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N. A. Russakovich, V. A. Bednyakov

DZHELEPOV LABORATORY OF NUCLEAR PROBLEMS: RESEARCH ACTIVITIES IN 2001 AND PLANS FOR 2002–2004

Report to the 91st Session
of the JINR Scientific Council
January 17–18, 2002

Dubna 2001

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Introduction

The Dzhelepov Laboratory of Nuclear Problems (**DLNP**) covers experimental investigation in modern particle physics, investigation of nuclear structure, study of condensed matter properties; theoretical support of the experimental research; medico-biological investigations; development of new detectors and accelerators as well as new experimental methods and facilities. The DNLP is nowadays the only laboratory at JINR where modern rare-decay experiments and **new physics searches**, like neutrinoless double beta decay, are under way. The thorough study of **neutrino** properties is also performed only in the 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.

In **2001** the DLNP took a decisive part in the organization of three very important scientific meetings, the **NANP-01** conference on non-accelerator new physics, a very famous conference in supersymmetry **SUSY-01** and the **Gomel school-seminar** on actual problems of particle physics.

Traditionally the NANP-01 conference traces a new modern direction in particle physics connected with physics beyond the standard model of electro-weak interactions with a certain emphasis on the non-accelerator searches. The extremely high level of the NANP conferences was confirmed, for example, by the decision of the SNO collaboration to present for the first time their evidence of the solar neutrino oscillations. This was especially remarkable in the light of the very idea of neutrino oscillations which was put forward by Bruno Pontecorvo in Dubna. It was decided to devote the next **NANP-03** conference to the 90th birthday of Bruno Pontecorvo.

The famous **SUSY-01** conference "Supersymmetry and Unification of Fundamental Interactions" was held in Dubna this summer. For the first time the 9th SUSY conference reached Russia where 30 years ago the Supersymmetry was discovered by Ya.Golfand and E.Likhtman. Practically all the key problems of modern particle physics, astrophysics as well as other related problems of mathematical physics have found their reflection at the conference. A very high scientific level of the talks and wide representation of the leading experiments and centers, large percentage of young people from over the world and Russia have confirmed huge scientific importance of the SUSY as a theory which is able to connect tightly high-energy accelerator physics with non-accelerator particle physics together with astroparticle phenomena of extremely high energy.

In August 2001 the **Gomel school-seminar** on actual problems of particle physics was held. The "Golden Sands" holiday center in the Gomel region traditionally hosted seminars on micro-world physics in 1971, 1973, 1977, 1997 and 1999. The initiative to hold all these meetings belongs to the outstanding scientists such as N.Bogolubov, F.Fedorov, V.Kadyshevsky, V.Bely, B.Bokut and their followers A.Sissakian, N.Skatchkov, N.Shumeiko, N.Russakovich, A.Bogush, L.Tomilchik, N.Maksimenko, Yu.Pleskachevsky, S.Shcherbakov and others.

This year the school-seminar was devoted to the 90th birthday of the outstanding Belarussian scientist Academician F.Fedorov and was organized by JINR (mainly DLNP), National Center of Particle and High Energy Physics (Belarussian State University), B.Stepanov Institute of Physics, V.Bely Institute of Mechanics of Metal Polymer Systems (Belarussian Academy of Sciences); F.Scaryna Gomel State University and P.Sukhoy Gomel State Technical University (Ministry of Education).

The main aim of the school-seminar was educating scientific youth, discussing up-to-date fundamental results in modern physics, exchanging information and experience in experimental methodology, making working contacts between scientists from leading international and national scientific centers. The agenda was packed with lectures and reports on physics and collider technologies, experimental and theoretical problems in particle physics. The problems of experimental equipment for new colliders and fundamental high energy interactions were the key ones. For the first time the new modern topic of neutrino, non-accelerator particle physics and astrophysics was included and discussed at the Gomel school. Lectures and reports were delivered by scientists from the institutes-organizers and world-known scientific centers. There were about 45 professors among lecturers of the school-seminar. The total list included about 120 participants.

It is commonly accepted that the Gomel school-seminars held in **Belarus** significantly facilitate the development of scientific contacts between JINR and Belarus. The organizers of the Gomel School-Seminar 2001, scientists and authorities of the Gomel region, the Golden Sands holiday center staff had welcomed the next school-seminar in 2003.

Elementary Particle Physics

The goal of the **NOMAD** experiment (Neutrino Oscillation MAgnetic Detector) is the search for neutrino oscillations in a wide-band neutrino beam from CERN SPS. It aims at detecting ν_τ charged current (CC) interactions in a predominantely ν_μ neutrino beam by observing the production of the τ^- through its various decay modes (so-called "appearance" neutrino oscillation search).

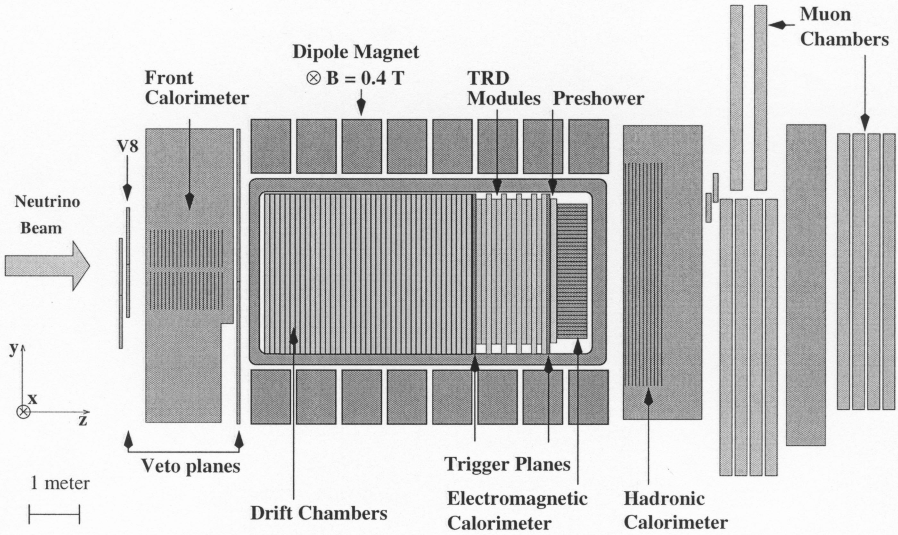

Fig. 1: A sideview of the NOMAD detector.

The detector (Fig. 1) reconstructs the event kinematics using the CERN-UA1 magnet. The target consists of 44 drift chambers with a total mass of 2.7 tons over a fiducial volume of $2.6\times2.6\times4.5$ m^3. It is followed by transition radiation detectors, additional tracking chambers and an electromagnetic calorimeter consisting of 875 lead glass blocks and including a preshower detector. A hadronic calorimeter made of iron and scintillator is located behind the electromagnetic calorimeter outside of the magnetic field volume. Additionally, a forward hadronic calorimeter is located in front of the magnet. A muon detector has two stations of large-area drift-tube chambers on both sides of an iron absorber. The NOMAD has finished data taking.

The analysis of a full [1] NOMAD data sample of 1.3 million ν_μ CC interactions yields no evidence for the oscillation signal in the range of $1 < \Delta m^2 < 1000\ \mathrm{eV}^2/c^4$. The *final* limits (Fig. 2, left) for the $\nu_\mu \to \nu_\tau$ oscillation probability and for the oscillation amplitude ($\sin^2 2\theta_{\nu_\mu\nu_\tau}$) at 90% C.L. for large $\Delta m^2 > 50\ \mathrm{eV}^2/c^4$ are:

$$P_{\nu_\mu\nu_\tau} < 1.63 \times 10^{-4}, \qquad \sin^2 2\theta_{\nu_\mu\nu_\tau} < 3.3 \times 10^{-4}.$$

The NOMAD limit is an order of magnitude better (lower) than the previous best result (FNAL CCFR-1995). The upper limit on the

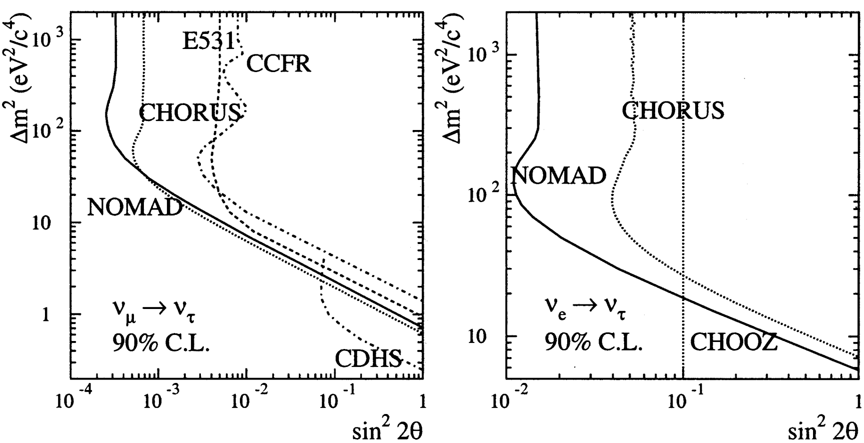

Fig. 2: The Δm^2–$\sin^2 2\theta$ plane for $\nu_\mu \to \nu_\tau$ (left) and $\nu_e \to \nu_\tau$ (right) oscillations. The regions excluded by NOMAD at 90% C.L. are shown (solid lines) together with the limits published by other experiments. The regions located at the right side of the curves are excluded.

probability of the $\nu_e \to \nu_\tau$ oscillation is set to $P_{\nu_e\nu_\tau} < 0.74 \times 10^{-2}$, which corresponds to $\sin^2 2\theta_{\nu_e\nu_\tau} < 1.5 \times 10^{-2}$ at large Δm^2 (Fig. 2, right). The current NOMAD limits for the $\nu_\mu \to \nu_e$ oscillation probability at 90% C.L. for the large Δm^2 and for the oscillation amplitude are

$$P_{\nu_\mu\nu_e} < 0.6 \times 10^{-3}, \qquad \sin^2 2\theta_{\nu_\mu\nu_e} < 1.2 \times 10^{-3}.$$

This result excludes the LSND-allowed region of oscillation parameters with $\Delta m^2 > 10\ \mathrm{eV}^2/c^4$ (Fig. 3).

The NOMAD programme also includes the *non-oscillation physics* investigations [2, 3, 4]. A sample of neutral strange particles has been

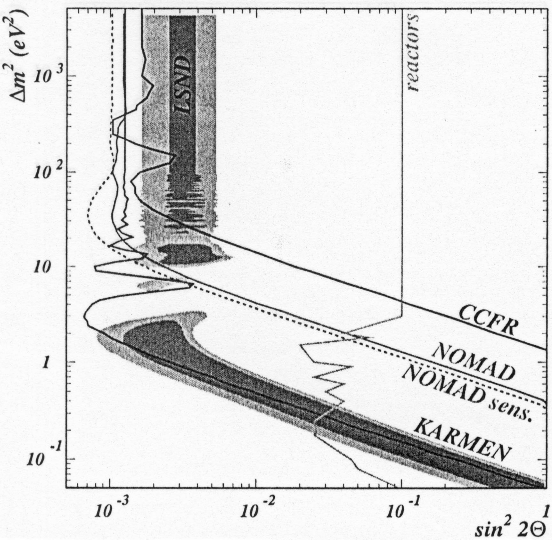

Fig. 3: The Δm^2–$\sin^2 2\theta$ plane for $\nu_\mu \to \nu_e$ oscillations. The regions currently excluded by NOMAD at 90% C.L. are shown together with the limits of the previous experiments. The NOMAD result excludes the LSND-allowed region of oscillation parameters with $\Delta m^2 > 10$ eV$^2/c^4$.

selected in ν_μ CC interactions: 15075 K^0_S, 8087 Λ^0 and 649 $\bar{\Lambda}^0$. The statistics is about an order of magnitude larger than that of previous bubble chamber experiments, while the quality of event reconstruction is comparable. The Λ^0 polarization in ν_μ CC interactions has been measured [3]. These results provide a test of different models describing the nucleon spin composition and the spin transfer mechanisms. The first measurement of the $\bar{\Lambda}^0$ polarization in ν interactions has been performed [4]. The polarization vector is found to be compatible with zero:

$$
\begin{aligned}
P_x &= -0.07 \pm 0.12(\text{stat}) \pm 0.09(\text{syst}), \\
P_y &= 0.09 \pm 0.13(\text{stat}) \pm 0.10(\text{syst}), \\
P_z &= 0.10 \pm 0.13(\text{stat}) \pm 0.07(\text{syst}).
\end{aligned}
$$

Both integral and differential production rates of neutral strange particles (K^0_S, Λ^0, $\bar{\Lambda}^0$) in ν_μ CC interactions have been measured. Decays of resonances and heavy hyperons with identified K^0_S and Λ^0 in the final state have been analyzed (Fig. 4). Clear signals corresponding to $K^{\star\pm}$, $\Sigma^{\star\pm}$, Ξ^- and Σ^0 have been observed [3]. These results are compared to the predictions of the LUND model. A stricking difference (a factor of 2 or 3) has been observed between the NOMAD data

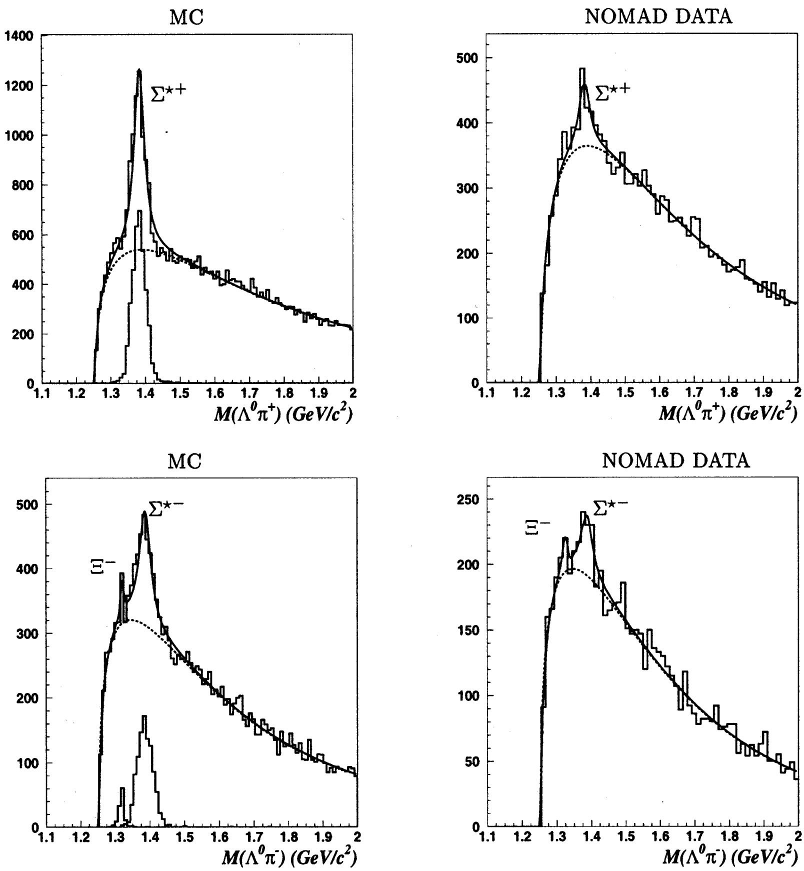

Fig. 4: $\Lambda\pi^+$ (top) and $\Lambda\pi^-$ (bottom) invariant mass distributions for both MC (left) and the NOMAD data (right). Clear peaks corresponding to $\Sigma^{*\pm}$ and Ξ^- are visible. The solid lines are the results of the fit, while the dotted lines describe the background term. In the MC plots the additional histograms refer to the reconstructed true heavy strange particles.

and the LUND predictions for relative yields of resonances and heavy hyperons.

In **2002** the collaboration expects to obtain the first results on the measurements of the Λ^0 and $\bar{\Lambda}^0$ polarization in ν_μ neutral current (NC) interactions; to measure for the first time the production rates of neutral strange particle and the yields of heavy strange hyperons and resonances in ν_μ NC interactions, as well as to obtain (and publish) the final results on the search for $\nu_\mu \to \nu_e$ oscillations.

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 LEP1 ($\sqrt{s} \simeq m_Z$) with the DELPHI detector [5]. The study of the process $e^+e^- \to e^+e^-\mu^+\mu^-$ provides a good way to test QED up to the fourth order of the QED coupling constant α. The QED predictions have been tested over the Q^2 range from several GeV$^2/c^4$ to several hundred GeV$^2/c^4$ by comparing experimental distributions with distributions resulting from Monte Carlo simulations. Selected events were used to extract the leptonic photon structure function F_2^γ. Azimuthal correlations were used to obtain information on additional structure functions, F_A^γ and F_B^γ, which originate from interference terms of the scattering amplitudes and enter the cross section in the form

$$\frac{d^3\sigma(e\gamma \to e\mu^+\mu^-)}{dx dy d\chi/2\pi} \simeq \frac{2\pi\alpha^2}{Q^2} \cdot \frac{1+(1-y)^2}{xy} F_2^\gamma \times \times \left(1 - (F_A^\gamma/F_2^\gamma)\cos\chi + \frac{1}{2}(F_B^\gamma/F_2^\gamma)\cos 2\chi\right),$$

where χ is an azimuthal angle. The measured ratios F_A^γ/F_2^γ and F_B^γ/F_2^γ are significantly different from zero and consistent with QED predictions (Fig. 5).

With the data collected in the DELPHI detector, the measurements of the 1, 3 and 5-prong topological branching ratios for tau-lepton decay were performed [7] and the following values were obtained:

$$B_1 = (85.316 \pm 0.093_{\text{stat}} \pm 0.049_{\text{sys}})\%,$$
$$B_3 = (14.569 \pm 0.093_{\text{stat}} \pm 0.048_{\text{sys}})\%,$$
$$B_5 = (0.115 \pm 0.013_{\text{stat}} \pm 0.006_{\text{sys}})\%.$$

The B_1 and B_3 results are more than twice as precise as the existing world averages of (84.59±0.33)% and (14.63±0.25)% respectively. The 5-prong branching ratio is in good agreement with the world average of $(0.107 \pm 0.009)\%$ and the best PDG fit of $(0.099 \pm 0.007)\%$ which include contributions from OPAL, CLEO and ALEPH measurements.

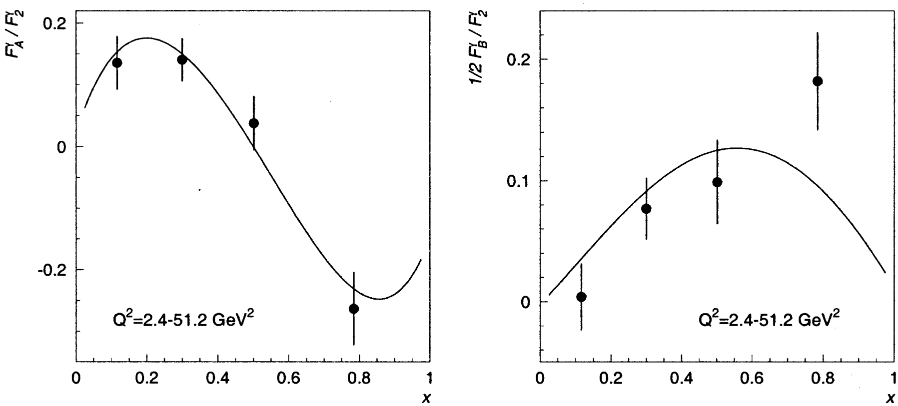

Fig. 5: Ratios of leptonic structure functions F_A^γ/F_2^γ (left) and $\frac{1}{2}F_B^\gamma/F_2^\gamma$ (right) averaged in the Q^2 range from 2.4 to 51.2 GeV^2 as functions of x. The lines show the QED predictions from [6].

In 2001 the Dubna group of DELPHI within the common LEP collaboration community presented in [8] a combination of preliminary electroweak measurements and constraints on the Standard Model.

The paper [8] contains averages from Z resonance results for hadronic and leptonic cross sections, leptonic forward-backward asymmetries, τ polarisation asymmetries, $\bar{b}b$ and $\bar{c}c$ partial widths and forward-backward asymmetries and $\bar{q}q$ charge asymmetry.

Above the Z resonance, averages are derived for difermion cross sections and asymmetries, W pair, Z pair and single W production cross section, electroweak gauge boson couplings and W mass and decay branching ratios. The results are compared with precise electroweak measurements from other experiments. The parameters of the Standard Model are evaluated, first using the combined LEP electroweak measurements, and then using the full set of electroweak results (see some examples in Fig. 6–9).

In **2002** (the last year of the topic) new results of improved quality are expected on the basis of the LEPII data analysis aimed at the determination of the Standard Model parameters. The QCD verification at LEPI and LEPII energies as well as electron-positron collision data analysis at LEPII energies will also be performed. Evaluations

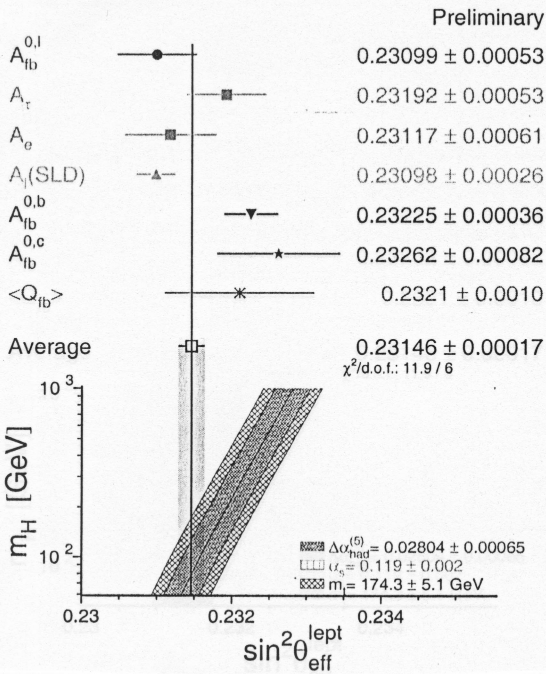

Fig. 6: Determinations of $\sin^2\theta_{\rm eff}^{\rm lept}$ from several asymmetries. The prediction of the Standard Model as a function of $m_{\rm H}$ is also shown. The width of the Standard Model band is due to the uncertainties in $\Delta\alpha_{\rm had}^{(5)}(m_{\rm Z}^2)$, $\alpha_{\rm s}(m_{\rm Z}^2)$ and $m_{\rm t}$. The total width of the band is the linear sum of these effects.

of LEP observables and their comparison with the data in the new energy region aimed at refining the parameters of the Standard Model will be carried out. Search for new physics phenomena also is planned.

The **DIRAC** experiment at CERN aims to measure the lifetime of $\pi^+\pi^-$ atoms ($A_{2\pi}$) in the ground state with 10% precision and to subject the understanding of chiral symmetry breaking of QCD to a crucial test.

In **2001** the dedicated processor “DC track-analyser” was produced and implemented in the trigger system of the DIRAC setup (this brings twice as large the rejection factor); a new 4-layer forward scintillation hodoscope for a energy lost measurement have been produced and implemented in the setup; a second stage of the neural network trigger have been also implemented [9]. For further development of the setup a microdrift chamber has been designed, produced and tested with the beam. In 2001 the total number of events taken with the Nickel target is about 1100 million (Fig. 10) and with the Titanium target

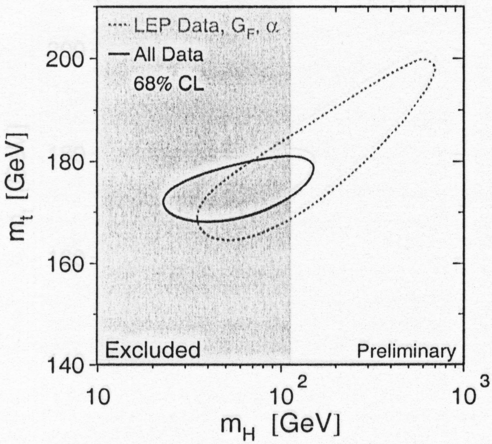

Fig. 7: The 68% confidence level contours in m_t and m_H for the fits to the LEP data only (dashed curve) and to all data including the CDF/DØ m_t measurement (solid curve). The vertical band shows the 95% CL exclusion limit on m_H from the direct search.

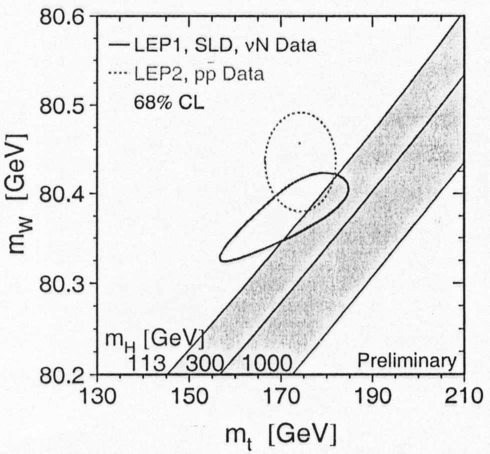

Fig. 8: The comparison of the indirect measurements of m_W and m_t (solid contour) and the direct measurements (dashed contour). In both cases the 68% CL contours are plotted. Also shown is the Standard Model relationship for the masses as a function of the Higgs mass.

about 550 million. About 5500 $\pi^+\pi^-$ atoms have been identified with the data obtained with the Nickel, Titanium and Platinum targets.

In **2002–2004** the DIRAC collaboration plans to obtain the final precision of 10% for the $\pi^+\pi^-$ atom lifetime. The processing of the collected data is planned for the lifetime measurement on the targets of Ni and Ti with a statistical accuracy of 14% in 2002 and with the final accuracy of 10% in 2003–2004.

In 2002–2003 the modification of the setup for simultaneous observation of $\pi^+\pi^-$ and πK atoms will be fulfilled in the case of approval of the addendum to the DIRAC proposal (CERN/SPSC 2000-032

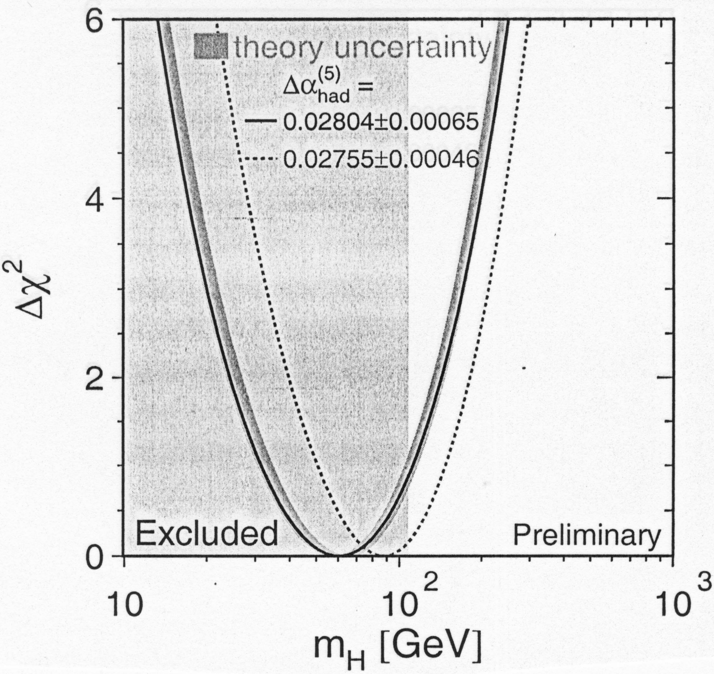

Fig. 9: $\Delta\chi^2 = \chi^2 - \chi^2_{min}$ *vs* $m_{\rm H}$ curve. The line is the result of the fit using all data; the band represents an estimate of the theoretical error due to missing higher order corrections. The vertical band shows the 95% CL exclusion limit on $m_{\rm H}$ from the direct search. The dashed curve is the result obtained by using the evaluation of $\Delta\alpha^{(5)}_{\rm had}(m^2_{\rm Z})$. The 95% confidence level upper limit on $m_{\rm H}$ (taking the band into account) is 165 GeV. The fit results in $m_{\rm H} = 88^{+60}_{-37}$ GeV and an upper limit on $m_{\rm H}$ of approximately 206 GeV.

SPSC/P282). Afterwards (in 2003–2004) the data taking for observation of πK atoms and their lifetime measurement will be performed.

The **ATLAS** detector is designed to obtain new experimental results on the most acute problems of elementary particle physics (discovery and investigation of Higgs bosons, study of production dynamics and decay modes of top quarks, B physics, discovery of SUSY particles) at the Large Hadron Collider (LHC). Many of the interesting physics questions at the LHC require high luminosity, and so the primary goal is to operate at a high luminosity (10^{34} cm^{-2} s^{-1}) with a detector that provides as many signatures as possible using

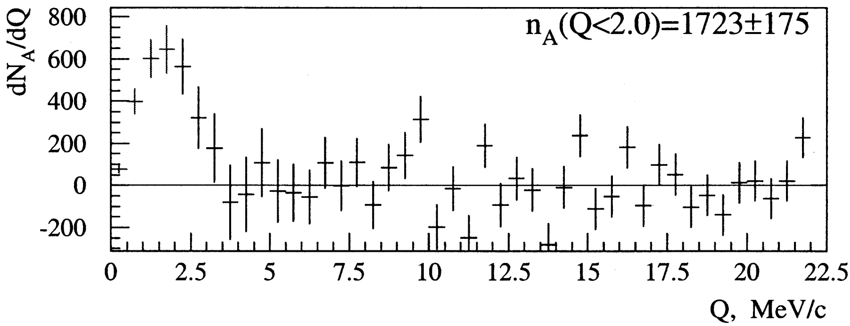

Fig. 10: Difference between the detected number of $\pi^+\pi^-$ pairs and the number of the pairs produced in the free state versus the pair relative momentum Q. The excess of events in the range of small Q is due to the pairs from the $\pi^+\pi^-$-atom breakup in the target. The number of the detected "atomic" pairs in the interval of $Q < 2$ MeV/c is 1723 ± 175. Only the events detected in 2000 with the Ni target are shown.

electron, gamma, muon, jet, and missing transverse energy measurements, as well as b-quark tagging. The ATLAS apparatus consists of an inner detector (tracker), an electromagnetic calorimeter (ECAL), a hadron calorimeter (HCAL) and a muon spectrometer. The hadronic calorimetry is provided by a scintillator tile calorimeter, consisting of one large barrel and two extended barrel cylinders on each side. The main purpose of the barrel hadron tile calorimeter is to measure electron, gamma, jet and missing energies (E_e, E_γ, E_{jet}, E_{mis}). The calorimetry is surrounded by the muon spectrometer. The responsibility of DLNP within the ATLAS collaboration includes production of muon chambers; production and assembly of the absorber of the Barrel part of the tile calorimeter; calculations of magnetic fields and forces; software development, etc.

In **2001** the ATLAS Muon Group produced drift tubes for BOS chambers (11800 units) and for BMS chambers (2500 units). All detectors have been tested for signal wire position deviation from the tube center (Fig. 11). Cosmic rays tests with working gas mixture were carried out. The amount of rejected tubes does not exceed 1%.

The setup for Monitored Drift Tube (MDT) Chamber assembly is mastered (Fig. 12). The system for comb-line adjustment on a

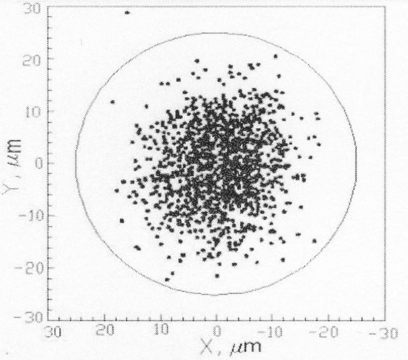

Fig. 11: Results of Roentgen test of aluminium tubes are given (scatter plot) in the form of a measured deviation of the location of a signal wire from the centre of the tube. The circle with a radius of 24 μm presents the limit for the deviations allowed by the required quality.

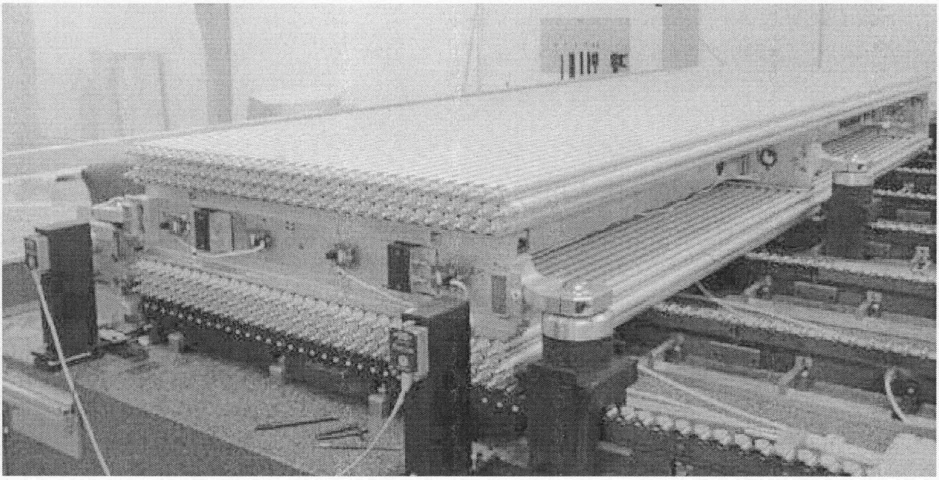

Fig. 12: Drift chamber BMS-5 is settled on the granite table after complete gluing of 6 layers of drift tubes (3 layers are under the supporting farm and 3 layers are above the farm). The chamber is held by side blocks by means of spherical piers. In the foreground one can see the elements of the optical system for outer (two towers) and inner (4 blocks of lightdiods) adjustment.

granite table and semiautomatic machine for glue drawing during drift tube gluing were tested and entered into full operation. Two BMS-5 chambers are assembled and sent to CERN. Machining of aluminium profiles for chamber spacers is organized at MZOR plant (**Minsk**) [10].

In **2002** the Muon group plans to assembly and test 10000 of drift tubes for BOS chambers and 7000 tubes for BMS chambers; to develop aluminium profiles for spacers at MZOR (**Minsk**) for BOS, BOL and BMS chambers; to develop and upgrade the automatic system for working gas mix preparation and drift tube filling; to develop and upgrade the automated system for the gas-leak control of drift tubes; to assemble eigth MDT chambers; to develop and constract the test bench for MDT chamber testing with the cosmic rays.

The modules and submodules production for the ATLAS **Hadron Tile Calorimeter** was organized at the DLNP of JINR. In **2001** full production of submodules was finished. By the end of 2001 a total of 55 modules will be constructed and delivered to CERN. The modules are the precision (within 3 mm) constructions 6 m long and 20 t weight. The remining 10 modules will be produced and delivered to CERN by the end of June **2002**.

The *performance of the ATLAS Calorimetry* is being investigated in Dubna. Hadron energy reconstruction for the ATLAS barrel prototype combined calorimeter, consisting of the lead-liquid argon electromagnetic part and the iron-scintillator hadronic part has been accomplished by the new non-parametrical method. The non-parametrical method utilizes only the known e/h ratios and the electron calibration constants and does not require determination of any parameters by a minimization technique. The extension of the longitudinal hadronic shower profile parametrization which takes into account non-compensations of calorimeters and the algorithm of the longitudinal hadronic shower profile curve making for a combined calorimeter are suggested (Fig. 13) [11]. The proposed algorithm can be used for data analysis from modern combined calorimeters like those in the ATLAS detector at the LHC.

The energy loss spectrum of 180-GeV muons has been measured with the 5.6-m-long finely segmented Module 0 of the ATLAS hadron calorimeter in the H8 beam of the CERN SPS [12]. The differential probability $\mathrm{d}P/\mathrm{d}v$ per radiation length of a fractional energy loss has been measured in the range $0.025 \leq \Delta E_{\mu}/E_{\mu} \leq 0.97$. It is compared with the theoretical predictions for energy losses due to bremsstrahlung, production of electron-positron pairs, and energetic

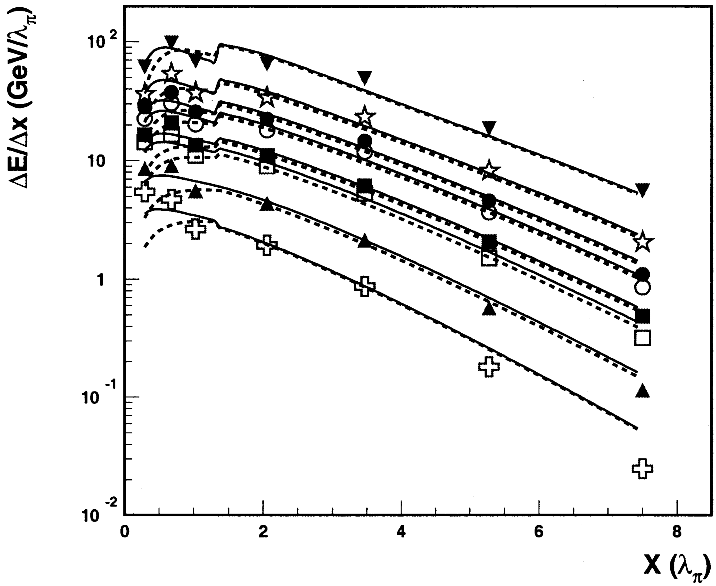

Fig. 13: The experimental differential longitudinal energy depositions at 10 GeV (crosses), 20 GeV (black top triangles), 40 GeV (squares), 50 GeV (black squares), 80 GeV (circles), 100 GeV (black circles), 150 GeV (stars), 300 GeV (black bottom triangles) as a function of the longitudinal coordinate x in units of λ_π for the combined calorimeter and the results of the description by Bock et al. (dashed lines) and modified (solid lines) parametrizations.

knock-on electrons. The iron elastic form factor correction to muon bremsstrahlung in the region of no screening of the nucleus by atomic electrons has been measured for the first time, and it is compared with different theoretical predictions.

Photomultipliers (PMTs) are widely used as light detection components of different types of scintillation and Cherenkov detectors. Analysis of the PMT pulse height spectra from faint light sources (usually called the single photoelectron spectra) is of great importance because it reveals many features and can be used to find relevant parameters of PMTs and detectors. Especially important is measurement of the energy deposited in detectors in terms of photoelectrons created on the PMT photocathode (absolute calibration). The deconvolution method for analysis of single photoelectron spectra of the new types of ultra-compact PMTs R 5600 and R 5900 with the metal channel dynode system was presented [13]. The detailed analysis of single photoelectron spectra shows that the method appropriately describes the process of charge multiplication in these PMTs. It enables one to find experimentally the PMT access factor needed for calculation of the energy-to-signal conversion factor (number of photoelectrons per GeV) for the PMT-based calorimeters. It can be used as an absolute calibration and monitoring tool for studying stability in time of metal-channel PMTs.

On March 1, 2001 the commissioning of the **D0** equipment started with the beginning of Tevatron operation. The JINR responsibility in the collaboration is the muon tracker of the forward-angle muon system (FAMUS). Dubna scientists took an active part in development of the software for this subsytem. The subsystem enters the normal operation. The muon tracking efficiency is 99.5%. The first muon seen by D0 was the one registered by this forward muon system. This hardware stage of cooperation was very successful. The JINR group (Fig. 14) organized the efforts of 11 industrial companies from 5 countries (Armenia, Belarus, Canada, Russia and USA) to produce detectors and electronics in time for Tevatron Run 2 start-up.

The Dubna group plans to participate in two fields of the physical programme — QCD studies and b-baryon physics.

The main goals of the investigations with D0 are top-quark physics and search for the Higgs boson and supersymmetric particles. The study of the hadron decays with two and more hadron jets in the final state is very promising. Therefore the precise hadron jet energy calibration (absolute jet energy scale determination) becomes extremely important. At present time the main contribution in the top-quark mass error comes from an uncertainty in the jet energy scale. The JINR group developed new selection criteria for events with associated production of hadronic jets, direct photons and Z^0 bosons that essentially improves the precision of setting the absolute jet energy scale for the conditions of the D0 experiment. The proposed criteria are based on the results Monte Carlo simulation of the above-mentioned

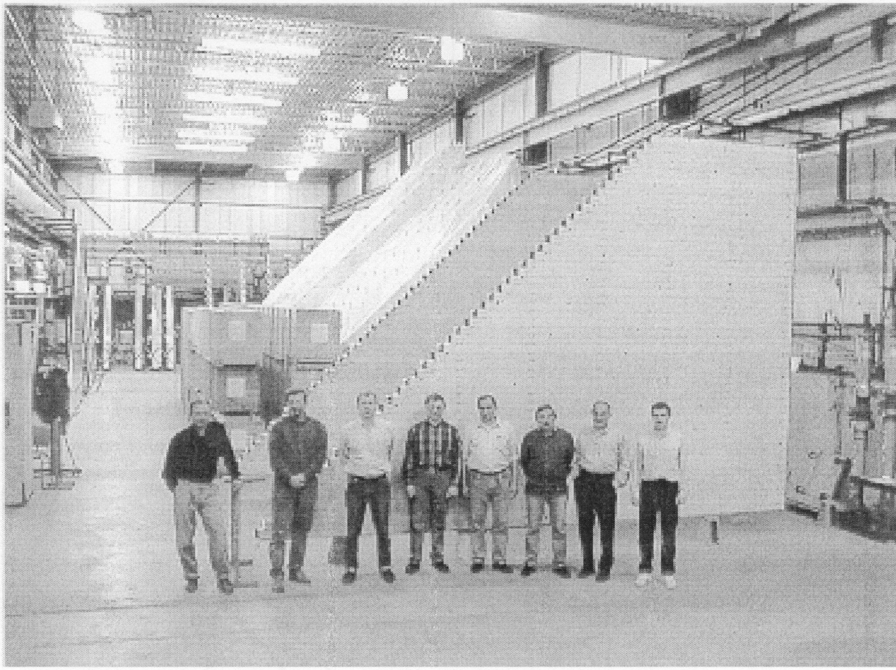

Fig. 14: JINR group in Fermilab during assembling of the MDT to the D0 setup.

processes in the D0 detector and their analysis. In parallel to the solution of the jet energy calibration problem, a possibility of experimentally studying of the gluon distribution function is proved. The proposal to study at D0 the gluon distribution in the earlier unexplored kinematic region was accepted by the D0 collaboration. Another field of particular interest will b the b-baryon physics, namely b-baryon spectroscopy. Until now, this area has been explored rather poorly. Only Λ_b mass and lifetime was measured. Ξ_b baryons were observed only indirectly. Meanwhile, information about Λ_b lifetime presented a puzzle: its value appears to be far smaller than that of B-mesons, although the heavy quark theory predicts them to be approximately equal. Therefore, it is important to obtain precise data about the hierarchy of b-baryon lifetimes.

The Dubna group plans to investigate non-leptonic decays of beauty baryons to fully reconstructable final states (Fig. 15): $\Lambda_b \to J/\psi + \Lambda$ and $\Xi_b \to J/\psi + \Xi$ with $J/\psi \to \mu + \mu$, $e + e$ (and the same

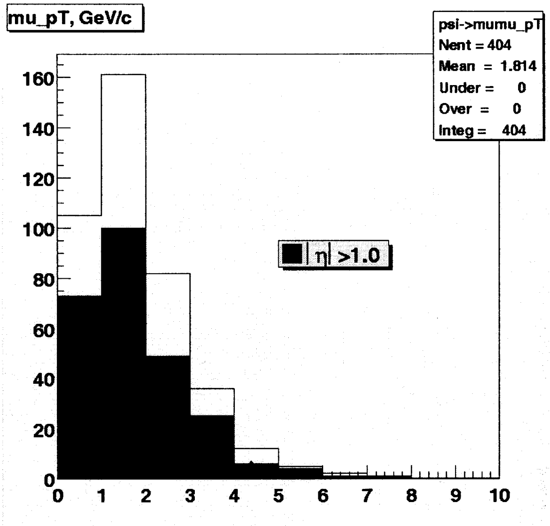

Fig. 15: Transverse momentum spectrum of muons from cascade decay of Ξ_b^- baryons produced in $\bar{p}p$ interactions at 2.0 TeV (Monte Carlo): $\Xi_b^- \to \Xi^- + J/\psi \to \mu^+\mu^-$. The colored area covers muons with |pseudorapidity| > 1.0 GeV/c (acceptance region of JINR monitored drift tubes).

for antiparticles). It is expected that with $2\,\mathrm{fb}^{-1}$ of data it will be possible to fully reconstruct 15000 Λ_b baryons and several hundreds Ξ_b baryons in the strange baryon $+J/\psi \to$ leptons decay mode, where a remarkable number of muons enter the forward-backward region and are registered by MDT chambers.

The new JINR–FNAL Memorandum of Understanding on the D0 project was signed for the *next 5 years.* The main JINR group committments include running of the forward muon tracking system and participation in data taking and analysis.

The **CDF** upgrade program was successfully completed by the international collaboration at the beginning of 2001. The JINR group in close collaboration with the INFN (Pisa, Italy) team considerably contributed to the on-line Silicon Vertex Tracker (SVT) and to the Scintillating counters of the Muon Detector.

The **SVT** is unique new trigger processor for the two-dimensional reconstruction of charged particle trajectories at Level 2 of the CDF trigger. The SVT links the digitized pulse heights found within the Silicon Vertex detector (SVX) to the tracks reconstructed in the Central Outer Tracker (COT) by the Level 1 Fast Track finder (XFT). The SVT will be used to tag events containing secondary vertices from the b-decay. In most cases the simple requirement of *one or two tracks with an impact parameter greater than a given threshold* will provide an adequate rejection factor ($\sim 10^3$).

One of the main SVT parts is the Associative Memory (AM) bank, which is essentially a "very fast library of track images". Library tracks closest to the real one are taken as a "best choice" and as a result in 10-14 μs one knows if the secondary vertex exists. JINR contributed greatly to the solution of a vitally important problem, namely to the preparation of the AM bank by simulating more than 32000 tracks. The achievement is that one is able to find a secondary vertex within 14 μs at the Level 2 trigger.

With JINR group's participation software tools to generate fitting constants (to be used for finding track parameters) and to generate the optimal pattern set (to be loaded into the Associative Memory) were developed. Design, construction and investigation of the Associative Memory board prototype were performed. The test program for checking and debugging the Associative Memory boards was developed. Real-time track reconstruction using information from the Silicon Vertex Detector was done.

Analysis of the data banks from the very first March–April runs showed the ability of the SVT to perform fast track reconstruction even without information from COT. The reconstructed impact parameter distribution and the impact parameter to ϕ correlation are shown in Fig. 16.

The CDF-II **muon system** (wire chambers and scintillating counters) is of key importance for broad physics programs ($t\bar{t}$ events, search for rare B-decays, asymmetry in W-decays and others).

In 2001 JINR constructed, delivered to FNAL and installed on the CDF more than 600 scintillating counters 1.6–3.2 m long. The major technological improvement in these new counters was the use of a wavelength-shifting (WLS) fiber ribbon to collect light locally and thus to reduce the average photon path in the scintillating material. During the 2001 data taking runs at the CDF JINR-made scintillating counters were successfully used for the muon triggering.

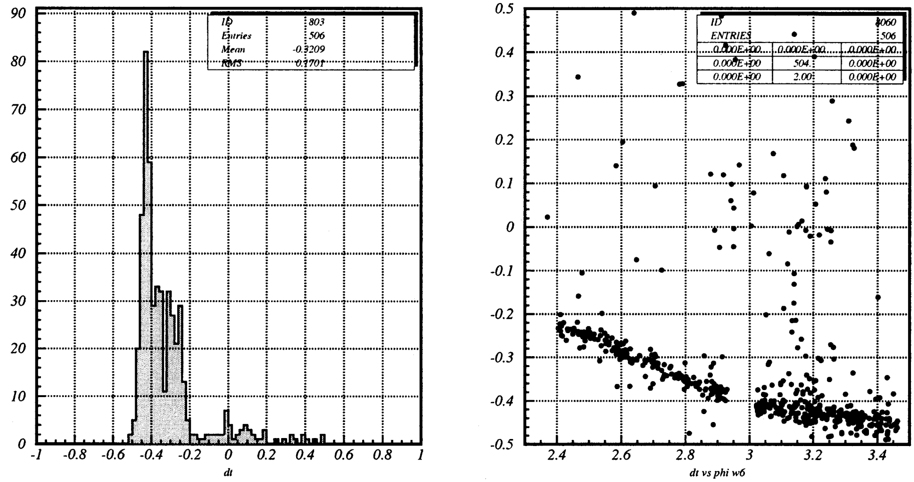

Fig. 16: Reconstructed impact parameter distribution (left) and correlation between the impact parameter and the angle ϕ (right) for tracks with $\chi^2 < 30$ cut.

About 3.6 pb^{-1} of data were collected by the end of September 2001 before the shutdown. Preliminary analysis demonstrates the high quality of the collected data (Fig. 17).

The main goal of the **COMPASS** experiment (NA58, CERN) is the investigation of hadron structure and hadron spectroscopy, which are both manifestations of non-perturbative QCD. The COMPASS spectrometer consists of a high-rate forward spectrometer with two independent magnetic spectrometer stages, each equipped with tracking, particle identification, calorimetry and muon detection.

In the COMPASS project, the Dubna–Torino collaboration is responsible for construction of a system of *multiwire proportional chambers* (MWPC). In **2001** a total of 13 MWPCs (active size 1780×1200 mm^2 and 1780×800 mm^2) were installed in the COMPASS setup together with more than 18000 channels of electronics. During the first run of COMPASS (about 4 months in 2001) this equipment successfully operated at a beam intensity of 2×10^8 particles per spill.

The responsibility of DLNP is construction of the muon filter of the first COMPASS spectrometer (μ-wall 1) — 16 chamber planes consisting of 1200 Proportional Tubes equipped with front-end electronics. In

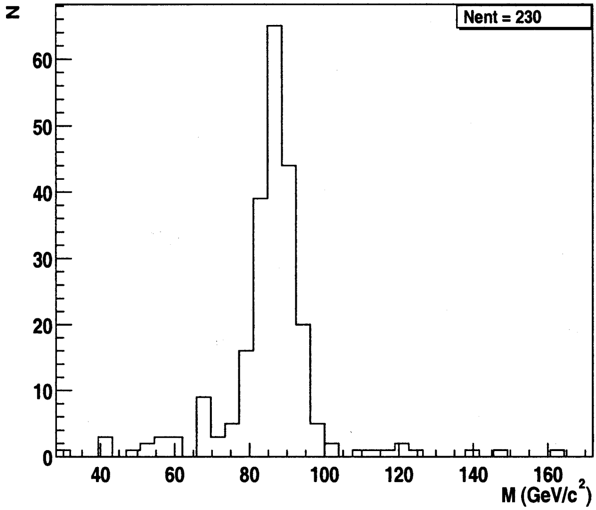

Fig. 17: Mass distribution of the selected $Z \to e^+e^-$ candidates (very preliminary)

2001 the **Muon Wall-1** (MW1) group has fulfilled production of the rest of hardware components of the system (detector support frames, analog signal cables, etc) and has delivered this equipment to CERN. Mechanical assembly of the MW1 system (1056 detectors onto 32 support frames, all frames groupped in two big muon stations, etc.) at CERN on the M2 beam line was completed. The group developed on-line and off-line monitoring programs and participated in data taking and MW1 data analysis. The group had an opportunity to measure the main characteristics of the MW1 system and confirmed their agreement with the results of last's year MW1 prototype exposure. The most important result of running with beam is confirmation of the design parameters of the VME prototype cards. Their mass production will start in Italy in 2002.

In **2002** the main MW1 tasks are the following: completion of assembly of the system, its commissioning with the beam and VME readout, participation in COMPASS data taking runs and the data analysis.

Investigations of nucleon-nucleon interactions and in particular their tensor component allow one to reveal the nature of the triton binding energy. To this end, new measurements of the spin-dependent total **cross section differences** ($\Delta\sigma_T$ and $\Delta\sigma_L$) in neutron-proton scattering at 16 MeV were proposed by the JINR–Prague collaboration at the Institute of Particle and Nuclear Physics, Charles University (Prague). For this experiment, being a continuation of previous measurements

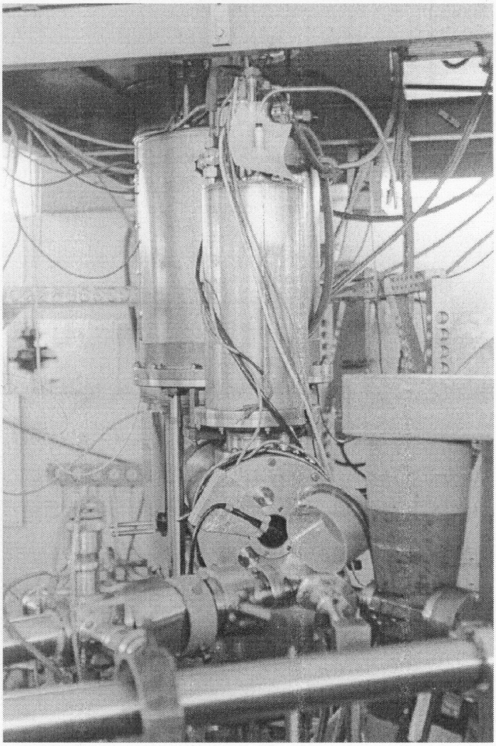

Fig. 18: The polarized target after modification at the Institute of Particle and Nuclear Physics, Charles University (Prague).

of the spin variables, the polarized target (Fig. 18) was modernized, successfully tested and a new polarization measurement system for deuterium and lithium nuclei was created. At the same time, this polarized target is also supposed to be used (as a test setup) for the study of irradiated samples during the realization of the project "Development of the Polarized Target with ^{6}LiD and its Use for Physics Experiments (PoLiD)". In 2001 development of containers for liquid-scintillator and monitor counters was completed and their production was organized at the workshop of the Institute of Particle and Nuclear Physics, Charles University, in Prague. The prototype of the pulse shape discriminator (PSD) was fabricated at the Institute of

Nuclear Problems (**Minsk** State University) and tested at the Van de Graaff laboratory of Charles University. The PSD prototype is capable separating pulses induced by gammas and neutrons in the neutron detectors. The system of fastening and adjustment of detectors has been developed with due concern for conditions of high density of units in the setup.

In **2002** upgrading of the polarized target apparatus (at the Van de Graaff accelerator of Charles University. Prague) for experiments with new polarized materials will be carried out and new experiments with a deuterium polarized target will start.

Design of the cryostat for irradiation of ^{6}LiD samples as well as manufacturing of the cupboard with inert substance are also planned. The collaboration plans to begin irradiation of ^{6}LiD samples with the microtron of the Polytechnic University of Prague.

It is worth *stressing* that the polarization research carried out by the JINR scientists in Prague has been the only investigation at a facility (accelerator) of a JINR member state until recently.

In the CERN experiment **HARP** one plans to measure comprehensively secondary hadrons by beams of protons and pions with momentum 2–15 GeV/c. The main motivation is twofold. For an optimal design of the intense neutrino source based on muon decay in a muon storage ring (neutrino factory) one needs to know pion yields. The yields are also needed to improve the calculation of the atmospheric neutrino flux which is required for a correct interpretation of the evidence for atmospheric neutrino oscillations. An additional motivation includes measurement of the yield of low-momentum backward-going pions and a better prediction of the fluxes in conventional neutrino beams like the neutrino beam from the KEK 12 GeV/c Proton Synchrotron, which is important for the interpretation of the results of the K2K experiment.

One of the elements of the HARP setup (Fig 19) is a set of large drift chambers from the NOMAD experiment used for tracking and momentum measurements. The responsibility of the JINR group in the HARP experiment is refurbishing, installation, commissioning and

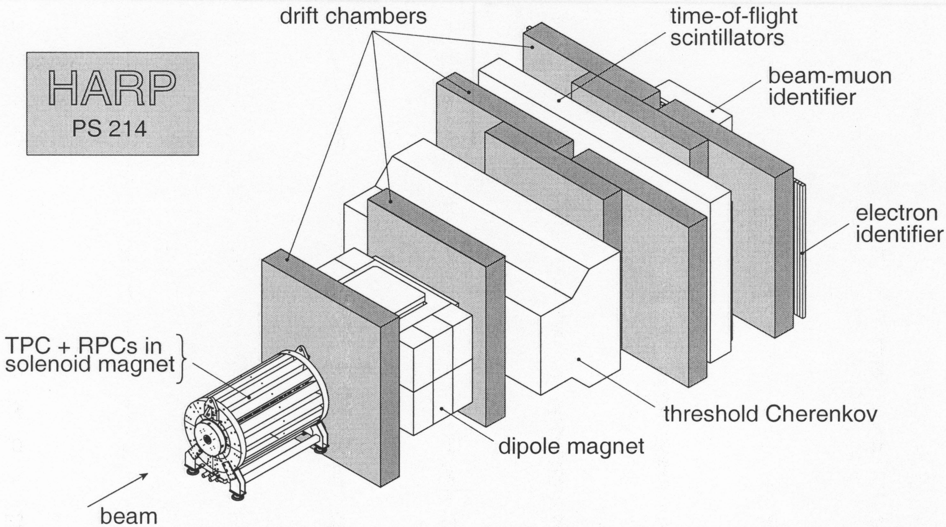

Fig. 19: Layout of the HARP experiment.

operation of the NOMAD drift chambers (NDC); assembling, testing and putting into operation the electromagnetic calorimeter, the muon identifier, the cosmic wall and the beam TOF system; development of the DAQ, monitoring, reconstruction and simulation software.

In **2001** all 23 NOMAD drift chambers required for the HARP experiment were modified, tested and were ready for operation. New gas mixture was chosen due to new safety rules at CERN. A new DAQ system for the NDC readout was developed in the framework of the general HARP data acquisition software. The electromagnetic calorimeter, the muon identifier, the cosmic wall and the beam TOF system were assembled, tested and put into operation. GEANT-4 simulation of the beam-line has been done.

In 2002 the JINR group of the collaboraiton plans to participate in the data taking and data analysis. The group will be responsible for the operation of the NDC during 2002. The group will continue the development of the on-line monitoring program for the detector subsystems NDC, ECAL, RPC and off-line software development for the track reconstruction in the NDC as well as software development for the MC simulation of the beam-line and setup responses. The group will provide efficient operation of the TPC and ECAL.

The high-twist contribution to the neutrino-nucleon structure function $xF_3^{(\nu+\bar{\nu})N}$ was estimated from the analysis of the data collected by the IHEP–JINR **Neutrino Detector** in the runs with the focused neutrino beams at the IHEP 70 GeV proton synchrotron. The analysis was performed within the infrared renormalon (IRR) model of high twists in order to extract the normalization parameter of the model. From the Next-to-leading QCD fit to the data obtained the value of the IRR model normalization parameter $\Lambda_3^2 = 0.69 \pm 0.37$ (exp) $\pm$ 0.16 (theor) GeV^2 was extracted. From a similar fit to the CCFR data the value $\Lambda_3^2 = 0.36 \pm 0.22$ (exp) $\pm$ 0.12 (theor) GeV^2 was obtained. The average over both results is $\Lambda_3^2 = 0.44 \pm 0.19$ (exp) GeV^2 [14]. The above-mentioned "Neutrino Detector" experiment was completed at JINR in 2001.

In 2001 the **HYPERON** experiment aimed at determining the form factors and constants of the Kaon decays at the U-70 accelerator of IHEP (Protvino) was completed under JINR topic 02–2–0982–92/2001. In the framework of the HYPERON experiment the measurements of the $K^{-}\pi^o e^+\nu_e$ decay (K_{e3}) form factors were performed and results of very good quality were obtained. The most accurate estimates of the scalar and tensor contributions to the decay matrix element were also achieved. For the first time an estimate of the upper limit of the $K_s^0 \rightarrow e^+e^-$ decay suppressed in the standard model was obtained in the reaction of K^+ meson transformation into K^o at Be target. The measurements of the Dalitz plot slope parameters for the $K^+ \rightarrow \pi^+\pi^0\pi^0$ decay were performed and for the first time the quadratic dependence of the matrix element on kinematic variables was demonstrated.

Under the project the minidrift chambers as well as "electrodeless" drift chambers were developed, created and investigated; the time-projection chamber was created and Gas Cherenkov counters were developed. A new method for production of light mirrors on the basis of foam plastic was invented.

Under the project HYPERON 20 PhD and 3 Doctor theses were defended by scientists from JINR member states [15].

A new topic **"Study of rare processes"** aims at testing the Standard Model of particle physics via measurement of the branching ratio of the decay $K_{\mathrm{L}}^{0} \rightarrow \pi^{0}\nu\bar{\nu}$ which concerns direct CP-parity violation, in experiment **E391a** at KEK during 2002–2006.

The decay $K_{L}^{0} \rightarrow \pi^{0}\nu\bar{\nu}$ is a direct CP violation process. Since the theoretical ambiguity due to the QCD correction is very small, measurement of the $K_{L}^{0} \rightarrow \pi^{0}\nu\bar{\nu}$ decay branching ratio is uniquely valuable in a search for new physics through the unitarity triangle and is crucial for a profound understanding of the CP violation phenomena. A series of experiments is planned at KEK to measure the branching ratio of the $K_{L}^{0} \rightarrow \pi^{0}\nu\bar{\nu}$ decay; one is a kind of pilot experiment using the present 12 GeV Proton Synchrotron(PS) and another is a high-sensitivity experiment using the JHF 50 GeV PS.

The nearest plans of the JINR team in the E391a collaboraiton include development of GEANT4-based simulation software and designing of a mechanical structure of experimental setup E391a as well as design and manufacture of the veto detector (so-called CC3 detector) of the setup.

Low and Intermediate Energy Physics

Precise measurement of the probability of the pion β-decay allows a rigorous test of charged quark-lepton current universality, unitarity of the Cabbibo-Kobayashi-Maskawa mixing matrix and search for a possible manifestation of "new physics". The goal of the **PIBETA** experiment is to improve the accuracy from 4% to 0.5% at the first stage. Data taking for precise measurement of the pion beta-decay rate was continued in 2001 and statistics obtained allows the decay rate to be determined with an accuracy of about 0.5%.

The work on precise measurement of radiative pion decay ($\pi \rightarrow e\nu\gamma$) was started. There are indications that a tensor interaction (forbidden in the standard model) could contribute to this decay. A new trigger was suggested which allows the $\pi \to e\nu\gamma$ events to be collected simultaneously with the data taking for the study of the pion beta-decay. This increases the sensitivity of the experiment to possible tensor interaction by a factor of 10. Data taking for radiative pion decay is under way. A full set of new anode wire electronics for the PIBETA proportional chambers (576 channels) have been manufactured in Dubna and installed into the PIBETA setup. The new electronics demonstrated stable and efficient work during more than 4 months of non-stop data taking on a high-intensity beam. An important feature of the new electronics is that both analogue (preamplifiers) and digital (data readout) parts are combined into a single module. This allows one to exclude numerous connecting cables which were necessary in all previous experiments.

In **2002–2004** the PIBETA collaboration will perform collection, filtering and analysis of experimental data for the pion beta-decay. The upgrade of different parts of the setup is also planned. The study of the radiative pion decay ($\pi \to e\nu\gamma$) at the PIBETA setup (data taking and analysis) will be carried out. Final expected results include the measurement of the pion β-decay rate with the 0.5% accuracy. A new estimate of the contribution of the tensor interaction to the $\pi \to e\nu\gamma$ decay will be obtained on the basis of 10 times greater statistics.

The joint INFN–JINR project **DUBTO** is aimed at studying pion-nucleus interactions at energies below the Δ-resonance. The experimental setup **STREAMER** is a self-shunted helium-filled streamer chamber in a magnetic field, equipped with two CCD videocameras for video-recording of nuclear events occurring in the chamber volume. The DUBTO collaboration is thus reviving the self-shunted streamer chamber technique, developed in the 1970s at the JINR Laboratory of Nuclear Problems together with the Turin section of the INFN (Italy), and modernizing data acquisition and processing.

The self-shunted streamer chamber (Fig. 20) serves simultaneously as a thin target and a triggerable track detector and permits obtaining measureable track images of very low-energy secondary charged particles produced in nuclear reactions (thus, in ^{4}He at atmospheric pressure, the track lengths of a 1.5 MeV proton and a 5.0 MeV α-particle, for example, exceed 20 cm).

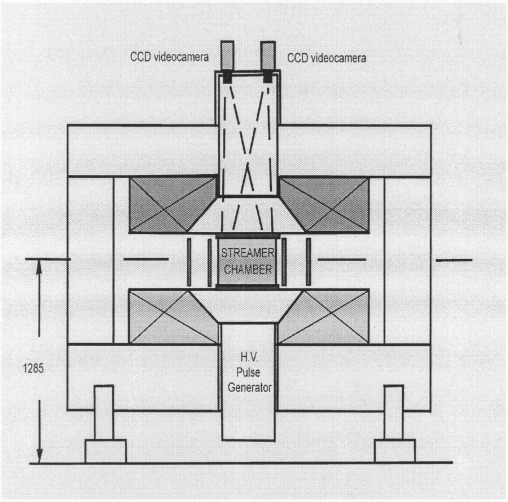

Fig. 20: Sketch of the DUBTO Streamer chamber ($47 \times 60 \times 16\,\mathrm{cm}^3$) in the magnet MC-4A ($B = 0.690 \pm 0.005\,\mathrm{T}$).

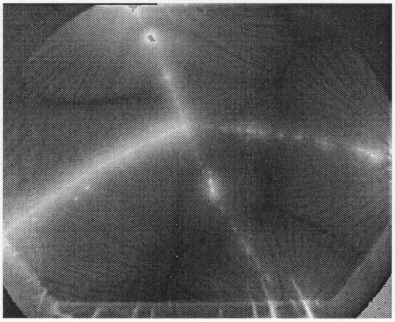

Fig. 21: Videoimage of a 3-prong π^4He interaction event. The tracks of the incident (from the right) and scattered (downward at an angle of $\sim 100^o$) pions are clearly distinguishable from the tracks of the strongly ionizing reaction products.

Figure 21 shows the videoimage of a π^4He-interaction event with tracks of the incident and scattered pions and of two strongly ionizing particles (either 2 protons, or a proton and a triton). The final identification of the heavy secondaries is based both on the determination of ionization losses and on complete reconstruction of the event kinematics, in which the technique of artificial neural networks is also applied.

In 2001 the experimental setup was installed at beam channel XIII of the JINR phasotron. Preliminary on-line data processing is performed and includes scaling, storage, compression, and creation of a database of images. About 2500 videoimages of π^{+4}He-interaction events were collected and transformed for further processing. Much effort was spent to create dedicated software for reading, measuring and analysing the videoimages. The z-distribution (z is in mm) of reconstructed reaction vertices in the chamber is shown in Fig. 22 and the accuracy of the vertex reconstruction in the horizontal plane is seen from the distribution of radii of the intersection areas of the reconstructed (helical) tracks for individual events (Fig. 23).

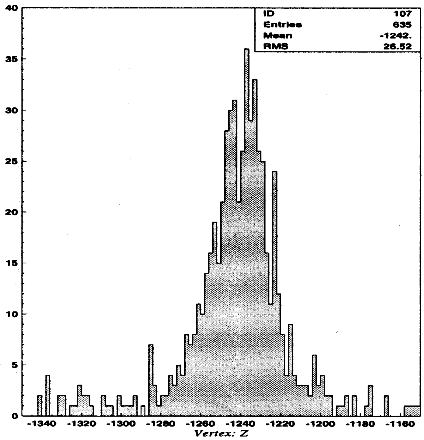

Fig. 22: z-distribution of event vertices in the streamer chamber; the z-axis is directed from the center of the lens of the CCD videocamera upward away from the streamer chamber volume.

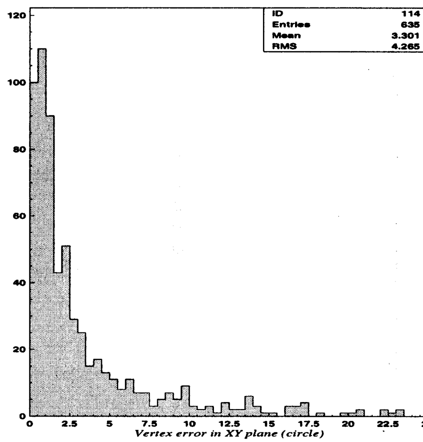

Fig. 23: Distribution of the radii (in mm) of the intersection areas of the tracks of the reconstructed events in the streamer chamber.

For event identification, i.e. distinguishing the following π^{+4}He events with a scattered pion recorded:

$$\pi^+\,{}^4\mathrm{He} \rightarrow \pi^+\,2p\,2n, \tag{1}$$

$$\pi^+\,{}^4\mathrm{He} \rightarrow \pi^+\,p\,{}^3\mathrm{H} \tag{2}$$

the technique of artificial neural networks (a layered feed-forward ANN from the JETNET3 package) was applied. The feature variables used for event identification are suitable kinematic parameters. Figure 24 shows the test distributions of output signals from the ANN corresponding to reaction (1) (shaded histogram) and reaction (2) (empty histogram) for simulated events. The overlap of histograms amounts to about 7%. Figure 25 shows the same distribution for real events. It

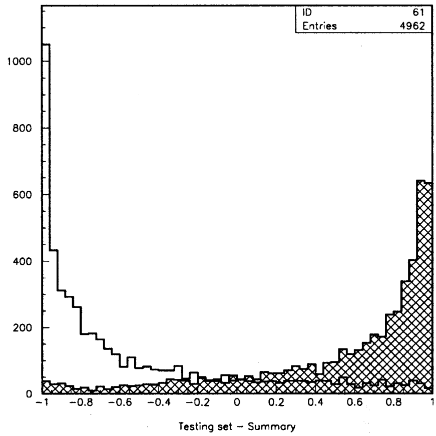

Fig. 24: Distribution of the output signal from the ANN resulting from processing the set of test patterns: events corresponding to patterns of reaction (1) are presented by the shaded histogram.

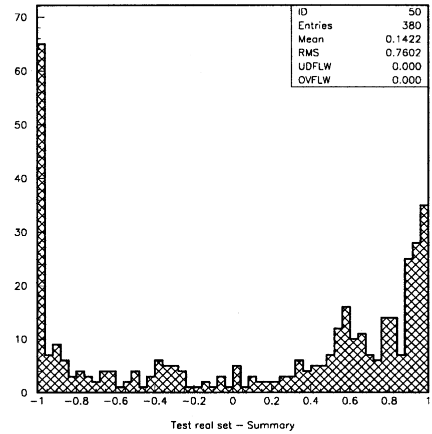

Fig. 25: Distribution of the output signals from the ANN resulting from processing of 212 real events.

turns out that over 50% of the recorded three-prong events represent breakup reaction (1). At present the actual branching ratio for the reaction channels with three charged secondaries is being determined accurately. The same technique is applied in the case of two-prong events.

In the **next 5 years** the following tasks are to be fulfilled. The setup STREAMER is to be shifted from beam channel XIII to new beam channel III with improved characteristics (intensity up to 10^6 $\pi^{\pm}/s$, smaller $\Delta p/p$, smaller angular spread). This will be done as soon as the new beam is extracted and its parameters are known and will take about 2–3 months. A new vaccum beam-line with live (scintillation) collimators will be installed. New electronics (CAMAC) is to be purchased and installed for the trigger system.

The investigation of $\pi^{\pm}\,{}^4$He reactions requiring fully measureable kinematics of slow charged particles will be carried out. Three-prong $\pi^{\pm}\,{}^4$He-reactions will be studied for clarifying reaction branching ratios, collective resonance behaviour, absorption at low energies, etc. To find reaction branching ratios (elastic scattering, excitation of ^{4}He nucleus with emission of γ-quantum, knockout of a neutron) the two-prong events will be studied. Measurement of the πNN-effective mass in breakup and DCX reactions will be performed for clarifying the production mechanism of the d' Dibaryon. Search for exotic responses in inelastic pion-helium interactions is also planned.

In 2001 the near-forward cross section for the $pp \to pn\pi^+$ reaction has been measured at 492 MeV with the large-acceptance magnetic spectrometer **ANKE** (Fig. 26) placed at an internal target position of the storage ring COSY-Jülich [16]. Protons and pions emitted at

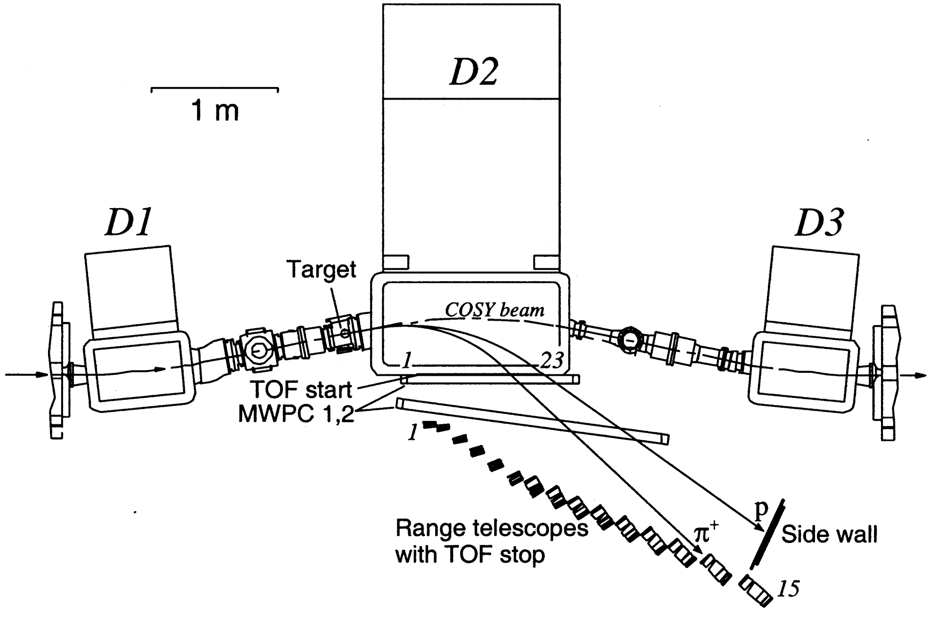

Fig. 26: The layout of magnetic the spectrometer ANKE.

angles smaller than 2^o were detected in coincidence with measurement of their 3-momentum. Under these conditions, the excitation energy in the np system was below 3 MeV over the measured momentum range. This is the region of the np final-state interaction peak, which was measured with an accuracy of a fraction of a MeV. The shape of the peak (Fig. 27) allows one to conclude that the fraction of final spin-singlet np pairs is below 10% [17]. By using the results of the scattering theory [18], this limit is confirmed through comparison with the cross section for $pp \to d\pi^+$. The smallness of the singlet contribution is consistent with trends seen in lower energy data.

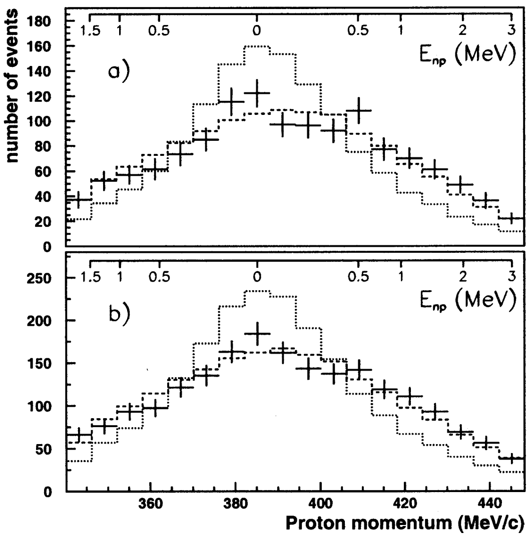

Fig. 27: Proton momentum spectra of the $pp \to pn\pi^+$ reaction for the events with $\theta_\pi < 2^o$ and $\theta_p < 2^o$ (a) and $\theta_p < 2.5^o$ (b). The dashed histogram shows the simulation with a pure spin-triplet final state. A statistical mixture of spin states leads to the dotted histogram inconsistent with the experiment.

A-dependence of the forward K^+-production in pA-collisions has been studied at energies from 1.2 GeV to 2.3 GeV to extend investigation started at ANKE at 1.0 GeV [19].

Study of the deuteron breakup process $p + d \to (pp)_S + n$ with forward production of the S-wave proton pair $(pp)_S$ has been performed at energies from 0.5 GeV to 2.0 GeV. The experiment was carried out at ANKE with a deuterium cluster target and involved measurement of the 3-momentum of each of the protons. Missing-mass distributions (Fig. 28) reveal clear evidence for a peak at the neutron mass value. The events selected at this peak show a distinct concentration at energies less than about 3 MeV, that is, in an S-wave state of the produced proton pair. The deuteron breakup at such cumulative conditions is observed for the first time. It is ex-

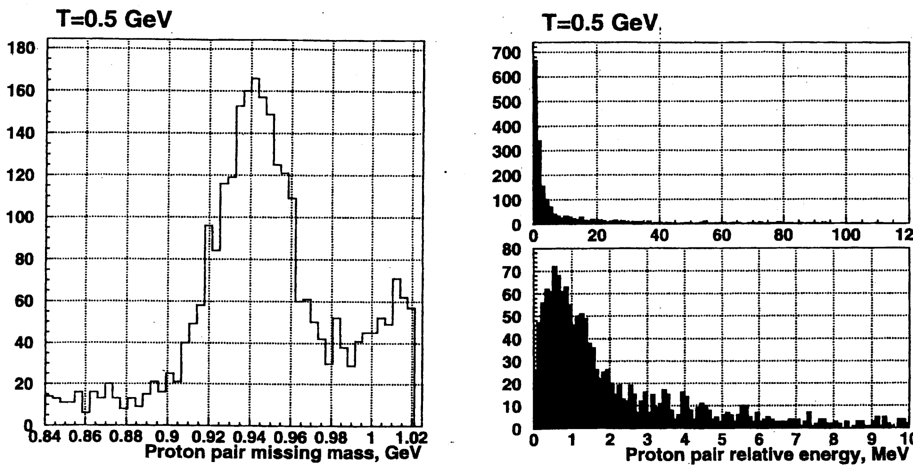

Fig. 28: Cumulative deuteron breakup $p + d \to (pp)_S + n$ with forward emission of the S-wave proton pair. Left: missing-mass spectrum for $pd \to p + p + X$. Right: relative energy spectrum for the proton pairs from the neutron missing-mass peak.

pected [20] that at such specific kinematics it should be dominated by the one-nucleon-exchange mechanism, providing information on the short-range NN-interaction, including the half-off-shell $^1S_0$-scattering amplitude at high momentum transfers. The Dubna group essentially contributed to the development of the ANKE detector system, software, and physical programme.

In **2002–2004** the Dubna team in the ANKE collaboration plans to participate in polarization study of the cumulative breakup of the deuteron; subthreshold $K^{\pm}$-meson production (correlation measurements and A-dependence of cross sections); ω-meson production in np-collisions near the threshold; α_0- meson production in pp-collisions. The Dubna group will also take part in working up new proposals concerning, for example, observation of the NN*-component of the deuteron; study of the spin-flip NN-scattering amplitude in the deuteron breakup; investigation of ϕ-meson production in the near-threshold region. Participation in development of the data processing software, analysis of the above-listed experiments and significant contribution in hardware work, like commissioning of the ABS target, Negative Side Detector, creating of the Multichannel Vertex Detector and construction of new version of the multiwire proportional chambers, are also in plans of the Dubna team of the ANKE collaboration.

The project **CATALYSIS** is aimed at studying physical problems of muon-catalyzed nuclear fusion reactions. The experimental research of the main characteristics of the processes in a mixture of hydrogen isotopes including tritium at high density of a mixture is under way. The installation **TRITON** is mounted in the muon channel of the JINR phasotron and is used in the experiments.

The measurements of the temperature dependence of the cycle rate of muon-catalyzed fusion reactions in a deuterium-tritium mixture (temperature 300–800 K, tritium concentration 15–65%, density 0.2–0.8 LHD) were performed using the Tritium High-Pressure Target (1500 bar, 800 K). Experiments aimed at searching for muon-catalyzed fusion parameters in a triple H/D/T mixture were fulfilled (Fig. 29).

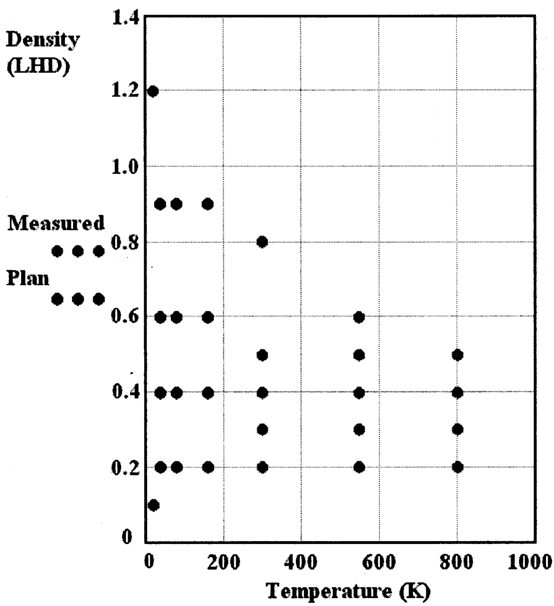

Fig. 29: Experimental condition of the measurements of the muon catalyzed fusion parameters in the D/T mixture (1 LHD = 4.25×10^{22} nuclei/cm^3). Planned and measured points are given.

In **2001** the following main results are obtained. The measurements of the formation rate of the $dd\mu$ molecule in the temperature range 80–800 K are finished with the Deuterium High-Pressure Target (DHPT, 1500 bar, 800 K). The results in the temperature range 350–800 K have been obtained for the first time. The experimental search for the suppressed reaction $d + d \rightarrow {}^4\mathrm{He} + \gamma$ from the state of a muonic molecule has been performed with the same target. The upper limit of the gamma-yield at the level of $2 \cdot 10^{-5}$ is reached [21].

In **2002–2004** the following improvement are planned to meet the needs of the experiments: elaboration of the Tritium Cryogenic High-Pressure Target (TCHPT) with the temperature range 40-300 K; elaboration of the Liquid Tritium Target (LTT) with the working temperature 21 K; elaboration of the Solid Deuterium Target (SDT) with the temperature range 4-40 K; elaboration of the highly effective γ-spectrometers based on crystalline NaI(Tl) of large dimensions (Ø200 × 100mm); improvement of the effectiveness of the system of data collection with the aid of the elaborated processor unit for rejection. On this basis the following results are expected. Experiments on the measurements of the temperature dependence of the cycling rate in the binary mixture D/T will be performed with the use of the TCHPT in the temperature range 40-300 K at the tritium concentration 35–55% and the mixture density 0.2–0.9 LHD (Fig. 30).

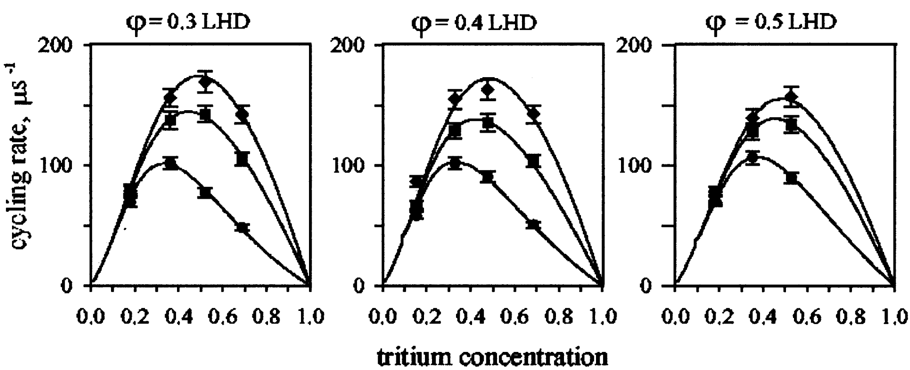

Fig. 30: Measured values of the cycling rate, λ_c, as a function of the tritium concentration for different densities and temperatures: $T = 300\,\mathrm{K}$ (circles), $T = 550\,\mathrm{K}$ (squares) and $T = 800\,\mathrm{K}$ (rhombuses).

Experiments on the measurements of the $tt\mu$-molecule formation rate will be performed with the use of the LTT. The nuclear reaction rate will be revised and the estimation of the influence of the (α–n)-correlation in the final state will be made.

Experiments on the measurements of the temperature dependence of the $dd\mu$ formation rate in ortho-deuterium from the hyperfine states 1/2 and 3/2 of the deuterium mesoatom will be performed with the use of the SDT in the temperature range 4–40 K.

Experiments on the search for the reaction of radiative capture $d + d \rightarrow {}^4\mathrm{He} + \gamma$ from the muonic molecule state will be repeated with the use of the Deuterium High-Pressure Target (DHPT) and full absorption γ-spectrometers in order to lower the threshold of the reaction registration down to 1–2 orders of magnitude.

The joint JINR–PINP project **FAMILON** with the surface muon beam of the JINR phasotron is aimed at measururing the branching ratio of the two-particle (neutrinoless) decay of a muon into an electron and a massless Goldstone boson (familon). This decay $\mu \rightarrow \alpha\, e$ can proceed only with violation of the lepton number conservation law and it is forbidden in the Standard Model. The isotropic nature of the angular distribution in the decay $\mu^+ \rightarrow e^+\alpha$ allows this process to be discriminated from the background process $\mu^+ \rightarrow e^+\bar{\nu}\nu$. The expected energy resolution for muon-decay positrons (at a level of 10^{-3}) allows a factor of 3 improvement of the previous result (obtained at TRIUMF).

In June 2001 a test run was performed with the surface muon beam of the JINR phasotron. The data acquisition was tested in the real conditions. The first μSR spectra were obtained with the magnetic spectrometer. At 10^5 muon stops per second the data acquisition rate was about 10^2 events per second.

In **2002–2004** the intensity of the muon beam and the luminosity of the spectrometer are planned to be increased. For the improvement of the energy resolution of the spectrometer the measurement of the topography of the magnetic field is planned. The future progress in the study of the two-body decay of the muon will be provided by the use of an "active target" consisting of foils and thin drift chambers in the magnet. A prototype of the "active target" was tested in the first run [22].

Under the project **MUON** aimed at investigating the muon properties and the muon interactions with matter the following research was performed in 2001.

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 measurements of the muon magnetic moment in a range of elements was published in [23].

The study of condensed matter by the μSR technique was continued. The μSR experiments with *silicon* were aimed to investigate the effect of impurities on the relaxation rate of the magnetic moment of the shallow acceptor centre. The measurements were carried out with several silicon samples with p- and n-type impurities of different concentrations. The temperature dependence of the relaxation rate and the residual polarization of the negative muon gave information about the shallow acceptor centre in silicon [24]. The change in the character of the temperature dependence and a many times increase in the relaxation rate of the magnetic moment of the electron shell of the muonic atom are found at the impurity concentration above 10^{18} cm^{-3} [25].

The study of the compound $Ce_3Pd_{20}Ge_6$ as a *system with "heavy electrons"* was continued. Below 0.4 K the increase in 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 at the external transverse field was seen. This fact may be attributed to the increase in total moments of the superparamagnetic cube containing 8 Ce atoms and their ferromagnetic ordering with decreasing temperature.

Scientific research in **2002–2004** includes measurement of the magnetic moment of a Dirac particle in the bound state, investigation of muon behaviour in condensed matter with the experimental complex **MUSPIN** and methodological study of the application of the experimental setup with the track analysis to the μSR experiments.

Measurement of the magnetic moment of a deeply bound electron cannot be carried out in practice. This phenomenon can be studied for the negative muon in the 1S-state of different atoms. Theoretical calculations predict that for light elements the relativistic correction to the magnetic moment of the bound muon is comparable with the radiative correction. For heavy elements there are practically no experimental data on the relativistic correction to the magnetic moment of the bound muon. To this end the magnetic moment of the negative muon in the 1S-state both in light and heavy atoms will be measured.

The experimental complex **MUSPIN** on the muon beam lines of the JINR phasotron allows one to solve a wide range of problems in the field of muon behaviour in matter and solid state physics. The main efforts will be concentrated on the following researches:

a) *Investigation of the behaviour of the residual polarization of negative muons in silicon.* On the basis of the results obtained at DNLP the relaxation rate of the magnetic moment of the electron shell of the acceptor and the rate of the transition of the acceptor center from the neutral (paramagnetic) to the ionized (diamagnetic) state were found. These results are very important and the experiments will be continued; b) *the study of the anomalous muonium Mu* in silicon.* The Mu* diffusion coefficients will be mesured for the first time; c) *the s tudy of magnetism in the materials with "heavy electrons"*, i.e. materials with the effective electron mass 100 times larger than the free electron mass. This leads to unusual magnetic behavior which differs from classic dia- or paramagnetism. The research will be concentrated on the systems Ce-Pd-Ge(Si).

With the variable-energy proton beam from the JINR phasotron, the energy spectrum for high-energy γ-rays ($E_\gamma \geq 10$ MeV) from the process $pp \rightarrow \gamma\gamma X$ emitted at 90^0 in the laboratory frame has been measured at 216 MeV for the first time (Fig. 31). The resulting photon energy spectrum extracted from $\gamma - \gamma$ coincidence events consists of a narrow peak (5.3σ) at a photon energy of about 24 MeV and a relatively broad peak (3.5σ) in the energy range of (50—70) MeV. This

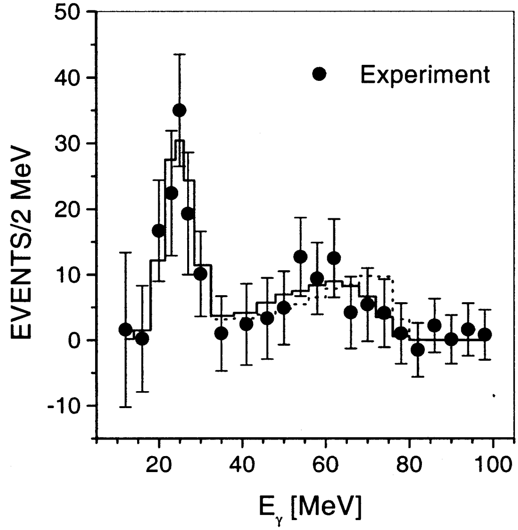

Fig. 31: Experimentally observed energy spectrum for photons from the $pp\gamma\gamma$ process and energy spectra for photons from the process $pp \rightarrow \gamma d_1^\star \rightarrow \gamma\gamma pp$ calculated with the help of Monte Carlo simulations for two $d_1^\star$ decay scenarios: without the final state interaction (solid line) and with the final state interaction (dashed line).

behavior of the photon energy spectrum is interpreted as a signature of the **exotic dibaryon resonance** $d_1^\star$ with a mass of about 1956 MeV which is assumed to be formed in the radiative process $pp \rightarrow \gamma\ d_1^\star$ followed by its electromagnetic decay via the $d_1^\star \rightarrow pp\gamma$ mode [26].

The data obtained, however, are still incomplete, and additional careful studies of the reaction $pp \rightarrow pp\gamma\gamma$ are needed to get proper parameters (mass, width, spin, etc.) of the observed dibaryon state.

The project **NEMO** is aimed at searching for neutrinoless 2β-decay in ^{100}Mo by the JINR–LAL–CNBG–ITEP collaboration. In **2001** the constraction of the NEMO-3 spectrometer was completed [27]. The chemical and physical purification of the sources was totally fulfilled. All 20 sectors of the detector were mounted in the LSM (Modane, France) underground laboratory (Fig. 32).

In September 2001 the NEMO-3 spectrometer was fully assembled for the longtime measurement with the following double beta-decay samples installed: ^{100}Mo (7.2 kg), ^{82}Se (1 kg), ^{116}Cd (0.6 kg), ^{130}Te (1.3 kg), ^{150}Nd (48 g), ^{96}Zr (20 g) and ^{48}Ca (10 g).

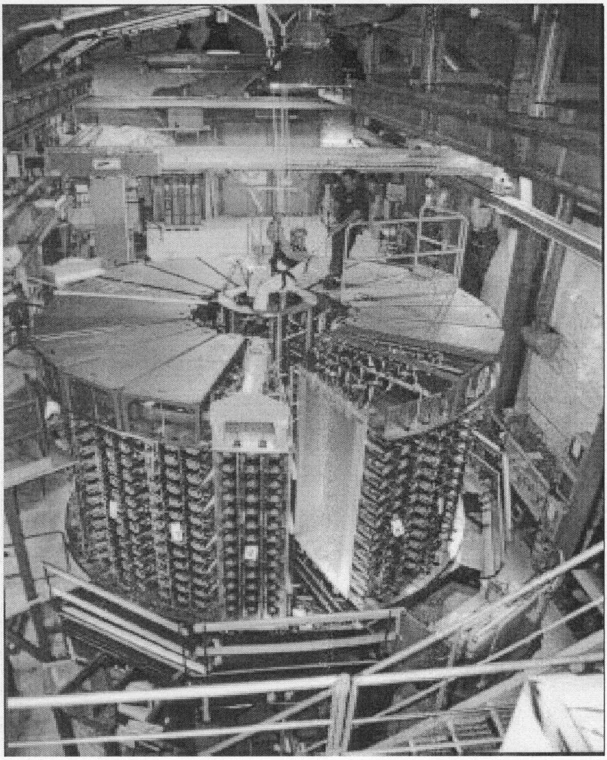

Fig. 32: Spectrometer NEMO-3 at the end of its construction: the 19th sector is being mounted.

Most of the mechanical parts of the NEMO–3 spectrometer (carpentry, copper frame, passive iron shielding), as well as most of the plastic scintillators (6 tons), front-end electronics, cables were made at JINR. Some enriched isotopes were also provided by JINR. The "software group" of JINR plays a leading role in the development of the programs for the data analysis and visualization, including tracking recognition, time and energy calibration, etc.

The first three NEMO-3 sectors operated during 2000–2001. Adjustment of Geiger and scintillator channels and the different tests were carried out. The trial runs *proved* the normal operation of NEMO-3 spectrometer.

Data taking by NEMO–3 is planned to be started in February 2002. During **2002–2004** the mounting of the magnet, steel shield and neutron shield (water and/or wood) will be carried out step by step. Separate measurements will be carried out before each step. It is supposed that the completely assembled NEMO-3 spectrometer will operate during **5 years**. The main characteristics of the NEMO-3 spectrometer such as energy and time resolutions of the scintillator calorimeter, the space resolution of the tracking detector, the internal and external background will be carefully studied. The preliminary results for the $2\nu\beta\beta$ mode of all isotopes measured will be obtained. The finally expected results for neutrinoless mode of double beta decay include

$$\lim T_{1/2}^{2\beta 0\nu}(^{100}\mathrm{Mo}) \approx 10^{25}\mathrm{yr},$$

which corresponds to $\langle m_\nu \rangle^{(\mathrm{Majorana})} \sim 0.2 - 0.4\,\mathrm{eV}$, and high-precision half-time $T_{1/2}^{2\beta 2\nu}(^{100}\mathrm{Mo},\ ^{116}\mathrm{Cd},\ \mathrm{etc})$ measurements of the two-neutrino mode.

The project **AnCor** is aimed at measuring angular correlations with neutrinos in the processes of nuclear β-decay and μ-capture sensitive to the Scalar, Pseudoscalar and/or Tensor Weak interactions. The collaboration includes JINR, CSNSM, UCL, KUL and PSI. The very idea of all these experiments, all the preparation of the experimental equipment, as well as the data acquisition software and most of the data analysis were carried out at JINR.

Data analysis of ^{14}O experiment was completed in **2001** [28]. During the investigation the adopted technique was significantly improved and about 2×10^6 useful events were collected. Unfortunately, it is difficult to extract the improved result for the scalar coupling using the huge amount of data collected. Studying beta-decay of this specific nucleus, one stroked with unexpectedly strong (10%–15% of the effect observed) interatomic interaction of recoiling daughters. This effect introduces large systematic error that is problematic to take into account precisely. Looking at the problem from the opposite side, one can conclude that the beta-neutrino angular correlation in the beta-decay is very sensitive to interatomic interaction in matter.

New search for scalar coupling in beta-neutrino correlations in the beta-decay of ^{32}Ar was started in the frame of the ANCOR project in 2001. To this end a new experimental setup is under development in JINR. It includes 14 cooled planar HPGe detectors which will detect 3.35 MeV monoenergetic protons and positrons ($E \leq 5.1$ MeV) emitted in the pure Fermi β-decay of short-lived ^{32}Ar nuclei. The angle between the positrons and neutrinos will be extracted from the kinematic shift of the proton energy measured with a high precision.

The following results are expected in **2002–2004**.

Measurement of the β-ν angular correlation in the Fermi β-decay of ^{32}Ar will be done at GANIL and the upper limit for the admixture of scalar interaction at the level of a few per cent will be obtained ($|C_S|/|C_V| \leq 0.1$).

Measurement of the γ-ν angular correlation in the allowed ($0^+ \rightarrow 1^+$), unique ($0^+ \rightarrow 2^-$) and first-forbidden ($0^+ \rightarrow 1^-$) μ-capture in a gaseous Ne target will be performed at PSI in summer 2002 and the upper limit for Scalar interaction $(g_S + C_S)/g_V$ and the strength of the Induced Pseudoscalar interaction g_P/g_A with a precision of a few per cent will be measured.

The correlation coefficients will be extracted from the precise analysis of the specific Doppler-broadened shape of γ-lines following the muon-capture. Precise measurements of the partial muon capture rates will be done for enriched ^{48}Ti, ^{76}Se, ^{100}Ru and ^{106}Cd targets. These results would be very useful for the independent check of the Nuclear Matrix Elements calculated by many groups for the 2β-decay of ^{48}Ca, ^{76}Ge, ^{100}Mo and ^{106}Cd (^{48}Ca$\rightarrow^{48}$Ti, ^{76}Ge$\rightarrow^{76}$Se, ^{100}Mo$\rightarrow^{100}$Ru and ^{106}Cd$\rightarrow^{106}$Pd).

The aim of the project **AC/μC** is measurement of the Doppler-broadening of γ-rays following muon capture and search for scalar weak couplings.

In **2001** the data analysis of the ^{16}O-experiment was completed. The 277 keV γ-rays following ordinary muon capture (OMC) on ^{16}O were measured with high-precision HPGe detectors. The Doppler-broadened shape of this γ-line is determined by the gamma-neutrino correlation coefficient a_2^1, which is in turn sensitive to the sum of induced and genuine scalar couplings $C_S + g_S$ as well as nuclear matrix elements (NME) of OMC transitions [29]. This experiment complements, in the muon sector, the ANCOR project performed in nuclear β-decay. Various candidates for new experiments of this type were investigated during the test run, which was carried out in 2001 at PSI (Villigen, Switzerland). It was realized that ^{20}Ne is the best candidate from the experimental point of view. It also seems that NME calculations for OMC on this nucleus are reasonable (Fig 33).

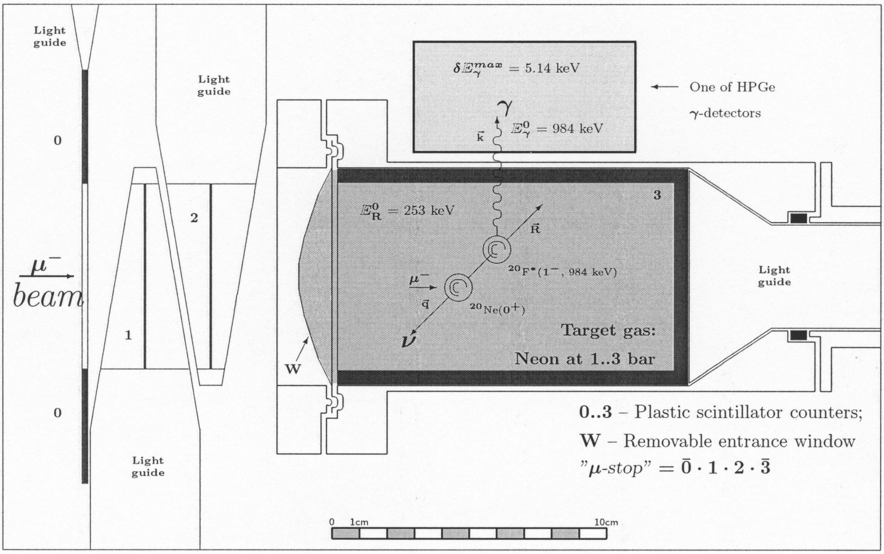

Fig. 33: Set-up with gaseous Ne.

In **2002–2004** the test run data analysis will be finished. The main experiment with the ^{20}Ne target will be carried out at PSI. The data analysis and the test of other nuclei will be performed. As results a set of spectroscopic data concerned the mu-capture on various nuclei (energies and relative intensities of μX-rays, yield of gammas following muon capture) will be obtained. Most of these data will be published for the first time. New estimations of scalar and induced pseudoscalar weak couplings in muon capture on ^{20}Ne will be obtained.

The project **TGV** is aimed at searching for double β-decay of ^{48}Ca and double e-capture of ^{106}Cd with the low-background and high-sensitivity Ge multidetector spectrometer TGV (Telescope Germanium Vertical). After one-year operation of the TGV-1 spectrometer with 1 g of enriched ^{48}Ca the value $T_{1/2}^{2\beta2\nu}(^{48}\text{Ca}) = (4.2^{+3.3}_{-1.3}) \times 10^{19}$ yr was obtained. In 2001 the first stage of the experiment was finished, and the spectrometer TGV-1 was dismounted. A new spectrometer TGV-2 was developed and built in Dubna. It includes 32 HPGe planar detectors mounted in the same low-background cryostat, an acquisition and data-selection system with the corresponding high-precision spectroscopic electronics, etc. 20 grams of enriched ^{48}Ca were chemically purified from radioactive Co and Ra and converted into the CaF_2 form. 16 thin disk samples containing 10 g of ^{48}Ca are being prepared with a pressing procedure developed at JINR. Preliminary tests indicate a satisfactory purity of the final samples. The basement of the TGV-2 and the lower part of its passive shielding have been prepared in the Modane Underground Laboratory.

In **2002–2004** it is planned to perform new measurement of the 2β-decay of 10 g of ^{48}Ca. The measurement of $T_{1/2}^{2\beta2\nu}(^{48}\text{Ca})$ at the level of 10^{19} yr with a precision which will confirm or disprove the Shell Model predictions. The measurement of double e-capture of the same amount of ^{106}Cd will be performed during 2002–2004. This will allow the first *direct* observation of the double e-capture $\text{T}_{1/2}^{2K2\nu}(^{106}\text{Cd})$ at the level of 10^{19} yr.

In **2001**, under the project **LESI** devoted to investigation of interaction between light nuclei at ultralow energies, the following research was carried out. Methodological experiments aimed at measuring the energy distribution of ions on the basis of registration of optical radiation of the expanding deuterium liner were performed with the high-current ion accelerator at the Institute of High-Current Electronics RAS (Tomsk). The experiments allowed the conclusion that the proposed approach showed high potential for reconstruction of the ion flow energy distribution in the expanding liner in the inverse Z-pinch geometry [30]. The experimental set-up including a high-current generator, a load unit, detecting and diagnostics equipment is presented in Fig 34.

Two ^{3}He detectors for measurement of the neutron yield from the *dd* reaction are designed and built. Measurements of the neutron record-

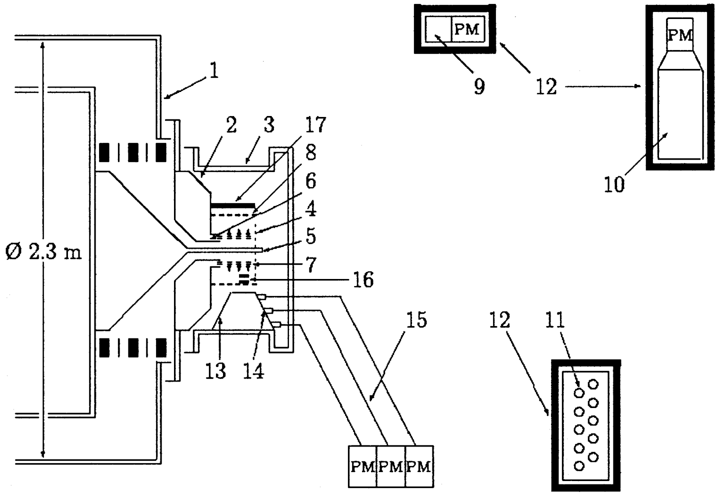

Fig. 34: 1 — high current generator, 2 — load unit, 3 — diagnostic chamber, 4 — wire mesh cathode, 5 — return current rod; 6 — supersonic Laval nozzle, 7 — liner, 8 — current-intercepting squirrel cage, 9 — scintillation detector I, 10 — scintillation detector II, 11 — thermal neutron detector, 12 — Pb shielding, 13 — cone, 14 — collimator, 15 — light guide, 16 — B-dot probe, 17 — CD polymer target, PM — photomultiplier.

ing efficiency and neutron lifetimes in the above detector exposed to a neutron flux from the *dt* reaction (at the Van de Graaf electrostatic generator of the Laboratory of Neutron Physics) and from the ^{252}Cf and Pu-Be sources are performed [31].

Plans for **2002–2003** include creation of a new setup for studying the *dd* and *pd* reactions at the collision energy 0.5–3 keV at the new accelèrator complex MIG; study of the background conditions at the new impulse generators (MIG and TEMP) and new measurements of the so-called astrophysical S-factor and the efficient cross section of the *dd* and *pd* reactions with the MIG and the TEMP. The S-factor is related to the cross section by the equation $\sigma(E) = \frac{S(E)}{E}\exp\left(-31.29\sqrt{m_d/2E}\right)$, where E is the collision energy and m_d is the deuteron mass.

In the framework of the **YASNAPP–2** project the radiochemical investigations, investigations of short-lived nuclides and radioactive decays of long-lived nuclides as well as atomic-nuclear processes are under way. The nuclear spectroscopy methods are used for studying transmutation of radioactive nuclides, processes initiated by electronuclear neutrons, and other reactions.

Radioactive decay of short-lived nuclides in the transition region (from $^{146}_{64}Gd_{82}$ to strongly deformed $N > 90$ nuclei) was investigated in the on-line mode at the ISOL facility by using modern spectrometers with solid-state detectors. Strength functions for the beta decay of odd isotopes $^{147,149,151}Tb$ were measured (the Gamov-Teller resonance with $M_T = +1$ was observed, its fine structure was revealed and analyzed). By using α-spectrometry methods and a full γ-ray absorption spectrometer, masses of some isotopes with $A = 156$ were determined. The structure of $^{156}_{67}Ho_{89}$ was comprehensively investigated and five isomeric states with $T_{1/2} > 10\,s$ were observed. Off-line studies of the decay of neutron-deficient Ho isotopes with atomic masses $A = 156, 158, 160$ and ^{152}Tb were performed. Emphasis was placed on searching for 0^+ nuclear excited levels in the even-even nuclei of Dy and Gd and on clarification of their nature. Many of such levels were earlier reported to be found in (p, t) and (t, p) reactions for Dy and Gd respectively. Energies of nuclear decays of $^{156,158}Er$ were determined by the $K_x - \gamma$ coincidence method and their complicated decay schemes were detailed. The problem with the so-called "anomalously fast" first forbidden $(0^+ \rightarrow 1^-)$ nuclear β-transitions was finally resolved. The decay schemes of nuclear excited levels arising in α-decay of ^{221}Fr and β-decays of ^{213}Bi and ^{209}Pb were investigated by $(\alpha$–$\gamma)$ and $(\gamma$–$\gamma)$ coincidence. New weak branches of ^{211}Po and 221Fr α-decays were found. The existence of the 10.6 keV low-energy nuclear transition in the ^{225}Ac decay was revealed by using the ESA-50 electrostatic spectrometer in measurements of conversion electron lines. Low-energy electron spectra from decay of ^{57}Co, 73As, ^{111}In, ^{155}Eu, ^{172}Lu, ^{241}Am, ^{241}Pu and ^{225}Ac were investigated at a high instrumental resolution. Strong influence of relativistic effects on the $KL_1L_2(^3Po)$ Auger transition intensity was proved. Influence of the source support material on energies of Auger and conversion electrons was observed for the first time. Successful search for low-energy nuclear transitions in the ^{158,160}Er decay was performed. An upper limit of 0.40% (95% C.L.) on the admixture of heavy neutrinos with masses from 14 to 17 keV/c^2 was set from the investigation of the beta spectrum of ^{241}Pu with two electrostatic spectrometers ESA12 and ESA50. A possibility of correctly evaluating the beta spectrum without using any phenomenological parameters was also demonstrated.

Methods of producing radionuclides with high radiochemical purity and high specific activity were developed for the ^{111}In, ^{111m}Cd, ^{175}Hf, ^{177}Lu and other isotopes of rare-earth elements. A new technique of the perturbed angular correlation (PAC) measurements with one detector was offered. Several experiments were carried out to study the influence of decay aftereffects on the HFI parameters measured by the PAC method. Transmutation rates were determined for radioactive nuclei ^{129}I, ^{237}Np, ^{239}Pu and ^{241}Am in secondary neutron fluxes generated by 1.5, 3.7, and 7.4 GeV protons from the JINR Synchrophasotron in Pb and U targets. Space distribution of the neutron fluxes was measured by radiochemistry.

Cross sections for production of several tens of residual nuclei were determined by irradiating the above-mentioned radioactive targets (except ^{241}Am) with the 660-MeV proton beam delivered by Phasotron. The experimental results were compared with the calculations by the cascade evaporation model. Light and medium residual production cross sections were measured in fragmentation reactions of 0.66, 1.0, and 8.1 GeV protons with tin isotopes ($A = 112, 118, 120, 124$). Strong dependence of the experimental cross sections on the isotopic spin of the targets and residuals was observed. The structure of nuclei near double magic ^{208}Pb was studied. A new weak (8×10^{-6} per decay) branch of the ^{211}Po alpha decay to the 1633 keV ^{207}Pb level was discovered. Investigations of α–γ coincidences at the ^{225}Ac decay were finished. Data more reliable than in previous papers were obtained. 15 new weak γ transitions were attributed to this decay and placed in the decay scheme. Many transitions earlier ascribed to the ^{225}Ac decay were not confirmed. The internal conversion electron spectrum at the decay of ^{225}Ac was investigated with the beta-spectrometer ISA-50. The 10.6 keV γ transition, which was required for fulfillment of the intensity balance, was revealed [32].

In **2002–2004** one plans the following research at the YASNAPP-2 facility. Identification of the previously found isomers ^{156}Ho (10 s, 7 min), ^{160}Ho (3 s), ^{157}Tm (1.5 s), ^{157}Yb (38 s) will be finished at the ISOL facility. A time spectrometer of the "mini-crystal ball" type for searching for μs-isomers in odd-odd nuclides of Ho will be used. The investigation of the α-decay of rare-earth nuclides of the transition region (with $N = 89$) will be completed. The positron spectra of short-lived Yb, Tm and Er isotopes are going to be investigated with the aim to determine masses of many nuclei up to $B_p \approx 0$ from the data on Q_β and Q_α. The investigations of radioactive decays of relatively long-lived Er and Ho nuclides (A=156–161) will be finished. The origin of the monopole excitation in the odd-odd daughter nucleus will be revealed. The role of F-forbidden transitions in Ho ($A = 158, 160$) and ^{152}Eu will be determined and the features of filling of $h_{11/2}$ and $S_{1/2}$ shells in light isotopes of Tm and Ho will be studied. The search for new isomeric states in a decay chain of ^{225}Ra will be continued. The available ^{229}Th preparation (25 μCi) gives a good chance to find extremely low-populated (10^{-6} per decay) isomeric states. The investigations of the decay of ^{210,211}At isotopes will be completed. ^{57}Co sources are to be investigated by means of Mossbauer spectroscopy to find out why there appears a low-energy satellite of the $KL_2L_3(^1D_2)$ Auger line in ^{57}Fe observed in our previous measurements. A search for the 10th KLL Auger line $(KL)_2L_3(^3P{-}1))$ will be performed. A possibility of using the K-32 conversion electron line in ^{83m}Kr for energy calibration of tritium experiments will be investigated.

Radiochemical support of the above-mentioned experiments and creation of the radionuclide generators ^{44}Ti$\rightarrow^{44}$Sc; ^{90}Sr$\rightarrow^{90}$Y; ^{225}Ra(Ac)$\rightarrow^{213}$Bi; ^{241}Pu$\rightarrow^{237}$U will be done. Experiments on transmutation of radioactive nuclei (Pu isotopes) and various physical processes in an accelerator-driven hybrid system (extended Pb target plus U blanket) will be carried out with the relativistic beams of the JINR

Nuclotron. Measurements of the nuclear reaction cross sections in interactions of Phasotron proton beam with radioactive targets (Pu isotopes) will be conducted. ^{99m}Tc and ^{129}I transmutation with secondary neutrons generated by the Phasotron proton beam in a Pb target will also be studied.

Search for new isomers in the ^{225}Ra decay chain, studies of decays of ^{211}At, ^{210}At and daughter nuclei are planned to continue. If it possible to get about 100 hours per year for on-line YASNAPP-2 experiments, study of the nuclear structure in the region of the double magic ^{146}Gd can be planned.

Relativistic nuclear physics

The Project **FASA** ("Study of decay of hot nuclei produced by relativistic light ions") is devoted to the investigation of the mechanism of the thermal multifragmentation, which takes place in collisions of the light relativistic ions with a heavy target. This is a new, multibody decay process in which many fragments (IMF) with masses heavier than α-particles and lighter than fission fragments are emitted from a very hot target spectator. This process is directly related to a liquid-gas phase transition in nuclear matter. It is interpreted as a spinodal decomposition of hot and diluted system.

The evolution of the reaction mechanism with increasing projectile mass is of special interest. The comparative study of multifragmentation of gold nuclei induced by relativistic protons, helium and carbon ions (accelerated by the JINR synchrophasotron) has been performed [33]. The data obtained support the conclusion that in all the cases thermal multifragmentation takes place, which is a statistical break-up process governed by nuclear heating. It is illustrated with Fig. 35, which shows fragment charge distributions for different collisions. They are very similar and are well described by the combined model which includes modified intranuclear cascade calculations followed by the statistical multifragmentation model. The more detailed study demonstrates a transition from pure "thermal decay"

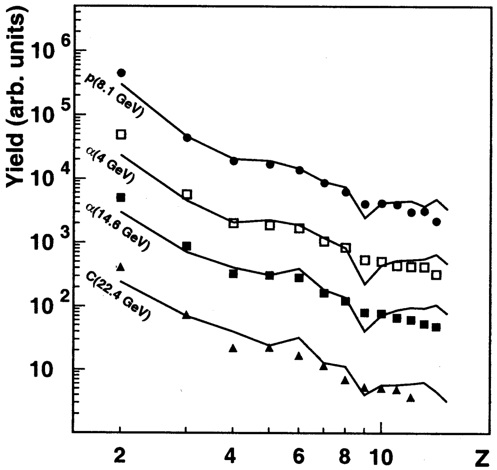

Fig. 35: Fragment charge distributions obtained for p+Au at 8.1 GeV, ^{4}He+Au at 4 GeV, ^{4}He+Au at 14.6 GeV and ^{12}C+Au at 22.4 GeV. The curves are calculated by the statistical model.

(for p+Au collisions) to disintegration "decorated" by the onset of the radial collective flow, which is observed for ^{4}He(14.6 GeV)+Au and ^{12}C(22.4 GeV)+Au collisions. It reveals itself in the fragment kinetic energy spectra which became harder for heavier projectiles. This collective flow is driven by the thermal pressure, its mean total energy is estimated to be around 115 MeV both for helium and carbon beams, while the mean thermal excitation energy of fragmenting nuclei is 400–450 MeV.

The comparative study of multifragmentation of gold nuclei induced by relativistic protons, helium, carbon and heavier ions will be continued with a modified FASA setup in **2002–2004**. A new counter array is developed. It is composed of 25 dE-E telescopes for correlation measurements. It gives a better possibility for measuring IMF-IMF angular (and relative velocity) correlations, which are important for the time scale study.

New data on the dependence of the decay time of the system upon the excitation energy and the projectile mass will be obtained. The data will be obtained on the evolution of the decay mechanism of very hot nuclei from pure thermal multifragmentation to that influenced by the dynamic effects with increasing projectile mass. A new information on the space configuration of the system at the moment of disintegration will be gained from IMF kinetic energy measurements correlated with fragment multiplicity and charge. The external beam of JINR Nuclotron provides the best conditions for the realization of this program.

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**.

Test of the prototype electron gun for the electron cooling system of MUSES project (RIKEN, Japan) was performed on the experimental test bench "Recuperator". Development of the electron cooling systems for the storage rings ACR (RIKEN) and NIRS (Chiba, Japan) and the electron cooling system with a circulating electron beam for the storage ring COSY (FZJ, Germany) was continued. Within the framework of the agreement between JINR and ITEP (Moscow) the physical motivation and preliminary design of the electron cooling system for the storage ring TWAC ITEP were performed. The results of the work show that the electron cooling system can increase the efficiency of TWAC by 2–3 times in experiments with external targets.

The project LEPTA is aimed at constructing a small positron storage ring with electron cooling of circulating positrons. Main elements of the LEPTA magnetic system are constructed (Fig. 36). The measurement of the magnetic field homogeneity and construction of additional correction coils were performed.

Backing of the LEPTA vacuum chamber for the achievement of the necessary pressure of the residual gas was carried out. The construction of the positron injector was started. The positron trap for storage of positrons before the injection into the LEPTA ring is under construction. The positron source on the basis of the radioactive ^{22}Na source was designed. A special software package was developed for particle dynamics calculation in the storage ring with strong coupling

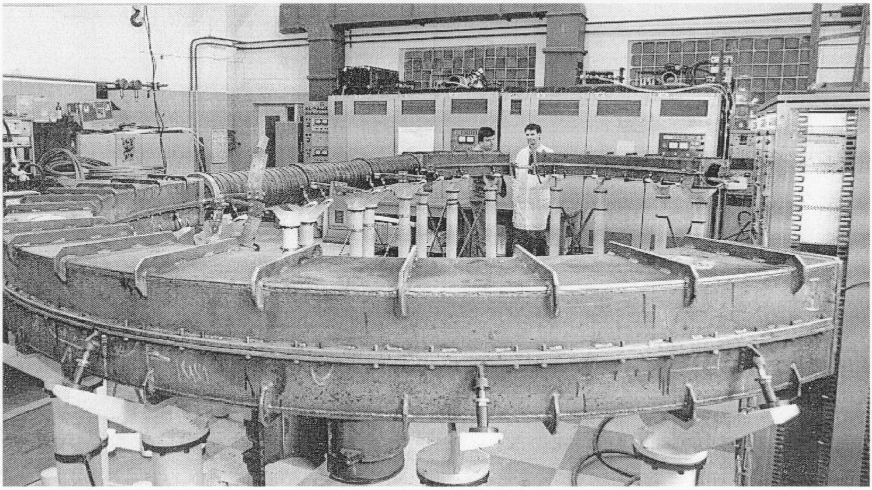

Fig. 36: Magnetic system of LEPTA.

between transverse degrees of freedom. The program for calculation of electron cooling of positrons was also elaborated [34].

In **2002–2004** the following results are expected. The design and construction of the electron cooling system for the storage rings TWAC ITEP (Moscow) and NIRS (Chiba, Japan) will be completed. The participation in the design of the accelerator complex MUSES (RIKEN, Japan) and development of the storage ring COSY (FZJ, Germany) will be continued. Tuning the LEPTA ring by the optical method using a single-pass electron beam will be performed. Commissioning of the LEPTA ring and experiments with a circulating electron beam as well as commissioning of positron injector and experiments with circulating positron beam are planed. Experiments with the electron cooling of circulating positrons will also start.

Under the project **"JINR Phasotron upgrading and development"** (topic 1038) the following main acitivities are expected in **2002**–2003.

The 2nd and 3rd stages of the modernization of the front part of the phasotron beam channels will be realized. The proton beam channel for the electonuclear process investigation will be designed. The design of the proton radiography beam and the test of the Li target for the therapeutic neutron beam production will be fulfilled. The external injection into the Phasotron as well as the high current cyclotron injector will be designed. The extraction of the proton beams with energy 48 and 60 MeV and deuteron beams with energy 16, 22 and 30 MeV from the cyclotron AIC-144 will be realized. The computer codes for calculation of space charge effects in cyclotrons and synchrocyclotrons will be developed.

In November 2001 the spallation product yields, angular distributions and fluxes of neutrons and charged particles from lead–vismut (Pl–Bi) target were measured with the experimental electronuclear installation **SAD** (Self-Amplifier Dubna) at the JINR Phasotron. The measurements were performed in a wide proton energy range up to 600 MeV for four different angles in the range of 45^o–120^o. The experiment was realized by a collaboration of JINR and Polish physicists.

The main goal of the JINR topic **"Further Development of Methods and Instrumentation for Radiotherapy and Associated Diagnostics with 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 the seven-compartment Medico-technical complex of DLNP (MTC).

In collaboration with MRRC of Obninsk and the Radiological department of the Dubna hospital the research on proton therapy of cancer patients with the Phasotron beams in treatment room No 1 of MTC was continued and spread out. In **2001** more than 50 patients were fractionally treated with the 150-MeV medical proton beam. The total number of the proton irradiation sessions exceeded 594. With the Cobalt gamma-unit "Rokus-M" 69 patients were irradiated (2520 irradiation sessions). A therapeutic 150-MeV uniform proton beam with the cross section of 80×80 mm (instead of 60×60 mm used before) was delivered to room No 1. The main dosimetric characteristics of this beam were measured and added to the planning software. The increase in the cross section of the proton beam allowed us to treat tumours of higher dimensions. An X-ray tube and contrivances to fix X-ray sensitive plates of the commercial diagnostic device “ERGA” to the beam were installed in the same treatment room. It allowed one to make X-ray images of a patient and an autograph of a proton beam simultaneously on the same film in about 3 minutes right before the irradiation run for each direction of irradiation. This verification of the patient's position with respect to the proton beam guarantees the irradiation accuracy of 1–2 mm. It also became possible to spread out the set of localisations and to start radiotherapy and radiosurgery of intracranial targets.

The following research work is planned in **2002**. The clinical researches on proton therapy of cancer patients in treatment room No 1 of MTC will be continued. The therapeutic 160-MeV proton beam with a sharp distal fall-off Bragg peak and with a dose rate enough for radiotherapy will be delivered to room No 1. Development and improvement of detectors and tools for clinical dosimetry of the medical hadron beams will be performed.

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