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Report to the 95th Session
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The Dzhelepov Laboratory of Nuclear Problem (**DLNP**) cover experimental investigation in modern particle physics, investigation of nuclear structure, study of condensed matter properties; theoretical support of the experimental research; medicobiological 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 neutrino properties is also performed only in DLNP. The 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

The **DELPHI** collaboration has studied the muon pair production in the process $e^+e^- \to e^+e^-\mu^+\mu^-$ on the basis of the data taken at LEP with the DELPHI detector. The data taking at LEP collider was finished at the end of 2000. However, the analysis of the collected data is still under way and it will take several years more to produce the final results. One of the most interesting results was the measurement of energy dependence of the strong coupling constant α_s [1]. The "running" of α_s was unambiguously demonstrated within the single experiment DELPHI.

Among the most important DELPHI result obtained in 2003 is final publications on Higgs boson searches at LEP2 [2]. Many possible scenarios were explored, including Standard Model Higgs; supersymmetric Higgs; double-charged H^{++}; fermiophobic Higgs; flavor-blind Higgs. In all cases the result was negative and upper limits of about 100-115 GeV/c^2 were set on Higgs mass.

Large progress in measurement of the W boson mass was achieved, especially in understanding and reducing the systematic errors on M_W. Results are preliminary, final results are expected within one year.

Another result of 2003 was the measurement of tau pair production in gamma-gamma collisions $\gamma\gamma\to\tau\tau$ [3]. Upper limit on the electric dipole (d_τ) and the limits on magnetic (a_τ) moments of the tau-lepton were extracted from the measurements: $-0.052<a_\tau<0.013$, $|d_\tau|<3.7\cdot10^{-16}$ e·cm. The result on a_τ is the most precise in the world.

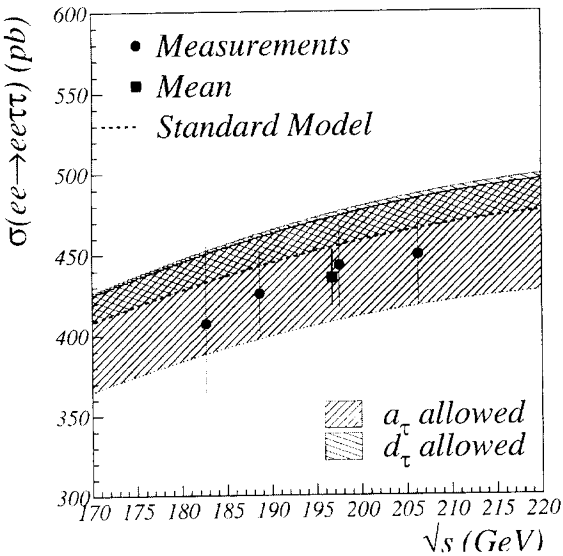

Fig.1. Energy dependence of $\gamma\gamma\to\tau\tau$ cross-section.

In **2004** the DELPHI collaboration plans to complete precise determination of the W-bozon mass; fermion pair production at highest collision energies; studies on b-quark physics; various searches for new particles or new phenomena.

The goal of the **NOMAD** (Neutrino Oscillation MAgnetic Detector) is search for $\nu_\mu\to\nu_\tau$, $\nu_e\to\nu_\tau$ and $\nu_\mu\to\nu_e$ oscillations and studies of neutrino interactions. The NOMAD scientific programme also includes studies of Λ and $\bar{\Lambda}$ polarization in the ν_μ and $\bar{\nu}_\mu$ neutral current interactions and studies of neutral strange particles and heavy strange hyperons in ν_μ NC interactions.

In 2003 the final results of a search for $\nu_\mu\to\nu_e$ oscillations in the NOMAD experiment have been obtained [4]. The experiment looked for the appearance of ν_e in a predominantly ν_μ wide–band neutrino beam at the CERN SPS. No evidence for oscillations was found. The 90% confidence limits obtained are $\Delta m^2 < 0.4eV^2$ for the maximal neutrino mixing, and $\sin^2 2\theta_{\nu_\mu \nu_e} < 1.4 \cdot 10^{-3}$ for large Δm^2. This result excludes the LSND allowed region of oscillation parameters with $\Delta m^2 > 10eV^2$ [5].

A carefully prediction of the neutrino beam composition (Fig.2) is crucial for the $\nu_\mu \to \nu_e$ oscillation search. The method for the calculation of the flux and composition of the West Area Neutrino Beam used by NOMAD in its search for neutrino oscillations has been developed [6]. The energy-dependent uncertainty achieved on the ν_e / ν_μ prediction needed for a $\nu_\mu \to \nu_e$ oscillation search ranges from 4% to 7%, whereas the overall normalization uncertainty on this ratio is 4.2%.

The NOMAD programme is also includes the non-oscillation physics. The production rates of neutral strange particles and the yields of heavy strange hyperons and resonances in ν_μ NC interactions have been measured for the first time: $T_{\Lambda 0} = (5.2 \pm 0.1)\%$, $T_{K_S^0} = (8.3 \pm 0.1)\%$, $T_{\bar{\Lambda} 0} = (0.46 \pm 0.03)\%$. The measurement of the Λ^0 and $\bar{\Lambda}^0$ polarization in ν_μ NC interactions have been performed [7]. Spin alignment of $K^{*\pm}$ vector mesons has been measured in both charged and neutral current samples of the NOMAD data.

In **2004** the collaboration expects to finalize the analysis of quasi-elastic $\nu_\mu n \to \mu^- p$ cross-section, measurement of the axial mass value M_A. Such a measurement is of great importance for neutrino physics, especially for the interpretation of the results from atmospheric neutrino experiments.

The **DIRAC** experiment at CERN aims to measure the lifetime of $\pi^+\pi^-$ atoms to test low energy QCD predictions. In 2003 the data taking at the accelerator PS CERN were carrying out during 4 month [8, 9]. The total number of events taken with two Nickel targets (single and multi layer) is about 309 million. Up to October 2003 about 20000 $\pi^+\pi^-$ atoms have been identified in the data obtained in 1999-2003 with the Nickel, Titanium and Platinum targets. In this selection strong cuts have been imposed. The system of microdrift chambers with readout electronics has been tested on the beam. The time and space resolutions of the chamber have been confirmed. About 100 million of events were collected with the chambers to measure the efficiency of used detectors to double-track events.

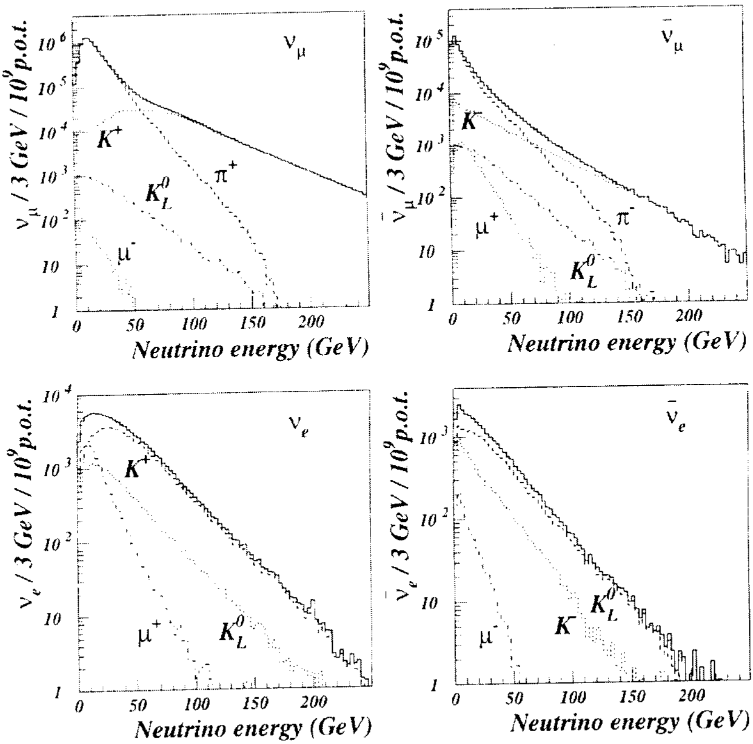

Fig.2. Composition of the ν_μ, ν_μ, ν_e, ν_e energy spectra at NOMAD, within the transverse fiducial area of 260x260 cm^2.

In **2004** the DIRAC collaboration plans to analyze the measurements of multiple scattering angles in the target, detectors and elements of the setup to reduce the systematic errors arising due to uncertainties in the multiple scattering description. Analysis of the micro-drift chambers test to study systematic errors in the experimental data will be needed. Design and production of the TDC-ADC electronic unit with a readout system for the scintillation fiber detector and its test with scintillating fiber detectors of different types at PS CERN will be performed. In 2004 development of the addendum to the DIRAC project on the measurement of the $\pi^+\pi^-$ atom lifetime with accuracy of 5%, observation of πK atoms and long-lived states of $\pi^+\pi^-$ atom is planned. Collaboration plans to develop the proposal on the $\pi^+\pi^-$ and πK atom lifetime measurement for the accelerator J-PARC in Japan following the recommendation of J-PARC directorate after approval of the Letter of Intent.

The quality of the muon measurement is one of the guiding design criteria for the **ATLAS** experiment.Muon spectrometer is the outer layer of ATLAS detector (average dimensions about 22 meters high and 44 meters long). For fixing the muon trajectory the determination of at least 3 points in the muon track is needed. All together it leads to a area of the 5500 meters squared which have to be covered by muon detectors (or 400000 single drift tube detector, grouped in 1200 chambers). Given the large area of the muon spectrometer it was necessary to devise a cheap but precise means of collecting the data. The proposal (and first experimental confirmation) of using drift tubes with working gas overpressure was done by JINR group and was selected by ATLAS as the main solution for coordinate detector for precision muon chambers (MDT). The construction of the Muon Spectrometer is shared between many laboratories in Russia, JINR, Germany, Italy, Holland and USA. The responsibility of JINR muon group is production of BMS-BMF chambers or about 20% of total amount of ATLAS muon drift tubes. In 2003 JINR muon group has completed single drift tubes production and test (24800 tubes), proceed with muon chambers production and test [10].

The **ATLAS Tile Calorimeter Barrel** assembly of JINR production modules has been successfully accomplished. For the first time the ATLAS Tile Calorimeter modules has received the energy calibration constants.

On October 30 at CERN was successfully completed the raising of the ATLAS Hadron Barrel Tile Calorimeter on the earth level. 65 modules for the Barrel were assembled in Dubna with about 100 microns precision achieved due to laser methods that were developed at JINR.

The erection of the 1350 tons heavy Barrel within a severe design tolerances with a permanent (on line) mechanic precision control is a unique technical operation of the efficient scientific, engineering and management cooperation of CERN, JINR and research centers and industry of their member countries.

Successful completion of Barrel assembly by large international team of technicians, engineers and physicists is an event of a principal significance: were solved many unexpected technical problems (like plastic deformations) and left no doubts in the successful execution of forthcoming Barrel assembly in the pit, - on "-100 meters" level.

Newly Dubna development software has been successfully applied for the ATLAS TILECAL cells energy calibration [11]. The electron and pion calibration constants for the various cells, energies and angles have been obtained from the data. The detail study of the electron and pion energy resolutions has manifested experimentally the correctness of our calibration algorithms. The electron and pion energy resolutions have been studied. The obtained calibration constants have been included in the TILECAL calibration database.

The conceptually new method of a fast Monte Carlo simulation of a hadron calorimeter response is proposed [12]. The key idea of the method is using the three-dimensional parameterization of the hadronic shower from the ATLAS TILECAL testbeam data. The obtained results of the fast simulation are in good agreement with the TILECAL experimental data. This method is being incorporated in the ATLAS fast Monte-Carlo.

One of the first ATLAS physics result – the energy spectrum and the cross section of photonuclear interactions of 180 GeV muons in iron $(\mu + Fe \rightarrow \mu' + hadrons + X)$ were measured at the CERN SPS using modules of the ATLAS Tile Calorimeter [13]. The differential cross section $(N_A / A) v d\sigma / dv$ for a muon fractional energy loss $v = \Delta E_\mu / E_\mu$ was measured in the range 0.1<v<1. The integrated cross section $(N_A / A)\int_{0.1}^{1} v d\sigma / dv$ is $(0.26 \pm 0.03_{stat} \pm 0.03_{syst}) \cdot 10^{-6}$ cm^{2}g^{-1}.

For 2003 period the four TILECAL test beam data taking runs at SPS (CERN) were carried out. Some important results were reported on the various conferences [14-16].

The JINR group is actively involved in conducting the **D0** experiment at Tevatron (Fermilab) having the highest for the moment proton-antiproton c.m.s. collision energy of 2 TeV. The group has made a valuable contribution to upgraded D0 detector (Fig.3) for Run II capable of running at highest possible luminosity around 10^{32} $1/(cm^2)s$.

The main goals of D0 collaboration include: search for Higgs boson and effects of SUSY, copious production of top quarks and W bosons, QCD studies and b-physics, search for unexpected phenomena which may happen at this highest energy etc. Two areas of the JINR group present interest are QCD studies and b-baryon physics.

The study of the hadronic decay channels of those particles that are characterized by two and more hadron jets production in the final state is a very perspective. Thus, the task of the most precise hadron jet energy calibration (also called as the task of "the absolute jet energy scale determination") becomes extremely important for the Collaboration. It is worth emphasizing that at the present time the main contribution to the top quark mass error comes from an existing uncertainty in the jet energy scale.

The JINR group at D0 has developed the new selection criteria for events with an associated production of hadronic jets and the direct photons allowing improving essentially the precision of setting of absolute jet energy scale for the conditions of D0 experiment. It is shown that the main source of the photon (or Z^0) and jet transverse momenta imbalance is the radiation in the initial (ISR) and final states (FSR). Another new requirement of a jet isolation, introduced for the first time, allows to select topologically clean "photon/Z^0+jet" events which would provide almost 1% accuracy of the absolute jet energy scale determination.

In parallel to the solution of the jet energy calibration task, a possibility to carry out experimental research of a proton structure, namely, gluon distribution function, is proved. It was shown that the samples of the "γ+jet" events selected for the jet energy calibration can be used for this aim (Fig.4). The proposal to study at D0 the gluon distribution in earlier unexplored kinematical region (by HERA, DESY) was accepted by the D0 collaboration and it is meant to be a good development of the traditional investigations of nucleon structure functions started earlier by JINR in the framework of BCDMS collaboration (NA4 experiment, CERN).

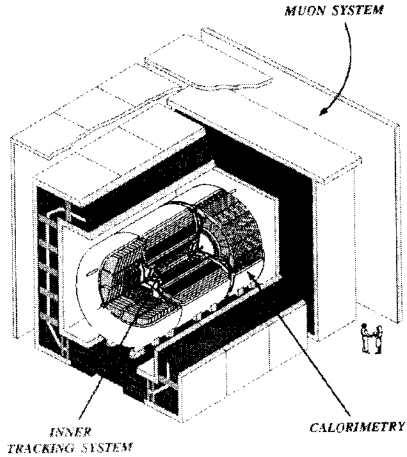

Fig.3. The D0-detector 3d-view.

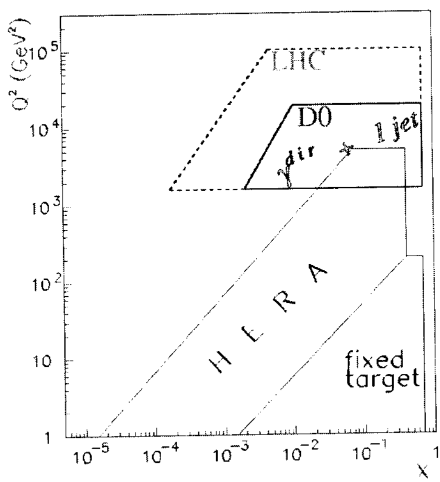

Fig.4. The kinematical region of the pp→γ+jet at Tevatron and LHC. Fixed traget experiments and HERA regions are also given.

The interest of D0 collaboration will be also focused on the b-baryon physics, namely b-baryon spectroscopy. Until now, this area was explored rather weakly. JINR group are trying to investigate non-leptonic decays of b-baryons to fully reconstructable final states: $\Lambda_b \rightarrow J/\psi + \Lambda$ and $\Xi_b \rightarrow J/\psi + \Xi$ with further leptonic decay of J/ψ ($\mu^+\mu^-$ or e^+e^-). It is possible with these decays to determine unambiguously the mass and lifetime of those b-baryons (the same is valid also for antibaryons). Expected mass resolution of Ξ_b in D0 detector was estimated with Monte-Carlo simulation and equals 0.14 GeV/c^2 FWHM at the mass peak of 5.84 GeV/c^2.

In 2003 the **JINR/CDF group** started c, b, t-quark physics researches on the UPGRADED CDF, the preliminary data on top-mass measurement were obtained. The CDF/JINR group in 2003 provided the efficient CDF functioning on the FNAL TEVATRON and participated in Run II experimental data accumulation; carried out the Run II CDF data physics analysis aimed at high measurement of the top-quark mass; provided the efficient functioning of the TRIGGER based on Silicon Vertex Tracker (a specialized detector for FAST ON-LINE search of secondary vertices); took active part in the modernization of CDF MUON COMPLEX and of High Voltage Slow Control System for the muon scintillator counters [17-21].

The method and adequate codes for high precision top-quark mass measurement in the "$p\bar{p} \rightarrow$lepton + jets" topology was developed and implied. The method and codes were successfully tested with simulated data (Fig. 5). Preliminary results on top-quark mass in single lepton decay mode were obtained based on first 72 pb^{-1} CDF Run-II data. Jet-tagging was not used to enlarge statistics and the measured value of top-mass was $m_t = 171.2 \pm^{14.4}_{12.5} (stat.) \pm 9.9 (syst.)$ GeV/c^2. New codes for top-mass measurement in di-lepton decay mode were developed and tested on Monte-Carlo sample. First results on top-quark mass in di-leptone mode are expected by Spring **2004**.

New method of statistical data analysis for mass of the top-quark measurement was created. New codes for on/off-line monitoring of Silicon Vertex Tracker with fast Associative Memory created a possibilities for fast permanent SVT control. The D^0 mass distribution (Fig.6) is one of the on-line applied checks to CDF Si-complex. The SVT is the key element of the CDF Level-II trigger (14 mksec) serving nowadays in Run-II for secondary vertex recognition (a principal signature of b-quark) and for factor 10^3 background suppression.

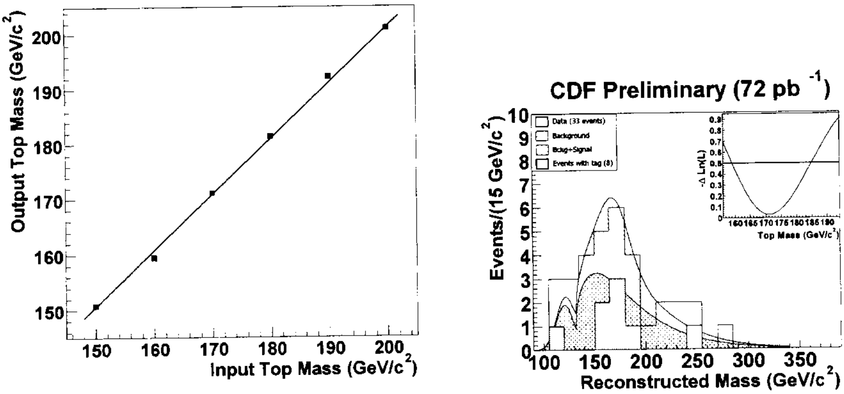

Fig 5. Reconstructed mass of the top-quark as a function of input top-mass assumed in Monte Carlo (left). Fitted mass of the top-quark spectra for top-candidates selected from first 72 pb^{-1} CDF data.

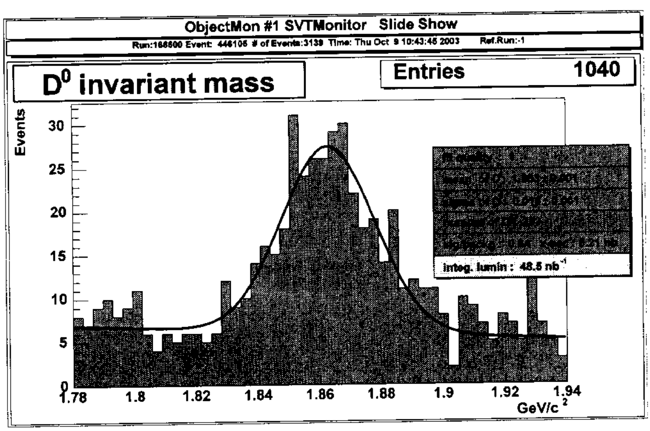

Fig.6. Reconstructed D^0 invariant mass, obtained by SVT on-line monitoring codes.

The search for a new physics phenomenon of thermalisation in the Very High Multiplicity $p\bar{p}$ - scattering ($\sqrt{S}$ = 2 TeV) has been coherently started by DLNP, BLTP and INFN/Bologna and first data on hadron yield correlation were obtained. Modernized and implemented Slow Control System (the high Voltage Supply System

Monitoring) of Scintillator Counters was included in CDF muon trigger creation. The new group of scintillator counters was installed on CDF; detectors are included in "modernized CDF muon trigger" and now are participating in heavy quark events selection.

Directly at the DLNP a CDF analysis was started. It became possible due to the LIT scientific personnel help in providing an efficient and stable "JINR-FNAL" computer communication. In **2004** the collaboration plans to obtain the preliminary result on M(top) in di-lepton decay mode. Maintenance and support of the developed with JINR participation CDF detector systems during the Run-2 data taking at FNAL TEVATRON will be continued.

The **HARP** experiment [22, 23] was designed to perform a systematic and precise study of hadron production for beam momenta between 2 and 15 GeV/c, for target nuclei ranging from hydrogen to lead. The apparatus is a large acceptance spectrometer, with two distinct regions: a forward region (up to polar angles of about 350 mrad) where the main tracking device is a set of drift chambers [24] recuperated from the NOMAD experiment (NDC) and a large angle region, where the main tracking device and the particle-identification detector is a TPC, complemented by a set of RPC detectors.

HARP physics goals are the measurements of pion yields to enable a quantitative design of the proton driver of neutrino factories [25] and to make it possible more precise calculations of the atmospheric neutrino flux. In addition, the energy-range is suitable to measure particle yields for the prediction of neutrino fluxes for the MiniBooNe and K2K experiments.

In 2003 the responsibility of the JINR group in the HARP experiment has been refurbishing, installation, commissioning and operation of the NOMAD drift chamber in the HARP experiment, including work on the DAQ and software. A first set of calibration and alignment of the NDC's has been performed. The spatial resolution of the NDC's about 350 microns has been achieved after a careful alignment procedure. The algorithms for the NDC reconstruction have been developed. The segment reconstruction algorithm in the NDC's proposed by the JINR group has now been chosen as the default reconstruction algorithm by the collaboration due to its high efficiency and purity [26]. A systematic hardware measurement and data analysis to understand various distortions affecting the TCP have bee performed. Inhomogeneities of the magnetic and electric fields in the active TCP volume lead to displacements of cluster coordinates and therefore to track distortions. Based on a detailed modeling of the magnetic and static electric field inhomogeneities precise correction maps for both effects have been calculated [27]. The CERN-Dubna-Milano algorithm for the TCP cross-talk correction has been developed. Results have been obtained on the application of this algorithm to the test-charge and Krypton calibration events.

The calibration of the RPC's has been carried out. The calibration and alignment of the MWPC have been done. The development of the algorithms for the MWPC track reconstraction and particle identification using the beam TOF system and beam Cherenkov counters. Results of this analysis are to be used for the beam line simulation and calculation of muon contamination in the beam [28]. Preliminary analysis of the data taken with the water target to estimate the yields of electrons and pions in interactions of 1.5 GeV/c protons with water is being carried out. This data are necessary for correct interpretation og the results of the LSND neutrino experiment.

In **2004** the water data analysis to be completed. The development of the reconstruction program for the NDC's, TCP, RPC's and beam detectors to be finalized. Analysis of the data taken with the K2K and MiniBooNe targets, muon background simulation needed in particular for the analysis of the K2K and MiniBooNe targets to be carried out.

The main goal of the experiment **HYPERON** [29] in 2003 was to design and build the setup for study of meson-nuclear effects in charge exchange reactions with neutral mesons in the final state and carrying out two runs to test the apparatus. The base units of the setup are the electromagnetic calorimeter, tagging system and proportional chambers.

The tagging system is designed for tagging of the charge exchange reactions with neutral mesons in the final state. The mesons are tagged by outlet angles of the recoil protons essentially different for different reactions. It allows to reject the background processes at the trigger level.

Proportional chambers are assigned for the beam particle momentum determination. During the year large work was done to put operation all services for beam chambers (gas, air-cooling, low voltage, high voltage, chamber electronics, data conversion and transmission). Hexagonal chambers are mounted and assembling of chamber communications was done.

Hodoscopic lead glass calorimeter is assigned for detecting photons coming from neutral meson decays. It was necessary to supply and mount 640 new ADC's (system MISS) because the old ADC's (system SUMMA) become worthless. Till now 320 ADC's are connected up and tested.

Data acquisition system was developed which allows to accept some thousands events per spill. It also gives a possibility to control the detectors in online regime and perform event reconstruction on other computers simultaneously with data taking. Event reconstruction program is already installed.

Two short test runs were performed in December 2002 and in April 2003 in which the calorimeter electronics was tested. The apparatus functions satisfactorily in spite of very old trigger electronics.

In **2004** the tagging system will be delivered and mounted in Protvino till the run, the making of the LED monitoring system will be finished. The data taking run will be performed in December. The preliminary results on A-dependence in the charge exchange meson-nuclear reaction will be obtained till the end of 2004.

The **TUS space experiment** has been proposed to address some of the most important astrophysical and particle physics problems. By the EAS measurements the energy spectrum, composition and angular distribution of the Ultra High Energy Cosmic Ray (UHECR) at $E>10^{19}$ eV are supposed to study (the region of Greisen-Zatsepin-Kusmin cutoff) from a space orbit.

TUS is a pilot experiment, its launch is expected on the RESURS-O satellite at 2006-07. After the experiment the next generation KLYPVE apparatus (~10 sq.m Fresnel mirror and 50x50 PMTs) will be constructed and launched to ISS for study UHECR including the events initiated by neutrinos. The press-form prototypes for the Fresnel mirror of TUS detector were produced in 2003. The first two Fresnel mirror modules from different materials were produced also. A special device was designed and constructed for measurements and tuning of the mirror modules on-line with CCD camera and PC. The work is in a progress. We plan to produce a full scale Fresnel mirror in the next year to test in a ground experiment of UHECR study.

A package (SLAST) of programs simulating both fluorescent and Cherenkov light produced by extensive air showers (EAS) initiated by a UHECR particle entered the atmosphere are developed. The produced light signal is attenuated to the Space Telescope using Lowtran7.1 radiative transfer code. The Fresnel mirror, the electronics and trigger are simulated. The full simulation chain including air showers development, fluorescent and Cherenkov light production, the optics response, trigger and electronics responses is under development. Algorithms for the UHECR arrival direction reconstruction and algorithms for the determination of the altitude of EAS maximum which is crucial for the UHECR energy and atmosphere depth of EAS maximum reconstructions are developed.

The **E391a experiment** is aiming to search for kaon rare decay process, $K_L \gamma \pi^0 \nu\nu$ decay, by using a pencil beam and the detector system having a very high performance of photon vetoing. This experiment was approved on April 2000 and the detector construction is being done for data taking from February **2004**. The E391a detector consists of three mechanically independent sections, which means three sections are stand-alone and combined to a unit after individual fabrications. Now all three basic sections are fabricated. At the end of December their assembly in setup will begin. And after a vacuum test we hope to begin data taking according to the schedule. Detection of the $K_L \gamma \pi^0 \nu\nu$ decay is a challenging trial in the experimental point of view and there are still many pessimistic opinions about the real measurement. The E391a has a very important role to show a clear answer for them and guide us to the next step for precise measurement of branching ratio of the decay.

Low and Intermediate Energy Physics

The main result of **NEMO-3** project in 2003 is the start of the NEMO-3 detector at the normal working mode. Final tunning of the detector, laser survey system and neutron shield installation were finished and from February 14 detector is taking data under stable conditions [31-34]. Calibration measurements with sources were performed more frequently (each 2-3 months) then it was planned (2-3 times per years). The reason is improvement of precision of calibration and better investigation of time evolution of parameters of calorimeter. Useful exposition time of the detector in 2003 is ≈5500 hours (230 days).

Unexpectedly high level of Radon concentration ≈20-30 mBq/m^3 was found inside the NEMO-3 from the analysis of first data. R&D of methods and techniques to eliminate Radon from laboratory air were performed during 2003. Finally NEMO-3 detector was covered by Radon-free tent at October and Radon-free factory on the base of cooling charcoal filter will be built in the beginning of next year. Data analysis of first data collected (February-September, 3834 h) were done. The preliminary results for half-lives of NEMO-3 sources were defined.

The best values were obtained for the main NEMO-3 isotope ^{100}Mo (7.2 kg) (Fig.7). The current limit of neutrinoless double beta decay was found:

$$^{100}Mo\ T_{1/2}^{2\beta0\nu} > 2.3\cdot10^{23} y \quad (90\% \quad C.L.), \quad m_\nu < 0.6-1.4\ eV.$$

83000 events were collected for 2β2ν-decay of ^{100}Mo giving negligible statistical error:

$$^{100}Mo\ T_{1/2}^{2\beta2\nu} = (8.2 \pm 0.0025_{stat.} \pm 0.8_{syst.})\cdot 10^{18}\ y$$

The main efforts are concentrated now on the decreasing of the systematic error of measurement. Results obtained for other isotopes are follow:

^{82}Se $\quad T_{1/2}^{2\beta2\nu} = (9.52 \pm 0.25_{stat} \pm 0.9_{syst})\cdot 10^{19}\ y,\ T_{1/2}^{2\beta0\nu} > 1.0\cdot10^{22}\ y \quad (90\%\ C.L.)$

^{116}Cd $\quad T_{1/2}^{2\beta2\nu} = (2.69 \pm 0.09_{stat} \pm 0.3_{syst})\cdot 10^{19}\ y,\quad T_{1/2}^{2\beta0\nu} > 1.6\cdot10^{22}\ y \quad (90\%\ C.L.)$

^{150}Nd $\quad T_{1/2}^{2\beta2\nu} = (7.5 \pm 0.3_{stat} \pm 0.7_{syst})\cdot 10^{18}\ y,\quad T_{1/2}^{2\beta0\nu} > 3.6\cdot10^{21}\ y \quad (90\%\ C.L.)$

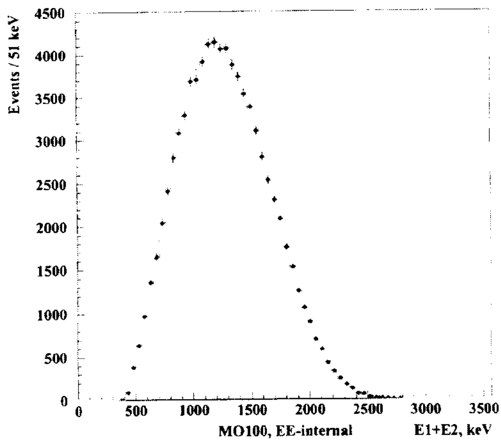

Fig.7. ββ-signal of 100 Mo. 3834 hours of measurement (2-9.2003), 83000 events.

A new high efficiency spectrometer **TGV** [35] was created using of construction materials of very low level of radioactive impurituies (U + Th < 0.1 ppb). The spectrometer TGV-2 was intended for the investigation of double beta decay of ^{48}Ca and double electron capture of ^{106}Cd. 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). Detectors were mounted vertically one over another together with thin (50 mg/cm^2 - 100 mg/cm^2) homogenius double beta emitters in a special design ultra low-background cryostat. The detector part of the TGV-2 was embedding into a passive shielding, including a shielding against Radon and a neutron shielding. Some original methods of an active suppression of radioactive background and electronic noise, namely distinguishing beta-particles and gamma - rays and using of two separate spectroscopy amplifiers with different shaping time in each channel were developed respectively for the double beta decay and double electron capture investigations . The electronic scheme of TGV-2 was based on the CAMAC modules produced by JINR. The TGV-2 was mounted in the Modane underground laboratory (4800 m w.e.), France. The background of the spectrometer TGV-2 was tested in a series of long term measurements in a low energy (< 50 keV) and a full energy (< 5 MeV) regions and obtained suitable for the study of 2K2ν and 2K0ν decays of ^{106}Cd and 2β2ν, 2β0ν decays of ^{48}Ca. The new limits on β-decay of ^{48}Ca to the 6^+ ground state, excited 5^+ and 4^+ states in ^{48}Sc and $\beta^-\beta^-$ decay of ^{48}Ca to the first 2^+, second 2^+ and first 0^+ excited states of ^{48}Ti were obtained in a long term low-background measurement of about 10 g of enriched ^{48}Ca.

In the beginning of **2004** the background measurements will be finished and the first investigation of double electron capture of ^{106}Cd on the TGV-2 spectrometer will be performed. Then the study of double beta decay of ^{48}Ca will be started on TGV-2 .

The present work of **AnCor** collaboration extends the search for the genuine scalar interaction on the muonic sector. Here the genuine scalar coupling C_s could be different and even enhanced and would contribute to various observable quantities in muon capture summed with the induced scalar coupling (C_s+g_s). The investigation reaction is a two-step process which consist in the first-forbidden ($0^+ \rightarrow 1^-$)-transition of ordinary muon capture in a zero-spin ^{16}O nucleus followed by γ-emission from the excited recoiling daughter nucleus.

As the life time of the 1^- -level is relatively long (almost 4 ps), a low density target – oxygen gas at a few bar pressure – must be used in order to reduce the slowing-down of the recoil nuclei in the target material. At the same time, the percentage of muons stopped in the gas with respect to other constructional materials should be as high as possible. Following these conditions, a special gas target was constructed and used at the μE4 beam-line of PSI. The γ-spectra was measured at atmospheric pressure with HPGe detector in a 3-week experiment (Fig.8).

Using the method based on the Doppler effect and developed in [36], one can investigate the correlation between the momenta $\vec{q}$ and $\vec{k}$ of the neutrino and the γ-quantum. In this case the shape of the Doppler-broadened γ-line is determined by the convolution of the detector response function (calibrated with a reference ^{169}Yb source) and the correlation function W which can be approximated by: $W = 1 + a_2^1 \cdot P_2(\vec{k}\vec{q})$, where $P_2(\cos\theta)$ is a Legendre polynomial. The correlation coefficient a_2^1 depends on the relative values of the nuclear matrix elements (NME) and the Weak Interaction couplings. In the experiment the a_2^1 value has been obtained [37] $a_2^1 = 0.096 \pm 0.020$.

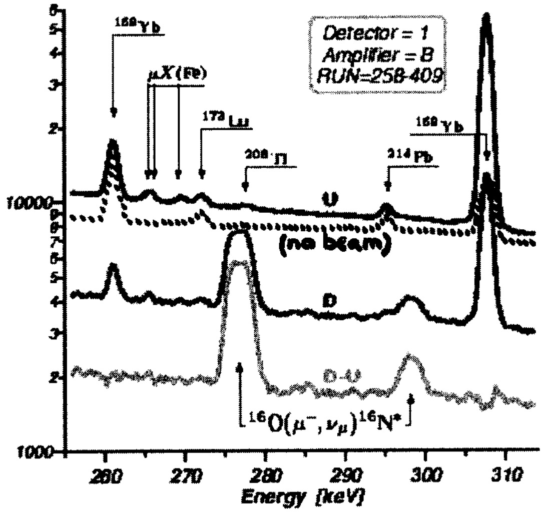

Fig.8. Fragments of γ-spectra measured with an oxygen gas target: U – uncorrelated (with and without beam), D – delayed, D-U – differential.

To transform this model-independent value to the Scalar coupling estimation (Fig.9) the NME was calculated with three different residual interactions: ZBMI, REWIL and ZWM. All of them lead to the similar (C_s+g_s) value different from zero. The best way to confirm or to disprove such non-trivial result would be a repetitive experiment with another target nucleus. After several tests, neon gas at atmospheric pressure has been chosen as the most promising candidate.

Several interesting processes take place when a muon is captured by the ^{20}Ne nucleus. Amount them are: the first-forbidden ($0^+ \rightarrow 1^-$)-transition sensitive to the Scalar coupling, the allowed ($0^+ \rightarrow 1^-$)- and two unique ($0^+ \rightarrow 2^-$)-transitions sensitive to the Induced Pseudoscalar coupling, and also transitions to the Giant Dipole Resonance states followed by the neutron emission. The γ-lines corresponding to the above processes are Doppler-broadened due to the nuclear recoil caused by the neutrino and the neutron emission.

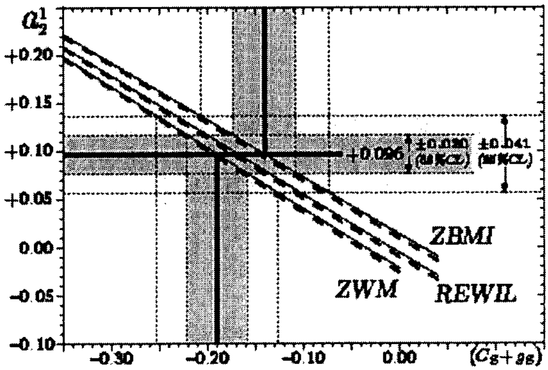

Fig.9. Transformation of the correlation coefficient a_2^1 to the (C_s+g_s) value.

In 2003 AnCor collaboration used the ordinary muon capture to the relevant excited states as a probing tool for the nuclear wave functions involved in the amplitudes of many virtual transitions of the 2β-decay [38]. In order to obtain reliable information for the most interesting 2β-decaying nuclei, AnCor collaboration proposed to measure the partial μ-capture rates in ^{48}Ti and other enriched targets [39]. As a first step, one-gram targets of ^{48}Ca, ^{48}Ti, ^{76}Se, ^{106}Cd, in ^{116}Sn and ^{150}Sm were irradiated with slow muons at the μE4 area of the PSI "muon factory" (Villigen, Switzerland) and measured with four large volume HPGe detector. The total muon-capture rates have been extracted with a good accuracy. Some measurements [40] were performed with enriched ^{48}Ca and ^{48}Ti targets and were compared to a natural metallic calcium (97% of ^{40}Ca) (Fig .10).

The highest attention was paid to the ^{48}Ti target. It was measured almost during one week and provided statistics high enough to get the intensities of most of the γ-lines and to analyse their balance in order to extract the partial capture rates with the required precision (10-20 %). Detailed data analysis is in progress the future plans depend on its results.

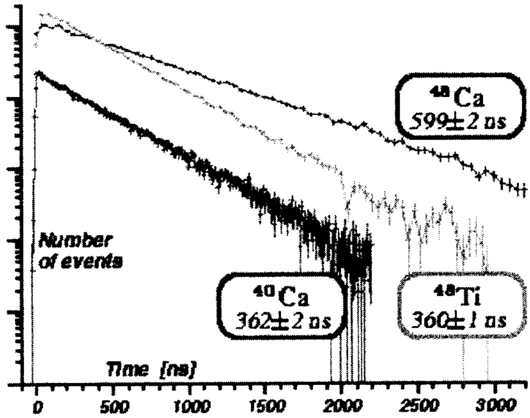

Fig.10. Time evolution of γ-lines following the μ-capture by ^{40}Ca, ^{48}Ca and ^{48}Ti targets (spectra are not normalized).

In the frame of **LESI** experiment over the period 1996–2002 investigations of the dd–reaction in the deuteron collision energy range 1.8–3.7 keV were carried out with the SGM accelerator (I=950 kA, τ=80 ns) at HCEI (Tomsk). The experimental values of the astrophysical S–factor and effective cross section for dd–reactions in this energy range are obtained for the first time. In 2003 an experimental apparatus was mounted and commissioned at a more powerful pulsed accelerator (I=2.5 MA, τ=80 ns) at HCEI (Tomsk). This was done to continue the study of mechanism for reaction between light nuclei at a "higher" energies of 3–10 keV in comparison with the energy range attained at the SGM accelerator. The importance of these studies arises form the necessity of correctly comparing their results with the calculations and the results of the experiments carried out at classical accelerators [41, 42].

Various methods not only for studying the inverse Z–pinch formation process at the MIG accelerator but also for measuring the energy distribution ion in the liner are developed. The information on the latter is extremely important for correct interpretation of the experimental results because dependence of the nuclear reaction cross-section on the collision energy in the given energy range is of the exponential character. The results of testing these methods indicate that they are suitable for getting correct information on the energy distribution of ions incident on the target. Estimates of the expected pd –reaction yield in relation to the background level of the γ–detectors obtained in the experiments at the MIG accelerator stimulate continuation of the pd–reaction studies. In 2001 the investigations on generation of colliding plasma fluxes for studying dd, pd and d^3He reactions in the astrophysical energy range were started. They are carried out at the SRINP TSU (Tomsk) in parallel with the investigations at the HCEI. The already obtained results indicate that the proposed method for generation of intense colliding plasma fluxes with energy above 3 keV holds much promise [43].

In **2004** experimental study of the pd–reaction in the proton–deuteron collision energy range 3–10 keV at the MIG accelerator and investigation of the dd–reaction with the use of colliding deuterium plasma fluxes in the energy interval 3–6 keV will be performed.

At the spectrometer **ANKE** (COSY, FZ-Julich) the energy dependence [44] of differential cross section of the deuteron break-up $p+d\rightarrow(pp)+n$ with forward emission of a proton pair with the relative energy less than 3 MeV has been analyzed. A theoretical model taking into account one-nucleon exchange, Δ-isobar excitation and single scattering [45] was employed . A strong dependence of the calculated cross sections on the form of used NN-potential was found: Reid Soft Core and Paris potentials result in decline of the cross section with the energy growing significantly less than in the experiment, the observed dependence may be reproduced [46] only with use of the more modem, CD Bonn potential. More detailed comparison will be done after processing of the data obtained by the ANKE collaboration during this year runs.

The project **CATALYSIS** is aimed at studying physical problems of muon-catalyzed nuclear fusion reaction (MCF). Measurements of the MCF nuclear reactions in the hydrogen isotopes mixture $\mu \rightarrow \mu$ + D/T$\rightarrow$ t$\mu \rightarrow$ dt$\mu \rightarrow$ ^{4}He + n + μ are completed. In the gaseous mixture the dependences of cycling rate on temperature (T=45÷800K), on density (ϕ=0.2 ÷ 0.9 of liquid hydrogen density), on tritium concentration (Ct = 17 ÷ 80%) were measured.

In the frame of the project **MUON** the measurements of the magnetic moment of the negative muon in the 1S-state of different atoms were performed. The negative muon in the bound state should possess a magnetic moment different from the free muon one due to relativistic motion. Up to now there have only been three measurements of the magnetic moment of the negative muon in the 1S-state of different atoms. The results of the present measurements for the light elements are in a good agreement with previous measurements of the magnetic moment of the negative muons in the light elements. In the case of heavy elements (Zn, Cd) the significant deviation of the experimental data from the theoretical calculations was found.

The study of the condensed matter by the μSR-technique was continued. The experiments with silicon were aimed to investigate the effect of impurities on the relaxation rate of the magnetic moment of the shallow acceptor center. The measurements were carried out on more then 20 silicon samples with p- and n-impurities of different concentrations. The constant of the hyperfine interaction of the Al shallow acceptor center in undeformed silicon is determined for the first time: $A/h(^{27}Al\}=-2.2 \pm 0.2)$ MHz. The estimation of the wave function density of the hole on the Al in Si was obtained: $|\Psi(0)|^2 \sim 3.8 \cdot 10^{-3}$.

It was found that the hyperfine interaction in the shallow acceptor centers is weaker than in the donors. This fact supports the idea about significant input of the p-wave into the wave function of the ground state of the acceptor impurity. The temperature dependence of the relaxation rate of the shallow acceptor center in undeformed silicon is determined for the first time for the impurity concentration from $\sim 5 \cdot 10^{12}$ to 10^{20}cm^{-3} and in the temperature range 4.2-50 K.

It was found that Si with the isoelectron impurity at $T < 50$ K the relaxation of the shallow acceptor center is due the spin-lattice interaction and the the relaxation rate depends on temperature as $\nu \sim T^q$, $q \approx 3$. In degenerate silicon the relaxation by spin-exchange scattering of "free" charge carriers on the acceptor dominates at $T < 30$ K. The effective cross-sections for the spin-exchange scattering of holes (σ_h) and electrons (σ_e) on the Al acceptor in Si are estimated as : $\sigma_h \sim 10^{-13}$ cm^2, $\sigma_e \sim 8 \cdot 10^{-15}$ cm^2 at the acceptor (donor) impurity concentration $n_a(n_d) \sim 4 \cdot 10^{18}$ cm^{-3}.

The study of the systems with "heavy fermions" by the positive muon was continued. The compound Ce3Pd20Ge6 was studied. Below 0.4 K the increase of the muon spin depolarization rate represents the development of quasi-static ordering of magnetic moments of electronic origin supposedly random oriented. The clear frequency shift of muon spin precession at external transverse field was seen. This fact may be attributed to the increasing of total moments of the superparamagnetic cube containing 8 Ce atoms and their ferromagnetic ordering with decreasing temperature [47-52].

The analysis of the experimental data taken with the unique **PIBETA** spectrometer is going to finish [53, 54]. The PIBETA collaboration have recorded about two orders of magnitude more rare pion and muon decay than was available in the entire world data sets on the $\pi^+ \to \pi^0 e^+ \nu$, $\pi^+ \to e^+ \nu$, $\pi^+ \to e^+ \nu\gamma$ and $\mu^+ \to e^+ \nu\bar{\nu}\gamma$ channels. The event statistics are the follow:

Decay	PIBETA data set	World data set
$\pi^+ \to \pi^0 e^+ \nu$	> 50 k events	1.77 k events
$\pi^+ \to e^+ \nu$	> 580 M events	0.35 M events
$\pi^+ \to e^+ \nu\gamma$	> 60 k events	1.35 k events
$\mu^+ \to e^+ \nu\bar{\nu}\gamma$	> 500 k events	8.5 k events

Current preliminary working result for the pion beta decay branching ratio is $BR \approx 1.038 \pm 0.004(\text{stat.}) \pm 0.007(\text{syst.}) \times 10^{-8}$. The Standard Model prediction according to PDG data is $BR = 1{,}038 - 1{,}041 \times 10^{-8}$ (90%C.L.). In the previous measurement $BR = 1{,}026 \pm 0.039 \times 10^{-8}$ was obtained. The work is continued to examine more precisely the factors which determine the systematic errors. With the main pi-beta trigger in the region with e^+ and γ emitted into opposite hemispheres, each with energy $E > 52$ MeV ~50000 events of radiative pion decays ($\pi^+ \to e^+ \nu\gamma$) were recorded. On the base of this data set the value of the pion axial formfactor $F_A = 0.0123(4)$ was obtained.

With the $\pi^+ \to e^+ \nu$ decay trigger in the region with photon energy $E_\gamma > 55.6$ MeV, positron energy $E_e > 20$ MeV and an angle between photon and positron $\theta_{\gamma e} > 40°$ ~5000 events of radiative pion decays (RPD) were recorded. The results of the analysis of this RPD data set turned out to be quite unexpected, while certain indications of such possibility already existed. Theoretically RPD is defined by two electroweak formfactors, axial (F_A) and vector (F_V). In the Standard Model in accordance with the CVC hypothesis F_V is defined by π^0 lifetime and equals 0.0259(5). We obtained $F_V =$

0.0139(10) when fitted experimental data by both formfactors. Discrepancy with the SM value is about 12 standard deviations. It is possible to obtain a satisfactory fit to our data assuming that there is a small contribution of a tensor interaction to the RPD defined by tensor formfactor $F_T \approx$ -0.0022(4) . It is well known that tensor interaction is absent in the Standard Model, so a phenomenon beyond the Standard Model have been discovered (Fig.11). The resulting value of F_T is -0.0017±0.0001.

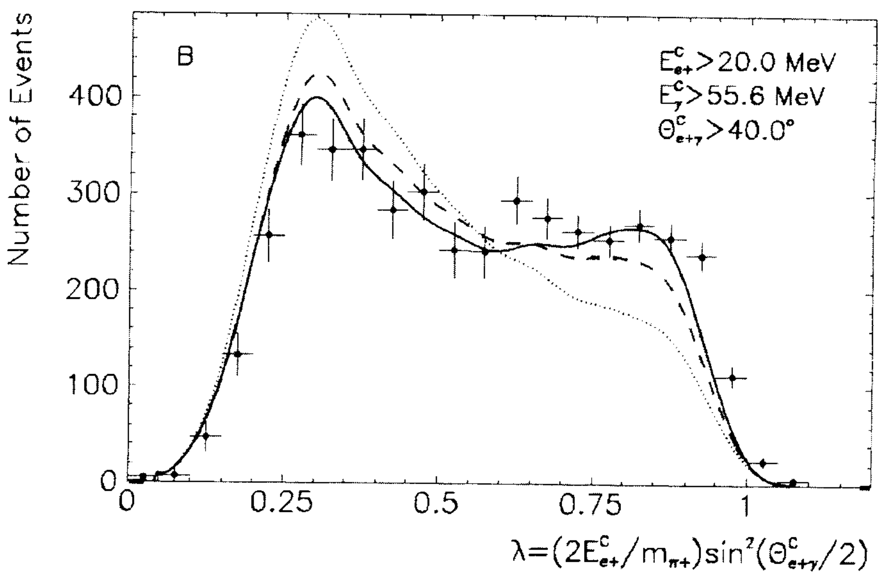

Fig.11. Measured spectrum of the kinematic variable λ in $\pi^+ \to e^+ \nu\gamma$ decay for the kinematic region B: dotted curve – fit with the pion form factor F_V fixed by the CVC hypothesis, F_A taken from the PDG 2002 compilation; dashed curve – fit with F_V and F_A released of all constraints, and F_T=0; solid curve – fit with F_V constrained by CVC, F_A and F_T unconstrained.

In the region with photon and positron energy $E_{\gamma e}$ > 10 MeV and angle between them $\theta_{\gamma e} > 40°$ ~80000 events of radiative muon decays ($\mu^+ \to e^+ \nu\bar{\nu}\gamma$) were recorded. This data set is in good agreement with SM prediction. The branching ratio obtained is $\Gamma_{\mu\to e\nu\nu\gamma} \approx$ 2,563 ± 0,050(стат.) ± 0,050(сист.) × 10^{-2} . The SM value is $\Gamma_{\mu\to e\nu\nu\gamma} \approx$ 2,584

$\times 10^{-2}$. New value of the parameter η= 0.00±0.05 was obtained. This parameter differs from zero if week interaction is not pure V-A one. Earlier η=0.02±0.08 was estimated experimentally.

In connection with unexpected phenomenon in RPD in **2004** PIBETA collaboration plans to carry a new precise investigation of RPD with pion beam intensity ~ 0.1 MHz. With such intensity accidental background will be suppressed by more than one order degree and will be of the 1-3% in compare with RPD. In 2004 necessary prophylactic and tuning of the PIBETA detector will be carry out to prepare it for new runs. Preliminary runs will be carry out on the cosmic and the pion beam.

DUBTO represents a joint JINR–INFN project aimed at studying pion-nucleus interactions at energies below the Δ-resonance. The experimental device STREAMER made use of [55] is a self-shunted streamer chamber, filled with helium at atmospheric pressure, in a magnetic field, equipped with two CCD video cameras for registering nuclear events occurring in the fiducial volume of the chamber. The self-shunted streamer chamber serves simultaneously as a thin target and a triggerable track detector and permits obtaining measurable tracks of secondary charged particles of very low energies (thus, for example, the path ranges of a 1.5 MeV proton and of a 5.0 MeV α-particle in ^{4}He at atmosperic pressure exceed 20 cm). This technique was developed in the 70-ies at the JINR Laboratory of nuclear problems in collaboration with the Turin section of INFN (Italy).

In the experiment DUBTO the streamer chamber was exposed to the pion beam of the JINR phasotron of the Laboratory of nuclear problems; the beam intensity amounted to $1–5\cdot 10^4$ s^{-1} at a pion momentum of 218 MeV/c.

The beam parameters (intensity of ~10^4 $\pi^{\pm}$/s, the spread in momentum of $\Delta p/p$ ±8%) and the parameters of the data acquisition system (the memory time of the streamer chamber ~1 μs, the time for reading out information and resetting the CCD matrices ~2.0 s) have permitted to obtain about 20000 stereo images of pion intereactions with helium nuclei at a pion beam momentum ~218 MeV/c. Dedicated software has been developed for reading, measuring and analysing video images, recorded as sets of pixels of the CCD matrix of the video camera.

The difference in luminosity permits to unambiguously distinguish the incident and scattered pion tracks from those of the secondary strongly ionizing particles (a proton and a tritium nucleus). The secondary pion, scattered downward at an angle of ~100°, is readily identified by its ionization losses, while identification of the two heavy reaction products also requires analysis of the reaction kinematics.

One of the tasks of DUBTO consists in obtaining information on the effective πNN mass at low energies, where the influence of the Δ-resonance is small, which can be done by determining the invariant mass of the scattered pion and the two secondary neutrons in the 3-prong breakup reaction $\pi^{\pm 4}He \rightarrow \pi^{+}2p2n$. For identification of this reaction channel we applied an artificial neural network (ANN) [56].

Approximately 100 events of the reaction $\pi^{\pm 4}He \rightarrow \pi^{+}2p2n$, that satisfied rigorous selection critieria and the condition of two neutrons interacting in the final state [3], revealed a distribution (see Fig.12) of the effective invariant πNN mass exhibiting the same resonance behaviour, as the distribution obtained in a study of proton-proton interaction at an energy of 920 MeV at ITEP [57], and a maximum at ~2.07 GeV. A similar result is obtained with negative pions. At present a statistic of approximately 20000 events is being processed.

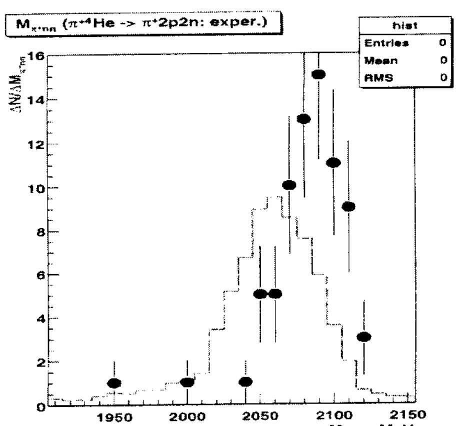

Fig.12. $\pi^{\pm}$nn mass distribution: histogram – simulation, full circles – experiment.

Another physical result, obtained by our collaboration, consists in the first observation of positive pion bremsstrahlung on helium nuclei. Thus, measurement of the momenta of recoil nuclei in two-prong $\pi^{\pm 4}$He interaction events permitted to separate events of purely elastic scattering from events of pion bremsstrahlung on the ^{4}He nucleus, i.e. for the first time pion bremsstrahlung on helium has been observed and its branching ratio determined:

Reaction	1980	2003
$\pi^{\pm 4}He \to \pi^+ He^4$	0.588±0.076	0.380±0.021+0.049–0.043
$\pi^{\pm 4}He \to \pi^+ He^4 \gamma$	–	0.322±0.019+0.112–0.026
$\pi^{\pm 4}He \to \pi^+ He^4 n$	0.240±0.038	0.136±0.013+0.025–0.018
$\pi^{\pm 4}He \to \pi^+ He^4 p$	0.176±0.053	0.162±0.014+0.000–0.000

In **2004** the collaboration plans to carry out two runs at the JINR phasotron at a pion energy of 70 MeV for obtaining data on various $\pi^{\pm 4}$He reaction channels at low energies; complete $\pi^{\pm 4}$He data processing at 100 MeV; submit articles on $\pi^{\pm 4}$He interactions at 100 MeV for publication.

The purpose of **Aerogel** project is development and improvement of the technique of samples of silica aerogel prodaction and construction on their basis cherenkov aerogel counters of wide application in the field of physics intermediate both high energy, and research of their parameters and characteristics. The improvements relates to the samples of aerogel with a low parameter of refraction ($n \leq 1{,}02$) mainly [58, 59]. The device for the control over quality and uniformity of separate samples of aerogel is created. Also, the device is developed and created for are sharp aerogel, which allows with good accuracy to join samples at assembly cherenkov counters practically any sizes. Process of heating of autoclaves on the set temperature that allows to improve operating conditions of the attendants is automated and standardisation of the quality of received samples of aerogel at the given stage is achieved.

Preparation and modelling researches of the automated system of dump of pressure from autoclaves under the set program is conducted. Together with ITEP and VBLHE JINR characteristics of aerogels (received in our Laboratory) in space beams and on accelerators were studied. The output of photoelectrons in samples with n=1,06-1,03 at 6 cm thickness is 5-6 on event at 97 % of efficiency of registration of pions that is comparable to the data received on samples from Novosibirsk and Japan in one experiment.

In **2004** the further development of the production technology aerogel samples with a low parameter of refraction: increase in an output samples and improvement of their optical properties (a transparency, optical uniformity) will be performed. Automation of a control system by pressure on a 1-liter autoclave will be studied. Studying an opportunity and expediency in conditions of development of technology of photonic crystals synthesis – a material representing interest for optical electronics – will be performed.

In the frame of **FAMILON** project the modernization of the magnetic spectrometer and the surface muon beam were performed. New proportional chambers with coordinate information read-out and DAQ system were designed and produced. New programs of the Monte-Carlo simulation of the set-up and the program of the off-line analysis of the experimental data were prepared.

In 2001 the work variant of the set-up was mounted on the muon beam of the phasotron. Then the test run have been performed on the surface muon beam of the JINR phasotron. The data acquisition system was tested in the actual conditions. The first muSR spectra with magnetic spectrometer were obtained. In 2002-2003 the new elements of the FAMILON set-up were tested on the muon beams of PNPI synchrocyclotron and JINR phasotron (proportional chambers, parallel plate avalanche detectors) to obtain the energy resolution of the FAMILON set-up on the level 10^{-3}.

For the decrease of the energy dispersion at the measurement of the positron energy it was suggested to apply the active target (live) on the basis of parallel plate avalanche detectors. The prototype of such detector (4 plates 60x60 mm^2 in size) was designed and manufactured. In November 2002 and June 2003 the operation of the detectors was studied on the surface muon beam of JINR phasotron. The possibility of the measurement of the muon stop point in the active target due to the analysis of the signal amplitude was demonstrated. The high efficiency of the parallel plate avalanche detectors (98,5% on a plateau) was shown.

The main steps in **2004** are the manufacturing of the new DAQ system for the proportional chambers, test of the new system and the methodical and the physical runs on the JINR phasotron. (100 hrs)

Relativistic Nuclear Physics

The scientific goal of **FASA**-project is study of thermal multifragmentation. This is a new multibody decay mode of very hot nuclei characterized by the copious emission of the intermediate mass fragments (IMF, $2<Z<20$). The hot nuclei are produced as a target spectators in the collisions of light relativistic ions with heavy targets. The 4π- setup FASA on the Nuclotron beam is used in these experiments.

It is proved [60, 61] that this process is the "liquid-fog" phase transition (of the first order) which takes place at the temperature T_f =(5-7) MeV. The hot nucleus expands by the thermal pressure and enters the phase instable spinodal region. Due to density fluctuations, a homogeneous system converts into the mixed state, consisting of liquid droplets (IMFs) surrounded by nuclear gas. The final state of this transition is a nuclear fog, which explodes due to Coulomb repulsion and is detected as multifragmentation. The existence of nuclear spinodal region is the consequence of the similarity between van der Waals and nucleon-nucleon interactions. As a result, the equations of the state are very similar for so different systems. At the same time, the liquid-fog phase transition is a specific nuclear transition, because it is highly influenced by the Coulomb field. This scenario is proved by the following observations: multifragmentation has an energy threshold; the density of the system at the break up time is reduced: $\rho_b \approx (1/3 — 1/4)\ \rho_o$; the mean life time of the fragmenting system is very small ($\approx$ 50 *fm/c*) which is of order of the density fluctuation time scale. Characteristic temperature T_f is less than T_c – critical temperature for the liquid-gas phase transition.

The significance of the liquid-fog phase transition for nuclear physics is evident, but it may be not so fundamental as the transition to quark-gluon plasma. However, it does definitely exist! Moreover, its investigation may be useful for understanding the supernova dynamics.

Another type of nuclear phase transition, a *"liquid-gas"* transition (of second order), is expected to occur at higher temperatures. The top of the spinodal region corresponds to the critical temperature T_c for this transition. At this critical point the liquid and gaseous phase become identical, the surface tension $\sigma_s(T)$ vanishes, and only the gas phase is possible above T_c. The most motivated expression for $\sigma_s(T)$ is the following:

$$\sigma_s(T) = \sigma_s(0) \cdot \left(\frac{T_c^2 - T^2}{T_c^2 + T^2} \right)^{\frac{5}{4}} .$$

According to the statistical multifragmentation model (SMM), the fragment charge distribution $Y(Z)$ crucially depends on the contribution of the free surface energy to the final state entropy. This allows determination of the T_c value from the shape of measured $Y(Z)$. It is demonstrated in Fig.13 (left) which presents the measured fragment charge distribution for p (8.1 GeV) + Au collisions and the calculations performed with T_c as a free parameter. The lines show the calculated distributions for T_c = 7, 11 and 18 MeV. The calculations are close to the data for T_c = 18 MeV. It is known that the shape of $Y(Z)$ is well approximated by the power law: $Y(Z) \sim Z^{-\tau_{app}}$. Fig. 13 (right) gives the results of the power-law fits for the data and model calculations. Similar result is obtained for p+Au collisions at 3.6 GeV.

Comparisons of the experimental power-law exponent (for p+Au at 8.1 GeV) and model predicted ones for different assumed values of T_c is shown in Fig.14. The measured power-law exponent is given as a band with a width determined by the statistical error. The size of the symbols for the calculated values of τ_{app} is of the order of the error bar. The critical temperature is found to be T_c = (17±2) MeV from the best fit of the data and calculations. The obtained value of the critical temperature is model dependent, but it is stable in respect to the variation of the parameters of SMM model. It seems to be reliable as the model used describes well large variety of the experimental data. Note that in some papers the lower value of the critical temperature is declared.

But the analysis of these works reveals that the break-up temperature T_f is actually measured.

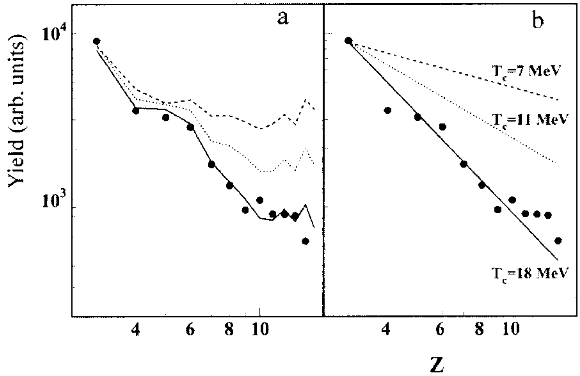

Fig. 13. Fragment charge distribution for p + Au at 8.1 GeV (dots): *a*) the lines are calculated by INC+SMM model, assuming T_c = 7 MeV, 11 MeV and 18 MeV; *b*) the power-law fits.

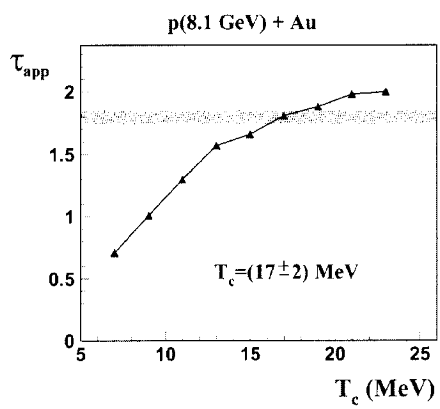

Fig.14. Estimation of the critical temperature T_c for the nuclear liquid-gas phase transition from the fragment charge distribution. The last is approximated by the power law: $Y(Z) \sim Z^{\tau\ app}$. The measured τ_{app} value (shown by the band) is compared to the model predicted ones with T_c as a free parameter. It is found that T_c=(17±2) MeV.

In **2004** further investigation of the evolution of the thermal multifragmentation mechanism with increasing the projectile mass from the relativistic protons to neon will be performed. As result, the nature of the collective flow observed for the beams heavier than helium will be established. Obtaining and analysis of the experimental data on IMF multiplicity, their charge and energy distributions, as well as the angular and velocities correlations, to get the new information on the nuclear *liquid-fog* phase transition will be planed. The expansion dynamics of hot nuclei driven by the thermal pressure, measuring the mean time of the expansion will be investigated. Experimental method for that is now under development.

Applied Scientific Research

Under the JINR topic **"Physics and Technique of Particle Accelerators"** design and construction of the Low-Energy Particle Toroidal Accumulator (**LEPTA**) together with design of electron cooling systems were performed in 2001. Within the frame of contracts with scientific centres GANIL (Caen, France), GSI (Darmstadt, Germany), BNL (Upton, USA) the special software libraries were developed for calculation of electron cooling process and beam dynamics of charged particles in storage rings and focusing channels. Common investigations of the ion beam stability during electron cooling were performing at proton synchrotron with charge-exchange injection COSY (Juelich, Germany).

The pulsed electron beam was used for optical testing and adjustment of main elements of LEPTA. Results of tests show a good agreement with design parameters. The construction of the positron injector for the LEPTA ring is in the final stage. Solenoids and vacuum chamber of the positron trap are constructed. Creation of the positron source based on ^{22}Na isotope was completed.

The program of experiments with positronium in-flight was developed. The positronium beam will be generated in the LEPTA by the electron cooling application to circulating positron beam. The first experiments are planned the following: direct comparison of the electron and positron electric charges, orto- and para-positronium life-time measurements, positronium spectroscopy.

In **2004** software development for simulation of electron cooling process and beam dynamics in ion storage rings RHIC (BNL), HESR (GSI), IR (RIKEN), LSR (ICR, Kyoto University) will be planed. The development of conceptual project of electron cooling system for Nuclotron, development of electron cooling systems for storage rings TWN (ITEP), IR (RIKEN) and NIRS (Chiba), testing of their elements will be performed.

Assembling of the LEPTA ring and first experiments with circulating electron beam, design and construction of the positron injector for LEPTA, further development of the program code for the nonlinear dynamics simulations in storage rings with strong transverse coupling will be continued. Within the framework of LEPTA project hereinafter the development of technical design of positron accumulator for generation of directed flux of antihydrogen atoms on antiproton ring are planed.

The main goal of the theme "**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 seven-compartment Medico-technical complex (MTC) of DLNP.

In 2003 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. During 2003 total of 95 patients (143 targets) were fractionally treated with the medical proton beam. The total number of the single proton irradiations has exceeded 2000. Other 55 patients were irradiated with Co-60 gamma-unit "Rokus-M" (more than 1600 irradiations).

To form a spread-out Bragg peak a set of special devises, ridge filters, has been designed and constructed for new therapeutic proton beam with the sharp dose distal fall-off. The filters allow delivering the beam with the flat dose maximum from 8 to 60 mm long according to the sizes of a target to be irradiated. All necessary dosimetric characteristics of the beam have been measured and inserted into a treatment planning system for 3D conformal proton radiotherapy which allowed us to use this beam in the treatment sessions.

To short the time needed for verification of the patient setup relative to the proton beam position and to increase the accuracy of the verification an automated machine for X-ray films developing was purchased and put into operation. To increase the quality assures (QA) standards of proton radiotherapy a system for "on-line" control of main characteristics of the proton beam (symmetry, homogeneity and range in water) has been designed, constructed and put into operation. The system allows carrying out measurements directly during irradiation of patients. The design of a removable deck for patient setup in the supine position during proton radiotherapy in treatment room 1 has been started. It will allow irradiation of new class of tumours such as prostate cancer.

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