DZHELEPOV LABORATORY OF NUCLEAR PROBLEMS

ELEMENTARY PARTICLE PHYSICS

The main activity under the **ATLAS** project in 2006 was concentrated on the installation and commissioning of the ATLAS muon chambers produced in previous years, on preparation for the physics research with real ATLAS data, on installation and support of ATLAS software in JINR, as well as on data preparation and distributed analysis based on the Grid technology.

In 2006 cabling and commissioning of the ATLAS BMS/BMF muon chambers (installed in 2005) continued. The cabling and commissioning is well within the overall ATLAS installation schedule determined by the access requirements and cabling sequence. About 75% of the chambers were connected to the gas system. In October 2006 a cosmic ray run of the 13th sector of the muon spectrometer was launched.

The calculation of processes important for the ATLAS physics programme was incorporated into the SANC framework. A new event generator for the Higgs boson decays $H \to ZZ \to 4\mu$ was developed [1]. The generator takes into account the electroweak radiative corrections and the quantum effects due to the presence of identical particles in the final state. Another Higgs decay $H \to \mu\mu\gamma$ was also implemented [2]. The full decay width is $1.3 \cdot 10^{-6}$ GeV ($M_H = 130$ GeV/c^2) compared to $2.4 \cdot 10^{-7}$ for $H \to 4\mu$ decay.

An extensive study of the Drell–Yan processes $qq' \to W \to \mu\nu$ and $qq \to Z \to \mu\mu$ has been performed. Full calculations of the $O(\alpha)$ for the electroweak and strong sectors were completed [3, 4]. Differences of up to $\sim 10\%$ with the lowest order calculations were found.

The possibility of the Higgs boson discovery in the decay channel $H \to ZZ \to 4\mu$ has been studied. A wide range (120–180 GeV/c^2) of possible Higgs mass was explored. The so-called «irreducible» background $pp \to ZZ \to 4\mu$ was suppressed by a factor of 2–3. The other background from $pp \to tt$ and $pp \to Zbb$ was suppressed by 2–3 orders of magnitude, making it almost irrelevant for the signal selection. A new type of background was discovered, which was never taken into account before: random coincidence (in the same bunch crossing) of two independent productions of a single Z ($pp \to Z \to 2\mu$). The contribution of this background is about 10% of the total background.

A comparison of the predictions of the PYTHIA event generator with the one created by the SANC group (which took into account radiation corrections and quantum effects of identity of the final state particles (muons)) was performed. It was found that the identity effects predicted slightly better signal/background separation (the signal/background ratio improved by 5–10%) (Fig. 1).

The significance of the Higgs boson signal was evaluated for different possible values of its mass with allowance for the quantum effects of identity predicted by SANC. Figure 2 shows the distribution of the invariant mass for the signal ($M_H = 130$ GeV/c^2) and the background (mainly $pp \to ZZ$). The signal significance is expected to be 12–15 standard deviations after three years of the LHC running.

The procedure for the ATLAS muon spectrometer calibration using the Drell–Yan events $pp \to Z \to 2\mu$ was developed. It was shown that this process allowed precise estimation of the spectrometer efficiency and calibration of the muon momentum measurement. The high efficiency and purity of the selected sample also allow the Drell–Yan events to be used for the precise determination of the LHC luminosity using the ATLAS experimental data.

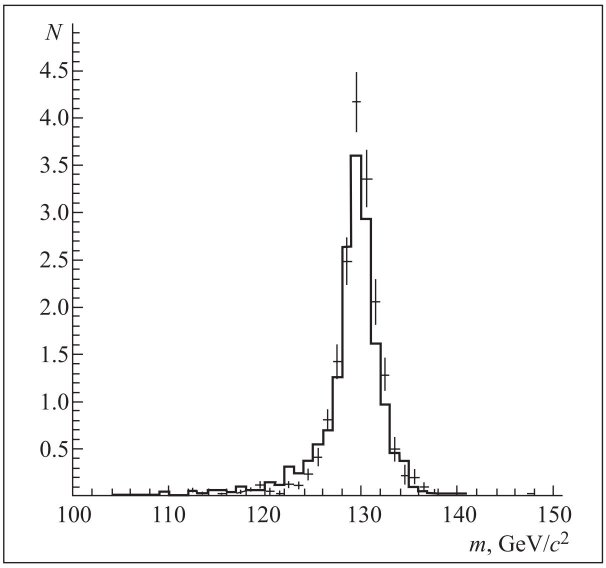

Fig. 1. Reconstructed invariant mass of the Higgs boson, simulated by the PYTHIA (line) and SANC (crosses) generators

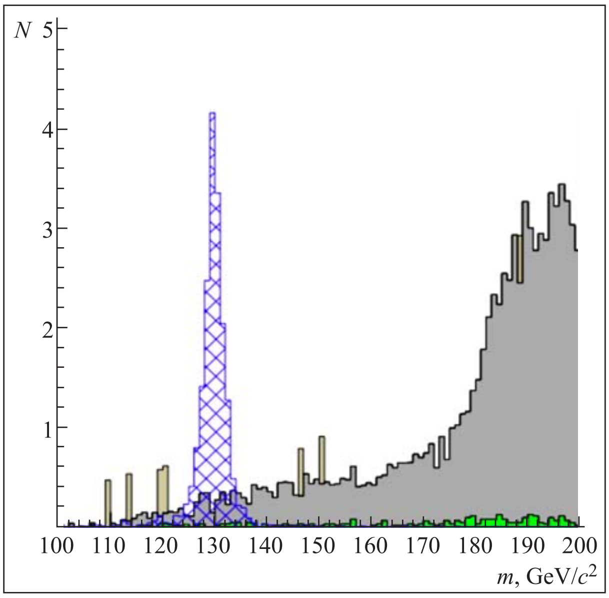

Fig. 2. Invariant mass distributions for the signal (M_H = 130 GeV/c^2) and background (mainly $pp \to ZZ$)

The latest versions of the ATLAS software are routinely installed and supported at the JINR central computer farm at LIT. This software (and the LIT hardware) was widely used in 2006 in the studies within the ATLAS physics programme. The user programmes of the physics analysis were adapted for ATHENA.

JINR participates in the EGEE-RDIG initiative, whose goal is to develop the Russian Tier-2 centre. The main task of JINR in the ATLAS Grid is Monte-Carlo simulation and distributed data analysis. During 2006 JINR participated in the large-scale testing of the ATLAS system of distributed data processing and mass production of simulation data (Computing System Commissioning and Service Challenge). Currently, the user analysis programmes are being adapted to Grid technologies.

With the aim of understanding the performance of the **ATLAS Tile Hadronic Calorimeter** to electrons 11% of modules were exposed to electron beams with various energies by three possible ways: cell scan at $\Theta = 20°$at the centres of the front face cells, η-scan and tilerow scan at $\Theta = 90°$ for the module side cells. The electron energy resolutions of the EBM–(ANL-44), EBM+ (IFA-42) and BM (JINR-55) Modules of the ATLAS Tile Calorimeter at the energies $E = 10$, 20, 50, 100 and 180 GeV and $\Theta = 20°$ and 90° and η-scan were extracted from the July 2002 test-beam run data using the fit filter method of the PMT signal reconstruction [5]. The statistical and constant terms for the electron energy resolution were determined by fitting of the quadratic $\sigma/E = a_s/E^2 + b_s$ and linear $\sigma/E = a_l/E^2 + b_l$ expressions to the data obtained. The energy resolution results have been compared with the Monte-Carlo–based parametrization. Good agreement is observed for the linear fit. Comparison of the corresponding values of the electron energy resolution obtained by the flat filter and fit filter methods shows their coincidence within the errors.

On the basis of exposure of the ATLAS Tile Calorimeter to electron beams with various energies, the e/mip values as a factor of the absorber thickness were determined using different beam incident angles [6]. The transition effect ($e/mip < 1$) and, for the first time, its behavior as a function of the absorber thickness are observed (see Fig. 3). The e/mip ratio decreases logarithmically when the absorber thickness increases. This is well described by the GEANT4 version 6.2 Monte-Carlo simulations. The detailed calculation of the Tile Calorimeter Sampling Fraction parameter (TSF) GEANT4 Monte-Carlo simulation of the ATLAS hadronic calorimeter (TileCal) within ATHENA (common software framework of ATLAS) was carried out [7]. Sensitivity of the e/h ratio of the ATLAS Hadronic Tile Calorimeter to the proton contamination in the positive-pion beams was studied [8]. It turned out that the joint application of the proton contamination correction and the correction for the event selection criteria to the e/π ratios led to the unchanged value of the e/h ratio: $e/h = 1.36 \pm 0.01$.

The **SANC** project includes theoretical predictions for practically all Standard Model (SM) $1 \to 2$ and $1 \to 3$ decays and many $2 \to 2$ processes at the one-loop precision level. In 2006 the implementation of fermion–boson processes $f_1\bar{f}_1ZZ \to 0$ and $f_1\bar{f}_1HZ \to 0$ in the framework of the SANC system was performed [1]. The further precision study of Drell–Yan processes was carried out in [3, 9]. The simplest QCD processes [10] were included in the SANC system. The precision calculations of the semileptonic decay widths [11] are continued. Work on SANC application to LHC physics is being carried out. SANC version v1.00 is accessible from server at CERN (http://pcphsanc.cern.ch/(137.138.180.42)), and version v1.10 at JINR (http://sanc.jinr.ru/(159.93.75.10)). The system is started to be widely used for physical applications.

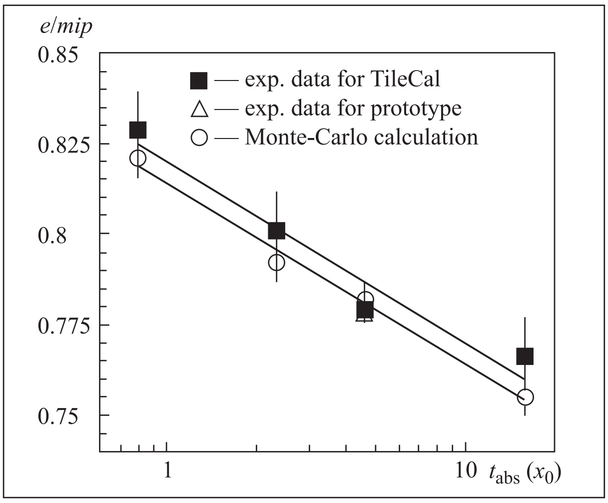

Fig. 3. The e/mip ratio as a function of the absorber thickness $t_{\rm abs}$ of the Tile Calorimeter period (in radiation lengths). Black squares are experimental points. The open triangle is the prototype result, open circles are the GEANT4 (version 6.2) Monte-Carlo calculations for the TileCal test beam setup

The main results of the **JINR/CDF** group in 2006 are the measurement of the top-quark mass ($M_{\rm top}$) and providing efficient operation of the CDF II setup. A contribution of principal significance to precise measurement of $M_{\rm top}$ in «lepton + jets» topology [12], $M_{\rm top} = 173.4 \pm 2.5\,({\rm stat.}) \pm 1.3({\rm syst.})$ GeV/c^2, was made. Method was updated for the top-quark mass measurement in the dilepton decay channel. Work on the $M_{\rm top}$ measurement is in progress at the JINR computer complex due to the LIT support.

Efforts of the Dubna group are also focused on the efficient and stable operation of the detector for broad c-, b-, t-quark physics studies at the highest available energies. The Muon Control and Monitor System were successfully upgraded.

A new method to extract the $M_{\rm top}$ is proposed by the University of Athens/Dubna group. The transverse momentum of electrons and muons produced in the $t\overline{t} \to$ dilepton and the $t\overline{t} \to$ lepton + jets channels are sensitive to $M_{\rm top}$ and can be accurately measured providing the $M_{\rm top}$ with a very small systematic error and, at large enough integrated luminosity, with a very small total error. The method is not affected by uncertainties in the jet energy scale and is applicable to both Tevatron and LHC collider experiments.

Parton level study of a possibility of correlation measurements in VHM events has shown that although the CDF resolution in particle parameter reconstruction weakens the correlation, it still remains visible and at least two-particle correlations can be measured [13].

During this year the main efforts of the **DIRAC** collaboration were aimed at upgrading the setup. A new vacuum channel, two new heavy gas Cherenkov counters, new front-end and readout electronics for scintillating detectors were manufactured at JINR. Beam test was carried out for two planes of the new Scintillating Fiber Detector with fibers 0.27 mm in diameter and a working area of 100×100 mm together with the new front-end electronics. The system of microdrift chambers was upgraded at JINR and delivered to CERN with the new front-end electronics. Data analysis for obtaining the value of the $\pi^+\pi^-$ atom lifetime with systematic and theoretical errors, including generation of a new set of Monte-Carlo events, was performed.

The rare kaon decay, $K_L^0 \to \pi^0\nu\overline{\nu}$, is considered as an ideal process for understanding the origin of CP violation and a critical test for the standard model. The theoretical uncertainty in the branching ratio, which is predicted to be $(3 \pm 0.6) \cdot 10^{-11}$ in the standard model with parametric uncertainties from other experiments, is only 1–2%. The decay has been considered as an ideal process in the quark flavor physics for a critical test of the standard model, as well as a search for new physics beyond it. The present experimental limit is $5.9 \cdot 10^{-7}$.

The KEK-PS **E391a** is the first dedicated experiment to search for this decay. It employs two main concepts: a pencil beam and a hermetic photon veto system in a highly evacuated decay region. The experiment started the data taking in February 2004, aiming at improving the current experimental limit by some orders of magnitude. As a result, the single event sensitivity for the $K_L^0 \to \pi^0\nu\overline{\nu}$ decay was calculated as the reciprocal of the product of the averaged value of the numbers of K_L^0 decays estimated from $K_{\pi 2}$ and $K_{\pi 3}$ with the acceptance for the $K_L^0 \to \pi^0\nu\overline{\nu}$ decay estimated by a simulation to be $1.17 \cdot 10^{-7}$. Since there is no event in the signal region and the expected level of background is negligibly small, an upper limit for the $K_L^0 \to \pi^0\nu\overline{\nu}$ decay is $2.9 \cdot 10^{-7}$ at 90% confidence level by multiplying a factor of 2.3 to the single event sensitivity [14], this is the main result in 2006.

The E391a setup has taken data since January 2005 as Run II. From the prompt analysis and comparison with the Run-I data, the membrane events reduced close to one order of magnitude. The acceptance for the $K_L^0 \to \pi^0\nu\overline{\nu}$ decay was estimated by using Monte Carlo and real data, which improved more than 4 times compared with that of Run I. After upgrading the E391a has taken data since November 2005 as Run III. E391a was the last particle physics experiment using the 12-GeV proton synchrotron, which was closed in December 2005.

In comparison with the original plan, the E391a project has two main changes: the collaboraion spent a lot of time in 2005 for additional data taking and the received volume of experimental data now exceeds the original amount (Run I) more than twice.

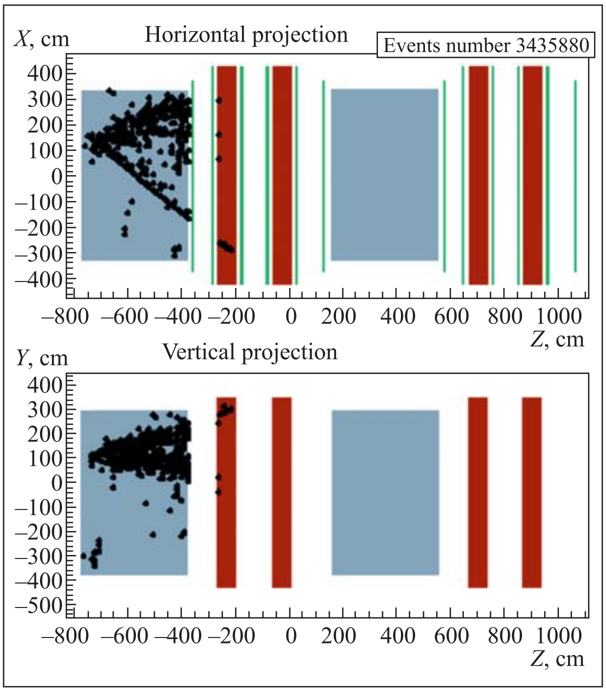

Fig. 4. First neutrino events recorded in OPERA

The year 2006 was a very important period for the **OPERA** experiment. The neutrino beam from CERN to Gran Sasso (CNGS) started up, all the electronic detectors of OPERA were successfully commissioned, and two first data taking runs with the CNGS beam took place. As a result, the electronic detectors recorded the first neutrinos sent from the CERN SPS (Fig. 4). The main detector for the neutrino oscillation search is nuclear photoemulsions, OPERA's target bricks are made of those emulsions interlaced with thin lead plates. The mass production of those bricks started in 2006 as well [15, 16].

JINR was taking an active part in the Target Tracker detector commissioning, as well as in the software development for the Target Tracker data analysis, an important issue in the OPERA experiment.

The **TUS** space experiment is aimed at measuring the energy spectrum, composition and angular distribution of the Ultra High Energy Cosmic Ray at $E \approx 10^{19}-10^{20}$ eV to study the region of GZK cutoff. The TUS space fluorescence detector is to be launched in 2009 as a separated platform in the Foton-4 mission prepared by a Samara enterprise. A new platform for TUS was designed and its production is under preparation. A precise 3D Carl Zeiss device was put into operation in 2006 for measurement of the three-dimensional surface with 5 μm accuracy and optical properties of the Fresnel mirror prototypes. The energy resolution of the fluorescence detectors is heavily related to the uncertainties in the fluorescence production yield. Recently the collaboration of the JINR (Dubna) and LAPP (Annecy, France) scientific groups has measured the fluorescent light yield.

The aim of the **NUCLEON** project is direct Cosmic Ray measurements in the energy range $10^{11}-10^{15}$ eV and charge range up to $Z \approx 40$ in the near-Earth space to resolve mainly the knee problem in the CR spectrum: a change of the slope from $E^{-2.7}$ to $E^{-3.0}$ at $\sim 10^{15}$ eV. Design and production of the technological prototypes of the NUCLEON trigger system was done in 2006. Different space qualification tests of the system were fulfilled at the RADUGA. The beam test at CERN SPS was done together with the other NUCLEON detectors. An analysis of the data obtained is in progress.

LOW- AND INTERMEDIATE-ENERGY PHYSICS

The **NEMO-3** detector located in the Modane Underground Laboratory (LSM, France) is searching for neutrinoless double-beta decay $(0\nu2\beta)$ $N(A,Z) \to N(A,Z{+}2){+}2e^-$, which would be an indication of new fundamental physics beyond the Standard Model such as the absolute neutrino mass scale, the nature of neutrino (either Dirac or Majorana), and neutrino hierarchy. The goal of the running NEMO-3 is to check effective Majorana neutrino mass $\langle m_\nu \rangle$ at 0.2–1.0 eV sensitivity ($T_{1/2}^{0\nu\beta\beta}$ (^{100}Mo) $\sim 4 \cdot 10^{24}$). The SuperNEMO plan is 0.04–0.1 eV with $T_{1/2}^{0\nu\beta\beta}$ (^{82}Se) $\sim 2 \cdot 10^{26}$ y.

The NEMO-3 detector has been taking «Radon-free» data (Phase II) at stable conditions since December 2005. Total statistics accumulated is 800 and 572 days for Phase I and Phase II, respectively. Huge $2\nu2\beta$ statistic accumulated allows us to check fine effects such as tests of theoretical models that describe $2\nu2\beta$ process (Fig. 5). The possible presence of $2\nu\beta\beta$ processes with majoron emission for the isotopes ^{100}Mo and ^{82}Se has been tested studying the $\beta\beta$ spectra (Fig. 6). In particular, new limits on «ordinary» majoron (spectral index 1) decay of ^{100}Mo ($T_{1/2} > 2.7 \cdot 10^{22}$ y) and ^{82}Se ($T_{1/2} > 1.5 \cdot 10^{22}$ y) have been obtained. Corresponding bounds on the majoron–neutrino coupling constant are $\langle g_{ee} \rangle < (0.4-1.8) \cdot 10^{-4}$ and $< (0.66-1.9) \cdot 10^{-4}$ [17].

The new programme with the aim of extending the threshold energy region is assumed by the **ANKE** collaboration. Single pion production in proton–proton

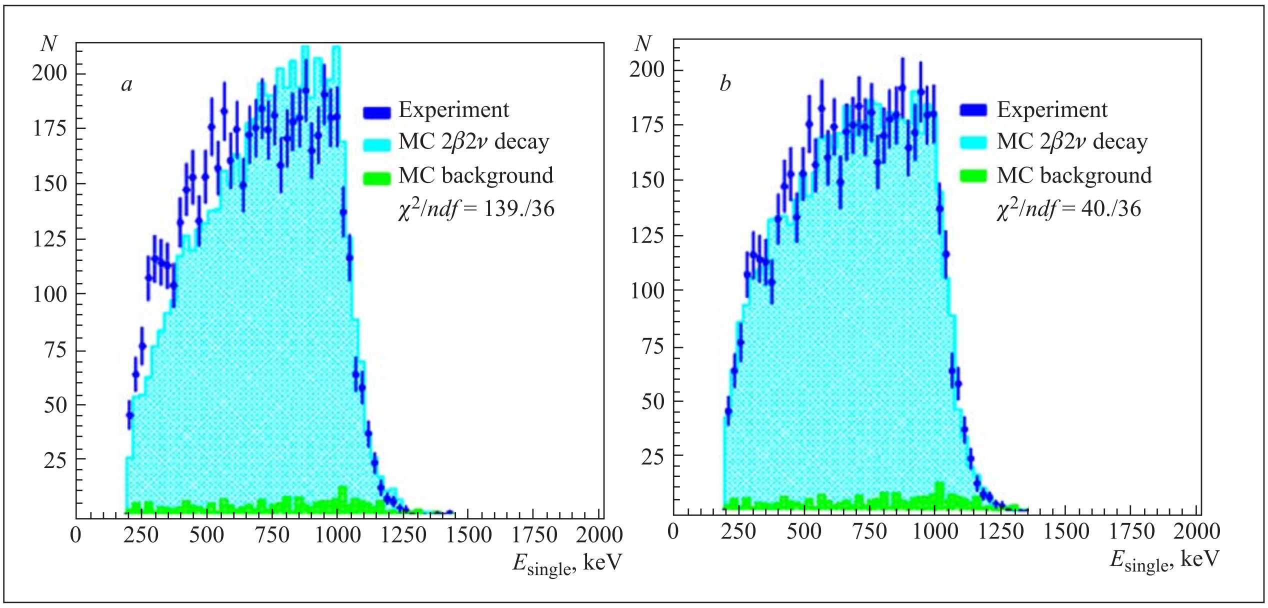

Fig. 5. Measured single electron energy spectrum of $\beta\beta$ decay in ^{100}Mo in comparison with theoretical shapes simulated according to the High State Dominance (*a*) and the Single State Dominance (*b*) models. Points mark experimental data. Calculated $2\nu\beta\beta$ signal is drawn by light histogram, while the simulated subtracted background is shown by dark histogram. Events with sum energy of two electrons above 2 MeV were selected in order to suppress the background significantly. The exposure is 4.57 kg $\cdot$ y

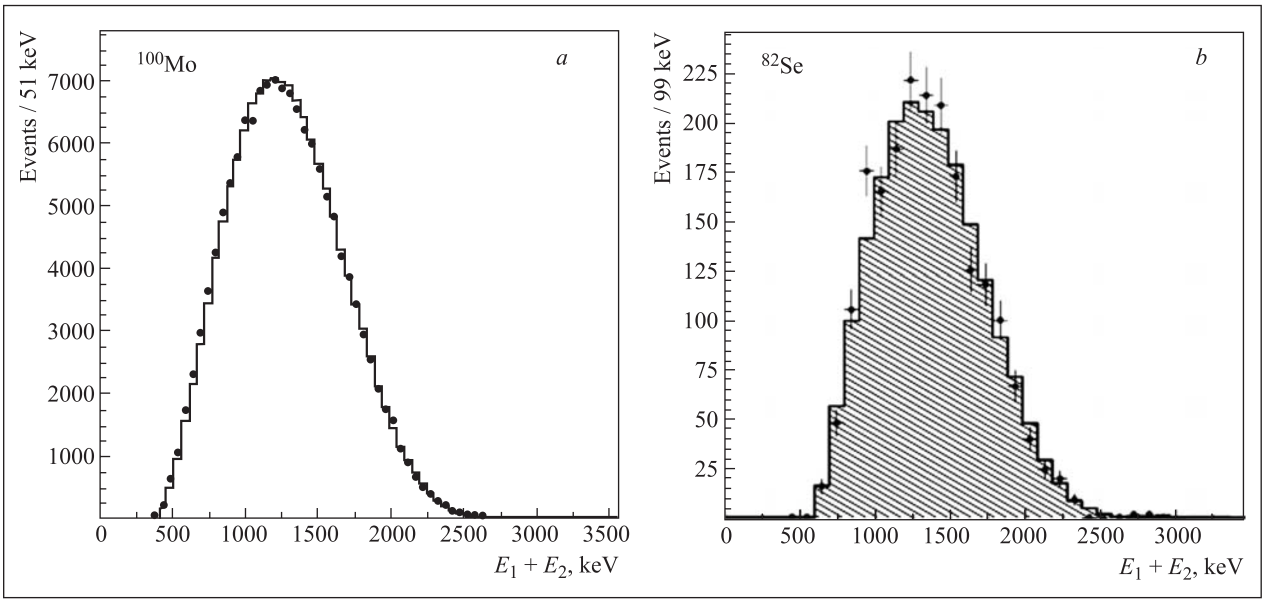

Fig. 6. Experimental energy sum spectra of two electrons emitted in $\beta\beta$ decay for ^{100}Mo (*a*) and ^{82}Se (*b*), which has been used in [17] for search of $\beta\beta$ decay with majoron emission

collisions is the first inelastic process to test our understanding of the meson-baryon dynamics of the nucleon–nucleon interaction. The most appropriate reaction, $pp \to d\pi^+$, has been a subject of intensive study for a long time. In contrast, very little was known about the isospin partner of this reaction, the process $pp \to (pp)_s\pi^0$, where $(pp)_s$ is a proton pair in the $^1S_0$ state. Despite having kinematics very similar to that of $pp \to d\pi^+$, the process involves very different transitions in the nucleon–nucleon system and, in particular, the role of the Δ isobar, dominating there, is expected to be much suppressed because the S-wave ΔN intermediate state is forbidden. An active study of the process only began in the last decade and was restricted by the near threshold energy region. To extend this region, the **ANKE** collaboration at COSY (Jülich) assumed a programme which was launched by measurement of the differential cross sections of the $pp \to (pp)_s\pi^0$ process at 0.8 GeV [18]. Although the cross sections are over two orders of magnitude smaller than those of $pp \to d\pi^+$, the process is well identified (Fig. 7). The angular dependence of the cross section (Fig. 8) reveals a forward dip even stronger than at lower energies 0.310–0.425 GeV. The results should provide a crucial extra test of pion production models used for description of nucleon–nucleon collisions at intermediate energies.

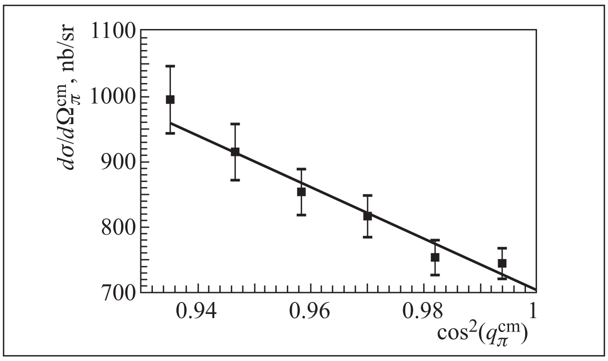

Fig. 7. Reactions seen at the momentum correlation plot in the ANKE experiment at 0.8 GeV

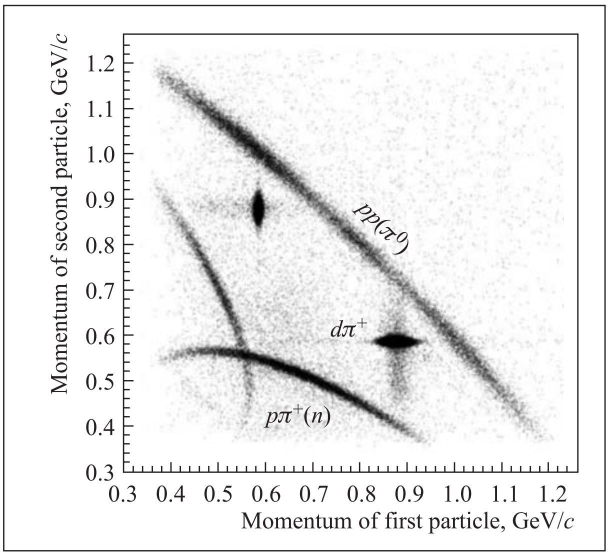

Fig. 8. Angular dependence of the $pp \to (pp)_s\pi^0$ differential cross section for the relative energy in the proton pair $E_{pp} < 3$ MeV

Within the framework of the **LESI** project, reactions between light nuclei (pd, dd, d^3He) at 2–12 keV are studied [19]. The interest in this kind of reactions is caused by a possibility of verifying symmetries in strong interactions, determining the contribution to interaction from exchange currents, checking the standard Solar model. Research of the given processes in the indicated energy region is rather problematic since intensity of the beams of the accelerated particles produced by classical accelerators is not sufficient and cross sections of nuclear reactions are extremely small. The use of plasma accelerators with the liner plasma formation in the direct and inverse Z-pinch configuration allowed receiving the quantitative information on the astrophysical S factors and effective cross sections of the pd and dd reactions (Fig. 9). However, the highly accurate

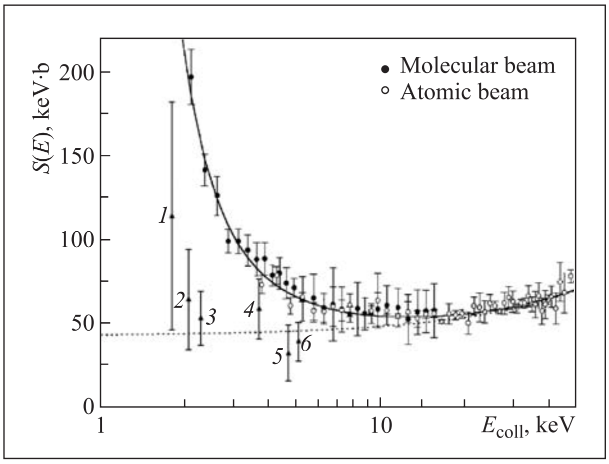

Fig. 9. Astrophysical S factors for the dd reaction as a function of the deuteron collision energy. Closed circles, closed triangles and closed squares are the data from other publications using TaD target (CD_2target). Points *1–4* are the results obtained with the liner plasma accelerator, *5–6* (CD_2 target) — with the Hall accelerator

measurement of the S factors and cross sections of the pd, dd and d^3He reactions with the use of the plasma in the Z-pinch configuration is rather problematic. The absence of reproducibility of the experimental conditions from «shot» (the act of the accelerator operation) to «shot» caused by the specificity of the work of accelerators of this class imposes certain restrictions on accuracy of the measurements. This stimulated development of alternative methods for formation of intense charged-particle beams in the ultralow energy region. For further research we developed and built a pulsed ion source with the closed Hall current allowing acceleration of plasma ions H^+, D^+ and $^3He^+$ in the collision energy range $E_{\rm coll} = 2-12$ keV. The preliminary results of measuring the astrophysical S-factor and effective cross sections for the dd reaction using the deuterated polyethylene target (CD_2) in the experiment at the created Hall accelerator of the Scientific Research Institute of Nuclear Physics (Tomsk, Russia) are as follows:

$$S(4.7\ \text{keV}) = (31.9 \pm 16.9\,(\text{stat.}) \pm \pm 3.2\,(\text{syst.}))\ \text{keV}\cdot\text{b},$$

$$\tilde{\sigma}_{dd}(4.3 < E_{\rm coll} < 5.1\ \text{keV}) = = (3.2 \pm 1.7\,(\text{stat.}) \pm 0.3\,(\text{syst.}))\cdot 10^{-31}\ \text{cm}^2,$$

$$S(5.1\ \text{keV}) = (38.9 \pm 11.7\,(\text{stat.}) \pm \pm 3.1\,(\text{syst.}))\ \text{keV}\cdot\text{b},$$

$$\tilde{\sigma}_{dd}(4.7 < E_{\rm coll} < 5.5\ \text{keV}) = = 6.6 \pm 2.0\,(\text{stat.}) \pm 0.5\,(\text{syst.})\cdot 10^{-31}\ \text{cm}^2.$$

The observed values of the S factor and effective cross sections $\widetilde{\sigma}_{dd}$ for the dd reaction are in agreement with the results obtained by JINR group earlier in the experiments at liner plasma accelerators (in a configuration of both direct and inverse Z pinch). As seen from Fig. 10, there is a difference between the results of the dd experiment with the CD_2 and TaD (TiD) targets, which must be clarified. The preliminary results have confirmed the fact that the proposed technique using the Hall accelerator can be effective to study nuclear reactions between light nuclei in the ultralow energy region.

DUBTO is a joint JINR–INFN (Italy) experiment dedicated to studies of pion-nuclear interactions at energies below the Δ resonance with the use of visualization techniques such as the self-shunted streamer chamber technique, developed at JINR, and the nuclear photoemulsion technique. The streamer chamber is filled with the working gas mixture (at present, ^{4}He $+10^{-3}$ admixtures) at atmospheric pressure ($\rho(^4\text{He}) = 0.000178$ g/cm^{-4}).

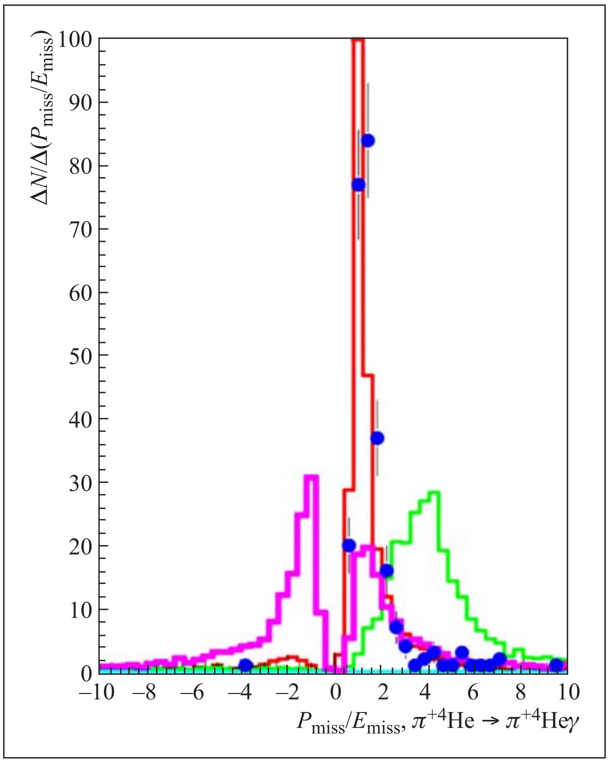

Fig. 10. Distribution of the ratio between missing momenta and missing energy for two-prong events identified as $\pi^{\pm}\ ^4\text{He} \to \pi^{\pm}\ ^4\text{He}\gamma$ events (experimental points); the simulated phase space histograms correspond to elastic scattering (two similar symmetric peaks), photon production (narrow high peak) and neutron knockout $\pi^{\pm}\ ^4\text{He} \to \pi^{\pm} n\ ^3\text{He}$

The main results include the first observation of the reaction channel $\pi^{\pm}\ ^4\text{He} \to \pi^{\pm}\ ^4\text{He}\gamma$ in pion interactions with helium nuclei (Fig. 10); revealed resonance behavior of the invariant masses $M_{\pi^+ nn}$ and $M_{\pi^- nn}$, measured in breakup reactions $\pi^{\pm}\ ^4\text{He} \to \pi^{\pm}\ ppnn$, and similar resonance behavior in double charge exchange (DCX) reactions of π^+ mesons in nuclear photoemulsion [20]. The first direct estimation of the muon neutrino mass from the $\pi^+ \to \mu^+\nu$ decay event was performed: $m_\nu < 2.2$ MeV [21]. At present ~ 25000 $\pi^{\pm}\ ^4$He interaction events have been obtained.

In 2006 the analysis of radiative pion decay (RPD) experimental data obtained by the **PIBETA** collaboration in 2004 in a special experiment was finished. This new experiment was necessary because in 1999–2001 experiment on the RPD in the kinematical region determined by the angle between the photon and the positron $\theta_{\gamma,e} > 40°$, the photon energy $E_\gamma > 55.6$ MeV and the positron energy $E_e > 20$ MeV (region B), $\sim 20\%$ less RPD events were recorded than it was expected according to the calculations based on the Standard Model (SM).

New data were obtained on the PSI pion beam with the 50–100 KHz stop rate. Such an intensity provided suppression of accidental coincidences by a factor of approximately an order of magnitude in comparison with the PIBETA experiment of 1999–2001.

Data treatment and analysis of the new data was carried out independently by two groups of the collaboration (from Virginia and from Dubna) in order to get more reliable results. Dubna physicists did not carry out such a delicate and labour-consuming analysis before.

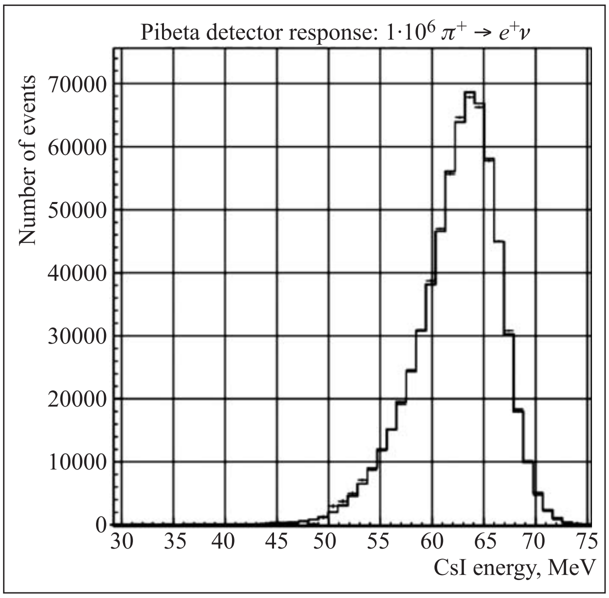

Fig. 11. Positron energy spectrum in $\pi^+ \to e^+\nu$ decay. The continuous curve is the Monte-Carlo simulation

In 2006 the collaboration treated and analyzed the whole experimental statistics on RPD ($\sim 6.12 \cdot 10^{11}$ pion stops). Decays $\pi^+ \to e^+\nu$ and $\mu^+ \to e^+\nu\nu$ necessary for energy calibration were investigated. About ~ 240000 $\pi^+ \to e^+\nu$ decays were analyzed. Positron energy spectrum in this decay is shown in Fig. 11. In Fig. 12 the measured spectrum of positrons in the decay

$\mu^+ \to e^+\nu\nu$ is shown. It is evident from the figures that the measured spectra well agree with calculation.

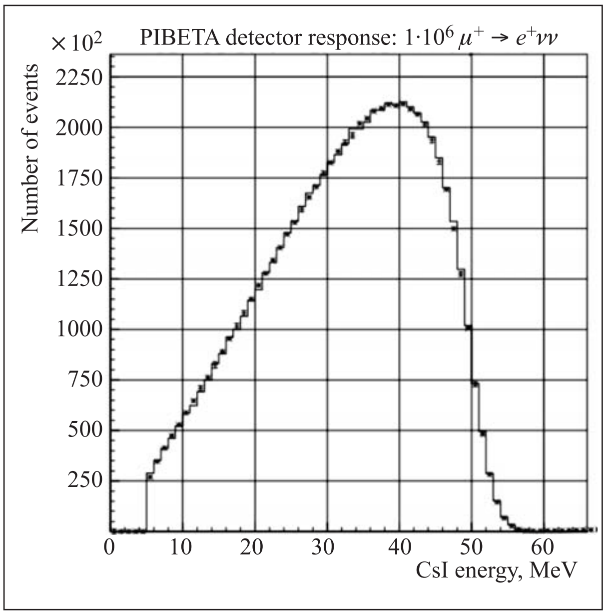

Fig. 12. Positron energy spectrum in $\mu^+ \to e^+\nu\nu$ decay. The continuous curve is the Monte-Carlo simulation

There have been found 17085 radiative pion decays. Of them 7261 events were defined in kinematical region B where the deficit of events was observed earlier. The distribution of these events as a function of the parameter $\lambda = (2E_a/m_\pi)\cdot\sin^2(\theta_{\gamma,e}/2)$ is shown in Fig. 13. The measured branching ratio of $\pi^+ \to e^+\nu\gamma$ in region B is $(14.59 \pm 0.26)\cdot 10^{-8}$, while the SM value is $(14.490 \pm 0.005)\cdot 10^{-8}$. Thus, the experimental data of 2004 are in good agreement with SM.

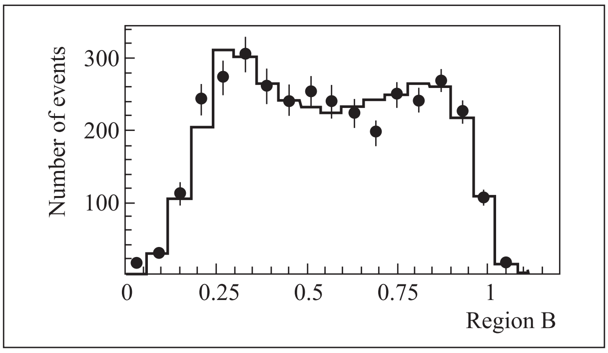

Fig. 13. Distribution of the $\pi^+ \to e^+\nu\gamma$ events as a function of the parameter $\lambda = (2E_a/m_\pi)\cdot\sin^2(\theta_{\gamma,e}/2)$. The continuous curve is the Monte-Carlo simulation

RELATIVISTIC NUCLEAR PHYSICS

Existence of the spinodal region for the hot nuclear matter was predicted more than 30 years ago. Nuclear rigidity is equal to zero on the border of this region. Experimental information about the spinodal state of nuclear matter is gained by studies of the process of nuclear multifragmentation. The **FASA** collaboration made a remarkable contribution in this field [22].

The spinodal decomposition is associated with the *liquid–fog* phase transition in a nuclear system rather than with the *liquid–gas* transition. This scenario is evidenced by the following observations made by a number of collaborations, and FASA too:

• density of the system at the breakup is 2–3 times smaller than the normal one ρ_0 [23];

• the lifetime of the fragmenting system is very small, $\sim 2\cdot 10^{-22}$ s (or ≈ 70 fm/c). It was measured for the first time in Dubna (1994) by analysis of IMF–IMF (imtermediate mass fragment) angular correlations [24];

• the breakup temperature ($T = 4{-}6$ MeV) is lower than the critical temperature for the *liquid–gas* phase transition, which is found by FASA to be $T_c = (17 \pm 2)$ MeV.

The last point is crucial for the statement about observation of the spinodal state of nuclear matter. Therefore, a new and more refined analysis of the data to get a more reliable value of the critical temperature and breakup volume was done in 2006 (see Fig. 14) [25]. It is found that $T_c \geqslant 18$ MeV and $V_t/V_0 = 3$ (or $\rho_t = 1/3\rho_0$).

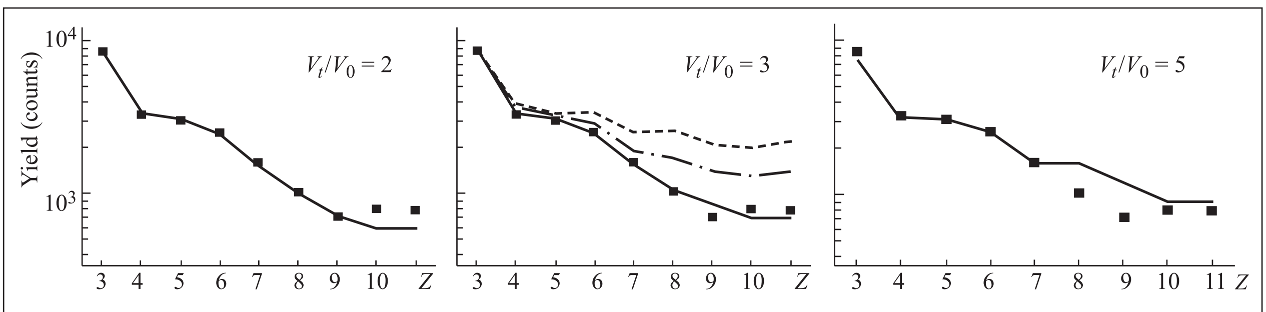

Fig. 14. IMF charge distributions for $p(8.1$ GeV$)$ + Au collisions. Symbols: measured IMF charge distributions. Solid lines: calculated IMF charge distributions assuming $T_c = 18$ MeV and breakup volumes indicated. Dashed and dot-dashed lines: calculated IMF charge distributions for $T_c = 7$ and 11 MeV

Modernization of the FASA setup was accomplished in 2006. The new setup, FASA-3, consists of 25 closely packed telescopes $dE(\text{gas}) \times E(\text{Si})$. It was created at the H. Niewodniczanski Institute (Cracow). It allows measurement of the IMF–IMF correlation both in respect to relative angle and in respect to relative velocity with selection of fragments by charge and energy.

Further experimental studies are of great interest for getting more information on the properties of the spinodal state of nuclear matter. The scenario of the spinodal decomposition is evidenced largely by the fact that the breakup temperature is smaller than T_c, critical temperature for the liquid–gas phase transition. The value of T_c obtained by the FASA collaboration supports this scenario. We plan to perform a new study to improve the reliability of determination of this *key thermodynamic parameter*.

APPLIED SCIENTIFIC RESEARCH

Computer modelling of the $^3He^{2+}$ ions dynamics for different frequency characteristics were performed within the framework of **JINR Phasotron** beams modernization programme. Simulation results show that for all frequency modes of operation none of ions succeeded in crossing of critical transition energy. It is necessary to provide special actions for changing the accelerating field parameters in the moment of critical energy crossing.

Under the JINR topic «**Physics and Technology of Particle Accelerators**» the cryogenic source of slow positrons (CSSP) for the LEPTA ring was tested. The experimental investigation of the slow positron flux from the CSSP was done with the ^{22}Na radioactive isotope of 0.8 MBq activity. The slow positron flux obtained had an intensity of $5.8 \cdot 10^3$ particles per second at an average energy of 1.2 eV with the spectrum width of about 1 eV (Fig. 15). The positron slowing-down efficiency was reached at the level of about 1%, which corresponds to the best world results. The characteristics of positron sources of such a design — dependences of the slow positron gain, the spectrum of slow positrons and the spectrum width on the freezing neon thickness — were measured for the first time.

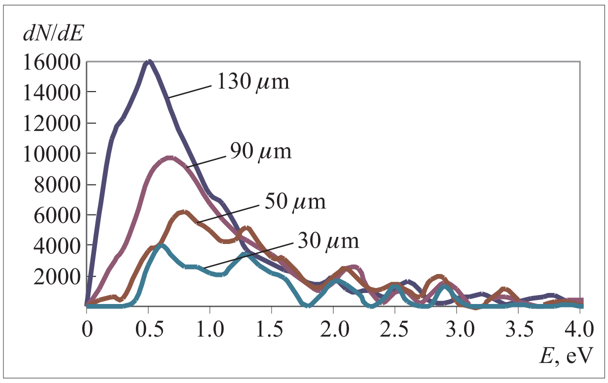

Fig. 15. Positron spectra at different thickness of the frozen neon layer obtained with the electrostatic spectrum analyzer

The positron trap was assembled and tested with the electron beam emitted by a special electron gun. The electron gun can emit the electron beam in the energy range of 10–50 eV with an energy spread of 3 eV and an electron current of a few hundred femtoampers. The number of electrons stored in the trap was as large as $N_{\max} = 1.7 \cdot 10^8$, which corresponds to the space charge limit for this trap. An electron lifetime of about 30 s was obtained (Fig. 16).

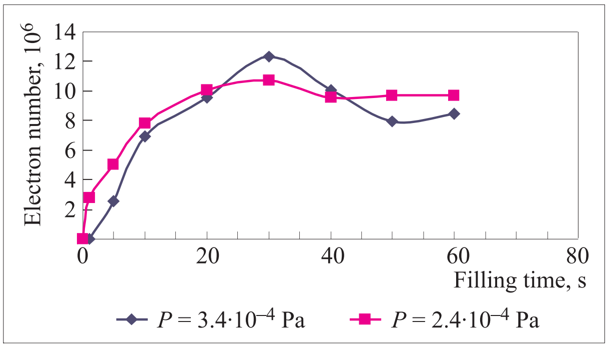

Fig. 16. Number of electrons stored in the trap vs storage time

The main goal of the topic «**Further Development of Methods and Instrumentation for Radiotherapy and Associated Diagnostics with the JINR Hadron Beams**» is to carry out medicobiological and clinical investigations on cancer treatment, to improve equipment and instrumentation, and to develop new techniques for treatment of malignant tumours and for associated diagnostics with medical hadron beams of the JINR Phasotron at the Medicotechnical Complex (MTC) of DLNP.

Radiotherapy of cancer patients was carried out with the use of the Rokus-M Co-60 gamma unit. A total of 49 patients received fractionated courses of treatment (about 2000 single irradiations) during 2006. Work on repairing the equipment damaged by fire was carried out. To date, the line for transportation of the therapeutic proton beam to the treatment rooms is completely ready for work. The results of measuring radioprotective action of 633-nm wavelength laser radiation on survival of the C3H10T1/2 fibroblast mouse cells under the action of gamma radiation or 150 MeV protons were analyzed. It turned out that both preliminary and subsequent laser irradiation of fibroblasts led to an increase in the survival of cells damaged with ionizing radiation (the value of the dose-changing factor is within 1.3–2.2). Simultaneous irradiation of the C3H10T1/2 cells with laser radiation and protons also led to an increase in their survival. It was found that the radioprotective action of the 633-nm wavelength optical radiations is transferred to the fibroblast cells according to the mechanism of the «bystander» effect, too. The results obtained show that the 633-nm laser radiation can be used in the process of radiation therapy or surgery for radioprotection of parts of the body, in particular, the skin or nasal and oral mucous membranes. A comparative analysis of the genetic action of γ-rays and fission neutrons on exons and introns of Drosophila genes was carried out. New data supporting the first finding about nonrandom distribution of DNA lesions within the gene under study detected by the PCR assay were obtained. The work on 2D-, 3D-simulation and visualization of the spatial arrangement of the male animal sperm genome was continued in collaboration with JINR LIT [26].

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