Russian Academy of Sciences
Lenin Order Siberian Branch

BUDKER INSTITUTE OF NUCLEAR Physics

ANNUAL REPORT

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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 the “Round Table”— Scientific Council of the Institute.

The total number of the Institute’s staff is approximately 3000 and among them: about 420 researchers, over 50 postgraduates, 760 engineers and technicians, about 350 laboratory assistants and 1300 workers. Among the researchers, there are 5 full members and 6 corresponding members of the Russian Academy of Science, about 50 doctors of science and 160 candidates of science.

The Institute if one of the world leading centers in several important fields of the high energy physics, controlled thermonuclear fusion and applied physics. 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 has proved to a a reliable partner both in carrying the joint research and in the developments in the field of physics and has a good reputation in the whole world as a reliable supplier of the highly technological equipment for the research and industrial purposes.

Some of the BINP main achievements in the science and technology are the following:

In the field of elementary particles and nuclear physics:

• pioneering works on the development of the colliding beam technique, which at present, is the main method in high energy physics:

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

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

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

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

Standard model, which is being carried out jointly with the Brookhaven National Laboratory, (1984 - 2005);

• development of the resonance depolarization technique for the precise measurement of the elementary particle masses, achievement of the record value of the mass measurement accuracy for K-, ρ-, ω-, φ-, ψ- mesons and Υ- mesons, (1975-2004);

• discovery of the parity violation effects in the atomic transitions confirming a unified theory of the electroweak interactions, (1978);

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

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

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

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

In the field of theoretical physics :

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

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

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

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

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

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

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

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

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

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

In the field of accelerator physics and technology:

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

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

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

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

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

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

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

• theoretical and experimental studies of the stochastic instability and "collision effects" limiting the colliders luminosity (since 1966);

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

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

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

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

In the field of plasma physics and thermonuclear fusion:

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

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

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

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

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

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

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

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

In the field of synchrotron radiation and free electron lasers:

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

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

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

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

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

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

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

The following works were recognized by the Scientific Council as the best in 2005:

Precision measurements of the hadron crossections with the SND and CMD-2 detectors at the VEPP-2M collider

Measurements of the proton formfactor with the ISR technique in the energy range 2E = 1.88 - 4 GeV at the BaBar detector

Development of the electron cooling system of a new generation and its commissioning at the storage ring LEIR at CERN

The ion fast heating effect at relaxation of the electron beam in a plasma on the multimirror magnetic trap (GOL-3 device)

Beginning of the systematic experiments with the use of terahertz radiation from FEL at the Siberian Center of Photochemical Studies

Development and industrial realization of the low-dose systems of radiagraphic control for inspection of passengers.

Chapter 1

Physics of Elementary Particles

1.1 Detector CMD-3

The longitudinal cross section of the CMD-3 detector is shown on fig. 1. The major activities of the Collaboration in 2004 were development of the detector subsystems, design and production of digitizing electronics, development of data acquisition, ONLINE, OFFLINE and Monte Carlo simulation software.

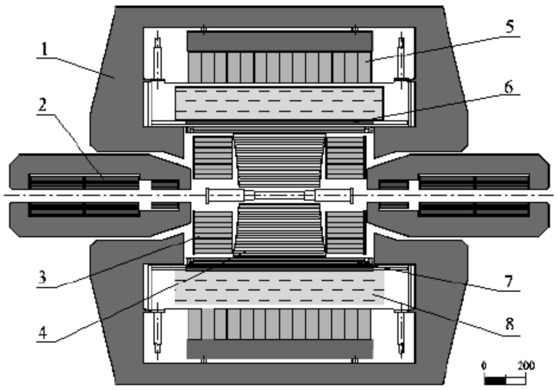

Figure 1: Longitudinal cross section of the CMD-3 detector. 1 — magnet yoke; 2 — VEPP-2000 superconducting solenoids; 3 — Endcap electromagnetic BGO calorimeter; 4 — Drift chamber; 5 — Barrel electromagnetic CsI calorimeter; 6 — superconducting solenoid of CMD-3, 7 — Z-chamber, 8 — LXe electromagnetic calorimeter.

The parts of the drift chamber case received by fall of 2004. Them were produced in tight collaboration with Italian colleagues from University of Lecce. All the parts of the chamber are made from carbon fiber composite by the Italian company, which has a good experience of using this material in Space projects. After a number of tests of mechanical and electrical properties the installation of sensitive and field wires has been started.

It was checked, that tension of Z-chamber wires does not changed during its operation in CMD-2 detector and the chamber can be installed in the CMD-3 with minor changes only. The most important difference with CMD-2 is the choice of the other number of chamber sectors to match the new symmetry of the Drift Chamber cells. It was necessary for proper use of both chambers in trigger system. All other works with the chamber will be done after its installation into detector at spring 2005.

During 2004 a number of successful physics runs were performed with Liquid Xenon electromagnetic calorimeter. In these runs the calorimeter was completely (400 liters) filled with LXe. The main goal of runs was the gain of experience in dealing with this complex device. It was found that xenon remains pure during the operation. The absorption length of primary electrons exceeds 2 centimeters ensuring the spatial resolution be not worse than 2 millimeters in a good agreement with the expected value. During runs with cosmic rays particles the big sample of experimental data was collected. In the end of 2004 the calorimeter was installed in VEPP-2000 and now works necessary for its operation with collider are being performed.

CsI calorimeter of the CMD-3 will mainly (about 70% of total amount) consists of crystals used in former CMD-2 detector. The certification of these crystals has been completed and first CsI line was produced.

The production of BGO crystals blocks forming elements of BGO endcap electromagnetic calorimeter was completed. All crystals were equipped with semiconducting photodiodes. The first part (about one third of the total amount) of charge sensitive preamplifiers for the calorimeter has been already produced and the production of remain part is under way now. In 2004 the chiller for Calorimeter thermo stabilization has been bought. This machine allows one to increase and stabilize the light output of BGO crystals.

The winding of the superconducting solenoid coil was performed in 2004. Since the solenoid is placed before a barrel calorimeter, its thickness has to be minimal, according to design it will be about 0.13 X_0. As a result of cryogenic tests of the liquid helium vessel it was found that consumption of liquid helium is about two liters per day that is much better than that we have had with CMD-2.

New digitizing electronics (T2Q plate) for the drift chamber was tested with the drift chamber Prototype. The spatial resolution at 100 mcm level was obtained. The analog part of electronics for calorimeters was developed. New charge sensitive amplifier schematic equally suitable for all calorimetric systems of the detector was designed and tested.

For the framework of the CMD-3 Data Acquisition System the User Library has been developed and tested. The Library is a superstructure for MIDAS package, which was chosen as the core of the Data Acquisition System. Prototypes of the basic programs were developed. Tests of the system reliability and throughput were performed. The framework of the OFFLINE data processing system was developed as well. The development of the Monte-Carlo Simulation package was started and is going on at full speed.

In 2004 the processing of data collected with CMD-2 detector has been continued. The cross section of 4 charged pions production was measured in center of mass energy range from 1040 MeV to 1380 MeV. In this energy region the process is dominant and the precise measurement of the cross section allows one to increase the accuracy of calculation of hadronic vacuum polarization contribution to the anomalous magnetic moment of muon. Comparing data from e^+e^- colliders with those received from τ lepton decays one can test the CVC hypothesis. The measurement of the $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ cross section is important for searching for excitations of light vector mesons as well as new types of the particles consisting of quarks and gluons, so-called "hybrids".

Measurement of cross section of the processes with three photons in a final state in C.M. energy range from 600 up to 1380 MeV was also performed in 2004. As a result of this study the new values of branching ratios of decays $\rho \to \eta\gamma$, $\omega \to \eta\gamma$, $\phi \to \eta\gamma$ were obtained, as well as branching ratios of the decays $\rho \to \pi^0\gamma$, $\omega \to \pi^0\gamma$, $\phi \to \pi^0\gamma$. These results are important for tests of a number of theoretical models, in particular, non-relativistic quarks models and Vector Dominance Model.

In work participated:
Anisenkov A.V., Aulchenko V.M., Ahmetshin R.R., Bashtovoy N.S., Barkov L.M., Banzarov V.S., Bondar A.E., Bragin A.V., Vorobyev A.I., Gorbachev D.A., Grebeniuk A.A., Grigoryev D.N., Epifanov D.A., Zaytsev A.S., Zverev S.G., Zinchenko A.V., Ignatov F.V., Kazanin V.F., Karpov S.V., Kakhuta K.I., Kozyrev A.N., Krokovny P.P., Kuzmin A.S., Logashenko I.B., Lukin P.A., Mikhailov K.Yu., Nikulin M.A., Okhapkin V.S., Pestov Yu.N., Popov A.S., Popov Yu.S., Prijmenko L.A., Ryskulov N.M., Ruban A.A., Redin S.I., Sibidanov A.L., Snopkov I.G., Solodov E.P., Talyshev A.A., Titov V.M., Fedotovich G.V., Khazin B.I., Shwartz B.A., Eidelman S.I., Yudin Yu.V.
Roberts B.L. *(the Boston University, Boston, USA)*
Tompson J. A. *(University of Pittsbugh, Pittsburgh, USA)*
F.Grancagnolo *University of Lecce, Lecce, Italy*
Publications: [5], [6].

1.2 Present status of the SND group activities

1. SND upgrade for VEPP-2000.

The second stage of experiments with the drift chamber prototype was finished in 2005. During the first stage of measurements, in 2004, high intensity of noise from the signal wires had been found. In test experiments with the specially designed chamber two main mechanisms, leading to the high noise level, were revealed: photonic back-reaction and cold emission from the surface of the field-forming wires. Wire specimens at hand were tested and the one with the least noise level was selected. After this, the prototype was repaired with the wire system completely replaced. 2005 tests have shown that the noise level was successfully lowered to the level comprehensible in SND experiments. The main parameters of the tracking system, obtained in 2004 measurements, were confirmed by analysis of the new data, the results were published in the BINP preprint "SND upgrade and data analysis - the present status". In 2006 it is planed to finish the analysis of the drift chamber prototype date and to publish the final results.

In this year the main part of the work was done to manufacture the SND basic tracking system, including assembly of the casing of the system and precision installation of 1300 wires. Presently installation of elements of the registering and high-voltage front-end electronics located directly on the tracking system case comes to the end and quality checks of assembly are carried out. Checks include: the control of the wire structure tensions, checking the air tightness of the case, high-voltage tests, checks of wire breakage, short circuit, etc.

In 2005 works have been continued on manufacturing the SND particle identification system on the basis of high density aerogel. In the beginning of year the necessary quantity of preamplifiers has been produced, compact high voltage dividers were developed and manufactured, the scheme of configuration of electronics in the case of the system was designed. All details of the system casing have been produced and the first full-size segment of the system was assembled. The particle identification system consists of three identical segments, in each of which there are three independent counters. For carrying out the counter tests, one of counters has been filled by aerogel with a refraction coefficient $n = 1.13$. In the measurements cosmic muons with an impulse $p > 1$ GeV/c were used that allowed to select muons with Cherenkov radiations more than 95% from maximal. During the tests the signal magnitude from the counter and light collection homogeneity were measured, for what the spectra in five different points of the counter were collected. The average magnitude of the signal in all measured points exceeds 10 photoelectrons. Fig. 1 shows one of the collected spectra.

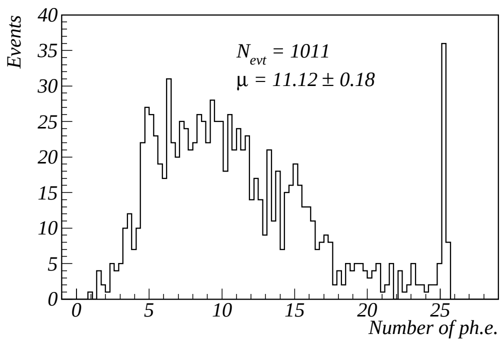

Figure 1: Distribution of signals from the Cherenkov counter of detector SND versus number of photoelectrons from cosmic muons with an impulse $p > 1$ GeV/c.

To control the stability of the counter parameters, signal magnitude measurements were repeated after eight months. This time, the signal magnitude was approximately 20% lower on the average, that can be attributed with presence of a moisture in the aerogel. For reduction of this effect of system parameters degradation, the decision was made to use a pure argon prorolling system that will allow to prevent penetration of damp air inside the system. At the end of the year new details of the system casing have been developed and handed over in manufacture, in which the up-to-day experience was taken into account and the noticed constructive deficiencies were corrected.

In this year the production of the gas proportional counters modules was completed for the SND external system. Tightness of the modules and wire tensions were checked. The system was constructed for mixing of the gas components in the stream. Testing of the scintillation counters of the external system has begun.

A time resolution was measured of the third layer scintillation counter from the SND calorimeter with the vacuum phototriode and flash ADC by using cosmic rays. The flash ADC was developed in the laboratory 6. The time resolution of about 2 nanoseconds was obtained at 50 MeV energy deposition in the counter.

In 2005, the T2A and PA24 plates were manufactured for digitizing information from the SND drift chamber in future experiments. The design of the Input-Output processor was finalized and a test set of processors was produced. These processors are used to read information from the electronics in the KLUKVA standard.

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

- Creation of the interface to information modules in the format KLUKVA, working under the Ethernet protocol, is finished. The pilot party (5 pieces) of the information modules has been received and tested. RSI interface to the CAMAC command modules and new ADCs (A24) for the calorimeter have been also received.

- The infrastructure was created for connections of the tertiary trigger procedures, and for event based procedures of calibration and control of the detector. The web-interface was realized for dynamic display of the detector subsystems performance statistics in the form of diagrams and graphs.

- The calibration database was created. A role-based differentiation of access privileges to the databases of the detector has been realized. The configuration database has been replenished with more realistic description of the detector channels, the data scheme was created for configuration of the first level trigger.

- The software had been modernized in view of the new equipment (the KLUKVA, CAMAC interfaces). In particular, it has demanded an additional development of the non trivial synchronous event builder.

- The data acquisition system software has been tested on a test configuration (the calorimeter signal digitizing modules, noise signal, the trigger from the generator). Design productivity of 1 kHz events rate has been reached.

Tests of electronics and new software were performed by using cosmic particles in an experiment with the calorimeter: electronic plates of the calorimeter, as well as units of the trigger dealing with calorimeter, were prepared for work and installed in crates. Namely shapers, ADCs, Input-Output processors, interfaces of the primary trigger, summators of the energy deposition in the calorimeter towers. By means of the new software for the SND data acquisition system, events were collected and recorded corresponding to passages of cosmic muons trough the calorimeter.

During 2005, the following works were done for the SND "off-line" mode software:

– A new version of the software assembly system (more flexible and productive) was developed;

– Attention was paid to the repeatability of data processing results. In particular, Read/Write procedures of objects in experimental files were reconsidered. It was decided not to use code compilation with optimization in data processing;

– Interactions with the SND "on-line" software was adjusted, that has allowed to organize the test run on cosmic events;

– The descriptions of geometry of the calorimeter and the muon system were completed for the MC simulation with Geant4;

– An algorithm of generation of ionization clusters was developed (but not yet realized) to expend the Geant4 program;

– Work was continued on reconstruction of the tracking system.

2. VEPP-2M data analysis.

Analysis of the process $e^+e^- \to \pi^+\pi^-$ is completed. The cross section of this process was measured in the energy domain $\sqrt{s}$ from 390 up to 980 MeV. Accuracy of the measurement is 1.3% for $\sqrt{s} \geq 420$ MeV and 3.2% at $\sqrt{s} < 420$ MeV. Energy dependence of the mesured cross section was analyzed within the framework of vector meson dominance model. The following parameters of the ρ-meson were determined:

$$\begin{aligned} &m_\rho = (774.9 \pm 0.4 \pm 0.5) \text{ MeV}, \\ &\Gamma_\rho = (146.5 \pm 0.8 \pm 1.5) \text{ MeV}, \\ &\sigma(\rho \to \pi^+\pi^-) = (1220 \pm 7 \pm 16) \text{ nb}. \end{aligned} \tag{1.1}$$

G-parity forbidden decay cross section $\sigma(\omega \to \pi^+\pi^-) = (29.9 \pm 1.4 \pm 1.0)$ nb was identified with high accuracy, that corresponds to relative decay probability $B(\omega \to \pi^+\pi^-) = (1.75 \pm 0.11)\%$. The relative phase between the ρ and ω mesons $\phi_{\rho\omega} = (113.5 \pm 1.3 \pm 1.7)^\circ$ was determined that contradicts to the value 101°, expected from the $\rho - \omega$ mixing. The measured cross sections agree within the combined systematic error of measurements 1.6% with cross sections calculated within the conserved vector current framework using τ lepton decay spectral function.

Using the measured cross section, the contribution to the anomalous magnetic moment of muon $(g-2)/2$ from the $\pi^+\pi^-\gamma$ intermediate state in the vacuum polarization has been calculated: $a_\mu(\pi\pi, 390 \text{ MeV} \leq \sqrt{s} \leq 970 \text{ MeV}) = (488.7 \pm 2.6 \pm 6.6) \times 10^{-10}$. In Fig.2 the ratio $\sigma_{exp}/\sigma_{fit}$ of the $e^+e^- \to \pi^+\pi^-$ cross sections, measured in different experiments, to the fit curve approximating the SND experimental data is shown.

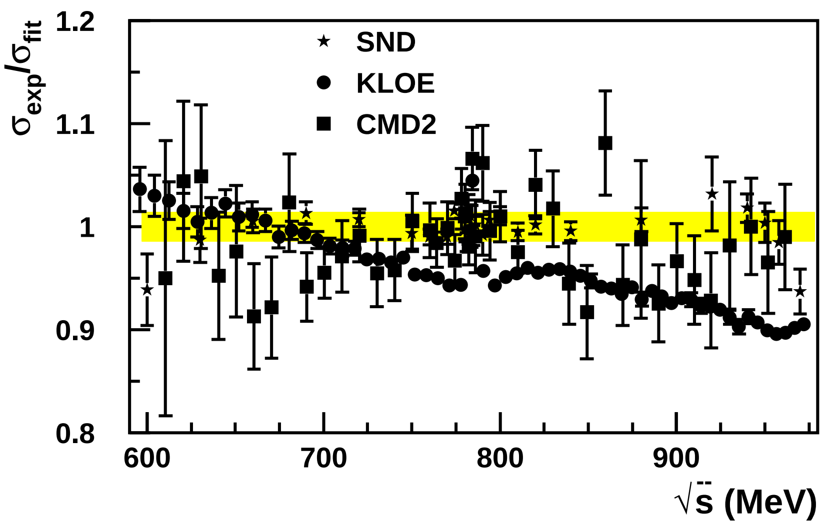

Figure 2: Ratio $\sigma_{exp}/\sigma_{fit}$ of the $e^+e^- \to \pi^+\pi^-$ cross sections, measured in different experiments, to the fit curve approximating the SND experimental data. The shaded area shows the systematic error of the SND measurements. The SND data, as well as the CMD-2 and CLOE results are presented.

3. Participation in international projects.

Data analysis was completed for the inclusive charmless B-meson decays. On the basis of the experimental statistics corresponding to the integrated luminosity of about 90 inverse femtobarns, Cabbibo-Kobayashi-Maskawa matrix element $|V_{ub}|$ was determined with about 10% accuracy, that is one of the most exact measurements of this fundamental parameter of weak interactions.

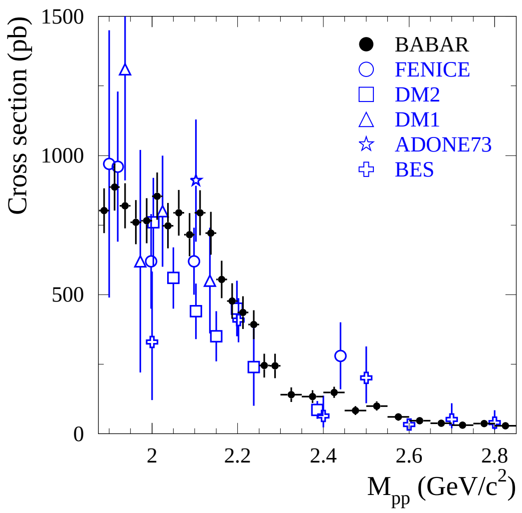

Figure 3: Cross section of the $e^+e^- \to p\bar{p}$ process near the threshold, measured by BABAR by using the ISR method and results of other e^+e^- experiments: FENICE, DM2, DM1, ADONE73, BES.

With use of the ISR method, based on registration of events with hard photon radiation from the initial particles, the proton electromagnetic form factor was measured from the threshold up to 4 GeV.

At present the results of this measurement are the most precise. In Fig.3 results of the $e^+e^- \to p\bar{p}$ process cross section measurement are presented.

4. Developments in experimental methodics.

In 2005 work was continued on creation of the system of drift chambers for the proton electromagnetic form factor measurement experiments at VEPP-3 accelerator of Budker INP. A test variant of the proportional chamber with cathode strips has been manufactured, its count rate as a function of voltage and time resolution were measured. The width of the count-rate plateau was 200 volts at an exposition of the Fe^{55} isotope; the time resolution measured on cosmic particles was 6 nanoseconds (RMS) at efficiency of registration more than 90 %. In the third and forth quarters of 2005 two proportional chambers intended directly for use in the VEPP-3 experiment were manufactured, preparation for their tests has begun.

Together with the laboratory 3-12, the contract work was finished in 2005 on delivery of the extended set of the X-ray radiation detector OD3 to Kurchatov center of synchrotron radiation (KSRS, Moscow). As the customer of works the Institute of theoretical and experimental biology has acted (Pushchino, the Moscow region). The detector will be used to study biological mechanisms of muscle contraction and in a wide spectrum of other biochemical researches. In 2005, the contract was concluded with the Institute of crystallography of the Russian Academy of Science on delivery of the OD3 detector with asymmetric cathode for work on the KSRS photon beam. The detector is completely furnished, tested and passportized. Term of delivery to Moscow – the first quarter of 2006.

1.3 Detector KEDR

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

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

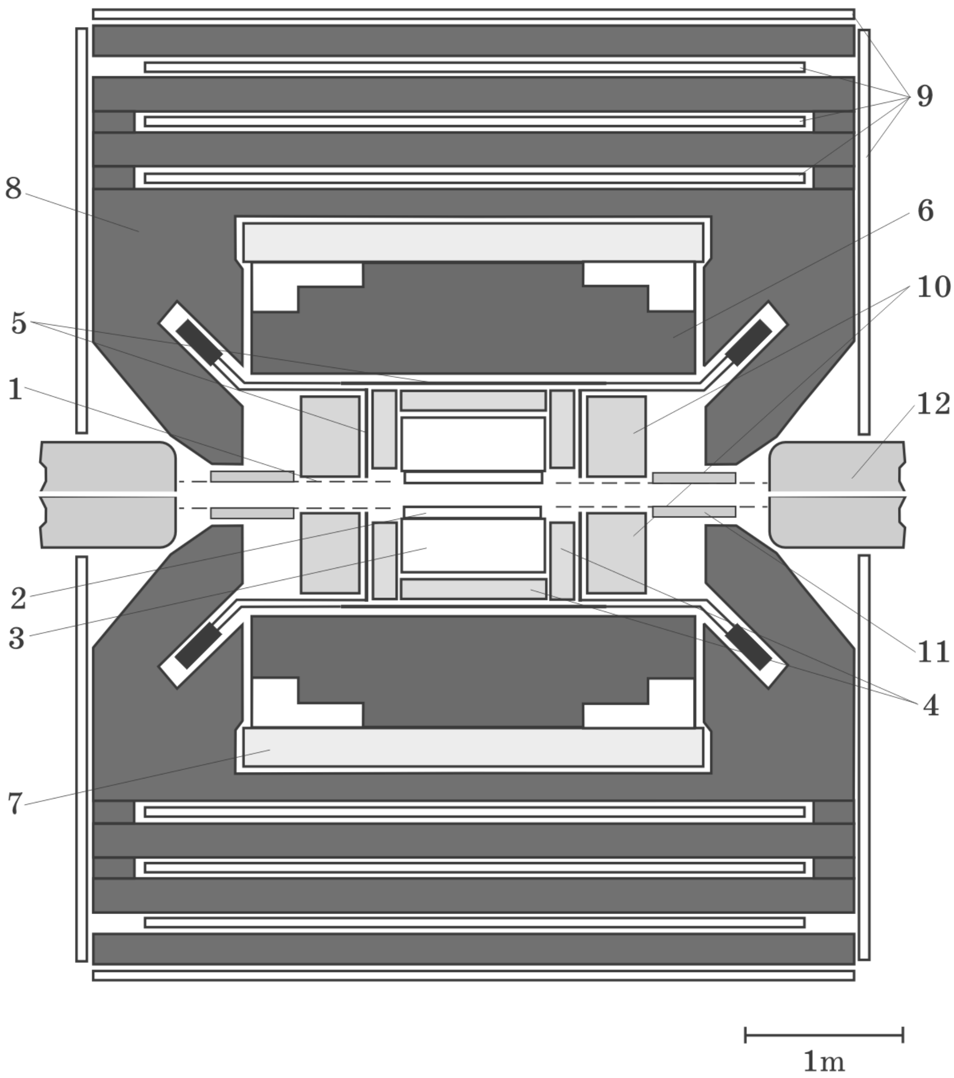

Figure 1: The KEDR detector. 1 - vacuum tube of the collider, 2 - vertex detector, 3 - drift chamber, 4 - aerogel Cherenkov counters, 5 - time of flight counters, 6 - liquid krypton barrel electromagnetic calorimeter, 7 - superconducting solenoid, 8 - magnet yoke, 9 - muon chambers, 10 - end cap electromagnetic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

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 inner radius is 125 mm, an external radius is 535 mm. Jet type cell with six anode wires is used in the drift chamber. Distance of drift is about 30 mm. Clean dimethyl ether (DME) is used as the working gas. Usage of DME in the cell of our type with the large drift distance, in which coordinate resolution is limited by diffusion, made it possible to obtain the average spatial resolution on the cell better than 100 mkm.

Chamber contains about 32000 wires, 1512 of them are sensitive. The length of the wires is 970 mm. Wires form 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 ensures π/k separation up to 600 MeV/c and K/p separation up to 1200 MeV/c at the 2 sigma level.

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

There is a program of the event 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.

During 2005, 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.

During year 2005 cutting of aerogel for the counters of the second layer of the system was finished. The new fastening design of PMTs in the counter which prevent PMT movement in the magnetic field was developed. The work on calibration of under threshold efficiency of the counters and development of the program code for particle identification are in progress now.

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

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

Liquid krypton barrel electromagnetic calorimeter. LKr calorimeter is the set of cylindrical ionization chambers with liquid krypton as working media. The inner radius of calorimeter is 75 cm and the thickness of active zone is 68 cm (14.8 radiation length). The total amount of liquid krypton is 27 tons. The electrodes of the ionization chambers are made of G10 foiled with copper and their thickness is 0.5 mm. The anode-cathode gap of chambers is 19.5 mm and high voltage is about 1 kV. The signal is read out from high voltage electrodes divided into rectangular pads forming towers oriented to the interaction point. In the radial direction, all the towers are divided into three sections. The eight grounded electrodes of the first section are divided into strips for the photon coordinates measurement. The total number of electronics channels is 7204; 2304 are towers, 4936 — strips.

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

In 2005, 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.

During this year, 83 channels (6.7% of total channel number) were broken. The main reason of channel break is a bad work of phototriodes in magnetic field.

Muon system. Muon system consists of 88 blocks of streamer tubes arranged in three layers inside the KEDR magnetic yoke. The total number of channels is 544. Muon system was used at all KEDR experiments during year 2005. Regular monitoring of system status is performed upon experimental data and calibrations by generator and cosmic events.

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

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

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

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

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

The TS includes 8 blocks of drift tube hodoscopes. Each block contains 6 double layers of drift tubes. Tubes have diameter of 6mm and allow to register scattered particles with a spatial 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.

Progress for year 2005. Six blocks were equipped with new electronics. The total set of electronics will be ready to summer of 2006. The amount of channels out of operation are 5-7%. All T-modules of digitizing electronics were changed to the new ones. The tuning of high voltage supply was performed. The accuracy of coordinate measurements is 0.3–0.4 mm. The triggering electronics were developed for tagging system. It helps significantly raise the detection efficiency for processes $\gamma\gamma \to \pi^0$ and $\gamma\gamma \to \pi^+\pi^-$. The track reconstruction program is developed for the whole system.

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%.

Main results in 2005:

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. Luminosity monitors interfere with measurements of beam energy with the help of backward scattering. We need to move aside luminosity monitor to made such measurements. The solution was found which permits to work with both systems at once. Presently beam energy is measured continuously – one measurement every 20 minutes with accuracy 50 keV.

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

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

Briefly, one can say that the trigger requires two charged particles with $P_t > 50$ MeV or two neutral particles with at least one of them having the energy more than 500 MeV. It was the first time in 2005 we used the neutral trigger from the barrel calorimeter independently of the end cap calorimeter.

In 2005, the tagging system has been added into the trigger; it is used for a study of two-photon processes. In the presence of one scattered electron the trigger requires two charged particles or one neutral.

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 2005 with a full range design 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 are 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 ever 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 day, in a mode of throttling. The piston type expander machine reduces the consumption down to 600 liters per 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 2005.

During 2005 the KEDR detector have collected data in the energy region of τ-lepton threshold and in the regions of J/ψ, ψ' и $\psi(3770)$ resonances. (Fig. 2).

Recorded luminosity integral was 3.6 pb^{-1}, the mean “recording” luminosity was $0.63 \cdot 10^{30}$ cm^{-2}s^{-1}. The ratio of time spent and malfunctions are presented in Figures 3, 4.

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

The exact measurement of τ–lepton mass together with the known values of its time of life and decay probabilities into electron, neutrino and anti-neutrino helps to perform exact testing of the hypothesis of lepton universality – one of the main postulates in weak interactions theory.

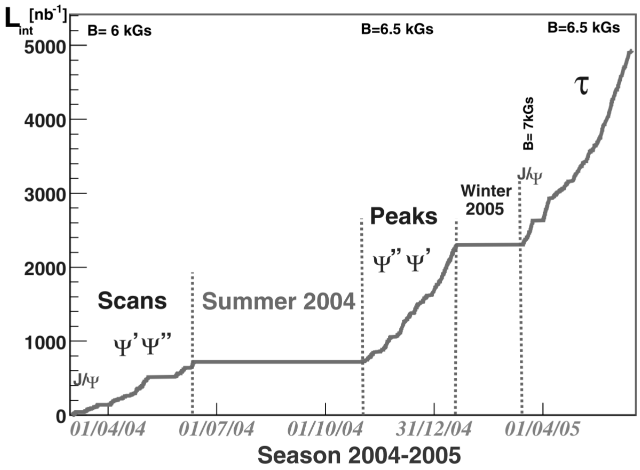

Figure 2: Rate of luminosity collection.

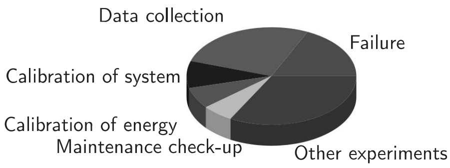

Figure 3: The ratio of time spend during experiment.

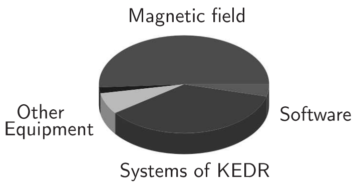

Figure 4: The ration of malfunctions of systems.

Up to now τ–lepton mass was measured with the required accuracy only in one experiment [1], several questions exist to its data processing procedure [2].

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

Preliminary results on τ–lepton production cross section near threshold are presented in Figure 5.

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

$$M_\tau = 1776.77^{+0.45}_{-0.35} \pm 0.10 \text{ MeV},$$

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

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

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

$$M_\tau^{KEDR} - M_\tau^{PDG} = -0.22^{+0.45}_{-0.35} \pm 0.10 \text{ MeV}.$$

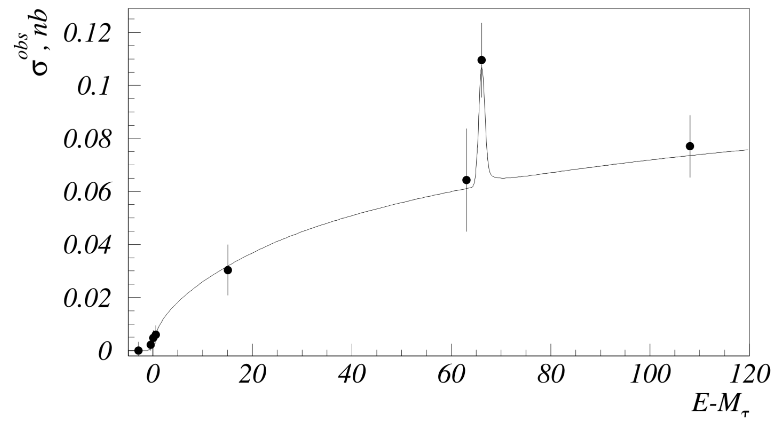

Figure 5: The observing τ–lepton production cross section near threshold (preliminary results).

We are planning to improve detection efficiency of $\tau\tau$ events. This will help to improve the accuracy of mass measurement to the level of world average. The further accuracy decrease need additional luminosity integral collection in 2006.

Processing of data collected in 2004 in the energy region of ψ'– and $\psi(3770)$ is in progress (Fig. 6). The preliminary results on masses of ψ' г $\psi(3770)$ and total width of $\psi(3770)$ were presented on European conference on particle physics in Lisbon [3].

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

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

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

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

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

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

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

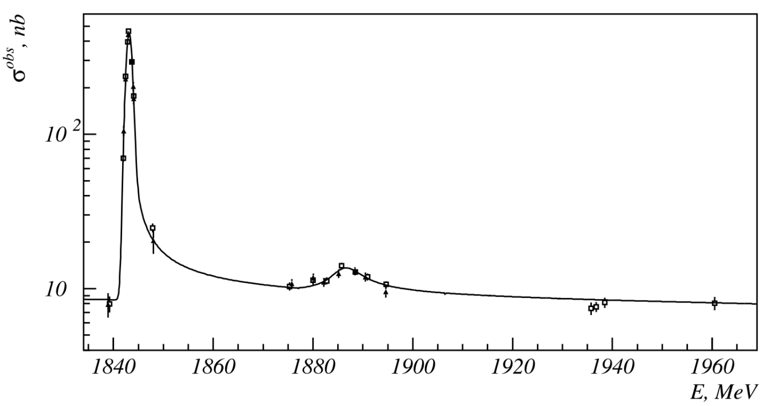

Figure 6: Observed production cross section of ψ'– and $\psi(3770)$–mesons (preliminary).

Literature :

1. J. Z. Bai *et al.* [BES Collaboration], Phys. Rev. D **53** (1996) 20.

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

3. V. V. Anashin *et al.* [KEDR/VEPP-4M], Proc. of International Europhysics Conference of High Energy Physics, Lisbon, Portugal, 2005 (to be published).

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

1.4 Detectors for HEP

On the SND detector, we continued the work on manufacture and adjustment of electronics for various systems of SND including:

- 80 peak detectors for data boards are produced;
- 6 interface boards are produced for the primary trigger of the drift chamber (PTI DC);
- Production of 11 of 20 input-output processors (In/Out) is completed;
- 60 data boards (T2A(M)) are produced and adjusted.

We continue production of electronics for the scattered electrons systems detecting (SEDS) of the KEDR detector.

Within the frame of the program for development of the general purpose electronics, we developed and produced some types of CAMAC units.

We have carried out the tests (under real conditions) of a 32-channel module for formation and digitizing of signals for the KMD-3 detector calorimeter, the correction was introduced into the basic circuit and printing board of the module. We have prepared an order for production of a pilot series of 6 pieces.

1.5 X-ray detectors

In 2005, we continued the intense work on a 256-channel one-coordinate detector DIMEX. We have selected the detector operating regimes providing the parameter stability. The detector was used in the real experiments on a study of dynamics of explosion.

On the second detector sample at 384 channels (DIMEX-384), we have changed the chips of electronics. The detector is being prepared for the real experiments instead of DIMEX-256, which is planned for the use in some other experiments.

In 2005, we continued the work with the OD-4 detector designed for experiments on a wide-angular scattering in synchrotron radiation. Compared to OD-3, where a wire structure is used, in OD-4, a multi-stage gas electron multiplier (GEM) is used, which enables both the high gas amplification (over 10000) and construction of the detector in the shape of an arc with an arbitrary angular aperture.

In 2005, we prepared the drawings of the OD-4 housing and placed the order on its manufacture to ZAO "Nauchpribor" (Oryol). A 32-channel prototype of electronics was developed and manufactured.

In 2005, at the Kurchatov SR Center, Moscow, the OD-3 detector was installed and put into operation with some components of the transport channel produced by the agreement with the Institute of Theoretical and Experimental Biology (Pushchino).

The similar detector with an asymmetric chamber is manufactured by the agreement with the Institute of Crystallography (Moscow). The detector at KSRC is planned to be assembled in March, 2006. The contract value is 1.85 mln roubles.

We started the upgrade of the OD-3 series detectors aimed at improvement of their reliability and parameters.

1.6 Other works:

Within the frame of the international projects, the section staff took an active participation in the work on the BELLE detector (KEK, Japan). Within the frame of the work on the detector upgrade, we develop prototypes of a new electronics for the barrel section of the calorimeter with CsI(Tl) crystals and the end cap with pure CsI.

In 2005, we made a large work on preparation of materials for production of electronics for the barrel section of the calorimeter in Japan.

The work is presented in: [109]

1.7 Micro-Pattern Gaseous Detectors

The development of detectors based on multi-GEM structures was continued in 2005. The work was performed in several directions:

1) Development of cryogenic avalanche detectors based on GEMs.

2)Upgrade of the KEDR tagging system.

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

I. 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 2005, the works on the cryostat with the 2 l test chamber operated in the temperature range of 77-300 K, inside which the triple-GEM was mounted, were continued (Phase 1). In parallel in collaboration with the group of Columbia University (Nevis laboratories), the works on He cryostat with the 1 l test chamber operated in the temperature range of 2-300 K , inside which the triple-GEM was mounted, were started (Phase 2).

The results obtained by the end of 2005 are summarized below.

Phase 1:

GEM-based two-phase Ar, Kr and Xe cryogenic detectors for coherent neutrino scattering, PET and dark matter searches. A specialized cryogenic (liquid nitrogen) setup was developed at the Budker Institute for this phase. For the first time, the successful operation of gaseous and two-phase (liquid-gas) avalanche detectors based on GEM structures has been demonstrated at cryogenic temperatures: in the two-phase mode in Ar, Kr and Xe and in the gaseous mode in He, Ar, Kr and Xe. The stable operation of GEM-based two-phase Ar avalanche detectors at high gains, reaching 10000, and of two-phase Kr and Xe avalanche detectors at moderate gains, reaching several hundreds, was observed.

Phase 2:

GEM-based He and Ne cryogenic detectors for solar neutrino detection. A specialized cryogenic (liquid helium) setup was developed at the Columbia University (Nevis Labs) for this phase. For the first time, the operation of GEM structures in gaseous He and Ne at rather low temperatures, down to 2.6 K in He and around 50 K in Ne, was demonstrated. The GEM operation in the Penning mixtures Ne+H_2 and He+H_2 provided very high gains, exceeding 10000, at cryogenic temperatures and high densities.

The design of a new GEM-based two-phase detector of a volume of 10 l, for operation in Ar and Xe, was completed. The implementation of its parts was started. The studies of cryogenic avalanche detectors will be continued in 2006.

II. The system of tagged electrons is a substantial part of the KEDR experiment; it allows for detecting electrons scattered from the colliding point at small angles. These electrons characterize photon-photon interaction and their detection and the measurement of their momentum is an important physical task. The existing system of tagged electrons based on drift tubes have a limited spatial resolution; it measures the particle coordinate in one direction only which substantially restricts the signal/background separation capability.

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

In 2005 the detectors in the arm of the spectrometer were mounted. Four detectors were fully tested using a radioactive source and were mounted at VEPP-4m. At the moment the detector operation in real conditions is studied.

III. In 2005 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, A. E. Bondar, A. F. Buzulutskov, A. A. Grebenuk (lab. 3.2), D. Pavlyuchenko, L. I. Shekhtman, R. G. Snopkov, Y. A. Tikhonov, A. A. Vasiljev, V. V. Zhulanov.

The work is reflected in the following papers:
[80], [81], [288], conference 2, preprint 130, preprint 131.

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 $1.63 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$, which is the highest luminosity ever achieved in the world.

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

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

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

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

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

For five and half years the detector BELLE has been storing the experimental data. At the end of 2005 the accepted integrated luminosity was more than 500 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 discussed 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.A. Sidorov, B.A. Shwartz, Yu.V. Usov, V.N. Zhilich.

1.9 The photon collider

In 2004, the project of International Linear Collider (ILC) was inaugurated (instead of TESLA, NLC, JLC) based on a superconducting technology (TESLA-like) [?]. In addition to the e^+e^- physics program, the ILC will provide an opportunity to study $\gamma\gamma$ and γe interactions, where high energy photons can be obtained using Compton backscattering of the laser light off the high energy electrons. The passed year was devoted to the choice of the baseline ILC configuration. The photon collider is the second stage of the ILC but there are many special requirements which should be included to the project from the very beginning. Our participation in the development and promotion of the photon collider can be seen from the list of talks at international conferences:

The interaction region for the photon collider [277].

Comparison of photon colliders based on e^-e^- and e^+e^- beams [278].

Crossing angle at the photon collider [279].

Photon collider at ILC [280].

Physics options at the ILC. GG6 summary at Snowmass2005 [281].

The Photon Colliders: first 25 years [282].

The Photon Colliders at ILC [283].

Technical Problems of Photon Colliders [284].

Stabilization of luminosity at the photon collider [285].

Crab crossing angle at the photon collider [286].

The construction of the laser system prototype is foreseen in plans of the accelerator test facility ATF2 at KEK [preprints 128–129].

Chapter 2

Electro - and photonuclear physics

2.1 Experiments utilizing internal targets

I. During 2005 the analysis of the data of the experiment on measurement of tensor powers T20, T21 and T22 in photo-disintegration of polarized deuteron was continued. Several analysis stages have been completed. A comparison of the preliminary results and some theoretical predictions are shown in Fig.1 . In general the calculations follow the data, however for a few kinematic regions, namely for T20 at high photon energy and small proton emission angle and for T22 at high photon energy and large proton emission angle, one can observe substantial discrepancies. To compare with the earlier experiment a part of data, where the acceptances of two experiments overlap, was selected. The results are shown in Fig. 2 together with theoretical predictions.

II. A study of the proton electromagnetic form-factors, the important properties of this particle, allows one to understand deeper the nature of the proton as well as a nature of interactions of its constituents - the quarks. Until not far ago, the proton form-factors (electric and magnetic) were determined by separation of longitudinal and transverse contribution to elastic electron – proton scattering (so called Rosenbluth technique). However recent measurements of the ratio of these two form factors, performed at TJNAF (Thomas Jefferson National Accelerator Facility, USA) using polarized method, showed significant discrepancy with the earlier measurements. This problem is being widely discussed. It is suggested that most probable source of this discrepancy is a validity of using a one-photon exchange approach for the interpretation of the results of unpolarized measurements.

Taking into account two-photon exchange contribution is a complicated task because of a lack of correct calculations (due to difficulties in accounting for proton excitations in the intermediate state) on the one hand, and because of absence of sufficiently accurate experimental data on the other hand. Two photon exchange contribution can be experimentally determined comparing the cross sections of electron-proton and positron-proton elastic scattering.

Such measurements at VEPP-3 have been planned to be carried out in 2005. Particle detector has been prepared (see Fig 3). However the experiment was postponed until 2006 due to a change in the schedule of the VEPP-4 Facility. Meanwhile the works to improve the stability of parameters of the hydrogen target have been carried out and a 100-hour test run has demonstrated a stable operation of the target. New volumes for Titanium sublimation pumps were designed and their manufacture will be completed soon. The pumps should substantially improve vacuum conditions in the experimental straight section of VEPP-3.

III. The preparation of the next experiment at VEPP-3 utilizing the tensor-polarized deuterium target – coherent photo production of neutron pion on the deuteron (see BINP Annual Report - 2004) – is continued.

This is one of fundamental processes for nuclear physics, it provides important information on the structure of pion–nucleon and nucleon–nucleon interactions. The effects connecting with spin-dependent components of nuclear forces are proposed to be studied in this reaction for the first time. The measurement will by carried out at VEPP-3 at photon energy 200–500 MeV and pion emission angle in a range 100°–140°, where these effects are predicted to be greatly pronounced.

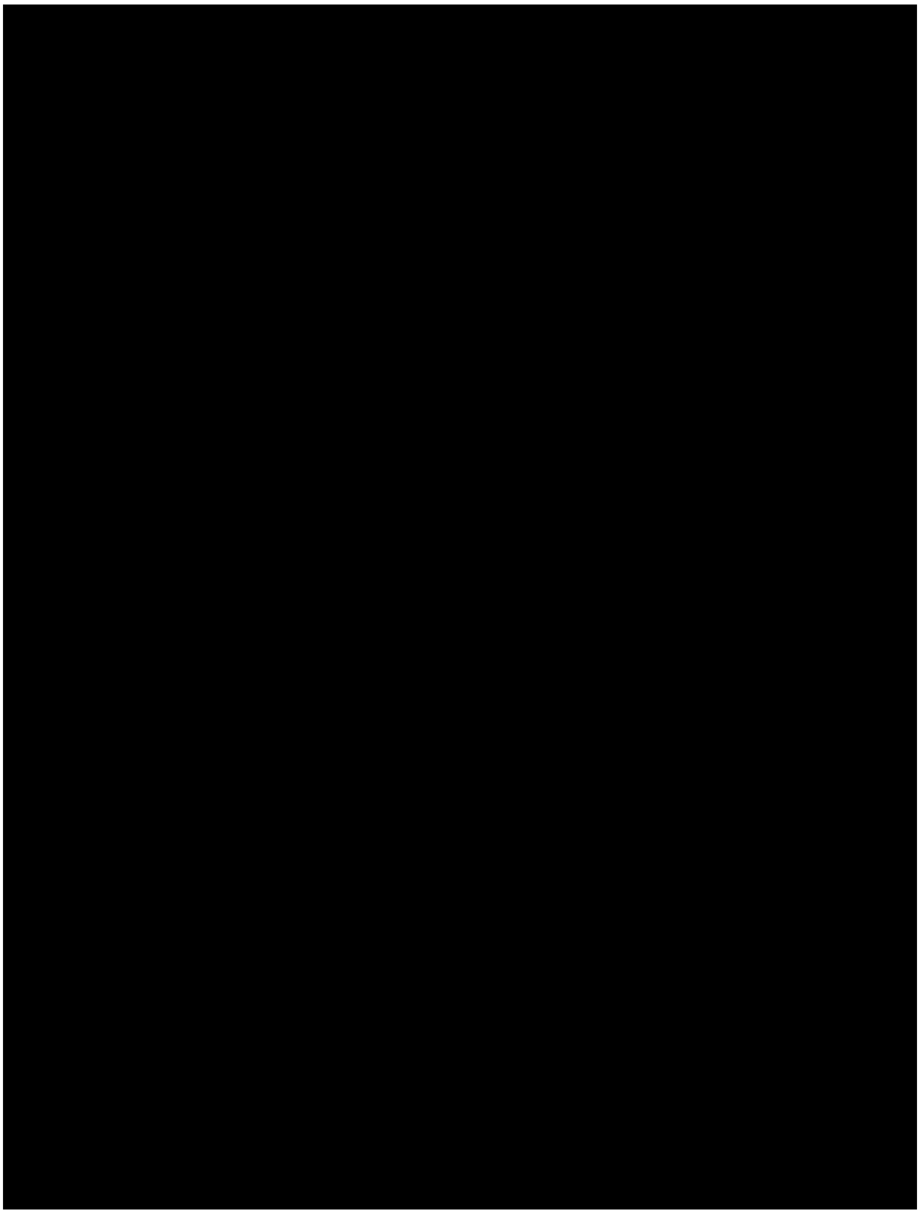

Figure 1: Preliminary results of the deuteron photo-disintegration experiment for tensor analyzing powers $\mathbf{T}_{20}$, $\mathbf{T}_{21}$, $\mathbf{T}_{22}$ for six ranges of photon energy as a function of proton emission angle. Curves are theoretical predictions: K.-M. Schmitt and H.Arenhoevel (solid lines), M.I. Levchuk (dashed lines).

A study of efficiency of High-Frequency spin transitions as a function of coordinate in the aperture of the RF Unit, where these transitions are induced, has been carried out. That was done in order to investigate the origins of low target polarization, observed in the previous experiment. The transition efficiency was found to be close to 100% for the whole aperture of the RF Unit. Further studies are being undertaken to find the source of low target polarization.

IV. The collaboration with Jefferson Laboratory, USA is continued. Physicists from BINP made a significant contribution to the preparation of the experiment on measuring the neutron electric form-factor at large transferred momentum - up to 3.5 GeV/c^2, which is more than twice larger than for existing data. The experiment will use longitudinally-polarized electron beam and polarized gas ^{3}He target. Scattered electron and recoil neu-

Figure 2: Preliminary results of the deuteron photo-disintegration experiment for tensor analyzing powers $\mathbf{T}_{20}$ and $\mathbf{T}_{22}$ as a function of photon energy. Full circles – this experiment, empty circles – data from earlier measurements (S.I. Mishnev *et al.*) Theoretical predictions are: solid curves – from K.-M. Schmitt and H. Arenhoevel, dotted lines – from M.I. Levchuk, dashed and dotted-dashed – from Yu.P. Melnik and A.V. Shebeko with $\lambda = 1.2$ GeV and $\lambda = 4\mathbf{m}_\pi$ respectively.

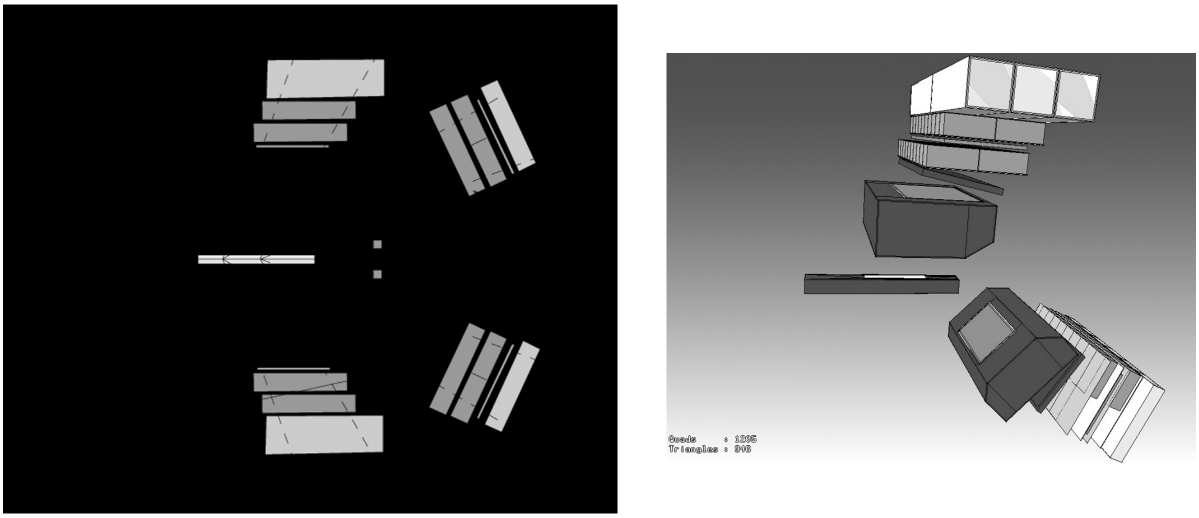

Figure 3: Left: a schematic diagram of the detector system of the experiment on determination of two-photon contribution to elastic electron-proton scattering. Right: a model of the detector for Monte-Carlo simulation with GEANT4.

tron will be detected in coincidence. BINP participants took part in the design, construction and commissioning of two new detectors for this experiment: BigBite – large-acceptance magnetic spectrometer of electrons, and BigHAND – big neutron detector, as well as in the development of trigger electronics and read-out software for these detectors. During 2005 the detectors were brought to a complete readiness. Data collection run will be carried out in February-May 2006.

In 2005 the analysis of data was completed and results were prepared for publication for the earlier experiment performed in JLab with BINP participation: a study of Real Compton Scattering on the Proton at large energy and angles. The analysis has demonstrated that in this kinematic region (s=5-11 GeV^2 and t=1.5-6.5 GeV^2) perturbative QCD, where transferred momentum is distributed between three active quarks by two gluon exchange, does not properly describe experimental data, while a "handbag" model – with one active quark absorbing and re-emitting the photon – shows a good agreement with the experiment. Results on measuring of polarized observables (polarization transfer from circularly-polarized photon to proton) have been already published in Phys. Rev. Letters.

By the contract with TJNAF an expertise of a complex superconducting magnet for Hall A has been performed with participation of other BINP's divisions: Laboratory-11, Experimental Shop, Department of Scientific-Design. This magnet is a key element of the new magnetic spectrometer which is proposed to be constructed in the frame of 12 GeV energy Upgrade project of the Thomas Jefferson National Accelerator Facility. The spectrometer is based on a set of big superconducting dipole and quadrupole magnets. The basic ideas which were put into the design of the spectrometer were verified; notes, remarks and recommendations were presented together with the analysis of technological feasibility and the expected cost of a construction of such magnets in the BINP Shop.

V. In 2005 a collaborative activity at the Institute of Modern Physics, Lanzhou, China in a frame of the joint grant of RFBR, Russia and NSFC, China was continued. At Lanzhou the Heavy Ion Storage Ring for the experiments with internal target is in commissioning stage. During 2005 the regimes of cluster target were studied with various gases including hydrogen and helium. In a case of hydrogen jet a target density of 2×10^{13} at/cm^2 has been obtained. It was found that to get an intense helium jet one has to achieve deeper cooling of the nozzle.

Experiments performed at BINP utilizing internal targets are carried out in a collaboration with physicists from Tomsk, St.-Petersburg, NIKHEF (Amsterdam, The Netherlands), ANL (Argonne, USA), IKF JGU (Mainz, Germany), Sacle (France).

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

Publication: [1] ÷ [11], [256] ÷ [261], preprint 48.

Chapter 3

Theoretical physics

3.1 Strong interaction

Gluon reggeization in QCD

V. S. Fadin

Nucl. Phys. Proc. Suppl. **146** (2005) 102-107

The Reggeization hypothesis can be proved using the "bootstrap" relations, required by the compatibility of the gluon Reggeization with the s-channel unitarity. It is extremely nontrivial, that an infinite number of the bootstrap relations for the multi-particle production amplitudes can be fulfilled if the Reggeon vertices and trajectory satisfy several bootstrap conditions. All these conditions are derived and all but one are proved to be satisfied.

Quark Regge trajectory in two loops from unitarity relations

A. V. Bogdan, V. S. Fadin

Phys. Atom. Nucl. **68** (2005) 1599-1615, [Yad. Fiz. **68** (2005) 1659-1675]

The two-loop quark Regge trajectory is obtained at arbitrary space-time dimension D using the s-channel unitarity conditions. Although explicit calculations are performed for massless quarks, the method used allows to find the trajectory for massive quarks as well. At D $\to$ 4 the trajectory turns into one derived earlier from the high-energy limit of the two-loop amplitude for the quark-gluon scattering. The comparison of two expressions, obtained by quite different methods, serves as a strict cross check of many intermediate results used in the calculations, and their agreement gives a strong evidence of accuracy of these results.

Non-forward BFKL pomeron at next-to-leading order

V. S. Fadin, R. Fiore

Phys. Lett. B **610** (2005) 61-66 [Erratum-ibid. B **621** (2005) 61-66]

The kernel of the BFKL equation for non-zero momentum transfer is found at next-to-leading order. It is presented in various forms depending on the regularization of the infrared singularities in "virtual" and "real" parts of the kernel. The infrared safety of the total kernel is demonstrated and a form free from the singularities is suggested.

Non-forward NLO BFKL kernel

V. S. Fadin, R. Fiore
Phys. Rev. D **72** (2005) 014018

Details of the calculation of the non-forward BFKL kernel at next-to-leading order (NLO) are offered. Specifically the calculation of the two-gluon production contribution is shown. This contribution was the last missing part of the kernel. Together with the NLO gluon Regge trajectory, the NLO contribution of one-gluon production and the contribution of quark-antiquark production which were found before it defines the kernel completely for any colour state in the t-channel, in particular the Pomeron kernel presented recently.

The gluon reggeization in perturbative QCD at NLO

V. S. Fadin
hep-ph/0511121

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

A proof of the reggeized form of amplitudes with quark exchanges

A. V. Bogdan, V. S. Fadin
Nucl. Phys. **B740**(2006) 36-57, hep-ph/0601117

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

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

V. S. Fadin, R. Fiore, M. G. Kozlov, A. V. Reznichenko
hep-ph/0602006

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

Is the BELLE result for the cross section $\sigma(e^+e^- \to J/\psi + \eta_c)$ a real difficulty for QCD ?

A.E. Bondar, V.L. Chernyak

Phys. Lett. **B 612** (2005) 215-222

It is shown that difficulties in reconciling the values of the cross section $\sigma(e^+e^- \to J/\psi + \eta_c)$ measured at BELLE and calculated within non-relativistic QCD (NRQCD) are caused not by some misinterpretation of the data or other exotic explanations, but by poor applicability of NRQCD to such processes.

We use general theory of hard exclusive processes in QCD together with more realistic models of relativistic wave functions of charmonium, and show that the BELLE result can be naturally explained.

Double charmonium production at B-factories

V.L. Chernyak

Proceedings of the International Conference "New Trends in High Energy Physics", pp. 123-130; 10-17 September 2005, Yalta, Ukraine (BITP, Kiev)

Described are the experimental results and various theoretical calculations of the cross sections of two charmonium production at B-factories BELLE and BABAR.

Correlator of heavy-quark currents at small q^2 in the large-β_0 limit

A.G. Grozin, C. Sturm

Eur. Phys. J. **C40** (2005) 157–164

The correlator of vector heavy-quark currents at small q^2 is considered in the large-β_0 limit. The leading IR renormalon ambiguity of the sum of the perturbative series is canceled by the UV renormalon ambiguity of the gluon condensate. Asymptotic behaviour of the perturbative series is obtained in a model-independent way, up to a single unknown normalization factor. Gluon-virtuality distribution functions for the perturbative correction are calculated.

B-meson distribution amplitudes

A.G. Grozin

Int. J. Mod. Phys. **A20** (2005) 7451–7484

B-meson light-cone distribution amplitudes are discussed in these lectures in the framework of HQET. The evolution equation for the leading-twist distribution amplitude is derived in one-loop approximation. QCD sum rules for distribution amplitudes are discussed.

Lectures on QED and QCD

A.G. Grozin

hep-ph/0508242, 103 p.

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

Summing next-to-next-to-leading logarithms in $b \to c$ transitions at zero recoil

A.G. Grozin
hep-ph/0509328, 12 p.

Perturbative corrections to $b \to c$ transitions at zero recoil are considered in the two-step matching scheme. The matching coefficient for the $b \to c$ currents from the intermediate effective theory (between the scales m_b and m_c) to the low-energy effective theory (scales below m_c) has been found with two-loop accuracy. The next-to-next-to-leading logarithms has been summed in the leading order in m_c/m_b. Higher-order corrections are estimated in the large-β_0 limit.

Loop corrections to the form factors in $B \to \pi l\nu$ decay

G.G. Kirilin,
eprint: hep-ph/0508235 (2005)

The semileptonic decay $B \to \pi l\nu$ has been studied. In particular the factorizable contribution to symmetry breaking corrections to the form factors at large recoil has been considered. Loop corrections to the hard Wilson coefficient and to the jet function have been calculated. It has been also demonstrated that the contribution of the so-called soft-messenger modes vanishes.

3.2 Quantum electrodynamics

Coulomb corrections to bremsstrahlung in electric field of heavy atom at high energies.

R.N. Lee, A.I. Milstein, V.M. Strakhovenko, and O. Ya. Schwarz
ZhETF **127** (2005) 5

The differential and partially integrated cross sections are considered for bremsstrahlung from high-energy electrons in atomic field with the exact account of this field. The consideration exploits the quasiclassical electron Green's function and wave functions in an external electric field. It is shown that the Coulomb corrections to the differential cross section are very susceptible to screening. Nevertheless, the Coulomb corrections to the cross section summed up over the final-electron states are independent of screening in the leading approximation over a small parameter $1/mr_{scr}$ (r_{scr} is a screening radius, m is the electron mass, $\hbar = c = 1$). Bremsstrahlung from an electron beam of the finite size on heavy nucleus is considered as well. Again, the Coulomb corrections to the differential probability are very susceptible to the beam shape, while those to the probability integrated over momentum transfer are independent of it, apart from the trivial factor, which is the electron-beam density at zero impact parameter. For the Coulomb corrections to the bremsstrahlung spectrum, the next-to-leading terms with respect to the parameters m/ε (ε is the electron energy) and $1/mr_{scr}$ are obtained.

Virtual light-by-light scattering and the g factor of a bound electron

R.N. Lee, A.I. Milstein, I.S. Terekhov, S.G. Karshenboim
Phys. Rev. **A 71** (2005) 052501

The contribution of the light-by-light diagram to the g factor of electron and muon bound in Coulomb field is obtained. For electron in a ground state, our results are in good agreement with the results of other authors obtained numerically for large Z. For relatively small Z our results have essentially higher accuracy as compared to the previous ones. For muonic atoms, the contribution is obtained for the first time with the high accuracy in whole region of Z.

The g factor of an electron or muon bound by an arbitrary central potential

S.G. Karshenboim, R.N. Lee, A.I. Milstein
Phys. Rev. **A 72** (2005) 042101

We consider the g factor of a spin-1/2 particle (electron or muon) bound by an arbitrary central field. We present an approach which allows one to express the relativistic g factor in terms of the binding energy. We derive the general expression for the correction to the g factor caused by a deviation of the central potential from the Coulomb one. As the application of this method, we consider the corrections to the g factor due to the finite nuclear size, including vacuum polarization radiative correction. The effect of the anomalous magnetic moment is also taken into account.

Laser-dressed vacuum polarization in a Coulomb field

A.I. Milstein, I.S. Terekhov, U.D. Jentschura, C.H. Keitel
Phys. Rev. **A 72** (2005) 052104

We investigate quantum electrodynamic effects under the influence of an external, time-dependent electromagnetic field, which mediates dynamic modifications of the radiative corrections. Specifically, we consider the quantum electrodynamic vacuum-polarization tensor under the influence of two external background fields: a strong laser field and a nuclear Coulomb field. We calculate the charge and current densities induced by a nuclear Coulomb field in the presence of a laser field. We find the corresponding induced scalar and vector potentials. The induced potential, in first-order perturbation theory, leads to a correction to atomic energy levels. The external laser field breaks the rotational symmetry of the system. Consequently, the induced charge density is not spherically symmetric, and the energy correction therefore leads to a "polarized Lamb shift." In particular, the laser generates an additional potential with a quadrupole moment. The corresponding laser-dressed vacuum-polarization potential behaves like $1/r^3$ at large distances, unlike the Uehling potential that vanishes exponentially for large r. Our investigation might be useful for other situations where quantum field theoretic phenomena are subjected to external fields of a rather involved structure.

Generation of circularly polarized photons for a linear collider polarized positron source

V.Strakhovenko, X.Artru, R.Chehab, and M.Chevallier
Nucl.Instrum.Meth. **A 547**(2005)320-333

Various methods of obtaining longitudinally polarized positrons for future linear colliders are reviewed . Special attention is paid to the schemes using circularly polarized high-energy photons for positron production. Most effectively such photons are obtained from electrons passing through a helical undulator or colliding with a circularly polarized laser wave. Spectrum and polarization of radiation emitted during helical motion of electrons are considered in detail. A new simple presentation of known formulas is used to account for the influence of the wave intensity, of the electron-beam angular divergence, of the collimation of radiation, and of the lateral and temporal profiles of the laser bunch on the radiation properties.

Results on the coherent interaction of high energy electrons and photons in oriented single crystals

A. Apyan,..., V. Strakhovenko,..., et al. (Na59 Collaboration)
Nucl.Instrum.Meth. **B 234**(2005)128-137

The CERN-Na59 experiment examined interactions of multi-GeV electrons and photons with oriented single crystals. The linearly polarized (up to 55%) photon beams were obtained from 178 GeV unpolarized electrons incident on an oriented Si crystal. A new crystal polarimetry technique was established for measuring the linear polarization of photons in the 20-170 GeV range. The polarimeter is based on the polarization dependence of the pair production cross section at the planar alignment of a crystal. Germanium and diamond crystal targets were used as analyzers. A birefringence phenomenon, the conversion of the linear polarization into circular one, was observed for photons with energies around 100 GeV.

Polarizing mechanisms for stored p and $\bar{p}$ beams interacting with a polarized target

A.I. Milstein and V.M. Strakhovenko
Phys.Rev. **E 72**(2005)066503

The kinetics of the polarization buildup during the interaction of stored protons (antiprotons) with a polarized target is considered. It is demonstrated that for small scattering angles, when a projectile remains in the beam, the polarization buildup is completely due to the spin-flip transitions. The corresponding cross sections turn out to be negligibly small for a hydrogen gas target as well as for a pure electron target. For the latter, the filtering mechanism also does not provide a noticeable beam polarization.

Conceptual design of a polarized positron source based on laser Compton scattering

S. Araki,..., V. Strakhovenko,..., et al.
physics/0509016 (2005)

A scheme is described for producing polarized positrons at the ILC from polarized γ-rays created by Compton scattering of a few-GeV electron beam off a CO_2 or YAG laser. This scheme is very energy effective using high finesse laser cavities in conjunction with an electron storage ring.

Coherent bremsstrahlung, coherent pair production , birefringence and polarimetry in the 20-170 GeV energy range using aligned crystals

A. Apyan,..., V. Strakhovenko,..., et al (Na59 Collaboration)
hep-ex/0512017 (2005)

The processes of coherent bremsstrahlung (CB) and coherent pair production (CPP) based on aligned crystal targets have been studied. The experimental arrangement allowed the measurement of single-photon cross sections. The used theoretical approach predicts both the cross sections and polarization observables very well for the experimental conditions investigated, indicating that the understanding of CB and CPP is reliable up to energies of 170 GeV. Also new results are presented for photon emission at the Strings-Of-Strings (SOS) orientation, where the enhancement of hard photon radiation is larger than in the CB case.

Radiation from polarized electrons in oriented crystals at high energy

V. N. Baier and V. M. Katkov
Nucl. Instr. and Meth.,**B 234**(2005) 106-115

Radiation from high energy electrons in an oriented crystal can be considered in a frame of the quasiclassical operator method which appears to be a most satisfactory approach to the problem. Under some quite generic assumptions the general expression is derived for the probability of circularly polarized photon emission from the longitudinally polarized electron in oriented crystal. The particular mechanism of radiation depends on interrelation between the angle of incidence ϑ_0 (angle between the momentum of initial electron and axis (plane) of crystal) and angle $\vartheta_v \equiv V_0/m$ (V_0 is the scale of a potential of axis or a plane relative to which the angle ϑ_0 is defined). When $\vartheta_0 \ll \vartheta_v$ one has magnetic bremsstrahlung type of radiation (with corrections $\propto \vartheta_0^2$ which are due to inhomogeneous character of field in crystal). When $\vartheta_0 \gg \vartheta_v$ one obtains the theory of coherent bremsstrahlung, while for $\vartheta_0 \geq \vartheta_v$ one arrives to the modified theory of coherent bremsstrahlung. At high energy radiation in oriented crystals is strongly enhanced comparing with standard bremsstrahlung.

Concept of Formation Length in Radiation Theory

V. N. Baier and V. M. Katkov
PHYSICS REPORTS, 409 (2005) 261-359

The features of electromagnetic processes are considered which connected with finite size of space region in which final particles (photon, electron-positron pair) are formed. The longitudinal dimension of the region is known as the formation length. If some external agent is acting on an electron while traveling this distance the emission process can be disrupted. There are different agents: multiple scattering of projectile, polarization of a medium, action of external fields, etc. The theory of radiation under influence of the multiple scattering, the Landau-Pomeranchuk-Migdal (LPM) effect, is presented. The probability of radiation is calculated with an accuracy up to "next to leading logarithm" and with the Coulomb corrections taken into account. The integral characteristics of bremsstrahlung are given. The LPM effect for pair creation is also presented. The multiple scattering influences also on radiative corrections in a medium (and an external field too) including the anomalous magnetic moment of an electron and the polarization tensor as well as coherent scattering of a photon in a Coulomb field. The polarization of a medium alters the radiation probability in soft part of spectrum. Specific features of radiation from a target of finite thickness include: the boundary photon emission, interference effects for a thin target, the multi-photon radiation. The experimental study of LPM effect is described. For electron-positron colliding beams following items are discussed: the mechanisms of radiation, the beam-size effect in bremsstrahlung, the coherent radiation and mechanisms of electron-positron creation.

Summary of experimental studies, at CERN, on a positron source using crystal effects

X.Artru, V.Baier, K.Beloborodov, A.Bukin, S.Burdin, T.Dimova,
V.Druzhinin, M.Dubrovin, V.Golubev, S.Serednyakov, V.Shary, V.Strakhovenko
(International Collaboration: Russia, France, Germany, Switzerland, total 28 authors)
Nucl. Instr. and Meth., **B 240** (2005) 762-776

A new kind of positron source for future linear colliders, where the converter is an aligned tungsten crystal, oriented on the $< 111 >$-axis, has been studied at CERN in the WA103 experiment with tertiary electron beams from SPS. In such sources the photon resulting from channeling radiation and coherent bremsstrahlung create the e^+e^- pairs.

Electron beams, of 6 and 10 GeV, were impinging on different kinds of targets: a 4 mm thick crystal, a 8 mm thick crystal and a compound target made of 4 mm thick crystal followed by 4 mm amorphous disk. An amorphous tungsten target 20 mm thick was also used for the sake of comparison with the 8 mm crystal and to check the ability of detection system to provide the correct track reconstruction. The charged particles coming out from the target were detected in a drift chamber immersed partially in a magnetic field. The reconstruction of the particle trajectories provided the energy and angular spectrum of the positrons in a rather wide energy range (up to 150 MeV) and angular domain (up to 30°). The experimental approach presented in this article provides a full description of this kind of source. A presentation of the measured positron distribution in momentum space (longitudinal versus transverse) is given to allow an easy determination of the available yield for a given momentum acceptance. Results on photons, measured downstream of the positron detector, are also presented. A significant enhancement of photon and positron production is clearly observed. This enhancement, for 10 GeV incident beam, is of 4 for the 4 mm thick crystal and larger than 2 for 8 mm thick crystal. Another important results concerns the validation of the stimulation for the crystals, for which a quite good agreement was met between the stimulation and the experiment, for positrons as well as for photons.

Coherent and incoherent pair creation by a photon in oriented single crystal

V. N. Baier and V. M. Katkov
Physics Letters, **A 346** (2005) 359-366

q The new approach is developed for study of electron-positron pair production by a photon in oriented single crystal. It permits indivisible consideration of both coherent and incoherent mechanisms of pair creation and includes the action of field of axis (or plane) as well as the multiple scattering of particles of the created pair (the Landau-Pomeranchuk-Migdal (LPM) effect). From obtained integral probability of pair creation, it follows that multiple scattering appears only for relatively low energy of photon, while at higher photon energy the field action excludes the LPM effect. The found probabilities agree quite satisfactory with recent CERN experiment.

3.3 Electroweak theory

Vacuum polarization radiative correction to the parity violating electron scattering on heavy nuclei

A.I. Milstein, O.P. Sushkov
Phys. Rev. **C 71** (2005) 045503

The effect of vacuum polarization on the parity violating asymmetry in the elastic electron-nucleus scattering is considered. Calculations are performed in the high-energy approximation with an exact account for the electric field of the nucleus. It is shown that the radiative correction to the parity violating asymmetry is logarithmically enhanced and the value of the correction is about -1%.

Effects of core polarization on the nuclear Schiff moment

V.F. Dmitriev, V.V. Flambaum, R.A. Sen'kov, N. Auerbach
Phys.Rev.**C 71** (2005) 035501

Schiff moments were calculated for a set of nuclei with full account of core polarization effects. A finite range P and T violating weak nucleon-nucleon interaction has been used in the calculations. While in the absence of core polarization the Schiff moment depends on one combination of the weak interaction constants, in the presence of core polarization the Schiff moment depends on all three constants separately. The dominant contribution comes from isovector, $\Delta T = 1$, part of the weak interaction. The effects of core polarization were found to have in general a large effect on the Schiff moments.

On shielding of nuclear electric dipole moments in atoms

V.F. Dmitriev, I.B. Khriplovich, R.A. Sen'kov
hep-ph/0504063

We demonstrate explicitly that some recent calculations of atomic electric dipole moments (EDM) are incomplete. A contribution overlooked therein is pointed out. When included, it cancels exactly the result of those calculations, and thus restores the standard conclusions for nuclear EDM in atoms.

3.4 Gravity

Discrete quantum gravity in the framework of Regge calculus formalism

V.M.Khatsymovsky
ZhETF 128(3) (2005) 489.

An approach to the discrete quantum gravity based on the Regge calculus is discussed which was developed in a number of our papers. Regge calculus is general relativity for the subclass of general Riemannian manifolds called piecewise flat ones. Regge calculus deals with the discrete set of variables, triangulation lengths, and contains continuous general relativity as a particular limiting case when the lengths tend to zero. In our approach the quantum length expectations are nonzero and of the order of Plank scale $10^{-33}cm$. This means the discrete spacetime structure on these scales.

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

V.M.Khatsymovsky
E-print archive gr/qc/0506072, to appear in Physics Letters B.

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

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

A.A. Pomeransky
Phys. Rev. **D 73** (2006 044004), e-print: hep-th/0507250 (2005)

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

Remark on Immirzi Parameter, Torsion, and Discrete Symmetries

I.B. Khriplovich, A.A. Pomeransky
e-print: hep-th/0508136 (2005), accepted for publication in Phys. Rev. D

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

Quantized Black Holes, Their Spectrum and Radiation

I.B. Khriplovich

World Scientific, to be published; gr-qc/0506082

Under quite natural general assumptions, the following results are obtained. The maximum entropy of a quantized surface is demonstrated to be proportional to the surface area in the classical limit. The general structure of the horizon spectrum is found. The discrete spectrum of thermal radiation of a black hole fits the Wien profile. The natural widths of the lines are much smaller than the distances between them. The total intensity of the thermal radiation is estimated.
In the special case of loop quantum gravity, the value of the Barbero – Immirzi parameter is found. Different values for this parameter, obtained under additional assumption that the horizon is described by a U(1) Chern – Simons theory, are demonstrated to be in conflict with the firmly established holographic bound.

Quasinormal modes for arbitrary spins in the Schwarzschild background

I.B. Khriplovich, G.Yu. Ruban
Symm. Integr. Geom. 1 (2005) 013; gr-qc/0511056

The leading term of the asymptotic of quasinormal modes in the Schwarzschild background, omega n = - i n/2, is obtained in two straightforward analytical ways for arbitrary spins. One of these approaches requires almost no calculations. As simply we demonstrate that for any odd integer spin, described by the Teukolsky equation, the first correction to the leading term vanishes. Then we derive analytically the general expression for this correction for all spins, described by the Teukolsky equation.

Quantum corrections to spin effects in general relativity

G.G. Kirilin,
Nucl. Phys. **B 728** (2005) 179, eprint: gr-qc/0507070

Quantum power corrections to the gravitational spin-orbit and spin-spin interactions, as well as to the Lense-Thirring effect, were found for particles of spin 1/2. These corrections arise from diagrams of second order in Newton gravitational constant G with two massless particles in the unitary cut in the t-channel. The corrections obtained differ from the previous calculation of the corrections to spin effects for rotating compound bodies with spinless constituents.

3.5 Nonlinear dynamics and chaos

Dynamics of Hamiltonian Systems under Piecewise Linear Forcing.

V.V.Vecheslavov, JETP **100**, No.4 (2005), p.811

A two-parameter family of smooth Hamiltonian systems perturbed by a piecewise linear force is analyzed. The systems are represented both as maps and as dynamical systems. Currently available analytical and numerical results concerning the onset of chaos and global diffusion in such systems are reviewed. Dynamical behavior that has no analogs in the class of systems with analytic Hamiltonian is described. A comparison with the well-studied dynamics of a driven pendulum is presented, and essential differences in dynamics between smooth and analytic systems are highlighted.

Contribution from the Secondary Harmonics of a Disturbance to the Separatrix Map of the Hamiltonian System

V.V.Vecheslavov
TechPhys **50**, No.7 (2005), p.821

The special role of low-frequency secondary harmonics with frequencies that are sums of and differences between primary frequencies entering into the Hamiltonian in explicit form has been already discussed in the literature. These harmonics are of the second order of smallness and constitute a minor fraction of the disturbance. Nevertheless their contribution to the amplitude of the separatrix map of the system may be several orders of magnitude higher then the contribution from primary harmonics end, thereby, govern the formation of dynamic chaos. This work generalized currently available theoretical and numerical data on this issue. The role of secondary harmonics is demonstrated with a pendulum the disturbance of which in the Hamiltonian is represented by two asymmetric closely spaced high-frequency harmonics. An analytical expression for the contribution of the secondary harmonics to the separatrix map amplitude for this system [s derived. Theoretical predictions are compared with numerical date.

Quantum synchronization

O.V. Zhirov and D.L. Shepelyansky,
e-print: cond-mat/0507029 (2005), accepted for publication in Eur. Phys. Journal D

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

Dissipative decoherence in the Grover algorithm

O.V. Zhirov and D.L. Shepelyansky,
e-print: quant-ph/0511010 (2005), accepted for publication in Eur. Phys. Journal D.

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

Disordered environment and dephasing in quantum electron transport through ballistic quantum dots

Valentin V. Sokolov
To appear in the special issue of Math. and General A .

Weak interaction with the disordered environment partly suppresses chaotic quantum interference of electrons in ballistic quantum dots. In the framework of the random matrix theory we propose a microscopic model of the quantum dephasing, which in the case of isolated doorway electron resonances perfectly reproduces the results of Buettiker's phenomenological model of dephasing. However, when these resonances strongly overlap the residual interference because of repopulation of the doorway states by the particles reinjected by the environment manifests itself as the weak localization effect. We consider how the weak absorption in the environment, which is accounted for by the widths of quasi-particles, influences the weak localization. We discovered that the size of the transient domain between the perfect reflection and perfect absorption exponentially sensitive to the quasi-particle widths. For the second limiting case, our results are identical to those of the Efetov's homogeneous imaginary potential model while in the transient region we express the mean transport cross section in terms of the distribution of the decay rates of the form factor of the S-matrix two-point autocorrelation function. We analytically calculate this distribution, which is of a great interest by itself, for the case of Gaussian Unitary Ensemble relevant in the case of presence of an external magnetic field.

Quantum dephasing and decay of classical correlation functions in chaotic systems

Valentin V. Sokolov, Giuliano Benenti, Giulio Casati
Quant-ph/0504141 v2 5 Sep 2005; Submitted in Phys. Rev. Lett.

We relate the decay of the quantum Loschmidt echo with the dephasing induced in the system by the internal classical chaotic motion in the absence of any external environment. In the semiclassical limit, the echo is expressed in terms of an appropriate classical correlation function. We show this analytically by the example of a nonlinear driven oscillator and then demonstrate it numerically for the kicked rotor model.

Chapter 4

Plasma physics and controlled thermonuclear fusion

4.1 First results of experiments with the compact mirror in GDT

In 2005, experiments aimed at generation and confinement of the dense anisotropic ion plasmoid were continued in the gas dynamic trap linear system (so called Synthesized Hot Ion Plasmoid or SHIP experiments). In these experiments, population of ions having energies of 5-10 keV with the density $\sim 10^{13}$ cm^{-3} was produced in the additional compact mirror section attached to the GDT end. Compact mirror experiment was deemed as an approach to study fast ion plasmas with a narrow angular distribution ($\sim 5^{\circ}$). Under such conditions one can reach boundaries of instabilities caused by asymmetry of particle distribution in the phase space. Also projected experiment parameters are close to that expected in testing zones of the neutron source based on the gas dynamic trap concept, which was proposed recently [P.A.Bagryansky et al., Fusion Engineering and Design, 70, 13-33 (2004)].

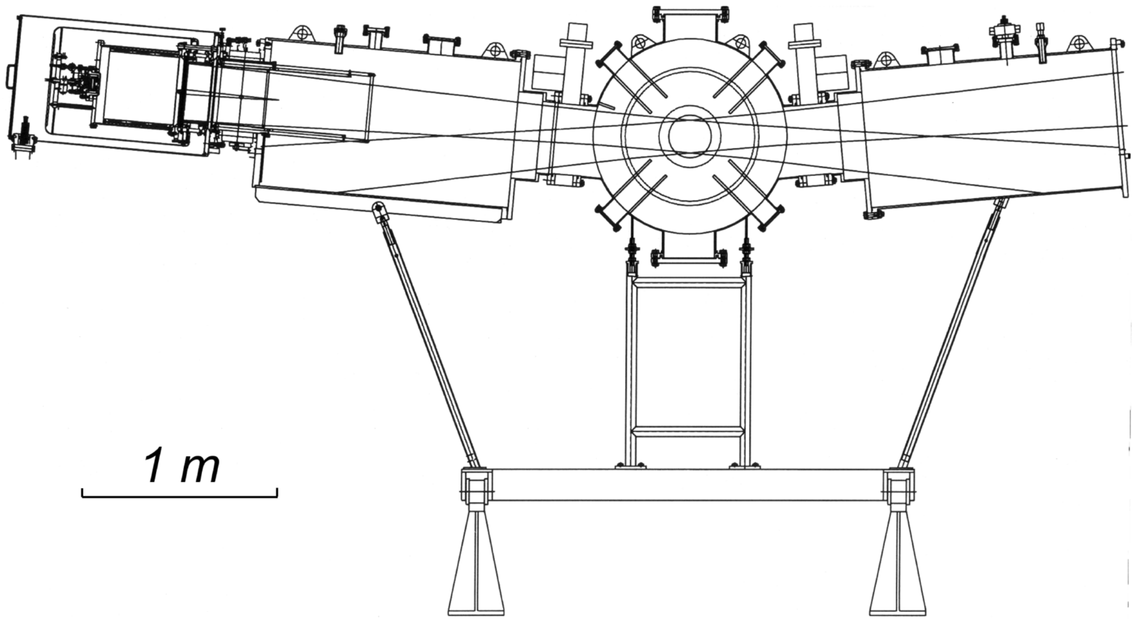

Figure 1: View of the compact mirror vessel and one of neutral beam injectors.

Preparational work for this experiment required modification of mirror unit design, namely, an additional magnetic field coil and a compact vacuum vessel were installed (Fig.1, 2). Corresponding axial profile of magnetic field is shown in Fig. 3. The small mirror formed by these means, has magnetic field in the central plane of 2.5 T and mirror ratio of 2 for the mirror-to-mirror distance of 43 cm.

The experiment scenario was as following. Compact mirror section is filled with background plasma streaming in from the central cell. The density of streaming plasma is n$\approx 10^{13}$ см$^{-3}$ and electron temperature about 60 eV. Two focused hydrogen beams perpendicularly inject a total current 15 Atom Amperes with the energy of 17 keV in the 0.8 ms pulse. According to beam calorimetry measurements, total beam energy amounted $W_{beam} \approx 200$ J, characteristic beam diameter was $2R_{beam}$=8 cm.

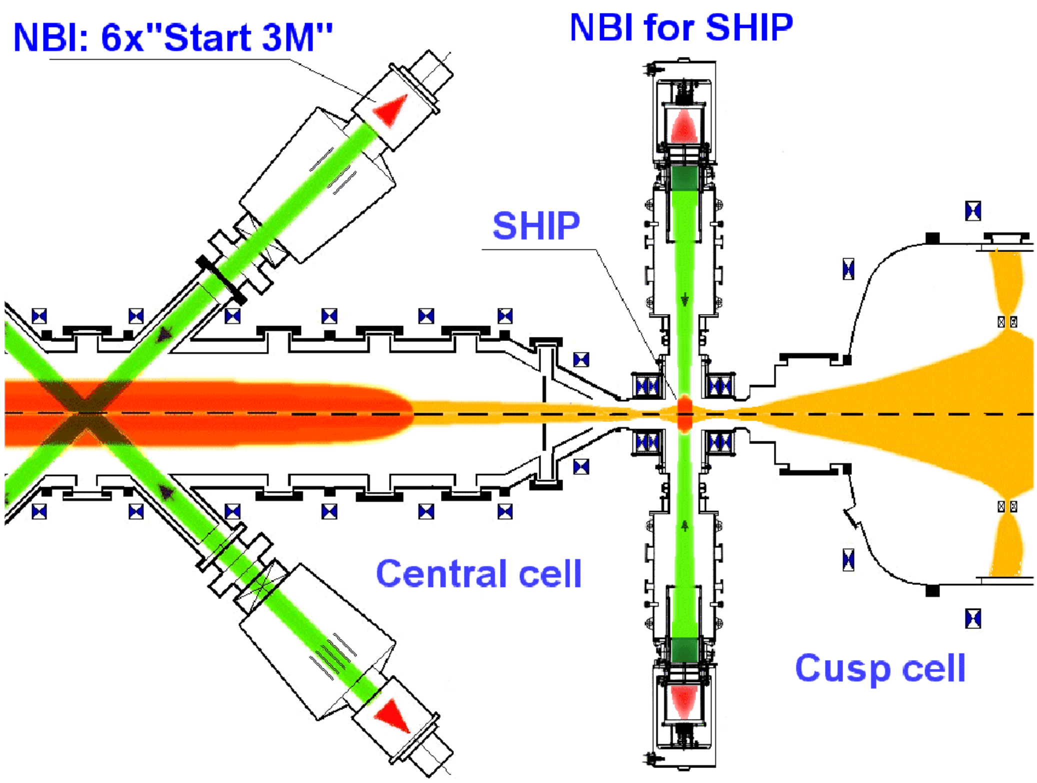

Figure 2: Compact mirror section mounted between the GDT central cell and the expander vessel.

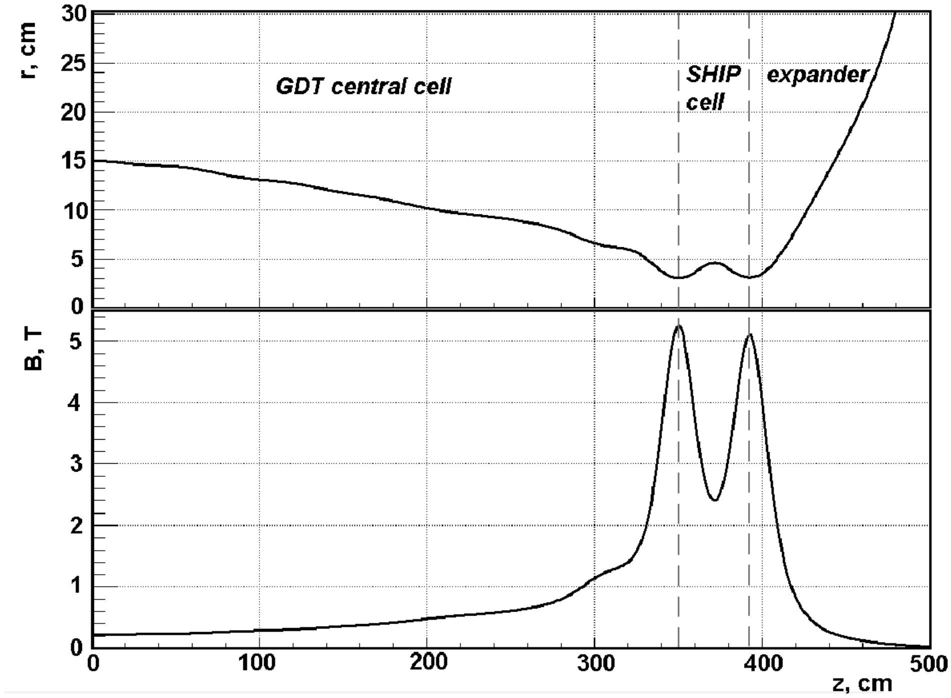

Figure 3: Profile of the magnetic field force line corresponding to the radius r0=15 cm (at the central plane) and magnetic field axial profile (bottom).

For measurements of charge-exchange power losses, several pyroelectric bolometers were installed at the vacuum chamber wall. One of them had a capability to move along the mirror axis. It allowed to obtain the axial distribution of the energy flux on the wall, see Fig. 4. The profile width at 1/e level is 8 cm; flux decreases rapidly with increase of the distance to the center. This observation can be qualified as an evidence that the main contribution to the transverse energy loss is made by charge-exchange of fast ions having small axial velocity. Thus, we can neglect energy losses to both end walls and the total charge-exchange loss power can be easily calculated as W_{CX} =7.5 kW (Fig. 5).

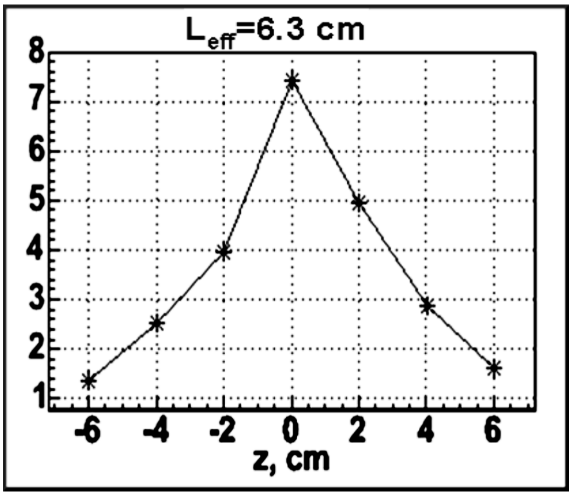

Figure 4: Axial profile of charge-exchange power losses on the side wall.

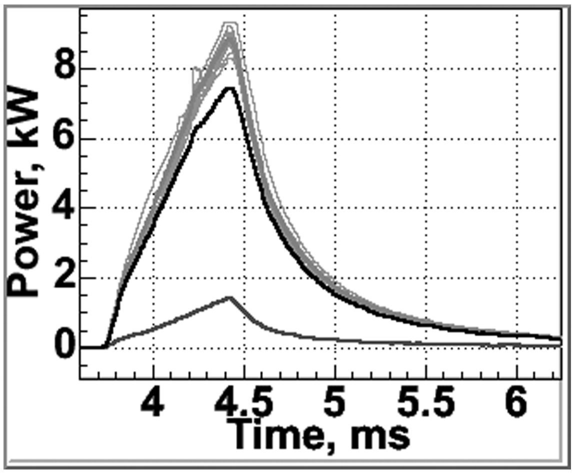

Figure 5: Total power of charge-exchange losses.

Important to note, that this value agrees with the estimated loss power of fast ions due to neutralization in the warm atom cloud formed by charge-exchange collisions beam particles and background plasma ions.

One can conclude that no significant particle losses caused by gas recycling from the wall were observed. One is the most important diagnostic task was monitoring of the electron density in experiment. For this purpose, the dispersion interferometer based on a CO_2 laser was used. Fig. 6 shows time evolutions of electron linear density during neutral beam injection (NBI) into the SHIP cell (red line) and without injection (black line) measured by dispersion interferometer. Enhancement of electron density from $<n_e l>=0.8 \cdot 10^{14}$ см$^{-2}$ to $<n_e l>=1.8 \cdot 10^{14}$ см$^{-2}$ caused by neutral beams indicates build up and confinement of fast ions in the compact mirror. Comparison of electron linear densities with NBI and without NBI allowed us to estimate the maximal value of fast ion linear density $<n_f l>=1.4 \cdot 10^{14}$ см$^{-2}$ and linear density of the streaming plasma $<n_w l>=0.4 \cdot 10^{14}$ см$^{-2}$ during NBI pulse. We can conclude that the average value of fast ion density is two times greater than density of unperturbed streaming plasma and it three times exceeds the warm ion density in the presence of NBI.

Fig. 7 shows the spatial profile of fast ion density measured by imaging energy analyzer of fast neutrals [S.V.Murakhtin, and V.V.Prikhodko, Transactions of Fusion Science and Technology 47, pp. 315-317 (2005)]. Measured profile was normalized to the value of fast ion linear density $<n_f l>=1.4 \cdot 10^{14}$ см$^{-2}$ acquired by the dispersion interferometer. Maximal fast ions density amounts $n_{fast} = 1.2 \cdot 10^{13}$ см$^{-3}$, axial width at 1/e level is 5 cm, diameter is 13 cm.

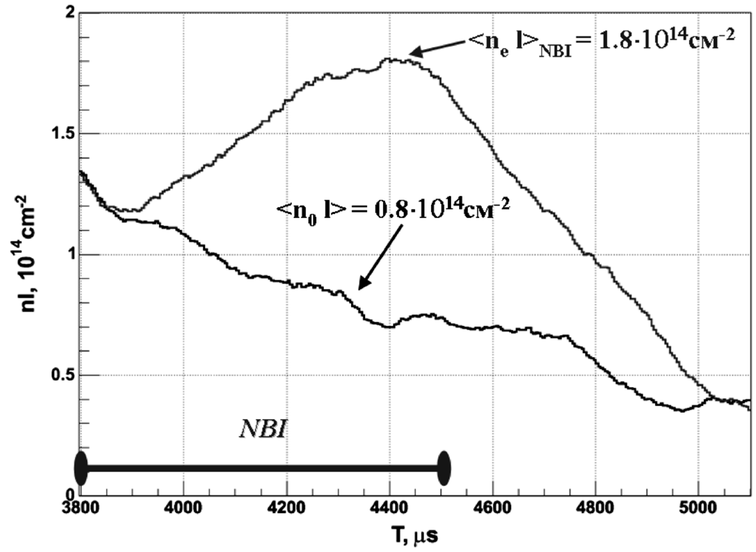

Figure 6: Electron line-integrated density in the compact mirror: upper curve - with neutral beams injection, lower curve - no injection.

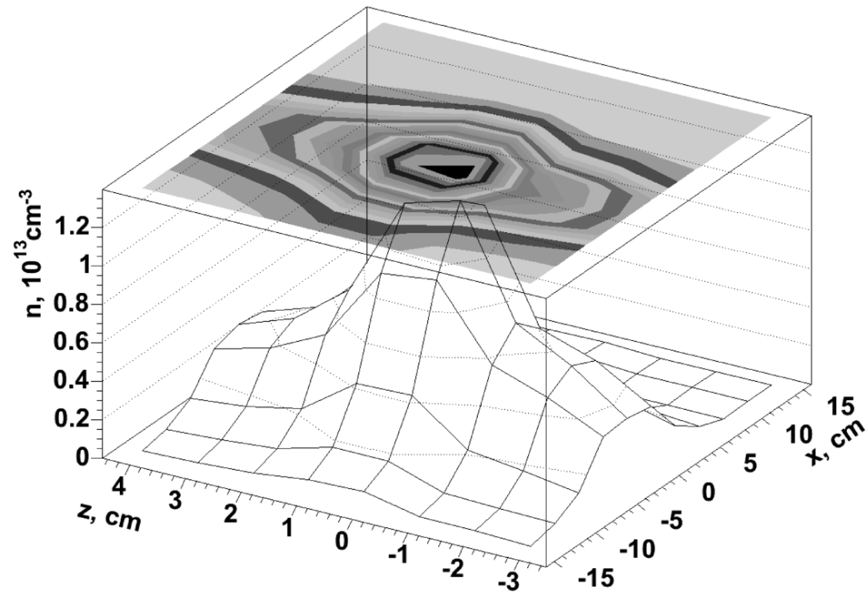

Figure 7: Density of fast ions in the compact mirror.

The mean energy of anisotropic ions was measured as 6 keV. According to measurement results, ions with different energies have similar spatial profile, thus allowing to calculate total energy content as an integral of the distribution multiplied by the mean energy.

Based on the estimation, maximal energy content of the ion population is W_{ship} = 8 J. Similar results were also obtained by the diamagnetic probe measurements, see Fig. 8. The same figure also shows results of numerical modeling by means of ITCS Monte-Carlo code [A.V. Anikeev et al., Transaction of Fusion Science and Technology 47 pp.212-214 (2005)]. Integrated transport code system (ITCS) was developed in collaboration with Research Centre Rossendorf (Forschungszentrum Rossendorf) for modeling of plasma confinement in axially symmetric mirror devices. It comprises several modules for calculation of gas profiles, distributions of background plasma and fast ions taking into account interaction between them. Agreement between experimental observations and ITCS calculation results permits to summarize that fast ion confinement is mostly determined by binary Coulomb collisions and charge exchange processes on injected beams and background plasma (ITCS considers only that processes). Any remarkable plasma losses caused by instabilities or additional charge exchange due to wall gas recycling, were not encountered. In experiments with the compact mirror an evidence of development of ambipolar potential was observed. Rise of ambipolar potential is connected with build-up of fast ion density exceeding density of background plasma.

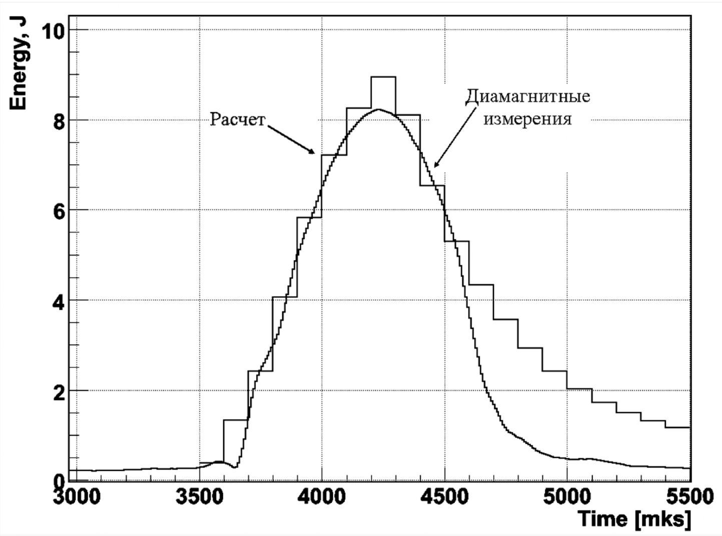

Figure 8: Fast ion energy content: smooth curve - diamagnetic probe signal, step-like curve - ITCS calculation.

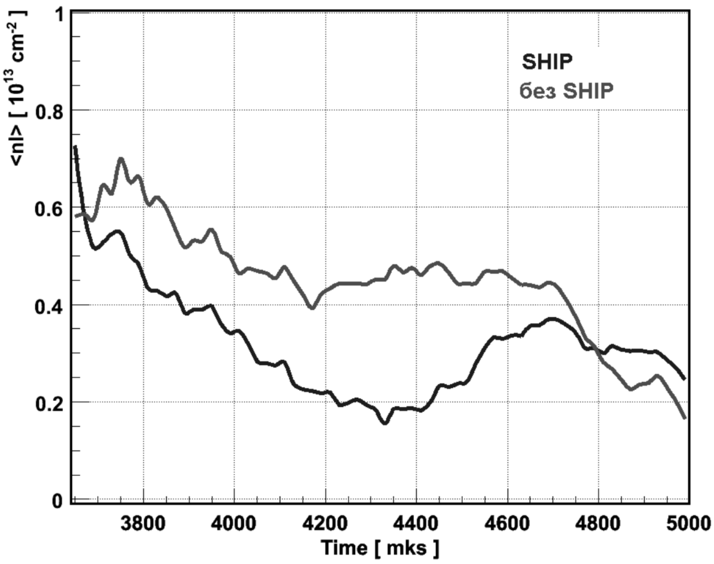

Figure 9: Line-integrated density of plasma flowing from the compact mirror to the expander (8-mm RF interferometer).

Fig. 9 presents time evolutions of outflowing plasma linear density measured by 8-mm

RF interferometer located beyond the outer mirror. One of curves in fig. 9 corresponds to a shot with neutral beam injection, another was obtained in a shot without injection. Rapid breakdown of the plasma flux coincides with the beginning of NB pulse. Ion density increase during injection leads to the potential barrier development causing partial trapping of outgoing plasma flow. Plasma flux minimum was recorded at time t=4.4 ms, plasma linear density measured by the dispersion interferometer in the compact mirror, reached its maximum at the same time (see Fig. 6). Fig. 10 shows the ion current

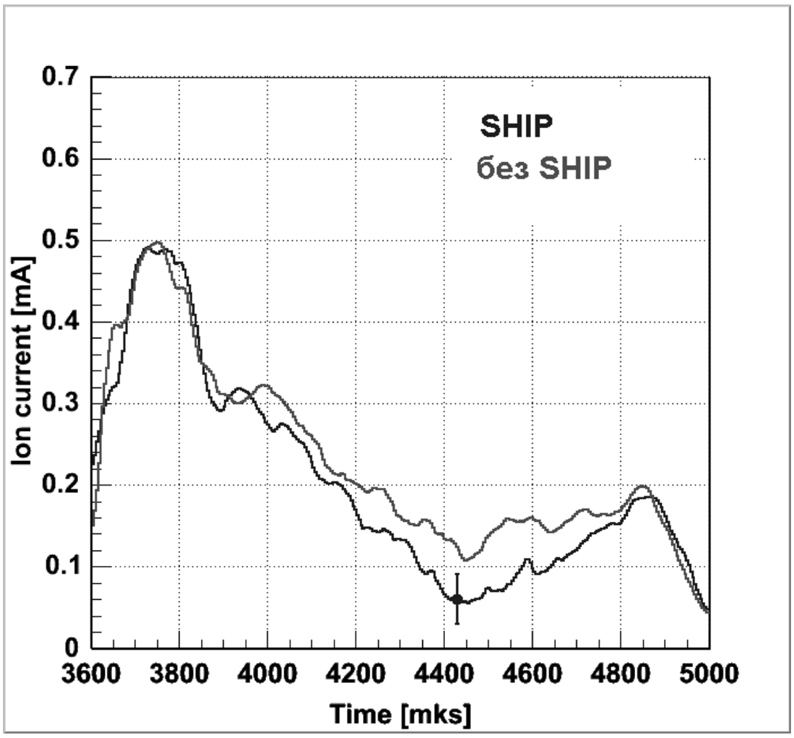

Figure 10: 10 On-axis ion current beyond the compact mirror cell.

signal measured in the expander. Sharp density peak in the region of t=3.8 ms can be explained by fast change of the plasma density profile at the initial stage of beams injection. Combining Figs. 9 and 10, we can note that maximum of density of fast ions confined in the compact mirror caused two-fold decrease of ion flux from the central GDT cell, compared with experiments without NB.

Summarizing described above we can draw the conclusions as follows:

1. Experiments with the compact mirror (SHIP) with moderate neutral beams parameters were carried out in GDT;

2. The maximal value of sustained anisotropic fast ion density $1.2 \cdot 10^{13}$ см^{-3} was two times greater than the density of unperturbed streaming plasma and three times greater than the warm ion density during NB injection in the compact mirror. Mean ion energy amounts 6 keV.

3. Fast ion confinement is determined by binary Coulomb collisions and charge-exchange of fast ions on neutral beam particles. No evidence of MHD or micro instabilities was observed.

4. Rise of ambipolar potential caused two-fold decrease of plasma flux from the central GDT cell.

Acknowledgements This work was performed partially by auspices of the grant of Civilian Research and Development Foundation (CRDF) № RP1-2553-NO-03.

4.2 Beam-plasma instability and formation of electron holes

N.S. Buchelnikova, V.E.Karlin.
Preprints INP № 2005-13,2005-14

The instability of a high-density electron beam ($n_b/n_0 = 0.3$ and 0.5; $V_0/V_T \sim 2.7$-15.9) in a plasma was studied in numerical experiments. It was shown that the evolution of the beam-plasma instability is followed by the trapping of the beam-electrons and the plasma-electrons, which leads to the formation of the electron holes (eh-structures on the phase plane). The coalescence of the electron holes leads to the formation of a quasistationary single electron hole (BGK-wave).

If the beam-velocity is high and the beam-density is low, the trapping of the plasma-electrons is not essential and the trapping of the beam-electrons leads to the formation of the bunch-type BGK-wave.

4.3 Multilayer x-ray optics

In 2005, we continued the work in the following directions:

• improvement of technology for manufacturing x-ray mirrors and multi-layer diffraction gratings;

• development of the soft x-ray range spectrometers on the base of multi-layer mirrors and diffraction gratings.

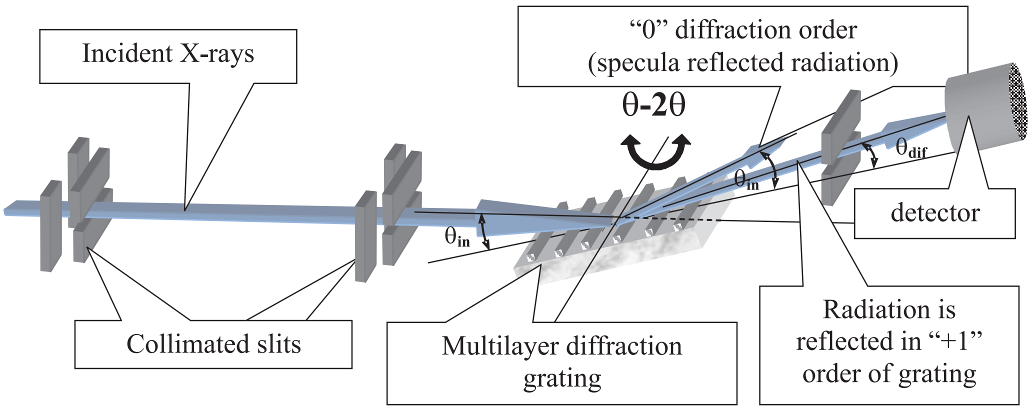

Figure 1: Schematic diagram of an x-ray spectrometer with the multi-layer mirror changed by the multi-layer grating.

The main results achieved in 2005 are the following: The technology of magnetron spraying the multi-layer mirrors with the period gradient along the surface was improved. We have found out the optimum parameters of mutual positioning of a subtrate and the source, where we can observe W/Si spraying of the gradient multi-layer mirrors with given parameters at the area of 100x150 mm.

We produced a retunable spectrometer designed at an energy of photons within the range 500-1500 eV. The spectrometer design scheme was upgraded aimed at exchange of the multi-layer mirror by the multi-layer grating. A simplified schematic diagram is shown in Figure.

In contrast with the conventional multi-layer mirror spectrometers, the newly constructed spectrometer will have a two times better energy resolution and the simplified circuit without filters cutting a long wave part of the spectrum. In this case, the spectrometer aperture ratio will be the same as that in the multi-layer mirror spectrometer.

4.4 Extension of the scope of plasma turbulence study

During the last 15 years, comprehensive studies of physical mechanisms governing plasma heating by high power electron beam were performed on GOL-1M device. The majority of theoretical predictions about the key role of Langmuir turbulence, including its spatial spectrum transformation and, and, finally, transfer of turbulence energy to plasma electrons were supported experimentally. Many new results were obtained in regimes with effective plasma heating where no much quantitative theoretical results exist due to complication of real heating conditions (significant magnetic field, non-Maxwellian distribution function of plasma electrons, and attendant low frequency turbulence). In addition to better penetrating to physics of plasma turbulence, new diagnostics techniques were developed and experience in turbulence study was gained by the GOL-1M team.

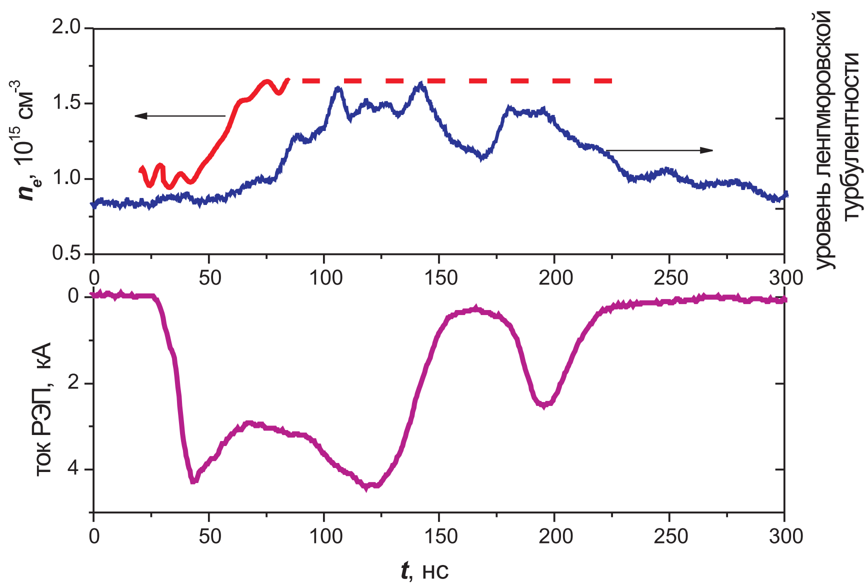

Figure 1: Time history of electron beam current, plasma density, and Langmuir turbulence spectral density.

Simultaneously, a considerable progress in plasma heating and confinement was made on much larger GOL -3 machine. The machine team here managed to reach the record for open system plasma parameters with the use of plasma turbulence. This device is unique in the sense that turbulence here improves plasma heating and confinement relative to classical predictions based on pure Coulomb collisions. It is harsh contrast with the majority of other fusion machines where particle and energy leakage across the confined magnetic field caused by turbulence is the major plague.

To facilitate the further progress in the program of GOL 3 machine it was natural to recruit the experimental methods and instruments developed for turbulence observation on GOL 1M device. In addition, it was decided to combine the efforts of two teams to concentrate on developing of multiple mirror system for plasma heating and confinement with the use of microturbulence. The main diagnostics instruments were moved to GOL 3 machine that is located in another building.

Before the move, the main efforts of the GOL 1M team were concentrated on observation of behavior of Langmuir turbulence driven by 100 ns electron beam in partially ionized plasma. The partially ionized plasma is typical for the beginning of plasma heating on GOL 3 machine. It was found, that plasma density rapidly rises within first 20 ns by factor 1.5-2 and then reaches the steady-state level. At this time, the Langmuir turbulence also grows to the detectable level and then its intensity follows the electron beam current as it shown in the figure. It should be noted, that temporal scale on GOL 3 machine is much longer: the heating process takes 5-10 μs, so the steady-state condition should persists during the entire process of plasma heating. In the same time, the diagnostics instruments were modified with the aim of observation on the GOL 3 machine. The results obtained in 2005 were presented at XXXIII International Conference on plasma Physics and Fusion Research in Zvenigorod (near Moscow) in 2006.

In work participated:
V.S. Burmasov, L.N. Vyacheslavov, I.V. Kandaurov, E.P. Kruglyakov, S.S. Popov, L.N. Sanin.

Publication: [115].

4.5 GOL-3 facility

Introduction

In 2005 at the GOL-3 facility works under the basic program of research of confinement of a dense plasma in a multimirror trap were conducted. Layout of the facility is presented in Fig. 1.

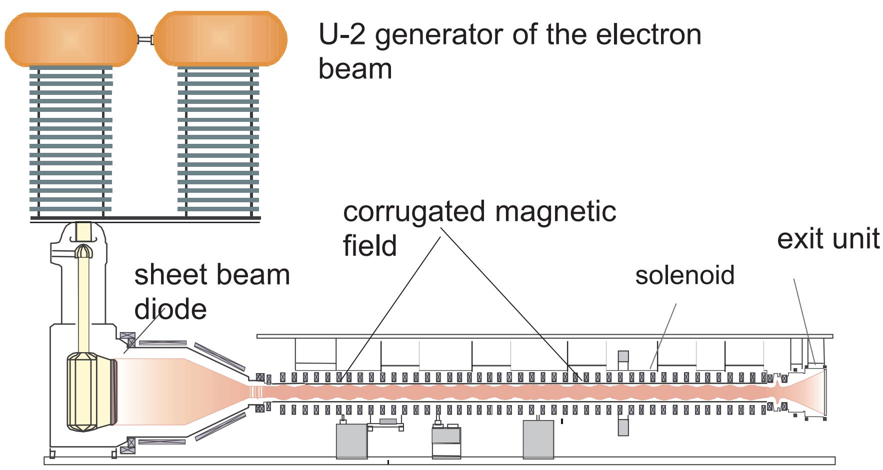

Figure 1: Layout of the GOL-3 facility.

The solenoid consists of 110 coils with an independent feed and has the general length about 12 m. In the multimirror configuration the magnetic field has 55 corrugation periods (cells of multimirror trap) with a field in maxima 4.8 T, in minima 3.2 T and a cell length 22 cm. The mirror ratio in corrugated field is 1.5, that operating mode of GOL-3 corresponds to a “weak corrugation” regime. The solenoid ends with a single magnetic mirrors with a field 8-9 T.

The required axial distribution of density of hydrogen or deuterium is created in the metal vacuum chamber ø10 cm, located inside of the solenoid, by several pulsed valves. Then an initial plasma with averaged over length density of $\sim 10^{15}$ cm^{-3} and temperature $\sim$2 eV is created by a special linear discharge. After that the relativistic electron beam is injected into this plasma. The beam parameters are the following: energy of electrons $\sim$0.9 MeV, a current $\sim$25 kA, full duration $\sim$8 microseconds, energy content $\sim$120 kJ, diameter of the beam $\sim$5 cm. As a result of collective heating the plasma gets ion temperature of scale 1-2 keV (in the hottest part of the plasma column). Using of multimirror system (the corrugated magnetic field) allows us to confine the hot plasma much longer than in a simple solenoidal trap. As it was shown earlier, fast heating of plasma ions cannot be explained by transfer of energy from electrons to ions by binary collisions. The new collective mechanism of energy transfer from the heating electron beam to ions essentially depended from presence in installation of the periodically-non-uniform (corrugated) magnetic field therefore was suggested. Experiments of a season of 2005 were directed on finding-out features of fast plasma heating in the trap.

Besides physical experiments, on the GOL-3 facility modernization of some systems and units are gradually executed. In 2005, the new entrance unit including the coils, forming an entrance magnetic mirror, and corresponding section of the vacuum chamber had been made and mounted on installation.

4.5.1 Modernization of the input mirror unit

One of problems of modernization of the GOL-3 facility, which was executed in 2005, was development and creation of new entrance unit. This unit is located between the ending of section of compressing of the electron beam of accelerator U-2 and the solenoid. This unit consists of the coil of a strong field, that forms a magnetic mirror at the input of the solenoid, and section of the vacuum chamber. Now the magnetic system of GOL-3 includes three coils of a strong field; one forms a magnetic mirror in the beginning of the facility, which separates the plasma column from accelerator U-2, two others, located at the end of solenoid, form magnetic system of a source of preliminary plasma. The entrance coil of strong field existed earlier allowed to receive up to 12 T in the aperture of 80 mm. Owing to the small aperture of these coils the plasma column on sites of a strong field was in close proximity to walls of the vacuum chamber. It, in particular, could lead to the accelerated cooling of the plasma due to cross-field energy loss to a wall and to occurrence of heavy impurities in plasma. Besides, during the operation the high field coils have practically worked out the lifetime.

New mirror coil is made by connecting of two standard coils of solenoid GOL-3 with minimally possible gap. Such technical decision allows one to increase aperture of the high field coil till the diameter of 157 mm, and also to unify system of fastening and joining of the solenoid.

In 2005, the entrance mirror coil was replaced with the new large aperture high field coil. Thus the vacuum chamber of this section was also changed. A site of the small-diameter chamber in an entrance mirror section was excluded.

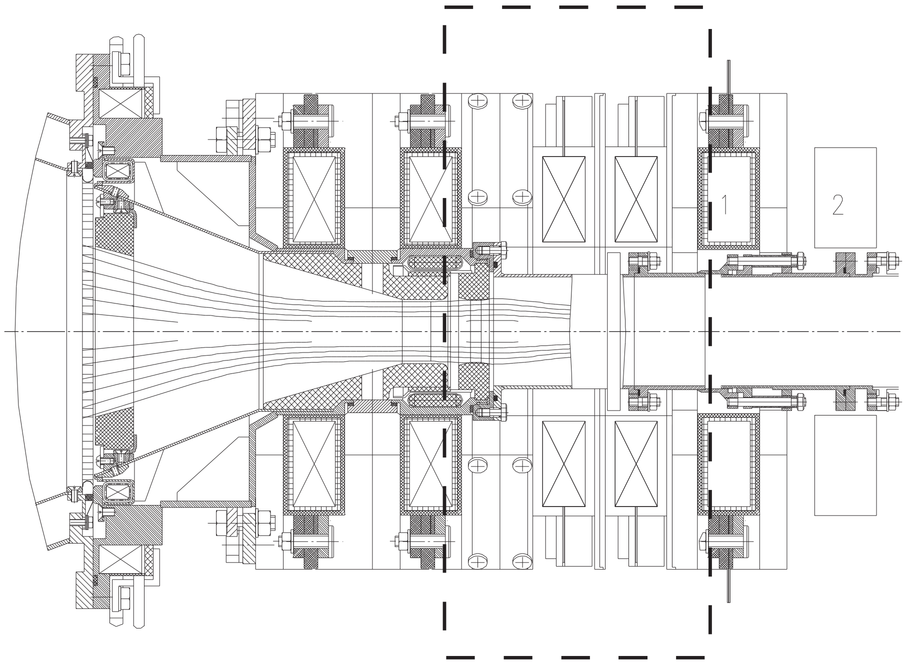

Figure 2: Design of the input section of GOL-3. New elements are within the frame.

A foil-replacement unit, which was not used in the latest configurations, was also dismounted.

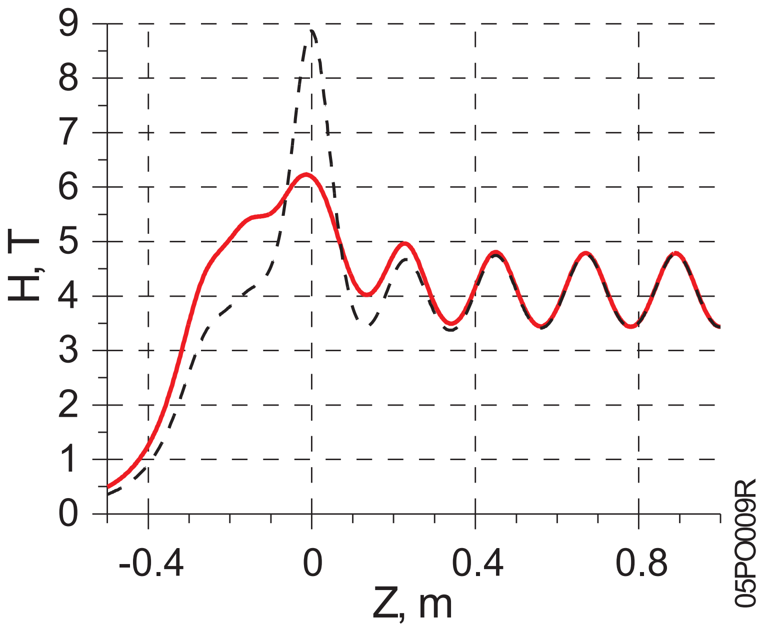

Figure 3: Magnetic field near the entrance mirror of GOL-3 in previous configuration (dashed line) and now (solid line).

The basic physical results of the given modernization are: increase in the current output from system of plasma creation through an entrance mirror in the beam compression chamber (that has favorably affected the beam stability in the plasma and allowed to increase efficiency of injection), removal of a wall of the vacuum chamber from hot plasma in the high field section. From the technical point of view reliability of work of the facility as a whole is improved and the probability of occurrence of emergencies is reduced.

4.5.2 Fast heating of ions and plasma movement in the multimirror system

At injection of the electron beam in the multimirror trap, there are gradients of a plasma pressure as within the limits of a separate cell of the trap (because of dependence of efficiency of plasma heating on the attitude nb/np, and, hence, from the local magnetic field H_{max}/H_{min}), and as a whole on length of all the system. As a result there are flows of the plasma as in separate cells of the trap (the directions of plasma movement in this case can be opposite each other), and macroscopical movement of the plasma along the trap - see Fig.1.4. Both these movements in the corrugated field lead to transfer of energy from electrons to ions much faster, than transfer of energy due to binary collisions.

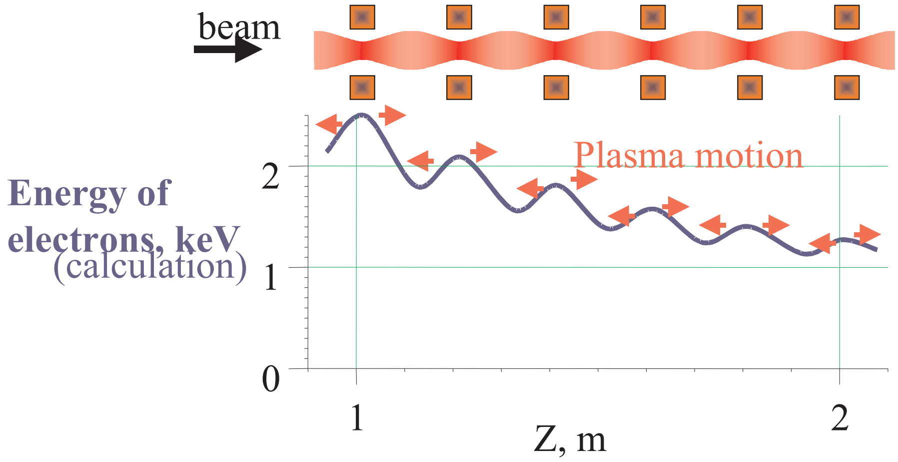

Figure 4: Top: the configuration of the magnetic field of the GOL-3 facility at the section with coordinates from 1 m up to 2 m. Collective heating of plasma electrons occurs in maxima of the magnetic field more effectively, the general falling of heating over length is connected with increase of phase space of the beam. Bottom: average energy of plasma electrons at the end of heating (calculation by K.V.Lotov and I.V.Timofeev), arrows show directions of acceleration of plasma by electron pressure.

Let's consider the described mechanism in more detail. In each maximum of the magnetic field the density of the beam current increases, thus efficiency of heating of electrons improves. Due to anomalously high collision frequency the electron temperature has no time to equalize along the magnetic field. As a result, in these places there are maxima of pressure under which action the plasma is accelerated towards minima of the magnetic field. Arising counter plasma streams collide, mix up, and as the result, heating of ion component of the plasma occurs. Ion component of the plasma heats up much faster, than it is possible at classical (binary) energy transfer from electrons to ions. Such method enables us to heat up plasma to temperature 2 keV at density (0.5-1)$\cdot 10^{15}$cm^{-3}. This temperature is already high enough that it was possible to measure a flux of products of fusion D-D reactions. For GOL-3 facility the most convenient for measurements reaction branch is D+D $\rightarrow$ ^{3}He+n (2.45 MeV).

New diagnostics of products of thermonuclear reactions has been developed for studying features of the collective mechanism of fast ion heating with the high spatial and time resolution. As calculations show, plasma streams from areas of the maximal heating extend towards each other, accelerated by ambipolar electric field, with the speed corresponding to 1-2 keV deuteron energy. Thus it was necessary to expect prominent features on dynamics of neutron emission from the trap. First, there should be a certain delay in occurrence of neutrons from the plasma, equal to time of acceleration of plasma in each cell. Secondly, the specified deuteron energy is much less than energy at which there is a maximum of cross-section of thermonuclear D−D reactions. It means, that the output of thermonuclear neutrons will be rather sensitive to a shape of the velocity distribution function of ions.

The discussed mechanism of fast heating of ions predicts a " head-on" collision of counter streams of plasma near to the central section of each separate corrugation cell and the subsequent Maxvellization of distribution function. Therefore it was expected, that the neutron signal will appear with some delay in respect to the beam start, it will have greater amplitude during short time and then the long phase of neutron emission from the plasma with a smaller level of a signal will be observed.

4.5.3 Neutron diagnostics with local detectors

Neutron diagnostics, which has been developed for study of dynamics of neutron radiation, is a set of local detectors. The detector consists of 45x10x15 mm scintillator in an opaque case, coupled by a quartz-polymer fiber (with diameter of 1 mm) with the remotely located photomultiplier. In immediate proximity from the plasma the stream of hard radiation is high enough, therefore detectors work in a current mode. The big flux of particles at the detector location and operation in the current mode allow us to work with scintillators of a small size. Owing to the small sizes the local detectors can be placed in any installation site directly onto an external surface of the vacuum chamber. Earlier (by means of previously developed system of digital pulse-shape discrimination of neutrons and secondary gammas) it has been shown, that light scintillators allow to measure the neutron flux adequately. In addition the separate detector with BGO crystal of the same size was applied to monitoring of a background of hard radiation (this scintillator is less sensitive to neutrons).

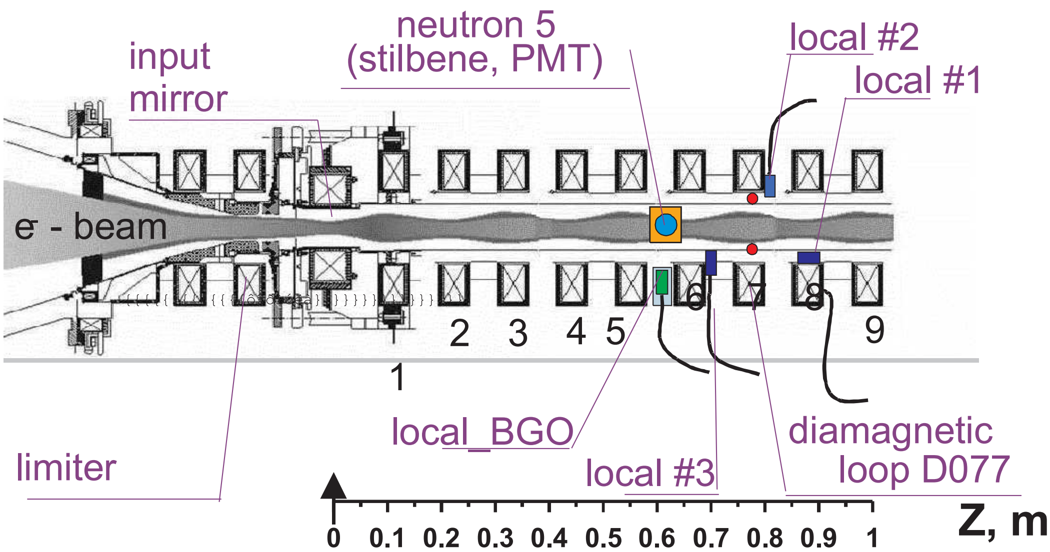

Figure 5: The scheme of an arrangement of local neutron detectors in an initial part of GOL-3 (one of variants, an arrangement was changed depending on a task for an experiment).

The important feature of the discussed technique is that it essentially uses construction elements of magnetic system of GOL-3 as some kind of neutron collimators. Coils of the GOL-3 solenoid are reeled up by a copper tape with an epoxy-cardboard insulation between coils. The fraction of hydrogen atoms in coils is great enough that coils served as effective moderators of neutrons, therefore local detectors detect radiation only from one cell of the multimirror traps.

For absolute calibration of local detectors in a real geometry of GOL-3 facility the industrial generator of neutrons L=±101T which has a radiating zone of a small area was used. The generator worked in a single-pulse mode, number of neutrons for a pulse is $\sim 5 \cdot 10^6$, average pulse duration ~0,75 microseconds. The generator of neutrons was placed inside of exact copy of a magnetic system with plasma chamber of GOL-3 and moved along the axis to find function of the response of the detectors located at different points in respect to solenoid coils. For the local detectors working in the current mode, relation of a signal amplitude and quantity of the neutrons, which are passing through scintillator, has been found. Influence of coils on attenuation of the neutron signal was investigated also. It is established, that one pair of adjacent coils provides collimation of neutrons down to 25° and decrease of the signal from the source placed directly under the coil makes 3,5 times.

4.5.4 Results

The maximum of distribution of neutron emission along the facility was at the distance of ~1 meter from the entrance mirror. Here the following phenomena are observed in all details: at 4-5 microseconds after the beginning of the beam injection first of all intensive irregular neutron flashes occur. Further there is a regular, periodic modulation of neutron emission (see Fig. 6). Placement of local detectors for this case is shown in Fig.5.

Good correlation of periodic flashes of neutron radiation for the detectors located one after another in one corrugation cell is observed. Frequency of flashes coincides with frequency of the fluctuations noted on a derivative of a diamagnetic signal (for the neutron placed in immediate proximity from the loop location). The waveform of the third detector except for the main signal shows influence of the next cell (in which there is a detector neutron5). In the given shot the modulation frequency in the left cell was higher, than that in the right one. The proof of the neutron nature of periodic flashes is in the last waveform of the local detector with heavy BGO scintillator which effectively detects only hard x-ray and the gamma radiation. Modulation of this signal is insignificant.

Oscillations of neutron radiation from the plasma are localized in space and are observed from two areas adjoining to a site with the hottest plasma. Time of existence of such periodic fluctuations changes at a change of an operating mode of GOL-3 and approximately corresponds to time of existence of significant gradients of plasma pressure. These facts indicate that an energy source for occurrence of fluctuations can be a plasma flow through a cell of the multimirror trap from a zone with a higher pressure.

It is necessary to note three features of the presented signals. First, the period of fluctuations coincides with time of flight of deuterium ions through one cell of the multimirror trap with the speed corresponding average local thermal speed (with an available accuracy). Secondly, on signals from Figs.1.6 and 1.7 shift of a phase of fluctuations for the detectors located in different points of the same cell of the multimirror trap is visible.

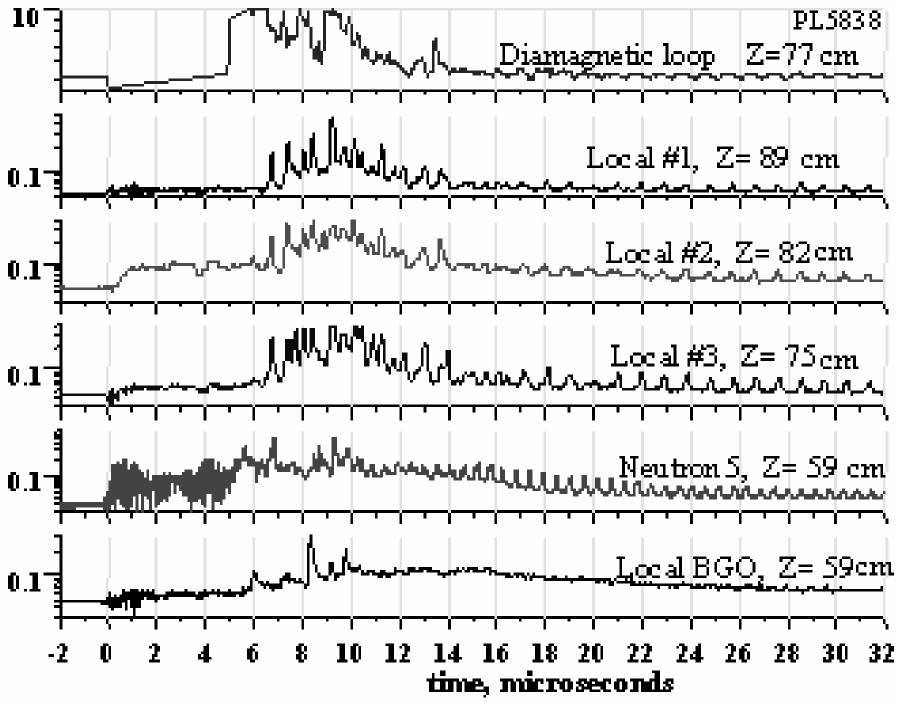

Figure 6: Waveforms of signals (from top to down): a derivative of a signal of the diamagnetic probe located on coordinate of 77 cm; signals of neutron detectors (coordinates 89, 82, 75 and 59 cm); a signal of the gamma detector (coordinate of 59 cm). Signals of radiation detectors are shown in logarithmic scale for convenience.

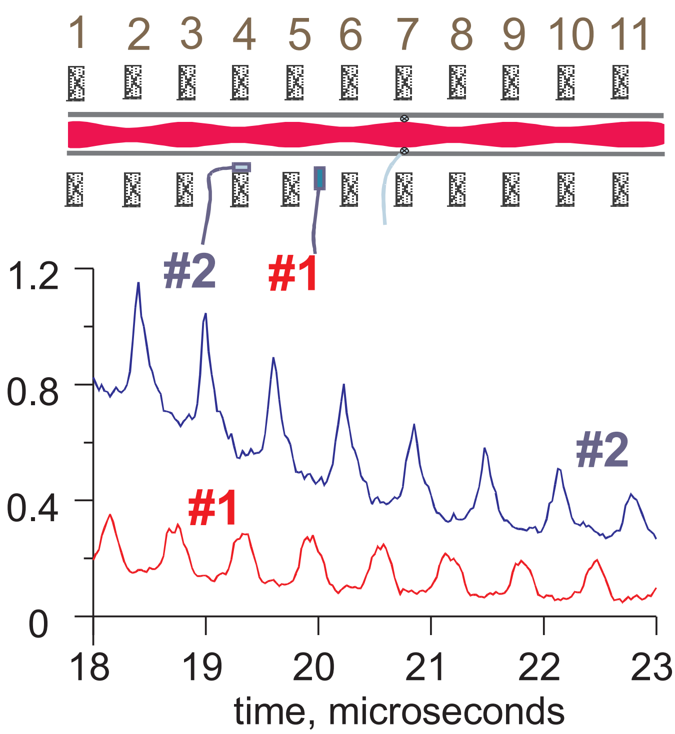

Figure 7: Signals of two local detectors located near to the opposite ends of a same cell of the multimirror trap. Top: the layout of an arrangement of detectors in this case.

The local detectors located side-by-side, detect phased fluctuations, and the detectors located at ends of one cell - counterphased. Thirdly, such intensive modulation is not observed on diamagnetic and other measured signals. It means, that these fluctuations of a neutron flux cannot be explained by formation of density waves of appreciable amplitude. The experimental environment in a whole is explained in the best way by excitation and existence during certain time of instability of bounce-like oscillations.

The absolute number of neutrons, which pass through the detector during the lifetime of the hot plasma, is (1-2)$\cdot 10^8$ neutrons. It corresponds to(1-4)$\cdot 10^{11}$ neutrons radiated by the plasma for a shot under the assumption of isotropic emission. Intensity of neutron emission strongly changes during a shot, and by the moment of an establishment of equilibrium ion temperature it noticeably falls. Calculated ion temperature corresponding an equilibrium neutron signal in the hottest part of the plasma is 1-1.5 keV, i.e. it coincides quantitatively with results of measurement of this value by spectral and charge exchange diagnostics.

4.5.5 Model for instability of bounce oscillation

Observable oscillations of a neutron flux are explained by a model developed by A.D.Beklemishev. Substantive provisions of the model are stated below. The stream of plasma caused by spatially nonuniform heating by the electron beam along the solenoid, under certain conditions excite bounce oscillations of density in a separate cell of the multimirror trap. Particles move with effective potential energy:

$$U_{eff} = \mu B(z) + q\phi_0(z) \quad .$$

Trapped particles oscillate between local mirrors with the frequence

$$\omega_b = \pi \left[\int_{-z_0}^{z_0} \frac{dz}{v_{\|}} \right]^{-1} .$$

At an expansion of hotter plasma through a corrugation cell a perturbation of density of trapped ions occurs, their velocity distribution function becomes essentially non-equilibrium. At a certain parameters of the plasma stream from the outside, the plasma flow through a cell is blocked periodically with the frequency

$$\omega^2 = \bar{\omega}_b^2 + \frac{ZT_e}{ml^2} \sim \frac{c_s^2}{l^2}$$

and modulation of concentration of transiting ions occur. The developed instability should reduce effective scattering length of longitudinal velocity vector for weakly transiting ions till the length of one corrugation period. Thus effective thermalization occurs of longitudinal energy of the plasma stream, which was acquired during ambipolar counter-acceleration of plasma bunches, and also during equalization of a plasma pressure gradient along the solenoid. Finally the plasma temperature increases, and longitudinal losses of particles decrease.

4.5.6 Summary

Experimental studies of dynamics of neutron emission in separate cells of the multimirror trap GOL-3 are carried out. The purpose of these experiments was finding-out of mechanisms of fast heating and subsequent confinement of ions in a multimirror trap. Oscillations of neutron flux as a phenomenon related to non-uniform heating of the plasma was discovered by specialized neutron diagnostics. The mechanism of occurrence of periodic flashes of a neutron flux is established. The developed instability of bounce oscillations observable in the experiment promotes the further heating of ions and decreases the plasma losses through the device ends. Absolute calibration of local detectors by means of the pulse generator of neutrons is done. The ion temperature of equilibrium plasma during the confinement phase is 1-1.5 keV, according to measurements by neutron diagnostics.

Participants of work :

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

Chapter 5

Electron - Positron Colliders

5.1 Proposal For Polarized Protons Acceleration At U-70

Introduction

At present moment there is a reach experience in an acceleration of polarized protons in synchrotrons. But in each concrete case one have to choose more appropriate equipment and to solve problems how to implement these parts in the existing machine lattice. First attempt to consider this problem for U-70 have been done in 1984 year. However, proposed measures have demanded big enough efforts to enlarge one straight section by displacements of a number of dipole magnets. First of all, let's remind main approach to description of spin motion in accelerators. It is good known that particles motion in modern accelerators is described with extremely high accuracy by the semi-classical approach. But for the spin, there is no quasi-classical limit when orbital quantum number are large. Even at highest energies, an electron, or a proton remains in eigen states "up" or "down" as particle with spin $\frac{1}{2}$ (in units of $\hbar$). The quantum operator for this spin is $\hat{\boldsymbol{S}} = 1/2 \cdot \hat{\boldsymbol{\sigma}}$, where

$\hat{\boldsymbol{\sigma}} = \boldsymbol{\sigma} = (\sigma_x, \sigma_y, \sigma_z) = \left[\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}; \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}; \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \right]$ — Pauli matrices.

Follow the Ehrenfest's theorem we determine in the particle rest frame a classical vector of spin in any state $|\psi\rangle$ as a quantum average of spin operator $\boldsymbol{S} = \langle \psi^\dagger | \hat{\boldsymbol{\sigma}} | \psi \rangle$. This vector $\boldsymbol{S}$ precess in the rest frame around magnetic field $\boldsymbol{B}_c$ together with particle magnetic moment $\boldsymbol{\mu} = q\boldsymbol{S}$:

$$\frac{d\boldsymbol{S}}{d\tau} = \boldsymbol{\Omega}_c \times \boldsymbol{S}.$$

Spin precession frequency $\boldsymbol{\Omega}_c = -(q_0 + q')\boldsymbol{B}_c$, where $q_0 = \frac{e}{m}$ and q' are normal and anomalous parts of gyromagnetic ratio q. (We shall take later $c = \hbar = 1$).

A relativistic generalization of this spin motion equation to a laboratory frame have been done in different ways by many authors (see, for example, [1]). The most easy-to-use for accelerator applications view can be presented in the next form:

$$\boldsymbol{S}' = \frac{d\boldsymbol{S}}{d\theta} = \boldsymbol{W}(\theta) \times \boldsymbol{S} \tag{5.1}$$

with

$$\boldsymbol{W}(\theta) = -\frac{q_0}{\gamma} \Big[\Big(1 + \gamma\, a\Big) \boldsymbol{B}_\perp + (1 + a)\, \boldsymbol{B}_\parallel + \Big(\frac{\gamma}{\gamma + 1} + \gamma\, a\Big) \boldsymbol{E} \times \boldsymbol{V} \Big].$$

Here we decomposed the magnetic fields in two projections $\boldsymbol{B}_\parallel$ and $\boldsymbol{B}_\perp$ (along and perpendicular to particle velocity $\boldsymbol{V}$ and introduce instead of time t a generalized accelerator azimuth θ and so called *magnetic anomaly* of a particle $a = \frac{q'}{q_0}$. For protons: $a_p = 1.792847351 \pm 2.8 \cdot 10^{-8}$.

Similar to the orbital motion we share the spin precession frequency in two parts: [2] $\boldsymbol{W}(\theta) = \boldsymbol{W}_0(\theta) + \boldsymbol{w}$. The periodical part $\boldsymbol{W_0}(\theta + 2\pi) = \boldsymbol{W}_0(\theta)$ gives spin rotations by fields on the CO, whereas $\boldsymbol{w}$ is a small distortion ($|\boldsymbol{w}| \ll |\boldsymbol{W}_0|$), connected with momentum off particle oscillations. It's evidently, the solution of the spin motion equation (1) at any azimuth θ with $\boldsymbol{W}(\theta) = \boldsymbol{W}_0(\theta)$ is a periodical unit vector $\boldsymbol{n}_0(\theta + 2\pi) = \boldsymbol{n}_0(\theta)$, which is the spin precession axis. A spin rotation around $\boldsymbol{n}_0(\theta)$ by an angle ϕ substitutes all spin rotations by arbitrary local fields along the CO.

There is a simple approach to find the spin closed orbit $\boldsymbol{n}_0(\theta)$ using the SU(2) matrices. It's known, that a spin rotation on the i-th part of the orbit is described by the matrix: $T_i = I \cdot \cos\frac{\phi_i}{2} - i(\boldsymbol{n_i}\cdot\boldsymbol{\sigma})\sin\frac{\phi_i}{2}$, where $\boldsymbol{n_i}$ is a local precession axis.

Now, if we know the spin transfer matrix after one particle turn, which is a product of local rotations: $T = T_m \cdot T_{m-1} \cdots T_2 \cdot T_1$, then it's easy to find:

$$\boldsymbol{n}_0 = \frac{i}{2\pi\sin\pi\nu} tr(\boldsymbol{\sigma}\cdot T); \qquad \cos\pi\nu = \frac{1}{2}tr(T), \tag{5.2}$$

where we defined (similar to the betatron tunes) a spin tune $\nu = \frac{\phi}{2\pi}$, which evidently is a ratio $\boldsymbol{W}_0$ to the Larmor frequency:

$$\boldsymbol{\omega} = -\frac{q_0}{\gamma}\Big[\boldsymbol{B}_\perp + \frac{\gamma^2}{\gamma^2-1}\boldsymbol{E}\times\boldsymbol{V}\Big]. \tag{5.3}$$

Two others (perpendicular to $\boldsymbol{n}_0$) eigen solutions of the spin equation are complex vectors $\boldsymbol{\eta}$ and $\boldsymbol{\eta}^*$ rotating clockwise and contra-clockwise around $\boldsymbol{n}_0$ with the spin tune: $\boldsymbol{\eta}(\theta+2\pi) = \boldsymbol{\eta}(\theta)\, e^{-i\nu\theta}$.

A precession axis for spin of off-momentum particles is slightly differs from $\boldsymbol{n}_0$ and can be found in the form $\boldsymbol{n} = \sqrt{1+|C|^2}\,\boldsymbol{n}_0 + Re(iC\boldsymbol{\eta}^*)$; $|C| \ll 1$. Putting this $\boldsymbol{n}$ into (1) we come in the linear approximation to the short-cut equation:

$$C' = w_\perp = (\boldsymbol{w}\cdot\boldsymbol{\eta}^*)\,. \tag{5.4}$$

Spin resonances

In usual case of a machine with the vertical guiding field $K_z = \frac{B_z}{\langle B_z\rangle}$ the spin precession axis $\boldsymbol{n}_0$ coincides everywhere with the unit vector along the guiding field: $\boldsymbol{n}_0 = \boldsymbol{e}_z$ and $\boldsymbol{\eta} = (\boldsymbol{e}_x - i\boldsymbol{e}_y)\, e^{-i\nu_0\tilde{\theta}}$, where $\tilde{\theta} = \int_0^\theta K_z d\theta$. From (1) and (3) we see, that spin tune in the accelerator frame ($\boldsymbol{e}_x$; $\boldsymbol{e}_y$; $\boldsymbol{e}_z$) is equal to $\nu = \nu_0 = \gamma\cdot a$. Linear dependence of the spin tune on particle energy creates many troubles while acceleration.

Focusing elements are unavoidable at any circular accelerator as well as the betatron oscillations. It's appeared immediately as a distortion for the spin motion. A vertically deviated particle meets the radial component of the focusing magnetic fields. Using the particle motion equation this distortion can be described by $w_\perp = \nu_0 z'' = \nu_0 g_z z$. Putting that into (4) one finds, that $\boldsymbol{n}$ oscillates around $\boldsymbol{n}_0$ with the betatron tune ν_z. In the resonance case $\nu = \nu_k = k \pm \nu_z$ (so called "intrinsic resonances") spin will rotate around the horizontal axis with a precession frequency w_k , which is the resonance strength:

$$|w_k| = |A_z|\frac{\nu_0}{2\pi}\oint g_z|f_z|e^{i(\nu_k\mp\nu_z)\tilde{\theta}}d\theta,$$

where we used the Floke form for the solution of z-motion equation: $z = A_z f_z + c.c.$. One can see, that the strength of the intrinsic resonances enhances with the particle energy and depends on the vertical oscillation amplitude A_z.

Other spin distortion is connected with vertical deviations of the CO, caused by radial imperfection fields $K_x = \frac{B_x}{\langle B_z\rangle}$. In this case putting into (4) the forced periodical part of the vertical motion Z_s we get strengths of imperfection resonances $\nu = k$:

$$|w_k| = \frac{\nu_0}{2\pi}\oint Z_s'' e^{-ik\tilde{\theta}}d\theta = \frac{\nu_0}{2\pi}\oint K_x F_3(\theta) e^{-ik\tilde{\theta}}d\theta\,,$$

where $F_3(\theta) = \frac{dn}{dz'}$ is a spin response function, that reflects a sensitivity of $\boldsymbol{n}$-vector to vertical kicks. [6]

These imperfection spin resonances take place in each 523.342 MeV for protons and their strengths increase with beam energy faster than the intrinsics ($F_3 \sim \gamma$). The stronges imperfection resonances follow also the machine periodicity $k = mP$ (m — integer). But unlike to the intrinsic resonances one can adjust the vertical closed orbit to minimize w_k up to level depending on his experimental techniques.

Spin resonance crossing

Since the spin tune is proportional to the energy, spin resonance crossings are unavoidable while acceleration. A gap between two imperfection resonances is equal to 523.342 MeV for protons. The intrinsic resonances are located symmetrically around each imperfection resonance. So, the acceleration of polarized particles looks as very complicated issue.

In the simplest case of a separate resonance $\nu = \nu_k$ with a strength w_k a final polarization ζ_f after one crossing with tune rate $\dot{\delta} = \frac{d(\nu-\nu_r)}{dt}$ will differ from the initial value ζ_0:

$$\zeta_f = \zeta_0 \left(2e^{-\Psi} - 1\right), \tag{5.5}$$

where $\Psi = \frac{\pi w_k^2}{2\dot{\delta}}$ is a spin phase advance in the resonance zone (tune $\delta \sim w_k$) [3].

When $\Psi \ll 1$ (fast crossing) polarization loss is small: $\delta\zeta \simeq \zeta_0\Psi$. More interesting is the opposite case: $\Psi \gg 1$, which leads to a spin flip ($\zeta_F \simeq -\zeta_0$) with an exponentially low depolarization: $|\delta\zeta| = 2\zeta_0 e^{-\Psi}$.

Both situations are widely used in accelerator practice. A suppression of the resonance strength (orbit corrections) or increasing tune rate (tune jump) leads to the fast crossing and vice versa an artificial resonance enhancement helps to safely reverse the polarization. It's appeared, that the so called partial Siberian snake is more convenient way for an enlargement of imperfection resonances [4], [5].

However, it's evident, that with increasing of the energy these games become more and more complicated.

Siberian snakes

To suppress spin resonances totally in 1976 it was suggested to introduce in machine lattice a special chain of magnets, which will rotate spin by 180 degrees by pass [6]. It easy to see, in this case the spin tune $\nu = 1/2$ independently of the beam energy and the resonance condition does not arise more. This approach was called the Siberian snake. It can be arranged in different magnet combinations, which rotates spin around any axis. At that the periodical precession axis $\boldsymbol{n}_0$ at opposite to the snake azimuth lies in the horizontal plane with the same angle to the CO as the snake axis.

The simplest snake is one solenoid with the longitudinal integral field proportional to the beam energy; (37 Tm for 10 GeV protons). Some disadvantage of the solenoidal snake is a $x - z$ coupling, introduced by the longitudinal field. There are a number of schemes with combinations of solenoids and skew quads, that don't excite the coupling outside the insertion. But such schemes require, as rule, a long straight section free from other equipments.

More compact Siberian snakes can be designed from dipole magnets by combinations of horizontal and vertical bends. How it's seen from the expression (1), spin rotations by transverse fields don't depend on energy for high energy particles, whereas the action on spin by longitudinal fields is inverse proportional to the energy. But the main disadvantage of transverse fields is big orbit deviations and, as a consequence, a wide aperture of the magnets and so on. Many years it has restricted considerably applications of the transverse fields for snake constructions.

However, these problems can be minimized in the case of helical magnets [7]. A set of full twist helices with mirror symmetry provides the compensation of orbit distortions outside the snake taking them very moderate inside the insertion. This advantage creates interesting possibilities to use helical magnets for both full snake and for partial one [8]. Moreover, such systems have shown a great flexibility for obtaining practically arbitrary snake axis. This fact is appeared very important for the acceleration of polarized protons at RHIC [9].

5.2 Proton synchrotron U-70 and spin resonances

The proton synchrotron U-70 is operating successfully in Protvino since 1967 (see Fig.1). The beam is accelerated in the proton linac Ural 30, then in the booster and injected into U-70 with the kinetic energy 1.5 GeV, where then its energy is increased during 2 seconds up to 70 GeV.

The synchrotron lattice has 12 periods FODO structure. Each period consists from 20 dipoles with alternative gradient. Optical functions and the structure of the one period are shown in the Fig.2

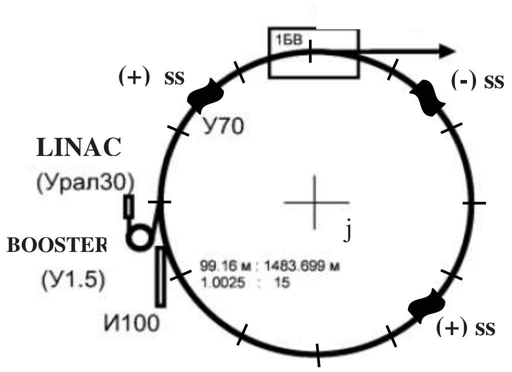

Figure 1: U-70 complex layout.

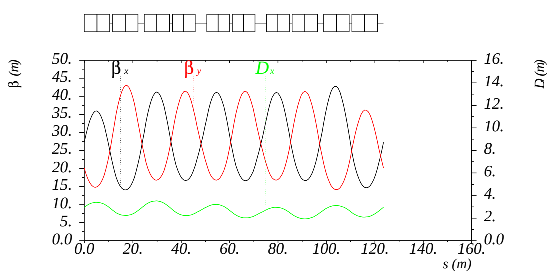

Figure 2: Optical functions of U-70.

To understand the situation with depolarizing resonances at U-70 first of all an evaluation of intrinsic spin resonance strengths has been done for normalized vertical beam emittance $\epsilon_z = 10\pi\ mm \cdot mrad$ and betatron tunes $\nu_z = 0.8$ and $\nu_x = 0.77$. The ASPIRRIN computer code was used for that [5].

As it was expected, the calculations shown, that for high energy ($\nu_0 \simeq 100$) resonances $\nu_0 = kP \pm \nu_z$ (P is a machine periodicity) grow up to $|w_k| \sim (0.2 \div 0.4) \cdot \omega_0$ by $A_z \simeq 1mm$ (dotted lines in the Fig.3).

The same picture contains also results of estimations of imperfection resonances: $\nu_0 = kP$ (solid lines). At that, we assumed vertical displacements of any dipoles by

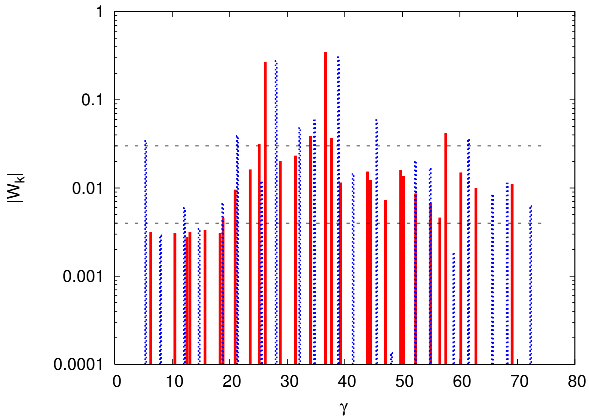

Figure 3: Spin resonances at U-70

$\pm\,0.5\,mm$. It's seen, that before acceleration of polarized protons one has to pay a serious attention to a bending magnets alignment. At the present moment (after almost 40 years machine operation) geodesic measurement data give misalignment in one order magnitude worse than it's needed.

Two horizontal dashed lines at the Fig.3 indicate two levels of the resonance strength, when according to the Froisart-Stora conditions (5), safe resonance crossings are possible. The lower line is the limit for the fast crossing. The adiabatic regime (spin flip) is available above the upper line. So, from these calculations one can conclude, that it's necessarily to search other approaches for successive acceleration of polarized protons at U-70.

Siberian snakes at U-70

The first attempt to modify U-70 to polarized proton acceleration have been taken yet at 1984. However, proposed scheme of the Siberian snake has required big machine changes and it was not accepted.

The present proposal suggests to install three identical partial snakes in three periods of U-70 lattice, as it's shown in the Fig.1. Each snake will be inserted in one of two 4 meter straights between bending magnets (see the chain of magnets in the Fig.2).

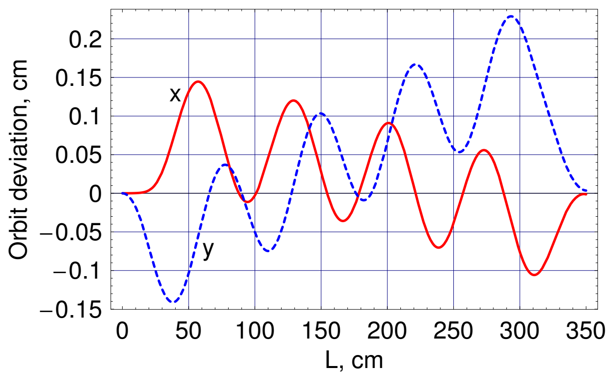

Figure 4: Orbit inside the snake

An optimized snake design takes $3.5\,m$ and consists of 4 periods of two-thread helical coil (a period $l\,=\,70\,cm$; aperture $15\,cm$). The super-conducting coil is wound between the iron poles and is surrounded by the 40 cm diameter iron yoke.

Parameters of the coil, iron and supply current have been optimized to reach on the axis the magnetic field up to $4.2\,T$. 3-D magnetic field calculations (including fringe fields) have been done by the MERMADE code . Then the differential equation of a particle motion was solved in the calculated nonlinear fields . Obtained particle trajectories inside the snake are shown in the Fig.4 for the energy $25\,GeV$. The orbit deviations are inverse proportional to the beam energy. They will achieve $2.5\,cm$ on the injection energy $E = 2.5\,GeV$. Since the spin resonances are weaker at the low energy, some modulation of the snake power supply can be apply to avoid aperture limitations during the injection.

To compensate some CO distortions, caused by the fringe fields, two dipole coils are wound at the snake edges. At this stage the dipole coils current was tuned for the CO adjustment (no orbit deviations outside the snake).

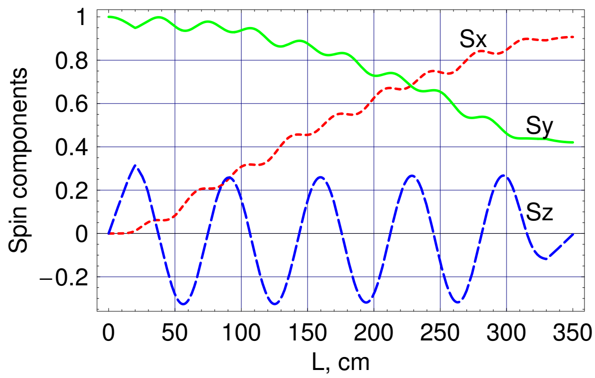

Figure 5: Spin rotation inside the snake

An estimation of the machine optics distortions has shown, that three snakes together disturb a little bit the optical functions. To vanish this effect totally also thin quadrupole coils have to be added on the both edges of each snake.

At the next step a solution of the BMT-equation for spin rotations was found in the helical fields along the determined particle pass through the snake. Parameters of the snake design have been optimized to rotate spin by 60 degrees. Spin vector components behavior along the snake is given in the Fig.5 for initially vertical spin.

From the Fig.5 it's seen, that the snake axis is practically longitudinal. It means, that spin SU(2) transfer matrix through the snake is equal to $T_S = I \cdot \cos\frac{\pi}{6} - i\sigma_y \cdot \sin\frac{\pi}{6}$. Taking this fact into account it's easy to find the one turn spin map with three snakes "on". Follow the mention above approach we get a behavior of the spin closed orbit $\boldsymbol{n}_0$ and the spin tune ν versus the beam energy.

In Fig.6 the solid line presents a fractional part $\{\nu\}$ of the spin tune against ν_0. Points in Fig.6 correspond to the same strongest spin resonances as in the Fig.3. One can see, that a strength of imperfection resonances, exited by the snakes, has only two fixed values: 0.18 and 0.5. It means, that resonant conditions for the weak intrinsic resonances ($|w_k| \le 0.1$) can't appear in the proposed snake scheme, if the fractional parts of the betatron tunes don't exceed 0.2. Moreover, the scheme is tuned by a choice of the snake polarities to the case, when two more strongest intrinsic resonances ($|w_k| \simeq 0.3$ without the snakes) meet the spin tune 0.5. Fig.7 demonstrates spin behavior, caused by the snake induced imperfection resonances. We see a periodicity of full spin flips. For simplicity of spin manipulation while injection and extraction it's better to do that, when the polarization is vertical.

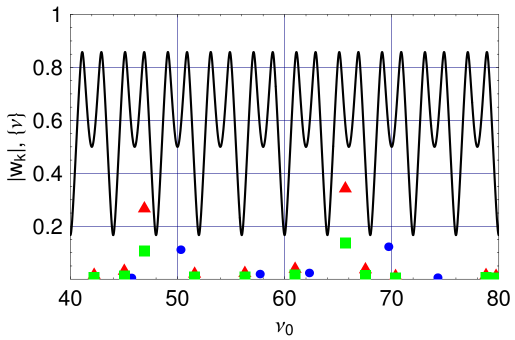

Figure 6: Spin tune with snakes and strong resonances

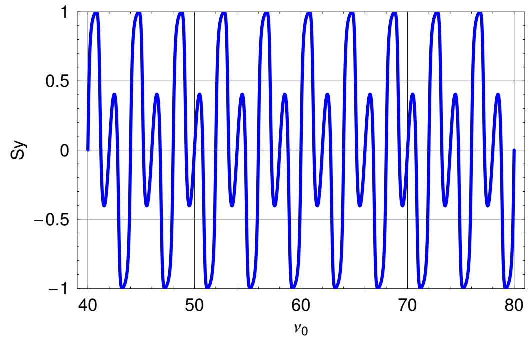

Figure 7: Vertical polarization versus ν_0

Conclusion

The present consideration has shown, that the polarized proton acceleration at U-70 is possible with relatively moderate machine modification. The installation of three helical partial Siberian snakes in three period of machine structure can provide the suppression of all intrinsic resonances. To avoid undesirable interferences the snake and machine imperfection resonances the latter have to be minimized by the magnet alignment with accuracy $\pm 0.5mm$.

The draft design of the helical magnet with field $B \simeq 4.5T$ is proposed. The estimations of parasitic snake influences on the particle dynamics has been estimated. Weak steering dipole and quadrupole coils have to be wound on the snake edges to keep the optics and orbit deviations inside the snake insertions.

Of course, to prove the full situation for polarized proton acceleration an additional spin and particle tracking simulation are needed.

5.3 VEPP-2000 complex

The work on construction of electron-positron collider VEPP-2000 with the energy in center of mass up to 2 GeV continues in BINP. In 2005 manufacturing the equipment for this collider is almost completed. Fig. 8 shows the work of experimental workshop on production the equipment for new collider for the whole period of construction.

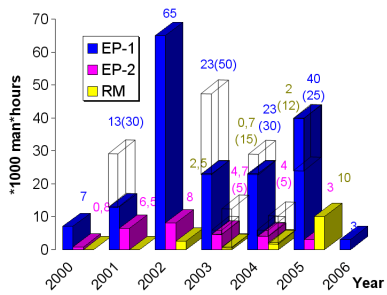

Figure 8: Experimentalworkshop for VEPP-2000

Assembling of VEPP-2000 vacuum chamber was contained for a long time by manufacturing RF cavity and absence of mirrors for outputting SR. After these questions were solved vacuum chamber of the first half of the ring was assembled and the vacuum $\simeq 10^{-10}$ torr was obtained. Fig. 9 shows this semi-ring just before New year 2006.

Assembling of the second semi-ring is going with solving many small questions of consisting the collider elements and injection channels. One can see the density of elements composition in the injection drift in Fig. 10.

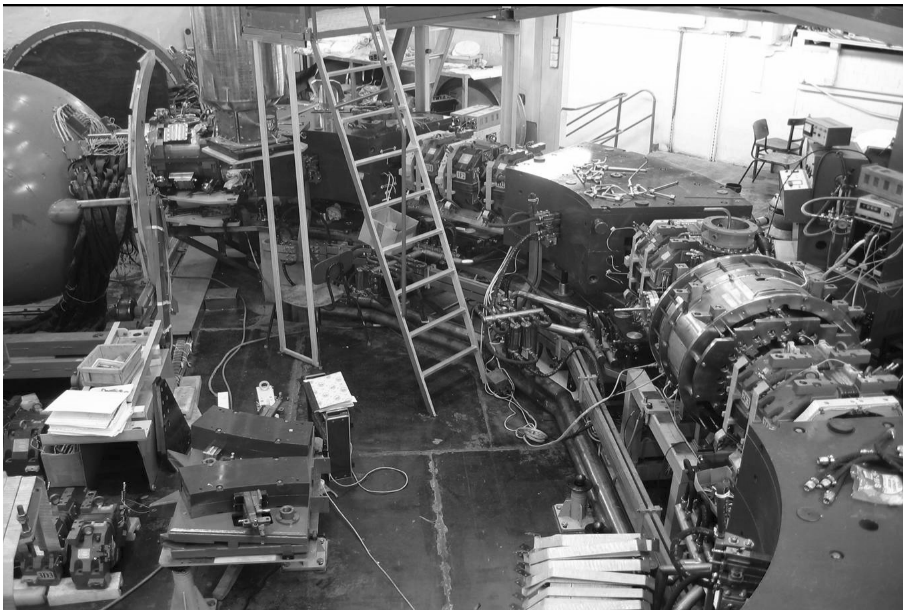

Figure 9: Semi-ring of VEPP-2000

Figure 10: Injection drift of VEPP-2000

One of the most high-technology elements of VEPP-2000 is superconducting solenoid at 13 T magnetic field. Fig. 11 shows first ready and installed in collider this complicated device. Rest 3 solenoids are in different stages of completion in "a link" between experimental workshop—VEPP-2000. But one can see the end of this link in April 2006.

In good stage of completion are powering and control systems of VEPP-2000 complex.

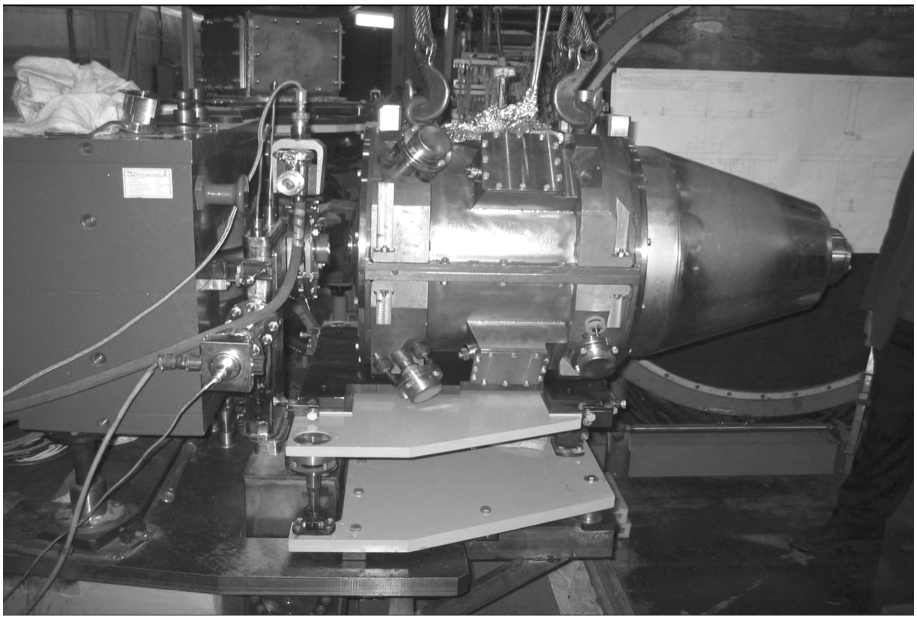

Figure 11: Superconducting solenoid of VEPP-2000

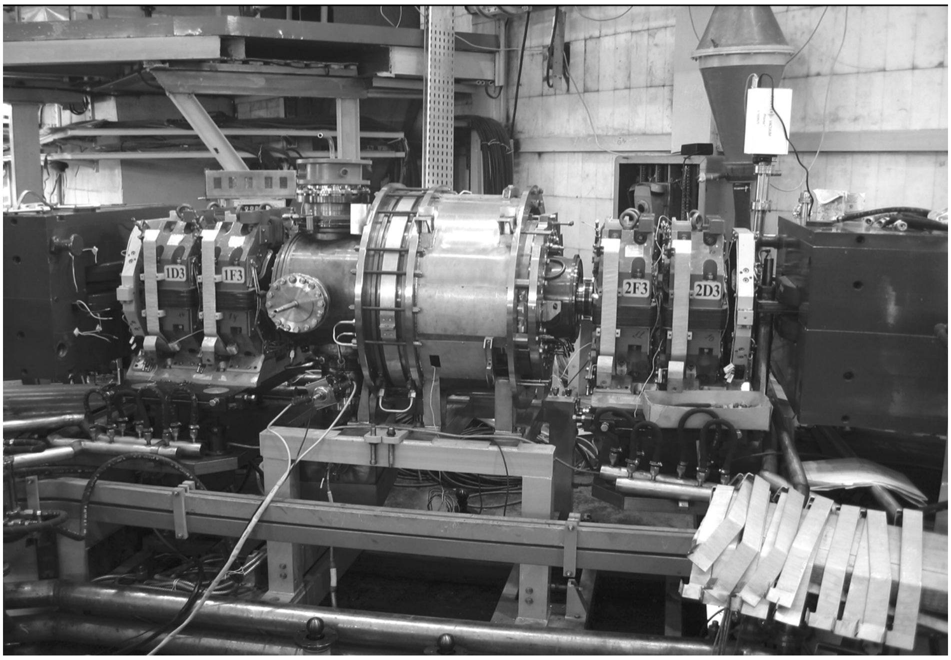

Figure 12: RF cavity of VEPP-2000

Power system

Rectifier for BEP. High-current elements of injection channel BEP–VEPP-2000 are fed in series with BEP guiding magnets. We need to make powering of this structure with one power supply. A rectifier was constructed, which consists of 8 sections devided into 2 groups of 4 sections. These groups are connected by power buses with 2 groups of oil transformer windings. One group is connected as "triangle" scheme, the other — as "star". Thus the rectifier works in six-phase scheme, this providing low level of pulsations and hence simplifies the system of ripple rejection. To make possible the work of BEP with different beams in each section a reversing bridge in 4 thyristor keys is installed. The transformer of ripple rejection and contactless sensor of current are installed in series with load. This scheme allows to get stability of feed current on a level 10^{-4}. Parameters of this rectifier are:

Voltage, V	250
Maximal load current, A	10000
Pulsation level, %	0.01

Control of rectifier is provided by CAN-ADC and CAN-DAC modules, which allow to work with rectifier from PC by CAN protocol.

Rectifier for VEPP-2000 is made without reverse unit in six-phase scheme with transformer of ripple rejection and contactless shunts. Parameters of rectifier are:

Voltage, V	120
Maximal load current, A	10000
Pulsation level, %	0.01

RF system. RF cavity of VEPP-2000 is powered from generator working on 172 MHz. The generator consists of 4 amplifier stages connected in series. Cumulative gain of power is 30000. With the output power level of clock generator being 2 W we measured 60 kW in RF cavity. With the help of CAN-DAC-ADC modules managed from PC different regimes of RF cavity are possible:

1. Stabilization of RF voltage and phase of RF voltage and feeder current
2. Stabilization of feeder current and phase of RF voltage and feeder current
3. Stabilization of RF voltage and feeder current. In this regime the RF voltage is stable, the feeder current is provided by RF cavity tuning.

To keep RF generator's tubes when breakdown a fast protection scheme is used. The minimal time to turn off plate supply from the moment of breakdown is about 45 μs.

Control system of VEPP-2000

Accelerator complex VEPP-2000 from automatization point of view is very complicated system of more then 2000 channels of control and management. The main goals of a new control and observation systems are maximal convenience for operator work as well as simplicity to configure and easy expansibility of such system.

In complex control system two protocols are used: old and good proved for automatization of scientific research standard CAMAC; and new, cheap and modern standard CANbus. Control system is based on PC working under OS Linux. This allows one to realize reliable and high-quality control system, which is based on modern elements and modern schemes.

The software of control system are divided in a few subsystems: type of controlled elements (pulse, permanent) and complex subsystems (ILU, B3M, BEP, VEPP-2000, injection channels). The control system is realized in client-server technology. Server part of software is responsible for connection to physical units of control: sensors, D-to-A converters, A-to-D converters, RF control units etc. We assume to have several servers.

Client part designed for operator work on control, view information of current stage and other tasks (save, recovery previous states) is realized as individual programmes.

Access to information about all subsystems configuration is implemented as data bases. They contain all the information about current state: quantity, inner numbers and other identification data of control channels; type, place and access method to the control blocks; various calibrations and converting coefficients. The structure of this data base is a key point of the whole control system. Adding or changing recordings in data base it is possible in easy way to tune control system configuration according to current tasks and needs. Moreover, tuning (in the case of changing or adding records) is easy and structured procedure, which doesn't need to compile or rebuild the main software. Additional advantage of such scheme is that structure of software is identical for all complex subsystems. All aforesaid can be illustrated in Fig. 13.

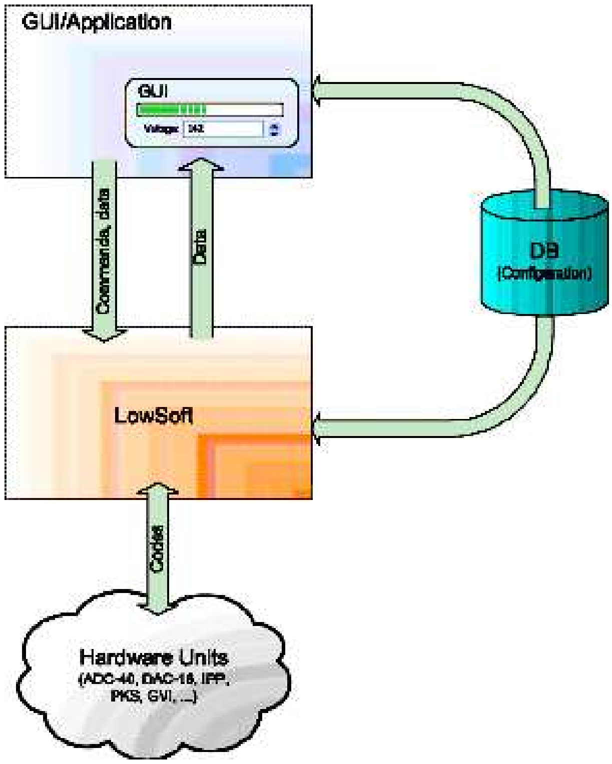

Figure 13: Structure of the control software

Now in this scheme we realize such subsystems: control of low-current corrections of the whole complex (ILU, B3M, injection channels, BEP), thermocontrol. Control subsystems of the guiding field of BEP and VEPP-2000, high-current elements (quads and solenoids), pulse elements of ILU, B3M and injection channels are under testing and debugging. Now we develop subsystems of vacuum control, measurement the beam position with aim of secondary-emission sensors and image-current sensors, TV observation of the beam and others.

As an example of programs using this technique Fig. 14 and Fig. 15 show control of low-current corrections of BEP and thermocontrol respectively. In Fig. 16 one can see the network scheme of VEPP-2000 at present time.

Figure 14: Two client programs to control BEP corrections working with one server

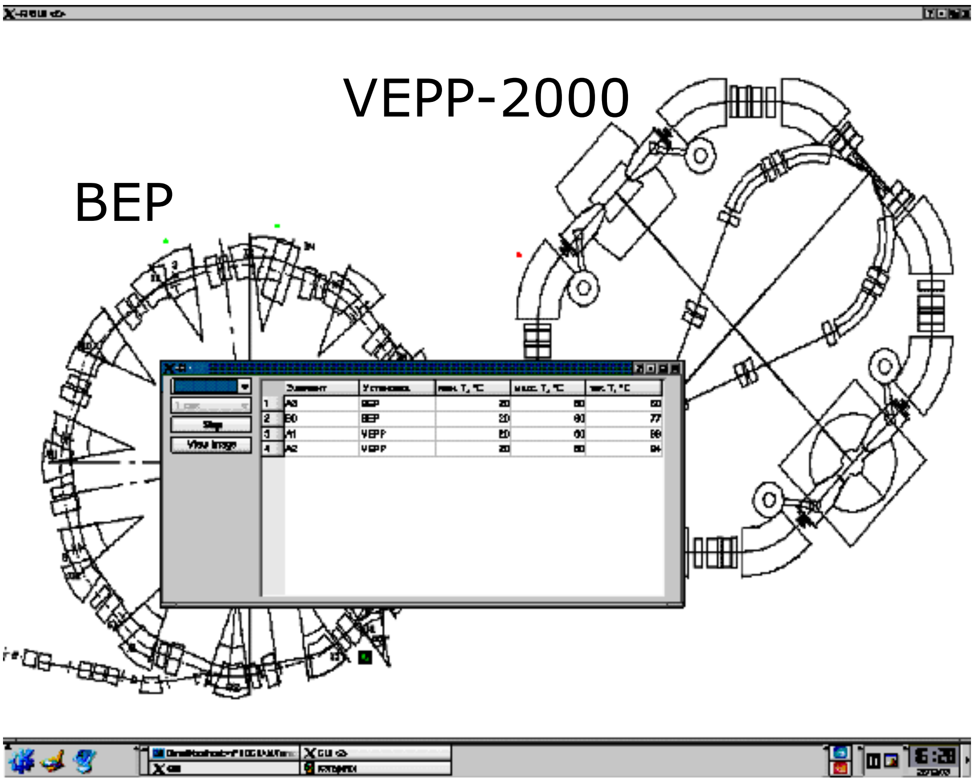

Figure 15: Program of thermocontrol visualizing

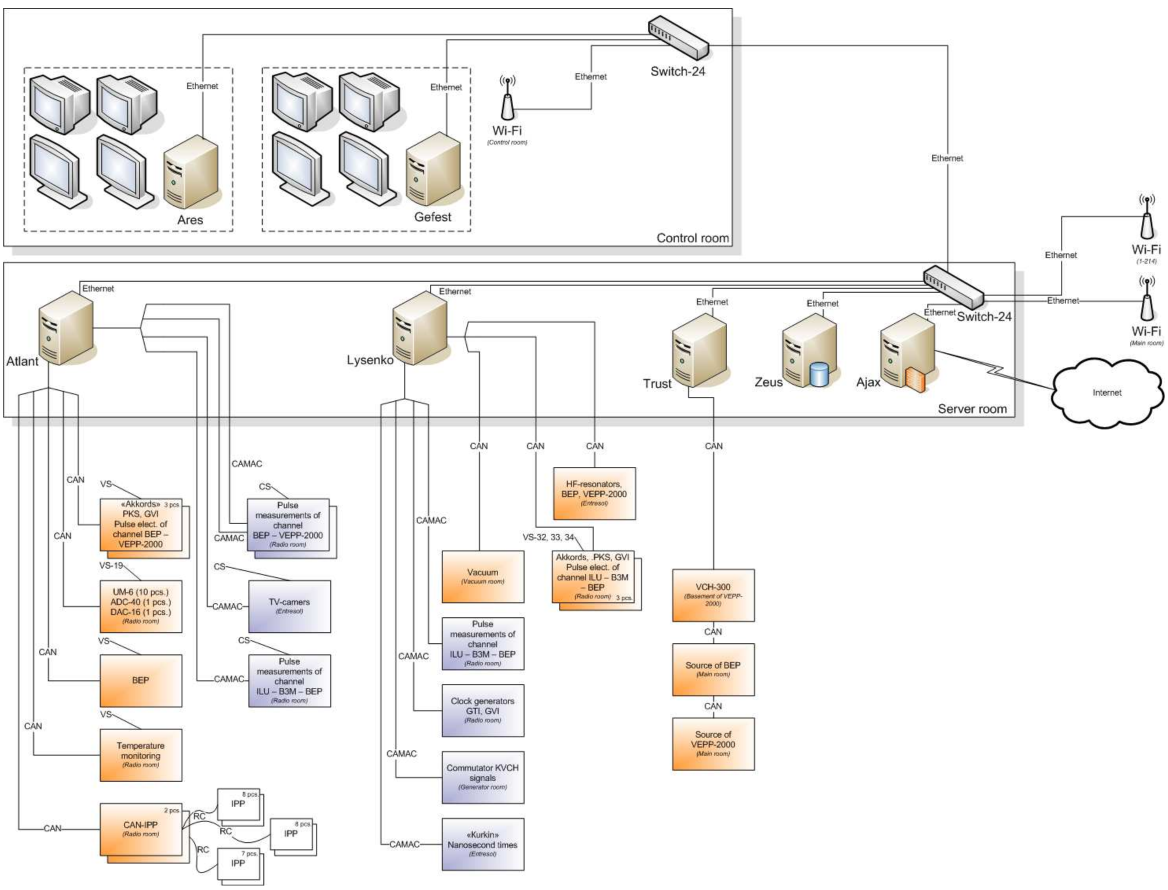

Figure 16: VEPP-2000 complex network

5.4 Starting the injection complex of VEPP-2000

In October 2005 the work on starting the injection complex of VEPP-2000 has begun. The main purpose of that work was testing new electronics and software running under Linux OS. All modules of controlling the various powering systems and beam parameters are adjusted and work reliably.

As a result by New Year we got electron beam with the energy 125 MeV accelerated and extracted from synchrotron B-3M.

After commissioning of high-current rectifier, which feeds the magnetic system of storage ring BEP, the tuning of electron beam injection into BEP as well as debugging beam diagnostics will start.

In parallel the complete revision of technical conditions of electron-to-positron converter was done. Lithium lenses were going through the procedure of re-assembling and some modifications in their construction were done, which will improve the characteristics of these unique lenses.

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5.5 VEPP-4M

Introduction

As in previous years, the main direction of the VEPP-4M complex activity was providing the elementary particle physics experiments jointly with the KEDR detector. Fig.1 shows the time (in comparison with the previous years) taken directly for these purposes, i.e. the time of gathering statistics by KEDR in the regime of colliding beams. Remind that in 2003, the detector systems were repaired and upgraded and there were no high energy physics experiments.

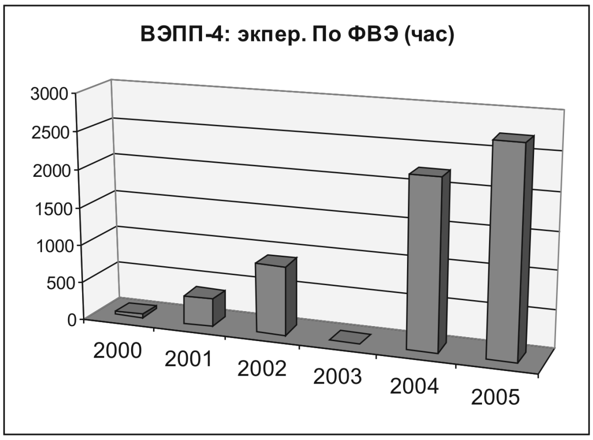

Figure 1: Experimental time of VEPP-4M (high energy physics).

Some other direction of the accelerator complex activity included experiments with synchrotron radiation at the VEPP-3 storage ring (Fig.2), a study of behavior of the charged particle beams in the VEPP-4 storage ring, upgrade and improvement of operating efficiency of the complex components, workout of the beam energy precise calibration technique, etc.

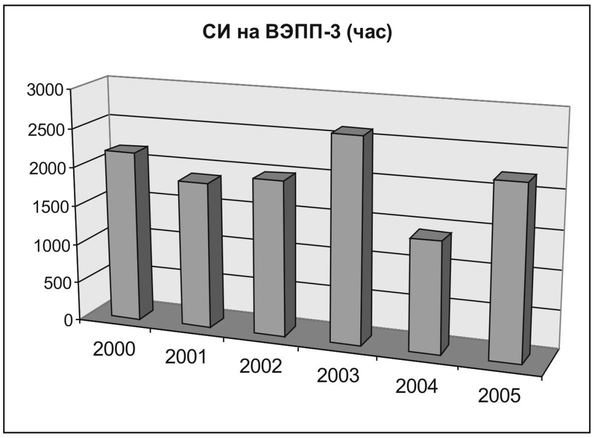

Figure 2: Experimental time of VEPP-3 (synchrotron radiation).

Time required in 2005 for repairing of the components and systems of the accelerator complex was substantially (nearly twice as much) reduced compared to that in previous years (Fig.3) and amounted 680 hours.

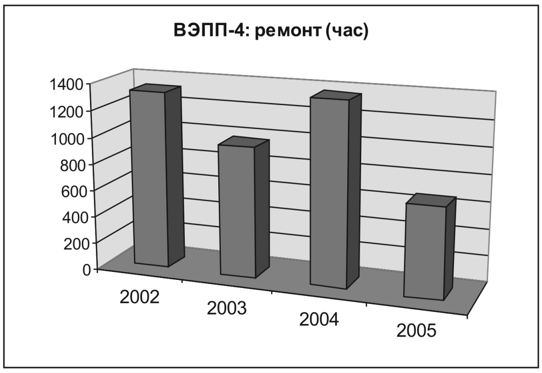

Figure 3: Repair of the complex systems in 2005.

The analysis shows that the main causes of malfunctions were the following: failure in the control system electronics (12% of the total time of shutdown), malfunction of the "Positron" injection system (10% and 6% of them are referred to the shutdown of the B-4 booster-synchrotron because of fail in a powerful commutator reswitching the synchrotron main field polarity and engineering systems as the supply of electric energy, distilled water, conditioners, etc - 14%).

5.5.1 HEP experiments

In 2005, we gathered statistics in the vicinity of the generation threshold of τ-lepton as well as in the range of resonances J/ψ, ψ' and $\psi(3770)$. This work took 2720 hours (or 43% of the total operation time of the complex), the luminosity integral was detected to be 3.6 pb^{-1}, the beam energy was calibrated 500 times. The maximum luminosity attained at VEPP-4 in 2005 in a 2x2 bunch operation run exceeded the value $2 \cdot 10^{30}$ cm^{-2}c^{-1} (Fig.4), In this case, the mean luminosity per shift (12 hours) was $\sim 0.8 \cdot 10^{30}$ cm^{-2}c^{-1} and the luminosity integral per shift was gathered to be $\sim 25 \div 30$ nb^{-1}.

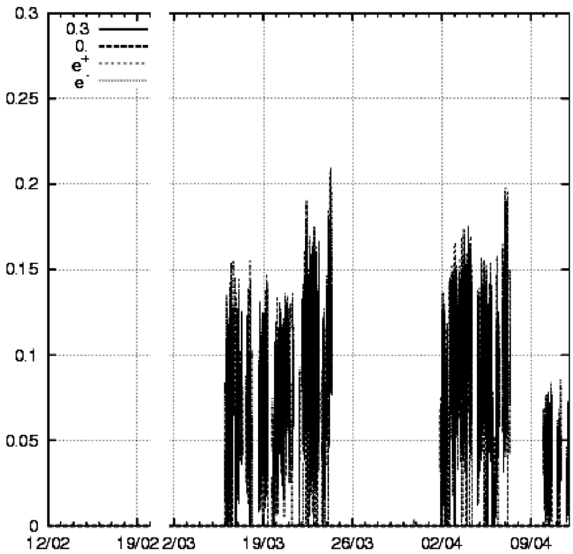

Figure 4: Detected luminosity of VEPP-4M (x10^{31} cм$^{-2}$c^{-1}).

Fig.5 shows the growth of the VEPP-4M maximum luminosity for a period of five years. At the end of 2003, the 2x2 bunch operation regime was realized and further increase in luminosity was provided by a fine tuning of the complex operation.

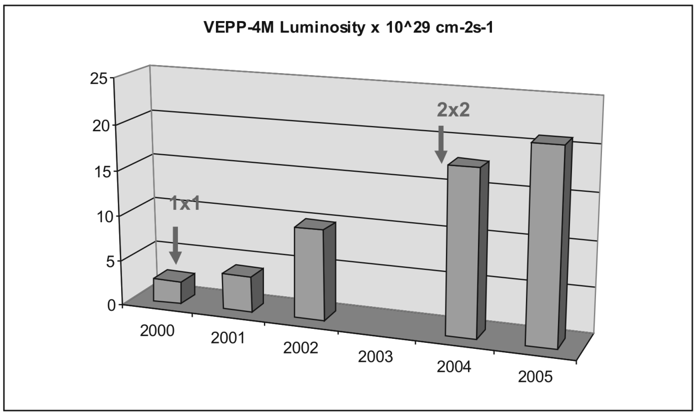

Figure 5: VEPP-2M maxiumum luminosity. In 2002 and later–a 2x2 bunch operation run.

The main goal of the experiments was precise measurements of a mass of τ-lepton, verification of masses of D-mesons, a study of decays ψ'. Fig. 6 shows some preliminary results on the generation crossection of τ-lepton in the vicinity of its generation threshold.

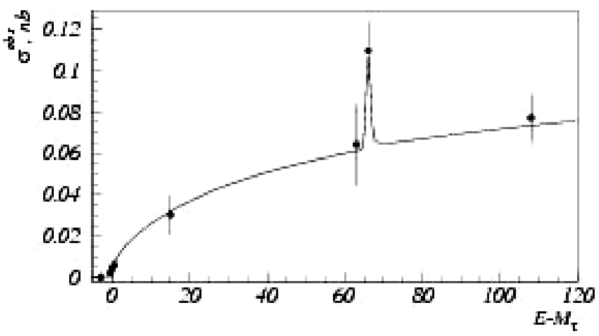

Figure 6: Observed generation crossection of τ-lepton generation threshold (preliminary results).

Despite the preliminary results, the obtained τ-lepton mass $M_\tau=1776^{+0.45}_{-0.35}\pm0.07$ MeV is already close to the mean world accuracy of ($\pm$ 0.3 MeV).

Gathering statistics in region of J/ψ-meson was required for experimental determining the energy spread for VEPP-4M, whose value is essential for experiments on measurements of the τ-lepton mass.

5.5.2 Beam energy calibration

One of the important components of the HEP program at VEPP-4 is the beam energy precise calibration. At present, two calibration techniques are realized and being operated: with the use of the resonance depolarization and with the help of the inverse Compton scattering (ICS). The first technique is of the record accuracy ($\sim10^{-6}$) but it is rather time consumable and depolarizes electrons making impossible the periodical calibration by the same beam. In spite of the fact that the second method accuracy is lower ($\sim 3{\cdot}10^{-5}$), it is convenient in operation and does not depolarize the beam, therefore, it can be used directly in the process of statistics gathering. The use of both approaches improves the reliability of the results obtained and provides the required accuracy. In this case, the energy is measured with a precise technique of resonance depolarization both in the beginning and at the end of gathering the luminosity integral and the monitoring is provided with ICS in the process of gathering and enables the control and correction of possible variations in the beam energy.

Method of resonance depolarization

The main direction of the resonance depolarization method development in 2005 was providing a possibility of reliable energy calibration on the threshold of the τ- lepton generation (1777 MeV) in the vicinity of the spin resonance ν_s =(1762.6 MэB) limiting substantially the beam lifetime. It turned out that by switching off all the plates of the beam electrostatic separation one can substantially (from 10-20 min up to $\sim$ 1 hour and more increase the polarization lifetime, therefore, the energy can reliably be measured not just only on the τ threshold but also at 5 MeV lower energy (Fig.7)

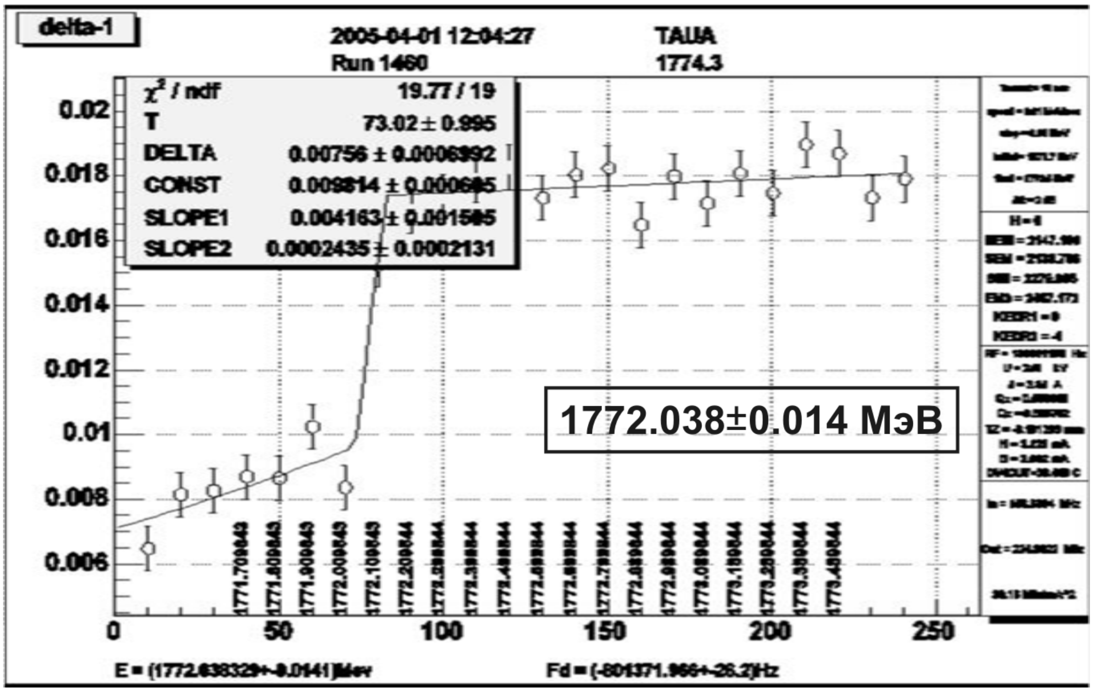

Figure 7: Beam energy measurement at an energy of 1772 MeV.

Another result important in practice was the experimentally obtained estimate of the error introduced into energy determination by the KEDR compensating magnets. Inaccuracy in compensation of the integral value of the detector main field affects both the absolute value of the measured energy and the polarization lifetime (that is of special importance at the τ-lepton generation energy. Fig.8 shows the shift of the beam energy mean value from the current value in the coil of compensating solenoid.

Fig.9 shows the polarization lifetime as a function of the compensating solenoid current. It is seen that incorrect compensation of the KEDR main magnetic field can substantially decrease the lifetime of the particle polarization state.

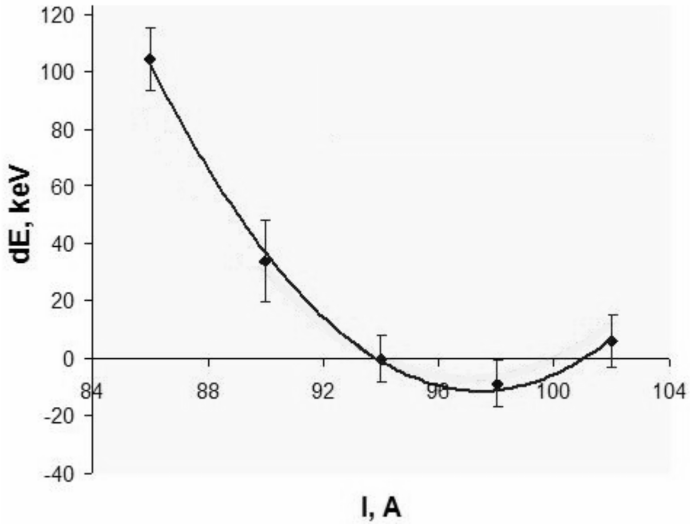

Figure 8: Beam energy variation as a function of the KEDR compensating solenoid current.

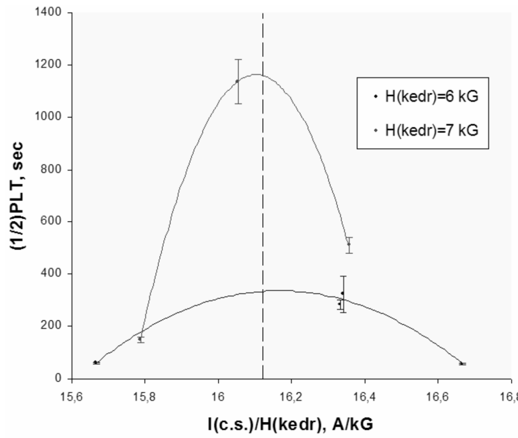

Figure 9: Lifetime of the beam polarized state as a function of the compensating solenoid current reduced to the magnetic field value in the middle of KEDR.

The obtained data are used during gathering the luminosity integral and energy calibration in the vicinity of the τ-lepton generation threshold.

Energy measurements with the inverse Compton scattering

The first experiments carried out in 2004 have shown the method to be promising, which enable quick determination of energy ($\sim$ 10 $\div$ 30 min) within the accuracy of $\sim$ 3 $\div$ 4$\cdot$10^{-5} and measurement of its energy spread with no requirement of beam polarization.

In April, 2005, the CO2 laser GEM Select 50 (Coherent Radiation) with a wavelength of 10.591 mkm (a photon energy – 0.117 eV) and a continuous radiation power of 25-50 W was installed at VEPP-4. The laser radiation is interacting with an electron beam at the VEPP-4M straight section at zeroth angle and inversely scattered it is detected by the Germanium detector Canberra GC2518 with an operative area volume of 120 ml. The mean energy of the beam and energy spread are determined by the edge of the Compton scattering (an energy of γ-quanta of 6 MeV). Fig.10 shows the measurement results of the electron beam energy and energy spread obtained during one shift(24 hours) together with energy calibration by the resonance depolarization technique. The system enables one to find out and eliminate occasional deviations of the beam energy of 200-300 keV during gathering statistics. In this case, the luminosity monitor protects the detector from the strong bremmstrahlung γ-quanta and, at the same time, supresses the radiation soft component. The accuracy in determining energy was achieved to be $\sim$ 60 keV in 30 min during gathering the luminosity integral and (the luminosity monitor is introduced) and in 10 min if the luminosity monitor is out.

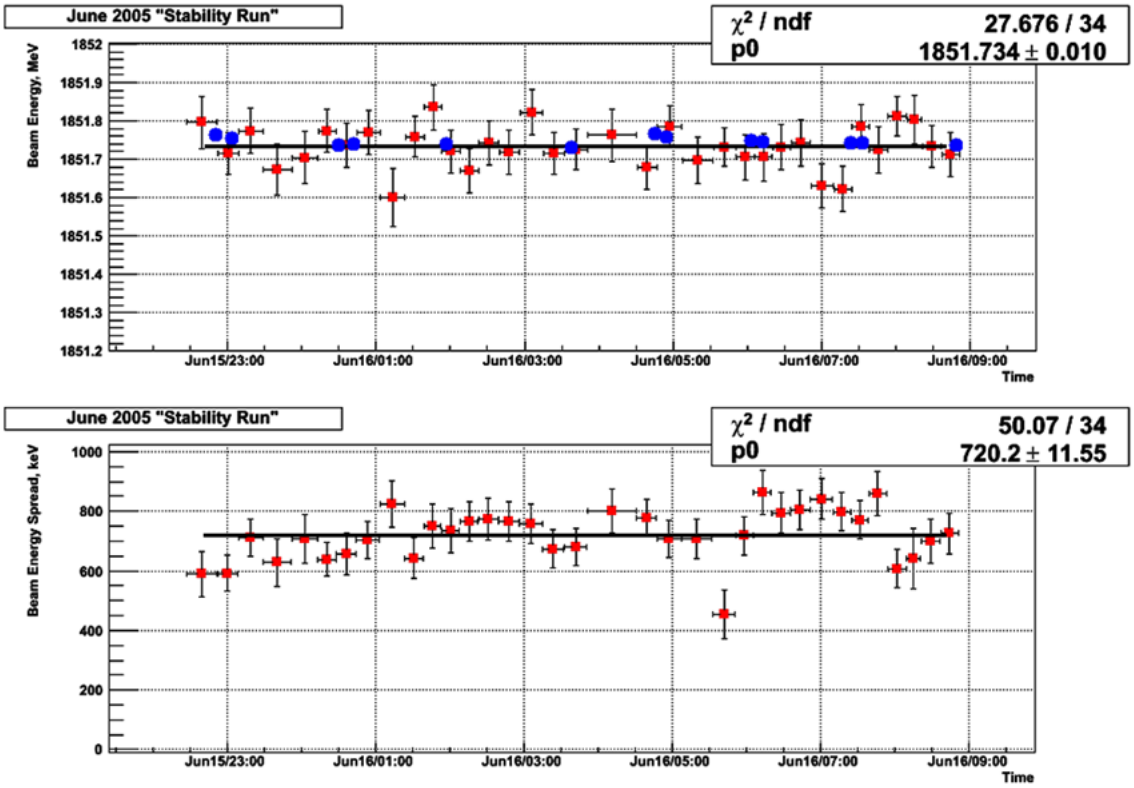

Figure 10: Up - energy measurements, down - energy spread measurement with ICS (red points) and with the resonance depolarization (blue points).

5.5.3 Upgrade and improvement of the complex operation

Feedback system

An increase in intensity of VEPP-4 beams is the task important for improvement of the complex operation efficiency. At the same time, the accelerator large impedance, which leads to excitation of the collective instabilities, limits the ultimate current of a bunch by the value of 3-5 mA at enrgy of 1.5-2 GeV in the 2x2 bunch operation regime.

Aimed at overcoming this limit and suppressing the microwave-instability, we make at VEPP-4 a system of a fast feedback system, which will enable to increase the electron current value in a bunch up to 40 mA in the 2x2 bunch operation regime within the energy range from 1.8 GeV to 5 GeV.

At present, we developed a power electronics, the full set is already manufactured for one channel (the amplifier power is 400 W, the penetration band is up to 25 MHz), all the necessary cabling is made, the digital part of the system (ADC, DAC and a signal processor) is in process of manufacturing. Fig.11 shows the outer view of the produced equipment.

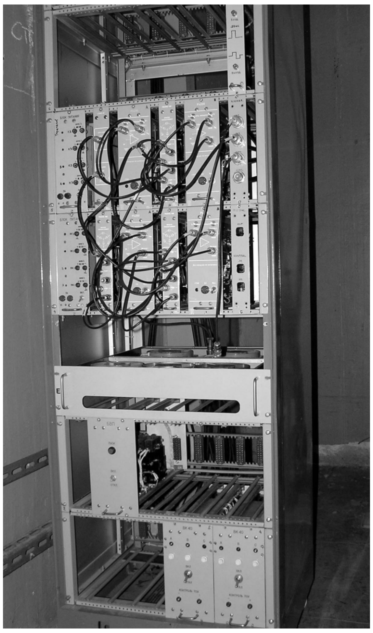

Figure 11: A system for suppression of the transverse instabilities at VEPP-4.

We started operation of VEPP-4M with beams. Fig.12 shows the signal measurement in a load of plates of the electrostatic "kicker". Fig.13 shows the positron beam signal measured from the "kicker" plates.

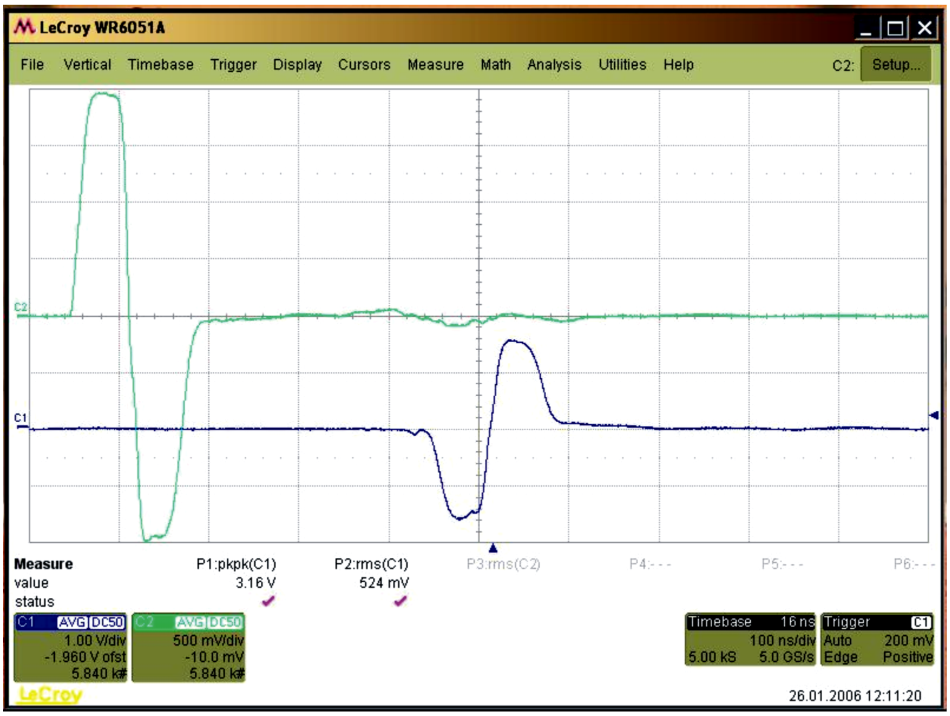

Figure 12: Amplifier output signal (green beam) and that in the load of the "kicker" plates (blue beam)

We also develop a system for suppression of the longitudinal coherent oscillations, radiofrequency amplifiers which are available for the system and the broad-band resonator-kicker is put into production.

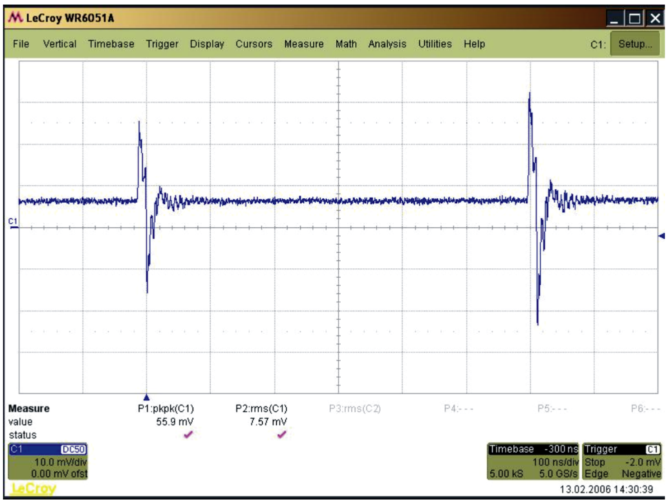

Figure 13: A positron beam signal (two bunches) measured from the "kicker" plates.

Development of a single-mode resonators

The work, which is very important for future, is the development of new accelerating resonators with suppression of the high order modes for VEPP-4M. Installation of such resonators would enable a substantial improvement of a situation with the longitudinal coherent oscillations. In 2005, the design of such a resonator was developed (Fig.14) and its parameters are given in Table 1. The full electromagnetic calculation of the resonator configuration was carried out and the pilot sample of the resonator was produced (M1:5) with suppression of the higher order modes. The resonator was used in measurements of the higher order mode spectrum in comparison with the conventional resonator. An example of the results obtained is shown in Fig.15. At present, we started manufacture of the resonator units.

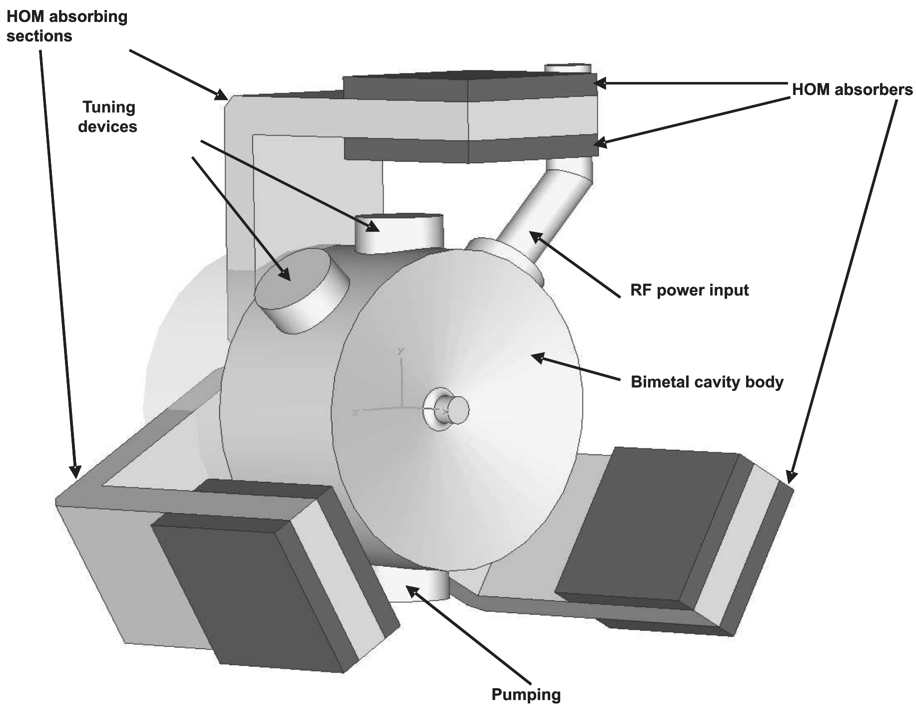

Figure 14: Outer view of a single-mode resonator for VEPP-4M.

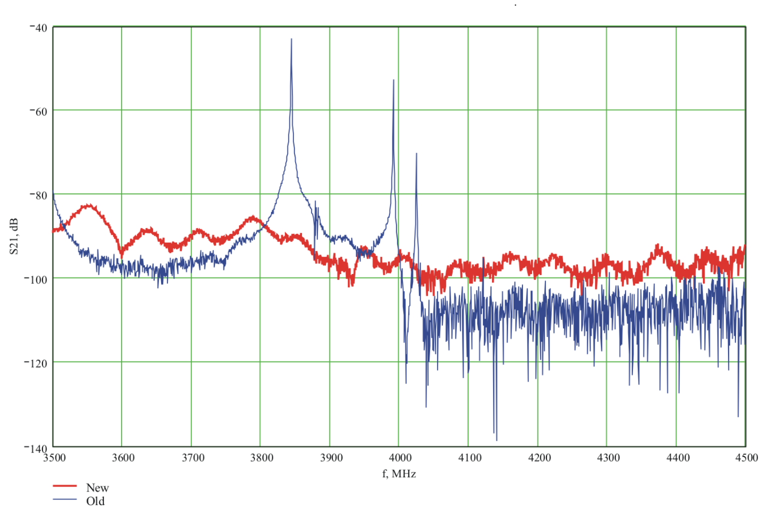

Figure 15: Spectrum of the higher order harmonics measured at the pilot sample of a single-mode resonator (red) compared to that from the conventional bimetal resonator.

Table 5.1: Main parameters of a single-mode resonator for VEPP-4M.

Operating frequency	181.8 MHz
Frequency retuning range	≈ 300 kHz
Duty factor of the operating mode	34000÷36000
Flight-through coefficient	0.86
Characteristic resistance (with an account for flight)	112 Oм
Shunt resistance (taking into account passage)	3.8÷4.0 MOhm
Duty factors of higher order modes	⩽ 300
A power introduced into the beam 4x40 mA, at U = 850 kV	68kW
A power introduced into the beam 4x40mA, at U = 850 kV	68 kW

Stabilization of the cooling water temperature

A stability of the distilled water temperature at VEPP-4M is an essential factor of the reliable and efficient operation of the complex. On the one hand, Up-the cooling water temperature of VEPP-4M resonators, Down-luminosity. The change of the cooling water temperature leads to the undesirable shift in the beam energy, on the other hand, the temperature drift of the accelerating resonators causes the phase oscillations, decrease in luminosity and increase in the particle loss rate.

Fig16 shows graphically the variation of the cooling water temperature of VEPP-4M resonators and luminosity for the same period of time. It is seen that temperature variation by 1°' causes a decrease in luminosity due to occurrence of the phase oscillations, and its change by 2°' makes one to separate the beams since the increased particle losses influence detrimentally on the detector drift chamber. For stabilization of the resonator temperature, special thermostates are developed to keep the given temperature within the accuracy $\approx 0.1 \div 0.05$ °' (Fig.17).

The cooling water temperature is measured both at the thermostat input and its output and the built-in processor matched to the heating element provides the feedback.

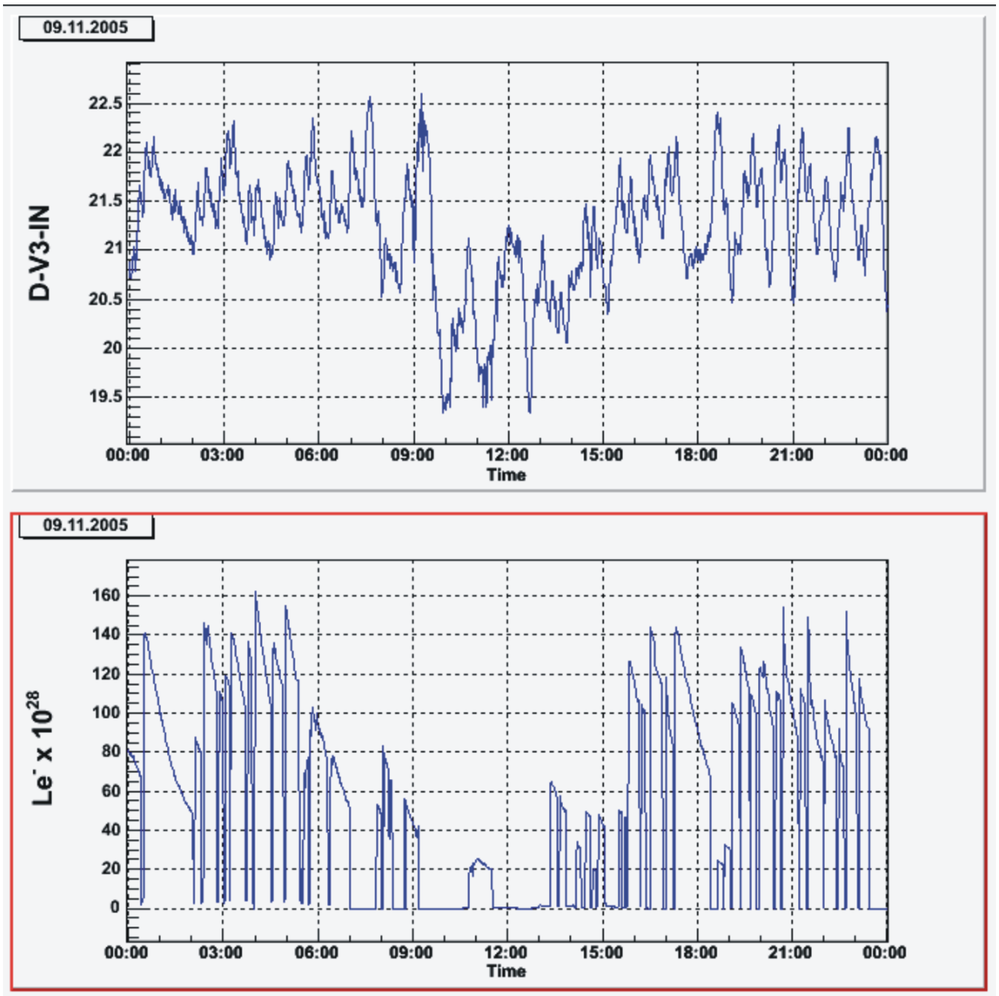

Figure 16: Up - cooling water temperature of VEPP-4M resonators, Down- luminosity.

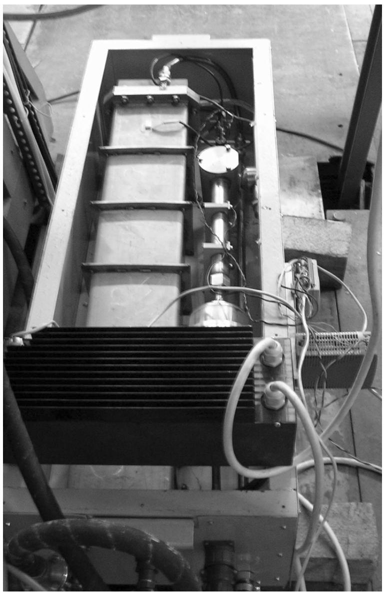

Figure 17: Outer view of the thermostatic device installed near the VEPP-4M resonator.

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5.5.4 International collaboration and contract works

In 2005, the contract activity of the VEPP-4M complex staff included the following:

• Collaboration with CERN on production of the "warm" dipole magnets for the LHC straight sections is nearing completion: production of MCBW (20 pc), MBXWT (3 pc), MBXWS (3 pc) is completed earlier than planned. Production of MBW (17 of 24 are delivered to the customer) and MBXW (21 of 29 are delivered to CERN) will be completed in 2006.

• Production of quadrupole (QTG) magnets of the proton channel for the neutrino experiment Gran Sasso (CERN-DESY) is completed.

• The work on production of the aluminum coils of the quadrupole magnets of SR source PETRA II is continued.

• Delivery of commutations for MBI and MBG (CERN) is completed.

• For the proton synchrotron PS CERN, the 6m aluminum coils of the bending magnets are manufactured. Installation of these coils into the bending magnets of 25 in total was carried out by the staff of L-3 and EW (Fig.18) during 2005.

• We completed manufacture of tooling for repair of quadrupoles for PS (CERN).

• The contract on production of 6 various types of correcting magnets 24 in total with the Japanese firm Toshiba is completed.

• We started production of sextupole magnets for SR source ALBA (Spain, Barcelona).

Figure 18: Staff of L-3 near the repaired magnet for PS (CERN).

In 2005, the staff of Laboratory took an active part in the work on various foreign and international accelerator projects as CLIC (CERN, Switzerland), DAFNE (LNF, Italy) , PETRA III (DESY, Germany), ALBA (Spain), etc. and presented reports in the Russian and International Conferences, Workshops and Symposia.

5.6 VEPP-5 injection complex

In BINP SB RAS the construction of VEPP-5 injection complex is in progress. A complex comprises a pre-injector and a damping ring.

Damping ring

In 2005 the mounting and adjusting works on power supply system for bending magnets and lenses of the damping ring were completed. Test of RF and inlet/outlet system was done. The mounting and adjusting works on beam diagnostic system were started. There was carried out the test of magnetic and vacuum systems for electron and positron inlet channels. Fig 1 shows the picture of the damping ring. It is ready for beam operations.

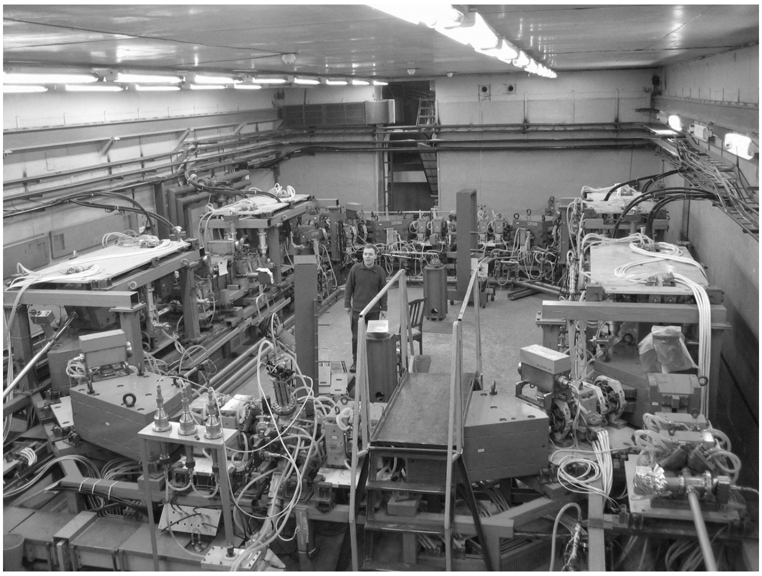

Figure 1: Picture of a damping ring.

Pre-injector

Three accelerating structures of the pre-injector third accelerating module have been produced this year. The forth structure, as well as the high power RF loads are currently in production. All the parts produced are already mounted inside the pre-injector hall. The mounting and adjusting works on magnetic and vacuum system of a linear accelerator of positrons are in progress. The completion of the production of the fourth accelerating structure and RF loads makes possible the electron acceleration in the third accelerating module, as well as their following injection to a damping ring at a designed energy of 500 MeV.

Works participants:

A.A. Akimov, O.Yu. Bazhenov, P.A. Bak, M.F. Blinov, Yu.M. Boimelshtein, D.Yu. Bolkhovityanov, A.I. Butakov, R.Kh. Galimov, B.I. Grishanov, R.M. Gromov, S.M. Gurov, E.A. Gusev, N.S. Dikansky, F.A. Emanov, I.V. Kazarezov, S.N. Klyuschev, A.N. Kosarev, A.A. Korepanov, N.Kh. Kot, D.E. Kuklin, V.I. Kokoulin, R.M. Lapik, N.N. Lebedev, P.V. Logachev, A.I. Mikajylov, P.V. Martyshkin, L.A. Mironenko, V.M. Pavlov, A.V. Petrenko, I.L. Pivovarov, O.V. Pirogov, V.V. Podlevskih, F.V. Podgorny, T.V. Rybitskaya, S.L. Samoilov, V.S. Severilo, Yu.I. Semenov, B.A. Skarbo, A.A. Starostenko, A.R. Frolov, V.D. Khambikov, A.S. Tsigunov, A.G. Chupyra, S.V. Shiyankov, T.A. Yaskina et. al.

5.7 Electron cooling

Main direction of works in 2005 was tuning and testing of electron cooler for LEIR damping ring at CERN. This ring is a part of the injection circuit of the largest in the world hadron beam-beam collider LHC, which is under construction at CERN. Electron cooling will be used for storage of the intense bunches of lead ions in order to provide the ion-ion collisions at LHC. The electron cooler was developed, built and tested in 2004 in BINP. Later it was dismounted and delivered to Geneva on December 17, 2004. In summer, 2005 its mounting was completed and the test with an electron beam was carried out. In November the first successful experiments were done on the cooling of four charging ions of oxygen in the damping ring. Our colleagues at CERN consider the results of ion cooling as quite successful. They emphasize that for the first time in the world the electron cooling was used with an electron beam, which profile may be changed essentially for cooling parameters optimization.

Figure 2: Picture of an electron cooler after it was mounted at the LEIR straight channel.

The work was carried out on the development of the high voltage cooling for COSY storage ring. It is planned to replace the existing cooler with the one for 2 MeV energy in order to extend the experimental abilities of the synchrotron.

An energetic activity was directed on the development of the low energy proton storage ring with an electron cooling. In order to reach the maximum luminosity in the low energy ring, it was proposed to use the longitudinal magnetic field. This allows the solution of the space charge problem, one way or another. In August, there was the workshop in Moscow on the results of works in this direction. V.Reva and V.Vostrikov reported on the main BINP achievements in this field. Other work participants (JINR, Dubna; VNIITF, Snezhinsk; LBN, USA) approved of these results and suggested to make the calculations for 3D model.

Works were carried out on the development of the carbon complex with an electron cooling for cancer therapy. Results were reported on the workshop on the fundamental science contribution to the medicine, which was held in Akademgorodok in August, 2005.

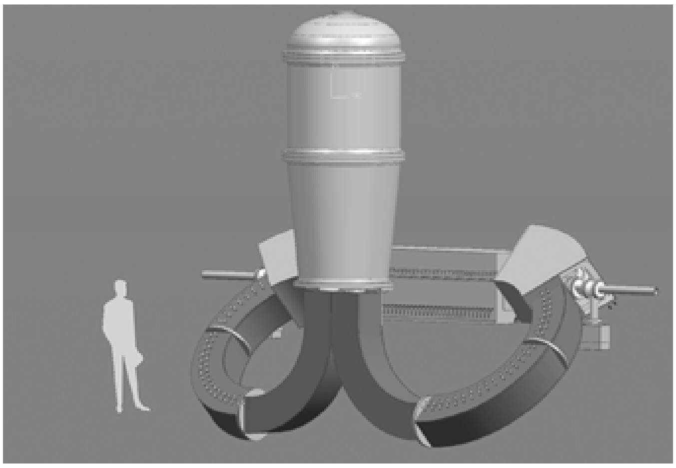

Figure 3: The layout of the electron cooler for COSY.

The accelerator mass spectrometer (AMS) for dating over the isotope ratio is under development in BINP, as ordered by SB RAS. At the present time the production of the accelerators main system is in completion. There was built and mounted the low energy part of the complex. The experiments are in progress with gas and spattering sources of negatively charged ions, aimed at the generation and transporting the ions into tandems first accelerating tube. The experiments were done with magnesium vapor rechargeable target on the separate test-bench. The target is prepared for the installation on the accelerator. The prototype of AMS high voltage power supply system is mounted. Works are done on the preparation of AMS power supply system for the first experiments on the particle acceleration and recharging to be started in the beginning of 2006. As a result of the experiments, there was completed the systems elements, and the stable operation without breakdowns is reached at an accelerating voltage of around 550 kV and the use of air as an insulating gas. An insulating gas system is completed. There was developed and manufactured the ion beam parameters registration system and the ion source power supply system. There was developed and partially produced the AMS control system on the basis of ADAM and CAMAC modules and LabVIEW software. Electronics under high voltage is controlled with ADAM optical connection modules. There was developed and produced the gas turbine prototype for the power supply of the high voltage operating electronics. The prototype is supplied with an insulating gas flow from the compressor under the ground potential. The work is in progress on the modification of the turbine aimed at its efficiency increase. In the beginning of 2006, after 180° combined bend production, there are planned the assembling of AMS high voltage part and the experiments on the particle acceleration and recharging. The work is supported by INTAS foundation.

Participants of the work:

N.I. Alinovskiy, V.V. Anashin, V.N. Bocharov, M. Bryzgunov, A.V. Bubley, M.A. Vedenev, V.F. Veremeenko, R.V. Voskoboinikov, V.A. Vostrikov, V.K. Gosteev, A.D. Goncharov, I.V. Gornakov, Yu.A. Evtushenko, N.P. Zapyatkin, M.N. Zakhvatkin, A.V. Ivanov, I.V. Kazarezov, V.R. Kozak, V.I. Kokoulin, V.V. Kolmogorov, E.S. Konstantinov, S.G. Konstantinov, I.A. Koop, A.M. Kryuchkov, A.S. Medvedko, L.A. Mironenko, V.M. Pavlov, V.M. Panasyuk, V.V. Parkhomchuk, D.V. Pestrikov, S.P. Petrov, S.A. Rastigaev, V.B. Reva, B.A. Skarbo, B.M. Smirnov, B.N. Sukhina, M.A. Tiunov, V.G. Shamovskiy, Yu.M. Shatunov, K.K. Shrainer et. al.

Work results are presented in publications:[293]÷[296], [351]÷[356].

5.8 Neutron target prototype

Nowadays in LNL-INFN (Italy) the project on the study and the production of short-lived radioactive isotopes is under realization. The development of a high intensity neutron production target is a part of this project. BINP proposed the design of a high temperature solid target with a converter cooled by thermal radiation.

The proposed target design comprises the converter assembled with plates fastened to rotating metal disk and cooled by thermal radiation (fig. 4). The most strained part of this target is a converter which should have the temperature of 1700-2000 ^{o}C for the effective cooling.

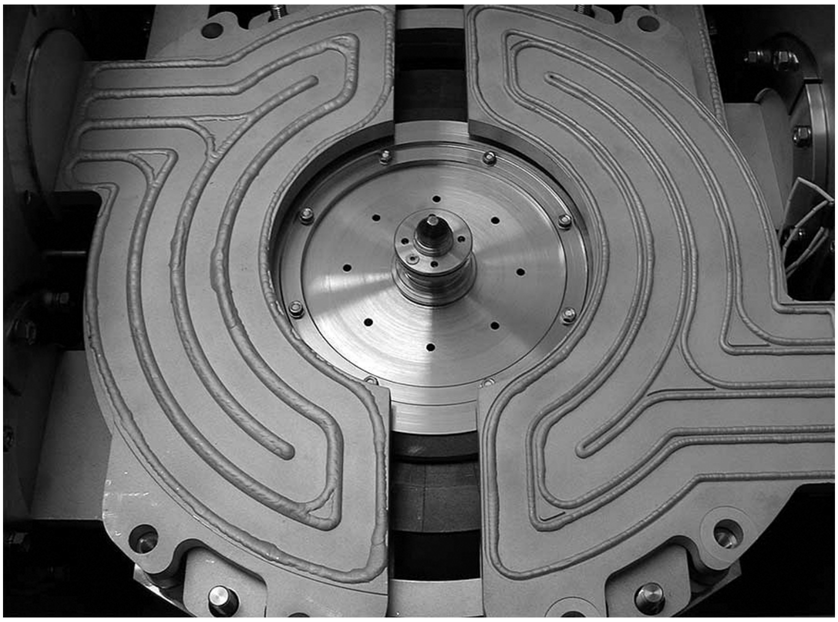

Figure 4: The neutron target prototype.

Test of materials-candidates for the converter production were carried out in BINP under conditions simulating the target operation mode. Test comprised the distributed volume heating-up of the samples with an electron beam up to conditions simulating the converter operating mode.

As the materials for the converter there were tried the heat resistant materials, such as graphite, glass carbon, boron carbide, and the original graphite-like material on the basis of ^{13}C isotope.

Graphite materials proved their principal adaptability in the proposed variant of a neutron production target.

Up to now there were completed:

• development and testing of a neutron target prototype,

• study and optimization of various schemes of the neutron target,

• preliminary design of the bioprotection shielding,

• conceptual design of the radioactive ion source which provide the dismounting and the replacement of the target system in a way excluding the staff presence inside the radiation area,

• conceptual design of a bioprotection system.

Work was carried out within the framework of ISTC Project №2257.

Upon the completion of the project it is proposed to continue the works on the development of the radioactive ion source on the basis of the neutron target within the framework of SPES project.

Participants of the work:

M.S. Avilov, A.V. Antoshin, D.Yu. Bolkhovityanov, A.V. Tsygunov, K.V. Gubin, E.I. Zhmurikov, A.R. Frolov, N.N. Lebedev, P.V. Logachev, P.V. Martyshkin, S.N. Morozov, A.A. Starostenko, S.V. Shiyankov et. al.

Work results are presented in publications:

[111], [298]÷[300], preprints 1, 2, 11.

5.9 Liquid lead target prototype for positron production

In BINP SB RAS the development of liquid lead target prototype for positron production (ILC) is in progress. The conventional solid WRe targets stand the incident power of up to $2 \cdot 10^{12}$ GeV/mm^2 per short pulse (less than 100 ns). In order to overcome this limit, the liquid metal target was proposed. In this target the jet of metal at a temperature of around 300 °C is pumped between the windows which the beam passes through.

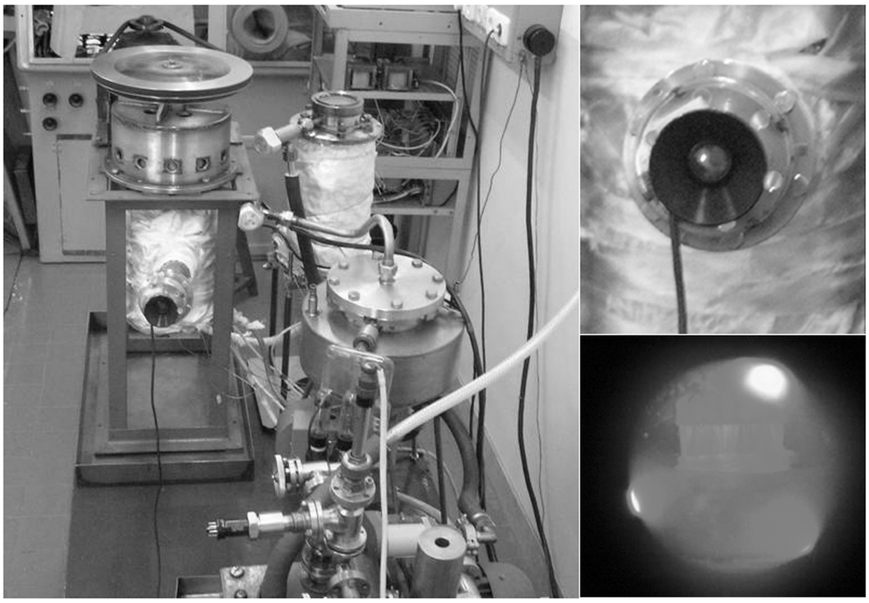

Figure 5: Liquid lead target prototype.

For this goal there was completed and tested the existing gear pump. The pump operated for around 6000 hours, pumping the 90% Pb and 10% Sn alloy at an operating temperature of 300 °C. After 6000 hours of operation no damage was detected

Participants of the work:

M.F. Blinov, V.A. Golikov, I.E. Zhul, P.V. Logatchev, S.N. Morozov, V.A. Popov.

5.10 Works of electron gun team

• Participation in the test of 200 keV 2 kW accelerator for USA. The accelerator is successfully tested and delivered.

• There were developed, designed and manufactured iridium-cerium cathode assemblies for multiple charged ions installation for BNL, USA. Cathodes have diameters of 9.5 mm and 14.5 mm, and designed for long-term operation at cathode current densities up to 20 /^{2} and pulse width up to 0.1 s

• The team took part in the works on the manufacturing of electron welding installation (fig. 6). The operating voltage was up to 60 kV, current adjustment was $1 \div 250$ mA. The installation has the wide range of distances to the welding point and possibilities for electron emission control.

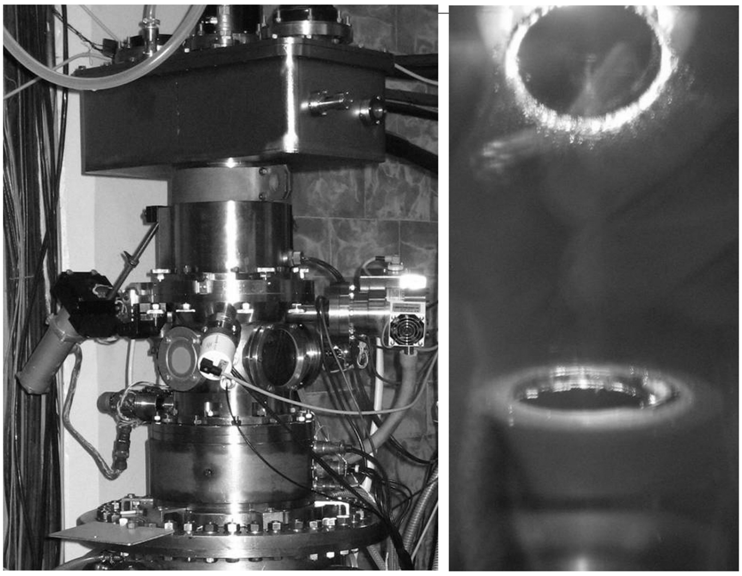

Figure 6: Electron welding.

• There were manufactured, tested and delivered the cathode assemblies with lanthanum hexaboride emitters for KAERI microtron, Korea. These cathodes has the lifetime tens times more than those usually applied for microtrons.

• A series of works were carried out on Charge State Breeder BRIC installation at INFN-LNL, Legnaro. There were upgraded:

– ion optical system;
– ion extractor's shutter;
– ion extraction from a trap;
– time-of-flight channel's shutter.

There were reached the full extraction of ions from a trap and their transporting through the whole optical system. There were improved the resolution of the peaks of ions of various charge after the time-of-flight channel.

• There was studied the cathode materials for different applications under borderline vacuum conditions.

Participants of the work:
M.A. Batazova, K.V. Gubin, G.I. Kuznetsov, P.V. Martyshkin, V.M. Pavlov et. al.

Work results are presented in publications:[301], [302], [303].

5.11 Vacuum studies

5.11.1 Measurements of Secondary Electron Yield for NEG TiZrV

Suppression of electron multipacting in beam channel is actual task of particle accelerator physics. Coating of vacuum chamber walls with material with low secondary electron yield is one of the foreground study tasks to solve this problem. In consequence of good sorption properties of non-evaporable getter (NEG) films TiZrV it is very interesting to coat the vacuum chamber walls with this material. In the scope of joint collaboration between BINP and KEK (Tsukuba, Japan) dedicated to study of electron emission from NEG TiZrV the direct measurements of secondary emission yield (SEY) for this material were carried out.

In the BINP, the 10x30 mm samples were coated with TiZrV simultaneously with experimental vacuum chamber for KEKB accelerator (KEK, Japan). The special experimental setup was also created in BINP to measure SEY of these samples. The baking temperature of vacuum chamber of this setup was limited to 100° C so as to avoid the absorption of water onto the NEG coating. The sample pieces could be heated up to 300°C separately. The base pressure was obtained on the order of 10^{-7} Pa after baking of vacuum chamber for 24 hours. The electron gun generates a beam with diameter of about 1.5 mm, which was directed to the sample with a normal incident angle. The electron current was 10 nA, and the energy range was from 20 eV to 600 eV. These parameters were sufficient to measure the maximum of SEY (δ_{max}) which is usually observed at primary electron energy of less than 500 eV. The measured energy spectra of the SEY of NEG coating are presented in Fig. 1. The maximal SEY before activation was 2.3 - 2.5. After activation (baking) at 255°C and 300°C, however, SEY decreased to 1.5 - 1.6 and 1.2, respectively.

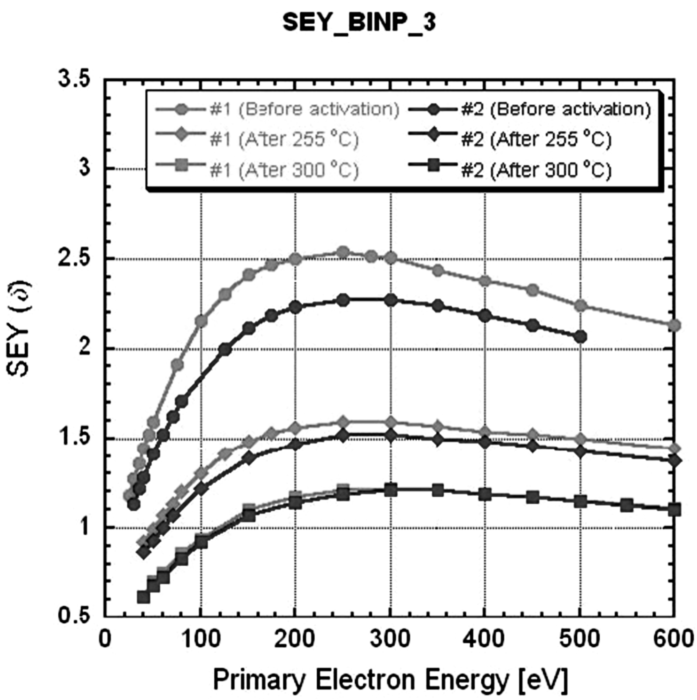

Figure 1: Dependence of Secondary Emission Yield (SEY) on energy of primary electrons.

There are some assumptions to explain the results of measurements. One possible reason is that the baking temperature of the test chamber was low in our case, and not sufficient for degassing. The areas of sample pieces were much smaller than that of the test chamber, and the desorbed gas from the test chamber could affect the surface of NEG coating. The second possible reason is that the samples were kept under the atmosphere long time before this measurement. As a consequence, the NEG might have been partially oxidized. Taking to account these circumstances, we plan to perform the new detailed experiments with wider range of energy of primary electrons.

5.11.2 The experimental study of activation and adsorption properties of evaporable getter Zr-V-Fe

The possibility of activation of modern getters by means of outside baking is interesting in practice because in that case the additional high current feedthroughs and electrical isolation of getters are not necessary. It very simplifies the design of experimental setup. The present work is dedicated to study of activation of getter St707 SAES Getters (Zr(70%)-V(24.6%)-Fe(5.4%)) by means of outside baking.

For this purpose the special experimental setup was created in the BINP. The getter pump was made as cartridge to obtain the largest specific adsorption capacity. Constantan tape covered with St707 getter was placed like starry-shaped (star- polygonal) solid inside slots. The cartridge with 5 slots is shown in Fig. 2. The total length of tape is 10 m. Cartridge has length of 150 mm, inner diameter 90 mm, and outer diameter 145 mm. The distance between strips is 7 mm. Activation of getter was performed by means of outside baking out. Baking of cartridge in this setup can be performed with assigned behavior at temperature to 400°C. Before activation of cartridge the vacuum chamber with getter was baked at 150°C during 36 hours. Then the setup was cooled down, but temperature of cartridge continued to remain near 150°C approximately. Activation of cartridge was carried out at 350°C during 4 hours.

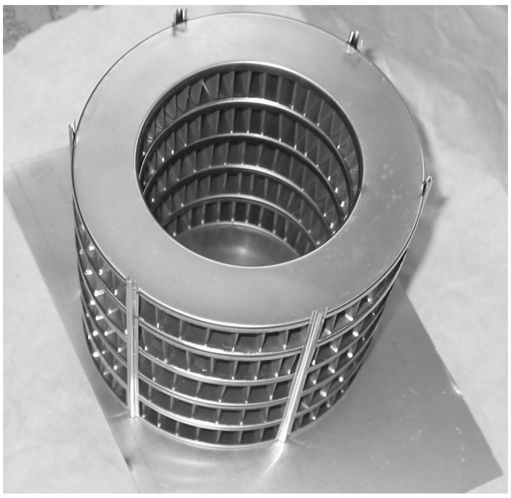

Figure 2: Cartridge with NEG (side view, view from above).

The check of efficiency of activation of NEG cartridge was performed by means of comparison of results of measurements of effective sticking probability of H_2 onto internal cartridge surface with values computed with use of angular coefficients method. The computed dependences of effective sticking probability at distances between strips (pitches of placing of tape) for sticking probabilities at open getter surface a=0.01, 0.03, 0.05 and experimentally measured value for distances between strips of 7 mm are shown in Fig. 3. It can see in Fig. 3 that experimentally measured value corresponds to the sticking probability at open getter surface of 0.02-0.03. This result is in a good accordance with results of measurements of open strip [C. Benvenuti and P. Chiggiato "Pumping characteristics of the St707 Non-evaporable getter (Zr 70 -V 24.6-Fe 5.4 wt %)", 1995]. Thus, it can conclude that activation of getter under used conditions was performed successfully. Following measurements of cartridge adsorption capacity for CO (2 litre*Torr) corroborated that activation of getter with almost 100% efficiency was obtained. In three weeks after activation of cartridge the total pressure of residual gas in the vacuum chamber of experimental setup decreased to $3{\cdot}10^{-12}$ Torr.

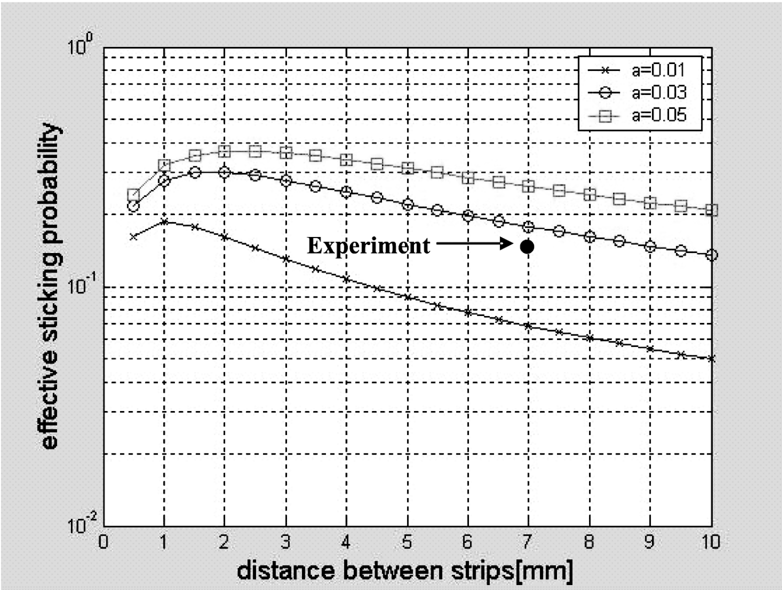

Figure 3: Computed dependence of effective sticking probability on distances between strips for sticking probabilities at open getter surface a=0.01, 0.03, 0.05.

5.11.3 Production of vacuum phototriodes

The great work aimed to production of phototriodes with ⌀52 mm and ⌀32 mm for calorimeters SND and KEDR is carried out. The technical parameters of these devices have to meet the requirements:

- quantum yield of phototriode $\geqslant 10\%$ ($\lambda = 415$ MM);
- amplification factor ~ 10;
- energy resolution measured for photopeak of gamma-quantum of radioactive source ^{137}Cs $\leqslant 15\%$;
- operation in magnetic field with magnitude up to 2T.

For this task in BINP the new computer-based system of phototriode production was started to develop since 2003. The computer-based system bases on two vacuum pump stands designed for production of photocathodes "KRIOP" because the technical equipment and computer program created for same stand at the eighties become obsolete.

The new system lets to simultaneously produce the bi-alkaline or multi-alkaline photocathodes for six phototriodes placed on the vacuum pump stand. The equipment of the stand bases on use of electronic units in the KAMAK standard and two special unites in “Vishnya” standard. The computer program is created with use of programming language “C” under operational system Linux. At present time the main part of program is debugged, and program updating for the computer-aided technology of production of a bi-alkaline photocathode (K_2CsSb) is in progress.

The special stand was constructed to measure the main parameters of phototriodes. In this stand the phototriode is used as photodetector of scintillation detector based on monocrystal NaI(Tl).

The computer program of the stand control is created with use of programming language “C” under operational system Linux. Besides, other special stand was created to check the availability of phototriodes in the external magnetic field. This stand lets check the dependence of output signal of phototriode on angle (from 0° to 90°) between device axis and direction of magnetic field with fixed magnitude of field.

In 2005 the 230 photriodes with ⊘32 mm were produced in the scope of collaboration between BINP and enterprise “Ecran”. The main parameters of photriodes have been measured. Moreover, the tests of the availability of phototriodes in the external magnetic field were also carried out. The plans for close future are optimization of computer-aided technology of activation of photocathodes and start of production of phototriodes with ⊘52 mm and ⊘32 mm for calorimeters SND and KEDR. The preprint with descriptions of computer-based system of phototriode production and stands for measurements has been published.

5.11.4 Production of electrovacuum components for Large Hadron Collider (LHC)

At present a great number of vacuum and electrovacuum components for Large Hadron Collider (LHC) constructed in CERN are produced in BINP. Complexity of design and high requirements to the technical parameters of manufactured articles demanded the development of a number of new production engineering, methods and techniques. For instance, the precision electron beam welding, laser welding and soldering with indium in atmosphere of hydrogen for high-frequency electrical contacts were commercialized a process to produce the connector assemblies of vacuum chamber of beam channel (Fig. 4, 5). Coating with gold, rhodium and check of impedance of electrical contacts are also performed in BINP. The pulse electrolytic thick deposition of copper onto stainless steel was commercialized a process to produce the high current monitors of beam. As a whole, 152 types of vacuum units will be produced in BINP for LHC, total product to 12 000 pieces.

It deserves mention of the successful in production of 600A and 6000A LHC current leads with heat transfer to helium bath less than 0.1 and 1 W, respectively (Fig.6). The behavior of deep fusion penetration (to 15 mm) of copper joints by means of use the electron beam weld equipment was commercialized a process (Fig. 7). The automated furnace was created to provide with precision vacuum soldering for superconductive ceramics strips (Fig. 8). The special equipment for covering with organic matter coating from gas phase was purchased (Fig. 9), and technology of coating with Parylene-C was commercialized a process. Now this coating is one of the most effective preservatives from moisture.

Figure 4: “Cold” connector assemblies for vacuum chamber of LHC beam channel.

Figure 5: “Warm” connector assemblies for vacuum chamber of LHC beam channel.

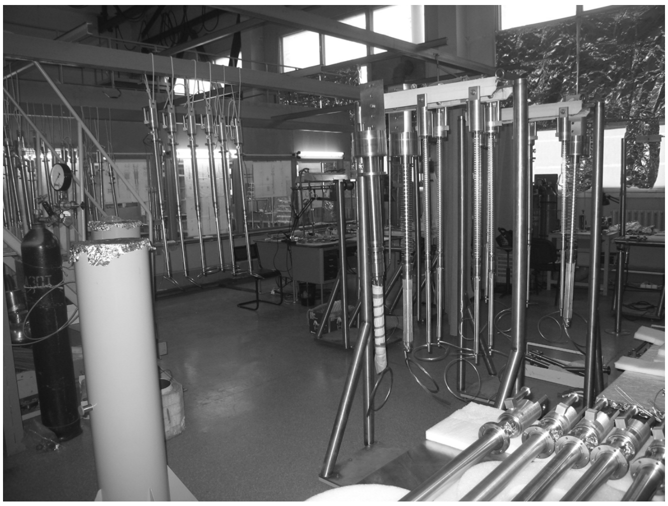

Figure 6: Assembly of 600A and 6000A current leads.

Figure 7: Loading of 6000A current lead into electron beam weld equipment.

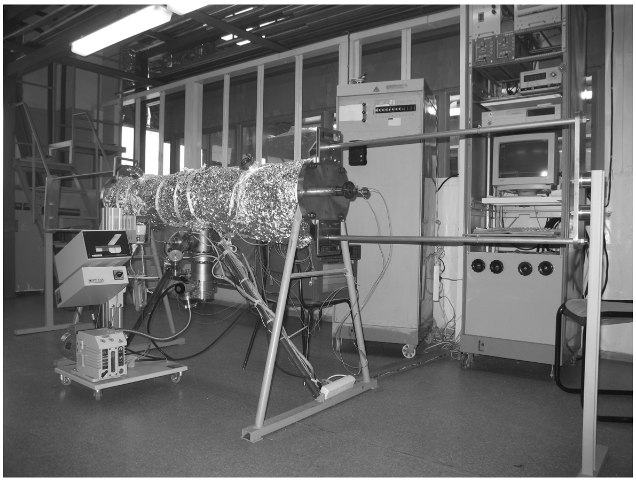

Figure 8: Vacuum furnace for automatized soldering for superconductive ceramics.

Figure 9: Equipment for covering with organic matter coating from gas phase.

Publication:
[1]÷[4], [254], [255], preprint 21.

Chapter 6

Synchrotron Radiation Sources and Free Electron Lasers

Introduction

There are now two centers of joint usage functioning on the base 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 2005 included the following directions:

• investigations followed by development of new technologies with the application of SR from the VEPP-3 storage ring;

• creation of experimental equipment for SR operation (lines, experimental stations, X-ray optics, monochromators, and detectors);

• development and creation of accelerators – dedicated SR sources;

• development and creation of special magnetic systems for SR generation, i.e. wigglers, undulators, and superbends;

• teaching and professional training of students and post-graduates.

In 2005, 1878 hours were allotted for work with SR at the VEPP-3 storage ring. The experiments used 10 stations on 7 SR beamlines.

The working program of the Siberian Center for Photochemistry Research for the year 2005 included the following directions:

• creation of experimental stations and execution of investigations on the operating high-power terahertz laser;

• further activity on creation of the multi-turn accelerator-recuperator and the more powerful IR-range free electron laser on its base;

• participation in foreign projects dealing with development and creation of high-power FELs;

• teaching and professional training of students and post-graduates.

6.1 Work on SR beams from VEPP-3

6.1.1 Extreme states of matter

The station "Extreme states of matter" is intended for contrast radiography and small angle X-ray scattering at study of detonation and shock-wave processes. There is only one such station in the world. In 2005, there were 620 hours of work with SR beam and 119 experimental explosions were performed at this station. The station allows one to carry out experiments with as much as 30 grams of explosives. A particular feature of the station is the usage of the explosion chamber with thin beryllium windows to pass the SR beam and the one-coordinated detector with the time resolution of 100 ns.

Explosion chamber. The explosion chamber is made of stainless steel; to minimize X-ray radiation losses, the windows for SR entry and exit were made of 2 mm beryllium. For the windows to stay hermetic after the explosion, the chamber was equipped with special "shock wave dampers". The chamber windows and faucets are sealed and the chamber can be evacuated and filled with inert gases (helium). Its design allows remotely-controlled vertical motion of an experimental assembly inside the chamber with an accuracy as high as 5 microns. Explosive charges are initiated with high voltage detonators.

The detector unit is a steel hexahedron 20 mm thick comprising a high-accuracy mechanism to move the detector, X-ray detector DIMEX and a high-speed shutter. To move the detectors, the unit is equipped with a two-coordinate high-accuracy scanner. It is possible to move the detector in the vertical and horizontal directions, with accuracy as high as 5 microns.

Specially for this station, the one-coordinate detector DIMEX was developed to study dynamics of fast processes on SR beams. The detector allows one to accumulate and memorize information about X-ray flux distribution in a time shorter than the inter-bunch interval in the storage ring ($\sim$ 100 ns for VEPP-3). The detector has 32 frames accumulated in such a fast regime. Its aperture is 25,6 mm along the coordinate to measure and $\sim$ 2 mm in the normal direction. Filling the chamber with the Xe-CO_2 mixture (80%- 20%) under a pressure of $>$ 7 atmospheres provides spatial resolution 200 microns and efficiency to 30 keV photons not less than 50%.

CURRENT INVESTIGATIONS AND PROJECTS SUPPORTED.

SR investigation of the detonation and shock-wave processes.

These works were conducted within the RAS programs “Investigation of detonation processes in gaseous, heterogenous and condensed media, including their engineering application.” and “Investigation of behavior of homogenous and heterogenous media under high energy impact”.

These works were supported by SB RAS grants №120 “SR investigation of formation and dynamics of nanostructure growth in the detonation and shock-wave processes” and “SR application for investigation of dynamical processes in continuous media” of the RAS Presidium program for basic research “Thermal physics and mechanics of intense energy impact”.

The works were also supported by RFBR grants №05-03-32752 “Investigation of the dynamical balance of nanodiamonds in detonation waves.” and №04-02-16903 “SR investigation of short-lived excited states under extreme conditions of high temperature and pressure”.

The investigations were performed jointly by Lavrentiev Institute of Hydrodynamics SB RAS, Budker Institute of Nuclear Physics SB RAS, Institute of Solid State Chemistry and Mechanochemistry SB RAS. Methods applied in the investigations (especially the small angle X-ray scattering measurement with submicrosecond time resolution) are unique and nobody else in the world uses them. The experimental results obtained will be of great value for understanding the nucleation and growth of nanoparticles both of graphite and diamond in the detonation and shock wave.

Explosion experiments that were carried out can be divided into two groups: measurement of distribution of intensity of X-radiation and small angle X-ray scattering.

Restoration of density distribution in the chemical reaction zone in pressed hexogen is an important result. The existence of the chemical reaction zone in this explosive is still discussed in literature.

Experiments on shock compression of aerogel at initial densities of 0,25 g/cm^3 and 0,15 g/cm^3 were the first case when shock adiabats of aerogel have been obtained.

In order to improve time resolution at SAXS measurement, the no-reset operation mode of the DIMEX detector was tried. It turned out to be possible to record SAXS signals in 125 ns, the VEPP-3 storage ring working in the two-bunch mode. The linear resolution in these experiments was as high as 0,1 mm at detonation rate $\sim$ 8 km/s.

Obtaining the first experimental data on density of gaseous cumulative jets

Motion of dense cumulative jets (copper, tungsten-copper composite, etc.) has been studied in detail in many laboratories over the world. However, the existing physical methods do not allow studying the physics of motion of low-dense cumulative jets, i.e. the gaseous ones.

The experimental difficulties are caused mainly by low sensitivity of standard X-ray registration methods because of the low contrast of the object under study. Gas-dynamic computer simulation made for the trotyl-hexogen explosive in the leading laboratories over the world has estimated the density to be $\rho \approx 0{,}15$ g/cm^3. It was the first time that the gaseous cumulative jet image was observed and its density and speed were found out at this experimental station . In these experiments, the gaseous jet was forming at detonation of a pipe-form trotyl-hexogen (50/50) charge (Fig.1).

Figure 1: Experiment arrangement. The grey tube is the initial explosive charge (240 mm long, 12 mm in diameter), the black zone is the cumulative jet position in two frames, B and C.

Measurement of very small density of cumulative jet through the walls of the explosive charge of the density $\rho_0 \approx 1{,}7$ g/cm^3 was another difficulty. The jet speed measured U = 15,6 km/s coincides with the design data and the density measured $\rho \approx 0{,}05$ g/cm^3 turned out to be three times smaller than the gas-dynamic theory prediction. The result obtained is very important for the theory of cumulation.

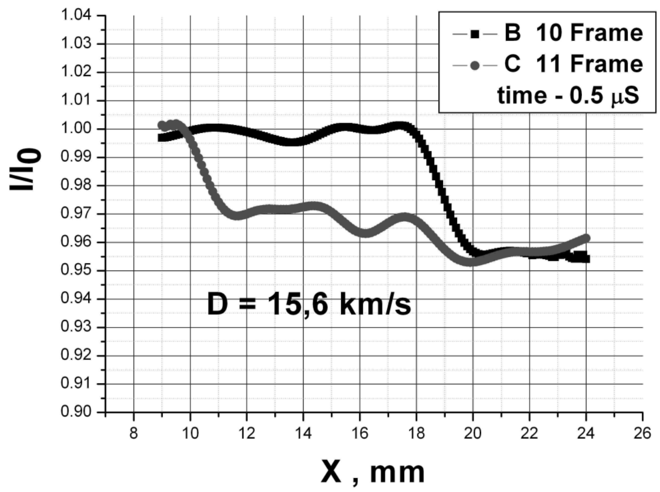

Figure 2: Relative absorption of SR along the charge axis in the frames B and C made with an interval of 0,5 microsecond. Speed of the front edge of the jet is 15,6 km/s.

Investigation of aerosil behavior under the shock-wave impact: the equation of state and the process of destruction.

Experiments on shock adiabat determination (determination of the equation) of state were carried out for aerogel with surface as large as 1000 m^2/g. The compression and density values obtained were U = 1,0 - 1,7 km/s and 0,15 - 0,25 g/cm^3, correspondingly.

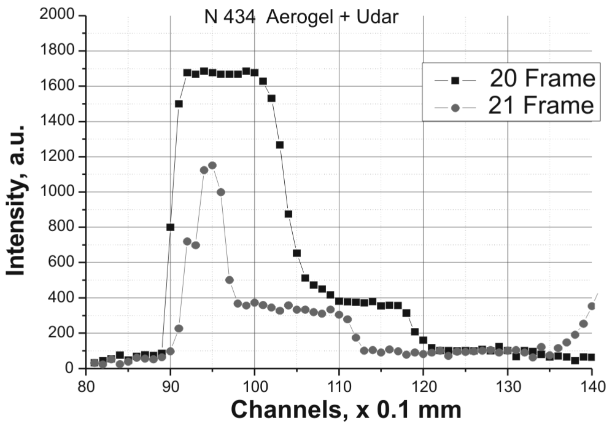

Figure 3: Intensity distribution in two frames at shock compression of aerogel. Frames 20 and 21 show the distribution before and after the shock wave reflection at the obstacle, correspondingly.

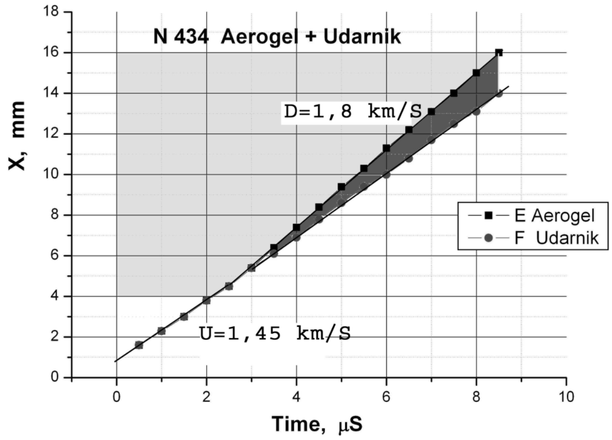

Figure 4: x-t diagram of the motion of the shock wave and bullet (udarnik). The bullet speed is 1,45 km/s; the shock wave speed in the aerogel is 1,8 km/s.

The same samples were used in the year 2005 in a series of experiments to study their destruction by shock waves. We have revealed that processes initiated by the shock wave in aerogel are in threshold dependence on the shock wave speed:

1) at a shock wave speed less than 2,6 km/s the aerogel is destroyed with no changes in its inner microstructure, i.e. the structure of the particles that form it (the particle is 5 nm in size);

2) at a shock wave speed more than 2,6 km/s, the shock waves initiate significant changes in the microstructure, which are accompanied by destruction of microparticles followed by agglomeration into conglomerates of normal logarithmic distribution.

Figure 5: General view of the "LIGA" station.

The SR beamline 15 m long, 60 to 100 mm in diameter is separated by a Be foil (100 microns) from the storage ring and by Be foils (100 microns+300 microns) from the experimental station. The inner volume of the beamline is maintained under vacuum about $10^{-}5$ Pa. The beam position monitor and the unit of diaphragms are installed inside the beamline.

SR beams can be extracted to the LIGA station of the VEPP-3 storage ring both from the 3-pole 2 T wiggler and from the 11-pole one with field varying from 0 to 1 T.

Figure 6: “Clean” room.

That broadens the wave range of the SR used, in accordance with requirements of specific applied problems. Spectral range of SR is obtained with removable foils (Be, Al and others).

Samples are prepared, resists are applied and etched and electrotyping is performed in the specially-prepared premise, “Clean room” with specialized equipment: a centrifuge, a vacuum desiccator, microscopes, a fume hood and a system for dust removal from the atmosphere.

CURRENT INVESTIGATIONS AND PROJECTS SUPPORTED.

Methodological studies of PMMA and SU-8 X-ray resists and X-ray lithography regimes. BINP SB RAS.

• RFBR project №03-02-16718, “Investigation of the possibility of development of the LIGA method for manufacture of microstructures with a pre-set profile”. (the years 2003 to 2005)

• The youth project of SB RAS for the year 2006, “Development of quasi-optical selective elements on the base of metal grid structures for frequency and spatial selection of terahertz radiation“ (the years 2006 and 2007)

• Interdisciplinary SR project, “Ray technologies of synthesis of microstructured components for ophthalmology, micro-optics and micro-photoelectronics with the application of new hybrid optical materials” (the years 2006 to 2008)

6.1.3 Anomalous scattering and precision diffractometry

The station “Anomalous scattering” is intended for precision X-ray diffractometry investigations of structure of polycrystal materials Below is the statistics of shifts of the station in the year 2005:

Hours claimed	2009,0
Hours worked	1198,2
Efficiency of the station operation (hours)	59%

Brief annotations of the main works done at the station in the year 2005

Investigation of the structure of meso-structured silicate materials and their derivatives. Meso-structured materials show ordering of structure units, i.e. meso-pores of the nanometer range, without any long-range order at the atomic level in the silicate matrix. Such matrix are promising as concerns adsorption, catalysis, microelectronics, optics and other fields of science and engineering. Samples of meso-structured silicates of different origin were studied, including samples synthesized with the use of different mixtures of ionic and non-ionic surfactants, in order to control the diameter of mesa-pores during the synthesis. Results of the work on synthesis of Ti-containing catalyst on the basis of meso-structured material obtained with the use of the agent mixture have been published. Samples with post-synthesis application of heteropoly acid into silicate meso-pores were also studied.

Investigation of the structure and substructural characteristics of catalysts of deep oxidation of hydrocarbons. The phase composition and substructural characteristics of CeO_2 samples obtained through self-propagating surface thermosynthesis from cerium ammonium nitrate $(NH_4)_2Ce(NO_3)_6$ nH_2O $(NH_4)_2Ce(NO_3)_6$ $H_2[Ce(NO_3)_6]$ $CeO(NO_3)_2CeO_2$ deposited onto glass tissue have been studied.

It was shown that the sample practically does not have micro-stresses and stacking faults and diffraction line broadening is caused by size of CeO_2 particles, which do not exceed 5 nm.

Investigation of phase composition of catalysts of carbon nano-fiber synthesis Carbon nano-fibers are used as a carrier of metal catalysts applied in fuel elements. A series of samples of Ni-Cu-Al catalysts of the synthesis of catalytic filament carbon was studied: the initial catalyst and 15, 30, 60 and 1200 minutes of reaction time. In accordance with the synthesis terms, the catalyst has the following composition: Ni - 65%, Cu - 25%, Al_2O_3 - 10%. Reflection positions of the initial sample differ from those of pure metals this fact approves the partial dissolution of metals within each other. The amount of nickel dissolved in copper is estimated to be a few per cent (<5%) and that of copper dissolved in nickel is estimated to be 25%. A typical feature of the system under study is that the catalyst lattice constants vary inhomogeneously as the reaction runs and the catalytic filament carbon grows.

Investigation of the phase composition of thin films. This work was aimed at investigation of semiconductor films obtained through plasma-chemical decomposition of volatiles as well as at the influence of the synthesis terms and substrate on the structure and phase composition of the layers made. The structure and phase composition of thin films of cadmium sulphide, cadmium and zinc sulphides mixed on different types of substrates were studied as well as the influence of the synthesis terms and substrate on the sulphide structure and the structure and phase composition of thin films of boron carbonitrides. The influence of the initial gas mixture composition and synthesis terms on the silicon carbonitride structure and the impact of thermal treatment on the structure were also studied.

6.1.4 X-ray fluorescent element analysis

Theme: Study of distribution of macro- and microelements in different parts of human myocardium and human great vessels.

The work is carried out within the framework of the science cooperation contract with Meshalkin science-and-research institute of circular pathology.

Revealing inter-element relations in the myocardium tissues of different heart parts can give important information for research of the mechanisms of normal and pathological physiological processes in the heart. Infarct cases are accompanied by extremely high Zn and Ni concentrations (observed for all patients under survey), which is quite different for healthy people.

In the course of the study, the element composition was studied in the following myocardium parts of patients suffering from ischemia and myocardium infarct: the left and right ventricles of heart, the left and right auricles, the infarct area, the infarct periphery, the infarct nidus periphery and the cicatrice zone. According to the analyses carried out, there is a correlation between the content of Zn and Ni in the myocardium both of healthy and of sick people. In the case of infarct, concentrations of these elements increase several times as compared with healthy people. This is typical of tissue of all myocardium parts analyzed. For sick people, the Zn and Ni concentrations are as high as 1.4% mass and 0.0017% correspondingly. 250 samples of heart tissue have been analyzed and about 1200 roentgen fluorescent spectra were obtained within the framework of this work in the year 2005.

Theme: Work with archeological dig material. Altai, Ukok, the Pasyryk culture, the Institute of Archeology and Ethnography SB RAS.

Work with archeological material is continued. That is mainly analysis of plants from burial places of the Pasyryk culture. Analysis of the hemp has confirmed the earlier hypothesis of copper passing from the bronze censer to the herm seeds. According to the studies, the copper content was above 2%.

Theme: High-resolution reconstruction of the Siberian climate of the last millennium by records of bottom sediments of continental lakes.

RFBR grant: №03-05-64949-a **"Geochemical response of the lake sedimentation system to fast climatic changes in Central Asia".**

RFBR grant: №05-05-97224-r baikal a **"Paleo-climate of the Baikal area periphery in the post-glacial period"**

RFBR grant: №05-05-97229-r baikal a **"Present-day sedimentation in Baikal as the basis for high-resolution reconstruction of the climate of the last millennium"**

Aim of the work: Development of the methods for microanalysis and scanning XFA of geological samples. Study of microelement distribution in sediments of mountain lakes in order to perform paleo-climatic reconstructions.

Matter of the work: Core samples of bottom sediments of lakes of the Transbaikalia area, the southern part of Lake Baikal, the deep-water of Lake Teletskoe and Lake Khotonnur (Western Mongolia) have been scanned at energies of 17, 25 and 42 keV. Thin sections of bottom sediments, epoxy-impregnated sediments and diamond samples with micro-impurities were used to perform methodological works. Methodological works to estimate repeatability of the method and limits of content detection on standard rock samples were performed.

Results: time series of content of 25 to 30 rockforming elements and microelements have been obtained with resolution of 0.1 to 1 mm. The number of conditional samples (spectra) is $\sim$ 45000; the number of element detection is $\sim$ 900 000. Metrological characteristics of the scanning SR XFA method have been obtained.

An example of the results obtained. Variations of the normalized (from 0 to 1) XRD (X-ray density) values and Br content in annual layers (varves) of bottom sediment samples have been obtained. The step of scanning was 100 microns. Details of the inner (seasonal) arrangement of the annual layers can be seen. The light (spring-summer) layer is characterized by lower density as denser, large-size particles precipitate. The autumn period has the minimal density – precipitation of clay and organic substances that accumulated during the summer. The winter period is characterized by precipitation of the clay fraction and consolidation and early diagenesis of the sediment. The bromine content reflects the maximal precipitation of organic substances and can be an indicator of bio-productivity of the lake and thus it reflects the summer temperatures. The range of bromine concentration is <1 to 5 g/t. There are about 15 points in each layer. The inner dispersion (the estimation error) does not impede revealing clear patterns. It takes 20 seconds to measure a point. The time of scanning presented in a picture of a 8 mm range is 30 minutes. XRD of K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Ag, Sn, Sb, I, Ba, La, Ce, Th, U were estimated simultaneously .

Theme: Analysis of peatbog drill cores from Western Siberia.

Bogs of Western Siberia are a good object to study the dynamics of arrival of mineral substance from the atmosphere onto the surface. The high "convex" bogs, where the biological mass has been growing in isolation from the groundwater inflow, are of particular interest.

Therefore, the microelement content of time-stratified horizons of a peat bed is considered to be defined by mineralization of the atmosphere dust (aerosol) and rain and snow water. We have earlier studied the microelement content of a 1 meter peat section from a high bog and separated the layers of the 20th century and preceding layers of the last millennium. Flows of 26 chemical elements have been estimated with the use of a complex of analytical methods, including SR XFA. The speeds obtained coincide with those published for the Baikal region. The so-called group of "volatiles" Cd, Hg, Sb, Pb, Zn, As, Br, and Cu, which have been saturating the atmosphere dust over Western Siberia during the last millennium, has been singled out .

Now SR XFA is used to study the microelement content of horizons of peatbogs at three points at a distance of 200 to 300 km from each other. The peatbog thickness is 2.5, 5.3 and 4.4 m; their age is 4000, 7000 and 11000 years, correspondingly. It was the first time when a 5 meter peat core drill was scanned with a step of 1 mm, which corresponds to a time step of 1 to 2 years. In the spectra recorded, at an initial energy of 26 keV, there were statistically significant signals for Fe, Cu, Zn, Br, Sr, and Zr obtained across the entire section. In two intervals, higher (the age of 500 years) and lower (the age of 6500 to 7000 years), scanning with an initial energy of 42 keV was performed and signals from the Kα series of J, Ba, Sn, Sb,(Cd) were obtained. Time distribution of microelements representing groups of chemical elements of different biochemical properties is expected to allow the study of the dynamics of arrival of mineral substance on the surface during the entire Holocene period.

Theme: SR XFA application in ecological-and-geochemical investigations.

SR XFA has been used for element analysis of plant tissues: larch needles (Larix cajanderi Mayr), dwarf birch leaves (Betula divaricata Ledeb.), osier leaves (Salix viminalis L.), and dwarf pine needles (Pinus pumila) to study the impact of atmosphere pollution caused by the coal and fuel-and-energy industry objects in the Neryungri region (Yakutia) and by the tin industrial complex in Novosibirsk (2005) as well as to investigate the geochemical background of the region of gold deposits in the Central Aldan area (2004) and the region of gold-and-uranium deposits in the Elcon horst (Yakytia, 2005).

As the result of the SR XFA application, we

• revealed natural and man-caused anomalies in the gold deposit field (Yakutia, Aldan);

• revealed the atmosphere pollution plumes at the Novosibirsk tin industrial complex and in the vicinity of the city of Neryungry and created a mathematical model of man-caused pollution;

• performed biogeochemical investigations of element concentrations in the tissues of Yakutia plants and determined the background and anomalous levels;

• estimated the man-caused natural radionuclide pollution in conjugate ecosystems at the dumps of mine workings in the gold-and-uranium deposit region of the Elkon horst (Yakutia) and studied uranium behavior under the supergene conditions of the mountain-and-taiga landscapes of Yakutia.

Theme: Investigation of the continental sediment history to reveal climatic-and-stratigraphic correlations and to make paleo-landscape reconstructions.

The contents of elements in the sediments of Lake Hubsugul (Mongolia), Lake Kerek (Western Siberia) and the salt lake of Shira (Khakassia) were determined. The measurements were made in the regime of scanning with steps of 100, 200 and 1000 microns and the same apertures. The elements varied from K to Ba, depending on the sediment type. Usually, the panorama covered 10 to 15 elements.

For Hubsugul, this series of measurements continues the experiment on continuous scanning of the 50-meter sediment column with a 1 mm resolution. This resolution corresponds to a time interval of several decades. By now, we have studied over 40 meters of the core drill, i.e. almost one million-year history (over 20000 measurements were made in 2005). Results on some elements allow one to link the concentration variations observed with the changes in the biogenic life of the lake as well as with the changes in the erosion intensity in the basin and in the authigenic mineralization flow from the lake onto the bottom caused by changes in the environment and climate of this central continental region. This study allowed us to identify traces of a very significant reorganization of the ecosystem of Lake Hubsugul at the turn of 420 to 470 thousand years. No evidences of the great significance of this event for Central Asia have been found earlier. This reorganization at Hubsugul was characterized by later appearance of rhythmic oscillations, both for the biogenic component of sediment (reconstructed by the Br distribution) and in the markers of the mode of the lake water exchange with the basin (by the excess/deficit of soluble Ca relative to the classical component).

We also studied the sediments of several columns from the internal-drainage salt lake of Shira (Khakassia). The natural water balance in it is provided by the river and rain income, vaporization and subterranean hydro-geological regime. The climatic conditions of the region are arid and strongly continental. Variations in the level of internal-drainage lakes usually give a very contrast reflection of paleo-variations of temperature and climatic humidity caused by changes in vaporization and atmospheric precipitations.

4 core samples by the north-south transect have been studied in detail and over 15 000 measurements have been made.

Theme: Investigation of the composition of ancient metal products from archeological monuments of Eastern Siberia.

Composition of 60 copper-bronze archeological finds from the sites of the Baikal area has been analyzed. The aim of the work was to study and systemize the chemical composition of alloys in order to reconstruct the order of development of ancient metal production in Eastern Siberia. Such macro-components as Cu, Zn, As, Sb, Sn, Ag, and Pb were quantitatively identified (in different proportions) in the alloys. Besides, there were identified a number of micro-elements. The data obtained allowed the archeologists from Irkutsk Engineering University (A.V. Kharinsky, G.V.Turkin) to reveal that all the objects are classified as bronze and had been made by different methods; there were no copper objects among them. These data allow one to find out the sources of metallurgical methods and have a fresh look at the periodization and chronology of the Copper and Bronze Age in the Baikal area. Non-destructiveness of analysis was an advantage of the SR XFA method, which makes it possible to save the unique finds.

6.1.5 Diffractometry at a quantum energy of 33.7 keV

The purpose of the station is to study matter structure at pressure as high as 6.5 kbar(in the "cylinder-piston" device)and 100 kbar(in diamond anvils) or either at high (up to 1200 °C) or at low temperature (below -190°C) with the SR XFA methods. A single-crystal silicon (111) Laue-scheme monochromator was used. In order to lower the heat impact of "white" SR on the crystal, an aluminum attenuator 1 mm thick was installed in front of the monochromator. To better cool the crystal, the monochromator housing was filled with helium under a pressure of 0.3 atm. The image-plate detection system mar-345 of the Marresearch company, with the option of readout and deletion of diffractometer recordings, was mounted on the station of the 4th SR beamline, which resulted in abrupt increase of the number of experiments at the station.

Statistics of the station operation in the year 2005. 1689 hours of work with the beam were claimed. 1251.5 hours of the beam time were used. The efficiency of work was 74%. 3027 files were shot. The high-temperature chamber was developed, manufactured and installed on the station in 2005. This chamber allows conduction of diffraction investigations in the air at temperatures up to 1200°C.

Brief annotations of works in the year 2005.

Structural studies of high-pressure clathrate hydrates (IIC SB RAS). This theme is interesting for crystallography and physics of high pressure. The structural types revealed can be of interest as topological models for frame structures on the basis of silicon, germanium, SiO_2 and others. Investigation of properties and conditions of their formation is very important for solution of problems of ecology and future energetics. By some reports, most hydrocarbon resources are under the sea and ocean bottom in the form of clathrate hydrates. This work resulted in definition of the structure of high-pressure acetone hydrate. The structure turned to be very close to the earlier-studied structure of tetrahydrofurane hydrate. However, it may be the first time when we have faced a new phenomenon not typical of normal-pressure gas hydrates (GH), i.e. lowering of the host frame symmetry due to the ordering of the guest sub-system. Only the cases of partial ordering in the guest sub-system have been known by now. Besides, this study showed a practical way to create hardened single-phase crystal samples of high-pressure gas hydrates (HPGH), which is an opportunity of further study of such compounds which would be difficult to conduct in situ.

X-ray investigation of hardened high-pressure argon hydrate. This work develops the previous structural studies of high-pressure gas hydrates and deals with the behavior of hardened high-pressure gas hydrates. The X-ray diffraction was used to study the properties of high-pressure-synthesized argon hydrate (the H structure) and methane hydrate of the cubic I structure. It was revealed for the first time that high-pressure gas hydrates can be hardened, i.e. they can be studied under atmospheric pressure and at low temperature. The example of the argon hydrate of the H structure showed that the self-conservation phenomenon can be observed for high-pressure hydrates. Temperature-dependent changes in the powder roentgenogram of both the hydrates were investigated. It was shown that at temperature about 200 K significant amounts of ice Ic are very likely to appear in these systems. The heat expansion curves that have been studied for both the hydrates turned to be close to those for other gas hydrates.

Investigation of the behavior of micro-porous frame aluminosilicates (zeolites) under compression in different media (Institute for mineralogy and petrography (IMP) SB RAS). The main directions of the IMP activity is the experimental study of the structural mechanism of adaptation of micro-porous aluminosilicates to increasing pressure, depending on the type of their frame, the out-frame water-cathion complex and composition of the compression medium. The study of the structural behavior of micro-porous aluminosilicates under high pressure is important both for the up-to-date interpretation of evolution of frame minerals and for development of physical chemistry of nano-pore compounds. That includes, in particular, the pressure-induced phenomena of super-hydration and ionic conductivity anomalies in zeolites, which are very promising as concerns their application in technologies. In the year 2005, the compressibility of natural fiber zeolite $CaAl_2Si_3O_{10}x3H_2O$, wide-pore synthetic zeolite Na-A ($12NaAlSiO_4x27H_2O$) in water up to 45 kbar was studied with the use of the high pressure chamber.

Investigation of the mineral composition of kidney stones by the SR diffraction methods (ISSCM SB RAS, IK SB RAS). The SR diffraction method was used to investigate the phase composition of kidney stones placed into a special phantom object imitating the human body. Lumps of hog blubber 3 kg in total and a hog kidney were used. The total thickness of the biological tissue reached 165 mm. Diffractograms of 50 uroliths were obtained, including those of mixed composition. In all cases, the mineral composition was reliably identified. The rated dose at accumulation of each of the diffractorgrams did not exceed 5 milliziverts. The investigations performed showed the possibility of creation of a diagnostics system to find out the mineral content of kidney stones in vivo.

Investigation of phase formation order at chemical interaction of solid and liquid metals (ISSCM SB RAS). Solid and liquid metals can interact in different processes: agglomeration with participation of liquid phase, soldering, metallurgical process, SHS processes etc. The solid-phase component in the investigation was solid copper-based solutions obtained via mechanical-physical melting. The liquid component was gallium and its eutectic alloys with indium and tin.

These investigations showed intermetallic $CuGa_2$ to form first at chemical interaction of solid metal alloys with liquid eutectics. After some time, typical of different systems, crystallization of the liberated elements begins. The liberated elements form a phase with larger grains. In some systems, it crystallizes as a monocrystal. If there are intermetallic compounds in the system of liberated elements, the arising intermetallic will have the maximal content of the liquid-phase element. If there are both liberated elements in the liquid phase, they will form two intermetallics.

Lead tri-tellurides.

SR diffraction was used to perform structural investigations of triple and non-stochiometric tellurides and lead selenide [$Pb_{1-x}Sn_xTe$ (x=0.29), $Pb_{1-x}Mn_xTe$ (x=0.05), $Pb_{0.45}Te_{0.55}$, $Pb_{0.55}Te_{0.45}$, $Pb_{1-x}Sn_xSe$ (x=0.125)]. The previous data of thermal emf under high pressure for these compounds indicated both a shift in the phase transformation pressure and difference in the electron structure of these triple compounds; that was the beginning of the study of structural phase changes. It was revealed that, in spite of quite different composition, all compounds undergo similar structural changes from the NaCl structure to an intermediate high-pressure phase and then to CsCl. It was found that it is the orthorhombic structure Pnma (not GeS and TlI, as it was supposed earlier) that forms in all lead tellurides. However, the structural type of the intermediate phase of high-pressure $Pb_{1-x}Sn_xSe$ can not be described either by GeS or by Pnma lattices. Now this structure is being defined more exactly with SR measurement results. Shifts in the pressure of transition to the intermediate high-pressure phase that were revealed by thermal emf were confirmed by the investigation of structural features of the transition. For instance, it can be concluded that replacement of lead by manganese or tin significantly lowers the transition pressure. Excess of lead in the PbTe crystal contributes to the phase transformation and also makes the pressure lower, while excess of tellurium shifts the transformation to higher pressures.

Organic superconductor Θ-(BEDT-TTF)$_2$CsZn(SCN)$_4$. It is the first time when a structure was investigated under super-high pressure in organic superconductive salt on the basis of the "BEDT-TTF" group. Measurement of electrophysical properties under pressure revealed a number of anomalies that are possibly linked with structural changes. It was found out that under compression up to 5 GPa the crystal volume lessens by $\sim$ 40%. Now the hypothesis of structural phase transformation in this crystal (as a typical representative of the "BEDT-TTF" family of superconductors) is being tested. This work was financially supported by RFBR 04-02-16178.

Diffraction studies of particularities of structural features and temperature-time evolution of multi-component oxide melts (in situ) and glasses. (Institute for Mineralogy and Petrography SB RAS).

Results of SR diffraction experiments and treatment of them with construction of the radial distribution function (RDF) for electron density in the samples will contribute to the study of oxide melts and revelation of the influence of time-temperature processing of melts on their properties in the solid state. The work was performed within the framework of RFBR grant 04-05-64438-a and Integration project SB RAS №155.

An in situ diffraction investigation of melts Na_2SiO_3, Na_2SO_4 and $NaNO_3$ was fulfilled in the vicinity of the melting temperatures, at over-heating by 50-100°C and in the super-cooled state. Nine RFD characterizing regularities of interatomic distance variations in these melts were constructed. In the supercooled melts, there was revealed a certain shift of diffraction maximums as well as a significant lowering of their intensity, which reflects the pre-crystallization self-structuring phenomenon.

6.1.6 "Diffraction movies"

The purpose of the station is to study phase transformations during chemical reactions with participation of solid-state bodies; to obtain both the qualitative (phase formation stages) and quantitative parameters of these reactions. This facility allows one to carry out investigations in the field of both wide (WAXS) and small (SAXS) angles. In the year 2005, teams of IIC, ISSCM, IK (SB RAS) and ISM (RAN)(the city of Chernogolovka) worked jointly at the station. About 60 samples were studied.

Brief annotations of the works made.

"In situ" investigation of decomposition of complex aggregates of noble metals.

This work is interesting because the decomposition product is conditioned by the reaction terms. It is very difficult (if possible) to obtain the resultant solid solutions from pure metals with conventional methods (melting). It was found out that, depending on the gaseous medium, either the solid solution arises at once or, phases of individual metals crystallize first and only then the solid solution forms. (IIC SB RAS).

Investigation of decomposition of bismuth oxi- and carboxylates.

These compounds are applied in medicine. It is important to know the ways of their synthesis and phase transformations at heating. Besides, metal carboxylates are often initial substances in obtaining pure metals or their oxides. (ISSCM SB RAS).

Investigation of annealing of mechanically activated metal-carbon mixtures.

When an M + C (in particular, M can be Ni) mixture is activated, there arise nanopacticles of metals, carbides and solid solutions of carbon in the metal. During annealing in an inert atmosphere, carbon is evolved on the surface of nanoparticles as a graphite (crystal) carbon "fur". (ISSCM SB RAS).

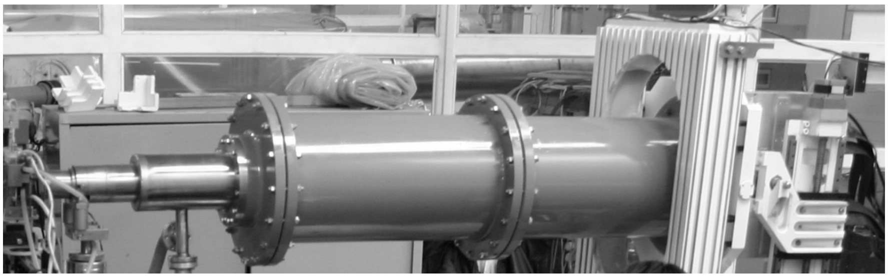

Figure 7: The small-angle facility ordered by ITEB(Puschino).

Investigation of the kinetics of interaction of gallium-activated aluminum with water and spirits.

It was shown that this reaction results in aluminum hydroxides (in the form of pseudo-boehmite mainly) and hydrogen, in the case of water, and alcoholates and hydrogen, in the case of spirits. (IK SB RAS).

An attempt was made to investigate the SHS processes in the system Al-Ni-Co.

This reaction is interesting because its products are quasi-crystals, i.e. crystals with the fifth order axis of symmetry. The work is complicated by rather unstable combustion behavior and morphological particularities both of the initial mixtures and of the products. (ISSCM SB RAS).

Within the preparation for the joint project with the Byelorussia National Academy of Science, experiments to study phase formation in mechanically activated mixtures NiO+Al were started.

Mechanical activation results in nano-size particles of NiO covered by aluminum (because it is more plastic). Reaction of aluminum and nickel oxide results in nickel and aluminum oxide. Then nickel reacts with the excess of aluminum, which produces intermetallide. The result will be nanocomposite: intermetallide -aluminum oxide. The purpose of the investigation is to find out the phase formation sequence in the combustion regime. (ISSCM SB RAS).

Besides, significant part of the station operation time was linked with testing new detectors made for other institutions.

For instance, a small-angle facility ordered by ITEB (Puschino) was assembled in September, 2005. It comprised the vacuum volume from the sample to the detector with a focus distance of 1.5 m, the detector itself and two movers. The experiments with 3 ms time resolution were conducted to study muscle behavior. The facility was supplied to the customer to Kurchatov Institute after successful ending of the experiments.

6.1.7 EXAFS spectroscopy

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

Brief annotations of the works made.

STUDY OF THE SURFACE STRUCTURE OF NANOPARTICLES BY THE METHOD OF EXAFS SPECTROSCOPY OF PROBE MOLECULES(Institute of Catalysis SB RAS, Novosibirsk, Institute of Petrochemical Synthesis RAS, Moscow, Instituto de Ciencia de Materiales, Centro Mixto CSIC-Universidad, Sevilla, Spain).

This work deals with the study of the real structure of nanoparticle surface and of surface defects. The surface is supposed to be decorated with probe molecules that contain a heave metal atom which environment can be traced by the EXAFS spectroscopy method. Trials of a large number of probes and various nano-systems made it possible to state general requirements to probe molecules and the absorption methods as well as to define what objects can be studied in this way. This method can be used for a rather wide range of objects, in particular, for applied catalysts (oxide, sulphide and metallic) and has fewer restrictions than the conventional methods to investigate nanoparticle surfaces. Selenium compounds have turned out to be the best probes.

It was shown that H_2Se is adsorbed on defects whose types are different for different precursors. The aluminum-nickel catalysts for obtaining filament carbon through methane decomposition have been investigated. It was shown that the working sides of catalyst are a complex structure of low short steps. The bi-metal sulphide catalysts (Ni-Mo)S_2/Al_2O_3 have been investigated. It was shown that selenophene is absorbed through selenium coordination on the nickel atom localized on the side surface of the MoS_2 nanoparticle. This work was supported by RFBR (project 03-03-32340a) and NATO grant (Ref. EST. CLG 979855).

STUDY OF THE NANOCOMPOSITE SYSTEM FOR SYNGAS PRODUCTION BY THE XAFS METHOD (Institute of catalysis SB RAS, Novosibirsk, Institute of Chemical Engineering & High Temperature Processes, Patras, Greece).

This work studies local structure of the nanocomposite system on the basis of cerium dioxide and lanthanum manganite. The system is used for syngas production by the XAFS method. Much attention has been paid recently to development of membranes assisting in conversion of methane to syngas, oxygen being transported due to mixed O^{2-} /electron conductivity. Development of such membranes is now a priority task of the science of materials. Besides, materials with mixed ion/electron conductivity are very interesting because they can be used as anodes or cathodes in solid oxide fuel elements.

Doped cerium and $LaMnO_3$Gd or Pr oxides were prepared by the Pechini method. Binary composites were prepared via adding precursors of doped CeO_2 to spirit suspension of lanthanum manganite with following evaporation and baking at 500°C. Then the powder samples were pressurized into pellets and baked in air at temperature as high as 1300°C. All measurements of XAFS spectra of Mn-K, Pr-L_3, Gd-L_3, La-L_3 and Ce-L_3 edges were made at Siberian SR Center (SSRC).

It was found out that the Pechini method provided homogenous mixing of components of all the samples prepared. It was shown that local arrangement of Ce atoms in all cases is close to that for the reference sample CeO_2 (a cubic structure of the fluorite type). Analysis of the XFAS spectra of the La-L_3 absorption edge also did not reveal significant differences in the lanthanum local arrangement for samples of $LaMnO_3$ and nanocomposites, which indicates minimal penetration of La into the structure of cerium oxide. On the other hand, analysis of the RAD curves obtained from the EXAFS spectra of the Mn-K edge of nanocomposites calcined at high temperature (1300°C) have revealed some differences from those for low-temperature samples. In so doing, there was observed a drop of the amplitude of the first Mn-O peak as well as shift and resolution of the far Mn-Me peaks too. Appearingly, that is linked with distortions of the pseudo-cubic structure of the nano-size domains of $LaMnO_3$ in nano-composites, the level of their doping with Gd or Pr cathions staying indefinite. The work was supported by INTAS (01-2162), ISTC 2529, NATO (CBP NUKR. SFPP. 980878), NATO (Ref. EST. CLG 979855) and RFFR (03-03-32340a).

APPLICATION OF PROBE MOLECULES TO STUDY NANOPARTICLE SURFACE BY THE EXAFS SPECTROSCOPY METHOD (Institute of catalysis SB RAS, Novosibirsk, Institute of Petrochemical Synthesis RAS PAH, Moscow, Instituto de Ciencia de Materiales de Sevilla, Centro Mixto CSIC-Universidad de Sevilla, Spain).

It is suggested to study the real structure of nanoparticle surface and surface defects via decorating the surface with probe molecules containing a heave metal atom and traceable by the EXAFS spectroscopy method. That can be used for a rather wide range of objects, in particular, for applied catalysts (oxide, sulphide and metallic) and has fewer restrictions than the conventional methods to investigate nanoparticle surfaces.

The developed methods of selective surface absorption of probe molecules of various nature allow optimal investigation of the surface.

The role of probes was played by inert gases (Kr, Xe), HBr, Br_2, halogen-organic compounds, selenium oxides, selophene, etc.

The objects to study were α-Fe_2O_3, ZrO_2/SiO_2, TiO_2, sulphide catalysts ((Ni-Mo)S_2/Al_2O_3), and applied metallic catalysts (Ni/C, Pd/Al_2O_3).

The approach used was shown to be perspective for testing surfaces of catalysts and studying reaction behavior. The work was supported by RFFR (project 03-03-32340a) and NATO grant (Ref. EST.CLG 979855).

INVESTIGATION OF $La_{1-x}Sr_xCoO_3$ (x = 0.0 ÷ 0.5) BY THE METHODS OF X-RAY SPECTROSCOPY OF ABSORPTION AND NEUTRON DIFFRACTION (Joint Institute for Nuclear Research, Dubna, Boreskov Institute of Catalysis SB RAS, Novosibirsk,Institute of Solid State Physics of Latvia university, Riga,Hahn-Meitner Institute of Berlin, Germany, Institute of Physics of Solid-State and Semiconductors, Minsk, Byelorussia).

High-resolution methods of X-ray spectroscopy of absorption and neutron diffraction were used to study the correlation of local atomic and electron structure with changes of structural parameters of the crystal lattice in the compound $La_{1-x}Sr_xCoO_3$ at doping it with strontium (x = 0.0, 0.2, 0.3 and 0.5). The XANES method was used to study the valent state of cobalt. Replacement of La^{3+} with Sr^{2+} was shown to lead to insignificant increase of the Co - Co distance and appearance of mixed distribution of ions Co^{3+} and Co^{4+}, mainly in the intermediate spin state. The Rietveld method was used to refine the cobaltite structure and to analyze the dependencies of the Co-O distance and inter-atomic angle Co-O-Co on the doping level.

EXAFS INVESTIGATIONS OF THE LOCAL ATOMIC STRUCTURE OF DISORDERED NANO-CRYSTAL ALLOYS Fe-Ge (Physic and Technology Institute UB RAS, Izhevsk,Boreskov Institute of Catalysis, Novosibirsk).

The work presents the results of EXAFS studies (K-edges of FE and Ge) of binary solid oversaturated nano-size solutions $Fe_{1-x}Ge_x$ (x=15-40 at.% Ge) obtained by mechanical fusion. The single-phase nano-crystal disordered state of the alloys was certified by the methods of X-ray diffraction, Mossbauer spectroscopy and magnetic measurements. The EXAFS spectra were analyzed via solving the inverse binary problem by combined data on the two absorption edges. Parameters of the partial paired correlation functions indicate a high degree of local static distortions of the crystal lattice, existence of a near chemical ordering, which grows with the Ge concentrations, and the "local" stage of formation of a hexagonal macro-structure in the BCC lattice.

6.1.8 Metrology and EXAFS spectroscopy in the soft X-ray range

(Budker Institute of Nuclear Physics SB RAS, Boreskov Institute of Catalysis SB RAS).

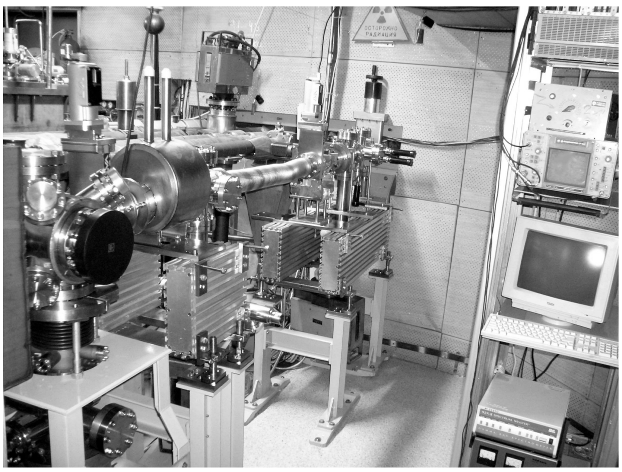

Figure 8: General view of the station for work with the soft X-radiation on VEPP-3.

This station (Fig.8) is unique and differs from all other SR experimental stations on the VEPP-3 storage ring. The station as a whole is high-vacuum and there are no leak-tight foils separating it from the vacuum chamber of the storage ring. The station is intended for a wide range of basic and applied research in the soft X-ray range of 100-5000 eV in the field of metrology (calibration of X-ray detectors, elements of X-ray optics, etc.), catalysis (EXAFS and XANES), and the science of materials (the magnetic dichroism methods MCD and MLD).

The work was made within:

– project no. 2500 of the International Science-and-Technology Center (ISTC);

– project no. 2920 of the International Science-and-Technology Center (ISTC);

– project no. 3943 of the Foundation for development of small science-and-technology enterprises.

Start-up of the first stage of the line and station; first activity on the beam. The first stage of the line and station was started up in 2005; first measurements were made on the "white" beam. The work on construction of the high-vacuum monochromator was continued. The unit to monochromate the "white" SR beam was manufactured and installed on the beam. It is based on a pair of parallel multilayer mirrors and will be used until the monochromator is manufactured. The unit allows one to obtain monochromatic radiation in the region of 100 to 1500 eV with $\Delta E/E=10^{-1}-10^{-2}$ resolution. The main disadvantage of the monochromatization unit as compared with the monochromator is the impossibility of on-line energy retuning without vacuum failure. The block has been tested under SR beam and has undergone check of alignment required to mount it. An interlock system was created to prevent the SR beam from getting onto the emergency vacuum gate in case of operation of the vacuum protection system.

The first measurements on the beam dealt with development of originally-new methods to calibrate scintillation counters (SC) for the soft X-ray region. The task of absolute spectral calibration of detectors in the VUV and soft X-ray ranges (determination of absolute spectral sensitivity and registration efficiency) is still actual. The only universal way to solve it is to use a cryogen bolometer working at the liquid helium temperature. Such bolometers are expensive and there are only a few of them all over the world. At the same time, the need in calibrated detectors of radiation for the above-mentioned ranges is rather high, because of space research, investigations in the field of physics of plasma and controlled thermonuclear fusion, needs of the up-to-date scientific instrument-making and other fields of application.

The new method of absolute calibration of scintillation counters in the soft X-ray range was suggested as one of possible solutions of this task. This method is based on determination of the statistical distribution of the number of electrons leaving the photocathode of photomultiplier tube. Combined with determination of thickness of the scintillator "dead" layer through self-calibration, this method is expected to allow one to calibrate SC in the region of 500-5000 eV with error about 10-15%.

In the course of measurements, there were obtained amplitude spectra of signals of an SC on the basis of photomultiplier PEM-130 with scintillator YAP. These works were done without monochromatization units, on fluorescent radiation from targets excited with the "white" SR beam. The targets were made of aluminum (1.48 keV), silicon (1.74 keV) and copper(8 keV). Besides, a set of reference single- and multi-electron amplitude spectra of SC were obtained with the use of a luminodiode. The spectra obtained are being treated now. To end the work it is necessary to make additional measurements, which are planned for the year 2006.

6.1.9 X-ray tomography and microscopy

The purpose of the station is to solve tasks linked with non-destructive survey of objects of archeology, geology and science of materials, tasks that require high-spatial-resolution 3D analysis of inner structure of objects. The second class of tasks is linked with certification and implementation of X-ray optics in SR experiments. (The station is being developed at the moment)

Expected parameters of the station.

Energy range of monochromatic radition obtained at the station	10 - 60 keV
Registration area	50 mm
Spatial resolution of the method	100 microns
Time of shooting a sample	⩾15 min

Statistics of the station operation: in the year 2005, experiments linked with development of the X-ray computer tomography method took 505 hours; investigations of characteristics of X-ray-optics elements took 432 hours.

Fields of application:

<u>Archeology:</u> non-destructive determination of inner structure of unique samples.

<u>Mineralogy:</u> investigation of contrast intrusions in minerals and other geological objects.

<u>Science of materials:</u> non-destructive investigations of inner pre-destruction micro-deteriorations in material.

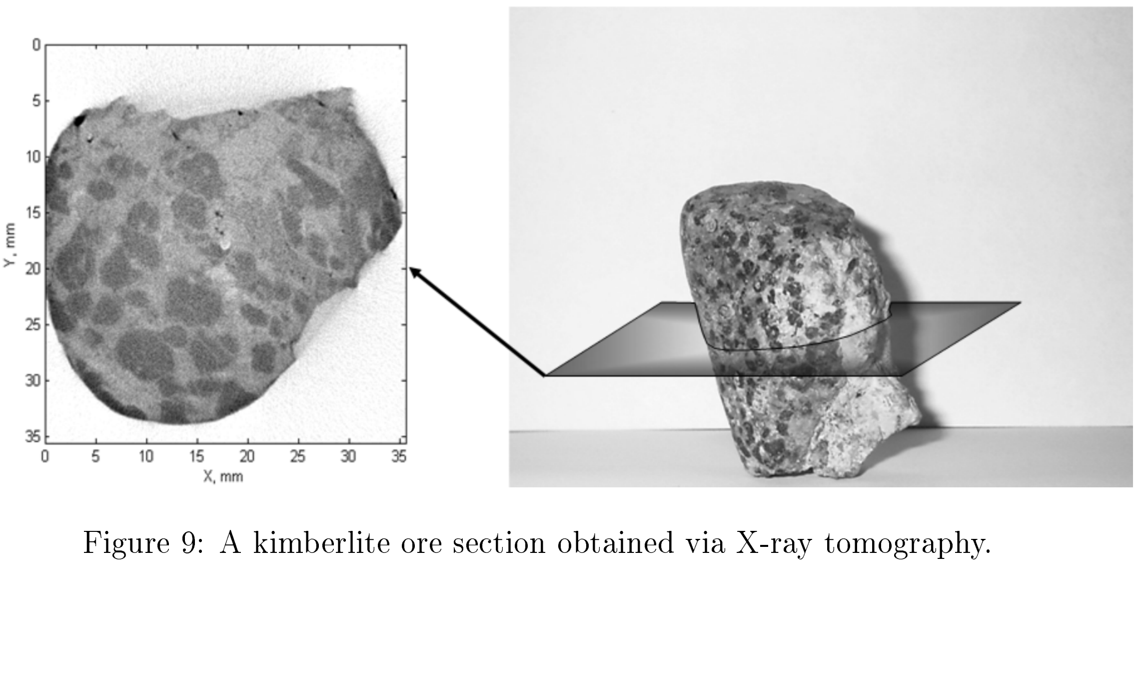

Figure 9: A kimberlite ore section obtained via X-ray tomography.

6.2 Work with terahertz beams

6.2.1 About terahertz radiation

Last decade is characterized by the abrupt growth of basic and applied works in the field of generation and application of radiation in the wavelength range from 30 microns to 0,3 mm, which corresponds to the frequency range of 10 to 1 THz. It is a region between photonics and electronics, overlapping with the regions of long-wave far IR radiation and RF millimeter waves. Lately there appeared a number of new types of terahertz radiation sources, from milliwatt generators of sub-picosecond broadband pulses on the basis of femtosecond lasers to free electron lasers generating tunable narrowband coherent radiation of average power as high as hundreds of watts.

The interest to the terahertz radiation is caused by the following:

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

• this radiation can pass well through turbid media and fine materials because of abrupt suppression of the Rayleigh scattering ($1/\lambda^4$);

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

• this is the area of hydrogen bonds and VanderWaals'forces of intermolecular interaction;

• the energy of photons of the terahertz radiation lies in the energy gap of superconductors;

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

Usage of the Novosibirsk free electron laser as a terahertz radiation source allows one

• to continuously tune the radiation wavelength in the range of 120-235 microns with monochromaticity better than 0,3%;

• to achieve high average power (up to 400 W);

• to have short pulses of radiation (less than 100 ps);

• to have high peak power (0,5 - 1 MW);

• to have a completely spatially coherent source with a longitudinal coherence length of $\sim$ 2 cm.

To commission the user stations and to use the free electron laser efficiently it is necessary to solve a few problems. First, outcoupling of radiation from the laser and transporting it to the stations. Second, creation of several user stations. Third, characterization of the FEL radiation parameters that the users need to know. Then, to work efficiently it is necessary to solve the problem of detectors (single- and two-coordinate), monochromators and optical elements (exit windows, polarizers, focusing mirrors and lenses). Little can be bought through catalogues from Russian and foreign companies. The equipment has to be developed and manufactured by the experimentalists. Therefore, the main attention in the year 2005 was paid to solution of these tasks as well as to provision of users activity at the working stations. At the same time, much effort was aimed at projecting the second stage of the free electron laser. This stage will extend the generation spectrum to 30 - 300 microns

6.2.2 General information on terahertz radiation sources based on electron beams and parameters of the Novosibirsk FEL

There are three main types of radiation generators. First, synchrotrons, whose radiation has been used in applied areas for decades. Late results of synchrotron radiation application gave unique results in very different areas of science. That is confirmed by the long-term experience of the Synchrotron Radiation Center at BINP. Synchrotron ra-

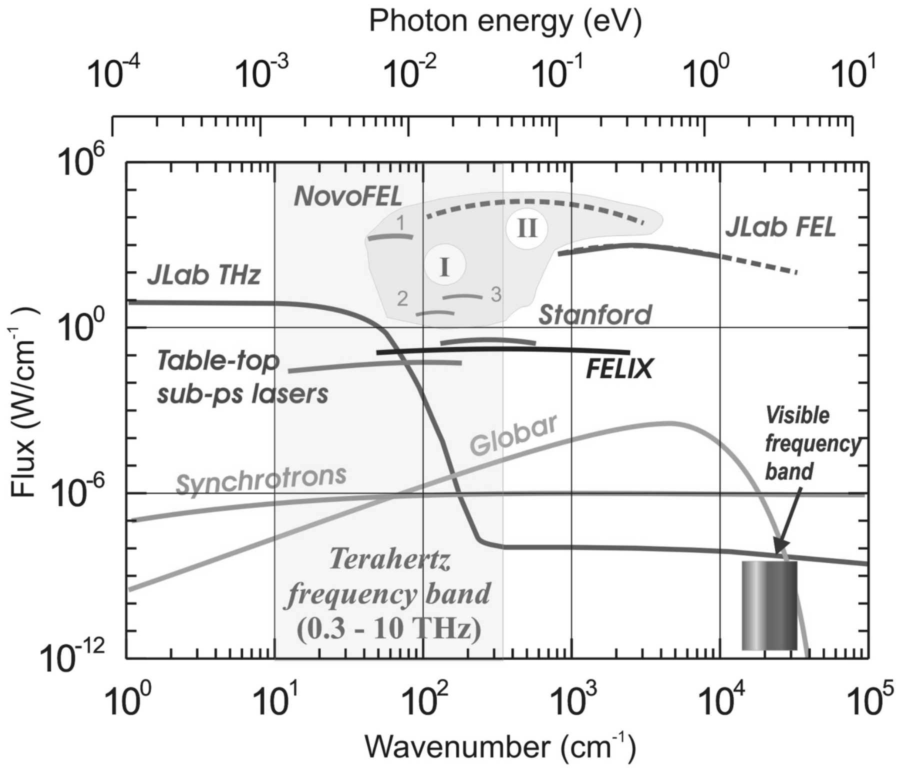

Figure 10: Spectral power density of some sources in the terahertz and adjacent ranges, including those of the Jefferson Laboratory (JLab FEL), the Stanford University, the FOM Institute in the Netherlands (FELIX) and the terahertz source of Jefferson Laboratory (JLab THz) among them as well as of the fundamental, second and third harmonics of the Novosibirsk FEL (NovoFEL). The Roman figure II marks the expected spectral power density of the second stage of the Novosibirsk FEL.

diation sources generate broadband radiation when electrons move in a magnetic field. However, their radiation intensity in the terahertz range has been relatively low until recently (fig.10). That is why no research has been done with their application in the terahertz range.

The situation has significantly changed last years, after the suggestion that ultrashort high-density electron bunches could be used for radiation generation. If bunch length is much shorter than the radiation wavelength, then the latter is completely coherent. The radiation source recently commissioned at the Jefferson laboratory (JLab THz) is based on this idea. The source generates broadband radiation (see Fig.10) of average power about 100 W. There are plans to construct a high-power source of this type in the Brookhaven National Laboratory (the USA) and on the 4th generation source in Daresbury (Great Britain).

Another source of long-wave radiation is the Smith-Parcell source, where the electron beam generates radiation while traveling close to the metal grid surface. The first sources of this type used electron beams of relatively low voltage. There is a more powerful source, with the 15 MeV electron beam. Sources of this type have low power and can hardly compete with synchrotrons and free electron lasers.

The most powerful sources able to generate terahertz radiation are free electron lasers (FELs). Their radiation can be continuously tuned over a rather broad spectral range. Among terahertz lasers working for a long time the noteworthy are the lasers in Stanford University, California University in Santa Barbara, FELIX and INEA (Frascatti). Their parameters are presented in table 1. These devices are real user machines used by specialists from many scientific laboratories to perform a lot of works in very different fields - from the material science to biology and medicine.

Free electron lasers do not have very high generation efficiency. That is why next FEL generation, designed to generate radiation with high average power, have to use electron accelerators with electron energy recuperation. The most powerful FEL today is the laser of the Jefferson Laboratory with average generation power as high as 10 kW.

Table 6.1: Characteristics of some terahertz FELs.

	Stanford	**UCBS**	**UCSB**	**FELIX**	**ENEA Compact FEL**
$\lambda(\mu$**m)**	15÷80	63÷340	340÷2500	3÷250	2000÷3500
ν**(THz)**	3.75÷20	0.88÷4.8	0.12÷0.88	1.2÷100	0.09÷0.15
Micropulse width	2÷10 ps	-	-	6÷100cycles	50 ps
Micropulse Rep Rate	11.8 MHz	-	-	1000 MHz, 50 MHz, 25 MHz	3 GHz
Micropulse Energy	1μJ	-	-	1÷50 μJ	0.5 μJ
Macropulse width	0.5÷5 ms	1÷20 μs	1÷6 μs	5 ms	4μs
Macropulse Rep Rate	0 ÷20 Hz	0 ÷7.5 Hz	0 ÷1.5 Hz	10 Hz,	1÷10 Hz
Average Power	<1 W	5÷100 mW	5÷100 mW	< 1 W	4÷40 mW
Peak Power	<500 kW	< 6 kW	< 15 kW	< 10 MW (@ 20μm > 1 MW (@ 100 μm)	10 kW (@ 2600 μm)
Peak Fild	<250 kV/cm	< 70 kV/cm	< 20 kV/cm	< 10 MV/cm (@ 20μm < 2 MV/cm (@ 100 μm)	3.5 kV/cm (@ 2600 μm)

Table 6.2: Characteristics of the Novosibirsk FEL radiation.

Wavelength of the first harmonic	(120 ... 235) μm
Spectral area of the 2nd and 3rd harmonics	(40 ... 117) μm
Relative spectral width	(0.3 ... 1) %
Diameter of the Gauss beam at the beamline outlet	80 mm
Degree of radiation polarization	> 99.6 %
Spatial coherence	Complete
Temporal coherence	(40 ... 100) ps
Maximal average power,	0.4 kW (@11.2 MHz)
Pulse duration	(40 ... 100) ps
Repetition rate	(2.8 ... 11.2) MHz

Its spectrum is, however, out of the terahertz range, the most powerful source of which is the first stage of the Novosibirsk FEL with average generation power as high as 400W.

Having rather high monochromaticity, this radiation is at the same time fully coherent over the wave front and has time coherence in the range of 40 - 100 ps, limited by the electron pulse duration. Below is description of experiments in which some parameters of the laser were measured.

6.2.3 The line to couple out terahertz radiation of the free electron laser

The optical cavity of the FEL is made by two mirrors placed in the vacuum volume (Fig.11). The hole in the left mirror is used to couple out radiation; that in the right one is used to receive the beam of the helium-neon laser, which is used to adjust the mirrors of the optical cavity and the radiation beamline.

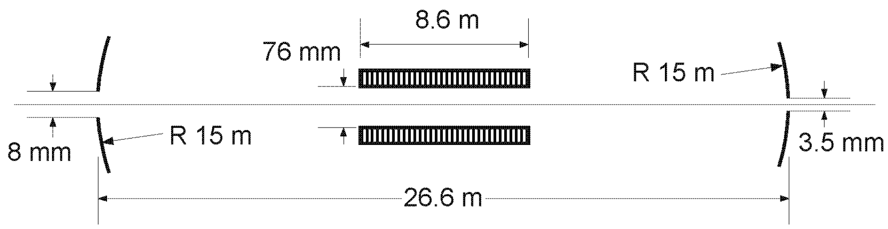

Figure 11: Schematic layout of the FEL optical cavity.

Since the maximal wavelength of radiation λ is rather large (235 microns), its divergence is also high - 1.22 λ/D = 0.03 (D = 8 m, the mirror exit hole diameter). Therefore, transportation of radiation by tens of meters requires focusing. This in itself is a technical problem since there is no refractive optics (lenses) with sufficiently small absorption in the terahertz range; spherical mirrors lead to astigmatism of focusing while toroidal or ellipsoidal mirrors of large size are very complicated and expensive to manufacture. In order to decrease angular divergence, a spherical copper mirror with a 2.5 m radius of curvature was used. Radiation is incident on it at a small (of about 7°) angle to the normal.

To provide ultrahigh vacuum in the FEL and accelerator-recuperator, their vacuum volume is separated from the line by the diamond window. Since the electrical field of FEL radiation is horizontal, the window has been turned through the Brewster angle around

Figure 12: Line in the user hall. One can see stairs down to the experimental stations.

the vertical axis, which provides practically complete transmission of radiation through the window. To minimize the window size, it is located near the exit hole of the optical cavity mirror, where diameter of the radiation beam is minimal. The diamond plate is 40 mm in diameter, 0.7 mm thick and is vacuum-sealed with indium wire. The line itself consists of five sections comprising plane mirrors connected by tubes. The vacuum system is made of stainless steel and is fixed on special suspension brackets. The line has to be evacuated or filled in with inert gas because terahertz radiation is highly adsorbable in air (by water vapor mainly).

6.2.4 User stations

1. **STATION TO INVESTIGATE PHYSICOCHEMICAL AND BIOLOGICAL PROPERTIES OF MATERIALS AFTER TERAHERTZ RADIATION INFLUENCE**

Purpose:

The station is intended for investigation of size of particles, morphology and biological activity of products of ablation/desorption of biological structures and inorganic materials under the terahertz radiation impact.

Equipment of the station:

• a diffusion spectrometer for aerosols, to find out size of particles in the range of 3-200 nanometers,

• a photoelectric counter of aerosol particles, to find out size of particles in the range of 0.3-10 microns,

• equipment for sampling for chemical-biological and electron-microscopic analysis.

2. **DIAGNOSTICS STATION**

Purpose:

Diagnostics and control of parameters of terahertz radiation from the free electron laser.

Equipment:

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

• Fourier spectrometer made by the BRUKER company, to measure the radiation wavelength

and emission line width,

• two-dimension scanning radiation sensor, to measure the light beam profile,

• terahertz radiation visualizer based on a thermal screen and BINP-developed thermal imager,

• terahertz radiation visualizer based on a thermal image plate made by the Micken Instrument company,

• Shottky-diode Q-meter for the FEL optical cavity.

3. **STATION FOR OPTICAL-ACOUSTIC SPECTROSCOPY**

Purpose:

Investigation of gas adsorption spectra in the terahertz range.

Equipment:

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

4. **STATION FOR INVESTIGATION OF CHEMISTRY OF METAL-ORGANIC COMPOUNDS UNDER FEL RADIATION IMPACT**

Purpose:

Mass spectrometric investigation of disintegration of metal-organic compounds at adsorption by molecules under FEL radiation impact in the molecular beam and on the surface.

Equipment:

• a time-of-flight mass-spectrometer MSH-6,

• a Knudsen cell system for molecular beam generation ,

• a 32 Mb fast ADC of the NI 5112 type.

6.2.5 Development and construction of specialized equipment

The task of development of relevant equipment is top priority because of the lack of standard equipment to detect and record terahertz radiation at construction and operation of experimental stations. The first task that was realized last year was development, manufacture and commissioning of the “beamline” - the system for delivery of radiation from the Novosibirsk FEL to user stations. Since this system is of large importance, it is described in a separate section. This line should be created subject to the fact that intensity of Novosibirsk FEL radiation is several orders of value higher as compared with all other existing sources of terahertz radiation. On one hand, there is the hazard of equipment destruction. On the other hand, the high power allows one to develop methods that are impossible for other light sources.

In order to measure the high-power submillimeter FEL radiation, two calorimeters were developed and commissioned. The most accurate device to measure power is a simplest exposure calorimeter based on a heat-insulated sapphire plate. Sapphire is an ideal material for such measurements because of the rather long terahertz radiation absorption path. Correspondingly, the imaginary part of its refractive index is much less than the real one. Besides, the real part can easily be measured and is almost constant over the wide wavelength range. As a result, the portion of power reflected from the sapphire plate is well known (25%) (and verified experimentally) and it does not change with the wavelength. So, the sapphire plate is an ideal “black body” with an emissivity factor of 75%. This device is much simpler than a hypothetic ideal black-body calorimeter (with a 100% emissivity factor).

Another device, which fits better for on-line measurements, is a modified industrial gigahertz calorimeter MKZ-71. The waveguide absorbing attachment in this device was replaced with a special quasi-optical conical absorber on copper base, with detonation ceramic coating. However, there are additional heat losses in this device, because of its structural particularities. Therefore, its readings should be increased by a value about 25%.

The reference pyroelectric detector of FEL radiation installed behind one of the mirrors of the optical cavity has been modernized. Now, between the detector and the exit window there is no atmosphere gap that would impair measurements on water absorption lines.

There were a lot of experiments made with thermal image plates by the Macken Instruments company. The plates have good spatial and time resolution and allow one, after a simple calibration with the help of the sapphire calorimeter and wire polarization attenuator, to measure absolute distribution of intensity of sub-millimeter radiation.

The MDR-23 monochromator has been commissioned after modernization. It was equipped with additional sub-millimeter and infrared diffracting screens and wider slits. This monochromator was used to record the first, second and third harmonics of FEL radiation. This device has the advantage of real spatial separation of harmonics over other spectral devices applied in the FEL experiments. That is important for many experiments.

Experiments with the Fabry-Perot grid interferometer were continued. This device was used to construct the calibration dependence of the FEL radiation wavelength on the undulator current. This dependence is used by FEL operators to set up a necessary wavelength for experimentalists.

Experiments on measurement of FEL parameters with the help of fast detectors based on Shottky diodes have been continued. Losses in the modernized optical cavity with large exit hole have been measured. They turned out to be very close to the analytical calculation made earlier. Taking the high power of radiation into account, we created (or adapted for the terahertz range) three systems for terahertz radiation visualization. The thermograph developed by ISP SB RAS, whose matrix of 128x128 pixels is sensitive to the near IR radiation in the range of 2.5 - 3 microns, monitors distribution of terahertz radiation power density in real time. The thermograph can record with frame speed up to 40 Hz the IR images of the screen installed in the path of the laser radiation beam.

Trying to achieve good time resolution, BINP SB RAS and ISP SB RAS have joined their effort to develop a special screen. Its spatial resolution is restricted by the relatively small number of pixels. So, construction of a large-matrix radiation detector is an actual task for the near future. To obtain images with good time resolution for measurements in the terahertz range, we have adapted the thermal image plate made by the Macken Instruments company for detecting radiation of lasers of the near and middle IR range.

This device is based on thermal quenching of luminescence of phosphor illuminated by a mercury lamp. The plate glows yellow-orange. The scintillator being heated, the luminescence is quenched. Shooting the plate with video camera, one can study the time dependence of intensity distribution in a terahertz beam with a frame speed of 25 Hz.

The two above-described visualization methods give qualitatively the intensity distribution across the terahertz beam. However, to get absolute values of radiation power density it is necessary to confront the surface temperature to measure with the incident radiation power. Having simultaneously measured the absolute value of radiation power, for instance, with the sapphire calorimeter, and having calibrated the luminescence quenching value, one can also carry out absolute measurements with the thermal image plate.

The thermosensitive visible interferometer is a device to measure not temperature but directly the terahertz beam energy absorbed. This device detects the change in the optical path difference for probe red radiation of the semiconductor laser when terahertz radiation is absorbed in a plane-parallel K8-glass plate. Since the thermo-optical parameters of the glass are well-known and the terahertz radiation refraction factor of the glass has been measured, the power density distribution of terahertz radiation incident on the plate surface can easily be restored in absolute units via changing the interference pattern.

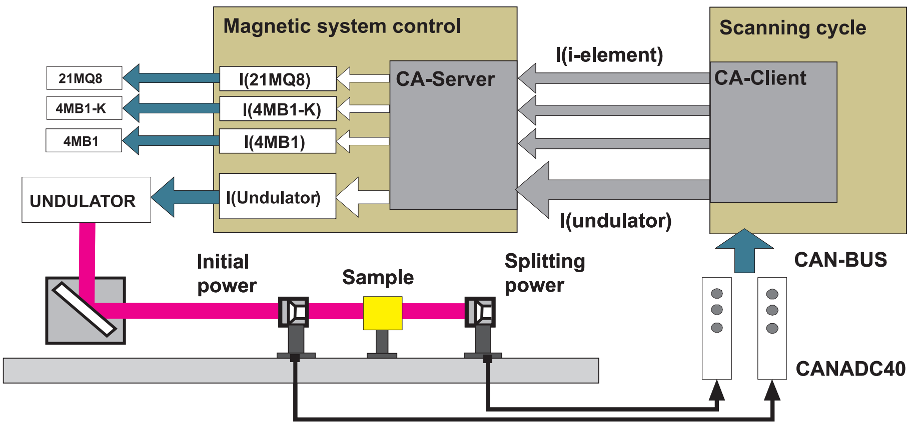

Figure 13: System for automatic scanning of the FEL generation wavelength.

The system developed for automatic scanning of the FEL generation wavelength and reporting it to the user net is very useful. The control program for the magnetic system with the embedded remote control server Epics Channel Access allows scanning coherent FEL radiation over the wavelength.

The client program organizes the cycle of step-wise change of the undulator current, within given limits and with a given step. Simultaneously, requests for changes in some other magnetic elements are sent if it is necessary for setting the required wavelength. The program gives a 3 second pause after the change of currents, which is necessary to settle the undulator field. Then the intensity is measured, both of the total (incident) power of radiation and that absorbed in the sample or passed through it. The desired spectrum is obtained via the found out dependence of the second value on the current normalized to the first value, since it can slightly vary during the measurement cycle. Now the possible range of scanning over the undulator current is 700-800 A, which corresponds to the wavelength range of 117-160 microns.

The usage of kinoform elements to control terahertz radiation seems to be very promising. Really, it is very difficult to find for transmitting optics materials that would not absorb terahertz radiation. Besides, since wavelengths in the terahertz range are 0.1 to 0.2 mm, manufacture of kinoform materials in this case is much simpler than for the visible band. We have carried out the first tests of Fresnel-zone plates reflecting at a 45°C angle. They were elliptic structures etched on foil-cladpaper-basedlaminate up to 14 cm in size. Even this simple device allowed us to focus radiation into a spot less than 1 mm in diameter. Their diffraction efficiency is relatively small in this simplest configuration. However, high FEL radiation intensity allows one to use them to make images. If they are made as phase refractive elements (which is not a problem for a NC machine), the efficiency can be as high as almost 100%.

6.2.6 Some results obtained in the year 2005

Soft ablation of biological molecules under sub-millimeter radiation (ICKC SB RAS, ICG SB RAS, BINP SB RAS). The aim of the work was to study ablation ("sublimation of material without melting") of samples with "biological" molecules (DNA, proteins, etc.) caused by the free electron laser radiation. The main idea was that, since the quantum energy is extremely small in the terahertz spectral range, the molecules can be "evaporated" staying non-destroyed.

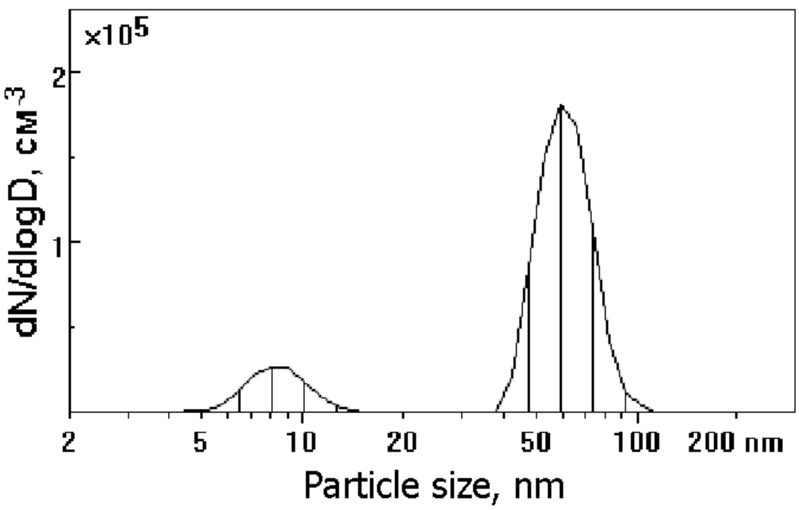

Figure 14: Size distribution of aerosol particles resulting from soft ablation of the circular DNA of the plasmid pBScript (type 3.6) and phage DNA (type 48).

It turned out that selecting right radiation power, one can achieve the regime when molecules are "evaporated" without being destroyed. This effect can be seen in Fig.14 (a target consisting of two DNA molecules 10 times different in size). It should be noted that nobody has managed to avoid de-fragmentation of biological molecules at ablation with lasers with wavelength from ultraviolet to 10 microns. This result can lead to creation of new biotechnologies.

Image visualization and holography in the terahertz range (BINP SB RAS).

Development of the above-described visualization methods was an important component of creating instruments for investigations on the Novosibirsk FEL. Those methods were tested in the unique experiments on demonstration of the possibility of recording holograms in the terahertz range. We recorded two holograms: the simplest Gabor hologram at refraction of the Gauss beam from the FEL at the spherical mirror with a small hole in the middle and the Fresnel hologram with the wave front splitting.

In the first case we recorded a system of concentric rings, exactly as in the theory. In the second case, it was a hologram of a figurine. Taking into account that the scene depth exceeded the FEL radiation coherence (about two centimeters), the result of restoration can be assumed to be rather close to the original. That allows us to turn to creation of holographic schemes for detailed investigation of refractive objects and those partially transparent for terahertz radiation. In particular, that is of interest for introscopy of condensed media, investigation of their deformation and destruction and study of gaseous fluxes. Another field where holography can be applied is investigation of powders and phase objects. Since the frequency of laser pulses is high and it is possible to separate two pulses with an arbitrary delay starting from 90 ns (and even shorter if the wave front of one pulse is split), it is possible to record two subsequent holograms and to obtain a "two-exposure" holograms. The capability of continuous change of the laser wavelength allows recording a series of holograms at several wavelengths and thus obtaining spectrally selective holograms.

6.2.7 Development of the Center for Photochemistry Research on the basis of the accelerator-recuperator and the second stage FEL for the area of 3-10 THz.

A full-scale accelerator-recuperator (AR) uses the same accelerating RF structure as the first stage AR but it is situated, unlike the latter, horizontally. Thus, one of them can be constructed without demounting the other. The operation regime can be chosen via simple switching the bending magnets. The full-scale AR is constructed as a racetrack microtron; the scheme of electron beam energy recuperation coincides with that of acceleration but the phase of pass through the accelerating structure is mirrored.

The main parameters of the full-scale AR are as follows:

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

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

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

Solving numerically the equations for weak signal amplification, we have calculated amplification in such FEL for different parameters of the main mode of the optical cavity. Amplification should exceed the optical cavity losses, which depend on the refraction factor of the mirrors. Multi-layer dielectric mirrors have high reflection coefficients but are narrowband and can fail at large (above 100kW) power in the optical cavity. That is why it is supposed to use copper mirrors with golden coating.

A program was created to model FEL operation with rather short electron bunches. The program has been tested with application of experimental data (radiation spectrum, dependence of the power on the optical cavity length, etc.) obtained on the FEL first stage.

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

Since the undulator period is rather big, the electromagnetic structure can be used. The fields were calculated with the MERMAID program developed at BINP. They allowed us to choose the pole width at which the field amplitude is close to that of the infinite width case.

The task of vertical focusing in the undulator is a serious one. Focusing can be quantitatively characterized with the concordant beta function

$$\beta = \frac{\Upsilon d}{\sqrt{2\pi}K}.$$

For the energy = 20 MeV and the undulation parameter K = 1 $\beta = 0.5$ m. Making the undulator a little more complicated, we can provide amplification of β by 1.5-2 times and horizontal focusing. Numerical computations of field in the modified undulator allowed us to find out the optimal pole shape. This shape gives the same focusing in the vertical and horizontal directions as well as minimal non-linearity of focusing.

The first and second integrals of vertical field on the undulator ends can be made zero via varying the gap in the first two and last two pairs of poles with the help of vertical shift of the poles. Moreover, the first and last poles are surrounded by one turn of current while all the rest poles are surrounded by two. There are two correctors on each of the undulator poles. They induce vertical magnetic field. The “optimal” Rayleigh length of the optical cavity - 2 m - can be found by the given undulator length of 4 m. Such Rayleigh length makes the transversal sizes of the main mode of the optical cavity minimal on the ends of the vacuum chamber of the undulator.

The total length of the optical cavity, i.e. the distance between its mirrors, L is found from the condition of synchronization of longitudinal modes

$$\frac{2L}{c} = \frac{n}{f_O},$$

where c is the velocity of light, f_0 is the bunch repetition frequency and n is an integer. For the existing electron gun of the accelerator-recuperator, $f_0 = 22.5$ MHz, thus L = n·6647 mm.

To lower radiation intensity on the surface of the mirrors of the optical cavity, the cavity should be maximally long. That is why the maximal possible length of 20 m has been chosen.

At large ratios of L / the Rayleigh length, the tolerances of the angular adjustment of the mirrors become tougher. For a symmetrical optical cavity with mirrors of the radius

R, misalignment of one of the mirrors by the angle $\Delta\Theta$ leads to displacement of the optical axis on the opposite one by

$$\Delta x = \frac{R^2}{2R - L}\Delta\Theta \ .$$

On the other hand, the Rayleigh length is defined by the formula

$$z_0 = \frac{1}{2}\sqrt{L(2R - L)},$$

hence,

$$\Delta x \approx \frac{L^3}{16{z^2}_0}\Delta\Theta \quad .$$

Taking into account that for the main mode with the wavelength λ the mean-square dimension on the mirror is $\sqrt{\frac{\lambda}{4\pi}\left(z_0 + \frac{L^2}{4Z_0}\right)}$, we find out the requirement for the angle adjustment accuracy

$$\Delta\Theta < \frac{z_0^2}{L^2}\sqrt{\frac{\lambda}{4\pi z_0}} \quad .$$

At $z_0 = 2$ m and $\lambda = 40$ microns, $\Delta\Theta < 1{\cdot}10^{-5}$, which can be provided by commercial mirrors.

It seems to be reasonable to try slightly increasing the Rayleigh length relative to the "optimal" one. For instance, choosing R = 10,9 m, we have $z_0 = 3$ m. At $\lambda = 100$ microns, the mean-square mode dimension on the undulator ends and on the mirrors equal 6 mm and 17 mm, correspondingly. For the diffraction losses to be small, the refracting surface diameter should be not less than six times as large as the mean-square dimension. Taking into account possible operation at wavelengths over 100 microns as well additional 10 mm to fix the mirror, the mirror diameter can be chosen to be 160 mm. The given curvature radius should be kept up with an accuracy of $\pm$ 0.1 m. The scheme of the optimized optical cavity is shown in Fig.15. It is close to that of the already existing FEL cavity for 1-3 THz.

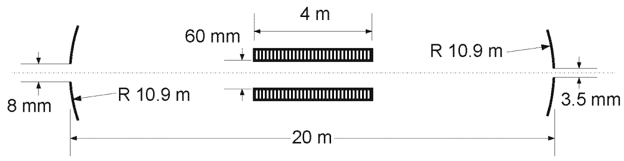

Figure 15: Scheme of the optical cavity of the second stage FEL.

It is a serious problem that the mirror curvature radiuses change because the mirrors are heated by radiation. To calculate this effect, a special program was created. It helps to optimize the mirror thickness and shape of the cooling details.

6.2.8 Workshop on terahertz radiation

The First workshop"Generation and application of terahertz radiation" (Novosibirsk, November 24-25, 2005) was devoted to the results obtained in the research supported by the RAS Presidium Program "EM waves terahertz region". 22 reports covering all the themes of the RAS Presidium program as well as a number of investigations beyond the Program were presented and discussed at the meeting. Now the Proceedings of the working meeting have been published. The total number of publications by the

program is 72, not counting works in press.

The first group of the six projects dealt with development of terahertz radiation sources. Creation of terahertz radiation sources of different type, spectrum, power and operation mode is an important task, providing the further development of this field of science and efficiency of its applications. Since the terahertz range is between the fields of electronics and photonics, it allows usage of generation radiation methods typical of both the spectral intervals.

Project "Development of sub-millimeter range orotrons (IAP SB RAS)". The possibility of continuous orotron operation at a frequency of 140 GHz with an output power of 200 mW has been shown. The orotron for operation in the frequency range of 0,2-0,4 THz has been developed. This generator has been studied experimentally in the long-wave part of the range.

Project "Development of pulse and continuous gyrotrons of the range of 0.3-1.0 THz (IAP RAN)". To develop application of the terahertz range at high power, the three promising types of gyrotrons with generation frequencies of 0,29-0,41 THz were developed: the conventional gyrotron on the main cyclotron resonance with a 11 T field provided by the "dry" cryomagnet (a frequency of 0,3 THZ, a radiation power of 3 kW in the continuous regime); the large-orbit gyrotron on the third cyclotron harmonic (frequencies of 0,37-0,41 THz, power as high as 20 kW in the microsecond pulse regime); the gyro multiplier with the self-exciting entrance section (a frequency of 0,28 THz, a power of 30 W in the continuous regime). Besides, the gyrotron on the main cyclotron resonance for a generation frequency of 1 THz with pulse field as high as 40 T was developed. The methods developed open up possibilities of creation of efficient high-power THz gyro devices available for many laboratories.

Project "Parametric generation of terahertz range radiation in semiconductor laser diodes and wave guides (IPM RAS)". The possibility of creation of terahertz and multi-terahertz sources to realize parametric generation of difference harmonic in double-frequency lasers of the near IR range (a wavelength about 1 micron) working at ambient temperatures and based on quantum-well heterostructures InGaP/ InGaAs/GaAs (at the expense of the second-order lattice non-linearity because of the absence of inversion center in the GaAs lattice) as well as in exterior semiconductor waveguides was considered.

Project "Terahertz radiation generation via frequency multiplication on semiconductor structures (IPM RAS, IAP RAS)". The following was shown to be perspective:

1) low-barrier Shottky diodes for sensitive detectors of the sub-terahertz frequency range;

2) matrixes with end back-to-back diodes to create a high-power terahertz frequency multiplier;

3) artificial environment based on arrays of metal clusters implanted in a semiconductor matrix for the purposes of optical generation and transformation of THz-IR radiation. A measurement bench is being developed to study characteristics of THz range devices.

"Project for the second stage of the free electron laser for 3 -10 THz range (IPM RAS, BINP SB RAS)". The main elements for the second stage of the Novosibirsk laser have been designed. Commissioning of the laser will broaden the generation range from 120 - 240 microns of today to 3 - 300 microns, which will in turn broaden the range of experiments, including the high-frequency part of the terahertz range.

Project "Optical methods of generation of coherent ultra-broadband terahertz pulses (IAP RAS)". The results of generation and detection via optical methods of ultra-short electromagnetic pulses in the terahertz range were presented. Efficiency of generation and detection with pulses of the titanium-sapphire laser was compared for a relatively high energy (2MJ) and low repetition frequency (1kHz) and low energy (10nJ) and high repetition frequency (60 MHz). A spectral pulse width about 1,5 THz was achieved.

The second group of works deals with development of the element base and technologies to develop the terahertz science and technologies. First of all, that is terahertz detectors, both single-element and matrix. Another very important achievement is the development of the technology for growing artificial diamonds. It gives the possibility to couple out high-power terahertz radiation from sources and using them in process devices.

Project "Development and manufacture of superconductive elements and integrated receivers with working frequencies up to 1 THz (IRE RAS)." This project is aimed at development and study of integral superconducting receiving structures of the terahertz range with sensitivity only limited by quantum effects. A principally new concept of fully superconducting integral receiver of sub-millimeter waves was suggested for space and earth-based radio-astronomy as well as for environment monitoring. The integral receiver consists of one superconducting microcircuit and includes an MSI mixer, planar quasi-optical receiving antenna and superconductive oscillator generator on the basis of distributed tunnel junction.

Project "Study and development of the technology for high-speed growing of polycrystal diamond films and wafers via gas discharge in sub-millimeter wave beams (the CVD technology) (IAP RAS)". There was conducted a series of experiments on diamond film deposition on silicon substrates 60 and 75 mm in diameter in the gas mixture Ar/H2/CH4 at different mixture pressure and composition, speeds of gas fluxes and temperature of the substrate. The speeds of diamond film growth were as high as 9 microns per hour. Results of diamond growing in the 2,45 GHz 30 GHz MPACVD reactors were compared. The speed of diamond film growth in the 30 GHz reactor was 5 to 7 times larger than that in the 2,45 GHz one, the working parameters being equal. The experiments confirmed the possibility of using the technology of fast growing diamond films from the gaseous phase on the 30 GHz reactor to obtain thick high-quality diamond wafers. Experimental samples of diamond wafers 60 and 75 mm in diameter and 0,13 and 0,65 mm thick were obtained. Both the wafers are of high quality; their growth surface and thickness are homogeneous.

Project "Sub-millimeter matrix radiometer on highly sensitive bolometers (IRE RAS, IAP RAS)". The aim of manufacture of highly sensitive sub-millimeter matrix radiometers is to install them on space and earth-based telescopes for astronomy measurements and observations. In 2005, the technology of bolometer manufacture with the use of electronic lithograph was developed; the low-temperature laboratory bench was created; the topology of elements and matrixes of bolometer receivers was developed. The width of bolometer, a part of the receiving element, is 0,3 micron.

Project "Development and study of the ultra-high-sensitive bolometer on electron heating in a normal metal at ultra low temperatures (IRE RAS, IAP RAS)". The compact dilution cryostat for cooling ultra-high-sensitive terahertz micro-bolometers down to 50 mK was developed and studied. The electronic circuits to measure characteristics of such bolometers at ultra low temperatures have been developed and tested.

6.3 Development and manufacture of dedicated SR generators

6.3.1 Superconducting wigglers

Active contract works on development and manufacture of various superconducting cryogen-magnetic systems for SR generation were continued in the year 2005.

1. In January, 2005, the 63-pole wiggler with a very short period of 34 mm, pole gap of 13.5 mm and magnetic field of 2.2 T was delivered to and assembled in the territory of the CLS (Canadian Light Source, the city of Saskatoon, the state of Saskatchewan) storage ring. After final tests and a cycle of magnetic measurements, the wiggler was installed on the storage ring. It is actively used for experiments on diffraction, XAFS, DAFS and microscopy in the energy range of 4 to 40 keV. This SR generator has a particularity: to smooth spectrum in the region of low photon energies (4-10 keV), regularity of periodicity of magnetic poles was intentionally violated so that the period value varies from 33 to 34 mm. Another particularity of the magnetic system of the wiggler is that ultimately possible parameters of the superconducting wire used have been achieved and current in windings has come close to the theoretical limit, i.e. that of the short prototype. Besides, it was the first time of achieving zero consumption of liquid helium due to a successful engineering solution on application of refrigerating machines (recondensers).

Figure 16: The 63-pole wiggler with a field of 2.2 T on the CLS storage ring (Canada).

2. The “short” prototype of the magnetic system of the multi-pole wiggler for the DLS (DIAMOND Light Source, England) storage ring under construction has bee designed by the beginning of the year 2005 and tried in April, 2005. The full-size 49-pole wiggler with a period of 60 mm, magnetic field of 3.7 T and pole gap of 16 mm was assembled in its cryostat in December, 2005. Liquid helium consumption was again made zero in this wiggler. Assembly and tests of the wiggler in the DLS area are going to start in March, 2006. Installation and commissioning of the wiggler directly on the storage ring are planned for September, 2006.

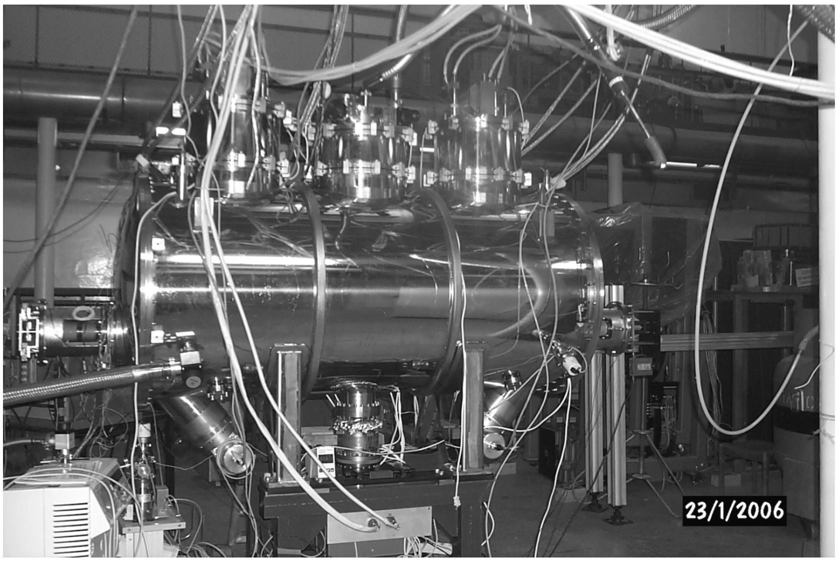

Figure 17: Tests of the 49-pole wiggler with a field of 3.7 T for the DIAMOND storage ring.

3. Designing of the magnetic system of the 21-pole wiggler with a field of 7.5 T and period of 164 m for the “Siberia-2” storage ring (RSC “Kurchatov Institute”, Moscow) was begun in 2005. Its “short ” prototype, at which a maximal magnetic field of 7.7 T was achieved, was manufactured and successfully tested in July, 2005. This wiggler will be the most powerful one among such facilities all over the world. The total SR power is going to be 100 kW. All magnetic poles for the full-size wiggler have been manufactured by December, 2005. The wiggler is going to be tested on its magnetic core in the experimental cryostat in February, 2006.

6.3.2 Non-superconducting magnetic systems for SR sources

12 magnetic elements (two fast correctors, four slow correctors , three quadrupole lenses and three bending magnets) have been manufactured and measured for the SLS SR source (PSI, Switzerland).

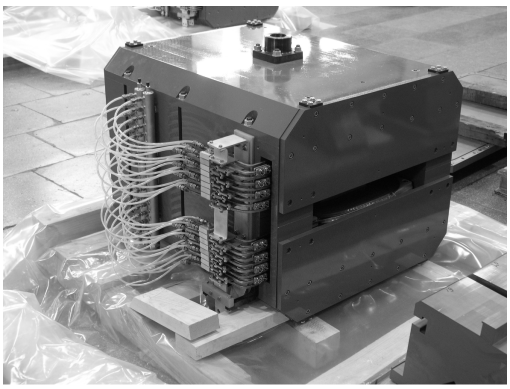

Figure 18: The bending magnet for the SLS SR source (PSI,Switzerland).

Magnetic calculations and drawings were made for the damping wiggler on permanent magnets for the accelerator - SR source Petra-3 (DESY, Germany)(the period λ=200 mm, the gap h=24 mm, the length L=4000 mm, and the maximal field B=1.6 T).

174 sextupole magnets have been manufactured for the Diamond SR source (England). Three electromagnets (superbends) with a maximal field of 3 T in the gap h=39 mm have been manufactured for SLS(PSI, Switzerland).

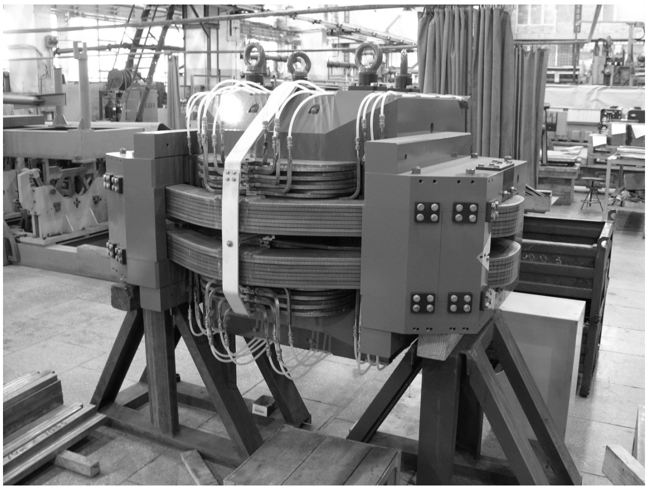

Figure 19: The 3 T superbend for SLS (PSI, Switzerland).

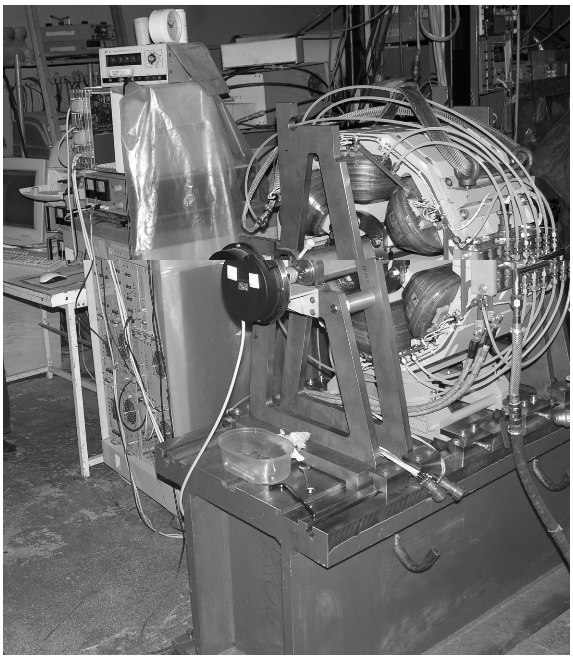

Figure 20: Magnetic measurements of a sextupole lens for Diamond.

Magnetic system for the metrology light source. The contract works on creation of the magnetic system (8 bending magnets, 24 quadrupoles, 24 sextupoles, and 4 octupoles) for the metrology light source – the 600 MeV storage ring under construction in Berlin on the base of the Metrology Institute (Germany) were continued in 2005.

High manufacturing accuracy requirements (± 20-30 microns for the pole area) have made it necessary to invite leading experts of the Institute. The works were done jointly by different departments of the Institute. The manufactured magnetic elements are to be delivered to the customer early in the year 2006. They are to be installed on the storage ring during the year 2006.

Elliptic undulators HU256 for Synchrotron Soleil. The contract work on manufacture of three elliptic undulators with a period of 256 mm for the SR source Soleil (France) was completed in 2005. The electromagnetic undulators have a close structure of the vertical (0.44 T) and horizontal (0.33 T) fields generated by 12 full and 2 correction periods with a total undulator length of 3,6 m. Calculations and test magnetic measurements were used to optimize dipole sorting, which allowed refinement of magnetic parameters of the undulators.

Within the contract on magnetic measurements of the undulators, a dedicated system on the basis of Hall generators has been developed. The accuracy of magnetic field measurement ($\leqslant$ 0,15 G) allows one to "measure " the first integral with an accuracy not worse than $\pm$ 50 G.cm. The undulators were delivered to the customer, where they were measured once more with Hall generators and "stretched wire". The undulators HU256 are to be installed on the stations "Cassiopee", "Pleiades", and "Antares" in the first half of the year 2006.

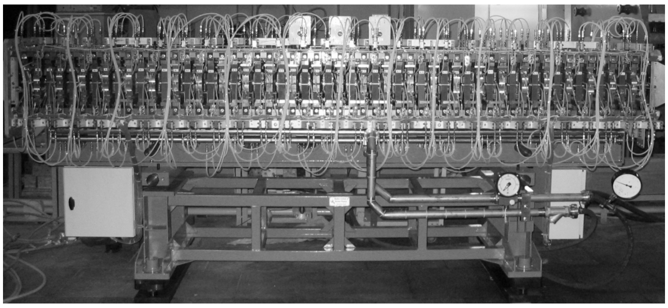

Figure 21: Elliptic undulator HU256 for Synchrotron Soleil (France).

Technological storage complex (TSC). Works on the storage ring-SR source for the scientific-manufacturing center of microelectronics and micromechanics (Zelenograd) were continued in 2005.

Figure 22: The BINP-KSRS-NIIFP team after the successful commissioning of the booster ring in Zelenograd (December, 2005).

The main systems of the booster ring have been mounted by the beginning of the year 2005. Works with beam were going on in the course of year. By the end of the year, the beam has been captured and accelerated in the booster ring.

6.3.3 Project of the compact storage ring-SR source

Further development of investigation methods with SR application at the Siberian SR Center is impossible without a dedicated source. The main problem is the strong competition among different investigation programs in the VEPP-3/VEPP-4 storage complex. Though time allotted for users is not always convenient for them, the interest of external users to the SR methods is continuously increasing. That is why the issue of creation of the dedicated storage ring for SR is quite urgent.

In 2002-2004, BINP developed and manufactured the prototype of the superconductive bending magnet for the BESSY-II storage ring (Germany) with a field as high as 9 T. Such magnets allow realization of the compact scheme of storage ring with a rather low electron energy (about 1 GeV). The high magnetic field in the bending magnets allows obtaining SR with a rather hard spectrum, and hence the most popular X-ray methods with SR application can be realized.

Economically, the high cost of the magnetic system of such a storage ring is compensated by the lower cost of the injection system and RF system as well as by abrupt reduction of expenses for construction of the infrastructure of the complex.

Hardness of the SR spectrum is one of the main parameters of such a system. The experience of SR application at different SR centers demonstrates that the most popular investigation methods use X-radiation with photon energies up to 40 - 50 keV.

It should be noted that there are a number of introscopy methods requiring the X-ray quantum energy to be as high as 120 keV. Such requirements arise in medical and processing X-raying and tomography. However, no simple and low-cost ways to generate high-power quantum fluxes of such energy have been found, which means that these methods can not be realized on such storage rings.

Though the interest to the hard X-ray range keeps growing, the investigation and technological methods in the soft X-ray range continue being developed. For instance, the relatively new method of mass production of micro-products (the LIGA technology) is based on application of SR with characteristic energy about 2 keV. That is why the scheme of the compact storage ring should provide for the possibility of organization of lines to couple out SR of both the hard and soft spectrum.

Such requirements can be met by a combined magnetic system structure including both superconducting and normal, “warm”, magnets. An advantage of such scheme is the possibility to get rid of excessive “compacting” of the storage ring and, hence, to provide sufficient freedom in designing lines of SR outcoupling. General considerations allow one to find out the optimal number of superconducting magnets in the structure. A large number of magnets results in significant increase of the whole-complex cost, and a small one deteriorates the storage ring symmetry and creates problems of beam instability due to critical resonances arising. It seems that the optimal number of superconducting magnets in the ring should be 4 (or 3, in rings with symmetry divisible by 3).

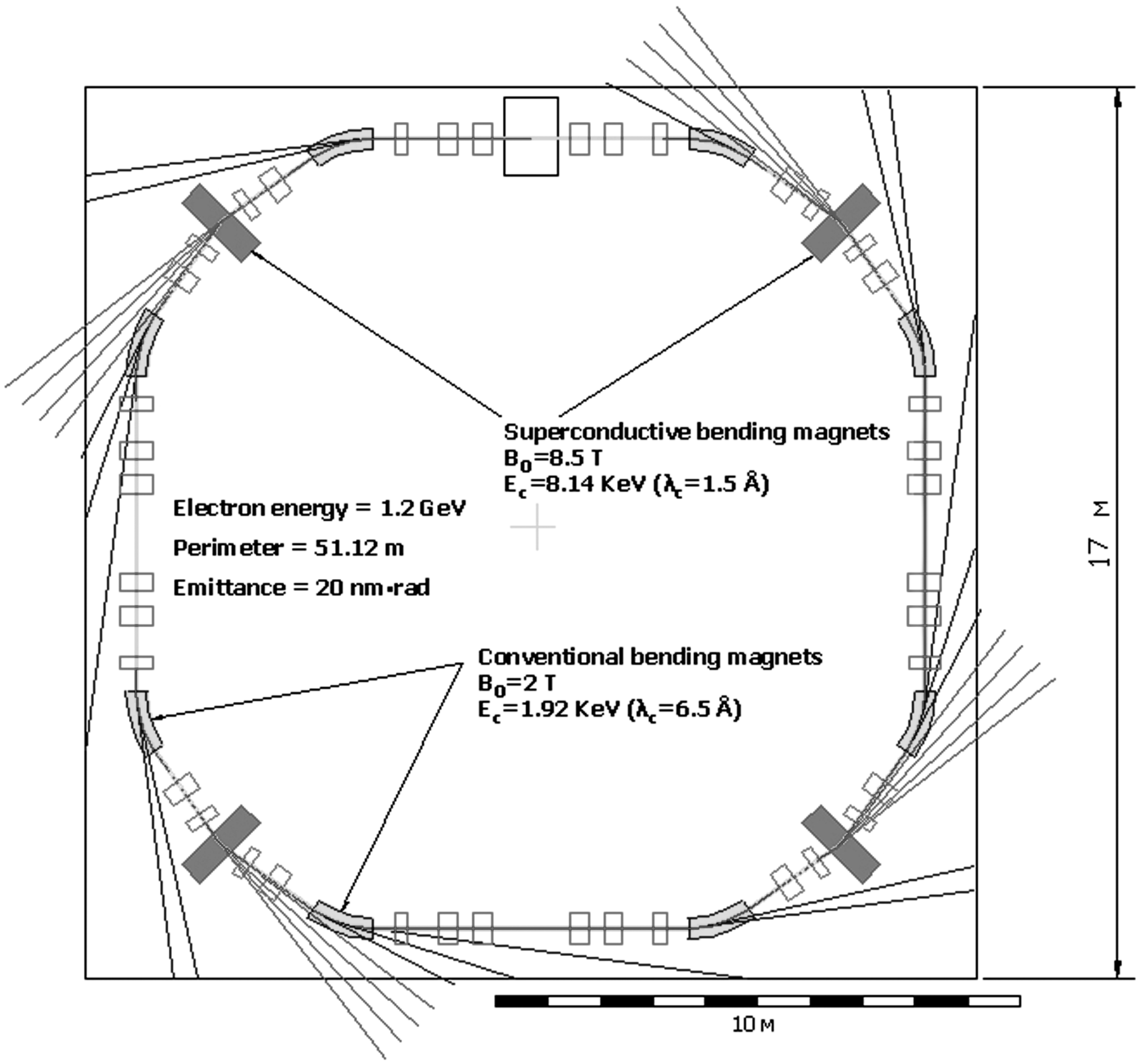

Figure 23: One of possible layouts of the compact storage ring on superconducting magnets.

Table 6.3: Main parameters of the compact storage ring-SR source (requirements).

Electron energy	1 - 1.5 GeV
Critical SR quantum energy	8 - 10 keV for SR from superconducting magnets 1 - 2 keV for beams from normal magnets
Phase beam volume	50 - 100 nm·rad
Beam current	300 - 500 mA
Beam life time	8 - 10 hours
Orbit perimeter	50 m
Size of the premise for the storage ring	20x20 m (without the space required for the user stations)

The electron energy in the storage ring can be 1 to 1.5 GeV, which is also close to the optimum as concerns arrangement of the injection system and bio-shield. In so doing, in superconducting magnets with a field of 8.5 T the critical energy of SR quanta will be about 10 keV, which provides a photon flux sufficient to realize the above-mentioned methods in the spectrum area up to 40 keV. Besides, using "warm" magnets to generate SR in the soft X-ray range, it is possible to meet requirements of users in this spectral area, too. If the electron energy is 1.5 GeV and the efficient magnetic length of the superconducting magnet with a field of 8.5 T is 20 cm, the beam bend angle in the magnet will be about 20°. That means that 3 to 4 lines can be constructed rather easily, to transport the SR beam from the magnet. So, productivity of the storage ring resources can be very high.

It is possible to define some requirements to the beam phase-space volume (emittance). Though the recent evolution of storage rings seems to tend to lowering of emittance, the photon flux that does not depend on the beam phase-space volume (all the rest conditions being the same) is very important in most cases of SR application. Of course, realization of some unique methods requires high spectral brightness but this project is aimed at increasing the number of users of conventional SR methods. Thus, the emittance should be of a reasonable value, e.g. as in SR sources of the second generation, 50 to 100 nm·rad. Since compactness of the facility is one of the main requirements, the phase-space volume seems unlikely to be made less without increasing the ring size. The perimeter of this storage ring should not exceed 50 m. Therefore, the size of the premise for the center can be 20 m x 20 m, though arrangement of user stations requires additional space.

One of possible schemes of such system is presented in Fig.23. The ring perimeter is 51.12 m. Such a storage ring can be arranged in a 17 mx17 m premise. In this variant, as many as 16 lines to couple out SR with hard spectrum can be organized as well a sufficient number of lines for soft X-radiation.

The horizontal beam emittance calculated is 20 nm·rad. So, the real emittance is likely to be better than that of dedicated storage rings-SR sources of the second generation.

Chapter 7

Radiophysics and electronics

Introduction

BINP works in the field of radiophysics and electronics are mainly concentrated in the Laboratory of Radiophysics. The main subject of the Laboratory activity is related to the study and development of radiophysical systems for the charged particle accelerators and storage rings, which are developed by BINP according to the State Programs "Colliding Beams", "High Energy Physics", "Synchrotron Radiation", "Physics of Microwaves".

Within the frame of these Programs, the Laboratory staff is involved in the development of such a radioelectronics equipment as the systems of power supply, control and diagnostics, computer control systems; the development of RF accelerating systems, RF and HF energy sources, studies of the charged particle beam behavior in interactions with the accelerating systems and other components and devices of the charged particle accelerators and storage rings. It is evident that the main results of the Laboratory activity are integrated into the study and development results obtained at the complex VEPP-4 and the development of new and upgraded complexes: VEPP-2000, Injection Complex VEPP-5; FEL; works on plasma physics.

As a consequence of a versatile character of the Laboratory works, some of them become the base of equipment and/or devices of an independent scientific and technological interest. Some results are applied and used in the work of other Institute's Laboratories, which carry out the work under contracts both with the national and foreign centers from the USA, Germany, R.Korea, Switzerland, Japan, Italy, China. It is worth mentioning here the contract works for the Korean Institute of Atomic Energy (KAERI, R.Korea) on the development, manufacturing and delivery of the components for the future microtron-recuperator and the work for the Institute of Modern Physics (IMP, Lanzhou, China). The joint work with these Institutes started a few years ago and it is planned to continue in future.

7.1 Development of the power supply systems for electrophysical facilities

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

Development of the high voltage (ranging from a few to tens of kilovolts) DC stabilized voltage sources are carried out in the Laboratory with a range of power:

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

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

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

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

A separate group of specialized power supply sources developed at the Laboratory are the sources of pulse voltages and currents. These devices serve the functions of modulators in the pulse sources of RF power; functions of the primary sources for the systems generating pulses of a nanosecond range of duration; functions of the current sources to supply of pulse electromagnets in the particle transfer channels, etc.

Given below is a short list of results obtained in the works carried out in 2005 and works to be continued in 2006 and in the future years.

1. In 2005, we mainly completed a long-term work on the upgrade of electronics for the "IST"-series precise sources designed for the power supply of electromagnets. These are devices of 50, 100, and 200 kW in power. Eight such devices were installed and put into operation at the KSRC complex (Kurchatov Institute, Moscow), two–at TNK, Zelenograd, seven of them – for the storage ring of VEPP-5 Injection Complex. The latter will be continued in 2006.

2. We continued the work on the power supply source of the RF-300-12 and RF-400-8 types. Remind that each source occupies one floor of the "Vishnya" type rack and has an operating current of up to 300A at voltage of 12V (RF-300-12) and 400A, 8V for RF400-8, respectively. The current stability is better than 10^{-4}. Each source is equipped with two DCCTs: one is for providing stabilization and another - for independent measurements. The rack-cabinet can contain of up to 8 such sources. The system is equpped with a multichannel control module DAC/ADC "CDAC20" comprising also the digital status register. The units are connected to the complex control system with the CAN-BUS interface. We developed a version of sources whose family is planned to be used for the power supply of the VEPP-2000 magnetic system components. In the family of these precise sources, there is a version designed for supplying the superconducting magnets. The sources are equipped with the system of energy extraction from magnets in case of a quench. At present, the whole set of sources is manufactured, adjusted and they are being installed at the complex. A group of RF300 sources is put into operation at the linac of VEPP-5 where they are used for the power supply of quadrupole lenses (warm electromagnets). About ten of such sources are installed at various stands at BINP where they are used for supplying the warm magnets, for tests of superconducting wigglers and dipole magnets, which are developed and delivered under the contracts. The accumulated experience enabled us in 2005 to complete the development of a specialized source RF400-8 in the "Euromechanics" standard for its use at the test stand for superconducting magnets of the Kurchatov Institute (Moscow). One of such sources is delivered to the customer and the second sample will be put into operation in the beginning of 2006. In future, we

plan to manufacture a small series of such devices.

3. As mentioned in the reports of 2003 and 2004, the UM-family (power supply source for correcting magnets) in addition to UM-4 (± 10A, ± 20V) and UM-3/10 (± 3 A, ± 10 V) was extended by the version of UM-6 (± 6 A, ± 100 V). The sources are monitored by CANDAC 16 and controlled by CANADC 40. In 2005, we manufactured up to 150 of such sources. A half of them placed in several racks is installed at VEPP-2000 complex making the full set of the BEP corrector power supply system. On the base of the UM-6 electronics, we also developed a four-quadrant source UM-25 with a rated current up to 25 A and voltage of up to 100 V. A small series of these UMs is planned to be manufactured next year. We continued the work equipping the fore-injector and storage ring-cooler with the corrector power supply systems. Three racks with the total number of channels of 100 is being commissioning. The adjustment and tests are planned to be finished in the first half of 2006.

Table 1 shows the basic nomenclature of the electromagnet power supply sources, which have been developed or upgraded and produced in the last years and successfully used at the BINP facilities and other organizations. The Table does not comprise the power supply sources, which were developed and produced as a "single" model.

Table 7.1: DC current sources for the power supply of electromagnets.

Type	Imax	Umax	Pmax	dI/I	Type Cooling	Size
	A	V	kW	%	—	m^3
B-1000	1000	15	15.0	0.01	Water/Air	
B-2000	2000	6	12.0	0.01	Water/Air	1.8x0.7x0.5
RF-300-12	300	12	3.6	0.01	Air	One storey “Vishnya”
RF-400-8	400	8	3.2	0.01	Air	One storey “Vishnya”
IST-1000(*)	1000	50	50	0.01	Water/Air	2.2x1.4x0.8
RF-100-’K	100	60	6	0.01	Water/Air	“Vishnya ”-6 chnls.
UM-4	±10	±20	0.2	0.1	Air	“Vishnya”-32 chnls.
UM-4M	+20	+20	0.4	0.1	Air	“Vishnya” - 16 chnls.
UM-6/100	±6	±100	0.3	0.1	Air	“Vishnya“-32 chnls.
UM-3	±3	±20	0.06	0.1	Air	“Vishnya”- 48 chnls.
UM-25	±25	±100	1.0	0.1	Water.Air	

Rack "Vishnya" – 8 storeys, 0.55x0.55x2.0 m^3

(*) - upgrade including replacement of electronics and update of power circuits.

4. In 2005, we manufactured electronics of the main power supply for bending magnets of BEP and VEPP-2000. These systems are of a megawatt range of power. Their power parts based on thyristor rectifier sections are being developed and manufactured jointly by several BINP departments under coordination of the work by the VEPP-2000 team. The control and measurement electronics is made in the Euromechanics standard. In 2005, we started the adjustment of the power supply systems for BEP and magnetic system of the VEPP-2000 ring and some preparatory work for their commissioning.

5. A successful development of a series of Diagnostic Injectors of Neutral Atoms (DNBI) in previous years (project leader - head of Lab.9 A.A.Ivanov) made a peak load in 2004-2005 both in the development and manufacture and delivery. In 2005, the injectors have been successfully put into operation at operational Tokamaks in Madrid, Madison,

Boston, and Padova. A slight upgrade of the injector in Losanne was made in 2005. We continue the work on the Injector components for the W-7X Complex being constructed in Germany.

Remind that one of the key devices of DNBI is a high voltage source with the output voltage of 55-65 kV and a current of a few amperes and duration ranging from 50 milliseconds to a few seconds (depending on the version). The sources have a unique possibility of a 100% modulation of the output voltage with a frequency of up to 500 Hz. The DNBI power and control electronics is placed in several racks of the Euromechanics standard.

6. Within the frame of the BINP work on the electron cooling systems for protons and heavy ions, in the last few years, BINP has developed for IMP (Lanzhou, China) two cooling systems with the electron energy of up to 35 keV and 300 keV. These systems are equipped with the unique electronics comprising not only high voltage sources with the abovementioned voltages and low current (of a few milliamperes) but also a set of all the control voltages for a gun under high potential: in total, on the order of ten channels including that transferring a power over 10 kW to the potential of 300 kV. The systems comprise also a branching net of monitoring, control and diagnostics In the period from 2003 to 2004, both the systems have been delivered to IMP, Lanzhou and awaited for the readiness of the accelerating rings. Unfortunately, in a 300 kV system, we failed to get the required high voltage stability (level error 10^{-5}) and achieve the low level of ripples. Improvement of the system will be continued in 2006.

7. In 2005, also within the frame of BINP-CERN collaboration, we attained a good progress in production of the components and systems of energy extraction from the 600 A correcting superconducting magnets of LHC. In total, 205 systems should be manufactured including an essential amount of mechanical work as well as large amount of electronics located in the Euromechanics crates. By the end of 2005, a major part of the work has been done with the simultaneous assembly, adjustment and tests of the systems at the CERN premises. The matter is that the systems are partially disassembled for their transportation. The work on commissioning the systems inside the CERN tunnel is planned to be completed in 2007.

8. During 2005, we continued the development and manufacturing of the components and units of the "Energy-plant" and its power supply, monitoring and control systems for the electron beam welding machine. The work started in the beginning of 2004 by the contract with NITI “Progress”, Izhevsk. The "plant" is based on a 60 kV gun with a beam power of up to 15 kW. The "plant" comprises about 20 channels of the monitoring and control, some specialized power supply, and adjustment and over 40 measurement and control channels. The development is planned for two years and it is carried out jointly by radiophysics Laboratory and laboratory headed by P.V. Logachev. At the end of 2005, the first "Energy-plant" was assembled and prepared for tests at the stand.

9. We continued the development of a new generation of pulse generators for supplying the magnetic components of the beam transporting channels. The systems are primarily designed for a 500 MeV channel for transporting the electron and positron beams from the injection complex to VEPP-4 and VEPP-2000, which is currently under development at BINP.

10. It is also worth mentioning that in 2005, we continued the work on technical support to keep operational the earlier produced systems and their units being operated at the BINP facilities.

7.2 Development of the systems and devices for automation of physical experiments

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

• Development and delivery of the fully assembled systems (systems of monitoring, control, diagnostics, and computer systems) with further participation of authors in adaptation of the systems to physical facilities;

• Development of elements for the control, monitoring and timing of the power supply systems with the further installation of the systems onto the charged particle accelerators and storage rings with a study of their influence on the complex as a whole;

• Installation of the unified individual modules (CAMAK, VME, Vishnya) on the operational or new installations and stands;

• Development of new approaches, technique and as a consequence, new devices enabling the solution of the experimental physics problems at a new level;

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

• Repair and technical maintenance of several thousands of electronic units and systems developed at BINP and currently operated.

Equipment developed and produced at BINP is widely used not only in SB RAS Institutes but also in many research organizations both in Russia and abroad. The nomenclature of the annually produced equipment is as wide as several tens of types of the digital, analog and digital-to-analog devices, units or modules.

Among works performed in 2005, it is worth mentioning the following:

• We continued the development of a new automated control system for the VEPP-2000 complex. Various subsystems of the pulse and DC power supply were subject to tests, the operability of a multichannel vacuumeter of a new generation was checked, electronics for a new version of the beam position monitor (based on CCD) was partially tested also.

• We continued the development, production and installation into the new and operational facilities of the control and measurement equipment using the CAN-BUS channel as an interface. At present, a set of equipment with this interface comprises the devices given in Table 7.2:

• Next 70 units with CAN-BUS interfaces are produced, adjusted and put into operation in the control systems of various electrophysical facilities. It is worth mentioning that the devices of this family are widely used for the contract works. For the last 3 years, over 100 modules in sets of the power supply sources have been delivered to KAERI (R.Korea), IMP (China), JINR (Dubna), Kurchatov Institute (Moscow). NITI "Progress" (Izhevsk).

• In view of the ever growing amount of various magnetic field measurements at BINP, the decision was made in 2002 to develop a set of VME modules, which could enable precise measurements of fields both with the Hall probe based matrices and with the rotating coils. At present, such a set comprises:

- a precise ADC with the built-in analog commutator;

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

Name	**Short characteristics**
CANDAC16	A 16-channel, 16-bit DAC, 8-bit input output registers
CANADC40	A 40-channel, 24-bit ADC (of a class 0,03%), 8-bit output and input registers
CDAC20	A 20-bit DAC, A 5-channel, 24-bit ADC (of a class 0,003%), 8-bit input and output registers
CEDAC20	A 20-bit DAC, a 5-channel, 24-bit ADC (of a class 0,003%), 8-bit input and output registers, Euromechanics standard
CAC208	A 8-channel, 16-bit DAC, a 20-channel, 24-bit ADC (of a class 0,003%), 8-bit input and output registers
CGVI8	A 8-channel, 16-bit generator of delayed pulses, 8-bit input and output registers
CPKS8	A 8-channel, 16-bit code-duty factor converter
SLIO24	CANbus interface - a 24-bit two-directional bus, built in board
CKVCH	Commutator of rf-signals 8-1, 2*(4-1), 4*(2-1)
CANIPP	CANbus interface - 2 branches of BPM-type
CANIVA	A 16-channel vacuummeter (current of the ion pump)
CURVV	A multi-purpose register of input/output (2 output and 4 input 8-bit registers)
CAC168	A 8-channel, 16-bit DAC, a 16-channel, 24-bit ADC (of a class 0,03%), input/output registers, built in board
CAN-DDS	A CAN-DDS module is a divider of the input clock frequency with the remotely retunable a fractional coefficient. The module is designed for its use in the feedback circuit of triggers at VEPP-5 and VEPP-2000
CAN-ADC3212	For connection of the feedback circuit in the thermal adjustment scheme of the cavity, temperature control at certain points cavity and providing blockings. A 24-channel 12- bit differential ADC with reswitchable amplification factor; a 4-channel 12-bit two-pole DAC.

- a 32-channel commutator with the commutation error of 1 μV, for operation with the Hall probes, a precise (0.001%) current generator is envisaged in the module;

- a precise integrator with the digital output.

• On the base of these modules, the stand for measurements of magnetic field multipoles in the quadrupole and sextupole lenses was developed, produced and successfully used in the contract works with the Diamond Light Source (DLS). In 2005, we completed measurements of the multipole components and magnetic axis position in sextupole lenses for Diamond. For these measurements, the relevant software was developed resulted in a possibility to carry out measurements of the quadrupole and octupole lenses.

At present, the stand is used for measurements of the quadrupole, sextupole, and octupole lenses produced by the contract for BESSY-PTB. We have performed measurements of the charts and field integrals of three electromagnetic undulator for SOLEIL. The measurements have been carried out with the help of a new specialized VME-system with the Hall probes and thermostabilized carriage with the horizontal and vertical positioning of the probes (for X- and Z-fields). The system high quality enabled measurement of the first integral with an error not exceeding ±50 G*cm at the undulator length of 3.8 m. The earlier developed software was improved that enabled one to take into account the spatial position and inclination angles of the glued Hall probes.

A set of VME-equipment with the Hall probes was installed and put into operation at the stand of magnetic measurements in the building №13. With the help of this complex, we performed measurements of the undulator prototype for DESY. The same set of equipment is installed at the stand of magnetic measurements in EP-1. It is used for measurements the dipole magnets, correctors and quadrupole lenses for PSI. We produced equipment, written the programms and put into operation the stand for measurements of magnetizing vector of the permanent magnets, which will be used for the assembly of sections of undulators for DESY.

- We started the development of stands on the base of the "Digital output integrators" and sets of rotating coils for measurements of the undulator parameters.
- We started the development of equipment for the two-coordinate monolithic Hall probes.
- We continued the work on transferring EPICS components to the earlier developed CAMAC and VME crates. This provides a smooth shift to the modern data gathering systems. For construction of the EPICS system, one can use the entire set of the CAMAC and VME modules available at BINP. A relatively low cost of the developed controllers as well as the use of the open and free of charge software enable the developments of the EPIC-system at minimum expenses. Within the frame of this work, we developed a new Power PC based VME-controller, the next ten pieces of the intellectual CAMAC controllers and 15 ports CAN-Ethernet were produced and adjusted. The devices are designed for the use at installations with the CAN-BUS interface.
- The unit for matching CAN-BUS interface with the VME channel is developed and produced, the corresponding drivers are also produced.
- The first experiments with Wi-Fi standard equipment have been carried out for evaluating the applicability of the standard in the BINP automation systems.
- By the contract with CERN, the first 6 crates with 8-channel arc detectors were produced. The final version has passed successfully the tests at the Protvino test stand. The decision was taken to produce the whole set.
- For the search for the hardly diagnosed malfunctions in powerful rf-generators of FEL, we developed and put into operation a 6-channel system for detection and fixation of arc discharges.
- For the replacement of the popular but physically outdated crate controller K0607, we developed in 2003 a new one based on the modern components. In 2005, we produced and put into operation next 15 controllers in 25 interface boards (20 pieces for PCI bus).
- Development of the digital registrators of two-dimensional optic images (digital cameras) the Fast Ethernet interface is continued. The next series of new units is produced and they are tested in the beam diagnostic systems at VEPP-4 and VEPP-2000. In the new units, the CCD control microprograms are updated thus enabling realization the regime of a synchronous start of storage the image (detection uncertainty was decreased from 80 ms down to 100 mks).
- We continued the development of equipment for studying fast processes with SR beams: development of a fast 12-channel, 16 digit ADC with the detector signal processing channels (channels provide integration of short pulse signals, suppression of noises, an individual tuning of amplification in channels and the polarity selection of the the input

signal); the ADC synchronization unit is developed and produced.

• For replacement of the physically outdated equipment for the correction system of the VEPP-4 magnetic field, a 16 channel interpolating DAC with the interface MIL-STD-1553B was developed with the use of the modern components. The module is fully compatible with the previous version. We carried out tests on the operational storage ring with the replacement of the old module by the new version. The order on production of the whole set (28 pc) of the interpolating ADC was placed.

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

• We started the development of the port-multiplexer for data gathering at the KMD-3 detector. The first samples are produced and the built-in software is under preparation.

• Development of the new digital registrator ADC-502 is completed and a set technological documentation is prepared. The test programs for this module are written. The registrator is designed for the replacement of the outdated ADC-850SK.

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

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

• An 8-channel unit for gathering data from dosimetric probes is developed and given for tests at FEL. Upon completion its tests, we plan to equip all the BINP installations with such devices.

• For the work with the KEDR gas systems, a number of modules, which are designed for measurements and control of the gas flows, are produced and adjusted.

• We started the development of the rf-timer for the FEL injector at KAERI (R.Korea).

• Development of the controller for power supply for the superconducting magnets is completed. The power supply source will be used not only in BINP, therefore, a possibility of the autonomous operation is envisaged.

• We started tests of the first version of the electron gun modulator and filament power supply source for the electron-beam welding machine under real production conditions. These devices are put at potential of up to 60 kV and have an operative control including the current value modulation with a frequency of up to 200 Hz.

• As the completion of the contract works, we took part in the commissioning of the superconducting wigglers at the storage rings CLS (Canada) and Diamond (England). In both cases, the automated control systems were successfully integrated into the general systems of automated control of the storage rings.

• We continued improvement of the Laboratory site. http://www.inp.nsk.su/div /l6-1/weblab6/start.html. By the idea of authors, the site should facilitate the more efficient and correct use of the laboratory developments. To this end, in addition to descriptions of various modules, some application notes are placed. The site is regularly innovated.

• We continued the development of electronics for the beam position probes based on measurements of image current with a new measuring electronics based on the new unit IPP-32. Installation of the equipment at VEPP-2000 is planned for 2006.

• Development of equipment for a damping system of the beam transverse motion instabilities at VEPP-4 is continued. Within the frame of the work, we completed the development of the wide band amplifiers operated in the amplitude linear mode. The bandwidth of the amplifiers is 50 MHz and the output power is up to 400 W in the operation run with the matched load. The amplifiers are designed for operation to kickers located in the half-rings. A part of the system is already produced and the work is planned to be continued in 2006.

• Production of the pick-up station electronics and some units of the beam position measurements system both for the VEPP-2000 collider and injection complex storage-ring cooler. The systems are based on a specially developed 4-channel, 12-bit ADC having the clock frequency of measurements of up to 45 MHz. In 2005, a set of the equipment was tested at the VEPP-4 complexes, worked out and prepared for further tests and manufacturing.

• Let us remind, that the measurement system based on the similar equipment (28 pick-up stations) with the use of the same ADC was put into operation in 2003 and successfully used at the microtron-recuperator (FEL) and at the injector complex at KAERI. We started production of the system units for the second order of FEL. Upon the completion of the work, the number of pick-up stations will be twice as much as that at the microtron-recuperator now.

• We started the upgrade of the beam position (orbit) measurement system in the channel of the injection complex linac. The system is based on the strip line type monitors and it is oriented to the repetition rate of measured beams ranging from a few Hz up to 50 Hz. For the positron part of the linear accelerator aiming at the improvement of its sensitivity, a special development of the preamplifiers and stronger shielding of separate modules and channels of measurement system was performed. Electronics for 9 pick-ups of the positron channel is completely developed and partially produced. 18 of 28 CAMAC Modules are produced now. The remaining - are at the stage of adjustment.

• In 2005, for the linac of the injection complex, we started the development of a new module of interlocks and signal measurements designed for the updated control system of the modulator and for protection of klystron of 5045 -type. For the same system, we tuned the software for a new unit of fast protection realized on a signal processor. Both the devices have been tested at the complex in 2005.

• Development of the precise NMR magnitometers is continued. Depending on a set of electronics and a version of probes, the magnitometer covers the field range from 0.02 T to 11 T. The relative measurement error does not exceed $10^{-5} \Rightarrow 10^{-6}$ depending on the field level and its homogeneity. A set of such an equipment is produced for the VEPP-2000 complex for the planned measurements of magnetic fields in each of 8 bending magnets of VEPP-2000 and in the 13th magnet of BEP. The field range is from 0.3 to 2.4 T. It is also prepared a magnetometer for the KMD-3 detector. The measurement field range is of the order of 1.5 T. The software for OC LINUX is developed.

In 2005, within the frame of contract works we delivered a 10-channel NMR magnetometer to Fermilab (USA) for the electron cooling device operating for cooling of the antiproton beams. The main feature of the system is a low level of fields on the order of 300 G at a high accuracy of measurements required. The achieved measurement error did not exceed $(1 - 3)\cdot 10^{-6}$.

Note, that some units of the NMR system as, for example, the frequency synthesizers are used at VEPP-4 in the precision measurements with polarized beams.

• Remind, that within the frame of the long-term collaboration with SLAC and FNAL on measurements of the slow vertical and angular displacements of the magnets and other components and units of the storage rings, we completed the development of a hydrostatic monitor of vertical displacements with two built-in tiltmeters. The tiltmeters have an angular resolution of 10 microradians with a dynamic range of ± 17 milliradians. We managed to place them in the same volume with the vertical displacements monitor at the same dimensions of the monitor body. The sensitivity of monitors was of fractions of a micron with the signal/noise ratio still good. A small series of such probes has been delivered to Fermilab in 2005. The delivery of a few probes to SLAC is planned for 2006.

• Within the frame of BINP-SLAC collaboration, we completed the development of a new displacement monitor being operated with the use of the ultrasonic measurement technique. The monitor was successfully tested both at the stands of BINP and SLAC with the achieved accuracy in calibration of displacements of one micron. Further continuation of the work is planned for 2006.

• Development of the drive equipment for step motors is continued. The most popular at BINP were the units of ESD-5-type designed for the control of a step motor of the SD-5D1MU3-type. At present, 40 units of ESD5-type are produced and adjusted for the upgrade of the NPC machines at the BINP Experimental Workshop:

– 20pieces - for three machines KD-46.

– 8 pieces - for two spark machines.

– 8 pieces - for two machines N33.

– 3 pieces have been delivered by contract to ZAO "Opticon", Novosibirsk.

• In 2005, we completed one of the stages of the development of the Starter-Generator-Unit (SGU) for the VAZ car. The SGU pilot sample was installed at the VAZ-21102 model of serial production. As far as we know, this is the first experiment on installing in the car of the Russian made SGU. The basic functions of SGD were realized during tests:

– Fast start of a car;

– Generator regime;

– Regime "Start-Stop".

During 2005, we carried out the road and climatic tests of the real sample. During these tests, we studied the most important characteristics of a combination engine-SGU under various conditions, obtained some interesting results and made some plans on improvement of electronics, control algorithms and software. The tested model has shown a good operability of SGU. Its all main functions were realized. Unfortunately, we did not get the expected reduction in fuel consumption but the reason was found out and an appropriate improvement is planned for 2006.

• Several thousands of CAMAC modules of various types are kept in operation on the devices at BINP and Russian and foreign organizations.

7.3 Developments for BINP Experimental Workshop

As in the previous years, we continued our support of the BINP Workshop in automation of some technological operations, control of the product parameters, in the development or improvement of technologies.

• Two samples of the "soldering machine", where the copper buses are heated with AC current of a few kiloamperes and the graphite electrodes are used as heating elements, are successfully operated in 8th Bld. of Workshop. The third machine is ready, tested and awaits its commissioning.

• As in previous years, we maintain the earlier developed systems designed for the thermal diffusion welding of copper foils with the welding area of up to 100x100 mm^2.

• At the BINP Workshop, we keep operational the earlier produced automated control systems of 12 technological devices for thermal treatment of components of physical devices being in production (6 devices in 8th Bld.; 4 -in Workshop-I; 2 - in 13th Bld.).We started the development of equipment for several new ovens, which are planned to be commissioned at Workshop in 2006.

• The fast acting laser modulator for the drum photoplotter was developed and successfully introduced into operation.

• Jointly with the printing boards section of EW-2 we worked out the technology of applying inscriptions on the printing boards with the serigraphy technique and introduced this operation into the production cycle.

7.4 Studies related to the modeling and solving the electrostatic and electrodynamic problems

The most important works of 2005:

1. Works on further improvement of programs for calculations of the electrostatic and magnetostatic fields of the electron and ion guns. Including:

• In the ESAM program complex, we realized a possibility of a selfmatching calculation of emission from the cathode and the beam dynamics in the electric RF field at the quasistatiaonary approach, which enabled calculation of the electron bunch parameters generated by the cathode-grid units place in the RF cavities or accelerating structures when except for the DC displacement voltage, an additional RF voltage is applied to the grid-cathode gap.

• A set of codes MAG3D is continued to be adapted to Windows and substantially improved for the three-dimensional calculations of magnets taking into account the core saturation effect.

2. The work was carried out on numerical calculations, modeling and design of electric guns as well as magnetic systems. Among them:

• Within the frame of the ISTC contract, with a set of codes MAG3D we developed the magnetic system of a continuous circular scanning system at the proton beam target with an energy of 2.5 MeV for the Boron-Neutron-Capture Therapy (BNCT) installation being under development.

• Development of a new multi-gap RF-accelerator ILU-12 with an energy of electrons 5 MeV and the beam mean power of 300 kW is continued. We calculated the real form of the current micro pulse injected from the cathode-grid unit placed at the accelerator first gap.

• Within the frame of works on FEL, we have demonstrated a possibility to use the cathode-grid unit of the GS-34 tube for the inner injection into RF cavity - FEL injector. We calculated the real form of the current micro-pulse and emittance of the beam injected from the cathode-grid unit.

• Within the frame of the BINP-Fermilab (USA) collaboration, we carried out calculations of the dynamics of electron beam with an energy of 4.3 MeV and current of up to 0.5 A from the cathode to the Pelletron acceleration tube output, which is designed for cooling a 8.9 GeV proton beam in the Recycler ring of the Tevatron Complex. The calculations enabled explanation of an ambiguous dependence of the current density profiles of a beam measured at the tube output on the output lens current and to choose the optimum operation run for the electron-optical channel of the accelerating tube.

7.5 Linear accelerator-injector for TNK facility

Linear accelerator-injector was developed and produced at Budker INP for TNK facility (Zelenograd). The facility includes two electron storage rings: 450 MeV booster ring and 2.0 GeV main ring. 2.8 GHz linear accelerator (LA) serves as an electron source (Fig.1). The injector consists of the disk-and-washer (DAW) accelerating structure, pulsed 20 MW RF power source, waveguide section, and electron-optic channel EOC-1.

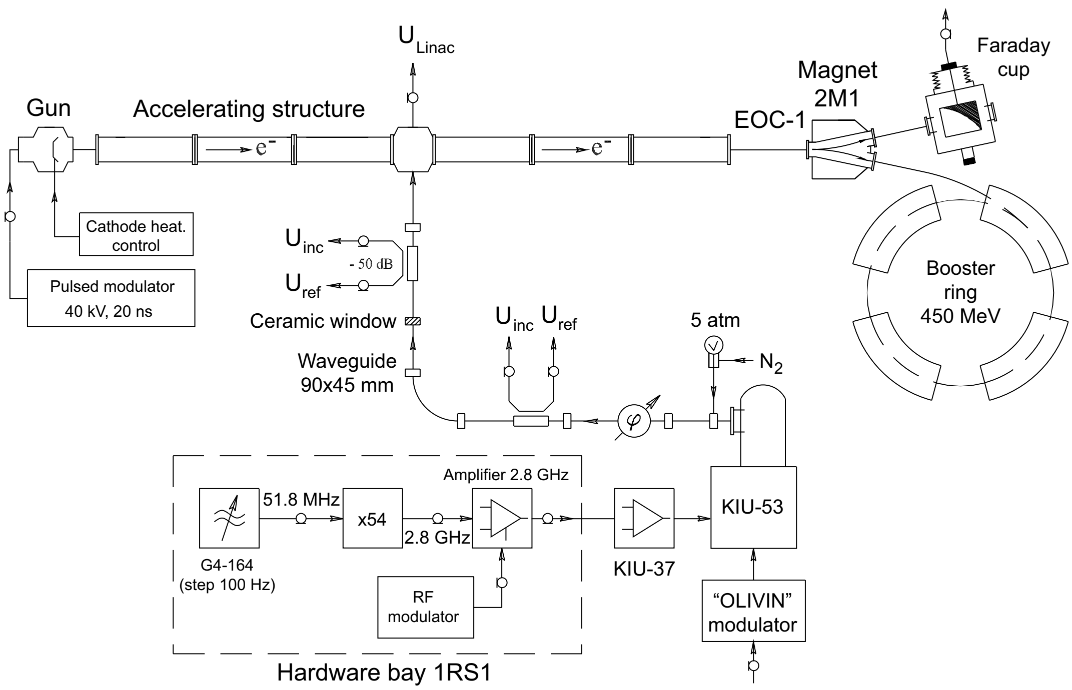

Figure 1: Linear accelerator sketch.

LA operates in standing wave pulsed mode. The accelerating structure consists of 6 regular 1-meter-long sections; it is excited at its center from "Olivin" klystron station via 90x45 mm^2 waveguide. The linac operates in storage power mode. An electron beam (4 A/40 kV/$\sim$20 ns) from the diode gun enters the accelerating structure with no pre-bunching. In the accelerating process, it is divided into bunches following one after another with 2.8 GHz frequency. The electron beam is transported to the booster ring input via the electron-optic channel.

In December, 2005 the linear accelerator was commissioned to provide injection of the electron beam into the booster ring. RF system for "Olivin" klystron station excitation was assembled and restored in accordance with the scheme presented in Fig.1 to provide the linear accelerator startup. RF structure, waveguide section, and gun were conditioned. Figures 2,3 present oscillograms of the voltage in the accelerating structure and incident and reflected wave voltage shape in the waveguide during conditioning process. Electron energy of $\sim$60 MeV and 50 mA current were obtained in energy range of $\sim$1%. The diagram in Fig.4 shows measured accelerated beam current at Faraday cup at various values of deflecting magnet 2M1 fields.

In December, 2005, the beam from the linac was captured into the booster ring.

Linear

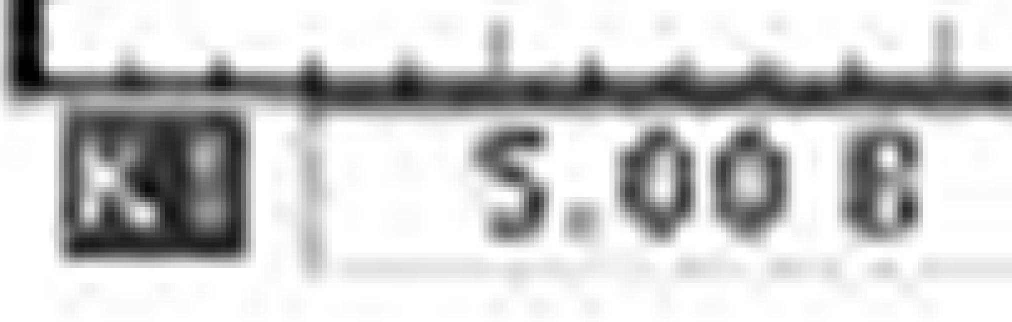

Figure 2: Upper beam — U_{linac} (voltage in the accelerating structure). Lower beam — U_{inc} (signal is weakened by 10 dB attenuator). U_{anod} at KIU-53 $\approx$ 195 kV.

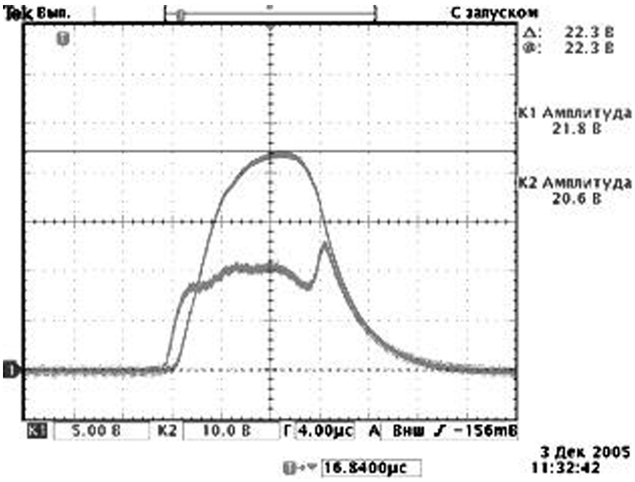

Figure 3: Upper beam — U_{linac} (voltage in the accelerating structure). Lower beam — U_{ref} (with no attenuator). U_{anod} at KIU-53 $\approx$ 195 kV.

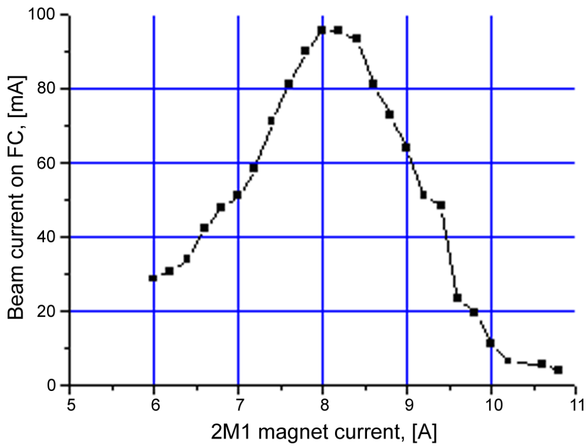

Figure 4: Beam current at Faraday cup versus deflecting magnet 2M1 current.

7.6 700 MHz cavity for X-ray source "NESTOR"

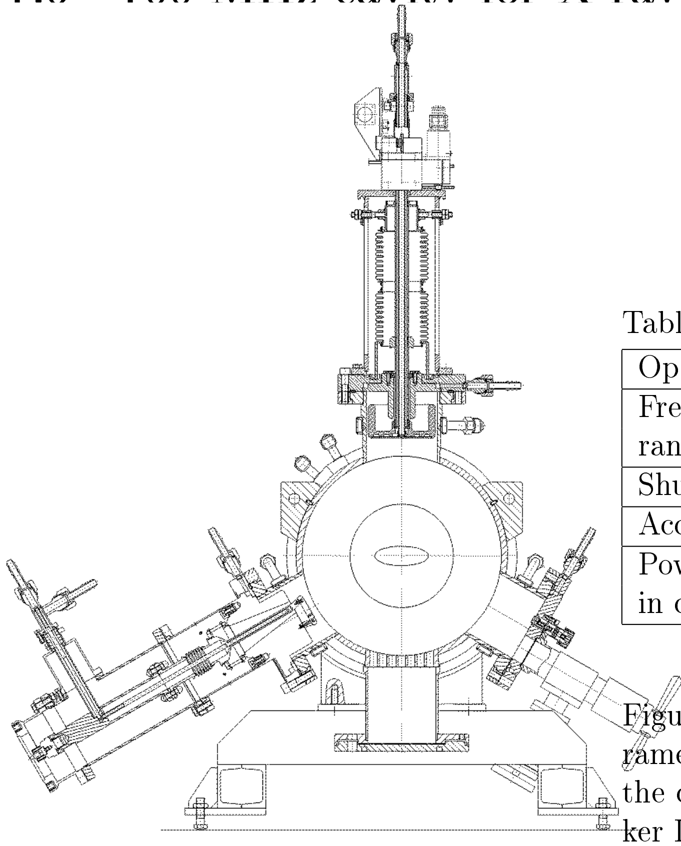

Figure 1: Cavity sketch.

een developed for NSC KIPT (contract storage ring is 40÷225 MeV, revolting

Table 1: Cavity parameters.

Operating frequency, MHz	699.3
Frequency tuning range, %	0.1
Shunt impedance, MOhm	>2.0
Accelerating voltage, kV	> 200
Power dissipated in cavity, kW	15

Figure 1 present the sketch, the cavity parameters are listed in table 1. At present, the cavity is being manufactured at Budker INP workshop.

7.7 Accelerating structures for SPL project, CERN

In 2005, the work was continued in collaboration with VNIITF (ISTC Project #2875) on development of technological base for serial production of accelerating structures of the types CCDTL (352 MHz, energy range of accelerated H^- ions of 40–90 MeV) and SCL (704 MHz, energy range of accelerated H^- ions of 90–160 MeV) for SPL project. The goal is to demonstrate on prototypes ability of serial production at BINP+VNIITF of such structures. To do so, operating prototype of CCDTL which consists of 2 tanks is under construction now together with SCL periodicity unit. CCDTL shells are produced at VNIITF, and drift tubes — at BINP. The final assembling will be made at BINP. At present, shells, aluminium mock-ups, and copper parts of the drift tubes are finished. After RF measurements with aluminium mock-ups, the copper parts will be adjusted and installed into CCDTL tanks. Full power level tests will take place at CERN. SCL prototype is at BINP workshop. The work is to be done in the middle of 2006, the decision on SPL project funding at CERN is expected to be made at year-end.

7.8 Creation of 5 MeV, 300 kW industrial linear accelerator

At Budker INP, development and manufacturing of high-power linear accelerator named ILU-12 for industrial applications (ISTC Project №2550) are underway. The project goal is to design a prototype of a quite simple and reliable 2 MeV electron accelerator with average beam power of 300 kW. The project feature is a problem of obtaining the high-power electron beam with narrow energy spectrum that is required for effective transformation of the beam kinetic energy into the energy of γ-quanta. In 2005, the following work was carried out:

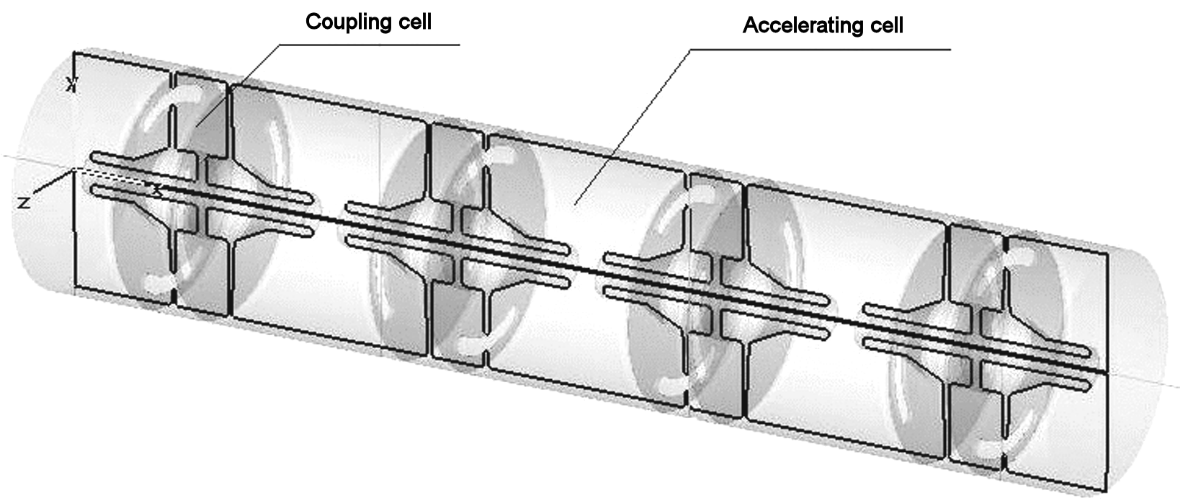

Figure 1: General view of the accelerating structure.

1. Numerical 3D simulation of the accelerating structure has been carried out. Accelerating structure general view is shown in Fig.1. Quadrupole field additions due to the coupling slots has been found, its influence on the beam transverse dynamics has been estimated.

2. The accelerating system mock-up (5 cells in 1:5 scale) has been manufactured; its main parameters (coupling frequencies, coupling constants, field distribution) have been measured.

3. Accelerating structure final geometry has been determined on the base of simulation and measurement results.

4. The beam transverse and longitudinal dynamics has been simulated from the RF gun cathode up to the accelerator output. Beam profiles have been obtained for various cross-sections of the accelerator (Fig.2).

5. The work on creation of RF power source for accelerating structure tests is underway.

6. The work on manufacturing and tuning of RF measurement devices is underway.

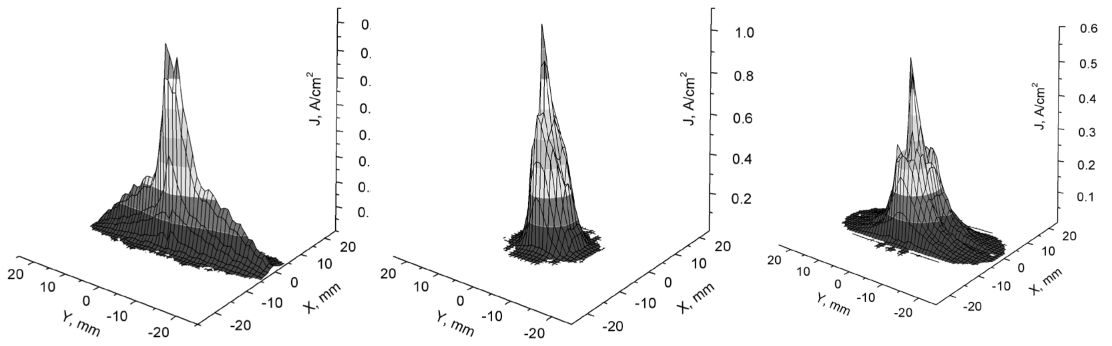

Fig. 2: Beam simulated profiles at various acceleration stages.

Participants of the work

Lab.6-2, Lab.6-0, Lab.14, NKO: V.L. Auslender, I.V. Gornakov, I.G. Makarov, G.N. Ostreiko, A.D. Panfilov, G.V. Serdobintsev, V.V. Tarnetsky, M.A. Tiunov, V.G. Cheskidov, K.N. Chernov.

Publications: [323], [324], [395], [396].

7.9 RF System for VEPP-5 damping ring

In 2005, RF system for VEPP-5 damping ring was assembled and tested after modifications in some individual parts. RF system parameters are defined by the requirement for short high-power bunches in the damping ring at 510 MeV energy. It is achieved by choosing high accelerating voltage amplitude and high RF order 700 MHz that corresponds to the 64th harmonic of the particle revolution frequency. RF system block diagram is shown in Fig.1. It consists of RF power source, circulator, waveguide section, RF cavity, and control system.

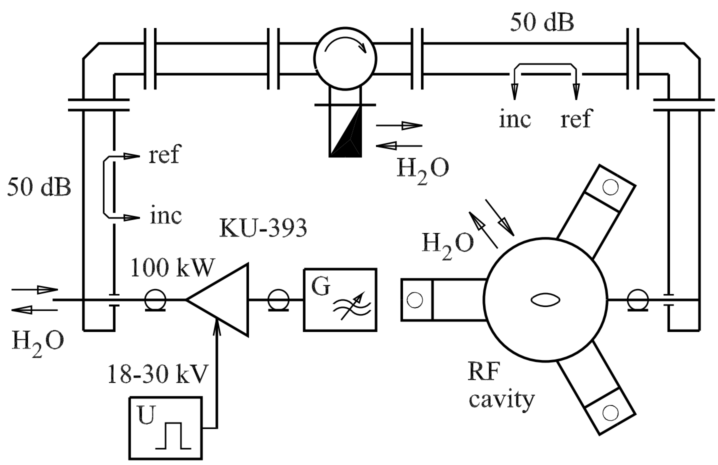

Figure 1: RF system block diagram.

RF power source and waveguide section

100 kW klystron KU-393 serves as RF power source. Klystron generator parameters are listed in Table 7.1.

Table 7.1: RF cavity parameters:

Frequency, MHz	700
Voltage, kV	27
Beam current, A	5.4
Output power, kW	65
Efficiency, %	45
Gain, dB	46

Table 7.2: Circulator parameters:

Feedthrough power, kW	100
Loss power, dB	0.3
Reverse attenuation, dB	>20
Input VSWR,	<1.6
Dissipated power, kW	<15

The klystron is fed from the 200 kW six-phase rectifier. The voltage is controlled by thyristors. A resistor is inserted into the circuit to prevent the klystron damage during discharges. The klystron solenoid consists of five coils, each of them is fed from a separate source.

RF power is transmitted through the aluminium rectangular waveguide (292.1 $\times$ 146.05 mm). The waveguide attenuation is 0.0035 dB/m. The klystron and cavity are connected to the waveguide via wave-to-coax connectors with VSWR less than 1.05 at the operating frequency. The feedthrough power is measured with directional couplers. The Y-circulator is installed into the waveguide section to uncouple the klystron from the cavity. Y-circulator parameters are listed in Table 7.2. At first, the klystron generator was connected to the matched watercooled load via the waveguide section. The maximal power in continuous mode of 65 kW has been obtained.

RF cavity

A cylindrical copper cavity with small protrusions in the aperture area is made by brazing the discs to the sidewall. At present, the cavity is installed into the damping ring (Fig.2).

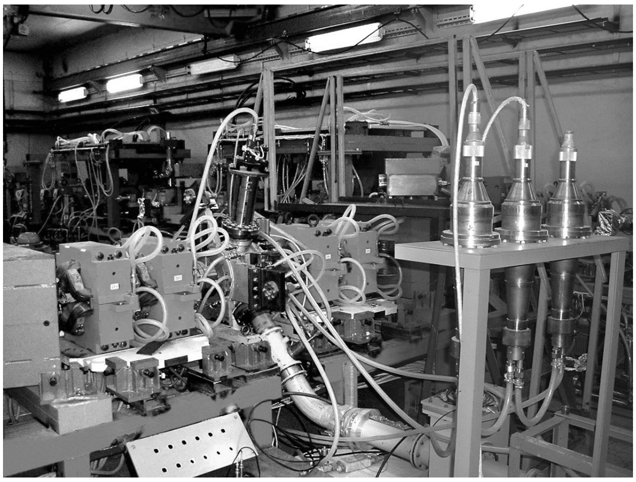

Figure 2: Cavity installed into VEPP-5 damping ring.

RF power is transmitted to the cavity through 75-Ohm coaxial feeder. At the operating frequency, VSWR of the wave-to-coax adapter is better than 1.15. The inductive power input is used. A cylindrical window made of 22XC ceramics isolates the cavity vacuum volume from the atmosphere. The frequency is tuned by the contact-free plunger. The cavity walls and plunger are cooled by water. Power input and plunger vacuum parts are coated with TiN to suppress the RF discharge.

The cavity HOMs were heavily loaded to provide phase stability of short bunches in the ring. Coupling with HOMs is provided by three waveguides, uniformly azimuthally distributed, with cutoff frequency of 908 MHz. HOMs' energy are distributed via wave-

Table 7.3: Cavity parameters.

Operating frequency, MHz	700
Shunt impedance, MOhm	4
Q-factor	20000
Transit time factor	0.748
Accelerating voltage, kV	200
Frequency tuning, MHz	1.6

to-coax adapters into these waveguides and then to the external loads. Within the range 0.95–2.2 GHz, VSWR of the adapters is less than 2 and measured Q-factors of the majority of HOMs do not exceed 100. Q-factor of the operating mode E_{010} decreased by 7.5% during connection of the loads. The main cavity parameters are listed in Table 7.3.

Control system

The Master Oscillator is a source of reference signals and the driver signal for the RF power amplifier. There is a feedback loop to control the RF voltage amplitude at the cavity gap. RF signal from the cavity sampling loop comes to the amplitude detector of the Modulator. Output of the amplitude detector is connected to a differential amplifier. The other input of the amplifier has a signal of DC voltage from DAC controlled by a computer. Output signal from the differential amplifier controls the Gain Control stage of the RF power amplifier.

The other feedback loop controls the phase of the RF cavity voltage in relation to the reference signal of the Master Oscillator. Phase difference between signal from sampling loop and that of the reference signal is measured by the Phase Meter. Output signal of the phase meter controls the electronic Phase Shifter installed into the RF power amplifier channel. The time constant of the two feedback loops is about 300 seconds and the amplitude and phase modulation index of the RF cavity voltage is less than $2{\cdot}10^{-3}$.

The frequency of the RF cavity fundamental mode should be constantly tuned to the resonance to compensate the cavity temperature alterations due to changes in the cooling water temperature or operating regime. The Phase Meter measures the phase difference between the RF signal and the signal which is proportional to the current in the RF cavity coupling loop. The phase meter output signal drives the tuner mechanism through the Servo amplifier. Time constant of the feedback loop is about 200 msec, the tuning error is less than 5°.

The Interlock module switches off the Modulator in emergency condition. The driver RF signal for the klystron is removed in this case.

Control and monitoring of the RF system from computer are made through the CAN-BUS serial network.

Results of RF system tests

A new power input with enlarged loop was installed, so that the cavity was matched with the feeder with no transformer. The cavity was installed into the damping ring and isolated from its chamber by two vacuum valves. $2{\cdot}10^{-9}$ torr vacuum was obtained in the cavity, so it was decided to carry out RF tests without pre-heating.

In the accelerating voltage range of 30–100 kV, vacuum degradation together with multipactor discharge typical voltage oscillations were observed. After 5-hour conditioning in the pulsed mode, continuous regime was activated and multipactor range was easily passed at rapid voltage rise.

In continuous regime, accelerating voltage of 300 kV was obtained for a long time at 11.5 kW power dissipated in the cavity and 10^{-8} torr vacuum. At resonant tuning, the reflected wave is rather small (VSWR=1.19) and cavity voltage is determined by measured incident wave power and cavity parameters. The maximal heating (up to 60°C) was observed at the cavity sidewall near the frequency turning flange. The temperature frequency deviation was 150 kHz. The klystron generator operated at the anode voltage of 20.2 kV and gain of about 46 dB.

55 hours long multipactor zone conditioning has been carried out in continuous mode. During conditioning, cavity voltage was smoothly changed in 30–120 kV range with 1 kV/s speed; values of incident and reflected waves, ion pump current were recorded. The maximal cavity loading by the multipactor was observed at 50-60 kV. In that area, the reflected wave was decreased (VSWR decreasing from 6.5 to 5.5) after conditioning, and vacuum calculated on the ion pump current was improved from $1.5{\cdot}10^{-7}$ torr up to $8{\cdot}10^{-8}$ torr.

At operating voltage on the cavity gap of 200 kW, the reflected wave is low (VSWR= 1.15), ion pump current is $2{\cdot}10^{-5}$ A. It corresponds to $2{\cdot}10^{-8}$ torr vacuum. At this voltage, the system has been operating for 40 hours. RF system operating with the beam in VEPP-5 damping ring will be started after electron injection from the linear accelerator.

Publications on this work: [327].

7.10 RF system for TNK facility

In 2005, the work on assembling, setting-up, and high-power level testing of TNK-1 booster ring was carried out in Zelenograd by Lab. 6-2 staff. IN December, the electron current was captured into the synchrotron regime at the first time. 60 MeV linear accelerator serves as an electron source for TNK-1 ring. TNK-1 booster ring for the maximal energy of 450 MeV will be used as injector for the main storage ring TNK-2 and as independent synchrotron radiation source.

The booster ring operation features was considered when choosing its RF system's parameters (see table 7.1).

RF system frequency is 34.52 MHz that corresponds to the first harmonic of TNK-1 revolution frequency. The maximal accelerating volatge value has been chosen to provide the output bunch length less than 60 cm at the energy of 450 MeV.

RF system includes the accelerating cavity, RF power source with the feeder section, and control system.

Table 7.1: TNK-1 booster ring parameters:

Operating frequency, MHz	700
Frequency multiplier	1
Frequency tuning range, kHz	± 325
Accelerating voltage, kV	1÷15
Cavity Q-factor %	6280
Shunt impedance, kOhm	103
RF generator power, kW	5

Accelerating cavity

The non-vacuum accelerating cavity (Fig. 1) is made of copper and consists of two halves, which enclose the storage ring vacuum chamber. The cavity is formed by coaxial line shortened by the capacitance between the disc (6) and cavity wall (5). The vacuum chamber has a ceramic insertion (4) made of 22XC ceramic in the accelerating gap area. The insertion was heated together with the chamber up to 300°C. Insertion electrodes are connected to the cavity walls by flexible junctions (3). The limiting accelerating voltage of 15 kV is determined by breakdown strength of the 4 cm capacitance gap and ceramic isolator height of 5 cm. The coaxial line inner part and cavity wall (8) are watercooled.

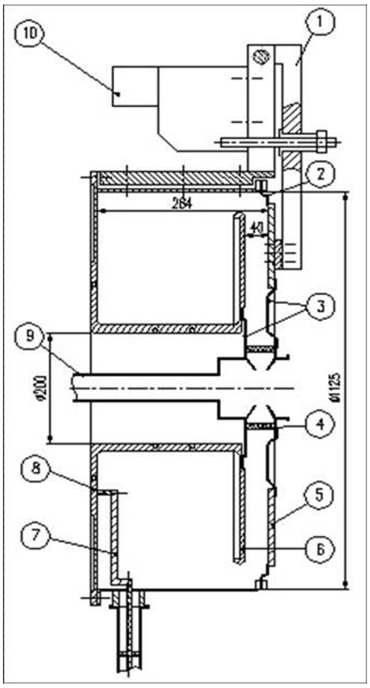

Figure 1: Cavity sketch.

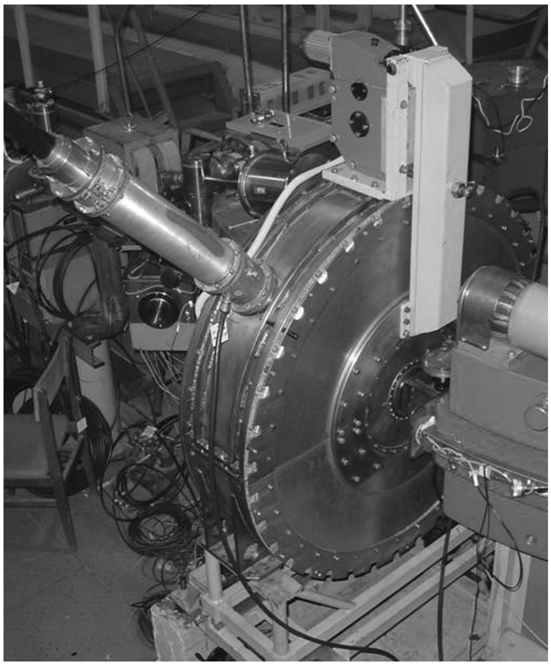

Figure 2: Cavity installed into TNK-1 ring.

Frequency is tuned by varying the capacitance gap by shifting the cavity side wall (5). This wall is connected to the shell by flexible plates (2), placed equidistantly along the diameter. Force from the stepping motor of ShD-5D1MU3 type (10) is transmitted via reducer to the wall via the lever (1). This cavity tuning should compensate the resonant frequency shift due to the heat drift, beam induced detuning, and changes during the initial booster alignment. The loop input (7) is used for coupling with the feeder. Coupling with the feeder is somewhat higher than the optimal value, so that the reflected wave in the feeder decreases with the cavity loading by the stored beam.

The cavity has been installed into the booster ring (Fig.2). The following results were obtained after applying RF power to the cavity. At low voltage of about 1.5 kV on the cavity, slight vacuum degradation was observed in the ring chamber due to multipactor discharge in the insulator unit. After 0.5 hour RF conditioning, the normal vacuum was restored. At resonance tuning and further cavity voltage increasing, VSWR measured with directional coupler was 2.20.

At the maximal voltage of 15 kV, 1.1 kW power was dissipated inside the cavity, and the compensative ring outside the cavity had a temperature of 50°C. According to the simulation results, at 15 kV an additional 80 W are dissipated in the insulator unit , and the center of this unit is overheated by 11°C.

RF power source

5 kW RF power source for 34.52 MHz frequency is made as a single bay including feeding system, air-cooling system, control system, and two electron-tube RF amplifier stages. Input power is 5 W at 17.26 MHz.

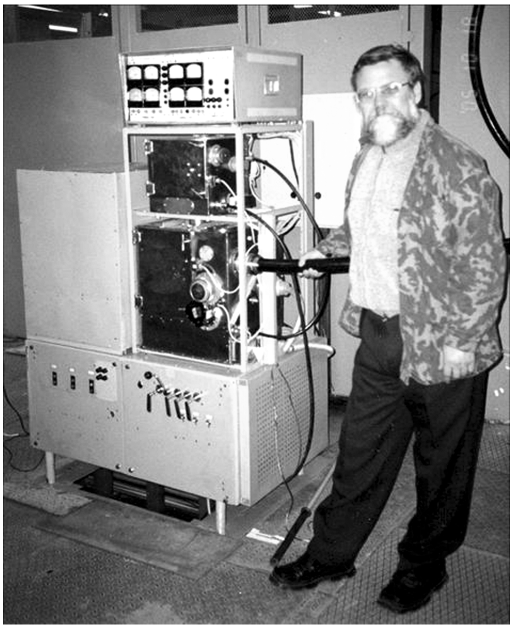

Figure 3: RF power source.

The first stage of RF power amplifier is frequency doubler with the common cathode scheme based on GU-34B-1 tetrode. The second stage is a power amplifier with the common cathode scheme based on GU-34B-1 tetrode. The both tetrodes are air-cooled from the built-in fan.

Units for the anode circuit eigenfrequencies tuning together with interstage coupling tuning units are made contactless based on variable vacuum capacitors. Such design provides reliability of these units operation and eliminates arcing during adjustments. The output stage anode circuit eigenfrequency tuning may be controlled from the damping ring control desk. This procedure is usually needed for the accelerating structure frequency characteristic correction to obtain stable phase motion of the electron bunch.

The generator is supplied by three-phase 380 V, 50 Hz current network. Power consumption does not exceed 15 kW.

The power source is coupled with the accelerating cavity with RK50-44-17 cable. Before being installed into TNK-1 ring it was tested in loaded on 50 Ohm load regime and in unloaded mode. In both cases the power source demonstrated a stable operation at any position of its tuning units. Power of 6 kW was obtained in the load.

Control system

The control system (Fig.4) regulates RF generator power with feedback circuits: by cavity voltage and by power input loop current, and the power. For that the signals from voltage probes at the cavity and cavity driving current are applied to amplitude detectors of the modulator. Input voltages from the detectors are compared with appropriate DC reference voltages; amplified residual signals control the output power of controlled amplifier. The control is carried out to provide that the values of these parameters do not exceed the given ones.

The control system carries out automatic cavity frequency adjustment by phase dif-

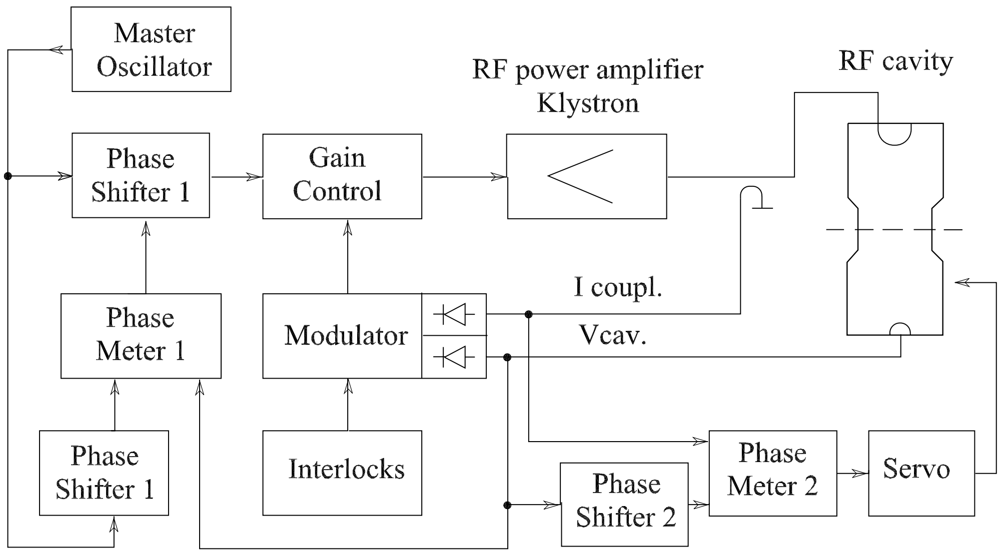

Figure 4: Control system block diagram.

ference between the driving current and cavity voltage, or by ratio of cavity voltage to the driving current. The first system is used for minor cavity detunings (about one pass band), the second – for major detunings (about fifteen pass bands). For the first system, signals from the probes of driving current and cavity voltage are applied to phase meter 2. If the phase difference differs from the given value, the output phase meter signal controls the cavity adjusting motor via the servo amplifier.

Self-tuning system for major detunings uses the signal from the cavity voltage probe and signal from DAC, which is in some relation with the reference signal for AGC by the cavity driving current. The signal difference amplified by the differential amplifier controls the servo amplifier. Modulator operating mode was selected to stabilize cavity driving current. So, the cavity voltage is achieved by appropriate detuning. The cavity voltage is decreased by decreasing the DAC voltage and increasing the cavity detuning.

The control system has the circuit for cavity voltage phase binding to the reference RF signal, which is also used in injection synchronization system. This circuit contains phase meter 1, at which inputs the signal from cavity voltage probe is applied together with the reference RF signal. The phase meter output voltage controls the electronic phase shifter in the power generator driving circuit.

The cavity RF voltage and its detuning together with injection synchronization may be automatically controlled by PC.

Participants of the work:
E.I. Gorniker, S.A. Krutihin, I.V. Kuptsov, G.Ya. Kurkin, V.M. Petrov, A.M. Pilan, I.K. Sedlyarov.

7.11 RF gun for microtron-recuperator injector

In 2005, the work was started in Lab. 6-2 on creation of RF gun. Static 300 kV electron gun of the microtron-recuperator will be replaced by the RF gun operating at 90 MHz frequency.

Firstly, the thermocathode lifetime may be prolonged because of better vacuum conditions in the cavity. Moreover, ions generated from residual gas ionization by the electron beam have appreciably lower energy when reaching the cathode. In the cavity RF field, their energies are inversely to the ion masses. For protons, it is less than 1 keV (in static field — up to 300 keV regardless of ion masses).

Though the electron beam in the RF injector has the same main parameters (emittance, duration, energy) as in the static gun, there are two features. Firstly, the dark current in the RF injector has severely lower value due to its pulsed nature, so it exists only during positive RF voltage half-cycles, and, primarily, because the particles of this current are not focused at the same place as the beam, according to the dynamics. So, the collimator placed in this area cuts off the considerable part of the dark current.

Table 7.1: RF injector main parameters.

RF gun electron energy	295 keV
RF gun bunch duration	1 ns
maximal average current	100 mA
maximal bunch repetition rate	90 MHz
bunch duration at the microtron input (rms)	25.5 ps
injector electron energy	1.5 MeV
bunch particle energy spread	(rms) 17 keV
transverse normalized bunch emittance	27 mm mrad

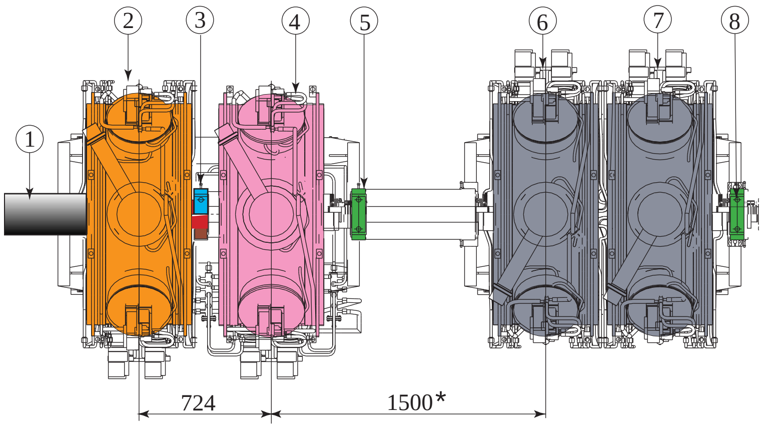

Figure 1: RF injector with RF gun project. 1 – cathode-grid unit modulator; 2 – 90 MHz RF gun cavity ; 3 – focusing lens and collimator (the lower part is shown as section); 4 – bunching cavity (the real one, the drift gap between the cavity and accelerating cavities is shorten to 1500 mm); 5, 8 – existing magnetic lenses; 6, 7 – existing accelerating cavities;

The second feature is that electron bunches of the RF injector suit better for their further shortening by the microtron method — particle bunching in the drift space. For such bunching, energies of particles in bunches should be specially distributed along the bunch linearly or close to it. Non-linear energy distribution the bunches obtain while passing the bunching 180 MHz cavity. Bunches from the RF injector have already non-linear energy distribution determined by the frequency of 90 MHz (RF gun cavity resonant frequency). A regime is possible when such non-linearities can compensate one another, so the resulting distribution becomes more linear. Simulations prove that the bunch length in this case is shorter by 30%.

Important factor of the injector operating is an absence of high voltage in its circuits. All the electronics is under the zero potential, that substantially simplifies the RF gun cathode unit adjustment and maintenance. The modulator may be produced as a replaceable unit, which can be placed in its socket and coaxial connector of the cathode unit.

RF injector will allow us to obtain bunches with 90 MHz frequency and so increase the average beam current up to 100 mA. Table 1 lists the main parameters of the RF injector electron beam.

Figure 1 presents a new RF injector project for the microtron-recuperator. RF gun cavity and bunching cavity are placed on the same pedestal. Distance between the bunching cavity and the first accelerating cavity should be shortened down to 1500 mm. To do so, some part of the bar on the entresol must be removed. Figure 2 presents the sketch of the RF gun section. The simulated parameters of the RF injector are listed in Table 7.2. At present, the work is underway on RF gun cavity and RF power input modernization technique. Oxygen-free copper has been ordered at CERN for the cavity inner part and lags, as well as M1 copper for the collimator. Moreover, standard plunger units have been ordered for the resonant frequency tuning.

Table 7.2: Simulated parameters of the RF injector at average beam current of 100 mA.

Maximal bunch repetition rate	90 MHz
Peak bunch current for bunch injected from the cathode-grid unit (GS-34)	1.5 A
Bunch duration relative to the base	1.39 ns
Power dissipated in the grid	2.7 W
Accelerating voltage, kV	200
Field strength at the grid	0.5 MV/m
Transverse normalized bunch emittance of the cathode-grid unit	20 π mm mrad
RF gun bunch electron energy	295 keV
RF gun cavity voltage (90 MHz)	300 kV
RF gun voltage phase Фаза at bunch center injection moment (bunch particle energy maximum)	68°
Bunching cavity voltage 180 MHz	137.5 kV
Electron energy after the bunching cavity	192.1 keV
Bunching cavity voltage phase relative to phase of particle with the maximal energy (434 keV) after the cavity	-148.8°
Voltage on each of accelerating cavities	793 kV
RF power 90 MHz, entered the gun cavity	53.8 kW
RF power 180 MHz, extracted from the beam in the bunching cavity	-8.19 kW
RF power entered each of accelerating cavities	270.8 kW
Beam power at the injector output	150 kW
Maximal magnetic field induction on the axis of the 1st solenoid	26.5 mT
Maximal induction on the axis of 2nd solenoid	11.09 mT
Maximal induction on the axis of 3rd and 4th solenoids	13.3 mT

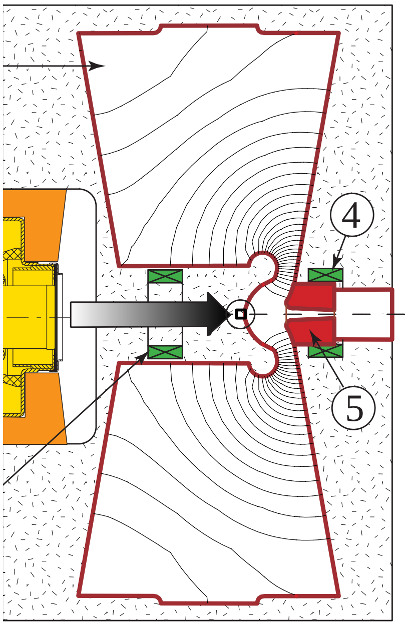

Figure 2: Injector RF gun in section. 1 – solenoid for magnetic field compensation on the cathode; 2 – cathode-grid unit of metal-ceramic tube GS-34; 3 – RF cavity 90 MHz — cavity of 180 MHz microtron modernized for 90 Mhz frequency; 4 – focusing solenoid; 5 – 6 kW watercooled collimator.

7.12 RF system for VEPP-2000 storage ring

Single-mode RF cavity

In 2005, manufacturing of the RF cavity [1] was completed at EP-1 workshop, electron-vacuum subdivision (section 3, master A.N. Kosarev).

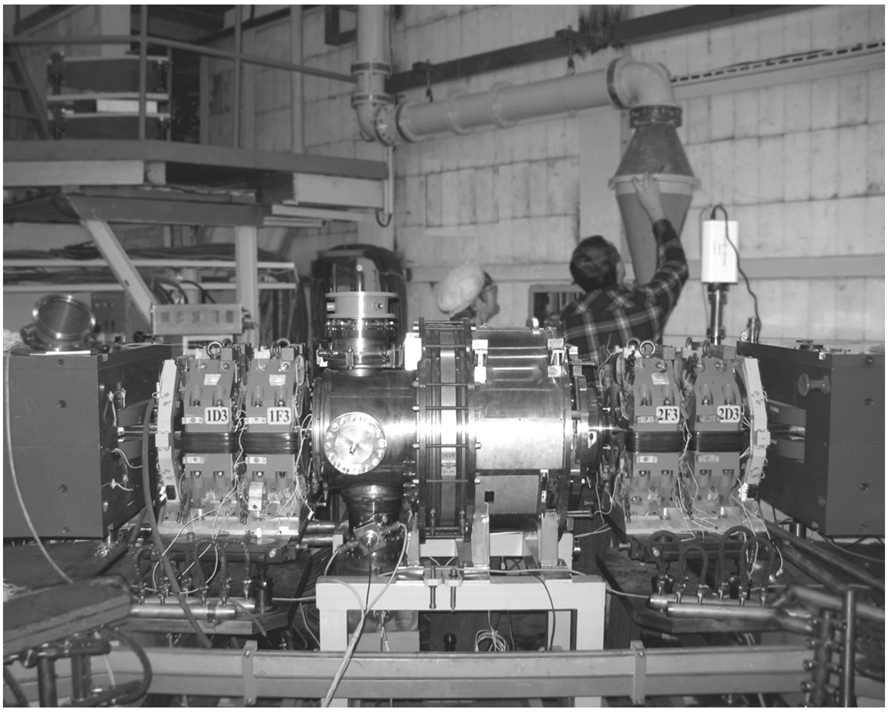

Figure 1: VEPP-2000 storage ring section with RF cavity.

The cavity has been delivered to BINP and installed into the VEPP-2000 ring. Figure 1 presents the section of VEPP-2000 storage ring with the cavity. The cavity was heated up to 200°C temperature together with 1/4 part of the accelerating channel; $2{\cdot}10^{-9}$torr vacuum was obtained. The work is underway on preparing the cavity for high power level RF tests, watercooling system is under assemblage together with the feeder and RF power input, cable circuits are laid.

RF power source and control system

During 2005, low-level tuning, adjusting, and testing were carried out on the RF power source for VEPP-2000 accelerating system. The generator RF section consists of three stages based on GU-92A, GU-92A, and GU-101A tetrodes. Previously manufactured stages with operating frequency of 181 MHz identical to the microtron-recuperator generators were used to produce the generator. Switching to the frequency of 172 MHz has demanded some changes in tuning elements and filtering circuits of the greed feeding. 172 MHz RF power source has been tested at 65 kW power level while operating on the 75 Ohm dummy load. Functional layout of the system practically was not changed. Some electron devices were manufactured anew because of change of the operating frequency. Computer control of the RF system was modernized. Archaic CAMAC equipment has been replaced by CAN standard modules. Test of the RF system with the cavity will take place in the nearest future.

Participants of the work:

V.S. Arbuzov, A.A. Bushuev, V.N. Volkov, E.I. Gorniker, E.K. Kenzhebulatov, A.A. Kondakov, I.A. Koop, Ya.G. Kryuchkov, S.A. Krutihin, I.V. Kuptsov, G.Ya. Kurkin, N.V. Mityanina, V.N. Osipov, V.M. Petrov, A.M. Pilan, E.A. Rotov, I.K. Sedlyarov, Yu.M. Shatunov.

Chapter 8

Powerful Electron Accelerators and Beam Technologies

8.1 Radiation technologies and ELV electron accelerators

In 2005 the deliveries of ELV accelerators were continued. During one year only four ELV accelerators have been delivered to the customers and seven ELV accelerators, which have been delivered earlier, were started up. One of the most important moments is the delivery and start up of ELV-12 accelerator together with South-Korea Company EB-TECH at the treatment facilities of dye-manufacture at Taegu (R.Korea). This unique accelerator has 400 kW electron beam power. First mega experiments of dye outflows have been already made on this accelerator. The photos below show: treated water under accelerator extraction device (Fig.1), reactor hall (Fig.2) and control cabinet of the electron-beam purification complex (Fig.3).

Figure 1: Treated water under accelerator extraction device.

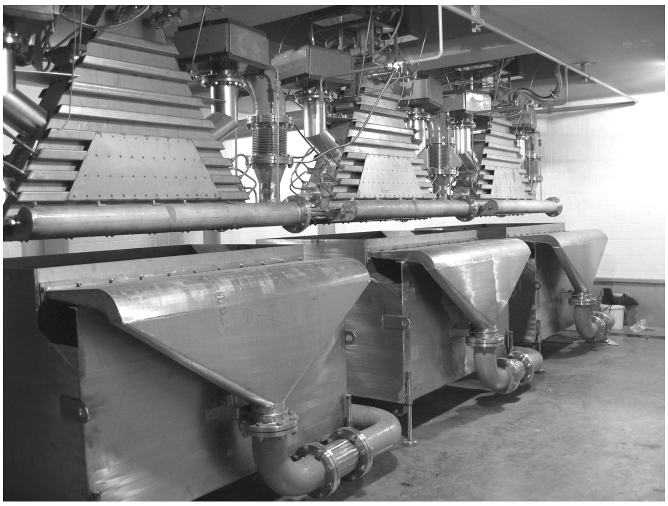

Figure 2: Reactor hall.

Figure 3: Control cabinet of the electron- beam purification complex.

It is necessary to note the start up of the accelerator in Novokuibyshevsk (Samara region, Russia). There, besides standard applications like polyethylene cable insulation and film treatment, the new technology is planned to be used. This new technology is butyl rubber crumb treatment for the purpose of after-generation. The peculiarity of the project is the accelerator bunker that is built inside existent factory section the industrial process of which is changed. Figure 4 shows the accelerator bunker and a part of processing equipment.

Figure 4: Accelerator bunker and a part of processing equipment at "Novatek- Polymer" Company (Novokuibyshevsk (Samara region, Russia)

One of the accelerators has been delivered to India, which is the new commercial and cooperation region for us.

At the station equipped by accelerator with focused beam extraction into atmosphere (building 17) intensive works have been held.

The welding experiments have been carried out together with Pohang University. The adjustment tests of carbon target have been made in cooperation with laboratory 5. The experimental obtaining of nano-powders was realized in collaboration with ITAM.

8.2 Accelerators type ILU and their applications

Introduction

Since 1970 the Budker Institute of Nuclear Physics of the Siberian Branch of Russian Academy of Sciences is developing and supplying to industry and research organizations the linear electron accelerators type ILU. These machines are purposed for wide applications in various technological processes and so are designed for long continuous and round-the clock work in industrial conditions.

Main parameters of ILU accelerators produced by Institute are given below. Their energy range is from 0.7 to 5 MeV and beam power is up to 50 kW.

Parameters	**ILU-8**	**ILU-6**	**ILU-6M**	**ILU-10**	**ILU-10M**
Energy range, MeV	0.5÷1.0	1.2÷2.5	1.0÷2.5	2.5÷5.0	2.5÷4.0
Electron beam power (max), kW	25	40	20	50	20
Average beam current (max), mA	25	25	20	15	8
Productivity at dose rate of 10 Mrad, kg/hour	500	850	450	850	450
Weight, tons. Accelerator	1.75	2.2	2.2	2.9	2.5
Weight, tons. Local shield	76	–	–	–	–

8.2.1 Accelerators supplies

Since 1983 the ILU type accelerators are delivered abroad where they are used for research works and for work in industrial technological lines. Some of these machines are working 2-3 shifts per day during many years and successfully stand such a load. Reliability of accelerators work and their technological level is proved by new deliveries of these machines.

The compact electron accelerator for energy of 200 keV and beam power up to 2 kW was commissioned and shipped to the USA customer.

In 2005 the ILU-6 accelerator was manufactured along with the technological equipment irradiation of cables and wires. The equipment was delivered to customer in the city of Dimitrovgrad, Russia, and the radiation technological installation was put into operation.

The ILU-8 accelerator in the city of Moscow, Russia, firm "PRESTIGE-AVTO-2", was modernized in 2005 according to the contract. The accelerator is put into operation with required parameters. The accelerator control system was connected with the control system of the conveyor manufactured in Korea. The radiation technological line started the production of heat-insulating and noise absorbing polymer materials.

8.2.2 Modernization of ILU-8 accelerator to meet the requirements for food industry equipment and shipment of the first machine to Japan

• The new feedback feeder was developed, manufactured and tested. This new feeder improves the stability of accelerator's functioning - it permits to work in the whole energy and beam power range without regular feedback tuning.

• The new power supply synchronization system was introduced. The new system generates the beam pulses synchronized with pulses of the feeding voltage in the whole pulse repetition rate range even if the working frequency is not divisible by feeding voltage frequency. The result is the increase in accuracy of accelerator's parameters - up to 1%.

• The new beam extraction device with additional transverse beam scanning was developed to satisfy the new beam distribution requirements.

• The new control rack was developed for new control system permitting to connect the accelerator's control system with the control system of the production line for drinks.

• The system for scanning magnet adjustment was developed that permits to adjust the beam scanning plane with accuracy up to 2 mm.

• The ILU-8 accelerator is manufactured, shipped and installed in the show-room of the Mitsubishi Heavy Industries, Nagoya, Japan.

Figure 1: RF generator of the ILU-8 accelerator in the MHI show-room, Nagoya, Japan.

8.2.3 Development of the new industrial accelerator ILU-12 and new irradiation systems

In 2005 the development of new accelerator ILU-12 with energy 5 MeV and beam power up to 300 kW continued. The RF system is manufactured and mounted. The radiation bunker is prepared for the mounting of the accelerator. The power supply system is in the state of mounting.

In 2005 the original magnet scanning system for ILU-10 accelerator was developed. This system is designed to realize the electron beam irradiation of the polymer tubes having diameters up to 160 mm and wall thickness up to 20 mm, the electron energy is 5 MeV. The circular irradiation is organized with electron beam hitting at normal to surface. The circular irradiation is realized with help of alternating magnetic field in the irradiation zone under the scanning horn. The mock-up of the system is manufactured and the testing irradiation of the big diameter polymer tubes was carried out. In 2007 such system will be shipped with the ILU-10 accelerator to the firm “PLASTOPOLYMER”, Moscow.

8.2.4 Works on magnet prototype for conversion systems

In 2004-2005 two magnet prototypes were manufactured along with their pulse power supply sources for use in electron-positron conversion systems. The following parameters were achieved: Maximum pulse magnet field of 10 Tesla, total magnet current of 100 kA, pulse duration of 26 mks.

The power supply system for pulse conversion magnet of the injection complex VEPP-5 was manufactured and put into operation basing on the results of this work. Parameters of power supply system: Maximum capacitive storage voltage 1.2 kV, storage power intensity 90 J, average consumed power 4 kW, pulse repetition rate 50 Hz.

Participants of works:
V.L.Auslender, A.A.Bryazgin, G.A.Glagolev, V.A.Gorbunov, I.V.Gornakov, A.M.Molokoedov, L.A.Voronin, M.V.Korobeynikov, A.N.Lukin, I.G.Makarov, S.A.Maximov, V.E.Nehaev, G.N.Ostrejko, A.D.Panfilov, V.I.Podobaev, V.I.Serbin, G.V.Serdobintsev, A.V.Sidorov, V.V.Tarnetsky, M.A.Tiunov, V.O.Tkachenko, A.A.Tuvik, B.L.Faktorovich, V.G.Cheskidov, A.M. Yakutin.

Results of works are published in:
[394]÷[401], preprint 25

Chapter 9

Physics for medicine

9.1 X-ray radiation detectors for medicine and people inspection

9.1.1 A Low-dose Digital Radiographic Device (LDRD) “Siberia”

In 2005, we continued upgrade of the Low-Dose Radiographic Device LDRD “Siberia-N”. At the device being produced at ZAO “Nauchpribor”, we have made the following changes: :

1. We shifted to the new X-ray optics, which enabled operation with the direct image of lungs at a dose of 4mkSv with the resolution of 2p.l./mm.
2. A new plastic housing of an improved design is used for the device.
3. ZAO “Nauchpribor” started the development of a new detector D2048 with an increased spatial resolution of 2.5 p.l./mm (by the BINP technology).
4. By the contract we have delivered D-2048 detector to Malaysia and signed the contract on the delivery of the D-1536 detectors to “Aktyubroentgen” (Kazakhstan).
5. We continued deliveries of D1048 detectors for medical devices produced by ZAO "Nauchpribor" (Oryol), BEMZ (Berdsk), "Electrokhimpribor" (Lesnoi).

9.1.2 A System of Radiographic Control (SRC)"SibScan"for inspection of people.

We continued works on the SRC "SibScan" designed for inspection of people. In April, 2005, the SRC pilot sample was sold to the "Eastline" company and installed in the section-“C” of the airport Domodedovo (Moscow). In October, 2005, the SRC pilot sample was changed by its industrial version. In December, 2005, the second SRC device was commissioned in the section “D” of the airport. The contract was signed on the delivery of SRC devices to the airports of Khanty-Mansiisk and Sankt-Petersburg. Two certificates and a patent were obtained for SRC this year. The contract on the SRC technology transfer to the Chinese company “Nuctech” is signet.

Figure 1: LDRD for chest prophylactic examination (ФМЦ-НП-О) in the new plastic housing.

Figure 3: SRC "SibScan" in section-"C" of the airport "Domodedovo".

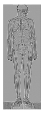

Figure 2: The image made at SRC: The knife and gun are made of a 4 mm thick plastic. A bar of explosive at the thigh.

9.1.3 Mammography

In 2005, we continued the work on the development of a low-dose mammograph. In order to improve the statistical accuracy and the contrast sensitivity, we have selected a 4-line version of the detector.

9.2 The works on creation of accelerator based neutron source for neutron-capture therapy and fast neutron therapy

The physical project of neutron source was published in Nuclear Instruments and Methods in Physics Research A 413/2-3 (1998) 397-426. The financing of the project was carried due to fund of ISTC and DOE-IPP grants, lab.9-0 (money earned in other international contracts) and partially from the fund of the Institute. Designed scheme of the BNCT complex is shown in Fig.1 and described in 2004 Year Report.

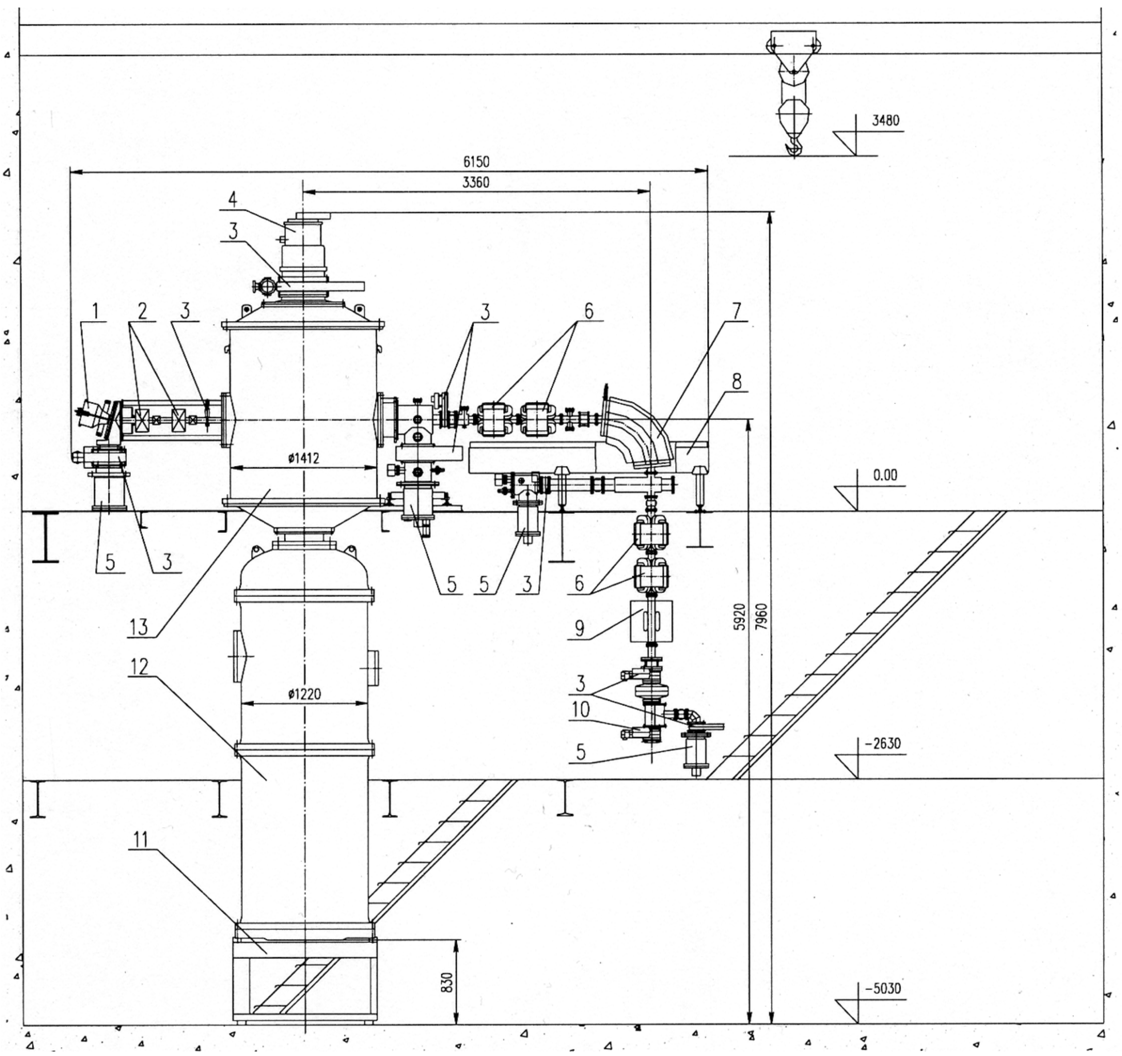

Figure 1: BNCT complex.

Results obtained in 2005:

• The rectifier project parameters for BNCT complex were obtained after preventive reassembly of ELV high voltage source.

• We finished started works on mastering the modes of vacuum heating of the vacuum tank 13 (Fig.2).

• The stable (up to 15 mA) H- current with project emittance was achieved on H-source stand.

• The largest electrode of the high voltage accelerating gap is produced (Fig.3).

• Manufacture of high voltage electrode* (Fig.4), venetian blind-caps* for electrodes of the high voltage accelerating gaps (Fig.5) and inner components of the tandem feedthrough insulator* (Fig.6) are completed.

• Low energy beam tract 2 (Fig.7) of the tandem is prepared for operation together with ion source 1.

• Manufacture of components of the source flange version 1 is continued.

• Components of both the high energy channel 6, 7, 8, 9 and its power supply units are continued.

• Thermal tests of neutron target are completed and the possibility of target cooling by water was demonstrated (Fig.8).

• Manufacture of base elements of the neutron target unit 10 is completed (Fig.9).

• The design and manufacture both of the electrotechnical part of the complex and its infrastructure were continued.

• The work on the shift of the monitoring and control of the complex parameters to the LABView software is continued.

Figure 2: Vacuum tank with heaters.

Figure 3: The cylinder part of electrode of the last high voltage accelerating gap (packed for transportation).

* - the tandem design see in 2001 year BINP Report.

Figure 4: High voltage electrode of the tandem.

Figure 5: Venetian blind-caps.

Figure 6: Components of the inner part of the tandem high voltage feedthrough insulator.

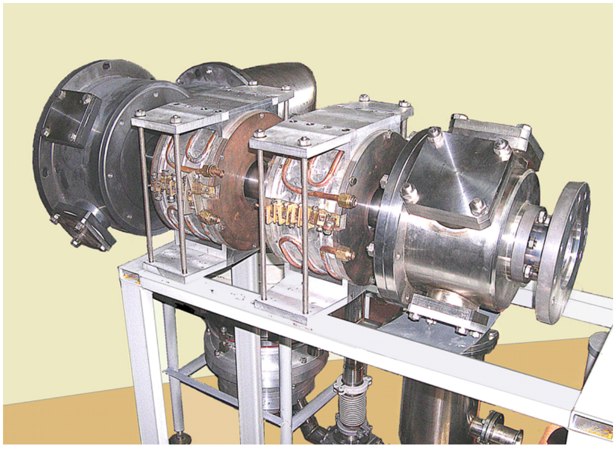

Figure 7: Low Energy Beam Line.

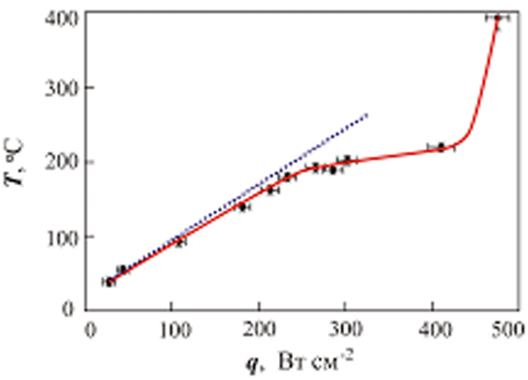

Figure 8: Temperature of the target surface T as a function heating power density q at the cooling flow rate of 3 m/s: experimental curve-solid line; design curve for the cooling turbulent flow without boiling-dashed line.

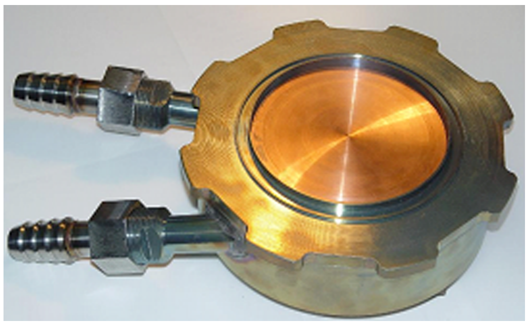

Figure 9: Assembly of the target unit.

Publications :
[328] ÷ [332], [358], preprint 3.

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[2] *Oleg B. Malyshev, Vadim V. Anashin, Rodion V. Dostovalov, Nikita V. Fedorov, and Alexander A. Krasnov, Ian R. Collins and Vladimir L. Ruzinov.* Method and setup for photodesorption measurements for a nonevaporable-getter-coated vacuum chamber // J. Vac. Sci. Technol. A, v.23, №3, May/June 2005 p.570-576.

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14. *Fadeev S.N.* Release of powerful relativistic focused electron beam into the atmosphere for technological applications // 01.04.20 - physics of charged particle beams and accelerator techniques, Author. papers of thesis for the degree of candidate of technical science: Novosibirsk, 2005, BINP, SB RAS.

Participation in Conferences

1. MDI Workshop on ILC, 6-8 January, 2005, SLAC, Stanford;
2. ILIAS 2nd Annual Meeting, 7-8 February, 2005, Prague, Czech Republic.
3. XXXII Zvenigorod Conference on Plasma Physics and Controlled Fusion, 14-18 February, 2005, Zvenigorod, Russia.
4. XXXIX St.Petersburg Winter School, 14-20 February, 2005, St.Peterburg, Repino, Russia.
5. 6th International Ural Seminar: Radiation Damage Physics of Metals and Alloys. 20-26 February, 2005, Snezhinsk, RF.
6. 2nd International Remote Scientific-Practical Conference: New Technologies in Medicine, St.Peterburg, 13-15 March, 2005, RF.
7. 5th Meeting of the ITPA Topical Group on Diagnostics, 14-18 March, 2005, Culham, UK.
8. International Conference: VII Kharitonov Thematic Scientific Readings: Extreme States of Matter, Detonation, Shock Waves. 14-18 March, 2005, Sarov, RF.
9. International Workshop on Linear Colliders (LCWS05), 18-22 March, 2005, Stanford, California, USA;
10. 5th International Workshop on Personal Computers and Particle Accelerator Controls, 22-25 March, 2005, Japan.
11. Workshop on Source of Epithermal Neutrons and Resonant Gammas Based on Tandem Accelerator, 1 April 2005, Novosibirsk, BINP, Russia.
12. Neva Radiologic Forum: Science - Clinic, St.Petersburg, 9-12 April, 2005, Russia.
13. 11th International Conference on Elastic and Diffractive Scattering: Towards High Energy Frontiers. - The 20th Anniversary of the Blois Workshops, 15-20 May, 2005, Chateau de Blois, Blois, France.
14. Particle Accelerator Conference (PAC-05), 16-20 May, 2005, Knoxville, Tennessee, USA,
15. 7th Russian Workshop: Problems of the Theoretical and Applied Electron-Ion Optics, 25-27 May, 2005, Moscow, Russia.

16. DIPAC'05, 6-8 June, 2005, Lyon, France.
17. Beauty 2005 Workshop, 20-24 June, 2005, Assisi (Perugia), Italy.
18. International Workshop on Biosphere Origin and Evolution, 26-29 June, 2005, Novosibirsk, Russia.
19. 32-nd European Physical Society Conference on Plasma Physics and Controlled Fusion, 27 June - 1 July 2005, Tarragona, Spain.
20. 22nd International Symposium on Lepton-Photon Interactions at High Energy (LP 2005), 30 June - 5 July, 2005, Uppsala, Sweden.
21. EPS International Europhysics Conference on High Energy Physics (HEP-EPS 2005), 21-27 July, 2005, Lisbon, Portugal.
22. International Conference on Strongly Correlated Electron Systems (SCES-05), 26-30 July, 2005, Institute for Solid State Physics, Vienna University of Technology.
23. 2005 International Linear Collider Physics and Detector Workshop and 2nd ILC Accelerator Workshop, 14-27 August, 2005, Snowmass, Colorado;
24. 11th International Conference on Hadron Spectroscopy (Hadron05), 21-26 August, 2005, Rio de Janeiro, Brazil.
25. 27th Free Electron Laser Conference, 21-26 August, 2005, Stanford, California.
26. 12th Lomonosov Conference on Elementary Particle Physics, 25-31 August, 2005, Moscow, Russia.
27. International Conference Photon: its First Hundred Years and the Future (includes PHOTON2005 and PLC2005), 30 August - 8 September 2005, Warsaw and Kazimierz, Poland.
28. Europhysics Conference on New Trends in Nuclear Physics Applications and Technology NPDC19, 5-9 September, 2005, Pavia, Italy.
29. Conference: New Trends in High-Energy Physics, 10-17 September, 2005, Yalta, Crimea, Ukraine.
30. XI International Conference on Ion Sources (ISIS-05), 12-16 September, 2005, CAEN, France.
31. XIX International Workshop on Charged Particle Accelerators, 12-18 September 2005, Ukraine, Alushta, Crimea.
32. International Workshop on Beam Cooling and Related Topics (COOL-05), 18-23 September, 2005, Galena, USA,
33. 19 International Conference on Magnet Technology, 18-23 September, 2005, Genova, Italy.
34. Conference: Hadron Structure and QCD: from low to high energies, 20-24 September, 2005, St. Petersburg, Russia.
35. 5th Seminar SB RAS - UB RAS: Thermodynamics and Materials Science, 26-28 September, 2005, Novosibirsk, Russia..
36. 5th International Conference on Nuclear and Radiation Physics, 26-29 September, 2005, Alma-Ata, Kazakhstan.
37. 12th International Symposium on Laser-Aided Plasma Diagnostics, 26-29 September, 2005, Snowbird, Utah, USA.
38. Materials of the 6th Scientific Practical Conference of the Medics: Modern Medical and Diagnostic Methods in Medical Practice, Novosibirsk, 28-29 September, 2005, RF.

39. 4th International Vereschagin Baikal Conference, 26-30 September, 2005, Irkutsk, RF.
40. 11th International Workshop on High Energy Spin Physics (DUBNA-SPIN-05), 27 September - 1 October, 2005, Dubna, Russia.
41. Nucleon-05 Workshop, 12-14 October, 2005, Frascati, Italy.
42. XI International Conference on Charged Particle Accelerators Applied in Medicine and Industry, St-Petersburg, (ICAA'05), 10-14 October, 2005, St.Petersburg.
43. 4th International Conference - Carbon: Fundamental Problems of a Science, Materials Science, Technology, 26-28 October, 2005, Moscow.
44. ICFA Mini-Workshop on Frontiers of Short Bunches in Storage Rings, 7-8 November, 2005, Frascati National Laboratories, Italy.
45. ICALEPCS'05, 10-14 November, 2005, Geneva, Switzerland.
46. 3rd ECFA Workshop on Physics and Detectors for ILC, 14-17 November, 2005, Vienna.
47. Russian Conference RSNE NANO-2005, 14-19 November, 2005, Moscow.
48. 5th Conference on Nuclear and Particle Physics (NUPPAC-05), 19-23 November, 2005, Cairo, Egypt.
49. Universary Session-Conference: Physics of Fundamental Interactions, Devoted to 60th Year of ITEP // 5-9 December, 2005, Moscow, Russia.
50. XLIII International Students Scientific Conference: Student and Scientific-Technical Progress, 2005, Novosibirsk.
51. 11th All-Russian Scientific Conference of Students-Physicians and Young Scientists, 2005, Ekaterinburg.
52. XIII Symposium on Combustion and Explosion, 2005, Chernogolovka.
53. 1st Russian Conference of Young Scientists on Physics and Chemistry of High-Energy Systems, 2005, Tomsk.
54. XI Russian Conference on Diagnostic of High-Temperature Plasma, 2005, Troitsk, RF.
55. Production and Neutralization of Negative Ions and Beams: AIP Conference, 2005.
56. 15th National Conference on Nuclear Physics: Frontiers in the Physics of Nucleus, 2005, St.Peterburg.
57. International Workshop on High Energy Electron Acceleration Using Plasmas, 2005, Paris, France.

List of Collaboration Agreements between the Budker INP and Foreign Laboratories

N°	Name of Laboratory	Title or Field of Collaboration	Dates	Principal Investigators
N°	1	2	3	4
1.	CERN (Swiss)	1. Research and development of the detectors for LHC	1992	A. Bondar, Yu. Tikhonov (INP), T. Nakada, P. Yenni (CERN)
		2. Development of the LHC elements	1996	L. Evans (CERN), V. Anashin (INP)
2.	DESY (Germany)	Joint research in the field of accelerator physics and elementary particle physics	1992	A. Vagner (DESY), A. Skrinsky (INP)
3.	SLAC (Stanford) USA	1. Research and development of linear colliders and final focus test	1992	D. Dorfan (SLAC), A. Skrinsky (INP)
		2. Beam detector for B-factory	1993	A. Onuchin (INP), D. Hitlin (SLAC)
		3. Electron-positron colliding beams (B-factory)	1995	D. Siman (SLAC), A. Skrinsky (INP)
4.	BNL (Brookheven) USA	1. Measurement of the magnetic muon anomalous	1991	J. Bunse (BNL), L. Barkov (INP)
		2. Joint research of RHIC spin	1993	S. Ozaki (BNL), Yu. Shatunov (INP)
5.	ANL (Argonn) USA	1. Experiments with polarized gas jet target at VEPP-3	1988	C. Jones (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, B. Chirikov (INP)
8.	University of Pittsburgh (USA)	Experiments on VEPP-2M and ϕ-factory	1989	S. Eidelman, E. Solodov (INP), V. Savinov (USA)
9.	University of Lund (Sweden)	Experiments on photo-nuclear physics	1992	B. Schreder (Sweden), L. Barkov (INP)
10.	University of Uppsala (Sweden)	Rare decays of light mesons with WASA detector (experiment)	1989	B. Shwartz (INP), S. Kullander, H. Calen (Sweden)
11.	Daresbury (England)	Generation and utilization of SR	1977	I. Munro (Daresbury), G. Kulipanov (INP)

N°	1	2	3	4
12.	CAT, BARC (DST, India)	1. Development of SR sources 2. Industrial applications electron beam technologies	1987	D. Bhavalkar, S. Ramamurty (CAT), A. Skrinsky, V. Auslender, G. Kulipanov (INP)
13.	University of Duke (USA)	Free electron lasers	1992	J. Wu (Duke), N. Vinokurov (INP)
14.	POSTECH (S.Korea)	SR experiments, accelerator design, beam lines insertion devices	1992	H. Kim (POSTECH), A. Skrinsky, N. Mezentsev (INP)
15.	KAERI (Korea)	Development of accelerator-recuperator	1999	B.Ch. Lee (KAERI), N. Vinokurov (INP)
16.	BESSY (Germany)	Development of the wigglers for BESSY-2	1993	E. Jaeschke (BESSY), A. Skrinsky, N. Mezentsev (INP)
17.	KEK (Japan)	1. Experiments at B-factory with detector BELLE 2. Electron-positron factories (B-, ϕ-factories)	1992 1995	A. Bondar (INP), F. Takasaki (KEK) Sh. Kurokawa (KEK), E. Perevedentsev (INP)
18.	RIKEN Spring-8 (Japan)	Collaboration in the field of accelerator physics and synchrotron radiation	1996	H. Kamitsubo (Japan), G. Kulipanov (INP)
19.	BNL (USA)	Collaboration on electron-ion colliders	1993	I. Benzvi (USA), V. Parkhomchuk (INP)
20.	Research Centre Rossendorf (Germany)	Physical foundations of a plasma neutron source	1994	K. Noack (FRG), E. Kruglyakov, A. Ivanov (INP)
21.	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)
22.	GSI (Germany)	Collaboration in the field of accelerator physics: electron cooling; electron-ion colliders	1995	A. Eickhoff (GSI), Yu. Shatunov, V. Parkhomchuk (INP)
23.	FERMILAB (USA)	Collaboration in the field of accelerator physics: electron cooling; conversion system	1995	O. Finli (FERMILAB), V. Parkhomchuk (INP)
24.	Institute of Morden Physics Lanchzou (China)	Particle accelerator physics and techniques	2000	S. Yang (IMP, China), V. Parkhomchuk (INP)
25.	Center of Plasma Research, Tsukuba (Japan)	Collaboration on Open traps	2003	Ya. Kitahara, K. Yatsu (Japan), E. Kruglyakov, A. Skrinsky (INP)
26.	INFN-LNF (Italy)	Development of collider project DAFNE-II	2004	S. Biscari (INFN), E. Levichev (INP)

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Lenin Order Siberian Branch

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