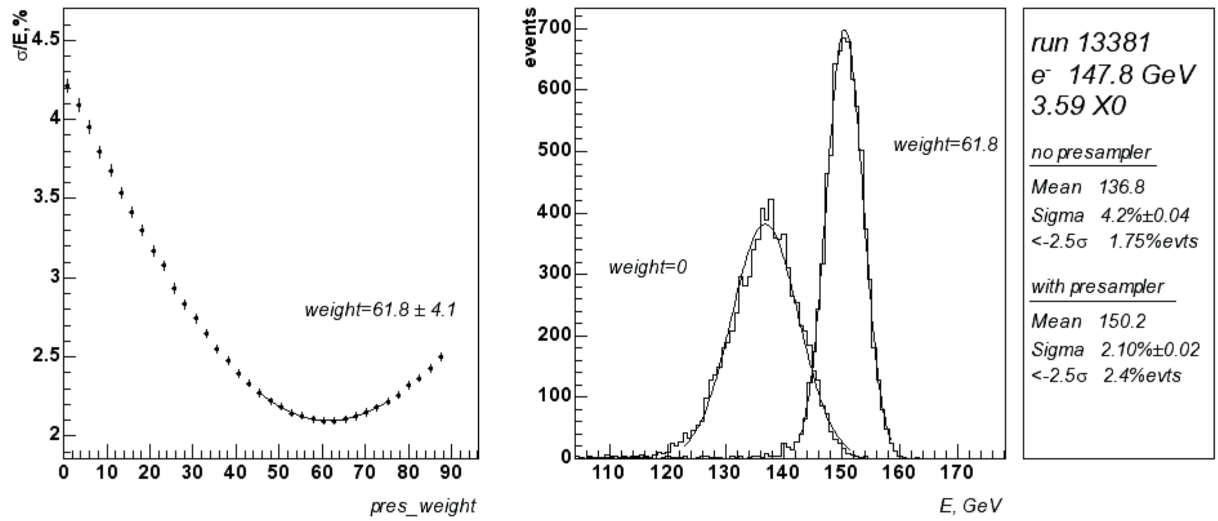


Fig. 1. On the left - the energy resolution vs the energy-release weight in the presampler. On the right - power spectra before (weight = 0) and after (weight = 61.8) weightings of the energy-release in the presampler. The thickness of dead substance before the presampler is 3.59 radiation lengths. The test beam data (CERN, 2002).

BINP has substantially contributed to the engineering equipment of the systems and the infrastructure of the detector; superconducting 20-кA wires for all the magnets of the ATLAS detector (the central solenoid, face and barrel toroids) and also large (25m in diameter) rings for precision fixture of muon chambers have been developed, manufactured and mounted in the LHC accelerator tunnel.

Physicists of the group take an active part in the works on calorimeter starting-up, its calibration, creation of the software for simulation and reconstruction of events in the detector, analysis of interesting physical processes.

At the end of 2009 (November, 20th), after a year interval caused by the necessity to eliminate an aftereffect of the damage in the accelerator superconducting magnets, a successful starting of the accelerator and detectors has been performed.

Less than for a 24-hour period, circulating beams at the injection energy of 450 GeV have been obtained and the physicists could register the first events in the detectors. The beam parameters gradually improved, the number of particles in a bunch (up to several units$\times 10^{10}$) and the number of bunches (up to 16) increased.

On November, 23, colliding beams at the energy in a centre-of-mass system s=900 GeV were obtained, and on the 8th of December – at the energy s=2.36 TeV (thus, establishing a world record). In a collision mode, the statistics of 540 thousand events at the energy s=900 GeV and 34 thousand events at the energy s=2.36 TeV was collected.

The first results show a very good condition of the detector systems and the software, there is a good agreement of data with the results of a proton-proton collision simulation at these energies. After the scheduled shutdown at the end of February, 2010, switching-on of the accelerator and detector and operation during ~ 1.5 year at the energy s=7 TeV is planned in order to collect the luminosity of the order of one inverse femtobarn.

Further energy increase up to the designed one (s=14 TeV) is planned.

The physicists of the group participate in data collection, monitoring of their quality and the analysis. The events with single beams with high energy-release in the detector have shown that all 1536 channels of the liquid-argon calorimeter presampler are efficient. The time resolution was better than 1.5 nanoseconds even without corrections of cell position. The pulse shape and electronics noise are in a good agreement with the calculations and the previous measurements in beam tests. The work on upgrading of the slow-control systems, on reliable and effective recording of the measured parameters in the databases is being conducted.

The improvement of the detector systems calibration and the corresponding software is being continuously performed. The works on the analysis of physical processes are also livened up. The improvement of the algorithm of a top quark-antiquark pair reconstruction in semi-lepton mode of decay has been offered (with registration of a lepton and four hadron jets in final state). The programs for reconstruction have been created and the works on check and optimization of the method of definition of tau-lepton life time in channel $Z \rightarrow \tau^+ \tau^- \rightarrow$ hadrons have been started.

Since spring 2009 works on studying the possibility of observation of heavy Majorana neutrino in the channel with two leptons and two jets in final state within the Left-Right Symmetric Model have been conducted under collaboration with the Pittsburgh and Uppsala universities. This model can explain the presence of nonzero mass of usual light neutrino (which follows from the observation of their oscillations) and the origination of asymmetry between matter and antimatter (baryon number B and lepton number L can be violated separately, under condition of B-L conservation). It is necessary to note that this model is complementary to many models of supersymmetry, as the latter are characterized by missing transverse energy in an event. The results of simulation show that for small masses of heavy right W' boson (<1 TeV) and right neutrino (50-300 GeV), the process can be singled out from the Standard model background and several hundreds of reverse picobarns can be already observed on luminosity integral.

A large work on the development of a computer infrastructure and the corresponding matching software is also being conducted. The data from the experiment of such scale (several petabytes of input data per year) can be kept and processed only at a well co-ordinated work of many powerful computing clusters worldwide using GRID distributed computing high technology. Power of the local GRID – BINP cluster - steadily grows, the carrying capacity of communication channels is being improved. Cooperation with the computer centers of NSU and the Siberian Branch of the Russian Academy of Science is being developed. Also the group of our employees works on the analysis and optimization of distribution of problems in GRID system for the entire LHC project. Another team works in the Trigger and DAQ group of administrators. They have suggested and implemented the program of the equipment and software upgrading.

At present, the LHC collider modernization project is being developed for the purpose of increasing the luminosity up to 10^{35} cm^{-2}sec^{-1}. In this connection, the works on modernization of the ATLAS detector for operation at such luminosity are started. BINP team participates in the experiment in studying the operating capacity of the ATLAS liquid-argon calorimeters at the luminosity of 10^{35} cm^{-2}sec^{-1}. For these purposes mini-modules of the electromagnetic, hadron and face calorimeters, which are placed in cryostats with a liquid argon have been produced. In Protvino, irradiation of the modules (the beam intensity can vary over a wide range, $10^{7}\div10^{12}$ particles/sec) is being performed using the extracted beam of protons with 50-GeV energy of U-70 accelerator. BINP team is entirely responsible for the mini-module of the electromagnetic calorimeter and participates in the data collection and analysis (the previous run was in November, 2009).

The following employees participate in the work:

A.V.Anisyonkov, E.M.Baldin, T.V.Bedareva, O.L.Beloborodova, S.D.Belov, V.S.Bobrovnikov, A.G.Bogdanchikov, A.R.Buzykaev, A.S.Zaitsev, V.F.Kazanin, V.I.Kaplin, A.A.Korol, K.Yu.Kotov, D.S.Krivashin, R.E.Kuskov, V.M.Malyshev, D.A.Maximov, A.L.Maslennikov, I.O.Orlov, S.G.Pivovarov, S.V.Peleganchuk, K.Yu.Skovpen, A.M.Sukharev, A.A.Talyshev, Yu.A.Tikhonov, A.I.Khoroshilov, A.G.Shamov.

1. 10 Belle Experiment

BELLE experiment is one of the basic experiments in elementary-particle physics. The primary goal of the experiment is studying of one of the mysteries in elementary-particle physics − CP-violation. In 2001 in this experiment, CP-violation in $B^0 \to J/\psi\ K^0$ decay was discovered for the first time, which corresponded to the Cobayashi-Maskawa model prediction. Today, basing on CP-violation measurements in various decays of B-mesons, three angles of the Unitarity Triangle are calculated; angle φ_1 is calculated with the accuracy better than one and a half degree. The accuracy of direct measurements of two other angles remains low, of the order of ten-twenty grades. Up to the present, no significant deviations from the Standard Model have been discovered in the course of measurement of CP-violation and rare decays of B-mesons.

However, for its proper check and search of the phenomena behind its limits, an essential increase of the accuracy of CP-violation measurement in various channels of B-meson decays, and also the probabilities and motion characteristics of rare decays of B-mesons is necessary. Another important problem, at the solution of which the experiment is aimed, is studying of the properties of strong interaction in hadrons. The hadron physics is being rapidly developed due to numerous discoveries in the area of their spectroscopy, decays and production. About ten new states with a pair of charmed quarks have been discovered in the BELLE experiment. The majority of theorists assume that it is difficult to explain unusual properties of the majority of the discovered states without admitting the existence of exotic systems.

Experimental study of exotic and traditional hadrons provides an additional information necessary for understanding of the nature of strong interaction. Besides B-mesons, a comparable quantity of tau-lepton pairs is produced at B-factory, this gives the possibility to carry out precise measurements of relative probabilities of various decay modes and searching of the decays prohibited in Standard Model. These research allows conducting search of manifestations of New physics in lepton sector.

BINP SB RAS team takes an active part in the BELLE project right from its start. Novosibirsk physicists have made a large contribution to the creation of the electromagnetic calorimeter of the BELLE detector both at a design stage and at the manufacturing of elements of this largest-in-the-world calorimeter on the basis of iodide caesium monocrystals, at the stages of its assemblage and tuning.

In 2009 the collection of statistics and processing of the experimental information were continued. The collider luminosity exceeded its designed value and reached 2.1×10^{34} cm^{-2} s^{-1}, and the integrated luminosity at the end of year exceeded 1000 inverse femtobarns. For today, КЕКВ is the installation with a record luminosity and allows obtainment of new physical results. The following step is creation of super B-factory.

BINP SB RAS physicists are deeply involved into the work with the detector and into processing of experimental data. BINP team participates in the analysis of three- and four-body decays of B-mesons, processes with production of charmed particles, and is also engaged in τ-physics.

In 2009, the research of a τ-lepton decay was continued. The BELLE collaboration has studied all possible decays with η-meson in a final state. Interest to them is caused by search of $\tau^- \to \eta\pi^- \upsilon_\tau$ decay, which is strongly suppressed in Standard Model. The above-mentioned decays with η-meson are a strong source of a background as their probabilities are higher than for $\tau^- \to \eta\pi^- \upsilon_\tau$ decay. The results of work, given in Table 1, considerably surpass the previous measurements performed at the CLEO and ALEPH detectors in accuracy, and are in agreement with them within experimental uncertainties. This has provided a considerable advance in the search of $\tau^- \to \eta\pi^- \upsilon_\tau$ decay.

Table 1. Comparison of the BELLE and CLEO results

Channel		N_{ev}	B_{exp}
$\pi^- \pi^+ \eta \upsilon_\tau$	BELLE, 2009 CLEO, 1992	5675 ± 111 125 ± 16	(1.35 ± 0.03 ± 0.08) × 10^{-3} (1.7 ± 0.2 ± 0.2) × 10^{-3}
$K^- \eta \upsilon_\tau$	BELLE, 2009 CLEO, 1992	1545 ± 51 61 ±14	(1.58 ± 0.05 ± 0.09) × 10^{-4} (2.6 ± 0.5 ± 0.4) × 10^{-4}
$K^- \pi^0 \eta \upsilon_\tau$	BELLE, 2009 CLEO, 1992	241 ± 34 47 ± 12	(4.6 ± 1.1 ± 0.4) × 10^{-5} (17.7 ± 5.6 ± 7.1) × 10^{-5}
$K_S \pi^- \eta \upsilon_\tau$	BELLE, 2009 CLEO, 1992	45 ± 8 15.1 ± 4.5	(4.4 ± 0.7 ± 0.2) × 10^{-5} (11.0 ± 3.5 ± 1.1)× 10^{-5}

Besides, searching of New physics in the sector of charged leptons, namely decays with lepton flavor violation was continued. In 2009 the results of the first search of $\tau^- \to e^- f_0$ (980) and $\tau^- \to \mu^- f_0$ (980) decays with f_0 (980) reconstruction on decay in $\pi^+\pi$ were published. Though such decays were not observed (see Fig. 1: there are no events in a signal ellipse), the obtained upper limits for probability of such decays, 3.2×10^{-8} and 3.4×10^{-8} , respectively, are already close to theoretical predictions and provide essential restrictions on parameter space, admissible in theoretical models.

The BINP team studied the properties of particle η_c and its excited state η_c(2S). These particles are the bound states of $c\bar{c}$ quarks (so-called charmonia). Decay of *B* meson to *K* meson and charmonium, which, in its turn, decays to hadrons ($K_S K\pi$), was considered as their source. Fig. 2 shows the distribution of invariant mass $K_S K\pi$ (the peaks correspond to the states η_c, J/ψ, χ_{c1} and η_c (2S), bottom diagram - a combinatory background. It is visible, that there are the events, which are neither a signal (peaks), nor a combinatory background - the so-called non-resonant amplitude. In this work the interference between a signal and non- resonant amplitude was first studied and the estimation of the influence of this interference on the analysis results was performed. The results of this study are the products of partial widths of the B-meson and charmonium decays, and also the values of masses and widths of η_c and η_c (2S) mesons.

Due to a large volume of data, the results have small statistical errors and allow the improvement of the corresponding world-average values.

The results of the work are being prepared for publication.

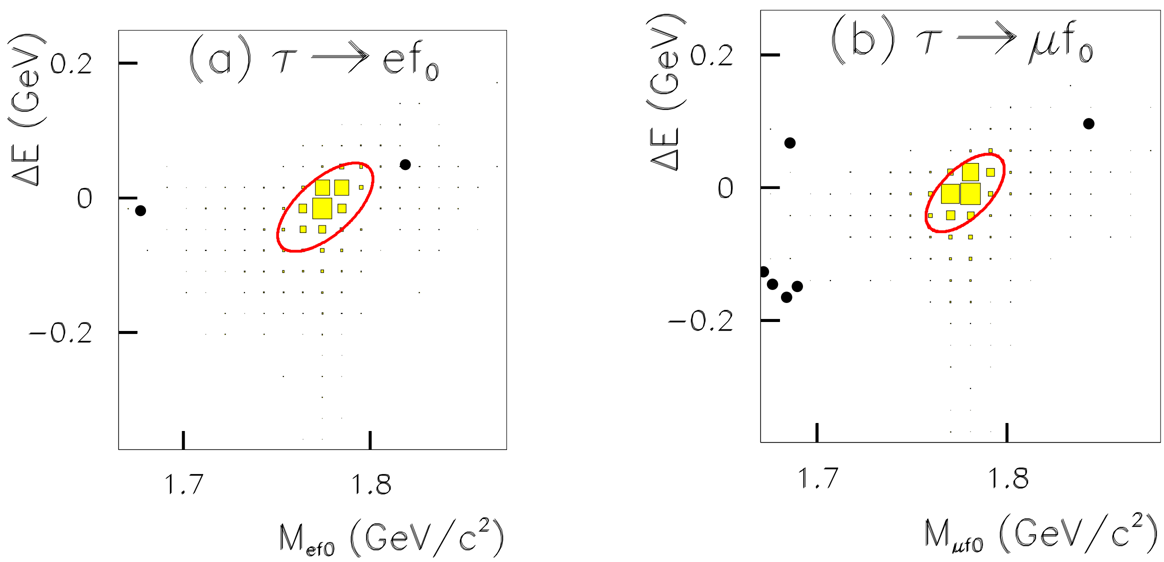


Fig. 1. The results of searching the decays $\tau^- \to e^- f_0(980)$ and $\tau^- \to \mu^- f_0(980)$.

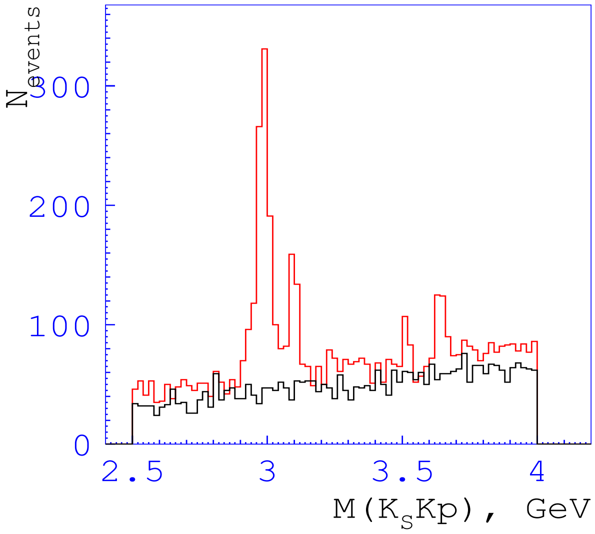


Fig. 2. Distribution of invariant mass $K_S K\pi$.

In 2009 the analysis of experimental data for the purpose of measuring the mixing angle ϕ_3 with the usage of new available statistics of the Belle experiment (605 fb^{-1}) was continued. Three channels of decays: $B^+ \rightarrow DK^+$, $B^+ \rightarrow D^*K^+$ c $D^* \rightarrow D\pi^0$ and $D^* \rightarrow D\gamma$, and the corresponding charge-conjugation were used in the analysis. The method uses the interference between D^0 and $\bar{D}^0$ for determination of angle ϕ_3, strong phase δ and relations r of the suppressed and permitted amplitudes. As a result, the obtained angle is

$\phi_3 = 78.4°{}^{+10,8°}_{-11,6°} \pm 3.6° \pm 8.9°$, where 3.6° – systematic error, and 8.9° – modeling error.

Statistical significance of CP violation ($\phi_3 \neq 0$) in the given measurement is ($1\text{-}5\times10^{-4}$) or 3.5 standard deviations. The results of work are being prepared for publication.

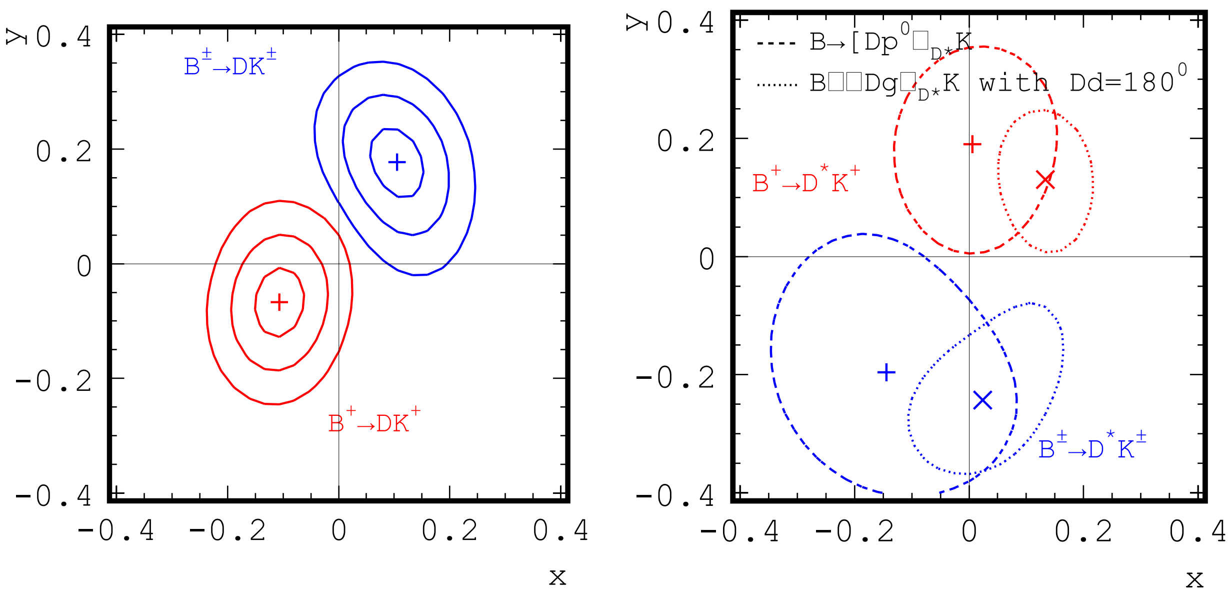


Fig. 3. Results of a signal fitting with arbitrary parameters x and y characterizing CP violation.

Due to a resent discovery of a mysterious family of Y states with quantum numbers $J^{PC}=1^{--}$, scientists paid attention to the multiply measured inclusive cross-section $e^+e^- \rightarrow$ hadrons. Until recently, the parameters of ψ-states were determined from this cross-section without taking into account their possible interference, and only in 2008, for the first time, interference of about ten final states from ψ-resonances decays was taken into consideration. However, for description of these decays, physicists based on the predictions of theoretical models, so the gained result remained model-dependent and, consequently, not very reliable. The attempt to include *Y*-state into the description of cross-section results in set of free parameters and is doomed to failure. The only way, which gives a possibility of a reliable determination of ψ parameters, of studying their decays and, also, of setting the upper limits for probabilities of *Y* decays to *D*-meson final states is measurement of the cross-sections of exclusive processes.

The next stage of the B-factory work is planned to be modernization of both: the detector (BELLE II) and the collider, to increase the luminosity of the installation up to 8×10^{35} cm^{-2}sec^{-1}, this will provide measuring of all angles of the Unitarity Triangle with the accuracy of up to few percent and, possibly, will allow to cross the limits of the Standard Model.

The increase of luminosity and background load on the collider imposes new requirements on the detector systems. Modernization of the calorimeter is required to provide its effective work. The BINP team participates in methodical works on modernization of the detector calorimetric system. This team has developed and offered the scheme of calorimeter modernization. For a cylindrical part of the calorimeter, the replacement of the counters electronics by the circuit with continuous digitization of the counters amplitude and the subsequent fitting of the data by the response of the certain form is planned. This procedure allows determination both energy and time of signal arrival. Use of the time information allows suppressing the frequency of false cluster origination by several times.

For the face part where background conditions are the heaviest, replacement of scintillation crystal CsI (Tl) by crystals of non-activated CsI with a shorter de-excitation time is supposed. It will allow the improvement of time resolution of the counters by 30 times and, taking into account the signal form trimming, provision of background suppression by more than 150 times.

In 2009 BINP developed the circuits of shaper-digitizers and concentrators in VME standard. These modules were made in Korea, tuning was carried out at KEK, and the first tests of these modules are being performed (Fig. 4).

Fig. 4. The electron module of the 16-channel shaper-digitizer in VME standard and the electron module of the concentrator in VME standard.

Noise and linearity measurements have been performed for the shaper-digitizer. The obtained linearity is better than 3×10^{-3} for the dynamic range corresponding to the energy range from 10 MeV to 10 GeV (Fig.5).

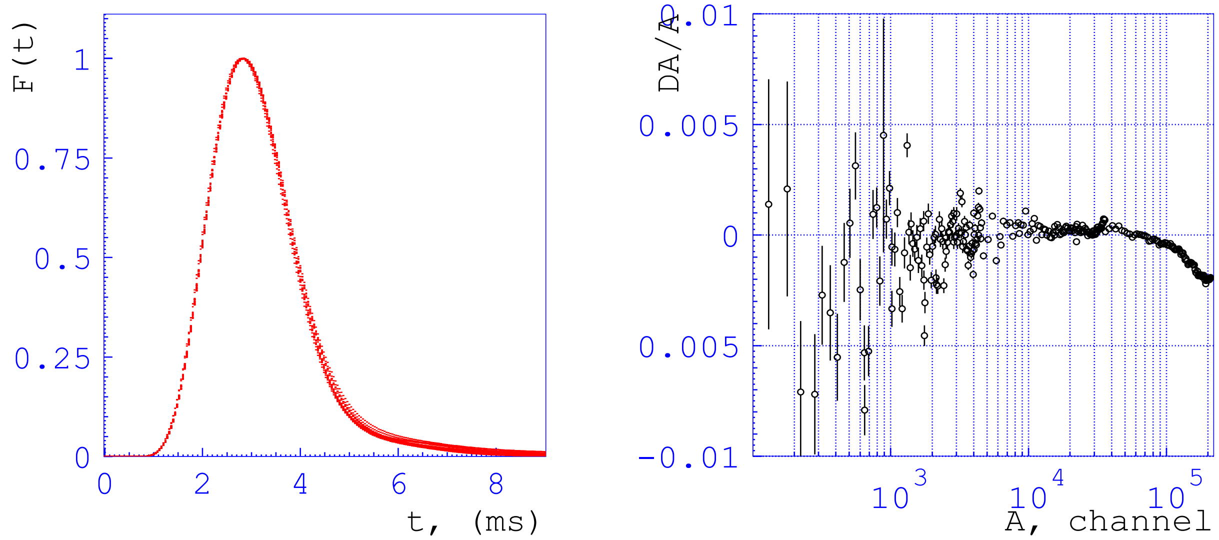


Fig. 5. The pulse shape from the shaper and the deviation from linear dependence of the shaper module.

For a face calorimeter where crystals of pure CsI are supposed to be used, the application of new photodetectors is necessary. Photopentodes − photo multipliers with three dynodes (Fig. 6) – are planned to be used for this purpose. Such devices can operate in a magnetic field of up to 1.5 T.

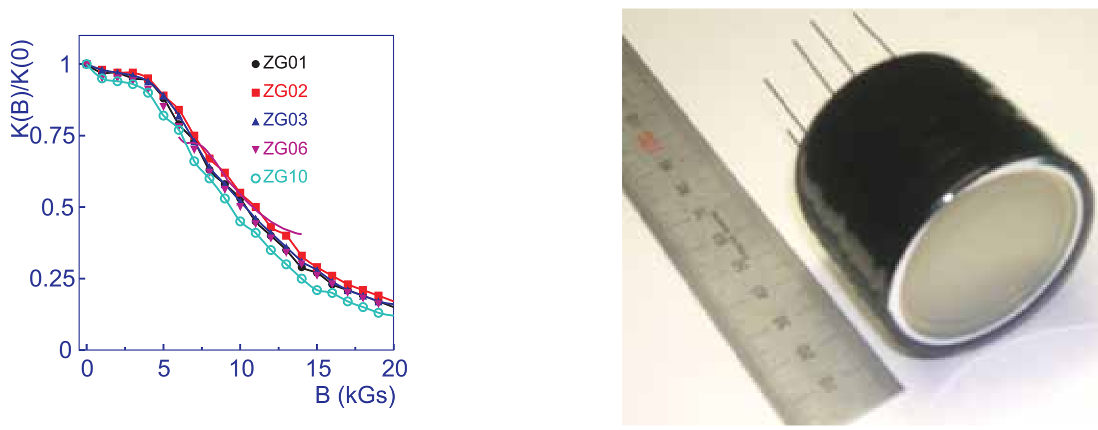


Fig. 6. Hamamatsu vacuum pentode.

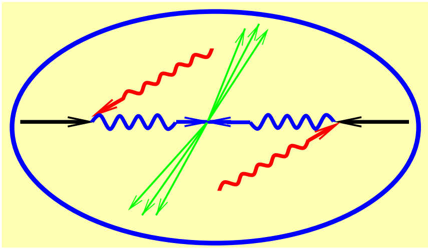
Long-term working capacity and characteristics stability of devices is very important at operation on a large installation. BINP team has conducted tests of the dependence of photopentodes sensitivity on a full charge collected on the anode. Two stands have been created for this purpose. One stand has been assembled at KEK and allowed the measurement of the device sensitivity without magnetic field. Photopentodes for the current integral corresponding to 20 years of BELLE II detector operation have been tested on this stand.

The second stand has been assembled at BINP. This stand provided the measurements both without magnetic field and with it. Photopentodes in magnetic field for the current integral corresponding to 3 years of BELLE II detector operation have been tested on this stand. The measurements have shown satisfactory work of devices in both cases. Behavior tendencies of photopentodes sensitivity in magnetic field coincide with the measurements without magnetic field.

Scintillator luminescence time and its persistence are the important characteristics for operation under large background loadings. To study these characteristics of CsI crystals, the stand allowing the measurement of luminescence time up to 10 nanoseconds and the components of persistence up to 10 ms has been developed and assembled. Measurements of the crystals produced by different suppliers have been carried out at this stand.

Hermetical calorimeter with minimal gaps between crystals is important for obtainment of the high energy resolution. Therefore, it is necessary to provide exact sizes of the counters; and checking the dimensions of the crystals got from the manufacturer is also important. An installation for checking the dimensions of the BELLE detector counters has been produced. In 2009, BINP team has revised and improved the software of this installation; this will allow using it for measurement of BELLE II counters.

1.11 The Photon Collider



In 2004, the project of International Linear Collider (ILC) based on a superconducting technology was launched. In addition to the e^+e^- physics program, the ILC will provide an opportunity to study $\gamma\gamma$ and γe interactions (photon collider or PLC), where high energy photons can be obtained using Compton backscattering of the laser light off the high energy electrons. In 2007 the ILC Reference Desigh Report (RDR) was published. In 2008 two detector conceptions were approved for further development. Owing to a high ILC cost further plans are quite uncertain. The situation can change after discovery of new physics at the LHC.

Meanwile the ILC community is searching for possible ways of the cost reduction. One of such suggestions is a construction of the photon collider Higgs factory as a precursor to ILC. In order to produce a single Higgs boson with the mass 120 GeV at the photon collider one needs the electron energy 2E=160 GeV, while the Higgs production in e^+e^- to HZ requires 2E=230 GeV and a positron production system. We repoted our view on this suggestion at the conference ILC08/LCWS08. A detailed discussion took place at TILC09. Although we are most interested in creation of the photon collider but, in our opinion, it would be more reasonable to construct from the very beginning the linear collider on the energy 2E=230 GeV capable to produce the Higgs boson (if it really exists) in e^+e^- mode. From a financial points of view such photon collider is unlikely to be significantly cheaper because e^+e^- beams will be constructed in parallel, all this will lead only to incremental cost of the collider. Moreover, the physics community will never agree with additional delay of e^+e^- experiments by 5-6 years.

Our participation in the development and promotion of the photon collider in 2009 can be seen from the list of papers and talks at international conferences:

Partcicipants of the work: V.I. Telnov.

2

ELECTRO- AND PHOTO-NUCLEAR PHYSICS

2.1 Experiments with internal targets.

I. In 2009 completion of preparing to and, then, carrying out the experiment on measurement of the ratio (R = σ+/σ-) of elastic electron-proton and positron-proton scattering cross-sections were the main tasks of the group.

The peculiarity of this experiment is in the possibility to determine the contribution of the two-photon exchange (TPE) into the process of the electron-proton elastic scattering. In its turn, data on TPE will enable explanation of the dramatic contradiction in the results of recent experiments on measurements of the proton form-factors performed at TJNAF (USA) using the polarization technique with the results of the previous non-polarized measurements where the form-factors were determined via the analysis of differential cross-section of reaction in the assumption of the validity of one-photon approximation.

By now, there are a lot of theoretical publications demonstrating the importance of TPE for the interpretation of the experiments performed using non-polarized technique. However, to solve the problem, new experimental data on two-photon exchange contribution are required.

In the summer the target and the detector were installed on the VEPP-3 storage ring. Then the work on check and adjustment of the equipment was done. At the same time the BSQ device (Backscattered Compton Quanta) was moved from the VEPP-4 ring to VEPP-3 for measurement of electron/positron beam energy.

Work with a beam started in September with tuning of various operating modes of the storage ring. The target and particles detector operation with stored beams has been adjusted and work on decrease of background has been performed. The collection of experimental data was started at the end of September. The efficiency of the data collection, determined as integral of the electron/positron beam current at a constant thickness of a target of approximately 10^{15} atoms/cm^2, increased and has reached the level of ~1 kC/24hrs (Fig. 1).

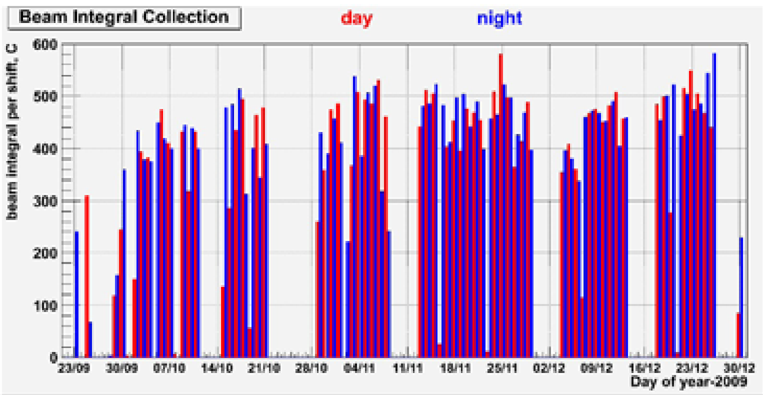


Fig. 1. Shift beam integrals at the VEPP-3 storage ring.

To decrease the regular measurement errors of R = σ+/σ- it was important to provide similar conditions of work with electron and positron beams: e^+ and e^- beam energies were constantly measured by Compton backscattering (CBS) installation and were close to each other, beam positions were constantly monitored by BPMs and also were approximately identical. Several times during the data collection process a beam position was measured with a help of mechanical beam probes, the analysis of the data collected with the detector will also give the information about beam position during the experiment.

For the same purpose (decrease of the regular errors) electron and positron beams were regularly interchanged (Fig. 2).

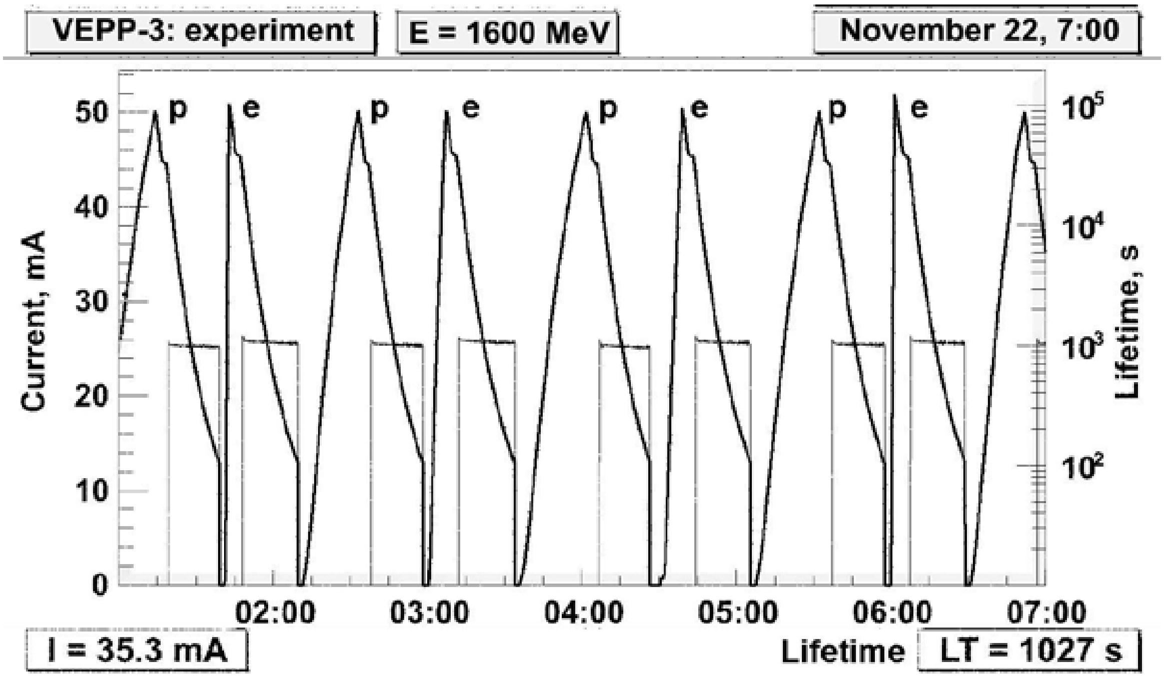


Fig. 2. e^+e^- beam diagram in the VEPP-3 storage ring.

The experiment lasted till the end of the year, the planned electron/positron beam current integral (Fig. 3) has been accumulated.

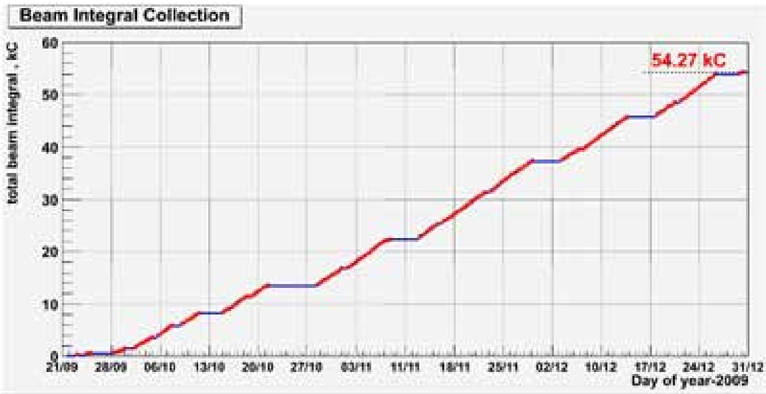


Fig. 3. VEPP-3 beam current accumulation during the experiment.

The preliminary data analysis shows high enough data quality, the results are planned to be obtained in 2010.

II. At VEPP-3, the work on construction of the system for tagging quasi-real photons (PTS) were in progress. The tagging system will extend the possibilities for photoreaction studying at VEPP-3 significantly. For example, it is proposed to continue the experiment in the photo splitting of deuteron by photons of large energies. In this process, according to the data of non-polarized measurements, the transition to quark-gluon description of the reaction occurs just from the energy of ~1 GeV. It seems to be important to find a verification of this fact in polarized measurements. The experiments in coherent meson production will be resumed. 3D modeling of the magnets is performed. The saturation curves of the PTS magnet triplet (multiplied by a corresponding coefficients) are almost identical (see Fig. 4).

Field integrals of the magnets along the electron beam trajectory depending on a full current of magnets are presented. Horizontal lines show the levels of the integrals at injection and experiment energies.

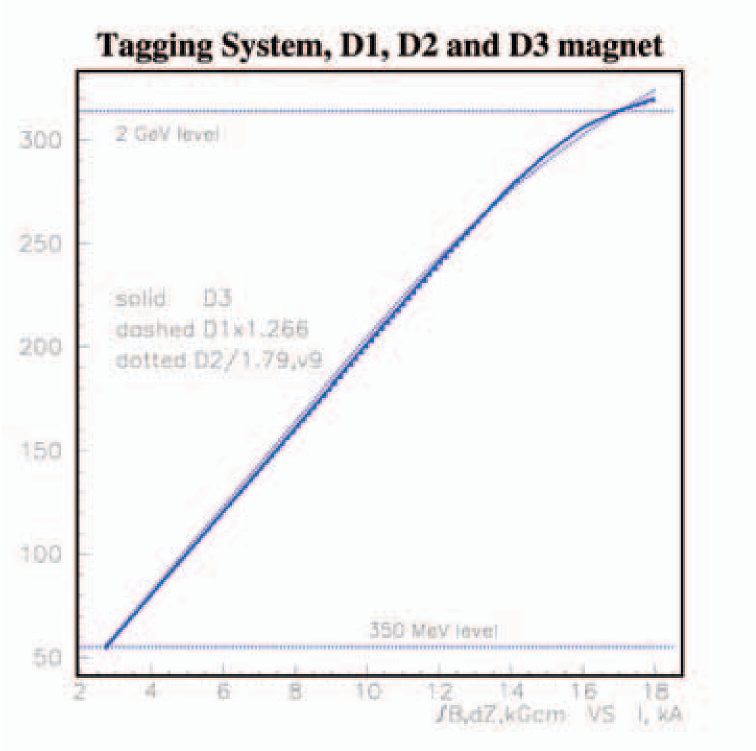


Fig. 4. Saturation curves of D1, D2 and D3 magnets.

The proximity of the saturation curves of three magnets will allow feeding the magnets from one (currently available) high-current power supply. Slight differences of the fields from the required ones are eliminated via using correction coils. The design work on these magnets is finished, manufacturing is started.

The vacuum chamber of an experimental section is divided into three parts.

Manufacturing of the central part containing an accumulating cell of the target is close to completion.

Design work on the first (at a beam pass direction) part of the vacuum chamber is finished, its manufacturing is started. Design work on the last part of the vacuum chamber is almost completed.

To improve operative diagnostics of VEPP-3 electron beam position, a BPM station will be installed near PTS coordinate detectors; besides, beam position will be monitored with a help of synchrotron radiation from the central PTS magnet and bremsstrahlung from a target. Measurement of the electron beam position (and, if necessary, correction/stabilization of the beam position) in this place - in immediate vicinity of the coordinate detectors measuring the coordinates of passing electrons, which are involved in reaction in the target - will considerably simplify the procedure of determination of the energy of these electrons and will make it more reliable. A design work on these devices is started.

Solutions on the design of the absorber of synchrotron radiation from PTS magnets (total power of radiation is up to 1 kW) are found. Design work is started.

III. Work on improvement of the polarized target parameters has been resumed. Earlier the stand reproducing operation conditions for the target at the experiments has been created, its modernization is performed.

A procedure of cell coating with a material, which preserves depolarization of atoms, was changed. The technique developed in BATES laboratory was taken as a basis.

Also it has been decided to make the vacuum stand for fixing (heating in vacuum) of an accumulating cell covering. The stand has been developed and manufactured, and fixing of a trial covering has been performed. The thickness of the covering measured with a help of ellipsemeter was about 20 micrometers. The part of atoms recombinated on the cell walls has been measured, it was 0.29±0.08.

Measurements of degree of an atomic beam polarization will require essential decrease of noises in the detector or application of another scheme of registration of the molecular and atomic beams coming out of the accumulating cell.

Changes in the scheme of the polarized atoms source (PAS) pumping, which were designed earlier, are now at implementation stage. On the one hand, they should result in increase of the source jet intensity, on the other hand, the time between stops for PAS regeneration should increase.

Experiments with internal targets are carried out in collaboration with the groups from Tomsk, St. Petersburg, NIKHEF (the Netherlands), ANL (USA), IKF JGU (Mainz, Germany).

Participants of the work from BINP:

L.M. Barkov, V.F. Dmitriev, A.V. Gramolin, I.V. Karnakov, B.A. Lazarenko, E.B. Levichev, S.I. Mishnev, N.Yu. Muchnoi, D.M. Nikolenko, I.A. Rachek, R.Sh. Sadykov, Yu.V. Shestakov, L.I. Shekhtman, D.K. Toporkov, S.A. Zevakov.

3

THEORETICAL PHYSICS

3.1 Strong interaction

QCD amplitudes with the gluon exchange at high energies
(and gluon reggeization proof)

A.V. Reznichenko, M.G. Kozlov

Frascati Physics Series Vol. XLVIII (2009), pp. 1-6 Young Researchers Workshop:
"Physics Challenges in the LHC Era"
Frascati, May 11 and 14, 2009, ISBN 978–88–86409–57–5

We demonstrate that the multi-Regge form of QCD amplitudes with gluon exchanges is proved in the next-to-leading approximation. The proof is based on the bootstrap relations, which are required for the compatibility of this form with the s-channel unitarity. It was shown that the fulfillment of all these relations ensures the Reggeized form of energy dependent radiative corrections order by order in perturbation theory. Then we prove that all these relations are fulfilled if several bootstrap conditions on the Reggeon vertices and trajectory hold true. All these conditions are checked and proved to be satisfied for all possible t-channel color representations. That finally completes the proof of the gluon Reggeization in the next-to-leading approximation and provides the firm basis for BFKL approach therein.

Effect of quark-mass variation on big bang nucleosynthesis

V.F. Dmitriev, J.C. Berengut, V.V. Flambaum,

arXiv:0907. 2288 Phys.Lett. Vol.B683, pp.114-118, 2010

We calculate the effect of variation in the light-current quark mass, m_q, on standard big bang nucleosynthesis. A change in m_q at during the era of nucleosynthesis affects nuclear reaction rates, and hence primordial abundances, via changes the binding energies of light nuclei. It is found that a relative variation of $\delta m_q/m_q = 0.016 \pm 0.005$ provides better agreement between observed primordial abundances and those predicted by theory. This is largely due to resolution of the existing discrepancies for ^{7}Li. However this method ignores possible changes in the position of resonances in nuclear reactions. The predicted ^{7}Li abundance has a strong dependence on the cross-section of the resonant reactions ^{3}He(d,p)^{4}He and t(d,n)^{4}He. We show that changes in m_q at the time of BBN could shift the position of these resonances away from the Gamow window and lead to an increased production of ^{7}Li, exacerbating the lithium problem.

Three-loop HQET vertex diagrams for $B^0 - \overline{B}^0$

A.G. Grozin and R.N. Lee

Journal of High Energy Physics, 0902 (2009) 047

Three-loop vertex diagrams in HQET needed for sum rules for $B^0 - \overline{B}^0$ mixing are considered. They depend on two residual energies. An algorithm of reduction of these diagrams to master integrals has been constructed. All master integrals are calculated exactly in *d* dimensions; their ε exgansions are also obtained.

Three-loop on-shell Feynman integrals with two masses

S.Bekavac, A.G.Grozin, D.Seidel, V.A.Smirnov

Nucl. Phys.B819 (2009) 183--200

All three-loop on-shell QCD Feynman integrals with two masses can be reduced to 27 master integrals. Here we calculate these master integrals, expanded in ε, both exactly in the mass ratio and as series in limiting cases.

Light quark mass effects in the chromomagnetic moment

S.Bekavac, A.G.Grozin, D.Seidel, M.Steinhauser

arXiv:0906.0130 (4 p.)

We present the three-loop QCD corrections to the quark chromomagnetic moment including two different nonzero masses. This is a necessary ingredient to obtain the corresponding corrections to the chromomagnetic coefficient in the Heavy Quark Effective Theory (HQET) Lagrangian.

Introduction to effective field theories
1. Heisenberg-Euler effective theory, decoupling of heavy flavours

A.G.Grozin

arXiv:0908.4392 (47 p.)

This is the first part of lectures about effective field theories. Decoupling of heavy-particle loops is considered (heavy leptons in QED, heavy quarks in QCD).

Matching QCD and HQET heavy-light currents at three loops

S.Bekavac, A.G.Grozin, P.Marquard, J.H.Piclum, D.Seidel, M.Steinhauser

arXiv:0911.3356 (23 p.); submitted to Nucl. Phys. B

We consider the currents formed by a heavy and a light quark within Quantum Chromodynamics and compute the matching to Heavy Quark Effective Theory to three-loop accuracy. As an application we obtain the third-order perturbative corrections to ratios of B-meson decay constants.

Matching of the low-x evolution kernels

V.S. Fadin, R. Fiore, A.V. Grabovsky

arXiv:0911.5617 [hep-ph]; to be published in Nucl. Phys. B

It is demonstrated that the ambiguity of the low-x evolution kernels in the next-to-leading order (NLO) permits one to match the Mőbius form of the BFKL kernel and the kernel of the colour dipole model and to construct the Mőbius invariant NLO BFKL kernel in N=4 supersymmetric Yang-Mills theory.

BFKL approach and dipole picture

V.S. Fadin

AIP Conference Proceedings, V. 1105, pp. 340-345

Inter-relation of the BFKL approach and the colour dipole model is discussed. In the case of scattering of colourless objects the colour singlet BFKL kernel can be taken in the special representation called Mőbius form. In the leading order (LO) it coincides with the kernel of the colour dipole model. In the next-to-leading order (NLO) the quark parts of the Mőbius form and the colour dipole kernel are in accord with each other, but the gluon parts do not agree. Possible sources of this discrepancy are analyzed.

Scalar contribution to the BFKL kernel

R.E. Gerasimov, V.S. Fadin

To be published in "Yadernaya Fizika"

Supersymmetric non-Abelian gauge theories, in particular the Yang-Mills theory with N=4 supersymmetry which is intensively discussed now in connection with its integrability, contain scalar particles. The contribution of such particles to the kernel of the BFKL equation is calculated. A great cancellation between the virtual and real parts of this contribution, analogous to the cancellation in the quark contribution in QCD, is observed. The reason of this cancellation is discovered. This reason is common for contribution of particles with any spin. Understanding of this reason permits to obtain the total contribution without the complicated calculations, which are necessary for finding separate pieces.

On the discrepancy of the low-x evolution kernels

V.S. Fadin, R. Fiore, A.V.Grabovsky

arXiv:0904.0702 [hep-ph]. Nucl. Phys. B820 (2009) 334

It is shown that in the case of the forward scattering the most part of the difference between the Mőbius form of the BFKL kernel and the BK kernel in the next-to-leading order (NLO) can be eliminated by the transformation related to the choice of the energy scale in the representation of scattering amplitudes. Change of the nonforward BFKL kernel under this transformation is derived as well. The functional identity of the forward BFKL kernel in the momentum and Mőbius representations in the leading order (LO) is exhibited and its NLO validity in N=4 supersymmetric Yang-Mills theory is proved.

Ambiguities of the NLO BFKL kernel

V.S. Fadin, A.V.Grabovsky

Proc.of XVII Int.Workshop on Deep-Inelastic Scattering and Related Topics, Madrid, Spain, April 2009,http://dx.doi.org/10.3360/dis.2009.19

Ambiguities of the low x evolution kernels in the next-to-leading order (NLO) are discussed. It is argued that their use can eliminate the discrepancy of the Mőbius form of the BFKL kernel and the BK kernel. For the case of the forward scattering it is demonstrated in an explicit way. It is shown also that the forward BFKL kernels in the momentum and Mőbius representations are functionally identical in the leading order and that in the NLO their identity is broken only by running of the coupling constant.

Exclusive $\gamma^*\gamma$ - processes

V.L. Chernyak

arXiv: 0912.0623 [hep-ph], pp. 1-12 Invited talk at the International Workshop: "From phi до psi»,, 13-16 October 2009, Beijing, China (to be published in Proceedings).

a) The review is presented of the current status of theoretical calculations in QCD of large angle cross sections "$\gamma+\gamma \to \bar{M}$ M, M = π^+, π^0, K^+, K^0,η". Comparison is performed with the predictions of the "handbag" model and recent experimental measurements of these cross sections.

b) The review is presented of the current status of theoretical calculations in QCD of form factors "$\gamma^*\gamma \to$P", P=π^0, η, η'. Comparison is performed of various models of the leading twist pion wave function $\varphi(x,\mu)$ with the recent experimental mesurements of these form factors.

A three-loop check of the a-maximization in SQCD with adjoint(s)

V.L. Chernyak

arXiv: 0912.3379 [hep-th], pp. 1-4

The 'a - maximization' was proposed by K. Inrtiligator and B. Wecht for finding anomalous dimensions of chiral superfields at the infrared conformal fixed points of the renorm-group flow. Using known explicit calculations of anomalous dimensions in the supersymmetric QCD perturbation theory, it is checked here at the three-loop level.

Space-time dimensionality *D* as complex variable: Calculating loop integrals using dimensional recurrence relation and analytical properties with respect to *D*

R.N.Lee

Nucl. Phys. B, (2009) in press.

We show that dimensional recurrence relation and analytical properties of the loop integrals as functions of complex variable D (space-time dimensionality) provide a regular way to derive analytical representations of loop integrals. The representations derived have a form of exponentially converging sums. Several examples of the developed technique are given.

3.2 Nuclear physics and parity nonconservation

Coulomb energy contribution to the excitation energy in ^{229}Th and enhanced effect of α variation

V.F. Dmitriev, V.V. Flambaum, N. Auerbach

Europhys.Lett. Vol.85, p.50005, 2009

We calculated the contribution of Coulomb energy to the spacing between the ground and first excited state of ^{229}Th nucleus as a function of the deformation parameter δ. We show that despite the fact that the odd particle is a neutron, the change in Coulomb energy between these two states can reach several hundreds KeV. This means that the effect of the variation of the fine structure constant $\alpha=e^2/\hbar c$ may be enhanced $\Delta U_c/E \sim 10^4$ times in the E=7.6 eV «nuclear clock» transition between the ground and first excited states in the ^{229}Th nucleus.

α-Particle Spectrum in the Reaction $p+{}^{11}B \to \alpha + {}^8Be^* \to 3\alpha$

V.F. Dmitriev

Physics of Atomic Nuclei, Vol.72, pp.1165–1167, 2009

Using a simple phenomenological parametrization of the reaction amplitude we calculated α-particle spectrum in the reaction $p+{}^{11}B \to \alpha + {}^8Be^* \to 3\alpha$ at the resonance proton energy 675 keV. The parametrization includes Breit-Wigner factor with an energy dependent width for intermediate $^8Be^*$ state and the Coulomb and the centrifugal factors in α-particle emission vertexes. The shape of the spectrum consists of a well defined peak corresponding to emission of the primary α and a flat shoulder going down to very low energy. We found that below 1.5 MeV there are 17.5% of α's and below 1 MeV there are 11% of them.

Electric dipole moments, from e to τ

A.G.Grozin, I.B.Khriplovich, A.S.Rudenko

Yad. Fiz.72 (2009) 1251—1253 [Phys. Atom.Nucl.72 (2009) 1203--1205]

We derive an upper limit on the electric dipole moment (EDM) of the τ-lepton, which follows from the precision measurements of the electron EDM.

Upper limits on electric dipole moments of τ-lepton and W-boson

A.G.Grozin, I.B.Khriplovich, A.S.Rudenko

Nucl. Phys.B821 (2009) 285--290

We discuss new upper limits on the electric dipole moments (EDM) of the τ-lepton and W-boson, which follow from the precision measurements of the electron and neutron EDM.

Upper Limits on Electric and Weak Dipole Moments of Tau-Lepton and Heavy Quarks from e^+e^- Annihilation

A.E. Blinov, A.S. Rudenko

Nucl. Phys. B (Proc. Suppl.) 189: 257-259, 2009

The total cross-sections measured at LEP for e^+e^- annihilation into $\tau^+\tau^-$, $c\,\bar{c}$ and $b\,\bar{b}$ at $2E \cong 200$ GeV are used to derive the upper limits for the electric dipole moments and the weak dipole moments of the τ-lepton, c-, and b- quarks.

3.3 Quantum electrodynamics

Coulomb effects in the spin-dependent contribution to the intra-beam scattering rate

V. M. Strakhovenko

arXiv: 0912.5429 v1 [physics.acc-ph], 2009

Coulomb effects in the intra-beam scattering are taken into account in a way providing correct description of the spin-dependent contribution to the beam loss rate. It allows one to calculate this rate for polarized e± beams at arbitrarily small values of the ratio $\delta\varepsilon/\varepsilon$, characterizing relative change of the electron energy in the laboratory system during scattering event.

Polarization of particles in electromagnetic showers developing in media

V. Strakhovenko

http://indico.cern.ch/event/53079 Invited talk given at the workshop "Posipol 2009",

Lyon, France, June 23-26, 2009

Theoretical description of development of electromagnetic showers in amorpous media is given taking into account polarizations of all particles involved. Cases where the shower may be initiated by the longitudinally polarized electron or by the circularly polarized photon are considered. Results obtained are crucially needed for designing a polarized positron source.

$(Z\alpha)^4$ order of the polarization operator in Coulomb field at low energy.

G.G. Kirilin and R.N. Lee

Nucl. Phys. B, 807 (2009) 73

We derive the low-energy expansion of $(Z\alpha)^2$ and $(Z\alpha)^4$ terms of the polarization operator in the Coulomb field. Physical applications such as the low-energy Delbrűck scattering and "magnetic loop" contribution to the g-factor of the bound electron are considered.

Electron shielding of the nuclear magnetic moment in a hydrogenlike atom.

V.G. Ivanov, S. G. Karshenboim, and R.N. Lee

Phys. Rev. A, 79 (2009) 012512

We obtain the shielding of the nuclear magnetic moment by the electron in $ns_{1/2}$ state in the hydrogen-like ion with arbitrary nuclear charge Z. The calculation is based on the decomposition of the shielding correction into two terms corresponding to the intermediate states with j=1/2 and j=3/2. The former is evaluated using the j=1/2 projection of the correction to the electron wave function due to the external magnetic field, while the latter is calculated applying the j=3/2 projection of the correction to the wave function due to the hyperfine interaction between the electron and the nucleus.

Barrier control in tunneling e^+ - e^- photoproduction

A. Di Piazza, E. Lotstedt, A.I.Milstein, C.H. Keitel

Phys.Rev.Lett.103, 170403 (2009).

Tunneling electron-positron pair production is studied in a new setup in which a strong low-frequency and a weak high-frequency laser field propagate in the same direction and collide head-on with a relativistic nucleus. The electron-positron pair production rate is calculated analytically in the limit in which in the nucleus rest frame the strong field is undercritical and the frequency of the weak field is below and close to the pair production threshold. By changing the frequency of the weak field one can reduce the tunneling barrier substantially. As a result tunneling pair production is shown to be observable with presently available technology.

Strong suppression of Coulomb corrections to the cross section of e^+e^- pair production in ultrarelativistic nuclear collisions

R.N. Lee, A.I. Milstein

Zh. Exp. Teor. Fiz., 136, ‘. 1121-1126 (2009)

The Coulomb corrections to the cross section of e^+e^- pair production in ultrarelativistic nuclear collisions are calculated in the next-to-leading approximation with respect to the parameter $L = \ln(\gamma_A \cdot \gamma_B)$ ($\gamma_{A,B}$ are the Lorentz factors of colliding nuclei). We found considerable reduction of the Coulomb corrections even for large $\gamma_{A,B}$ due to the suppression of the production of e^+e^- pair with the total energy of the order of a few electron masses in the rest frame of one of the nuclei. Our result explains why the deviation from the Born result were not observed in the experiment at SPS.

Electroproduction of electron-positron pair in oriented crystal at high energy

V. N. Baier and V. M. Katkov

Physics Letters A 373 (2009) 1874-1879.

The process of electroproduction of the electron-positron pair by high energy electron in an oriented single crystal is investigated. Two contributions are considered: the direct (one-step) process via the virtual intermediate photon and the cascade(two-step) process when the electron emits the real photon moving in the field of axis and afterwards the photon converts into the pair. The spectrum of created positron (electron) is found. It is shown that the probability of the process is strongly enhanced comparing with the corresponding amorphous medium.

Recent development of quasiclassical operator method
V. N. Baier and V. M. Katkov
Journal of Physics: Conference Series 198 (2009) 012003

The basis of the quasiclassical operator (QO) method is described. Application of the method for series of problems are discussed. These are processes in the superposition of plane wave and constant field, radiation in linear colliders, radiation in inhomogeneous fields, the new approach to the pair creation by a photon in a magnetic field, the theory of radiation in oriented crystals, radiation spectra taking into account the energy loss.

Pair creation by a photon in an electric field
V. N. Baier and V. M. Katkov
BINP preprint 2009-38

The process of pair creation by a photon in a constant and homogeneous electric field is investigated basing on the polarization operator in the field. The total probability of the process is found in a relatively simple form. At high energy the quasiclassical approximation is valid. The corrections to the standard quasiclassical approximation (SQA) are calculated. In the region of relatively low photon energies, where SQA is unapplicable, the new approximation is used. It is shown that in this energy interval the probability of pair creation by a photon in electric field exceeds essentially the corresponding probability in a magnetic field. This approach is valid at the photon energy much larger than the «vacuum» energy in electric field: $\omega \gg eE/m$. For smaller photon energies the low energy approximation is developed. At $\omega \ll eE/m$ the found probability describes the absorption of soft photon by the particles created by an electric field.

3.4 Gravity

Integration over connections in the discretized gravitational functional integrals
V.M.Khatsymovsky
Mod. Phys. Lett., in print; E-print archive arXiv: 0912.1109.

Integration over connections in the discretized gravitational functional integral is considered. Gravity is represented as simplicial (piecewise flat) manifold. First order formalism with independent area tensors and connections is considered. We prove that the result (the probability distribution) is suppressed at large areas exponentially. It is important for the consistency of the simplicial approach in the Einsteinian gravity. The probability distribution has maxima corresponding to the spectrum of the area operator in the continuous time limit when the simplicial edges tends to zero in a certain direction.

On positivity of quantum measure and of effective action in area tensor Regge calculus
V.M.Khatsymovsky
E-print archive arXiv:0707.3331.

We define for any 4-tetrahedron (4-simplex) the simplest finite closed piecewise flat manifold consisting of this 4-tetrahedron and of the one else 4-tetrahed\-ron identical up to reflection to the present one (call it bisimplex built on the given 4-simplex, or two-sided 4-simplex). We consider arbitrary piecewise flat manifold. Gravity action for it can be expressed in terms of sum of the actions for the bisimplices built on the 4-simplices constituting this manifold. We use representation of each bisimplex action in terms of rotation matrices (connections) and area tensors. This gives some representation of any piecewise flat gravity action in terms of connections. The action is a sum of terms each depending on the connection variables referring to a single 4-tetrahedron. Application of this representation to the path integral formalism is considered. Integrations over connections in the path integral reduce to independent integrations over finite sets of connections on separate 4-simplices. One of the consequences is exponential suppression of the result at large areas or lengths (compared to Plank scale). It is important for the consistency of the simplicial description of spacetime.

Capture of dark matter by the Solar System

I.B. Khriplovich and D.L. Shepelyansky

International Journal of Modern Physics D Vol. 18, No. 12 (2009) 1-10

We study the capture of galactic dark matter by the Solar System. The effect is due to the gravitational three-body interaction between the Sun, one of the planets, and a dark matter particle. The total mass of the captured dark matter particles is found. The estimates for their density are considerably less reliable. The most optimistic of them give an enhancement of density of dark matter by about three orders of magnitude as compared to its value in our Galaxy. However, even this optimistic value remains below the best present observational upper limits by about two orders of magnitude.

Comment on «Rovibrational quantum interferometers and gravitational waves»

I.B. Khriplovich, S.K. Lamoreaux, A.O. Sushkov, O.P. Sushkov

Phys. Rev. A, in press

In a recent paper, Wicht, Laemmerzahl, Lorek, and Dittus [Phys. Rev. A 78, 013610 (2008)] come to the conclusion that a molecular rotational-vibrational quantum interferometer may possess the sensitivity necessary to detect gravitational waves. We do not agree with their results and demonstrate here that the true sensitivity of such interferometer is many orders of magnitude worse than that claimed in the mentioned paper. In the present comment we estimate the expected energy shifts and derive equations of motion for a quantum symmetric top (diatomic molecule or deformed nucleus) in the field of gravitational wave, and then estimate the sensitivity of possible experiments.

3.5 Nonlinear dynamics and chaos

Quantum Chaos: Degree of Reversibility of Quantum Dynamics of Classically Chaotic Systems, in: ``Topics on Chaotic Systems: Selected Papers from CHAOS2008 International Conference”

V.V. Sokolov, O.V. Zhirov, Giuliano Benenti, Giulio Casati

(Chania, Crete, Greece, 3-6 June 2008), World Scientific, pp. 314-322, (2009)

We present a quantitative analysis of the reversibility properties of classically chaotic quantum motion by relating the degree of reversibility to the rate at which a quantum state acquires a more and more complicated structure during its time evolution. This complexity can be characterized by the number $M(t)$ of harmonics of the (initially isotropic, i.e. $M(0)=0$) Wigner function, which are generated by the time t. We show that, in contrast to the classical exponential increase, this number can grow after the Ehrenfest time t_E not faster than linearly. It follows that if the motion is reversed at some arbitrary moment T immediately after applying an instant perturbation with intensity describes by the parameter ξ then there exists a critical perturbation strength, $\xi_c(T) \approx \sqrt{2}/M(T)$, below which the initial state is well recovered, whereas reversibility disappears when $\xi \gtrsim \xi_c(T)$. In the classical limit the number of harmonics proliferates exponentially with time and the motion becomes practically irreversible. The above results are illustrated in the example of the kicked quartic oscillator model.

Quantum Dynamics Against a Noisy Background

V.V. Sokolov, O.V. Zhirov, and Yaroslav A. Kharkov

e-print: arXiv:0909.4179 [quant-ph] (2009);

Europhys. Lett.88 (2009) 60002

By the example of a kicked quartic oscillator we investigate the dynamics of classically chaotic quantum systems with few degrees of freedom affected by persistent external noise. Stability and reversibility of the motion are analyzed in detail in dependence on the noise level σ. The critical level $\sigma_c(t)$, below which the response of the system to the noise remains weak, is studied versus the evolution time. In the regime with the Ehrenfest time interval t_E so short that the classical Lyapunov exponential decay of the Peres fidelity does not show up the time dependence of this critical value is proved to be power-like. We estimate also the decoherence time after which the motion turns into a Markovian process.

Ballistic Electron Quantum Transport in Presence of a Disordered Background

V.V. Sokolov

e-print: arXiv:0912.0382 [cond-mat.mes-hall] 2 Dec 2009

Effect of a complicated many-body environment is analyzed on the electron random scattering by a 2D mesoscopic open ballistic structure. The temperature of the environment is supposed to be zero whereas the scattering energy E can be close to or somewhat above the Fermi surface in the environment. The both decoherence and absorption phenomena are treated within the framework of a unit schematic microscopic model. The single-particle doorway resonance states excited in the structure via external channels are damped not only because of escape through such channels but also due to the ulterior population of the long-lived background states. Transmission of an electron with a given E through the structure turns out to be an incoherent sum of the flow formed by the interfering damped doorway resonances and the retarded flow of the particles re-emitted into the structure by the environment. Due to environmental many-body effects, some part of the returning electrons lose their energy and disappear from the resonance energy interval thus imitating absorption, violation of the time reversal symmetry and, as a consequence, suppression of the weak localization. All these effects are controlled by the only parameter: the spreading width that uniquely determines the decoherence rate.

Quantum synchronization and entanglement of two qubits coupled to a driven dissipative resonator

O.V. Zhirov and D.L. Shepelyansky

e-print: arXiv:0904.0289v1 [cond-mat.supr-con](2009); Phys. Rev.B,80, 014519(2009).

Using method of quantum trajectories we study the behavior of two identical or different superconducting qubits coupled to a quantum dissipative driven resonator. Above a critical coupling strength the qubit rotations become synchronized with the driving field phase and their evolution becomes entangled even if two qubits may significantly differ from one another. Such entangled qubits can radiate entangled photons that opens new opportunities for entangled wireless communication in a microwave range.

Google matrix, dynamical attractors and Ulam networks

D.L. Shepelyansky and O.V. Zhirov
e-print: arXiv:0905.4162v2 [cs.IR] (2009)

We study the properties of the Google matrix generated by a coarse-grained Perron-Frobenius operator of the Chirikov typical map with dissipation. The finite size matrix approximant of this operator is constructed by the Ulam method. This method applied to the simple dynamical model creates the directed Ulam networks with approximate scale-free scaling and characteristics being rather similar to those of the World Wide Web. The simple dynamical attractors play here the role of popular web sites with a strong concentration of Page Rank. A variation of the Google parameter α or other parameters of the dynamical map can drive the Page Rank of the Google matrix to a delocalized phase with a strange attractor where the Google search becomes inefficient.

Correction to the Moliere's formula for multiple scattering

R.N. Lee, A.I. Milstein
Zh. Exp. Teor. Fiz., 135 (2009) 1125

The semiclassical correction to Moli¨re's formula for multiple scattering is derived. The consideration is based on the scattering amplitude obtained with the first semiclassical correction taken into account for an arbitrary localized but not spherically symmetric potential. Unlike the leading term, the correction to Molire's formula contains the target density n and thickness L not only in the combination nL (areal density). Therefore, this correction can be referred to as the bulk density correction. It turns out that the bulk density correction is small even for high density. This result explains the wide range of applicability of Moli¨re's formula.

Induced Current and Aharonov-Bohm Effect in Graphene

R. Jackiw, A.I.Milstein, S.-Y. Pi, I. S. Terekhov
Phys. Rev. B 80, 033413 (2009).

The effect of vacuum polarization in the field of an infinitesimally thin solenoid at distances much larger than the radius of solenoid is investigated. The induced charge density and induced current are calculated. Though the induced charge density turned out to be zero, the induced current is finite periodical function of the magnetic flux F. The expression for this function is found exactly in a value of the flux. The induced current is equal to zero at the integer values of F/F0 as well as at half-integer values of this ratio, where F0 = 2pc/e is the elementary magnetic flux. The latter is a consequence of the Furry theorem and periodicity of the induced current with respect to magnetic flux. As an example we consider the graphene in the field of solenoid perpendicular to the plane of a sample.

4

PLASMA PHYSICS AND CONTROLLED THERMONUCLEAR FUSION

4.1 Confinement of hot ion plasma with β=0.6 in the gas dynamic trap

A so called vortex confinement of plasma in axially symmetric mirror device was studied. This recently developed approach enables to significantly reduce transverse particle and heat losses typically caused by MHD instabilities which can be excited in this case. Vortex confinement regime was established by application of different potentials to the radial plasma limiters and end-plates. As a result, the sheared plasma flow at periphery appears which wraps the plasma core. Experiments were carried out on the gas dynamic trap device, where hot ions with a mean energy of $E_h \approx 9$keV and the maximum density of energetic ions $n_h \approx 5\times10^{19}m^{-3}$ were produced by oblique injection of deuterium or hydrogen neutral beams into a collisional warm plasma with the electron temperature up to 250 eV and density $n_w \approx 2\times10^{19}m^{-3}$. Local plasma β approaching 0.6 was measured. The measured transverse heat losses were considerably smaller than the axial ones. The measured axial losses were found to be in a good agreement with the results of numerical simulations. Recent experimental results support the concept of the neutron source based on the gas dynamic trap.

4.1.1 Introduction

The development of fusion energy sources requires materials which can withstand energetic neutrons and plasma during decades. The Gas Dynamic Trap (GDT) in Novosibirsk [1] was intended to be used for development of a fusion neutron source to test and validate appropriate materials [2]. Recent results with β=0.6 [3] provides a firm basis for extrapolating to a fusion relevant neutron source. Relative to previous magnetic mirror neutron sources [4,5], the GDT concept uses simpler axisymmetric magnets and consumes less tritium providing about $2MW/m^2$ neutron flux. Besides testing materials, the GDT based neutron source can be used in a fusion driven system for burning minor actinides of nuclear waste [6].

The main part of the Gas Dynamic Trap device is an axially symmetric magnetic mirror with high mirror ratio for confinement of plasma, which consists of two ion components with different energies (Fig.1). First of them is warm ions with isotropic in velocity space Maxwellian distribution function, with temperature about 200 eV, density $n_w \approx 2\times10^{19}m^{-3}$. These ions are confined in the gas-dynamic regime[1]. The second component is hot ions, which are produced as a result of oblique injection of hydrogen or deuterium beams into plasma. Energies of injected atoms are in the range of 22-25 keV. The hot ions are confined in the adiabatic regime performing bounce oscillations between the mirror points near the mirror ends. Energy confinement time of hot ions is determined by the electron drag and turns out to be much less than its angular scattering time. Thus the hot ions have anisotropic in the velocity space distribution function, relatively small angular spread, and their density and pressure are peaked in the mirror points. The mean energy of the hot ions is $E_h \approx 9$keV, and their density near the mirror points reaches $n_h \approx 5\times10^{19}m^{-3}$. The temperature of electrons reaches $T_e \approx 250$ eV.

In 2009 the GDT device was substantially upgraded: power of atomic injection system was increased, magnetic field was increased, and diagnostics were updated. The GDT parameters after upgrade are listed in Table 1.

The experimental program at the GDT device is focused at obtaining the fundamental knowledge of physics of plasma confinement in the open magnetic traps and on the other hand at gaining a database for development of a high-flux neutron source.

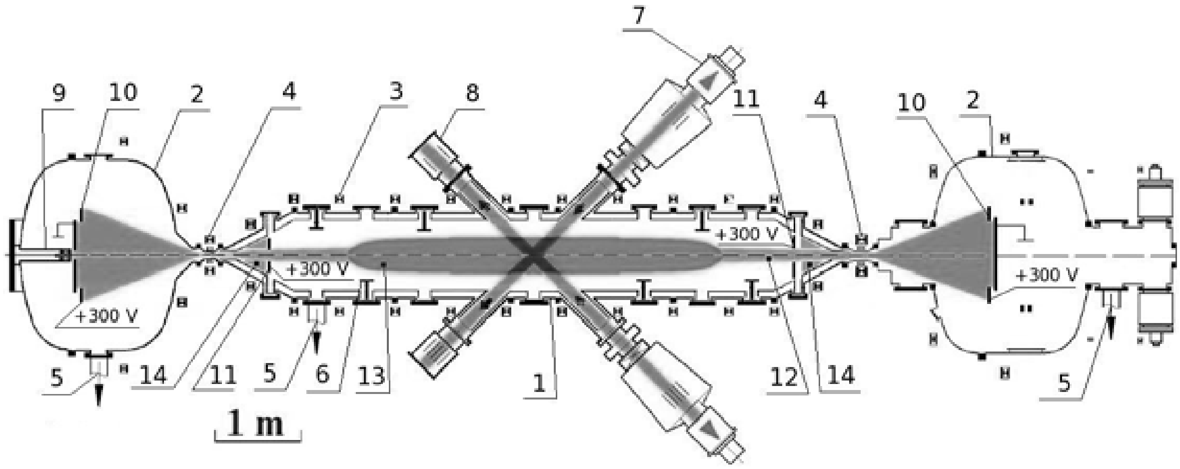


Fig. 1 Schematic of the GDT device: 1 – central vacuum vessel; 2 – end tanks; central solenoid coils; 4 – mirror coils; 5 – vacuum pumping ports; 6 – titanium evaporators; 7 – neutral beam injectors; 8 – neutral beam dumps; 9 – initial plasma source; 10 – sectioned end-plates (central parts are grounded, internal rings are biased with approximately +300 V; 11 - biasing limiters; 12 – warm plasma column; 13 – hot ion column; 14 – boxes for cold gas fueling.

In the general case the magnetic field of an axially symmetric magnetic trap is not providing the MHD stable plasma confinement [7]. In this work we present the results of experiments where the "vortex confinement method" was used for the suppression of perpendicular losses due to development of unstable MHD modes in the axially symmetric mirror device without additional stabilizing magnetic cells. This involves the differential plasma rotation at periphery. Interaction between shear flows and plasma motions due to instabilities in axially symmetric mirrors can lead to an improved radial confinement [8], observed also in the GDT experiments and confirmed by simulations [9]. Shear flows, driven by using the biased end-plates and limiters, in combination with finite-Larmor-radius effects are shown to be efficient to radially confine high-β plasma even with magnetic hill on axis. Interpretation of the observed effects as the "vortex confinement", i.e., confinement of the plasma core in the dead-flow zone of the driven vortex, agrees rather well with simulations. Theoretical scaling laws predict such confinement scheme to be also applicable at higher plasma temperature and density.

Local plasma β approaching 0.6 was measured in the steady-state regime of plasma confinement. At the same time the longitudinal losses of particles and energy are in a good correspondence with gas-dynamic model of collisional plasma streaming through the mirrors and the role of perpendicular losses is insignificant. Recent experimental results support the concept of the neutron source based on the gas dynamic trap.

Table I. Parameters of the GDT device

Mirror-to-mirror distance	7 m
Magnetic field at the mid-plane	up to 0.35 T
Mirror ratio	33
Total neutral beam power	up to 5 MW
Trapped beam power	1.8 MW
Time of neutral beams operation	5 ms
Injection angle	45°
Warm ion density at the mid-plane	$2\times10^{19} m^{-3}$
Fast ion density at turning points	up to $5\times10^{19} m^{-3}$
Electron temperature	up to 250 eV
Plasma radius at mid-plane	0.14 m

4.1.2 Experiment

Typical experimental scenario at the GDT device was the following:

- At first the magnetic field was created.

- Then the preliminary plasma having temperature of 10 eV filled the trap with the help of plasma source behind the mirror at one of the GDT sides. Exit aperture of the source was in the plane where magnetic field was 100 times less than that in the mirrors. Duration of the plasma source operation was 4 ms.

- After the plasma generator shutoff the injection of neutral beams started. The injection system consisted of 8 injector modules. The duration of neutral beam injection was 5 ms.

- At the same time started the injection of gaseous hydrogen or deuterium azimuth evenly into the peripheral plasma with the help of two pulsed valves located near the magnetic mirrors where plasma had relatively small diameter. The duration of gas injection was usually a little bit longer than 5 ms. The central vacuum vessel and the end tanks are pumped out by 1.5 m^3/s turbomolecular pumps each. In order to improve wall conditions in the central cell of vacuum chamber Ti-evaporators have been installed which are capable of deposition a sufficiently thin metallic film on the inner surface of the chamber in shot time just before plasma shot [10].

For the suppression of the perpendicular losses due to the development of MHD instabilities was implemented an earlier experimentally and theoretically well-grounded method of vortex confinement [9]. Vortex confinement occurs when the radial profile of electric potential in plasma has stepped structure, and potential jump is located in the peripheral radial area of plasma column. This potential profile was created with the help of special electrodes: radially segmented plasma absorbers located behind the mirrors near the planes where magnetic field is 100 times less than magnetic field in the mirrors, and also by means of radial limiters inside the trap close to the magnetic mirrors. The positive relative to the grounded internal sections of plasma absorbers voltage of 200-300 eV was applied to the radial limiters and external sections of plasma absorbers which are projected one onto another along the magnetic field lines. Such radial electric potential distribution generates the zone of plasma differential rotation in the peripheral radial area of plasma column. It turns out that combination of plasma differential rotation with its motion at the saturation stage of unstable MHD modes leads to formation of a steady state vortex structure of plasma flux lines.

The analysis of the influence of the shear flow on the plasma confinement in the mirror system was carried out in the work [5]. Analytical and numerical models of vortex confinement occurring in the presence of electric potential drop in plasma close to the limiter radius were developed. The model takes into account the most essential effects: electric contact with limiters and end plasma absorbers, electron temperature gradient, finite ion Larmor radius effects, and thus is capable to describe the non-linear development of different large-scale instabilities. Particularly Kelvin-Helmholtz, flute-like and temperature-gradient instabilities are described.

Plasma vortex confinement described by the model is that hot central discharge part can be confined in the stagnant zone of vortex flow. If this flow is generated and supported by the external sources then the regime with small convective loss can be achieved. Though the plasma remains linearly unstable, convection is saturated at a low level, and the main thing is that the central convective cell does not reach the limiter. Non-linear convection saturation as well as the generation of the vortex flow are connected with the end current dissipation. This dissipation is especially effective for large-scale modes m=1, preferential selection of which occurs in plasma with hot ions due to finite ion Larmour radius effects. The main conclusion of the work [5] is that for gas dynamic trap the method of vortex confinement allows to minimize the power of energy perpendicular loss to the 10-15% of longitudinal loss power. And the additional energy consumption for the maintenance of the vortex confinement regime does not exceed several percents of total plasma heating power. These conclusions are also valid for the projected neutron source based on the GDT device.

4.1.3 Results

Several experimental series were carried out with different combination of hot ion and warm ion masses. The closest to the steady-state regime was the regime with hydrogen injection into the hydrogen plasma. The highest value of the diamagnetism was obtained in the regimes with deuterium injection into hydrogen or deuterium plasma. These facts are connected with the different value of energy confinement time of hot ions which is determined basically by the electron dragging and is proportional to the ion mass:

$$\tau_{ei} = \frac{3}{4\sqrt{2\pi}} \cdot \frac{m_i}{\sqrt{m_e}} \frac{T_e^{3/2}}{z^2 \cdot \Lambda \cdot e^4 \cdot n},$$

where m, z –mass and charge of hot ions, m_e, e, n, T_e – mass, charge, density and temperature of the electrons, Λ - Coulomb logarithm.

In the figure 2 local magnetic field perturbation, versus total energy of fast ion population is shown in the regime with deuterium injection into hydrogen plasma. Measurements were made at the centre of plasma column in the area of ion reflection with the help of beam-spectroscopic diagnostics based on the Motional Stark effect. Spatial resolution of the measurement of local magnetic field variation was 3 cm, time resolution – 1 ms. Mean value of local magnetic field variation to the vacuum magnetic field ratio in the series of measurements was $\Delta B/B_v$=0.32, maximal value obtained in one of the shots reached $\Delta B/B_v$=0.37.

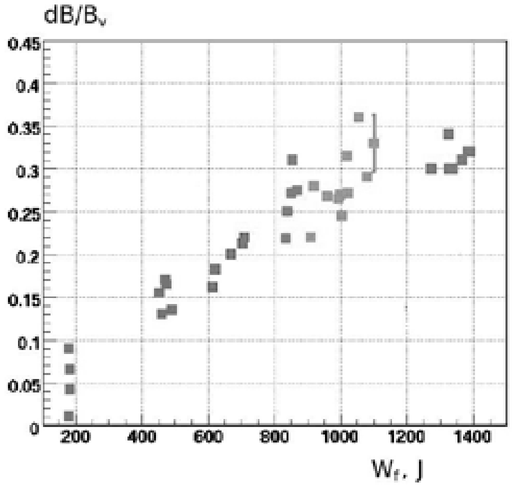


Fig. 2. Local magnetic field perturbation measured on the axes at the turning points region of hot ions versus total energy of fast ion population.

Value of the parameter β was calculated using the plasma equilibrium equation in the paraxial approximation:

$$\beta = 2 \cdot \frac{\Delta B}{B_V} - \left(\frac{\Delta B}{B_V} \right)^2,$$

where B_v – value of the vacuum magnetic field, $\Delta B = B_v - B$ – magnetic field variation due to the plasma diamagnetism, B – measured value of the magnetic field. Parameter β=0.54 corresponds to the $\Delta B/B_v$=0.32, β=0.6 corresponds to the maximum value $\Delta B/B_v$=0.37. Using values of β, B, and the mean energy of hot ions $<\varepsilon>$ maximum value of hot ion density can be estimated $n_h = \frac{\beta \cdot B_v^2}{8\pi \cdot <\varepsilon>}$

For the regime with β=0.6, $<\varepsilon> \approx 9$ keV from the estimation it follows that $n_h \approx 5\times10^{19}$ m^{-3}.

To evaluate the role of the perpendicular loss in comparison with the longitudinal one and to make the scaling of electron temperature dependence on the power of plasma heating the series of measurements of different parameters were made at the regimes with different power of atomic beam injection. The system of atomic beam injection consists of 8 injector modules. Series of measurements were conducted at the regimes with hydrogen injection into hydrogen plasma using 2, 4, 6 and 8 injectors. Trapped power of the injected beams, plasma density and temperature and the power of charge-exchange loss of the hot ions were measured.

The estimation of the electron temperature at the GDT device defined by the balance of heat fluxes in plasma was made taking into account the following considerations:

1. It is assumed that there is a steady-state regime relative to the all processes which define the plasma confinements at the GDT device
2. Stationary balance is determined by the equality of heating power of the atomic injection and the power of longitudinal loss in the case of gas dynamic plasma flow through the mirrors and absence of perpendicular loss.

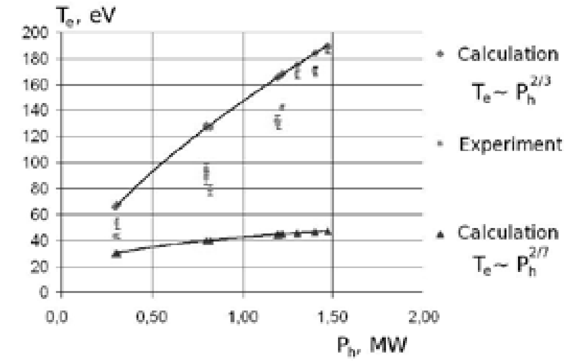


Fig. 3. The dependence of the electron temperature experimentally measured laser-scattering system (gray squares) and calculated temperature obtained from the equation (2) (dark squares) on the power of plasma heating. Results of calculations of electron temperature based on classical Spitzer's heat conductivity are plotted also for comparison (triangles).

According to conclusions of the work [1] which are in a good agreement with the results of experiment [2] the ion and electron flux densities at the middle cross-section of the mirror in the case of gas dynamic plasma flow are:

$$q_i = q_e = 1.53 \cdot n_w \cdot \left(\frac{T_e}{2\pi m_w} \right)^{1/2},$$

where m_w – the mass of warm ions, n_w – the density of warm ions in the trap. From the results of work [1,2] it also follows that every electron-ion pair exiting the trap should carry the mean energy of $8 \cdot T_e$ and the density of energy flux at the mirror cross-section is:

$$Q = 7.89 \cdot q_i \cdot T_e.$$

Equating the longitudinal loss power into 2 throats and plasma heating power it turns out:

$$P_{\parallel} = 2 \cdot Q \cdot S_m = \frac{2 \cdot Q \cdot \pi \cdot a^2}{R} = P_h, \qquad (1)$$

where $S_m = \pi \cdot a^2/R$ – the area of middle cross-section of the mirror, a – plasma radius at the central section, R – mirror ratio, P_h – power of plasma heating by the atomic injection (it is equal to the trapped atomic beam power after deduction of charge-exchange loss of hot ions, it is considered that other possible loss channels of hot ions are negligible). Having substituted appropriate expression in the equation (1) and expressing T_e, we obtain in practical units:

$$T_e = 765 \cdot \left(\frac{P_h \cdot R}{n_w \cdot a^2} \right)^{2/3}, \qquad (2)$$

where P_h should be expressed in MW, n_w – in 10^{19} m^{-3}, a – in cm, T_e – in electron-Volts.

In the figure 3 the dependence of the electron temperature experimentally measured with the help of laser-scattering system and the calculated temperature obtained from the equation (2) on the different power of plasma heating are shown. One can see that for the temperatures T_e>150 eV results of estimation are in a good agreement with measured values. Note that estimations were carried out in the frame of hypothesis about negligible level of transversal heat flux in comparison with longitudinal one. Results of calculations of electron temperature based on classical Spitzer's heat conductivity are plotted also for comparison.

Two circumstances are following from the data plotted on the figure 2:

1. transversal energy flux is negligible in comparison with the longitudinal one in the regime of vortex confinement. Scaling (2) based on the steady state balance between heat power and longitudinal heat loss in the gas dynamic regime of plasma flow through the mirror throats is in a reasonable agreement with experimental data.
2. Taking into account scaling (2) one can predict value of electron temperature more than 1 keV for heat power of ≈20 MW in the projecting neutron source based on the das dynamic trap. According results of computer simulations [6] this value of T_e is quite suitable for effective production of neutrons.

4.1.4 Conclusions

On the basis of the experiments presented in this work the following conclusions can be made:

1. The longitudinal particle and energy loss are in the good agreement with the model of gas dynamic flow of the collisional plasma through the mirrors, and the perpendicular heating power loss does not exceed 15% of total plasma heat power.
2. Obtained results in the aggregate with some earlier results are the sufficient argument supporting feasibility of the project of the neutron source based on the gas dynamic trap.

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4.2 Multimirror Trap GOL-3

4.2.1 Introduction

Scientific program of 2009 was targeted to several specific tasks of physics and technology of multiple-mirror confinement systems for a high-temperature plasma. Development of experimental base was continued in 2009 in parallel with experiments under scientific programs. New advances in a technology of generation of a long-pulse electron beams with the plasma emitter were achieved. The diagnostic complex of GOL-3 was improved with several new diagnostics which will be discussed later in the text.

Layout of the facility is presented in Fig.1. The 12-meter-long solenoid consists of 103 coils with an independent feed. In the regular multimirror configuration the magnetic field has 52 corrugation periods (cells of multimirror system) with 22 cm length, the field in maxima is 4.8 T, in minima is 3.2 T. The mirror ratio of the corrugated field is 1.5. That means that the operating mode of GOL-3 corresponds to a "weak corrugation regime". The solenoid terminates in single magnetic mirrors with a field of 8-9 T. The exit unit consists of the plasma creation system and exit expander tank with the end beam collector. Magnetic field strength decreases to 0.05 T at the collector surface reducing therefore specific heat flux at the surface. Metals therefore can be used as material for the collector plate.

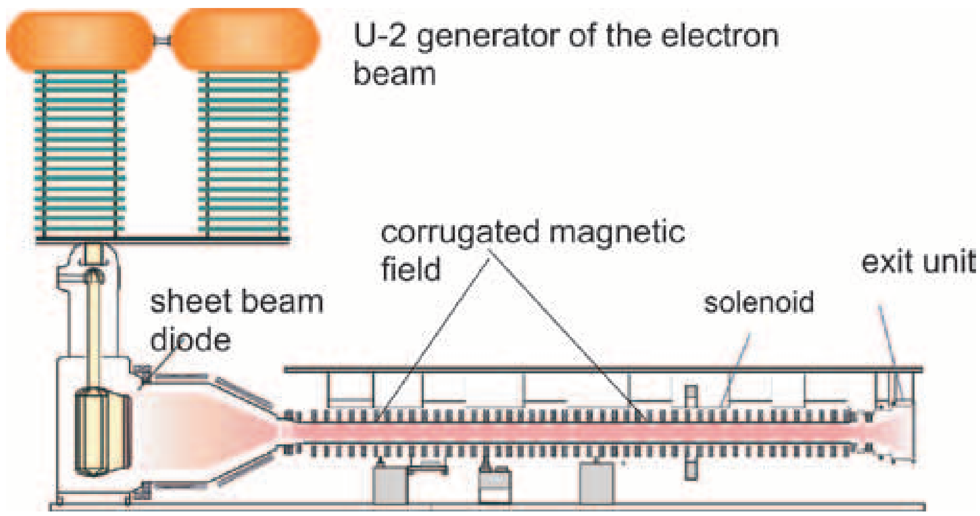


Fig. 1: Layout of GOL-3.

A typical experimental scenario is the following. Several gas-puff valves create required axial deuterium density distribution in a metal vacuum chamber Ø10 cm, placed inside the solenoid. Then a special linear discharge creates a start plasma with length-averaged density of $\sim 3 \cdot 10^{20}$ m^{-3} and temperature ~2 eV. After that the relativistic electron beam with the following parameters is injected into this plasma with the following parameters in a standard regime: electron energy is ~0.8 MeV, current is ~25 kA, duration is ~12 μs, energy content is ~120 kJ, the beam diameter is ~4.1 cm (this value corresponds to 3.2 T magnetic field as in minima of corrugated magnetic field). Such the beam is formed in a slit relativistic diode of the beam generator U-2 and then it is transformed to a circular shape and compressed by a magnetic system of U-2. As a result of collective heating the plasma gets ion temperature 2÷3 keV (in the hottest part of the plasma column). In the next section results from a new experimental scenario with tenfold-decreased current and cross-section of the beam will be discussed. Use of the multimirror confinement scheme (the corrugated magnetic field) allows to confine the hot plasma much longer, than in a simple solenoidal trap.

4.2.2 Experiments with the beam of reduced cross-section

Extended experimental campaign devoted to studies of interaction of the beam with reduced cross-section with the plasma and neutral gas started in 2008. Check of existence of turbulent thermal insulation of the plasma at the order of magnitude smaller current and power of the beam was the main physical task for the mentioned experiments. Initial specific beam parameters (initial angular spread and beam current density) remain the same as in the standard regime. The beam cross-section was reduced down to 13 mm at ~1.5 kA peak current. For this purpose a small central part was cut from the standard beam by means of the graphite limiter placed in the area of a final beam compression before its injection in the solenoid. The beam diameter become significantly smaller than diameters of the vacuum chamber and of the plasma, so further in the text such beam will be referred as thin beam.

Main features of interaction of the thin beam with the plasma were already discussed in the Report for 2008. Therefore only new results will be presented further in this Section. Despite the fact that the beam transport through the plasma column was stable in general, some displacement of the beam-heated zone in respect to calculated one was observed. These displacements were different not only in different shots but also can change in the course of one experiment.

Two sets of waveforms are shown in Fig. 2 which include waveforms of the diode voltage (smooth envelopes) and of three channels of the multifoil analyzer of the beam spectrum. The left part correspons to a special calibration shot into vacuum with the beam of decreased energy. Signals from the analyzer are continuous and last for expected duration despite being heavily spiked due to known microstructure of the beam. At the same time in a typical shot with the plasma the same signals undergo simultaneous breaks and recoveries. The quantity and duration of such breaks varies from shot to shot. At the same time output of an exit bremmstrahlung monitor remains smooth and continuous in all the cases. The beam relaxation efficiency calculated as a relative decrease of the mean energy of electrons remains practically constant over those fragments of waveforms where such calculation is possible. Such situation can be naturally explained by the beam footprint displacement from the analyzer position. The displacement amplitude at the surface of the exit collector is at least comparable with the analyzer aperture.

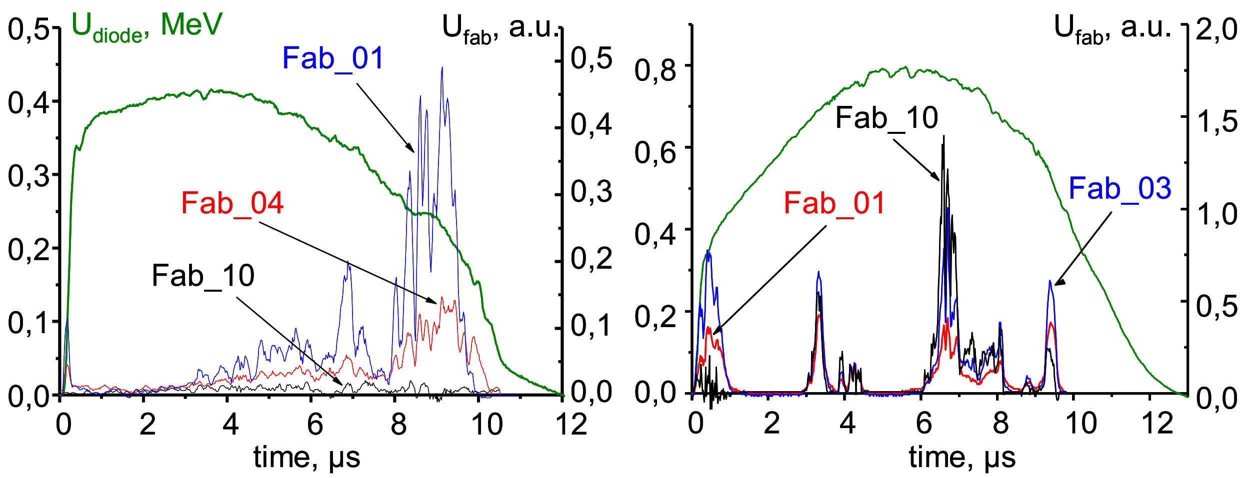


Fig. 2: waveforms of the diode voltage (smooth envelopes) and of three channels of the multifoil analyzer of the beam spectrum. The left part is for a shot into vacuum, the right part is for a shot into the plasma.

Signs of the beam displacement from the axis are detected also with other diagnostics. In particular, a typical result of electron energy spectrum measurement by a Thomson scattering system is shown in Fig. 3. Simultaneous measurements in two points were done. One point was at the axis (at the expected beam center) and another was 6 mm apart (at the expected edge of the beam-heated zone). At the stable beam transport the mean electron energy in the center should always be larger than at the edge, such situation is presented in Fig. 3. Nevertheless other cases were also observed, namely, equality of the mean energies, hotter electrons in the edge channel or negligible plasma heating in both channels. Such behavior evidences for large shot-to-shot displacement of the beam position. We should note that the observed displacement of the beam at the Thomson scattering system location (at 415 cm from the beam input) is still small enough and the beam remains within the preliminary plasma cross-section.

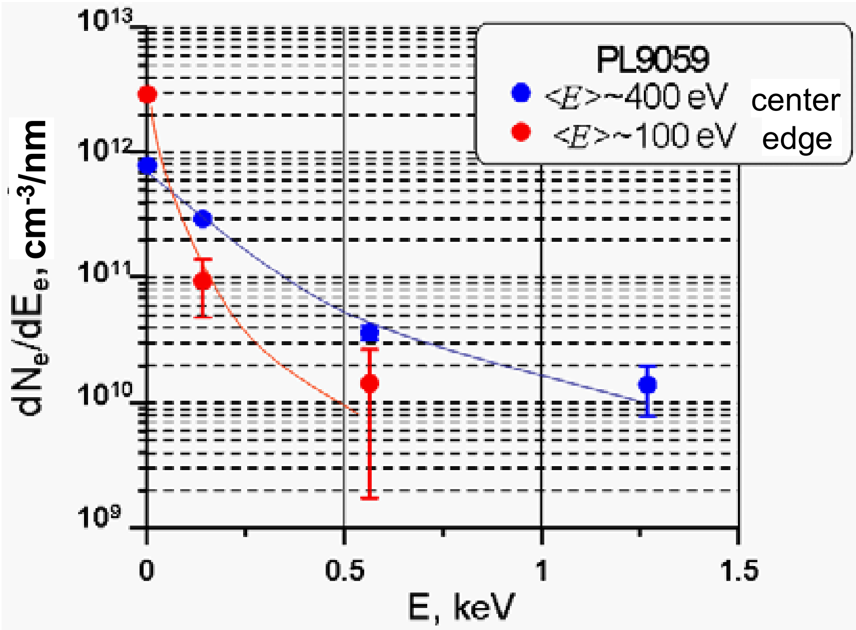


Fig. 3: Energy spectrum of plasma electrons measured by a Thomson scattering system simultaneously for the point at the axis (at the expected beam center) and 6 mm apart (at the expected edge of the beam-heated zone).

Direct comparison of regimes with the beam injection into preliminary-prepared low-temperature plasma and into deuterium gas of the same density became possible in the experiments with the thin beam for the first time at GOL-3. Earlier such experiments were not possible due to two reasons. Full current of the "standard" beam exceeded significantly the limiting vacuum current and fast development of the Kruskal-Shafranov instability occurred at the beam injection into a neutral gas (or into a plasma with insufficient ionization degree). In such a case the beam was dumped to the wall with some damage of it.

Measurements with different diagnostics demonstrate that efficiency of the beam relaxation in the gas is about twofold worse than in the plasma of the same number density. The same twofold difference was observed for the peak energy which the beam leaves in the plasma. Similar conclusion on significant role of preliminary ionization for obtaining the good beam relaxation was earlier made in the experiments at GOL-3-I with shorter plasma column (those experiments were done with uniform magnetic field).

Experiments with the beam injection into the non-ionized gas enable studies of features of formation of the return current which in turn creates the edge plasma. Observed time-integrated VUV profile is broader than the expected one (see, e.g., Fig. 4). Interesting that ionization of the gas and formation of the edge plasma occur not only within the expected beam cross-section but in the whole cross-section of the vacuum chamber (see Fig. 5). Therefore at later stages of the experiment the evolution of the beam-plasma system is similar to that observed in the experiments with the preliminary plasma.

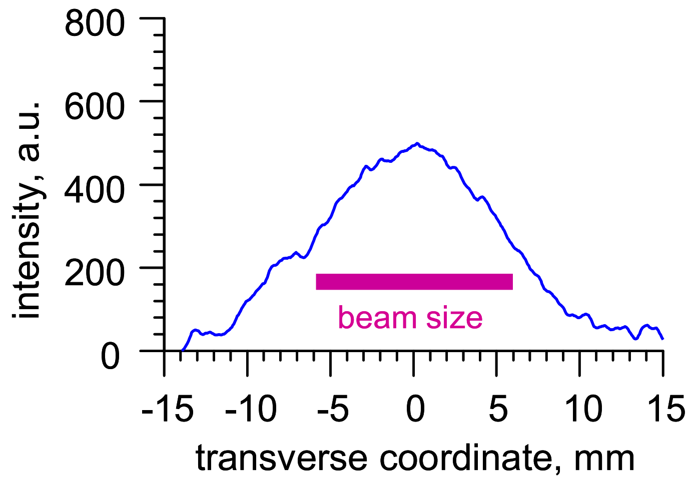


Fig. 4: Radial profile of OV 76.0 nm emission (shot into the gas).

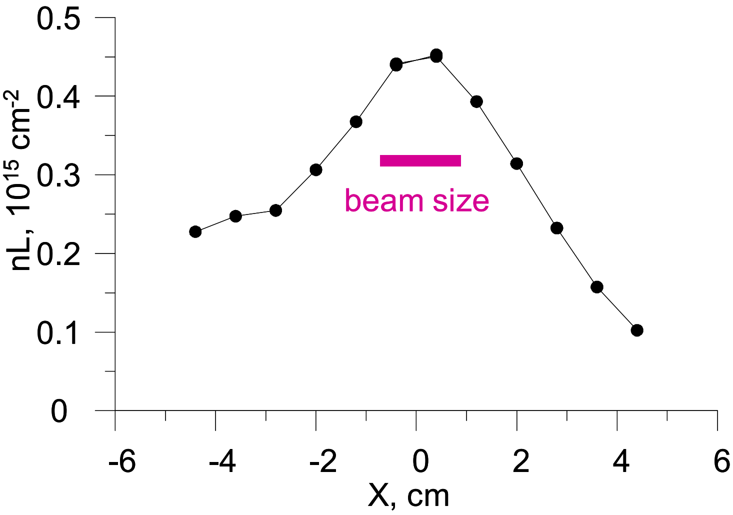


Fig. 5: Increment of linear plasma density in 10 μs after the beam injection starts measured by neutral beam attenuation.

4.2.3 Measurement of subterahertz emission from the plasma

Diring the intensive relaxation of an electron beam in a plasma with a high level of Langmuir turbulence a process of nonlinear merging of two Langmuir plasmons into an electromagnetic wave is possible. The wave frequency corresponds approximately to double plasma frequency. Therefore information on dynamics of radiated spectrum allows deeper understanding of the beam-plasma interaction process and of the plasma properties which are varying during the experiment.

For typical values of plasma density $10^{20}\div10^{21}$ m^{-3} the linear frequency of $2\omega_p$ emission is within the range 180÷565 GHz. We have developed a specialized four-channel radiometric diagnostics based on quasi-optical anisotropic mesh structures for registering intensity and spectrum of radiation in the vicinity of the double plasma frequency in 2008. Such system was applied for the first time in experiments with microsecond electron beams. In 2009 new physical results form the "thin beam" operation regime were obtained.

Typical waveforms from polarization studies of $2\omega_p$ electromagnetic emission are shown in Fig. 6 which indicates that parallel to the magnetic field polarization is the dominating.

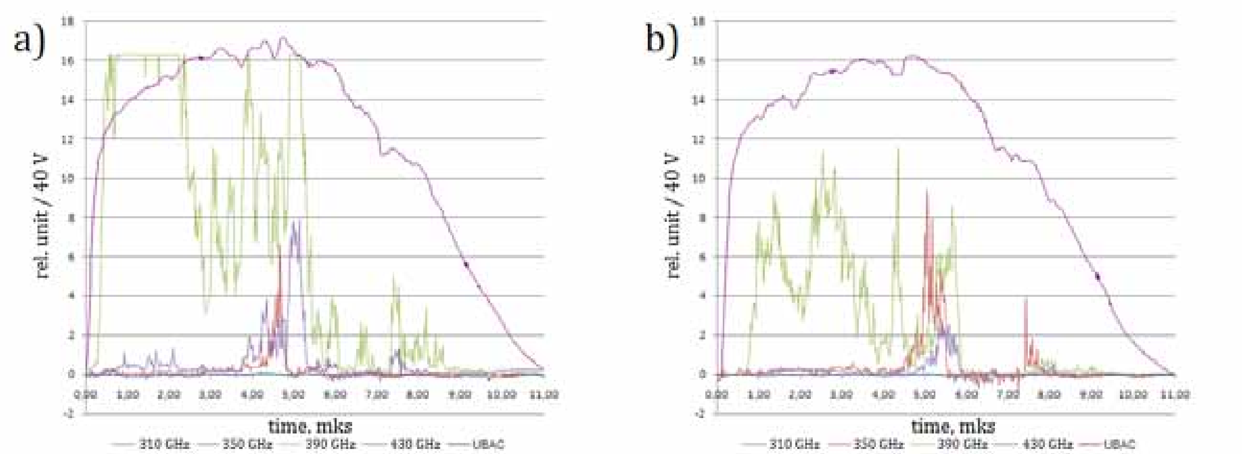


Fig. 6: Waveforms of the diode voltage (upper curves) and signals of sub-THz detectors for two cases: a) polarisation is parallel to the magnetic field; b) polarization is transverse to the magnetic field.

A significant new result revealed with the electron beam of decreased diameter is the demonstration of existence of a high-frequency structure of the microwave radiation. The radiation dynamics is shown in Fig. 7 at 2 ns time resolution. The waveforms are evidently composed from a large number of partially-overlapped short radiation bursts with 2-5 ns duration with a 1-3 μs background envelope.

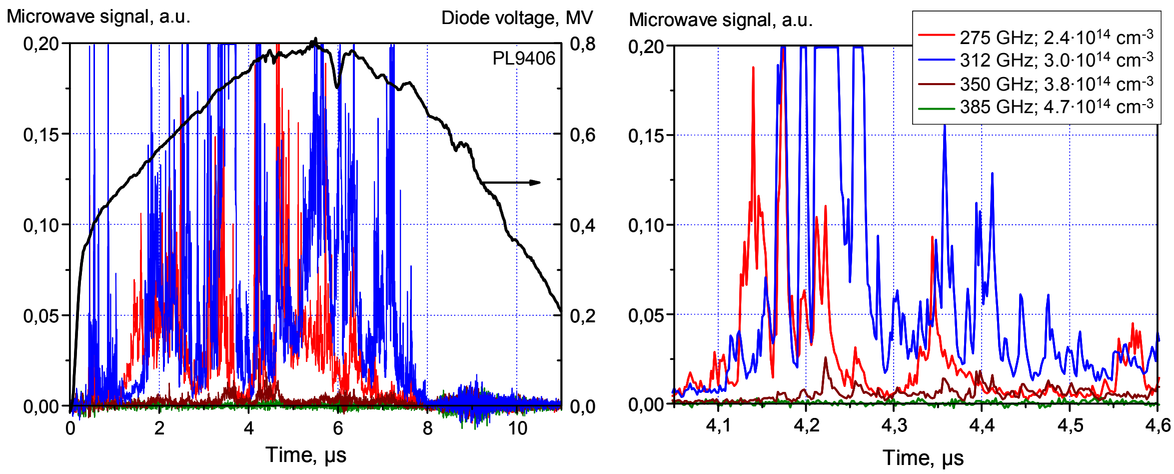


Fig. 7: Waveforms of the diode voltage (upper smooth curve) and signals of sub-THz detectors. Left part corresponds to full duration of the beam, right part is a fragment.

Most probable interpretation of the observed radiation structure is the following. The radiation is emitted from a compact plasma zones with an increased density of Langmuir plasmons. Theory predictions and preceded GOL-M experiments nominate a good candidates for such compact radiation zones. They are dynamic density dips (caverns) which emerge at the final stage of development of Langmuir turbulence. Lifetimes and spatial scales of dynamic density dips observed earlier in GOL-M experiments correspond to measured duration of individual microwave pulses. Measurements in the experiments with the full-sized electron beam did not reveal such structure due to a much larger quantity of simultaneously radiating zones.

A shift of radiation spectrum to higher frequencies was observed in some experiments that can correspond to growth of the plasma density (see Fig. 8).

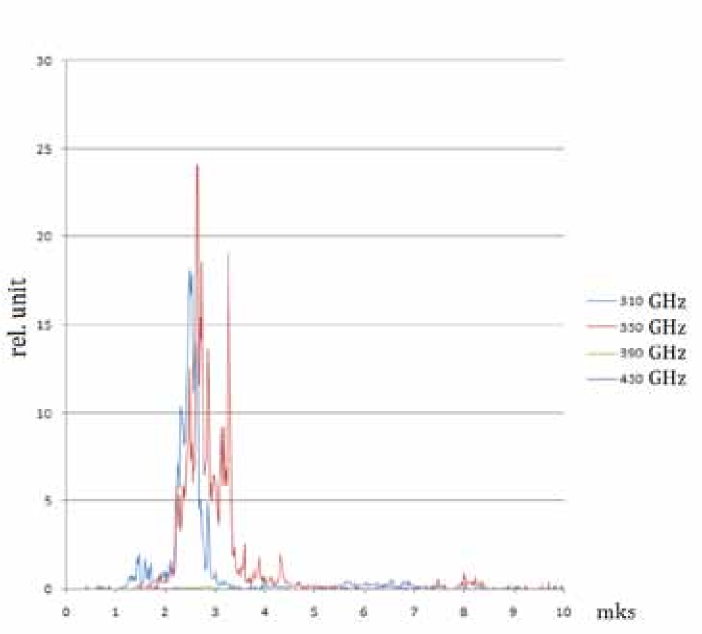


Fig. 8: Dynamics of signals from different spectral channels in the same shot. The case with shift of the spectrum to higher frequencies is shown.

4.2.4 Stabilization of the electron beam

As was already mentioned, some displacements of the electron beam from the axis were observed in the experiments. These displacements do not lead to the beam dump to the wall; this means that amplitude of the displacement was limited within the plasma column. This differs the observed beam dynamics from the well-known Kruskal-Shafranov instability which was observed earlier in unstable GOL-3 operation regimes.

Several causes of the observed instability are possible. One of them is an asymmetry of return plasma current. In the discussed configuration of the experiment the exit beam receiver was placed in the low-field part of the exit expander in order to decrease the specific energy load to its surface down to allowable level. Such placement of the receiver complicates formation of the return current through the plasma column, therefore the return current can became non-axisymmetrical. This in turn can provide displacement of the beam as a whole and loss of its shape.

A special experimental series with varied conditions of formation of the return current was completed to check this assumption. For this purpose a heavy gas (krypton) was puffed in the vicinity of the beam receiver. Net puffed mass and gas distribution along the axis were varied in the experiments.

Displacement of the footprint from the expected position and change of its shape were detected with an X-ray imaging system in own bremsstrahlung of the beam. Right part of Fig. 9 shows a typical image of the footprint in a standard operation regime with the thin beam. The center of the footprint is displaced from the expected field line and is shape is distorted and non-symmetric. Krypton puffing near the beam receiver improves the footprint shape. A shot with almost ideal symmetry and position of the footprint is shown in the left part of Fig. 9. We should note that improvement of conditions for the return current generation with the gas puffing does not eliminate all causes of the beam transport instability. Therefore the gas-puffing technology results not in absolute but in statistical improvement of the beam transport. Averaged over large series of shots improvement of stability of the beam-plasma system occurs with the reduced deviations of the beam shape and position in optimal gas-puffed regimes. Dependence of the beam asymmetry on the axial length of the krypton cloud (which is represented as delay of the beam start after the puffing) is shown in Fig.10. The optimum is clearly seen.

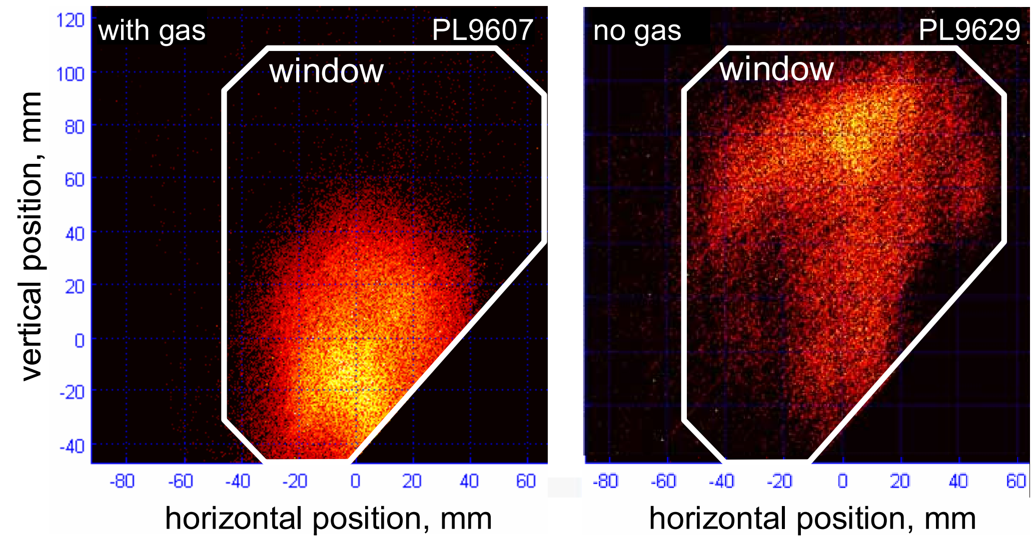


Fig. 9: Hard X-ray image of the beam footprint at the exit receiver. Exposure is 1 μs. Left part: krypton was puffed near the receiver. Right part: no gas-puffing. White line shows the field-of-view of the X-ray imager which is restricted by the device structure.

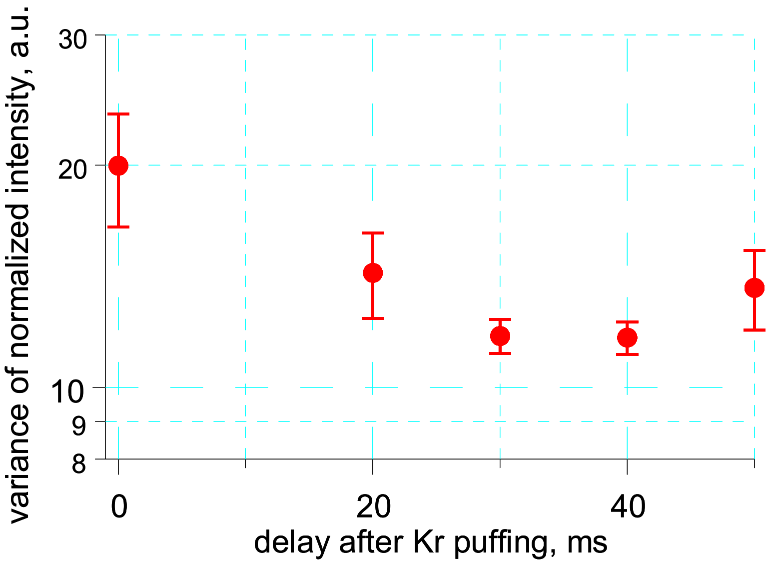


Fig. 10: Dependence of asymmetry of the X-ray image of the beam footprint on the delay of the beam start after the krypton puffing.

Similar statistical improvement is also visible from several other diagnostics. Significant decrease (up to 6 dB in 0-1 MHz spectral band) of the level of spectral components of signals from magnetic pickup coils which are sensitive to deviations of a magnetic surface was observed. Mean energy losses to the wall measured by a set of bolometers decreased by half in optimal puffing regimes; the maximum energy losses to the wall also decreased correspondingly in each regime.

In general the completed experimental series demonstrated that conditions for generation of the return current at the surface of the beam receiver are important for stable beam transport through the plasma column. This result was clearly shown in the experiments with the beam of reduced diameter.

4.2.5 Beam parameters refinement at the U-2 accelerator

During 2009 the modernization of basic units of the accelerator U-2 has been performed. It includes optimizing geometry of magnetically insulated ribbon diode, as well as design, manufacturing and testing new high-current discharge switches for the capacity storage of the U-2 device.

Optimization of the diode geometry

With the aim to improve parameters of high-power microsecond ribbon beam especially to increase its brightness we carried out a series of computer calculations by means of code POISSON-2 for simulation of the beam generation in different diode geometries. In these calculations the optimal geometry of the anode surface, as well as the configuration of magnetic field in the diode region were chosen. According to the obtained results the technical project of the new diode was created in the Design office of BINP. After the manufacture of the anode and the transport channel units the diode was assembled in the vacuum chamber of the accelerator U-2. The schematic of the new diode geometry is presented in the Fig. 11.

Its peculiarity is the smoothed form of the anode surface in transition to a transport channel which should provide the essential reduction of the angular spread obtained by the beam electrons in nonhomogeneities of electric and magnetic fields. In calculations we took into account the fields created by external sources, as well as by self space charge and currents of the beam.

In September 2009 the assembling of the new diode was started, and in October the first ribbon beam was received in new geometry. In the result of first experiments with new diode it was shown that the basic parameters of the beam (the energy of the electrons 0.75 MeV, beam current up to 30 кA, time duration 10-12 ms) remained on the same level, as earlier, but the angular spread of the beam electron is decreased. On this indicate the results of experiments on generation of the beam in small guiding magnetic field in the diode (~0.1 T), in which the beam was compressed by magnetic field in more than 60 times in its cross section. Oscillogramms of the diode voltage and the beam current in typical shot are presented in Fig. 12.

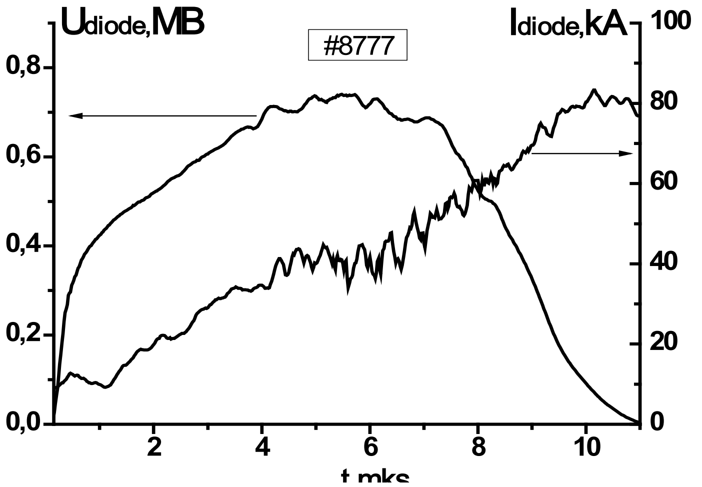


Fig. 12: Oscilloscope traces of the diode voltage U_d and the diode current I_d in one of the typical shots.

Design and testing of the prototype model of high-current discharge switch

High-current discharge switches are applied in the capacity storage of the U-2 accelerator for the formation of the microsecond high-voltage pulses. The previously used discharges designed by All-Union Electrotechnical Institute (Moscow) are inaccessible now. During 25 years of exploitation they drawn its life time and needed replacement. On this reason the design of new switch with higher working parameters was started in Lab. 10 and Design office of BINP. The photo of designed and manufactured sample of switch and its elements is presented in the Fig. 13. Before mounting in the capacity storage the new switch was tested in a separate module of storage assembled on a special test bed. The testing experiments were performed at the operating voltage of 50 kV, switching current of 120 kA and the passed charge 2 K. In series from 500 till 2000 pulses we have tested 7 samples of switches, which all passed the test successfully. During testing the new switches showed high reliability, the absence of breakdowns and self-triggering and durable work of the discharge electrodes. Now 6 switches are mounted in the capacity storage of the accelerator U-2 and passes testing in the operating conditions of the accelerator. The other are ready for mounting.

Fig. 13: Photo of the high-current discharge switch, manufactured at BINP.

The creation of new switches will provide the increase of the operating voltage of the capacity storage and the increase of the energy content in it to the design objectives. In its turn it gives the possibility to increase the beam energy content and hence to achieve the higher parameters of heated plasma in the experiments on GOL-3 facility.

4.2.6 Development of technology of creation of a long-pulse intensive electron beams based on plasma emitters

In 2009 installation was completed and tests were carried out of high-voltage pulse generator (GIN), intended to form the pulse of accelerating voltage for the source of electron beam with arc plasma emitter. The GIN works on the principle of partial discharge of high-voltage capacitor bank. Key elements of the GIN are: high voltage rectifier (200 kV, 10 kW), a storage capacitor assembly (200 kV, 1.2 μF), as well as the main and crowbar spark discharge switches. The crowbar switch, which forms trailing edge of a voltage pulse, simultaneously protects an accelerating gap from arching after breakdowns. The spark switches have a multi-gap design and work on the air at atmospheric pressure. The range of crowbar controllability is 30 – 180 kV, the voltage drop on the crowbar when it fired is no more than 500 volts.

With the GIN operated on resistive load the possibility was demonstrated of obtaining the quasi-rectangular pulses of accelerating voltage with preset duration and amplitude in a range from 40 to 150 kV. The magnitude of decline of accelerating voltage during the pulse is determined by capacity of high-voltage capacitor bank and by the load current. At the current level of 100 A and capacity of a high-voltage bank of 1.2 μF the relative decrease in accelerating voltage will be less than 10% with a pulse duration of 100 microseconds and accelerating voltage of more than 100 kV. The constant voltage level is important for maintaining the maximum beam current throughout the pulse, since (as it was shown earlier in test-bench experiments with 30 keV electron beam) decline accelerating voltage leads to a broadening of the elementary beam in each aperture of the diode and thereby increased deposition of electron beam on the edge of the openings in the anode electrode. In turn, an increase of current precipitation on aperture edges higher than the certain critical level leads to a breakdown of the diode gap.

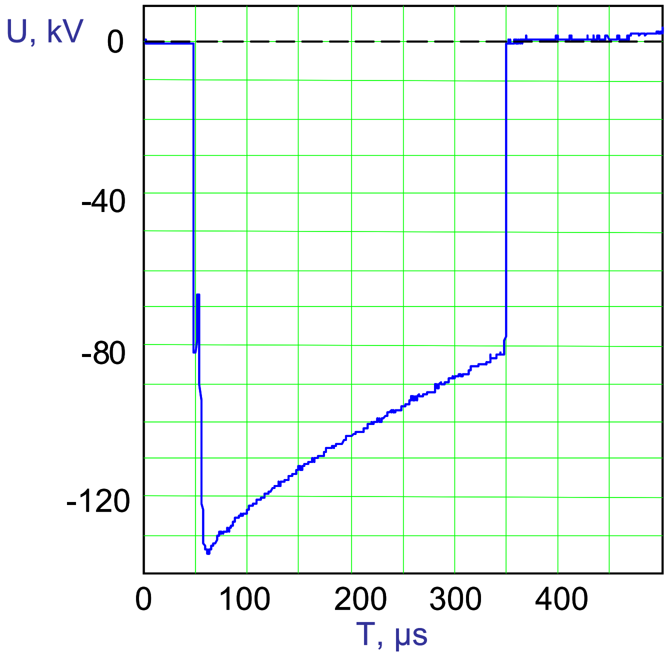


Fig. 14: High voltage capacitor of GIN (200 kV, 1.2 μF) and the voltage pulse formed on resistive load of 1270 Ohm (GIN capacity is 2.54 μF).

The design of high-voltage capacitor bank provides the possibility of future increase its capacity by increasing the number and capacity of capacitors At special test stand with accelerating voltage up to 30 kV a series of experiments was carried out on generation of sub-millisecond electron beam in the source with arc plasma emitter and the diode-type electron optical system with 37 round apertures, drilled (as it was in the previous experiments) in the order of hexagonal "grid", under the conditions of the external magnetic field with value to 0.15 T.

The purpose of the experiments was to study the physical approaches to producing a beam of sub-millisecond duration with a maximum current density and total current, as well as investigate the possibility of achieving sub-kiloampere current level in the source of the beam with a single arc generator operating in a longitudinal magnetic field ~ 0.1 T.

Experiments in this direction will continue in 2010.

4.2.7 Summary

Experiments aimed at the development of a physical knowledge base for a mutimirror-trap-based fusion reactor are continued at the multimirror trap GOL-3. Physical data quality is improved both due to improvements of diagnostic eqiupment and due to dedicated experimental runs. New plasma heating technologies are developing in order to improve plasma parameters. Development of analytical and numerical models of a plasma in GOL-3 is in progress. Applied research contracted by outer organizations was carried out.

Participants of this work:
A.V.Burdakov, A.P.Avrorov, A.V.Arzhannikov, V.T.Astrelin, V.I.Batkin, A.D.Beklemishev, V.B.Bobylev, V.S.Burmasov, P.V.Bykov, G.E.Derevyankin, V.G.Ivanenko, I.A.Ivanov, M.V.Ivantsivsky, P.V.Kalinin, I.V.Kandaurov, I.A.Kotelnikov, K.N.Kuklin, S.A.Kuznetsov, A.G.Makarov, M.A.Makarov, K.I.Mekler, S.V.Polosatkin, S.S.Popov, V.V.Postupaev, A.F.Rovenskikh, A.A.Shoshin, S.L.Sinitsky, V.F.Sklyarov, N.V.Sorokina, V.D.Stepanov, A.V.Sudnikov, Yu.S.Sulyaev, I.V.Timofeev, Yu.A.Trunev, L.N.Vyacheslavov, V.A.Yarovoy.

4.3. Beam Injectors of Hydrogen Atoms and Ions

4.3.1 Beam Injectors of Hydrogen Atoms

For plasma heating in the TAE device (USA) two injectors of focused beams of hydrogen atoms with 25 keV energy, 1 MW beam power, 5 ms pulse duration were produced and supplied. Project of modernization of others TAE heating neutral beam injectors supplied by BINP under contract in 2008 is executed. Goal of the modernization is to reduce beam energy from 40 keV to 20 keV at the same injection power. For necessary increase of ion beam current an ion optical system with enlarged beam emission diameter and reduced sizes of an elementary cell was chosen.

On the MST device (Madison, USA) heating neutral beam injector was put into operation. Energy of hydrogen atoms is set to 25 keV, beam power - 1 MW and pulse duration - 20 ms. The focused neutral beam is injected into plasma through a branch pipe of 10 cm in diameter.

Conceptual design study of a powerful steady state injector of 500-1000 keV hydrogen neutral beam on the basis of negative ions is developed. To achieve high enough overall efficiency of injector, neutralization of a negative ion beam in plasma or photon target and recuperation of deflected residual ion beams are applied.

4.3.2 Continuous Hydrogen Negative Ion Source.

During 2009 year the development of continuous wave negative ion source was carried on at the experimental stand. The main scope of the work was:

- to provide DC operation with the beam current of 15 mA;
- to simplify source construction and maintenance;
- to provide source automatic control.

Several modifications have been made and successfully tested:

- magnetic system based on NdFeB magnets with internal yoke;
- discharge chamber with easily replaceable cathode and cesium heaters;
- optimization of thermal conditions of discharge electrodes in order to prevent accumulation of cesium inside the discharge chamber and to decrease cesium outflow to IOS and accelerator;
- software and operational scenario for automatic start of the source and stable operation during long term runs.

Source improvements allow do decrease electrode erosion by secondary ions and extend resource of the source. Several cycles of long operation with duration longer than 100 hours and beam current 15 mA have been successfully performed.

Hydrogen negative ion source is presented in Fig.1.

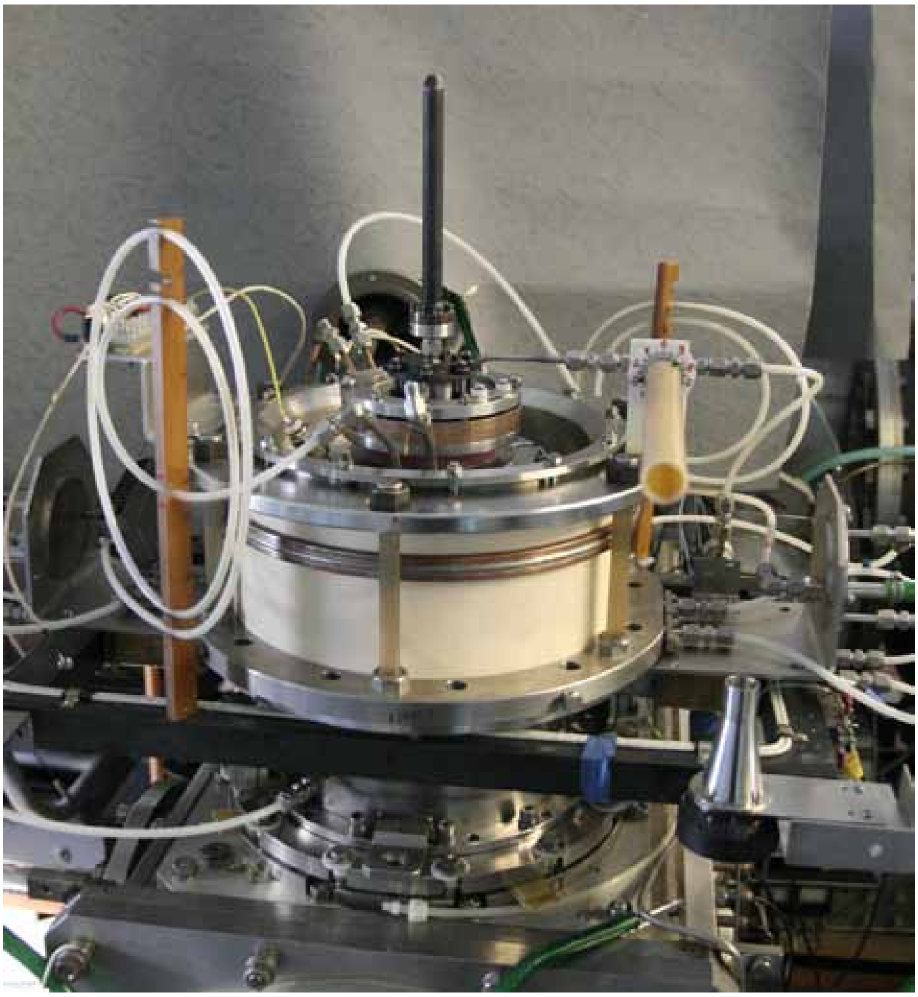


Fig. 1: DC hydrogen negative ion source.

4.3.3 Continuous Radio-Frequency Proton Source

Radio-frequency ion source has been developed for operation in continuous mode with beam modulation. Under standard conditions a duty factor is 25%. The ion source produces a proton beam with current of 70 mA and energy of 50 keV. The beam is extracted and accelerated by using a four electrodes ion-optical system with single aperture. Initial beam diameter is set to 8 mm. An important characteristic of the beam is small beam divergence, amounting to less than 0.5 deg.

Ion source is designed to operate in many applications in such areas as diagnostic of high temperature plasma, accelerator technique, ion implantation, ion lithography.

In the ion source the plasma is produced by an inductively driven RF-discharge with a frequency of 4.6 MHz. The plasma is generated inside a ceramic cylinder protected with water cooled copper Faraday shield with axial slits. All internal metal surfaces of the plasma chamber including Faraday shield, rear flange and plasma electrode are covered with thin ceramic layer to reduce recombination losses of the plasma.

Ion beam is extracted and accelerated by the ion optical system (IOS). The central part of the electrodes has inserts made of molybdenum. Molybdenum has high strength to sputtering by ions and fast atoms. Molybdenum part is soldered to the massive copper holders with water cooled channels at the periphery.

Ion source is presented in Fig.2. Source photo with removed external case and internal electrostatic shield is presented in Fig.3.

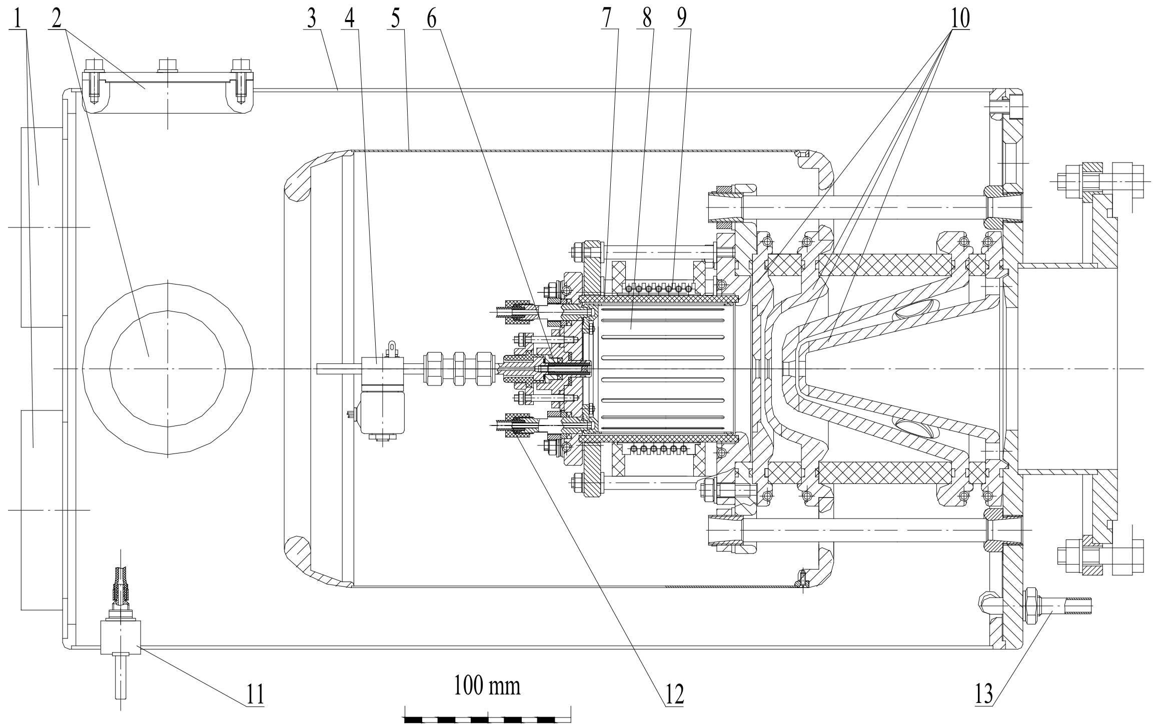


Fig. 2: RF ion source: 1 - electric fans, 2 - flanges for connecting RF and HV power cables, 3 - metal case, 4 - gas valve, 5 - internal electrostatic shield, 6 – triggering unit, 7 - ceramic discharge chamber, 8 - Faraday shield, 9 - RF antenna, 10 - ion optical system, 11 - gas feed, 12 - Faraday shield cooling manifold, 13 - grids cooling manifold.

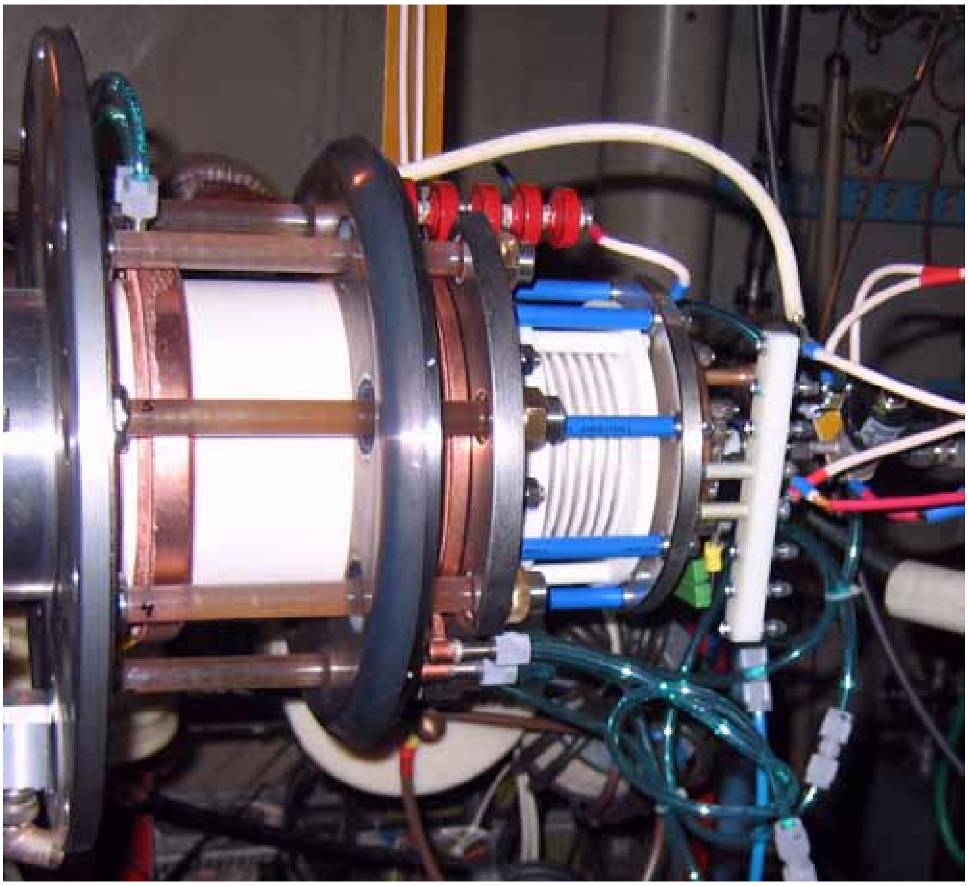


Fig. 3: Radio frequency ion source.

4.3.4 Combined source of filtrated cathodic-arc plasma for deposition of thin films and protective coatings

The combined source includes six pulsed cathodic-arc sources creating a stream of metal or carbon plasma filtered off from particulates due to reflection of the ions stream from Hall bed near to anode in the transverse magnetic field. This method of filtering provides 70% plasma efficiency.

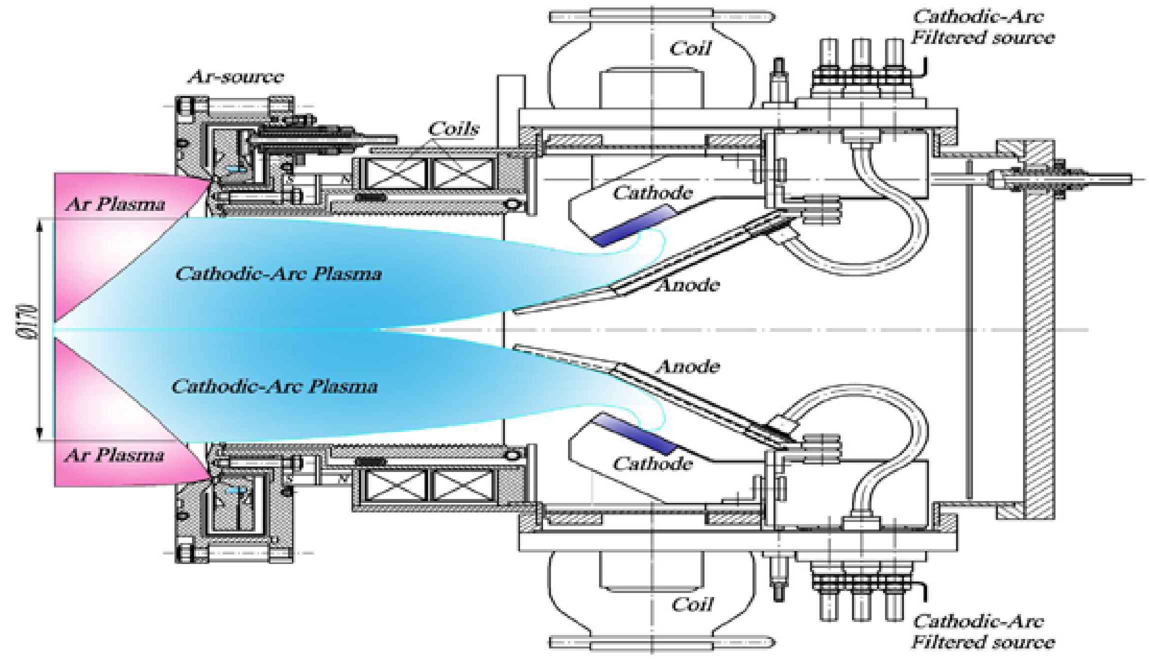


Fig. 4: Combined source of filtrated cathodic-arc plasma.

Main source parameters:

- Duration of pulses is 1 ÷ 5 ms.
- Pulsed ion current of the one source is up to 30 A (average current is 1A).
- Sources work by turns. Simultaneous operation of three sources is possible. Thus total pulsed ions current is 90A (average current 3A).

The circular ion source with the confined electrons drift and with a speed-up of the plasma in the anode layer (source with anode layer) operates in pulsed or in a quasi-steady operation and can be used for prod　using of argon ions with current up to 2 A at a partial argon pressure in volume not above 5 x 10^{-4} Torr.

Thus the pulsed cathodic-arc plasma source and the circular source with an anode layer can operate synchronously with each other. Plasma streams from both sources are capable to fall onto the same areas of the surface by turns or simultaneously, and to provide, in particular, the technology regime of spraying in conditions of assist ions of inert or active gases with a wide range of energies. Simultaneous bombarding radiation by ions from both sources allows expanding considerably a range of the devices used at reception composite and nanocomposite coating.

In cathodic-arc source the higher open-circuit voltage (up to 450V) is used. At that condition the steady discharge can be realized not only with cathodes from titanium, zirconium, copper, etc. metals, but also with cathodes from such materials as carbide of boron (B_4C). It allows to obtain the coats containing boron (and carbon) by means of the cathodic-arc plasma source. Also it is possible for receptions of coats containing boron to apply a source with the anode layer using as a working medium gaseous diborane (B_2H_6) or tetraborane (B_4H_{10}).

The presented combined sources can be used for:

- metal or graphite coating deposition,
- production of composite or nancomposite coatings,
- production of diamondlike coatings,
- production of metal nitride coating, for example, TiN, ZrN, the technology of metal nitride can be optimized and developed with using of the circular ion source for oscillation of nitrogen ions,
- production of coatings of several metal nitrides, carbonitrides or boron nitrides, for example, TiAlN, ZrCN, Ti-B-CN, Ti Al-BN,
- production of biocompatible coatings, for example, Ti-(Ca, Zr, Si)-(C, N, O, P),
- production of low friction coatings, for example, Ti-(Ca, Si, Nb, Zr)-(C, N, O),
- productions of semiconductor structures, for example, $SnO_{2,}$
- at applying a high bias voltage to the workpieces for cleaning, etching, warming up and other types of workpiece surface training with metal ions,
- productions coatings with an opportunity to influence hardness, on density or porosity,
- productions coatings with the refined adhesion,
- and also at supplying of a high potential of bias to work pieces for purification, pickling, pre-heating and other aspects of aging of surfaces of preparations by ions of metals and noble gases,
- for the purpose of obtaining of a stream of dense plasma for other problems.

The source allows:

- Adjustability over a wide range of plasma producing due to change of a discharge current and frequency of pulses. It allows to carry out the significant decrease of power at some stages of spraying.
- Opportunity to drive an energy distribution of the corpuscles used for formation of films due to change of magnitude of the transverse magnetic field in is cathodic-arc sources, a voltage influencing magnitude on a discharge gap.

The range of use of the coats manufactured in by means of the combined source, includes following fields: hard-wearing coats; low-friction coating; superhard coating; an edge tool; drill bits; the tool and devices for a biomedicine and applications; biological implants; coats resistant to chemical affecting; optics and coats on pellucid emulsion carriers, devices of an electronics; nanotechnology.

High efficiency of the combined source demands intensive cooling of details at drawing coats. The carrousel with planetary twirl of details and cooling of moving details due to liquid-metal contact is used.

Work is carried out under the contract with LUMIKS P.T.I. Ltd., Israel.

5

ELECTRON-POSITRON COLLIDERS

5.1 VEPP-2000 in 2009

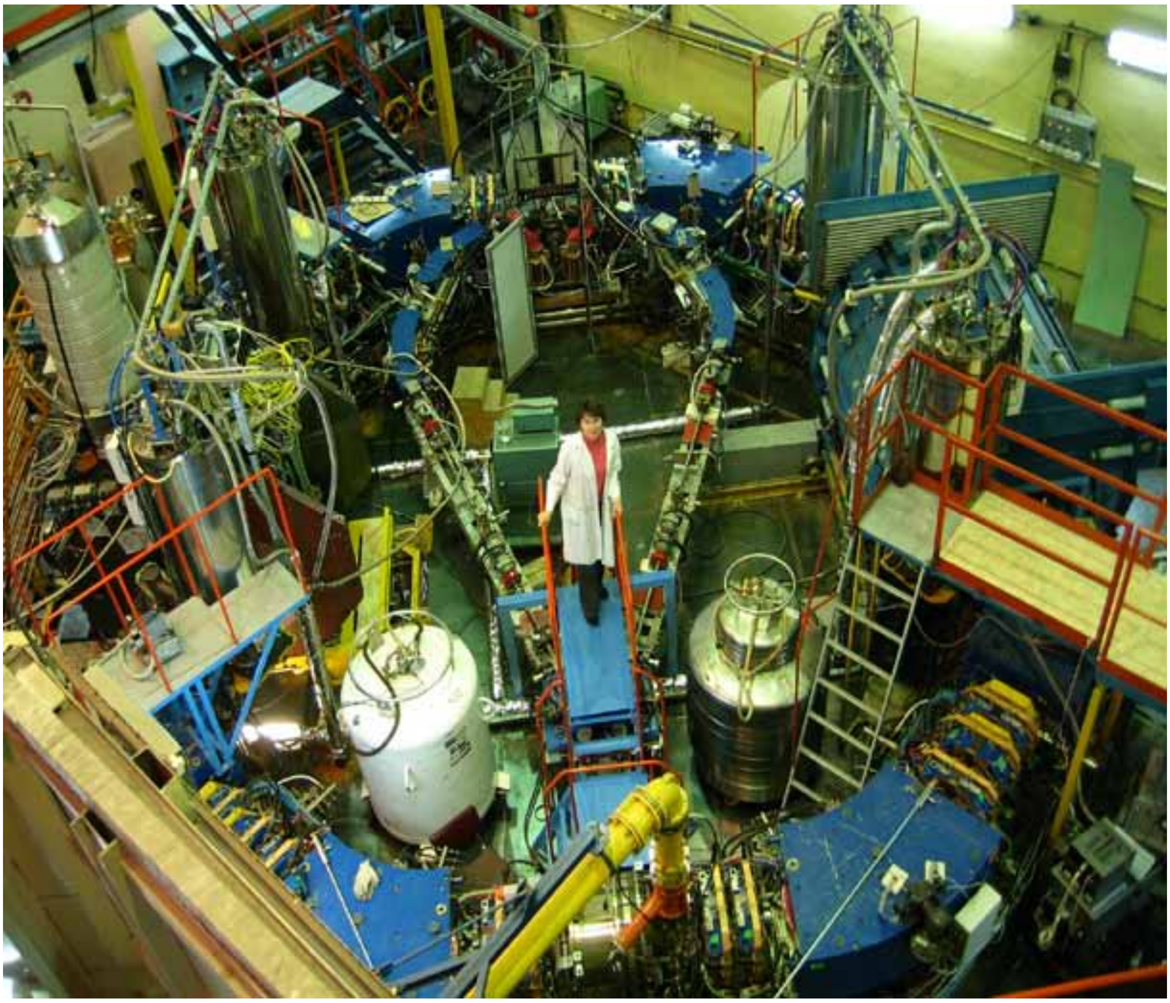


Fig. 1: In VEPP-2000 hall.

In the end of 2008 modernisation of superconducting solenoids has been finished, as a result the expense of liquid helium has decreased in 2 times. After installation of solenoids 2009 has begun with training of the vacuum chamber with synchrotron radiation. This procedure is necessary for receptions of working pressure in the vacuum chamber (~10^{-10}Torr). To achieve small values of desorbtion it is required to have integral of a bunch current nearby 10 A·h in each bunches' direction. This work was made in the special «technical» mode without solenoids also has occupied practically two months. Such long term is appreciably connected with possibility to work with bunches only at night, as in the afternoon in experimental hall works on assemblage and adjustment of CMD and SND detectors were made.

The next compelled stop in the middle of March has happened because of errors of the operator which has led to damage of current input in one solenoid. On elimination of consequences of this error whole month has left, so real work with a bunch in a design mode (round bunches) has begun only in April. However, by this time at Institute already strict economy measures have been accepted, that in particulars has not allowed to buy the helium necessary for work of solenoids. This situation was delayed on half a year. However, on the helium rests in the end of April on VEPP-2000 the first physical experiment was made together with detector SND. Measurement of a curve of excitation φ-meson is presented on Figure 2.

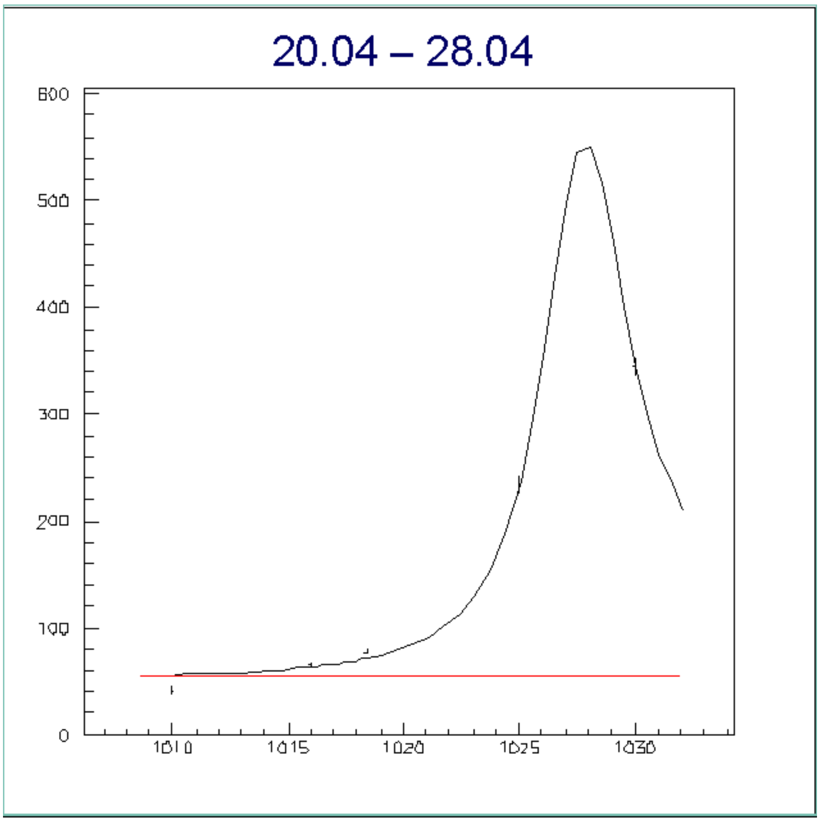


Fig. 2: φ-meson resonance.

As, thanks to efforts of VEPP-2M, the weight of φ-meson is known with a high accuracy, the first experiment on VEPP-2000 has allowed to calibrate energy scale of the storage ring by measurement of a magnetic field with system of NMR gauges installed in all magnets (a Figure3).

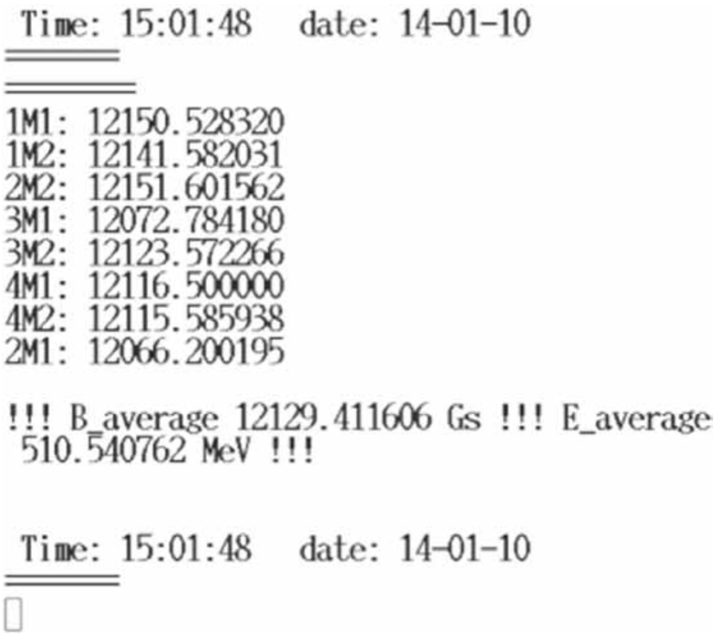


Fig. 3 : Energy measurement with NMR.

Further amendments of energy scale connected with change of magnets' effective length is supposed to make by measurements of energy with a method of resonant depolarization. For this purpose in the summer of 2009 on VEPP-2000 we installed probes for registration of the particles which have undergone scattering in a bunch (Figure 4). As depolarizer it is supposed to use available block of plates for build-up oscillations of bunch. Besides, there is a preparation of operative energy measurement by a spectrum of Compton scattering of laser photons as it becomes on VEPP-4.

Fig. 4: Installed probes for particles registration.

During summer on VEPP-2000 repair of mirrors and injection section was made, probes were installed. These operations required to open half of vacuum chamber of the storage ring. So in September the work with beam started in technical regime without solenoids. At the end of this work in October it was found out that CMD detector has ripened enough to be installed into VEPP-2000. For this purpose it was necessary to remove two solenoids from the ring, temporarily mount them on CMD for assemblage of the whole vacuum chamber. Then all this construction with many electronics and wires has driven on rails in VEPP-2000 gap. Fortunately, all has passed smoothly enough and solenoids have precisely returned on the native places. However this operation has required again to train vaccum chamber with the beam. So, VEPP-2000 has returned to normal work in a mode of round beams only in December. As a result of adjustment of all systems the state of affairs at the moment of Institute scientific session (15-16 January, 2010) is illustrated by following figures.

For the first time in VEPP-2000 the electron current 150 mA is stored in one bunch. The effectiveness of transportation of bunches from booster ring BEP to VEPP-2000 in storage mode is about 60-70 percent. Figure 5 shows working regime of electrons and positrons accumulation in VEPP-2000.

The measurement of betatron tunes is tuned up (Figure 6) by fast Fourie analysis the signals of oscillating bunch from pick-up electrodes, which arises after kick the bunch by traveling field of inflector. Moreover for precise measurements the inflector of opposite bunch is used, which because of weak reflection allows us to kick a bunch on parts of mm. The accuracy of this method is about 10^{-4}. With the same precision we can compensate transverse coupling of beam oscillations by skew-quadrupole corrections.

After repair of mirrors optical observations of the beams are continuously carried out in 16 points of orbit by registration the light from magnets ends. Optical diagnostics allows one simultaneously determine coordinates and sizes of electron and positron bunches.

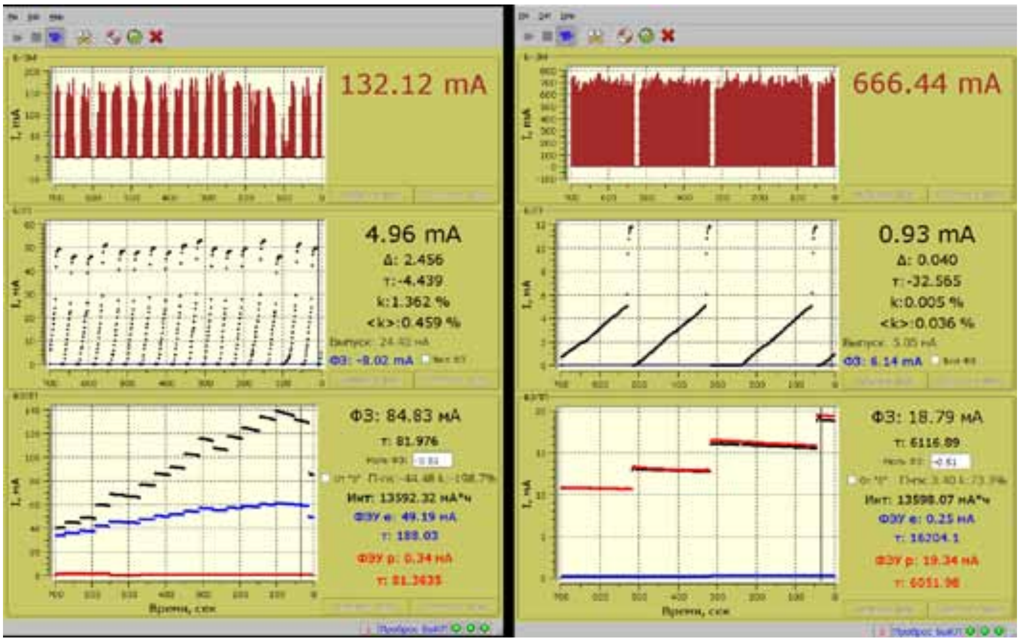


Fig. 5: Regime of current accumulation in VEPP-2000.

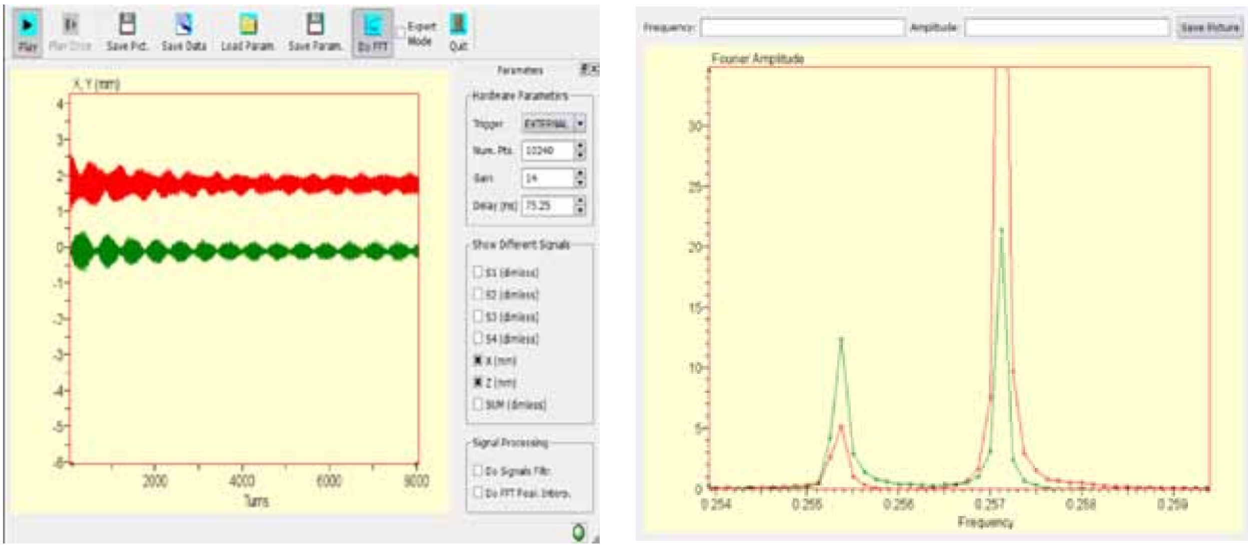


Fig. 6: Betatron tunes measurements with FFA.

Fig. 7: Optical diagnostics on VEPP-2000.

This system together with pick-ups is used to tune optics of the ring with special prepared «handles» as well as with general method of response matrix. Figure 7 shows measurements of dispersion function in the VEPP-2000 ring. Red dots are measured horizontal dispersion that is zero with high accuracy in drifts between achromats. In the lower part of figure by blue dots parasitic vertical dispersion is shown, which doesn't exceed few percents.

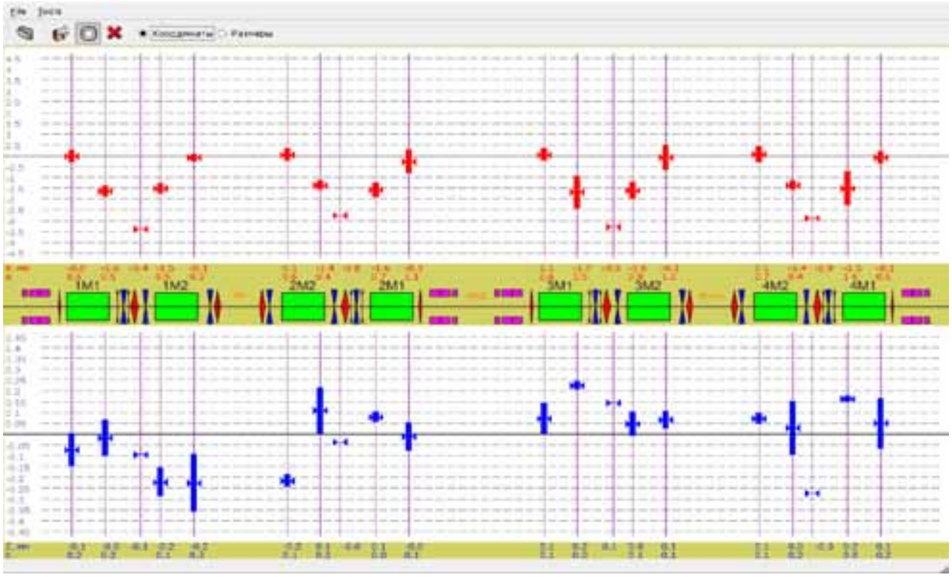


Fig. 8: Dispersion functions of VEPP-2000.

After the training of vacuum chamber by synchrotron radiation life-time of the beam $\ll 1$ mA is about 10 hours. With working currents the life-time is reduced because of desorbtion and effects of scattering inside the bunch. For another thing particle losses grow up in linear resonances region. Positron beam (I^+=10 mA) life-time depending on working point is presented in Figure 9.

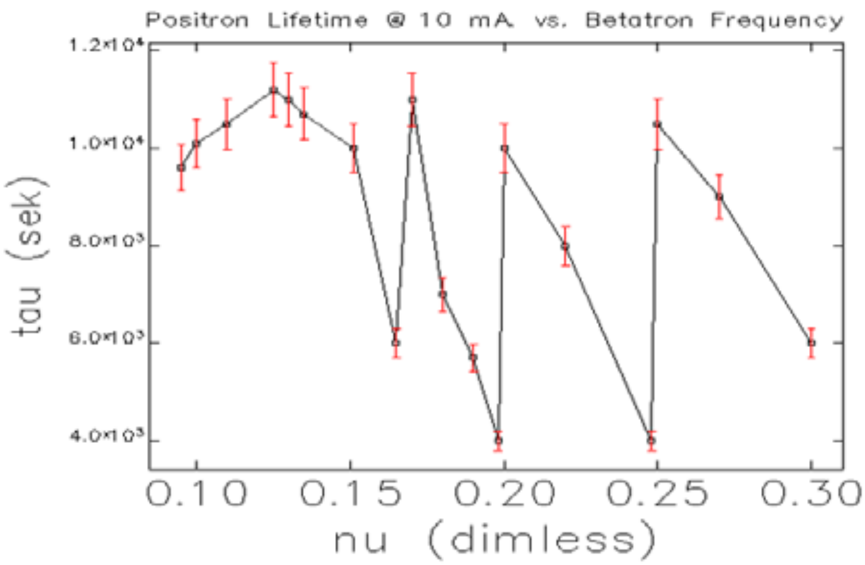


Fig. 9: Positrons life-time vs. fractional part of betatron tune.

A wide region of betatron tunes is analyzed to study beam-beam effects in «weak-strong» and «strong-strong» modes. The threshold beam current depending on working point on resonance in «strong-strong» mode is shown on Figure 10.

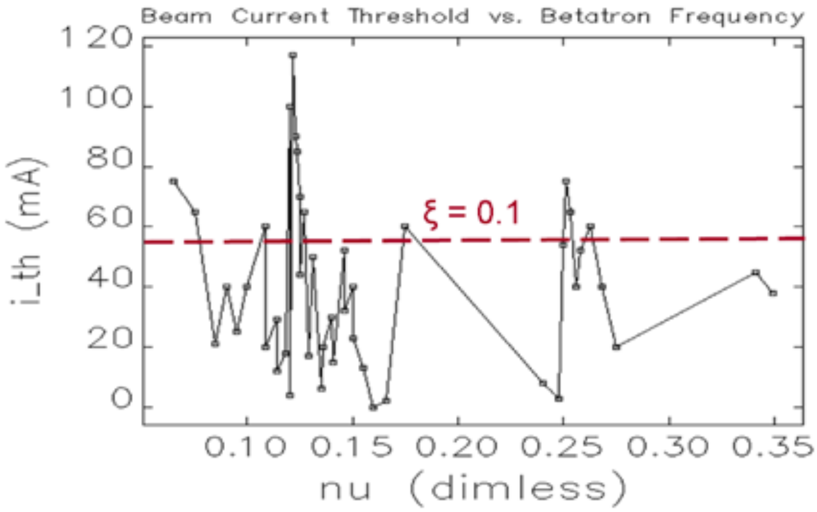


Fig. 10: Threshold current of electrons vs. fractional part of betatron tune.

Practical work (injection, storage) in «strong-strong» mode is presented on Figure 11.

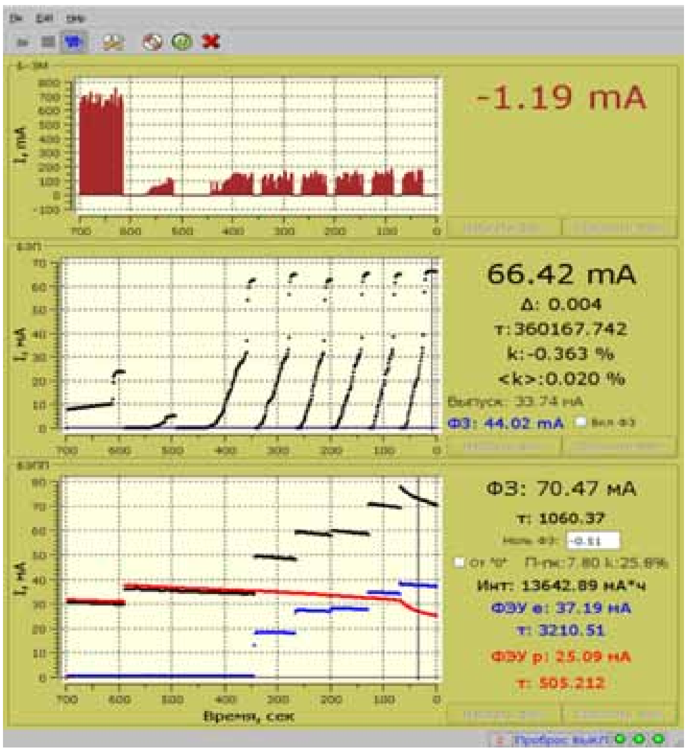


Fig. 11: VEPP-2000 work in «strong-strong» mode.

«Sag» of positron current is due to working point shift by opposite beam, and this can be compensated for preliminary change of betatron tune. Then it is possible to obtain the space charge parameter $\xi \sim 0.1$ (Figure 10).

5.2 VEPP-4 Accelerator complex

5.2.1 Operating time distribution

In 2009, high-energy physics experiments were continued at the VEPP-4M electron-positron collider with the KEDR detector. The experiment for determination of a width limit of narrow resonances in 0.9-1.55 GeV beam energy range has been prepared and carried out

Commissioning of the “Deuteron” facility has been finished in 2009. A data collection run has been performed for the experiment in measuring the relation of cross-sections of elastic scattering of electrons and positrons on a proton. The experiment is aimed at determination of two-photon exchange contribution into the scattering process

In addition to high-energy physics and nuclear physics, extensive studies were performed with use of synchrotron radiation generated by the VEPP-3 and VEPP-4M storage rings. For experiments with SR beams, 10 experimental stations work at VEPP-3, and one station – at VEPP-4M

A series of works for modernization of the VEPP-4M electron-positron collider has been done: a system of selective depolarizer has been developed and tested with the electron beam; the configuration of the system of beam energy measurement by the Compton backscattering method has been optimized; the X-ray pinhole camera has been produced, installed and calibrated for position and angle stabilization of the beam in the experimental area of VEPP-4M.

The distribution of operating time of the VEPP-4 accelerator complex for 2009 is shown in Fig. 1.

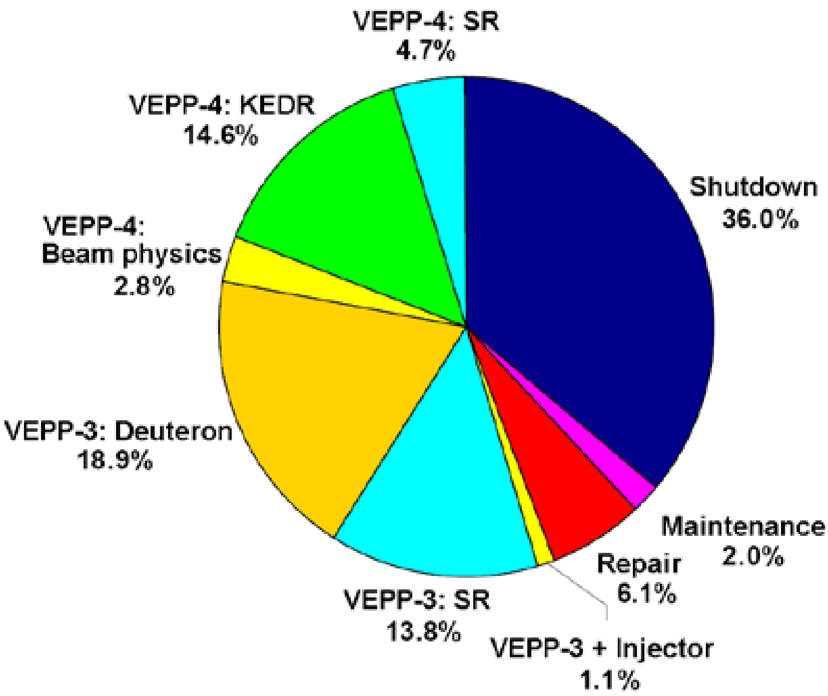


Fig. 1. Distribution of operating time of the VEPP-4 accelerator complex

As it is seen in Fig. 1, the operating time is mainly divided between the nuclear-physics experiments at the “Deuteron” facility (18.9 %), high-energy physics experiments with the KEDR detector (14.6 %), and experiments with use of synchrotron radiation (13.8 %). In 2009, the most part of time was occupied with scheduled shutdown (36.0 %). Operating time for beam and accelerator physics was obviously insufficient (2.8 %) because of a very intensive time schedule of experiments. Nevertheless, the accelerator physics studies are necessary as to keep the facilities in operation conditions required for experiments, and to perform actual experiments on particle beam physics. The regular maintenance works (2.0 %) are carried out weekly. Losses of time due to malfunctions (6.1 %) and repair are rather small this year, taking into account a large number, complexity and deterioration of the equipment, most part of which has been in use for decades.

5.2.2 High-energy physics

In 2009, the high-energy physics experiments with the KEDR detector were continued. Till recently, the data collection was carried out in a relatively narrow energy range: from 3.1 up to 3.9 GeV in the center-of-mass system (area of J/ψ-, ψ '-and ψ" mesons and of the production threshold of τ-leptons). Now an experiment for precision measurement of the cross-section of e^+e^- annihilations into hadrons in a wide energy rang from 1.8 GeV up to 8-10 GeV in the center-of-mass system and for search of narrow resonances in the range from 1.8 GeV up to 3.1 GeV, where such experiments were not performed earlier, is started.

The cross-section of e^+e^- annihilations into hadrons is usually characterized by the *R* parameter, which is equal to the relation of this cross-section to the theoretically calculated cross-section of the e^+e^- annihilations into muons. *R*-value is one of the major characteristics in the quark physics, in particular, it determines the value of hadron contribution into the anomalous magnetic moment of muon and a renormalization of the electromagnetic coupling constant. Measurement of *R* in the energy range from 5 up to 7 GeV seems to be the most interesting. This range was studied earlier only in the experiments with the detectors MARK-I and Crystal Ball. However, the MARK-I results are considered erroneous now, and the Crystal Ball result has not been published in journals, so there are no reliable data included into PDG.

In the beginning of 2008, within the frameworks of preparation for *R* measurement in the range of high energies, the beam background was studied at the energy of above 4 GeV. In 2009, the first stage of the experiment was performed: scanning of the energy range from 3.1 to 1.85 GeV for search of narrow resonances. The monitoring of beam parameters during the energy scanning was provided with the system of the energy and energy spread measurement based on Compton backscattering (CBS) of laser quanta. The beam energy measured during the experiment for searching narrow resonances is shown in Fig. 2. For the calibration of CBS system, in the beginning of the experiment a set of precision measurements of the beam energy was carried out by the method of resonant depolarization

In this experiment, the main problem is essential decreasing of the luminosity *L* with the decrease of beam energy *E*, theoretical calculations give the $L \sim E^4$ dependence. Besides, since the VEPP-4M collider was not planned to be used at such low energies, there are additional problems aggravating the luminosity losses. In particular, at low energy the negative influence of the collective effects of beam dynamics and of the beam-beam effects increases, this leads to reduction of the limiting beam currents.

The measured luminosity as a function of the beam energy is shown in Fig. 3 in comparison with the theoretical curve $L_{calc} = L_{max}$@1,55GeV·$(E/1{,}55\text{GeV})^4$. The measured luminosity goes down faster than the theoretical one, when the beam energy decreases from initial 1.55 GeV down to 1.4 GeV. At the energy of 1.35 GeV the current of gradient wigglers has been increased, this has allowed us to compensate partially the losses of luminosity. By switching on the dipole wigglers (I = 1.35 kA), which increase the bunch length (beam energy – 1.3 GeV), it was possible to keep the luminosity not worse than the expected one in the 1.3-1.1 GeV energy range. A further increase of the dipole wiggler current has allowed us to lower the beam energy down to 0.934 GeV providing the luminosity slightly below the design values. In Fig. 3, the measured luminosity is also compared with the values measured in 1998, one can see that the double improvement is reached at the energy of 1.0 GeV.

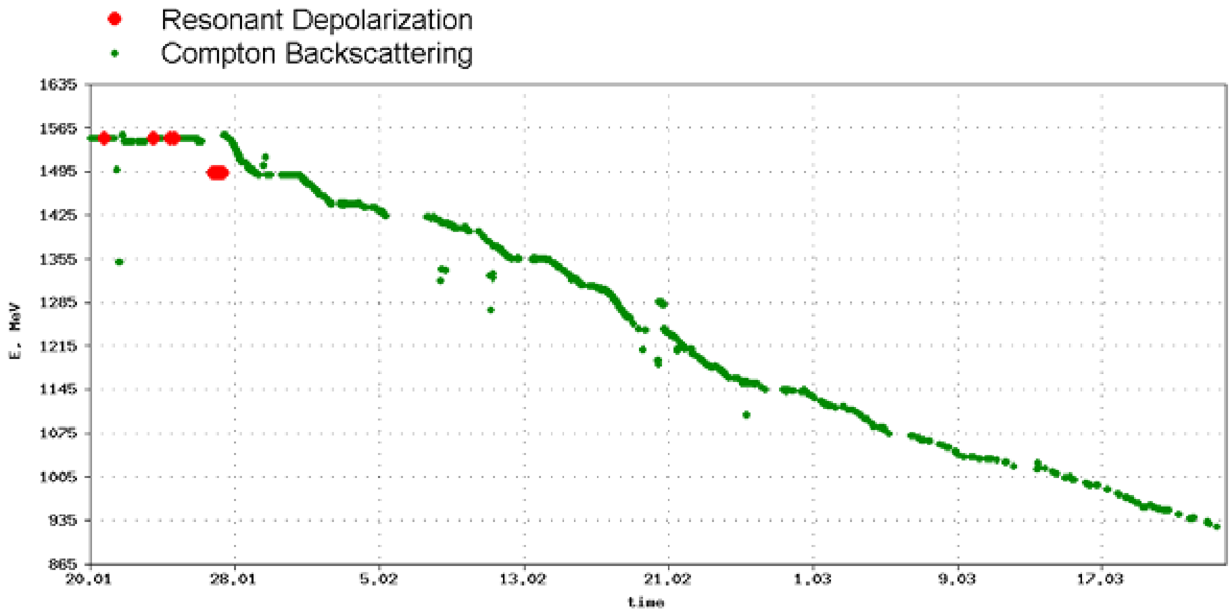


Fig. 2. The measured beam energy during the experiment to search narrow resonances.

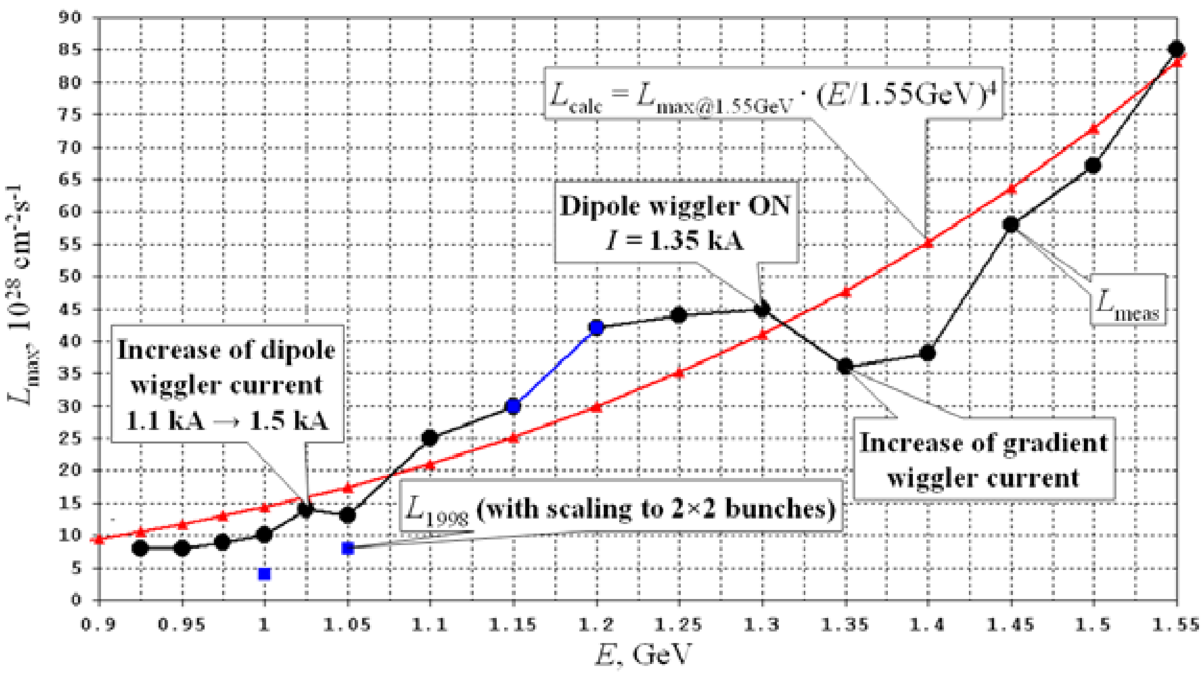


Fig. 3. Measured and theoretical luminosities as functions of beam energy

During the experiment, the total luminosity integral of about 300 nb^{-1} has been recorded. The cross-section of e^+e^- annihilations into hadrons was measured in one thousand points on the energy axis. No statistically significant resonances were found in the investigated energy range. The data processing is being continued. It is expected, that the upper limit of the electron width of narrow resonances will be about 100-150 eV.

5.2. 3 Nuclear physics

Investigation of electromagnetic form-factors of proton, which are the major characteristics of this particle, provides a better understanding the nature of proton, as well as the nature of interaction of quarks forming a proton. Rather recently, the form-factors were measured with application of new polarization techniques at the TJNAF laboratory (USA). The measurement results show remarkable contradiction with the data of the earlier experiments, in which the form-factors were taken from the analysis of differential cross-sections. As it is supposed, the most probable reason of these disagreements is the inconsistent application of one-photon approach for interpretation of the measured data. However, taking into account the corrections caused by the two-photon exchange faces difficulties: on the one hand, a lack of reliable correct calculations, on the other hand, a lack of precise experimental data. Therefore, new experiments are necessary to solve the problem of accurate estimation of two-photon exchange contribution.

This contribution can be measured experimentally by comparison of the elastic cross-sections of elastic scattering of electrons and positrons by a proton. In 2009, such experiment was performed at the “Deuteron” facility (Fig. 4). The beam of electrons or positrons with 1.6 GeV energy is scattered by the inner gas target, which is a record-breaking intensity jet of gas (deuterium or hydrogen) injected into the vacuum chamber of the VEPP-3 storage ring

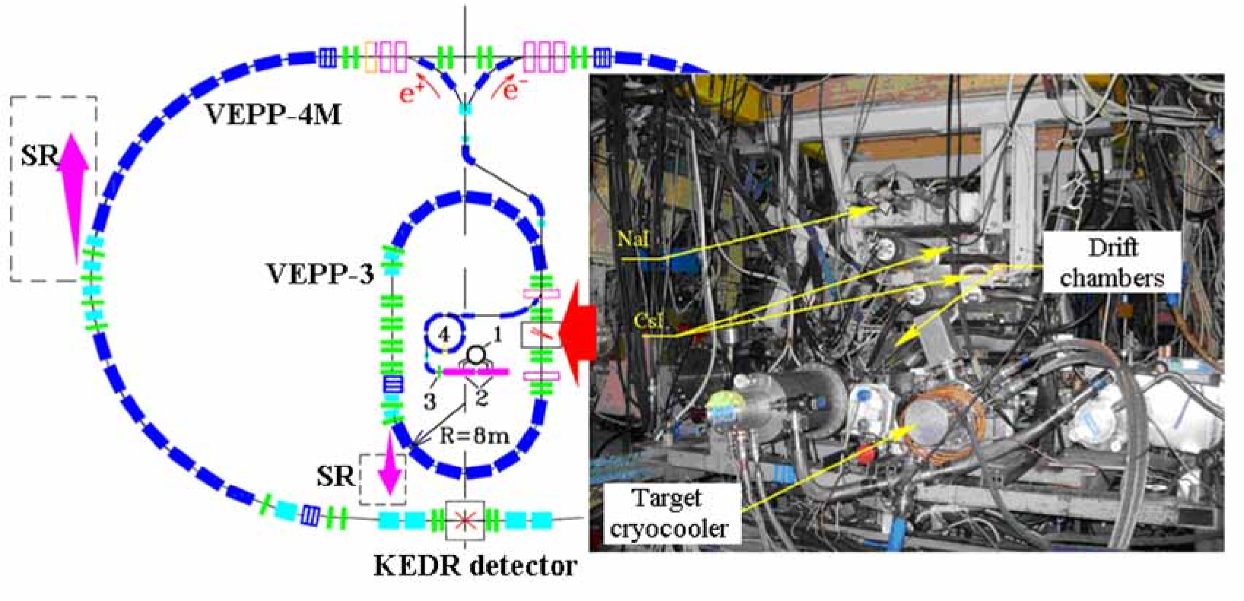


Fig. 4. “Deuteron” facility .

Earlier, preparatory works including the first experimental run at VEPP-3 (2007) have been done. After that a set of operations to improve the working parameters of the facility were carried out. In the first half of 2009 the preparations were finished and in the summer 2009 the target and the detector were installed to the VEPP-3 storage ring

At the same time, the system of beam energy measurement by Compton backscattering has been transferred from the VEPP-4M collider to the VEPP-3 storage ring. According to the experiment requirements, the maximal difference between the energy of electrons and positrons should not exceed 1 MeV. This requirement is rather rigid, because the data collection runs with electron and positron beams are performed in turn, with the magnetization cycle and change of polarity of the VEPP-3 magnet system. The energy of electron/positron beams measured by the CBS method during the “Deuteron” experiment is shown in Fig. 5. After optimization of the VEPP-3 operations the energy of electron and positron beams was kept within the given range stably enough.

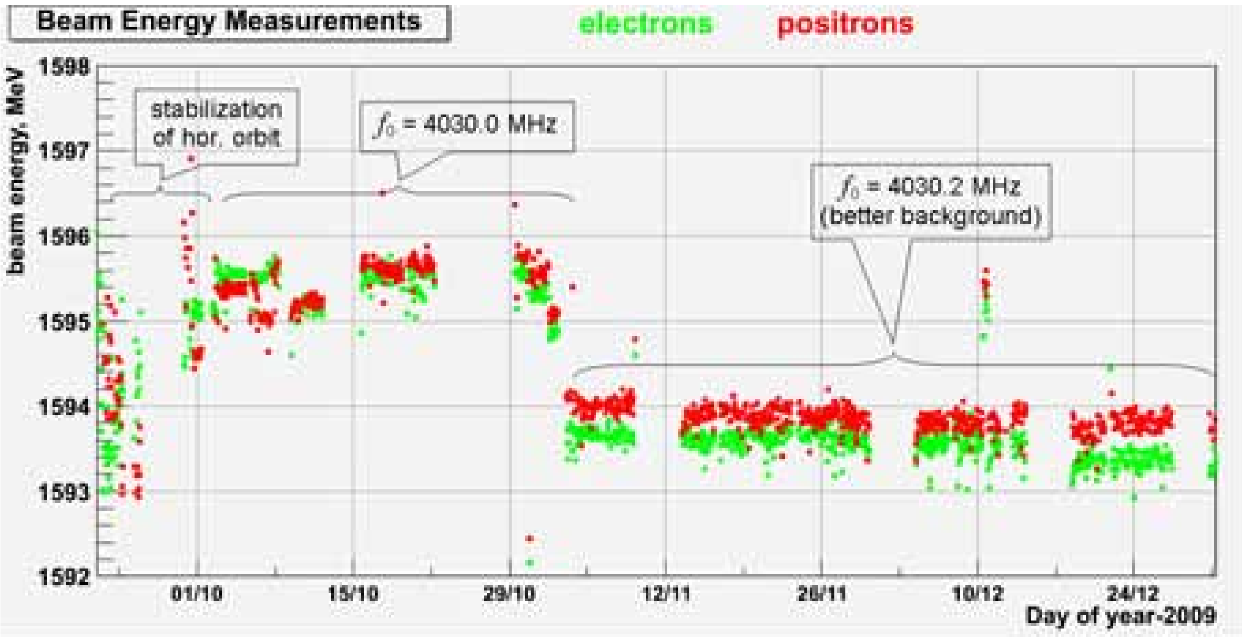


Fig. 5. Measuring of the electron/positron beam energy by CBS method during the «Deuteron» experiment .

The “Deuteron” experiment started in September, 2009 with the adjustment of various operating modes of the VEPP-3 storage ring, checkout of operation of the gas target and particle detector in the presence of interaction with particle beams, works to decrease background, etc. The data collection was started in the end of September. Efficiency of the data collection (measured as the integral of electron/positron beam current at constant target thickness of about 10^{15} atoms/cm^2) gradually increased and has reached a level of 1 kiloCoulomb per day (Fig. 6).

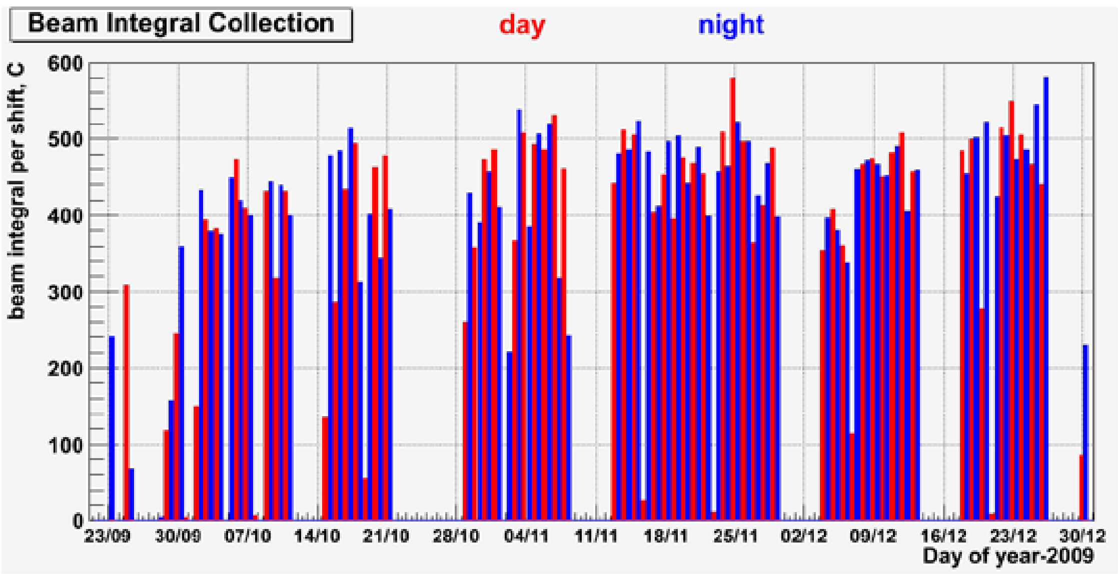


Fig. 6. Integral of electron/positron beam current per shift (12 hours)

To decrease systematic errors, it is important to keep identical conditions of operation with electron and positron beams. The data collection with of electron/positron beams is regularly alternated. The beam orbit is routinely monitored by the system of pickup-electrodes, the particle detector data analysis also gives the information about the beam position. The beam energy during the experiment is regularly measured by the CBS system.

Fig. 7 shows the example of time diagram of the beam current during one shift (12 hours). One can see that accumulation of positrons requires much greater time than accumulation of electrons. During acceleration of the beams from the injection energy of 350 MeV up to the experiment energy of 1600 MeV the beam current decreases a little; then for the period of data collection, the gas target is switched on and the beam current exponentially drops with the lifetime of approximately 1000 seconds. Note that without the target the beam lifetime is approximately 30 thousand seconds.

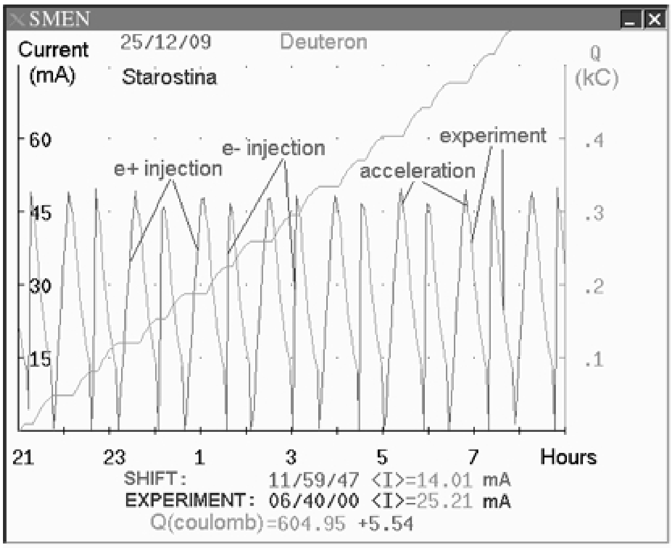


Fig. 7. Electron/positron beam current during one shift (12 hours).

The diagram of beam current integral during the experiment with the “Deuteron” facility is given in Fig. 8. The breaks in data collection (horizontal sections of the graph) mainly result from the time meant for operation with the synchrotron radiation beams and for maintenance operations with the target, detector and VEPP-3

For the whole time of the experiment, the total beam current integral of 54.3 kiloCoulombs has been collected taking into account the detector efficiency. As it was planned, the data collection was finished by the beginning of 2010; the beam current is 90% from the supposed one and is quite sufficient for data processing.

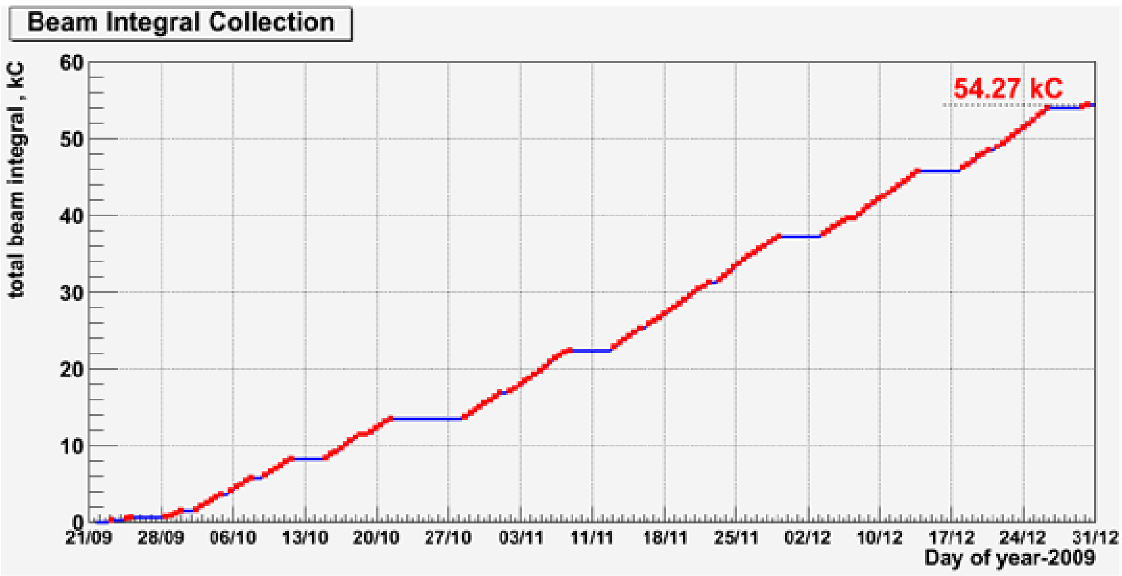


Fig. 8. Beam current integral during the “Deuteron” experiment .

5.2.4 Selective depolarizer

A selective depolarizer developed and installed at the VEPP-4M electron-positron collider provides new opportunities for experiments with resonant depolarization. With this depolarizer, it is possible to perform a selective depolarization of one of the pair of electron or positron bunches. Selectivity of the beam excitation, which means that electromagnetic field acts on one bunch without influence on others, is provided with time gating of the synthesizer signal. The strobe is started by the synchronizing pulse referenced to the beam revolution frequency, and the beam excitation is switched on for the time of beam passing through the kicker formed by strip lines.

Since the working frequency band of the power amplifier is limited from below, a "tail" of the excitation pulse can influence other bunches, if a simple time gating of the sine signal is used. To minimize this influence, the excitation pulse of a special shape not containing a constant component is formed. Fig. 9 illustrates the signal formation. The synthesizer has two independent channels of formation of a sine signal. The signals of each channel transit through the switches to the adder forming the output signal. The control circuit of the switches forms signals of a switch closing for the time τ at the moments t and $t+\tau$, which are synchronized with the revolution frequency. Thus, the control program sets in channels 1 and 2 a signal of the fixed frequency F with a phase shift between the channels, equal to $\Delta\varphi = 2\pi F \tau + \pi$.

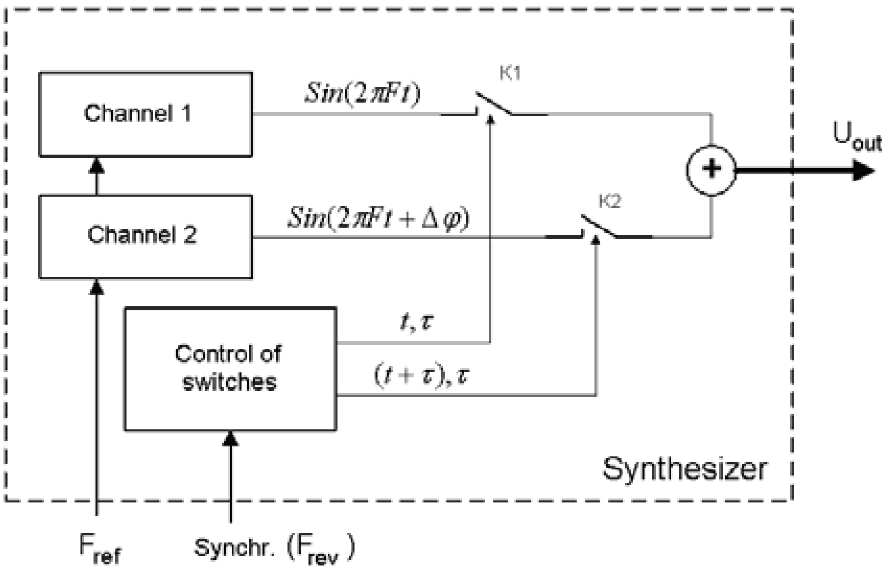


Fig.9. Formation of the synthesizer output signal.

The approximate shape of the generated signal is given in Fig. 10. Two control signals of the switches K1 and K2 are figured in the upper part, sine signals U1 and U2 of two channels of the synthesizer and the sum signal Uout are shown below. The frequency of sine signals is approximately equal to a half of the revolution frequency Frev, the proper phase shift is provided. The time scale corresponds to one period of beam revolution Trev=1.2mks, the time positions of two bunches following one after another with the interval Trev/2 are shown. Thus, the excitation signal Uout influences the bunch №1, and the influence on the bunch №2 is minimized because the signal does not contain a constant component for any phase of initial sine signals at the moment of time t.

Testing of the selective depolarizer was carried out by comparison of count rates of Touschek particles from two electron bunches, one of which was influenced by the depolarizer field at the frequency of betatron resonance (see Fig. 11). The depolarizer frequency was changed in the given range with the velocity of 18 Hz/s. The amplitude voltage on the kicker plates was set at a level of some tens of volts. In this experiment, the scintillation counters were not moved into the aperture

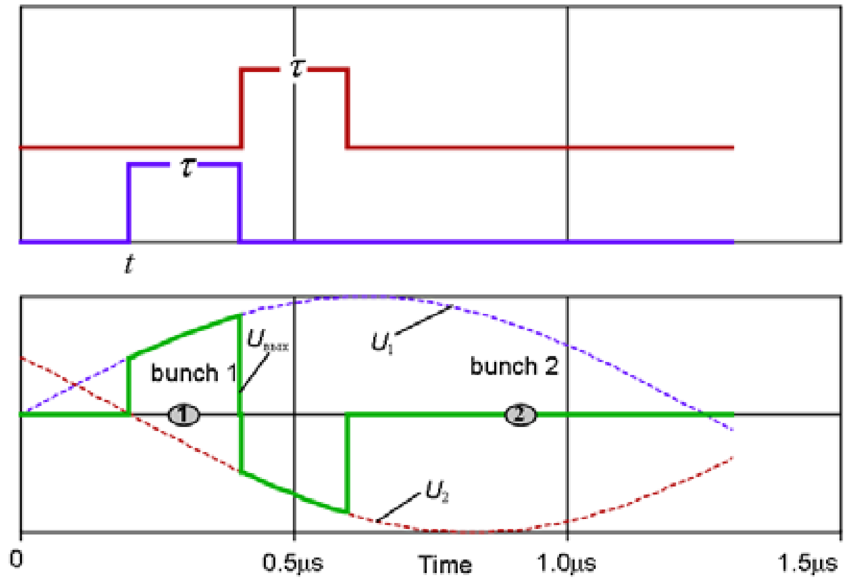


Fig. 10. Signal of the selective depolarizer.

of vacuum chamber, their edges remained close to the chamber walls. When the depolarizer frequency coincides with frequency of vertical betatron oscillations, the vertical beam size increases, this leads to partial diminution of the count rate. For the second bunch, the count rate changes in time monotonously, decreasing due to a finite lifetime of the beam; this confirms a high degree of the depolarizer selectivity.

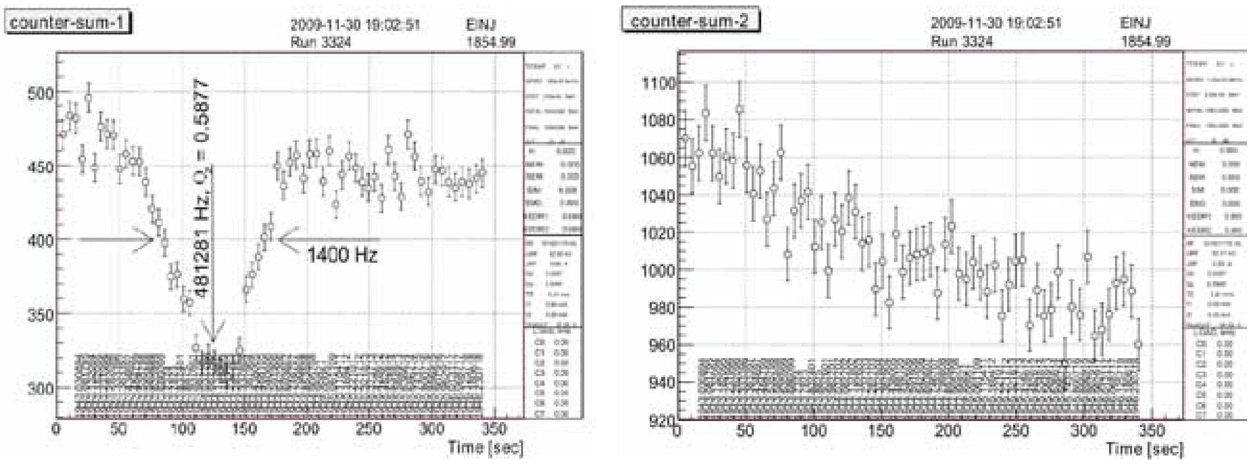


Fig. 11. Time dependence of the count rate (Hz) of electrons scattered from bunches 1 (a) and 2 (b) during scanning the frequency of selective depolarizer acting on bunch 1.

As can be seen from Fig. 11, one can estimate the betatron frequency spread in the bunch observing the dip of the count rate in a corresponding range of the frequency scanning. The measured FWHM of the betatron frequency spread is about 10^{-3} in terms of the revolution frequency (818.9 kHz). If the beam emittance is known, the measured frequency spread enables the estimation of an effective value of cubic nonlinearity of the guiding field.

5.2.5 New optical beam diagnostics

The insufficient time resolution of the electronics of the beam position monitor makes it impossible to achieve the required accuracy in measuring the orbit in the situation when the electron and positron beams simultaneously circulate in the collider. However, in high-energy physical experiments at the VEPP-4M collider with the KEDR detector it is necessary to provide a long-term stability of the beam orbit in the region near the interaction point. This is required for reliable operation of important diagnostic devices, such as the luminosity monitor and the system for measuring the energy by Compton backscattering.

An optical technique based on the use of a multipinhole camera has been proposed for stabilizing the orbit of the electron and positron beams in the NEM2 and SEM2 bending magnets adjacent to the interaction point. The X-ray multipinhole camera possesses geometrical properties similar to an ordinary pinhole camera for visible light. Passing through a small hole, light forms an inverted image of the source with a transformation ratio equal to D/d, where d is the distance from the source to the screen, and D is the distance from the screen to the recording device (a CCD array). At present, one complete set of diagnostics has been produced and installed in the electron direction for recording of synchrotron radiation from the NEM1 magnet (Fig. 12).

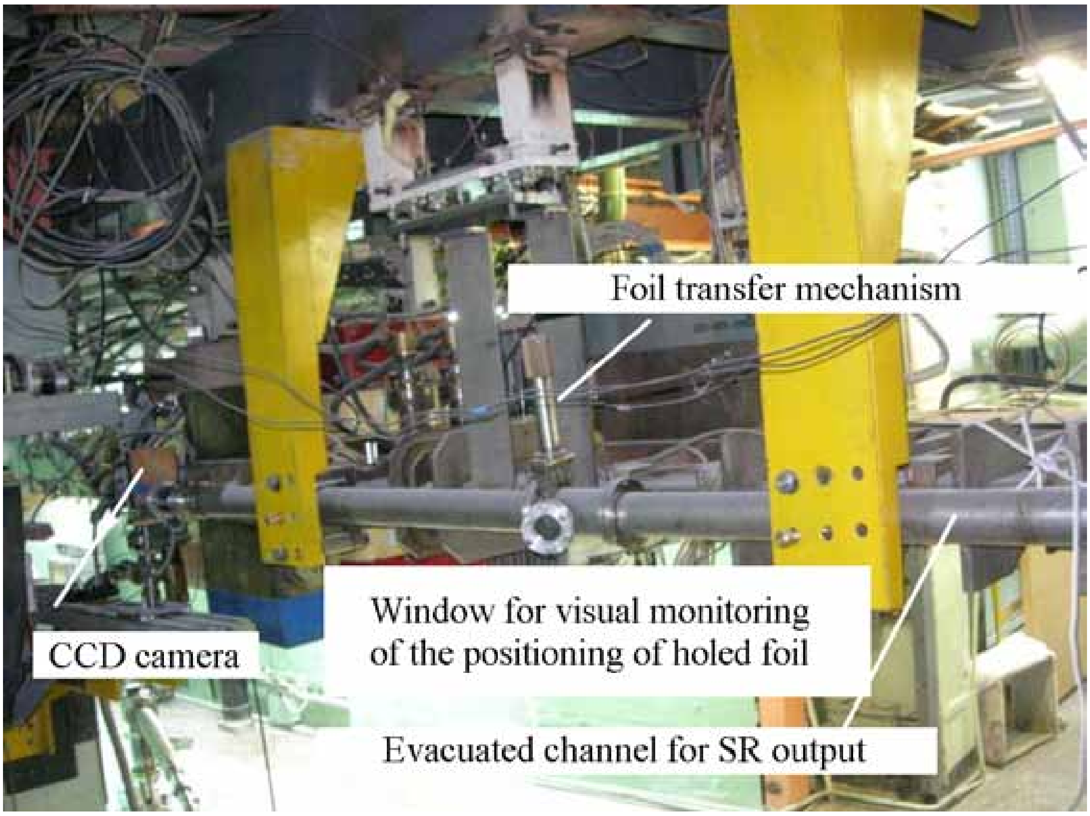


Fig. 12. X-ray multipinhole camera.

If a metal screen has a few holes located in line at a distance of ~$3\sigma_y$ from each other (σ_y is the transverse beam size), we will have an instrument permitting simultaneous measurements both of the transverse location of the beam and its angle of inclination at the radiation point - pepper-pot monitor. The spacing between the outer holes must be about $3d\psi$, where ψ is the angular divergence of synchrotron radiation and d is the distance from the radiation point to the screen

The existing configuration of the instrument allows determination of solely the vertical angle. In the horizontal direction, only the displacement can be monitored, but even this fact is of great importance for the problem of reliable measurement of the beam energy.

The idea of simultaneous measurements of the beam's transverse displacement and angle of inclination is illustrated in Fig. 13. If the transverse cross section and the angle of inclination are zero, X-ray synchrotron radiation creates a beam image at the metal screen, so that the center of the image is located exactly in the middle between two outer holes and the superposition of images formed by holes forms a symmetric figure on the phosphor (see Fig. 13a). The transverse displacement of the beam without an angular displacement causes all images on the phosphor and, therefore, their envelope to be shifted by value $y_1 = -yD/d$, see Fig. 13b. The inclination angle φ of the beam in the transverse plane without the offset results only in a shift of the envelope of the beam images by $y_2=\varphi d$ value; the images do not shift, only their intensity changes (Fig. 13c).

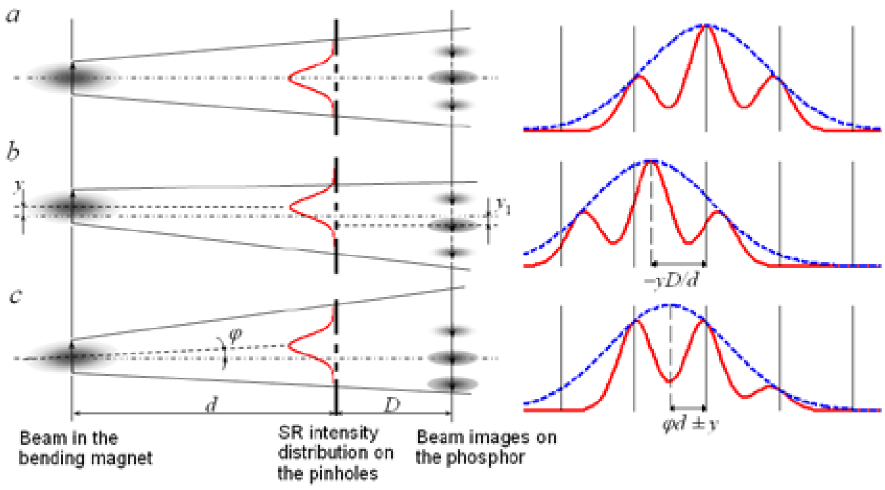


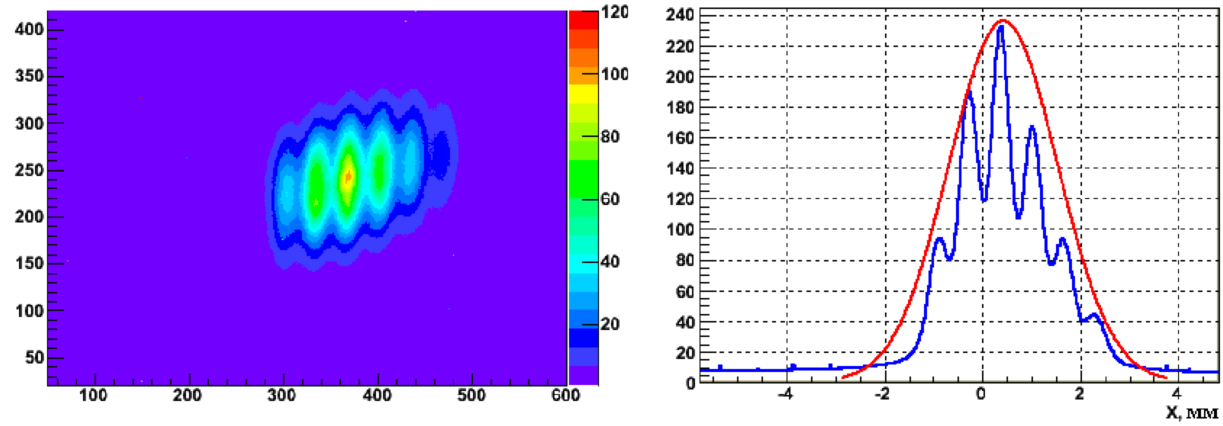
Fig. 13. Multipinhole camera: measurement principle.

So, the algorithm to determine both the beam position offset and inclination angle is the following:

1. measurement of the y_1 shift of the beam images;
2. measurement of the y_2 shift of their envelope;
3. calculation of the beam offset $y = -y_1 d/D$;
4. calculation of the inclination angle $\varphi = (y_2 \pm y)/d$, "+" sign corresponds to the case $y_2 < y$, "–" sign – to the case $y_2 > y$.

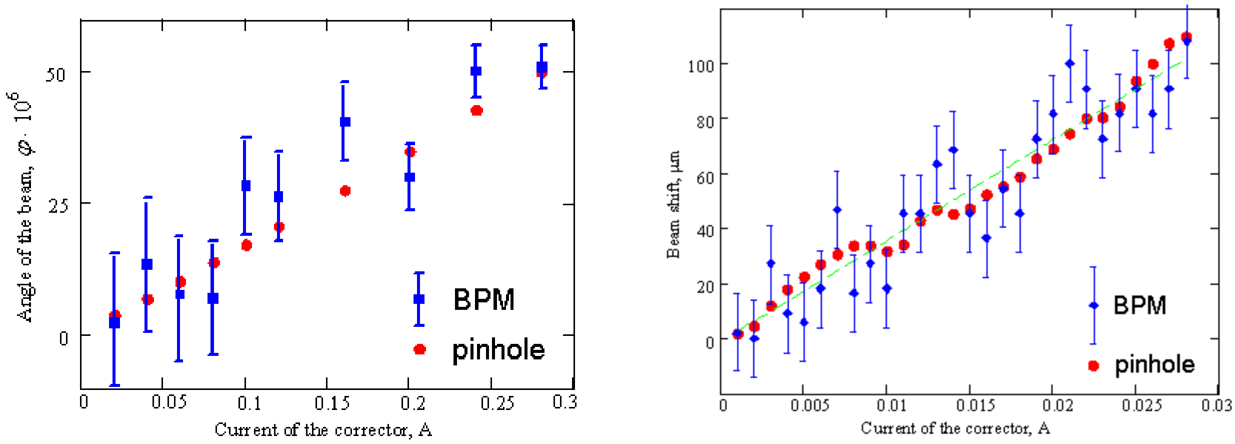
Soft X-ray radiation from the bending magnet, ejected outwards through a beryllium foil, is used to construct the beam image by the multipinhole camera. The spectral composition of radiation is such that it is almost fully absorbed in the atmosphere at a distance of ~1.5 m. Taking this into account and, in addition, to avoid damage to the beryllium foil, radiation is ejected toward the phosphor through a tube pumped down to a rough vacuum. The phosphor produced from ZnS converts an X-ray image into visible light; the beam image is thereafter transferred by the objective lens to the CCD array and read back to the computer (Fig. 14a). Processing of measured data yields the envelope of the beam images (Fig. 14b), which is used to determine the transverse displacement and angle of inclination of the beam at the radiation point.

To test the efficiency and accuracy of the diagnostics we have calibrated the multipinhole array with the pickup electrodes. The calibration had two stages. At the first stage, we created the wave of the orbit by the vertical corrector and measured the beam inclination with the BPMs and the pinhole array (Fig. 15a). The beam inclination is proportional to the field of corrector. We estimate the angular resolution of the array as 2 μrad in the dynamic range for the angular measurement of 50 μrad. A bigger beam inclination causes disappearance of one of the local maxima. It is the restriction supported by the software of the diagnostics. Such value of the inclination corresponds to the wave on the orbit that is unacceptable for collider operation



a b

Fig. 14. Beam image (a) obtained using the multipinhole camera and envelope (b) reconstructed by the experimental results.



a b

Fig. 15. Calibration of angular (a) and spatial (b) resolution of the multipinhole camera.

At the second stage of the pinhole array calibration, we created a bump at the point of the SR observation by means of three correctors (Fig. 15b). The bump amplitude is proportional to the currents of the correctors. The measured r.m.s. resolution of the multipinhole camera is about 1.5 µm in the dynamic range for linear shift measurement of 100 µm. At a bigger shift of the beam, the software does not determine all six maxima as in the case of the angular displacement of the beam. Obviously, the angular and spatial dynamic ranges of the array may be extended by increasing the number of pinholes, but in this case the requirements to the projection optics of CCD camera become more severe.

As it is seen, the pinhole array data demonstrate a significantly smaller r.m.s. errors in comparison with the pickup-electrode BPMs, but in much smaller range. In particular, this advantage of the multipinhole camera results from essentially greater base length for measurement of small angles.

Today, we do not pose the problem of measuring the vertical and radial beam sizes at the observation point, but, theoretically, this is possible.

5.3 VEPP-5 injection complex

Fig. 1: Final four sections of positron linear accelerator.

Fig. 2: Klystron gallery.

Damping ring parameters:

	DESIGNED	ACHIEVED
Energy	510 MeV	380 MeV
Particles per bunch	$2\cdot10^{10}$	$2\cdot10^{10}$
Injection frequency	50 Hz	10 Hz
U_{RF}	700 kV	230 kV
σ_S	4 mm	8 mm

In 2009 on VEPP-5 damping ring an electron beam with parameters near the designed ones was obtained. Injection energy in damping ring reached 380 MeV. All sextupole magnets and quadrupole correctors of the ring were mounted; linear and non-linear electron optics was measured in details, and on the base of beam measurements the precise electron optics model was developed. Due to the chromatism of the dumping ring compensated the maximum beam current in single bunch regime was obtained (I_b=35 мA, that corresponds the designed beam current).

Also the measurements of length, emittance and energy spread on the small beam current were done with using the method of coherent betatron envelope analysis. Results of these measurements are in good agreements with calculated beam parameters (fig.3).

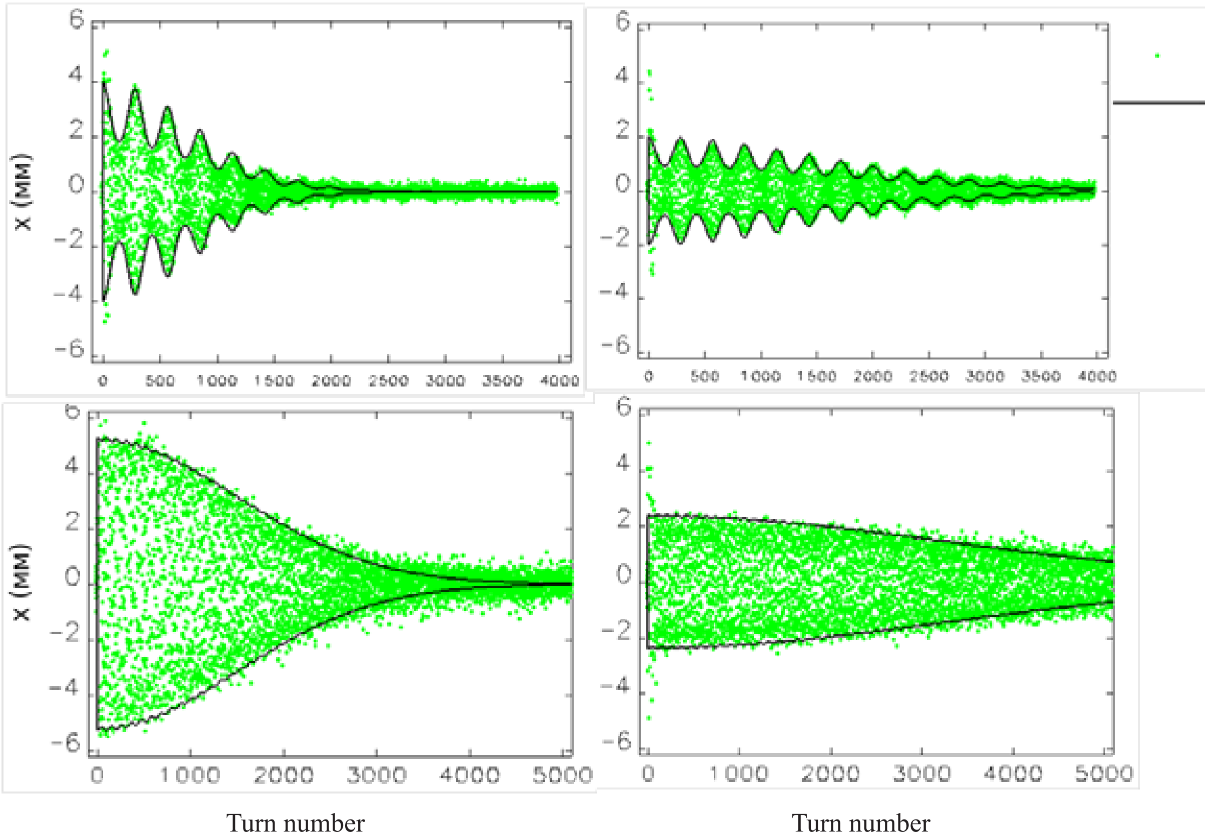


Fig. 3: Coherent betatron oscillations of the electron beam in the dumping ring after the inflector kick. The calculated curve is shown by solid line; the points are used to mark the turn-to-turn measurements of beam position monitor. The upper graphs shows the measurements in the case of uncompensated chromatism ξ= -6.0 (all sextupoles are turned off). Bottom graphs shows the case with ξ= +2.8, and the synchrotron frequency is appreciably greater one on the upper graphs.

On injection complex linear accelerators the beam emittance measurements; also measurements of focusing system parameters were being done.

At year-end last four sections of the positron accelerator were setup and mounted, and were power supplied. Also to the year-end the forth klystron for linear accelerator HF-system was obtained

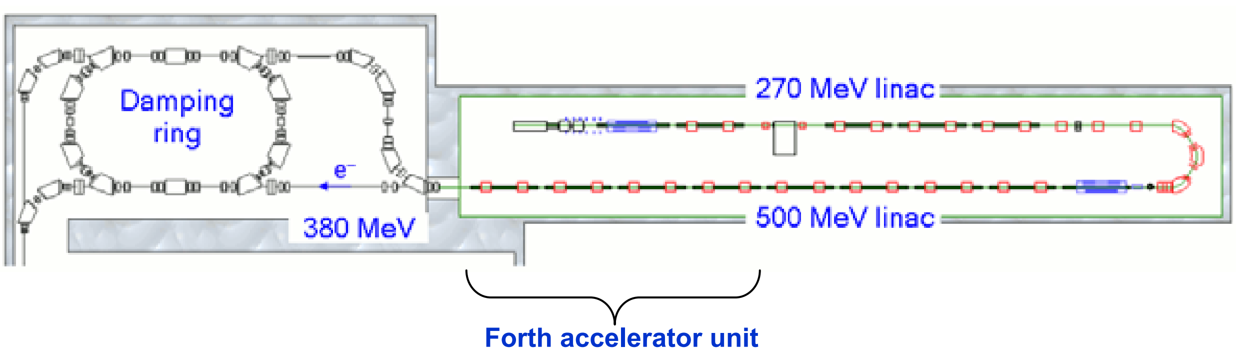


Fig. 4: VEPP-5 injection complex scheme.

5.4 Devices developed for high-voltage electron cooling

New generation of accelerators for studying nuclear physics in 1-8 GeV/n energy range requires an effective cooling to obtain high luminosity. For example, the planned experiment PANDA for research of meson resonances requires the target density of $4{\cdot}10^{15}$ hydrogen atoms per cm^{-2} and an order of 10^{10} antiprotons in HESR storage ring. In this case peak luminosity will reach the values of $2{\cdot}10^{31}$ $cm^{-2}sec^{-1}$. The experiment resolution is determined only by energy spread in antiproton beam, which should be better than 10^{-4}. Estimations show that to achieve such parameters, it is necessary to reach the time of cooling of about 0.1-10 sec that strongly differs from the cooler operating currently on 4.34 MeV RECYCLER FNAL with cooling time of about 15 minutes.

COSY storage ring and future antiproton storage ring HESR will allow performing a number of experiments in the field of precision spectroscopy. However, the cooled ion and antiproton beams with high phase density are necessary for their successful implementation. The project under implementation of high-energy cooler for COSY storage ring will allow an essential increase of its luminosity due to application of a pellet target at simultaneous decrease of beam energy spread.

Manufacturing of a 2 MeV electron cooler will result in creation of a unique system of high-voltage cooling. Together with using a high-density internal target, the given method will provide a high yield of useful events for unique reactions of elementary particle physics. Scientific and technical development of the project is connected with accumulation of knowledge for development of electron cooling in the range of proton beam energies with energy of several GeV and is an important step for usage of precision ion beams. The progress attained in the given project, is essential for creation of 8 MeV electron cooler in HESR storage ring, which is the important part of future project FAIR (GSI).

Fig. 1 represents the design of an electron cooler [357,358]. It includes a high voltage tank with 2 MeV electrostatic accelerator installed inside, transport channels and cooling section. Main parameters of a high-voltage cooler are given in Table 1.

Table 1. Main parameters of 2-MeV electron cooling installation.

Energy range	0.1 ... 2 MeV
High voltage stability	$< 10^{-4}$
Electron current	0.1 ... 3 A
Electron beam size	10 ... 30 mm
Length of cooling section	2.69 m
Toroid radius	1.00 m
Magnetic field in cooling section	0.5 ... 2 kGs
Vacuum in the chamber of cooling section	10^{-9} ... 10^{-10} mbar
Length of straight section for cooling	6.39 m
Maximal height	5.7 m
Distance from a floor to ion beam trajectory	1.8 m

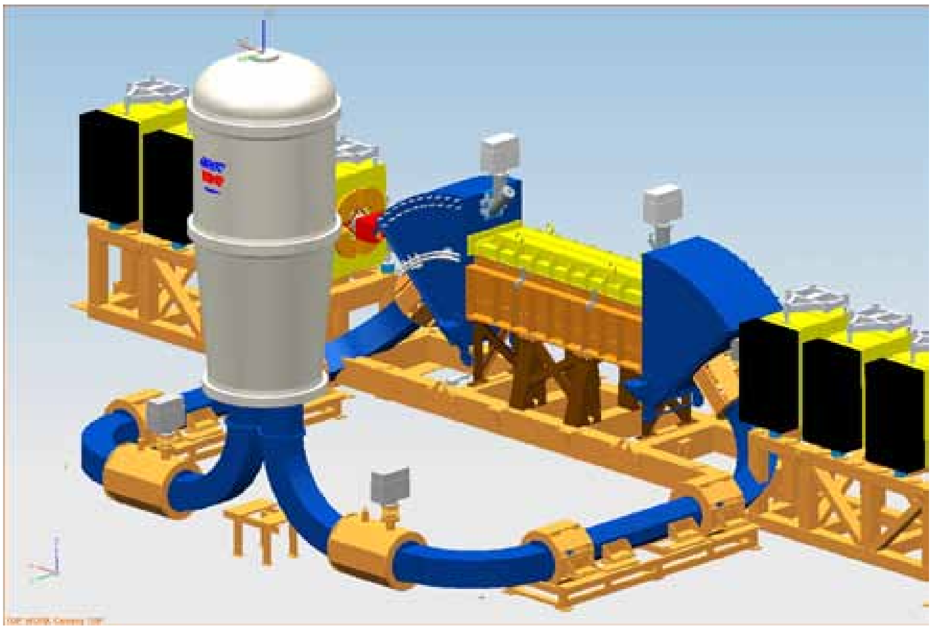


Fig. 1. 3D view of 2-MeV electron cooling installation.

5.5 Work on Accelerator Mass Spectrometer

Accelerator mass-spectrometry (AMS) – is a modern supersensitive method of isotope analysis of substance. The method is based on counting certain atoms in the sample of substance, therefore, the weight of the sample does not exceed 0.001 gram. AMS allows the measuring the percentage of rare isotopes in substance at 10^{-12} concentration and less.

AMS complex is based on electrostatic tandem accelerator [140]. Acceleration of ions of the sample up to the energy of several MeVs provides a multistage selection of ions at passing through electromagnetic fields, stripping of ions to charge 3+, destroying background molecular ions of close masses, and application of nuclear physics detectors at final identification of isotope [141,142].

Results for 2009:

- Stable 500-kV voltage is obtained on high-voltage terminal of the electrostatic tandem (in air, without filling the tank with sulfur hexafluoride).
- The negative ion sputtering source with a drum for 23 samples is installed. The current of carbon negative ions of 5 mkA is obtained.
- Tuning of the beam passing through AMS accelerator is carried out. The transmission factor of ions is 1 % for C^{3+} and 13 % for C^{2+} (520 keV C^- ions are stripped in a target with magnesium vapour of the electrostatic tandem high-voltage terminal).
- Registration of the isotope of 14 amu carbon is performed (radioisotope concentration in the modern sample at level 10^{-12}) by the system of time-of-flight detectors (Fig. 2).
- Process of the carbon sample analysis is automated (the ion source drum with samples is rotated with the set time interval for new sample, measurement of the current of ^{12}C ions and counting of each ^{14}C ion are performed). The statistical error of counting every radiocarbon for acceptable time is few percent.
- In cooperation with CGU «Caenozoic Geochronology», samples of a present-period tree with a binding to annual rings are made for AMS. Testing of these samples, which has revealed an essential spread of carbon-14 content connected both with nuclear tests and with the methods of manufacturing the samples.

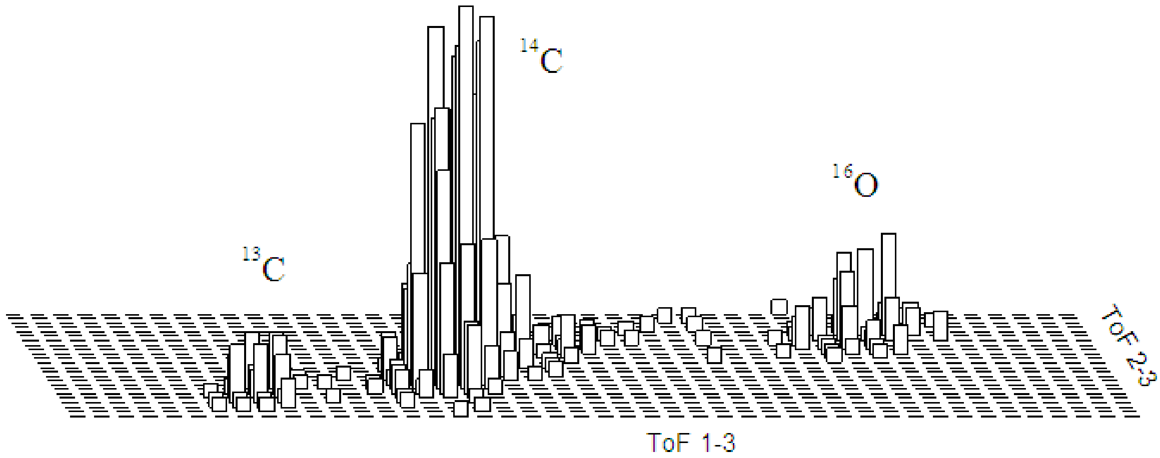


Fig. 2. Radiocarbon registration in the modern sample in two time-of-flight intervals (the masses, which differ from ^{14}C, are eliminated by many orders at passing through the AMS complex duct.

5.6 Vacuum systems

5.6.1 Thin-film coatings

At the Institute, the experiments on magnetron deposition of metal coatings and measurement of their vacuum and electrophysical properties are performed. Taking into consideration vacuum properties, it is expected that films of pure metals will possess a considerably smaller intensity of gas emission without heating and, thereby, will allow a considerable decrease of the power of pumping systems of large electrophysical installations. Fig.1 represents the pressure dynamics in a three-meter chamber coated with a film of 99.999 %-purity aluminum.

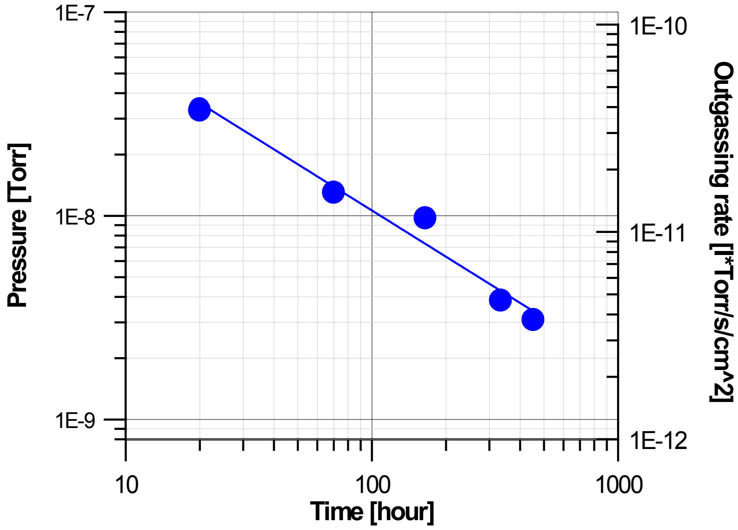


Fig. 1. Pressure in a 3-m chamber with Al coating.

Experiments with coatings of copper and silver as the most probable candidates for XFEL vacuum chambers (Hamburg, Germany) are planned.

5.6.2 Flat flange joint

Currently, flat flange high-vacuum split joints are widely used. Advantages of the given type of the joint are obvious: a) free-shape sealing contour and b) simplicity of surface preparation. VAT company already produces a number of standard sizes of copper sealing for flat flanges. However, the single-piece ordering of sealing parts of nonstandard form is time-consuming and rather costly. Therefore, implementation of the basic advantage of the flat joint – i.e. manufacturing of the joint with the certain sealing contour is possible only with simple and reliable technique of manufacturing the metal sealing.

In 2009 BINP developed the manufacturing technique for a free-shape metal sealing based on photolithography with the subsequent chemical etching. The functional concept of the given type of sealing is shown in Fig. 2.

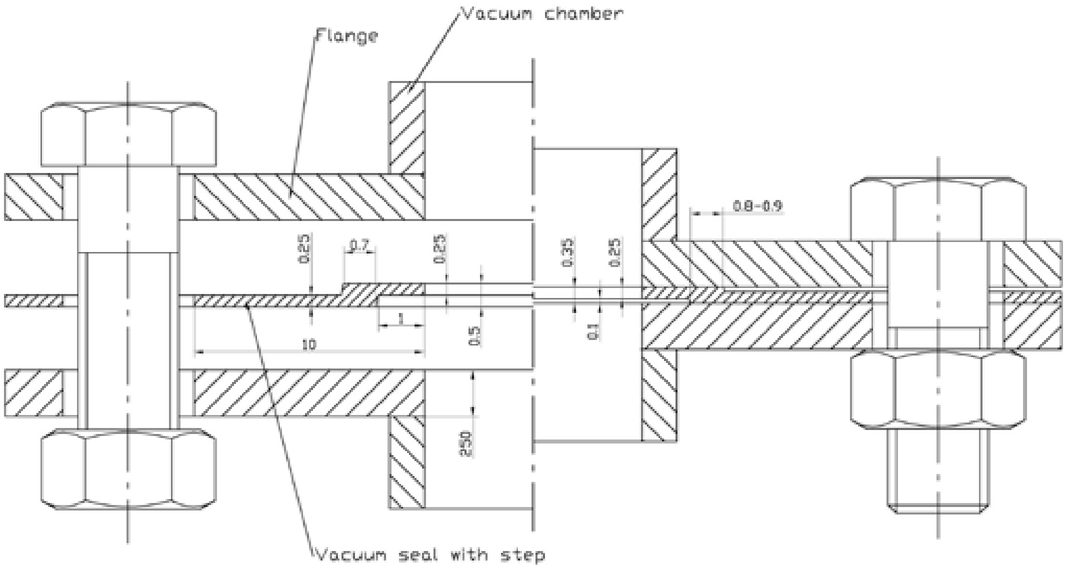


Fig. 2. Functional concept of flat-type sealing with a step.

The step is crushed and the sealing body metal expands providing good tightness at bake-out and at thermocycling.

The basic sizes of the test sample of the sealing are shown in Fig. 3. The given sizes are specially chosen: this sealing is planned to be used for a certain flange joint (beam buncher, XFEL Hamburg) consisting of two smooth flat flanges with the rectangular-shape inner aperture with the sizes of 400*40 mm.

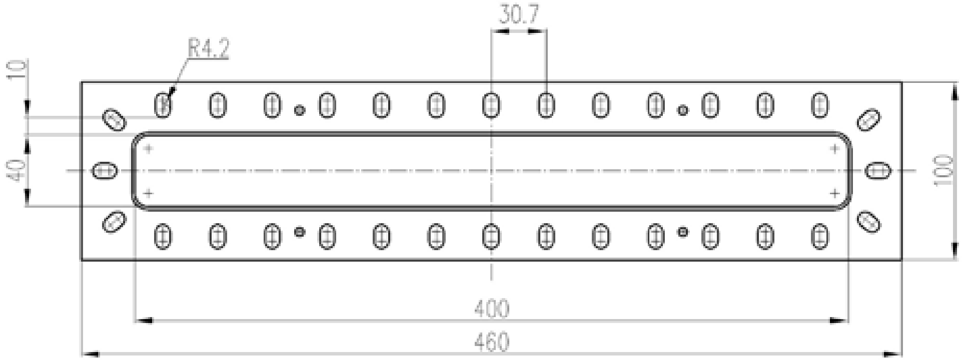


Fig. 3. The basic sizes of the test sample.

100mm-wide and 0.5mm-thick copper tape of M0b–type was used as the work material for sealing. The basic stages of techniques are represented in Fig. 4.

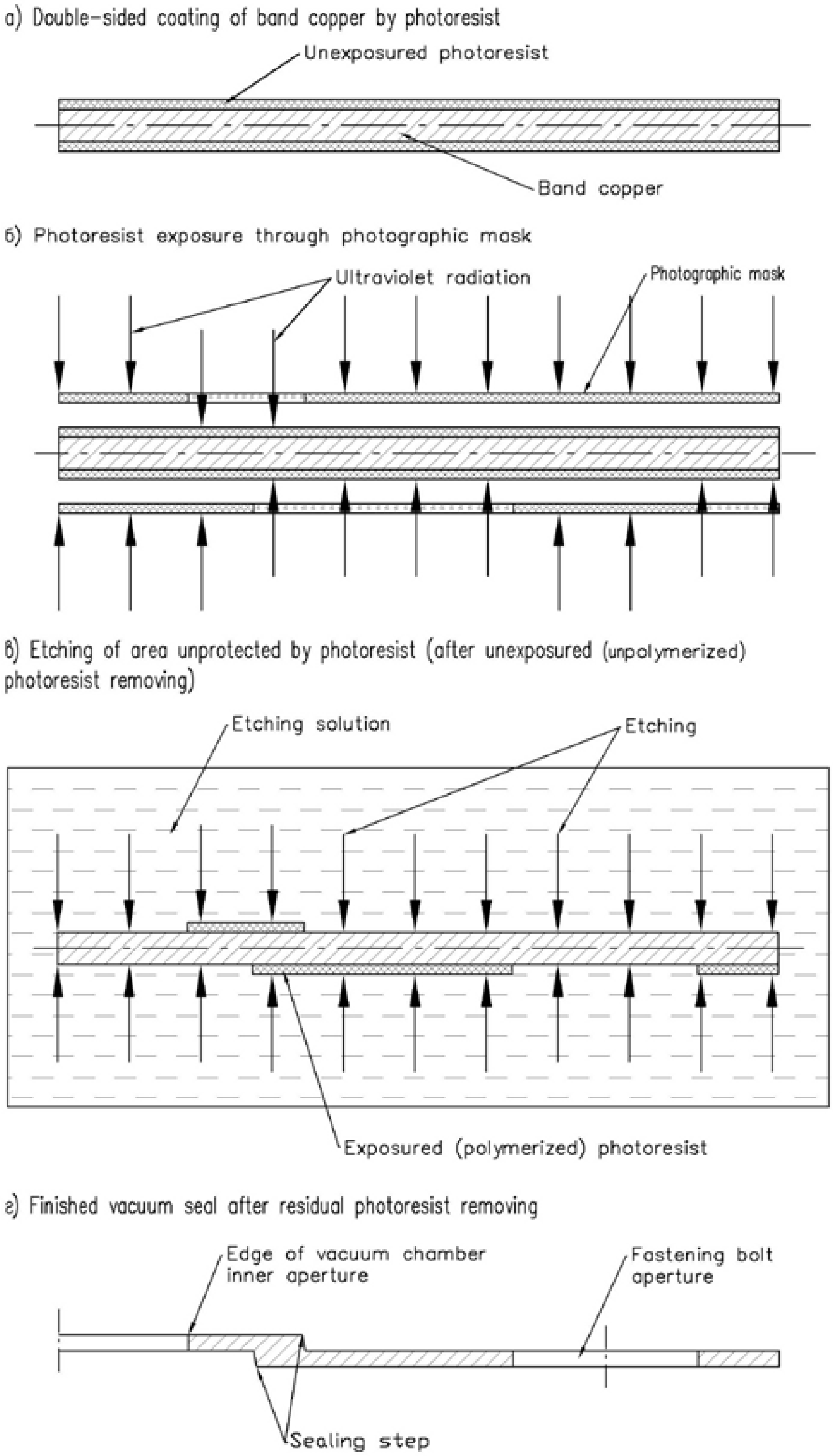


Fig. 4. The basic stages of manufacturing the flat sealing with an asymmetrical step.

Use of a 0.5mm-thick copper tape for manufacturing the flat sealing with an asymmetrical step has appeared to be very efficient as it is necessary to etch half-thickness of the tape from each side to obtain a 0.25mm-high step. Thus, it is possible to make the hole of the inner aperture and the holes for bolts and pins automatically; i.e. one operation of etching provides the final form of the sealing, which is ready for utilization just after vacuum baking out. However, at high temperatures, pure copper oxidizes in air considerably. To prevent oxidation of the sealing surface, it is possible to apply silver coating up to 20 micron thickness galvanically.

To date, 2 types of sealing have been tested: copper and silvered. To determine the minimum force of bolt tightening, the bolts were tightened stepwise with force-step of 5 N*m. From the force of 10 N*m, helium leak testing was carried out after each step by means of the mass-spectrometer. As a result, hermetization of the sealing occurred already at 10 N*m tightening force and the level of helium-leakage signal was $I_{He} = 10^{-12}$A. Further, for more reliable hermetization, the bolts were tightened till the moment of 15 N*m, at which all further tests were performed.

It is necessary to note that no considerable force was applied to the flange joint during the testing, though, in real conditions, the joint can be subject to disruptive or shearing forces. Imitation of real working conditions was not carried out. Thus, in order to compensate external actions, increasing of tightening moment up to 20 – 25 N*m is recommended.

Copper sealing without coating was heated maximum up to 275 ºC and silvered – maximum to 350 ºC . 9 heating-cooling cycles were performed for each sealing: heating with average speed of 75 ºC/hour, holding for 10 minutes, cooling with speed of 55 ºC/hour. Also, a 24-hour heating at the maximum temperature was carried out for each sealing. Throughout all tests for measurements of the mass-spectrometer, helium-leakage did not exceed $I_{He} < 10^{-12}$A (inleakage $< 10^{-10}$ l*Torr/sec).

Main advantages of the given method of manufacturing the copper sealing with a step are as follows:

Possibility to produce finished sealing for one manufacturing operation in case of flat sealing with small thickness (not more than 0.5 mm) with an asymmetrical step;

Convenience and efficiency at the stage of developing the design of the sealing: changing of the design requires replacement of only a photomask – as manufacturing of a photomask is much easier, than, for example, a new die in case of producing the sealing with a punching method.

Possibility of manufacturing the sealing with any shape of the inner aperture.

Providing the evenness of the connected chambers almost of any cross-section without application of additional components (for example, RF contacts).

Possibility to manufacture the sealing with very small ratio of the hermetization surface area to the sealing total area, when in case of a punching method excessive forces for formation of sealing step are required.

5.6.3 High-vacuum optical window of the infra-red range

The vacuum equipment for measuring the beam energy with the method of Compton backscattering of CO_2 laser beam on relativistic particles in the VEPP-4, BEPC-II (IHEP, Beijing) accelerator complexes was made in BINP. The main part of the equipment is a vacuum chamber with the copper mirror coated with a layer of 0,3 micron-thick gold and a window for injection/extraction of synchrotron and laser radiation. The copper mirror is adjustable in all directions and water-cooled. The window should provide passage of the laser radiation with wave length λ=10,6 microns and the synchrotron radiation (SR) within the camera sensitivity range (0.4-1 microns). The SR extraction is necessary for tuning of the laser radiation injection.

In 2008-2009, the technique of soldering of GaAs optical monocrystal to a titanium ring with lead solder alloy was developed for manufacturing of SR and laser radiation extraction/injection window. The window consists of DN63 standard flange, Conflat type, 304L steel, and GaAs crystal plate with diameter of 50.8 mm and thickness of 3 mm, soldered to the flange using a system of transition rings (Fig. 5).

Fig. 5. GaAs high-vacuum window design.

The windows were tested many times. The spectrum of the residual gas is represented in Fig. 6. The window transmission spectrum is shown in Fig 7. This technique allows production of high-vacuum window with other crystals. The window design provides possibility to heat the vacuum chamber up to 250˚C and allows obtainment of high vacuum.

The equipment is successfully installed at the VEPP-4 and BEPC-II accelerator complexes. Pressure in the installation vacuum chamber is about $P=1\times10^{-10}$ Torr.

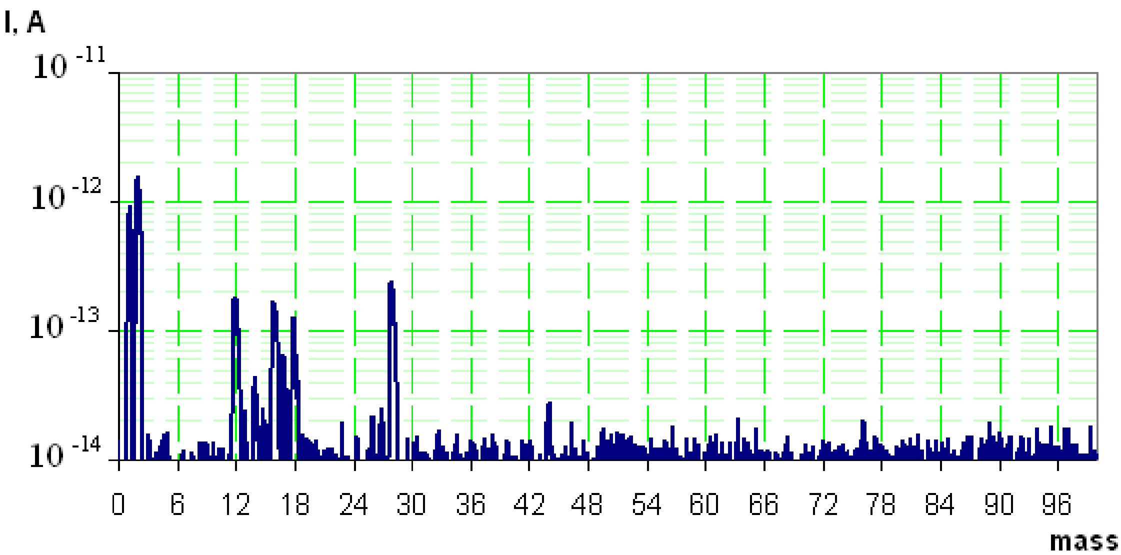


Fig. 6. Residual gas spectrum in the vacuum chamber with GaAs window after testing.

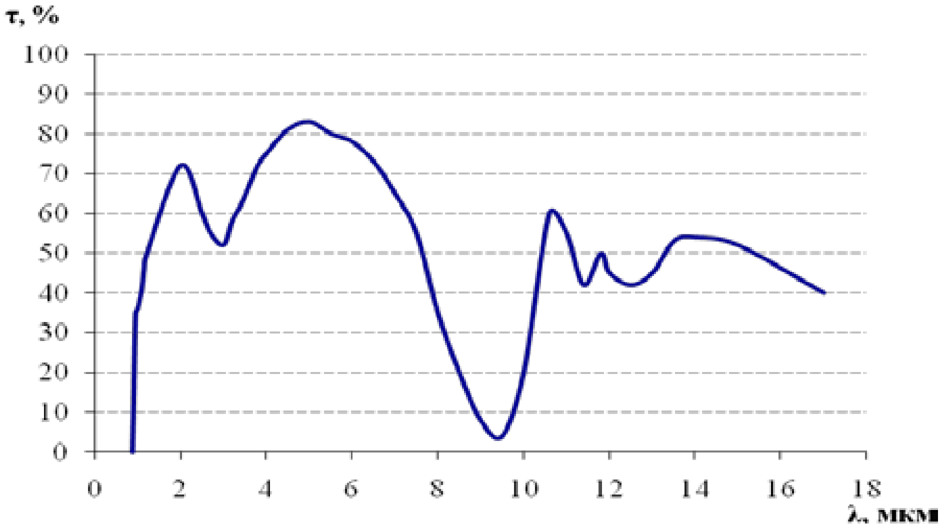


Fig. 7. GaAs transmission spectrum protected with SiO_2 film of 0.6-micron thickness.

The work is partially supported with Russian Foundation for Basic Research grants: 08-02-00328-a, 08-02-00251-a, RFBR-SFNS-08-02-92200-a, SB RAS Basic Research Project N32 carried out together with Academy of Sciences of the Peoples Republic of China.

5.7 Electron-Positron Factories and Beam Physics.

In 2009 the activity was focused on the studies aimed at the creation of electron-positron factories and the improvement of their parameters.

There were completed two works on studying the feasibility of suppressing beam-beam effects in the machines using crab crossing and crab waist. It turned out that in case of beam collisions with a low disruption parameter it is possible to find such a combination of crab crossing and a crab waist inserts that will compensate all colliding beam sinchro-betatron resonances and coupling resonances due to the crossing-angle collisions. In this case not only the values of the geometrical luminosity but also the instability of colliding bunches are similar to those developing in case of head-on collisions.

In the beams with a considerable overlapping of sinchro-betatron modes single-turn instabilities of transverse coherent oscillations attain the features of the beam breakup instability. The increments of these instabilities are decreased with time which helps to damp them. The study of the wake memory effect disclosed that though the wake memory leads to the eigenvalue spectrum appearing in the task, the absence of leading modes in it, as well as the presence of essential singularities in the corresponding dispersion equations is reflected in such a dependence of coherent oscillation versus time that are typical to the beam breakup effect. As a result, in this asymptotic region of parameters all transverse modes can be completely damped, e.g. with the wide-band feedback system. This peculiarity exists both for one bunch oscillations and for a train of identical bunches ending with a long gap.

5.8 Pulse Magnet for the Positron Source of the KEK Super-B Factory

In the framework of the collaboration between KEK (Japan) and INP on the improvement of the available positron source for the KEK B-factory in 2009 there were carried out the tests of the pulse matching magnet and the power supply to it (Fig. 1).

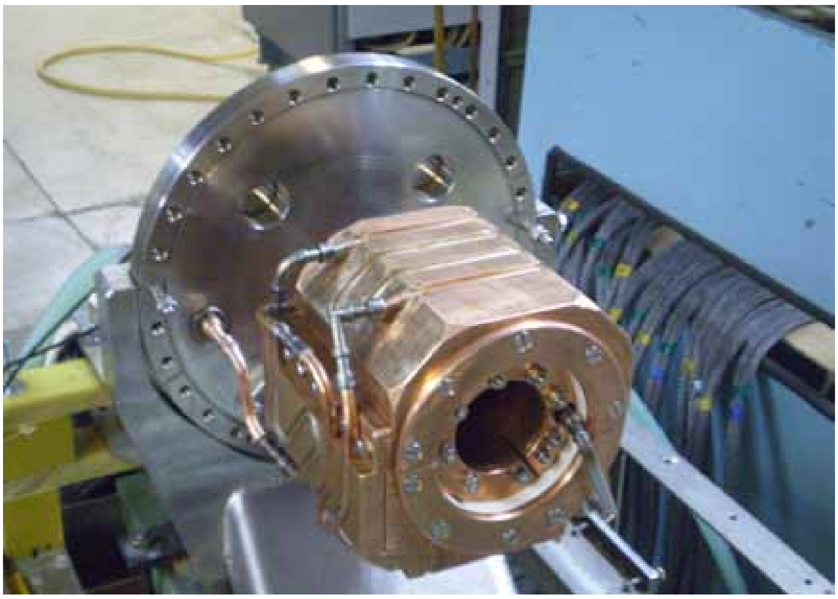


Fig. 1. Pulse matching magnet inside the vacuum chamber (the flange of the vacuum chamber is off).

The main goals of these tests were to attain the 100 kGs design value of the magnetic field of the spiral flux concentrator with a 50 Hz pulse repetition frequency and to carry out the endurance test of the magnet and the power supply.

During the first half of 2009 the pulse magnet was successfully trained and there was attained the design field with the required repetition frequency. The magnet training was performed in a staged manner. At each next stage the magnetic field was gradually increased, while the pulse repetition frequency in order to prevent the breakdown was correspondingly reduced down to the values of 1-2 Hz. When the pulse repetition frequency gradually attained 50 Hz the magnetic field was further increased.

In the second half of 2009 there was performed the endurance test of the magnet and the pulse generator. The main goal of this test was to detect how many pulses this pulse magnet can endure with no visible changes and damages. The fact is that a pulse conversion magnet operating at a real positron facility during one year at a repetition frequency of 50 Hz gets approximately 10^9 pulses. Therefore, in order to get a certain answer about the life-time of the magnet of a particular design one should have 20-25 million pulses at the repetition frequency approaching the operational one.

In the course of the endurance test there was found a drawback in the design of the pulse magnet power supply. The charge circuit choke and the magnetizing choke were overheated. This made it impossible to test of the pulse magnet at nominal parameters (100 kGs and 50 Hz) for a period longer than 1 hour. As a result it was decided to low down the repetition frequency to 25 Hz.

During November the pulse magnet reached about 22 million pulses at the repetition frequency of 25 Hz. After that the magnet was removed from the vacuum chamber and the magnetic fields were measured. There were no essential changes in the magnetic field distribution detected before and after the endurance test.

After the endurance test there was started the work on improving the pulse magnet power supply.

5.9 Electron beam sources of multicharge ions

BINP develops and produces electron beam sources of multicharge ions with a high density of the electron beam in the vicinity of the ion trap $\geq 10^3$ A/cm². These ion sources produce multicharge ions of various elements, both of gaseous and solid materials. In these sources there is employed the method of pulsed dosed inlet of atoms of solid elements into the ion trap.

Ion sources of this type can be used for heavy ion accelerator complexes, in low energy interactions and other applications, i.e. in the production of superfine nano-structures in nanotechnologies, in the production of high-precision analyzers including those for medical purposes. Ion sources of C(4+) can be used in medical accelerator complexes for the treatment of oncological diseases.

In case of obtaining the estimated super high vacuum of $\sim 5*10^{-12}$ Torr in the vicinity of the ion trap the parameters of this facility will produce multicharge ions of all elements, including nuclei of niobium, caesium, barium, chlorine, fluorine and multicharge ions of iodine.

There has been currently designed and manufactured an electron-beam ion source MIS-1 (Fig. 2) which focusing magnetic system is based on a superconducting solenoid with a loop flux return. It provides for a homogeneous magnetic field of 3 T in the drift structure over the length of 700 mm. The estimated compression of the electron beam is no less than 10^3, insuring its density in the ionization zone $2 \cdot 10^3$A/cm² at an electron beam current of 20 A. The capacity of the ion trap is $\sim 10^{12}$. For attaining such a compression of the electron beam a two-step compression is used.

Fig. 2. MIS-1 (left) and its drift chamber (right).

EOS of MIS-1 is estimated to obtain an electron beam of 20A at an energy of 50 keV and is based on a short-focusing electron gun with a spherical impregnated cathode. The cathode is 34 mm in diameter, its curvature radius being 21.5 mm. A special structure and the design of the focusing magnetic system of MIS-1, matched with the electron-beam system (EOS), guarantees the basic condition – the laminarity of the intense electron beam over the whole length of EOS, the stability of the magnetic flux passing through the cross section of the electron beam from the cathode to the collector.

The focusing superconducting magnetic system of the ion source MIS-1 is a vertical construction and consists of a 1 m long superconducting solenoid placed in a cryostat, an outer flux return, two electromagnetic lenses located in the vicinity of the electron gun and the electron collector. The winding of the superconducting solenoid is made of sections in order to provide a homogeneous focusing field of 3 T throughout the maximum length of the drift structure. In the central part of the top and the bottom poles of the flux return there are located magnetic diaphragms of a special shape to provide the required distribution of the magnetic fields in the vicinity of the electron gun and the electron collector.

The control system is based on the principle of total operation and control of all the parameters of the power supply systems from the central computer. The system is based on the ADC and DAC units (CAC208), delayed pulse generators CGVI8, developed and produced at INP [2], with a CANBUS interface. The spectrum of the multicharge ions obtained at the MIS-1 facility will be analyzed with the help of the electromagnetic mass spectrometer using CANIPP units with a CANBUS interface. The central computer is connected to the facility through a peripheral gateway CAN-Ethernet. The operator can operate and control all the parameters of the MIS-1 facility. The operation period of the facility can be set up from 100 ms up to 20 s, the duration of the operation pulses with the electron beam can be set up in the range from 100 μs up to 2 s and more.

In 2009 there was carried out a lot of work to mount and debug the MIS-1 systems.

- The focusing magnetic system of MIS-1 was improved and checked. After training the superconducting solenoid there was obtained the maximum operation field of 3 T. For the fields inside the solenoid equal to 1T, 2T and 3T there was measured the distribution of the magnetic field at the axis of the magnetic system. The measurements have shown good coincidence of the experimental and estimated results.
- Following the recommended improvements the drift structure and the other technological units of MIS-1 are presently under assembly.
- The power supply and control systems are currently under pre-commissioning.
- There have been currently developed basic functional power supply and control systems for the electron beam source of multicharge ions MIS-1.
- There have been developed an electron gun power supply unit, an anode modulator securing the reliable switch on/off of the electron beam of up to 20 A, a pulse modulator for adjusting the electron optical system EOS of MIS-1, a regulated high-voltage rectifier at a power of 100 kVA and a voltage in the range from 1 to 9 kV.

The necessary improvement of the power supply system and the control system of the MIS-1 drift structure is presently under way. The system of the dozed inlet of atoms of solid elements into the ion trap of the drift structure has been complete.

5.10 VEPP-2000 Injection-Extraction System

In 2009 the injection system of VEPP-2000 was operated in a usual supporting mode. There was also launched the so called “training mode” when the pulsers regularly fire directly onto the load excluding the inflection plates. When it is necessary to deflect a bunch, the required mode is set up with the help of switchboards and employing synchronization and the bunch is normally deflected. It helped to avoid the situations when after a big break between the operations there was only a slight change in the thyratrons’ temperature which led to the system operation at a wrong moment and the bunch was lost.

A series of preventive switching was carried out at the VEPP-5 complex to check and fix the malfunctions in the high-voltage loads if any.

Fig. 3. The TPI-1K-35 pseudo-spark switch with the isolating housing filled with a carbogel (up to 40 kV) and without housing (up to 20 kV).

Following the provisions of the contract in force there were performed tests of the pseudo-spark switches TPI-1K-35 (Fig. 3). There were checked the long-term stability, the jitter, the high-voltage capacity, the feasibility of reaching the short rise time. The obtained rise-time duration was achieved in less than 10 nanoseconds which seems a very good result for the model scheme. These pseudo-spark switches are planned to be installed in the pulser developed under the contract for the NESTOR facility, Kharkov.

Under the same contract there was also upgraded and put into production the wideband high-voltage load with a build-in divider (Fig. 4) similar to the one used at VEPP-2000. This load with a filling of SF6 can stand up to 90 kV at a pulse duration of up to 30 ns. The load resistance is 50 Ohm. The output voltage ratio is 200. At a rise time of 2-5 ns the reflection does not exceed 2%. The measurement block quality is shown in the oscillograms below (Fig. 5).

Fig. 4. High-voltage wideband load with a build-in divider.

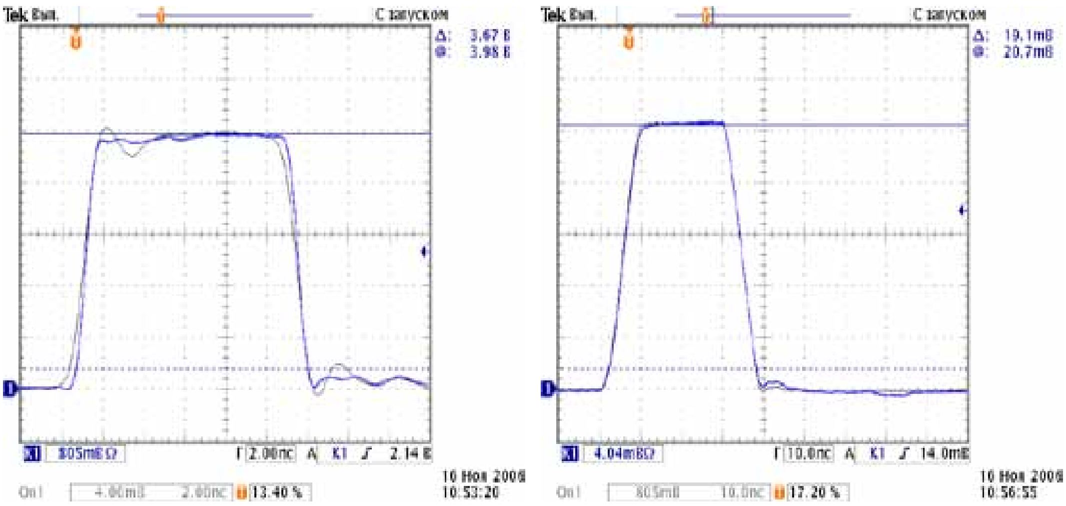


Fig. 5. Input and output oscillograms by overlay.

Besides this work there was carried out a series of tests on using short HV pulses for disintegration of biological objects. This kind of work is also performed at other electrophysical laboratories bears not only an experimental but also an applied character. E-coli and baking yeast cells were tested with short high-voltage pulses. The objects were placed in standard cuvettes for electroporation (Fig. 6).

It was shown that under the action of the electric field the cells were destroyed. Nucleic acids were accumulated in the cell infusion. They were registered with the help of electrophoresis in the agarose gel (Institute of Cytology and Genetics). The Latin square was used as a matrix. This helped to determine that the significant factors were the pulse amplitude and pulse quantity. The pulse duration did not change, as the main idea of this work was to design a compact pulser at a pulse duration of 15-50 ns per several kilovolts operating in a megahertz (or a burst) mode. These pulsers can be employed in various fields of accelerator physics, like in the extraction system of fast scanning bunches. These experiments are described in more detail in the papers under publication.

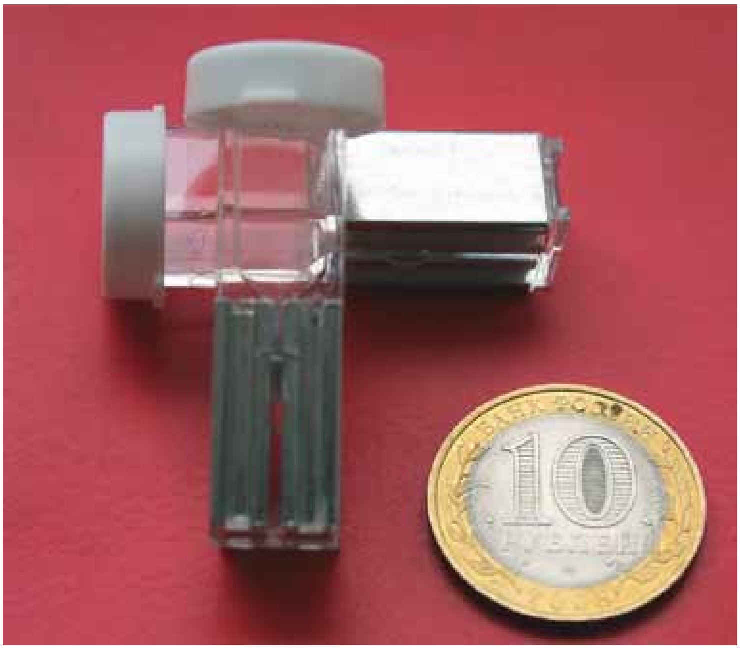


Fig. 6. Cell electroporation cuvettes.

5.11 Development of a high-power neutron production target

In the framework of the collaboration between INP, INFN-LNL (Legnaro, Italy), GANIL (Cayenne, France) and VNIITF (Snezhinsk), INP proceeded with the development of the high-power neutron target for the projects aimed at obtaining the radioactive ion beams of the second generation (SPES and SPIRAL-II). The target is a rotating metal disk with a fixed-on graphite converter cooled by self thermal radiation. The liquid metal (LM) devices using an alloy of 90% Pb + 10% Sn are used for the rotating drive, the hanger and the heat-exchange contour.

The goal of the present stage is to develop and test:

- A full-size target designed at a 200 kW primary beam;
- LM driving and heat-exchange contours, including pumps/motors, heat-exchange channels and a heat-exchange unit, a delay window, and contour parameters control devices;
- The technology of a preliminary check of particular elements and units of the neutron target, including the creation of a special test bench on the basis of a powerful now-energy electron accelerator, as well as experimentally check and improve the above methods at this test bench.

In the course of the above work during 2009:

- There been completed numeric simulation of target liquid metal assemblies and subsystems, namely, the heat exchanger and the cooling panels. There were the calculations of design and parameters of LM devices for target prototype operated with the 60 kW electron beam (electron gun upgraded configuration) performed. Parameters of 200 kW (Fig.7) target's cooling panel conventional and reduced thickness designs were determined also. Finally, some aspects of a delay window (operating conditions, destruction time of front wall etc.) are considered. It is shown:
- Using the new beam profiles in thermo-mechanical analysis did not affect much on the distribution of temperature and stress over the target, as well as on their maximum values.
- When designing the target and defining the dimensions one should take into account the degradation of graphite thermal conductivity as a result of radiation damages. This effect is more

pronounced at lower operating temperatures. At a temperature higher than 1000 ^{0}C the annealing effects begin to recover the damages and, hence, to compensate the losses in thermal conductivity. At the neutron converter nominal temperature of 1850 ^{0}C the annealing process has to recover the majority of defects induced by neutron irradiation.

There has been created a test bench (Fig. 8) including an electron accelerator (at 60 keV, 30 kW), experimental chambers, a LM contour, pump-out and heating systems control and measurement equipment:

- Experimental and supplementary chambers and LM contour parts were manufactured and mounted.
- Systems for pumping, heating/temperature stabilization, etc. are installed and adjusted;
- An electronic kit for the test bench operation was produced. The power and measurement electronics as well as the control system and the data acquisition system were mounted and debugged.
- The experimental hall was overhauled to house the test bench. Its basic systems were updated, including the ventilation, the light and the power supply, the distilled water supply, etc. A new cathead was mounted.
- An electron accelerator with beam energy up to 60 keV and power up to 30 kW was manufactured and tested.
- All the basic LM equipment for the test bench was manufactured, including the LM heat-exchange contour of the target cooling, the auxiliary units and pipes for the LM contours, the diagnostic devices of the experimental chambers and LM contour parameters.

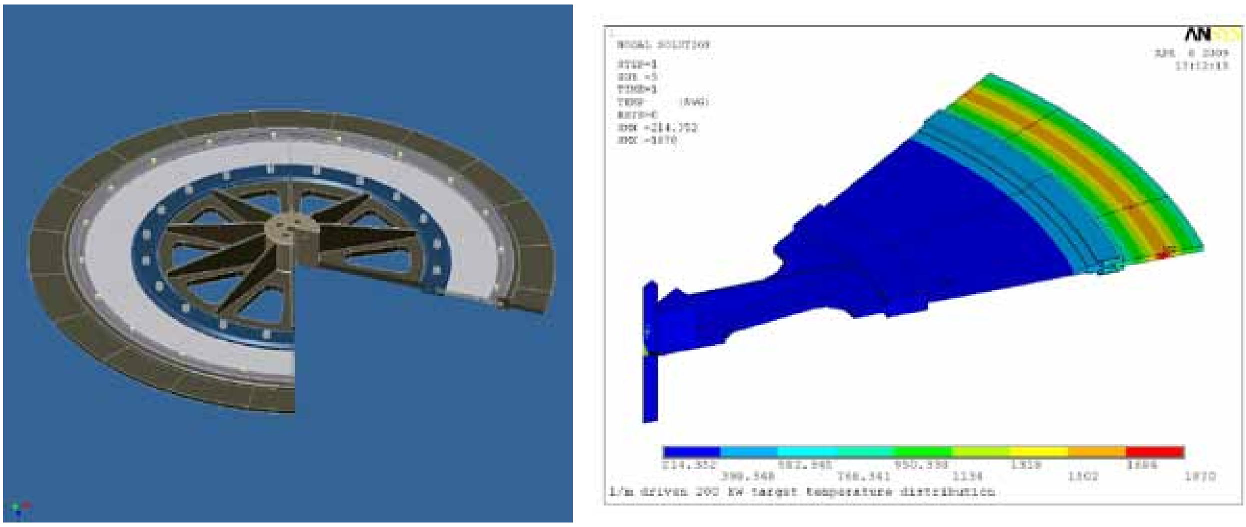


Fig. 7. A 200 kW target (left) and temperature distribution in the target at a beam of 200 kW, 4 cm (4σ), and a target diameter of 140 cm.

The basic LM devices (Fig. 9-12): motor/pumps, cooling plates, heat exchange unit, delay window, pressure and LM consumption gauges were manufactured and tested. The test showed a good performance of the devices. In the course of experiments the electron beam, 2 mm in diameter, at an energy of 60 kV was directed onto the delay window. The maximum non-destructive power density was detected. It made 55 kW/cm^2 at an LM flow rate of 0.9 m/s and 110 kW/cm^2 at a flow rate of 1.33 m/s. The peak beam power was equal to 1.8 and 3.6 kW, respectively, more than

Fig. 8. Test bench.

the design modes of the target operation. The heat exchange unit took away the heat flux at a power of 2.8 kW per segment, the estimated power being 3 kW. The LM pump operated in a regular mode. The LM motor also operated in a regular mode at low speed. At high speed (and at a pressure drop in the motor) the motors cogwheels were jammed. The source of this malfunction was found, the drawbacks in the design were corrected.

Fig. 9. LM pump.

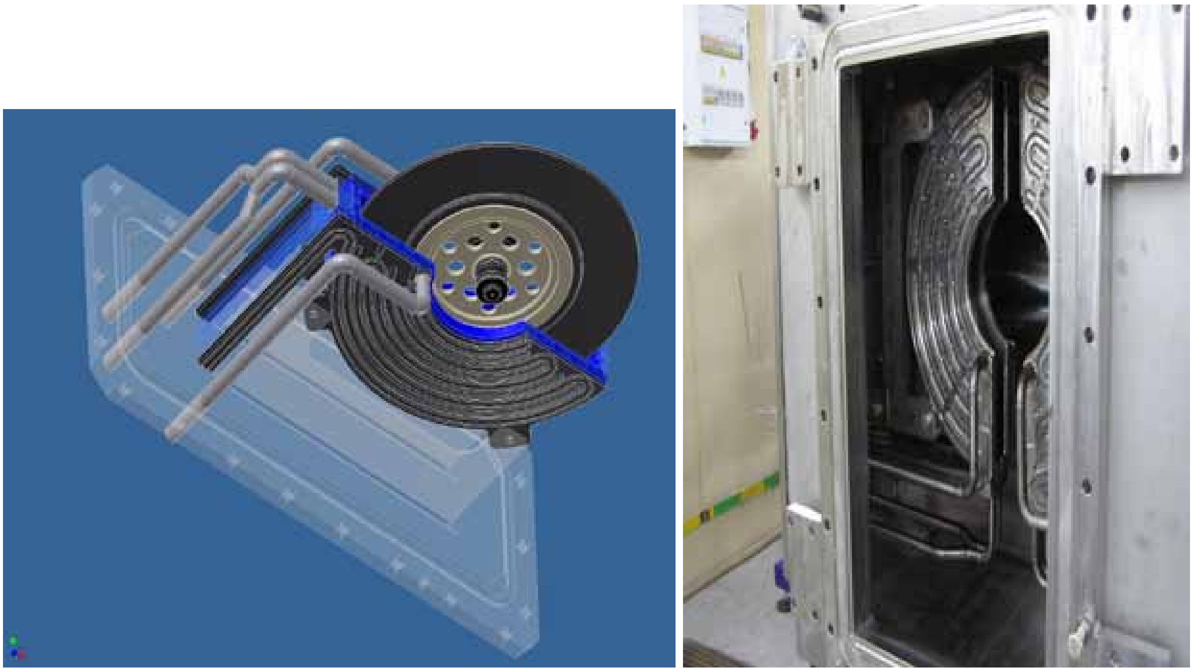


Fig. 10. LM cooling plate.

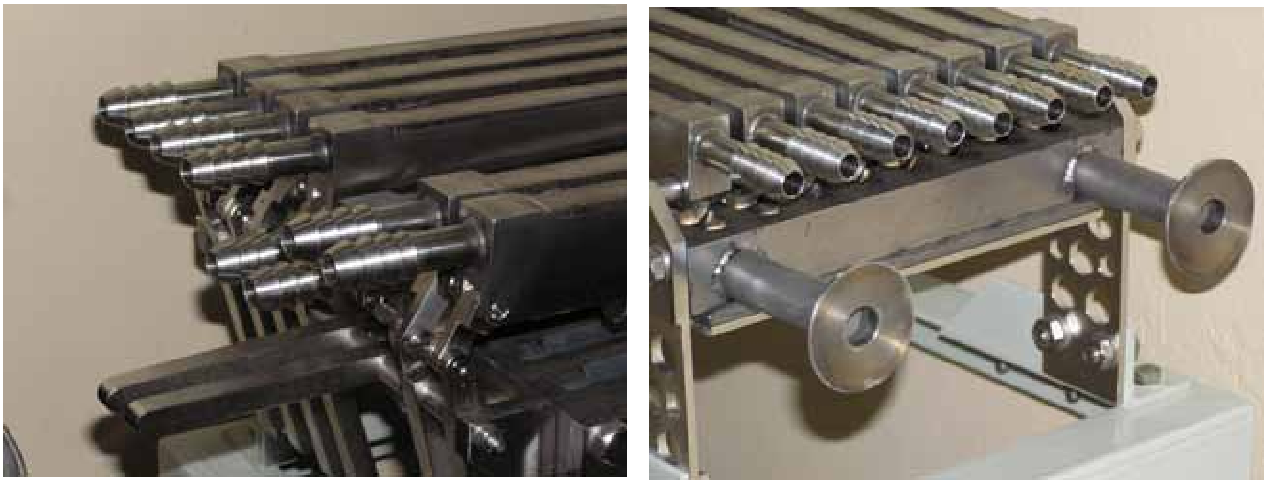


Fig. 11. LM heat-exchange unit.

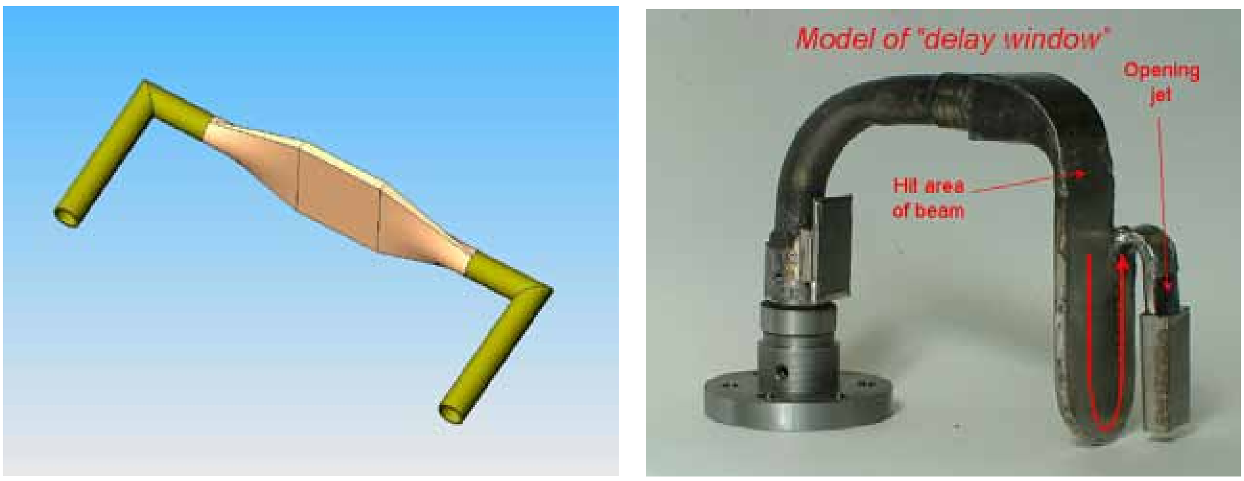


Fig. 12. Layout and model of delay window.

The available variants were analyzed and technical solutions chosen for a joint assembly of the neutron target subsystems in view of its operation at the SPIRAL-II facility (GANIL, France). There were developed the rotary drive of the neutron target and the shielding of the LM uranium fission target for the SPIRAL-II facility. There was presented an optimized variant of the LM system assembly in the target module of the SPIRAL2 facility under design. The geometry of the vacuum chamber of the target module was optimized for the sake of a more convenient assembly of the LM elements, as well as for utilizing the primary beam of various (low) power. The delay window was also optimized. There was also worked out a concept scheme of a remote disassembly of the internal parts and components from the target unit.

The graphite material for the target converter was chosen. This material is produced in EU CGD brand by HENCHKE product, Germany. The material was subjected to tests and studied for the properties and structure. For the sake of accuracy of calculating the operation modes and the target lifetime there were measured the thermal conductivity, the heat capacity and the evaporation rate of the following graphites: MPG, CGD and POCO.

The main result obtained was the choice and the basis for the technical solutions for the units and systems of the powerful neutron target with a due attention to the fact that they will be used at the facilities like SPES (INFN-LNL, Italy) and SPIRAL-II (GANIL, France).

This work was carried out with the support of ISTC (grant №3682), it was don jointly by Lab. 5-0, Lab. 5-1 and NKO.

6

SYNCHROTRON RADIATION SOURCES AND FREE ELECTRON LASERS

Introduction

BINP facilities and laboratories are the basis for the Siberian Synchrotron and Terahertz Radiation Center (SSTRC), which has two directions of activity. The first is “synchrotron radiation”: works on synchrotron radiation (SR) beams from the VEPP-3 and VEPP-4M storage rings and development and construction of SR generation systems for SR centers in Russia and abroad. The other, “terahertz radiation”, direction covers works on the radiation of Novosibirsk free electron laser (FEL) in the terahertz range (120-240 μm and 40-120 μm), further development of Novosibirsk FEL and participation in FEL projects abroad.

The work program for the «synchrotron radiation” direction in 2009 covered the following issues:

- conduction of basic and applied research as well as development of new technologies
- using the synchrotron radiation of the VEPP-3 and VEPP-4M storage rings;
- creation of experimental equipment for work with SR beams (beamlines, user stations, X-ray optics, monochromators, and detectors);
- development and creation of dedicated SR source accelerators;
- development and creation of special magnet systems for SR generation – wigglers and undulators;
- teaching and professional training of students and graduates.

In 2009, 1197 hours of operation were allotted for the “synchrotron radiation’” regime (1956 hours in 2008) on the VEPP-3 storage ring. 432 hours of work in the “SR” regime were allotted on VEPP-4M (240 hours in 2008). The experiments involved 11 stations on 7 beamlines for SR extraction from VEPP-3 and 2 SR stations on SR from VEPP-4M. The works were carried out by research groups from 55 institutes and other organizations.

The work program for the “terahertz radiation” direction for the year 2009 included the following:

- development of user stations and research activity on the operating single-orbit laser in the terahertz range(110-240 μm);
- completion of the mounting and commissioning of the two-orbit accelerator-recuperator; beginning of experiments on the beam extracted from the second-stage FEL in the wavelength range of 40-120μm;
- works on the creation of the 3rd and 4th tracks of the energy recovery linac;
- participation in foreign projects on the development and construction of high-power FELs;
- teaching and professional training of students and post-graduates.

710 hours of operation time were allocated for research on terahertz radiation beams from Novosibirsk FEL in 2009 (430 hours in 2008 and 780 hours in 2007); the reduction in 2008 was caused by works on the mounting of the two-orbit energy recovery linac for the 2nd stage FEL. Experiments with the terahertz radiation beams were carried out at 5 user stations by members of 8 SB RAS institutes and Science and Technology Center of Unique Instrument Making of the Russian Academy of Science (Moscow) as well as by teachers, students, and graduates of Novosibirsk State University and Novosibirsk State Technical University.

Works of the Siberian Synchrotron and Terahertz Radiation Center in 2009 were carried out under financial support from the Federal agency on science and innovation (FASI) within the Program of development of joint use centers (state FASI contracts 02.552.12.7001 and 02.552.11.7081) as well as from a lot of SB RAS integration projects, RFBR projects and other sources of financing, which are mentioned below.

6.1 Works on SR beams from VEPP-3

6.1.1 Station “Explosion (Extreme states of matter)”

The station “Explosion (Extreme states of matter)is intended for registration of passed radiation and small angle X-ray scattering (SAXS) at investigation into detonation and shock-wave processes. It is the only station of such type in the world.

Participant organizations in 2009:
1. Lavrentiev Institute of Hydrodynamics SB RAS (LIH), Novosibirsk;
2. Institute of Problems of Chemical Physics RAS, Chernogolovka;
3. Institute of Thermophysics of Extreme States RAS (Moscow);
4. Institute of Strength Physics and Materials Science SB RAS, Tomsk
5. Institute of Solid State Chemistry and Mechanochemistry SB RAS (ISSCM), Novosibirsk;
6. Institute of Chemical Kinetics and Combustion SB RAS, Novosibirsk;
7. Budker Institute of Nuclear Physics SB RAS, Novosibirsk;
8. Russian Federal Nuclear Center “All-Russian Research Institute of Technical Physics” (RFNC ARRITP), Snezhinsk

Research themes and additional sources of financing in 2009:

1. Investigation into the processes of small-angle X-ray scattering (SAXS) at detonation of trotyl, hexogen and 50/50 TH. SB RAS integration project 23 “Synchrotron diagnostics of fast processes including explosion ones”.

2. Synchrotron radiation investigation into irreversible processes caused by high-intensity impacts on condensed media (RFBR grant 06-02-17335-a).

3. Investigation into the shock compressibility of aerogel of three different initial densities in the range of plunger velocities of 2 to 3 km/sec. RAS Presidium program for Basic Research П-09 “Study of matter under extreme conditions” coordinated by RAS member V.E. Fortov.

4. Investigation into detonation processes in gaseous, heterogeneous and condensed media aimed among other things at development of technology basics. Investigation into detonation and shock-wave processes using synchrotron radiation. Contract on science-and-technology collaboration of BINP SB RAS, RFNC ARRITP (Snezhinsk), ISSCM SB RAS, and LIH SB RAS.

5. Investigation into the synthesis of metal nanoparticles under extreme conditions of detonation. RFBR grant 07-02-19382 “Synchrotron radiation investigation into physical-chemical processes under extreme conditions of high temperatures and pressures: fast destruction and synthesis”. SB RAS Program for the year 2009, section 5.1.4. “Development of methods of active physical influence on chemical transformations”.

6. Study of irreversible processes in condensed (continuous and porous) media running under intensive external impacts including shock-wave ones. State program 0120.0 406861.

7. Study of the behavior of homogenous and heterogeneous media under high-energy impact. Development of methods to measure density distribution on the detonation front of cylindrical charges of small diameter with a resolution of 100 µm. State program 0120.0 406860.

8. Measurement of density distribution along cumulative gas jet at detonation of 50/50 TH. State program 0120.0 406862.

9. Non-stationary phenomena in multiphase media (dynamics of flow structure, phase transitions, cumulative synthesis, and mathematical simulations).

10. Investigation into the capabilities of 30-60 keV synchrotron radiation to explore detonation and shock-wave processes in explosive charges up to 1500 g; designing of the “Detonation” station on VEPP-4M (RFBR grant 07-02-01079-a).

An example of work in 2009:

Investigation into solid condensate formation during detonation of explosives (RFNC ARRITP, Snezhinsk)

Chemical explosives used at RFNC ARRITP are intended mainly for optimal compression of spherical articles due to high pressure on the detonation front. However, besides the pressure, which is mainly caused by generation of the gases CO_2, CO, N_2, H_2O, and NO_2, there may arise condensed carbon as an amorphous phase, graphite or diamond. The more condensed carbon arises, the lower pressure can be achieved, which is ultimately undesirable.

Members of BINP, LIH and ISSCM SB RAS developed a direct dynamical method of watching solid phase formation in the zone of chemical reaction of detonation, which allows measuring concentration of arising nanoparticles. The method is based on SR scattering on the arising nanoparticles: the integral intensity of scattering is proportional to the number of nanoparticles, and the shape of scattering gives information on the nanoparticle sizes. The method is development of the statistical method of small angle X-ray scattering (SAXS), which has been applied to exploration of nanoobjects.

In 2009, a batch of explosives from RFNC ARRITP based on triaminobtrinitrobenzene (TATB) was examined, and information on the phase composition in the chemical reaction zone during detonation was obtained. The main issues of interest were: 1) whether the carbon condensed phase arises in the chemical reaction zone; 2) If yes, how much; 3) If yes, where does it arise, in which region of the chemical reaction zone; 4) What crystallographic shape does carbon take – amorphous, graphite or diamond; 5) What conditions can decelerate or lessen formation of carbon condensed phase.

Pressed TATB charges of 20 mm in diameter were under study. According to the results, nanoparticles of d~1.5 nm are detected on the detonation front. Then the particle sizes are weakly increasing and reach d≈2.6 nm in the time t=*3*-4 µsec. Judging by the SAXS signal amplitude, one can suppose that there are no traces of nanodiamonds in the TATB explosion products.

The issue of carbon condensation at detonation of oxygen-deficient explosives is still disputable. The answer will be important both for understanding of the physical aspect of the phenomenon and for estimation of the amount of energy released at exothermal coagulation of carbon clusters.

According to estimates, under our experimental conditions, the SAXS method allows detecting radiation scattered from particles of a few nanometers to hundreds of nanometers in size.

During one SR flash, a detector registers scattering over all the channels (makes one frame), recording SAXS scattering vs. angle. Since the detonation front moves along the Z axis with a constant velocity of 7.5 km/sec (for TATB with a density of 1.81 g/cm^3), in two periods of SR pulse repetition T = 0.5 µsec the detector will have recorded another SAXS distribution (another frame), thus forming a sequence of SAXS signal distributions. In fact, it is X-ray diffraction movie with a time shift of 0.5 µsec and frame duration of 1 nsec.

A noticeable SAXS signal was detected at irradiation of initial explosives, which practically vanished on the detonation front. It may be caused by the presence of noticeable intercrystalline pores in the initial explosive, which are eliminated at compression of the explosive under the impact of high-power shock wave. Besides, even if particles of condense carbon arise in this zone, where compression of the explosive is maximal, the "contrast" value – squared difference of the density of carbon particles and that of the explosive, $(\rho-\rho_0)^2$ – turns out to be relatively small. Then the signal amplitude is growing smoothly; the angle distribution of SAXS is also varying.

In the large, the SAXS dependence on time is approximately the same at detonation of condensed explosives (TNT, RDX/TNT, and TATB) but the integral SAXS amplitude (summed over all the channels of the detector) differs noticeably (Fig.1). The TNT/RDX mixture has the highest integral SAXS signal. That of TNT and TATB charges is noticeably smaller. That means that the scattering particles are of less density and most probably graphite-like. Not detectable traces of nanodiamonds are observed in TNT and TATB. Even if there are any, their size does not exceed 1 nm.

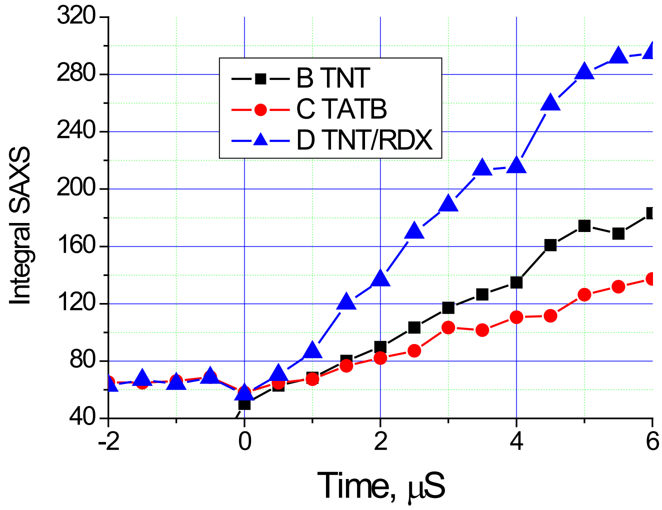


Figure 1: Integral SAXS dependence on time at detonation of TNT, TATB and TNT/RDX.

It follows from the measurement of SAXS distributions that nanoparticles of *d~1.5-2.5* nm in size are registered immediately after detonation front. Then the particle size is increasing weakly and reaches *d*≈2.5 nm by the time *t=3* µsec (for TATB). Judging by the SAX signal amplitude, no traces of nanodiamonds over 1 nm in size were found in the products of TATB explosion.

6.1.2 Station “LIGA technology and X-ray lithography”

In 2009, the specialized laboratory area “Clean room” was equipped with high-technology equipment: a plasmachemical facility AUTO 500 made by EDWARDS (England) for cleaning of substrates and application of coatings; facility POLI-300 for polishing of substrates and LIGA products; scanning electron microscope Hitachi S-3400N; computer-aided laboratory press made by Schmidt Technology (USA).

Themes of work in 2009:

Development of technology stages of the LIGA process:

- low-cost method of production of X-ray masks for LIGA in a one-step process;
- methods of checking the quality of X-ray masks;
- a method of production of microprofile optical elements;
- a method of production of loose-hanging copper mesh structures;
- a method of production of copper press-stamps;
- a method of production of polymer microproducts via hot forming, as exemplified by manufacture of microfluid systems.

Works in 2009 were supported by SB RAS Integration project №55 and RFBR project 07-02-01459-a.

Participant organisations:
Budker Institute of Nuclear Physics SB RAS, Novosibirsk;
Institute of Organic Chemistry SB RAS, Novosibirsk;
Institute for Automatics and Electrometry SB RAS, Novosibirsk;
Institute of Solid State Chemistry and Mechanochmeistry.

Examples of works in 2009:

Development of a low-cost one-step technology process for production of X-ray masks (XM)

The existing methods of production of XM for the LIGA technology are labor-consuming and expensive, basing on a two-step process. First, an intermediate pattern is made using the electron-beam lithography and galvanoplastics of absorbing coating. Soft X-ray lithography uses this intermediate pattern to make a picture in a thick layer of polymethylmethacrylate, and subsequent galvanoplastics of an X-ray absorbing material (e.g., gold) creates a working pattern for hard SR. Prospecting work requires a large number of pilot samples of microstructured articles with typical critical sizes of more than 5 μm.

Thus we developed a photolithography-based method of production of XM in a one-step process, with an absorbing picture of rhenium or gold on substrates of two kinds: of glass carbon and foil of thermal expanded graphite.

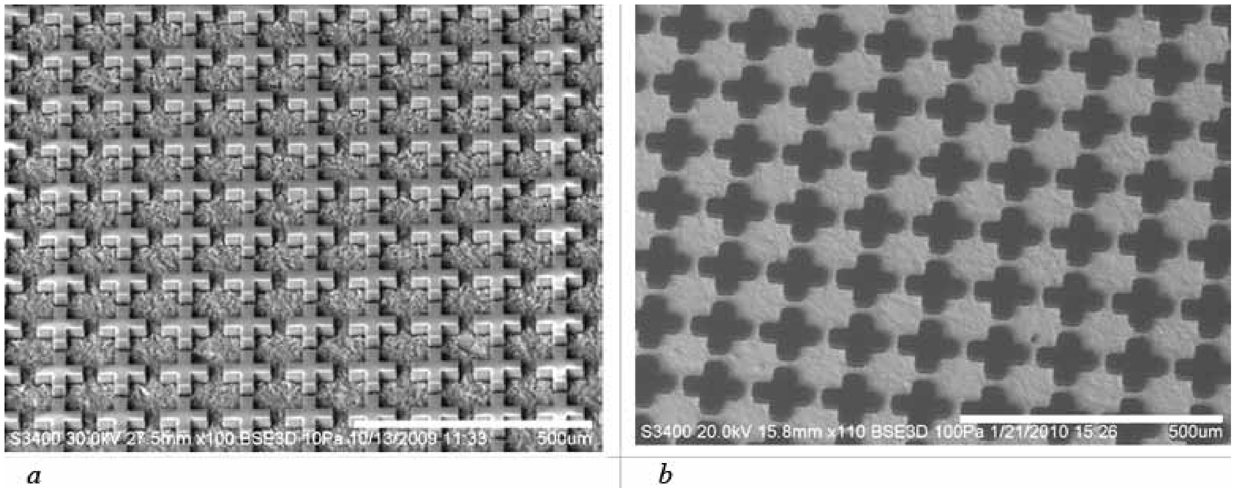


Figure 2: a) An XM workpiece before galvanoplastics (a photolithography-made SU-8 structure on glass carbon).The line width is 30 μm, the picture height is 30 μm; b) an XM after electrochemical deposition of a 20 μm gold layer on the workpiece.

At first, the required structure is made in the SU-8 resist using a standard photolithography technology. Then this structure is coated with a layer of rhenium or gold. An optimized method of galvanic deposition of rhenium-nickel alloy on glass carbon substrates was developed, due to which the rhenium content in the coating is ~ 90%. Sulfite-thiosulfate electrolyte was tried for galvanic deposition of gold on the photoresist-free areas of glass carbon substrate. This electrolyte provides rather high velocity of deposition and gold coating quality in micron-scale pores. So-obtained gold deposition is sufficiently smooth and has no breaks with coating thickness of about 30 μm. Results of XM manufacture meet requirements for deep X-ray lithography conduction at the LIGA station of the VEPP-3 storage ring. Calculations of the contrast value of masks with a 500 μm substrate of glass carbon show that the absorber thickness optimal for work with VEPP-3 radiation at the LIGA station is 17-22 μm.

The microstructure pattern and composition of the absorbing layer were checked using a scanning electron microscope (SEM). An additional check of the XM quality was made directly with X-ray radiation at the SR station “X-ray microscopy and tomography” on the VEPP-3 storage ring with using monochromatic radiation with the wavelength λ=0.9 Å, corresponding to the maximum SR spectral intensity at the LIGA station. Images obtained at the station “X-ray microscopy and tomography” allow directly checking the quality and contrast of XM in X-rays. In X-ray micrographs, defective areas of insufficient contrast look as light spots in a dark X-ray contrast field, while image obtained with a scanning electron microscope does not give unambiguous information on the contrast of the mask.

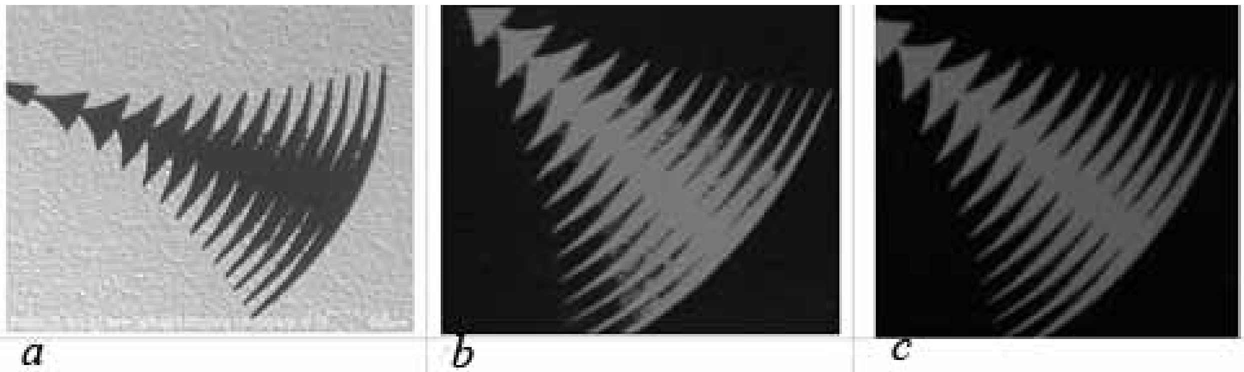


Fig. 3: a) pattern image obtained with the SEM; b) X-ray image of a pattern with insufficient thickness of the absorbing layer (*Au*), obtained at the station “X-ray microscopy and tomography”; c) X-ray image of the pattern after additional increase in the thickness of the absorbing layer of gold, obtained at the station “X-ray microscopy and tomography”.

A process of manufacture of polymer microproducts by the method of hot forming was developed. For that end, a method of manufacture of copper press stamps with micropicture using X-ray lithography and electrodeposition was developed. A laboratory facility for production of surface microreliefs on polymer plastics was created on the basis of a laboratory press (made by Schmidt Technology) with addition of a device for automatic setting of the temperature of sample to form. First results in the production of prototypes of microfluid analytic systems were obtained on samples of organic glass (GOST 17622-72).

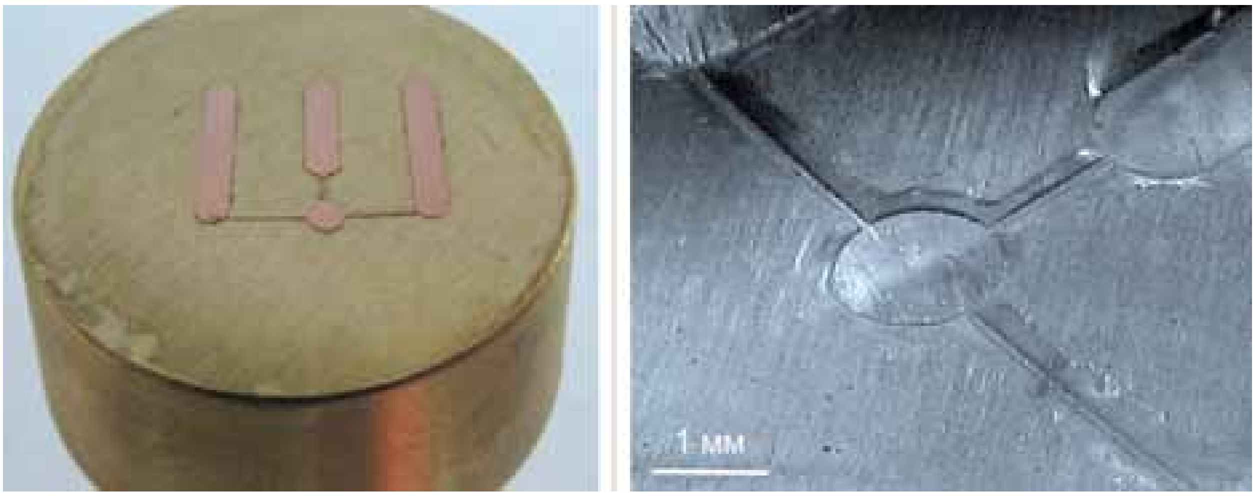


Fig. 4: A brass stamp made by the LIGA technology with galvanically deposited copper topological picture (the relief height is ~ 35 µm, the minimum lateral size is ~ 50 µm) and a biochip microrelief made with this stamp on acrylic resin.

6.1.3. Station “High-resolution diffractometry”

The station is intended for precision study of the structure of polycrystal materials by methods of X-ray diffractometry.

Participant organiations:

Boreskov Institute of Catalysis (BIC) SB RAS, Novosibirsk
Nikolaev Institute of Inorganic Chemistry (NIIC) SB RAS, Novosibirsk
Institute of Semiconductor Physics (ISP) SB RAS, Novosibirsk
Institute of Solid State Chemistry and Mechanochemistry (ISSCM) SB RAS, Novosibirsk

Institute of Chemistry and Chemical Technology (ICCT) SB RAS, Krasnoyarsk,
Tomsk Polytechnic University (TPU).
Tomsk State University (TSU).
Institute of Strength Physics and Materials Science (ISPMS) SB RAS, Tomsk.

Works in 2009 were carried out with financial support from SB RAS and RFBR:

1. SB RAS interdisciplinary integration project №82 "Oxygen permeability of massive and applied membranes on the basis of perovskites of mixed permeability",

2. RFBR grant 09-03-90424-Укр_ф_а "Development and study of metal-oxide catalysts for heterogeneously catalytic processes of hydrogen production and purification"

Works in 2009:

1. Structure of mezostructured silicates of the Solid Core - Mesoporous Shell type with different mezopore diameters, different diameters of the silicate core and different thickness of the mesoporous coating (Boreskov Institute of Catalysis SB RAS).
2. Mezostructured silicate materials, variation of the mezopore sizes with different temperature of hydrothermal treatment (Boreskov Institute of Catalysis SB RAS, Institute of Chemistry and Chemical Technology SB RAS (Krasnoyarsk)).
3. Thin films of mezostructured silicate materials (Boreskov Institute of catalysis SB RAS).
4. Heterostructures based on germanium and silicon. Quantum dots (Institute of Semiconductor Physics SB RAS, Boreskov Institute of Catalysis SB RAS).
5. Scintillation materials of new generation on the basis of triple molybdates (Nikolaev Institute of Inorganic Chemistry SB RAS).
6. Oxygen-conducting materials based on perovskite-like oxides (Boreskov Institute of Catalysis SB RAS, Institute of Solid State Chemistry and Mechanochemistry SB RAS).
7. Reinforcing coatings based on titanium nitride (Tomsk Polytechnic University).
8. Structural changes and relaxation processes in palladium at hydrogen intrusion (Tomsk Polytechnic University).
9. Copper-cerium catalysts for hydrogen production and purification from CO admixtures (Boreskov Institute of Catalysis SB RAS).
10. Relaxation processes in zirconium at plastic deformations (Institute of Strength Physics and Materials Science SB RAS, Tomsk).
11. Catalysts based on nickel-aluminum intermetallic compounds for processes of carbon-dioxide conversion of methane (Boreskov Institute of Catalysis SB RAS, Tomsk State University).

Some works in 2009:

1. Mezostructured materials

More than 90% of industrial chemical processes are now realized on adsorbents and heterogeneous catalysts. The efficiency of their application depends not only on the chemical and phase composition but also on the textural characteristics: specific density, volume of pores, and their effective size distribution. Therefore, purpose-oriented regulation of the textural parameters of catalysts and adsorbents is an important task. As concerns catalysis, silicate mezostructured mezophase materials (MMM) have attractive and unique properties such as large specific surface of up to 1000 m^2/g and more, large porosity (over 1 cm^3/g), and narrow spread of pore sizes .

Silicate SBA-15 with two-dimensional hexagonal arrangement of pores of heterogeneous sizes close to cylindrical in shape is a typical MMM. The textural parameters of such materials can be regulated via variation of the temperature of hydrothermal treatment (HTT), which is carried out in the course of synthesis before removal of the structure agent Pluronic P123. The textural characteristics (specific surface of mezopores, specific density of mezopores, and size distribution of mezopores and micropores) are derived from the nitrogen sorption isotherms, while the structural characteristics (parameter of two-dimension unit cell and tacticity degree) are found from X-ray diffraction at the station "Anomalous scattering" at the Siberian Synchrotron Radiation Center. Size distribution of pores is presented in Fig.5.

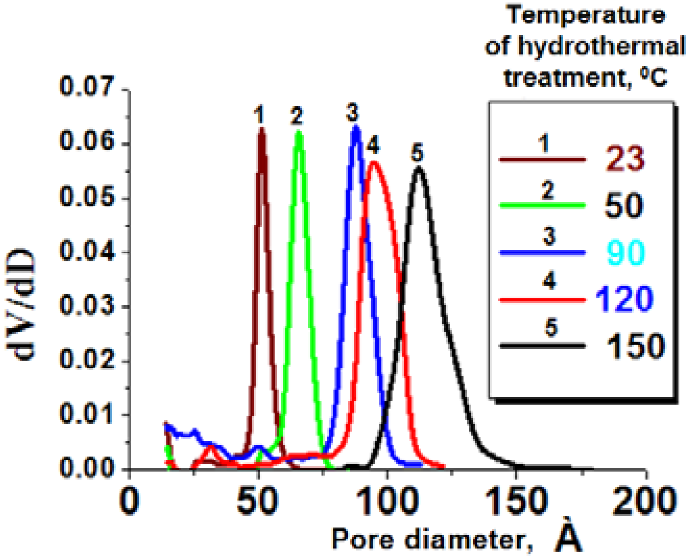


Fig. 5: Size distribution of mezopores for SBA-15 at different temperatures of hydrothermal treatment (23°C to 150°C).

Calculated textural and structural characteristics are presented in Table 1.

Table 1.

THT temperature	Specific surface, m^2/g			Pore volume, m^3/g			d_{10}, nm	a_0, nm	Pore diameter*, nm
	$A_{БЭТ}$, m^2/g	$A_{вн}$, m^2/g	A_{mezo}, m^2/g	V_{Σ}, cm^3/g	V_{micro}, cm^3/g	V_{mezo}, cm^3/g			
23°C	607	41	456	0.54	0.073	0.49	8.02	9.26	5.1
50°C	708	16	460	0.70	0.11	0.67	9.19	10.61	6.5
90°C	871	100	648	1.13	0.11	0.99	10.50	12.13	8.7
120°C	601	170	578	1.16	0.02	0.95	10.76	12.43	9.5
150°C	450	151	391	1.22	0.03	1.01	11.02	12.74	11.2

When the HTT temperature is increasing from 23 to 150°C, the supramolecular cell parameter is rising from 9.3 to 13 nm and the pore size is growing from 6.5 to 12 nm in the produced mezophase materials. The mezopore volume increases, and the pore volume decreases. So, variation of the HTT temperature allows reaching the targeted change in the structural-textural parameters of mezostructured materials.

2. Oxygen-conducting materials based on perovskite-like oxides

The interest in perovskite-like oxides is caused by their unique properties, e.g., mixed electron-ion (oxygen) conductivity, which allows their application as electrodes in fuel elements and oxygen-permeable membranes. Relaxation processes occurring at heating in air of samples of strontium cobaltite doped with iron and niobium were studied. The samples were baked in vacuum in advance to produce the oxygen-deficient phase of perovskite-like mixed oxide (Fig.6a). The study was carried out *ex situ*, i.e., the sample was heated in vacuum, then it was cooled and moved to the atmosphere. Experiments had shown earlier that relaxation processes going at room temperature are so slow that no noticeable changes in the sample structure takes place for more than three months, which makes application of this method possible in this case.

Heating of sample in vacuum results in the origination of the second phase, which is isostructural to the initial one but has a larger oxygen deficit. The unit cell parameter of the first phase stays practically unchanged, independently on the temperature of heating, while for the second phase a continuous growth is observed at increasing temperature. Since the oxygen content in the structure lessens with increase in the temperature of heating, and diffraction patterns are registered at room temperature, changes in the elementary cell parameter can be caused only by variation of oxygen stoichiometry. It means that the second phase has oxygen deficit, which varies at different temperatures of heating.

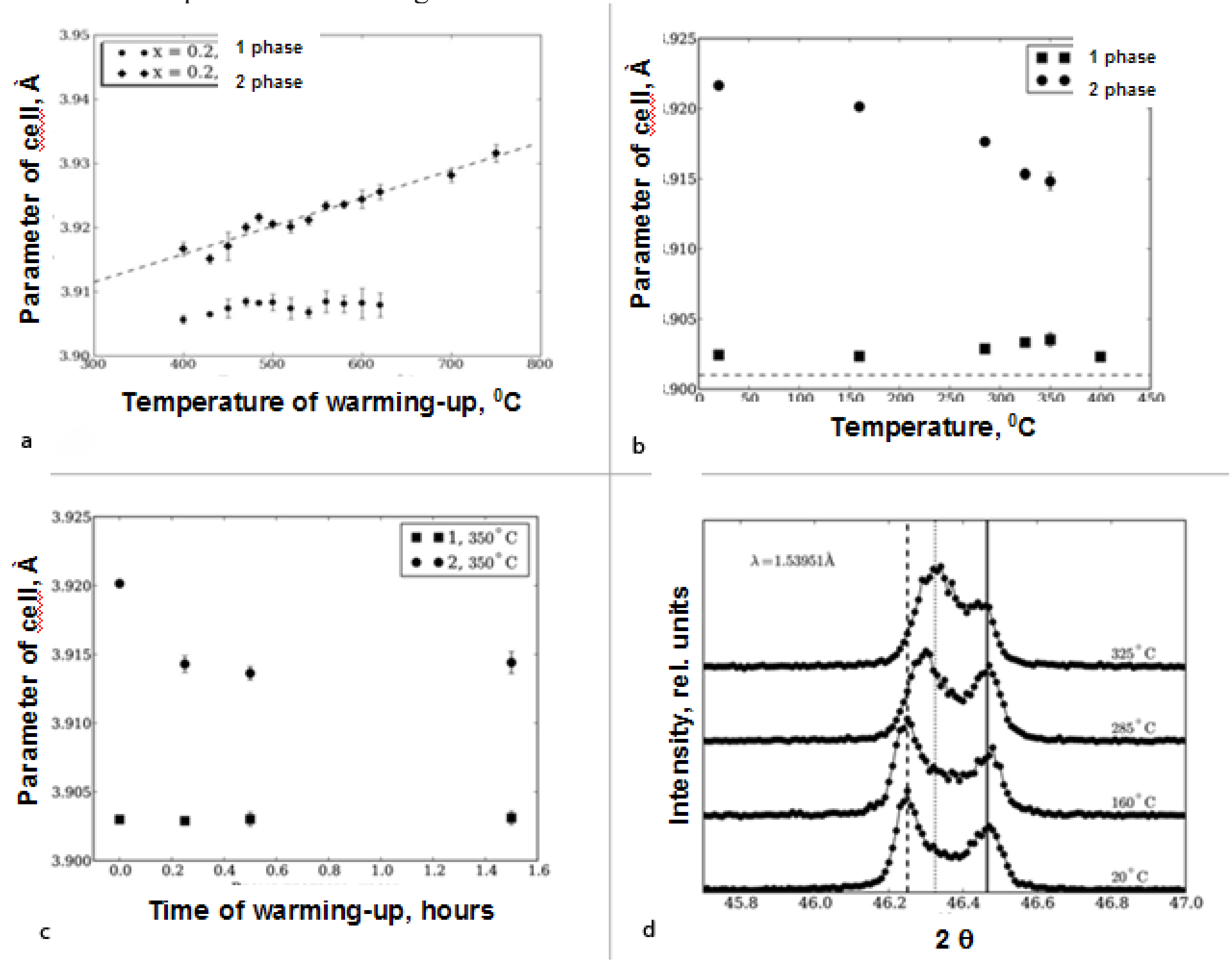


Fig. 6: Variation in the elementary cell parameter for strontium cobaltite (a) with temperature of baking in vacuume; (b) with temperature of heating of oxygen-deficient sample in air; (c) with time of heating of the oxygen-deficient sample in air; (d) shift of the (200) reflection with temperature of heating of the oxygen-deficient sample in air.

If the oxygen-deficient oxide is heated in air, one can expect oxygen intrusion into the structure, and the higher the temperature, the bigger the oxygen flow into the sample and the less oxygen deficit in it. In this study of relaxation processes, oxygen-deficient samples were heated *ex situ* in air in the temperature range of 160-400°C (Fig.6b) for 15 min to 67 hours (Fig. 6c). The temperature of heating in vacuum of 550°C was selected because namely at this temperature the largest split of reflections in diffraction patterns was observed.

Fig.6d shows diffraction patterns of the 200 line profile in dependence on the temperature of heating T<400°C (the radiation wavelength λ=1.53951Å). When the temperature of heating is changed, the relative intensities of reflections of different phases do not change, only a shift of the second phase reflection to the area of larger angles is observed. That is why oxygen intrusion into the structure does not lead to a change in the ratio of the two phase content in a sample but only influences the second phase stoichiometry.

Creation of the new station "Precision diffractometry II" (VEPP-3, SR beamline 6)

The station "Precision diffractometry II" was constructed on beamline 6 for SR extraction from the VEPP-3 storage ring. The station is intended for precision examinations of polycrystal materials by the methods of X-ray diffractometry. Monochromatization of radiation is performed via a single bounce from a monochromator crystal placed at an angle of ~15.7° to the initial beam direction with deviation of the monochromated beam upward in the vertical plane.

The monochromator design implies placing 5 various crystals on the rotating unit, which allows selection of one of 5 possible radiation energies depending on the type of the crystal applied. One of the positions of the rotating unit is free in order to pass the initial beam to another user station mounted on the same beamline. Si(111), Si(220) and Ge(111) crystals are placed on the rotating unit now.

The station uses the precision goniometer HUBER 480 with an angle step of 0.005°. A panel for fixation of detection system is mounted on the vertically-located goniometer. The detecting equipment may be either a one-coordinate detector OD-3-350 with a focal distance of 350 mm or a set of scintillation detectors with analyzing crystals placed before them. In this case, a 4-channel detection scheme with an interval of 20° between the channels is realized. The sample holder may be an open cuvette, high-temperature HTK-2000, reactor chamber XRK-900 (Anton Paar), etc. A computer-aided automation complex controls the station.

In 2009, the first works were carried out at the station: the photon energy range was defined, X-ray patterns of the standard sample SRM676 (corundum) were obtained. The reactor chamber XRK-900 (Anton Paar) was used to get experimental data on the change in the structure and phase composition of Ni-Al intermetallic catalyst for carbon-dioxide conversion of methane under the reaction environment conditions at temperatures of up to 830°C (Boreskov Institute of Catalysis SB RAS, Tomsk State University).

6.1.4 Station "X-ray fluorescence element analysis"

The station is intended for determination of the element composition of different samples: geological rocks, biological tissues, aerosols, etc. by the method of synchrotron radiation X-ray fluorescence element analysis using SR (SR-RFA). The element analysis can be done both in the local and scanning regimes.

Participant organizations:

Budker Institute of Nuclear Physics SB RAS (BINP SB RAS), Novosibirsk;
Sobolev Institute for Geology and Mineralogy SB RAS (SIGM SB RAS), Novosibirsk;
the Institute of Chemical Kinetics and Combustion SB RAS (ICKC SB RAS), Novosibirsk;
Nikolaev Institute of Inorganic Chemistry SB RAS (NIIC SB RAS), Novosibirsk;
Meshalkin Research Institute of Cardiac Pathology (MRICP), Novosibirsk;
Sukachev Institute for Forest SB RAS (SIF SB RAS), Krasnoyarsk;
the Institute of Natural Resources, Ecology and Cryology SB RAS (NREC SB RAS), Chita
the Institute of the Earth's Crust SB RAS (IEC SB RAS), Irkutsk
the Limnological Institute SB RAS (LI SB RAS), Irkutsk.

Themes of work in 2009:

1. Development of instrument detection of platinum metals and silver by the XFA-SR method (Sobolev Institute for Geology and Mineralogy SB RAS, Novosibirsk; Institute of Natural Resources, Ecology and Cryology SB RAS, Chita). This work was done within the framework of SB RAS Integration project №83 "Development of a complex of instrument nuclear methods of detection of platinum metals, rhenium, gold and silver in hard-to-penetrate rocks and ores of complex composition".

2. Estimating and monitoring the effects of large fires on the carbon cycling and propagation and forest health and sustainability (the Institute of Chemical Kinetics and Combustion SB RAS, Novosibirsk; Sukachev Institute for Forest SB RAS, Krasnoyarsk). Within the framework of NASA project NRA-99-OES-06 "Estimating and Monitoring Effects of Area Burned and Fire Severity on Carbon Cycling, Emissions, and Forest Health and Sustainability".

3. Express analysis of genetic variance in quantitative attributes in populations of woody plants: efficiency of methods that do not require digenesis (the Institute of Chemical Kinetics and Combustion SB RAS, Novosibirsk; Institute of Natural Resources, Ecology and Cryology SB RAS, Chita; Sukachev Institute for Forest SB RAS, Krasnoyarsk). RFBR project 07-04-01714a.

4. Heterogeneous chemistry and atmosphere physics. Influence of atmospheric aerosols on biogeochemical cycles (the Institute of Chemical Kinetics and Combustion SB RAS, Novosibirsk; Institute of Natural Resources, Ecology and Cryology SB RAS, Chita; Sukachev Institute for Forest SB RAS, Krasnoyarsk). SB RAS Program: – 18.3. Chemistry and physical chemistry of environmental objects.

5. Development of methods to study distribution of chemical elements in biological tissues with vascular pathology by the method of X-ray fluorescence using SR (Meshalkin Research Institute of Cardiac Pathology, Novosibirsk; Nikolaev Institute of Inorganic Chemistry SB RAS, Novosibirsk; Budker Institute of Nuclear Physics SB RAS).

6. Development of methods of analysis of chemical composition of new materials (crystals and films) using XFA-SR with no standard sample (Budker Institute of Nuclear Physics SB RAS; Nikolaev Institute of Inorganic Chemistry SB RAS, Novosibirsk). INTAS –SB RAS grant 06-1000013-9002 “New layered 3-d materials for spintronics”; RFBR grant 07-03-91555-ННИО/А.

7. Examination of cores of bottom sediments of salt lake Shira (Khakassia) in order to reconstruct environmental state in past and forecast climatic process in future. Institute of Petroleum-Gas Geology and Geophysics SB RAS; Institute of the Earth’s Crust SB RAS; Sobolev Institute for Geology and Mineralogy SB RAS, Novosibirsk; Limnological Institute SB RAS, Irkutsk. RFBR grant 08-05-00392-a; SB RAS integration grant №38 “Mineral lakes of the central Asia – archive of paleoclimatic records of high resolution and amended fluid ore”.

Some works in 2009:

Examination of cores of the bottom sediments of lake Shira

Examination of cores of bottom sediments of continental lakes, mineral lakes of the Central Asia in particular, is conditioned by the interest in the information on past environmental changes and hopes for predictions of climatic course in future as well by the desire to estimate their mineral resources.

Data of scanning X-ray analysis of 5 bottom sediment cores from salt lake Shira (Khakassia) revealed that all the cores share common features of Sr distribution with depth. Strontium contrastly enriches (up to 6000 g / t) two layers in the sediment layers, these layers are present both in relatively deep sediments (water depth over 12 m) and relatively shallow (less than 12 m), where the extracted material was initially oxidized - without signs of black hydrotroilite. The layers enriched with strontium are not very notable visually and have much in common with many other horizons. Anomaly of strontium in the two layers is their unique identifier and allows correlation of sediments sampled in different parts of the lake. Sr content correlation of data in the five studied cores is shown in Fig. 7. The correlation was performed subject to the information on the rates of sedimentation at various places of the lake where the cores were taken. We suppose simultaneous formation of each layer over the entire area of Lake Shira. The causes of the anomaly and routes of arrival of significant amounts of Sr to the sediment are not clear yet. An electron microscope equipped with a fluorescence detector showed absence of mineral phases that would be strontium raisers (though with one exception, which should be a subject of a separate discussion, but does not claim to universality). It seems that strontium is scattered in the carbonate structure, and increase in its amount is connected either (1) with a significant enrichment of water with dissolved strontium compounds (for example, at lowering of the lake level) at the time of sediment formation or (2) change in the composition and pH of the water, resulting in fall-out of strontium. The latter version is also proved by high correlation of content of strontium with that of uranium: anomalous concentrations of the latter in the two layers under consideration reach 45 g / t. Some concomitant increase in the concentrations of Zr, Ti and other elements coming with suspension also allow conceding a sorption nature of uranium (and, apparently, of strontium, at least in part) in these horizons. Changes in the environment that caused the Sr anomalies in the sediments are yet to be studied, but there is no doubt in their universal nature all over the lake and their ubiquitous presence in the curative mud, which is one of the main resources of lake Shira.

Experimental data of the year 2009 are still being processed. Interpretation of some results is possible only at continuation of the measurement of bottom sediment cores of lake Shira started previous years.

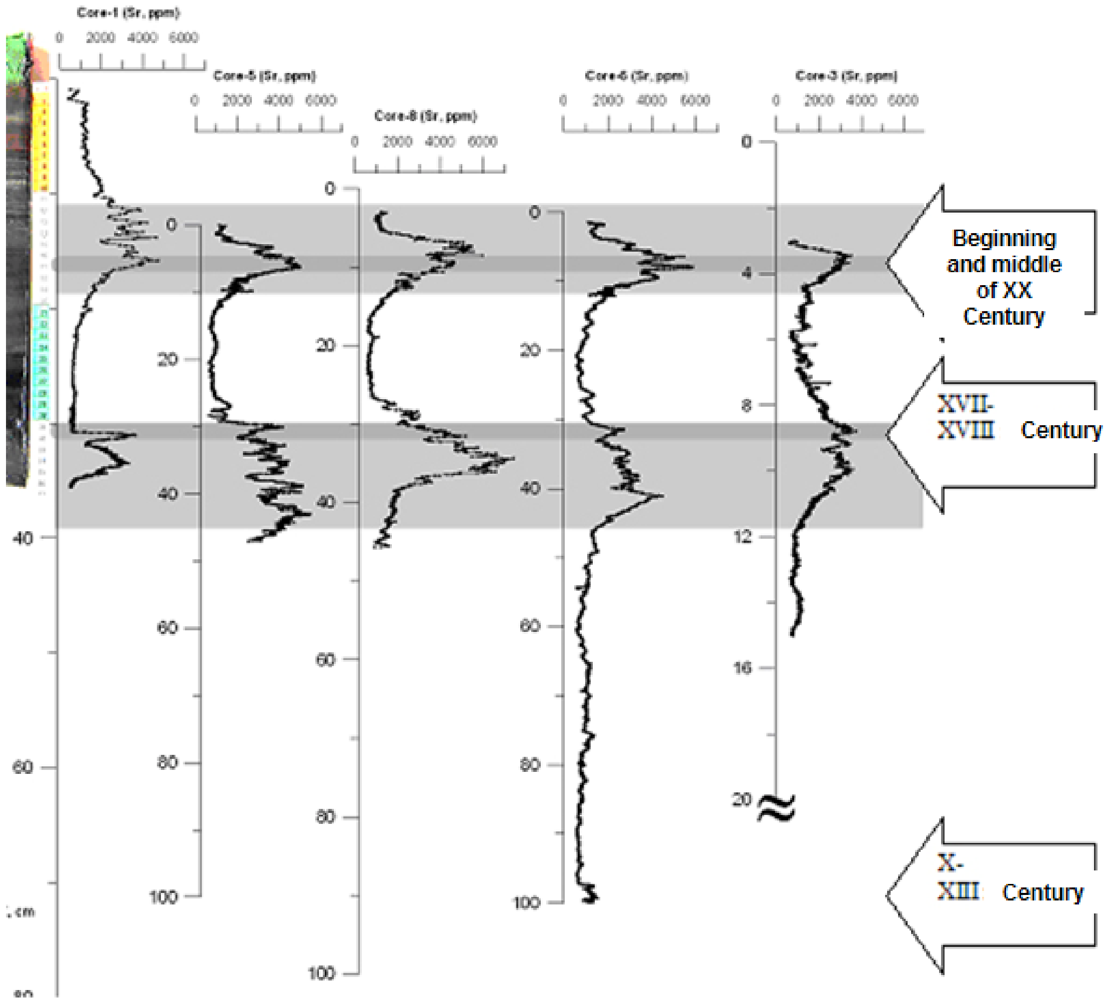


Fig. 7: Strontium content in the five examined cores.

6.1.5 Station "Diffractometry at high pressures"

The station is intended for diffraction studies with the application of hard X-rays under high pressures and/or temperatures.

Participant organizations:

the Institute of Solid State Chemistry and Mechanochemistry SB RAS (ISSCM SB RAS), Novosibirsk;

Sobolev Institute for Geology and Mineralogy SB RAS (SIGM SB RAS), Novosibirsk;

the Institute of Inorganic Chemistry SB RAS (IIC SB RAS), Novosibirsk;

the Institute for Metallurgy of the Ural Branch of RAS (IM UB RAS), Yekaterinburg.

Works in 2009 were carried out with support from RFBR projects 08-03-00738-a, 08-03-00636-a, 07-08-00338-a, 07-05-00113-a and SB RAS Project on collaboration with third-party organizations 138.

Works in 2009:

1. Research on the processes of contact melting and eutectic crystallization in the Bi-In, Bi-Sn, and In-Sn systems (ISSCM SB RAS).

2. Studies of the effect of activations on the regulation of processes of interaction of solid metals and their compounds with metal melts for creation of functional materials of desired structure and properties (ISSCM SB RAS).

3. Investigation into the ordering of vacancies in non-stoichiometric oxygen-conducting perovskites ABO3 (ISSCM SB RAS).

4. Diffraction studies of phase transformations in microporous aluminum silicates at high pressures (SIGM SB RAS).

5. Studies on crystallization of molecular crystals from solutions and diffraction studies of their structure *in situ* (IIC SB RAS).

6. Research on the crystal structure of the high-pressure phase of PbSnS (IM UB RAS).

Some of works in 2009:

Diffraction research on phase transformations in porous aluminum silicates at high pressures (Sobolev Institute for Geology and Mineralogy SB RAS, Novosibirsk)**.**

The increased interest in studying the behavior of microporous minerals, zeolites in particular, at high pressures is due to the great technological importance of nanoporous materials on their basis. One of their features is mobility of interstitial molecular components. Compression of zeolites in penetrating aquatic environment may lead to the effect of superhydration – origination of additional water molecules in the structural cavities of zeolite. Superhydration is accompanied by an increase in the internal pore volume and redistribution of bonds within the water-cation complexes filling the cavities, which may lead to a drastic change in the physico-chemical properties of the compound, e.g., to an increase in the diffusion mobility of water molecules, ionic conductivity and other effects.

In connection with the recently opened abnormality of ion conduction in synthetic zeolite NaA at its compression in aqueous medium at 1 GPa, there arises a problem of structural interpretations of this phenomenon. According to the available data, the relatively low compressibility of NaA in water is indirect evidence in favor of entry of additional water molecules (superhydration) without significant deformation of the frame and phase transformations. It should be noted that these data were obtained for hydrostatic conditions of compression of zeolite in excess of water, whereas the conductivity was measured by the impedance method at non-hydrostatic conditions, which implies a more complex mechanism of deformation. Here are presented results of studying the compressibility and structural changes in zeolite NaA at non-hydrostatic compression in water up to 3 GPa.

2 series of experiments were conducted: (1) quasi-hydrostatic compression of fine-crystalline synthetic zeolite NaA in abundance of pure water at 0-3.7 GPa for comparison with previous data, and (2) compression in non-hydrostatic conditions provided by mixing zeolite powder with water in approximately equal bulk amounts (wet NaA), which corresponds to the method of sample preparation for measurement of conductivity by the impedance method. The sample was placed in a high-pressure cell with diamond anvils. The powder diffraction measurements were carried out on beamline 4 of the VEPP-3 storage ring (λ=0.3685Å); the electron cell parameters (space group *Pm*-3*m*) and the structure of NaA zeolite at 0 and 0.37 GPa were defined more exactly by the Rietveld method using the software package GSAS.

Up to 0.8 GPa, the compressibility of wet NaA is close to that in hydrostatic conditions. At $P \geq 1$ GPa, the long range ordering of the zeolite structure is violated (the beginning of amorphization), which is manifested in a marked broadening of the diffraction peaks and reduction in the cell volume as compared with hydrostatic compression. The diffraction peaks almost disappear at 2 GPa, which corresponds to the pressure of amorphization of zeolite in the absence of compressing medium. Note that despite the start of amorphization the volume of a wet NaA cell is much closer to superhydrated zeolite in hydrostatic water environment than to the volume of "collapsed" structure of zeolite being compressed in a non-penetrating medium. This means that the superhydrated state is preserved in partially amorphized wet NaA at 1-2 GPa. After unloading, the diffraction profile and initial volume of zeolite recover, similar to experiments on impedance measurements of ionic conductivity.

The structure of zeolite NaA was defined more exactly at the pressure P=0.37 GPa, corresponding to the lower limit of anomalous increase in the ionic conductivity. The main difference from the structure at normal pressure is the increase in the occupancy of water positions Ow1, Ow2 and Ow5, which leads to an increase in the total water content in zeolite by about 30%.

After pressure release down to 0 GPa the superhydrated state of zeolite NaA is partially preserved: the total water content is 10% higher than the original one, and the occupancy of the water positions Ow1, Ow2 and Ow5 is higher as compared with the initial structure.

Summarizing the data obtained, we can conclude that the structural mechanism of the anomalous pressure-induced conductivity in zeolite NaA includes a combination of two main factors: (1) superhydration of zeolite pores, which amplifies and creates new ways for the interstitial ion-molecular diffusion, and (2) partially disordering of the structure, induced by amorphization in nonhydrostatic conditions, which, according to other studies, accompanies a gain in the conductivity in zeolites of the LTA type. Refinement of the structure at 0.37 GPa revealed a selective refilling of non-frame water and cation positions, leading to an increase in the total content of H_2O in NaA at 30%.

Research on the processes of contact melting and eutectic crystallization (Institute of Solid State Chemistry and Mechanochemistry SB RAS)

Interaction of substances in solid and liquid states is manifested in various fields of industry: sintering with liquid phase participation in SHS processes, at soldering, in metallurgical processes, and at mechanochemical synthesis. Despite the importance of the issue, there is no rigorous theory of interaction of substances in the solid and liquid state. Contact melting occurs in systems with eutectic points in the state diagram. For example, silicon melts at 1414 ºC and gold at 1064 ºC, but if a zone of contact between gold and silicon is heated above 370 ºC, a liquid phase will arise and the process of melting will begin.

For the In-Sn system it was experimentally found that there are two limited regions of solid solutions based on indium and solid solutions based on tin and two intermediate phases: β, having a face-centered tetragonal lattice, and γ, having a simple hexagonal lattice. The system has an eutectic at 47 at.% of tin in the alloy with a melting point of 119 ºC.

Foils of metals under study 50-70 microns thick were laid next to each other, with an overlap of 0.2 mm, clamped between cover glasses and placed in a sample holder of a high-temperature chamber. A sample was heated to a temperature 2 ºC exceeding the eutectic one and kept at this temperature till disappearance of reflections from the solid phase in the investigated volume. After that, the sample was cooled with a speed of 2 ºC / hour. In the process of melting and crystallization, diffraction patterns were recorded with the detector mar 345.

To investigate distribution of phases along the zone of contact melting, a method for simultaneous X-ray diffraction and X-ray fluorescence analysis was proposed. A semiconductor detector was placed over the sample, normally to the X-ray beam axis. Excited fluorescence radiation was registered with the help of the detector. Radiation applied (E_{qu} = 33.7 keV) allowed exciting the K-series of fluorescent radiation from elements with atomic numbers less than that of iodine. In this way, the phase and elemental composition was registered along the zone of contact melting.

Origination of a liquid phase in the zone of contact of two metals was detected from the shift of reflections from the crystallites in the diffraction pattern. Reflections are shifted because the liquid phase propagates over the grain boundaries and they become mobile.

The indium-tin system. 50 minutes after origination of the liquid phase, reflections from the indium phase and several reflections from the $InSn_4$ phase stay in the diffraction pattern. Besides, diffuse scattering from a large crystallite in a non-reflecting state, probably $InSn_4$, is registered in the diffraction pattern. When the melting zone widens up to the beam size, a diffraction pattern from the melt (halo) is registered. When the temperature of sample gets below the eutectic point, origination of individual reflections is observed. 15 minutes later, the diffraction pattern consists of individual reflections from the $InSn_4$ fine-crystalline phase and two superimposed patterns of diffuse scattering from crystallites commensurable with the beam size. Cooling down to 110ºC practically has no influence on the diffraction pattern appearance. When the heater is switched off and the sample is cooled together with the oven, intermediate shooting at temperature near 55ºC shows decay of large crystallites into smaller ones and origination of small-angle boundaries. Position of diffraction maximums corresponds to the phase $InSn_4$ and In_3Sn phase with a slightly deformed lattice.

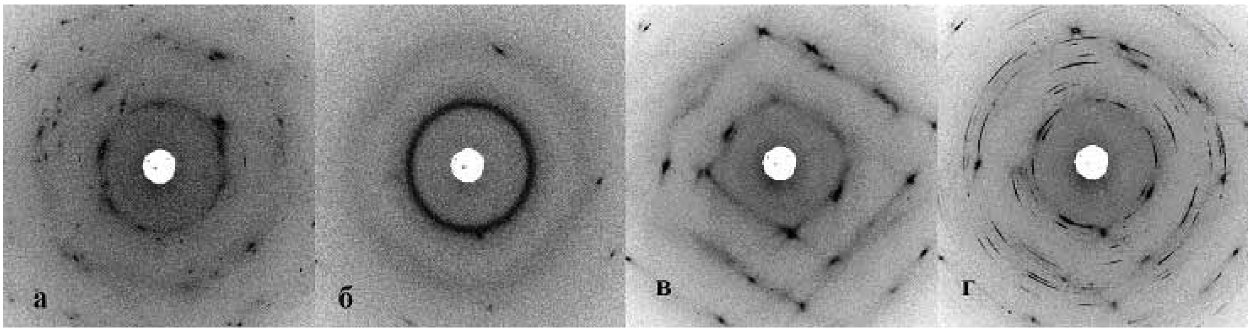


Fig. 8: Fragments of diffraction patterns obtained in the course of contact melting and subsequent crystallization: a – 50 minutes after the melting start; б – at the beginning of the crystallization process; в – at slow cooling down to 110 ºC; г – at 55 ºC.

Origination of diffuse scattering in the diffraction pattern (the big hexagon in Fig.8a) is evidence of formation of a monocrystal, which may be a pre-melting phase. The irregular octagon that can be seen in the diffraction pattern at crystallization of the eutectic composition may represent a pre-crystallization phase. Diffraction patterns in Fig.8в and 8г show growth and decay of the bicrystal, correspondingly.

6.1.6 Station "X-ray microscopy and tomography"

The station "X-ray microscopy and tomography" is intended for 3D examination of samples with high spatial resolution.

Themes of works in 2009:

- Study of the morphology of natural diamonds by the method of X-ray topography.
- Study of growth dislocations in synthetic diamonds by the method of X-ray topography.
- Obtaining data on the three-dimensional structure of samples of explosives and rocket fuel using computed X-ray tomography (CXT) with high spatial resolution
- Examination of archeological articles by the non-destructive CXT method.
- Quality control for X-ray masks for LIGA technology.

Participant organizations:
Budker Institute of Nuclear Physics SB RAS, Novosibirsk;
Sobolev Institute of Geology and Mineralogy SB RAS;
Lavrentiev Institute of Hydrodynamics SB RAS, Novosibirsk;
the Institute of Chemical Kinetics and Combustion SB RAS, Novosibirsk;
the Institute of History and Material Culture RAS, St. Petersburg.

The works were carried out within the framework of:

1. RFBR grant 09-05-00985-a “Zonal-and-sectoral structure of diamonds from the kimberlite deposits of Yakutia as reflecting the evolution of conditions of their formation”.

2. SB RAS Interdisciplinary integration project №51 “Environmental influence on the morphology, real structure and isotope composition of carbon of diamond”.

The station is based on the Bragg Magnifier, using Bragg diffraction from asymmetrically-cut crystals.

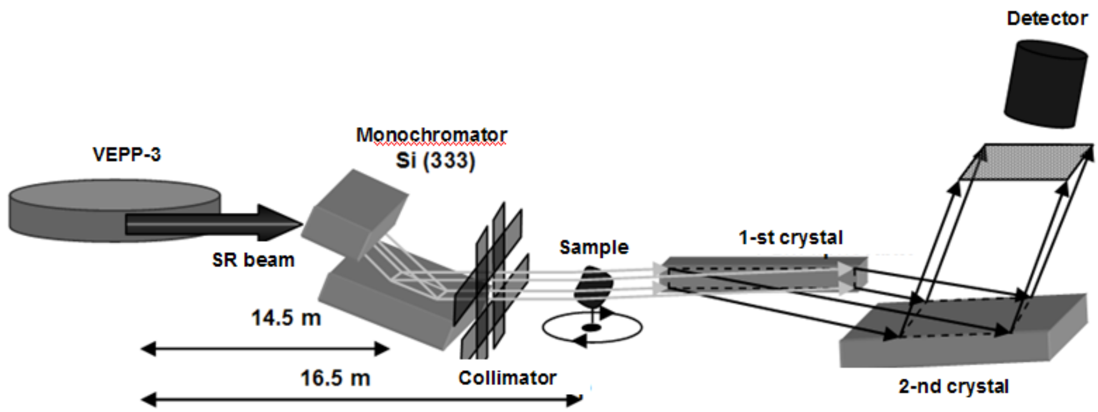


Fig. 9: Scheme of operation of the station “X-ray microscopy and tomography”.

Diffraction from two asymmetrically-cut crystals makes it possible to obtain a magnified image in the X-ray range. 20-fold magnification factor allows obtaining an image with a spatial resolution of 2-3 μm or better.

Microstructure pattern and composition of the absorbing layer of X-ray pattern was checked using monochromatic radiation with the wavelength λ=0.9 Å, corresponding to the maximum of the SR spectral intensity at the LIGA station. Images obtained allow direct inspection of the manufacturing quality and contrast of pattern in X-rays.

The asymmetrically-cut crystals have a rocking curve that is a few seconds of arc and thus reflect only those rays that are near the Bragg angle. Thereby details on the boundary of the media become emphasized, which is due to the X-ray refraction in the object under study. The refraction contrast allows obtaining high-quality images of objects that are low-contrast in the X-ray range. This property of the facility is very important for examination of the composition of energy materials (EM), e.g., rocket fuel, and explosives that weakly absorb X-rays.

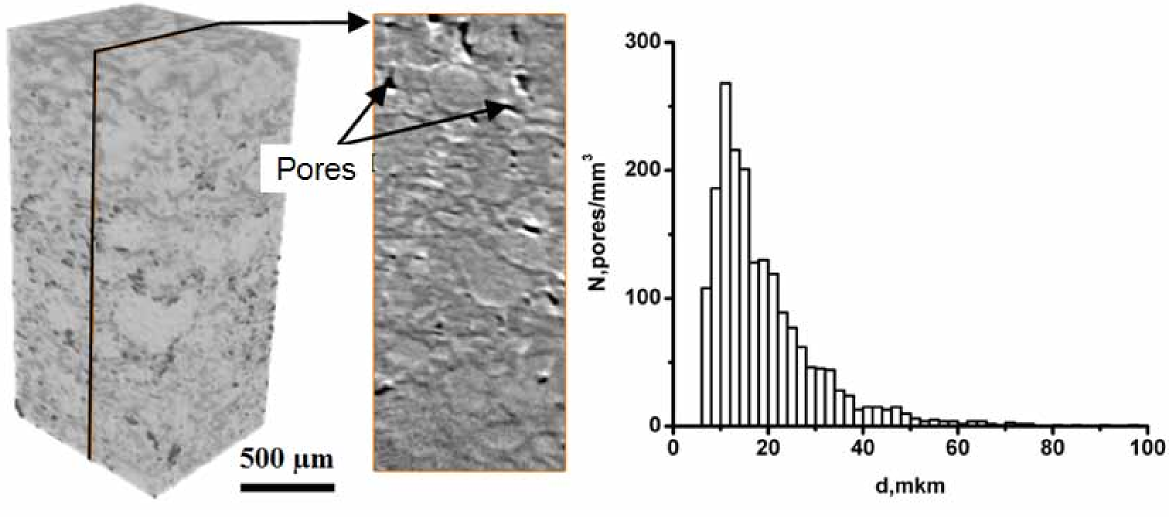


Fig. 10: 3D image of an EM with a plot of volume distribution of pore sizes.

Examination of the 3D structure of EM using CXT allows estimation of manufacturing quality from volume distribution of density in an object under study. The presented X-ray tomograms (Fig.10) showed the possibility of obtaining distribution of pores as small as 5-6 μm. The presence of inhomogeneities and pores influences the rate of combustion and detonation front propagation and is an important parameter at EM production. A distinctive feature of such an approach at EM examination is the possibility of viewing the inner structure in any plane and under any angle.

Works on the study of the morphology of natural diamonds from kimberlite pipes and placers of the Yakutia diamondiferous province continued in collaboration with Sobolev Institute of Geology and Mineralogy SB RAS. The X-ray topography (XT) method allowed obtaining data on defects linked with irregularities in the crystal lattice of diamond.

Besides, XT is an ideal technology to study the growth dislocations in synthetic diamonds invisible at examination with anisotropic etching. Fig.11 presents examples of topograms of natural and synthetic diamonds.

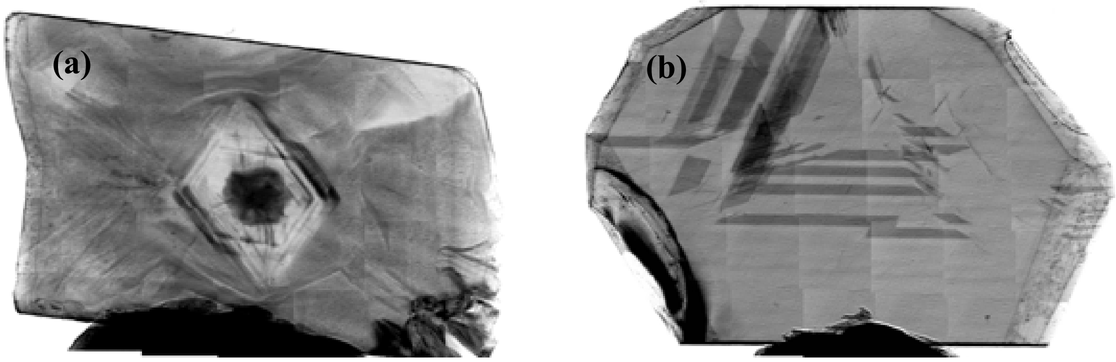


Fig. 11: X-ray topograms of natural (a) and synthetic (b) diamond.

Archaeological articles from the upper reaches of the Lena were studied with the XCT method using polychromatic radiation (40-80 keV) (Fig. 12).

It is possible to draw conclusions from these data about the culture and areas of distribution of the humans in the Paleolithic era.

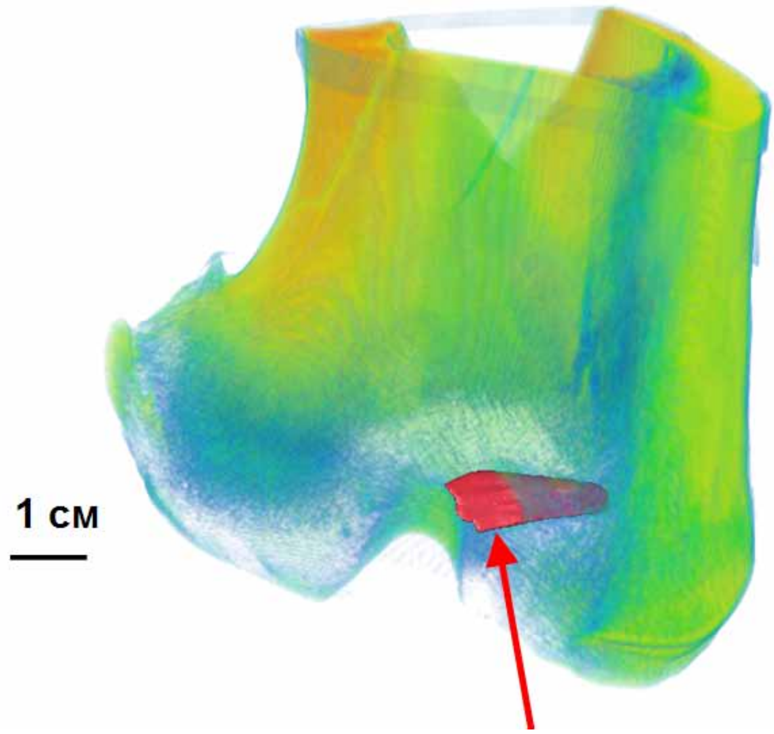


Fig. 12: Spearhead used by the ancient human in a buffalo bone found in the upper reaches of the Lena (X-ray tomogram).

6.1.7 Station "Diffraction movie"

The station is intended for exploration of phase transformations during chemical reactions involving solid states as well as obtaining both qualitative (the phase formation stages) and quantitative (kinetics) parameters of these reactions. The station enables investigations in the area of both wide (WAXS) and small (SAXS) angles.

Participant organizations:
the Institute of Solid State Chemistry and Mechanochemistry SB RAS, Novosibirsk.
the Institute of Inorganic Chemistry SB RAS, Novosibirsk.
Institute of Hydrocarbons Processing SB RAS, Omsk.

In May 2009, the station was equipped with the two-coordinate detector MarCCD (SX165) with the goniometer mardtb. The data reading time (dead time) is 3-5 sec, which is much less than that of Mar345, based on the ImagePlate technology. Thus, it is a good temporal resolution to investigate processes occurring within tens of seconds. Since the full diffraction cone is registered,

1) integration over the ring can significantly improve the statistics,

2) it is possible to obtain information about the texture and grain size of sample.

In addition, the wavelength used (about 1.5 Å) allows registering diffraction patterns at small angles for d ~ 100-150 Å. The collimation system of mardtb ensures formation of a narrow SR beam, which is relevant for research with high spatial resolution.

Works carried out at the station in 2009:

1. Investigation into formation of ordered structures of silver nanoparticles at decomposition of silver carboxylates (ISSCM SB RAS).
2. Study of patterns of formation of noble metal nanoparticles at decomposition of complex salts (IIC SB RAS, the work was carried out under RFBR grant 08-03-00603-a).
3. Investigation into the phase composition of the frozen front of the reaction of surface self-propagating synthesis of catalysts (Institute of Hydrocarbons Processing SB RAS, Omsk, the work was carried out under RFBR grant 08-03-00355-a).

Examples of works:

Definition of sizes of photonic crystals produced during formation of crystals from silver nanoparticles.

This is continuation of previously initiated studies on the synthesis of so-called colloidal crystals consisting of ordered monodisperse silver nanoparticles in order to refine the technology of photonic crystal production.

The technological process of synthesis of photonic crystals includes (Fig. 13):
1. choice of the source material, study of phase transitions in silver carboxylates and creation of environment optimal for formation of monodisperse particles of silver;
2. monitoring and managing the self-assembly of photonic crystals with size up to 25 microns;
3. study of the structure of the photonic crystals obtained .

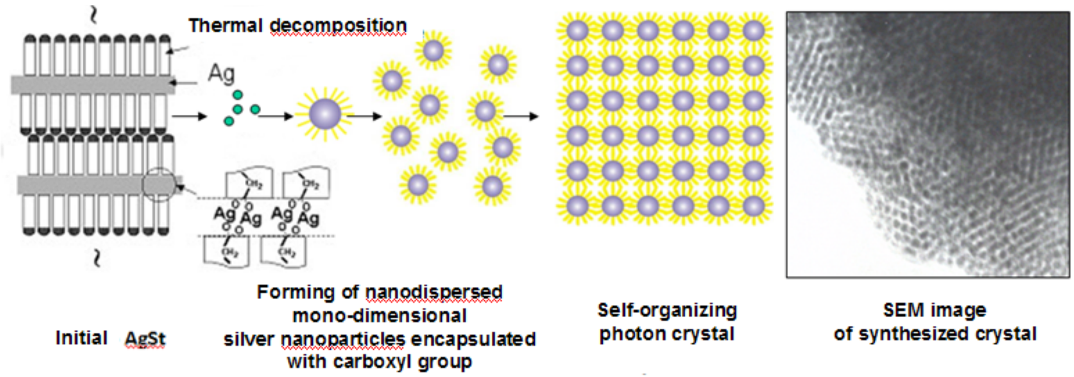
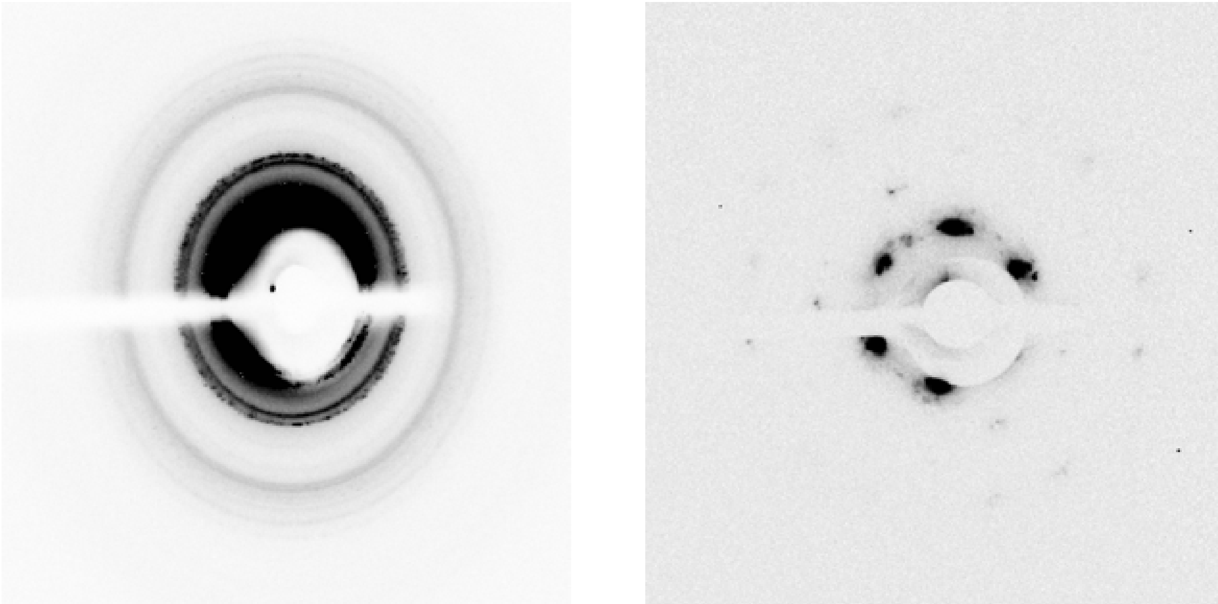


Fig. 13: Technological process of synthesis of photonic crystal from encapsulated silver nanoparticles.

Previous studies of thermally induced phase transitions in silver carboxylates conducted using the one-coordinate detector OD-3 showed that encapsulated silver nanoparticles that arise during thermal decomposition are of the same size and form an ordered structure.

Usage of the two-coordinate detector MarCCD made it possible to define the size of the final product – self-organizing photonic crystals – by reducing the aperture of the SR beam collimator up to the transition from the diffraction pattern of "polycrystalline" sample to that of "monocrystal".

The sample obtained via heating silver stearate was cooled and placed in the sample holder of the two-coordinate detector MarCCD. The resulting diffraction pattern of the sample illuminated with an X-ray beam 200x300 mm in size is presented in Fig. 14. Then the beam size was gradually reduced to 25x25 microns. The diffractogram is shown in Fig. 1 b).



a) b)

Fig. 14: Two-dimension diffraction patterns of structures synthesized from encapsulated nanoparticles: the SR beam size is a) 200x300 μm, b)25x25 μm.

Comparison of these pictures shows that when the beam size is big, the number of crystals caught up in it is large and they give diffraction rings – a typical diffraction pattern of a polycrystalline object. At a significant decrease in the beam size, the number of crystals decreases to one, giving a diffraction pattern as from a single crystal. Thus, the resulting crystal size for this ordered structure must be of the order (not more than) of 25 microns. This effect could be detected only by using a two-coordinate detector.

6.1.8 Station "EXAFS"

The destination of the station is exploration of the structure of the local environment of atoms of a selected chemical element (the coordination number and interatomic distances). The subject of analysis is the volume, surface, or surface layers, depending on the technique applied.

Participant organizations:

Boreskov Institute of Catalysis SB RAS, Novosibirsk;

Pisarzhevsky Institute of Physical Chemistry of the Ukraine NAS, Kiev, Ukraine;

Lomonosov Moscow State University, Department of Materials Science, Moscow, Russia;

The Institute for Applied Physics UR RAS, Izhevsk;
Udmurt State University;
Hahn-Meitner-Institut, Berlin, Germany;
Institute of Spectroscopy RAS, Troitsk;
the Institute of Solid State Physics and Semiconductors, Minsk, Belarus;
Saratov State University;
the Institute of General and Inorganic Chemistry RAS, Moscow;
the Institute of Petrochemical Synthesis RAS, Moscow;
the Institute of Materials, Seville, Spain.
University of Seville, Spain.

The works were financed under RAS Presidium Program № 27 “Fundamental research of nanotechnology and nanomaterials”, grant of the Federal Agency for Science and Innovation 02.513.11.3203, RFBR grants awarded in 2008: RFBR (08-03-01016a), RFBR (AF-080391758a), RFBR (08-03-92502-НЦНИЛа), RFBR (08-03-00823a), RFBR (08-03-01150a), RFBR (08-02-00404a), RFBR (08-03-00603a), and grants awarded in 2009: RFBR (09-03-01012a), RFBR (09-03-90424-Укр_ф_а), RFBR (09-03-00089a), RFBR (09-03-00133a), RFBR (09-03-00328a), RFBR (09-03-00514a), RFBR (09-05-98019a), RFBR (09-03-00780a), RFBR (09-03-00346a).

Main directions and summary of results of works in 2009:

1. The method of XAFS spectroscopy was applied to investigation into the genesis and characteristics of active component formation for a wide range of model and real applied (oxide and metal-oxide) heterogeneous catalytic systems, Pt, Pd, Ru, Au, Pd-Ce, Pd-Co, Pd-Mn, Au-Ce-Zr, Au-Ce, Cu -Zr-Ce, etc. (catalysts for oxidation of CO and hydrocarbons, heterometalic multicomponent nanostructured catalysts for conversion of industrially-important substrates, such as methanol, methane, ethanol, etc.). For correct structural XAFS study and development of effective methods of formation of active components with predetermined structural and functional properties, purpose-oriented phase synthesis of model compounds which are precursors of these systems was performed. Additionally, a comprehensive study by various physical and chemical methods of XRD, TEM, XPS, etc was carried out for all the compounds synthesized. As a result, new data on the morphology, atomic structure, local structure, charge state, symmetry of the nearest environment, status of components and phase composition were obtained. This unique information enabled developing new and effective methods of application of coatings modified with highly dispersed metal-oxide catalytic systems (from inorganic and organometallic precursors, based on the sol-gel method and various mono-and heteronuclear metal complexes) on oxide substrates of various nature.

2. A comprehensive structural analysis of the features of formation of the active component of fine-grained Pd-containing catalyst nanosystem (for carbon dioxide reforming of methane to synthetic gas) stabilized on a TiO_2 matrix by the methods of XAFS spectroscopy, XFA and XPS was done. The naocomposite was prepared from bimetallic precursor PdCo(μ-OOCMe)$_4$(NCMe) and PdMn(μ-OOCMe)$_4$(NCMe), with subsequent treatment in a few ways: calcination in air and argon, irradiation with SHF. The genesis and local structure of Pd-containing catalysts prepared in various ways were studied in detail. Possible variants of structural models were considered in detail.

3. A study of the status and structure of the active component of copper-zirconium catalyst was carried out by the methods of XAFS spectroscopy, X-ray diffraction, XPS and UV. Model catalysts with different copper content (1-10% Cu) were prepared by impregnation on yttrium-stabilized tetragonal zirconia. It was found that a small portion of copper is localized in the form of individual ions dissolved in the surface layers of the cubic lattice of the oxide ZrO_2, while a major portion of the copper exists in the form of linear chains stabilized on the surface of the carrier. A model of copper-cerium catalyst deposited on the monoclinic zirconium oxide was investigated by the methods of XAFS spectroscopy and XRD. The optimum composition of catalyst for the reaction of joint conversion of CO and hydrogen was found. Forms of stability of copper localized on the catalyst

surface were studied in details. It was shown that at low coatings (less than 5%), copper ions are located predominantly on the surface of CeO_2. Increasing of the coating to 10% and more leads to formation of bulk CuO phase on the catalyst surface and consequently to a decrease in activity.

4. Features of formation of filamentary nanostructures of germanium were investigated by the methods of EXAFS spectroscopy, X-ray diffraction and electron microscopy of high resolution. The main method of synthesis of these structures was that of thermal evaporation of material on mesoporous films of aluminum oxide obtained by anodic oxidation and used as a template. Control synthesis was conducted at the same temperatures of deposition on smooth films of aluminum oxide, quartz and silicon. The materials synthesized are characterized by a high degree of ordering of individual nanometer-scale structures within the body of the aluminum oxide matrix. During the development of the regimes of production it was established that the length of the filamentary Ge nanostructures depends on the temperature of the matrix under spraying. In the temperature range from -150˚C to 150˚C the material has no time to penetrate deeply enough into the pores of the matrix. At higher temperatures, adhesion of the sprayed material to the matrix material deteriorates, which allows vapors to penetrate more deeply into the pores. It was found that filamentary germanium nanostructures in the matrix consist of smaller amorphous clusters as compared with control samples obtained at the same temperatures. After annealing argon at 450˚C, germanium crystallizes, and after annealing in air, complete oxidation of the nanostructures under study occurs.

5. Structural XAFS study of the PdO–CeO_2 nanosystemafter reducing and oxidative pre-treatment was carried out in comparison with monometallic analogs deposited on alumina. The study resulted in development of a new method of preparation of highly dispersed mixed-oxide PdO–CeO_2 nanosystem stabilized on an oxide carrier. A new approach to synthesis, providing direct contact of PdO nanoparticles with CeO_2 on the surface of the carrier, consists in using heterometallic complex $PdII_2CeIV_2$ (m-OOCMe)$_{12}$ $(H_2O)_2$ as a precursor. It was shown that strong interaction between Pd and cerium oxide affects the ability of reduction of both PdO and CeO_2, which in turn leads to increased low-temperature activity in oxidation of CO at sudden change in the form of the curve of ignition-decay.

6. A structural EXAFS study of ordered arrays of ZnSe nanopoints obtained by thermally spraying material onto the matrixes of mesoporous alumina with ordered arrangement of channels was carried out. Besides that, the system was investigated by methods of high-resolution transmission electron microscopy and XRD. New data on the geometric dimensions of nanopoints in the array were obtained as well as parameters of the local atomic structure, interatomic distances and coordination numbers in comparison with the data for ZnSe films synthesized on smooth nonporous surface of Al_2O_3. Basing on analysis of the data, it was found that nanopoints of zinc selenide are small nanocrystalline inclusions of non-stoichiometric composition in the amorphous phase of the matrix material.

In total, 28 publications, including articles in refereed journals (18) and articles in conference proceedings (10), were published or accepted for publication after the works carried out at the EXAFS-spectroscopy station in the year 2009. More than 15 reports were delivered at scientific conferences.

Examples of works in 2009:

Study of the genesis of deposited gold nanosystems stabilized on mixed oxide matrix

It is known that gold, because of its electronic structure, is the most chemically inert platinum group metal, but gold nano-scale formations dispersed in different matrices exhibit high catalytic activity for many industrially important reactions. It is clear that a detailed and accurate analysis of the nature of gold formations is very important for development of new efficient gold catalysts for various applications.

Genesis of gold formations arising at application of gold on mixed nanoscale oxides of aluminum, cerium and zirconium prepared by the sol-gel method using organometallic compounds of these metals was investigated. According to complex analysis of XAFS spectroscopy data using data of electron diffuse reflectance spectroscopy (EDRS), X-ray photoelectron spectroscopy (XPS) and transmission electron microscopy (TEM), mixed oxides Al-Ce-Zr-O prepared by the sol-gel method are a highly effective material for stabilization of different forms of gold: gold cations Au^{3+} localized on the surface of carrier in a slightly distorted octahedral coordination for samples treated with hydrogen at 150°C; metallic gold nanoparticles of about 2 nm in size as well as gold clusters less than 1 nm in diameter in samples reduced with hydrogen at 300°C.

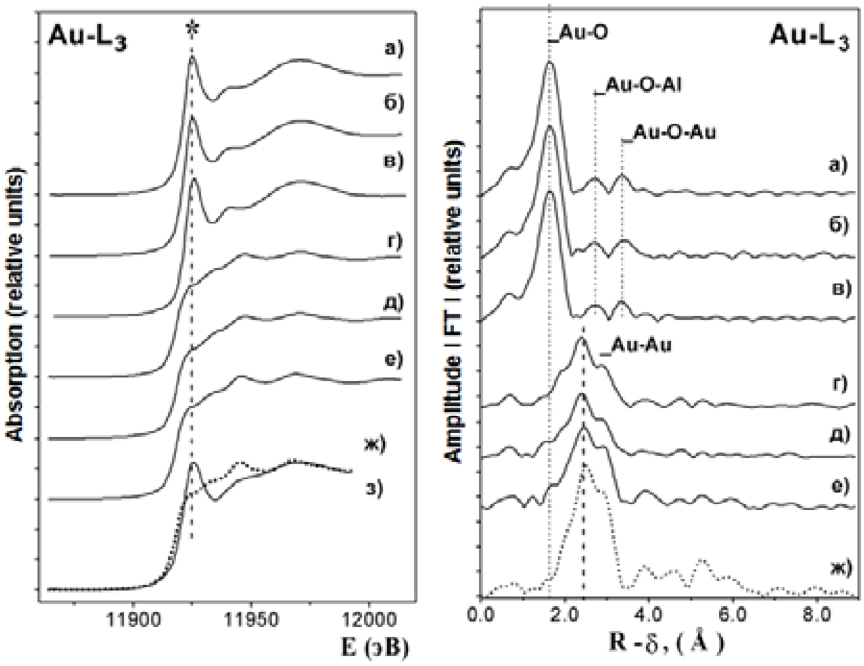


Fig. 15: XANES spectra (Au-L_3 edge, * - the white line) and functions of radial distribution of atoms (RDA) of local environment of gold for the samples studied and reference samples: а) Au-Al_2O_3, 150°C; б) Au-Al_2O_3-$CeZrO_2$, 150 °C; в) Au-Al_2O_3-CeO_2, 150 °C; г) Au-Al_2O_3, 300°C; д) Au-Al_2O_3-$CeZrO_2$, 300°C; е) Au-Al_2O_3-CeO_2, 300°C; ж) gold foil - Au^0 (dotted line, *0.5); з) gold oxide - Au_2O_3.

Investigation into the features of formation of the active component of low-percent applied platinum catalytic nanosystems.

It is known that platinum is one of the most active and stable catalysts for oxidation of CO and hydrocarbons. That is why the Pt/γ-Al_2O_3 system is widely used for oxidative purification of exhaust gases of industrial enterprises and automobile engines. It is obvious that the particle size and state of platinum in catalysts are key factors in control of catalytic activity via changing the nature of active centers, and these parameters themselves are set via a certain procedure of catalyst preparation.

A series of fine-grained low-percent platinum catalysts with different sizes of the active component particles that was deposited on γ-Al_2O_3 demonstrated the possibility of regulating the state of platinum applied on the surface of carrier by varying the conditions of preparation of the catalyst. To study the local structure and electronic state of platinum applied, the XANES / EXAFS spectroscopy method was used. Besides that, the samples were characterized using high-resolution transmission electron microscopy (HRTEM). It was shown that various forms of platinum particles – 3D or surface oxides Pt (II) or Pt (IV), mixed metal-oxide structures, 3D particles of metallic platinum and flat surface particles Pt^0 – strongly interacting with the carrier can be obtained on the carrier surface.

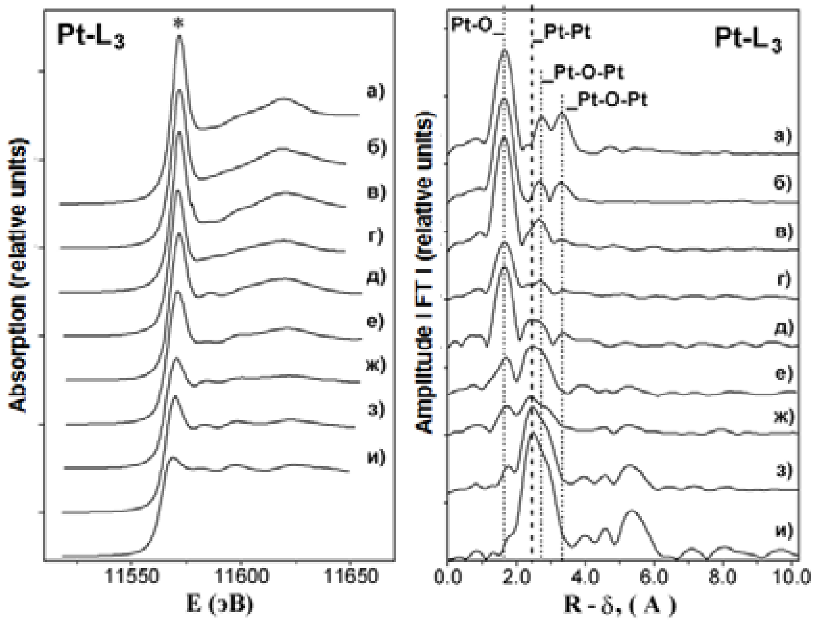


Fig. 16: а) PtO_2; б) II; в) I; г) III; д) IV; е) V; ж) VI; з) VII; и) Pt фольга (*0.5). XANES spectra ((Pt-L_3 edge, *- white line) and functions of radial distribution of atoms (RDA) of the local environment of platinum for the samples of catalysts under study Pt/γ-Al_2O_3 and comparison samples.

6.2 Work on the beams of SR from VEPP-4

6.2.1 Station "Cosmos" for metrology in the VUV and soft X-rays

Testing of HTS bolometer on SR beam

Participating organizations: BINP SB RAS, Vavilov State Optical Institute (St. Petersburg)

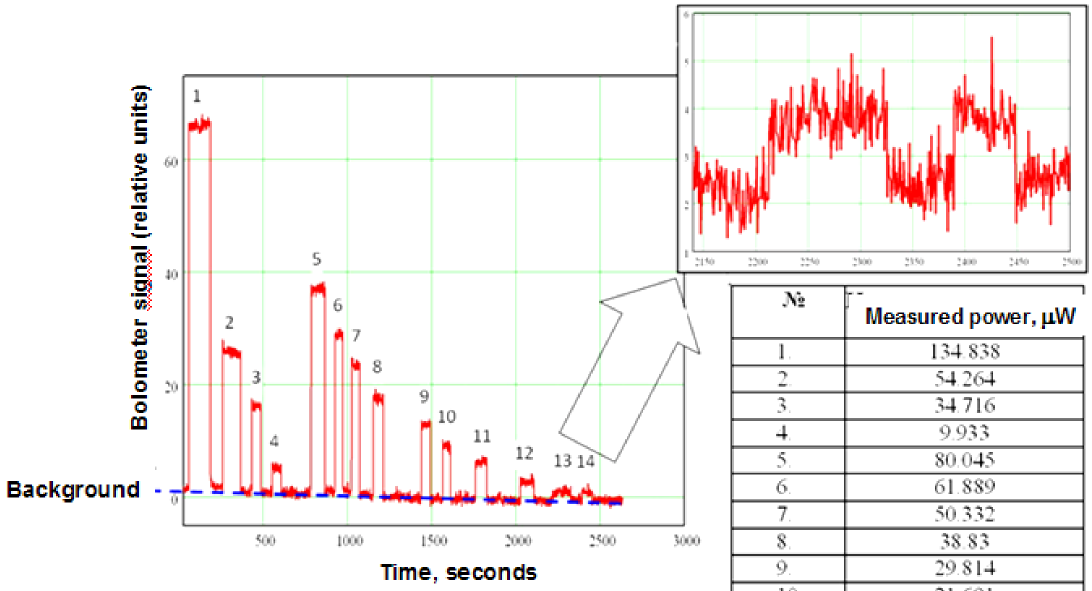
The work was performed under ISTC Project 2920.

The station was equipped with a prototype of the reference detector, which is a bolometer with superconducting film as a temperature meter. Measurement of the intensity of incident radiation is based on the substitution of radiant power absorbed in the substrate of the sensitive element of bolometer with the electric power of the heater located on its front side. The detector was made together with the GOI (St. Petersburg) as part of the ISTC project. The bolometer was tested on a white SR beam. During the test, the power of input beam was varied within 135 μW- 3 μW via reducing the storage ring current drive (within 900-55 μA) and inserting film filters of different permeability into the beam.

The minimum registered power was 3.2 μW, the signal-to-noise ratio being 1/2. In this experiment, the detection ability of the bolometer was limited by the dark signal fluctuation.

The result of the work:

The efficiency of the device at operation on a real SR beam was demonstrated. After bringing the bolometer to the limit values (the limit detectivity is 10 nW), comparing its readouts with those of a similar device at the PTB (Berlin, Germany) and its formal certification, the metrology station will receive an absolute detector, which will be used as the primary standard for calibration of other types of detectors.



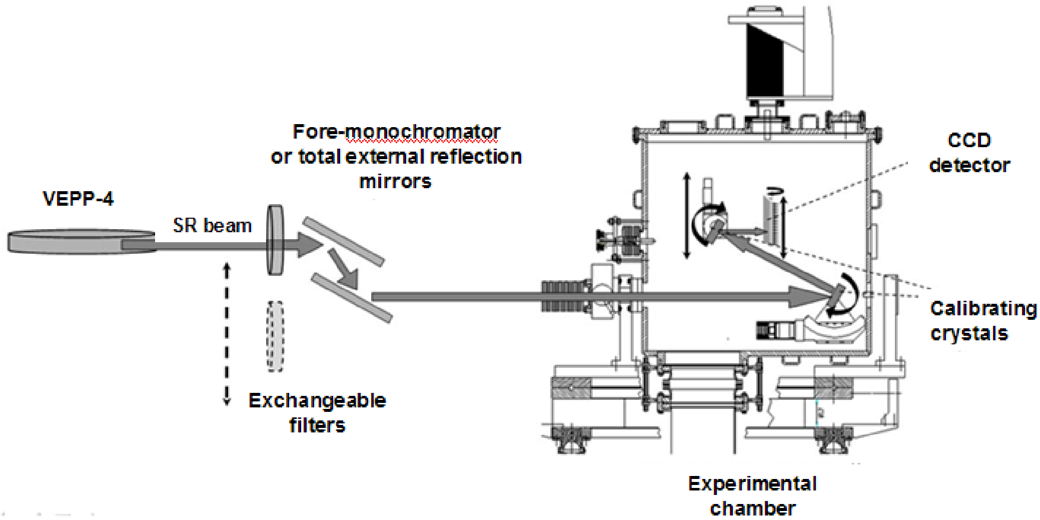
№	Measured power, µW
1.	134.838
2.	54.264
3.	34.716
4.	9.933
5.	80.045
6.	61.889
7.	50.332
8.	38.83
9.	29.814
10.	21.691
11.	15.387
12.	7.841
13.	3.576
14.	3.203

Fig. 17: Results of test of the HTSC bolometer on SR beam.

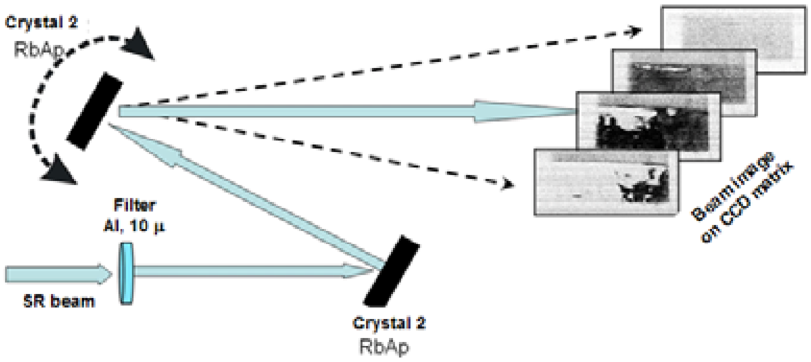
6.2.2 Preliminary certification of crystals for a monochromator

Participant organization: BINP SB RAS and Lebedev PI RAS

A reflectometer allowing implementation of various optics to calibrate X-ray optics was installed in the experimental volume of the station and launched. The structure of the reflectometer includes a set of three angular and one linear motor-driven movers allowing realization of various optical calibration schemes. The measuring needs of the reflectometer are provided by a set of semiconductor detectors of the AXUV type (made by IRD Inc., USA) and SPD type (developed by Ioffe PTI, St. Petersburg) and two-coordinate detector based on CCD matrix “e2v CCD47-20” with a spatial resolution of 13 microns. The electronics of the detector was developed by Lebedev PI RAS (Moscow).



The first results were obtained at certification of crystals for the space-based image-forming telescope being designed at the Lebedev PI RAS. A white SR beam was passed through a 10-µm aluminum filter and sequentially reflected from two parallel crystals. The beam intensity was measured after its reflection from the first crystal and then from the second one. The intensity ratio gave the peak reflectance. The rocking curve was measured and the spectral resolution was found by changing the angle of the second crystal relative to the first one. Rubidium bi-phthalate RbAP crystals (of the chemical formula C_6H_4(COOH)(COORb) showed the best results.



The work was conducted in the second order of reflection from 001 plane, which corresponded to an energy of 991.3 eV (the Bragg angle was 75°). The measured peak reflectivity of the crystals was 1.2%, the relative spectral resolution $\Delta E/E = 3 \cdot 10^{-4}$. Basing on the morphology of SR beam reflected from the crystals, their quality was assessed.

Results of the work:
Technique: A normal incidence reflectometer was put into operation at the station.
Practice: The reflection coefficient of the crystals and their spectral resolution were measured, recommendations on the use of these crystals in the X-ray telescope were given.

6.3 Working with beams of terahertz radiation

6.3.1 Novosibirsk terahertz free electron laser

Novosibirsk free electron laser (FEL) remains the world's most powerful source of terahertz radiation. The maximum average radiation power achieved at a pulse repetition frequency of 11.2 MHz, is 500 W. In 2009, Novosibirsk FEL worked for users for about 710 hours. In the standard mode of operation for users with a repetition frequency of 5.6 MHz, the average radiation power on workstations depended on the radiation wavelength and tuning of the accelerator system and was 50 - 150 W. In so doing, the FEL radiation is linearly polarized and fully spatially coherent, the wavelength is tunable in the range of 120 - 240 microns, the relative spectral width is less than 1% (full width at half maximum), and the pulse width is 100 ps (full width at half maximum).

In 2009, work on the FEL involved members of Budker Institute of Nuclear Physics SB RAS, the Institute of Chemical Kinetics and Combustion SB RAS, the Institute of Cytology and Genetics SB RAS, Rzhanov Institute of Semiconductor Physics SB RAS, Lavrentiev Institute of Hydrodynamics SB RAS, the Institute of Theoretical and Applied Mechanics, the Technological Design Institute of Scientific Instrument Making, the Institute of Atmospheric Optics (Tomsk), and the Scientific and Technological Center of Unique Instrumentation RAS (Moscow) as well as teachers, students and graduates of Novosibirsk State University and Novosibirsk State Technical University.

One of the two major tasks in 2009 was the organization of regular work at six user workstations. The second challenge was launching the second stage of the Novosibirsk FEL.

6.3.2 Experimental stations on THz beams

The station "Metrology" is intended for diagnostics, monitoring and optimization of parameters of the FEL radiation and conducting physical experiments with this radiation. In 2009, the following works were carried out.

1) The interaction of submillimeter-range radiation with low trapping levels in narrow-gap semiconductor-ferroelectric PbSnTe:In at liquid helium temperatures in the predominance of electron injection from the contacts and current limited by space charge was studied. Depending on the level of injection and the radiation wavelength, both increase and decrease in current were observed with complex dynamics of current change at laser irradiation "switched on" and "off". Results obtained can be explained within a model taking into account the complex energy distribution of trapping levels having different cross-sections of electron capture in the band gap and the heterogeneity of the electric field between the cathode and the anode under conditions of injection current limited by space charge. The work was carried out by members of the Institute of Semiconductor Physics and BINP under RFBR project 07-02-01336-a "Study of the interaction of submillimeter-scale radiation with the PbSnTe: In phonon subsystem near the point of ferroelectric phase transition, SB RAS Presidium program №2720 "Creation of highly sensitive photodetectors based on PbSnTe:In films for optical methods and spectroscopy in the terahertz frequency range", SB RAS Presidium program №2734 "Investigation into the spectrum of electronic states in Si/CaF2/BaF2/PbSnTe:In nanoheterostructures".

2) The spectral properties of two-dimensional arrays of optically active structures based on three-dimensional microshells were under study. The angles of rotation of linear polarization of terahertz radiation of up to ± 17 deg/layer in samples of 1x2 cm^2 in area were obtained. The spectra of dichroism, transmission and reflection for waves of linear and two circular polarizations were measured. Features of these structures as metamaterials were studied. It was shown that at certain frequencies, the effective refractive index of bulk material created on the basis of the measured layers can reach negative values. The work was done by members of the Institute of Semiconductor Physics and BINP SB RAS under RFBR project 09-02-12303-офи-м "Investigation into the interaction of terahertz radiation with new functional resonant metamaterials for devices to control polarization, phase, intensity and direction of propagation" and SB RAS interdisciplinary integration project №24 "Metamaterials based on high-precision micro- and nanoshells for the terahertz and infrared ranges".

The station for physico-chemical and biological studies is intended for study of the effects of radiation on micro- and nanostructure objects and examination of products of ablation of nucleic acids, proteins and enzymes, polymers and mineral clusters.

In 2009, work with biological objects at this station and the station "Chemistry" was conducted with financial support under the following grants: Project 27.8/69 of RAS Program "Basics of fundamental research on nanotechnology and nanomaterials", SB RAS integration interdisciplinary project №39, RFBR grant 09 - 02-12100.

The soft ablation phenomenon, which was discovered at Novosibirsk terahertz radiation shared-use center, allows non-destructively transferring complex biological macromolecules to the aerosol phase and generating aerosol nanoparticles from powders and colloidal solutions. For practical application of this phenomenon it is necessary to conduct a study comparing the fractional composition of the resulting aerosol nanoparticles and the size of the original molecules and clusters identified by traditional methods.

Determination of the mass of biological macromolecules is today a laborious and costly process. The soft ablation phenomenon makes it possible to significantly simplify and accelerate the process of molecular weighing. To investigate the possibility of comparing the size of biological macromolecules in the aerosol form with molecular masses, fragments of the λ-hind DNA were studied. Four monodisperse fraction of this DNA with known masses were under study. The commercially available preparation of lambda phage DNA hydrolyzed with restriction endonuclease HindIII (made by "SibEnzyme") was used for the experiment. Electrophoretic separation of the preparation was done in 1% agarose gel, from which then individual fragments of DNA hydrolyzate were preparatively separated. These samples underwent ablation under the action of free electron laser radiation with the following parameters: λ = 128 ± 2 microns, the pulse duration was 50 ps, the frequency was 5.6 MHz, the power was 20 W.

The size increased with the mass, and the obtained dependence of size on mass (Fig.18) can be approximated with a function proportional to the cube root of the diameter [1].

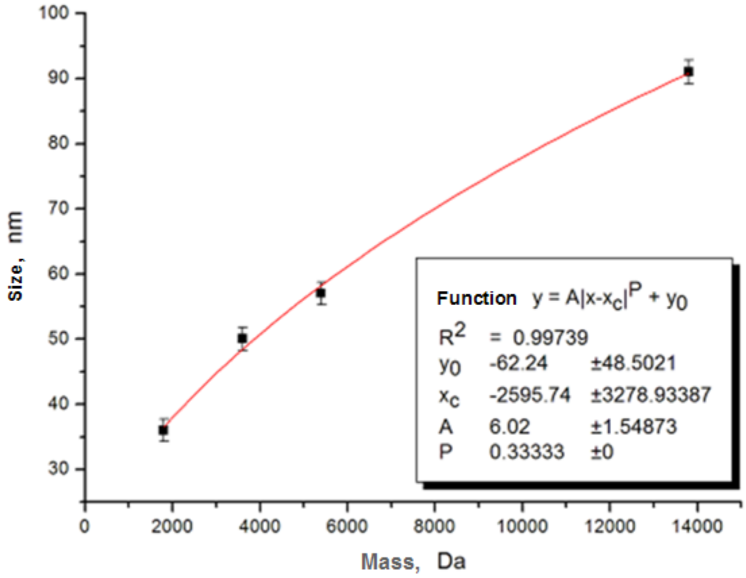


Fig. 18: Dimensions and weight of the four fractions of the λ-hind DNA.

The phenomenon of non-destructive ablation [2] can also be used for controlled generation of nanostructures of different origin in the aerosol phase for further their scientific and technological application: coating, sizing, the study of biological and catalytic activity, etc.

Comparative experiments with nanopowders of various origins conducted during the reporting period showed that THz radiation of the free-electron laser (FEL) in a pair with a diffusion spectrometer of aerosols [3] gives a more accurate and detailed information about their size in comparison with the traditional methods of electron microscopy and dynamic light scattering. Since our method does not require complicated procedures for sample preparation and allows determination of particle sizes in 10 minutes, we believe that development of this method will be extremely helpful for our scientific community dealing with the creation and study of nano-objects of biological and inorganic origin.

The experiments were performed with commercially available silicon oxide nanopowders (tarkosil, made by BINP), and synthetic diamonds (made by scientific-production enterprise "Altai"). The samples were investigated by the methods of scanning electron (SEM) and atomic force microscopy (AFM), dynamic light scattering (DLS) and our method.

Fig. 19 and 20 show the results of comparison of size distributions of samples by these methods [4].

Thus, based on our comparative study it was shown that the method of non-destructive terahertz laser ablation gives results comparable with other methods of determination of the size of nanoparticles. Besides, it is more efficient and more informative and requires minimal sample preparation. For further development of the technique it is necessary to expand the circle of substances and materials under study in order to determine the scope of the method and its possible limitations. In our opinion, the method of non-destructive laser ablation can be widely applied to various nanotechnology applications.

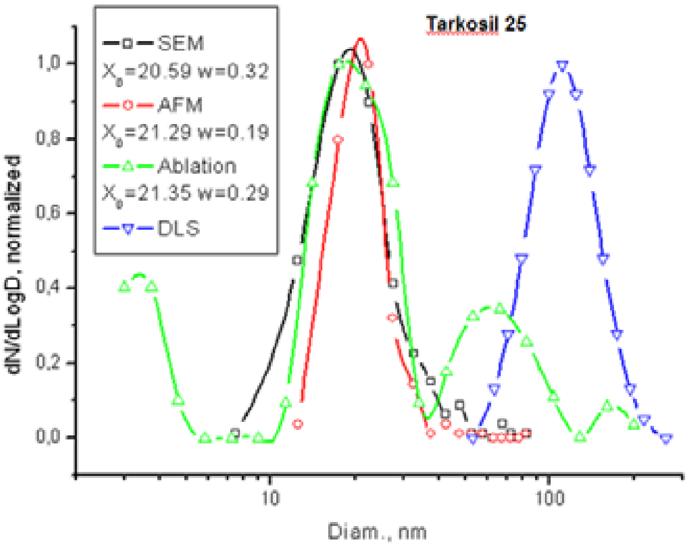


Fig. 19: Comparison of the size distributions of silicon dioxide nanopowder (tarkosil) obtained by non-destructive ablation (Ablation), dynamic light scattering (DLS), atomic force (AFM) and scanning electron microscopy (SEM). The figure shows the size of the major factions in nanometers.

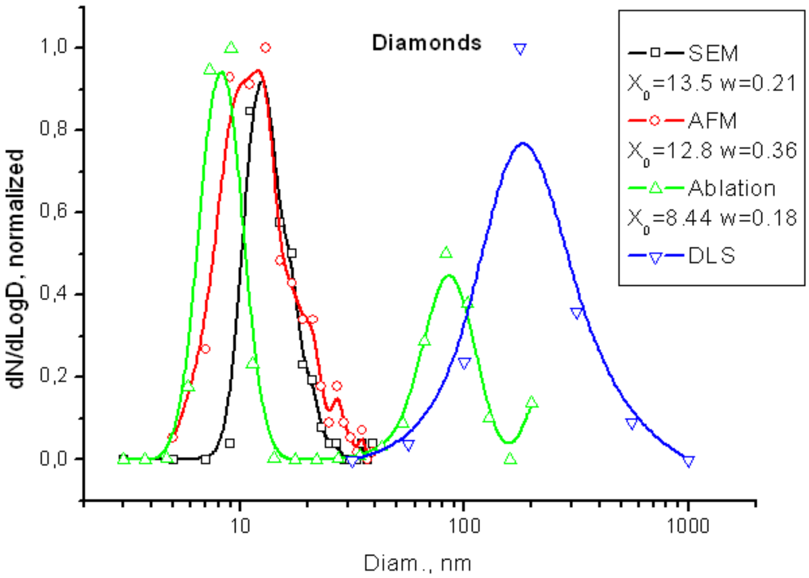


Fig. 20: Comparison of the size distributions of diamond nanopowder (scientific-production enterprise “Altai”) obtained by non-destructive ablation (Ablation), dynamic light scattering (DLS), atomic force (AFM) and scanning electron microscopy (SEM). The figure shows the size of the major factions in nanometers.

In total, 180 aerosol spectra obtained via ablation were registered and 80 different samples were investigated. Members of the Institute of Chemical Kinetics and Combustion, the Institute of Cytology and Genetics and Budker Institute of Nuclear Physics SB RAS participated in this work.

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[1] * M.S. Vagin, A.S. Unitsyn, A.K. Petrov, A.S. Kozlov, S.B. Malyshkin, V.M. Popik, T.N. Goryachkovskaya, S.E. Peltek, Investigation into the possibility of determining masses of biological nano-objects via terahertz laser ablation // Vestnik NSU. Series: Physics. - 2009. - v. 4, - no. 3. - P. 74 - 77

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- V. 62, N. 3-4. - P. 209-237.
[4] * A.S. Unitsyn, M.S. Vagin, A.K. Petrov, A.S. Kozlov, S.B. Malyshkin, V.M. Popik, S.E. Peltek, Investigation into the dispersion of products of submillimeter-scale laser ablation of inorganic nano-systems. Vestnik NSU. Series: Physics. - 2009. - v. 4, - no. 2. - P. 8 – 12.

Station "Chemistry" allows work with radiation beams of large diameter. In 2009, the following works were carried out.

1) **Study of the impact of terahertz radiation on genetic material.** It is known that the energy of bonds stabilizing the secondary structure of DNA lies in the terahertz region. Therefore, it is possible to search for resonant frequencies of terahertz radiation destroying these connections and, consequently, the secondary structure of DNA without destroying the primary structure of the polymer chains of DNA. To study this phenomenon a model system allowing visualization of this process using fluorochrome-labeled oligonucleotides was developed. pUC18 plasmid DNA was used as a model object. If hydrogen bonds are destroyed in some areas of DNA under the influence of terahertz radiation, hybridization with oligonucleotide occurs at this place. The results of hybridization were visualized by electrophoretic separation of DNA in 1% agarose gel. Robustness of the model system in the case of conventional thermal denaturation of DNA was tested. The model system was irradiated with terahertz radiation with the following wavelengths: 125, 129, 139, 140, 141, and 200 μm with exposure times of 5 to 30 minutes. It was shown that selected DNA segments do not have resonant frequencies at these wavelengths.

2) **Study of the impact of terahertz radiation on stress-sensitive systems of cell**. The basis of work of genosensors is the ability of cells to activate their defense systems in response to the impact of damaging agents. Cascades of gene of protection systems of bacterial cell are activated in the presence of agents that damage the structure and function of cell. Namely promoters of these genes are sensitive parts of a biosensor structure. In the created artificial genetic structures, promoters of the genes of protective systems trigger the synthesis of the reporter fluorescent protein (GFP, Green Fluorescent Protein) in the cells of E.coli, the accumulation of which is easily tested using conventional fluorescence microscope. A series of stress-sensitive genosensors created by ICG SB RAS using promoters of genes yfiA and katG served as a model object. As a result of the experiments it was revealed that under the action of terahertz radiation GFP is accumulated in the system based on the genosensor katG, which indicates induction of protective mechanisms of E.coli cells. The system based on the genosensor yfiA did not respond to THz radiation. The difference in the reaction of genosensors is associated with the selective influence of terahertz radiation on different protective systems of E.coli cells.

3) **Study of the integral proteomic response of E.coli cell to terahertz radiation.**

Unlike genome, proteome is not a constant feature of cell and responds specifically to changes in environmental conditions. E.coli cells – an organism which is well studied in the genetic and proteomic aspects – were chosen to be the main object of study. Analysis of the E.coli proteome before and after terahertz irradiation was done by up-to-date methods of proteomic analysis, including two-dimensional electrophoresis (Fig. 21) with subsequent identification of proteins by the method of MALDI-TOF mass spectrometry (Fig. 22).

The impact of terahertz radiation on biological objects of three types was studied. No effect on the secondary structure of DNA was revealed. Induction of protective mechanisms of cells and changes in the expression of the genes Glutamine synthetase, Phosphoglucosamine mutase, Glucarate dehydratase, Cysteine desulfurase, Uridine phosphorylase Escherichia coli in response to terahertz radiation were showed.

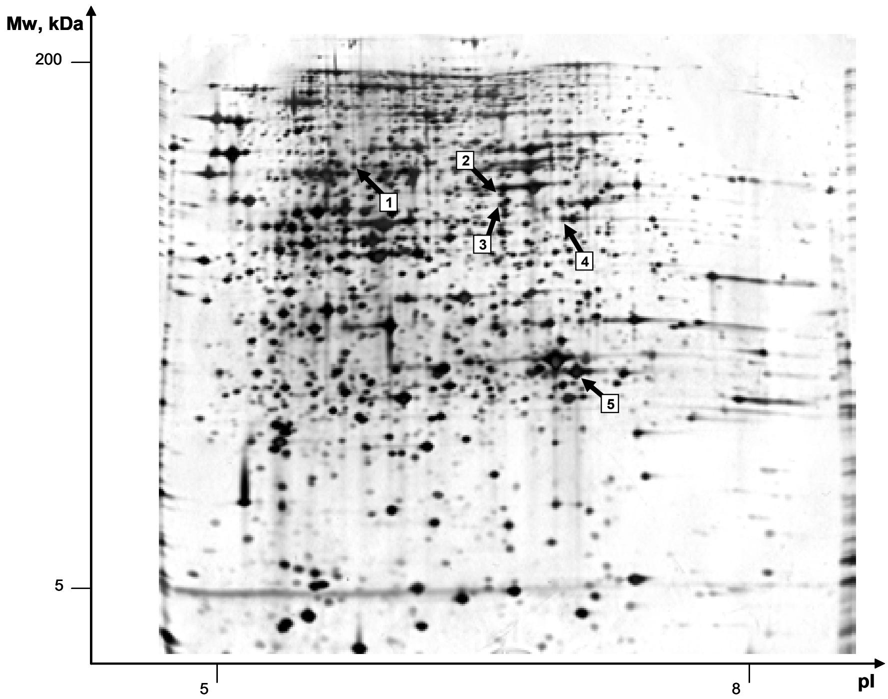

Fig. 21: Electrophoregram in two-dimensional 12% PAAG-SDS of the total protein of E.coli after exposure to THz radiation. Arrows indicate identified fractions whose expression differed more than two times compared with the factions of the reference specimen.

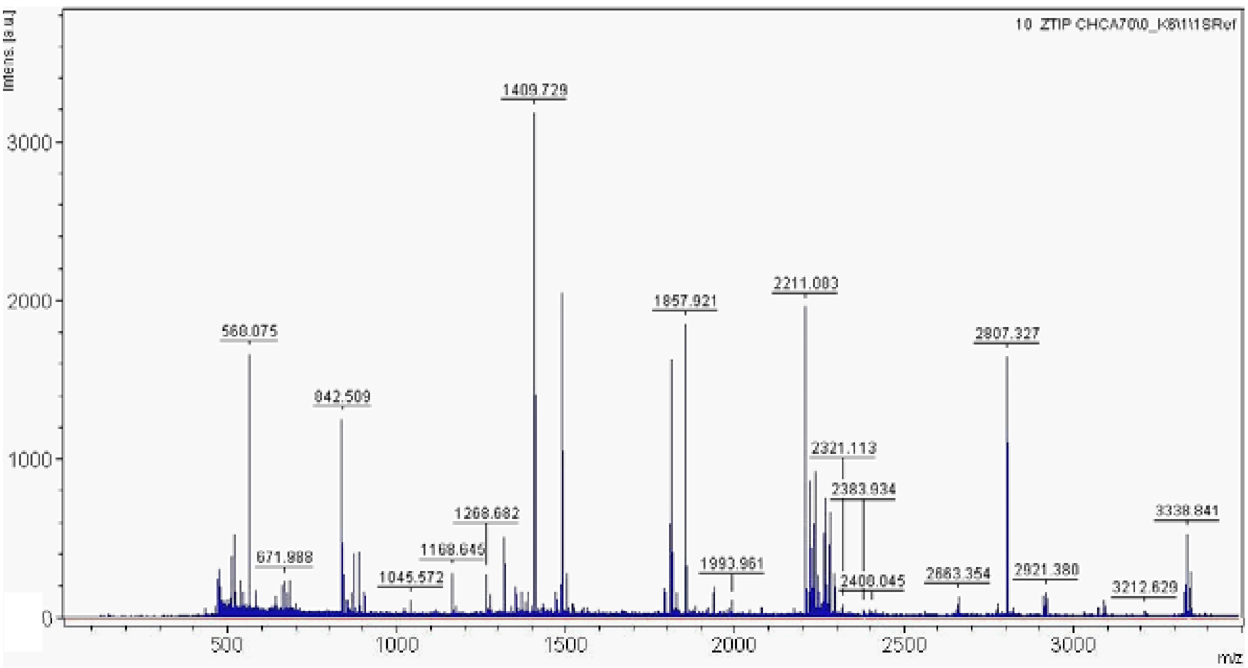

Fig. 22: Peptide mass spectrum of the tryptic hydrolyzate of electrophoretic fraction №3 of the total protein of E.coli.

The work was carried out with the participation of members of the Institute of Chemical Kinetics and Combustion, Institute of Cytology and Genetics and Budker Institute of Nuclear Physics SB RAS.

The station "Spectroscopy and introscopy is designed for study of the absorption spectra of substances and substances as well as for any quasi-optical experiments with visualization of images.

The station consists of an optical table, a set of lenses, mirrors, and diffractive optical elements, opto-mechanical elements (including computer-controlled high precision motorized translational and rotational movers), thermograph, bolometer array detectors, thermosensitive fluorescent radiation detectors, thermosensitive Fizeau interferometer, pyroelectric detectors CCD camera with a microchannel amplifier PI Max2, digital recorders of signals Handyscope-3 and Handyscope-4, Tektronix oscilloscopes, resonant amplifiers, acousto-optic detectors, disk storage unit for 6 terabytes and other equipment.

In 2009, works at the station were conducted with the support of the following grants:

1. RFBR grant 07-02-13547-офи-ц "Development of methods for constructing the total internal reflection spectrometers for biomedical applications with the terahertz free-electron laser as a source of radiation"

2. RFBR grant 09-02-12158-офи_м "Development of the basic physics of tomography, holography and metrology using a source of coherent monochromatic terahertz radiation"

3. SB RAS integration project № 89 "Development of the method of terahertz imaging spectroscopy of frustrated total internal reflection with the function of near-field microscope"

The following results were obtained:

The first imaging ATR spectrometer of the terahertz range with a wide working area, capable of working in real time, was created [1, 2]. The general view of the imaging ATR spectrometer is shown in Fig. 23. The radiation source is Novosibirsk free electron laser generating a continuous sequence of pulses of about 100 ps long with a repetition frequency of 5.6 MHz. The radiation wavelength can be smoothly tuned in the range from 120 to 240 microns with a relative lasing line width of $0.3 \div 1\%$. Samples are placed on one of the replaceable silicon prisms. Vanadium-oxide microbolometer focal plane array detector with 320×240 elements developed at the ISP SB RAS allows recording images of radiation reflected from the prism/sample interface in real time at 20 frames per second. Dynamics of ATR spectra of different objects were registered for the first time in the terahertz range. An example of observation of dissolution of an ethanol drop in water is shown in Fig. 24.

Work on the creation of microbolometer array detectors for the terahertz range continued. Members of ISP SB RAS created a model microbolometer array detector in which each microbolometer is integrated with an individual antenna. Experiments on the FEL showed that the sensitivity of such a detector is 5-6 times higher than that of a normal detector [3].

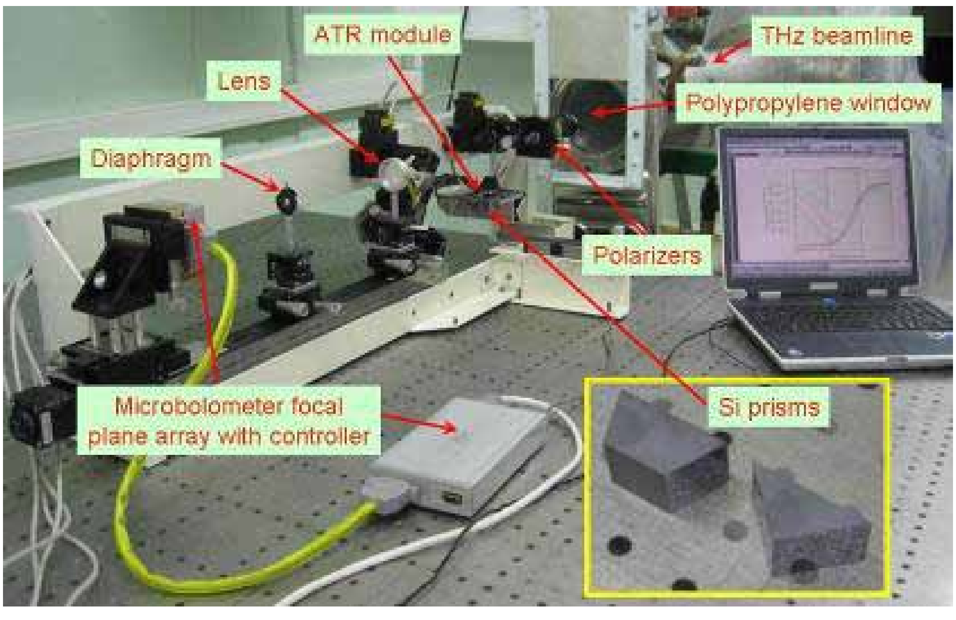

Fig. 23: General view of the frustrated total internal reflection spectrometer with silicon prisms.

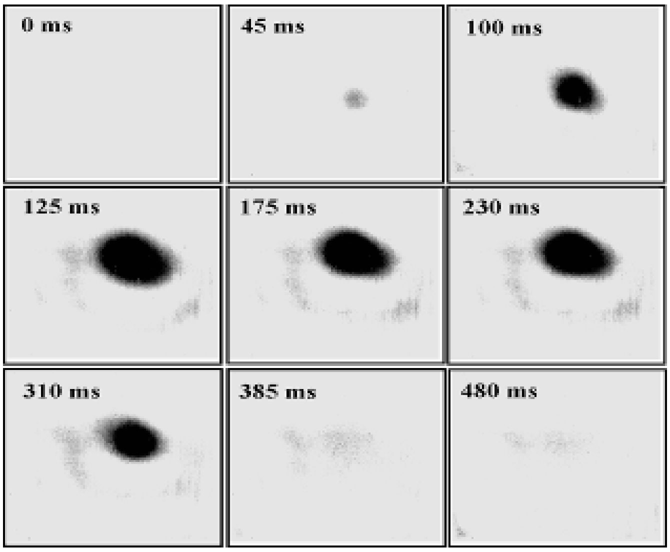

Fig. 24: Images obtained with the microbolometer array in the ATR spectrometer at injection of a drop of ethanol into a cell with water placed on the surface of a silicon prism: the radiation source is the free electron laser, the radiation wavelength is 130 microns, p-polarization, the incdence angle is 57˚.

A detailed study of the speckle structure of images of objects illuminated by coherent monochromatic terahertz radiation of the free electron laser was conducted [4]. Statistics of speckles in this range were investigated for the first time and speckle photography in the terahertz range in real time was demonstrated. The results allow starting the development of methods of speckle metrology in the terahertz range [6].

The Technological Design Institute of Scientific Instrument Making developed transmissive diffractive optical elements (DOE) made of high-pressure polypropylene that are intended for operation in intense beams of terahertz radiation (see references [4, 5] in the conference proceedings). Tests of six DOE samples using microbolometer array detectors showed very high quality of the focal spot in beams with an average radiated power of 100 - 150 Watts. Technology development is going on.

Experiments to study methods for capture of free terahertz waves and formation of surface plasmons (SP) on the metal-air interface were carried out. It was shown that SP arise from p-polarization of incident radiation at diffraction on obstacles (slots of special form), whereas in the case of s-polarization no such seizure occurs. This clearly indicates the emergence of SP. Experiments have shown, however, that at generation of SP in the diffraction regime, besides SP, the detector registers a diffracted free wave. Alternative methods of capture to separate the SP and the free wave are studied. In addition, a method for separation of these waves with the help of "geodetic elements" was suggested [5]. An example of possible use of such elements is shown in Fig. 25.

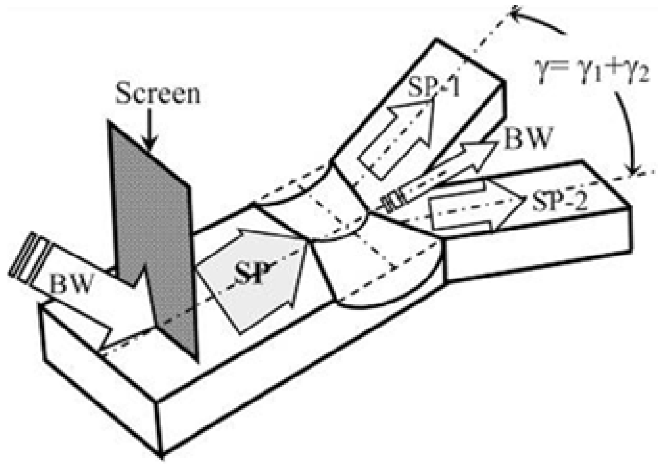

Fig. 25: An example of using geodetic elements for spatial separation of free wave and surface plasmon.

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6. O.I. Chashchina, B.A. Knyazev, G.N. Kulipanov, N.A. Vinokurov. Real-time speckle metrology using terahertz free electron laser radiation. Nuclear Instruments and Methods in Physics Research, Ser. A, V. 603, Issues 1-2, P. 50-51, 2009.

At **the station for molecular spectroscopy**, members of the Institute of Chemical Kinetics and Combustion SB RAS and BINP SB RAS were working under SB RAS integration project №102 “Development of the Faraday THz LMR spectrometer using a free electron laser”.

The ability to use terahertz radiation (1 - 10 THz or 30 - 300 microns) for detection of free radicals is significant first of all for flame diagnostics. This area contains lines of rotational transitions of many free radicals which play an important role in combustion processes. These include the radicals OH, CN, CH, CH_2, and others. An attractive feature is the small dispersion of long-wave radiation on particles of micron-scale size. In contrast to existing optical methods of detection of radicals using laser radiation of the visible and ultraviolet ranges, a method that uses radiation of the terahertz range may be suitable for study of strongly scattering media, which is opaque in the visible range. Flames with a high content of carbon particles are an example of such objects. The aim of this study is to investigate the possibility of using FEL terahertz radiation for detecting paramagnetic particles in a gas.

The terahertz region contains lines of rotational transitions of relatively small molecules with a small moment of inertia. In addition, there must be permanent dipole moment. These requirements are best met by bi- and triatomic hydrides, such as a water molecule H_2O and hydrogen radicals OH, CH, CH_2. Since usually water concentration in the flame is much larger than the concentration of free radicals, most lines of flame absorption in the terahertz region belongs to the spectrum of H_2O.

The radical OH is a convenient object of study because of the presence of intense absorption lines in the terahertz region. Two absorption lines of the radical OH, at 1835 GHz and 2512 GHz, get to the region of FEL retuning. These lines correspond to transitions from the lower rotational levels of electron states $^2\Pi_{1/2}$ (½→ 1½) and $^2\Pi_{3/2}$ (1½→ 2½).

A sensitive method of detecting paramagnetic particles is registration of rotation of the plane of polarization in a magnetic field (the Faraday effect). Rotation of the plane of polarization in a magnetic field arises from the difference in the refractive indexes for waves with the left and right circular polarizations. Due to anomalous dispersion of the refractive index for radiation with a frequency close to the frequency of the absorption lines of paramagnetic particle, the value of rotation of the plane of polarization increases greatly at achievement of resonance. The high sensitivity of the Faraday method is provided by the possibility of measuring small angles of rotation of the polarization plane of radiation.

Fig. 26 presents a diagram of the experimental setup. The facility consists of an electromagnet, between the poles of which a burner is located, an input polarizer, an analyzer (output polarizer), a radiation detector and necessary optical elements. FEL radiation is directed along the magnetic field through holes drilled in the poles of the magnet. To focus the radiation a combination of convex and concave spherical mirrors was used. The beam diameter near the burner was about 1 mm. Radiation intensity after the analyzer was registered by the pyroelectric detector MG-33. Since pyrodetectors are sensitive to variable signals, the radiation was modulated with a rotating disk with holes at a frequency of 300 Hz. Variable signal from the radiation detector was recorded by the synchronous detector USD-2 and input into the computer.

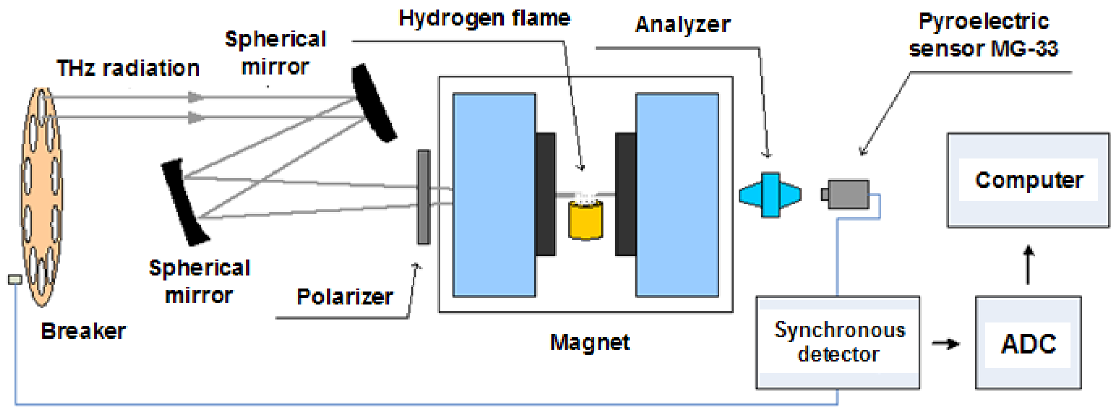


Fig. 26: Experimental setup for detection of Faraday rotation of the plane of polarization of FEL radiation in the flame.

FEL radiation is linearly polarized, but the degree of polarization turned out to be rather low – 99.5%. An additional polarizer was installed before the entry to the electromagnet in order to improve the degree of polarization. Its axis was aligned along the direction of polarization of laser radiation. The broadband polarizer of the company Tydex (St. Petersburg) was used as the analyzer. It provided suppression of unwanted polarization to 10^{-3} in the wavelength range of 120 - 180 microns. The direction of the axis of the analyzer was turned through $\pi/2+\varphi_0$ relative to the direction of polarization of the laser, where φ_0 is a small deviation.

Before the measurement, the FEL radiation frequency was tuned to the absorption line. The Fourier Spectrometer Bruker IFS-66V was used to measure the spectrum of the laser radiation. The measurements themselves consisted in comparison of the intensity of radiation passed through the analyzer when magnetic field was switched off and on. If the polarization plane rotates through an angle $\Delta\varphi$ with the magnetic field switched on, the intensity of radiation on the detector is

$$I = I_0 \cdot \sin^2(\varphi_0 + \Delta\varphi) \approx I_0 \cdot (\varphi_0^{\,2} + 2\,\varphi_0 \cdot \Delta\varphi + \Delta\varphi^2) \qquad (1)$$

Correspondingly, the change in the intensity when the field is switched on and off is

$$\Delta I \approx I_0 \cdot (2\,\varphi_0 \cdot \Delta\varphi + \Delta\varphi^2) \qquad (2)$$

Operation of the facility was tried on the absorption lines of NO before work with flame. An NO-filled optical cell with polyethylene windows was placed instead of the burner in these experiments. NO molecules have a permanent magnetic moment, and the Faraday effect must be observed on the absorption lines of NO as well as on the absorption lines of free radicals.

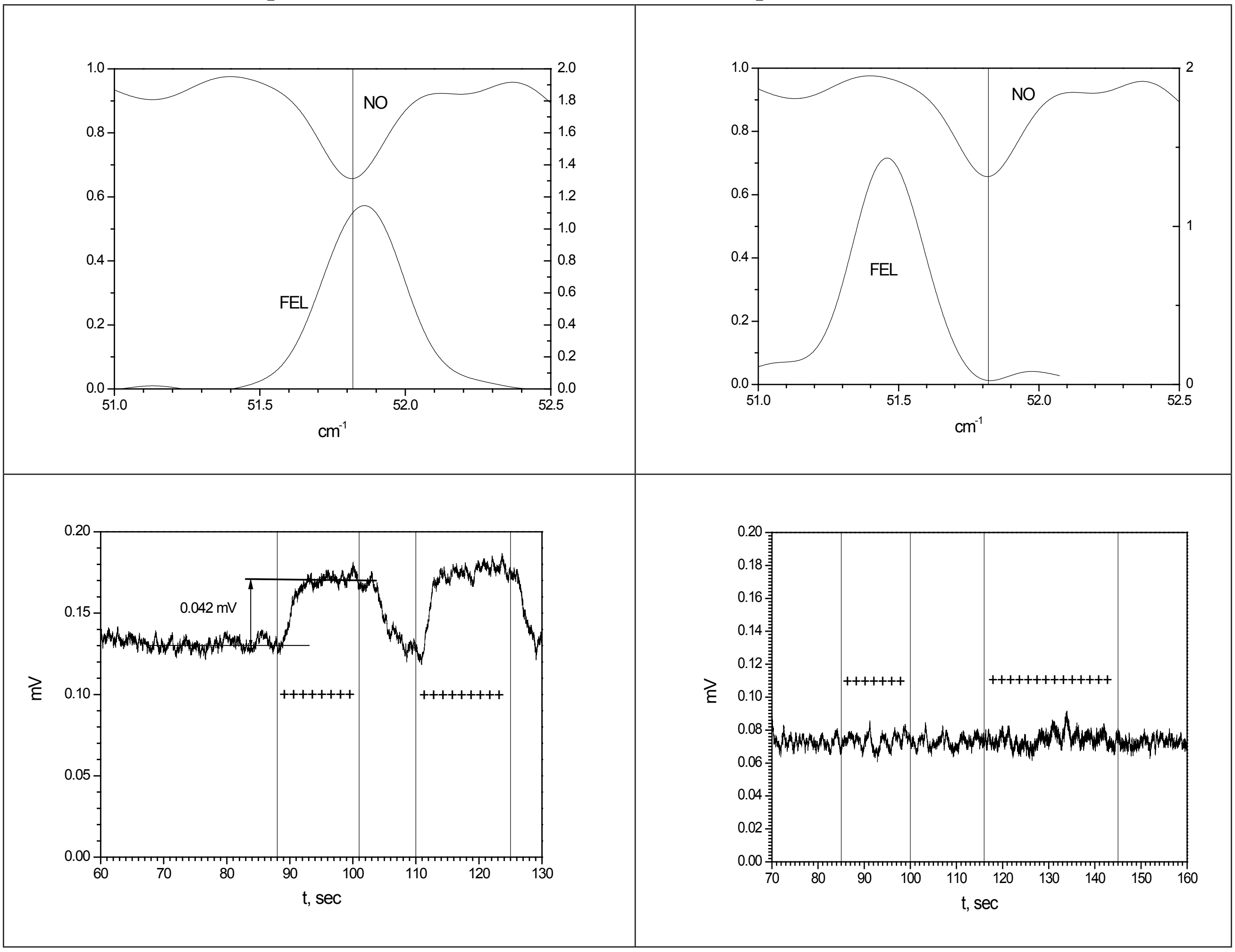


Fig. 27: Observation of the Faraday effect in the rotational spectrum of NO. The FEL radiation spectrum is at the top. The vertical line shows the position of the absorption line of NO $^2\Pi_{3/2}(16.5) \leftarrow {}^2\Pi_{3/2}(15.5)$. Below is shown the change in radiation intensity when a magnetic field of 8 kG is turned on and off.

Fig. 27 gives the results of experiments with NO. Magnetic-field-induced rotation of the polarization plane of the terahertz FEL radiation was observed. The effect was observed when laser radiation was tuned to the absorption line of NO molecule. The FEL radiation spectrum and absorption line in the rotational spectrum of NO are shown in the top left graph. The intensity of radiation that passed the cell with NO and analyzer is shown in the bottom left graph. When a magnetic field is switched on (the moments of switching on and off are marked by the vertical lines), the plane of polarization rotates, which leads to a change in the intensity of radiation that passed the analyzer.

When the field is turned off, the intensity is restored. Some delay is due to the fact that because of the large inductance of the electromagnet coil the magnetic field increases slowly. If the laser line is tuned away from the absorption lines of NO, as shown in the right pictures, the magnetic field has no effect on the polarization of terahertz radiation.

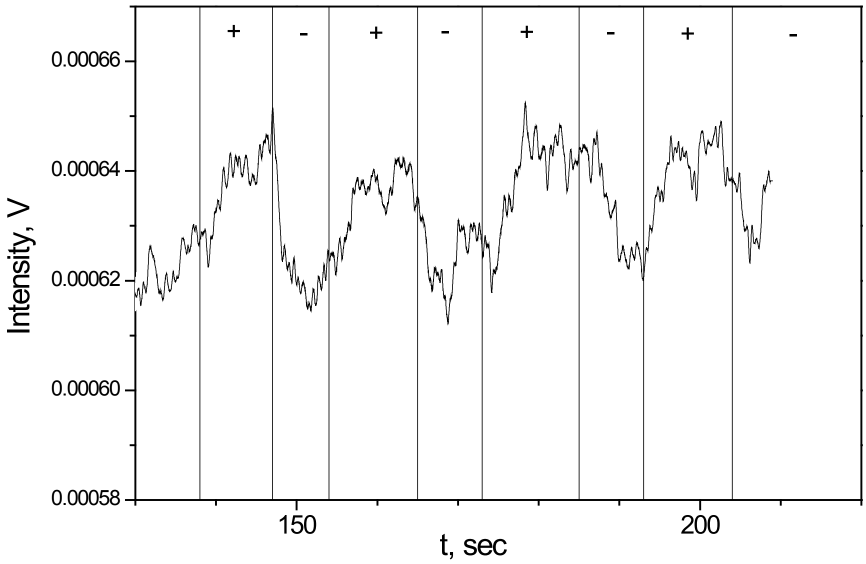


Fig. 28: Change in the plane of polarization in a magnetic field at a frequency of 1843 GHz of the OH radical.

Fig. 28 shows the results of experiments on the rotation of the polarization plane on the line $^2\Pi_{1/2}$ (½→ 1½) of the OH radical. The above-mentioned burner was placed between the poles of the magnet. The effect was registered when the FEL was tuned to the frequency of 1843 GHz. The FEL line width at half maximum was 18 GHz. The angle of rotation of the plane of polarization of the laser radiation calculated by formula (2) was $1.4 \cdot 10^{-3}$ rad.

Thus, for terahertz radiation tuned to the absorption lines of the OH radical in flame at atmospheric pressure, the value of rotation of the plane of polarization in a magnetic field is measurable ($\sim 10^{-3}$ rad). Today the main way to increase the sensitivity is to reduce the FEL radiation noise. It will allow: a) increasing the frequency modulation of magnetic field from 0.1 Hz to 300 -1000 Hz, b) using symmetric modulation of magnetic field from - H to + H.

6.3.3 Second stage of Novosibirsk FEL

Work on the development and commissioning of the second stage of Novosibirsk FEL was supported through SB RAS Integration Project № 6/2006 “Development and production of the second stage FEL”, RAS “basic” project for basic research №2.6.6.4 “Creating the FEL for the terahertz and infrared ranges with an average power of up to 50 kW”, SB RAS Integration Project №52 “Commissioning of the second stage FEL and development and manufacture of elements of the third stage FEL” of state contract №02.740.11.0430 for R&D on “Commissioning of the second stage of the powerful free electron laser and development of elements of the third stage”, and RFBR Initiating Project 09-02-12121-офи_м “Development of methods for measuring parameters of high-power terahertz radiation and methods of managing these parameters”.

To move to the region of higher frequencies of the terahertz range, the second stage of the free electron laser (FEL) is created. For a FEL operating in the frequency range of 3 - 10 THz to appear, the world’s first energy recovery linac (ERL), with two tracks (i.e., with a fourfold passage of electron beam through high-frequency resonators) was built and launched.

The full-scale ERL uses the same accelerating RF structure as the ERL of the first stage, but is, unlike the latter, in the horizontal plane (Fig. 29). Thus, there is no need to dismantle one for construction of the other. An operation mode is selected via simply switching the bending magnets.

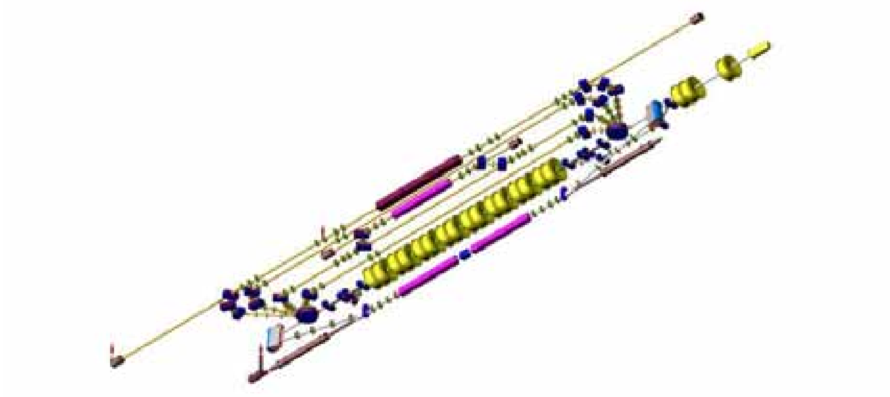


Fig. 29: The scheme of the full-scale 4-pass ERL (plus one track in the vertical plane with the FEL of the THz range of 110-240 microns).

The second stage FEL is placed on the second track of the ERL. It is planned to install a powerful FEL of the near IR range for wavelengths of 5 - 12 microns on the last (40 MeV) track of the ERL.

In 2009, the optical resonator of the second stage FEL was mounted. Fig. 30 shows a scheme of the optical resonator. It is a two-mirror resonator with a Rayleigh length of about 3 m. The hole in the left mirror is used to output radiation in the extraction beamline, and the hole in the right mirror is used for input radiation of the alignment laser.

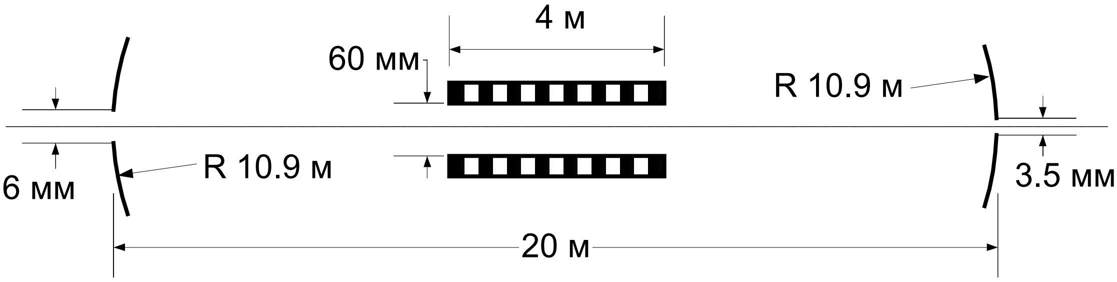


Fig. 30: Scheme of the optical resonator

Fig. 31: Left mirror with the output window.

Fig. 31 shows the left mirror. Radiation emerging through the hole in the mirror passes through the vacuum window. The latter is a diamond plate rotated through the Brewster angle around a vertical axis, which ensures complete passage of radiation in the extraction beamline.

Units of the optical cavity are adjusted with the required accuracy. Remote control of the mirrors was adjusted, and an exact alignment of the mirrors was carried out. The required accuracies of coordinate adjustment (0.2 mm) and angular alignment of the mirrors ($5 \cdot 10^{-5}$ rad) were achieved.

After alignment of the optical cavity the mode of generation of stimulated emission was achieved at the second stage FEL. The average radiation power was 0.5 kW, and the wavelength was tunable from 40 to 80 microns. Similarly to the first stage FEL, the second stage FEL by far exceeds similar foreign installations in the average radiation power of its spectral range.

A radiation extraction beamline to guide the second stage FEL radiation to the existing user stations was designed. The structure of the channel includes four mirrors and a chamber filled with dry nitrogen.

Thus, in 2009, the free electron laser at the second track of the ERL started operating. Extraction of its radiation to the user stations is planned for 2010.

6.3.4 Results of 2009 and plans for 2010

Main results of work in 2009:

1. Regular work of users on the THz FEL of the first stage was provided.
2. Elements of the magnetic system of the third and fourth tracks of the ERL were mounted.
3. The second stage FEL was commissioned (on the 2nd track of the ERL).
4. The beamline for extraction of radiation of the second stage FEL was made and installed.
5. The beamline for radiation extraction and existing user stations were upgraded, and work on the construction of new stations continued.

Plans for 2010:

1. Commissioning of the beamline for extraction of radiation of the second stage FEL.
2. Completion of the installation of the vacuum chamber of the third and fourth tracks of the ERL.
3. Design of an optical resonator for the FEL on the fourth track.
4. Continuation of the work on the creation of new stations.
5. Continuation of the designing and manufacturing of units of the test bench of the RF injector.
6. Continuation of the work for users.

6.4 Development and creation of intended SR generators

6.4.1 Superconductive wigglers

Several contract works on the development and manufacturing of various cryogenic superconducting magnet systems for SR generation were conducted in 2009.

1. A 49-pole wiggler with a period of 48 mm, magnetic field of 4.3 T and pole gap of 14 mm was delivered and assembled in the area of the DLS storage ring (Diamond Light Source, UK) in March 2009. This is a second superconducting wiggler made by BINP for DLS under a contract. After final tests and a series of magnetic measurements the wiggler was installed on the storage ring and started working in a usual mode (Fig. 32). This beamline for radiation with high intensity of photons in the spectral range of 10-150 keV is called JEEP (Joint Engineering, Environmental and Processing). It will be used for materials science, chemical engineering, geology and nondestructive examination of large mechanical products (e.g., aircraft parts).

Fig. 32: Mounting the 49-pole wiggler with a field of 4.3 T on the DLS storage ring.

2. A three-pole shifter with a field of 7.5 T on the LSU-CAMD storage ring (U.S.) was again put into operation in September 2009, after a full upgrade of the cryogenic system. This wiggler, manufactured by BINP in 1997, had successfully worked on the storage ring for 12 years. However, such an important feature as liquid helium consumption ceased to meet modern requirements. Therefore, under a separate contract, the magnetic system of the wiggler was extracted from the old cryostat and placed in a newly manufactured cryostat. The magnetic system itself remained practically unchanged. In the new cryogenic system without the use of liquid nitrogen, the liquid helium consumption was reduced almost by 50 times, which allows re-filling with helium once every 4 months instead of every three days earlier. The upgraded cryogenic system uses one cryocooler made by the Sumitomo firm with a productivity of 1.5 Watts at 4.2 K for cooling the helium vessel and the current leads as well as a cryocooler with temperatures of 20 and 60 K for cooling the screens. Currently, the upgraded shifter continues successful operation on the LSU-CAMD storage ring (Fig. 33).

Fig. 33: Moving the upgraded shifter with a field of 7.5 T to the LSU-CAMD storage ring.

3. A 35-pole wiggler with a field of 3.6 T and a period of 60 mm for the LNLS storage ring (Kampinas, Brazil) was delivered, assembled and fully tested in August 2009 (Fig. 34). In December 2009, this wiggler was installed directly on the storage ring.

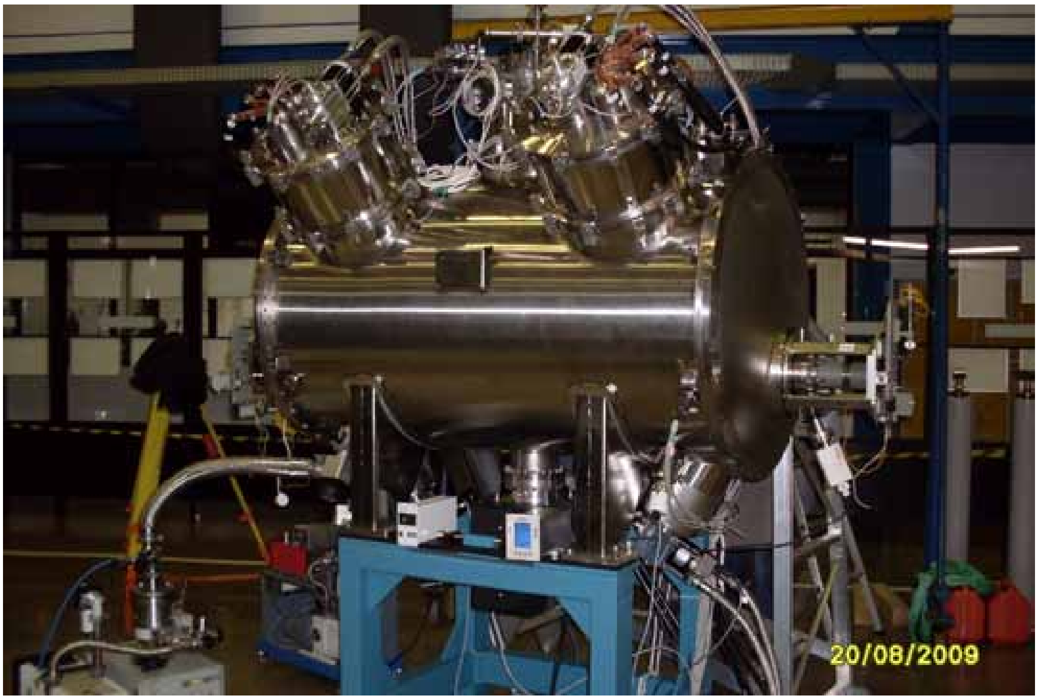


Fig. 34: The 35-pole wiggler with a field of 3.6 T and a period of 60 mm on the LNLS storage ring (Kampinas, Brazil).

4. A full-size magnetic system of a 119-pole wiggler 1892 mm long with a period of 31 mm, magnetic field of 2.2 T and pole gap of 12.6 mm for the ALBA-CELLS storage ring under construction (Spain) was manufactured and successfully tested in 2009. This wiggler is already very close in its parameters to undulators. Its distinctive feature is winding a thin superconducting wire with a diameter of 0.55 mm with record current characteristics for such a cross (240 A in 7 T).

When such a thin wire is used, it is necessary to pay special attention to the protection of the superconductor from combustion as well as to energy output at breakdown of superconductivity. The point is that the ultimate current parameters of the wire are achieved by reducing the cross section of copper required for stabilization of the superconductor. A large number of superconducting coils connected in series imposed additional stringent requirements on the quality of manufacture and method of testing of each of the superconducting coils as well as the quality of electrical contacts between them. The magnetic system was successfully tested in a submersible cryostat, and the required parameters of magnetic field were achieved (Fig. 35). An own cryostat of the wiggler is being manufactured now. Testing the wiggler in the cryostat is scheduled for February 2010, and in April 2010 it will be installed and commissioned directly on the ALBA-CELLS storage ring.

Fig. 35: Magnetic system of the 119-pole wiggler with a field of 2.2 T and period of 31 mm for the ALBA-CELLS storage ring (Spain).

6.4.2 Damping wigglers on permanent NdFeB magnets for the SR source for Petra-III (Hamburg)

A contract on the manufacture of 21 damping wigglers on permanent magnets for the SR source for Petra-III (DESY, Hamburg) was completed.

Wigglers for Petra-III are installed in two straight sections, by 10 wigglers in each, and are intended for reduction of electron beam emittance in the ring.

The wigglers have the following magnetic parameters:

Period	20 cm
Field amplitude	15.6 kG
Vertical gap	24 mm
Length	4 m

First, a full-scale wiggler prototype was made, and then, upon approval of the wiggler design by DESY experts, all 20 wigglers were built and tuned, which took a year and a half. During 2008-2009, all the wigglers were installed on the PETRA-Ш ring. In February 2009, commissioning of the accelerator started, and a decrease in electron beam emittance in the ring to a record value of 10^{-9} m • rad was achieved by the end of the year.

In addition to the wigglers for PETRA-Ш, BINP also designed and manufactured absorbers of synchrotron radiation from the wigglers with a total capacity of 800 kW and the vacuum system for the straight sections.

Fig. 36: Wigglers made by BINP in the straight sections of PETRA-Ш.

6.4.3 Radiation-resistant dipole magnet for the ion accelerator under construction at GSI (Germany)

The international acceleration research center GSI is being built in Germany. Russia participates actively in this research center. BINP designed and is constructing a radiation-resistant dipole magnet for Super-FRS that is intended to output beams of secondary ions (secondary ions are obtained by bombarding a target with accelerated ions or protons) to the research stations. Since the dipole magnet is located after the target, the secondary ions have a large scatter in angles and coordinates.

The dipole magnet has a pole gap of 0.18 m, uniform ($\pm 3 \cdot 10^{-4}$) magnetic field region of ± 0.195 m in the horizontal, effective magnetic length of 2.4 m and radius of curvature of 12.5 m The weight of the magnet is about 100 tons. The dipole magnet is to retune magnetic field in the range from 0.15 T to 1.6 T in 120 seconds. The dipole magnet will be located in a zone of strong induced radiation, and an important feature of the magnet is complete absence of any structural elements containing organic compounds.

The contract work on the development and manufacture of the first (of three) of radiation-resistant dipole magnets for the accelerator center GSI (Germany) was started in 2007 and completed in 2009.

In 2009, the iron yoke was manufactured and assembled, the radiation-resistant coils were made, and the magnet as a whole was assembled Magnetic measurements are scheduled for early 2010.

Fig. 37: Radiation-resistant dipole magnet of the H type.

6.4.4 Beamlines for transport of carbon ion beam to patients for the center for cancer treatment at the University of Gunma, Japan

For the center for cancer treatment at the University of Gunma (Japan) BINP designed, manufactured and delivered 4 high-energy beamlines (400 MeV/nucleon) and 1 technical beamline (from the injector to the synchrotron, 4 MeV/nucleon). The delivery includes 15 bending magnets, 26 quadrupoles, 24 correctors and vacuum chambers.

The installation and testing of beamlines for the transport of carbon beam to the patient on the accelerator at the University of Gunma was performed in 2009. In autumn 2009, a successful transport of beam through the beamlines was carried out, the project beam intensity on the target of $1.4 \cdot 10^9$ pps (particle per second) was reached at the full power, the preclinical testing program on phantoms was completed.

Treating the first patient is scheduled for March 1, 2010.

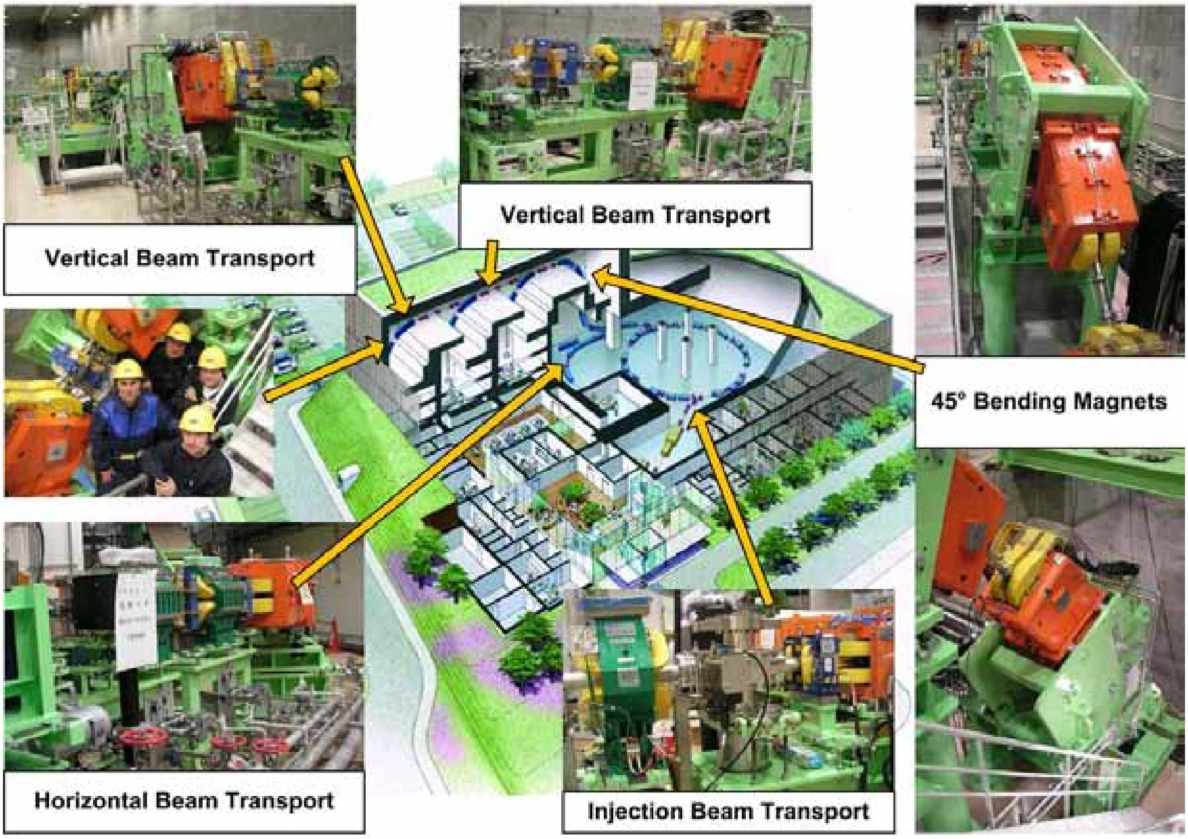


Fig. 38: Beamlines designed and manufactured by BINP on the carbon ion accelerator of the center for cancer treatment at the University of Gunma.

6.4.5 Technological storage ring complex (TSRC "Zelenograd")

A long training of the linear accelerator was completed by the beginning of 2009, which increased the energy of electrons at the exit of the linear accelerator (LA) to 65 MeV as well as one-time capture of electrons into the minor storage ring (MSR). After optimizing the parameters of power and control systems and debugging the software, an operation mode was achieved which allows accumulating as much as 70 mA electrons in the MSR. The further increase in the accumulated current is associated with prolonged degassing of the vacuum chamber walls with a synchrotron radiation beam. Regimes to increase the energy of electrons accumulated in the MSR to an energy of 450 MeV and regimes for bypassing electrons from the MSR to the electron-optical beamline EOB-2 to the main ring were refined. The injection complex is ready to start operation for the large storage ring.

Installation of magnetic elements on the large storage ring (LSR) and upgrading of high-current power sources were continued and completed simultaneously with the work on the injection complex.

The vacuum system of the LSR was completely manufactured and assembled, and its pumping-out started during 2009. In addition, BINP fabricated an RF generator on new oscillating tubes and 180 MHz bimetallic resonators. Commissioning of the whole complex is planned for late 2010.

Fig. 39: Mounting the vacuum system of the LSR of the SR source “Zelenograd”.

6.4.6 Development of a new SR source for the Siberian SR Center

In 2009, development of a new synchrotron radiation source for the Siberian SR Center continued. At this stage, the attention was focused on the development of a conceptual construction project for the complex of buildings and estimation of parameters of the required engineering systems.

A storage ring SR source is the main element of each SR center. Unfortunately, there are not many SR sources in Russia and absolutely no sources that meet the up-to-date requirements to such complexes. Many domestic research groups have to carry out experiments at foreign centers, often on unfavorable terms, which creates a lot of additional problems.

The Siberian Synchrotron Radiation Center (SSRC) was organized at Budker Institute of Nuclear Physics more than thirty years ago. For a long time it was the only Russian center where constant work on SR beams in the X-ray range was carried out. There is a unique infrastructure at Center that allows carrying out unorthodox research. The efficient operation of the Center is also defined by close cooperation with neighboring institutions of the Siberian Branch of RAS and strong interdisciplinary connections. In addition, close links with other scientific centers in Siberia (Tomsk, Krasnoyarsk, Irkutsk, and Barnaul) led to establishment of joint research teams involved in various joint projects in various scientific fields.

However, one of the main problems of the Siberian Synchrotron Radiation Center is now the lack of modern synchrotron radiation source. The current storage rings VEPP-3 and VEPP-4M are not specialized synchrotron radiation sources, and parameters of their radiation do not meet the modern requirements. It should also be noted that these storage rings were built more than 30 years ago and now they are rather vulnerable to serious malfunctions, which further reduces the potential beam time.

Superconducting bending magnets with a large field allows creation of a compact storage ring for generation of synchrotron radiation with a sufficiently hard spectrum. A large field in such magnets also permits achieving a hard SR spectrum at sufficiently low energy of electrons, which in turn can substantially reduce the cost of the entire complex.

This project suggests a combined scheme, which includes both superconducting bending magnets – hard SR sources – and conventional magnets (relatively soft X-ray and VUV radiation).

Table 1. Main parameters of the storage ring SR source.

Parameter	**Value**
Electron energy	2.2 GeV
Field in the bending magnets	8.5 T in superconductive magnets 1.6 T in normal magnets
Critical energy of SR quanta	30 keV for SR from superconductive magnets 6 keV for beams from normal magnets
Number of bending magnets	4 (superconductive) 32 (normal)
Angle of bending in the magnets	15° in superconductive and central normal magnets 7.5° in side normal magnets
Phase-space volume of beam (horizontal equilibrium emittance)	~ 5 nm·rad
Beam current	500 – 1000 mA
Beam lifetime	8 – 10 hours
Orbit perimeter	214 m
Injection type	at full energy with the possibility of top-up mode

The project implies usage of 4 superconducting magnets. Since the angle of rotation in a magnet is rather large (15º), up to 3 beamlines for extraction of hard SR from each magnet can be arranged.

The main purpose of optimization of the magnetic structure was to minimize the natural horizontal emittance, which provides high spectral brightness of the source. The secondary objectives in the optimization process were as follows:

• the maximum values of beta-functions must not exceed 30 m throughout the super-period;

• straight sections must have a zero dispersion function in order to avoid further amplification of emittance;

• the structure should have points with good separation of beta-functions, in which sextupole lenses can be installed to compensate for the natural chromaticity;

• the strength of the quadrupole and sextupole lenses should not exceed the standard technologically achievable values: gradients in the quadrupole lenses should not exceed 50 T/m;

• the structure should allow installation of magnets of 2 types: normal warm magnets and superconducting magnets with a field of 8.5 Tesla;

• it is desirable to have a large number of straight sections, to install devices for SR generation (wigglers and undulators).

The Triple Bend Achromat (TBA) scheme was chosen to be the basic structure. This scheme allows using magnets of two types as the central magnets (provided that angles of bending are equal) with almost the same configuration of optical functions at the ends of TBA cells regardless of the type of the central magnet. This feature, in turn, allows combining TBA cells of different types, i.e., the number of superconducting magnets in the structure may vary. At a 12-fold symmetry of the ring, the number of superconducting magnets can be 2, 3, 4, 6 or 8.

The geometric scheme of one super-period is presented in Fig. 40. The super-period consists of three TBA cells. The central magnet in the middle cell is a superconducting one. In the side cells, the central magnets are warm ones. The angle of orbit bending in all the central magnets is the same and equals 15 degrees. All side magnets are of normal conductance, with a field of 1.6 T and angle of bending of 7.5 degrees.

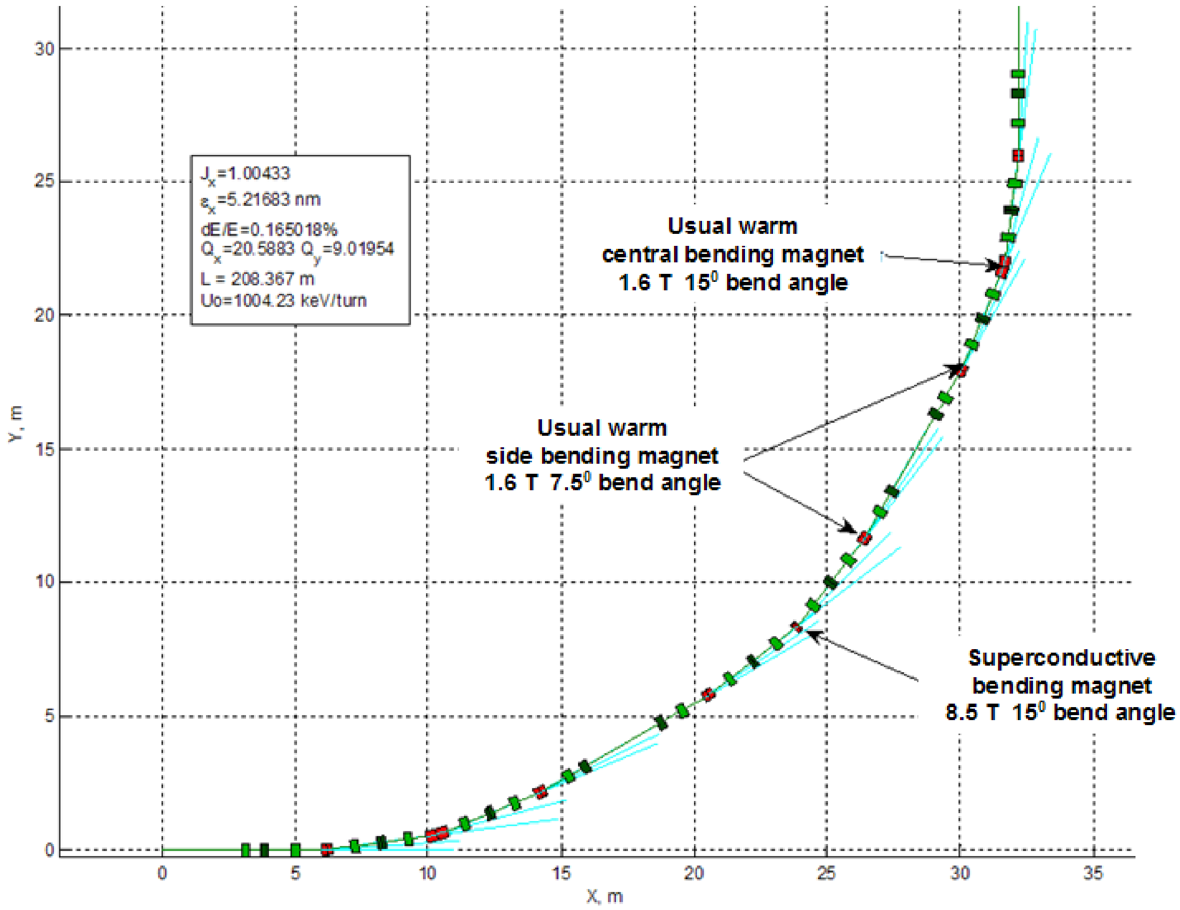


Fig. 40: Geometrical scheme of the super-period of the magnetic structure of the storage ring

The full angle of bending in one TBA cell is 30 degrees, and that in the whole super-period is 90 degrees. The lengths of the straight sections are 3 m for the internal sections of the super-period, i.e., between the central and side TBA cells. The external sections, i.e., between the super-periods, have a length of 7 m. In total, there are 8 short sections, 2 of which are planned for placement of the RF station and injection system. The rest can accommodate an SR generation device (wigglers or undulators).

The long sections are intended for installation of long undulators to produce beams of undulator radiation of high brightness.

The design equilibrium emittance in this scheme is 5.5 nm·rad, i.e., this source can be referred to the 3rd generation sources. The full perimeter of the orbit is 208.4 m.

Cryogenic system.

The current BINP technology enables creation of superconducting bending magnets with zero consumption of liquid helium. Operation of the system is maintained by cryogenic "coolers" and "re-condensers". Thus, liquid helium and liquid nitrogen are consumed only at primary cooling of the system after assembly (or repair).

Vacuum system

The vacuum system includes the pumping system (pumps with power supplies), a set of gates with RF window, and the vacuum chamber of the storage ring.

Currently, BINP is finishing the development of technology of spraying NEG (Not Evaporated Getters) coating on the inner surfaces of vacuum chambers. This technology allows achieving extremely low pressure in the chamber. Such techniques are widely used in the up-to-date accelerators. This technology can be applied to making the vacuum chamber in the project.

Fig. 41: General view of the complex of buildings for the new source for the Siberian Synchrotron Radiation Center.
1 - circular building for the SR source storage ring with the experimental hall;
2 - central building to house the injection complex with a crane-beam;
3 - building for the workshop and processing equipment;
4 - building with laboratories and offices.

The preliminary design resulted in a general concept of arrangement of the buildings. A sketch of the buildings was drawn (Fig. 41) with sectional elevations and floor plans (this work was funded by the Federal Agency for Science and Innovation (FASI) under the Program for development of shared-use centers (FASI state contract 02.552.11.7081).

Besides, the required capacity of major engineering systems was assessed and their specifications and estimated cost were defined.

Power system: the total capacity of all systems installed is 9 MW. The total thermal power removed from the system with distilled water is 2 MW. The preliminary cost of creating the SR Center, including the building, the synchrotron radiation source and the first six experimental stations, is estimated to be 2.8 billion rubles.

Location of the complex

This project suggests locating the complex in the area of the Institute of Nuclear Physics at the crossing of Budker and Ionosphernaya streets.

In line with this concept, the design of the accelerator complex was started. This work will result in preparation of design estimates for the conceptual design of the center, which is scheduled to continue in 2010.

6.5 Conferences, meetings, workshops

6.5.1. Russian-Germanic school for young professionals "Synchrotron radiation"

The 2nd Russian-Germanic school for young professionals "Synchrotron radiation" was held at BINP on 19 to 23 October 2009. Its main objective is to ensure the effective mastering by young researchers and teachers of the best scientific and methodological advances in the field of synchrotron radiation generation and use with in-depth analysis of the techniques of X-ray diffraction, small angle scattering as well as of research on fast processes on synchrotron radiation.

There were 106 students at the School, including 98 young professionals (younger than 35 years) from the following cities: Gatchina, Dubna, Yekaterinburg, Zelenograd, Ivanovo, Izhevsk, Irkutsk, Kazan, Krasnoyarsk, Moscow, Novosibirsk, Saint Petersburg, Sarov, Snezhinsk, Tomsk, Chernogolovka, Karlsruhe (Germany) and Almaty (Kazakhstan).

The School program included 29 lectures including those delivered by a member and corresponding member of RAS, nine doctors and ten candidates. Besides, three lecturers from Germany took part in the School. Students learned the history of synchrotron radiation sources in Russia and abroad,learned about the perspectives of development of new projects of SR sources, THz and infrared radiation (G.N. Kulipanov "Sources of synchrotron radiation and free electron lasers. The history, status and prospects", K.V. Zolotarev, "Theory of synchrotron radiation", and "Source of synchrotron radiation on superconducting magnets", N.A. Mezentsev "Superconducting wigglers and undulators as a source of hard X-rays", N.A. Vinokurov "Novosibirsk free electron for the laser terahertz range").

The themes of the rest lectures included different detectors for experiments with beams of synchrotron radiation, techniques using SR for study of materials: EXAFS, small-angle scattering, and resonant scattering of SR; application of these techniques to research on materials under high pressure, gas hydrate, mono-crystals, fast processes (detonation and shock-wave), phase composition of nano-materials, solid-state reactions, etc.; techniques of THz radiation application. All lectures are posted on the school website on the Internet at: http://ssrc.inp.nsk.su/school09/.

Practical training took an important place in the School work: special time in the work of six stations of the Siberian SR Center was allocated for that end. Groups by three students had the opportunity to study the work of each of these stations:

- study of detonation processes (station "Explosion");
- high-resolution diffractometry and anomalous scattering;
- X-ray fluorescence element analysis;
- station for diffractometry in the region of 30-34 keV;
- X-ray tomography and microscopy;
- diffractometry with high temporal resolution ("diffraction movie");
- EXAFS spectroscopy.

The database of the students of this School will be useful for informing young scientists about events at the Siberian SR Center, vacancies, public research programs, etc.

The Russian-Germanic school for young professionals "Synchrotron radiation" was held with financial support from the Federal Agency for Science and Innovations (FASI) (FASI contract 02.741.11.2029) and the Russian Foundation for Basic Research (RFBR grant 09-02-06165-г).

Fig. 42: Group shot of the School students and teachers.

6.5.2 8th conference of the students and graduates of the Siberian Synchrotron and Terahertz Radiation Center (SSTRC)

The 8th conference of students and graduates of the Siberian Synchrotron and Terahertz Radiation Center was held on April 27, 2009. 19 reports were presented at the conference, including 10 reports by students of NSU and NSTU and 5 reports by graduates from 3 institutes of SB RAS: BINP, SSCM, Institute of Inorganic Chemistry (Novosibirsk), and IGC (Irkutsk). This year, the Conference was also part of the Contest for BINP Young Scientists. The high level of many of the presented works was noted. Two first, two second and four third places were awarded with diplomas and rewards in the form of cash bonuses and gifts. A special prize was awarded to the repeated prize winner of the conference Bondarenko A.V.

Fig. 43: Delivery of a report and awarding.

6.5.3 Participation of the SSTRC members in other scientific events

Scientific session "BINP – 2010". Budker INP SB RAS, Novosibirsk, 23-24 January 2009.

All-Russian workshop on radiophysics of millimeter and submillimeter waves. Nizhny Novgorod, 2-5 March 2009.

III International conference "Fundamental bases of mechanochemical technologies", Novosibirsk, May 27-30, 2009.

The 9th International symposium on measurement technology and intelligent instruments: ISTC special session, Saint-Petrsburg, 29 June – 2 July, 2009.

II International symposium: Topical problems of biophotonics (TPB-2009). Inst. of Appl. Physics, Nizhny Novgorod – Samara – Nizhny Novgorod, 19-24 July, 2009.

6th International conference XAFS'14, Camerino, Italy, 26 – 31 July 2009.

Russian-Japanese Workshop (review conference) "State of materials research and new trends in material science". Novosibirsk, 3-5 August 2009, Russia.

31st International free electron laser conference FEL'09. Liverpool, UK. 23-28 August, 2009.

Second international workshop – exhibition "Strategy of development of large-scale research infrastructures of the Russian Federation and cooperation with the European Union". Russian centre for science and culture, Copenhagen, Denmark, September 7-8, 2009.

XXI conference on applied crystallography: Zakopane, Poland, 20-24 Sept. 2009.

The 34th International conference on infrared, millimeter, and terahertz wave IRMMW-THz'2009. Busan, Korea, Sept. 21– 25, 2009.

2nd International conference on X-ray analysis. Ulaanbaatar, Mongolia, September 23-26, 2009.

The 1st All-Russian Scientific Conference "Methods of studying the composition and structure of functional materials". Novosibirsk, 11-16 October 2009.

All-Russian Conference "Development of network of shared scientific equipment". Krasnodar, 12-18 October 2008.

The international scientific conference on the 75th anniversary of Al-Farabi KNU "Universities in the XXI century: innovation and new technology", Almaty, 14-15 October 2009.

School for young professionals "Synchrotron radiation. Diffraction and scattering". Budker INP, Novosibirsk, 19-23 October 2009.

7th International Specialized Exhibition "Laboratory Expo-2009". Moscow, 10-13 November 2009

International school for young scientists "Advanced Research in Photon Sciences. Experimental Capabilities of the European XFEL", Moscow, November 11-13, 2009.

VII National Conference "X-ray, synchrotron radiation, neutrons and electrons for study of nanosystems and materials. Nano-bio-info-cognitive technology" (XSNE - NBIC 2009). Moscow, 16-21 November 2009.

7

RADIOPHYSICS AND ELECTRONICS

Introduction

BINP works in the field of radiophysics and electronics are concentrated mainly in the Radiophysics Laboratory. The main subject of the Laboratory's activity is related to the study and development of radiophysics systems for the charged particle accelerators and storage rings, which are developed at BINP according to the State Programs "Colliding Beams", "High Energy Physics", "Synchrotron Radiation", "Physics of Microwaves".

Within the frame of these Programs, the Laboratory team is involved into the development of various radio-electronic equipment (power supply systems, control and diagnostics systems, computer control systems), into the development of RF accelerating systems, RF and SHF energy sources, studies of the charged particle beam behavior in interactions with the accelerating systems and with other elements and devices of the charged particle accelerators and storage rings. It is evident that the main results of the Laboratory's activity are integrated into the study and development results obtained at the complexes: VEPP-4; VEPP-2000, Injection Complex; FEL; works on plasma physics.

As a consequence of a versatile character of the Laboratory's works, some of them become the basis for the development of the equipment and/or devices of an independent scientific and technological interest. Some results are applied and used in other research areas of the Institute to execute contracts both with the national and foreign centers from the USA, Germany, Switzerland, Japan, China, South Korea.

It is worth mentioning here the contract works for CERN on development of the LHC components completed in 2008-2009; the works for Zelenograd on creation of the TNK SR Source to be carried out during several years; the development of neutral atoms injectors for Tri Alpha Energy (USA). Commissioning works at the TAE complex are already performed in a research mode.

Some results of the works carried out by the Laboratory in 2009 and plans for the works to be continued in 2010 and in future are given below.

7.1 Power supply sources for electrophysics facilities

7.1.1 Stabilized current sources

Development of the stabilized current sources for supplying various electrophysics facilities and their components is one of the main tasks of the studies carried out in the Radiophysics Laboratory. First of all, the devices of this class comprise DC sources for supplying electromagnets of the charged particle storage rings. An output current of the source (depending on the purpose) ranges from a few amperes to tens of kiloamperes, thus, an output power — from tens of watts to hundreds of kilowatts and to several megawatts.

As a rule the current sources should have a broad range of adjustable current values (up to 60 dB) and high precision of adjustment and stabilization (an error not exceeding 0.01%). The current sources are rather complex electrophysics devices with the computer test and control and with a complex system of interlocks and inner control. Analogous devices are not produced in Russia.

1) In 2009 we continued the long-term work on the upgrade of electronics for the IST-series precise sources, which are designed to power the electromagnets. These devices are of 50 kW, 100 kW and 200 kW output power with thyristor control and with the ripple damping channel. The sources are controlled by built-in single-channel 16-bit DACs (CEAC121); noncontact magneto-modulation current sensors (DCCT) are used to measure the current. In 2009 six ISTs at TNK complex (Zelenograd) were upgraded (two – for 2kA/30V and four – for 1 kA/115V).

Three ISTs (2kA/50V) and one IST (1kA/90V) were upgraded for the Injection complex. Upgrading includes replacement of electronics, capacitor banks and cabinet cabling.

The electronics to reverse of the load current was developed for ISTs of K-500 beams transporting channel. There devices are intended for transportation of electrons and positrons to the complexes VEPP-2000 and VEPP-4. The prototype of the reverse unit was successfully tested at the end of 2009. In 2010, the channel ISTs and the power supply of magnetic system BEP are planned to be equipped with these units.

In 2009 Low Voltage Equipment Plant (LVEP, Rasskazovo, Tambov region) supplied BINP with two current sources - new modification of IST source – (1000A/200kW and 1000A/100kW): "Euromechanics" standard electronics was developed and produced at BINP, and the power components were developed at LVEP. The sources are planned to be used for new projects, testing of one of the sources started at the end of 2009. A new contract on delivery of four 400A sources which also are based on BINP control electronics was signed.

2) As it has been noted in the previous report, in 2008 the crate and set of blocks were manufactured for TPV current source (7kA/1MW; TNK complex). In 2009 Low Voltage Equipment Plant produced the rectifier, and BINP specialists performed cabinets cabling. The further works on assembling of input/output buses and other components of the supply system, as well as the source testing are planned for 2010. Assembling and testing site is Zelenograd.

3) It is necessary to note, that in 2008 – 2009 an intensive development of the power supplies under the HITS contract (Heavy Ion Therapy System) was carried out: the converter with 10 Hz frequency and megawatt reactive power, and also the source with subsecond change of output current. The works were interrupted by cessation of the contract, however it was decided to design and manufacture the source prototype with 10 Hz frequency for testing the prototype of the Booster bending magnet. In 2009 the basic components of the source were manufactured, this will allow as the assembling and testing of the prototype in 2010.

4) The development of the "Switch Mode"-technology power supplies with 10 kW output power and their installation at the BINP facilties were in progress:

- Delivery to "Cryomagnet" company (Moscow) of four-quadrant current sources (300A/8V) for feeding of the superconducting solenoids is finished: two sources were delivered in 2008 and two – in 2009.
- Two four-quadrant sources of this type have been developed and delivered for feeding superconducting wiggler supplied by BINP under the contract to Kurchatov Institute(Moscow).
- A new version of a four-quadrant source has been developed for supplying superconducting solenoids of the VEPP-2000 accelerating complex, a prototype has been produced, the documentation for a batch production has been prepared.
- Modernization of 32 sources RF-300-12 at the VEPP-2000 complex was carried out during the summer period.
- Sources of a unipolar current with the maximum parameters of 300A/18V for supplying the FEL magnetic system components: in 2008 seven sources of this type were installed at the complex, the other five (from the series) were installed at FEL in the first half of 2009. Note that five sources from this series have been delivered to JINR (Dubna) and operate successfully at the IREN complex.

Each of the above-mentioned Switch Mode sources is equipped with two noncontact current sensors: one is to provide stabilization, another – for independent measurements. Each current source is also provided with built-in control DAC/ADC module. Long-term relative instability of the source output current does not exceed 5×10^{-5}.

5) Within the frame of the Switch Mode technology, we realized a rather interesting solution - the development of the alternating current source of the power over 10 kW with operating frequency of 400 Hz for feeding the ELV primary winding, operating in the "tandem" mode with the ELV output voltage over a million volts. The source is a combination of the power unit developed earlier for the Electron-beam welding power source and a specially developed

unit synchronous detector with the power of over 10 kW operating at the carrier frequency of 20 kHz. The prototype of the source, which provides the "tandem" with the required power, is produced.

6) Design, development and manufacturing in small batches of rather low-power current sources for feeding correction electromagnets and/or special devices was in progress. The results in this area are as follows:

- The set of current sources for feeding TNK MR multipole lenses is produced. The set consists of MPS-20-100 current sources (±20A, 100V) - 11 pieces, and also MPS-20-50 current sources (±20A, 50V) - 3 pieces. The listed current sources are prepared for delivery including two Eurorack 38U cabinets.
- The prototype of the electric drive of the direct-current motor is developed for the EW-1 EBW facility. The drive provides the control of the DC motor speed, the control of the drive is carried out through CANbus.
- The development of power supplies of correction electromagnets for COSY project (installation of electron cooling for Germany) is in progress. The sources of MPS-series (6A), the prototypes which have shown good results at the VEPP-2000 complex are planned for this purpose.
- The set of current sources for feeding TNK MR correctors is produced and adjusted. In total - about 200 channels (5A, 30V). The major part of them is delivered to Zelenograd to be put into operation after the installation of magnetic system and after cabling.
- One more rack (32 channels) for feeding the correctors (5A, 30B) is put into operation at the injection complex. Totally, it is already the complete set of three racks at the complex.
- The beam helical scan is put into operation at the BNCT installation - two channels of current control units (several kilowatts each). The scan processor provides a constant linear speed of the beam, this results in a good uniformity of radiation dose in the whole field of the target.
- About 20 channels of bipolar current sources of the UM-1, UM-3 and UM-10 types with 1-A, 3-A and 10-A output currents, respectively, are developed, manufactured and put into operation. The sources are installed at the FEL, BNCT and EBW complexes.

7.1.2 High Voltage DC stabilized sources

The laboratory successfully develops of DC stabilized high voltage sources in the power ranges:

- tens of watts — power supply of electrostatic devices for bending or focusing the charged particles;
- from several hundreds of watts to tens of kilowatts — to supply the powerful high-voltage devices.
- hundreds of kilowatts — to supply the injectors of neutral atoms and anode power supplies for RF and SHF amplifiers.

The devices are of a high stability and accuracy in adjustment; they are protected against short circuits and breakdowns, are equipped with a computer control of currents and voltages, and also with the distributed status control.

Electronics for diagnostic and heating injectors of neutral atoms

Development of the diagnostic and heating injectors of neutral atoms in previous years created in 2007-2009 a long-term workload for the participants of these works both in the sphere of designing and in manufacturing and delivery. The peak of work seems to be still ahead. In the results listed below the boundary line between the development of electronics and the development of the injector is vague.

In 2009 the following works concerning the sphere of injectors were successfully performed:

1. The set of electronics of the atomic injector (25 kV/52 A/20 ms) for plasma heating is developed, manufactured, adjusted and put into operation at MST installation (Madison, USA). The injector is equipped with two similar plasma generators (two arc-discharge-based plasma generators), therefore, two sets of electronics were produced to provide operation of the plasma generators based on arc-discharge. Special high-voltage supply on the basis of the distributed energy storage system consisting of 24 sections was developed and manufactured. The injector is equipped with a lock grid power supply (600V/10A), with the power supply sources for magnetic insulation solenoids and gas valves, with the set of electronics units (about 10 pcs) for control, measurement and protection.

The complete set of the "heating" injector electronics for MST includes the following power supplies:

- Arc discharge current sources with stabilized current of up to 600 A (2pcs.);
- Charging inverters of arc-supply accumulators and high-voltage power supply accumulators of up to 7 kW (2pcs.);
- Lock grid power supply with variable voltage of up to 600V, current of up to 10 A and a possibility of a fast protection and recovery of voltage after break downs.
- Power supply sources of the magnetic insulation solenoids with the current of up to 15 A (30 V voltage), 2 pcs.;
- Gas injection valve supply (control) boards, total - 5 pcs.;
- Fast protection, parameter measurement and interlock units.

2. The development of two systems of a high-voltage supply of the heating injectors for "Compass-D" tokamak (Prague, the Czech republic) is finished and the systems are being manufactured. The parameters of the power supplies are: 40kV/15A/500ms. High-voltage supplies consist of twelve series-connected RF rectifiers powered from twelve controlled 10-kHz inverters.

Infeed cabinets (dynamotor-powered) and 10kHz/60kW/500ms inverters were designed in 2009. These inverters and control, measurement and protection units are being manufactured. The prototype of the 10kHz/500V/4kV step-up transformer is designed and tested, manufacturing of 24 transformers has started. 4kV/15A rectifiers (without transformers) are produced. One rectifier channel (inverter+transformer+rectifier) is tested, nominal parameters for one channel are obtained.

3. Two sets of electronics equipment for heating injectors for TAE (the "TAE2" contract) are under production. Main parameters of the injectors are: 20 kV/60A/5ms. The arc current source provides the stabilized current of up to 1200 A (150-V voltage), high-voltage source is analogous to the source for Madison (20kV/60A/5ms). Twenty pieces of various modules of electronics for supply, control, measurements and protection are developed, manufactured and are being installed.

4. A modernization (total alteration) of the arc current source of the diagnostics injector in MST (Madison, the USA) was carried out in 2009. The stability was improved, the power - increased. The high-voltage power supply was upgraded – the output power was increased.

5. The manufacturing/adjustment of the seventh set of 40kV/40A/1s high-voltage supply similar to TAE-1 for usage at BINP at the stand in room 101, DOL is in progress. 48 racks are assembled, half of them are tested.

Energy Modules Electronics for EBW

In 2009, together with the staff of the NITI "Progress" (Izhevsk), an intensive work on adaptation of the electron beam welding (EBW) energy modules and devices at the factories of our country was carried out.

As a successful result of a long-term work of the BINP and NITI "Progress" on these subjects, five EBW devices with our energy modules operate in technological chains at the factories of Russia. One EBW device delivered to NITI in 2009 is being tested at their stand and one more energy module - at the BINP stand. The delivery of the energy module to NITI "Progress" is planned for the first half of 2010.

- Simultaneously, within the year under review, the design, development and manufacturing of the elements and units of the energy modules and their systems of power supply and control for EBW devices and for the related subjects was in progress. The most interesting (most significant) works performed in this area in 2009 are as follows:
- The development of the rectifier and 60kV/60kW converter for a high-voltage source has started. The assembled samples of the rectifier and the converter are tested at 25 kW output power. After purchase of 60kW low-voltage load the tests will be continued. The source converter is made in the Euromechanics cabinet as a module structure. It consists of the input filter, the rectifier and the chopper-based voltage-stabilizer assembled directly in the rack. The 20-kHz inverter with the control and indication unit, and also the unit for matching with the high-voltage transformer is assembled in plug-in crates. The high-voltage transformer is made as a subdivided transformer placed in a vessel with the organic-silicon isolating and cooling liquid of "SOFEKSIL-TSZh" type.
- This device became a prototype for creation of the AC source (20 kHz, 40kW) required to power a high-voltage column with 2-MV voltage in the COSY project (contract). It is necessary to note that in 2009 the development of another version of electronics of high-voltage section of the COSY electron cooling system started; and a very complicated set of the power, control and measurement electronics that is planned to be placed in the "Head" of the high-voltage column is also being developed . Works on COSY will be continued in 2010 and the next years.
- A new version of the control unit of the alternating current source (20 kHz) for Energy modules is designed. It comprises additional inputs for the rectified-voltage ripple monitoring (300 Hz), a more precise measurement of output current, and a higher stability of operation at the multiple and regular breakdowns.
- The set of synchronous rectifier electronics for the stand of magnet testing is under development. New electronics provides generation of the sinusoidal signal galvanically decoupled from mains with frequency from a few Hertz to hundreds of Hertz, amplitude of up to 150 V, power of up to 15 kW. Electronics set consists of the mains input unit and the inverter unit assembled on the basis of analogous units of a high-voltage source for EBW energy module and of the synchronous rectifier unit. Our alternating current source for supply of "Tandem" within the frames of the HITS project has served as a prototype for this device.
- The power supply for the heating of the cathode with a pulse current of emission of up to 2 кA is developed, tested and put into commission. The power consumed from the source is up to 2 kW in a continuous operation. The feature of the source is that the heating current rise in it should be carried out within several minutes (controlled parameter) at the continuous monitoring of functioning. The source control unit has 2 DAC channels, 5 ADC channels and 5-bit input/output registers. Communication is carried out through CAN and RS232.
- The design of high-voltage supply systems (the second modification) for a negative-ion source (the contract with IBA, Belgium) is finished: several controlled precise stabilizers with voltage of up to 40kV, power of up to 2 kW. At the end of 2009 our team successfully carried out acceptance tests of the negative-ion source for the IBA representatives. The delivery of one of the sources to Belgium is planned in 2010.
- At the end of 2009 the development of electronics for K-500 (electron-positron transport channels) was resumed, the components were purchased, the prototype of the pulse generator for magnetic elements of channels was successfully manufactured and tested. Generator storage capacitor is 100 μF, maximal voltage – 700 V with preliminary setting of the current pulse polarity. Operating frequency of pulse repetition is 1 Hz. Monitoring and control are carried out through CEAC124 control unit. Electronics is made in the "Euromechanics" standard. The order for manufacturing a small batch of pulse generators is directed to EW-2.
- Another version of the pulse generator with the same storage capacitor is developed for the LIA focusing system. Four generators are produced and installed at LIA; adaptation of the generators to the system and obtainment of the required accuracy of operation are being currently performed.

It is necessary to mention that in 2009 the technical support of the previously produced systems and their units operating at the installations of the Institute and outside was also provided.

7.2 Development of measuring systems and devices for automation of the physical experiments

Participation of the Laboratory in automation of the devices, stands and large physical complexes consists in:

- development and delivery of the systems for the control, monitoring, diagnostics, of the computer systems with a further participation of the developers in adaptation of the systems to the physical facilities;
- development of the elements for control, monitoring and timing of the power supply systems with their further integrated installation on charged particle accelerators and storage rings with a study of their influence on the complex as a whole;
- delivery of the individual unified modules (CAMAC, VME, Vishnya, Euromechanics) to the operational or new installations and stands;
- development of new approaches, techniques and, as a consequence, new devices enabling the solution of experimental problems at a new level;
- upgrade of the existing systems of automation, control and diagnostics at the operational physical facilities;
- repair and technical maintenance of several thousands of units of electronics and the systems developed at the Laboratory and being currently used.

The BINP developed and produced equipment is widely used not only in SB RAS Institutes, but also in many research organizations both in Russia and abroad. The nomenclature of the annually produced equipment is as wide as several tens of types of the digital, analog and digital-analog devices, units or modules.

- Next 150 units with CAN-BUS interface are produced, adjusted and put into operation in the control systems of various electrophysical facilities. For this year, the family was enlarged by two new modules: CEDIO_A – input/output multiport register and GZI-CAN – 4-channel delayed-pulse generator, delay range – 80ns – 10,28 μs.
- Note that the devices of this family are widely used in the contract works. For the past years, over a half of the produced modules (in total – 800 pcs.) in the sets with various power supply systems and as a part of control-measuring complexes have been delivered to JINR (Dubna), KISR (Moscow), TNK (Zelenograd), NITI “Progress”(Izhevsk), KAERI (R.Korea), IMP (China).
- BINP intensively uses a number of new systems for various magnetic measurements on the basis of a new-generation equipment, providing precise measurements of the fields both with the Hall-probe matrices and with the moving coils. The set comprises:
  - a precise ADC with the built-in analog multiplexer;
  - a 32-channel multiplexer with the commutation error of 1μV;
  - a precise (0.001%) current generator for the work with the Hall probes;
  - a precise integrator with the digital output.
- The prototype of the system for measuring the multipolar magnetic elements is developed. The system includes the precise and high-performance electronics providing “in-flight” measurements, the Hall probe, which measures two orthogonal components of the field in one space “point”

and the laser interferometer giving the possibility to read the coordinates from it synchronously with the field measurement. The system will provide not only a substantial reduction of the measurement time but also a considerable improvement of the measurement accuracy.

- Pilot samples of VSDC2 modules, designed for the measurement of pulse magnet fields in the channels of the BINP accelerator complexes are produced. The samples are successfully tested at the VEPP-2000 complex. The device should replace the outdated module BIIP-4.
- Pre-commissioning of the TNK control system (Zelenograd) proceeded. Installation and testing of the new equipment is performed, the unit of the clock-pulse generator (CPG) based on new components with CAN-interface is developed, the euro-crate for measurement of pulse parameters of the input/output devices with sets of new IVI and BIIP units is prepared. The crate is intended for replacement of the currently operating CAMAC-equipment within modernization of the TNK control system.
- Creation of the control system for the 4-track FEL is continued. The development of the beam phase meter on the FEL resonator track has started.
- Development of the control system for the induction accelerator (LIA) is continued.
- The stand control equipment for testing the LIA inductors and modulators is commissioned. Studying of the operation of the equipment under the influence of powerful pulse noises and high-voltage breakdowns is being carried out.
- For LIA control system the batch of 35 pieces of ADC-200ME PMC–boards – 12-bit digital recorders with a 5-nanosecond interval between readouts is produced. The boards are installed on the carrier into Compact PCI crate.
- PMC-boards of DL-200ME 16-channel timers and pulse formers for them intended for creation of the LIA timing system are developed and produced in the required quantities. The timers provide the time resolution of 5ns delay on the basis of 150 μs.
- The necessary software for tuning and testing of ADC-200ME and DL-200ME boards is prepared.
- In-house module completely meeting the Compact PCI standard is developed for replacement of expensive carriers of the PMC-boards required in large quantities in the LIA control system. Testing of the pilot sample of this module is being carried out.
- Work on implementing of modern intellectual control units in control systems of physical installations is continued. The next batch of control units and CAN-Ethernet gateways for various installations of the Institute is produced. See Table 1.
- The development of the digital registers with Fast Ethernet interface for detection of optical images was continued. The next batch of the units for observation of SR beams at VEPP-4M, VEPP-2000 was manufactured.
- Creation of control microprograms for the registration system based on ILX554 linear CCD for long-term modernization of the SR VEPP-3 X-ray beam stabilization system and also of microprograms for the camera with fast registration of one- and two-dimensional images for turn-by-turn beam diagnostics in storage rings is started.
- The system for observation of the welded joint position in the electron beam welding device at EW-1 is developed and tested in actual operating conditions. The gained results show that workshops can get one more useful and convenient tool.
- Electronics for operation with a magnesium target in the “Tandem” is produced and being successfully used. The device includes a multi-lamel current sensor that should reliably detect a current of several tens of nanoamperes and withstand against high-voltage breakdowns of up to 1 MV.
- The system for the time-of-flight analysis of the ion composition at the HITS tandem-injector output is developed and tested. The system includes the pulse former (1 kV, 20 nanoseconds) for the carbon ion source modulator and a set of fast low-noise amplifiers for registration of small modulated currents from Faraday cups. Several series of measurements of ion beam composition are performed.

Table 1: A family of devices with the CAN-BUS interface

Name	**Short characteristics**
CANDAC16	a 16-channel, 16-bit DAC, 8-bit input/output registers
CANADC40	a 40-channel, 24-bit ADC (of 0.03% class), 8-bit input/output registers
CDAC20 CEDAC20	a 20-bit DAC, a 5-channel, 24-bit ADC (of 0.003% class), 8-bit input/ output registers («Vishnya» and «Euromechanics» standard)
CEAC51	a 20-bit DAC, a 5-channel, 24-bit ADC (of 0.003% class) 8-bit input/ output registers, («Euromechanics», 3U standard)
CAC208 CEAC208	a 8-channel, 16-bit DAC, a 20-channel, 24-bit ADC (of 0.003% class), 8-bit input/output registers, («Vishnya»and «Euromechanics» standard)
CEAC124	a 4-channel, 16-bit DAC, A 12-channel, 24-bit ADC (of 0.003% class), 4-bit input/output registers, («Euromechanics» 3U standard)
CEAC121	a 1-channel, 16-bit DAC, a 12-channel, 24-bit ADC (of 0.003% class), 4-bit input/output registers («Euromechanics» 3U standard), designed for the control of fast sources
CEAD 20	20/40-channel, 24-bit ADC (of 0.003% class), 4-bit input/output registers («Euromechanics 3U»)
CGVI8	a 8-channel, 16-bit generator of delayed pulses, 8-bit input/output registers
CPKS8	a 8-channel, 16-bit code-duty factor converter
SLIO24	CANbus interface - a 24-bit two-directional bus, built-in board
CKVCH	Commutator of RF-signals 8-1, 2*(4-1), 4*(2-1)
CANIPP	CANbus interface - 2 branches of BPM-type
CANIVA	a 16-channel vacuummeter (current of the ion pump)
CURVV	a multi-purpose register of input/output (2 output and 4 input 8-bit registers)
CIR8	a register of discrete signals (interruption register, BSI, input/output) registers)
CAC168	a 8-channel, 16-bit DAC, a 16-channel, 24-bit ADC (of 0.03% class), input/output registers, built-in board.
CAN-DDS	a CAN-DDS module is a divider of the input clock frequency with the remotely tunable fractional coefficient.
CAN-ADC 3212	For connection of the feedback circuit into the thermal adjustment scheme of RF cavities.
CANGW	Ethernet port -CAN/RS485
VME-CAN	Interface VME-CAN
CEDIO_A	Multiport input/output register
GZI-CAN	4-channel generator of delayed pulses, 80 ns – 10.28 μs

- For replacement of the outdated equipment for the power supply systems of the main magnetic components of VEPP-4, the development of a precise (0.002%) interpolation DAC with MIL-STD-1553B interface with the use of modern components was continued. The module will be compatible with the previous version. Five of the first samples are successfully tested at the operational installation. All outdated modules are planned to be replaced by new modules to increase an operational reliability of power supply systems.
- The required quantity of the port-multiplexers for data acquisition at the CMD-3 de-

tector is produced. The built-in software is being tested and corrected in actual operating conditions.

- 8 sets of the control electronics for the neutral beam injectors (the diagnostic and heating versions of injectors) are produced and delivered to the customers. The systems are based on the commercially available components. The software is unified for both versions of the injector and provides the integration into the common control system.
- The wide-band amplifiers for the photoreceivers on the base of avalnche photodiodes for realization of modern beam diagnostics at the VEPP-4 storage ring are produced.
- The development of a new generation of power supply sources, control board and grid-pulser of the injector electron gun of the free electron laser is continued.
- Electron gun and channel control system is developed and manufactured under the contract of modernization of the IMP ion cooling system (China). The system comprises about 20 electronics modules including fast high-voltage generators (3 kV) with controlled amplitude.
- The next batch of modules designed for measurements and control of the gas flows is produced and adjusted for the work with the KEDR detector gas systems. The modules are provided with the test programs.
- The time interval meter in the nanosecond range with the CAN-BUS interface is produced and delivered for testing at the installation.
- Electronics and beam position monitors based on measurement of image currents (next version) are developed for usage at K-500 channel and are being manufactured. The earlier-produced equipment and monitors are installed at the BEP-VEPP beam transport channel of the VEPP-2000 complex and are successfully used for beam transportation.
- The development of the feedback system designed for damping the beam transverse motion instabilities at the VEPP-4M storage ring was continued. In the frame of this work, a series of experiments with a beam in a single-bunch mode was performed with good results: the system allowed increasing of the number of particles in one bunch by two-three times depending on the operation mode. The obtained information served as a basis for development of a new version of the digital part of the equipment and software. The work with the system at VEPP-4 with a beam started at the end of 2009.
- The wide-band monitor of beam position and current is produced and installed at LIA.
- In 2008-2009 at FEL, an adjustment on the beam diagnostic systems for the 3^{d} and 4th tracks and adjustment of the whole complex on the base of beam orbit measurements were carried out.
- In 2009 the systems of betatron frequencies measurement at Siberia-1 and Siberia-2 storage rings were put into operation by a method of a sinusoidal excitation. The systems are developed, manufactured and delivered under the contract with Kurchatov Institute (Moscow) in 2008. About 20 units of newly-developed high-frequency precise electronics modules are is used in the systems.

The system of a beam equilibrium orbit measurement is developed for the TNK storage ring (Zelenograd). A pilot sample of this electronics is produced and tested at VEPP-4. Production of the units for the whole system has started.

The prototype of the electronics for beam position measurement at VEPP-4 is developed and manufactured. The system is planned to be capable of independent measurement of electron and positron orbits.

New version of the NMR magnetometer is developed. New 4-channel NMR magnetometer is delivered under the contract University of Florida (USA). Depending on a set of electronics and of a version of probes, the magnetometer covers the field range from 0.02 T to 11 T. The relative error of measurements does not exceed 10^{-5} or even 10^{-6} depending on the field level and its homogeneity.

The series of measurements of fields in bending magnets at FEL was performed with the NMR magnetometer. The measurements showed the efficiency of an additional magnetic core of bending magnet.

The development of the new matching and fast-protection unit for the modulator of 5045 klystron (Injection complex) is started in order to replace the units developed about 15 years ago. The unit prototype is almost ready for adjustment and testing.

The development of the commutator for feeding the vacuum ion-getter pumps is started. The prototype of its control electronics for nominal current of 50 A at voltage of about 30 V is being assembled.

Within the frame of contract works with Montana state (the USA), we started the development and production of the system comprising 12 ultrasonic and 12 capacitive hydrostatic sensors (upgraded as compared to the previous version). The system is provided with its own software. Contract termination date is the 1st half of 2010.

Under the contract with KEK (Japan), the delivery of 10 capacitive hydrostatic sensors is being prepared. Contract termination date is the 1st half of 2010.

Cooperation on a technical support of the hydrostatic system of magnetic-elements position monitoring at the Tevatron collider (FermiLab, the USA) is in progress. The system was created by BINP employees and has been operating at FermiLab for over 10 years. The delivery of the upgraded electronics for the purpose of radiation resistance improvement of the sensors is planned for 2010.

The development of semi-conductor RF generator for an ion source of the diagnostic injector of W7-X stellarator (Germany) is continued.

We continued improvement of the Laboratory site:http: www.inp.nsk.su/div16-1/weblab6/start.html. The site should facilitate the correct use of the Lab.6 developments. To this end, in addition to the descriptions of various modules, some application notes appeared. The site is renewed regularly.

7.3 Studies related to simulation and solving the electrostatic and electrodynamic problems of accelerator physics

The most important works performed in 2009 are as follows:

1. Works on further improvement of programs for calculations of the electrostatic and magnetostatic fields, the electron and ion guns including:

A new set of MAGEL3D programs designed for the three-dimensional calculations of the systems of magnets (taking into account the effect of core saturation) and of electrodes and also for trajectory analysis of charged particles in electric and magnetic fields is created.

The development of BEAM3D program, which enables the design of three-dimensional channels for transportation of the charged particle beams formed by the components preliminary calculated with the MAG3D program taking into account the thermal spread of transverse velocities of the beam particles is finished.

A set of UltraSam_RF programs for calculations of RF systems taking into account spatial charge of a beam in a quasi-static approximation was essentially improved.

2. We performed the numerical calculations, simulation and design of the electron guns, electron and ion beams and magnetic systems including:

Within the contract with the TAE laboratory (the USA) by means of SAM, MAGEL3D and BEAM3D programs, the new system of generation, acceleration and transportation of 10A quasi-stationary ion beam of 10MW power, taking into account the transverse temperature and a beam space charge was developed. The system includes a considerable quantity of magnets and electrode-optical elements of a complicated structure.

By means of SAM program, a small-size electrostatic tube for acceleration and formation of high-energy ion beam of a low power is developed.

The comparative analysis and an explanation of experimental results on transportation of hydrogen ions in tandem accelerator of the BNCT installation were carried out by means of BEAM3D program.

Calculations of a collector of the electron-cooling installation for the COSY storage ring were carried out by means of UltraSAM program.

Simulation of the emission and dynamics of electron beam in FEL gun was performed with UltraSAM_RF program.

7.4 Upgraded RF system of the "Siberia-2" storage ring – SR source

The upgrade project for RF system of the Sibeia-2 storage ring is completed. The purpose of the upgrading was as follows:

1) improvement of operating reliability by replacement of two old double-chamber cavities by three new bimetal cavities, which are analogous to the cavities installed at the microtron-recuperator of Novosibirsk FEL.

2) increasing of total accelerating voltage from 1,2 MV up to 1,5 MV to provide the operation of the Siberia-2 storage ring with superconducting wiggler. The possibility to increase the voltage up to 1,8 MV.

In 2007 one old cavity was replaced by a section of two bimetal cavities. In September 2009 one more bimetal cavity was installed instead of the second old cavity. This single cavity was installed into the storage ring in such a way that the distance between its center and the center of the first cavity of the section is equal to the operative wavelength λ = 1655 mm (Fig.1). These two cavities are powered from a 200 kW generator. The second cavity of the section is powered from another 200 kW generator.

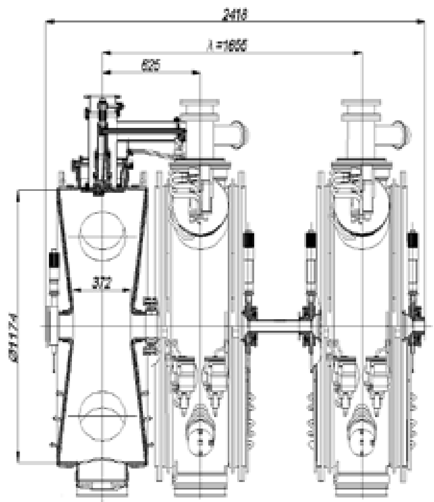


Fig. 1: Location of three cavities in the storage ring.

The updated parameters of the storage ring and the parameters of the upgraded RF system are represented in Table 1.

Table 1: Siberia-2 storage ring parameters and the parameters of the upgraded RF system.

Parameters of Siberia-2 storage ring	Electron energy	E max	GeV	2.5
	Total losses per turn	AEм + AW	keV	1021
	Beam current	Ibeam max	A	0.29
	Total accelerating voltage	2U1+U2	kV	1500
First RF channel: 200 kW generator and two cavities	Accelerating voltage	2U1	кB	820
	Effective shunt impedance	2Reff.	MOhm	8.6
	Thermal losses in two cavities	2Pcav.1	kW	39
	Power introduced to the beam	2P1beam	kW	157
2nd RF channel: a 200 kW generator и and one cavity	Accelerating voltage	U2	kV	680
	Effective shunt resistance	Reff.	MOhm	4.3
	Thermal losses in a cavity	Pcav.2	kW	54
	Power transferred into the beam	P2beam	kW	139

At lower currents of a beam the total accelerating voltage can be increased, this will give the possibility of future installation of additional devices - SR sources - into the store ring.

The design of the cavity is presented in the Scientific report of the Institute for 2008. The main parameters of the cavities are given in Table 2.

Table 2: Parameters of the cavity

Operation frequency	f	181.139 MHz
Frequency tuning range	Δ f	±150 kHz
Accelerating voltage	U·T	0.1÷0.9 MV
Transit time factor	T	0.9
Quality factor of the cavity		40000
Shunt impedance, *Re		4.3 MOhm
Power losses in cavities, P at U·T =0.9MV		94 kW

*Re=$(U \cdot T)^2/2P$

The RF system has two channels. Each channel is provided with the RF generator with the output stage based on two GU-101A tetrodes and with 200kW output power. The design of the generator is described in detail in [V.S.Arbuzov, et al. “Megawatt RF systems for the accelerators developed at BINP SB RAS, Novosibirsk”, Proceedings of RuPAC-2002, vol.1, p. 63, Obninsk, 2004]. The generators are placed at a considerable distance from the accelerating cavities. RF power is transferred to the storage ring area through rectangular waveguides (width 986 mm, height 150 mm). The cavities are connected with the waveguide by the waveguide-to-coaxial transitions with a wave resistance of 75 Ohm.

The new scheme of installation of the cavities required designing of another system of coaxial feeders providing RF power distribution between the cavities and optimal summation of accelerating voltage.

The structural layout of a coaxial section with waveguide-coaxial transition is shown in Fig. 2.

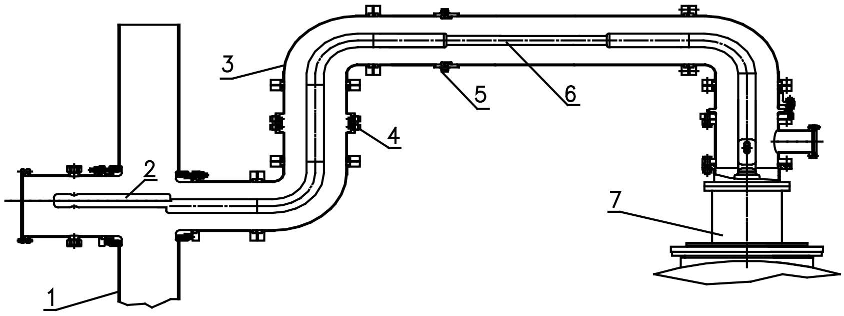


Fig. 2: Scheme of RF feeder from the waveguide to one of the cavities: 1 – waveguide, 2 - waveguide-coaxial transition, 3 - coaxial feeder with wave resistance of 75 Ohm, 4 – directional coupler, 5 – measurement loop, 6 – matching transformer with wave resistance of 100 Ohm, 7 – accelerating cavity.

In the first channel, waveguide-coaxial transition simultaneously serves as the power divider between two cavities and provides matching of RF transition section at 100kW power in each cavity. In the second channel, the parameters of waveguide-coaxial transition are chosen to provide the matching of RF transition section at the maximum power of 200 kW supplied to the single cavity.

Power division is carried out by connection of two coaxial lines into one waveguide cross-section symmetrically relative to the middle of its wide wall. The equivalent scheme of double waveguide-coaxial transition can be presented in the form of a six-pole. Cross-sections of arrangement of the poles in coaxial lines and in the waveguide can be chosen in such places that the equivalent scheme at operating frequency would match the scheme represented in Fig. 3.

Calculated cross-sections of coaxial line connection are displaced inside the waveguide by 45 mm - poles 2 and 3. Pole 1 – connection to the waveguide - is located at cross-section of position of the axes of coaxial lines. Impedances are normalized for a wave resistance in each equivalent line. Then the transformation ratio from the decoupling of the lines, equivalent to the coaxial ones, to the waveguide is equal to $\sqrt{2}$.

Excitation currents of the cavities are measured at the cross-sections of coaxial lines corresponding to the voltage nodes at total detuning of the cavities. The distance from poles 2 and 3 to the cross-sections in the lines, where this voltage node is located, is chosen multiple of the odd number of the wavelength quarters in the feeder. Thus, the cavity excitation currents are equal, are determined only by the voltage at pole 1 and do not depend on the values Z2 and Z3. In this case, the cavity voltage is proportional only to its input resistance. If the equivalent length of the line between the anode of the generator output tube and poles 1 is set multiple of the half of the wave length, then the voltage value at poles 1 is always limited by the maximal amplitude at the anode.

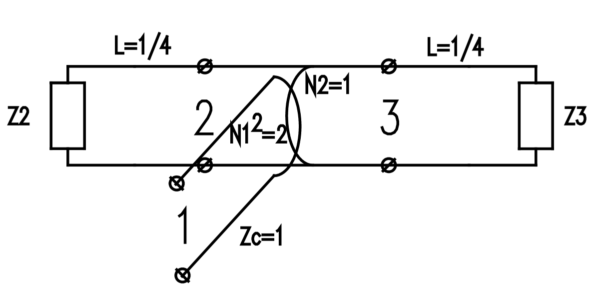


Fig. 3: The equivalent scheme of waveguide-coaxial transition: 1 – waveguide terminals, 2 and 3 – coaxial line terminals, Zc – normalized wave resistance, Z2 and Z3 – input resistance of the cavities.

New electronic RF-system control units are produced and put into operation. The control system controls the amplitude and phase of accelerating voltages of the cavities, performs their automatic tuning, and also generates signals for synchronization of injection of electron bunches from the injector.

The feature of RF system operation is a relatively high loading of the cavity by a beam. Thus, the instability of bunch phase motion can occur and their acceleration will be impossible. This is the result of the situation when, at a casual shift of bunch phase sidewards, the current induced in the cavity by the flying-through charged particles changes amplitude and phase of the total voltage of the cavities providing the shift of the bunch equilibrium phase in the same direction. Magnitude of this deviation can be larger than the initial deviation of a bunch, thus, creating static instability.

The calculations showed that at a correct choice of the parameters of a feedback circuit that stabilizes the accelerating voltage amplitude, it is possible to suppress this instability in operational range of the beam currents. The results of the calculations are shown in Fig. 4.

Simulation of an electron bunch motion in the Siberia-2 storage ring was performed during the calculations. The initial deviation of a bunch for both diagrams is set equal to 3 degrees. Transition process consists of damping synchrotron oscillations and, in the absence of a feedback (schedule 1), the bunch motion is then unstable. Introduction of a feedback (schedule 2) suppresses the instability. A bunch current in the first case is 0,24 A, in the second – 0,3 A.

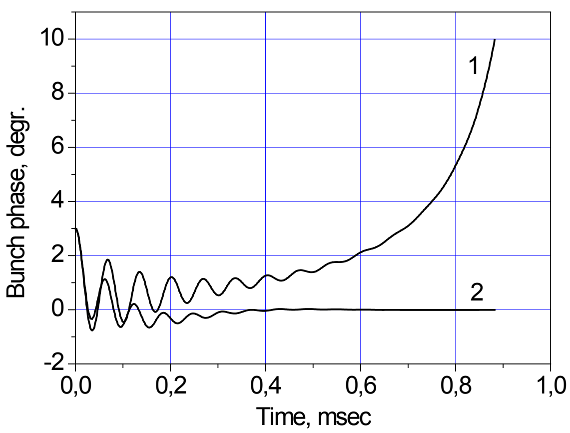


Fig. 4: Phase motion of a bunch: 1 – without feedback, 2 - with feedback.

At present, the Siberia-2 storage ring operates in a design mode and a maximal current of 120 мA at a 2,5 GeV energy was obtained in December, 2009. A further increase of current in the storage ring was restricted by decrease of a beam life-time because of an intense gassing of vacuum chamber walls.

Three bimetal cavities in the Siberia-2 storage ring are shown in Fig. 5.

Fig. 5: Three bimetal cavities in the Siberia-2 storage ring.

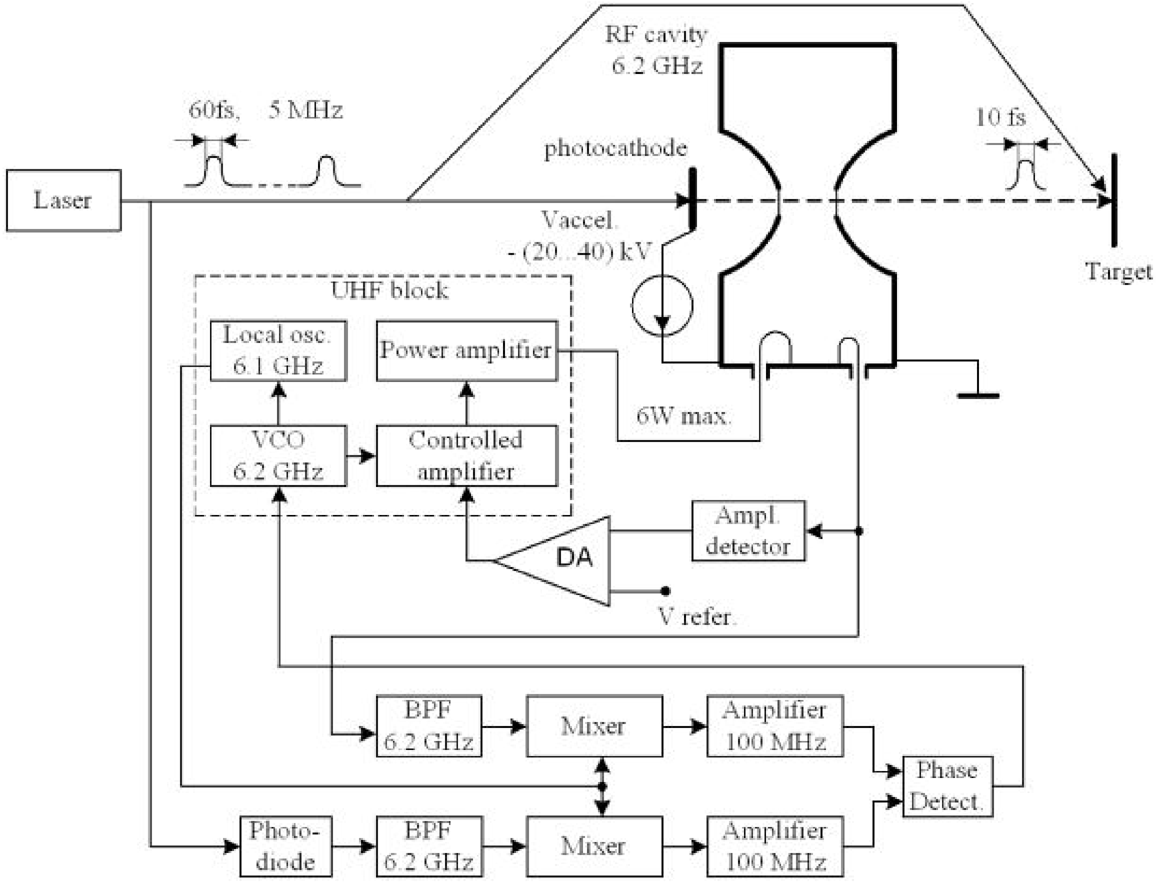
7.5 Electron source for the electron diffraction experiments

Superfast electron diffraction is a powerful method of diagnostics in structural kinetics of substance and superfast chemistry [Dwyer J. R., Hebeisen C. T., Ernstorfer R., Harb M., V. B., Jordan R. E. and Dwayne Miller R. J., Phil. Trans. R. Soc. A. 364 (2006) 741-778]. In the experiment, the investigated substance of the target is excited by a laser pulse of duration of about ten femtoseconds and then a short electron bunch is directed on a target. Electrons, while passing through substance, create a diffraction image which is registered. The time resolution of the given method is determined by the duration of electron bunches and the stability of delay of these pulses relative to the laser pulses.

BINP jointly with the Max Plank Institut fur Quantenoptik,(Garching, Germany) carries out the work on the development of the installation for such experiments [L.Veisz, G.Kurkin, K.Chernov, A.Apollonsky, F.Krausz, E.Fill. Hybrid dc-ac electron gun for fs-electron pulse generation. New Journal of Physics 9(2007)p 451.]. The design time resolution of the installation is 10 fs.

The source of electron bunches has the photocathode (Fig.1). Electrons emitted from the photocathode by a laser pulse, are, at the beginning, accelerated by constant voltage 20 – 40 kV. Laser pulse duration is 60 fs, however, because of initial spread of electron velocities, the duration of electron bunches after acceleration increases up to 700 fs. Then electron pulses are passed through the grouping cavity, which is operating at the frequency multiple of the frequency of the laser pulse-repetition. RF voltage frequency of the cavity is 6.2 GHz and the amplitude on its accelerating gap is chosen to provide the maximal grouping of bunch at the distance of 100-200 mm from the grouping cavity.

For achievement of a 10-fs time resolution, the requirement to oscillation phase stability is about $4 \cdot 10^{-4}$ rad. According to the calculations, the maximal voltage amplitude on the cavity should be 3 kV. For obtainment of such voltage, a SHF power source with an output power of about 4-6 W is necessary. The requirement to oscillation amplitude stability in the cavity is about ± 0.25 %.



Block-diagram of the installation.

The set of electronics of the installation provides the required level of excitation of the grouping cavity, a synchronization of RF voltage phase of the cavity with laser pulses. The set includes a SHF unit consisting of 6.2 GHz GUN master generator with a voltage-controlled frequency, controllable semi-conductor amplifier of 6.2-GHz signal of and the output amplifier with the maximal output power of 6W.

For stabilization of voltage amplitude a feedback circuit is provided at the cavity gap. The signal from a measuring loop of the cavity comes to the amplitude detector. The detector output voltage is compared to the constant reference voltage by means of operational amplifier (OA). OA output controls the gain of the controllable amplifier of SHF unit.

The GUN phase detector FD of the circuit of frequency phase control operates at a 100 MHz frequency. This frequency is obtained from 6.2 GHz input signals by means of mixers. The heterodyne signal frequency, generated in SHF unit, is shifted downwards relative to GUN frequency by 100 MHz and is supported by PAFC internal circuit in SHF unit.

SHF unit is a low-noise source of SHF signals with the output frequencies of 6.2 GHz and 6,1 GHz was developed and produced at Krasnoyarsk Scientific Center SB RAS (Krasnoyarsk). The rest of the equipment was produced at BINP.

At present a set of the equipment for generation of electron bunches of a femtosecond duration is produced, its preliminary adjustment is performed. The equipment is delivered to Max Plank Institute (Garching, Germany). Currently the work on obtaining electron bunches with the design parameters are being carried out at Max Plank Institute.

The set includes the following main equipment: a controllable source of a high voltage (Fig. 1), the grouping cavity (Fig. 2), the phase detector (Fig. 3), SHF unit – controllable source of SHF power (Fig. 4), the control unit (Fig. 5).

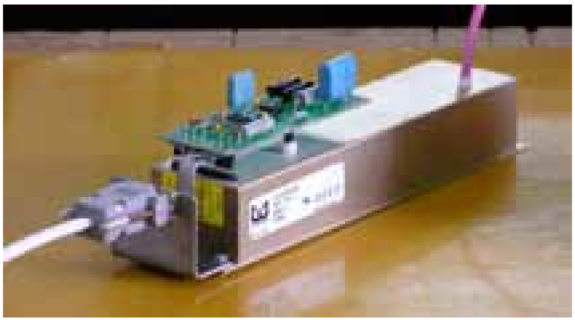


Fig. 1: Photocathode.

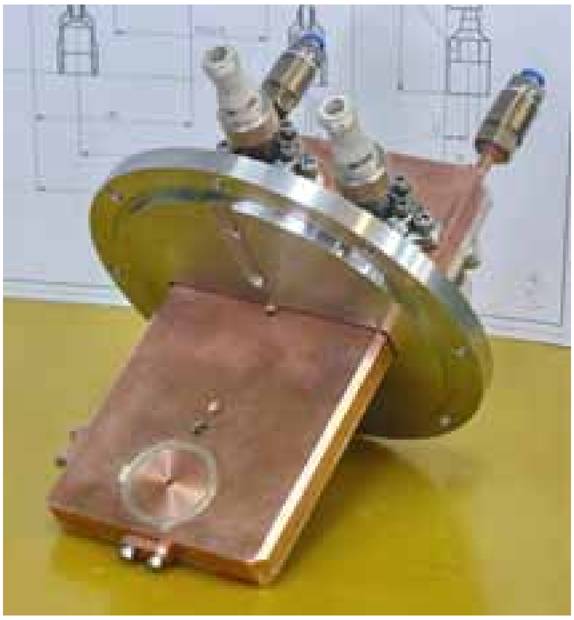


Fig. 2: Grouping cavity.

Fig. 3: Phase detector.

Fig. 4: SHF unit.

Fig. 5: Control unit.

7.6 RF system of a 2.2 GeV storage ring — SR source in Zelenograd

Under the contract with NIIFP, Moscow, Lab.6-2 developed a project of RF system for a new storage ring - SR source at Zelenograd.

The storage ring RF system operates at frequency of 181,33 MHz and consists of two separate bimetal cavities installed at the accelerator at a distance of a half wavelength between their centers, one 300kW power supply generator, power transfer line and the control system. The description of certain components of the RF system is given in the Scientific Report of the Institute for 2008.

In 2009 at the experimental workshop, manufacturing of two cavities and the elements of the section in which they will be installed was finished. The parameters of main and high modes of the cavity in the range of up to 1100 MHz are measured.

During the stand testing one cavity was heated twice at temperatures 260 ºC and 230 ºC and $2\cdot10^{-10}$ torr vacuum was obtained. In the second cavity, after two heatings at temperatures 335 ºC and 245 ºC, the vacuum better than $8\cdot10^{-8}$ torr could not be obtained. In one of connecting pipes of the drum of this cavity between the external stainless steel and the internal copper, a volume was detected, from which gas flowed into the main volume. After pumping out of this volume by means of the separate welded pump of KMN type, $8\cdot10^{-11}$ torr vacuum was obtained in the cavity

Each cavity was connected to the FEL injector generator. Training by RF field was carried out and the accelerating gap voltage increased up to 750 kV. At operating in the storage ring, maximal voltage at the accelerating gap of each cavity is 600 kV.

The sections of the transfer rectangular waveguide and coaxial feeders connecting the waveguide to the cavities are produced. All components of the RF generator are manufactured and assembled. Two TH 781 tubes of THALES (France) production are received and will be installed in the output stage of the generator. 90% of electronic units of the control system are produced and tuned.

At present both cavities and all coaxial feeders are prepared for delivery to Zelenograd. Installment of the cavities into the storage ring, at-site assembling of the generator and power transfer line as well as adjustment and commissioning of the whole RF system is planned in 2010.

Participants of work:
V.S.Arbuzov, E.I.Gorniker, E.K.Kenzhebulatov, A.A.Kondakov, N.L.Kondakova, S.A.Krutikhin, G.Ya.Kurkin, I.V.Kuptsov, L.A. Mironenko, V.N.Osipov, V.M.Petrov, A.M.Pilan, I.K.Sedlyarov, A.G.Tribendis, V.A.Ushakov
Design department: O.I.Deichuli, N.A.Kiselyova, V.G.Cheskidov.

7.7 RF system of neutral beam injectors of the COMPASS tokamak

In 2009 BINP and Institute of Plasma Physics (IPP), the Czech Academy of Sciences signed the contract on development and manufacturing of two powerful injectors of neutral beams for plasma heating in COMPASS tokamak. One of the basic systems of the injector is RF system.

Main parameters of the system:

Operating frequency	MHz	4 ± 5%
Load power	kW	30
Pulse/pause duration	sec	0,3 / 900
Anode supply voltage	kV	10
DC voltage on “antenna”	kV	40

RF system consists of a control rack, powerful output stage on 4CW50000E tetrode manufactured by Eimac, anode rectifier, output decoupling transformer and «antenna». The system is placed in cabinets of “ Euromechanics» standard .

The following devices are placed in the control rack: the power supply of a tetrode screen grid; the power supply of a control grid; the modulator providing automatic frequency control and stabilization of RF voltage amplitude on the load; systems of interlocks, protection and control of the generator.

The output stage is mounted in the cabinet (800×800×2000) as a shielded RF section divided by a horizontal partition. Filament transformer and input circuit elements are located in the bottom part of the section, the tube and anode circuit elements are installed in the upper part. The stage is based on 4CW50000E tetrode according to the scheme with the common cathode. Water cooling is used for tube anode and air cooling – for contact rings. The ventilating fan and the components of water cooling system are located in the bottom part of the cabinet, under the RF section.

The anode power supply is mounted in the cabinet 800×800×2000. Two cells analogous to the cells of a 40 kV accelerating voltage source are used in this source. Output decoupling transformer provides transfer of RF power to the "antenna", which is under a 40 kV potential. Five rings made of 5BM amorphous iron (240x140x15) are used as a core. The transformer is placed in a tank with oil. The transformer secondary winding has a middle point, this allows a symmetric connection of the antenna.

At present the whole system is designed and is under production. The major part of electron units is produced.

Participants of work:
A.A.Kondakov, N.L.Kondakova, S.A.Krutikhin, S.V.Motygin, V.N.Osipov.

7.8 High-frequency gun for a microtron-recuperator

In 2009 manufacturing of 90 MHz RF gun for a microtron-recuperator started. In future, the gun will be installed instead of the currently-operating electrostatic gun. The new gun will allow the increase of an average current in the microtron-recuperator up to 100 мA in a high-quality electronic bunch.

At the BINP experimental workshop, 5 orders are executed, two of which are already finished. The cathode assembly and the modulator case are manufactured, other orders (power input and upgrade of the bimetal accelerating cavity) should be finished in the first quarter of 2010.

RF strength of electric field on the internal surfaces of the cavity forming its accelerating gap is twice larger than in all other cavities operating at BINP. Diamond turning and electron beam welding in vacuum will be used at machining of these surfaces to provide a stable work of the cavity at such field strength in a continuous operation. The equipment for electron beam welding of a copper part and the wall of the cavity of a 1200 mm diameter and weight of 200 kg is being developed.

7.9 Power-amplification stages of modular type based on TH781 tetrode

For excitation of RF cavities of some accelerators, both at BINP and at other research centers, generators of continuous power at frequency of 181 MHz are developed and produced. The required output power of the generators is from 150 kW to 600 kW and is attained by addition of the powers generated by different quantity (from 1 to 4) of the tube modules in the output stage. The aufbau principle of such multi-tube output stages of generators is represented in the previous annual reports. At present, powerful GU101A tetrodes of VHF range are applied in these generators. The total number of the installed modules with these tubes is 22. The long term operation of the generator has shown that at the power, generated by one tube, less than 120 kW, the tube service life is more than 4000 hours. At the increase of RF power from one tube up to 120 – 150 kW, the service life decreases down to 1000 hours and in some cases to a smaller magnitude.

During development GU101A tubes, in order to increase the service life of the tubes in generators, they were supposed to be later replaced by the tubes with GU105A pyrolitic-graphite grids, service life of which is several times longer. However, as the production of these pyrolitic-graphite grids have been stopped, BINP decided to develop and manufacture RF generators on tubes with TH781 pyrolitic-graphite grids produced by THALES (France). The warranty period of these tubes is 3500 hours. The producer of the tubes supposes that at frequency of 180 MHz, at an output power of up to 150 kW, the tubes work not less than 7000 hours.

To minimize expenses for manufacturing and installation in RF systems of the accelerators, new generators are produced on the basis of cases of GU101A generators with keeping former principles of addition of powers, modules of tuning and connection with load. Besides, the fact that purchasing of all tubes takes a considerable period of time was taken into account. Therefore, the developed design of the tube module for TH781 allows installation of the modules with GU101A tubes and TH781 tubes into one stage simultaneously. The main parameters of TH781 tube an, for comparison, of GU101A tube are represented in Table 1.

Table 1.

Parameters	TH781	GU101A	unit
Anode dissipation power	250	250	kW
Screen grid dissipation power	4	3	kW
Control grid dissipation power	1.5	1.5	kW
Anode voltage	22	14	kV
Anode voltage at operation at 180-200 MHz frequency	10	8	kV
Screen grid voltage	1800	1200	V
Control grid voltage	- 800	- 600	V
Anode pulse current	140	100	A
Heating voltage	10	15	V
Heating current	340	660	A
Transconductance	0.12	0.2	A/V
Anode-grid2 capacitance	54	108	pF
Cathode-grid1 capacitance	230	350	pF
Grid1-grid2 capacitance	270	400	pF
Anode-cathode capacitance	0.32	1.1	pF
Anode-grid1 capacitance	2.2	12	pF
Cathode-grid2 capacitance	14	28	pF
Max. diameter	168	295	mm
Max. length	425	525	mm

As seen from the table, the diameter and inter-electrode capacitances of TH781 tubes are twice smaller. TH781 heating/filament power is three times less, and a transfer capacitance - 2–4 times. A draft of TH781 location in the generator module is given in Fig.1. Sizes of the structure of module anode circuit with TH781 are chosen to provide the same transformation ratio value between the anode line connecting the modules and the tetrode anode as it is at modules with GU101A. Within the range of about 10 % this ratio can be controlled by changing the diameter of the disk of anode circuit adjustment .

Test of the single-module stage has been successfully carried out. The operating mode of the stage loaded by a 50 Ohm load equivalent is represented in Table 2.

Table 2.

Parameters	**Value**	**Unit**
Operating frequency	180,4	MHz
RF power in load equivalent	150	kW
Heating voltage	8.5	V
Heating current	315	A
Anode voltage	7.9	kV
Screen grid voltage	900	V
Control grid voltage	- 230	V
Anode current	29	A
Screen grid current	1.9	A
Control grid current	1.5	A
RF power at stage input	~12	kW
Stage efficiency factor	67	%

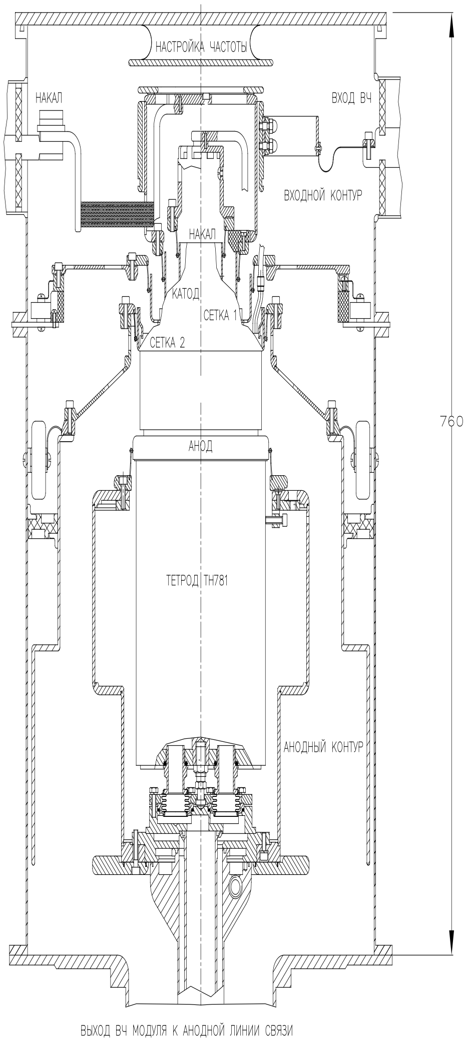


Fig. 1: TH781 tetrode location in the case of the tube module of generator.

Besides, test of the stage loaded by accelerating cavity in the RF system of FEL injector was performed. It is revealed that due to a small value of a tube transfer capacitance, the generator is not self-excited at azimuthal resonances of an anode circuit and does not demand connection of the resistors damping these resonances.

The four-tube stage has been assembled out of one tube module with TH781 and three modules with GU101A. Stage test was carried out including RF system of FEL. 8 accelerating cavities of a microtron-recuperator served as a stage load. The stage operating mode at a 6000 kV total voltage on 8 cavities (power in cavities - 420 kW) is represented in Table 3. In this mode the calculation of the power dissipated on the tube anodes was performed using the measured value of the temperature difference of water at the exit and an entry of the tanks of cooling the tube anodes.

Taking into account power losses in RF transfer line of about 1%, i.e. of about 4 kW, the power in the cavities estimated by the generator criteria is 389 kW - this is rather close to the value of 420 kW estimated according to calibration of the cavities.

AS seen from the Table, the difference of values of the powers generated by the module with TH781 and the module with GU101A does not exceed 10 %. This value can be reduced by means of a more careful tuning of the stage. However, this work is not carried out as a further replacement of the tubes and a final adjustment are supposed to be executed after the installation of 4 tubes.

Table 3.

Parameters	1-GU101A	2-GU101A	3-GU101A	4-TH781	Unit
Operating frequency	180,4				MHz
RF power in cavities (according to calibrations of cavities)	420				kV
Heating voltage	12	12	12	8.5	V
Heating current	580	580	580	315	V
Anode voltage	9				kV
Screen grid voltage	960				V
Control grid voltage	- 200	- 200	- 200	- 180	V
Anode current	25.5	24.7	25	20.7	A
Screen grid current	0.12	0.12	0.3	0.35	A
Control grid current	0.3	0.26	0.1	0.56	A
Tube power consumption from all power supplies	236	230	232	189	kW
Power dissipated on anode	149	137	136	104	kW
Tube-generated RF power	87	93	96	85	kW
RF power at the module input	~8	~8	~8	~8	kW
RF power at the module output	95	101	104	93	kW
Total power at generator output	393				kW

A power level was raised up to the value of 566 kW (according to the cavity calibrations), matching a 7000 kV voltage at the cavities, in order to check the possibilities of the generator. The obtained operating mode is represented in Table 4.

Table 4.

Parameters	1-GU101A	2-GU101A	3-GU101A	4-TH781	Unit
RF power in cavities (according to calibrations of cavities	566				kW
Anode current	32.4	31.2	31.1	27.9	A
Screen grid current	0.4	0.2	0.4	0.7	A
Control grid current	0.5	0.5	0.4	0.9	A
Tube power consumption from all power supplies	298	288	287	254	kW
Power dissipated on anode	-	-	-	124	kW
RF power at the module output	~145	~145	~145	130	kW

At present, the generator with one TH781 tube constantly operates at the FEL installation with power of about 530 kW (6800 kV on 8 cavities).

Participants of work:
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Design department: V.G.Cheskidov .

7.10 A 200 kW RF generator for linear accelerator

In Summer 2008 Budker Institute of Nuclear Physics and the Federal State Enterprise "Russian Federal Nuclear Physics Center" All-Russian Research Institute of Experimental Physics signed the contract on the development of a 180 kW RF generator of continuous power at a frequency of 100 MHz. RF generator will be used for excitation of the linear electron accelerator being created by the customer.

According to the contract terms, BINP should design and manufacture the RF generator, its power supply system and units of radioelectronics for RF power control. The generator has two RF stages based on tetrodes GU-92A and GU-101A, a 500 W transistor preamplifier, inter-stage coaxial feeder, the water and air cooling collectors of the generator. The power supply system consists of the 14 kV high voltage source of the anode power supply withthe fast protection circuit, low-voltage power supply sources, circuit of control and protection of the generator. The power consumption of the generator power supply sources from the three-phase mains of alternate current 380 V/50 Hz is 420 kW.

It was decided to produce two sets of the equipment. The stand for testing the first RF generator at 50 Ohm load is assembled and delivered to the customer. The second analogous generator whose frequency will be tuned down to 90 MHz for carrying out the test of the FEL injector RF gun will be assembled. The required power of the generator is 60 kW.

In 2009 the design of RF stages of the generator, collectors of water and air cooling and components of power supplies is finished. By the end of 2009 the majority of details of the generator and power supplies were manufactured in BINP experimental workshop. In January 2010 the assemblage of generator stages was started, wiring of the high-voltage power supply is nearing completion.

Participants of work:
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7.11 Accelerating structures for the Linac4 CCDTL, CERN

Manufacturing of accelerating structures for linear accelerator Linac4 – a new injector for LHC, CERN started in 2009. BINP SB RAS together with RFNC-ARITP (the Russian federal nuclear centre – the All-Russian research institute of technical physics, Snezhinsk) within 2.5 years should create 7 accelerating modules CCDTL (Coupled Cavity DTL, the linear accelerator with drift tubes and coupling cells) for acceleration of H^- ions in the energy range from 50 to100 MeV. Each CCDTL module consists of three accelerating cavities (with 2 drift tubes in each cavity) and two coupling cells between them. Each module is connected to its RF-amplifier (klystron). Operating frequency is 352 MHz. The total length of CCDTL section is about 25 m.

Computer simulation of CCDTL cavities is performed, the design of elements of accelerating structures is developed, design drawings are released, technological elaboration is carried out, production tools are made. Two full-size pilot samples of drift tubes for checking of design and technological solutions are being manufactured in BINP workshops.

The work is carried out with financial support from ISTC (International scientific and technical centre, Moscow).

Participants of work:
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8

POWERFUL
ELECTRON ACCELERATORS
AND
BEAM TECHNOLOGIES

8.1 Radiation technologies and ELV series electron accelerators

Laboratory №12 continues the deliveries, design and assembling of industrial accelerators of ELV series. The accelerator certification requires a lot of efforts. In 2009 one more sanitary-epidemiological conclusion (hygiene certificate) from Federal Supervision Agency (ROSPOTREBNADZOR) for ELV-4 accelerator had been obtained. This document is very important. That is confirmed by the fact that due to bureaucratic circumlocution of Federal Supervision Agency the warranty period during one of the delivery was set not from the moment of accelerator commissioning, but from the date of submission of this document.

In 2009, the mobile accelerator of 0.65 MeV energy of accelerated electron and 20 kW beam power was delivered to Republic of Korea. This accelerator was designed and manufactured together with our long-standing collaborator EBTech company Co Ltd. (Daejeon city, R. of Korea). The accelerator in local radiation shielding, control cabinet with frequency converter, chiller for accelerator cooling and system of extraction device foil cooling are directly built-in in a trailer. In the same place the device of ozone catalytic decomposition was installed. The power supply of accelerator may be provided by external electrical supply network as well as by means of autonomous diesel generator. This diesel generator is also installed inside the trailer. In another wagon there are gas system, control system and accelerator operator working place. Figure 1 shows the trailer during its transportation. Note, the mover (tractor) itself is not included into accelerator delivery. First of all it is caused by the fact, that R. of Korea is a small country and there are many transportation companies.

Fig. 1: Trailer with mobile accelerator is ready to be transported.

High-voltage rectifier and accelerator tube of this accelerator are designed by such a way, that they may stand vertical and horizontal accelerations being up to 0.5 g.

One of the first tests was made along the ways of R. of Korea. During 4 hours the accelerator passed 150 km. In spite of good quality of the ways, we had found that maximum accelerations were within 0.5–1.0 g. This test was successfully finished.

During the tests the advantages as well as disadvantages of new design had been found out. The presence of the device of ozone catalytic decomposition is an advantage: ozone concentration at catalytic decomposition system exhaust is lower than maximum permissible concentration (MPC), and the presence of radiation chamber non-hermeticities leads to the blowing out of air with high ozone concentration from the chamber and the occurrence of specific smell near the trailer. Small size of radiation chamber is optimal in the view of decreasing of weight and overall characteristics of the device, but it itself leads to extra-heating of device walls, extraction device elements, scanning electromagnets and vacuum pumps. Figure 2 shows the working process of accelerator assembling.

Fig. 2: Assembling of vacuum system of mobile accelerator.

It is not easy to suppose, how popular and demanded those accelerators would be. But there is an interest to the installations like those and their pilot copies. Recently, the same delivery to the USA is prepared by the same executives.

The work on further development and modernization of standard ELV accelerators are carried out also. Thus, up to 2009 the maximum power of electron beam of ELV series accelerators of 100 kW was achieved at ELV-6 accelerator (by means of double sections) with the energy of up to 1.2 MeV and at ELV-8 accelerator within the energy range of 2-2.5 MeV. Standard accelerator ELV-4 within the energy range of 1-1.5 MeV has a power of 50 kW. Due to modernization of ELV-4 accelerator high-voltage rectifier and power supply system, at the same accelerator sizes, the beam power was increased up to 100 kW. First two accelerator with the parameters of 1 MeV*100 mA were delivered to Turkey and Republic of Korea. Figure 3 shows ELV accelerator at «DURFOAM» manufacture in Turkey.

In Saint Petersburg ("Radiant" company) the high-voltage source based on ELV rectifier was delivered and assembled. The parameters of the source are as follows: rectifying voltage is 150…250 kV and the load current is 200 mA that is the maximum power of high-voltage source is 50 kW. For us it is the first experience using low energies. Further, it is supposed to use this high-voltage source for power supply of low-energy electron accelerator with the beam extraction into air.

In the course of the year the joint work at injector of carbon accelerator booster for cancer therapy together with laboratories 5-2, 6 and 9-0 was continued. The structure of high-voltage source was worked out, the electricity strength of accelerator tube was tested, re-chargeable target was re-designed and adapted for the operation under SF_6 gas pressure. Non-separated beam of negative carbon ions was accelerated. Ion-optical system was settled and recharge efficiency was measured. To the end of the year, 90° separating magnet was produced and installed, i.e. the facility is completely assembled.

Fig. 3: ELV-4 accelerator at Turkish manufacture.

Fig. 4: General view of injector of carbon accelerator booster.

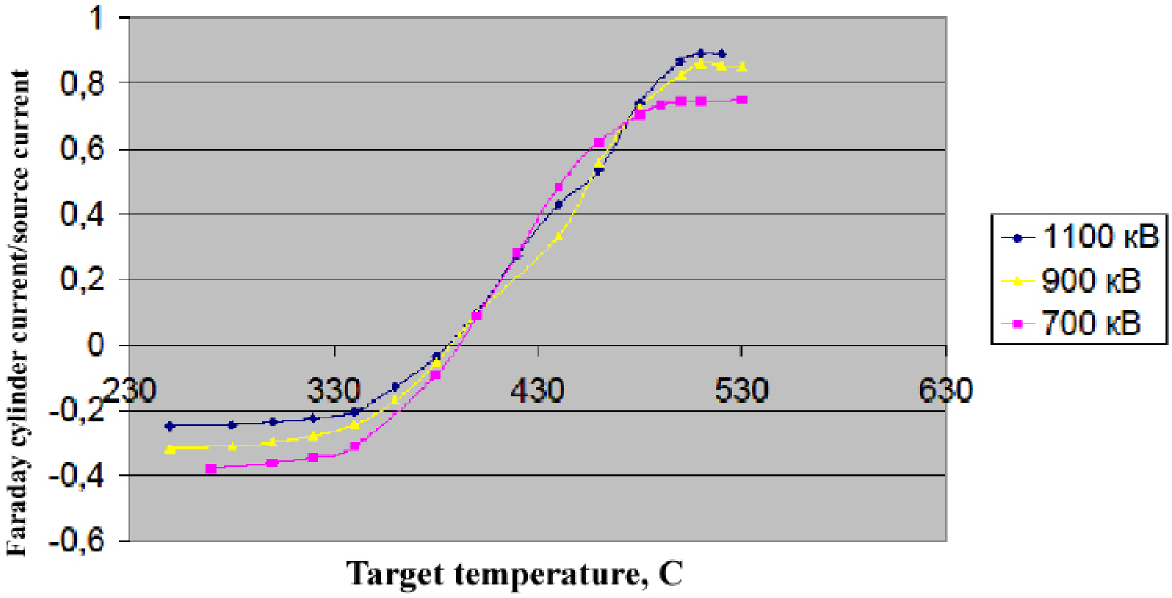

Fig. 5: Ratio of carbon ion recharge at different energies depending on target temperature.

The experiments at the laboratory test bench equipped with ELV-6 accelerator generating focused electron beam were continued.

Within contract works the nanopowders of W, W_2O_5 oxide and WC carbide as well as of nanopowder of yttrium oxide (Y_2O_3) were obtained and examined.

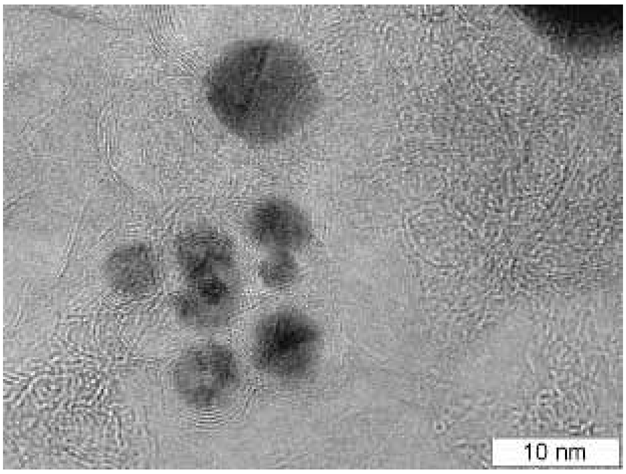

Fig. 6: Nano-size particles of tungsten, transmission electronic microscopy.

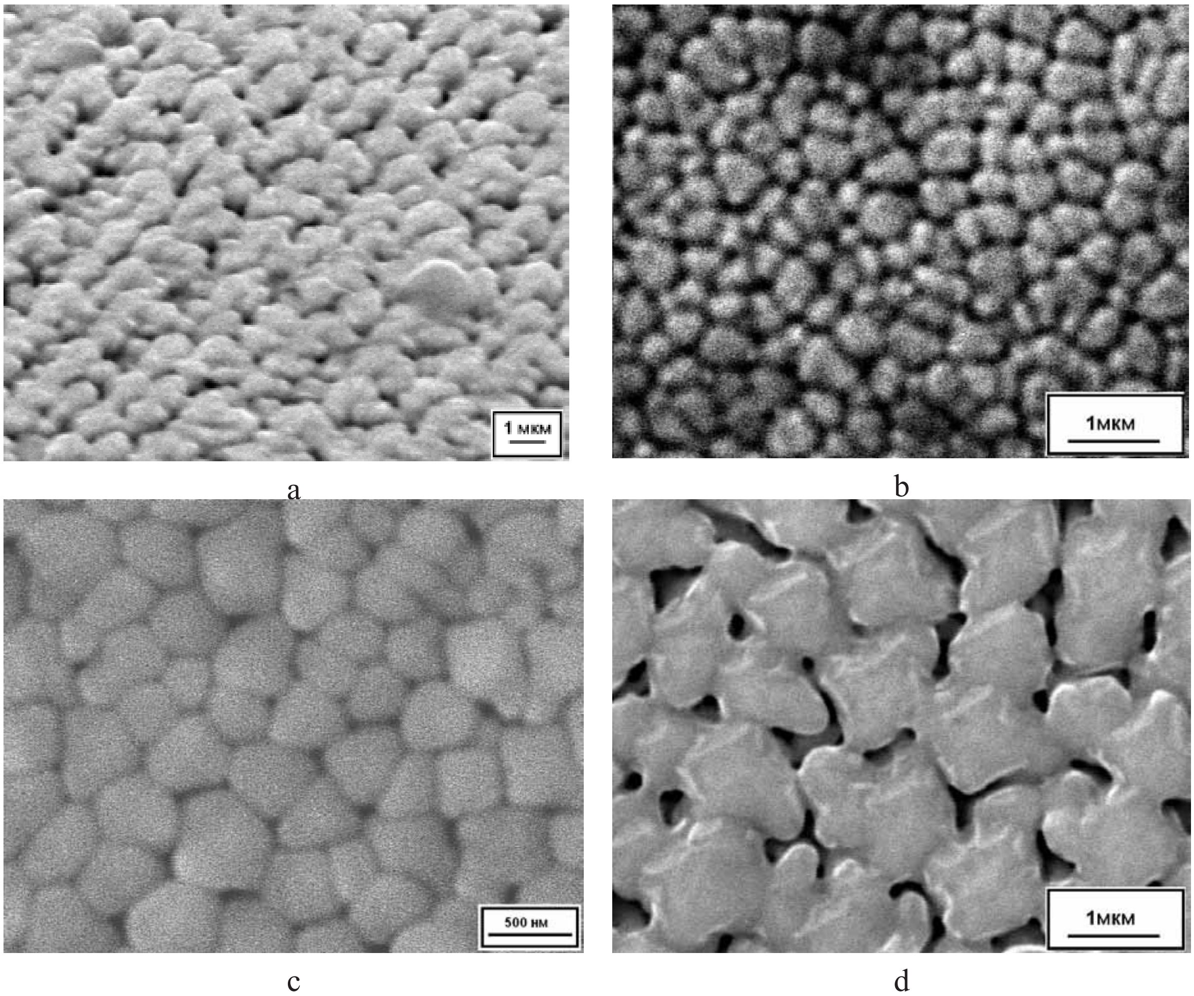

Fig. 7: Structure of fused layer surface (a – side view, b, c, d – view from above): a, c, d – tungsten fused by carbide, b – fusion by chrome carbide.

Small quantities of nanopowders produced earlier (Cu, TiO_2, Ag, Si) were continued to be examined in order to specify their characteristics.

After the under-beam equipment modernization we succeeded in producing in inert atmosphere of ultra-pure nanopowders of bismuth and bismuth oxide (Bi_2O_3) with the grade of no lower than 99,999% for Novosibirsk plant of less-common metals and Novosibirsk chemical pharmaceutical factory.

The experiments of surfacing of different powders on titanium, copper, aluminum and steel basis to get extra-hard and hardwearing coats are carried out. Those works are made in cooperation with Institute of Strength Physics and Materials Science, Siberian Branch of the Russian Academy of Sciences (Tomsk city) within cooperation with Novosibirsk State Technical University and the specialist of Science and Technology University (Pohang city, Republic of Korea).

8.2 ILU accelerators and their applications

8.2.1 Accelerator supplies

Since 1983 the ILU accelerators are supplied abroad where they are used for researches and are working in the industrial lines. The reliability and technical level of these machines is confirmed by the new supplies.

The accelerator ILU-6 that was continuously working since 1983 in the firm "RadPol", Czluchow town, Poland, was modernized. The maximum energy before modernization was 1.7 MeV, after modernization the machine is working at energy of 2.5 MeV with beam current up to 8 mA and at energy of 1.7 MeV with beam current up to 1.3 mA. In March 2010 this accelerator was put into operation in the industrial line for polymer goods irradiation.

The ILU-8 machine with local biological shield was manufactured, assembled and tested in BINP according the contract with the "Chuvashkabel" plant, Cheboksary, Russia, in 2009. After testing the machine was disassembled and shipped to Cheboksary where it was assembled inside the biological shield and put into operation along with the line for wire irradiation.

The ILU-10 machine with energy up to 5 MeV and beam current up to 10 mA was manufactured and commissioned according the contract with Siberian Center for Pharmacology and Biotechnology, see Fig. 1.

Fig. 1. Ready ILU-10 in the Institute.

8.2.2 Development of modular industrial electron accelerator ILU-14

The ILU-14 is the new machine in the ILU family, it is based on the ILU-12 machine. It is the powerful (up to 100 kW) multi-gap multi-cavity machine for energy range 7.5-10 MeV, the accelerating structure design is shown in Fig.2.

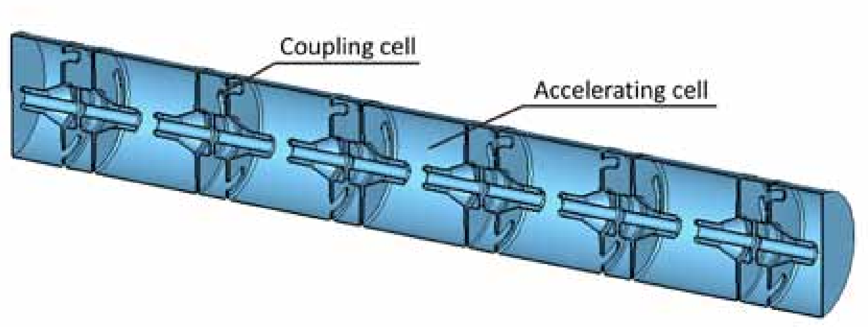

Fig. 2. ILU-14 accelerating structure design.

The parameters of the machine are given in the Table 1.

Table 1. ILU-14 parameters.

Electron energy, MeV	7.5–10
Average beam current, mA	up to 10
Resonator frequency, MHz	176
Energy spread (r.m.s.), %	3.5
Accelerating structure efficiency, %	72
Total efficiency, %	~30
Dimensions, м	8×2×2

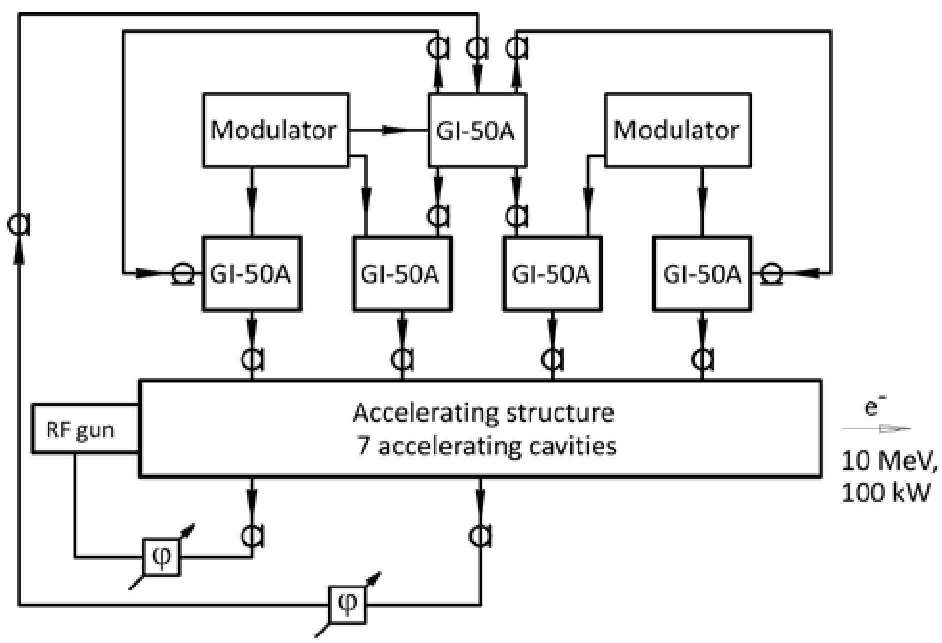

Fig. 3. ILU-14 block diagram.

The ILU-14 block diagram is shown in Fig. 3. The main elements are: bi-periodical accelerating structure with coaxial coupling cavities consisting of 7 accelerating cells; RF autogenerator comprising 5 stages on GI-50A triodes; 4 RF power inputs; triode RF electron gun having the option to apply the additional RF biad voltage on grid-cathode gap; and 2 modulators. The view of the accelerator along with RF generator and RF waveguides is shown in Fig. 3

9

PHYSICS FOR MEDICINE

9.1 VITA-facility (Vacuum Insulation Tandem Accelerator)

During 2009 the next works were carried out:

- Series of experiments to increase the proton beam current on Li target have been carried out.
- The powerful beam profilometer has been made, beam profile has been measured, and information about the stability of the current and the ability to control the position of beam center have been obtained.
- Proton beam spiral sweeper has been put into operation.
- Due to software optimization the bending magnet operation and the high-voltage tandem-accelerator power supply have been synchronized, which allowed conducting experiments with the beam energy quick variations.
- Neutron generation experiments at a proton beam current up to 0.7 mA in a stable mode have been started, and neutron flux was about $2 \cdot 10^{10}$ per sec, and breakdowns followed with a period of about 4 minutes. At 2.8 mA the interval between breakdowns decreases to 1 minute. Now it is planned to perform experiments on the irradiation of cellular products and mice.

Fig. 1: The photo of the VITA-facility

Scientific project 2.6.5.7 “Neutron source for neutron cancer therapy based on electrostatic tandem-accelerator”. Project supervisor: Prof. A. Ivanov

9.2 X-ray detectors for medicine and people screening

9.2.1 Medical radiography

In 2009 a new promising alternative of device MARK (Combined Radiographic Low Dose Apparatus) is offered and developed. The apparatus represents a multipurpose X-ray-diagnostics complex with the function of microdose bicontrast polyposition examination of a stomach in cancer screening. The design is developed and offered under the recommendation of the Center of New Medical Techniques ИХБФМ SB RAS. The offered apparatus is capable of performing all types of radiographic examinations including the preventive ones. The linear detector – 2560-channel ionization chamber with 250-micron resolution - is used for screening; and a flat panel with the resolution of 143x143 microns is used to get diagnostic images. The linear detector with the length of 660 mm is produced and tested. This multifunctional apparatus with unique possibility to perform a microdose screening of a stomach cancer has no world analogues.

The Institute has manufactured and delivered to joint-stock company “Nauchpribor” (Orel) 9 pieces of 1536-channel detectors for using them at manufacturing of digital scanning fluorographs FLD-NP-O.

9.2.2 Radiaographic Control Sistem (RCS) "Sibscan" for people screening

In 2009 experimental operation of a new model of the device in airport “Tolmachevo”, Novosibirsk was in progress. Resistant non-failure operation of RCS has been achieved at daily examination of ~ 1000 persons. New software was developed and supplied. New electronics for RCS control, more simple, compact and reliable, was developed and tested.

Manufacture of a series (5 pieces) of RCS devices of the new modification, which has shown a successful operation in airport “Tolmachevo”, is started in joint-stock company “Nauchpribor” (Orel).

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24. *V.M. Khatsymovsky.* On positivity of quantum measure and of effective action in area tensor Regge calculus. - E-print: arXiv:0707.3331.
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26. *Valentin V. Sokolov.* Ballistic electron quantum transport in presence of a disordered Background. // E-print: arXiv:0912.0382 [cond-mat.mes-hall] 2 Dec 2009.
27. *V.M. Strakhovenko*. Quantum electrodynamics. Coulomb effects in the spin-dependent contribution to the intra-beam scattering rate. // arXiv: 0912.5429 v1 [physics.acc-ph], 2009.
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Authorial Papers-2009

1. *Surin M.И.* Development of the methods of creation and study of highly reliable compact superconducting magnetic systems for scientific instrumentation and experimental physics. // 01.04.01 – instruments and methods of experimental physics. Author. papers of thesis for the degree of doctor of technical science: Novosibirsk, 2009, BINP, SB RAS.
2. *Khatimovsky V.M.* Descrete quntum gravity in Regge formalizm. // 01.04.02 - theoretical physics; 01.01.03 - mathematical physics. Author. papers of thesis for the degree of doctor of phys.-math. science: Novosibirsk, 2009, BINP, SB RAS.
3. *Logachev P.V.* Non-destructive diagnostic of intensive charge particle beams by low energy electron beam. // 01.04.20 – physics of charged particle beams and accelerator techniques, Author. papers of thesis for the degree of doctor of phys.-math. science: Novosibirsk, 2009, BINP, SB RAS.
4. *Vainer B.G.* Multichannel spectrometry and matrix infra-red imaging based on use arsenide-indium photosensitive MIS-structures with charging injection. // 01.04.01 – instruments and methods of experimental physics; 01.04.10 – semiconductor physics. Author. papers of thesis for the degree of doctor of phys.-math. science: Novosibirsk, 2009, BINP, SB RAS.
5. *Bragin A.V.* Thin superconducting solenoid for the CMD-3 detector. // 01.04.01 – instruments and methods of experimental physics. Author. papers of thesis for the degree of candidate of technical science: Novosibirsk, 2009, BINP, SB RAS.
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7. *Soldatkina E.I.* Transversal confinement of the differentially rotating plasma in the GDT device. // 01.04.08 - physics of plasma, Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2009, BINP, SB RAS
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9. *Epifanov Д.A.* Study of the reaction $e^+e^- \rightarrow \pi^+\pi^-\pi^\circ\pi^\circ$ in the region of φ-meson resonance with the CMD-2 detector. // 01.04.16 - elementary particle physics, and atomic nuclear physics. Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2009, BINP, SB RAS.
10. *Popov A.S.* Investigation of the process $e^+e^- \rightarrow e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^0$ with the KEDR detector. // 01.04.16 - elementary particle physics, and atomic nuclear physics. Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2009, BINP, SB RAS.
11. Anchugov O.V. High-voltage systems for controlling bunches in accelerators of charged particles // 01.04.20 - physics of charged particle beams and accelerator techniques, Author. papers of thesis for the degree of candidate of technical science: Novosibirsk, 2009, BINP, SB RAS.
12. *Shvedov D.A.* Fast systems of an injection and extraction for the charged particles accelerators. // 01.04.20 - physics of charged particle beams and accelerator techniques, Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2009, BINP, SB RAS.
13. *Zhuravlev A.N.* Development of optical diagnostics of the charged particle beams on the VEPP-4M facility. // 01.04.20 - physics of charged particle beams and accelerator techniques, Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2009, BINP, SB RAS.

Participation in Conferences

1. XXXVI International Zvenigorod Conference on Plasma Physics and Controlled Fusion, Zvenigorod, 9-13 February 2009, Russia.
2. 8th International Ural's Workshop: Radiation Physics of Metals and Alloys, 23 February - 1 March, Snezhinsk, Russia.
3. All-Russian Workshop on the Radiophysics of Millimeter and Submillimeter Waves, 2 - 5 March 2009, Nizhny Novgorod, Russia.
4. 1st International Conference on Technology and Instrumentation in Particle Physics, March 11 - 17, 2009, Tsukuba, Japan.
5. IV International Scientific-Technical Conference, 18-20 March 2009, Moscow, Russia.
6. 17th International Conference on Computing in High Energy and Nuclear Physics (CHEP 2009), 21 - 27 March, 2009, Prague.
7. DPG Conference, March 30 - April 2, 2009, Greifswald, Germany.
8. International Workshop on Linear Colliders (TILC09), April 17 - 21, 2009, Tsukuba, Japan.
9. Particle Accelerator Conference (PAC09), 4 - 8 May, 2009, Vancouver, Canada.
10. International Topical Meeting on Nuclear Research Applications and Utilization of Accelerators, SM/EB-30, 4 - 8 May, 2009, Vienna, Austria.
11. AustriaInternational Conference ''Photon09'', DESY, May 11 - 15, 2009, Hamburg.
12. XIV Frascati Spring School ''Bruno Touschek`` in Nuclear, Subnuclear and Astroparticle Physics, 11 - 15, May, INFN National Laboratories in Frascati, Italy.
13. 11th Pisa Meeting on Advanced Detectors, May 24 - 30, 2009, La Biodola, Isola d'Elba, Italy.
14. 9th All-Russia Workshop: Theoretical and Applied Electron and Ion Optics, May 27 - 29, 2009, Moscow.
15. 9th International Conference on Electron Beam Technologies (EBT'09), 1 - 4 June, 2009, Varna, Bulgaria.
16. International Conference: Chaotic Modeling and Simulation (Chaos 2009), June 1 - 5, 2009, Chania, Crete, Greece.
17. 59th International Meeting on Nuclear Spectroscopy and Nuclear Structure (Nuclear 2009), 15-19 June 2009, Cheboksary, RF
18. VII International Conference dedicated to the Academician Ershov A.P. Memory: Informatic System Perspectives, Institute of the Informatic Systems of the Siberian Branch of the Russian Academy of Sciences, 15-19 June, 2009, Russia.
19. International Seminar: Structural Bases of Material Modification by Unconventional Technologies (MNT-H), 16-19 July, 2009, Obninsk, Russia.
20. Workshop «Posipol 2009», June 23 - 26, 2009, Lyon, France.
21. International Conference on Fluxes and Structures in Fluids: Physics of Geospheres, June, 2009, Moscow, Russia.
22. 9th International Symposium on Measurement Technology and Intelligent Instruments (ISMTII-2009), June 29 – July 2, 2009, Saint-Petersburg, Russia.
23. International Conference: Nonlinear Dynamics in Quantum Systems (in Commemoration of Boris Chirikov), Siberian Federal University, July 6 - 10, 2009, Krasnoyarsk, Russia.
24. 3rd Young Scientist Meeting on Metamaterials (YSMM'09), July 7 - 8, 2009, Leganes, Madrid, Spain.
25. Europhysics Conference on High Energy Physics (EPC2009), 16 - 22 July 2009, Krakow, Poland.
26. II International Symposium: Topical Problems of Biophotonics (TPB-2009), 19 - 24 July, 2009, Nizhny Novgorod, Samara, Russia.
27. Russian-Japanese Workshop: State of Materials Research and New Trends in Material Science, 3 - 5 August, 2009, Novosibirsk, Russia.
28. XXIV International Symposium on Lepton Photon Interactions at High Energies, 16 - 22 August, 2009, Hamburg, Germany.
29. 31st Free Electron Laser Conference (FEL 2009), 23 - 28 August, 2009, Liverpool, BT Convention

Centre, UK.

30. COOL 09, August 31 - September 4, 2009, Lanzou.
31. VIII International Workshop on Charge Particle Accelerator: Beam-Beam Accelerator Physics, August 31 - September 5, 2009, Alushta, Ukraine.
32. XXI International Workshop on Charged Particle Accelerators, 6 - 12 September, 2009, Alushta, Ukraine.
33. XXII International Symposium on Nuclear Electronics & Computing (NEC 2009), 7 - 14 September, 2009, Varna, Bulgaria
34. 7th Sibirian Seminar on Superconducting and Related Problems, 16-17 September 2009, Novosibirsk, Russia.
35. 13th International Conference on Ion Sources (ICIS'09), 20 - 25 September, 2009, Gatlinburg, Tennessee, USA.
36. 14th International Conference on RF Superconductivity (SRF2009), 20 - 25 September, 2009, Berlin, Germany.
37. 34th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz 2009), September 21 - 25, 2009, Busan, Korea.
38. 39th European Microwave Conference, 28 September - 2 October, 2009, Rome, Italy.
39. Young Specialist School: Synchrotron radiation. Diffraction and scattering, Novosibirsk: Budker INP, Russia.
40. 2nd Nanotechnology International Forum, October 6 - 8, 2009, Moscow, Russia.
41. 1st All-Russian Conference: Methods of Examination of the Composition and Structure of Functional Materials, 11 - 16 October 2009, Novosibirsk, Russia.
42. Satellite Symposium on Neutrons for Therapy, 12 October 2009, Cape Town, South Africa.
43. 11th Neutron and Ion Dosimetry Symposium, 12 - 16 October 2009, Cape Town, South Africa.
44. XII International Conference on Accelerator and Large Experimental Physics Control Systems (ICALEPCS 2009), 12 - 16 October, 2009, Kobe, Japan.
45. 6th International Workshop on e^+e^- Collisions from φ to ψ (PHIPSI09), 13 - 16 October, 2009, Institute of High Energy Physics, Beijing, China.
46. Universities of the 21th Century: Innovation and New Technology: International Scientific Conference devoted to the 75th anniversary of Al Farabi Kazakh National University, 14 - 15 октября 2009, Almaty.
47. III All-Russian Youth School-Seminar with International Participation: Innovation Aspects of Fundamental Investigations on Actual Problems of Physics, 25-30 October, 2009, BINP, Novosibirsk, Russia.
48. 51st Annual Meeting of the Division of Plasma Physics, November 2 - 6, 2009, Atlanta, GA, USA.
49. 2nd Workshop on Nonlinear Beam Dynamics in Storage Rings, November 2 - 4, 2009, Diamond Light Source, Oxford, Great Britain.
50. 7th Internaional Specialized Exhibition: Expo-2009 Laboratory, 10 - 13 November 2009, Moscow.
51. VII National Conference on the Application of X-Ray and Synchrotron Radiation and Neutrons and Electrons for Examination of Nanosystems and Materials. Nano-Bio-Info-Cognitive Technology, 16-21 November 2009, Moscow.
52. Physics Branch of Physical Sciences Department of Russian Academy of Sciences Conference, 23-27 November, 2009, ITEP, Moscow.
53. XIII All-Russian Conference: High-Temperature Plasma Diagnostics, 2009, Zvenigorod, Russia.
54. Laser Plasma Accelerator Workshop, 2009, Kardamili, Greece.
55. III International Kreindel Seminar: Plasma Emission Electronics, 2009, Ulan-Ude, RF.
56. 36th EPS Conference on Plasma Physics. 2009, Sofia, Bulgaria.
57. 9th International Conference: Films and Coats-2009, Saint Petersburg, Russia.
58. International Conference on Physics Mechanics, Computer Design and Development of New Materials, 2009, Томск, Russia.
59. XIII International Conference on Interaction of Radiations with Solids, 2009, Minsk, Belorussia.

List of Collaboration Agreements between the Budker INP and Foreign Laboratories

	Name of Laboratory	Title or Field of Collaboration	Dates	Principal Investigators
№	*1*	*2*	*3*	*4*
1	*Daresbury (England)*	Generation and utilization of SR.	1977	*G. Kulipanov (INP); I. Munro (Daresbury)*
2	*BESSY (Germany)*	**D**evelopment of the wigglers for BESSY-2.	1993	*A. Skrinsky, N. Mezentsev (INP); E. Jaeschke (BESSY)*
3	*Research Centre Rossendorf (Germany)*	**P**hysical foundations of a plasma neutron source.	1994	*E. Kruglyakov, A. Ivanov (INP); K. Noack (Germany)*
4	*Nuclear Centre "Karlsruhe" (Germany)*	1. **D**evelopment of conceptual project and data base for neutron source on the basis of GDT device. 2. **S**imulation of processes in diverter of ITER device.	1994	*E. Kruglyakov, A. Ivanov, A. Burdakov (INP); G. Kessler (Germany)*
5	*GSI (Germany)*	**C**ollaboration in the field of accelerator physics: electron cooling; electron-ion colliders.	1995	*Yu. Shatunov, V. Parkhomchuk (INP); H. Eickhoff (GSI)*
6	*DESY (Germany)*	**E**lementary-particle physics, synchrotron radiation, accelerator physics and technology, electronics and experimental equipment.	1995	*A. Skrynsky, G. Kulipanov (INP); A. Vagner, K. Scherff (DESY)*
7	*CELLS (Spain)*	**C**ollaboration in the field of application of new equipment for SR sources.	2008	*E. Levichev (INP); Joan Bordas and Orpinell (CELLS)*
8	*CIEMAT (Spain)*	**A**ccelerator technology and plasma physics.	2007	*E. Levichev (INP), J. Rubio (CIEMAT)*
9	*INFN (Italy)*	**D**evelopment of intense source for radioactive ion beams for experiments in nuclear physics	1984	*P. Logachev (INP); L. Techio (INFN)*
10	*University of Milan (Italy)*	**T**heoretical and numerical studies of dynamic chaos in classic and quantum mechanics.	1991	*A. Skrynsky, V. Sokolov (INP); T. Montegazza, J. Kasati (Italy)*
11	*INFN-LNF (Italy)*	**D**evelopment of collider project DAFNE-II	2004	*E. Levichev (INP); S. Biscari (INFN-LNF)*
12	*University of Padua (Italy)*	**D**evelopment of cryogenic detectors for experiments in neutrino physicist.	2008	*Yu. Tikhonov, A. Bondar (INP); A. Gudlielmi (Italy)*
13	*National Nuclear Center. Park of Nuclear Technology (Kazakhstan)*	**D**evelopment and application of industrial accelerators, generation and utilization of neutron beams, development of SR sources, RF-generators.	2007	*G. Kulipanov (INP); K. Kadyrzhanov, A. Kusainov (Kazakhstan)*
14	*National Nuclear Center. Al-Farabi National University (Kazakhstan)*	**C**reation and development of a multi-purpose research complex of radiation technology and teraherz radiation.	2009	*G. Kulipanov (INP); K. Kadyrzhanov, B. Zhumagulov (Kazakhstan)*

№	1	2	3	4
15	*Institute of Morden Physics and Techniques, Lanchzou (China)*	**C**ollaboration in the field of accelerator physics: electron cooling	2000	*V. Parkhomchuk (INP); S. Yang (KHP)*
16	*WOER Company, Shenzhen, (China)*	**U**sing of electron accelerator ILU-10, exchanging of personal, information and experimental equipment.	2005	*A. Bryazgin (INP); Leo Li (WOER).*
17	*SINAP Shanghai, (China)*	**R**esearching in field of industrial electron accelerators.	2006	*A. Bryazgin (INP); Hu Hounku (SINAP).*
18	*IHEP (China)*	**W**ork of Chinese scientists on BINP installations, work of BINP scientists on IHEP installations.	2007	*A. Skrinsky (INP); H. Chen (IHEP)*
19	*Industrial and Technological Center of Cooperation with Russia and Belorussia of Heilongjiang Province (P.R.C) (China)*	**E**xchange of information about BINP-developed devices and the technology and product demand of the Chinese factories	2009	*D. Grigoriev (INP); Zhan Hun-Vei (P.R.C)*
20	*POSTECH (Korea)*	**C**reation of beam accelerators, add-on devices, SR experiments.	1992	*A. Skrinsky, N. Mezentsev (INP); H. Kim (POSTECH)*
21	*KAERI (Korea)*	**D**evelopment of FEL and accelerator-recuperator.	1999	*N. Vinokurov (INP); B.Ch. Lee (KAERI)*
22	*BNL, Brookhaven (USA)*	1. **M**easurement of the magnetic muon ano-maly. 2. **J**oint research of RHIC spin.	1991 1993	*L. Barkov (INP); J. Bunse (BNL)* *Yu. Shatunov (INP); S. Ozaki (BNL)*
23	*ANL, Argonn (USA)*	1. **E**xperiments with polarized gas jet target at VEPP-3. 2. **SR** instrumentation.	1988 1993	*L. Barkov (INP); R. Holt (ANL)* *G. Kulipanov, A. Skrinsky (INP); G. Shenoy (USA)*
24	*University of Pittsburgh (USA)*	**E**xperiments on VEPP-2M and ϕ-factory.	1989	*S. Eidelman, E. Solodov (INP); V. Savinov (USA)*
25	*University of Duke (США)*	**F**ree electron lasers.	1992	*N. Vinokurov (INP); J. Wu (Duke)*
26	*BNL, Brookhaven (USA)*	**C**ollaboration on electron-ion colliders.	1993	*V. Parkhomchuk (INP); I. Benzvi (USA)*
27	*FERMILAB (USA)*	**C**ollaboration in the field of accelerator physics: electron cooling; conversion system.	1995	*V. Parkhomchuk (INP); O. Finli (FERMILAB)*
28	*FERMILAB (USA)*	**E**xchange of scientists and engineers for scientific research.	2005	*A. Skrinsky (INP); P. Oddone (FERMILAB)*
29	*SLAC, Stanford (USA)*	**O**btainment of submicron beams and intensive positron beams, development of B-factory elements, detectors, RF-generators based on magnicons.	1994	*A. Skrinsky (INP); Persis Drel (SLAC)*

№	1	2	3	4
30	*Institute of Plasma Physics ASCR (Czech Republic)*	**C**ollaboration in the field of plasma physics and plasma diagnostics research.	2008	*A. Ivanov (INP); P. Hruška (Czech Republic))*
31	*CERN (Switzerland)*	**1**. **R**esearch and development of the detectors for LHC. **2**. Development of the LHC elements.	1992 1996	*A. Bondar, Yu. Tikhonov (INP); T. Nakada, P. Yenni (CERN)* *V. Anashin (INP); L. Evans (CERN)*
32	*Paul Scherrer Institute (Switzerland)*	**C**ollaboration in the field of particle physics.	2009	*D. Grigoriev (INP); D. Mecom (Paul Scherrer Institute)*
33	*CERN (Switzerland)*	**R**esearch and development of micro-pattern detector technology..	2009	*Yu. Tikhonov (INP); S. Bertolucci (CERN)*
34	*CERN (Switzerland)*	**C**ollaboration in the development of the electron-positron colliders with super-high luminosity.	2009	*E. Levichev (INP); S. Myers (CERN)*
35	*RIKEN Spring-8 (Japan)*	Collaboration in the field of accelerator physics and synchrotron radiation	1996	*G. Kulipanov (INP); H. Kamitsubo (Japan)*
36	*KEK (Japan)*	**R**esearch in accelerator physics and allied fields, development of elementary particle detectors.	1995	*A. Skrinsky (INP); A. Suzuki (KEK)*
37	*Center of Plasma Research, Tsukuba (Japan)*	**C**ollaboration on Open traps.	2007	*A. Ivanov (INP); T. Imai (Japan)*

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