Russian Academy of Sciences
Lenin Order Siberian Branch
BUDKER INSTITUTE OF NUCLEAR PHYSICS

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Contents

Introduction

The Institute of Nuclear Physics SB RAS was founded in 1958 on the base of the headed by G.I.Budker Laboratory for new methods of acceleration of the Institute of Atomic Energy headed at that time by I.V.Kurchatov.

Academician G.I. Budker was the founder and first Director of the Institute. Since his death in 1977 to the present time, the Director of the now called “The Budker Institute of Nuclear Physics , BINP SB RAS” is academician A.N.Skrinsky. In May, 2008, BINP celebrated its 50th anniversary.

All the research and production activity of the Institute is governed by “Round Table”— Scientific Council of the Institute.

The total number of the Institute’s staff is over 3000 and among them: 355 researchers, over 40 postgraduates, nearly 800 engineers and technicians, about 350 laboratory assistants and 1000 workers. Among the researchers, there are 4 full members and 6 corresponding members of the Russian Academy of Science, about 50 doctors of science and 160 candidates of science.

The Institute is one of the world leading centers in several important fields of the high energy physics, controlled thermonuclear fusion and applied physic. In the majority of its research fields, the Institute is unique in Russia.

Basic trends of the Institute activity

I. Fundamental studies.

1. Research studies in the elementary particle physics based on the operational and being developed electron-positron colliders.
2. Studies in the field of the electro- and photonuclear physics based on the use of the storage rings of charged particles.
3. Research studies in the field of plasma physics and controlled thermonuclear fusion based on the open systems.

II. Development and production of new unique devices for the fundamental studies and high technologies.

1. Electron-positron colliders at superhigh luminosity (e^+e^- factories).
2. Development of the concept and technology of the linear electron-positron colliders.
3. Synchrotron radiation sources.
4. Powerful lasers based on high energy electron beams (free electron lasers FEL).
5. High intense generator of thermonuclear neutrons based on the plasma "gasdynamic" trap.
6. Development of powerful electron accelerators and the development on this base of the electron-beam technologies including the ecologically oriented technologies.

7. Development and production of the equipment and devices for medical purposes on the base of the accelerator and detector studies of the Institute.

III. Participation in the work envisaged by the international and intergovernmental agreements, contracts and other obligations of the international scientific-technical collaboration agreements.

IV. Training of the highly qualified scientific personnel on the following specialities:

☐ elementary particle physics and nuclear physics;
☐ physics of the charged particle beams and accelerators;
☐ theoretical physics;
☐ physics and chemistry of a plasma;
☐ high energy physics instrumentation;
☐ physics of equipment;
☐ automation of physical studies.

Every year, over 200 students of the 3rd-6th years from NSU and NSTU pass the apprenticeship in the Institute laboratories and about 90 magistrate and bachelor of science diploma works are defended every year.

BINP is involved in a broad range of mutually beneficial collaborations with various Laboratories and industrial organizations:

• over 100 experimental groups from various Russian and foreign research Institutes make use of the BINP facilities:

• BINP is involved in a broad range of mutually beneficial collaborations with various Laboratories and Universities of the USA, Germany, Great Britain, France, Italy, Netherlands, Finland, Sweden, China, Japan, R.Korea, India and with the European Center for Nuclear Research - CERN; in addition to the joint research studies, BINP is also involved in the contract works on the development and manufacture of the novel equipment for these laboratories;

• BINP is also involved in the joint design and development works with many Russian organizations equipped with modern technologies.

• over 150 BINP made electron accelerators are operated at various technological lines in Russia, Ukraine, Belorussia, Germany, Japan, China, Poland, Chekhia, Hungary, Rumania, R.Korea, Italy, India.

BINP is a reliable partner both in carrying the joint research and in the developments in the field of physics and has a good reputation in the whole world as a reliable supplier of the highly technological equipment for the research and industrial purposes.

Some of 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 the electron-positron colliding beams, 1965,
☐ the world first experiments on the electron-positron interactions, (1967),
☐ the first in the world observation of the double bremmstrahlung process , (1967),
☐ pioneering works on the two-photon physics, (1970);

• a study of characteristics of the vector mesons at the electron-positron colliders VEPP-2, VEPP-2M, (since 1967);

• discovery of a parity violation of hadrons in the electron-positron annihilation, (1970);

• precise measurement of the vacuum hadron polarization contribution into the value of the muon anomalous magnetic momentum for one of the most sensitive tests of the

Standard model, which is being 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-, ρ-, ω-, φ-, ψ- mesons and Υ- mesons, (1975-2004);

• discovery of the parity violation effects in the atomic transitions confirming a unified theory of the electroweak interactions, (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 inverse scattering (1980–1982); experimental observation of the photon splitting in the nucleus Coulommb field , (1997);

• development of new techniques for detecting high energy charged and neutral particles and 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 inspection “SibScan”(since 1981).

In the field of theoretical physics :

• development of the resonant theory of dynamic chaos and pseudochaos in the 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);

• prediction of the coherency effect in 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 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 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 method that is presently used practically on all the 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 colliders 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 ionization colliding method 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 protection of environment as ELV-12 of 500 kW in power and 1 MeV in energy and ILU-10 at a power of up to 50 kW and an 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 realization (1959) of a "classic" open trap (mirror machine) for confinement of a hot plasma;

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

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

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

• development of the high intense surface-plasma sources of negative ions, which are 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 base of the open trap (since 1987);

• theoretical prediction of the Langmuir collaps (1972), experimental observation of the strong Lngmuir turbulence and Langmuir wave collapce in the magnetic field, (1989 - 1997);

• development of a series of the unique powerful sources of hydrogen atoms for a study of the 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 base 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 SR dedicated 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), achievement 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 base of the most promising scheme using the microtron-recuperator (since 1987); obtaining 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 best works in 2008 were recognized by Scientific Council as follows:

1. An electron-positron collider VEPP-2000.

The record luminosity for a single bunch of $L_{max} = 10^{31}$ cm^{-2}s^{-1} at an energy in the center of mass of 1 GeV was detected in the round beam regime at the electron-positron collider VEPP-2000.

2. An electron-positron collider VEPP-4M – detector KEDR.

A series of experiments of the precision measurement of the elementary particle masses has been performed at the electron-positron collider VEPP-4M with detetector KEDR. Masses of J/Ψ, Ψ' and Ψ'' - mesons , τ - lepton and charged D - meson are measured with an accuracy best in the world.

3. Free Electron Laser.

At the first in the world accelerator-recuperator with two tracks at FEL, the mean design current was achieved.

4. Accelerator mass-spectrometer.

Preliminary tests of the accelerator mass-spectrometer AMS have been completed. In the course of the tests, the cosmogeneous isotope ^{14}C was first in the world detected in the sample of charcoal. The mass-spectrometer is installed in the collective user center SB RAS “Geochronology of Cainozoe” and its adjustment is in progress.

5. Contract work of BINP.

Within the frame of the contract with TAE (Tri Alpha Energy, USA), a 6 MW system of atomic injection was produced and commissioned.

6. Plasma physics and thermonuclear fusion.

For the first time, in the regime of the gasdynamic confinement of plasma (GDL facility) its was demonstrated the suppression of the longitudinal losses by the ambipolar electric field.

7. Teoretical works.

7.1. A new technique was developed for reducing the loop integrals determining the contribution of higher orders of perturbation theory into the amplitudes of physical processes, which is based on the fact the operator generating identities of integration by parts form the Li algebra.

7.2. The gravitational lensing was studied at cosmologic distances in the presence of the cosmologic constant. It was shown that the cosmologic constant does not affect the lensing.

7.3. In a super symmetrical quantum chromodynamics (with N_c colors and N_f fragrances for cases of the equal and unequal quark masses), the hadron mass spectrum and form of the corresponding effective Lagrangians were found our for various energy fields.

In 2008, BINP hosted seven International Coferences, Seminars and Workshops:

№	Meeting	Dates
1.	10-th International Conference on Instrumentation for Colliding-Beam Physics (INSTR08)	29 February -5 March 2008
2.	The 40th ICFA Advanced Beam Dynamics Workshop on High Luminosity e+e- Factories (FACTORIES'08)	14 -16 April 2008
3.	International Seminaron Physics of accelerators, High energy physics and Thermonuclear research, devoted to the 90th anniversary of academician G.I.Budker and to the 50th anniversary of the Institute	18 − 22May 2008
4.	International Seminar dedicated to the memory of Boris V. Chirikov	23 May 2008
5.	Advanced Beam Dynamics Workshop "NANOBEAM- 08"	25 − 30 May 2008
6.	XVII International Synchrotron Radiation Conference "SR-2008"	15 − 20 June 2008
7.	10-th International Workshop on Tau Lepton Physics	20 − 25 September 2008

In 2008, six scientific Schools of BINP SB RAS became prize-winners of the competition of the Grant Council at President of Russian Federation on the support of the leading scientific schools in the period 2008-2009 in the knowledge field "Physics and astronomy" and two schools became then winners of the RossScience competition in the frame of the Federal Special scientific-technical Program "Studies and developments on the priority directions of the development of scientific-technological complex of Russia in 2007 − 2012". Three persons of BINP staff became prize-winners of the competition of the Grant Council at the President of Russian Federation on the support of young scientists: doctors and candidates of science. One of our colleagues was awarded by the honor title as the "Honoured worker of science of Russian Federation" two our colleagues are awarded by medal of the order "Services for Motherland" II grade, and one was awarded the Cherenkov Prize of RAN for the outstanding achievements in experimental high energy physics, two young physicists obtained the nominative prizes of the Novosibirsk region administration for the scientific achievements in the field of fundamental and applied studies.

The Councils with the right of accepting the doctor and candidate theses continued the work. There were 7 meetings with the defense of 2 doctor and 5 candidate theses.

There were conducted 65 excursions round the Institute for school children, students and teachers of schools and higher schools and staff of other organizations with the total number of visitors of 1365 and three lectures have been read in other organizations.

Chapter 1

Physics of Elementary Particles

1.1 CMD-3 Detector

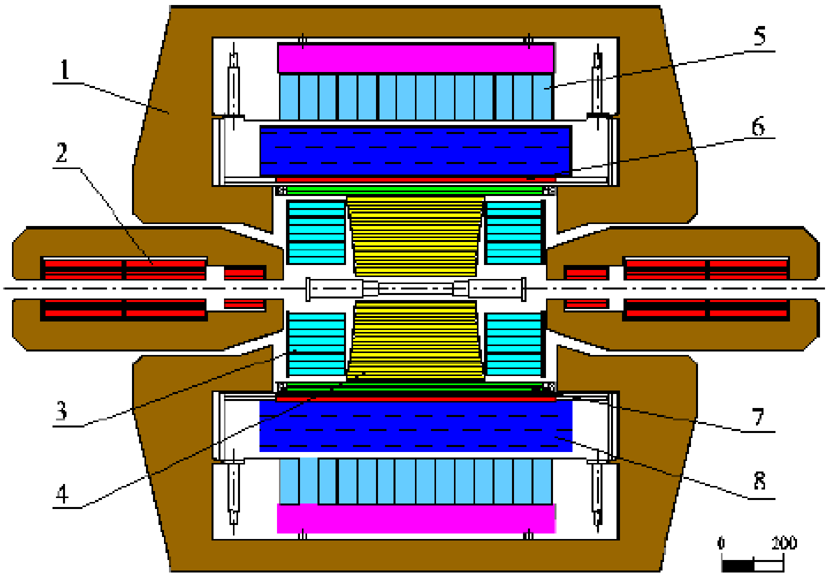

Figure 1: CMD-3 Detector. 1 — magnet yoke; 2 — VEPP-2000 superconducting solenoids; 3 — endcap BGO electromagnetic calorimeter; 4 — drift chamber; 5 — barrel CsI electromagnetic calorimeter; 6 — CMD-3 superconducting solenoid; 7 — Z-chamber; 8 — barrel LXe electromagnetic calorimeter.

Schematic longitudal cross section of the CMD-3 detector is shown in Figure 7.

During 2008 works on detector systems manifacturing and the systems parameters measurements were continuing.

All digitizing electronics for the CMD-3 drift chamber - T2Q modules - were produced in the Institute workshop, and now installed into the detector after tuning. To measure coordinate resolution in the drift chamber cells, cells efficiency and number of other important parameters the physics runs run on cosmic rays particles were performed. The parameters were measured very close to its projected values.

Readout electronics of Z-chamber, used for precise measurement of charged track coordinates and in trigger, was now arranged to use Ethernet network. Data Acquisition and OFFLINE event reconstruction software for Z-chamber is developing now.

All octants of barrel CsI electromagnetic calorimeter have been assembled and installed into the detector at VEPP-2000 experiemental hall. All digitizating electronics (UFO-32) blocks for the calorimeter have been produced in the Institute Workshop. Its tuning and installation of the electronics are performing now as well as it integration into the detector data acquisition system. Tests of the calorimeter using events with cosmic particles are continuing now.

System of scintilating Time-of-flight counters has also been installed into the detector. The main purpose of the system is registration of nucleon-antinucleon production in the center-of-mass energy range greater than 1.8 GeV.

The endcap electromagnetic BGO calorimeter has been fully prepared to installation into the detector. All required digitizing electronics for the calorimeter was produced and now its tuning is performing.

Several runs were performed with the tests of cryogenic and magnetic systems, which have been already installed in the VEPP-2000 experimental hall. In the tests the magnetic field value 1.35 T was obtained and such magnetic field magnitude will be used in future experiments. In the stable magnetic field mode the liquid helium cosumption was obtained to be 4 – 4.2 litres/hour, which is very close to the projected value.

In 2008 new powerful server for OFFLINE data analysis has been installed into the CMD-3 detector Data Acquision System. The server will satisfy the requirements of data acquision system for reasonable time in future.

The software for OFFLINE event reconstruction is developed at full speed. The module for the event readout from MIDAS system (core of the CMD-3 data acquisition system) has been developed as well as converting of the event into the ROOT format. System of the events visualization and software for the event reconstruction "in real time" has been created.

In 2008 the analysis of the process $e^+e^- \to K^+K^-$ in center-of-mass energy range 1010 – 1034 MeV using data, collected with CMD-2 detector, was peformed with systematic accuracy 2.2%. $\phi(1020)$ parameters were measured in decay mode $\phi \to K^+K^-$:

$$\begin{aligned} B(\phi \to e^+e^-) \cdot B(\phi \to K^+K^-) &= (14.27 \pm 0.05 \pm 0.31) \times 10^{-5} \\ \sigma_0(\phi \to K^+K^-) &= (2016 \pm 8 \pm 44)\ \text{nb} \\ m_\phi &= 1019.441 \pm 0.008 \pm 0.080\ \text{MeV/c}^2 \\ \Gamma_\phi &= 4.24 \pm 0.02 \pm 0.03\ \text{MeV} \end{aligned}$$

The parameters measurements have similar or higher precision than the world averages results.

Participants of work:

Anisyonkov A.V., Aulchenko V.M., Akhmetshin R.R., Bashtovoy N.S., Barkov L.M., Banzarov V.Sh., Bondar A.E., Bragin A.V., Viduk S.N., Vorobyov A.I., Grebeniuk A.A., Grigoriev D.N., Epifanov D.A., Zaytsev A.S., Zverev S.G., Zinchenko A.V., Ignatov F.V., Kazanin V.F., Karpov S.V., Kakhuta K.I., Kozyrev A.N., Kuz'min A.S., Logashenko I.B., Lukin P.A., Mikhailov K.Yu.,Okhapkin V.S., Pestov Yu.N., Pirogov S.A., Popov Al.S., Popov Yu.S., Ryskulov N.M., Ruban A.A., Redin S.I., Sibidanov A.L., Snopkov I.G., Solodov E.P., Talyshev A.A., Titov V.M., Fedotovich G.V., Khazin B.I., Shwartz B.A., Eidelman S.I., Yudin Yu.V.

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1.2 The SND detector

1. SND upgrade for experiments at VEPP-2000.

In 2008 the series of experiments for registration of cosmic particles with the SND tracking system was further continued. The scheme of experiments is described in detail in the previous BINP annual report. From April to June and from August to November about 200 thousand events were recorded. In June additional electronics have been connected to the drift chamber to register signals from the cathode strips. About 100 thousand cosmic ray events were recorded with fully assembled electronics of the tracking system.

Using the recorded data, efforts were continued to tune simulation programs, as well as the calibration programs that determine the coordinates of the particle tracks from the ionization drift time and from the charge division in the signal wires, and the calibration programs that are needed in particles' ionization-loss measurements. Thus, for the charge division method the obtained resolution in the z-coordinate was 1.5÷2 mm, which is slightly better than in 2007 experiments (∼2 mm) and is close to the designed value (1.5 mm).

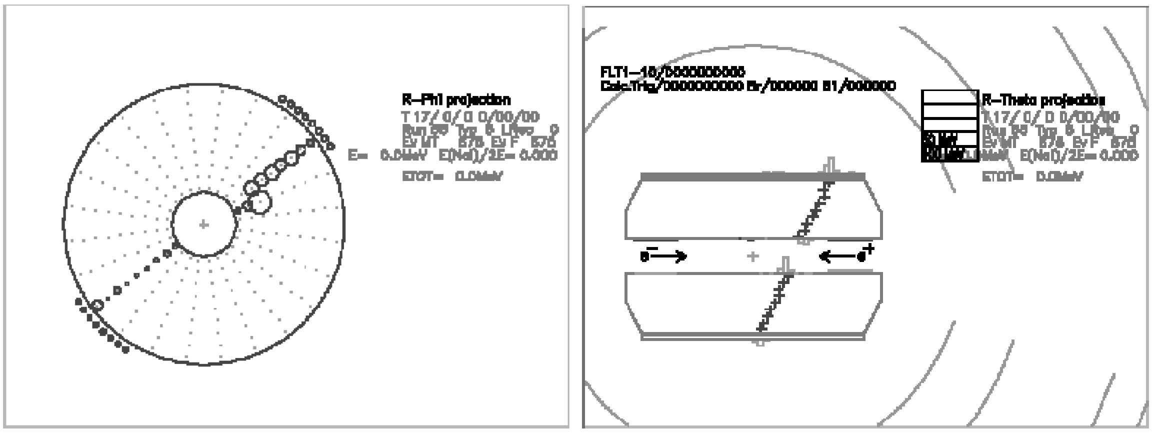


Figure 1: A track of cosmic muons recorded by the SND tracking system. In $r\varphi$-plane circles show the fired anode wires of the drift and proportional chambers. In rz-plane crosses show the fired anode wires of the drift chamber, while bars — triggered cathode strips.

On-line electronics control software for the tracking system provides the histograms of amplitude and drift time spectra. All data are stored in the form of tables and histograms which are available at a special WEB-page by means of SND operator interface.

In early December 2008, an experiment was conducted with the ^{90}Sr β-isotope, whose goal was the absolute calibration of the longitudinal coordinate in the drift chamber, defined by the induced charge magnitude on the cathode strips. A data processing of this experiment is still underway.

At December 15, 2008 the tracking system was installed at the VEPP-2000 interaction interval. Work is currently under way to connect the tracking system to the recording electronics.

In 2008, the assembly of the aerogel Cherenkov counters with the refractive index n = 1.13 was completed (Fig. 2). The readout electronics system of the aerogel counters was also assembled. Preparations for the installation of the Cherenkov counters in the SND detector is under way. By the end of 2008, manufacturing of a new version of aerogel counters with the refractive index n = 1.05 came to its final stage. In early 2009, it is planned to complete the assembly of this version of the system.

Figure 2: A photograph of the SND Cherenkov counter.

In spring, the replacement of vacuum phototriods was performed at a half of the SND calorimeter third layer. Work started on the preparation of the calorimeter for experiments at VEPP-2000 in 2009.

In 2008, the bench testing of all modules of the proportional and scintillator counters of the SND muon system was completed. The barrel part of the muon system is installed in the detector and is connected to the corresponding electronics of the data acquisition system of the detector. In the near future, testing of the muon system is planned by using cosmic ray particles, full-assembled electronics and data acquisition system software.

In preparation for the neutron electromagnetic form-factor measurement experiment, a measurement of the time resolution of the scintillation NaI(Tl) counter of the SND calorimeter was performed by using cosmic muons and a new muon telescope on the basis of micro-channel plate PMTs with better than 0.6 ns time resolution. The obtained time resolution of the SND calorimeter counter was 1.7 ns for 70 MeV energy deposition. The staff of the Sector 3-12 (V. M. Aulchenko) developed a flash ADC to measure the time-of-flight of the particles through the SND calorimeter. Test samples of designed ADCs are in the production stage.

An optimization of the selection criteria for events $e^+e^- \to n\bar{n}$ was performed by using the experimental data recorded in experiments with the SND detector at VEPP-2M and the GEANT4 modeling of this process. The results simulation the need for additional background suppression based on the antineutron time-of-flight measurements.

At present, electronics of all subsystems of the detector are fully assembled and ready to work. Its testing is conducted in the electronic console room of the detector.

Data Acquisition System (DAS) software of the SND detector is finalized and modernized, taking into account the requirements of the experiment:

- using DAS of SND, the luminosity was measured at the first trial start-up of VEPP-2000 with colliding beams;
- the complete transition of the SND cluster computers to the operating system Scientific Linux 5 was performed;
- the reliability of intercommunication of applications with databases of the experiment was improved;
- readout of the PA24M plates was implemented (cathode of the proportional chamber);
- project for the T2AM plate (drift chamber) was improved, readout with suppression of not fired channels was realized;
- TA plates' (Cherenkov counters and external muon counters) readout and recording classes were implemented;
- the results of testing and maintenance runs were used to improve the efficiency of the system and fix the errors.

Continuous operation of the data acquisition system during several days demonstrated the reliability of the software: the system worked without a need of restarts, the rate up to 1 kHz was ensured in the data storage and processing.

In January 2008, by using the SND calorimeter, VEPP-2000 luminosity was measured via the events of the $e^+e^- \to e^+e^-$ and $e^+e^- \to \gamma\gamma$ processes. Study of the dependence of the specific luminosity on the magnitude of currents has shown a promise for round beams - the beam-beam interaction effects were found to be suppressed compared with the flat beams option. The maximum recorded luminosity was 8×10^{30} cm^{-2} s^{-1} with the correspondent currents product $I_{e^+} \times I_{e^-} \simeq 1600$ mA^2.

2. VEPP-2M data analysis. In 2008, an article was published devoted to the study of $e^+e^- \to \omega, \rho \to \pi^0 e^+e^-$ processes. In this paper the probability $B(\omega \to \pi^0 e^+e^-) = (0.761 \pm 0.053 \pm 0.064) \cdot 10^{-3}$ of the conversion decay $\omega \to \pi^0 e^+e^-$ was measured and an upper limit $B(\rho \to \pi^0 e^+e^-) < 1.2 \cdot 10^{-5}$ (90% CL) was set on the probability of the decay $\rho \to \pi^0 e^+e^-$. The transition form factor was measured at three values of the 4-momentum transfer squared.

Preliminary results were obtained and published verifying the conserved-vector-current hypothesis in the processes $e^+e^- \to K\bar{K}$ and $\tau \to K^-K^0\nu_\tau$. In the corresponding paper, the results of SND measurements for the cross sections of the $e^+e^- \to K^+K^-$ and $e^+e^- \to K_SK_L$ processes were used up to 1.4 GeV center of mass energy, and the results of DM1 and DM2 experiments – for higher energies. Simultaneous approximation of cross sections of these processes allowed one to separate the isovector and isoscalar contributions in the total cross section $e^+e^- \to K\bar{K}$. The decay spectrum observed by CLEO in the decay mode $\tau \to K^-K^0\nu_\tau$ is consistent with the calculations based upon the isovector amplitude obtained in the SND experiment, thus confirming the conserved-vector-current hypothesis.

A preliminary result was obtained for the $e^+e^- \to e^+e^-\gamma\gamma$ process cross section in the full energy range covered by VEPP-2M ($2E$=0.36–1.38 GeV). The measurement is consistent with the theoretical calculation (Fig.3). The statistical error of the measurement is 3.8 %. The estimated systematic error is $\simeq 8\%$.

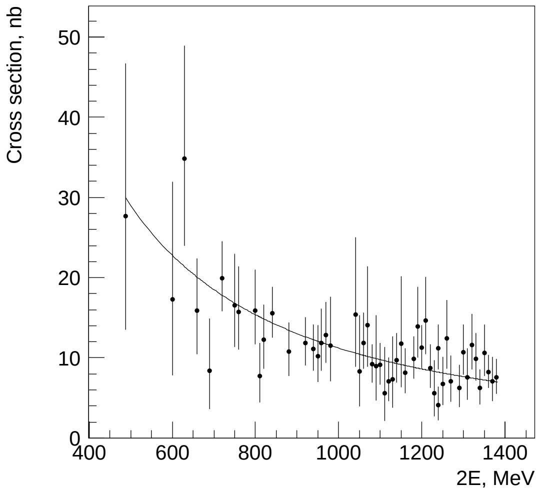


Figure 3: The cross section of the $e^+e^- \to e^+e^-\gamma\gamma$ process measured by SND detector in the full VEPP-2M energy range, preliminary results. The solid line shows the result of QED calculation.

A paper containing the analysis of the process $e^+e^- \to \mu^+\mu^-$ in energy range above 1 GeV has been submitted for publication.

Analysis is near completion for the following processes: $e^+e^- \to \eta\pi^+\pi^-(\eta \to 2\gamma)$, $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$, $e^+e^- \to K^+K^-\pi^0$, $e^+e^- \to K^\pm K_S\pi^\mp$. Work is continued on the analysis of the following processes: $e^+e^- \to \pi^0\gamma$, $e^+e^- \to \pi^+\pi^-$ ($2E$ >1 GeV), $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$, $e^+e^- \to \pi^+\pi^-\gamma$.

3. Participation in international projects.

In 2008, the BABAR collaboration published and prepared for publication about 80 papers. With the direct participation of BINP physicists, data analysis is 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 2008 the following cross sections were measured: $e^+e^- \to K^+K^-\eta$, $K^+K^-\pi^0$, $K^0_sK^\pm\pi^\mp$. These data are currently the most accurate. From the cross section approximations, the parameters of the $\phi(1680)$-meson were defined. A preliminary result was obtained on the cross section $e^+e^- \to \pi^+\pi^-$. In the $\rho(770)$-meson region, the systematic error in this cross section measurement is less than 1%. The results were reported at the scientific conference TAU08.

In 2008, work began on the measurement of the transition form factors for the $\gamma^* \to \gamma P$ processes, where P is a pseudoscalar meson (π^0, η, η', η_c). Form factors are measured in the two-photon reactions $e^+e^- \to e^+e^-P$, where one of the final state electrons is scattered at large angle. In 2008, the results on the π^0-meson transition form factor were obtained which are being prepared for publication.

Data analysis is continued on the inclusive charmless semileptonic decays of the B-meson based on the full BABAR statistics of 460 fb^{-1}. The aim of this analysis is to improve the accuracy of the measurement of the Cabibbo-Kobayashi-Maskawa matrix element $|V_{ub}|$.

Laboratory staff members are involved in the design and development of a energy calibration system for $c-\tau$ factory BEPC-II at IHEP of Chinese Academy of Sciences

(Beijing) based on the Compton backscattering. The main objective of the system is to ensure the collider beam energy measurement with relative accuracy of about 10^{-5} needed for the τ-lepton mass measurement. In 2008, the optical part of the system has been installed at BEPC-II. In the same year, laser-to-vacuum insertion system was designed which ensures entering of the laser beam into the collider vacuum chamber. The manufacturing of the system has began.

4. Developments in experimental methodics.

In 2008, work was continued on the development of X-ray detectors. The first detector from the OD-3M series with new electronics has been assembled and transferred for testing. Preparations are under way to build two more new OD-3M detectors.

In 2008, the SND group published nine papers including electronic preprints, eight papers were presented at international conferences, three were presented at the scientific session of the Nuclear Physics Division of Russian Academy of Sciences. The laboratory has nine 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, A.D. Bukin, D.A. Bukin, M.A. Bukin, A.V. Vasiljev, V.M. Vesenev, E.P. Volkova, V.B. Golubev, T.V. Dimova, V.P. Druzhinin, 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 masses. The detector consists of the following systems (Fig. 1): vertex detector, drift chamber, aerogel Cherenkov counters, time of flight scintillation counters, barrel electromagnetic calorimeter based on liquid krypton, end cap electromagnetic calorimeter based on CsI crystals, superconducting solenoid, muon system, tagging system and luminosity monitor.

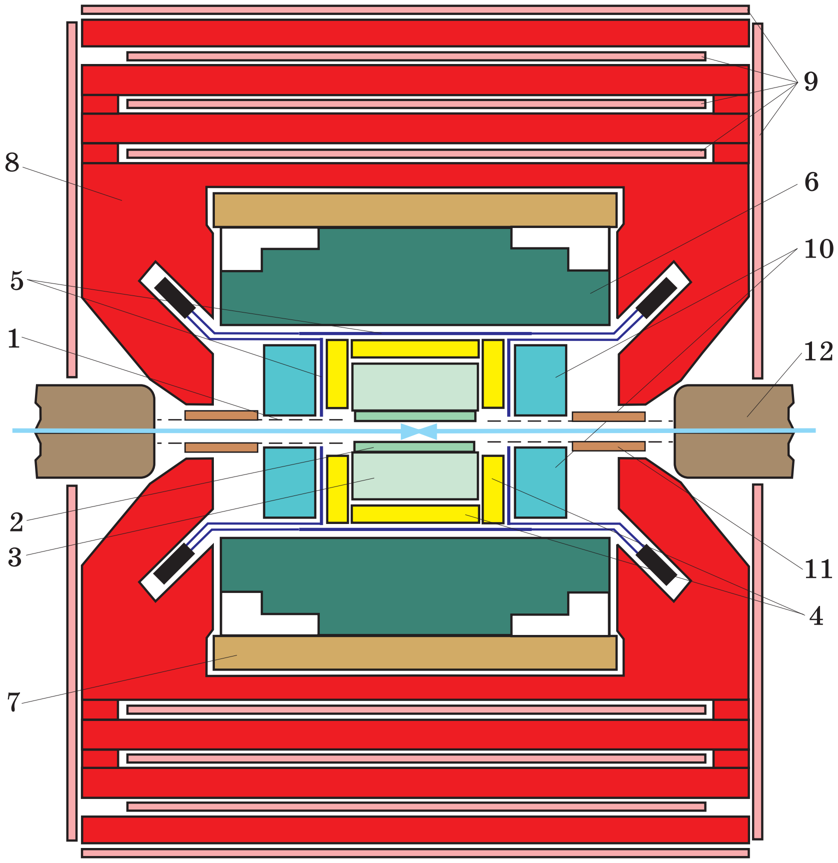


Figure 1: The KEDR detector. 1 — vacuum tube of the collider, 2 — vertex detector, 3 — drift chamber, 4 — aerogel Cherenkov counters, 5 — time of flight counters, 6 — liquid krypton barrel electromagnetic calorimeter, 7 — superconducting solenoid, 8 — magnet yoke, 9 — muon chambers, 10 — end cap electromagnetic calorimeter based on CsI crystals, 11 — compensating solenoids, 12 — quadruples.

Vertex detector. The vertex chamber of the KEDR detector (vertex detector, VD) is placed between the main drift chamber and the collider vacuum chamber. Its purpose is to increase the solid angle coverage of the coordinate system up to 98%. VD consists of 312 cylindrical drift tubes with the length of 670 mm and the diameter of 10 mm mounted in 6 concentric layers around the vacuum chamber. The drift tube is made of a cylindrical cathode (20 μm thick one-layer aluminized mylar) filled with a gas mixture, and a central anode wire. The tubes are operated in the proportional mode and allow the determination of the charged track distance to the center of the tube by measuring the drift time of the ionization. This design features a small radiation thickness along the track path (about 0.2% of the radiation length). The amplitude of the signal and the coordinate along the tube are not measured. As a gas mixture, argon with the admixture of 30% of carbon dioxide under 0.1 atm over pressure is currently used.

For the reconstruction of charged tracks, the information from the VD is combined with the drift chamber data. In addition, the VD hits are used in the decision of second-level trigger which allows to suppress the fraction of the background events. The spatial resolution of the VD using cosmic tracks is 170 μm. The resolution is limited by the crosstalk hit probability.

Drift chamber. The drift chamber of the KEDR detector has cylindrical shape, its length is equal to 1100 mm, an inner radius is 125 mm, an external radius is 535 mm. Jet type cell with six anode wires is used in the drift chamber. Distance of the drift is about 30 mm. Clean dimethyl ether (DME) is used as the working gas. Usage of the DME in the cell of our type with the large drift distance, in which coordinate resolution is limited by diffusion, made it possible to obtain the average spatial resolution better than 100 μm.

Chamber contains about 32000 wires, 1512 of them are sensitive. The length of the wires is 970 mm. Wires forms seven super-layers of the cells — four axial with the wires parallel to the axis of beams and three stereo with the angle of slope of wires in the axis of the chamber ±100 mrad for measuring the coordinate along the wire. In total there are 42 measurements of coordinate and ionizing losses for the particle intersecting entire chamber. Solid angle for the particles passing through three super-layers is 87% and decreases to 70% for the intersection of all seven super-layers.

The designed momentum resolution with the measurement only in the DC in a magnetic field of 1 T with 42 measurements of coordinate with the accuracy of 100 μm and the measuring base of 370 mm is equal to:

$$(dP_\perp/P_\perp)^2 = (0.004)^2 + (0.01 \times P_\perp)^2,$$

where $P_\perp$ is particle transverse momentum in GeV/c.

With established in this season magnetic field of 0.6 T and because of the shorts in seventh super-layer, which substantially decreased the measuring base, achieved resolution is

$$dP_\perp/P_\perp = 0.08 \times P_\perp.$$

With 42 measurements of ionizing losses designed resolution on dE/dx is 10.3%, that ensure π/K separation up to 600 MeV/c and K/p separation up to 1200 MeV/c at the 2 r.m.s. level.

Aerogel Cherenkov counters. Threshold aerogel counters of the KEDR detector are made of aerogel with the refractive index of 1.05 as a Cherenkov radiator. This gives the possibility to separate π- and K-mesons with momenta from 0.6 to 1.5 GeV/c. The light collection is performed with the help of wavelength shifting bars where Cherenkov light is reemited, captured into the angle of total internal reflection and transported to the photodetector (ASHIPH method). The ASHIPH system of the KEDR detector contains 160 counters in two layers. The counters are arranged in such a way that a particle from the interaction point with a momentum above 0.6 GeV/c should not cross the shifters of both layers. At the same time most of the particles will cross two counters in good conditions. For such particles the identification power will be higher.

Time-of-flight system. The time-of-flight system of the KEDR detector consists of 32 barrel and 64 end cap counters covering 95% of the total solid angle. The each barrel counter is equipped with two photomultipliers, that guarantees detection more than 99% of charged particles. The full set of system parameters calibrations give the possibility to reconstruct the particle time of flight with the accuracy close to designed one. The barrel counters have mean time resolution of 350 ps, end cap — 320 ps. Such time resolution gives the possibility to separate π and K mesons up to 680 MeV/c momentum.

Liquid krypton barrel electromagnetic calorimeter. The LKr calorimeter is the set of cylindrical ionization chambers with a liquid krypton as working media. The inner radius of the calorimeter is 75 cm and the thickness of th active zone is 68 cm (14.8 radiation length). The total amount of a liquid krypton is 27 tons. The electrodes of the ionization chambers are made of with the thickness is 0.5 mm coated by copper foil. The anode-cathode gap of chambers is 19.5 mm and high voltage is about 1 kV. The signal is read out from high voltage electrodes divided into rectangular pads forming towers oriented towards the interaction point. Radially all the towers are divided into three sections. The eight grounded electrodes of the first section are divided into strips for the precise photon coordinates measurement. The total number of electronics channels is 7204; 2304 are in towers, 4936 — strips.

The calorimeter energy resolution for large energy scale was measured on the e^+e^- scattering events and the value is $3.0 \pm 0.1\%$. The expected energy resolution is 2.3 %. There is the clean peak from decays of the neutral π-meson in the two photon mass spectrum measured by LKr calorimeter. The invariant mass resolution of the calorimeter for the π^0 is 9.5 ± 0.5 MeV (Monte Carlo gives 8.5 MeV). The spatial resolution for minimum ionization particles was measured on the cosmic events and the value is $0.7 \div$ $\div\, 0.8$ mm in accordance with the expectations.

The end cap electromagnetic calorimeter based on CsI crystals. The end cap calorimeter of the KEDR detector based on CsI(Tl) crystals consists of 2 end caps divided four quadrants each. The calorimeter thickness is 300 mm which is equal to 16.2 rad. length. The total number of scintillation crystals is 1232, including 1184 crystals of $60 \times 60 \times 150\,\text{mm}^3$ size and 48 crystals of $60 \times 60 \times 300\,\text{mm}^3$ size. The end cap calorimeter covers 21% of total solid angle.

The scintillation light is read out by the vacuum phototriodes coupled with the preamplifiers. Signals from preamplifiers are formed by F15 shapers and digitized by A32 ADCs. The noise of electronics is equivalent to 400 keV per ADC channel.

Muon system. Muon system consists of 88 blocks of streamer tubes arranged in three layers inside the KEDR magnetic yoke. The total number of channels is 544.

Spatial longitudinal resolution is about 3.5 cm. This resolution does not exceed deviation of coordinate, caused by multiple scattering in the detector media for muon with energy 1.5 GeV emitted the from interaction point. The registration efficiency of the one layer is about 95%. This allows us to detect and identify minimal ionizing particles.

Tagging System. The Tagging System (TS) is designed to enhance the detector ability to study the two-photon processes. Such processes are described by a diagram $e^+e^- \to e^+e^- X$, where the system X is originated from two virtual photons emitted by colliding electron and positron. This mechanism is very close QED process $\gamma\gamma \to X$ which is practically unavailable for a direct observation. Measuring the energies of scattered e^+ and e^- (tagging) one can calculate parameters of the system X even without its reconstruction in the central detector.

The TS includes 8 blocks of drift tube hodoscopes. Each block contains 6 double layers of drift tubes. The tubes have diameter of 6 mm and a spatial resolution about 400 μm. The total number of tubes is 1440.

TS blocks are placed on both side of the interaction point at distances 4–16 meters. The scattering electron and positron deflections in the transverse magnetic field of the collider allow to calculate the energy. The TS can measure the energy of the emitted photon with the resolution of (0.2–0.5)% in the region of 50–1000 MeV. An invariant mass resolution for the system is about 5–10 MeV for masses around 1 GeV.

Luminosity Monitor. The instant measurements of the collider luminosity are performed by the luminosity monitor system (LM) through the measurement of the single bremsstrahlung radiation rate ($ee \to e^+e^-\gamma$). Gammas from electron and positron beams with the energy more than 300 MeV are detected with the help of two scintillator-lead sandwiches ($18X_0$ thickness). Each sandwich consists of 4 modules and is read by 16 PMTs. The whole system has 40 readout amplitude channels. For beam position measurement two coordinate wire chambers with inductive readout are used. Gamma quanta from single bremsstrahlung events convert in the lead with the thickness of 2 mm, electrons and positrons are detected with coordinate counters.

The designed energy resolution is about 4% at 1 GeV. The present energy resolution is 6–7%. This is enough for experiments in the energy region of the ψ resonances. The relative accuracy of the luminosity measurements is 3–4%, absolute is about 5%. Regular measurements and corrections of the beam orbit ensure the stability of the luminosity measurement better than 5%.

Trigger. The goal of the trigger system is the on-line selection of interesting events at acceptable rate of background events. The trigger of the KEDR detector has two levels. The primary trigger (PT) receives inputs from the time-of-flight scintillators, from the barrel and end cap electromagnetic calorimeters. For the secondary trigger (ST) in addition to these systems signals from the drift chamber, the vertex detector, the muon system and from the scattered electrons tagging system are used. Signals from the systems are used to produce "arguments" of the trigger. The PT and ST conditions are logical sum of logical products of these arguments. The decision time is 450 ns for PT and 18 μs for ST.

Cryogenic supply system. The KEDR cryogenic supply system has operated in 2008 with a full project power. It has provided a workability for all cryogenic components of the KEDR in experiments with VEPP-4M e^+e^- collider. The main cryogenic elements of the KEDR detector is the calorimeter based on a liquid krypton and the superconducting solenoids.

The central electromagnetic calorimeter has been filled by 27 tons of liquid krypton and being stabilized permanently in a temperature region of 119–120 K for a long time, more then three years.

The storage and the delivery of a liquid nitrogen is carried out by means of two storage tanks with a total capacity of more then 100 tons. One tank is used as a gas-producing machine to provide a warm gaseous nitrogen to blow on end caps of the KEDR drift chamber. This essentially improves its technical characteristics.

The KEDR superconducting magnet system is based on a liquid helium. It consists of the main and two compensating solenoids. The magnetic field in the main solenoid is 0.6 T and in the compensating solenoids is 2.35 T.

The helium refrigerator provides liquid helium consumption up to 1100 liters per day, in a mode of throttling. The piston type expander machine reduces the consumption down to 600 liters per day. Completed in 2005 upgrade of vacuum system of helium delivery lines as well as replacement of defective elements of the expander machine provided a record-breaking low consumption of liquid helium per day: down to 400 liters.

1.4 KEDR main results in year 2008

During 2008 the KEDR detector have collected data in the energy region of the J/ψ resonance.

Recorded luminosity integral was approximately 1.7 pb^{-1} and 1.3 pb^{-1} of them was recorded in J/ψ-peak.

In 2008 the KEDR collaboration have obtained and published the preliminary results on the τ lepton mass measurement based on full statistics. The new results have been obtained for neutral D-meson, J/ψ, $\psi(2S)$ and $\psi(3770)$-meson mass measurements, $J/\psi \to \gamma\eta_c$ branching fraction measurement and $\Gamma_{ee}\cdot\mathrm{Br}(\psi(2S) \to \tau^+\tau^-)$, $\Gamma_{ee}\cdot\mathrm{Br}(\psi(2S) \to \mu^+\mu^-)$, $\Gamma_{ee}\cdot\mathrm{Br}(J/\psi \to e^+e^-)$, $\Gamma_{ee}\cdot\mathrm{Br}(J/\psi \to \mu^+\mu^-)$ products measurements.

1.4.1 τ lepton mass measurement

The main goal of experiment was precise τ lepton mass measurement. The precise measurement of τ lepton mass together with the known values of its time of life and decay probabilities into electron, neutrino and anti-neutrino helps to test the hypothesis of lepton universality — one of the main postulates in the weak interactions theory.

At the start of the our experiment τ lepton mass was measured with 0.5 Mev precision by only BES experiment. The measured cross section of $e^+e^- \to \tau^+\tau^-$ versus beam energy and the fit is shown in Figure 2. The preliminary result based on 14.3 pb^{-1} of data is

$$M_\tau = (1776.81^{+0.17}_{-0.19} \pm 0.15)\,\mathrm{MeV}\ \text{(preliminary)}.$$

The data collected at the $\psi(2S)$ peak (about 0.8 pb^{-1}) were used to determine the product $\Gamma_{ee} \times \mathrm{Br}(\psi(2S) \to \tau\tau)$:

$$\Gamma_{ee}^{\psi(2S)} \times \Gamma_{\tau\tau}^{\psi(2S)} / \Gamma = (8.0 \pm 2.2)\,\mathrm{eV}\ \text{(preliminary)}.$$

In Figure 3 is shown the comparison with the other experiments. The grey line denotes PDG average and error for τ lepton mass measurement. The new KEDR result is the most precise.

The preliminary results were presented at the International Workshop on e^+e^- collisions from φ to ψ (Frascati, Italy), the 10-th International workshop on τ lepton physics (Novosibirsk, Russia), the International Workshop on Heavy Quarkonia 2008 (Nara, Japan), and at the Nuclear Physics Division of Physical Sciences Department of RAS conference 2008.

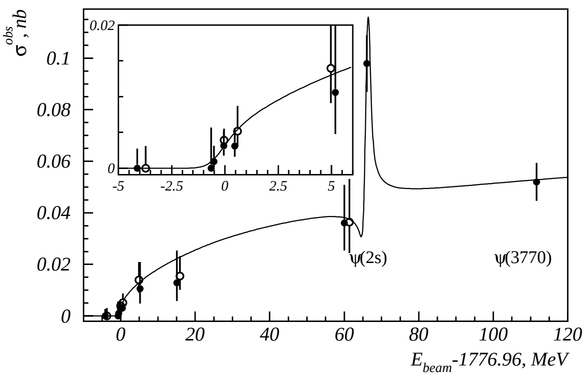


Figure 2: $e^+e^- \to \tau^+\tau^-$ cross section

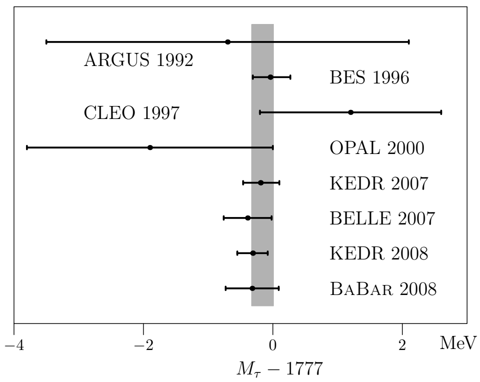


Figure 3: τ lepton mass

1.4.2 J/ψ and $\psi(2S)$ mass measurement

Several scans of J/ψ (in 2005) and $\psi(2S)$ (in 2004 and 2006) were performed during τ lepton mass measurement experiments to control beam energy spread. The new preliminary results on J/ψ and $\psi(2S)$ mass confirm the our recent results obtained in 2003 that were included in the PDG average.

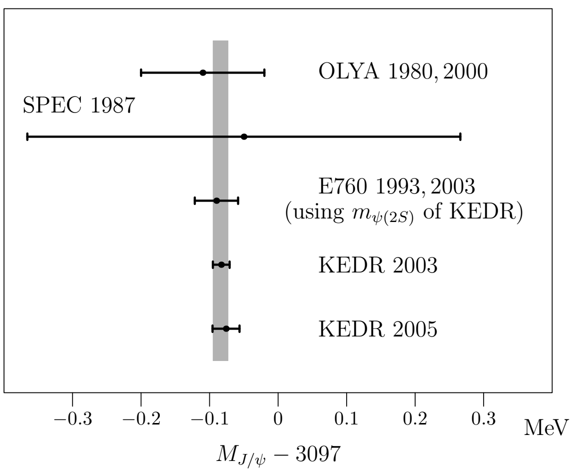


Figure 4: J/ψ-meson mass

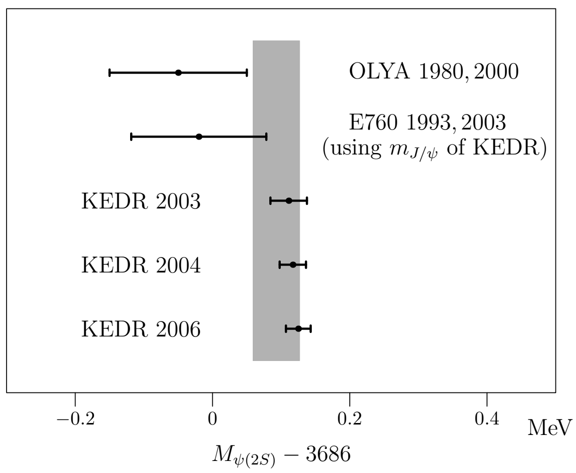


Figure 5: $\psi(2S)$-meson mass

In Figure 4 is shown the comparison of the new J/ψ-meson mass measurement with the other experiments. The grey line shows PDG average and error for J/ψ-meson mass. The preliminary results were presented at the International Workshop on Heavy Quarkonia 2008 (Nara, Japan).

In Figure 5 is shown the comparison of our new $\psi(2S)$-meson mass measurements with the other experiments. The grey line shows PDG average and error for $\psi(2S)$-meson mass. The new $\psi(2S)$ mass measurements are the most precise at present time. Taking them into account the precision of $\psi(2S)$-meson mass knowledge achieves $3.2 \cdot 10^{-6}$ that puts $\psi(2S)$ on the sixth place in the list of the most precisely measured elementary particle masses (Table 1.4.2).

The preliminary results were presented at the International Workshop on e^+e^- collisions from φ to ψ (Frascati, Italy), the International Workshop on Heavy Quarkonia 2008

Particle	$\Delta M/M \times 10^6$
p	0.1
n	0.1
e	0.1
μ	0.1
$\pi^{\pm}$	2.5
$\psi(2S)$	3.2
J/ψ	3.5
π^0	4.5

Table 1.1: Mass measurement precision

(Nara, Japan), and at the Nuclear Physics Division of Physical Sciences Department of RAS conference 2008.

1.4.3 $\psi(3770)$-meson mass measurement

The resonance $\psi(3770)$ was discovered thirty years ago, but its theoretical description is still unclear. The existing models predict parameters of the resonance that differs from the experimental data.

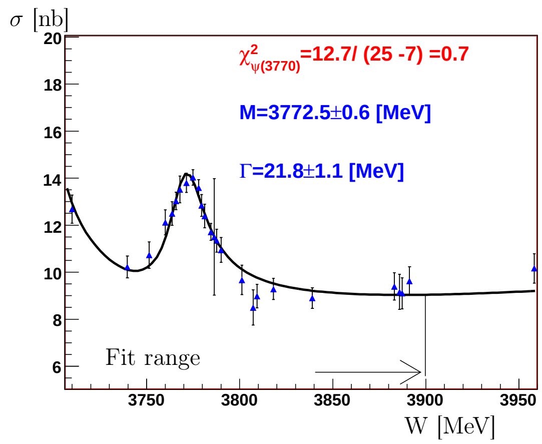


Figure 6: $\psi(3770)$ scan

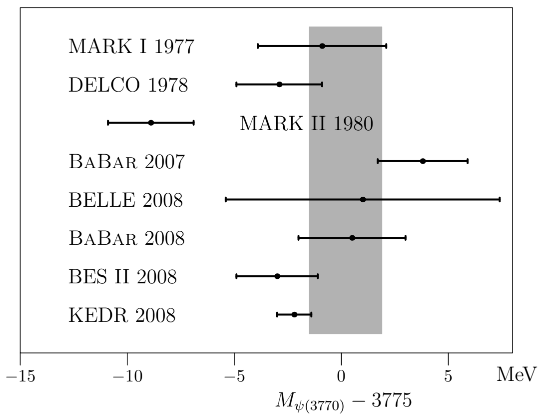


Figure 7: $\psi(3770)$ mass

During 2004 and 2006 the three scans of the $\psi(3770)$ — resonance with the detector KEDR were performed and the integrated luminosity $\int Ldt \approx 2.4$ pb^{-1} was collected. Our preliminary 2008 year result gives $\psi(3770)$ mass as:

$$M_{\psi(3770)} = (3772.8 \pm 0.5 \pm 0.6)\,\text{MeV (preliminary)}.$$

In Figure 7 is shown the comparison with the other experiments. The grey line shows PDG average and error for $\psi(3770)$-meson mass measurement.

The preliminary results were presented at the International Workshop on e^+e^- collisions from φ to ψ (Frascati, Italy), the International Workshop on Heavy Quarkonia 2008 (Nara, Japan), and at the Nuclear Physics Division of Physical Sciences Department of RAS conference 2008.

1.4.4 D meson mass measurement

Neutral and charged D mesons are the lightest states in the open charm systems. The knowledge of their masses is essential as a starting point for the measurement of the masses of exited states. Besides this, the measurement is important to establish the nature of the recently discovered $X(3872)$ state, the mass of which is close to the $D^0 - D^{*0}$ threshold. Before 2007 the world average of D masses was based on the results of ACCMOR, MARK-II, HRS and Photon Emulsion experiments, their precision was about 0.5 MeV. In 2007 the CLEO-c collaboration published the result of D^0 mass measurement with the precision of 0.18 MeV in the analysis of $D^0 \to K_S\varphi$ decay. The analysis of $\psi(3770) \to D\bar{D}$ decays aiming the measurement of neutral and charged D-meson masses has been performed at KEDR experiment. The preliminary values obtained are

$$M_{D^0} = (1865.37 \pm 0.42 \pm 0.27)\,\mathrm{MeV},$$
$$M_{D^\pm} = (1869.39 \pm 0.45 \pm 0.29)\,\mathrm{MeV}.$$

The value of D^0 mass is consistent with the more precise CLEO-c measurement the measurement of the $D^\pm$ mass is presently the most precise direct measurement, and it agrees with the world average value.

In Figures 8 and 9 are shown the comparison with the other experiments for neutral and charged D-mesons, respectively. The grey line shows PDG average and error for D-meson mass measurement.

The preliminary results were presented at the Nuclear Physics Division of Physical Sciences Department of RAS conference 2008.

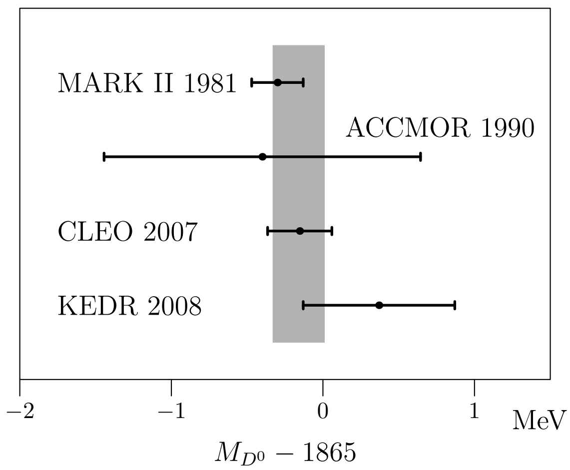


Figure 8: D^0 mass

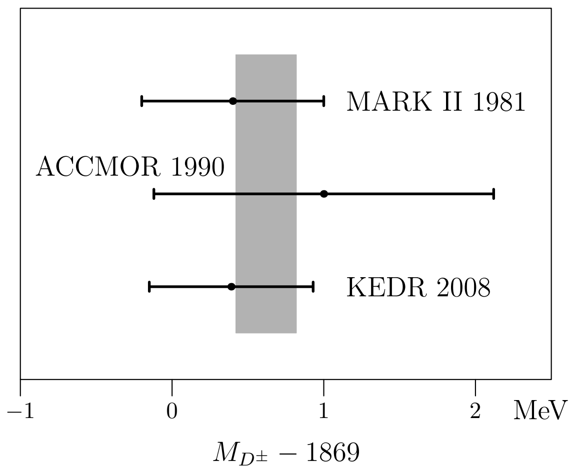


Figure 9: $D^\pm$ mass

1.4.5 $J/\psi \to \gamma\eta_c$ branching fraction measurement

The measurement of the radiative decay $J/\psi \to \gamma\eta_c$ branching fraction is interesting, because there is the strong difference between the theoretical predictions and the experimental data. There are a few measurements performed by Crystal Ball (1986), BABAR (2006), CLEO-c (2008). The measurement of Crystal Ball $(1.3 \pm 0.4)\,\%$ is the most reliable, since inclusive photon spectra had been analyzed. Results of BaBar $(0.8 \pm 0.2)\,\%$ and CLEO $(2.0 \pm 0.3)\,\%$ were obtained in exclusive decays and are in a bad agreement with each other. The branching value obtained by Crystal Ball is notably less than theoretical predictions based on potential models and QCD sum rules $(2.5 \div 3)$ %. At the same time this calculation is considered as quite reliable, so we have evident disagreement with experiment now. Therefore, an additional independent measurement of this branching is necessary, preferably in the inclusive photon spectrum, and this measurement may lead us to understanding of the above difference.

At the moment the KEDR detector have collected $1.6\,\mathrm{pb}^{-1}$ of the integrated luminosity at the J/ψ energy region. Approximately half of it was analyzed and the preliminary result of measurement of decay $J/\psi \to \gamma\eta_c$ branching fraction in an inclusive photon spectrum obtained

$$\mathrm{Br}(J/\psi \to \gamma\eta_c) = (1.1 \pm 0.3)\% \quad \text{(preliminary)}.$$

In Figure 10 is shown the comparison with the other experiments. The grey line shows PDG average and error for $J/\psi \to \gamma\eta_c$ branching fraction.

The preliminary results were presented at the Nuclear Physics Division of Physical Sciences Department of RAS conference 2008.

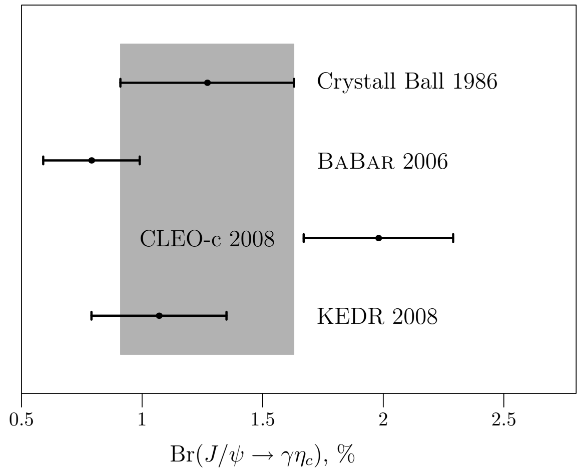


Figure 10: $J/\psi \to \gamma\eta_c$ branching fraction

1.4.6 $\Gamma_{ee} \times \Gamma_{ee\,(\mu\mu)}/\,\Gamma$ for J/ψ meson.

In 2005 J/ψ scan was performed during τ lepton mass measurement for beam energy spread control. This scan was used for determination $\Gamma_{ee} \times \Gamma_{ee}/\,\Gamma$ and $\Gamma_{ee} \times \Gamma_{\mu\mu}/\,\Gamma$. Unlike determination of the branching fractions $\Gamma_{\ell^+\ell^-}/\Gamma$, to get these combinations one needs precise knowledge of the beam energy spread.

Previously $\Gamma_{ee} \times \Gamma_{ee}/\,\Gamma$ was measured in the DASP experiment in 1979 with a precision of about 6%. The value $\Gamma_{ee} \times \Gamma_{\mu\mu}/\,\Gamma = 0.335 \pm 0.007\,\mathrm{keV}$ from PDG is known better. $\Gamma_{ee} \times \Gamma_{\mu\mu}/\,\Gamma$ is based on the results from the CLEO and BaBar ISR-experiments. The KEDR results are in a good agreement with the PDG average.

The final result obtained from J/ψ scan are

$$\Gamma_{ee} \times \Gamma_{ee}/\,\Gamma = 0.3365 \pm 0.0064\,(\mathrm{stat}) \pm 0.0049\,(\mathrm{syst})\ \mathrm{keV}$$
$$\Gamma_{ee} \times \Gamma_{\mu\mu}/\,\Gamma = 0.3360 \pm 0.0052\,(\mathrm{stat}) \pm 0.0061\,(\mathrm{syst})\ \mathrm{keV}$$

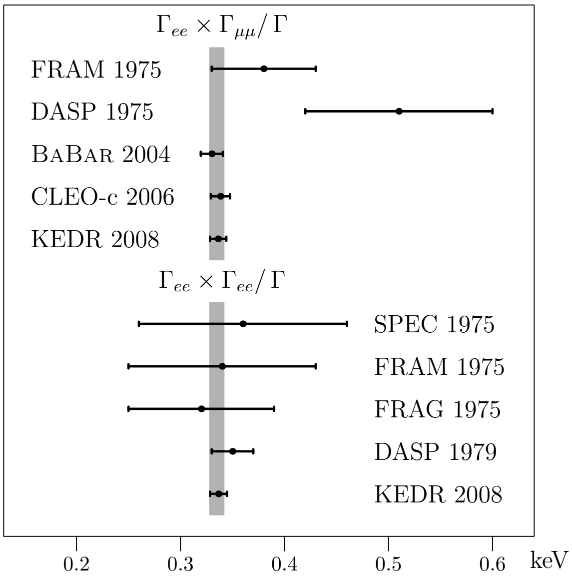


Figure 11: $\Gamma_{ee} \times \Gamma_{ee\,(\mu\mu)}/\,\Gamma$ for J/ψ-meson

In Figure 11 is shown the comparison with the other experiments. The grey line shows PDG average and error for $\Gamma_{ee} \times \Gamma_{\mu\mu}/\,\Gamma$ mass measurement. The new KEDR results are the most precise.

The preliminary results were presented at the International Workshop on e^+e^- collisions from φ to ψ (Frascati, Italy), the International Workshop on Heavy Quarkonia 2008 (Nara, Japan), and at the Nuclear Physics Division of Physical Sciences Department of RAS conference 2008.

1.4.7 $\Gamma_{ee} \times \Gamma_{\mu\mu}/\,\Gamma$ for $\psi(2S)$-meson

The combination of widths $\Gamma_{ee} \times \Gamma_{\mu\mu}/\,\Gamma$ is one of the fundamental resonance's parameters and thus it is important for a theory. It also helps to obtain other resonance's parameters useful for both theoretical and experimental studies.

There is no PDG value of this quantity being measured at the moment. This measurement is more technically complicated than, for instance, measurement of branching. Parameters like widths and branchings of $\psi(2S)$ are calculated by PDG using combined fit of results of several experiments.

The statistics taken at the VEPP-4M collider and the KEDR detector in 2004–2007 has been analyzed. Total integral luminosity accounted for more than $2.2\,\mathrm{pb}^{-1}$. In Figure 12 is shown the example of $e^+e^- \to \mu^+\mu^-$ cross section in the region of $\psi(2S)$. In Figure 13 is shown values of $\Gamma_{ee} \times \Gamma_{\mu\mu}/\,\Gamma$ obtained from different statistic intervals. Grey line is the final result.

Preliminary result for $\Gamma_{ee} \times \Gamma_{\mu\mu}/\Gamma$ for $\psi(2S)$ is obtained:

$$\Gamma_{ee} \times \Gamma_{\mu\mu}/\,\Gamma = (17.4 \pm 0.44 \pm 0.7)\,\mathrm{eV}.$$

Using PDG value for Γ_{ee} one could get

$$\mathrm{Br}(\psi(2S) \to \mu^+\mu^-) = (79 \pm 2 \pm 5) \cdot 10^{-4}$$

while PDG fit value is

$$B(\psi(2S) \to \mu^+\mu^-) = (74 \pm 8) \times 10^{-4}.$$

The preliminary results were presented at International Workshop on e^+e^- collisions from φ to ψ (Frascati, Italy), International Workshop on Heavy Quarkonia 2008 (Nara, Japan), and at Nuclear Physics Division of Physical Sciences Department of RAS conference 2008.

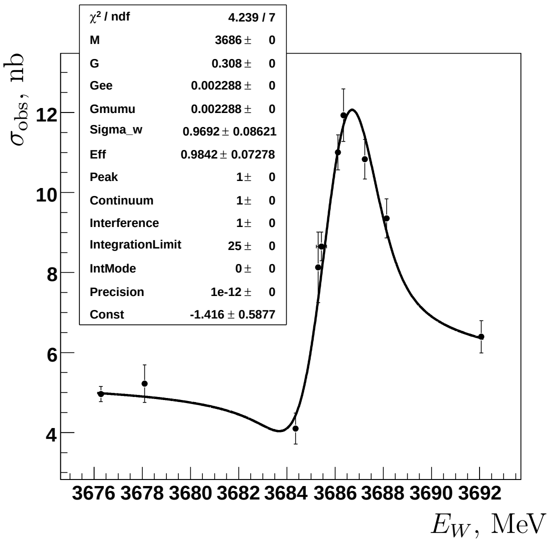


Figure 12: $e^+e^- \to \mu^+\mu^-$ cross section

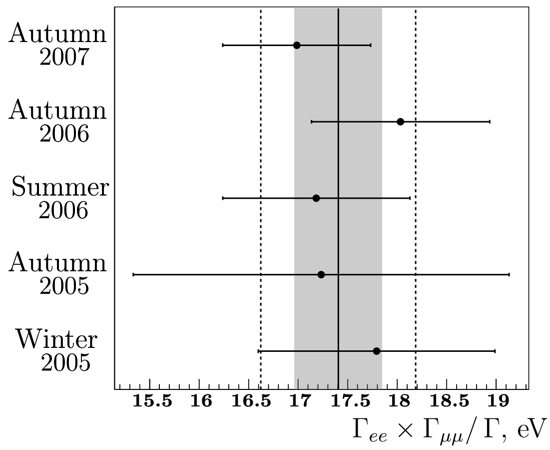


Figure 13: $\Gamma_{ee} \times \Gamma_{\mu\mu}/\Gamma$ for $\psi(2S)$-meson

1.5 Detectors for HEP

In 2008, as in the previous year, in the field of KEDR detector electronics the main efforts were concentrated on the maintenance of continuous around-the clock operation of the detector electronic circuits. The work of the detector KEDR electronics was reduced mainly to the current repair works. In 2008, the development and construction of equipment for the scattered electron system of the detector KEDR. At present, the system is being introduced into the detector data accumulation system. The work on the electronics upgrade for various systems of the SND detector is completed. Starting from the Summer of 2007, the calorimeter electronics is operated in a full scale in measurements of VEPP-2000 luminosity.

For the CMD-3 detector electronics, the production of boards of digitizing electronics are nearing to completion and the major part of them is either tuned or put into operation.

1.6 X-ray detectors

In 2008, a series of experiments have been performed on the dynamics of explosions and measurements of sample parameters at SR channel with the use of one-coordinate detector DIMEX-1 for 256 channels. One more 512 channel detector is manufactured in a new housing more convenient for its maintenance. The detector used the printing board of electronics with the strip structure applied for the detector.

In 2008, we continued the work on the OD-4 detector for experiments on wide-angle scattering with SR. In OD-4, instead of wire structure, as, for example, in OD-3, we used a multi-stage gas electron multiplier (GEM) that enables us in addition to the high gas amplification (over 10000) to construct the detector in the form of an arch with an arbitrary angular aperture. A 256 channel detector prototype is produced.

In the frame of upgrade of the OD-series detectors aimed at improvement of their reliability, we produced, tested and delivered to the customer the one-coordinate X-ray detector of next generation – OD-3M.

1.7 Other works:

Within the frame of the international Projects, the staff of Lab. 3-12 continued its active participation in the works related to the upgrade of the BELLE detector data collection system (KEK, Japan). The first prototypes of a new electronics are produced in Japan and tested: for the calorimeter barrel part – based on crystals CsI(Tl) and for the end part – on crystals of pure CsI. At the end of 2008, some samples of a new electronics in VME standard have been produced by our design in S.Korea and delivered to KEK (Japan), where they are presently being tested.

Publications:
[141], [142], [148],[149].

The staff of Lab. 3-12 are the co-authors of over 10 publications within the frame of the BELLE Collaboration (KEEK, Japan).

1.8 Micro-Pattern Gaseous Detectors (MPGDs)

The development of detectors based on Gas Electron Multipliers (GEMs) was continued in 2008. The work was conducted in several directions:

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

2) Upgrade of the KEDR tagging system.

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

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

1) The overall objective of the cryogenic avalanche detectors project is to advance neutrino, dark matter and medical imaging techniques through the development of specialized devices based on Gas Electron Multipliers (GEMs) operated 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 in noble gases at cryogenic temperatures in the gaseous and two-phase (liquid-gas) modes. The GEM-based cryogenic avalanche detectors might be used in the field of coherent neutrino-nucleus scattering using two- phase Ne, Ar and Xe, solar neutrino detection using two-phase or high-pressure He and Ne, dark matter searches using two-phase Ar and

Xe, Positron Emission Tomography (PET) using two- phase Xe, and digital radiography using two-phase Ar and Kr.

In 2008 the works with the cryostat with 2 l chamber operated with two-phase Ar at temperature 84−87°K, inside which the triple-GEM was installed, were continued. The works with the cryostat with 10 l chamber were also continued. The results obtained by the end of 2008 are summarized below.

For the first time the successful performance of thick GEMs in a two-phase Ar avalanche detector has been demonstrated. Three types of thick GEMs were studied: GEM based on G10, GEM based on Kevlar and resistive electrode GEM. Only G10 based thick GEM showed a stable performance in the two-phase mode. The operation of the thick GEM in two-phase Ar with gain reaching 3000 and with the detection threshold of 20 electrons. The noise rates of thick GEMs were also measured. Using the pulse-shape analysis, the noise rate was managed to be reduced down to 0.007 Hz per square cm.

In 2008 the first batch of Russian thick GEMs based on G10 was produced at the printed circuit board division.

The study of electron emission properties of two-phase Ar avalanche detectors has been started.

Assembling of experimental setup of the two-phase detector with a 10 l cryogenic chamber has been accomplished. The setup includes the gas system, the system of liquid nitrogen supply and the vacuum system.

The studies of cryogenic avalanche detectors will be continued in 2009.

2) The system of tagged electrons is a substantial part of the KEDR experiment; it allows for detecting electrons scattered from the colliding point at small angles. These electrons characterize photon-photon interaction and their detection and the measurement of their monemtum is an important physical task. The existing system of tagged electrons based on drift tubes have a limited spatial resolution; it measures the particle coordinate in one direction only which substantially restricts the signal/background separation capability. To obtain the ultimate momentum resolution of scattered electrons and to improve signal/background separation, it was suggested to place detectors based on triple-GEM with two-coordinate readout in front of each of 8 system stations. These detectors allow to measure the coordinate in the beam orbit plane with $\sim$ a 0.1 mm resolution. In the perpendicular direction the spatial resolution will be $\sim$ 0.25 mm in the region of $\pm$1cm near the orbit and about $\sim$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.

In 2008 at the dedicated test setup the basic properties of GEM-based detectors were studied using cosmic rays: the spatial resolution and the detection efficiency. The measured spatial resolution of the detector in the direction corresponding to the plane of the beam orbit made up 73 microns (standard deviation), while the efficiency on the plateau was 98%. By November 2008 all the detectors were installed at VEPP-4M and the system commissioning in the whole was done. The system operation in frame of the acquisition system of the KEDR detector was debugged. At the moment the detectors tuning and the study of their parameters in the real experimental environment at the accelerator is being conducted. During the 2008-2009 winter run the combined operation of the GEM-based detectors and the old tagged system is planned.

3) In 2008 the MPGD group of the Budker Institute entered the international collaboration RD51 at CERN for the development of MPGDs, created in 2008. Our group participated in all stages of the collaboration proposal preparation.

4) In 2008 we continue to participate in the R&D of detectors for the TPC of Linear Collider. The multi-GEM structures are currently considered to be the most promising candidates for the TPC endcap detector.

The following people of Lab. 3 participated in the work:
V.M. Aulchenko, N.S. Bashtovoy (Lab.2), A. E. Bondar, A. F. Buzulutskov, A. A. Grebenuk (Lab. 2), D.V. Pavlyuchenko, L. I. Shekhtman, R. G. Snopkov, Y. A. Tikhonov, V. V. Zhulanov.

The work is reflected in the following papers and reports:
[246], [259], [302], [306a].

1.9 Participation in the Belle experiment

The BINP group has been actively taking part in the Belle project since its very beginning in 1994. The collaborators from the Budker Institute made an essential contribution to the construction of the electromagnetic calorimeter of the Belle detector at the stage of its design as well as to the production of the elements for this world largest calorimeter based on CsI(Tl) monocrystals, to the assembling and adjustment of the calorimeter.

During 2007-2008, the Belle detector continued collecting statistics and processing the experimental information. The collider luminosity has exceeded the design value and reached 1.71×10^{34} cm^{-2} s^{-1}, and the integrated luminosity has exceeded 850 inverse femtobarn by the end of 2008. At present, KEKB is a unique facility with a record luminosity allowing to obtain new physical results. The beams in the KEKB storage rings collide at the angle of 22 mrad. A way to increase luminosity is to provide head-on beam collisions in the center-of-mass frame feasible with the help of specific crab cavities. The developement of the crab cavities continued for a few years, and they were installed at the B-factory in winter of 2007. This is one of the steps toward the construction of the super B-factory.

In 2008, new interesting results on the measurement of CP-violation parameters in B-meson decays were obtained, new decay modes of B-mesons and new particles were discovered. For example, the observation of the first entirely leptonic B decay into tau and antineutrino was confirmed using the experimental data on the decays of 657 million $B-\bar{B}$ pairs. This measurement was performed using a new method and yielded the value of the decay probability of $Br(B \to \tau\nu) = 1.65^{+0.38}_{-0.37}(stat.)^{+0.35}_{-0.37}(syst.) \times 10^{-4}$ which is consistent with the previous measurement.

The forward-backward asymmetry was first discovered in the $B \to K^*l^+l^-$ decay in 2008 at the B-factory. Within the Standard Model (SM), this process is described by an electroweak 'penguin' amplitude. The obtained asymmetry values are somewhat higher than those predicted by the SM which may be a manifestation of new physics.

The researchers from the BINP SB RAS actively participate in the detector work and the processing of the experimental data. The BINP group contributes to various studies of three- and four-particle B-meson decays as well as of processes with production of charmed particles. The work on the study of the process $B \to D\pi\pi$ was carried on, where production of excited states with open charm, D^{**+} mesons, was observed. The results of this analysis were published in the journal Physical Review and reported at various international conferences.

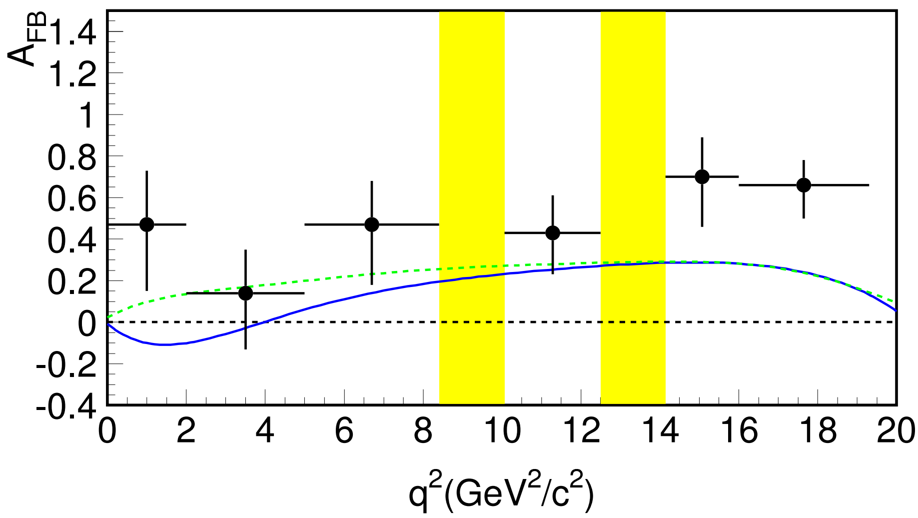


Figure 1: Asymmetry as a function of q^2. The curves correspond to the SM prediction with different parameters.

The analysis of the experimental data on the measurement of the mixing angle φ_3 was continued in the years 2007-2008 using the new available statistics of the Belle experiment (around 400 million B-mesons). Three decay channels with the three-particle final state $D \to K_0\pi^+\pi^-$ have been used in the analysis: $B \to DK$, $B \to D^*K$, and $B \to DK^*$. A larger number of events compared to the previous Belle analysis was used in this study resulting in the improvement of the statistical error, the event selection procedure and the statistical analysis, as well as to the improvement of the systematic uncertainties. A paper based on the results of this analysis was published in the journal Physical Review D.

In addition to B-physics, B-factories offer an opportunity to obtain high-precision results on τ-lepton decays. The BINP researchers have performed an analysis of the three-particle decay $\tau^- \to K_S\pi^-\nu$, meauring the probability of the decay $B(\tau^- \to K_S\pi^-\nu) = (0.404 \pm 0.002(stat.) \pm 0.012(syst.))$ with a significantly higher accuracy than before, and studying the spectrum of intermediate states. The contributions of the $K^{*-}(892)$, $K_0(800)$ and the presence of heavier excited states were discovered in the spectrum of two-particle $K_S\pi$ states.

The large integrated luminosity collected at the Belle detector allows to observe new particles and measure their parameters. For example, the $\Upsilon(4260)$ state, previously observed in the BaBar experiment, and a new state with the mass around 4 GeV and a large width were discovered in the $e^-e^+ \to J/\psi\pi^+\pi^-$ channel. Events with double charmonium production have been observed where new non-typical charmonium-like states $X(3940)$ and $X(4160)$ have been discovered.

In addition to data analysis, the BINP phisicists are responsible for the calibration of the calorimeter and the luminosity measurement. The high statistical accuracy of the data collected at the facility imposes strong requirements on the uncertainties of the luminosity measurements and the calibration of the detector systems.

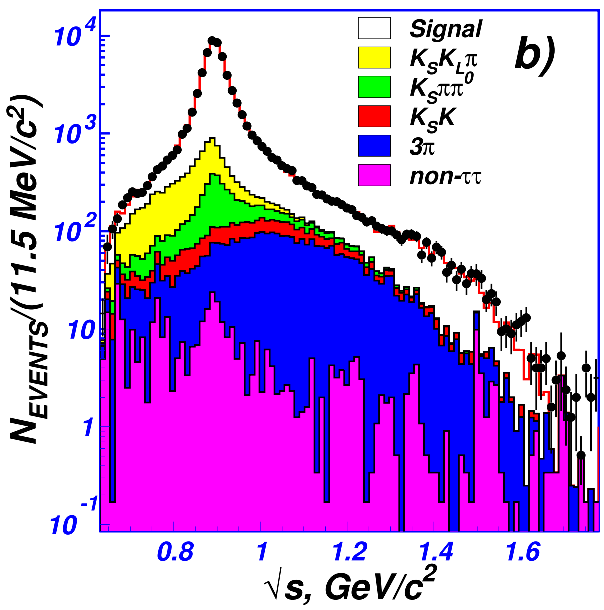


Figure 2: $K_S\pi$ invariant mass spectrum in the decay $\tau^- \to K_S\pi^-\nu$.

The measurement of the branching ratio $\mathcal{B}(D^0 \to \pi^+\pi^-\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+\pi^0) = (10.12 \pm 0.04(\text{stat}) \pm 0.18(\text{syst})) \times 10^{-2}$ has been performed using a 532 fb^{-1} data sample of the Belle detector, where the $D^0 \to K^-\pi^+\pi^0$ mode was used as the normalization to avoid a significant amount of uncertainties due to the detection of charged particles. The accuracy of this measurement is comparable with the world average one. This measurement is the first step of the high-precision Dalitz analysis of the $D^0 \to \pi^+\pi^-\pi^0$ decay which will allow to determine the S-wave contribution in the $\pi^+\pi^-$ channel in D-meson decays. A detailed study of $D^0 \to \pi^+\pi^-\pi^0$ along with other CP-symmetric final states of D^0 can be used to improve a statistical accuracy of the measurement of the γ angle of the Cabibbo-Cobayashi-Maskawa matrix. The value of the CP-asymmetry in the $D^0 \to \pi^+\pi^-\pi^0$ decay has also been measured: $A_{CP} = (0.43 \pm 1.30)\%$. The latter is consistent with zero which corresponds to no CP violation. The accuracy of the measured CP-asymmetry is significantly higher than that of the previous measurements. The results were published as Phys.Lett.B662:102-110,2008.

At the next stage of the B-factory operation it is planned to upgrade the detector as well as the collider in order to increase the luminosity of the facility up to 5×10^{35} cm^{-2}s^{-1}, making feasible measurements of all angles of the unitarity triangle with the accuracy of several percent, and may be observation of effects beyond the Standard Model. The BINP group takes part in the hardware development aimed at the upgrade of the calorimeter.

In 2008, new electronics chips for the barrel calorimeter, enabling continuous digitalization of the signal from scintillation counters, were produced and tested in Japan. Continuous digitalization allows to measure an amplitude, time and quality of the signal. 10 such modules have been assembled and tested. In summer 2008, these modules were installed into the data aquisition system of the Belle detector for readout from 120 counters. An algorithm of online energy and time reconstruction in the counters has been developed. This algorithm has been tuned and adjusted using the cosmic data, and the calibration constants for each channel have been determined. A special set of experimental data was collected at KEKB in autumn 2008 in order to test the electronics and the algorithm of energy and amplitude reconstruction. The tests shown predictable values and stable functioning of the algorithm.

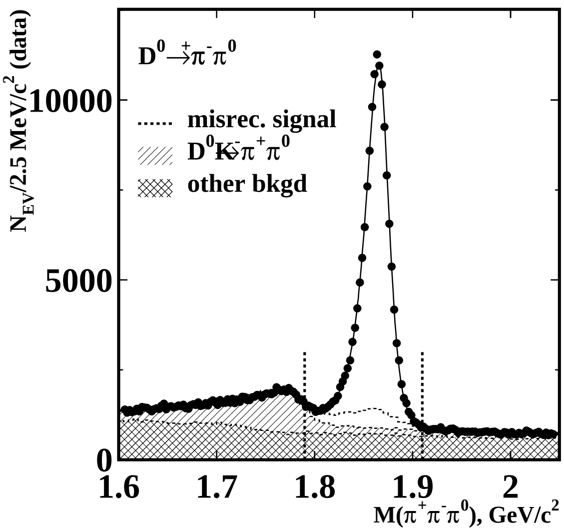


Figure 3: $M(D^0 \to \pi^+\pi^-\pi^0)$ invariant mass: points correspond to the experimental data, solid line - to the sum of simulated signal and different types of background contributions.

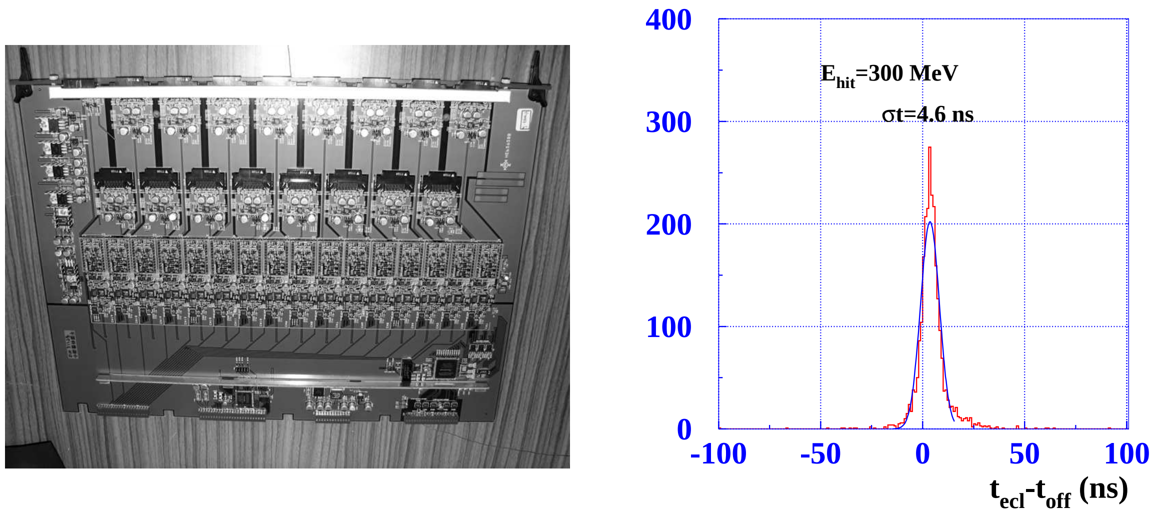


Figure 4: (a) Electronics board for 16 channels. (b) Time resolution for 300 MeV energy output obtained with the new electronics.

The development of the endcap calorimeter, where radiation hardness should be much higher, is based on pure CsI crystals and is underway. The study of radiation hardness of pure CsI crystals has been carried out during 2007-2008. It was shown that the radiation characteristics of the crystals produced in Kharkov satisfy background conditions of the Belle detector.

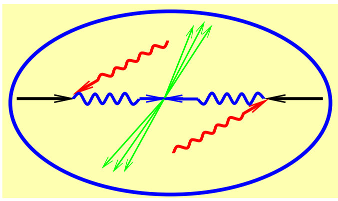
Project participants:
K. E. Arinstein, V. M. Aulchenko, I. V. Bedny, A. E. Bondar, A. N. Vinokurova, N. I. Gabyshev, A. Yu. Garmash, D. A. Epifanov, V. N. Zhilich, V. V. Zhulanov, O. A. Zyukova, P. P. Krokovny, A. S. Kuzmin, A. O. Poluektov, Yu. V. Usov, B. A. Shwartz, V. E. Shebalin, S. I. Eidelman.

1.10 Participation in Particle Data Group

Since 1991 S.I. Eidelman has been participating in the work of Particle Data Group (PDG), an international collaboration performing systematization of the data on various properties of elementary particles.

One of his responsibilities is selection of new publications on experiments and phenomenology of elementary particles involving a regular scan of 26 magazines. In addition, he is responsible for the subgroup of PDG working on unstable hadrons and hadronic resonances. Every second year (on even years) PDG publishes a handbook reflecting progress in the field during two last years while on odd years update is done on the PDG website. Due to efforts of S.D. Belov a so called mirror site of the PDG data base exists on the website of the Budker Institute providing fast access for BINP employees.

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 the middle of 2007 the ILC Reference Desigh Report (RDR) has been published. Owing to a high ILC cost further plans are quite uncertain. In 2008 US and UK have decreased financing of the ILC R&D program. 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, construction in several stages. 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 $2E \sim 160$ GeV, while the Higgs production in $e^+e^- \to HZ$ requires 2E=230 GeV and a positron production system. The International Steering Committee on Linear Colliders (ILCSC) has charged the GDE committee to explore such possibility.

We have performed a preliminary study and repoted our view on this suggestion at the conference ILC08/LCWS08 (as well as have informed the ILCSC)[369]. 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 where one can study better the Higgs decay channels. The photon collider can give additional information such as the Higgs two-photon width.

From a financial and technical points of view, such photon collider is unlikely to be significantly cheaper or easier. As in the e^+e^- case it needs damping rings with small emittances and, in addition, a very sofisticated laser system. Moreover, at 2E=160 GeV and $\lambda = 1/3$ μm, the minimum energy of the final electrons after multiple Compton scattering is only about 2 GeV. They will spiral in the detector magnetic field and hit quads generating backgrounds. There are no such problems at 2E=200 GeV and $\lambda = 1$ μm. The intermediate case, 2E=185 GeV and $\lambda = 1/2$ μm, needs an additional study. Thus, the minimum energy of the photon collider Higgs factory will be not much less than that needed for the e^+e^- collisions.

In any case, the detailed study of such possibility will be very useful for a further advance of the photon collider.

Our participation in the development and promotion of the photon collider in 2008 can be seen from the list of papers and talks at international conferences:

Introduction to the Photon Linear Collider [90].

The photon collider at ILC [365].

Laser cooling of electron beams [366].

Status of the photon collider at ILC [367].

High energy photon colliders [368].

Photon collider before e+e-, has it sense?[369].

Chapter 2

Electro - and photonuclear physics

2.1 Experiments with internal targets

1. As already reported in the previous BINP annual report, in 2007 we performed the first stage of experiments on determining $R = \sigma(e^+)/\sigma(e^-)$ ratio of differential cross-sections for elastic electron-proton and positron-proton scattering. Such an experiment is of interest since it will enable us to determine the contribution of the two-photon exchange (TPE) in the process of the electron-proton elastic scattering. As assumed, data on TPE will enable explanation of the dramatic contradiction in results of recent experiments on measurements of the proton form-factors performed at TJNAF (USA) using the polarization technique with the results of early measurements where the form-factors were extracted from the differential cross-section of the reaction. By now, there is a lot of theoretical publications demonstrating the importance of an account for TPE for the interpretation of the experiments performed by the nonpolarized technique. However, to solve the problem, new experimental data on the two-photon exchange contribution are required.

In addition to the experiment at VEPP-3, measurements of TPE are planned at TJ-NAF (USA), and at DESY (Germany), but their readiness to start data collection is expected not earlier than in 2011.

The analysis of the first stage of the experiment at VEPP-3 confirmed the correctness of the chosen configuration of target and detector, as well as of the measures to suppress the systematic errors. With the collected statistical material we checked the whole data analysis procedure and obtained the intermediate result (see Fig. 1).

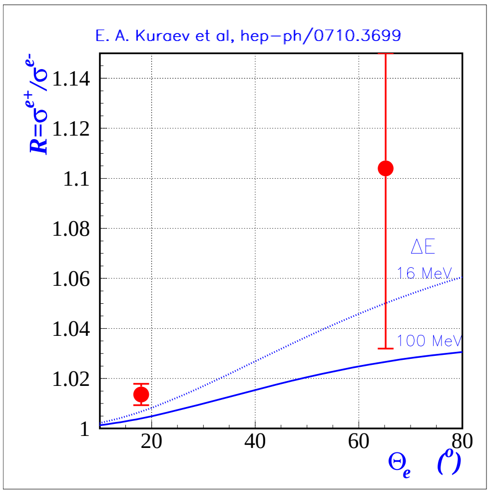


Figure 1: Preliminary results of the 2007 run at VEPP-3 on measurements of the ratio of cross-sections of elastic (e^+p) and (e^-p) scattering. The curves are predictions of Kuraev, et al.

We carried out a number of works aimed at reducing the systematic errors and increasing the data collection efficiency:

• We repaired the Cold Head and cryocooler used for reducing the target temperature. As a result, we attain the stable temperature of $\sim 20°$K at the storage cell.

• We made some changes in the hydrogen supply system in order to minimize the duration of the transient process of establishing equilibrium pressure at the target.

• The degraded anode wires of the drift chambers are replaced, thereby the detection efficiency was improved.

• The vertex chambers are revised to improve their operation stability and detection efficiency.

• The e^+/e^- beam position probes are added.

• New (coordinate) aperture counters are made for the Möller/Bhaba luminosity monitor, and sandwiches are repaired.

For completion of the experiment, the second (main) data taking run at VEPP-3 is required. The continuous collection of statistics during two months will enable an increase of the statistic accuracy by an order of magnitude.

II. Coherent photo-production of a neutral pion at a deuteron γd $\to$ d'π^0 is one of the important processes in nuclear physics, which provides a valuable data on a structure of the pion-nucleon and nucleon-nucleon interactions.

Whereas theoretical studies of this reaction with prediction on the differential cross-sections and on various polarization observables using various approaches to the process description have been carried out for rather long time, the detailed experimental data appeared only recently. Regarding the polarization observables, there are only a few measurements of Σ-asymmetry, but there is no data on T_{2i} (tensor analyzing powers of the reaction).

In 2008 we have carried out an analysis of experimental data on the reaction γd $\to$ d'π^0 which were selected from the statistical material, obtained during the experiment on measurements of T_{2i} in a reaction γd $\to pn$ (deuteron photodisintegration), performed at VEPP-3 in 2003.

Fig.2 shows the detector arrangement in the experiment γd $\to pn$.

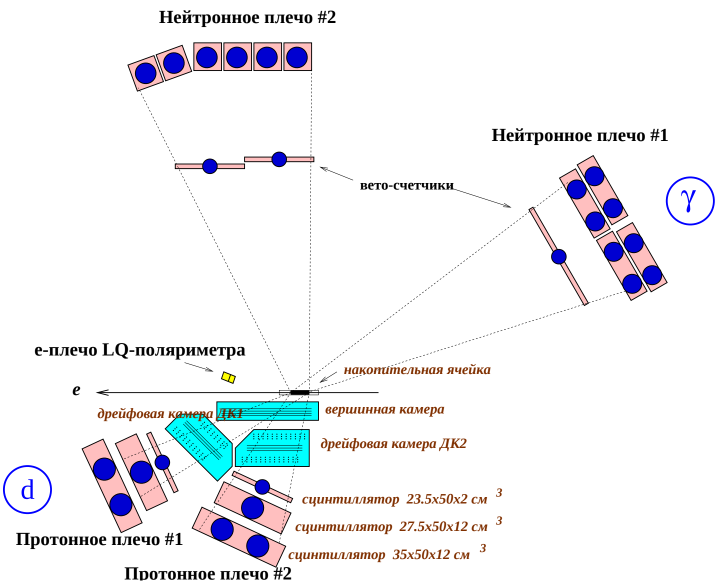


Figure 2: Layout of detectors at the experiment on photo-disintegration of a deuteron (side view). Events of the γd $\to$ dπ^0 reaction were detected by coincidences of the proton arm #1 (deuteron) and a neutron arm #1 (one of gamma-quanta from the neutral pion decay).

Products of the coherent pion production were detected in coincidence: recoil deuteron was detected by the proton arm #1 and one of gamma-quanta from the neutral pion decay

- by the neutron arm #1. At such an experimental setup, in a major part of event the angle of scattered electron is close to zero. In this case the virtual photon is nearly at the mass surface; therefore such a setup can be referred to a study of the pion *photo*-production process.

In contrast to the reaction $\gamma d \to pn$, where momenta of both partners of two-particle reaction are determined, here we have the complete information only for the recoil deuteron. Under assumption of the process $\gamma d \to d'\pi^0$, this is enough for reconstruction of the reaction kinematics, but the question occurs on contributions of other processes whose products could give $(d\gamma)$-coincidences in the detector. For example, these are such reactions of coherent photo-production as $\gamma d \to d'\pi^0\pi^0$, $\gamma d \to d'\eta$, $\gamma d \to d'\pi^0\pi^+\pi^-$. Of these three reactions some experimental data are only available for the photo-production of η meson. However, there are theoretical predictions on the coherent photo-production of pairs of π^0 mesons and on coherent photo-production of η meson. By using this information one can find out the upper estimation, which shows that the contribution into detector rate from these two processes should be low—not higher than $\sim$1%. There is no reason to assume that the process $\gamma d \to d'\pi^0\pi^+\pi^-$ or the coherent photo-production of other mesons (ρ, ω, φ *etc.*) could give a substantially larger contribution.

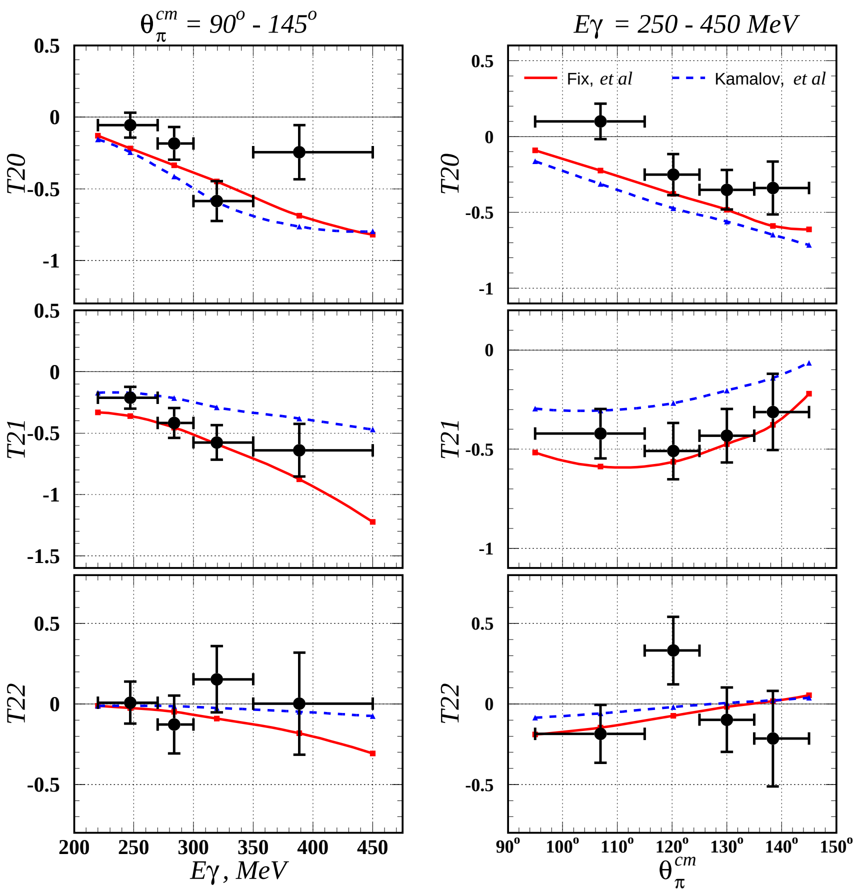


Figure 3: Preliminary experimental results on measurement of the tensor analyzing power components for the reaction $\gamma d \to d'\pi^0$. Left panel - as a function of the photon energy, Right panel- as a function of the π^0 meson emission angle in the center of mass system. Theoretical curves: solid – Fix calculations, dashed – Kamalov et al.

The preliminary experimental results are given in Fig.3. The left panel shows T_{2i} as a function of the photon energy. In this case all the events within the angle range $\theta^{cm}_{\pi^0} = 90° \div 245°$ are taken into account. In the right panel T_{2i} are plotted as a function of the pion emission angle with the photon energy range 250÷450 MeV. The statistical error and averaging interval (over E_γ or over $\theta^{cm}_{\pi^0}$) are shown for each point.

One can see that there is a correspondence between the experimental results and calculations with a slight preference to the Fix calculations.

Let us remind that (see previous reports) we prepared the experiment on T_{2i} measurements for reaction $\gamma d \to d'\pi^0$ where besides the deuteron both gamma-quanta from the neutral pion decay will be detected by the calorimeter, assembled from 150 CsI crystals. Such a measurement will allow to obtain the data in wider kinematic range and enable several times reduction of the statistical error.

III. To extend the possibilities of polarized experiments, we continued the work on construction the system for tagging the quasi-real photons (PTS). The tagging systems for quasi-real photons have been already used earlier at the electron storage rings, and in particular, at VEPP-3. However, then for an analysis of the scattered electron energy we used the magnetic fields of the storage ring dipoles. In that case PTS detectors had to be located rather far from the target and their angular and energy acceptances turned out to be small. In the new project the use of a specialized magnetic system will allow us to obtain PTS with a wide angular and energy acceptance. Besides, a possibility appears to determine the transverse photon polarization for a majority of events.

The main parameters of a photon tagging system:

• the tagged photon energy: up to 1500 MeV, resolution 5–15 MeV
• electron vertical angle acceptance: ±10 mrad, resolution: 1 mrad
• electron horizontal angle acceptance: ±30 mrad, resolution: 2 mrad.

In 2008, we completed the design of the central part of the straight section and started its construction. Design of the vacuum chamber has been started. The design of the dipole magnets is nearly completed. The Monte-Carlo simulation of PTS is continued.

IV. We continued the work at the “polarized target” stand aimed at revealing the reasons of low polarization during experiments. A new mass-spectrometer for detection of atoms was installed in the polarimeter. A signal of the molecular deuterium from the storage cell is detected, but its value is small, exceeding the noise level by a few times. In order to increase the signal of passing-through atoms and molecules, the mass-spectrometer electrode geometry was changed. For attaining better vacuum, we introduced cooling of magnets with the liquid nitrogen. That should lead to a decrease of the noise signal. Measurements of the atom beam signal from the cell as a function of cell temperature will be done soon. A new heat-able pure-metallic system for coating the cell with a material, which preserves polarization of atoms during their collisions with cell walls, is prepared. We developed the scheme and started production of components of the system improving the gas pumping rate in the source, which should lead to an increase in the atom beam intensity.

V. Collaboration with the Jefferson Laboratory (Newport News, USA) is continued. Experimental data obtained in the joint experiment carried out at Hall-A of TJNAF accelerator complex are under analysis and close to its completion for publication in 2009.

Two new experiments are scheduled to be carried out with participation of BINP staff:

1) Precision measurement of the neutron magnetic form factor up to Q^2=18.0 (GeV/c)^2 by the ratio method.

2) Measurement of the neutron electromagnetic form factor ratio G_n^e/G_n^m at high Q^2.

These experiments will be carried out after completion of the upgrade of the TJNAF accelerator, which is aimed at increasing the maximum electron energy up to 12 GeV. Production of a new experimental equipment – detectors and target – will start in the near future.

VI. The group takes part in the contract work with TAE. The cryogenic pumps for injectors of neutral atoms with the high pumping rate by hydrogen on the base of cryocoolers have been developed and tested. The measured pumping rate by hydrogen of 96000 l/s turned out to be close to the design value. Twelve cryogenic pumps out of totally fourteen produced have been delivered to TAE (USA) and put into operation.

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

Participants of the work from BINP:

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Chapter 3

Theoretical physics

3.1 Strong interaction

The dipole form of the BFKL kernel in supersymmetric Yang–Mills theories

V.S. Fadin, R. Fiore
Phys. Lett. B **661** (2008) 139-144

The dipole (Möbius) representation of the colour singlet BFKL kernel in the next-to-leading order is found in supersymmetric Yang–Mills theories. Ambiguities of this form and its conformal properties are discussed.

Basics of BFKL approach

V.S. Fadin
Acta Physica Polonica, B **39** No. 9 (2008) 2193-2212

The paper gives an introductory discussion of the BFKL approach to the theoretical description of QCD processes at high energy and fixed (not growing with energy) momentum transfers. The role of the gluon Reggeization which determines the multi–Regge form of QCD amplitudes with gluon exchanges is emphasized. The region of applicability of the BFKL approach is discussed and the BFKL representation of elastic scattering amplitudes with t–channel quantum numbers different from the gluon ones is derived.

BFKL approach and dipole picture

V.S. Fadin
Preprint INP 2008-33
To be published in Proceedings of the International conference "DIFFRACTION 2008"

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 Möbius 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 Möbius 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
Preprint INP 2008-36
Submitted to "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
Preprint INP 2008-40
Submitted to Phys. Rev. D

In the next-to-leading order (NLO) the most part of the difference between the Möbius form of the BFKL kernel and the BK kernel in the case of the forward scattering can be eliminated by the BFKL kernel transform related to the choice of the energy scale in the representation of scattering amplitudes. The functional identity of the forward BFKL kernels in the momentum and Mobius representations in the leading order remains valid in the NLO in $N = 4$ supersymmetric Yang-Mills theory.

On Mass Spectrum in SQCD. Unequal quark masses

V.L. Chernyak
arXiv: 0805.2299 [hep-th], pp. 1-17 (submitted to JHEP)

The dynamical scenario is considered for SQCD with N_c colors and $N_c < N_F < 3N_c$ flavors with small nonzero unequal current quark masses $0 < m_l < m_h \ll \Lambda$, in which the colorless chiral quarks pairs condense coherently in the vacuum, $\langle Q\bar{Q}\rangle \neq 0$, while quarks alone don't condense, $\langle Q\rangle = \langle\bar{Q}\rangle = 0$ (the diquark- condensate phase). So, theory is not higgsed, all gluons remain massless and color is confined. This condensation of diquarks results in formation of dynamical constituent masses of quarks and appearance of light "pions" (similarly to QCD). The mass spectrum of SQCD in this phase is described. Also described are mass spectra in different phases of this theory, depending on the numbers of lighter and heavier quarks and the ratios of their current masses.

On Mass Spectrum in SQCD, and problems with the Seiberg duality. Another scenario

V.L. Chernyak
arXiv: 0811.4283 [hep-th], pp. 1-22 (submitted to JHEP)

$\mathcal{N} = 1$ SQCD with $SU(N_c)$ colors and N_F flavors of light quarks is considered within the dynamical scenario, which assumes that quarks can be in two different phases only. These are: a) either the HQ (heavy quark) phase where they are confined, b) or they are higgsed, at the appropriate values of parameters of the Lagrangian.

The mass spectra of this (direct) theory and its Seiberg's dual are obtained and compared, for quarks of equal or unequal masses. It is shown that in all cases when there is the additional small parameter at hand (this is $0 < (3N_c - N_F)/N_F \ll 1$ for the direct theory, or its analog $0 < (2N_F - 3N_c)/N_F \ll 1$ for the dual one), the mass spectra of the direct and dual theories are parametrically different.

Group structure of the integration-by-part identities and its application to the reduction of multiloop integrals.

R.N.Lee
JHEP 2008 (2008) 031

The excessiveness of integration-by-part (IBP) identities is discussed. The Lie-algebraic structure of the IBP identities is used to reduce the number of the IBP equations to be considered. It is shown that Lorentz-invariance (LI) identities do not bring any information additional to that contained in the IBP identities, and therefore, can be discarded.

Three-loop HQET vertex diagrams for $B^0 - \bar{B}^0$ mixing.

A.G. Grozin and R.N. Lee
arXiv:0812.4522[hep-ph]

Three-loop vertex diagrams in HQET needed for sum rules for $B^0 - \bar{B}^0$ 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 epsilon expansions are also obtained.

Three-Loop Chromomagnetic Interaction in HQET

A.G. Grozin, P. Marquard, J.H. Piclum, M. Steinhauser
Nucl. Phys. **B789** (2008) 277–293

We compute the three-loop QCD corrections to the quark chromomagnetic moment and thus obtain the matching coefficient and the anomalous dimension of the chromomagnetic interaction in HQET. As a byproduct we obtain the three-loop corrections to the quark anomalous magnetic moment.

Asymptotic freedom: History and interpretation

A.G. Grozin
arXiv:0803.2589 (22 p.)

In this lecture, the early history of asymptotic freedom is discussed. The first completely correct derivation of β_0 in non-abelian gauge theory (Khriplovich, 1969) was done in the Coulomb gauge; this derivation is reproduced (in modernized terms) in Sect. 2. A qualitative physical explanation of asymptotic freedom via chromomagnetic properties of vacuum (Nielsen, 1981) is discussed in Sect. 3.

Three-loop results in HQET

A.G. Grozin
Nucl. Phys. (Proc. Suppl.) **183** (2008) 302–307 [arXiv:0805.1474]

Recent results and methods of three-loop calculations in HQET are reviewed.

Higher radiative corrections in HQET

A.G. Grozin
arXiv:0809.4540 (33 p.),
to be published in DESY Conference Proceedings

After a brief introduction to Heavy Quark Effective Theory, we discuss α representation in HQET and methods of calculation of some kinds of HQET diagrams up to three loops.

Spin effects in $p\bar{p}$ interaction and their possible use to polarize antiproton beams

V.F. Dmitriev, A.I. Milstein, V.M. Strakhovenko
Nucl. Instr. and Meth. **B 266** (2008) 1122

Low energy $p\bar{p}$ interaction is considered taking into account the polarization of both particles. The corresponding cross sections are calculated using the Paris nucleon-antinucleon optical potential. Then they are applied to the analysis of the polarization buildup which is due to the interaction of stored antiprotons with polarized protons of a hydrogen target. It is shown that, at realistic parameters of a storage ring and a target, the filtering mechanism provides a noticeable polarization in a time comparable with the beam lifetime.

3.2 Nuclear physics and parity nonconservation

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

V.V. Flambaum, N. Auerbach, V.F. Dmitriev
arXiv:0807.3218v2

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$\rightarrow \alpha +^8 Be^* \rightarrow 3\alpha$

V.F. Dmitriev
arXiv:0812.2538v1

Using a simple phenomenological parametrization of the reaction amplitude we calculated α-particle spectrum in the reaction p+^{11}B$\rightarrow \alpha +^8 Be^* \rightarrow 3\alpha$ 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.

Constraints on $N\bar{N}$ interaction from the process $e^+e^- \to N\bar{N}$ near threshold

V.F. Dmitriev and A.I. Milstein
Nucl. Phys. B (Proc. Suppl.) v. 181-182 (2008) 66

We use the Paris nucleon-antinucleon optical potential for explanation of experimental data in the process $e^+e^- \to p\bar{p}$ near threshold. It is shown that the cross section and the electromagnetic form factors are very sensitive to the parameters of the potential. We use the data to obtain bounds on the absorptive part of the potential in the channel with $J = S = 1$.

Electric dipole moments, from e to τ

A.G. Grozin, I.B. Khriplovich, A.S. Rudenko
arXiv:0811.1641 (4 p.), to be published in Yad. Fiz.

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.

3.3 Quantum electrodynamics

Correction to the Molière's formula for multiple scattering.

R.N.Lee and A.I. Milstein
arXiv: 0812.2076[physics.atom-ph]

The quasiclassical correction to the Molière's formula for multiple scattering is derived. The consideration is based on the scattering amplitude, obtained with the first quasiclassical correction taken into account for arbitrary localized but not spherically symmetric potential. Unlike the leading term, the correction to the Molière's formula contains the target density n and thickness L not only in the combination nL (areal density). Therefore, this correction can be reffered 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 region of applicability of the Molière's formula.

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

G.G. Kirilin and R.N. Lee
arXiv: 0812.2076[physics.atom-ph]

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 Delbrück scattering and "magnetic loop" contribution to the g factor of the bound electron are considered.

Polarization effects in non-relativistic ep scattering

A. I. Milstein, S. G. Salnikov, V. M. Strakhovenko
Nucl. Instr. and Meth. **B 266** (2008) 3453

The cross section which addresses the spin-flip transitions of a proton (antiproton) interacting with a polarized non-relativistic electron or positron is calculated analytically. In the case of attraction, this cross section is greatly enhanced for sufficiently small relative velocities as compared to the result obtained in the Born approximation. However, it is still very small, so that the beam polarization time turns out to be enormously large for the parameters of $e^{\pm}$ beams available now. This practically rules out a use of such beams to polarize stored antiprotons or protons.

Polarized and unpolarized positron sources for electron-positron colliders

X.Artru, R.Chehab, M.Chevallier, V.M.Strakhovenko, A.Variola, A.Vivoli
Nucl. Instr. and Meth. **B 266** (2008) 3868

Two types of a positron source are under study for e^+e^- colliders as ILC or SuperB factory. In the first one, a multi-GeV electron beam generates in an oriented W crystal by channelling radiation a large number of γ which, consecutively, create e^+e^- pairs in an amorphous target put after the crystal. Such method has been successfully tested at CERN and KEK and is now operating at KEK. In the second one, the electron beam collides with a circularly polarized laser beam creating Compton backscattered γ circularly polarized, which impinge on a thin amorphous target where they generate longitudinally polarized positrons. In both cases, simulation results are provided and the choice of the parameters is discussed for ILC as for the SuperB factory.

Delbruck scattering in combined Coulomb and laser fields

A. Di Piazza, A. I. Milstein
Journal reference: Phys. Rev. A vol. 77, 042102 (2008)

We study Delbrück scattering in a Coulomb field in the presence of a laser field. The amplitudes are calculated in the Born approximation with respect to the Coulomb field and exactly in the parameters of the laser field having arbitrary strength, spectral content and polarization. The case of high energy initial photon energy is investigated in detail for a monochromatic circularly polarized laser field. It is shown that the angular distribution of the process substantially differs from that for Delbrück scattering in a pure Coulomb field. The value of the cross section under discussion may exceed the latter at realistic laser parameters that essentially simplify the possibility of the experimental observation of the phenomenon. The effect of high order terms in the quantum intensity parameter χ of the laser field is found to be very important already at relatively small χ.

Screening of Coulomb Impurities in Graphene

Ivan S. Terekhov, Alexander I. Milstein, Valeri N. Kotov, Oleg P. Sushkov
Journal reference: Physical Review Letters 100, 076803 (2008)

We calculate exactly the vacuum polarization charge density in the field of a subcritical Coulomb impurity, $Z|e|/r$, in graphene. Our analysis is based on the exact electron Green's function, obtained by using the operator method, and leads to results that are exact in the parameter $Z\alpha$, where α is the "fine structure constant" of graphene. Taking into account also electron-electron interactions in the Hartree approximation, we solve the problem self-consistently in the subcritical regime, where the impurity has an effective charge Z_{eff}, determined by the localized induced charge. We find that an impurity with bare charge Z=1 remains subcritical, $Z_{eff}\alpha < 1/2$, for any α, while impurities with $Z = 2, 3$ and higher can become supercritical at certain values of α.

Quasiclassical description of bremsstrahlung accompanying alpha decay including quadrupole radiation

U. D. Jentschura, A.I. Milstein, I.S. Terekhov, H. Boie, H. Scheit, D. Schwalm
Journal reference: Phys.Rev.C 77 (2008) 014611

We present a quasiclassical theory of alpha decay accompanied by bremsstrahlung with a special emphasis on the case of 210Po, with the aim of finding a unified description that incorporates both the radiation during the tunneling through the Coulomb wall and the finite energy E_γ of the radiated photon up to E_γ on the order of $Q_\alpha/\sqrt{\eta}$, where Q_α is the alpha-decay Q-value and eta is the Sommerfeld parameter. The corrections with respect to previous quasiclassical investigations are found to be substantial, and excellent agreement with a full quantum mechanical treatment is achieved. Furthermore, we find that a dipole-quadrupole interference significantly changes the alpha-gamma angular correlation. We obtain good agreement between our theoretical predictions and experimental results.

Spectrum and polarization of coherent and incoherent radiation and the LPM effect in oriented single crystal

V. N. Baier and V. M. Katkov
Nuclear Instruments and Methods in Physics Research B **266** (2008) 3828-3834

The spectrum and the circular polarization of radiation from longitudinally polarized high-energy electrons in an oriented single crystal are considered using the method which permits inseparable consideration of both the coherent and the incoherent mechanisms of photon emission. The spectral and polarization properties of radiation are obtained and analyzed. It is found that in some part of the spectral distribution the influence of multiple scattering (the Landau-Pomeranchuk-Migdal (LPM) effect) attains the order of 7 percent. The same is true for the influence of multiple scattering on the polarization part of the radiation intensity. The degree of the circular polarization of the total intensity of radiation is found. It is shown that the influence of multiple scattering on the photon polarization is similar to the influence of the LPM effect on the total intensity of radiation: it appears only for relatively low energies of radiating electron and has the order of 1 percent, while at higher energies the crystal field action excludes the LPM effect.

Opportunity to study the LPM effect in oriented crystal at GeV energy

V. N. Baier and V. M. Katkov
Physics Letters A **372** (2008) 2904-2910

The spectral distribution of electron-positron pair created by photon and the spectral distribution of photons radiated from high-energy electron in an oriented single crystal is calculated using the method which permits inseparable consideration both of the coherent and incoherent mechanisms of two relevant processes. The method includes the action of field of axis (or plane) as well as the multiple scattering of radiating electron or particles of the created pair (the Landau-Pomeranchuk-Migdal (LPM) effect). The influence of scattering on the coherent mechanism and the influence of field on the incoherent mechanism are analyzed. In tungsten, axis $< 111 >$ for the pair creation process at temperature T= 100 K the LPM effect attains 8 % at photon energy 5 GeV and for the radiation process at T= 293 K the LPM effect reaches 6 % at electron energy 10 GeV.

Electroproduction of electron-positron pair in a medium

V. N. Baier and V. M. Katkov
Pis'ma v ZhETF, **88** (2008) 88-92

The process of electron-positron pair creation by a high-energy electron in a medium is analyzed. The spectral distribution over energies of created particles is calculated for the direct and cascade mechanisms of the process. The Coulomb corrections are included. The new formulation of the equivalent photons method is developed which takes into account the influence of multiple scattering. It is shown the effects of multiple scattering can be quite effectively studied in the process under consideration.

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

V. N. Baier and V. M. Katkov
Budker INP 2008-28

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.

Cerenkov radiation of spinning particle

I.B. Khriplovich
arXiv:0808.1500; ЖЭТФ 135 (2009) 1

The Cerenkov radiation of a neutral particle with magnetic moment is considered, as well as the spin-dependent contribution to the Cerenkov radiation of a charged spinning particle. The corresponding radiation intensity is obtained for an arbitrary value of spin and for an arbitrary spin orientation with respect to velocity.

3.4 Gravity

Spinning Relativistic Particles in External Fields

I.B. Khriplovich
arXiv:0801.1881;
Acta Physica Polonica B, Proceedigs Supplement, 1 (2008) 197

The motion of spinning relativistic particles in external electromagnetic and gravitational fields is considered. A simple derivation of the spin interaction with gravitational field is presented. The self-consistent description of the spin corrections to the equations of motion is built with the noncovariant description of spin and with the usual, "naïve" definition of the coordinate of a relativistic particle.

Barbero-Immirzi parameter in Regge calculus

V.M. Khatsymovsky
arXiv:0804.2389[hep-th]

We consider Regge calculus in the representation in terms of area tensors and self- and antiselfdual connections generalised to the case of Holst action that is standard Einstein action in the tetrad-connection variables plus topological (on equations of motion for connections) term with coefficient $1/\gamma$, γ is Barbero-Immirzi parameter. The quantum measure is shown to exponentially decrease with areas with typical cut-off scales $4\pi G$ and $4\pi G\gamma$ in spacelike and timelike regions, respectively (G is the Newton constant).

Gravity action on discontinuous metrics

V.M. Khatsymovsky
arXiv:0808.1039[gr-qc]

We consider minisuperspace gravity system described by piecewise flat metric iscontinuous on three-dimensional faces (tetrahedra). There are infinite terms in the Einstein action. However, starting from proper regularization, these terms in the exponential of path integral result in pre-exponent factor with δ-functions requiring vanishing metric discontinuities. Thereby path integral measure in Regge calculus is related to path integral measure in Regge calculus where length of an edge is not constrained to be the same for all the 4-tetrahedra containing this edge, i.e. in Regge calculus with independent 4-tetrahedra. The result obtained is in accordance with our previous one obtained from symmetry considerations.

Independent 4-tetrahedra connection representation of Regge calculus

V.M. Khatsymovsky
arXiv:0808.1041[gr-qc]

We consider simplest piecewise flat manifold consisting of two identical 4-tetrahedra (call it bisimplex). General relativity action for arbitrary piecewise flat manifold can be expressed in terms of sum of the (half of) bisimplex actions. We use representation of each bisimplex action in terms of certain rotation matrices (connections). This gives representation of any minisuperspace piecewise flat gravity system in terms of connections which do not connect neighboring 4-tetrahedra (more appropriate would be call these self-connections). If Regge calculus with independent 4-tetrahedra is considered, i. e. when the length of an edge is not constrained to be the same for all the 4-tetrahedra containing this edge, self-connection representation leaves 4-tetrahedra independent also in connection matrices sector. Action remains sum of independent 4-tetrahedra terms.

Defining some integrals in Regge calculus

V.M. Khatsymovsky
arXiv:0808.1042[gr-qc]

Regge calculus minisuperspace action in the connection representation has the form in which each term is linear over some field variable (scale of area-type variable with sign). We are interested in the result of performing integration over connections in the path integral. To find this function, we compute its moments, i. e. integrals with powers of that variable. Calculation proceeds through intermediate appearance of δ-functions and integrating them out and leads to finite result for any power. The function of interest should therefore be exponentially suppressed at large areas and it really does being restored from moments. This gives for gravity a way of defining such nonabsolutely convergent integral as path integral.

Attributing sense to some integrals in Regge calculus

V.M. Khatsymovsky
arXiv:0810.1630[math-ph]

It is found that the definition of the nonabsolutely convergent integrals in Regge calculus earlier obtained by us in the preceding work by analytical continuation from Euclidean version of the theory agrees with direct consideration in genuine Minkowsky spacetime. In particular, at some values of some constant of the theory we find a set of local maxima in the dependence of the result (that is, of probability distribution) on the area. These maxima turn out to correspond to (equidistant) area eigenvalues following within earlier considered operator approach to the *continuous time* Regge calculus.

Does Cosmological Term Influence Gravitational Lensing?

I.B. Khriplovich, A.A. Pomeransky
International Journal of Modern Physics D, **17** (2008) 2255Ц2259

In this paper, we analyze the bending of light by galaxies or clusters of galaxies in the presence of the Lambda term. Using Friedmann-Robertson-Walker (FRW) coordinates, which are used for the description of actual observations, we demonstrate that the cosmological constant does not practically influence the lensing effect.

Passage of small black hole through the Earth. Is it detectable?

I.B. Khriplovich, A.A. Pomeransky, N. Produit, G. Yu. Ruban
Preprint arXiv:0801.4623[hep-ex]

We examine the energy losses of a small black hole passing through the Earth, and in particular, the excitations created in the frequency range accessible to modern acoustic detectors. The dominating contributions to the effect are due to the coherent sound radiation of the Cherenkov type and to the conversion of black hole radiation into sound waves.

3.5 Nonlinear dynamics and chaos

How Well a Quantum System Can Retain Memory of Its Initial State?

Valentin V. Sokolov, Oleg V. Zhirov.
preprint: arXiv:0808.3050v1 [nlin.CD] 22 Aug 2008; Europhys. Lett. **84** (2008) 30001.

In classical mechanics the local exponential instability effaces the memory of initial conditions and leads to practical irreversibility. In striking contrast, quantum mechanics appears to exhibit strong memory of the initial state. We relate the latter fact to the low (at most linear) rate with which the system's Wigner function gets during the evolution a more and more complicated structure and we establish the existence of a critical strength of external influence below which such a memory still survives.

Complexity of Quantum States and Reversibility of Quantum Motion.

Valentin V. Sokolov, Oleg V. Zhrov, Giuliano Benenti, and Giulio Casati. preprint: arXiv:0807.2902v1 [nlin.CD] 18 Jul 2008; Phys. Rev. E **78**, 046212 (2008).

We present a quantitative analysis of the reversibility properties of classically chaotic quantum motion. We analyze the connection between reversibility and the rate at which a quantum state acquires a more and more complicated structure in its time evolution. This complexity is characterized by the number $\mathcal{M}(t)$ of harmonics of the (initially isotropic, i.e. $\mathcal{M}(0) = 0$) Wigner function, which are generated during quantum evolution for the time t. We show that, in contrast to the classical exponential increase, this number can grow not faster than linearly and then relate this fact with the degree of reversibility of the quantum motion. To explore the reversibility we reverse the quantum evolution at some moment T immediately after applying at this moment an instant perturbation governed by a strength parameter ξ. It follows that there exists a critical perturbation strength, $\xi_c \approx \sqrt{2}/\mathcal{M}(T)$, 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.

Synchronization and bistability of qubit coupled to a driven dissipative oscillator

O.V. Zhirov and D.L. Shepelyansky
Phys. Rev. Lett., **100**, 014101 (2008).

We study numerically the behavior of a qubit coupled to a quantum dissipative driven oscillator (resonator). Above a critical coupling strength the qubit rotations become synchronized with the oscillator phase. In the synchronized regime, at certain parameters, the qubit exhibits tunneling between two orientations with a macroscopic change of the number of photons in the resonator. The lifetimes in these metastable states can be enormously large. The synchronization leads to a drastic change of qubit radiation spectrum with the appearance of narrow lines corresponding to recently observed single artiямБcial-atom lasing [O. AstaямБev et al., Nature (London) **449**, 588 (2008)].

Effective action, magnetic excitations and quantum fluctuations in lightly doped single layer cuprates

A. I. Milstein, Oleg P. Sushkov
Journal reference: Phys. Rev. B 78, 014501 (2008)

We consider the extended 2D $t - t' - t'' - J$ model at zero temperature. Parameters of the model corresponds to doping by holes. Using the low doping effective action we demonstrate that the system can 1) preserve the long range collinear antiferromagnetic order, 2) lead to a spin spiral state (static or dynamic), 3) lead to the phase separation instability. We show that at parameters of the effective action corresponding to the single layer cuprate $La_{2-x}Sr_xCuO_4$ the spin spiral ground state is realized. We derive properties of magnetic excitations and calculate quantum fluctuations. Quantum fluctuations destroy the static spin spiral at the critical doping $x_c \approx 0.11$. This is the point of the quantum phase transition to the spin-liquid state (dynamic spin spiral). The state is still double degenerate with respect to the direction of the dynamic spiral, so this is a "directional nematic". The superconducting pairing exists throughout the phase diagram and is not sensitive to the quantum phase transition. We also compare the calculated neutron scattering spectra with experimental data.

MONOGRAF

System of the blood circulation and the arterial hypertension: biophysical and genetic-physiological mechanisms, mathematical and computer modelling. Chapter 4: Global simulation of the human arterial system

E.A. Biberdorf, A.M. Blochin, N.I. Popova, U.L. Trachinin
Novosibirsk: Publishing house SB RAS, 2008 (в печати).

The work is connected with the participation of authors in Project №46 (Competition of interdisciplinary, integrated projects for fundamental investigations of Siberian Branch of Russian Academy of Sciences) "Investigation and simulation of physiological, molecular-genetic and biophysical mechanisms of forming the arterial hypertension with the aim of creating the optimal programs for early diagnosis, prediction of complications and their prophylaxis." The attempt is first made to simulate on a computer the cardiovascular human system as the numerical solution of the gemodynamic system by the orthogonal sweep method. This mathematical model owing to own simplicity permits to simulate the blood flow in all blood stream (a global simulation), i. e. for all 55 arteries of the vascular human tree.

Chapter 4

Plasma physics and controlled thermonuclear fusion

4.1 Research at GDT facility

The most considerable results at GDT facility were obtained in two experimental campaigns. The first study was devoted to the effect of significant suppression of axial plasma losses from the GDT central cell. This phenomenon was qualified as ambipolar plugging. The second major effort was directed to study of microinstabilities in anisotropic distribution of hot ions confined in the compact mirror cell. Results of numerical study were also significant. The goal of these simulations was the analysis of the perspective of projected GDT based neutron source to act as a driver of a minor actinides burner. Below you can find the detailed description of these studies separated by three sections.

4.1.1 Suppression of axial losses by generation of ambipolar plug in GDT

I. Introduction

Effectiveness of application of the ambipolar plug for partial suppression of axial (longitudinal) plasma loss in GDT was studied. To build the ambipolar plug, an additional axially symmetrical mirror cell of relatively small volume was attached to the one side of the GDT central cell (so called compact mirror). This additional mirror section was filled with background plasma (density n = 10^{13} cm^{-3}, temperature T = 70 eV) streaming from the GDT central cell. To create the population of hot ions with strong anisotropy, two focused hydrogen or deuterium neutral beams with energy of 22 keV and the current density 0.5 atom amperes were injected perpendicularly to the magnetic axis of the machine. In the experiment with 0.8 MW beams injection, we observed formation of the hot-ion cloud (or plasmoid) with anisotropic velocity distribution function with the average energy about 13 keV and density $\sim 5 \times 10^{13}$ cm^{-3}. It was shown, that confinement of hot ions in the compact mirror is driven by charge exchange on injected beam atoms and electron drag governed by "classical" Coulomb collisions. At the same time, development of the Alfven ion cyclotron instability was detected when the density of hot ions exceeded 2.5×10^{13} cm^{-3}. The effect of ambipolar suppression was displayed by the following observation: the ion density with NB injection in the compact mirror exceeded the one in the regime without NB injection by the factor of 5. In this experiment, the density of maxwellian plasma component in the central part of GDT was 2.5×10^{13} cm^{-3}. The observed effect was qualitatively explained by transition between the gas-dynamic regime of the central cell plasma confinement to the adiabatic (mirror) regime.

II. Experiment

In the reported experiments, the configuration of the GDT facility was as shown in Figure 1. Additionally to the main (central) mirror and two expander end tanks, the compact mirror section was installed. Magnetic field in GDT has axially symmetric configuration. Mirror ration in the central cell in these experiments was R=20, magnetic field in its central section was B_0=0.27 T. To create the ambipolar plug, the standard construction of mirror coil unit was modified. One additional coil and special vacuum chamber were mounted (see Figure 1). Magnetic field in the central cross section of the compact mirror cell was B_0=2.7 T, mirror ratio was R = 2, the distance between the centers of magnetic mirror coils was ∼43 cm, the inner diameter of vacuum chamber was ∼ 70 cm.

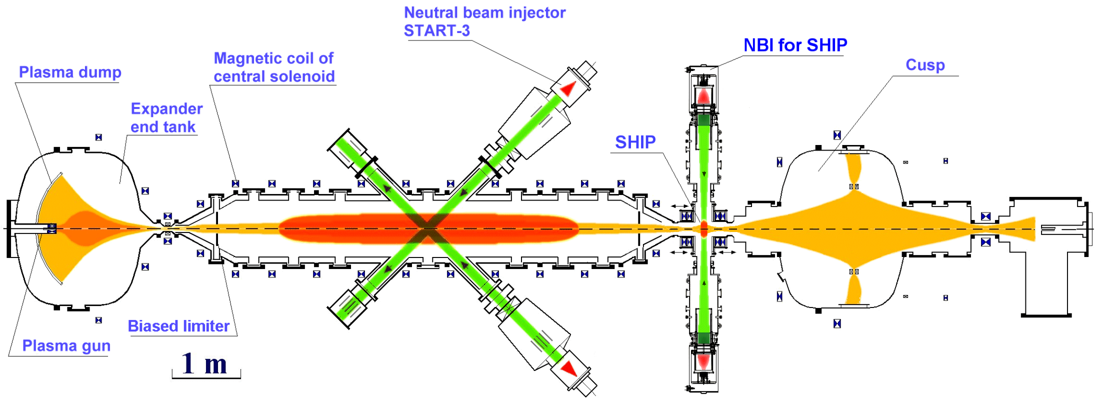


Figure 1: The gas dynamic trap layout.

Particle balance of collisional plasma component during heating by neutral beams injection was maintained by hydrogen gas-puff. This was done by special device combined with mirror unit at the side of the main plasma source (see Figure 1). The rate of gas-puff was adjusted so that the target plasma density radial profile in the central cell remained constant during the major part NB injection duration with the maximal on-axis density of $n_0=2.5\cdot10^{13}$ cm^{-3}. Transverse plasma losses were suppressed by so called vortex confinement mode. Plasma in the compact mirror consisted of two components, namely the target plasma and hot ions. Target plasma was streaming from the central cell along magnetic field lines through the compact mirror into the expander end tank. Hot ions were created by injection of two atomic beams with the total power of 0.8 MW and particle energy of 21-22 keV. The injection pulse duration was 4 ms. Deuterium beams were injected perpendicularly to magnetic field to obtain the minimal size of the region occupied by fast ion and therefore to gain their maximal density. Beams were ionized in the compact mirror and formed the population of anisotropic hot ions with the density two times greater than plasma density in the central cell. Warm plasma density in the area of hot ions in the compact mirror was the order less than the fast ions density.

III. Results of measurements

Parameters of warm plasma in the central cell

Electron temperature and density were measured by means of Thomson scattering system for the radii of r_0 = 0 - 8 cm. In this area of the plasma column, the density and temperature practically did not depend on the radius were measured as $n_0 \approx 2.5\cdot10^{13}$ cm^{-3} и $T\approx100$ eV, respectively. In the peripheral plasma area for the radii close to the limiter boundary (r_0 = 13 cm), the temperature of ∼30 eV was measured with by triple Langmuir probes. Basing on the measurement results, we used the following simplified temperature and density radial profiles for further calculations and estimates (see Figure 2).

Hot ion density radial profile in the compact mirror is shown in Figure 3. Measured time evolution of the on-axis fast ions density in the compact mirror is shown in Figure 4. According to the diamagnetism and temperature measurements in the central cell of GDT, process of accumulation of hot ions in the compact mirror was not accompanied by any significant changes of averaged plasma parameters in the central cell.

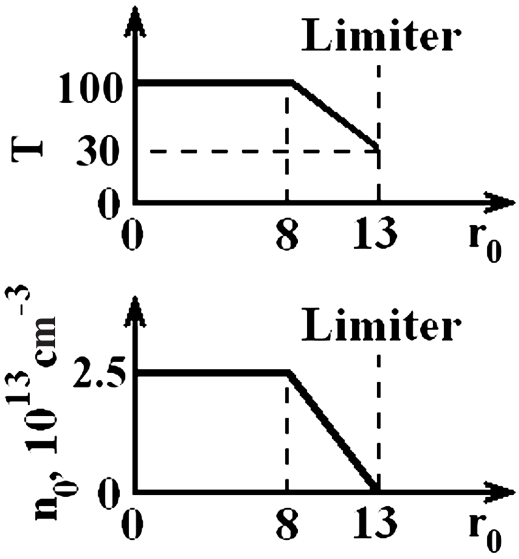


Figure 2: Electron temperature profile (upper plot) and warm plasma density profile (lower plot) in the central GDT cell. Temperature measurement accuracy was ΔT_e=5 eV, relative accuracy of plasma density measurement was $\Delta n/n$=10÷15%.

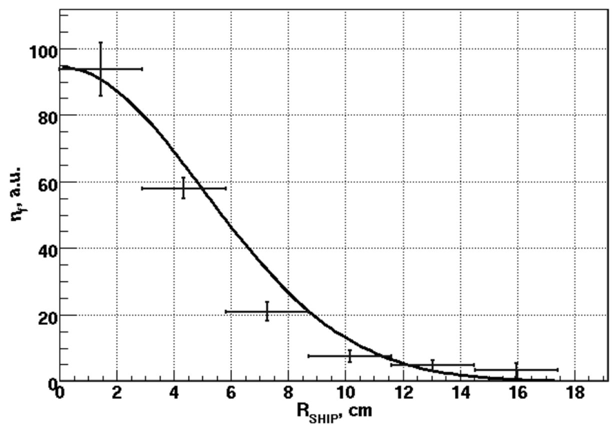


Figure 3: Fast ion density radial profile in the compact mirror (relative units): dots–experimental data, solid curve: Gauss approximation. Radii are in the central section of compact mirror.

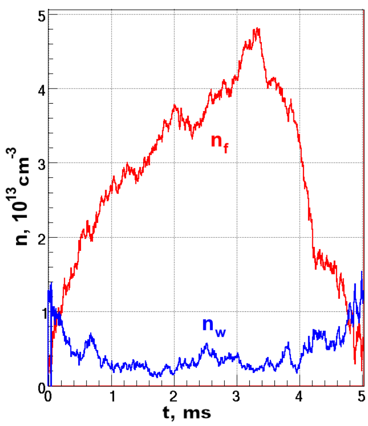


Figure 4: Time evolution of fast ions density nf and warm ion density nw near the axis of compact mirror. Time reference point is the beginning of NB injection in the compact mirror.

Ion current in the expander

The main diagnostic for analysis of the axial current suppression, was a multi-grid probe located in the expander vessel in the cross section corresponding to the mirror ratio of R_d = 0.7. By this probe both time evolution curves (Figure 5) and radial profiles (Figure 6) were measured in the expander. First stage of 1-1.5 ms duration corresponded to the transition, which normally happens at the NB injection startup. Warm plasma was heated from the initial temperature of 1-5 eV up to 100 eV, this was accompanied by radial redistribution of central cell plasma density. Then after t=1.5 ms central cell plasma reached steady-state conditions while hot ions density in the compact mirror continued to increase. Thus, axial loss suppression in the equilibrium regime could be observed for warm plasma density in the range from n_f=3·10^{13} см$^{-3}$ at t=1.5 ms to n_f=4.5·10^{13} см$^{-3}$ at t =3-3.5 ms. Suppression degree was j_0/j≈5 within this period of time, although absolute values of current density on the axis were slightly increasing.

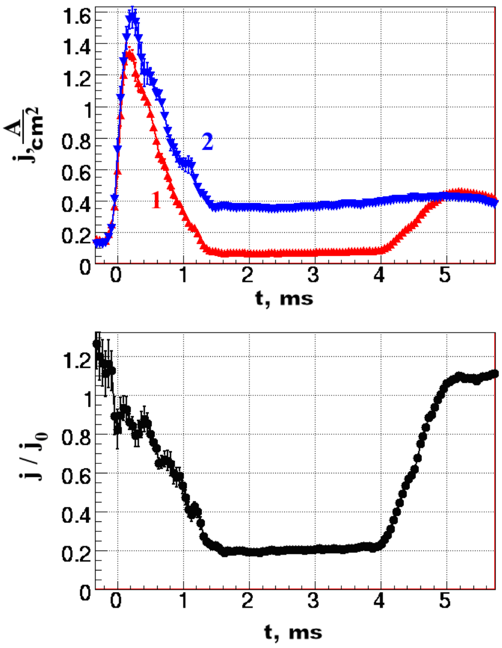


Figure 5: Upper plot: time dependences of ion current on the system axis with (#1) and without (#2) NB injection in the compact mirror. Lower plot: relative current suppression (ratio of the 1st and 2nd curves). Time reference point is the beginning of NB injection in the compact mirror.

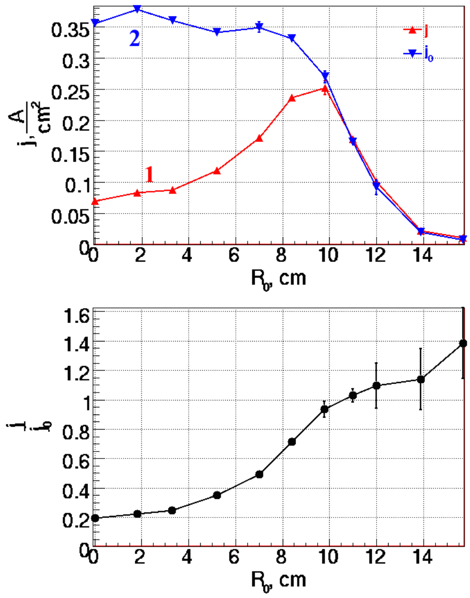


Figure 6: Upper plot: radial profiles of ion current with (#1) and without (#2) NB injection in the compact mirror. Lower plot: profile of the relative current suppression (ratio of the 1st and 2nd curves). Currents were measured 2 ms after injection start in the compact mirror; radii are projected along the magnetic field lines to the GDT midplane.

To find out the degree of longitudinal loss suppression for the hot ions density less than n$_f$=3·10^{13} см$^{-3}$, the additional series of experiments with reduced injection power in the compact mirror was done. The results of these measurements are represented as dots in Figure 8. It should be noted that central cell plasma parameters in this series of experiments were different from those in the main (powerful NB) series. Namely, the electron temperature was lower (70 eV) and the density was a little greater. However, normalized parameters for both series coincided well. Energy spectrum of ions moving along the axis in the expander, was measured by of 45° energy analyzer. Results of the measurements with and without injection in the compact mirror are shown in Figure 8. Disappearance of particles with energies less than 525 eV in the regime with neutral beam injection in the compact mirror (CM), indicates on the effect of suppression due to the potential barrier development.

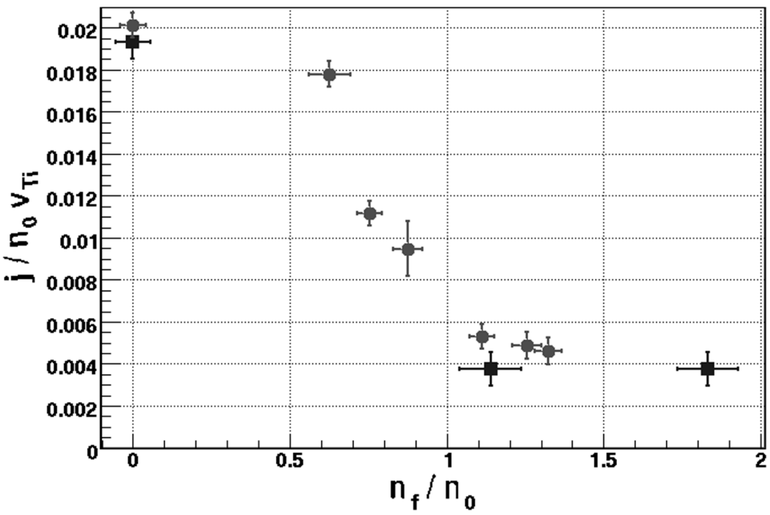


Figure 7: Dependence of current density in the expander on fast ion density in the compact mirror. Values are normalized to the product of the warm plasma parameters in the central cell: density n_0 and thermal ion velosity v_{Ti} . Squares and circles mark data obtained in experiments with maximal axial loss suppression and with reduced NB injection power in the compact mirror, respectively.

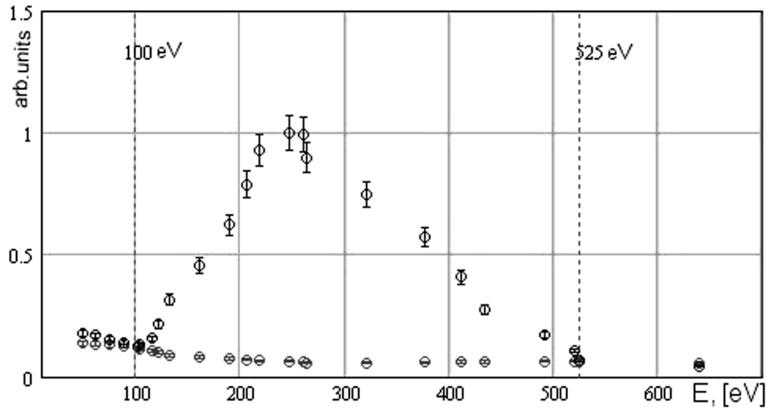


Figure 8: Ion energy spectrum in the expander (relative units). Upper graph was obtained in regimes without injection in the compact mirror, lower graph—in regimes with maximal longitudinal loss suppression (powerful NB injection).

IV. Discussion

The main issues of the reported experiments can be summarized as following.

• Longitudinal loss dependence on fast ions density in the compact mirror features the threshold. Suppression is observable in the rather small range of fast ion densities 0.5< n_f/n_0 <1.2-1.3.

• The ion flux suppression degree in the expander remains practically constant and equals 5 in the CM fast ion densities range 1.3< n_f/n_0 <1.9.

• Significant suppression occurs when ambipolar potential is less than temperature $\ln(n_f/n_0)$<1.

• Degree of flux suppression varies at different radii. Near the axis ion flux is suppressed by 5 times, for the radii r_0 >10 cm suppression was negligible.

Constancy of plasma flux suppression degree in the expander for the range of CM fast ion densities of 1.3<n_f/n_0<1.9 (see Figure 7) can be explained in the following way. Ion current is produced basically by fast ions which scatter to the loss cone in the central cell of GDT. This conclusion was made upon the energy spectrum analysis of ions streaming from the central cell through the compact mirror.

Radial dependence of the suppression degree for warm ions (see Figure 6) can be explained by an interference of three mechanisms. The first factor is provided by the selected method of MHD instability suppression. To trigger the vortex confinement regime, the radial limiters were biased by the potential $\approx +150$ V (see Figure 1), where the end wall sections were grounded. Results of special measurements and calculations show that the plasma potential radial profile in the central cell has the maximum ($\varphi_{max} \approx$+150 V) near the limiter radius (R_0 = 13 cm) in this regime. Potential is decreasing at minor radii with the typical scale of $\delta \approx 6$ cm. Thus the central GDT cell plasma potential is some greater in plasma periphery close to the limiter. This naturally leads to the reduction of potential drop between the created ambipolar plug and central mirror and therefore to the reduction of ambipolar suppression effect in this area.

The second factor is a natural cooling of warm plasma near the limiter. This leads to the growth of parameter L/λ_0 in this region and weakening of the warm ion flux suppression degree of ambipolar mirror.

The third factor is an absence of similarity between the hot ion density profile in the compact mirror and warm plasma density profile in the central cell (see Figure 2 and Figure 4). In consequence of more peaked CM hot ion profile, the nf/n ratio decreases by approximately 30% when moving from r_0 =0 to r_0 =10 cm. It should also contribute to reduction of ambipolar suppression degree in the limiter area.

According to the simple estimation assuming Boltzmann distribution law for electrons and ions of warm plasma and quasi-neutrality as well, the ion flux suppression degree in the expander cannot exceed $j_0/j \approx$2 for the ratio n_f/n_0 of 1.2. However, the measurements showed that j_0/j =5. Such significant difference can be explained by the following reason. The confinement regime becomes boundary between the gas-dynamic and adiabatic when the warm plasma temperature is 100 eV and the density is $2.5{\cdot}10^{13}$cm^{-3}.

To conclude, let us state the main results of this study:

• The ambipolar effect of suppression of warm plasma flux from the central cell of GDT was demonstrated. Maximal suppression of 5 times was registered when ambipolar potential was less than the plasma electron temperature (eφ<T).

• This result can be explained by transition from the regime of filled loss cone in the central cell with low values of ambipolar potential (eφ << T) to the regime of empty loss cone where eφ>T.

4.1.2 Study of microinstabilities in anisotropic distribution of hot ions

When plasma parameters in the CM achieved certain threshold values, we observed plasma potential oscillations at frequencies close to the ion-cyclotron frequency corresponding to the magnetic field in the equatorial plane of compact mirror. This could be qualified as an evidence of microinstability development due to a strong plasma anisotropy in compact mirror. For furher analysis of the developing microinstability in CM, the set of high-frequency electrostatic and magnetic probes was used.

Observed oscillations appeared to have the clearly seen threshold. Figure 9 shows the signal form the CM diamagnetic loop and the amplitude of high-frequency magnetic field oscillations. Oscillations were triggered upon exceeding a threshold point of diamagnetism of hot-ion plasmoid, corresponding approximately to the hot ion density n > 3 x 10^{13} cm^{-3} with the average energy of 12- 13 keV. In these experiments the ratio of plasma transverse pressure to magnetic filed pressure $\beta = 0.02$, anisotropy parameter A = 35 (ratio of the perpendicular kinetic energy $<E_\perp>$ to the parallel kinetic energy $<E_\perp>$ averaged over the velocity distribution of ions), the ratio of the ion gyroradius to the plasmoid radius $a_i/R_p \approx 0.23$.

To calculate the phase and the frequency of oscillations, digital time-series data from the probes were Fourier analyzed and cross power spectral densities were determined. In Figure 10, the cross amplitude spectrum of two signals from the azimuthal probes in the centre of compact mirror is drawn. A coherent oscillation appears as a narrow maximum at the frequency mode f_0 =39.65 ±15 MHz. The second maximum corresponds to the second frequency harmonic. The value of magnetic field in plasma (taking into account plasma diamagnetism) at the midplane of compact mirror in these experiments was 27.6±0.3 kGs. Corresponding ion-cyclotron frequency is $f = 42 \pm 0.5$ MHz. Thus a certain shift of the measured oscillation frequency relatively to the expected AIC mode frequency $f_0 < f_{ci}\ (1 - <E_\parallel>/<E_\perp>)$, was detected.

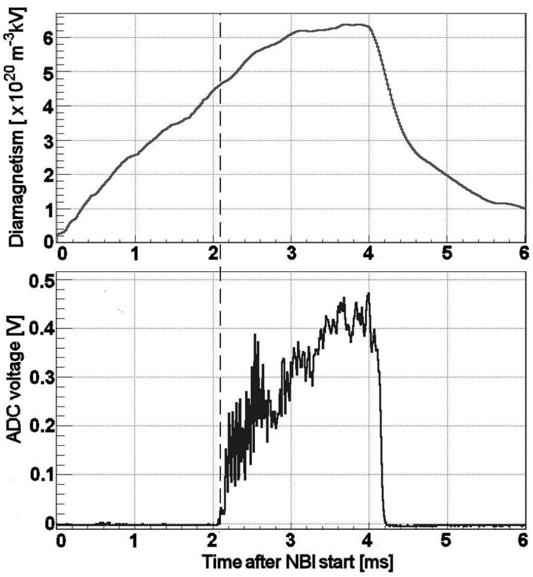


Figure 9: The diamagnetism of hot ions and amplitude of frequency magnetic field oscillations versus time.

Azimuthal mode structure of instability was delivered by the phase shift between potential oscillations measured by probes arranged on the arc with the radius of 4.5 cm from the CM axis. In Figure 11, the results of transverse (azimuthal) mode analysis are shown. The recorded phase shifts versus the angles between azimuthal probes is plotted for ten-shot series where experimental conditions were held approximately constant. Solid line corresponds to the mode -1, dashed line—to the mode -2. It is seen that in the most experiments azimuthal mode -1 was observed, and the second mode appeared eventually. Oscillations with higher mode numbers were not detected. A negative m sign indicates propagation of perturbation in the electron diamagnetic motion direction.

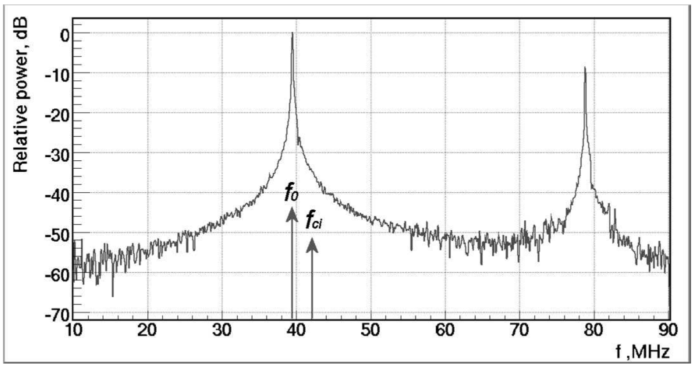


Figure 10: The cross amplitude spectrum.

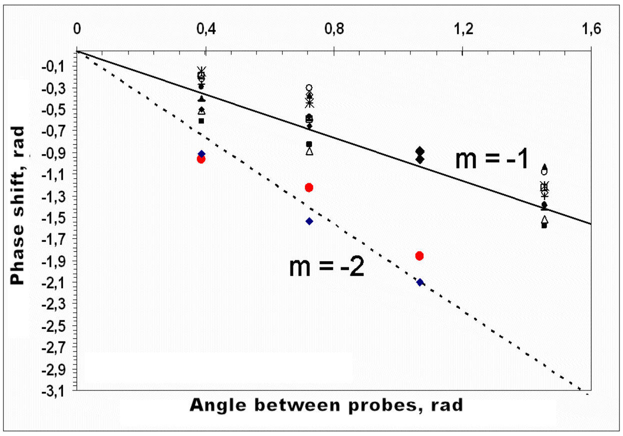


Figure 11: Azimuthal mode analysis.

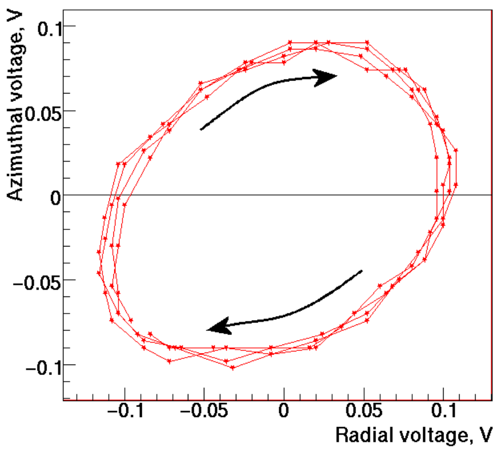


Figure 12: Azimuthal vs radial induced loop voltages. The field vector rotates in the direction of ion gyration.

Figure 12 shows $V_r(t)$ versus $V_\varphi(t)$ plot, which is the loop-probe voltages induced by $\dot{B}_r(t)$ and $\dot{B}_\varphi(t)$ wave components. The calculated amplitude of azimuthal and radial component of magnetic field oscillations were about 100 mGs. The amplitude of axial magnetic field fluctuations is more than an order smaller. The probe was located at the radius of 15 cm from the centre. Rotation of the perpendicular B in clockwise direction in the picture corresponds to the rotation in the direction of ion gyration (a left polarized wave).

In summary, registration of small azimuthal mode numbers, oscillation frequency below the diamagnetically shifted ion-cyclotron frequency and rotation of the wave magnetic field in the direction of ion gyration are weighty arguments that fluctuations observed in the compact mirror of GDT are connected with the development of Alven ion cyclotron instability.

Phase shift between the signals from the electrostatic probes on the same magnetic field line (one in the centre of compact mirror and another one in the expander) was random in different shots. This means that axial wavelength is significantly less than the separation between the probes (~70 cm) and the fluctuations are not flute-like.

Accordingly they can not be considered as an evidence of developing of drift-cyclotron loss-cone instability (DCLC). This point is also confirmed by the measurements by the array of probes arranged with 1.5 cm separation along the magnetic line in the expander. Correlation analysis shows that the axial wave length is not greater than 2 cm.

The main results obtained during this work are the following:

• By means of electric and magnetic high-frequency probes, electromagnetic fluctuations in plasma in the compact mirror were investigated. These fluctuations were caused by strong anisotropy of ion distribution function in the velocity space. Amplitude of the fluctuations was approximately 100 mGs.

• Microinstability developing in the compact mirror, was qualified as Alfven ion-cyclotron instability (AIC). This was argued by observations of small azimuthal modes numbers m = 1-2, oscillation frequency below the diamagnetically depressed ion-cyclotron frequency and rotation of the magnetic field of the wave in the direction of ion gyration.

• The threshold of the AIC fluctuation was determined relative to the density of hot ions, ratio of ion pressure to magnetic filed pressure β, anisotropy A and the ion gyroradius to the plasmoid radius ratio a_i/R_p AIC microinstability developed when the density of hot ions nf was greater than 3×10^{13} cm^{-3}, β=0.02, anisotropy A = 35, a_i/R_p = 0.23, for the ratio a_i / R_p of about 0.23.

4.1.3 The GDT-based fusion neutron source as driver for a minor actinides burner

Reprocessing of long-lived radioactive nuclear wastes, including plutonium, minor actinides and other fission products, is a very important problem of nuclear technology and at present is being studied and discussed worldwide. Subcritical reactor systems seem to be quite perspective for afterburning of plutonium and minor actinides in the case of availability of owerful neutron source. For this purpose, a neutron source of accelerator type, a so called Accelerator Driven System (ADS), currently is considered as the most perspective one. This system produces primary neutrons in reactions of nuclear spallation caused by accelerated high-energy particle beam.

However, in the recent years growing interest is attracted by the possibility of construction of subcritical reactor with DT plasma. This plasma produces 14 MeV neutrons in thermonuclear fusion reactions. Such system promises a number of advantages in comparison with accelerator driven system. One advantage is the following: 14 MeV thermonuclear neutrons have significantly higher energy compared with neutrons generated in the accelerator-based source in reactions of spallation.

This feature provides additional possibilities in increasing of the performance of neutron generation in (n,2n) and (n,3n) reactions, as it will be shown below.

Substantial advantage of the GDT-based neutron source is that parameters $\beta \sim 1$ can be achieved. This allows to develop a compact facility with low power and tritium consumption.

In the GDT version for the neutron source for fusion material research (the "basic version" for further discussion), the axially-symmetric mirror system has the length of 10 m. Superconducting coils produce magnetic field $B_0 \sim 1$ T in the central part and up to $B_m = 15$ T in the mirrors (strong magnetic field regions), so the mirror ratio $R = B_m/B_0 = 15$ (see Figure 13a).

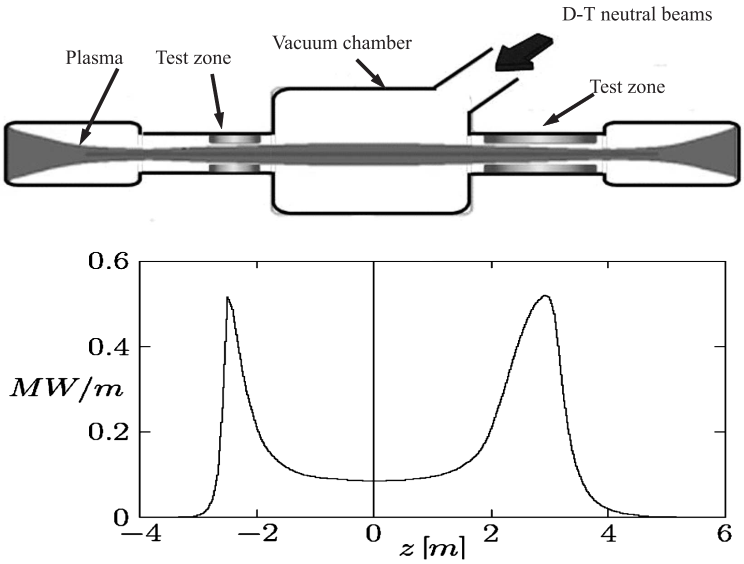


Figure 13: (a) Shematic representation of the GDT-based neutron source and (b) longitudinal profile of neutron flux output power.

In the mirror system two-component plasma is confined. One component is collisional target plasma having Maxwellian particle distribution function which is isotropic in velocity space. Its electron temperature is 0.75 keV and the density is 2 - $5 \cdot 10^{20}$ m^{-3}. Another component is hot deuterium and tritium thermonuclear ions. These ions appear in the result of high-power neutral D and T beam injection. They are confined in the collisionless, adiabatic regime. Fast deuterons and tritons are colliding with each other and enter into a fusion reaction. In this case, the total neutron power is 1.25 MW. Energy of injected neutral beams is considered to be 65 keV and the total power of neutral injection - 36.3 MW (18.9 MW of D^0 and 17.4 MW of T^0). Total electric power consumption equals to 60 MW for the basic version of GDT neutron source. Application of an additional recuperation systems allows to reuse up to 25-35 MW of this heating power. For a conventional efficiency for the thermal to electrical power conversion, saving of electric power consumption from the grid will be at least 10 MW.

Neutral beams are injected at the angle of 30° to the axis. In this case, the hot ion density profile near the turning points and therefore the neutron flux density profile from thermonuclear reactions between fast D and T ions appear to be strongly peaked (Figure 13b).

The "basic version" of the projected neutron source directed originally to fusion material research, was also used as a start variant for further analysis and optimization of performance of different neutron sources as subcritical reactor's drivers. The technical idea of GDT-based neutron source (NS) requires to arrange the GDT vertically and to surround both neutron production zones ("n-zone") by two subcritical fission systems. As a result, the NS "basic version" has two n-zones with the total length of 1 m that provide the integral neutron flux power of 0.44 MW (see Fig. 13). For the sake of simplicity, we consider the sizes of zones equal to 0.5 m each where 0.22 MW of neutron power ($P_n{}^{useful}$) is emitted from each side (that can be easily achieved if the GDT solenoid is symmetric). The result of the first optimization of neutron source geometry was an extension of n-zones from 0.5 m up to 1.5 m each. It provided a growth of total useful neutron power up to 1.5 MW (2 × 0.75 MW). The total electrical power consumption of the "extended" neutron source was 80 MW considering energy recuperation (variant V_1 in the Table 4.1).

Table 4.1: Results of modeling of subcritical systems based on GDT neutron sources and ADS.

Source :	**ADS**	**GDT basic**	**V_1**	**V_2**
P^*_{suppl}, MW	20	50	80	150
$P_n^{usefull}$, MW (total)	0.25	0.44	1.5	4
S_n, neutron/sec	1.25 x 10^{18}	2 x 10^{17}	7 x 10^{17}	1.8 x 10^{18}
h_{fis}, MeV/neutron	1316	2710	3446	3684
P_{fis}, MW (total)	263	87	380	1044
P_{el}^{out}, MW ($\eta = 40\%$)	105	35	152	418
$Q=P_{el}^{out}/P^*_{suppl}$)	5.3	0.7	1.9	2.8
MA reprocessing, kg/year	36(1.2 LWR)	23(0.8 LWR)	52(1.8 LWR)	144(5 LWR)

The result of the next-step optimization was further extension of the zones with maximal neutron power. In this version of neutron source there are two zones of 4 m each with the total useful neutron power of 4 MW (2 × 2 MW). For this version, the total electric power consumption equals to 150 MW. Table 1 shows the result of comparison of three noted neutron source versions. Variant V_2 of NS is a system with two MA-burners with the total nuclear power greater than 1 GW (522 MW in each subcritical reactor) and with the energy efficiency Q ∼ 2.8. Planned productivity of MA reprocessing in this version is 144 kg per year. It corresponds to the annual accumulation of MA in spent fuel from 5 standard light-water nuclear reactors (LWR).

4.2 Multimirror Trap GOL-3

Introduction

Scientific program of 2008 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 2008 in parallel with experiments under scientific programs. Technology of plasma heating by a high power neutral beam injection was in progress. 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 it 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 the material for the collector plate.

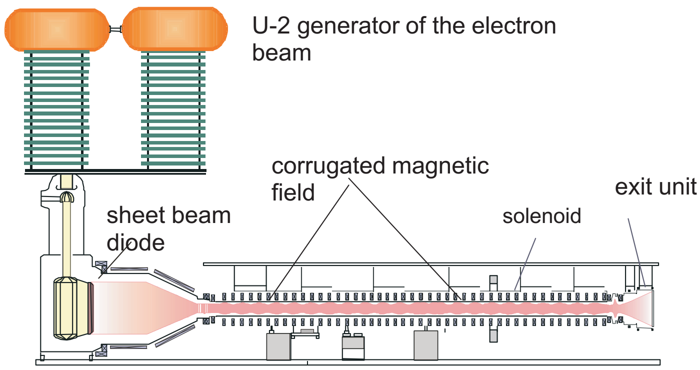


Figure 1: Layout of GOL-3.

A typical experimental scenario is the following. Several gas-puff valves create required axial deuterium density distribution in a metal vacuum chamber ∅ 10 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: 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). Use of multimirror confinement scheme (the corrugated magnetic field) allows to confine the hot plasma much longer, than in a simple solenoidal trap.

4.2.1 Study of evolution of electron distribution function during the beam heating of plasma

In 2008 large series of experiments directed at studying of dynamics of electron distribution function during the beam heating phase and after its end was performed. Such data is important as for better understanding of process of electron beam relaxation in the plasma and transfer of energy from relativistic electron beam to plasma electrons by means of Langmuir turbulence, and for use at processing of experimental data from other diagnostics. Feature of electron distribution function in beam-plasma system is that it is essentially non-Maxwellian. Therefore it should be known in wide energy interval.

Measurements were done by a Thomson scattering system with Nd-glass laser (1058 nm, 40 J, 15 ns) as a source of probing light pulse. Light was detected at 90° and 8° scattering angles. The wave vector of scattered light was chosen which corresponds to transverse to the magnetic field component of electron velocity. Intensity of scattered light was measured in eight spectral channels by infrared avalanche photodiodes with corresponding preamplifiers and was digitized by ADC-1220 (50 MHz sampling rate, 12 bits, 32 K memory) manufactured by Lab. 9. The Thomson scattering system is located at 415 cm from the input mirror, i.e. is rather far from area of peak energy deposition from the beam.

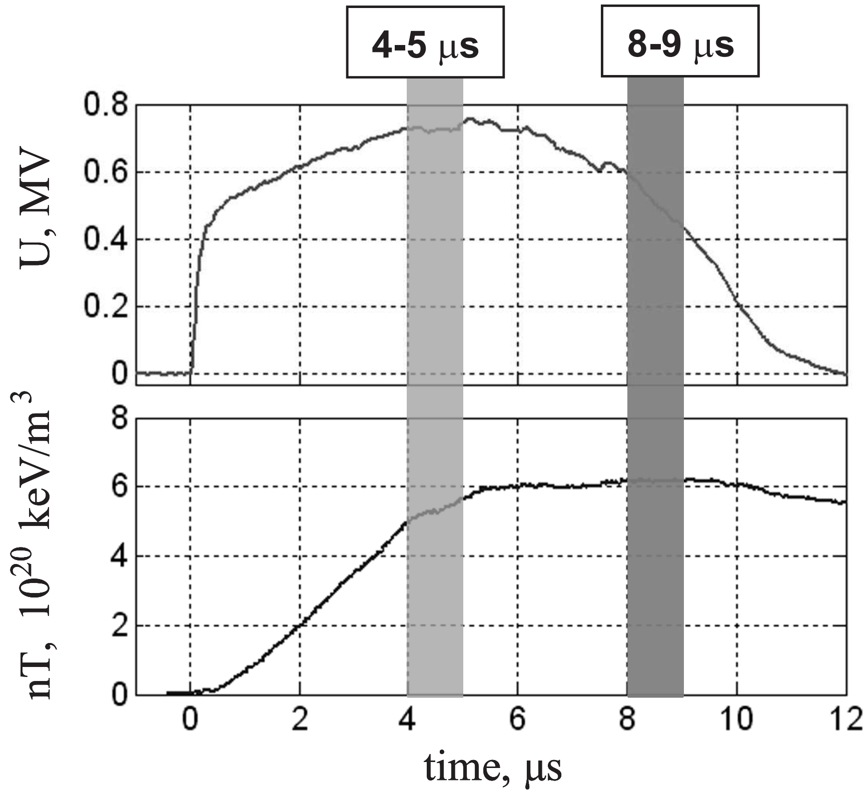


Figure 2: Dymamics of plasma heating. Top: cathode voltage of the U-2 beam generator; bottom: plasma diamagnetic pressure at Z= 475 cm. Marked are time intervals at 4÷5 and 8÷9 microseconds from the beam start for which electron distribution function is shown in Fig. 3.

Figure 2 shows typical waveforms of cathode voltage of the U-2 beam generator which corresponds to initial energy of the beam electrons and of the plasma pressure near the Thomson scattering system. Measurements of electron distribution function demonstrated that it remains non-Maxwellian as during the beam injection into the plasma and at some time after the beam ends. A significant feature which was firstly reported in the discussed experiments was a change of electron distribution function shape near the peak of the plasma pressure. From the previous experiments it was known that plasma heating practically stops somewhat earlier than peak power of the electron beam, the plasma pressure remains almost constant during some time at decrease of the beam power. Measurements by Thomson scattering shown that electron distribution function also changes at that time.

Figure 3 shows that density of electrons with transverse energies below 100 eV and above 3 keV remains practically the same for both time intervals, but density of 0.5÷2 keV electrons decreases almost 10-fold for 8÷9 μs. Distribution function becomes therefore more non-equilibrium. This result is important for understanding as of beam-plasma interaction physics, and for role of microturbulence in confinement of particles and energy in the trap. Interpretation of results of these measurements is model-dependent, therefore more detailed analysis will be done later with the use of data from other diagnostics.

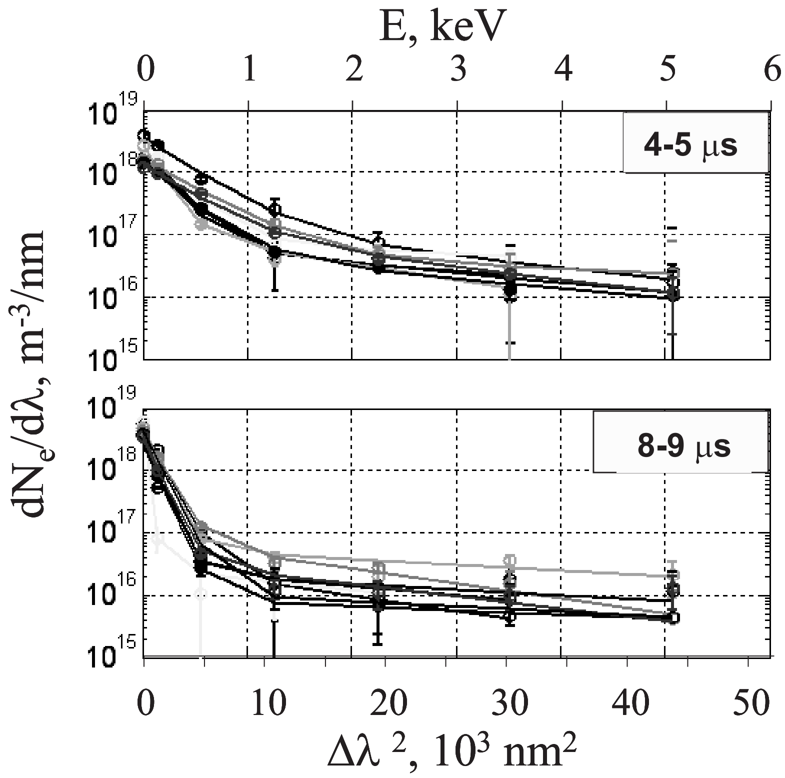


Figure 3: Scattering spectra corresponding to transverse component of electron velocity. Top X-axis shows energy for electrons with purely transverse velocity vectors. Several shots are shown as demonstration of reproducibility.

4.2.2 Experiments with the beam of reduced cross-section

GOL-3 facility operates in a present configuration of magnetic system since 2004. Since that operation regimes optimal for plasma heating and confinement were found, therefore achievable plasma parameters were limited by technical characteristics of various subsystems. In 2007 modernisation of diode unit of the beam generator U-2 was completed. This resulted in doubling of the beam current density (diameter of the beam was reduced from 60 to 41 mm with total current conserved). Such modernisation allowed to complete several new experiments described above. Reduction of the cross-sections of the beam and of the heated plasma to 13 mm became the next step. 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. Further in the text such beam will be referred as thin beam. The total current of a thin beam was up to 2 kA, the current density of the thin beam in the plasma remained the same as for the full-sized one, and quality of the thin beam improves because of smaller average pitch angle due to smaller own magnetic field at the beam edge. Change of configuration of the experiment in comparison with previous modes is illustrated by Fig. 4. The total energy content of the thin beam decreases by a factor of ~10.

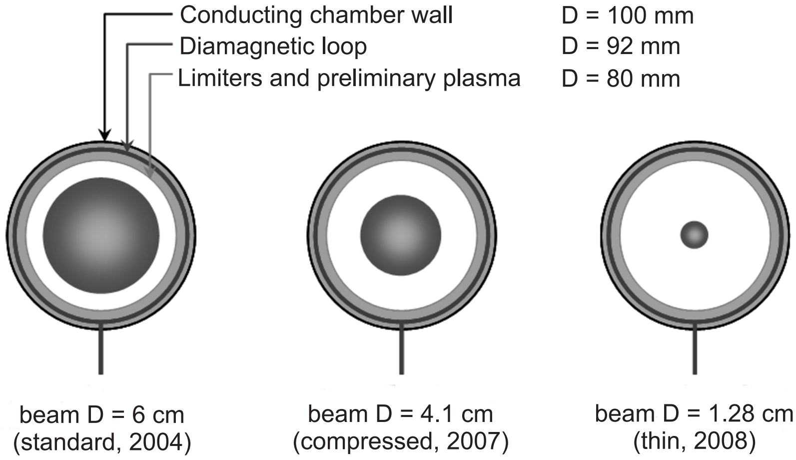


Figure 4: Geometry of the experiment in different operating modes of GOL-3. The cross-section of hot plasma corresponding to calculated beam diameter is shown with in the centre for the following three cases: for the initial beam (at the left), for the beam the increased current density (in the center) and for the thin beam (at the right). Diameters of hot area are shown for minima of magnetic field corrugations which are equal to 3.2 T. The beam current equals 20∼25 kA for first two cases and ∼2 kA for the thin beam.

Experiments with the thin beam were directed to solution of several physical problems. Feature of this beam is that total beam current becomes essentially less than a limiting vacuum current. Therefore experiments became possible not only with injection of the electron beam in the preliminary prepared low-temperature target plasma, but also with the beam injection in vacuum and in non-ionized gas. Experiments with the beam injection in vacuum allows us to made independent calibration of the multifoil analyzer of the beam energy spectrum (results will be discussed later) and to made some other cross-checks. Comparison of dynamics of plasma heating and confinement at the beam injection into gas and plasma of identical density was also important. Besides it, at reduction of the beam diameter the ratio of the hot plasma cross-section to its perimeter worsened. Accordingly, the role of transverse energy and particle losses increases comparing with in the usual operation mode with a good confinement where transverse losses do not exceed 10% in global energy balance. Spatial distribution of axial currents flowing along the plasma changes also, i.e. helical structure of the magnetic field in the confinement area (on which quality of plasma confinement in GOL-3 depends) changes too.

Results of experiments with the thin beam appeared more interesting, than it was expected. The plasma heating within some interval at first two meters from the beam injection point appeared better, than it was expected at simple recalculation for the new diameter of the electron beam (see Fig. 5). We should notice that for the thin beam there is a pressure maximum in axial distribution over the plasma length at this coordinate while for a full-sized beam this maximum is displaced closer to the input mirror and has smaller amplitude. At the rest of the plasma column the beam moves through the plasma already in partially relaxed condition so the plasma heating coincides with that was observed with the standard beam, as it was expected (see Fig. 6).

In the experiments with the thin beam the high current density of the electron beam which reaches ≈2 kA/cm^2 in maxima of the corrugated magnetic field is conserved. At such current density of the beam the beam-plasma system should be unstable in respect to Kruskal-Shafranov instability because of the large system length, as the safety factor

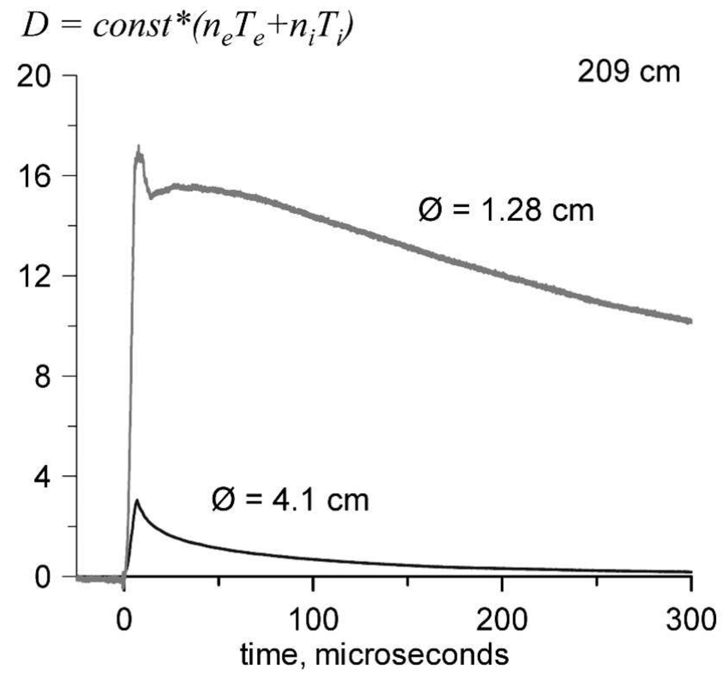


Figure 5: Dynamics of plasma pressure from diamagnetic measurements for the cases of thin and standard electron beams at 209 cm distance from the input mirror. Waveforms are normalized for calculated vacuum cross-section of the electron beam for both cases.

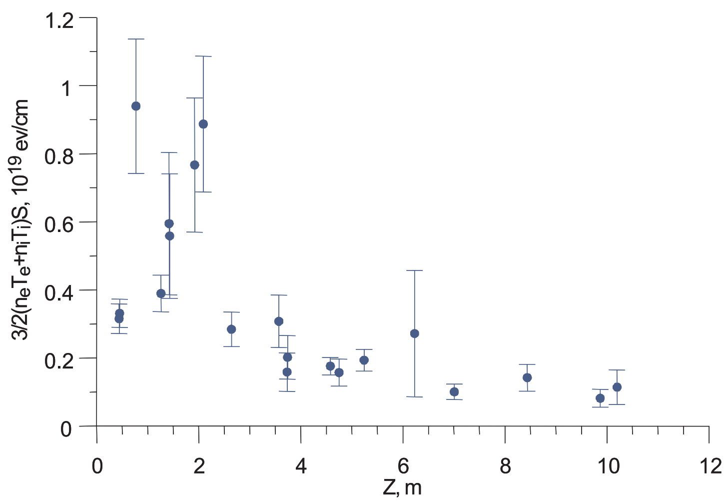


Figure 6: Axial dependence of plasma energy content per unit length in the experiments with the thin beam. Statistical spread for a series of 20 shots is shown. Data was recalculated for 4 T magnetic field corresponding to mean field in the corrugation cell.

$q \approx 0.3$ about three times below the instability threshold (coming at $q<1$). Displacement of the beam from its expected position calculated with vacuum magnetic field was really observed in the experiment. This was detected by radial profiles of attenuation of a probing neutral beam and on spatial distribution of VUV emission of multiply ionized oxygen impurity ions. The beam appeared displaced in different points of plasma section from a shot to a shot. Thus the beam transportation through the plasma was steady as a whole, i.e. the beam dump to the chamber wall with fast plasma decay was not observed. Energy confinement in the experiments with the thin beam was good in general. The observable phenomena can testify that Kruskal-Shafranov instability really develops, but displacement of the beam in respect of its initial position saturates because of self-organization of the plasma and formation of globally stable specific structure of return plasma currents in it.

4.2.3 Measurement of exit energy spectrum of the electron beam

One of important problems in studying the beam-plasma interaction is measurement of an energy spectrum of electrons at the output of the beam from the plasma column. This characteristic determines the degree of the beam relaxation energy, its average losses. It also allows estimating the energy density of Langmuir fluctuations in part of the wave spectrum resonant with the beam using theoretical models. To measure the energy spectrum of magnetized electrons we have prepared simple and reliable diagnostics, based on different ranges of electrons in an absorber foils at various initial energies. In these measurements the electrons outgoing from the trap were dumped in a set of consequent metal foils. Having measured the currents from the foils one can determine the distribution of thermalized electrons on depth in the target. Solution the inverse problem gives reconstruction of the energy spectrum of the incident electrons. Similar multifoil analyzers have been suggested, tested and used for the measurement of the energy spectrum of a beam in other experiments in our laboratory.

It is well-known that the procedure of spectrum reconstruction is an ill-defined problem, characterized by significant errors of the solution. To decrease the reconstruction errors and suppress parasitic fluctuations in solution we had optimized the thicknesses of the foils as well as the energy interval partition. Besides it in the process of reconstruction we used prior information on positive definiteness of the energy spectrum. The solving code was based on Tanaba-Huang projection method which is persistent to the errors in measurements of the absorbed electrons currents, uncertainties in distribution functions of thermalized electrons on the depth and in the model presentation of the spectrum. Using this diagnostics we have obtained the energy spectrum of electrons at the output from the trap in the experiments on interaction of thin beam with current density $j \sim 2$ kA/cm^2 and 1.3 cm diameter with the plasma and neutral gas.

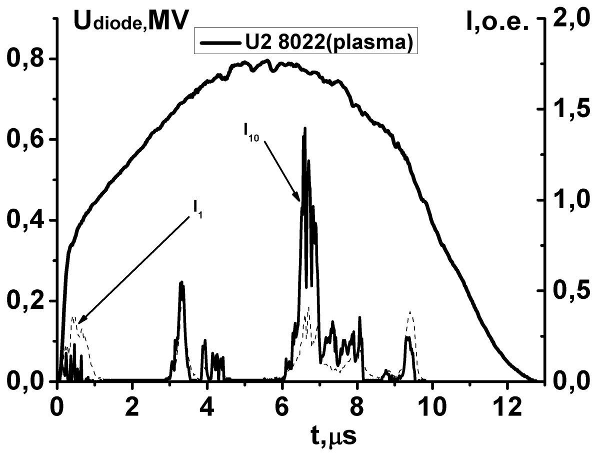


Figure 7: Waveforms of the diode voltage and of currents from the first and the last foils of the multifoil analyzer.

Figures 7, 8 and 9 demonstrat time evolution of the diode voltage, currents from two foils of the multifoil analyzer, spectrogram of the beam and mean electron energy in a typical shot with the beam injection into the plasma.

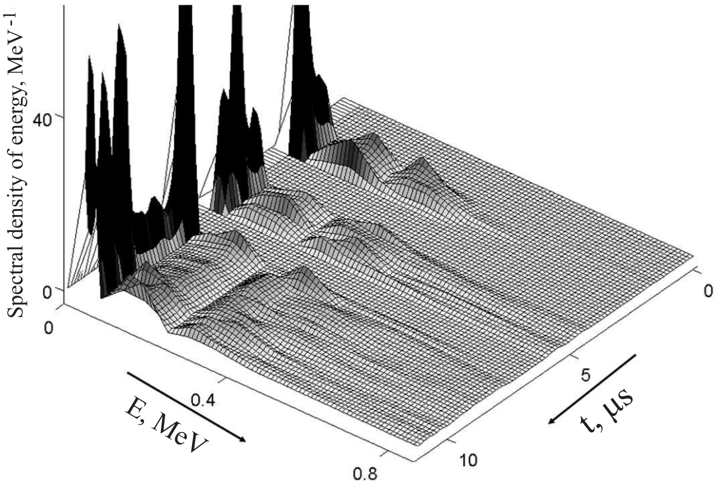


Figure 8: Energy spectrum of electrons in the range 30 keV ÷ 0.8 MeV at the exit of the beam from the plasma.

It is seen that intense relaxation of the beam in the plasma is observed which is accompanied by essential broadening of the energy spectrum and its shift to lower energies of electrons. A group of electrons with energies in the range 30÷100 keV is observed; this group consists of both strongly decelerated electrons of the beam and accelerated electrons of the plasma. The density of this group is comparable to the beam density. Average loss of the beam energy in the plasma estimated from the energy spectrum in the range 0.1÷0.8 MeV exceeds the level of 50%. At the beam injection into a neutral gas the plasma heating efficiency decreases, the average loss of the beam energy becomes somewhat lower and does not exceed 35÷40%.

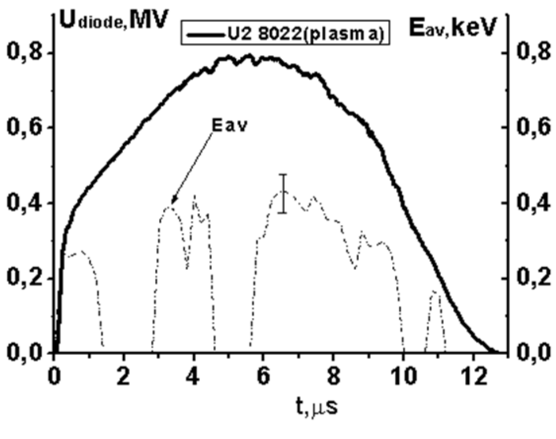


Figure 9: Time dependencies of the initial beam energy (the diode voltage) and average energy of electrons in the range 100 keV ÷ 0.8 MeV at the output from the plasma.

4.2.4 Registration of subterahertz emission from the plasma

A distinctive feature of plasma with a developed Langmuir turbulence is possibility of electromagnetic radiation emission in the vicinities of the plasma frequency ("ω_p process") and of the double plasma frequency ("$2\omega_p$ process"). In the ω_p process the electromagnetic wave, generated due to conversion of plasma oscillations on density fluctuations, strongly attenuates in the plasma. It does not allow one to retrieve directly the parameters of turbulent plasma in its internal region from ω_p emission. Such a drawback ceases in the case of $2\omega_p$ emission appeared as a result of nonlinear merging of two Langmuir plasmons. 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 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.

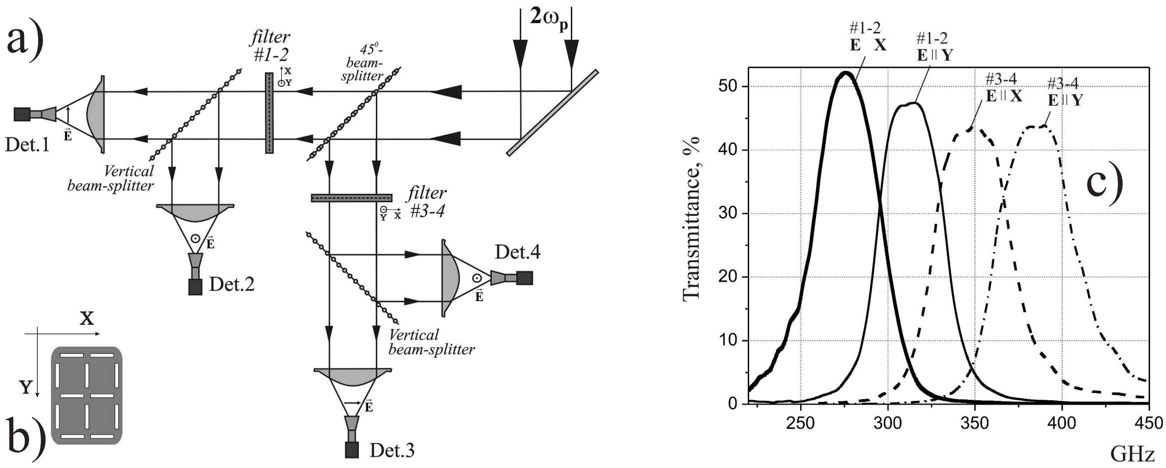


Figure 10: a) layout of radiometric $2\omega_p$ diagnostics; b) topology of filter meshes; c) spectral transmittance of mesh filters.

The diagnostics is realized on basis of a quasi-optical scheme where the incoming radiation beam is de-multiplexed by polarization beam-splitters onto four spatially separated beams. Each beam is filtered by appropriate metal-mesh bandpass filter and then detected by a highly sensitive semiconductor receiver matched with a horn-lens antenna (Fig. 10a).

The radiation receivers are quasi-monolithic units with a Shottky diode, which is mounted inside a units waveguide section and integrated with a microstrip line used for wideband "waveguide-diode" matching. The built-in preamplifier with rise time < 5 ns provides about four orders of magnitude for the dynamic range of signal registration (1 μW ÷ 10 mW). In the existing configuration the receivers have the highest sensitivity within the frequency range 210÷550 GHz. For bandpass frequency selection we have developed a set of interference filters based on double inductive metal meshes with topology of resonant slots separated by a quarter-wavelength intermesh gap. The meshs topological pattern is illustrated in Fig. 10 b. The frequency response of employed mesh filters is shown in Fig. 10 c. Due to strong polarization sensitivity of receivers, special anisotropy was introduced into the mesh pattern to provide a noticeable ($\sim$ FWHM) frequency shift of selected transmission bands for cross-polarized components of the incident radiation. It allowed us to use only two mesh filters instead of four for realizing a 4-channel radiometric system that reduced its production costs. Filter fabrication was realized by means of a photolithography employed for creating of the mesh pattern on the surface of metallized polypropylene films, which were fused into a multilayer structure afterwards using a thermal pressing method. One-dimensional photolithographically produced grids with 8μm pitch were used as polarization beam splitters. Spectral calibration of radiometric units has been performed at a unique submillimeter BWO-spectrometer in the A.M. Prokhorov General Physics Institute, RAS (Moscow).

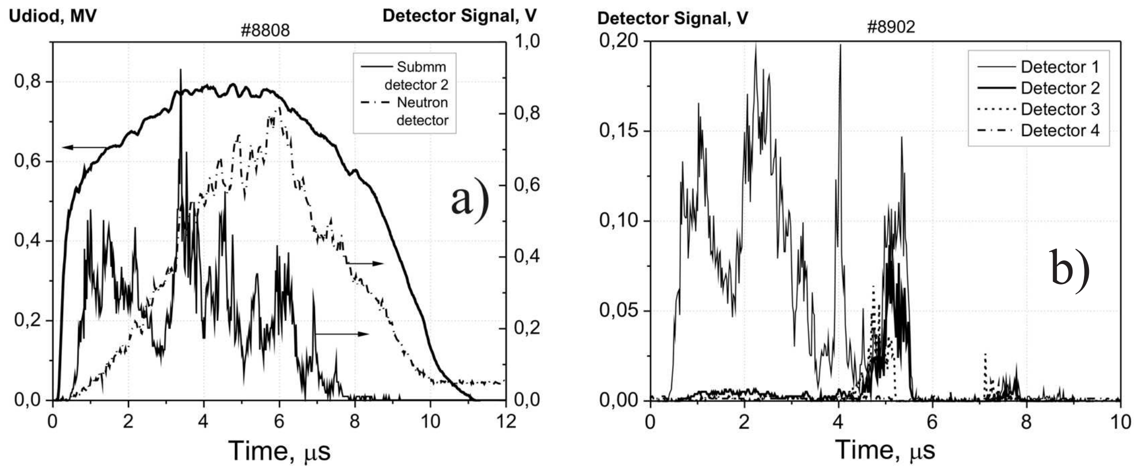


Figure 11: a) typical waveforms: electron beam generator voltage, and signals of neutron and sub-mm detectors (without filter); c) example of waveforms from the 4-channel $2\omega_p$ diagnostics with a predominated lowest-frequency signal.

Studies of $2\omega_p$ emission were done in the region of maximal plasma heating. The radiation coupling of the plasma chamber with the radiometer was realized via the teflon window 70×30 mm^2, followed by a quasi-optical transmission line on the basis of a hollow dielectric tube ∅ 54 mm. The opposite window of the plasma chamber was also made transparent for radiation.

Emission of submillimeter radiation was experimentally observed during the period of electron beam injection (Fig. 11a). Sharp spikes of emission with duration 10÷100 ns were detected against a slower background envelope along with spectrum transformation at the final stage of E-beam injection (Fig. 11b) that points out at plasma density change. At present, we continue experiments for clarifying details of underlying mechanism of sub-mm emission and study its power spectrum in different operational regimes of the GOL-3 facility.

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

In 2008 the works were continued aimed at the development of technology of high current electron beams with long pulse duration (0.1÷1 ms), high current density and energy of electrons in the range of hundreds keV on the basis of plasma emitter. At special test stand the first experiments were performed on the magnetic compression of electron beam generated in the source with arc plasma emitter and the diode type electron-optic system (EOS) with circular accelerating apertures. Energy of electrons in test-bench source was 26 keV with 0.25 ms beam pulse duration. Scheme of the experiment is shown in Figure 12. The beam is produced in axial magnetic field of 0.1 T and further transported and adiabatically compressed in the magnetic field of mirror configuration. The beam current which passes through the magnetic mirror bottleneck is measured with Faraday cup (FC). The total emission current, beam current precipitation on the drift tube wall (prior to entering into the magnetic mirror) and the current on the anode of EOS are also measured.

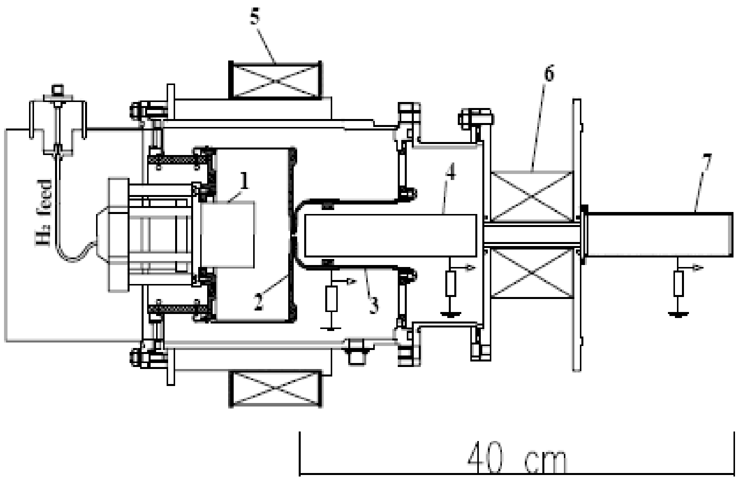


Figure 12: Schematic of the experiment. 1 is arc plasma source, 2 is emission electrode, 3 is extracting electrode, 4 is liner, 5 is magnetic coil, 6 is mirror coil, 7 is Faraday cup.

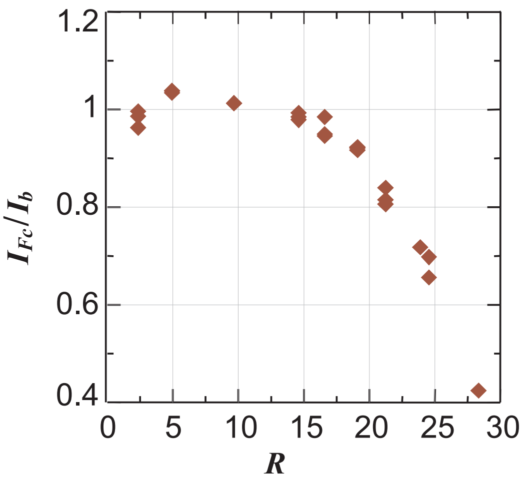


Figure 13: Beam transmission through the magnetic mirror bottleneck depending on mirror ratio R.

During the experiments the mirror ratio R was varied over a wide range, while maintaining the constant magnetic field within the EOS region. The ratio of the FC current to the full beam current depending on R is shown in Fig. 13 (for single-aperture EOS). At $R = 20$ (which corresponds to 90% of the beam transmission through the magnetic mirror bottleneck) the current density at the maximum of magnetic field reaches the value of 400 A/cm^2. At further increase of the mirror ratio the beam electrons were partially reflected back, that, in turn, corresponded to increase of currents at the drift tube wall and at the anode of EOS.

Experimental results do not contradict the expectations derived from the numerical modelling. Let us note that the basic contribution to the starting pitch-angles of beam electrons in these experiments was caused by a defocusing action of anodic aperture.

Together with the test-bench experiments, the prototype of the source of long-pulse electron beam with arc plasma emitter was designed, manufactured and installed into the end tank of the GOL-3 in 2008. The beam source is intended for obtaining of a beam with the energy of electrons of 150 keV, the pulse duration about 100 μs and the beam current in the range of hundreds of amperes. The scheme and photographic layout of the beam source are shown in Fig. 14.

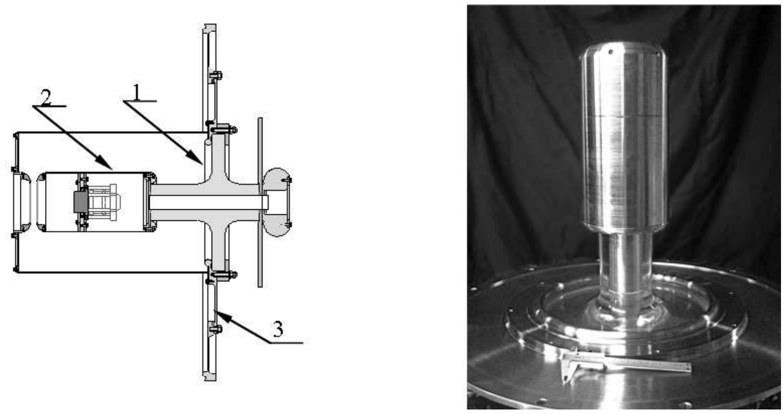


Figure 14: Schematic and photo of the beam source intended for installation into the exit plasma expander of GOL-3: 1 is feedthrough insulator; 2 is arc emitter; 3 is mounting flange.

Within the framework of developing of pulsed-power source for new beam the high-voltage capacitors assembly 1.2 μF x 200 kV was mounted at GOL-3. The 200 kV multi-gap switch intended for the commutation of capacitors assembly to the beam source was also prepared and tested. The “cold” (without the beam) tests of the source for dielectric strength were performed successfully. Tests were conducted both at static voltage of 150 kV and in pulsed operation regime with the maximum voltage exceeding 180 kV.

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.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, I.V. Kandaurov, K.N. Kuklin, I.A. Kotelnikov, 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, Yu.S. Sulyaev, I.V. Timofeev, Yu.A. Trunev, L.N. Vyacheslavov, V.A. Yarovoy.

4.3 Elmi facility

4.3.1 Two-stage THz-generator: principles of operation and schematic of experiment

In the beginning of 2008 we have completed the technical design of the whole project for experimental realization of two-stage generation of THz radiation and to the middle of the year the manufacturing the main units has been finished. The schematic of planned experiment is shown in Figure 1.

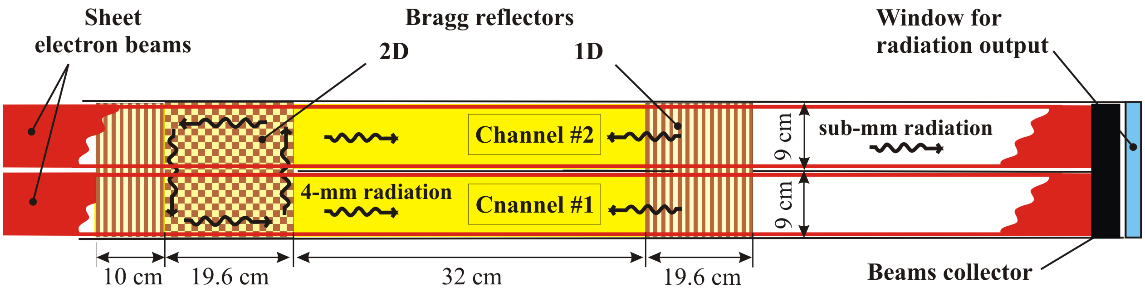


Figure 1: Schematic of experiment on intercavity scattering 4-mm radiation on sheet REB.

In this experiment the lower ribbon electron beam propagating in the periodical magnetic field pumps high-power electromagnetic wave in the resonator. The space of the resonator consists of two joined sections: upper and lower. Each section is formed by upstream 2-D Bragg reflector, homogeneous rectangular waveguide and the downstream reflector on the base of 1-D Bragg reflector of narrow band reflectivity. The joint of the resonator sections in first series of experiments is planned by means of side slit between sections which through 4-mm radiation from the lower section will pass to the upper one. This scheme permits to use high-power 4-mm radiation generated in lower section of the resonator as an electromagnetic undulator for free electron laser realized in the upper section of the resonator, where the second sheet beam is transported by homogeneous longitudinal magnetic field. It was shown earlier that the wavelength of scattered radiation in the case of oncoming movement of 4-mm radiation and the relativistic beam lies in the range 0.1-0.3 mm depending on the γ-factor of the beam electrons. For the case of transverse direction of 4-mm wave propagation relative to the beam, the wavelength range is shifted to 0.2-0.6 mm. To generate radiation we plan to use sheet electron beams of 3-4 mm thickness 7 cm wide having the electron energy of 1 MeV and current density of 1-3 kA/cm^2. The electron beams should be transported in narrow slit channels with longitudinal magnetic field of 2 T. At the amplitude of quasistatic undulator magnetic field about 0.2 T the expected efficiency of 4-mm wave generation is about 10%. In this case the density of the radiation power of 4-mm radiation is estimated on the level of 0.5 GW/cm^2 at the strength of electric field in the resonator about of 10^6 V/cm. The achievement of such parameters should provide the spatial gain factor in the second stage of the experiment on THz generation on the acceptable level of $\Gamma \sim$ (3-5) м$^{-1}$.

4.3.2 Experiments on simultaneous generation and transport of two high-current sheet beams

During 2008 the series of experiments on simultaneous generation and transport of two high-current sheet beams was successfully completed. At the end of this series spontaneous mm-wave radiation generated by the electrons of two sheet beams in the undulator magnetic field in the absence of Bragg resonator has been registered in the band 68-80 GHz. As it is seen from the results of the radiation power measurements (Figure 2) the signals are not correlated, so the beams generate independently.

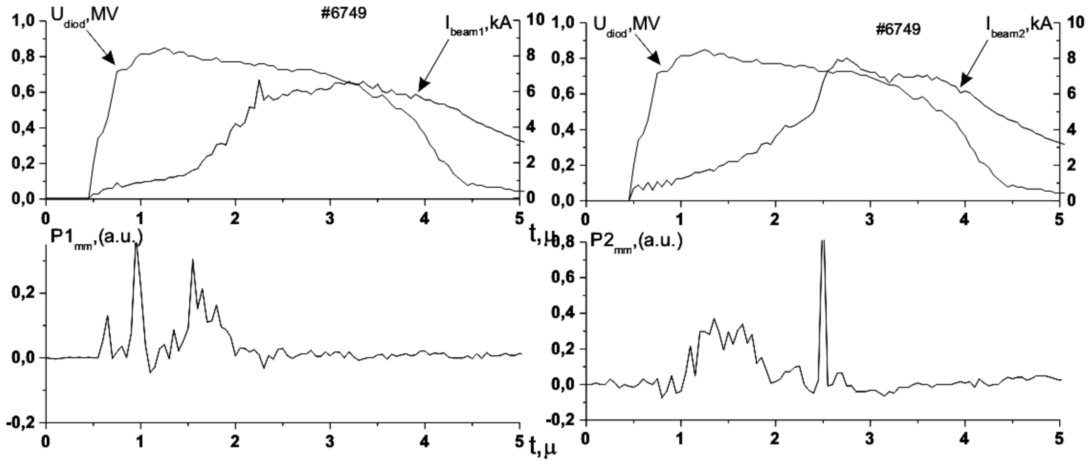


Figure 2: Signals of mm-radiation in the band 68-80 GHz generated simultaneously by two sheet beams at their movement in slit channels with undulator field (left graph refers to lower beam, the right one to the upper beam).

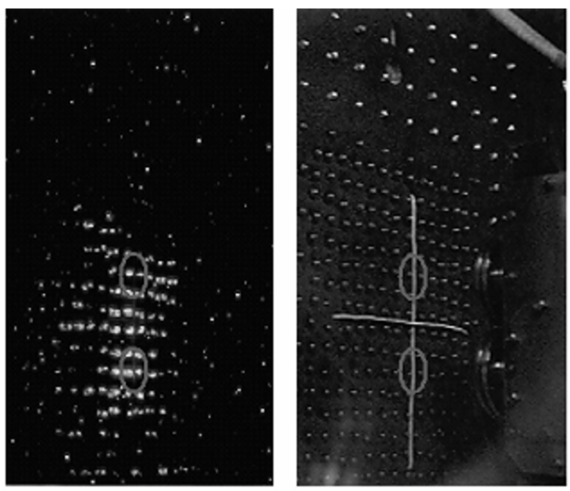


Figure 3: The image of neon bulb emission under the mm-wave radiation, outgoing from transport channels (left graph) and the photo of a panel with projections of windows intended for the output of radiation.

Besides that by means of neon bulb panel we have registered the spatial picture of the radiation power from the upper and lower transport channels outgoing through the windows. The image of bulb luminescence is shown in Figure 3.

So, in the result of experiments on simultaneous generation and transport of intense sheet REBs we have obtained two similar sheet beams with cross section 0.4x7 cm at the current density 1.5 kA/cm^2 that is required by the experimental conditions for effective two stage THz generation.

4.3.3 Electrodynamic system for the experiments on two-stage generation of THz radiation

In the first experiments on implementing the two-stage scheme for generation of the THz radiation the combined planar Bragg resonator will be used as an electrodynamic system. This resonator consisting of upstream 2-D and downstream 1-D Bragg reflectors separated by the smooth waveguide (see Figure 1) was designed in 2008. The possibility of the single-mode single-frequency generation of 4-mm radiation in such resonator was demonstrated in simulations and computer modeling and obtained in the experiments at the ELMI-device in 2005.

On the photos (Figure 4,a) the parts of 1-D (down-stream) and 2-D (up-stream) Bragg gratings are shown. The place of the resonator sections joint with 2-D grating is presented in Figure 4,b. The specially angled scatterers along the edges of 2-D grating are intended for suppressing the parasitic “cut-off” modes related to the transverse radiation flows on this grating. The efficiency of using such scatterers in comparison with different microwave absorbers has been demonstrated earlier.

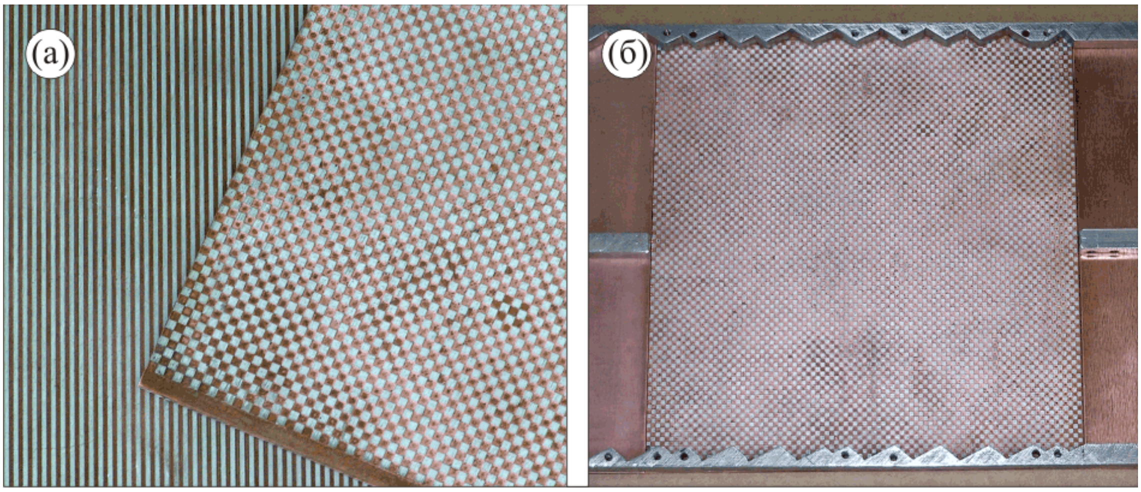


Figure 4: a) The parts of 1-D (down-stream) and 2-D (up-stream) Bragg gratings; b) the place of the resonator sections joint with 2-D grating.

Thus using the described electrodynamic system in the first experiments we should investigate the single-pass amplification of the THz radiation stimulated by scattering of the 4-mm radiation at the angle of 90° on the 2-D Bragg reflector as well as 180° (back) scattering, that should be realized along the full length of the resonator due to reflection from the down-stream 1-D grating in the second channel. Further development of the electrodynamic system will be carried out to optimize parameters of Bragg structures (specifically the coupling coefficient of the 2-D reflector defining the actual coupling between channels), and to create resonator for the THz radiation to obtain the generation mode and significant increase of the output power. Development of such resonator in consideration of the existent geometry and parameters of the ELMI-device is a particular complex problem.

4.3.4 Diagnostics of millimeter and sub-millimeter radiation

For investigation of the 4-mm radiation spectrum generated in the free electron maser two types of spectral diagnostics have been developed and implemented. The first one is a four-channel quasioptical diagnostic for registration of the radiation flow density in a wide frequency range. It is based on the quasioptical transmission line with the four band-pass Fabry-Perot filters used as the frequency selective elements. The microwave radiation passed through the filter is registered by the low-power crystal detector and then digitized by the ADC with time resolution of 5 ns. The four-channel diagnostic provides survey registration of the radiation spectrum in the frequency band of 72.5-77 GHz where all modes of the FEM combined resonator are located. The frequency resolution of the diagnostic depends on the filters pass-band which typical amount is about 0.7 GHz.

The second diagnostic is intended for the precisional analysis of maser radiation spectrum. It is based on the single-channel heterodyne. The microwave radiation from the maser is mixed with the signal from the driving oscillator on the non-linear detector (mixer). The intercarrier frequency signal from the mixer is registered by the oscilloscope. The frequency of the driving oscillator can vary in the range of 60-79 GHz with the accuracy of ± 10 MHz. The frequency range covered by the heterodyne diagnostic in a single pulse is limited by the oscilloscope bandwidth (4 GHz), though the upper possible intercarrier frequency for the used mixer is 12 GHz.

For registration of the sub-millimeter radiation spectrum generated in FEM, as well as in the beam-plasma experiments on the GOL-3 device, the four-channel quasioptical diagnostic has been developed (see Fig. 5).

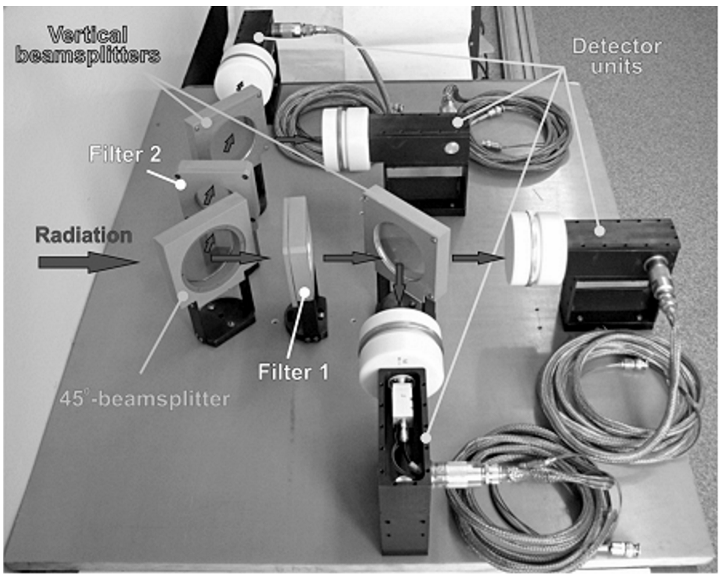


Figure 5: Four-channel quasioptical diagnostic.

In this diagnostic the spatial dividing of the input sub-mm radiation flow on four beams is used with the subsequent frequency filtering by the quasioptical band-pass filters. After filtering the radiation beams are focused with the horn-lens antennas and the radiation power is registered by the highly-sensitive semiconductor receivers. This diagnostic is unique and contains various original technical solutions for active and passive quasioptical components. The mesh interference filters based on the two-layer self-resonant inductive metallic meshes separated by the quarter-wave gaps are used as the quasioptical band-pass filters. This solution provides the relative pass-band in the range of 10-30% with the out-of-band attenuation of 20-40 dB (Fig. 6). For manufacturing of mesh filters the photolithographic technique of the mesh structure forming on the metalized polypropylene film was used with the subsequent thermal pressing of single films into the multi-layer interference structure. For calibrating of separate components of radiometric system (detector units, filters, polarizing beam splitters) as well as ready-assembled diagnostic a unique sub-terahertz BWO-spectrometer was used (spectrometer was developed in the Prohorov Institute of General Physics RAS).

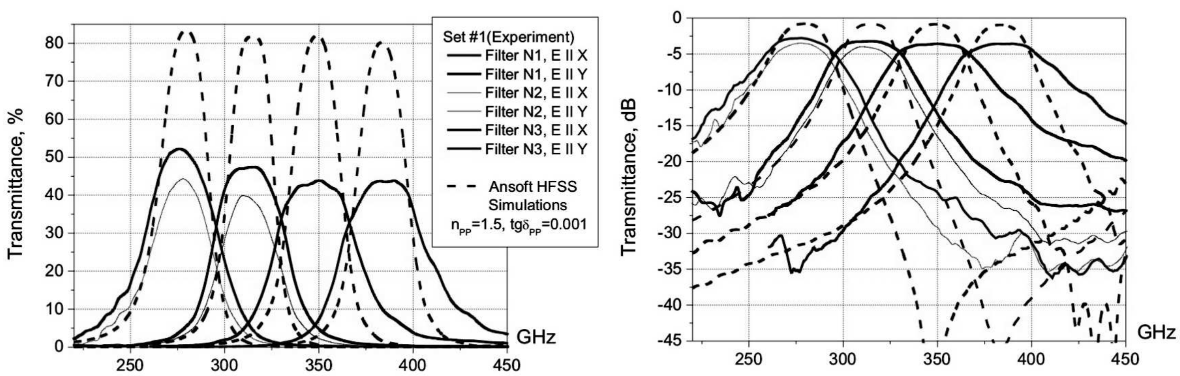


Figure 6: Spectral transmission of the two-mesh filters with configuration 8x40mmPP+Mesh+4x40mmPP+Mesh+8x40mmPP.

In the result the following units were prepared for the experiments on the two-stage generation of terahertz radiation: diode for generation of two high-current sheet beams, two-channel Bragg resonator for generation of high-power millimeter radiation with its subsequent scattering on the beam and frequency conversion to the terahertz range, diagnostics for registration and analysis of millimeter and sub-millimeter radiations.

4.4 Plasma theory

Research in plasma theory was conducted in several areas.

4.4.1 Plasma equilibrium

A set of formulas for interpreting the diamagnetic measurements of compact plasmoid is derived preprint 1, [401, 179]. The effect of conductive walls of the experimental chamber on the diamagnetic signals is taken into account for the case where the plasmoid radius is compatible with the chamber radius.

In the framework of MHD, a theoretical model describing favorable effect of the biasing potentials on the plasma confinement in open traps is worked out. A threshold of the transition to the regime with improved confinement is studied [404, 181]. Interrelations between the reduction of the parallel transport and enhancement of the perpendicular electron transport in the turbulent plasmas of GOL-3 is found [405].

4.4.2 Plasma stability

In the area of the *plasma stability* linear ballistic-type flute modes in presence of sheared plasma flow are studied. The effect of Finite Larmor Radius on these modes is analyzed [180, 402, 401].

A non-linear stage of Alfven ion-cyclotron instability arising in anisotropic finite pressure plasmas is studied [409] . Class of precise solutions of Maxwell-Vlasov set for Alfv́en wave of an arbitrary amplitude in collisionless plasmas is found. On basis of them solutions for weak collision case when the anisotropy is maintained by fast ion injection are built up. The obtained analytical and numerical results allow to detach a range of parameters of the wave and plasma, where the equilibrium between them can exist.

4.4.3 Particle beams

Investigations of electron-optical characteristics of diodes with plasma electrodes are carried out in area of sub-millisecond-range high-power electron beam generation. For this purpose the model of plasma boundary is used which shape is determined by condition of equality of charge particle flows that fall onto plasma boundary within plasma and the same extracted from plasma boundary into diode gap. This model allows to expand a range of problems under solution and to simulate accelerating structures with several plasma regions that emit particles of different kinds. The model is realized in algorithms of the code POISSON-2 and simulations of one-aperture bipolar diode with cathode and anode plasmas are fulfilled, comparison with experiment is made. A multi-slit coaxial diode with 160 kV potential and 1.5 kA beam current in magnetic field based on a plasma cathode was calculated. Beam characteristics are acceptable for plasma heating in GOL-3 experiment [442].

A well-known Pierce solution that allows focusing a beam of charged particles using properly shaped electrodes outside the beam aperture is generalized to the case of an accelerating system with inhomogeneous emission current density [183]. It is shown that the defocusing effect of the space charge can, in principle, be evenly compensated over the entire cross section of the beam. In contrast to the beam with a uniform emission current density, both the electric potential and the transverse electric field must be controlled along the beam boundary in order to eliminate the angular divergence. However, eliminating the angular spread evenly across the beam constitutes a mathematically ill-posed problem which needs to be solved with the use of one or another method of regularization. An alternative way of diminishing beam emittance is proposed for the beam where the emission current is uniform across the entire aperture except for a narrow beam edge layer and a simple formula for the Pierce electrodes is derived. Numerical simulation has proved the reasonable accuracy of our analytical theory.

4.4.4 Nonneutral plasmas

New effects caused by violation of the axial symmetry of a separatrix separating passing and trapped particles of non-neutral plasma were found both numerically and analytically [406, 407, 408]. It appears that in the presence of z-symmetric perturbations with azimuthal mode number $m > 0$, which do not cause significant transport as itself but violate the axial symmetry of the separatrix (located in the section $z = 0$), the transport caused by z-antisymmetric perturbations rises many times and has scalings different from the symmetric separatrix case. The similar problem takes place in the rotating frame when non-linear resonance decay of z-symmetric diocotron mode with $m = 2$ to z-antisymmetric $m = 1$ perturbations is studied. The predicted effects were found in experiments.

A relativistic effect is found that restricts the maximal radius of a plasma equilibrium configuration at a level of few centimeters (for a typical density of charged plasmas in existing devices) [184]. A similar effect, though with a different nature, is expected for tube-like configurations of charged plasmas [185, 410, 412].

The effect of a weakly tilted magnetic field perturbations on the equilibrium of a nonneutral plasma confined in a Malmberg-Penning trap is analyzed [185, 410, 413]. A constraint is introduced, that in combination with the Poisson equation allows to select admissible plasma equilibria in the trap in the presence of a non-uniform and a non-axisymmetric magnetic field. Longitudinal plasma currents (analogous to the Pfirsch-Schlüter currents in Tokamaks) appearing in a nonneutral plasma even in the absence of magnetic drifts are explicitly computed in the case of a uniformly tilted magnetic field.

4.4.5 General problems of plasma physics

The history of plasma physics origin is reviewed [188] on the eve of 80th anniversary of the 1st paper on plasma physics by I. Langmuir. It is mentioned that the period of plasma physics formation as a science is mythologized. Even the birthday of plasma physics and the parentage of the word “plasma” are disputed.

Chapter 5

Electron - Positron Colliders

5.1 Studying the beam-beam effects on VEPP-2000

5.1.1 Storage ring optics correction

After reception first colliding beams in VEPP-2000 ring it was spent theoretical and experimental research of optimization beam focussing at IP depending on experiment energy. Strategy of controlling the solenoidal focussing strength has been developed, which takes into account all the factors having influence on receiving the maximal luminosity of VEPP-2000 collider.

Deviations of collider focussing system from computed one have experimentally been tested. A primary factor that has influence on beam-beam effects is the dispersion function's symmetry violation, this leads to marked dispersion in IPs. As a result of correction made the horizontal dispersion function (dark blue points) has been adjusted in compliance with projected optics (Figure. 1). A slight residual vertical dispersion (red points) will require additional measurements.

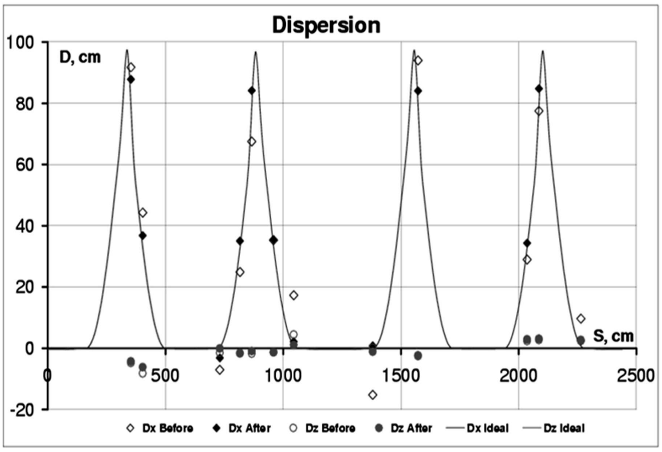


Figure 1: Dispersion function is present at achromatical bends only

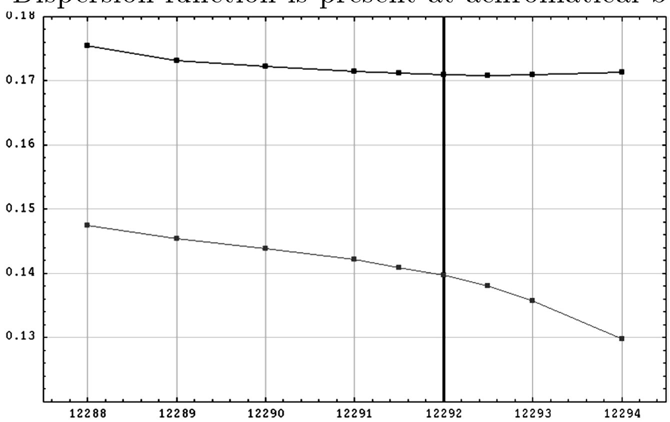


Figure 2: Chromaticity of betatron oscillations depending on frequency of accelerating voltage.

The next step was measuring the chromaticity of betatron oscillations by frequency tuning of RF cavity accelerating voltage. By matching the currents in two families of sextupoles we made positive chromaticity of horizontal and vertical oscillations and chose RF frequency in a linear range: $f_0 = 12291$ kHz (Figure. 2).

After correcting the collider focussing system the measurement of betatron oscillations' damping decrement has shown complete fit to theoretical calculations (Figure. 3).

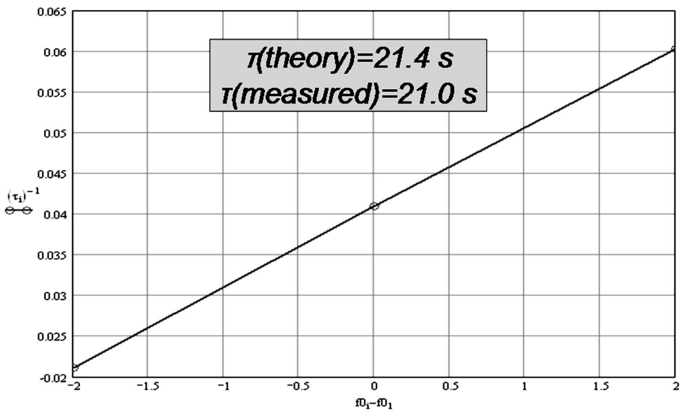


Figure 3: Damping decrement vs. tune shift of accelerating voltage.

Scanning of betatron tunes region and measurement of dynamical aperture (Figure. 4) confirmed the optimal values for working point $\nu_x \approx \nu_z \approx 0.1$.

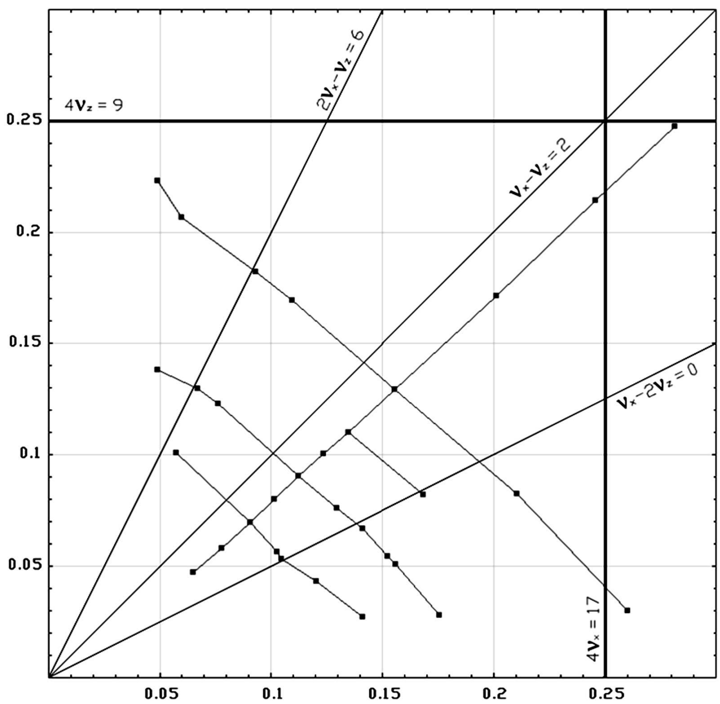


Figure 4: Dynamical aperture studying

All the steps listed above have allowed us to increase the value of space charge parameter ξ in "strong-weak" mode. The Figure 6 shows sizes σ_x, σ_z of positron beam (1–3 mA) measured in several points in the ring during electron beam current changes. Point 3 (in a dipole near to IP) corresponds to minimal value of β_x. The horizontal beam size behavior in this point matches its measurement at IP. One can see from this figure that horizontal beam size (lower blue curve) slightly changes in a wide range of electron beam currents.

This behavior was observed up to electron beam current of 50 mA that corresponds the value $\xi = 0.1$.

For illustrations in Figure 9.1.1 we show the results of computations the beam-beam effects for VEPP-2000 structure at energy $E = 1$ GeV that we made early. One can see that the beams at IP keep round geometry with slightly increase of transverse sizes up to values of $\xi = 0.15$.

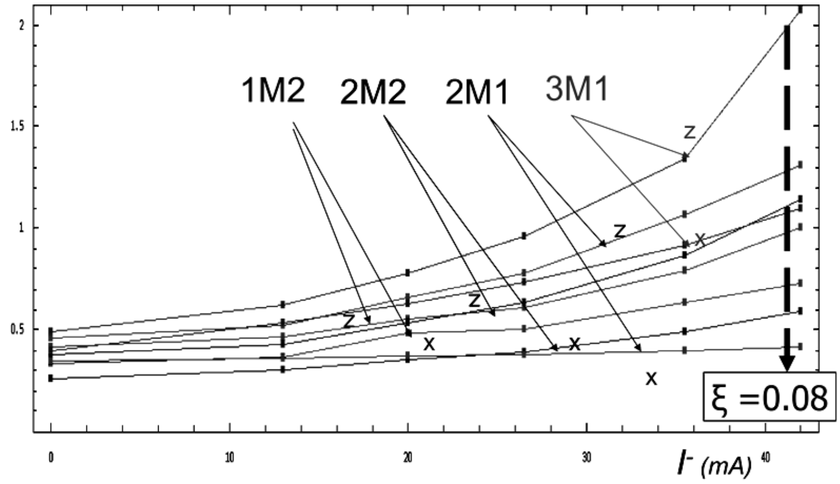


Figure 5: Positron beam sizes vs. electron beam current

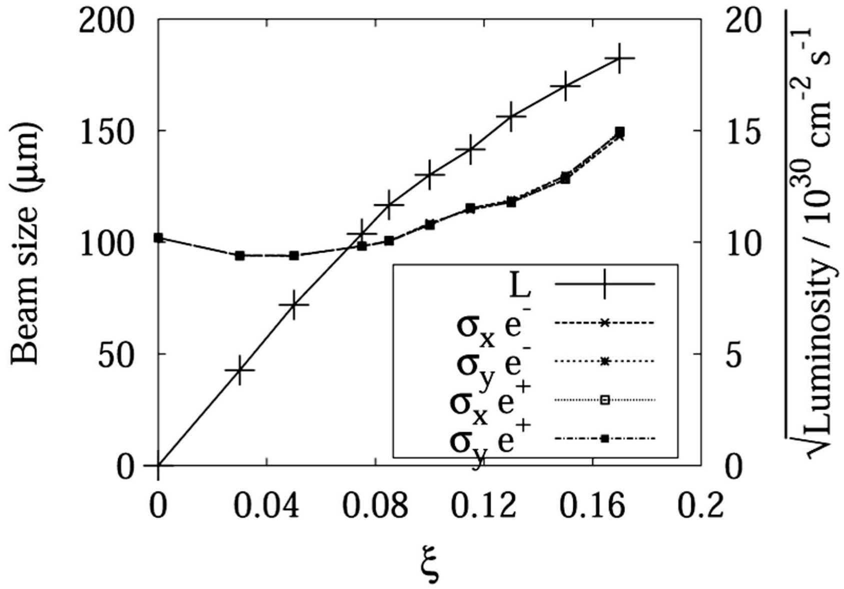


Figure 6: Beam sizes vs. current (numerical)

5.1.2 Luminosity with SND detector

After tuning the storage ring optics and studying the beam-beam effects in "weak-strong" mode it is possible to store big and approximately equal currents of electrons and positrons and to get luminosity. The Figure 7 shows the typical cycle of the accelerator complex work with big currents. The red curve represents positron current measured with photomultiplier, the blue curve - electron one and the black curve is sum of currents measured with ferroprobe.

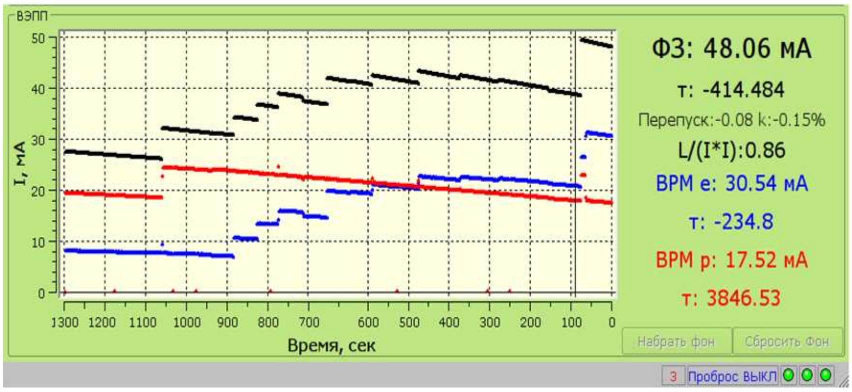


Figure 7: Cycle of storing electrons and positrons

Testing shifts with measuring the luminosity have been spent at beam energy of 500 MeV. On-the-fly measurement of luminosity by electron-positron couples scattering at large angles was made by SND calorimeter (Figure 8). The CMD detector at that time performed test of its superconducting solenoid being out of experimental range.

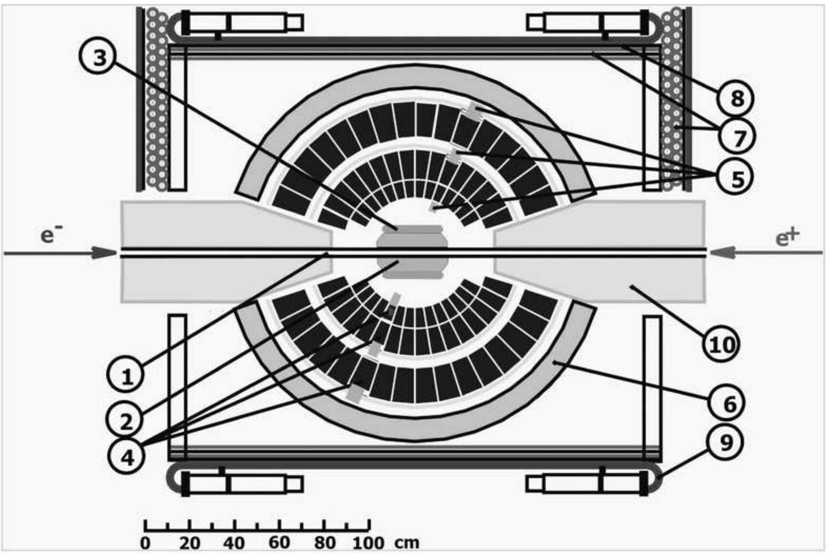


Figure 8: SND detector

In the beginning background loads of SND detector have been measured separately from electrons and positrons, these have appeared rather small that has allowed to measure the luminosity practically without background.

Information about current luminosity was updated every 10 seconds. Such rapid exchange of information with detector allowed us quickly optimize beam-beam regime normalizing to product of stored electrons and positrons currents.

Record value of registered luminosity $L_{max} = 1.05 \times 10^{31}$ cm^{-2}s^{-1} has been received at colliding beams currents 43 mA (electrons) and 42 mA (positrons). In the future by transfer to injecting positrons from putting into operation injecting complex VEPP-5 it is possible to receive twice as large the luminosity.

Designed-in large flexibility in distribution of currents in solenoids' sections allows us to significantly decrease the value of β-function at IP with decrease beams energy. As a result the collider luminosity depends on energy not as E^6 but only as E^4. With the beams energy of 500 MeV optimal value of *beta*-function is 4.5 cm as expected. Optimized dependence of luminosity on beam energy is presented in Figure 9.

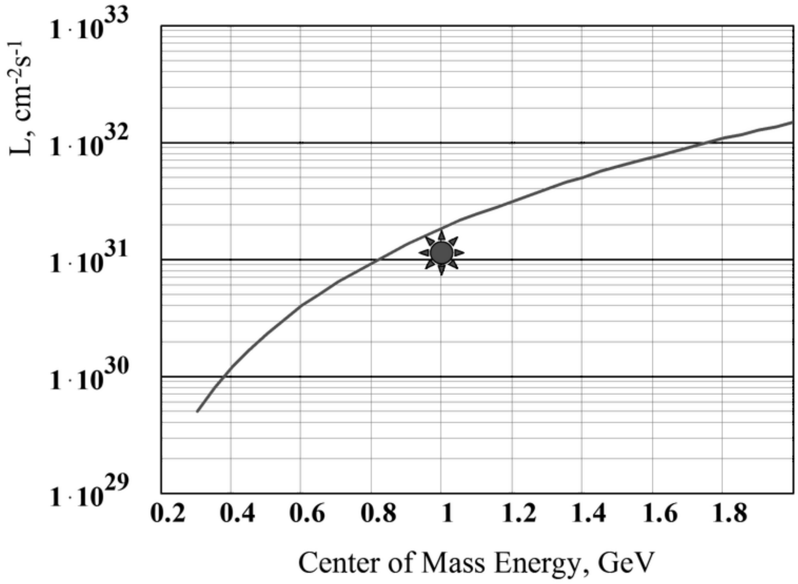


Figure 9: VEPP-2000 luminosity vs. energy

The luminosity received already in first shifts of detector work proves round beams advantage and allows us to predict with big confidence achievement of projected luminosity of VEPP-2000 ring $L_{max} = 1.05 \times 10^{32}$ cm^{-2}s^{-1} at energy 2×1 GeV.

5.2 Measuring beams energy in VEPP-2000 storage ring

The need of rapid measuring the energy in VEPP-2000 ring in colliding mode arises during the work of storage ring in the whole energy range from 200 MeV up to 1000 MeV. We considered two ways of absolute energy scale calibration.

5.2.1 Method of resonance depolarization

The first variant is based on using the method of resonance depolarization developed in VEPP-2M complex and continuing to be used now in VEPP-4M complex. In this case it is supposed to work on luminosity under zero integral of longitudinal field in solenoids in each of two experimantal drifts. The round beam mode in this variant is supported by choosing working point at linear coupling resonance. This regime has been successfully tested during commissioning of VEPP-2000 complex. With integral of longitudinal field being zero in SND and CMD tune of free spin precession is the same as in a ring without solenoids.

The only difference from ordinal situation is significant decrease of the radiation polarization time due to influence of edge fields of solenoids and large magnetic field in bending magnets of VEPP-2000.

Using various schemes of solenoids' polarity (polarization time and degree in schemes "$+-+-$" and "$+--+$" are shown in Figs. 10, 11) one can make precision calibration of beams energy with resonance depolarization in various energy ranges of VEPP-2000 ring.

In addition there exists a possibility to polarize electron or positron beam in booster ring BEP with further injection almost polarized beam in VEPP-2000 ring.

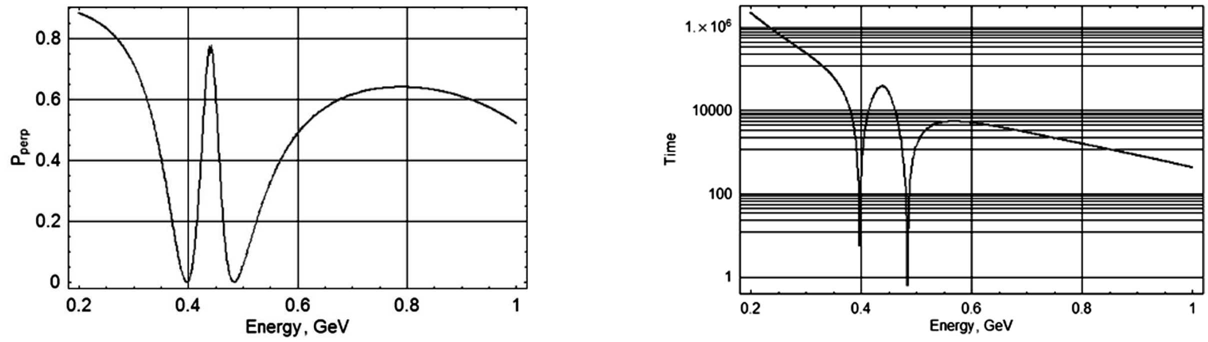


Figure 10: Polarization degree (left) and time (right) vs. energy in scheme "$+--+$"

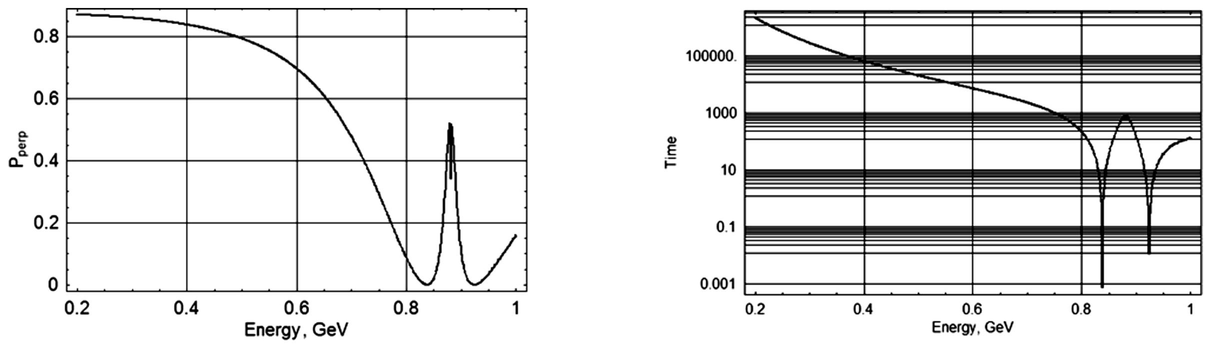


Figure 11: Polarization degree (left) and time (right) vs. energy in scheme "$+-+-$"

5.2.2 Compton scattering

The second variant of energy calibration is based on Compton scattering of laser photons on counter electron beam. This method has developed in VEPP-4M ring. In this scheme one registers scattered in 180° photons having energy of few MeV by germanium detector of full absorption working under cryogenic temperatures. Absolute calibration of such detector is implemented by parallel registration gamma quanta emitted by isotop source. At present time we checked all technical questions of laser method of energy calibration in VEPP-2000 storage ring. The channel of gamma quanta ejection from vacuum chamber is developed. It is supposed to make purchases of the necessary standard equipment also.

Publications:
[343], [200], [201], [202], [148], [203], [459], [460], [461], [462], [463], [464], [465], [466], [467], 2e-print.

5.3 Accelerator Complex VEPP-4

5.3.1 Operation time distribution

In 2008, experiments in high energy physics continued at the VEPP-4 with detector KEDR. Collection of data in the experiment on the tau-lepton mass measurement is completed and experiments in the region of c-quark generation are continued.

In addition to the high energy physics, experiments with the use of synchrotron radiation are carried out at VEPP-4. The main fields are the material science, studies of explosive substances, archaeology, biomedicine, nanotechnology, etc.

Experiments on a study of the beam dynamics and accelerator physics are carried out regularly. The works performed recently are the following: an experiment of comparison of the spin precession frequencies of electron bunches with the record resolution, the direct comparison of techniques for measurements of the beam energy spread, a study of the beam dynamics when crossing the betatron resonances.

Preparation for the work in the energy range up to 4 GeV was performed in 2008. The background load of KEDR detector was measured. The counting rate of the Touschek electrons as a function of energy was measured in the range 1.85 - 4 GeV. This experimental dependence was first obtained for such a broad energy range at one facility. The long term tests have been performed for the complex systems at the energy of 4 GeV (thermal regime, reliability, etc).

Figure 1 shows the time distribution over different kinds of operation at VEPP-4 complex in 2008.

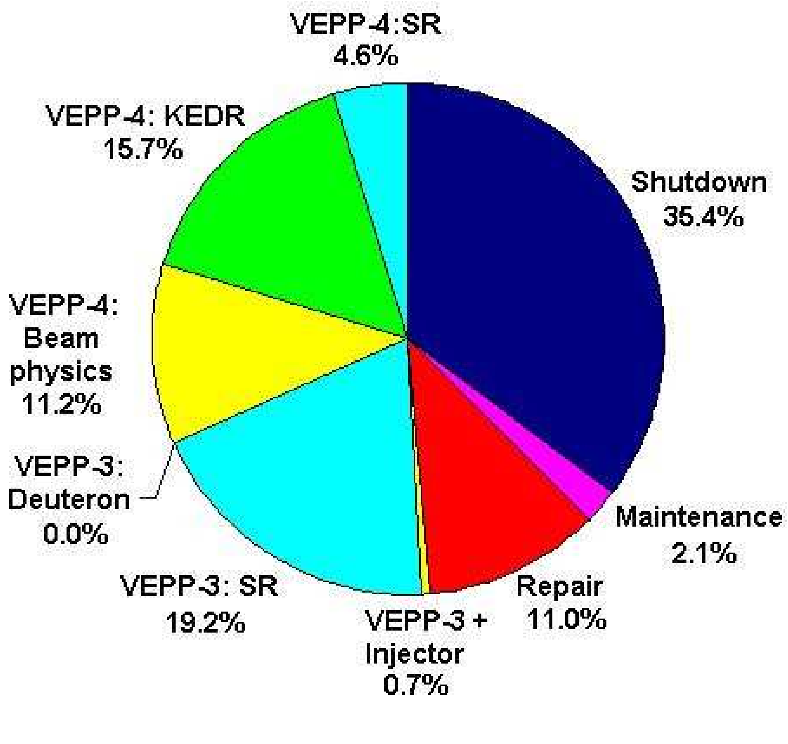


Figure 1: Operation time distribution at VEPP-4 complex

5.3.2 High energy physics

In operation at a low energy (1.5 – 3.0 GeV) the peak luminosity of the electron-positron collider VEPP-4M achieves the value $2 \cdot 10^{30}$ cm^{-2}s^{-1}. The average value during collection of statistics is about 10^{30} cm^{-2}s^{-1}. The average rate of collection of luminosity integrals is of 30 nb^{-1} per week. Figure 2 shows the luminosity integral collection diagram for the period 2004-2008.

In 2008, we finished gathering statistics in the experiment of the precision measurement of the tau-lepton mass on the threshold of its generation, which was the main experiment in high energy physics at VEPP-4 complex in the period 2004-2007. The main aim of the experiment was refinement of the tau-lepton mass, which knowledge at the known values of lifetimes and decay probabilities to the electron, neutrino and antineutrino enable verification of the lepton versatility hypothesis, which is one of basic postulates of the Weinberg-Salam theory of electroweak interaction. By the beginning of our experiment, the tau-lepton mass was measured within the accuracy of 0.5 MeV only in one experiment with the BES detector.

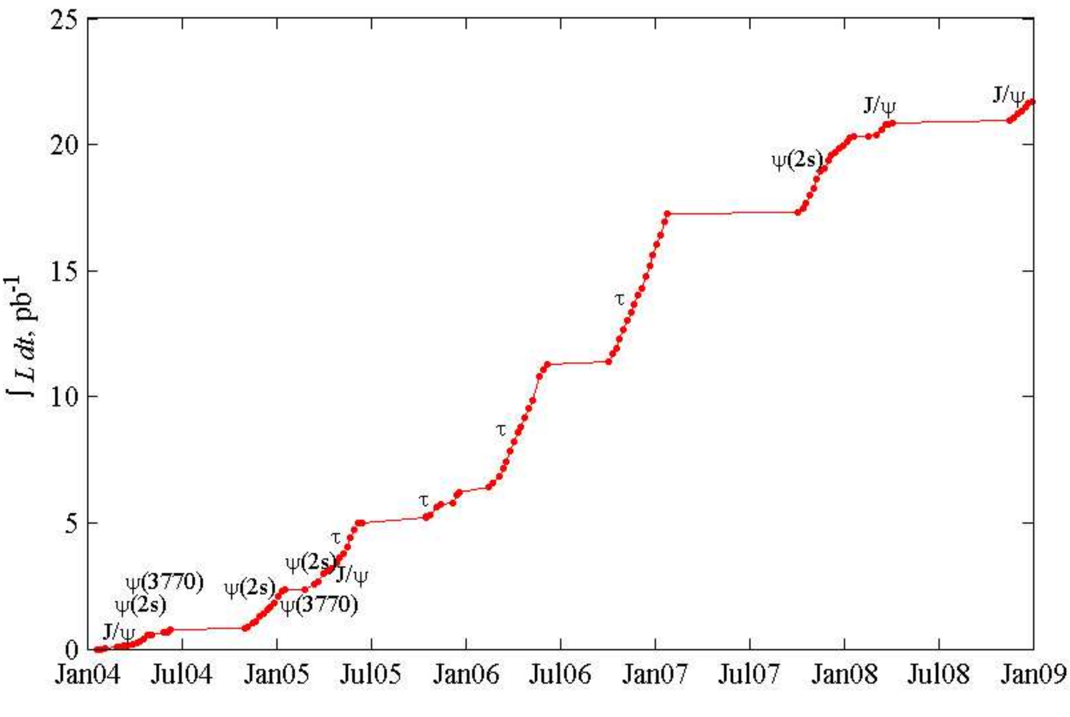


Figure 2: Luminosity integral

Experimental data acquisition give presently the world best accuracy of the tau-lepton mass measurement:

PDG 2006	$1776.90^{+0.29}_{-0.26}$ MeV
BES 1996	$1776.96^{+0.31}_{-0.27}$ MeV
BELLE 2006	$1776.77^{+0.35}_{-0.35}$ MeV
KEDR 2007	$1776.69^{+0.17}_{-0.19}$ MeV

In the season 2007-2008, we continued gathering statistics with KEDR detector in the region of c-quark generation. Preliminary data on measurements of the charged and neutral D-meson, ψ''-mesons were obtained with the accuracy comparable or higher than those world average. Unlike the decay probability itself, measurements of productions of the lepton width by the decay probability require the precise measurements of the energy and energy spread of the beam and it is complicated in the competing experiments at CLEO-c and BES. The statistics collected will enable an essential correction of the value of the above-mentioned products and allow us to obtain the value of Γ_{ee} for J/ψ- and ψ''-mesons thereby to correct the value of their total widths Γ_{total}.

Experiments on high energy physics carried out at VEPP-4M collider with KEDR detector are supported by 11 grants of the Russian Foundation for Basic Research.

5.3.3 Synchrotron radiation

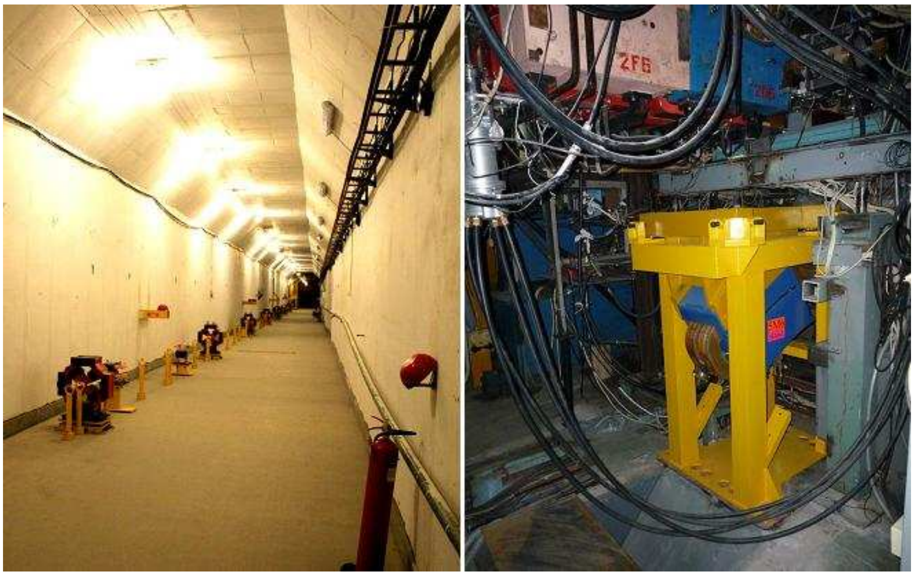
At the storage ring VEPP-3, there are 9 SR output channels with 12 experimental stations. In 2008, operation with SR beams was carried out at 10 experimental stations. Construction of the metrological station "Cosmos" at VEPP-4M is completed and the first cycle of studies was performed. The fundamental and applied experiments carried out at the complex covered a broad range of the fields of the first priority in the development of the science, technology and engineering in RF:

- Industry of nanosystems and materials;
- ecology and rational use of nature;
- power engineering and energy saving;
- alive systems;
- information-telecommunication systems and electronics.

SR sources VEPP-3 and VEPP-4 as well as bunkers and experimental stations are the collective usage facilities. Over 30 Russian and foreign organizations carried out various experiments at these facilities.

5.3.4 Injection complex−VEPP-3 channel

We continue the work on construction of the particle transport channel from the injection complex to the storage ring VEPP-3. Commissioning of the injection complex and the channel will provide the complex VEPP-4 – KEDR with sufficient amount of positrons for further high energy physics experiments. By the end of 2008, all the magnetic components are manufactured and installed in the channel and the only geodesic alignment of magnets is left. 15 inductive beam position monitors and 15 mechanical units for the phosphor screens have been produced. We started production of the vacuum system. Figure 3 shows photos of the magnets installed in the channel (a) and at the input section in the VEPP-3 experimental hall (b).



a) b)

Figure 3: Injection complex – VEPP-3 channel

5.3.5 Stabilization of the VEPP-4M guiding magnetic field

For the long-term stabilization of the magnetic field of VEPP-4M bending magnets, the feedback system based on the NMR probe installed in the calibration magnet, has been developed. The system allows us to reduce the DC component of the guiding magnetic field drift by approximately one order of magnitude down to the level of 1 keV per day. The system block diagram is given in Figure 4.

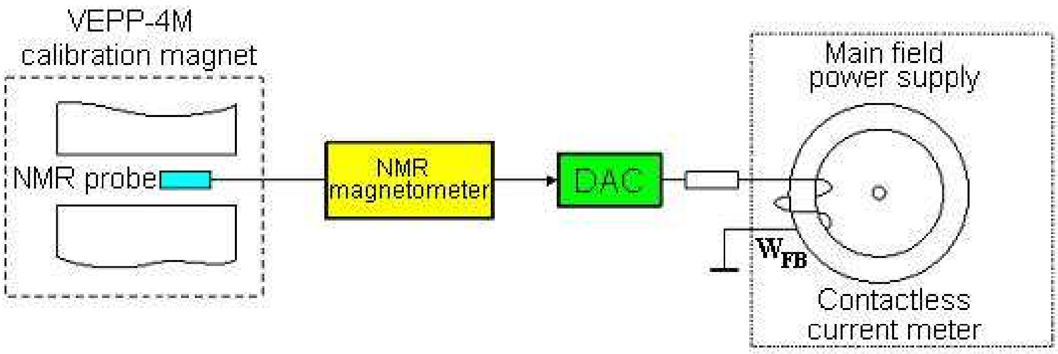


Figure 4: The system for suppression of the guiding magnetic field ripples

The field measurement error does not exceed $0.5 \cdot 10^{-6}$. The frequency band of the stabilization contour is 0.1 Hz, the field regulation range is $\pm 10^{-4}$. Figure 5 shows the field measured by the NMR probe for two operation regimes of the guiding field power supply: with the feedback on and off. The lower figure in the smaller scale is referred to the case of the feedback on. The field values are given in Oersteds, 10^{-3} Oersted corresponds approximately to 1 keV energy of particles circulating in the storage ring.

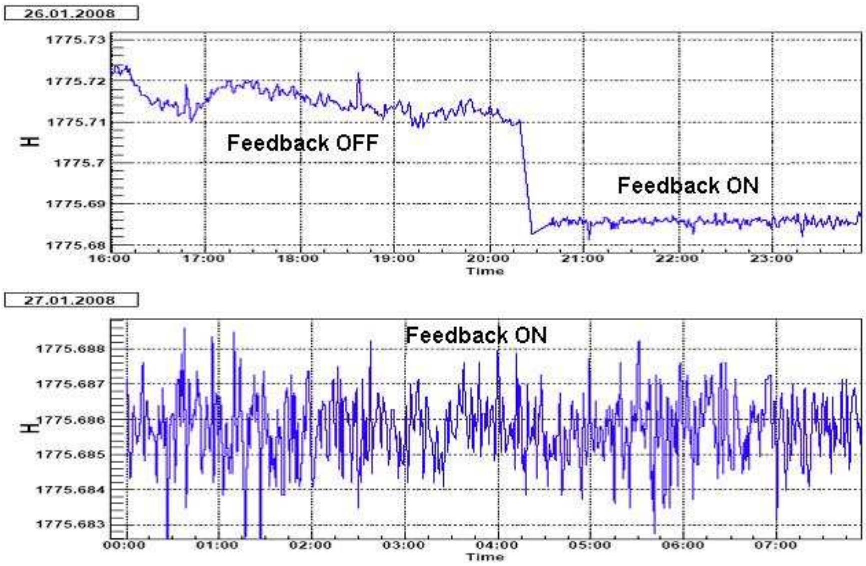


Figure 5: Suppression of ripples with the stabilizing system

Using the ripple suppression system the field stability was improved by 10 times, which is important for studying a possibility of improving the CPT experiment accuracy.

5.3.6 Experiments with polarized beams

In 2008, we started a new series of experiments within the program of studying new sources of possible systematic errors in the planned experiment on the CPT theorem verification at the VEPP-4M storage ring. The experiments have been performed under conditions providing the efficiency higher than that in previous experiments.

Two new detection systems for the Touschek polarimeter were put into operation. The detection efficiency has been increased by ten times. The total counting rate of the scintillation counter system has been increased from $0.1 - 0.2$ MHz to $1.5 - 2.0$ MHz. The use of the new detection system reduces by a factor of 2 the time required for energy calibration with the resonance depolarization technique. The thermal stabilization of the cooling system of the VEPP-4M magnets was provided with an accuracy of 0.1 °C. In the studies on "super thin" scanning (at rates of 2.5 eV/s and 5 eV/s) the typical resolution of determining the resonance depolarization frequency is a few units of 10^{-9}. This level of accuracy, which is presently an absolute record accuracy, we could only achieve in single instances.

Figure 6 shows the process of the depolarizer frequency scanning with the rate of 2.5 eV/s (the rate is given in units of the energy scale since the spin precession frequency of the particle and its energy are proportional to each other). One can see the depolarization jump determined by the difference in the counting rates of the Touschek particles from two electron bunches. One of the bunches was initially polarized and another was non-polarized. The duration of the delayed depolarization jump (14 ± 3 s) depends on its intrinsic width and on relative drift velocity of the spin frequency line. The resolution of the depolarization frequency measurement is of $1.5 \cdot 10^{-9}$.

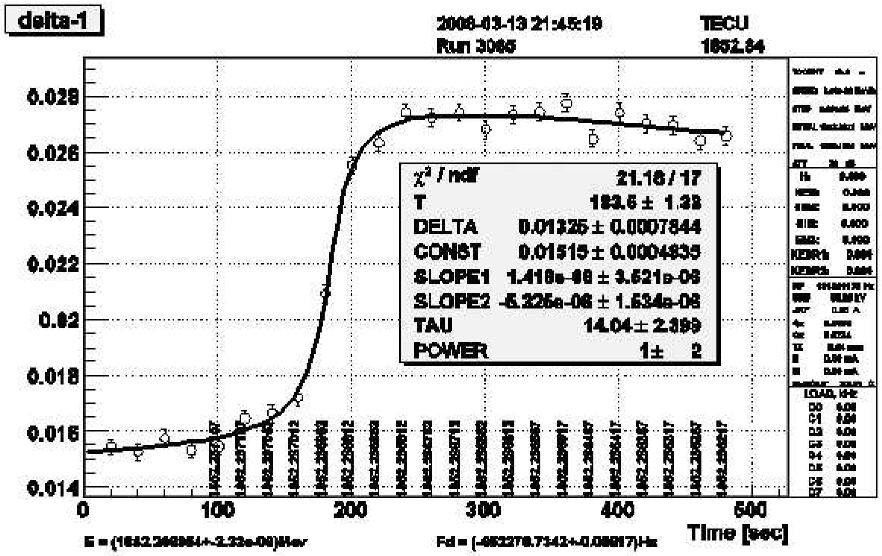


Figure 6: "Super thin" scanning

5.3.7 Beam energy Compton monitor

In 2008, we continued the development of a system of routine measurements of the beam energy, which is based on the Compton back-scattering technique (CBS). With the help of mirrors, the laser radiation is introduced through the transparent window into the vacuum chamber of the storage ring and interacts with electrons of the VEPP-4 beam at zeroth angle. The back-scattered gamma-quanta are registered by the detector.

In the system, we used CO_2 laser. CO_2 molecules are excited by the high-frequency electromagnetic discharge. The laser radiation power is of 40 W, the wavelength is 100 μm. The relative width of the laser radiation spectrum does not exceed $3.5 \cdot 10^{-6}$, the mean photon energy can be considered constant within accuracy of 10^{-8}.

To register the Compton back-scattered gamma-quanta, the germanium detector is used. In 2008, two new HPGe detectors ORTEC, one of which is 57.8 mm long and 52.7 mm in height, another is 75.8 mm long and 53.1 mm in height. The detectors are equipped with the autonomous cooling system, which does not require the liquid nitrogen.

For the absolute calibration of the system, we use radioactive isotopes ^{60}Co, ^{137}Cs, ^{24}Na, ^{228}Ac, which are the sources of $\gamma-$radiation, placed near the detector. Isotopes irradiate $\gamma-$quanta, whose energy is known with high accuracy. In September of 2008, the source of gamma-quanta at the energy of 6.13 MeV was obtained. The average counting rate of the $\gamma-$quanta emitted by the calibration isotopes is of 1 kHz. The counting rate of the Compton $\gamma-$quanta depends on the VEPP-4M electron beam intensity and its average value is of 10 kHz. For one whole spectrum of the Compton back-scattering, the detector registers about 5 millions readings that takes from 5 to 30 minutes depending of the $\gamma-$quanta flux intensity. As a result, each spectrum contains an information on the detector energy scale, position and width of the Compton backscattering edge.

At the end of 2008, the VEPP-4M beam energy was directly measured with detector calibration by the radiation of the ^{24}Na radioactive isotope. Figure 7 shows the edge of the measured Compton spectrum with the visible peak of the isotope radiation.

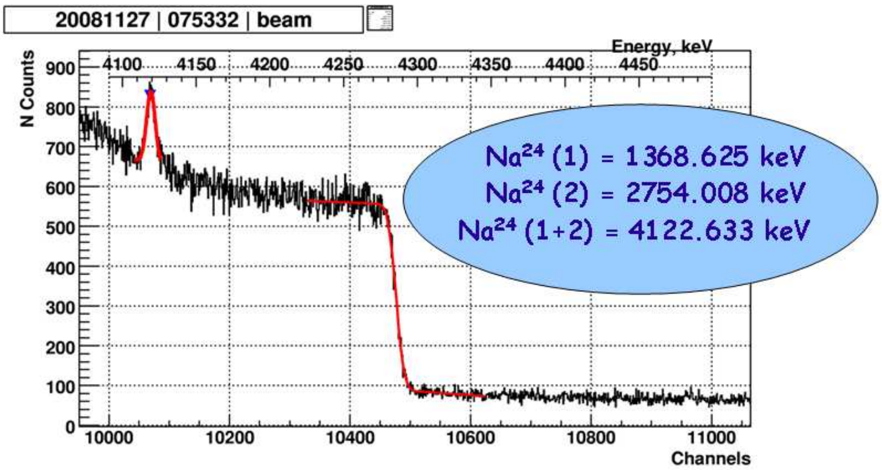


Figure 7: Direct measurement of the beam energy using Compton backscattering technique (27.11.2008)

It is planned in the near future to remove the laser-particle interaction area out of the VEPP-4M beam collision point, which will allow us to reduce the luminosity background and provide the continuous operation without removal of the luminosity monitor. The place in the VEPP-4M tunnel is already prepared. It is necessary to assemble the unit for the laser radiation input into the VEPP-4M vacuum chamber.

5.3.8 A study of beam dynamics when crossing the betatron resonances

The problem of crossing resonances may turn out to be rather vital for the lepton accelerators with a very small emittance such as the damping rings for linear colliders or particle super-factories with the crab-waist scheme of beam collision. In such machines, the beam is injected with rather large emittance, which then decreases down to the $1 \div 2$ pm. During the damping process, resonance crossing may occur due to large shift of the betatron frequency (up to $0.1 - 0.2$) caused by the space-charge effects or cubic nonlinearity introduced by the strong sextupoles, which are compensating the natural chromatism.

A combination of these two effects can either increase of decrease the resonance crossing rate leading either to the particle capture (in the adiabatic limit) or to the growth of the beam transverse size.

In 2008, the experimental studies of the beam dynamics in the process of crossing of the betatron resonances have been performed at VEPP-4M. The third-order resonance $3\nu_y = 23$ was crossed by electron beam at various velocities. The resonance force was varied with the separate skew-sextupole magnet whereas the nonlinear shift of betatron frequencies was controlled with the octupole lenses. In the course of experiment, a number of parameters was measured such as the particle loss rate, beam dimensions, transverse distribution, phase trajectories, amplitude-dependent frequency shift, etc. All the measurements have been performed at low current of the electron beam of 0.5 mA in order to avoid the coherent effects.

For a study of phase trajectories, the coherent betatron oscillations are excited with the help of a fast pulse kicker. For measurements of the beam center-of-mass motion, the electrostatic beam position monitor was used in the turn-by-turn mode with the spatial resolution of 50 mkm. Figure 8 shows the phase trajectories of betatron oscillation in the vicinity of the third-order resonance, which are obtained from the experimental data.

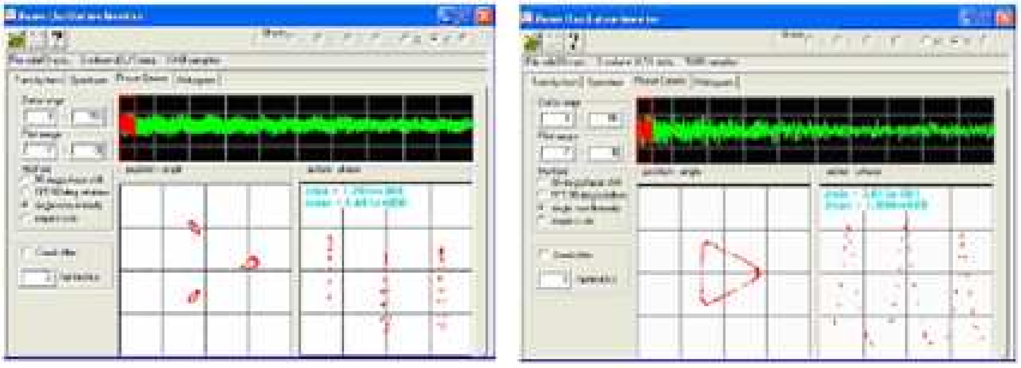


Figure 8: Phase trajectories near the third-order resonance

The particle loss and beam distribution tails were measured by the scintillation counters inserted into the vacuum chamber. The counters can be moved with the step motors with an accuracy no lower than 0.1 mm. CCDЦ cameras were used for measurements of the beam transverse dimensions and its position. The CCDЦ camera can be triggered from the external trigger pulse, the time error is of 100 μ s.

For the turn-by-turn measurements of the beam transverse distribution during tens of thousands turns, we used the unique device based on the multi-anode photomultiplier R5900U-00-L16 HAMAMATSU. This device enables the turn-by-turn measurement of the beam transverse profile in 16 points during 2^{17} turns.

With the high velocity of resonance crossing and small nonlinearity, neither changes in the beam transverse distribution nor particle loss were not observed. By slowing the resonance crossing velocity at the linearity close to zero, the beam losses were observed at the same transverse distribution. It means that at low value of nonlinearity, the resonance is unstable and it has no islands of stability. But since the resonance force is low, the instability range is very narrow and particle losses occur only at low velocity of the resonance crossing.

With the increase in the resonance force, either increase in the beam transverse size or particle capture into the stability islands have been observed depending on the ratio of the sextupole or octupole forces. The beam expansion depends on resonance crossing direction (increase or decrease in the betatron frequency) and it increases with the deceleration of resonance crossing.

Figure 9 shows turn-by-turn measurements of the beam vertical profile demonstrating the moment of the resonant creation of the stability island and its further motion as well as the beam vertical distribution corresponding to various moments of time (cross-section lines A, B, C and D).

It is worth mentioning that with the change of resonance crossing direction, instead of particle capture into the stability island we observed a slight expansion of the beam. Such a "hysteresis" of the nonlinear resonance is well known and it was earlier already studied theoretically. In future, we plan the numerical simulation of the experiments conditions for comparison with measurement results.

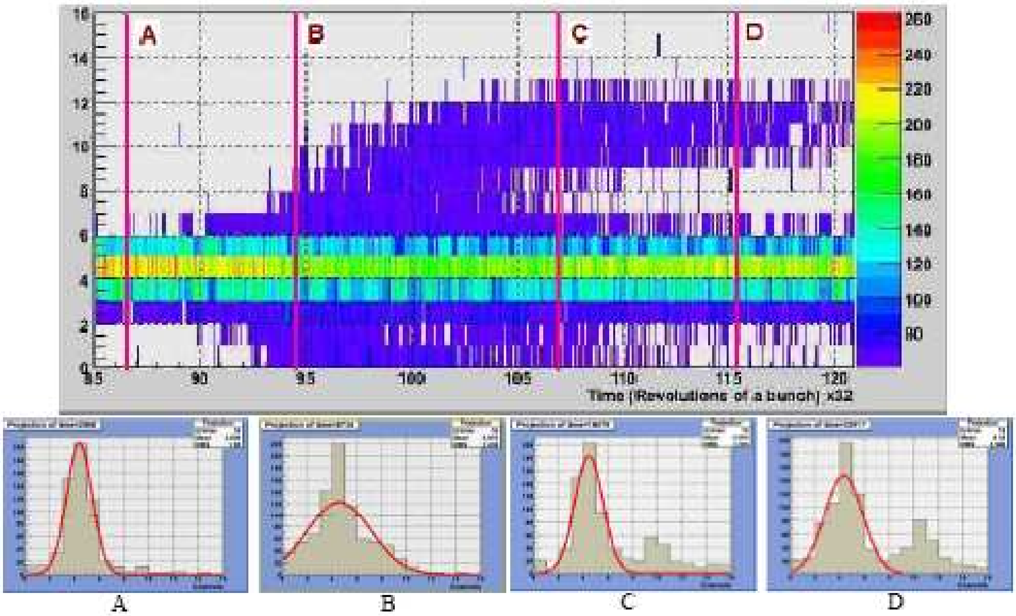


Figure 9: Formation of the stability islands

5.4 Beam-beam effects in electron-positron factories

During 2008 the study of luminosity limitation in colliding beam factories was continued in Laboratory 5-0. It is revealed that colliding beam fields non-linearity, though being the reason of the large frequency spread of betatron oscillations, results in Landau anti-damping of colliding beams coherent oscillations (D.V. Pestrikov). This instability has the resonance nature and appears close to any rational quantity of frequency value. These oscillations can only be stabilized at rather high amplitude value results in notable correction of coherent frequency shift of the unstable modes and their subsequent withdrawal from the resonance. This phenomenon is common for all the coherent resonance instabilities.

For beam-beam machines which use the closed orbit angular crossing at the collision point, it is determined (N.S. Dikansky and D.V. Pestrikov) that at large Pivinsky angles the regular combination of beam crab crossing and crab waist results in precise zeroing of the syncro-betatron resonance power as well as the odd betatron resonance power due to non-coherent beam interaction at the collision point. Such optics allows the luminosity limitation by beam-beam effects in the collider not to be greater the one for collider with zero length of beam-beam interaction area.

5.5 MIS-1 electron-beam ion source

Electron-beam sources of multi-charge ions (EBIS) are now under development in BINP. The sources provide the gain of the multi-charge ions of various elements (both solid and gaseous) and ensure the high-density (over 10^3 A/cm^3) electron beam in the ion trap. The method of pulsed and dosed solid elements atoms intake inside the ion trap has been realized for the sources.

At present time, the MIS-1 electron-beam ion source is under mounting and testing. Its focusing system is developed on the basis of superconducting solenoid with a closed magnetic circuit. It produces 3 T uniform magnetic field 70 cm along the drift structure. The electron bunch rated compression should be not less than 103 which provides the density of $2{\cdot}10^3$ A/cm^2 over the ionization area at 20 A beam current.

The MIS-1 electron optic system (EOS) is designed to obtain 20 A 50 keV electron beam. It is realized on the basis of short-focus electron gun whose spherical cathode is 34 mm in diameter and has 21.5 mm radius of curvature. The electron beam resulting compression exceeds 10^3. The electron beam density is $2{\cdot}10^3$ A/cm^2 at 70 cm distance along the ionization area. The ion trap capacity is $\sim 10^{12}$.

At high vacuum conditions ($\sim 5{\cdot}10^{-12}$ Torr) inside the ion trap, the installation parameters allow the production of multi-charge ions of all elements including Xe, Cs and Ba nuclei.

The number of separated multi-charge ions per one cycle could be within the range of 10^8 - 10^{10}. The accelerating voltage could reach 50 kV.

5.5.1 Focusing magnetic system with a superconducting solenoid

The dedicated structure and the design of MIS-1 focusing magnetic system, being matched with EOS, guarantees the laminarity of intense electron beam all along the EOS, as well as the uniformity of the magnetic flux through the electron beam cross-section, from cathode to collector. This allows providing the necessary matching of electric and magnetic fields in the region of short-focus spherical electron gun.

The cathode works under 30 Gs magnetic field. In the electron gun crossover, where the compression reaches 100, 0.3 T field magnetizes the electron beam. The 3 T focusing magnetic field of a superconducting solenoid and a magnetic circuit provides further electron beam compression, not less than 10. Finally, the compression of 10^3 will be reached. The magnetic field distribution over the electron collector ensures the high level of electron beam energy recuperation.

The focusing magnetic system of MIS-1 ion source is vertically oriented and consists of: 1 m long superconducting solenoid located inside the cryostat; an external magnetic circuit; a pair of electromagnetic lenses located within the electron gun and electron collector area.

Magnetic diaphragms are centrally located on the upper and lower magnetic circuit poles and have the special shape in order to provide the required magnetic field distribution within the electron gun and collector area.

A superconducting solenoid coil is sectioned in order to produce the 3 T uniform focusing field along the maximum feasible drift structure length of 700 mm, which meets the high (up to 10^{12}) ion trap capacity requirements. The source's focusing system is fully mounted. A cryostat with a superconducting solenoid is vacuum tested and filled with liquid nitrogen and helium. The magnetic measurements along the axis are done at 100 A current; the value of 1 T shows the good agreement with calculations. It should provide the electron beam compression up to 10^3. While training at 200 A current and 2 T field, the solenoid reached the normal conditions.

After the whole structure was analyzed, the works are done on the technical improvement of the superconducting solenoid cryostat aimed at the securing of a reliable operation at 3 T rated field.

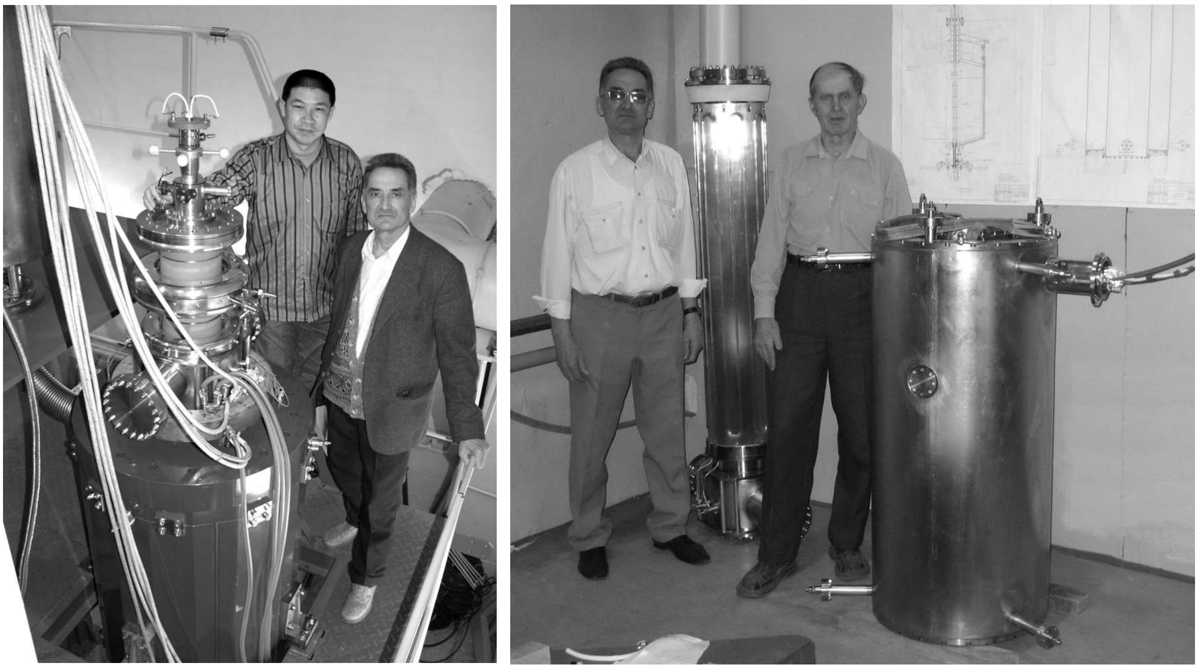


Figure 1: Left - general view of a source; right - vacuum chamber and superconducting solenoid inside the cryostat.

5.5.2 Anode modulator

An efficient anode modulator of an electron diode gun should provide the ionizing electron beam switching on and off.

Working pulse duration is 100 μs to over 2 s.

Working frequency is 0.01 Hz to over 50 Hz depending on the working pulse duration.

Anode modulator output voltage is controllable:

Locking voltage: -5 kV to -15 kV;

Operating voltage: $+10$ kV to $+50$ kV.

Electron high-voltage switchers are mounted on the cascade connected GMI-14B tetrodes with the special grid modulator developed. Grid modulator control is carried out via the high-voltage optical couplers. A particular operating condition of a high voltage electron switcher enables the wavefront duration less than 5 μs and economical working regime of a switcher at stationary opened mode 0.5 to 20 mA.

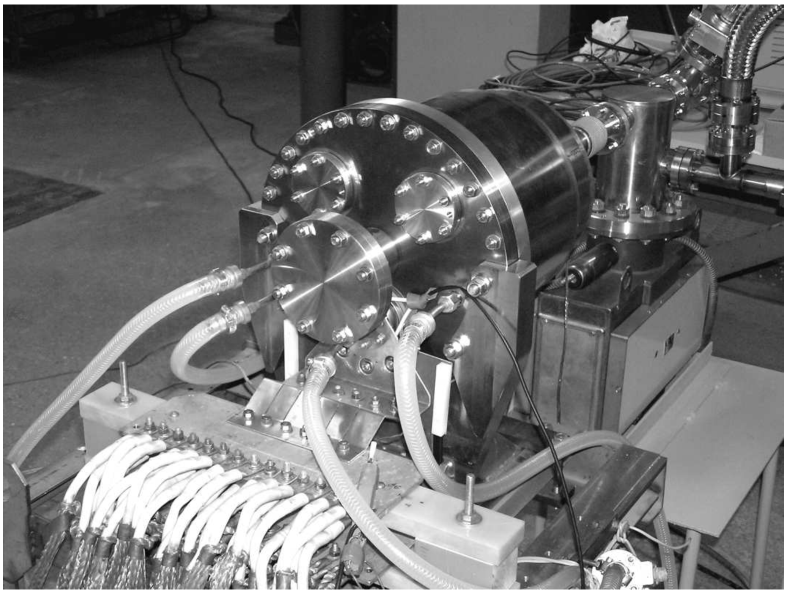
Such working regime of an electron high-voltage switcher provides the essential working resource for GMI-14B tetrodes and high working ability of the whole anode modulator as well.

Following power supply systems are mounted:

1) Power supply, control, blocking, and alarm box.
2) Electron gun supply unit.
3) 200 kW high-voltage rectifier.

4) Anode modulator.
5) Pulse modulator.
6) Power frame for the magnetic focusing system, i.e. the superconducting solenoid, upper and lower lenses.
7) "JunctionBox" unit for superconducting solenoid control.

5.6 Magnetic flux pulsed concentrator



!

Figure 2: General view of a concentrator.

In the framework of collaboration with KEK Accelerator Center (Japan) aimed at the positron source upgrade in order to increase the number of positrons for future Super B-Factory, the spiral magnetic flux concentrator with the maximum magnetic field of 100 kGs is produced.

The flux concentrator was initially tested on air with the magnetic field increased up to 50 kGs, and up to 50 Hz current pulse repetition rate. The test aimed at the long-term stable maintenance of a given value of the magnetic field with 50 Hz current pulse repetition rate. The magnet operated over 100 hours without any breakdown.

Further test aimed at the increase of magnetic field value, could only be performed under high vacuum conditions. In order to do this, the concentrator was put into vacuum volume with the residual pressure of 10^{-7} torr. There was carried out the commutation of power supply electric circuits, and after two days of test the stable operation of a concentrator is reached. The magnet operation mode was similar to one for an open-air test. During the first days of test in a single pulse mode it was managed to increase the value of a magnetic field up to 86 kGs.

5.7 Development of the intense neutron production target

In BINP SB RAS within the framework of collaboration between BINP, INFN-LNL (Legnaro, Italy) and VNIITF (Snezhinsk), the target complex for second-generation radioactive ion beam production facilities SPES and SPIRAL-2 was proposed and is now under development. The neutron production target is the basic assembly for these facilities. The target is aimed at the production of the intense flux (10^{14}-10^{16} s^{-1}) of high-energy ($\sim$ 1-20 MeV) neutrons as a result of primary proton/deuteron beam irradiation. Primary beam parameters are: energy 40 - 100 MeV; power up to 200 kW, spot size 1 - 4 cm. The target is designed as a rotating metal disk with the graphite converter attached to it. The converter is cooled by thermal radiation. Liquid metal (LM) devices are used as the drive unit, suspension assembly, and heat removal circuit. 90% Pb + 10% Sn alloy acts as the liquid agent.

The main goal of the present activity is the development and testing of:

• full-scale target designed to accept the 200 kW primary beam;

• LM circuits for drive and heat removal units, including motors/pumps; heat removal channels and heat exchanging device; protecting window; circuit parameters control devices;

• separate elements preliminary test technology, including the construction of a dedicated test facility on the basis of high-power low-energy electron accelerator, as well as the experimental check-out of the methods and principles proposed. Following are the results of works carried out during 2008:

• Preliminary calculations of operational conditions for the full-scale target designed for 200 kW deuteron beam deposition have been performed. Its main parameters are: diameter under beam 120 cm, length of converter plates 8 cm, maximum temperature 1850^0C for 4 cm wide Gauss beam, rotation frequency 10 - 20 Hz. There was carried out the simulation of basic thermo-mechanical phenomena in the target being irradiated with intense deuteron beam.

• There was completed the designing of the LM gear and target cooling system prototypes, namely: LM motors and pumps, suspension assembly, target converter, converter's cooling channels, experimental and auxiliary LM contour volumes. Their production is completed in general. There was carried out the preliminary analysis of main thermal and fluid dynamics parameters of LM devices.

• A graphite material produced in EU (CGD brand, HENCHKE production, Germany) has been selected as the converter material; its testing and properties investigation have been performed. It is determined that all mechanical, thermal, and electrophysical properties fully satisfy the task to be solved.

• A set of methods for neutron target elements and subsystems quality control has been determined and their engineering development has been performed. There were determined the basic parameters of test facility different systems and elements for their experimental check-out. Test facility technical designing and system integration is completed.

• The production of various systems and elements for the test facility, including 30 kW 60 kV electron source, is completed in general. Reconstruction and modernization of test facility experimental hall is done. The hall is prepared for equipment mounting.

Work is supported by ISTC (Project № 3682) and is carried out by common efforts of laboratories 5, 5-1, 6 and Design Office.

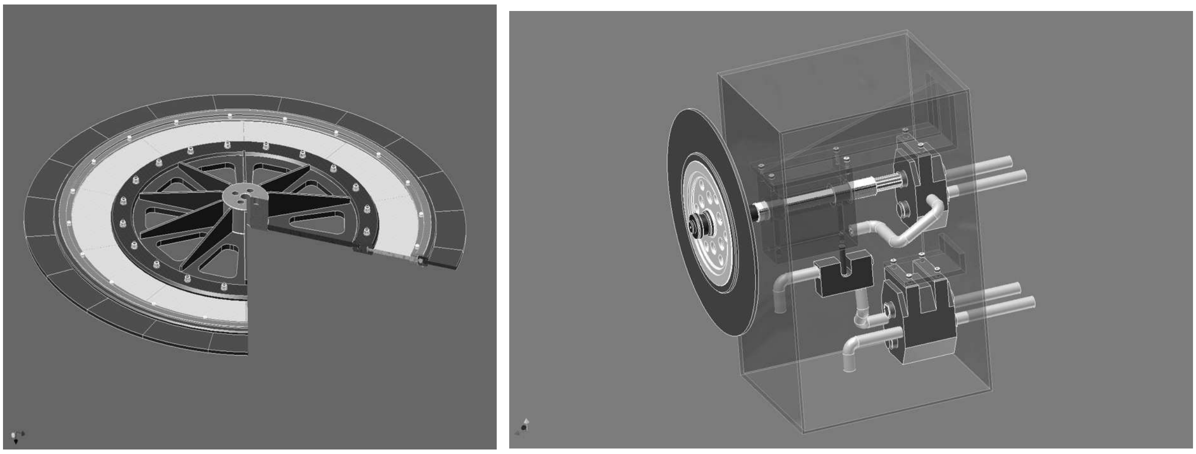


Figure 3: Design of 200 kW target (left) and target assembly (right).

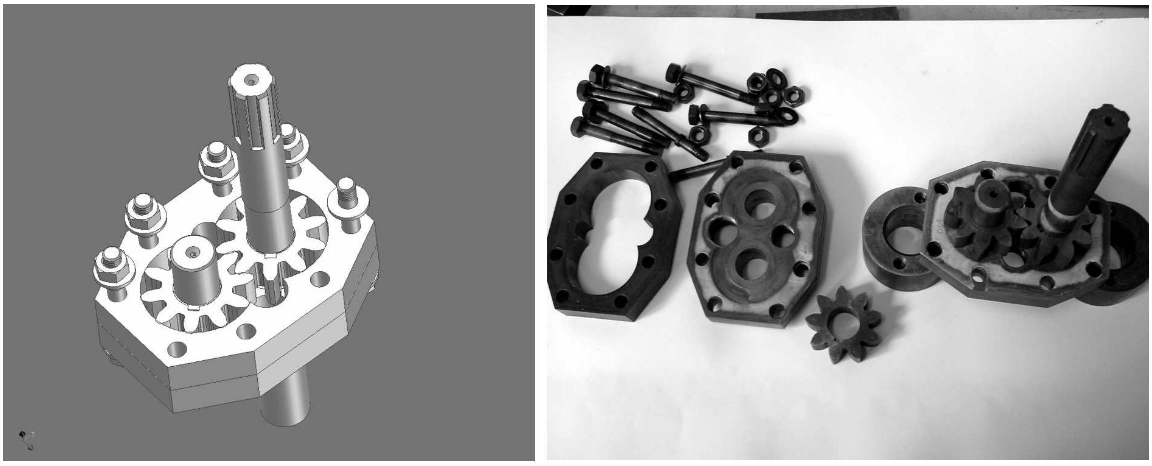


Figure 4: Design of LM motor/pump (left) and its elements after the test (right).

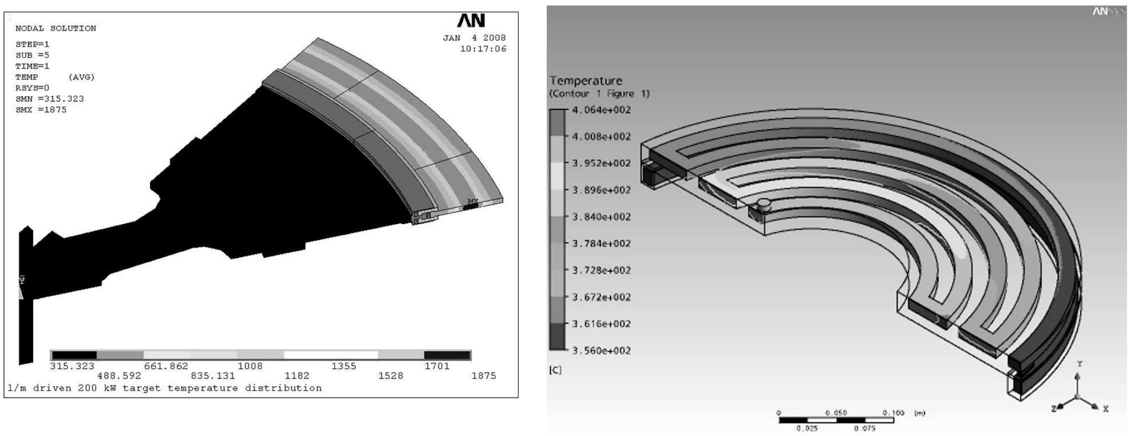


Figure 5: Numerical simulation of temperature distribution over the target (left) and over the cooling channel (right).

5.8 Operating works on the inlet/outlet system of VEPP-5 injector complex

In 2008, the operation works are carried out on the inlet/outlet system of VEPP-5 complex. Feeding pulse generator required the stable filament source of hydrogen generator. The source is now developed and is under production. High-voltage dummy loads also required the technical upgrade. As it is seen from the pictures presented, the destruction of resistor's contact surfaces takes place in distilled water. So, some improvements are made to its design. There was also developed the resistor used as the divider low arm, whose dimensions are similar to manufacturing one. Its work in 2008 gave no rise to complain. Broadbandness of the resistor, though never reached the one for manufacturing sample, yet satisfied the customer at a selected operation mode.

Figure 6: High voltage load element after 6-month operation in water.

By common efforts of Laboratory 5 and Laboratory 11 there were also carried out the operating works on the VEPP-2000 inlet system. The uninterrupted and trouble-free operation of inlet system generators is reached. Control codes for tracking both rapid and slow changes in pulse position are written by D. Berkaev. In spite of the progress, new model of generator for inlet system bar power supply is under development. The generator provides the cold thyratron operation.

Figure 7: Manufacturing resistor (left) and its in-house design (right).

5.9 VEPP-5 injection complex

VEPP-5 injection complex is a powerful modern source of intense beams of electrons and positrons at energies of 500 MeV, which can provide all the BINP colliding beam machines for the next ten years. The complex consists of the linear electron accelerator at an energy of 300 MeV, linear accelerator of positrons at an energy of 500 MeV and the storage ring – cooler.

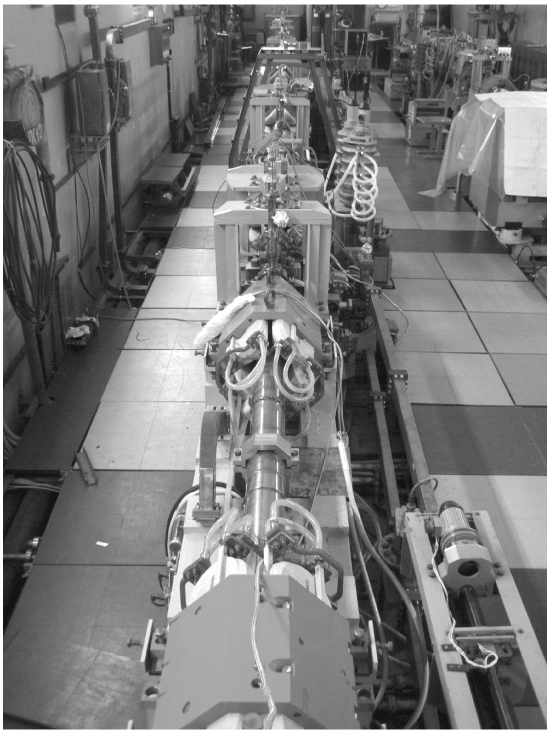


Figure 1: Photo of the positron linear accelerator of the injection complex.

The most complex and decisive parts of the complex are already tested at the design parameters as, for example, the positron generation system has shown a record efficiency. In 2008, we continued production of components for the last accelerating module of the positron linear accelerator. The control and measurements system for RF phase at the foreinjector linear accelerators was also adjusted and put into the trial operation. Construction and tuning the numerical model of the accelerator complex based on measurements carried out with an electron beam was in an active stage.

5.10 Electron-beam welding

In 2008, on the base of the long-term test results, we performed a fundamental upgrade of the BINP designed and manufactured power supply units for the electron-beam welding devices.

As a result of the upgrade, we achieved a new operation quality of the power supply units, namely, the probability of vacuum breakdowns during welding was substantially reduced, operation reliability of all the power supply unit components was improved. We plan the work on further improvement of the power supply source aimed at the improvement of its properties maintaining the quality level of the electron-optical channel and cathode lifetime.

Figure 2: General view of the poiwer supply unit for the electron-beam welding devices developed at BINP.

5.11 Quadrupole lenses for the synchrotron ALBA

The contract signed in May, 2008 on production of 119 magnets for the main ring of the ALBA synchrotron (Barcelona) was successfully completed. In 2008, all the serial quadrupole magnets have been measured and delivered to the customer.

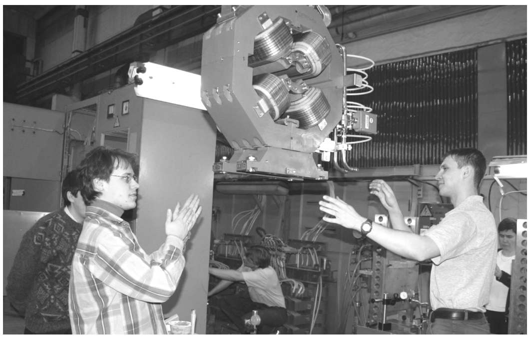


Figure 3: Installing the quadrupole magnet to the girder for magnetic measurements by rotating coil in the presence of the customer

5.12 A device for the transfer of rotation to vacuum

In recent time, for the motion transfer from one medium to another, The more frequently used are devices with the magneto-liquid tightening (MLT). A few of such devices have been developed, designed, produced and tested at BINP in Lab.5-1.

Figure 4 shows the photo of the device and its design is give in Figure 5 –

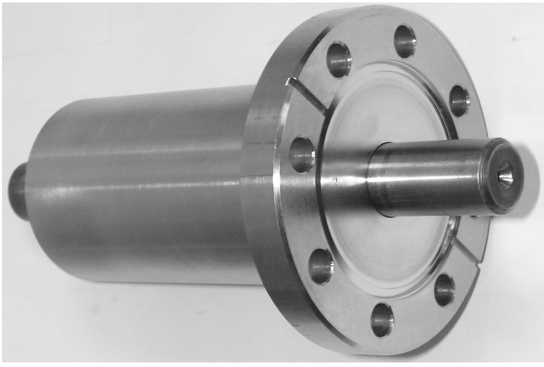


Figure 4: General view of the device for introducing rotation into vacuum.

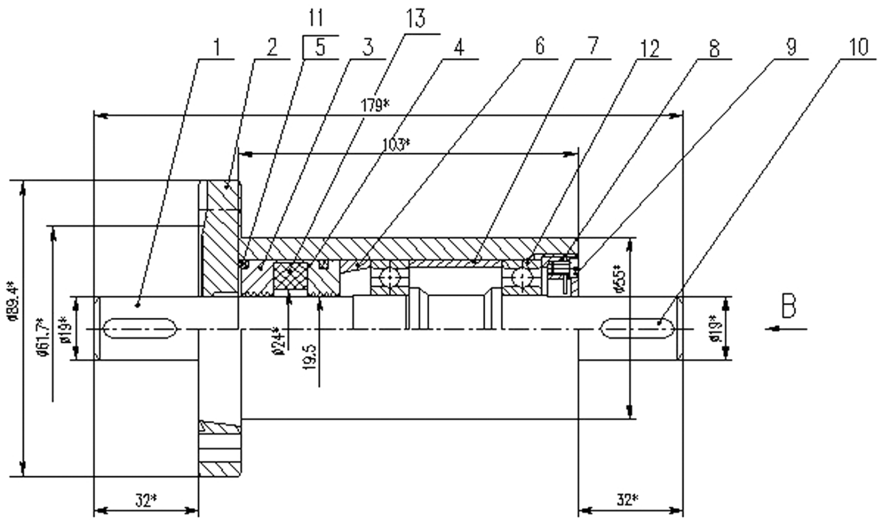


Figure 5: Schematic diagram of the device for introducing rotation into vacuum.

Here: 2 – is a body of the nonmagnetic stainless steel; 1 – a shaft made of the tempered steel-45, which is transferring rotation into the vacuum vessel; 3 and 4 – are the circular magnet poles made of steel-3; 5 – is a rubber vacuum tightening, which can be replaced if necessary by the Indium packing; 14 – is the rubber vacuum tightening; 12 – are two ball bearings, 13 – the ring magnet made of the (Nd-Fe-B) alloy, the residual induction is – 9 kG.

In the gap between the shaft and magnetic poles, there is the magnetic liquid FLS 040.040 with the following parameters: density – 1.4 g/cm^3, viscosity – 0.5 Pa·s (at 20^{o}C). The saturation magnetizing at the magnetic field intensity is no less than 500 kA/m – 47 kA/m, operation temperature is – 120 – 130^{o}C, vacuum vessel pressure is $10^{-5} - 10^{-7}$ mbar.

The gap between the shaft and magnetic pole teeth is 0.05-0.1 mm. The magnetic field in the gap is of the order 1500 kA/m therefore the ML saturation magnetization is used completely.

Figure 6 shows variation of vacuum (the first start) in the vessel with the ion pump switching on(60 l/s) and the fixed shaft. In about 10 minutes, vacuum inside the vessel achieves the value $0.5-1\cdot10^{-6}$ mbar (point A). At this time, the shaft starts rotation(1000 turns/min) – point A in Figure 7. In this case, the pressure in the vessel increases up to $4-5\cdot10^{-6}$ mbar (point B in Figure 7).

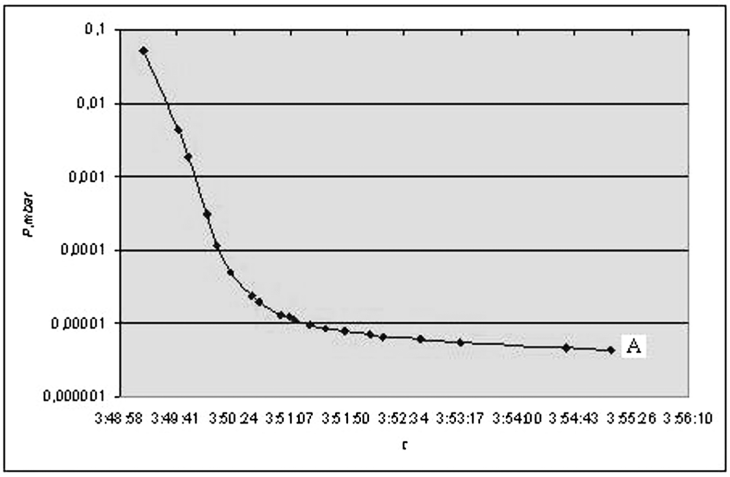


Figure 6: Change of vacuum in time without rotation of the shaft.

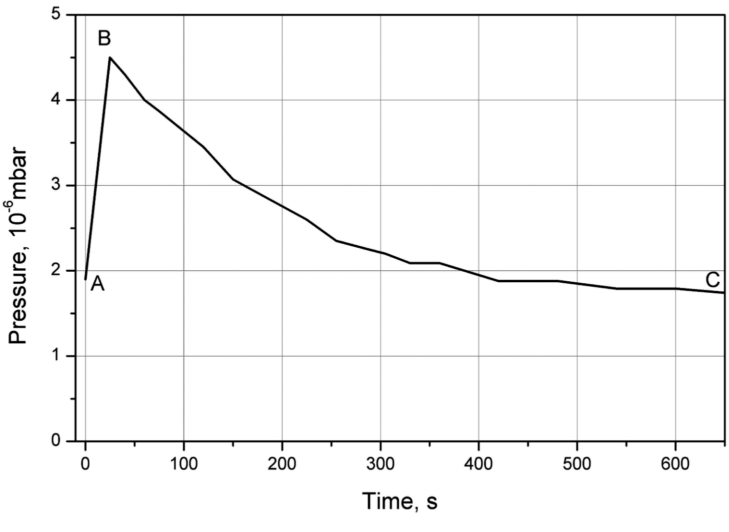


Figure 7: Change of vacuum in time during rotation of the shaft.

The device body temperature increases also (Figure 8) achieving 35-40^{o}C due to ML viscosity whose viscosity factor is 0.5 Pa·c. After that, the temperature is not practically changed.

Upon achieving point B the pressure decreases. In 10-15 minutes, the pressure reaches its stationary value of the order $2\cdot10^{-6}$ mbar (the point C in Figure 7), remaining practically unchanged of 8-10 hours (a working day).

Two pieces of the device were tested during 100-120 hours in such a regime. If the shaft rotation is off (point C in Figure 7, 9), in approximately an hour, vacuum returns to its initial value(point A in Figure 7).

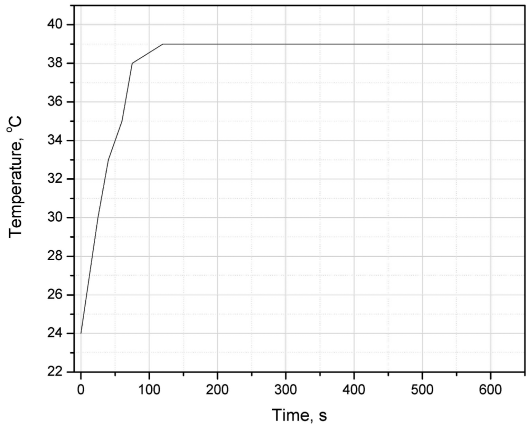


Figure 8: Body temperature change in time.

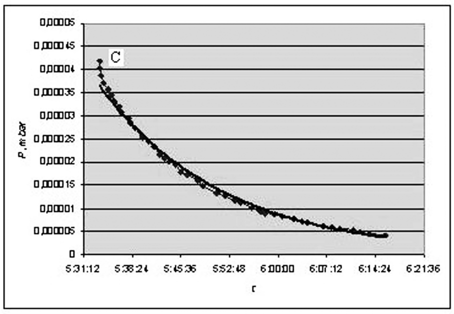


Figure 9: Vacuum level returns to its initial value.

An analysis shows(see Figure 7) that with rotation of the shaft the leak into the vacuum vessel increases both because of leek from the vacuum vessel walls with temperature raise and due to the increase of leek through ML during rotation.

However, with the shaft fixed, atmosphere leak through ML was not observed. In this case, vacuum value is (1.5-2)$\cdot 10^{-6}$ mbar. Leaks were detected with the helium leak detector.

Leak increases substantially with an increase in rotation rate. So, at 3000 t/min (operation duration of 30 min) the pressure in the system increases up to $5 \cdot 10^{-6}$ mbar, and temperature up to 90 °C.

Thus, this device without essential changes can be used for transferring rotation into the vacuum vessel with the vacuum level of $10^{-5} - 10^{-6}$ mbar within the limit of 2000 t/min. For higher rates, the appropriate cooling system should envisaged.

As to the device lifetime, it is known that devices using ML FLS 040.040 are being operated over 6 years without ML recharge.

More specific data is that the lifetime of the device is 8000 hours of operation. For obtaining more reliable data it is necessary to carry out additional studies.

Participants of the work:
A.A.Akimov, A.V.Antoshin, P.A.Back, M.A.Batazova, M.F.Blinov, Yu.M.Boimelshtein, D.Yu.Bolkhovityanov, A.I.Butakov, R.Kh.Galimov, S.M.Gurov, E.A.Gusev, F.A.Emanov, S.N.Klyushev, A.N.Kosarev, A.A.Korepanov, N.Kh.Kot, G.I.Kuznetsov, N.N.Lebedev, P.V.Logachev, A.I.Mikhaiylov, L.A.Mironenko, V.M.Pavlov, V.E.Palchikov, A.V.Petrenko, I.L.Pivovarov, O.V.Pirogov, V.S.Popov, F.V.Podgorny, T.V.Rybitskaya, S.L.Samoilov, V.S. Severilo, Yu.I.Semyonov, B.A.Scarbo, T.V.Sokolova, A.A.Starostenko, D.P.Sukhanov, A.P.Frolov, V.D.Khambikov, A.S.Tsyganov, A.G.Chupyra, S.V.Shiyankov, T.A.Yaskina, etc.

Publications:
[155], [156], [157], [377].

5.13 Works on the Accelerator Mass Spectrometer

The accelerator mass spectrometry complex (AMS) is being developed at BINP. It is designed for supersensitive isotope analysis of matter. The additional possibilities of filtration of the isobar ion background are put into basic concepts of its design. In 2008, the preliminary tests of AMS complex were completed at the stand site of BINP. The tests have been carried out at a low voltage (250 kV) of the AMS high voltage terminal because of the absence of radiation protection. In the beginning of 2008 the first reliable measurements of ^{14}C were made at the spectrometer. To this end, the sample was pressed in a steel punch from A mixture of the clear clay with water was u mple was pressed into the copper cathode of vas about 9 milligram.

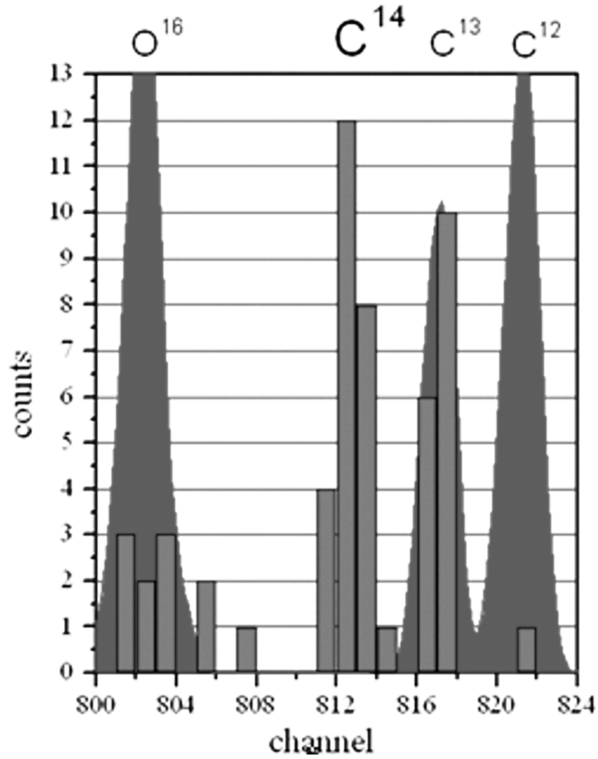


Figure 1: First measurements of $^{14}C^{3+}$ ions. Comparison of the charcoal and graphite carbon spectra. A clear signal of ^{14}C is seen at the charcoal.

Main results of preliminary tests of the complex:

• Atoms of the studied carbon sample (pressed charcoal) were transformed into negative ions by sputter ion source.

• The ion beam was guided through the entire channel of AMS complex with stripping into positive ions in the magnesium vapor stripping target. The beam passage coefficients were 25%, 1.5%, 0.03% for ions in the charge states 1+, 2+, 3+, respectively.

• The ion isobar background was suppressed and the cabon radioisotope in a charge state 3+ was detected by the time-of-flight detector of ions.

• The time-of-flight detector of ions with the use of super thin organic foils and Microchannel Plates was produced and tested.

At present, AMS is disassembled at BINP and transported to Center "Geokhronology of cenozoy" where the equipment is being assembled in the radiation protected bunker. Presently AMS is still under assembly (Nov.2008). Works on the isotope analysis of matter at higher voltage of the high voltage terminal (>500 kV) will start in 2009.

Main results of the work were presented at RUPAC 2008 [373], in more detail in reports sent to JETP and PTE [158], [159], [160], [161], [373].

5.14 Developments for high voltage electron cooling

In 2008 Lab.5-2 carried out the developemt of the high voltage section for 2 MeV electron cooling system for the accelerator COSY (Juelich, Germany). This work is an extention of the work on the section design in 2007.

In the process of the work, the prototype of high voltage section, which consists of the metal body, turbogerator, power and control electronics and two coils of the magnetic field, was designed and produced.

Each section is power supplied by the torbogenerator placed in the section. This generator converts the compressed air energy (applied along the plastic pipes from a compressor), into electric energy. The power electronics unit performs two functions: power supply of the magnetic field coils with a current up to 2 A and generation of high voltage up to 60 kV. The digital electronic unit is based on the processor TMS320F2808PZA (Texas Instruments) with the clock frequency of 100 MHz and it provides the control of the power electronics and link with computer. Both units are placed on the same board and divided by their high voltage and low voltage parts.

In the first tests of electronics it was found out that after the breakdown inside high voltage part, the circuit becomes unoperational because the breakdown in the solid filling material used in the circuit may cause changes of its structure and the breakdown at this place can occur at much lover voltages. Therefore, we took the decision to change the high voltage part by placing it in a special container filled with the transformer oil. Due to the convective flows, oil is permanently stirred thus the circuit returns into its initial state after breakdown. Tests have shown that with the use of oil as a filling material the circuit is stable to such breakdowns.

During tests, we found out that the secondary winding of the transformer in the multiplication scheme has a large parasitic capacitance with ground. This scheme forms the resonance circuit with the resonant frequency of the order of 10 kHz (parallel resonance) and 80 kHz (serial resonance). Therefore the resonance operation regime was selected for the transformer primary winding. To this end, with additional contours the frequency of the parallel resonance was shifted to the required value and the circuit was tuned to operation at a frequency close to the new frequency of the parallel resonance. This regime allowed us to reduce dissipation both in the transisor switches and transformer.

The 39 MOhm resistive load was connected to each arm of the section during tests. The high voltage stability was measured with two independent techniques: with the ADC processor in the circuit itself and by means of the external oscillograph. In both cases the voltage stability was better than to 10^{-4}.

At high voltages, the breakdown occured between secions. After breakdowns, the system was automatically returned to its initial state and continued its normal operation thus demonstarating the system resistance to breakdowns.

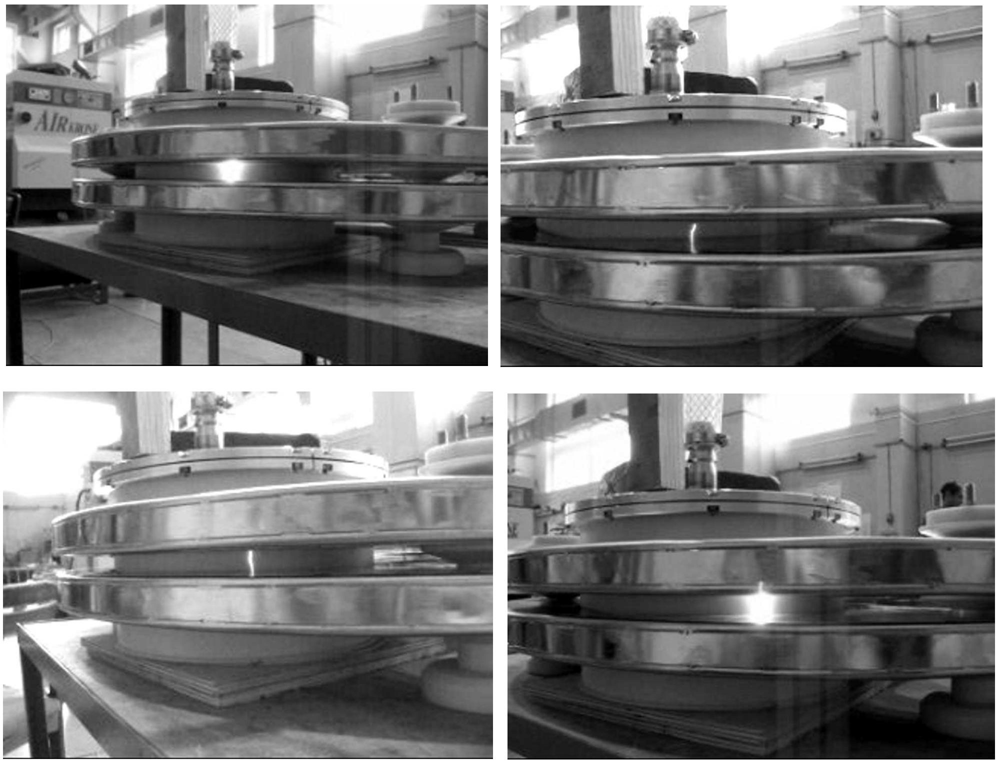


Figure 2: Photos of breakdowns between two sections at voltage of the order of 22 kV.

Results of the work were presented at the International Conference EPAC'08 (Genova, Italy)[162].

In the feedback circuit, we used the PID regulation technique, which was realized digitally in the processor. One of the main problems in all these systems with such a feedback is the selection of the PID model parameters. The most convenient way for this purpose is determining optimum parameters by the transfer function of the controllable section. As a rule, the transfer function of the entire section is calculated by the transfer fuctions of its individual units. However, for large and complex circuits it is very complicated. In addition, the transfer function can vary in operation because of heating, for example. Another method is based on measurements of the amplitude and phase-frequncy characteristics of the section controlled. To this end, however, it is necessary to "break" the feedback line, which is also unconvenient if there is a necessity to measure periodically the transfer function just during operation for tuning the beedback circuit parameters. Therefore, we developed the method of measuring the controlled section transfer function without breaking the feedback circuit. The results of this work are given in the article

"Determining the controlled object transfer function by characteristics of the closed system with feedback coupling" to be published in Vestnik NSU [374].

The work is presented in publications: [162], [374].

5.15 Developments for the Carbon Therapeutical Accelerator Complex (HITS)

In June, 2008, we started a big HITS (Heavy Ion Therapy System) contract for the delivery of two therapeutical complexes designed for curing cancer by carbon ions with an energy up to 430 MeV/neucleon.

We carried out the work on preparation of the design project for the electron cooling system providing cooling of the carbon beam mainly in the main ring of the HITS complex. The calculations of operation regimes providing the ion beam extraction into distribution channels were suggested and performed. The status of work was presented at the RUPAC'08 conference.

In the Laboratory 5-2, we carried out the simulation and experimental works in the frame of this contract. The first report was prepared and successfully accepted in September, 2008. The important part of the first report - a design project of the HITS building for housing the accelerator equipment and istallations, treatment rooms, etc. The staff of Lab.5-2 jointly with BINP radiation protection department took an active part in the design work of the HITS complex building; we carried out a great amount of work on calculations of the radiation shielding (wall thicknesses) with an account for requirements to irradiate 2500 patients per year and requirements to the engineering supply. By the results of the work the chinese side started the design-construction works.

The work is presented in publications:[163], [375].

5.16 Vacuum technologies

5.16.1 Tin-film getter coatings

One of the most promising techniques to provide vacuum in the accelerators seems to be the use of the distributed pumping based on the physical-chemical adsorption of a gas at special substances – getters sprayed in the form of a foil on the inner walls of the beam chamber. The practical interest is a possibility to activate the modern getters with the external heating since in this case, there is no need in additional high current leads, insulaton of getters that substantially simplifies the installation design. The present work is devoted to a study of getters TaTi and TaTiZrV as an attempt to find out coatings with the lower activation temperature (150 °C) and better sorption and emission properties.

To this end, at BINP we developed an installation for deposition the getter coatings and installation for studying the gas absorbing and activating properties of getters. The getter deposition was performed in a cylindrical chambers (2500 mm long and 98 mm in inner diameter). The coating thickness is on the order of 1 μм. Prior to getter activation, the whole installation was heated at temperature of 250 °C, and 80-100 °C temperature was maintained at the getter. Table 1 shows the getters analysis in comparison. Figure1 shows the getter CO saturation as a function of time.

Table 5.1: Comparative analysis of getters.

	TaTi	**TaTiZrV**
Activation temperature, °C	400	200
Adhesion coefficient by H, %	0.5	0.8
Adhesion coefficient by CO, %	2.3	4.5
Sorption capacity, mol/cm^2	-	4E+14

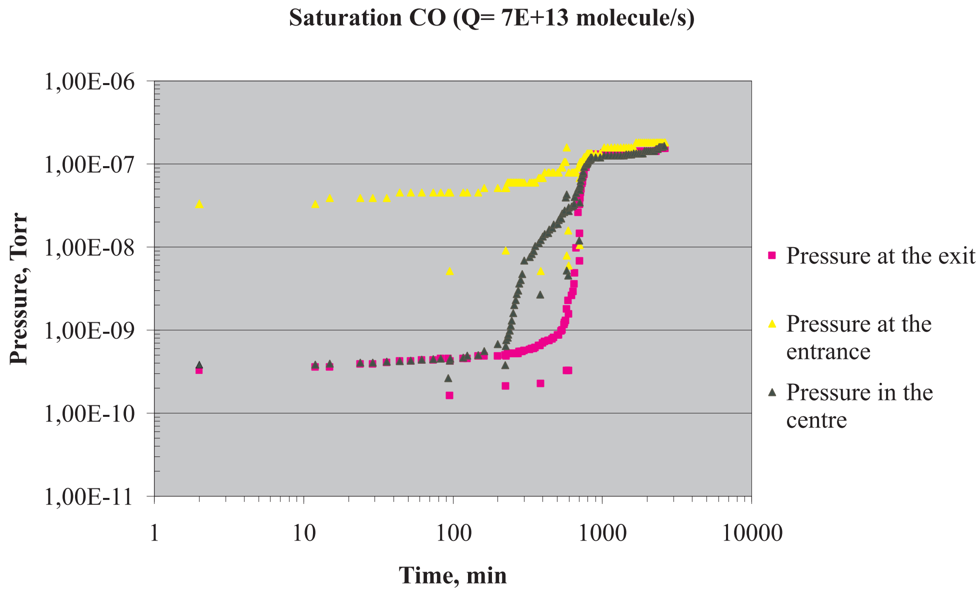


Figure 1: Getter CO saturation as a function of time.

5.16.2 Photoelectron equipment

• The production technology of the photothriode with the photocathode diameter of 25 mm is developed. The photocathode – is a bialkaline with a quantum efficiency η=15÷20% at the wavelength (λ=410 nm) and amplification factor of K∼10.

• The production technology of the cone widows with the RF welding is developed. The operation diameters of the window are 16 mm, 33 mm and 43 mm.

• The input window of arsenide gallium was developed for the beam energymeasurements with the Compton back scattering method.

Transmission range is - 09÷20 μм;
Maximum heating temperature - 250°C;
Operation pressure is no worse than - 5x10^{-10} torr.

5.16.3 International collaboration

• Within the frame of collaboration BINP-DESY (Hamburg, Germany) in 2008 we completed the design, manufacture and assembly of vacuum components of two beam cooling sections for the new generation SR Source PETRA-III. The total length of sections is 200 meters. One of the most complex tasks (from the viewpoint of design of the beam vacuum chambers) was to provide the distributed absorption of 900 kW SR power maintaining vacuum at the level 10^{-9} torr. Absorption of SR is distributed between 16 absorbers of up to 30 kW in power, four absorbers at a power of up to 90 kW (Figure 2,3) and two end absorbers of up to 130 kW in power (Figure 4,5).

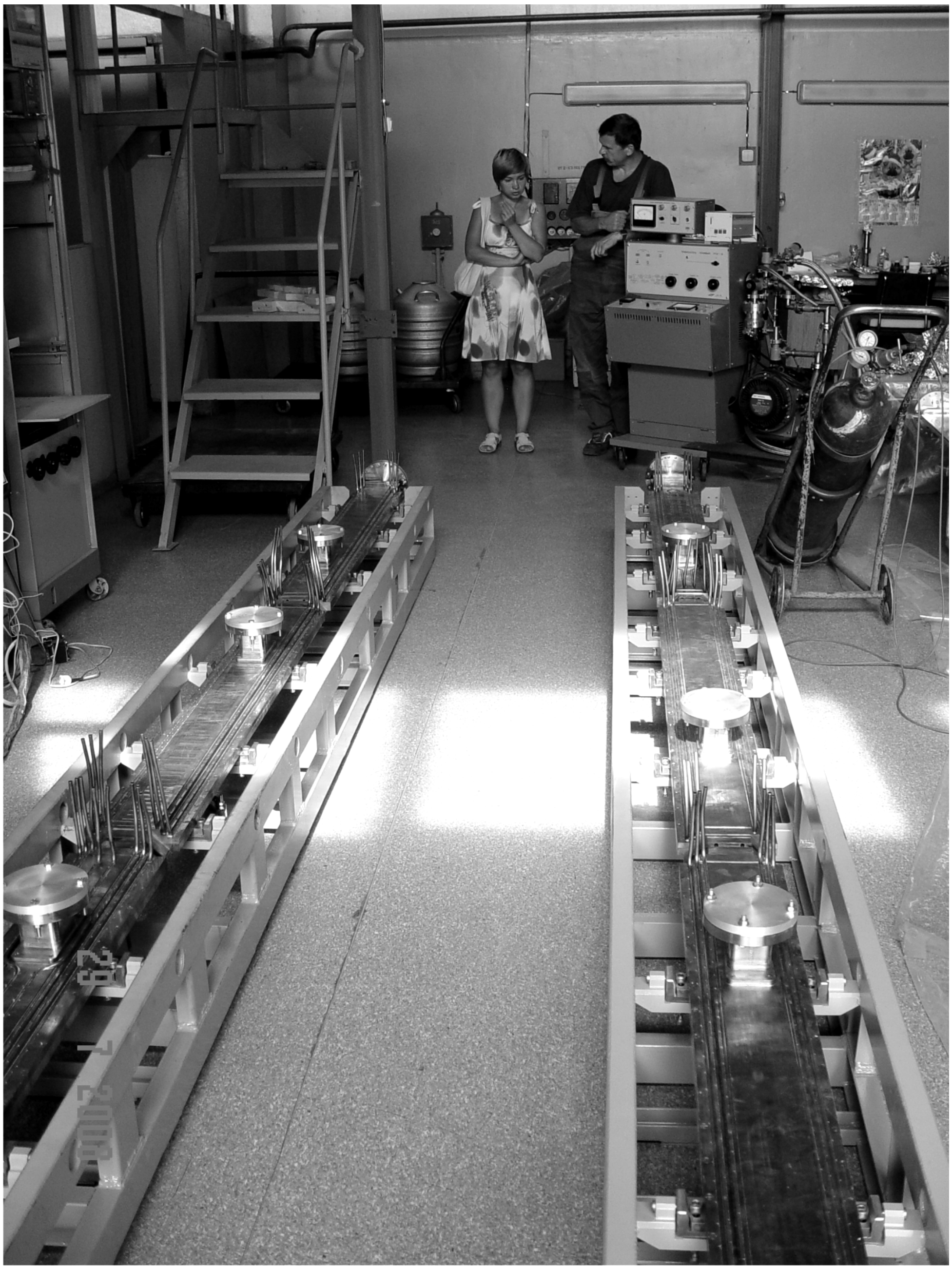


Figure 2: 90 kW absorbers. Vacuum tests at BINP.

All the absorbers are made with vacuum soldering of the high accuracy machined copper units. The total length of the solder seams was over 200 m. The design and production of the powerful absorber of radiation for PETRA III is bright example of the BINP high technological level in production of vacuum equipment.

Figure 3: A 90 kW absorber in PETRA III tunnel.

Figure 4: A 130 kW absorber. Assembly at PETRA III ring.

• We mastered production of the thin-wall (0.3 mm) 4 m long vacuum chambers (Figure 6) for the synchrotron SIS18 (GSI, Germany). The chamber consists of seven similar sections (Figure 7). The basic new technological operations are the following: production of a thin-wall pipe course with electron-beam welding and vacuum brazing of rigidity ribs by the CuSn12 solder at temperature 1050°C.

Figure 5: 130 kW absorber components.

Figure 6: Vacuum chamber of quadrupole lens SIS18.

Figure 7: A section of the quadrupole lens SIS18 vacuum chamber

• Production of the curved prototype vacuum chamber of SIS100 dipole magnet GSI, Germany) (Figure 8). In order to minimize distortions of the magnetic field and resistive losses (a load to the cryogenic system) due to Fuko currents, the chamber was made of a 0.3 mm thick the stainless steel. In order to avoid an additional current contour along the cooling pipes, the latter are insulated from the rigidity ribs by a 75 μm thick ceramic layer Al_2O_3. This was resulted in the double reduction in resistive losses. At present, by its technical characteristics, the chamber is the most acceptable prototype of the vacuum chamber of the curved cryogenic dipole magnet SIS100.

• In the frame of the contract №26165 with IHI (Yokohama, Japan), the vacuum system of the carbon ion transport channel was manufactured and subjected to vacuum tests.

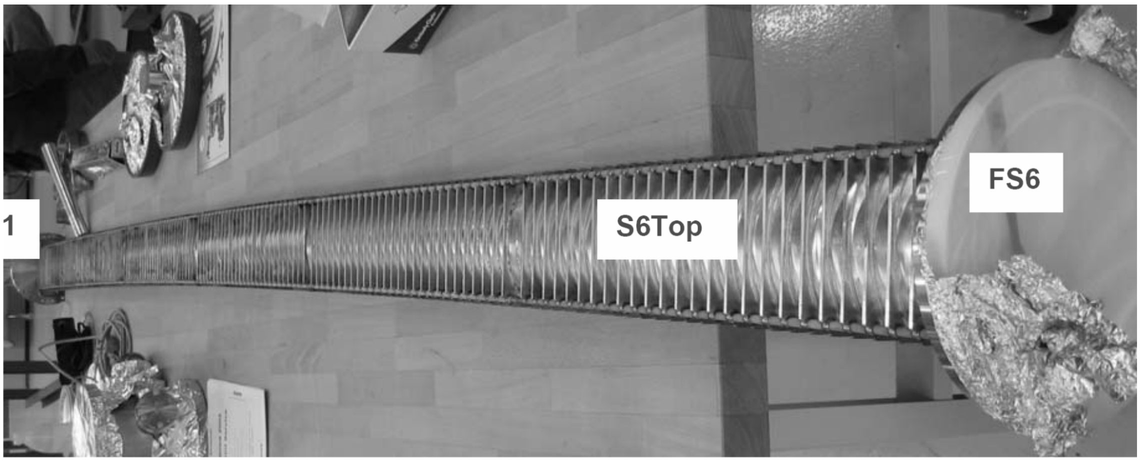


Figure 8: A prototype of the vacuum chamber of the radius dipole magnet SIS100.

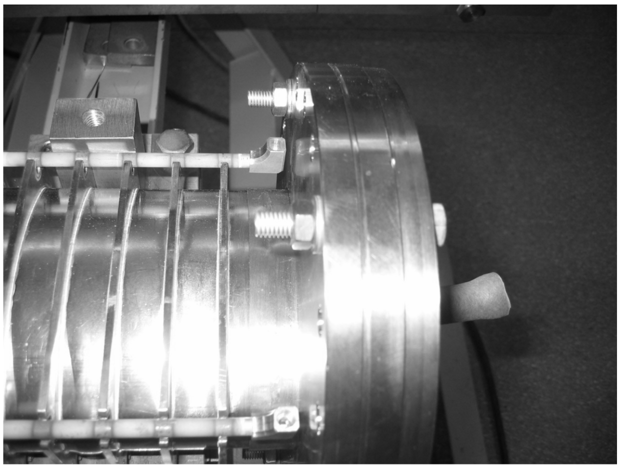


Figure 9: Cooling pipes are insulated from the rigidity ribs by a layer of Al_2O_3.

Chapter 6

Synchrotron Radiation Sources and Free Electron Lasers

Introduction

Siberian Synchrotron and Terahertz Radiation Center (SSTRC) is now working on the basis of BINP facilities and laboratories. The Center's activity includes two directions:

- "synchrotron radiation", works on synchrotron radiation (SR) from the VEPP-3 and VEPP-4M storage rings as well as development and creation of systems for SR generation for Russian and foreign SR centers;
- "terahertz radiation", works with the radiation of the Novosibirsk free electron laser in the terahertz range (120 - 240 microns), further development of the NovoFEL and participation in foreign FEL projects.

The work program for the "synchrotron radiation" direction for the year 2008 included the following:

- basic and applied research and development of new technologies using SR from the VEPP-3 and VEPP-4M storage rings;
- creation of experimental equipment for operation with SR beams (beamlines, experimental 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 such as wigglers and undulators;
- teaching and professional training of students and post-graduates.

In 2008, 1956 hours of operation were allotted for the "synchrotron radiation" regime (1938 hours in 2007). The net time of work with SR beams was 1648 hours. 240 hours of work in the "SR" regime were allotted on VEPP- 4M (there was no regular work on SR beams from VEPP-4M in 2007). Experiments involved 11 stations on 7 beamlines for SR extraction from VEPP-3 and 2 SR stations from VEPP-4M.

The work program for the "terahertz radiation" direction for the year 2008 included the following:

- construction of user stations and research activity on the operating high- power laser in the terahertz range;
- mounting and commissioning of the two-orbit accelerator-recuperator for the 2nd stage FEL for the wavelength range of 40-120 microns;
- participation in foreign projects on the development and construction of high-power FELs;
- teaching and professional training of students and post-graduates.

430 hours of operation time were allocated for research on the terahertz radiation beams from the NovoFEL in 2008 (780 hours in 2007, the reduction caused by works for the commissioning of the two-orbit accelerator-recuperator for the 2nd stage FEL). Experiments with the terahertz radiation beams were carried out at 5 user stations by members of 10 SB RAS institutes, teachers, students, and post-graduates of the Novosibirsk State University and Novosibirsk State Technical University as well as by members of two Moscow institutes – Kapitza Institute for Physical Problems and Central Design Bureau for Unique Instrumentation RAS.

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:

- Lavrentiev Institute of Hydrodynamics SB RAS;
- Institute of Solid State Chemistry and Mechanochemistry (ISSCM)SB RAS;
- Budker Institute of Nuclear Physics SB RAS;
- Institute of Thermophysics of Extreme States RAS (Moscow);
- Russian Federal Nuclear Center (Snezhinsk).

Investigation into detonation and shock wave processes using synchrotron radiation.

This work was carried out under Agreement on Science and Technology Cooperation among BINP SB RAS (Novosibirsk), (Snezhinsk), (ISSCM) SB RAS (Novosibirsk), and IGL SB RAS (Novosibirsk). Triaminotrinitrobenzol (TATB)-based explosives are the safest in use. Unlike other explosives, at heating this type of explosive decomposes into inexplosive substances. Development, study, and trials of these explosives are a priority now.

- The goal of the work is to study the structure of detonation front propagating over cylindrical samples of pressed TATB-based explosives (Figure1);

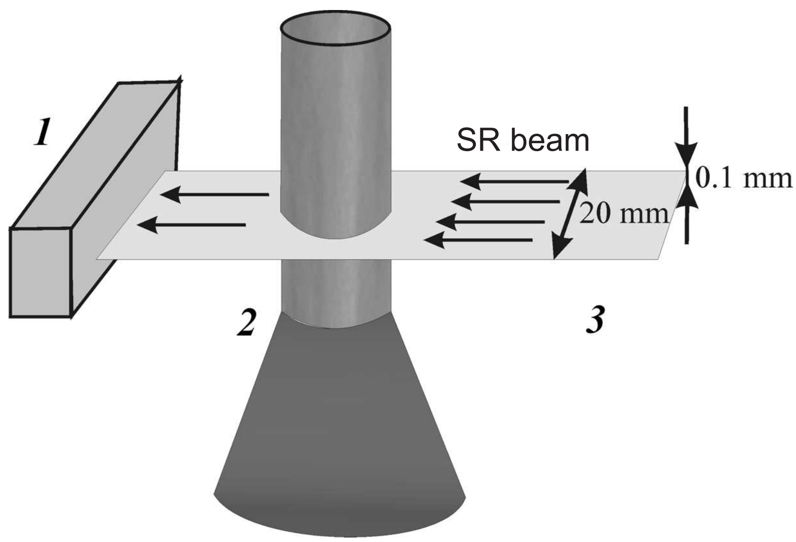


Figure 1: Schematic depiction of the X-ray experiment: 1 - the X-ray detector DIMEX, 2 - the explosive charge to study, 3 - the synchrotron radiation beam.

- acquisition of experimental information on the flow parameters downstream the detonation front (Figs. 2 and 3);

- acquisition of experimental information on the phase and chemical transformations in shock and detonation waves propagating across solid TATB-based explosives.

The following has been obtained experimentally: density distribution on the front at TATB-based explosive detonation, density values in the Von Neumann spike and in the

Chapman-Jouget plane, distributions of densities, and velocities pressures downstream the detonation front. The found densities and pressures allow deriving the adiabatic exponent for detonation products, which has been done for TATB-based explosives. Evolution of condensed particle sizes beyond the detonation front has been obtained. At detonation, the condensed particle size is weakly increasing in time from 1.7 nm to ~ 2,5 - 3 nm. Judging by the SAXS signal amplitude, no traces of diamonds were revealed at detonation of this explosive.

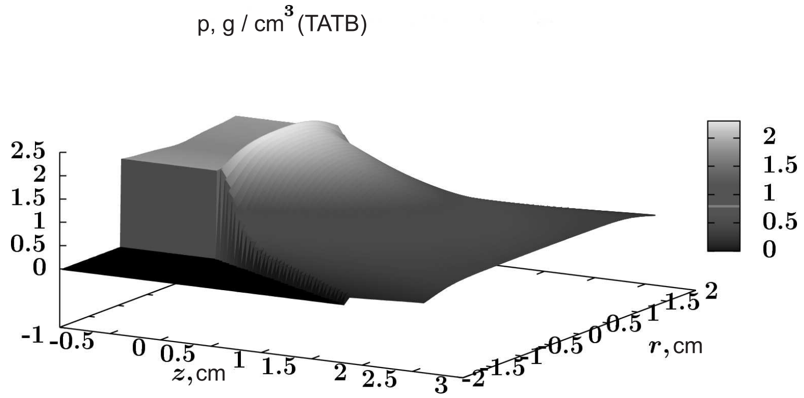


Figure 2: Spatial density distribution ρ(r,z),g/cm^3. A charge of a TATB-based explosive (SPEC 75 11903 -538-90).

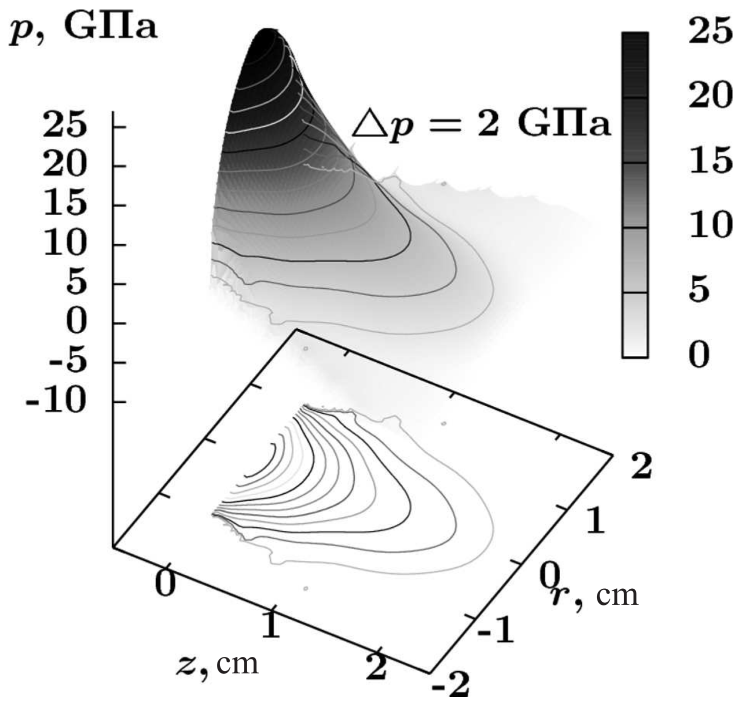


Figure 3: Spatial distribution of pressure. A charge of a TATB-based explosive.

Results

Remote and nondisturbing measurement of density on the detonation front of a TATB-based explosive was carried out for the first time. Dynamics of condensed carbon particles were obtained.

Analysis of irreversible processes in condensed (continuous or porous) media under intense external impacts including shock wave ones

This work was carried out within the framework of State Program 0120.0 406861 “Study of behavior of homogenous and heterogeneous media under high-energy impact”.

Irreversible processes in condensed (continuous or porous) media under intense external impacts including shock waves are one of the main directions of research in the extreme state physics. Investigation into such processes gives us information on the mechanical and thermodynamic properties of substances. This information, in turn, becomes a basis for behavior models and equations of state in a maximally wide area of phase diagram. Special attention is paid to irreversible deformation and destruction, phase microstructure and mezostructure transitions, and interaction of substances with radiation of various types. Lavrientiev Institute of Hydrodynamics together with Budker Institute of Nuclear Physics and Institute of Solid State Chemistry and Mechanochemistry have developed and approved a technique for analysis of the detonation and shock wave process with SR application. This technique has revealed new possibilities of obtaining information on the processes and states of media under study under extreme impact. Dynamics of deformation of high-porous substances (aerogel and stivlon) and brittle polymeric materials (acrylic resin and epoxy resin) under shock wave and explosive loading were investigated in this work. Percussive adiabats of aerogels of various initial densities have been determined.

Development of a technique to measure density distribution on the detonation front of cylindrical charges of small diameter with a resolution of 100 μm

This work was carried out within the framework of State Program 0120.0 406861 “Analysis of the behavior of homogenous and heterogeneous media under high- energy impact”.

The aim of the work is reconstruction of the mechanical parameters of a stationary gas flow, such as fields of mass velocity vector and pressure, from the density distribution measured on a synchrotron radiation beam. This technique bases on the application of the equations of mass flow and pulse conservation and can be applied for flows of media with an arbitrary equation of state.

Application of the data of fast X-ray tomography together with this technique made it possible to find out spatial distributions of the density, velocity, and pressure at stationary detonation of cylindrically-symmetrical charges of pressed trotyl and its mixture with hexogen (50/50). Adiabats of unloading of products of explosion in the pressure-density coordinates have been defined from the obtained data. It was shown that the equation of state of detonation products is well described with the polytrope gas model with an adiabatic exponent $\gamma \approx 3$.

Two kinds of charges were investigated in this work: trotyl pressed to a density of 1.6 g/m^3, the detonation velocity D = 6.9 km/s (TNT), and pressed mixture of trotyl with hexogen (50/50) pressed to a density of 1.7 g/cm^3, the detonation velocity D = 7.6 km/s (TH). Diameter of the charges was 15 mm, the distance from the initiated end to the section to observe was 60 mm. Initiation was executed with a planar wave generator.

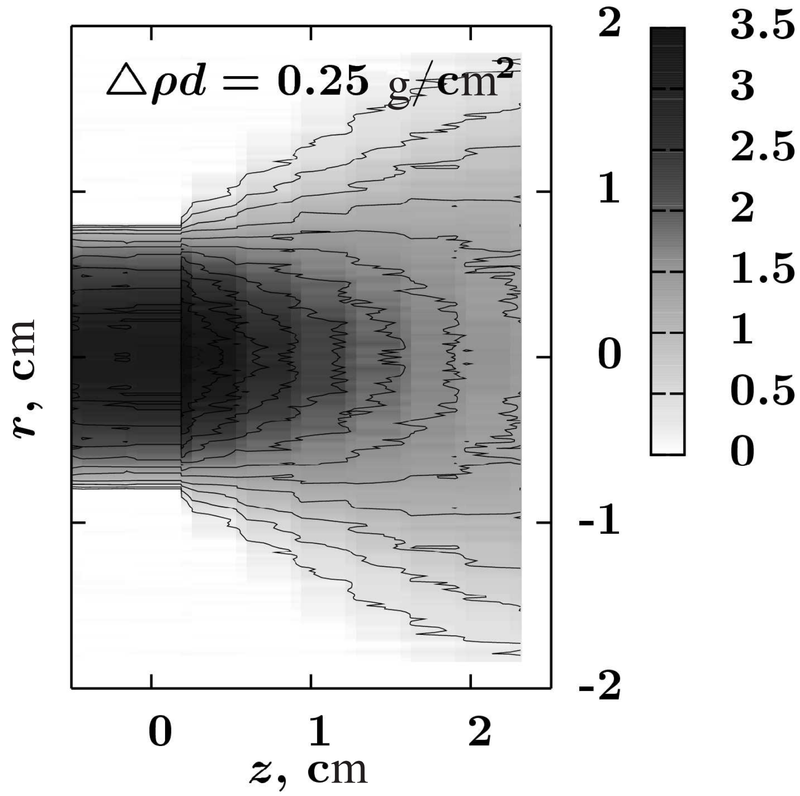


Figure 4: Spatial distribution of the amount of the exposed substance (ρd, g/cm^2), the TNT charge.

6.1.2 LIGA technology and X-ray lithography

They at the station have been working on the development of a method to manufacture X-ray masks for the LIGA technology as well as production of microstructures for technological applications. LIGA masks are key elements for deep X-ray lithography with SR application to manufacture high-aspect-ratio microstructures for a broad range of scientific research (microfluid analysis systems, selective grid structures for terahertz radiation, etc.).

In 2008, the works on the development of the technique of deep mictrostructure manufacture with the application of deep X-ray lithography continued. In particular, creation of masks for deep X-ray lithography on SR and manufacture of mictrostructures with the application of the created masks were worked through.

The participant institutions are

• Budker Institute of Nuclear Physics SB RAS;

• Novosibirsk Institute of Organic Chemistry SB RAS;

• Institute for Automatics and Electrometry SB RAS;

• Institute of Chemical Kinetics and Combustion SB RAS;

• The Novosibirsk Branch of the Federal State Enterprise “Eye microsurgery” of the Ministry of Health of the RF;

• The Novosibirsk State Technical University.

Below are given themes of the some of the works of the year 2008.

Beam technologies for synthesis of microstructured components for ophthalmology, microoptics and microphotoelectronics with the application of new hybrid materials

The work was carried out within the framework of SB RAS Interdisciplinary integration project #15.

The goal of the work is to develop methods of spatial half-tone modulation of SR in order to create a 3D relief of surface microstructuring. The end user of the new technologies is the optics industry, medicine (especially, ophthalmology), photoelectronics, and other high-tech industries. The most typical and topical products are the raster patterns of microlenses and microprisms, hybrid diffraction-refraction objectives, intraocular lenses, and synthesized holograms.

A method of formation of 3D microprofiles in a positive X-ray resist (PMMA, as an example), using the dynamic X-ray lithography for formation of diffraction elements for the visual range, has been suggested and tested. For production of the half-tone distribution of the SR exposure dose at irradiation of the resist, it was suggested to translate the resist relative to a special-type binary X-ray mask fixed in the SR beam.

During the period under report, 2 working X-ray masks with different microstructures with the Re-Ni absorbing layer on the glass-carbon substrate were manufactured. The specialized structure of the pattern of the mask provided the required heterogeneity of irradiation dose in the PMMA, which allowed obtaining a “saw-shape” profile after etching the PMMA, both for the linear prisms and diffraction zone circles. 20 test samples with microstructures in the PMMA resist were manufactured with the application of masks produced by the methods of the deep X-ray lithography. Test samples were obtained, the possibility of the application of the suggested method for formation of 3D microstructures in a positive microresist was demonstrated (Figs. 5 and 6).

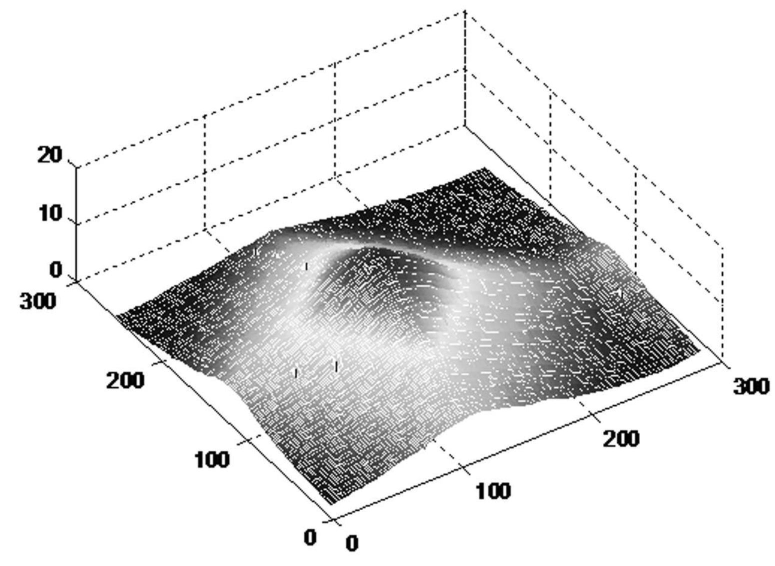


Figure 5: Profilogram of elementary microprism in PMMA. The microprism size is 300x300 microns.

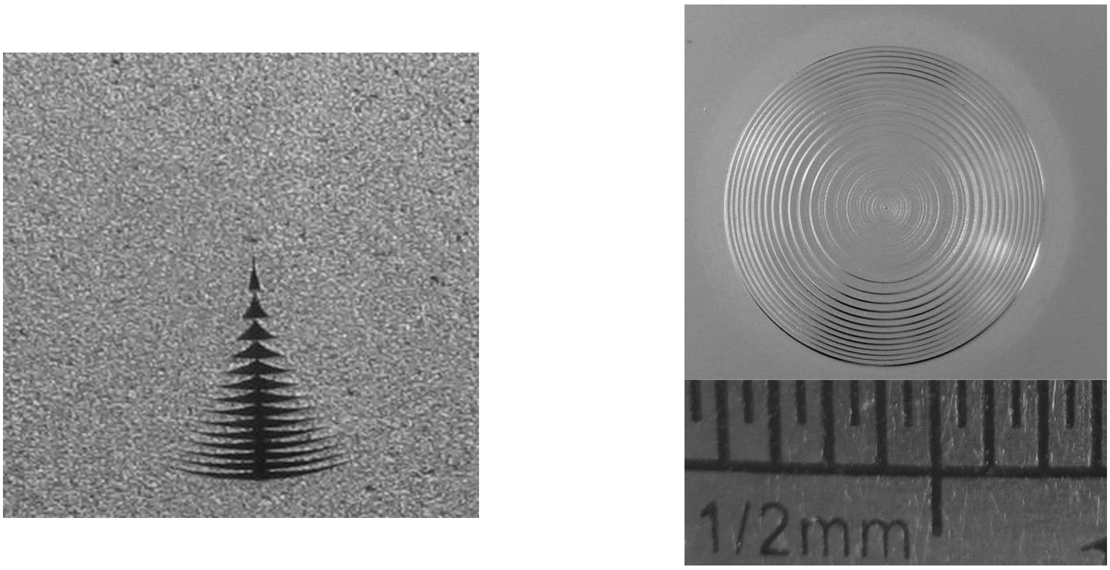


Figure 6: X-ray mask of an intraocular multifocal lens with the Re/Ni absorbing layer on the glass-carbon substrate (a blow-up fragment of the mask is on the left). A prototype of an intraocular multifocal lens with diffraction microrelief; the prototype was made in PMMA by the method of the deep X-ray lithography (on the right).

Study of radiation-induced thermal processes in thick layers of PMMA during irradiation with an SR beam

The work was carried out within the framework of RFBR grant #06-02-17415: “Study of radiation-induced thermal processes in thick layers of PMMA during irradiation with SR”.

The work is aimed at understanding and controlling radiation-induced thermal processes arising in thick layers of X-ray resist during irradiation with an intense SR beam.

Polymethylmethacrylate (PMMA) is widely used as a positive resist in the X-ray lithography. In the course of exposing resist layers hundred to thousands of microns thick to SR, it is impossible to avoid radiation-induced heating of the material, change of the resist properties and, at in a wrongly-selected regime, the resist layer can get deformed or destroyed. Thereby, to study the thermal properties of thick resist layers under irradiation is important for understanding of the processes going in a polymer under the SR influence.

Samples of sheet PMMA were exposed to SR with exposure doses of 2, 4, 6, and 8 kJ/cm^3. This interval of doses corresponds to the steepest part of the characteristic curve and is of the largest interest for the LIGA technology. The obtained samples were investigated by the methods of differential scanning calorimetry (DSC) and thermogravimetry (TG), in order to determine the thermophysical properties of the resist. Besides, the samples were investigated at the chemical-biological station of the Siberian Center for Photochemical Research, which is equipped with the diffusion aerosol spectrometer (DAS) intended for automatic determination of the concentration and spectrum of aerosol particles. This station utilizes the radiation of the free electron laser (FEL) with a wavelength of $\lambda \approx 130$ μm ($E_{ф} < 0.01$ eV),which guarantees "soft" (nondestructive) ablation of the initial molecules. Results obtained by the DSC method show (Figure7)that PMMA with a zero exposure dose is characterized by the glass-transition temperature T$_c \approx 110$°C, while PMMA with irradiation doses of 2, 4, 6 and 8 kJ/cm^3 is characterized by peaks corresponding to a glass-transition temperature of about T1$_c \approx 65$°C.

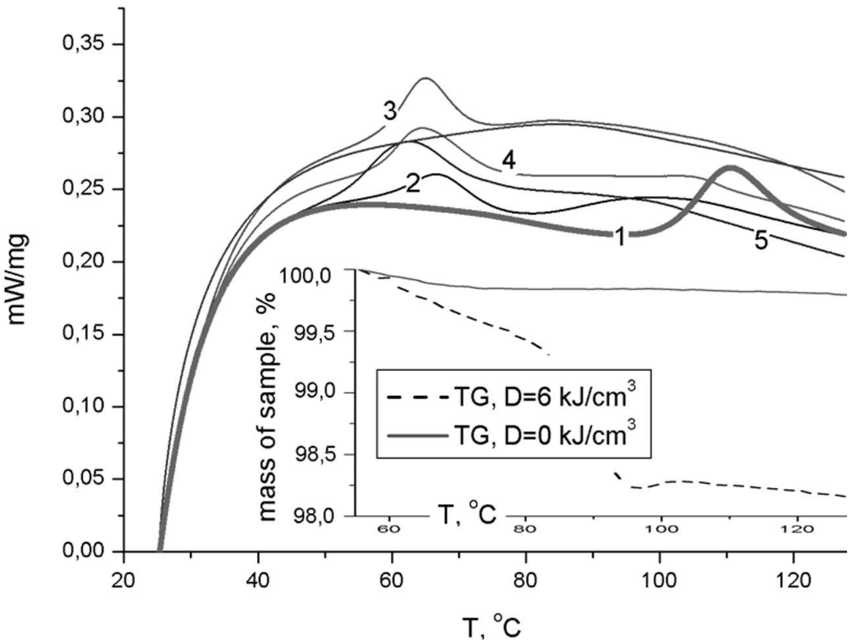


Figure 7: DSC curves for PMMA with doses of 0, 2, 4, 6, 8 kJ/cm^3 (lines 1-5, correspondingly). Insert: Variation of the PMMA weight with doses of 0 and 6 kJ/cm^3 (the TG method).

The DAS results characterize the distribution of only high-polymeric fractions in the samples studied. Their behavior is evidence of the number-average molecular weight increasing with the dose growth in this exposure interval. From the obtained results it follows that in the dose interval under study, the glass-transition temperature of irradiated PMMA will be much less than that of a unirradiated sample, both because of the significant decrease in the amount of linear molecules, which enforce the polymer, and due to the substantial increase in the concentration of the low-polymeric fraction, the number-average molecular weight of which gets less with the dose growth. The dependence of the size of the macromolecules of the irradiated PMMA on the exposure dose value has been determined experimentally and a descriptive model agreeing well with the characteristic curve behavior has been given.

6.1.3 Station "High-resolution diffractometry"

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

Below are listed institutions that participated in the works in 2008:
- Boreskov Institute of Catalysis SB RAS,
- Nikolaev Institute of Inorganic Chemistry SB RAS,
- Institute of Chemistry and Chemical Technology SB RAS, Krasnoyarsk,
- Pisarzhevsky Institute of Physical Chemistry of the Ukraine NAS, Kiev,
- Lomonosov MSU, Moscow.

Subjects of some works in 2008:

Exploration of the mesoporous coordination polymer MIL-101 with a zeolitic crystal structure, big area of surface, and thermal resistivity

The work was done within the SB RAS Program "Chemical design of catalysts and adsorbents with a highly-organized supramolecular nanostructure". The goal of the work is working through the technology of synthesis of new functional mesoporous materials for utilization as sorbents, catalysts and catalyst carriers, and heterogenous catalysts of liquid phase oxidation for pollution-free processes. In the known literature, there are no reports about in situ studies of formation of metal-organic mesoporous polymer. Results of the work can be used for production of catalysts of fine chemical synthesis for oxidation of organic compounds in soft conditions using ecology-friendly oxidizers, e.g., hydrogen peroxide.

A few years ago, works on the synthesis and study of mesoporous materials with a huge specific surface area and mesopore size, surpassing silicate mesoporous materials in the corresponding parameters. These compounds under a common name of Metal-Organic Framework (MOF) are mesoporous coordination polymers, have a zeolite-like structure, in which the coordination polyhedrons of chromium are connected by bridges of terephthalic acid residuals. Such structure is resistant to the action of air, water, and plain solvents and to thermal processing in a rather wide range of temperatures. This material can be used for immobilization of catalytically active particles such as polyoxometalates in mesopores.

It has been shown earlier that when monosubstituted polyoxometalates are brought in mesopores of coordination polymers, the main motive of the structure is conserved. A few cycles of liquid phase oxidation of alkenes with pollution-free oxidizers will not lead to destruction of the frame, which allows using them in corresponding oxidizing processes. Preparatory experiments on in situ study of the formation of the zeolite-like structure of the MOF by the X-ray diffraction method were carried out in 2008.

The typical times of the MOF structure formation are several hours to several days, depending on the environment and product composition. Formation of the product is accompanied by sedimentation from the initial solution. That allows studying the process of MOF formation in the real-time regime, using a high- accuracy diffractometer. The initial solution is placed in a capillary; the X- ray images are assumed to have a time step of $\sim$ 20 minutes. The preliminary experiments carried out have shown a possibility in principle of conduction of this work.

Study of phase formation in the Cs-Zn-Li system of double and triple molybdates

The work was carried out within SB RAS Interdisciplinary program 38.2 "Growth and properties of crystals"

The goal of the work is to find new functional materials for use as the working media of solid-state lasers.

Results on the phase composition of Li-Cs-Zn molybdates have been obtained for the first time. These results allow estimation of the individuality of the triple phase. Molybdates and tungstates are promising functional materials in the contemporary science intensive manufacture, meeting to a substantial extent the need of laser, ferroelectric, scintillation, nonlinear-optical and other materials. By now, plain and double molybdates of alkali and polyvalent metals have been characterized rather fully. That allows starting the study of triple molybdates and investigation into the influence of the specific particularities and combinations of cations on the structure and properties of compounds and materials. With today's level of knowledge of molybdates and tungstates, it is possible to obtain new materials in other classes of compounds, first of all, complex oxides. Thereby, further study of new groups of molybdates and tungstates is still topical.

An X-ray diffraction study of a series of triple molybdates consisting of Cs_6Li_2-$2xZn_4$ $+x(MoO_4)_8$ has been conducted with a step in x of 0.1, from 0 до 1. The unit cell parameter of these compounds of cubic structure changes weakly in this interval of compositions. Thus, the experiment had to be carried out with the application of a high-accuracy diffractometer of high resolution, on SR in the region of large diffraction angles. As a result, a reflex splitting with formation of a two-phase system was observed in the region of x$\sim$0.4 $\div$ 0.5, which means that the Cs_6Li_2- $2xZn_4+x(MoO_4)_8$ compound does not make a continuous solid solution and there is a phase transition in this region. Figure 8 presents the behavior of variation of the unit cell parameter, obtained via more accurate determination of the parameter from the positions of reflexes over the entire range of the X- ray picture. It can be seen that the largest error of the unit cell parameter determination also falls in the region x$\sim$0.4-0.5, which is indirect confirmation of phase transition presence in this region.

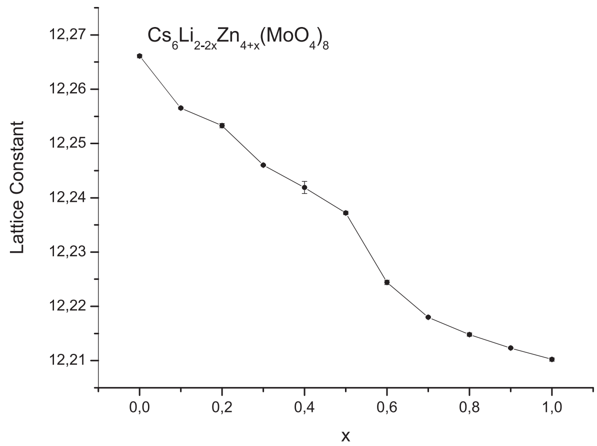


Figure 8: Dependence of unit cell parameter Cs_6Li_2-$2xZn_4+x(MoO_4)_8$ on the lithium content.

6.1.4 Station “X-ray fluorescent 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 fluorescent element analysis (SR-RFA). The element analysis can be executed both in the local and scanning regimes.

Participant organizations:

- the Institute for Geology and Mineralogy SB RAS, Novosibirsk;
- he Institute of the Earth Crust SB RAS, Irkutsk;
- Budker Institute of Nuclear Physics SB RAS, Novosibirsk;
- the Institute of Chemical Kinetics and Combustion SB RAS, Novosibirsk;

- Nikolaev Institute of Inorganic Chemistry SB RAS, Novosibirsk;
- the Institute for Soil Science and Agrochemistry SB RAS, Novosibirsk;
- the Institute for Forest SB RAS, Krasnoyarsk;
- the Institute for Ecology of Plants and Animals UB RAS, Ekaterinburg;
- Central Siberian Botanical Garden SB RAS, Novosibirsk.

Below are given themes of some works in 2008.

Analysis of the late-pleistocene sediments of the lakes of the Western Baikal area

The work was carried out within the framework of SB RAS Interdisciplinary project #88 “Hydro-mineral resources of the Mongolia-Baikal region”.

The goal of the work is to find out the long-term and short-term tendencies in the change of the natural environment and climate in past for forecasting such changes in future. In the complex approach to reconstructions of climate and paleoenvironment changes from sediment chronicles of the Central Asia lakes that have not been studied earlier, the study of the element content and quantitative ratios of elements, especially in carbonate sediments, plays an important role. The studies require construction of a continuous and detailed scale of distribution of a number of elements in the core material.

In 2008, the bottom sediments of the small lakes of the Olkhon region were studied. The X-ray fluorescent analysis was used to study both continuous samples of sediments (scanning of a core with a step of 1 mm) and discrete ones (pellets). The contents of 20 elements were studied in order to reveal which of them could be indicators of climate on the objects under study, i.e., carbonate sediments of the small salted lakes.

Main result:

1. Curves of element distributions in a sediment section of the small salted lake Tsagan-Tyrm have been defined.

2. It was revealed which elements and ratios of elements have indicator signs for reconstruction of paleoclimate and can be used at exploration of other similar objects (Figure9).

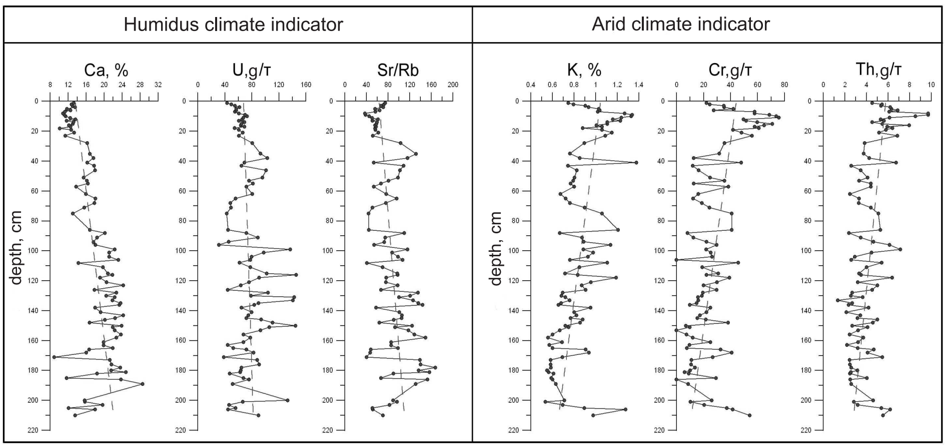


Figure 9: Distribution of geochemical indicators of paleoclimate changes in a sediment section of the lake Tsagan-Tyrm.

Study of the microelement content of the vegetation of the taiga regions of Yakutia.

The work was carried out within the framework of RFBR grant # 08-05-00137 "Patterns of the abiogenous mass transfer of man-caused radionuclides in fresh- water bodies by the example of the ecosystem of the river Yenisei ".

The problems of man-caused influence are especially topical in the north-east of Russia due to the influence of the mineral resource and processing industry on the northern ecosystems, which are less stable and have less potential of recreation as compared with the ecosystems of the middle latitudes. Complex biogeochemical works in the areas of Yakutia, which have very different natural environment, are carried out practically for the first time.

In the conditions of Yakutia, data on the microelement content of the Kayander larch (Larix cajanderi Mayr) and integrated biogeochemical data on the taiga landscapes as a whole have been obtained. The microelement analysis is done using methods certified in accordance with the RF standards. The microelement content of the tissues of plants growing within the gold-uranium deposits of the Elkon horst and Tomtor rare metal deposit was under study. The influence of the man-caused pollution on the microelement content of the tissues of plants was specially studied.

Below are given first results on the basis of analysis of 100 samples:

a)The plant is maintaining constant concentrations of K, Ca, and Mn in its tissues regardless of the intensity of their nutritional arrival and regardless of the composition of the substrate. The content of the biophilic metals Cu and Zn in the larch is also regulated rather by the plant itself than by external factors. Accumulation of Fe, Mo,Pb, Ag, Sb, As, Tl, Rb, Y, Sr, Zr, Nb, U, and Th depends on the intensity of their nutritional arrival, i.e., on the composition of the substrate. Mosses and lichens, like a sponge, accumulate microelements in direct dependence on the intensity of their arrival.

b) Plant tissues on the granites, syenites, and shonkinites of the Aldan shield, and carbonatites of the Tomtor rare-metal deposit contain high concentrations of Rb, Y, Sr, Zr, and Nb. In the vegetation of the Tomtor rare-metal deposit, besides the content of rare elements, the torium content is also increased. In the vegetation of the Elkon ore field, the content of uranium and thorium is increased. The influence of gold ore is manifested as high content of chalcophile gold drivers such as Ag, As, Sb, Tl, Zn, and Cu in the plant tissues.

c) Larch is the same sensitive biogeochemical indicator as mosses and lichens. Due to the large accumulation of microelements, the coniferous nodes of the larch carry more information than the needles.

Exploration of the influence of atmosphere aerosols upon the biogeochemical cycles

The work was carried out within the framework of the SB RAS Integration project # 5.23 "Geochemical manifestation of genetic heterogeneity of populations of the main forest-foring species" and 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".

280 vegetation samples (bark and wood) on clonal pine plantations have been studied for estimation of the level of genetic heterogeneity of the population. Together with the Institute of Ecology of Plants and Animals, the Ural Branch of RAS (Yekaterinburg), the role of animals in formation of the biogenic exchange of chemical elements in natural

terrestrial ecosystems and under extreme chemical pollution were studied. Multielement analysis of samples of tissues of small birds feeding on insects has been done. The influence of man-caused pollution on prairieweed plant has been studied with the participation of the Central Botanic Garden.

Development of SR XFA methods to analyze the chemical composition of new materials (crystals and films) without any reference sample

The work was carried out within the framework of SB RAS - INTAS grant 06-1000013-9002 “New layered 3D materials for spintronics”.

The goal of the work was to develop the technology of synthesis of high- quality samples synthesized on the base of layered matrixes of $CuCrS_2$ and $Pb_3Mn_7O_{15}$ and to find out the influence of the technology on the real (crystal and chemical) structure. The materials are antiferromagnetic semiconductors – new layered 3D materials for spintronics. As a result of the experiments carried out, the stoichiometric composition of given samples of materials has been determined experimentally and details of the difference between two parties of samples synthesized by different technological schemes were shown.

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 temperatures.

The station is equipped with an image-plate detecting system mar-345 by the company Marresearch with a system for in situ reading and erasing diffractograms. This system can sharply increase the number of experiments carried out at the station. A new system for detection of diffractograms, without image plate application, MAR-CCD, was received and is now being mastered. At the end of 2008, a new high-pressure chamber with diaphragm loading, was received. It has been already tested experimentally. The chamber allows on-line variation of pressure applied to a sample.

Participant organizations:

- the Institute of Solid State Chemistry and Mechanochemistry SB RAS, Novosibirsk;
- the Institute for Metallurgy of the Ural Branch of RAS, Yekaterinburg.

Below are listed some works in 2008:

Exploration of the phase formation at mechanochemical ferric oxide reduction with aluminum

The work was carried out within the framework of SB RAS interdisciplinary integration project # 98 “Mechanocomposites – precursors for creation of materials of new properties ”.

Studies of the products of interaction of ferric oxide with aluminum under heating were conducted. The experiments have shown that a temperature increase of up to 300°C leads to annealing of the iron or of the solid solution of aluminum in the iron. Holding at a temperature of 720°C for 6 hours leads to recrystallization of the iron or its solid solution (Figure10).

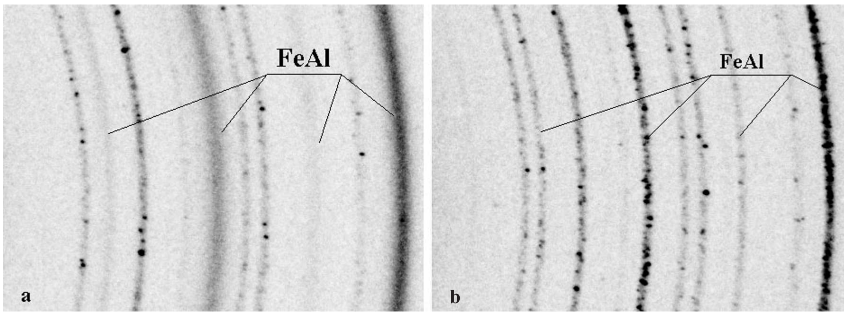


Figure 10: Fragments of diffraction patterns from products of interaction of ferric oxide with doubled aluminum amount as compared with the stoichiometric amount.
a) product after mechanoactivation, b) after 6 hours of holding at a temperature of 720°C. All unmarked reflexes belong to the corundum.

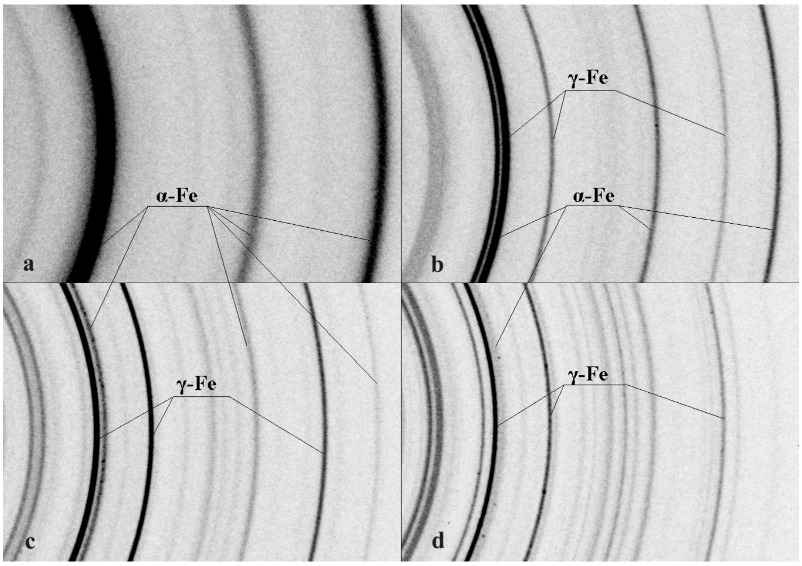


Figure 11: Fragments of diffraction patterns obtained from products of interaction of ferric oxide with solid solution of aluminum in iron at a temperature of 720°C. a) the initial substance; b) 1 hour of holding; c) 3 hours; d)6 hours. All unmarked reflexes belong to the ferric oxides.

Figure11 presents fragments of diffraction patterns obtained from products of interaction of ferric oxide with solid solution of aluminum in iron. It can be seen from the diffractograms that the initial substance consists of α- iron with small admixtures of hercynite. At heating, the iron gets annealed. At temperature above 620°C, phase transition of α-iron to γ-iron starts. Holding at a temperature of 720°C for 6 hours makes the entire α-iron transform to γ-iron.

Usually, this phase transition occurs at temperatures above 912°C. Besides, it should be noted that the size of the crystallites of α- and γ-iron remained submicron, judging by the diffraction rings, after the holding at a temperature of 720°C for 6 hours, though in the products of interaction of ferric oxide with aluminum there occurs recrystallization of iron. No rise of aluminum oxide phases was observed at the heating. It can be asumed that the heavily deformed or amorphous aluminum oxide is located over the surface of crystallites of nano-iron in a layer a few nanometers thick. That is why no reflexes from aluminum oxides are observed in the diffractograms. It is these layers what impedes iron recrystallization. The application of mechanochemical ferric-oxide reduction with aluminum and its solid solutions makes it possible to obtain a wide class of composite materials of various morphological properties.

Influence of the atomic crystal and electron structure on the induced magnetic anisotropy and magnetic properties of soft ferromagnetics

The work was carried out within the framework of

1. RAS Presidium program # 3.2 "Influence of the atomic crystal and electron structure on properties of condensed media."

2. RFBR grant 06-02-17082 "Study of the effect of directional ordering of atoms and its influence on fine particularities of the structure and magnetic properties of soft iron-based ferromagnetics".

Direct structural explorations have revealed, for the first time, the structural nature of the formation and stabilization of magnetic anisotropy in crystal alloys α-FeSi after thermomagnetic and thermomechanical treatment. The magnetic anisotropy was earlier predicted by the hypothesis on directional ordering of atoms and backed up by numerous indirect data.

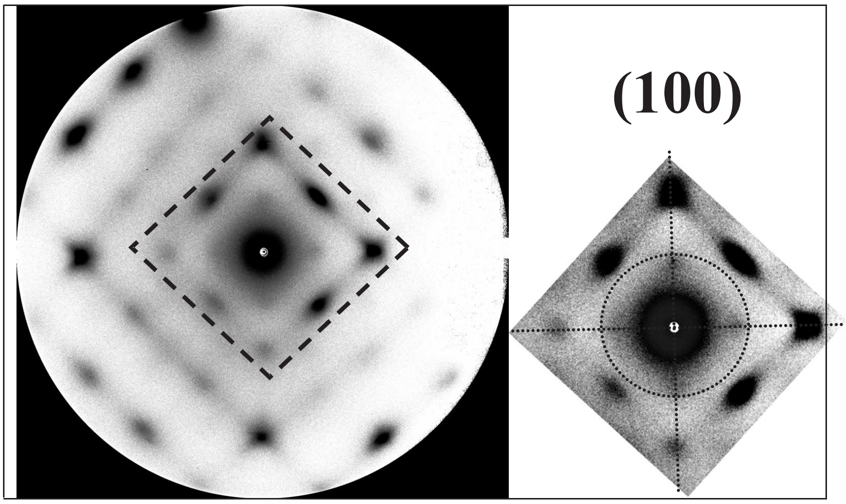


Figure 12: Diffraction pattern from a monocrystal of α-FeSi (6 at.% Si) registered by a double-coordinate detector. Spots of superstructure reflexes (100) are at the intersection of the dotted lines and the circumference (in the insert on the right).

It has been shown that induction of transversal magnetic anisotropy in the nanocrystal alloy FeSiCuNbB (FINEMET) is caused by the anisotropic residual tensions in the lattice of the nanocrystals in the direction of application of load at thermomechanical treatment and the negative nature of the magnetoelastic interaction in the nanocrystals with a silicon content close to the stehiometry of Fe_3Si.

It has been shown that magnetic properties of iron-based soft crystal (α-FeSi) and nanocrystal alloys (FINEMET) are closely linked with their structure, which is formed in the course of annealing in a magnetic field and under a stretching load.

6.1.6 Station “X-ray microscopy and tomography”

The station “X-ray microscopy and tomography” is intended for high-resolution examination of the 3D structure of samples.

Participant organizations:
• Budker Institute of Nuclear Physics SB RAS, Novosibirsk;
• V.S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk;
• Lavrentiev Institute of Hydrodynamics SB RAS , Novosibirsk;
• the Institute of Chemical Kinetics and Combustion SB RAS, Novosibirsk.

Some of the works in 2008:

• Microtomography of weak-contrast samples with the application of SR from the VEPP-3 storage ring.

• Study of the sequence of growth of natural diamonds by the methods of X-ray topography.

• Acquisition of data on the 3D structure of samples of explosives and rocket fuel by the method of computerized tomography with high spatial resolution.

The work was carried out within the framework of

1. RFBR grant #07-05-00746 “Role of the subducted earth’s crust in formation of diamonds from the placers of the North-East of the Siberian platform”.
2. SB RAS Interdisciplinary integration project # 7 “Nature of microheterogeneity of the lithospheric mantl ”.

The main contribution into the resolving ability of X-ray detectors on the base of CCD and CMOS matrixes is made by the thickness and grain value of applied scintillators. The scintillation screen thickness depends on the range of registered X-rays and varies from 50 to 200 μm. Magnifying X-ray optics is used to exceed the spatial resolution of detector. Bragg Magnifier, based on Bragg diffraction from an asymmetrically-cut crystal, is an example of such optics.

Diffraction from an asymmetrically-cut crystal makes it possible to obtain an image magnified in one direction. Usage of two crystals with mutually perpendicular diffraction planes gives a magnified image of sample, which allows obtaining an image of high spatial resolution using standard X-ray detectors. In our case, the facility is able to register an image with a spatial resolution of 3 μm at 20-fold magnification factor.

This facility was used for realization of the X-ray topography (XT) method, which allowed obtaining data on defects linked with irregularities in the crystal lattice of natural diamonds.

The XT method was used for examination of a series of natural diamonds from kimberlite pipes and placers of the Yakutia diamondiferous province. Figure14 presents examples of topograms obtained for two diamonds of different habitus. One can see well a plastic deformation of the crystals which manifests as contrast bands.

Together with the tomography data (Figure15a), particularities of the structure of natural diamonds can give information on processes that occurred in the earth’s crust many years ago.

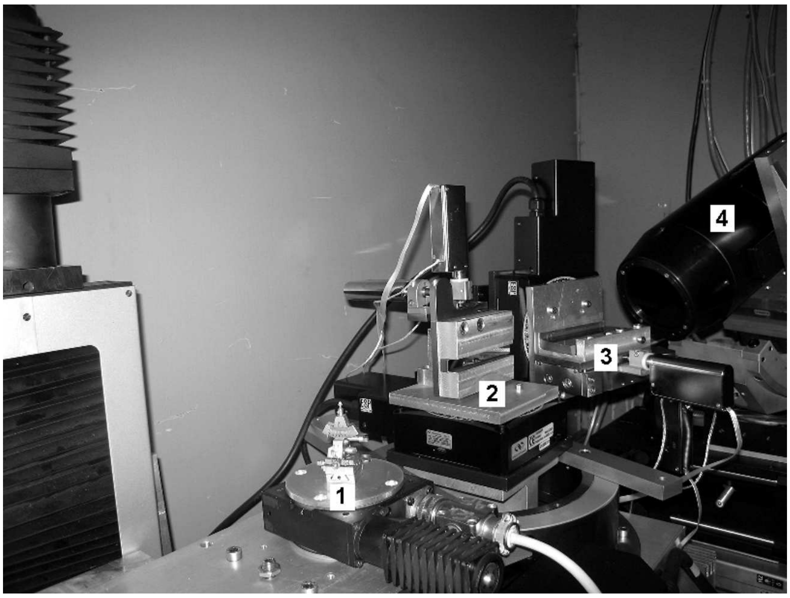


Figure 13: View of the scanning facility: 1) the sample to study, 2) the first crystal, 3) the second crystal , 4) the detector (a 4008x2760 CCD matrix).

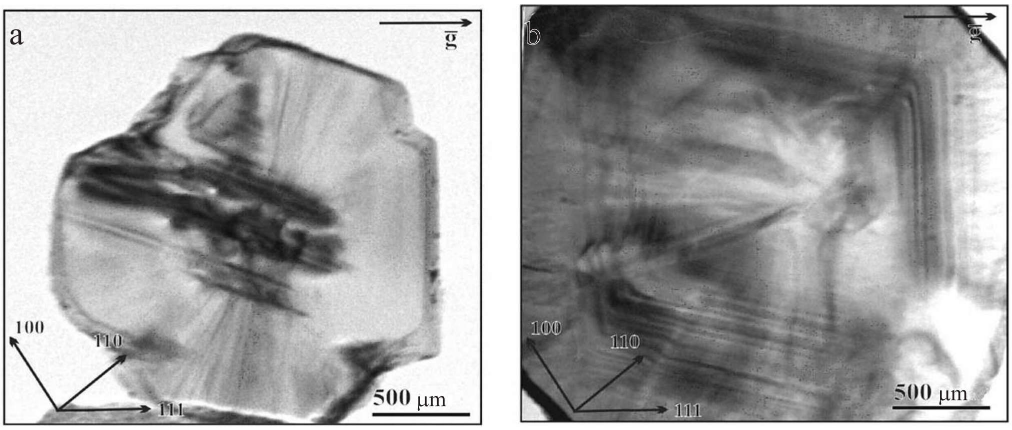


Figure 14: X-ray topograms of natural diamonds. (111) Bragg reflection.

The method of X-ray tomography with high spatial resolution makes it possible to estimate the quality of manufacture of explosives (Figure 15b). Inhomogeneities and pores influence the propagating detonation front inside the explosive.

The operating facility has another important property – the asymmetrically-cut crystals work as angular analyzers of the radiation passed through the samples, i.e., they reflect only those rays that meet the Wolf-Bragg condition, which results in emphasizing details in the media interface in the image. Thereby, weak-contrast objects can be visualized in the X-ray range. Such studies are very topical for works on examination of the quality of polymeric microstructures created by the LIGA technology method, creation of homogenous organic structures, and study of biological objects (Figure 15c).

The X-ray tomography method with the application of polychromatic radiation allows obtaining 3D data on the inner structure of rather large samples (5-6 cm) with a spatial resolution of 100 μm. Figure16 presents an example of examination of diamondiferous rock. Due to its big size, the sample was sawed up into suitable parts and studied by parts.

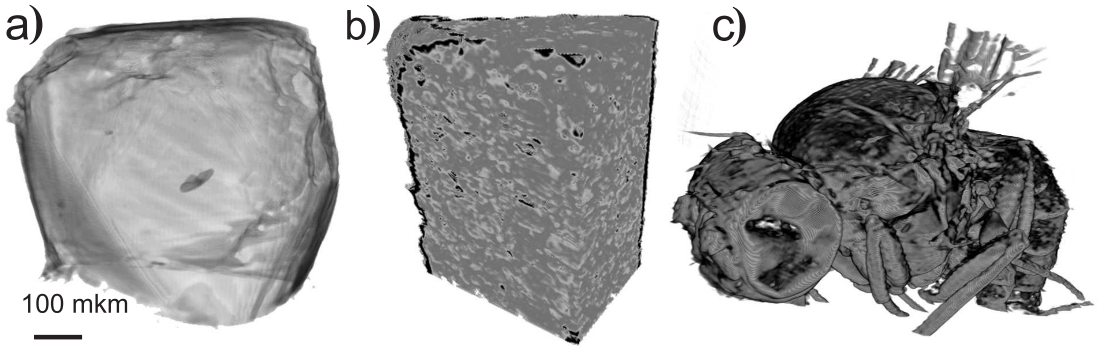


Figure 15: a) 3D image of a diamond, b) 3D density distribution inside a sample of trotyl-hexogen mixture, c) common fruit fly.

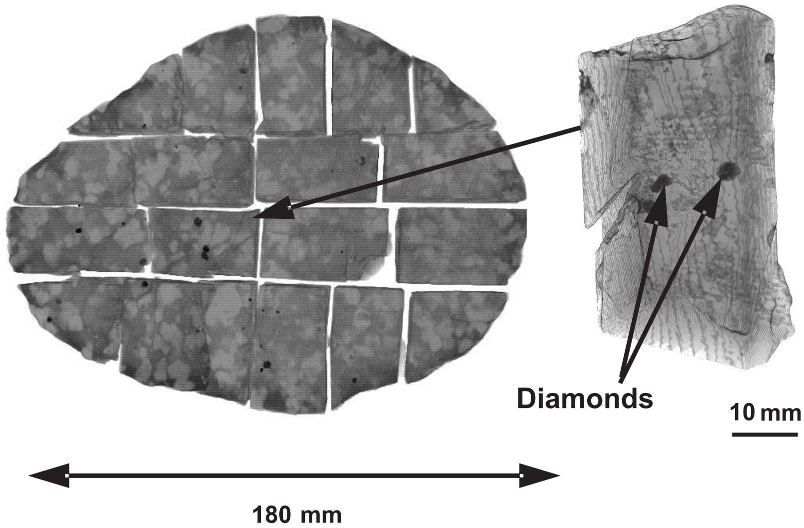


Figure 16: X-ray tomogram of diamondiferous rock with a spatial resolution of 100 μm with the application of polychromatic SR (40-80 keV).

Data on the mineral composition and computed coefficients of X-ray decay factors of the rock-forming and secondary phases (minerals) can be used to obtain information on the texture particularities and distribution of diamond crystals in the volume of diamondiferous rocks of contrast composition. Results of the tomography examinations made it possible to characterize the genetic interactions and sequence of crystallization of diamonds and associate minerals.

6.1.7 Station "Diffraction cinema"

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;
- Boreskov Institute of Catalysis, SB RAS, Novosibirsk;
- Budker Institute of Nuclear Physics SB RAS, Novosibirsk;
- the Institute of Metallurgy of the Ural Branch of RAS, Yekaterinburg;
- the Physical-Technical Institute of the Ural Branch of RAS, Izhevsk;
- the Federal State Enterprise Novosibirsk Mechanical Plant "Iskra", Novosibirsk;
- the Institute of Powder Metallurgy (IPM), Minsk, Belarus;
- the Institute of Mechanics and Reliability of Engines (IMRE), Minsk, Belarus.

Below are given themes of some works in 2008.

Study of the stages of oxidation of capsulated metal particles

The work was carried out within the framework of ISSCM program # 15 "Experimental and theoretical study of chemical transformations, structure, and properties of substances and materials. Development of contemporary physical-chemical exploration methods".

Search of methods of synthesis of nanoparticles of metals and study of their physical and chemical properties have been one of the most popular research directions recently, which is due both to the nanoparticles' properties different from those of bulk metals and to the possibility of various practical applications of such materials. It should be noted that metal particles of the nanometer range, as a rule, are not stable and oxidize fast at storage. Special measures are taken to prevent their interaction with the air oxygen and thus to stabilize them. One of the methods is creation of metal-carbon compositions in which the metal particle is encapsulated in a carbon shell.

Metallic copper and bismuth nanoparticles encapsulated in a carbon shell have been prepared in electric arc charge. To determine the stages of oxidation of such particles, in situ SR diffractometry examinations were carried out. By the example of copper, it has been found out that its oxidation follows the classical scheme (Figure 17).

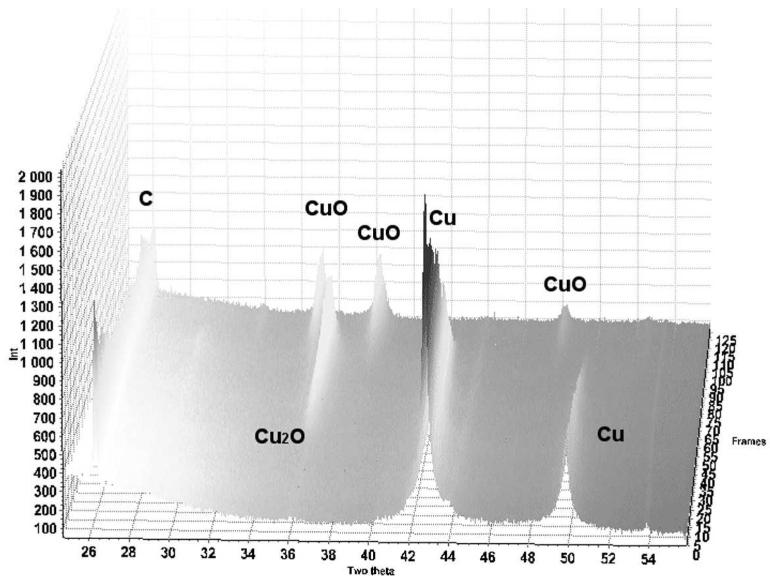


Figure 17: Dynamics of phase formation at annealing of encapsulated particles of copper.

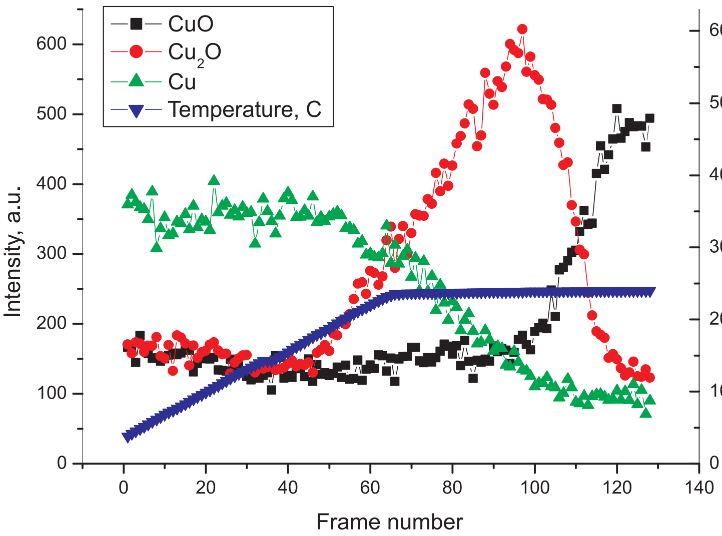


Figure 18: Kinetics of the arising phases. The temperature scale is given on the right.

At the first stage, at a temperature of 170-180°C, a decrease in the intensity of the metal copper reflexes and formation of the Cu_2O phase are observed. Later on, at holding at T = 240°C, the intensity of the Cu_2O reflexes gets less and reflexes of the CuO phase appear. It should be noted that the intensity of carbon reflexes practically does not change, i.e., carbon does not oxidize.

The carried out electron-microscope examinations have shown that formation of the oxide phases takes place on the surface of the carbon capsules: copper diffuses through the carbon shells during the oxidation process, forming oxide layers on the surface. After treatment of the oxidized samples with acids, e.g., the hydrochloric acid, the X-ray patterns contain only carbon reflexes, and the sample consists of hollow carbon capsules.

Study of the phase transformations at SHS reduction of SiO2 with aluminum

The work was carried out within he framework of Interdisciplinary integration project #98 "Mechanocomposites – precursors for creation of materials with new properties".

The conventional way of obtaining silicon is to reduce its oxide with carbon at a temperature of about 2500°C. However, the aluminothermy method can be applied not only for reduction of metals but also for reduction of silicon from its oxide. The reaction goes by the following scheme:

$$SiO_2 + Al \rightarrow Al_2O_3 + Si$$

The obtained silicon is free of carbides and the aluminum oxide can be washed away with an acid.

Thereby, the raw material for the semiconductor industry becomes cleaner.

Initial materials are treated in ball mills. The resulting aggregates are composites, where the aerogel particles are enclosed in the aluminum shell. This reaction has been studied both in the slow annealing regime and in the SHS regime, in order to reveal the stages in both cases.

In the SHS regime, the time of one frame was 0.2-0.5 second, their total amount being 128. Figure 19 illustrates the dynamics of phase transitions in this case. Due to the amorphism of the aerogel (SiO_2), only aluminum peaks can be seen in the initial X-ray pattern. During the reaction, their position and intensity change abruptly, which is linked with the heating and, seemingly, melting of the aluminum. No phases are found in the first two frames. Then the silicon and corundum peaks (Al_2O_3) arise. Thereby, one can suppose that the SHS process in this system as well as in metal ones goes through formation of the liquid phase. The diffractogram of the products enabled identification of the final phases – silicon, corundum, and residuals of unreacted aluminum.

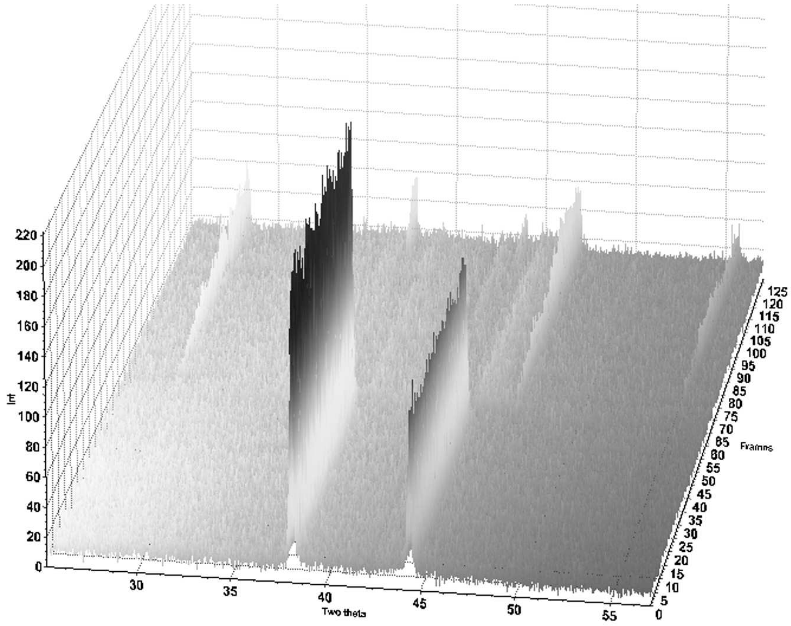


Figure 19: Survey picture of phase transformations in the SHS reaction SiO_2+Al. Time of one frame is 0.5 s.

In the regime of slow annealing, the rate of heating was 10-12 degrees per minute. Formation of products starts even before the aluminum melting. A diffractogram made after cooling showed that the degree of transformation was rather low in that regime – intense peaks of the initial aluminum can be observed. Besides the well-crystallized silicon, wide peaks of an undetermined compound are observed in the products of the reaction. It can be supposed that Al_2O_3, arising at aerogel reduction, reacts with the aerogel itself, with formation of a complex aluminum oxide and silicon because no pure Al_2O_3 was revealed.

6.1.8 Station "EXAFS-спектроскопия"

The destination of the station is exploration of the structure of the local environment of a selected chemical element (the coordination number and interatomic distance). 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, Russia;
- Pisarzhevsky Institute of Physical Chemistry of the Ukraine NAS, Kiev;
- Lomonosov Moscow State University, Department of Materials Science, Moscow, Russia;

- the Physical-Technical Institute, the Ural Branch of RAS, Izhevsk, Russia;
- the Udmurt State University, Izhevsk, Russia;
- the Joint Institute for Nuclear research, Dubna, Russia;
- the Institute of Solid State Physics at the University of Latvia, Riga, Latvia;
- Hahn-Meitner-Institut, Berlin, Germany;
- the Institute of Spectroscopy RAS, Troitsk, Russia;
- the Institute of Solid State Physics and Semiconductors, Minsk, Belarus.

Below are given themes of some works carried out in 2008.

Determination of the local structure of doped nanosystems based on mixed oxides of cerium and zirconium

The work was carried out within the framework of SB RAS Interdisciplinary integration project #4.15 "Nanocomposite catalysts for the processes of hydrogen production and refining".

The main goal of this work is the development of the scientific basis for production of efficient catalysts for catalytic processes of manufacture of a CO-free hydrogen-enriched gaseous mixture for fuel elements. The work was carried out in two stages: at the first stage, triple systems – copper-bearing catalysts based on cerium and zirconium oxide – were under study; at the second stage, binary applied copper-cerium catalysts based on oxides of cerium, manganese, and aluminum were studied.

1st stage: *Main result:* Formation of the active component (copper oxides) in triple copper-cerium-zirconium catalysts and binary catalysts – copper-cerium and copper-zirconium systems – has been studied. Particularities of formation of copper compounds on the surface of carriers that were revealed in the binary systems exist in the triple copper-cerium-zirconium catalysts, too. For instance, interaction of copper with the cerium oxide and monoclinic zirconium oxide has been shown with the XPS and EXAFS methods. The change of copper state has been traced from separate ions to the volume phase of CuO as its content in the catalysts was increasing from 2 to 20 % in weight.

2nd stage: *Main result:* The interest in the copper-cerium catalysts is caused by their application in the PROX process – selective oxidation of carbon monoxide for hydrogen refining after its production from any organic raw material. The phase composition and state of the active component in the catalysts containing 10%Cu/20%CeO_2 on the oxides of zirconium, titanium, manganese, and aluminum before and after the reaction have been studied by the XFA and EXAFS methods. A catalyst applied to the zirconium oxide is the most active in the reaction. The catalytic reactivity decreases significantly in the absence of one of the catalyst components. Cerium oxide plays a particular role in the catalysts – it performs the function of a reversible source of oxygen. In the absence of cerium oxide, CuO is reduced in all the catalysts: during the reaction, to the metallic copper phase (in case of Al_2O_3 and ZrO_2 carriers) and to cuprous oxide Cu_2O (in case of TiO_2 and MnO_2 carriers). The largest amount of Cu_2O is registered for the TiO_2 carrier. Thereby, cerium oxide stabilizes the active state of copper oxide CuO if the carrier does not change. If the phase composition of the carrier changes, e.g., the carrier is reduced (in case of MnO_2), the stabilizing role of CeO_2 is neutralized.

Study of the atomic structure of thin nanocomposite films of the germanium isoelectronic sequence

The work was carried out within the framework of RFBR grant # 06-03-32662 and Contract
02.513.11.3217 with the Federal Agency for Science and Innovations "Research and developments in the priority directions of the development of the Russian science-and-technology complex for 2007-2012".

Germanium and materials of its isoelectronic sequence (gallium arsenide and zinc selenide and sulfide) are materials traditionally applied in the manufacture of semiconductor devices. During the recent years, techniques (the epitaxial one, first of all) that allow obtaining various nanoobjects from the above materials have developed. The best example of such objects are quantum points of germanium on the surface of monocrystal silicon.

In this connection, growing interest is attracted by nanocomposites based on germanium and materials of its isoelectronic sequence in a dielectric matrix or a wide-gap semiconductor matrix. Due to the spatial separation of the elements, such structures hamper charge transfer between separate quantum points and protect nanostructures against external influences. Besides, the presence of matrix makes it possible to substantially decrease the efficiency of recombination of electron-hole pairs on defects of the semiconductor, which offers great opportunities for designing components of nanoelectronics.

At this stage, samples of thin Ge films sputtered on quartz and silicon substrates were studied at different temperatures of the substrate.

Results of the EXAFS examinations of Ge films are presented in Figure20. The presence of only one peak, which corresponds to the first coordination sphere, implies prevalence of the amorphous phase in the films. At the same time, the local atomic structure of the sample prepared via annealing at a temperature of 450°C is close to the crystal one, the contribution of such phase being as high as 80%.

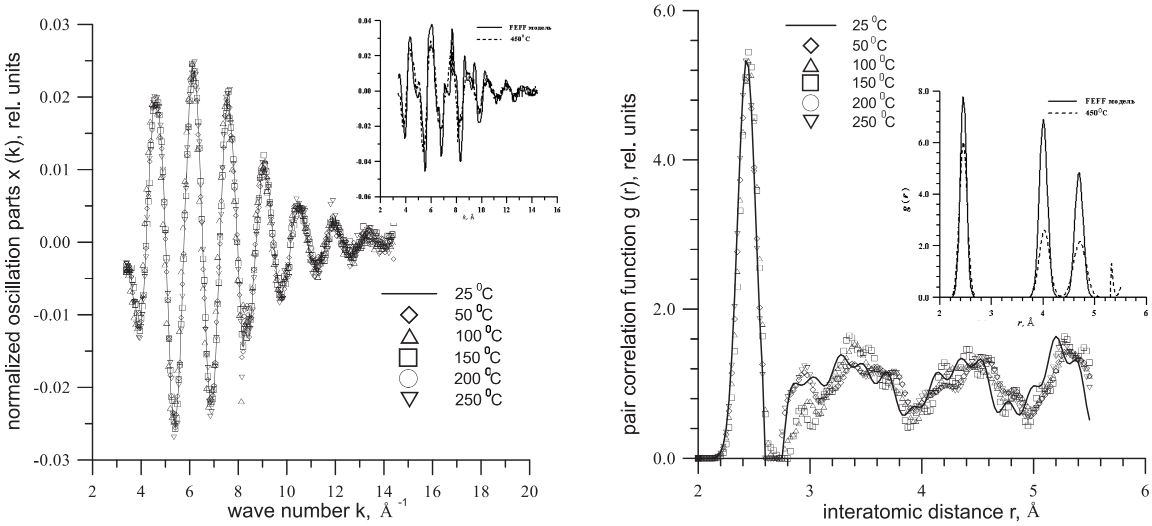


Figure 20: Normalized oscillation parts of the absorption spectra on the K-edge of Ge (on the left) and pair correlation functions of Ge (on the right).

Figure 21 presents AFM images of the surface of samples. The images were obtained at substrate temperatures of 25°C (sample 1), 50°C (sample 2), 100°C (sample 3), and 250°C (sample 6). Smooth amorphous surface with separate spherical inclusions is observed for all samples.

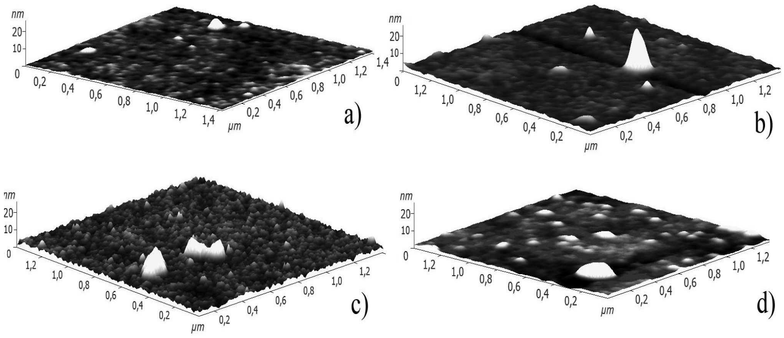


Figure 21: 3D AFM images of the Ge film surface that were obtained at condensation points of 25 (a), 50 (b), 100 (c), and 250 (d) °C.

Figure22 presents how thermal treatment of amorphous sample influences the morphology of its surface. Annealing at a temperature of 450°C substantially changes the grain size and density of grain distribution. The formed Ge films do not inherit the texture and defects of the SiO_2 substrate (Figure23). At a substrate temperature of 100°C , spherical inclusions 0.5-1.5 nm high and 60-70 nm in size are observed on the surface. In the case of sample 6, analysis of the phase contrast images gave 81% of the amorphous phase and 19% of the crystal phase, which agrees with the EXAFS data.

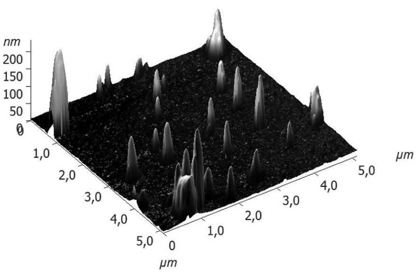


Figure 22: 3D AFM images of the Ge film surface that were obtained via annealing at a temperature of 450°C.

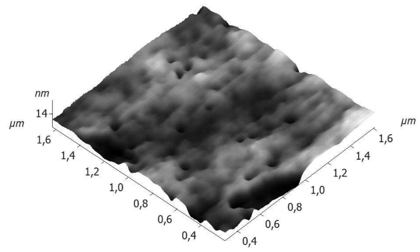


Figure 23: 3D AFM images of the SiO_2 substrate surface.

Main result: AFM and EXAFS examinations of the surface morphology and local atomic structure of the volume of Ge films have been carried out. It has been shown that the films have amorphous-and-nanocrystal composition, the percent of the amorphous and crystal phases depending on the condensation point. The dependence of the grain size for the sample obtained at a condensation point of 100°C does not correspond to the classical linear dependence, which requires additional explorations.

Exploration of the local atomic and electron structure of cobaltites

The work was carried out within the framework of RFBR grant 06-02-81038.

Complex oxides of the rare earth and transition metals are a subject of intense experimental and theoretical study due to their unique electrical, magnetic, optical, mechanical, and catalytic properties. One of oxide families of the $A_{n+1}B_nO_{3n+1}$, or else $[n(ABO_3)A'O]$, formula under intense study is known as the Ruddlesden-Popper homologous series.

In comparison with perofskite, it has an excess in the A$'$ cations, which create with oxygen regular layers by type of the NaCl structure, which anchylose with the perofskite blocks. The n value corresponds to the number of layers of joined- vertices octahedrons in each perofskite block, which is infinite in the *xy* directions.

Oxides in which the B positions are occupied by Co, Ti, Mn, Fe, V, Sn, and Al atoms are well known examples of such compounds. Special attention is paid to cobaltites, cuprates, and manganates because since the time of discovery of high-temperature superconductivity ($LaSr_2Cu_2O_{6-\delta}$), and colossal magnetic resistance ($Sr_{1,8}$,$La_{1,2}Mn_2O_7$) an insistent need to study the nature of these phenomena has arisen.

Main result: A new oxide phase $LaSr_2CoMnO_{7,01}$, relating to the Ruddlesden-Popper homologous series $A_{n+1}B_nO_{3n+1}$, (n=2), has been synthesized. Its structural characteristics (Figure 24) and magnetic properties have been investigated. The temperature dependence of the magnetic susceptibility obeys the Curie-Weiss law in the temperature interval of 250- 350 K. In the region of low temperatures, magnetic anomalies due to the competition between the antiferromagnetic and ferromagnetic ordering and transition to the cluster-glass state are observed. The charge state of the transition metals has been estimated from the magnetic measurements and XANES spectroscopy.

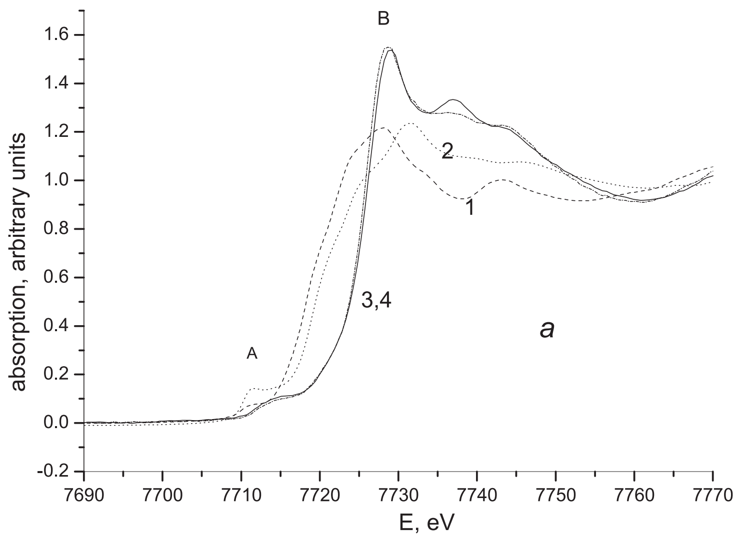


Figure 24: Experimental spectra of the X-ray absorption K-edge of Co. 1 - CoO, 2 - Co_3O_4, 3,4 - $LaSr_2CoMnO_7$ and $La_{0,75}Sr_{0,25}CoMnO_6$.

6.2 Works on SR beams from VEPP-4

6.2.1 Station "VUV Metrology and soft X-ray range"

The station is intended for absolute and relative calibrations of various equipment in the wide spectral range of photons of 10 eV to 10 keV.

Participant organizations:
- Budker Institute of Nuclear Physics SB RAS, Novosibirsk;
- Ioffe Physical-technical Institute, Saint-Petersburg.

Below are given themes of some works in 2008.

Comparative study of the radiation resistance of the AXUV and SPD detectors.

The work was carried out within the framework of the ISTC project #2920 "Absolute power meter based on the HTSC thermometer for SR".

The detectors were irradiated with a "pink" SR beam at station 10 of the VEPP- 3 storage ring. The hard component of the SR was cut off with total external reflection platinum mirrors, the soft component was cut off with a filter (1 μm of polypropylene + 0.1 μm of tin). 98% of the radiation power is in the region of 150-300 eV. The zone characteristics of both detectors are given in Figs. 25 and 26.

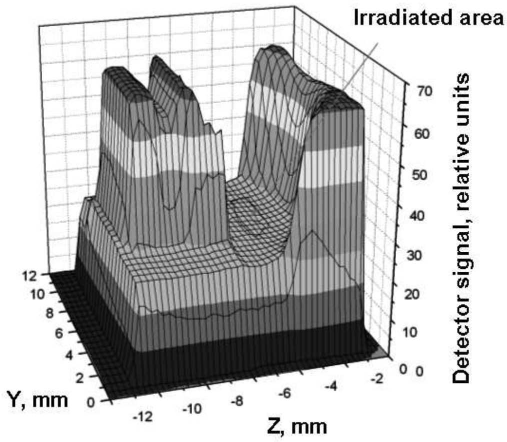


Figure 25: Zone characteristic of the AXUV detector after irradiation. The dose is $7{\cdot}10^6$deg. The clutter area is 1x3 mm^2. A substantial degradation of the detector is observed.

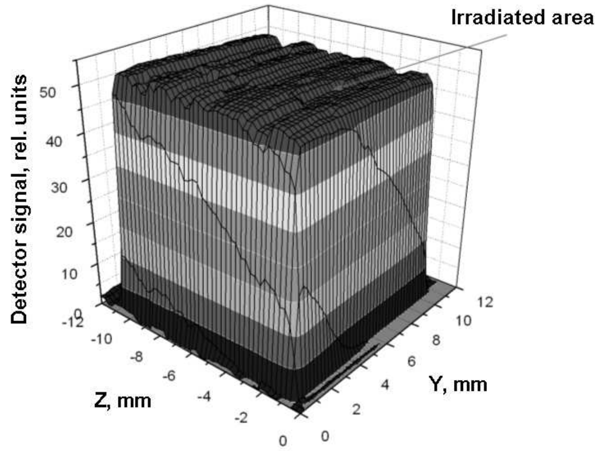


Figure 26: Zone characteristic of the SPD detector after irradiation. The dose is $8{\cdot}10^7$ deg. The clutter area is 1x3 mm^2. No degradation of the detector is observed.

A substantial superiority of the radiation resistance of the SPD detector as compared with the AXUV one has been stated.

Working through calibration techniques for semiconductor detectors

Since the station does not have its own calibrated detector, the AXUV-100 detector was used for referring the spectral sensitivity. Its spectral sensitivity is well known from literature. Within the framework of the measurements, the spectral responses of the AXUV-100 and SPD detectors were compared. The spectral regions of 80 - 165 eV and 200 - 650 eV have been covered. It has been shown that the sensitivity of the SPD detector over the measured range is 85-97% of that of the AXUV detector.

A technique of determination of the detector sensitivity homogeneity over the surface has been worked through. Measurements of the homogeneity were carried out at different photon energies and gave similar results. Measurements were carried out via scanning with the detector a relatively thin (usually of 0.5 mm^2) monochromatic beam. The AXUV-100 and SPD detectors have been tested. The measurements were carried out at a photon energy of 110.5 eV. Inhomogeneity of about 1.5-2% was observed for both detectors.

Within the framework of working through the calibration technique, measurements of boron surface density were carried out on the SPD detector (Figure27).

Using the same self-calibration method, it has been found out that on the surface of both detectors there are no carbonic layers able to influence the spectral characteristics of the detectors in the soft X-ray region.

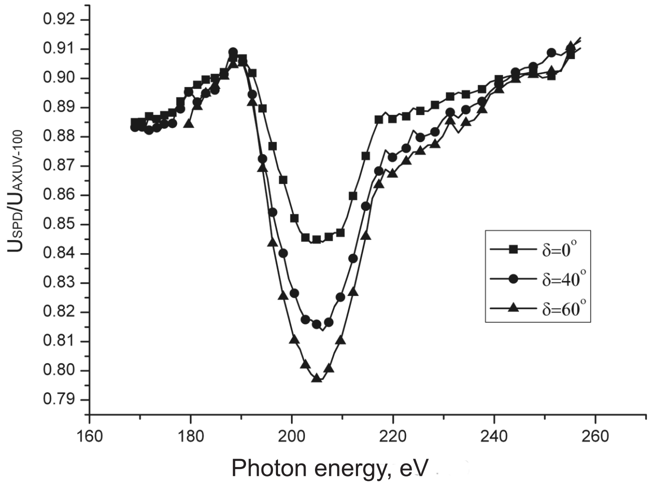


Figure 27: Relative spectral response of the SPD detector near the K-edge of boron as a function of the radiation incidence angle. (δ is the angle between the normal to the detector surface and incident beam). The AXUV-100 detector signal, having no particularities of the spectral characteristic near the K-edge of boron (160-260 eV), was used as the normalization spectrum. The surface density of boron on the detector (about 0.85 mkg/cm^2) was determined from the ratio of the dips of the spectral characteristic for different angles δ and boron absorption tables.

Exploration of the quality of multilayer X-ray mirrors with the help of a two-coordinate detector

In 2008, a detector based on a "back illuminated" CCD matrix sensitive in the VUV and soft X-ray region was purchased for the station.

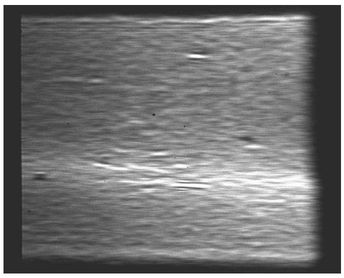


Figure 28: SR beam homogeneity after the two-mirror monochromator at an energy of 258 eV (Ni/C mirrors, a period of 60 A). The observed "flutter" arises because of the beam wave front distortion on the pock marks of the mirrors and thereby the quality of their manufacture can be estimated.

The detector has a resolution of 13 μm and size of 1024x1048 cells. A number of measurements of the structure of homogeneous SR beam after its reflection from the multilayer mirrors of the detector of the station have been executed (Figure 28).

6.2.2 System for stabilization of SR beam position on the VEPP-4M storage ring

The planned development of works on the SR beamlines of the VEPP-4M storage ring implies solution of the task of stabilization of SR beam position in these beamlines. For this purpose, dedicated ultrahigh-vacuum beamline #13 was designed and built in 2008. Two identical position-sensitive ionization chambers with a split collector were used as the electron beam position pickups. At known values of vertical linear displacement of the SR beam in both ionization chambers, a simple computation gives the value of the deviation of SR beam axis from the median of the storage ring as well as the value of the vertical displacement of the irradiation point. The obtained parameters can be used for correction of the electron beam orbit with the corresponding components of the magnetic structure. A photo of the beamline is given in Figure30. Its functional scheme is given in Figure 29.

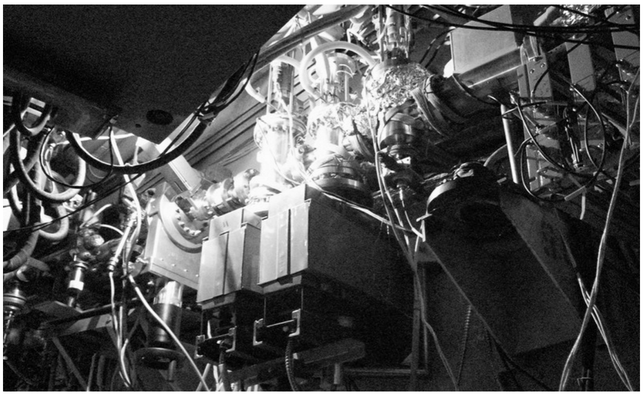


Figure 29: Photo of the entry part of beamline #13 of VEPP-4M.

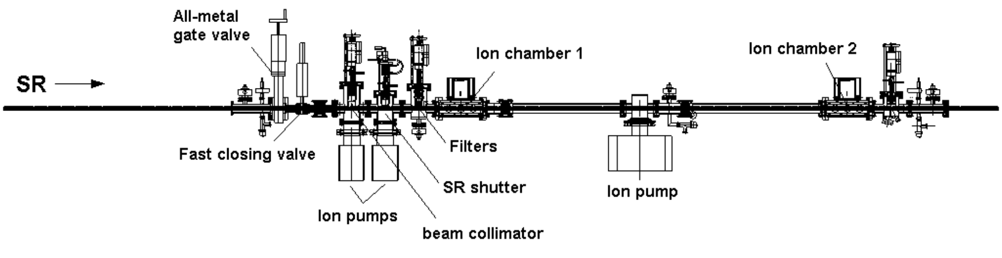


Figure 30: Scheme of beamline #13 of the VEPP-4M storage ring. The distance from the irradiation point to the first chamber is 8790 mm, to the second chamber 14306 mm.

An ultra-high vacuum sliding shutter is installed at the entrance to the beamline. A beryl foil 200 μm thick is welded into the plate of the shutter. Blocking the beamline with this shutter, one can cut the soft part off the spectrum (energy $<$ 2 keV). Experiments were done at a vacuum level of about $1{\cdot}10^{-8}$ Torr. The typical value of the electron beam current in the storage ring varied within the region of 3 to 1 mA. The beam energy in the storage ring varied from 1.85 GeV to 1.07 GeV at various regimes.

In the first experiments, it was found out that when the beryl foil was inserted on the beamline axis, the useful signal in the ionization chamber exceeded the noise level with a factor of 2÷2.5 or less, while the SR-induced signal from the ionization chamber without the beryl foil (the soft part of the spectrum is present) exceeded the noise level by more than two orders of magnitude.

Figure 31 presents an example of observation of the electron beam behavior in the storage ring as a function of time. Signal U_1 corresponds to the voltage across the lower plate of the front ionization sensor, signal U_2 to the voltage across the upper plate. The voltage difference between U_1 and U_2 reflects the value of vertical displacement of the ionization chamber axis from the SR beam axis.

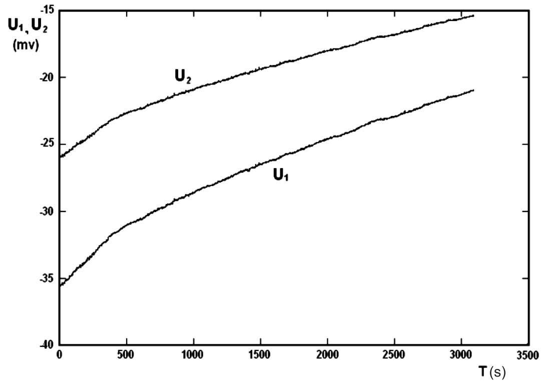


Figure 31: Voltage across the upper and lower plates of the front ionization chamber at a stationary electron beam in the storage ring. $E_{el.beam}$ ~ 1.85 GeV, current ~ 1.5 mA.

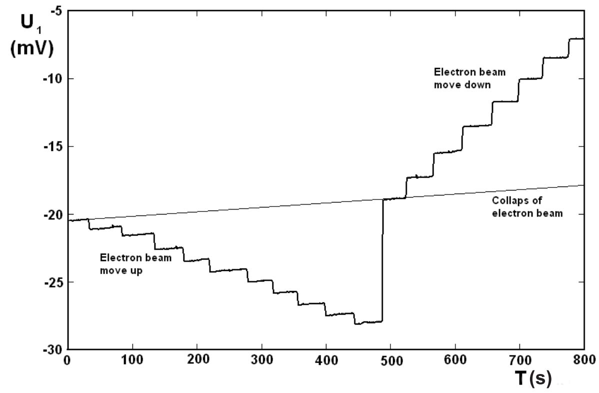


Figure 32: Voltage across the upper plate of the chamber in dependence on the vertical displacement of the electron beam in the storage ring relative to the axis of the chamber.

The impossibility of moving any of the ionization chambers across the SR beam complicated the determination of the calibration dependence of signals from the chambers on the vertical displacement of the SR beam. Figure32 presents the result of “inverse” calibration, when the ionization chamber is still and the SR beam is moving relative to it with a step of 100÷140 μm.

From the first results, one can conclude that ionization chambers with a split collector can be used in conditions that take place in real front ends of storage rings. Upgrading the electronics unit will enable work with even higher vacuum in future. Later on, the studies are planned to be transferred to beamline 10 of the VEPP-3 storage ring.

6.3 Work with terahertz radiation beams

6.3.1 The Novosibirsk terahertz free electron laser

The Novosibirsk terahertz free electron laser (NovoFEL) remains a terahertz radiation source of the highest power in the world. The maximum value of the average radiation power at a pulse repetition rate of 11.2 MHz is 400W. In 2008, users operated the laser at a standard repetition rate of 5.6 MHz (the pulse duration was 100ps; the relative pulse duration was 180 ns). The average power at the user stations depended on the radiation wavelength as well as on the tuning of the acceleration system. It was 50 to 150 W at standard regimes. The laser radiates a monochromatic, fully polarized radiation, which is tunable in the interval of 120 to 240 μm.

In 2008, staff members of Budker Institute of Nuclear Physics SB RAS, the Institute of Chemical Kinetics and Combustion SB RAS, Rzhanov Institute of Semiconductors SB RAS, Lavrientiev Institute of Hydrodynamics SB RAS, the Institute of Theoretical and Applied Mechanics SB RAS, the Engineering and Design Institute of Scientific Instrument-making, the Institute of the Optics of the Atmosphere SB RAS (Tomsk), and the Science-and-Engineering Center for Unique Instrument-Making RAS (Moscow) and teachers, students, and post-graduates of the Novosibirsk State University and Novosibirsk State Technical University worked on the laser. The free electron laser has become a basis for the Science-and-Education innovation center "Terahertz radiation and its application ", which unites the NSU and nine SB RAS institutes. An annual experimental elective course has been organized for students. More than nineteen students have done their term papers, degree works, and master's theses.

One of the main tasks for the year 2008 was to organize regular works at the six already-existing user stations. The second task was to assemble the main elements of the magnet-vacuum system for the second stage of the NovoFEL and commission the two-orbit energy recovery linac.

6.3.2 User stations on the THz radiation beams

Works were carried out within the framework of

1. RFBR grant #07-02-01459-a "Development and study of metal grid structures obtained by the LIGA technology methods and intended for the frequency and spatial selection of the high-power radiation of the terahertz free electron laser (FEL)";

2. SB RAS interdisciplinary project # 107 "Study of the interaction of the photon subsystem Pb1-xSnxTe<In> with terahertz radiation in conditions of ferroelectric instability and development of terahertz radiation detectors";

3. RAS Presidium program "Development of diffraction optical elements for the terahertz range";

4. RAS Presidium program "Development of matrix of microbolometers for terahertz radiation visualization";

5. RFBR grant 07-02-13547 "Development of the methods of construction of total internal reflection spectrometers for biomedical applications, the terahertz free electron laser used as the radiation source".

Station "Metrology"

The station is intended for diagnostics, control, and optimization of radiation from the free electron lasers as well as for conducting physical experiments with this radiation.

Below are given themes of some works in 2008.

Exploration of the optical parameters of CVD diamonds in the terahertz and IR ranges

The task was to measure the optical parameters of CVD diamonds. These studies are important due to four factors: the unique potential properties of windows of CVD diamonds, the strong dependence of these properties on the technology of diamond growing, the absence of necessary information on specific plates, and insufficient information on the properties of CVD diamonds in the terahertz range. In particular, two samples of windows were under study, the possibility of their application in the high-power beams of the Novosibirsk FEL of the second and third stages kept in mind. The plates were investigated with a complex diagnostic system including the Fourier spectroscopy, calorimetry on the high-power beams of the terhertz FEL, and a system of 2D visualization based on thermofluorescent screens. One of the plates was made by the Element Six (De Beers) company and the other by the Institute of Applied Physics (Nizhni Novgorod).

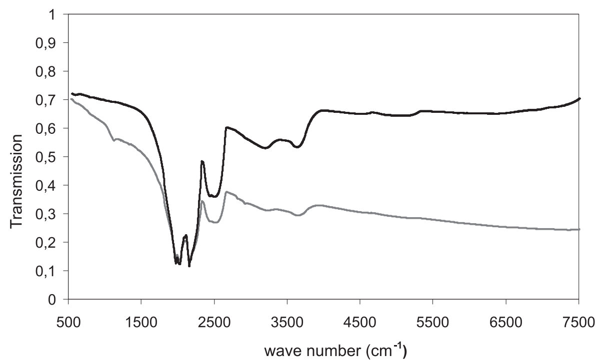


Figure 33: Transmission of the plates (exit windows) of CVD diamond: the black line is for the plate made by the Element Six company, the grey line is for the plate made by the Institute of

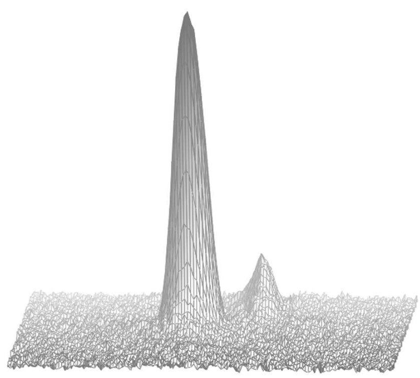


Figure 34: Image of the initial beam on the thermofluorescent screen after passing through the plate made by the Institute of Applied Physics. Besides the main beam, a diffraction beam and scattered radiation can be seen.

The influence of the so-called nondiamond inclusions (black points) in the first plate on the absorption in the material was under a special study. The Fourier spectroscopy method was used to measure the transmission of both plates in the IR range. Using the thermofluorescent screen, we studied changes in the radiation intensity distribution after the radiation passing though the plates.

Main results:

1) No influence of the nondiamond (carbon) inclusions on the absorption in the terahertz range was revealed.

2) It was found out that the window made by the Institute of Applied Physics had poor transmission in the IR range, which was caused by the scattering because of the strongly heterogeneous structure of the polycrystal.

3) An additional diffraction beam tilted relative to the main one at an angle of 2 degrees was found, which was evidence of some regular heterogeneity in this plate.

4) Terahertz Gauss beams were passed practically without distortions through the plate made by the Element Six company.

Study of the FEL operation regimes and measurement of the FEL radiation parameters

The goal of the work was to study various regimes of FEL operation, which influence strongly the radiation parameters in the spectrum-time domain. Parameters of the optical cavity were measured. These parameters together with the electron beam parameters define the frequency range of generation and possible retuning of the FEL.

Three FEL operation regimes were revealed after the complex spectrum-time measurements at the station “Metrology” including the unique measurements of the FEL pulse structure. Those are the single-mode regime, with a narrow generation line and high time coherence; the multimode regime, with a set of narrow lines and high time coherence; and the quasi-single-mode regime with a very wide generation line and low time coherence. Processing of the experimental data showed that the two last, “non-classical” regimes were caused by the modulation instability. It was shown that this instability could be suppressed via tuning the electron bunch repetition frequency off the resonance frequency, which is defined by the optical cavity length. A smooth transition between the above regimes at smooth tuning off the electron bunch repetition frequency was demonstrated.

The Novosibirsk FEL differs from other FEL, in particular, in the large light pulse duration, which, theoretically, allows obtaining a narrow generation line. However, a long pulse is a potential source of various instabilities, including modulation instability with a period equal to the length of light pulse slip relative to the electron one. That is why the so-called Fourier limit in the generation line width can be achieved only in a regime stabilized with respect to this instability. Such stabilization is attained by means of detuning the repetition frequencies of the electron ad light pulses.

In the strong instability regime, the multi-mode generation is observed. Strong interaction between the modes makes it look like the quasi-single-mode one with a spectrum width one order of magnitude larger than that in the stable regime. Such regime may be useful and has already been applied for spectroscopy tasks. The FEL generation range is defined by the growth of diffraction losses in the optical cavity. Correct computation and minimization of these losses, along with the other factors determining the gain and stability of the optical cavity, allow maximum expansion of the frequency range of the FEL retuning, which is very important for user experiments.

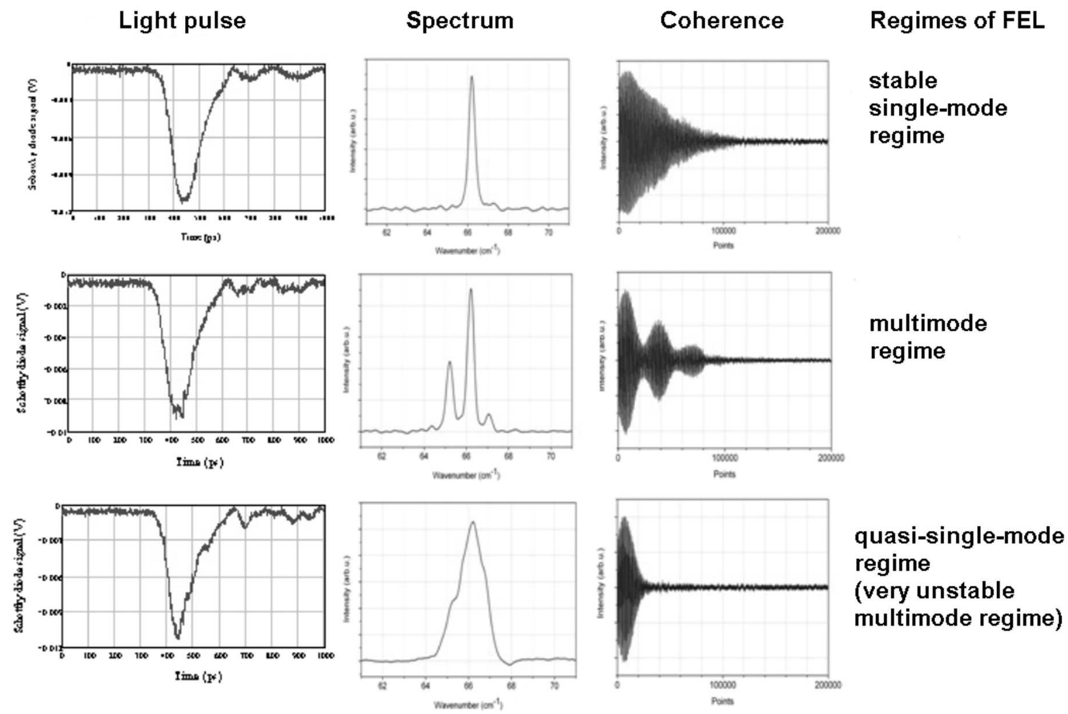


Figure 35: Light pulses, radiation spectra, and autocorrelation functions (of coherence) in the three typical regimes of FEL operation.

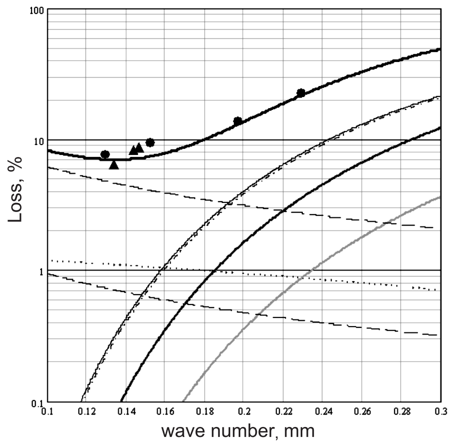


Figure 36: Computed components of losses in the optical cavity and their sums (the bold solid line) and experimental data (dots) for various wavelengths.

<u>Main results:</u>

1) Three typical regimes of the FEL operation – stable single-mode regime, multimode regime, and quasi-single-mode regime (very unstable multimode regime)– were revealed experimentally. They depended on the value of stabilizing tuning-off of the frequencies of electron and light pulses.

2) These regimes define the spectral-time parameters of the FEL.

3) Efficient generation of high harmonics is observed only in the stable regime.

4) FEL losses and gain were measured in the maximally wide range. Losses in the optical cavity were in good agreement with the theoretical computation on the basis of which the cavity was designed.

6.3.3 Station "Spectroscopy and introscopy"

The station is intended for exploration of inorganic, organic, and biological materials and objects by methods of spectroscopy and spectral-selective introscopy as well as for development of means and methods of visualization in the terahertz range.

Below are given themes of some works in 2008.

Development of spectroscopy and spectral-selective introscopy methods for materials and objects in the terahertz range of the electromagnetic spectrum and use of these methods for experimental exploration of inorganic media and biological substances

The tunable pulse-periodic free electron laser with a power of radiation at the user station of 100 - 200 W was used as a source of monochromatic, coherent, plane-polarized radiation. The shadow measurement system has been upgraded as well as the system for holographic measurements in the terahertz range, radiation registered by a thermosensitive luminescent screen with the PI Max2 chamber with a microchannel optical amplifier. An absolute meter of terahertz, IR, and UV radiation power density has been created on the basis of the Fizeua interferometer. Spectral characteristics of bone tissues of laboratory rats of two genetic lines at different ages were examined in the terahertz range.

A 320x240 bolometer matrix has been constructed for terahertz radiation visualization. Statistical analysis of the speckle structure of terahertz images has been done. It has been shown that this phenomenon, which was observed in the terahertz range for the first time, can be a basis for expansion of the sphere of speckle metrology application. A real-time speckle photography in the terahertz range has been demonstrated.

A prototype of the terahertz image-forming, frustrated total internal reflection spectrometer has been constructed. Experiments on registration of dynamical objects and substances were carried out. The terahertz tomographic facility has been constructed and pilot examinations of both opaque and phase objects have been performed. Projections of bone fragments were registered. A technique for reconstruction of tomograms has been developed. Deformations of film materials were studied on the Toepler facility, which combines the possibilities of shadowgraphy of the visible and IR ranges. The Talbot effect was investigated in the terahertz and visible ranges. It has been demonstrated that this effect can be used both for Talbot interferometry of phase transformations in objects under study and for measurement of distances and radiation wavelength. These devices for terahertz introscopy and spectroscopy allow conduction of a wide range of basic and applied investigations.

6.3.4 The second stage of the Novosibirsk FEL

The work was carried out within the framework of SB RAS Integration project "Development and construction of the second-stage FEL".

The full-scale project of the Novosibirsk FEL includes two energy recovery linacs (ERL) with the common injector and common acceleration structure as well as three free electron lasers. One of them is installed on the first ERL (the first stage FEL), and the two other lasers on the second and fourth tracks of the second, 4-orbit, ERL (Figure37). The first linac has one track, located in a vertical plane. Undulators of the first-stage FEL are placed on this track. The first FEL was commissioned in 2003. Regular experiments with terahertz radiation in the wavelength of 120 to 240 μm have been conducted on it since 2004.

Work on the construction and commissioning of the second stage of the Novosibirsk FEL is underway now. The second-stage accelerator uses the same acceleration structure as the first-stage linac but it is located in a horizontal plane and thus its assembly practically has no influence on the operation of the first accelerator (Figure37). Operation is switched from one accelerator to the other via turning on the circular bending magnets installed on the common track.

The second-stage accelerator will have four tracks, which will allow increasing the beam energy and attaining a shorter radiation wavelength in the FEL (Table 6.1).

The accelerator can work in two regimes (Figure 37). In the first one, the electron beam, after injection, passes the accelerating structure two times and gets to the second track, where its energy is 20 MeV. Then, assisted by the bending magnets, it is directed through the bypass, on which the second FEL undulator is installed. In so doing, the time of beam flight over the second track is increased by half period of the accelerating RF field. As a result, after the bypass, it gets in the acceleration structure in the deceleration phase and, after a twice-repeated deceleration, it gets in the dump. If magnets of the bypass are switched off, the beam keeps gaining energy and finally gets on the fourth track, where undulators of the third FEL are located. The final energy of the beam on the fourth track is 40 MeV.

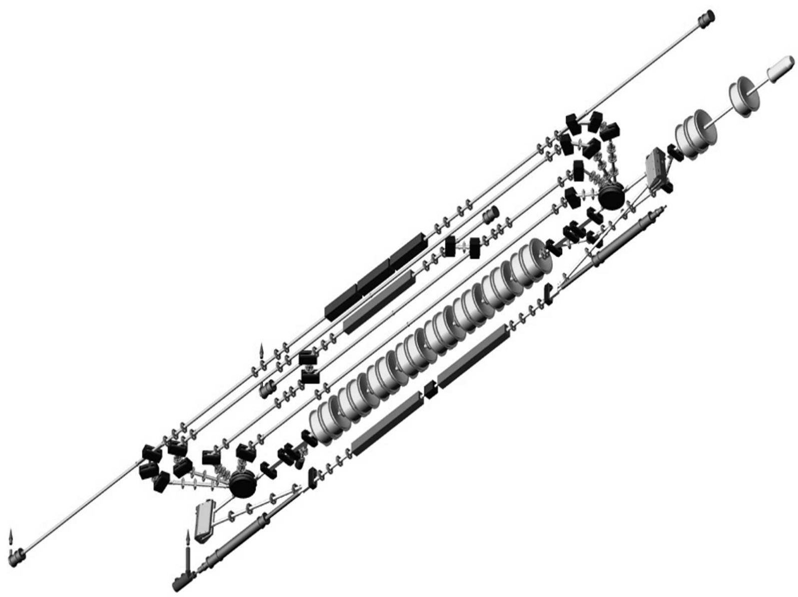


Figure 37: Full-scale scheme of the Novosibirsk FEL.

For the FEL of the second track, an electromagnetic undulator with a period of 12 cm and length of about 4 m is used. Its design is practically identical to that of the first-stage undulator. The optical cavity of the second FEL consists of two copper mirrors with holes for radiation extraction in the center. The distance between the mirrors is about 20 m, which corresponds to a light bunch repetition rate of 7.5 MHz. The range of retuning of the second FEL wavelength will be 40 to 120 μm.

Table 6.1: Main parameters of the ERL and two second-stage FEL (two-orbit/four- orbit). Parameters expected after upgrade of the injector are given in brackets.

Beam energy, MeV	20/40
Number of tracks of the accelerator	2/4
Bunch repetition frequency, MHz	22 (90)
Average beam current, mA	30 (100)
FEL radiation wavelength, μm	40-120/5-40
Maximum radiation power, kW	2/10

Two tracks of the accelerator and bypass have been assembled and commissioned. The rather low level of losses allowed attaining an electron bunch repetition rate of 7.5 MHz, which is required for FEL operation, and a corresponding average current of 9 mA.

6.3.5 Results of the year 2008 and plans for the year 2009

Main results of the year 2008:

1. Regular work of users at the first-stage THz FEL was provided.
2. The vacuum chamber of the first and second tracks of the second stage (together with the bypass) was mounted. Many elements of the magnetic system of the second-stage ERL were assembled and mounted.
3. The optical cavity of the second-stage FEL was mounted and adjusted.
4. The first two tracks of the ERL were commissioned. The achieved parameters are sufficient for FEL operation on the second track.

Plans for the year 2009:

1. Commissioning of the second-stage FEL (on the second rack of the ERL).
2. Manufacture and installation of the beamline for extraction of the second- stage FEL radiation.
3. Mounting of the elements of the magnetic system and vacuum chamber of the third and fourth tracks of the ERL.
4. Designing of the optical cavity for the FEL on the fourth track.
5. Upgrade of the extraction beamline and existing user stations; continuation of the work on construction of new ones.
6. Continuation of the designing of the test bench of the RF injector.
7. Continuation of the work for users.

6.4 Development and manufacture of dedicated SR sources

6.4.1 Superconducting wigglers

Contract works on the development and manufacture of various superconducting cryogen-magnetic systems for SR generation continued in the year 2008.

1. In 2008, a "short" prototype of the magnetic system of the multipole wiggler (Figure 38) for the ALBA-CELLS storage ring (Spain) under construction was designed and successfully tried. The manufacture of the full-scale 119-pole wiggler with a period of 30 mm, magnetic field of 2.2 T and pole gap of 12.6 mm is underway now. Installation and commissioning of the wiggler directly on the storage ring is planned for June 2009.

Figure 38: Assembly of the "short" prototype of the multipole wiggler with a period of 30 mm and magnetic field of 2.2 T for the ALBA-CELLS storage ring (Spain).

2. The magnetic system of the 35-pole wiggler with a field of 3.6 T and period of 60 mm (Figure 39) for the LNLS storage ring (Campinas, Brazil) was designed and manufactured.

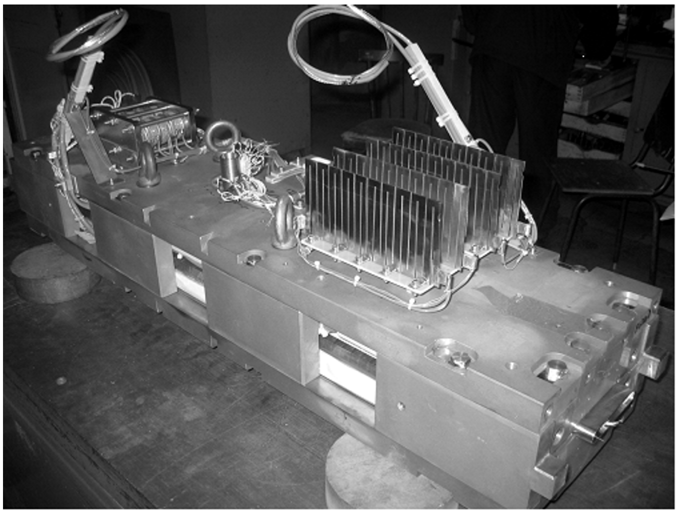


Figure 39: Magnetic system of the multipole wiggler with a field of 3.6 T and period of 60 mm for the LNLS storage ring (Campinas, Brazil).

In July 2008, the magnet was successfully tested in an immersion cryostat, and the design field level was achieved. Starting and test of the wiggler with its cryostat is planned for January 2009.

3. In December 2008, the 49-pole wiggler with a period of 48 mm, magnetic field of 4.3 T and pole gap of 14 mm for the DLS (Diamond Light Source, England) storage ring was assembled and passed a full round of tests and measurements. It is already the second superconductive wiggler made by BINP for DLS. In this wiggler (Figure 40), zero consumption of liquid helium and required parameters of magnetic field quality were achieved. In February 2009, assembly of the wiggler and measurements of its parameters will start in the area of the DLS storage ring. Installation and commissioning of the wiggler immediately on the storage ring are planned for March 2009.

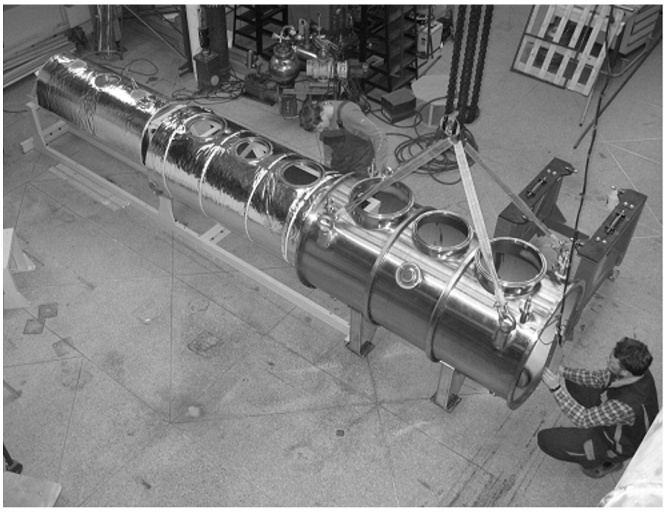


Figure 40: Process of assembly of the 49-pole wiggler with a field of 4.3 T for the DLS storage ring in its cryostat.

6.4.2 Damping wigglers on permanent NdFeB magnets for the SR source Petra III (Hamburg)

The contract work on the manufacture of 21 damping wigglers on permanent magnets for the SR source Petra III (DESY, Germany) was completed in 2008.

The wigglers are installed in two 80-meter straight sections, 10 items per one (one wiggler is spare), and intended for lowering the electron beam emittance in the ring to a record value of 10^{-9} m·rad.

The wigglers have the following parameters:

Table 6.2: Parameters of the wiggler for the SR source Petra III .

Period	20 cm
Field amplitude	15.6 kGs
Vertical gap	24 mm
Length	4 m

At first, a full-scale prototype of the wiggler was made. Then, after approval of the wiggler design by DESY experts, all 20 wigglers were manufactured and tuned in a year and a half. Figure 41 shows installation of the first wigglers into the straight sections. The wigglers have been installed on the PETRA III storage ring by now. Commissioning of the accelerator will start at the end of February 2009.

Besides the wigglers, BINP has also manufactured for PETRA III absorbers for SR from the wigglers of a total power of 800 kW and the vacuum system for the straight sections.

To meet the very strict requirements to the value of nonlinearity in the operating aperture of wiggler (18x40 mm^2), we had to place special multipole correctors on the wiggler ends. The correctors are to compensate nonlinearity of the vertical and horizontal fields.

Figure 41: Installation of the wigglers in the straight sections of PETRA III.

After compensation of nonlinearities in the operating aperture of wiggler, the value of the first field integral did not exceed 25 Gs x cm in most wigglers, and the second field integral was − 25000 Gs x cm^2 or less. Figure 42 presents results of the tuning of the 20 wigglers.

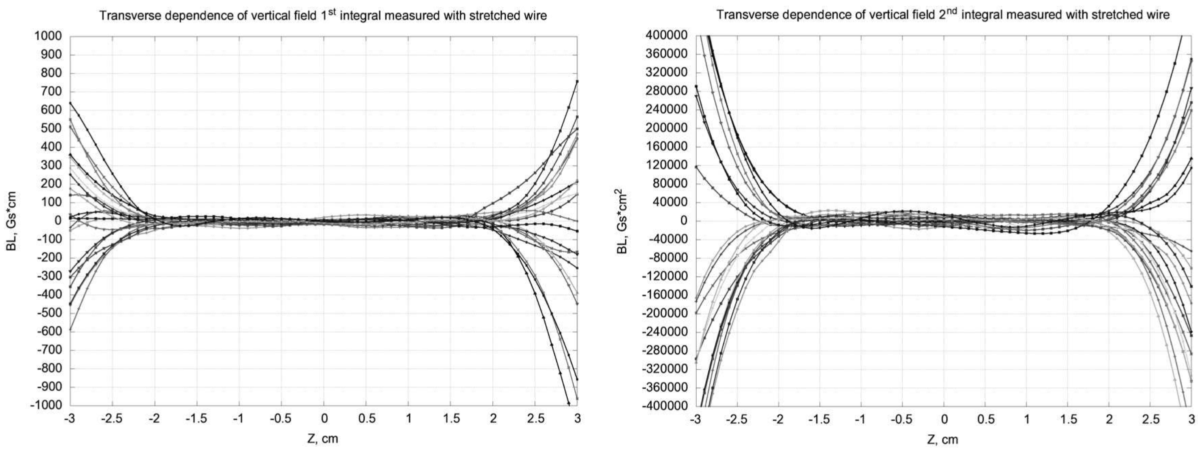


Figure 42: Results of the tuning of the 20 wigglers.

6.4.3 Radiation-resistant dipole magnet for the ion accelerator under construction at GSI (Germany)

An international research acceleration center is under construction in Germany. Russia assists actively to this center. BINP SB RAS has developed and is now constructing a dipole magnet for Super-FRS. This magnet is intended for extraction of secondary ion beams, secondary ions arising after bombardment of a target with accelerated ions or protons. The secondary ions have a large spread of angles and coordinates because the dipole magnet is placed downstream the target.

The dipole magnet has a pole gap of 0.18 m, region of homogeneous ($\pm$ 3$\cdot$10^{-4}) magnetic field of $\pm$ 0.195 m horizontally, efficient magnetic length of 2.4 m, and bending radius of 12.5 m. The weight of the magnet is about 100 tons. The dipole magnet is to retune a magnetic field in the range of 0.15 T to 1.6 T in 120 seconds. The dipole magnet will be placed in a zone of strong induced radiation and thus has to be free of any structural components containing organic compounds.

Figure 43: Iron yoke of the radiation-resistant H-type dipole magnet.

Figure 44: Part of the H-type dipole magnet.

The contract work on the development and construction of the first (of three) radiation-resistant magnet for the acceleration center GSI (Germany) started in 2007 and will be completed in June 2009. Another two similar magnets are planned to be made in 2010.

In 2008, designing of the dipole magnet was finished, its iron yoke was manufactured and assembled, manufacture of accessories for production of radiation-resistant coils is close to completion.

6.4.4 Engineering storage complex (ESC)

Works on the injection part of the complex continued in 2008. The elements of the magnetic and vacuum systems were subjected to geodetic alignment from bottom up; additional probes were installed on the electron-optical beamline EOB-2 to improve the aiming of electron beam at extraction from the minor ring (MR) to EOB-2. New beam diagnostic electronics was connected both in the minor ring and in EOB-2.

In order to improve control over all elements of the injection complex subject to the application of the CAN equipment, the configuration of the control system was changed and a new version of the software was written and put into operation.

A lasting training of the linear accelerator (LA) was carried out. It allowed increasing the electron energy at the LA exit up to 65 MeV and magnifying the one-time capture of electrons in the MR. After optimization of the parameters of the supply and control systems and debugging of the software, an operation regime allowing accumulation of up to 70 mA electrons in the MR was achieved. Further increase in the accumulated current is associated with a long-duration degassing of the vacuum chamber walls with an SR beam. Regimes of elevation of the energy of electrons accumulated in the MR up to 450 MeV were worked through as well as regimes of bypassing electrons from the MR to EOB-2. The injection complex is ready to start working for the large storage ring.

Simultaneously with the works on the injection complex, activity on the mounting of magnetic elements on the large ring (LR) and modernization of the high-current power supplies continued.

In 2008, BINP manufactured an RF generator on new oscillating tubes and 180 MHz resonators. Works on the manufacture of the new vacuum chambers of the LR and power supplies for the ion pumps are framing well.

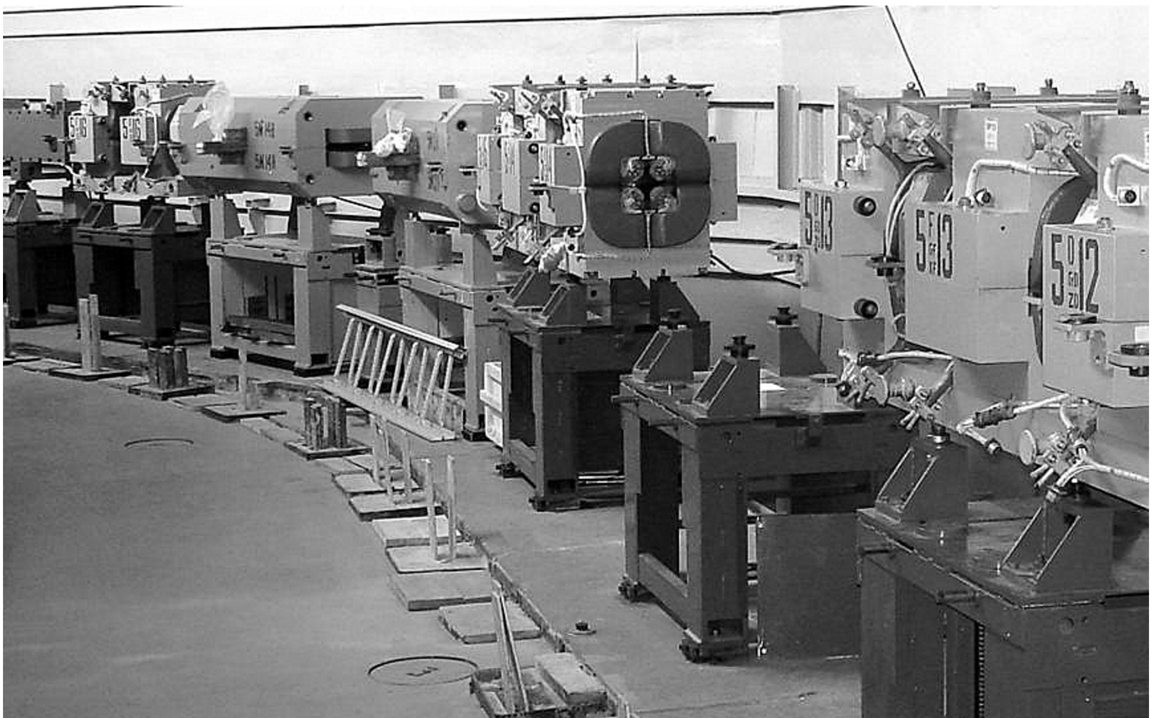


Figure 45: Elements of the magnetic system of the Large Ring.

6.4.5 Development of the new SR source for the Siberian SR Center

Works on the designing of the new SR source continued in 2008. Main attention was paid to the development of the conceptual design of construction of the group of buildings. Initially, the entire structure was planned to be placed in one specialized building comprising the experimental hall, protected hall for the storage ring, injection complex hall, and user premises: laboratories, works, and offices. The list of required premises and floor plans for this concept were made. It was also planned to mount a radial hoisting crane able to service all the experimental halls (the hall of experimental stations, the main ring hall, and the hall of the injection complex). However, after financial analysis of the construction, it was decided to change the concept in order to substantially reduce its cost.

The new construction concept implies placing the Siberian SR Center in a group of standardized buildings.

A rough scheme of the group is shown in Figure46.

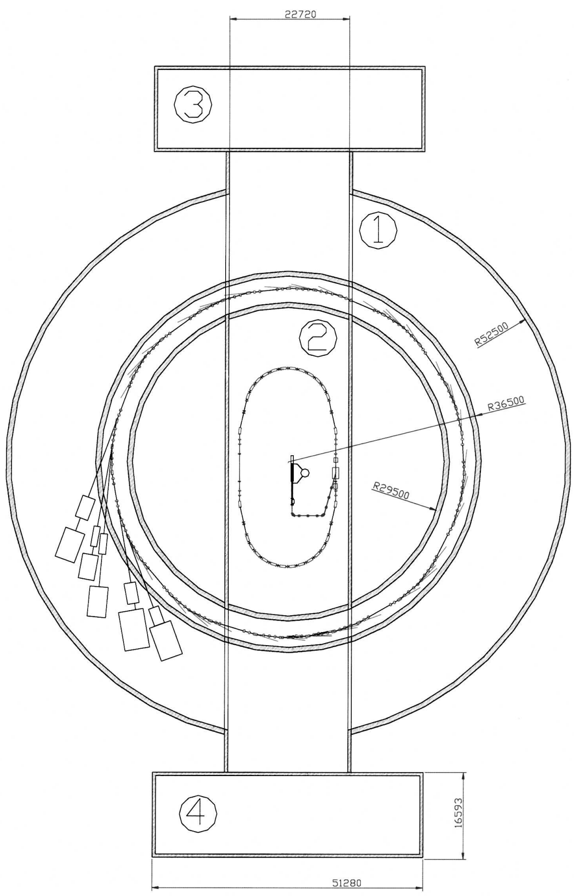


Figure 46: Model view:
1) the circular building of the SR-source storage ring with the experimental hall;
2) the central building for the injection complex with the beam crane;
3) the building for the works and manufacturing equipment;
4) the building for the laboratories and offices.

The group of buildings for the SR Center includes 4 main buildings, description and destination of which are given below.

Circular building

The building is to comprise the SR-source storage ring and user stations. The building is single-storey and 5 meters high. The inner diameter of the circle is 59 m, the outer one is about 110 m. The inner edge of the circle is occupied by the tunnel for the storage ring. The external cross-section of the tunnel is 6.5x4.5 m; its walls and ceiling are made of monolithic concrete. The external side wall is 1 m thick, the interior and top walls are 0.5 m thick. At the place where the tunnel intersects the central building, the tipping site is placed and thus the upper part of the tunnel should be dismountable.

Central building

The central building passes through the center of the circular building and intersects the circle at two places. It is to comprise the injection complex, beamlines, and loading sites. The building is equipped with a cat-crane with a lifting capacity not less than 5 tons. The height of the building is defined by the possibility of loading of elements up to 3 m high and 5 t heavy in the storage ring tunnel.

Engineering building

This building is to comprise processing equipment, mechanical works, experimental equipment and working rooms of SR users. The building is connected with the central one. Wagons enter the central building through a sluice 5 m high, located on the first floor.

Laboratory-and-office building

This building is intended for working rooms, laboratory premises, "clean" rooms, administration premises, etc. A passage is to connect the building with the central building or circular one. Sizes of the building are given for reference and may be changed. In the new variant of arrangement of the complex, there is no common crane for mounting the magnetic system of the storage ring and experimental stations. It is planned to use mobile hoist units for these works. Besides, the new variant allows doing without the expensive dome-shaped roof of the initial variant.

Arrangement of the complex

In this project the complex is placed in the area of BINP SB RAS, near the intersection of the street Ionosphernaya and Ac. Budker street (former Physicoff street). Position of the complex in the BINP area is shown in Figure 47.

Designing of the complex was started in accordance with the stated concept. Compilation of the draft design is to be completed in the first quarter of 2009. Cost of the construction will be defined and the design-and-estimation documentation will be prepared basing on this draft design. The conceptual design of the Center is to be ready by the end of the year 2009.

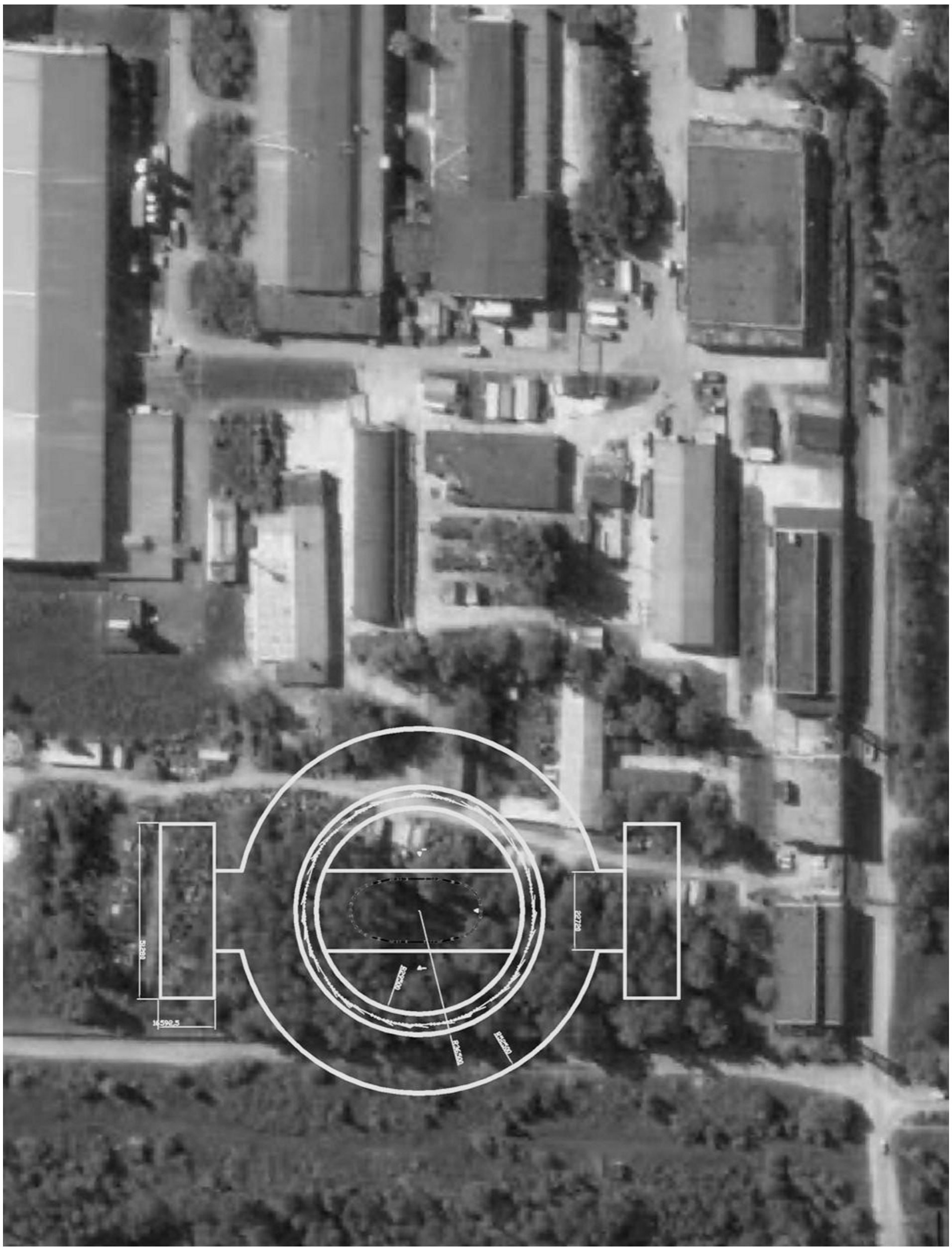


Figure 47: Approximate arrangement of the group of buildings for the new SR source.

6.5 Conferences, meetings and workshops

6.5.1 XVII International Conference on synchrotron radiation application "SR-2008"

XVII International Conference on synchrotron radiation application "SR-2008" was held at BINP SB RAS from 16 to 20 June 2008. Such conferences have been conducted biyearly since 1975. The conference was financially supported by the RFBR and the Federal Agency for Science and Innovation. Forty five of the one hundred and forty seven official participants of the Conference arrived from various Russian cities (Dubna, Zelenograd, Izhevsk, Irkutsk, Krasnoyarsk, Moscow, Nizhni Novgorod, Puschino, Rostov-on-Don, Saint-Petersburg, Saratov, Sarov, Tomsk, and Chernogoovka). Fifty five participants of the Conference represented Novosibirsk institutes, besides about forty BINP members. Seven participants represented institutions of the USA (SuperPower Inc), Germany (Institute of Microstructure Technology and BESSY- II) and France (Laboratoire Charles Fabry Institut d'Optique, Palaiseau, ESRF). 58 talks and 111 poster reports were presented during the four days of the Conference.

Traditionally, the Conference subjects covered all issues associated with the generation and application of synchrotron and terahertz radiation, which can be seen from the list of the Conference sections: "Statuses and scientific programs of Russian and foreign SR and FEL centers", "SR spectroscopy", "Equipment for SR", "SR diffraction and scattering", "X-ray fluorescent analysis on SR", "Technologies with SR application", "FEL and terahertz radiation sources" and "Terahertz radiation application". Reports associated with the prospects of the development of the Russian SR community as a whole and Siberian Center based on the future specialized SR source Siberia HB, in particular, also aroused quick interest.

Within the framework of the Conference, exhibitions and workshops of manufacturers and suppliers of scientific equipment were held, including SuperPower Inc. (USA), Intech (Russia), Scientific Equipment (Russia), and Anest Ivata (Japan). As a result, the conference participants could learn more about the equipment and form contacts with those companies. In accordance with a tradition lasting since 1986, proceedings of the Conference will be published as a separate volume in the journal "Nuclear Instruments and Methods in Physics Research, Section A NIMA)". Participants of the Conference "SR-2008" think the conference was successful and very fruitful.

6.5.2 Specialists training school "Synchrotron radiation in contemporary technologies"

From 6 to 12 October 2008, Siberian Synchrotron and Terahertz Radiation Center with participation of Boreskov Institute of Catalysis SB RAS, BINP SB RAS, and Novosibirsk State University held the Specialists training school "Synchrotron radiation in contemporary technologies" for young scientists, teachers, students, and post graduates. The school on SR was aimed at training of experts in the application of SR methods in the tasks of determination of the structure and element composition of complex, first of all nanosize, objects that cannot be studied with traditional methods.

The Program Committee, chaired by Siberian Synchrotron and Terahertz Radiation Center (SSTRC) director academician G.N. Kulipanov, included leading experts in the field of SR application. The Organization Committee consisted mainly of the SSTRC members. The program of the school included 32 teaching periods of lectures and 40 teaching periods of practical training. Lectures were delivered by leading members of the SSTRC, Southern Federal University, and Institute of Molecular Physics (Puschino). Materials presented by the lecturers became a basis for a published collection of detailed theses of the lectures. The collection was distributed among the school participants.

37 people that had passed advance registration and 5 listeners, who had decided to listen to part of the lectures without the practical training, participated in the school. The 37 school participants included

– 3 researchers with an academic degree,
– 23 junior researchers without academic degree and post-graduates, and
– 11 students.

Figure 48: Participants of the School: lecturers and audience.

Participants of the school represented 11 cities and 19 institutions of Russia. They were suggested to file applications for examination of their own samples by the methods of EXAFS, diffractometry, and X-ray spectroscopy. A plan for advanced training under the program “Synchrotron radiation in modern technology” based on the school program was developed with participation of the Novosibirsk State University. After the school, 37 participants of the school were presented certificates of advanced training under the program “Synchrotron radiation in modern technology”.

After conduction of the school, three institutions made a request on carrying out long-term joint works. Those were the Institute of Metallurgy, the Urals Branch of RAS, Lukin State Research Institute of Physical Problems, and the Institute of Chemistry and Chemical Technology SB BAS. It was decided to conduct next school with more specialized subjects, devoted to the application of diffraction methods on SR.

6.5.3 The 7th conference of the students and post-graduates of the SSTRC

On 7 May 2008, the 7th conference of the students and post-graduates of the Siberian Synchrotron and Terahertz Radiation Center (SSTRC) was held. 13 reports were presented at the conference, including 10 reports by students of the NSU and NSTU and 3 reports by post-graduates from 3 institutes of SB RAS: BINP, ISSCM, and IIC. The commission noted the high level of practically all submitted works and awarded one first, two second, and three third places with corresponding diplomas and gratuities. The two youngest participants of the conference - 3rd year students of the physical & engineering department of the NSTU - were awarded with honorary diplomas.

6.5.4 Participation of the SSTRC members in other scientific undertakings

Scientific session "BINP - 2008", 25-26 January 2008, Budker INP SB RAS, Novosibirsk.

International seminar dedicated to the memory of Boris V. Chirikov, 23 May 2008, Novosibirsk, Russia

11th international symposium "Order, disorder, and properties of oxides ODPO-2008", Rostov-on-Don - the settlement of Loo, September 2008.

11th international symposium"Phase transformations in metals and alloys, OMA-2008", Rostov-on-Don - the settlement of Loo, September 2008r.

10th scientific and technical conference "Medical technologies on guard of health", 28 September - 5 October 2008, Monastir, Tunis.

IX workshop "Mineralogy of technogenesis", 26-29 June 2008, Miass.

The first international interdisciplinary symposium "Physics of low dimensional systems and surfaces" Low Dimensional Systems (LDS-2008). 5-9 September 2008, Rostov-on-Don - the settlement of Loo.

VI All-Russia conference on X-ray spectral analysis. 5-10 October 2008, Krasnodar.

Meeting "X-ray optics - 2008",Chernogolovka, 6-9 October 2008.

20th International scientific and technical conference on photoelectronics and night vision devices 27-30 May 2008, Moscow.

Meeting "Actual problems of semiconductor photoelectronics" Photonics-2008: Novosibirsk, 19-23 August 2008, Novosibirsk.

International conference "X Kharitonov thematic scientific readings", 11 - 14 March 2008, Sarov, RFNC-VNIIEF. - Sarov, 2008.

XV International conference "Mathematics, computers, education", 28 January-2 February, 2008, Dubna, JINR, MSU.

International optical congress "Optics - XXI Century", Conference "Basic problems of optics-2008", 20-25 October 2008, Saint-Petersburg.

Student conference "Optics and photonics", OSA & SPIE, Student Chapter, Institute of Automatics and electrometry , 10-11 November 2008.

Russian - German Workshop “Kurchatov center of synchrotron radiation and nanotechnology”, February 18-19, 2008, Moscow.

VI International conference on bioinformatics of genome regulation and structure (BGRS’2008), Novosibirsk, Russia, June 22-28, 2008.

High-level courses for the CIS countries on the contemporary methods of exploration of nanosystems and materials (SIN-NANO), 7 -26 July 2008, Moscow - Dubna.

XXI Russian particle accelerator conference: RuPAC-2008, Zvenigorod, 28 September - 3 October, 2008.

Joint Accelerator School-08 (JAS-08), RRCAT, Indore, India, January 7-18, 2008.

European conference on X-ray spectrometry (EXRS 2008). - Cavtat, Croatia, 16-20 June 2008.

33rd International conference on infrared, millimeter and terahertz waves, Sept. 15-19, 2008, Pasadena, California, USA.

18th International Conference on Plasma Surface Interactions, Toledo, Spain, May 26-30, 2008.

Chapter 7

Radiophysics and electronics

Introduction

BINP works in the field of radiophysics and electronics are mainly concentrated in the Laboratory of Radiophysics. The main subject of the Laboratory activity is related to the study and development of radiophysicsl systems for the charged particle accelerators and storage rings, which are developed at BINP according the State Programs "Colliding Beams", "High Energy Physics", "Synchrotron Radiation", "Physics of Microwaves".

Within the frame of these Programs, the laboratory team is involved in the development of such a radioelectronic equipment as the power supply systems, control and diagnostics, computer control systems; the development of RF accelerating systems, RF and HF energy sources, studies of the charged particle beam behavior in interactions with the accelerating systems and other components and devices of the charged particle accelerators and storage rings. It is evident that the main results of the Laboratory 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 works, some of them become the base of equipment and/or devices of an independent scientific and technological interest. Some results are applied and used in the work of other Laboratories, which carry out the work under contracts both with the national and foreign centers from the USA, Germany, R. Korea, Switzerland, Japan, China. It is worth mentioning here the contract works for CERN on the development of the LHC components; the work for Zelenograd of the SR Source TNK; the development of injectors of neutral atoms work for Tri Alpha Energy (USA). The collaboration with these centers is in a good progress.

Given below are some results of works carried out in 2008 and some plans on work to be continued in 2009 and in future.

7.1 Power supply sources for electrophysical facilities

7.1.1 Stabilized current sources

Development of the stabilized current sources for supplying various electrophysical facilities and their components is one of the main tasks of studies carried out in the Laboratory of Radiophysics. First of all, the devices of this class comprise DC source for supplying electromagnets of the storage rings. An output current of the source (depending on purpose) ranges from a few amperes to tens of kiloamperes and output power – from tens of watts to hundreds of kilowatts and to a few 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 themselves are rather complex electrophysical devices with the computer test and control and with a complex system of interlocks and inner control.

1) In 2008 we continued the work carried out for many years on the upgrade of electronics for the IST-series precise sources, which are designed for feeding electromagnets. These devices are of 50 kW, 100 kW, 200 kW in power. Eight ISTs at TNK(Zelenograd) were upgraded by replacement of electronics, wiring and capacitor banks. All the necessary components for the next 20 ISTs are manufactured including those for K-500 channel and VEPP-5 that amounts about 120 units of 6 types of electronics modules.

2) For TNK complex we also produced a crate and a set of units for TPV power supply source, which will be used for feeding the dipole magnets of the TNK main ring. The current is 7 kA and power consumption is about 1 MW.

Production of the source power part components is arranged at Low Voltage Apparatus Plant (LVA, Rasskazovo, Tambov region). At BINP, we developed, designed and manufactured five sets of a new electronics in the standard of Euromechanics; LVA developed the power part of the source. At the end of the year, LVA produced a pilot unit of the source (900 A, 250 kW). Production of one more source is nearing completion. The sources are planned to be used in new projects.

3) Upon readiness of the sources and storage rings BEP and VEPP of the VEPP-2000 complex for stationary operation with high currents we continued tuning the megawatt order sources with a current of up to 9 kA. Next year we plan to equip the BEP sources with the reverse driver that will enable us to reduce the time for current polarity change thus BEP will be better prepared for operation with K-500 channel.

4) In 2008, we continued the development and installation at the BINP facilities of the power supply sources with the output power of up to 10 kW produced under the **Switch Mode technology:**

• A bipolar current source with maximum parameters 300 A, 8 V, which is designed for feeding the superconducting solenoids of VEPP-2000 complex. Four pilot samples are produced and two of them are delivered to the Cryomagnet firm (Moscow).

• A monopolar current source with parameters:1000 A and 5 V is developed. Two samples were manufactured and delivered to the firm Cryomagnet.

• The development of the monopolar current source with parameters 300 A and 18 V designed for feeding the FEL magnetic system is completed. At present, seven such sources are installed at the complex and the remaining five sources (from a series)are delivered to JINR (Dubna) and put successfully into operation at the IREN complex. Development of this promising version will be continued. Note that each of abovementiond sources is equipped with two contactless current probes (DCCT): one is for providing stabilization, and another – for independent measurements. The system is equipped with the DAC/ADC control module of the “CDAC20” type.

5) Within the frame of the **Switch Mode technology**, we realized a rather interesting solution as the development of the alternating current source of higher than 10 kW with operating frequency 400 Hz for feeding the ELV primary winding operated in the “tandem” regime 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 source and a specially developed unit of the synchrotron detector of a power over 10 kW operated at the carrier frequency 20 kHz. The prototype of the source, which provides the “tandem” with the required power, is produced. The operating version of the source will be realized 2009. The power supply sources of 20 kHz type are decided to be used for feeding the electron collector in the ion beam cooling system, for feeding dipole electromagnets and quadrupole lenses of the HITS synchrotron magnetic system using both the 15 kW and 30 kW versions. Next version at the output power up to 60 kW and the version with the output current up to 1000 A are being developed.

6) A set of electronics is adjusted for feeding the BNCT beam helical scanning magnet.

7) We continued the development, improvement and production in small series of the low power current sources providing the feeding of the correct electromagnets and/or special devices. The total numbers for this activity looks like following:

• A set of electronics for feeding corrections of a booster storage ring TNK (Zelenograd) is produced and put into operation. The set comprises two crates comprising 11 MPS channels with the control through CAN-bus.

• A set of electronics is produced for feeding the quadrupole lenses and beam probe correctors for UT-BATTELLE, LLC (USA). The set comprises a 8-channel crate with MPS-6 crate controller of CAN-bus type.

• We developed, manufactured and put into operation about 30 channels of bipolar current source of the UM-1, UM-3 and UM-10 types with the output currents 1 A, 3 A, and 10 A, respectively. The sources are installed at the complexes FEL, BNCT and EBW.

8) Many abovementiond devices and their components will be used as prototypes of the power supply sources in the project HITS whose development started at BINP in 2008.

9) Pulse power supply:

• Three pulse power generator were put into operation for the input/output septum magnets of the TNK project in Zelenograd. The voltage at the generator capacitances is up to 7 kV.

• Development of a new generation of the pulse generators for feeding magnetic components of the beam transport channels is continued. The systems are primarily oriented to a 500 MeV electron and positron transport channel being developed for beam transport from the Injection complex to VEPP-4 and VEPP-2000.

It is worth mentioning that in 2008 we continued work on technical maintenance of earlier produced systems and units being operated at BINP and other organizations.

7.1.2 High voltage sources of DC stabilized voltage

In the laboratory, we successfully develop high voltage sources of DC stabilized voltage in the power ranges:

• tens of watts – power supply of electrostatic devices for bending or focusing the charged particles;

• from a few hundred 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 HF amplifiers.

The devices are of high stability and accuracy in adjustment; they are protected against short circuits and breakdowns, equipped with a computer control of currents and voltages and with the distributed status control.

The following works successfully performed in 2008 are worth of special mentioning:

1) Production and assembly of power supply components for Tokamak T-10 (Kurchatov Institute, Moscow), which was proceeded over 2.5 years, is finally completed. The source complete set of electronics includes:

• HV power supply sources with the parameters: U(max)=40 kV, I(max)=6 A, T(max)=20 ms with a possibility of a 100% amplitude modulation from 2 ms/2 ms to 20 ms/20 ms.

• Arc discharge current source with I(max)=600 A at the discharge voltage U(arc)=80 V and a possibility of a current amplitude modulation.

• Power supply for the third grid, charge converter, etc.

• All the necessary auxiliary power supply sources for the valves, solenoid of magnetic insulation, trigger, etc. The equipment adjustment and its commissioning as well as its delivery and commissioning at Kurchatov Institute are planned for 2009.

2) In 2008, we had finished the production and adjustment of the HV source prototype for the RUDI-x diagnostic injector for the superconducting stellarator W7-x (Greiswald, Germany). However, the required parameters (Umax=60 kV, Imax=12 A) a possibility of modulation from the continuous current to meander 2 ms/2 ms are not yet obtained. We started the upgrade aimed at a 1.5 factor increase in the HV source power and also began production of other systems for the W7-x injector control and its power supply.

3) A set of power electronics is produced and put into operation for feeding the plasma emitter based on the arc discharge for Lab.9:

• An arc current source with I(max)=600 A, U(arc)=80 V, T=2-3 s with a possibility of the arc discharge current modulation.

• The power supply source of the third grid of the diagnostic injector with U(max)=−800 V, I(max)=10 A and a possibility of a fast recovery of voltage after breakdowns.

• Power supply source of the magnetic insulation solenoid, gas valves, “trigger”, etc. This set of the power equipment jointly with a HV power supply source allowed to carry out test of the upgraded ion source of the diagnostic injector produce for operation with MST, Madison, USA.

4) In 2008, equipment for the power control electronics for the heating injector (25 kV/65 A/20 ms) by the contract with the University of Wisconsin (Madison, USA). Delivery and acceptance are planned for September, 2009.

Injector components:

• Two arc current sources are produced with the parameters I(max)=600 A, U(arc)=80 V, T=25 ms.

• Produced and adjusted are: the power supply sources for the magnetic insulation solenoid, gas valves, “trigger”, etc. (totally by two sets each).

• We started production of the basic components of HV power supply source with parameters (Umax=30 кV, Imax=65 A, Tmax=20 ms).

• A set of control/measurement electronics was created.

5. Works by the contract with TAE (USA):

• Six sets of the HV power supply sources with parameters Umax=45 kV, I max=45 A, Tmax=1s are manufactured and delivered to the customer.

• About 40 sets of electronics are manufactured for the control, measurements and protection of the HV power supply sources.

• We continued the work on production of the 7th set of equipment for the perspective works to be started in 2009.

• Seven sets of the anode power supply sources for RF generators are produced.

6) During this year, we continued the development and production of the components and units for electron beam welding devices (EBW): one set was put into operation at the NITI "Progress". Two sets are subjected to the prior to delivery tests at the BINP stands. In 2008, one set with a beam power up to 30 kW in the continuous operation regime was delivered to the NITI “Progress”. Four sets of EBW Energy Modules were put into operation at the NITI "Progress". Two Energy Modules “power generating units” are subjected to the prior to delivery tests at the BINP stands. In 2008, we upgraded two sets of the high voltage and power parts of the gun power supply for the earlier developed 60 kV, 250 mA EBW Energy Modules. At the same time, at the laboratory of Dr. P. Logachev, the design of its cathode units was modernized. These combined actions improved substantially the device operation parameters.

7. Development of three sets of the high voltage units of the power supply system of the ion sources is completed and technological drawings are given to the workshop. These

sets are designed for the IBA (Belgium) and for the test stand of the ion source. The work will be continued in 2009.

8) A set of electronics is prepared and adjusted for the prototype of high voltage section of the COSY system of electron cooling; the prototype has passed the preliminary tests. We started the work on the development and production of electronics for the system of electron cooling of the HITS project: dynamitron, collector as well as the control electronics at a potential of 300 kV.

7.2 Development of measuring systems and devices for automation of physical experiments

Participation of the laboratory in automation of the devices, stands and large physical complexes consists in:

• development and delivery of ready systems for the control, monitoring, diagnostics, of computer systems with further participation of developers in adapting the system to the physical facilities;

• development of elements for the control, monitoring and timing of the power supply systems with their further installation on the 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 consequency, 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 units of electronics and systems developed at the laboratory and currently operated. The BINP developed and produced equipment is widely used not only in SB RAS Institutions 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-to-analog devices, units or modules.

Next 60 units with CAN-BUS interfaces are produced, adjusted and put into operation in 2008 in the control systems of various electrophysical facilities. For this year, the family was enlarged by two new modules: CEAC121 and CEAD20. Both modules are made in the Euromechanics standard. CEAC121 is designed for generation of the reference voltages of an arbitrary form for the newly developed power supply systems of the ion synchrotrons and CEAC121 is very convenient for various power supply systems of a new generation. Note that devices of this family are widely used in the contract works. For the last three years, over 200 modules in sets with various power supply systems of physical devices have been delivered to KAERI (R.Korea), IMP (China), JINR (Dubna), KISR (Moscow), TNK (Zelenograd), NITI "Progress"(Izhevsk).

Table 7.1: 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 a class 0,03%), 8-bit input/output registers
CDAC20 CEDAC20	A 20-bit DAC, a 5-channel, 24-bit ADC (of a class 0,003%), 8-bit input/output registers ("Vishnya" and "Euromechanics" Standard)
CEAC51	A 20-bit DAC, a 5-channel, 24-bit ADC (of a class 0,003%) 8-bit input/ output registers, ("Euromechanics", 3U standard)
CAC208 CEAC208	A 8-channel, 16-bit DAC, a 20-channel, 24-bit ADC (of a class 0,003%), 8-bit input/output registers, "Vishnya"and "Euromechanics" standard
CEAC124	A 4-channel,16-bit DAC, A 12-channel, 24-bit ADC (of a class 0,003% 4-bit input/output registers, ("Euromechanics" 3U standard
CEAC121	A 1-channel,16-bit DAC, A 12-channel, 24-bit ADC (of a class 0,003%) 4-bit input/output registers "Euromechanics" 3U standard), designed for the control of fast sources
CEAD 20	20/40-channel, 24-bit ADC (of a class 0.003%), 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-pupose register of input/output (2 output and 4 input 8-bit registers)
CIR8	A register of discrete signals (interruption register, input/output registers)
CAC168	A 8-channel, 16-bit DAC, a 16-channel, 24-bit ADC (of a class 0,03%), input/output registers, built-in board
CAN-DDS	A CAN-DDS module is a divider of the input clock frequency with the remotely retunable fractional coefficient. The module is designed for it use in the feedback circuit of triggers at VEPP-5 and VEPP-2000
CAN-ADC 3212	For connection of the feedback circuit into the thermal adjustment scheme of the cavity, temperature control at certain points cavity and providing blockings. A 24-channel 12-bit differential ADC with reswitcheable amplification factor; a 4-channel 12-bit bipolar DAC.
CANGW	Ethernet port -CAN/RS485
VME-CAN	Interface VME-CAN

The main results obtained with participation of the laboratory are given below:

• In view of the ever growing amount of various magnetic field measurements at BINP, a new set of new generation modules was developed in the VME standard, which enables one carrying out the precise measurements of the fields both with the Hall probe based matrices and with the rotating coils. At present, a set comprises:

– a precise ADC with the built-in analog multiplexer;

– a 32-channel multiplexer with the commutation error of 1 μB; for the work with the Hall probes s precise (0.001%) current generator is envisaged in the module;

– a precise integrator with the digital output.

• On the base of the developed equipment, we produced several systems at the stands of magnetic measurements in 13th Bld. and EW-1, which are widely used for various contract works. A set of codes was written down for these systems.

• We upgraded the equipment and software for the EW-1 stand of precise measurements of the multipole components in magnetic lenses. In 2007-2008, the stand was actively used for measurements and mechanical tuning of the lenses manufactured by the contract with ALBA(Spain). After thorough study and removal of some factors affecting the measurement quality, we managed to attain the accuracy of the order 0.01%.

• A full set of measurements and tunings have been performed for 21 wigglers produced at BINP for PETRA-III (Hamburg, Germany). For the high quality adjustment at DESY, we developed a unique system for measurements of field lst integral distribution along the wiggler.

• The stand was produced and software was prepared for measurements of the 45 magnets produced by the contract with IHI (Japan). The mobile stand was delivered to the customer to provide the high quality measurements at the customer premises.

• We continued the development of equipment for the fast system of the Hall measurements with the continuously moving carriage with a two-coordinate probe. Such a system will enable not only to reduce the measurement time but to improve the measurement accuracy.

• We continued the work on development of modern universal electronics based on the induction technique for measurements of magnetic fields in accelerators. It is assumed that the new electronics will be widely used not only for measurements of instantaneous values of the pulsed fields, in accelerators but it will allow to achieve high accuracy in measurements with rotating coils, strings, etc at the stands of magnetic measurements. We already started to study the first module prototype parameters.

• The work is continued of introducing modern intellectual controllers into the control systems of the physical facilities. The next series of controllers and CAN-Ethernet port was produced for the BINP facilities.

• A trial series of the modern digital registers ADC-200ME(5 ns, 12-bit) is developed and produced in the PMC standard. The stand and software are nearly ready for tests of the devices.

• Development of the control system for the induction accelerator (LIA) is continued.

• For replacement of the popular but physically outdated crate controller K0607, a new version based on modern element base was developed. Next 20 controllers and interface boards were produced and put into operation in 2008.

• We continued the work on the development of the digital registers with Fast Ethernet interface for detection of optical images. A set of units was manufactured for observation of SR beams at VEPP-4M, VEPP-2000.

• we started the development of the X-ray detector (based on the highly sensitive 2000-element linear CCD) for the diagnostics (alignment) of SR beams scanned by the linear CCD.

• The system for detection of the junction position in the electron beam welding device is developed. The shot of the size 1000*1000 points is formed during one second after an analysis of the secondary electron beam current. The primary electron beam current is 20-50 mkA. The corresponding software will enable the electron beam position correction automatically.

• The work on improvement of the electronics operation reliability in the control and power supply systems of the electron beam welding is continued.

• We started the development of special modules for the automation system of HITS: a digital synthesizer of the clock generator, timing device for formation of the time diagrams of many pulse devices.

• The scheme of pulse generation (1kV, 20 ns) is developed for the carbon ion source modulator. The fast amplifier of the current receiver signal (Faraday cylinder) is developed and produced. The device is designed for the time flight analysis of the ion composition at the tandem-HITS injector output.

• Electronics for operation with the magnesium target in the tandem is developed. The device comprises a multi-lamel current probe, which should reliably detect current of a few tens of nanoamperes and withstand simultaneously the high voltage breakdowns up to 1 MV.

• For replacement of the outdated equipment for the power supply systems of the main magnetic components of VEPP-4, we continued development of a precise interpolation DAC with the MIL-STD-1553B interface with the use of modern components. The module will be compatible with the previous version.

• We continued the development of the port-multiplexer for data acquisition at the KMD detector. The built-in software is being subjected to tests. The KMD-3 data acquisition system is at the stage of commissioning.

• We completed the development and production of 8 sets of the control electronics for the neutral beam injectors (the diagnostic and heating versions of injectors). The system is based on the commercially available components. The software is unified for the injector both versions and integration into the common control system is envisaged.

• A set of CAN-BUS wire-optofiber-wire is developed and produced.

• The wide band amplifiers were developed for the photoreceivers on the base of avalnche photodiodes for realization of modern beam diagnostics at the storage ring VEPP-4M.

• We continued the development of a new generation of power supply sources and control board of the injector electron gun of the free electron laser.

• A new high frequency timer for the free electron laser injector is put into operation.

• Development of specialized modules started for the HITS automation system: digital synthesizer of the clock generator, timing device for formation of the time diagramms of many pulse devices.

• For the work with the detector KEDR gas system, the next batch of modules designed for measurements and control of the gas flows was produced and adjusted. The reserve control unit of the detander-helium liquifier is put into operation.

• We continued the development of the time interval meter in the nanosecond range with the CAN-BUS interface.

• Next five controllers of the power supply units for superconducting magnets are produced and put into operation. The power supply sources will be used not only at BINP, therefore a possibility of the autonomous operation (without external control computer) was envisaged. To this end, the controller is equipped by LC display and a miniature control panel.

• A sycle of experiments was performed to study a possibility of using the solid body for synthesizers in the high voltage nanosecond generators based on the SOS diode. A 15 kV pulse was obtained at the load of 75 Ohm with a front of 3 ns and jitter less that 0.2 ns.

• Electronics and beam position monitor based on measurement of image currents (next version) were developed for the use in K-500 channel. Technological drawings are in processing. The earlier produced equipment and monitors are installed at the beam transport channel BEP-VEPP of the VEPP-2000 complex and successfully operated for the beam transport.

• We continued the development of the feedback system designed for damping the beam transverse motion instabilities at VEPP-4M. In 2008, in the frame of this work, a series of experiments was performed with a beam in a single bunch regime with good resuts: the system allows to increase the number of particles in one bunch by two-three times depending on the operation regime. The record beam current was of 30 mA. The obtained information enabled the more strickt formulation of requirements to the processor part of the equipment and software. A new version of the processor and its software was developed in 2008. The work with a beam and the system upgrade will be continued in 2009.

• In the period 2008-2009, we put into operation the electronics of beam position measuring systems at the VEPP-2000 complex and storage-ring cooler of injector complex. The systems are based on specially developed pickup stations and 4-channel, 12-bit ADC having the clock frequency of measurements of up to 45 MHz. The systems are successfully used during commissioning of the facilities.

• The beam position and current monitor for the induction accelerator is developed and now it is under manufactory.

• In 2008, at FEL (Bld.11), an intense work was carried out on the beam diagnostic system adjustment for 2nd stage of FEL and adjustment of the whole complex on the base of beam orbit measurements. The work is nearing completion.

• Within the frame of contract works, the betatron oscillations frequency measurement systems were developed and produced for the booster storage ring of TNK (Zelenograd) and electron storage rings Siberia 1 and Siberia-2 for Kurchatov Institute.

• Development of the precise NMR magnetometers continued. Depending on a set of electronics and a version of probes the magnetometers 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 in the field range 0.3-2.4 T. Within the frame of the work on measurements of the particle mass at VEPP-4, the field precise stabilization regime was realized in a calibrated magnet. A multihour stability of the field was achieved to be 0.5 ppm. Measurements systems of magnetic fields with NMR method are installed at Siberia-2 and the booster storage ring at TNK.

• We started development of the probes and processing electronics for measurements of the beam position and intensity for HITS project started at BINP.

• A driver for a two-phase step motor of machine CM-900 (EW- 2)was developed.

• Within the frame of contract works with SLAC (USA) we delivered 49 ultrasonic and 138 capacitive hydrostatic sensors of the verical motion of the LCLS component. BINP staff participated in the work on putting into operation of the sensors in the LCLS control system. The sensors have the resolution of an order of a few fractions of a micron, are easily calibrated and presently are among the best in the world. Some sensors are delivered to FermiLab.

• In the frame of the work, we jointly with SLAC and Fermilab modified and adjusted the software of for the ultrasonic hydrostatic level sensors. The software modification was performed also for the data acquisition system from the sensors.

• We continued improvement of 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 descriptions of various modules, some application notes appeared. The site is renewed regularly.

7.3 Studies related to modeling and solving the electrostatic and electrodynamic problems

Most important works performed in 2008:

1. Works on further improvement of programs for calculations of the electrostatic and magnetostatic fields, the electron and ion guns including:

• A set of programs UltraSam for calculations of RF systes with account for the spatial charge of a beam in a long wave approximation was essentially improved.

• We continued the development of the Windows based set of programs MAG3D initially designed for the three-dimensional calculations only magnets with an account for the effect of core saturation.We added a possibility of calculation of the three-dimensional systems of electrodes and analysis of a trajectory in the electric and magnetic field.

• We started the development of the BEAM3D program, which enables the design of three-dimensional channels for guiding the charged particle beams in the real electric and magnetic fields formed by components initially calculated with the MAG3D program taking into account the thermal spread of transverse velosities of the beam particles.

2. We performed the numerical calculations, modeling and design of the electron guns, electron and ion beams and magnetic systems including:

• In the frame of the contract with the Kurchatov Center of synchrotron radiation and nanotechnologies, for the upgrade of the linear accelerator-injector we calculated the electron gun optics with a hole in the cathode, through which it is assumed to extract the electron beam accelerated to a double energy value.

• In the frame of the contract on the development of the ion accelerator complex (HITS) for cancer therapy, a 10 Hz choke was developed for the power supply system of the booster synchrotron magnets.

• Within the frame of the same contract, a new electron gun was developed for the electron cooling device of the main synchrotron, which differs by substantially decreased cathode area keeping the moderate transverse temperature of a beam.

• In the frame of collaboration with Lab.9 we developed with programs SAM, BEAM and MAG3D an energy analyzer for the hydrogen neutral particles and deuterons with the use of the stripping target accelerating focusing system, bending magnet and deflecting capacitor.

• A new project of the low energy channel was developed in collaboration with Lab.9 with programs SAM, BEAM and MAG3D for guiding and injection of hydrogen negative ions to the tandem accelerator of BNCT device, which is significant by the presence of an additional bending magnet and the accelerating tube.

7.4 Upgrade of powerful RF generators of FEL stand

At present, the RF system of FEL microtron uses RF generators of maximum output power 600 kW whose 4-tube output circuits are based on the water cooled generator tetrodes produced at SED-SPb, S.Petersburg. The generator frequency is 180 MHz. All the RF generators and power supply sources are produced at BINP SB RAS and then assembled and put into operation by the BINP staff.

The GU101A tube anode voltage was selected to be 8 kV and limited by RF heating of the tetrode screen grid in continuous operation. The raise of the anode voltage and consequently an increase in the RF power leads to reducing the tube lifetime. The long term operation of the installation has shown that the satisfactory lifetime of the tube of 2000 hours can be achieved at a constant operation of the generator at the output power level of 500 kW.

An increase in the generated power and lifetime of tubes can be reached with the use of novel technologies in their production with the use of the pyrolitic graphite as a material of the control and screen grids. The studies have been performed at the Svetlana OKB in the 1980s of the previous century. Several samples with pyrolitic graphite grids GU105A have been produced for tests in BINP generators aimed at further replacement of tubes GU101A. However, the work on production of these tubes ceased.

At present, the powerful tubes with pyrolitic graphite electrodes are produced by THALES (France) and widely used in the foreign accelerator facilities. This is TH781 – tetrode with pyrolitic graphite grids. This tetrode provides the continuous power up to 200 kW at frequencies up to 200 MHz. The warranty period of the tube is 3500 hours – i.e. 3.5 times longer than that of GU101A.

Development of the accelerator engineering for the free electro laser and dedicated electron storage rings - SR sources requires an increase in the power, lifetime and reliability of the tube operation. As a result of this, some additional units enabling the replacement of GU101A at BINP available generators by TH781 are being developed and produced. The developed design allows using simultaneously the GU101A and TH781 tubes at the 4-tube output circuit thereby providing the gradual replacement of tubes.

TH781 tubes are planned to be used also in a 2-tube output stage of the RF system generator of the storage ring TNK.

In May, 2009, it is planned to carry out the first test of the TH781 tube in the single tube output stage of RF generator and then to study operation of one TH781 tube jointly with three tubes GU101A in a 4-tube output circuit generator of FEL RF system.

In future, it is planned to replace GU101A tubes by TH781 tubes in RF systems produced by BINP by the foreign contracts.

Participants of the work (Lab. 6-2:)

Arbuzov V.S., Gorniker E.I., Kondakov A.A., Pilan A.M. and V.G.Cheskidov (DB).

7.5 Electron source for the electron diffraction experiments

In 2008, the BINP Laboratory of radiophysics jointly with the Max Plank Institut fur Quantenoptik, Garching, Germany carried out the work on the development of the source of electron bunches of a few tens of femtoseconds in duration. The source is a part of the experimental device for the diagnostics in the substance kinetic structure and superfast chemistry. The device scheme is shown in Fig.1.

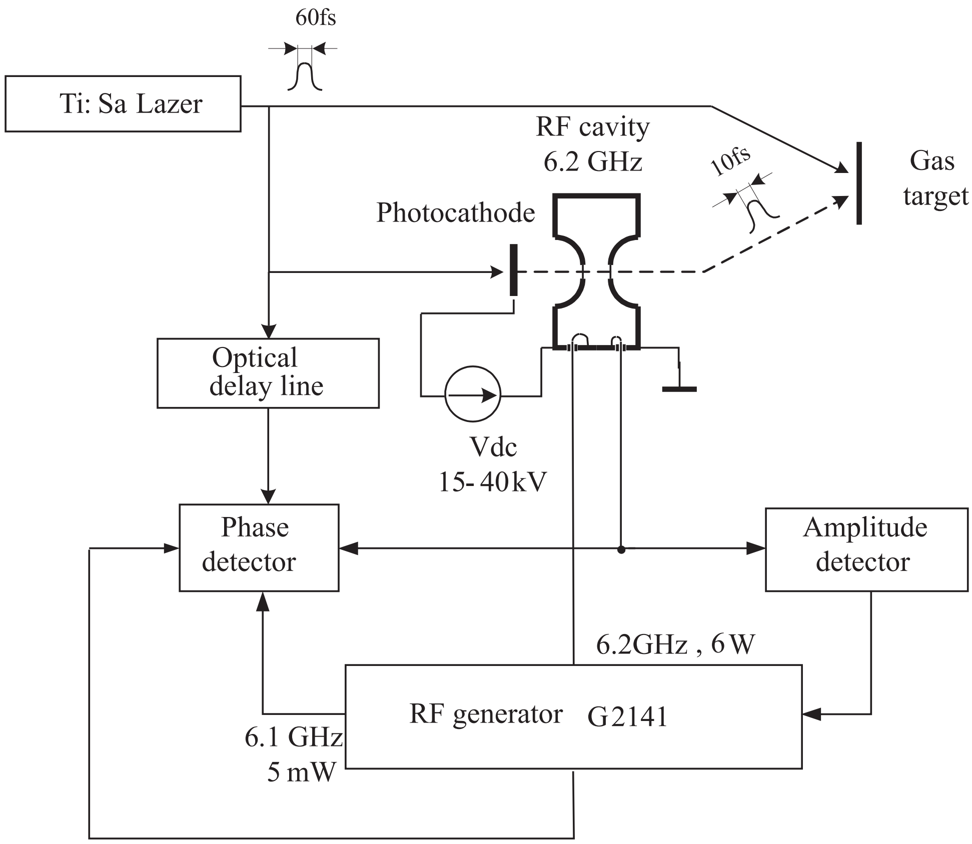


Figure 1: Installation diagram for experiments on a study of electron diffraction in gases.

The schematic diagram shows an improved version of the installation for carrying out experiments according to the scheme "pump and probe". In order to improve the resolution in time, behind the diode-type gun used in similar cases, the modulating cavity with operative oscillation mode E_{010}, at frequency of 6.2 GHz was installed. The cavity wall is at zero potential and plays the role of the electron gun anode. A 40 keV electron bunch formed by the gun acquires the velocity modulation. While passing the cavity gap it is focused in the longitudinal direction in the gas target plane. The expected bunch length at the target is of the order of tens femtoseconds.

Rf generator with the output power up to 6 W at a frequency of 6.2 GHz is developed and produced at Krasnoyarsk Scientific Center SB RAS (Krasnoyarsk). A specialized phase detector, high voltage source up to 40 kV and waveguide unit (Fig.2) have been produced at BINP. The delivery is planned for March, 2009.

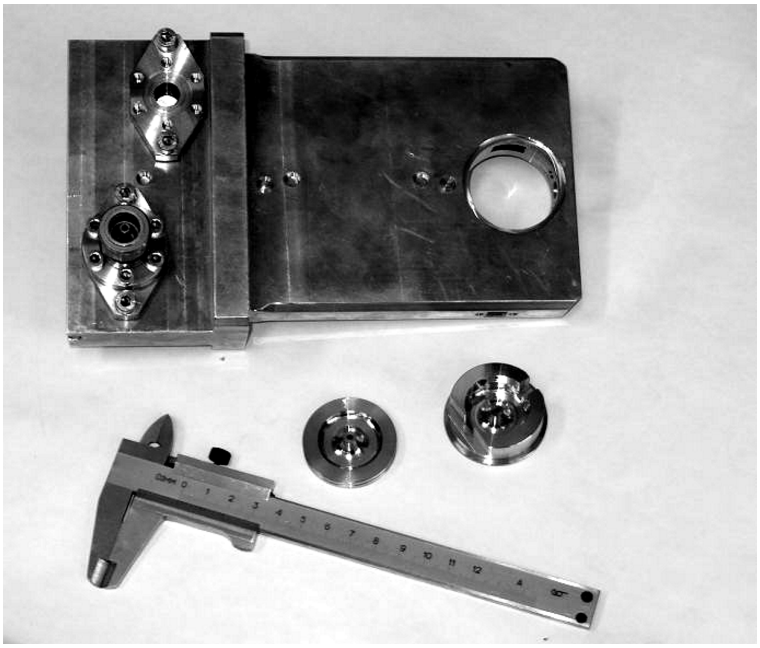


Figure 2: Details of the wave guide cavity unit after its production at BINP EW.

Participants of the work:
I.A.Zapryagaev, G.Ya.Kurkin, V.Z.Persov, V.V.Tarnetsky, K.N.Chernov. The work is presented in publications: L. Veisz, G. Kurkin, K. Chernov, V. Tarnetsky, A. Apolonski, F. Krausz and E. Fill, Hybrid dc- ac electron gun for fs-electron pulse generation, New Journal of Physics 9 (2007) 451.

7.6 RF system of a 2.2 GeV storage ring – SR source

By the contract with NIIFP, Zelenograd, Lab.6-2 developed a project of RF system for a new dedicated storage ring - SR source at Zelenograd. Elements of the system are being produced at BINP workshop. The storage ring has maximum energy of 2.2 GeV, radiation loss at this energy with an account for wigglers and superconducting snakes is of 513 keV and current up to 0.3 A.

The storage ring accelerating system will be operated at Frequency of 181,33 MHz that corresponds to 70th harmonics of the revolution frequency. In order to compensate for the radiation losses and for obtaining satisfactory lifetime of the beam, the total accelerating voltage of 1 MV is required at this frequency. Injection of particles into the storage ring is performed at an energy of 450 MeV when the radiation losses are only 0.72 keV. This is posing additional requirements to the RF system tuning at the operative frequency and detuning the higher order modes of accelerating cavities for providing the beam phase stability. The accelerating voltage amplitude should vary in a wide range. Control of the voltage and phase of accelerating voltage is performed by the control system. The main parameters of the RF system are given in Table 7.1.

RF system consists of two separate bimetal cavities installed at the accelerator at a distance of a half wavelength between their centers, one power supply generator, power transfer line and the control system.

Table 7.1: Parameters of RF system of a 2.2 GeV storage ring.

Operation frequency	181,33 MHz
Harmonic number	70
Frequency tuning range	±180 kHz
Number of cavities	2
Gap voltage of two cavities, U	0,2÷1,2 MV
Transit time factor	0,9
Quality factor of the cavity	39000
Shunt impedance, R*	2x5,2 MOhm
Power losses in cavities, P for U=1200kV	2x35 kW
Generator power	300 kW

*R = $U^2/2P$

7.6.1 Accelerating cavities

The cavity design is similar to those of the microtron recuperator of Novosibirsk FEL. The cavity body (Fig.1) is made of bimetal (8mm copper and 7 mm of stainless steel) obtained with the diffusion bonding technique. The water cooling channels of the body are located in the outer layer of the stainless steel. RF current flows along the inner copper surface.

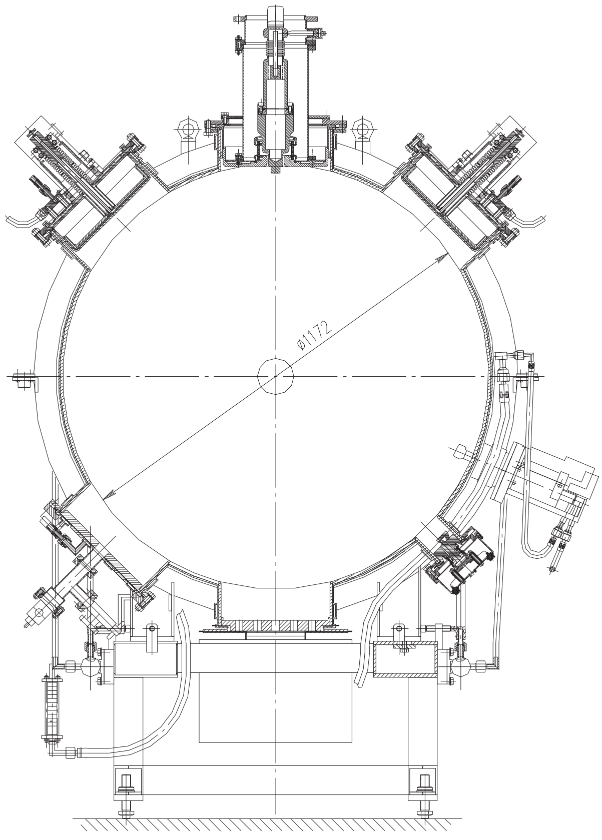


Figure 1: Schematic diagram of the cavity.

The operation mode is E010. Each cavity has two contactless tuners for the operating mode and two tuners for the Higher Order Modes (HOM). The protruding part of HOM tuners has a shape of a butterfly and it is oriented along the longitudinal axis of the cavity.

These tuners have only slight influence on the operation mode frequency but they tune the cavity HOM frequencies. The HOM tuners positions are chosen in such a way that the voltage of HOMs induced by the passing electron bunches could not cause the step-up of the beam phase oscillations both in the single bunch and in a multibunch operation modes of the storage ring. On the top of the cavity there is a coaxial power input with the cylindrical ceramic window. The gap voltage is measured by the inductive probe.

At the cavity from below the ion sputter pump is installed. Two vacuum gates with the RF shield are connected to the cavity flanges placed at the cavity axis. Each cavity will be pumped out and heated at temperature 300°C. At the stand, each cavity will be connected to RF generator and tested in the voltage range up to 1000 kV in continuous mode.

7.6.2 Transfer line and RF generator

The generator of up to 300 kW of continuous power at the output is installed in the RF system. The generator output is a two-tube circuit of the module design using TH781 tetrodes of THALES (Fr) production. Each tube of the output circuit is driven from the preliminary circuit with the tetrode GU92A (produced by "Svetlana", S.Petersburg). Both preliminary circuits are excited from the similar stages based on GU92A. To the latter the power of up to 20 W comes from the transistor amplifier. The low voltage and anode power supply sources are located in separate cabinets. The anode rectifier is equipped with the protection thyristor switch preventing destruction of tube grids during sparking. High voltage removed from anode in time less than 50 microsecond. For the transfer of RF power, the rectangular aluminum waveguide is used. At the level of 300 kW of continuous power, the rectangular waveguide is more reliable and technologically simpler compared to the coaxial line and the size of the waveguide (width 986 mm, height 150 mm) can be substantially less than those optimal by the losses in the walls.

The generator and cavities are connected with the waveguide by the waveguide to coaxial transitions. The schematic diagram of the RF channel from the waveguide to one of cavities is shown in Fig.2.

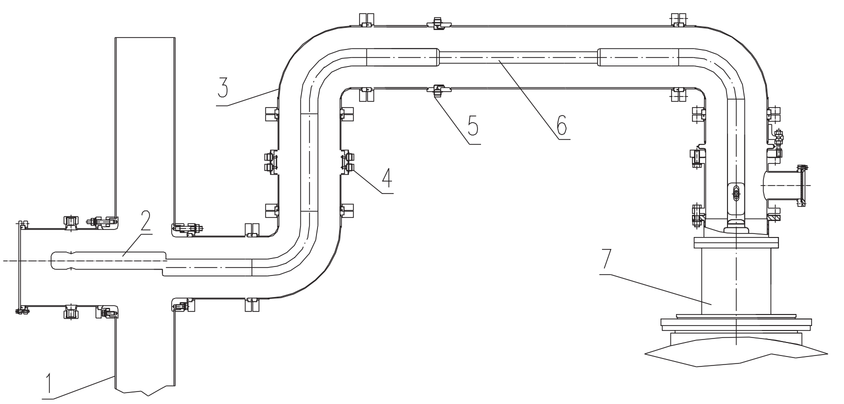


Figure 2: Scheme of RF feeder from the waveguide to one of the cavities.

Each cavity (7) is connected to the waveguide (1) by the coaxial feeder (3) with the wave impedance of 75 Ohm. Cavities are driven in the counter phase due to opposite orientation of the power input loops. RF power of the RF generator is divided equally between two cavities with the waveguide to coaxial transition (2). Both coaxial feeders are connected to the same crossection of the waveguide symmetrically with respect to the middle of its wide side. The equivalent transition scheme is an ideal transformer with three windings. With the matched coaxial feeders, the waveguide is also matched. The design enables one to change easily the coupling coefficients of the waveguide with cavities with respect to each other within the limit ±10%. This effect is achieved by rotating the eccentrically shifted parts of the inner conductor of the feeder inside the waveguide.

The distance from equivalent transformer of the waveguide-coaxial transition to the voltage nodes in coaxial feeder during strong detuning of the cavity is multiple to the odd number of the wavelength quarters in the feeder. Thus, during detuning of any cavity, the cavity excitation currents do not exceed the values determined by the maximum power in the tuned system. In the feeder coaxial part, a quarter wavelength transformer (6) is installed, which matches the waveguide channel at the beam maximum current. The transformation coefficient can be changed within the limits from 1 to 1.33.

The transformer is placed at a distance equal to a quarter wavelength from the voltage node during the cavity detuning. The position of loops (5) measuring the cavity input power current is shifted to a half wavelength from this voltage nodes. The feeder VSWR is measured with the directional couplers.

7.6.3 RF system control

The control system has feedback loops for control and stabilization of the total accelerating voltage of cavities and the feedback loop for automatic tuning the RF cavity resonance frequency.

An RF voltage is formed from signals of the cavity RF field inductive probes, which presents the total accelerating voltage for the passing electrons. This voltage is phased with the reference signal 181.33 MHz from the storage ring Master oscillator. In this way the accuracy of injection of electron bunches into the storage ring is achieved.

The stabilization feedback loops for the cavity RF voltage amplitude and stabilization of the voltage phase to the reference signal have the time constant of $\tau \approx 200$ μs. The time constant of the autotuning of the cavity is ~ 0.2 s. In the system, there is also the interlock unit, which protects the RF system components and personal in the hazardous situation. All the basic parameters of the RF system are controlled and monitored from PC.

Participants of work:
V.S.Arbuzov, E.I.Gorniker, A.A.Kondakov, S.A.Krutikhin, G.Ya.Kurkin, I.V.Kuptsov, V.N.Osipov, V.M.Petrov, A.M.Pilan, I.K.Sedlyarov, A.G.Tribendis, V.A.Ushakov.

7.7 A of the longitudinal feed back system for damping the phase oscillations of a beam in VEPP-4M

In December, 2008, the feedback system for damping of the beam longitudinal oscillations in the storage ring VEPP-4M was successfully put into operation. The system consists of two pairs of the kicker cavities. Each pair of cavities affects the passing particles only in one direction. This effect is achieved because of the spatial shift of cavities in each pair by thequarter operating wave length and due to feeding cavities with the RF voltages shifted in phase by 90 degrees. The phase oscillations of two bunches can be presented as the sum of the in-phased and counter-phased oscillations. The in-phased mode of oscillations is suppressed by applying RF voltage of the even harmonics of the revolution frequency to the cavities and the counter-phased mode is suppressed by applying voltage of the odd harmonics.

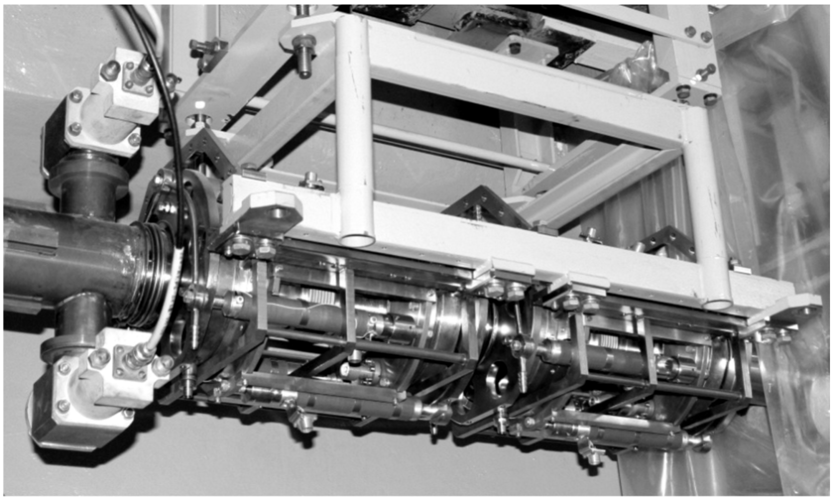


Figure 1: A wide band cavity – kicker.

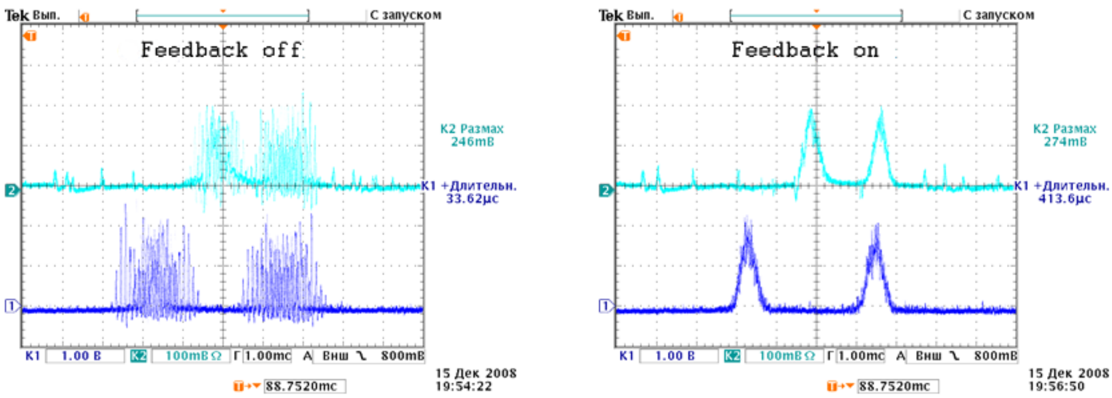


Figure 2: An oscillogram of the beam longitudinal oscillations with the feedback switched on.

According to the preliminary estimates, the damping decrement of longitudinal oscillations introduced into the storage ring is 500 1/s, which by several tens times increases the total decrement of the longitudinal oscillations in the storage ring. Oscillations of the beam with the feedback on/off are shown below in the oscillograms.

At present, the system is under final tuning. Upon completion, the feedback system will be put into standard operation.

Participants of the work:
Lab.6-2 staff- V.S.Arbuzov, S.A. Krutikhin, G.Ya.Kurkin, S.V. Motygin, V.N.Osipov, V.M.Petrov, E.A.Rotov, and DB staff- G.Ya.Kryuchkov.

7.8 RF system for TAE Laboratory

In 2008, by the contract with Tri Alpha Energy we finished the development and manufacture of RF systems for powerful injectors of neutral beams. The structural scheme of RF system is given in Fig.1.

RF system consists of the output circuit based on tetrode 4CW100000E produced by Eimac (USA), control rack, anode rectifier and uncoupling output transformer The system is located in three cabinets of the "Euromechanics" standard.

The generator output circuit is based on tetrode 4CW100000E according to the scheme with the common cathode and water cooled anode. Excitation to the control grid of the tube is applied from the transistor amplifier with a maximum power of 500 W. The output circuit is placed in a cabinet with the size 800*800*2000 mm^3.

Basic parameters of the system

Operation frequency, MHz	4 ± 3,5%
Load power, kW	60
Pulse duration, sec	0,1÷1,5
Duty factor	600
DC voltage at "antenna", kV	40

In the control rack there are: power supply sources of the screen and control grids of the thetrode, RF generator control which provides the generator switch on/off, protection circuits of the thetrode and power supply sources against emergency regimes as well as protection of personnel against electrical shock. In the same rack there is a modulator providing automatic tuning frequency of Master Oscillator (MO) and stabilization of RF voltage at "antenna". With the plasma in the source, the shunt impedance and the resonance frequency of anode circuit are changed. The MO frequency is tuned during RF pulse in such a way that RF voltage on the tube control grid and on the anode should always be in a counter-phase. As a result, the anode contour tuning to the resonance is kept.

The amplitude stabilization system keeps the given shape of RF pulse during variations of the shunt impedance in a plasma and also compensates the influence of ripples of the power supply sources. A +14 kV anode rectifier is based on diodes by the Larionovs scheme without the ripple filter. The rectifier power is 160 kW. The anode voltage control required for switching the generator on/off and for tube conditioning is performed by variation of the phase angle of thyristor opening in the of primary windings of the anode transformer. The rectifier is equipped with the system of the "fast protection" removing the anode voltage from the tube in 50 microsecond at the sparking in the tube. The anode rectifier is mounted in the cabinet with the size 800*800*2000 mm^3. The anode transformer is placed separately.

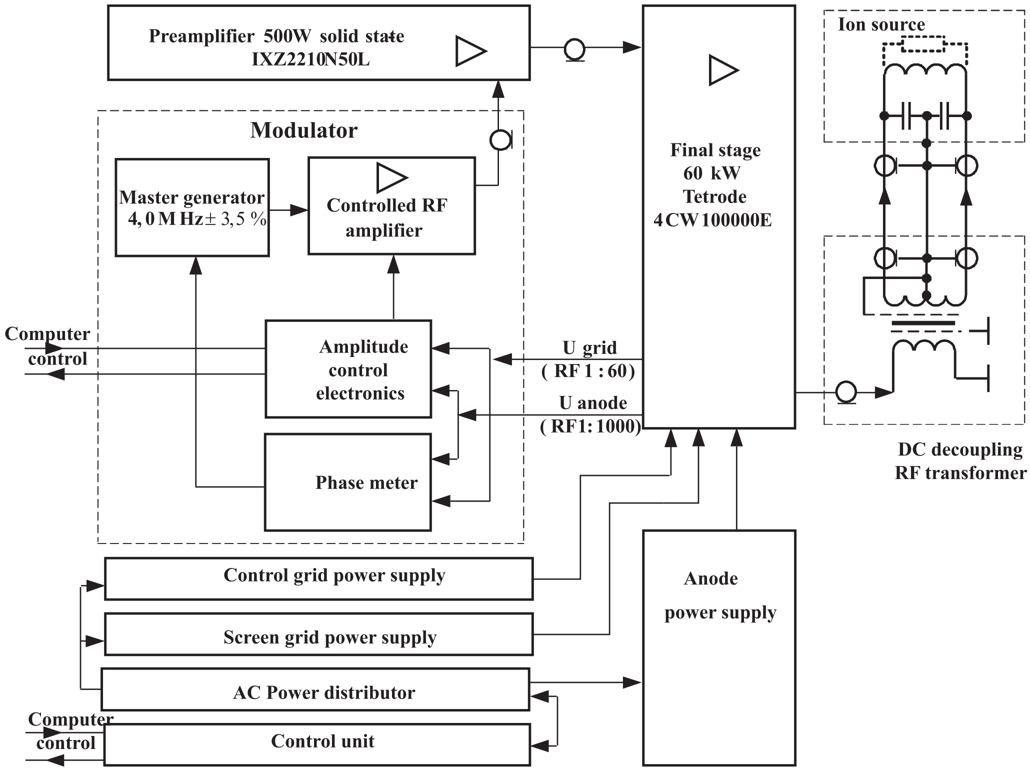


Figure 1: Structural diagram of RF system.

The isolation transformer provides the RF power transfer to an "antenna" being at the potential of 40 kV. The transformer core is made of the Fe-based soft magnetic alloy and placed in the tank filled with oil. The transformer secondary winding has the middle point thus enabling to perform the symmetrical connection of the antenna and thereby to reduce the parasitic radiation of RF power.

At present, all six sets of RF system are manufactured, mounted and put into operation in USA.

Participants of the work:
V.S.Arbuzov, V.L.Golovin, E.I.Gorniker, E.I.Kondakov, S.A.Krutikhin, G.Ya.Kurkin, A.S.Mayatsky, S.V.Motygin, V.N.Osipov, V.M.Petrov, V.A. Savchenko.

7.9 A 200 kW RF generator for VNIIEF (Sarov)

In Summer of 2008, the contract was made between the Budker Institute of Nuclear Physics and the Federal State Enterprise "Russian Federal Nuclear Physics Center" All Russian Research Institute of Experimental Physics in Sarov on the development of a 180 kW RF generator of continuous power at a frequency of 100 MHz. According to the contract conditions, BINP should design and manufacture the RF generator, its power supply system and radioelectronics units for RF power control. The generator has two RF stages based on thetrodes GU-92A and GU-101A, a 500 W transistor preamplifier, interstage 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 with the fast protection circuit, low voltage power supply sources, control system and RR generator protection. The power consumption of the generator power supply sources from the three-phase mains of alternate current 380 V/50 Hz is 400 kW. It was decided to produce two sets of the equipment. Now the stand is under assembly in Bld. 11, where the first RF generator will pass the load tests at 50 Ohm load and will be delivered to the customer. Then the second generator will be assembled whose frequency will be tuned down to 90 MHz for carrying out the test of the FEL injector RF gun. The required power of the generator for this test is 60 kW. For 6 months of 2008, the basic scheme of the RF circuits was developed and the design of the thetrode GU-101A based output circuit was completed. The drawings are submited to technological department for processing. We also developed the design and scheme of the power supply source, control circuits, interlocking and protection circuits of the RF generator. At present, the assembly of cabinets of the RF power supply commenced.

Participants of the work:
V.S.Arbuzov, K.A.Biryuchevsky, E.I.Gorniker, A.A.Kondakov, N.L.Kondakova, S.A.Krutikhin, G.Ya.Kurkin, N.V.Matyash, S.V.Motygin, V.N.Osipov, V.M.Petrov, V.V.Aksyonov, V.A.Savchenko, V.S.Stepanov.

7.10 Linear accelerator-injector of the TNK complex

At the TNK complex (Zelenograd), the 80 MeV electron Linear Accelerator (LA) is operated in a pulse mode with the repetition rate of 1 Hz. The accelerating structure with washers and diaphragms at the operating frequency of 2.8 GHz is composed of six 1 m long regular sections with the power input in the middle. The electron beam 4 A / 40 kV / 18 ns /1 Hz from the diode gun goes to the accelerating structure without preliminary bunching. The electron beam is transported from the linear accelerator to input of the booster synchrotron by electron-optical channel (EOC-1). At present, LA provides operation of the booster.

In 2008, complex we continued the work on linear accelerator at the TNK. In March-April, operation of the the klystron generator “Olivin” was recovered after damage of the solenoid and the klystron cooling system. It was necessary to produce a new “jacket” for cooling the solenoid and klystron KIU-53 and fully replace oil in the pulse transformer unit. At the same time, the operation regime of the system was recovered and the operation stability of the high voltage modulator “Olivin” was tested at high level of the anode voltage $\sim$ 230 kV. Breakdowns in the anode pulse were not observed.

Frequencies of the waveguide system were measured and the waveguide length was corrected aiming at finding its closest resonance frequencies symmetrical with respect to the LA operational frequency.

The linear accelerator as an electron beam injector at TNK was put into operation in October-November. To this end it was necessary:

1. to obtain an accelerated electron beam at the LA output and guide it along EOK-1 channel to the Faraday cylinder (FC);

2. to perform training of the linear accelerator at operation with the electron beam aiming to obtain electron beam energy of $\sim 70 \div 75$ MeV;

3. to put RF system into operation, to check stability of external triggers in automated regime.

Starting from 6-th November, LA complex operation was in the around-the clock work. The klystron station cooling system was operated continuously and after heating, its operation was stable. The linear accelerator body temperature was stabilized near the value 27°C. An intense RF training of LA structure with a beam enabled us to achieve the stable current of electron beam at injection with an energy over 70 MeV, which allowed to reach the stable regime of current accumulation $\sim$ 20-40 mA. All said above facilitated the successful conduct of a beam along EOK-2 channel to the Main ring input.

At present, the technical condition of the high voltage modulator "Olivin", gas part of the waveguide and operation conditions of LA allow to realize the linear accelerator operation and obtain an electron current with energy of 73-75 MeV providing operation of the booster synchrotron. Dependence of a current at FC at variations of a current in the bending magnet 2M1 was experimentally measured (see Figure1).

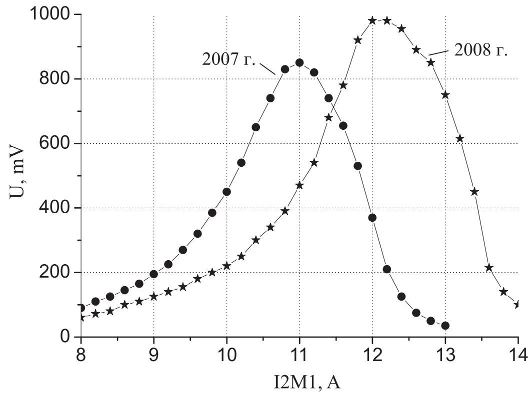


Figure 1: Dependence of a current at FC at variations of a current in the bending magnet 2M1.

Participants of the work:
Lab.6-2 staff: Ostreiko G.N., Serdobintsev G.V., Matyash N.V., Chernov K.N., Lab-8 staff: Ushakov V.A., Filipchenko A.V., Lab.6-1 staff: Kozak V.P., Tararyshkin S.V., Lab.1-3 staff: Anchugov O.V., Shvedov D.A.

7.11 Upgrade of RF system of the storage ring "Siberia-2"

The upgrade project for RF system of the storage ring Sibeia-2 was developed and technological drawings were prepared by the contract with RRC Kurchatov Institute, Moscow. In this project, in addition to the available section of two bimetal cavities, the third bimetal cavity will be manufactured and installed to replace the old two-chamber cavity. The new cavity will be installed into the storage ring in such a way that the distance between its center and a center of one of the section cavities will be equal to the operative wavelength. To these cavities, the power will be applied from a 200 kW generator. The second cavity of the section is supplied from another 200 kW generator.

Rf power from each generator is transferred along the waveguide with the crossection 986 x 150 mm^2. From the waveguide, power is applied to the cavity through the coaxial to waveguide transition and 75 Ohm coaxial feeder. A new scheme of installing cavities required the design of another system of the coaxial feeders providing the RF power distribution between cavities and optimum summing of accelerating voltages. The storage ring "Siberia-2" is operated at the maximum energy of 2.5 GeV. The synchrotron radiation losses in the bending magnets at this energy are of 681 keV per one turn and additional losses with switching on the superconducting wiggler are 340 keV. RF system is operated at a frequency of 181.14 MHz that corresponds to the 75th harmonic of the revolution frequency.

With the available maximum RF power of generators, the distribution of the accelerating voltages in cavities, loss power in cavities and for a beam as well as the ultimate current of the storage ring at maximum energy are determined. The calculation results are given in Table 7.1.

Table 7.1: Parameters of Siberia-2 and upgraded RF system

Parameters of storage ring Siberia-2	Electron energy	E max	GeV	2,5
	Total losses per turn	ΔEм + ΔW	кэВ	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	кВ	820
	Effective shunt impedance	2Reff.	MOhm	8,6
	Thermal losses in two cavities	2Pрез.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	Pres.2	kW	54
	Power transfered into the beam	P2beam	kW	139

At present, by technological drawings, experimental workshop started manufacture of the cavity and feeder components. The electronic units for RF control is under development.

Participants of the work:
Gorniker E.I., Kenzhebulatov E.K., Krutikhin S.A., Kuptsov I.V., Kurkin G.Ya., Motygin S.V., Osipov V.N., Petrob V.M., Pilan A.M., Rotov E.A., Sedlyarov I.K.; Lab.6-2. Deichuli O.I.-Lab.8-1, Kiselyova N.A.-RDB.

7.12 Preparation of the VEPP-4M RF system for operation at an energy of 4 GeV

For a long time, the VEPP-4M storage ring had been operated at a low energy of 1.5-2 GeV. In this regime, three cavities of five were tuned down in frequency and the total voltage of 600 kV was maintained only at two cavities.

In the processes of RF system preparation for its operation at higher energies, the power inputs were replaced at two earlier detuned cavities.

After replacement of the power inputs, their coupling with cavities was adjusted, the cavities were pumped out and vacuum of 10^{-8} Torr was obtained without baking out. In the course of further pumping the vacuum was improved.

By shifting the rods in the waveguide channel we established the coupling of the cavity with RF generator, which provided the acceptable operation regime of the output tube. All five cavities are driven from one RF generator. The total voltage of 2 MV was obtained at the 40 kW power applied from the RF power generator. In the storage ring VEPP-4M, a current of 15 mA was obtained at energy of 4 GeV.

In the output two-tube stage with tetrodes GU101A only one tube was in operation. The filament heater and RF driver were switched off for the second tube. In this regime the RF generator is capable to operate at 4 GeV and low energies without additional tuning.

When the second tube is switched on, the maximum output power of the generator increases up to 250 kW and the total voltage at five cavities can raised up to 5 MW.

Participants of the work:
Gorniker E.I., Kuptsov I.V., Sedlyarov I.K., (Lab.6-2); Erokhov V.N., Fomin M.Yu. (Lab.1-3); Mironenko L.A.(Lab.1-4).

7.13 Accelerating structure for the Linac4 new injector, CERN)

In 2008 we finished the work on the ICTC 2875 Project. Within the frame of the Project BINP jointly with RFNC-VNIITF (Snezhinsk) we developed and manufactured the prototype of the accelerating structure CCDTL (Cell-Coupled Drift Tube Linac). The prototype was successfully tested at CERN with operation parameters of the field intensity and duty factor. Proposals were prepared for the development of 7 accelerating structures CCDTL for Linac4 within the frame of two new projects of ICTC. The proposals obtained the financial support. The works will start in 2009.

Participants of the work:
Kenzhebulatov E.K., Rotov E.A., Tribendis A.G. (Lab.6-2); Kryuchkov Ya.G.(RDB).

7.14 Preparation of the physical substantiation for accelerating stations of the Booster of the accelerating complex NICA

In the Joint Institute of Nuclear Research (Dubna) (JINR), the project of the accelerating center NICA with colliding beams was developed on the base of the Nuclotron. The injector for Nuclotron will be booster synchrotron after some upgrade.

In April, 2008, the agreement was signed between BINP and JINR on the preparation of the conceptual design for accelerating stations for the booster. Table 7.3 shows parameters of the accelerating stations ordered by the customer.

Within the frame of the contract, the conceptual design was prepared for the accelerating stations that should provide the parameters given in Table 7.1.

During the bunch injection from the Booster to Nuclotron, accelerating systems of both accelerators are operated at the first harmonic of revolution frequency. The booster

Table 7.1: Parameters of accelerating stations.

№	Parameter	
1.	Frequency range, MHz	0.593 - 2.405
2.	Harmonic number	4/1
3.	External diameter of cavity, m	<1.2
4.	Chamber dimensions, mm	160 x 70
5.	Cavity length, m	$\leq$2
6.	Number of cavities	$\leq$4
7.	Voltage minimum amplitude at adiabatic capture, V	100
8.	Voltage amplitude at acceleration, kV	7 $\div$ 7.7
9.	Voltage amplitude during injection of a bunch into Nucleotron, kV	10

circumference is 216 m, the Nuclotron circumference is 251.52 V. A single bunch is injected. An accuracy of injection into the Nuclotron separatrix center is -1 ns. Coupling of the accelerating voltage frequency with the booster magnetic field is provided and correction of the frequency according to the beam position monitors is introduced.

Pressure in the vacuum parts of accelerating stations does not exceed $5{\cdot}10^{-11}$ torr. The booster RF system will have two accelerating station. The accelerating station consists of accelerating cavity, RF power generator with the power supply sources and control system. The accelerating cavity is the coaxial line shorted at ends. The inner pipe of the coaxial line has a gap in the middle. The coaxial line is filled with cores of amorphous magnetic alloy. The vacuum chamber is inserted into the inner pipe of the coaxial line. A ceramic insulator located in front of the gap of the coaxial line inner pipe is inserted into the vacuum chamber. Under the cavity, there is an RF power generator and its power supply source. The generator output stage has a push-pull schematic. In this stage, vacuum tubes EIMAC 4XC15.000A are used. The generator and cavity are combined in one unit.

The accelerating station control systems are included into the control system of the whole complex NICA. They provide the required frequency and amplitude of accelerating voltages for booster operation and synchronize operation of the booster RF system with all the systems of the accelerating complex.

The work on the contract was completed and it was accepted by the customer.

Participants of the work :
V.S.Arbuzov, Yu.A. Biryuchevsky, S.A.Krutikhin, G.Ya.Kurkin, V.M.Petrov, A.M.Pilan.

Chapter 8

Powerful Electron Accelerators and Beam Technologies

8.1 Radiation technologies and ELV-type accelerators

Introduction

In 2008 the laboratory continued to develop and deliver ELV direct-action accelerators to the customers. The accelerators were delivered to Republic of Korea, Singapore and "Kavkaz-kabel" Plant. The accelerators with technological lines in China, Kazakhstan, Singapore, "Kavkaz-kabel" Plant, "ROSSKAT" Ltd. were assembled and adjusted.

The experiments of development of electron-beam technologies have been carried out. Particularly, further examinations of electron-beam methods of oxide superdispersed powders were continued.

8.1.1 HITS injector

In the beginning of 2008 the decision to produce HITS injector on the basis of tandem high voltage source had been made. The initiator of this proposition was V.V.Parkhomchuk. For that time, in his laboratory the tandem with carbon negative ion source, charge-exchange target from magnesium vapor were already operating. The tandem was used for ion C^{13} separation in AMS facility.

Development and creation of injector were charged with Laboratory N 12 in cooperation with a team of S.G.Konstantinov dealed with ion source and channel to tandem, laboratory N 6 responsible for control electronics and power supply, laboratory N 5-2 working with magnesium target, optics and PC control.

During 2008 the tandem with two accelerator tubes, magnesium target and electronic control has been put together. High voltage tests of the system have been carried out. It was tested at 1.25 MeV voltage. Power supply has been inspected. In 2009 it is supposed to check working capacity of complete system.

8.1.2 High-automated complexes for electron-beam treatment of cable isolation

Technologies of radiation cross-linking of polymers are extensively used in the industry. The use of radiation-modified compositions on the basis of polyethylenes for wire (cable) isolation elevates considerably maximum operating temperatures. That enables to densify current in lead of a cable (conductive cable) and, thereby, to save expenses for costly metal (copper and aluminum) as well as to use cheap polyethylene instead of expensive teflon or polypropylene. Moreover, after radiation cross-linking the product scores other important advantages in comparison with untreated wires and cables. These are, first of all, reduction of deformities caused by mechanical loads, enhancement of chemical resistance, oil-resisting property, improvement of wear resistance, shape memory effect and initiation of shrinking availability. The use of electron-beam technologies gave an opportunity to develop the production of wide range of wires, cables, heat-shrinking products (heating cables, power and ship cables, airborne wires and cables, as well as atomic power plant

(A-plant) wires). All of them are of improved reliability at assembly and operation as in regular service and in extreme conditions.

Radiation quality depends on accelerator itself as well as on under-beam equipment. Thus, the accelerators should provide stability of electron beam parameters, such as energy, beam current and radiation band width. In order to enhance absorbed dose azimuthal homogeneity they should be provided by 4-side irradiation system. The main specification of the system of cable transportation through radiation zone is transportation rate of speed, which should be proportional to beam current rate. Proportionality coefficient called "specific rate" depends on the type of irradiated product and accelerator parameters. Taking into account information mentioned above, the specialists of the laboratory together with the customer's representatives formulated, firstly, the requirements and, after, worked out the high-automated systems for electron-beam treatment of cable isolation. With different contribution to the work, the specialists of the institute started up the complexes in "Podol'sk kabel plant", "Rosskat Ltd. (Russian Cable Technologies)", "Cable plant "Kavkaz-kabel"". High level of automation enables to reduce the quantity of service staff, operating at irradiation complex. Practically, there is no necessity in permanent presence of accelerator control panel operator. Effective visualization of irradiation process (energy, beam current, cable transportation speed) allows the operators of transportation line to control and set the treatment conditions directly at working place close by pay- off and take up machines.

<u>Accelerators</u>

At first, powerful ELV series accelerators (Figure 1) were developed for industrial applications.

Figure 1: ELV-8 accelerator design.

Our institute proposes ELV series accelerators with the energy from 0.4 up to 2.5 MeV and accelerated electron beam current up to 100 mA and maximum power up to 100 kW for polymer treatment. Due to high electron beam power in a wide energy range, high efficiency of electrical energy conversion into accelerated electron beam energy and easy control system, ELV series accelerators are the most popular accelerators in Russia, as well as in China and Republic of Korea. Recently, more than 120 accelerators were produced and delivered to industrial enterprises and to research-and-development centers of Russia and some foreign countries. The main parts of these accelerators are successfully used for cable isolation treatment.

4-side irradiation system

In due time, the laboratory proposed to develop the system of 4-side irradiation, which allowed us to enhance dramatically the quality of cable products treatment. Together with enhancement of absorbed dose azimuthal homogeneity, this method enables to decrease accelerated electrons energy, that considerably expands the range of accelerator applications in the area of irradiation of big diameter cables. New system of irradiation exchanged the traditional early applied systems of 2-side irradiation and enhanced the quality of manufactured products and raised labour productivity. The cables are laid out under the beam in such a way that at each turn (lap) the upper and lower surfaces of a cable swap their places. If beam trajectories are crossed 90° angularly, than, taking into account the exchange of surfaces, 4-side irradiation is achieved. It is important that the cable passes the irradiation zone few times. Figure 2 and Figure 3 shows the extraction device with 4-side irradiation system.

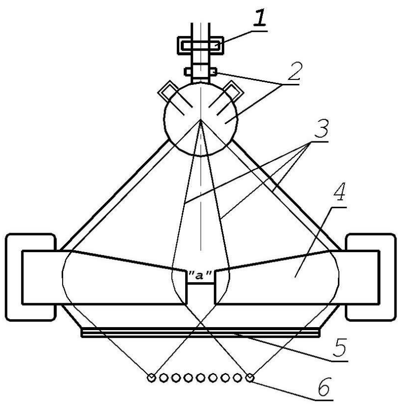


Figure 2: 4-side irradiation forming principle.

Figure 3: 4-side cable irradiation.

Under-beam transportation system

Universal under-beam transportation system (UBTS) was developed in our laboratory. Its design is shown in Figure 4.

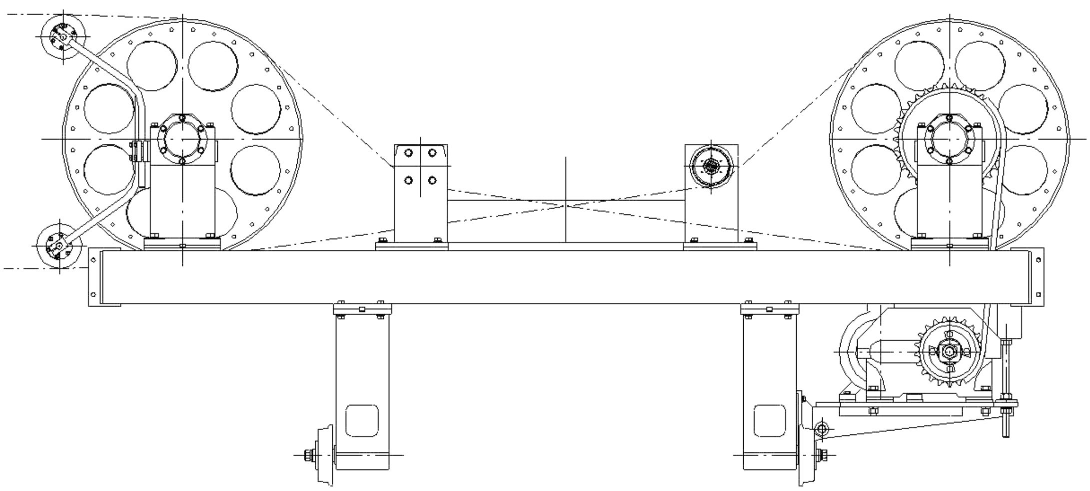


Figure 4: UBTS sketch.

UBTS consists of 2 drums, one of which is driving and another one is guided. That reduces the risk of stretching of treated product and prevents the decrease of cable cord diameter. Big diameters of the drums (900 mm) allow treatment of monoconductor cable with 36 mm^2 section (Figure 5) and exchange tape guide rollers enable to treat multiconductor cables with the diameter up to 42 mm. Minimum pitch diameter of treated wire for this facility is 1 mm, but during the experiment we successfully irradiated cable of 0.12 mm^2 (Figure 6).

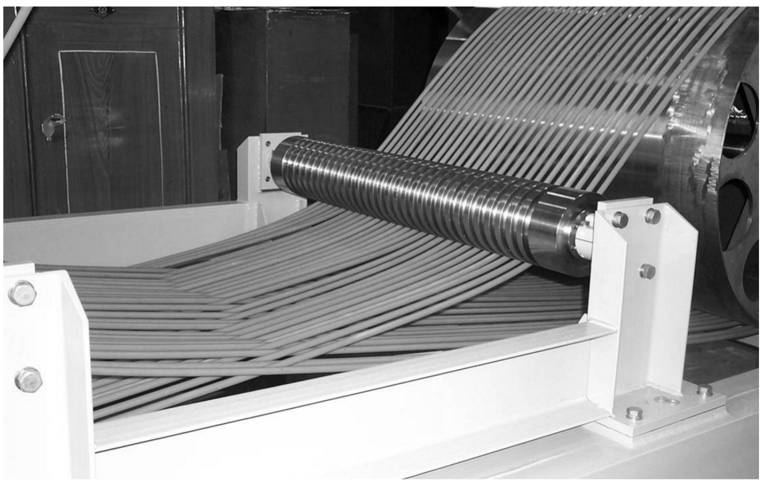


Figure 5: Cable wire bar of 36 mm^2 cord section.

Irradiated chamber with UBTS, extraction device and 4-side irradiation system delivered to “Rosskat Ltd”. is shown in Figure 7. In UBTS we use the asynchronous motor (induction motor) with frequency drive. The rotation frequency is set by accelerator control system. The operation drive has a wide dynamic range, that is proportionality between transportation speed and beam current is saved within wide speed range. That enables to realize a smooth start of the technology and to refuse movable target. Irregularity of absorbed dose at UBTS acceleration from 0 right up to 250 m/min does not exceed 5%.

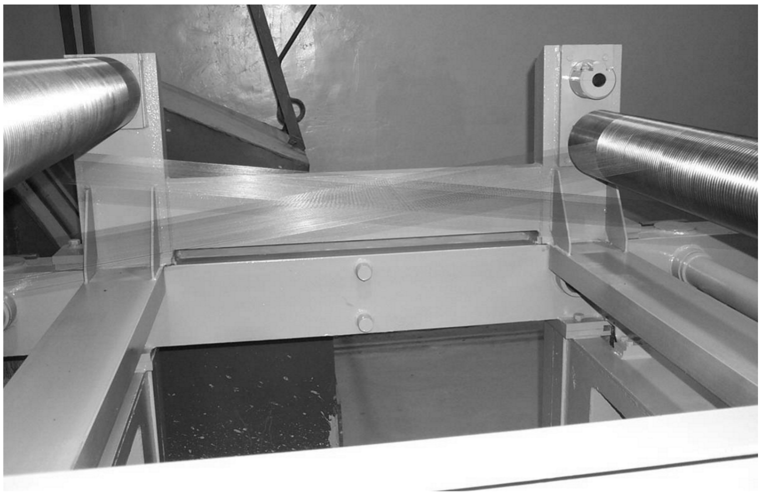


Figure 6: Cable wire bar of 0.12 mm^2 cord section.

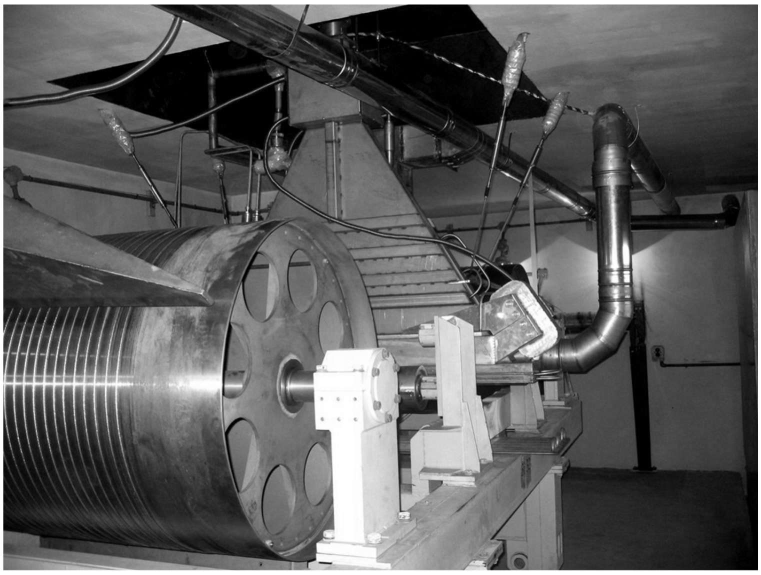


Figure 7: Irradiation chamber at "Rosskat Ltd".

Pay off and take up machines

Unfortunately, pay off and take up machines of cable industry are not universal for wide spectrum of diameters of treated cables (and wires). That is why during irradiation process when exchanging one type of a cable into another one, it is necessary to change pay off and take up machines. Thus, at Podol'skkabel plant, there are 6 pay off and take up machines, manufactured by VNIIKP-MASh Ltd., which are meant for 2 accelerators. They enable to treat 3 types of cables of 42 to 1 mm diameters. Each accelerator may operate at the same time together with any two pay off and take up machines. All units control (accelerator, UBTS and pay off and take up machines) is automated. Though, the master system is accelerator control unit and the systems of cable transportation are driven ones. Present approach enables to carry out complete automation of full the equipment complex for irradiation and transportation of treated wires (cables) by means of simplest soft hardware. In Rosskat Ltd. the accelerator is joined with pay off and take up machines manufactures by company "Rosendal" (Austria). The main characteristic property of this complex is and absence of compensator accumulators before pay off and take up machines, and necessary control system parameters are provided by electron methods. The plant “Kavkaz-kabel” operates with pay off and take up machines and compensators of domestic manufacture, which are perfectly joined with accelerator control system. The most impressive is accelerator ELV-4 supplied to “Salipt” Company in Dongguan city in China. There are 6 pay off and take up machines, which are joined with 1 accelerator (Figure 8).

Figure 8: Pay-off and take up facilities in “Salipt” Company, Dongguan city, China.

Data-computing center

Treatment information is displayed at the screen.

Its size allows reading the information from any point of working room. The following parameters are permanently shown: energy, beam current, line speed, the quantity of residual cable at pay-off drum, the time necessary for treatment of this cable residue.

Conclusion

Due to high quality of isolation treatment confirmed by long secure service of cables in extreme conditions of oil industry we may insist that 4-side irradiation method together with given set of the equipment and control system aufbau principles will be needed today and in future.

Participants of the work:
M.E. Veis, N.K. Kuksanov, R.A.Salimov, P.I.Nemytov, Yu.A.Golubenko, A.I.Korchagin, S.N.Fadeev, A.V.Lavruckin, D.A.Kogut, I.K.Chakin

8.2 Accelerators type ILU and their applications

8.2.1 Accelerator Deliveries

Since 1983 ILU type accelerators are delivered all over the world. They are used for research works and for work in the industrial technological lines. Some of these machines are operating 2-3 shifts per day during many years. Their reliability and technological level are proved by new deliveries of the equipment.

The accelerator ILU-10 with energy of 5MeV and beam current up to 10mA was mounted and put into operation in the firm "RadPol", Poland. This accelerator is the basic element of the line for irradiation of polymer products. The technologies for 4-sided irradiation of thick-wall polyethylene tubes and joints for high voltage cables.

The accelerator ILU-8 was manufactured under the contract with the firm "Chuvashkabel", town of Cheboksary, Russia. The delivery, mounting and put into operation of this machine is planned for 2009. The machine will be used for irradiation of wires. The local radiation shield for this machine is drawn and is in the state of manufacturing.

The accelerator ILU-10 with energy of 5 MeV and beam current up to 10 mA was manufactured and commissioned under the contract with the firm "Siberian Center for Pharmacology and Biotechnology", Novosibirsk, Russia.

8.2.2 Development of new beam scanning system for ILU accelerators

The new active beam scanning system for ILU accelerators was developed, manufactured, mounted and tuned. This system is put into operation as an element of the new ILU-10 machine that was put in operation in 2008 in Poland. The scanning magnets in this system are fed from the separate power supply independent from the accelerator's power supply system. The scanning magnet feeding pulse is formed by discharge of the storage capacity through the inductance of the scanning magnet and correction LC chain. The new beam scanning system permitted to provide the dose field uniformity at the level of ±5% in the wide range of pulse beam current and pulse repetition rate up to 50 Hz.

8.2.3 Development of modular industrial electron accelerator ILU-14

The linear accelerator ILU-14 is the new machine in the ILU line. It is the powerful (up to 100 kW) multi-gap multi-cavity modular machine purposed for energy range of 7.5-10 MeV. The machine to be mounted using the modules of the accelerating structure (accelerating and connecting cavities) and modules of the RF stages on the triode tubes GI-50A. Each module is the finished device that is the commercial product of the Experimental Workshop of the Institute. The parameters of the machine are determined by the set of the modules suiting the needs of the end-user.

The most demanded machine for today is the accelerator for energy range of 7.5 - 10 MeV and average beam power up to 100 kW. This machine can work either in electron beam mode or in X-ray mode (Bremsstrahlung generation mode). It can compete with other accelerators and with isotope sources on the market of the irradiation installations. The working parameters of the machine are given in Table 8.1.

Table 8.1: ILU-14 Parameters.

Electron energy, MeV	7.5÷10
Working frequency, MHz	176
Energy dispersion (r.m.s.),%	3.5
Accelerating structure efficiency,%	72
Plug-to-beam efficiency, %	$\sim$ 30
Accelerator dimentions, m	8x2x2

The flow block scheme of the ILU-14 machine is given in Fig.1.

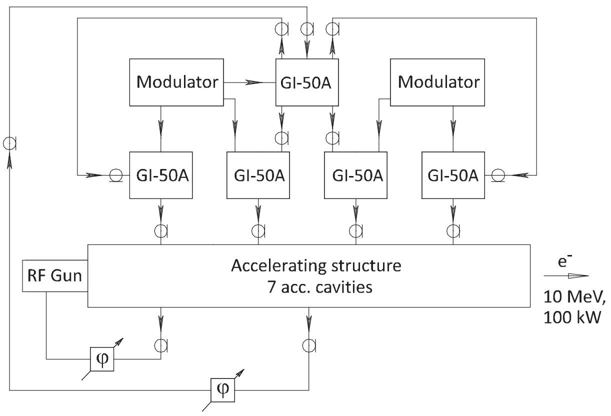


Figure 1: The scheme of the ILU-14 machine for energy of 10 MeV and beam power up to 100 kW.

Main elements are:

– biperiodic accelerating structure with 7 accelerating cells and on-axis coupling cavities;

– RF autogenerator containing 5 stages on GI-50A triodes;

– 4 RF power inputs;

– triode RF gun with possibility to apply the RF voltage to the grid-acthode gap;

– 2 modulators.

The modular structure of the accelerator permitted to test the main accelerator elements on the special test bench in the radiation bunker. The flow block of the test bench is given in Fig.2.

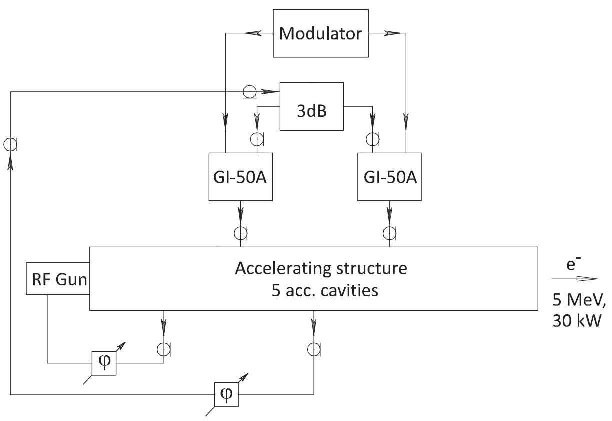


Figure 2: The flow block of the test bench.

The test bench comprises the modular accelerating structure, RF autogenerator on 2 stages and modulator (power supply) for ILU-8 machine. All the components except for modulator are the ILU-14 modules. The accelerating structure (see Fig.3) is the chain of the couples cavities.

The RF power from the autogenerator (Fig.4) is supplied via 2 lines with length of 2λ and 2 RF power inputs into the accelerating structure. The feedback loop takes away from the accelerating structure approximately 300 kW of RF power for feedback. This feedback RF power is supplied to the 3 dB bridge where it is divided fifty-fifty and then supplied to the RF stages inputs. The output power of the ILU-8 modulator is not very high, and it could permit to work with pulse repetition rate only up to 35 Hz.

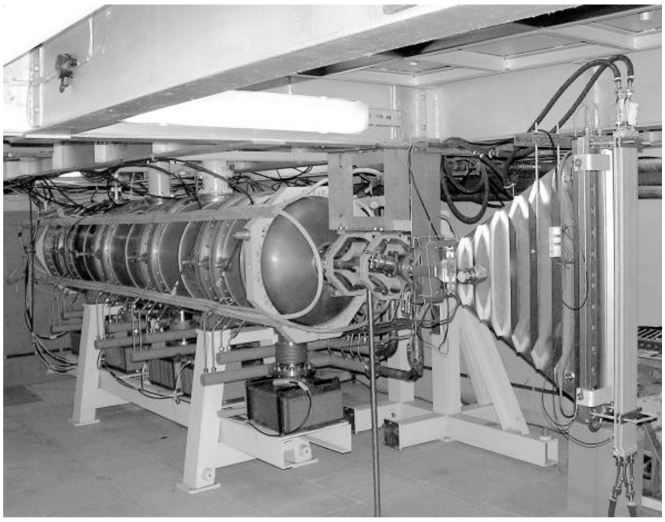


Figure 3: The modular accelerating structure for energy of 5 MeV on the test bench.

Figure 4: RF autogenerator on GI-50A triodes.

The permitted to check the following:

• electrical strength of the accelerating structure at the acceleration rate corresponding to ILU-14 work at energies of 7.5 MeV and 10 MeV);

• efficiency of accelerating structure cooling;

• injection of the required pulse beam current by the RF electron gun;

• to measure beam energy spectrum and beam transportation efficiency coefficient;

• RF power system elements (RF power inputs, feeders, etc.) capacity for work.

The results of the experiments:

• Maximum energy 7.5 MeV;

• Maximum pulse beam current of 600 mA at energy of 5 MeV;

• Maximum beam transportation efficiency of 96%;

• Maximum pulse beam power of 2.9 MW;

• Electron structure efficiency of 73% at energy of 5 MeV;

• Average beam power of 33 kW at pulse repetition rate of 35 Hz.

The common work of the Sector 6-21, Laboratory 6-2 and Laboratory 6-0 on ILU-14 development will be continued in the year of 2009.

8.2.4 Development of new technologies

The complex oxide compositions were synthesized by thermal-radiation technology. The contract sterilization works were performed all over the year. The works were carried out on working accelerators ILU-6 and ILU-10.

Participants of the work:
A.A. Bryazgin, V.V. Bezuglov, V.A. Gorbunov, I.V. Gornakov, A.M. Molokoedov, L.A. Voronin, M.V. Korobeynikov, A.N. Lukin, I.G. Makarov, S.A. Maksimov, V.E. Nekhaev, G.N. Ostreyko, A.D. Panfilov, V.V. Podobaev, V.I. Serbin, G.B. Serdobintsev, A.V. Sidorov, V.V. Tarnetskiy, M.A. Tiunov, V.O. Tkachenko, A.A. Tuvik, B.L Faktorovich, V.G. Cheskidov, A.M. Yakutin.

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[169]÷[172], [239], [389], [394]÷[396], preprints 4, 10, 11.

Chapter 9

Physics for medicine

9.1 The works on creation of accelerator based neutron source for neutron-capture therapy and fast neutron therapy

The physical project of neutron source was published in Nuclear Instruments and Methods in Physics Research A 413/2-3 (1988) 397-426.

Designed scheme of the tandem was described in 2001 Year Report and designed scheme of the complex for explosive detection by nuclear resonant absorption method and for boron neu-tron-capture therapy was described in 2004 Year Report.

9.1.1 Results obtained in 2008

We have achieved the stationary operation regimes of the source with the beam current from 1 mA to 5 mA and energy from 17 kV to 21 kV at the input of low energy tract opposite the beam current from 0.2 mA to 2 mA at the output of low energy tract.

With the purpose of modernization of ion source:

• nonseparable metal-ceramic unit of ion-optical system was changed for collapsible unit.

• There were installed the additional heat-resistant shields inside the system of ion source and was increased the cooling of high voltage (h.v.) accelerating electrode platform.

• It was manufactured the new separation and control system for cooling distillate in different units of source.

With the purpose of reliability growth of h.v. source feed system we tested the silicone liquid (Sophecsil), as insulation for h.v. units, placed inside the tanks, instead of the SF6. Tests were successful.

The project of working pumping system replacement for more productive one (with arc-titanic spray-type pumps) was prepared also.

The heavy-current and new design ion source was tested last year. During more than 160 hours cycle in the test bench experiments ion source produced current equal to 15 mA.

The single electrostatic lens (Figure1) was designed and manufactured for the purpose of more effective beam focusing before the inlet of low energy tract. The lens is prepared for research work and tests in the test bench.

The tandem was exploited without dismantling approximately 2 years. In free mode regime (without current) the period between breakdowns under 1 MV voltage was fixed equal to some hours.

For the purpose of more effective exploitation of glass-metal units indium gaskets the upper component of power unit for feedthrough insulator was designed and manufactured.

For more effective pumping of ion source gas the arc-titanic spray-type pump was manufactured and tested.

We began the research work with the radiation fields of tandem.

It was finished the high voltage tract unit alignment (Figure2). By means of laser beam, passed along tract geometric axis, the tract units deviation is less, than 1 mm.

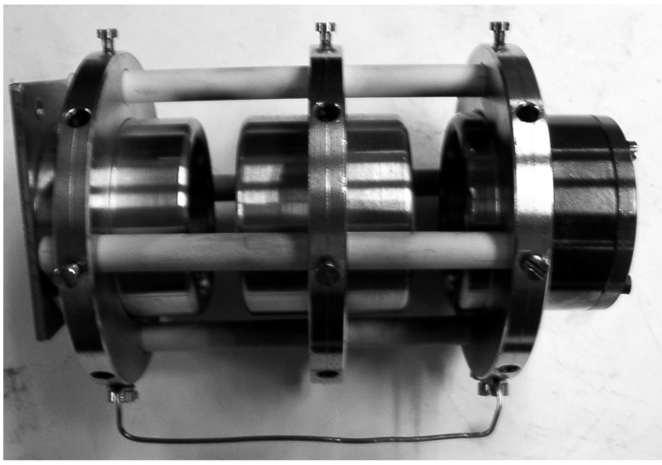

Figure 1: The single electrostatic lens.

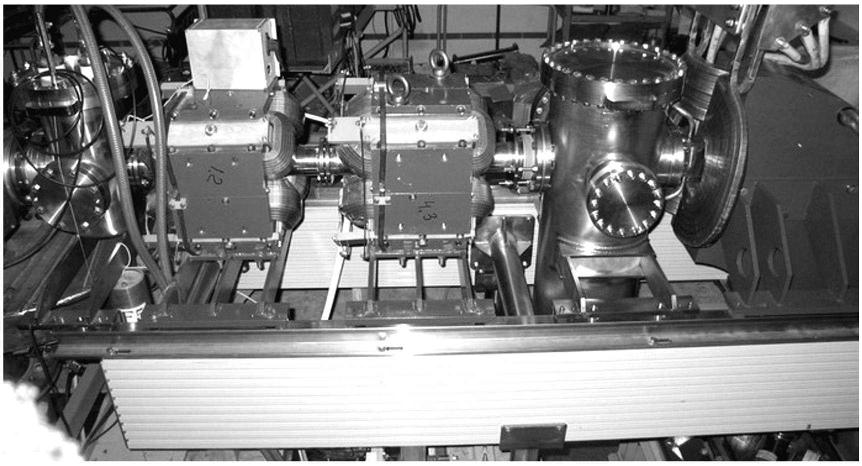

Figure 2: Horizontal part of the high energy tract. At the center – a pair of quadrupole lenses, to the right – the bending magnet.

There were completed the experiments with 1.84 MeV and (100-200) mkA proton beam, passing through high voltage tract. The beam diameter before the inlet of bending magnet was determined as 15 mm.

The beam current was measured by secondary-emissive detectors before the inlet of bending magnet, after the outlet of bending magnet and on the surface of lithium target. The beam passes through magnet practically without losses.

The bending magnet current observed dependence is very agreed with calculated one.

We focused the proton beam diameter up to some mm on the surface of graphite target, placed before the bending magnet, by using of pair of quadrupole lenses. The quadrupole lenses currents observed dependence is very agreed with calculated ones also.

The new, improved gamma detector on the base of big BGO crystal (diameter = 80 mm and length = 100 mm) has allowed to increase the effectiveness of gamma - rays registration up to 96%.

The cycle of experiments for generation and resonant absorption gammas with energy 9.17 MeV in nitrogen was made by means of improved gamma diagnostic.

We have suggested new method for normalization the measured data: using nonresonance spectral line with gamma energy equal to 8.06 MeV. We can do more accurate measuring thanks to penetrability of such gammas is similar to penetrability of resonant gammas.

During the cycle of experiments for generation the gammas we used thin target: 5 μm tantalum foil, as a base for 0.53 μm ^{13}C layer. Upper layer was dusted on the surface of tantalum by laser ablation method. We measured excitation curve under gammas energy equal to 9,17 MeV. This experiment has allowed to specify the momentary instability of proton beam energy. The momentary instability is equal to 0,07% from beam energy.

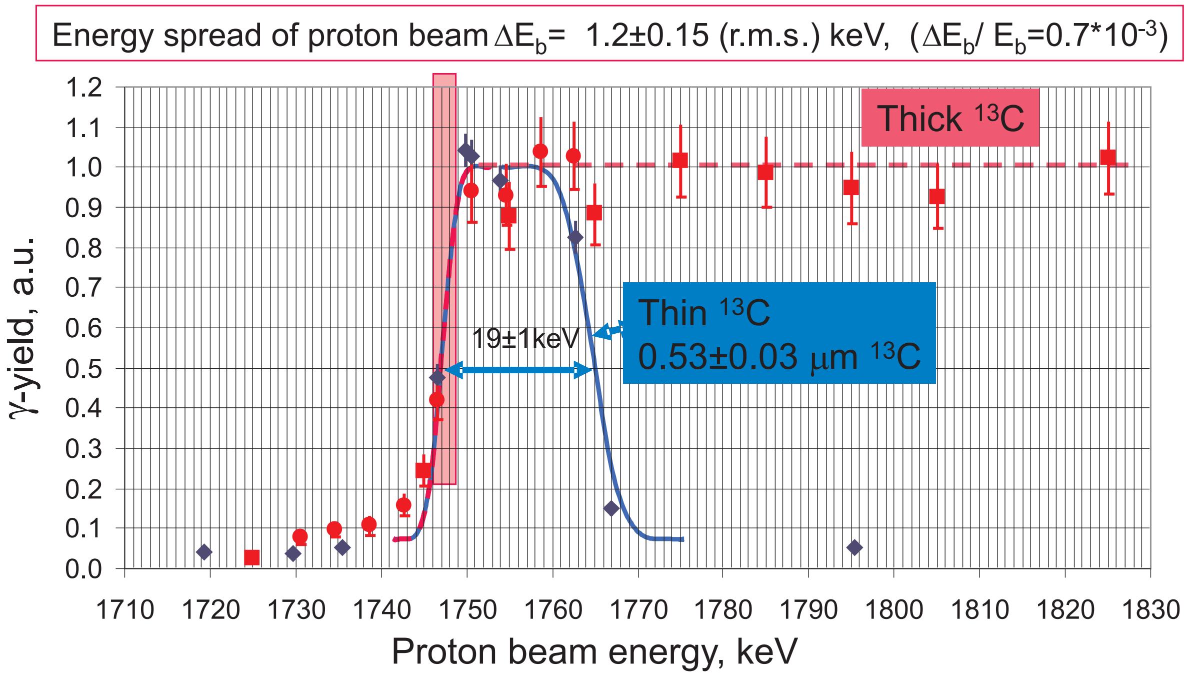

Figure 3: The excitation curves for the thick and thin targets.

The cycle of experiments for gammas absorption inside nitrogen-containing substance (melamine with different thickness) has been demonstrated, that gammas flow resonant attenuation considerably exceed the measurement error. Thanks this result, we can detect the nitrogen-containing substances in vitro rather surely.

Also it was assembled and prepared for the tests the mobile target, which can operate under increased proton beam power up to 2.5 kW/cm^2. Using this target, we‘ll can detect the nitrogen- containing substances in the real time scale.

In 2008, for the first time, on BNCT we have generated neutrons under dropping 1.92 MeV proton beam onto lithium target. We have limited proton beam current up to $\sim$ 100 mkA over radiation safety of activated target during the starting experiments.

On the base of NaI diameter 6 cm and length 6 cm crystal and Photonis XP3312B photomultiplier was manufactured and calibrated the gamma - detector. Together with detector we combined the fast-acting spectrometric ADC, collimator and program system for gamma spectrum analysis. Gammas appear as the result of dropping proton beam onto lithium target.

Figure5 shows the measured gamma-spectrum of the lithium target when the 1.7 MeV proton beam (below, than threshold of reaction for neutron generation) and with beam energy equal to energy of threshold i.e. 1.92 MeV). The bright spectrum line corresponding

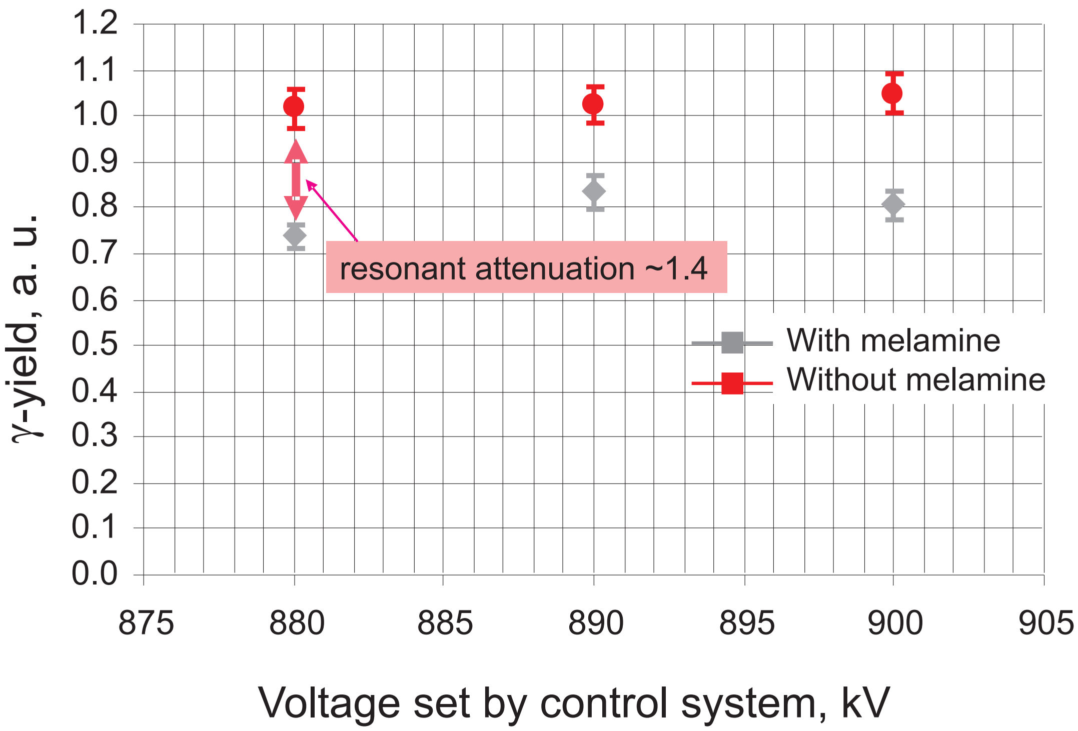

Figure 4: The resonant absorption gammas inside the melamine 38 cm target.

to 477 keV, corresponding to lithium nuclei excitation by protons, is observed in the below threshold spectrum.

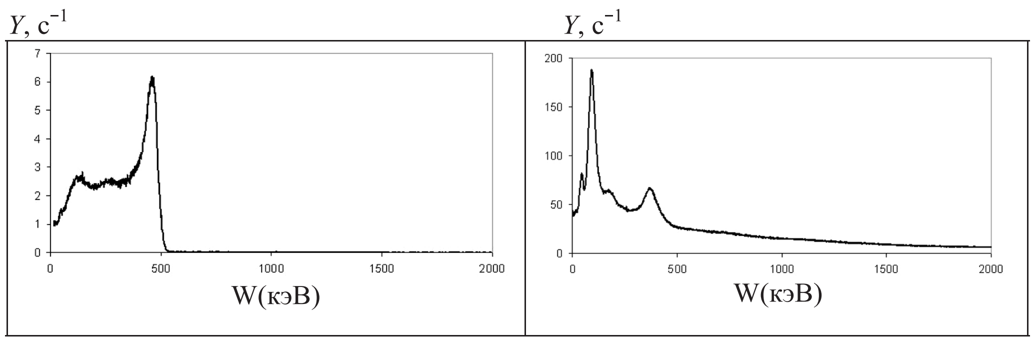

Figure 5a. Gamma - spectrum for 1.7 MeV proton energy.

Figure 5b. Gamma - spectrum for 1.92 MeV proton energy.

In the neutron generation regime it was appeared gammas from neutron adsorption by constructive material of complex, but especially from neutron adsorption by iodine in the detector scintillator.

The NaI detector can be used as an activation detector thanks to it's high response to neutrons.

The produced (after capture of epithermal neutrons mainly on the iodine nuclei) isotope ^{128}I decays with ejection of 2.2 MeV electron (probability is 93.6%). Besides ^{128}I, there is isotope ^{24}Na with velocity of appearance equal to 2% velocity of appearance ^{128}I.

Figure 6 shows the activation detector spectrum after neutron generation has been made. Such spectrum is similar of β-decay spectrum. The velocity of detector activation was determined from counting rate and time of neutron generation and current of proton

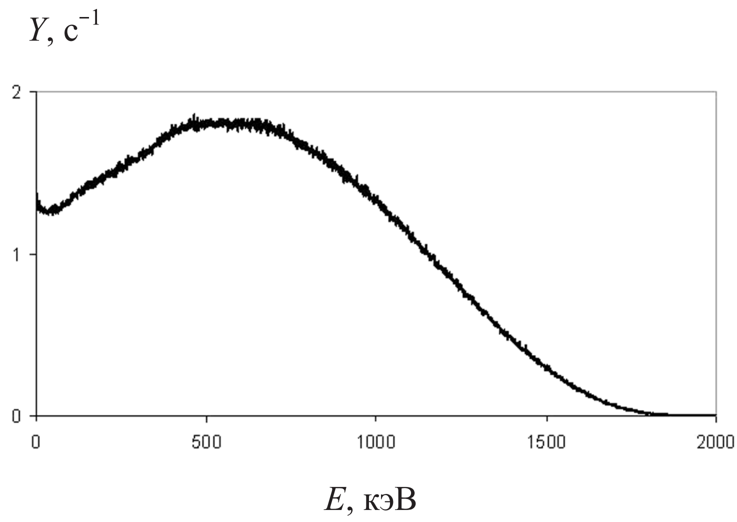

Figure 6: Gamma - spectrum of activated detector.

beam was calculated by MCNP method. Calculated current was in a good agreement with experimental one (140 mkA).

After experiments on generation of neutrons, the neutron generating target was removed for measurements of its activity. So, for example, the measured activity of $4 \cdot 10^5$ s^{-1} was equal to calculated activity (with accuracy of 4%) and corresponds to generation of $2 \cdot 10^{12}$ neutrons.

For the primary analysis of neutron generated spectrum we used bubble - detectors BDT и BD100R (Bubble Technology Industries, Canada). BDT looks as transparent retort fill by polymer with impregnation of overheat liquid. The BDT maximum sensitivity for heat energy neutrons is equal to $\sim 10^{-3}$ bubbles/neutron$\cdot$cm^2. BD100R is the other, has the maximum sensitivity for more, than 100 keV neutrons. In our experiments we registered the ratio bubbles in BDT detector and bubbles in BD100R detector equal to 15-20. This ratio corresponds to calculated spectrum with average energy 40 keV, realized in near threshold regime.

Work results are presented publications:

[137]÷[149], [370], preprint 14.

9.2 X-ray detectors for medicine and examination of people

9.2.1 Medical Radiography

In 2008, we developed the project of the medical radiographic device MARC (abbreviation of the Russian name Combined Radiographic Low Dose Apparatus) that enables to get the shot of the whole patients body (in a lying position) with the size 2000x660 mm^2 with the resolution of 250 μм (of a pixel size) with a low dose of irradiation. After obtaining the observation shot and its analysis, it is envisaged a possibility of an additional study of the suspicious locations with the help of a small detector with high resolution of 50 μm (of a pixel size). The detector for this apparatus was developed and the pilot sample is currently in the process of it production. The detector for LDRD Siberia device was upgraded. The device with a new 1536 channel detector was put into operation in a hospital of the Tomsk Research Center. With the aim of improving the image quality, we measured at the device LDRD Siberia the background caused by the scattered radiation. We made some changes in the device, which allow to reduce the influence of the scattered radiation to the image quality. For ZAO Nauchpribor (Oryol), five 1024-channel detectors and four pieces of 1536-channel detectors have been produced and delivered for fluorographs FMZ-MP-O (a modification of the LDRD Siberia device).

9.2.2 RCS Radiaographic Control System "Sibscan" for examination of people

A draft version of the modified device RCS Sibscan is developed, which is designed for its use in the penal settings. The work on preparation of the technological documentation for production of the device is in good progress. The first system of radiographic control produced by BINP license in China by the firm Nuctech is installed and successfully operated in the airport of Beijing. Within the frame of the contract Nuctech produced and delivered to BINP 5 detectors D768 for the complete set of RCS Sibscan.

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[137], [138], [139], [140], [141], [142], [143], [370], [144], [145], [146], [147], [148], [149].

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89. *Aubert B., ..., Blinov V.E., Bukin A.D., Buzykaev A.R., Druzhinin V.P., Golubev V.B., Onuchin A.P., Serednyakov S.I., Skovpen Yu.I., Solodov E.P., Todyshev K.Yu., (BABAR Collaboration).* Branching fractions and CP-violating asymmetries in radiative B decays to $\eta K\gamma$. // SLAC-PUB-13228.

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91. *Aubert B., ..., Blinov V.E., Bukin A.D., Buzykaev A.R., Druzhinin V.P., Golubev V.B., Onuchin A.P., Serednyakov S.I., Skovpen Yu.I., Solodov E.P., Todyshev K.Yu., (BABAR Collaboration).* Measurement of the CKM angle γ in $B^0 \to \bar{D}^0(D^0)K^{*0}$ with a Dalitz analysis of $D^0 \to K_S\pi^+\pi^-$. // SLAC-PUB-13229.

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94. *Corti G., Shekhtman L.* Estimates of the remanent dose rates in the LHCb experimental area. // e-Print: LHCb-2008-045, CERN, Geneva, 2008.

95. *Dikansky N.S., Pestrikov D.V.* Effect of the crab waist and of the micro-beta on the beam-beam instability. // doi: 10.1016/j.nima.2008.12.066. - NIM in Physics Research A (in press).

96. *Dikansky N.S., Pestrikov D.V.* Compensations of beam-beam resonances using crab-bibg schemes at large Piwinski crossing angles. // doi: 10.1016/j.nima.2008.12.211. - NIM in Physics Research A (in press).

97. *Achasov M.N., Aulchenko V.M., Beloborodov K.I., Berdyugin A.V., Bogdanchikov A.G., Bukin A.D., Bukin D.A., Dimova T.V., Druzhinin V.P., Golubev V.B.,. Koop I.A, Korol A.A., Koshuba S.V., Lysenko A.P., Pakhtusova E.V., Perevedentsev E.A., Serednyakov S.I., Shatunov Yu.M., Silagadze Z.K., Skrinsky A.N., Tikhonov Yu.A., Vasiljev A.V.* Study of the process $e^+e^- \to \mu^+\mu^-$ in the energy region 980, 1040-1380 MeV. // e-Print: arXiv: 0810.0571.

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99. *Grozin A.G.* Asymptotic freedom: History and interpretation. // arXiv: 0803.2589 (22p).
100. *Grozin A.G., Lee R.N.* Three-loop HQET vertex diagrams for B^0–$\bar{B}^0$ mixing. // arXiv: 0812.4522[hep-ph], 12p.
101. *Grozin A.G., Khriplovich I.B., Rudenko A.S.* Electric dipole moments, from e to τ. // arXiv: 0811.1641, 4p (to be published in Yad. Fiz.)
102. *Lee R.N. and Milstein A.I.* Correction to the Molière's formula for multiple scattering. // arXiv: 0812.2076 [physics.atom-ph].
103. *Kirilin G.G. and Lee R.N.* $(\mathbf{Z}\alpha)^4$ order of the polarization operator in Coulomb field at low energy. // arXiv: 0812.2076[physics.atom-ph].
104. *Sokolov Valentin V., Zhirov Oleg V.* How well a quantum system can retain memory of its initial state? // Preprint: arXiv:0808.3050v1[nlin.CD], 22 August, 2008.
105. *Sokolov Valentin V., Zhirov Oleg V., Benenti Giuliano, and Casati Giulio.* Complexity of quantum states and reversibility of quantum motion. // Preprint: arXiv:0807.2902v1 [nlin.CD], 18 July, 2008.
106. *Хриплович И.Б.* Черенковское излучение частицы со спином. // arXiv: 0808.1500.
107. *Khatsymovsky V.M.* Barbero-Immirzi parameter in Regge calculus. // arXiv: 0804.2389[hep-th].
108. *Khatsymovsky V.M.* Gravity action on discontinuous metrics. // arXiv: 0808.1039[gr-qc].
109. *Khatsymovsky V.M.* Independent 4-tetrahedra connection representation of Regge calculus. // arXiv: 0808.1041[gr-qc].
110. *Khatsymovsky V.M.* Defining some integrals in Regge calculus. // arXiv: 0808.1042[gr-qc].
111. *Khatsymovsky V.M.* Attributing sense to some integrals in Regge calculus. // arXiv: 0810.1630[math-ph].
112. *Flambaum V.V., Auerbach N., Dmitriev V.F.* Coulomb energy contribution to the excitation energy in ^{229}Th and enhanced effect of α variation. // arXiv: 0807.3218v2.
113. *Dmitriev V.F.* α-Particle spectrum in the reaction p+^{11}B$\rightarrow \alpha +^8 Be^* \rightarrow 3\alpha$. // arXiv: 0812.2538v1.
114. *Khriplovich I.B., Pomeransky A.A., Produit N., Ruban G.Yu.* Passage of small black hole through the Earth. Is it detectable? // Preprint: arXiv:0801.4623[hep-ex].
115. *Chernyak V.L.* On mass spectrum in SQCD. Unequal quark masses. // arXiv: 0805.2299[hep-th], p.1-17 (submitted to JHEP).
116. *Chernyak V.L.* On mass spectrum in SQCD, and problems with the Seiberg duality. Another scenario. // arXiv: 0811.4283[hep-th], p.1-22 (submitted to JHEP).
117. *Bondar A., Buzulutskov A., Grebenuk A., Pavluchenko D., Snopkov R., Tikhonov Y., Breskin A.* Thick GEM versus thin GEM in two-phase argon avalanche detectors. // e-Print: arXiv:0805.2018.
118. *Bondar A., Buzulutskov A., Grebenuk A., Pavluchenko D., Tikhonov Y.* Recent results on the properties of two-phase argon avalanche detectors. // e-Print: arXiv:0807.0530.

Авторефераты

1. *Buzulutskov A.F.* Detectors of ionizing radiation and photodetectors based on gas electron multipliers. // 01.04.01 - instruments and methods of experimental physics, Author. papers of thesis for the degree of doctor of phys.-math. science: Novosibirsk, 2008, BINP, SB RAS.
2. *Miginsky S.V.*. Оптимизация электронно-оптических каналов на основе модели локально холодного пучка. // Optimization of electron beam lines in terms of locally cold beam model. // 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, 2008, BINP, SB RAS.
3. *Ignatov F.V.* Measurement of the pion form-factor in the energy range $1.04 - 1.38$ GeV 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, 2008, BINP, SB RAS.
4. *Rachek I.A.* Experimental study of photodesintegration of tensor-polarized deuteron. // 01.04.16 - elementary particle physics, and atomic nuclear physics, Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2008, BINP, SB RAS.
5. *Sibidanov A.L.* Measurement of the cross section of the process $e^+e^- \to \pi^+\pi^-$ at the CMD-2 detector in the 370-520 MeV energy range. // 01.04.16 - elementary particle physics, and atomic nuclear physics, Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2008, BINP, SB RAS.
6. *Ivanov A.V.* Simulation of electron-optical systems of new generations of electron coolers. // 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, 2008, BINP, SB RAS.
7. *Steshov A.G.* Elements of magnetic system for specialized synchrotron radiation source MLS. // 01.04.20 - physics of charged particle beams and accelerator techniques, Author. papers of thesis for the degree of candidate of technical science: Novosibirsk, 2008, BINP, SB RAS.

Участие в конференциях

1. 10th International Workshop on Accelerator Alignment, KEK, February 11-15, 2008, Tsukuba, Japan.
2. International Conference: X Kharitonov Topical Scientific Readings, 11-14 March 2008, Sarov.
3. XXXV International (Zvenigorod) Conference on Plasma Physics and Controlled Fusion, 11-15 February, 2008, Zvenigorod, Russia.
4. 22nd Les Rencontres de Physique de la Vallee d'Aoste, 24 February - 1 March, 2008, Aosta Valley, Italy.
5. 10th International Conference on Instrumentation for Colliding Beam Physics (INSTR'08), February 28 - March 5, 2008, BINP, Novosibirsk, Russia.
6. XXIII International Conference: Matter Status Equations, 1-6 March, 2008, Jel'brus village.
7. XLVI International Scientific Students Conference, NGU, 26-14 April, 2008, Novosibirsk, Russia.
8. International Workshop on e^+e^- Collisions from φ to ψ, Laboratori Nazionali di Frascati, 7-10 April, 2008, Frascati, Italy.
9. 40th ICFA Advanced Beam Dynamics Workshop on High Luminosity e+e- Factories, April 14-16, 2008, BINP, Novosibirsk, Russia.
10. International Workshop on High Energy Photon Collisions at the LHC, April 22-25, 2008, CERN.
11. 17th Topical Conference on High-Temperature Plasma Diagnostics, Albuquerque, 11-15 May, 2008, New Mexico.
12. International Advanced Beam Dynamics Workshop (Nanobeams2008), May 25-30, 2008, BINP, Novosibirsk, Russia.
13. XX International Scientific and Technical Conference on Photoelectronics and Night Vision Equipment, 27-30 May 2008, Moscow, Russia.
14. International Power Modulator Conference, May 2008, Las Vegas, USA.
15. International Conference: Chaotic Modeling and Simulation (Chaos2008), June 3-6, 2008, Chania, Crete, Greece.
16. ECFA Workshop on Linear Colliders, June 9-12, 2008, Warsaw.
17. 35th EPS Conference on Plasma Physics, 9-13 June 2008, Hersonissos.
18. 2nd International Conference on Current Problems in Nuclear Physics and Atomic Energy, June 9-15, 2008, Kiev, Ukraine.
19. 35th IEEE Int. Conf. on Plasma Science (ICOPS 2008), Karlsruhe, June 15-19, 2008, Germany.
20. XVII Internftional Synchrotron Radiation Conference (SR-2008), June 15-20, 2008, BINP, Novosibirsk, Russia.
21. 9th International Workshop on Non-Neutral Plasmas, Columbia University, June 16-20, 2008, New York, USA.
22. Heraeus-Seminar: Polarized Antiprotons, Bad Honnef, June 23-25, 2008, Germany.

23. International Workshop on Ultra High-Intensity Lasers in Nuclear and Particle Physics, ECT, Trento, June 23-27, 2008, Italy.
24. 11th European Particle Accelerator Conference (EPAC'08), June 23-27, 2008, Genoa, Italy.
25. 58th International Meeting on Nuclear Spectroscopy and Nuclear Structure (NUCLEUS 2008), June 23-27, 2008, Moscow, Russia.
26. XIV International Conference on Methods of Aerophysical Research (ICMAR 2008), June 30 - July 6, 2008, Novosibirsk, Russia.
27. DESY Conference, 1 July, 2008, Hamburg.
28. Workshop on Low x Physics, July 6-10, 2008, Crete, Greece.
29. 7th International Conference on Open Magnetic Systems for Plasma Confinement, July 15-18, 2008, Daejeon, Korea.
30. 7th International Workshop: Strong Microwaves - Sources and Applications, July 27 - August 2, 2008, Nizhny Novgorod, Russia.
31. 34th International Conference on High Energy Physics (ICHEP 2008), 30 July - 5 August, 2008, Philadelphia, Pennsylvania.
32. II Helmholtz International Summer School: Heavy Quark Physics, August 11-21, 2008, Dubna.
33. International Conference (DIFFRACTION 2008), September 9-14, 2008, La Londe-les-Maures, France.
34. International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz 2008), Pasadena, California, September 15-19, 2008, USA.
35. XX Symposium: Modern Chemical Physics, 15-26 September, 2008, MSU boarding house "Burevestnik", Tuapse.
36. International Meeting of Radiation Processing, September 21-25, 2008, London.
37. 9th International Conference on Modification of Materials with Particle Beams and Plasma Flows, 21-26 September 2008, Tomsk, Russia.
38. 15th International Symposium on High Current Electronics, 21-26 September, 2008, Tomsk, Russia.
39. 2nd International Congress on Advanced Electromagnetic Materials in Microwaves and Optics, Pamplona, September 21-26, 2008, Spain.
40. 10th International Workshop on Tau-lepton Physics, September 22-25, 2008, Budker INP, Novosibirsk, Russia.
41. 3rd Alushta International Workshop on the Role of Electric Fields in Plasma Confinement in Stellarators and Tokamaks, Alushta (Crimea), September 22-27, 2008, Ukraine.
42. Satellite Meeting: On the Need for a Super-Tau-Charm Factory (Tau-08), September 26-27, 2008, BINP, Novosibirsk, Russia.
43. XXI Russian Conference on Charged Particles Accelerators (RuPAC-2008), September 28 - October 3, 2008, Zvenigorod, Russia.
44. International Conference: Differential Equations. Function Spaces. Approximation Theory (devoted to 100 anniversary S.L. Sobolev), 5-12 October 2008, Novosibirsk, Russia.

45. International Workshop-Exhibition: Strategy of development of large-scale research infrastructures of the Russian Federation and cooperation with the European Union, October 20-21, 2008, Athens, Greece.
46. 7th International Workshop on Personal Computers and Particle Accelerator Controls, 20-23 October 2008, Ljublljana, Slovenia.
47. Materials of the VI Russian Seminar: Modern Instruments for Plasma Diagnostics and their Using for Monitoring of Matters and Environment, 22-24 October, 2008, Moscow, Russia.
48. 13th International Congress on Neutron Capture Therapy, 2-7 November 2008, Florence.
49. International Workshop on Linear Colliders (ILC2008, LCWS08), Chicago, November 16-21, USA.
50. APS Meeting, November 17-21, 2008, USA.
51. International Forum on Nano-Technologies, 3-5 December, 2008, Moscow, Russia.
52. International Workshop on Heavy Quarkonium (QWG2008), 2-5 December 2008, Nara, Japan.
53. Nuclear Physics Division of Physical Sciences Department of Russian Academy of Sciences Conference 2008, 22-25 December, 2008, Institute of High Energy Physics, Protvino.
54. 4th Specialized Forum: Modern Systems of Safety - Antiterror, 2008, Krasnoyarsk, Russia.
55. Novosibirsk Inter-Institutes of Higher Education Scientific Student Conference "Intellectual potential of Siberia", 2008, Novosibirsk, Russia.
56. 17th International Conference on High-Power Particle BEAMS (BEAMS'2008), Xi'an, 2008, China.
57. 22nd IAEA Fusion Energy Conference, Geneva, 2008, Swissland.
58. International Conference: Engineering of Scintillation Materials and Radiation Technologies (ISMART-2008), Kharkov, Ukraine.

List of Collaboration Agreements between the Budker INP and Foreign Laboratories

N°	Name of Laboratory 1	Title or Field of Collaboration 2	Dates 3	Principal Investigators 4
1.	CERN (Swiss)	1. Research and development of the detectors for LHC	1992	A. Bondar, Yu. Tikhonov (INP), T. Nakada, P. Yenni (CERN)
		2. Development of the LHC elements	1996	L. Evans (CERN), V. Anashin (INP)
2.	DESY (Germany)	Joint research in the field of accelerator physics and elementary particle physics	1992	A. Vagner (DESY), A. Skrinsky (INP)
3.	SLAC (Stanford) USA	1. Research and development of linear colliders and final focus test	1992	D. Dorfan (SLAC), A. Skrinsky (INP)
		2. Beam detector for B-factory	1993	A. Onuchin (INP), D. Hitlin (SLAC)
		3. Electron-positron colliding beams (B-factory)	1995	D. Siman (SLAC), A. Skrinsky (INP)
4.	BNL (Brookheven) USA	1. Measurement of the magnetic muon anomalous	1991	J. Bunse (BNL), L. Barkov (INP)
		2. Joint research of RHIC spin	1993	S. Ozaki (BNL), Yu. Shatunov (INP)
5.	ANL (Argonn) USA	1. Experiments with polarized gas jet target at VEPP-3	1988	R. Holt (ANL), L. Barkov (INP)
		2. SR instrumentation	1993	G. Shenoy (USA), G. Kulipanov, A. Skrinsky (INP)
6.	INFN (Italy)	Development of intense source for radioactive ion beams for experiments in nuclear physics	1984	L. Techio (INFN), P. Logachev (INP)
7.	University of Milan (Italy)	Theoretical and numerical studies of dynamic chaos in classic and quantum mechanics	1991	T. Montegazza, J. Kasati (Italy), A. Skrinsky, V. Sokolov (INP)
8.	University of Pittsburgh (USA)	Experiments on VEPP-2M and φ-factory	1989	S. Eidelman, E. Solodov (INP), V. Savinov (USA)
9.	Daresbury (England)	Generation and utilization of SR	1977	I. Munro (Daresbury), G. Kulipanov (INP)
10.	University of Duke (USA)	Free electron lasers	1992	J. Wu (Duke), N. Vinokurov (INP)

N°	1	2	3	4
11.	POSTECH (Korea)	SR experiments, accelerator design, beam lines insertion devices	1992	H. Kim (POSTECH), A. Skrinsky, N. Mezentsev (INP)
12.	KAERI (Korea)	Development of accelerator-recuperator	1999	B.Ch. Lee (KAERI), N. Vinokurov (INP)
13.	BESSY (Germany)	Development of the wigglers for BESSY-2	1993	E. Jaeschke (BESSY), A. Skrinsky, N. Mezentsev (INP)
14.	KEK (Japan)	1. Experiments at B-factory with detector BELLE 2. Electron-positron factories (B-, φ-factories)	1992 1995	A. Bondar (INP), F. Takasaki (KEK) Sh. Kurokawa (KEK), E. Perevedentsev (INP)
15.	RIKEN Spring-8 (Japan)	Collaboration in the field of accelerator physics and synchrotron radiation	1996	H. Kamitsubo (Japan), G. Kulipanov (INP)
16.	BNL (USA)	Collaboration on electron-ion colliders	1993	I. Benzvi (USA), V. Parkhomchuk (INP)
17.	Research Centre Rossendorf (Germany)	Physical foundations of a plasma neutron source	1994	K. Noack (FRG), E. Kruglyakov, A. Ivanov (INP)
18.	Nuclear Centre "Karlsruhe" (Germany)	1. Development of conceptual project and data base for neutron source on the basis of GDT device 2. Simulation of processes in diverter of ITER device	1994	G. Kessler (FRG), E. Kruglyakov, A. Ivanov, A. Burdakov (INP)
19.	GSI (Germany)	Collaboration in the field of accelerator physics: electron cooling; electron-ion colliders	1995	A. Eickhoff (GSI), Yu. Shatunov, V. Parkhomchuk (INP)
20.	FERMILAB (USA)	Collaboration in the field of accelerator physics: electron cooling; conversion system	1995	O. Finli (FERMILAB), V. Parkhomchuk (INP)
21.	Institute of Morden Physics Lanchzou (China)	Particle accelerator physics and techniques	2000	S. Yang (IMP, China), V. Parkhomchuk (INP)
22.	Center of Plasma Research, Tsukuba (Japan)	Collaboration on Open traps	2003	Ya. Kitahara, K. Yatsu (Japan), E. Kruglyakov, A. Skrinsky (INP)
23.	INFN-LNF (Italy)	Development of collider project DAFNE-II	2004	S. Biscari (INFN), E. Levichev (INP)

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