DZHELEPOV LABORATORY OF NUCLEAR PROBLEMS

NEUTRINO PHYSICS AND RARE PHENOMENA

Within the **Daya Bay** Collaboration, a group of JINR scientists participated in measurement of the neutrino mixing angle θ_{13}. The mixing angle θ_{13} is one of three mixing angles describing the Pontecorvo–Maki–Nakagawa–Sakata neutrino mixing matrix named PMNS and it remained unknown till March 2012. The statistical significance of the published result exceeded five standard deviations, which allowed us to claim a discovery of a new type of neutrino oscillations due to the mixing between the first and the third neutrino generations described by the mixing angle θ_{13}. At the conference «Neutrino-2012», the Daya Bay Collaboration reported a new result based on a factor of 2.5 increase in the statstic and improvement in evaluation of the systematics uncertainties. The new result $\sin^2 2\theta_{13} = 0.089 \pm 0.010(\text{stat.}) \pm 0.005(\text{syst.})$ excludes the zero value of θ_{13} at about eight standard deviations [1–3].

The unambiguously proved existence of these oscillations opens up new possibilities for further studying the baryon asymmetry of the Universe, neutrino mass hierarchy, and other fundamental problems in elementary particle physics and astrophysics.

In 2012, the **OPERA** experiment continued to collect data in the CNGS neutrino beam, and about 4000 events were registered in the target. It was the last year of data taking with the CNGS beam. After five years of operation, OPERA collected a total of about 18000 neutrino interactions in the detector target. So far 56 charm events, 29 electron–neutrino events and 2 tau-neutrino events have been identified. Discovery of the second tau-neutrino event in the CNGS was reported at the «Neutrino-2012» conference. Currently, the analysis of the data continues at 10 institutes both in Japan and in Europe (including JINR), where the automatic scanning stations are available. In 2012, as a result of several checks, the technical reasons of the unexpected result for the neutrino velocity were realized, and the correct measurements were performed by OPERA with the bunched CNGS beam. Finally, the neutrino velocity was measured to be equal to the speed of light with the highest up-to-date precision [4–6].

In 2012, the Dubna group of the **Borexino** Collaboration participated in the data-taking shifts and took an active part in the physical analysis of the accumulated data within the «antineutrino», «rare physics», «*pp*-neutrino» and «backgrounds» working groups. An achievement of this year is significant background reduction during the devoted purification campaign. The analysis of the current data resulted in the following values for the most important contaminants: $^{85}\text{Kr} < 6.4\,\text{cpd}/100$ tons; $^{232}\text{Th} < 2.2 \cdot 10^{-18}$ g/g; $^{238}\text{U} = (3.3 \pm 1.4) \cdot 10^{-19}$ g/g; $^{210}\text{Bi} = 17 \pm 3\,\text{cpd}/100$ tons; $^{210}\text{Po} < 400\,\text{cpd}/100$ tons. The results of the first measurement of the solar *pep*-neutrino flux and limits on the CNO-neutrino flux are published at the beginning of the year [7]. In another paper, Borexino confirmed the absence of the day-night variations in the Be-7 neutrino flux at the 1% level [8]. The Borexino data has been used to set limits on the hypothetical 5.5 MeV solar axions that can be produced in the $p + d \to {}^3\text{He} + \text{A}$ reaction in the Sun. The limits are 2–4 orders of magnitude stronger than those obtained in previous laboratory-based experiments using nuclear reactors and accelerators [9].

The **EDELWEISS-II** experiment is dedicated to the direct detection of WIMPs trapped in the Galactic halo. The minimal purpose of the experiment is to achieve sensitivity to an important class of SUSY models («Focus Point») predicting the cross section between a nucleon and a WIMP of the order of 10^{-44} cm^2, corresponding approximately to one collision per day per 500 kg of matter. Recently the EDELWEISS Collaboration demonstrated that the background limiting sensitivity of the experiment mainly arises from the inability to reject events occurring close to the surface of the detector, for which deficient charge collection can mimic the ionization yield of nuclear recoils. Despite advances in reducing the surface contamination in EDELWEISS-II (mostly due to ^{210}Pb daughters), sensitivity levels were still limited to $5 \cdot 10^{-43}$ cm^2. Therefore, within EDELWEISS, detectors with an innovative interleaved electrodes design (ID detectors) were developed. They are able to discriminate against events occurring within 1 mm from the detector surface. In 2012, this technology was further developed using fully interdigitized FID800 detectors (all surfaces covered by ring electrodes). In comparison to ID detectors, FID800 detectors show at least an order-of-magnitude improvement of background suppression. About 10 kg of new detectors were tested and calibrated in 2012. Together with the new detectors, the whole experimental setup was updated in 2012, first of all it was cryogenic system, shielding, and new fast data acquisition.

An important result of EDELWEISS in 2012 was obtained for the so-called low-mass WIMPs. For WIMPs of mass 10 GeV/c^2, the observation of one event in the WIMP search region results in a 90% CL limit of $1.0 \cdot 10^{-41}$ cm^2 on the spin-independent WIMP-nucleon scattering cross section, which constrains the parameter space associated with the findings reported by the CoGeNT, DAMA, and CRESST experiments. This extends our search from the traditional region where our limits on the WIMP-nucleon spin-independent cross section derived from the previous data is $4.4 \cdot 10^{-44}$ cm^2 for a WIMP mass of 85 GeV/c^2 [10].

The **SuperNEMO** project is aimed to search neutrinoless double beta decay ($0\nu\beta\beta$), which would allow testing the neutrino nature, absolute mass scale and hierarchy, and shedding light on a set of fundamental principles of physics: CP violation, leptogenesis, GUTs. With $\sim$ 100 kg of ^{82}Se or/and ^{150}Nd $\beta\beta$-source, SuperNEMO plans to go two orders of magnitude further in comparison with NEMO-3 in sensitivity, $T_{1/2}$ $(0\nu\beta\beta) \sim 1 \cdot 10^{26}$y (effective Majorana mass $\langle m_e \rangle \sim 30-100$ meV), which is at the level of the world's best new generation projects in the field. Within the NEMO-3 experiment, data analysis and preparation of publications were in progress during 2012 (NEMO-3 experiment was terminated in 2011). The NEMO-3 «$\beta\beta$-factory» has successively reached all its goals claimed in the original proposal. A lot of excellent results were obtained for seven isotopes ^{100}Mo, ^{82}Se, ^{116}Cd, ^{130}Te, ^{150}Nd, ^{96}Zr, and ^{48}Ca, including different modes: $0\nu\beta\beta$, $2\nu\beta\beta$, transition to excited states, right currents, etc. The obtained limit T$_{1/2}$ $(0\nu\beta\beta) > 1.0 \cdot 10^{24}$ y (90% CL) corresponds to the limit on the effective Majorana mass $\langle m_e \rangle < 0.31-0.96$ eV, which is compatible with the world's best results.

The **BES-III** experiment at the Beijing electron–positron collider BEPC-II continued to take data in 2012. Together with the data collected in 2009–2011, the BES-III experiment has the world's largest samples of J/ψ (1.2 billions of events), ψ' (0.5 billions of events), ψ(3770) (2.9 fb^{-1}) and ψ(4040) (0.5 fb^{-1}). In addition, several energy scans were carried out during 2012, including the scan near the τ-production threshold, lineshape scans around J/ψ and ψ' and data taking in the range 2.2–3.4 GeV for the R-ratio measurement.

Several interesting physics results were obtained and published in 2012. Spin–parity analysis of the pp-mass threshold structure in J/ψ and ψ' radiative decays was performed [10]. Quantum numbers of the new structure $X(pp)$ were identified as 0^{-+}, its properties and product branching ratio were determined [11] The isospin violating decay $\eta(1405) \rightarrow f_0(980)\pi^0$ was observed for the first time in both the charged and the neutral modes [12]. Measurements of the η_c mass and width in $\psi' \rightarrow \gamma\eta_c$ were accomplished and published, providing the currently world's best results [13]. The analysis of the first observation of the η_c(2S) state in charmonium decays was completed and published in 2012 [14]. The direct two-photon transition was observed in the charmonium system for the first time in the reaction $\psi' \rightarrow \gamma\gamma J/\psi$, which could be useful for better understanding of X, Y, Z states and the charmonium system in general [15]. Preliminary results were obtained in the branching ratio measurements of the leptonic decay $D^+ \rightarrow \mu^+\nu_\mu$ and semileptonic decays $D^0 \rightarrow K^+e^-\nu_e$ and $D^0 \rightarrow \pi^+e^-\nu_e$. The main efforts of the JINR group in 2012 were concentrated on several physics topics. One was the light hadron spectroscopy performed in collaboration with the PNPI group (Gatchina). The partial wave analysis of $J/\psi \rightarrow KK\pi$ was completed and reported to the Collaboration. Now it is being prepared for publication. The branching ratio and the helicity basis form factors were measured in the semileptonic decay $D^+ \rightarrow K\pi^+e^+\nu_e$ using the $\psi(3770)$ data sample. The analysis is close to completion and the analysis memo is being prepared. This year, the JINR group analyzed data of the J/ψ lineshape scan taken in May 2012 with the aim to measure the phase shift between EM and strong amplitudes in J/ψ decay. The $J/\psi \rightarrow \rho\pi$ cross section was measured at several energy points around J/ψ. The preliminary results were reported to the collaboration. Interpretation of the results and fitting to obtain the phase shift are under way.

The **TUS** space experiment is aimed to study the energy spectrum, composition, and angular distribution of the UltraHigh Energy Cosmic Ray (UHECR) at $E \sim 10^{20}$ eV. The fluorescent and Cherenkov radiation of Extensive Air Showers (EAS) generated by UHECR particles will be detected on the night side of the Earth's atmosphere from the space platform at heights of 400–500 km. There are two main parts of this detector: a modular Fresnel mirror and a matrix of PMTs with related DAQ electronics. In 2012, comprehensive TUS equipment tests were done on the board of the «Michail Lomonosov» space platform. The space mission is planned for the second part of 2013. The optical parameter measurements of the TUS Fresnel mirror were fulfilled at JINR [16]. Groups from Romania (ISS) and Ukraine (KNU) joined the TUS experiment preparation. Preparation of simulation, on-board express-analysis, and off-line EAS-event reconstruction programmes is in progress.

The main aim of the **NUCLEON** space experiment is measurement of the cosmic ray flux, composition and possible anisotropy of the cosmic rays in the energy range 10^{11}–5.10^{14} eV. The NUCLEON mission is planned for operation at the end of 2013 at the RESURS-type satellite with the exposure time in the orbit about five years. The JINR responsibility is the design, production, and tests of the NUCLEON trigger system including the FE and DAQ electronics to produce the 1st and 2nd level trigger signals. The flight model of the NUCLEON detector was tested at the SPS CERN in 2012. The off-line analysis of the collected data is in progress. Now the detector is being prepared for the comprehensive tests at Samara space center Progress together with the RESURS-P2 space platform.

HIGH-ENERGY PHYSICS

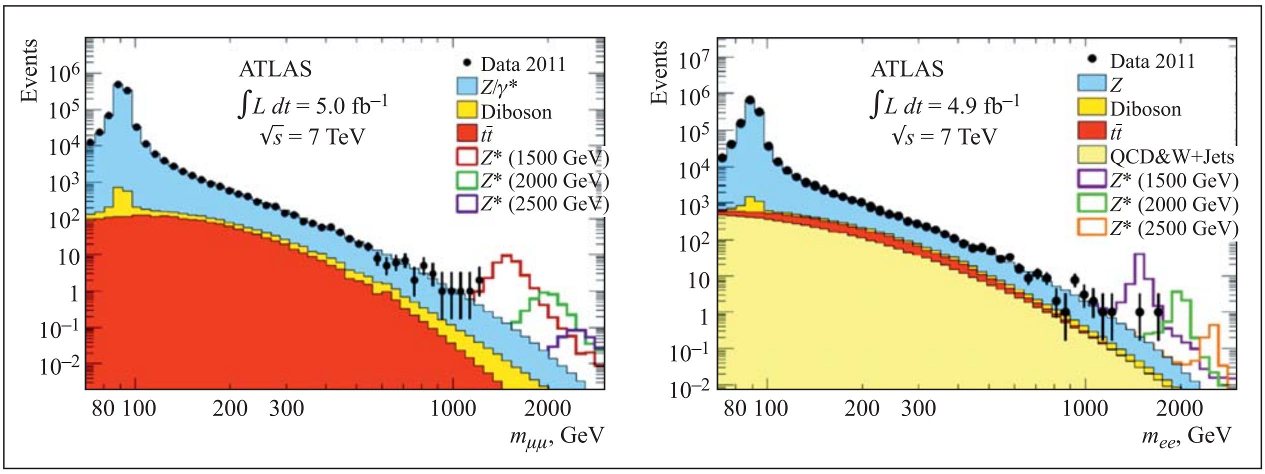
A long-expected positive result was obtained in the search for the Higgs boson at **ATLAS** in 2012. An appreciable contribution to the preparation and conduct of the experiment was made by the DLNP scientists from the Department of Colliding Beams, Hadron Processes, New Accelerators, and the Sector of Elementary Particles and a few other Laboratory divisions.

The ATLAS beam from JINR performed inclusive search for supersymmetry (SUSY) in the ATLAS experiment at the LHC in proton–proton collisions at a center-of-mass energy $\sqrt{s} = 7$ TeV in final states with seven or more jets, missing transverse momentum and one isolated electron or muon. The search was based on the data from the full 2011 data-taking period, corresponding to an integrated luminosity of 4.7 fb^{-1}. This final state signature is very useful for QCD background suppression and could correspond to intermediate heavy SUSY particle production. Observations are consistent with Standard Model expectations, and limits are set on a number of SUSY models: MSUGRA/CMSSM, simplified models and a model with bilinear R-parity violating couplings embedded inside MSUGRA/CMSSM [17]. Further plans include data analysis with «data-driven» background estimation.

The JINR ATLAS group presented the results of the search for the new excited Z boson at the ATLAS detector in 2011 [18]. The results were based on the analysis of *pp* collisions at a center-of-mass energy of 7 TeV corresponding to an integrated luminosity of 4.9 fb^{-1} in the dielectron channel and 5.0 fb^{1}in the dimuon channel (see the Figure). Since good agreement between experimental data and expectation of the Standard Model was observed in both channels, the existence of Z^* was excluded at the 95% confidence level for all masses below 2.20 TeV

The main results of the **CDF project** are the «Tevatron average» mass of the top quark obtained with the total uncertainty reduced to 0.94 GeV/c^2, study of the correlations in high-multiplicity charged hadron events, the first Dubna tests of the LYSO-type crystals to be used as elements of the e.m. calorimeter for Mu2e experiment at FNAL, and tests of the scintillator counter efficiency in the neutron beam.

Using top–antitop pairs at the Tevatron proton–antiproton collider, the CDF and D0 Collaborations with the participation of the Dubna group measured the top-quark mass in different final states for integrated luminosities up to 5.8 fb^{-1}. The combination



The invariant mass distributions for the dimuon (left) and dielectron (right) channels. Experimental data are compared with the sum of the Standard Model backgounds and three Z^* samples overlaid of these measurements results in a more precise value of the mass than any individual decay channel can provide. Considering correlated uncertainties, the resulting Tevatron average mass of the top quark is $M_{\rm top} = (173.18 \pm 0.56({\rm stat.}) \pm 0.75({\rm syst.}))$ GeV/c^2, which corresponds to the total uncertainty of 0.94 GeV/c^2, or the precision of $\pm 0.54\%$ [19, 20], making this the most precise determination of the top-quark mass.

The $K_2(n)$, $K_3(n)$ energy correlators, components of the correlators, and their ratios $R_3(n)$ as a function of charged hadron multiplicity, n, for $p_T > 0.5$ GeV/c and $|\eta| < 1$ in $p\bar{p}$ interaction at 1.96 TeV were studied using the Tevatron CDF2 detector and the data collected with the minimum-bias and high-multiplicity triggers. We corrected correlators for the track reconstruction efficiency. For the first time, the shape of the correlators K_2, K_3 and their ratio R_3 in the high-multiplicity region are investigated. For the high-multiplicity processes, $n \geqslant 22$, the mean energy slowly increases with multiplicity; the ratio $R_3(n)$ for events with no jets of energy above 14 GeV and the multiplicity larger than 22 is below one and decreases to ≈ 0.4 if the multiplicity reaches 36; the chemical potential μ increases with n slower than αn^2 predicted by the theory. The mean value of R_3 in the investigated multiplicity region is $0.610 \pm 0.079 \pm 0.025$.The observed value of $R_3(n) < 1$ and the increase in $\mu(n)$ with $n \geqslant 22$ are the very first experimental evidence for the thermalization phenomenon. There is disagreement between the Monte Carlo and experimental results.

To understand the neutron background influence on the Mu2e cosmic ray veto system, test measurements of the plastic scintillator counter were performed on the neutron beam line of the IREN facility at JINR, Dubna. The very first estimates of the neutron detection efficiency for the neutron kinetic energy range of 1.18–4.7 eV and for the range of 0.032–0.16 eV were found to be about $3 \cdot 10^{-4}$ and $4 \cdot 10^{-4}$, respectively.

Within the framework of the **DIRAC** experiment the six-month data-taking run for observation of the long-lived (metastable) states of $\pi^+\pi^-$ atoms was performed. About $5.1 \cdot 10^9$ primary events were collected. Before the data taking began, a new permanent magnet required for this measurement was produced. The magnet poles of 60 mm along the beam were made of Sm-Co and provided the 2550-Gs field at the magnet center. The radiation hardness of the magnet is 2 orders of magnitude higher compared to the magnet hardness used in 2011. Since the new magnet has the different size and weight, a new support and retractable mechanism was designed and produced. In parallel with the main data taking, statistics required for 1%-accurate measurement of multiple scattering in thin metal foils was collected and a new ionization hodoscope with a higher granularity was tested in the DIRAC setup for further setup upgrading. The off-line software was modified.

The **SANC** project includes theoretical predictions for many 3- and 4-particle Standard Model (SM) processes at the one-loop precision level (QCD and EW NLO). In 2012, two new 4-boson processes were implemented into the SANC environment : the production process $\gamma\gamma \to \gamma Z$ and decay $Z \to 3\gamma$, and the standard SANC modules for the processes of the single-top production at the LHC were described. Further application of the SANC results to the analysis of the ATLAS data is going on [21, 22]. We continued evaluation of the so-called «missed higher-order corrections», that is, those which are not taken into account by the standard ATLAS programmes for simulation of cross sections for the W- and Z-boson production. The main result of 2012 is creation of advanced versions of Monte-Carlo tools (integrator and generator) for the analysis of the LHC data with allowance for the interplay of the next-to-leading (NLO) QCD and EW corrections. A careful analysis of the contribution of QED radiation from final-state charged leptons for the processes at the LHC was performed. These results are important for increasing the precision of data processing and are already used for evaluating the overall theoretical uncertainties in the analysis of Drell–Yan-like production processes.

In 2012, a new technology was developed for making modules of the electromagnetic calorimeter for the **COMPASS-II** and **NICA/MPD** experiments. The new technology is based on using shashlyk-type scintillation structures and on reading out the signals by silicon avalanche photodetectors of a new generation proposed at JINR. A prototype COMPASS-II electromagnetic calorimeter consisting of 504 towers was beam-tested at CERN, where it showed the required parameters. The new technology will also be used for the NICA/MPD electromagnetic calorimeter.

LOW- AND INTERMEDIATE-ENERGY PHYSICS

The **SPRING** experiments were carried out with the ANKE setup at the COSY accelerator in the field of intermediate-energy hadron physics using polarized proton (deuteron) beams and/or polarized hydrogen (deuterium) jet targets. The results of the experiments on near-threshold pion production using polarized beams are published [23, 24]. Measurement of the differential cross section and vector analyzing power in the reactions $\vec{p}p \to \{pp\}_s\,\pi^0$ and $\vec{p}n \to \{pp\}_s\,\pi^-$ made it possible to perform phase analysis and extract complex amplitudes of the processes. The amplitudes will then be analyzed within the chiral theory in order to establish relation between the pion production in nucleon–nucleon collisions and the low-energy three-nucleon scattering.

The neutron–proton charge-exchange amplitudes were studied [25]. In the reaction $\vec{d}p \to \{pp\}_s n$ at the deuteron energies 1.2, 1.6, 1.8, and 2.27 GeV, the differential cross section and two tensor analyzing powers Axx and Ayy were measured. At the energies of 1.2 and 2.27 GeV, the experiment was also done in a double polarized approach (i.e., with both the beam and the target polarized). This allowed the spin correlation parameters Cxx and Cyy to be measured. The results appreciably complement the neutron–proton part of the SAID data base.

According to the **PAX** programme, the experiment on the so-called «spin-filtering» has been successfully carried out [26]. The polarization build-up in the initially unpolarized beam resulting from its circulation through a polarized hydrogen target was measured. The obtained effective polarizing cross section $\sigma_{\rm meas} = 23.4 \pm 3.9(\text{stat.}) \pm 1.9(\text{syst.})$ mb agrees very well with the theoretical prediction $\sigma_{\rm theor} = 26.9$ mb, which indicates full understanding of the underlying process.

The **MEG** experiment is one of PSI «flagship» particle physics experiments at the proton accelerator facility in Switzerland. The goal of the experiment is the search for the $\mu \to e\gamma$ decay with a branching ratio sensitivity of 10^{-13} in order to explore the region predicted by many theoretical models beyond the Standard Model. The data collected by MEG in 2009–2010 show no evidence for an excess of events above the expected background as yet. This new MEG result does however exclude, with 90% confidence, that more than one muon in approximately five hundred billion does decay into a positron (positive electron) and a photon. This therefore translates into the most stringent constraint on the existence of the $\mu \to e\gamma$ decay to date (BR $< 2.4 \cdot 10^{-12}$, 90% CL) and improves the previous best limit by a factor of five. Even while collecting thirty million muon decays a second in the detector, the experiment will require about two more years of data-taking to reach the expected sensitivity. The search for this process in a low-energy, high-intensity and high-precision type of experiment is a powerful means of investigating promising «New Physics» models such as Supersymmetric Grand Unified theories (SUSY-GUT) or theories with extra dimensions and is thus complementary to these searches at high-energy TeV-scale accelerator facilities like the LHC at CERN. The MEG Collaboration has already performed 2011–2012 data collection campaign. The experiment is expected to run at least until the end of summer 2013; this will allow reaching a sensitivity of $\sim 5 \cdot 10^{-13}$, (30–50) times better than the present upper bound.

Based on the rare pion and muon decay results of the PIBETA experiment, the **PEN** collaboration has undertaken a precise measurement of the $\pi^+ \to e^+\upsilon(\gamma)$ decay branching ratio ($\text{BR}_{\pi e2}$) at the Paul Scherrer Institute to reduce the present 40-fold experimental precision lag behind theory to $\sim (6{-}7)$ fold. Because of large helicity suppression, $\text{BR}_{\pi e2}$ is uniquely sensitive to contributions from non-(V–A) physics, making this decay a particularly suitable subject for study. Even at the current precision the experimental value of $\text{BR}_{\pi e2}$ provides the most accurate available test of lepton universality. During the 2008–2010 runs, PEN accumulated over $2 \cdot 10^7 \pi^+ \to e^+\upsilon$ (π_{e2}) events; a comprehensive maximum-likelihood analysis is currently under way. The new data will also lead to improved precision of the earlier PIBETA results on radiative π and μ decays.

In 2012, the joint JINR-INFN (Italy) Collaboration **PAINUC** continued handling and analyzing the existing data on $\pi^{\pm 4}$He interactions. The three-prong events for determining the branching ratios of various channels were studied, for instance, in order to separate the channel involving a proton and a triton in the final state from the total breakup of the helium nucleus, when two protons and two neutrons are produced in the final state; it turned out that strongly ionizing particles (protons, tritons) are most reliably identified by the following parameter: the product of the relative track and the square momentum of the particle. In 2012, work was also under way for improving the parameters of the pion beams of energies below the Δ resonance in the phasotron of DLNP; the pion beam was extracted via the phasotron muon beam guide of DLNP and brought to the experimental hall (laboratory 4) in direction XIII and was used in the PAINUC experiment.

In accordance with our semiempirical model of the excitation of collective resonances developed in 2011 [27] which expains the parameters of inelastic pion scattering from nuclei in the Δ-resonance region (such as, for example, the uniform distribution of angles between two strongly ionizing heavy secondaries in the three-prong events with a pion in the final state and the distribution of three-nucleon invariant masses observed in the absorption of positive pions in helium), the strength of interaction with the surrounding nuclear medium falls steeply within a range of 1 fm.

According to the recommendation of the 33rd Session of JINR PAC for nuclear physics, the project «Experimental Study of Nuclear Fusion Reactions in a $pt\mu$ System» (project **TRITON**) has been started. The goal of the project is to obtain new experimental data on low-energy nuclear reactions catalyzed by negative muons in a hydrogen isotope medium, in the area where they are absent or in conflict with modern theory. By means of 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. In the course of preparation of the Phasotron infrastructure, the negative muon beam channel is modernized in the low-background laboratory of the Phasotron. To modernize the registration system of the TRITON setup, a full-absorption detector for conversion muons and a sectioned electron telescope to record the alleged electron-positron pairs are made. The data-collection system is tested [28].

Within the **NN-GDH** project, in the beam of polarized tagged photons of the accelerator MAMI-C (Mainz, Germany) a series of experiments were carried out using a polarized target with frozen proton spin, designed and developed at JINR in cooperation with INR RAS and INP (Mainz). As a part of the investigation of the spin structure of nucleons, the measurements of the Compton effect on the proton in the Δ resonance with polarization degrees of freedom were carried out with the aim to produce the world's first experimental data on the spin polarizabilities — hitherto unknown fundamental structural constants of the proton, which describe the response of the spin proton to the multipolarity of the photon. The experimental data are under processing. Spin asymmetries of the cross section for π^0 and $2\pi^0$ photoproduction on protons were measured, and the first data on the polarization observables T and F were obtained, which allows determining the contribution of different resonances and verifying the theoretical models. Construction of an active (scintillation) polarized target began, which will allow measuring the Compton effect on protons at the energies below the threshold for π mesons and getting the spin polarizability in a model-independent way [29].

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 tumour. Now the first hospital center of radiation medicine is being built in Dimitrovgrad (Russia) under the guidance of the Federal Medical and Biological Agency for practical application of advanced radiation therapy methods in domestic medical radiology. In 2011–2012, Joint Institute for Nuclear Research in collaboration with the Ion Beam Applications (IBA, Belgium) designed and performed assembling, magnetic field shimming and beam tests of the C234 V3 cyclotron. The **C235 V3** cyclotron outperforms IBA's medical cyclotrons installed in 11 leading oncological clinics worldwide.

Test experiments with extracted proton beams of C235 V3 were performed in summer and autumn 2012. The following results were obtained in the experiments with the internal and extracted beams: isochronism of the profile of the formed mean magnetic field was verified, the RF-system accelerating frequency of 106.27 MHz and the magnetic coils current of 760.7 A were finally chosen; the beam was accelerated in the central region to radii of 300 mm without significant vertical losses; the acceleration efficiency from the radii of 300 mm to the extraction region without collimation diaphragm amounts to 72% (for a production-type IBA cyclotron it amounts to 50%); coherent beam displacement from the median plane during acceleration does not exceed 2–3 mm, which ensures no vertical loss in the acceleration region; the efficiency of the new extraction system designed and proposed at JINR was 62% in the first experiments (it is 50% in production-type IBA accelerator with the previous design of the extraction system). During the final adjustment of the cyclotron in Dimitrovgrad, the extraction efficiency will increase to 75% in accordance with the experimental results obtained in other production-type IBA cyclotrons with the new JINR extraction system.

The cyclotron will be installed in the hospital centre in Dimitrovgrad (Russia) in 2013 [30, 31].

The main goals of the research in the scope of the theme **«Medical and Biological Researches with the JINR Hadron Beams»** are 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 on 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. Ninety-four 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 with the Co-60 gamma-therapy unit «Rokus-M». The development of a software-hardware complex for the model of a multileave proton beam collimator with four pairs of leaves was continued. The full-scale collimator will consist of 33 such pairs of leaves and will be used in the so-called dynamic proton beam treatment technique [32].

Together with the Division of Radiation Dosimetry of the Institute of Nuclear Physics (Prague, Czech Republic) the measurements of secondary-particle background were carried out in the patient treatment room with thermoluminescent and track detectors. These measurements will be continued using other kinds of detectors. In collaboration with the Great Poland Cancer Centre (Poznan, Poland) the experiments are continued at the proton beam using radiochromic films, and the heterogeneous Alderson phantom simulating human anatomy were continued to verify all technological stages of prerradiation procedure and therapeutic irradiation of the patients. The results confirmed highly accurate matching of the maximum dose distribution with the irradiated target.

It is well known that oppressed hemogeny is one of the most serious consequences of irradiation of man. Therefore, procedures and medicines capable of restoring hemopoietic functions of the organism play an extremely important role in therapy of radiation injuries. The results of our previous studies showed the possibility of using laser radiation to simulate the depressed hematogenesis in the organism after the action of ionizing radiation. On the basis of these results, we developed and designed a new device which could be applied both in radiation protection of biological objects and in radiation damage therapy [33]. A prototype of the device was constructed. The corresponding application to an invention was submitted.

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