Russian Academy of Sciences
Lenin Order Siberian Branch

BUDKER INSTITUTE OF NUCLEAR Physics

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Contents

Introduction

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

Academician G.I. Budker was the founder and first Director of the Institute. Since his death in 1977 to the present time, the Director of the now called "The Budker Institute of Nuclear Physics , BINP SB RAS" is academician A.N.Skrinsky.

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 2800 and among them: about 420 researchers, over 50 postgraduates, 760 engineers and technicians, about 350 laboratory assistants and 1200 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 are recognized by the BINP Scientific Council as the best in 2007:

1. **VEPP-2000:**

The complex was successfully commissioned. The electron and positron beams were successfully injected and stored. The collision of the "round" beams occurred and the first luminosity was attained.

2. **SND-detector:**

An analysis of the generation process of a pair of charged K-mesons is completed. The cross-section obtained is generally agreed with the previous measurements but it has a higher accuracy. The cross-section as a function of energy is well described by the model of vector dominance with an account for the state $\phi(1680)$.

3. **Injection Complex of VEPP-5:** All the systems of the storage ring cooler are put into test operation. An 300 MeV electron beam with a current up to 20 mA was injected and captured in the ring.

4. **International Collaboration:**

In 2007, the experimental indication to the presence of the DO-anti-DO mixing was first obtained in collaborations Belle and Babar with participation of BINP staff. The standard model predicts that it should be small therefore, its study is important for the search for indications of novel "physics".

5. **GDL Facility:**

An increase in duration of the atomic injection at GDL from 1 to 5 ms enabled us to shift to a study of the quasi-stationary regime of confinement. The density of fast ions with a mean energy of 10 keV was attained to be $3x10^{13}$cм$^{-3}$. In this case, the parameter β exceeds 40%.

6. **Proton accelerator-tandem:**

At the tandem-proton accelerator designed for the Boron-neutron capture therapy and detection of explosives, the proton current of 2 mA at energy 1.9 MeV was obtained and the successful experiment was carried out on generation of gamma-radiation with an energy of 9.17 MeV at the carbon isotope ^{13}C and its resonance absorption at the liquid nitrogen target.

7. **Industrial electron accelerators:**

An electron beam with energy 1,0÷1,5 MeV and power up to 100 kW capable to evaporate practically any substance was extracted from the ELV-accelerator. This property was used for obtaining the nano-dispersion powders of silicon oxides and other materials as metals and nitrides by evaporation. This method is used for the first time in the world. The result of the work is the development of the pilot facility for obtaining nano-dispersion powder of the silicon oxide from the natural quartz sand. The work is carried out jointly with the Institute of the Theoretical and Applied Mechanics SB RAS.

8. **Theoretical works:**

The Kernel of the equation determining the energy dependence of QCD amplitudes was found in the space of the impact parameters in the next to leading approximation.

It is shown that interaction of antiprotons with polarized protons of the hydrogen target in the storage ring enables to obtain the beams of polarized antiprotons with parameters providing the possibility of carrying out polarized experiments at GSI.

In 2007, three leading scientists of BINP (G.N.Kulipanov, A.S.Medvedko, N.A.Mezentsev) were awarded by the RF Government Prize in the field of science and technology.

In 2007, BINP hosted the International Conference on Free Electron Lasers.

Chapter 1

Physics of Elementary Particles

1.1 CMD-3 Detector

During 2007 works on production and testing of CMD-3 detector systems have been continuing.

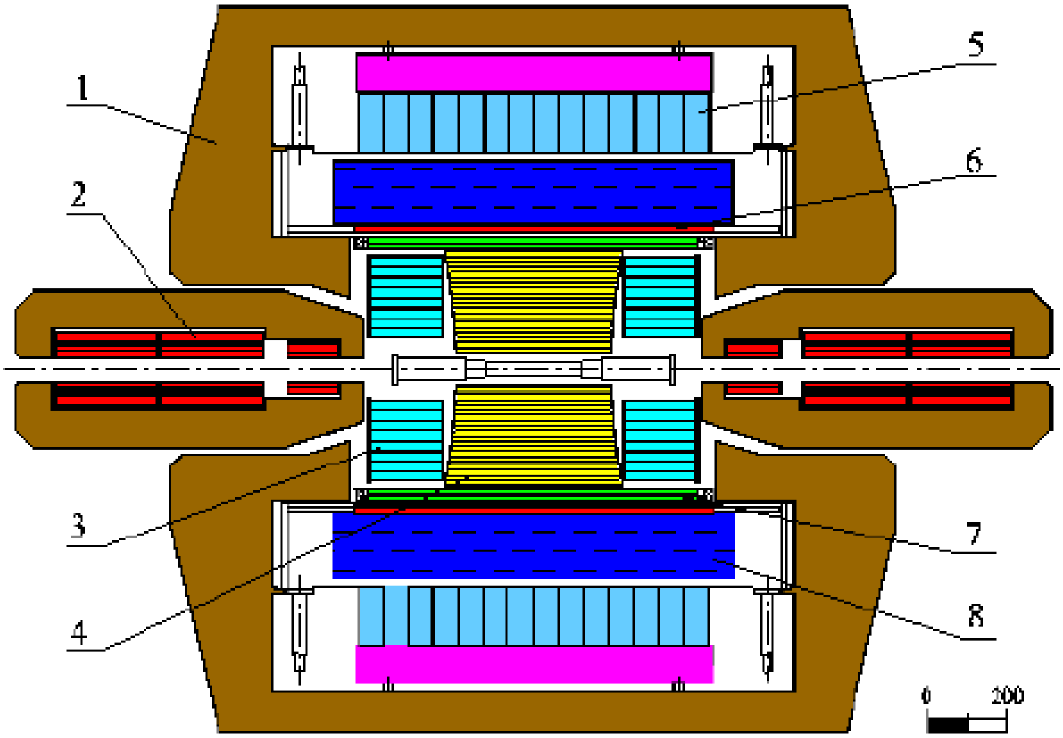

Figure 1: CMD-3 Detector. 1 — magnet yoke; 2 — VEPP-2000 superconducting solenoids; 3 — BGO electromagnetic calorimeter; 4 — Drift Chamber; 5 — CsI electromagnetic calorimeter; 6 — CMD-3 superconducting solenoid; 7 — Z-chamber; 8 — LXe electromagnetic solenoid.

Longitudal cross section of the CMD-3 Detector is shown in Fig. 1.

The drift chamber signal cables assembling has been finished. All digitizing electronics for the CMD-3 drift chamber — T2Q modules — were produced at the Institute workshop. To test the electronics and the chamber performation the physics runs run on cosmic rays particles were performed. The spatial resolutions 100 - 120 mcm and 3 mm have been obtained for $R - \varphi$ and RZ planes respectively in excellent agreement with project expected values. Tuning of the CMD-3 Charged Trigger Systems has been started. The trigger will be used for experiments with e^+e^- beams.

Z-chamber, used for precise measurement of charged track coordinates and in trigger, was installed into detector at VEPP-2000 experimental hall together with the digitizing electronics. Data Acquisition and OFFLINE event reconstruction Software for the Z-chamber is in preparation.

Ramping system for the CMD-3 detector superconducting solenoid has been manufactured and tested. It allows to ramp current up to 1000 A, which corresponded to magnetic field value 1.5 Tl. After the tests all elements of the superconducting system were installed and tested in the detector at VEPP-2000 experimental hall. Works on decreasing of liquid Helium consumption are now performing.

All octants for CsI barel electromagnetic calorimeter have been assembled. Two octants have been installed into the CMD-3 detector at VEPP-2000 experimental hall and used in physics runs with cosmic rays particles. In particular, first part of UFO-32 digitizing electronics for the calorimeter was tested in the runs. The total amount of the UFO-32 electronics (40 modules) is now under construction at the Institute workshop. System for the measurement of the CsI calorimeter temperature and humidity has been assembled and tested now. Software for OFFLINE event reconstruction in the calorimeter is under development.

The BGO endcap calorimeter was completely assembled and ready for installation into the CMD-3 detector at VEPP-2000 experimental hall. Works on production and testing of the calorimeter termostabilization system is close to its finish. Production of radiofrequency cables is almost finished too.

There was the physics run using cosmic rays particles in which Z-chamber, scintillating counters and LXe calorimeter have worked together. In the run LXe calorimeter was completely equipped with the analog electronics. The detector trigger in the run was based on signals from Z-chamber and muon counters. In the run the time and spacial resolutions of the systems have been studied.

In 2007 new powerful ONLINE server has been installed into the CMD-3 detector Data Acquisition System. The server will satisfy the requirements of the Data Acquisition system for reasonable time in future. Readout of the electronics in KLUKWA standard was performed and tested using Ethernet network. Software for the different detector parameters control was completely developed and now is used in all test runs.

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

Participants of work:
Anisyonkov A.V., Aulchenko V.M., Akhmetshin R.R., Bashtovoy N.S., Barkov L.M., Banzarov V.Sh., Bondar A.E., Bragin A.V., Viduk S.N., Vorobyov A.I., Grebeniuk A.A., 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., Kuzmin A.S., Logashenko I.B., Lukin P.A., Mikhailov K.Yu., Okhapkin V.S., Pestov Yu.N., Pirogov S.A., Popov A.S., Popov Yu.S., Ryskulov N.M., Ruban A.A., Redin S.I., Sibidanov A.L., Snopkov I.G., Solodov E.P., Talyshev A.A., Titov V.M., Fedotovich G.V., Khazin B.I., Shwartz B.A., Eidelman S.I., Yudin Yu.V.

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1.2 The SND detector

1. SND upgrade for experiments at VEPP-2000.

After final assembling in December 2006, the SND tracking system was placed in the electronic console room of SND. All of 216 signal wires were connected to the regular SND registering electronics - analog amplifiers and information plates T2AM in the KLUKVA standard. During January - June 2007, a series of experiments were performed to measure basic parameters of the system by using particles of cosmic radiation.

First switchings revealed somewhat high frequency of firing of separate wires, caused by the small particles of dust which were remained in the volume of the tracking system after assembling. Several series of trainings of the wire structure were carried out with the reversed polarity voltage equaled to 70 percent of the nominal voltage, with the subsequent washing of the gas volume of the tracking system by alcohol. Such measures made it possible to noticeably reduce the noise level of the signal wires and to obtain the designed gas amplification factor, equal to $\simeq 0.5 \cdot 10^6$, in all drift cells of the tracking system.

For the switching on of the tracking system the high-voltage divider was used, whose potentials were calculated and optimized according to the results of tests with the full-scale prototype of tracking system in 2005 - 2006. The selected divider made it possible to obtain the designed uniformity of the gas amplification factor at the level of 10% for all layers of signal wires. This, in turn, made it possible to ensure the registration efficiency at the level not lower than 98% for each registration cell under the designed threshold of discriminators. The construction of the tracking system involves the parallel high-voltage power supply for the purpose to decrease the influence of the detector load by the charged particles tracks on the stability of the gas amplification factor.

In conducting the experiments with the cosmic ray particles, several versions of the trigger were used. In one of the versions the start of the readout electronics was triggered by the coincidence signal of two photomultipliers of the scintillation counter, located in the cylindrical cavity of the tracking system. In the second version the coincidence of signal from the scintillation counter photomultiplier with the signal of the logic of tracks, developed for experiments with the SND detector at VEPP-2000, was required. For each wire fired in the event, the response time of the discriminator with the accuracy of the order of one nanosecond and a sequence of signal amplitudes from both sides of the wire, measured with the step of 25 nanoseconds (digital oscillograms), were recorded. The recording rate of events was about 0.2 Hz. In total, more than 30 thousand tracks of cosmic ray particles were recorded.

For the drift time based coordinate resolution measurements, the event reconstruction program, based on the Kalman filter, was used. The drift velocity was assumed to be a constant and its value, as well as the dependence of the coordinate resolution on the drift distance were determined from simulation. The linear approximation of the dependence of coordinate on the drift time contained two parameters for each layer. Experimental events were used to determine the final values of the linear approximation parameters and the corresponding coordinate resolutions for all nine layers. For this goal the suitably defined likelihood function was minimized. The likelihood function included all reconstructed cosmic ray tracks with four and more hits. The track parameters were fixed in the minimization.

The described algorithm served as the basis of the pilot version of the calibration program for the dependence of coordinate on the drift time. The obtained dependence is in a good agreement with calculations and results of simulation. Averaged over the length of the ionization drift, the coordinate resolution corresponds to the designed value and equals to 150 μm. For small drift lengths the resolution noticeably worsens and this is connected with statistical nature of the distribution of primary clusters of ionization along the track. For the large lengths of drift, the contribution of the drift velocity dependence on the distance and direction of the drift becomes appreciable. The obtained experimental results will be subsequently taken into account in the calibration procedure of the dependence of coordinate on the drift time.

The initial version of the calibration program for the coordinate determination along the beam axis is realized. The coordinate is determined by the charge division method with the registration of signals from both sides of the high-resistance signal wire. The calibration of coordinate is performed in several steps. At first, the results of the generator calibration of the amplitude channels of the registering electronics are applied to the measured values of charges, which makes it possible to take into account the non-uniformity of the response of the used electronics. In the second stage, the events with the tracks, which wholly lie in one of the drift cells, are selected. The analysis of such events makes it possible to take into consideration displacements of each signal wire relative to the general system of coordinates of the detector. Third stage – absolute calibration of the coordinate scale along the beam axis.

The average coordinate resolution in the beam axis direction, measured according to the results of the 2007 experiments, was 2 mm, which is close to the designed value of 1,5 mm. Subsequently, the refinement of this coordinate resolution with the aid of the information from the cathode strips, placed on the surfaces of the inner covering of the housing of the tracking system facing the gas volume, is planned.

Figure 1: The photograph of the SND tracking system during the tests.

The first segment of the aerogel counter was manufactured in 2007. Measurements with this segment, by using the cosmic ray particles, gave the results statistically consistent with the analogues results obtained with the test prototype counter earlier. In the second half of 2007, assembling of the two remaining segments of the counter was conducted. The installation of the front-end electronics in the housings of the segments is near the end at the given moment, after which the last stage of assembling will be executed – packing of aerogel into segments.

In the same year, the electronics for the proportional counters of the SND muon system was manufactured and established. The proportional counters modules were tested with the aid of a radioactive isotope source, as well as with the cosmic ray particles, and they are ready for installation at the detector. Muon system readout electronics was also manufactured. The main part of the barrel scintillation counters were tested with cosmic muons. In 2008 it is planned to install the muon system at the detector and to connect it to the SND data acquisition system.

At present electronics of all subsystems of the SND detector is completed and ready to work. Its testing is conducted in the electronic console room of the detector.

For purposes of preparation of the nucleon form factors measurement experiment, the shaper of the calorimeter counter pulses for measuring the time of flight was designed and constructed. Soon measurements of the time resolution of the SND calorimeter counter with this shaper will be performed to optimize its parameters. Work is continued on optimization of the selection criteria for events with neutron-antineutron pairs formation and to the suppression of background. For this goal events simulated in GEANT4, as well as experimental events collected by the SND detector at VEPP-2M collider, are used.

Software of the data acquisition system was polished up and modernized taking into account the requirements of the experiment:

– estimation of the luminosity according to the trigger is realized;

– readout of the “yes-no” plates is realized;

– selection of events for the visualization according to the logical formula of trigger masks is realized;

– access to the data bases through the Web-interface was optimized;

– possibility to launch the tertiary trigger L3 is realized for the analysis of events in the off-line regime, without interaction with the on-line processes;

– a new feature of the tertiary trigger modules parametrization is realized: at the beginning of the program there is a possibility to select from where the parameters of the modules will be taken: from the DB (as it was earlier) or from the file (through AppParams);

– the stoppage scenario of processes is improved: warning signals about the stoppage and processing were added for each process;

– the Readout context restoration process is realized;

– intake of the channel firings is conducted: counting of the firings of channels was added in L3;

– display of the data from VEPP (currents) and SND measurements of luminosity is added to the operator interface;

– scaling of the scalers plot is improved;

– the tertiary trigger masks is added into the event record;

– profiling of the L3 functioning is carried out;

– the possibility to start the different assemblings of framework (optimized, check-out version for adjustments and so forth.) is realized in L3Shell;

– errors were corrected according to the results of the test and operational runs, the operational effectiveness of the system is improved.

The transition of the SND cluster computers to the operating system Scientific Linux 5 is started. This OS is assumed to be the final working version, that is it will be used in the entire period of the data collection and analysis.

For Monte-Carlo simulation of the SND detector, responses of the tracking system, calorimeter and muon system are realized. The simulation of the tracking system response takes into account primary ionization fluctuations, drift and diffusion of the ionization, gas amplification. The module is added to the calorimeter response simulation to take care of the light collection non-uniformity. In the trigger simulation all subsystem of the detector, except the Cerenkov counter, are included. At present the event reconstruction program for the SND tracking system is modernized in order to increase the event reconstruction rate.

In 2007 with the aid of the SND calorimeter, using the created data acquisition system, the luminosity Of the VEPP-2000 collider was measured by using events of the processes $e^+e^- \to e^+e^-$ and $e^+e^- \to \gamma\gamma$. The measured luminosity over beam current (the specific luminosity) turned out to be about $10^{28}\text{sec}^{-1}\text{cm}^{-2}\text{mA}^{-1}$.

Figure 2: The SND detector at the VEPP-2000 collider.

2. VEPP-2M data analysis. In 2007 the article dedicated to the measurement of the total cross section of the process $e^+e^- \to K^+K^-$ in the energy range $\sqrt{s} = 1.04 \div 1.38$ GeV was published. The total integrated luminosity in the experiment was 6.7 pb^{-1}. The average statistical error of the measurement is equal to 4.4 %, the systematic error —

5.2 %. The cross section is described by the vector dominance model taking into account the contributions of the light vector mesons ρ, ω, ϕ and first excitations of these states.

Analysis of the process $e^+e^- \to \mu^+\mu^-$ in the energy region above 1 GeV is near completion. Work is continued on the analysis of the processes $e^+e^- \to \pi^+\pi^-$ ($2E$ >1 GeV), $e^+e^- \to e^+e^-\gamma\gamma$ and number of others, recorded during the experimental cycle at VEPP-2M with the SND detector.

3. Participation in international projects. In 2007 the BABAR collaboration have published 58 articles, four of which were prepared with determining participation of the BINP group. With the use of a new method, which makes it possible to decrease the theoretical error, determination of the Cabbibo-Kobayashi-Maskawa matrix element $|V_{ub}|$ from the inclusive charmless B-meson decays was carried out. By the method of radiative return, the cross sections of the e^+e^- annihilation into the hyperon pairs $\Lambda\bar{\Lambda}$, $\Lambda\bar{\Sigma}^0$, $\Sigma^0\bar{\Sigma}^0$ were measured, as well as the cross sections of the following processes $e^+e^- \to K^+K^-\pi^+\pi^-$, $K^+K^-2\pi^0$, $2(K^+K^-)$ and $e^+e^- \to 2(\pi^+\pi^-)\pi^0$, $2(\pi^+\pi^-)\eta$, , $K^+K^-\pi^+\pi^-\pi^0$, $K^+K^-\pi^+\pi^-\eta$ for energies from the thresholds up to 4.5 GeV. Many of these cross sections were measured for the first time. The results of these investigations were reported at the international conferences LP07 – 13th International Symposium on Lepton-Photon Interactions at High Energy, and at HADRON07 – XII International Conference on Hadron Spectroscopy.

4. Developments in experimental methodics. In 2007, together with Lab. 3-12, work was continued on the modernization of the X-ray radiation detector OD-3. The basic difference of the new detector from its predecessor is the use of a new readout electronics. The contemporary element base makes it possible to perform the full processing of the recorded signals in the compact electronic section in immediate proximity of the sensitive volume of the detector, made on the basis of multiwire proportional chamber. For the data transfer and detector control from the remote computer, the standard protocol Ethernet is used. Together with an increase in compactness and ergonomic quality of the installation, this solution is used to improve a number of the metrological and performance properties of the detector and to increase its reliability.

In the spring of 2007 the first switchings of the prototype detector with the part of the registration electronics took place, and at the end of the same year the full-scale tests of the first OD-3M detector, completely prepared and equipped, began. The first results, obtained with the radioactive isotope Fe55, confirmed the attainability of the designed operational and metrological parameters of the new detector. In accordance with the established contract terms and conditions, at the beginning of the 2008 year the first installation OD-3M will be delivered to the Kurchatov center of synchrotron radiation (KSRS, Moscow).

In the work participated:

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

1.3 Detector KEDR

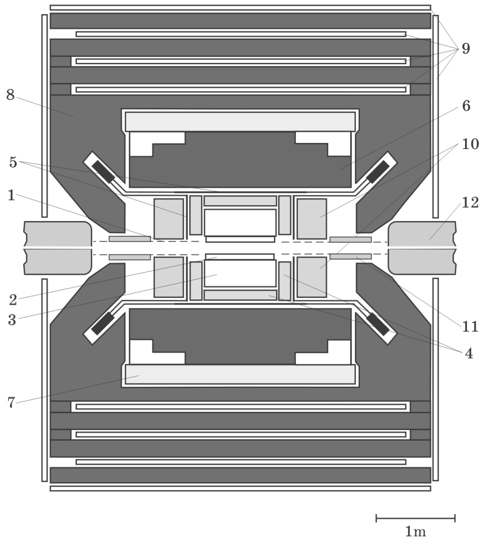


Figure 1: The KEDR detector. 1 - vacuum tube of the collider, 2 - vertex detector, 3 - drift chamber, 4 - aerogel Cherenkov counters, 5 - time of flight counters, 6 - liquid krypton barrel electromagnetic calorimeter, 7 - superconducting solenoid, 8 - magnet york, 9 - muon chambers, 10 - end cap electromagnetic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

The KEDR is the universal magnetic detector working on e^-e^+ collider VEPP-4M in the energy region from 3 to 11 GeV in the center of masses. The detector consists of the following systems (Fig. 1): vertex detector, drift chamber, aerogel Cherenkov counters, time of flight scintillation counters, barrel electromagnetic calorimeter based on liquid krypton, end cap electromagnetic calorimeter based on CsI crystals, superconducting solenoid, muon system, tagging system and luminosity monitor.

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 um 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 um. The resolution obtained at VD using cosmic tracks is 170 um. 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 innner 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 mkm 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 2007 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 mkm in the axial layers and 220 mkm 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 reemits, captured into the angle of total internal reflection and transported to the photodetector (ASHIPH method). The ASHIPH system of the KEDR detector contains 160 counters in two layers. The counters are arranged in such a way that a particle from the interaction point with a momentum above 0.6 GeV/c should not cross the shifters of both layers. 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 2006-2007 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 2007. 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.

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 2007 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 2007.

During 2007 the KEDR detector have collected data in the energy region of τ-lepton threshold and in the regions of J/ψ, ψ' resonances.

The main tasks of experiments were precise measurements of masses of τ–lepton, D-mesons, investigation of decays, for example measurement of ψ' 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.

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 2.

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

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

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

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

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

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

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.

In the present work the measurement of the $\psi(3770)$ mass and total width has been completed.

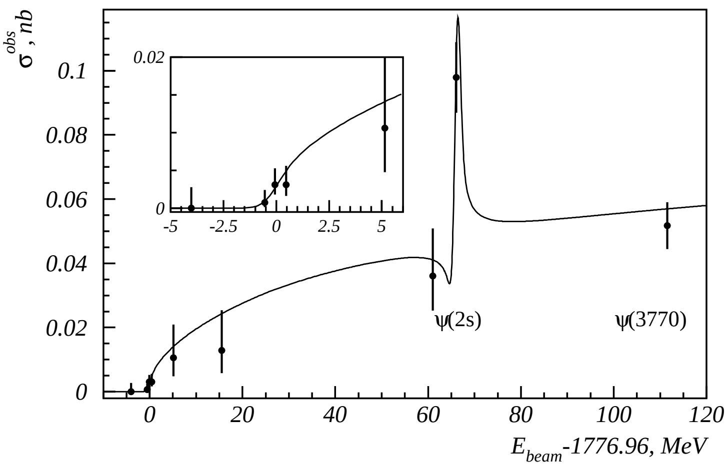


Figure 2: The observing τ–lepton production cross section near threshold (preliminary results).

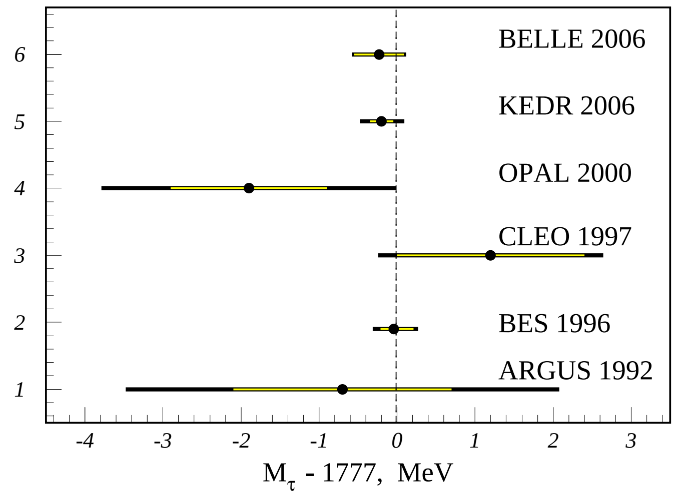


Figure 3: The τ-lepton mass.

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

During 2004 and 2006 the three scans of the $\psi(3770)$ - resonance with the detector KEDR were performed and the integrated luminosity $\int Ldt \approx 2.4$ pb^{-1} has been collected.

Our preliminary results and that of the previous experiments are shown below.

Experiment	$M_{\psi(3770)}$ [MeV]	$\Gamma_{\psi(3770)}$ [MeV]
MARK-I	3774.1 ± 3	28 ± 5
DELCO	3772.1 ± 2	24 ± 5
MARK-II	3766.1 ± 2	24 ± 5
BELLE	$3778.4 \pm 3.0 \pm 1.3$	–
BES-II	$3772.8 \pm 0.7 \pm 0.3$	$26.9 \pm 2.4 \pm 0.3$
PDG2007	3772.4 ± 1.1	26.3 ± 1.9
KEDR(preliminary)	$3772.9 \pm 0.6 \pm 0.8$	$25.8 \pm 3.0 \pm 3.0$

The results of the experiment have been reported at HEP2005 .

Neutral and charged D mesons are the lightest states in the open charm system. The knowledge of their masses is essential as a starting point for the measurement of the masses of exited states. Despite this, the measurement is important to establish the nature of the recently discovered X(3872) state, the mass of which is close to the $D^0 - D^{*0}$ threshold. Before 2007, the measurement of D masses was based on the results of ACCMOR and MARK-II experiments, the world average precision was about 0.5 MeV. In 2007 CLEO-c collaboration published the result of D^0 mass measurement with the precision of 0.18 MeV in the analysis of $D^0 \to K_S\phi$ decay. The analysis of $\psi(3770) \to D\bar{D}$ decays aiming at the measurement of neutral and charged D meson masses has been performed at KEDR experiment. The preliminary values obtained are $M(D^0) = 1865.43 \pm 0.60 \pm 0.38$ MeV and $M(D^+) = 1869.39 \pm 0.45 \pm 0.29$ MeV. The value of D^0 mass is consistent with more precise CLEO-c measurement obtained with the different technique; the measurement of the D^+ mass is presently the most precise direct measurement, and it agrees with the world average value.

The combination of widths is one of the fundamental resonance's parameters and thus is important for theories. It also helps to obtain other resonance's parameters useful for both theoretical and experimental studies.

There is no PDG value for the quantity being measured at the moment.

This measurement is more technically complicated than, for instance, measurement of branching. Parameters like widths and branchings of $\psi(2S)$ are calculated by PDG using combined fit of results of several experiments.

The statistics taken at VEPP-4M collider and KEDR detector in 2004-2006 has beep processed. Total integral luminosity accounted for is more than 2 pb^{-1}.

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

$$\frac{\Gamma_{ee}\Gamma_{\mu\mu}}{\Gamma} = 17.9 \pm 0.5 \pm 0.9 \text{ eV}.$$

Using PDG value for Γ_{ee} one could get $B(\psi(2S) \to \mu^+\mu^-) = (79 \pm 2 \pm 5) \times 10^{-4}$ while PDG fit value is $B(\psi(2S) \to \mu^+\mu^-) = (74 \pm 8) \times 10^{-4}$.

This preliminary result was presented at scientific session-conference Russian Academy of Science in November 2007.

1.4 Detectors for HEP

On the KEDR detector, in 2007 as in previous year, the main efforts in the filed of 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, it provided the storage of a large volume of experimental data. In addition, for the detector calorimeters, a new more reliable version of the digitizing electronics (A32 board) was produced. The work on upgrade of electronics for various systems of the SND detector is practically finished. Starting from the summer of 2007, the calorimeter electronics is being operated in the full extent in measurements of the VEPP-2000 luminosity. The beginning of experiments is planned for the autumn 2008.

For the KMD-3 detector, 45 highly complex printing boards were produced out of BINP. At present, these boards are under assembly at the BINP radio-workshop. The first tests of samples of the board serial production under real conditions have shown their full correspondence to technical reauirements.

1.5 X-ray Detectors

In 2007, we continued intense experiments on the dynamics of explosions at the SR channel with the use of a 256 channel one-coordinate detector DIMEX-1. A new design of the body and printing board of electronics with applied strip structure were produced for a 512 channel detector. Production of the detector is planned for April, 2008.

In 2007, we continued the work on detector OD-4 for experiments on the wide-angular scattering at SR. In OD-4, instead of a wire structure as, for example, in OD-3, a multi-layer gas electron multiplier (GEM) that enables in addition to the high gas amplification (over 10 000)to construct the detector in the form of an arc with an arbitrary angular aperture. During a year, we performed all the necessary preparatory works for manufacture of the 256 channel detector prototype. Within the frame of the upgrade of detectors of the OD-3 series aiming at improvement of their reliability and parameters, we are carrying out the intense work on the development and manufacture of the 0ne-coordinate detector of the next generation OD-3M. By the contract with КЦСИ, at the end of 2007, we produced the first detector. In January, 2008, we plan to start its tests with SR beam.

1.6 Othe works

Within the frame of international collaboration, the staff of the section continued an active participation in the work related to the upgrade of the DAG-system at BELLT detector (KEK, Japan). The first samples of the novel electronics are developed and tested. The samples were produced in Japan: for the Barrel part of the calorimeter “ based on CsI(Tl) crystals and for the end part of the calorimeter” on the base of at the plants of the Japanese industry: for the Barrel part of the calorimeter based on Cs(Tl)-crystals and for the end part of the calorimeter on the base of the pure CsI crystals.

1.7 Micro-Pattern Gaseous Detectors

The development of detectors based on multi-GEM structures was continued in 2007. 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 2007 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 also continued. The results obtained by the end of 2007 are summarized below.

The measurements of signals, induced by nuclear recoils from neutron scattering from Cf-252 source, were continued in the two-phase Ar avalanche detector. In particular, it was shown that at the background of gamma-ray signals onecan observe also the signals induced by nuclear recoils.

For the first time the successful detection of both scintillation and ionization signals in two-phase Ar avalanche detector under irradiatoion of beta-particles was demonstrated using CsI photocathode deposited on the first GEM. Such mode of operation is needed in particular for the selection of nuclear recoil sigals when detecting dark matter. For the anode signal it was obtained 30 photoelectrons per 600 keV of the energy deposted in the liquid Ar. At that, the technique for the deposition of CsI photocathode on GEM using vacuum evaporation and for the measurement of CsI quantum efficiency at 185 nm was developed.

The investigations on thick GEM performance in two-phase argon avalanche detector have been started. The implementation and assembling of the gas system and the system of liquid nitrogen supply for the two-phase detecor with a 10 l cryogenic chamber were started. The studuies of cryogenic avalanche detectors will be continued in 2008.

2) The system of tagged electrons is a substantial part of the KEDR experiment; it allows for detecting electrons scattered from the colliding point at small angles. These electrons characterize photon-photon interaction and their detection and the measurement of their monemtum is an important physical task. The existing system of tagged electrons based on drift tubes have a limited spatial resolution; it measures the particle coordinate in one direction only which substantially restricts the signal/background separation capability. To obtain the ultimate momentum resolution of scattered electrons and to improve signal/background separation, it was suggested to place detectors based on triple-GEM with two-coordinate readout in front of each of 8 system stations. These detectors allow to measure the coordinate in the beam orbit plane with a 0.1 mm resolution. In the perpenndicular 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 2007 the detectors in positron arm of the system were assembled. At the moment

7 detectors in total are installed at VEPP4M ring: 3 detectors in the electron arm and 4 detectors in the positron arm. In addition 3 detectors are fully tested and installed in the laboratory. They are used for the measurement of characterisitics under irradiation of cosmics rays. Also during 2007 the software was being developed and debuged, needed for the system operation in frame of the KEDR detector. The system commissioning in the whole is planned to be in the second half of 2008.

3) In 2007 we continue to participate in the R&D of detectors for the TPC of Linear Collider. The multi-GEM structures are currently considered to be the most promising candidates for the TPC endcap detector.

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

The work is reflected in the following papers and reports:
[76], [77], [78], [272], [273].

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 $1.7 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$, 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 1% accuracy.

For seven years the detector BELLE has been storing the experimental data. At the end of 2007 the accepted integrated luminosity was more than 760 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 $\phi_1 = Arg(\frac{V_{cd}V_{cb}^\star}{V_{td}V_{tb}^\star})$. 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 statisticaly significant large CP violation effect: $\sin 2\phi_1 = 0.728 \pm 0.056(stat.) \pm 0.023(syst.)$.

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 first observation of doubly charmed B-meson decay to Λ_c, Λ_c, and K-meson has been done and corresponding branching fractions have been measured: $Br(\bar{B}^+ \to \Lambda_c\Lambda_c K^+) = (6.5 \pm 1.0 \pm 1.1 \pm 3.4)10^{-4}$, $Br(\bar{B}^0 \to \Lambda_c\Lambda_c K^0) = (7.9^{+2.9}_{-2.3} \pm 1.2 \pm 4.2)10^{-4}$.

B-decays to the final state with a charmed strange meson have been observed for the first time $\bar{B}^0 \to D_s^+ K^-$, $\bar{B}^0 \to D_s^+ \pi^-$. The branching ratios of these decays are following : $Br(\bar{B}^0 \to D_s^+ K^-) = (4.6^{+1.2}_{-1.1} \pm 1.3) \times 10^{-5}$ and $Br(\bar{B}^0 \to D_s^+ \pi^-) = (2.4^{+1.0}_{-0.8} \pm 0.7) \times 10^{-5}$. The decay $\bar{B}^0 \to D_s^+ K^-$ happens due to the W exchange diagram only, so measurements of this branching ratio provide valuable information for understanding of such processes.

We study production of the orbital excitation of D-mesons(D^{**}) in B-decays. In the hadron decays $B^- \to D^{(*)+}\pi^-\pi^-$ the production of all four expected neutral D^{**} has been observed and their parameters have been measured. It is the first observation of the broad states. This study allows to understand the validity of Heavy quark effective theory in such processes.

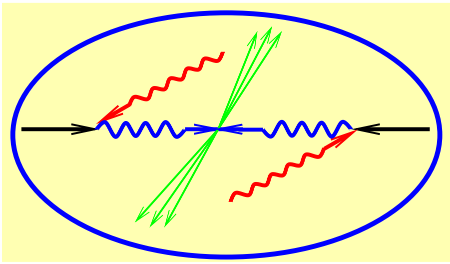
The team of our Institute observed and measured the branching fraction for the processes $\bar{B}^0 \to D^0 \bar{K}^{(*)0}$, which can be used for the ϕ_3 angle measurement. The measured branching ratios are: $Br(\bar{B}^0 \to D^0 \bar{K}^0) = (5.0^{+1.3}_{-1.2} \pm 0.6) \times 10^{-5}$ $Br(\bar{B}^0 \to D^0 \bar{K}^{*0}) = (4.8^{+1.1}_{-1.0} \pm 0.5) \times 10^{-5}$.

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 disscussed to increase the luminosity to the level of $10^{35}\mathrm{cm}^{-2}s^{-1}$, 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.E. Shebalin, B.A. Shwartz, Yu.V. Usov, A.N. Vinokurova, V.N. Zhilich, O.A. Zyukova.

1.9 The Photon Collider



In 2004, the project of International Linear Collider (ILC) based on a superconducting technology was launched. In addition to the e^+e^- physics program, the ILC will provide an opportunity to study $\gamma\gamma$ and γe interactions, where high energy photons can be obtained using Compton backscattering of the laser light off the high energy electrons.

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.

Unfortunately, the compatibility with the photon collider was lost in preparation of the ILC Reference Design Report (RDR). Driven by a perceived need to reduce as much as possible the initial ILC cost, the RDR accelerator team considered only the basic e^+e^- mode and was a bit too overzealous in cost-cutting. It made the unwise decision to propose a collider with a single IP and a 14 mrad crossing angle, not compatible with the photon collider, which requires a crossing angle of 25 mrad.

While reducing the initial ILC cost by a few percent, the single-IP solution with no space for the photon collider risked a great escalation of the cost of upgrades, to no small part due to the need for substantial additional excavation in the IP region half-way through the ILC lifetime, which would be highly impractical and perhaps technologically or politically impossible. It is obvious that the total cost is minimal when all underground construction work is done at once rather than in two or more stages, with their considerable set-up costs and the disruption they would cause to ILC operation.

Gravely concerned with the risks of the single-IP, 14 mrad crossing-angle solution and its near incompatibility with the photon collider, the author of this note, V.I. Telnov, being the leader of the photon collider project, strongly disagreed with this aspect of the RDR and made great efforts to change the situation.

Fortunately, common sense has prevailed. The next step in the ILC is the Engineering Design Report. At the ILC Interaction region engineering design workshop, IRENG07, I once again formulated the requirements to the ILC design imposed by the upgrade path to the photon collider, and they were accepted. The GDE team agreed that the baseline ILC configuration should be modified in order to make it compatible with the photon collider option, and all underground excavation work the photon collider would require should be done from the very beginning. So, the photon collider is back on track.

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

Ultimate parameters of the photon collider at the ILC [116].

Layout of the photon collider at the ILC [117].

Present status of the photon collider, what next [348]?

Introduction to the Photon Linear Collider [349].

ILC Reference design: Executive Summary [350], Physics [**?**], Accelerator [352], Detectors [353].

Photon collider: ILC configuration and IR issues [354].

How to make ILC with 14mr compatible with gamma-gamma? [355].

Status and technology of photon collider [356].

Remarks and some ideas on laser beamsize monitors [357].

Partcicipant of the work: V.I. Telnov.

Chapter 2

Electro - and photonuclear physics

2.1 Experiments utilizing internal targets

I. In 2007, we performed the first stage of the experiment of determining $R = \sigma(e^+)/\sigma(e^-)$ ratio of the differential cross-sections for elastic electron-proton and positron-proton scattering. The experiment is interesting since it will enable us to determine the contribution of the two-photon exchange (TPE) in the process of the electron-proton elastic scattering. These experiments have been carried out in 1970s but the measurement accuracy was insufficient. Revival of interest to the measurements of the two-photon exchange contribution occurred recently in connection with the dramatic difference in results of recent experiments on measurements of the proton form factor (TJ-NAF, USA) performed with the use of polarization technique and previous results of the non-polarized measurements where the form factors were determined from measurements of differential cross-sections in various kinematics. Previous experimental results are assumed to be correct but the interpretation made within the one-photon approximation is mistaken; for the correct finding the proton form factors, it is necessary to take into account TPE. However, as said above, there are no yet data of TPE and no reliable calculations of TPE. The calculations performed by different authors give different results.

In our experiment, for measurements of R we used the internal target technique that turned to be adequate to the problem because the effective use of positrons generated by injector.

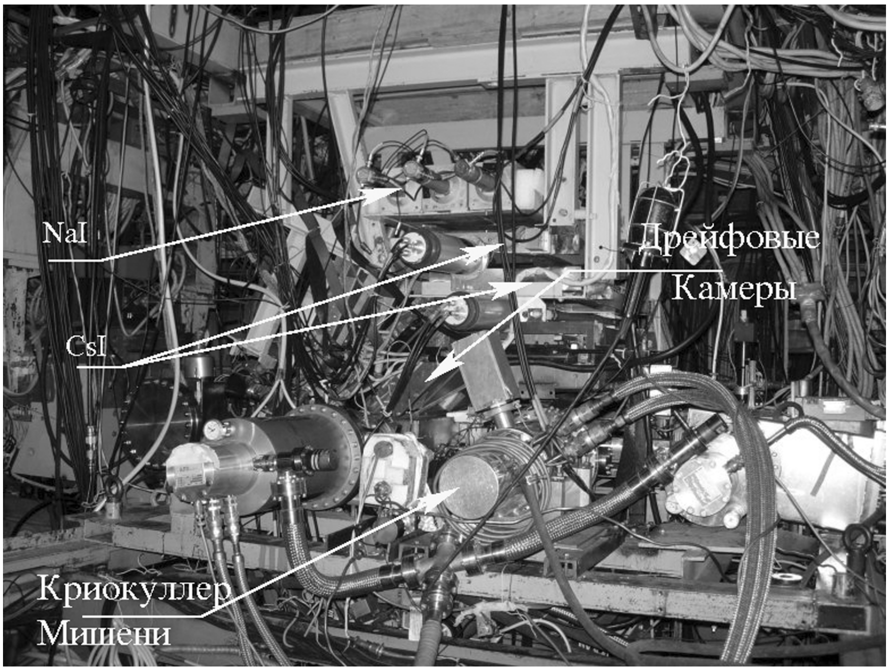


Figure 1: The particle detector and the target installed at the VEPP-3 storage ring. Only upper part of detector may be viewed.

The work took 2.5 months from 16 April to 2nd July. During the first stage (~1 month), after dismounting the polarimeter section and replacement of the drift gates by the new ones, we installed the experimental section with the internal target and attain vacuum. Then we installed the detector, changed commutation of the power supply sources of the VEPP-3 quadrupole lenses, assembled the data collection and control system (see Fig.1). Then we tuned up some operation regimes of VEPP-3 (∼0.5 month): with the internal target for the electron/positron beams for operation with SR, for operation with extraction at VEPP-4.

Note that despite the small dimensions of the cross-section of the target storage cell, the rate of positron storage at VEPP-3 was not reduced because of the use of optics compressing the electron/positron beams in experimental section. At the next stage, we clarified the electron/positron beam regimes for minimization the detector noises, tuned the beam positioning; arranged measurements of the electron/positron beam energies with the Compton scattering (see Fig.2), the main units of the installation were temporarily removed from VEPP-4. Note that both these circumstances are very important for suppressing the systematic errors of measurements.

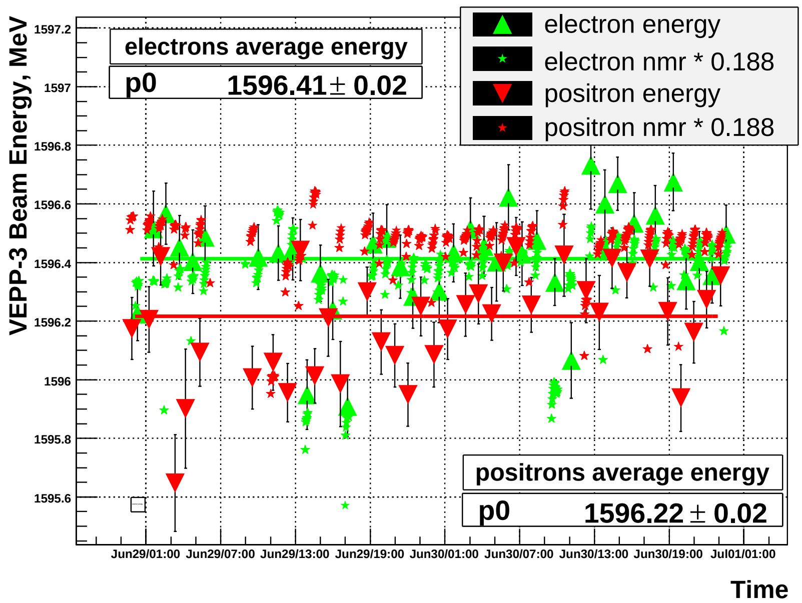


Figure 2: Electron/positron beam energies measured by the Compton backscattering device.

Set of statistics was performed in three stages with lowering the background load of detector at each next step: with the initial trigger, then with the changed trigger, then a cleaning (delta-electrons) magnet was added. The total useful integral of the electron/positron beam current was gathered to be 6 kG.

The analysis of data proved the correct solutions taken on the target, detector as well as measures on suppressing the systematic errors. By present, we performed several stages of processing: the primary check, introduction of corrections to the time drift of amplitudes and times, corrections of sprectra, obtaining the physical values (time of flight out angles of particles, their energies and time of flight). All four types of events are separated reliably: –elastic (ep)-scattering at small ($\Theta_e \sim 10^o$), average($\Theta_e \sim 25^o$) and large angles ($\Theta_e \sim 65^o$, see Fig.3), as well as events of the monitor luminosity, where $(e^+e^-)/(e^-e^-)$-scattering was detected.

The gain of statistics enables one to obtain the significant result in the region of the transmitted intermediate pulse. In order to complete the experiment, we need another the main one as ance of work at VEPP-3. We found also some malfunctions of equipment and took some measures to remove them.

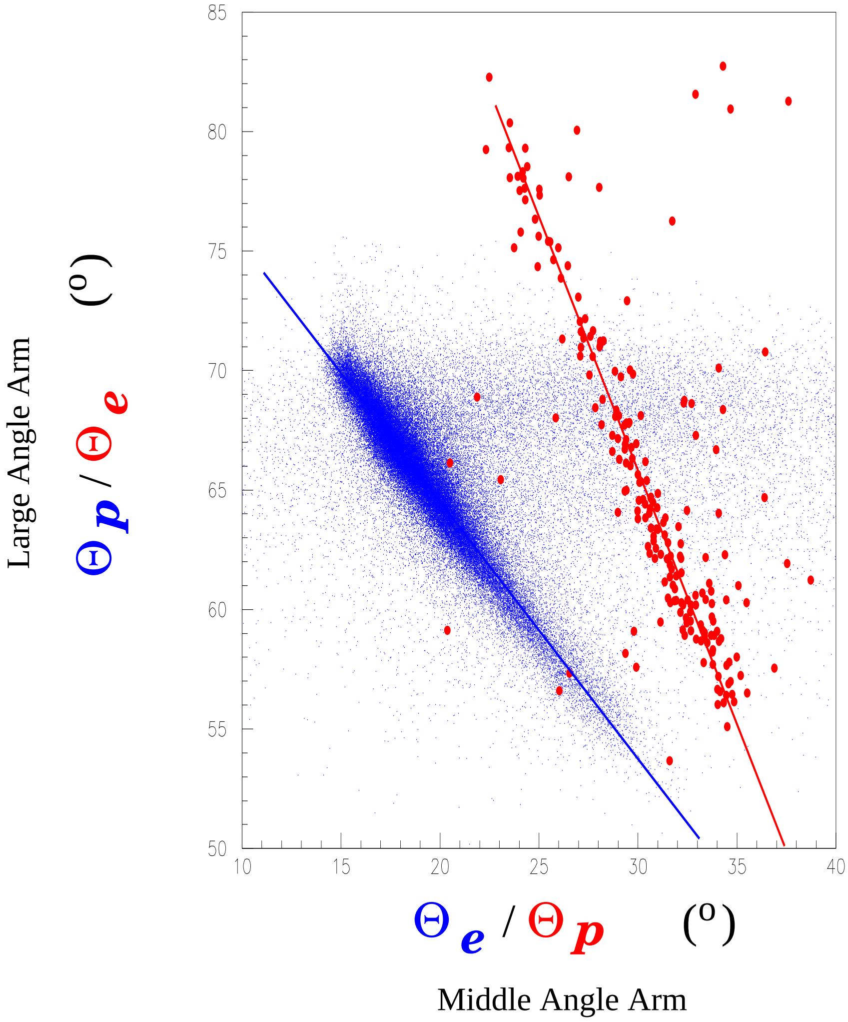


Figure 3: Distribution of events over the scattering angles of electron/positrons and flight out angles of the recoil protons. Small points are scattering events at an average angle $\Theta_e^*\Theta_p^*$), big points – scattering events at a large angle($\Theta_e\Theta_p$). Each arm of the detector detects either the scattered electron/positron or the recoil proton. Lines are the calculated positions of these two types of events.

II. In 2007, the experiment on measurement of the tensor observables in the reaction of photo disintegration of polarized deuteron was completed and published in Phys. Rev. Lett. 98 (2007) 182303. The measurements were performed with a high accuracy and in a broad kinematic region (previous measurements carried out also at BINP are improved in all the parameters) have shown, in particular, that it was very important to take into account the relativistic effect of the pion delay at high photon energies. In addition, at the photon energies lower than the pion generation threshold, the modern models describe the data well, but at high energies, rather serious discrepancies with calculations that demonstrates the necessity of their further improvement.

III. In order to get a possibility to expand this and other polarization experiments to the range of photon higher energies (up to 1.5 GeV), where, by the data of non-polarized experiments, in some reactions the transition of the nucleon-meson description to the quark-gluon description is occurred. The system of tagging quasi-real photons is developed (see Fig.4).

In 2007, we started the design work of the system.

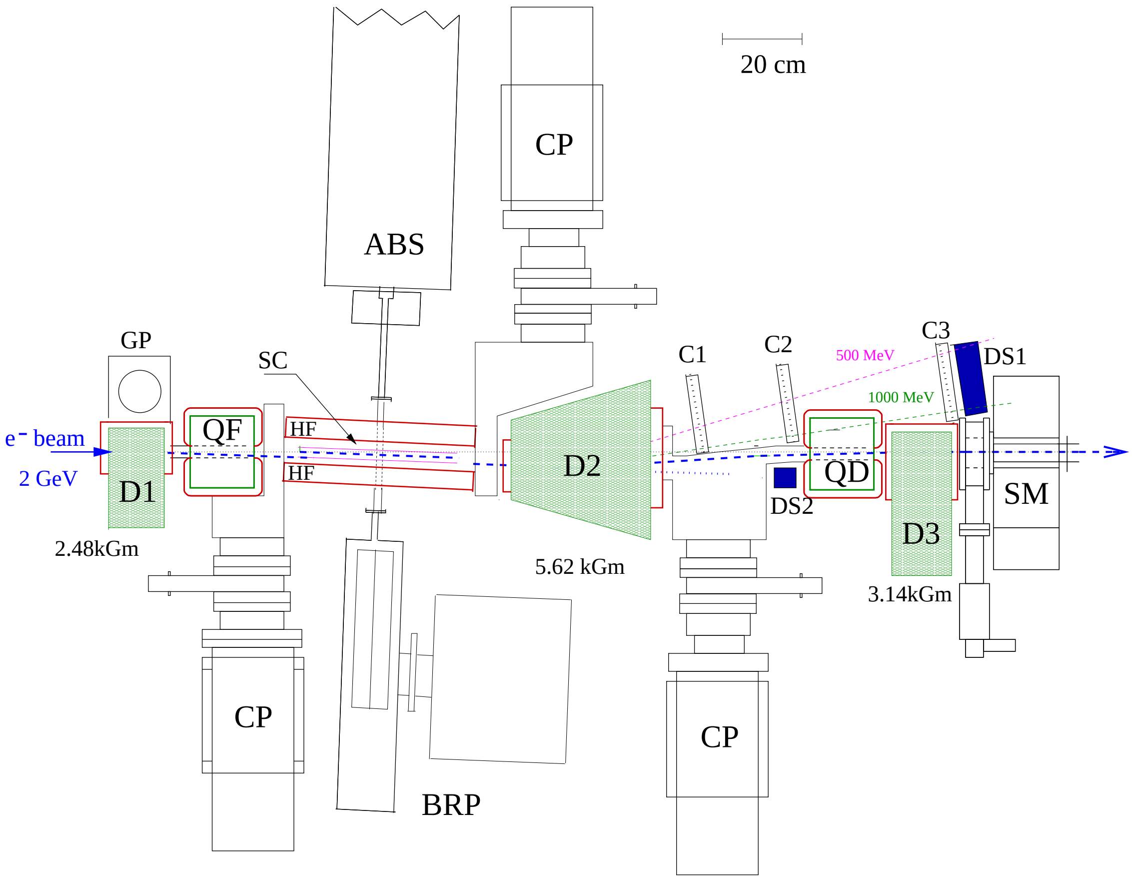


Figure 4: Schematic diagram of the experimental straight section with a system of tagging the virtual photons. QF, QD, SM are quadrupole lenses, sextupole. Elements of the tagging system: D1, D2, D3 are three dipole magnets, C1, C2, C3 are coordinate chambers, DS1, DS2 are the scintillation sandwiches. Target components: ABS is a source of polarized deuterium atoms, SC is a storage cell, HF is the target magnet, BRP is the Breit-Rabi polarimeter, CP, QP are the cryogenic and getter pumps.

IV. We continued the work on the stand of polarized target aimed at finding out the reasons of a low polarization during the experiment. A new mass-spectrometer is installed for detection of atoms. A signal of the molecular deuterium from the storage cell is reliable detected. In the near future, we will measure the atom beam signal from the cell as a function of its temperature.

V. Collaboration with the Jefferson Laboratory (Newport News, USA) is continued. The results of the joint experiment on measurements of the Compton scattering cross-section of real photons on a proton at large transmitted – Phys. Rev. Lett. **98**(2007)152001. We are planning to participate in two new experiments:

1) A study of polarization transmission in the wide-angle Compton scattering on a proton;

2) Measurements of the ratio of proton form factors at the transmitted pulse of up to 15 $(\mathrm{GeV}/c)^2$ with the use of the polarization technique.

VI. Our group takes part in the contract work with TAE. On the base of cryocoolers, we developed the cryogenic pumps with the pumping rate of the order of 100000 liters per second for the injector of neutron hydrogen atoms. We will produce 14 pieces. The first cryopump will be tested in the near future.

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

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

Publications:
[6], [7], [8], [251], препринт 82.

Chapter 3

Theoretical physics

3.1 Strong interaction

On the coordinate representation of NLO BFKL

V. S. Fadin, R. Fiore and A. Papa
Nucl. Phys. B **769** (2007) 108

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
Phys. Lett. B **647** (2007) 179

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.

The dipole form of the gluon part of the BFKL kernel

V. S. Fadin, R. Fiore, A. V. Grabovsky and A. Papa
Nucl. Phys. B **784** (2007) 49

The dipole form of the gluon part of the colour singlet BFKL kernel in the next-to-leading order (NLO) is obtained in the coordinate representation by direct transfer from the momentum representation, where the kernel was calculated before. With this paper the transformation of the NLO BFKL kernel to the dipole form, started a few months ago with the quark part of the kernel, is completed.

BFKL approach and dipole model

V. S. Fadin
In: “New Trends in High-Energy Physics", Eds. P.N. Bogolyubov, L.L. Jenkovszky, and V.K. Magas, Kiev, 2007, pp. 258-266

Inter-relation of the BFKL approach and the colour dipole model is discussed. It is shown that the kernel of the colour dipole model is not equivalent to the colour singlet BFKL kernel. However, in the case of scattering of colourless objects it is possible to take the colour singlet BFKL kernel in the special form called Möbius or dipole form. The leading order contributions to this form and to the kernel of the colour dipole model do coincide, as well as the quark parts of the next-to-leading order contributions. Comparison of gluon parts is not possible because for the kernel of the colour dipole model this part is not known yet. The Möbius form of this part, as well as of the supersymmetric generalizations of the BFKL kernel, is presented, and conformal properties of this form are discussed.

Quantum Chromodynamics at high energies

M.G. Kozlov, A.V. Reznichenko, V.S. Fadin
Vestnik NGU. Series: Physics. 2007. Vol. 2, N. 4, pp. 3-31

Short and utmost simple review of methods and results of summation of perturbation series at large energies and limited momentum transfers in modern theory of strong interactions – Quantum Chromodynamics – is given. High emphasis is placed on the BFKL approach and on the comparison of this approach with the colour dipole model.

The coordinate representation of NLO BFKL and the dipole picture

V.S. Fadin
Proceedings of the 12th International Conference on Elastic and Diffractive Scattering (Blois Workshop) - Forward Physics and QCD; DESY-PROC-2007-02; arXiv:0712.3633 [hep-ph]

For scattering of colourless objects, the freedom in definition of the BFKL kernel resulting from invariance of scattering amplitudes under simultaneous transformations of the kernel and impact factors permits to present the kernel in the dipole form. This form is found in the next-to-leading order (NLO) by direct transfer from the momentum space to the coordinate one.

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

V.S. Fadin, R. Fiore
arXiv:0712.3901 [hep-ph]

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

On Mass Spectrum in SQCD, and Problems with the Seiberg Duality. Part I: equal quark masses

V.L. Chernyak
arXiv: 0712.3167 [hep-th], pp. 1-24

It is argued that SQCD with N_c colors and $N_c < N_F < 3N_c$ flavors, and with small but nonzero current quark masses $m_Q \neq 0$, is in the diquark-condensate phase, where the colorless chiral quarks pairs condense coherently in the vacuum, $\langle Q\bar{Q}\rangle \neq 0$, while quarks alone don't condense, $\langle Q\rangle = \langle\bar{Q}\rangle = 0$, so that theory is not higgsed, all gluons remain massless and color is confined. This condensation of diquarks results in formation of dynamical constituent masses of quarks and appearance of light "pions" (similarly to

QCD). The mass spectrum of SQCD in this phase is described, and comparison with the Seiberg dual description is performed. It is shown that the direct and dual theories are different (except, possibly, for the perturbative strictly super-conformal regime).

Radiative corrections to the Reggeized quark - Reggeized quark - gluon effective vertex

A.V. Bogdan, A.V. Grabovsky
Nucl.Phys.B773:65-83,(2007).

This paper is devoted to the calculation of the Reggeized quark-Reggeized quark-gluon effective vertex in perturbative QCD in the next-to-leading order. The case of QCD with massless quarks is considered and the correction is obtained in the D->4 limit. This vertex appears in the quark Reggeization theory, which next-to-leading order extension is now under construction.

Lectures on QED and QCD: Practical calculation and renormalization of one- and multi-loop Feynman diagrams

A.G. Grozin
World Scientific (2007), ISBN-13 978-981-256-914-1,
ISBN-10 981-256-914-6, 224 p.

The increasing precision of experimental data in many areas of elementary particle physics requires an equally precise theoretical description. In particular, radiative corrections (described by one- and multi-loop Feynman diagrams) have to be considered. Although a growing number of physicists are involved in such projects, multi-loop calculation methods can only be studied from original publications. With its coverage of multi-loop calculations, this book serves as an excellent supplement to the standard textbooks on quantum field theory. Based around postgraduate-level lectures given by the author, the matherial is suitable for both beginners and graduate students.

On one master integral for three-loop on-shell HQET propagator diagrams with mass

A.G. Grozin, T. Huber, D.Maître
JHEP **07** (2007) 033.

An exact expression for the master integral I_2 arising in three-loop on-shell HQET propagator diagrams with mass is derived and its analytical expansion in the dimensional regularization parameter ε is given.

Three-Loop Chromomagnetic Interaction in HQET

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

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

Light quark mass effects in the on-shell renormalization constants

S. Bekavac, A.G. Grozin, D. Seidel, M. Steinhauser
JHEP **10** (2007) 006

We compute the three-loop relation between the pole and the minimally subtracted quark mass allowing for virtual effects from a second massive quark. We also consider the analogue effects for the on-shell wave function renormalization constant.

The B-meson mass splitting from non-perturbative quenched lattice QCD

A.G. Grozin, D. Guazzini, P. Marquard, H.B. Meyer, J.H. Piclum, R. Sommer, M. Steinhauser
Proceedings of Science (Lattice 2007) 100

We perform the non-perturbative (quenched) renormalization of the chromo-magnetic operator in Heavy Quark Effective Theory and its three-loop matching to QCD. At order $1/m$ of the expansion, the operator is responsible for the mass splitting between the pseudoscalar and vector B-mesons. These new computed factors are affected by an uncertainty negligible in comparison to the known bare matrix element of the operator between B-states. Furthermore, they push the quenched determination of the spin splitting for the B_s-meson much closer to its experimental value than the previous perturbatively renormalized computations. The renormalization factor for three commonly used heavy quark actions and the Wilson gauge action and useful parametrizations of the matching coefficient are provided.

Final state interaction effects in $N\bar{N}$ production near threshold

V.F.Dmitriev, A.I.Milstein
Phys. Lett. B 658, 13 (2007).

We use the Paris nucleon antinucleon optical potential for explanation of experimental data in the process e+e- $p\bar{p}$ 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.

3.2 Nuclear physics and parity nonconservation

Bremsstrahlung in alpha decay reexamined

H. Boie, A.I.Milstein et al
Phys. Rev. Lett. 99, 022505 (2007).

A high-statistics measurement of bremsstrahlung in the decay of ^{210}Po is performed up to γ ray energies of 400 keV. Data are in good agreement with theoretical results, as obtained here within the quasiclassical approximation, as well as within the exact quantum mechanical calculation. It is shown that due to the small effective electric dipole charge of the combined system of the α particle and of the daughter nucleus, there is a significant interference between electric dipole and quadrupole contributions to the differential probability. This interference substantially alters the angular correlation between α particle and emitted photon. The relative contribution to the matrix element of bremsstrahlung from the tunneling region is discussed.

3.3 Quantum electrodynamics

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

R.N.Lee, A.I.Milstein ZhETF 131, 472 (2007).

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

Photon splitting in a laser field

A. Di Piazza, A.I.Milstein, C.H.Keitel
Phys. Rev. A76, 032103 (2007).

Photon splitting due to vacuum polarization in a laser field is considered. Using an operator technique, we derive the amplitudes for arbitrary strength, frequency and polarization of the laser field. The case of a circularly polarized laser field is studied in detail and the amplitudes are obtained as three-fold integrals. The asymptotic behavior of the amplitudes for various limits of interest are investigated. Using the results obtained we discuss the possibility of experimental observation of the process.

Coulomb corrections to the Delbrück scattering amplitude at low energies

G.G. Kirilin, I.S. Terekhov
submitted in Physical Review A, eprint: arXiv:0708.0745.

We study the Coulomb corrections to the Delbrück scattering amplitude. We consider the limit when the energy of the photon is much less than the electron mass. The calculations are carried out in the coordinate representation using the exact relativistic Green function of an electron in a Coulomb field. The resulting relative corrections are of the order of a few percent for a large charge of the nucleus. We compare the corrections with the corresponding ones calculated through the dispersion integral of the pair production cross section and also with the magnetic loop contribution to the g-factor of a bound electron. The last one is in a good agreement with our results but the corrections calculated through the dispersion relation are not.

Pair creation by a photon in a strong magnetic field

V. N. Baier and V. M. Katkov
Phys.Rev.D**75**, 073009-1-12 (2007)

The process of pair creation by a photon in a strong magnetic field is investigated basing on the polarization operator in the field. The total probability of the process is found in a relatively simple form. The probability exhibits a "saw-tooth" pattern because of divergences arising when the electron and positron are created at threshold of the Landau energy levels. The pattern will be washed out at averaging over any smooth photon energy distribution. The new results are obtained in the scope of the quasiclassical approach: 1) in the case when the magnetic field $B \ll B_0$, (B_0 is the critical field) the new formulation extends the photon energy interval to the case when the created particles are not ultrarelativistic; 2) the correction to the standard quasiclassical approximation is found showing the range of applicability of the approach at high photon energy as well. The very important conclusion is that for both cases $B \ll B_0$ and $B \geq B_0$ the results of the quasiclassical calculation are very close to averaged probabilities of exact theory in a very wide range of photon energies. The quasiclassical approximation is valid also for the energy distribution if the electron and positron are created on enough high levels.

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

V. N. Baier and V. M. Katkov
Proceedings of SPIE Volume: **6634**, 3-18 (2007)

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.

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

V. N. Baier and V. M. Katkov
Preprint BINP 2007-22
Nucl.Instr.and Meth B, (in print)

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

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

V. N. Baier and V. M. Katkov
Preprint BINP 2007-34.
Physics Letters A, (in print)

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

Approximate Selection Rule for Orbital Angular Momentum in Atomic Radiative Transitions

I.B. Khriplovich, D.V. Matvienko
Phys. Lett. A 368 (2007)348.

We demonstrate that radiative transitions with $\Delta l = -1$ are strongly dominating for all values of n and l, except small region where $l \ll n$.

3.4 Gravity

Density of dark matter in Solar system and perihelion precession of planets

I.B. Khriplovich
Int. J. Mod. Phys. D 16 (2007) 1475.

Direct model-independent relation between the secular perihelion precession of a planet and the density of dark matter $\rho_{\rm dm}$ at its orbit is indicated, and used to deduce upper limits on local values of $\rho_{\rm dm}$.

Can one detect passage of small black hole through the Earth?

I.B. Khriplovich, A.A. Pomeransky, N. Produit, G.Yu. Ruban
Phys.Rev.D, in press; preprint arxive:0710.3438

The energy losses of a small black hole passing through the Earth are examined. In particular, we investigate the excitations in the frequency range accessible to modern acoustic detectors. The main contribution to the effect is given by the coherent sound radiation of the Cherenkov type.

On the possibility of finite quantum Regge calculus

V.M.Khatsymovsky
Phys. Lett. B 651 (2007) 388.

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 form of the path integral measure showing that probability distribution for these linklengths is concentrated at certain nonzero finite values of the order of Plank scale. That is, the theory resembles an ordinary lattice field theory with fixed spacings for which correlators (Green functions) are finite, UV cut off being defined by lattice spacings. The difference with an ordinary lattice theory is that now lattice spacings (linklengths) are themselves dynamical variables, and are concentrated around certain Plank scale values due to *dynamical* reasons.

On positivity of quantum measure and of effective action in area tensor Regge calculus

V.M.Khatsymovsky
E-print archive arXiv:0707.3331.

Because of unboundedness of the general relativity (GR) action, the continued to Euclidean region path integral in general relativity requires special definition. In the discrete GR with independent area tensors and finite rotation matrices the Euclidean path integral can be represented by moving integration contours over finite rotations to complex plane so that it includes exponent with effective action with positive real part. We argue that positivity (probability interpretation) of thus obtained quantum measure on the areas is expected on the most part of region of variation of area tensors.

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
Phys. Rev E **75**, 093702,(2007).

We investigate the role of classical dynamical chaos in the suppression of the quantum interference in the absence of any irregular external influence. To this end an extension

of fidelity mixed states is introduced, which we name allegiance. Contrary to the ordinary fidelity, such a quantity directly accounts for for the quantum interference. It can be measured in a Ramsey interferometry experiment. We show in the semiclassical approximation that, if the system is classically chaotic and the evolution starts from a wide incoherent mixed state, the decay of allegiance is exactly expressed, due to the dephasing induced by the classical dynamical chaos, in terms of an appropriate classical correlation function. Our results are derived analytically for the case of a nonlinear driven oscillator and then numerically confirmed for the kicked rotor model.

Decay rates statistics of Unstable classically chaotic systems

Valentin V. Sokolov
cond-mat:0711.1640v1 11 Nov 2007; to appear in Proceedings of the International Workshop on Nuclei and Mesoscopic Systems WNMP07.

Decay law of a complicated unstable state formed in a high energy collision is described by the Fourier transform $K(t)$ of the two-point correlation function of the scattering matrix. Although each constituent resonance state decays exponentially the decay of a state composed of a large number $N \gg 1$ of such interfering resonances is not, generally, exponential. We introduce the decay rates distribution function $w(\Gamma)$ by representing the decay law in the form of the mean-weighted decay exponent $K(t) = \int_0^\infty d\Gamma\, e^{-\Gamma t}\, w(\Gamma)$. In the framework of the random matrix approach we investigate the properties of the distribution function $w(\Gamma)$ and its relation to the more conventional statistics of the decay widths. The latter is not in fact conclusive as concerns the evolution at the times shorter than the characteristic Heisenberg time. Exact analytical consideration is presented for the case of systems without time reversal symmetry.

Frenkel-Kontorova model with cold trapped ions

I. Garcia-Mata, O.V. Zhirov and D.L. Shepelyansky
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.

Synchronization and bistability of qubit coupled to a driven dissipative oscillator

O.V. Zhirov and D.L. Shepelyansky
e-print: arXiv:0710.1967v1[cond-mat.supr-con](2007), (http://arxiv.org/abs/0710.1967v1), Phys. Rev. Lett., *accepted for publication.*

We study numerically the behavior of qubit coupled to a quantum dissipative driven oscillator (resonator). Above a critical coupling strength the qubit rotations become synchronized with the oscillator phase. In the synchronized regime, at certain parameters, the qubit exhibits tunneling between two orientations with a macroscopic change of number of photons in the resonator. The life times in these metastable states can be enormously large. The synchronization leads to a drastic change of qubit radiation spectrum with appearance of narrow lines corresponding to recently observed single artificial-atom lasing [O. Astafiev *et al.* Nature **449**, 588 (2007)].

Structure of the spin-glass state of $La_{2-x}Sr_xCuO_4$: the spiral theory

A.Luscher, A.I.Milstein, O.P.Sushkov
Phys. Rev .Lett. 98, 037001 (2007).

Starting from the t-J model, we derive an effective field theory describing the spin dynamics in the insulating phase of $\mathrm{La}_{2-x}\mathrm{Sr}_x\mathrm{CuO}_4$, $x \lesssim 0.055$, at low temperature. Using Monte Carlo simulations, we show that the destruction of Néel order is driven by the single-hole localization length κ. A phase transition at 2% doping is consistent with the value of κ 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.

Effective action of the weakly doped t-J model and spin-wave excitations in the spin-glass phase of $La_{2-x}Sr_xCuO_4$

A.Luscher, A.I.Milstein, O.P.Sushkov Phys. Rev. B 75, 235120, (2007).

We derive the low-energy effective field theory of the extended t-J model in the regime of light doping. The action includes a previously unknown Berry phase term, which is discussed in detail. We use this effective field theory to calculate spin-wave excitations in the disordered spin spiral state of $\mathrm{La}_{2-x}\mathrm{Sr}_x\mathrm{CuO}_4$ (the spin-glass phase). We predict an excitation spectrum with two distinct branches: The in-plane mode has the usual linear spin-wave dispersion and the out-of-plane mode shows non-trivial doping dependent features. We also calculate the intensities for inelastic neutron scattering in these modes.

Theoretical Kaleidoscope

I.B. Khriplovich
RCD, 2007

The book is based on lectures on additional chapters of theoretical physics given in various years at the Department of Physics, Novosibirsk University, Russia.

Chapter 4

Plasma physics and controlled thermonuclear fusion

4.1 GDT device

4.1.1 Modernization of atomic injection system on GDT device (second step)

In the Budker Institute of Nuclear Physics the modernization of the Gas Dynamic Trap (GDT) device is realizing for increasing electron temperature up to 200-300 eV. The new system of atomic beams injection with beam energies of 25 keV, total power of 10 MW and pulse duration of 5 ms is planning to be created. These injectors have focusing ion-optical system which allows to increase significantly the beam current density.

In the frame of first step of modernization designing, constructing and launching of new modern power supply system for these injectors had been done in 2006 year. New power supply system consists of 8 modules is working now instead of out-of-date power supply system of START-3 injectors which did was not satisfied for experiment requirements due to its low power and short pulse duration (4 MW, 15 kV, 1 ms). This activity allowed us to begin experiments with long pulse duration using START-3 injectors which were replaced by new generation injectors in 2007 year. For this purpose the serial production was organized and new injectors with "hole" focusing ion- optical system (fig. 1a) which allow to have atomic beams of hydrogen or deuterium with energies of 22-25 keV and power up to 800 kW each were yielded of operational parameters. In order to increase the transparency of injectors ion-optical system (IOS) the new "slit" grids (fig. 1b) were constructed and prepared for testing. These grids allow to increase IOS transparency from 0.5 to 0.75 and consequently to obtain increasing of beams power.

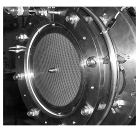


Figure 1: Photograph of new focused injectors IOS:
a) (left) "hole" IOS used in serial injectors;
b) (right) "data" IOS with increased transparency prepared for testing.

As a result of second step of modernization the combined atomic injection system had been successfully operated in beginning of summer 2007. This system consisted of two old START-3 type injectors with long pulse duration, four new generation injectors with "hole" IOS (two pilot injectors and two serial ones).

Figure 2 shows oscillograms of current and voltage for all six injectors in normal operation mode of GDT device. Time averaged power of injection after modernization came up to 3.5 MW (4 MW at maximum). In consequence of partly upgraded atomic injection system record plasma parameters in GDT were obtained. Activity on increasing of tomic beams total power continues and appears the main point of modernization program.

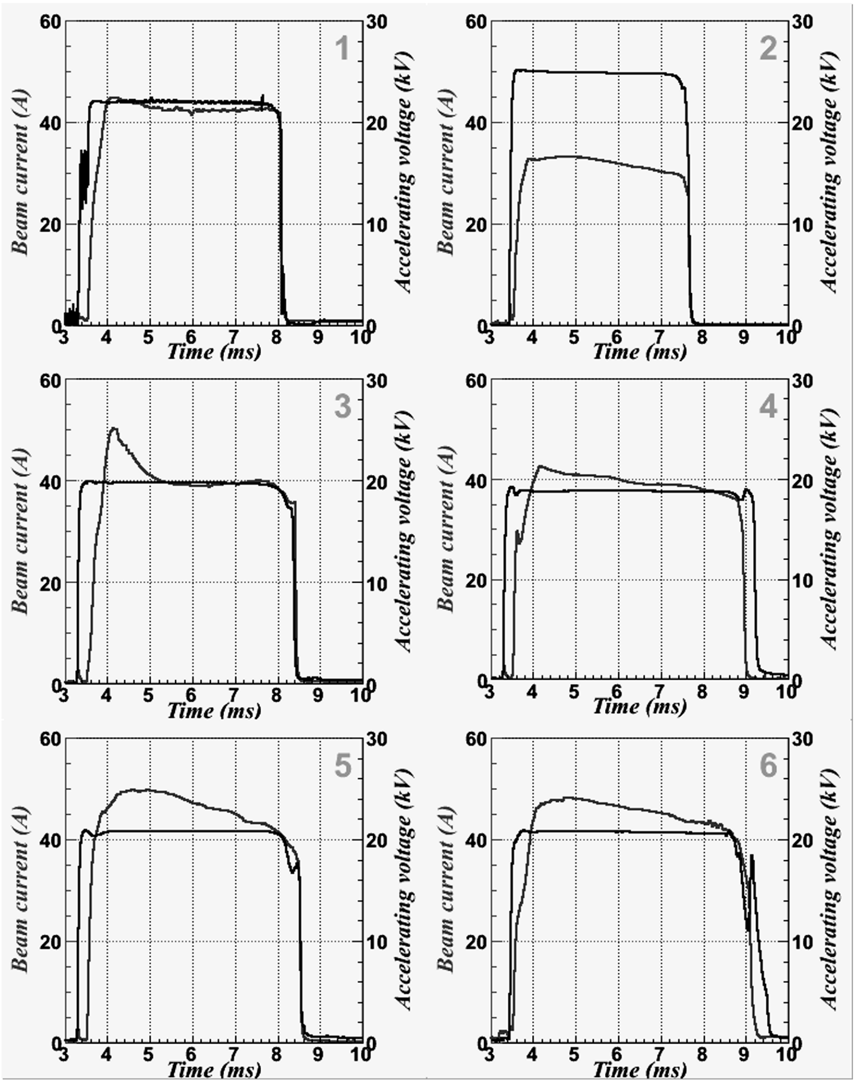


Figure 2: Beam current and accelerating voltage for upgraded system of atomic beam injection of GDT device.

4.1.2 Realization and investigation of stationary confinement of plasma with subfusion parameters in gas dynamic trap

Increasing of atomic injection pulse duration from 1 to 5 ms allowed us to investigate a quasi- stationary confinement mode which means that experiment duration is longer than all characteristic time scales of plasma relaxation that is longitudinal target plasma confinement time and time of fast ions drag on target electrons. According to estimations and modeling results fast ion distribution function became close to equilibrium one because the characteristic energy lifetime relate to drag on electrons is $\tau_E \approx 700\mu$s, which is much shorter than injection pulse duration. Besides part using of new generation injectors allowed us to significantly increase plasma parameters in GDT. For the best accumulation of fast particles, for sustaining of material balance in plasma during the long injection pulse and for creating and investigating of anisotropic plasma with maximum energy content and pressure the experiment with peripheral gas puffing was realized. Gus puffing was realized in regions of strong magnetic field near the both magnetic mirrors by means of special gas box (see fig.3).

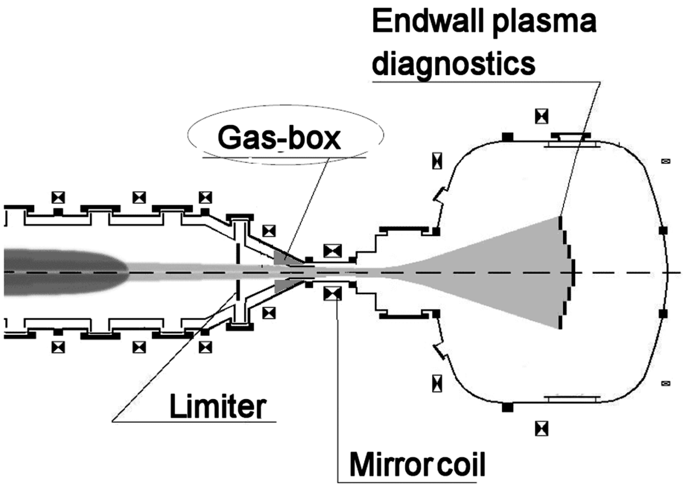


Figure 3: Scheme of peripheral gas puffing in GDT.

In this region transversal plasma dimension is comparable with neutrals free path length before its ionization in warm target plasma, therefore atoms penetrates till the GDT device axis. As a result relatively narrow target plasma density profile with characteristic radius about 8-10 cm was obtained (fig. 4).

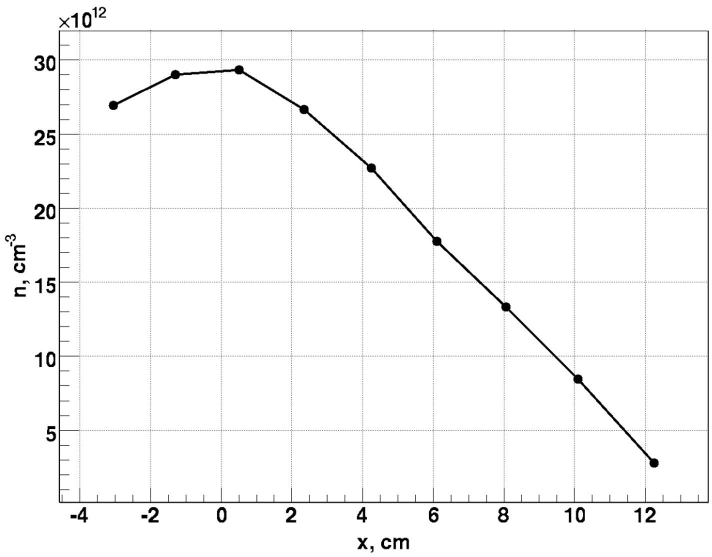


Figure 4: Plasma density profile in GDT central plane (limiter radius is 14.5 cm).

Part using of new generation injectors, peripheral gas puffing and optimization of electric potential radial profile allowed us to realize the stationary plasma confinement. In experiments on fast deuterium atoms injection the stationary confinement of two component plasma with the high relative pressure $\beta \approx 60\%$ was realized. However plasma diamagnetism increased by factor of 1.5 in compare with similar regime of 2006 year. Also the fast ions energy content approached to 1 kJ. The fast ion density with mean energy of 10 keV approached to $3x10^{13}cm^{-3}$ in its turning points and became comparable with target plasma density. Electron temperature exceeded 100 eV in this regime. Figure 6 shows the radial profile of plasma electron temperature obtained by means of Thomson scattering system.

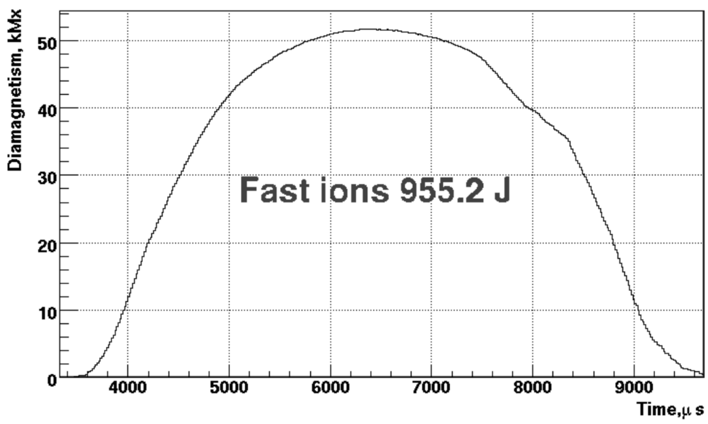


Figure 5: Plasma diamagnetism in fast particles turning points and estimated energy content of fast deuterons.

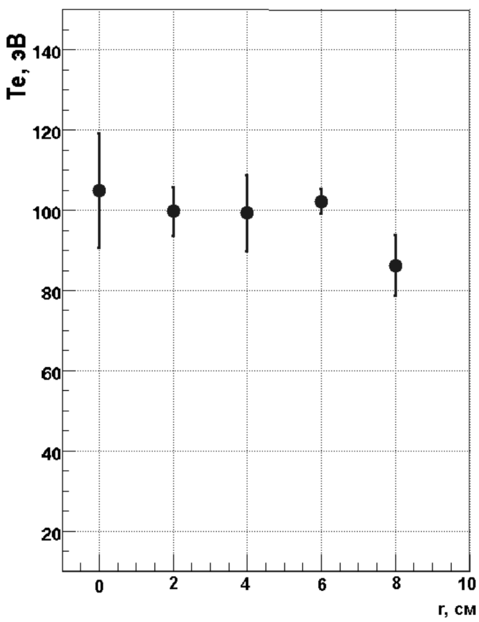


Figure 6: Plasma electron temperature profile for regimes with deuterium injection.

Using hydrogen atomic beams injection gives us a stationary confinement regime with the maximal high temperature for the moment. Fast ions energy content was lower than in case of deuterium injection and appeared about 700-800 J. The electron temperature measured on axis by Thomson scattering system at different times after injection start (time=0 is the moment of beam injectionstart) is shown at fig. 7.

At the same figure the solid line is a result of numerical calculations by integrated code ITCS. The code includes different modules which use the theory of coupled coulomb collisions and equations of classic magnetic hydrodynamics for modeling of confinement and heating of target plasma and also for simulations of accumulation and relaxation of

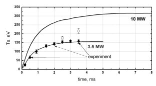


Figure 7: Electron temperature in GDT using high power atomic injection:
• - experimental data with additional gas puffing;
○ - data from "decay" experiment; solid curves - ITCS simulations for injection power of 3.5 MW and 10 MW.

fast ions in GDT device. It's clear that during 2-2.5 ms plasma temperature became a constant of about 150 eV which is in a good agreement with predictions of theory for present power of neutral beam injection of 3.5 MW. In special "decay" experiment when target plasma density didn't maintain constant during injection pulse by means of gas puffing electron temperature exceeded 200 eV.

Comparison of experimental results with numerical calculations allows to conclude that plasma heating provided by coulomb deceleration of fast ions on target warm electrons, and maximum temperature is defined by balance between power trapped by plasma and longitudinal losses power during the gas dynamic flow of target plasma. Therefore it's possible to make a numerical prediction that electron temperature will exceed 300 eV if total injection power is 10 MW (see upper solid curve at fig. 7). Situation with using of deuterium-tritium plasma will correspond the conditions of neutron source with neutron energies of 14 MeV and flow density of 0.5 MW/m^2.

At present time modernized GDT device allows to carry out a series of experiments which are very important in the context of fusion applications. For example, in 2007 year series of experiments on investigations of radial electric field influence on plasma confinement in GDT have been completed (see details in the BINP report 2006). By means of special radial electrodes "transport barrier" providing stable stationary plasma confinement is formed. Herewith particle flux across the magnetic field is not exceeded 1% of longitudinal flux. Theoretical description based on experimental results let to recommend this method as effective instrument of plasma MHD- stabilization for thermonuclear systems such as neutron source based on GDT device.

4.1.3 Accumulation and confinement of hot anisotropic plasma in the end compact mirror cell of GDT device

The new series of experiments with a hot anisotropic ion plasmoid in small mirror cell was started in 2005 and continued in 2007. Figure 8 shows the scheme of experiment.

To construct the compact mirror cell the additional vacuum chamber and magnetic coil were mounted near the mirror existed. This additional mirror cell has magnetic field in central cell of B_0=2.5 T, mirror ratio of R=2 and distance between mirrors of L=43 cm. The new futures of these experiments in contrast to series of 2005 year was the increased power and pulse duration of atomic beams creating the plasmoid.

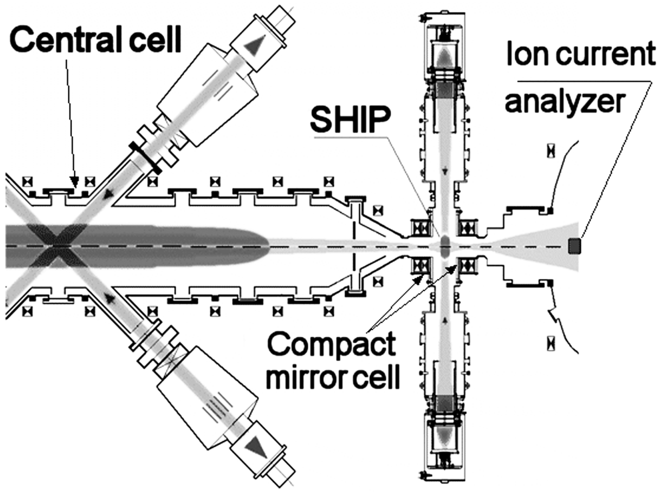


Figure 8: Scheme of experiment with compact end mirror cell at GDT device

The scenario of described experiment was as follows. The compact mirror cell was filled in with warm target plasma from GDT central cell. Density of flowing plasma was of $n_0 \approx 10^{13}$ см$^{-3}$ and its temperature T=80 eV. To crate the plasmoid the 90-degrees injection of two focused atomic beams (4 ms pulse duration, total power 1 MW and particles energies 23 keV) was used. Figure 9 shows the oscillograms of injected and trapped in plasma power. At the same picture the simulated magnitudes of these parameters used for modeling by ITCS code are shown [A.V. Anikeev et al., Transaction of Fusion Science and Technology 47 pp.212-214 (2005)]. Integrated transport code (ITSC, Integrated Transport Code System) was developed in collaboration with Forschungszentrum Dresden-Rossendorf for plasma modeling in axisymmetric open traps. It consists of modules which allow to calculate neutral gas densities, target plasma and fast ions distribution functions including its interaction to each other.

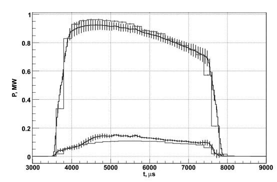


Figure 9: Injected and trapped power in compact end mirror cell: error bars - experiment, solid curve - ITCS calculation.

Figure 10 shows the fast ions density vs trapped power and calculated curve by ITCS code which considering couple Coulomb collisions kinetics and charge exchange on atomic beams. The density of fast ions with mean energy of 15 keV was about 4x1013cm^{-3} in the center of compact cell. This magnitude is four times higher than warm plasma density out of plasmoid (n_0) and almost ten times higher than warm plasma density in the center of compact cell.

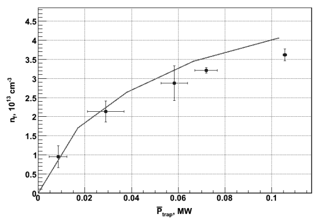


Figure 10: Fast ions density vs trapped power: error bars - experiment, solid curve - ITCS calculation.

Comparison of experimental data with simulations shows that fast ions confinement is defined by classic kinetics of couple Coulomb collisions and charge exchange on atomic beams. It wasn't found any significant losses of particles and energy due to presence of microinstabilities or other non-classic mechanisms.

Note that fast ions density achieved in end mirror cell of GDT is three times higher than previous record value obtained at TMX device at four times higher power of atomic beams. In these experiments on hot anisotropic plasma confinement in compact mirror cell the effect of ambipolar suppression of warm plasma flow from central cell of GDT.

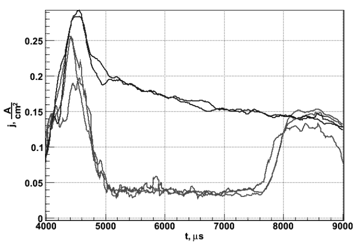


Figure 11: Ion current density flowing along the axis to the expander: upper curve - without injection to compact mirror cell, bottom curve - with injection.

Figure 11 shows the warm particles flow along the axis measured by three-grids probes in expander tank behind the compact cell. Measurements were carried out in experiment with neutral injection to the compact cell and without one. It's obvious from Fig. 11 that plasma flow from the central cell became four times smaller at maximum density of hot ions in the compact cell. Results obtained are in a good agreement with estimations of influence degree of ambipolar potential obtained on maxwellian plasma longitudinal losses from GDT device.

Publication: [127], [128], [129], [369], [370], [371].

4.2 Multimirror Trap GOL-3

Introduction

In 2007 works in several directions were conducted at the multimirror trap GOL-3.The first one is study of physics of heating and multimirror confinement of a plasma in the trap that is the primary goal of the installation. The second important research task is study of influence of a high-power plasma stream on candidate first wall materials which is a part of a general program of a fusion power development. In parallel with experiments under scientific programs, development of experimental base was continued in 2007. Reconstruction of the electron beam generator - accelerator U-2 was done, which resulted in increase of operation time of the megavolt diode. A new exit unit with a magnetic expander and a receiver of the plasma stream has been mounted and put into operation. For the first time a neutral beam injector "Start" was put into operation at GOL-3. Development of a technology of generation of a long-pulse electron beams with the plasma emitter proceeded. The diagnostic complex of GOL-3 was essentially improved.

Layout of the facility is presented in Fig.1. The 12-meter-long solenoid consists of 103 coils with an independent feed. In the regular multimirror configuration the magnetic field has 52 corrugation periods (cells of multimirror system) with 22 cm length, the field in maxima is 4.8 T, in minima is 3.2 T. The mirror ratio of the corrugated field is 1.5. That means that the operating mode of GOL-3 corresponds to a "weak corrugation regime". The solenoid terminates in single magnetic mirrors with a field 8-9 T.

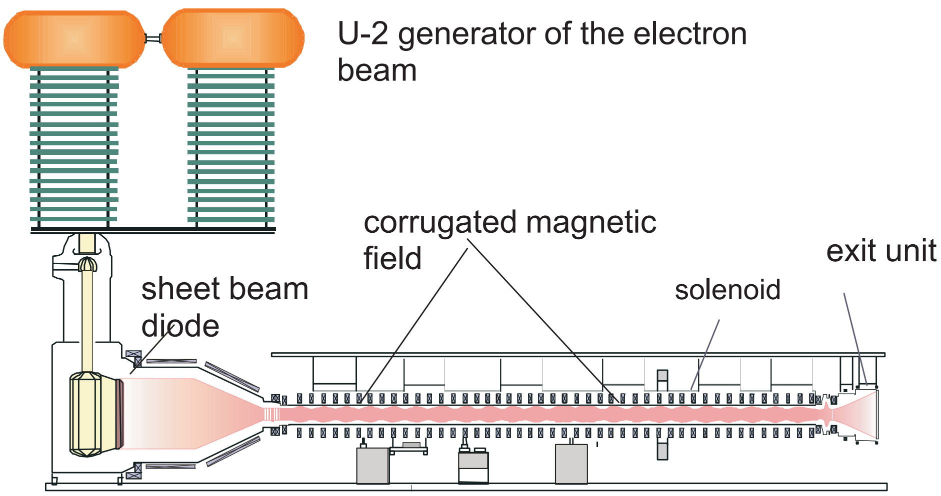


Figure 1: Layout of the multimirror trap GOL-3.

A typical experimental scenario is the following. Several gas-puff valves create required axial deuterium density distribution in a metal vacuum chamber ∅10 cm, placed inside the solenoid. Then a special linear discharge creates a start plasma with length-averaged density of $\sim 10^{21}$ m^{-3} and temperature ∼2 eV. After that the relativistic electron beam with the following parameters is injected into this plasma: electron energy is ∼0.9 MeV, current is ∼25 kA, duration is ∼8 μs, energy content is ∼120 kJ, the beam diameter is ∼5 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 confining the hot plasma much longer, than in a simple solenoidal trap.

4.2.1 Increase of the beam duration in U-2

A further development of the experiments on generation and confinement of hot dense plasma in the GOL-3 device assumes application of a long-pulse (∼100μs) electron beam for maintenance of small-scale plasma turbulence at a high level for suppression of axial heat losses and therefore for improvement of the plasma lifetime. As the first step in this direction, the prolongation of the beam pulse generated by the accelerator U-2 was performed this year. Since the beam duration is limited by shortening of the cathode-anode gap due to plasma motion in the diode, this gap was increased from 10 to 12.5 cm for these experiments. To optimize the beam transport and compression in the magnetic field at the new diode geometry and also for conditioning of high-voltage surfaces of a cathode holder of the generator, the preliminary experiment with the beam dump to a collector was carried out. The collector was installed inside the magnetic compression system with a magnetic mirror ratio equal to 15 in respect to the cathode field.

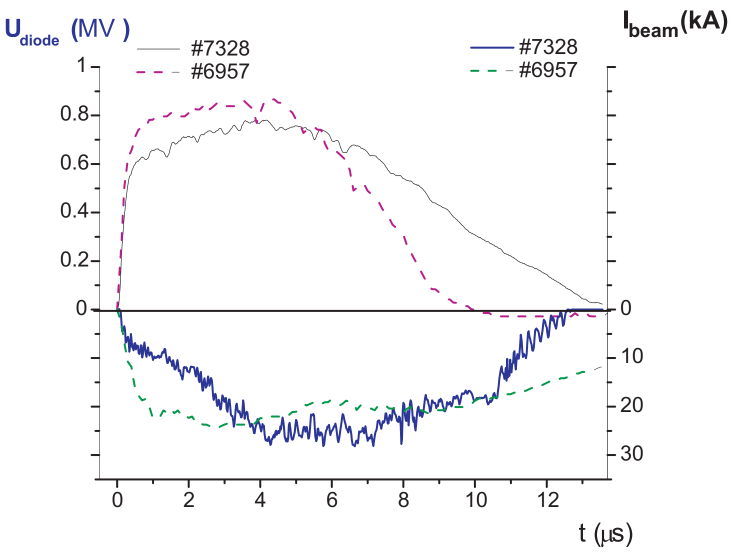


Figure 2: Cathode voltage (top) and beam current of the U-2 generator (bottom) before and after thebeam prolongation works (dashed and solid lines, correspondingly).

These experiments showed stable generation of the beam with duration above 10 μs when the cathode potential was gradually increased in such a way that at least 20 kA of the beam current exists to the time moment when the diode voltage approaches the megavolt level. Such current value is essential for magnetic self-insulation of high-voltage surfaces of the cathode holder. So, at increase of voltage rise time from 1 to 3 μs with a small decrease of the peak diode voltage the beam duration increased from 9 to 14 μs.

As the prolongation of the pulse was reached due to the increase of the diode gap so the beam current somewhat decreased. As a result the total energy content of the beam at the collector practically remains the same as before. After that series of experiments the investigations on the dense plasma heating in GOL-3 started. They have demonstrated that despite some decrease in the beam power the duration of the plasma heating stage increased with the prolonged pulse of the beam. This fact confirms the work on elongation of the beam pulse was valuable.

4.2.2 Exit expander of a plasma stream

A new exit plasma receiving vessel was mounted at GOL-3 in the beginning of 2007. It consists of a vacuum tank with ~1 m inner diameter and an exit plasma receiver of 85 cm diameter. The plasma receiver is mounted on a sectioned insulator which allows floating potentials up to 150 kV with respect to the wall. Magnetic system of this unit consists of three low-turn coils, which are powered serially with the exit mirror coil of GOL-3 with a current of about 6 kA.

New exit tank with metal plasma receiving plate enables to solve several scientific and technical problems. The first problem is a need to decrease energy and power density of the plasma stream at the receiver plate. Previous design utilized a 50-cm graphite plasma receiver whose peak surface temperature was above 1000°C. A new exit unit features greater expansion of the plasma stream in the gradually decreasing magnetic field. This enabled use of metals as the material for the receiver plate even for planned increase of the beam energy content. Use of metal electrodes instead of graphite and additional pumping system in a close proximity from the receiver tank improves also vacuum conditions both in the end tank and in the main vacuum chamber. Special stations for tests of candidate first wall materials under the high-specificenergy content plasma stream are scheduled for installation in the exit tank.

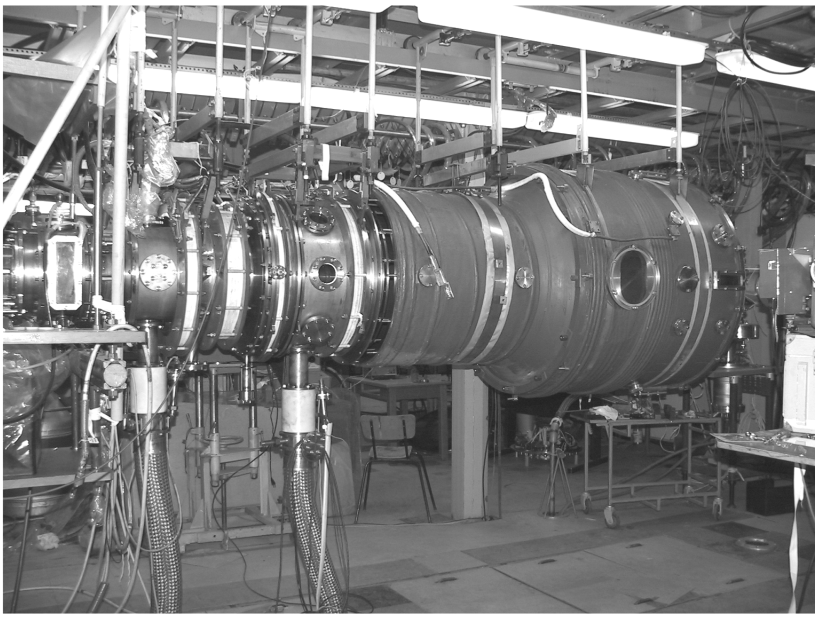


Figure 3: New exit expander with a plasma receiver during joining with GOL-3.

4.2.3 First experiments with a neutral beam injection in GOL-3

Sources of accelerated neutral beams are widely used for plasma heating in magnetic confined systems. In 2007 the first experience of using this technology was obtained at GOL-3. Neutral beam injector based on START-2 design was put into operation. Most components of the injector and its power supply system were donated by Lab. 9 of BINP. Injector was installed at the central part of the solenoid for normal injection in respect to the magnetic field axis. At first experiments the energy of accelerated atoms was 15 keV, the equivalent current was ≈30 A, the pulse duration was 0.8 ms, and the beam diameter was 130 mm. Beam passage across the plasma column was controlled by the multichannel current profilometer. This permits us to study radial distribution of the plasma density by attenuation of the neutral beam.

The feature of GOL-3 is high enough concentration (≈10^{21} m^{-3}) of gas puffing. This results in additional losses of injected neutrals. In order to reduce such losses the facility was put into a special operation mode, with the plasma and the gas densities in the vicinity of atomic injector decreased to 10^{20} m^{-3} while near needle valves it reached $1.8{\cdot}10^{21}$ m^{-3}. The experience of neutral beam injection is successful in general. The rate of beam atoms, trapped into the plasma, reached 84%. Beam loss due to ionization of neutrals in the gas on the way to plasma column is below 20%. The main source of non-productive loss of the beam power is a cold edge plasma, which stops 3/4 of injected atoms. The second problem is a fast cooling of electron component of the plasma, that restricts accumulation time of fast particles by the value of 50-100 μs.

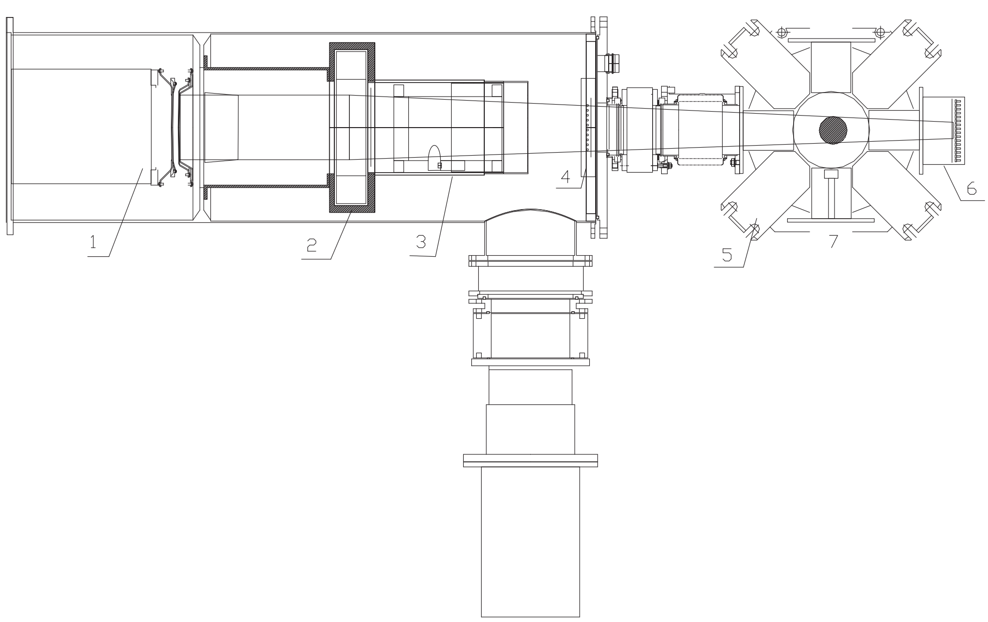


Figure 4: Layout of neutral beam injection system at GOL-3:
1 - source of accelerated ions, 2 - magnetic focuser, 3 - charge exchange chamber,
4, 6 - secondary-emission profilometers, 5 - magnetic system of GOL-3,
7 - diamagnetic loop.

In present experiments the existing grid assembly formes the beam with low angular divergence. Aperture of used for NBI input port of GOL-3 is significantly less than the beam diameter, so the most part of the beam power is lost at the construction elements before the beam arrives at plasma. In future we plan to develop the optimized grid system with geometric focusing. In the considering experiments injector was used as a diagnostic of radial profile of the plasma density.

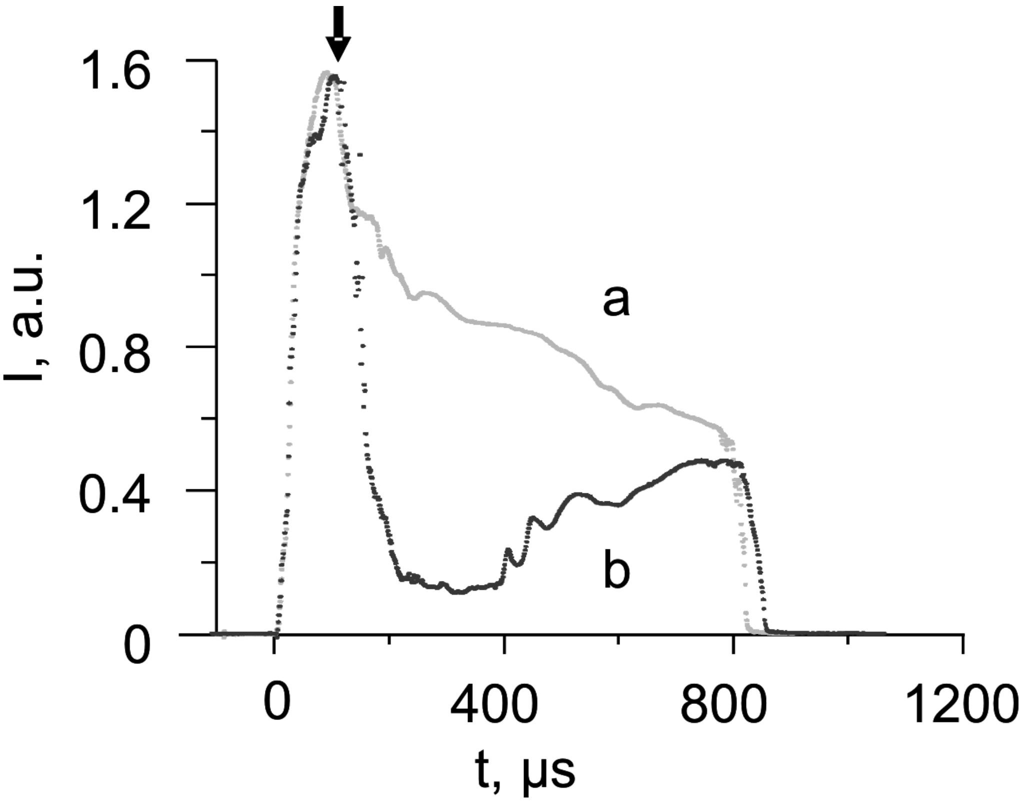


Figure 5: Neutral beam attenuation by the GOL-3 plasma. Curve (a) is the current of the central collector of the profilometer, NB injector only, (b) is the same signal at NBI into the GOL-3 plasma. t = 0 corresponds to NBI start, start of the plasma is marked by the arrow.

4.2.4 Study of erosion of carbon targets under action of high-temperature plasma stream

Plasma-surface interaction studies are one of the main directions of research at GOL-3 facility. Unique feature of the GOL-3 facility is ability to carry out experiments of high-power plasma stream exposure to construction materials. The energy density, achieved during irradiation of the targets - up to 20 MJ/m^2 - is similar to what is supposed at the divertor plates of largest modern operating and proposed tokamaks. Recently processes of explosive destruction of carbon, durability of tungsten targets, and long-distance propagation of surface plasma along the magnetic field were studied at GOL-3. The aim of the experiments of 2007 was investigation of carbon targets erosion under irradiation of plasma stream with moderate (2 MJ/m^2) energy release, that corresponds to that expected in the ITER divertor in the ELM type I regime.

A set of optical diagnostics was used for study of target erosion processes (Fig.6). It includes a survey visible spectrometer, a high-resolution spectrometer, and an imaging system for measurements of spatial distribution of intensities of several spectral lines. All optical systems were absolutely calibrated by standard light source for radiation power measurements. A plate from MPG-6 graphite with a rod of 50 mm length and 10 mm diameter from the same material mounted in the center of the plate was used as a target. The rod was used for study of carbon vapor and plasma expansion across the magnetic field.

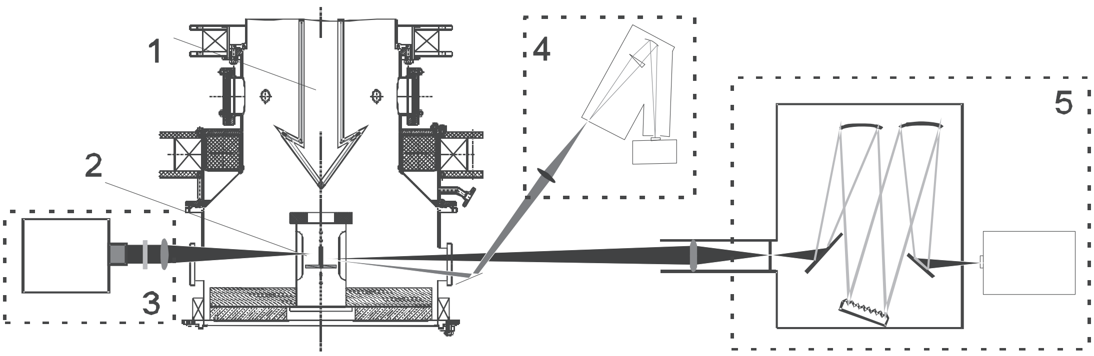


Figure 6: Layout of a surface plasma diagnostics; 1 - plasma stream, 2 - target, 3 - imaging system for measurements of spatial distribution of intensity of spectral lines, 4 - survey spectrometer, 5 - high-resolution spectrometer.

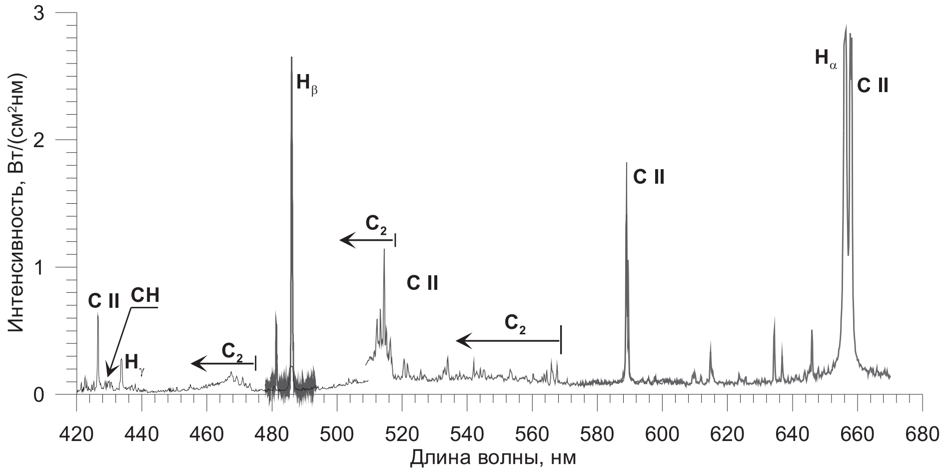


Figure 7: Spectrum of surface plasma radiation (combined from parts measured in different shots).

Spectrum of surface plasma radiation is shown in Fig.7. Lines of hydrogen Balmer series (H_α and H_β), of single-ionized carbon CII, and radiation spectra of molecules C_2 (Swan band $d^3\Pi$ - $a^3\Pi$) and CH (Gero band $A^2\Delta$ - $X^2\Pi$) dominate in the spectrum. Measurements of intensities of spectral lines of carbon ions and hydrocarbon molecules allow us to determine fluxes of hydrocarbons from the target surface as well as total flux of carbon atoms into the plasma. Parameters of the plasma required for carbon flux calculation were determined by spectroscopy methods (plasma density and ion temperature - from analysis of shape of H_α spectral line, electron temperature - from ratio of intensities of C II ion lines).

Molecules C_2 (460-478 nm, 507-516 nm, 530-565 nm), and CH (420-435 nm), whose spectral bands are observed in the spectrum, appear due to dissociation of methane- and ethane- like hydrocarbons that born in a surface of a target. Such hydrocarbons have no optical bands and can not be observed directly by optical spectroscopy. Correlation between molecular flux from the surface and radiation power of certain band is described by the parameter D/XB , named the inverse photon efficiency. This parameter determines a number of molecules going from a surface corresponding to each emitted photon of certain optical transition.

Experimental data of CH and C_2 molecules spectral bands emission can be fairly well described by a model proposing that chemical erosion occurs via creation of ethane-like molecules. Hydrocarbon flux determined from experiments equals to Φ_{C2Hy} =(1 - 1.2)$\cdot 10^{18}$ molecules/(cm^{2}s), that gives chemical erosion rate $2\cdot 10^{18}$ atoms/(cm^{2}s).

Full number of carbon atoms going to plasma (that is full target erosion rate) can be derived from measurements of radiation power of spectral lines of single-charged carbon ions. Concentration of carbon ions found from radiation power of spectral line CII (658.1 nm) is equal to $n_{CII} = 8\cdot 10^{14}$ cm^{-3}, that gives estimate of erosion rate $3.2\cdot 10^{20}$ atoms/cm^{2}s corresponding to erosion depth of 7 nm per shot. Such erosion depth is in satisfactory agreement with calculations of carbon surface evaporation under given power density load.

Thus in the investigated regime the chemical erosion gives about 0.5% of full number of carbon atoms going to the plasma. Estimates show that physical sputtering under action of hot ions going from the main part of facility as well as of carbon ions from the surface plasma is not contribute sufficiently to the erosion rate. Full erosion depth is $\sim 1\mu$m or $\sim 10^{19}$ atoms/cm^2 per shot, that in a factor of 10-100 exceeds either measured value of carbon atoms in the plasma and the estimate of evaporation rate. At the same time the surface erosion has nonuniform structure. Deep craters and flacking of surface layer are observed in SEM images of the irradiated surface. That means that brittle destruction of the surface occurs even under the low-energy-density loads. Such destruction results in a dust creation that determines the overall erosion rate but can not be detected by spectroscopy methods.

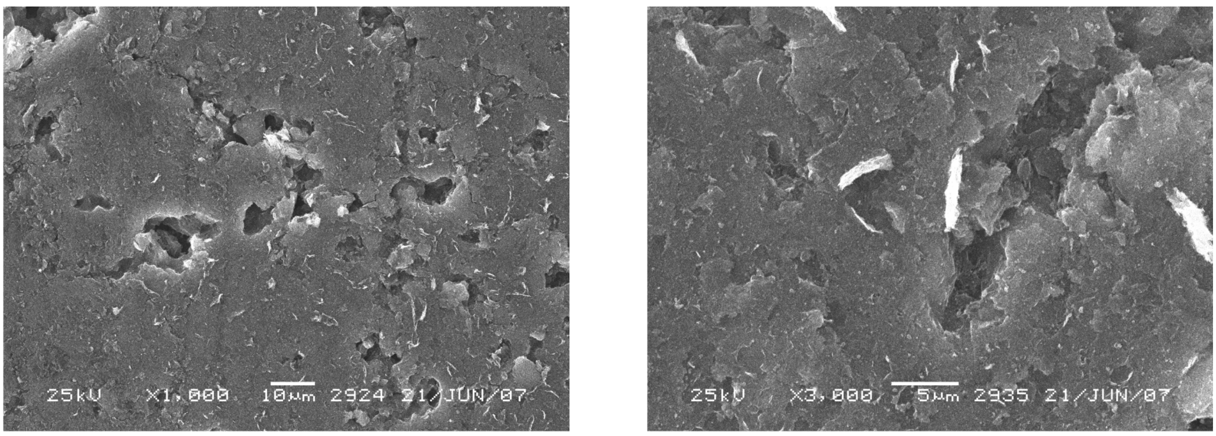


Figure 8: Defects of surface of irradiated carbon samples (SEM photos).

4.2.5 Development of the technology of intensive long-pulsed electron beam formation on the basis of plasma emitter

In 2007, within the framework of the long-range plan on upgrade of the GOL-3 facility, the works were continued on obtaining a high-power electron beam with the duration in the range of hundreds of microseconds, which has high brightness and large energy content, and purposed for heating and stabilization of a plasma in the multimirror trap. The works were conducted in two directions: experiments were continued on the stand with the beam source on the basis of arc plasma electron emitter, together with this the concept of the "next step" was elaborated, which is targeted for creation of a beam source with accelerating voltage of 150 kV and by an order of magnitude higher beam energy content. In the experiments at the stand basic efforts were concentrated around two tasks: the study of the influence of external magnetic field on the beam formation and an increase of the beam current by using the multi-aperture electron optical systems (EOS). The electrodes of these EOS were manufactured as grids with round openings, positioned in the hexagonal order. Number of openings varied from 6 to 19 in different experiments. Together with the grid-type electrodes, the first tests were performed with the EOS with annular slit apertures at the end of 2007.

Figure 9: Left: anode of 19-aperture EOS. Right: emission electrode of slit-type EOS. Size of the openings and the slit width is about 3 mm.

The traces of currents and voltage for 19-aperture EOS are shown in Fig. 10. The maximum achievable beam current and pulse duration were determined by the possibilities of the power- supply system available for the stand experiments. The beam current of 130 A (pulse top averaged) was reached, which corresponds to emission current density in the openings of 80 A/cm^2. Up to 95% of the arc discharge current is passed towards the emissive electrode (EOS cathode), and about 52% of that current was extracted to the beam, that is close to the geometric transparency of the EOS grid. Even higher current density (above 130 A/cm^2) was achieved in the experiments with 7 and 6-aperture EOS with the maximum beam current of 70 - 75 A.

With exceeding of the maximal current density the duration of the beam pulse falls sharply (from 2 to 3 times), and with attempts on further increase of the current the breakdown of accelerating gap is developed in several microseconds with the average interelectrode electric field strength of approximately 120 kV/cm. Experiments evidenced that these parameters, apparently, are very close to the maximally accessible for the EOS of given design at the operating voltage of 30 kV. Experiments with the slit-type EOS are at the initial stage now, however, the first studies showed the applicability of such type of EOS and a good potential for further development.

The study of the influence of external magnetic field on the beam forming showed that the application of weak magnetic field leads to an increase of the emission current density. The beam parameters given above were obtained in the field of $4{\cdot}10^{-3} \div 6{\cdot}10^{-3}$ T. At the same time, with exceeding of a certain “critical” value about $8{\cdot}10^{-3}$ T, the extractable beam current density decreases. The reasons for the strong dependence of a maximally obtained beam current density on the magnetic field are studied at present. Apparently, this is connected with the influence of magnetic field on the initiation and the dynamics of the plasma, which is formed during transport of the beam in the anode openings region and in the beam line, and with the subsequent influence of this plasma on the work of the electron beam source.

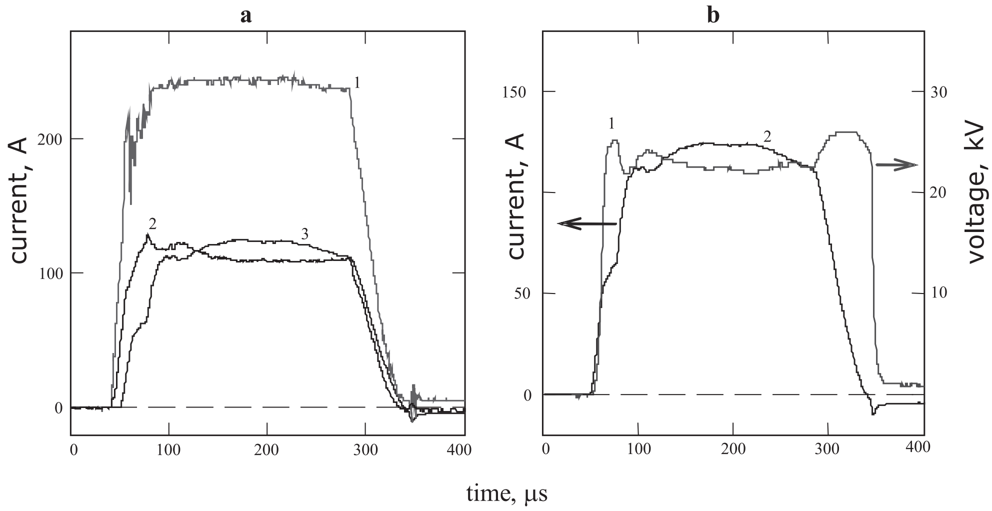


Figure 10: Beam waveforms for the 19-apertured EOS. Marked with numbers are:
a) 1- arc discharge current, 2- current to emission electrode, 3- beam emission current;
b) 1- accelerating voltage, 2- beam emission current (the same as in Fig.10a).

4.2.6 Upgrade of control and data acquisition systems of GOL-3

A scheduled upgrade of diagnostic system of GOL-3 was completed in 2007. The improvements were done for some diagnostics but mainly for communication and data acquisition electronics. After the regimes with improved confinement were found in GOL-3, a previously existed system became obsolete due to hardware limitations of ADCs Ф4226, which were the main digitizers since mid-1980ies. A synchronous measurement system A1225/32 (12 bit, 50 MHz, 32 Kwords, up to 64 channels in a 3U, 84HP crate) was chosen as a new bulk digitizer following a proposal of the electronics group form Lab.9 (A.D.Khilchenko, A.N.Kvashnin, V.F.Gurko, P.V.Zubarev, D.V.Moiseev). Each crate is controlled by a 32-bit processor module WebARM with the embedded operation system μLinux and Ethernet interface. About 120 measurement channels were manufactured that enabled us to switch several most important diagnostics to the new system. Pace and amount of this work were determined by the available funding. Two dedicated Ethernet segments were built. One segment is for digitizers and digital oscilloscopes, the second segment is for a distributed set of digital cameras. All the hardware use fiber optics links for electromagnetic compatibility in a high-noise environment of GOL-3.

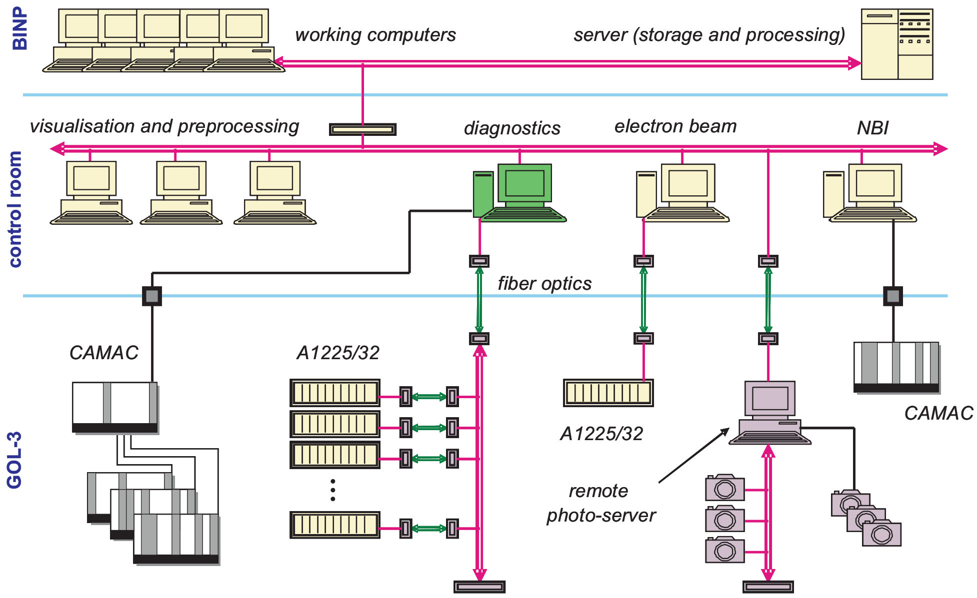


Figure 11: Structure of control and data acquisition of GOL-3.

The data acquisition system was completely reconfigured. Now we have two dedicated computers which have physical connection with old hardware, which require cable links. One of them controls digitizers and remaining CAMAC equipment, it is placed in the control room. The second dedicated computer is a remotely-operated server of digital cameras (both for USB- and Ethernet-linked) which is placed in a sub-level near GOL-3. Separate autonomous control remains for a subsystems which require capability of independent operation (electron beam generators U-2 and U-3, magnetic system, neutral beam injector). The rest workplaces in the control room are used for visualization and preliminary processing of raw experimental data and usually have no direct access to the hardware.

SUMMARY

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

Participants of this work:

A.V.Burdakov, A.V.Arzhannikov, V.T.Astrelin, V.I.Batkin, A.D.Beklemishev, V.B.Bobylev, V.S.Burmasov, G.E.Derevyankin, V.G.Ivanenko, I.A.Ivanov, M.V.Ivantsivsky, I.V.Kandaurov, V.V.Konyukhov, I.A.Kotelnikov, A.G.Makarov, M.A.Makarov, K.I.Mekler, S.V.Polosatkin, S.S.Popov, V.V.Postupaev, A.F.Rovenskikh, A.A.Shoshin, S.L.Sinitsky, Yu.S.Sulyaev, I.V.Timofeev, Yu.A.Trunev, L.N.Vyacheslavov, V.A.Yarovoy, Ed.R.Zubairov.

4.3 ELMI-device

Introduction

To produce high-power (P ∼ 1GW) pulses of coherent millimeter wave radiation the concept of a planar free electron maser (FEM) with two-dimensional distributed feedback (2-D DF) was suggested and developed by scientists from BINP and IAP (Nizhnii Novgorod). This feedback should provide a stable phase synchronism in the radiation flow generated by the beam with large transverse size in comparison with the radiation wavelength. The possibility of such feedback realization was proved in the experiments on the planar FEM at the ELMI-device in which a single mode generation of 4-mm radiation with power ∼ 10 MW and pulse duration 0.4 μs was observed.

Basing on the results of simulations that demonstrated a possibility of simultaneous generation in a single accelerating diode of a few sheet beams with acceptable parameters for microwave generation we have suggested a new two-stage scheme of FEM with two sheet beams for generation of high - power THz radiation. The mechanism of THz wave generation in this scheme is based on the effect of stimulated scattering of the pumping electromagnetic wave on the relativistic electron beam. In suggested scheme the original pumping wave with frequency 75 GHz is generated by the first electron beam in the FEM with planar resonator supplied with 2-D Bragg reflectors for provision of spatial coherence of the radiation. This wave is delivered through a special waveguide to another adjacent slit channel, where it propagates in the opposite direction to the second sheet electron beam. The scattering of this wave in the direction of the beam produces $4\gamma^2$ multiplication of the initial frequency that converts radiation to THz band at the electron energy about 1 MeV.

For such project realization two problems should be solved. The first one is to design the accelerating diode, suitable for simultaneous generation of two high-current sheet beams. Another one is concerned with determination of conditions for stable equilibrium transport of intense sheet electron REBs in the moderate magnetic fields inside the slit vacuum channels. In this connection the aim of our experimental investigations at the ELMI - device in 2007 was realization of simultaneous two-beam generation in a single diode and their transport in the slit channels.

4.3.1 Computer simulations

The main problem in generation of high power REBs suitable for generation of THz radiation in two-stage scheme is achievement of limit brightness of the beam that is proportional to the current density of the beam j and inversely proportional to the square of its angular divergence - Θ^2. Simple estimations have shown that for acceptable efficiency of the wave energy transfer to the THz band, the level of the beam density j ∼ 3 кA/cm^2 at the spread of longitudinal velocities of the beam electrons $\Delta V_{\shortparallel}/V_{\shortparallel} \approx \Theta^2/2 < 10^{-2}$ is required. It should be noted that to generate mm-wave radiation the value of this spread about $5{\cdot}10^{-2}$ is sufficient. Early analytical consideration and computer simulations have shown that for the electron beam generated in the magnetically insulated diode with ribbon geometry at the diode voltage 1 MV and relatively low electron current density 150 A/cm^2 in the magnetic field 0.6 T inside the slit channel it is possible to reduce the angular divergence below the value $\Theta \sim 2{\cdot}10^{-2}$. It was achieved by proper choice of the diode geometry and configuration of the magnetic field which set conditions for subtraction of contributions to the angular divergence from the electric and magnetic fields inhomogeneities. In the case of four beams generated simultaneously in a uniform accelerating unit in the results of computer simulations we have demonstrated the possibility to reach sufficiently high brightness of the beams adequate for generating mm- wave radiation. To investigate the prospects of such beams application for two-stage scheme of THz - wave generation we have performed computer modeling of simultaneous generation of two sheet beams in the magnetically insulated diode and the output of these beams in narrow slit channels. Obtained results confirmed the possibility to achieve the level of the angular divergence $\Theta \sim 5{\cdot}10^{-2}(\Delta V_{\shortparallel}/V_{\shortparallel} \sim 10^{-3})$ at a considerably high current density about 1 kA/cm^2 in the magnetic field 1.7 T.

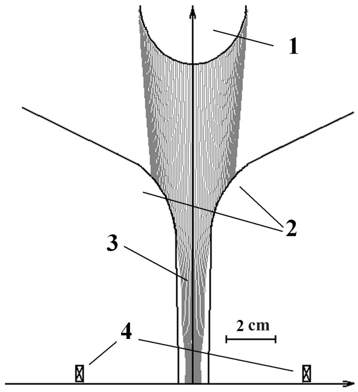


Figure 1: 1 – cathode, 2 – anode, 3 – e - beam, 4 – magnetic field coils on the channel.

As example of such simulations the Fig. 1 illustrates the trajectories of the electrons in the diode calculated by means of code POISSON-2 that solved 2-D self-consistent stationary problem on generation of the sheet beam in the diode. In the result of simulations the appropriate design of magnetically insulated diode including the location of magnetic coils has been realized.

4.3.2 Experimental results on generation and transport of two sheet beams

The experiments on the simultaneous generation of two sheet beams and their transport in slit vacuum channels have been realized basing on the results of computer simulations. Schematic drawing of these experiments is presented in Fig. 2.

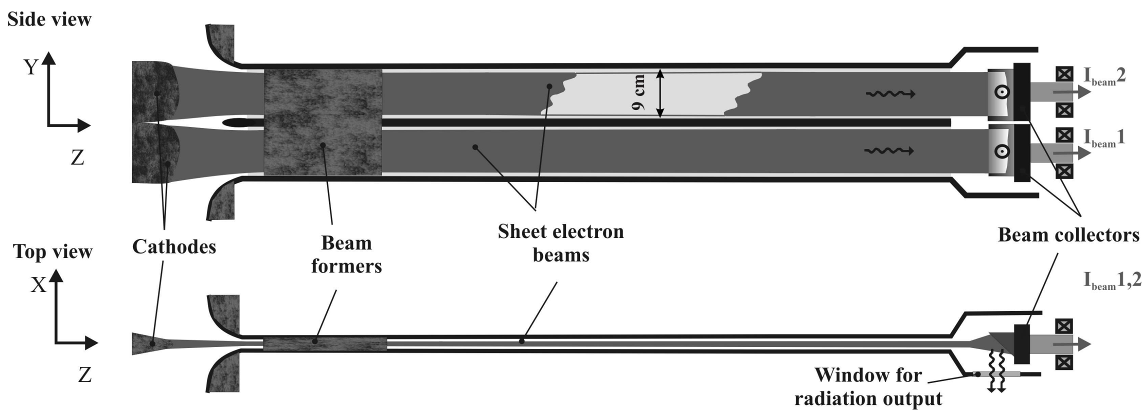


Figure 2: Schematic drawing of the experiments on simultaneous generation of two sheet beams.

Two sheet beams are generated by two vertically elongated cathodes placed one over another (see side view). These cathodes are made of a fibrous graphite material to ensure homogeneous emission from their surfaces. The guiding magnetic field has adiabatic growth from 0.35 T in the diode up to 1.7 T in the channel that provides magnetic compression of the beam and rise of its current density up to 1-1.5 kA/cm^2. According to simulations for such magnetic field growth the pitch angle of the beam electrons should not exceed a few degrees. The outer areas of the beam cross sections have been cut off in special graphite formers at the beam entrances into the slit channels. Then just central parts of the beam cross sections with sizes 0.4x7 cm having minimal pitch angles of the electrons, entered the channels (see Fig. 2). After transport through the 140 cm long channels with the magnetic field 1.7 T the beams were dumped in the graphite collectors placed in the decreased magnetic field. The sheet beam thickness in this experiment was 0.4 cm and the distance between the channel walls was 0.9 cm. Gap between the beam bounds and the channel walls should provide possibility of the beam oscillations under the transverse undulator field without contact of electrons with the channel walls.

Typical traces of the diode voltage and the beam currents measured on the collectors are presented in Fig. 3. It is clearly seen that the time dependences of the beams currents are practically the same but the values have some difference.

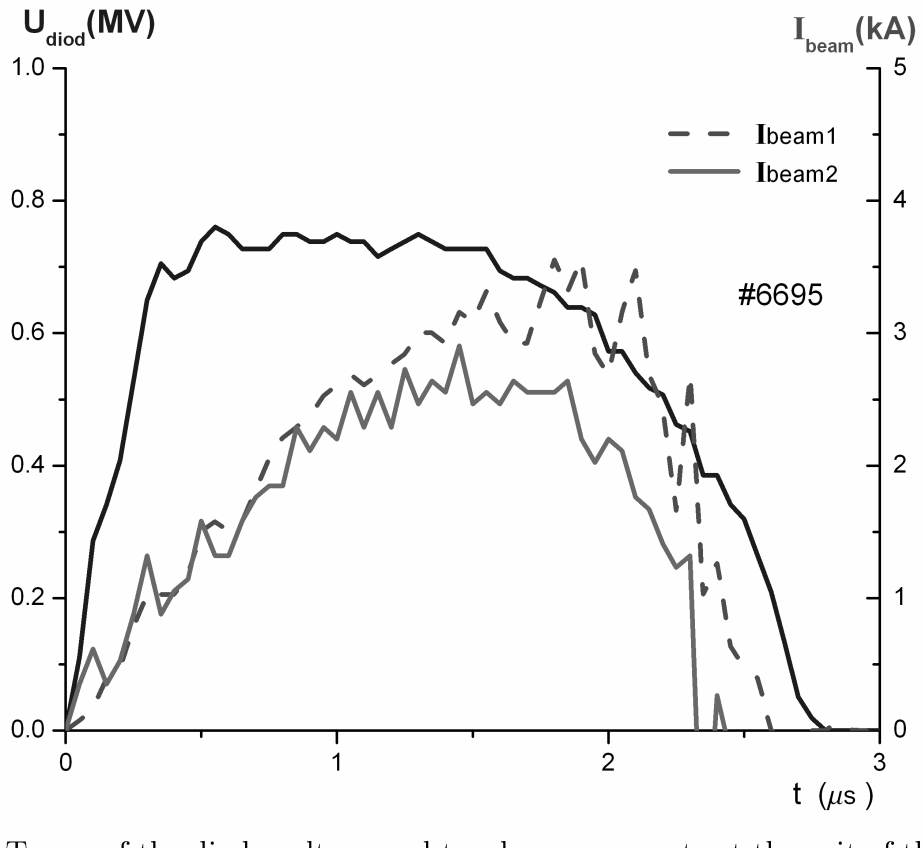


Figure 3: Traces of the diode voltage and two beams currents at the exit of the channels.

To understand this difference and to discover possible deformation of the beams cross sections the registration of the beams traces on a thin (1 mm thickness) stainless steel plates have been used. These plates have been mounted on special holders inside the channels. Ander the beam exposure the material of the plate heated up to evaporation creating the trace close to the beam cross section. Really this trace was slightly large than the beam size due to the trace edges melting. The reason of the beams currents difference has been explored by analysis of the beams traces. As a result it has been discovered that this difference is caused by tilt of the guiding magnetic field lines about the direction of the channel axis at the angle ~ 0.01 radian. To eliminate this defect in the magnetic field geometry, concerned with inaccuracy in winding of magnetic coil, the special correcting coil has been used. This coil has eliminated the tilt of the magnetic field without any damage on the beam cross section shape. After that good coincidence of the beams currents has been achieved. Taking into account the results of computer simulations the analysis of drift displacements of the ends of the beams cross sections and their shape deformations has shown that the beam space charge neutralization f is larger than $1/\gamma^2$ but far from unity. Since the initial thickness of the sheet beams was not equal to equilibrium quantity, some deformations of the beam cross sections at the transport length 140 cm have been observed in accordance with the simulation results. At the same time at the transport length 50 cm the ribbon shape of the beam cross section was good enough, and the gap between the beam and the channel walls was still about 0.1 cm. Thus any deviations of the beam cross section shape along 70 cm channel section after the beam former, where FEM resonator will be placed, seems to be negligible.

Conclusion

1. Scheme and conditions for simultaneous generation of two sheet REBs in magnetically insulated diode and their subsequent transport through the slit channels have been selected during computer simulations.

2. Experiments on two - beam generation and transport have been prepared and realized basing on the simulation results. Two sheet beams with close parameters, 0.4x7 cm cross sections and current densities up to 1.5 kA/cm^2 in a guiding magnetic field 1.7 T have been generated in the experiment.

Thus the created geometry of ELMI-device seems to be acceptable for the experiments on generation of terahertz radiation.

4.4 Plasma theory

Research in plasma theory was conducted in several areas.

In the area of the *wakefield acceleration,* acceleration of positrons in the wakefield of an electron beam is numerically analyzed for different regimes. A new way of achieving both the high acceleration efficiency and the good beam quality in a plasma wakefield accelerator is found. Relaxation of an electron beam in the trapping regime was studied in detail [113, 114, 115].

In the area of the *GDT-based neutron source,* possibility of utilizing a gas-dynamic trap as a 14 MeV neutron source for a driver in a sub-critical burner of radioactive waste was analyzed, [362, 369]. A theoretical model of stabilization of the m=1 convective mode in the GDT plasma by application of electric potentials to external electrodes was developed and studied in detail [363, 364, 365].

In relation to the *multiple-mirror confinement* of a hot dense plasma in the GOL-3 trap [131] the following theoretical studies were conducted: the mechanism of turbulent suppression of the longitudinal plasma transport was identified as a result of the development of the bounce-instability [366], numerical models for the fast heating stage of the discharge [368], and for the tearing-caused evolution of the current profile [377] were developed. New, previously undescribed by the theory regimes of the multiple-mirror confinement were found [121].

In the theory of *charged plasmas* an unexpected relativistic effect was described, that is restricting the maximal radius of the equilibrium plasma configuration at a level of several centimeters (at a typical density of charged plasmas in existing devices) [122, 123]. A similar effect, though with a different nature, is expected for tube-like configurations of charged plasmas [124].

In the theory *of beams of charged particles* the well-known Pierce solution is generalized to the accelerator systems with several electrodes [125]. Conditions for existence of such generalized solution are found, and a way of minimizing emittance of the beam for cases when such solution is formally absent is suggested [340].

Several papers, [126], were initiated with relation to teaching at the physical department of the Novosibirsk State University.

Chapter 5

Electron - Positron Colliders

5.1 Commissioning of electron-positron collider VEPP-2000

In 2007 a start of VEPP-2000 complex is carried out successfully. General view of collider is shown on the Fig 1.

Figure 1: VEPP-2000 ring

The most important focussing elements in a storage ring are superconducting solenoids with the field of 13 T. Each solenoid is divided into two sections: main part 40 cm length with the field 13 T and anti-solenoid (10 cm, 8 T). By present time the solenoids are tested in immersed cryostat, after several breaks the field of 13 T has been reached.

Then final assembly with vacuum volume and LiHe tank has been made. Tests of installed solenoids showed LiHe consumption twice bigger as compared with calculated one. Inner tube of helium vessel (50 mm diameter) is a part of collider's vacuum chamber, thus it is used for cryogenic pumping of experimental straights. Synchrotron radiation from bending magnets is absorbed by a liner inside chamber.

Storage optics includes 5 families of quadrupoles (maximal gradient is 50 T/m), each family consists of 4 quads and has common power supply with a current 300 A. Chromaticity of solenoidal and quadrupole focussing is corrected by two sextupole families in technical drifts with large dispersion function. To increase dynamical aperture ($\geq 15\sigma_{x,z}$) the third sextupole family is used in injection and RF drifts. Orbit's correction is performed with 1–2 % correcting coils in dipoles and quads.

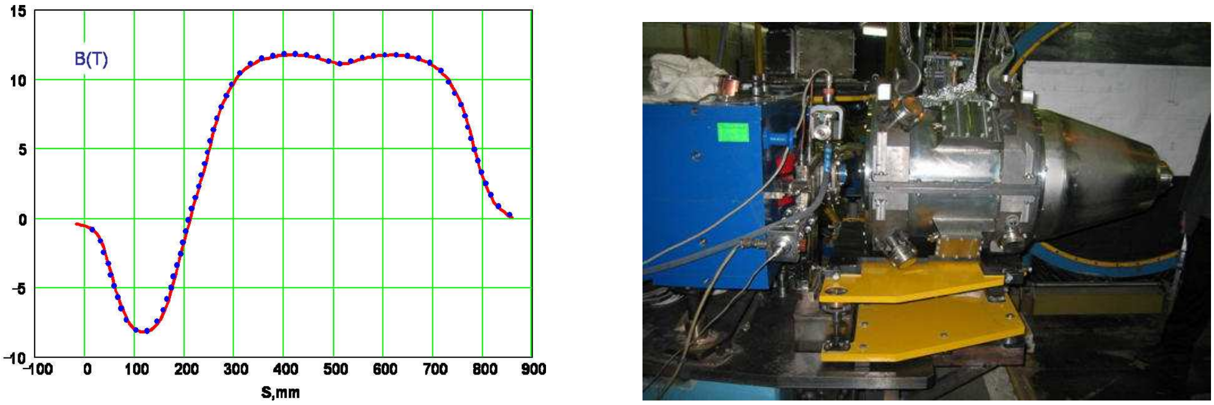


Figure 2: Longitudinal solenoid field (left). Installed into the ring solenoid (right)

Vacuum pumping of IP straights is carried out by means of inner tube of LiHe vessel. In other parts of the ring combined ion and getter pumping is used to reduce desorption of vacuum chamber by SR. Stainless steel vacuum chamber is equipped with copper water-cooled SR absorbers and provides vacuum 10^{-6} Pa with beam currents of 2×150 mA.

Each vacuum chamber has water-cooled triangle mirror which reflects visible part of SR. Then the light is directed into system of optical diagnostics. CCD cameras are used for registration of coordinates and sizes of the beam into 16 points along the ring, 4 pickups are installed in technical straights.

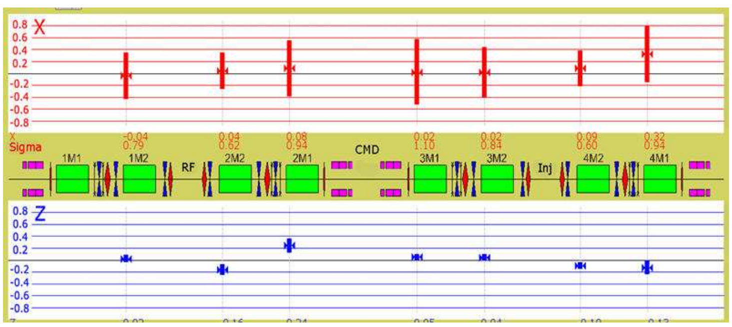


Figure 3: Sizes and coordinates of the beam taken from CCD

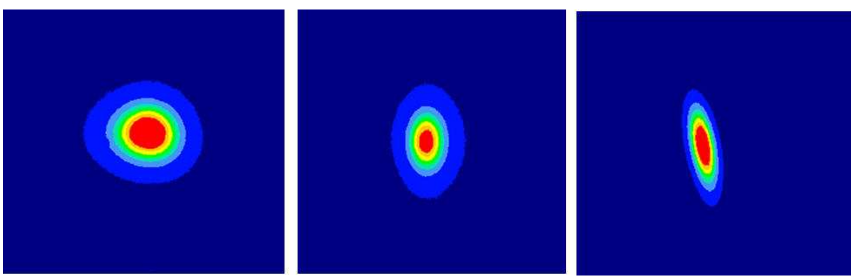


Figure 4: View of positron beam from CCD matrixes in several points along the ring

Before starting VEPP-2000 ring the injection part of accelerating complex was restored: 3 MeV linac ILU, 250 MeV synchrotron B-3M, booster ring BEP. For initial adjustment of injection into VEPP-2000 a regime without solenoids was used.

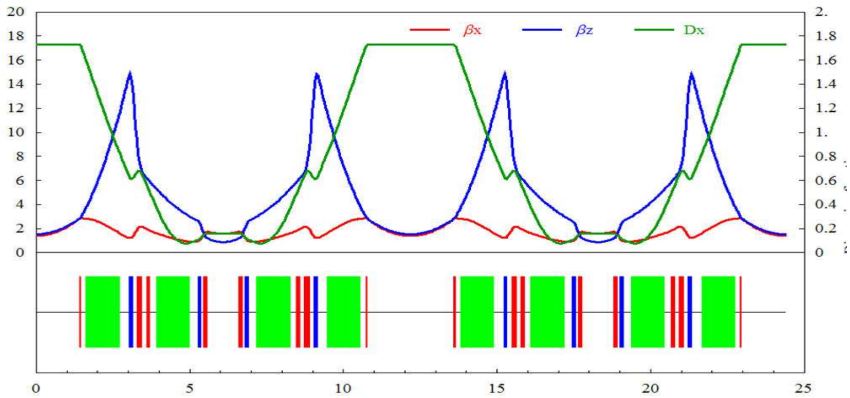


Figure 5: Optics of VEPP-2000 without solenoids

This "soft" optics is differ from round beam one, except injection drift. First circulating beam was captured at the energy 140 MeV, then at energy 508 MeV. At this energy systems of control, beam diagnostics and correction were checked and calibrated.

When effectiveness of injection has been reached at a level 70–80 % the vacuum chamber was degased by means of electron beam SR in both directions. Beam current was increased up to 150 mA, lifetime was about 1000 s.

VEPP-2000 worked about half a year in regime without solenoids. This was caused by low production of LiHe in BINP, which was insufficient to make experiments on VEPP-4 and to work with VEPP-2000 solenoids. At the end of May 2007 a cryogenic system of VEPP-2000 started to work.

First of all it was necessary to be convinced of a correct alignment of the cooled solenoids. This was done by measurements of closed orbit distortions in response of correctors. Each solenoid sections was tested at low field 4 T. Center coordinates of each part of solenoid were obtained from response matrix, then required mechanical shifts were applied. After such preliminary alignment the simplest round beam regime ($\pm$ *pm*) was activated: 1 T in anti-solenoids and 10 T in nearest to IP section of main solenoid.

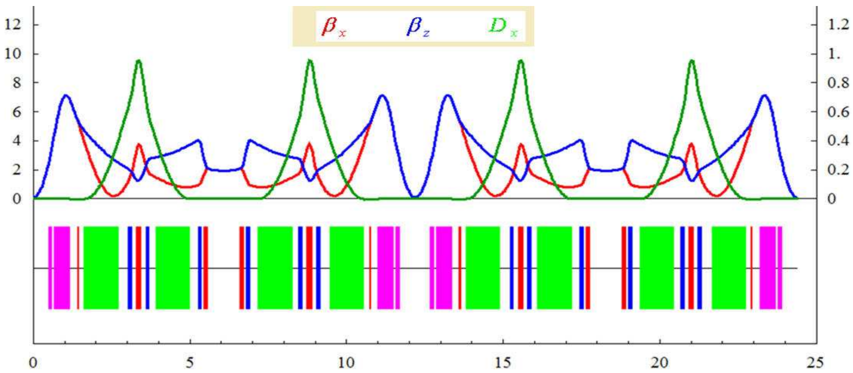


Figure 6: VEPP-2000 optics with solenoids, $\beta^* = 4.5$ cm

Electron beam was successfully injected immediately after powering on solenoids, working point was near half-integer resonance. Then some corrections of orbit and optical functions were applied to shift the working point close to integer resonance. SVD method was used to minimize sum of currents in dipole correctors and deviations in focussing strength of quads and solenoids from projected symmetry. Finally the regime was obtained with $\Delta\nu_1 \approx \Delta\nu_2 \approx 0.1 \div 0.15$ and moderate orbit distortions $\Delta x \approx \Delta z \leq \pm 1.5$ ьь) from quads' axes (Figure 7).

At that time it was possible to inject into VEPP-2000 only 3–4 mA of positrons. Hence we decided to make round beam test in weak-strong regime. Simulations predicted in this case weak dependence of beam size at IP on counter beam strength ξ. We measured horizontal and vertical sizes of positron beam in several points on the ring. Figure 8 shows dependence of RMS beam size on electron beam current in three points. Behavior of horizontal size at point 3 coincides with IP and is in good agreement with results of simulations.

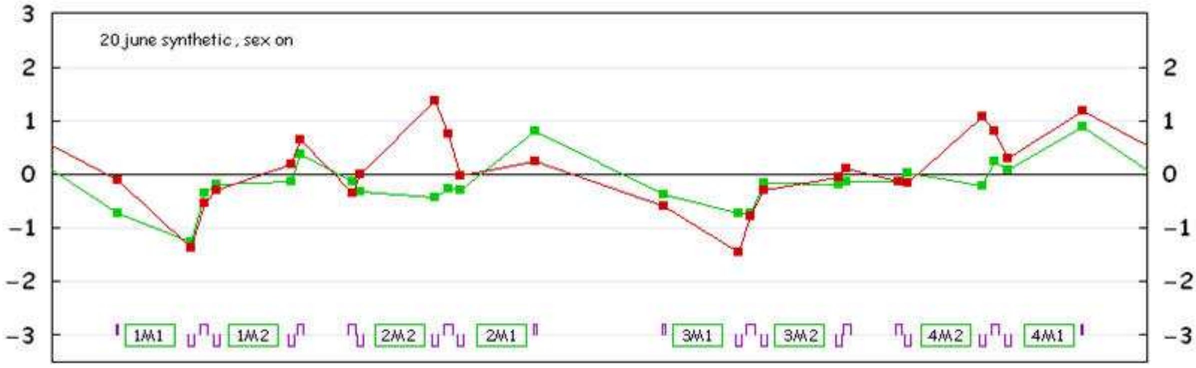


Figure 7: Closed orbit in focussing elements after SVD procedure

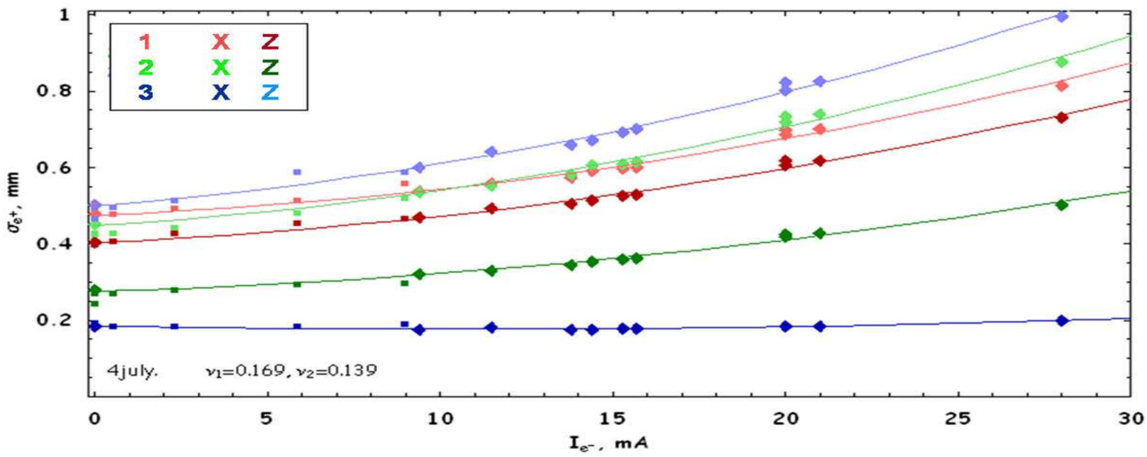


Figure 8: Positron beam size (3 mA) vs. electron current

In work participated:

[397], [398], [399], [400], [401], [401], preprints 1, 2.

5.2 VEPP-4M

Introduction

In 2007, the main directions of the VEPP-3/VEPP-4M complex activity comprised the following:

• Experimental studies in HEP with the detector KEDR.

• Experiments on scattering of electrons and positrons on protons at VEPP-3 ("Deuteron").

• Experiments with synchrotron radiation at VEPP-3 experimental stations.

• Work with synchrotron radiation at the VEPP-4 station " Cosmos".

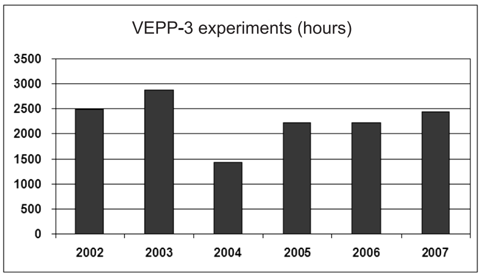
• Instrumentation studies aimed at improvement of efficiency in the complex systems and quality of experimental programs.

Distribution of the calendar time over various kinds of the VEPP-4M activity in comparison with the calendar time distribution in a few last years is given in Table 5.1

Table 5.1: *VEPP-4M operation over several years.*

	Activity	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
1	Scheduled shutdowns	2100	3276	1668	1284	1290	2580
2	Maintenance	162	186	246	258	252	174
3	Repair	1332	978	1368	654	822	420
4	VEPP-3	318	648	120	36	48	204
5	SR, SR + Deuteron	1314	2874	1428	2220	2232	1956
6	Deuteron , Deuteron + SR	1170					480
7	VEPP-4 adjustment	1308	798	1698	1374	552	936
8	Experiments at VEPP-4	906		2256	2694	3540	1608
9	SR at VEPP-4					12	60
10	Total (hour)	8610	8760	8760	8520	8748	8418
11	Total number of working hours	4698	36727	5382	6288	6324	4980
12	Working hours /Total number of hours	0,54	0,41	0,61	0,73	0,72	0,59

Working hours are calculated as a sum of lines 5-9. Remind that in 2003, there was no HEP experiments because of upgrade. Diagrams in Figs. 1,2 illustrate Table 5.1.



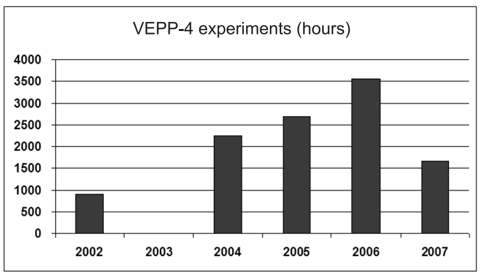


Figure 1: Experimental time of VEPP-3 and VEPP-4 (HEP, SR and nuclear physics).

It is worth mentioning that in 2007, the time spent for repair of the complex systems was managed to be twice reduced compared to that in 2006.

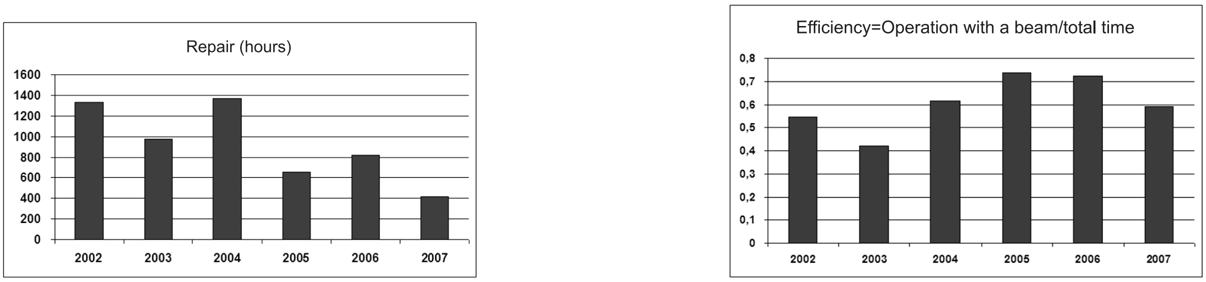


Figure 2: Left is the time spent for repair, right is the ratio of the time, when either VEPP-3 or VEPP-4 were operated, to the total calendar.

5.2.1 HEP experiments

In 2007, we continued gathering statistics at KEDR detector in the region of generation of c-quarks and τ-lepton with the rate exceeding that of the previous year by a factor 1.5.

In 2007, the luminosity integral of this experiment was doubled to be 13 pb^{-1}. The luminosity integral 3 pb^{-1} was gathered at the peak of Ψ'-meson. Accuracy of the τ-lepton mass measurements obtained at the half of the gathered statistics is of the world average value:

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

Comparison of the result by the τ-lepton mass with other measurements is given in Fig.4.

At present, we continue the collected data processing and at the end of 2007, we expect for the preliminary result on the τ-lepton mass for the total statistics. In addition, in previous year, the precision measurement of the neutral and charge D-mesons was carried out at the complex.

$$M(D^0) = 1865.43 + 0.60 + 0.38 MeV,$$

$$M(D^+) = 1869.39 + 0.45 + 0.29 MeV.$$

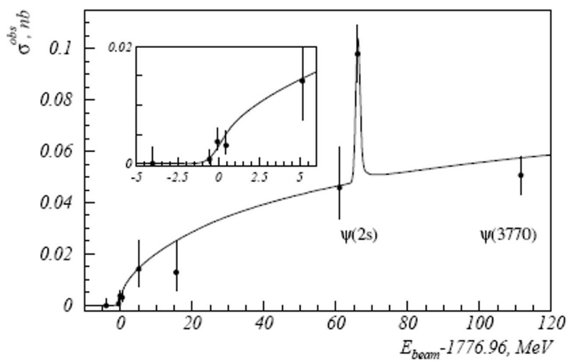


Figure 3: Measured dependence of τ-lepton generation cross-section near the threshold.

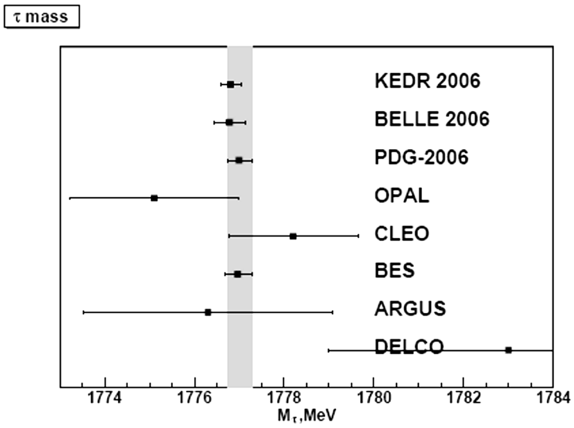


Figure 4: Comparison of measurements of the τ-lepton mass.

5.2.2 A study of proton structure at VEPP-3

In 2007, we carried out the first stage of the experiment of determining the ration of differential cross-section of the electron-proton and positron-proton acattering. This experiment will enable us to determine the contribution of two-photon exchange in the process of the electron-proton scattering and it might allow to explain the contradiction in data on the proton form factors measured with various techniques. At the first stage, a new experimental section comprising the internal target and detector was installed at VEPP-3, at the second stage, the joint operation regimes of the storage ring and experimental equipment were adjusted and measurements were performed. Equipment installed in the VEPP-3 straight section was shown in Fig.5.

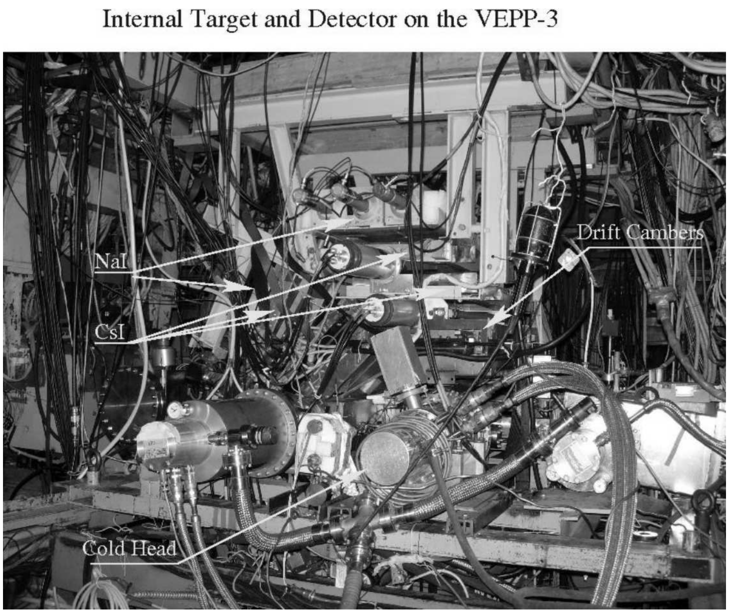


Figure 5: Experimental section.

Fig.6 shows the diagram of the electron and positron beam current at VEPP-4M during measurements.

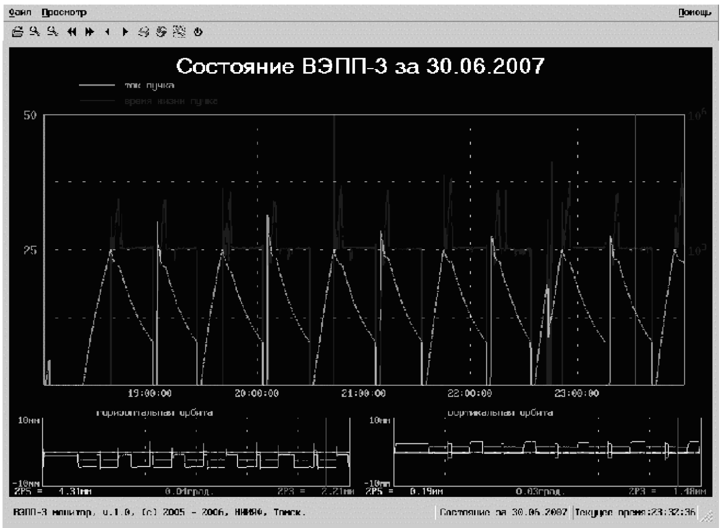


Figure 6: Current of the electron (even peaks) and positron(odd peaks) at VEPP-3 as a function of time.

The electron and positron beam energy was controlled by the inverse Compton scattering technique, which already used at VEPP-4M. The total useful current integral of the electron/positron beams was collected to be 6 kC. In addition, in 2007, the experiment on measurements of the tensor observables in the reaction of photodisintegration of the polarized deuteron was completed at the “Deuteron” installation and published in Phys. Rev. Lett. 98 (2007).

5.2.3 Experiments with the use of synchrotron radiation

The traditional field of the complex activity is carrying out experiments with the use of synchrotron radiation from the VEPP-3 and VEPP-4M storage rings. In 2007, 1956 working hours were allocated for SR experiments at 10 stations and 7 SR extraction channels. At the stations, research groups from 60 Institutes and other organizations performed experiments. After a long interruption, in 2007, we activated the work with SR beams from VEPP-4. In 2007, we completed the work on the development, manufacturing and commissioning of a special metrological SR station on the base of VEPP-4 (“Cosmos” station). The station is designed for the absolute and comparative calibrations of various equipment in a broad range of photon spectra from 10 eV to 10 keV.

In 2007, we tested two monochromators of the “Cosmos” station at SR beam and measured the photon fluxes behind the monochromators. We obtained the preliminary results on attestation of the Cosmic sun patrol equipment (a set of radiation detectors designed for the international cosmic station).

5.2.4 Accelerator physics and instrumentation

An increase in bunch current with the transverse (vertical) feedback

An increase in intensities of the VEPP-4 beams is an important task for the improvement of the complex operation efficiency. At the same time, a substantial impedance leading to excitation of the collective instabilities limits the maximum beam current by the value of 5 mA at an energy of 1.5-2 GeV and 10 mA at 4-5 GeV.

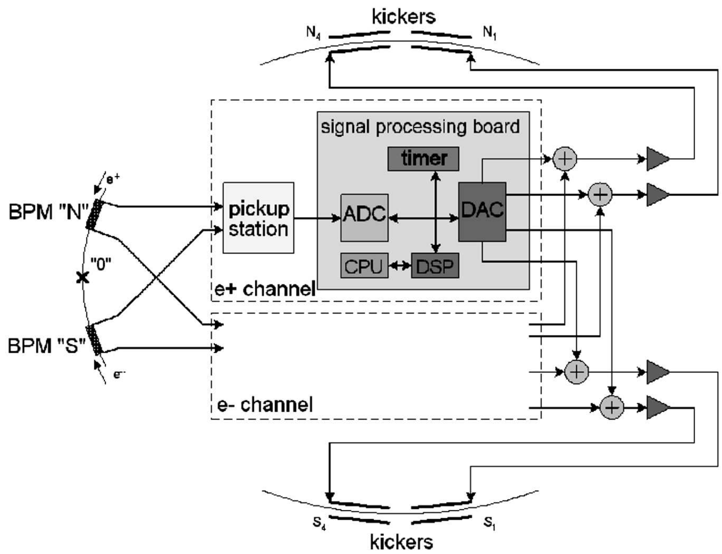


Figure 7: Schematic of the transverse FB of VEPP4M.

In order to overcome the limit and suppress the TMC-instability, at VEPP-4M, we developed the fast feedback system (FB) that will enable an increase in the bunch electron current up to 30-40 mA within the energy range from 1.8 GeV to 5 GeV in the 2x2 bunch operation regime.

At present, the system comprises (Fig.7) the pick-up electrode measuring the beam position, 4 kickers (in the north and south inserts of the VEPP-4M half-rings), 4 power amplifiers of 400 W power each with an amplification band up to 20 MHz, and the digital part base of the DSP processor TMS320C6713(frequency of 225 MHz, memory - 2Mx32 bit), which realizes FB algorithm.

The first results of the transverse FB system operation at VEPP-4M relates to the system behavior at different values of the coefficient and phase of the feedback, beam current, the sign and value of chromaticity.

Fig.8 shows turn by turn measurements of the pick-up SRP3 for 1024 turns for the case of a large positive chromaticity. Figure shows the current extracted from VEPP-3 I_{V3}, initial current I_{inj} and the current in 1024 turns I_{1024}, the latter was just considered as an indication of the FB system operation efficiency. For the chromaticity value $C_z = 4$, $C_x = 2$,the use of FB enables an increase in the injected beam up to ~30 mA. Switching FB off causes the beam drop down to ~5 mA (Fig.9).

An increase in the beam current leads to amplification of desorption under SR beam action, which in its turn, deteriorates by an order a mean vacuum at VEPP-4 and decreases the beam lifetime as is seen from the lower diagram in Fig.9.

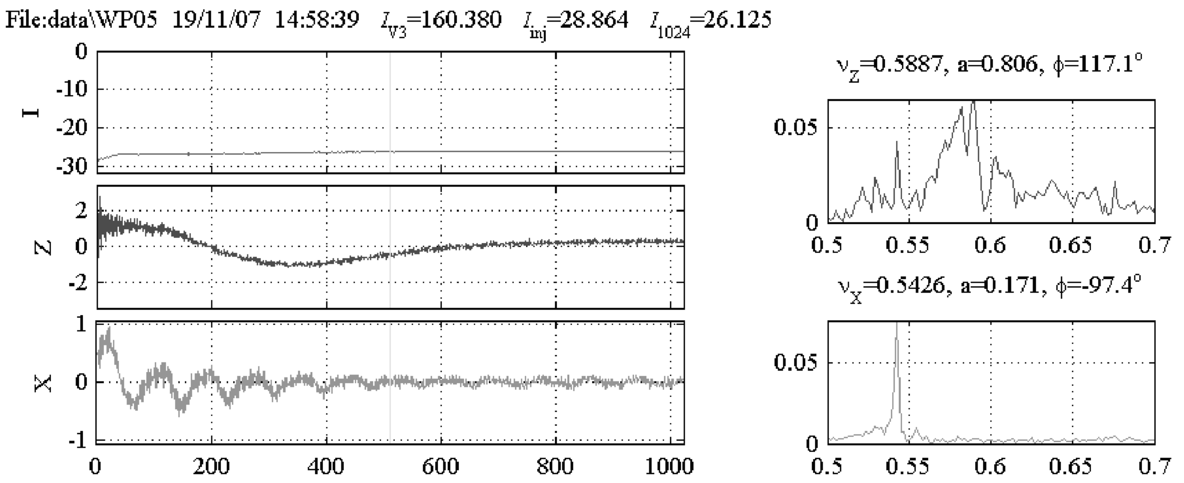


Figure 8: Injection with parameters $C_z = 4$, $C_x = 2$, K =2500, Fb phase 320°. On the left, the beam current and its focal point position are shown depending of the turn number. On the right-the Fourier spectrum of the beam oscillations.

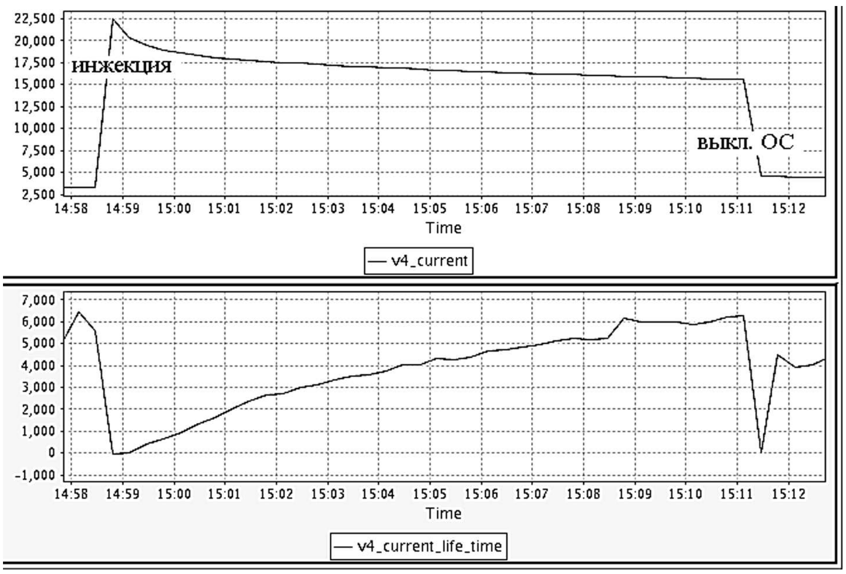


Figure 9: Beam current (above) and lifetime: I_{inj} = 29 мA, $C_z = 4$, $C_x = 2$.

Longitudinal FB system

Development and construction of the system suppressing the longitudinal coherent oscillations is under completion. The system comprises two channels (for electrons and positrons) each enabling suppression both of the co-phase and counter-phase oscillation modes, a unit of heterodynes and modulators, 100 W amplifiers and two longitudinal kickers broad band resonators with the following parameters:

- RF frequency 325.55 MHz,
- Number of the revolution frequency harmonics 397.5,
- Characteristic resistance 15 Ohm,
- Q-factor is 1000,

• Shunt impedance is 15 kOhm,
• RF voltage is 1000 V.

The resonator kicker installed at VEPP-4 is shown in Fig. 10. It it expected that the system will contribute the damping decrement of 500 s^{-1}.

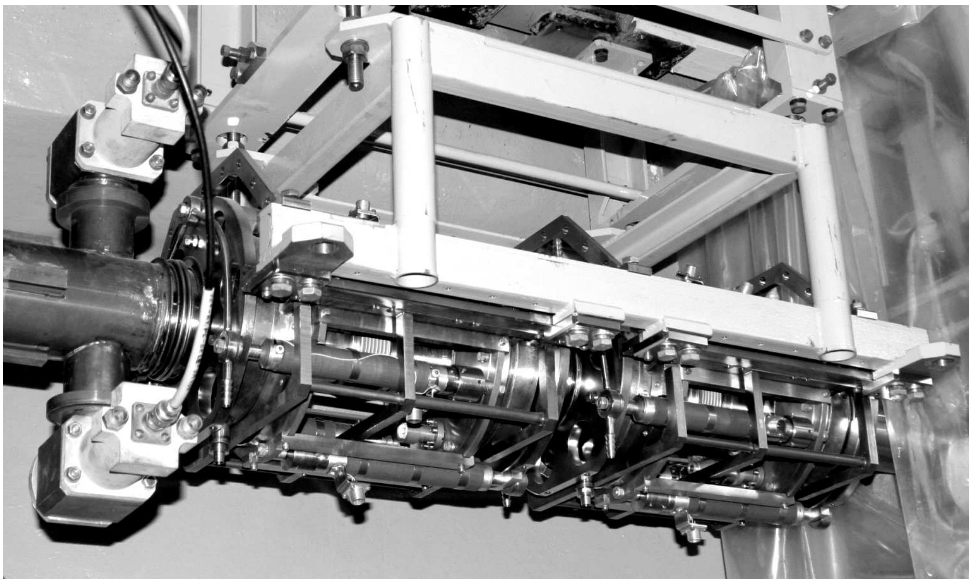


Figure 10: Broad band resonator-kicker of feedback installed at VEPP-4M.

Precise measurements of beam energies

Two techniques for measuring the beam energy are used at VEPP-4M: a) with the use of resonance depolarization (RD) and b) with the use of the inverse Compton scattering (ICS). The first technique has a record accuracy ($\sim 10^{-6}$), but it takes too much time and depolarizes electrons thus making impossible the periodic calibration with the same beam. The accuracy of the second technique is not so high ($\sim 2 \div 3 \cdot 10^{-5}$), but it is more efficient and does not require the beam polarization and it can be used directly in the process of gathering the luminosity integral. The use of the two approaches improves the reliability of the obtained results and provides the required accuracy. In this case, an energy is measured with a precise method of resonance depolarization both in the beginning and at the end of the process of gathering integral and monitoring executed with ICS in the process of gathering enables us to correct probable variations of the beam energy.

Both these techniques are described in detail in previous BINP reports and also in publications and reports at conferences.

For the RD technique, in 2007, the main efforts were concentrated on the improvement of experiment accuracy by comparison of depolarization frequencies. To this end:

• In the cross-over channel of VEPP-3-VEPP-4M, we installed and adjusted the pulse solenoid with the field integral of 25 kG x 2 m. This circumstance enabled an essential increase in polarization of positrons injected into the VEPP-4M ring. A depolarized "jump" observed with RD technique on positrons becomes two times higher thus expanding possibilities of the precise comparison of energies e^+ and e^- and also in experiments with colliding beams.

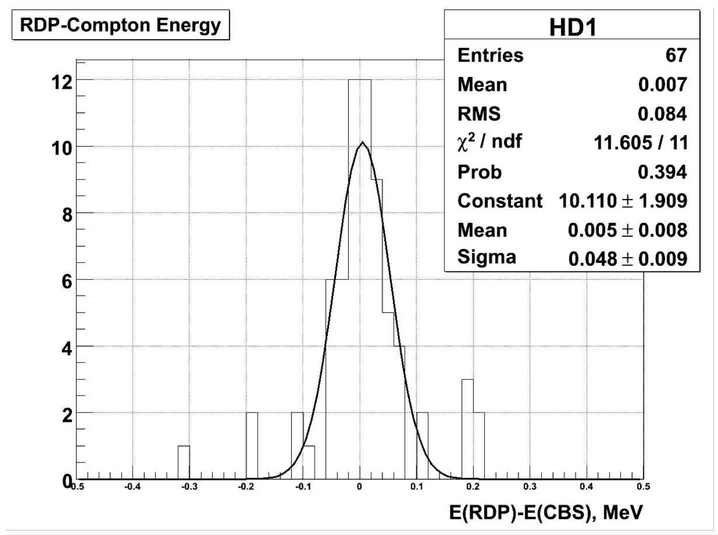


Figure 11: Difference in the energy values measured with the resonance depolarization and inverse Compton scattering techniques. Approximation of the Histogrammic approximation by the Gauss distribution give the difference of σ_E =50 keV.

• Experiments on measurements of difference in energies of e^+ and e$^-$ beams were first carried out at VEPP-4M in the regime of simultaneous scanning of their spin frequencies that enabled, in particular, to specify the systematic error in measurements of the Ψ'-meson mass.

• The record resolution in measurements of the depolarization frequency $\sim 3{\cdot}10^{-9}$ was detected.

• Comparison of depolarization frequencies of two electron bunches was first performed in the simultaneous scanning at different value of their currents ratio, which is important for studying the contribution of the current dependence of the spin frequency into a systematic error of the RD technique.

The ICS technique (installation ROKK-1M) was used in 2007 for monitoring the beam energy during measurements of the τ-lepton mass in experiments of scanning the narrow resonances Ψ' and J/Ψ at VEPP-4 and at VEPP-3for comparison energies of electrons and positrons in the experiment on measurement of the charge asymmetry in the elastic e$^\pm$- p scattering. Fig.11 shows the difference of the beam energy values measured with the resonance depolarization (RD) and inverse Compton scattering (ICS) techniques.

5.2.5 Project of the super tau-charm factory (SCTF)

In 2006, for the super B-factory, P.Raimondi proposed a new promising scheme of beam collisions, which allowed a substantial increase (by 1-2 orders of magnitude compared to the present value) in the collider luminosity. The results of the use of the proposed approach to the C-Tau factory at BINP are briefly described below.

The idea of the new scheme of colliding beams called as Crab Waist Collision (CWC) comprise two key components:

(1) Collision of beams at a large Pivinsky angles

$$\phi = \frac{\sigma_z}{\sigma_x} tan\frac{\theta}{2} \approx \frac{\sigma_z}{\sigma_x}\frac{\theta}{2},$$

which leads to that now in modern facilities, the vertical beta-function is limited not by the bunch length $\sigma_z \sim 1$ cm but rather the beam collision region $\beta_z^* \approx \sigma_z/\theta$(see left Fig.12) and it can be substantially decreased if the beam horizontal size is small.

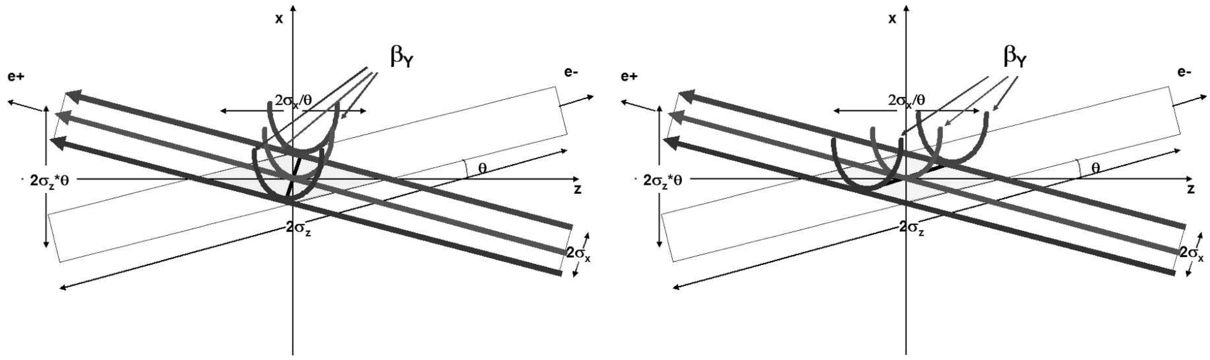


Figure 12: Illustration of the CWC-scheme. To the left collision of beams at a large Pivinsky angle but without the Crab Waist transform (beam waist of the vertical beta-function of the positron beam is perpendicular to the beam motion direction.) To the right the same but with the Crab Waist transform (beam waist of the vertical beta-function of the positron beam is turned with respect to the beam motion direction.

(2) 2nd key component of the new collision scheme is the presence of the local (near the collision point) of vertical focusing that depends on the particle horizontal coordinate:

$$y = y_0 + \frac{y'}{f} = y_0 + \frac{y' \cdot x}{2\theta}.$$

Such a focusing turns minimum (beam waist)of the vertical beta-function at the collision point thus decreasing the vertical motion modulation by horizontal, increases luminosity and expands the range of betatron frequencies where this high luminosity is attainable. The local focusing is performed by a pair of sextupole lenses located around the collision point. The lens strengths equal by the absolute value but opposite by signs and the betatron phase incursion correctly selected (Fig.13) provide both the Crab Waist transform and compensation for geometric aberration beyond the pair.

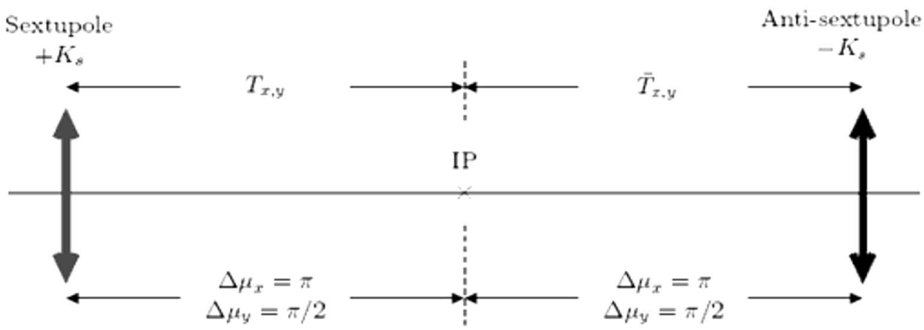


Figure 13: Arrangement of Crab Waist transform with a pair of sextupole lenses.

Advantages of a new approach are evident:

• The vertical beta-function can be decreased without decreasing the bunch length, therefore, problems related with coherent effects (instabilities, heating of the chamber by higher order modes of the beam electromagnetic field, coherent SR, etc.) are relaxed substantially.

• Luminosity can be increased without substantial increase in the beam current and spatial charge values.

• A small horizontal size and large cross-section angle solve automatically the problem of the parasitic collision points.

• CW transformation decreases substantially the number of coupling resonances in the operation frequency range. The physical program of the new complex can briefly be formulated as follws:

• A study of mixing D - $\bar{D}$ mesons.

• A search for CP-violations in decays of charmed particles.

• A study of rare and prohibited decay modes of charmed particles.

• The standard model verification in τ-lepton decays.

• A search for violation of the lepton number conservation.

• A search for CP/T violations in decays τ-leptons.

Requirements to the new factory proceeding from the new physical program are the following:

• The center of mass energy of colliding beam should be varied within the limits 3.0 $\div$ 4.5 GeV (from J/Ψ to charmed barions).

• Maximum luminosity $\geq 10^{35}$ cm$^{-2}s^{-1}$.

• At any rate, one of beams (e^{-}) should have the longitudinal polarization at the collision point.

• Asymmetry of colliding beam energies is not required.

• The beam monochromatization is not necessary.

• The required accuracy in energy calibration $\sim 5 \div 10 \cdot 10^{-4}$ is achieved by the use of the ICS technique and the presence of the transversely polarized beams is not mandatory.

In addition, injection into the new factory is performed from the injection complex (IC), which is presently under commissioning at BINP, and for the collider accommodation, it is desirable to use components of the available (buildings, tunnels, halls).

The preliminary arrangement of C-tau factory in Novosibirsk is shown in Fig.14. The collider is based on a two-ring scheme with the beam intersection angle at the collision point of 40 mrad. Each storage ring has two half-ring with a radius of ≈ 90 m and two long (≈ 100 m) straight sections, in one of which the accelerating cavities and injection system are placed. The second straight section is designed for the collision point arrangement.

The peak luminosity was optimized for energy of 2 GeV. In order to attain the luminosity $\geq 1 \cdot 10^{35}$см$^{-2}$с-1, the following parameters are required: horizontal emittance of 10 nmrad, beta-functions at the collision point of $\beta_x/\beta_y = 23$ mm/0.75 mm, collision angle of beams of $2\phi_x = 40$ mrad, bunch length of $\sigma_s = 10$ mm, number of bunches - ∼500, beam current-∼2.0 $\div$ 2.5 A.

All the values given above do not seem to be excessive from the viewpoint of cyclic accelerator technology and they were already attained earlier at various facilities.

Table 5.2shows the basic parameters of C-tau factory for three levels of energy.

A possibility of attaining the mentioned above luminosity is confirmed by mathematical modeling with the use of code LIFETRACK.

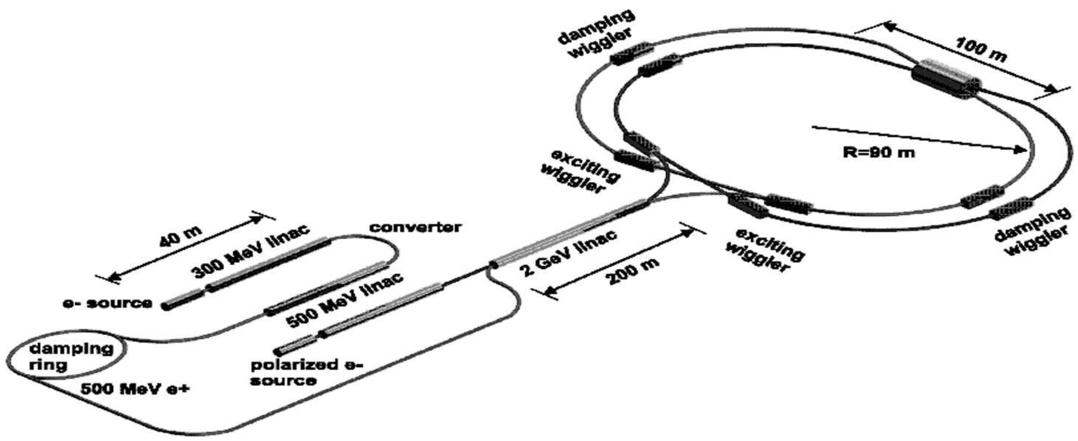


Figure 14: Schematic of C-tau factory.

Table 5.2: Basic parameters of SCTF (Novosibirsk)

Energy, GeV	1.5	2.0	2.5
Horizontal emittance, nm-rad	10		
Coupling coefficient, %	1		
Bunch length, mm	10		
Number of bunches	514		
Number of particles in a bunch	$5{\cdot}10^{10}$	$6.5\cdot10^{10}$	$8{\cdot}10^{10}$
Total number of particles	$2.6{\cdot}10^{13}$	$3.6{\cdot}10^{13}$	$4.1{\cdot}10^{13}$
Current in a bunch, мA	3.1	4.3	5.0
Total current, A	1.6	2.2	2.5
Energy loss/revolution, keV	260	340	430
Power of losses at SR, kW	410	750	1100
Dampint times, ms	30/30/15		
Beta-function at collision point, mm	23/0.75		
Intersection angle	40		
Parameter ξ_y	0.1		
Peak luminosity, $\mathrm{cm}^{-2}\mathrm{c}^{-1}$	$7{\cdot}10^{34}$	$1.3{\cdot}10^{35}$	$1.8{\cdot}10^{35}$

Fig. 15 shows the dependence of attainable peak luminosity from betatron frequency. It is seen that the use of Crab Waist transformation increase the luminosity, decreases the number of nonlinear coupling resonances in the vicinity of the operating point and expands substantially the maximum luminosity range.

At present, the design works on C-tau factory are in progress.

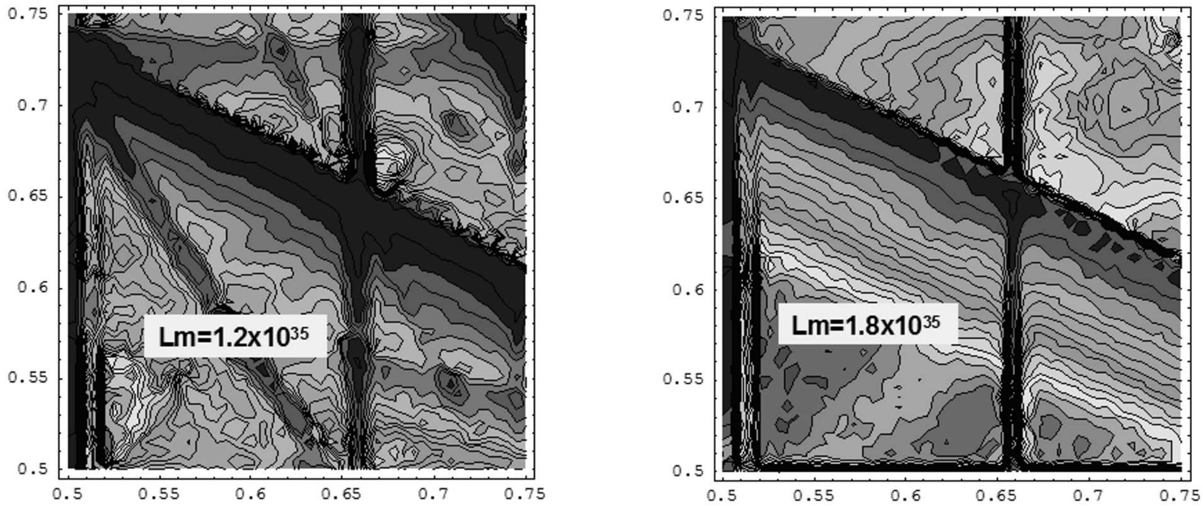


Figure 15: SCTF peak luminosity (in Novosibirsk) as a function of selection of the operation point of betatron frequencies
(To the left - without Crab Waist - transformation)
(To the right - with Crab Waist - transformation)

5.2.6 International collaboration and contract works

In 2007, the contract activity of the VEPP-4 team comprised the following:

• Production of aluminum coils of quadrupole magnets for the SR Source PETRA III (DESY) is completed.

• Helmholtz coils production for DESY is finished.

• Production of sextupole magnets for the SR Source ALBA (Spain, Barcelona) is continued. Magnets in the section of magnetic measurements are shown in Fig. 16.

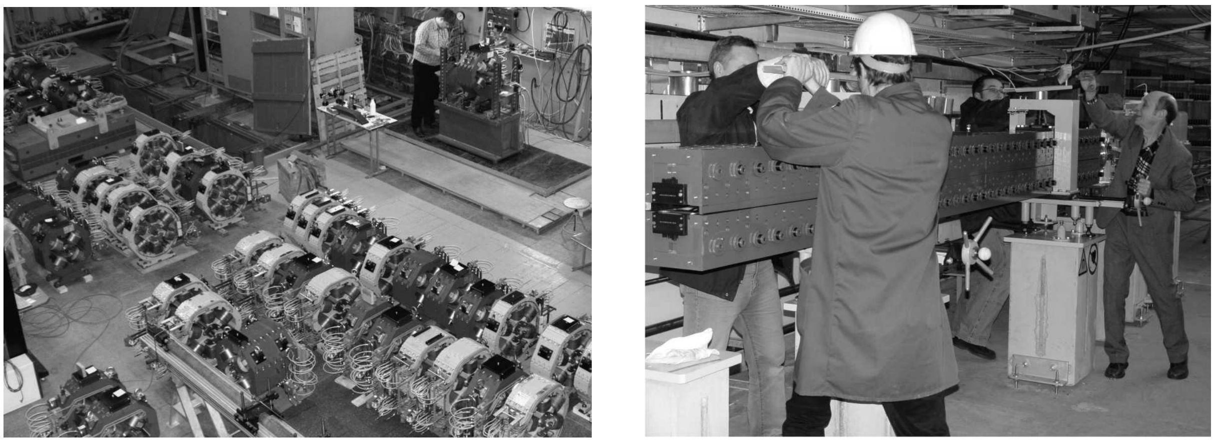


Figure 16: ALBA magnets are in the section of magnetic measurements (to the left). Assembly of the section cell for the DESY wigglers attenuators (to the right).

• Production of supports for wigglers-attenuatorsof the SR Source СИ PETRA III (DESY). Such a trial assembly of the first regular cell of the wiggler-attenuator section was performed at DESY(Fig.16).

• We continue the joint work (with Lab.6)on production of transformers and inductances for the SR Source PETRA III(DESY).

• Manufacture of supports for the magneto-vacuum system of the SR Source ALBA (Spain, Barcelona) is started.

5.3 Injection complex of VEPP-5

In 2007, all the systems of the damping ring cooler were adjusted for operation with beams. At an energy of 300 MeV, an electron beam was put into the damping ring cooler and captured in a betatron regime. The ring parameters are being measured.

In the current year, we achieved the electron beam acceleration in the 3rd accelerating module of the VEPP-5 foreiniector. The forth accelerating module is under construction.

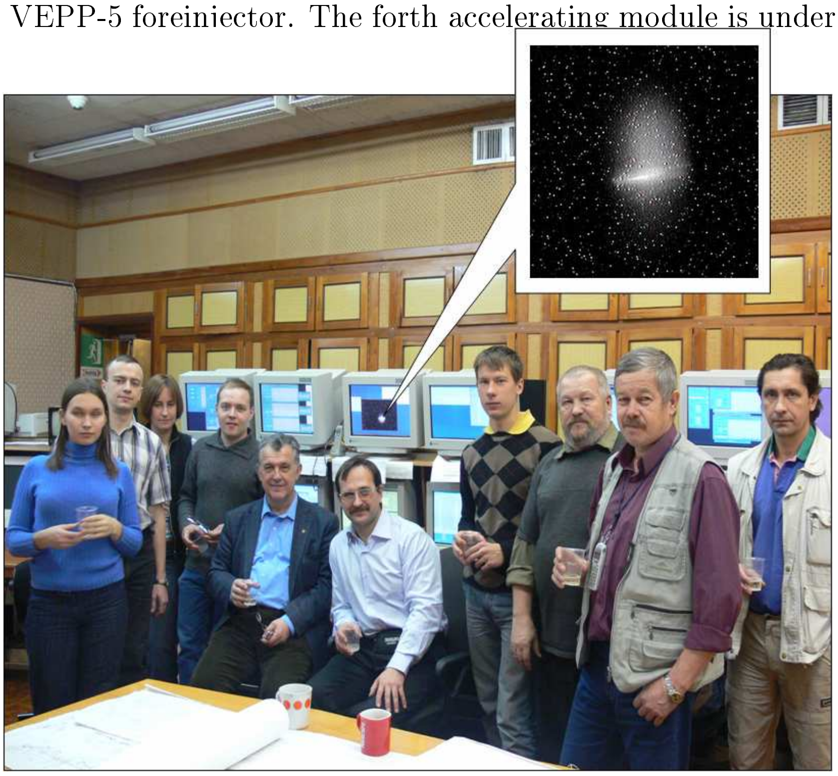


Figure 1: First synchrotron radiation of electrons in the damping ring - cooler.

5.3.1 Contract activity

• In May, 2006, we signed the contract on production of 7 quadrupole magnets Q13 (fig. 2) with an aperture 310 mm for the Rutherford Laboratory (England) ISIS Second Target Station (TS-2) Extracted Proton Beamline (EPB). In June, we signed another contract on production of 13 correctors. In April, 2007, the last correctors and quadrupoles were delivered to the customer. On 14, December, 2007,(earlier than it was planned) the first proton beam was guided to the target. http://ts-2.isis.rl.ac.uk

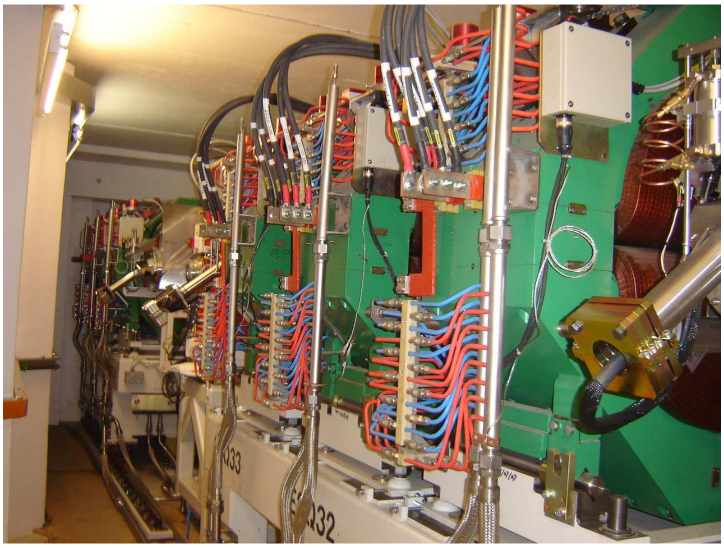


Figure 2: Two triplets of quadrupoles are installed at ISIS TS-2 in Rutherford Laboratory.)

• In May, 2006, we signed the contract on production of 119 quadrupole magnets and 122 sextupole magnets for the main ring of the ALBA synchrotron being constructed near Barcelona (Spain). In April, 2007, 5 prototypes of quadrupole magnets and 2 prototypes of sextupole magnets were delivered to the customer. http://www.cells.es

Figure 3: Installation of the first magnet prototypes on the girder prototype at CELLS (Barcelona)

5.3.2 Accelerator Mass Spectrometer Complex AMS

The most important result of works on the Accelerator Mass Spectrometer in 2007 is an approach to the level of determining the carbon isotope ratio $^{14}C/^{12}C \sim 10^{-13}$, that is approximately by the order of magnitude lower than the concentration of ^{14}C in modern carbon. All the basic components and systems of AMS are assembled and operational. Furhter, the accelerator is planned to be located in the underground radiation protected bunker of 6 x 6 x 7.5 meters in size for its operation with voltages up to 2 MV, which are optimal for using the charge state 3+ of carbon ions in experiments. It will increase the accuracy of determining the isotope ratio by two orders of magnitude. In collaboration with IAET SB RAS, we carried out the work on preparation structural documentation and tracked construction works, and works on creation of full scale systems of electric supply and ventilation of AMS. The planned period of completion of the main bulk of construction works and AMS move to "Geochronology of Kainozoi" Center (Kutateladze Str. 7) is planned for March, 2008.

In AMS, we envisaged a system of several electric, magnetic and combined filters for separation of interfering isobar ions. The molecular background ($^{13}CH^-$ & etc.) is suppressed by many orders by the charge exchange (stripping)of the ion beam in a magnesium-vapor target with destruction of molecules. To this end, the target thickness (density) should be increased by increasing the magnesium vapor temperature. The target was heated by current flowing along its shell. In the experiments on checking the molecule destruction process, the magnesium target was heated up to $520°C$.

The results of studies of the molecule destruction process as a function of the target thickness are given in Fig.1. In these measurements, AMS was adjusted to ions with charge state 2+ and mass 14. The target thickness was calculated by the temperature-pressure dependence (reference data)at the target length of 30 cm. For fitting data given in Fig. 1, we used the molecule destruction cross-section value of $5.5{\cdot}10^{-16}$ cm^2.

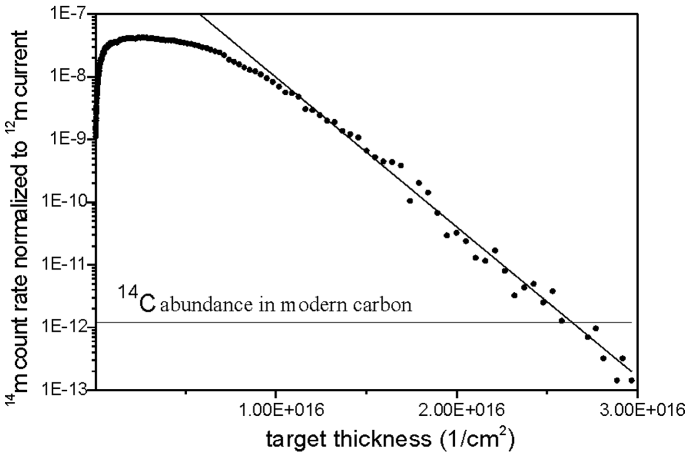


Figure 1: Destruction of molecules in a charge-exchange vapor-magnesium target.

An equilibrium charge states distribution of the ions passing through the target is achieved approximately with the target thickness $4{\cdot}10^{15}$ 1/cm^2 (at 430°C). Thus, the magnesium target thickness required for destruction of molecular ions is approximately ten times larger than that for stripping. In this case, the primary beam current decreases two times because of the ion angular scattering on the denser target. In these two experiments, the "old" graphite sample was used, i.e. with a low content of radiocarbon. The achieved level of measurements of the $^{14}C/^{12}C \sim 10^{-13}$ is approximately by an order of magnitude lower than the concentration of ^{14}C in modern carbon.

For detecting ion isotopes at the AMS output, we used Silicon ΔE-E detector. In the second half of 2007, we used an additional time-of-flight (TOF) system. We tested the TOF probes (developed in Lab. 5-2 BINP), 0.5 ns resolution achieved, it enabled obtaining high accuracy in separation of isotopes by their velocities. It increases the accuracy of background separation in measurements. The first experiments with the use of the probe's prototypes were performed.

On the 7th of Nov., 2007, construction of complex for studying antiprotons and ions GSI, FAIR, started at Darmstadt, Germany. It is planned to study a broad range of physical problems in the field of nuclear structure of matter, physics of antiprotons, plasma physics and atomic physics on this complex. According to the decision of the Government, Russia will also take part in this International Project. In order to reach high quality of antiproton beams in the HESR storage ring (brilliant beam quality mode), it is planned to use the electron cooling technique, which will allow carrying out the precise experiments on determining masses of the short lived and unstable nuclei and also to carry out the search for new particles related to strong interactions. In order to realize this physical program, a 4.5-8 MeV electron cooler is required.

At BINP SB RAS, we develop a project of construction of the universal module equipped with the energy generator, individual source of high voltage and magnetic field coil that enables to develop a fundamentally new modular concept of building the high energy electron cooling facilities. Each new installation is assembled of the ready unified modules to achieve any given energy.

In collaboration with the research center COSY (Germany, Juelich), we completed the technical design and manufactured the prototype of the universal high voltage modules. Fig.2 shows the drawing of one section of the high voltage column and a picture of the finished device. The section consists of the pneumatic generator, two coils for generating magnetic field in the accelerating tube and the unit of control electronics. The whole structure is placed into a metallic frame isolating its content from the high voltage tank volume.

The pneumatic generator of the high voltage section is produced and tested at pressure of 6 bar. Each generator comprises the rotor with 24 permanent magnets and stator with 36 coils, The generator generates a three-phase voltage with a shift of 120 degrees between the phases. The nominal frequency depending on the load is about 2 kHz. A large frequency of the mains is convenient allowing to reduce the overall dimensions of transformers in the power supply source and to suppress the mains voltage ripples. The nominal pressure for operation of the gas turbine is 4.6 bar. The nominal power from one generator is 600 W. The generator internal resistance is 65 Ohm.

Figure 2: High voltage section.

The control electronic circuit of high voltage section is based on the use of the signal processor TMS320F2808PZA (Texas Instruments). This approach enables us to combine in one device the solution of all the control problems such as: synchronization of processes, measurements of the section reference signals, control of the PWM signals for the high voltage power supply sources and solenoids, arrangement of feedbacks, interaction with the external control systems, etc. The clock frequency of the processor operation is 100 MHz that is substantially larger than the PWM control frequency 20 - 50 kHz.

Within the frame of the Agreement 44-88, jointly with the E.B. Zababakhin Institute RFNC VNIITF we continued designing of a low energy storage ring with electron cooling. In interaction of protons with an energy of 1.745 MeV with the isotope C^{13} based carbon target, the resonant gamma quanta with high absorption cross-section in nitrogen are generated. The use of the intense source of such γ-quanta can allow to realize the efficient method of search for explosives. The software was created for calculation of particle motion in a complex curvilinear geometry. The detailed calculations of magnetic fields distribution in storage ring have been performed also. Several versions of magnetic system of the storage ring were calculated. The most critical features of the design were determined. The most optimal design was selected from the viewpoint of the charged particle motion. For compensation of the interaction processes of proton beam with the target (ionization losses, fluctuation of ionization losses, small angle scattering on the target) and space charge effects the electron cooling technique is used. This method allows to achieve high quality of the proton beam on the target and provide the longer lifetime. Calculations and mathematical simulation of interaction of the proton beam with the internal target and electron cooling system were performed. It was shown that the use of the electron cooling enables one to obtain the high quality of proton beam on the target with thickness of a few units 10^{15} cm^{-2}.

The collaboration with the research center IMP (Lanzhou, China) was continued.In October, 2007, our colleagues took part in the commissioning of a 300 keV electron cooler. The electron cooler developed at BINP in 2004 was successfully operated in the CSRe ring. This is the 2nd electron cooler in this Institute. Such a storage ring can become a prototype of installations for medical centers for cancer therapy with irradiation by heavy particle beam.

Publications:
[106], [282], [283], [342], [372], [373], [374].

5.4 Work of a group of electron guns

- At the electron beam welding machines produced at BINP, we carried out tests of systems prior to their delivery to the customer.
- Beam probes for various installations:
  - Electron-optical calculations were performed.
  - Electron guns were produced for the beam probes.
- The cathode units were manufactured, tested and delivered to customers in our country and abroad for various installations and among them:
  - ELV accelerators
  - ILU accelerators
  - Linear accelerators
  - ELIT
  - Beam probes
  - Electron-beam welding
- Calculations of the electron-optical systems were performed for possible sources of high charged ions of radioactive isotopes.

5.5 Vacuum technologies

5.5.1 Sputtering of thin getter films onto internal surface of vacuum chambers walls

One of the most perspective methods to obtain the vacuum in the particle accelerators is use of distributed pump down based on physics-chemistry adsorption of species onto special materials - getters films deposited onto internal walls of beam vacuum chamber. The actual task is creation of the special stand to sputter the getter films onto vacuum chamber walls. It is the great interest also to find the alternative getter films with lower activation temperature and better sorbtion and emission properties.

The basic parameters influencing on getters sputtering rates and films compositions are type of used gas, voltage and current of discharge, cathode material, placement of cathode with respect to support placement, ratio of size of cathode to support one, support temperature during sputtering process. The clearness of cathode's and support's surfaces and compositions of discharge gas and cathode material are great importance.

In the scope of contract between BINP and DESY (Germany) in the BINP the TiZrV getter film must be sputtered onto beam aluminum vacuum chamber of new SR source PETRA- 3. These chambers with length of 4.2m have the difficult shape of cross-section with ellipse, circle and plate sections (see Fig.1). The height of chamber in the narrowest place is 10 mm, the full width is 130 mm. This task is very difficult from technical point of view because the uniformity of coating film ought to be obtained as along chamber length as for whole cross- section. The substantial chamber length requires the use of solenoid with length more 5 m and magnetic field along solenoid more than 600 Gs (at cathode diameter about 2 mm and discharge voltage about 250 V).

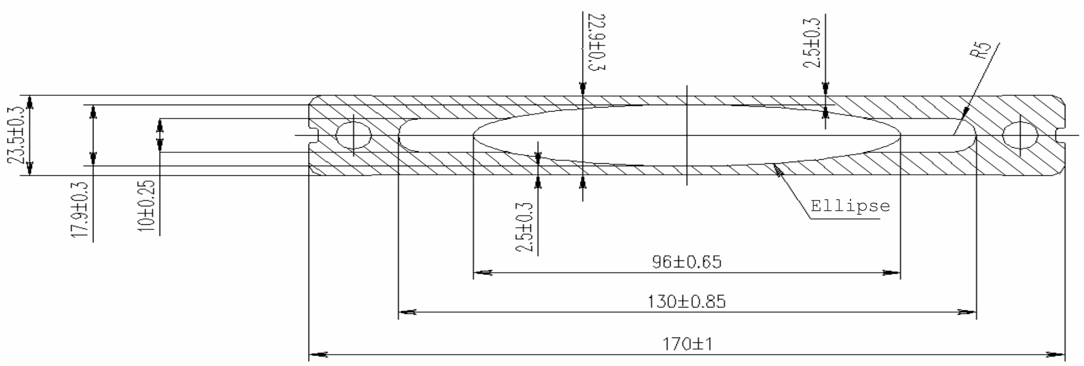


Figure 1: Cross-section of vacuum chamber.

The system of magnetron sputtering was developed in BINP (fig. 2). It consists of solenoid, cathode support system, system of support and control of heaters, vacuum system. Solenoid has length of about 6000 mm, internal diameter 600 mm, maximal magnetic field of 700 Gs, current of 1 kA. It is cooled with water.

The cathode support system has electrical vacuum feedthroughs an secures the leak-proofness of the vacuum system. Besides it lets to center the cathodes and to support them in pull-up state during whole magnetron sputtering process.

The system consists of four cathodes which are 0.5 mm diameter twisted wires of Ti, Zr and V (Fig. 3). The system of fixation and control of heaters secures the automatic control of heaters and the vacuum chamber temperature data acquisition during bake out and magnetron sputtering. Vacuum system secures pumping down to 10^{-9} mbar (before NEG deposition) and injection of krypton, hydrogen and dry air.

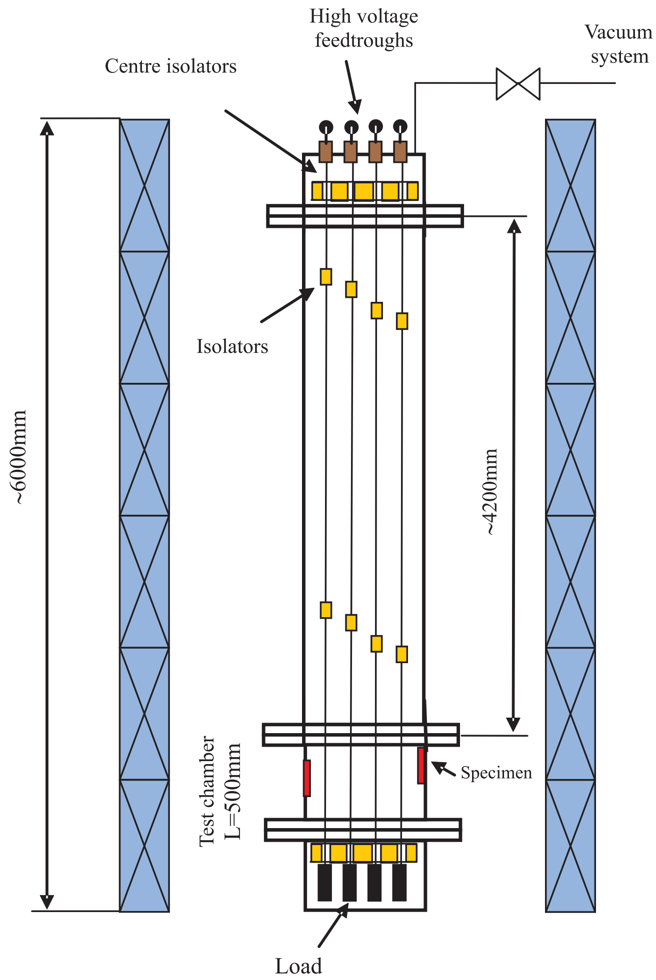


Figure 2: Magnetron sputtering setup.

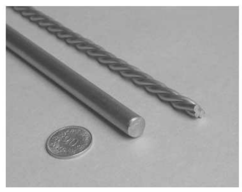


Figure 3: Cathode made with three twisted wires and cathode made as a bar with same diameter.

Two full overall dimensions aluminum chambers for PETRA-3 have been deposited with TiZrV. The mass composition and film thickness of these chambers were studied by SR- fluorescence analysis (XFA-SR). The specimens for measurements were cut from different sections of chamber (as along length axis Z as along width axis X). Besides, the chamber was cut into two equal sections along height (along axis Y). Thus there are top and down specimens. Position data of cathodes relatively to chamber centre are x1=-45mm, x2=-15mm, x3=15mm, x4=45mm. The average distribution of thickness of coatings of top and down specimens along axis X at Z = 2410 mm and theoretical distribution are shown on Fig. 4. Distribution of film thickness along axis Z at X = 0 mm is shown on Fig. 5. Heterogeneity of distribution should be caused by Y-eccentricity of cathodes, longitudinal heterogeneity of plasma discharge and thickness measurements errors.

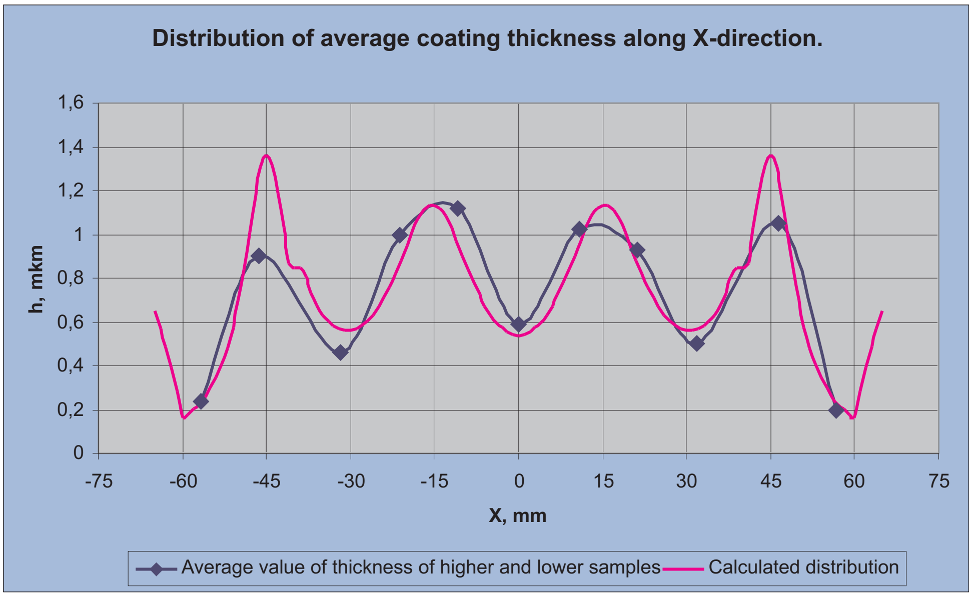


Figure 4: Distribution of film thickness along axis X of chamber cross section at Z = 2410 mm.

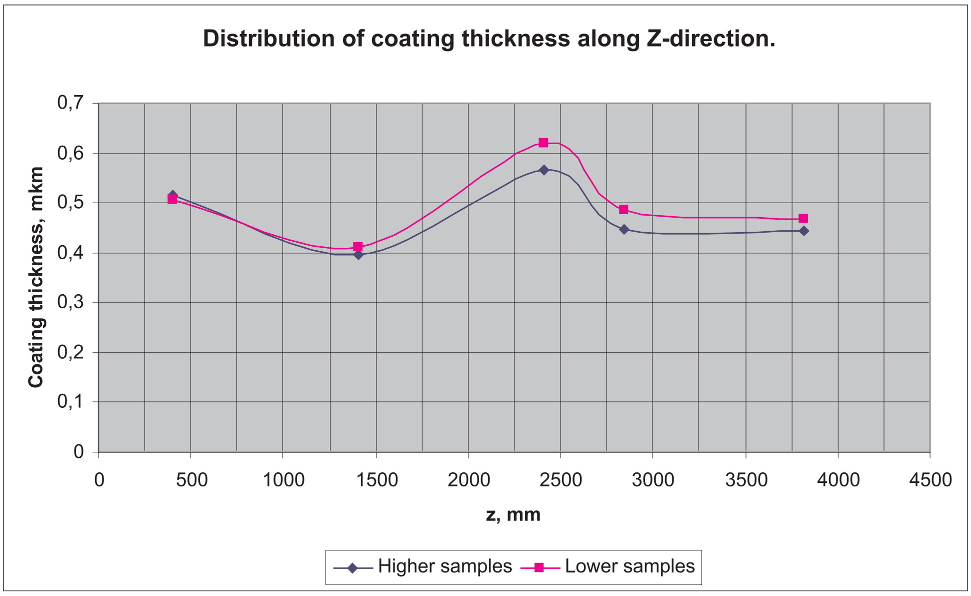


Figure 5: Distribution of film thickness along chamber length at X = 0 mm.

The changes of film composition for chamber cross section and for length are shown in Fig. 6 and Fig. 7 respectively. The average mass composition of film (without taking anomalous values to account) is Ti - 25%, Zr - 32% and V - 43% or in numbers of atoms Ti - 30.4%, Zr - 20.4% and V - 49.2%. It is conforms to optimal TiZrV composition recommended by CERN specialists (Switzerland). The pressure inside vacuum chamber reduced from 10^{-9} to 10^{-10} Torr after getter deposition. And pressure ratio for top and down sections of NEG coated vacuum chamber (at hydrogen injection) was in a three order of magnitude. The NEG activation experiment showed that whole NEG activation was obtained during 3 hours bake out at temperature of 180°C.

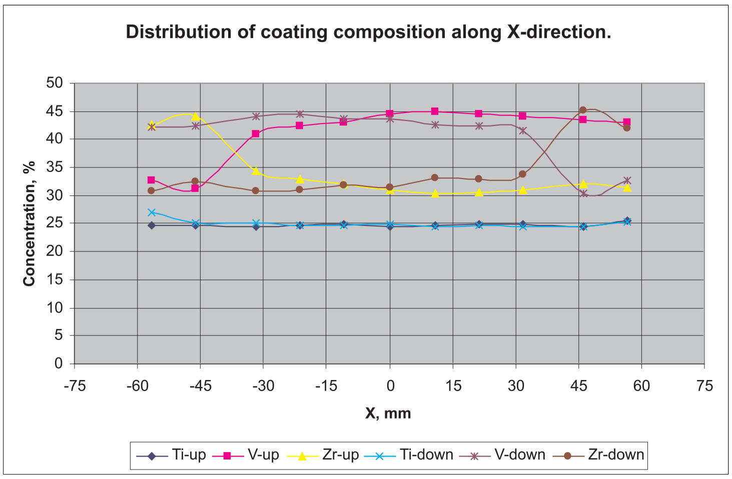


Figure 6: Distribution of film composition for chamber cross section at Z = 2410 mm.

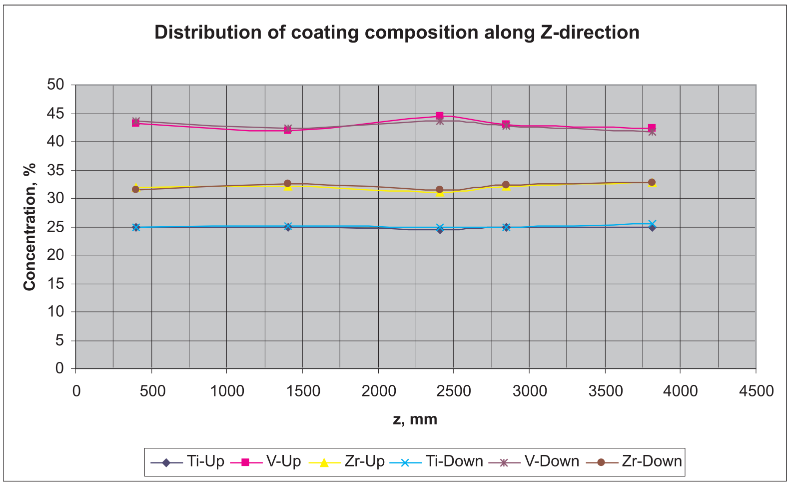


Figure 7: Distribution of film composition along chamber length at X = 0 mm.

5.5.2 Absorbers for PETRA-3

In the project of new SR light source PETRA-3 (DESY, Germany) the cooling of system electron beam requires two straight sections which consist of ten 4-meter length wigglers with constant magnets. In the scope of contract between BINP and DESY BINP prepares a design and produces all components of beam vacuum chambers for these sections. The most difficult task is the computation, design and production of absorbers for absorption of 900 kWt total power synchrotron radiation from wigglers. In sum 14 short (0.8 m), 4 long (4.5 m) and 2 end absorbers will be installed. In 2007 the production of short absorbers was started. First absorber has been installed in the PETRA-3 storage ring (Fig. 8).

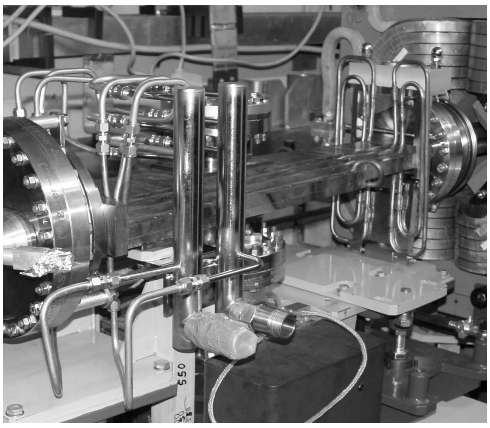


Figure 8: First 30 kWt absorber has been installed in PETRA-3 storage ring.

5.5.3 Participation in the LHC project at CERN

In the scope of plan of LHC construction in CERN (Geneva, Switzerland) the work package was performed. It includes the production and assembling of different components of LHC vacuum system. In particular, the production of great number of different components for vacuum system of main ring (perimeter 27 km) had been completed. In sum about 10000 cold components and more than 2000 different connection units for warm sections of storage ring have been made. In 2007 the vacuum systems of transfer lines TI-2 and TI-8 (each of them has 3 km length) from SPS to LHC storage ring and vacuum systems of protons dump extraction channels were assembled. Characteristic of quality of performed works is that particles beam passed through the transfer lines from the first attempt.

5.5.4 Development of vacuum system of proton - heavy ion synchrotron system for radiotherapy of carcinomas

At present time one of the most effective methods of medical treatment of cancer sickness is considered the method of ion - beam radiotherapy of carcinomas. For realization of this method the beam of protons or heavy ions from particle source is accelerated and sent onto carcinoma of patient. The vacuum system of same device must meet the requirements of 10^{-9} Torr for booster ring and 10^{-10} Torr for main ring of synchrotron. Vacuum system of synchrotron part of complex includes also the transfer line from injector complex to booster ring, transfer line from booster ring to main ring and extraction channels from main synchrotron ring to the patient. The vacuum chamber has to be made with thin-wall pipes (∼1 mm). This demand imposes solidity restrictions for choice of dimensions of chamber. The operating vacuum in synchrotron vacuum chamber can be obtained with combined ion-getter pumps (ion pump + titanium sublimation pump). In this work the problems of obtaining and keeping of vacuum for different operations modes were studied, and the characteristic demands for possible layout designs were concluded. Generic description of optimal ion synchrotron vacuum system has been drawn up.

Participants of works:

V.V. Anashin, A.A. Krasnov, R.V. Dostovalov, A.M. Semenov, A.A. Zhukov et al.

Publications: [249], [250],[5].

Chapter 6

Synchrotron Radiation Sources and Free Electron Lasers

Introduction

There are now two centers of joint usage that work on the basis of BINP facilities and laboratories: the Siberian Synchrotron Radiation Center and Siberian Center for Photochemistry Research.

The working program of the Siberian Synchrotron Radiation Center for the year 2007 included the following directions:

- research and development of new technologies with the application of SR from the VEPP-3 storage ring and start of works at VEPP-4;
- creation of experimental equipment for operation with SR (beam lines, experimental stations, X-ray optics, monochromators, and detectors);
- development and creation of accelerators operating as dedicated SR sources;
- development and creation of special magnetic systems for SR generation: wigglers, undulators, and superbends;
- teaching and professional training of students and post-graduates.

In 2007, 1938 hours was allotted for work with SR on the VEPP-3 storage ring in the "Synchrotron radiation" mode (2229 hours in 2006). Research groups from 60 institutes and other organizations were conducting experiments at 10 stations on 7 SR beamlines.

The working program of the Siberian Center for Photochemistry Research for the year 2007 included the following directions:

- creation of experimental stations and conduction of investigations on the operating high-power terahertz laser;
- start of the mounting of the multi-turn energy recover linac and a more powerful IR-range free electron laser on its basis;
- participation in foreign projects dealing with development and creation of high-power FELs;
- teaching and professional training of students and post-graduates.

In 2007, 780 hours of operating time was allotted for research on terahertz radiation from the Novosibirsk free electron laser at four experimental stations (730 hours in 2006).

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 for registration of passing radiation and small angle X-ray scattering (SAXS) at investigation into detonation and shock-wave processes. It is the only station of such type in the world.

Participant organizations:

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

The station enables experiments with up to 30 grams of explosives. The station includes

- *an explosion chamber for an explosive equivalent to 30 grams of trinitrotoluol;*
- *an assembly of detectors;*
- *an SR generation unit.*

This station is distinctive due to the use of an explosion chamber with thin beryllium windows to pass an SR beam and a system for high-precision remote- control travel of an experimental set of a detonation sample and the assembly of detectors.

Main work directions and results in 2007:

1. Nano-second dynamical tomography of density, mass velocity, and pressure of products of detonation of trotyl and a trotyl-hexogen system. The volume distribution of density, mass velocity, and pressure in products of detonation of these systems have been measured with SR for the first time.

2.Investigation into shock-wave processes in inert materials. The dynamics of deformation of highly porous substances (aerogel and stivlon) and a fragile polymer material (polymethyl methacrylate) at shock-wave and explosion loads were under study. It was the first time of SR measurement of volume distribution of density, mass velocity and pressure in products of detonation of trotyl. It has been shown that the constitutive equation for detonation products is described well by a polytropic gas model with the adiabatic exponent γ =2.8. Corrected adiabatic exponents in different areas of unloading have been determined.

We suggested a procedure to determine the spatial distribution of density of scattered products of explosion. A charge of detonating explosive was transilluminated with SR bursts, which were registered by a linear detector DIMEX. The registered absorption distribution was used to reconstruct the volume distribution of density of scattered products of explosion at a stationary detonation of a charge of pressed trotyl with a density of 1.65 g/cm^3 and 15 mm in diameter. This procedure is several times as accurate as procedures using flash X-ray tubes [CEP, 2007, № 2. Komrachkov, Sarov].

An exact information on the density distribution helps in reconstructing the spatial dependence of the mass velocity vector with the mass flow equation (1)($\frac{d/\rho}{dt}$ = 0 for a steady-state flow).

$$div(\rho\vec{\nu}) = 0 \qquad (1)$$

For calculations, the flow was assumed to be potential and such a scalar potential was introduced that $\vec{\nu} = \nabla\varphi$. Then we can rewrite (1) in the following form:

$$div(\rho \cdot \nabla\varphi) = 0 \qquad (2)$$

For the purpose of through computation without explicit separation of the explosion-vacuum boundary outside the area occupied by explosion products, the density was assigned a small value ρ=10^{-3} g/cm^3. This allowed us to solve equation (2) in a rectangular area with corresponding boundary conditions. The equation was solved numerically, by the iteration method.

Fig.1 presents the simulated field of velocities. At a distance of 1.3 cm, the velocity changes its sign, which is confirmed by direct measurements of the motion of a copper foil that was introduced into the explosive charge.

The experimental information on the velocity fields for certain explosives is of high practical importance. In particular, without these data, it is impossible to use manganin detectors to measure correctly pressure in the zone of scattering because the coordinate is indeterminate.

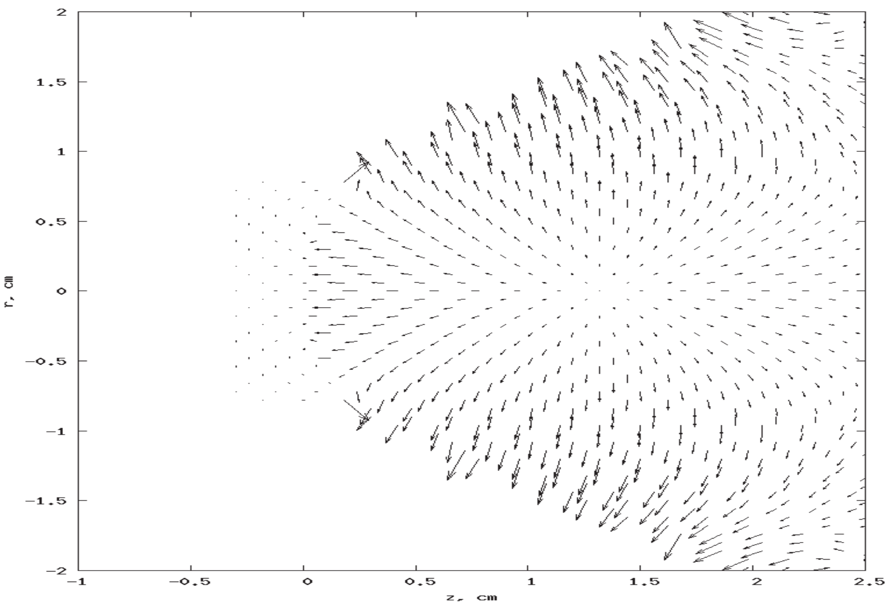


Figure 1: The experimentally-measured mass velocity field (directions of the substance move at different points) for the products of detonation of a cylindrical explosive charge 15 mm in diameter (fixed reference), where r and z are the cylindrical coordinates. The detonation front is at the coordinate z=o. One can see clearly that at a distance of 1.3 cm from the detonation front, the mass velocity changes its sign.

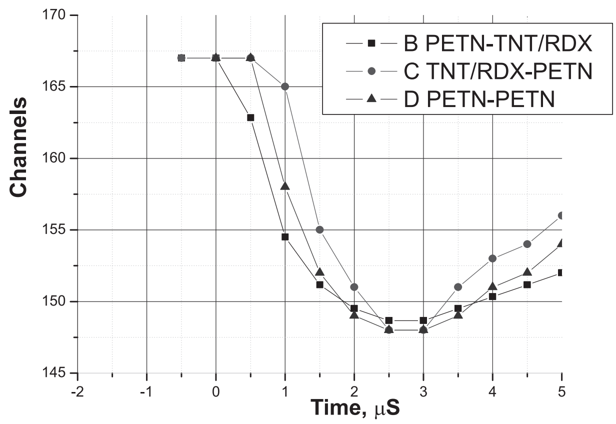


Figure 2: Foil position in explosives of different composition vs. time (in the channels of the detector, a 0.1 m step

IGL SB RAS, VNNITF, and ITES RAN developed jointly an explosive throwing device, which was used for shock compression of an inert medium (Fig.3). This device allows throwing aluminum and copper bullets with velocities up to 3 km/s. An investigation into the shock compression of aerogel for a knocker velocity of 2.2 km/s to 3 km/s was completed in 2007. The increase in the bullet velocity was achieved through the application of pellets of explosives of a higher explosive ability (pressed octogene) as well as through vacuumizing the explosion chamber before the experiments.

Measurements at loading with a bullet resulted in a shock adiabat for aerogel in the velocity range from 0.5 km/s to 3 km/s. Earlier, similar measurements under a direct impact by a detonation shock wave were done in the velocity range from 0.4 km/s to 1.2 km/s. So, the shock adiabat for aerogel was built for the entire velocity range.

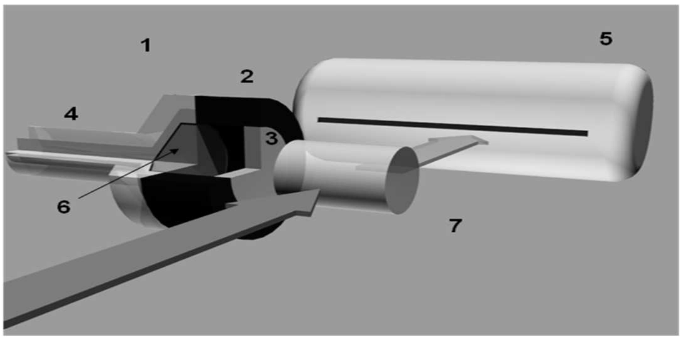


Figure 3: Set-up of a shock-wave experiment on an SR beam. 1- an explosive generator of a plane gas wave, 2 - the gas exploder barrel, 3 - a flat (bullet), 4 - a detonator, 5- the X-ray one-coordinate detector DIMEX, 6 - an explosive, 7- an aerogel sample to study.

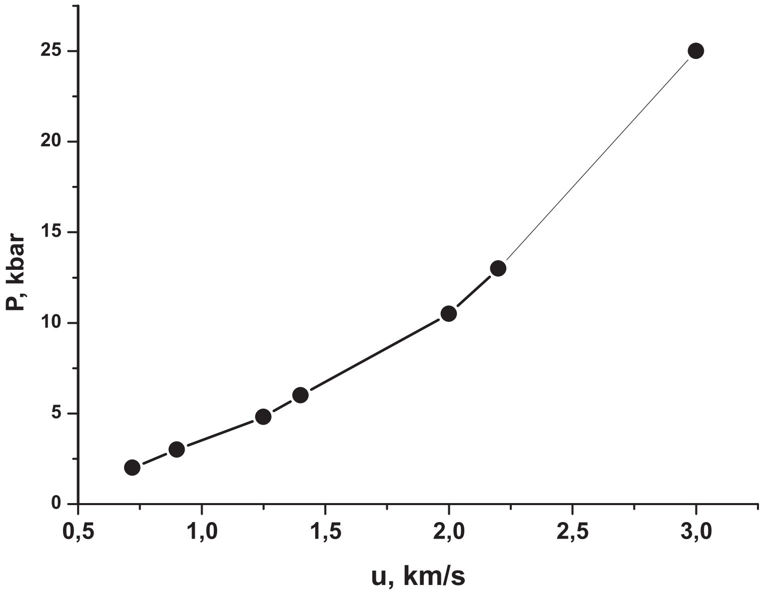


Figure 4: Experimentally-measured shock adiabat for aerogel.

6.1.2 LIGA technology and X-ray lithography

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

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

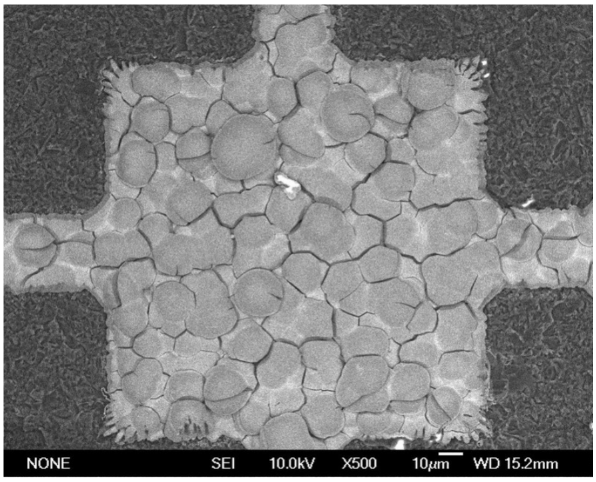
Works on the development of LIGA process stages at BINP SB RAS continued in 2007. The commissioning of a special-purpose laboratory premise “Clean room” for chemical-engineering stages of the LIGA process (preparation of substrates and application and processing of resists, and micro-galvanoplastics) was completed. The existence of a “clean room” is a requirement for the methods to manufacture micro-structures by the LIGA process. Development of methods to manufacture deep micro-structures using deep X-ray lithography continued. In particular, creation of masks for deep X-ray lithography using SR was under elaboration as well as manufacture of micro-structures on the basis of the created masks.

Figure 5: Part of the interior of the “clean room”.

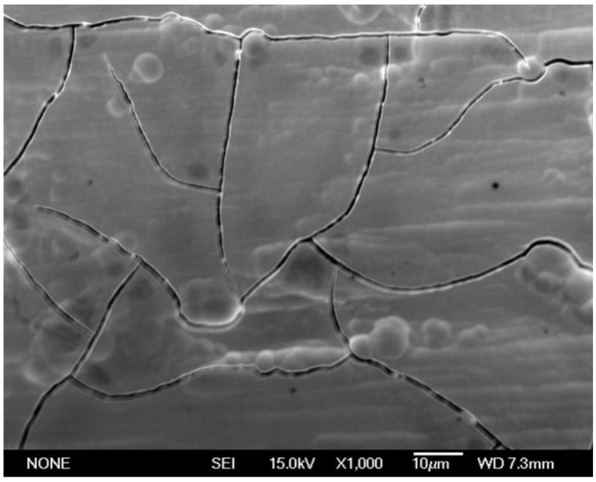
The “clean room” (Fig.5) is equipped with systems for ventilation and class “100” air cleaning. It has a centrifuge for application of resistive layers a few micrometers to hundreds of micrometers thick, a vacuum furnace to anneal samples, an ultrasound facility for fluid development of exposed resists, and a micro-galvanoplastics facility with a computer-controlled power supply along with the required control instrumentation.

Production of LIGA masks through electrotyping X-ray absorbing rhenium-nickel alloy patterns on glass graphite substrates was under elaboration. The following was under study: adhesion of the deposited rhenium-nickel alloy to a glass graphite surface, the influence of the ratio of components in the alloy on the coating quality, and practical applicability of such pattern production in the LIGA technology. It was found out that to provide adhesion and successful application of thick (up to 30μm) Re-Ni layers, it was necessary to create a copper sublayer in advance. If a lead anode was used, the Re/Ni/Cu percentage in the deposited layers was 93.9/6.0/0.1 by X-ray fluorescent analysis; for a nickel anode, it was 98.7/1.2/0.1.

An increase in the nickel fraction in the alloy results in an insignificant decrease in the X-ray contrast of the mask and, at the same time, improves the quality of the deposited layer a lot, i.e., reduces the grain (Fig.6). However, the metal surface has some micro-cracks due to inner strains in the metal. Optimization of the micro-galvanics condition and thus improvement of the quality of deposited layers is the object of further studies. Several X-ray masks with a Re-Ni coating were created basing on the experience gained. The resistive mask for galvanics was made by the photolithography method. The used substrates were of polished glass-carbon type SU-900. Microstructures were formed via contact photolithography with the application of a photomask made at IPS SB RAS. A micro-galvanics facility with a reversible current source for depositing metal layers with minimal roughness was created.



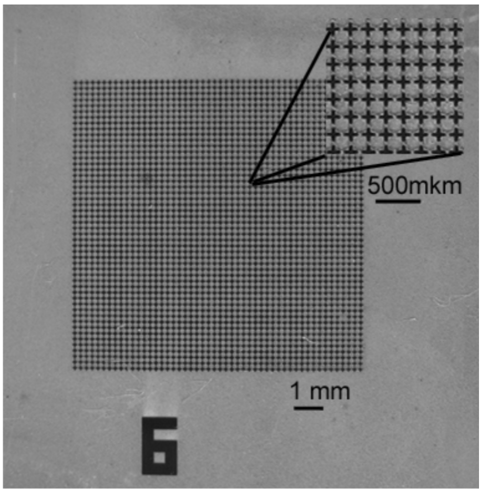
a) a Pb anode (with a microstructure)



b) a Ni-anode (without microstructure)

Fig.: 6 SEM photos of deposited Re-Ni layers on glass graphite substrates.

a)



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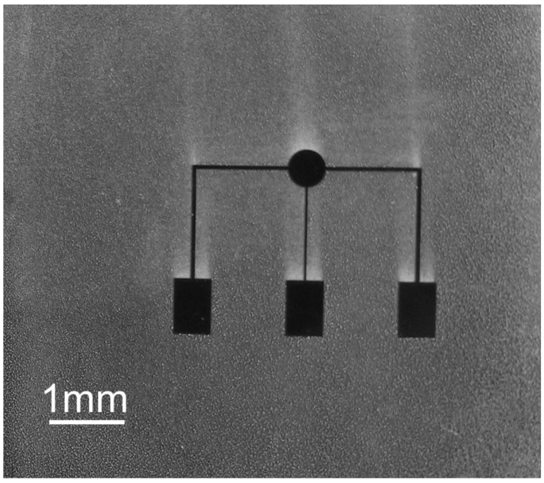
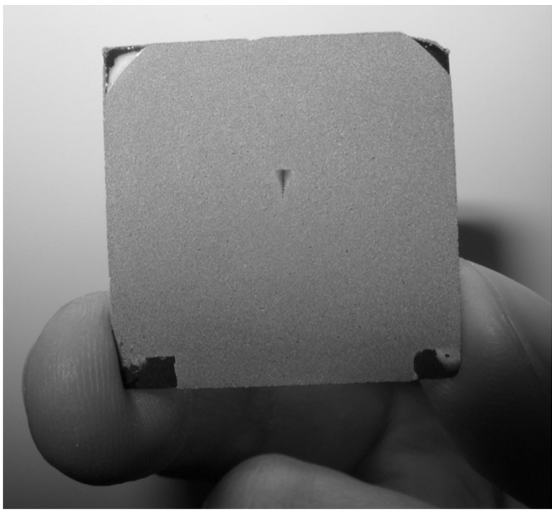
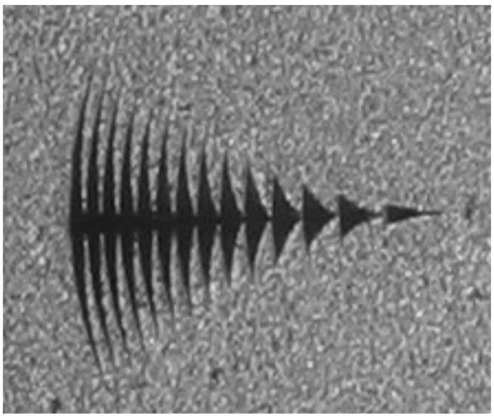






A blown-up fragment of the photo.
в)

Figure.:7 Photos of the X-ray masks made (a) for production of selection elements for terahertz radiation, (b) for micro-fluid analytical systems, (c) a multifocal intraocular lens.

Regimes of deposition of an X-ray absorbing layer on a glass-carbon surface were selected experimentally. The best results were achieved at depositing a copper sub-layer 3 to 6 μm thick with sequential application of a rhenium-nickel (80% of rhenium) layer about 15 μm thick on the copper. In this case, the SU-8 resist microstructure was a protective mask and defined the pattern in the metal layer. Several microstructure masks that are actual in the production of selection elements for terahertz radiation (Fig. 7a), micro-fluid analytical systems (Fig. 7b), and a multifocal intraocular lens were made in this way.

Works on the optimization of the regimes and process stages of X-ray mask creation and their use in the production of polymer microstructures by deep X- ray lithography are going on.

6.1.3 Precision diffractometry and anomalous scattering

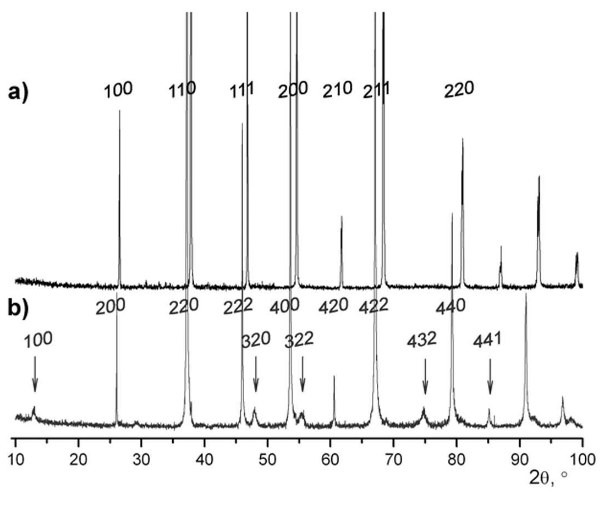
The " Anomalous scattering" station is intended for precision investigations into the structure of polycrystal materials by the X-ray diffractometry methods. Below are listed institutions that participated in the works in 2007:

- Boreskov Institute of Catalysis SB RAS,
- Nikolaev Institute of Inorganic Chemistry SB RAS,
- Institute of Chemistry and Chemical Technology SB RAS, Kransoyarsk,
- Pisarzhevsky Institute of Physical Chemistry of the Ukraine NAS, Kiev,
- Lomonosov MSU, Moscow.

Subjects of some works in 2007:

1. Exploration of oxygen-conductive materials.

The practical aim of the works is to improve oxygen-conductive membranes for cold fuel elements. The structural properties of non-stochiometric perovskites of the $Sr_{1-x}A_xCo_{0.8-y}Al_yFe_{0.2}O_z$ composition, where A=La, Ca, Ba, and $SrFe_{1-x}M_xO_z$, where M =W, Mo, were under investigation in connection with optimization of chemical composition of oxygen-conductive membranes that are used in catalyst reactors for partial oxidation of methane.



degree

Figure 8: X-ray images of samples of
(a) $Sr_{0.7}La_{0.3}Co_{0.5}Fe_{0.2}Al_{0.3}O_{2.68}$ slowly cooled in air in a furnace;
(b) $Sr_{0.7}La_{0.3}Co_{0.5}Fe_{0.2}Al_{0.3}O_{2.54}$ annealed at 900° C and hardened in vacuum (with the indexes of arising superstructure reflections).

High-resolution X-ray diffractograms of samples(Fig.8) demonstrate a high-quality diffraction picture with weak superstructure reflections, which can be linked both with defect ordering (oxygen vacancies and/or ions of admixtures) along with the doubling of the parameters of the lattice $2\alpha_p x 2\alpha\rho$ (7.763 Å)and with formation of a micro-domain texture, which adapts the differences in the compositions and oxygen non-stoichiometry of the components. In 2007, X-ray diffractograms were made for six samples of different composition and oxygen stoichiometry. Pictures with superstructure reflections were observed for $Sr_{0.7}La_{0.3}Co_{0.5}Fe_{0.2}Al_{0.3}O_z$ and $SrFe_{0.95}Mo_{0.05}O_z$ samples hardened in vacuum. The phase composition of a $SrCo_{0.6}Fe_{0.2}Nb_{0,2}O_{3-x}$ membrane applied onto a lanthanum hexaaluminate substrate was investigated. The sample synthesis relied on the data of high-temperature X-ray diffractometry of $SrCo_{0.7}Fe_{0.2}Nb_yO_{3-x}$ samples, y=0.1, 0.2, 0.3, showing that a material with the perovskite structure and an Nb content of 0.2 was the most suitable as an oxygen-conducting membrane in fuel elements. Lanthanum hexaaluminate (LHA) is porous, mechanically strong, and inert, which is necessary for a membrane carrier. The X-ray diffractometry of a membrane applied on LHA were made in the conventional Bragg-Brentano geometry as well as in the grazing geometry (grazing diffraction), which allowed minimizing the carrier influence (Fig.9).

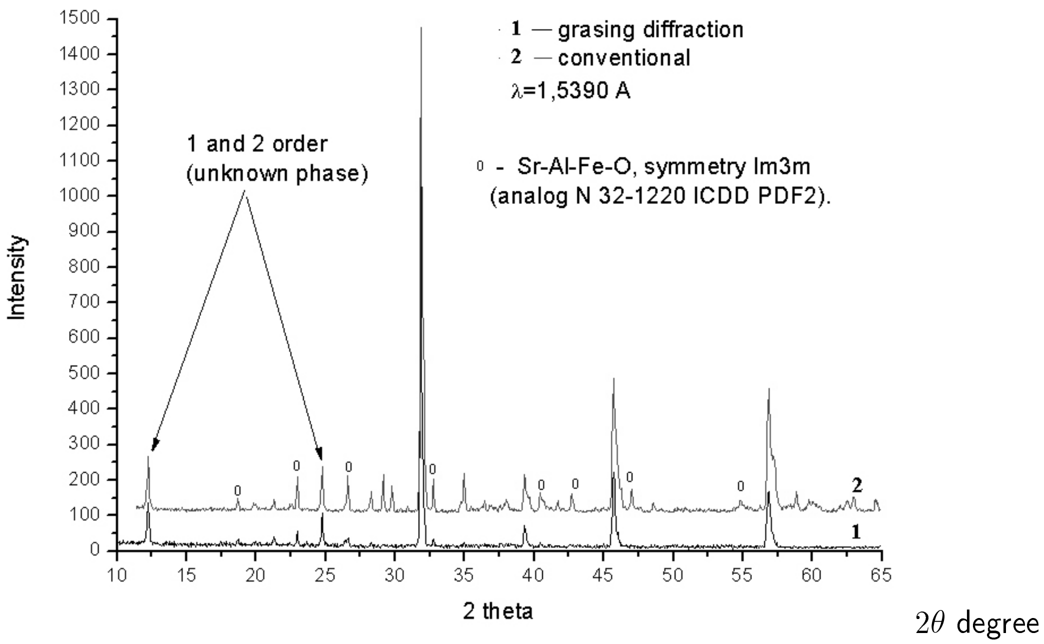


Figure 9: X-ray diffractogram of a membrane applied on lanthanum hexaaluminate.

The obtained data show the following:
1) the phase composition of the membrane differs from that of a bulk sample;
2) the phase composition of the membrane is heterogeneous over its depth;
3) the lattice parameter of the surface layer of the membrane (3.951 Å) increased as compared with a bulk sample (3.906 Å);
4) there is the $SrAl_2O_4$ phase in the volume or on the line between the membrane and carrier.

Measurements of oxygen conductivity of this system showed that there was practically no conductivity in this sample. That could be due to the strontium aluminate phase in the sample. Consequently, the set forth method of membrane synthesis does not provide oxygen conductivity and is subject to correction. The same sample was under exploration with different diffractogram methods.

2. Novel functionalized mesoporous materials.
The work was done within the SB RAS Program "Chemical design of catalysts and adsorbents with a high-organization supramolecular nanostructure".

A mesoporous coordination polymer MIL-101 with a zeolitic crystal structure, big area of surface, and thermal resistivity was under study. Methods of X-ray diffraction, low-temperature adsorption of nitrogen, and IR Fourier spectroscopy confirmed the structure of the obtained material (Fig.10). The catalyst activity of the coordination polymer MIL-101 in the reactions of oxidations of organic compounds - cyclohexane, cyclohexene, α-pinene and caryophyllene - by hydrogen peroxide and molecular oxygen was investigated for the first time. MIL-101 was shown to be slow-acting in the oxidation of alkanes and alkenes by molecular oxygen. However, it decomposes hydrogen peroxide at higher temperatures (above 50°C), generating free radicals, which oxidize alkenes. The main mechanisms of the processes of adsorption (25°C, MeCN) by the coordination polymer of monosubstituted polyoxometalates (POM)containing Ti and Co ions were investigated. POM are immobilized on MIL-101 through electrostatic bonding between POM ions and the positively-charged surface of the matrix. At that, 10which corresponds to one POM cluster on a nano-void of MIL-101, is bonded irreversibly. The obtained composite POM/MIL-101 materials retain the texture of the matrix and the crystal structure of both POM and MIL-101, which was confirmed by the methods of X-ray diffraction, low-temperature adsorption of nitrogen, and IR Fourier spectroscopy.

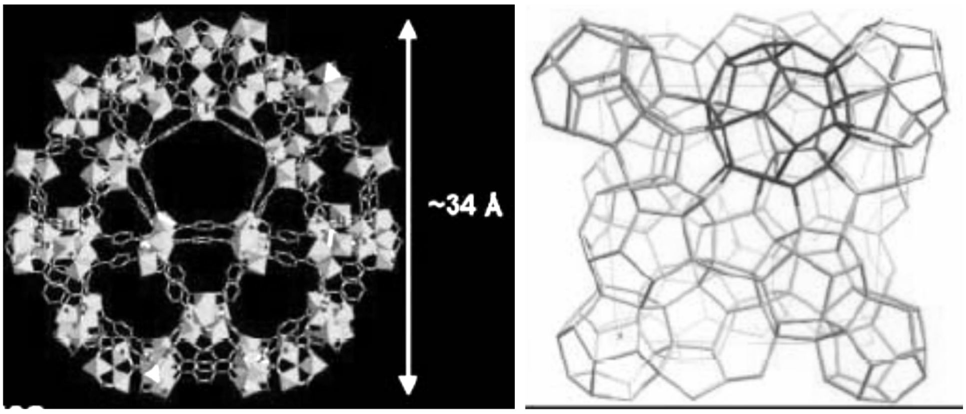


Figure 10: Structure of a MIL-101 fragment and zeolitic hierarchy of fragments.

Table 6.1: Physicochemical properties of composite catalysts M-POM/MIL-101

Material	Active metal percentage of, %	Specific surface of mesopores, m^2/g	Specific volume mesopores, cm^3/g
MIL-101	-	2220	1.13
Ti-POM/MIL-101	Ti/W/Cr = 0.13/4.14/12.1	1930	0.96
Co-POM/MIL-101	Co/W = 0.06/2.11	2050	1.03

Composite Co- and Ti-POM/MIL-101 materials are active and selective in alkene oxidation by environmentally safe oxidants - molecular oxygen and aqueous hydrogen peroxide, correspondingly. Heterogeneous M-POM/MIL-101 catalysts are of the same activity as corresponding homogeneous polyoxometalates. So, POM do not lose their activity at immobilization. The composite materials turned out to show structural instability under some conditions. Depending on the temperature and concentration of hydrogen peroxide, their structures can collapse in reactions when external parameters exceed their threshold values. If temperature and concentration do not exceed the critical values, the material stays stable during at least 5 cycles.

Composite materials on the basis of mesoporous coordination polymers and monosubstituted polyoxometalates turned out to be promising as catalysts in selective liquid-phase oxidation of alkenes by environmentally safe oxidants.

Meso-structured silicate materials.

The work was done within the framework of the SB RAS program " Chemical design of catalysts and adsorbents with high-organization supramolecular nanostructure".

A meso-structured silicate forms when solutions of natrium silicate (a source of SiO_2) and a surface-active substance (SAS, a net-forming constituent) mix with each other. The synthesis can be done both in a moderately-alkaline medium (e.g., MCM-41, MCM-48 etc.) and in a moderately-acid one (e.g., SBA-3 and SBA- 15). A moderately-acid media seem to be promising in the view of creation of catalytically active systems on the basis of meso-structured silicates. A hybrid meso-phase forms immediately after the mixing of initial solutions. The degree of the ordering of a meso-phase that was synthesized in a moderately-alkaline medium is higher than that of a meso-phase that was synthesized in a moderately- acid medium, the hydrothermal stability (HTS) of the resulting product being much worse in this case.

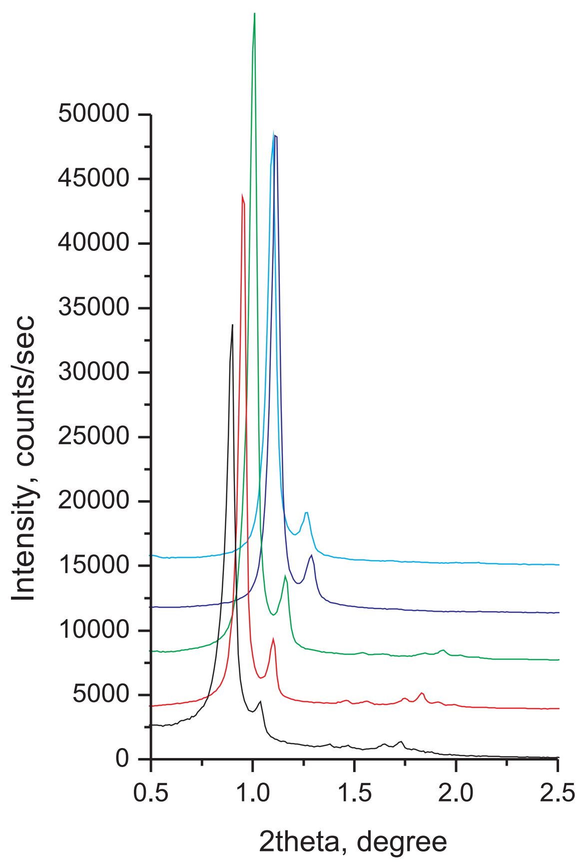


Figure 11: X-ray images of samples of meso-structured silicates of cubic- symmetry formed with the use of nonionic SAS.

The structure of meso-phase materials of cubic-symmetry formed with the use of nonionic SAS was being investigated. Such meso-phases have a much larger HTS because, in this case, the silicate wall thickness is approximately three times as large as the thickness of the wall of meso-phases synthesized with the use of ionic SAS. Besides, a big, up to 10-12 nm, size of mesopores is typical of these systems. Fig.11 presents characteristic X-ray images of these samples. The results of research are under processing in order to construct maps of electron density distribution in the samples.

X-ray diffraction control of structural parameters of samples was used to perfect the conditions of synthesis of Ti-,Fe-, Al-, and Ga- containing silicate meso-phases. A controlled synthesis of a silicate mesoporous meso-phase material was done, the $[Al_{12}FeO_4(OH)_{24}(H_2O)_{12}]^{+7}$ complex introduced at different stages. The aim of the work was to create a mesoporous catalyst for the reaction of full phenol oxidation by hydrogen peroxide in water solutions. With this purpose, an active component of $[Al_{12}FeO_4(OH)_{24}(H_2O)_{12}]^{+7}$ was introduced at different stages of mesoporous silicate matrix synthesis at $Fe/Si = 0.02$. The mesoporous material SBA-3 was created by a standard scheme of two-stage mixing of solutions of a surface-active substance (SAS) and a soluble form of silicon dioxide, with an interim ageing of the product in a mother solution. Fig.12 presents the pore diameter distribution. One can see that pores of the silicate matrix are relatively homogeneous. The surges of smaller and bigger diameters are most likely caused by pseudo-pores that arise in the places of contacts of crystallites as well as by the presence of some part of the amorphous phase.

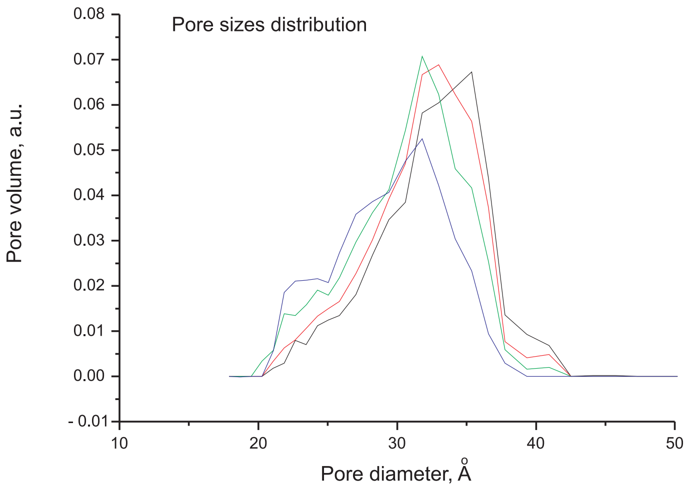


Figure 12: Distribution of meso-pore sizes in samples of different genesis.

High-activity golden catalysts for after-burning of carbon monoxide.
The work was done under the integration inter-disciplinary SB RAS program № 79.

Fine particles of gold applied on oxides of other metals are active catalysts for low-temperature oxidation of carbon monoxide. This is the reason for investigations into the application of Au catalysts to purify air in enclosed spaces, industrial emissions, and automobile exhausts of internal-combustion engines from CO. The most active catalysts have been obtained through application of gold on $Mg(OH)_2$ and oxides of metals of the 1st transition row. However, for a number of reasons, these carriers do not suit wide-ranging usage. Since 2001, they at the Institute of Catalysis have been studying ways of forming gold nanoparticles on aluminum oxide - a cheap and available carrier with controlled porosity and high tolerance to humidity. In order to optimize preparation methods for Au/Al_2O_3 catalysts, they have been investigating the factors that influence catalyst activity in CO oxidation and evaluating the possibility of practical usage of these systems for after-burning of the CO pollution in air and automobile exhausts. In this work, the electron density radial distribution was measured for investigating phase composition and local structure of a series of samples: an initial carrier of γ-Al_2O_3 and applied catalysts with a different content of gold. The metal gold phase shows well only in a sample containing 1.6% of metal Au^0 by weight. The absence of coordination peaks (CP) belonging to the Au^0 structure in other samples can be explained by three reasons: its small content, being in another phase (the phase of interaction with the carrier), or a high dispersion of metal particles. The specificity of the structure geometry of the γ-Al_2O_3 carrier, $AuAlO_2$ phase, and metal gold can provide epitaxial growth of metal particles on the carrier through an intermediate phase, which provides, in turn, the attachment and high-dispersion state of metal particles on the surface of the carrier, i.e., their thermal stability.

6.1.4 X-ray fluorescent element analysis

The station " X-ray fluorescent element analysis" is intended for determination of element composition of different samples: geological rocks, biological tissues, aerosols etc. with the help of synchrotron radiation X-ray fluorescent element analysis (SR-RFA). The element analysis can be executed both in local and scanning regimes, which depends on the sample size - a pellet or a linear-dimension sample.

Main technical characteristics of the station.

Energy range		10-45 keV
X-ray optical scheme: one-(or two-) crystal monochromator of pyrolytic graphite or silicon		
Input beam size		0.1x10 mm
Spectrum collection time		10 - 1000 s
Detection systems: Si(Li) semiconductor detector by the company "Oxford Instruments"		
Resolution of the detector		160 eV (on the 5.9 keV line)
Mass of a sample to measure		10^{-6} g$\div$ 1 g
Detection limit	- at multi-element analysis	$10^{-7}\div10^{-8}$g/g
	- with a dispersion filter	$10^{-8}\div$ 10^{-9} g/g
Spatial resolution		100 μm

Participant organizations in 2007:

1. Budker Institute of Nuclear Physics SB RAS, Novosibirsk;
2. Institute for Geology and Mineralogy SB RAS, Novosibirsk;
3. Institute for Oil-Gas Geology and Geophysics SB RAS, Novosibirsk;
4. Novosibirsk State University, Novosibirsk;
5. Vinogradov Institute of Geochemistry SB RAS, Irkutsk;
6. Limnology Institute SB RAS, Irkutsk;
7. Institute of Microbiology and Biophysics SB RAMS, Novosibirsk;
8. Regional Oncologic Dispensary, Novosibirsk;
9. Institute of Chemical Kinetics and Combustion SB RAS, Novosibirsk;
10. Central Siberian Botanical Garden SB RAS, Novosibirsk;
11. Institute for Forest SB RAS, Krasnoyarsk;
12. Institute for Soil Science and Agrochemistry SB RAS, Novosibirsk;
13. Institute for Ecology of Plants and Animals UB RAS, Ekaterinburg;

14. Meshalkin Research Institute of Blood Circulation Pathology, Novosibirsk;
15. Institute of Theoretical and Experimental Biophysics RAS, Puschino.

Analysis of the bottom sediments of Lake Baikal, Lake Telmen, Lake Hoton-Nur, and Lake Teletskoe belong to the most interesting works done at the station in 2007. The aim was to find out the regularities and mechanisms of formation of the Central Asia climate and environment. A specific task was to quantitatively reconstruct yearly variations of climatic parameters (air temperature and atmospheric precipitation) in the southern part of Western Siberia, in order to forecast possible future changes in the environment. Investigations cover three time intervals: late Holocene (0 years ago(nowadays) to 2000 years ago), the interval of 2000 to 4000 years ago (the interval of maximum spread of the annual layering in Lake Telmen) and the period from 4000 years ago to the last glaciation.

Little Ace Age and the period of medieval warming can be separated. A typical feature of the conducted reconstruction is the existence of a temperature trend in the period of 500 to 700 A.D., which is similar to the contemporary warming ((1850 - 2000 A.D.), or the so-called "global warming ". So, these investigations have not confirmed the hypothesis of exclusiveness of the contemporary meteorological conditions and their mainly man-caused character.

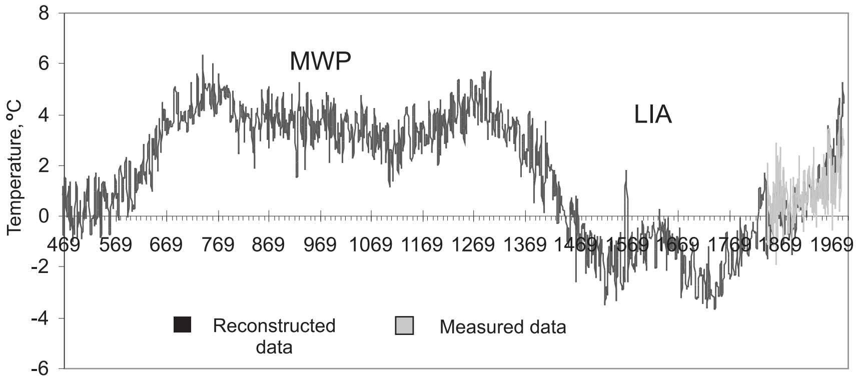


Figure 13: Reconstruction of quantitative variations in the average annual temperature in the Altai region during the last 1500 years against the data of geochemical analysis of the bottom sediments of Lake Teletskoe.

The bottom sediments of Lake Hubsugul are also under exploration. 50 meters of sediments from moist core sample KDP-01 with a spatial resolution of 1 m were under study. Experiments with the sediments enabled the very first detailed exploration of the geochemistry of the Hubsugul sediments of Pleistocene age (up to 1 million years). The observed variations are linked with alterations in the biogenic life in the lake in the past as well as with changes in the intensity of weathering in the water collection and in the mineralization flow from the lake to the bottom due to the changes in the environment and climate of this region.

Variations in the element concentrations and their ratios in long-time intervals of the core sample turned out to be of a cyclic nature. The lengths of the periods of these variations coincide with those of the orbital cycles that were defining the environmental and climatic changes in Pleistocene. On the basis of the most significant changes that were going in the rhythm of the 100-hundred eccentricity cycle, the sedimentary rock sequence has been correlated with the stages of the oceanic isotope stratigraphic scale, which is a common basis for selection of conditionally "glacial" and "inter-glacial" horizons.

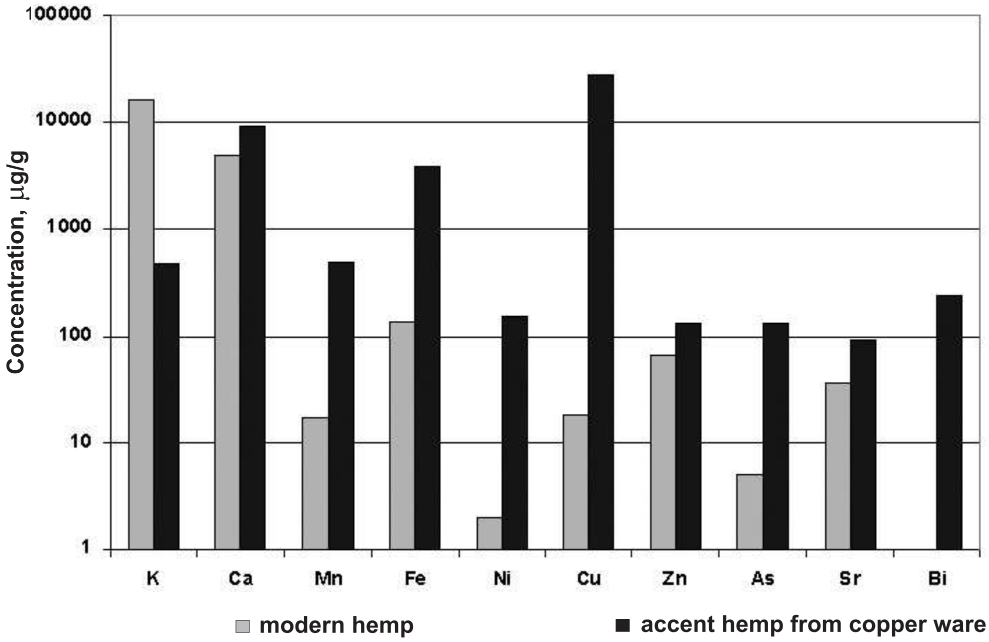


Figure 14: Element content in hemp from Ukok, the 20th century A.D., and in hemp from a censer, 5th to 6th centuries B.C.

A comparative analysis of Hubsugul chronicles and earlier-obtained data on Lake Baikal (station BDP-96/2) revealed traces of significant rearrangements in large Central Asia lake systems between 460 to 420 thousands years and 670 thousands years B.C. Manifestation of these events turned out to be the brightest in Lake Hubsugul. The reason is the position of the lake and in the near-critical regime of the lake system functioning, when a small decrease in the water delivery to the region could result in a lake recession below the outflow threshold.

Joint works with the Institute of Archeology and Ethnography in the investigations into the macro- and micro-element composition of fragments of plants and organic tissues from Ukok burial sites are going on. The earlier- found pronounced antagonism between copper and zinc in the hair of men, women, and children from the Ukok burial sites was explained to be caused by the ceremony of hemp vapor inhalation (the Scythian bath). For confirmation of this hypothesis, experiments were performed on determination of the element composition of contemporary hemp and remains of charry hemp seeds from the copper crockery that has been stored in the Hermitage. The analysis revealed that the copper content in the charry samples differed from that in fresh plant seeds by more than three orders. Therefore, inhaled vapors contained metal- organic copper compounds, which arose due to the contact of scorching stones with the inner surface of crockery, which led to copper poisoning.

Works on determination of element composition of benign and malignant endometrium tissues are also going on. For the first time, joint experiments were carried out on the investigation into the element composition of endometrium myoma and cancer in comparison with adjacent non-transformed tissues, expression of estrogenic receptors ER_α and ER_β and matrix metalloproteinases (MMP). Those are proteins containing Zn ions as a stabilizing element. Malignant new growths are supposed to arise together with a violation of balance in these proteins. The carried out investigations and analysis of clinical data have shown that Zn, K, and Ca concentrations in a malignant tumor are 1.4, 2.6, and 2 times as high as those in a non-transformed tissue, correspondingly, in most patients. Changes in the concentration depend on the age of patients, especially in myoma cases. There is a correlation between the expression factors of ER_α, ER_β, and MMP in a patient and K, Ca and Zn concentrations both in cases of malignant diseases of the female reproductive sphere and in cases of benign tumors. This conclusion indirectly proves that tumor processes in the female reproductive sphere are accompanied by a higher level of hormones.

6.1.5 Diffractometry at high pressures

The purpose of the station is to study the structure of polycrystal materials at pressures as high as 6.5 kbar (in a "cylinder-piston" device) and up to 100 kbar (in diamond anvils) or either at high (up to 1200°C) or low (below - 190°C) temperatures by the methods of X-ray diffraction analysis.

The station is equipped with a detecting system mar-345 by the company Mar-Research, based on an image plate and with a system for in situ reading and erasing diffractograms. This system can sharply increase the number of experiments carried out at the station.

Below are listed some works in 2007:

Investigation into the phase formation at interaction of copper and ferric oxides with aluminum during the process of mechanochemical activation (ISSCM SB RAS.

The work was done within SB RAS interdisciplinary integration project № 98.

Composite materials with a metal matrix surpass conventional cast alloys in their service performance. The routine method of production of cast alloys is a mechanical kneading of disperse particles into a melt. The main problem of this method is low wettability of the strengthening phases, especially of the oxide one, with a melted metal. One of the solutions is cladding of the oxide phase with a metal. This work was exploring the possibility of mechanochemical formation of nano-composites Cu/oxide, which can be used in dispersion strengthening of cast copper alloys. For the purpose of creation of nano- composites of such type, chemical reactions of copper oxide reduction with different reducing metals, in particular, aluminum, have been carried out under the conditions of mechanical activation.

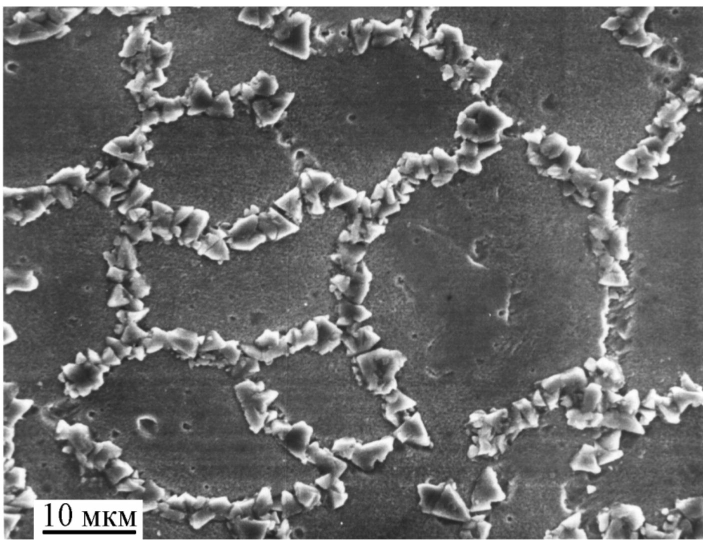


Figure 15: Al_2O_3 distribution in cast copper.

The carried out investigations have shown that at mechanical activation of copper oxide with a solid solution of aluminum, the Cu/Al_2O_3 composite arises in the copper. This composition material is fully kneaded into the melted copper. Electron microscopy confirms that the oxide phase crystallites are distributed over the boundaries of copper grains (Fig.15).

Structural investigations into high-pressure clathrate hydrates (IIC SB RAS).

The work was done under SB RAS interdisciplinary integration project № 43 " SR application in powder diffraction investigations into the phase transformations at high pressures ".

Two series of experiments were carried out in 2007. The first series was linked with exploration of powder diffractograms of Bi_2Te_3 compound at pressures as high as 60 kbar. The dependence of the unit cell volume on the pressure for Bi_2Te_3 is shown in Fig. 16. Experiments in this year differed from those carried out last year in the non-hydrostatic conditions of compression of samples. This time, a pure dry powder of Bi_2Te_3 was under compression. The necessity of this experiment resulted from the processing of results of the year 2006. Those data gave grounds to suspect that a solvent to create hydrostatic pressure could enter the crystal lattice of Bi_2Te_3 and make, at pressures above 40 bar, an "inflated" phase with a unit cell of the same type but of a bigger volume (see Fig.16). Without the solvent, this phase emerged even more clearly, which confirms its existence. Further work will be devoted to finding out the nature of this phase. Besides, a series of diffractograms of a double clathrate tetrahydrofurane and xenon hydrate was shot at different pressures. Such explorations of clathrate hydrates have been done for the first time. The main aim of the work was to reveal possible limits of compression of the hydrate frame as well as to find out baric boundaries of stability of double clathrate hydrates.

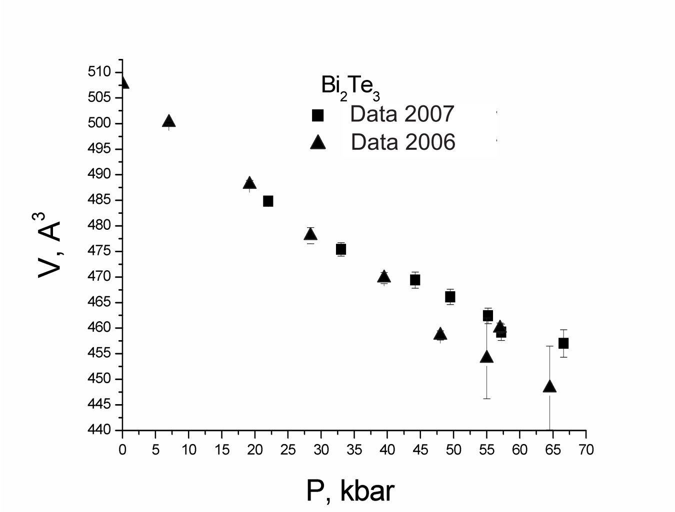


Figure 16: Unit cell volume (cub. angstrem) vs. pressure (Bi_2Te_3).

6.1.6 X-ray microscopy and tomography

This station is at the stage of creation and development of methods. In 2007, the methods of computer-aided X-ray microtomography and transmission X-ray topography were under elaboration.

Exploration of microdefects in natural diamonds by the methods of X-ray microtomography and topography (BINP SB RAS, IGGM SB RAS).

The work was done under SB RAS interdisciplinary integration project № 7 "The nature of micro-heterogeneity of the litosphere mantle".

The inner structure of natural diamonds was investigated by the methods of X-ray computed microtomography (XCM) and X-ray transmission topography (XTT) at the station " X-ray microscopy and tomography" with the application of SR from the VEPP-3 storage ring.

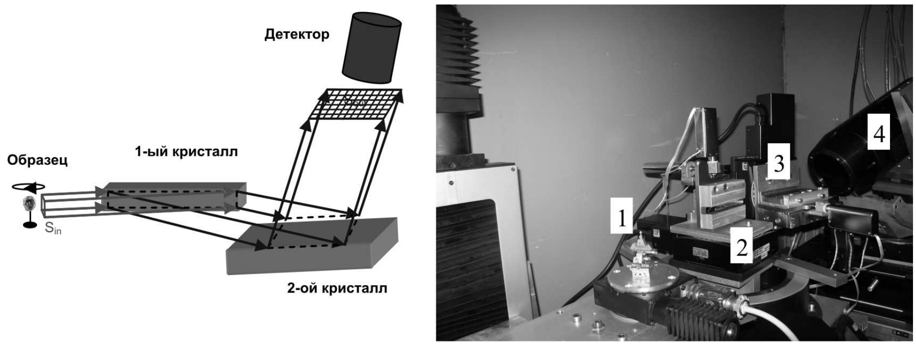


Figure 17: Scheme of the experiment and view of the scanning facility at the SR station "X-ray microscopy and tomography" on VEPP-3. 1 - a sample to explore, 2 - the first crystal, 3 - the second crystal, 4 - a detector (a CCD matrix, 4007x2760 pixels).

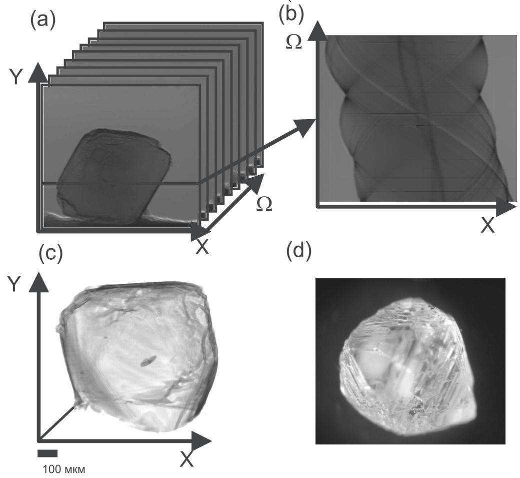


Figure 18: a) A set of projections obtained after scanning; b) a sinogram of a sample section; c) a reconstructed 3D image; d) a photograph of the diamond under exploration.

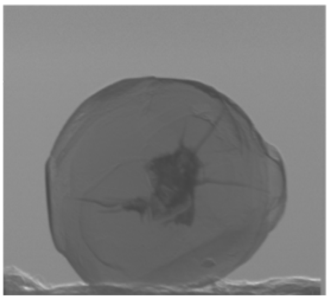


Figure 19: A deffect crystal lattice that was visualized by the XTT method.

Usually, the spatial resolution of XCM is defined by the resolution of the detector and equals tens of micrometers. Silicon crystals with an asymmetric cut and working plane (111) were used for better spatial resolution. Bragg diffraction from an asymmetrically-cut crystal allows increasing the image in one direction. Two crystals (Fig.17) with perpendicular diffraction planes were used, which allowed a 10 to 20-fold increase in the sample image and reaching a spatial resolution of 1 to 2 micrometers in a reconstructed image.

The XCM method was used to explore 14 samples of natural diamonds from kimberlite pipes of the Yakutia diamondiferous province (Fig.18).

The experiments resulted in data on distribution of micro-defects (micro-inclusions, micro-cracks etc.) and thus enabled reconstruction of a three-dimension image of the inner structure of crystals under exploration. In parallel with tomography investigations, the XTT method was used to explore defects linked with irregularities of the crystal lattice of natural diamonds (Fig.19).

The XTT-obtained particularities of the zonal and zonal-sectorial structure of diamonds are of a great importance for determination of the genetic interrelation and sequence of diamond crystallization. The carried out preliminary investigations have shown the XCM and XTT methods to be very efficient in determination of the internal structure of natural diamond crystals.

6.1.7 "Diffraction cinema"

The station is intended to explore phase transformations during chemical reactions involving solid states as well as to obtain both qualitative (the phase formation stages) and quantitative (kinetic) parameters of these reactions. The station enables investigations in the area of both wide (WAXS) and small (SAXS) angles.

6.1.8 Metrology station on VEPP-4M

In 2007, works on SR beams from the VEPP-4 storage ring were recommenced after a long stop (since 1985). The work on the creation and commissioning of a special metrology SR station on the basis of the VEPP-4 storage ring (the station "Space") was completed in 2007. This station is intended for absolute and relative calibrations of different equipment in a broad photon spectrum range from 10 eV to 10 keV.

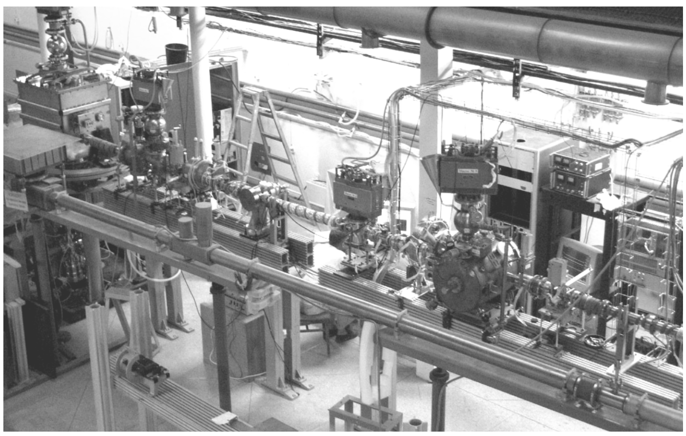


Figure 20: General view of the station "Space" in the SR experimental hall of VEPP-4M.

For the purpose of covering the entire spectrum range from 10 eV to 2000 eV, the station is equipped with two monochromators: a mirror one, on the basis of multilayer mirrors for the spectrum range of 100-1000 eV, and a grating one, for the range of 10-100 eV. Both monochromators provide a steady beam position during energy scanning. In 2007, the monochromators of the station "Space" were tested on a 1.8 GeV SR beam; photon beams were measured after the monochromators. Preliminary results on the certification of the equipment for the Space solar patrol (a set of radiation detectors to install at the International space station) were obtained.

6.2 Work with terahertz radiation beams

6.2.1 The Novosibirsk terahertz free electron laser

The Novosibirsk terahertz free electron laser (NovoFEL) remains a terahertz radiation source of the highest power all over the world. The maximum value of the average radiation power at a pulse repetition rate of 11.2 MHz is 400W. In 2007, users operated the laser at a standard repetition rate of 5.6 MHz (the pulse duration was 100 ps; the relative pulse duration was 180 ns). The average power at the user stations depended on the radiation wavelength as well as on the tuning of the acceleration system. It was 50 to 150 W at standard modes. The laser radiates a monochromatic, fully polarized radiation, which is tunable in the interval of 120 to 140 μm.

In 2007, the laser was used by staff members of Budker Institute of Nuclear Physics SB RAS, the Institute of Chemical Kinetics and Combustion SB RAS, Rzhanov Institute of Semiconductors SB RAS, Lavrientiev Institute of Hydrodynamics SB RAS, the Institute of Theoretical and Applied Mechanics SB RAS, the Engineering and Design Institute of Scientific Instrument-making, the Institute of the Optics of the Atmosphere SB RAS (Tomsk), and the Science-and-Engineering Center for Unique Instrument-Making RAS (Moscow). Besides, teachers, students, and post-graduates of the Novosibirsk State University and Novosibirsk State Engineering University were working on the laser. The free electron laser has become a basis for the recently created Science-and- Education innovation center "Terahertz radiation and its application ", which unites the NSU and nine SB RAS institutes. An yearly experimental elective course has been organized for students. More than twenty-five students have done their term papers, degree works, and master's theses.

One of the main tasks for the year 2007 was to organize regular works at the four already-existing user stations as well as to continue the construction and preparation of experimental equipment for two future stations. The second task was to assemble main elements of the magnet-vacuum system for the second stage of the NovoFEL.

6.2.2 User stations

Works at the user stations break up into two directions. First, since there is no standard equipment for registration and visualization of terahertz radiation, measurement and diagnostics means were under development as well as means for radiation control. Second, basic and applied investigations with the application of terahertz radiation to solve problems in biology, mechanics, optics, and semiconductor physics were underway.

1. Station for physics-chemistry and biological investigations (ICKC SB RAS, ICG SB RAS).

Purpose:

Investigation into ablation of nucleic acids, proteins, ferments, polymers, and mineral clusters. Investigation into the structure of biochips.

Participant organizations:

- Institute of Cytology and Genetics SB RAS, Novosibirsk;
- Institute of Chemical Kinetics and Combustion SB RAS, Novosibirsk;
- Budker Institute of Nuclear Physics SB RAS, Novosibirsk.

200 hours of the beam time.

The work was done under the federal task program " Investigations and developments in the priority directions of Russia's science-and-engineering complex development in 2007-2012": research works under lot"№ 5" "Task-oriented research and creation of a research reserve in the area of live systems by the crucial technology "Bioengineering technologies" (action 1.2 of the Program)" code "2007-2-1.2-09-01-083" by the theme "Diagnostics of DNA biochips using terahertz radiation ", state contract № 02.512.11.2068.

The main tasks of the works are as follows:

– exploration of ablation of biological and mineral materials and investigation into the influence of the free electron laser on biological objects;

– ablation application in the investigation into the identity of biochips made by different companies but by similar technologies;

– generation of the absorption spectra of biological molecules in the submillimeter range.

Ablation of nucleic acids and proteins was under investigation in 2007. It was shown that ablation could be non-destructive. The relation between the radiation wavelength and integrity of a molecule of horse-radish peroxidase at ablation was found out. Evidences of conformation transformations of the DNA structure under the influence of electromagnetic radiation in the range of 120 to 235 μm were obtained. The dependence of ablation of biological macromolecules on their size and absorption spectrum was studied. Model biochips were created and preparatory experiments to study the structure of biochips were carried out.

The ablation of horse-radish peroxidase was studied at different wavelengths of FEL radiation. It was found that the ablation took place at all studied wavelengths but activity remained only at a wavelength of 127 - 142μm. In a region of longer wavelengths, the ferment activity did not remain. A diffusion spectrometer of aerosols (DSA) was used to find out that molecules were denaturated and destructed, and small aerosol particles 3 to 6 nm in size arose at 154 μm wavelength irradiation, while a molecule stayed intact at 128 μm wavelength irradiation.

Aerosol particles have a tendency of aggregating in time, i.e., particles get bigger. This theory was confirmed in all cases of studied mineral aerosols. However, the picture is quite different in the case of biological macromolecules: both DNA molecules and proteins get smaller in time. In this case, we have not just an aerosol of molecules but an aerosol of molecules that have been irradiated with high-power terahertz radiation because, while staying in the chamber, a molecule had time to get several quanta of energy. By now, there have been no descriptions of conformation transformations of DNA or protein structure under the influence of electromagnetic radiation in the range of 120 to 235 μm. However, since the energy of hydrogen bonds is comparable with the energy of FEL radiation quantum, serious effects are expected.

The E.coli line was selected to be a live object for FEL influence exploration. This line carries a genetic structure - a high-sensitivity metabolic biosensor to test ecological purity of water, air, and food when the nature of a toxic agent is not known. FEL influence with a wavelength of 134 μm during 10 minutes and an average power of 50 W/cm^2 resulted in activation of the stress- sensitive biosensor.

The interest in the application of the terahertz region of the electromagnetic spectrum for recognition of chemical substances has increased recently. In 2007, we obtained the Fourier spectra of the horse-radish peroxidase, protein A, chondroitin, perftoran, and synthetic oligonucleotides.

Preliminary results on "soft" laser ablation of biomacromolecules without their destruction led to a suggestion on creating a scanner on this basis to analyze biochips without applying high-cost fluorescent tags. Realization of this method began with experiments on ablation of DNA fragments of a known size from hard surfaces. For that, individual DNA fragments of lambda phage that was hydrolyzed with the HindIII restrictase were selected preparatively by electrophoretic methods. Soft laser ablation of DNA fragments of a size of 3 000 nucleotide pairs (np), 9 000 np, and 23 000 np was carried out. The diffusion sizes of particles that were generated under FEL radiation correspond rather well to the linear dimensions of polymer chains of DNA involved in the experiment.

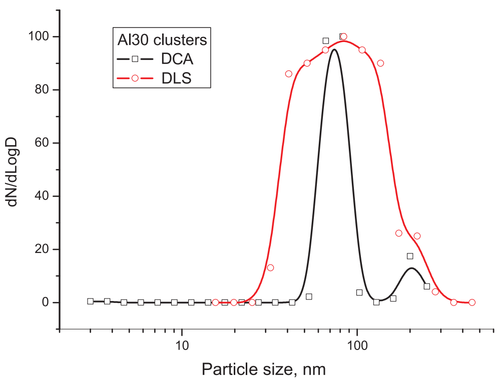


Figure 21: Comparison of the size distribution of colloid particles of aluminum oxide that were generated with soft ablation (DSA) and dynamical light diffusion (*DLS).

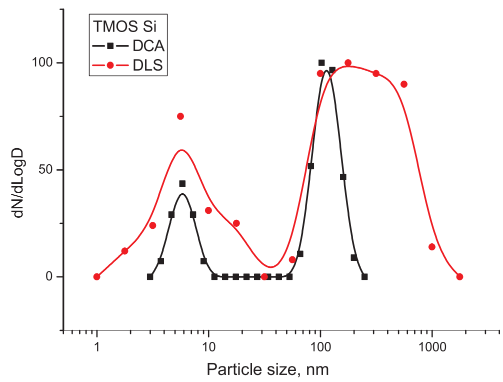


Figure 22: Comparison of the size distribution of colloid particles of silicon oxide that were generated with soft ablation (DSA) and dynamical light diffusion (*DLS).

The possibility of using soft ablation to explore polymerization and formation of colloid particles was also under investigation. Colloid solutions of aluminum and silicon oxides after drying on aluminum foil were used as samples. Size distributions of ablation-generated aerosol particles are in good agreement with those of particles of initial water colloid solutions that were obtained by methods of dynamical light diffusion (see Fig.21 and 22).

Under INTAS project №06-1000013-8569V, Aseev at the University of Helsinki (Finland) has determined the size of colloid particles by the method of dynamical light diffusion. In total, 180 spectra of ablation-generated aerosols were registered, 80 irradiated samples were investigated, and 1 biochip was prepared in 2007.

2. Metrology station (BINP SB RAS).

Purpose:

A station for diagnostics, control and optimization of terahertz radiation from free electron lasers as well as for conducting physical experiments with this radiation.

Equipment of the station:

• a spectral complex based on the up-graded monochromator MDR23, to measure the radiation wavelength and emission line shape, to adjust a selected radiation harmonic on-line, to filter a selected interval of spectrum or harmonic, and to carry out different optical measurements, in the optical range and to the submillimeter one;

• a vacuum Fourier spectrometer by the Bruker company, for metrological measurements of radiation wavelength, detailed measurement of radiation spectrum and its autocorrelation function (coherency), tuning of emission into the atmospheric transparency windows, diagnostics of the nitrogen drying system in the optical beamline, and spectral characterization of materials, filters and other physical objects;

• a measurement complex on the basis of in-house ultraspeed terahertz detectors with different Shottky diodes and oscillographs made by the Tektronix company, to measure the main phenomenological parameters of FEL (the gain factor, saturation intensity, and losses in an optical resonator) as well as of the light pulse structure with a time resolution of 10 to 20 picoseconds;

• a 152x152 mm terahertz radiation visualizer based on a thermal image plate by the Micken Instruments company and an optical camera-recorder for detailed measurement of distribution of radiation of quite high power;

• a terahertz radiation visualizer based on a scanning array of 30 piroelectric detectors with a stepper, to measure the average distribution of weak radiation;

• a set of different detectors for on-line control and various measurements in different spectral ranges, including detectors of a very high sensitivity and time resolution;

• two specially-developed calorimeters for terahertz radiation: a reference sapphire calorimeter and an up-graded gigahertz calorimeter MK 3-71;

• a set of different filters and polarizers for harmonic filtration (including spatial ones) and tuning of the terahertz radiation power.

Below is the list of works carried out at the metrology station in 2007:

– An acoustic-optical effect arising due to strong terahertz radiation absorption by water vapors was revealed and investigated. A strong sound arises at modulation of terahertz radiation power; evidently, a weaker sound results from auto-oscillations. Now the effect is used in simplest diagnostics (without instruments) of the frequency drift of FEL emission from the atmospheric transparency windows and of technical failures in FEL systems that lead to modulation of the FEL power.

– Losses in the optical resonator of the terahertz FEL in an extended spectral range were measured. The measured losses were shown to correspond well to a simple analytical theory the optical resonator is based on.

– A complex of spectrum-time measurements, including unique measurements of the FEL pulse structure, made it possible to reveal three regimes of FEL operation. Those include a single-mode narrow-line regime with high time coherency, a multi-mode regime with a set of narrow lines and high time coherency, and a quasi-single-mode regime with a very big linewidth and low time coherency. It was shown that the two latter "non-classical" regimes were caused by modulation instability.

It was shown that this instability could be suppressed through tuning-out the electron bunch repetition rate from the resonance frequency. A smooth transition between the above-mentioned regimes at a smooth tuning-out of the electron bunch repetition rate was demonstrated.

– The Fourier spectroscopy method was used to measure terahertz radiation absorption by residual water vapors in the optical beamline filled with nitrogen circulating through a special drying system. The efficiency of drying with a degassed zeolite was shown to be 500 times (the dew point is about -40°C) and to decrease down to 300 times after two months of operation. Although these parameters are quite good for such systems but they are not good enough to neglect absorption by water vapors over the entire FEL operation range. It is desirable to lower the dew point down to - 60°C. This direction is under elaboration now.

– A visualization system on the base of a thermo-fluorescent screen with a 152x152 mm operation field was used to measure radiation intensity distribution at the user stations.

The observed periodical intensity modulation in a direction normal to the electric field vector (uniform inclination fringes) results from the interference of a very weak radiation "halo" with the main beam. This modulation was filtered efficiently with the help of a diaphragm between two parabolic mirrors.

– A complex measurement of optical parameters of a CVD diamond in the terahertz range was carried out by three complementary methods, including a uniquely precise calorimetric measurement with the application of the high-power terahertz FEL radiation. This material is indispensable for high-power terahertz radiation, and its application in a more complicated system for radiation out- coupling will enable more than doubling the FEL power.

– An effect of a very bright threshold optical fluorescence of calcium- containing substances (paper, chalk, marble etc.) in focused beams of terahertz radiation has been revealed and investigated. It was proven experimentally that it was a thermal light, i.e., so-called "limelight" by calcium oxide, which is a resulting thermostable product of the above-listed substances. The threshold effect and unusually high brightness of the radiation were proven to be a consequence of the transition of calcium oxide from the state of an ideally "white" body to an ideally "black" one at a temperature of about 2000 ° K. A similar effect also shows on other thermostable white metal oxides and is linked with the reduction in the forbidden zone in these crystals at a strong excitation of their crystal lattice.

– Under interdisciplinary integration SB project №107 "Investigation into the interaction of the phonon subsystem $Pb_{1-x}Sn_xTe$<In> under the conditions of ferroelectric instability with terahertz radiation and development of detectors to visualize it", this material, which is promising for the manufacture of big matrixes, was investigated for the rise of photoconductivity in the terahertz range. Signals of photoconductivity have been registered over the entire range of the terahertz FEL radiation. Now, the processing of the measurement results is underway and further research is being planned.

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 as well as flames.

In 2007, the station was dealing with spectroscopy and introscopy of condensed media and biological objects, using an optical-acoustic cell to measure weak absorption in gases with a scheme of synchronous detection (the minimum measurable absorption equaled 10^{-5} см$^{-1}$) and a Fourier spectrometer by the Bruker company for the spectra of molecular gases in the terahertz region.

Zuev Institute of Atmospheric Optics SB RAS participated in the exploration of terahertz radiation transmission in atmosphere with water drops 5 μm in diameter. The total attenuation constants (due to the scattering and absorption by water drops) was investigated for a number of lengths of waves that get into atmospheric transparency micro-windows. The spectral dependence of the radiation attenuation constants in the range of 119 to 160 μm has been obtained.

The terahertz radiation transmission through a hydrogen-air flame at wavelengths of 119.3 μm and 163.4 μm, which correspond to the rotational spectral lines of the OH radical, was under study. The result was that the absorption coefficient did not exceed 10^{-3} at a wavelength of 1 cm. The same flame was explored by the method of laser-induced fluorescence. The spectra of the OH radical were obtained and the temperature profiles and concentrations of radicals were measured.

4. Chemical station (IIC SB RAS).

Purpose:

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

Equipment of the station:

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

Users at the chemical station of the Novosibirsk FEL continue the explorations of transformations in complex polyatomic molecules at thermal activation and under the influence of high-power electromagnetic radiation generated by the FEL by the methods of time-of-flight mass-spectrometry. The new objects of study are ketoiminate copper complexes, which are also volatile but less thermally stable, according to the data of thermal analysis. The smaller thermal stability is linked with the reduction in the average energy of the bond metal-ligand, which can in turn lead to easier bond activation under the IR irradiation.

High-temperature mass spectrometry was used to explore the mechanisms of thermal decomposition. It was found out that a complex was decomposing in two directions, i.e., with formation of both molecular and radical organic products, whose composition allowed expecting solid copper to be the only solid product arising.

A significant number of experiments when molecular beams of several investigated volatile complexes of metals with organic ligands were exposed to terahertz radiation (a 150 ?m wavelength and a maximum power of 100W) have been analyzed. The analysis showed that changes in the mass spectra, which were observed as variations in the relations of peak intensities, and formation of peaks of new particles, are linked mainly with uncontrolled overheating of part of the source. They are also linked with the interaction of radiation with compounds that are desorbed from the surface of the vacuum volume. In order to increase the area and time of molecular beam interaction with radiation, documentation was prepared to upgrade the optical system for injecting laser radiation into the operation volume of the station. The main elements are a spherical short-focus mirror (copper), a silicon membrane installed at the Brewster angle, and a multi-passage cylindrical copper cuvette.

There are plans to start using a pulse molecular source of vapors, which would enable a significant reduction in the influence of secondary processes. The manufacture of separate elements of this system has begun.

5. The "Spectroscopy and introscopy" station.

Purpose:

The station is intended for exploration of inorganic, organic, and biological materials and objects by methods of spectroscopy and spectral-selective introscopy as well as for development of means and methods of visualization in the terahertz range.

The redecoration of the premises and connection of mains supply for the stations "Spectroscopy and introscopy" and "Aerodynamic explorations" have been completed. The terahertz radiation transport beamline to these stations has been manufactured. The optical table, optical elements, and air-drying system for these stations have been purchased. The radiation registration systems have been prepared. First experiments by programs to be conducted at the station "Spectroscopy and introscopy" in 2008 have been carried out at the station "Molecular spectroscopy".

Reflective and refractive diffraction optical elements (DOE) for high-power terahertz radiation have been designed, manufactured, and tested. They became a basis for creation of quasi-optical systems for terahertz radioscopy of condensed media, including shadow and holographic systems. Experiments on the diffraction Gabor tomography have been conducted. Systems for visualization of terahertz radiation on the basis of a thermosensitive luminescent screen and a thermosensitive interferometer have been designed and calibrated. A transducer basing on an array of 160x120 micro-bolometers has been adapted for terahertz radiation registration. For the first time in the terahertz range, real-time object images have been obtained in the regimes of radioscopy and exposure to directed and diffusive laser radiation.

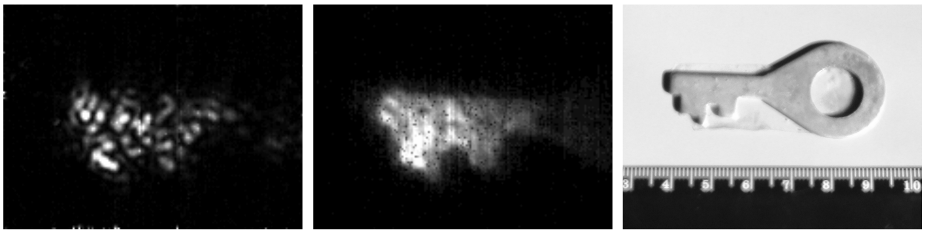


Figure 23: Image of the bit of a metal key (the right photo) made with an array of microbolometers. The object was under diffusive-scattered radiation of the terahertz laser. Left: the scatterer was fixed; at the center: the scatterer was rotating very fast.

A peak speed of terahertz image recording of 90 frames per second has been achieved. A speckle pattern arising when objects are under diffusive illumination by coherent radiation has been investigated. Fig.23 presents two frames that were registered when a model object was under illumination by FEL radiation reflected from a still rough metal surface and a fast-rotating one. It can be seen that the "averaging" of the speckle pattern due to its fast rotation provides a satisfactory image quality. An attenuated-total-reflection spectrometer has been created for the terahertz range. Spectra of aminoacids, DNA, and bone tissues of normal and pre-senile rats were under investigation. Some differences in the absorption spectra in rats of different ages and different genetic lines were noticed. A "pump-probe" system with the terahertz radiation application has been designed and its main elements have been manufactured.

6. The "Aerodynamical investigations" station.

The gas-dynamic system has been mounted (Fig. 24).

An optical system has been created for radiation delivery to the station. Optical systems have been prepared for registration of interaction of terahertz radiation with supersonic gas flows and exploration of the influence of energy input on the flow around bodies. A high-speed camera (Princeton Instruments) with a micro-channel luminance amplifier has been commissioned for shooting in the visual range with a time resolution as high as 2 ns.

Figure 24: Stages of the construction of a facility to investigate the terahertz radiation influence on gas flows via ray sounding in the visible band.

6.2.3 Development of the Center for photochemistry research on the basis of the energy recovery linac (ERL) and second-stage FEL for the range of 3 to 10 THz

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

In 2007, the works were going in three directions: (1) performance improvement and growth of the reliability of ERL operation with the laser system, (2) conduction of experiments with terahertz radiation, and (3) manufacture and assembly of the second stage of the ERL and FEL. 6.2.

Table 6.2: FEL performance.

Electron beam energy, MeV	12
RF system frequency, MHz	180,4
Bunch repetition frequency, MHz	11,2-22,25
Average current, mA	30
Maximum average out-coupled laser radiation power, W	400-500
Wavelength retuning range, ?m	120-240
Emission bandwidth $\Delta\lambda/\lambda$, (minimum)	$3{\cdot}10^{-3}$
Energy recovery efficiency, %	>95

In order to increase the bunch charge and average current of the ERL, in 2006, the cathode-grid unit of the electron gun was replaced with a cathode-grid unit of a bigger area. That required changing the modulator forming nanosecond pulses delivered to the cathode-grid gap as well as modernization of synchronization. This modernization of the electron gun allowed increasing the average electron beam current up to 30 mA in 2007, which is a world record for accelerator- recuperators.

For the sake of reliability growth and increase in the ERL RF system power, the generator tetrodes are to be replaced with lamps by the company Thales. A preliminary design of the corresponding modernization of the generator has been developed. The manufacture of corresponding units is planned for next year. The full scale ERL (the so-called second stage) uses the same RF structure but is located, unlike the preceding ERL, in a horizontal plane. The manufacture of the elements of the magnet-vacuum system of the second stage of the ERL was completed in 2007. Magnetic measurements of all bending magnets and quadrupole magnets have been conducted. Mounting of the magnet-vacuum system of the second stage in the ERL hall is close to completion (see Fig. 25 and 26). Fig.27 presents a scheme of the second stage of the FEL.

All power supplies for the magnet system of the two first tracks have been manufactured. The installation and wiring works are underway. The electronics and software to control the second stage of the ERL are ready.

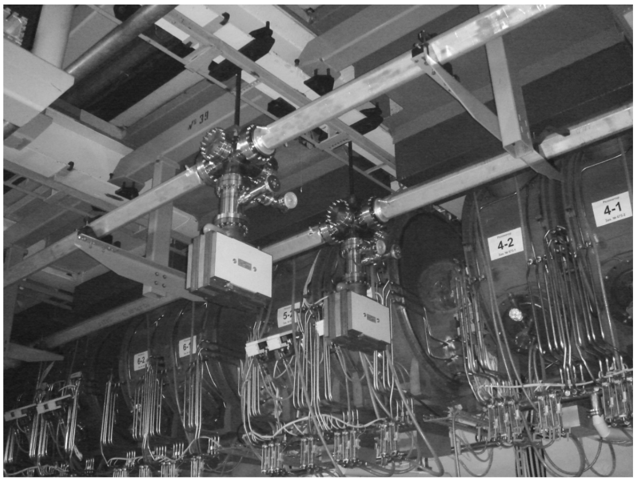


Figure 25: Aluminum vacuum chambers of the straight-forward intervals of the 2nd stage ERL with units for pumping and diagnostics.

Figure 26: Bending magnets and the upper halves of quadrupole magnets before the mounting of the vacuum chambers.

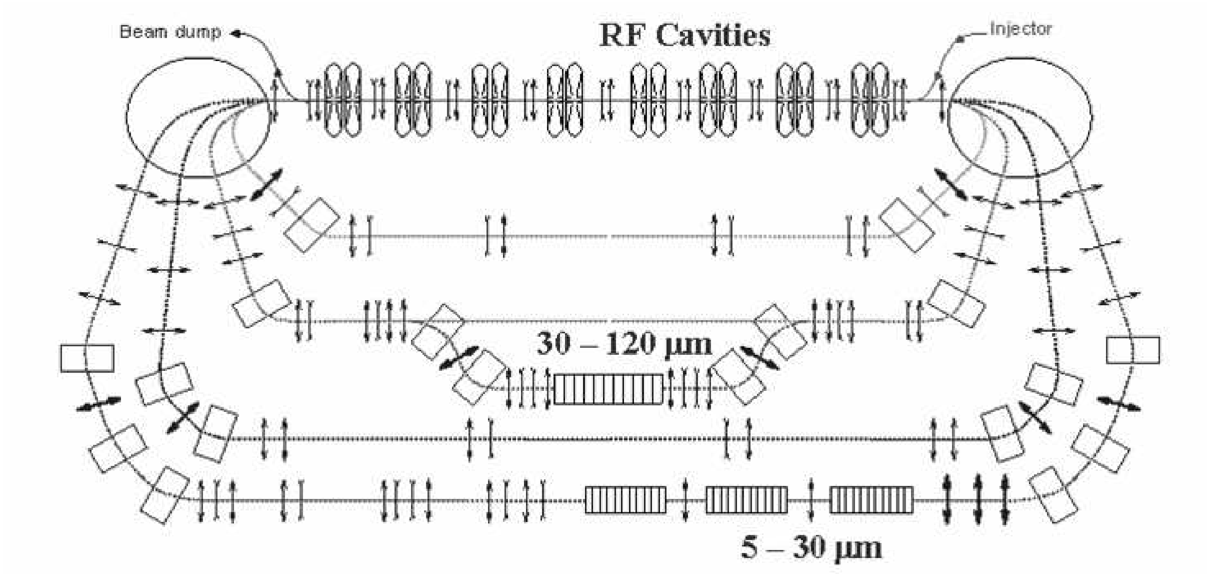


Figure 27: A scheme of the second stage of the FEL.

6.2.4 Main results of the year 2007 and plans for the year 2008

1. In 2007, users (biologists, chemists, and physicists) were working regularly with terahertz radiation. 780 hours of working time was allotted for research on terahertz radiation beams from the Novosibirsk FEL. 2. The design of the radiation out-coupling lines and four tracks of the second stage of the FEL was completed. 3. The magnet-vacuum system of the second stage has been manufactured and now is being mounted (without the 4th track). 4. Computation and optimization of the forth track FEL have been performed. 5. The station for the aerodynamic research has been mounted.

Plans for the year 2008:
1. Mounting and commissioning of the ERL with two tracks.
2. Powering-up the out-coupled radiation of the operating terahertz FEL.

6.3 Development and manufacture of dedicated SR sources

6.3.1 Superconducting wigglers

Active contract works on the development and manufacture of various superconducting cryogen-magnetic systems for SR generation continued in the year 2007.

1. Fabrication of a 27-pole 4.3 T superconductive wiggler with a period of 48 mm and a pole gap of 14 mm under a contract with Canadian Light Source (CLS, Canada) was completed in August 2007. The wiggler was delivered to CLS, assembled, and commissioned on the storage ring in October 2007. This wiggler will be used in biomedical investigations. It is already a second multi-pole wiggler that was manufactured by BINP for CLS. Both these wigglers have almost zero consumption of liquid helium.

Figure 28: The 27-pole superconducting wiggler with a period of 48 mm and a pole gap of 14 mm for biomedical investigations on the Canadian Light Source storage ring (CLS, Canada).

2. A 21-pole 7.7 T superconductive wiggler with a period of 164 mm under a contract with the RSC "Kurchatov Institute" for the SR source "Sibir -2" was assembled and passed a full cycle of tests on the customer's site in the spring of 2007.

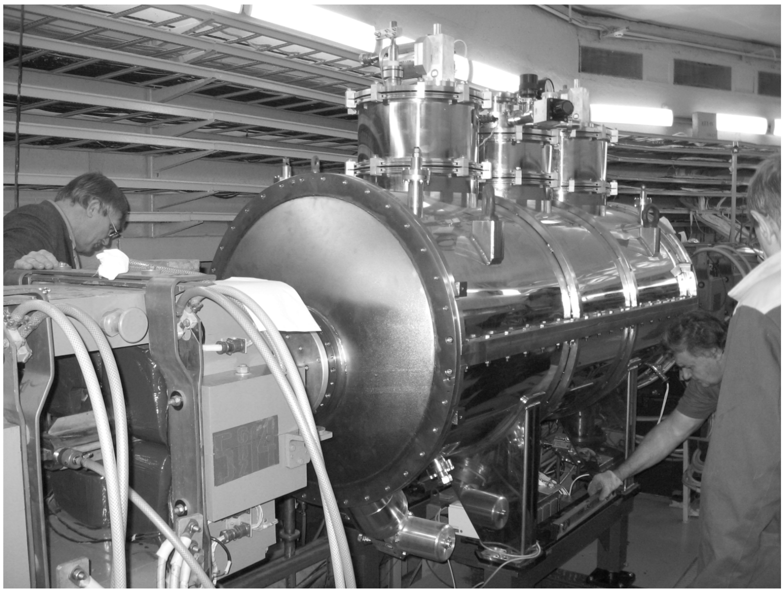


Figure 29: Mounting of the 21-pole 7.7 T superconductive wiggler with a period of 164 mm on the "Sibir -2" storage ring (the RSC " Kurchatov Institute", Moscow).

This wiggler has the highest power among facilities of such type. In the operation mode of the "Sibir -2" storage ring, the total power of radiation beam from the wiggler will exceed 100 kW. The liquid helium consumption is close to zero and the cryostat has to be filled with liquid helium at most once a year. The wiggler was installed on the "Sibir -2" storage ring in December 2007.

3. Three contracts on manufacture of superconductive wigglers started in 2007.

A prototype of a 35-pole 4.1 T wiggler with a magnet gap of 16.2 mm and a period of 60 mm for the LNLS storage ring (Brazil) was fabricated and successfully tested in November 2007.

A short prototype of a 123-pole 2.1 T wiggler with a magnet gap of 13.4 mm and a period of 31 mm for the ALBA-CELLS storage ring (Spain) was tested in December 2007. Required parameters were achieved at the test.

Manufacture of another prototype of a multi-pole wiggler for the Diamond Light Source storage ring (DLS, England) started in December 2007. It is a 49-pole magnet with a pole gap of 14.4 mm and a period of 48 mm. The expected magnetic field value is 4.1 T. It will be a second multi-pole wiggler installed on the DLS storage ring .

All these three full-size wigglers will be manufactured and installed on the corresponding storage rings - SR sources - in 2008.

6.3.2 Engineering storage complex (ESC)

Works on the ESC complex of storage rings (SR sources) for the research-and- production center of microelectronics and micromechanics (Zelenograd) continued in 2007. BINP designed and manufactured the ESC in the period from 1986 to 1992. The main purpose of the ESC is the manufacture of micromechanical products by the methods of X-ray lithography and LIGA technology. The electron energy is 2.0 GeV, the current is 300 mA, and the perimeter of the big storage ring is 115,7 m.

On February 8, 2007, the RF Government signed a decree №146-P " On the creation of the Center of high technologies on the basis of the engineering-and- production complex with the synchrotron "Zelenograd"" (which is a new name of the ESC), and a full-scale financing of the project started.

Modernization of the equipment of the ESC complex has begun thereafter. In 2007, BINP SB RAS replaced completely the electronics for the power supply system of the permanent magnets of the small ring and electron-optical channels, for the supply systems for corrections, and for the RF system of the small ring. The first stage of a new-generation control system on up-to-date solutions, computers, and components has been designed, manufactured, and commissioned. More than 500 control and monitoring channels have been commissioned.

New elements and electronics for the beam diagnostics system in the electron- optical channel EOC-2 and elements of the magnet system have been fabricated. The assembly of the vacuum chamber and adjustment of all magnetic components of the channel have started.

A thermostabilization system for the acceleration structure of the linear accelerator and a thermal control system for the whole injection complex have been designed, fabricated and mounted.

At the end of the year, after modernization of all the systems and debugging of the software, an electron beam from the linear accelerator to the small storage ring was captured, and the captured beam was accelerated up to a design value of 450 MeV.

Revision and modernization of all components of the magnetic system of the big storage ring - the components had been stored at BINP since 1992 - started in 2007. Magnetic measurements of the dipole magnets and necessary revision of the magnetic circuits have been carried out. The dipole magnets have already been installed on the ring, and the rest magnetic components are now under up-grade. Modernization of the

RF resonators and the anode supply system has begun as well as switching RF oscillators to new oscillating tubes. A complete design study of a new vacuum chamber of the big ring is planned for the year 2008.

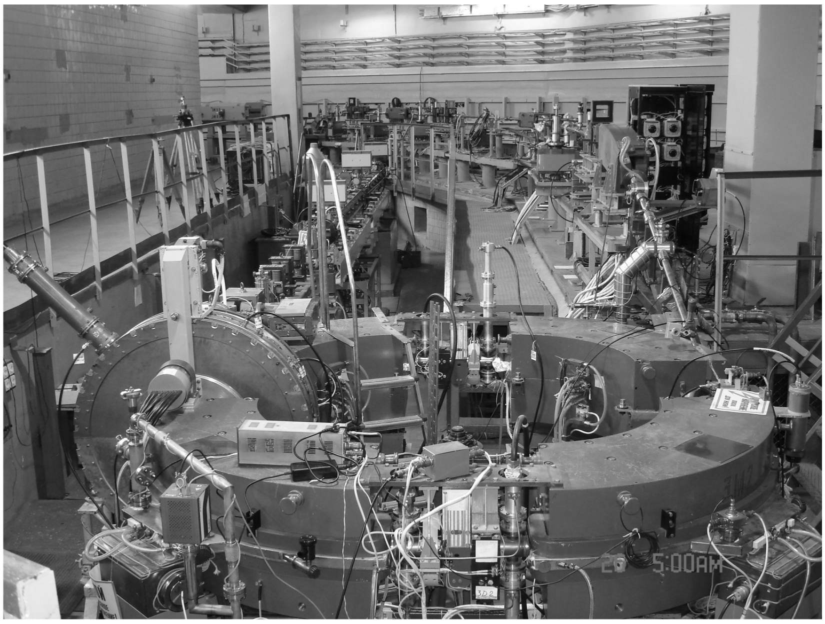


Figure 30: A general view of the mounted part of the ESC: the linear accelerator and electron-optical channel EOC-1 (on the left); the small storage ring in the foreground and electron-optical channel EOC-2 (at the top right).

Figure 31: Participants in the commissioning of the injection complex of the ESC and achievement of its design performance (the 75 MeV linear accelerator, electron-optical channel EOC-1, and small ring).

6.3.3 Magnetic system for the metrology light source (MLS)

Contract works on the assembly and adjustment of the magnetic system for the storage ring and the magnetic and vacuum systems of the electron-optical channel of the metrology light source (MLS) constructed in Berlin on the basis of the German National Metrology Institute (Physikalisch-Technische Bunde sanstalt) were completed in February 2007. The MLS source is intended for calibration of measurement instruments and sources of radiation in the spectral range of far IR and THz radiation to hard UV radiation.

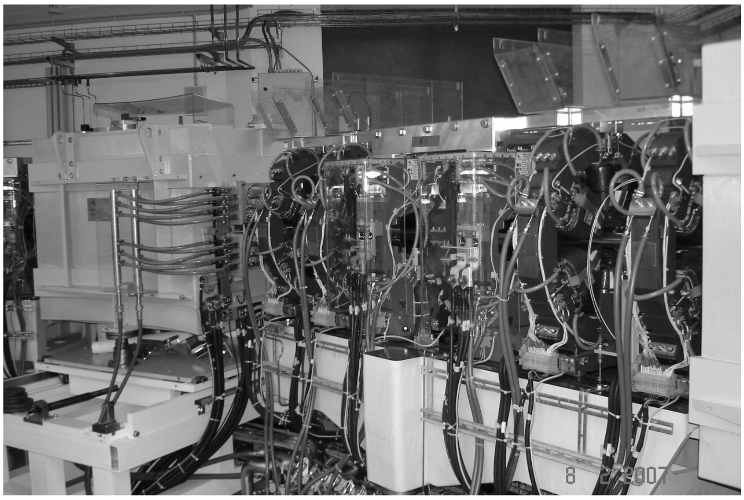


Figure 32: Dipole, quadrupole, sextupole, and octupole magnets on the MLS storage ring.

The MLS 600 MeV storage ring perimeter is 48 m. The magnetic system of the storage ring consists of 8 dipole, 24 quadrupole, 24 sextupole, and 4 octupole magnets. The magnetic system of the electron-optical channel between the microtron and the storage ring consists of 10 quadrupole magnets, 8 correctors, and a bending magnet.

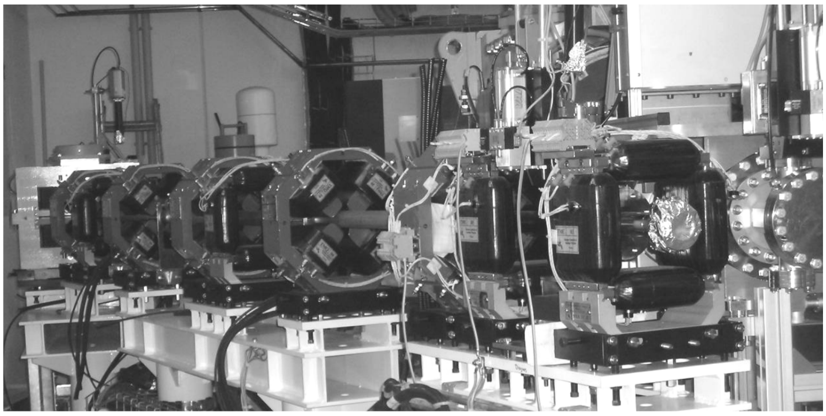


Figure 33: The section of the electron-optical channel between the bio-shield wall and the storage ring.

The first beam build-up at an injection energy of 100 MeV was obtained on June 6, 2007 (the beam current was 25 μA, and the lifetime was 1 hour). On August 14, the beam was accelerated up to the maximum operation energy (the beam current was $\sim$ 1 mA). Now, the SR source of the MSL is being prepared for work as well as the first stage of SR stations. The work is to start early in 2008.

6.3.4 Permanent magnet damping wigglers for Petra-III (Hamburg)

A contract work on the manufacture of permanent magnet damping wigglers for the accelerator-based SR source Petra-III (DESY, Hamburg) continued in 2007.

Figure 34: Trial mounting of a wiggler on the accelerator Petra-III (DESY, Hamburg).

The installation of the wigglers on the accelerator will enable a significant reduction in the electron beam emittance (due to radiation losses of electron energy in the magnetic field of the wigglers). Each wiggler has the period λ=200 mm, gap h=24 mm, length L=4 m, and maximum field B=1,58 T.

All the wigglers will be fabricated by the end of 2008. Works on the tuning of the magnetic performance of the wigglers will begin in 2008.

6.3.5 Prototype of a radiation-resistant dipole magnet for an ion accelerator under construction at GSI (Germany)

In 2007, a contract work on the design and manufacture of a prototype of a radiation-resistant dipole magnet for the acceleration center GSI (Germany) began.

The magnet has a radius of curvature of 13 m, a pole gap of 180 mm, and a magnetic length of 2.5 m. The good field region is ($\pm 3 \cdot 10^{-4}$) $\pm$190 mm. The weight of the magnet is $\sim$ 100 tons. Magnetic field in the magnet increases from 0.15 T to 1.6 T in 120 seconds. The magnet has a distinction of complete absence of any structural elements containing organic compounds (it is to work in high-radiation fields).

6.3.6 Development of a project of a dedicated SR source with the application of superconductive magnets

In June 2007, it was decided to change the main direction of the activity on the creation of a dedicated storage ring to be an SR source for the Siberian SR source. It was decided to give up the idea of a compact source (with a perimeter of about 60 m) and to take up creation of a standard-size complex (with a perimeter of about 200 m).

Below are the main arguments:

• the premises allotted for the compact storage ring (Block 1) were not optimal for such projects, as concerns accommodation of the storage ring itself and user stations; in particular, it was impossible to place long SR beamlines with X-ray optics required to use a small-emittance source with a maximum efficiency;

• engineering difficulties: it was complicated to realize the small- emittance scheme in such a small perimeter without serious problems with chromaticity and dynamic aperture;

• unsatisfactory characteristics of SR from a compact source (its spectrum is not hard enough even for beams from superconductive magnets; large angular divergence of the beams; impossibility of installing undulators for research in the EUV lithography field).

In consideration of up-to-date tendencies for such centers, the following main parameters have been chosen. (Table 6.3).

Table 6.3: Main parameters of the dedicated SR source.

Operation energy	2.2 GeV (the warm magnet SR spectrum will meet the requirements of most methods realized at the SR Center so far)
Perimeter	About 200 m
Number of periodicity components and, correspondingly, number of superconductive magnets in the structure	8 - 12
Emittance	About 4 nm
Current	up to 1 A (full-energy injection with possibility of current pumping)

Now the magnetic structure optimization along with the project of the requirements specification for the building is under development.

There are several organizational schemes for the magnetic structure of this storage ring. Since the storage ring will be the basis of the dedicated SR center, it is desirable to envisage the possibility of SR generation in all spectrum ranges in demand. It implies a sufficient quantity of straight sections of various lengths for installation of SR generation devices with parameters required for different research methods. Besides, bending magnets are to be used actively as SR sources for most stations. Methods that require hard X-rays will be realized on SR out-coupling beamlines from superconductive magnets. However, most stations can be installed on SR beamlines from warm magnets, where the SR spectrum enables a sufficient quantum beam with energy as high as 50 keV.

A modified Triple Bend Achromatic (TBA) scheme with a certain deviation from the conventional achromatic regime seems to be the most suitable. Below are some arguments in its favor:

• a TBA scheme enables using magnets of two different types as central and edge magnets, which is very important when superconductive magnets are used along with conventional ones;

• a TBA scheme enables realization of a rather big number of straight sections: this project implies application of 8 to 12 TBA cells, which means a possibility of the same number of straight sections;

• deviation from the“zero-dispersion” requirement for the straight sections enables additional reduction in the equilibrium emittance of the ring and, thus, flexible balance between the emittance magnitude and the dispersion function value in the sections is possible.

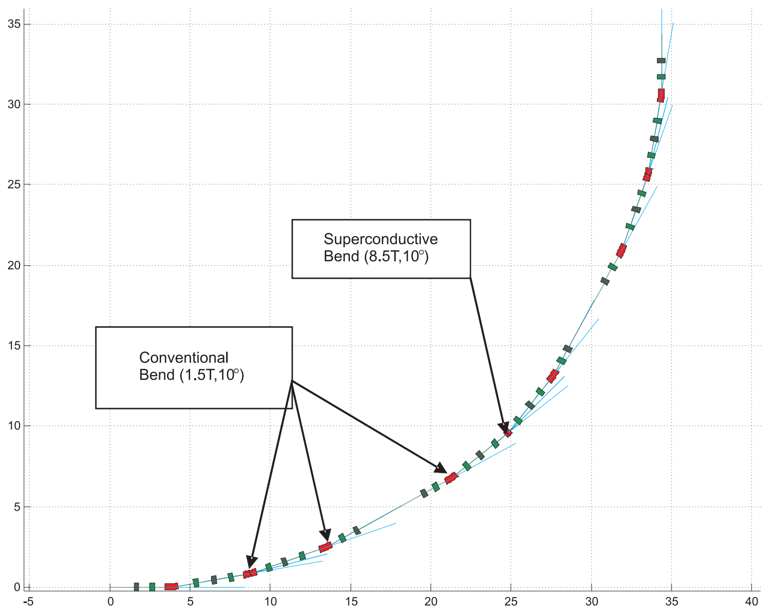


Figure 35: Scheme of one super-period of the magnetic structure of the storage ring serving as an SR source for the Siberian SR center. C

Fig.35 presents the general view of one super-period of the magnetic structure of the storage ring. Fig.36 presents the general arrangement of the complex (the main ring, booster synchrotron, and bio-shield). A preliminary design of the building has been completed, and a model of the building has been fabricated by now. The general view of the building is presented in Fig.37 and a photograph of the model in Fig.38.

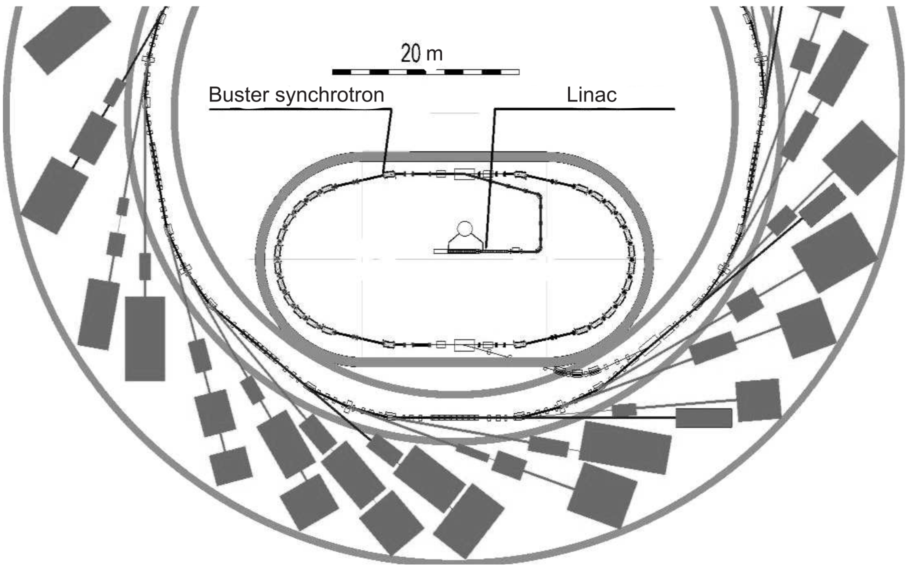


Figure 36: Scheme of the storage ring serving as an SR source, injection complex, and user stations.

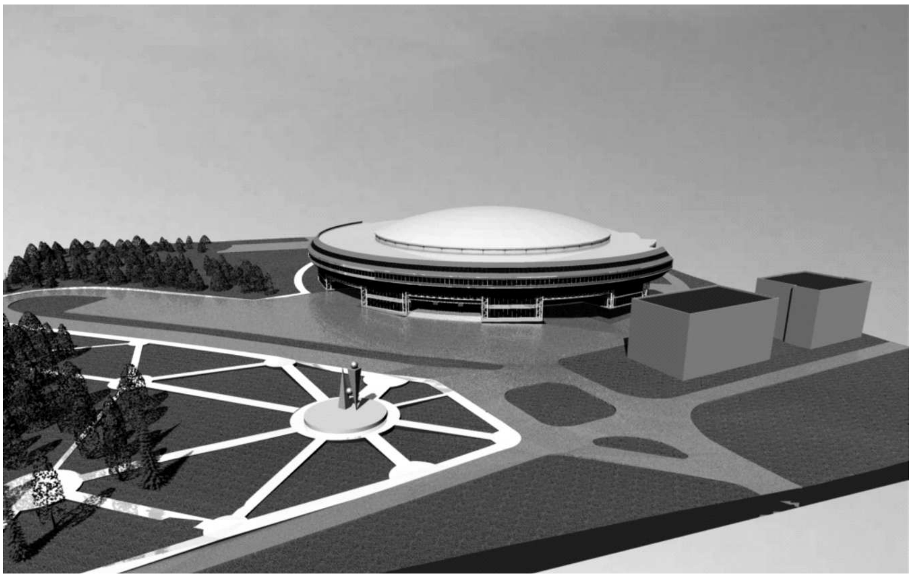


Figure 37: General view of the projected building for the SR center.

Figure 38: Model of the storage ring serving as an SR source (the building, injection complex, and user stations)).

6.4 Conferences, meetings and workshops

6.4.1 The 29th International Conference on Free Electron Lasers (FEL 2007).

The next, 29th, International Conference on Free Electron Lasers (FEL 2007) took place at BINP on August 26-31, 2007. About one hundred eighty people took part in it, approximately one hundred fifty of them arriving from the USA, Germany, Korea, France, Sweden, Japan, and other foreign countries. They were representing the main research centers in this field.

The scientific agenda of the conference covered all main issues of creation and application of free electron lasers (FEL): the FEL theory, technological issues, FEL application, X-ray FEL, high-power FEL, FEL on electron storage rings, new projects, and statuses of operating facilities. The conference program included daily plenary sessions along with stand reports.

Conferences of this series are annual and go off in different countries (the last one took place in Berlin) in late summer/early autumn. In our country, such conference has been hold for the first time. The permanently functioning international committee of the conference selects the conference venue, usually where operating facilities with a FEL are situated. So, the conference participants can, in addition to presenting their reports, be acquainted with operating facilities and experiments.

Figure 39: Photo of the participants in the 29th International Conference FEL- 2007.

BINP has conducted FEL investigations for more than thirty years. During this time, our Institute has become a Russia's leading center in the field of FEL creation and application. BINP activity and research methods are widely known both in Russia and abroad.

The high-power FEL for the THz range (wavelengths of 0.11 to 0.24 mm) was commissioned in 2003. It is the only facility of such type in Russia.

The up-to-date equipment has not mastered the THz range in full. The average power of the Novosibirsk FEL (400 W) surpasses by orders of value that of other sources in this range. Its peak power is as high as 1 MW. BINP together with the Institute of Chemical Kinetics and Combustion SB RAS have created the Siberian Center for Photochemistry Research based on the Novosibirsk FEL. Representatives of several SB RAS institutes work at the user stations. Record parameters of the FEL enable unique experiments. Construction of its second stage is underway, which will enable improving parameters of the operating Novosibirsk FEL (advance in the area of higher frequencies and increase in the average radiation power).

Of course, there are free electron lasers that are older than the Novosibirsk one: the first facility appeared in the USA in 1977; this direction has started rapid development since then. Now, there are about fifty such facilities with different parameters over the world. This number is not too small because those are very expensive big-sized facilities. All of them have been very useful as interim stages for trials of various variants of FEL design. The Jefferson Lab FEL has the highest power (14 kW). However, the wavelength ranges of it and of the BINP facility are different. Therefore, they do not compete but are mutually complementary. There is also an operating FEL of a higher power in Japan.

Free electron lasers have many different applications because they enable generation of electromagnetic radiation in those wavelength ranges where there have been no sources.

In particular, one of the main directions is X-ray free electron lasers, which are sources of coherent X-radiation and will find application in various fields of science. FEL can be in use in medicine though, at first, the THz radiation influence on live objects should be studied and only after that it can be applied to people.

There are different engineering applications of FEL: new technologies allow cutting metals, applying one metal on another (if it cannot be done in other ways) etc. Experiments on serial production of nano-tubes and nano-particles using FEL radiation have already started. Besides, scientists experiment with modification of different surfaces, e.g., a plastic surface becomes rough at irradiation, which can be useful both in industry and in medicine. In particular, filters with such surface have high absorbance because various admixtures deposit better on it.

Doctor N.A. Vinokurov - the Scientific Programme Committee Chair - commented on the results of the international conference:

" Although this conference is held annually and it may seem that no much new can appear during this time, there were many interesting reports. Every year, three to four facilities are commissioned over the world; there are significant advances. This, in fact, explains why the conference is held so frequently - this field is developing rapidly and, somehow or other, we learn something new every time. There is already a specific circle of contacts. Many high-quality experts have come here: some of them are our friends and we are glad to see them once more; others are our new acquaintances, they can look at what we have, which is also useful for all of us."

Many BINP members delivered their reports at the conference. There were reports about the BINP facility: radiation parameters and their measurement and optimization (report by Dr. V.V. Kubarev (BINP)). Dr. O.A. Shevchenko (BINP) made a very interesting report on the FEL theory in the theoretical session. He also spoke about the new type FEL project (the so-called ring FEL).

In the session devoted to high-power free electron lasers, Dr. A.N. Matveenko (BINP) presented a project of a FEL unit, which is called electron out-coupling of radiation. Besides, users from the Institute of Cytology and Genetics, Institute of Kinetics and Combustion etc. spoke about the results they obtained using radiation of the Novosibirsk free electron laser.

The conference ended with a very pleasant event - it was declared that an international prize for young scientists "FEL Prize winner - 2007" had been awarded to Dr. O.A. Shevchenko (BINP).

The conference "FEL-2007" contributed to the active interaction of scientists working in the field of FEL and THz radiation and further works in this direction, both all over Russia and in Novosibirsk in particular.

6.4.2 Round table "Nuclear and beam technologies "

The Russia-Kazakhstan symposium "Science and education in XXI century " took place in the Novosibirsk Akademgorodok on October 4-5, 2007. The symposium was timed to the summit between V. Putin and N. Nazarbaev, held in Novosibirsk on those days. The round table was organized by BINP SB RAS and the National Nuclear Center of the Republic of Kazakhstan.

12 reports were presented, including 5 reports by BINP members: "BINP industrial accelerators and nano-technologies" (R.A. Salimov), "X-ray facilities for medicine and safety" (S.E. Baru), "Carbon-particle accelerator for cancer therapy" (E.B. Levichev),

“Acceleration neutron source for cancer therapy”(A.M. Kudryavtsev), and “Synchrotron radiation source“Nomad” ” (K.V. Zolotaryev).

The latter report is worth special mentioning. Above, in section 6.3.6, a dedicated SR source with superconductive magnets for the Siberian SR Center was described. The heads of the National Nuclear Center of the Republic of Kazakhstan K.K.Kadyrzhanov (director general) and A.N. Borisenko (deputy director general) along with their colleagues made an acquaintance with the initial version of this project. After that, they took part in further development of the project and made much effort to make an agreement with the Government of the Republic of Kazakhstan on creation of an SR center in Kazakhstan based on such a source. BINP SB RAS is to manufacture this source under a series of contracts. Such a decision allows reduction in the cost of the two SR sources.

The decision on the creation of the SR Center in Kazakhstan had been coordinated at all levels, including the Kazakhstan Prime Minister, by the beginning of the Symposium and Summit (October 4, 2007). Stands with the description of the project and a model of the SR source called "Nomad" were placed in the SB RAS Exhibition Center. President of the Republic of Kazakhstan became acquainted with those stands and approved the project with an only amendment that the National SR Center should be located in the capital, Astana. President of the Republic of Kazakhstan had signed a decision on the creation of the National SR Center in Astana by the end of 2007.

Figure 40: President of the Republic of Kazakhstan N.Nazarbaev near the model of the SR source “Nomad”. The Director General of the National Nuclear Center of the Republic of Kazakhstan K.K. Kadyrzhanov and the Deputy Chair of the SR RAS Presidium G.N. Kulipanov are elucidating the information.

Among other reports, a report by A.V. Artamonov “Siberian Center for Pharmacology and Biotechnologies - history, status, and prospect” is also worth special mentioning. It was about development of a family of novel medicines based on the application of beam technologies for sewing medicines to biopolymers, which gives preparations of unique possibilities. A pleasant event preceded the Round table - clinic trials of the medicine had ended, and the Ministry of Health had approved production of one of these preparations, trombovazim.

Colleagues from Kazakhstan made two reports. The first was “Radiation technologies in the Kazakhstan industry” (A.N. Borisenko, NNC RK, Kurchatov), which was a review of the status and prospects for the application of industrial accelerators by BINP in new technologies. The second was a report by A.D. Vurim (NNC RK, Kurchatov), which suggested a wide use of atomic low-power stations based on reactors (earlier intended for the undersea fleet) in electrification of remote areas.

Figure 41: Prize by the Organizational Committee of the Exposition “Innovation potential of Russia-Kazakhstan cooperation in the field of science intensive technologies” awarded to BINP SB RAS and the National Nuclear Center of the Republic of Kazakhstan for their joint project “SR source Nomad”.

6.4.3 The 6th conference of the students and post-graduates of the Siberian Synchrotron and THz Radiation Center (SSTRC)

The 6th conference of the students and post-graduates of the Siberian Synchrotron and THz Radiation Center (SSTRC) was conducted on May 16, 2007. Students and post-graduates from four SB RAS institutes - BINP SB RAS, ISSCM SB RAS, IIC SB RAS, and IK SB RAS - presented 17 reports. The conference committee noted that practically all works were of high level and awarded one first place, one second place, and five third places supported by diplomas and money testimonials.

Figure 42: Presentation of the awardees with diplomas at the weekly round-table research-coordination meeting of the Center

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 at BINP according the State Programs "Colliding Beams", "High Energy Physics", "Synchrotron Radiation", "Physics of Microwaves".

Within the frame of these Programs, the Laboratory team is involved in the development of such a radioelectonic equipment as the power supply systems, control and diagnostics, computer control systems; the development of RF accelerating systems, RF and HF energy sources, studies of the charged particle beam behavior in interactions with the accelerating systems and other components and devices of the charged particle accelerators and storage rings. It is evident that the main results of the Laboratory activity are integrated into the study and development results obtained at the complexes: VEPP-4, VEPP-2000, Injection Complex of 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 Laboratories, which carry out the work under contracts both with the national and foreign centers from the USA, Germany, R.Korea, Switzerland, Japan, China. It is worth mentioning here the contract works for CERN on the development of the LHC components; the Korean Institute of Atomic Energy (KAERI, R.Korea) on the development, manufacturing and delivery of components for the future microtron-recuperator; the work for Zelenograd on the development of the SR Source - TNK. The collaboration with these centers is in a good progress.

Given below are some results of works carried out in 2007 and some plans on works to be continued in 2008 and in future.

7.1 Power supply sources for electrophysical facilities

7.1.1 Stabilized current sources

Development of the stabilized current or voltage sources for supplying various electrophysical facilities and their components is one of the main tasks of studies carried our in the Laboratory of Radiphysics. 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 purpose) ranges from a few amperes to tens of kiloamperes and output power - from tens of watts to hundreds of kilowatts and to a few megawatts. As a rule, the current sources should have a broad range of adjustable current values (up to 60 dB) and high precision of adjustment and stabilization (an error not exceeding 0,01%). The current sources themselves are rather complex electrophysical devices with the computer test and control and with a complex system of interlocks and inner control.

• In 2007, we practically finished the work carried out for many years on the upgrade of electronics for the IST-series precise sources, which are designed for feeding electromagnets. These devices are of 50 kW, 100 kW, 200 kW in power. Seven ISTs were installed at the VEPP-5 complex; two of them are installed at the stand of magnetic measurements in Bld.13. We started the design of electronics in the standard "Euromechanics" for ISTs of a new generation. This work is being carried out within the frame of the contract

BINP-MRTI (Moscow).

• We continued "working out" of two power supply sources of a megawatt power class with a current up to 9 kA for the storage rings BEP and VEPP-2000. The work is planned to be continued in 2008 upon readiness of the storage rings and sources to the stationary operation with high currents with an instability not exceeding 10-20 ppm and with the current reverse for BEP.

• Two power supply sources B-1000 (1 kA, 18 kW) are put into operation at the VEPP-2000 complex and two - at the TNK complex (Zelenograd).

• We continued a long-term work on commissioning the power supply sources (at various BINP facilities) designed for feeding the warm and superconducting magnets. At present, 36 sources are operated at VEPP-2000, 16 at VEPP-5, six at devices of Drs. V.V.Parkhomchuk and V.G.Abdulmanov. Two power supply sources are manufactured by the contract BINP-"Criomagnet" (Moscow). Let us remind that each source is located at one storey of "Vishnya" rack and has a current value either up to 300 A or 400 A depending on the version with a load power of up to 3.5 kW. Each source is equipped with two DCCT current monitors: one for providing stabilization, another for independent measurements. The current stability is better than 10^{-4}. The cabinet-rack comprises up to 8 such sources. The system is equipped with the DAC-ADC control module of "CDAC20"-type.

• Development of a pilot batch of DC sources with the current up to 300 A and power up to 5 kW (RF300-5) is in good progress. Two sources of this series are installed in 2006 at the BNCT stand and five new sources designed for second stage of FEL are manufactured in 2007 and now they are under tests.

• We continued a long-term work on commissioning at various BINP facilities of the power supply sources for feeding the correcting electromagnets: 64 channels of UM-6 (two cabinets) are installed at VEPP-2000 and a part of the bulk power sources is replaced.

• For the Injection Complex of VEPP-5, about 150 UM-3 and UM-4 based channels and also for the 2nd stage of FEL, about 100 channels are installed. A part of these control channels are put into operation in 2007, the remaining will be put into operation upon the readiness of complexes.

• Three 8-channel sets of current sources based on UM-3 are manufactured and delivered to NITI "Progress" (Izhevsk) within the frame of the contract works on delivery to NITI of Energo-Modules for the electron-beam welding. The contract work will continued in 2008.

• We delivered to JINR (Dubna) a 6-channel power supply system for feeding the quadrupole lenses ("Vishnya" rack with 6 UM-25-type channels) and a 32-channel system for feeding correctors("Vishnya" rack with 32 UM-4-type channels).

• According to contract with TNK (Zelenograd), we manufactured and put into operation a system for shunting electromagnets of the small storage ring, which is based on four channels of UM-25 (20 A, 15 V) units modified for such an operation regime.

• By the contract with TNK (Zelenograd), we manufactured and put int operation a 16-channel power supply system for feeding correcting magnets, which is based on UM-4 and an UM-25(25 A, 20 V) based single-channel power supply system for the bending magnet.

It is worth mentioning that in the last two years, we carried out an active work on introducing the "Euromechanics" standard into power supply systems for electromagnets and for electronics of other applications.

Below, Table 7.1 shows the basic nomenclature of the electromagnet power supply sources, which have been developed, manufactured or modified in the last few years by Lab.6 and successfully operated both at and out the BINP facilities. The Table does not comprise the power supply sources, which have been developed and produced as a single piece.

Table 7.1: DC current sources for feeding electromagnets.

Type	**Imax**	**Umax**	**Pmax**	**dI/I**	**Type Cooling**	**Sizes**
	A	V	kW	%	—	м^3
IST-1000-50	1000	50	50.0	0.01	Water/air	2.2x1.4x0.8
IST-1000-100	1000	100	100.0	0.01	Water/air	2.2x1.4x0.8 +Power transformer
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	One cabinet "Euro"
RF-300-8	300	12	4.5	0.01	Air	One storey "Vishnya"
ВЧ-400-8	400	8	3.2	0.01	Air	One storey "Vishnya"
ВЧ-300-15	300	15	5.0	0.01	Water/Air	1.5 storey "Euro"
UM-25	±20	±40	1.0	0.01	Air	8 channels(*)
UM-4M	±10	±20	0.2	0.1	Air	32 channels(*)
UM-6/100	±5	±100	0.24	0.1	Air	48 channels(*)
UM-3	±3	±20	0.06	0.1	Air	48 channels(*)
UM-1	±1	±40	0.04	0.1	Air	48 channels(*)

(*) - Number of channels in a 6-storey cabinet of the "Vishnya" or "Euromechanics" type.

• In the period 2004 -2006, within the frame of the BINP-CERN collaboration, we have successfully prepared and launched the production of components and units for current extraction from the 600 A correcting superconducting magnets of LHC. Totally, we have produced 205 systems including a substantial part of the mechanical and mechanical-assembly work and large volume of electronics located in the Euromechanics shassi. By the end of 2006, all the systems have been assembled, adjusted and tested at the CERN premises. In 2007, we carried an active work on their commissioning in the LHC tunnel. The work is planned to be finished in 2008.

7.1.2 High voltage sources of DC stabilized voltage

Laboratory is also involved in development of high voltage sources of DC-voltage with the following power range:

• tens of watts - to supply electrostatic devices for bending of focusing beams of charged particles;

• from a few hundred watts to tens of kilowatts - to supply the powerful high voltage devices.

• hundreds of kilowatts - to supply the diagnostic injectors of neutral atoms, anode circuits of RF amplifiers.

The devices have a high stability and accuracy of adjustment; they are protected against short circuits and breakdowns, have a computer control of currents and voltages, the distributed status control.

Development of a series of the diagnostic and heating injectors of neutral atoms (DNBI) in previous years (project leader-head of Lab.9 A.A.Ivanov) produced in 2007 the next load peak on the participants of this work both in the development and in manufacturing and delivery. It is worth mentioning the following successful works performed in 2007:

1. We completed the manufacture and assembly of the power supply components for the diagnostic injector of the T-10 Tokamak ((KINR, Moscow) whose basic element is the high voltage source with the following parameters: 50 kV, 6 A, 20 ms with a 100% amplitude modulation. The installation is equipped with the arc discharge current source with I(max)=600A at the discharge voltage of U (arc)= 80 V and a possibility of 100% amplitude modulation as well as with the set of other (supplementary) electronics as the power supply of valves, magnetic insulation of solenoid, trigger, etc. The injector commissioning and its delivery to the Kurchatov Institute is planned for 2008.

2. We started manufacture of electronics for the “heating” injector by the contract with the Wisconsin University (Madison, USA). The basic component of high voltage power source (Umax=30 kV, Imax=60 A, Tmax=20 ms) - a “cell” with the storage and commutation IGBT-switch, protection circuits, etc. is developed and now it is under technological design. We produced a pilot version of such a cell and obtained the required parameters (1 kV, 60 A, 20 ms). The system needs an arc current source with I(max)=1000 A, U(arc)=80 V, T=25 ms. The work on development of such a powerful electronics is planned to be continued in 2008.

3. The prototype of a high voltage power supply source for feeding the diagnostic injector for the superconduicting stellarator W7-X (Greiswald, Germany) is produced and now it is under assembly. However, the required parameters (Umax=60 kV, Imax=10 A, a possibility of modulation from the continuous regime to 2 мs/2 мs at full pulse duration of 10 s is not yet achieved. The work will continue during next two years.

4. A set of electronics for feeding the plasma emitter based on the arc discharge for the available stand is produced and put into operation. In this device, the arc current source has the following parameters: I(max)=600 A, U(arc)=80 V with a current two second pulse with a possibility of the arc discharge current amplitude modulation. Electronics has a set of power supply sources: of a third grid [U(max)=-800 V, I(max)=10 A] with a possibility of rapid switching on voltage after breakdowns; a power supply source for the magnetic insulation solenoid, gas gauges, УfiringФ, etc. This set of a powerful electronic for equipment jointly with the HV power source enabled us to carry out the routine work on a study of the sources of powerful proton beams.

5. In 2006, a contract was signed between BINP (project leader - A.A.Ivanov) and TAE (USA) on the development of six heating injectors of neutral atoms with parameters of HV power supply sources as: Umax=45 kV, Imax=50 A, Tmax=1s with a possibility of a 100% amplitude modulation up to 2 ms/2 ms. For obtaining such beams, we used a RF heating of plasma with a power of up to 60 kW at the same time interval. At the end of

2007, two first injectors with all the power and measuring electronics have been sent to the customer. The equipment occupied the volume of a marine container. Several laboratories of BINP are involved into the work on the injectors, which is planned for several years.

6. In 2007, we continued the development and manufacturing of components and units of “Energo-Modules’ and the systems of power supply, the monitoring and control systems for the electron beam welding machine (EBW). The next two energo-modules with a beam power of up to 30 kW in a continuous operation regime were delivered to NITI УProgressФ(Izhevsk). The energo-module is based on a 60 kV gun. Each unit comprise over 40 channels for measurements and control. Totally, we delivered six devices of a few modifications with the beam power up to 15 kW and up to 30 kW. The work is planned for a few years and it is carried out in close collaboration with the Laboratory headed by Dr. P.V.Logachev and NITI УProgressФ (Izhevsk) thus enabling an operative solution of existing problems and to carry the design work of installations of the next generation taking into account their operation under industrial conditions.

7. Completion of a two year work on the pulsed power supply systems (about 40 channels) enabled the commissioning of VEPP-2000 with the required parameters.

8. We continued the development of a new generation of pulsed generators for feeding the beam transport channel magnetic components primarily for the being developed 500 MeV transport channel of electron beams from the Injection Complex to VEPP-4 and VEPP-2000.

9. It is also worth mentioning that in 2007, we continued the technical support to keep operational the earlier produced systems and units being operated at the BINP facilities. Института.

7.2 Development of systems and devices for automation of physical experiments

Participation of Laboratory in automation of the experimental devices, stands and large physical facilities consists in:

• development and delivery of 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 their further installation on the charged particle accelerators and storage rings with a study of their influence on the complex as a whole;

• delivery of the individual unified modules (CAMAC, VME, Vishnya, Euromechanics) to the operational or new installations and stands;

• development of new approaches, techniques and as a consequence, new devices enabling the solution of experimental problems at a new level;

• upgrade of the existing systems of automation, control and diagnostics at the operational physical facilities;

• Repair and technical maintenance of several thousands of 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.

• Next 100 units with CAN-BUS interfaces are produced, adjusted and put into operation in the control systems of various electrophysical facilities including the “commemorative” 500th module. It is worth mentioning that devices of this family are also widely used in the contract works. For the last three years, over 200 modules in sets with various power supply sources have been delivered to KAERI (R.Korea), IMP (China), JINR (Russia) KSRC (Moscow), NITI “Progress” (Izhevsk).

Table 7.2: A family of the CAN-BUS interface devices

Name	**Brief characteristics**
CANDAC16	16-channel, 16-bit DAC, 8-bit input and output registers
CANADC40	40-channel, 24-bit ADC (of a class 0,03%), 8-bit input and output registers
CDAC20 CEDAC20	20-bit DAC, 5-channel, 24-bit ADC(of a class 0,003%), 8-bit input and output registers (“Vishnya”and “Euromechanics”)
CEAC51	20-bit DAC, 5-channel, 24-bit ADC (of a class 0,003%), 8-bit input and output registers (“Euromechanics” 3U)
CAC208 CEAC208	8-channel, 16-bit DAC, 20-channel, 24-bit ADC (of a class 0,003%), 8-bit input and output registers (“Vishnya” and “Euromechanics”)
CEAC124	4-channel, 16-bit ADC , 12-channel, 24-bit ADC (of a class 0,003%), 4-bit input and output registers (“Euromechanics” 3U) 8-bit input and output registers (“Euromechanics” 3U)
CGVI8	8-channel, 16-bit generator of delayed pulses, 8-bit input and output registers
CPKS8	8-channel, 16-bit code-duty factor converter
SLIO24	Interface CANbus - 24-bit two-channel bus, built-in board
CKVCH	Commutator of rf-signals 8-1, 2*(4-1), 4*(2-1)
CANIPP	Interface CANbus- 2 branches of IPP-type
CANIVA	16-channel vacuum meter (ion pump current)
CURVV	A multi-purpose input/output register (2 output and 4 input registers of 8-bit each)
CIR8	Register of discrete signals(register of breaks, CDC, Input/output registers)
CAC168	8-channel, 16-bit DAC, 16-channel, 24-bit ADC (of a class 0,03%), input and output registers, built-in board
CAN-DDS	CAN-DDS module is a divider of the input clock frequency with a remotely returnable fractional coefficient. The module is designed for its use in the feedback circuit of triggersat VEPP-5 and VEPP-2000
CAN-ADC3212	For connection of the feedback circuit in the cavity thermal tuning circuit, temperature control at certain points of cavity and for providing blockings. 24-channel 12-bit differential ADC with the gain control; 4-channel, 12-bit bipolar DAC.
CANGW	Ethernet port - CAN/RS485
VME-CAN	Interface VME-CAN

In view of the ever growing amount of various magnetic field measurements at BINP, the decision was made to develop a set of modules in VME standard that enabled to carry out precise measurements of fields both with the matrices of the Hall probes and with the rotating coils. Now, such a set comprises:

- a precise ADC with a built-in analog multiplexer;

- a 32-channel multiplexer with the commutation error of 1 meV, 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 stands of magnetic measurements in 13th Bld. and EW-1, which are widely used for the contract works. A set of codes was written down for these systems.

• We upgraded the equipment and software for the EW-1 stand of precision measurements of the multipole components in magnetic lenses, In 2007, the stand was actively used for measurements and mechanical tuning of the lenses manufactured by the contract with ALBA (Spain). We completed the development of the software for further improvement of the stand, which will enable the qualitatively new level of the stand control and presentation of measurement results.

• Two sets of equipment are produced and the required software was developed for magnetic measurements of the wiggler-attenuators being produced at BINP for PETRA-3 facility (DESY, Hamburg). The first set is used for measurements and adjustment of wigglers at BINP, and the second set is successfully used at DESY for testing wiggler parameter after transportation and necessary tuning. Measurements are carried out both with the Hall probes and with movable strings and coils.

• For the temporary stand at Bld.13, we manufactured and put into operation a portable system for testing the quadrupole lenses Q13 for the Rutherford Laboratory thus enabling the qualitative and timely satisfaction of the contract requirements.

• We develop the equipment for the fast acting system of the Hall measurements with the continuously moving carriage with a two-coordinate probe. Such a system will enable not only to reduce the time of measurements but to improve the accuracy of measurements.

• We are carrying out the development of the modern universal electronics based on the induction method for measurements of magnetic fields in accelerators. It is assumed that the new electronics will be widely used not only for measurements of the pulsed fields in accelerators but it will allow to achieve high accuracy in measurements with movable coils, strings, etc at the stands of magnetic measurements.

• The work is continued on introducing modern intellectual controllers into control systems of modern physical facilities. In particular, the software of the CAN-Ethernet port and VME controller was completed. Next ten VME controllers for various installations of BINP and 15 ports CAN-Ethernet were produced. 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 interfaces was manufactured for automation of various measuring stands.

• For replacement of the popular but physically outdated crate controller K0607, we have developed a new one based on modern components. In 2007, we produced and put into operation the next 20 controllers and 20 interface boards.

• We continued the work on the digital registers of two-dimensional images with the Fast Ethernet interface. A set of units was manufactured for observation of beams at VEPP-4, VEPP-2000 and for plasma diagnostics. A new version of registers of two-dimensional images is significant by the improved sensitivity, quantum efficiency and a possibility of operation with the outer synchronization, which enabled a study of the process in time. The registers can be operated both with built-in and with one or two external (connected in series)CCD matrices. The corresponding units of the external (connected) CCD are developed for observation of the VEPP-2000 positron beams. In addition, we developed the highly sensitive 2000-element linear CCD based units aimed at further upgrade of the SR beam stabilization system at VEPP-3 (and in future, of the compact storage ring, now under development at BINP).

• We continued the development of equipment for studying the fast-rate processes with SR beams: we completed development of a fast 12-channel, 16-digit ADC for the detector signal processing channels (the channels provide integration of the short pulsed signals, suppression of the noises in intervals, an individual tuning of amplification in channels and selection of the input signal polarity); the ADC synchronizing unit is developed and produced.

• For replacement of the outdated equipment for the power supply systems of the basic magnetic components of VEPP-4, we continued development of a precise interpolation DAC with the MIL-STD-1553B interface with the use of modern components. The module will be compatible with the previous version.

• We continued the development of the port-multiplexer for the data acquisition at KMD-detector. The built-in software is subjected to tests. Commissioning of the data acquisition system of KMD is continued.

• We started the development of the control system for the injector on neutral beams (the diagnostic and heating version of injectors. The system is based on commercially available components. The software is unified for the injector of both versions and it envisages integration into the common control system.

• BINP facilities are being equipped with new digital registers ADC-502 produced in 2007 (20 pieces) for replacement of the earlier produced ADC-850.

• We continued the development of a multi-channel system for measurements of the temperature and consumption of a cooling liquid. In this version, the probes have no movable parts and the module of electronics can be located at a long distance from the probes. These features allow to hope for the construction of the highly reliable monitor for operation under conditions of high level radiation.

• Development of the device of a new generation for measurements of the instantaneous values of magnetic fields in the channel pulsed components is continued.

• For operation with KEDR-detector gas systems, a number of modules, which are designed for measurements and control of the gas flows, were produced and adjusted. An improved control unit for the helium detander-liquifier was put into operation.

• RF timer for the FEL injector was subjected to tests.

• Next batch of controllers of the power supply units for superconducting magnets is produced and put into operation. Since the power supply sources will be used not only at our Institute, a possibility of autonomous operation (without external control computer) is envisaged. To this end, the controller is equipped with the LC-screen and miniature keyboard.

• We started the development of the next version of the electronics and beam position probes, which is based on measurements of image currents. The earlier produced equipment is installed in the beam transport channel of the BEP-VEPP of the VEPP-2000 complex and it is successfully used for guiding the beam.

• We continued the development of the feedback system designed for damping the beam transverse motion instabilities at VEPP-4. In 2007, within the frame of the work, the required number of the wide band amplifiers (25 MHz with a pulse power over 400 W operated in the amplitude linear mode) were installed at the VEPP-4 ring. The total number of the amplifiers is 20 (with a system of summing power). Amplifiers are operated for four wide band kickers of the strip-line type located in the quadrupole inserts of the north and south half-rings of VEPP-4. The results of the first experiments with beams were encouraging: the system allows to increase the number of particles in a bunch by a factor of 2-3 depending on the operation regime. Unfortunately, the load processing the processor feedback signals turned to be rather large even at a single bunch regime of operation, therefore, for a two-bunch operation regime, the system is not yet ready. The work with a beam and system improvement will be continued in 2008.

• The work with electronics for pick-up stations and other units of the beam position measurement systems for the VEPP-2000 and Storage Ring of the injection complex is continued. The systems are based on the specially developed pick-up stations and 4-channel, 12 bit ADC having the clock frequency of measurements of up to 45 MHz. In 2007, the equipment is installed at both storage rings and is used for adjustment of the operation regimes.

• We continued production of the electronics for beam diagnostic systems of the 2nd stage of FEL. The completion of work is planned for 2008. As a result, the number of pick-up station at the microtron-recuperator will be approximately doubled.

• In 2007, the work with electronics measuring the beam position (orbit) in the Injection Complex linac channel was continued. The system is based on 14 strip-line type monitors. The system is designed for measurement of a position of the electron and positron beams with the number of particles in a beam ranging from 10^8 to 10^{10}. The total volume of the electronics is two CAMAC crates. The system is oriented to the repetition rate of measured beams ranging from a few Hz to 50 Hz.

• Development of NMR precise 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 error of measurements does not exceed 10^{-5} or even 10^{-6} depending of the field level and its homogeneity. A set of such an equipment (in VME standard) is installed and operated at VEPP-2000 complex. The field is measured in each of 8 bending magnets and in 13th magnet of BEP. The fields are ranging from 0.3 to 2.4 Tesla. Within the frame of the work on measurements of the particle mass at VEPP-4, the field precise stabilization regime was realized in a calibrated magnet. The beam stability of the order of 0.5 ppm was achieved for a rather long period.

• Development of the drive equipment for the step motors is continued. The units of the ESD5 for the 5DMU3 type motors are the most popular at BINP. In 2007, we replaces several drives at VEPP-4 complex.

• Within the frame of the long-term collaboration between BINP and SLAC on measurements of the slow vertical displacements of the components and units of accelerators, at the end of 2006, we have signed the contract on manufacturing 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, which is rather attainable for the monitors we have developed. The firs batch of monitors was delivered to SLAC at the end of December, 2007. The final delivery is planned for the beginning of 2008. After that, we have to make the joint commissioning of the LCLS measurement system.

• We continued improvement of Laboratory site:
http://www.inp.nsk.su/activity/automation/index.ru.shtm. The site should facilitate the more efficient and correct use of the Laboratory achievements. To this end, in addition to descriptions of various modules, some application notes appeared. The site is renewed regularly.

7.3 Studies related to modeling and solving the electrostatic and electrodynamic problems

The most important works performed in 2007:

1. Works of further improvement of programs for calculations of the electrostatic and magnetostatic fields of the electron and ion guns including:

• On the base of Windows, we made ILUDYN-code for calculations at a quasistationary approximation of the electron beam dynamics in the ILU-type accelerators. In ESAM program, we realized a possibility to give the results of selfmatching calculations of the cathode emission and beam dynamics as the starting parameters that enabled a high accuracy modeling the dynamics of electrons from the cathode to the accelerator output.

• We continued development of the Windows based set of codes MAG3D for three-dimensional calculations of magnets taking into account the core saturation effect.

• We continued development of the Windows based set of codes ELEC3D for three-dimensional calculations of electrostatic systems and magnetic fields of coils. The program is used for modeling the dynamics of electrons in the electron cooling systems.

2. We performed the numerical calculations, modeling and design of the electron guns, electron and ion beams and magnetic systems including:

• Within the frame of the contract with DESY (Germany), with the use of the code set MAG3D, we developed magnetic systems of the choke and transformer designed for shaping the current in the power supply circuits of the quadrupole magnets of the DESY-II booster.

• In the hope for future contracts with IHI (Japan), we started the development of new multi-gap RF accelerators on the base of ILU-12 with an electron energy up to 10 MeV and the mean beam power up 100 kW. The real shape of the current micropulses injected from the cathode-grid unit, which is located in the accelerator first gap, was calculated with the ESAM code. On the base of these calculations, the beam dynamics in the accelerator and its output spectrum for various accelerator projects was calculated with the ILUDIN code.

• In collaboration with Lab.5-2, we calculated the beam current modulation level in the profile controlled electron gun during the voltage modulation on the control electrode. We found out the optimal modulation frequencies depending on the gun linear sizes.

• In collaboration with Lab.5-2, we studied a possibility of the proton beam transporting in the ILU-9 accelerator. We calculated the real values of the transmission coefficient of the accelerator by the mean current of a beam at different injection energies. We found out the optimum values for the beam injection energy for obtaining the maximum transmission coefficient at various proton energies at the accelerator output. Calculations facilitate interpretation of experimental results.

7.4 Linear Accelerator - TNK Injector (Zelenograd)

In November-December, 2007, the following works have been done at the accelerator - injector of the TNK complex (Zelenograd):

1. RF system of the klystron station ΦOLIVINΦ was commissioned which provides operation of the linear accelerator as an electron beam injector of the TNK complex.

2. Accelerated electron beam was obtained at the Faraday Cup (FC), located at the plane equivalent to the input of the beam into the booster (small storage ring). The linear accelerator was processed with electron beam in order to obtain electron beam energy of ∼70 Мэв.

3. External triggering of the УOLIVINΦ modulator was performed with a new modern set of equipment produced at BINP and was tested in practice in automatic regime using new electronics and new units of control codes. Stability of operation of the УOLIVINΦ high voltage modulator was tested.

4. Operation capability of the gun cathode protection by the vacuum and cooling water was tested in automatic regime.

For the commissioning of the linear accelerator, the equipment and operation capability of the RF system driving the УOLIVINΦ klystron station was tested in accordance with the scheme (see Fig. 1). The RF system was operated around-the-clock during 20 days.

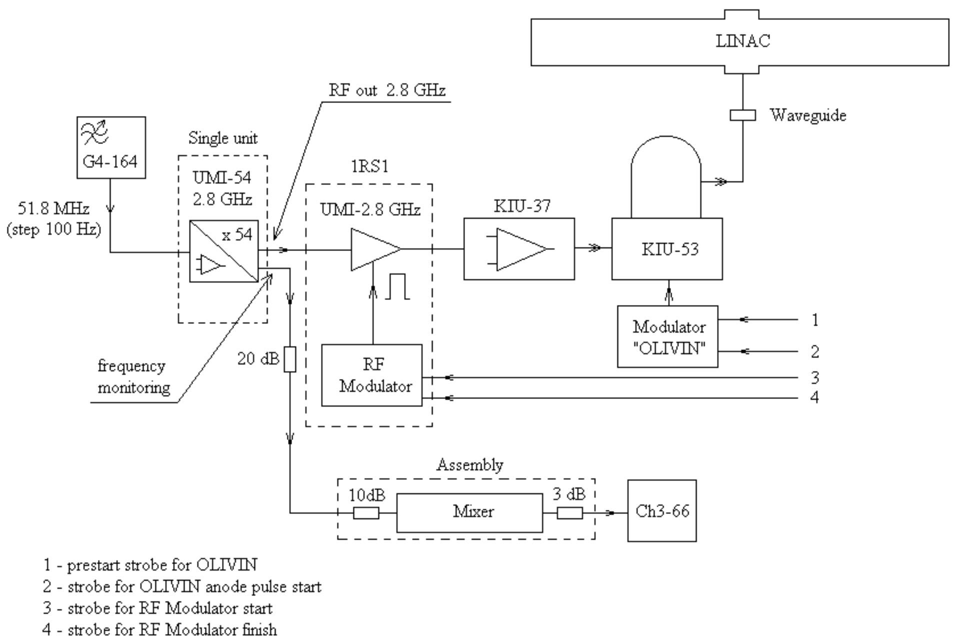


Figure 1: RF system ЛУ and Olivin klystron station.

RF system provides the excitation of the Olivin klystron station and remains to be a permanent scheme in the future. The set of instruments and equipment remains the same and provides adjustment of the frequency at the multiplier input (n=54) with 100 Hz steps of the G4-164 synthesizer. The power level in the waveguide at the KIU-53 output is regulated both with the anode pulse variation (150–230 kV), and by the KIU-37 anode voltage. By the attenuator at the KIU-37 input, an additional smooth regulation of the КИУ- 53 input power level was achieved.

At present, after linac conditioning, the stability of the linac field strength is sufficient for delivering the beam to FC at the maximum attained electron energy. The level and stability of the linac accelerating field is controlled by the Ulinac signal from the rf detector unit. The oscillogram of the signals is given in Fig.2.

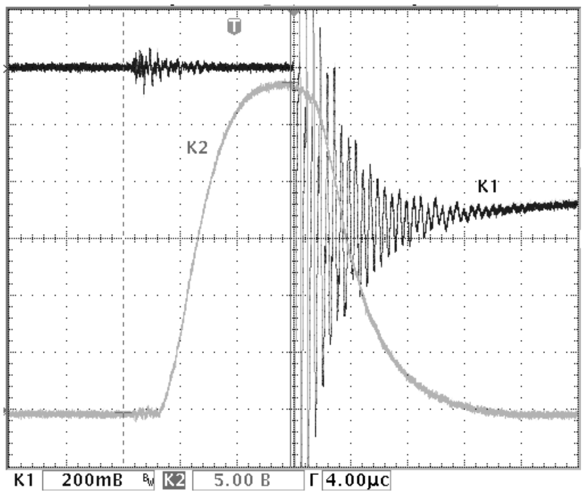


Figure 2: KIU-53: Uanode ≈ 210 kV. KIU-37: Uanode = 15.5 kV. External trigger. Conditioning regime. K1 - a signal from FC (FC capacity Cfc=3300 pF). K2 - amplitude of accelerating field in linear accelerator. Adjustment of the master clock by a frequency (Fmc=51.8355 MHz).

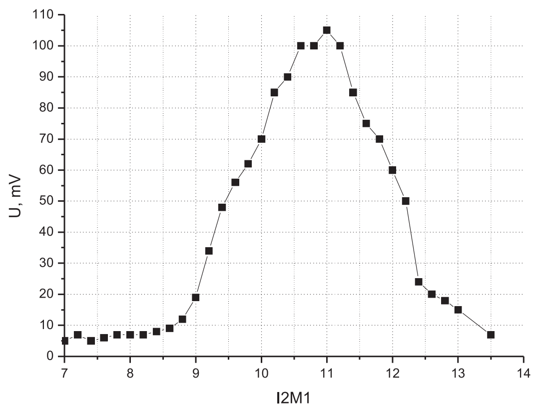


Figure 3: CF voltage as a function of current change in the bending magnet 2M1 (a current - in amperes).

FC beam current dependence on a current variation in the 2M1 bending magnet (see Fig.3) was experimentally measured. The obtained current settings in the electron optical channel turned out to be close to those obtained in the last year. All the components were controlled with the new codes.

Participants of the work:
O.V.Anchugov (Lab.1-3), B.R. Kozak, S.V.Tararyshkin (Lab. 6-1), Ostreiko G.N., Serdobintsev G.V., Chernov K.N.(Lab.6-1), V.A.Ushakov, A.V.Filipchenko (Lab. 8)

7.5 Accelerating RF stations for the ion synchrotrons SIS100, SIS300 and experimental storage ring NESR (GSI, Darmstadt, Germany)

The design work on accelerating RF stations for the ion synchrotrons SIS100, SIS300 and experimental storage ring NESR for the FAIR Project is completed. Each RF station consists of a ferrite cavity re-tuned by magnetizing and a tetrode generator with RS2054SK tetrode. The cavity maximum RF voltage is 20 kV, the frequency range is 0.9-3 MHz. The design is based on the module principle with easy replacement of components placed in the radiation hazardous zone (accelerator tunnel). RF stations have different sizes of the vacuum chamber and location of a generator with respect to the cavity (above or below). The required number of accelerating stations is for SIS100 - 20, SIS300 - 8, NESR - 1. The full set of the design documentation is prepared for production of the prototype. Fig.4 shows the general view of the accelerating RF station.

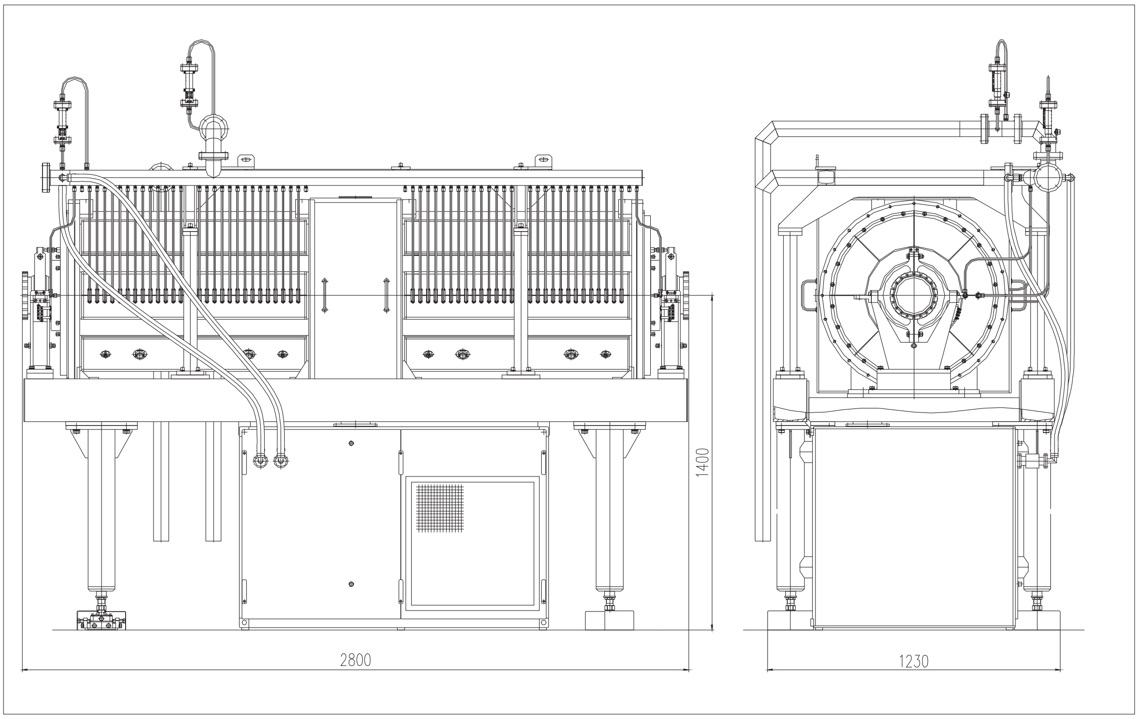


Figure 4: General view of accelerating RF station.

Participants of the work:
сотрудники лаб. 6-2 - V.S.Arbuzov, E.I.Gorniker, V.N.Osipov, G.Ya.Kurkin (Lab.6-2), V.M.Petrov, Yu.A.Biryuchevsky, Ya.G.Kryuchkov, A.R.Steinke(RDB).

7.6 A 700 MHz cavity for X-ray source “NESTOR”

The work on the contract № RU/03533872/E-04026 with the National Research Center УKharkov Physical-Technical InstituteФ on the development and manufacture of the RF cavity for the storage ring of the X-Ray source УNESTORФ was completed . Energy of the electrons in the storage ring is 40÷225 MeV and the circulating beam current is 180 mA. The cavity parameters are listed in Table 7.1. A description of the cavity design is given in the BINP annual report of 2006. The low level rf measurements and vacuum tests were performed. The cavity was delivered to the customer in August, 2007. Fir.5 shows the cavity assembly at the vacuum test stand.

Table 7.1:

Operating frequency,	MHz 699.3
Frequency tuning range, %	0.1
Shunt resistance, MOhm	> 2.0
Accelerating voltage, kV	> 200
Power disipated in the cavity, kW	15

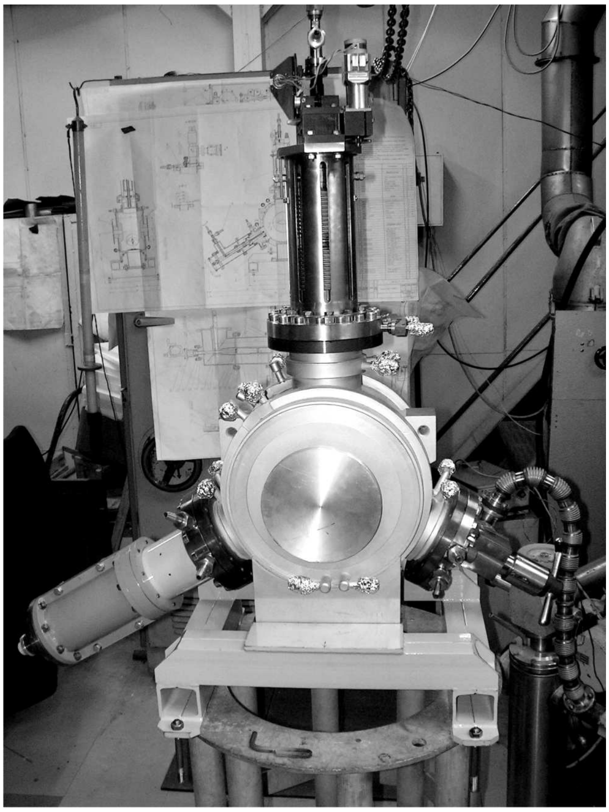


Figure 5: Cavity at the stand of vacuum tests.

Participants of the work:

I.G.Makarov, G.N.Ostreiko, I.K.Sedlyarov, G.V.Serdobintsev, K.N.Chernov (Lab. 6-2) and Ya.G.Kryuchkov (NKO).

7.7 Development of the prototype of 5 MeV, 300 kW industrial linear accelerator

Within the frame of ISTC Project 2550, development and construction of the prototype of a powerful linear accelerator ILU-12 with an electron beam energy up to 5 MeV and average beam power up to 300 kW was completed. The purpose of the work was the conceptual development of a cheap and reliable industrial accelerator with a simple design and minimum operational expenses and also, development of the accelerator prototype with all the supplementary equipment required for its tests. During the prototype tests, the electron beam energy of 5 MeV and pulse power 1.5-2 MW should be obtained.

In 2007, the structure conditioning at full voltage was performed, the beam passed through the accelerating structure, the

energy spectrum and transverse size of the electron beam at the accelerator output were measured. In June, 2007, the accelerator ILU-12 was successfully commissioned with the following parameters obtained during experiments:

- cathode pulse current 350 мA
- coefficient of the current passage through the accelerating structure is 95%
- maximum output energy is 5 MeV
- beam pulse power is 1.5 MW
- electron efficiency of the accelerating structure is 67%

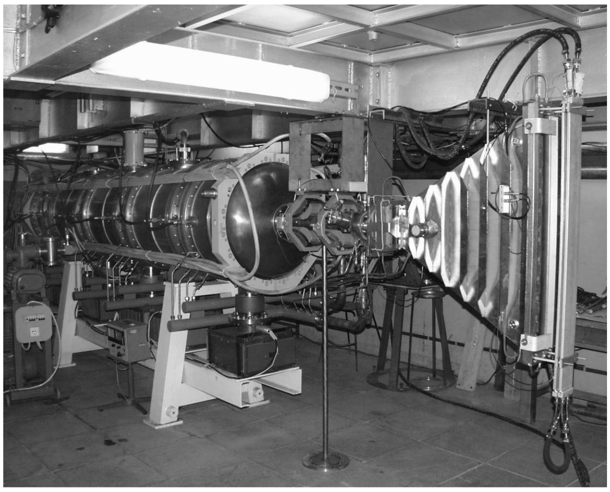


Figure 6: General view of the accelerating structure.

A possibility of manufacturing a powerful industrial accelerator, based on the tested prototype, was shown experimentally . With the use of a TH628 diacrode based RF generator, average beam power can be achieved up to 300 kW at an electron energy of 5 MeV.

With two additional accelerating cells, the accelerator can operate at the energy up to 7.5 MeV and the beam power can exceed 300 kW.

Participants of the work:

V.L.Auslender, A.D.Panfilov, A.P.Fedorov (Lab.14), M.A.Tiunov (Lab.6-0), I.G.Makarov, G.N.Ostreiko, G.V.Serdobintsev, V.V.Tarnetsky, K.N.Chernov, N.V.Matyash (Lab.6-2), I.V.Gornakov, V.G.Cheskidov (NKO).

7.8 Upgrade of RF system of "SIBERIA-1" storage ring

Upgrade of УSIBERIA-1Ф RF system includes production of a new power amplifier, modification of the accelerating cavity in order to increase the voltage and development of the new control system. The new RF system will allow for a short time (0.05 - 0.1 s) to increase voltage at the accelerating cavity from 15 keV to 30 keV that will improve substantially the injection efficiency to Siberia-2 due to shortening the bunch length.

Under the contract with KISR (Moscow), BINP developed and manufactured:

1. New RF power amplifier. In the output stage of the amplifier one GU-36B-1 tube is used in common cathode scheme. The stage amplification is 15 dB. A 500 W preamplifier is made on the transistor IXZ2210N50L produced by IXYS RF. RF power amplifier with power supply sources and cooling fan are assembled in a single cabinet. Fig.7 shows the new RF power amplifier. During the tests with dummy load, a power of 12 kW was obtained at a frequency of 34.5 MHz.
2. New units of the cavity and vacuum chamber components:
• split ring with larger rounding radius of 55 mm, which decreases by a factor of 1.8 the over voltage at the outer diameter of the cavity capacitive disk;
• insertion for the accelerating gap increase from 40 mm to 55 mm;
• two insulation units with longer ceramics for the vacuum chamber.
3. New control electronics, placed in the УVishnyaФ rack, was produced utilizing modern elements. The electronics has three feedback circuits. The first two circuits stabilize the amplitude and phase of the accelerating voltage at the cavity gap and the 3rd one provides the resonance tuning of the accelerating cavity. Monitoring and control of the RF system parameters are provided by computer via CANBUS interface instead of CAMAC used before.

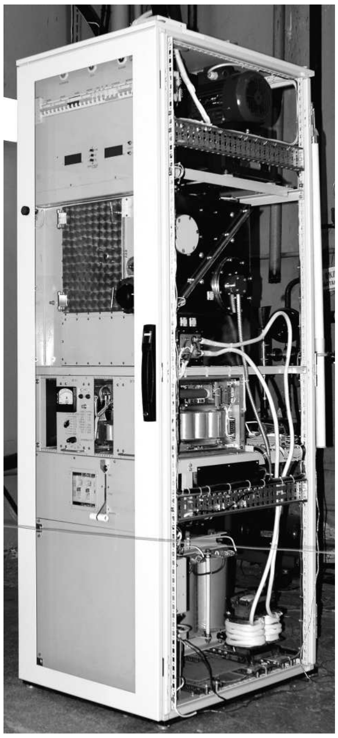


Figure 7: RF power amplifier for SIBERIA-1.

In June, 2007, the RF generator and control radio rack have been delivered to the Kurchatov Institute. The work on cavity modivication was postponed due to the lack of time In November, 2007, a group of BINP specialists visited Moscow for assembling and commissioning. The old equipment was dismounted, the cable channels were revised. The new RF generator and control system were assembled and installed instead of the old equipment.

After commissioning, the RF system of SIBERIA-1 was tested in the operation regimes, the regime of a short increase of the accelerating voltage of the existing cavity up to 18 kV was tested during injection of particles into the storage ring SIBERIA-2. The circulating current of 300 mA was obtained in SIBERIA-1.

Participants of the work:
Z.I.Arbuzov, E.I.Gorniker, S.A.Krutikhin, I.V.Kuptsov, G.Ya.Kurkin, S.V.Motygin,V.M.Petrov, A.M.Popov, I.K.Sedlyarov, S.V.Volobuev, V.L.Golovin, A.S.Mayatsky, V.A.Savchenko (Lab.6-2), Yu.A.Biryuchevsky (NKO).

7.9 Upgrade of RF system of SIBERIA-2 storage ring

For the upgrade of the SIBERIA-2 RF system under the contract with KISR (Moscow) the following equipment was developed and produced by BINP:

1. Accelerating section with two bimetal cavities.
2. Waveguide power divider for driving the new cavities by a single generator via two coaxial lines with matching transformers.
3. A set of electronic units providing operation of the RF system and synchronization of injection from SIBERIA-1 to SIBERIA-2.

Two existing 180.4 MHz cavities were retuned with special inserts to the frequency 181.13 MHz, which corresponds to 75th harmonic of the revolution frequency of the storage ring SIBERIA-2.

Taking into account high beam loading of the cavity, the power input loops of the cavities were turned in such a way to obtain maximum coupling coefficient. Prior to installing onto the cavities, power couplers were conditioned at a special stand up to the voltage corresponding to the transmitted RF power of 250 kW.

The assembled accelerating section was baked at BINP at temperature of 320 degrees, the obtained vacuum was $1{\cdot}10^{-9}$ torr. After that, each cavity was tested up to 950 kV.

In November-December, 2007, the BINP team disassembled one old accelerating cavity and replaced it by the section of two bimetal cavities, The section was equipped with two vacuum gauges that allowed to keep vacuum in the cavities during transportation. The water cooling system, new RF control rack and new cable communications between the cavities and rack were installed. Electronic units were mounted and tuned. Both new cavities are connected by coaxial lines to the coaxial-to-waveguide transitions, located symmetrically with respect to the axis of the wide wall of rectangular waveguide. The waveguide coupling coefficient was chosen in such a way that at a beam current of 300 mA and maximum energy, the waveguide sees matched load. The line lengths between the cavities and equivalent cross section of power division in the waveguide are the same multiples of quarter wavelengths. In this case, both at the tuned cavities and at detuning of any cavity, the current values in the cavity coupling loops are the same and in-phase.

The electric centers of the cavities are distant from each other by 625 mm that is by 204 mm shorter than a half wavelength, i.e. the effective summing of accelerating voltages requires a counter phase excitation of cavities. By a certain turn of the power input loops, the cavities are counter phase excited. As a result, the total accelerating voltage of the cavities with respect to the beam is decreased down to 0.93 of their arithmetical sum if these voltages are equal.

After the upgrade, the RF system of SIBERIA-2 storage ring remains to be a two-channel system. The generator output cascades of each channel utilize two tetrodes GU-101A. The output power of each generator is up to 200 kW.

In the first channel, the old cavity is used. The design of the old cavity is similar to the one of the cavities installed in VEPP-4. In the second channel, two new bimetal cavities are installed.

Table 7.2 shows the operating and test parameters of the upgraded RF system of SIBERIA-2 storage ring.

Fig.8 shows a picture of the accelerating section of SIBERIA-2 after installation of two bimetal cavities.

The upgraded RF system will provide compensation of both cavity УthermalФ losses and beam radiation losses in operation with currents up to 0.3 A at the energy E = 2.5 GeV.

Table 7.2: Parameters of RF system of SIBERIA-2 storage ring.

Channel	Channel 1	Channel 2	
Cavity	1-1	2-1	2-2
	(старый)	(new section)	
Operating frequency, MHz	181.13	181.13	181.13
Cavity Frequency tuning range, MHz	0.3	0.3	0.3
Cavity Q-factor Q_0	47200	42760	42490
Characteristic impedance ρ, Ом	217.6	133	133
Shunt impedance R_{sh}, MOhm	10.27	5.68	5.65
Coupling coefficient β=Q_0/Q_H-1	3.4	2.5	2.25
Operating gap voltage U_p, кВ	850	415	415
Transit time factor	0.82	0.9	0.9
Cavity losses at $U = U_p$, $P_{cav.}$ kW	35	15	15
Test gap voltage U_{max}, kV	950	950	950
Cavity losses at U=U_{max}, $P_{cav.}$, kW	44	80	80

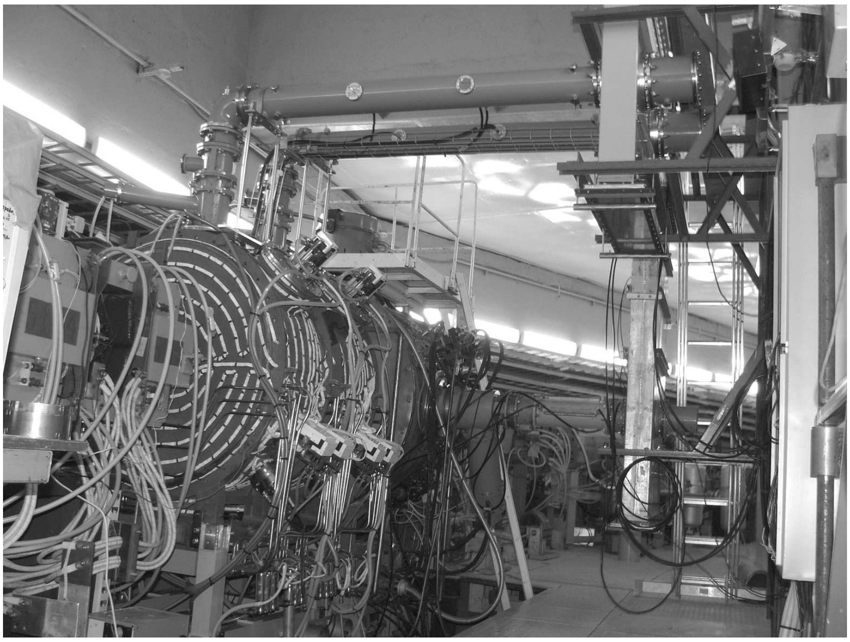


Figure 8: Accelerating section of SIBERIA-2 after upgrade.

Participants of the work:
Z.I.Arbuzov, E.I.Gorniker, E.K. Kenzhebulatov, A.A.Kondakov, S.A.Krutikhin, I.V.Kuptsov, G.Ya.Kurkin, E.Yu. Panfilova, S.V.Motygin, V.M.Petrov, A.M.Pilan, A.M.Popov, I.K.Sedlyarov, A.G.Tribendis, V.V.Aksenov, S.V.Volobuev, V.L.Golovin, A.S.Mayatsky, V.A.Savchenko (Lab.6-2), O.I.Deichuli, Ya.G.Kryuchkov, L.M. Shchegolev,(NKO), L.A.mironenko (Lab.1-4), M.A.Shcheglov (Lab. 8-1).

7.10 RF generator for TAE Laboratory

The contract on the development and production of six powerful injectors of neutral beams between BINP and Tri Alpha Energy, USA was signed in 2006. One of the injector main systems is RF generator for ionization of a gas (hydrogen or deuterium) in the ion source. The gas is heated with RF fields produced with the coil (УantennaФ) of a few windings around the ceramic chamber of the plasma emitter, The coil is under constant potential of the ion source of +40 kV. Therefore, RF excitation from the anode of the output cascade tube to УantennaФ is applied through the high voltage dividing transformer with a core made from amorphous iron. The transformer is placed in the tank filled with oil.

The generator is mounted in three cabinets of the УEuromechanicsФ standard - the output cascade cabinet, anode rectifier cabinet and the control rack. The generator output cascade is based on the 4CW100000E tetrode of the Eimac (USA) company. Excitation to the tube control grid is applied from the transistor amplifier of 500 W power. The output cascade is mounted in the cabinet with the dimensions of 800 x 800 x 2000 mm.

Table 7.3: Generator main parameters

Operating frequency, MHz	4 + 2,5%
Load power, kW	60
Generator pulse duration, s	0,1-1,5
Duty factor	600

A +14 kV anode rectifier is made of diodes by the Larionov scheme without rippling filters. With the pulse duration and duty factor given above, the rectifier power is 160 kW. Regulation of the anode voltage level, which is required for triggering generator and tube training, is provided by variation of the phase angle of opening thyristors in the transformer primary winding circuit. The rectifier is equipped with the "urgent protection" system, which takes off the anode voltage from the tube in 50 mks at breakdowns. The rectifier is mounted in the cabinet with the overall dimensions 800 x 800 x 2000 mm. The transformer is placed separately. In the control rack there are: power supply sources of the control and screen grid of the tetrode, system of blockings, protection and control of the on|off process of the generator.

In the same rack, there is a modulator providing automatic tuning of the master clock frequency and stabilization of the УantennaФ RF voltage amplitude. With the presence of plasma in the source, the loss resistance and the anode contour eigenfrequency of the output cascade are changed. The master clock frequency is re-tuned during RF pulse in such a way that the preset phase between the tube control grid voltage and anode voltage should not change. This system of the amplitude stabilization keeps the preset shape of RF pulse at variations of the plasma loss resistance and also compensates the influence of the power supply source ripples.

At present, two sets of RF system components are manufactured and the work with the beam was started.

Participants of the work:
Z.I.Arbuzov, E.I.Gorniker, A.A.Kondakov, N.L.Kondakova, S.A.Krutikhin, G.Ya.Kurkin, S.V.Motygin, V.N.Osipov, V.M.Petrov (Lab.6-2).

7.11 Accelerating structures for a new injector - LINAC-4, CERN

In 2006, the prototype of the CCDTL accelerating structure (Cell-Coupled Drift Tube Linac) was produced. The prototype consists of two accelerating cavities with two drift tubes in each cavity.

Accelerating cavities are connected to each other by the side coupling cell. The cavity bodies are made of stainless steel, copper plated inside. The drift tubes are made of copper parts electron beam welded to each other. In the beginning of 2007, at BINP, the prototype was assembled and went through vacuum tests, RF measurements and tuning. After that, the prototype was delivered to CERN and successfully tested at operating values of the field gradient and duty factor. The work was performed within the frame of ISTC Project 2875 jointly with RFNC-VNIITF (Snezhinsk). At present, the question of serial production (in the amount required for LINAC-4) of CCDTL structures jointly by BINP and VNIITF is under consideration.

Participants of the work:
T.K.Kenzhebulatov, V.M.Petrov, T.A.Rotov, A.G.Tribendis (Lab.6-2), Yu.A.Biryuchevsky, Ya.G.Kryuchkov (NKO).

7.12 A 1300 MHz buncher cavity for Cornell University, USA

Under the contract between BINP and Laboratory of elementary particle physics of Cornell University (USA), in 2007, a buncher cavity at a frequency of 1300 MHz was produced for the ERL injector. The cavity with operating voltage of 200 kV is designed for grouping bunches of electrons from a 500 keV photogun with the repetition rate of 1300 MHz.

The cavity design was suggested by the customer and it was presented in the annual report for 2006. At BINP, execution drawings of all cavity units were released, adapted to the technologies available at BINP workshop. The cavity has an Omega-shaped geometry and consists of three copper blanks brazed in a vacuum furnace. The cavity units are removable and connected to the body through Conflat-type gaskets.

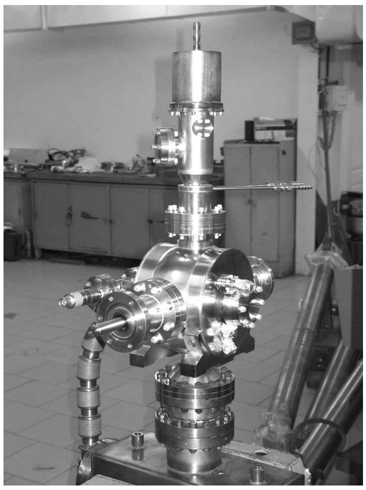


Figure 9: Cavity at the vacuum stand.

After the manufacturing, all cavity rf-parameters were measured. The measured values correspond to the design specifications. Then the cavity was baked (see Fig.9) at the temperature of 200 degrees. After baking and evaporation of titanium getter, vacuum of $5*10^{-11}$ torr was obtained. The cavity was delivered to Cornell University and now is ready to be installed to the injector.

Participants of the work:
T.K.Kenzhebulatov, A.M.Popov, I.K.Sedlyarov, A.G.Tribendis, V.V.Aksenov, V.V.Stepanov (Lab.6-2), L.A. Mironenko Lab.1-4), Yu.A.Biryuchevsky (NKO).

7.13 Feedback system for suppression of longitudinal beam oscillations in the VEPP-4 storage ring

Lab. 6-2 works on the development of a feedback system for suppression of longitudinal beam oscillations in the VEPP-4 storage ring.

The feedback system consists of two identical parts, each operating with its own 100 W amplifier and interacts with only one type of particles. Each part consists of two channels: one for suppressing the in-phase oscillations and another one for suppressing the anti-phase oscillations.

In the feedback system, two longitudinal kickers will be used (Fig.10), each kicker interacts with only one kind of particles. Longitudinal kicker is a system of two RF cavities excited by one generator.

The expected decrement introduced to the system is about 500 1/s, that is tens times more than the decrement obtained due to radiation losses.

The main part of the system is ready and now the assembly is in progress. The system commissioning is planned for the beginning of 2008.

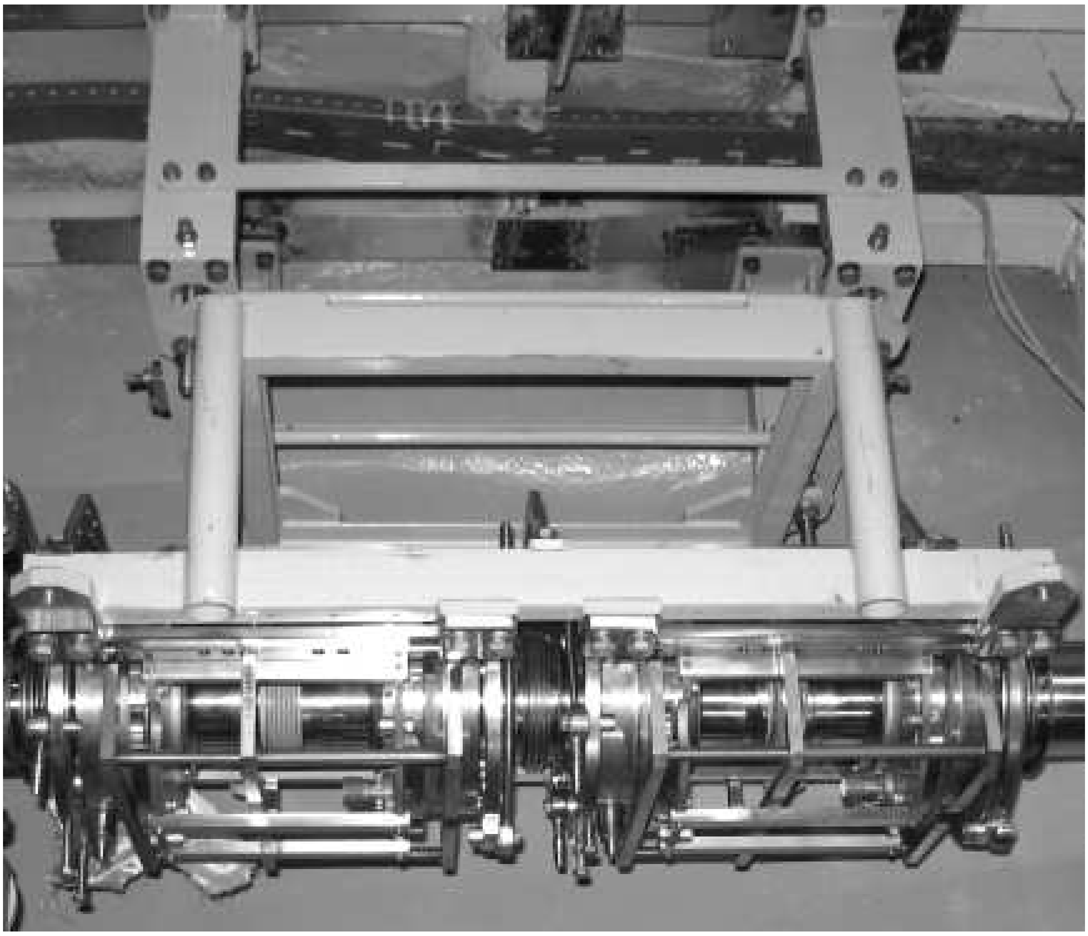


Figure 10: Kicker.

Participats of the work:
Z.I.Arbuzov, S.A.Krutikhin, G.Ya.Kurkin, S.V.Motygin, V.N.Osipov, V.M.Petrov, E.A.Rotov(Lab.6-2), Ya.G.Kryuchkov.

7.14 A cavity for testing electric strength of various materials at 34.272 GHz

Under the contract №RU/03533872/E-06010 with Omega-P, Inc (USA), a cavity for testing the electric strength of various materials at 34.272 GHz was developed an produced. For carrying out such tests, the cavity has two movable rods (Fig.10) plated with the tested material or made of the material. The rod ends have elliptical shape as shown in Fig.10. In order to avoid rf leakage through the coaxial line formed by the rods and cavity body, there is a couple of choke filters (Fig.11).

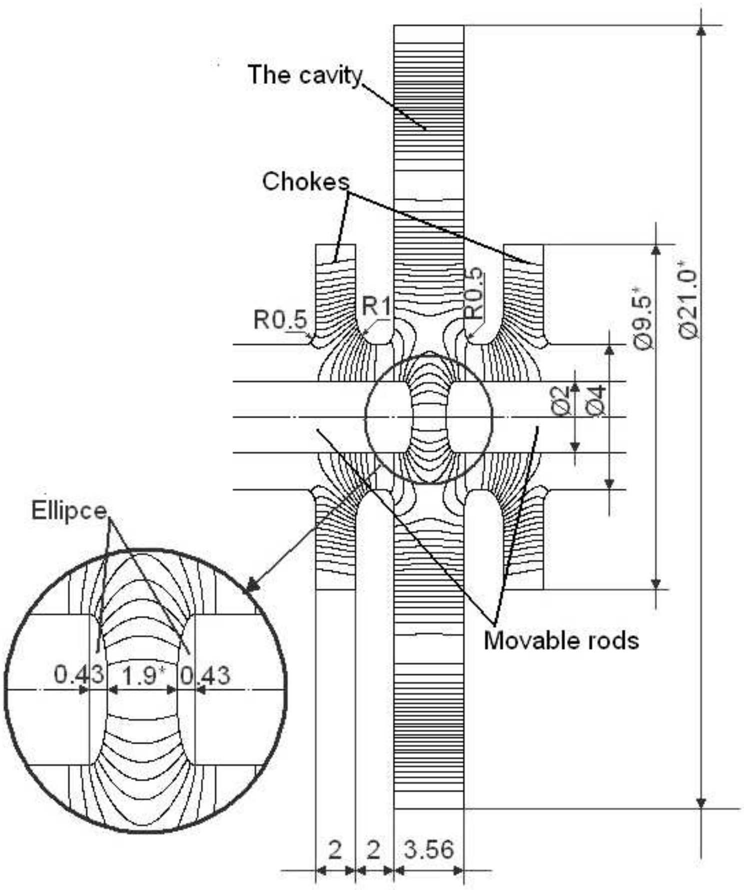


Figure 11: Axial cross-section of the cavity.

Cavity operating mode is E031. The cavity is excited with standard waveguide WR28. For compensation of the perturbation introduced by the coupling hole, there are three compensating holes. These holes are also used for pumping and for optical detection of discharge at the replaceable rods. Variation of the gap between the rods is achieved with special vacuum microscrew, which enables the rod motion with an accuracy of 8 micrometers. Further fine adjustment of the frequency is achieved by changing the cavity temperature. To do this, water cooling pipe is brazed to the cavity (Fig.12). The necessity of such fine tuning is caused by the fact that the cavity frequency is very sensitive to the rod positioning. So, a change in the gap between rods by 10 micrometers leads to the frequency shift by 17 MHz that is equal to the cavity bandwidth.

Figure 12: External view of the cavity and vacuum chamber.

Low level rf measurements have shown full correspondence of the main parameters, such as VSWR, transmission coefficient and loaded Q-factor, to the design values. Also, a possibility to tune the cavity to the operating frequency after replacement of the rods has been demonstrated.
Participats of the work:
I.A.Zapryagaev (Lab.6-2)and V.Z.Persov (NKO).

7.15 Beam diagnostic system for the free electron laser of Duke University, USA

In the beginning of 2007, a contract was signed with the FEL laboratory of the Duke University for the development and delivery of the beam diagnostic system based on the dissector in the electron storage ring. The contract has been fulfilled jointly with Lab.3-0. The delivered equipment consists of the dissector itself and the necessary set of radio electronics. The system allows to reproduce the shape of the light pulses of synchrotron radiation of individual bunches with the resolution of ∼30 ps. In October 2007, two BINP scientists visited USA for the delivered equipment commissioning and for participation in the experiments. The system of diagnostics was successfully mounted and tuned, the first experiments were performed. Rather interesting data was obtained about the shape of the FEL light pulses that improves understanding of the processes occurred in the storage ring.

Participats of the work:
E.I.Zinin (Lab.3-0 and G.Ya.Kurkin (Lab.6-2).

7.16 Thermocathode RF electron gun for the FEL microtron-recuperator

In 2007, a new thermocathode RF gun was developed for the FEL microtron-recuperator. The RF gun will produce electron bunches with energy of 300 keV and average beam current of 100 mA at bunch repetition frequency of 90 MHz. The gun is adapted to the existing RF system designed for bunching the beam, its pre-acceleration and injection into the microtron linac. One advantage of the new gun is the absence of high potential of 300 kV in the cathode control circuits that makes the service easier. Another advantage is that in the RF cavity there is no bombardment of the cathode by the residual gas ions thus the cathode lifetime is increased and the repetition frequency of the bunches can be increased up to 90 MHz.

The gun is a 90 MHz RF-cavity with built-in exchangeable grid thermocathode unit. The design of the RF-gun utilizes the existing parts of similar bimetal cavities, which are used in the microtron linac. The grid thermocathode unit can be the same as the one used in the existing DC gun. RF-gun design envisages a special replaceable unit, which is connected through the coaxial collet connector to the cathode unit, for placing there a circuit of the modulator forming the control pulses.

An order for finishing the RF-cavity and production of the gun pars was placed to the BINP Workshop. Design of the gun RF-generator was completed and the parts were prepared for its assembly. The stand for the RF-gun tests is under development.

Participants of the work:
V.N.Volkov, E.I.Gorniker, A.A.Kondakov, V.M.Petrov, I.K.Sedlyarov (Lab.6-2), V.K.Ovchar (Lab.6-1), A.R.Steinke (NKO).

Chapter 8

Powerful Electron Accelerators and Beam Technologies

8.1 Radiation technologies and ELV-type accelerators

In 2007 the Laboratory № 12 continued the deliveries, development and chief-installations of industrial accelerators as well as participated in innovative activity and in accelerator project for cancer therapy by carbon protons and ions.

The deliveries of 2007 are as follows:

1. Pondicherry, Siechem, cable plant, India ELV-8.

2. Shenzhen, Chanbao Co Ltd, cable and heat-shrinkage tubes irradiation, China (that is the 3rd ELV accelerator at this plant) ELV-4.

3. Guangzhou, Kaiheng corporation, cable plant, China - 2 accelerators: (these are 5th an 6th ELV accelerators at this plant) ELV-6, ELV-8.

4. Huangshi, cable plant, China ELV-8.

5. Neftegorsk, Rosskat Co Ltd., cable plant, Russia ELV-8.

6. Kuala Lumpur, Malaysia Institute of Nuclear Technologies, Malaysia ELV-4.

7. Kurchatov, Nuclear Technologies Centre, Kazakhstan ELV-4.

In 2007 the following accelerators have been put in commission:

1. Pondicherry, Siechem, cable plant, India ELV-8.
2. Capra, New Technologies Centre, Republic of Korea ELV-4.
3. Huangshi, cable plant, China ELV-8.

The accelerators operating already 15 to 20 years have been modified in Podolsk (Russia), Mozyr' (Belorussia), and in Hudzhou (China). The part of accelerators, which was being delivered, is provided by 4-side radiation system and cable spoolers.

During this year the conception of carbon accelerator booster injector for cancer therapy has been developed. Vasily V. Parkhomchuk has proposed to use the ELV rectifier in tandem version as a high-voltage source. Recently, the tandem design is stable and the stand for its examination is mounted in one of the housings of BINP main building basement.

At ELV-6 accelerator, which generates focusing electron beam, the experiments were continued. The encouraging results were got in the production of silica nano-dispersive powder. Semi-continuous technology of few kilograms of nano-powder production per hour has been worked out. Recently, basic efforts are directed onto production of more expensive powders, the obtaining of which by traditional methods are less profitable. Those works are carried out together with the Institute of Theoretical and Applied Mechanics.

The experiments on welding of different alloys onto various bases are carried out in cooperation with our colleagues from Tomsk (Russia) and from Pokhang University (Republic of Korea).

Figure 1: Комплекс электронно-лучевой обработки кабельной продукции в Китае.

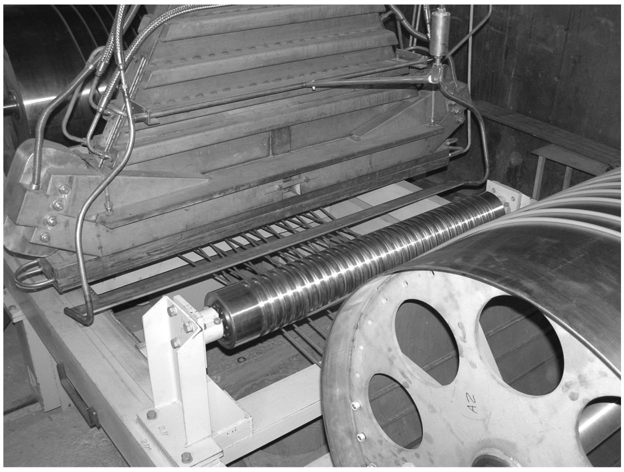


Figure 2: Транспортная система и 4-х-сторонее облучение кабеля для нефтепогружных насосов.

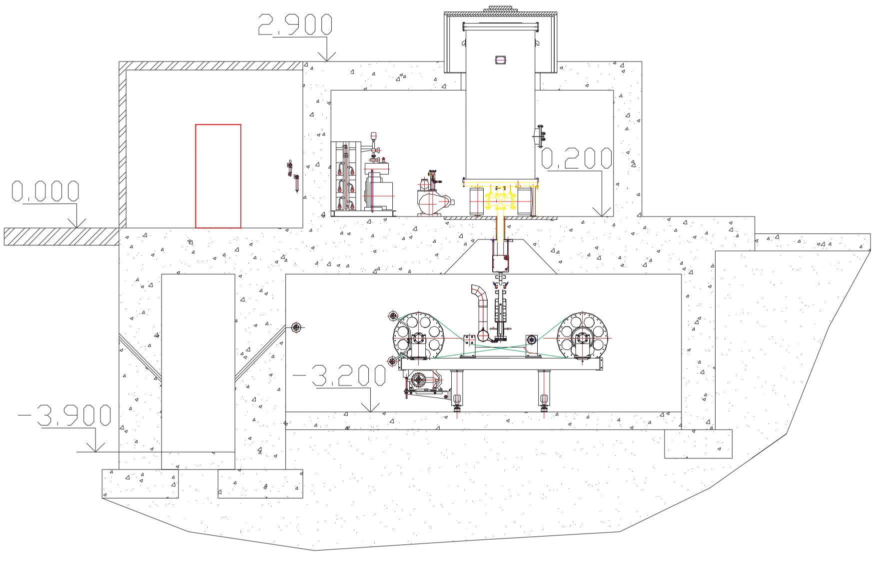


Figure 3: Проект здания для ОАО "Кавказкабель" (г. Прохлалный, Кабардино-Балкарская Республика, Россия.)

8.2 Accelerators type ILU and their applications

8.2.1 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 installed and the electron beam sterilization facility is put into work The sterilization technology for herbal raw materials is worked out.

The accelerator ILU-10 with energy 4.5 MeV and beam current up to 10 mA is prepared for commissioning. This accelerator with 4-sided irradiation system for thick polymer tubes treatment is prepared for the firm "RadPol", Poland.

The accelerator ILU-10 with energy 5 MeV and beam current up to 10mA is on the way to commissioning. This accelerator is prepared for the firm "Siberian Center for Pharmacology and Biotechnology" (SCPB), Russia.

The accelerator ILU-10M with energy up to 4 MeV and beam current up to 5 mA was commissioned and packed for shipment in city of Krasnoyarsk, Russia. The mounting of this machine will start in March 2008 after completion of the construction works at site.

8.2.2 ILU-9 accelerator

In 2007 the ion accelerator ILU-9 worked with the proton beam. The energy spectrums of the proton beam were measured. The injected protons were generated by the proton-ion source based on the arc-plasma discharge. The installation is shown in Figure 1.

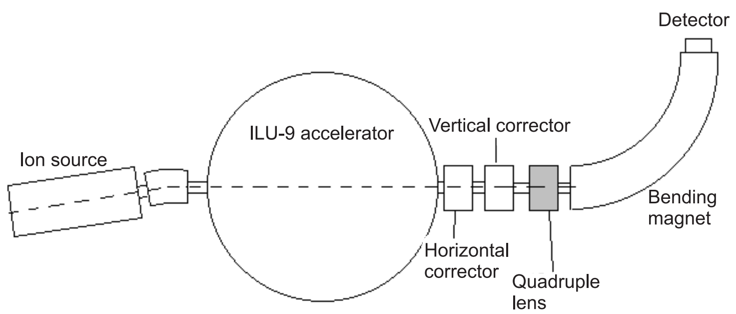


Figure 1: The design of the installation based on ILU-9 ion accelerator.

It comprises:
1) Ion source;
2) Particle separator (dipole magnet);
3) ILU-9 accelerator;
4)Vertical and horizontal correctors (quadruple lenses);
5) Bending magnet;
6) Detector.

The energy of the protons injected into the first accelerating gap of ILU-9 machine was 40-80 keV. The vertical collimation slots with width δ=1 mm were placed on the input and output of the bending magnet. The proton beam on the output of the bending magnet was detected by Faraday cup with amplifier during the beam channel tuning "regulation of the currents of the separator, vertical and horizontal correctors, quadruple lens" by the semiconductor silicon sensor during the measurement of the spectrums.

The energy spectrums were measured after the tuning of the machine in different regimes. The measured spectrum is shown in Figure 2. The result of the tuning is that 23% of all the protons of the beam are in the main peak having width of ± 0.25% from the maximum energy.

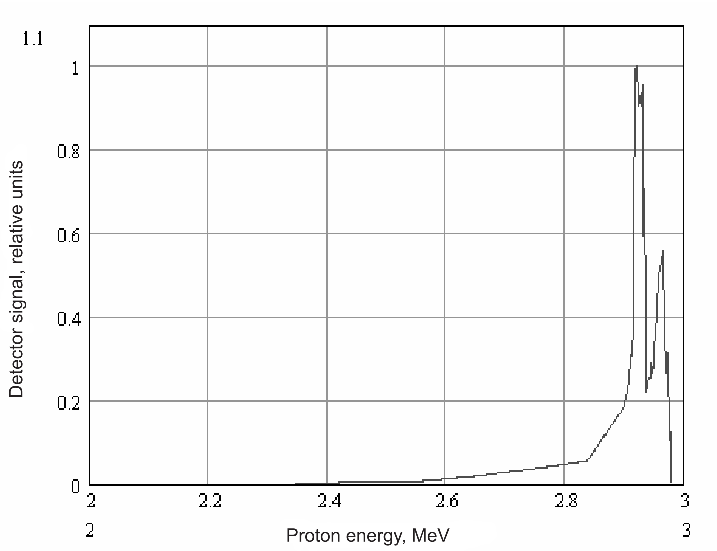


Figure 2: Proton beams energy spectrums on the output of the ILU-9 accelerator.

8.2.3 ILU-12 accelerator development

Linear electron accelerator ILU-12 is the new machine in the ILU line. It is the multi-cell machine with the maximal designed energy of 5 MeV. The accelerator was switched on in March 2007 and then it was developed and tuned to reach the required parameters. The energy of 5 MeV was achieved, and also the achieved pulse beam power of 1.5 MW and accelerating structure efficiency of 67% are close to the designed parameters. The improvement of the beam transportation and its energy spectrum were experimentally confirmed when the injection regime was optimized. The maximum beam power of 24 kW was achieved at pulse repetition rate of 40 Hz.

Experimental dispersion curve of ILU-12 accelerating structure is shown in Figure 3. It is in good agreement with 3D simulation results obtained with CST Microwave Studio and symmetric enough relative to the $\pi/2$ mode, so the neighbor coupling frequencies are maximally distanced from the operating frequency.

The bead-pull measurements were carried out to find the accelerating field amplitude distribution along the structure. The results are in good agreement with 3D simulation predictions.

Main measured parameters of the accelerating structure assembled with indium sealing are listed in Table 8.1.

The injected average beam current was measured depending on the constant cathode-grid voltage. Figure 4 presents simulated and measured cathode average current density on cathode-grid potential dependence for accelerating RF electric field tension value of 60 kV/cm on the grid surface.

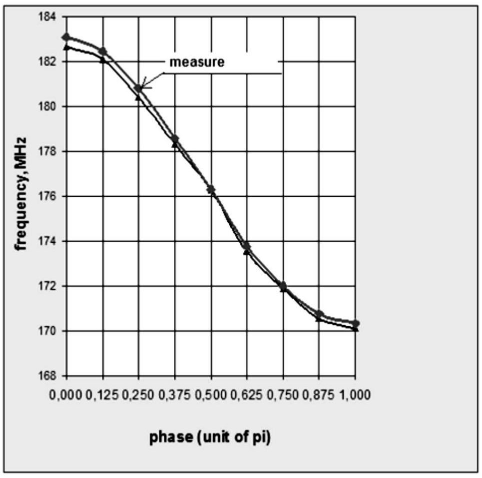


Figure 3: Calculated and measured dispersion curves of the accelerating structure.

Table 8.1:

Opearating frequency, MHz	176.308
Quality factor	~21000
Characteristic impedance, Ω	824
Shunt resistance, MΩ	17.3

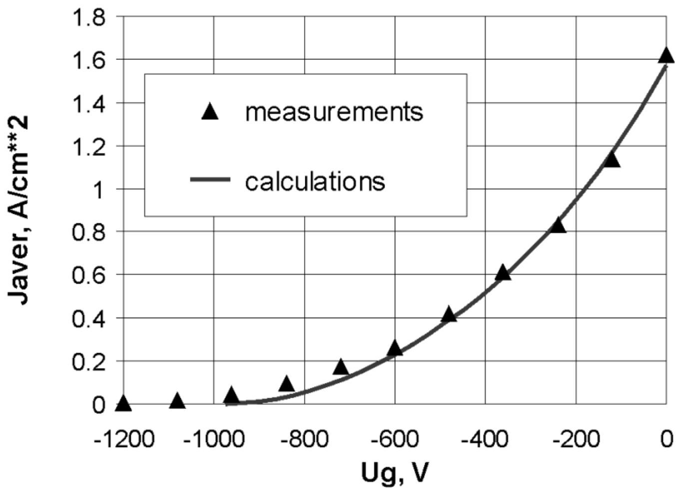


Figure 4: Experimental and calculated average current density of the grid-cathode assembly on constant grid-cathode voltage for Eacc=60 kV/cm.

Dependencies of the main electron beam initial and output parameters on electric field phase in the first gap were simulated for ILU-12 accelerator in quasi-stationary 2D approximation with paying regards to transit time angles and beam space charge effects (Figure 5).

It was proposed to apply an additional RF voltage of the operating frequency with proper amplitude and phase to the cathode-grid gap for the electron energy spectrum narrowing and longitudinal dynamics optimization. Figures 5-6 present results obtained at phase and amplitude optimized additional RF voltage. 3D model of the cathode-grid unit was developed on the base of 2D simulation results for beam initial parameters; electron trajectory analysis in the accelerating

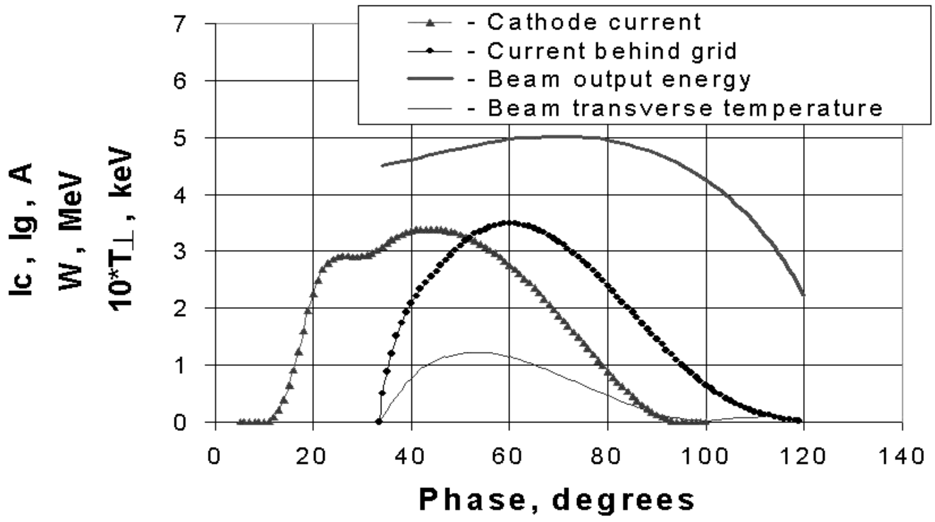


Figure 5: Dependencies of the current micro pulse and beam output parameters on accelerating field on the cathode phase.

structure was carried out (Figure 6).

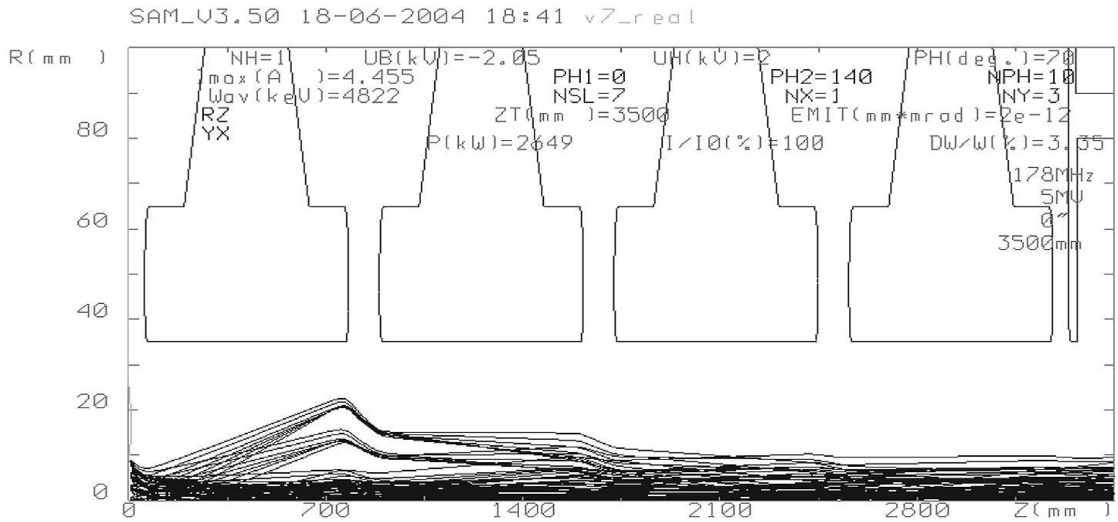


Figure 6: Typical electron trajectories in the accelerator.

The simulations allowed us to choose the optimal structure period and aperture as well as radius of curvature for the cathode-grid unit sphere.

The view of the assembled ILU-12 machine is shown in Figure 8.

The accelerating structure cooling system efficiency was experimentally verified in the actual industrial accelerator operating regime. To do so, the regime with 10 kW of average power was released in the structure, that was 10 times lower, that in the operating mode. The water flow was also decreased by a factor of 10 in relation to the operating mode and amounted to 30 l/min. The time dependence of the temperature gradient on the cooling system was measured for the accelerating cell coaxial part with maximal relative power losses (Figure 9). The steady temperature gradient was a little higher than 3°C.

The possibility to narrow the electron energy spectrum by applying an additional RF voltage to the cathode-grid gap was experimentally proven on ILU-10 accelerator, see Figure 10.

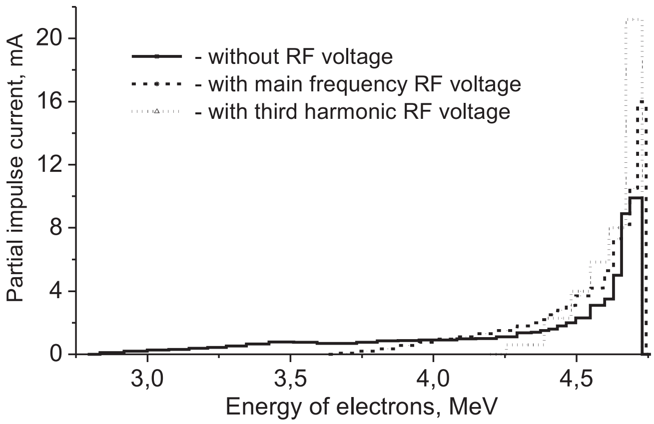


Figure 7: Measured electron beam energy spectrums at ILU-10 output.

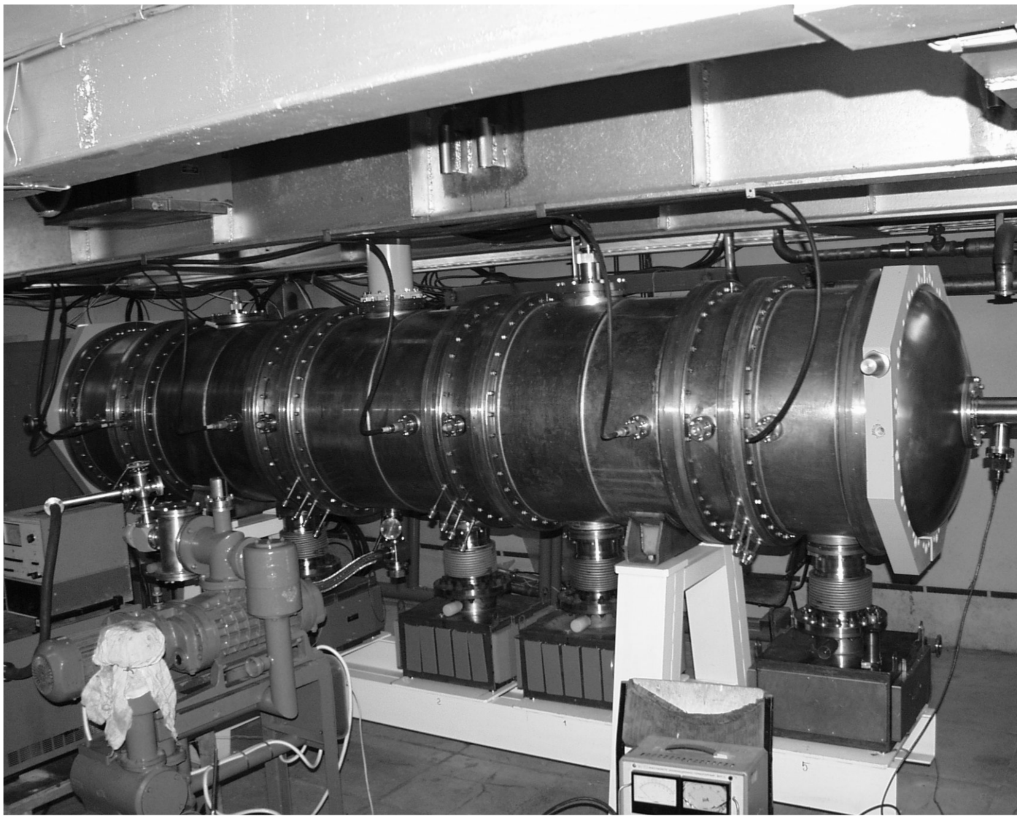


Figure 8: Assembled ILU-12 machine in bunker.

After that, the coupling between the accelerator and supplying feeder from the RF generator was optimized for operation with ~450-500 mA electron currents by turning the coupling loop. The measurement results for incident and reflected waves with no current in the structure are shown in Figure 10a. One can see that reflected wave amplitude reaches half the incident wave amplitude (unmatched regime with reflection factor $\Gamma = 0.5$). Figure 10b presents the measurement results at the cathode beam current of 300 mA with an additional RF voltage applied to the gun cathode. Reflected wave amplitude is close to zero (matched mode)

Measurements of the beam spot size at the accelerating structure output were carried out by burning the hole in 0.25 mm foil. The foil was placed before the Faraday cup at 1150 mm distance from the structure output; two regimes were realized - with and without applying additional RF

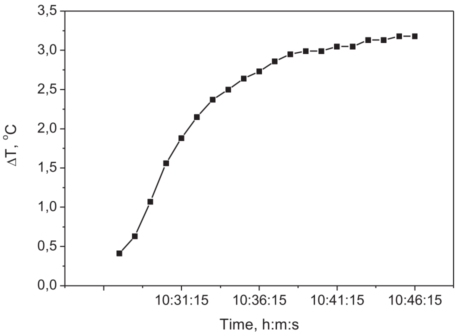


Figure 9: Measured time dependence of the temperature gradient in the accelerating cell coaxial part cooling system.

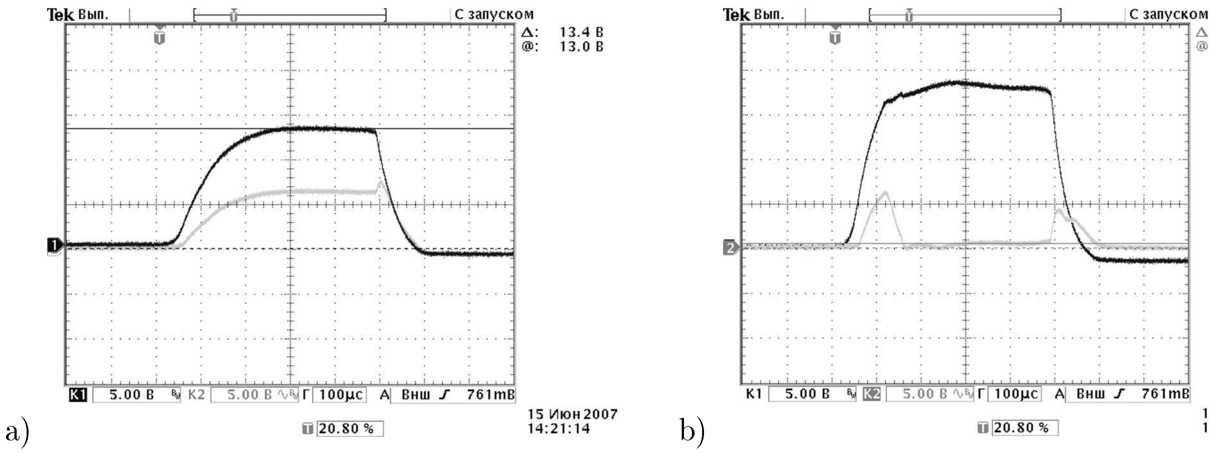


Figure 10: Measurement results for amplitudes of incident (bold curves) and reflected (plane curves) waves without (a) and with (b) the electron beam in the structure.

voltage on the triode gun cathode. Pulsed cathode current was 200 mA in both cases. Exposure time of the beam on the foil was about 2 minutes (time of reaching the steady-state Faraday cup current).

Figure 11 presents simulated (top) and experimental (bottom) 200 mA beam cross-sections for two beam transportation regimes: without (left) and with (right) the additional RF voltage on the triode RF gun. The real size of pictures is 50x50 mm^2. There is a good agreement between simulation and experimental results except for the apparent beam halo in photos. The beam has the maximal size in direction orthogonal to the grid slots, as it was predicted by simulations.

Successful commissioning of ILU-12 accelerator was carried out.

The following accelerator parameters were achieved:

- Pulsed cathode current of 350 mA;
- Beam current passing through the accelerating structure of 95%;
- Maximal electron energy at the accelerator output of 5MeV;
- Beam pulsed power of 1. 5MW;
- Accelerating structure electron efficiency of 67%;
- Average beam power of 24 kW.

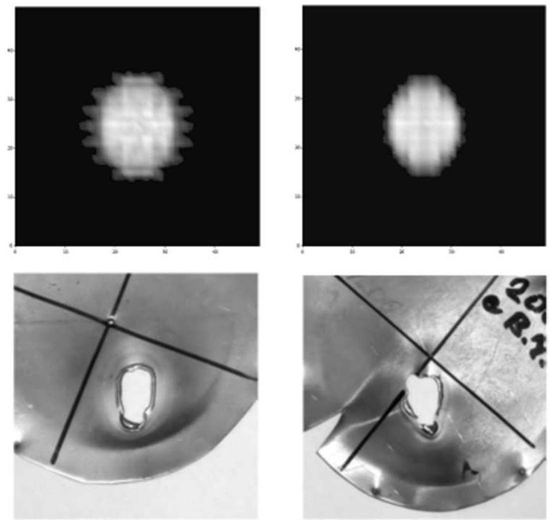


Figure 11: Simulated and experimental beam cross-sections.

8.2.4 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 samples of various materials supplied by other organizations were irradiated. The complex oxide compositions were synthesized by thermal-radiation technology.

Participants of the work:
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Publications:

[111], [112], [288], [343], [344], [345], [346].

Chapter 9

Physics for medicine

9.1 The works on creation of accelerator based neutron source for neutron-capture therapy and fast neutron therapy

The physical project of neutron source was published in Nuclear Instruments and Methods in Physics Research A 413/2-3 (1998) 397-426.

The financing of the project was carried due to fund of ISTC and DOE-IPP grants, lab.9-0 (money earned in other international contracts) and partially from the fund of the Institute. Since 2007 this work is supported also by the Ministry of Education and Science in the frame of the Federal Program “Supporting of Russian Unique Devices”.

Designed scheme of the tandem was described in 2001 Year Report and designed scheme of the complex for explosive detection by nuclear resonant absorption method and for boron neutron-capture therapy was described in 2004 Year Report.

1. Results obtained in 2007:

• It was achieved the maintainability engineering of H^- source as a part of complex. The source worked off more than 90 day shifts under 5 mA ion beam.

• It was demonstrated the stable regime for the tandem exploitation during the period of experiments with beam transportation and acceleration and during the period of experiments with γ- generating target.

• The value of maximal beam transportation was made under tandem voltage, equal tandem voltage, which was planned for the complex. H^- beam (from source with current up to 5 mA) was transported to the tandem inlet with current up to 3.2 mA (1.1 and fig.1, fig.2). The value of beam power on collector (40 cm from tandem outlet) was registered as 3.2 Kw. The energy of proton beam was equal to 1.8 MeV, so the current of proton beam was equal to $\sim$ 1.8 mA.

• It were manufactured and installed the units of high energy beam tract (HEBT) (Fig. 5, 6). These units are used for the transportation of proton beam up to neutron generating target.

• The cryogen pumping of stripper gas was put into operation and residual pressure inside the vacuum tank decreased as to factor $\sim$10.

• It was completed the first part of experiments to master the technique for detection nitrogen-containing substances by nuclear resonant absorption method (1.2 and fig 7, 8).

• It was discussed and made up the schedule for modernization of some units of complex for in- creasing the beam transportation from H- source up to final target.

1.1. Low energy beam tract (LEBT) is used for beam transport and matching with tandem accelerating structure (Fig. 1, 2). It consists of separately pumped vacuum channel, pumping and beam diagnostics chambers, and is equipped by two short solenoidal magnetic lenses and two magnet correctors. LEBT output aperture is used to protect first tandem electrode against illuminating by the beam halo.

To facilitate the alignment procedure the beam position monitors (BPM) were installed at the LEBL input and output. BPM consists of 5x5 electrically insulated tantalum wires. Gaps between wires are 5 mm.

As our experiments showed there is no possibility to measure the beam current striking the wire directly because of relatively large density of secondary plasma in the vicinity of BPM and large electron secondary emission from the wires. So, to find the beam radial profile the increase of wire resistance ΔR caused by the beam heating was measured. The beam current profiles among horizontally stretched wires are shown in Fig. 3. The wire number 3 is stretched along the LEBL diameter.

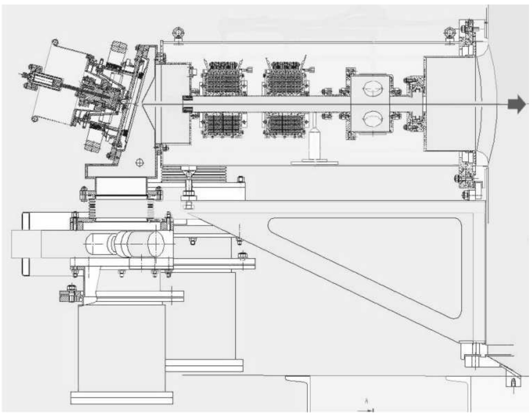

Figure 1: LEBT and H^- source (scheme).

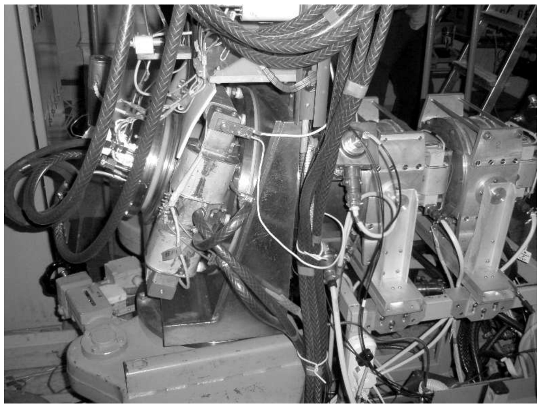

Figure 2: LEBT and H^- source.

The low energy beam line is equipped also with movable Faraday cup combined with two-dimensional current profile monitor. The beam current profile was measured by an array (8x8) of small electrodes placed behind the small holes properly perforated in cup bottom. This system is used for net current measurements and for preliminary beam line alignment (Fig 4).

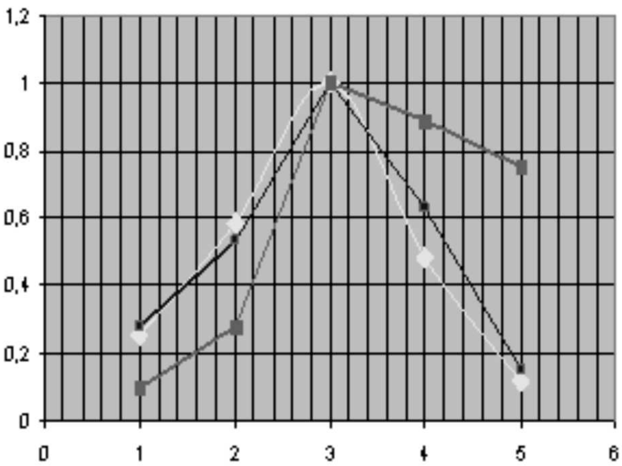

Figure 3: Beam current profiles in vertical direction for slightly different beam turning angles in source.

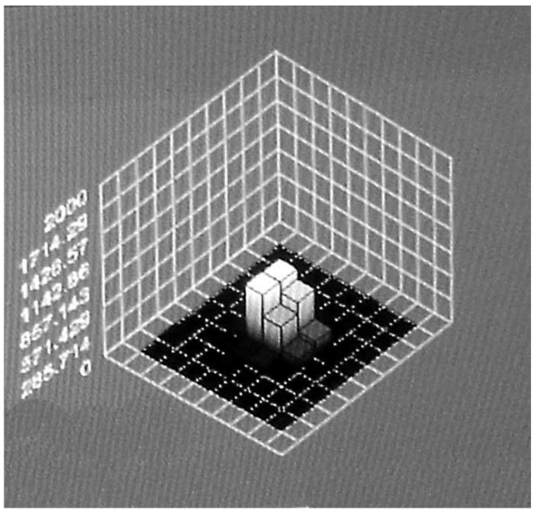

Figure 4: An example of two-dimensional current profile centered near beam line axis.

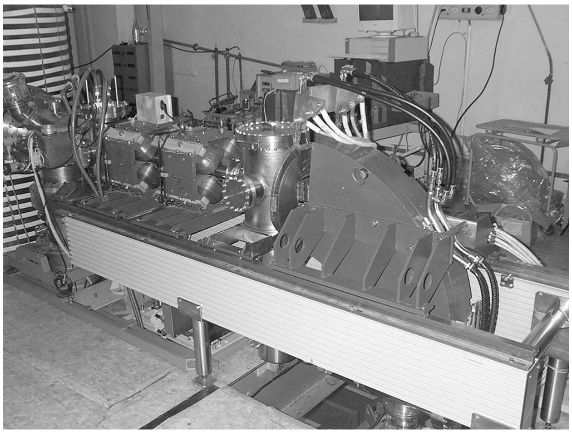

Figure 5: Horizontal part of HEBT: quadrupole lenses, vacuum volume for collector or carbon target, bending magnet.

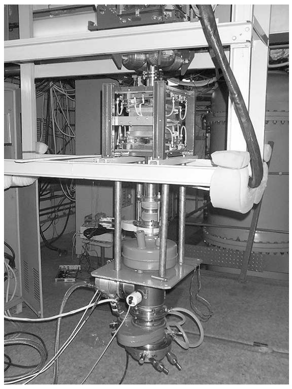

Figure 6: Vertical part of HEBT: quadrupole lenses, unit of the proton beam scanning, unit of the neutron generating target.

1.2. To carry out the experiments on generating 9.17 MeV gammas (from reaction $^{13}C(\rho,\gamma)^{14}N$) we have constructed the carbon-13 target capable to sustain 1 kW/cm^2 proton beam power density. The registration system (Fig. 7), including gamma-detectors, high-speed ADC, lead shield and gonyometer - rotating device with 0.1° positioning accuracy was constructed. This system allows to study the angular distribution of gammas generating in $^{13}C(\rho,\gamma)^{14}N$ reaction. In experiments it was confirmed that 9.17 MeV gammas were generated in carbon-13 target and were resonant absorbed in liquid nitrogen target. The measured coefficients of absorption in nitrogen and water (control experiment) are shown at Fig. 8. The proton beam energy was 1.82 MeV and current 100-300 μA. The estimated proton energy instability is 20 keV that corresponds to 1% of the beam energy.

To carry out full-scale experiments with explosion dummies we have developed the moving target designed to work with 2.5 kW/cm^2 power density proton beam. We have purchased the BGO scintillator with size ∅80x100 mm to increase energy resolution of gamma detector. Also, special software was written to process spectral data automatically.

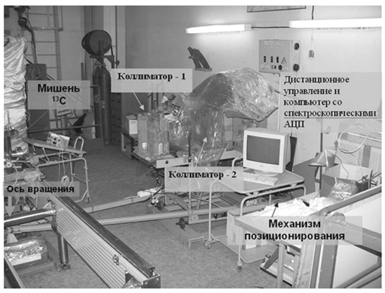

Figure 7: Goniometer assembly of complex.

Публикации:
[118], [119], [341], [358], [359], [360], [361], preprints 1, 2.

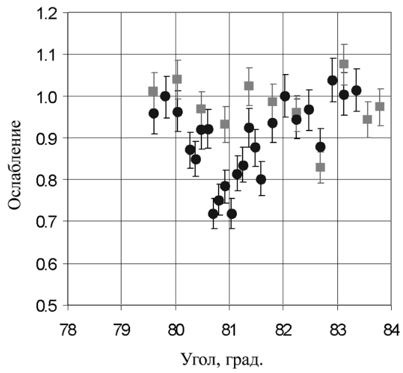

Figure 8: Coefficient of resonance gamma absorption in nitrogen 38 cm length (circles) in comparison to absorption in water (squares).

9.2 X-ray detectors for medicine and people inspection

9.2.1 A Low-dose X-ray Device (LDRD)“Siberia”

In 2007, for LDRD “Siberia”, a new detector with a spatial resolution of 250 μkm was developed. The detector has the higher efficiency of detecting X-ray radiation (70%) that enables lowering the radiation dose in the prophylactic inspection of lungs and becomes optimal in the use in the modern scanning digital fluorographs. We have manufactured seven detectors, which are delivered to Oryol (ZAO “Nauchpribor” to equip the FMCZ-fluorographs and to Aktyubinsk (“a ktyubroentgen” plant) for flyorographs “Sanjar”. On the base of a new detector, “Nauchpribor”(Oryol) has developed and produced a new fluorography FMCZ-NP-0 that has a modern design and high quality of image (Fig.1). We started the development of a new multiline gas detector (a kinestatic detector) with the resolution up to 4 l.p./mm and obtained new encouraging results. The use of a kinestatic detector enables the use of microdose scanning technology not only for development of fluorographs but also for X-ray diagnostic centers (RDC)where the higher resolution for the minimum scanning time is required.

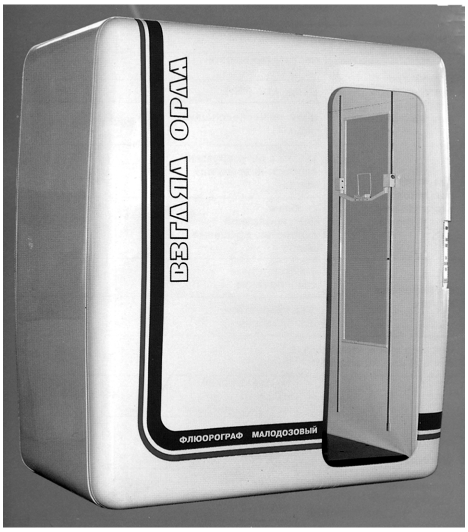

Figure 1: Fluorograph FMNZ-NP-0.

9.3 Radiographic Control System (SRC) “Sibscan” for people inspection

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During 2007, we have commissioned one more installation for the express inspection of air passengers SRC “Sibscan” (Fig.2) at the departure section №4 of the airport Tolmachevo (Novosibirsk). A modification of the SRC “Sibscan” (Fig.3) with an improved design and higher reliability was made at ZAO “Nauchpribor”, the contract was signed on the delivery of two such devices SRC “Sibscan” to USA and the devices are already delivered.

Figure 3: Modified SRC "Sibscan".

9.4 Mammography

In 2007, we continued the development of detectors for the digital mammography. We finished tests of the detector with four independent MIC, which are located one over another, each with an electrode step (strips) of 105 μm and the number of channels 1792. Such a design enables an increase in the number of detected photons bay factor 4 compared to the single chamber. As tests showed, the detector efficiency is about 72% for irradiation from the tube with a tungsten anode at voltage of 40 kV that corresponds to the design value. The detector spatial resolution is about 120 μm thus enables observation of objects with spatial frequency up to 5 l.p./mm. Commissioning of the nstallation for digital mammography is planned for 2008.

Also, in 2007, we completed the assembly of some individual modules of the GaAs based detector. Each module is a strip GaAs detector with strip step of 200 μm and 128 channels, which is equipped with the detection electronics. In future, such modules will be installed at a special substrate in two rows with a shift of 100 μm that will enable us to achieve the detector spatial resolution of the order 100 μm. Completion of the detector assembly is planned for 2008.

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87. *Raimondi P., Shatilov D., Zobov M.* Beam-beam issues for colliding schemes with large Piwinski angle and crabbed waist. // Preprint LNF-07/001, arXiv:physics/0702033.

Authorial papers-2007

1. *Fedotovich G.V.* Radiation corrections to the processes of e^+e^- annihilation and precise measurement of the hadronic cross sections with CMD-2 detector. // 01.04.16 - elementary particle physics, and atomic nuclear physics, Author. papers of thesis for the degree of doctor of phys.-math. science: Novosibirsk, 2006, BINP, SB RAS.

2. *Bolkhovityanov D.Yu.* VEPP-5 injection complex control system software. // 01.04.01 - instruments and methods of experimental physics, Author. papers of thesis for the degree of candidate of technical science: Novosibirsk, 2007, BINP, SB RAS.

3. *Bogdan I.S.* High energy QCD amplitudes with quark exchange. // 01.04.02 - theoretical physics, Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2007, BINP, SB RAS.

4. *Golkovsky M.G.* The calculation of temperature fields and forming of structure and properties of surface layers of metals and alloys at relativistic electron beam irradiation. // 01.04.07 - condensed physics matter, 05.16.01 - material science and heat treatment of metals Defence of dissertation: Institute of strength physics and material science SB of RAS, Tomsk. Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2007, BINP, SB RAS.

5. *Berdyugin A.V.* Processing $e^+e^- \to \eta\gamma$ in the $0.6 - 1.4$ GeV energy range. // 01.04.16 - elementary particle physics, and atomic nuclear physics, Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2007, BINP, SB RAS.

6. *Poluektov A.O.* Measurement of the unitarity triangle angle ϕ_3 in $B \to DK$ decays with Belle detector. // 01.04.16 - elementary particle physics, and atomic nuclear physics, Author. papers of thesis for the degree of candidate of phys.-math. science: Novosibirsk, 2007, BINP, SB RAS.

7. *Bogomyagkov A.V.* Central mass energy definition in high precision experiments on VEPP4-M. // 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, 2007, BINP, SB RAS.

8. *Evtushenko Yu.A.* Special power supplies for particle accelerators and storage rings elements. // 01.04.20 - physics of charged particle beams and accelerator techniques, Author. papers of thesis for the degree of candidate of technical science: Novosibirsk, 2007, BINP, SB RAS.

9. *Volkov V.N.* The prototype of the electron photocathode RF injector with superconducting cavity. // 01.04.20 - physics of charged particle beams and accelerator techniques, Author. papers of thesis for the degree of candidate of technical science: Novosibirsk, 2007, BINP, SB RAS.

Participation in Conferences

1. Asian Particle Accelerator Conference (APAC 2007), January 29 - February 2, 2007, (RRCAT), Indore, India.
2. International Conference on the Methods of Aerophysical Research, 5-10 February, 2007, Novosibirsk, Russia.
3. XXXIV International (Zvenigorod) Conference on Plasma Physics and Controlled Fusion, 12-16 February, 2007, Zvenigorod, Russia.
4. XLI PNPI Winter School, February 19-24, 2007, St.Petersburg, Repino, Russia.
5. 11th International Vienna Conference on Instrumentation (VCI), February 19-24, 2007, Vienna, Austria.
6. 7th International Ural Seminar: Radiation Damage Physics of Metals and Alloys, February 25 - March 3, 2007, Snezhinsk.
7. All-Russian Workshop on Millimeter- and Sub-Millimeter-Wave Radiophysics, 12-15 March, 2007, Nizhny Novgorod, Russia.
8. 3rd International Conference, IX Kharitonov's Scientific Readings, 12-16 March, 2007, Sarov, Rossia.
9. II All-Russian Conference by Nanomaterial & IV International Seminar "Nanostructured material-2007 Belarus-Russia", 2007, 13-16? March, Novosibirsk, Russia.
10. 42nd Rencontres de Moriond on QCD and Hadronic Interactions, 17-24 March, 2007, La Thuile, Italy.
11. Nevsky Radiological Forum-2007: New Horizons, 7-10 April, 2007, St.-Petersburg.
12. All-Union Workshop "Modern Problems of Theoretical and Applied Mechanics", 10-12 April, 2007, Novosibirsk, Russia.
13. Technical Meeting on "Prospects and Challenges in Application of Radiation for Treating Exhaust Gases" 14-18 May, 2007, Warsaw, Poland.
14. 8th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerator (DIPAC'07), 20-23 May, 2007, Venice, Italy.
15. 12th International Conference on Elastic and Diffractive Scattering (Blois Workshop): Forward Physics and QCD, DESY, May 21-25, 2007, Hamburg, Germany.
16. 8th International Conference "Films and Coatings-2007", 22-25 May, 2007, St-Petersburg, Russia.
17. Workshop "Posipol 2007", May 23-25, 2007, Orsay, France.
18. 8th All-Russian Workshop "Problems of Theoretical and Applied Electron and Ion Optics, 29-31 May 29-31, 2007, Moscow, Russia.
19. International Linear Collider Workshop (LCWS-ILC-07), May 30 - June 4, 2007, Hamburg.
20. Workshop on "Finding Explosives with NRA Technique" 21-22 June, 2007, St.Peterburg, Russia.
21. 22d Particle Accelerator Conference (PAC'07), June 25-29, 2007, Albuquerque, New Mexico, USA.
22. 15th International Symposium "Nanostructures: Physics and Technology", June 25-29, 2007, Novosibirsk, Russia.
23. International Conference "Physical Interpretation Theory of Relativity (PIRT-07)", 2-5 July, 2007, Moscow, Russia.

24. School on QCD, Low x Physics, Saturation and Diffraction, July 1-14, 2007, Copanello, Calabria, Italy.
25. 34th EPS Conference on Controlled Fusion and Plasma Physics, 2-6 July, 2007, Warsaw, Poland.
26. 17th International Vacuum Congress (IVC-17), 13th International Conference on Surface Science (ICSS-13): International Conference on Nano Science and Technology (ICN+T-2007), 2-6 July, 2007, Stockholm, Sweden.
27. International Conference (PHOTON 2007), July 9-13, 2007, Paris, France.
28. International Europhysics Conference on High Energy Physics (EPS-HEP2007), 19-25 July, 2007, Manchester, England.
29. VIII International Topical Meeting on Nuclear Applications and Utilization of Accelerator, July 29 - August 2, 2007, Pocatello, Idaho, USA.
30. International Conference (Lattice 2007), 30 July - 4 August, 2007, Regensburg, Germany.
31. International Symposium on Topical Problems of Biophotonics (TPB 2007), 4-11 August, 2007, Nizhny Novgorod-Moscow-Nizhny Novgorod, Russia.
32. 23rd International Symposium on Lepton-Photon Interactions at High Energy (LP07), 13-18 August, 2007, Daegu, Korea,
33. IV International Conference on Contemporary Physics, August 13-20, 2007, Ulaanbaatar.
34. 12th International Conference on Ion Sources (ICIS'07), August 26-31, 2007, Jeju, Korea.
35. 29th International Free Electron Laser Conference, August 26-31, 2007, Budker INP, Novosibirsk, Russia.
36. IBS Mini Workshop, Cockcroft Institute, 28-29 August 2007, Daresbury.
37. Workshop on Low x Physics, August 29 - September 1, 2007, Helsinki, Finland.
38. Workshop "Polarized Antiproton Beams - How?", August 29-31, 2007, Daresbury, UK.
39. Professor V.P. Sarantsev Memorial International Seminar, 2-9 September, 2007, Alushta, Ukraine.
40. XII Advance Research Workshop on High Energy Spin Physics (DSPIN-07), 3-7 September, 2007, Dubna, Russia.
41. Joint 32nd International Conference on Infrared and Millimetre Waves, and 15th International Conference on Terahertz Electronics (IRMMW-THz2007), 3-7 September, 2007, Cardiff, UK.
42. XX International Workshop on Charged Particle Accelerators (IWCPA 2007), September 9-15, 2007, Alushta, Ukraine.
43. European Congress on Advanced Materials and Processes (Euromat 2007), 10-13 September, 2007, Nuremberg, Germany.
44. International Workshop on Beam Cooling and Related Topics (COOL 2007), 10-14 September 2007, Bad Kreuznach, Deutschland.
45. V All-Russian Scientific Conference with International Participation "Innovative Technologies and Economics in Machine-Building Industry", September, 14-15 2007, Urga, Russia.
46. International Conference: New Trends in High-Energy Physics, September 15-22, 2007, Yalta, Crimea, Ukraine.
47. ILC Interaction Region Engineering Design Workshop (IRENG07), September 17-21, 2007, SLAC, Stanford, USA.
48. 3th International Symposium on Laser-Aided Plasma Diagnostics, 18-21 September, 2007, Hida Hotel Plaza, Takayama, Japan.
49. 7th International Conference "Interaction of Radiations with Hard Matter" (VITT-2007), September 26-28, 2007, Minsk, Belorussia.

50. 37th European Microwave Conference (EuMC-2007), 8-12 October, 2007, Munich, Germany.
51. XII International Conference on Hadron Spectroscopy (Hadron07), October 8-13, 2007, Frascati, Italy.
52. Scientific-Practical Conference "Nanotechnologies and Nanomaterials for Biology and Medicine", October 11-12, 2007, Novosibirsk, Russia.
53. International Conference of Accelerator and Large Experimental Physics Control Systems (ICALEPCS-2007), October 15-19, 2007, Knoxville, Tennessee.
54. 43rd ISTC Japan Workshop on Accelerator Science - Basic to Applications - in Russia / CIS, October 29-30, 2007 (KEK), Tsukuba, Japan.
55. III International Scientific-Practical Conference: Technical Means of Counteraction to Terrorist and Criminal Explosions, 30-31 October, 2007, St.-Petersburg.
56. VI National Conference on Application of X-ray, SR, Neutrons and Electrons for Material Characterization (RSNE 2007), 12-17 November, 2007, IC RAS, Moscow, Russia.
57. Nanodimensional Systems (Nansys2007), 21-23 November, 2007, Kiev, Ukraine.
58. Session-Conference. Section: Nuclear Physics BPS RAS, November 26-30, 2007, Moscow, Russia.
59. International Workshop on Physics and Technologies of Laser-Electron Interaction toward the ILC (LEI 2007), December 12-14, 2007, Hiroshima, Japan.
60. XII All-Russian Conference "High Temperature Plasma Diagnostic", 2007, Troitsk.
61. IX International Conference: Zababakhin Scientific Talks, 2007, Snezhinsk, Russia.

List of Collaboration Agreements between the Budker INP and Foreign Laboratories

N°	Name of Laboratory 1	Title or Field of Collaboration 2	Dates 3	Principal Investigators 4
1.	CERN (Swiss)	1. Research and development of the detectors for LHC	1992	A. Bondar, Yu. Tikhonov (INP), T. Nakada, P. Yenni (CERN)
		2. Development of the LHC elements	1996	L. Evans (CERN), V. Anashin (INP)
2.	DESY (Germany)	Joint research in the field of accelerator physics and elementary particle physics	1992	A. Vagner (DESY), A. Skrinsky (INP)
3.	SLAC (Stanford) USA	1. Research and development of linear colliders and final focus test	1992	D. Dorfan (SLAC), A. Skrinsky (INP)
		2. Beam detector for B-factory	1993	A. Onuchin (INP), D. Hitlin (SLAC)
		3. Electron-positron colliding beams (B-factory)	1995	D. Siman (SLAC), A. Skrinsky (INP)
4.	BNL (Brookheven) USA	1. Measurement of the magnetic muon anomalous	1991	J. Bunse (BNL), L. Barkov (INP)
		2. Joint research of RHIC spin	1993	S. Ozaki (BNL), Yu. Shatunov (INP)
5.	ANL (Argonn) USA	1. Experiments with polarized gas jet target at VEPP-3	1988	R. Holt (ANL), L. Barkov (INP)
		2. SR instrumentation	1993	G. Shenoy (USA), G. Kulipanov, A. Skrinsky (INP)
6.	INFN (Italy)	Development of intense source for radioactive ion beams for experiments in nuclear physics	1984	L. Techio (INFN), P. Logachev (INP)
7.	University of Milan (Italy)	Theoretical and numerical studies of dynamic chaos in classic and quantum mechanics	1991	T. Montegazza, J. Kasati (Italy), A. Skrinsky, V. Sokolov (INP)
8.	University of Pittsburgh (USA)	Experiments on VEPP-2M and ϕ-factory	1989	S. Eidelman, E. Solodov (INP), V. Savinov (USA)
9.	Daresbury (England)	Generation and utilization of SR	1977	I. Munro (Daresbury), G. Kulipanov (INP)
10.	University of Duke (USA)	Free electron lasers	1992	J. Wu (Duke), N. Vinokurov (INP)

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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)
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		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)
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18.	Nuclear Centre “Karlsruhe” (Germany)	1. Development of conceptual project and data base for neutron source on the basis of GDT device 2. Simulation of processes in diverter of ITER device	1994	G. Kessler (FRG), E. Kruglyakov, A. Ivanov, A. Burdakov (INP)
19.	GSI (Germany)	Collaboration in the field of accelerator physics: electron cooling; electron-ion colliders	1995	A. Eickhoff (GSI), Yu. Shatunov, V. Parkhomchuk (INP)
20.	FERMILAB (USA)	Collaboration in the field of accelerator physics: electron cooling; conversion system	1995	O. Finli (FERMILAB), V. Parkhomchuk (INP)
21.	Institute of Morden Physics Lanchzou (China)	Particle accelerator physics and techniques	2000	S. Yang (IMP, China), V. Parkhomchuk (INP)
22.	Center of Plasma Research, Tsukuba (Japan)	Collaboration on Open traps	2003	Ya. Kitahara, K. Yatsu (Japan), E. Kruglyakov, A. Skrinsky (INP)
23.	INFN-LNF (Italy)	Development of collider project DAFNE-II	2004	S. Biscari (INFN), E. Levichev (INP)

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