VEKSLER AND BALDIN LABORATORY OF HIGH ENERGY PHYSICS

The activity of the V. I. Veksler and A. M. Baldin Laboratory of High Energy Physics in 2010 was concentrated on the completion of the Nuclotron-M project (the 1st stage of the NICA/MPD project) and participation in current researches in the world-class accelerator centers.

THE MOST IMPORTANT RESULTS IN THE DEVELOPMENT OF THE ACCELERATOR COMPLEX

Nuclotron-M

In 2010, the upgrade of the Laboratory accelerator complex was aimed at the completion of the Nuclotron-M project liabilities.

During the 41st [1] and 42nd runs the following tasks were fulfilled:

1. Modernization of the cryogenic complex. A new turbo compressor was put into operation, and the piston compressor was refurbished;
2. The Nuclotron power supply system has been completely upgraded. Almost 10 km of the power cable and all energy evacuation keys have been replaced;
3. Together with specialists from Bulgaria, Germany, and Slovakia new elements of the diagnostics (orbit correction system and digital system of the orbit diagnostics) have been installed;
4. The Xenon (^{124}Xe) ions have been successfully produced by Krion source, injected, and accelerated in the Nuclotron up to 1 GeV/n and then successfully extracted;
5. The beam losses on the first turns were reduced by the factor of 4;
6. The magnetic field in the Nuclotron magnet was increased up to the maximum design value of 2 T.

NICA

The Machine Advisory Committee (MAC) Meeting took place on the 4–5th of October 2010 and summarized the results of the work: *«The design of the NICA project is progressing well. Since the last meeting significant modifications for the concept of the NICA collider were adopted. There is a considerable progress in developing a new lattice for the collider and the ring design. However, more aggressive work on the design is required in order to stay within the proposed timeline for the project».*

In order to stay close to the presently proposed timeline of the project, MAC recommends to fix the configuration of the collider and choose the ring lattice by the middle of the next year. During the period of October 2010 – June 2011, it is recommended to evaluate different aspects and propose a lattice which meets all the necessary requirements.

IREN, LUE-200

The employees of the LHEP acceleration division actively take part in the project IREN, the key element of their obligation is the linear accelerator of the electrons LUE-200.

As a result of the continuous development of the basic systems of the LUE-200: the electron gun, RF power source, the accelerating and focusing systems — the repetition rate of the accelerator increased from 25 to 50 Hz.

In 2010, the LUE-200 operated in a regular steady mode with a beam current of 2.0–2.4 A, energy of 30 MeV and beam current pulse duration of 100 ns. The accelerator has fulfilled a physical experiment as the driver of a pulse neutron source IREN (on W target) for more than 700 hours.

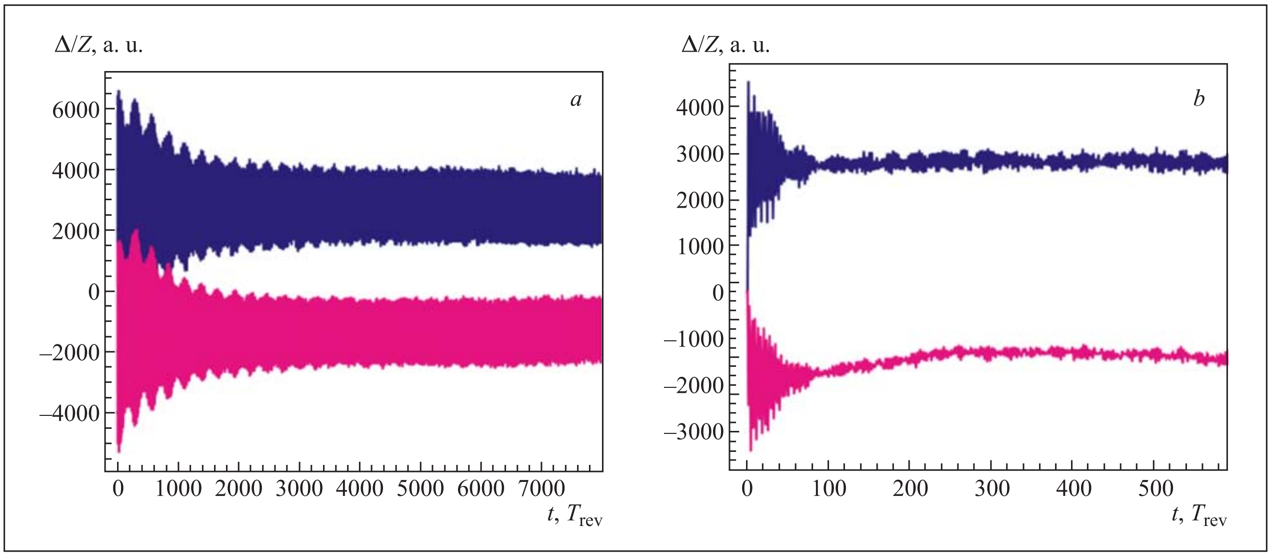

Fig. 1. Damping of horizontal injection errors (beam 1): damper OFF (*a*) and ON (*b*); signals from Q7 (top trace) and Q9 (bottom trace) pickups displaced by a quarter of the betatron oscillations' wavelength

LHC Damper

Final tests and tuning of a powerful transverse feedback system (LHC Damper) were completed in 2010.

The LHC Damper stabilizes the beam against coupled bunch instabilities and also damps the transverse oscillations of the beam originating from steering errors and kicker ripple.

The transverse feedback power system for the Large Hadron Collider is a joint project of the European Organization for Nuclear Research (CERN) and the Joint Institute for Nuclear Research (JINR). The RF power system of the LHC Damper designed and constructed at JINR is a part of the feedback system between beam position monitors and deflectors with integrated electric field of about 900 kV per turn.

Final tests of the LHC Damper were done in 2010. The damping time of 40 turns with a proton beam at 450 GeV was achieved (see Fig. 1). For the first time in the world an active damping was obtained for coherent oscillations of a proton bunch at the energy of 3.5 TeV. Stable and reliable operation of the LHC Damper during injection, ramp and collisions prevents transverse emittance blow-up, and in October 2010 allowed one to obtain the luminosity of more than 10^{32} cm$^{-2}\cdot$ s^{-1} [2].

THE MOST IMPORTANT RESULTS IN PHYSICS

The most significant results obtained by LHEP scientists in 2010 refer to the experiments carried out at CERN. Among the accomplished studies which have been world recognized there are:

NA48/2 Experiment

Observed by the NA48/2 experiment at the CERN SPS, the $\pi^0\pi^0$ invariant mass (M_{00}) distribution from $K^\pm \to \pi^\pm\pi^0\pi^0$ decay has shown a cusp-like anomaly at $M_{00} = 2m+$, where $m+$ is the charged pion mass. The Dalitz plot of this decay is fitted to a new empirical parameterization,accepted by PDG, that is suitable for practical purposes, such as Monte Carlo simulations of $K^\pm \to \pi^\pm\pi^0\pi^0$ decays.

The fits of the M_{00} distribution with the second order ChPT formulae have resulted earlier in the preliminary measurement of the a_0 and a_2 which are $\pi\pi$-scattering lengths at isospin states 0 and 2, respectively.

The analysis of NA48/2 data on $K^\pm \to \pi^+\pi\,\mathrm{e}^\pm\nu$ (Ke4) decay and on the cusp effect has been finished. As a combined result, the world most precise values of the ChPT theory base parameters: a_0 and a_2 and their difference, have been obtained (Fig. 2) [3]:

$$a_0 = 0.2210 \pm 0.0047_{\mathrm{stat}} \pm 0.0040_{\mathrm{syst}};$$
$$a_2 = -0.0429 \pm 0.0044_{\mathrm{stat}} \pm 0.0028_{\mathrm{syst}};$$
$$a_0 - a_2 = 0.2639 \pm 0.0020_{\mathrm{stat}} \pm 0.0015_{\mathrm{syst}}.$$

From the data collected during 2003 and 2004, about 600 k of $K^\pm \to \pi^\pm\pi^0\gamma$ decay candidates have been selected. The relative amounts of Direct Emission (DE) and Interference term of the decay amplitudes (INT)

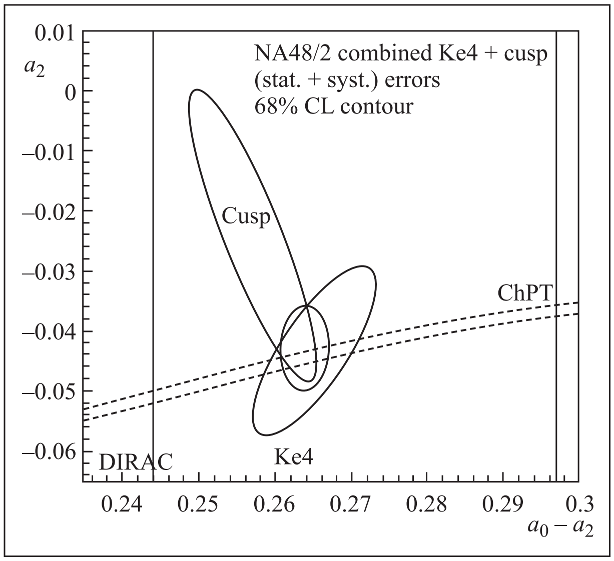

Fig. 2. Values of the $\pi\pi$-scattering lengths a_0 and a_2 obtained from two independent measurements (Ke4 decay and the cusp effect) with different samples in the NA48/2 experiment

with respect to the Internal Bremsstrahlung (IB) contribution have been measured in the range $0 < T_\pi^* < 80$ MeV: $\mathrm{Frac_{DE}}\,(0 < T_\pi^* < 80\ \mathrm{MeV}) = (3.32 \pm 0.15_{\mathrm{stat}} \pm 0.14_{\mathrm{syst}}) \cdot 10^{-2}$; $\mathrm{Frac_{INT}}\,(0 < T_\pi^* < 80\ \mathrm{MeV}) = (-2.35 \pm 0.35_{\mathrm{stat}} \pm 0.39_{\mathrm{syst}}) \cdot 10^{-2}$, where T_π^* is the kinetic energy of the charged pion in the kaon rest frame. This is the first observation of an interference term into the amplitudes of these decays. In addition, a limit on the CP violating asymmetry in the K^+ and K^- branching ratios for this channel has been determined to be less than $1.5 \cdot 10^{-3}$ at 90% CL.

In the framework of the new NA62 experiment preparation, the analysis of experimental data, collected with the 1st straw detector prototype, has been finished. As a result the feasibility of straw detector working in vacuum has been proved. The reached spatial resolution and efficiency are good enough for the NA62 purposes even at the maximum expected rates of 0.5 MHz per straw. Front-end electronics and two gas mixtures (slow and fast) have been tested, and the choice decision has been done.

A second prototype has been designed and manufactured in collaboration with the CERN group. It allows one to choose an optimal technology to construct the full-scale straw tracker module. It was tested at SPS beam in 2010 run, the collected data analysis is going on.

COMPASS Experiment

The analyses of the experimental data taken with the muon beam (2002–2007) using the deuterium and hydrogen targets, have allowed the physicists to test the Bjorken sum rule [4].

The inclusive double-spin asymmetries, A_1^p, were combined with those previously published for the deuteron to extract the nonsinglet spin-dependent structure function $g_1^{\mathrm{NS}}(x, Q^2)$. The integral of this function over x has been found to be in good agreement with the value predicted by the Bjorken sum rule and corresponds to the ratio of the axial and vector coupling constants $|g_A/g_V| = 1.28 \pm 0.07(\mathrm{stat.}) \pm 0.10(\mathrm{syst.})$ (Fig. 3). This is the most precise test of the Bjorken sum rule.

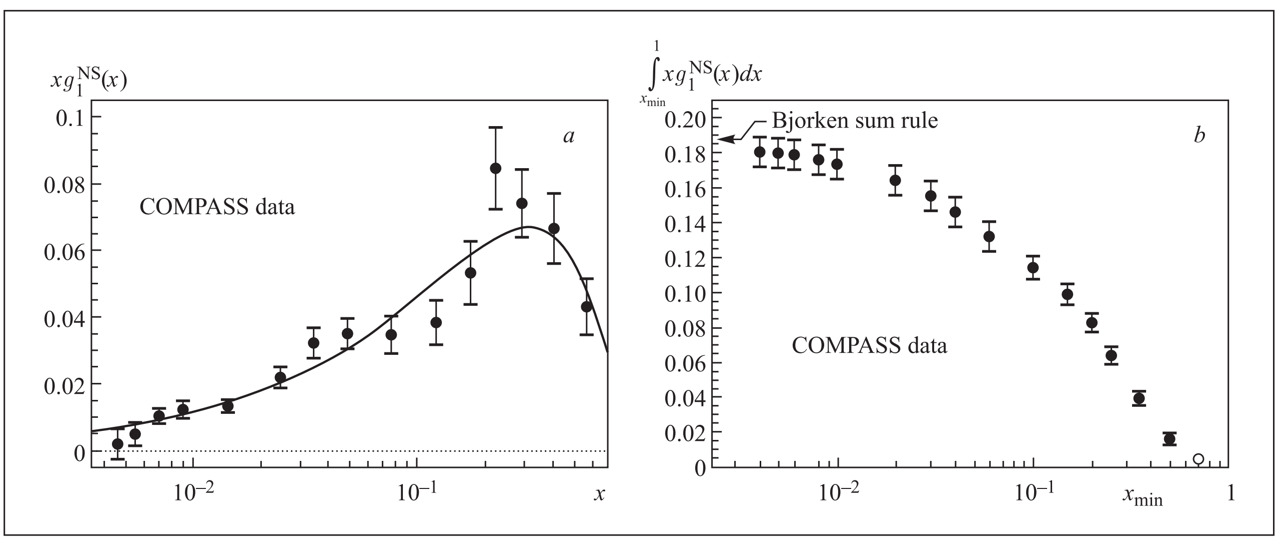

Fig. 3. *a*) Values of $g_1^{\mathrm{NS}}(x)$ at $Q^2 = 3\ (\mathrm{GeV}/c)^2$, derived from the COMPASS measurements of A_1^p and A_1^d and result of a three-parameter QCD fit at NLO. *b*) $\int_{x_{\min}}^1 g_1^{\mathrm{NS}} dx$ as a function of $x_{\min}$ obtained from the COMPASS data points. The open circle at $x = 0.7$ has been obtained from the fit. The arrow on the left side shows the value expected for the full range $0 < x < 1$ with $|g_A/g_V| = 1.269$

LHC operation in 2010 admitted the highlight of the year in the particle physics.

LHEP scientists have taken part in CMS, ALICE, and ATLAS experiments at CERN LHC.

CMS

The JINR obligations in the CMS project include the design and construction of the end-cap hadron calorimeter and part of the muon system ME1/1. All obligations have been fulfilled. In 2010, detectors demonstrated stable and efficient operation.

Since the end of 2009, the efforts of the JINR group in the CMS experiments have been focused on participation in data taking, data processing, and analysis during the first LHC runs at the energy of 0.9, 2.3 and 7 TeV in c.m.s. in low luminosity regime. Preparation for the physics run of 2011 with integrated luminosity of several fb^{-1}, was also performed.

The integrated luminosity of 43.17 pb^{-1} was obtained by the end of October 2010.

The detector operation and data taking shifts, including the fast detector monitoring, data taking monitoring, and data quality, were carried out in CMS Control Room at CERN as well as in the remote operation center in Dubna.

The main efforts of the JINR group in the CMS physics programme were concentrated on data taking, processing and analysis in the framework of the CMS working group aimed at searching for physics beyond the Standard Model and electroweak physics. The working group also carried out the muon and jet reconstruction.

The dimuon mass spectrum was studied (Fig. 4). The kinematic cuts were optimized, good agreement of the experimental data with the Monte Carlo predictions is shown [5]. The invariant mass values of different well-known resonances ($J/\psi, \Upsilon, Z^0$) were measured in the dimuon channel. The obtained values are in good agreement with the World data. More than 16000 candidates into Z^0-bosons and 400 candidates into Drell–Yan events with invariant mass above 120 GeV were found. The upper invariant mass of the Drell–Yan pair is 447 GeV.

ALICE

JINR obligations on the construction of the ALICE detector (dipole magnet, 127 modules of the transition radiation detector chambers, 800 lead tungsten crystals for the PHOS) have been also fulfilled.

The physics analysis in ALICE collaboration was carried out on the multiplicity, elliptic flow, anti-p/p ratio, strangeness, momentum distributions, Bose–Einstein correlations at pp-collision energies of 900 GeV, 2.36 and 7 TeV.

In October 2010, the lead–ion running started. On November 8, the stable running conditions for lead–lead collisions at $\sqrt{\sigma_{\mathrm{NN}}} = 2.76$ TeV were established. The integrated luminosity, which was delivered to ALICE during 4 weeks of running, was $\sim 9.5\ \mu\mathrm{b}^{-1}$.

Via the suppression of high p_t charged particles, ALICE has observed at the Pb-Pb collisions the phenomenon known as jet quenching. The maximum value of this suppression is 1.5–2 higher than at RHIC. The two-pion Bose–Einstein correlation effect has been studied with active participation of Dubna group [6], and the increase by 30% of the pion source radii and decoupling time as compared to RHIC experiments, was found.

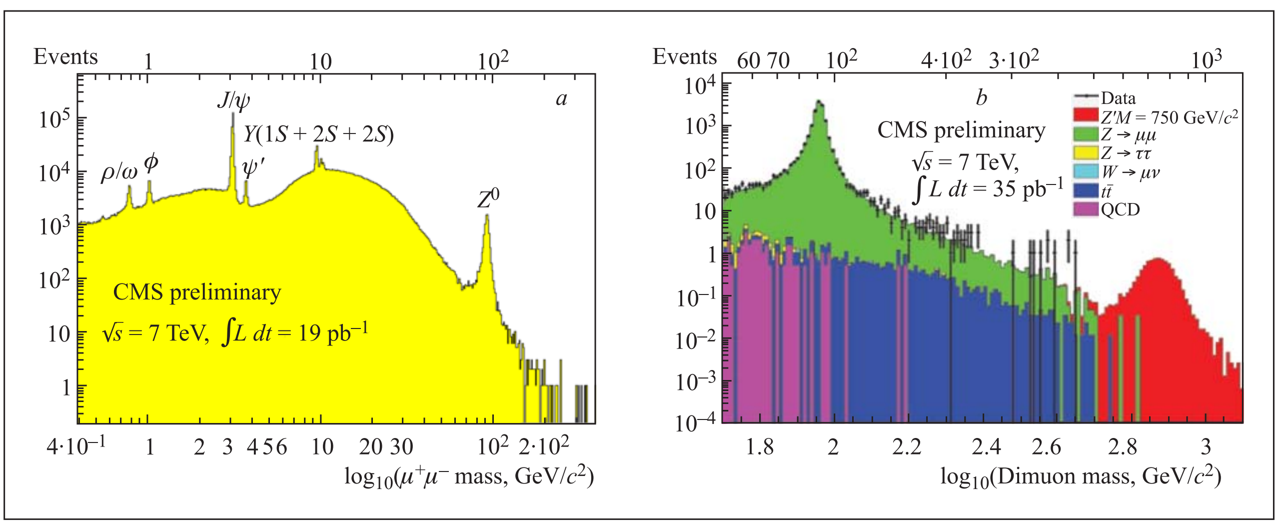

Fig. 4. The dimuon mass distribution (*a*) and comparison of data and MC predictions for DY mass more than 50 GeV (*b*) [5]

All together the new scientific results obtained by ALICE collaboration have confirmed that the much hotter nuclear matter produced at the LHC, which may be the quark–gluon plasma, behaves as a very low viscosity liquid (a perfect fluid), in keeping with earlier observations from Brookhaven's RHIC collider.

ATLAS

LHEP group participating in ATLAS was involved in the construction of the part of the liquid argon hadron calorimeter and transition radiation tracker (34 straw wheels). All obligations have been successfully fulfilled.

The integrated luminosity of 45 pb^{-1} was collected by ATLAS in 2010.

All detectors of the JINR responsibility operated reliably and efficiently [7]. The LHEP team participated in the combined QCD analysis of DIS and ATLAS pp data, analysis of the jets at 7 TeV, and in the search for the Higgs boson at the 3-lepton decay mode.

PROGRESS IN THE MPD PROJECT

The Multi-Purpose Detector (MPD) project was presented and approved for 5 years at the 33rd session of the PAC for particle physics in June 2010.

During the year, an essential serious progress was achieved in R&D for different MPD subsystems [8]:

1. Magnet

The conceptual design of the MPD superconducting solenoid has been prepared. The magnet will provide the homogenous magnetic field of 0.5 T in its aperture with the cylindrical coil and two correcting coils located on pole tips. The diameter of the aperture is 4 m, the distance between the pole tips is 5.24 m, and the magnet weight is 440 ton. The field un-uniformity in the tracking area is about 0.1%. The stored energy will be 7.8 MJ.

2. Internal Tracker

The R&D of the Internal Tracking System (ITS) of MPD was performed as a part of the 2010 work plan of the CBM-MPD STS Consortium developing Silicon Tracking Systems for the CBM setup at FAIR and MPD at LHEP JINR.

The most important results related namely to MPD were as follows. The design of the four-layer cylindrical system of double sided silicon microstrip sensors mounted on the ultralight carbon fiber support space frames, was accomplished proving a possibility of integrating the ITS within the spare inner volume between the beam pipe and the TPC inner surface. The designed IT was then used for computer simulations proving the necessity of IT integration into TPC especially in the case of multistrange hyperon identification. Simultaneous prototyping of hardware started with the manufacturing of full-size electro-mechanical mockups of large area sensitive modules whose usage is foreseen within the MPD ITS project.

3. TPC

• The 1st TPC prototype (32 channels of FEE and DAQ) has been fabricated and tested with cosmic rays.

• The 1st version of the track reconstruction programme has been developed and used for simulation.

• The electric field in the prototype field cage has been simulated by means of the MAXWELL programme.

• The chamber of the prototype has been fabricated and tested with a radioactive source. Two different gas mixtures were used during the test: Ar/Methan and Ar/CO_2, and the chamber was assembled with two different pad planes having the pad sizes 8×12 mm and 4×10 mm, respectively.

• The prototype of the TPC package has been designed and prepared (Kevlar cylinder with diameter $d = 950$ mm and length $L = 900$ mm, 2 mm wall is laminated with 50 micron Tedlar film).

• R&D on the GEM based TPC readout, has been performed in collaboration with GSI colleagues.

4. TOF

• The prototype of a multigap plane-parallel chamber (mRPC) has been assembled;

• The gaseous system was assembled and calibrated to provide the prototype mRPC with the working mixture.

• The full simulation chain of the particle identification system based on the TOF, TPC, and straw tubes information, has been carried out.

• MPD collaborators from China have prepared and tested the RPC prototype (size $52.5 \times 35 \times 4$ cm) with cosmic rays. The obtained efficiency and time resolution meet the requirements (see Fig. 5).

5. End-Cap Tracker of the Setup

Few different versions of the end-cap tracker geometry were described in the setup simulation programme MPD-Root. The energy losses of light charged hadrons (p, K, π) were calculated along their path through the matter of the end-cap tracker.

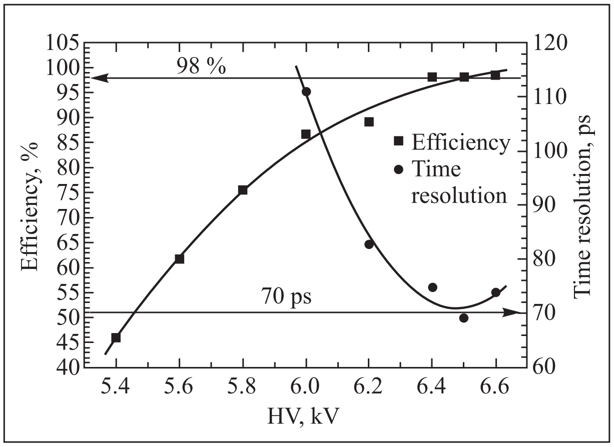

Fig. 5. RPC prototype efficiency and time resolution

6. Calorimetry

In 2010, the work with a calorimeter of the «shashlyk» type was carried out. The calorimeter module with the sizes of 12×12 cm, length of $20X_0$ type «KOPIO», was prepared for the test run. The new 16th block of fast digitizing ADC16 was used as a read-out electronics.

The data-taking run was successfully performed on the accelerator in Hamburg. The analysis of the obtained data will allow one to make a conclusion on the possibility of using the calorimeter of such construction for MPD and develop a technical requirement to manufacture the calorimeter module.

During the Nuclotron run, 9 modules (transverse size of 15×15 cm) with the sandwich structure along the beam of $40 \times (2$ cm of Iron$+ 0.5$ cm of Scintillator) have been tested. The work was carried out in a close co-operation with the group of INR RAS.

7. Forward Detector

Two modules of the FD with fast electronics based on purchased photomultipliers XP85012/A1 have been designed and produced in the framework of collaboration with the Radium Institute in St. Petersburg.

The plan for 2011 is to expand the work on the detector systems and complete mainly the R&D on FD module to transfer from the prototypes to the production stage.

8. Zero Degree Calorimeter

In collaboration with the companies «Micron» (Zelenograd) and «Zecotec», the prototype of the ZD calorimeter has been prepared. In May 2010, the prototype was tested at CERN on the T10 pion beam. The novel MAPD detectors were used as readout. The obtained energy resolution can be described by the equation $\sigma(E)/E = 55.5\%/\sqrt{E} + 3.7\%$, taking into account the leak $\sigma(E)/E = 56\%/\sqrt{E} + 1.8\%$. The prototype has demonstrated good linearity in a wide energy range. The obtained parameters allow one to optimize the calorimeter size.

9. Collaboration with CERN

In the framework of the agreement on collaboration between JINR and CERN signed in January 2010, four drift chambers of the former NA48 experiment have been delivered from CERN to JINR to be installed in the MPD. This operation is an example of fruitful exchange of technology that profits both the laboratories and enhances their collaboration in common projects.

10. Fixed Target Programme

The Nuclotron based fixed target programme which includes experiments with heavy-ion and polarized beams, is under preparation. The proposal of the experimental setup and scientific motivation will be presented at the next session of the PAC for particle physics.

APPLIED AND METHODOLOGICAL RESEARCHES

In the frame of the project «Energy + Transmutation», a new approach has been formulated for the first time on Accelerator Drive Systems (ADS), which is based on the energy yield increase effect while energy increasing for the subcritical assembly system. This effect was discovered at JINR in 2010.

At the deuteron energy increase from 1 to 4 GeV the number of fission events and energy yield grow by ~ 8–9 times and the beam power amplification coefficient in the natural uranium increases by a factor of ~ 2.

The reconstruction of the beam extraction channel to the experimental hall for the setup «Energy + Transmutation» has been completed.

In collaboration with the scientists from the Institute of Physics-Chemical Problems at BSU, the Laboratory has carried out the research of heating efficiency of magnetic and ferromagnetic nanoclusters for the SHF range to use them for the cancer-cell targeted therapy.

Experimental confirmation of the nanoclusters «baking» into samples of big sizes has been obtained under coherent SHF-exposure of pulsed FEL.

The 64-element detectors have been developed for project DVIN which are now being installed into the neutron generator to determine the neutron yield angles. Multielement-alpha detectors have been developed, manufactured and tested to be embedded into the portable neutron generators (NG). The producer of NG is the National Russian Research Institute of Automation named after N. L. Dukhov (NRRIA).

In 2010, a number of investigations have been fulfilled in the field of cryogenics. This work has resulted in manufacturing of radiation-hard magnetic-resistive temperature sensors for the range of temperature 0.1–10 K and fields of 0–8 G [9]. The tests of radiation resistive sensors have been carried out in a wide range of the temperature and magnetic field induction. The problem of manufacturing the fast sensors of the 2-phase flows of helium, hydrogen, and liquefied natural gas has been solved.

On the basis of developments in the field of acceleration technique for fundamental studies, the Laboratory has realized an innovation project to introduce a compact electron accelerator P-300-10/2 with the energy of $E = 300$ keV and mean current of 10mA for the radiation technology. The accelerator capacity is 95% (the measured value). By the present moment two accelerators have been shipped to Japan and China. The requests of the Chinese partners are determined as 30–40 accelerators for 3–4 years.

One of the main methodological developments of the Laboratory is microchannel silicon avalanche photodiodes (MCSAPHD) which are a solid-body analogue of the vacuum photoelectron amplifiers (PHEA).

At present the Laboratory carries out investigations of MCSAPHD as detectors of light pulses from scintillators in high-energy physics experiments as NICA/MPD (JINR), CMS, COMPASS (CERN), PANDA (GSI), as well as in nuclear medicine as elements of the PET and PET-MPT scanners.

Project «Development of High-Precision Straw Detectors» continued the work to construct segmented straw detectors able to operate at high loadings. Their prototypes with the segmentation step from 1 to 30 cm have been manufactured and tested at the straw tube 4 m long with normal and excess pressure [10].

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