Russian Academy of Science
Lenin Order Siberian Branch
G.I. 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.

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 approximately 3000 and among them: about 420 researchers, over 50 postgraduates, 760 engineers and technicians, about 350 laboratory assistants and 1300 workers. Among the researchers, there are 5 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 a "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 140 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 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 following works were recognized by the Scientific Council as the best in 2006.

1. VEPP-4-KEDR: The mass of tau-lepton was measured with the world best accuracy. The precise value of this mass is very important for verification of the lepton universality principle.
2. GOL-3: a hot plasma confinement regime was obtained in the corrugated magnetic field where its energetic lifetime exceeds by two orders of magnitude the time of free flow. This result is a serious step in the development of the thermonuclear reactor concept based on the multimirror trap.
3. Electron Cooling: with the use of the installations for electron cooling of ion beams developed and manufactured at the Institute, the effective cooling was obtained by electron beams with the controlled radial profile at the storage ring facilities LEIR (CERN) and CSRm(Lanzhou). The cooled ion beams are stored up to the required operating intensities and accelerated up to high energies.
4. SR Sources: the superconducting wiggler with the record parameters (21 poles, Nb-Ti, Bmax = 7.7 T with zeroth consumption of helium) was developed and produced for the SR source "Siberia-2" RRC Kurchatov Institute.
5. Industrial accelerators: ELV-12 is one of the most powerful in the world commissioned at the end of 2005 has been operated the whole 2006 in the nominal regime of 400 kW in the dye waste purification system in Taegu (R.Korea).

This year, academician A.N.Skrinsky was awarded by the RF State Prize "for the outstanding achievements in the field of high energy physics", three researchers were awarded by the Gold Medal and RAS Prize for the young scientists in 2006 (I.A.Ivanov, S.V.Polosatkin and Yu.S.Sulyaev).

Conferences held at the Institute in 2006:

1. International Seminar: "Selected chapters of the modern high energy physics and accelerator physics" – January, 2006;
2. International Workshop on Physics of electron-positron collisions at low energies – February, 2006;
3. International Workshop on Positron sources for the future linear colliders – May, 2006;
4. 16-th Russian Conference on the use of synchrotron radiation "SR-2006" – July, 2006;
5. Russian Conference on charged particle accelerators (RUPAC 2006) – September, 2006.

Chapter 1

Physics of Elementary Particles

1.1 CMD-3 Detector

The longitudinal cross section of CMD-3 detector is shown in Fig. 1.

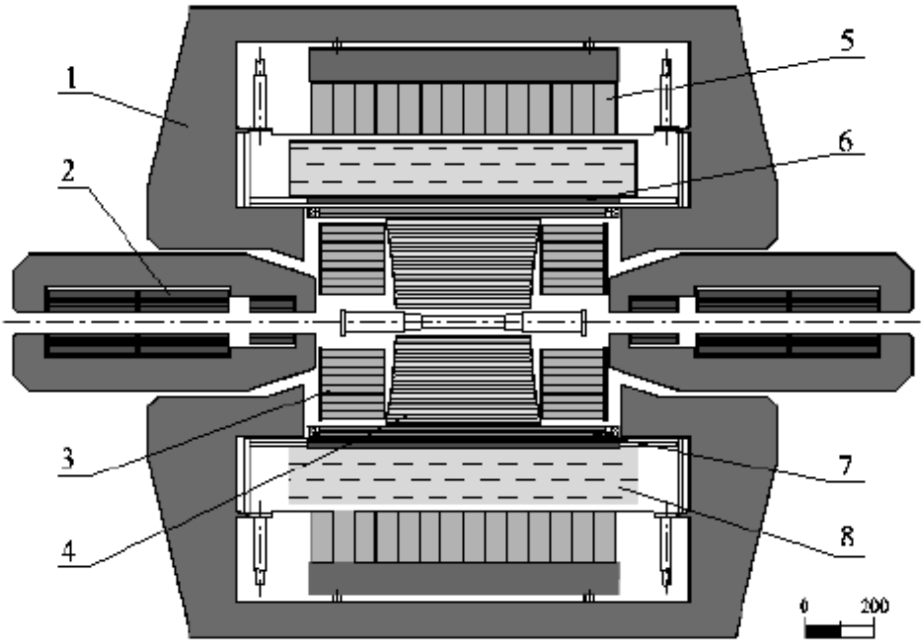


Figure 1: CMD-3 Detector. 1 — magnet yoke; 2 — VEPP-2000 superconducting solenoids; 3 — BGO electromagnetic calorimeter; 4 — drift chamber; 5 — CsI electromagnetic calorimeter; 6 — CMD-3 superconducting solenoid; 7 — Z-chamber; 8 — LXe electromagnetic calorimeter.

During 2006 construction and testing of CMD-3 detector systems as well as processing of CMD-2 detector experimental data have been successfully continued.

Tests of the detector drift chamber with cosmic rays particles were finished. During these tests the measurements of the chamber spacial resolution as well as measurements of ionization losses were made. Tuning of the drift chamber digitizing electronics was also performed. The obtained results of the measurements are better than that expected. As a result of the tests necessary modifications of the drift chamber electronics were made and its production was started.

Z-chamber, used for precise measurements of a particle track coordinates and in the detector trigger system, was installed at VEPP-2000 experimental gap together with its readout and digitizing electronics. ONLINE and OFFLINE software for the Z-chamber is in preparation now.

During the tests of superconductive solenoid the magnetic field of magnitude 0.7 Tl was obtained. At present time the solenoid is completely assembled and works on improvement of field ramping system are continued.

Production of 2500 channels of LXe electromagnetic calorimeter coordinate electronics was finished in the Institute Workshop. The electronics tuning and testing was also performed. Preparation for the calorimeter tests, using cosmic rays, is going at full speed. These tests will allow to measure the calorimeter characteristics and develop the software for OFFLINE processing of events in this detector system.

All 72 modules of CsI electromagnetic calorimeter were produced. Production and tuning of the calorimeter electronics analog part was finished. Two calorimeter octants were already assembled and installed into detector at VEPP-2000 experimental hall. Measurements of the octants physics characteristics are performing.

BGO electromagnetic calorimeter is completely ready for assembling into detector at VEPP-2000 experimental hall. Works on production and testing of thermostabilization system of the calorimeter are close to finish. Development of the OFFLINE software and Monte-Carlo simulation of events in the calorimeter is almost finished.

In 2006 first blocks of Amplifier-Shaper-Digitizers ("UFO-32"), which will be used in all calorimeters of the detector, were produced and tested together with charge-sensitive amplifiers. Development of electronics of the detector trigger system was finished and its testing was started. Design and testing of electronics for building event from different detector systems was also started.

CMD-2 Detector experimental data processing was continued in 2006. Analysis of the process $e^+e^- \to \pi^+\pi^-\pi^0$ dynamics at $\phi(1020)$ resonance allowed to determine the value of contact amplitude of the decay:

$$a = 0.101 \pm 0.044(\text{stat.}) \pm 0.017(\text{syst.})$$

and its phase:

$$\phi = -2.91 \pm 0.044(\text{stat.}) \pm 0.017(\text{syst.}).$$

These measurements pointed on the existence of the contact amplitude of the decay $\phi \to \pi^+\pi^-\pi^0$ with statistical significance greater than three standard deviations.

Analysis of process $e^+e^- \to \pi^+\pi^-$ was performed in CM energy ranges from 370 to 520 MeV and from 1040 to 1380 MeV. At each of the ranges the cross section of pion pairs production was measured with smallest systematic error significantly improving the calculation of hadronic contribution to vacuum polarization to anomalous magnetic moment of muon.

At first time the experimental confirmation of quantum-mechanical calculation of muon pair production at low energies was obtained with precision of 1%. Difference, averaged for all energies, is $(2.0 \pm 1.3(\text{stat.}) \pm 0.7(\text{syst.}))\%$.

In work participated:

Anisenkov A.V., Aulchenko V.M., Ahmetshin R.R., Bashtovoy N.S., Barkov L.M., Banzarov V.S., Bondar A.E., Bragin A.V., Vorobyev A.I., Gorbachev D.A., Grebeniuk A.A., Grigoryev 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., Krokovny P.P., Kuzmin A.S., Logashenko I.B., Lukin P.A., Mikhailov K.Yu., Nikulin M.A., Okhapkin V.S., Pestov Yu.N., Popov A.S., Popov Yu.S., Prijmenko L.A., 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.
Roberts B.L. *(the Boston University, Boston, USA)*
Tompson J. A. *(University of Pittsbugh, Pittsburgh, USA)*
F.Grancagnolo *University of Lecce, Lecce, Italy*

1.2 The SND detector

1. SND upgrade for VEPP-2000.

In 2006 manufacturing of the SND tracking system, having the cylindrical form and consisting of twenty four nine-layer jet type drift cells and the proportional chamber located close to the external brim, was completely finished. 1296 wires were installed in the system, high-voltage circuits and signal cables were soldered, checks were performed to test the assembly quality, as well as high-voltage tests and tests on the system tightness. In total, there are 516 signal wires. Number of channels of digitizing electronics equals 948. At the end of the 2006 year, the tracking system was placed in the VEPP-2000 experimental hall, connected to the high-voltage and registering electronics and to the gas supply system and was prepared for switching.

In 2006 tests have been completed on the long-term stability of the first full-sized aerogel test counter with refraction coefficient $n = 1.13$. Tests were performed from the beginning of 2005 till March 2006. As a source of particles in the measurements, cosmic muons with an impulse $p > 1$ GeV/c were used that allowed to select muons with Cherenkov radiations more than 95% from maximal. Measurements have revealed that average magnitude of the signal from the Cherenkov counter decreases according to the exponential law with the characteristic time $\tau \approx 3$ year. This attenuation of the signal is caused by reduction of aerogel light absorption length which depends on oxidized metal impurities in aerogel. To reduce the influence of an atmospheric moisture, in 2006 the case of the aerogel Cherenkov counter was manufactured in the form of three separate segments, each of which has a full-welded design.

Muon system of SND consists of 16 modules of gas proportional counters and 18 scintillation counters on the basis of plastic scintillator. The system of the gas proportional counters was completely renewed, while the scintillator counters are the same that were used earlier in experiments on the VEPP-2M collider. In 2006 all modules of proportional chambers have been manufactured and passed careful checks, the design of electronics for them was developed and its manufacturing has begun. All photo multipliers of the scintillator counters were tested. In 2007 it is planned to prepare the muon system for work, mount it on the detector and connect via cables to the readout system.

In 2006 the production of the first level trigger of the tracking system was finished. At present the electronics of two basic subsystems of the detector, calorimeter and tracking system, is completed and ready to work. Its testing in the electronic console room of the detector is under way.

In the same year, work was continued on the software development for the SND data acquisition system for new experiments:

- Testing and calibration of electronics, readout of events from the calorimeter were realized.

- The program of events visualization from previous experiment was adapted, work was begun on the creation of the check-out visualization library.

- Load measurement subunits (scalers) were integrated in the data acquisition system. The following tasks were realized: run trigger blocking, run synchronization with the readout of the scalers, mapping in the operator interface of the experiment's live time and data from the scalers. The data transfer to the VEPP-2000 control system was organized.

- The configuration of the data acquisition system was realized with the network storage disk as the distributed buffer.

- The live time dependence on the loading rate was investigated with the random trigger from the generator (dead time was found to be 8% for the loading rate of 1 kHz and data flow of 4 MByte/sec).

- Readout of events from the drift chamber was realized with the subsequent recording of them both in the full and in the reduced format.

- As a result of the test and regular runs, errors were corrected and the effectiveness of the system performance was improved.

In 2006 all programs of the calorimeter calibration and testing have been developed, trigger circuit of the detector was assembled for the signal ST - strobe (ST is formed if the energy release in one of the "NaI towers" exceeds 30 MeV). At the end of 2006 the capacity for work and the reliability of the calorimeter electronics and data acquisition system were tested in the long run with registration of the cosmic radiation. The run was continued for four weeks.

For the apparatus selection of events (primary trigger) only the signal ST was used. Frequency of the primary trigger firing and data recording to the disk was 200 - 250 Hz. The program selection of events (tertiary trigger) was also realized.

Before recording of cosmic events, the ADC pedestals were measured, the generator calibrations of amplifier-shapers and ADCs were performed. The recorded events were processed and calibration coefficients were determined for the conversion of the digital code from the counters into the energy release in MeVs. The test run showed that the SND calorimeter is in a satisfactory state and is ready for experiments on VEPP-2000.

For purposes of preparation of the nucleon form factors measurement experiment, the stand was assembled to measure the time and amplitude resolutions of the counter with the NaI(Tl) crystal coupled to the vacuum phototriode. The measurement was performed on cosmic rays with energy release of about 40 MeV. The time resolution close to 3 ns was obtained with various variants of forming electronics. This result agrees with the estimations based on simulation. The possibilities of the different variants of electronics are now additionally studied in order to get the specific recommendations for the new digital channel of the calorimeter with the measurement of the particle transit time.

The GEANT4 simulation of antinucleons annihilation in matter was carried out and for the antiprotons the comparison with the experimental data was performed. The comparison revealed the large differences between the experiment and the simulation ($\sim 100\%$). Adaptation of the simulation parameters to our case will be required and perhaps the search for ways how to improve annihilation processes simulation in matter.

2. VEPP-2M data analysis.

In 2006 the article was published dedicated to the measurement of the $e^+e^- \to K_S K_L$ process cross section in the energy range $\sqrt{s} = 1.04 \div 1.38$ GeV. The total integrated luminosity in the experiment was 9.1 pb^{-1}. At energies $\sqrt{s} \geq 1.2$ GeV the observed cross section exceeds the vector meson dominance model predictions taking into account only the $\rho(770)$, $\omega(783)$ and $\phi(1020)$ mesons. The measured cross section agrees with the previous experiments.

Analysis of the process $e^+e^- \to \eta\gamma$ is completed in channels $\eta \to 3\pi^0$ and $\eta \to \pi^+\pi^-\pi^0$. The cross section of this process was measured in the energy domain $\sqrt{s}$ from 600 up to

1380 MeV. Within the framework of the vector meson dominance model, analysis of the energy dependence of the measured cross section was carried out taking into account the contributions from the $\rho(770)$, $\omega(783)$, $\phi(1020)$, $\rho'(1465)$ resonances. The parameters of these mesons were determined:

$$\begin{aligned}
&\sigma_{\rho\eta\gamma} = (0.273 \pm 0.031 \pm 0.006)\ \text{nb},\\
&\sigma_{\omega\eta\gamma} = (0.795 \pm 0.080 \pm 0.017)\ \text{nb},\\
&\varphi_{\omega} = (12.0 \pm 7.9 \pm 0.3)^{\circ},\\
&\sigma_{\phi\to\eta\gamma} = (57.14 \pm 0.82 \pm 1.26)\ \text{nb},\\
&\varphi_{\phi} = (170 \pm 13 \pm 4)^{\circ},\\
&\sigma_{\rho'\eta\gamma} = (0.020 \pm 0.019 \pm 0.001)\ \text{nb},\\
&\varphi_{\rho'} = (61 \pm 31 \pm 2)^{\circ},
\end{aligned} \tag{1.1}$$

These parameters agree with the results of previous measurements and have the accuracy better or comparable with corresponding world averages. It should be noted that in this work the approximation of the $e^+e^- \to \eta\gamma$ cross section was performed with interference phases as the free parameters and therefore the obtained values of the decay probabilities do not depend on model assumptions about these phases.

Fig.1 shows the results of the $e^+e^- \to \eta\gamma$ process cross section measurements.

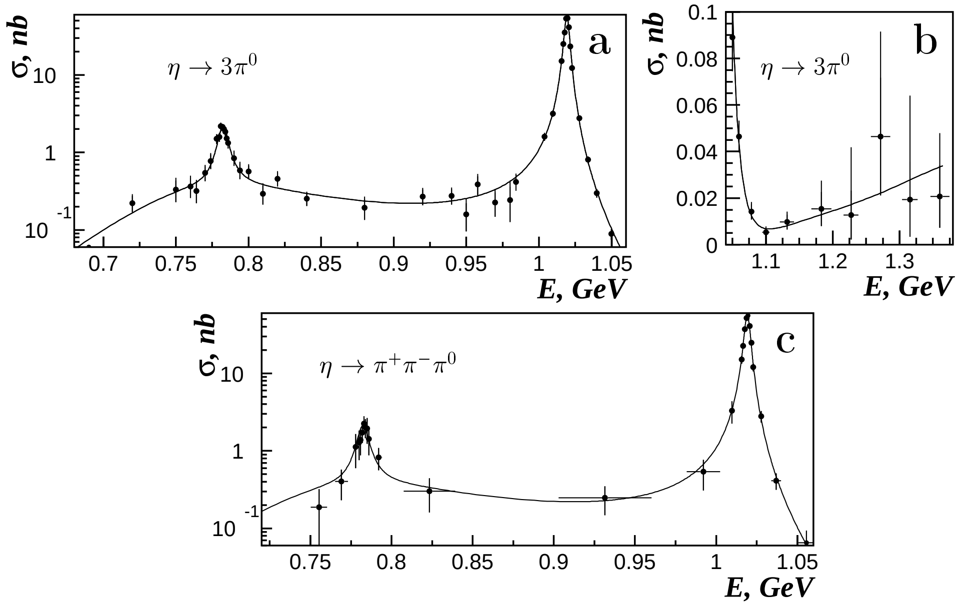


Figure 1: The cross section of the process $e^+e^- \to \eta\gamma$ measured in the decay channels $\eta \to 3\pi^0$ (a,b) and $\eta \to \pi^+\pi^-\pi^0$ (c).

For the processes $e^+e^- \to \pi^0\gamma$, $e^+e^- \to K^+K^-$, $e^+e^- \to \pi^+\pi^-$ ($2E$ >1 GeV), $e^+e^- \to e^+e^-\gamma\gamma$, and for several others, analysis is continued using experimental data recorded during the experiments on VEPP-2M with the detector SND.

3. Participation in international projects.

In 2006 the BABAR collaboration has published 66 articles, five of which were prepared with determining participation of the BINP group. These works include the most precise measurements of the Cabbibo-Kobayashi-Maskawa matrix element $|V_{ub}|$ from the inclusive charmless B-meson decays, measurement of the transition form factors of the η and η' mesons at q^2 of the virtual photon 112 GeV^2 and three papers on the measurement of the hadronic cross sections by the method of radiative return. The following cross sections were measured $e^+e^- \to p\bar{p}$, $e^+e^- \to 3(\pi^+\pi^-)$, $2(\pi^+\pi^-\pi^0)$, $K^+K^-2(\pi^+\pi^-)$ for energies from the threshold up to 4.5 GeV, and also the cross section of the reaction $e^+e^- \to \phi f_0(980)$. In this last reaction relatively narrow structure with a width of about 60 MeV was discovered at energy 2175 MeV (Fig. 2), which can be associated with the previously unobserved vector meson of possibly exotic four-quark structure ($ss\bar{s}\bar{s}$).

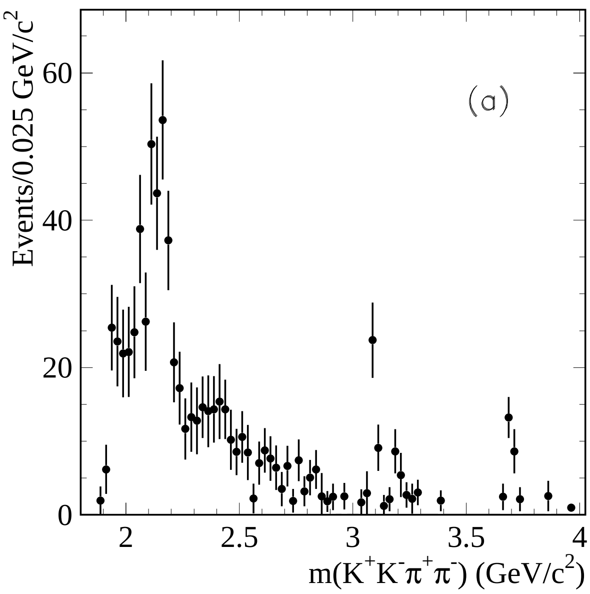


Figure 2: The invariant mass spectrum of the ϕ and f_0 mesons in the reaction $e^+e^- \to \phi f_0(980)$.

4. Developments in experimental methodics.

Together with the laboratory 3-12, in accordance with the contract with Shubnikov Institute of crystallography of the Russian Academy of Science (Moscow), the X-ray radiation detector OD-3 with asymmetric cathode was delivered for work in experimental channel in the Kurchatov center of synchrotron radiation (KSRS, Moscow). Work was begun on the modernization of the OD-3 detector, which includes the improvement of the detector construction and the conversion of its electronics on the new element base. Basic purposes of the modernization are: an improvement of the metrological and performance properties of the detector, an increase in the reliability, an enhancement in compactness and ergonomic quality of the installation. In 2007 it is planned to manufacture and test the first detector of the series OD-3.

In the work participated:

M.N. Achasov, V.M. Aulchenko, K.I. Beloborodov, A.V. Berdyugin, A.G. Bogdanchikov, A.A. Botov, A.D. Bukin, D.A. Bukin, A.V. Vasiljev, V.B. Golubev, T.V. Dimova, V.P. Druzhinin, D.P. Kovrizhin, A.A. Korol, S.V. Koshuba, A.E. Obrazovsky, E.V. Pakhtusova, V.M. Popov, S.I. Serednyakov, Z.K. Silagadze, K.Yu. Skovpen, Yu.V. Usov, P.V. Filatov, A.G. Kharlamov, 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 range 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.

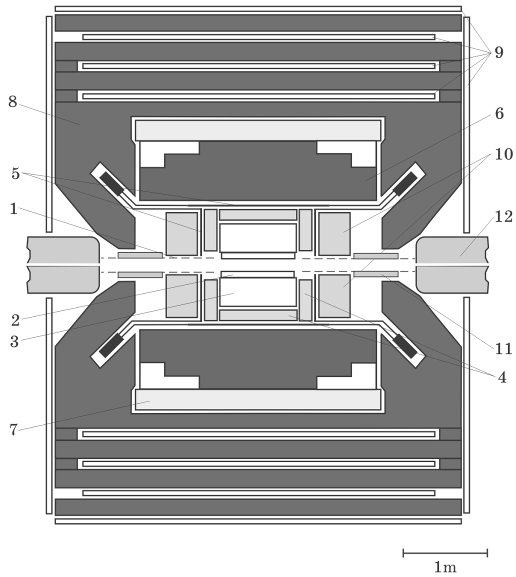


Figure 1: The KEDR detector. 1 - vacuum tube of the collider, 2 - vertex detector, 3 - drift chamber, 4 - aerogel Cherenkov counters, 5 - time of flight counters, 6 - liquid krypton barrel electromagnetic calorimeter, 7 - superconducting solenoid, 8 - magnet york, 9 - muon chambers, 10 - end cap electromagnetic 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 length of 670 mm and 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 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 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 drift tube obtained at the VD prototype using argon-carbon dioxide mixture is about 100 μm. The resolution obtained at VD using cosmic tracks is 170 μm. Further improvement is possible by increasing the gas amplification of the drift tubes (currently it is around 10^5). However, this is limited by the increase of the crosstalk hit probability. Currently, the modification of the VD preamplifier is designed with the aim to suppress crosstalk.

Drift chamber. The drift chamber of 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 drift is about 30 mm. Clean dimethyl ether (DME) is used as the working gas. Usage of 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 on the cell better than 100 mkm.

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 of that intersecting entire chamber. Solid angle for the particles, passing through three super-layers, composes 87% and decreases to 70% with the intersection of all seven super-layers.

Design pulse resolution with the measurement only in DC with the tension of the magnetic field 1T, 42 measurements of coordinate with the accuracy of 100 μm and to the measuring base of 370 mm is equal to:

$$(dPt/Pt)^2 >= (0.004)^2 + (0.01 \times P)^2,$$

where P is particle momentum in GeV/c.

With established in this season magnetic field of 0.65 T and because of the shorts in seventh super-layer, which substantially decreased the measuring base, achieved resolution is

$$(dPt/Pt)^2 >= (0.034 \times P)^2.$$

With 42 measurements of ionizing losses design 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 sigma level.

In 2005 all systems were worked in the normal mode, in the time of experiment it did not appear the new nonworking channels of electronics. Gas system worked in the pressure stabilization mode. During the experiment all parameters of the DC were checked, written in the data base and are used in statistics reprocessing. Occurred one break of wire in the second super-layer (2/3 of the layer were excluded from operation), the conducting peace of wire in 5 super-layer (entire layer excluded).

There is a program of the events reconstruction in the DC. Average spatial resolution is 115 μm in the axial layers and 220 μm in the stereo layers. The instability of the cleanliness of DME synthesized by Institute of Catalysis RAN periodically leads to the problems with the DC operation. Joint operations on the finishing of the technology of synthesis and DME cleaning is conducted.

The DC software is improving. The simulation is written, which considers the state of the DC parameters during the experiment, data of simulation are in agreement with the experiment. Work on the identification of particles on the ionizing losses continues.

Production of the new DC is going on — the production of prototype is begun, production of DC elements continued.

Aerogel Cherenkov counters. Threshold aerogel counters of the KEDR detector use aerogel with the refractive index 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 remits, captured into the angle of total internal reflection and transported to the photoreceptor (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. We would like to note that the aerogel counters system of the KEDR detector includes two layers and most of the particles will cross two counters in good conditions. For such particles the identification power will be higher.

The one layer of the system was installed into the detector in 2003. Starting from 2004 this system is working and collect data together with the other systems of the KEDR detector.

The single photoelectron calibration procedure was developed. Calibration parameters are recorded in the data base. The program of system slow control using experimental data was written. The signal amplitude from cosmic muons and from events of BhaBha scattering in the aerogel counters was measured. The amplitude is smaller than initial one by a factor 2-3. The main reason of this drop is collapse of optical contact between PMT and WLS due to displacement of PMT in the magnetic field of the detector. Currently 15 counters are out of order.

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 total spherical angle. Each barel counter is equipped with two photomultipliers, this guarantees detection efficiency for more than 99% of charged particles. The full set of system parameters calibrations give the possibility to reconstruct particle time of flight with the accuracy close to designed one. The barrel counters have mean timing resolution of 350 ps, end cap — 320 ps. Such timing resolution gives the possibility to separate π and K mesons up to 680 MeV/c.

In the frame of KEDR reconstruction the package for particle identification based on time of flight information was developed. Using this package first results on inclusive hadron production were received.

Liquid krypton barrel electromagnetic calorimeter. LKr calorimeter is the set of cylindrical ionization chambers with liquid krypton as working media. The inner radius of calorimeter is 75 cm and the thickness of active zone is 68 cm (14.8 radiation length). The total amount of liquid krypton is 27 tons. The electrodes of the ionization chambers are made of G10 foiled with copper and their thickness is 0.5 mm. 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 to the interaction point. In the radial direction all the towers are divided into three sections. The eight grounded electrodes of the first section are divided into strips for the photon coordinates measurement. The total number of electronics channels is 7204; 2304 are towers, 4936 — strips.

The calorimeter is filled out with liquid krypton from the beginning of 2004 and, as part of the KEDR detector, take part in the experiments on the VEPP-4M collider. On the experimental data the physical performances of the calorimeter were measured. The calorimeter energy resolution for large energy scale was measured on the BhaBha scattering events and the value is 3.0 ± 0.1 %. The expected energy resolution for this energy is 2.3 %. There is the clean peak from decays of the neutral π-meson on the two photon mass spectrum measured by LKr calorimeter. The resolution of the calorimeter on the π^0 mass is 9.5 ± 0.5 MeV (Monte Carlo gives 8.5 MeV). The space resolution for minimal ionization particles was measured on the cosmic events and the value is (0.7 - 0.8) mrad in accordance with the expectations.

In 2005-2006 the reconstruction software of the LKr calorimeter was extended by the module of the reconstruction in the end-cap calorimeters. Thus, the event reconstruction in the both calorimeters proceed within the same framework. The appropriate software package was included in the common procedure of the KEDR event reconstruction. The real calorimeter position in the detector was investigated with cosmic events by means of the track reconstruction in the strip structure of the calorimeter. In the same way it were determined positions of the end-cap calorimeter modules. The alternative method of the relative cosmic calibration of the end-cap calorimeters channels was realized by means of the information from the LKr calorimeter coordinate system. The initial e/π separation procedure, using the calorimeter and drift chamber information, was developed.

The end cap electromagnetic calorimeter based on CsI crystals. The end cap calorimeter of the KEDR detector based on CsI(Na) crystals consists of 2 end caps of 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 $60 \times 60 \times 150\ mm^3$ size and 48 crystals of $60 \times 60 \times 300\ mm^3$ size. The scintillation light is read out with the vacuum phototriodes followed with the preamplifiers. Signals from preamplifiers were formed by F15 shapers and digitized by A32 ADC.

Tests of the calorimeter stability include daily measurements of ADC pedestals and generator pulse calibration, as well as the cosmic runs about two times a week. Variation between two nearest pedestal measurements was about 0.5 ADC channels. Stability of the most electronic channels was better than 1%. At the same time $\simeq 64$ channels have much worse stability. We assume that this deterioration is concerned with unstable work of associated phototriodes in magnetic field. The noise of electronics was 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. Muon system was used at all KEDR experiments during year 2005. Regular monitoring of system status is performed upon experimental data and calibrations by generator and cosmic events.

Currently there are 30 broken channels. 9 channels are distributed in 8 blocks, 21 channels are found in 3 blocks. These channels are planned to be repaired during the next partial decomposition of system.

Spatial longitudinal resolution is about 4 cm. This resolution does not exceed deviation of coordinate, caused by multiple scattering in the detector media for muon with energy 1.5 MeV from interaction point. Registration efficiency of one layer is about 95%. This value allows us to detect minimal ionizing particles reliably and to identify sort of particles, coming from interaction point, by its range.

To stabilize proportions of gas mixture components the control of gas flows was automated using flow controller management device. Its software was updated to reach appropriate stability and usability. Due to insufficient level of chamber electronics stability the new versions of shaper-amplifier and expander electronics are being developed using modern chips.

Currently experimental data processing proceeds to work out technique of reliable identification by particle ranges. This technique will be used for obtaining physical results upon experimental data.

Tagging System. The Tagging System (TS) is designed to enhance the detector the ability to study the two-photon processes. Such processes are described with 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 to one of 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. Tubes have diameter of 6mm and allow to register scattered particles with a spacial resolution about 400 microns. The total number if tubes is 1440.

TS blocks are placed at both side of the interaction point at distances 4–16 meters. The scattering particle deflection in the transverse magnetic field of collider structure allows to calculate its energy. In our case TS can measure the energy of the emitted photon with resolution (0.2-0.5)% in the region 50–1000 MeV. An invariant mass resolution for the system X is about 5–10 MeV for masses around 1 GeV.

Luminosity Monitor. The operative measurements of the collider luminosity are performed by luminosity monitor system (LM) through measurement of single bremsstrahlung radiation rate ($ee\to e^+e^-\gamma$). Gamma quanta from electron and positron beams with energy more than 300 MeV are detected with the help of two scintillator-lead sandwiches (thickness $18X_0$). Each sandwich consists of 4 modules which is red 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 convert in the lead with the thickness of 2 mm, electrons and positrons are detected with coordinate counters.

The project energy resolution is about 4% at 1 GeV. Present energy resolution of luminosity monitors is 6–7%. This is enough for experiments in the energy region of Ψ resonances. The relative accuracy of luminosity measurements is 3–4%, absolute is about 5%.

Regular measurements and corrections of beam orbit ensure stability of luminosity measurement less than 5%. The joint data processing from luminosity monitor and tagging system has started to ensure better LM calibration.

Presently beam energy is measured continuously – one measurement every 20 minutes with accuracy 50 keV.

Trigger. The goal of the trigger system is on-line selection of interesting events at acceptable rate of background events. The trigger of the KEDR detector consists of 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. The trigger produces "arguments" out of signals from the systems. 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.

Main background in the detector is produced by beam halo particles hitting the narrow part of the beam pipe in the detector. During the first half-year of 2005 the typical rates after PT and ST were 2-7 kHz and 50-80 Hz, respectively. During the second half-year the rates were somewhat higher because the trigger conditions have been changed in order to increase the detection efficiency.

Briefly, one can say that the trigger requires two charged particles with $P_t > 50$ MeV or two neutral particles with at least one of them having the energy more than 500 MeV.

It was the first time in 2005 we used the neutral trigger from the barrel calorimeter independently of the end cap calorimeter.

Recording of fired calorimeter units has been arranged in order to simplify the test of the trigger performance.

Cryogenic supply system. The KEDR cryogenic supply system has worked in 2006 with a full range project power. It has provide a workability for all cryogenic components of the KEDR in experiments with e+e- collider VEPP-4M. The main cryogenic elements of the KEDR detector is a calorimeter based on liquid krypton and superconducting solenoids.

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

Storage and delivery of a liquid nitrogen is carried out by means of two storage tanks with a full capacity more of 100 tons. One tank is used as a gas-producing machine to provide a warmed 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 liquid helium. It consists of the main and two compensating solenoids. The magnetic field of 0.65 T was provided in the main solenoid. Failure in creating of the superconductor with a high critical current for the power supply of the main solenoid has not allowed us to reach the project field 1.83 T. The magnetic field ramping was 0.086 T per a day.

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

KEDR main results in year 2006.

During 2006 the KEDR detector have collected data in the energy region of τ-lepton threshold and in the regions of J/psi, ψ' resonances. (Fig. 2).

Recorded luminosity integral was 7.4 pb^{-1}, mean "recording" luminosity was $0.99 \cdot 10^{30}\ \text{cm}^{-2}\text{s}^{-1}$.

The main tasks of experiments were precise measurements of masses of τ–lepton, D-mesons, investigation of ψ'' decays, for example measurement of decay probability into $\tau^+\tau^-$.

The exact 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 perform exact testing of the hypothesis of lepton universality – one of the main postulates in weak interactions theory. Up to now τ–lepton mass was measured with the required accuracy only in one experiment [1], several questions exist to its data processing procedure [2].

The data collection in the energy region of J/ψ-meson was performed to measure beam energy spread of VEPP-4M collider. This is essential for τ mass measurements. The collected statistics will help also to define more exactly lepton width of J/ψ.

Preliminary results on τ–lepton production cross section near threshold are presented in Figure 3.

Preliminary results on τ-lepton mass and branching fraction for $\psi' \to \tau\tau$ are the following:

$$M_\tau = 1776.80^{+0.25}_{-0.23} \pm 0.15 \text{ MeV},$$

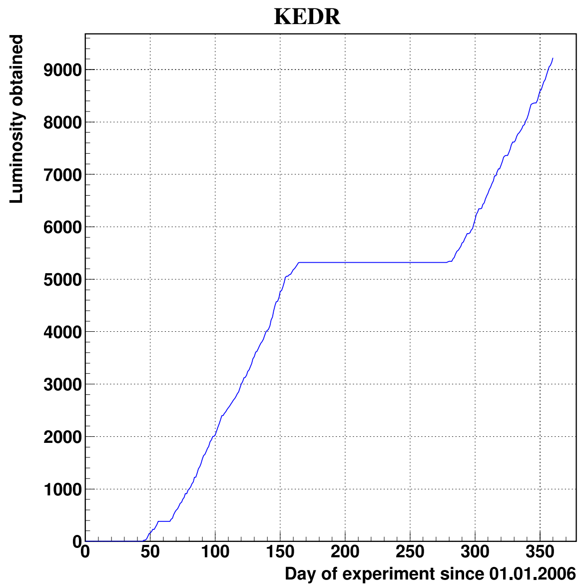


Figure 2: Rate of luminosity collection.

$$B(\psi' \to \tau\tau) = (2.0 \pm 0.85)\, 10^{-3},$$

$$M_\tau^{PDG} = 1776.99\,^{+0.29}_{-0.26}\ \mathrm{MeV},$$

$$B^{PDG}(\psi' \to \tau\tau) = (2.8 \pm 0.7)\, 10^{-3},$$

$$M_\tau^{KEDR} - M_\tau^{PDG} = -0.19\,^{+0.25}_{-0.23} \pm 0.15\ \mathrm{MeV}.$$

We are planning to improve detection efficiency of $\tau\tau$ events. This will help to improve the accuracy of mass measurement to the level of world average. The further accuracy decrease need additional luminosity integral collection in 2007.

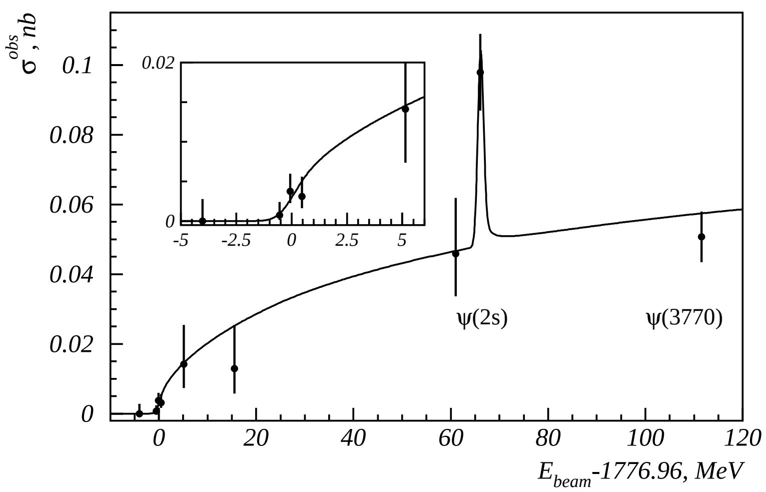


Figure 3: The observing τ–lepton production cross section near threshold (preliminary results).

Processing of data collected in 2004-2006 in the energy region of ψ'– and $\psi(3770)$ is in progress (Fig. 4). The preliminary results on masses of ψ' $\psi(3770)$ and total width of $\psi(3770)$ were presented on European conference on particle physics in Lisbon [3].

$$M_{\psi(2S)} = 3686.117 \pm 0.012 \pm 0.015 \text{ MeV}$$

$$M_{\psi(3770)} = 3773.5 \pm 0.9 \pm 0.6 \text{ MeV}$$

$$\Gamma_{\psi(3770)} = 29.0 \pm 6.7 \pm 3.0 \text{ MeV}$$

$$M^{PDG}_{\psi(2S)} = 3686.093 \pm 0.034 \text{ MeV}$$

$$M^{PDG}_{\psi(3770)} = 3770.0 \pm 2.4 \text{ MeV}$$

$$\Gamma^{PDG}_{\psi(3770)} = 23.6 \pm 2.7 \text{ MeV}$$

The accuracy of ψ' mass measurement was decreased on 40% [4] comparing with our previous results [5]. The accuracy of $\psi(3770)$ mass measurement by a factor of two better than current world average. Final results on masses of these states and on lepton widths of J/ψ, ψ' г $\psi(3770)$ will be published in this year.

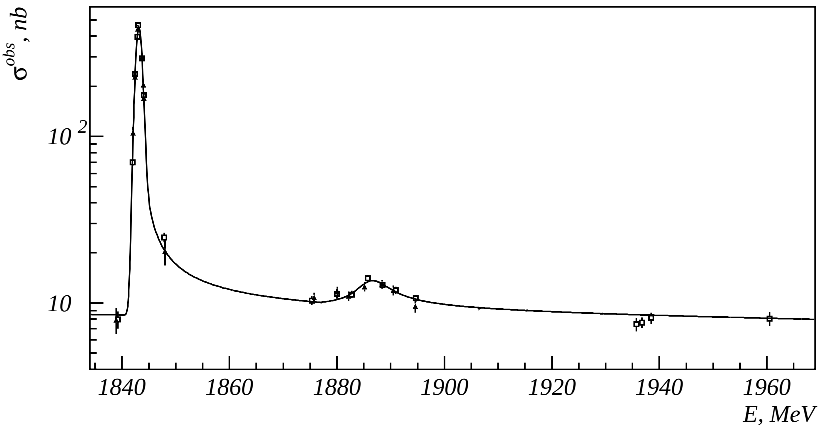


Figure 4: Observed production cross section of ψ'– and $\psi(3770)$–mesons (preliminary).

Literature:

1. J. Z. Bai *et al.* [BES Collaboration], ‘Measurement of the mass of the tau lepton,” Phys. Rev. D **53** (1996) 20.

2. A. G. Shamov *et al.* [KEDR/VEPP-4M], Nucl. Phys B(Proc. Syppl.) **144** (2005) 113.

3. Precision measurements of masses of charmonium states., V. V. Anashin *et al.* [KEDR/VEPP-4M], Proc. of International Europhysics Conference of High Energy Physics, Lisboa, Portugal, 2005.

4. New precise determination of the tau lepton mass at KEDR detector. A. G. Shamov *et al.* [KEDR/VEPP-4M], Proc. of 9th International Workshop On Tau Lepton Physics (Tau06) 19-22 Sep 2006, Pisa, Italy.

5. V. M. Aulchenko *et al.* [KEDR/VEPP-4M], Pysh. Lett. B **573** (2003) 63.

1.4 Detectors for HEP

On the KEDR detector, in the last year, our main efforts in electronics were concentrated on keeping the continuous round the-clock operation of the detector electronic systems. As a result, in addition to the stable operation of other systems, this provided the storage of statistics record by its amount for the last years.

The work on the upgrade of electronics for various systems of the SND detector reached the final stage. For the last year we have done a substantial amount of work including:

- the amplifiers for the muon system tubes are produced and their tests are started;

- a mapping unit is produced for the trigger system;

- production and adjustment of new Input-Output processors for the detector DAQ system are completed;

- the trigger system is assembled.

By the results of the tests under real conditions of a 32-channel module of forming and digitizing signals for the calorimeters of the KMD-3 detector, the correction of its circuit and the module and it is PB are performed and four modules are produced and tested. Technological order for its production is under preparation. Within the frame of the program of development of the general purpose electronics, the order was placed for producing the CAMAK modules of discriminators.

1.5 X-ray detectors

In 2006, we continued intense experiments on the dynamics of explosions at the SR channel with the use of the 256-channel one-coordinate detector DIMEX-1. The operation regimes of the detector providing the stability of it 6s parameters are chosen.

The second similar detector DIMEX-2 at 384-channels is tested and prepared for its use under conditions of the real experiments.

In 2006, we continued the work on the OD-4 detector for experiments on the wide-angular scattering in SR. In OD-4, instead of the wire structure as, for example, in OD-3, we use a multi-layer gas electron multiplier (GEM) that enables in addition to the high amplification (over 10 000) to construct the detector in the form of an arc with an arbitrary angular aperture.

In 2006, by our technological drawings, ZAO "Nauchpribor" (Oryol) produced the body of the detector. In the body, we mounted the electron multiplier and detecting strip cathode structure with the connected plate of the prototype of electronics with 32 channels. The first measurements were carried out with isotope. In the near future, we plan to carry out experiments with SR beam. Within the frame of the upgrade of the OD-3 series detectors aimed at improvement of their reliability and parameters, we are carrying out intense work on the development of the one-coordinate detector of the next generation – OD-3M. The design is developed and a 16-channel prototype of the plate of electronics is produced.

1.6 Other works

Within the frame of the international projects, the staff of the section actively participated in the work related to the upgrade of the DAQ system of the BELLE detector (KEK, Japan). The staff of the section developed and tested the prototypes of the new electronics for the Barrel part of the calorimeter based on CsI(Tl) crystals. They are prepared for the serial production in Japan.

1.7 Micro-Pattern Gaseous Detectors

The development of detectors based on multi-GEM structures was continued in 2006. The work was performed in several directions:

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

2) Upgrade of the KEDR tagging system.

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

1) The overall objective of this 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 unique advantage of multi-GEM multipliers is that they can operate in dense noble gases at high gains . In addition, 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 and Ar, 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 2006 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 mounted, were continued. The works with the cryostat with 10 l chamber were started. The results obtained by the end of 2006 are summarized below.

The purification technique was improved by using new Oxisorb filters, resulted in that the electron drift path in liquid Ar was increased to above 1 cm. Stable operation of GEM-based two-phase Ar avalanche detectors for one day was confirmed, with 1 cm thick liquid layer and at gains reaching 10000. For the first time, the successful operation the two-phase Ar avalanche detectors in a single electron counting mode has been demonstrated, in the gain range of 6000-40000. The measurements of signals, induced by nuclear recoils from neutron scattering from Cf-252 source, were started. Also, the measurements of scintillation signals in the two-phase Ar avalanche detector using CsI photocathode evaporated on GEM, were started.

The implementation and assembling of a new GEM-based two-phase detector of a volume of 10 l, for operation in Ar and Xe, was completed; the cryogenic tests of the detector were carried out. The studies of cryogenic avalanche detectors will be continued in 2007.

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 momentum 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 a 0.1 mm resolution. In the perpendicular direction the spatial resolution will be 0.25 mm in the region of +-1cm near the orbit and about 1 mm far away from the orbit plane. To obtain the required parameters a special structure of the readout plane has been developed with the variable angle of stereo-strips. Detector dimensions vary from 125*100 mm to 250*100 mm depending on the station type.

In 2005 all 8 detectors were assembled and tested for both arms of the spectrometer. 3 detectors were installed at VEPP4M ring.

3) In 2006 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 participated in the work:
V. M. Aulchenko, N.S. Bashtovoy , A. E. Bondar, A. F. Buzulutskov, A. A. Grebenuk, D. Pavlyuchenko, L. I. Shekhtman, R. G. Snopkov, Y. A. Tikhonov, V. V. Zhulanov.

The work is reflected in the following papers and reports:
[83], [84], [85], [86], [87], [88], [308], [309].

1.8 BELLE collaboration

Observation of CP-violation in B-meson decays is one of the most important problems in the modern high energy physics.

For this purpose the B-factory KEKB with design luminosity $10^{34} cm^{-2} s^{-1}$ has been constructed in KEK (High Energy Research Organization, Japan).

Since 1999 experiments on this collider are being carried out with the BELLE detector, which was created by joint efforts of the physicist of more than 50 institutes from 10 countries.

This year KEKB obtained luminosity $1.72 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$, which is the highest luminosity ever achieved in the world.

Since 1994 our Institute is one of the members of the BELLE collaboration. We participated in design and construction of the electromagnetic calorimeter and have been contributing to the work of the calorimeter group. The BELLE calorimeter consists of the 8736 CsI(Tl) scintillation crystals of 16 X_0 length. It provides detection of photons with good energy resolution and high efficiency in the energy range from several tens of MeV up to 10 GeV.

To obtain the design energy resolution, accurate calibration and monitoring of the counters are very important. Our Institute team coordinates this activity.

The absolute calibration of the calorimeter is based on the experimental data of the processes of elastic e^+e^- scattering and two photon annihilation. To study the calorimeter nonlinearity, the events of $e^+e^- \to e^+e^-\gamma$ process and $\pi^0 \to \gamma\gamma$ are used. After final calibration the energy resolution of 1.7% is obtained for gammas of two photon annihilation in good agreement with the expected value. Using $e^+e^- \to e^+e^-\gamma$ data as well as the two photon decay of neutral pion the nonlinearity function is obtained. The nonlinearity correction factor is less than 2% for energies higher than 100 MeV.

The important issue both for optimization of accelerator regimes and for experiment itself is the on-line luminosity measurement. In the detector BELLE a luminosity is calculated using a counting rate of elastic e^+e^- scattering as well as two photon annihilation $e^+e^- \to \gamma\gamma$, detected by the endcap calorimeters. The luminosity is measured by two sub-detectors of BELLE independently: by a small extremely forward calorimeter(EFC) based on radiation hard BGO crystals and by endcaps of the main ECL calorimeter. Our

Institute team is responsible for the ECL luminosity measurement system as well as for readout and utilization of the information of both systems.

At the end of 2001 the new luminosity measurement system which had been developed by our Institute was installed at BELLE detector. The upgraded system uses ϕ-segment signals of endcaps so the resulting signal is coincidence of two signals of forward and backward segments opposite in ϕ-angle. This system provides luminosity measurements for a higher level of background including the injection time. At the present time the on-line luminosity is measured with 2% accuracy.

For six and half years the detector BELLE has been storing the experimental data. At the end of 2006 the accepted integrated luminosity was more than 700 fb^{-1}. One of the main goals of the experiment is the measurement of the angles of unitarity triangle (ϕ_1, ϕ_2, ϕ_3). Currently the reconstructed number of events is not sufficient for an accurate measurement of all angles. The angle which is the easiest one to measure from both experimental and theoretical point of view is ϕ_1. In the Standard Model this angle is expressed via Kobayshi-Maskawa matrix elements as $\phi_1 = Arg(\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*})$. It is determined from the measurement of time asymmetry in $B\bar{B}$-decay, induced by the interference of decay amplitudes of these mesons to the CP-defined final state $J/\Psi K_S$,

$$A(t) = \frac{N_{\bar{B}}(t) - N_B(t)}{N_{\bar{B}}(t) + N_B(t)} = \sin(2\phi_1)\sin(\Delta m_d t) f_{CP}$$

Using integrated luminosity of about 80 fb^{-1} stored for summer of 2002 the value of the $\sin 2\phi_1$ has been measured. It shows a statistically significant large CP violation effect: $\sin 2\phi_1 = 0.728 \pm 0.056(stat.) \pm 0.023(syst.)$.

The team of our Institute studied and measured the angle ϕ_1 of the CKM Unitarity Triangle using time-dependent Dalitz analysis of $D \to K_S\pi^+\pi^-$ decays produced in neutral B meson decay to a neutral D meson and a light meson ($\bar{B}^0 \to D(^*)h^0$). The method allows a direct extraction of $2\phi_1$ and, therefore, helps to resolve the ambiguity between $2\phi_1$ and $\pi - 2\phi_1$ in the measurement of sin $2\phi_1$. We obtain sin $2\phi_1 = 0.78 \pm 0.44 \pm 0.22$ and cos $2\phi_1$=1.87+0.40+0.22-0.53-0.32 The sign of cos $2\phi_1$ is determined to be positive at 98.3% C.L.

The unitarity triangle angle ϕ_3 has been measured using a Dalitz plot analysis of the $K_S^0\pi^+\pi^-$ decay of the neutral D meson from the $B^\pm \to D(^*)K(^*)^\pm$ process. The method employs the interference between $D^0 and \bar{D}^0$ to extract the angle ϕ_3, strong phase Δ and the ratio r of suppressed and allowed amplitudes. We apply this method to a 357 fb^{-1} data sample collected by the Belle experiment. The analysis uses three modes: $B^+ \to DK^+$, $B^+ \to D^*K^+$ with $D^* \to D\pi^0$, and $B^+ \to DK^{*+}$ with $K^{*+} \to K_S^0\pi^+$, as well as the corresponding charge-conjugate modes. From a combined maximum likelihood fit to the three modes, we obtain phi_3=53+15-18(stat)±3(syst)±9(model) degrees. The corresponding two standard deviation interval is 8<ϕ_3<111 degrees.

In addition to the tasks of CP-violation, the team of our Institute is involved in analysis of B-meson three- and four-body decays as well as B-decays with charmed particle production.

The above listed results were presented at numerous physical conferences and are published in articles.

Although KEKB already operates with the highest luminosity the detector and collider upgrade are being discussed to increase the luminosity to the level of 10^{35}cm$^{-2}s^{-1}$, which allows to measure all unitarity triangle angles with several percent accuracy and gives possibility to observe effects behind the Standard Model. The team of the INP participates in the calorimeter system upgrade. The R&D works with pure CsI are carried out. These crystals are supposed to replace the CsI(Tl) counters in the calorimeter endcaps. The new electronics for the calorimeter readout is developed by the electronics group.

Participants:
V.M. Aulchenko, I.V. Bedny, A.E. Bondar, S.I. Eidelman, D.A. Epifanov, N.I. Gabyshev, A.Yu. Garmash, P.P. Krokovny, A.S. Kuzmin, N.I. Root, V.A. Sidorov, B.A. Shwartz, Yu.V. Usov, A.N. Vinokurova, V.N. Zhilich.

Literature:

1. M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973); N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963).

2. P. Krokovny *et al.*, Measurement of the CKM parameter cos(2phi_1) using time-dependent Dalitz analysis of $\bar{B}^0 \to D[K_S\pi^+\pi^-]h^0$. Phys. Rev. Lett. **97** (2006) 081801.

3. A. Somov, A.J. Schwartz *et al.*, Measurements of the branching fraction, polarization, and CP-asymmetry for $B^0 \to \rho^+\rho^-$ decays, and determination of the CKM phase phi_2. Phys. Rev. Lett. **96** (2006) 171801.

4. A. Poluektov *et al.*, Measurement of phi_3 with Dalitz plot analysis of $B^+ \to D(^*)K(^*)$ decay. Phys. Rev. **D73** (2006) 112009.

5. K. Ikado *et al.*, Evidence of the Purely Leptonic Decay $B^- \to \tau^-\bar{\nu_\tau}$. Phys. Rev. Lett. **97** (2006) 251802.

1.9 The Photon Colider

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, where high energy photons can be obtained using Compton backscattering of the laser light off the high energy electrons. The passed year was devoted to the choice of the reference design ILC configuration. The photon collider is the second stage of the ILC but there are many special requirements which should be included to the project from the very beginning. Our participation in the development and promotion of the photon collider can be seen from the list of papers and talks at international conferences:

History of Photon Colliders: first 25 years [80].

The Photon collider at ILC: status, parameters and technical problems [81].

Ultimate parameters of the photon collider at the ILC [303].

Layout of the photon collider at the ILC [304].

ATF2 proposal [109].

The photon collider at ILC: status and problems [306].

The photon collider at ILC: technical problems, (Summary at the ECFA-ILC workshop) [307].

Chapter 2

Electro - and photonuclear physics

2.1 Experiments with internal targets

I. In the current year, we completed the analysis of the experiment on measurements of the tensor analyzing powers of T20, T21 and T22 in the photodisintegration reaction of the polarized deuteron (gathering statistics 2002-2003, VEPP-3). On the subject of the work, the preprint was made and the article was prepared for publication. Experimental results: compared to the previous measurements, the errors in measurements of tensor powers are substantially reduced, the kinematic range of measurements is wider and the angular dependencies are obtained for the first time. Fig. 1 shows the comparison of the new data with the those of the previous experiments (1993, VEPP-3). It is seen that the measurement results coincide within the errors.

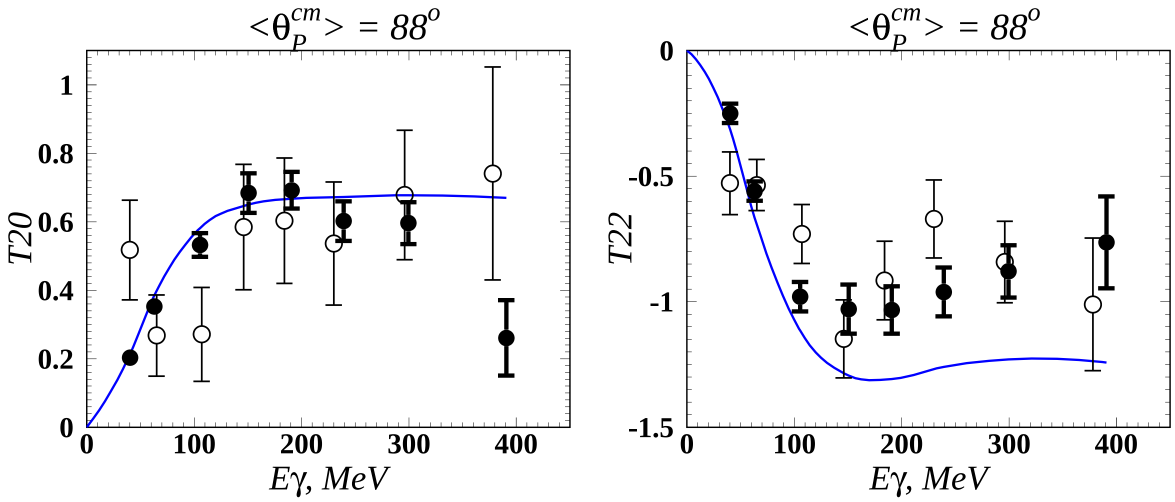


Figure 1: Comparison of the previous experiment (hollow circles) with the data of the new experiment (filled circles). Given here is only a fraction of the new data corresponding to the kinematic range of the previous experiment. Theoretical curves - calculations by Arenhövel.

The tensor power is a function with two variables that are usually E_γ^{lab} - a photon energy and ϑ_p^{cm} - the proton escape angle in the cm-system. Fig. 2 shows the results of this experiment and some theoretical predictions. Dependencies of the tensor power on the photon energy at averaging over two intervals of angles ϑ_p^{cm} are shown there.

As is seen from the Figure, at low photon energies, the theories describe well the experimental results. At $E_\gamma \approx 300$ MeV, the isobar configurations play an important role in some cases. Inclusion of the relativistic corrections (RC) is also necessary at large E_γ, which is especially clearly demonstrated by Schwamb calculations where RC are included most essentially (delay of virtual π mesons was taken into account). Since there are some differences between the calculations and experimental data, it is clear that the tensor powers are the strong test for the theory and it requires its further improvement. Note, by the way, that the vast data on the differential crossection of the deuteron photodisintegration are described by the same theories more successfully up to the photon $\sim$ 500 MeV.

An additional information on this experiment can be found out on BINP site: http://www.inp.nsk.su/~rachek/photodisintegration.html

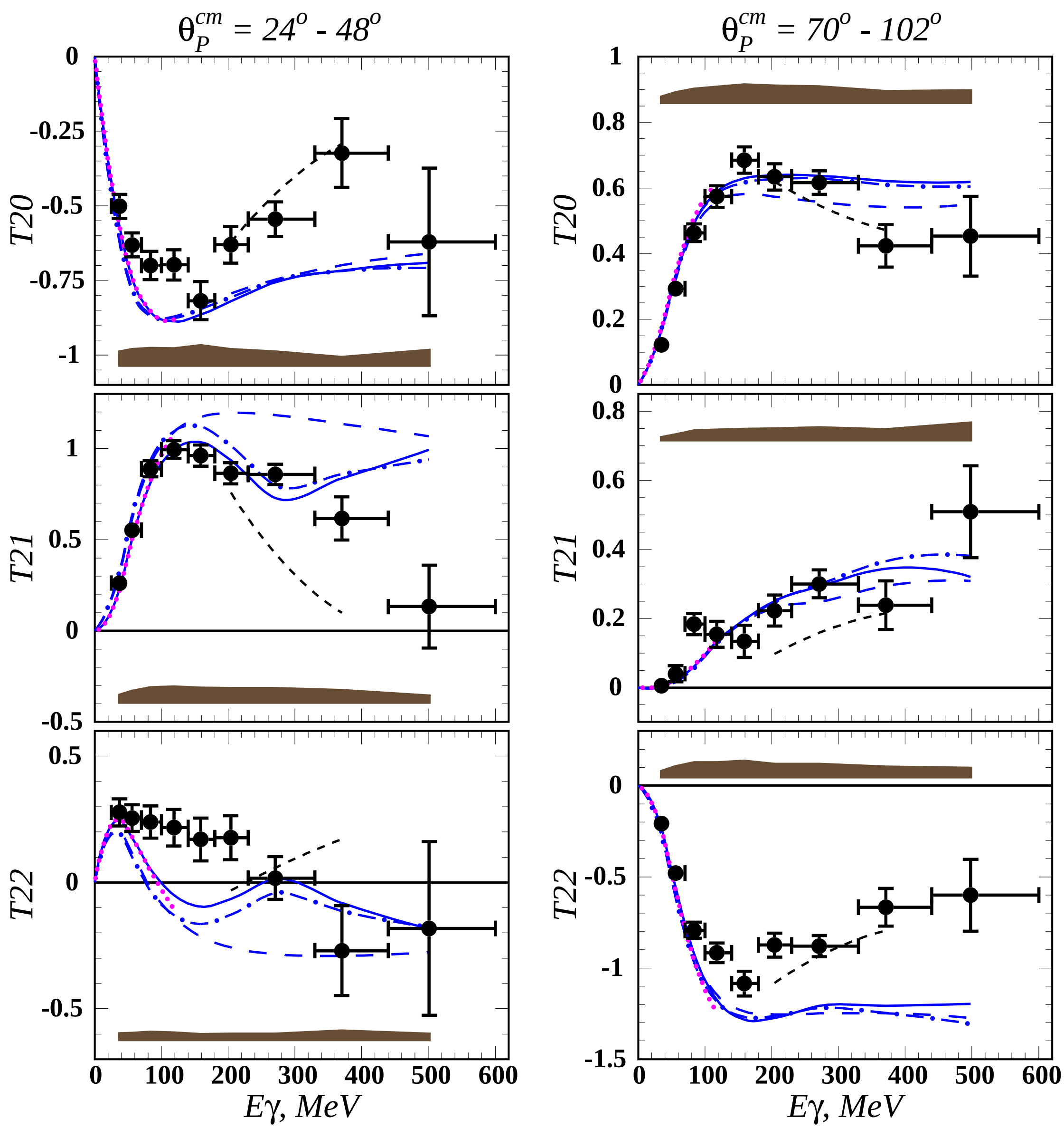


Figure 2: Tensor powers of the deuteron photodisintegration as a function of the photon energy. There are shown the statistical errors, horizontal sections – intervals of averaging over E_γ, shaded regions – systematic errors. Three curves of calculations Arenhövel: long dotted line – N+MEC, chain line – N+MEC+IC, solid line – N+MEC+IC+RC (only calculation). Point curves – predictions Levchuk (limited by $E_\gamma \leq 140$ MeVB) – nearly everywhere coincide with the solid curves. Schwamb calculations are shown by the short dotted line.

II. In the previous reports, we described the preparation for the next experiment on measurements of T20 in coherent photoproduction of the π^0 meson on a tensor polarized deuteron target. However, by present, because of intense schedule at VEPP-3 the time for the experiment is not determined. Therefore we decided to introduce some changes into detectors for expansion of the registration solid angle of the main process and for improvement of the target polarimeter parameters. This work is planned to be finished in the first half of 2007.

We continue the work on improvement of the polarized target. The stand was made for the search of the effects reducing the target polarization and finding the ways of their suppression.

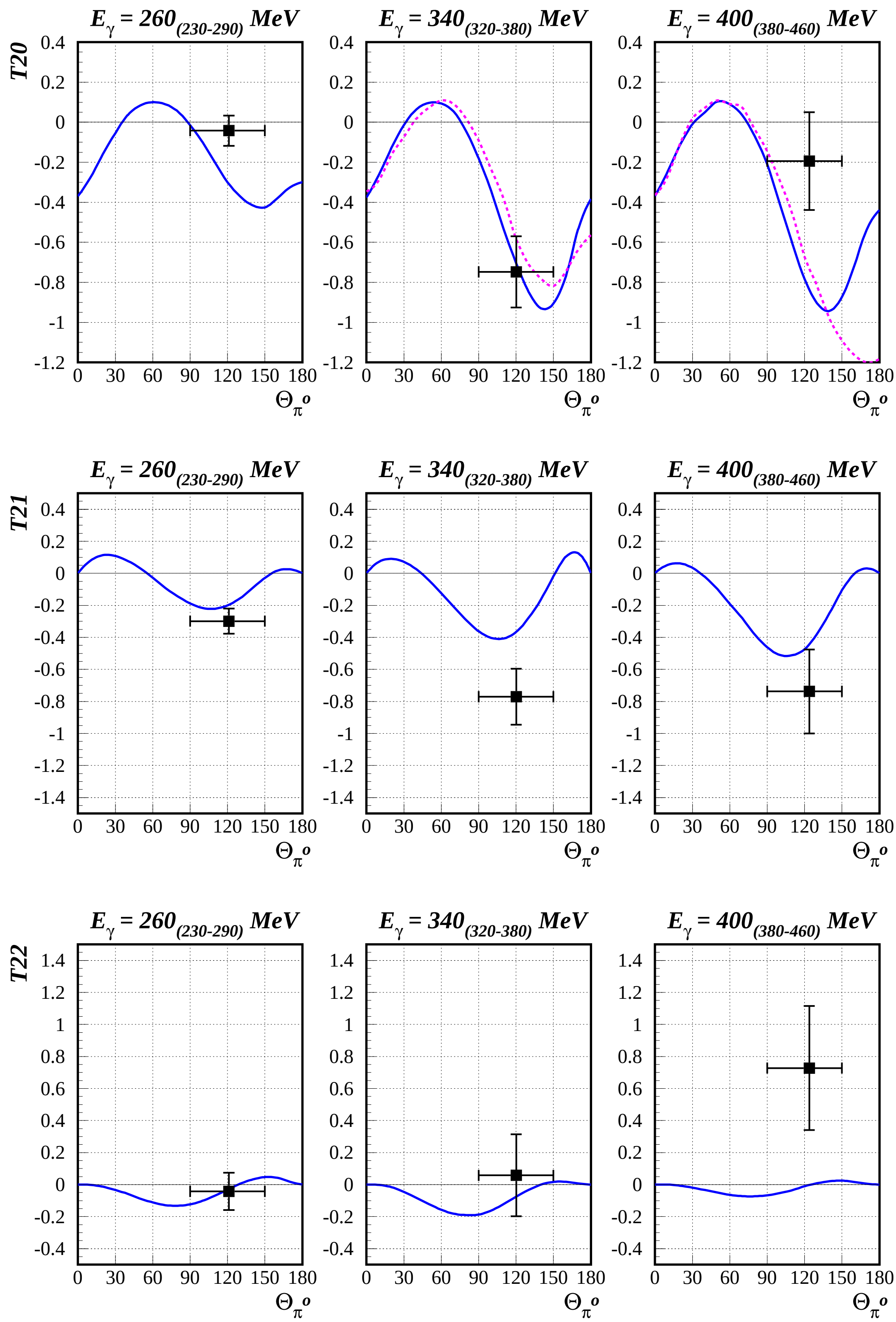


Figure 3: Tensor powers of the reaction of coherent photoproduction of the π^0 meson on a deuteron. Points – preliminary experimental results. Only statistical errors are given The horizontal bars are the intervals of averaging over Θ_{π^0}. The solid curves correspond to the calculations by Kamalov et al, dotted lines – predictions of Arenhövel et al.

Among the events of the experiment on the deuteron photodisintegration (see previous section) we separated events of $(d\gamma)$-coincidences, which (by some considerations) can be referred to the events of coherent generation of the π^0 meson on a deuteron. Fig. 3 shows the preliminary results obtained on the base of this statistics and some theoretical predictions. One can see, our data coincide with the calculations and confirm the prediction of high T20 and T21 in the region of Δ-isobar and at largeΘ_{π^0} (the pion escape angle in the center of mass system). This result is the first observation of the tensor powers in the reaction under consideration.

In the next experiment, we expect detail measurements of tensor analyzing powers in a wider kinematic region and with a high accuracy since the π^0meson will be detected by a special calorimeter made of CsI crystals and the registration arm will also be more adequate to the problem.

III. The experiment on measurements of $R = \sigma_{e^+p}/\sigma_{e^-p}$ (ratio of crossections of the positron/electron elastic scattering) is also delayed. Its beginning is planned after the summer 2007 shutdown of VEPP-3. The order of works is determined for the period of the experiment in the regime of sharing time with the SR groups. Note that the interest to such measurements is still very high. Up to now, it is not yet known the reason of contradictions in the data on proton form factor at the GeV transferred momenta obtained both with the old and new polarization technique. But the contribution of two photon corrections is still weakly studied. Measurements of R is one of the techniques to determine the contribution of the two-photon corrections.

By now, the main preparatory works have been done. Several remaining problems will be solved prior to the summer shutdown.

According to the initial plan, it is assumed to carry out measurements of R in three intervals of the transferred momentum: $Q^2 =$ 0.08−0.11 0.26−0.47 1.40−1.76 GeV^2/C^2. In this case, information at the lowest momentum transfer was planned to be used for determining the ratio of the luminosity integrals with the positron/electron beams under assumption of the negligibly small two-photon exchange corrections. However, later it was found out a possibility to build the luminosity integral on the base of the Meller/Bhaba processes whose crossections are well known. Such a monitor has some other advantages: its counting rate will be high thus providing high statistical accuracy; at the configuration selected, the monitor counting is weakly dependent of the beam energy and its position that enables one to hope for the smallness of the systematic errors. At present, all the monitor components are manufactured and the monitor is under assembly.

IV. Collaboration with the Jefferson Laboratory, USA (TJNAF) is continued. In 2006, we completed preparation and carried out the experiment on measurement of the neutron electrical form factor at high transmitted pulsed of up to 3.5 GeV^2/C^2. New data expand substantially the experimental range and measured accuracy of this parameter most important for the nucleon physics. BINP staff contributed substantially into the preparation and commissioning of two detectors for this experiment: a wide aperture spectrometer of electrons BigBite and the big neutron detector BigHAND. At present, the data obtained are under processing.

We finished processing of the earlier performed experiment at JLAB with participation of the BINP physicists – a search for partners of Θ^+ with high mass resolution. The resonance $\Theta^+(1540)$ – is an exotic 5-quark state with a peculiarity $S = +1$ predicted in the chiral quark soliton model and discovered (though with a low level of confidence)in a number of experiments, The existence of such a state is explained also in the frame of other quark models. If Θ^+– a pentaquark is really exist, then other more massive members of this symmetry group of other multiplets comprising the exotic states should also exist. In the performed experiment, we made an attempt to discover such 5-quark states: Θ^{++}, Σ_5^0, N_5^0 within the mass range of 1500-2000 MeV, under assumption that these resonances are narrow. By results of data processing, no one statistically essential resonance structure was found in the scanned mass range. We obtained the upper value of the photogeneration crossection of such states: less than 5% of the photogeneration crossection of the Λ-resonance if the expected width is $\Gamma < 10$ MeV. The results will be published in 2007.

V. In 2006, within the frame of the joint RFBR – China Grant we continued the joint work with the Institute of Modern Physics (Lanzhou, China) where the storage ring of heavy ions for experiments with the internal target (Heavy Ion Research Facility Lanzhou, Cooler Storage Ring, HIRFL-CSR) is at the stage of commissioning. The cluster target regimes were studied in the operation with various gases including argon(see Fig. 4) and hydrogen.

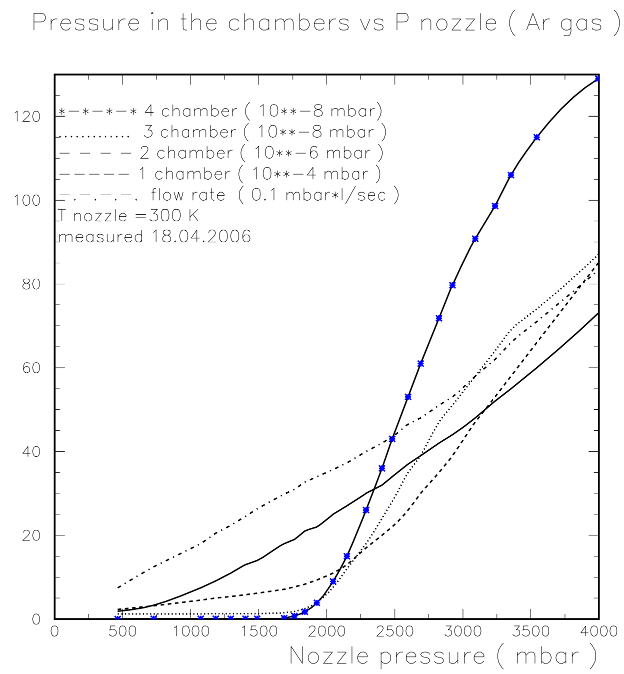


Figure 4: The distribution of pressure over the target chambers and gas consumption through the nozzle versus the argon pressure in front of the nozzle. The nozzle temperature is the room temperature.

The gas density in the argon and hydrogen jets is of the order of $1.0{\cdot}10^{13}$ atm/cm^3 and $1.75{\cdot}10^{13}$ atm/cm^3, respectively. The ultimate pressure obtained in the experimental straight section has the value $9.0{\cdot}10^{-12}$ mbar and it increases up to the value no higher than $1.5{\cdot}10^{-11}$ mbar when the jet is passing throught that is substantially less that expected during design. The long (of the order of 24 hours) runs of the target during which the jet parameters were changed within the limit of several percents have demonstrated the high reliability of its operation.

Experiments with the internal targets are carried out jointly with the experimental groups from Tomsk, Saint-Petersburg, NIKHEF (the Netherlands), ANL (USA), IKF JGU (Meinz, Germany).

Participants of the work from BINP: L.M.Barkov, V.F.Dmitriev, M.V.Dyug, S.A.Zevakov, B.A.Lazarenko, E.B.Levichev, S.I.Mishnev, D.M.Nikolenko, I.A.Rachek, R.Sh.Sadykov, D.K.Toporkov, Yu.V.Shestakov.

Chapter 3

Theoretical physics

3.1 Strong interaction

The gluon Reggeization in perturbative QCD at NLO

V. S. Fadin

Towards High Energy Scattering, Eds. M. Haguenauer, B. Nicolescu J. Tran Thanh Van, pp.321-328.

Compatibility of the Reggeized form of QCD multi-particle amplitudes with the s-channel unitarity requires fulfilment of an infinite number of the "bootstrap" relations. On the other hand, it turns out that fulfillment of all these relations ensures the Reggeized form of energy dependent radiative corrections order by order in perturbation theory. It is extremely nontrivial, that all these relations are fulfilled if the Reggeon vertices and trajectory satisfy several bootstrap conditions. The full set of these conditions in the next-to-leading order was derived in the last year and the ultimate condition was shown to be satisfied recently. It means that the Reggeization hypothesis is proved now in the next-to-leading approximation.

A proof of the Reggeized form of amplitudes with quark exchanges

A. V. Bogdan, V. S. Fadin

Nucl. Phys. B **740** (2006) 36-57, [arXiv:hep-ph/0601117].

A complete proof of the quark Reggeization hypothesis in the leading logarithmic approximation for any quark–gluon inelastic process in the multi-Regge kinematics in all orders of α_s is given. First, we show that the multi–Regge form of QCD amplitudes is guarantied if a set of conditions on the Reggeon vertices and the trajectories is fulfilled. Then, we examine these conditions and show that they are satisfied.

Proof of the multi-Regge form of QCD amplitudes with gluon exchanges in the NLA

V. S. Fadin, R. Fiore, M. G. Kozlov and A. V. Reznichenko

Phys. Lett. B **639** (2006) 74-81 [arXiv:hep-ph/0602006].

The multi–Regge form of QCD amplitudes with gluon exchanges is proved in the next-to-leading approximation. The proof is based on the bootstrap relations, which are required for the compatibility of this form with the s-channel unitarity. We show that the fulfillment of all these relations ensures the Reggeized form of energy dependent radiative corrections order by order in perturbation theory. Then we prove that all these relations are fulfilled if several bootstrap conditions on the Reggeon vertices and trajectory hold true. Now all these conditions are checked and proved to be satisfied.

Non-forward BFKL kernel at NLO

V. S. Fadin

Acta Phys. Polon. B **37** (2006) 829-834.

The kernel of the BFKL equation at next-to-leading order is presented and discussed in general case of non-zero momentum transfer t and any possible t-channel colour state. Possible ways of use of the non-forward kernel are discussed. Apart from phenomenological applications extremely intriguing problems related to the kernel are violation of conformal invariance and consistency with the dipole picture of high energy scattering.

Non-forward BFKL at NLO

V. S. Fadin

In: "PoS - Proceedings of Science."

Structure of the kernel of the BFKL equation in the next-to-leading order is discussed. The two-gluon contribution to the kernel for non-zero momentum transfer is considered. Different forms of this contribution are suggested. Their properties are analyzed. The quark contribution to the kernel is transformed from momentum representation to coordinate one.

Small x processes in perturbative QCD

V. S. Fadin

In: "New Trends in High-Energy Physics", Eds. P.N. Bogolyubov, L.L. Jenkovszky, V.K. Magas, Z.I. Vakhnenko, Kiev, 2000, pp. 213-222

In the framework of perturbative QCD the most common basis for the theoretical description of small-x processes is given by the BFKL approach, based on the gluon Reggeization. Another approach to high energy scattering, which is very popular now, is the color dipole one. A current status of the BFKL approach is briefly discussed and relation between the BFKL and dipole approaches is analyzed.

On the coordinate representation of NLO BFK

V. S. Fadin, R. Fiore and A. Papa

arXiv:hep-ph/0612284.

The "non-Abelian" part of the quark contribution to the BFKL kernel in the next-to-leading order (NLO) is found in the coordinate representation by direct transfer of the contribution from the momentum representation where it was calculated before. The results obtained are used for the examination of conformal properties of the NLO BFKL kernel and of the relation between the BFKL and color dipole approaches.

The dipole form of the quark part of the BFKL kernel

V. S. Fadin, R. Fiore and A. Papa

arXiv:hep-ph/0701075.

The dipole form of the "Abelian" part of the massless quark contribution to the BFKL kernel is found in the coordinate representation by direct transfer from the momentum representation where the contribution was calculated before. It coincides with the corresponding part of the quark contribution to the dipole kernel calculated recently by Balitsky and is conformal invariant.

$\gamma\gamma \to \pi\pi$, KK: Leading term QCD versus handbag model

V.L. Chernyak

Phys. Lett. B **640** (2006) 246-251, hep-ph/0605072

The "handbag"model was proposed as an alternative, at the present day energies, to the leading term QCD predictions for some hard exclusive processes. The recent precise data from the Belle Collaboration on the large angle cross sections $\gamma\gamma \to \pi\pi, KK$ allow a check of these two approaches to be performed. It is shown that the handbag model fails to describe the data from Belle, while the leading term QCD predictions are in reasonable agreement with these data.

Selected topics in e^+e^- collisions

V.L. Chernyak
Nucl. Phys. (Proc. Suppl.) B **162** (2006) 161-171, hep-ph/0605327

A short review is presented of a check of QCD predictions for hard exclusive processes and properties of hadron wave functions in experiments on e^+e^- - collisions. A number of new results of the author obtained in this field is also presented.

Content : 1) The leading twist pion wave function, 2) "Improved" QCD sum rules with non-local condensates, 3) Pion and kaon form factors and charmonium decays: theory vs experiment, 4) $\gamma^*\gamma\pi^o$ - form factor, 5) The new non-local axial anomaly, 6) Cross sections $\gamma\gamma \to \pi^+\pi^-, K^+K^-, K_SK_S$.

Decoupling of heavy quarks in HQET

A.G. Grozin, A.V. Smirnov, V.A. Smirnov
J. High Energy Phys. **11** (2006) 022

Decoupling of c-quark loops in b-quark HQET is considered. The decoupling coefficients for the HQET heavy-quark field and the heavy-light quark current are calculated with the three-loop accuracy. The last result can be used to improve the accuracy of extracting f_B from HQET lattice simulations (without c-quark loops). The decoupling coefficient for the flavour-nonsinglet QCD current with n antisymmetrized γ-matrices is also obtained at three loops; the result for the tensor current ($n = 2$) is new.

Lectures on QED and QCD

A.G. Grozin
Lectures for young scientists **63**, Dubna, JINR E2-2006-33

The lectures are a practical introduction to perturbative calculations in QED and QCD. I discuss methods of calculation of one- and two-loop diagrams in dimensional regularization, $\overline{\text{MS}}$ and on-shell renormalization schemes, decoupling of heavy-particle loops.

3.2 Nuclear physics and parity nonconservation

Local spin spirals in the Neel phase of $La_{2-x}Sr_xCuO_4$

A. Lucher, A.I. Milstein, G. Misguich,O.P. Sushkov
Phys. Rev. B **73** (2006) 085122

Experimental observations of lightly doped $La_{2-x}Sr_xCuO_4$, $x < 0.02$, revealed remarkable magnetic properties such as the incommensurate noncollinear ordering (additional to the Neel ordering) and a tremendous doping dependence of the uniform longitudinal susceptibility. We show that the spiral solution of the t-t'-t"-J model obtained by taking into account the Coulomb trapping of holes by Sr ions describes these puzzling data perfectly well. Our solution firstly explains why the incommensurate structure is directed along the orthorhombic b-axis, and secondly allows a numerical calculation of the positions and shapes of the incommensurate neutron scattering peaks. Thirdly, we calculate the doping dependence of the spin-wave gap, and lastly, we study the longitudinal magnetic susceptibility and show that its doping dependence is due to the noncollinearity of the spin spiral.

Correlated electron current and temperature dependence of the conductance of a quantum point contact

C.Sloggett, A.I.Milstein, and O.P.Sushkov
ArXiv:cond-mat/0606649

We investigate finite temperature corrections to the Landauer formula due to electron-electron interaction within the quantum point contact. When the Fermi level is close to the barrier height, the interaction is strongly enhanced due to semiclassical slowing of the electrons. To describe electron transport we formulate and solve a nonlocal kinetic equation for the density matrix of electrons. The correction to the conductance G is negative and strongly enhanced in the region $0.5 * 2e^2/h < G < 1 * 2e^2/h$. Our results for conductance agree with the so-called "0.7 structure" observed in experiments.

Destruction of Neel order and local spin spirals in insulating $La_{2-x}Sr_xCuO_4$

A. Luscher, A.I. Milstein, O.P.Sushkov
ArXiv:cond-mat/0606679

Starting from the t-J model, we derive an effective field theory describing the spin dynamics in the insulating phase of $La_{2-x}Sr_xCuO_4$, $x < 0.055$, at low temperature. Using Monte Carlo simulations, we show that the destruction of Neel order is driven by the single-hole localization length kappa. A phase transition at 2% doping is consistent with the value of kappa known from the variable range hopping conductivity. The static spin structure factor obtained in our calculations is in perfect agreement with neutron scattering data over the whole range of doping. We also demonstrate that topological defects (spin vortex-antivortex pairs) are an intrinsic property of the spin-glass ground state.

Quasiclassical description of bremsstrahlung in alpha decay

A.I.Milstein, I.S.Terekhov, et al.
ArXiv:nucl-th/0606005

We revisit the theory of bremsstrahlung in α decay with a special emphasis on the case of ^{210}Po, with the aim of finding a unified quasiclassical 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 $E_\gamma \sim Q_\alpha/\sqrt{\eta}$, where Q_α is the α-decay Q-value and η 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 α-γ angular correlation. Thus, the assumption of a dipole pattern in the analysis of experimental data, obtained with the typically restricted restricted solid angles covered by detectors, is not adequate.

Final State Interaction Effects in $N\bar{N}$ Production near Threshold

V.F.Dmitriev and A.I.Milstein
Nuclear Physics B (Proc. Suppl.) 162 (2006) 53-56

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 electromagnetic form factors are very sensitive to the parameters of the potential. It turns out that final-state interaction due to a slightly modified absorptive part of the potential allows us to reproduce experimental data available.

Nuclear Schiff moment in nuclei with soft octupole and quadrupole vibrations

N.Auerbach, V.F.Dmitriev, V.V.Flambaum, A.Lisetskiy, R.A.Sen'kov, V.G.Zelevinsky
Phys.Rev. C74 (2006) 025502

Nuclear forces violating parity and time reversal invariance ($\mathcal{P},\mathcal{T}$-odd) produce $\mathcal{P},\mathcal{T}$-odd nuclear moments, for example, the nuclear Schiff moment. In turn, this moment can induce the electric dipole moment in the atom. The nuclear Schiff moment is predicted to be enhanced in nuclei with static quadrupole and octupole deformation. The analogous suggestion of the enhanced contribution to the Schiff moment from the soft collective quadrupole and octupole vibrations in spherical nuclei is tested in this article in the framework of the quasiparticle random phase approximation with separable quadrupole and octupole forces applied to the odd $^{217-221}$Ra and $^{217-221}$Rn isotopes. We confirm the existence of the enhancement effect due to the soft modes. However, in the standard approximation the enhancement is strongly reduced by a small weight of the corresponding "particle + phonon" component in a complicated wave function of a soft nucleus. The perspectives of a better description of the structure of heavy soft nuclei are discussed.

3.3 Quantum electrodynamics

Corrections to the energy levels of a spin-zero particle bound in a strong field

R.N.Lee, A.I.Milstein, and S.G.Karshenboim
Phys.Rev. A **73** (2006) 012505

Formulas for the corrections to the energy levels and wave functions of a spin-zero particle bound in a strong field are derived. General case of the sum of a Lorentz-scalar potential and zero component of a Lorentz-vector potential is considered. The forms of the corrections differ essentially from those for spin-1/2 particles. As an example of application of our results, we evaluated the electric polarizability of a ground state of a spin-zero particle bound in a strong Coulomb field.

Polarization operator approach to electron positron pair production in combined laser and Coulomb field

A.I.Milstein, C. Müller, K.Hatsagortsyan, U. Jentschura, C.H. Keitel
Phys.Rev. A **73** (2006) 062106

The optical theorem is applied to the process of electron-positron pair creation in the superposition of a nuclear Coulomb and a strong laser field. We derive new representations for the total production rate as two-fold integrals, both for circular laser polarization and for the general case of elliptic polarization, which has not been treated before. Our approach allows us to obtain by analytical means the asymptotic behavior of the pair creation rate for various limits of interest. In particular, we consider pair production by two-photon absorption and show that, close to the energetic threshold of this process, the rate obeys a power law in the laser frequency with different exponents for linear and circular laser polarization. With the help of the upcoming x-ray laser sources our results could be tested experimentally.

e^+e^- pair production in ultrarelativistic heavy-ion collisions at intermediate impact parameters

R.N. Lee and A.I. Milstein
ArXiv:nucl-th/0610008

Using the quasiclassical Green's function in the Coulomb field, we analyze the probabilities of single and multiple e^+e^--pair production at fixed impact parameter b between colliding ultrarelativistic heavy nuclei. We perform calculations in the Born approximation with respect to the parameter $Z_B\alpha$, and exactly in $Z_A\alpha$, Z_A and Z_B are the charge numbers of the corresponding nuclei. We also obtain the approximate formulas for the probabilities valid for $Z_A\alpha, Z_B\alpha \leq 1$.

Differential equations and high-energy expansion of two-loop diagrams in D dimensions

A.V. Bogdan and R.N. Lee
Nucl. Phys. B **732** (2006) 169

New method of calculation of master integrals using differential equations and asymptotical expansion is presented. This method leads to the results exact in space-time dimension D having the form of the convergent power series. As an application of this method, we calculate the two-loop master integral for “crossed-triangle” topology which was previously known only up to $O(\varepsilon)$ order. The case when a topology contains several master integrals is also considered. We present an algorithm of the term-by-term calculation of the asymptotical expansion in this case and analyze in detail the “crossed-box” topology with three master integrals.

Polarized radiation from electrons at off-axis crystal orientation

V. Strakhovenko

Advanced Radiation Sources and Applications, H.Wiedemann(ed)
Springer, 2006, pp. 55-62

A complete description of spectral and polarization characteristics of the radiation emitted by arbitrary polarized high-energy electrons is derived for the case when the electron velocity makes an angle with respect to some major crystal axis that is appreciably larger than the axial channeling angle. A possibility of the use of oriented crystals in a polarized hard-photon source is evaluated basing on the results of numerical calculations and on the elaborated qualitative picture of the phenomenon.

Electron-positron pair production and bremsstralung at intermediate energies in the field of heavy atoms

R.N. Lee, A.I. Milstein, V.M. Strakhovenko, O.Ya. Schwartz

Radiation Physics and Chemistry **75** (2006) 868-873

The Coulomb corrections (CC) to the processes of bremsstrahlung (BR) and pair production (PP) are investigated. The next-to-leading term in the high-energy asymptotics is found. This term becomes very essential in the intermediate energy region. The influence of screening on CC is small in the case of PP for the differential cross section and spectrum. This is true for the spectrum of BR, while the influence of screening on CC for the differential cross section of BR can be very large. The results for the total cross section of PP a compared with the available experimental data. This comparison has justified our analytical results and allowed to elaborate a simple ansatz for the next correction term.

Radiation from electrons passing through helical undulator or colliding with circularly polarized laser wave

V. Strakhovenko

http://posipol2006.web.cern.ch
Talk given at Posipol 2006, CERN, 26-28, April 2006

Helical undulator and laser wave are the only objects, which may provide, during the interaction with unpolarized relativistic electrons, a generation of circularly polarized photons needed for the development of the longitudinally-polarized positron source. In the talk, spectral-angular distributions and polarization of radiation for both schemes are compared, the role of the electron-beam angular divergence and of the collimation of radiation is clarified, the total yield during one beam passage is estimated.

Generation of polarized positrons in a target

V. Strakhovenko

http://posipol2006.web.cern.ch
Talk given at Posipol 2006, CERN, 26-28, April 2006

It is well known that positrons created by circularly polarized photons have a noticeable longitudinal polarization at the upper edge of the spectrum. In the talk, a dependence of the different aspects of the photoproduction process on the initial photon energy is discussed. In particularly, it is shown that a depolarization during multiple scattering can be neglected for relativistic positrons. A scheme to describe a development of the electromagnetic shower, taking into account polarizations of all involved particles, is suggested.

Effects of polarization in electromagnetic processes in oriented crystals at high energy

V. N. Baier and V. M. Katkov

Advanced Radiation Sources and Applications, H.Wiedemann(ed)
Springer, 2006, pp 97-108

Under some quite generic assumptions the general expression is derived for the probability of circularly polarized photon emission from the longitudinally polarized electron and for the probability of pair creation of longitudinally polarized electron (positron) by circularly polarized photon in oriented crystal in a frame of the quasiclassical operator method. The particular mechanism of radiation or pair creation depends on interrelation between the angle of incidence ϑ_0 (angle between the momentum of initial photon and axis (plane) of crystal) and angle $\vartheta_v \equiv V_0/m$ (V_0 is the scale of a potential of axis or a plane relative to which the angle ϑ_0 is defined). When $\vartheta_0 \ll \vartheta_v$ one has radiation or pair creation in an external field type of process (with corrections $\propto \vartheta_0^2$ which are due to inhomogeneous character of field in crystal). When $\vartheta_0 \gg \vartheta_v$ one obtains the theory of coherent radiation or pair creation, while for $\vartheta_0 \geq \vartheta_v$ one arrives to the modified theory of coherent pair creation.

Polarization effects for pair creation by photon in oriented crystals at high energy

V. N. Baier and V. M. Katkov

Nuclear Instruments and Methods in Physics Research B 243, 282-292, 2006

Pair creation by a photon in an oriented crystal is considered in the frame of the quasiclassical operator method, which includes processes with polarized particles. Under some quite generic assumptions the general expression is derived for the probability of pair creation of longitudinally polarized electron (positron) by circularly polarized photon in oriented crystal. In the particular cases $\vartheta_0 \ll V_0/m$ and $\vartheta_0 \gg V_0/m$ (ϑ_0 is the angle of incidence, angle between the momentum of the initial photon and axis (plane) of crystal, V_0 is the scale of a potential of axis or a plane relative to which the angle ϑ_0 is defined) one has the constant field approximation and the coherent pair production theory correspondingly. Side by side with coherent process the probability of incoherent pair creation is calculated, which differs essentially from amorphous one. At high energy the pair creation in oriented crystal is strongly enhanced comparing with the amorphous medium. In the corresponding appendixes the integral polarization of positron is found in an external field and for the coherent and incoherent mechanisms.

Coherent and incoherent radiation from high-energy electron and the LPM effect in oriented single crystal

V. N. Baier and V. M. Katkov

Physics Letters, A353, 91-97, 2006,

The process of radiation from high-energy electron in oriented single crystal is considered using the method which permits inseparable consideration of both coherent and

incoherent mechanisms of photon emission. The total intensity of radiation is calculated. The theory, where the energy loss of projectile has to be taken into account, agrees quite satisfactory with available CERN data. It is shown that the influence of multiple scattering on radiation process is suppressed due to action of crystal field.

Coherent and incoherent processes and the LPM effect in oriented single crystals at high-energy

V. N. Baier and V. M. Katkov
BINP Preprint 2006-33, Invited talk at International Conference "CHANNELING 2006" , Frascati, July 2006

The process of radiation from high-energy electron and electron-positron pair production by a photon in oriented single crystal is considered using the method which permits inseparable consideration of both coherent and incoherent mechanisms of photon emission from an electron and of pair creation by a photon and 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 total intensity of radiation and total probability pair creation are calculated. The theory, where the energy loss of projectile has to be taken into account, and found probabilities of pair creation agree quite satisfactory with available CERN data. From obtained results it follows that multiple scattering appears only for relatively low energy of radiating electron or a photon, while at higher energies the field action excludes the LPM effect.

Final State Interaction Effects in the $e^+e^- \to N\bar{N}$ Process near Threshold

V.F.Dmitriev, A.I.Milstein
nucl-th/0607003

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. It turns out that final-state interaction due to slightly modified absorptive part of the potential allows us to reproduce available experimental data. We also demonstrated that the cross section in $n\bar{n}$ channel is larger than that in $p\bar{p}$ one, and their ratio is almost energy independent up to 2.2 GeV.

3.4 Gravity

Upper limits on density of dark matter in Solar system

I.B. Khriplovich, (coauthor E.V. Pitjeva)
Int. J. Mod. Phys. **D 15** (2006) 615.

The analysis of the observational data for the secular perihelion precession of Mercury, Earth, and Mars, based on the EPM2004 ephemerides, results in new upper limits on density of dark matter in the Solar system. Work was presented at the International Conference Marcel Grossmann 11, Berlin, July 2006.

Quasinormal modes for arbitrary spins in the Schwarzschild background

I.B. Khriplovich, (coauthor G.Yu.Ruban)
Int. J. Mod. Phys. **D 15** (2006) 879.

The leading term of the asymptotic of quasinormal modes in the Schwarzschild background is obtained in two straightforward analytical ways for arbitrary spins. One of these approaches requires almost no calculations. As simply we demonstrate that for any odd integer spin, described by the Teukolsky equation, the first correction to the leading term vanishes. Then, this correction for half-integer spins is obtained in a slightly more intricate way. At last, we derive analytically the general expression for the first correction for all spins, described by the Teukolsky equation.

Work was presented at the International Conference Marcel Grossmann 11, Berlin, July 2006.

Is radiation of quantized black holes observable?

I.B. Khriplovich, (coauthor N. Produit)
Int. J. Mod. Phys. **D**, in press; astro-ph/0604003.

If primordial black holes (PBH) saturate the present upper limit on the dark matter density in our Solar system and if their radiation spectrum is discrete, the sensitivity of modern detectors is close to that necessary for detecting this radiation. This conclusion is not in conflict with the upper limits on the PBH evaporation rate.

Work was presented at the International Conference Marcel Grossmann 11, Berlin, July 2006.

The Work constitutes also the content of a lecture given at the International ITEP School, Moscow, February 2006, and of invited talk at the Seminar in Memory of M.P. Bronshtein, Sanct-Petersburg, December 2006.

On the area expectation values in area tensor Regge calculus in the Lorentzian domain

V.M.Khatsymovsky
Phys. Lett. B 633 (2006) 653

Wick rotation in area tensor Regge calculus is considered. The heuristical expectation is confirmed that the Lorentzian quantum measure on a spacelike area should coincide with the Euclidean measure at the same argument. The consequence is validity of probabilistic interpretation of the Lorentzian measure as well (on the real, i.e. spacelike areas).

Path integral in area tensor Regge calculus and complex connections

V.M.Khatsymovsky
Phys. Lett. B 637 (2006) 350.

Euclidean quantum measure in Regge calculus with independent area tensors is considered using example of the Regge manifold of a simple structure. We go over to integrations along certain contours in the hyperplane of complex connection variables. Discrete connection and curvature on classical solutions of the equations of motion are not, strictly speaking, genuine connection and curvature, but more general quantities and, therefore, these do not appear as arguments of a function to be averaged, but are the integration (dummy) variables. We argue that upon integrating out the latter the resulting measure can be well-defined on physical hypersurface (for the area tensors corresponding to certain edge vectors, i.e. to certain metric) as positive and having exponential cutoff at large areas on condition that we confine ourselves to configurations which do not pass through degenerate metrics.

On the possibility of finite quantum Regge calculus

V.M.Khatsymovsky
E-print archive gr/qc/0612143

The arguments were given in a number of our papers that the discrete quantum gravity based on the Regge calculus possesses nonzero vacuum expectation values of the triangulation lengths of the order of Plank scale $10^{-33}cm$. These results are considered paying attention to the possibility of having finite theory within this framework.

Complete integrability of higher-dimensional Einstein equations with additional symmetry, and rotating black holes

A.A. Pomeransky
Phys.Rev. D73, 044004 (2006)

A new derivation of the five-dimensional Myers-Perry black-hole metric as a 2-soliton solution on a non-flat background is presented. It is intended to be an illustration of how the well-known Belinski-Zakharov method can be applied to find solutions of the Einstein equations in D-dimensional space-time with D-2 commuting Killing vectors using the complete integrability of this system. The method appears also to be promising for the analysis of the uniqueness questions for higher-dimensional black holes.

Remark on Immirzi Parameter, Torsion, and Discrete Symmetries

I.B. Khriplovich and A.A. Pomeransky
Phys.Rev. D73, 107502 (2006)

We point out that the new interaction of spinning particles with the torsion tensor, discussed recently, is odd under charge conjugation and time reversal. This explains rather unexpected symmetry properties of the induced effective 4-fermion interaction.

Black ring with two angular momenta

A.A. Pomeransky and R.A. Sen'kov
e-print: hep-th/0612005

General regular black ring solution with two angular momenta is presented, found by the inverse scattering problem method. The mass, angular momenta and the event horizon volume are given explicitly as functions of the metric parameters.

Quantum corrections to the Schwarzschild metric and reparametrization transformations

G.G. Kirilin,
submitted in Physical Review D, eprint: gr-qc/0601020

Quantum corrections to the Schwarzschild metric generated by loop diagrams have been considered by Bjerrum-Bohr, Donoghue, and Holstein (BHD) [Phys. Rev. **D68**, 084005 (2003)], and Khriplovich and Kirilin (KK) [J. Exp. Theor. Phys. **98**, 1063 (2004)]. Though the same field variables in a covariant gauge are used, the results obtained differ from one another. The reason is that the different sets of diagrams have been used. Here we will argue that the quantum corrections to metric must be independent of the choice of field variables, i. e. must be reparametrization invariant. Using simple reparametrization transformation, we will show that the contribution considered by BDH, is not invariant under it. Meanwhile the corrections to the Schwarzschild metric considered by KK satisfies the requirement of the invariance.

3.5 Nonlinear dynamics and chaos

Quantum dephasing and decay of classical correlation functions in chaotic systems

Valentin V. Sokolov, Giuliano Benenti, and Giulio Casati
Quant-ph/0504141 v3 23 May 2006; to appear in Phys. Rev E **75**, 093702,(2007)

We investigate the role of classical dynamical chaos in the decay of the quantum Loschmidt echo (“fidelity”) in the absence of any irregular external influence. We show analytically and then demonstrate numerically that, if the system is classically chaotic and the evolution starts from a wide and incoherent mixed state, the initial incoherence persists due to the intrinsic classical chaos so that the quantum phases remain irrelevant. In such a case the decay of fidelity is related to that of an appropriate classical correlation function so that the internal dynamical haos produces a dephasing effect similar to the decoherence due to the disordered environment.

Dynamical chaos versus quantum interference

Valentin V. Sokolov, Giuliano Benenti, Giulio Casati
Quant-ph/0611191 v1 18 Nov 2006; Submitted in Phys. Rev. Lett.

We discuss the dephasing induced by the internal classical chaotic motion in the absence of any external environment. To this end an extension of fidelity for mixed states is introduced, which we name *allegiance*. Such a quantity, as distinct from the ordinary fidelity, directly accounts for quantum interference. On the other hand, this quantity can be measured in a Ramsey interferometry experiment. We show that in the semiclassical limit the decay of the allegiance is *exactly* expressed, due to the dephasing, in terms of an appropriate classical correlation function. This explains the relation between decays of fidelity and classical correlations discovered in our previous paper. Our results are derived analytically for the case of a nonlinear driven oscillator and then numerically confirmed for the kicked rotor model.

Quantum synchronization

O.V. Zhirov and D.L. Shepelyansky
Eur. Phys. J **D**38, 375-379 (2006)

Using the methods of quantum trajectories we study numerically a quantum dissipative system with periodic driving which exhibits synchronization phenomenon in the classical limit. The model allows to analyze the effects of quantum fluctuations on synchronization and establish the regimes where the synchronization is preserved in a quantum case (quantum synchronization). Our results show that at small values of Planck constant $\hbar$ the classical devilTs staircase remains robust with respect to quantum fluctuations while at large $\hbar$ values synchronization plateaus are destroyed. Quantum synchronization in our model has close similarities with Shapiro steps in Josephson junctions and it can be also realized in experiments with cold atoms.

Dissipative decoherence in the Grover algorithm

O.V. Zhirov and D.L. Shepelyansky
Eur. Phys. J **D**38, 405-408 (2006)

Using the methods of quantum trajectories we study effects of dissipative decoherence on the accuracy of the Grover quantum search algorithm. The dependence on the number of qubits and dissipation rate are determined and tested numerically with up to 16 qubits. As a result, our numerical and analytical studies give the universal law for decay of fidelity and probability of searched state which are induced by dissipative decoherence effects. This law is in agreement with the results obtained previously for quantum chaos algorithms.

Frenkel-Kontorova model with cold trapped ions

I. Garcia-Mata, O.V. Zhirov and D.L. Shepelyansky
e-print: cond-mat/0606135 (2006), Eur. Phys. J **D**41, 325-330(2007)

We study analytically and numerically the properties of one-dimensional chain of cold ions placed in a periodic potential of optical lattice and global harmonic potential of a trap. In close similarity with the Frenkel-Kontorova model, a transition from sliding to pinned phase takes place with the increase of the optical lattice potential for the density of ions incommensurate with the lattice period. We show that at zero temperature the quantum fluctuations lead to a quantum phase transition and melting of pinned instanton glass phase at large values of dimensional Planck constant. After melting the ion chain can slide in an optical lattice. The obtained results are also relevant for a Wigner crystal placed in a periodic potential.

Chapter 4

Plasma physics and controlled thermonuclear fusion

4.1 Influence of radial electric field on hige-beta plasma confinement in the gas dynamic trap

One of the most important subjects of the GDT (fig.1) research program is MHD-stability and transversal transport of high pressure two-component plasma. Influence of radial electric field on the plasma confinement was demonstrated in previous experiments on the GDT, which were dedicated to influence of plasma rotation in cross fields (axial magnetic field and radial electric field appeared due to natural electron temperature gradient) on its MHD-stability. It was observed in those experiments that positive influence of radial electric field on plasma confinement always corresponds to intermittent distribution of biasing potential on special radial electrodes - limiters and plasma absorbers. This effect was essential even in the case of special MHD-stabilizers were turned off.
[Bagryansky P.A., et al. *Fusion Science and Technology* **43** (2003) pp. 152-156.].

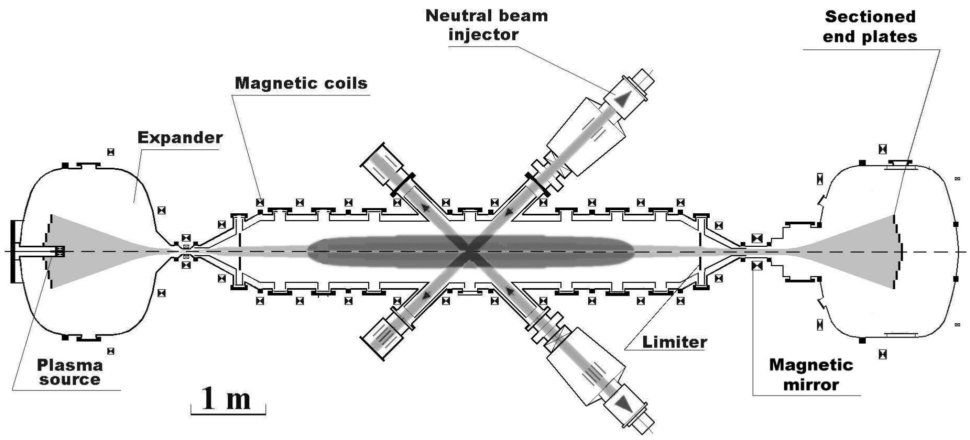


Figure 1: Scheme of GDT device.

The main goal of following experiments is investigation of possible mechanisms of MHD-instability suppression and improvement of high β plasma confinement. Contact between plasma and end plates and also the influence of radial electric field profile on MHD-stability and transversal transport of particles and energy were investigated.

To manage the radial electric field profile sectioned plasma absorbers consist of grounded central disk and three isolated concentric rings were installed in expanders regions of GDT. Each of that rings could be biased independently in the range of from 0 to +300 V. Inside of the central solenoid near the magnetic mirrors single isolated rings from stainless steel which limit plasma volume and could be biased in the same range (0÷300 V) were installed (fig. 1 and 2).

For these experiments special diagnostics based on electrostatic probes methods were created. Thirty two flat 15 mm diameter probes were installed on the end plasma absorber which is in front of plasma source. Those probes were used for registration of ion density flux spacial distribution and were spaced azimuthally equidistant, eight probes on each of four plasma dump sections. Such a diagnostics allowed to observe ion density flux distribution on the end walls vs time, time evolution of total longitudinal current after plasma source switch off. Also those probes allowed to obtain data about the characteristic radius of plasma and its asymmetry rate. We also used the Langmuir probe capable to work as well as in regime of floating potential measuring so as a triple probe for periphery plasma temperature and density measurements. For electric field and density fluctuations measurements special combined probe consists of two couples of electrodes were used.

One of possible mechanisms of MHD-stabilization in GDT is electric contact between plasma and radial electrodes–limiters and end plates. In paper [Bagryansky P.A., Soldatkina E.I. // *Proc. of XXXIII International Conference on Plasma Physics and Controlled Fusion, Zvenigorod,* 2006, p.80] influence of contact between plasma and limiters on MHD-stability was investigated. Plasma Debye layer resistance near the limiter was measured. Characteristic time of plasma column capacity discharge through the limiter resistance was estimated and compared with MHD-instability development time. Such estimations

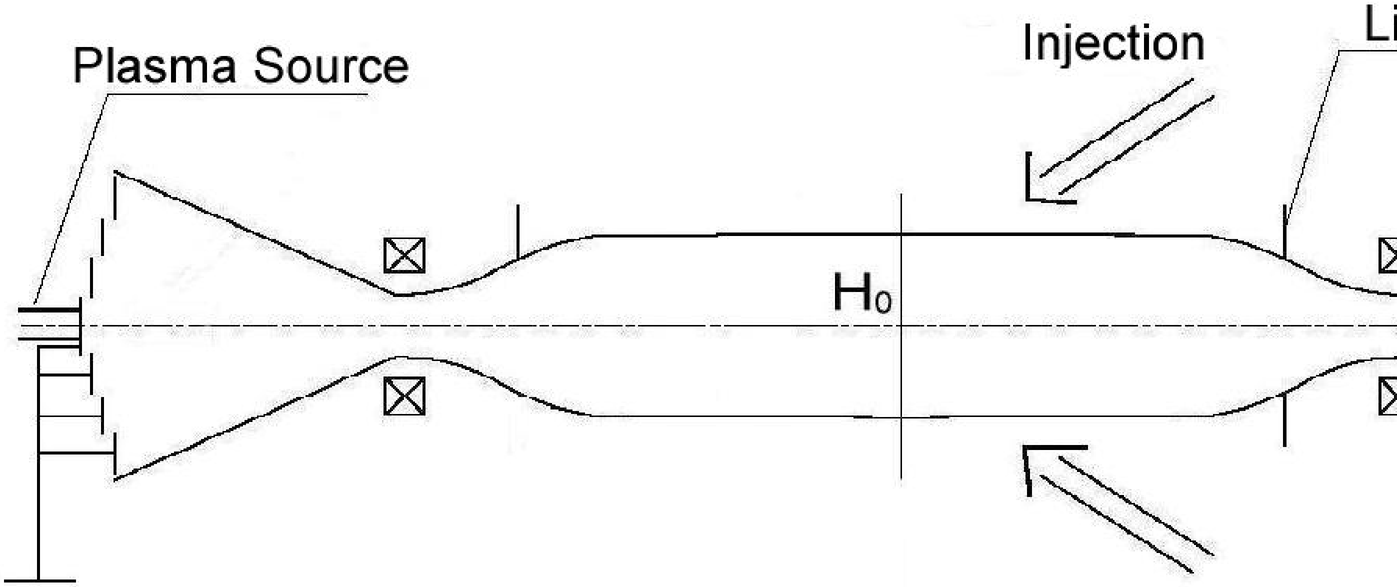


Figure 2: Scheme of experiment for estimation of resistance between plasma and end plates.

One of end plates was totally grounded, rings of another one were biased by different voltages and currents flowing to those rings were registered. In this way volt-ampere characteristic was obtained and magnitude of resistance was $R \approx 0.26\Omega$. This result is in a good agreement with estimations carried out according to flat probe theory.

To define how this value of resistance influences on the process of flute instability first mode development let's imagine the polarized plasma column as a flat capacitor discharging to the end plate through the Debye layer resistance near the plate. It is possible to estimate the plasma column capacity as $C \approx \frac{\varepsilon S}{4\pi d}$, where $\varepsilon \approx \frac{\omega_{pi}^2}{\omega_{ci}^2} = \frac{4\pi n m_i c^2}{B^2}$, we can obtain $C \approx 6\mu F$ if plasma density is $2{\cdot}10^{13}$ cm^{-3}, magnetic field in the centre of trap is 2 kGs and solenoid length is 7 m. Therefore the characteristic time of plasma column discharge through the end electrodes appears equal to $\tau_{rel} = RC \approx 1.6\ \mu s$.

It is well known that increment of flute instability can be easily estimated as $\gamma \sim \frac{V_{Ti}}{L}$, where L - length of GDT device, V_{Ti} - ion thermal velocity. Herewith the one increment depends on plasma pressure as a radical: $\gamma \propto \sqrt{p}$ [M.S. Chaschin, A.D. Beklemishev, // Reprint BINP SB RAS 2006-19, Novosibirsk 2006]. Hence for two-component plasma which includes populations of fast and target ions it is possible to define the increment as $\gamma^{(2)} \propto \sqrt{p_{fast} + p_{target}}$. According to results of diamagnetic measurements on GDT the fast ions pressure is about ten times higher than the pressure of warm target plasma. Taking out for a bracket $\sqrt{p_{target}}$ to a numerator and neglecting it in a subduplicate sum one can obtain an expression for flute instability development time in two- component plasma as:$\tau_{MHD} = \frac{L}{V_{Ti}}\sqrt{\frac{W_{target}}{W_{fast}}}$, where V_{Ti} - target ions thermal velocity, W_{target} and W_{fast} - energy content of target plasma and fast ions respectively. At plasma temperature about 80 eV and $W_{target} = 80$ J, $W_{fast} = 500$ J MHD-instability development time appears about 10 μs. Such a result allows one to draw a conclusion that the contact between plasma and end plates can significantly influence on flute instability increment. However in experiments without using any MHD-stabilizers in case of equal potentials on all the radial electrodes the plasma confinement time was much shorter than one defined by typical gas dynamic loses through magnetic mirrors. It means that in spite of small electric resistance between central plasma and end electrodes steady state confinement is not provided by the plasma-electrodes contact.

To manage the radial electric field in plasma different potential distributions on radial electrodes were created by means of adjustable voltage sources. It is important to note that the special cusp and expander coils were turned off, therefore the magnetic field force lines in expander regions were straight making none contribution to the Rosenbluth-Longmire MHD-stability criterion. It was shown in experiments that plasma confinement time in regime when potential jump between one or few couples of electrodes presents is much longer than the one time in typical MHD-unstable regime. Decreasing of instability increment was observed when the potential jump on electrodes was in the range of 90 V$< \delta\varphi <$ 300 V. In that case target plasma confinement time corresponded to time of its gas dynamic flow through the magnetic mirrors and fast particles confinement time was in a good agreement with estimated time of fast ions drag on target electrons due to Coulomb collisions.

Different types of regimes with plasma jumps were investigated. Jumps of potential were created on different radii, stable confinement regime with several jumps (so called intermittent potential). Plasma confinement time and its parameters were close to each other in all mentioned regimes. To define target plasma decay time end flat probes mounted in plasma absorbers and allowed one to measure total end current were used. Dispersion interferometer was situated in in region R=3 and allowed to observe linear plasma density decay. To observe the fast ions diamagnetic loop situated in its turning point (R=2) was used.

Figure 3 shows the radial profile of floating potential obtained by triple probe in the regime with biasing of limiter and outer ring of plasma dump by 150 V of electric potential. The inner electrodes of plasma dump were grounded in this regime. Maximal value of the radial electric field calculated from this profile is about 25 V/cm. Figure 3 presents the time evolution of electron line density measured after plasma source and atomic injection were switched off. Characteristic time of the plasma decay was about τ_{MHD} =1.63 ms (see fig. 4), which is in a reasonable agreement with confinement time calculated as axial gas dynamic flow time of warm plasma through the mirrors (τ_{GDT} = 1.3 ms). Time of plasma decay obtained by means of end plasma absorbers had a similar value. Fast ions lifetime in that regime was about $\sim$ 0.8 ms which is quite close to one estimated as time of fast ions drag on target electrons (τ_{ei} $\sim$0.75 ms).

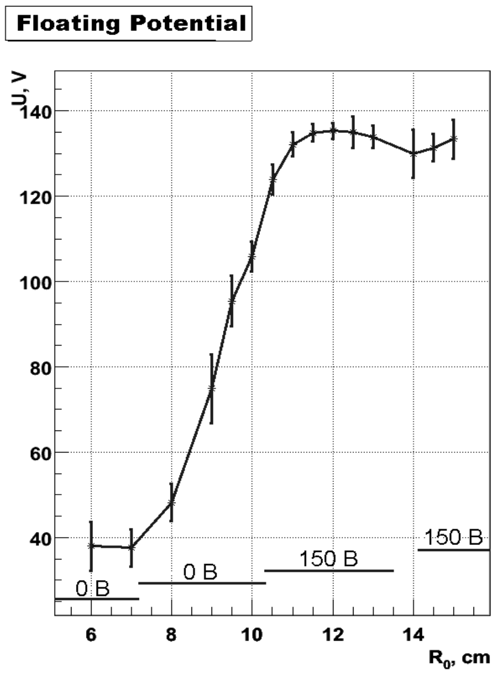


Figure 3: Radial profile of floating potential in the central plane of GDT in stable confinement regime and radial positions of absorber rings.

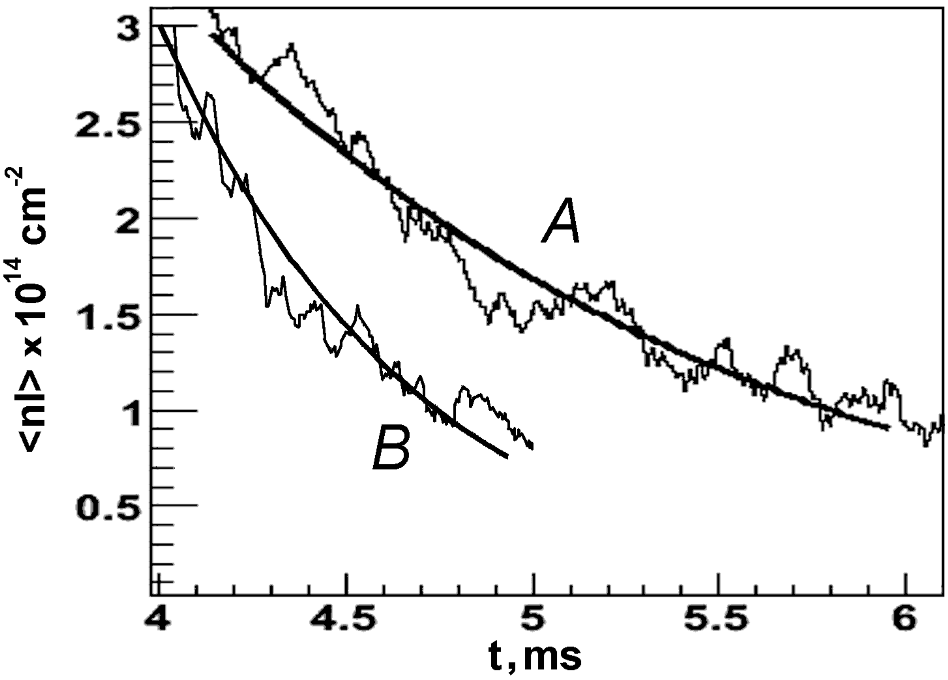


Figure 4: Time evolution of electron line density measured after plasma source was switched off. A - radial profile of plasma potential is intermittent; plasma decay time is $\approx$ 1.6 ms. B - radial electrodes are grounded, plasma decay time is $\approx$ 0.6 ms. Bold lines are exponential approximation of signals.

From results obtained we can draw a conclusion as follows: if radial potential jump presents in plasma the mechanism of differential rotation in cross fields (axial magnetic field and radial electric field) realizes. It is easy to estimate the time of outer plasma layer half-turn relate to inner one. Difference of drift velocities between $R_0 \approx 7$ cm и $R_0 \approx 9$ cm is about $\delta V_{dr} \approx 10^6$ cm/s (see fig. 4). Outer plasma layer ($R_0 \approx 9$ cm) has a half-turn relate to inner one ($R_0 \approx 7$ cm) during the time about $\tau_{shear} \approx 30$ μs. MHD-instability development time in GDT has a value about $\tau_{MHD} \approx 10$ μs. This estimations allow us to say that differential rotation can suppress MHD-instability or significantly decrease its increment altering the charges distribution which leads to instability development.

In contrast series of experiments with grounding of all the radial electrodes was carried out. That confinement regime was pronounced unstable and the floating potential appeared as in fig. 5 and didn't have any radial jumps. According to dispersion interferometer target plasma confinement time was about ~ 650 μs (compare with 1.6 ms in stable regime). Fast ions lifetime appeared about ~ 230 μs, it's more than 3 times smaller than one time in regime with differential rotation.

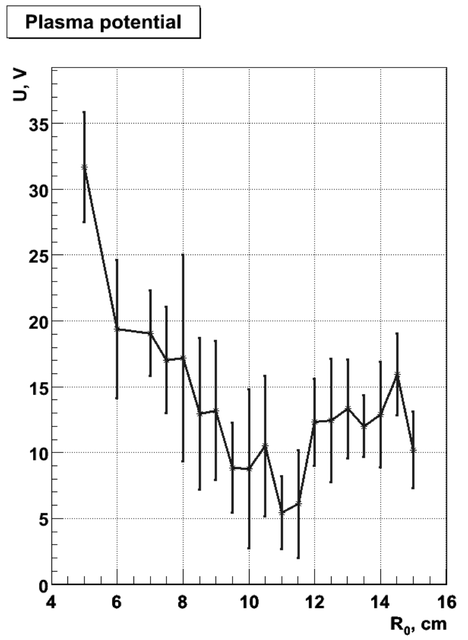


Figure 5: Radial profile of floating potential in the central plane of GDT in unstable confinement regime.

From experiments mentioned above one can conclude that differential rotation in periphery is able to improve plasma confinement. Also it's important to note that contact between plasma and conducting end plates can not completely provide plasma stabilization. This statement is approved by experiments with total grounding of radial electrodes.

Theoretical explanation of MHD-stabilization mechanisms in GDT is under development now. [M.S. Chaschin, A.D. Beklemishev, // Reprint BINP SB RAS 2006-19, Novosibirsk 2006], [Yu.A. Tsidulko // Proc. of XXXIII International Conference on Plasma Physics and Controlled Fusion, Zvenigorod, 2006, p.85].

It is well known that differential rotation can also lead to some instabilities and be a reason of increased transversal transport of particles and energy. By using of special combined probe measurements of transversal particle transport were carry out.

Its value was found as $2.7 \cdot 10^{14}$ s^{-1} cm^{-2} at radius 9 cm (all the radii are shown in GDT central plane). This value of particle flux corresponds to characteristic confinement time about ~ 130 ms, which is much higher than both real plasma confinement time in GDT and MHD-instability development time. Therefore we can draw a conclusion based on experimental results that particles transport perpendicular to magnetic field is negligible and differential rotation do not lead to transversal losses.

BASIC RESULTS:

Measurements allowed to estimate electric resistance between GDT central cell and end plasma absorbers were carried out. Results obtained are in a good agreement with flat probe theory and denote to possibility of significant influence of contact between plasma with end plates on flute instability increment. It was find out that presence of electric potential jump in plasma periphery allows to significantly improve plasma confinement time as compared with unstable regimes. It was shown that the presence of electric field in plasma with values in the region of jump about ≈ 40 V/cm leads to MHD-stabilization even in the case of unfavourable total curvature of magnetic field lines at high values of β. Particles losses perpendicular magnetic field were measured. Results obtained allow to conclude that transversal transport is negligible and do not play an essential role in regimes with differential rotation.

4.2 Start-up of upgraded atomic beams injectors power supply system with power up to 10 MW and duration of 5 ms for plasma heating in GDT

At the moment in Budker Institute of Nuclear Physics the plan of GDT device modernization for electron temperature increasing up to 200-300 eV is realizing. It is planning in the nearest future to create a new system of atomic injection with energy of 25 keV, total power of up to 10 MW and pulse duration of 5 ms. These injectors have a focusing ion-optical system which allows to significantly increase beams current density.

Under the first stage of modernization design, manufacturing and start-up of new power supply system for these injectors were carry out on GDT. New power supply system was installed instead of outdated one which was equipped by START-3 injectors and didn't satisfy all the experimental requirements because of its low power and small pulse duration (4 MW, 15 keV and 1 ms). Power supply system consists of eight equivalent independent modules (see figs. 6 and 7) each of which can supply one new type injector and have the following characteristic:

1) Ion-optical system (IOS) power supply:

a) Plasma grid: +25 kV of controllable voltage, 1% stability, current is up to 100 A, 5 ms duration.

b) Extracting grid: +22 kV of controllable voltage (+7%), 1% stability, 20 A, 5 ms.

c) Suppressing grid: -900 V of controllable voltage, %, 10 A, 5 ms.

2) Arc discharge: 120 V, controllable current is up to 1200A , 1% stability, 5 ms.

3) Minimum impulse repetition rate: - one per 30 seconds.

4) System is controlled by computer through fiber optic lines.

5) Ability of manual control.

6) Disposition - two power supply cabinets (high-voltage system of control on fig. 6, low- voltage power supply system on fig. 7). High-voltage modulator system has dimensions of 1x1x2 m. High-voltage line shelf has dimensions of 1x2x3 m.

To form the high-voltage impulse artificial line discharge to primary coil of step-up transformer is used. Output voltage is stabilized by the set of varistors. Voltage is applying to IOS extracting grid from ohmic dividing circuit which is connected to high-voltage output. Taking of special measures for discharge energy decreasing in protection system allowed to significantly increase the system reliability. Energy exuded in IOS during discharge does not exceed an amount of 1 J. Arc source power supply system is constructed

Figure 6: Overview of high-voltage part of new power supply system of GDT device (six of eight modules are shown).

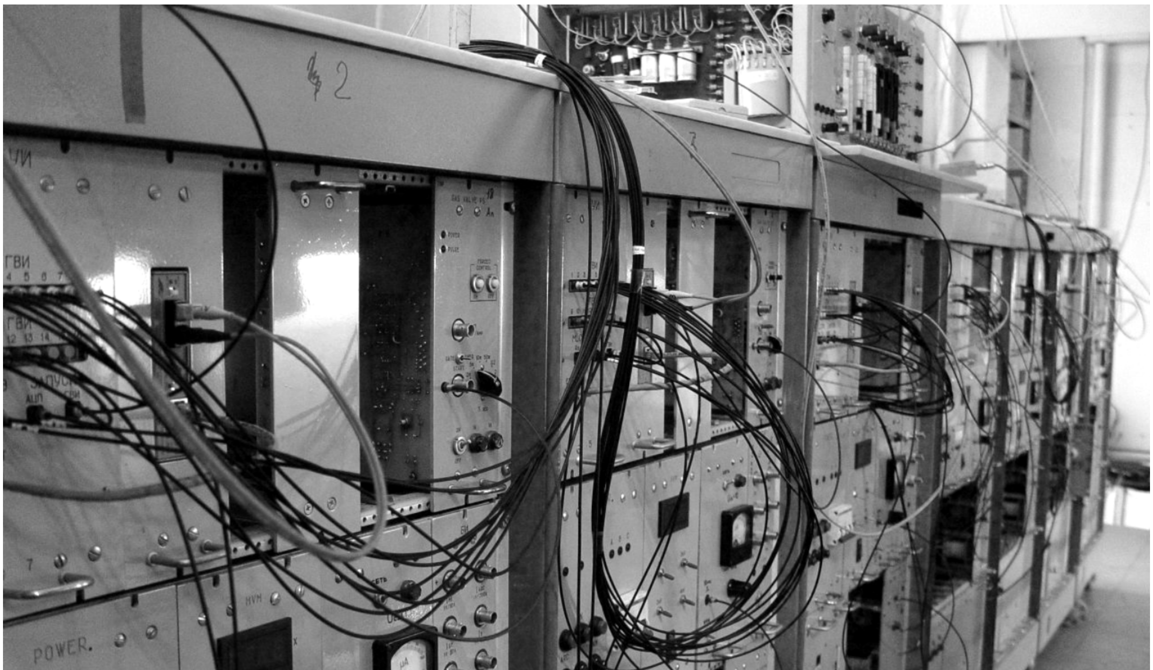


Figure 7: Low-voltage modules of power supply system of GDT device.

according to block scheme. Power supply blocks are installed on isolated platform which is under output voltage of high-voltage modulator during the pulse. These blocks are working in parallel. Each one allows to have a stabilized current up to 80 A. To provide reliable discharge initiation system of preliminary arc current ramp-up to the special inductance with following current switch to discharge distance is used. Power supply control is realized by means of special programmed logic controller "PIKON" developed in BINP. Connection between controller and system of control is performed by fiber optic lines which allow to avoid decoupling devices and protect control system from noises when using.

All the commissioning was complete until fall 2006 and experiments with new power supply system on GDT has begun.

4.3 Investigations of fast ions accumulation effect with increased atomic injection power and duration

In 2006 assembling and commissioning of new generation of atomic injection power supply systems for gas dynamic trap were finished. New power supply systems allow to increase atomic injection power up to 10 MW with duration of 5 ms and 25 keV injected atoms energy.

By the end of the year injection power more than 3 MW, duration of 5 ms and 18 keV particles energy were successfully obtained. Figure 8 shows time dependencies of current and voltage for all six injectors. Work on increasing of total injected power is in process now.

First experiments of fast ions accumulation in GDT with increased atomic injection duration were successfully carried out. According the estimations and computer modelling results fast ions distribution function in these conditions becomes close to equilibrium one because the characteristic energy lifetime defined by ions drag on target electrons $\tau_E \approx 700\mu s$ is much smaller than injection duration. In those experiments two work scenarios were investigated: "decay" scenario and experiments with additional gas puffing to the axis of GDT device used for plasma particles balance maintenance.

Temporal sequence of GDT systems work in "decay" regime was the following:

- magnetic system was switched on;
- warm target plasma was injected to the trap by special plasma generator situated in one of expanders;
- after plasma generator switching off atomic injection system was switched off.

Therefore atomic beams were injected to plasma in the stage of its exponential density decreasing due to plasma flow through the mirrors. Perfect illustration of this process is the figure 9 where the power trapped to plasma (which is proportional to linear target plasma density) in comparison with total neutral power beams power is presented. In figure 10 plasma diamagnetism in this regime is shown. On the initial stage of injection rising of diamagnetic signal is observable, the value of this signal is proportional to energy stored in fast ions. Then the fall of diamagnetism during 3 ms can be observed. It's important to note that the characteristic MHD-instability development time in view of mentioned plasma and magnetic field parameters can be estimated as few tens of microseconds. Basing on results of first experiment with increased atomic injection duration we can draw that plasma is stable relate to MHD-modes at injection times about 5 ms. According to Thomson scattering diagnostics averaged electron temperature was about 120 eV. Temperature was measured in the moment of 2 ms after injection start (5500 μs in figs. 9 and 10).

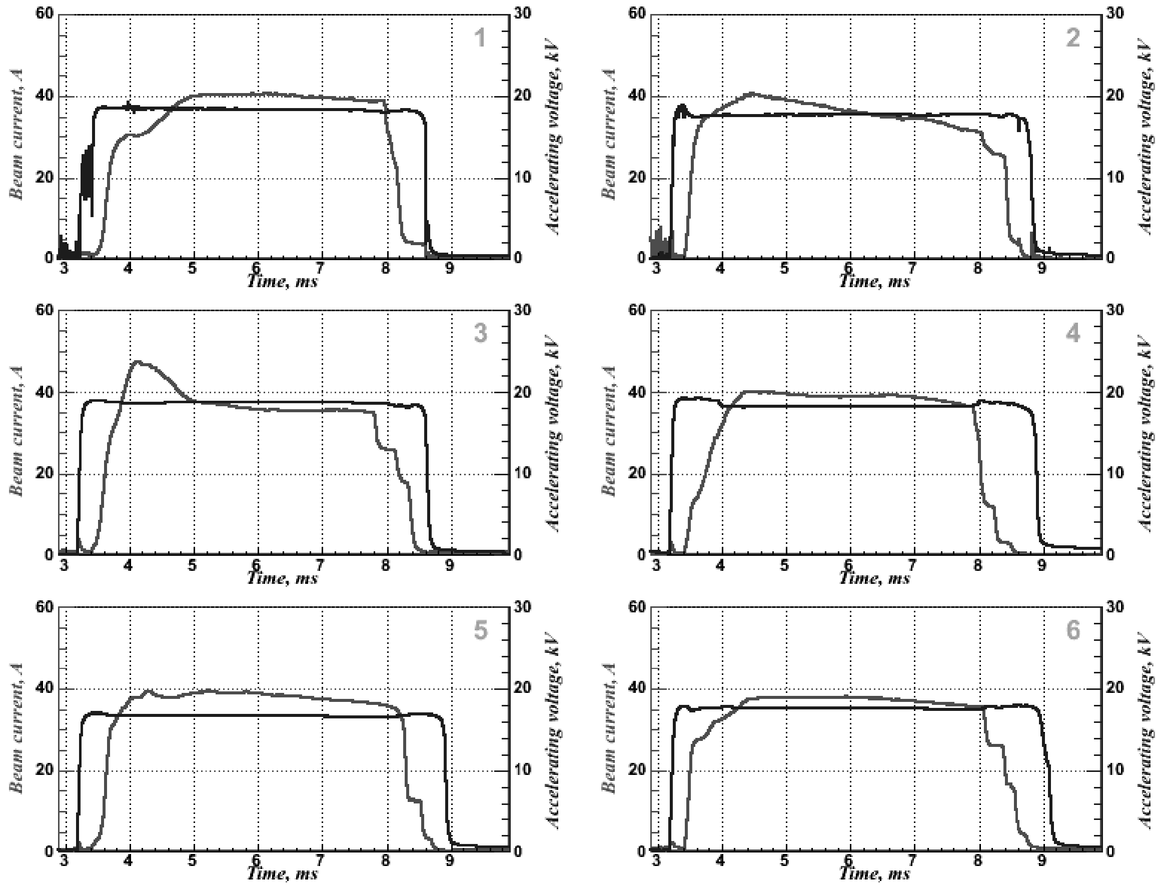


Figure 8: Beam current and accelerating voltage of START-3 injectors.

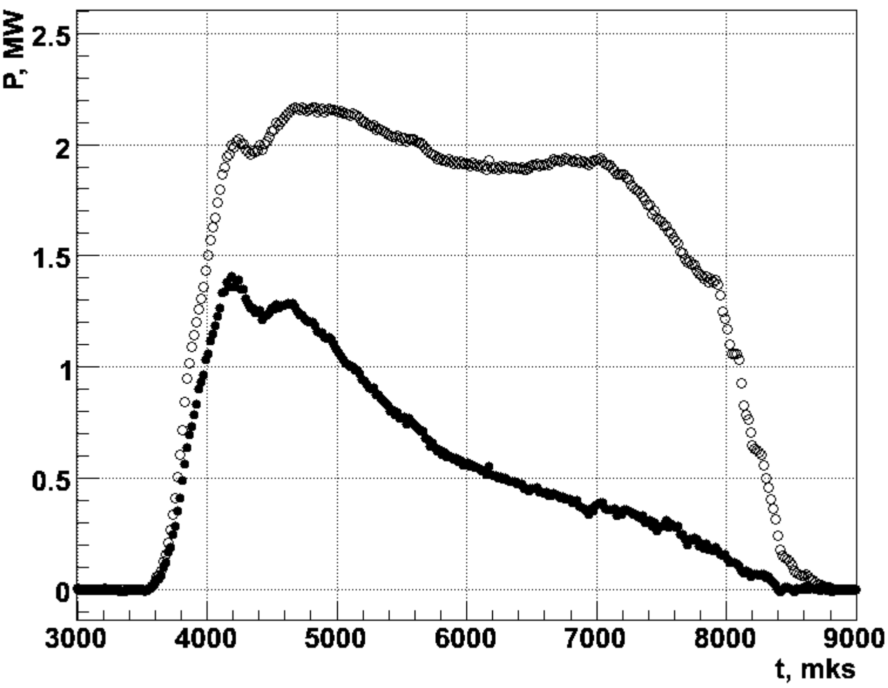


Figure 9: Injected (o) and trapped power in “decay” scenario with increased duration of atomic injection to GDT.

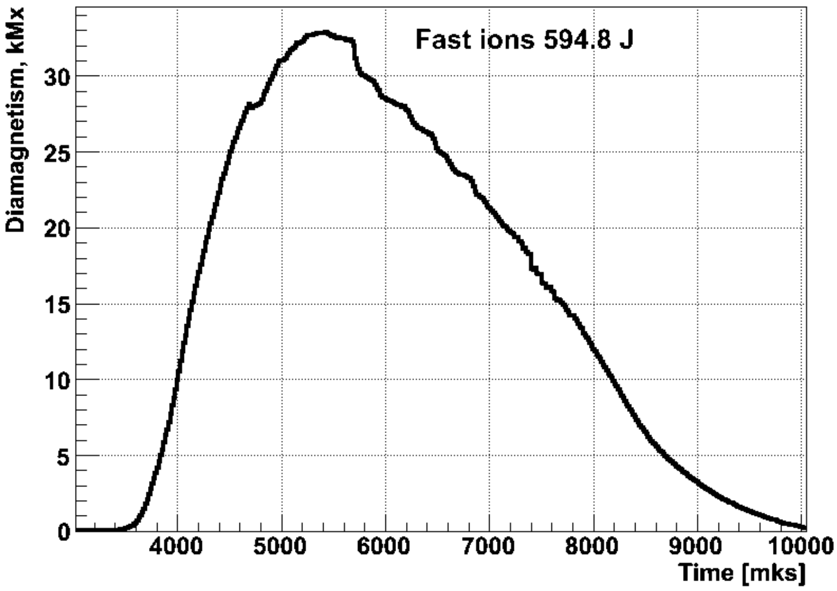


Figure 10: Fast ions diamagnetism vs time in “decay” scenario.

For better accumulation of fast particles, for plasma particles balance maintenance during long injection and for obtaining and investigations of anisotropic plasma with maximal energy content and pressure the scenario with gas puffing to the GDT axis was realized. Gas was injected by means of special capillary (see fig. 11) installed on the trap end after plasma generator switching off. As a result quite dense target plasma with maximal density up to 2x10^{14} cm^{-3} and radius about 4-5 cm was obtained.

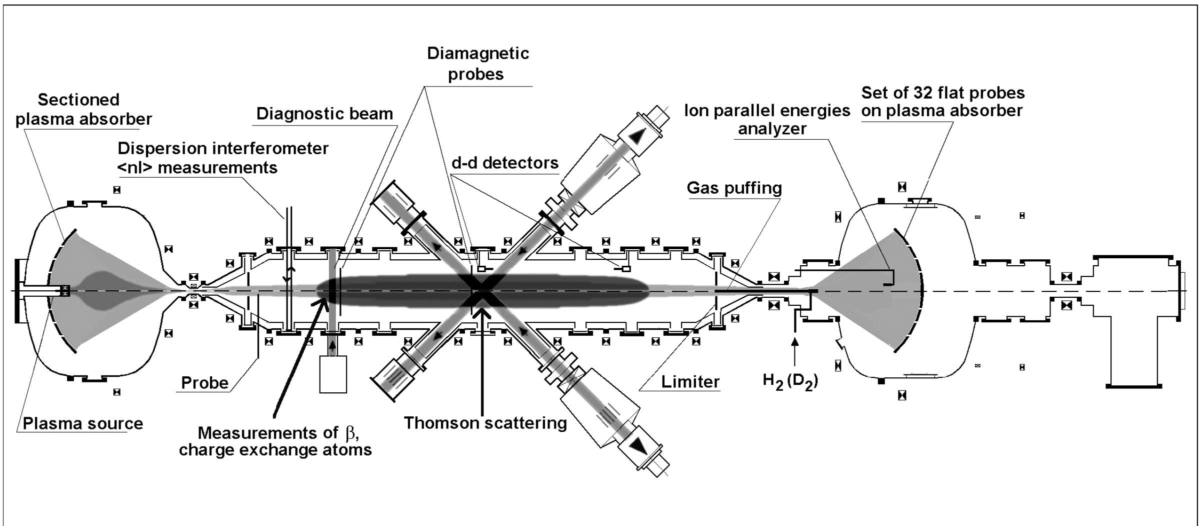


Figure 11: GDT device and positions of basic diagnostics.

In figure 12 temporal dependencies of injected and trapped power are presented, figure 13 shows energy content of target plasma and fast ions measured by diamagnetic loops. It is observable that accumulation of fast ions take place during all the injection time. Maximal value of fast ions energy content is about $\sim$ 900 J. Electron temperature in this regime was about $\sim$ 100 eV (fig. 14).

In experiments where anisotropic plasma dynamics in GDT was investigated radial profiles of β were measured by modernized MSE-diagnostics. Figure 15 presents the

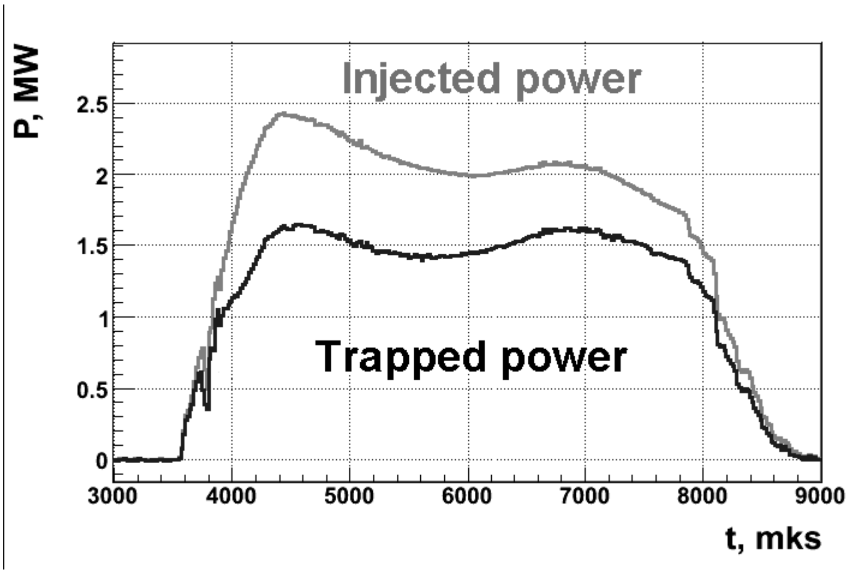


Figure 12: Injected and trapped power in scenario with additional gas puffing and increased duration of atomic injection to GDT.

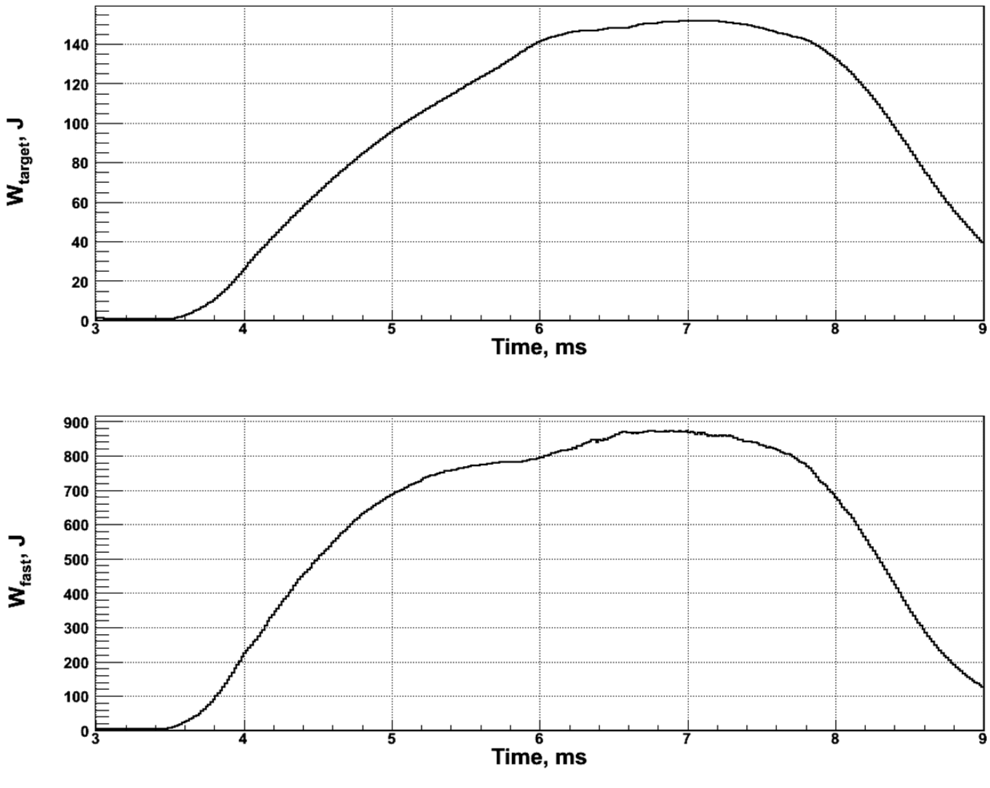


Figure 13: Energy content of target plasma and fast ions in experiment with additional gas puffing and increased duration of atomic injection to GDT.

results of β measurements in moments of 5 ms and 6.5 ms during injection pulse (3.5 ms - 8.5 ms). The formation of compact fast ions distribution occurs on the initial stage of injection in first millisecond. Parameter β versus time during the injection is shown in fig. 16, characteristic profile radius $\approx$ 8.5 cm altered negligibly. Figure 17 demonstrates the dynamics of charge exchange atoms flux transversal profile measured in fast ions turning

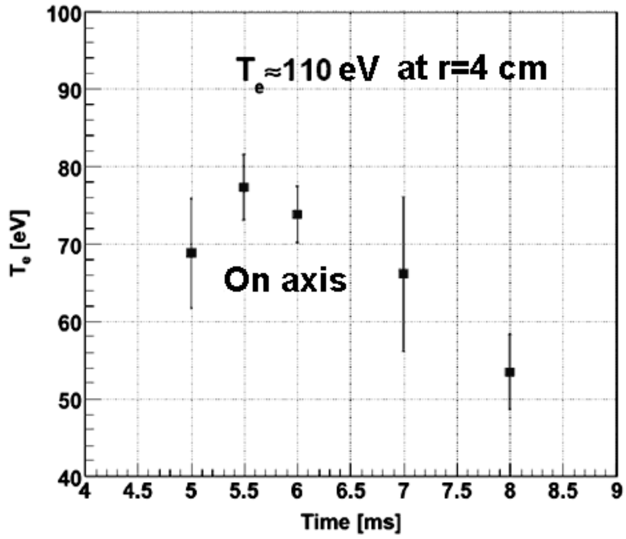


Figure 14: Electron temperature according to Thomson scattering.

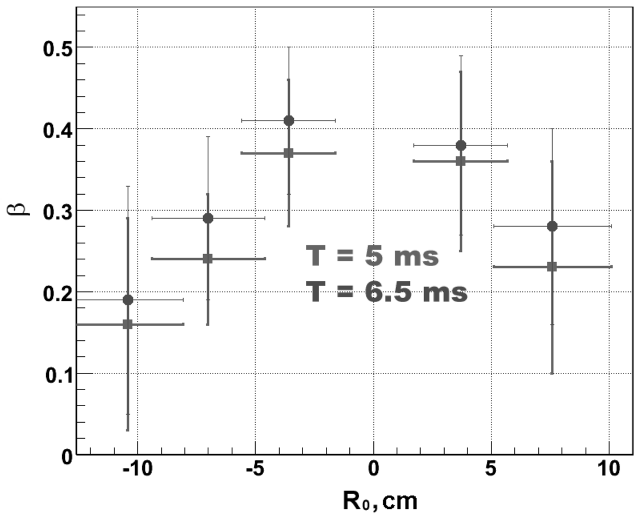


Figure 15: Radial profiles of β in fast ions turning point measured in the moments t=5 ms (■) and t=6.5 ms (•).

point. Locality of these measurements was provided by registration of atomic flux formed as a result of fast deuterium atoms charge exchange on diagnostic hydrogen beam which was as an artificial target. For atoms with energies of 17 keV (see fig. 17) which is close to injected one profiles for t=4÷6 ms remain compact with characteristic radius of ≈ 8 cm. Measurements results of such profiles for atoms with energies of 10÷17 keV also confirm the conclusion about formation of stable stationary population of anisotropic plasma with hot ions and maximal β about 0.4 observed in GDT experiment.

Hereby the stationary confinement regime of two component plasma with β more than 40%, with electron temperature higher than 100 eV, warm ions density of $2{\cdot}10^{14}$ cm^{-3} and fast ions density of $2{\cdot}10^{13}$ cm^{-3}.

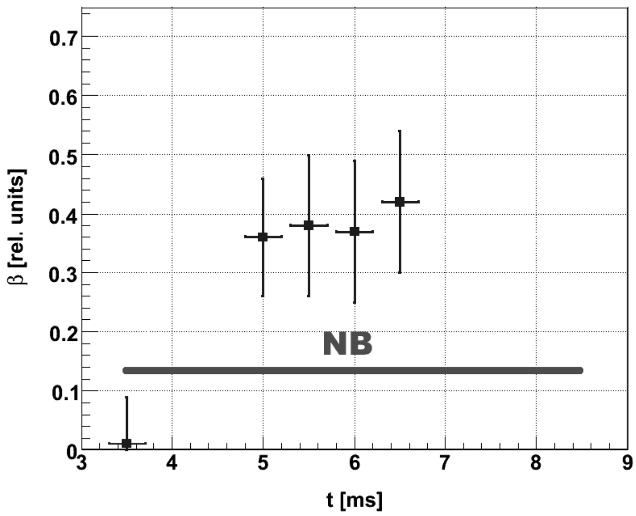


Figure 16: Parameter β vs time in fast ions turning point during the atomic injection pulse (r = 3.6 cm)

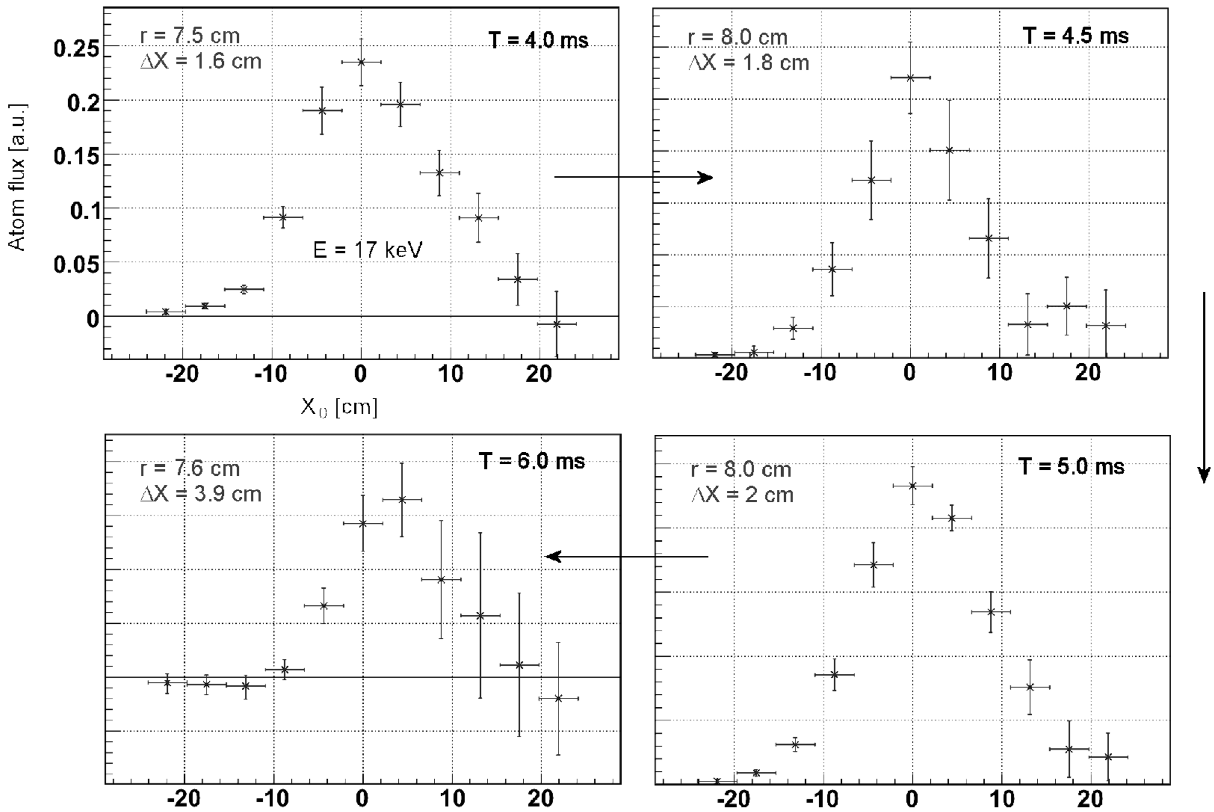


Figure 17: Dynamics of charge exchange atoms flux transversal profile in fast ions turning point. Measurements for energy of 17 keV which is close to injected one are carried out.

4.4 Theoretical studies

4.4.1 Studies of plasma wakefield acceleration

K.V.Lotov

Plasma wakefield acceleration of positron beams in the wake of a dense electron beam (in the blowout regime) is numerically analyzed. Acceleration is possible, if the energy content of the wakefield is not very high. This contrasts with electron acceleration, for which the optimum performance is associated with maximization of the peak driver current and wave energy. The positron beam must be placed between the first and the second bubble, in the region of increased density of plasma electrons. The efficiency of plasma-to-witness energy exchange can be as high as several tens percent. High efficiencies require precise location of the positron beam and sophisticated beam shapes. Unlike electron witness, the positrons always get an energy spread of about several percent caused by the transverse inhomogeneity of the accelerating field.

One possible way to demonstrate both the efficiency and beam quality in a plasma wakefield accelerator is to prepare matched drive and accelerated beams by removing a central slice from a single high-quality electron bunch (parent beam). For parameters of the parent beam given, the question arises how to maximize the number and energy of accelerated particles and minimize their energy spread and emittance. This question is addressed by numerical simulations. The optimum shape of the beams, required plasma length, achievable energy gain and energy spread are found as functions of the plasma density and parent beam characteristics. The required control accuracy of adjustable beam and plasma parameters is determined.

Publictions:[156], [410], [411], [412].

4.4.2 Investigation of relativistic electron beam relaxation in plasma in the trapping regime

K.V.Lotov, I.V. Timofeev

A model for collective relaxation of high-power relativistic electron beams in plasmas is proposed, which describes beam-plasma interaction in the regime when amplitudes of unstable waves are large enough to trap beam electrons. The distinctive feature of this regime is that the power lost by beam electrons as they interact with exited wave packets weakly depends on the energy of these packets. This makes the model insensitive to the nature of nonlinear processes in plasma, which are responsible for saturation of the beam instability. The model is thus rather universal and suitable for quantitative comparison with experimental data. The predicted profiles of energy release along the plasma column are in a good quantitative agreement with the ones measured at various experimental facilities.

4.5 GOL-3 facility

Introduction

During 2006 research on confinement of dense plasma in a long trap was continued at the GOL-3 facility. Layout of the facility is presented in Fig.1. The 12-meter-long solenoid consists of 110 coils with an independent feed. In the regular multimirror configuration the magnetic field has 55 corrugation periods (cells of multimirror system) with 22 cm length, the field in maxima is 4.8 T, in minima is 3.2 T. The mirror ratio of the corrugated field is 1.5. That means that the operating mode of GOL-3 corresponds to a "weak corrugation regime". The solenoid terminates in single magnetic mirrors with a field 8-9 T.

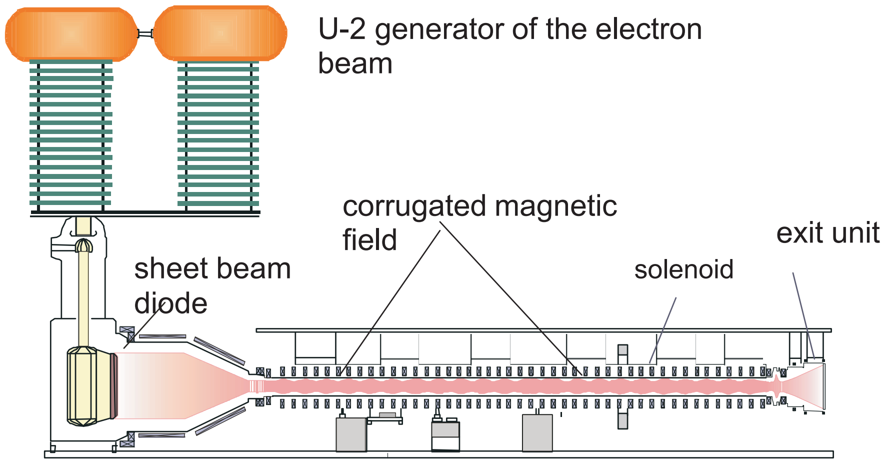


Figure 1: Layout of the GOL-3 facility.

Several gas-puff valves create required axial deuterium density distribution in a metal vacuum chamber ø10 cm, placed inside the solenoid. Then a special linear discharge creates a start plasma with length-averaged density of $\sim 10^{15}$ cm^{-3} and temperature ~ 2 eV. Then the relativistic electron beam with the following parameters is injected into this plasma: electron energy is ~ 0.9 MeV, current is ~ 25 kA, duration is ~ 8 μs, energy content is ~ 120 kJ, the beam diameter is ~ 4 cm. As a result of collective heating the plasma gets ion temperature 1÷2 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. As it was shown earlier, fast heating of plasma ions cannot be explained by energy transfer from electrons to ions through binary collisions. Therefore the new, collective mechanism of energy transfer from the heating electron beam to ions, which essentially depends on presence of a periodically-non-uniform (corrugated) magnetic field has been offered. In 2006 an activity on revealing physics of the processes governing plasma behaviour in the facility proceeded.

4.5.1 Measurement of dynamics of electron temperature

Detailed elaboration of physical processes, which lead to anomalously fast heating of plasma ions confined in the corrugated magnetic field, was the purpose of a series of experiments on measurement of electron temperature by Thomson scattering technique. In this technique the plasma is probed by a high-power laser pulse. A small fraction of the laser light scatters on plasma electrons by 90°. Intensity and spectrum of the scattered light depend on density and temperature of the plasma electrons. Existed system of Thomson scattering with Nd laser has been essentially rebuilt. The laser was reconfigured for operation at the first harmonic with 1.06 micron wavelength. The new system of registration consists of spectrograph with fiber-optical input and output of light, and several detectors with infrared avalanche photodiodes. Shift of diagnostics into operation at the first harmonic allowed to increase essentially energy in a laser pulse and, simultaneously, to improve conditions for detecting of a scattered light, as in a near infrared range there is no bright spectral lines in own radiation of plasma. The "blue" wing of scattered is analyzed up to wavelength corresponding 5 keV kinetic energy of electrons - see Fig.2.

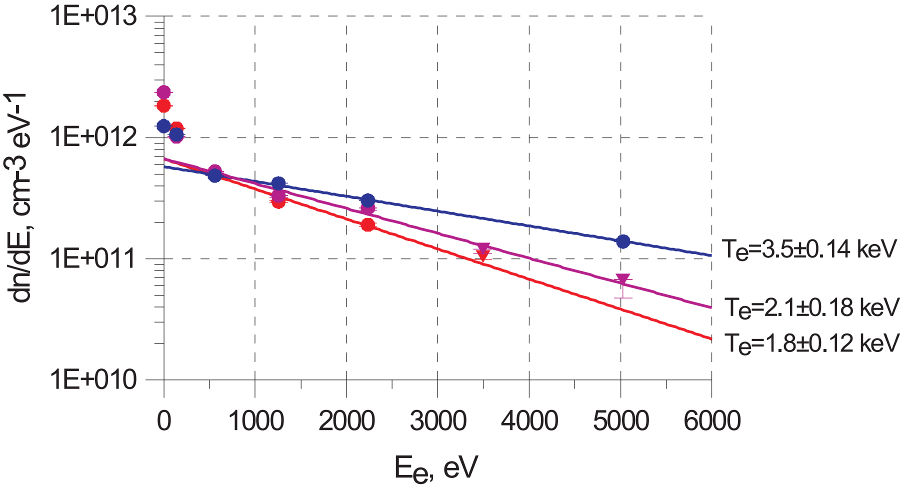


Figure 2: Electron distribution functions for three shots.

The primary goal of the reported series of experiments was measurement of dynamics of electron temperature during the injection of the electron beam and right after its termination. Predictably, during injection of the beam the maximal electron temperature reaches $\sim$ 4 keV in the observation point ($\sim$4 m from the entrance mirror). We shall remind, that, according to other diagnostics, plasma should have larger temperature closer to the electronic beam injection point, at coordinates of 0.5 $\div$ 2 m. Fig.3 shows results of measurement of electron temperature at different delays from start of the electron beam injection. It is necessary to note two important circumstances. The first one is that the high electron temperature, at a level of $\sim$1 keV, is observed practically during all time of injection of the electron beam. It is the positive fact as the high electron temperature in the GOL-3 facility can exist only at a strong level of turbulent suppression of axial electron heat loss. Measurements show, that such turbulent suppression of heat conductivity keeps down to large power fall of the electron beam. The second circumstance is that strong (in several times) shot-to-shot dispersion of results of measurements which significantly exceeds a level of accuracy of measurements is observed. Measurements have good locality (light is observed from a volume about 1 mm^3). At the same time other diagnostics which do not possess the similar spatial resolution, show insignificant fluctuations of parameters. The nature of strong local differences of temperature demands separate study.

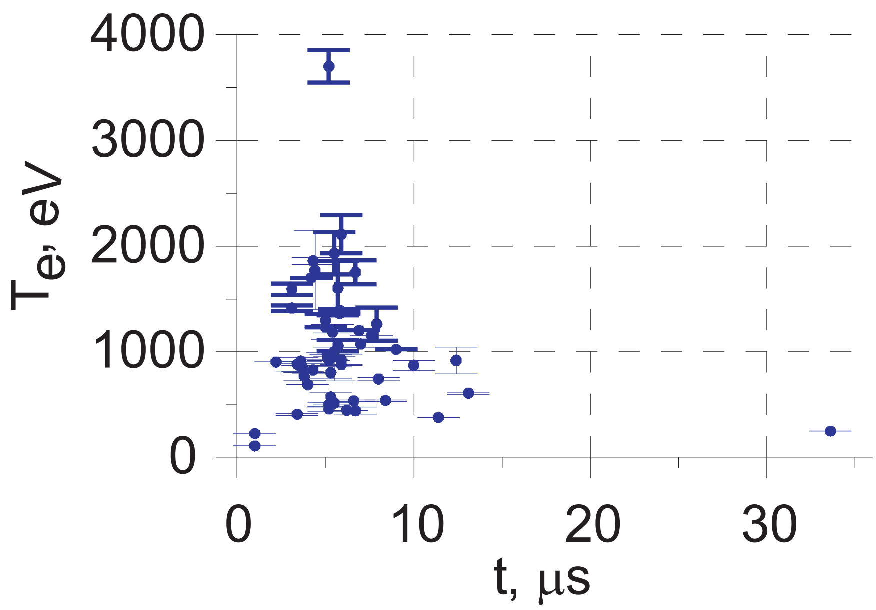


Figure 3: Dynamics of electron temperature according to Thomson scattering diagnostics.

4.5.2 Experiment with large corrugation degree

The classical theory of plasma confinement in a multimirror trap predicts, that time of plasma confinement in a trap should be proportional to a square of mirror ratio with other parameters being equal. In reality a change of a magnetic field configuration in the experiment leads to related change of some other important parameters, which govern plasma heating and confinement in the trap. A series of preliminary experiments with section of strengthened corrugation was done for check of an influence of a magnetic configuration on plasma processes in GOL-3. As prior to the beginning of such experiments there were no data about a margin of plasma stability in the modified system, the experiments were done at lowered energy content of an electron beam. The section with strengthened corrugation was created at beam-entrance section of the solenoid. For this purpose the first 20 coils have been re-connected to the existing power supply system, so that 5 corrugation cells with mirror ratio ~ 3 and length 44 cm were created. In order to exclude touching of the vacuum chamber walls and of limiters in areas of the weakened magnetic field by the electron beam, the height of the cathode of the beam generator U-2 was reduced from 140 down to 90 cm that led to reduction of the electron beam diameter down to 4.2 cm in 5 T magnetic field.

Experiments have shown that transport of the electron beam through the plasma is stable. Collective plasma heating to sub-fusion temperatures and emission of neutrons from D-D reactions is observed. At the same time, the absolute values of energy content and confinement time of the plasma were less, than in optimum modes at regular corrugation of the magnetic field. Such decrease of parameters can be accounted both for non-optimality of operation regime (in particular, transverse energy losses from the plasma dominated in the strong corrugation mode), and for the account of less favourable parameters of the experiment (energy content of the electron beam, plasma volume and a ratio between the cross-sections of hot plasma and cold periphery). The further experiments with strengthened corrugation are scheduled at higher parameters of an electron beam.

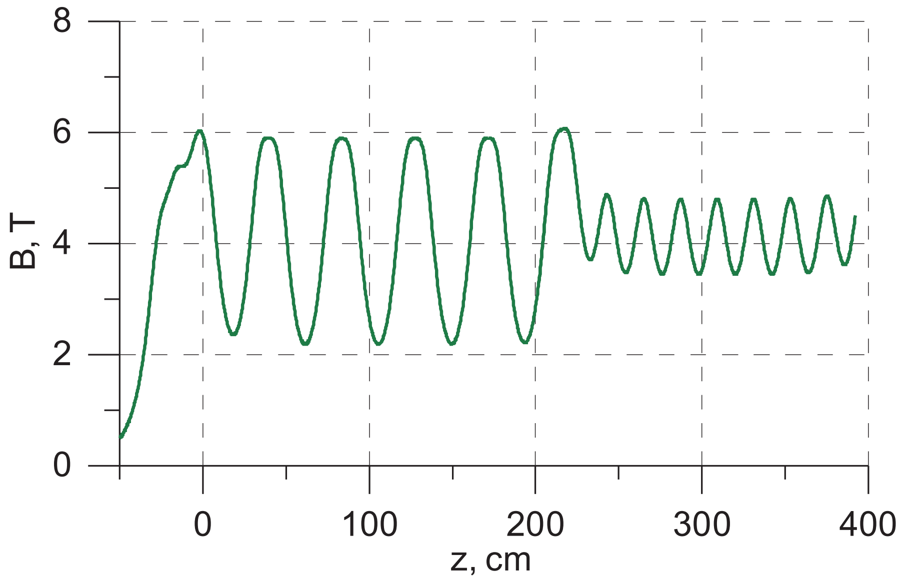


Figure 4: Configuration of the magnetic field in the experiment with the section of strong corrugation (the initial part of the solenoid is shown).

The important physical result, received during the experiments with strong corrugation of the magnetic field, is change of the period between flashes of neutron emission in an initial part of GOL-3 plasma. Such flashes have been found out experimentally. The theory identifies them as consequence of development in the plasma of a bounce oscillation instability of ions which velocity vectors are close to a "loss cone" in the phase space. In full conformity with current views the frequency of bounce oscillations has decreased at the transition to strong corrugation - see Fig.5.

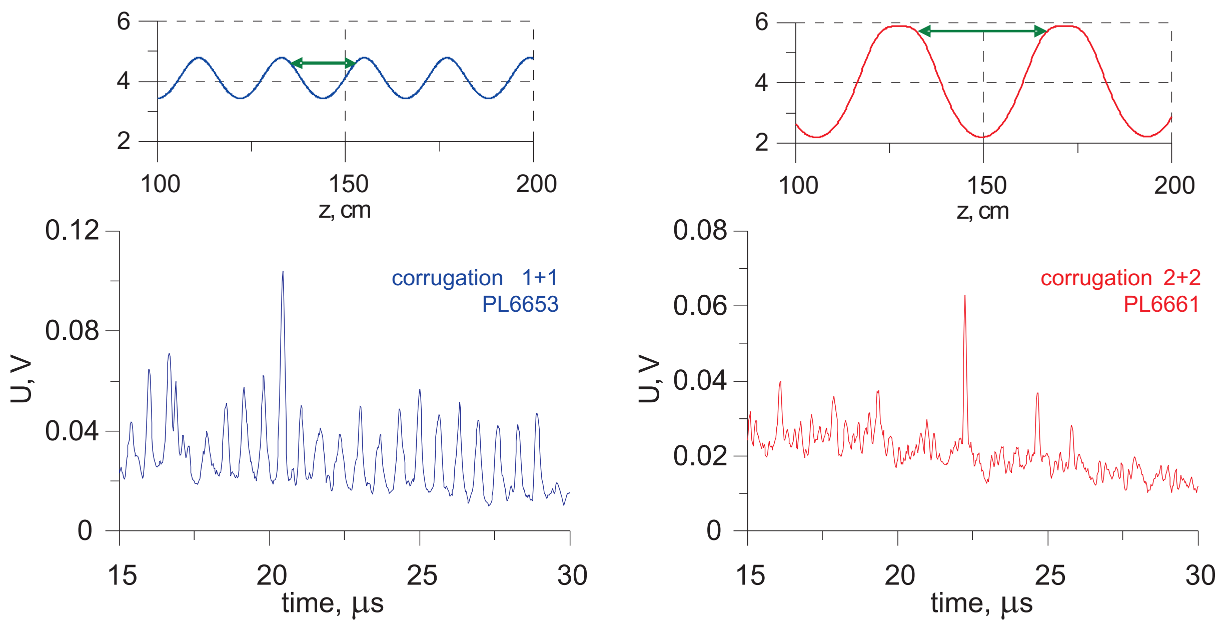


Figure 5: Comparison of the period between flashes of neutron emission at standard corrugation of the magnetic field at GOL-3 (at the left) and in the strong corrugation section (at the right). The increase in run length for ions between reflections in near-the-mirror areas for corresponding configurations is shown above the waveforms.

Such kind of particle instability is a positive effect as it intensifies an exchange between groups of trapped and transit ions near to ends of the trap, and, generally, improves the plasma confinement.

Comparison of the period between flashes of neutron emission at standard corrugation of the magnetic field at GOL-3 (at the left) and in the strong corrugation section (at the right). The increase in run length for ions between reflections in near-the-mirror areas for corresponding configurations is shown above the waveforms.

4.5.3 Modelling of magnetic structure in the plasma

Appreciable efforts in experiments at the GOL-3 facility were directed to search of the regimes stable in respect to outer helical modes. Conditions in which plasma and a beam are stable have been found as a result. Moreover, as follows from the experiment, artificial formation of radial current structure and creation of a sheared helical magnetic field favorably affects both process of plasma heating, and its subsequent confinement in the trap.

One of the most dangerous instabilities is MHD instability, initiated by the plasma currents. In particular, the tearing instability plays an important role in transport processes in tokamaks. Previously the tearing instability in linear traps (and even the opportunity of its existence) practically has been studied neither theoretically, nor experimentally. Numerical research of such kind of instability assumes the solution of the multivariate equations of two-fluid magnetic hydrodynamics. Such work was done in cooperation with Institute of Computational Technologies of Siberian Branch of Russian Academy of Science where the numerical schemes suitable for the solution of such problems have been developed.

Numerical simulation of processes in the GOL-3 facility is done within the limits of 1-D and 2-D two-fluid MHD models and 3-D reduced MHD models, which were realized by means of numerical (finite-difference) methods. The electron beam in these models was considered by additional members in the equations for a magnetic field. Corrugation of the magnetic field was omitted in these models.

Development of this instability occurs in the conditions which are essentially distinct from conditions for a tokamak. The plasma conductivity is determined by a level of the turbulence raised by the electron beam. Thus, the development of instability occurs at a background of large gradient of conductivity which is in a direct vicinity of a current layer. The current layer therefore is non-stationary. Development of tearing instability occurs already at a stage of its formation.

Solution of the 2-D problem allows to draw following conclusions.

1. Instability starts to develop already at a stage of the beam existence, but it finishes evolution after the beam end. Instability development time is about 7 μs, that is close to observable in the experiment.

2. Presence of the large gradient of conductivity in immediate proximity from a neutral surface leads to smaller width of the current layer, in comparison with a case of constant conductivity.

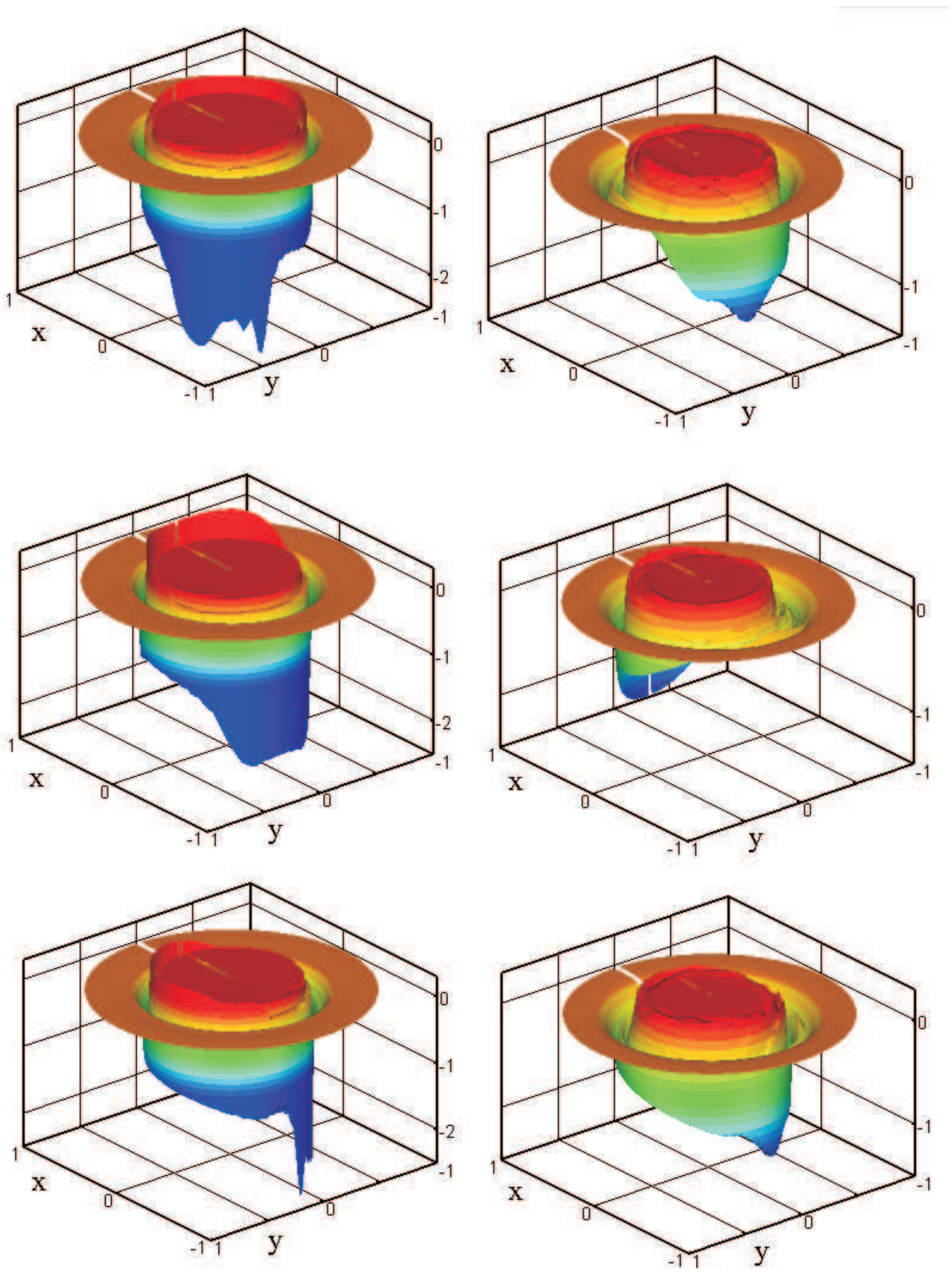


Figure 6: Distribution of current density in sections $Z=Z_0/4$ (top), $Z=Z_0/2$ (middle), $Z=3Z_0/4$ (bottom) during at t=200 (left) and t=700 (right) where Z_0 - length of the trap, and time is measured in Alfven times.

3. Distribution of a magnetic flux is those, that the internal magnetic flux is larger than external. It leads to hot plasma ejection to periphery. However misbalance of fluxes is not so large to lead to full loss of hot plasma. Nevertheless, there is a necessity of optimization of parameters of a beam so that instability remains internal.

Presence of ends at the GOL-3 facility means, that only certain modes will be raised in plasma. Dynamics of these modes can be tracked only at the solution of a three-dimensional problem. By virtue of complexity of a three-dimensional problem the model of a reduced (incompressible) magnetic hydrodynamics, which can be used in the case of large longitudinal field, has been used. Typical distributions of a current density in several sections on length at two moments of time are shown in Fig. 6. Calculations have shown, that for GOL-3 the mode **m**=**n**=1 dominates. So, in Fig. 7 evolution of amplitude of several lower modes in the case of the initial seeding by **m**=1, **n**=0 mode is shown. Eventually there are other modes (t=200). Further the mode **m**=**n**=1 becomes dominating (t=670).

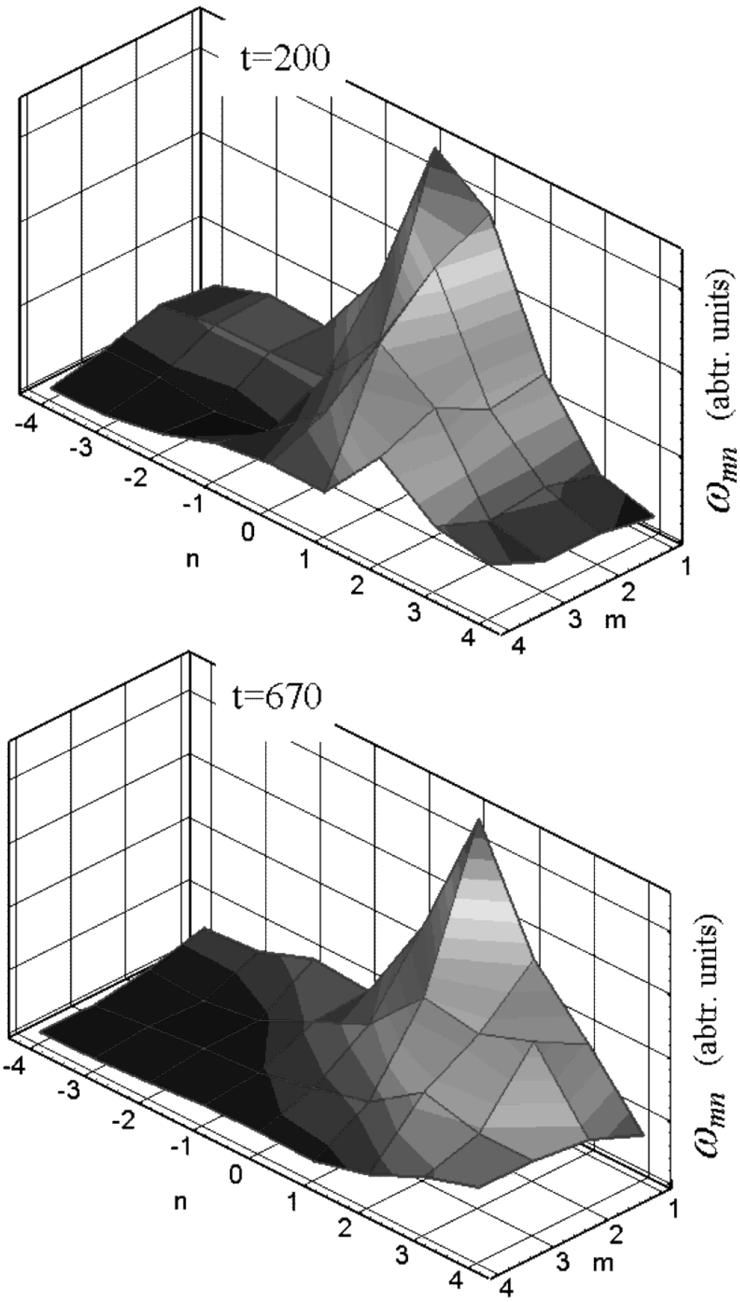


Figure 7: Distribution of amplitude of helical modes at the moments of time t=200 and t=670. Alfven times for the case of initial distribution with mode numbers **m**=1, **n**=0.

Calculations of a three-dimensional problem have shown the qualitative and quite good quantitative consent with two-dimensional calculations.

4.5.4 Development of technology of electron beams generation

One of parallel ways of development of the concept of a multimirror fusion reactor is creation of essentially new tools and technologies intended for heating and maintenance of stability of plasma in traps. The existing techniques of generation of high-current relativistic electronic beams allow receiving electronic beams of demanded capacity, but possess a number of essential restrictions. First of all, it is a short duration of a beam generation which in present systems is of the order of ten microseconds. It is essential to increase duration of a beam generation at keeping its sufficient brightness. This may be basically possible if to pass from thermo-emission or explosive-emission cathodes to plasma cathodes. Accordingly, development of a suitable technology of generation of electron beams in devices with a plasma cathode is required.

In 2006 a special technological test bench for studying new technology of generation of electron beams was created. The first series of experiments on generation of an electron beam of a 100-microsecond range of duration in a source with the plasma emitter based on an arc generator of plasma was done. The purposes of the first experiments were check of usability of the chosen scheme of the plasma emitter, generation of the beam with the maximum possible current density at a duration not less than 100 μs, and also check of electric strength of electro- optical system (EOS) in a source with the plasma emitter.

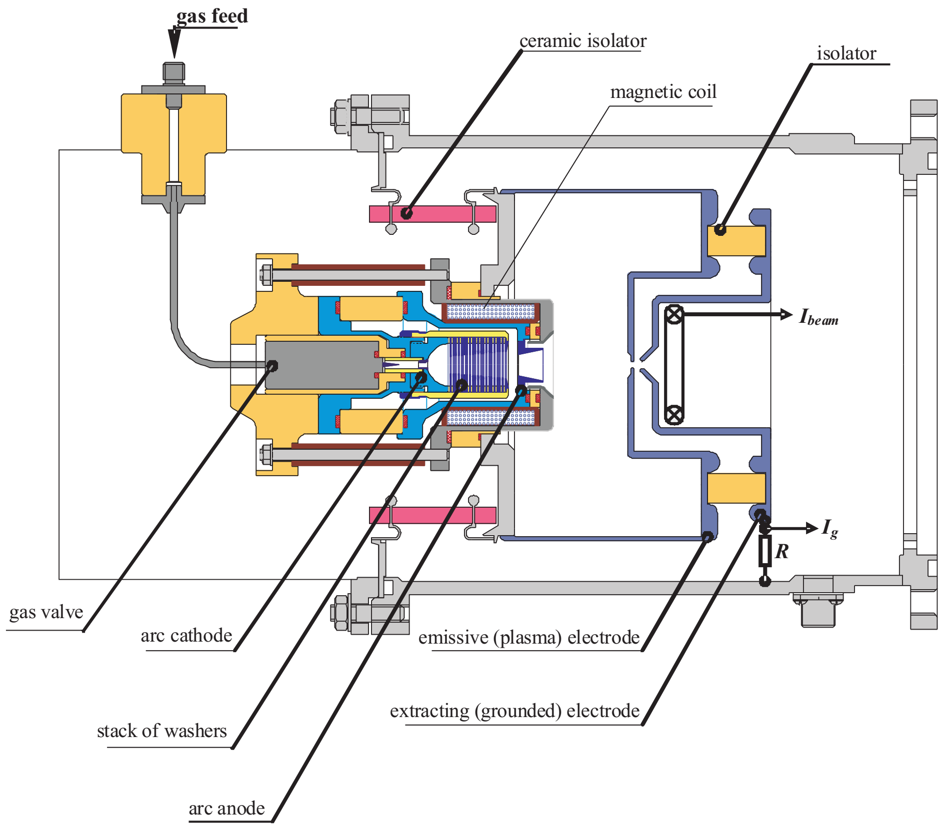


Figure 8: The schematic of the test bench source.

The schematic diagram of the source is shown in Fig. 8. Basic elements of the source are mounted on a high-voltage ceramic insulator. The arc is fired between the cold dural cathode and the copper anode. The discharge channel is formed by a set of the insulated metal washers. Hydrogen is filled through an aperture in the cathode with a pulse electromagnetic valve. The arc discharge is controlled by the power supply system on the basis of a forming LC-line. The largest operating current of the discharge reaches 630 A. Duration of the arc discharge is 0.25 ms. The plasma density is adjusted by the discharge current and by controlled puffing of working gas. Longitudinal magnetic field of about 0.1 T (magnetic insulation of the arc) is created by a special coil over the anode and the discharge channel for increase of plasma emission from the generator.

As a first step of experiments, which should be done for minimal time, a single-aperture diode EOS with electrodes from stainless steel was applied. Formation of a beam with the plasma emitter for start EOS geometry was numerically modeled with quasi-stationary code PBGUNS (ver. 5.04). Code PBGUNS allows to find equilibrium position of the emissive plasma boundary for given flux of plasma electrons, proceeding from the condition of zeroing of the electric field at it.

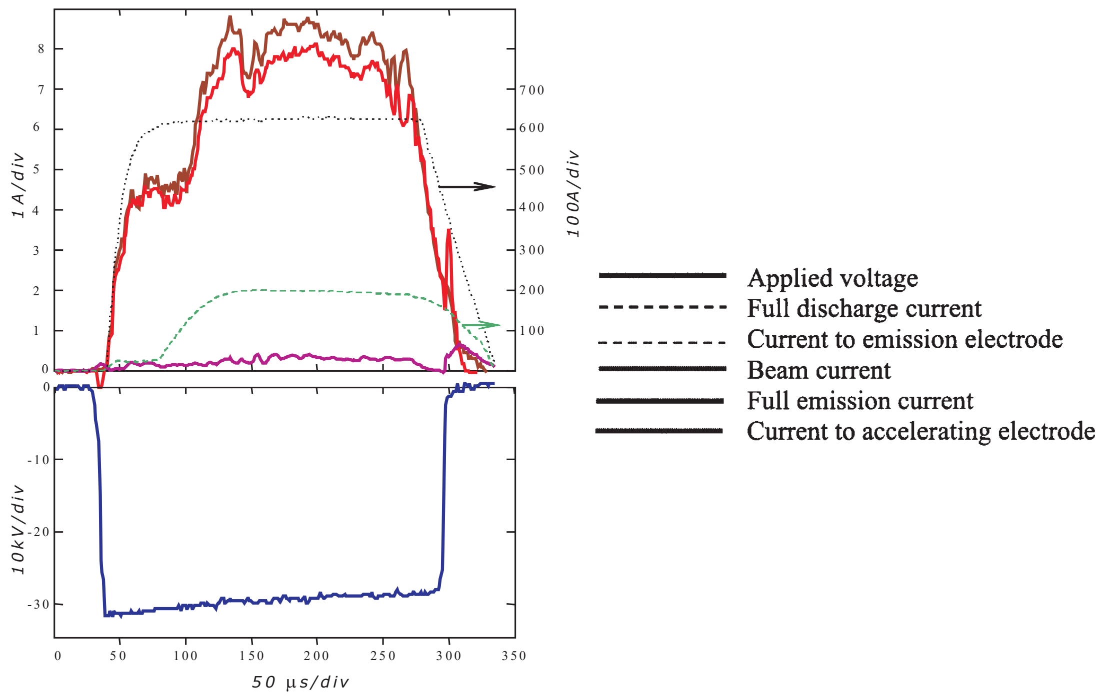


Fig.9. Typical waveforms of the beam (positive bias at the emissive electrode).

As a result of experiments the electron beam with a current density more than 100 A/cm^2 has been received at an accelerating voltage up to 30 kV. The beam duration was 250μs that is limited by a power supply system of the source. Higher current of the beam was received when forced switching of the arc current from the anode of the plasma generator to the emission electrode was made. For this purpose the emission electrode was positively biased in respect to the arc anode. The full current of a beam was nearby 7.5 A at 3 mm emission aperture (see Fig. 9). The measured beam current exceeds calculated maximal vacuum current which can pass through this EOS (approximately 6.7 A at 30 kV voltage), that may be explained, apparently, by influence of the plasma formed under action of the beam in post-anode space. The received results are favourable for the chosen concept of the plasma emitter and open prospect for development of a multi-aperture source with larger beam current and electron energy.

4.5.5 Studying of blistering at proton irradiation

In 2006 staff of the laboratory completed research of dynamics of modification of a surface of metals under influence of a powerful proton beam. In the radiation physics the blistering phenomenon is known, i.e. formation close to a surface of metal of the gas bubbles consisting of molecules of the irradiating beam (in this case hydrogen), see Fig. 10. At the increase of fluence the gas pressure in bubbles leads to their opening. Danger of the phenomenon consists that the surface of metal loses its physical and thermal properties. The customer of this work requests to develop recommendations on creation of a long-living target and to check up these recommendations on a real beam with high enough power.

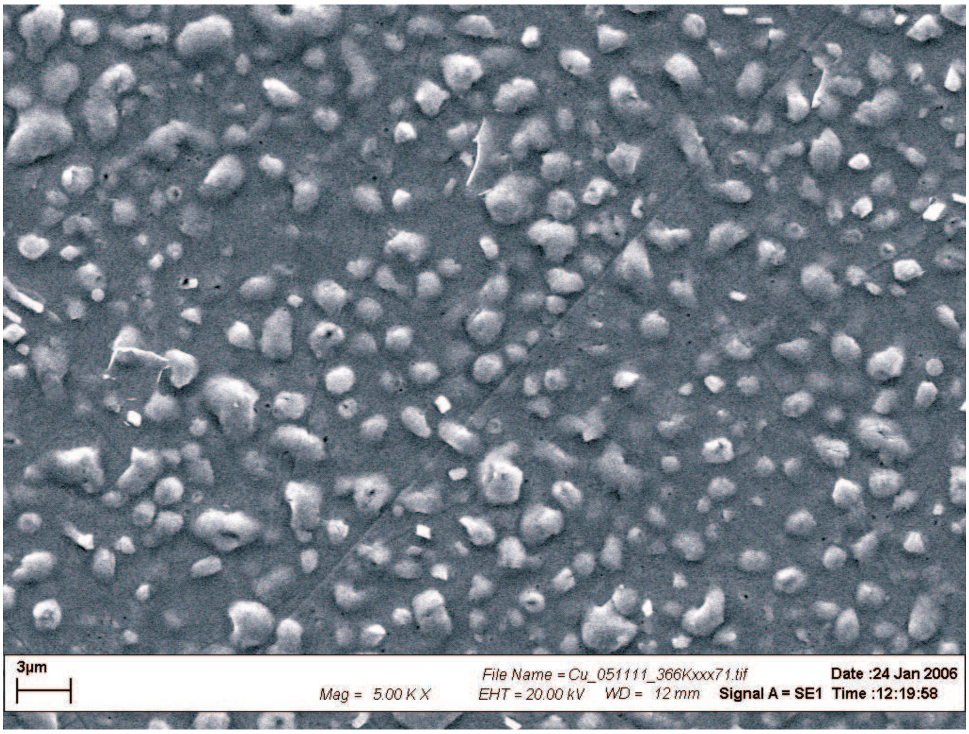


Figure 10: The image of a surface of a copper target, made with a scanning electron microscope. Fluence is $2.5{\cdot}10^{18}$ cm^{-2} at proton energy of 100 keV and target temperature of 370 K. Scale bar is 3 microns.

The special device was created in BINP for research of behaviour of materials at an irradiation by high energy protons. The proton beam has the following parameters: proton energy up to 200 keV, current density $0.1{\div}1.4$ mA/cm^2, a full current up to 2 mA. During irradiation the target temperature can be set within the limits of $300{\div}370$ K. The device consists of ECR ion source with system of extracting electrodes, 90° magnetic mass-separator, the sectioned accelerating tube and the high-voltage station with irradiated targets and diagnostics. Feature of the design of the device which has been created in short term that the target unit is under high potential.

A set of optical diagnostics shown in Fig.11 was created for a real time observation of a target surface directly during the irradiation. The technique is based on effect of increase of intensity of diffusely reflected light from a studied surface and reduction of mirror reflected light because of increase in a surface roughness due to blisters growth. The surface was illuminated by 632.8 nm monochromatic light and light of more broadband sources. Both mirror reflected and scattered to some fixed angles light were measured.

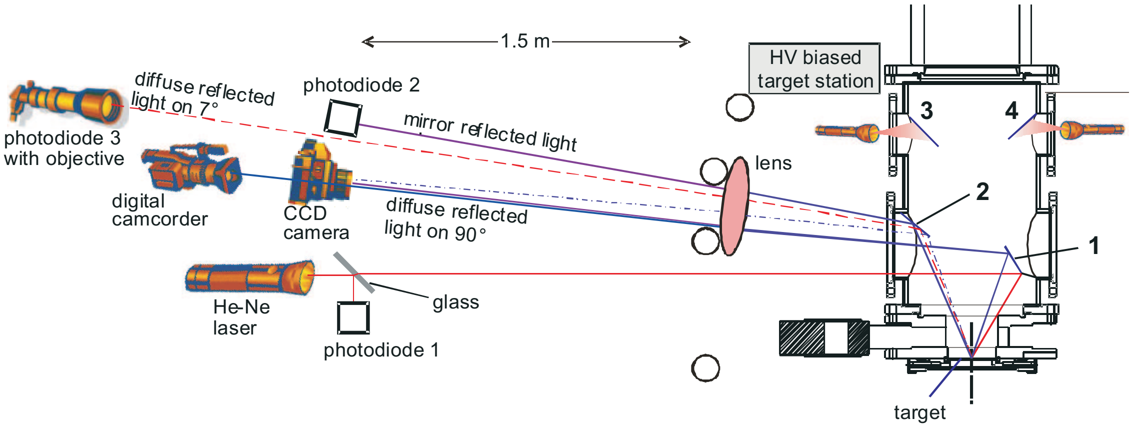


Figure 11: The optical scheme of diagnostics together with the test volume and the target. 1, 2, 3 - turning mirrors. The proton beam falls on a target from above. Equipotential skeleton of the high-voltage station is shown schematically by circles.

During works under the program of blistering study the irradiation of samples from copper (as the reference material possessing a low threshold of the beginning of blisters formation) and other structural materials was done. Dependences of the threshold on target temperature and on proton energy were studied. To the customer it has been shown, that for the proposed candidate material the blisters formation does not occur up to extreme doze values specified in the task.

CONCLUSION

Experiments aimed at development of a physical knowledge base, necessary for a multimirror fusion reactor concept, were continued at the GOL-3 facility. New diagnostic methods as well as dedicated experiments led to improvement of quality of the received information. New technologies of plasma heating which will allow increasing its parameters were in progress. Work on the analytical and numerical models describing behaviour of plasma in a trap proceeded. Applied researches under orders of external organizations were done.

Participants of this work:
A.V.Burdakov, A.V.Arzhannikov, V.T.Astrelin, V.I.Batkin, A.D.Beklemishev, V.S.Burmasov, L.N.Vyacheslavov, G.E.Derevyankin, V.G.Ivanenko, I.A.Ivanov, M.V.Ivantsivsky, I.V.Kandaurov, V.V.Konyukhov, I.A.Kotelnikov, S.A.Kuznetsov, A.G.Makarov, K.I.Mekler, V.S.Nikolaev, S.V.Polosatkin, S.S.Popov, V.V.Postupaev, A.F.Rovenskikh, A.A.Shoshin, S.L.Sinitsky, V.D.Stepanov, Yu.S.Sulyaev, Yu.A.Trunev, Ed.R.Zubairov.

4.6 ELMI-device

One of the key problems being solved by joint investigations of the Budker Institute of Nuclear Physics and the Institute of Applied Physics is to generate 4-mm radiation pulses with high temporal and spatial coherence. These investigations are carried out on the basis of a free electron maser (FEM) driven by a sheet electron beam. To synchronize waves generated by different parts of such a beam a planar Bragg resonator with 2-dimensional distributed feedback was suggested and applied in experiments at the ELMI-device. In recent series of the ELMI experiments we used a hybrid resonator consisting of an upstream reflector formed by a pair of Bragg gratings with 2-D corrugation and a downstream one with 1-D corrugation gratings.

2-D distributed feedback is realized in this resonator by means of sequential scattering of a forward (with respect to the beam propagation direction) wave to a transverse one which then is scattered to a backward wave on the 2-D corrugation of the upstream reflector. The downstream 1-D reflector closes the feedback reflecting a forward wave to a backward one. This process should provide existence of a few eigen modes in the resonator which differ in longitudinal index and are very close in frequency (δf $\sim$ 250 MHz). These modes called "grating" ones were chosen as operating modes of the FEM. But in current experiments at the ELMI-device with a width of the resonator 10 cm an additional reflection of one transverse wave to another one propagating in opposite direction occurs on side walls of the 2-D reflector, it leads to appearance of parasitic high-Q so-called "cut-off" modes. These modes can be easily excited by the forward wave scattered on the 2-D corrugation of upstream reflector. To suppress these parasitic modes in recent experiments we used microwave absorbers of different geometry and wave dispersers which were placed instead of side walls of the 2-D reflector. In the presented paper we describe the results of numerical simulations, "cold" and "hot" experiments which show the influence of 2-D reflector geometry on the mode spectrum of the resonator and the FEM radiation spectrum. In the final chapter possibilities of sub-mm radiation generating in a two-stage scheme based on the existing planar FEM are presented.

4.6.1 Results of resonator simulations and "cold" tests

Schematic of experiments on planar FEM generation is shown in the Fig. 1. A sheet e-beam with cross-section 0.4x7 cm, the beam current up to 3 kA and the electron energy about 1 MeV propagates through the planar resonator in a guiding magnetic field. The undulator component of the magnetic field has the period 4 cm and the amplitude up to 0.2 T and the longitudinal one has a value of magnetic induction 1.2 T.

The hybrid resonator consists of two Bragg reflectors connected by regular waveguide with the cross-section $0.95x10$ cm and length 32 cm. The upstream reflector is formed by two parallel 2-D Bragg gratings with 19 cm length. Each grating has "chessboard" corrugation with 4 mm period in both directions and the depth 0.2 mm. Special microwave absorbers or dispersers for transverse waves were placed on the side walls of this 2-D reflector. The downstream reflector with the same length 19 cm consists of 1-D gratings which are corrugated by parallel grooves with period 2 mm and the depth 0.07 mm.

Spectrum properties of such combined resonator have been investigated in computer simulations and "cold" measurements. In case of the "closed" 2-D reflector, when its side walls reflect transverse waves with high efficiency, additional excitation bands arise in the

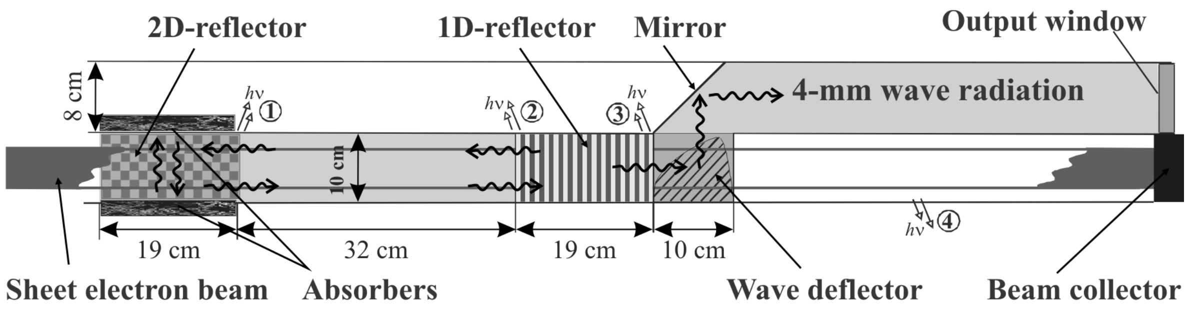


Figure 1: Schematic of ELMI experiments.

vicinity of 73 and 77 GHz in addition to the main band near Bragg frequency 75 GHz. These bands are produced by establishing "cut-off" modes trapped between closed ends of the reflector. Because of 2-D scattering in the upstream reflector these modes are connected with forward and backward waves. In turn the forward wave energy is pumped by e-beam. For the case without absorbers at side walls of the 2-D reflector the Q-factors of the "grating" and the "cut-off" modes are close to 500 and 2000 respectively. In "cold" tests of the resonator both types of the modes are registered. To suppress "cut-off" modes "thin" absorbers (with absorption ∼50%) have been placed at the side walls of the upstream reflector. In this case, the Q-factor of "cut-off" modes decreases to the level of the "grating" ones. In the next series of "cold" tests "thick" absorbers (with absorption ∼90%) have been installed. In this case the "cut-off" modes have not been observed at all. The next figure (Fig. 2) demonstrates the detailed structure of "grating" modes obtained in "cold" tests in the case of "thick" absorbers. Similar frequency properties of the resonator were registered for the case when the side wall absorbers were replaced with wave dispersers, formed by comb structure with period about 2 cm. The resonator with thick absorbers as well as with dispersers was investigated in "hot" experiments.

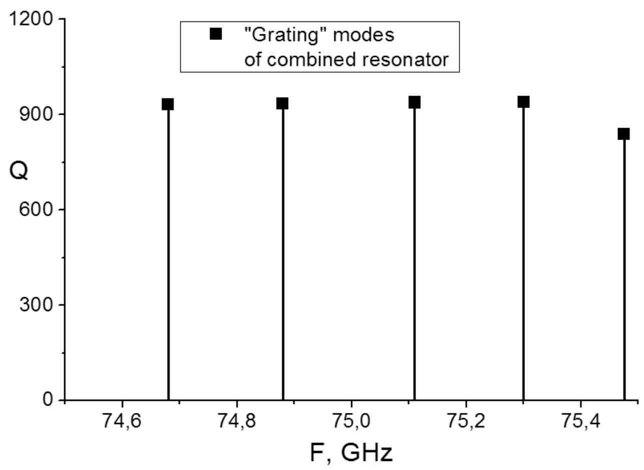


Figure 2: Q-factor of "grating" modes in combined resonator with absorbes on the side walls of 2-D reflector .

4.6.2 Results of "hot" experiments in 4-mm band

For measuring a frequency spectrum of the FEM radiation several diagnostics were used. The first one is a wide-band 4-channel quasi-optical diagnostics realized on basis of a quasi-optical transmission line containing four pass-band Fabry-Perot filters as spectrally selective elements. The second diagnostics is a single-channel heterodyne measuring system intended for a detailed analysis of a maser spectrum.

Results of spectral measurements of the FEM radiation power obtained for a typical shot in series of experiments with the hybrid resonator for the case of "thick" absorbers been used to suppress "cut-off" modes generation are shown on Fig. 3 (top row). Application of "thick" absorbers in the hybrid resonator permits us to observe in "hot" experiments the single- or quasi-single "grating" modes generation during several hundred nanoseconds. As an example, we present in the Fig. 3 a shot demonstrating FEM operation on the modes with frequencies 75.3 and 75.48 GHz, which coincide with "cold" ones given in the Fig. 2.

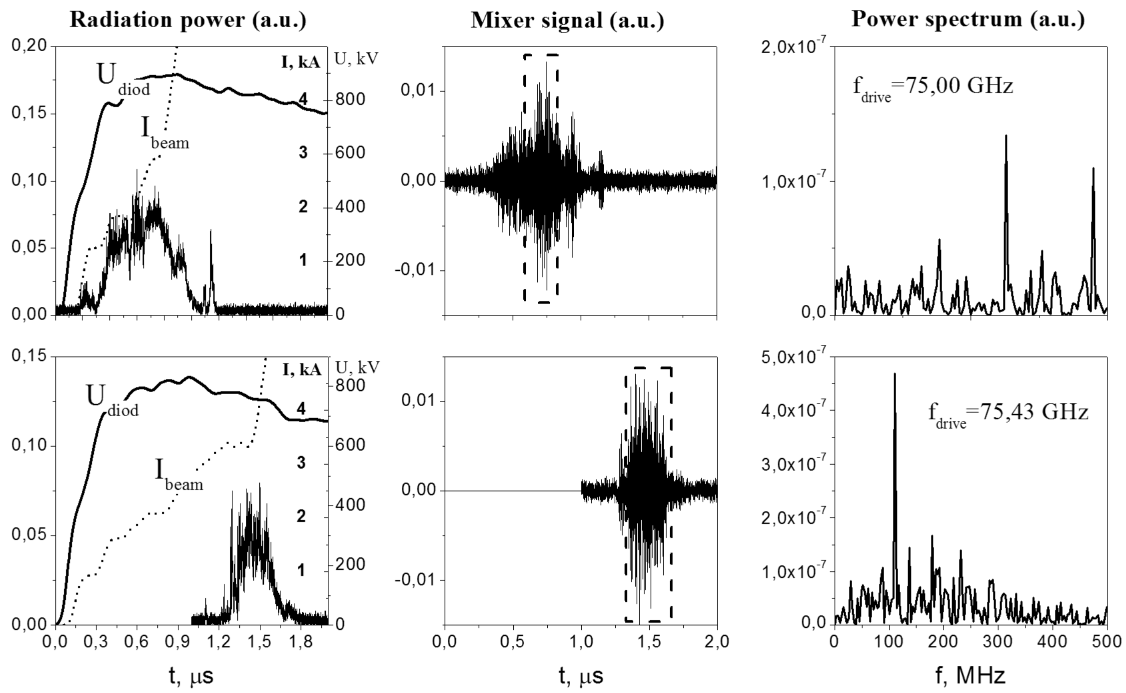


Figure 3: Diode voltage, beam current and signals from heterodyne diagnostics in two cases: "cut-of" modes were suppressed by (top row), and dispersers (bottom row).

Application of a special wave dispersers for "cut-off" modes suppression allow us to obtain single-frequency generation in the band 75-76 GHz during practically all microwave pulse duration (see Fig. 3, bottom row). However generation in the bands related to the "cut-off" modes is still noticeable in "hot" experiments both with absorbers and dispersers. This can be explained by influence of the wall plasma initiation with discharge in high level E-field of the EM-wave pumped by high-current e-beam.

4.6.3 On the possibility of sub-mm radiation generating at the ELMI-device

Recently a wide area of possible applications for sub-mm and terahertz radiation with wavelength 0.3–0.03 mm has been outlined. As a result different methods of generation such radiation are under development. As one of the possible ways we have proposed two-stage scheme for sub-mm radiation generating based on stimulated scattering of 4-mm radiation on the high-current relativistic (E $\sim$ 1 MeV) e-beam (see Fig. 4). In this scheme powerful 4-mm radiation accumulated at the first stage in the resonator of a planar FEM (with sheet REB and stationary undulator magnetic field) is used at the second stage as an electromagnetic undulator for a planar sub-mm FEL. Overview of such two-stage generator with parameters acceptable for the technical implementation at the ELMI-device is following.

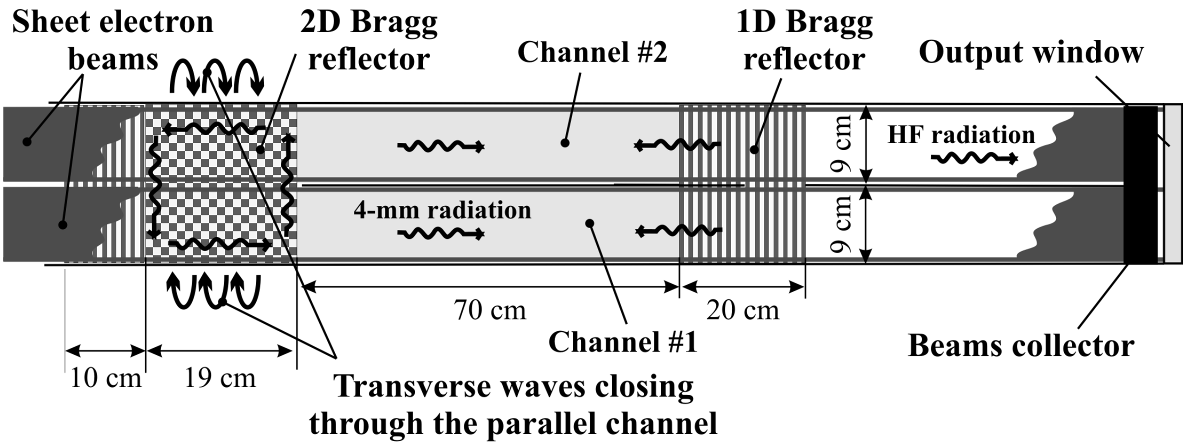


Figure 4: Two-stage sheme for THz-radiation generation by a pumping wave back-scattering.

Let us outline the wavelength band that can be covered in these experimental conditions. At the first stage we plan to use a FEM with hybrid Bragg resonator which was developed in the recent ELMI experiments with generated radiation wavelength λ_0 =4 mm. Taking into account this wavelength of incident radiation which should be scattered by the electrons with kinetic energy about 1 MeV at the second stage of generation, we can estimate the output radiation wavelength: $\lambda = \lambda^0/\mu_0$, where $\mu_0 \approx 4\gamma^2$ in case of back-scattering of the incident wave, and $\mu_0 \approx 2\gamma^2$ in case of 90°-scattering ($\gamma = \sqrt{1-\beta^2}$ is a e-beam relativistic factor). The expected wavelengths of the scattered radiation at output of the two-stage scheme are presented in Fig. 5. The radiation in the band of 0.1-0.3 mm can be obtained in case of 4-mm radiation incidents upon the electrons in the direction opposite to the beam electron velocity. If the incident radiation propagates in the transverse direction with respect to the beam electron longitudinal velocity the radiation wavelength should be in the band of $\sim$ 0.2-0.6 mm.

For both stages we suppose to use sheet beams with 3-4 mm thickness and 10 cm width with a current density more than 1 kA/cm^2. The e-beams pass the slit channels at presence of longitudinal guiding magnetic field with the strength $\sim$ 1 T. In the channel 1 the electrons oscillate in undulator magnetic field and generate 4 mm pump wave with efficiency 10-15%. In this case the electric field strength of 4-mm radiation inside the FEM resonator can amount to 10^6 V/cm, and 4-mm radiation with the approximate E-field level will be scattered by relativistic e-beam in channel 2.

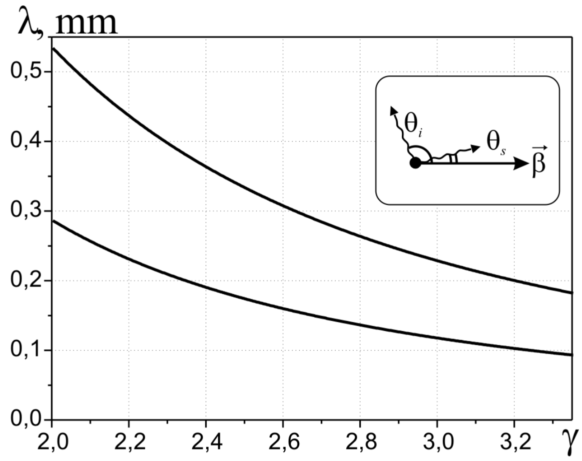


Figure 5: Conversed wavelength due to scattering of 4-mm radiation on beam electrons as the function of the beam γ-factor (bottom line – back-scattering, top line –) 90°-scattering .

For the first experiments we plan to observe scattered signal amplification in the scheme presented in Fig. 4 in the absence of the resonator (mirrors) for sub-mm radiation. In computer simulations and recent experiments at the ELMI-device the single frequency operation of 4-mm free electron maser during several hundred nanoseconds even with sufficient beam energy fluctuations has been demonstrated. It means that generation of sub-mm radiation with the same pulse duration is possible.

From the recent ELMI experiments power flux density up to I_0 =0.5 GW/cm^2 in 4-mm radiation pulses with duration $\sim$ 0.3μs generated in FEM (channel 1) can be reached. 4-mm radiation with the same power density level will be scattered on the supplementary electron beam in the channel 2. Taking into account this power flux density the spatial growth rate for scattered sub-mm radiation at the beam current density j = 3 kA/cm^2 is estimated as $\Gamma \sim$ 3-5 m^{-1} and this value seems to be acceptable for the first experiments. For reasons given we plan to observe super-radiation pulses in frequency band 1-2 THz. Velocity spread requirements for the electron beam can be expressed as $\frac{\delta V_z}{c} << \frac{\lambda_0 \cdot \Gamma}{4 \cdot \gamma^2} = 2 \cdot 10^{-5}$. The required value of the velocity spread can be obtained by an accurate choice of geometry of magnetic field configuration in accelerator diodes and an appropriate strength of guide magnetic field. Analysis of this problem has shown that for experimental conditions of the ELMI-accelerator we can increase the guiding magnetic field up to 3 T with accordingly increasing transverse undulator field. This should provide appropriate parameters for the first step of two-stage experiments on production of sub-mm radiation.

Conclusion

So, both simulations and "cold" tests have demonstrated the existence of high-Q "grating" and "cut-off" modes in the hybrid Bragg resonator. In "hot" experiments at the ELMI-device the existence of regimes with single-frequency generation lasting 300 ns with high level of the radiation spectral density near the frequencies of the "grating" modes has been observed. Theoretical investigations allow us to propose technical implementation of a two-stage generator for the sub-mm band on the base of planar FEM as a highly prospective project.

Chapter 5

Electron - Positron Colliders

5.1 Commission of VEPP-2000 complex

Introduction

Physical start-up of VEPP-2000 storage ring is done. During this work assembling of the vacuum chamber was finished and the projected vacuum was obtained (up to $1 \cdot 10^{-11}$ Torr), RF systems as well as precision systems of pulse and permanent magnets feeding (with accuracy 10^{-4}) were tuned up. 4 superconducting solenoids were assembled and installed on the ring, their cryogenical tests were also done.

Conversion system for production of positrons based on lithium lenses was reconstructed.

Automatization system of complex control and beam diagnostics in all the channels and accelerators of VEPP-2000 complex is activated. Secondary emission pickups and pickups on strip circuit are used to measure beam coordinates (with accuracy of 0.2 mm) and beam current (with accuracy of 0.2 mA). This information is manipulated on-line in computer. As a result of the work done a circulating beam of electrons in VEPP-2000 storage ring is achieved, optical diagnostics of the beam in storage ring based on CCD matrixes is worked.

5.1.1 Starting the injection part of VEPP-2000 complex

Beginning of VEPP-2000 commissioning was in October of 2005 as reconstruction of its injection part: linear accelerator ILU – synchrotron B-3M – booster storage ring BEP. Physically these facilities didn't change, but 5 years break in their work lead to significant efforts in recovery of vacuum system and power systems of pulse feeding. Starting the injection part of the accelerator complex took place in context of general modernization of all the automated control of VEPP-2000 complex. This, of course, made additional difficulties, but on the other side served as a bench for debugging all the elements of the automated control including software.

As far as facilities were ready accelerated beam was obtained 10.15.2005 in B-3M, and in June of 2006 in BEP.

5.1.2 VEPP-2000 collider

Electron-positron storage ring VEPP-2000 is designed for to make experiments with colliding electron-positron bunches. It is developed on the place of an old collider VEPP-2M with the beam energy 1.5 times greater (up to 2×1 GeV) and the luminosity up to $1 \times 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$. General view of VEPP-2000 with injection channels is on Fig. 1.

At the end of August 2006 VEPP-2000 was ready to admit the beam at energy 140 MeV. The reasons of working at so low energy will be explained in the following. One of them is the absence of generators of inflector pulses (20 ns, 70 kV). At that time we had only one temporary generator with the voltage less than 12 kV.

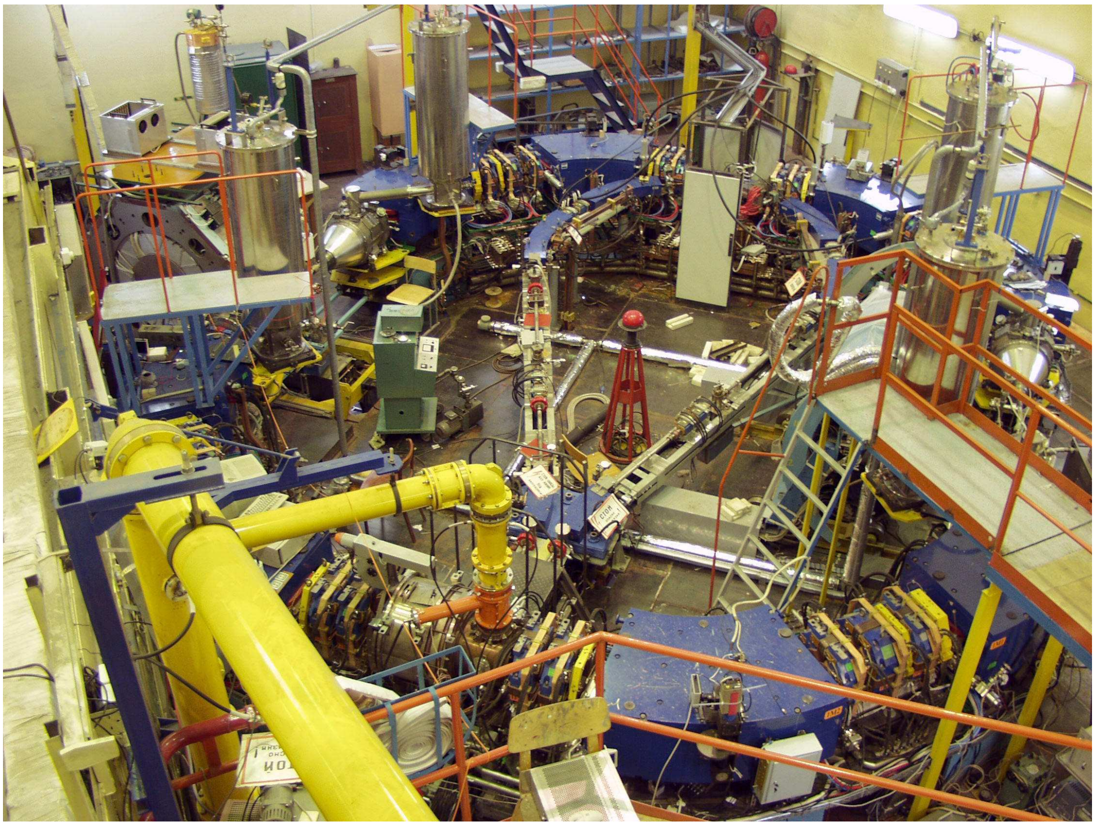


Figure 1: VEPP-2000 collider

5.1.3 Receiving design vacuum

System of high-vacuum pumping consists of 16 ports with getter-ion pumps installed on the edges of bending magnets' vacuum chambers, one more getter-ion pump coupled with RF cavity, 4 cryopumps that are constructed from cold surface of vacuum chamber in solenoids at a temperature of 4.2 K. To prevent cryosurface from SR the use of perforated liner cooled by liquid nitrogen is supposed. Holes in liner should provide line pump speed at the level of 5 l/s/cm in nitrogen.

In Fig. 2 vacuum chambers in bending magnets and injection space of VEPP-2000 ring are shown. All the connections of vacuum chambers are made by argon-arc welding. To prevent vacuum system of VEPP-2000 from depressurizing of BEP's vacuum chamber or injection system emergency automated vacuum gate with pneumatic drive is installed and its efficiency is verified.

All the elements of VEPP-200 vacuum chamber went through the procedures of mechanical and chemical clearing as well as heated in the vacuum at the temperature of $350°C$ during 24 hours to be preliminary outgassed. After assembling the vacuum chamber was additionally heated to $250°C$ during several days (Fig. 3). For pumping during heating procedure two pumping ports were used, that are equipped with nitrogen traps to prevent VEPP-2000 vacuum chamber from oil vapors. As a result of this technology average vacuum in the ring is better then 10^{-9} Torr, and in the RF cavity which was heated at the temperature of $120°C$ the vacuum is about 10^{-9} Torr.

The system of vacuum automated control (Fig. 4) monitors measuring of pressure in VEPP-2000 chamber by magnetron gage and the current of ion pumps as well as corresponding software. Two analyzers of residual gases "Prizma" are installed too, verifying their work and calibrating on most residual gases is done.

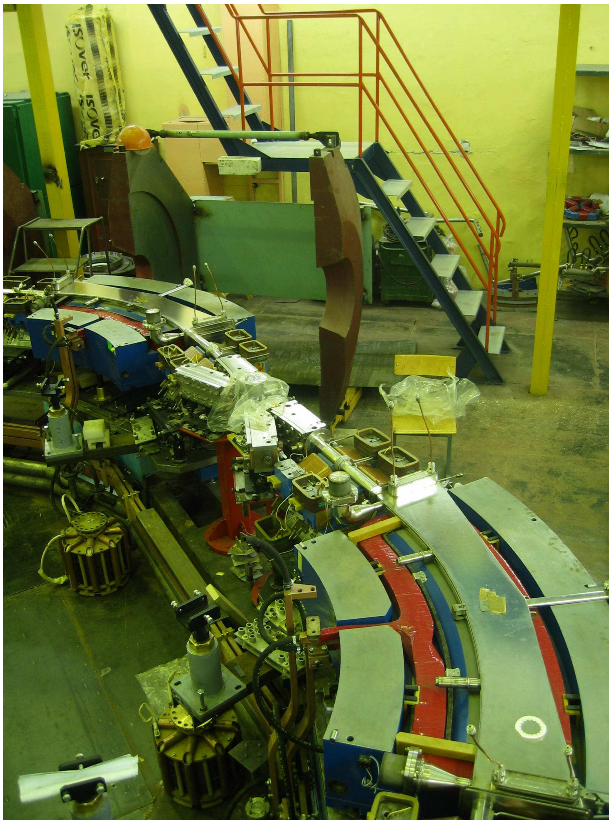


Figure 2: Vacuum chamber of bending magnets in connection with vacuum chamber of injection drift

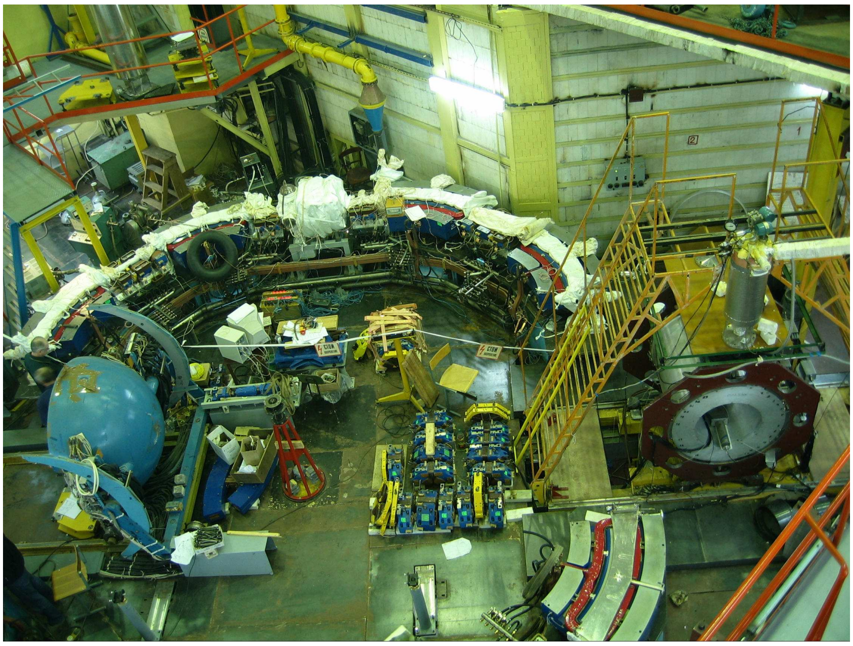


Figure 3: Heating of the vacuum chamber

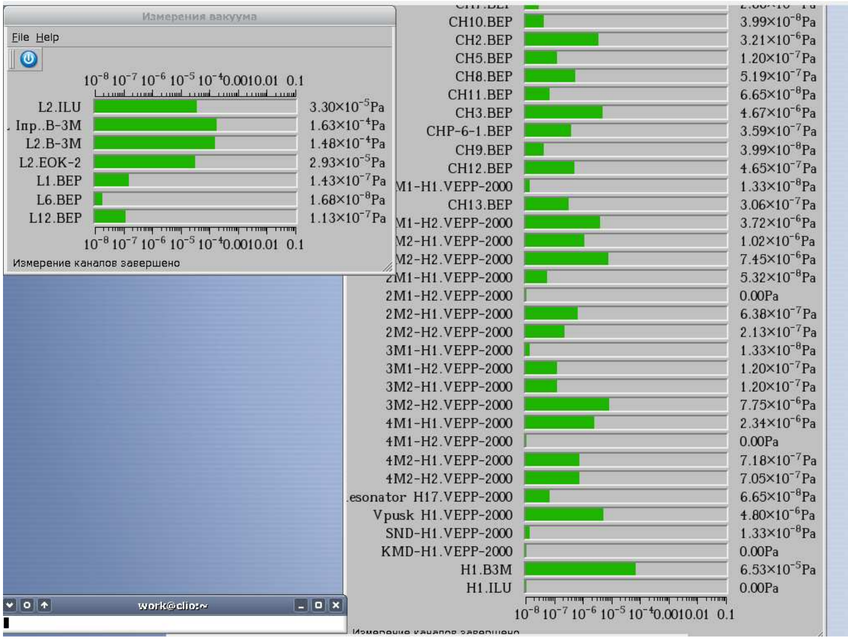


Figure 4: Vacuum measuring

5.1.4 System of automated control

From the automatization point of view VEPP-2000 complex represents more than 500 channels of management and more than 1000 channels of control. Common use of so many channels applies strong demands on the system of complex control. Automatization system of VEPP-2000 accelerator complex is based on several PC under Linux, that are connected in a local network. Scheme of VEPP-2000 automatization is shown in the Fig. 5.

On the choice of communicating protocol between hardware and control computer one should follow standards, popularity, support, capacity and other important criterion. Two main protocols are chosen for automatization of VEPP-2000 complex: well-known and approved oneself in the area of research automatization CAMAC standard and relatively new protocol of industrial communication CAN-bus.

CAMAC standard is used where great capacity is needed, e.g. in the channels of beam observation, as well as in the sub-systems where changing on more modern standards was qualified as unpractical. CAN-bus protocol is the base protocol in VEPP-2000 automation system. It is very convenient for spaced control systems and allows one to decrease the number of wired communications.

The principles of VEPP-2000 complex's software development are based on hardware architecture. Special servers control one or more CAN-bus or CAMAC buses and allow client programm to access to channels of management and control corresponding to these buses. Differential characteristic of such approach is that several client programmes can simultaneous manage and make monitoring and control of hardware. Applications can exchange system common events and commands (e.g. regime change, working energy change etc.) via special server of messages. The second feature of this architecture – hiding the details of work with certain block of hardware and realization of certain server from operator (user). All the information on hardware configuration is kept in special developed data bases, own for each sub-system. All the above is illustrated in the Fig. 6.

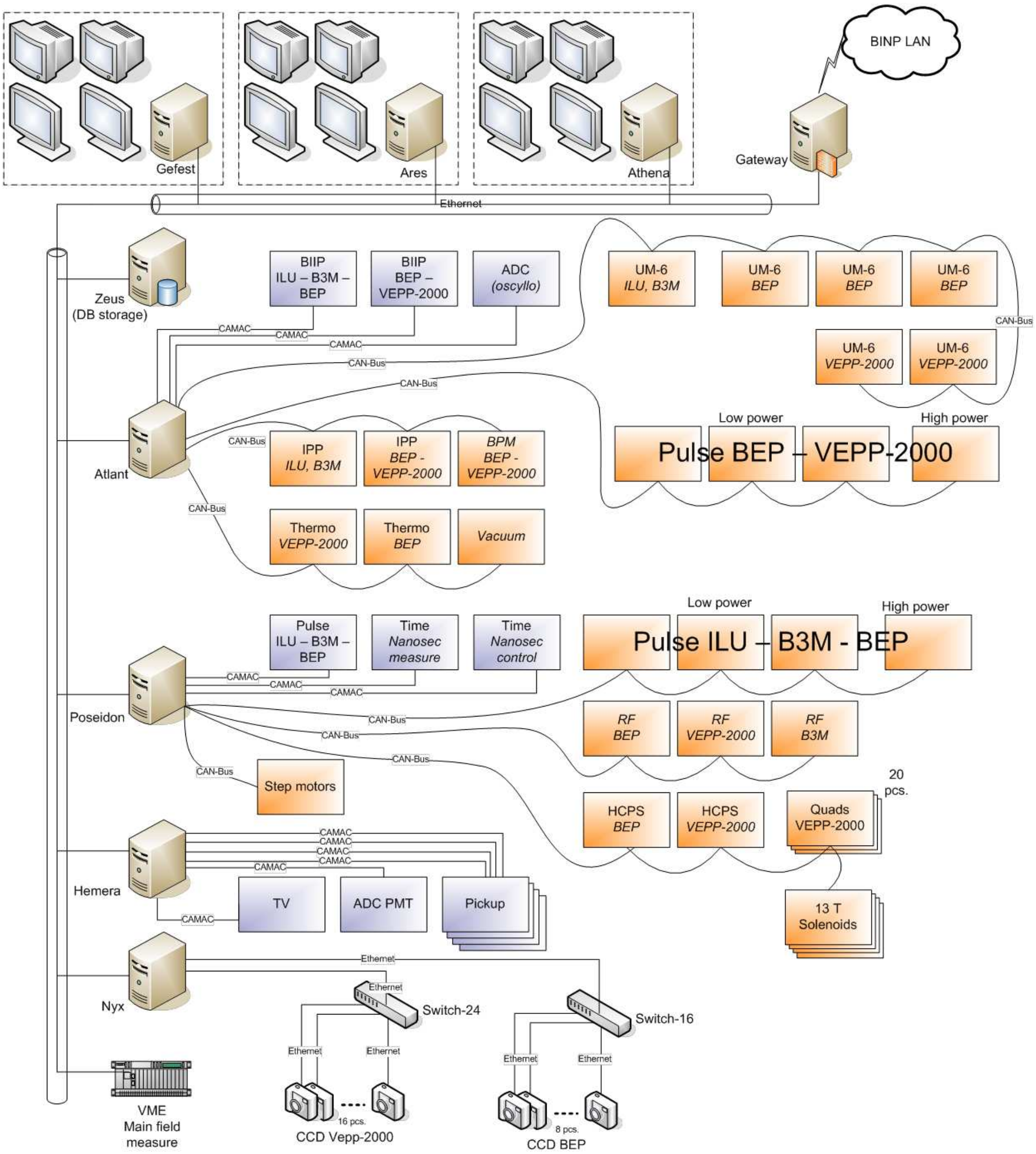


Figure 5: Hardware of the automated control system of VEPP-2000 complex

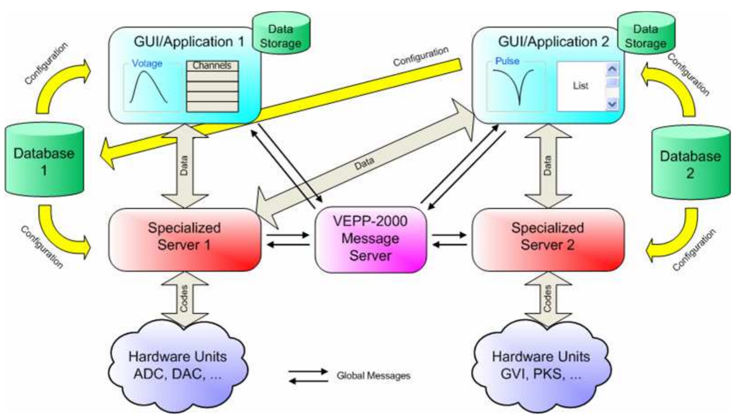


Figure 6: Principles of software architecture of accelerator complex VEPP-2000

5.1.5 Electron-optical channels of electrons and positrons injection and their power supplies

Injection in the VEPP-2000 ring takes place in horizontal plate in the straight section opposite to RF cavity. Injection system assumes one-turn injection with pre-kick of accumulated beam. Two kickers of constant wave are placed inside the vacuum chamber of two bending magnets on both sides of injection straight. Passage of the beam through nonlinear field of kicker was simulated by multipoles combination, then injected beam was checked on stability with the aim of tracking through the magnetic structure of VEPP-2000 ring. General view of injection channels and placement of elements along the channels are shown in Fig. 7.

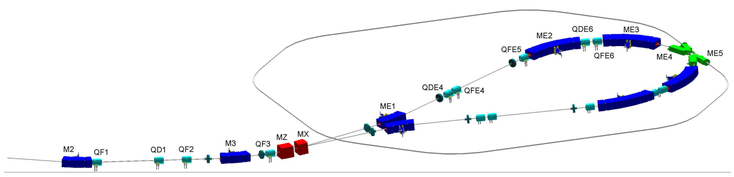


Figure 7: Injection channels of VEPP-2000

Because of space lack injection straight is divided into two magnets – low-field admission magnet (20 kGs) and high-field additional turn (30 kGs). Both magnets are developed in coaxial scheme with laminated yoke. The view of injection section is in Fig. 8.

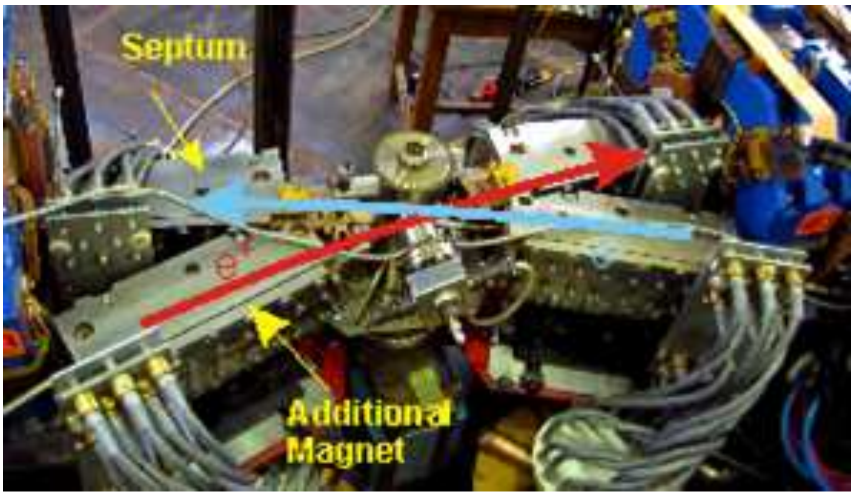


Figure 8: Top view of injection section

Unfortunately, injection magnets were manufactured in experimental production with different bending radius by mistake that leads to incomplete bending of the beam. In waiting the right bending magnets we decided to use permanent magnet to beng particles on lack 1.5 degree on energy 140 MeV.

Hard demands on injection the beams in VEPP-2000 collider require precise consistence of optical functions of channels and the ring. For focussing the beam in these channels pulse quadruples are used with the maximal gradient of 7 kGs/cm. General view of the quad and measurement of magnetic field gradient are presented in Fig. 9.

Power supplies of pulse elements are developed in BINP and represent a capacitor that is discharged via thyristor pin on load.

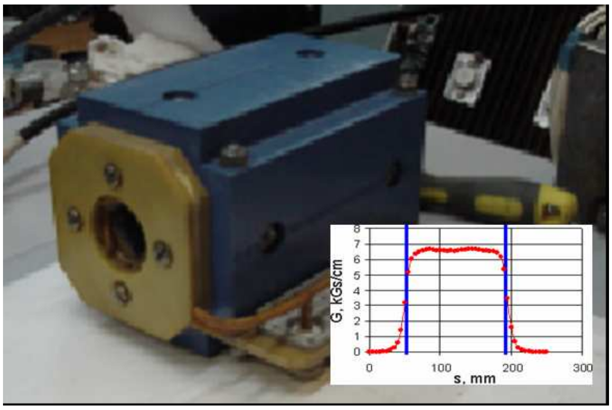


Figure 9: Pulse qudrupole

5.1.6 Tuning the injection channels

In the injection channels two types of beam position monitors are used: secondary emission monitors and image current monitors (Fig. 10). Secondary emission monitor allows one to estimate beam centroid and size as well as beam current. Image current monitor allows us accurately measure centroid position and passed current.

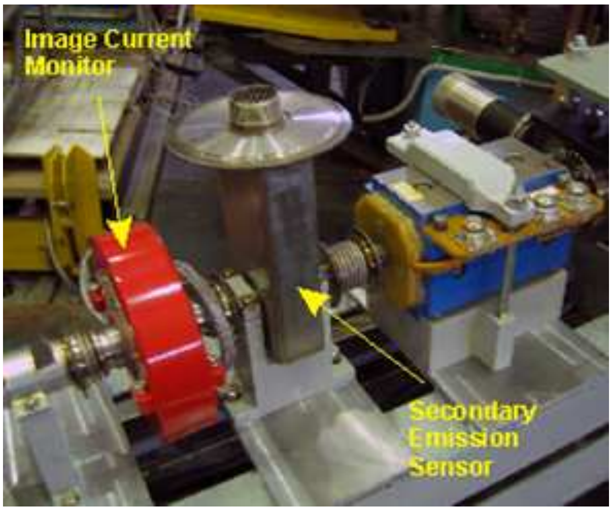


Figure 10: Beam position monitors installed in the injection channel

To work with these monitors a software package was written, graphical interface is presented in Fig. 11 and Fig. 12.

Unfortunately, many mistakes made during construction and manufacturing of secondary emission monitors led to significant loss and scattering of particles. These things together with forced constraints of aperture in channel's bending magnets led to the efficiency of beam delivery from BEP to VEPP-2000 being less than 10 percents at the energy of 140 MeV. This significantly complicated passing the beam through the injection channel, but on 15 September 2006 the electron beam was successfully injected into VEPP-2000. The Fig. 13 shows oscillogram from photomultiplier installed in one of the ring's magnets.

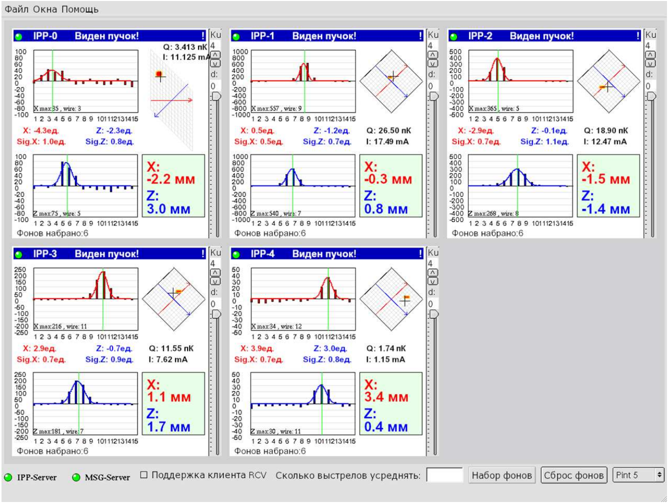


Figure 11: Beam density distribution as measured by secondary-emission monitors in electron channel

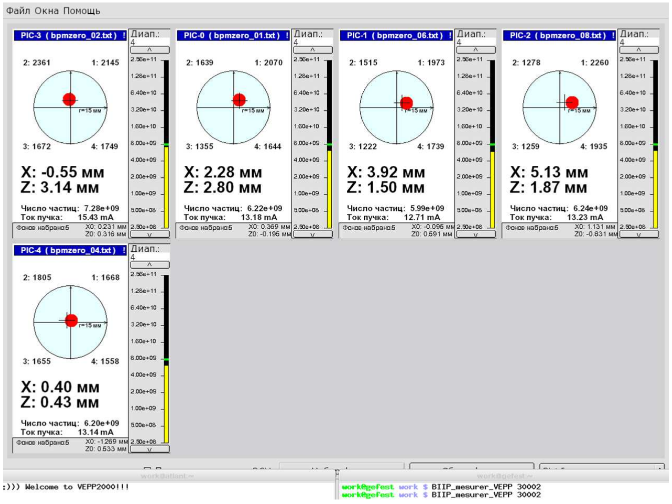


Figure 12: Data from image current monitors

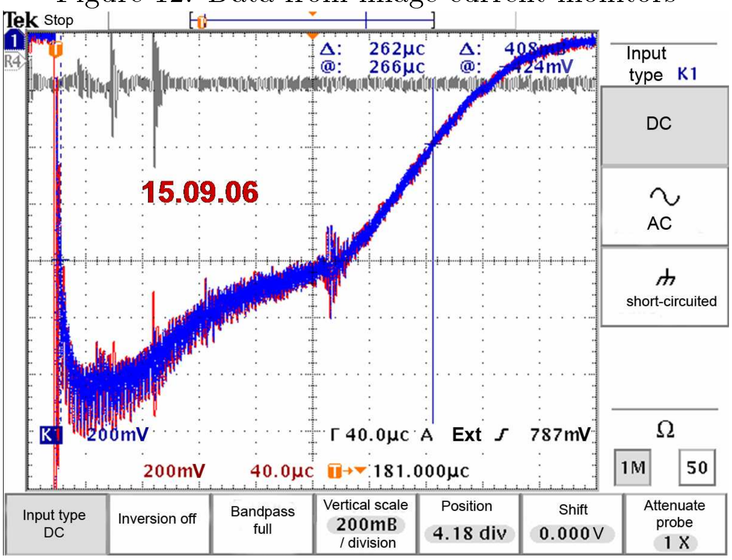


Figure 13: Signal on photomultiplier from the beam in VEPP-2000. Lifetime in betatron regime is about 400 μs

5.1.7 Capture of bunches in synchrotron accelerating regime

The main optical regime of the storage ring due to working point is close to integer resonances $Q_x = 4.1, Q_z = 2.1$ is characterized by high sensitivity to position of solenoids' optical axes. It is required to set the position of field symmetry axes with accuracy of 0.2 mm herewith amplitude of closed orbit distortion being about 3.4 mm. Correction of induced by solenoids orbit distortions is complicated by unusual orbit twist. Such non-typical optics insertions appears as very complicated task.

For the first injection into VEPP-2000 ring it was proposed to use accessory focussing structure with solenoids fully turned off. This approach allows us simplify putting in operation main systems of accelerator (CCD matrixes, pick-ups, measuring tunes, RF system etc.), as well as check working efficiency of all the injection elements (septum magnets, kickers). On the other hand intermediate starting optics permits turning on solenoids separately, in particular we can make sure their influence on the distorted orbit twist is right, as well as make rough preliminary mechanical alignment using the beam as a probe sensitive to solenoid's axis position. After correction of orbit's distortions by available dipole correctors and if necessary by mechanical moving of solenoidal modules smooth transition is performed to the nominal optical structure with the working points is close to an integer resonance and small β-function in the middle of experimental drifts.

This approach to the primary tuning of the ring proved in practice as very convenient method of getting circulating beam. By measuring several first hundreds of turns in a regime with RF cavity turned off the revolution frequency of particles in the ring's magnetic field was measured $f = 12292$ kHz, which consists with calculated value with accuracy better than 1 kHz. Therefore there was no additional effort to capture particles when RF cavity is on. At the first powering of RF cavity the beam is captured in synchrotron regime without any losses in intensity.

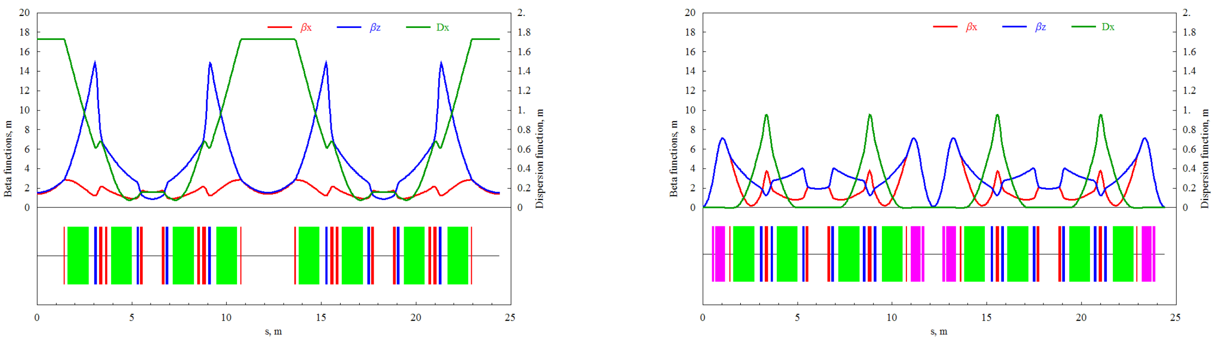
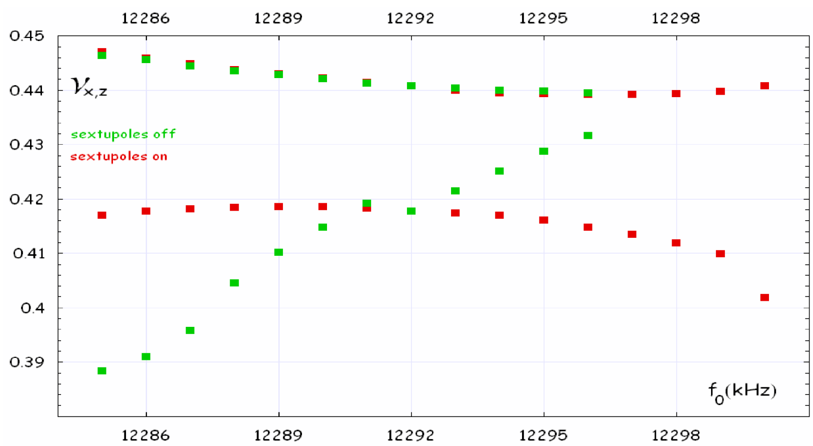


Figure 14: Optical functions of VEPP-2000 ring in the tuning regime (left) and in normal round beams regime

5.1.8 Measuring captured beam parameters and tuning the VEPP-2000 optics

After we got stable beam capture it is possible to measure parameters of VEPP-2000 collider optics.

One of routine items of ring's optics studying is the measurement of betatron tunes chromaticity. We took a dependance of betatron tunes on revolution frequency with sextupoles are off (Fig. 15), that demonstrates significant discrepancy with designed value of a natural chromaticity. Probable, this discrepancy can be explained by the fact that magnetic conductivity of massive vacuum chamber in dipole magnets is differ from one and is equal (as from precise magnetic measurements) to $\mu = 1.005$. Configuration of vacuum chamber creates slight nonlinear magnetic fields including sextupole one. Due to large length of bending magnets the contribution of this unaccounted sextupole in chromaticity is remarkable. Nevertheless this nonlinearity in consequence of it's low value and distribution along the ring should not influence on the dynamical aperture, the chromaticity can be easily compensated by designed sextupoles in tuning regime and in working mode with round beams (Fig. 14).



Natural chromaticity (theory)	**-1.41**	**-2.80**
Measurements, sextupoles are off ■ (green)	**+1.08**	**-8.56**
Measurements, sextupoles are on ■ (red)	**+1.51**	**+1.08**

Figure 15: Chromaticity measuring

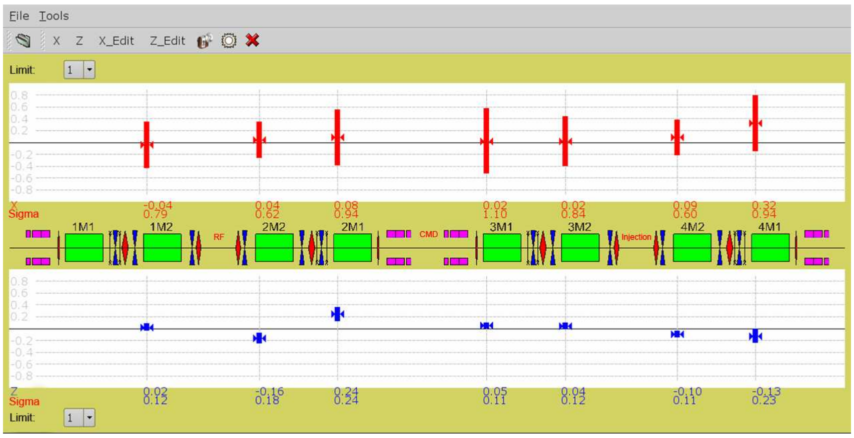


Figure 16: Measuring the orbit and beam sizes

Orbit measurement in VEPP-2000 collider is carried out by means of two systems: pick-ups (one per quadrant) and CCD matrixes (16 units, by 8 in electron/positron channel). Fig. 16 shows the result of on-line processing the images from CCDs as coordinates and sizes of the beam along collider structure. Software developed for CCDs allows one easily make orbit's correction with the aim of preliminary taken response matrixes. One can see from this figure that an average distortion along the orbit is 0.2 mm and the beam size is in good agreement with designed value.

Conclusion

The work done in 2006 on commission of VEPP-2000 complex permitted to check working efficiency of all the complex's systems and determine their disadvantages. All the systems demonstrates good reliability and came to close to designed values.

We obtained circulating beam of electrons in VEPP-2000 ring. System of complex's automated control successfully passed the first tests. Optical diagnostics with CCD matrixes is adopted, this showed high resolution capability and convenience in measurement beam coordinates and sizes.

5.2 VEPP-4M

Introduction

As in previous years, the main direction of the VEPP-4M complex activity was providing the elementary particle physics experiments jointly with the KEDR detector. Fig.1 shows the time (compared to the previous years) taken directly for these purposes, i.e. the time of gathering statistics by KEDR in the regime of colliding beams. Note that in 2003, the detector systems were subjected to upgrade and repair works and there were no experiments in high energy physics. High energy physics experiments have totally taken 3540 hours, nearly one thousand hours more than that in 2005.

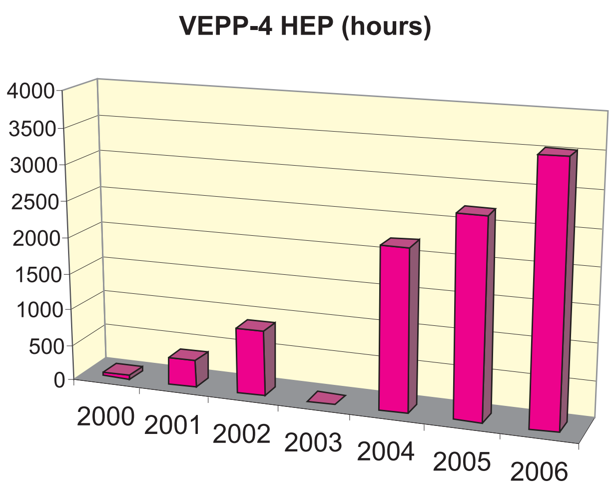


Figure 1: Experimental time of VEPP-4M (high energy physics).

Gathering the luminosity integral over the years is shown in Fig.2. It is seen that we managed to increase substantially the luminosity gathering statistics mainly because of improvement in the efficient operation of the complex and due to automation of tuning the maximum luminosity. The other directions of the accelerator complex activity included experiments with synchrotron radiation at the VEPP-3 storage ring (2232 hours, Fig.3), a study of the charged particle beam behavior in VEPP-4, upgrade and improvement of the operation efficiency of the systems, workout of the beam energy precise calibration technique, etc.

Though the time required for repair work in 2006 increased compared to that in 2005, nevertheless it remained at the level substantially lower than that in previous years (Fig.4).

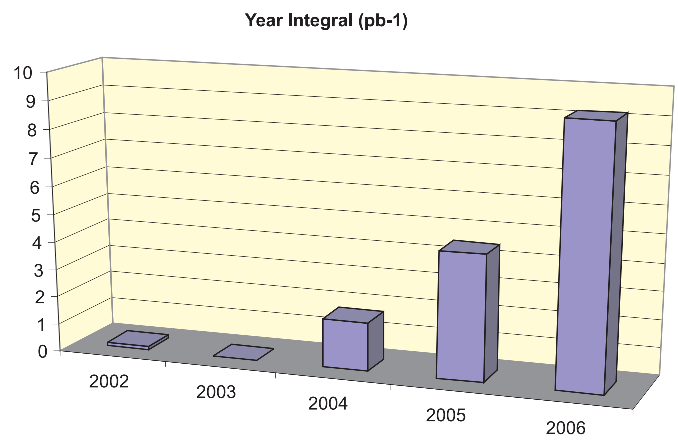


Figure 2: Gathering the luminosity integral (nb-1).

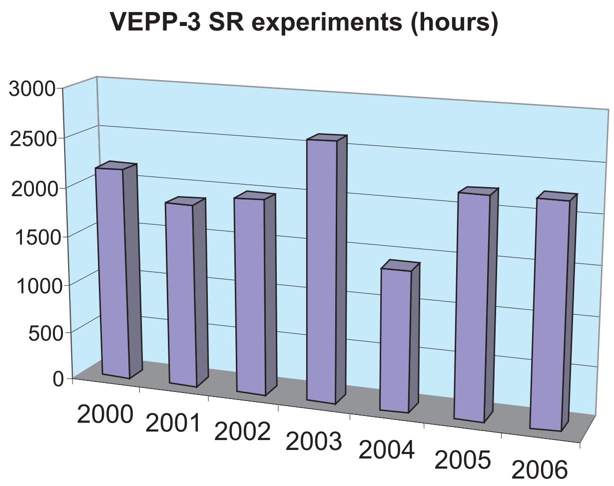


Figure 3: Experimental time at VEPP-3 (synchrotron radiation).

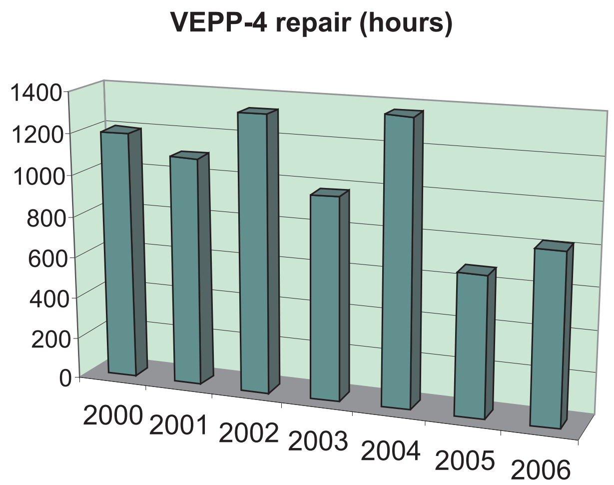


Figure 4: Repair of the complex components in 2006.

5.2.1 HEP experiments

In 2006, we gathered statistics mainly in the vicinity of the production threshold of the τ-lepton and in the range of the resonances Ψ' and Ψ''. Distribution of the luminosity integral over the kinds of experiments is shown in Fig.1. Some parameters of VEPP-4M during experiments are given in Table 2. The table shows a substantial growth of all the parameters compared to those attained in previous years. So, the average rate of gathering the luminosity integral during a week has become twice as much higher. The luminosity curve averaged over a week (only time of statistics gathering was taken into account, i.e. with the colliding beams are re-united) is shown in Fig.5.

Table 5.1: *HEP experiments at VEPP-4M in 2006.*

Region	$\int$**Ldt,pb**$^{-1}$	**Purpose**
$\Psi' + \Psi''$	2.8	m,$\Gamma_{ee}(\Psi')$,M,$\Gamma_{ee}(\Psi'')$
Ψ'(Peak/substr)	1.6	B($\Psi' \to \tau\tau, ...$)+ M_τ
Threshold	6.2(+2)	M_τ
Backaround	1.2	M_τ
Total:		6262 nb^{-1}

Table 5.2: *Some operation parameters of VEPP-4M*

	2005	2600
Average luminosity, cm^{-2}c^{-1}	0.63x10^{30}	0.99x10^{30}
Average rate of gathering, nb $^{-1}$/week	153	315
Week record, nb^{-1}/week	370	545
Month record, nb^{-1}/mnth	1300	1640
Time of gathering statistics, mnth.	7.5	7.5

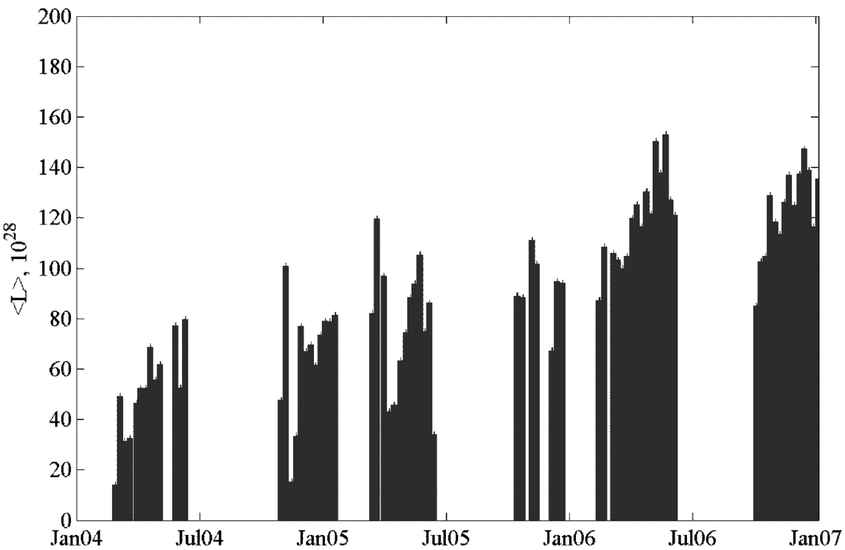


Figure 5: A week average luminosity of VEPP-4M.

5.2.2 Beam energy calibration

One of the basic components of the experiments on measuring of the particle masses is a precise calibration of the beam energy. At present, at VEPP-4M there are two operational techniques measurements of the beam energy: with the help of the resonant depolarization of a beam and with the inverse Compton scattering. The first method has a record accuracy $\sim 10^{-6}$ but it requires substantial time consumption and depolarizes electrons making impossible to calibrate periodically with the same beam. Though the accuracy of the second technique is lower, ($\sim$3x10^{-5}), it is more convenient and does not require polarization of a beam and it can be used directly in the process of gathering the luminosity integral. The use of these two approaches improves the reliability of results obtained and provides the required accuracy. In this case, the energy is measured with a precise method of the resonant depolarization both in the beginning and at the end of integral gathering and the monitoring provided by ICS in the process of gathering enables one to control and correct some energy variations.

Both these techniques are described in detail in the previous BINP reports as well as in publications and conference reports.

The basic results in 2006 can briefly be formulated in the following way:

• 458 calibrations of energy have been performed by RD technique in experiments on τ-threshold and in the range of resonances of the Ψ-family.

• The beam monitoring accuracy performed with the inverse Compton scattering method (ICS) was obtained to be 60 keV.

• The sources of systematic errors when measuring energy value with the ICS method have been studied in comparison with the RD method data and restoration of energy by the NMR and temperature.

Fig.6 shows the results of energy measurements and the beam energy interpolation at VEPP-4M for five days of April, 2006.

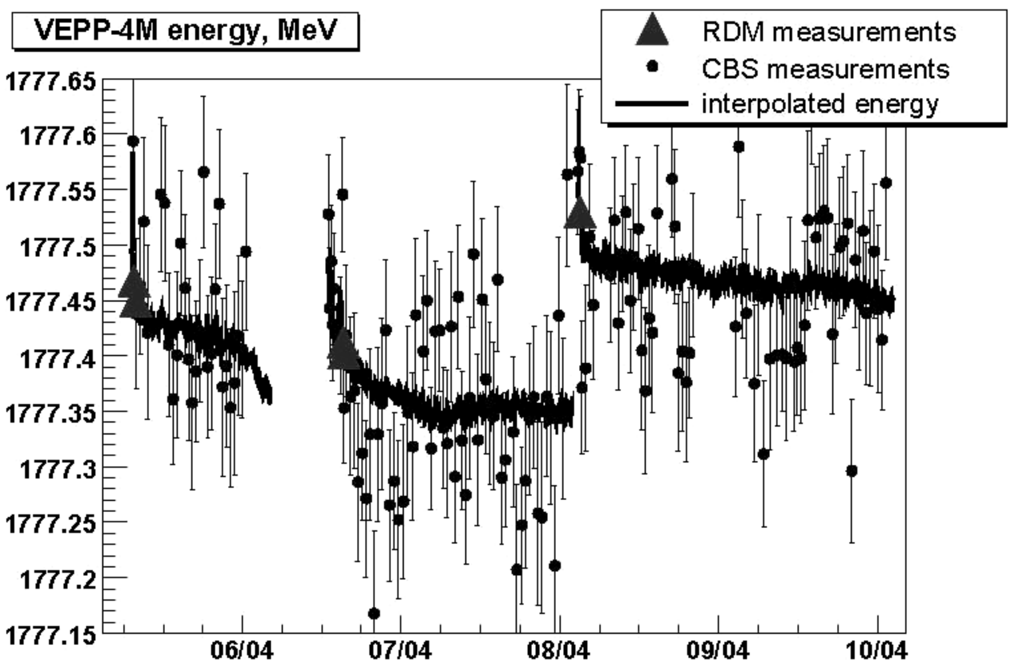


Figure 6: Energy measurements at VEPP-4M by RD technique (triangles), ICS points and interpolation (the black line).

Comparison of the energy measurements by the resonance depolarization and inverse Compton scattering techniques shows rather good coincidence. Fig.7 shows the comparison histogram of measurements by two techniques for the period of three months. A root-mean square difference is at the level of 42 keV.

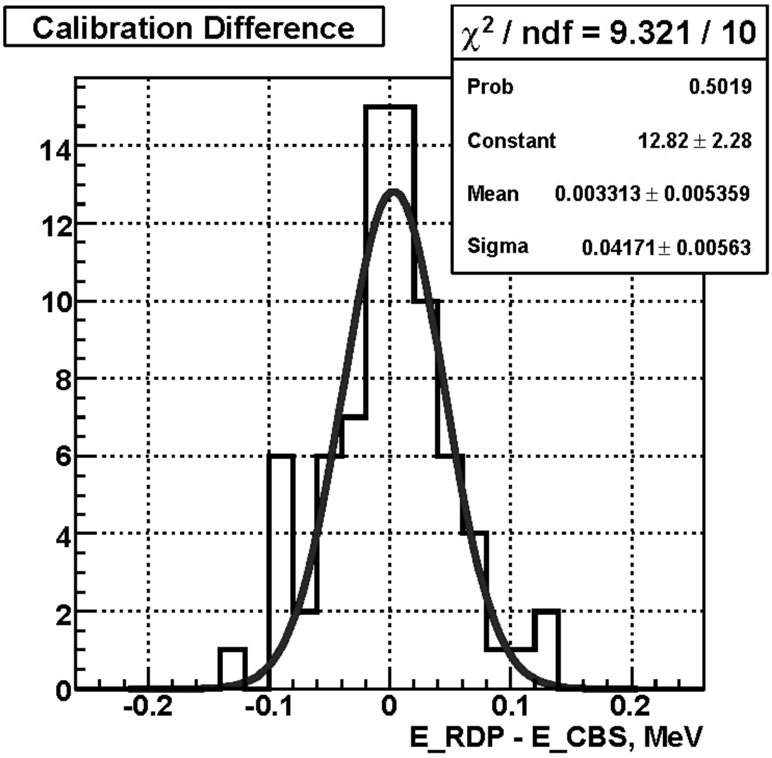


Figure 7: Comparison of energy measurements by two methods.

5.2.3 Upgrade and improvement of the complex operation

Improvement of the efficiency and reliability of the complex operation are the priorities in the work of the Laboratory 1-3. In 2006, we developed a set of codes for automatic adjustment of the VEPP-4M parameters for attaining the maximum luminosity that in many respects determined and increase in the statistics compared to that gathered in previous years.

All the RF cavities are equipped with the systems of temperature stabilization of the cooling water thus enabling to reduce substantially the frequency of occurrence the beam phase oscillations leading to a decrease in luminosity and an increase in background.

A system consists of the volume with a 20 kW heater and set of thermosensors and microprocessor electronics ADAM capable to stabilize the temperature of water cooling the cavity at the level of ±0.5°C (Fig.8).

In order to increase the beam intensities at VEPP-4M, the fast feedback systems are developed (the transverse one for increasing the TMC-instability threshold in the 2x2 bunch regime within the energy range from 1.8 GeV up to 5 GeV and the longitudinal one for suppression of the longitudinal oscillations of bunches

The transverse feedback system is under commissioning: on of four channels is fully assembled and completed and the electron beam is under adjustment. Fig.9 shows the equipment of the transverse feedback system in the experimental hall of the VEPP-4M complex. Fig.10 shows the stage of assembly of a wide band resonator-kicker in the workshop.

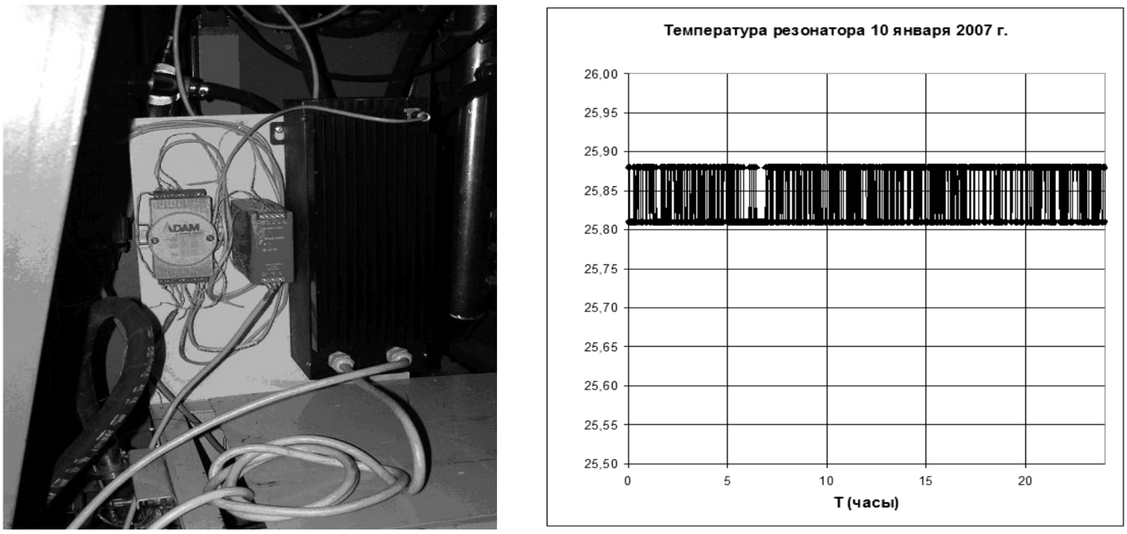


Fig. 8. A system of thermostabilization (left)and temperature curve of the cooling water at the input of RF cavity of VEPP-4M (right).

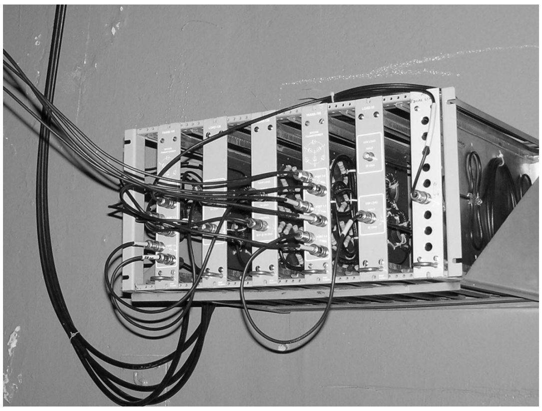


Figure 9: Transverse feedback electronics.

Figure 10: Details of the transverse feedback cavity.

Among other works on improving the reliability of the accelerator complex it is worth mentioning the replacement of interpolating DACs monitoring the power supply sources by the new ones compatible with the old DACs but produced on the base of new element base, development of the modern and higher accuracy system of the thermal control, new equipment of the optical diagnostics, etc

5.2.4 International collaboration and contract works

In 2006, the contract activity of the Lab 1-3 staff included the following:

• The BINP-CERN collaboration on the production of the "warm" dipole magnets for the LHC collider straight section is completed.

• Production of the aluminum coils of the quadrupole magnets of the SR source PETRA III (DESY, Hamburg) is continued.

• For the proton synchrotron PS CERN, we produced the 6 meter long aluminum coils of the bending magnets. Installation of these coils in the bending magnets is realized by the staff of experimental workshop and Lab.1-3

• Production of the sextupole magnets for the SR source ALBA (Spain, Barcelona) is continued.

• Production of the supports for the wigglers-attenuators for the SR source PETRA III (DESY) is continued.

• Jointly with Lab.6 we started the work on the production of transformers and inductances for the SR source PETRA III (DESY).

5.3 Injection complex of VEPP-5

The VEPP-5 injection complex is a powerful source of intense electron and positron beams at an energy of 500 MeV, which will satisfy all the needs of BINP in the electron-positron colliding beams for the next ten years.

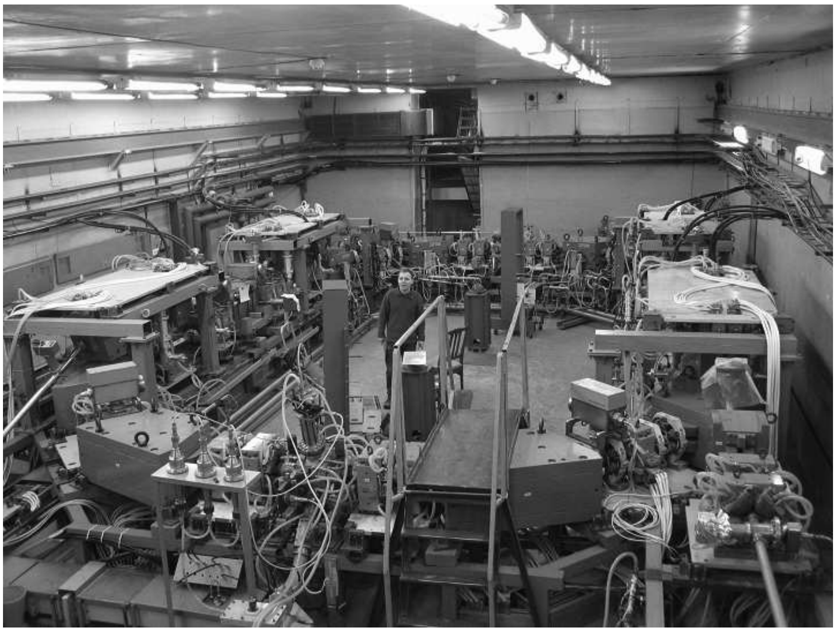


Figure 1: A picture of the damping ring.

The complex consists of an electron linear accelerator at an energy of 300 MeV, positron linear accelerator at an energy of 500 MeV and a damping ring. The most compound and determining parts of the complex are already tested for the design parameters. For example, the positron generation system has shown the record efficiency.

In 2006, the mounting ang adjusting work of damping ring beam diagnostic system were completed. All damping ring systems including the control system are put into operation now. The ring are ready to accept the beam.

The forth (the last) accelerating structure of the third accelerating module of the forinjector VEPP-5 has been produced. The powerful RF loads are in production. The produced parts of the third module have been mounted in the forinjector hall.

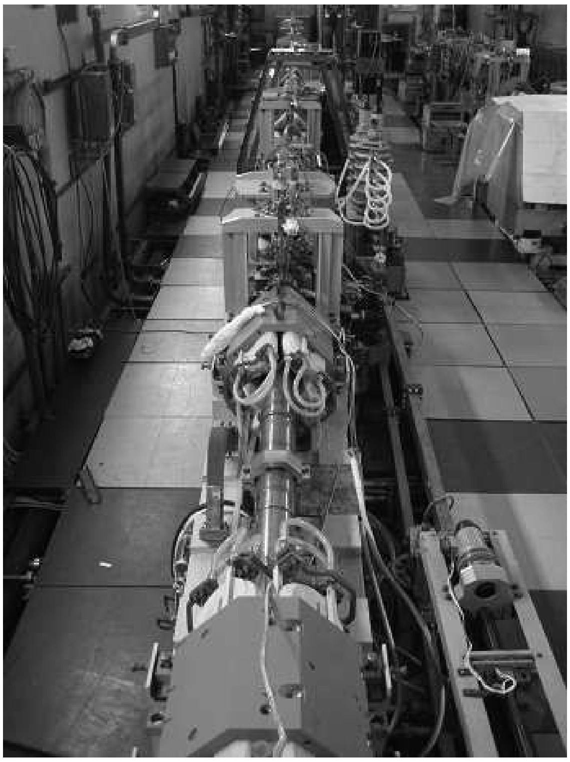


Figure 2: A picture of the positron linear accelerator.

The system of RF power multiplying of the 3rd accelerating module has been tested. The mounting and adjusting of the magnetic and vacuum systems of the positron linear accelerator has been completed. When production of RF loads is completed, it will be possible to accelerate positrons in the 3rd module and inject them into the damping ring at the design energy of 500 MeV.

The input-output system and its control system have been mounted and tested as well as the charging system for the forming lines. A new version was proposed for the dividing part of the high voltage loads mounted at kickers. The long-term tests have been carried out at the nominal regime of 42 kW, repetition rate of 25 Hz. For the period of tests, the dividing coefficients remained at the initial level. It is planned to add into complex control system for the near future.

The first generator assembled at Laboratory-5 was installed at VEPP-2000. The injection into the VEPP-2000 ring was realized at 140 MeV and then at 500 MeV.

Commutators enabling operation both with electrons and positrons and generators will be installed in the near future. Further work will be related to active interactions with the team of VEPP-2000.

5.4 Contract activity

- In May, 2006, the contract was signed for production of seven quadrupole magnets Q13 (Fig. 3) for the Rutherford Laboratory (England) ISIS Second Target Station (TS-2) Extracted Proton Beamline (EPB).

Aperture Diameter	$310\,mm$
Effective Length	$500\,mm$
Peak Field Gradient	$8.2\,T\,m^{-1}$
Field Quality	$\pm 0.5\%$
Tumber of Turns per Pole	80
Maximum Current	$1070\,Amps$
Maximum Voltage Drop	$118\,Volts$
Maximum Power Dissipation	$126\,kW$

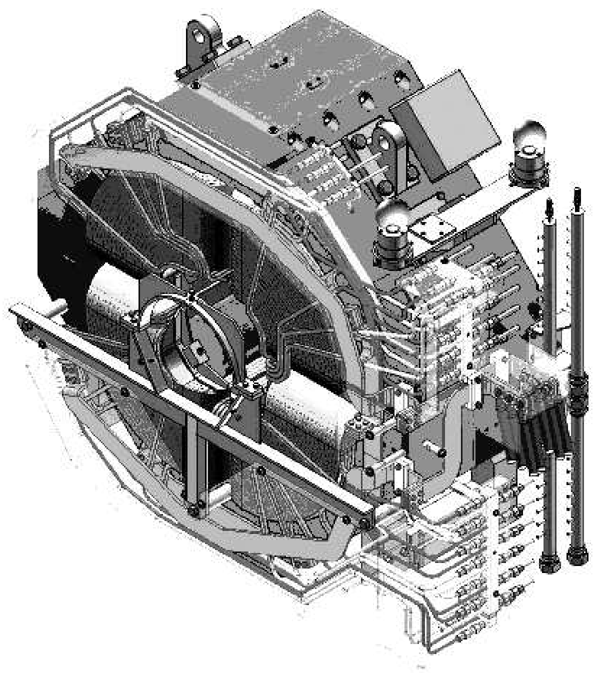


Figure 3: Quadrupole Q13.

- In 2004, it was signed the contract with CERN on manufacturing 11 quadrupole lenses and 26 sextupole magnets. At the end of 2006, all the magnets was delivered to CERN.

5.5 Electron Cooling

An important event of 2006 was a study of the Pb ions at the storage ring LEIR. The storage ring forms the Pb ion bunches for the largest in the world collider with the hadron colliding beams LHC. The electron cooler was developed, manufactured and tested at the Budker Institute of Nuclear Physics, Novosibirsk. Then it was disassembled and on 17

December, 2004, it was delivered to CERN. Its assembly and test with an electron beam was completed in Summer, 2005. Fig. 4 shows the oscillograms of the LEIR operation run with the storage and acceleration of ions of the required intensity.

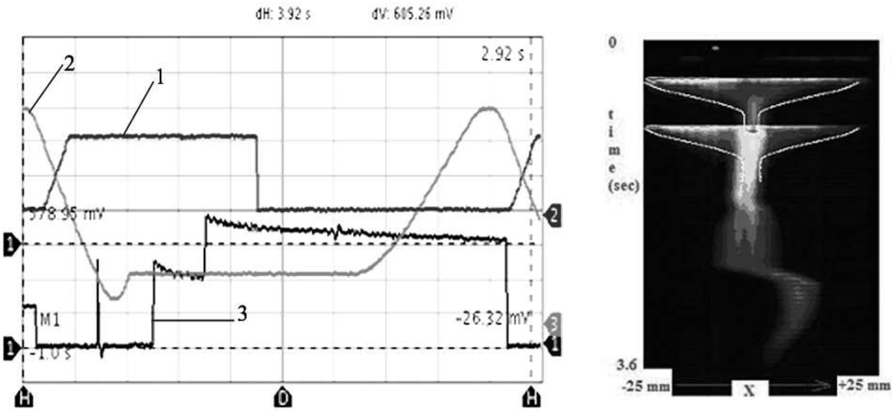


Figure 4: The typical operation cycle of the storage ring LEIR (left):
1 – start and switch off of the electron beam, 2 – the magnetic field cycle, 3 – the ion beam intensity. Variations of the ion beam profile with two successive injections, cooling and acceleration up to 70 MeV/n (see to the right)

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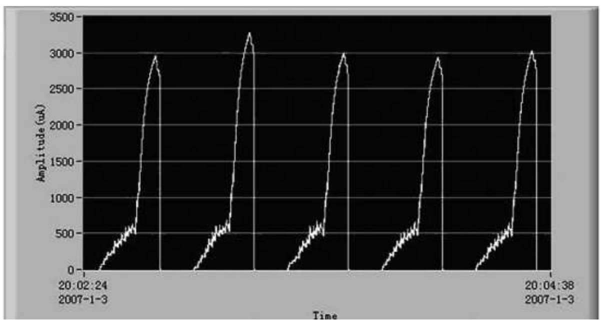

Figure 5: Storage of 10 injection pulses at an energy of $7\,MeV/n$ and then acceleration up to $1\,GeV/n$ at the storage ring with electron cooling CSRm (IMP, Lanjow, China).

In 2006, at the acceleration complex CSRm, the electron cooler with the control of the electron beam profile started its successful operation. A small team from BINP managed to achieve the stage of the first experiments with the ion beam storage. This enabled a substantial progress in the control and diagnostics. By the end 2006, at CSRm it was stored and accelerated a beam of carbon ions of rather high intensity (up to $3\,mA$ accelerated up to $1\,GeV/n$). In this case, the optimum for the storage of the maximum ion beam turned to be the shape of an electron beam with a strong hole in the center (the ratio of the density in the center to the edge point is $1/6$). This experiment demonstrates correctness of the idea of suppressing the electron heating by the hollow electron beam, which was put into the design of the electron cooling.

We continued to work on the development of the high voltage cooling for the storage ring COSY. The prototype of the electric generator with the pneumatic turbine for providing the power supply of the electron cooler sections. This generator turned to be necessary for the Accelerator Mass Spectrometer thus enabling its tests under real conditions. According to the order, we developed the electron cooling section and started its manufacture for the electron cooler COSY.

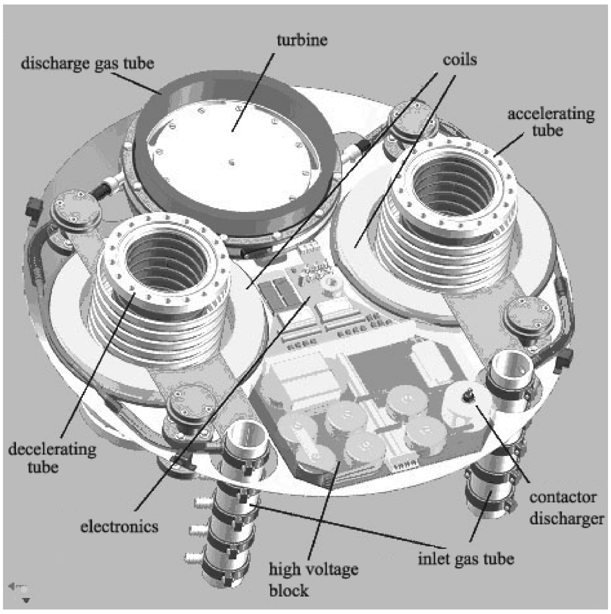

Figure 6: A version of the electron cooler section for COSY.

5.6 Acceleration mass-spectrometer complex AMS

Within the frame work of the integration project SB RAS, in 2006, we carried out the work on calibration and optimization of the operation regimes of the acceleration mass-spectrometer complex (AMS) when measuring the cosmogeneous nuclei ^{14}C и ^{10}Be in the natural objects.

One of the most important results of 2006 was creation of the entire AMS structure and its commissioning at BINP.

In 2006, the AMS main systems were tested and adjusted. In July, 2006, the first beam of carbon ions was detected at the complex output and the beam was traveled without acceleration and stripping through the whole AMS channel with the acceleration and charge exchange at the accelerating voltage of up to $400\,kW$. The beam was registered at the AMS output by the semiconductor and scintillation counters (crystals BGO and CsI). It proved the operability of the whole complex and its systems.

Experiments have been carried out with the gas and spray sources of the negative carbon ions.

A spraying ion source demonstrated a long stable operation and it was used in the first test measurements of the isotope ratios in samples. The magnesium target has shown a stable operation at temperature of 450 °C during ~800 hours without magnesium replacement. Applicability of the vapor-magnesium target for operation in the AMS complex is proved. (see. Fig. 7).

In 2006, the test measurements have been carried for the following samples:

• Pure graphite

• Metallurgical silicon (for detection of small admixtures in a substance at the background of the basic substance), Fig. 8

• Activated charcoal for checking a possibility to work with the pressed samples

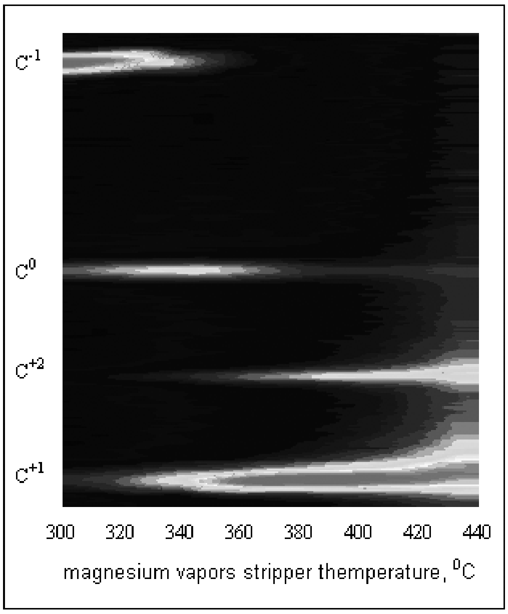

Figure 7: The charge content of a 400 keV ion beam as a function of the charge-exchange target temperature.

• Enriched ^{13}C graphite for checking the concentration of isotopes
The basic isotope ratios obtained for samples are close to the tabled values (see Table 5.1).

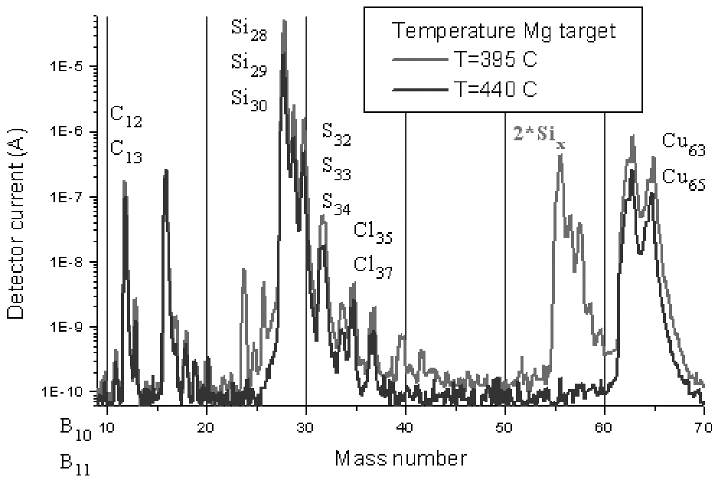

Figure 8: Spectrum of metallurgical silicon. Beam cleaning from the molecular clusters by the denser stripping target is observed at higher temperature).

The main experimental works on the acceleration and detection of ions have been carried out at the accelerating voltage of $100 - 250\,kV$ because of an increase in the radiation background with the raise of voltage. High accuracy measurements ^{14}C requires accelerating voltage of 1 MV, it is necessary to put the installation into the protected area (bunker). The design-construction documentation is prepared for construction of the bunker for location of AMS planned for the May, 2007.

Chem.element	Relative signal	Measured % content isotopes/tabled value
^{16}O	0.022	99.77/99.76
^{18}O	$5 \cdot 10^{-5}$	0.227/0.204
^{20}F	10^{-5}	100/100
^{28}Si	1	92.16/92.18
^{29}Si	0.05	4.6/4.71
^{30}Si	0.035	3.22/3.12
^{32}S	0.0019	95.72/95
^{34}S	0.000085	4.282/4.22
$^{35}Cl_{35}$	0.00022	75.86/75.53
^{37}Cl	0.00007	24.14/24.47
$^{63}Cu_{63}$(from holder) of the sample in spraying ion source)	0.015	63.83/69.1
$^{65}Cu_{65}$(from holder of the sample in spraying ion source)	0.0085	36.17/30.9

Table 5.1: Measured isotope ratios in a sample of metallurgical silicon.

5.7 Works of electron gun team

• On the installation of the electron-beam welding, we continued the work on welding materials in the wide range of thicknesses. We studied the possibility of the focusing, deflecting, adjusting systems, the centering of the electron optical system, welding rate etc. We have carried out the resource studies of the cathode unit at the nominal load. The results of tests of all these parameters turned to be close to the design values.

• Electron beam probe:

- Electron-optical system is selected
- Calculations are performed
- The cathode units are manufactured and tested.

• The cathode units were manufactured and delivered to the customers both in our country and abroad. Among them are:

- ELV-type accelerators
- ILU-type accelerators
- Linear accelerators
- Microtron
- Electron beam probe
- Electron beam welding
- High-charge ion installation

• We have carried out calculation of the electron-optical systems for the possible ion sources of radioactive isotopes.

5.8 Vacuum Studies

5.8.1 Sorption studies

Experimental investigations of activation and gas adsorption properties of non-evaporated getter Zr-V

This work is dedicated to studies of conditions of reactivation of getter St'182 SAES Getters (Zr-V). For this purpose the special experimental stand was created in BINP. The getter pump was made in the form of cartridge to obtain the most sorption capacity. Konstantan tape covered with Zr-V was placed in the form of several strips. The total area of cartridge was 350 cm^2. The hydrogen was being injected during reactivation of cartridge. The efficiency of reactivation of getter cartridge was checked by measurement of effective sticking probability for H2.

The results of measurements show the dependence of getter pumping speed on H2 gas flux and temperature. The sticking probability keeps like constant at temperature more than 120...150C and gas flux up to $3{\cdot}10^{-2}$ (litre·torr)/(sec·sm^2). It follows that gas diffusion coefficient in getter has great value. The measured sticking probability values are in the range from 1.5% to 3%.

Cryosorption studies

The solution for limitation of gas density increase in beam vacuum chamber with walls at cryogenic temperature is use of special cryosorbtion materials (cryosorbers). The cryosorbers are required to fix on the external (i.e. protected on SR, electrons and ions) surface of special perforated tube - beam screen placed inside vacuum chamber. As a result the cryosorbed molecules will be accumulated on the cold surface protected on photons, emitted electrons and ions of residual gas.

The most difficult adsorbed gases at temperature in the range from 5 to 20 K are hydrogen, helium and neon. The partial pressures of saturated vapors of other species at same temperatures are enough low for operation of modern colliders like LHC (CERN, Geneva, Switzerland). Usually the helium and neon in contrast from hydrogen are not the basic residual gases. The previous study of adsorbtion of hydrogen onto LHC vacuum chamber prototype let to define the most optimal technological material which is an effective cryosorber for hydrogen - carbon fiber material UVIS- AK-T. This cryosorber was proposed for use in LHC. The adsorption pumping of He is the particular interest because He can slow leak to vacuum chamber from cryogenic system of machine. The experiment for study of adsorption of He by UVIS-AK-T cryosorber was carried out. The experimental result show that specific capacity of cryosorber is more than 1 monolay for unity area of adsorption surface of cryosorber at temperature T$\sim$16 K.

The work was performed by
V.V. Anashin, R.V.Dostovalov, A.A.Krasnov, N.A. Pimonov, A.M. Semenov.

5.8.2 Participation in MLS project

The storage ring for low energies was begun to construct in Berlin under the order of Federal Physics-Engineering Department (PTB) of Germany. This storage ring will be used as etalon photon source for ultraviolet photon energies. The pressure inside vacuum chamber of this storage ring - Metrology Light Source (MLS) - will obtain to 10^{-11} mbar. All components facing into vacuum volume due to meet the requirements of vacuum system manufacture to the required pressure have to obtain surely. In accordance with pilot project the MLS vacuum system have to pump down by turbo-molecular pumps. The required pressure has to obtain by ion pumps. For this purpose all-metal vacuum system components including pumps with magnets have to bake out at temperature of 250°C.

BINP manufactured the different components of vacuum and magnetic systems of MLS storage ring and electron-optical transferline for transportation of charged particles into the main ring. BINP also participated in development of detail project of MLS transferline. The presence of great number of ceramic units (including non-standard units) in vacuum system components manufactured by BINP required the professional use as standard technologies of manufacture of same vacuum systems as search of original alternative technical solutions. As a result the BINP gain unique scientific, engineering and manufacture experience that results to wider capabilities for development and manufacture of new baked vacuum systems with ceramic units for charged particles accelerators.

At this moment all vacuum components have been produced. Now the MLS is assembled in Berlin.

The works for MLS project were performed by joint collaboration between BINP labs 1-4, 8-0 and Engineering Department by use of production facilities of BINP workshop EP-1.

Публикации: [281], [282], [283].

Chapter 6

Synchrotron Radiation Sources and Free Electron Lasers

Introduction

There are now two sharing centers basing on BINP facilities and laboratories: Siberian Synchrotron Radiation Center and Siberian Center for Photochemistry Research. The working program of the Siberian Synchrotron Radiation Center for the year 2006 included the following directions:

- investigations and development of new technologies with the application of synchrotron radiation (SR) from the VEPP-3 storage ring and preparation for works at VEPP-4M;
- creation of experimental equipment for operation with SR (beamlines, experimental stations, X-ray optics, monochromators, and detectors);
- development and creation of dedicated SR source accelerators;
- development and creation of special magnetic systems for SR generation, i.e. wigglers, undulators, and superbends;
- teaching and professional training of students and post-graduates.

In 2006, 2229 hours of operation time were allotted for work in the SR regime at the VEPP-3 storage ring (1245 hours in 2004 and 2159 hours in 2005). The experiments used 10 stations on 7 SR beamlines.

The working program of the Siberian Center for Photochemistry Research for the year 2006 included the following directions:

- creation of experimental stations and execution of investigations on the operating high-power terahertz laser;
- further work on the creation of the multi-turn ERL and still more powerful IR range free electron laser on its base;
- participation in foreign projects on the development and creation of high-power FELs;
- teaching and professional training of students and post-graduates.

730 hours of working time were allotted for investigations on terahertz beams from the Novosibirsk FEL (180 hours in 2005). The work with terahertz beams was conducted at 4 experimental stations.

6.1 Work on SR beams from VEPP-3

6.1.1 Extreme states of matter

The station "Explosion" (Extreme states of matter) is intended to register passed radiation and small angle X-ray scattering in order to study detonation and shock-wave processes. There is only one such station in the world, allowing experiments with as much as 30 g of explosive. The station consists of:

- an explosion chamber for 30 g of explosive of trotyl equivalent;
- a detector unit;
- an SR beam-forming unit.

A particular feature of the station is the explosion chamber with thin beryllium windows to pass the SR beam as well as the system for the high-precision distance-controlled movement of experimental assembly and detector unit. In 2006, the time resolution of small-angle X-ray scattering was improved to 125 ns (earlier 500 ns) at an exposure time of 1 ns, which is of principal importance for the measurement of the kinetic dependencies of fast chemical reactions with a characteristic time of 500 to 1000 ns, i.e. detonation synthesis of nanodiamonds and synthesis of metal nanoparticles and non-equilibrium alloys (joint developments by LIH, BINP and ISSCM).

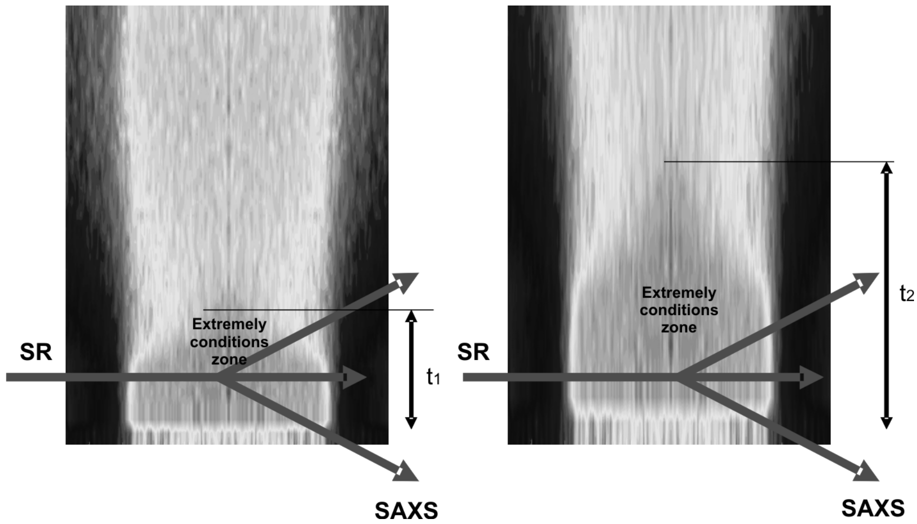

Figure 1: Increase in the time of extreme detonation state at nanodiamond synthesis from t_1 to t_2 due to the change in the hydrodynamical conditions of scatter.

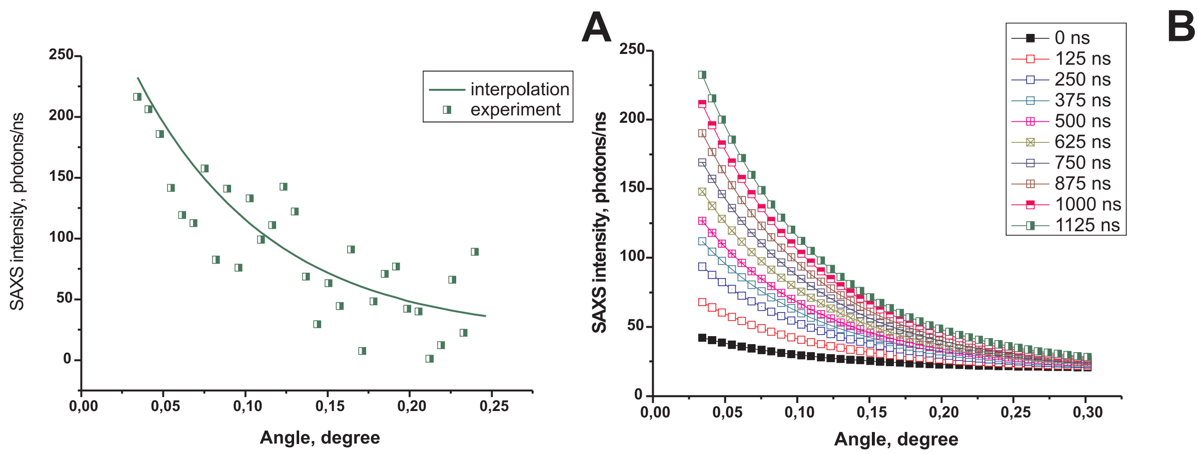

Fig.2. Experimental curves of small-angle X-ray scattering (SAXS) during the detonation of the TNT/RDX (50/50) system at explosion.
A. A typical SAXS curve (and an interpolation curve) at the moment t = 1125 ns after the detonation front passage.
B. The same interpolation curve with a number of other curves obtained at different moments after detonation. Each curve has an exposure of 1 ns, the interval between the curves being 125 ns.

The kinetic curves obtained are an evidence of the unusual behavior of materials under study and their chemical transformation at extremely high temperature (5000-10000° C) and pressure (0.3-1 Mbar). It was revealed experimentally that nanodiamond synthesis was extremely sensitive to hydrodynamic conditions (pressure release) rather than to pressure and temperature variation. Surpassing the thresholds of pressure and reaction temperature was important. This result made it possible to develop a method to retain reactants at extremely high temperature and pressure with the possibility of diagnostic SR-beam probing of an object under study. This method allows prolongating the time of reactants staying in the extreme conditions by an order of magnitude. At the study of the detonation synthesis of nanodiamonds it was revealed that if a reactant was staying in extreme conditions for a longer time, the rate of nanodiamond seed formation became slower though these physical conditions were more preferable for carbon to form a diamond structure. Variation of the terms of experiment allowed controlling the rate of diamond seed formation over a wide range. It has been shown that, theoretically, the process of diamond origination can be stopped.

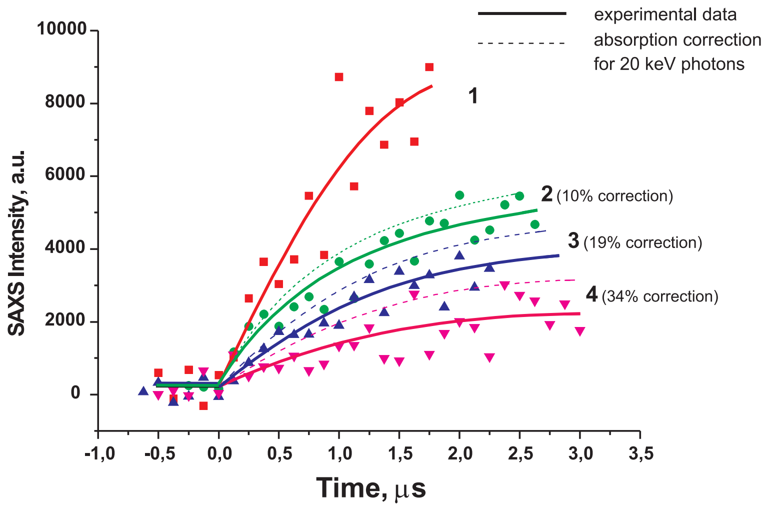

Figure 3: Curves of integral dependencies of SAXS (integration carried out over the angle range from 0.034 to 0.3 degree) for the TNT/RDX (50/50) system under different unloading conditions defined by the PMMA muff thickness:
- (1), 1.5 mm - (2), 3 mm -(3), 6 mm - (4).

The revealed effects were explained with the help of the Bachman diagram (the C-H-O diagram for diamond). According to the diagram, a diamond can originate only in a narrow field of concentrations. If the reactants are retained in extreme conditions for a long time, the state of the system in the Bachman diagram also becomes fixed in an area where no diamond can originate. To provide chemical conditions for diamond formation, it is necessary to shift the system to an area where a diamond can arise. So, the rate of diamond formation can be controlled via adjusting such a shift in the Bachman diagram.

6.1.2 LIGA technology and X-ray lithography

These works aim at the manufacture of X-ray masks for LIGA technology and production of microstructures for technological applications. The participating institutions are

– Budker Institute of Nuclear Physics SB RAS;
– Institute of Cytology and Genetics SB RAS;
– Institute for Automatics and Electrometry SB RAS.

The beam time expended in 2006 is 180 hours.

This work was carried out within the framework of

– SB RAS youth project - 2006: "Development of quasioptical selective elements on the base of metal grid structures for frequency and spatial selection of terahertz radiation";

- - SB RAS interdisciplinary project No.15: "Beam technologies for synthesis of micro-structured components for ophthalmology, micro-optics and micro-photoelectronics with the application of new hybrid materials";

- - RFBR grant No.06-02-17415-a: "Investigation into radiation-induced heat processes in thick PMMA layers under SR irradiation".

A one-step method is being developed for the production of LIGA masks for the X-ray lithography formation of deep (up to hundreds of microns) polymer structures with minimal linear sizes of 10 microns. For this purpose, the main technological processes of LIGA mask manufacture were developed, such as preparation of wafers for masks (glass carbon and glass carbon with a nickel sublayer), application of thick (15 to 30 microns)layers of X-ray resist SU-8, formation of microstructures with an SR micro-beam, etching of irradiated samples, and galvanoplastics of X-ray absorbing materials onto a wafer for an X-ray mask (copper, tungsten and gold).

The pattern of structure is formed in a "thick" layer of resist via direct writing with an SR micro-beam (4 to 30 keV). That makes unnecessary to create an intermediate mask for exposure with "soft" (1 to 4 keV) SR. Thus, the manufacturing process becomes much easier and LIGA masks cost less. Test X-ray masks were manufactured by the above process and were used at the LIGA station to create and to try micro-systems for instant genetic analysis (in cooperation with ICG SB RAS). Polymer microfluid analytic systems (MFAS) are topical for biological applications such as determination of dynamical parameters of biological systems and high-resolution processes; study of genomes, genetic networks and biological macromolecules (DNA, RNA and proteins) in femto- and nano-volumes of surrounding fluids; conduction of high-efficiency experiments with one or a few cells; study of intercellular interactions of separate cells; fixation of separate cells moving in a micro-fluid flow; and creation of a new generation of biological and chemical sensors for testing of surroundings.

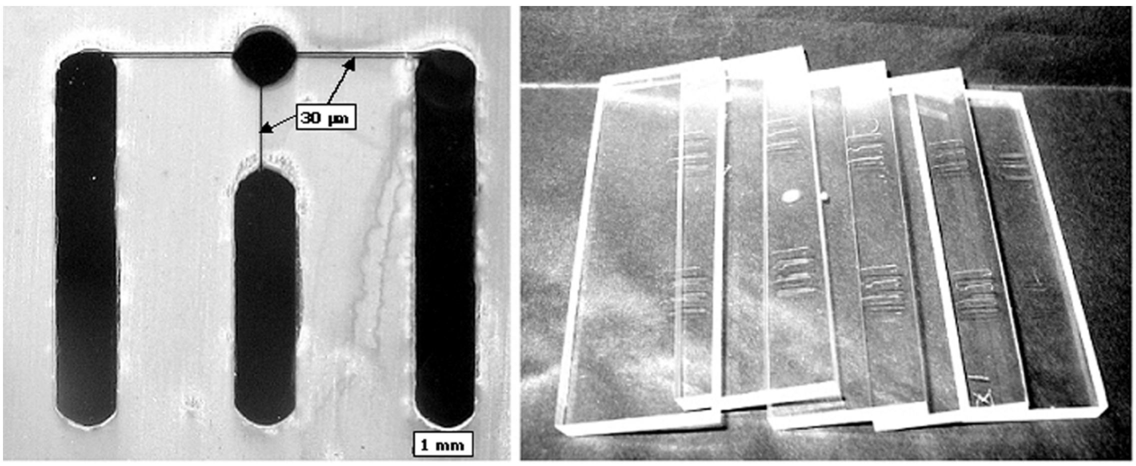

Figure 4: A gilded LIGA mask for the MFAS and about 30 PMMA samples for MFAS (with channels 30 to 40 microns deep and 40 microns wide) for instant test (the samples were tested successfully at ICG SB RAS).

The MFAS is a system of channels 30 to 40 microns wide and deep made in PMMA, together with reaction chambers. A microfluid system allows realizing the three main advantages of a tiny experimental facility: observing a separate cell, saving chemicals and saving time.

Results obtained with the MFAS at ICG SB RAS proved this approach to be applicable. The YfiA gene promoter was used to register the fluorescence of cells fixed in a micro-channel and containing a gene-sensitive structure. Furthermore, the effect of the influence of 1mM hydrogen peroxide on the fluorescence of the cells of the MC4100 line *E.Coli*, transformed by the pRS-prYfi-GFPvaa plasmid, was stated.

The results of work in 2006 are as follows: the entire cycle (from a mask to a product) of manufacture of microstructures with linear dimensions from ten microns at a depth of several tens of microns was shown to be realizable. Besides, in order to provide investigations in 2006, the work on mounting and equipping the “Clear room” was continued, including mounting the ventilating system and draft hoods.

6.1.3 Anomalous scattering and precision diffractometry

Purpose of the station:

The station “Anomalous scattering” is intended for the precision X-ray diffractometry studies of the structure of polycrystal materials. Below are listed the most interesting woks carried out in 2006.

Subject : Study of the formation and properties of meso-structured silicate materials. Participant organizations:

- Boreskov Institute for Catalysis SB RAS, Novosibirsk;
- Institute for Chemistry and Applied Chemistry SB RAS, Krasnoyrsk.

Beam time expended: 70 hours.

Meso-structured materials show ordering of structure units – nanometer meso-pores in a silicate matrix, possibly without any long-range order in the silicate structure. Such materials have extremely high specific surface area and large specific volume of meso-pores. They are promising materials for various fields of science and engineering – chemistry, catalysis, microelectronics, optics and so on.

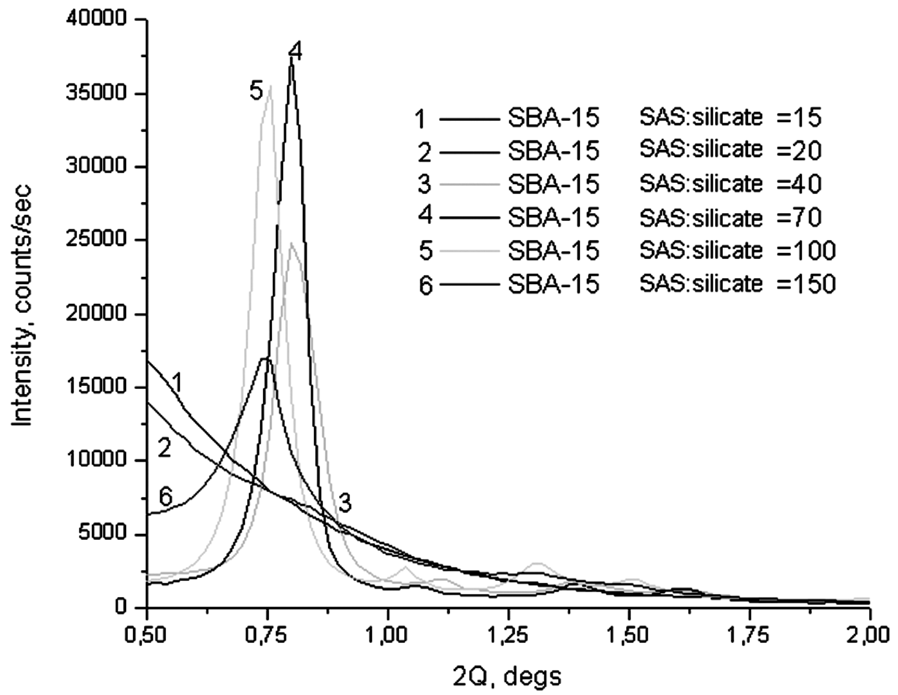

Figure 5: X-ray patterns of the meso-structured silicate material SBA-15 synthesized with various “SAS: silicate” ratios in the initial mixture.

The influence of the "surface-active substance (SAS): silicate" ratio in the initial mixture on the composition and structure of the resulting product in the SBA-15 system (synthesis with the application of a nonionic SAS Pluronic P123, which is a material with meso-pores of ~10 nm in diameter and a silicate wall ~3 nm thick) was investigated. It was shown that no meso-phase arose at excessive silicate and unstructured silica gel dominated in the product. As the SAS content in the reaction mixture grew, the quantity of ordered meso-structured silicate increased and the meso-phase unit cell parameter went up. The optimal quantitative ratio of chemicals was SAS : silicate= 70-80. If SAS is in excess, bi-porous systems with less ordered meso-pores arise (Fig. 5).

Subject : Study of the structure and substructural characteristics of catalysts for deep oxidation of hydrocarbons.

Participant organizations:

- Boreskov Institute for Catalysis SB RAS, Novosibirsk;
- Topchiev Institute for Petrochemical Synthesis RAS, Moscow.

Beam time expended: 48 hours.

Compounds based on cerium oxide and zirconium oxide are promising catalysts in various processes, oil processing among them, as well as catalysts for purification of exhaust gases of internal-combustion engines. This work was examining samples of applied cerium oxide.

The phase composition and substructural characteristics of CeO_2 samples obtained via self-propagating surface thermofusion from cerium ammonium nitrate $(NH_4)_2Ce(NO_3)_6{\cdot}nH_2O$ applied on glass tissue were investigated. Preparation of catalyst involved the impregnation of glass tissue with the solution of preceding compound, desiccation and then the surface thermofusion itself. The final product was obtained after the passage of combustion front over the sample. The investigation showed that there were practically no microstresses and stacking faults in CeO_2 particles of a sample made in this way. Diffraction line broadenings in cerium oxide were caused by the sizes of the area of coherent scattering of CeO_2 particles. According to diffraction estimates, these sizes did not exceed 5 nm.

Subject: Study of the phase composition of catalysts for carbon nano-fiber synthesis.

Participant organizations: Boreskov Institute for Catalysis SB RAS, Novosibirsk;

Beam time expended: 300 hours.

The work was done within the framework of the program "Hydrogen power engineering".

Carbon nano-fibers are used as carriers of metal catalysts applied in fuel elements. A series of 5 samples of Ni-Cu-Al catalysts for the synthesis of catalytic fiber carbon (CFC) was studied: an initial catalyst and the catalyst after 15, 30, 60 and 1200 minutes of the reaction of hydrocarbon reforming and growth of carbon fibers. In accordance with the conditions of synthesis, the catalyst had the following composition: Ni - 65%, Cu - 25%, Al_2O_3 - 10%.

Subject: Study of the phase composition of surface layers of steel before and after application of coating.

Participating organizations: Novosibirsk State Technical University (NSTU).

Beam time expended: 70 hours.

The work was done within the framework of the research program of NSTU.

Surfaces of materials are modified for better wearability, durability etc. with different coatings applied on products via ion-plasmous and gas-dynamical sputtering, chemical deposition and so on. 20 samples (coatings baked on a steel base) have been shot. Powder hard-alloy compositions BK6 (94% of WC and 6% of Co by weight) and T15K6 (79% of

WC, 15% of TiC, and 6% of Co by weight) were used as the coating. 45 pre-borated or pre-cemented samples of steel U8 without chemical-and-thermal pre-processing were used as the steel base. Besides, 4 samples of steel U8 microalloyed with Ti and Nb and after non-vacuum electron-beam processing were shot. The diffraction patterns shot from the surface of samples were studied in order to analyze the changes in the phase composition of the material.

The processing of the data obtained resulted in the following:

- The X-ray diffraction method confirmed the formation of the fragile phase of M_6C at sintering of the powder WC-Co mixture on the steel base surface.

- It was revealed that iron borides arose in the surface layer of the steel base and the volume fraction of fragile phase in the coating material decreased at certain borating regimes.

- It was revealed and verified with the metallographic method that the volume fraction of fragile phase decreased as the time of main metal cementation increased.

6.1.4 X-ray fluorescent element analysis

The station " X-ray fluorescent element analysis" is intended for the determination of the element composition of different samples, such as geological rocks, biological tissues, aerosols etc. with the help of the synchrotron radiation X-ray fluorescent element analysis (SR-RFA). The application of synchrotron radiation (SR) as a source of X-ray quanta allows significant improvement of the conventional X-ray fluorescent element analysis:

• the high intensity of SR lessens the time for analysis or makes the requirements to the sample sizes and masses significantly less strict and reduces the size of the area to analyze; besides, it enables scanning analysis;

• the natural polarization of SR in the horizontal plane allows reducing the background induced by the radiation scattered on a sample and improvement of the detection limit;

• the wide spectrum of SR allows one to select the energy of driving quanta to make the analysis of elements of interest the most optimal.

Element analysis can be done both in local and scan modes.

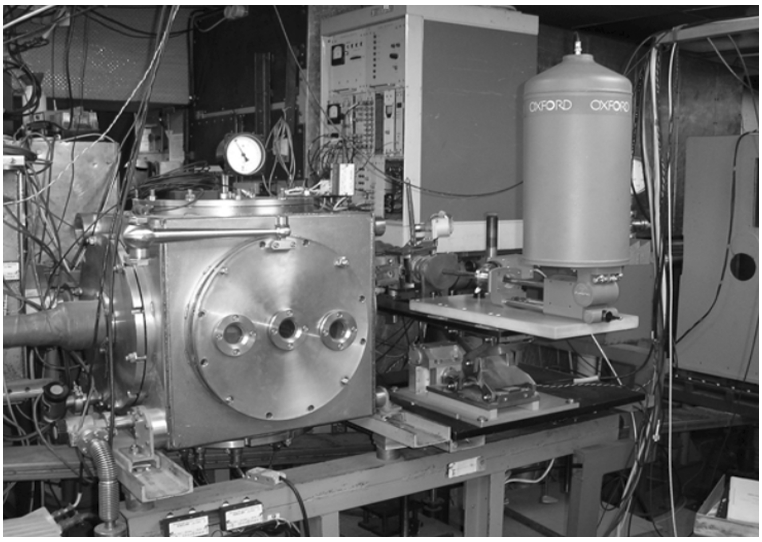

Figure 6: General view of the station for X-ray fluorescent element analysis.

2000 hours were worked at the station in 2006.

Participant organizations:
—— Budker Institute of Nuclear Physics SB RAS, Novosibirsk;
—— Institute for Geology and Mineralogy SB RAS, Novosibirsk;
—— Institute for Oil-Gas Geology and Geophysics SB RAS, Novosibirsk;
—— Novosibirsk State University, Novosibirsk;
—— Vinogradov Institute of Geochemistry SB RAS, Irkutsk;
—— Institute for Forest SB RAS, Krasnoyarsk;
—— Limnology Institute SB RAS, Irkutsk;
—— Institute of Microbiology and Biophysics SB RAMS, Novosibirsk;
—— Institute of Chemical Kinetics and Combustion SB RAS, Novosibirsk;
• Central Siberian Botanical Garden SB RAS, Novosibirsk;
• Institute for Soil Science and Agrochemistry SB RAS, Novosibirsk;
—— Institute for Ecology of Plants and Animals UB RAS, Ekaterinburg;
− − —— Meshalkin Research Institute of Blood Circulation Pathology, Novosibirsk;

Modernization: the station was partially modernized in 2006: a monitor for primary SR beam intensity was installed and a new program package was developed to automate the station operation.

Experiments and results:

A lot of investigations in the following lines were carried out at the SR-XFA station in 2006:

• Certification of the methods to determine the element composition of geological objects and biological tissues (JIGGM SB RAS and IIC SB RAS).

• Analysis of the element composition of the bottom sediments of continental lakes by the XFA scan method, for paleoclimatic studies (LI SB RAS, Irkutsk; JIGGM SB RAS and VIG SB RAS, Irkutsk).

• Analysis of the element composition of atmospheric aerosols (ICKC SB RAS).

• Analysis of the element composition of biological tissues (ICKC SB RAS and IIC SB RAS).

• Analysis of the element composition of archeological and anthropological samples (LI SB RAS, Irkutsk).

• Geochemical analysis of geological samples (JIGGM SB RAS).

Measurement methods for the SR-XFA determination of the element composition of samples of magmatic, metamorphic, sedimentary metamorphic and sedimentary rocks were developed. “Measurement methods for the SR-XFA determination of the element composition of samples of magmatic, metamorphic, sedimentary metamorphic and sedimentary rocks” were certified by the Siberian Research Institute for Metrology, certificate No.3-06 dated 13.06.2006.

Besides, methods to determine chemical element concentration in biological tissues were certified in 2006. “Methods for the SR-XFA measurement of the mass fraction of chemical elements in samples of biological tissues” were certified by the Urals Research Institute for Metrology, certificate No. 253.11.09.343/2006.

The analysis of the bottom sediments of lake Baikal (core BDP99-19-1B), lake Telmen (cores Telmen St2 SGC, Telmen St2 BGC and Telmen St2 BC), and lake Shira as well as of the peat bog “Ochkovoe” in panoramic and scan modes can be referred to the most interesting works. The aim was to obtain high-resolution records of geochemical signals for paleoclimate changes in the bottom sediments of the lakes of Central Asia. The concentration profiles of the following elements were obtained: K, Ca, Ti, Mn, Fe, Cu, Zn, As, Br, Rb, Sr, Y, Zr, Nb, Mo, Th and U. These works have been continued.

The influence of the genetic variance of pine on the content of different macro- and microelements in the plaggen horizon was estimated. The multi-element composition was measured in different parts of the bush acinquefoil, a plant growing in the areas of the Middle Urals with background and man-caused pollution and indicating environmental metals pollution (the results are presented in Fig.7).

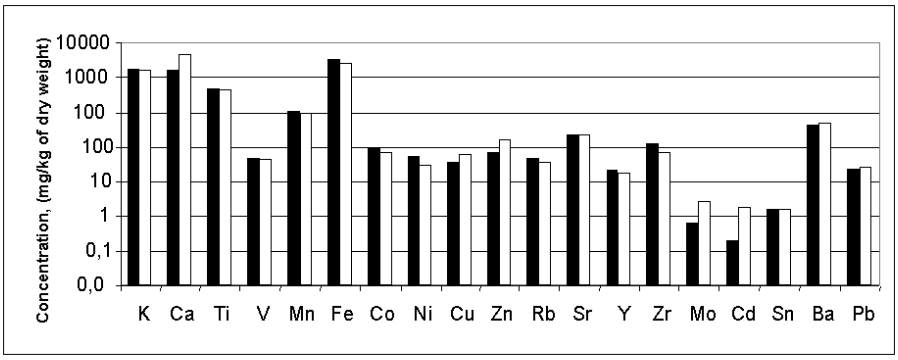

Figure 7: Element content in the soil from a plot under man-caused radionuclide pollution (Eastern Urals radioactive trail) (■) and a reference (□) plot.

It was found that the content of Ti, V, Fe, Ni, Cu, Zn, Br, Zr and Ba is higher and that of Mn, Ag, Sn, I, and Cd is lower in plants from the polluted plot as compared with the plot under background pollution.

One of the most interesting SR-XFA results was the determination of impurity elements in the burnstone from the fumarole fields of the Ebeko volcano (the Kurils). Literature information about impurity elements in burnstone is very scant because of the complicatedness of chemical decomposition and analysis of burnstone. The scant information about the burnstone composition bases on spectral semi-quantitative analysis. The SR-XFA method was used to analyze a collection of burnstone samples that was collected in the fumarole fields of the active Ebeko volcano. It was the first time when a wide range of elements in burnstone was determined. Some of these elements, such as primary elements, impurity elements and some metals (Ca, K, Mn, Fe, Y, Ga, Rb, Sr, Ni, V, and Zn), are carried as aerosols and some (As, Sb, Se, Te, Br, I, Hg, Ag, Cu,Cr, Ni, Sn, and Mo) in the gaseous phase.

The composition of 60 copper-bronze archeological finds from the sites of the Baikal area was analyzed. The aim of the work was to study and to systemize the chemical composition of copper-bronze alloys in order to reconstruct how ancient metal production had developed in Eastern Siberia. Some macro-components such as Cu, Zn, As, Sb, Sn, Ag, and Pb were quantitatively identified (in different proportions) in the alloys. Besides, there were identified a number of micro-elements. The data obtained allowed the archeologists from the Irkutsk Engineering University to classify all the objects as bronze and made by different technologies; there were no pure copper objects among them.

In order to reveal the sources of natural and antropogenic pollution and to estimate the man-caused load on the environment, the seasonal variation of the multi-element composition of atmospheric aerosols (AA) in the area of Siberia (the city of Novosibirsk and villages of Kluchi and Karasuk) was determined. The man-caused environmental plumes around the cities of Nerungry and Novosibirsk were also determined. The main tracer elements of man-caused pollution were found.

Figure 8: Schematic view of the station at operation with the detector mar-345.

Some of the subjects of work in 2006:

– **Structural mechanism of anomalous expansion of microporous aluminosilicates at high pressures of H_2O.**

Participant organizations: Institute for Mineralogy and Petrography of JIGGM SB RAS.

Beam time expended: 84 hours.

Compression of some microporous aluminosilicates in a water medium up to 1 to 2 GPa results in a very interesting effect of over-hydration, i.e. penetration of additional water molecules into structural voids. Over-hydration is accompanied by the expansion of inner pores and radical redistribution of bonds inside water-cation complexes filling the voids, which can cause an abrupt change in the physical-chemical properties of the compound, such as augmentation of the diffusive mobility of water molecules, ionic conductance etc.

SR was used to obtain a series of 53 diffractograms for synthetic ceolite NaA at compressing it in a water medium up to 2 GPa. That was linked with the anomaly of ionic conductance revealed in the range of 0.5 to 1 GPa. At 0.5 GPa the structure begins getting disordered, which is manifested by a visible broadening of diffraction peaks. This disordering is linked with the non-hydrostatical conditions of compression in a small volume of water. This is accompanied by additional hydration of the structural voids of NaA, which is evidenced by the small compressibility of ceolite in the range of 0 to 1 GPa.

– **X-ray diffraction study of oxygen-permeable perofskites.**

Participant organizations: Institute of Solid State Chemistry and Mechanochemistry SB RAS.

Beam time expended: 24 hours.

The work was done within SB RAS complex integration project No.48 "Development of membrane catalysts and sensors on the base of oxygen-permeable perofskites for reactions of partial oxidation of methane and oxidizing dehydration of hydrocarbons C_3-C_5".

To create high-efficiency solid fuel elements it is necessary, in particular, to solve the task of lowering the operation temperatures of fuel elements down to 400 - 600°C through the application of solid electrolytes with higher oxygen or proton conductance. The up-to-date solid electrolytes on the base of stabilized zirconium oxide have low conductance at temperatures below 800°C. In 2006, first experiments with perofskites of various composition and different oxygen nonstoichiometry were conducted. In total, 25 samples were studied and 96 diffractograms were shot. The experiments showed that the application of SR together with a 2D X-ray detector made it possible to obtain diffraction information with better sensitivity and angular resolution as compared with the information obtained with conventional diffractometers. Besides, paired reflexes, corresponding to different phases, were found. Such linkage between reflexes might be explained by the inheritance of the mutual orientation of seeds of one phase relative to another. The processing of the data obtained has already begun.

– **Investigation into the phase formation at chemical interaction of solid mechanical composites with liquid metals.**

Participant organizations: Institute of Solid State Chemistry and Mechanochemistry SB RAS.

Beam time expended: 84 hours.

The work was done within the framework of the SB RAS interdisciplinary project No.98 " Mechanical composites as precursors for creation of materials with new properties".

– **X-ray diffraction study of the mineral composition of kidney stones.**

Participant organizations:

–– Institute of Solid State Chemistry and Mechanochemistry SB RAS;

–– Novosibirsk regional hospital.

Beam time expended: 12 hours.

The work was done within the framework of RBRF grant No.06-02-17277-a: "Development of devices and methods for in vivo SR study of kidney stones".

– **X-ray diffraction study of the structure of scandium fluoride at high pressure.**

Participant organizations: Institute of Physics SB RAS, Krasnoyarsk.

Beam time expended: 53 hours.

The work was done within the framework of SB RAS complex integration project No.3.7 "Optical, magnetometric and caloric effects in dielectrics, magnetics and relaxors".

In normal conditions, the structure of scandium fluoride crystal can be referred to the ReO_3 type, i.e. a system in which a lot of trifluorides crystallize and which is a model object in the study of phase transitions in dielectrics. On the other hand, there are voids in the structure of this crystal that enable penetration of rare earth ions into it. Together with the broad band of optical clarity and high chemical stability, this material becomes a promising medium for non-linear optics and quantum electronics.

Successions of transitions from a cubic phase to low-symmetry ones can be observed in some other trifluorides at changes in temperature; no such transitions were found in scandium fluoride. It has been predicted in theory that the structure of this crystal can be distorted at high hydrostatic pressures and signs of such transitions have been observed with the help of the combinational scattering method. In this connection, there arises the necessity of verification with an independent experimental method if there are high-pressure phases in this crystal and determination of their structure.

In 2006, phase transitions in synthetic ScF_3 at 3 and 5 GPa in a high-pressure chamber with diamond anvils were investigated. Diffractograms of high-pressure phases were obtained. The first high-pressure phase was proved to be trigonal, which agrees with the theoretical computation and does not contradict the spectral data. The computation of the structural parameters of this phase is underway. It was also found that another high-pressure phase arises in the crystal at 5 GPa and the transition becomes irreversible.

– **X-ray diffraction study of the structure of oxide melts.**

Participant organizations: Institute for Mineralogy and Petrography JIGGM SB RAS.

Beam time expended: 36 hours.

Melt media of complicated oxide composition, which are primarily silicate, make the base of magmatogene mineral formation (petrogenesis). Exactly they are the media of crystallization of a lot of remarkable compounds widely-used in science and practice, both modern and future.

Those who carry out the project involving this work believe that the key factor, underestimated and thus not investigated properly, is the particular role of cross-linking cations. A specific feature of these diffraction and spectroscopic investigations is that they are carried out in situ, which allows one to directly obtain information about the object (process) under study.

In order to verify new theoretical ideas on the particular role of cross-linking cations in the processes of crystallization of silicate melts of complicated composition, in 2006 there were made X-ray diffraction examinations of four samples. Each sample was shot at three temperatures: at an overheating by 10 degrees over the melt point, at an overheating by 100 degrees and at a temperature 10 degrees below the melt point.

– **Structural studies of high-pressure clathrate hydrates.**

Participant organizations: Institute of Inorganic Chemistry SB RAS.

Beam time expended: 48 hours.

The work was done within the framework of SB RAS interdisciplinary integration project No.43 "Powder diffraction studies of phase transformations at high pressures with SR application".

This theme is interesting for crystallography and physics of high pressure. The structural types revealed can be of interest as topological models for frame structures on the basis of silicon, germanium, SiO_2 and others.

Clathrate hydrates are inclusion complexes where the host frame is made of hydrogen-bond molecules of water and the polyhedral voids of this frame can accept a large number of guest molecules, from hydrogen and helium to big organic molecules. If the guests are normally-gaseous substances, these compounds are often called gaseous hydrates.

Numerous structural and physical-chemical examinations of hydrates arising in the water-methane and some other systems have been done last years. Last summer several cores with hydrate were elevated from the bottom of Lake Baikal (Kukui canyon). In those layers, taken from about 1 meter below the bottom, the composition of gas (methane + ethane, the amount of ethane varying) in different layers, at a distance of 20 to 30 cm, varied a lot. It was supposed that gaseous hydrates in these layers could have different structures. First X-ray diffraction examinations done at the station last year showed the presence of cubic structure I in a sample with a small amount of ethane. Namely such structure was expected. The second sample turned out to be completely degraded. Immediately after that, Japanese researchers revealed cubic structure II in another piece (they have taken the largest part of the core with them), with the NMR method this time.

In 2006, a newly obtained sample was surveyed. The sample was examined at 9 points and cubic structure II was found in several places. This is the first time when hydrates of two different structures have been found in one core.

6.1.6 X-ray microscopy and tomography

Subject: Visualization of the 3D structure of unique objects by the methods of X-ray computed tomography.

Participant organizations:

- Budker Institute of Nuclear Physics SB RAS;
- Institute of Geology of JIGGM SB RAS.

Beam time expended: 360 hours.

The work was done within the framework of

– SB RAS interdisciplinary integration project No.7 "Nature of micro-heterogeneity of the lithosphere mantle" and

– the program of the foundation for assistance in the development of small enterprises in the field of science and engineering, project No. 4814.

The method of X-ray computed tomography (XCT) allows obtaining 3D information about the inner structure of sample without its destruction. A sample is examined with X-rays, which are differently absorbed in its parts. The attenuation of X-rays along the beam is an integral characteristic of the density of object. This attenuation is described by the well-known law

$$I = I_0 epx(-\int_L \mu(s)ds),$$

where I_0 is the intensity of the X-ray source, I is the intensity of X-ray beam after passing the way L in the object, and μ is the linear coefficient of X-ray attenuation. Thus, the grade of difference among the components inside a sample depends on their linear coefficients of absorption. Transformed by the Radon method, projections obtained during rotation of a sample allow one to restore its X-ray density as a function of three coordinates.

Such examinations are of great interest for works with unique archeological finds. Non-destructive examinations of inner micro-defects in materials at a fore-destruction stage are interesting for the materials science. The examination of the inner structure of diamondiferous minerals makes it possible to reveal the relations among silicate, carbonate, and sulphide components (as the most common primary inclusions and minerals accompanying diamonds) and diamond itself are of key importance in finding out physical-chemical conditions of the genesis of diamond and diamondiferous rocks.

SR is the brightest radiation in the X-ray range and an SR source can provide an X-ray photon flow four and more orders higher than that from a conventional X-ray unit. That provides high-quality images of projections of the inner structure of object, in less time and with higher spatial resolution.

This work realized the method of computed tomography with the application of SR from the VEPP-3 storage ring at the station "Microscopy and tomography". Preliminary examinations to work through the method were done at the digital X-ray facility "Sibir". The scheme that was used to pick up X-ray tomograms is shown in Fig.9

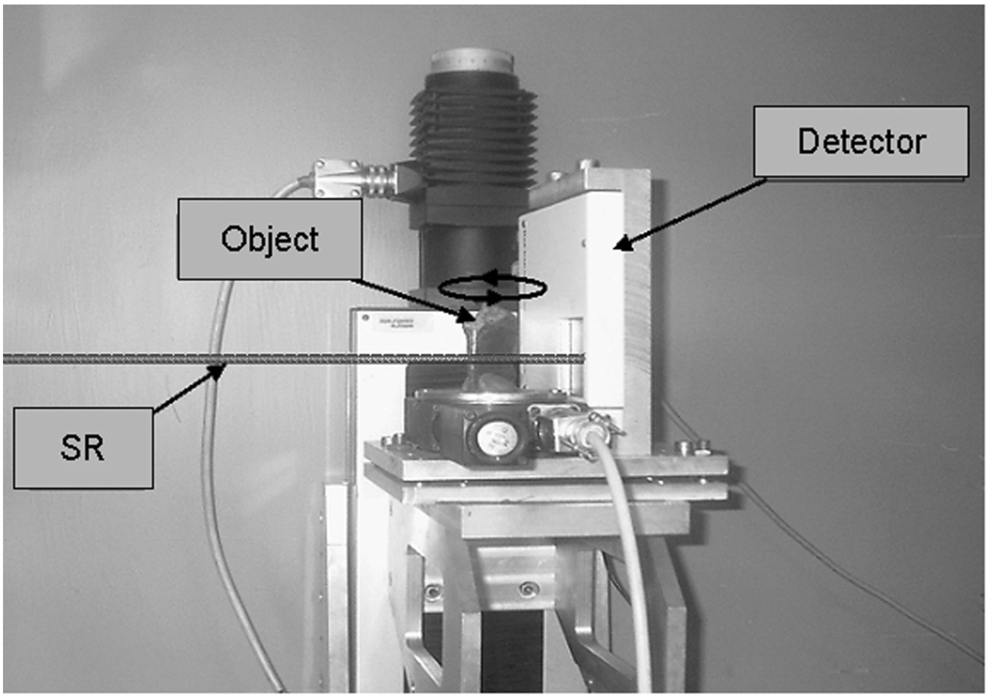

Figure 9: Scheme to pick up X-ray tomograms at the station "X-ray microscopy and tomography".

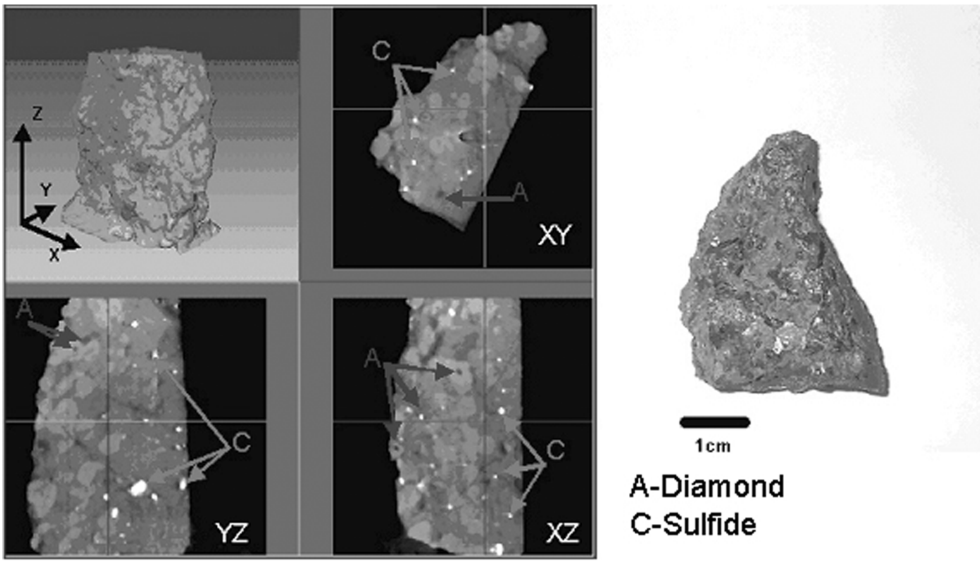

Figure 10: Distribution of rockforming minerals in sample UD-107 obtained at the station "X-ray microscopy and tomography".

The method of X-ray computed tomography was used to examine 10 diamondiferous eclogite xenoliths from the kimberlite pipe Udachnaya (Yakutia). The information obtained made it possible to reconstruct the inner structure of sample with a spatial resolution of 100 microns, which gave the possibility of learning the distribution of rockforming (garnet and clinopiroxene) and accessory (diamond, rutile and sulphides) minerals, differing in the density of X-ray absorption. These examinations allow one to find out the genetic mutual relations and the order of crystallization of diamonds and associate minerals. An example of a reconstructed 3D image and some of 2D sections is shown in Fig.10.

6.1.7 EXAFS spectrocopy

The objects to investigate are X-ray amorphous samples in the liquid-phase and solid states; X-ray structural methods thus can not be applied to these samples. The main specialization is the study of highly-dispersed objects such as catalysts and nano-materials. EXAFS spectroscopy studies the structure of local environment of atoms of a certain chemical element (the coordination number and interatomic distances). Depending on the methods applied, the object of analysis is the volume, surface or surface layers. The following methods were implemented: "transmission", X-ray fluorescence, full photocurrent, and X-ray-stimulated optical luminescence. Methods to prepare samples for the examination of reaction-active compounds and catalysts in inert conditions were developed. It is possible to examine samples at temperatures of 77 to 900 K in a specified atmosphere.

Tasks to solve and information to obtain: The structure of the local environment of atoms of a certain chemical element is investigated (the coordination number and interatomic distances). Depending on the methods applied, the object of analysis is the volume, surface or surface layers.

Station performance specification:

Elements to study	starting from Ti.
Concentration of the element to study	0.1-100 mass.%
The range of interatomic distances measured	1.5-8 Å(±2%)
The error of coordination number determination	± 10-20%
The error of Debye factor determination	± 40%.

Some of the works carried out in 2006:

Study of the local atomic and electron structure of cobaltites by the method of X-ray absorption spectroscopy.

Participant organizations:

– Joint Institute for Nuclear Research, Dubna;
– Boreskov Institute for Catalysis SB RAS, Novosibirsk;
– Institute for Solid State Physics of the Latvian University, Riga, Latvia;
– Hahn-Meitner Institute, Berlin, Germany;
– Institute for Spectroscopy RAS, Troitsk, Russia;
– Institute for Physics of Solid State and Semiconductors, Minsk, Byelorussia.

Beam time expended: 96 hours.

The work was done within the framework of the JINR topical plan for research works and international cooperation for the year 2006.

The interest in cobalities has grown recently because of the revealed effect of gigantic magnetic resistance and due to the synthesis of new compounds manifesting unusual magnetic and electrical properties. A cycle of measurements of the X-ray absorption spectra of cobaltites (EXAFS and XANES) at the Co K edge ($E_K = 7710$ eV) was done in 2006. The measurements were supplemented with the examinations of samples by the high-resolution X-ray diffraction methods at the station "Precision diffractometry and anomalous scattering".

Development of synthesis methods and structural study of nanoparticles of 3d and 4d metals of a specified morphology. Applied systems stabilized on oxide matrixes.

Participant organizations:

– Boreskov Institute for Catalysis SB RAS, Novosibirsk;
– Institute of Petrochemical Synthesis RAS, Moscow;

– Institute for General and Inorganic Chemistry RAS, Moscow;
– Institute for Chemical Physics RAS, Moscow;
– Instituto de Ciencia de Materiales de Sevilla, (Spain);
– Centro Mixto CSIC-Universidad de Sevilla, (Spain).

Beam time expended: 48 hours.

The work was done within the framework of the RAS Presidium Basic Research Program "Streamlined synthesis of substances of specified properties and creation of functional materials on their base".

The aim of the work was to develop methods to synthesize Pd and Co nanoparticles with a non-regular structure stabilized on an oxide matrix (TiO_2) and to study its local structure with the EXAFS method. Polynuclear pivalate complexes of these metals were used as initial complexes in the synthesis of nano-clusters. The influence of preparation method and reducing agent on the local structure of particles was investigated. Besides, the morphology of substances obtained was determined in dependence of their composition, the method of their stabilization on an oxide matrix and compacting.

Examination of the local structure of nanocomposite system on the base of CeO_2 and $LaMnO_3$ with the methods of EXAFS and XANES spectroscopy.

Participant organizations:
– Boreskov Institute for Catalysis SB RAS, Novosibirsk;
– Institute of Solid State Chemistry and Mechanochemistry SB RAS, Novosibirsk;
– Institute of High Temperature Processes&Chemical Engineering, Patras, Greece;
– Institute of Chemistry, Humboldt University, Berlin, Germany;
– Ohldenburg University, Ohldenburg, Germany.

Beam time expended: 72 hours.

Lately much attention has been paid to the development of membranes allowing conversion of methane to synthesis gas, oxygen (from the exterior side of membrane) being transported due to mixed O^{2}-/electron conductivity. The development of such membranes is now the most topical task of the materials science. Materials with mixed ion/electron conductivity are also of much interest for usage as anodes or cathodes in solid-oxide fuel elements.

To study the properties of such membranes, the EXAFS and XANES spectra of Mn K, Pr L_3, Gd L_3, La L_3, and Ce L_3 absorption edges of prepared nanocomposite samples were recorded. 12 samples were examined and 60 spectra were recorded. The XAFS data obtained showed that the Pechini method provided homogeneous mixing of components for all samples prepared. The local environment of Ce atoms was shown to be close in all cases to that of the reference sample of CeO_2 (a cubic structure of the fluorite type). The analysis of the XAFS spectra of La L_3 absorption edge revealed no significant differences in the local environment of lanthanum for $LaMnO_3$ samples and nanocomposites, which is an evidence of the minimal penetration of La into the structure of cerium oxide. On the other hand, the analysis of information obtained from the EXAFS spectra of Mn-K absorption edge of nanocomposites calcined at high temperature (1300°C) revealed some differences from such spectra of low-temperature samples, the amplitude of the first Mn-O peak decreasing and far Mn-Me peaks shifting and splitting. Most probably, it is linked with the distortions in the pseudo-cubic structure of nano-sized domains of $LaMnO_3$ in nanocomposites, the grade of their doping with Gd or Pr cations staying unknown.

Examination of the microstructure and environment of the atoms of transient metals (Co and Ni) in carbon nano-tubules.

Participant organizations: Institute of Inorganic Chemistry SB RAS, Novosibirsk.

The work was done within the framework of the scientific research program of IIC SB RAS on the study of chemical and physical properties and structure of new carbon-containing nano-materials

Exploratory work to elucidate if the EXAFS method can be applied in the examination of the microstructure and environment of transient metal atoms (Co and Ni) in carbon nano-tubules.

6.2 Work with terahertz beams

6.2.1 Terahertz radiation sources on the base of relativistic electron beams and parameters of the Novosibirsk FEL

Last decade is characterized by a sharp growth of basic and applied works in the field of the generation and application of radiation in the wavelength range of 30 microns to 0,3 mm, which corresponds to the frequency range of 10 to 1 THz.

The interest in terahertz radiation is caused by the following:

- this radiation is non-ionizing (the photon energy is 0,04 to 0,004 eV);

- this radiation can pass well through turbid media and fine materials because the Rayleigh scattering declines sharply($1/\lambda^4$);

- this is the area of rotational spectra of moleculues, vibrations of biologically important collective modes of DNA and proteins and vibrations of solid state plasma;

- this is the area of hydrogen bonds and van der Waals' forces of intermolecular interaction;

- the energy of photons of terahertz radiation is in the energy gap associated with superconductivity.

Till recently, the amount of terahertz radiation sources in physical laboratories was small and almost none in chemical, biological and medical laboratories. The usage of free electron lasers as terahertz radiation sources made it possible to create sharing centers on their basis in the USA, Holland and Japan. They are used by scientists of different specialties. The national programs of terahertz radiation application are underway in the USA, Japan and Europe.

There are two promising types of radiation generators using the radiation of relativistic electrons. First of all, those are synchrotrons, whose radiation has been used for several decades. The application of SR has given unique results in very different fields of science, which can be proved by the long-term operation of the Siberian Synchrotron Radiation Center at Budker Institute of Nuclear Physics SB RAS. SR sources generate broad-band radiation at movement of electrons in a magnetic field. However, their radiation intensity in the terahertz range was relatively low until recently (see fig.11). That is why no research was done with the application of SR sources in the terahertz range.

The situation has significantly changed last years, after the suggestion that ultra-short high-density electron bunches could be used for radiation generation. If the bunch length is much shorter than the radiation wavelength, then the latter is completely coherent. A radiation source recently commissioned at Jefferson laboratory (JLab THz), which generates broadband terahertz radiation (its spectrum is presented in fig.11) with an average power of about 100 W, is based on this idea. There are plans to construct a high-power source of such type at Brookhaven National Laboratory (the USA) as well as at the fourth-generation source in Daresbury (Great Britain). The source generates broadband radiation (see Fig.11) of average power of about 100 W.

Free electron lasers (FELs) are the most powerful sources able to generate terahertz radiation. Their radiation can be continuously tuned over a rather broad spectral range. Among terahertz lasers working for a long time the noteworthy are the lasers at Stanford University, California University in Santa Barbara, FELIX and INEA (Frascatti). These devices are real user machines, on which specialists from numerous scientific laboratories have performed a lot of works in very different fields – from the materials science to biology and medicine. The generation efficiency of free electron lasers is not very high. That is why the next generation FELs, designed to generate radiation with high average power, should use electron accelerators with electron energy recuperation.

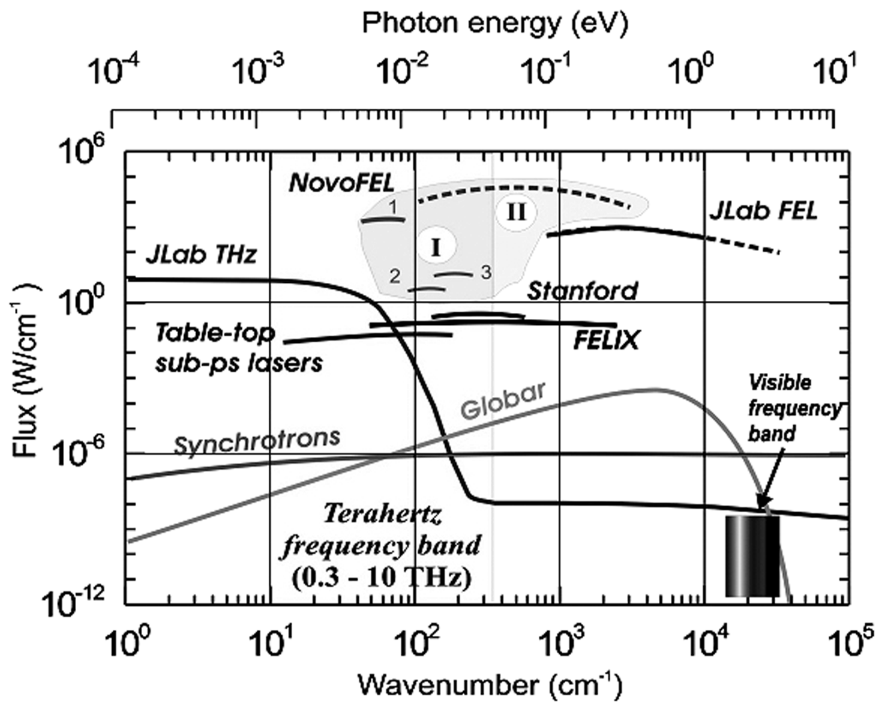

Figure 11: Comparison of the time-averaged spectral power of different radiation sources. *The Novosibirsk FEL - the Novosibirsk Free Electron Laser, Russia (I designates the terahertz laser in operation, where 1,2,and 3 are the harmonic numbers; II designates the infra-red laser being constructed); JLab THz is the source of coherent synchrotron radiation from the bending magnets; Jlab FEL is the free electron laser of Jefferson Laboratory, the USA; FELIX is the IR free electron laser of the Institute of Plasma Physics, the Netherlands.*

The most powerful FEL today is the laser of Jefferson Laboratory with average generation power as high as 10 kW. Its spectrum is, however, out of the terahertz range, the most powerful source of which is the first stage of the Novosibirsk FEL with average generation power as high as 400 W.

The usage of the Novosibirsk free electron laser as a terahertz radiation source makes it possible

- to smoothly tune the radiation wavelength in the range of 120-235 microns with monochromaticity better than 0,3%;
- to achieve high average power (up to 400 W);
- to generate short pulses of radiation (less than 100 ps);
- to provide high peak power (0,5 - 1 MW);

• to have a fully spatially coherent source with a longitudinal coherence length of ∼ 2 cm. Now, at a rather high monochromaticity, this radiation is at the same time fully coherent over the wave front and has temporal coherence in the range of 40 - 100 ps, limited, apparently, by the electron pulse duration.

Table 6.1: *Characteristics of the Novosibirsk FEL radiation.*

The first harmonic wavelength	(120 ... 235) μm
Spectral area of the 2nd and 3rd harmonics, the power being 1 to 3% from the first harmonic	(40 ... 117) μm
Relative spectral bandwidth	(0.3 ... 1) %
Diameter of the Gauss beam at the beamline exit	80 mm
Degree of radiation polarization	>99.6%
Lateral coherence	Full
Temporal coherence	(40 ... 100) ps
Maximal average power	0.4 kW (at 11.2MHz)
Pulse duration	(40 ... 100) ps
Repetition frequency	(2.8 ... 11.2) MHz

For efficient operation of the free electron laser it was necessary to solve several problems. First, it was beam out-coupling out of the laser and its transportation to the user stations. Second, it was the construction of several experimental stations of different purpose (radiation delivered to each), with detectors (single- and two-coordinate), monochromators and optical elements (exit windows, polarizers, focusing mirrors and lenses). Little can be bought through catalogues from Russian and foreign companies. In general, experimentalists have to develop and manufacture the equipment. Third, the study of FEL radiation and improvement of its characteristics were very important.

Therefore, the main attention in the year 2006 was paid to the solution of these tasks as well as to the provision of users activity at the working stations. At the same time, much effort was aimed at constructing the second stage of the free electron laser. This stage will extend the generation spectrum to 30 - 250 microns.

6.2.2 User stations

Users (biologists, chemists and physicists) started their regular work on the terahertz radiation of the Novosibirsk FEL in 2006. The works are carried out by the members of Budker Institute of Nuclear Physics SB RAS, Institute of Chemical Kinetics and Combustion SB RAS, Institute of Cytology and Genetics SB RAS, and Institute of Physics of Semiconductors SB RAS. Four of the six user stations were committed in 2006 (Fig.12).

1. Biological research station (ICKC SB RAS, ICG SB RAS).

Purpose:

The purpose of the station is the study of the disperse structure, morphology and biological activity of products of ablation/desorption of biological structures and inorganic materials under the influence of terahertz radiation.

Equipment of the station:

- a diffusion spectrometer for aerosols, to find out the disperse structure of particles in the range of 3 to 200 nanometers;

- a photoelectric counter of aerosol particles, to find out the disperse structure of aerosol particles in the range of 0.3 to 10 microns;

- equipment for sampling for chemical-biological and electron-microscopy analysis.

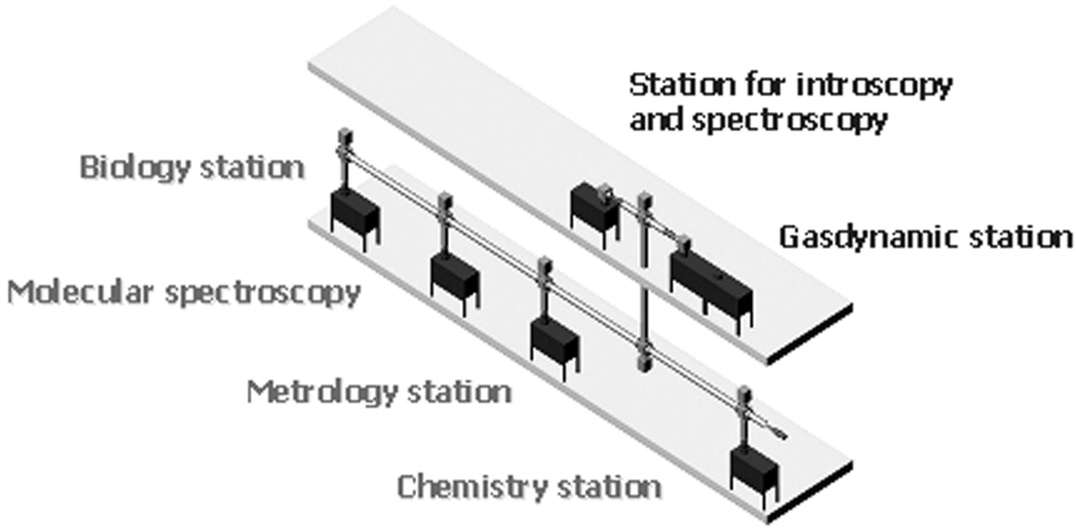

Figure 12: User stations on terahertz radiation beams (left - 4 operating stations, right - 2 stations under construction).

Figure 13: Beamline for terahertz radiation out-coupling to the lower experimental hall and user stations of the first stage.

2. Metrology station (BINP SB RAS).

Purpose:

A station for diagnostics and control of the parameters of terahertz radiation from the free electron laser; later on it will be a station for metrology in the terahertz range.

Equipment of the station:

• a spectral complex based on the monochromator MDR23, to measure the radiation wavelength and emission line width;

• a Fourier spectrometer made by the BRUKER company, to measure the radiation wavelength and emission line width;

• 2D scanning sensor for terahertz radiation, to measure the light beam profile;

• terahertz radiation visualizer based on the thermal screen and thermal imager developed by IPS SB RAS;

• terahertz radiation visualizer based on the thermal image plate made by the Micken Instruments company;
• a Shottky-diode Q-meter for the FEL optical cavity.

3. Station for molecular spectroscopy (ICKC SB RAS, IAO SB RAS).

Purpose:

The station is intended to study gas absorption spectra in the terahertz range by the method of optical-acoustic spectroscopy.

Equipment of the station:

an optical-acoustic cell to measure weak absorption in gases with a synchronous detecting scheme. The minimal measurable absorption is 10^{-5} cm^{-1}.

4. Chemical station (IIC SB RAS).

Purpose:

The station is intended for the mass spectrometric study of disintegration of metal-organic compounds at absorption by molecules under FEL radiation influence, in the molecular beam and on the surface.

Equipment of the station:
• a time-of-flight mass-spectrometer MSH-6;
• a Knudsen cell system for molecular beam generation;
• a 32 Mb fast ADC of the NI 5112 type.

6.2.3 Development of the Center for photochemistry research on the base of the energy recovery linac and second-stage FEL for the range from 3 to 10 THz

The second stage of the energy recovery linac (ERL) and FEL.

The second-stage energy recovery linac (ERL) uses the same accelerating RF structure as the first stage ERL, but, unlike the latter, it is located in the horizontal plane. Thus, constructing one of them does not require demounting the other. The operation regime can be chosen via simply switching the bending magnets.

The second-stage ERL (Fig.14) is constructed by the scheme of racetrack microtron. The scheme of electron beam energy recovery is the same as the scheme of acceleration but the phases of pass through the accelerating structure are mirrored.

Main design parameters of the full-scale ERL are as follows:

Full energy of injection, MeV	2;
Maximal beam energy, MeV	40;
Maximal repetition frequency, MHz	90;
Maximal average current of beam, mA	150.

There are plans to install a high-power FEL of the near IR range with wavelengths of 5 to 12 microns on the last track (40 MeV) of the ERL and another FEL with wavelengths of 40 to 100 microns on the second track (bypass). The expected power of each of the FELs is 10 kW.

The second-track FEL is installed on the bypass. If the magnets of the bypass are switched off, the beam goes along the second track axis and keeps accelerating. If they are switched on, the beam goes through the second track FEL. In this case, the trajectory is 66 cm longer; that is why the "waste" beam arrives to the RF cavities of the ERL later and is decelerated. We have chosen for the second-track FEL a scheme close to that of the first-stage FEL. The undulator period d =120 mm was chosen subject to the electron energy (15 - 20 MeV) and the range of wavelength tuning (40 - 100 microns). The total length of the undulator is about 4 meters. It is restricted by mechanical problems (the yoke is rigid and it is difficult to manufacture a long yoke with the required accuracy).

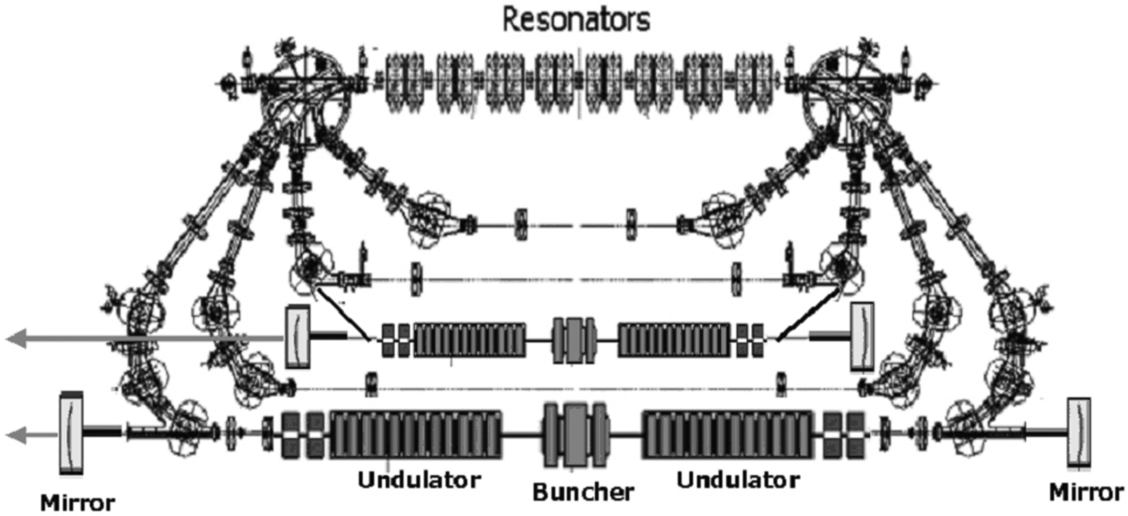

Figure 14: Scheme of the second-stage ERL.

Solving numerically the equations for weak signal amplification, we have calculated amplification in such FEL for different parameters of the main mode of optical cavity. The amplification should exceed the optical cavity losses, which depend on the refraction factor of mirrors. Multi-layer dielectric mirrors have high reflection coefficients but are narrowband and can fail at large (tens of kilowatts) power in the optical cavity. That is why copper mirrors with golden coating have been suggested.

The optical system for the second-stage FEL has been optimized. The design average power of radiation exceeds 10 kW at a relative line width less than 1% and a peak power of several MW. At the undulator length $L_u = 4$m the minimal aperture of its vacuum chamber is $2\sqrt{\lambda L_u}$. For the maximal wavelength of 100 microns it is 40 mm. To take into account the increased Rayleigh length as well as to reduce the requirements to the accuracy of geodesic alignment of the vacuum chamber elements, we have chosen the aperture to be 60 mm and the inter-pole gap to be 70 mm.

6.2.4 Main results of the year 2006 and plans for the year 2007

The year 2006 was the year when users (biologists, chemists and physicists) began their regular work with terahertz radiation. The experimental station of the Institute of Inorganic Chemistry SB RAS was constructed. A room was prepared and equipment was manufactured for the experimental station of the Institute for Theoretical and Applied Mechanics SB RAS. A system for dehumidification of nitrogen was developed and commissioned, as a result, beam can be coupled out of the accelerator hall to users premises without losses. The manufacture of the magnetic-vacuum system of the second stage of the FEL and associate electronics is underway. About 50% of the equipment has been manufactured already. The magnetic measurements of the elements of the magnetic system (bending magnets and quadrupole lenses) have begun. All the elements of the suspension for the magnetic-vacuum system have been created and installed in the accelerator hall.

Plans for the year 2007:

- completion of the design of channels for beam out-coupling and the fourth track of the second stage of the FEL;
- construction and installation of the second-stage magnetic vacuum system (without the fourth track);
- commissioning of the ERL with two tracks;
- powering-up the out-coupled radiation of the operating terahertz FEL;
- computation and optimization of the fourth-track FEL.

6.3 Development and manufacture of dedicated SR generators

6.3.1 Superconducting wigglers

Active contract works on the development and manufacture of various superconducting cryogen-magnetic systems for SR generation were continued in the year 2006.

1. By the beginning of the year 2006, a 49-pole superconducting wiggler for the storage ring of Diamond Light Source (DLS)(a period of 60 mm, magnetic field of 3.7 T and inter-pole gap of 16 mm) has been assembled in its cryostat. In 2006, the wiggler was delivered to DLS, assembled and commissioned on the storage ring.

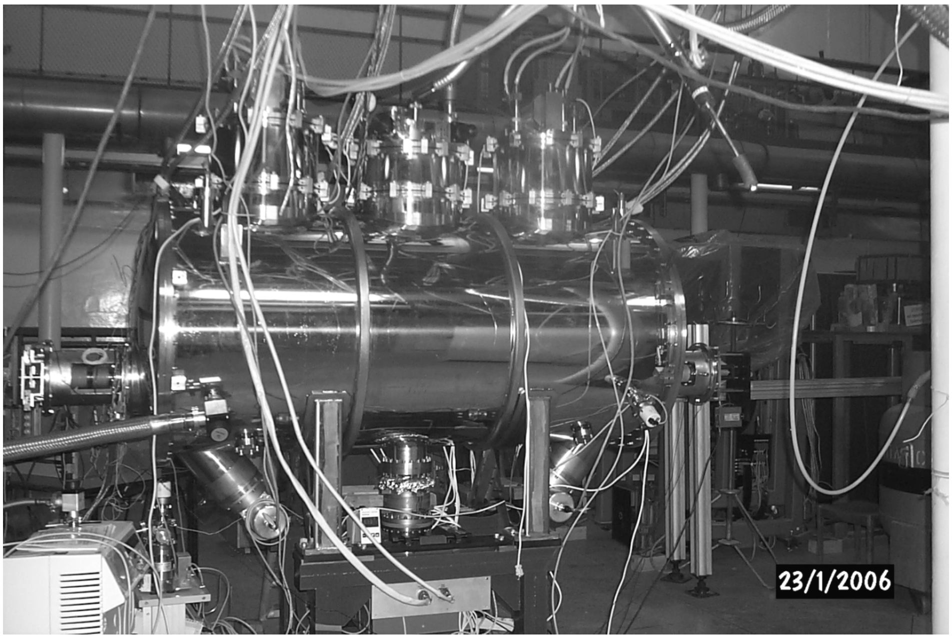

Figure 15: Tests of the 49-pole, 3.7 T wiggler for the Diamond storage ring.

2. The 21-pole, 7.7 T superconducting wiggler with a period of 164 mm, manufactured under a contract with the Russian Scientific Center "Kurchatov Institute" for the SR source "Sibir -2", was tested in December 2006. This wiggler will be the most powerful among similar facilities all over the world. The total power of radiation from the wiggler exceeds 100 kW. Liquid helium consumption is close to zero and the cryostat is to be filled with liquid helium once a year at most. The installation of the wiggler on the "Sibir-2" storage ring is planned for the beginning of the year 2007.

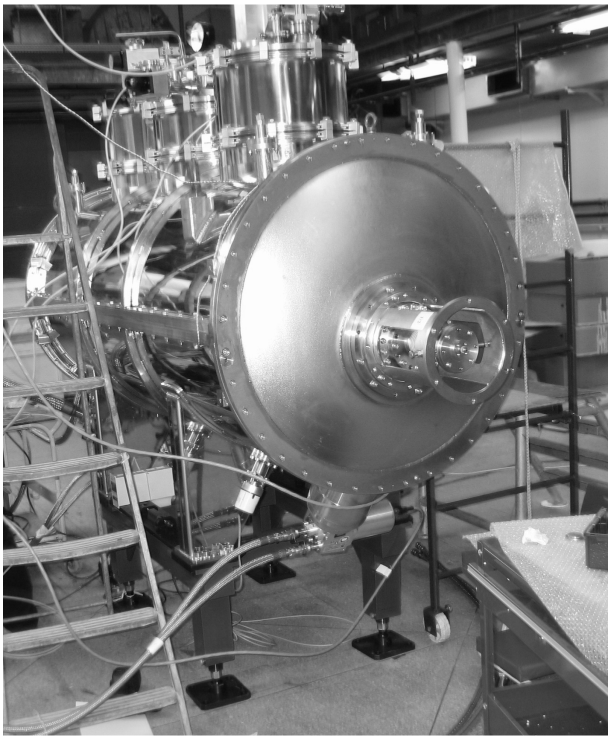

Figure 16: 21-pole, 7.7 T superconducting wiggler for the “Sibir-2” SR source.

6.3.2 Booster synchrotron for Duke University

The construction of the 1.2 GeV booster synchrotron for Duke University was completed in 2006. BINP specialists designed and manufactured all systems of the synchrotron, including the magnetic system, vacuum chamber, systems for injection and out-coupling and RF system.

Figure 17: Mounting the booster synchrotron for Duke University.

6.3.3 Magnetic system for the metrology light source (MLS)

Contract works on the creation of the magnetic system for the metrology light source (MLS) under construction in Berlin on the base of the Metrology Institute (Germany) were completed in 2006. The MLS complex consists of a 600 MeV storage ring 48 m in perimeter and 100 MeV microtron. 8 dipole magnets with parallel edges (the angle of bend is 45°), 24 quadrupoles, 24 sextupoles, and 4 octupoles were manufactured for the magnetic system of the storage ring. The magnet cores are laminated (a 0.5 mm sheet), glued for mutlipole magnets and combined (glued-welded) for dipole magnets. The high manufacturing accuracy (± 20 microns for the pole region) was provided by the high-precision of core stamping and stacking in special jigs. Magnetic measurements with a system of Hall coils for dipole magnets and with a radial rotating coil for multipole magnets confirmed the high quality of magnetic fields. The magnetic elements were delivered to the customer and installed on the storage ring (Fig.18). The vacuum chamber was mounted and the magnetic system of the storage ring was adjusted.

Besides, an electron-optical beamline between the microtron and storage ring was designed, manufactured and mounted at the MLS complex. The magnetic system of the beam line consists of 10 quadrupole magnets, 8 correctors and a dipole magnet.

First beam experiments at the MLX complex are planned for the first half of the year 2007.

Figure 18: Mounting of the MLS storage ring.

6.3.4 Damping wigglers on permanent magnets for Petra-III (Hamburg)

Magnetic calculations and drawings were made for the permanent magnet damping wiggler for the accelerator-based SR source Petra-3 (DESY, Germany)(the period λ=200 mm, the gap h=24 mm, the length L=4000 mm, and the maximal field B=1.6 T). The manufacture of 21 wigglers was begun. The contract time lasts from 2006 to 2007.

Figure 19: The first permanent magnet damping wigglers for Petra-III on the magnetic measurement bench.

6.3.5 Technological Storage ring Complex (TSC).

Works on the Technological Storage ring Complex (TSC) for the science-manufacture center of microelectronics and micromechanics (Zelenograd) were continued in 2006. The TSC was designed and constructed by BINP in the period of 1990 - 1996. Its main purpose is the manufacture of micromechanical products by the methods of X-ray lithography and LIGA technology. The design energy of the TSC is 1.6 GeV. In future, it can be increased up to 2.5 GeV via the installation of the second accelerating cavity and powering up the RF system. In the period of 1997-2001, the project was not financed. The stage-by-stage erection and commissioning of all TSC systems started only in 2002. The capture and acceleration of electron beam in the booster ring (minor storage ring) was achieved by the beginning of 2006. In 2006, works on the achievement of the design parameters for the linac and minor storage ring of the complex were continued, with simultaneous assembling the electron-optical line (EOL-2) and adjusting its elements of the magnetic system for the design position. For this purpose, the accelerating structure of the linac was trained, in order to increase the accelerated particle energy up to 70 MeV.

To accumulate particles in the minor storage ring it was necessary to increase the electron lifetime via warming-up the vacuum chamber of the storage ring and improving the vacuum. After the warming-up, the vacuum P $\sim 5{\cdot}10^{-11}$ Pa was achieved in the minor storage ring. The vacuum chamber of the EOL-2 was assembled and the magnetic system was adjusted. At the present time, the vacuum chambers of the linac, minor storage ring and EOL are under continuous pumping-down.

The BINP specialists are revising all TSC elements that were not dispatched in the 90s and modernizing the power system for the permanent magnets, RF system of the main storage ring, beam diagnostics and automatic control system of the complex.

Delivering the electron beam, accelerated up to 450 MeV in the booster ring, to the injection section is planned for the beginning of 2008. The mounting of the elements of the main storage ring is also expected to start early in 2008.

Figure 20: General view of the mounted part of the TSC: the linac (bottom left), the booster ring (in the foreground) and the electron-optical line EOL-2 (upper right).

6.3.6 Project of the compact storage ring, an SR source for the Siberian Synchrotron Radiation Center

One of the major problems of the Siberian Synchrotron Radiation Center is the lack of a dedicated SR source. At present, most work is done on the SR beamlines from the VEPP-3 storage ring. However, only a small part of working time is allotted for operation with SR, because of the strong competition among different research programs on the VEPP-3/VEPP-4 storage ring complex. This complicates the planning and realization of long-term research projects. It should also be noted that since VEPP-3 is not a dedicated SR source, some important features of the source are far from meeting the up-to-date requirements and ideas, which also restricts the scope of research with the X-ray methods.

Till recently, the Siberian SR Center has been the only such center in Russia, forming a unique community of numerous users both from SB RAS institutes and from other scientific centers of Russia. The center possesses an infrastructure required for exterior users to work efficiently. It is evident that construction of dedicated SR source for the Siberian SR Center is a topical and important task.

In 2002-2004, BINP developed and manufactured a prototype for the 9 T superconductive bending magnet for the storage ring BESSY-II (Germany). Such magnets allow realizing a compact scheme of storage ring with a rather low electron energy (about 1 GeV). The high magnetic field in the bending magnets allows obtaining SR with a rather hard spectrum, which is necessary to realize most popular X-ray methods with SR application. Economically, the high cost of the magnetic system of such a storage ring is compensated by the lower cost of the injection system and RF system as well as by a sharp reduction of construction costs of the infrastructure of the complex.

The SR spectrum hardness is one of the main parameters of such a system. The experience of SR application at different SR centers has demonstrated that most popular investigation methods use X-radiation with photon energies up to 40 - 50 keV. It should also be noted that in spite of the ever-increasing interest in the hard X-ray range, research and engineering methods in the soft X-ray range keep developing. For instance, the relatively new method of mass production of micro-products (the LIGA technology) is based on the application of SR with a characteristic energy of about 2 keV. That is why a right scheme of compact storage ring should provide the possibility of organization of lines for SR out-coupling both for hard and soft spectrum.

Most adequately, such requirements can be met by a combined magnetic system structure including both superconducting and normal, "warm", magnets. An advantage of such scheme is the possibility to get rid of excessive "compacting" of storage ring and, hence, to provide sufficient freedom in designing lines for SR out-coupling.

It should be noted that the yoke and cryostat in the existing structure of superconducting magnet are O-shaped, and thus, if these magnets are positioned one after another, the SR out-coupling lines will cross the cryostats of the next magnets. To couple SR beams out of superconducting magnets, it is necessary to place conventional C-shaped bending dipoles between them.

General considerations allow one to find out the optimal number of superconducting magnets in the structure. A large number of such magnets would significantly increase the whole-complex cost, and a small number would deteriorate the storage ring symmetry and create problems of beam instability due to arising critical resonances. Besides, since this project is aimed at a large number of lines to couple out SR with hard spectrum, a small number of magnets would significantly increase the unit cost of each line. Taking the above into account, it was decided to use 6 superconducting magnets and 12 conventional magnets, each with an angle of bend of 20°.

The electron energy in the storage ring can be 1 to 1.5 GeV, which is also close to the optimum as concerns the arrangement of injection system and bio-shield. In so doing, in 8.5 T superconducting magnets the critical energy of SR quanta will be about 10 keV, which provides a photon flux sufficient to realize the above-mentioned in the spectrum area up to 40 keV. Besides, if "warm" magnets are used to generate SR in the soft X-ray range, it is possible to meet users requirements in this spectral area, too. In this project, the operation energy was chosen to be 1.2 GeV.

If the electron energy is 1.2 GeV and the efficient magnetic length of 8.5 T superconducting magnet is 20 cm, the angle of beam bend in the magnet is about 20°. That means that 3 to 4 SR beamlines can be extended from the magnet rather easily.

So, the storage ring resources can be used very efficiently. The modern ideas for organization of the magnetic structure of SR source storage rings allow achieving a rather low value of horizontal emittance. Subject to the rather low operation energy of electrons, an emittance of the order of 10 nm is quite realizable (usually, this value is considered to be a border between the SR source facilities of the second and third generation). The perimeter of such storage ring should be within 50 m. So, premises for the center could be 20 x 20 m in size, some additional space required for user stations.

Structure and parameters of the storage ring.

This project is supposed to use a TME (Theoretical Minimum Emittance) structure, which allows achieving an ultimately low emittance for a given angle of beam bend in one magnet. This scheme makes it possible to combine two types of magnets, superconducting and conventional. Full-energy injection has been suggested. A special synchrotron similar to that developed and manufactured by BINP for the Duke University FEL can be used as a booster synchrotron (booster). The injector consists of two systems, the linac and booster. The linac accelerates electrons up to 150 MeV. The booster for Duke University allows electron acceleration up to 1.2 GeV with a frequency of 1 Hz. The application of an intermediate booster for electron acceleration permits full-energy injection to the main ring, which, in turn, allows obtaining ultimately high current (up to 1 A) and unlimited beam lifetime in the ring. It is planned to use a 180 MHz commercial single-mode cavity. The available model allows achieving RF voltage as high as 600 kV, which is quite enough for storage ring operation (energy losses in this scheme are 120 keV per turn, without considering additional devices for SR generation). The operating power of the cavity provides storage ring operation for a beam current as high as 1 A. Main parameters of the storage ring are presented in Table 2.

Table 2. Main parameters of the compact storage ring serving as an SR source.

Electron energy	1.2 GeV
Field in the bending magnets	8.5 T in superconducting magnets 1.65 T in conventional (warm) magnets
Critical energy of SR quanta	8.6 keV for SR from superconducting magnets 1.9 keV for beams from conventional magnets
Number of bending magnets	6 superconducting magnets 12 conventional (warm) magnets
Angle of bend in the magnets	20° in all magnets
Phase-space volume of beam not worse than	10 nm·rad
Beam current	up to 1 A
Beam lifetime	8 - 10 hours
Orbit perimeter	57 m

The photon flux will increase 10 times and the brightness 1000 times as compared with the VEPP-3 storage ring.

Magnetic structure

It is planned to use 6 superconducting magnets and 12 warm magnets. The ring includes 2 superperiods, each consisting of four TEM cells on warm magnets and two superconducting magnets, serving as "dispersion suspensors". Such configuration is schematically presented in fig.21

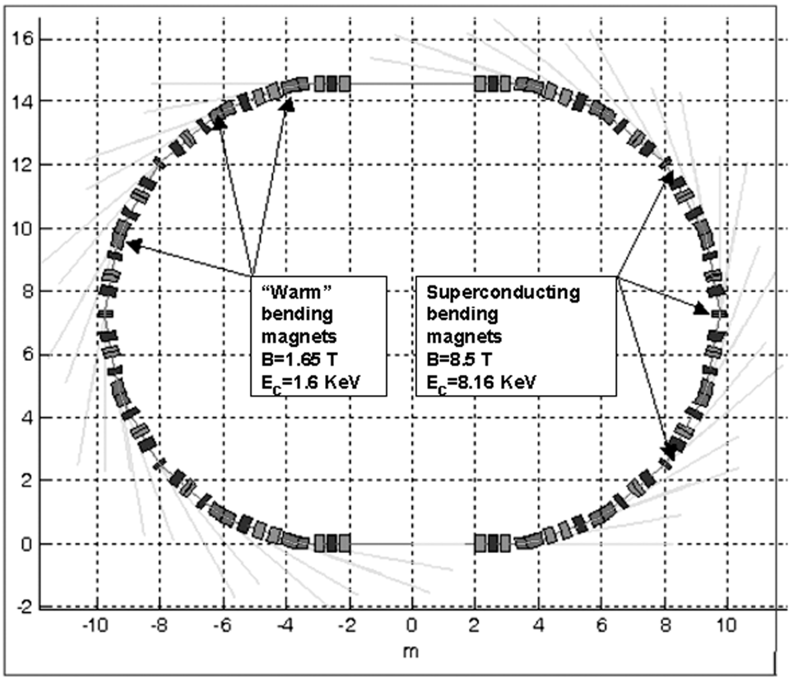

Figure 21: Potential scheme of the complex.

This scheme provides for two 5-meter sections. One of them is planned to accomodate the cavity and injection system, the other can be used for placing additional devices for SR generation (such as multi-pole wigglers or undulators). This straightforward section can accommodate an undulator to generate radiation in the EUV (Extreme Ultra Violet, $\lambda \sim 13.6$ nm) range for experiments in X-ray lithography.

Cryogenic system.

A technology applied now at BINP SB RAS allows creation of superconducting bending magnets with zero consumption of liquid helium. The system is maintained with cryogenic "coolers" and "re-condensers". Thus, liquid helium (as well as liquid nitrogen) is consumed only at the moments of primary cooling of the systems after assembly or repair.

Building.

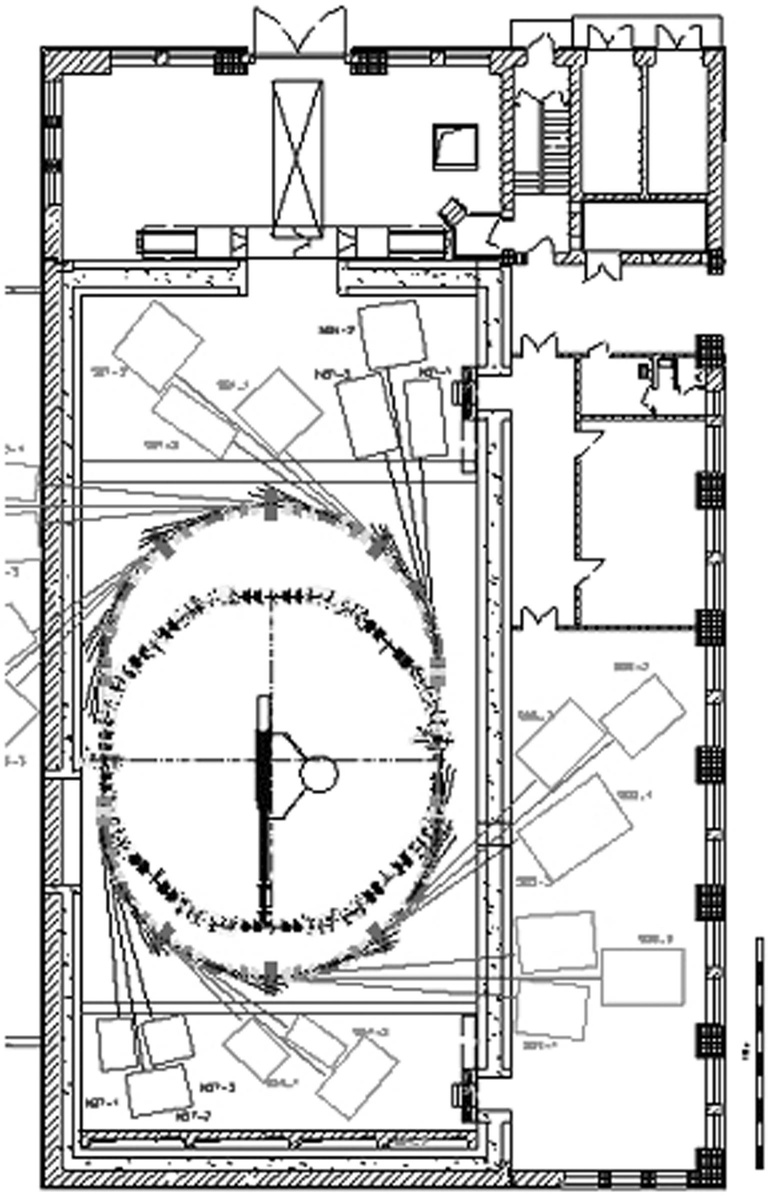

Figure 22: Possible arrangement of the complex and user stations.

BINP SB RAS has a premise, where the storage ring under discussion can be built. The premise has an infrastructure required for mounting such facilities. Since the beam operation energy is rather low, the existing walls of the premise can be used for bio-shield without additional modification, which lowers sharply the construction cost. Unfortunately, all user stations (except for the first-stage stations) cannot be placed in the premise because of its dimensions. That is why it is necessary to provide for an extension for SR beamlines and a number of stations. An arrangement scheme is presented in fig.22.

The premise has a lot of rooms where preparation of samples can be organized as well as rooms that can be reequipped for twenty-four-hour work of numerous users.

User stations. The design parameters of the storage ring and related SR parameters allow realization of most popular research methods with SR application:

- X-ray fluorescence analysis;
- X-ray diffraction analysis (including elements of protein crystallography);
- time-resolved diffractometry, including sub-microsecond diffractometry;
- EXAFS, XAFS, XANES-spectroscopy;
- defectoscopy and X-ray tomography (including phase contrast).

Warm magnets in the structure of storage ring and, correspondingly, beamlines to couple out SR in the soft X-ray and VUV range allow a lot of research and engineering experiments in the field of

- photoelectron and Auger spectroscopy;
- X-ray lithography;
- LIGA technology;
- X-ray microscopy and microtomography;
- metrology;
- lithography with the usage of undulator to generate radiation in the EUV range ($\lambda \sim 13.6$ nm).

6.4 Conferences, meeting and workshops

6.4.1 Russian-British workshop for young scientists “Terahertz Radiation: Science and Technology".

Russian- British workshop for young scientists “Terahertz Radiation: Science and Technology" was held at BINP SB RAS on February 2-5, 2006. The workshop was organized by representatives of the Royal Society and Moscow branch of the British Council together with the leaders of BINP SB RAS. This workshop was planned as a small-scale event for the young scientists to have the possibility of active communication.

The workshop coordinator from the Great Britain side was Peter Weightman, professor of University of Liverpool, a leading member of a laboratory in Daresbury, where he is responsible for the terahertz line of a large facility a little similar to the Novosibirsk FEL. The Novosibirsk FEL is now one of the most powerful facilities of this type all over the world, which explains why scientists of different science are interested in it. The coordination duties from the Russian side were performed by B.A. Knyazev, Ph.D. (BINP SB RAS).

Thirteen British scientists, five of them being professors and university lecturers and the rest students and post-graduates, took part in the workshop. 16 scientists, five of them being professors and having the Ph.D. degree and the rest undergraduates and post-graduates, were presenting Russia.

The three days of the workshop were devoted to lectures about the most topical problems, delivered by all of the guest professors. Young scientists made reports on their works. The workshop language was English, which was done intentionally, in order to stimulate Russian young scientists to study foreign languages.

The workshop showed that the Great Britain party was interested both in conducting terahertz radiation experiments at the high-power Novosibirsk FEL (their terahertz radiation source is planned to be commissioned in 2011) and in attracting young Russian scientists to the British long-term program of research in the field of terahertz radiation. A discussion of possible joint projects was started.

6.4.2 XVI International conference “SR-2006”

On July 10-14, 2006 BINP SB RAS was conducting XVI International conference on SR application “SR-2006” (such conferences have been conducted since 1975). The conference was financially supported by ISTC, Russian Federation Ministry for Education and Science and RFBR. More than sixty scientists from various cities of Russia and former Soviet Union (Baku, Dubna, Zelenograd, Izhevsk, Irkutsk, Krasnoyarsk, Kursk, Moscow, Nizhny Novgorod, Omsk, Putschino, Rostov-Don, Saint-Petersburg, Saratov, Sarov, Tomsk, Kharkov and Chernogolovka) took part in the conference. Fifty participants represented Novosibirsk institutes. Fourteen scientists came from institutions of the USA (ANL and Cornell University), Korea (KAERI), France (SOLEIL, Talence, and ESRF), Germany (Univ. of Technology, IMT/FZK, and Inst. of Mineralogy), and Canada (CLS). Besides, about sixty members of BINP SB RAS participated in the conference. During the four days of the conference, 66 oral and 125 stand reports were made.

Traditionally, the conference covered all issues related to the generation and application of synchrotron and terahertz radiation. The scientific subjects of the conference are reflected in the list of the main plenary sessions: "Statuses and scientific programs of Russian and foreign SR centers and FELS", "SR and nanotechnology", "Insertion Devices", "SR spectroscopy", "X-ray optics", "Detectors and equipment", "SR study of combustion and explosion processes", "Diffraction and SR scattering", "Bio-medical applications of SR", "SR X-ray fluorescent analysis", "LIGA technologies", "FELs, terahertz radiation sources and their application". Large interest was arisen by reports on the perspective plans for developing a sharing center on the base of a forth-generation source of the MARS type and compact dedicated SR source with the use of superconducting magnets.

Due to a rather big number of SR-linked projects (realized, in force and planned), it was the second conference the International Science-and-Technology Center (ISTC) paid a close attention to and provided a financial support for. That is why an "ISTC session" was organized at the conference. The session was devoted to ISTC-supported projects (in force and planned) of Russian institutes.

Traditionally (since 1986), the Conference Proceedings are planned for publication in a separate volume of the journal "Nuclear Instruments and Methods in Physics Research, Section A (NIMA)". In addition, part of the reports presented at the conference is planned for publication in the Russian journal "Poverkhnost", which has an English version, as it was done after the previous conference.

The participants of the conference believe to be successful and very fruitful. No doubt, many scientific ideas that arose during the conference will be developed further.

6.4.3 Other conferences

Traditional (since 2003) annual conferences of students and post-graduates (both from BINP SB RAS and other organizations) working at the Sharing Center were conducted in the springs of the years 2005 and 2006. 15 students and post-graduates were granted diplomas and cash bonuses.

Besides, a number of students and post-graduates participated in other student conferences: the 12th All-Russia scientific conference of students in physics and young scientists, XLIV International student conference "Student and scientific-and-technological advance" and conferences of students and young scientists conducted independently at different organizations.

Leading members of the Siberian Center of synchrotron and terahertz radiation participated actively in the 2nd and 3rd All-Russia conferences of sharing centers (Moscow, MSU, November 29, 2005; Kazan, KSU, October 25-28, 2005), presenting oral and stand reports on topical issues of the activity and development of such centers.

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 radiophysical systems for the charged particle accelerators and storage rings, which are developed by BINP according to the State Programs "Colliding Beams", "High Energy Physics", "Synchrotron Radiation", "Physics of Microwaves".

Within the frame of these Programs, the Laboratory staff is involved in the development of such a radioelectronics equipment as the systems of power supply, 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 complex VEPP-4 and the development of new and upgraded complexes: VEPP-2000, Injection Complex VEPP-5; 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 Institute's Laboratories, which carry out the work under contracts both with the national and foreign centers from the USA, Germany, R.Korea, Switzerland, Japan, Italy, China. It is worth mentioning here the contract works for CERN on the development of the LHC components, the Korean Institute of Atomic Energy (KAERI,R.Korea) on the development, manufacturing and delivery of the components for the future microtron-recuperator. These joint works started a few years ago and it is planned to continue in future.

7.1 Development of the power supply systems for electrophysical facilities

Development of the stabilized current or voltage sources for supplying various electrophysical facilities and their components is one of the main problems of studies carried out in the Laboratory of Radiophysics. First of all, the devices of this class comprise DC sources for supplying electromagnets of the storage rings. An output current of the sources (depending on the 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 magawatts, respectively. As a rule, the current sources should have a wide range of adjustable current values (60-80 dB) and high precision of adjustment and stabilization with an error not exceeding 0.01%. The current sources themselves are rather complex electrophysical devices with the computer control and test, with a system of interlocks and inner controls.

Development of the high voltage DC stabilized voltage sources are carried out in the Laboratory with a range of power:

- tens of watts - to supply of the electrostatic devices for bending or focusing beams of charged particles;
- from a few hundred watts to tens of kilowatt - to supply of the powerful high voltage devices.

• hundreds of kilowatt - to supply of the diagnostic injectors of the neutral atoms, to supply of anode circuits of RF amplifiers.

These devices have a high stability and adjustment accuracy, they are protected against breakdowns and short circuits, have a computer control of currents and voltages; have the distributed status control.

Given below is a short list of results obtained in the works carried out in 2006 and works to be continued in 2007 and in future.

1. A large amount of work has been done during the last two years on the upgrade of electronics for the precise source of the IST-series designed for feeding electromagnets. These devices are of a power of 50 kW, 100 kW, and 200 kW. For this period, eight ISTs have been put into operation at KSRS (Kurchatov Institute), two at TNK in Zelenograd and seven for the storage ring cooler. Now, all of them are put into real operation and show the required parameters.

2. We continued the work on the power supply source of the RF-300-12 and RF-400-8 types. Remind that each source occupies one floor of the “Vishnya” type rack and has an operating current of up to 300A at voltage of 12V (RF-300-12) and 400A, 8V for RF-400-8, respectively. The current stability is better than (1-2)$\cdot 10^{-4}$. Each source is equipped with two DCCTs: one is for providing stabilization and another - for independent measurements. The rack-cabinet can contain of up to 8 such sources. The system is equpped with a multichannel control module DAC/ADC "CDAC20" comprising also the digital status register. The units are connected to the complex control system with the CAN-BUS interface.

We have developed several versions of these sources. About 20 of RF-300 are put into operation at the linac of VEPP-5 complex where they are used for feeding the quadrupole lenses. Approximately the same number of RF-300 are installed at the VEPP-2000 to provide a separate feeding of the ring quadrupole lenses. In the family of these precision sources, there is a group of sources designed for the power supply of the superconducting magnets. These sources are equipped with the system of energy extraction from the magnet in case of quench. It is planned that in 2007, VEPP-2000 solenoids will be equipped with these sources. In addition, about ten of RF-300 and RF-400 are installed at various stands of the Institute for the power supply of the warm magnets, for the test of superconducting wigglers and dipole magnets developed and delivered by the Institute according to contracts. A new version of the series RF-300-8 (in a standard of Euromechanics)was developed under the contract with the Kurchatov Institute (Moscow). Two single polarity sources are delivered to the customer and as a result of the successful tests, we plan to produce a small series of these devices. In parallel, we made a contract on the development and delivery of the bipoloar current sources.

3. The work on equipping the storage ring-cooler, VEPP-2000 and FEL with the power supply systems of correctors was continued. We put into operation about 20 channels with UM-1, about 100 on the base of UM-6 and 60 UM-4M based channels. In 2007, we plan to put into operation about 100 additional power supply channels for correctors at the BINP facilities and according to contract requirements.

4. In 2006, the UM family (Power Amplifiers-power supply sources of the correcting magnets) was widened by current sources of the UM-20 type. They are produced as the development of UM-6 electronics as the next advanced circuitry and they can provide a current up to 20 A or even up to 25 A at the output voltage of up to 40 V, 100 V, 180 V depending on the version. The first series of these UMs will be installed in the beginning of 2007 at VEPP-2000 (BINP) and JINR (Dubna). In future, these current sources should replace the outdated model TIR-25. These sources are drived with CANDAC 16, and output signal measurements are provided with the CANADC 40.

5. We developed and produced several current sources with an output power of up to 6 kW(RF-100-50). Two of them with a current of up to 100 A are installed at the beam transport channel of the BNCT complex and a few more with a current up to 300 A and upon finishing adjustment will be installed at FEL complex (11th bld). All these sources are made in the "Euromechanics" standard and in future, they are planned to occupy the corresponding "technological niche".

6. As the next step in the "Switch Mode" technology of the current sources, we plan to develop a 1 kA device with the output power of 15 (or 20)kW. The IGBT switches will be operated at a frequency of up to 20 kHz. It is planned to occupy one of the "Euromechanics" rack for the channel. Some components of these PS is under development now. Upon realization, these devices will replace the thyristor based V-1000 current sources, which have been developed more than 15 years ago and their manufacture is labor consuming.

7. It is worth mentioning separately the successful commissioning of two power supply sources for the VEPP-2000 complex: supplying the BEP and VEPP-2000 bending magnets. These are systems of a Megawatt range of power (see Table 1). Their power part is based on the thyristor rectifier sections and the controlling and measuring electronics is made in the Euromechanics standard. The developments and manufacture of the sources have been carried out during the last few years. On the autumn 2006, the sources yielded the current value up to 5 kA providing the work on the complex adjustment (the limitation has no relation with operation of the power supply sources). The measured long term instability of the current and its ripples did not exceed 10-20 ppm in both the sources that is a very good result.

Table 1 shows the basic nomenclature of the electromagnet power supply sources, which have been developed or upgraded and produced in the last years and successfully used at the BINP facilities and other organizations.

8. A successful development of a series of Diagnostic Injectors of Neutral Atoms (DNBI) in previous years (project leader - head of Lab.9 A.A. Ivanov) made a peak load in 2004-2005 both in the development, manufacture and delivery. In 2006, the injectors have been successfully put into operation at operational Tokamaks in Losanne (upgrade) and Padova. We continue the work on the Injector components for the W-7X Complex being constructed in Germany. In the middle of 2006, we began the development of six injectors for the USA. This work is planned for a few years.

Remind that one of the key devices of NBI is a high voltage source with the output voltage of 55-65 kV and a current of a few amperes and duration ranging from 50 milliseconds to a few seconds (depending on the version). The sources have a unique possibility of a 100% modulation of the output voltage with a frequency of up to 500 Hz. The NBI power and control electronics is placed in several racks of the Euromechanics standard.

Table 7.1: DC current sources for the power supply of electromagnets.

Type	**Imax**	**Umax**	**Pmax**	**dI/I**	**Type Cooling**	**Size**
	A	V	kW	%	—	m^3
IST-1000-50	1000	50	50.0	0.01	Water/Air	2.2x1.4x0.8
BEP-10000-240	10000	240	1600.0	0.005	Water/Air	—
VEPP-10000-120	10000	120	1200.0	0.003	Water/Air	—
B-1000	1000	15	15.0	0.01	Water/Air	1.8x0.7x0.5
RF-300-12	300	12	4.5	0.01	Air	One storey “Vishnya”
RF-400-8	400	8	3.2	0.01	Air	One storey “Vishnya”
RF-100-50	100	50	5.0	0.1	Air	One storey “Euro”
UM-4	±10	±20	0.2	0.1	Air	32 chnls.(*)
UM-20	±20	±40	1.0	0.01	Air	8 chnls.(*)
UM-6/100	±5	±100	0.24	0.1	Air	48 chnls.(*)
UM-3	±3	±20	0.06	0.1	Air	48 chnls.(*)
UM-1	±1	±40	0.04	0.1	Air	48 chnls.(*)

(*) - Number of channels in a 6-storey cabinet of the “Vishnya” or “Euro”-type.

9.During 2006, we continued the development and manufacturing of the components and units of the "Energo-module" and its power supply, monitoring and control systems for the electron beam welding machine.

Two E-modules with a beam power of up to 15 kW have delivered in 2006 to Izhevsk and put into tests at the electron-beam welding installation produced at the NITI Progress. At the same time, we started the development and production of two E-modules with a beam power of 30 kW. Nearly all the components of these units are produced, adjusted and prepared to the tests. In 2007, after tests the E-modules will be delivered to the customer (NITI Progress, Izhevsk). Remind, that the Energo-Module is based on an electron gun with the operation voltage of 60 kV and it comprises about 20 channels of the control, feeding and monitoring, over 40 channels of measurements. All the units of the E-module have a developed system of the protection and blockings. The development has real prospects for the serial production and its delivery by several Energy units per year. The work is being carried out jointly with the Laboratory of P.V. Logachev.

10. A set of high voltage (up to 40 kV) power supply sources for the Source of negative ions developed for the IBA (Belgium) is designed, developed and now is at the stage of tests. The source of hydrogen negative ions should be operated in a continuous mode providing the beam current up to 10-15 mA with an energy up to 40 keV.

11. In 2004, within the frame of the BINP-CERN collaboration we have prepared and set the production of the current extraction from the 600 A correcting superconducting magnets of the LHC. In 2006, this work was successfully completed: 205 systems occupying over 100 cabinets of Euromechanics have been produced, delivered to CERN,

assembled, installed at the LHC tunnel and tested. The work on commissioning the system in the LHC tunnel is planned for 2007.

12. It is worth mentioning that in 2006 (as in previous years), we continued the technical support to keep operational the systems and units operated at the installations in our Institute and other organizations.

7.2 Development of the systems and devices for automation of physical experiments

Participation of the Laboratory in automation of experimental devices, stands and large physical facilities consists of:

• Development and delivery of the fully assembled systems (systems of monitoring, control, diagnostics, and computer systems) with further participation of authors in adaptation of the systems to physical facilities;

• Development of elements for the control, monitoring and timing of the power supply systems with the further installation of the systems onto the charged particle accelerators and storage rings with a study of their influence on the complex as a whole;

• Installation of the unified individual modules (CAMAK, VME, Vishnya, Euromechanics) on the operational or new installations and stands;

• Development of new approaches, technique and as a consequence, new devices enabling the solution of the experimental physics problems at a new level;

• Upgrade of the existing systems of automation, control and diagnostics at the operational physical facilities;

• Repair and technical maintenance of several thousands of electronic units and systems developed at laboratory and currently operated.

Equipment developed and produced at BINP is widely used not only in SB RAS Institutes but also in many research organizations both in Russia and abroad. The nomenclature of the annually produced equipment is as wide as several tens of types of the digital, analog and digital-to-analog devices, units or modules.

Among works performed in 2006, it is worth mentioning the following:

• We have completed the development of a new automated control system for the VEPP-2000 complex. The operation with a beam enabled us to continue the tests of various subsystems of the pulsed and DC power supply for the operability of electronics and systems of a new generation: a multi-channel vacuum meter, a new version of the beam position monitor (BPM), digital CCD-chambers, etc.

• The preliminary work was performed for the development of the automated control system for a 4-track microtron-recuperator of FEL.

• The design of the modernized control system for the LU, EOK, MN of the Zelenograd technological complex (TNK) was developed.

• We continued the development, production and installation into the new and operational facilities of the control and measurement equipment using the CAN-BUS interface. At present, a set of equipment with this interface comprises the devices given in Table 7.2:

Table 7.2: A family of devices with the CAN-BUS interface

Name	**Short characteristics**
CANDAC16	A 16-channel, 16-bit DAC, 8-bit input and output registers
CANADC40	A 40-channel, 24-bit ADC (of a class 0,03%), 8-bit output and input registers
CDAC20 CEDAC20	20-bit DAC, A 5-channel, 24-bit ADC (of a class 0,003%), 8-bit input and output registers ("Vishnya" and "Euromechanics")
CAC208 CEAC208	A 8-channel, 16-bit DAC, a 20-channel, 24-bit ADC (of a class 0,003%), 8-bit input and output registers ("Vishnya" and "Euromechanics")
CGVI8	A 8-channel, 16-bit generator of delayed pulses, 8-bit input and output registers
CPKS8	A 8-channel, 16-bit code-duty factor converter
SLIO24	CAN-Bus 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 IPP-type
CANIVA	A 16-channel vacuummeter (current of the ion pump)
CURVV	A multi-purpose register of input/output (2 output and 4 input 8-bit registers)
CIR8	Register of discrete signals (register of breaks, CDC, Input and output registers)
CAC168	A 8-channel, 16-bit DAC, a 16-channel, 24-bit ADC (of a class 0,03%), input and output registers, built in board
CAN-DDS	A CAN-DDS module is a divider of the input clock frequency with the remotely retunable a fractional coefficient. The module is designed for its use in the feedback circuit of triggers at VEPP-5 and VEPP-2000
CAN-ADC3212	For connection of the feedback circuit in the thermal adjustment scheme of the cavity, temperature control at certain points cavity and providing blockings. A 24-channel 12- bit differential ADC with gain control; a 4-channel 12-bit bipolar DAC.
CANGW	Ethernet port - CAN/RS485
VME-CAN	Interface VME-CAN

• Next 75 units with CAN-BUS interfaces are produced, adjusted and put into operation in the control systems of various

electrophysical facilities. It is worth mentioning that the devices of this family are widely used for the contract works. For the last 3 years, over 100 modules in sets of the power supply sources have been delivered to KAERI (R.Korea), IMP (China), JINR (Dubna), Kurchatov Institute (Moscow). NITI "Progress" (Izhevsk).

In view of the ever growing amount of various magnetic field measurements at BINP, the decision was made in 2002 to develop a set of VME modules, which could enable precise measurements of fields both with the Hall probe based matrices and with the rotating coils. At present, such a set comprises:

- a precise ADC with the built-in analog multiplexer;

- a 32-channel multiplexer with the commutation error of 1 μV, for operation with the

Hall probes, a 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 measuring stands in 13th bld. and EW-1, which are widely used for work in various contracts. A set of programs was prepared for these systems.

• We continued the development of stands on the base of the " Integrators with digital outputs" and sets of rotating coils for measurements of the undulator parameters.

• We continued the development of equipment for the two-coordinate monolithic Hall probes.

• The work is continued on introducing the modern intellectual controllers in the control systems of the modern physical facilities. In particular, the software of the CAN-Ethernet port and VME controller was completed. Next 6 VME controllers for various installations at the Institute and 16 ports of CAN-Ethernet have been manufactured. The use of the controllers enables unification of the system software and the use of the commercially available control systems as, for example, EPICS.

• The work on the CAN-BUS interface with the VME base is continued. The library and test programs have been developed for OC VxWorks. A set of four interfaces was produced for automation of the superconducting wiggler as well as for the stand for magnetic measurements.

• By the contract with CERN, a full set of equipment for the arc detectors was produced. The first 14 crates are installed in the LHC tunnel.

• For replacement of the popular but outdated crate controller 0607, in 2003, we have developed a new one based on the modern components. In 2006, next 15 controllers and 25 interface boards (20 for PCI bus) are put into operation.

• Development of the digital registrators of two-dimensional optical images (digital cameras) with the Fast Ethernet interface is continued. We developed and produced a set of units for observation of a beam in the VEPP-4 and VEPP-2000 collidiers and for diagnostics of a plasma. A new version of the two-dimensional image registrators is characteristic by its higher sensitivity and quantum efficiency. The registrators can be operated either with one or two external (connected in series) matrix CCD. The corresponding units of the external (connected) CCD are developed for observation of the positron beams at VEPP-2000 collider. In addition, we developed 2000-element linear CCD aimed at further modernization of the SR beam stabilization system at VEPP-3 storage ring (and in future, of the compact storage ring under development).

• We continued the development of equipment for studying fast processes with SR beams: development of a fast 12-channel, 16 digit ADC with the detector signal processing channels (channels provide integration of short pulse signals, suppression of noises, an individual tuning of amplification in channels and the polarity selection of the input signal); the ADC synchronizing unit is developed and produced.

• For replacement of the physically outdated equipment for the correction system of the VEPP-4 magnetic field, a 16 channel interpolating DAC with the interface MIL-STD-1553B was developed with the use of the modern components. The module is fully compatible with the previous version. All the old DACs (28 pieces) are replaced by the new ones thus enabling a substantial improvement of the operation reliability of all the systems of correction of the VEPP-4 magnetic field.

• We continued the development of the port-multiplexer for data gathering at the KMD-3 detector. The built-in software is ready. The preliminary adjustment of the KMD-3 data gathering system is planned for the second quarter of the year.

• We started the development of the control system for the injector of neutral beams (the diagnostic and heating versions of injectors). The system is based on the commercially available components. The software is unified for both versions of the injector and it envisages integration into the common system of control.

• Development of the new digital registrator ADC-502 is completed and some prototype modules are assembled. The register is designed for the replacement of the outdated ADC-850SK.

• We have replaced the physically off-dated CAMAC-equipment by the upgraded equipment for the control system of the power supply sources of the vacuum pumps at the VEPP-5 injection complex.

• We continued the development of a multi-channel system for measurements of the temperature and consumption of the cooling liquid. In this version, the probes have no movable parts and the module of electronics can be located at s substantial distance from the probes. These features allow to hope for the construction of the highly reliable monitor for operation under conditions of higher level radiation.

• Development of a new generation device for measurements the instantaneous values of the magnetic field in the channel pulsed magnets is continued.

• For the work with the KEDR gas systems, a number of
modules, which are designed for measurements and control of the gas flows, are produced and adjusted. An improved control unit for the helium detander-liquifier was put into operation.

• We continued the development of the timer for the free electron laser.

• Two controllers of the power supply units for superconducting magnets are produced and delivered to the customer. Since the power supply sources will be used not only at our Institute, a possibility of the autonomous operation (without external control computer) is envisaged. To this end, the controller is equipped with LC-screen and miniature keyboard

• We continued improvement of the Laboratory site: http://www.inp.nsk.su/div
/l6-1/weblab6/start.html. By the idea of authors, the site should facilitate the more efficient and correct use of the laboratory developments. To this end, in addition to descriptions of various modules, some application notes are placed. The site is regularly innovated.

• We continued development of electronics for the beam position monitors based on measurements of image currents. The equipment is installed in the beam transport channel of BEP-VEPP of the complex VEPP-2000 and it is successfully used for guiding the beam. Equipment is compatible with the IPP-32module.

• Development of equipment for a damping system of the beam transverse motion instabilities at VEPP-4 is continued. Within the frame of the work, we completed the development of the wide band amplifiers operated in the amplitude linear mode. The bandwidth of the amplifiers is 50 MHz and the output power is up to 400 W in the operation run with the matched load. The amplifiers are designed for operation to kickers located in the half-rings. A part of the system is already produced and the work is planned to be continued in 2007.

• Production of the pick-up station electronics and some units of the beam position measurements system both for the VEPP-2000 collider and injection complex storage-ring cooler. The systems are based on a specially developed 4-channel, 12-bit ADC having the clock frequency of measurements of up to 45 MHz. In 2006, a set of equipment is installed at VEPP-2000 and prepared for its furher use.

• Let us remind, that the measurement system based on the similar equipment (28 pick-up stations) with the use of the same ADC was put into operation in 2003 and successfully used at the microtron-recuperator (FEL) and at the injector complex at KAERI. We started production of the system modules for the second order of FEL. Upon the completion of the work, the number of pick-up stations will be twice as much as that at the microtron-recuperator now.

• Modernization was performed of the beam position (orbit) measuring system in the injection complex linac. The system is based on the strip-line type monitors and it is oriented to the repetition rate of measured beams ranging from a few Hz up to 50 Hz. In 2006, we put into operation new electronics of 5 probes of the electron linac and one probe of the positron linac. Electronics for the remaining 8 pick-ups of the positron linac is ready, it is installed at the linac and calibrated. The system is oriented to measurements of the electron and positron beam positions with the number of particles in a beam ranging from 10^8 to 10^{10}. The total volume of electronics for these systems is two crates of CAMAC.

• Development of the precise NMR magnetometers is continued. Depending on a set of electronics and a version of probes, the magnetometer covers the field range from 0.02 T to 11 T. The relative measurement error does not exceed $10^{-5} \Rightarrow$ or even 10^{-6} depending on the field level and its homogeneity. A set of such an equipment (in VME standard) is installed and operated at the VEPP-2000 complex. The field is measured in each of 8 bending magnets and in 13th magnet of BEP. The field range is 0.3-0.4 T. The probes are also installed at the KMD detector. The software for OC LINUX is developed. For improvement of the equipment, a new version of the magnetometer is developed located only at one VME board. Note, that the part of NMR magnetometers-synthesizers are used separately, for example, at VEPP-4 complex in the experiments with precise measurements of the polarized beam parameters.

• Development of the drive equipment for the step motors is continued. The units of the ESD for the 5DMU3 type motor are the most popular at BINP. At present, a few tens of ESD5 units are produced and adjusted for the upgrade of the NPC machines at the BINP Experimental Workshop.

• Within the frame of the continuing collaboration between BINP, SLAC and FNAL on measurements of the slow vertical displacements of the components and units of accelerators, in the period 2004-2005, we successfully developed the volume and ultrasonic hydrostatic monitors of vertical displacements. As a result of the joint (together with the SLAC staff) tests, the contract was signed between BINP and SLAC (at the end of 2006) for production of 40 ultrasonic and 116 capacitive monitors for their use in the hydrostatic system of alignment of components of LCLS - (Linac Coherent Light Source, USA). The system should have the resolution better than a micron that is rather attainable for the monitors we have developed. The work completion is planned for the beginning of 2008.

7.3 Studies related to the modeling and solving the electrostatic and electrodynamic problems

1. Works on further improvement of programs for calculations of the electrostatic and magnetostatic fields of the electron and ion guns. Including:

• In the ESAM program complex, we realized a possibility of a selfmatching calculation of emission from the cathode and the beam dynamics in the electric RF field at the quasistationary approach, which enabled calculation of the electron bunch parameters generated by the cathode-grid units placed in the RF cavities or accelerating structures when except for the DC displacement voltage, an additional RF voltage is applied to the grid-cathode gap.

• We continued development the Windows based set of codes MAG3D for three-dimensional calculations of the magnets with an account for the core saturation effect.

2. The work was carried out on numerical calculations, modeling and design of electric guns as well as magnetic systems. Among them:

• We performed a simulation of the pulse electron source for the VEPP-5 injection complex.

• Development of a new multi-gap RF-accelerator ILU-12 with an energy of electrons 5 MeV and the beam mean power of 300 kW is continued. We calculated the real form of the current micro pulse injected from the cathode-grid unit placed at the accelerator first gap.

• Calculations of a magnet for the negative ion source was performed by the contract with IBA.

7.4 Developments for BINP Experimental Workshop

As in the previous years, we continued our support of the BINP Workshop in automation of some technological operations, control of the product parameters, in the development or improvement of technologies.

• Two samples of the “soldering machine”, where the copper buses are heated with AC current of a few kiloamperes and the graphite electrodes are used as heating elements, are successfully operated in 8th Bld. of Workshop. The third machine is ready, tested and awaits its commissioning.

• As in previous years, we maintain the earlier developed systems designed for the thermal diffusion welding of copper foils with the welding area of up to 100x100 mm^2.

• At the BINP Workshop, we keep operational the earlier produced automated control systems of 12 technological devices for thermal treatment of components of physical devices being in production (6 devices in 8th Bld.; 4 -in Workshop-I; 2 - in 13th Bld.).We started the development of equipment for several new ovens, which are planned to be commissioned at Workshop in 2006.

• The fast acting laser modulator for the drum photoplotter was developed and successfully introduced into operation.

• Jointly with the printing boards manufacturing section of EW-2 we worked out the technology of applying inscriptions on the printing boards with the serigraphy technique and introduced this operation into the production cycle.

7.5 Status of linear accelerator – injector of TNK complex

In November-December, 2006, we continued the work on the linear accelerator-injector of the TNK complex (Zelenograd). The purpose of the work was:

• conditioning of the linear accelerator aimed at increase in energy of electron beam up to 70 MeV;

• conducting the accelerated electron beam to the Faraday cylinder (FC) located at the plane equivalent to the input of a beam into the booster (a small storage ring);

• stabilization of the modulator "Olivin" pulse amplitudes and fine regulation of the anode voltage of KIU-53 from 170 kV to 230 kV jointly with the authors of the modulator design, RIMP, Sankt-Peterburg);

• installation of the Linac gun protection by vacuum and cooling in the automated regime.

Fig.1 shows the schematic diagram of the accelerator. The station " Olivin" with the klystron KIU-53 is used as a source of RF power. In order to attain the energy of electrons of 70 MeV at the LU output, it is necessary to apply along the waveguide channel to the structure a power of the order of 16 MW. At the end of 2005, the electron beam energy of the order of 50 MeV was achieved at the Linac output. Its further raise was limited by the electric strength of the structure and waveguide channel. In November, 2006, the work on the linear accelerator was continued.

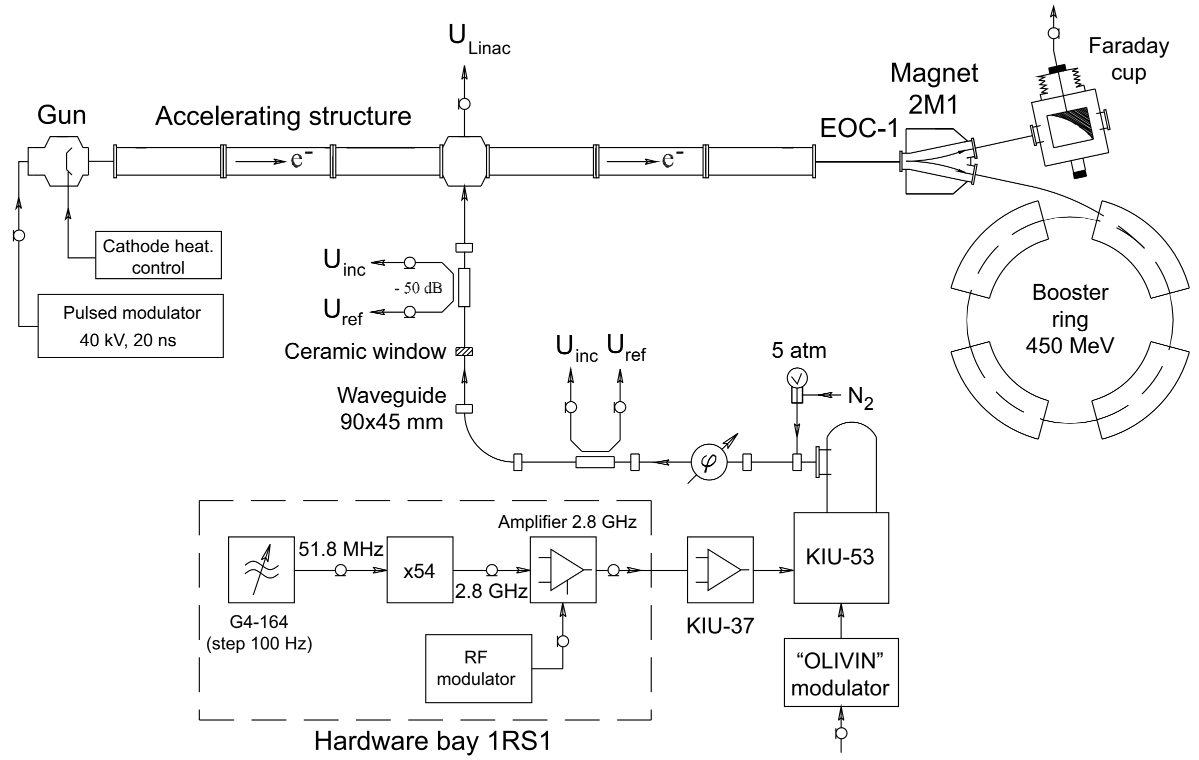

Figure 1: Linear accelerator sketch.

As a result of a two week conditioning, we obtained the stable level of the field intensity in the accelerating structure of 230-240 kW/cm, which is enough for obtaining the required energy of electrons at the Linac output. The level and stability of the accelerating field in Linac was controlled by the signal U from the structure central cavity. Fig.2 shows oscillograms of the incident wave voltage (K1) and voltages of the accelerating structure (K2).

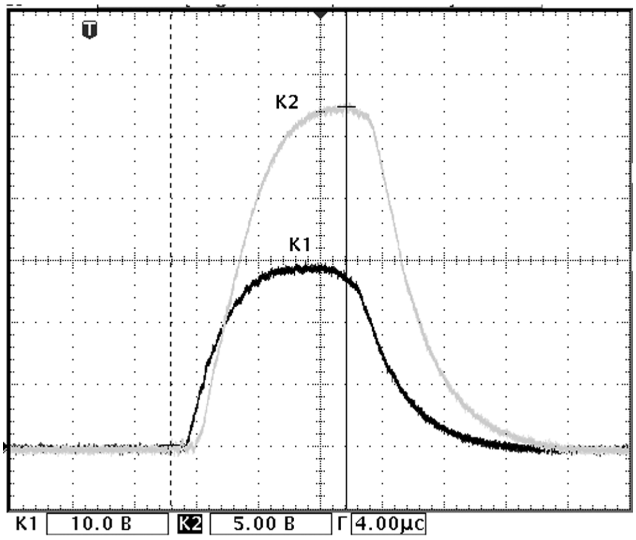

Figure 2: Oscillograms of voltages of the incident wave (K1) and voltages in the accelerator structure (K2). In this case, the anode voltage at KIU-53 is 210 kV, at KIU-37 = 12.7 kV, Rf field frequency is 2799.2 MHz.

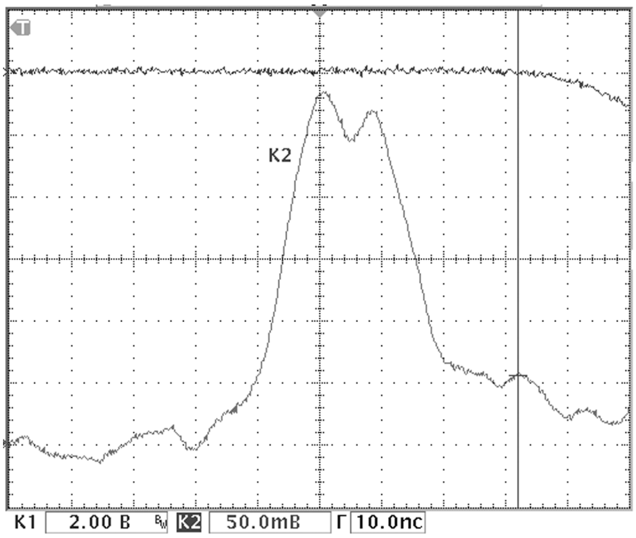

Figure 3: The shape of the accelerated beam at the Linac output (K2). The scale inolute is 10 ns/div.

The beam was observed with the current monitor located just at the Linac output (Fig.3) and with the help of the Faraday Cylinder (FC) behind the bending magnet of 2M1 spectrometer. Optimization of beam current passage at a given current of 2M1 magnet within the limits 12-13 A was performed with the correctors of the focusing lenses in the accelerating structure and the electron-optical channel EOK-1. For measurements

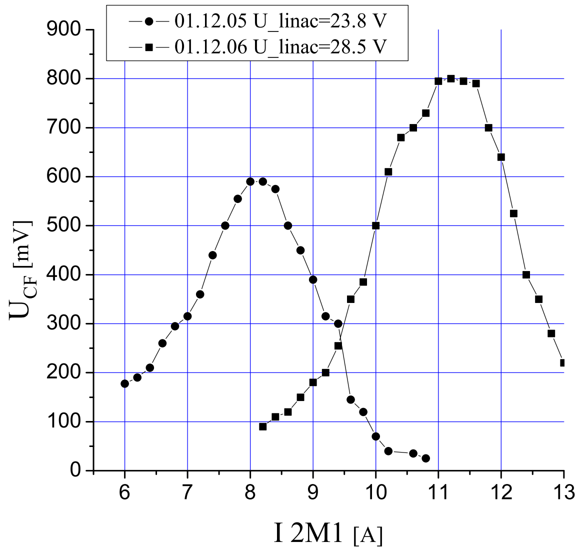

Figure 4: Dependence of FC voltage amplitude on variation of a current in the bending magnet of 2M1 spectrometer. (Left part-2005 after RF training , the right part-2006.)

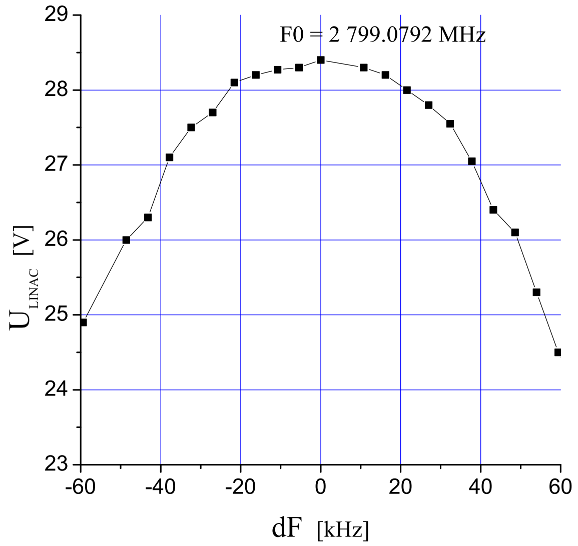

Figure 5: Amplitude-frequency characteristics of LU.

of the electron energy, the bending magnet of 2M1 spectrometer was used jointly with the Faraday Cylinder. Fig.4 show the measurement results of the dependence of the FC voltage proportional to the applied charge with variation of the current of the bending magnet of spectrometer 2M1: the left picture obtained in experiments in 2005 corresponds to an energy of 50 MeV and the right part the result attained in December, 2006 corresponds to the beam energy of 70 MeV. The channel pipe of 16 mm in diameter is used as a collimator in front of FC. .

As a result of the work done, all the accelerator systems are functioning stably and provide attaining energy of the electron beam at the level of 70 MeV. Further increase in energy is possible during the acceleration permanent operation.

In the period from 27.11.2006 to 09.12.2006, in the work on the commissioning of the linear accelerator at the TNK complex in Zelenograd the following staff of BINP took part: O.V.Anchugov, E.N.Koking, N.V.Matyash, G.N.Ostreiko, G.V.Serdobintsev, A.V.Filipchenko, K.N.Chernov.

7.6 Development of the prototypes of RF stations for accelerators SIS100/300 and NESR GSI, Darmstadt, Germany

In 2006, we continued the collaboration with the research centers GSI (Darmstadt, Germany) on the Project FAIR. The contract signed in 2006 envisages the development of the prototypes of RF stations for accelerators SIS100, SIS300 and NESR.

The basic parameters of RF stations are given in Table 1.

Parameter	**SIS100**	**SIS300**	**NESR**
Range of operation frequencies, MHz	1.1 ... 2.8	1.1 ... 2.8	0.9 ... 2.7
Maximum amplitude Of accelerating voltage, kV	20	20	15
Accelerated ion current	2.6 A (U^{73+})	2.6 A (U^{73+})	2.6 A (U^{73+})
Length standard, mm	2800	2800	2800
Aperture of vacuum chamber, mm	150	150	200
Output voltage Of the beam RF system, Ohm	<3000	<3000	<3000
Operation regime of RF station	Continuous.	Continuous.	Continuous.
RF maximum power of generator, kW	65	65	50

RF station comprises the accelerating cavity, RF power generator, power supply sources and the control system. The accelerating cavity consists of two quarter-wave sections of the coaxial line whose free ends form the accelerating gap. The space between coaxials is filled with the 400 NN ferrite. For tuning the cavity operation frequency, the ferrite magnetization is used. The output circuit of RF generator is based on a single tube-tetrode RS2054SK of Tales/Siemens. There is a possibility to replace it by the tube CW100000 of Eimac production. For driving the tetrode, we use a 1.2 kW pre-amplifier that is operated within the whole range of frequencies without tuning. The tube is power supplied from the anode rectifier with an output voltage of 12 kV and power of 120 kW. The bias sources of the screen and control grids as well as the filament power supply are envisaged. The fast acting protection circuits of the output tubes remove the tube anode voltage in case of sparking in the tube.

The control system provides regulating of the accelerating voltage amplitude and cavity automatic tuning with the feedback circuits and protects the system components and personnel in case of hazard situation. For computer monitoring and control of the RF station, the interface equipment of PLC standard (Siemens S7) is used.

The signed contract envisages two stages of its execution. At the first stage, which was completer at the end of 2006, Specification of RF station prototypes with the basic technical and technological solutions and operation regimes of the components was developed and delivered to the customer. The aim of the second stage of the contract is the detailed workout of the project of RF station prototypes, development of the technical documentation sufficient for placing the order of production. The completion of the stage is planned for the end of April, 2007.

Participants of the work: V.S.Arbuzov, Yu.A.Biryuchevsky, E.I.Gorniker, S.A.Krutikhin, Ya.G.Kryuchkov, G.Ya.Kurkin, V.N.Osipov, B.M.Petrov, A.M.Pilan.

7.7 A 700 MHz cavity for X-ray source "NESTOR"

By the contract № RU/03533872/E-04026 with the National Research Center "Kharkov Physics Technical Institute" we have developed and constructed the RF cavity for the storage ring of the X-ray source "NESTOR". An energy of electrons in the storage ring is 40÷225 МэВ, a circulating current is 180 мА. The cavity parameters are given in Table 1. The schematic diagram of the cavity is given in Fig.1. Fig.2 shows a photo of the cavity.

Table 1.

Operating frequency,	MHz 699.3
Frequency tuning range, %	0.1
Shunt impedance, MOhm	> 2.0
Accelerating voltage, kV	> 200
Power scattered in the cavity, kW	15

A cylindrical copper cavity with a small protrusion in the aperture area is produced by soldering discs to the cowling. HF power is applied to the cavity along a 75 Ohm coaxial feeder. The power input is inductive. The cylindrical window made of 22 XC ceramics separates the cavity volume from atmosphere. The frequency retuning is provided by the contactless plunger. A signal from the signal loop is coupled through the vacuum tight connector (a channel 16x7). The cavity is pumped out by the ion pump connected to the lower flange. The cavity walls, power input and plunger are water cooled. Low power measurements have shown good correspondence between the design and real parameters. High power tests are not included into the contract, they are planned to be done by the customer.

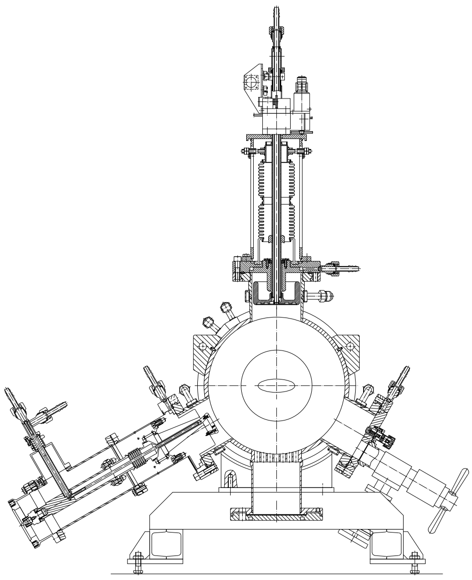

Figure 1: Schematic diagram of the cavity.

Figure 2: General view of cavity.

Participants of the work:

Ya.G.Kryuchkov, I.G.Makarov, G.N.Ostreiko, I.K.Sedlyarov, G.V.Serdobintsev, K.N.Chernov.

7.8 Development of the prototype of a 5 Mev, 300 kW industrial linear accelerator

The development and construction of a powerful linear accelerator (ILU-12)for industrial application with an energy of 5 MeV and beam mean power of 300 kW is being carried out at BINP within the frame of the ISTC Grant, Project 2550. In 2006, we have performed the following kinds of work:

1. Manufacture of the accelerating structure and its adjustment are completed. All the main parameters of the structure as the coupling coefficient, Q-factor and distribution of the field in cells have been measured.

The design and measured parameters of the structure are given below.

Parameter	**Design**	**Measurements**
Frequency, MHz	176.276	176.308
Q-factor	22000	19590
Shunt impedance,MOhm	18	17

Fig.1 shows a general view of the accelerating structure and results of measurements of the partial frequencies after adjustment of the structure. The design and experimental dispersion curves are shown in Fig.2. The divergence of the curves is caused mainly by 1 MHz deviation of the partial frequency of the first (by the beam motion) coupling cavity. This event made a slight influence on the field distributions in the accelerating cells.

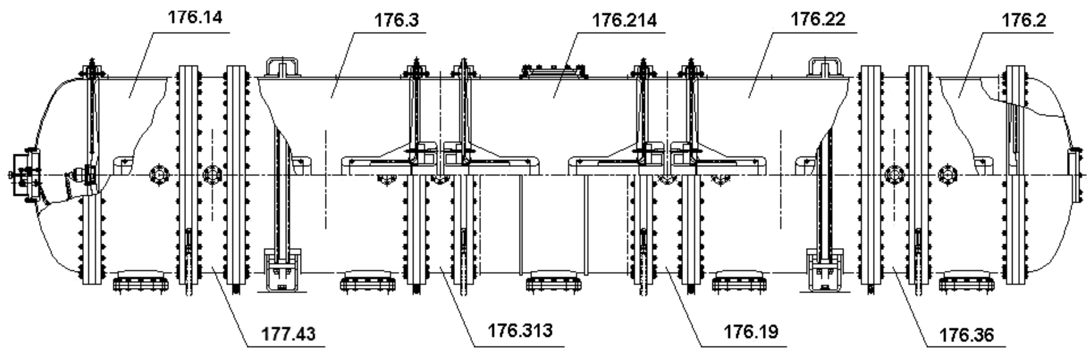

Figure 1: General view of accelerating structure. The partial frequency values of the cells (MHz) are shown after adjustment.

2. RF power input coupler of the accelerating structure is produced and tested. Tests of RF power coupler have been carried out at the stand, which consists of the vacuum vessel and RF generator at a frequency of 176 MHz. (Fig.3).

The generator power is 2 kW, pulse duration is 100 mks, repetition rate is 1 kHz, duty factor is 10. This power is enough for carrying out lead tests with the use of the resonat properties of the coaxial contour. The tests have shown that conditioning of the coupler enables one to pass the multipactor zone at the operation power levels and lower by an order of magnitude. The insulator withstands the voltage by 20

3. The accelerating structure was assembled in the vertical position and vacuum tested. Then, it was put into horizontal position on the support, vacuum test was repeated

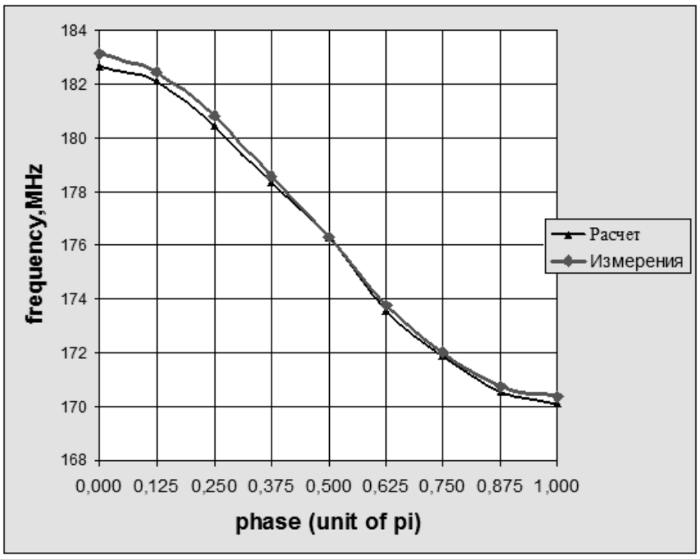

Figure 2: Dispersion curve of the accelerating structure.

Figure 3: Stand for tests of power leads.

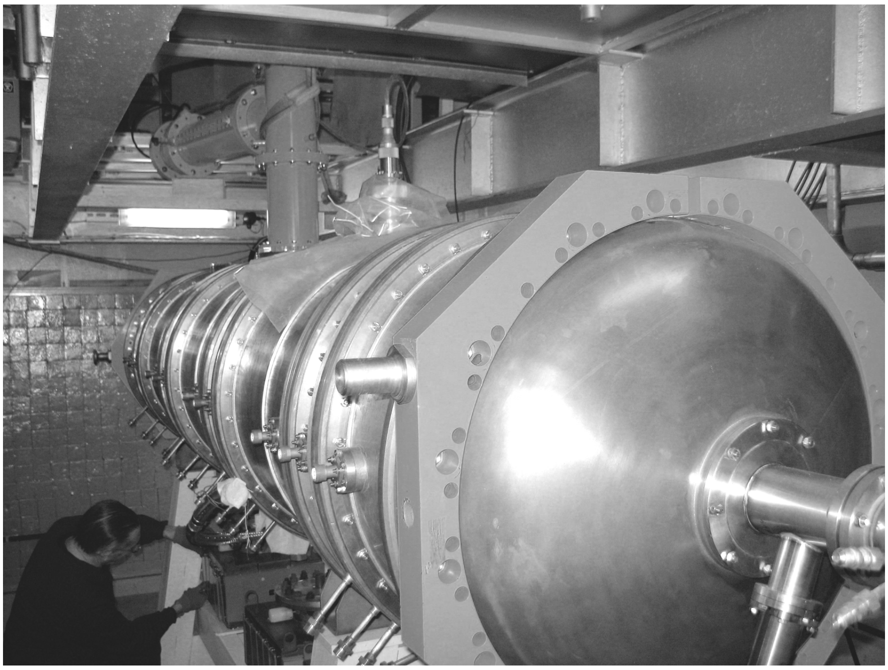

Figure 4: Accelerating structure with the power lead.

and the RF power coupler installed. The structure was matched with a 50 Ohm feeder. Fig.4 shows the accelerating structure with the RF power coupler installed

4. A 176 MHz and power up to 3 MW generator is developed. At the low level of power, the matching and calibration of RF probes was carried out.

Participants of the work from Labs: 6-0, 6-2, 14, RDB:
V.L.Auslender, I.G.Makarov, I.V.Gornakov, N.V.Matyash, G.N.Ostreiko, A.D.Panfilov, G.V.Serdobintsev, V.V.Tarnetsky, M.A.Tiunov, A.P.Fedorov, V.G.Cheskidov, K.N.Chernov.

Publications:
[140], [147], [353], [383].

7.9 Upgrade of RF system of the storage rings Siberia-1 and Siberia-2

In 2006, two contracts were signed between BINP and Kurchatov Center of Synchrotron Radiation and Nanotechnology (KCSRNT), Moscow on the delivery of the equipment and upgrade of the RF systems operated now on the storage rings Siberia-1 and Siberia-2. The storage ring Siberia-2 with the electron energy up to 2.5 GeV and current up to 0.3 A is a powerful SR source. The storage ring Siberia-1 with the electron energy up to 450 MeV and current up to 0.5 A is operated as the Siberia-2 injector and also as the individual source of synchrotron radiation.

RF system of the storage ring Siberia-1.

Upgrade of the RF system of the storage ring Siberia-1 comprises the following: the delivery of more powerful new RF generator, essential upgrade of the accelerating cavity and development of a new control system. In the old RF system, the maximum voltage of the cavity did not exceed 15 kV. The new RF system should allow for the short time 0.1-1 s to raise the voltage at the accelerating cavity from 15 kV up to 30 kV thus enabling one to reduce the length of the bunch at an energy of 450 MeV before extraction and and to substantially improve the efficiency of injection into the storage ring Siberia-2 during injection of a beam from Siberia-1.

A new 10 kW generator will be installed instead of the 5 kW old RF generator with the output stage based on 2 tubes GU-5B. The output stage of the RF generator is based on the tube GU-36B and it is driven by the new transistor pre-amplifier with the output power of 500 W.

The available accelerating cavity of the storage ring Siberia-1 will be disassembled and upgraded. The cavity is a coaxial line shortened by the capacitance. The cavity is an air one, in the region of the accelerating gap, the vacuum chamber has an insertion made of VK94-1 ceramics connected to the cavity walls through the flexible crosspoints. In order to provide the electrical strength at 30 kV, the following upgrade of the cavity is suggested (see Fig.1):

1. the disk diameter of the available cavity is reduced and the cut ring is soldered to it with the radius increased from 10 mm to 55 mm.

2. the capacitance gap is increased from 38 mm up to 56 mm due to the insertion between the disk and cowling.

3. in the vacuum chamber of the storage ring, the insulator unit is replaced by the new one with elongated ceramics.

The inner sizes of the resonator cavities are selected in such a way that the resonance frequency is remaining the same - 34,5 MHz. We also envisage the improvement of the power lead and the tuning mechanism for the operating frequency. All the drawings for the upgraded units of the cavity are prepared and the units are in production. A 134.5 MHz powerful generator is being assembled and adjusted by the staff of Lfv.6-2. The radiorack is mounted for the RF control low level electronic modules. The parameters of Siberia-1 RF system after upgrade are given in Fig.1.

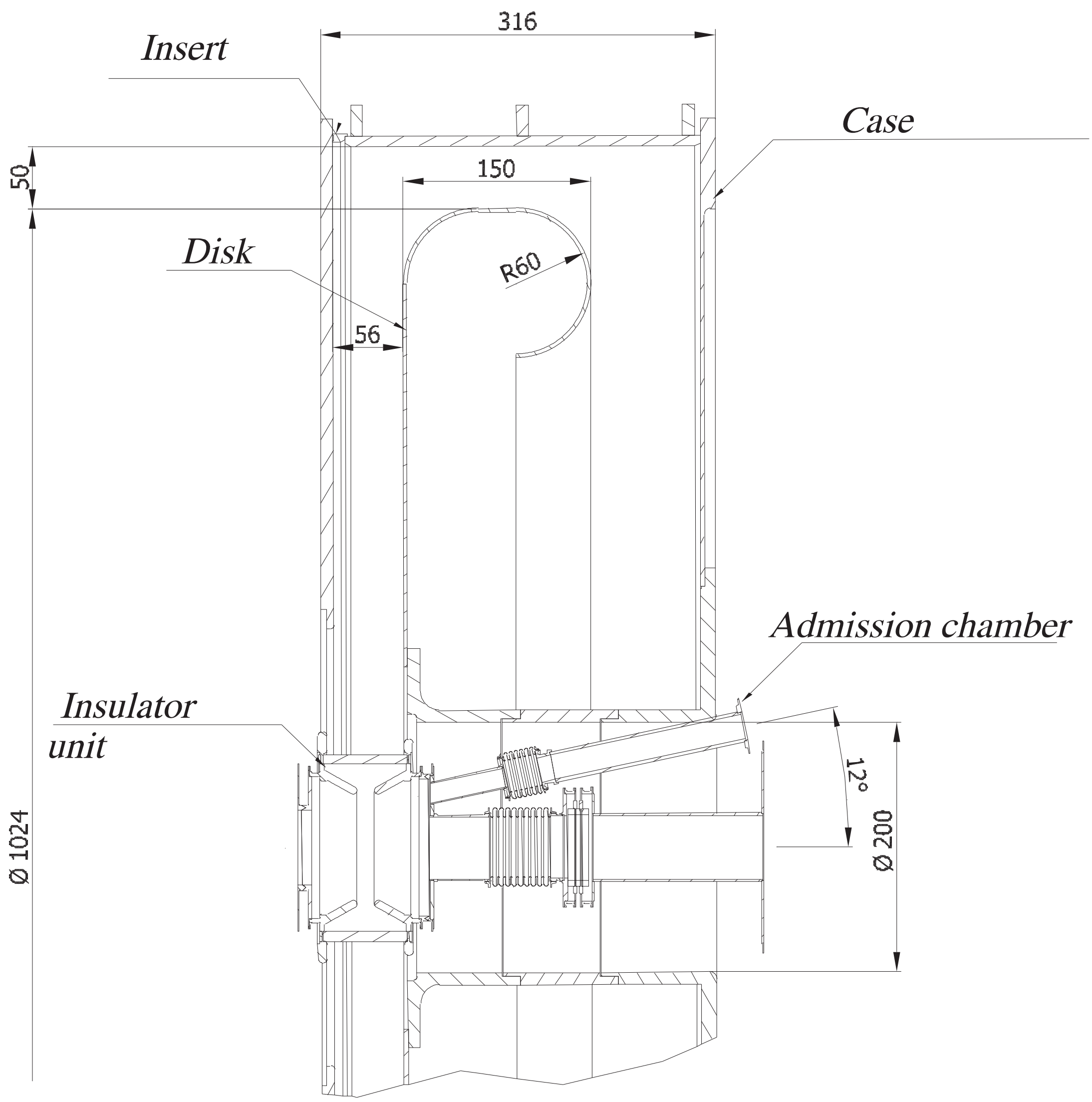

Figure 1: Drawing of the upgraded cavity of Siberia-1.

Table 1.

Operating frequency	34,5 MHz
Q-factor of the cavity	6100
Cavity shunt impedance	100 kOhm
Repetition factor	1
Accelerating voltage	2-30 кВ
Frequency retuning	1%
Maximum power of losses in the cavity (30kV)	4,5 kW
RF generator power	10 kW

RF system of the storage ring Siberia-2.

In the Kurchatov Institute, it is planned to improve the parameters of the storage ring Siberia-2 as a source of synchrotron radiation by installing into the ring an additional source of synchrotron radiation-a superconducting wiggler. As a result of this, the energy loss per turn at an energy of 2.5 GeV will increase from 680 keV/trn up to 1040 keV/trn. Therefore there are requirements to the RF system of the storage ring Siberia-2 after its upgrade: to provide an increase in the total accelerating voltage from 1.1 MV up to

1.8 MV, to compensate the increased power of radiation losses and improve the operation reliability. The available RF system has two independent channels operated at a frequency of 181.14 MHz. Each channel consists of the RF cavity similar to the cavity of the storage ring VEPP-4, waveguide with the crossection 986x100 and the 200 kW RF generator.

According to the contract, one of the available cavities in the storage ring Siberia-2, where the raise of voltage over 600 kV is complicated because of spoil of vacuum, will be removed and replaced by the section made of two bimetal cavities similar to the accelerating section of the microtron-recuperator of the Novosibirsk FEL. The cavity body is made of bimetal (8 mm copper and 7 mm stainless steel) obtained with the diffusion welding. Each cavity has two tuner for the frequency of the operative mode and two tuners for high order modes (see Fig.2). On top, there is a power coaxial coupler with a cylindrical ceramic window. For measurements of the gap voltage, there is an inductive sampling loop. Below on the cavity the ion pump is installed. The operating frequency of the bimetal cavities is 180.4 MHz. In order not to change substantially the size and shape of its body, the preliminary tuning to a frequency of 181.14 MHz of each cavity is achieved by a special insertion installed inside the cavity port intended for its preliminary pumping. The cavities (Fig.2) are connected to the waveguide with separate 75 Ohm coaxial feeders, which are designed and produced within the frame of this contract. The RF generator power is divided equally between two cavities in the wavegiude section with a double waveguide coaxial transition. Both coaxials are put into the same crossection of the waveguide symmetrically with respect to the middle part of its broad side.

The equivalent circuit of the transition is an ideal transformer with three windings. With the matched coaxial feeders, the waveguide is also matched. The design enables the sufficiently easy change of the coupling coefficients of the waveguide with the cavities with respect to each other within the limits ±10%. The transition design is very simple, it is a central conductor of the coaxial feeder passing through the waveguide. The distance of the equivalent transformer of the waveguide-coaxial transition to the crossection of the voltage unit position in the feeder during detuning of the cavity is multiple to the odd number of the wave length quarters of the feeder. Thus, during the detuning of each cavity, the cavity excitation currents do not exceed the values determined by the maximum power in the tuned system.

Since it is impossible to obtain the required coupling coefficient of the cavity with the feeder by variation of the coupling loop position(β max=2), a 93 Ohm a quarter wave length transformer matching the waveguide channel at maximum current of a beam is installed.

The newly produced part of the storage ring straight section comprises: the cavity section with two vacuum valves, the radiation receiver for protection of cavities against SR, sylphon isolations and vacuum valves for the remaining cavity. The valves are made with the internal RF contacts. At present, the units of cavities, feeders and components of the straight section are being manufactured at the workshop EW-1.

After upgrade, the accelerating RF system of Siberia-2 will consist of one old cavity with the effective shunt resistance of Rsh =6,9 MOhm and a section of two bimetal cavities with the effective shunt impedance of 4.2 MOhm each[1]. Each channel is fed by the separate RF generators of 200 kW each whose output stages are based on two tetrode tubes GU101A. The section cavities are excited in a antiphase due to the turn of the power input coupling loops. The centers of the cavity accelerating gaps are at a distance of 62.5 cm from each other. This is by 20.2 cm less than the half wavelength at the operating frequency. Taking this fact into account, for attaining the section accelerating voltage of 900 kV for the coasting electron bunch, the accelerating voltage at each cavity

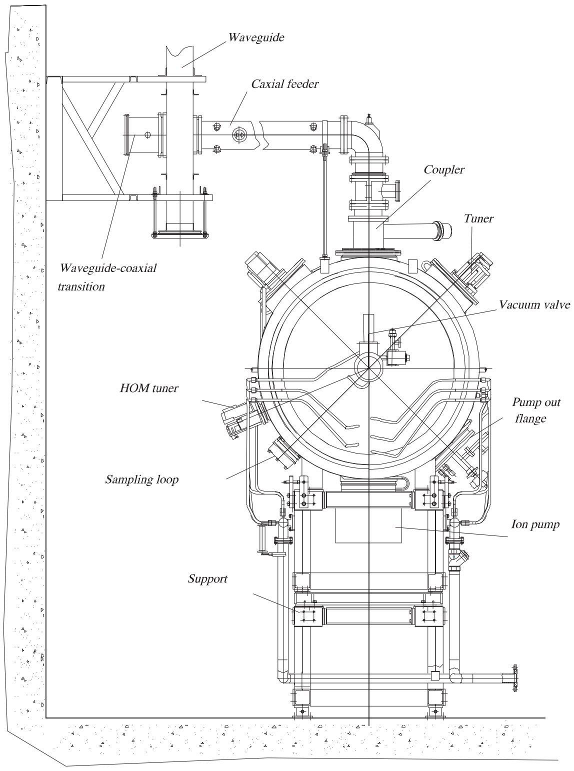

Figure 2: Schematic of connections of the bimetal cavity of Siberia-2.

should be 485 kV, i.e. the total voltage is 970 kV. In this case, the loss power in the walls of two cavities is 56 kW. In the second channel, at the accelerating voltage of 900 kV the power of losses in the cavity walls will be 59 kW. The total accelerating voltage attained at three cavities is 1.8 MW and the maximum RF power delivered to the beam can be of 285 kW.

[1] Rsh = U^2acc./2P, where Uacc. Is the cavity accelerating voltage, P is the power of losses at this voltage.

Participants of the work:
V.S.Arbuzov, Yu.A.Biryuchevsky, S.V.Volobuev, E.I.Gorniker, O.I.Deichuli, E.K.Kenzhebulatov, A.A.Kondakov, S.A.Krutikhin, Ya.G.Kryuchkov, I.V.Kuptsov, G.Ya.Kurkin, L.A.Mironenko, S.V.Motygin, V.N.Osipov, V.M.Petrov, A.M.Popov, A.M.Pilan, E.A.Rotov, I.K.Sedlyarov, A.G.Tribendis, L.M.Shchegolev.

7.10 Accelerating structures for Linac4, CERN

In 2006, we continued the work on manufacture of the prototypes of accelerating structures for LINAC4 (CERN). The work was performed jointly with the RFNC-VNIITF, Snezhinsk with the financial support of ISTC. Within the frame of the ISTC project 2875, a section of the accelerating structure CCDTL (Cell Coupled Drift Tube Linac) at a frequency of 352 MHz was produced (see Fig. 1).

The cavity bodies are made in Snezhinsk, the floating tubes, outer units and final assembly are performed at BINP. The vacuum tests, measurements of rf-parameters and adjustment of the section cavities have been done and the section was delivered to CERN for carrying out the tests with the operating voltage. The section will be used in Linac4

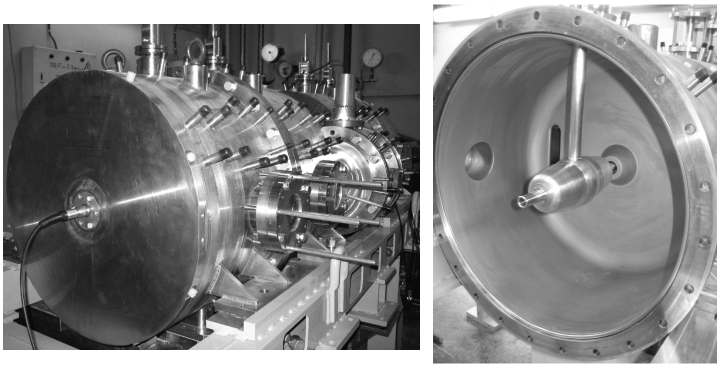

Figure 1: Секция CCDTL.

as a component of the first CCDTL (Cell Coupled Drift Tube Linac) module. Within the frame of the project, we also produced the cell (a periodicity element)of the SCL (Side Coupled linac) structure at a frequency of 704 MHz (Fig.2). The cell is a technological prototype subjected to the vacuum test and measurements of the cell rf-parameters.

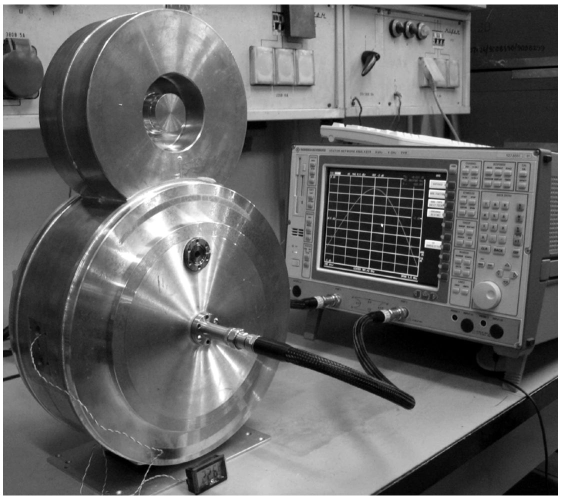

Figure 2: SCL Cell

Participants of the work:
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7.11 A grouping cavity for the injector of ERL LEPP, Cornell University

In 2006, the contract was signed on the development of the grouping cavity at a frequency of 1300 MHz for the injector of the Energy Recovery Linac (ERL) of the Laboratory of the elementary particle physics of the Cornell University. The design and technological workout of the order is completed

Participants of the work:
I.K.Sedlyarov, A.G.Tribendis, Yu.A.Biryuchevsky (RDB)

Chapter 8

Powerful Electron Accelerators and Beam Technologies

8.1 Radiation technologies and ELV electron accelerators

During 2006 Laboratory № 12 had delivered five accelerators and one transportation system:

1. Shengzhen, China	ELV-4
2. Shengzhen, China	ELV-6
3. Guangzhou, China	ELV-6
4. Apollo, Republic of Korea& China	ELV-8
5. Kapra, Republic of Korea	ELV-8
6. Podol'sk, Russia	transportation system

Five accelerators and one transportation system have been put into operation.

1. Shengzhen, China	ELV-4
2. Shengzhen, China	ELV-6
3. Podol'sk, Russia	transportation system
4. Guangzhou, Grain Elevator, China two accelerators	ELV-8
5. Daegu, Republic of Korea	ELV-12

It is necessary to note the start-up of two 100 kW electron accelerators ELV-8 for desinsection of grain in China (Figure 1), and 400 kW electron accelerators ELV-12 for dyeing wastewater treatment in Daegu, Republic of Korea.

Figure 1: Guangzhou, Grain Elevator, China.

8.2 Application of high power electron accelerator in wastewater treatment

(*) The article is made upon the release of the report "APPLICATION OF HIGH POWER ELECTRON ACCELERATOR IN WASTEWATER TREATMENT" presented by B. Han , S.M. Kim, J.K. Kim, Y.R. Kim, EB TECH Co., Ltd., Daejeon, Korea J.S. Choi, S.J. Ahn, Korea Dyeing Technology Centre, Daegu, Korea, R.A. Salimov, N.K. Kuksanov, BINP, on RUPAC-2006 , September 2006, BINP, Novosibirsk, Russia

Electron beam treatment of wastewater leads to their purification from various pollutants. It is caused by the decomposition of pollutants as a result of their reactions with highly reactive species formed from water radiolysis: hydrated electron, OH free radical and H atom. Sometimes such reactions are accompanied by the other processes, and the synergistic effect upon the use of combined methods such as electron beam with biological treatment, adsorption and others improves the effect of electron beam treatment of the wastewater purification.

In the process of electron-beam treatment of wastewater there are utilized chemical transformations of pollutants induced by ionizing radiation. At sufficiently high absorbed doses these transformations can result in complete decomposition (removal) of the substance. Under real conditions, i.e., at rather high content of pollutants in a wastewater and economically acceptable doses, partial decomposition of pollutant takes place as well as transformations of pollutant molecules that result in improving subsequent purification stages, efficiency of the process being notably influenced by irradiation conditions and wastewater composition.

We investigated the complex wastewater from textile dyeing companies in Daegu Dyeing Industrial Complex (DDIC). DDIC includes about hundred factories occupying the area of 600,000m2. Purification of the wastewater is performed by union wastewater treatment facilities (chemical treatment and 2 steps of biological treatment). Current facility treats up to 80,000m3 of wastewater per day, extracting thereby up to 500m3 of sludge. Rather high cost of purification results from high contamination of water with various dyes and ultra-dispersed solids.

The results of laboratory investigations showed the electron beam treatment of wastewater to be perspective for its purification. The most significant improvements result in decolorizing and destructive oxidation of organic impurities in wastewater. Installation of the radiation treatment on the stage of chemical treatment or immediately before biological treatment may results in appreciable reduction of chemical reagent consumption, in reduction of the treatment time, and in increase in flow rate limit of existing facilities by 30-40%.

Being convinced with the feasibility of laboratory scale tests, a pilot plant for a large-scale test (flow rate of 1000 m^3 per day) of wastewater has constructed in October 1998 and operated with the electron accelerator of 1 MeV, 40 kW. The size of extraction window is 1500 mm in width and Titanium foil is used for window material. The wastewater is injected under the e-beam irradiation area through the injector to obtain the adequate penetration depth. The speed of injection could be varied upon the dose and dose rate. Firstly, the wastewater has passed under the irradiation area, then directly into the biological treatment system. Many years' experience of pilot plant operation had shown high efficiency of the method of electron-beam wastewater treatment.

On the evaluation of economies and efficiency of pilot scale electron beam treatment facility, industrial scale plant for treating textile dyeing wastewater has constructed from 2003 to 2005 for

- decreasing the amount of chemical reagent up to 50%,
- improving the removal efficiency of harmful organic impurities by 30%,
- decreasing the retention time in Bio-treatment facility.

According to the data obtained in laboratory and pilot plant experiments with DDIC wastewater, the optimum absorbed dose for electron-beam treatment was chosen to be near 1 kGy. For those purpose the 400 kW electron accelerator with three separate irradiators ELV-12 was installed as a source of ionizing radiation. The plant is located on the area of existing wastewater treatment facility in DDIC and to have treatment capacity 10000 cubic meters of wastewater a day using one 1 MeV, 400kW accelerator, and combined with existing bio- treatment facility.

Figure 2 shows three extraction devices of ELV-12 electron accelerator with jet technological units located under them.

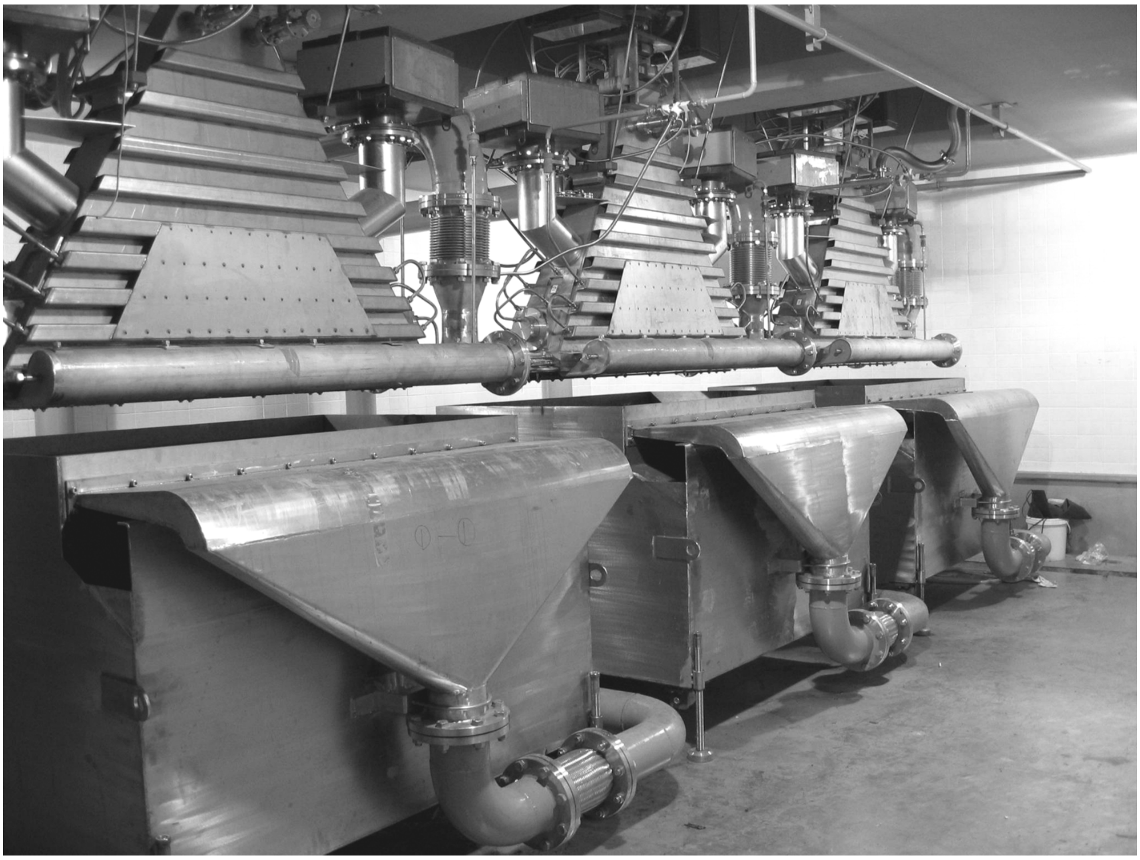

Figure 2: Wastewater treated with e-beam Electron accelerator ELV-12 for dyeing wastewater treatment in Daegu DIC, (Republic of Korea)

Presently, the dyeing wastewater treatment complex based on ELV-12 electron accelerator facilities successfully operates in Daegu (Republic of Korea). It is the first plant in the world operating as a full-scale industrial treatment facility with the use of electron-beam technologies.

8.3 Accelerators type ILU and their applications

Introduction

A line of radio frequency (RF) accelerators type ILU is developing and produced in Budker Institute of Nuclear Physics, Siberian Branch of the Russian Academy of Science, for more than thirty years. Accelerators of this line are purposed for wide application in various technological processes. They are designed for long continuous work in industrial conditions. Key parameters of ILU accelerators cover energy range from 0.7 to 5 MeV beam power up to 50 kW. Their main parameters are given in Table 1.

Parameters	**ILU-8**	**ILU-6**	**ILU-6M**	**ILU-10**	**ILU-10M**
Energy range, MeV	0.5÷1.0	1.2÷2.5	1.0÷2.5	2.5÷5.0	2.5÷4.0
Electron beam power (max), kW	25	40	20	50	20
Average beam current (max), mA	25	25	20	15	8
Productivity at dose rate of 10 Mrad, kg/hour	500	850	450	850	450
Weight, tons. Accelerator	1.75	2.2	2.2	2.9	2.5
Weight, tons. Local shield	76	–	–	–	–

Accelerator Deliveries

Since 1983 accelerators of type ILU 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 busy 2-3 shifts per day during many years and successfully maintain such loading. Reliability their work and their technological level are proved by new deliveries of the equipment. The accelerator ILU-6 was manufactured under the contract with the firm “EVALAR”, town of Biisk, Russia. This machine is purposed to work in the installation purposed for radiation processing of medicinal raw materials. The accelerator is prepared for installation at the customer’s site.

Two-window beam extraction system for the ILU-8 accelerator

The new beam extraction system with 2 beam windows for ILU-8 machine was developed, manufactured and put into operation on the customer’s site in 2006. The accelerator ILU-8 operating in Japan has energy 1 MeV and beam power up to 20 kW. This beam extraction system was developed for simultaneous processing of two types of products. The design of the system is shown in Fig. 1. The device has two scanning horns with beam windows, the beam is extracting into atmosphere by turns through both windows covered with titanium foil. The additional side beam window can be used for extraction of small part of beam power - controlled from 0% to 20%, while the main window can be used for extraction of 80-100% of total beam power. The device comprises the scanning horn with spallation pump, focusing lens, the main scanning magnet, a bending magnet and system of adjusting lenses. This system is handed successfully over to the customer.

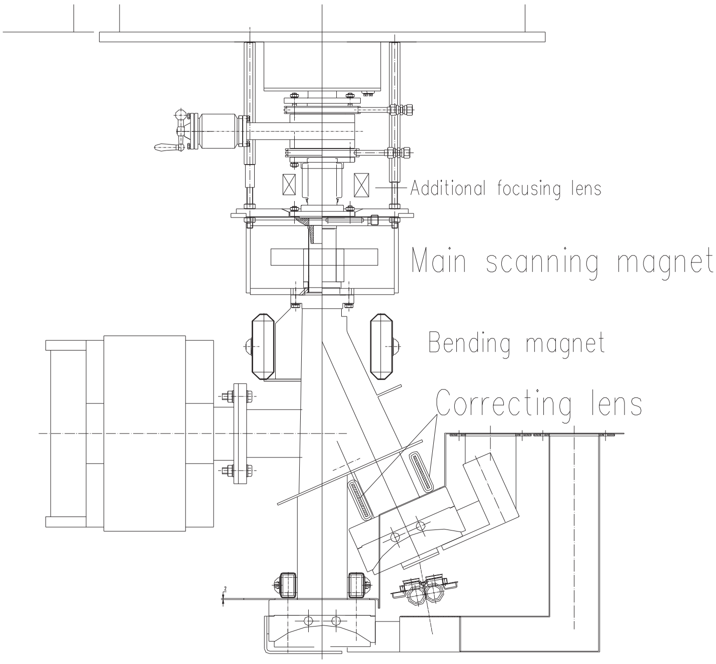

Figure 1: Two-window beam extraction system for the ILU-8 accelerator.

Development of the accelerator to ILU - 12

In 2006 continued the common works with Laboratory 6 on creation of the accelerator prototype ILU-12 with energy up to 5 MeV and pulse beam power up to 2 MW. Its accelerating structure (including electron gun unit) was manufactured and mounted (see Fig. 2) in the radiation protected bunker.

Figure 2: Mounted accelerating structure.

Measurements of eigen frequencies of all cells (see Fig. 3) were carried out and the fine tuning of accelerating structure according to calculations is performed.

Within the framework of the same project the works were carried out to suppress the excitation of RF resonant discharge (multipactor) inside the accelerating structure. The installation for TiN layer sputtering with vacuum tank having dimensions of 600x500x 500 mm was mounted for treatment of RF system details. The project of bigger vacuum system for TiN layer sputtering with the big chamber permitting to cover the details of ILU-12 resonators is developed. The order for manufacturing of vacuum system is handed over in shop. 2 RF loops for ILU-12 were covered by TiN layer for technology approbation.

Figure 3: Inner view of the accelerating cell.

The ILU-9 accelerator

In 2006 the ion accelerator ILU-9 was supplied with the proton-ion source using the plasma arc discharge. The possibility to increase the accelerating voltage in the existing design of accelerating structure was studied for ions H_2^{+1} and ions with $Z/A = 1/3$. Some changes in design of a power input loop were performed (the loop area in resonator was decreased) to this end. The result was the generation and acceleration of H_2^{+1} beam.

The voltage on the accelerating gaps of drift tubes was increased up to design values, practically twice exceeding the previously achieved voltage at acceleration of protons. The accelerated beam was fixed by the semi-conductor detector after passage through a titanium foil having thickness of 35 micron. At the last stage of experiments the accelerating voltage was increased in 1.5 times from design value that allows to accelerate a beam of ions with $Z/A = 1/3$.

Further it is supposed to carry out works on measurement of phase volume and a spectrum of the accelerated beams of protons and ions H2+1 and also to study the possibility to accelerate the ions of carbon C_{12}^{+4} with use of a carbon ions source with the appropriate increase in voltage on the accelerating gaps of drift tubes without changes in design of accelerating path.

Contract works and development of new technologies

The contract sterilization works were performed all year. The new radiation technologies were elaborated on working accelerators ILU-6 and ILU-10. The laboratory actively participated in various grants and contracts with Agencies of Russian Government and as in various research projects with other organizations.

Regularly the immobilization of proteolytic enzymes on polyethylenoxide was carried out by means of ionizing radiation. These works were carried out in collaboration with Siberian Center for Pharmacology and Biotechnology and Institute of Cytology and Genetics to develop the new generation of thrombolytic and proteolytic preparations.

The influence of electron irradiation on properties of semiconductor diodes was studied together with the Novosibitrsk Semiconductor Plant to improve the electric characteristics of diodes. The studies of reorganizations in a dopant-defective subsystems of silicon crystals were carried out Together with Institute of semiconductors of the Siberian Branch of the Russian Academy of Science. To this end the silicon crystals were irradiated by electrons at normal and increased temperatures. There are expectations that the irradiation will change the defective structure of the crystals and it will change the kinetics of oxygen-containing complexes formation during the following annealing. The infrared spectroscopy studies of these crystals will permit to determine the changes in the introduction, rate of introduction and formation and annealing temperatures for oxygen-vacancy and VnOm complexes, thermodopants and oxygen precipitates.

The experiments on solid state synthesis of lithium ferrites were carried out together with Tomsk Polytechnical University.

Participants of works:

V.L.Auslender, A.A.Bryazgin, G.A.Glagolev, V.A.Gorbunov, I.V.Gornakov, A.M.Molokoedov, L.A.Voronin, M.V.Korobeynikov, A.N.Lukin, I.G.Makarov, S.A.Maximov, V.E.Nehaev, G.N.Ostrejko, A.D.Panfilov, V.I.Podobaev, V.I.Serbin, G.V.Serdobintsev, A.V.Sidorov, V.V.Tarnetsky, M.A.Tiunov, V.O.Tkachenko, A.A.Tuvik, B.L.Faktorovich, V.G.Cheskidov, A.M. Yakutin.

Results of works are published in:

[473], [474], [475], [476], [477], [478], [479], [480], [481], [176].

Chapter 9

Physics for medicine

9.1 X-ray detectors for medicine and people inspection

9.1.1 Low-Doze X-Ray Device (LDRD) "Siberia"

In 2006, we continued the work on the upgrade of the Low-Doze Digital X-Ray Device LDRD "Siberia-N". In 2006, the development of a new X-ray detector D1536 was finished and the first sample was manufactured. Measurements carried out with the detector demonstrated that the detector has better spatial resolution and higher efficiency of detection of X-ray gamma-quanta than that of the BDR-2 detector. For example, the spatial resolution of D1536 is 260 μkm compared to 400 μkm of BDR-2. D1536 is the most optimum for the digital fluorography. The sample was delivered to Kazakhstan to Aktyubinskroentgen plant by the contract. The plant is planning manufacture of the X-ray devices with the use of D1536 detector. BINP and the plant have made the contract on the delivery of 50 detectors D1536. In the beginning of 2006, we have completed the development of the D1024 with the spatial resolution of 400 μkm, which also is intended for substilution of BDR-2 presently produced at GNPP "Vostok" and it is used in the LDRD "Siberia-N". Electronics of D1024 is shifted to the more advanced element base and the ionization chamber design is improved. The pilot sample of the detector is produced and tested. Delivery of the detectors for the set of fluorographs made in ZAO "Nauchpribor" (Oryol), BEMZ (Berdsk), "Elektrokhimpribor" (Lesnoi) was continued. During the year, we have produced 30 detectors.

9.1.2 Radiographic Control System (RCS)"Sibscan" for people inspection.

We have carried out the work on improvement of SRC "Sibscan"; two devices have been produced and installed in the airports of Russian cities Khanty-Mansiisk and Novosibirsk. A new X-ray detector for SRC "Sibscan" is developed, manufactured and tested. It is designed for substitution of BDR-2, which is now purchased by INP from GNPP "Vostok". In Oryol, a new design of the scanning mechanics is designed and manufactured for SRC "Sibscan", which differs from the existing version by the higher reliability, simplicity in production and its lower cost.

9.1.3 Mammography

In 2006, we continued the development of the detector for the digital mammography. The work proceeded in two directions: the multi-electrode ionization chamber (MIC) based detector and GaAs based detector. This year, we finished assembly and started tests of the MIC based 4-plane detector. Each detector plane is an independent MIC with a step of electrodes (strips) of 105 μkm and 1792 channels. Such design increases the number of detected photons by 4 times compared to the standard single-plane version. The first test have shown than on the whole, the detector is operational and its design has no essential imperfections. Also in 2006, we started assembly of separate modules of the GaAs based detector. Each module is a strip Arsenide-Gallium detector with a strip step of 200 μkm and 128 channels equipped with the detection electronics. In future, such modules will mounted at a special substrate in two rows with a 100 μkm displacement that enables one to achieve the detector final spatial distribution $\sim$100 μkm. The detector assembly completion is planned for 2007.

9.2 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 (1998) 397-426.

The financing of the project was carried due to fund of DOE-IPP grant, lab.9-0 (money earned in other international contracts) and partially from the fund of the Institute.

Designed scheme of the BNCT tandem is shown in 2001 Year Report. The scheme of the complex on the base of tandem for neutron therapy and, in addition, for the detection of nitrogencontaining substance by nuclear-resonant adsorption method was described in 2004 Year Report.

Results obtained in 2006:

• Manufacture of 1MV glass-ceramic feedthrough insulator (Fig.1), electrodes of the high volt- age accelerating gaps (Fig.2), flange variant of H- source (Fig.3), stripper (Fig.4) are completed.

• Manufacture of basic control systems for power supply units of tandem are completed.

• The some elements of the complex supervisory control infrastructure on the base of LABView software are set in operation.

• The major portion of electrotechnical and gas-vacuum-water infrastructure for the experimental hall is set in operation.

• The tandem, H- source, low energy tract (Fig.5) and the model of gammas target (Fig.6) are as- sembled together.

• It is obtained voltage level equal to 200 kV for the every from 6 accelerating gaps of tandem and voltage level equal to 1 MV for all gaps (Fig.8).

• Resonant gammas for the Nuclear Resonant Adsorption method were registered (Fig.9 - right-hand peak) during the experiment with proton beam and carbon gammas target.

Figure 1: 1MV glass-ceramic feedthrough insulator.

Figure 2: Electrodes of the high voltage accelerating gaps.

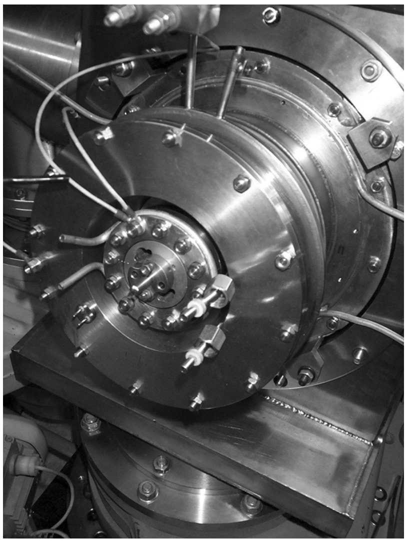

Figure 3: The flange variant of H-source.

Figure 4: Stripper.

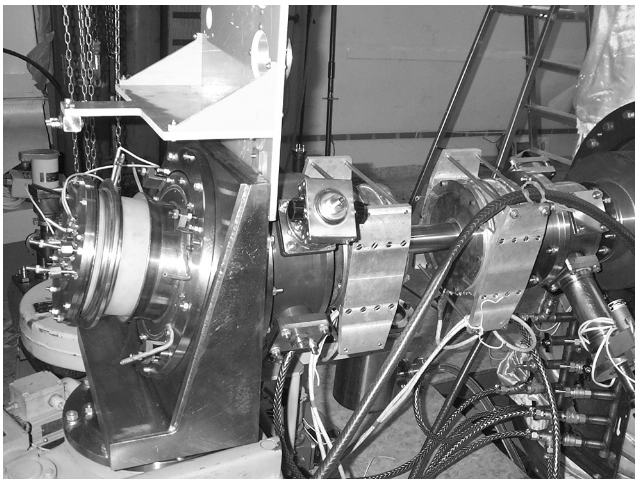

Figure 5: H^- source and low energy tract of tandem.

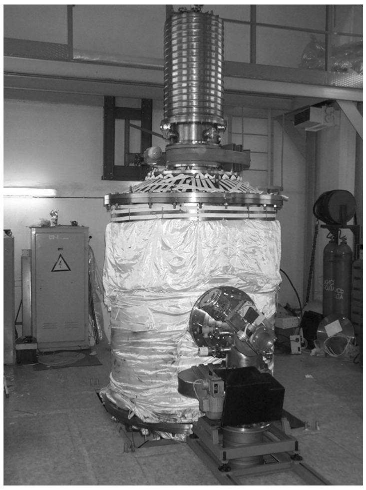

Figure 6: The model of gammas target assembled with tandem.

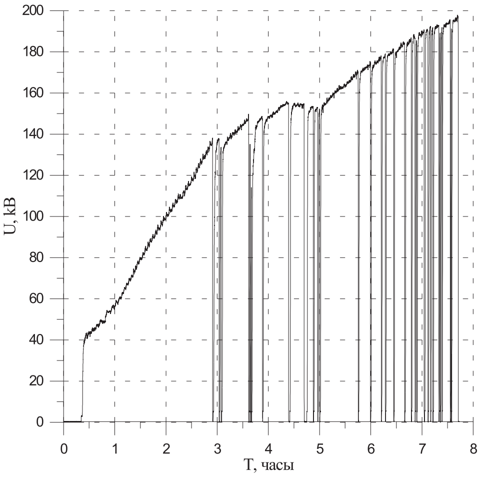

Figure 7: Training curve for the single accelerating gap of tandem.

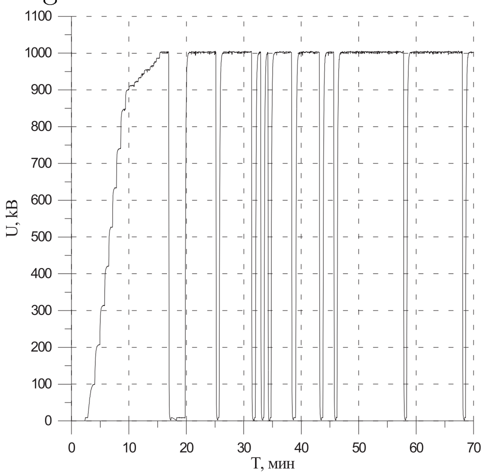

Figure 8: Training curve for the 6-accelerating gaps tandem.

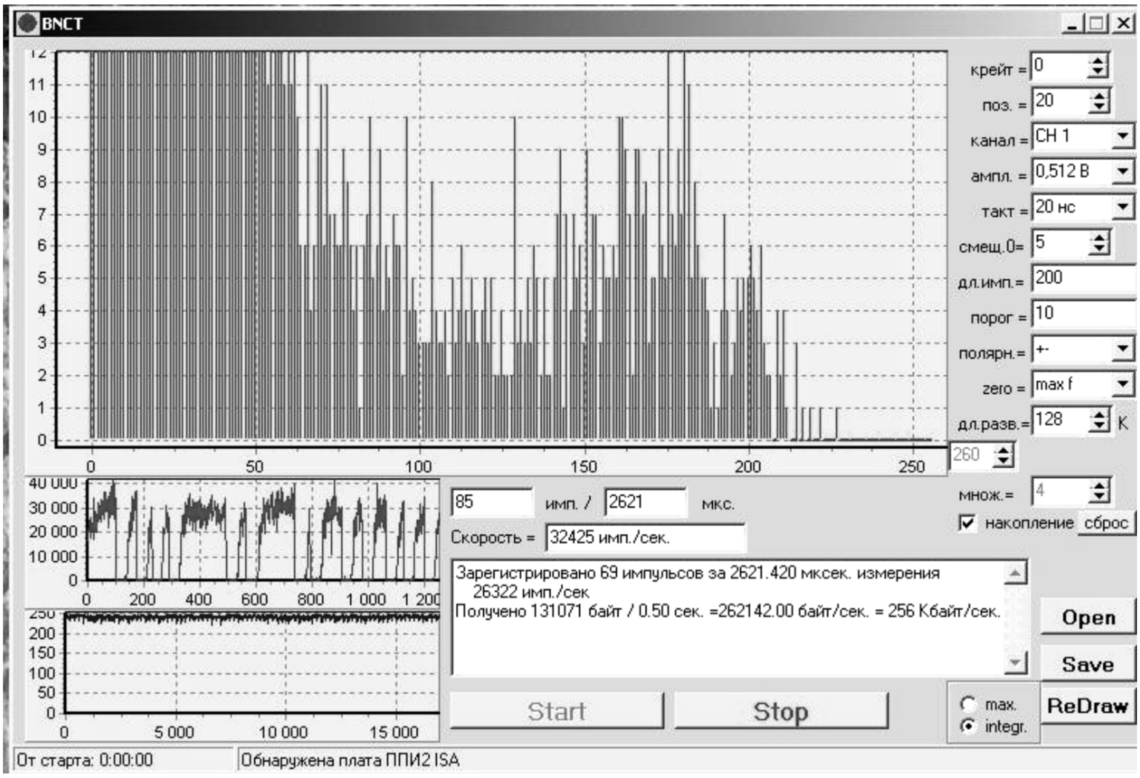

Figure 9: Spectrum of gamma-rays, registered in the experiment with 1.8 MeV proton beam and carbon gammas target.

Publication:
[152], [153], [154], [403], [404], [404], [404], [404], [405], [?], [155], [406], [407], [408].

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115. *Pakhlova G., Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., B. Shwartz, V. Sidorov, Yu. Usov, V. Zhilich, V. Zhulanov, et al. (Belle Coll.).* Measurement of the near-threshold $e^+e^- \to D^{(*)}\bar{D}^*$ cross section using initial state radiation. // hep-ex/0608018.

116. *Ishino H., Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., B. Shwartz, V. Sidorov, Yu. Usov, V. Zhilich, V. Zhulanov, et al.*

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118. *Lin S.-W., Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., B. Shwartz, V. Sidorov, Yu. Usov, V. Zhilich, V. Zhulanov, et al. (Belle Coll.).* Observation of B decays to two kaons. // hep-ex/0608049.
119. *Chang M.-C., Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., B. Shwartz, V. Sidorov, Yu. Usov, V. Zhilich, V. Zhulanov, et al. (Belle Coll.).* Observation of the Decay $B^0 \to J/\psi\eta$. // hep-ex/0609047.
120. *Urquijo P., Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., B. Shwartz, V. Sidorov, Yu. Usov, V. Zhilich, V. Zhulanov, et al. (Belle Coll.).* Moments of the electron energy spectrum and partial branching fraction of $B \to X_c e\nu$ decays at Belle. // hep-ex/0610012.
121. *Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., Shwartz B., V. Sidorov, Yu. A. Sokolov, Usov, V. Zhilich, V. Zhulanov, et al. (Belle Coll.).* High statistics study of the $f_0(80)$ resonance in $\gamma\gamma \to \pi^+\pi^-$ production. // hep-ex/0610038.
122. *Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., Shwartz B., V. Sidorov, Yu. Usov, V. Zhilich, V. Zhulanov, et al. (Belle Coll.).* Observation of the decay $\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$. // hep-ex/0611026.
123. *Tajima O., Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., Shwartz B., V. Sidorov, Yu. Usov, V. Zhilich, V. Zhulanov, et al. (Belle Coll.).* Search for invisible decay of the $\Upsilon(1S)$. // hep-ex/0611041.
124. *Schwanda C., Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., Shwartz B., V. Sidorov, Yu. Usov, V. Zhilich, V. Zhulanov, et al. (Belle Coll.).* Moments of the hadronic invariant mass spectrum in $B \to X_c l\nu$ decays at Belle. // hep-ex/0611044.
125. *Satoyama N., Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., Shwartz B., V. Sidorov, Yu. Usov, V. Zhilich, V. Zhulanov, et al. (Belle Coll.).* A search for the rare leptonic decays $B^+ \to \mu^+\nu_\mu$ and $B^+ \to e^+\nu_e$. // hep-ex/0611045.
126. *Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., Shwartz B., V. Sidorov, Yu. Usov, V. Zhilich, V. Zhulanov, et al. (Belle Coll.).* Study of $\bar{B}^0 \to D^0\pi^+\pi^-$. // hep-ex/0611054.

127. *Kusaka A., Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., Shwartz B., V. Sidorov, Yu. Usov, V. Zhilich, V. Zhulanov, et al. (Belle Coll.).* Measurement of CP asymmetry in a time-dependent Dalitz analysis of $B^0 \to (\rho\pi)^0$ and a constraint on the CKM angle ϕ_2. // hep-ex/0701015.

128. *Schümann J., Anipko D., Arinstein K., ..., Aulchenko V., Bedny I., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Garmash A., Krokovny P., Kuzmin A., Poluektov A., Shwartz B., V. Sidorov, Yu. Usov, V. Zhilich, V. Zhulanov, et al. (Belle Coll.).* Search for B decays into $\eta'\rho$, $\eta'K$, $\eta'\phi$, $\eta'\omega$, $\eta'\eta^{(')}$. // hep-ex/0701046.

129. *Akhmetshin R.R., Aulchenko V., Bondar A., Eidelman S., Epifanov D., Gabyshev N., Krokovny P., Kuzmin A., Shwartz B., V. Sidorov, et al. (CMD-2 Coll.).* High-statistics measurement of the pion form factor in the ρ meson energy range with the CMD-2 detector. // hep-ex/0610021.

130. *Barberio E., ..., Eidelman S., et al. (Heavy Flavor Averaging Group).* Averages of b-hadron properties at the end of 2005. // hep-ex/0603003.

Authorial papers-2006

1. *Davydenko V.I.* Intense focused fast atom beams for active corpuscular plasma diagnostics. // 01.04.20 - physics of charched particle beams and accelerator techniques, Author. papers of thesis for the degree of doctor of phys.-math.science: Novosibirsk, 2006, BINP, SB RAS.

2. *Kovalenko Yu.V.* Structure and hardware of control and data acquisition system of AMBAL-M plasma device. // 01.04.01 - instruments and methods of experimental physics, Author. papers of thesis for the degree of candidate of technical science: Novosibirsk, 2006, BINP, SB RAS.

3. *Yudin Yu.V.* Electronics for the BGO-based Spectrometric Systems of the CMD-2 Detector. // 01.04.01 - instruments and methods of experimental physics, Author. papers of thesis for the degree of candidate of technical science: Novosibirsk, 2006, BINP, SB RAS.

4. *Terekhov I.S.* Calculation of the radiative corrections to weak and electromagnetic processes in a strong Coulomb field. // 01.04.02 - theoretical physics, Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2006, BINP, SB RAS.

5. *Kirilin G.G.* Quantum corrections to the gravitational long-range interactions. // 01.04.02 - theoretical physics, Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2006, BINP, SB RAS.

6. *Rakshun Ya.V.* Features of the local structure of quasi-crystals of the Al-Cu-Fe system. // 01.04.07 – condensed matter physics Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2006, BINP, SB RAS.

7. *Solomakhin A.L.* Dispersion interferometer based on CO_2 laser. // 01.04.08 – physics of plasma, Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2006, BINP, SB RAS.

8. *Gubin K.V.* High-temperature target for production of intense flaw of high-energy neutrons. // 01.04.20 - physics of charged particle beams and accelerator techniques. - Author. papers of thesis for the degree of candidate of technical science: Novosibirsk, 2006, BINP, SB RAS.
9. *Avilov V.S.* The numerical analysis of the solid neutron production target design based on the experiments with its elements' prototype. // 01.04.20 - physics of charged particle beams and accelerator techniques. - Author. papers of thesis for the degree of candidate of technical science: Novosibirsk, 2006, BINP, SB RAS.
10. *Matveenko A.N.* Dynamics of electron beam in accelerator-recuperator of FEL. // 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, 2006, BINP, SB RAS.
11. *Starostenko A.A.* Application of a low energy electron beam as a method of nondestructive diagnostics of charged particles intensive beams. // 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, 2006, BINP, SB RAS.

Participation in Conferences

1. International Seminar: Selected Chapters of the Modern High Energy Physics and Accelerator Physics, January, 2006, BINP, SB RAS, Novosibirsk, Russia.
2. International Workshop on Physics of Electron-Positron Collisions at Low Energies, February, 2006, BINP, SB RAS, Novosibirsk, Russia.
3. International Conference on Linear Colliders (ILCWS06), 9-14 March, 2006, Bangalore, India.
4. Conference: Medical Information Technologies, 29-30 March, 2006, Moscow (Russia).
5. 11th International Conference on Ion Sources, March, 2006.
6. International Symposium on the Development of Detectors for Particle, Astro-Particle and Synchrotron Radiation Experiments (SNIC), April 3-6, 2006, SLAC, Menlo Park, CA, USA.
7. TPC Applications Workshop, 7-8 April, 2006, LBNL, Berkeley, CA, USA.
8. All-Russia Scientific Forum (RADIOLOGY-2006), 25-28 April, 2006, Moscow, Russia.
9. 6th International Chemical and Biological Medical Treatment Symposium, April 30 - May 5, 2006, Spiez, Switzerland.
10. 16th Topical Conference on High-Temperature Plasma Diagnostics, 7-11 May, 2006, Williamsburg, Virginia.
11. 9th International Conference on SRI (SRI 2006), May 28 - June 2, 2006, Dalgu, Korea.
12. International Workshop on Positron Source for the Future Linear Colliders, May, 2006, BINP, SB RAS, Novosibirsk, Russia.
13. 33th European Physical Society Conference on Controlled Fusion and Plasma Physics, June 19-23, 2006, Roma.

14. 10th European Particle Accelerator Conference (EPAC'06), 26-30 June, 2006, Edinburgh, Scotland, UK.
15. 16th Annual Conference of Nuclear Society of Russia: Non-Energetic Usage of Atomic Energy, 29 June, 2006, Moscow.
16. 6th International Conference on Open Magnetic System for Plasma Confinement, 7-21 July, 2006, Tsukuba, Japan.
17. XVI International Conference on the use of Synchrotron Radiation (SR-2006), July 10-14, 2006, BINP, Novosibirsk, Russia.
18. 33rd International Conference on High Energy Physics (ICHEP 06), 26 July - 2 August, 2006, Moscow, Russia.
19. V International Scientific Conference and III Conference-School of Young Scientists: Radiation and Thermal Effects and the Processes in Inorganic Materials, 28 July - 4 August, 2006, Tomsk, Russia.
20. International Conference Marcel Grossmann 11, July 2006, Berlin.
21. 28th Free Electron Laser Conference, 28 August - 1 September, 2006, BESSY, Berlin, Germany.
22. International Conference: Basic Science for Biotechnology and Medicine, 3-7 September, 2006, Novosibirsk, Russia.
23. XX Russian Conference on Charged Particle Accelerators (RuPAC 2006), 10-14 September, 2006, BINP, SB RAS, Novosibirsk, Russia.
24. 8th International Conference on Modification of Materials with Particle beams and Plasma Flows, 10-15 September, 2006, Tomsk, Russia.
25. 11th International Conference and School on Plasma Physics and Controlled Fusion, 11-16 September, 2006, Alushta, Crimea, Ukraine.
26. 40th ICFA Advanced Beam Dynamics Workshop on e^+e^- Factories 2006, 15-17 September, 2006, BINP, Novosibirsk, Russia.
27. New Trends in High-Energy Physics, 16-23 September, 2006, Yalta, Crimea, Ukraine.
28. 31st International Conference on Infrared and Millimeter Waves and 14th International Conference on Terahertz Electronics (IRMMW-THz 2006), 18-22 September, 2006, Shanghai, China.
29. 9th International Workshop On Tau Lepton Physics (Tau06), 19-22 September, 2006, Pisa, Italy.
30. DAE-BRNS-PSI Symposium on Power Beams and Materials Processing (PBAMP-2006), BARC, 21-21 September, 2006, Mumbai, India.
31. International Scientific and Practical Conference: Development of Antituberculosis Therapeutical Agents of Novel Generation. Problems, Approaches, Prospects, 26 September, 2006, Moscow region, Himki.
32. III All-Russian Conference Sharing Centers, October 5-28, 2006, Kazan, RF.
33. 12th International Congress on Neutron Capture Therapy, 9-13 October, 2006. Takamatsu, Kagawa, Japan.
34. 5th International Conference: Carbon: Fundamental Problems of Science, Materials Science, Technology, 18-20 October, Moscow (Russia).
35. ECFA-ILC Workshop on the Linear Collider ILC, 7-10 November, 2006, Valencia, Spain.

36. VI Conference of the Young Scientists (KoMU-2006), 20-24 November, 2006, Izhevsk, Russia.
37. XXIII Zvenigorod Conference on Plasma Physics and Controlled Fusion, February, Zvenigorod, Russia.
38. XXXIX St.Petersburg Winter School, 20-26 February, 2006, St.Petersburg, Repino, Russia.
39. International Meeting on Radiation Processing (IMRP2006), 26 February - 3 March, 2006, Kuala Lumpur, Malaysia.
40. International ITEP School, February, 2006, Moscow.
41. Seminar in Memory of M.P. Bronshtein, December, 2006, St.Petersburg, Russia.
42. 5th Workshop of SB RAS and UB RAS: Thermodynamics and Materials Science, 2006, Novosibirsk (Russia).
43. 19th International Conference on the Application of Accelerators in Research and Industry, Fort Worth, Texas, USA.
44. 16th International Conference on High-Power Particle Beams, 2006, Oxford, UK.
45. 13th International Congress on Plasma Physics (ICPP 2006), Kiev, Ukraina.
46. 16th International Conference on High-Power Particle BEAMS (BEAMS'2006), Oxford, UK.
47. 14th International Symposium on High Current Electronics, 2006, Tomsk, Russia.
48. 2nd International School for Young Scientists and Specialists: Interaction of Hydrogen with Constructional Materials. Methods of Investigation (IHISM'06 Junior), 2006, St.Petersburg State University, Russia.
49. 21st IAEA Fusion Energy Conference, Chengdu.
50. VI International Workshop on Strong Microwaves in Plasmas, 2006, N. Novgorod, Russia.
51. 8th International Conference on Electron Beam Technologies (EBT 2006), 2006, Varna.
52. Conference: Information Technologies, Systems and Instruments in Agro-Industrial Complex (AGROINFO-2006), 2006, Novosibirsk, Russia.

List of Collaboration Agreements between the Budker INP and Foreign Laboratories

	Name of Laboratory	Title or Field of Collaboration	Dates	Principal Investigators
N°	1	2	3	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	1992	A. Bondar (INP), F. Takasaki (KEK)
		2. Electron-positron factories (B-, ϕ-factories)	1995	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)

Research Personnel

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27.	Corr. Member RAS	Khriplovich I.B.
28.	Academician	Chirikov B.V.
29.	Doctor of phys.-math. science, Professor	Shatunov Yu.M.
30.	Candidate of phys.-math. science	Taskaev S.Yu. – Representative of Trade Union
31.	Doctor of phys.-math. science	Lotov K.V. – Representative of Council of Young Scientists

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