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DZHELEPOV LABORATORY OF NUCLEAR PROBLEMS: RESEARCH ACTIVITIES IN 2008

Report to the 105th Session
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According to the JINR Road Map, the modern particle and nuclear physics program of research can be classified into four interrelated directions – the energy-increasing accelerator direction (the Energy Border), the intensity-increasing accelerator direction (the Intensity Border), the accuracy-increasing non-accelerator direction (the Accuracy Border) and the particle astrophysics direction (the Cosmic Border). Following the above-mentioned general directions of the modern development of particle and nuclear physics, the DLNP activities within 2008 were concentrated in four main domains: neutrino physics and rare phenomena (Intensity, Accuracy and Cosmic Borders); DLNP participation in the development of domestic facilities and research at these facilities; international partnership programs at unique accelerator facilities (Energy and Intensity Borders) like Tevatron (FNAL), LHC (CERN), FAIR (GSI), ILC; applied research, in particular, proton therapy and medical accelerator facility development.

Neutrino Physics and Rare Phenomena

The main purpose of the **GEMMA** experiment is the measurement of the (anti)neutrino magnetic moment with sensitivity at the level of $(4 \div 7) \cdot 10^{-12}\ \mu_B$. 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 center. Analysis of the first phase allowed 6200 and 2064 hours for the reactor *On* and *Off* periods to get a new neutrino magnetic moment upper limit of $5.8 \cdot 10^{-11}\ \mu_B$. Preliminary analysis of the second phase (6798 hours *On* and 1020 hours *Off*), performed together with the first one gives $(3.8 \div 4.0) \cdot 10^{-11}\ \mu_B$. The third phase was started in June 2008, it is in progress and is planned to go on up to the autumn 2009. As a result the sensitivity at the level of $(2.0 \div 2.5) \cdot 10^{-11}\ \mu_B$ is expected.

In 2009 simultaneously with GEMMA-I data taking and analysis, R&D and construction of the GEMMA-II spectrometer will be in progress. The improvements of the new facility with respect to the operating one will be the following: the neutrino flux will be increased up to $5.4 \cdot 10^{13}$ v/cm²/s due to the location of the spectrometer under new reactor 3, 8 m from the center of its active zone; the detector mass will be increased by a factor of 4, the level of external background is expected to be reduced by a factor of 2-3; the low-energy threshold will be reduced down to 1.5-2.0 keV due to new low-noise electronics and better electric shielding. The upgraded GEMMA-II spectrometer is planned to be put into operation at the end of 2009. As a result, the neutrino magnetic moment sensitivity at the level of less than 10^{-11} μ_B is expected.

The main purpose of the **NEMO 3** experiment is the search for the double beta decay process with two (2νββ-decay) or zero (0νββ-decay) neutrinos in the final state in seven different ββ-isotopes. The experimental search for the 0νββ-decay is of major importance in particle physics. If this process is observed, it will reveal the Majorana nature of the neutrino and allow an access to the absolute neutrino mass scale. The NEMO-3 experiment has been taking data since February 2003 in the Modane Underground Laboratory (LSM) located in the Frejus tunnel at a depth of 4800 m water equivalent.

In 2008 the double beta decay of ^{100}Mo to the 0^+_1 and 2^+_1 excited states of ^{100}Ru was studied using the NEMO 3 data. After the analysis of 8024 h of data taking the half-life for the two-neutrino double beta decay of ^{100}Mo to the excited 0^+_1 state is measured to be $T_{1/2}(2\nu\beta\beta) = \left(5.7^{+1.3}_{-0.9}(stat.) \pm 0.8(syst.)\right) \cdot 10^{20}$ y. The signal-to-background ratio is 3. Information about energy and angular distributions of emitted electrons was also obtained. No evidence for neutrinoless double beta decay to the excited 0^+_1 state was found. The corresponding half-life limit is $T_{1/2}(0\nu\beta\beta)(0^+ \to 0^+_1) > 8.9 \cdot 10^{22}$ y (at 90% C.L.). The search for the double beta decay to the 2^+_1 excited state allowed the determination of limits on the half-life for the two-neutrino mode $T_{1/2}(2\nu\beta\beta)(0^+ \to 2^+_1) > 1.1 \cdot 10^{21}$ y (90% C.L.) and for the neutrinoless mode $T_{1/2}(0\nu\beta\beta)(0^+ \to 2^+_1) > 1.6 \cdot 10^{23}$ y (90% C.L.) [1].

The main purpose of the **GERDA** (GErmanium Detector Array) experiment is to search for neutrinoless double beta decays of ^{76}Ge. GERDA will operate with bare germanium detectors (enriched in ^{76}Ge) situated in liquid argon (LAr). The experimental setup is under construction in the underground laboratory of LNGS (Italy). The main parts of the GERDA setup were installed in November 2008. Eight enriched germanium detectors of HdM and IGEX are handled, characterized and tested, the same energy resolutions as previously are obtained. They are being refurbished for mounting in the cryoliquid. The LArGe test facility with one ton of liquid argon is designed. All elements of LArGe are produced and prepared for installation. The commissioning of the completed of GERDA setup is scheduled for **2009.**

The GERDA collaboration consists of about 80 physicists from 13 institutions coming from five countries. Scientists from JINR participate in the most important parts of the collaboration tasks. The radioactivity of a large fraction of the construction materials was measured by several low-background Ge gamma-spectrometers, in particular at JINR. The special facility for development and construction of a scintillator veto was prepared. Several modifications of the muon veto modules on the basis of plastic scintillator and optical fibers were developed and tested. As a result, the optimal modules were chosen and created. The first lot (10 of 40) of plastic scintillator modules was assembled, equipped with electronics and tested at JINR.

The point-like pure alpha source ^{148}Gd with the required activity has been prepared at JINR and incorporated in the Mini-LArGe setup to investigate its response function and uniformity of the light collection. With this source a good transparency of the LAr scintillator at the 0.5 m scale was demonstrated. A special system for coordinate manipulation with the alpha source inside the up-scaled LArGe facility was created. It was shown that Ge crystals can work directly in liquid argon with the leakage current and energy resolution corresponding to their standard values. Their parameters are stable after a few dozen cycles of removing from and submerging in the liquid gas. It shows the feasibility of the overall GERDA project.

Investigation of double beta decay processes ($\beta^+\beta^+$, β^+EC, EC/EC) of ^{106}Cd was performed at the Modane underground laboratory using a low-background 32 detector spectrometer **TGV-2** (Telescope Germanium Vertical) with a total sensitive volume of ~400 cm^3 (about 3 kg of Ge). The evaluation of the experimental data accumulated for ~10000 hours of measurements (2007-2009 years) was made and the limit on the 0vEC/EC decay of ^{106}Cd $T_{1/2} \geq 1.5 \cdot 10^{20}$ y (90% CL) was obtained. The new limit on the half-life of the 2vEC/EC decay of the ^{106}Cd was obtained: $T_{1/2} \geq 4.5 \cdot 10^{20}$ y (90% CL). The limits on the half-lives of others branches of ^{106}Cd decay were improved (at 90% CL): $T_{1/2}(2\nu\beta\beta^+) \geq 1.4 \cdot 10^{20}$ y and $T_{1/2}(2\nu\beta^+EC) \geq 1.1 \cdot 10^{20}$ y for the $0^+ \rightarrow 0^+$, g.s. transitions, $T_{1/2}(2\nu\beta^+\beta^+) \geq 1.6 \cdot 10^{20}$ y, $T_{1/2}(2\nu\beta^+EC) \geq 1.1 \cdot 10^{20}$ y and $T_{1/2}(2\nu EC/EC) \geq 6 \cdot 10^{19}$ y for the $0^+ \rightarrow 2^+$, 512 keV transitions, $T_{1/2}(2\nu\beta^+EC) \geq 1.5 \cdot 10^{20}$ y and $T_{1/2}(2\nu EC/EC) \geq 5 \cdot 10^{19}$ y for the $0^+ \rightarrow 0^+_1$, 1334 keV transitions [2].

The French-German-Russian **EDELWEISS** experiment is dedicated to the direct detection of WIMPs trapped in the Galactic halo. The experiment is operated in the Laboratoire Souterrain de Modane. EDELWEISS uses high purity Germanium cryogenic detectors with simultaneous measurement of phonon and ionization signals at a temperature about 20 mK. All parameters of the EDELWEISS-II setup were validated in 2006-2007 with calibration and low energy background runs. The mean phonon channel energy resolution (for a charge collection voltage of 5 V) was measured to be 2 keV while the best results are at a level of 1.2 keV for the Ge/NTD detectors. Energy resolutions of the ionization channels were around 1.5-2 keV. Gamma discrimination capabilities above 10^4 were

measured. Now a low-backgrounds physics run is in progress with the 28-detector setup with the aim to reach sensitivity to the WIMP nucleon cross-section of ~10^{-7} pb for a WIMP mass of 100 GeV. Forty detectors will be added in the coming two years to enhance progressively the sensitivity to WIMPs [3-5].

Within the framework of the E391a experiment the analysis of the data earlier robtained is continued. The new upper limit for branching ratio of the $K^0_L \rightarrow \pi^0 + \nu + \nu$ decay $6.7 \cdot 10^{-8}$ (90% C.L.) is experimentally defined. The measured experimental value is now the most accurate in the world. The analysis of the work of the E391a main barrel calorimeter is carried out. Search for a new pseudo-scalar particle in $K^0_L \rightarrow \pi^0\pi^0 + X$ decays is made. Such a particle with a mass of 214.3 MeV/c^2 was suggested by the HyperCP experiment. No evidence for X was found, and the upper limit on the branching ratio was set to be $2.4 \cdot 10^{-7}$ at the 90%C.L. [6-8].

Within the framework of the **PEN** international collaboration the **PIBETA** detector has been upgraded to optimize it for a precise measurement of the $\pi^+ \rightarrow e^+\nu$ decay ratio at PSI . Data collection runs were successfully completed in 2008. Data for $4.7 \cdot 10^6$ raw $\pi \rightarrow e\nu$ events were recorded, before analysis cuts are applied, the statistical uncertainty was $\frac{\delta B}{B} = 5 \cdot 10^{-4}$ [9].

In 2008 the first data -taking run was conducted with the **MEG** detector to search for the $\mu^+ \rightarrow e^+\gamma$ decay at a level of 10^{-14}. While this decay is forbidden in the Standard Model, some fundamental theories predict it at a level of about 10^{-14} to the main decay mode. Even non-observation of the decay at the foreseen level of sensitivity would place a stringent constraint on these theories and on the general nature of the new physics.

In 2008 the **OPERA** experiment had a first long data taking run with almost full intensity of the LNGS beam. About 1680 neutrino events were registered in the detector. In 2009 about 2500 new events are expected in the OPERA target. This means that the total number of the events registered together with the events of 2008 should be enough to find the first tau-neutrino in the CNGS muon neutrino beam. This will be the first observation of the neutrino oscillations in the appearance mode. So far, the experimental data have demonstrated the effect of oscillations only in the disappearance mode.

In 2008 the JINR group, along with active participation in the data-taking at LNGS, created the first automatic emulsion scanning station identical to those used by other OPERA participants. Along with this work, the activity related to the development of the software for the «brick finding» - localization of the neutrino event vertices – actively continued. For the simulated events, the efficiency of the vertex location in the first most probable brick was found to be ~75%; in two most probable bricks, 87%. In 2008, when a large amount of real events became available, the efficiency was checked and the algorithms of the track reconstruction and hadronic shower analysis were tuned.

One of the important tasks of the JINR group in **2009** will be analysis of the effects related to the hadronic rescattering in the events, which is one of the most important background in the tau neutrino search. At the moment, development of the user's interface software, which allows such a study with the help of the virtual Monte-Carlo approach is completed (this tool allows a flexible use of different simulation codes like GEANT4, FLUKA).

The **Borexino** experiment continues data taking after the successful start in May 2007. The main efforts of the collaboration during the last year were aimed at improvement of the result of the ^{7}Be solar neutrino flux measurement. At present a new analysis based on 192 live-days of data has been performed. The final result on the ^{7}Be neutrino flux is $49 \pm 3(stat.) \pm 4(syst)$ cpd/100 tons of scintillator [10]. The expected signal in the high metallicity Standard Solar Model is 74 ± 4 cpd/100 tones, the MSW-LMA scenario reduces this count to 48 ± 4 cpd/100 tons. The hypothesis of non-oscillating neutrinos is inconsistent with the measurements at 4σ CL.

Another interesting result obtained with 192-day statistics is the new strongest limit on the neutrino magnetic moment. The study of the maximum allowed deviations from the pure electroweak electron recoil shape for ^{7}Be neutrinos performed with the Borexino data led to a new limit on the effective neutrino moment $\mu_\nu < 5.4 \cdot 10^{-11}$ μ_B at 90% CL.

The **TUS** space experiment has been proposed to address some of the most important astrophysical and particle physics problems – to study the energy spectrum, composition and angular distribution of the Ultra High Energy Cosmic Rays (UHECR) at $E \approx 10^{19}$ -10^{20} eV in the region of the so-called GZK cutoff. The free path of $5 \cdot 10^{19}$ eV protons is about 50 Mpc due to interaction of the primary particles, mainly protons with the relict CMB photons.

A few international space experiments like TUS/KLYPVE and JEM-EUSO are under preparation to increase statistics up to a factor of 100 together with a higher accuracy and additionally with the global data-taking: the latter is important for the search for the UHECR sources in whole sky space.

JINR and the ENERGY corporation are responsible for the design, production, and tests of the optical system based on the multimodule Fresnel mirror of complicated structure 1.8 m in diameter. A technological mirror prototype was produced using precise molds that were made and measured in Dubna.

The main aim of the **NUCLEON** experiment is measurement of cosmic ray flux in the energy range 10^{11}-5.10^{14} eV and charge range up to $Z \approx 30$ in the near-Earth space. This measurement is motivated by the "knee" problem: a change in the slope and composition of the cosmic rays energy spectrum from $E^{-2.7}$ to $E^{-3.0}$ at energies about 10^{15} eV. The JINR responsibility is the design, production and tests of the scintillator trigger system including DAQ electronics etc.

The beam test of the technological trigger system prototype was carried out in 2008 at the CERN SPS H2 test beam. Data were taken at different NUCLEON apparatus orientations with respect to the beam direction to check the trigger rejection efficiency.

The main results of the **JINR/CDF** group in 2008 are the measurement of the top-quark mass (M_{top}) and the efficient operation of the CDF II. A contribution of principal significance to precise single M_{top} measurement in the "dilepton" mode at the integrated luminosity of 2.9 fb^{-1}, $M_{top} = 165.5^{+3.4}_{-3.3}(stat.) \pm 3.1(syst.)$ GeV/c^2 was made [11, 12]. The method was updated for the top mass measurement in the dilepton decay channel. To increase the number of the selected events, the so-called lepton + track selection was used.

With 3.0 fb^{-1} of the data analyzed at the CDF, and at DO, the 95% C.L. upper limits on Higgs boson production are a factor of 1.2, 1.0 and 1.3 higher than the SM cross section for a Higgs boson of mass m_H=165, 170 and 175 GeV, respectively. The TEVATRON excluded the standard model Higgs boson of m_H=170 GeV at 95% C.L.. These results significantly extend the individual limits of each experiment and provide new informations on the mass of the standard model Higgs boson beyond the LEP direct searches [13].

In **2009** the CDF collaboration plans to perform the high-precision M_{top} measurement using the b-tagging jet information on the maximum available CDF integrated luminosity, to continue to investigate the meantimer role for the selection of the muon events in $0.6 \le |\eta| \le 1.0$ region, to create the extension of the Muon trigger in the $1.0 \le |\eta| \le 1.25$ region to increase the muon-trigger-based selection data samples.

In the framework of **D0** experiment the first direct observation of the beauty baryon Ω_b was performed. This discovery has been ranked among the few most significant achievements in physics in 2008 by the American Physical Society.

The Beijing electron positron collider BEPC-II produced the first collisions on July 2008 in the detector **BES-III**, after several years of upgrading. Luminosity of $1.2 \cdot 10^{32}$ $cm^{-2}c^{-1}$, which is 12% of the design value, is currently achieved. The main goals of the experiment are studies in charmonium physics, physics of charmed mesons, tau leptons, and light hadron spectroscopy. The main activity of the JINR group in the BES-III experiment was participation in the preparation of the

physics research program of the experiment, development of the off-line software and physics analysis tools, and participation in the data taking. One of the main goals at the BES-III for the JINR group is physics of tau leptons. Another task is measurement of hadron spectral functions in tau decay, where BES-III could provide an independent cross-check of the existing measurements. Study of two-photon collisions at the BES-III was continued. A dedicated Monte-Carlo event generator was developed to provide a reliable tool for calculating hadron production in two-photon reactions at low energies. The JINR group studies selected decays of scalar charmonium states and D^0. A method to measure the branching ratio and decay product polarization for the $D^0 \to K^* + \rho^0$ decay was proposed. Preliminary Monte-Carlo study was carried out. It was shown that a accuracy comparable with the current PDG value can be achieved during the first stage of data-taking (1-2 months at luminosity 10% of nominal).

During 2008, the JINR group joined a new research activity at BES-III, which is light hadron spectroscopy. It is one of the main BES-III goals. Partial wave analysis (PWA) is the most advanced and most suitable technique for light hadron spectroscopy to deal with complicated multibody decay chains. However, to analyze BES-III data using PWA, one has to overcome several difficulties, caused by greatly increased size of a data sample in comparison with the previous experiment BES-II. During 2008, a new analysis tool for PWA was developed by the JINR group together with the PNPI (Gatchina) group. Currently, this tool allows analyzing J/ψ decays into three pseudoscalar mesons and radiative decays into two pseudoscalar mesons. Performance of this tool makes it possible to deal with the BES-III data fast enough. [14]

In **2009** the group plans to participate in the BES-III detector calibration and performance study, to perform partial-wave analysis of ψ (2S) and J/ψ decays into three pseudoscalar mesons and radiative decays into two pseudoscalar mesons, to prepare the algorithm for the off-line BEPC-II luminosity measurement using

Bhabha and dimuon events, to measure the branching ratio and decay product polarization for the $D^0 \to K^* + \rho^0$ decay.

Within the framework of the **ATLAS TileCal** project the pion energy reconstruction is performed by the new local hadronic calibration method on the basis of the 2004 combined test beam data in the energy range 10 – 350 GeV and η=0.25 [15]. In this method energies deposited in each cell are weighted. The weights are determined by the Monte Carlo simulation. This method was modified by applying cuts in weights. Various cuts were investigated and the best one was not found. The fractional energy resolution obtained with the conventional method of determination of the energy deposit in the dead material between the LAr and Tile calorimeters is $(67\pm 2)\ \%/\sqrt{E} + (3.9 \pm 0.2)\ \% + (95\pm 22)\ \%$. The energy linearity is within ±1%. The cesium miscalibration of the Tile1 and Tile2 longitudinal samplings was corrected. The mean value of energy linearity was increased by about 1% and became 1.002±0.002. The energy resolution did not change. The weighting was performed without knowing the beam energies. A special procedure was developed for this purpose. In this case the energy resolution shows 9% degradation. Linearities are within ±1%, the values with and without E-beam coincidence. The offset for these weights is 4%, which is significantly less (9%) than for the previous weights. The use of the Neural Networks for the determination of the energy deposit between the LAr and Tile calorimeters demonstrated essential improvement of energy resolution. It reached the design energy resolution for hadrons in the ATLAS detector $50\%/\sqrt{E} + 3\%$.

In the course of computational experiments with Monte-Carlo events for the ATLAS Combined Test Beam 2004 setup the Artificial Neural Networks (ANN) technique was used to reconstruct energy losses in dead materials between the barrel LAr and Tile calorimeters (Edm) [16]. The information content of different sets of variables (parameters) which describe particular features of the hadronic shower of an event in ATLAS calorimeters are used as input vectors in the constructed ANN procedure. It was shown that ANN procedures allows one to reach 40% reduction in the Edm reconstruction error compared to the conventional procedure used in the ATLAS collaboration.

Using the Geant3 simulation package, an impact of the selection criteria tested in a broad range of selection cuts was investigated for the pseudorapidities η=0.35 and 0.45 and incident energies in the range from 10 to 180 GeV in [17]. From the investigation it follows that the experimentally used selection criteria have a noticeable but not critical impact on determination of the e/h ratio.

The measurement of the electromagnetic (EM) scale calibration constant for 11% of the Tile Calorimeter modules exposed to electron and muon test beams at the CERN SPS was summarized [18]. The Tile Calorimeter modules are currently installed in the ATLAS detector. The analysis took into account the recent improvements in the Tile Calorimeter cesium calibration, charge injection system calibration and Fit Method energy reconstruction. The overall conversion factor between the measured charge and the energy deposited by the measured particles for Tile Calorimeter cells is 1.050±0.003 pC/GeV.

A fully instrumented slice of the ATLAS detector was exposed to test beams from the SPS (Super Proton Synchrotron) at CERN in 2004. The response of the central calorimeters to very low-energy pions (3 to 9 GeV) is presented [19]. The linearity and the resolution of the combined calorimetry (electromagnetic and hadronic calorimeters) was measured and compared to the prediction of the detector simulation program using the Geant4 toolkit.

In 2008, the JINR group worked mainly on the application of the **SANC** system to the LHC and e^+e^- collider physics. Its present status includes theoretical predictions for practically all Standard Model (SM) $1\to2$ and $1\to3$ decays and many $2\to2$ processes at the one-loop precision level. SANC version v1.10 is available at the servers at CERN http://pcphsanc.cern.ch/ and Dubna http://sanc.jinr.ru/.

The group continued precision study of Drell–Yan processes [20-22], which practically completed a large part of research in this direction. The precision calculations of various decay and production channels of the top-quark were continued. The study of fermion-boson processes, ffbb, at the partonic level were continued [23]. After a convolution with parton density functions, the processes pp→HZ,H, Z, ZZ are of interest for LHC physics and e^+e^- annihilation for electron linacs; this work is under way now and some parts of calculations are in the stage of finalization.

The main purpose of the **DIRAC** experiment is the lifetime measurement of $\pi^+\pi^-$, π^+K^- and π^-K^+ atoms to test precise predictions of low-energy QCD. In 2008 the full setup tuning including detectors and electronics was finished. The six-month run for the setup tuning and data-taking with a Ni target at the upgraded DIRAC setup was carried out for observation of atoms consisting of π^+K^- and π^-K^+ mesons and for lifetime measurement of $\pi^+\pi^-$ atoms with an accuracy better than 6%. Processing and analysis of the data collected in 2001-2003 was finished, the $\pi^+\pi^-$ atom lifetime was founded with the accuracy of 10%, and the results are ready for publication. The program for the off-line data analysis was updated in order to decode and analyse the data collected by new electronics modules of the upgraded DIRAC setup. The data collected in 2007 were processed and the paper about the search for the atoms consisting of π^+K^- and π^-K^+ mesons is prepared on the bases of these data.

In **2009** the collaboration plans a six-month data-taking run for improvement of the accuracy in the $\pi^+\pi^-$ atoms lifetime up to 6% and for lifetime measurement of atoms consisting of π^+K^- and π^-K^+ mesons. Analysis of the data collected in 2008 for observation of atoms consisting of π^+K^- and π^-K^+ mesons will be continued.

In 2008 under the **SPRING** project the reaction $pp\to\{pp\}_s+\pi^0$ was studied in a wide energy range of 0.5-2.0 GeV with detection of a $^1S_0$ pp pair. This reaction is a kinematical analog of the well-studied process $pp\to d+\pi^+$, but the dominating

contribution of the intermediate state Delta-isobar is suppressed due to spin-parity constraints, and therefore other mechanisms may become visible. The energy (Fig. 1) and angular dependences of the differential cross section were measured, the ratio of singlet and triplet matrix elements was deduced from the comparison with the $pp\to d+\pi^+$ data.

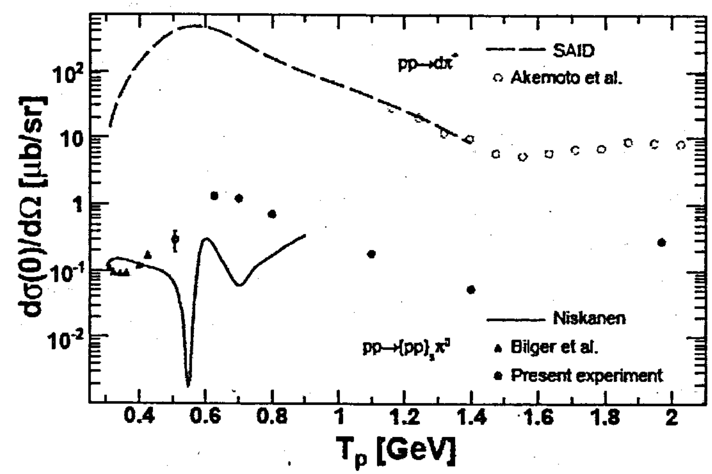

Fig. 1. Differential cross section of $pp\to\{pp\}_s+\pi^0$ (full circles), model predictions (J.Niskanen, full line) and comparison with the $pp\to d+\pi^+$ data (dashed line and empty circles).

The process of inverse diproton photodisintegration, $pp\to\{pp\}_s+\gamma$, was observed For the first time at intermediate energies. Similar to the extensively studied deuteron photodisintegration, it gives information about NN-interactions at short distances. Previous experiments on diproton photodisintegration were fulfilled using diproton configurations contained within light nuclei and therefore suffered from large background arising from three-nucleon absorption. In contrast, the decay $pp\to\{pp\}_s+\gamma$ with free diprotons in the $^1S_0$ state involved is completely free of such complications. The angular dependence of the differential cross section was measured at the beam energy 0.35, 0.5 and 0.55 GeV (Fig. 2). Though the S-wave contribution of ΔN in the intermediate state is suppressed, the observed increase in the cross section with increasing energy may be explained by excitation of Δ in higher-order waves [24-27].

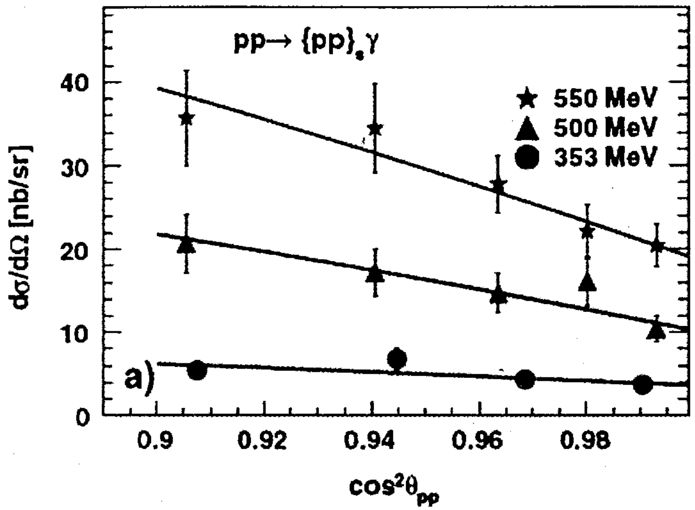

Fig. 2. Angular dependence of the differential cross section of $pp \to \{pp\}_s + \gamma$.

Applied Scientific Research

A compact superconducting isochronous cyclotron **C400** has been designed at IBA (Belgium) in collaboration with JINR (Dubna). Carbon ions beams with energies up to 400 MeV/u are successfully used to treat radioresistant tumors. This cyclotron can accelerate all ions with the charge-to-mass ratio 0.5. Ions $_{12}C^{6+}$ and $_{4}He^{2+}$ will be accelerated to the energy 400 MeV/u and extracted by the electrostatic deflector, H_2^+ ions will be accelerated to the energy 270 MeV/u and extracted by stripping. The present status of the C400 design may be summarized as follows: the isochronous magnetic field with adequate focusing characteristics and optimized extraction is obtained by computer simulation with the 3D TOSCA code; beam dynamic simulations are done with multiparticle tracking codes for the acceleration

and extraction regions; the axial injection line, inflector and central region are designed; the RF cavity is designed by the CST Microwave Studio; ion losses due to residual gas interaction are calculated. A group of international experts emphasized the high quality of the research work done by JINR. The project will be ready for construction in the nearest future.

The main goal of the topic "Further Development of Methods and Instrumentation for Radiotherapy and Associated Diagnostics with the JINR Hadron Beams" is to carry out medico-biological and clinical investigations of 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 at the Medico-technical complex (MTC) of DLNP.

The regular sessions of proton therapy aimed to investigate its effectiveness treating different kinds of neoplasm were carry out in collaboration with the Medical Radiological Research Centre (Obninsk) and the Radiological Department of the Dubna hospital. Six treatment sessions, total duration of 26 weeks, have been carried out. 87 new patients were fractionally treated with the medical proton beam. The total number of the single proton irradiations (fields) exceeded 4500. Other 27 patients were irradiated with Co-60 gamma-therapy unit "Rokus-M". The planned recharging of radioactive source in the gamma-therapy unit "Rokus-M" was carried out, which allows using the unit for clinical and radiobiological investigations till 2018.

Radiobiological research on the regularities of the manifestation of the adaptive response and "bystander" effect of the combined irradiation of fibroblast cells by different kinds of ionizing radiation was also continued.

Based on the results of experiments of the recent several years a patent for the invention is obtained: RU 2 330 695 C2 – method of protection against the damaging action of ionizing radiation in the experiment (Authors: Voskanyan K. S., Mytsin G. V., Gaevskiy V. N.).

The research on chromosomal damages in cells at different stages of the cells cycle after the proton beam irradiation were continued in collaboration with the Laboratory of Radiation Biology using the model of human blood lymphocytes.

Within the framework of the fundamental research on radiation biology of animal and human genes,. the first experiments on the study of heritable DNA alterations at the mini-gene black of Drosophila melanogaster after action of Co-60 gamma-rays were performed using the PCR technique. The work on 2D-3D simulation and visualization of higher order organization of the entire haploid male germ cell genome was successfully continued in collaboration with LIT, JINR and the Megarosette-loop model for such genome was developed [28, 29]

In **2009** DLNP plans to continue clinical research on proton radiotherapy of different neoplasms with the JINR Phasotron beams in treatment room No 1; to develop hardware and software for verification of patient set up based on the X-ray digital detector; to develop the equipment for dynamic conformal irradiation of deep seated neoplasms with the proton beam; to continue studies of dosimetric characteristics of various types of thermoluminescent and track detectors at the hadron beams, etc.

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