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DZHELEPOV LABORATORY OF NUCLEAR PROBLEMS: RESEARCH ACTIVITIES IN 2005

Report to the 99th Session
of the JINR Scientific Council
January 19–20, 2006

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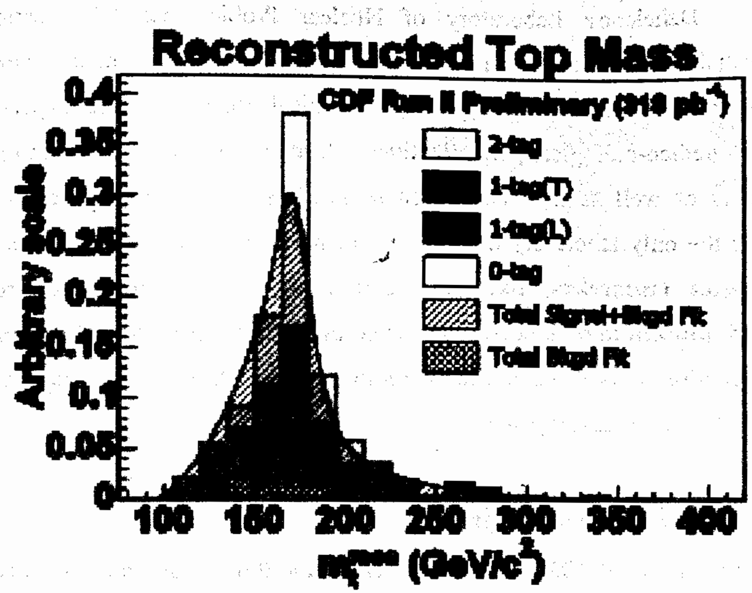
The Dzhelepov Laboratory of Nuclear Problem (**DLNP**) carries out experimental research in modern particle physics, investigation of nuclear structure, study of condensed matter properties; theoretical support of the experimental research; medico-biological investigations; development of new detectors and accelerators as well as new experimental methods and facilities. The DLNP is nowadays the only laboratory at JINR where modern rare-decay experiments and **new physics researches**, like investigation of neutrino properties, are also performed. Modern important trends in experimental astroparticle and underground physics are also under close consideration in the Laboratory — new projects in the fields are also under development.

Elementary Particle Physics

In the frame of **CDF** project the very main 2004 results are the world best *M(top)* measurements and CDF efficient operation providing. Significant achievements were announced by the April, 21 and July, 28 2005 "*FNAL TODAY*" issues: JINR-INFN-FNAL team made a contribution of a principal significance to the world most precise *M(top)* measurement in the so-called "lepton + jets" topology [1, 2] $M_{top} = 173.5 + 3.7 / -3.6(stat.) \pm 1.3(syst.)$ (Fig.1, top) and made the improved precision *M(top)* measurement in the so-called "dilepton" topology [3-5] $M_{top} = 169.9 + 9.2 / -9.3(stat.) \pm 3.8(syst.)$ (Fig.1, bottom).

A new method to extract the *M(top)* is proposed by a University of Athens/Dubna group. Transverse momentum of electrons and muons produced in the $t\bar{t} \rightarrow dilepton$ and the $t\bar{t} \rightarrow lepton + jets$ channels are sensitive to *M(top)* and can be accurately measured [6, 7] providing the *M(top)* with a very small systematic error and, at large enough integrated luminosity, with a very small total error. Method is not affected by uncertainties in the jet energy scale and in b-tagging and is applicable to both Tevatron and LHC collider experiments.



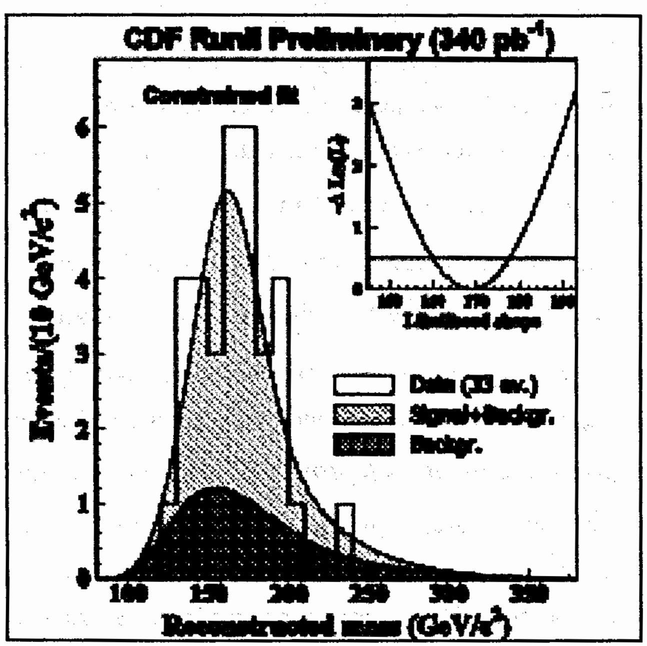


Fig.1. Reconstructed top mass for "lepton + jets" mode (top) and for dilepton mode (bottom).

In **2006** the JINR/CDF group plans to significantly reduce the error of the *M(top)* to 2 GeV/c^2 level which will enable us to establish a new limits on Higgs mass, measure the top quark charge to make sure it is consistent with the SM.

In the year 2005 the **D0** experiment has accumulated more than 1 fb^{-1} as written on the tapes. The JINR group has actively participated in this success by supporting the D0 forward-backward muon tracking system. What concerns the physics analysis, the group continues the search for χ_b baryon by developing dedicated algorithms and study of direct photon production aimed at jet energy scale calibration and determination of gluon distribution function. The first important result obtained on this way with leading contribution of JINR/DLNP group is the inclusive measurement of the isolated photon cross section.

In high energy $p\overline{p}$ collisions the dominant source for production of photons with moderate and high transverse momentum p_T^γ is direct (or prompt) photons. They are called direct since they are produced directly from parton-parton interactions and not from the hadron decays (such as π^0, η, K_S^0). These photons come unaltered from the hard process and therefore can give us a clean test of the hard scattering dynamics. Direct-photon production is complimentary to Deep Inelastic Scattering, Drell-Yan pair production and to inclusive production of jets. But the photon identification is free from the uncertainties caused by the fragmentation of partons into hadrons or by experimental issues related to jet identification and energy measurement, and thus has an advantage over jet production measurement. In the region up to $p_T^\gamma \cong 150$ GeV direct photons are mainly produced through the Compton scattering $qg \to q\gamma$ and thus their production cross section is sensitive to the gluon density inside the colliding hadrons. A high center of mass energy at the Tevatron and the statistics accumulated currently in Run II allows us to test quantum chromodynamics (QCD) and gluon distribution in the region of large Q^2 and in a wide range of

$x_T : 0.02 < x_T < 0.30$. Measurements of the isolated photon cross section also allows tests of the next-to-leading order (NLO) and resumed QCD calculations, phenomenological models of gluon radiation, studies of photon isolation and the fragmentation process. In addition, photons in the final state may be an important sign of new particles and/or physics beyond the standard model. For this reason it is necessary to study and to understand the "conventional" sources of photons. Unfortunately, this measurement is complicated by the presence of the energetic neutral measons, produced in the core of hadronic jets that mimic the photon signal. But the selection criteria (including the photon isolation) and the identification method that have been found allows substantially to get rid off the background events and register the photon signal with a reasonable accuracy.

In D0 we have measured the photon production cross section over a wide range of the photon transverse momentum $p_T^\gamma, 23 < p_T^\gamma < 300$ GeV (Fig.2), that significantly (in ~2.5 times) extends previous analogous measurements. In the presented p_T^γ interval the photon cross section falls by more than five orders of magnitude. The uncertainties of our measurement are comparable with existing theoretical ones. We concluded that the found photon cross section agree with the theoretical predictions in the whole p_T^γ interval within uncertainties. We had just five events with $p_T^\gamma > 300$ GeV (which were not used in this analysis) but due to increasing Tevatron luminosity we hope to have much more statistics **in the next 2-3 years** [8]. It would allow us to study the region up to $p_T^\gamma \cong 500-600$ GeV and to check predictions of the "standard" theory as well as to look for possible "traces" of new physics.

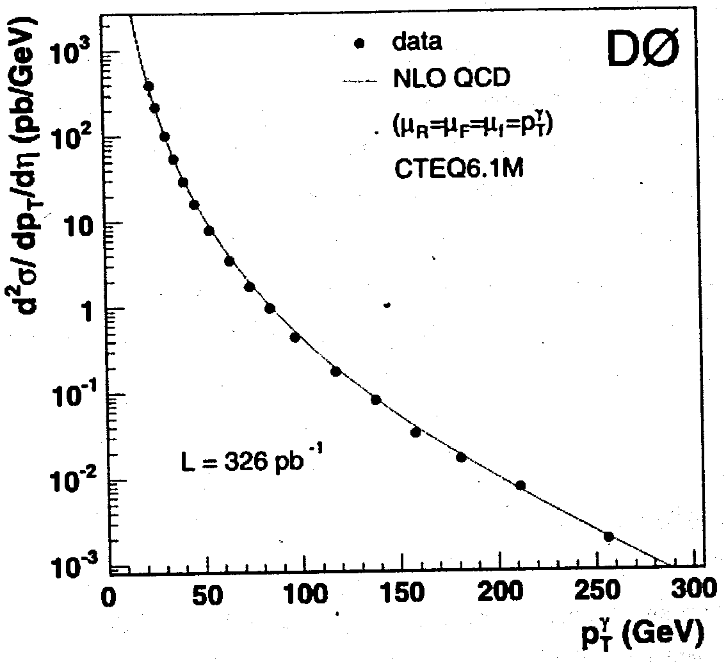


Fig.2. The inclusive cross section for the production of isolated photons as a function of p_T^γ. The results from the NLO pQCD calculations are shown as solid line.

In the frame of **DIRAC** experiment all data collected in 2001–2003 were processed with the updated program and constants. The scheme of the setup including dimensions of all detectors was revised to accounts the kinematic of $\pi^\pm K^\mp$ atoms and the particle identification system. The new vacuum channel has been designed and manufactured at JINR. The new readout electronics which will be used for almost all scintillation detectors are deigned and the prototypes are being manufactured. The precise measurement of the multiple scattering in thin scatterers was performed. 60% of all drift chambers have been already repaired, the rest will be repaired before the run in 2006. Investigation of production of the long-lived states of $\pi^+\pi^-$ atoms was performed [9]. The new Scintillating Fiber Detector (SFD) with fibers diameter of 0.27 mm have been designed and its electronics prototype was design and manufactured. The heavy-gas Cherenkov counter for pion identification was designed. Design the new trigger scheme and design and construction of a part of the new DAQ were performed.

In **2006** analyses of all data collected in 2000-2003 for the lifetime measurement with a statistical accuracy of about 10% on the Ni and Ti targets and evaluation of systematic errors in the lifetime, manufacturing of detectors and electronics for the setup upgrade and installation and tuning of all new and modified detectors, readout system, trigger and DAQ are planned. The first run with modified setup for calibration and data taking for observation of the $\pi^+\pi^-$ atom in the long-lived states will be performed.

For **ATLAS Hadron Tile Calorimeter** the significant attention was paid to the R&D-works and quality control methods; special role was indicated of JINR created laser metrology in achievement of the high precision when assembling of the main structural calorimeter units: submodules and modules.

With the aim of establishing of electromagnetic scale and understanding of performance of the ATLAS Tile hadronic calorimeter to electrons 12% of modules have been exposed in electron beams with various energies by three possible ways: cell-scan at $\Theta = 20^\circ$ at the centers of the front face cells, η-scan and tilerow scan at $\Theta = 90^\circ$ for the module side cells. The work of JINR group is devoted to the determination of the electromagnetic energy calibration constants of the EBM-(ANL-44), EBM+ (IFA-42), BM (JINR-55) TILECAL modules at energies E = 10, 20, 50, 100 and 180 GeV and $\Theta = 20^\circ$ and $\Theta = 90^\circ$ and η scans on the basis of the July 2002 testbeam run data using the flat filter [10] and fit filter [11] methods of the PMT signal reconstruction. For flat filter method the obtained average electron calibration constants equal to 1.157±0.002, RMS = 2.6±0.2 % for $\Theta = 20^\circ$,

1.196±0.005, RMS = 5.7±0.3 % for $\Theta = 90^\circ$ and 1.143±0.005, RMS = 3.7±0.3 % for η-scan. For fit filter method the obtained average electron calibration constants equal to 1.046±0.002, RMS=3.0±0.2 % for $\Theta = 20^\circ$, 1.082±0.004, RMS=5.3±0.3 % for $\Theta = 90^\circ$, 1.046±0.004, RMS=3.8±0.3 % for η-scan. In [12] the electron energy resolutions of the EBM- (ANL-44), EBM+ (IFA-42) and BM (JINR-55) Modules of the ATLAS Tile Calorimeter at energies 10, 20, 50, 100 and 180 GeV and $\Theta = 20^\circ$ and $\Theta = 90^\circ$ and η-scan from the July 2002 testbeam run data using the flat filter method of the PMT signal reconstruction were extracted. The parameters of the electron energy resolution for the quadratic fit are equal to $a = 29 \pm 1.6\,\%\sqrt{GeV}$, $b = 3.0 \pm 0.4\,\%$ at $\Theta = 20^\circ$ and $a = 22 \pm 1\,\%\sqrt{GeV}$, $b = 2.3 \pm 0.3\,\%$ at $\Theta = 90^\circ$. The results for energy resolution have been compared with the Monte Carlo based parameterization. Good agreement is observed for the linear fit. The obtained calibration constants have been included in the TILECAL calibration database, ATLAS software and will be used for the energy calibration of the ATLAS Tile hadronic calorimeter.

New results on the cross-section measurements of the positive pion production for the K2K beam line are performed, using only the **HARP** forward spectrometer [13]. The neutrino beam of the K2K experiment originates from the decay of light hadrons, produced by exposing an aluminium target to a proton beam of momentum 12.9 GeV/c. The HARP measurement of the double-differential cross-section, $d^2\sigma^{\pi+}/dpd\Omega$ of positive pion production for protons of 12.9~GeV/c momentum impinging on a thin Al target of 5% nuclear interaction length (λ_I) is presented, i.e. reproducing closely the conditions of the K2K beam-line for the production of secondaries.

The K2K is 250 km long-base line accelerator experiment. In the case of long-base line experiments where the event rate in a "far" detector is compared with the rate in a "near" detector, knowledge of the initial hadron yields as a function of secondary momentum and angle at the production point is very important.

The HARP forward spectrometer is well matched to the angular and momentum ranges for the K2K beam line. The tracking of forward-going particles in forward spectrometer is performed by a set of large (3x3 m^2) drift chambers (NDC's). The 23 NDC's drift chambers were placed upstream and downstream of the 0.5 T dipole magnet. The π^+ production data was fitted with Sanford-Wang parametrisation. The HARP cross-section measurement is shown in Fig.3 (the data points with error bars), in a comparison to the best fit Sanford-Wang parametrisation (histograms). A detailed error analysis has been performed. Overall, the total uncertainty on the pion production cross-section measured over the entire phase space ($0.75 < p < 6.5$ GeV/c) and ($30 < \theta < 210$ mrad) is estimated to be 5%.

The HARP cross-section measurements have been used to determine a new prediction of the ratio of neutrino fluxes at the "far" and "near" detectors of the K2K experiment. This quantity is defined as the ratio of fluxes in the absence of neutrino oscillation effects. Fig.4 shows the energy dependence of predicted ratio based on the HARP data, compared with the prediction, used up to now by K2K collaboration. The points with error bars are based on the HARP data. In future the more precise HARP measurements of the far/near ratio will be used to reduce the error on neutrino oscillation parameters in the K2K experiment.

In **2006** the collaboration plans to measure the cross-section of hadron production at proton momentum 8.9 GeV/c on the Be target for the analysis of the MiniBoone experiment at Fermilab (USA), to measure the forward and large-angle $\pi^\pm$ spectra up to 8 GeV/c protons on Ta target for the design of the proton driver of a Neutrino Factory Project, to measure spectrum of $\pi^\pm$ at proton momentum 1.5 GeV/c on the water targets, to possibly explaining the anomalous $\bar{\nu}_e$ signal reported by the LSND Collaboration.

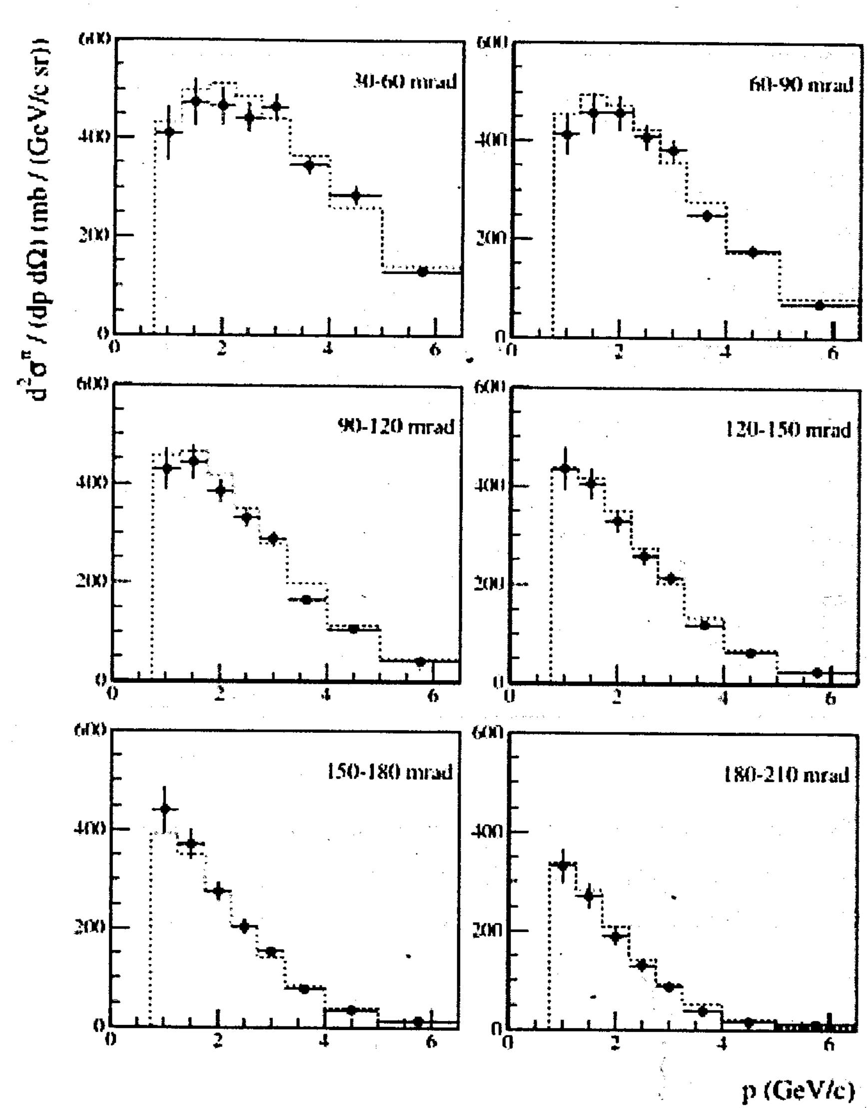


Fig.3. Measurement of the double-differential π^+ production cross-section $d^2\sigma^{\pi+} / dpd\Omega$ for incoming protons of 12.9 GeV/c on an aluminium target as a function of pion momentum, in bins of pion polar angle θ.

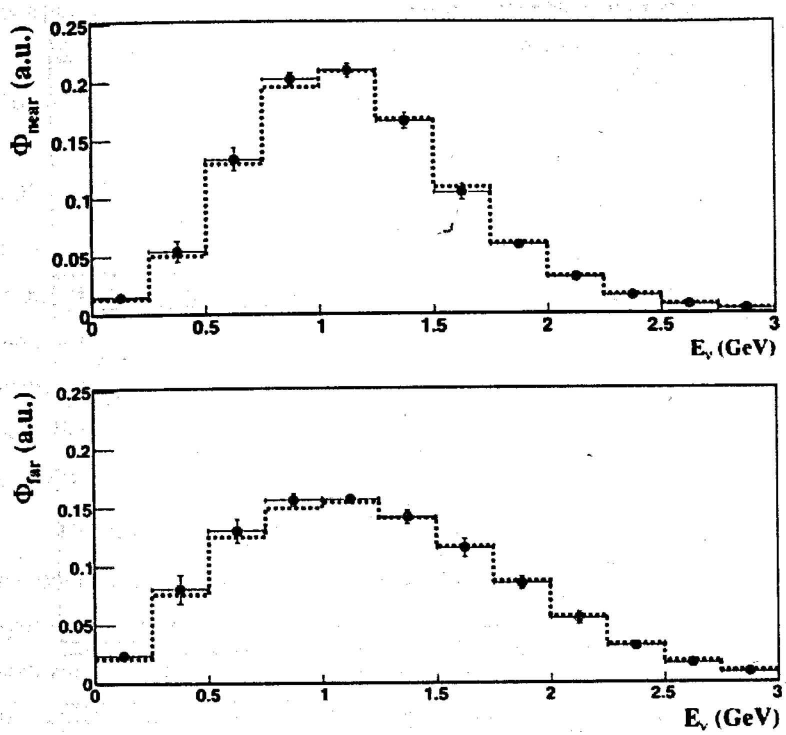


Fig.4 (a). Unit-area normalized flux predictions at the K2K near (top) and far (bottom) detector locations, respectively, while right panel shows the far-to-near flux ratio (empty squares with error boxes show K2K model results).

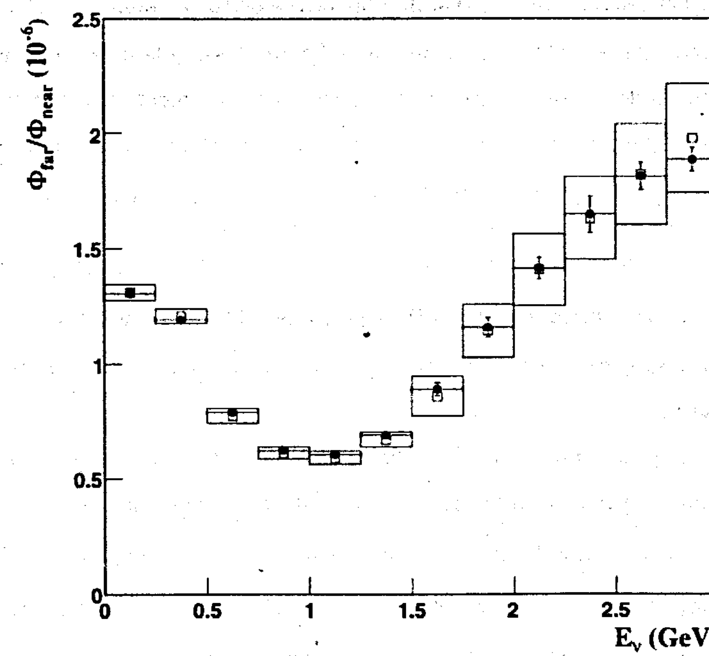


Fig.4 (b). Muon neutrino fluxes in the K2K experiment as a function of neutrino energy, as predicted by the default hadronic model assumptions in the K2K beam Monte Carlo simulation (dotted histograms), and by the HARP π^+ production measurement (filled circles with error bars).

Within the **SANC** project, the team members worked in 2005 on creation of new FORM programs for calculation of $F \to 3f$ decays and of $f\bar{f} \to bb$ processes at the one-loop level; on CC and NC Drell--Yan processes at LHC; on interfacing libraries of partonic densities to the SANC environment; on implementation of soft and hard Bremsstrahlung contributions for various $2 \to 2$ processes.

SANC version ***v1.00*** is accessible from servers at Dubna *http://sanc.jinr.ru/ (159.93.75.10)* and CERN *http://pcphsanc.cern.ch/ (137.138.180.42).* The system is started to be widely used for physical applications. The one-loop electroweak corrections to the charged current Drell--Yan processes were revisited within the automatic SANC system [14]. Contributions with mass singularities were treated including higher order leading logarithmic corrections. The theoretical accuracy in the description of the processes was studied. In [15] the implementation of processes $f_1\bar{f}_1 ZZ \to 0$ and $f_1\bar{f}_1 HZ \to 0$ into the framework of SANC system was described. The f_1 stands for a massless fermion whose mass is kept non-zero only in arguments of log functions and $\to 0$ means that all 4-momenta flow inwards. These results are supposed to be used for a more precise treatment of four-fermion H decay modes at LHC.

During the year **2006** the SANC system, which is supposed to be extended for more complicated processes. In particular, it is planned to complete calculations of $H \to 4\mu$ process in one-Z resonance approximation and to implement several QCD processes. In the frame of SANC development it is planed to calculate the decay $H \to 2\mu 2\nu$ in one- and double-W resonance approximation, to calculate the process $f\bar{f} \to HW$ at one loop, to calculate the processes $gg \to BB, \gamma\gamma \to BB\ (BB = Z, \gamma, H, W)$ at one loop, to create environment for one loop calculations of $5 \to 0$ processes and apply it for the complete calculations of the decay $H \to 4f$.

The **TUS** space experiment has been proposed to address some of the most important astrophysical and particle physics problems. It aimed to measure energy spectrum, composition and angular distribution of the Ultra High Energy Cosmic Ray (UHECR) at $E \approx 10^{19} - 10^{20}$ eV to study the region of GZK cutoff. R&D stage of the TUS project is close to the end. At present the first prototypes of the detector are under testing including the design and development of the space mirror-concentrator. The launch of the MSU satellite "Tatiana" is used to test the TUS photo sensors and their electronics and to measure the UV light emitted by the Earth atmosphere. The "Tatiana" satellite was launched on January 20, 2005. The energy resolution of fluorescence detectors is heavily related to the uncertainties in the fluorescence production yield. Recently collaboration between the JINR (Dubna, Russia) and LAPP (Annecy, France) scientific groups performed a measurement of the fluorescent light yield [16, 17].

In **2006** the collaboration plans to complete the Fresnel mirror R&D for the TUS ground prototype, to finish the design and production a special tool for Fresnel mirror measurements.

The aim of the **NUCLEON** project is direct CR measurements in the energy range $10^{11} - 10^{15}$ eV and charge range up to $Z \approx 40$ in the near-Earth space to resolve mainly the knee problem in CR spectrum. The special interest of the JINR is the search for a signal of heavy particle production with $M \approx 0.5$ TeV as expected for the lightest and stable SUSY or WIMP particle that is needed for the dark matter understanding. Design and production of the first full scale trigger double sided module of the NUCLEON trigger system was done. The second prototype is in production now.

In **2006** design, production and tests of the trigger system prototype of the NUCLEON detector, development of the MC simulation program for the NUCLEON trigger system and design, production and tests of the prototype FE electronic of the trigger system will be expected.

The experiment **HYPERON** aimed to study of nuclear transparency dependence on the atomic number and color screening effects in charge exchange reactions with neutral mesons in the final state. The new data acquisition system was developed which allows receiving experimental data at very high speed 9 Mbyte/sec. It means that we can receive practically all events which pass trigger. The data acquisition system was tested on the calorimeter in the HYPERON-M experiment in the December 2004 run.

In December 2004 data taking was started but without using proportional chambers and tagging system. About $1.8 \cdot 10^7$ trigger events with Be Al and Cu targets were collected. Preliminary data processing was done and we understood that we should set more hard trigger conditions to reject background. Data from three targets are not enough to get reliable information about A-dependence of the nuclear transparency.

Low and Intermediate Energy Physics

The **NEMO-3** detector located in the Modane Underground Laboratory (LSM, France, 4800 m.w.e.) is searching for neutrinoless double-beta decay (0ν2β) which would be an indication of new fundamental physics beyond the Standard Model such as the absolute neutrino mass scale, the nature of neutrino (either Dirac or Majorana), and neutrino hierarchy. The main goal of the NEMO project is to reach (0.1-0.3) eV sensitivity for the effective majorana neutrino mass $\langle m_\nu \rangle \left(T_{1/2}^{0\nu2\beta}\left({}^{100}Mo\right) \sim 10^{25\,y}\right)$.

During 2005 year data collection from NEMO-3 detector was continued in regular mode at stable conditions. New statistics (~236 effective days of data taking since beginning of 2005) is free from Radon background, which was highly suppressed to the end of first stage of experiment. The total NEMO-3 exposition is 762 days since February of 2003. Data analysis of first Phase I of experiment (2003-2004) was performed during 2005 [19]. After analysis of 389 effective days of data collected no evidence of 0ν2β was found neither in ^{100}Mo, nor in ^{82}Se (Fig.5) with the corresponding limits (90% C.L.):

$$T_{1/2}^{0\nu2\beta}\left({}^{100}Mo\right) \geq 4.6 \cdot 10^{23}\ y \Rightarrow \langle m_\nu \rangle \leq 0.7 - 2.8\ eV,$$
$$T_{1/2}^{0\nu2\beta}\left({}^{82}Se\right) \geq 1.0 \cdot 10^{23}\ y \Rightarrow \langle m_\nu \rangle \leq 1.7 - 4.9\ eV$$

NEMO-3 is also sensitive to other possible 0ν2β-mechanisms. In the hypothesis of gluino or neutralino exchange, a limit on the trilinear R-parity-violating supersymmetric coupling $\lambda_{111} < 1.6 \cdot 10^{-4}$ for ^{100}Mo is obtained. In the hypothesis of a right-handed weak current, the limit is $T_{1/2}^{0\nu2\beta}\left({}^{100}Mo\right) = 1.7 \cdot 10^{23}\ y$ at 90%

C.L., corresponding to an upper limit on the coupling constant of $\lambda < 2.5 \cdot 10^{-6}$. The analysis of 2ν2β-decay of a set of isotopes was also done (Fig.6). A real estimate of the final NEMO-3 sensitivity was obtained taking into account the directly measured background. After five years of data collection (in 2009) the expected sensitivity at 90% C.L. will be $T_{1/2}^{0\nu2\beta}\left({}^{100}Mo\right) \geq 2.0 \cdot 10^{24}\ y$, leading to $\langle m_\nu \rangle \leq 0.3 - 1.3$ eV, which is in accordance with project goal and on the level of best world results obtained up to now. R&D program of next generation SuperNEMO 0νββ-project was performed in parallel with NEMO-3 processing.

In **2006** the collaboration will support NEMO-3 data taking performing maintenance required as well as data analysis, focusing besides the improvement of 0νββ-sensitivity on data analysis and publication of results for 2νββ-transitions to exited states of ^{100}Mo, 2ν2β-decay of ^{48}Ca and other isotopes. 3-year SuperNEMO R&D program will be lunched. JINR group will be focused on R&D of calorimeter making and testing new plastic scintillators. One should emphasize that the improvement of energy resolution of the calorimeter up to 7% at 1 MeV (against 15-17% in NEMO-3) is one of the most important R&D goals. Other our tasks are R&D for Radon monitoring, as well as software development and simulations in order to find optimal design of SuperNEMO module.

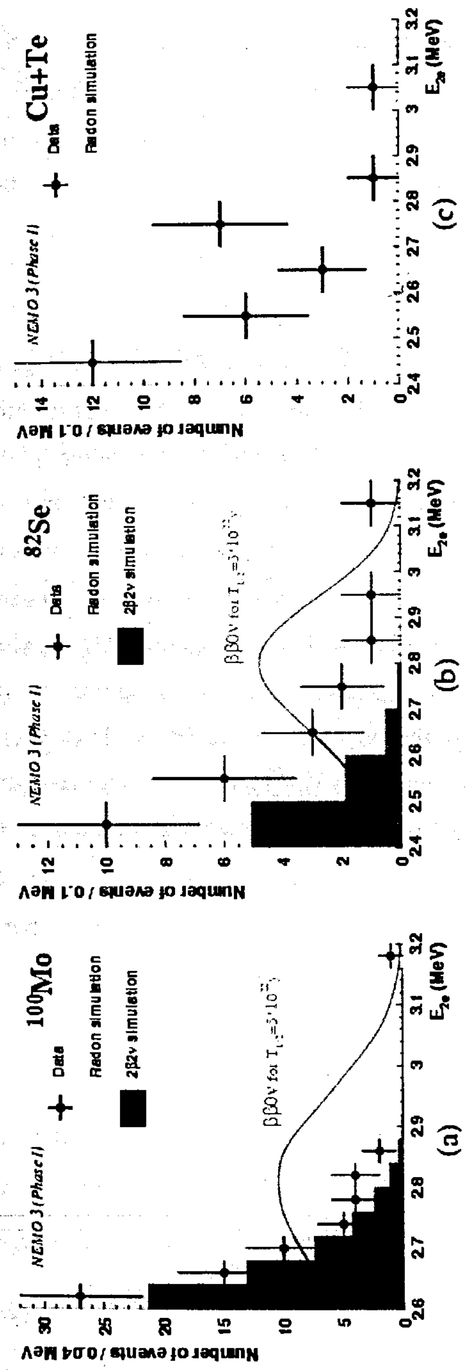


Fig.5. Spectra of the energy sum of the two electrons in the 0νββ-energy window after 389 effective days of data collection from February 2003 until September 2004 (Phase I): (a) with 6.914 kg of ^{100}Mo; (b) with 0.932 kg of ^{82}Se; (c) with Copper and Tellurium foils. The shaded histograms are the expected backgrounds computed by Monte-Carlo simulations: dark (blue) is the 2νββ contribution and light (green) is the radon contribution. The solid line corresponds to the expected 0νββ-signal if $T_{1/2}^{0\nu2\beta} = 5\cdot10^{22}$ y.

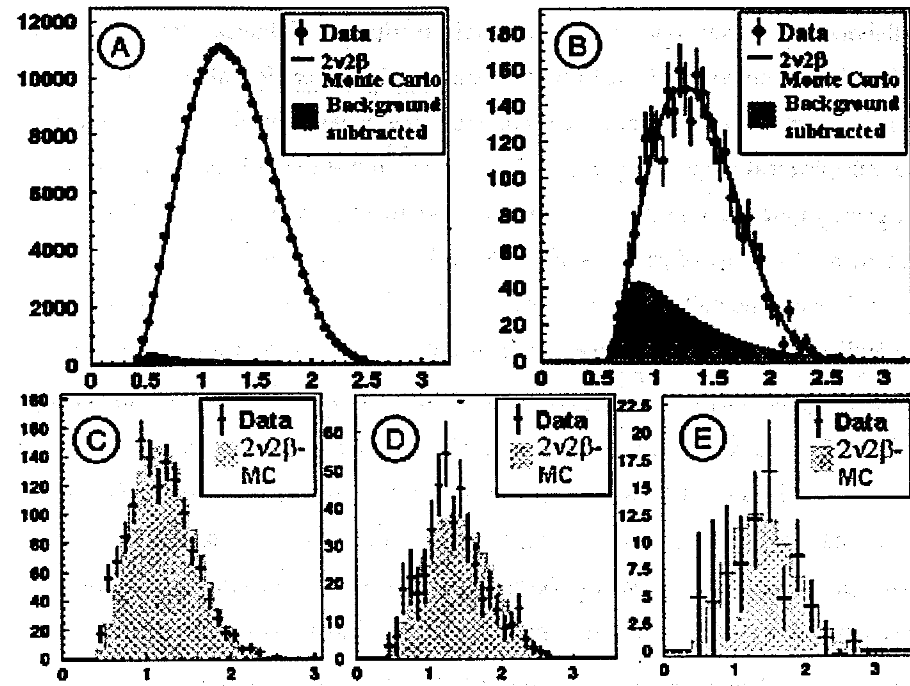


Fig.6. Energy sum spectra of two electrons emitted in 2β-decay for a set of isotopes. Points correspond to experimental data, expected simulated 2ν2β-signal is shown by histogram while the subtracted background is shown by shaded histogram. Energy in MeV is in x-axis, while number of events is presented in y-axis. A) – ^{100}Mo, exposure 7.37 kg·y, 219000 events, signal-to-background ratio (S/B) is 40. B) – ^{82}Se, exposure 1.0 kg·y, 2750 events, S/B is 4. C) – ^{116}Cd, exposure 0.2 kg·y, 1371 events, S/B is 7.5. D) – ^{150}Nd, exposure 17 g·y, 449 events, S/B is 2.8. E) – ^{96}Zr, exposure 4.3 g·y, 72 events, S/B is 0.9.

The investigation of reactions between light nuclei at keV energy level is of great importance, because it could provide a direct verification of fundamental symmetries in strong interactions: such as charge symmetry, isotopic invariance, input of the meson currents, effect of nuclei screening, etc. It could also help in the solutions for the number of astrophysical problems. At present time **LESI** collaboration carries out at the Research Institute of Nuclear Physics at the Polytechnic University (Tomsk) the research on the generation of colliding plasma fluxes in the keV energy range and continues the nuclear reaction investigations at the astrophysical range energies (Fig.7). It is shown that the efficiency of converting the energy introduced in the discharges into the directed motion of plasma is 0.3–0.6 and the total number of particles in the fluxes is 10^{19} particles/pulse.

Besides the collaboration creates the new type of plasma accelerator based on the Hall ion source for the same aim. It is anticipated that the Hall accelerator will be able to generate the intense plasma flows ($I = 10$ A/cm^2) with small ion energy spread. This allows obtain the more precise information about characteristics of nuclear reactions at ultralow energies. A distinctive feature of proposed by us the above indicated methods are very promising for study of strong interactions between light nuclei at ultralow energies because there is the real possibility of substantially decreasing the lower measurement range for astrophysical S-factor and cross sections of nuclear reaction in question $\sigma \sim 10^{-33} - 10^{-37}$ cm^2 [20, 21].

In **2006** collaboration will continue the creation of the Hall plasma accelerator and precision study of the dependences of the pd-reaction astrophysical S-factors and cross sections on the collision energy in the range of 2-12 keV and the measurement of the nuclear dd-reaction characteristics in the astrophysical deuteron collision energy range using plasma opposing fluxes.

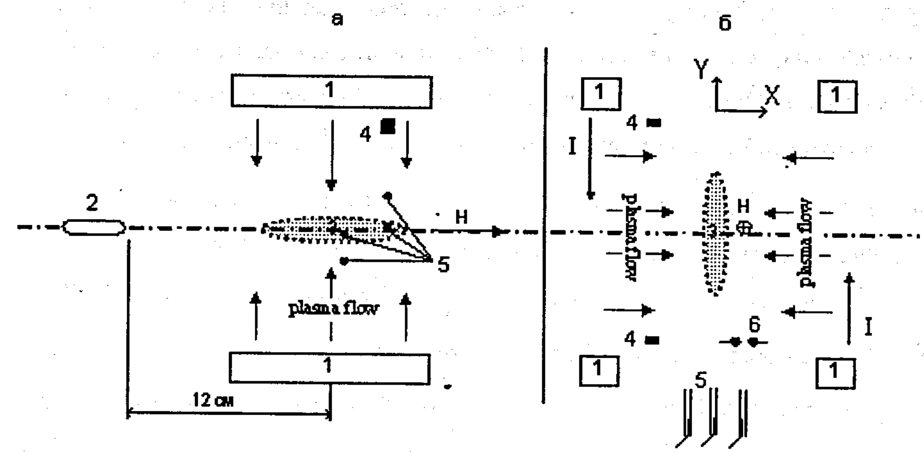


Fig. 7. Schematic of experimental setup in two projections, and locations : a- view along B-field; b- side view normal to B-field: 1 – discharge HV electrodes, 2 – spectrometer, 3 – region of plasma flows collision, 4 – voltage plate electrodes, 5 – light detector's collimators, 6 – floating probes.

In 2005 the analysis of pion radiative decay (PRD) experimental data, received by **PIBETA** collaboration in 2004 in a special experiment, was carried out. Necessity of this new experiment has been caused by that in 1999-2001 experiment a number of PRD events registered in a certain kinematic region "B" (defined by the following conditions: relative angle between gamma-quantum and positron $\theta_{\gamma,e} > 40°$, gamma-quantum energy $E_\gamma > 55.6$ MeV and positron energy $E_e > 20$ MeV), was ~20% less then the Standard Model predicted.

The new data have been obtained on the PSI pion beam with stopping rate of 50-100 KHz. Such intensity allowed us to reduce the accidental coincidence background rate by factor ~10 in comparison with the measurements of 1999-2001 devoted to examination of the pion beta decay (the RPD data were only a by-product). With the purpose of reception of more reliable results the collaboration decided to carry out the analysis of the new data independently by two groups of physicists (from Virginia and from Dubna). The Dubna physicists have no previous experience of such analysis. It is necessary to note, that the analysis of the data represents very delicate difficult task demanding extremely precise account of many various factors. During the year under review a preliminary analysis of the whole experimental PRD data set (corresponding to ~ 6.12×10^{11} pion stops) has been made. The $\pi^+\rightarrow e^+\nu$ and $\mu^+ \rightarrow e^+\nu\bar{\nu}$ decays have been studied. These processes are used to calibrate the data on the $\pi^+ \rightarrow e^+\nu\,\gamma$ decay [22]. About 240000 $\pi^+\rightarrow e^+\nu$ decays have been analyzed. The positron energy spectrum for this decay is shown in Fig.8. In Fig.9 the measured spectrum of positrons from the $\mu^+ \rightarrow e^+\nu\bar{\nu}$ decay is shown. From the figures it is visible, that the measured spectra well coincide with the simulated ones. 17085 RPD events have been found. From them 7261 events fall in the kinematic region B where the deficit of events was earlier observed. For the gamma-quanta registered with energy exceeding ~ 60 MэB, the deficit of events of ~ 11 % is observed at a statistical measurement accuracy ~ 2 %. It is important to underline that the data analysis is not yet fully completed, all current results are preliminary and any conclusion concerning existence of the anomaly would be premature. The number of events identified as the $\pi^+\rightarrow e^+\nu$ decay depends on adequacy of computer simulation of real processes, precision of calibration parameters and efficiency of background suppression. The systematic errors determining the overall precision of the experiment depend on perfection of these procedures.

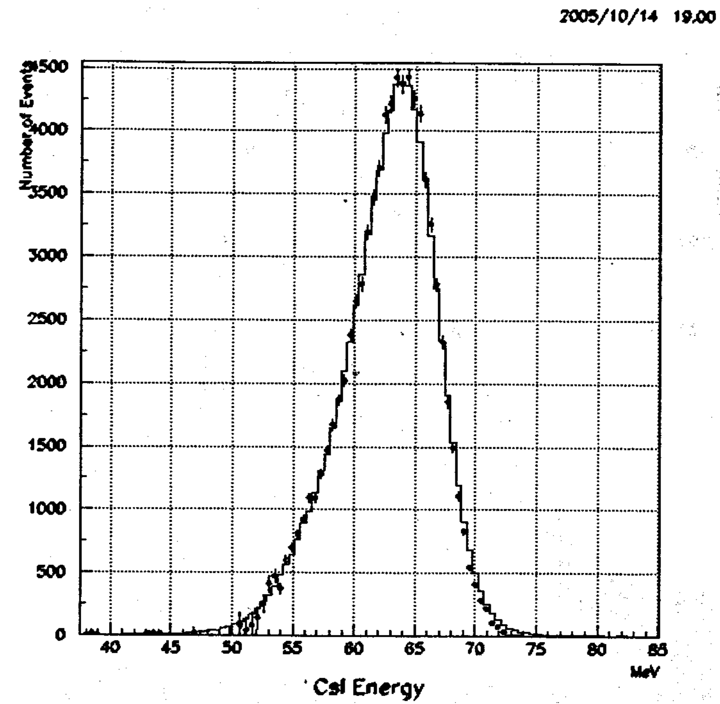


Fig.8. A spectrum of positrons from the $\pi^+\rightarrow e^+\nu$ decay. A continuous curve is a Monte Carlo simulation.

In **2006** the detailed analysis of the 2004 experimental data on radiative decay f the pion will be continued. A publication concerning the results of the experiment ill be prepared. It is planned to upgrade the PIBETA detector and optimize the ion beam for the more precise experimental investigation of the $\pi^+\rightarrow e^+\nu$ и $\pi^+\rightarrow$ $^+\nu\gamma$ decays.

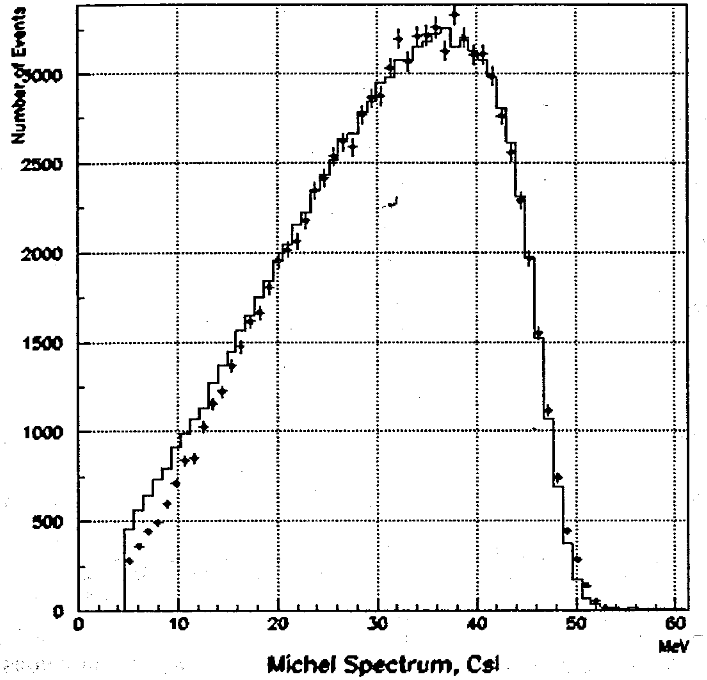


Fig.9. A spectrum of positrons from the $\mu^+ \to e^+ \nu \bar{\nu}$ decay. A continuous curve is a Monte Carlo simulation.

In the frame of **CATALYSIS** project the paper [23] finished in the course of the data analysis in D-T muon catalyzed fusion (MCF). First preliminary results have been obtained while performing the program of T-T catalysis data handling, the data treatment is now going with the use of an independent method. The experimental timing distributions of first and second registered neutrons (from catalysis) are shown in the Fig.10. The experiment on radiative deuteron capture from the state of mesomolecule ddμ is in preparation: the unique detector of γ-quanta is manufactured, which includes BGO crystal of diameter 130mm and height

60mm, immersed (for background discrimination) in the plastic scintillator; the construction of deuterium high pressure target is developed.

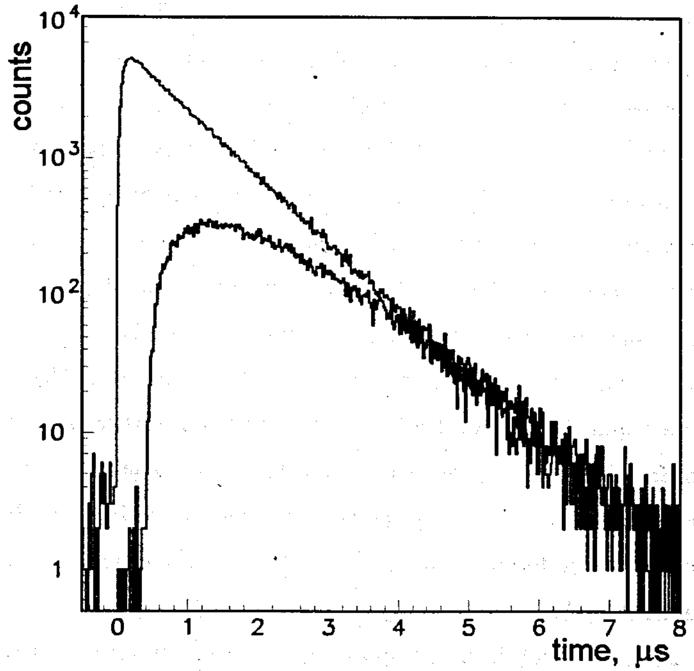


Fig.10. The timing distributions of first and second registered neutrons from T-T catalysis.

In **2006** the collaboration plans to finish T-T catalysis data handling in order to receive the parameters of muon catalyzed fusion in tritium and the information about the mechanism of the reaction with possible n-n and n-α correlations and to perform the complex study of the parameters of gamma-detector (analysis programs, calibration and line-shape, effectiveness of external background discrimination).

At the **ANKE** spectrometer (COSY, FZ-Juelich) the angular dependence of the vector analyzing power has been measured in the reaction $p\uparrow + d \to (pp)_s$ at 0.5 and 0.8 GeV [24]. The proton pairs $(pp)_s$ were selected with low kinetic energy of relative movement, less than 3 MeV, what determined $^1S_0$ state of the pairs. Kinematical conditions for this quasibinary reaction were chosen similar to those for the backward elastic pd scattering. It provides rather high momentum transfers in the process at energies in the 0.5-2.0 GeV range and a possibility for study short-range interactions in the three-nucleon system. Registration of the isotriplet state of the final nucleon pair instead of the isosinglet in the elastic pd scattering symplifies dynamics of the process significantly [25]. It makes the process preferable as a tool for study of a validity board for the traditional meson-nucleon approach and search for a manifestation of QCD degrees of freedom in the few-nicleon interactions. A meson-nucleon model (ONE+Δ+SS) was found capable to describe the energy dependence of the spin-averaged differential cross section in the 0.6-1.9 GeV energy range [26], but fails to reproduce the obtained polarization data. More refined in formation on a spin structure of the Δ-excitation mechanism is required for the data description. In this respect, more conclusive data may be obtained in measurement of the deuteron tensor analyzing power, planned at ANKE in **2006**. Such experiments will be performed with use of a polarized deuteron atomic beam source target installed at ANKE this year.

Search for double electron capture of ^{106}Cd was performed at the Modane underground laboratory (4800 m w.e.), France using a high efficiency low background spectrometer **TGV-2** (Telescope Germanium Vertical). The spectrometer was based on 32 planar type HPGe detectors with sensitive volume of 2040 mm^2 x 6 mm each (about 3 kg of Ge). The foils of Cd with the thickness of ~50 μm were inserted between the entrance windows of neighboring detectors. The main exposition of the TGV-2 experiment was started in February 2005 and used 10 g of ^{106}Cd with enrichment of 75%. The search for double electron capture of ^{106}Cd decay is in progress now. Some additional events above the background were obtained in the region of ~ 21 keV (KX Pd) of the double coincidence spectrum of ^{106}Cd accumulated for 6200 hours (Fig.11). They may point to the presence of the process of double electron capture of ^{106}Cd. Larger statistics and highly accurate long-term background measurements are needed for the careful analysis of these events. Really,

additional background in the region of ~23 keV caused by KX-rays of Cd decreases the sensitivity of the measurement. The new limit on the half-life of 2νEC/EC decay mode of ^{106}Cd $T_{1/2} > 6.6 \cdot 10^{19}$ y (90% CL) was obtained in a preliminary calculation of the experimental data. The present value is more than one order of magnitude higher than those obtained in previous experiments. The new value is close to the theoretical prediction for double electron capture of ^{106}Cd. The new limits on the other branches of ^{106}Cd decay - 2νβ^+/EC decay to the ground state of ^{106}Pd, 2νEC/EC and 2νβ^+/EC transitions to the first 2^+,512 keV excited state of ^{106}Pd were also obtained [27].

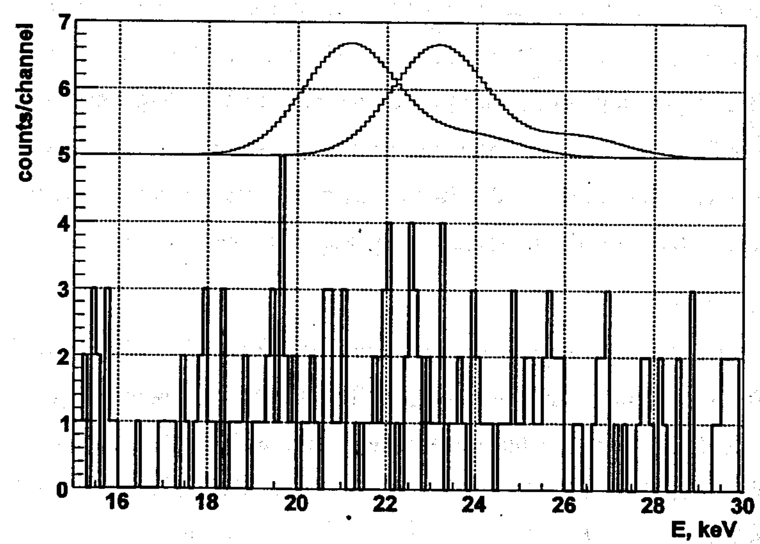


Fig.11. The double coincidence spectrum of ^{106}Cd accumulated for 6200 hours.

In the beginning of **2006** the measurements of ^{106}Cd will be finished and the background measurement will be performed with the similar samples of natural Cd. Then the study of double beta decay of ^{48}Ca will be started on TGV-2.

DUBTO represents a joint JINR-INFN project aimed at studying pion-nucleus interactions at energies below the Δ-resonance. The experimental device STREAMER used is a self-shunted streamer chamber filled with helium at atmospheric pressure, in a magnetic field, and exposed to the ~100 MeV pion beam of intensity $1 \div 5 \cdot 10^4$ s^{-1} of the JINR phasotron. The total number of $\pi^{\pm 4}He$ events recorded during the DUBTO runs amounts to about 25000, of which about 3000 events have been processed. The main results obtained in 2005 [28, 29] include the first observation of pion bremsstrahlung; determination of the cross sections of pion-helium reaction channels, measurement of the invariant mass $M_{pp\pi\pm}$ distribution in $\pi^{\pm 4}He$ breakup reactions, measurement of the invariant $M_{pp\pi-}$ distribution in positive pion DCX reactions on heavy nuclei (^{107}Ag, ^{109}Ag) in nuclear photoemulsion, pointing to existence of the so-called *d'*-resonance (Fig.12); estimation of an upper limit for the muon neutrino mass (m_ν<2.2 MeV), at a 90% confidence level; this value is the lowest estimate obtained with a visualizing detector, using the directly measured kinematic and dynamic parameters of a $\pi \to \mu\nu_\mu$ decay.

In **2006** collaboration plans the restoration of spectrometer STREAMER and other DUBTO equipment damaged in April 2005 by the fire, performing one run with pion beam, to continue the measurement and analysis of the experimental material obtained, to improve the results on the *d'*-resonance, pion bremsstrahlung, pion absorption.

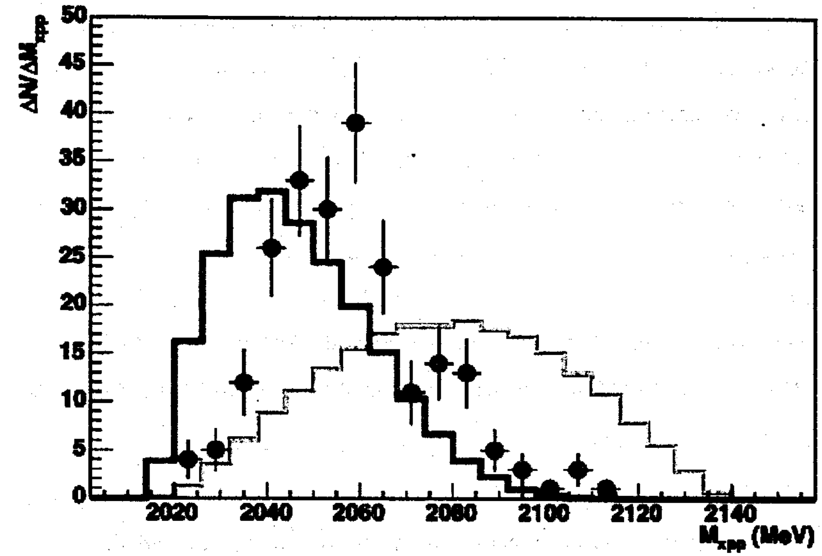


Fig.12. $pp\pi^-$ invariant mass distribution, the measured spectrum is shown by dots with error bars.

Relativistic Nuclear Physics

It is shown by **FASA** collaboration [30, 31] that thermal multifragmentation of hot nuclei is characterized by the *two* volume (or density) parameters. It has been done by analysis of the experimental data obtained with 4π-setup FASA for *p*(8.1GeV)+Au collisions (on the Nuclotron beam). Statistical Multifragmentation Model (SMM) was used in this analysis. Note that only *one* size parameter is used traditionally. The existence of two different size characteristics has a transparent meaning. The first volume, $V_t = (2.6 \pm 0.3) \cdot V_0$, has been determined from the shape of the intermediate mass fragment (IMF) charge distribution. This volume corresponds to the fragment formation stage, when the properly extended hot target spectator transforms into a configuration consisting of specified pre-fragments. They are not yet fully separated; there are links between them. The final channel of disintegration is completed during the evolution of the system up to the moment when receding and interacting pre-fragments become free. This is like as in ordinary fission. The saddle point resembles the final channel of fission by having a fairly well defined mass asymmetry. Nuclear interaction between fission pre-fragments ceases after descent of the system from the top of the barrier to the scission point. The size parameter obtained from the IMF charge distribution can hardly be called a freeze-out volume. It is proper to use the term "transition state volume" as like as for ordinary fission.

Another way to obtain the size of the system is analysis of the fragment kinetic energy spectra. As result, the mean volume of the system is found to be five times larger than the normal one: $V_t = (5 \pm 1) \cdot V_0$. Larger value of the size parameter obtained is a consequence of the main contribution of Coulomb repulsion to the IMF energy, which starts to work, when the system has passed the "multi-scission point". Thus, it is the freeze-out volume for multifragmentation in $p + Au$ collisions. It means that the nuclear interaction between fragments is still significant when the system volume is equal to V_t, and only when the system has expanded up to V_f, are the fragments freezing out.

Fig.13 illustrates the evolution of the system during the multifragmentation process. The evidence for the existence of two characteristic volumes of multifragmentation changes understanding the time scale of the process (see the bottom). Now one can imagine the following ingredients of the time scale: t_1 – the mean thermalizataion time of the excited target spectator, t_2 – the mean time of the expansion to reach the transition state, $(t_3 - t_2)$ – the mean time of descent of the system from the top of the barrier to the multi-scission point. The system configuration on the way to the scission point is composed from several pre-fragments connected by necks. Their random rupture is characterized by the mean time, τ_n, which is important ingredient of fragment emission time, τ_{em}. Another ingredient of τ_{em} is characteristic time of the density fluctuations in the transition state, τ_t. So, $\tau_{em} \approx \left(\tau_t^{\ 2} + \tau_n^{\ 2}\right)^{1/2}$. In earlier papers, the emission time was related *only* to the time characteristic of density fluctuations in the system at the stage of fragment formation, i.e. at $t \approx t_2$. The actual picture is much more complex. What are the values of these characteristic times? Thermalization or energy relaxation time after intranuclear cascade, t_1, is model estimated to be (10 – 20) fm/*c*. It is estimated in our previous paper that $<t_2 - t_1> \approx 70$ fm/*c* for *p (8.1GeV)+Au* collisions. Calculation within the QMD model results in estimation of t_3 to be equal (150-200) fm/*c*. A new theoretical consideration of the partition dynamic of very hot nuclei is needed. But, it is especially important to find a way to measure the value of t_3. Fragment emission time, τ_{em}, is measured by FASA collaboration in 2002 to be ≈ 50 fm/*c*.

In the case of ordinary fission, t_2 is specified by the fission width Γ_f, which corresponds to the mean time of order of 10^{-19}s (or ~ $3.3 \cdot 10^4$ fm/c) for the excitation energy around 100 MeV. The value t_3 was model estimated in a number of papers: $t_3 \approx 1000$ fm/c. A mean neck rupture time is estimated within the model of Rayleigh instability: $\tau_n = \left[1.5(R_n / fm)^3\right]^{1/2} \cdot 10^{-22}$ s. Generally, the values of τ_n are found to be less than 300 fm/c. Using this equation for the estimation of the mean time for the rupture of multi-neck configuration in fragmentation, one gets τ_n between 40 and 100 fm/c. This estimation is in a qualitative agreement with the measured values of the fragment emission time τ_{em}. Thus, ordinary fission characterized by much "slower" dynamics than multifragmentation. As for the space characteristics, the relative elongation of the very heavy systems (Z>99) at the fission scission point is similar to that for the multi-scission point of medium hot nuclei (rare earth region). Essence of the multifragmentation of hot nuclei is that the fragments are formed in result of the nuclear *liquid – fog* phase transition inside the spinodal region. But dynamic of the whole process is very similar to that of the ordinary fission.

In 2006 the new experiments on Nuclotron beam with modified FASA setup to measure IMF-IMF relative velocity correlations will be performed. Analysis of the experimental data to get the information about the pre-equilibrium emission in multifragmentation process will be continued.

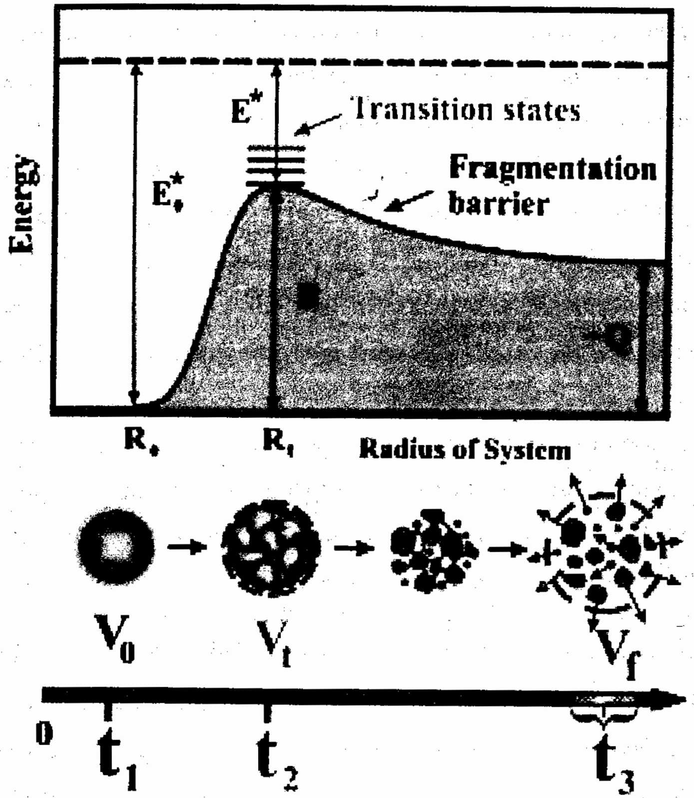


Fig.13. Upper: qualitative presentation of the potential energy of the hot nucleus (with excitation energy E_o*) as a function of the system radius. Ground state energy of the system corresponds to E=0, B is the fragmentation barrier, Q is the released energy. Bottom: schematic view of the multi-fragmentation process and its time scale.

Applied scientific Research

The work on development of cyclotron **CYTRACK** dedicated to track membrane production was finished. Numeric simulations for the beam injection into the cyclotron CYTRACK were carried out and reported in the International Scientific Seminar of memory of V.P.Sarantsev [32]. JINR Second Prize for applied investigations was awarded for the work on cyclotron CYTRACK development.

In **2006** DLNP plans the restoration of **JINR Phasotron** damaged in 2005 by the fire. After restoration the investigation of possibilities to form the scanning proton beam for the radiotherapy at the JINR Phasotron, consideration of different variants of the beam channel for the eyes tumor treatment and estimation of the possibility of ^{3}He and ^{4}He ions acceleration in the JINR Phasotron will be continued.

Under the JINR topic **"Physics and Technology of Particle Accelerators"** the LEPTA ring was tested with pulsed electron beam [33]. The dependence of the life time of the circulating beam on different parameters of the ring has been measured. It was found that the life time has a specific dependence of energy (Fig.14) – a smooth function $\tau(\varepsilon)$ with maximum around 4 keV. The left slope of the function curve $\tau(\varepsilon)$ is related to life time limitation by electron scattering on residual gas atoms, the right slope - the life time decrease with energy – was explained as influence of the inhomogeinities of longitudinal focusing magnetic field. The maximum life time obtained in the experiments was equal to 22 ms (about $5\cdot10^4$ turns). The positron injector has been tested with positrons from ^{22}Na source of a low (0.8 MBq) activity. The moderation of positron velocity in microlayer of Neon condensed at 10K was studied preliminary. The test of positron trap with electrons was started.

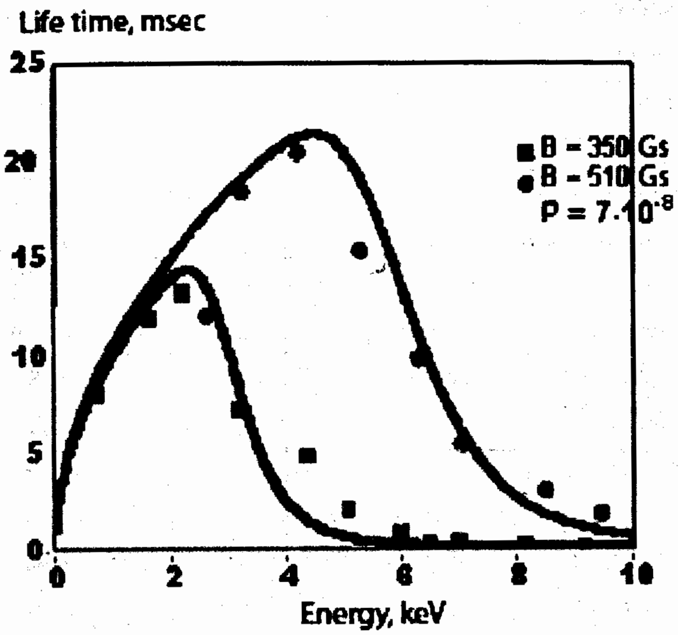


Fig.14. Dependence of the life time of the circulating beam on energy.

In **2006** within the framework of the LEPTA project it is planned to improve of the beam life time in the LEPTA ring by several orders of magnitude, to develop injection of positrons into the LEPTA ring, to begin of experiments on electron cooling of positrons.

The main goal of the topic **"Further Development of Methods and Instrumentation for Radiotherapy and Associated Diagnostics with the JINR Hadron Beams"** is to carry out medico-biological and clinical investigations on cancer treatment, to improve equipment and instrumentation, and to develop new techniques for treatment of malignant tumours and for associated diagnostics with medical hadron beams of the JINR Phasotron in a Medico-technical complex (MTC) of DLNP [34]. In 2005 in collaboration with the Medical Radiological Research Centre (Obninsk), Radiological department of Dubna hospital and medical research

centres of Check Republic and Bulgaria the research on proton therapy of cancer patients with the Phasotron beams in treatment room No 1 of MTC was continued. It was planned to carry out 6 treatment sessions during 2005, but unfortunately because of the fire accidence, which occurred in April in one of the Phasotron buildings only 1 accelerator run was carried out. 22 patients have received fractionated course of treatment with the medical 150 MeV proton beam. Other 49 patients were irradiated with Co-60 gamma-unit "Rokus-M" (about 2000 single irradiations). The beam test of a removable deck to the therapeutic chair for patient setup in the supine position during proton radiotherapy has been carried out. It will allow irradiation of new class of tumours such as prostate cancer. A set of radiobiological experiments on investigation of "bystander" and "hypersensitivity" effects and of combined optical and ionizing radiation action to the mouse cells were carried out with the proton beam and with gamma-radiation. Investigations on the molecular analyzing of radiation-induced mutations in animal and human genes were continued. The computer simulation of 3-D genome macroarchitecture in irradiated animal germ cells with the "position effect" of gene has been started.

In **2006** it is planned to complete the restoration of the equipment of the therapeutic proton beam lines, which were damaged during the fire accidence, to align the magnetic elements of the beam line and to deliver the therapeutic proton beam with the required characteristics to the treatment room No 1. The research on proton therapy of cancer patients with the JINR Phasotron beams in treatment room No 1 of MTC will be continued. The developed technique of prostate cancer treatment with the proton beam will be tested. The development of hardware and software complex based on an amorphous silicon flat panel detector for the verification of patients set-up during proton therapy will be started. The investigations on the molecular analyzing of radiation-induced mutations in genes and on 3-D simulation of genome macroarchitecture will be continued.

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