DZHELEPOV LABORATORY OF NUCLEAR PROBLEMS

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. One of the most interesting results was the measurement of energy dependence of the strong coupling constant α_s. The «running» of α_s was unambiguously demonstrated within the single experiment DELPHI.

Among the most important DELPHI results obtained in 2003 are final publications on the Higgs boson searches at LEP [1]. Many possible scenarios were explored, including Standard Model Higgs, supersymmetric Higgs, double-charged H^{++}, etc. In all cases the result was negative and upper limits of about 100–115 GeV/c^2 were set on the Higgs mass.

Large progress was made in measurement of the W-boson mass, especially in understanding and reducing the systematic errors of M_w. The results are preliminary, the final results are expected within one year. Another result of 2003 was the measurement of tau pair production in gamma–gamma collisions $\gamma\gamma \to \tau\tau$ [2]. The upper limit on the electric dipole (d_τ) and the limits on the magnetic (a_τ) moments of the tau lepton were extracted from the measurements: $-0.052 < a_\tau < 0.013$, $|d_\tau| < 3.7 \cdot 10^{-16}$ electron $\cdot$ cm. The result for $a_\tau$is the most precise in the world (Fig. 1).

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) experiment is search for $\nu_\mu \to \nu_\tau$, $\nu_e \to \nu_\tau$ and $\nu_\mu \to \nu_e$ oscillations and to study 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_μNC interactions.

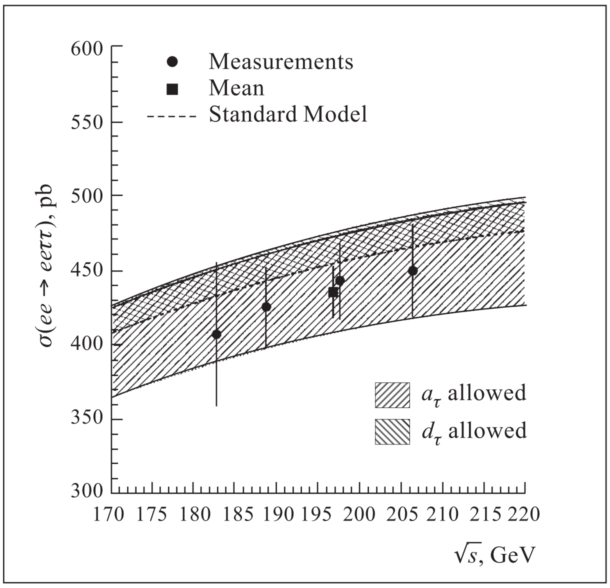

Fig. 1. Energy dependence of the $\gamma\gamma \to \tau\tau$ cross section

In 2003 the final results of the search for $\nu_\mu \to \nu_e$ oscillations in the NOMAD experiment were obtained [3]. No evidence for oscillations was found. The 90% confidence limits obtained are $\Delta m^2 < 0.4$ eV^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 $\Delta m^2 > 10$ eV^2.

A careful prediction of the neutrino beam composition (Fig. 2) is crucial for the $\nu_\mu \to \nu_e$ oscillation search. A method for the calculation of the flux and composition of the West Area Neutrino Beam used by NOMAD in its search for neutrino oscillations was developed [4]. The energy-dependent uncertainty of 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 of this ratio is 4.2%.

The measurement of the Λ^0 and $\bar{\Lambda}^0$ polarization in ν_μNC interactions was performed. Spin alignment of $K^{*\pm}$ vector mesons was measured in both charged- and neutral-current samples of the NOMAD data.

In 2004 the collaboration expects to finalize the analysis of the 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 CERN's PS accelerator was carried out in four months [5]. The total number of events taken with two nickel targets (single- and multilayer) is about 309 million. By October, 2003, about 20 000 $\pi^+\pi^-$ atoms were identified in the data obtained in 1999–2003 with the nickel, titanium and platinum targets. In this selection strong cuts were imposed. The system of microdrift chambers with readout electronics was tested on the beam. The time and space resolutions of the chamber were confirmed. About 100 million events were collected with the chambers to measure the efficiency of used detectors to register double-track events.

In 2004 the DIRAC collaboration plans to analyze the measurements of multiple scattering angles in the target, detectors and elements of the set-up to reduce the systematic errors arising from uncertainties in the multiple scattering description. Analysis of the test of micro-drift chambers will be needed to study systematic errors in the experimental data. 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 CERN's

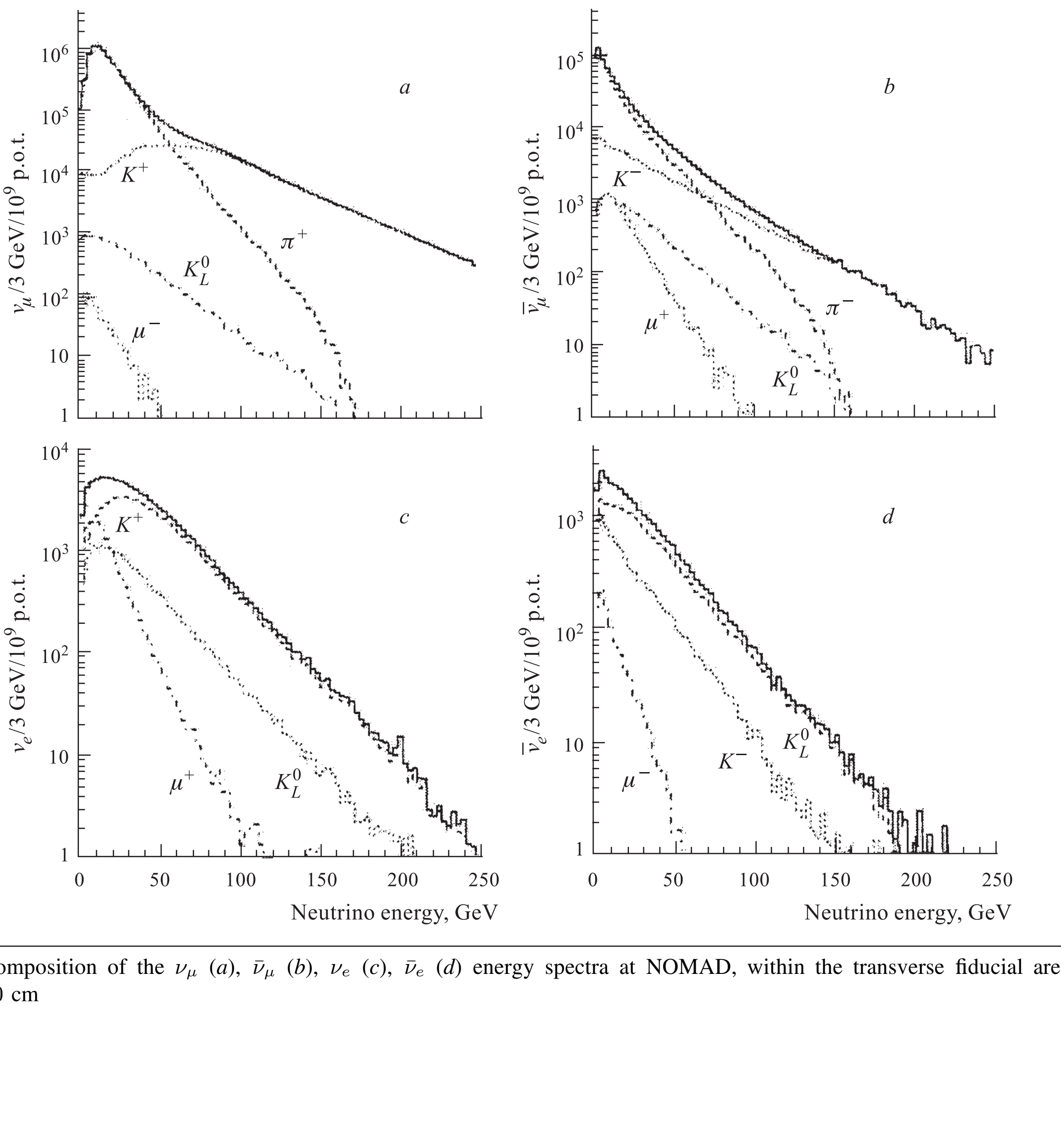

Fig. 2. Composition of the ν_μ (*a*), $\bar{\nu}_\mu$ (*b*), ν_e (*c*), $\bar{\nu}_e$ (*d*) energy spectra at NOMAD, within the transverse fiducial area of 260×260 cm

PS will be performed. In 2004 development of the addendum to the DIRAC project on the measurement of the $\pi^+\pi^-$-atom lifetime with an accuracy of 5%, observation of πK atoms and long-lived states of the $\pi^+\pi^-$ atom is planned. The collaboration plans to develop the proposal for the $\pi^+\pi^-$- and πK-atom lifetime measurement of the J-PARC accelerator in Japan.

The quality of the muon measurement is one of the guiding design criteria for the **ATLAS** experiment. The muon spectrometer is the outer layer of the ATLAS detector (about 22 m high and 44 m long). For fixing the muon trajectory the determination of at least three points in the muon track is needed, which leads to an area of 5500 m^2 to be covered by muon detectors (or 400 000 single drift tube detectors, grouped into 1200 chambers). The proposal of using drift tubes with working gas overpressure was made by the JINR group and was selected by ATLAS as the main solution for the 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 the USA. The responsibility of the JINR muon group is production of BMS/BMF chambers or about 20% of the total number of ATLAS muon drift tubes. In 2003 the JINR muon group completed production and test of single drift tubes (24 800 tubes) and continued production and test muon chambers [6].

The **ATLAS Tile Calorimeter Barrel** assembly of JINR production modules has been successfully accomplished. For the first time the ATLAS Tile Calorimeter modules have received the energy calibration constants. On 30 October the raising of the ATLAS Hadron Barrel Tile Calorimeter to the earth level was successfully completed at CERN. The erection of the 1350-ton-heavy Barrel within severe design tolerances with a permanent (on-line) mechanical precision control is a unique technical operation of the efficient scientific, engineering and management cooperation of CERN, JINR and research centres and industry of their member countries.

New software developed in Dubna was successfully used for the energy calibration of the ATLAS TILECAL cells [7]. The electron and pion calibration constants for various cells, energies and angles were obtained from the data. The detailed study of the electron and pion energy resolutions manifested experimentally the correctness of our calibration algorithms. The electron and pion energy resolutions were studied. The calibration constants obtained were included in the TILECAL calibration database.

A conceptually new method of fast Monte Carlo simulation of a hadron calorimeter response is proposed [8]. The key idea of the method is the use of the three-dimensional parameterization of the hadronic shower from the ATLAS TILECAL test beam data. One of the first ATLAS physics results — the energy spectrum and the cross section of photonuclear interactions of 180-GeV muons in iron ($\mu + \mathrm{Fe} \to \mu' + \mathrm{hadrons} + X$) — was obtained at CERN's SPS with the modules of the ATLAS Tile Calorimeter [9]. The differential cross section for the muon fractional energy loss $v = \Delta E_\mu / E_\mu$was measured in the range $0.1 < v < 1$. In 2003 four TILECAL test beam data-taking runs were carried out at the SPS. Some important results were reported at various conferences [10].

The JINR group is actively involved in conducting the **D0** experiment at the 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 the upgraded D0 detector for Run II capable of running at the highest possible luminosity around 10^{32} $\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$. Two areas of interest for the JINR group are QCD studies and b-baryon physics.

The task of the most precise hadron jet energy calibration (also called 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 the existing uncertainty in the jet energy scale. The JINR group at D0 has developed new selection criteria for events with associated production of hadronic jets and direct photons, allowing improving essentially the precision of setting the absolute jet energy scale for the conditions of the D0 experiment. It is shown that the main source of the photon (or Z^0) and jet transverse momentum imbalance is the radiation in the initial (ISR) and final states (FSR). Another new requirement of jet isolation introduced for the first time allows selection of topologically clean «photon/$Z^0 + \mathrm{jet}$» events, which would provide almost 1% accuracy of the absolute jet energy scale determination. In parallel with the solution of the jet energy calibration task, a possibility of carrying out experimental research into the proton structure, namely, the gluon distribution function, is proved. It was shown that the samples of the «$\gamma + \mathrm{jet}$» events selected for the jet energy calibration could be used for this aim (Fig. 3).

The interest of the D0 collaboration will also be focused on b-baryon physics, namely, b-baryon spectroscopy. Until now, this area has been explored rather poorly. The JINR group are trying to investigate nonleptonic decays of b baryons to fully reconstructable final states $\Lambda_b \to J/\psi + \Lambda$ and $\Xi_b \to J/\psi + \Xi$ with further leptonic decay of J/ψ ($\mu^+\mu^-$ or e^+e^-). With these decays it is possible to determine unambiguously the mass and lifetime of those b baryons (the same is also valid for antibaryons).

In 2003 the JINR/**CDF** group started c-, b-, t-quark physics research at the upgraded CDF; the preliminary data on top-mass measurement were obtained. In 2003 the JINR/CDF group provided the efficient CDF functioning at 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 the Silicon Vertex Tracker

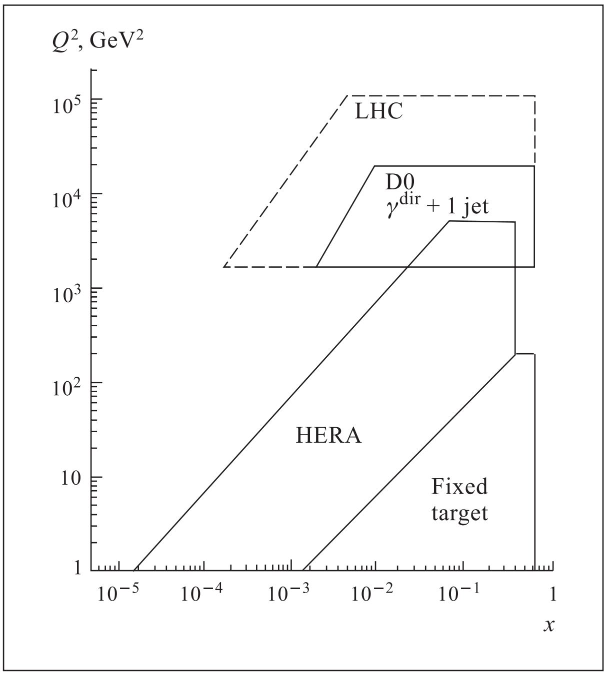

Fig. 3. Kinematical region of the $pp \to \gamma + \text{jet}$ reaction at the Tevatron and the LHC. Fixed target experiments and HERA regions are also given

(a specialized detector for Fast On-line search for secondary vertices), took an active part in the modernization of the CDF Muon Complex and High Voltage Slow Control System for the muon scintillator counters [11].

A method and adequate codes for high-precision top-quark mass measurement in the «$p\bar{p} \to \text{lepton} + \text{jets}$» topology were developed and used. The method and codes were successfully tested with simulated data (Fig. 4). Preliminary results on the top-quark mass in the single-lepton decay mode were obtained from the first 72 pb^{-1} CDF Run-II data. Jet tagging was not used to increase statistics, and the measured value of the top mass was $m_t = 171.2 \pm^{14.4}_{12.5}(\text{stat.}) \pm 9.9(\text{syst.})$ GeV/c^2. New codes for top-mass measurement in the dilepton decay mode were developed and tested with the Monte Carlo sample. The first results on the top-quark mass in the dilepton mode are expected by the spring of 2004.

A new method for analysis of statistical data from the top-quark mass measurement was created. New codes for on/off-line monitoring of the Silicon Vertex Tracker with the fast Associative Memory allowed fast permanent SVT control.

In 2004 the collaboration plans to obtain the preliminary result on m_t in the dilepton decay mode. Maintenance and support of the CDF detector systems (developed with JINR's participation) during the Run-II data taking at the FNAL Tevatron will be continued.

The **HARP** experiment [12] 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 recuperated from the NOMAD experiment (NDC), and a large-angle region, where the main tracking device and the particle identification detector is a TPC.

The HARP physics goals are the measurements of pion yields to allow a design of the proton driver of neutrino factories and 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.

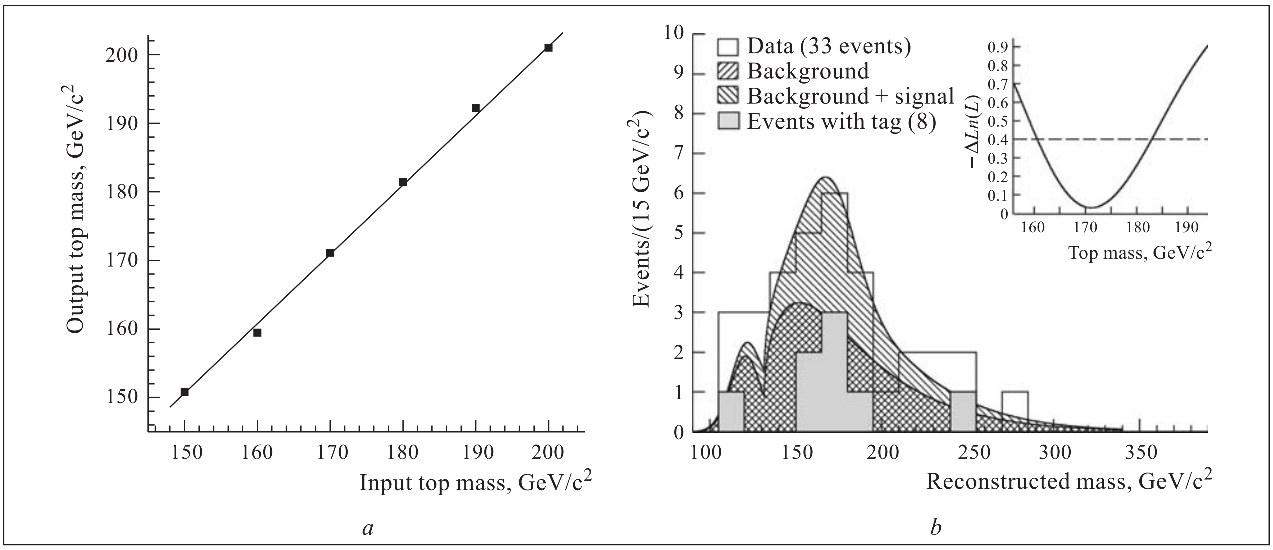

Fig. 4. a) Reconstructed mass of the top quark as a function of the input top mass assumed in Monte Carlo. b) Fitted mass of the top-quark spectra for top candidates selected from the first 72 pb^{-1} CDF data

In 2003 the responsibility of the JINR group in the HARP experiment was refurbishing, installation, commissioning and operation of the NOMAD drift chamber in the HARP experiment. A first set of calibration and alignment of the NDCs was performed. A spatial resolution of the NDCs of about 350 μm was achieved after a careful alignment procedure. The algorithm for the NDC reconstruction was developed. The segment reconstruction algorithm in the NDC proposed by the JINR group was chosen by the collaboration as the default reconstruction algorithm due to its high efficiency and purity. Systematic hardware measurements and data analysis were performed to understand various distortions affecting the TCP. 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 were calculated [13].

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. These data are necessary for correct interpretation of the LSND neutrino experiment results.

In 2004 the water data analysis is to be completed. The development of the reconstruction programme for the NDC, TCP, RPCs and beam detectors is 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 is to be carried out.

The main goal of the **HYPERON** experiment [14] in 2003 was to design and build a set-up for the study of meson-nuclear effects in charge-exchange reactions with neutral mesons in the final state and to carry out two runs to test the apparatus. The basic units of the set-up are the electromagnetic calorimeter, the tagging system and proportional chambers.

Proportional chambers are intended for determining the beam particle momentum. During the year much work was done to put into operation all services for beam chambers. Hexagonal chambers were mounted, and chamber communications were assembled. The hodoscopic lead–glass calorimeter is intended for detecting photons from neutral-meson decays. It was necessary to supply and mount 640 new ADCs (system MISS), because the old ADCs became worthless. Till now 320 ADCs have been connected up and tested.

A data acquisition system was developed which allows acception of a few thousand events per spill. It also gives a possibility of controlling the detectors in the on-line regime and of reconstructing events on other computers simultaneously with data taking. The event reconstruction program has already been installed.

In 2004 the tagging system will be delivered to and mounted in Protvino before the run, the constrution of the LED monitoring system will be completed. The preliminary results on A-dependence in the charge-exchange meson-nuclear reaction will have been obtained by 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 extensive air showers (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 be studied (the region of Greisen–Zatsepin–Kusmin cutoff) from a space orbit. TUS is a pilot experiment, it is expected to be launched on the RESURS-O satellite in 2006–2007. After the experiment the next-generation KLYPVE apparatus (~ 10 m^2 Fresnel mirror and 50×50 PMTs) will be constructed and launched to ISS for the study of the UHECR, including the events initiated by neutrinos. The press-form prototypes for the Fresnel mirror of the TUS detector were produced in 2003. The first two Fresnel mirror modules from different materials were also produced.

A package (SLAST) of programs simulating both fluorescent and Cherenkov light produced by EAS initiated by a UHECR particle on entering the atmosphere is developed. The Fresnel mirror, the electronics and the trigger are simulated. The full simulation chain including air shower 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 the EAS maximum which is crucial for the UHECR energy and atmosphere depth of the EAS maximum reconstruction are developed.

The **E391a** experiment is aimed at search for the rare kaon decay process, $K_L \to \pi^0 \nu\nu$ decay, by using a pencil beam and a detector system having a very high performance of photon vetoing. The E391a detector consists of three mechanically independent sections, which are fabricated individually and are then combined into a unit. Now all the three basic sections are fabricated. At the end of 2003 their assembly in the set-up began after a vacuum test. This experiment was approved in April, 2000, and the detector is being constructed for data taking from February, 2004.

LOW- AND INTERMEDIATE-ENERGY PHYSICS

The main result of the **NEMO-3** project in 2003 is the start of the NEMO-3 detector operation in the normal mode. Final tuning of the detector, installation of the laser survey system and the neutron shield were finished and since 14 February the detector has been taking data under stable conditions [15]. The useful exposure time of the detector in 2003 was about 5500 h (230 days).

An unexpectedly high level of radon concentration, ≈ 20–30 mBq/m^3, was found inside NEMO-3 from the analysis of the first data. R&D was performed during 2003 to find methods and techniques to eliminate radon from the laboratory air. Finally the NEMO-3 detector was covered by a radon-free tent in October, 2003, and a radon-free factory on the basis of a cooling charcoal filter will be built in early 2004. The first data collected (February–September, 2003, 3834 h) were analyzed. Half-lives of the NEMO-3 sources were tentatively defined. The best values were obtained for the main NEMO-3 isotope ^{100}Mo (7.2 kg) (Fig. 5). The current limit for the neutrinoless double beta decay was found to be

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

83 000 events were collected for the $2\beta2\nu$ decay of ^{100}Mo, giving a negligible statistical error:

$$T_{1/2}^{2\beta2\nu}(^{100}\mathrm{Mo}) = $$
$$= (8.2\pm0.0025(\mathrm{stat.})\pm0.8(\mathrm{syst.}))\cdot10^{18}\ \mathrm{y}.$$

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

$$T_{1/2}^{2\beta2\nu}\,(^{82}\mathrm{Se}) = (9.52\pm0.25(\mathrm{stat.})\pm$$
$$\pm0.9(\mathrm{syst.}))\cdot10^{19}\ \mathrm{y}, T_{1/2}^{2\beta0\nu} > 1.0\cdot10^{22}\ \mathrm{y}\ (90\%\,\mathrm{CL}),$$

$$T_{1/2}^{2\beta2\nu}\,(^{116}\mathrm{Cd}) = (2.69\pm0.09(\mathrm{stat.})\pm$$
$$\pm0.3(\mathrm{syst.}))\cdot10^{19}\ \mathrm{y}, T_{1/2}^{2\beta0\nu} > 1.6\cdot10^{22}\ \mathrm{y}\ (90\%\ \mathrm{CL}),$$

$$T_{1/2}^{2\beta2\nu}\,(^{150}\mathrm{Nd}) = (7.5\pm0.3(\mathrm{stat.})\pm$$
$$\pm0.7(\mathrm{syst.}))\cdot10^{18}\ \mathrm{y}, T_{1/2}^{2\beta0\nu} > 3.6\cdot10^{21}\ \mathrm{y}\ (90\%\ \mathrm{CL}).$$

A new high-efficiency spectrometer **TGV** [16] was built with the use of construction materials characterized by a very low level of radioactive impurities ($\mathrm{U}+\mathrm{Th} < 0.1$ ppb). The TGV-2 spectrometer was intended for the investigation of double beta decay of ^{48}Ca and double electron capture of ^{106}Cd. The spectrometer was based on 32 planar HPGe detectors with a sensitive volume of 2040 mm^2 $\times$ 6 mm each (about 3 kg of Ge). The detectors were mounted vertically one over another together with thin (50–100 mg/cm^2) homogenious double beta emitters in an ultra-low-background cryostat of a special design. The detector part of the TGV-2 was embedded into passive shielding, including shielding against radon and neutron shielding. Some unique methods for active suppression of radioactive background and electronic noise by distinguishing beta particles and gamma rays and by using 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 TGV-2 was mounted in the Modane underground laboratory (4800 m w.e.), France. The background of the TGV-2 spectrometer was tested in a series of long-term measurements in a low-energy (<50 keV) and full-energy (<5 MeV) regions and was found suitable for the study of the $2K2\nu$ and $2K0\nu$ decays of ^{106}Cd and $2\beta2\nu$, $2\beta0\nu$ decays of ^{48}Ca. The new limits on the 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 with about 10 g of enriched ^{48}Ca.

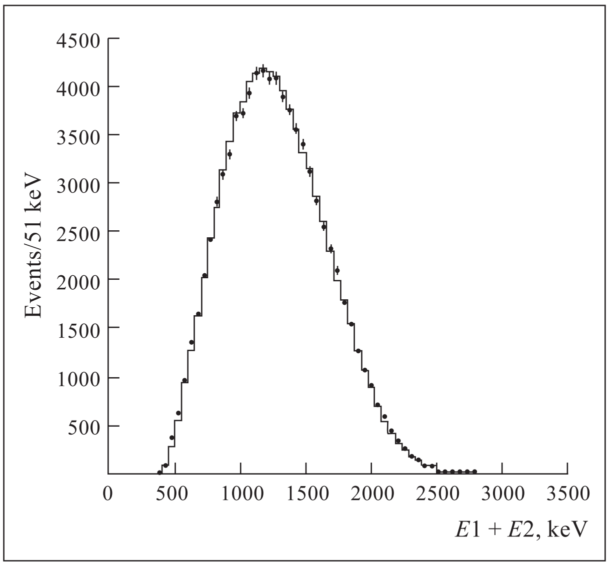

Fig. 5. $\beta\beta$ signal of ^{100}Mo. 3834 h of measurement (02.09.2003), 83 000 events

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

The present work of the **AnCor** collaboration extends the search for the genuine scalar interaction to 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 reaction under investigation is a two-step process which consists of the first-forbidden ($0^+\to1^-$)-transition of ordinary muon capture in a zero-spin ^{16}O nucleus followed by γ emission from the excited recoiling daughter nucleus. As the lifetime of the 1^--level is relatively long (almost 4 ps), a low-density target — oxygen gas at a pressure of a few bar — must be used 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. In view of these conditions, a special gas target was constructed and used at the μE4 beamline of PSI. The γ spectra were measured at the atmospheric pressure with an HPGe detector in a 3-week experiment.

Using the method based on the Doppler effect and developed in [17], one can investigate the correlation between the momenta $\mathbf{q}$ and $\mathbf{k}$ 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 as: $W = 1 + a_2^1 P_2(\mathbf{kq})$, 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 value $a_2^1 = 0.096 \pm 0.020$ was obtained [18].

To transform this model-independent value to the Scalar coupling estimation (Fig. 6), 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 a nontrivial result would be a repeat experiment with another target nucleus. After several tests, neon gas at the atmospheric pressure was chosen as the most promising candidate.

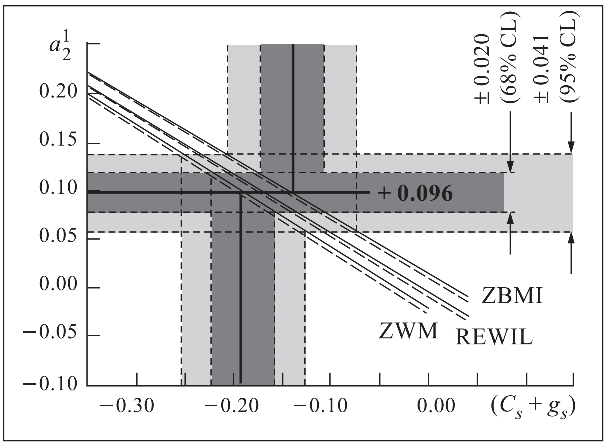

Fig. 6. Transformation of the correlation coefficient a_2^1 to the $(C_s + g_s)$ value

Several interesting processes take place when a muon is captured by the ^{20}Ne nucleus. Among them there are the first-forbidden $(0^+ \to 1^-)$-transition sensitive to the Scalar coupling, the allowed $(0^+ \to 1^-)$- and two unique $(0^+ \to 2^-)$-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.

In 2003 the 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. To obtain reliable information for the most interesting 2β-decaying nuclei, the AnCor collaboration proposed to measure partial μ-capture rates in ^{48}Ti and other enriched targets [19]. As a first step, one-gram targets of ^{48}Ca, ^{48}Ti, ^{76}Se, ^{106}Cd, ^{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 were extracted with a good accuracy. Some measurements were performed with enriched ^{48}Ca and ^{48}Ti targets and were compared to the results for natural metallic calcium (97% of ^{40}Ca) (Fig. 7).

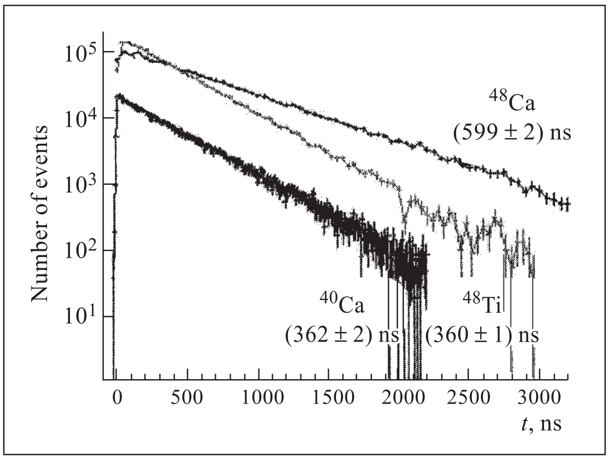

Fig. 7. Time evolution of γ lines following the μ capture by ^{40}Ca, ^{48}Ca and ^{48}Ti targets (spectra are not normalized)

Particular 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 γ lines and to analyze their balance for extracting the partial capture rates with the required precision (10–20%).

Within the framework of the **LESI** experiment, 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, $\tau = 80$ ns) at HCEI (Tomsk) in 1996–2002. The experimental values of the astrophysical S-factor and effective cross section for dd reactions in this energy range were obtained for the first time. In 2003 an experimental apparatus was mounted and commissioned at a more powerful pulsed accelerator ($I = 2.5$ MA, $\tau = 80$ ns) at HCEI (Tomsk). This was done to continue the study of the mechanism for the reaction between light nuclei at «higher» energies of 3–10 keV in comparison with the energy range attained at the SGM accelerator. The importance of these studies arises from the necessity of correctly comparing their results with the calculations and the results of the experiments carried out at classical accelerators [20].

Various methods not only for studying the inverse Z-pinch formation process at the MIG accelerator but also for measuring the energy distribution of ions in the liner were 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 results already obtained indicate that the proposed method for generation of intense colliding plasma fluxes with energy above 3 keV holds much promise [21].

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 **ANKE** spectrometer (COSY, Jülich) the energy dependence [22] of the differential cross section of the deuteron breakup $p + d \to (pp) + n$ with forward emission of a proton pair with a relative energy less than 3 MeV has been analyzed. A theoretical model taking into account one-nucleon exchange, Δ-isobar excitation and single scattering was employed. The calculated cross sections were found to depend strongly on the form of the NN potential used: the 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 [23] only with use of the more modern, Bonn potential. More detailed comparison will be done after processing of the data obtained by the ANKE collaboration during 2004.

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

Within the framework of the **MUON** project 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 that of the free muon 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 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) a 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 at investigating the effect of impurities on the relaxation rate of the magnetic moment of the shallow acceptor centre. The measurements were carried out with more than 20 silicon samples with p- and n-impurities of different concentrations. The constant of the hyperfine interaction of the Al shallow acceptor centre in undeformed silicon is determined for the first time: $A/h(^{27}\mathrm{Al}) = (-2.2 \pm 0.2)$ MHz.

It was found that in Si with the isoelectron impurity at $T < 50$ K the relaxation of the shallow acceptor centre is due to the spin-lattice interaction and 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 by the acceptor dominates at $T < 30$ K. The effective cross sections for the spin-exchange scattering of holes (σ_h) and electrons (σ_e) by 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. 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 randomly oriented. The clear frequency shift of muon spin precession in the external transverse field was seen. This fact may be attributed to the increased total moments of the superparamagnetic cube containing eight Ce atoms and their ferromagnetic ordering with decreasing temperature [24].

The analysis of the experimental data taken with the unique **PIBETA** spectrometer is coming to a close [25]. The PIBETA collaboration have recorded about two orders of magnitude more rare pion and muon decays than was available in the entire world data sets for 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 presented in Table 1.

Table 1

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

The current preliminary working result for the pion beta decay branching ratio is BR$\approx$ $(1.038 \pm 0.004(\mathrm{stat.}) \pm 0.007(\mathrm{syst.})) \cdot 10^{-8}$. The Standard Model prediction according to PDG data is BR$=$ $(1.038{-}1.041) \cdot 10^{-8}$ (90% CL). In the previous measurement BR$=$ $(1.026 \pm 0.039) \cdot 10^{-8}$ 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 where e^+ and γ are emitted into opposite hemispheres, each with energy $E > 52$ MeV, $\sim$50 000 events of radiative pion decays (RPD) ($\pi^+ \to e^+\nu\gamma$) were recorded. On the basis of this data set the pion axial form factor was found to be $F_A = 0.0123(4)$. Theoretically RPD is defined by two electroweak form factors, axial (F_A) and vector (F_V). In the Standard Model in accordance with the CVC hypothesis, F_V is defined by the π^0 lifetime and equals 0.0259(5). $F_V = 0.0139(10)$ was obtained by fitting the experimental data with both form factors. Discrepancy between our value and 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 tensor interaction to the RPD defined by the tensor form factor $F_T \approx -0.0022(4)$ (Fig. 8). It is well known that tensor interaction is absent in the Standard Model, thus a phenomenon beyond the Standard Model has been discovered. The resulting value of F_T is -0.0017 ± 0.0001.

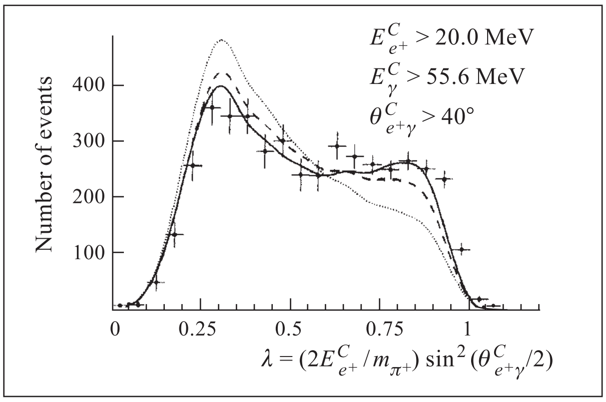

Fig. 8. Measured spectrum of the kinematic variable λ in the $\pi^+ \to e^+\nu\gamma$ decay: the dotted curve is the fit with the pion form factor F_V fixed by the CVC hypothesis, F_A is taken from the PDG 2002 compilation; the dashed curve is the fit with F_V and F_A free of all constraints and $F_T = 0$; the solid curve is the fit with F_V constrained by CVC, F_A and F_T unconstrained

In the region with the photon and positron energy $E_{\gamma e} > 10$ MeV and the angle between them $\theta_{\gamma e} > 40°$, $\sim$80 000 events of radiative muon decays ($\mu^+ \to e^+\nu\bar{\nu}\gamma$) were recorded. This data set is in good agreement with SM prediction. The branching ratio obtained is $\Gamma_{\mu\to\nu\nu\gamma} \approx (2.563 \pm 0.050(\mathrm{stat.}) \pm 0.050(\mathrm{syst.})) \cdot 10^{-2}$. The SM value is $\Gamma_{\mu\to\nu\nu\gamma} \approx 2.584 \cdot 10^{-2}$.

In connection with the unexpected phenomenon in RPD, in 2004 the PIBETA collaboration plans to carry out a new precise investigation of RPD with a pion beam intensity of ~ 0.1 MHz. With such an intensity, accidental background will be suppressed by more than one order and will be 1–3% in comparison with RPD. In 2004 the necessary preventive maintenance and tuning of the PIBETA detector will be performed to prepare it for new runs. Preliminary runs will be conducted with the cosmic-ray and pion beam.

DUBTO is a joint JINR–INFN project aimed at studying pion–nucleus interactions at energies below the Δ-resonance. The experimental device STREAMER [26] is a self-shunted streamer chamber filled with helium at the atmospheric pressure, in a magnetic field, equipped with two CCD video cameras for recording 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 a 5.0-MeV α particle in ^{4}He at the atmospheric pressure exceed 20 cm). This technique was developed in the 1970s at JINR's Laboratory of Nuclear Problems in collaboration with the Turin section of INFN (Italy).

In the DUBTO experiment 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.

One of the tasks of DUBTO is to get information on the effective πNN mass at low energies, when the influence of the Δ-resonance is small. This can be done by determining the invariant mass of the scattered pion and the two secondary neutrons in the three-prong breakup reaction $\pi^{\pm 4}\mathrm{He} \to \pi^+ 2p2n$. For identification of this reaction channel we used an artificial neural network (ANN).

Approximately 100 events of the reaction $\pi^{\pm 4}\mathrm{He} \to \pi^+ 2p2n$ that satisfied rigorous selection critieria and the condition of two neutrons interacting in the final state, revealed a distribution (Fig. 9) of the effective invariant πNN mass exhibiting the same resonance behaviour as the distribution obtained in the study of the proton–proton interaction at an energy of 920 MeV at ITEP [27] and a maximum at ~ 2.07 GeV. A similar result is obtained with negative pions.

Another physical result obtained by collaboration is 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 events of purely elastic scattering (to be separated) from events of pion bremsstrahlung on the ^{4}He nucleus; i.e., for the first time pion bremsstrahlung on helium was observed and its branching ratio determined (see Table 2).

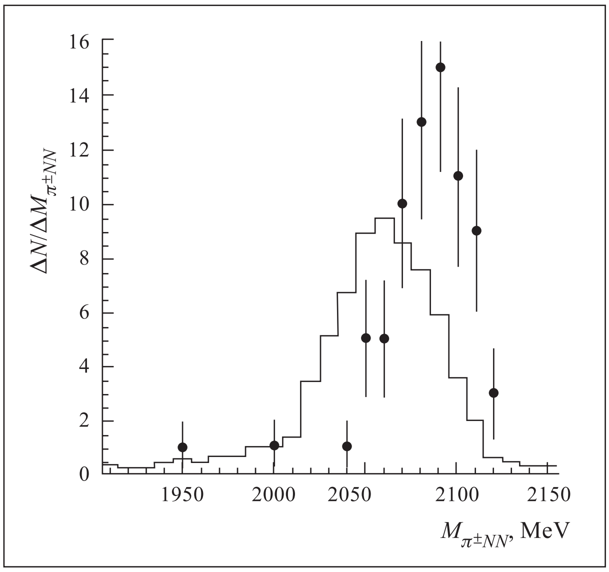

Fig. 9. $\pi^{\pm}NN$ mass distribution; histogram is the simulation, full circles are the experiment

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, to complete $\pi^{\pm 4}$He data processing at 100 MeV and to submit papers on $\pi^{\pm 4}$He interactions at 100 MeV for publication.

The purpose of the **Aerogel** project is the development and improvement of the technique for production of silica aerogel samples and construction on their basis of Cherenkov aerogel counters of wide application in intermediate- and high-energy physics, to investigate their parameters and characteristics. The improvements mainly extend to relates to the aerogel samples with a low index of refraction ($n \leqslant 1.02$) [28].

Preparation and modelling research of the automated system autoclave pressure release under the set program are conducted. The characteristics of aerogels obtained at the Laboratory were studied in space beams and at accelerators together with ITEP and JINR's VBLHE. The output of photoelectrons in 6-cm-thick samples with $n = 1.06{-}1.03$ is 5–6 per event at the 97% of pion detection efficiency, which is comparable with the data on the samples from Novosibirsk and Japan in one experiment.

In 2004 further development of the production technology of aerogel samples with a low index of refraction will be carried out to increase the output samples and improve optical properties (transparency, optical uniformity). Automation of a pressure control system for the 1-liter autoclave will be studied.

Table 2

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

Within the framework of the **FAMILON** project the upgrading of the magnetic spectrometer and the surface muon beam was performed. New proportional chambers with the coordinate information readout 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 in the muon beam of the Phasotron. Then the test run was performed in the surface muon beam of the JINR Phasotron. The data acquisition system was tested under the actual conditions. The first μSR spectra were obtained with the magnetic spectrometer. In 2002–2003 the new elements of the FAMILON set-up were tested in the muon beams of the PNPI synchrocyclotron and the JINR Phasotron (proportional chambers, parallel plate avalanche detectors) to obtain the energy resolution of the FAMILON set-up at a level of 10^{-3}. For decreasing the energy dispersion in the measurement of the positron energy it was suggested to use the active target on the basis of parallel plate avalanche detectors. The prototype of this detector (4 plates 60×60 mm in size) was designed and manufactured. In November, 2002, and June, 2003, the operation of the detectors was studied in the surface muon beam of the JINR Phasotron. A possibility of measuring the muon stop point in the active target due to the analysis of the signal amplitude was demonstrated. A high efficiency of the parallel plate avalanche detectors (98.5% at a plateau) was shown.

The main steps in 2004 are the manufacture of the new DAQ system for the proportional chambers, the test of the new system and the methodological and physical runs at the JINR Phasotron.

The scientific goal of the **FASA** project is the study of thermal multifragmentation. This is a new multibody decay mode of very hot nuclei characterized by copious emission of the intermediate-mass fragments (IMF, $2 < Z < 20$). The hot nuclei are produced as target spectators in the collisions of light relativistic ions with heavy targets. The 4π-set-up FASA on the Nuclotron beam is used in these experiments. It is proved [29] 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 is converted into a 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 the nuclear spinodal region is the consequence of the similarity between van der Waals and nucleon–nucleon interactions. As a result, the equations of 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 breakup time is reduced: $\rho_b \approx (1/3{-}1/4)\rho_0$; the mean lifetime of the fragmenting system is very small (≈ 50 fm/c) which is of order of the density fluctuation time scale. The characteristic temperature T_f is less than T_c, the critical temperature for the liquid–gas phase transition.

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 phases become identical, the surface tension $\sigma_s(T)$ vanishes, and only the gas phase is possible above T_c.

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. 10, *a*, 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: $Y(Z) \sim Z^{-\tau_{\rm app}}$. Figure 10, *b* gives the results of the power-law fits for the data and model calculations. A similar result is obtained for $p +$ Au collisions at 3.6 GeV.

The critical temperature is found to be $T_c = (17 \pm 2)$ MeV from the best fit of the data and calculations. The value of the critical temperature is model-dependent, but it is stable in respect to the variation of the SMM parameters. It seems to be reliable as the model used describes a large variety of the experimental data well. Note that in some papers a lower value of the critical temperature is asserted. But the analysis of these works reveals that the breakup temperature T_f is actually measured.

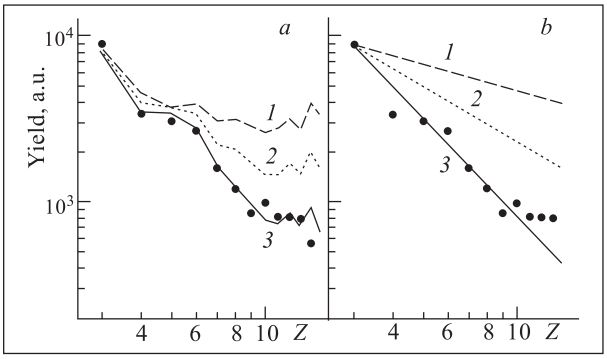

Fig. 10. Fragment charge distribution for $p +$ Au at 8.1 GeV (dots): *a*) the lines are calculated by the INC + SMM model, assuming T_c= 7 (*1*), 11 (*2*) and 18 MeV (*3*); *b*) the power-law fits

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 a result, the nature of the collective flow observed for the beams heavier than helium will be established. It is planned to set and analyze the experimental data on multiplicity of the IMFs, their charge and energy distributions as well as the angular and velocities correlations to get new information on the nuclear liquid–fog phase transition. The expansion dynamics of hot nuclei driven by the thermal pressure will be investigated by measuring the mean time of the expansion. The experimental method for that is under development now.

APPLIED SCIENTIFIC RESEARCH

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

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

In 2004 it is projected to develop software for simulation of electron cooling process and beam dynamics in the ion storage rings RHIC (BNL), HESR (GSI), IR (RIKEN), LSR (ICR, Kyoto University). The conceptual project of the electron cooling system for the Nuclotron and the electron cooling systems for the storage rings TWAC (ITEP), IR (RIKEN) and NIRS (Chiba) will be developed, their elements will be tested.

Assembling of the LEPTA ring and the first experiments with the 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 the LEPTA project it is planned to develop the technical design of the positron accumulator for generation of a directed flux of antihydrogen atoms in the antiproton ring.

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 seven-compartment Medico-Technical Complex (MTC) of DLNP.

In 2003, in collaboration with the Medical Radiological Research Centre (Obninsk), the Radiological Department of the Dubna hospital and medical research centres of the Czech Republic and Bulgaria, the research in proton therapy of cancer patients with the Phasotron beams in treatment room No. 1 of the MTC was continued. During 2003 a 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 at Co-60 gamma unit «Rokus-M» (more than 1600 irradiations).

To form a spread-out Bragg peak a set of special devises, ridge filters, have been designed and constructed for a new therapeutic proton beam with the sharp distal dose 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 were 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 shorten 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 assure standards of proton radiotherapy, a system for on-line control of the main characteristics of the proton beam (symmetry, homogeneity and range in water) was designed, constructed and put into operation. The system allows carrying out measurements directly during irradiation of patients.

REFERENCES

1. *Abreu P. et al. (DELPHI collab.)* // Phys. Lett. B. 2003. V. 565. P. 61.
2. *Abreu P. et al. (DELPHI collab.)* CERN Preprint EP 2003-058; Eur. Phys. J. (submitted).
3. *Astier P. et al.* // Phys. Lett. B. 2003. V. 570. P. 19.
4. *Astier P. et al.* // Nucl. Instr. Meth. A. 2003. V. 515. P. 800.
5. *Adeva B. et al.* // Nucl. Instr. Meth. A (in press); hep-ex/00305022;
   Santamarina C. et al. // J. Phys. B: At. Mol. Opt. Phys. 2003. V. 36. P. 4273.
6. *Bauer F. et al.* // Nucl. Instr. Meth. A. 2002. V. 478. P. 153.
7. *Budagov J. et al.* JINR, E1-2003-22. Dubna, 2003. 36 p.
8. *Kulchitsky Y. et al.* // Part. Nucl., Lett. 2003. No. 2[117]. P. 52–70.
9. *Alexa C. et al.* // Eur. Phys. J. C. 2003. V. 28. P. 297.
10. *Kulchitsky Y., Vinogradov V.* // Nucl. Instr. Meth. A. 2003. V. 502, Nos. 2–3. P. 708; P. 775.
11. *Bellettini G. et al.* CDF-6313; CDF-6770. 2003;
    Ashmanskas W. et al. // Nucl. Instr. Meth. A. 2003. V. 501. P. 201;
    Artikov A. et al. Intermediate Angle Muon Detectors for CDF II // Nucl. Instr. Meth. A. (submitted).
12. *Catanesi M. G. et al.* CERN-SPSC/99-35; SPSC/P315; CERN-SPSC-2003-024; SPSC-M-704. 2003.
13. *Bogomilov M. et al.* // Nucl. Instr. Meth. A. 2003. V. 508. P. 152.
14. *Russakovich N. L., Flyagin V. B.* // Part. Nucl., Lett. 2004. V. 1, No. 1(118). P. 50.
15. *Ohsumi H. (NEMO collab.)* // Nucl. Phys. A. 2003. V. 721 P. 529;
    Vasiliev V., Marquet Ch., Ohsumi H. (NEMO collab.) First Results from the NEMO-3 Double Beta Decay Experiment // Proc. of the 1st Yamada Symp. on Neutrinos and Dark Matter in Nuclear Physics, Nara, Japan, June 9–14, 2003 (in press);
    Kochetov O. (NEMO collab.) First Results from the NEMO-3 Experiment // Proc. of the IV Intern. NANP Conf., Dubna, Russia, June 23–28, 2003 (in press).

16. *Brudanin V. B. et al.* // Izv. RAN. Ser. fiz. 2003. V. 67, No. 5. P. 618.
17. *Briançon Ch. et al.* // Nucl. Phys. A. 2000. V. 671. P. 647.
18. *Shitov Yu. et al.* // Nucl. Phys. A. 2002. V. 699. P. 917.
19. *Briançon Ch. et al.* // PSI Experiment R-02-02.
20. *Bystritsky V. M. et al.* // Phys. At. Nucl. 2003. V. 66. P. 75; P. 1731.
21. *Dudkin G. N. et al.* // Phys. Rev. 2003. V. 29. P. 714.
22. *Komarov V. et al.* // Phys. Lett. B. 2003. V. 553. P. 179.
23. *Uzikov Yu.* // J. Phys. G: Nucl. Part. Phys. 2002. V. 28. P. B13;
Haidenbauer J., Uzikov Yu. // Phys. Lett. B. 2003. V. 562. P. 227.
24. *Mamedov T. N. et al.* JINR Preprint E14-2001-101. Dubna, 2001; JETP Lett. 2002. V. 76, No. 7. P. 440–443; Part. Nucl. 2002. V. 33, No. 4. P. 519–536; Physica B. 2003. V. 326, No. 1–4. P. 97–104; P. 15–18;
Ivanter I. G. et al. // JETP Lett. 2002. V. 77, No. 3. P. 147–148.
25. *Frlež E. et al.* JINR Preprint P13-2003-102. Dubna, 2003.
26. *Andreev E. M. et al.* // Nucl. Instr. Meth. A. 2003. V. 489. P. 99.
27. *Vorobyev L. S. et al.* // Phys. At. Nucl. 1998. V. 61, No. 5. P. 771–780.
28. *Akimov Yu. K.* // PTE. 2002. No. 5. P. 55–60; 2003. No. 3. P. 5–19.
29. *Karnaukhov V. A. et al.* // Phys. At. Nucl. 2003. V. 66, No. 7. P. 1282; Phys. Rev. C. 2003. V. 67. P. 011601(R).