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DZHELEPOV LABORATORY OF NUCLEAR PROBLEMS: RESEARCH ACTIVITIES IN 2006

Report to the 101st Session
of the JINR Scientific Council
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The Dzhelepov Laboratory of Nuclear Problems (**DLNP**) carries out experimental research in high energy particle physics, investigation of nuclear structure and nuclear reactions, study of condensed matter properties; theoretical support of the experimental research; medico-biological investigations; development of new detector and accelerator systems as well as new experimental methods and facilities. Modern important trends in experimental astroparticle and underground physics are also under close consideration in the Laboratoryas well as the most new and interesting topics in the domain of neutrino physics.

Elementary Particle Physics

Contain the framework of the **ATLAS** project the main activity was concentrated on installation and commissioning of the ATLAS muon chambers that had been produced in previous years, preparation for the physics research after the beginning of ATLAS data taking, installation and support at ATLAS software in JINR; data preparation and distributed analysis of ATLAS data based on the Grid technology.

In 2006 connection and commissioning of the ATLAS BMS/BMF muon chambers (installed in ATLAS in 2005) continued. Connection 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 program 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 $1.3\cdot10^{-6}$ GeV (M_H=130 GeV/c^2) compared to $2.4\cdot10^{-7}$ 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 ~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 discowered, 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 improvesd by 5-10%) (Fig.1).

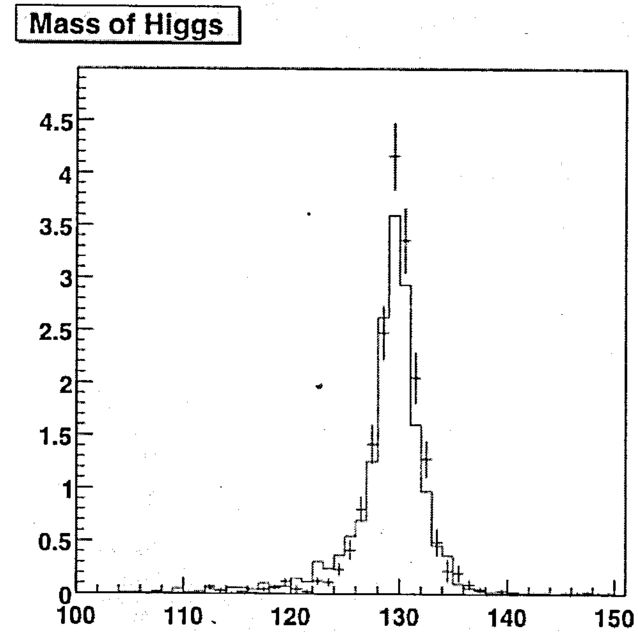

Fig.1. Reconstructed invariant mass of the Higgs boson, simulated by the PYTHIA (line) and SANC (crosses) generators.

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. Fig.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 3 years of 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 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 ($e/mip < 1$) was observed and, for the first time, its behaviour as a function of the absorber thickness (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) using single electron and pion GEANT4 Monte-Carlo simulation of the ATLAS hadronic calorimeter (TileCal) within ATHENA (common software framework of ATLAS) was carried out [7]. The study was based on the Monte Carlo Truth data provided by special GEANT4 Monte Carlo Simulation objects (Calibration Hits). This TSF value was used for reconstruction of TileCal single pions simulation data. It was done for the ATLAS Combined test beam 2004 (CTB2004) configuration setup. The results of the reconstruction were compared with the MC Truth and CTB2004 reconstructed experimental data. Good agreement between them shows quite evident improvement in the TileCal Monte Carlo Data reconstruction of hadronic shower energy in the electromagnetic scale. 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: $e/h = 1.36 \pm 0.01$.

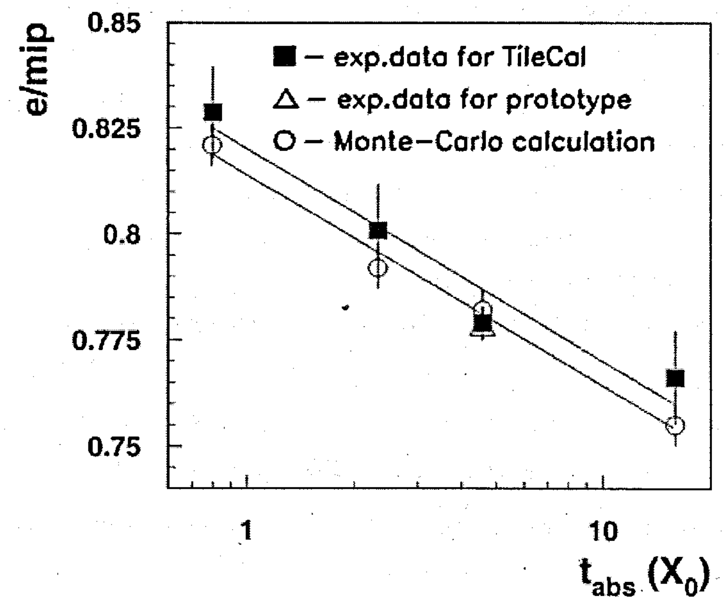

Fig.3. The e/mip ratio as a function of the absorber thickness t_{abs} of the Tile calorimeter period (in radiation lengths). Black squares are experimental points. The open triangle is the prototype result, open circles are the GEANT4 (version 6.2) Monte-Carlo calculations for the TileCal test beam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

In **2007** the collaboration plans to perform hadronic calibration of the ATLAS calorimeter, dead material energy loss studies on the Monte-Carlo hadronic calibration hist data; to perform the investigation of the ATLAS Combined calorimeter performance on the basis of experimental data of the ATLAS Combined test beam in 2004 and Monte-Carlo simulations.

Project **SANC** 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 $f_1\bar{f}_1HZ \to 0$ into 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 semi-leptonic decay widths [11] are continued. Work on SANC application to LHC physics is been 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.

During the year **2007** the SANC system is supposed to be extended for more complicated processes up to $1 \to 4$ decays and processes $2 \to 3$. In particular, it is planned: to complete the implementation of charged-current fermion-boson processes; to include the processes $gg \to BB$; $\gamma\gamma \to BB$ ($B = Z, \gamma, H, W$) at one loop; to continue creation of environment for one-loop calculations of $5 \to 0$ processes.

The main results of the **JINR/CDF** group in 2006 are the measurement of the top-quark mass (M_{top}) and providing efficient operation of the CDF II. A contribution of principal significance to precise single M_{top} measurement in "lepton + jets" topology [12], $M_{top} = 173.4 \pm 2.5(stat.+JES) \pm 1.3(syst.)$ GeV/c^2 "Lepton + jets" mode, was made. Method was updated for the top-quark mass measurement in the dilepton decay channel. Work on the M_{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_{top} is proposed by the University of Athens/Dubna group. The transverse momentum of electrons and muons produced in the $t\bar{t} \to dilepton$ and the $t\bar{t} \to lepton + jets$ channels are sensitive to M_{top}

and can be accurately measured providing the M_{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 2-particle correlations can be measured [13].

In **2007** the JINR/CDF group plans to reduce the error of the M_{top} to a level of 2 GeV/c^2 which will enable us to establish new limits on the Higgs-boson mass, to measure the top quark charge to make sure it is consistent with the SM and to continue VHM study at CDF II

During this year the main efforts of the collaboration **DIRAC** 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^2 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.

In **2007** the collaboration plans to perform the data taking for observation of the atoms consisting of π^+K^- and π^-K^+ mesons and for improvement of the accuracy in the lifetime measurement of $\pi^+\pi^-$ atoms.

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 (Fig.4). As a result, the electronic detectors recorded the first neutrinos sent from the CERN SPS (Fig.5). 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 [14, 15].

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.

Fig.4. OPERA electronic detectors are ready for data taking.

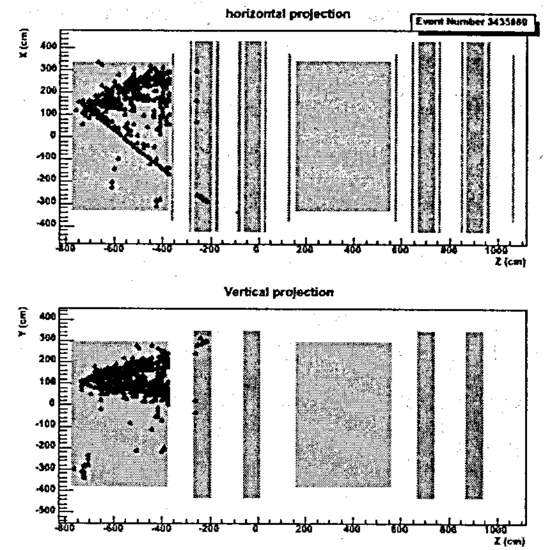

Fig.5. First neutrino events recorded in OPERA.

The main goal of OPERA in **2007** is to start up the detector with a full target and detection of the neutrinos in the emulsions. The JINR group will keep working on the Target Tracker software development, will take part in the data taking runs, and will continue creation of the scanning station for the emulsion scanning.

The **TUS** space experiment has been proposed to address some of the most important astrophysical and particle physics problems. It aimed to measure 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 the 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 this year 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, Russia) and LAPP (Annecy, France) scientific groups has measured the fluorescent light yield.

The aim of the **NUCLEON** project is direct CR 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 was fulfilled at the RADUGA. The beam test at SPS CERN 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, 4800 m.w.e.) is searching for neutrinoless double-beta decay ($0\nu\beta\beta$) which would be an indication of new fundamental physics beyond the Standard Model. Recent oscillation experiments (Super Kamiokande, SNO, and KamLand) has proved that neutrinos are massive particles. The study of $0\nu\beta\beta$ decay is one of the best ways to solve the remaining fundamental problems, such as the absolute neutrino mass scale, the nature of the neutrino (either Dirac or Majorana), and the neutrino hierarchy. The main goal of the NEMO project is to reach the 0.1-0.3 eV sensitivity for the effective majorana neutrino mass $<m_\nu>$ ($T_{1/2}^{0\nu\beta\beta}$ (^{100}Mo) up to ~ 10^{25} years).

NEMO-3 records tracks (in 20 m^3 volume with 6180 Geiger cells) and energies (1940 scintillator/PMT channels) of two electrons emitted from thin foils (30-60 mg/cm^2) of $\beta\beta$-decay sources (^{100}Mo, ^{82}Se, ^{150}Nd, ^{96}Zr, ^{116}Cd, ^{130}Te, ^{48}Ca). This so-called *tracko-calo* method gives unique information (single electron energy

spectrum, angular distribution between electrons, etc.), which cannot be obtained with other geochemical and calorimetric methods of $\beta\beta$-decay measurements.

The results obtained for double beta decay are presented in the next Table [16]:

Nuclei	Half-life, y
^{100}Mo	$7.11 \pm 0.02(stat.) \pm 0.54(syst.) \cdot 10^{18}$
^{82}Se	$2.8 \pm 0.3(stat.) \pm 1.0(syst.) \cdot 10^{19}$
^{116}Cd	$2.8 \pm 0.1(stat.) \pm 0.3(syst.) \cdot 10^{19}$
^{150}Nd	$9.7 \pm 0.7(stat.) \pm 1.0(syst.) \cdot 10^{19}$
^{96}Zr	$2.0 \pm 0.3(stat.) \pm 0.2(syst.) \cdot 10^{19}$
^{48}Ca	$3.9 \pm 0.7(stat.) \pm 0.6(syst.) \cdot 10^{19}$

The following limits for neutrinoless double beta decay and for neutrino mass the next limits were obtained: $T_{1/2}(^{100}Mo) \geq 5.8 \cdot 10^{23}$ y, $\langle m_\nu \rangle \leq 0.6-1.0$ eV, $T_{1/2}(^{82}Se) \geq 2.1 \cdot 10^{23}$ y, $\langle m_\nu \rangle \leq 1.2-2.5$ eV.

The double beta decay of ^{100}Mo to the 0_1^+ and 2_1^+ excited states of ^{100}Ru was studied using the NEMO-3 data. After the analysis of 8024 h of data the half-life for the two neutrino double beta decay of ^{100}Mo to the excited 0_1^+ state is measured to be $T_{1/2}(2\beta 2\nu) = [5.7^{+1.3}_{-0.9}(stat.) \pm 0.8(syst.)] \cdot 10^{20}$ y. the signal-to-background ratio is equal to 3. Information about energy and angular distributions of emitted electrons is also obtained. No evidence for neutrinoless double beta decay to the excited 0_1^+ state was found. The corresponding half-life limit is $T_{1/2}(2\beta 0\nu) > 8.9 \cdot 10^{22}$ y (at 90% C.L.).

The search for the double beta decay to the 2_1^+ excited state has allowed the determination of the half-life limits for the two-neutrino mode $T_{1/2}(2\beta 2\nu) > 1.1 \cdot 10^{21}$ y (at 90% C.L.) and for the neutrinoless mode $T_{1/2}(2\beta 0\nu) > 1.6 \cdot 10^{23}$ y (at 90% C.L.).

The new program with the aim to extend the threshold energy region is assumed by **ANKE** collaboration. Single pion production in proton-proton 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. With aim to extend this region, the **ANKE** collaboration at COSY (Juelich) assumed a program, which was launched by measurement of the differential cross sections of the $pp \to (pp)_s \pi^0$ process at 0.8 GeV [17]. Despite the cross sections are over two orders of magnitude smaller than those of $pp \to d\pi^+$, the process is well identified (Fig.6). The angular dependence of the cross section (Fig.7) 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.

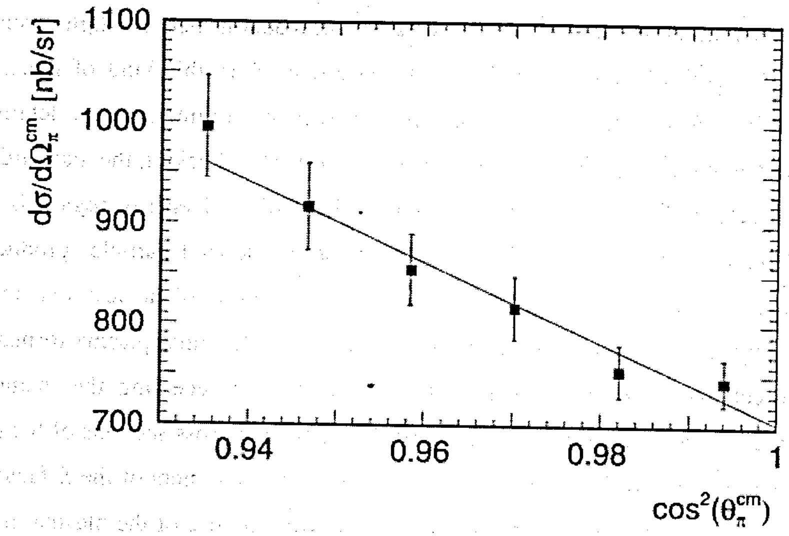

Fig.6. Reactions seen at the momentum correlation plot in the ANKE experiment at 0.8 GeV.

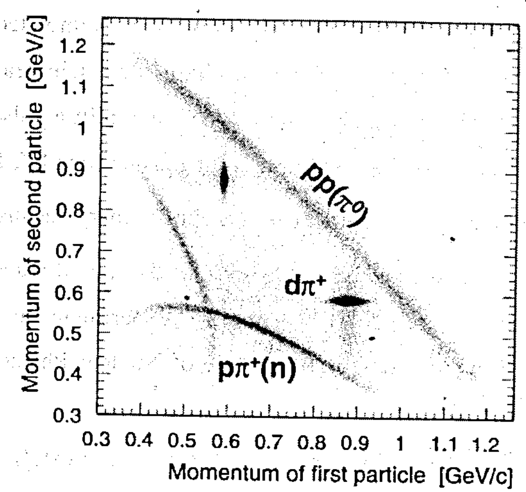

Fig.7. Angular dependence of the $pp \to (pp)_s \pi^0$ differential cross section for the relative energy in the proton pair $E_{pp} < 3$ MeV.

Within the framework of the **LESI** project reactions between light nuclei (pd, dd, d^3He) at 2-12 keV are studied [18]. 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.8). However the highly accurate 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_{coll} = 2-12 keV. The preliminary results of measuring the astrophysical S-factor and effective cross sections for the dd reaction with using the deuterated polyethelene target (CD_2) in the experiment at the created Hall accelerator of the Scientific Research Institute of Nuclear Physics (Tomsk, Russia) are follows:

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

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

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

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

The observed values of the S-factor and effective cross sections $\tilde{\sigma}_{dd}$ for the dd reaction are in agreement with the results obtained by us earlier in the experiments at liner plasma accelerators (in a configuration of both direct and inverse Z-pinch). As seen from Fig.8, 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 with using the Hall accelerator can be effective to study nuclear reactions between light nuclei in the ultralow energy region.

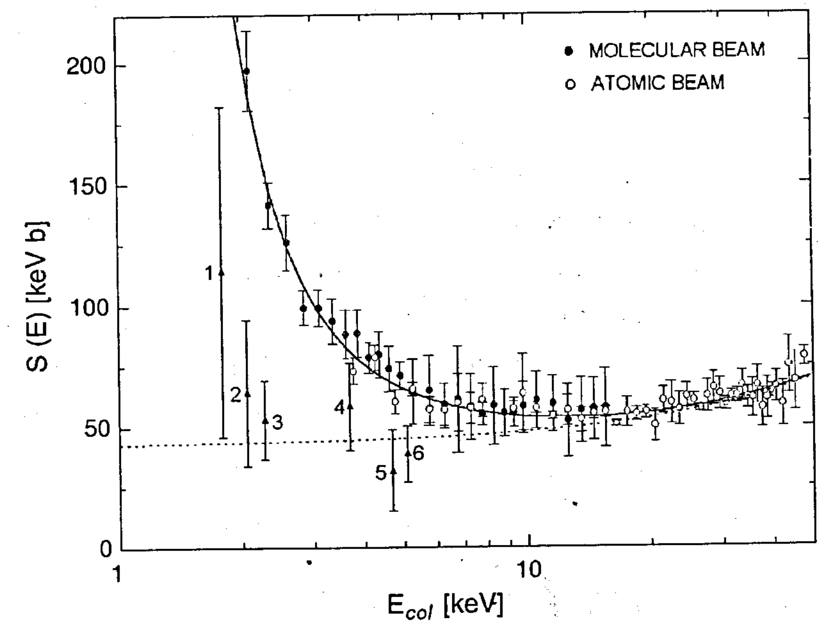

Fig.8. Astrophysical S-factors for the dd reaction as a function of the deuteron collision energy. Closed circles, closed triangles and closed squares are the data from other publications with using TaD target (CD_2 target) . Points 1-4 are the results obtained with the liner plasma accelerator, 5-6 (CD_2 target) – with the Hall accelerator.

In **2007** the collaboration plans to optimize the main parameters of ion flows at the output of the Hall accelerator (achievement of the ion current density on a target $j \geq 1$ A/cm^2); to research conditions of ion beam transportation from the source up to the target ensuring operation of the source in the frequency mode f = 1Hz, by means of optical radiation detectors, an energy analyzer, a pulse sensor of pressure. For research of the dd- reactions in the ultralow energy region the collaboration plans to carry out joint experiments on investigations of the dd reaction at ultralow energies with using high-power ion accelerators at the Federal State Scientific Institution "Scientific Research Institute of Nuclear Physics" (Tomsk, Russia); to develop techniques of detection of nuclear reaction products and diagnostics of the plasma flux formation using the Hall ion source and two counterstreaming plasma flows, propagating across the magnetic field and to get a clearer picture of the processes in the collision region of two counterstreaming plasma flows, propagating across magnetic field.

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, $^4He+10^{-3}$ admixtures) at atmospheric pressure ($\rho(^4He) = 0.000178$ g/cm^{-4}) and serves simultaneously as a triggerable vertex detector and a tracking device; the chamber is situated in a magnetic field and is equipped with two CCD video cameras for recording of nuclear events occurring in the chamber volume.

The main results include: the first observation of the reaction channel $\pi^{\pm} {}^4He \to \pi^{\pm} {}^4He\gamma$ in pion interactions with helium nuclei (Fig.9); revelaled of resonance behaviour of the invariant masses M_{π^+nn} and M_{π^-nn}, measured in breakup reactions $\pi^{\pm} {}^4He \to \pi^{\pm} {}^4ppnn$, and similar resonance behaviour in double charge exchange (DCX) reactions of π^+-mesons in nuclear photoemulsion

[19]. The first direct estimation of the muon neutrino mass from the $\pi^+ \to \mu^+\nu$ decay event was performed: $m_\nu < 2.2$ MeV [20]. At present ~25000 $\pi^{\pm} {}^4He$ interaction events have been obtained.

In **2007** the collaboration plans to continue the systematic study of elastic and inelastic pion-nucleus interactions, including the reaction channel in which the photon is produced, and pion absorption for revealing nuclear medium effects and possible FSI signatures and to implement these measurements includes further measurement of $\pi^{\pm} {}^4He$ reaction.

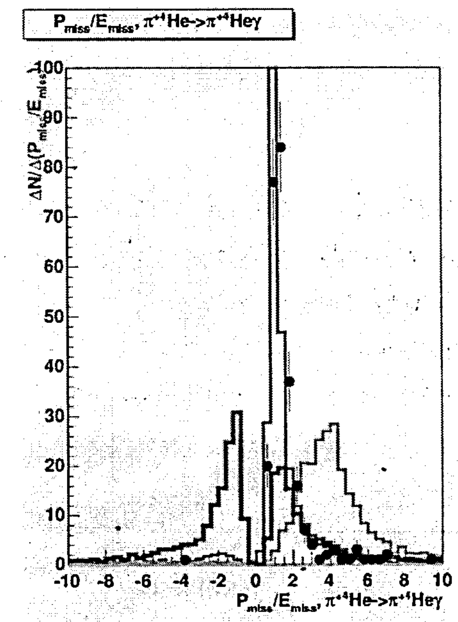

Fig.9. Distribution of the ratio between missing momenta and missing energy for two-prong events identified as $\pi^{\pm} {}^4He \to \pi^{\pm} {}^4He\gamma$ events (experimental points); the simulated phase space histograms correspond to elastic scattering (two

similar symmetric peaks), photon production (narrow high peak) and neutron knockout $\pi^{\pm}\,{}^4He \to \pi^{\pm} n\,{}^3He$.

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 $\theta_{\gamma,e} > 40^\circ$, the photon energy $E_\gamma > 55.6$ MэB and the positron energy $E_e > 20$ MэB (region B), ~ 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 intensity provided suppression of accidental coincidences by factor 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 our collaboration (from Virginia and from Dubna) in order to get more reliable results. Dubna physicists did not carry out such delicate and labour-consuming analysis before.

In 2006 the collaboration treated and analyzed the whole experimental statistics on RPD, according ~ 6.12 × 10^{11} pion stops. Decays $\pi^+ \to e^+\nu$ and $\mu^+ \to e^+\nu\nu$ necessary for energy calibration were investigated. About ~ 240000 decays $\pi^+ \to e^+\nu$ were analyzed. Positron energy spectrum in this decay is shown in Fig.10. In Fig.11 the measured spectrum of positrons in the decay $\mu^+ \to e^+\nu\nu$ is shown. It is evident from the figures that the measured spectrums well agree with calculation.

The 17085 decays RPD were founded. 7261 events from them 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.12. 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.

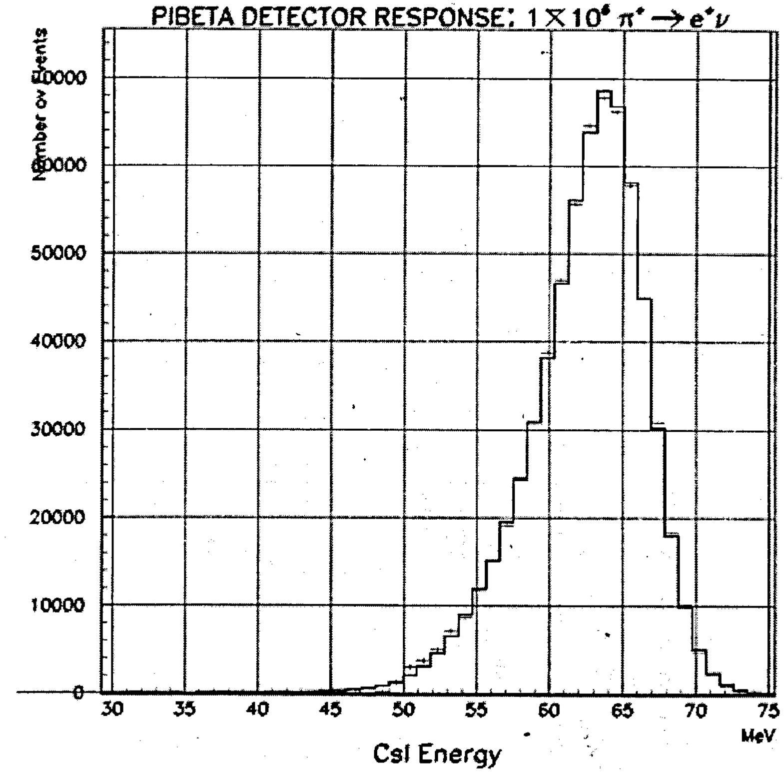

Fig.10. Positron energy spectrum in $\pi^+ \to e^+\nu$ decay. The continuous curve is the Monte Carlo simulation.

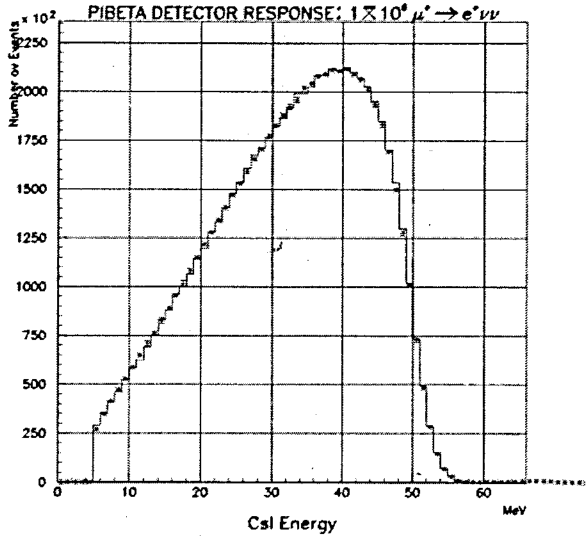

Fig.11. Positron energy spectrum in $\mu^+ \to e^+\nu\nu$ decay. The continuous curve is the Monte Carlo simulation.

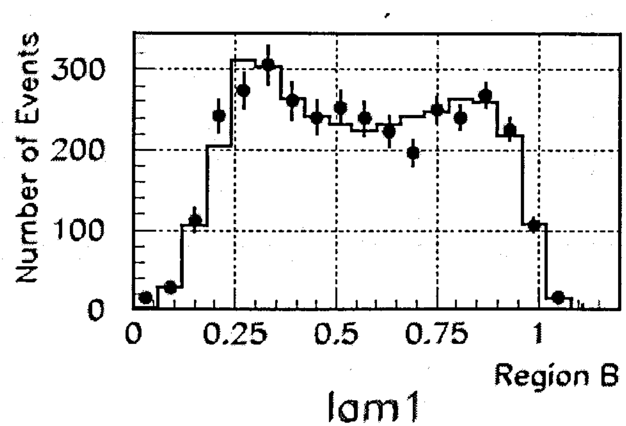

Fig.12. Distribution of the $\pi^+ \to e^+\nu\gamma$ events as a function of the parameter $\lambda = (2E_a/m_\pi)\cdot\sin^2(\theta_{\gamma,e}/2)$. The continuous curve is the Monte Carlo simulation.

In **2007** it is planned to repair and to improve the spectrometer PIBETA within the framework of the new project PEN. The goal of the PEN project is precise measurement of $\pi^+ \to e^+\nu$ decay with the accuracy 0.05 – 0.1 %. Such accuracy is equal toor better than the accuracy of theoretical calculations. In 2007 optimization of the necessary pion beam will be done. The PEN project is a work of the highest priority at PSI.

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 [21].

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 break-up is 2-3 times smaller than the normal one ρ_0 [22];
- the life-time of the fragmenting system is very small, ~$2\cdot10^{-22}$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 [23];
- the break-up 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 the new and more refined analysis of the data to get a more reliable value of the critical temperature and break-up volume was done this year (see Fig.13) [24]. It is found that $T_c \geq 18$ MeV and $V_t/V_0 = 3$ (or $\rho_t = 1/3\rho_0$).

Modernization of the FASA setup was accomplished in 2006 – FASA-3. FASA-3 consists of 25 closely packed telescopes $dE(gas) \times E(Si)$. It was created at the H.Niewodniczanski Institute (Cracow). It allows measurement of the IMF-IMF correlation both in respect to relative angle and 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. In **2007** new measurements of the IMF-IMF correlation function will be performed with the specification of charges and energies of both coincident fragments. Detailed information on the emission time and the space configuration of the system at the moment of disintegration will be obtained. New experimental study will be performed to clarify the details of the earlier stage of the reaction. First of all, it concerns the non-equilibrium emission of the intermediate mass fragments ($Z = 3-6$). This process is not well studied and seems to be puzzling. The collaboration plans to develop a procedure for separation of these fragments to measure their yield, energy spectra and angular distributions. Detection of the non-equilibrium fragments will be used as a trigger of the collision moment. The inclusion of these fragments in the correlation measurements together with IMF's from the statistical disintegration is the way to determine the *total* time scale of the reaction. It has never done before. The scenario of the spinodal decomposition is evidenced largely by the fact that the break-up 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.*

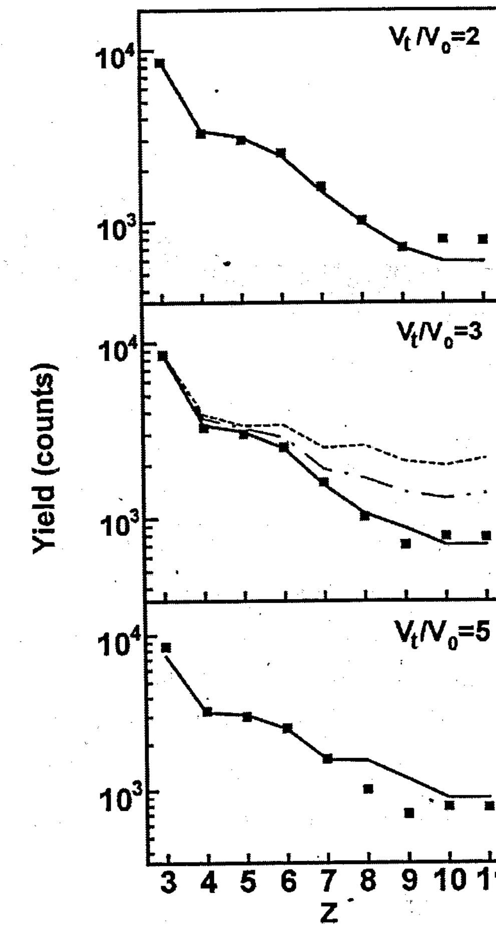

Fig.13. IMF charge distributions for $p(8.1\, GeV) + Au$ collisions. Symbols: measured IMF charge distributions. Solid lines: calculated IMF charge distributions assuming $T_c = 18$ MeV and break-up volumes indicated. Dashed and dot-dashed lines: calculated IMF charge distributions for $T_c = 7$ and $T_c = 11$ MeV.

Computer modelling of the $^3He^{2+}$ ions dynamics for different frequency characteristics were performed within the framework of **JINR Phasotron** beams modernization program. 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 activity of 0.8 MBq. 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.14). 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.

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 the energy spread of 3 eV and the 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. The electron life time of about 30 s was obtained (Fig.15).

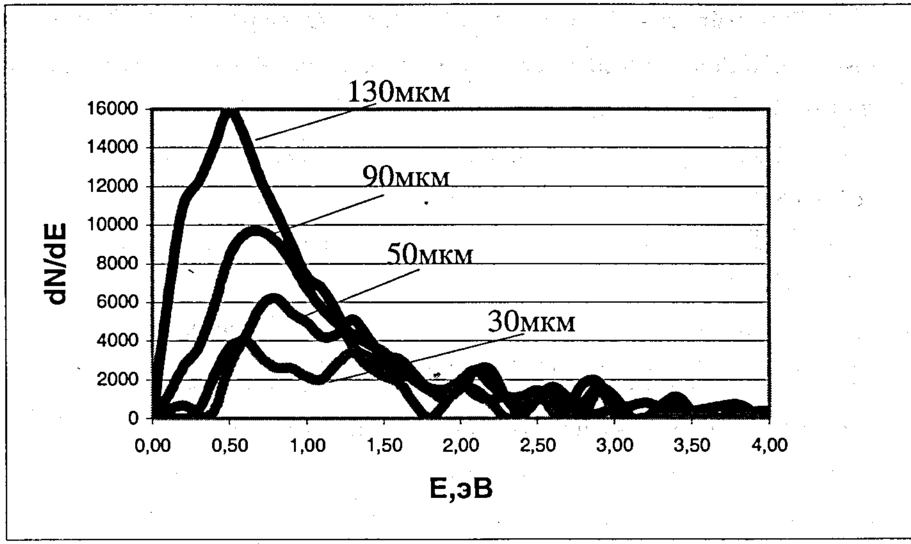

Fig.14. Positron spectra at different thickness of the frozen neon layer obtained with the electrostatic spectrum analyzer.

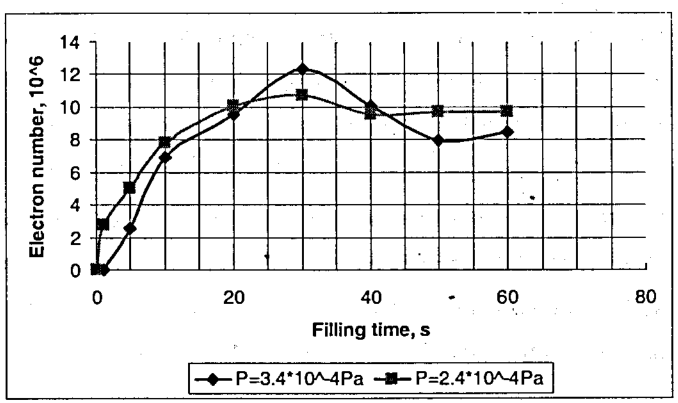

Fig.15. Number of electrons stored in the trap vs storage time.

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 medico-biological 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 Medico-technical complex (MTC) of DLNP.

Radiotherapy of cancer patients was carried out with the use of the Co-60 gamma-unit "Rokus-M". A total of 49 patients received fractionated courses of treatment (about 2000 single irradiations) during 2006. The work on repairing the equipment damaged by fire equipment 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 non-random 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 [25].

In **2007** it is planned to continue clinical research on proton therapy of different neoplasms with the JINR Phasotron beams in MTC treatment room No 1. The developed technique of prostate cancer treatment with the proton beam will be tested. The mechanism and regularities of the radioprotective effect of the 633-nm optical radiation on fibroblast cells will be investigated. The combined action of the gamma radiation and protons on mouse cells will be studied for the determination of the optimum combined irradiation regimen in radiotherapy. It is proposed to continue the fundamental researches on the comparative mutagenesis at the DNA gene level after action of different quality radiation and on the simulation of genomic macroarchitecture as well.

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