DZHELEPOV LABORATORY OF NUCLEAR PROBLEMS

NEUTRINO PHYSICS AND RARE PHENOMENA

In 2011, the experiment **OPERA** continued to collect data at the CNGS neutrino beam, about 4500 events were registered in the target. Currently the analysis of those data is carried on in 10 institutes both in Japan and in Europe (including JINR), where automatic scanning stations are available. The data analysis for 2008–2009 is fully completed [1].

The analysis of the 2009–2011 was performed to find the velocity of neutrinos in the CNGS beam through their time-of-flight and distance measurements. The unexpected results attracted great attention of the physics community. The OPERA Collaboration continues to perform various cross-checks to confirm the obtained results and prepare new measurements in 2012 [2].

Development of software for the event vertex location continued at JINR. The BrickFinder programme developed by the Dubna group was used as the main tool for the electronic data analysis and location of the emulsion brick to be extracted for the emulsion analysis. In 2011, the JINR group had full responsibility for this part of the data analysis and performed processing of all the data.

In 2011, the JINR group of the **Borexino** experiment participated in the data taking shifts and took an active part in the physical analysis of the accumulated data. At the beginning of the year the collaboration published a paper on the limits on antineutrino fluxes from the Sun and/or other possible nonidentified sources [3]; in the energy range of up to 8 MeV the existing limits were improved by some orders of magnitude. The job on this paper was coordinated by the Dubna group.

The main Borexino result of this year is the solar Be-7 neutrino flux measurement with a precision of 5% [4] — the target precision of the experiment. Nevertheless, given successful repurification of the scintillator (work on purification is in process) improvement of the precision to 3% is possible. Borexino also confirmed the absence of the day–night variations of the Be-7 neutrino flux at the 1% level [5].

The first measurement of the pep-neutrino flux and limits on the CNO-neutrino flux is another important achievement of this year [6]. The first paper on the muon measurement at Gran Sasso was published [7].

The **EDELWEISS-II** experiment is aimed at direct detection of WIMPs trapped in the Galactic halo. The experiment is operated in the Laboratoire Souterrain de Modane in the French Alps at a depth of 4700 mwe. EDELWEISS uses high-purity cryogenic germanium detectors with simultaneous measurement of phonon and ionization signals at a temperature about 20 mK. Recently the EDELWEISS Collaboration has demonstrated that the highest background limiting sensitivity of the experiment 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.

The EDELWEISS-II Collaboration has performed a direct search for WIMP dark matter with an array of ten 400 g heat-and-ionization cryogenic detectors equipped with interleaved electrodes. Limits on the WIMP-nucleon spin-independent cross section derived from the present data is $4.4 \cdot 10^{-44}$ cm^2 for the WIMP mass of 85 GeV (Fig. 1).

In 2011, new 800 g FID detectors with a significantly increased fiducial volume were tested in a few months' run for applicability in EDELWEISS and for potential in further suppression of the surface back-

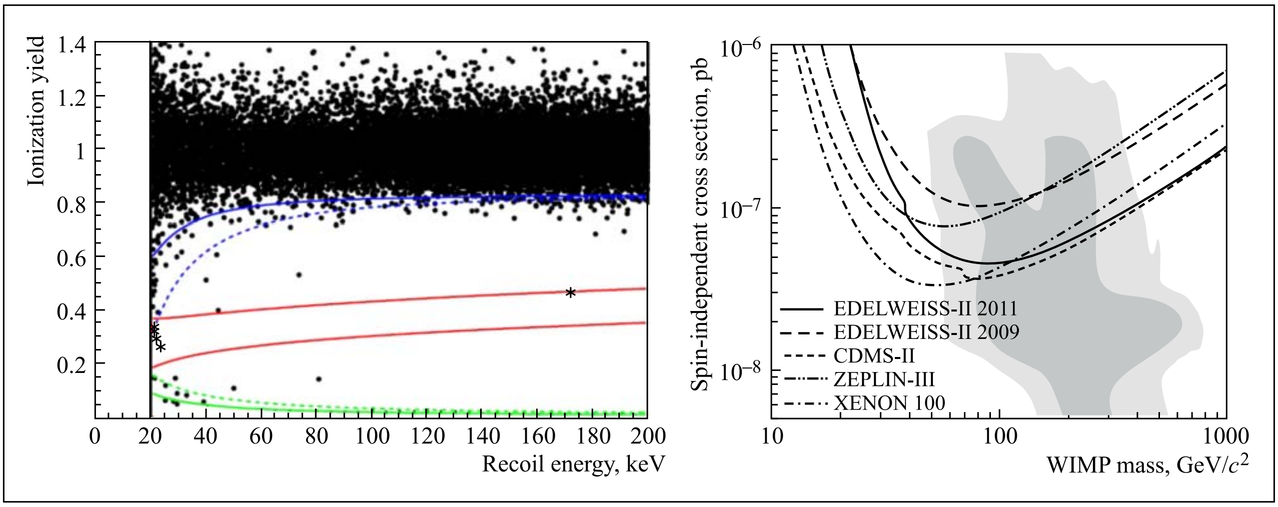

Fig. 1. Left: Ionization yield vs. recoil energy of fiducial events recorded by EDELWEISS-II. The WIMP search region is defined by recoil energies greater than 20 keV (vertical dashed line). The 90% acceptance nuclear and electron recoil bands (full blue and red lines, respectively) are calculated using the average detector resolutions. Right: Limits on the cross section for spin-independent scattering of WIMPs on nucleons as a function of WIMP mass from EDELWEISS-II

ground. In a coming year, low-backgrounds physics runs will be continued within the EDELWEISS experiment with the aim to reach sensitivity to WIMP-nucleon SI cross section of 10^{-44} cm^2 or better for a WIMP with the mass of 100 GeV/c^2. New 800 g FID detectors with a significantly increased fiducial volume will be added to the experiment to enhance the sensitivity to WIMPs. The aim for the coming two years is to have 3000 kg$\cdot$d with no surface background events at the nuclear recoil band above 15 keV threshold. This will provide the sensitivity at the level of $5 \cdot 10^{-45}$ cm^2 in successful competition with other world leading Dark Matter search experiments (Xe, Ar based, and CDMS).

The EDELWEISS collaboration decided to extend WIMP search to the low-mass WIMP region using low-threshold point-contact HPGe detectors built at JINR. In 2011, a test of one of these detectors weighing ~ 200 g started at the EDELWEISS site. In 2012, measurements will start with 400 g detectors in the low-threshold mode (threshold of a few hundred eV) to be competitive with the CoGeNT experiment [8, 9].

The experiment **GERDA** (GERmanium Detector Array) is one of the new-generation experiments aimed to search for neutrinoless double beta ($0v\beta\beta$) decay of ^{76}Ge at a high level of sensitivity. The ($0v\beta\beta$) decay is one of the most sensitive probes of still unknown neutrino properties such as neutrino type and their mass scale.

Considerable progress in development and installation of the GERDA experiment [10] has been achieved in the last years. Assembly of the GERDA setup was finished and commissioning of the setup started by using the first test string with three naked germanium detectors from natural Ge placed inside the stainless steel cryostat which contains 90 t of liquid argon (LAr).

In Phase-I of the GERDA experiment, liquid argon is only used as a passive shield. For the next phases of GERDA, additional methods of background reduction are required. The GERDA-LArGe test facility is designed to operate with HPGe detectors immersed in 1.4 t of liquid argon serving as scintillation veto. The main goal of the LArGe setup is development of methods aimed to reduce background of Ge detectors by using anticoincidence with LAr scintillation signals [11]. However, a new task was set for LArGe in 2011, namely, detailed investigation of concentration and behavior of ^{42}Ar in liquid argon.

The first commissioning runs performed with the string of three naked $^{\rm Nat}$Ge detectors from the past Genius-TF experiment revealed that due to presence of ^{42}Ar in the liquid argon the count rate is significantly above the rate expected on the basis of known experimental upper limits. However, even for the commissioning runs the background of the first string with three detectors made from materials enriched in ^{76}Ge was lower than the final background achieved in the Heidelberg–Moscow experiment and $2\nu\beta\beta$ decay of ^{76}Ge was clearly detectable after two weeks of measurements (see Fig. 2, left). The GERDA collaboration investigated the ^{42}Ar problem by testing different field configurations in LAr around the detectors and studying the shapes of the recorded background pulses. As a result, the optimal configuration of the electric field around Ge detectors was determined and it allowed Phase I of the experiment to start.

The commissioning of the GERDA setup was completed in the second half of 2011, and physical data taking with all existing ^{76}Ge detectors (eight detectors, total mass about 18 kg of ^{76}Ge, Fig. 2, right) started in November 2011.

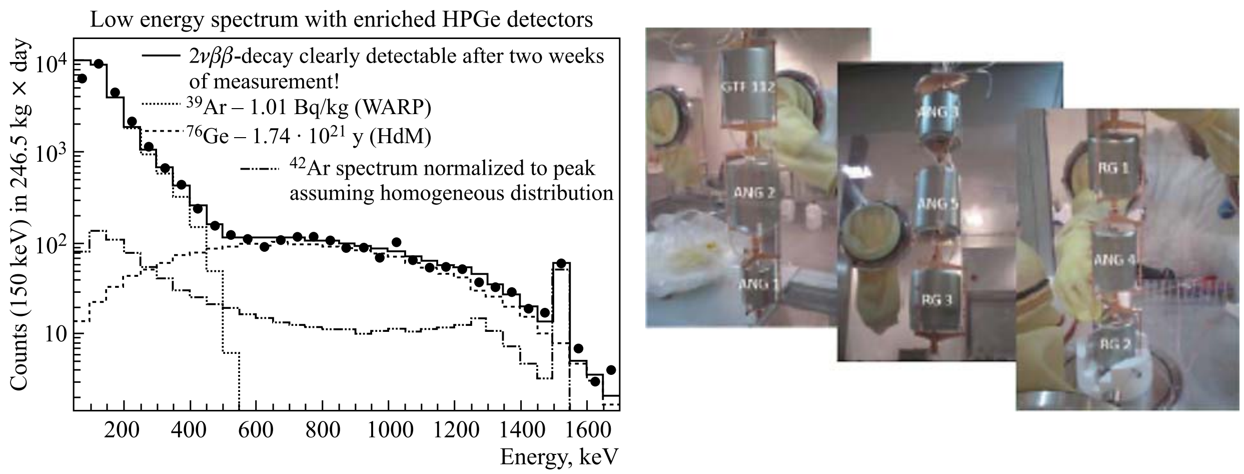

Fig. 2. Left: First results obtained with three detectors made from ^{76}Ge during the first commissioning runs. $2\nu\beta\beta$ decay of ^{76}Ge is clearly detectable after two weeks of measurements. Right: Before the start of Phase I of the GERDA experiment, eight naked HPGe detectors made from ^{76}Ge with the total mass about 18 kg and one control detector from $^{\mathrm{Nat}}$Ge are assembled in three strings before being placed into the GERDA cryostat

The **BES-III** experiment at the BEPC-II electron–positron collider continued running in 2011. The world's largest samples of J/ψ, ψ', $\psi(3770)$, $\psi(4040)$ decays have been collected. The threshold enhancement in the $p\bar{p}$ invariant mass spectrum in the $J/\psi \to \gamma p\bar{p}$ process was confirmed at BES-III. Preliminary PWA study in 2011 showed that this enhancement could be associated with a narrow 0^{-+} state. Also, existence of the $X(1835)$ resonance was confirmed, and two new states $X(2120)$ and $X(2370)$ were observed in 2011 [12].

Charmonium decays have been extensively studied in the experiment. The first measurements of the branching ratio of $\psi' \to \gamma\pi^0$ and $h_c \to \gamma\eta$ decays was made. The branching ratio of the decays $\chi_{cJ} \to \gamma V(\rho,\phi,\omega)$, $\chi_{cJ} \to VV(\phi,\omega)$ was measured as well. The doubly OZI-suppressed decay $\chi_{cJ} \to \phi\omega$ was observed for the first time [13].

In 2011, the main efforts of the JINR group together with the PNPI group (Gatchina) were concentrated on the light hadron spectroscopy. The PWA of $J/\psi \to K^+K^-\pi^0$ decay was completed. The original approach to taking into account the detector resolution in PWA allowed properties of the $K^*(892)$ state to be measured precisely. It was shown that PWA of $J/\psi \to K_sK\pi$ decay is needed as an independent cross-check. The event selection algorithm for this reaction is elaborated, and the PWA is under way [14, 15].

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 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. The TUS mission is now planned for operation at the dedicated «Mikhail Lomonosov» satellite.

The main task for JINR in 2011 is production of the Fresnel mirror and measurement of optical parameters. A special procedure was elaborated to measure the optical parameters of the mirror module. The Eclipse 700/1000 coordinate measuring machine from Carl Zeiss with a laser head and a web camera, were used for the PSF (point spread function) measurements of the lateral and central TUS Fresnel mirror modules [16]. The flight mirror is ready for mounting on the satellite platform. The optical parameters of the flight mirror are in reasonable agreement with the FoV of the TUS detector and with the PMT pixel size. The TUS mission is planned to start three-years data taking at the dedicated «Mikhail Lomonosov» satellite in 2012.

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}–$5 \cdot 10^{14}$ 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 comprehensive space qualification tests of the technological NUCLEON apparatus were fulfilled at the ARSENAL space center in St. Petersburg in 2010. The technological and flight models of the trigger system were produced and tested at the SPS CERN H2 test beams in 2011 with pions, electrons, and muons of energy 200–350 GeV. The data analysis is in progress. The flight NUCLEON detector production is in progress, too. The NUCLEON Collaboration goal is to be ready for launch and data taking from the orbit by the end of 2013.

HIGH-ENERGY PHYSICS

The main results of the **CDF project** are obtaining the CDF average mass of the top quark that corresponds to the total uncertainty of 1.09 GeV/c^2, searching for the Higgs, and maintaining of efficient operation of the CDFII. Combination of the published results from Run-I (1992–1996) with the most recent preliminary and published Run-II (since 2001 till now) measurements all totaling to 5.8 fb^{-1}, was done. With proper account of correlated uncertainties, the resulting preliminary CDF average mass of the top quark is $\mathrm{M_{top}} = 172.70 \pm 0.63$ (stat)± 0.89 (syst) GeV/c^2, which corresponds to the total uncertainty of 1.09 GeV/c^2, or equivalently to a 0.63% precision [17, 18].

The results from **CDF and D0** on direct searches for the standard model (SM) Higgs boson H in $p\bar{p}$ collisions at the Fermilab Tevatron at $\sqrt{s} = 1.96$ TeV were combined [19]. As compared to the previous Tevatron Higgs search combination, more data were added, additional new channels were incorporated, and some previously used channels were reanalyzed to gain sensitivity. The MSTW08 parton distribution functions and the latest theoretical cross sections were used for comparing limits to the SM predictions. With up to 8.2 fb^{-1} of data analyzed at CDF and up to 8.6 fb^{-1} at D0, our upper limits on Higgs boson production at the 95% CL are a factor of 1.17, 1.71, and 0.48 larger than the values of the SM cross section for the Higgs bosons of mass $\mathrm{m}_H = 115$, 140, and 165 GeV/c^2, respectively. There is a small (approx. 1 sigma) excess of data events with respect to the background estimation in searches for the Higgs boson in the mass range $125 < \mathrm{m}_H < 155$ GeV/c^2. A new and larger region at high mass between $156 < \mathrm{m}_H < 177$ GeV/c^2 is excluded at the 95% CL (Fig. 3).

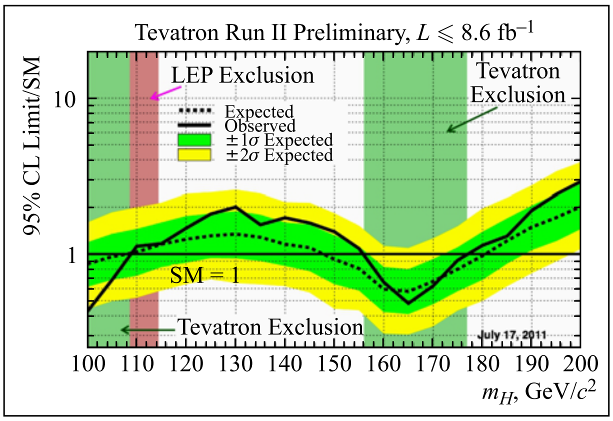

Fig. 3. New region for the Higgs mass

The efforts of the Dubna group are focused on the efficient and stable operation of the CDF detector for the broad c-, b-, t-quark physics study at the highest available energies. During the last year, the group maintained stable operation of the scintillation counters of the CDFII muon trigger. The aging studies of the CDF scintillation counters were continued.

In 2011, in accordance with the JINR Topical Plan, the activities of the Dubna team within the **ATLAS experiment** at the LHC were carried out in three general directions. The main one is the physical data analysis. In addition, the JINR staff members maintained stable operation of several ATLAS subsystems and participated in the ATLAS upgrade programme. Among the main 2011 achievements in the physical analysis there are several ones of highest success.

A new, modified gluon distribution density was proposed by the JINR scientists. It takes into account the dependence on the proton transverse momentum and can be used for description of the semihard and soft hadron processes at the LHC energies [20]. The first search for the charged θ baryon (the so-called 5Q-state) was carried out with the 2010 ATLAS data. This state was not observed via its decay into a proton and a neural kaon.

For the first time a search for charged and neutral chiral vector W^* and Z^* bosons was carried out at the LHC. The first limits on their masses and production cross sections were obtained. The inclusive high-mass lepton pair production $pp \to W^*/Z^*X \to \ell\ell' X$ (Fig. 4) was studied by the JINR-ATLAS people together with our PINP colleagues. The unique low mass limits were obtained: 1.15 TeV for the W^* and 1.35 TeV for the Z^* boson [21].

In 2011, members of the JINR team took part in the ATLAS heavy ion (HI) run and its analysis to study the so-called ultraperipheral HI collisions (UPC). The analysis of the 2010 Pb–Pb ATLAS data allowed the yields of direct dimuons and dimuon pairs from J/ψ-decays produced in the UPC to be observed and studied for the first time (at the LHC energies) [22]. The analysis of the 2011 HI run (with very much higher statistics) is under way and will be completed in early 2012.

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 $5.4 \cdot 10^9$ primary events were collected. The target station was modified before the data-taking to perform this observation. A new 100-μm beryllium

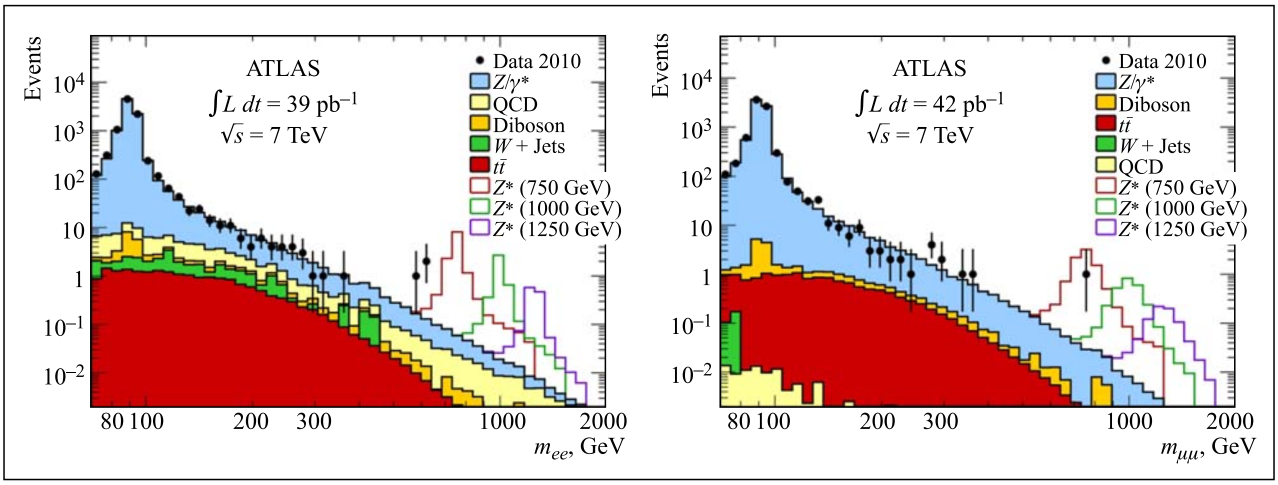

Fig. 4. Dielectron (left) and dimuon (right) invariant mass distribution, compared to the sum of all expected backgrounds and with three example Z^* signals overlaid

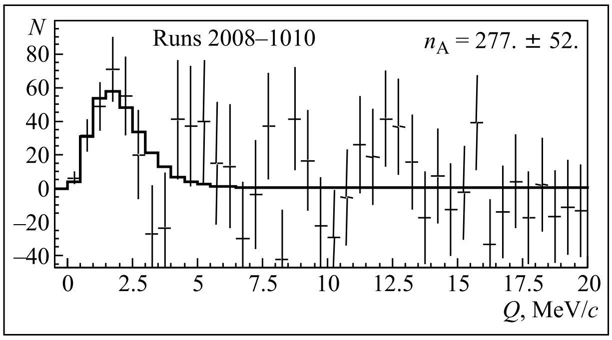

Fig. 5. CMS relative momentum distribution of the summed experimental data on $K^+\pi^-$ and π^+K^- pairs after subtraction of all pairs produced in free states and simulation of pairs from πK atoms breakup (solid red line)

target and remotely controlled actuators for retracting the permanent magnet and the additional platinum foil 2 μm thick were installed. The results on observation of atoms consisting of π^+ and π^- mesons were published. About 21200 events of the atom breakup were identified. The most precise value of the $\pi^+\pi^-$ atom lifetime was measured to be $\tau = \left(3.15^{+0.20}_{-0.19}\big|_{\rm stat}\ {}^{+0.20}_{-0.18}\big|_{\rm syst}\right) \cdot 10^{-15}$ s. From this value the difference of S-wave $\pi\pi$ scattering lengths with isotope spin 0 and 2 was extracted: $|a_0 - a_2| = \left(0.2533\ {}^{+0.0080}_{-0.0078}\big|_{\rm stat}\ {}^{+0.0078}_{-0.0073}\big|_{\rm syst}\right) M_{\pi^+}^{-1}$ [23]. The preliminary analysis of the data on observation of atoms consisting of π^+K^- and π^-K^+mesons is completed.

Now the number of identified events amounts to 277 ± 52 (Fig. 5). By the end of 2011 a new addendum for continuation of the experiment on observation of the long-lived states of $\pi^+\pi^-$ atoms in 2012 was prepared and submitted to SPSC.

The work on application of the **SANC** results to LHC physics has been carried out since 2004. In its present status SANC includes theoretical predictions for many three and four particle Standard Model (SM) processes at the one-loop precision level (QCD and EW NLO). In the year 2011, the elaboration of the SANC2 framework was continued. Based on the earlier created symbolic calculation environment, the work has been carried out to realize algorithm for one-loop calculations of the Passarino-Veltman reduction and scalarization. The main results of 2011 are evaluation of the so-called «missed higher order corrections» (for Drell–Yan-like single W and Z production processes), that is, those which are not taken into account by the standard ATLAS programmes (PYTHIA+PHOTOS, HERWIG); and QCD analysis of the 2010 year ATLAS results (33–36 pb^{-1}) in W- and Z-boson inclusive cross section measurements [24]. The activity included obtaining theoretical predictions of differential cross sections for Drell–Yan processes in the NNLO pQCD approximation. The predictions and their uncertainties and correlations were estimated for a set of parton density functions. Also, validation and comparison was carried for theoretical tools used for the strange sea quark density measurements based on the new ATLAS data [25].

LOW- AND INTERMEDIATE-ENERGY PHYSICS

In line with the scientific programme of the project **SPRING**, the experiments on near-threshold pion production with the use of polarized beams are carried out with the ANKE setup at COSY. Their goal is to establish connection between pion production in nucleon–nucleon collisions and low-energy three-nucleon scattering. Extraction of the pion production amplitudes would allow an analysis to be performed with the use of the chiral perturbation theory, when will be an important step in the understanding of pion dynamics at low energies.

In 2011, π^0 and π^- production in the reactions $\vec{p}p \to \{pp\}_s\pi^0$ on a hydrogen target and $\vec{p}n \to \{pp\}_s\pi^-$ on a deuterium target was investigated using a polarized proton beam of energy 353 MeV and cluster jet targets [26, 27]. Proton pairs of very low excitation energy thus leading to a $^1S_0$ state of this diproton $\{pp\}_s$ were selected. The differential cross section and the analyzing power was measured in the full angular range. Both observables can be described in terms of s- and d-wave (for final π^0) or s-, p-, and d-wave (for final π^-) pion production.

The lepton flavour violating (LFV) decay $\mu \to e\gamma$ is forbidden within the Standard Model (SM) of elementary particles. Even with the introduction of neutrino masses and mixing, SM predicts an immeasurably small branching ratio ($B < 10^{-51}$) for this decay. Conversely, new physics scenarios beyond SM, such as supersymmetric grand unified theories or theories with extra dimensions, predict branching ratios in the range 10^{-12} to 10^{-14}. This is close to the present limit set by the MEGA experiment, B $< 1.2 \cdot 10^{-11}$, which imposes one of the most stringent constraints on the formulation of these theories. Therefore, observation of $\mu \to e\gamma$ would be an unambiguous signature of new physics, while improvements on the existing limit would stringently constrain many of the new physics scenarios beyond SM.

In 2011, the **MEG** Collaboration reports the results of a search for the decay $\mu \to e\gamma$, the data for which were collected in the MEG experiment in 2009 and 2010. MEG operates at the 590 MeV proton ring cyclotron facility of the Paul Scherrer Institute (PSI) in Switzerland. The analysis of the data sample which corresponds to a total of $1.8 \cdot 10^{14}$ muon decays, gives a 90% CL upper limit of $2.4 \cdot 10^{-12}$ on the branching ratio of the $\mu \to e\gamma$ decay which is the most stringent limit on the existence of this decay [28].

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 amplitude of this rare decay is a classical manifestation of the V–A character of weak interactions. With a good theoretical understanding of the $\pi^+ \to e^+\nu(\gamma)$ decay, its measurement becomes the most accurate feasible test of lepton universality. Improved measurements could also be a highly sensitive test for all extensions of the Standard Model with pseudoscalar currents and for possible supersymmetrical corrections in lepton interactions. By now, $3.75 \cdot 10^{11}$ pions have been stopped in the experiment and $2.28 \cdot 10^7$ unfiltered $\pi \to e\nu$ decay events have been recorded, which corresponds to the statistical uncertainty better than $\delta B/B = 5 \cdot 10^{-4}$. This value close to the theoretically calculated branching ratio is at the level of better than one part in 10^{-4}. Measurements with this accuracy allow receiving on certain assumptions, restrictions on the masses of the charged Higgs $m_{H^+} > 6.9$ TeV, vector leptoquarks $m_p > 3.8$ TeV, and psevdoscalar leptoquarks $M_G > 630$ TeV. Statistics collected in the PEN experiment doubles the statistics for radiative pion and muon decays, further improving the accuracy of their measurements in our previous experiments.

In 2011, the joint JINR-INFN (Italy) collaboration **PAINUC** continued handling and analysing 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 square momentum of the particle.

In 2011, work was also under way for improving the parameters of the pion beams of energies below the Δ resonance in the phasotron of the DLNP; the pion beam was extracted via the phasotron muon beam guide of the DLNP and brought to the experimental hall (laboratory 4) in direction XIII and was used in the PAINUC experiment. It is worth mentioning that single γ-quantum production in the «elastic» scattering of negative pions at energies of 68 and 106 MeV is confirmed [29]. If the nucleus is treated as a black body, the Planck temperatures $E_{\rm Planck}$, corresponding to the energies 106 and 68 MeV, turn out to be 14.4 ± 1.6 and 14.6 ± 1.1 MeV, respectively.

The experiments carried out in 2011 within the project **MUON** were aimed at studying the interaction of the acceptor centers in germanium and in diamond by polarized muons. The temperature dependence of the spin relaxation rate of negative muons was measured in the n-type germanium sample (donor concentration $\lesssim 3.0 \cdot 10^{13}\ ^{-3}$) and in the three p-type germanium with the Ga concentration of $1.0 \cdot 10^{14}$, $3.0 \cdot 10^{14}$, and $5.0 \cdot 10^{15}$cm^{-3}. It was found that in n-type germanium the muonic atom is formed only in the diamagnetic state. At the same time, in the p-type samples at low temperatures the paramagnetic muonic atom is observed. The relaxation rate of the muon spin in the muonic atom depends on the temperature and concentration of gallium acceptor impurity.

The probabilities of finding the positive muon in various states in synthetic single-crystal and polycrystalline diamond were studied. In the IIa-type single-crystal sample at 150 K the contributions of the diamagnetic muon, «normal», and «anomalous» muonium were found to be 1.5, 57, and 8.1%, respectively. The missing fraction of muon polarization was 33.4%, which is approximately two times smaller than in Ia-type natural diamond, and two or three times greater than in IIa- and IIb-type natural diamonds. The muon spin relaxation rates in the «normal» and «anomalous» muonium states in the synthetic and natural diamond samples of the IIa- and IIb-type are similar.

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 the only 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 the fusion from muonic pt molecules: $pt\mu \rightarrow ^4\mathrm{He}\mu + \gamma$, $^4\mathrm{He} + \mu(\mathrm{conv})$, $^4\mathrm{He}\mu + e^+e^- + 19$ MeV [30]. The experiment will be conducted at JINR (Dubna, Russia) using the TRITON installation. The 50 cm^3 cryogenic target filled with liquid pt mixture (1%) will be exposed to the negative muon beam (10^4 s^{-1}, 100 MeV/c) of the JINR Phasotron.

Within the **NN-GDH** project a successful testing run of the Polarized Target in operating conditions with a trial data acquisition has been carried out with the 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. The new frozen spin polarized target (FST) developed by JINR and IKP was tested and operated in-beam. Thin internal superconducting holding coils to allow transverse and longitudinal nucleon polarization were developed and employed in the frozen polarization mode of the target for more than 5000 hours in the years 2010 and 2011 routinely. Proton polarization of above 90%, deuteron polarization of 75% and polarization relaxation time in excess of 1000 hours was achieved. Tests of a new thin foil target material made of polystyrene were carried out in the dilution cryostat at temperatures of 25 mK and magnetic fields of 2.5 T. The material was polarized up to more than 60% after only 3 hours of microwave pumping and showed reasonable relaxation times. Further tests are planned to investigate different parameters which are important for the PANDA experiment. Experimental measurements of the transverse asymmetries T and F in π^0 and η photoproduction have been performed and the data analysis is in progress. The world's first measurement of double polarized Compton scattering aimed at determining the spin polarizability has begun. A beam of circularly polarized energy-tagged photons (of energies up to 1557 MeV) is used in combination with the transversely polarized butanol target. The reaction products are detected using the Crystal Ball/TAPS 4π-photon spectrometer.

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.

Today, the first hospital center of radiation medicine is being founded 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. This center includes the center of proton therapy, which is based on the **C234 V3** cyclotron designed by JINR in collaboration with the IBA Group (Belgium). The first step in designing a new version of the C235 V3 cyclotron was beam dynamics analysis aimed at finding causes for ion losses during acceleration and extraction [31].

According to the agreement on scientific cooperation between the Ion Beam Application company (IBA) and JINR of 04.05.2011, in May and June 2011, preparation of the test bench for the assembly and commissioning of the cyclotron C235 for the proton therapy center in Dimitrovgrad was completed in DLNP Bldg. 5. In June the C235 cyclotron was delivered to Bldg. 5 and installed in the casemate. Assembly of the cyclotron was performed according to the drawings and process lists. The system for magnetic field measurements is completely ready for operation and calibrated. The DLNP design department has prepared documentation according to which jigs for handing the side surfaces of the removable edges of the cyclotron sectors were made in the SPA «Atom». So far, five maps of the magnetic field were measured in the process of shimming the magnetic field of the C235 and four side surface machining cycles were carried out. Magnetic field shimming and test experiments with extracted proton beams were planned to be carried out in 2011. The cyclotron is planned to be installed at the hospital therapy centre in Dimitrovgrad in 2012.

The main goal of the research in the scope of the 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).

Regular sessions of proton therapy aimed at investigating its efficiency to treat different kinds of neoplasm were performed in collaboration with the Medical Radiological Research Centre (Obninsk) and the Radiological Department of the Dubna hospital. During the year, seven treatment sessions, total duration of 28 weeks, were carried out. A total of 109 new patients were fractionally treated with the medical proton beam. The total number of the single proton irradiations (fields) exceeded 6500. Another 20 patients were irradiated at the Co-60 gamma-therapy unit «Rokus-M». The development of a software-hardware complex for the model of the multileave proton beam collimator with 4 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.

Measurements of the secondary particle background in the patient treatment room using thermoluminescent and track detectors were carried out together with the Division of Radiation Dosimetry of the Institute of Nuclear Physics (Prague, Czech Rep.). These measurements will be continued using other kinds of detectors [32].

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.

In this connection we carried out experiments to study the effect of 5 Gy γ rays and the combined effect of the radiation protection laser device with the wavelength of 650 nm (Invention patent RU 2 428 228 C2) and γ rays on the general mitotic index of the bone marrow cells (mitotic index of all nucleus-containing cells of the bone marrow) in experimental mice. It turned out that the mitotic activity of the bone marrow cells in mice irradiated only by laser light and that in mice irradiated by laser and gamma rays on the 15th day after the exposure is higher than the activity of the cells in intact mice. A year after the irradiation, the mitotic index in the mice exposed to combined irradiation was higher than in the mice irradiated only with gamma rays.

The results show that laser radiation in the red spectral region not only improves restoration of hemogeny after exposure of biological objects to ionizing radiation as we have showed earlier, but also increases mitotic activity of bone marrow cells. Consequently, laser irradiation of biological subjects can find application both in radiation shielding and in radiation sickness therapy.

REFERENCES

1. *Agafonova N. et al.* Search for $\nu - \mu$ to $\nu - \tau$ Oscillations in the OPERA Experiment in the CNGS Beam // New J. Phys. (submitted).
2. *Adam T. et al.* Measurement of the Neutrino Velocity with the OPERA Detector in the CNGS Beam // JHEP (submitted).
3. *Bellini G. et al. (Collab.)* Study of Solar and Other Unknown Anti-Neutrino Fluxes with Borexino at LNGS // Phys. Lett. B. 2011. V. 696. P. 191–196.
4. *Bellini G. et al. (Collab.)* Precision Measurement of the ^{7}Be Solar Neutrino Interaction Rate in Borexino // PRL 2011. V. 107. P. 141302.
5. *Bellini G. et al. (Collab.)* Absence of Day/Night Asymmetry of 862 keV ^{7}Be Solar Neutrino Rate in Borexino and MSW Oscillation Parameters. 1104.2150v1 [hep-ex] 12 Apr. 2011; Phys. Lett. B. (accepted 13 Nov. 2011).
6. *Bellini G. et al. (Collab.)* First Evidence of pep Solar Neutrinos by Direct Detection in Borexino. arXiv:1110.3230 [hep-ex]; Phys. Rev. Lett. (submitted).
7. *Bellini G. et al. (Collab.)* Muon and Cosmogenic Neutron Detection in Borexino // J. Instrumentation. 2011. V. 6. P05005.
8. *Armengaud E. et al. (EDELWEISS Collab.)* Final Results of the EDELWEISS-II WIMP Search Using a 4-kg Array of Cryogenic Germanium Detectors with Interleaved Electrodes // Phys. Lett. B. 2011. V. 702, No. 5. P. 329–335.
9. *Ahmed Z. et al. (CDMS and EDELWEISS Collab.)* Combined Limits on WIMPs from the CDMS and EDELWEISS Experiments // Phys. Rev. D. 2011. V. 84. 011102(R).
10. *Shevchik E. et al.* The Muon Panels I: Panel Tests and Efficiency Estimations, GERDA Scientific. Technical Report. 2011. GSTR-11-010; GSTR-11-011.
11. *Agostini M. et al.* LArGe–R&D for Active Background Suppression in GERDA // Proc. of TAUP-2011 Conf. J. Phys.: Conf. Ser. 2011 (in press).
12. *Ablikim M. et al. (BES-III Collab.)* // Phys. Rev. Lett. 2011. V. 106. 072002.
13. *Ablikim M. et al. (BES-III Collab.)* // Phys. Rev. D. 2011. V. 84. 091102.
14. *Ablikim M. et al. (BES-III Collab.)* // Phys. Rev. D. 2011. V. 83. 112005.
15. *Ablikim M. et al. (BES-III Collab.)* // Phys. Rev. D. 2011. V. 83. 012006.
16. *Tkachev L. et al.* The TUS Fresnel Mirror Production and Optical Parameters Measurement // 32nd Intern. Cosmic Ray Conf., Aug. 11–18, Beijing, China. ID-0305, 0306.
17. Combination of CDF Top Quark Mass Measurements (Winter 2011). CDF Note 10444.
18. *Flyagin V. B., Glagolev V. V.* The Top Quark Properties Measured in $p\bar{p}$ Collisions Using CDF Detector at 1.96 TeV // Part. Nucl. (submitted).

19. *CDF, D0 Collab.* Combined CDF and D0 Upper Limits on Standard Model Higgs-Boson Production with up to 8.6 fb^{-1} of Data. arXiv:1107.5518.
20. *Lykasov G. I. et al.* arXiv:1109.1469; presented at «Physics at LHC-2011», Perugia, Italy, June 2011, and at «Hadron Structure-2011», Strba, Slovakia, June 2011.
21. *ATLAS Collab.* // Phys. Lett. B. 2011. V. 700. P. 163; V. 701. P. 50;
Chizhov M. et al. arXiv:1110.5533.
22. *Pozdniakov V. N., Vertogradova Y. L.* Direct Photon and Photon-Jet Measurement Capability of the ATLAS Experiment at the LHC // Nucl. Phys. A. 2011. V. 855. P. 343–346;
Pozdnyakov V. et al. Measurement of the Muon Pair Production Cross Sections in Ultraperipheral Pb–Pb Collisions. ATL-COM-PHYS-2011-1361, ATLAS-COM-CONF-2011-182.
23. *Adeva B. et al.* Determination of $\pi\pi$ Scattering Lengths from Measurement of $\pi^+\pi^-$ Atom Lifetime // Phys. Lett. B. 2011. V. 704. P. 24–29
24. *Aad G. et al.* Measurement of the Inclusive W^{+-} and $Z\gamma$ Cross Sections in the Electron and Muon Decay Channels in pp Collisions at $\sqrt{s} = 7$ TeV with the ATLAS Detector // Phys. Rev. D. 2011 (accepted).
25. *Bardin D. et al.* Standard SANC Modules for NLO QCD Radiative Corrections to Single-Top Production // Part. Nucl., Lett. 2011 (submitted).
26. *Tsirkov D. et al.* Differential Cross Section and Analysing Power of the $\vec{p}p \to \{pp\}_s\pi^0$ Reaction at 353 MeV // Phys. Lett. B (submitted).
27. *Dymov S. et al.* Differential Cross Section and Analysing Power of the Quasi-Free $\vec{p}n \to \{pp\}_s\pi^-$ Reaction at 353 MeV // Phys. Lett. B (submitted).
28. *Adam J. et al.* // PRL. 2011. V. 107. P. 171801.
29. *Angelov N. et al.* Pion Induced Reactions on ^{4}He in the Δ-Resonance Energy Region // Intern. J. Modern Phys. A (in press).
30. *Baluev V. V. et al.* Experimental Search for the Radiative Capture Reaction $d + d \to {}^4\mathrm{He} + \gamma$ from the $dd\mu$ Muonic Molecule State $J = 1$ // JETP. 2011. V. 113, No. 1. P. 68–74.
31. *Syresin E. V. et al.* Development of Radiation Medicine at DLNP // Part. Nucl., Lett. 2011. V. 8, No. 4. P. 635.
32. *Kubančák J., Molokanov A. G., Vlček B.* Out-of-Field Dosimetry of the JINR Radiotherapeutic Proton Beam Using Thermoluminescent Detectors. JINR Commun. E16-2011-80. Dubna, 2011.