DZHELEPOV LABORATORY OF NUCLEAR PROBLEMS

NEUTRINO PHYSICS AND RARE PHENOMENA

In 2010, the **OPERA** experiment continued to collect data at the CNGS neutrino beam. At the end of the run about 4500 events were registered in the target at the integrated luminosity of $4.5 \cdot 10^{19}$ pot. Currently, the analysis of those data is carried out at 10 institutes both in Japan and in Europe (including JINR), where the automatic scanning stations are available. Analysis of the 2008–2009 data has brought a very important result: for the first time a candidate for the tau-neutrino event was registered in the muon–neutrino beam [1]. This is the first worldwide observation of the neutrino oscillations in the appearance mode (Fig. 1).

The main scientific result obtained with the **Borexino** detector is the first high significance (99.997% CL) confirmation of the geoneutrino presence in the registered antineutrino spectra [2]. A definite antineutrino signal is detected, well above the background, with the energy spectrum corresponding to the one expected due to decays of radioactive elements from the ^{238}U and ^{232}Th chains in the Earth. In this way, the presence of the radiogenic contribution to the terrestrial heat is confirmed for the first time (Fig. 2).

In the scope of the geoneutrino studies the ^{214}Bi spectrum shape was analyzed from the CTF (Borexino prototype) data, which is of interest from the point of view of the geoneutrino modeling [3]. The model-independent limits on the antineutrino fluxes at the Gran Sasso laboratory were set using the antineutrino data.

The main purpose of the **GEMMA** experiment is the measurement of the (anti)neutrino magnetic moment with the sensitivity at the level of $(4-7) \cdot 10^{-12}\ \mu_B$.

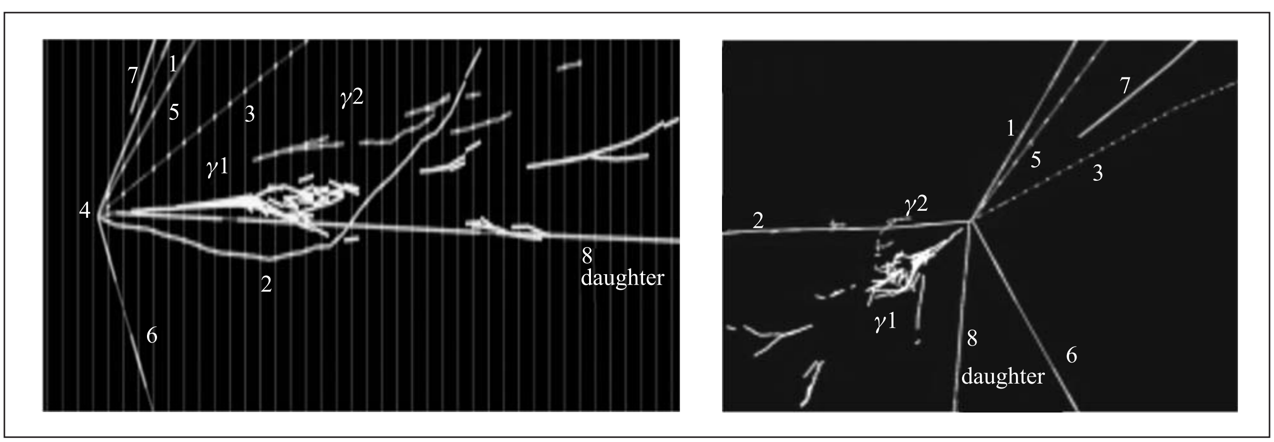

Fig. 1. The first candidate for the tau-neutrino event in the muon–neutrino beam

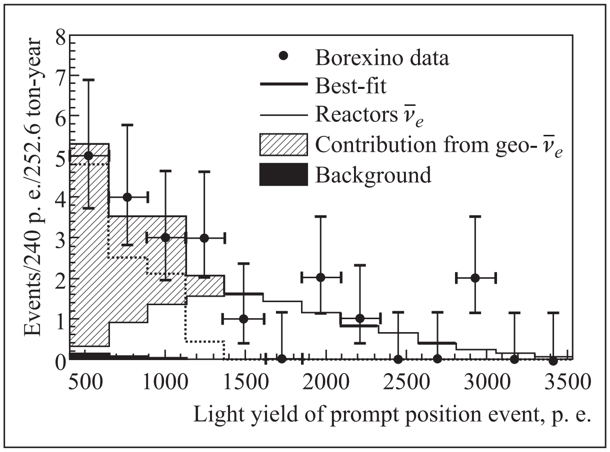

Fig. 2. Experimental antineutrino spectrum registered by Borexino during 537 days of the data taking. Expected contributions from geoneutrinos (shaded region) and reactor antineutrinos (thin line) are presented normalized to their best fit values. The background contribution (black region at the scale origin) is negligible

The GEMMA spectrometer consists of a 1.5 kg HPGe detector surrounded with a combined active and passive shielding. It is placed under 3 GW reactor 2 of the Kalininskaya Nuclear Power Plant 13.9 m away from the core centre. Analysis of the GEMMA-I data allowed the world's best upper limits to be obtained for the neutrino magnetic momentum at 90% CL with and without the atomic ionization mechanism: $5.0 \cdot 10^{-12}$ μ_B and $3.2 \cdot 10^{-11}$ μ_B, respectively. Upgrade of the spectrometer has been started.

The **NEMO-3** detector located in the Modane Underground Laboratory (LSM, France) is searching for neutrinoless double-beta decay which would be an indication of new fundamental physics beyond the Standard Model, such as the absolute neutrino mass scale, the nature of the neutrino (either Dirac or Majorana), and the neutrino hierarchy. The goals of the NEMO-3/SuperNEMO projects are to reach respective sensitivities of $0.2-1.0/0.04-0.1$ eV for the effective Majorana neutrino mass $\langle m_\nu \rangle$ $(T_{1/2}^{0\nu 2\beta}\left({}^{100}\mathrm{Mo}\right)/\mathrm{T}_{1/2}^{0\nu 2\beta}\left({}^{82}\mathrm{Se}\right) \sim 4 \cdot 10^{24}/2 \cdot 10^{26}$ y).

In 2010, the NEMO-3 detector is completing the data taking. The total NEMO-3 statistics accumulated from February 2003 till November 2010 is ~2246 days (6.1 years). The updated results of the $2\nu\beta\beta$-decay search based on the use of 4.5 years of the data taking were $T_{1/2}^{0\nu 2\beta}\left({}^{100}\mathrm{Mo}\right) > 10^{24}$ y, $\langle m_\nu \rangle < 0.47 - 0.96$ eV (90% CL). The studies of the $2\nu\beta\beta$ mode are continued. The result of the ^{96}Zr half-life measurement is $T_{1/2}^{0\nu 2\beta}\left({}^{96}\mathrm{Zr}\right) = [2.35 \pm 0.14\,(\mathrm{stat.}) \pm 0.16\,(\mathrm{syst.})] \times 10^{19}$ y (Fig. 3) [4, 5].

The **EDELWEISS-II** experiment running with active participation of DLNP is an international quest for Non-Baryonic Cold Dark Matter in the form of WIMPs with Cryogenic HPGe Detectors. The aim of the experiment is to detect rare events of scattering of WIMPs from the Milky Way galaxy off germanium nuclei.

A total effective exposure of 322 kg·day was obtained after 12 months of EDELWEISS-II operation in 2009–2010. The observation of few nuclear recoil candidates above 20 keV is interpreted in terms of limits

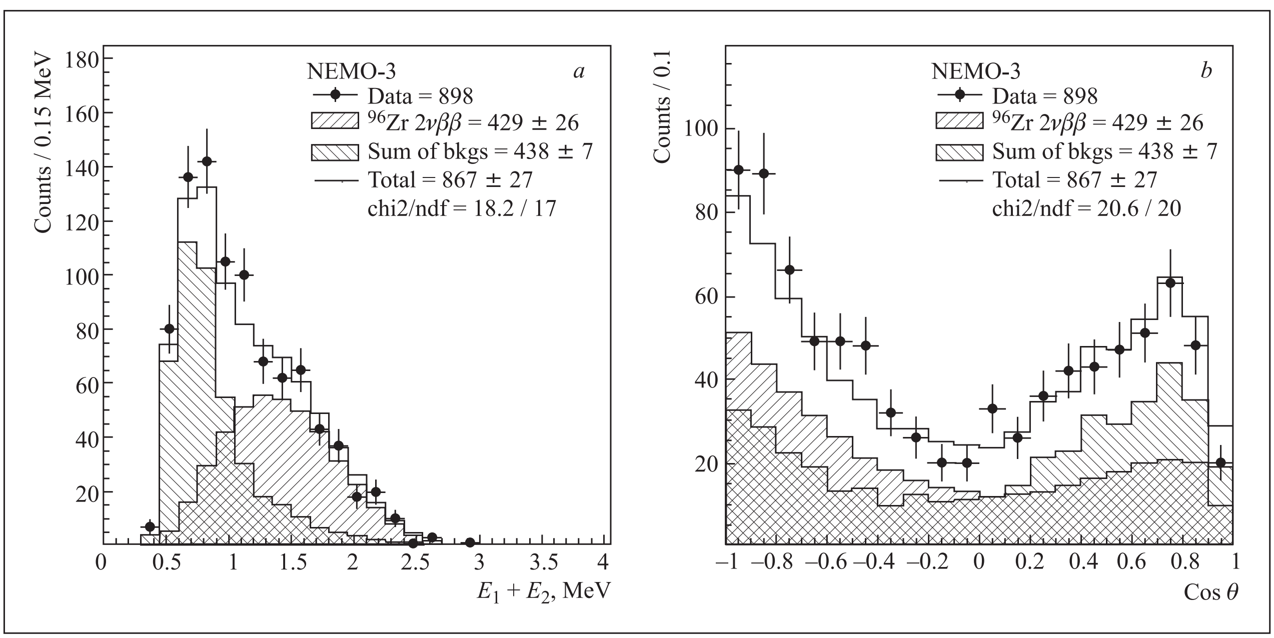

Fig. 3. Distributions of the total electron energy (a) and the angle between the electrons (b) in ^{96}Zr $2\nu\beta\beta$ process measured by the NEMO-3 detector

on the cross section of spin-independent interactions of WIMPs and nucleons. Cross sections of $5.0 \cdot 10^{-8}$ pb ($5.0 \cdot 10^{-44}$ cm^2) are excluded at 90% CL for WIMP masses of 80 GeV/c^2. This is one of three best results (together with CDMS and XENON100 experiments). Further analysis is going on in order to reduce the effective threshold of the detectors to better address the case of lower-mass WIMPs. The EDELWEISS Collaboration aims to increase the cumulated mass of the detectors in operation at the LSM, in order to soon probe the physically significant 10^{-44} cm^2 (10^{-8} pb) range of spin-independent WIMP–nucleon cross sections [6, 7].

GERDA and **MAJORANA** are a new generation of the experiments aimed to search for neutrinoless double-beta $0\nu\beta\beta$ decay of ^{76}Ge at a high level of sensitivity. Considerable progress in development and installation of the GERDA (GERmanium Detector Array) experiment [8] was made in 2010. Assembly of the GERDA setup was finished in summer 2010 and commissioning of the setup started since then by using the first test string with three naked germanium detectors from natural Ge placed inside the stainless steel cryostat which contains 90 tons of LAr. In the first half of 2010, scientists from JINR took an active part in assembling and installation of the LArGe setup designed as a prototype for the next phases of the GERDA experiment. In the second half of 2010, a wide programme of measurements with internal and external calibration sources was carried out. The BEGe (Broad-Energy Germanium) detector with the mass of 0.9 kg was deployed in the LArGe cryostat containing 1.4 t of liquid argon. The fist level of the plastic scintillator veto modules produced at JINR was installed on the top of the GERDA setup and test measurements of the count rate and veto efficiency was performed.

The **TUS** space experiment has been proposed to address some of the most important astrophysical and particle physics problems. It is aimed to study energy spectrum, composition, and angular distribution of the Ultra High Energy Cosmic Ray (UHECR) at 10^{19}–10^{20} eV in the region of GZK cutoff. The TUS detector will measure the fluorescence light radiated by the Extensive Air Shower of the UHECR. The TUS detector consists of a 7-segment Fresnel mirror-concentrator of 2 m^2 and a photoreceiver matrix at the mirror focal surface of 16×16 PMT pixels. JINR and the Rocket Space Corporation «Energia», Consortium «Space Regatta» (Korolev), are responsible for R&D and production of the Fresnel mirror-concentrator that is the most complicated TUS system due to operation in open space in the temperature range of ± 80°C. The full-scale technological Fresnel mirror prototype was produced in 2009. The flight TUS detector production is in progress. The mission is planned for operation at the end of 2011 at the dedicated «Mikhail Lomonosov» satellite [9].

The aim of the **NUCLEON** experiment is measurement of cosmic rays flux with high statistics near the «knee» region (energy range 10^{11}–$5 \cdot 10^{14}$ eV and charge range up to $Z \sim 30$) in the orbit space flight. It consists of the silicon and scintillator detectors, carbon target and tungsten γ-convertor. The JINR responsibility is the design and production of the NUCLEON scintillator trigger system including FE and digital electronics of the DAQ that will select useful events by the charged particle multiplicity measurement. The main task in 2011 is to produce and test the flight option of trigger electronics and the long-term stability tests of the technological trigger prototypes [10].

HIGH-ENERGY PHYSICS

The main results of the **CDF** project are obtaining of the CDF average mass of the top quark corresponding to the total uncertainty of 1.16 GeV/c^2, Higgs search, and maintenance of efficient operation of the CDFII. The total statistics obtained from Run-I (1992–1996) and Run-II (2001 till now) amount to 5.6 fb^{-1}. With due regard to the correlated uncertainties, the resulting preliminary CDF average mass of the top quark is $M_{\rm top} = 173.13 \pm 0.67({\rm stat.}) \pm 0.95({\rm syst})$ GeV/c^2, which corresponds to the total uncertainty of 1.16 GeV/c^2, or equivalently to a 0.67% precision [11, 12].

The combined results from **CDF and D0** at $\sqrt{s} = 1.96$ TeV were used for the direct search for the standard model (SM) Higgs boson H in $p\bar{p}$ collisions at the Fermilab Tevatron [13]. Compared to the previous Tevatron Higgs search, more data were added, additional new channels were included, and some previously used channels were reanalyzed to gain the necessary sensitivity. With up to 5.9 fb^{-1} of the analyzed data at CDF, and up to 6.7 fb^{-1} at D0, the 95% CL upper limits on the Higgs boson production cross section are 1.56 and 0.68 of the values predicted by the SM for the Higgs boson of the mass $m_{\rm H} = 115$ and 165 GeV/c^2. A new and larger mass region $158 < m_{\rm H} < 175$ GeV/c^2 was excluded at the 95% CL (Fig. 4).

In 2010, with the very first real data from **ATLAS** detector, the so-called minimum bias events, DLNP scientists have carried out search for and identification of ρ (770) and ϕ (1020) mesons, created in pp collisions at the LHC energy 7 TeV. The data relevant to the high multiplicity events were also studied for the collision energy of 900 GeV and 7 TeV. The attention was paid to study of jet identification uncertainties, jet calibration, and cross section measurements.

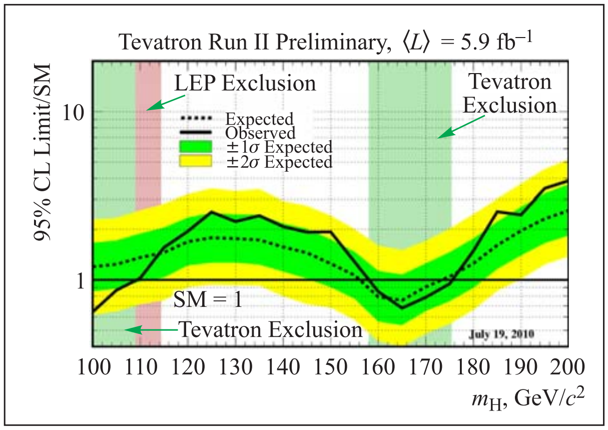

Fig. 4. New region for the Higgs mass

The data collected by the ATLAS experiment during the first months of the LHC run with 3.5 TeV proton beams and corresponding to the integrated luminosity of around 405 μb^{-1} were analyzed in order to observe ϕ(1020) mesons via their decays into two charged kaons. The kaons were identified by measurement of energy loss in the Pixel detectors of the ATLAS Inner Tracking System. Different approaches were used to fit the experimental data. They show agreement with the PDG values of the ϕ(1020) meson mass and width and consistency with each other.

DLNP physicists have drawn attention to a possible novel signal of new physics in dijet data from hadron collisions [14]. It is usually accepted that almost all exotic models predict that these two jets populate the central (pseudo)rapidity region where $y_{1,2} \sim 0$. By contrast, the excited Z^*-bosons do not contribute to this region but produce an excess of dijet events over the almost flat QCD background in $\chi = e^{|y_1 - y_2|}$ away from this region. With a special choice of parameters, this could lead to a dip in the centrality ratio distribution over the dijet invariant mass instead of a bump expected for the most exotic models. This interesting possibility is now under study with first ATLAS data.

A search for the exotic θ^+ (pentaquark) baryon via its decay into a proton and a neutral kaon was carried out by the DLNP scientists in 7 TeV proton–proton LHC collisions. The data collected by ATLAS experiment during periods A and B (76.1 million minimum-bias events) were analyzed. The neutral K_0 mesons were identified through their V_0-like decay into charged pion pairs, while protons were identified by measurement of energy loss in the Pixel detectors of the ATLAS Inner Tracking System. No evidence was observed for the narrow resonance in the selected set of ATLAS data, as opposed to the clear peaks from the known particles $K^*(890)+, \Lambda$ and $\Lambda(1520)$ states.

Since 2010, JINR has been participating in the new and rapidly evolving ATLAS Tier-3 activity. The aim of Tier-3 is analysis complementary to the data at Tier-2s. It allows interactive analysis of ATLAS data by individuals using local computing resources, speeds up data processing by paralleling with the aid of PROOF, and speeds up data access using distributed Xrootd data storage. A prototype ATLAS Tier-3 has been already installed at the DLNP computing farm.

Within the framework of the **DIRAC** project the six-month data-taking run with the Ni target for observation of atoms consisting of π^+K^- and π^-K^+ mesons and lifetime measurement of $\pi^+\pi^-$ atoms with the accuracy better than 6% was performed. The collected data exceed the amount of 2009 data by 30%. The data collected in 2001–2003 were processed and analyzed on the bases of the information from all detectors, the total amount of the observed $\pi\pi$ atoms is more than 21000. (Only 13300 atoms were reconstructed in the previous analysis.) The ground-state lifetime of $\pi^+\pi^-$ atoms was measured to be $\tau = 3.15 \cdot 10{-}15$ s, with the total statistical plus systematic error of about 9%. This allowed determining the $\pi\pi$-scattering length difference $|a_0 - a_2| = 0.253\ m_\pi^{-1}$, with the total error of about 4.3%, which is slightly better than the error of 5% anticipated for that stage of the experiment.

The work on application of the **SANC** results to LHC physics has been carried out since 2004. SANC currently includes theoretical predictions for practically all three-particle and many four-particle processes of the Standard Model at the one-loop accuracy level. The SANC group performed the precise analysis of Drell–Yan-type processes, which together with inclusion of the simplest QCD processes in the SANC environment and allowance for the contribution from photon sub-processes practically brought to the end this part of investigations. Then the group carried out precise calculations of the probabilities for semileptonic decays of the top quark. During 2010, the SANC system was extended for more complicated processes and works on its application to LHC physics. The main result of 2010 is the publications [15, 16] in collaboration with CERN physicists, which are directly concentrated with the analysis of the first experimental data on LHC.

LOW- AND INTERMEDIATE-ENERGY PHYSICS

Hadron interactions at intermediate energies were studied with the **ANKE** spectrometer at COSY (Julich). Hard bremsstrahlung production in proton–proton collisions was investigated. The deuteron photodisintegration, $\gamma d \rightarrow pn$, has long been used for studying fundamental properties of nucleons at short distances. Similar but independent information can be obtained from photodisintegration of diprotons. As there were no free diprotons, the latter was earlier investigated using diproton pairs formed within light nuclei,which resulted in high background. The process of inverse diproton photodisintegration $pp \to \{pp\}_s \gamma$, which is free of complications inherent in $\gamma d \to pn$ was studied [17]. In the 353–800 MeV beam energy range the differential cross sections were measured at small diproton c.m. angles. The energy dependence of the cross section reveals a broad peak consistent with excitation of the $\Delta\,(1232)\,N$ intermediate state. The cross section for diproton production in this reaction is two orders of magnitude smaller than for the deuteron photodisintegration.

The international **PEN** collaboration completed collection of statistics in the measurements of the branching ratio of the $\pi^+ \to e^+\nu(\gamma)$ decay at the Paul Scherrer Institute (PSI). The PIBETA facility at PSI was upgraded to be optimal for measuring the branching ratio of the $\pi^+ \to e^+\nu(\gamma)$ decay. A «massless» (structural material density 0.1–0.2 g/cm^3) time projection chamber m-TPC was made, which allowed vertices of pion decay in the target to be reconstructed and pion, muon, and positron energy loss to be corrected. The chamber also made it possible to eliminate events with pions and muons that decayed in flight. By now, $3.94 \cdot 10^{11}$ pions have been stopped in the experiment and $2.12 \cdot 10^7$ unfiltered $\pi \to e\nu$ decay events have been recorded, which corresponds to the statistical uncertainty better than $\delta B/ = 5 \cdot 10^{-4}$ [18].

In 2010, a regular data acquisition run was carried out at the **MEG** facility that was constructed to search for the $\mu^+ \to {}^+\gamma$ decay. Also, processing of the data collected in the previous runs is going on. The limitation for the decay probability obtained in 2010 from the results of the 2008 run is $< 2.8 \cdot 10^{-11}$ ($\sim 10^{14}$ muon decays analyzed). The data of the 2009 run should allow improvement in this value [19]. This decay is of interest in that while it is forbidden in the Standard Model, some fundamental theories allow its feasibility in the experiment like that. Therefore, this experiment has a good chance to get evidence for new physics beyond the Standard Model. Even if the decay is not detected at the given sensitivity level, limitations will be obtained for many exotic fundamental theories.

In 2010, the joint JINR–INFN (Italy) collaboration **PAINUC** continued handling and analyzing existing data on $\pi^\pm\ {}^4$He interactions, as well as working on improvement of the pion beam parameters at energies below the Δ-resonance. Among the results obtained one can note the observation of single γ-quantum production in the elastic scattering of negative pions at the energy of 68 MeV, this phenomenon was observed earlier at 106 MeV. If the nucleus is considered to be a black body, the Planck temperatures corresponding to the energies 106 and 68 MeV turn out to be 14.4 ± 1.6 MeV and 14.6 ± 1.1 MeV, respectively. In 2010, a semiempirical model of the excitation of collective resonances was developed. This model explains the parameters of inelastic pion scattering from nuclei in the Δ-resonance region, such as the distribution of three-nucleon invariant masses, observed in the absorption of positive pions in helium [20].

The experiments carried out in 2010 within **MUON** project were aimed at studying the interaction of the acceptor centers in germanium and in diamond by using polarized negative muons. In earlier experiments no frequency shift of the muon spin precession in diamond was observed at the level of $5 \cdot 10^{-3}$. The present experiment was performed at PSI (Switzerland) on the upgraded ALC setup in the 14 kG magnetic field in the range of 15–330 K in order to improve the measurement accuracy of the frequency shift. It was found that in polycrystalline diamond sample D6 the muon polarization amplitude did not depend on temperature and there was no positive (paramagnetic) shift of the muon spin precession frequency. However, there is a sufficient indication of the anomalously large negative frequency shift ($-1.4 \cdot 10^{-3}$) in the temperature range of 80–250 K. The observed shift seems to be much greater than that one may expect on the basis of the magnetic susceptibility and the chemical shift for ^{11}B, which is imitated by the muonic atom, in diamond. The accuracy of the muon precession frequency shift should be improved by measurements with higher statistics for a final conclusion [21, 22].

The study of the systems with the nanometer scale objects was continued. With the electronic paramagnetic resonance method, information about paramagnetic centers in the polymeric matrix of the membranes was obtained, the concentration of the nitroxyl radical and rotary mobility of the spin probe in them were determined. The patent was issued on the method of separating and purifying DNA and RNA on the monodispersed spherical particles with size 100–500 nm [23].

According to the recommendation of the 31st Session of the PAC JINR on nuclear physics, the project «Experimental Study of Nuclear Fusion Reactions in a $pt\mu$ System» (project **TRITON**) has been developed. The goal of the project is to obtain new experimental data on low-energy nuclear reactions catalyzed by negative muons in the hydrogen isotope medium in the area where they are lacking or contradict modern theory. Using muon catalysis, we address phenomena in pt fusion, which were previously investigated in only one experiment and now are at the frontier of nuclear few-body physics. The e^+e^--pair conversion for the pt reaction was not observed in flight (beam-target) and in the $pt\mu$ molecule. It would also be very important to clarify the existing discrepancy between theory and experiment in the $pt\mu$ system. For this purpose we propose an experiment to study fusion from muonic pt molecules: $pt\mu \to {}^4\mathrm{He}\mu{+}\gamma$, ${}^4\mathrm{He}{+}\mu(\mathrm{conv.})$, ${}^4\mathrm{He}\mu + e^+e^- + 19$ MeV.The experiment will be conducted at JINR (Dubna, Russia) using the TRITON installation. The 50 cc cryogenic target filled with liquid

pt mixture (1% T) will be exposed to the negative muon beam (10^4 s^{-1}, 100 MeV/c) of the JINR Phasotron.

Within the **NN-GDH** project the successful testing run of the Polarized Target in operating conditions with a trial data acquisition has been carried out with participation of DLNP physicists in December 2009. The investigations of spin asymmetries in the interactions of polarized photons with the polarized proton target at energies up to 1.5 GeV were actually started. In 2010, the runs with the polarized photon beam of the MAMI C accelerator on the New Polarized Target were successfully carried out according to the following experimental programme: first measurement of the spin asymmetry in meson photoproduction up to 1500 MeV using the linearly polarized photon beam and transversely polarized proton target; measurement of transverse asymmetries T and F in η photoproduction in the region of the S11(1535) resonance (circularly polarized photon beam and transversely polarized proton target); measurement of the helicity dependence of single and double pion photoproduction processes and the GDH integral on the neutron (circularly polarized photons up to 1450 MeV and longitudinally polarized deuteron target).

APPLIED RESEARCH AND ACCELERATORS PHYSICS

Today, cancer is the second highest cause of death in developed countries. Its treatment is still a real challenge. Protons and light ions allow depositing the radiation dose more precisely in a cancer tumor, reducing greatly the amount of dose received by healthy tissue surrounding the tumor. At JINR DLNP, possible causes of beam losses in the acceleration process at the **C235** medical proton cyclotron were investigated, the effect of the main resonances was analyzed, and the effect of the radial component of the magnetic field in the median plane of the accelerator was studied. Calculations and improvement of the extraction system were performed. The extraction efficiency increased from 60 to 77%. As a result of the studies, the design of the C235 cyclotron was substantially modified. New **C235 V3** version will be put into operation at the Federal Center of Nuclear Medicine in Dimitrovgrad (Ulyanovsk region). At present, all basic cyclotron systems are built. We plan to assemble this cyclotron at JINR in 2011 and perform tests with the extracted proton beam in 2012.

The last years have seen increasing interest in particle therapy based on $^{12}C^{6+}$ ions. In the scope of collaboration with IBA (Belgium) the computer modeling of the main systems and detailed simulations of the beam dynamics in the **C400** cyclotron have been performed. The results of the computer modeling show that the energy up to 400 MeV/u ($K = 1600$) can be obtained with the compact design similar to that of the existing IBA C235 cyclotron. Starting from the carbon ion source and using transmission efficiencies no larger than the calculated ones, we can estimate the ideal transmission of the carbon beam through the cyclotron. We find a transmission of 13% between the beam analyzed from the ion source and the beam extracted from the cyclotron. This is certainly on the high side, but this kind of transmission has been attained. The C400 cyclotron will also provide a proton therapy beam with the energy of 265 MeV. Losses of protons due to the charge exchange with the residual gas during acceleration will not exceed 10% and extraction will be without losses. The construction of the C400 cyclotron was started in 2010 within the Archade project (France) [24].

The main goal of the research in the scope of theme **«Medical and Biological Researches with the JINR Hadron Beams»** is to carry out medico-biological and clinical investigations on cancer treatment, to upgrade 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 in the DLNP medico-technical complex (MTC).

In collaboration with the Medical Radiological Research Centre (Obninsk) and the Radiological Department of the Dubna hospital, the regular sessions of proton therapy aimed to investigate its efficiency to treat different kinds of neoplasm were performed. During the year, seven treatment sessions, total duration of 28 weeks, were carried out. A total of 124 new patients were fractionally treated with the medical proton beam. The total number of the single proton irradiations (fields) exceeded 6000. Other 16 patients were irradiated at the Co-60 gamma-therapy unit «Rokus-M». A new technology for production of boluss (irregular-shape proton beam range modificators) was developed: boluses are made of special machinable wax with the help of a digital computer-controlled 3D milling machine. The technology allowed us to increase the reproducibility of the dose field formation in the proton treatment sessions. A model prototype of the multileave proton beam collimator with four pairs of leaves has been developed and constructed. The full-scale collimator will consist of 33 pairs of leaves and will be used in the so-called dynamic proton beam treatment technique.

Together with the Division of Radiation Dosimetry of the Institute of Nuclear Physics (Prague, Czech Rep.), secondary-particle background was measured in the patient treatment room using thermoluminescent and track detectors. On the basis of these measurements, the beam forming system in the treatment room was corrected. In collaboration with the Institute of Atomic Energy (Swierk-Otwock, Poland), the work on determination of the proton beam radiation quality factor with a recombination chamber was performed. In collaboration with the Great Poland Cancer Centre (Poznan, Poland), a series of dosimetric experiments was carried to verify the developed technique of bolus manufacturing from machinable wax. The results of the experiments proved the high accuracy of the proton beam dose formation with this technique, which allowed us to use it in the treatment sessions carried out at the MTC. Together with the Division of Radiation Dosimetry of the Institute of Nuclear Physics (Prague, Czech Rep.), the LET spectra of 135, 290, 400 MeV/u^{12}C ion beams were studied. Together with the International University Accelerator Centre (New Delhi, India), new thermoluminescent detectors produced from nanophosphors in India were studied. The work was done in the scope of the joint Russian-Indian RFBR grant in collaboration with the participants from the JINR Laboratory of Radiation Biology and FIAN.

An instrument variant of the laser irradiation device for protection of biological objects against the effect of ionizing radiation has been developed and constructed for practical use. The effect of 5-Gy gamma radiation itself and the combined effect of laser devices on survival, weight, and skin of C57VL/6 experimental mice was investigated [25].

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