JOINT INSTITUTE FOR NUCLEAR RESEARCH

2000-314

N. A. Russakovich, V. A. Bednyakov

DZHELEPOV LABORATORY OF NUCLEAR PROBLEMS

RESEARCH ACTIVITIES IN 2000

Report to the 89th Session
of the JINR Scientific Council
January 18–19, 2001

Dubna 2000

N. A. Russakovich, V. A. Bednyakov

DZHELEPOV LABORATORY OF NUCLEAR PROBLEMS

RESEARCH ACTIVITIES IN 2000

Report to the 89th Session
of the JINR Scientific Council
January 18–19, 2001

Dubna 2000

Introduction

The field of scientific activities of the Dzhelepov Laboratory of Nuclear Problems is unique. It covers experimental investigation in modern particle physics (at high, low and intermediate energies); investigation of nuclear structure (including relativistic nuclear physics and nuclear spectroscopy); study of condensed matter properties; theoretical support of the experimental research; medico-biological investigations; development of new accelerators and experimental facilities.

The Dzhelepov Laboratory of Nuclear Problems 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 this Laboratory. In 2000 three neutrino meetings, a workshop on neutrino oscillation experiments (NOMAD week), a workshop of the NEMO collaboration and an international conference on non-accelerator new physics in neutrino observations (NANPino), were held at the Dzhelepov Laboratory of Nuclear Problems. The latter 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. On the other hand, modern (with DELPHI, D0, CDF) and future (with ATLAS, COMPASS, CDF, etc) investigations of phenomena at high energies are also an area of constant interest and care fot the DLNP scientists. It was for the first time in the history of the ATLAS collaboration that the ATLAS week took place (Dubna, 21–26 June 2000) outside CERN. A total of about 350 participants were gathered together by the DLNP organizing committee to discuss progress in construction of the ATLAS detector. Choosing JINR as a place to hold the ATLAS week the collaboration confirmed the considerable contribution of JINR scientists to the fulfilment of the ATLAS project. Another large conference "LHC Physics and Detectors" was held in Dubna right after the ATLAS week. The Laboratory was also greatly involved in preparation of the meeting.

In the time being the Dzhelepov Laboratory of Nuclear Problems does not have a modern powerful home facility. Nevertheless the JINR phasotron is still considered to be a useful facility which provides a possibility of doing good physics (e.g. μ-catalyzed fusion, DUBTO project) and performing medico-biological and clinical research on treatment of tumour patients on the basis of the medico-technical complex and medical hadron beams.

Elementary Particle Physics

The **NOMAD** experiment in the CERN SPS neutrino channel yielded new data for the search for $\nu_\mu \to \nu_\tau$ oscillations. Greater statistics (1,350,000 charged-current muon neutrino interactions are recorded) and improved kinematic analysis used to identify ν_τ interaction acts made the experiment much more sensitive to oscillation parameters. Fifty-eight candidates for τ-neutrino interaction in the $\nu_\tau N \to \tau^- X$ reaction and 55 ± 5.4 background events in all τ-lepton decay modes considered were found. This number of candidates agrees with the number of background events. No $\nu_\mu \to \nu_\tau$ oscillations are found, which yields the upper limits for the oscillation amplitude in the mass squared difference interval $1 < \Delta m_{12}^2 < 1000$ eV^2 within the hypothesis of two types of neutrinos.

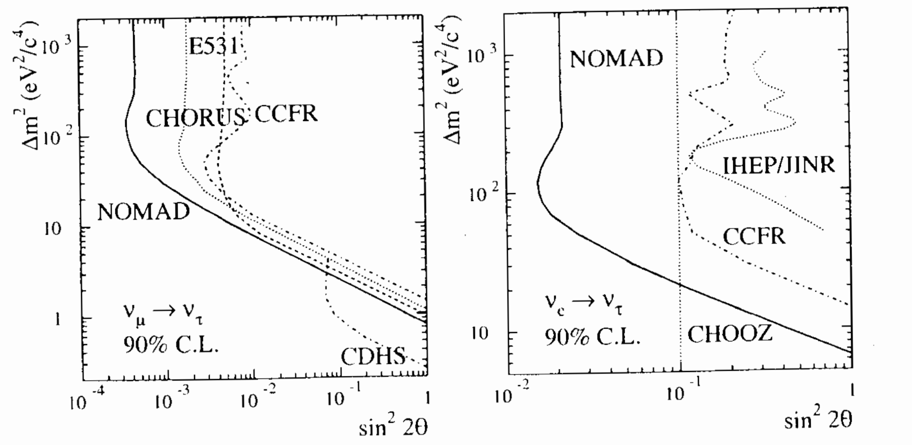


Figure 1: NOMAD 90% exclusion plot for $\nu_\mu \to \nu_\tau$ (left) and $\nu_e \to \nu_\tau$ (right) oscillations.

In the region of large Δm_{12}^2 ($\Delta m_{12}^2 > 50$ eV^2) the limits (90% C.L.) for the amplitude and probability of $\nu_\mu \to \nu_\tau$ oscillations (Fig. 1, left) are [1]

$$\sin^2 2\theta_{\nu_\mu\nu_\tau} < 4.0 \cdot 10^{-4}, \quad P_{\nu_\mu\nu_\tau}(\nu_\mu \to \nu_\tau) < 2 \cdot 10^{-4}.$$

This value of $P_{\nu_\mu\nu_\tau}(\nu_\mu \to \nu_\tau)$ is more than 10 times better than the previous best limit in the region of large masses $P_{\nu_\mu\nu_\tau}(\nu_\mu \to \nu_\tau) < 2,5 \cdot 10^{-3}$ (FNAL, E531-1986).

Similarly, the limits for the amplitude and probability of $\nu_e \to \nu_\tau$ oscillations for $\Delta m_{12}^2 > 50$ eV^2 (Fig. 1, right) are [1]:

$$\sin^2 2\theta_{\nu_e\nu_\tau} < 2,0 \cdot 10^{-2}, \quad P_{\nu_e\nu_\tau}(\nu_\mu \to \nu_\tau) < 1.0 \cdot 10^{-2}.$$

also 10 times better than the previous limits for the $\nu_e \to \nu_\tau$ oscillation parameters (FNAL, CCFR-1994).

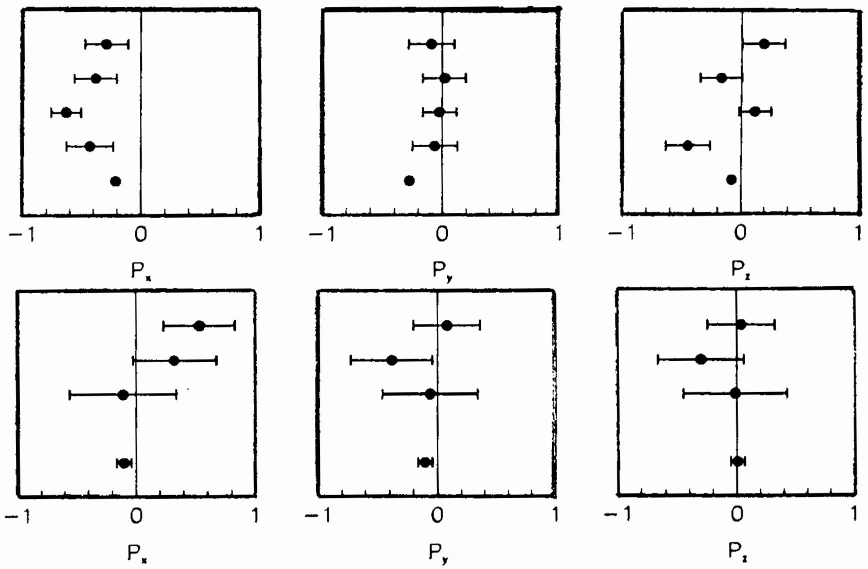


Figure 2: Λ^0-polarization in the target fragmentation ($x_F < 0$, upper panel) and current fragmentation ($x_F > 0$, lower panel) regions in the WA21 (ν_μ-p), WA21 ($\bar\nu_\mu$-p), WA59 ($\bar\nu_\mu$-Ne), E632 (ν_μ-Ne, only upper panel) and NOMAD experiments (from top to bottom).

The experiment NOMAD [2] yielded new data on polarization of Λ^0 hyperons in the charged-current neutrino interactions $\nu_\mu N \to \mu^- \Lambda^0 X$.

As many as 8087 events with Λ^0 hyperons were analyzed, which is 30 times more than in all previous neutrino experiments.

Longitudinal polarization of Λ^0 hyperons was measured (Fig. 2) both in the target fragmentation region

$$P_x(x_F < 0) = -0,21 \pm 0,04(\text{stat.}) \pm 0,02(\text{syst.}).$$

and in the current fragmentation region

$$P_x(x_F > 0) = -0,09 \pm 0,06(\text{stat.}) \pm 0,03(\text{syst.}).$$

Longitudinal polarization of Λ^0 hyperons is negative with the respect to the W boson direction and increases in the target fragmentation region. By measuring longitudinal polarization in the current fragmentation region it is possible to estimate the coefficient of spin transfer from the u quark to the Λ^0 hyperon $C_u^\Lambda = -P_x = 0,09 \pm 0,06(\text{stat.}) \pm 0,03(\text{syst.})$. It was the first time in neutrino experiments that considerable transverse polarization perpendicular to the Λ^0 hyperon production plane was observed

$$P_y = -0,22 \pm 0,03(\text{stat.}) \pm 0,01(\text{syst.}).$$

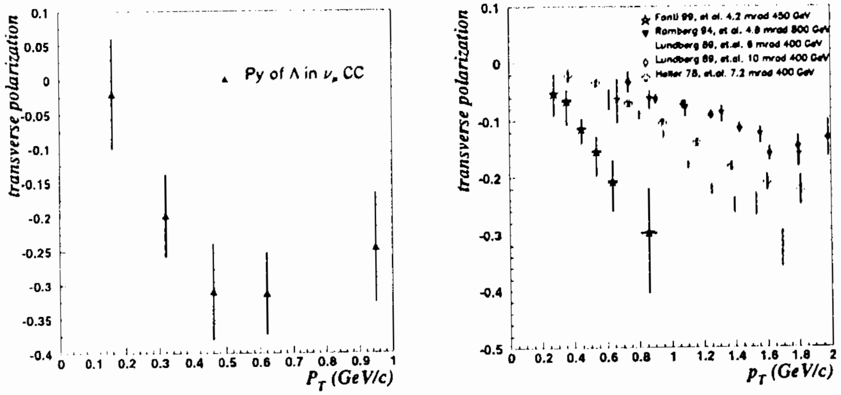


Figure 3: Dependence of the transvese Λ^0-polarization on p_T observed in the NOMAD experiment and in hadron-hadron interactions of unpolarized protons with unpolarized targets.

The quantity P_y increases with increasing transverse momentum of the Λ^0 hyperon relative to the hadron shower direction, which qualitatively agrees with the results of experiments with unpolarized hadrons and unpolarized targets (Fig. 3).

The new and more accurate experimental data make it possible to verify various models allowing for polarized strangeness in a nucleon in the region $x_F < 0$ and the mechanism for polarization transfer from the quark to the Λ^0 hyperon in the region $x_F > 0$.

In 2000 the data collected in the $e^+e^- \to e^+e^-(\gamma), \mu^+\mu^-(\gamma), \tau^+\tau^-(\gamma)$ and inclusive $e^+e^- \to q\bar{q}(\gamma)$ channels with the **DELPHI** detector at energies close to 183 and 189 GeV were analysed in order to extract the hadronic and leptonic fermion-pair cross sections, as well as the leptonic forward-backward asymmetries and angular distributions. No evidence for physics beyond the Standard Model was found and limits were set on contact interactions between fermions, the exchange of R-parity violating SUSY sneutrinos, Z' bosons and the existence of gravity in extra dimensions.

The scale Λ characterising contact interactions between leptons can be excluded at the 95% confidence level in the range $\Lambda < 4.4-1.07$ TeV depending on the model. For sneutrino exchange in R-parity violating supersymmetry, the genetic coupling in the purely leptonic part of the superpotential, $\lambda > 0.1$ can be excluded for $m_{\tilde{\nu}}$ in the range 130–190 GeV for all leptonic states at the 95% confidence level or above. Extra Z' bosons lighter than 300 GeV/c^2 can be excluded at the 95% confidence level. The 95% confidence level lower limits of 542 and 680 GeV on the string scale, M_S, in models of gravity involving extra dimensions are obtained for a combinations of $\mu^+\mu^-$ and $\tau^+\tau^-$ final states [3].

The reaction $e^+e^- \to \gamma\gamma(\gamma)$ was studied using the LEP high-energy data collected with the DELPHI detector at the centre-of-mass energies of 188.6–201.6 GeV, corresponding to integrated luminosities of 151.9–40.1 pb^{-1}, respectively. The differential and total cross sections for the process $e^+e^- \to \gamma\gamma$ were measured (Fig. 4). Good agreement between the data and the QED prediction for this process was found.

Lower limits on possible deviations from QED were derived. The 95% C.L. lower limits on the QED cut-off parameters $\Lambda_+ > 330$ GeV and $\Lambda_- > 320$ GeV were obtained. In the framework of composite models, a 95% C.L. lower limit for the mass of an excited electron, $M_{e^*} > 311\,\mathrm{GeV}/c^2$, was obtained considering an effective coupling value $\lambda_\gamma = 1$. The possible contribution of virtual gravitons to the process $e^+e^- \to \gamma\gamma$ was probed, resulting in 95% C.L. lower limits on the string mass scale $M_S > 713\,\mathrm{GeV}/c^2$ and $M_S > 691\,\mathrm{GeV}/c^2$ for $\lambda = +1$ and $\lambda = -1$ respectively (where λ is a $O(1)$ parameter of quantum gravity models) [4].

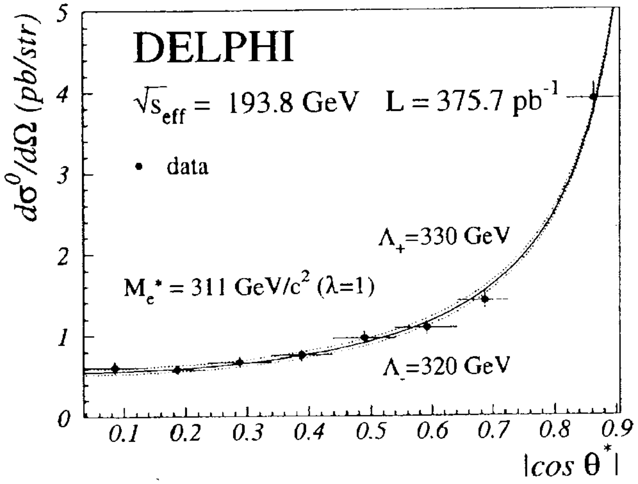


Figure 4: Born differential cross section obtained by combining all data sets at an effective centre-of-mass energy of 193.8 GeV (dots), compared to the QED theoretical distribution (full line). The dotted lines represent the allowed 95% C.L. deviations from the QED differential cross section, which correspond to the 95% C.L. lower limits on Λ_+ and Λ_- 330 GeV and 320 GeV respectively, to the 95% C.L. lower limit on excited electron mass 311 GeV/c^2 and to the 95% C.L. lower limits on the string mass scale 713 GeV/c^2 (for $\lambda = +1$) and 691 GeV/c^2 (for $\lambda = -1$).

From the data sample of integrated luminosity 155 pb^{-1} collected by DELPHI in collisions at a centre-of-mass energy of 188.63 GeV the individual leptonic branching fractions were found to be in agreement with lepton universality and the W hadronic branching fraction was measured to be $BR(W \to q\bar{q}) = 0.680 \pm 0.008(\mathrm{stat.}) \pm 0.004(\mathrm{syst.})$,

in agreement with the Standard Model prediction 0.675 and compatible with measurements at lower energies by other LEP experiments [5]. The total cross section for the doubly resonant WW process was measured to be $\sigma^{\mathrm{total}}_{WW} = 15.83 \pm 0.38(\mathrm{stat.}) \pm 0.20(\mathrm{syst.})$ pb, assuming Standard Model branching fractions (Fig. 5).

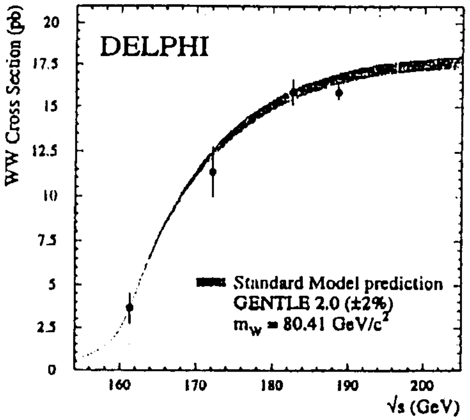


Figure 5: Measurements of the W^+W^- cross section compared with the standard model prediction using and $M_W = 80.41\,\mathrm{GeV}/c^2$ with a possible uncertainty of $\pm 2\%$ on the computation.

In 2000 the DELPHI collaboration studied the Lorentz structure of tau lepton decays [6]. Measurement of the Michel parameters (which describe weak couplings of charged leptons) and the average tau-neutrino helicity in tau lepton decays together with the first measurement of the tensor coupling in the weak charged current were carried out. The results obtained are consistent with the V A structure of the weak charged current in decays of the τ lepton.

The **DIRAC** experiment at CERN aims to measure the lifetime of $\pi^+\pi^-$ atoms ($A_{2\pi}$) in the ground state with a 10% precision, to obtain the difference $|a_0 - a_2|$ of $\pi\pi$ scattering lengths in the S-state with the isotope spin 0 and 2 with an accuracy of 5%, and to submit the understanding of chiral symmetry breaking of QCD to a crucial test.

The experimental setup is located at the CERN PS extracted proton beam with the energy of 24 GeV. The setup is a magnetic spectrometer with coordinate detectors aligned upstream of the spectrometer magnet near the target and with two telescope arms for pos-

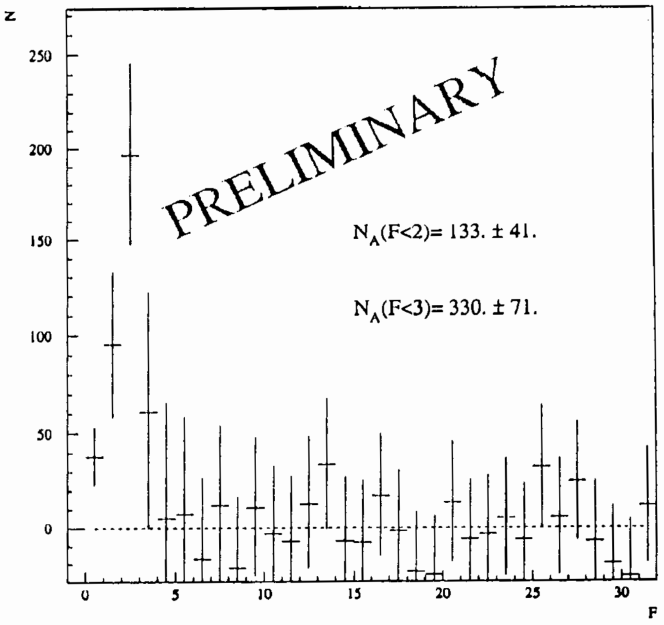


Figure 6: The difference N between the experimental distribution of $\pi^+\pi^-$ pairs and the approximating function, which describes the contribution of pion pairs produced in free states. The variable F along the abscissa is related to the relative momentum Q of pions in c.m.s. and calculated as $F = \sqrt{Q_X^2/\sigma_{Q_X}^2 + Q_Y^2/\sigma_{Q_Y}^2 + Q_L^2/\sigma_{Q_L}^2}$. Here $Q_{X,Y,L}$ are the components of the relative momentum and $\sigma_{Q_{X,Y,L}}$ are the setup resolution over corresponding components: $\sigma_{Q_X} = \sigma_{Q_Y} = 1\,\mathrm{MeV}/c$ and $\sigma_{Q_L} = 0.65\,\mathrm{MeV}/c$.

itively and negatively charged particles downstream of the magnet. The coordinate detectors are microstrip gas chambers, scintillation fibre detectors, and scintillation ionization hodoscopes. Each telescope is equipped with drift chambers, horizontal and vertical hodoscopes, a gas Cherenkov counter, a preshower and a muon detector. The last three detectors are used to suppress detection of electrons and muons, respectively. The relative momentum resolution of the setup σ_Q is about $1\,\mathrm{MeV}/c$. The required accuracy of the setup for the relative momentum is provided by a high resolution of the coordinate detectors and a small quantity of materials in the way of a particle.

The first signal of $A_{2\pi}$ observation in the experiment DIRAC was obtained after processing a part of the experimental data taken with

a platinum target in 1999. The difference between the experimental distribution of $\pi^+\pi^-$ pairs and the approximating function, which describes the contribution of pion pairs produced in free states, is shown in Fig. 6. The peak in the range $F \leq 3$ is caused by the additional pion pairs with a low relative momentum produced at the breakup (ionization) of $\pi^+\pi^-$ atoms inside the target.

At the beginning of 2000 the DIRAC setup was upgraded. Firstly, the dedicated hardware processor for selecting tracks in the drift chambers was developed and manufactured. The rejection factor is about 1.5. Secondly, the software part of the data acquisition was improved to provide a twice higher effective rate of accepting data. In 2000 the setup was running during 6 months and about 10^9 triggers were recorded. Now the data processing is in progress.

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 electron, gamma, muon, jet, and missing transverse energy measurements, as well as b-quark tagging.

The ATLAS apparatus consists of a inner detector (tracker), an electromagnetic calorimeter (ECAL), a hadron calorimeter (HCAL) and, a muon spectrometer.

The inner tracker on the basis of the Transition Radiation Detector (TRT) serves to identify electrons by recording transition radiation photons and to reconstruct particle tracks by a large number of recorded points. Highly granular Liquid Argon (LiAr) electromagnetic calorimetry with excellent performance in terms of energy and position resolutions covers the pseudorapidity range $|\eta| < 3.2$. The bulk of the hadronic calorimetry is provided by a novel scintillator tile calorimeter. The main purpose of the barrel hadron tile calorimeter is to measure electron, gamma, jet and missed energies (E_e, E_γ, E_{jet}, E_{mis}). The tile calorimeter is a cylinder of inner radius 2280 mm and outer radius 4230 mm. The cylinder is subdivided into a central barrel 5640 mm long and two edge barrels 2650 mm long each. Each of the three barrels consists of 64 independent modules. The whole calorimeter system contributes to the very good jet and E_T^{miss} performance of the detector. The LiAr calorimeter is contained in a cylinder with an outer radius of 2.25 m and extends to ±6.65 m along the beam axis. The outer radius of the tile calorimeter is 4.25 m and its length is ±6.10 m.

The calorimetry is surrounded by the muon spectrometer. The air-core toroid system, with a long barrel and two inserted end-cap magnets, generates a large field volume and strong bending power with a light and open structure. Multiple scattering effects are therefore minimal, and an excellent muon momentum resolution is achieved with three stations of high-precision tracking chambers. The ATLAS collaboration approved the use of the Monitored Drift Tube Chamber (MDT) detectors (planes of pressurized drift tubes with an advanced system of monitoring of the detector spatial position) in the muon system for precise determination of coordinates of tracks. The muon instrumentation is complemented with fast trigger chambers. The muon spectrometer defines the overall dimensions of the ATLAS detector. The outer chambers of the barrel are at a radius of about 11 m. The length of the barrel toroid coils is ±13 m, and the third layer of the forward muon chambers, mounted on the cavern wall, is located ±21 m from the interaction point. The overall weight of the ATLAS detector is about 7000 tons.

The responsibility of DLNP within the ATLAS collaboration includes production of 112 muon chambers (20% of the total area of the ATLAS muon spectrometer); production and assembly of the absorber of the Barrel part of the tile calorimeter; calculations of magnetic fields and forces; software development, etc.

In 2000 twenty-four modules (about 6 m long, 20 tons each) of the ATLAS hadron calorimeter were assembled at JINR. A total of 33 modules (250 submodules) out of required 65 (308) were assembled and 30 modules were delivered to CERN.

In 2001 twenty-four new modules and 58 submodules will be produced and delivered to CERN. The quality of the module assembling is controlled by measurements with a specially developed laser system. All produced modules are within tolerance (the deviation from the ideal "envelope" is less than 0.3 mm when the maximum deviation is 0.6 mm).

In 2000 hadron energy reconstruction for the prototype ATLAS barrel combined calorimeter, consisting of the lead-liquid argon electromagnetic and iron-scintillator hadronic parts, with a new non-parametrical method ("e/h method") was performed [9]. The method utilizes only the known e/h ratios and the electron calibration constants, it does not require determination of any parameters by the minimization technique.

The lateral and longitudinal profiles of hadronic showers detected by the prototype ATLAS iron-scintillator tile hadron calorimeter were investigated [10]. This calorimeter uses a unique longitudinal configuration of scintillator tiles. With a fine-grained pion beam scan at 100 GeV, a detailed picture of the transverse shower behaviour is obtained. The underlying radial energy densities for four depth segments and for the entire calorimeter are reconstructed. A three-dimensional hadronic shower parameterization is developed. The intrinsic performance of the ATLAS barrel and extended barrel calorimeters for the measurement of charged pions is studied [11]. Pion energy scans (E = 20, 50, 200, 400 and 1000 GeV) at two pseudo-rapidity points ($\eta = 0.3$ and 1.3) and pseudorapidity scans ($-0.2 < \eta < 1.8$) with pions of constant transverse energy (E_T = 20 and 50 GeV) are analysed. A simple approach that takes account of non-compensation and dead material effects is used for the pion energy reconstruction. The effect of electronic noise, cell energy cuts, and restricted cone size are also investigated.

Architecture of the hadronic calorimeter control system was elaborated, including determinations of functionality of every subsystems and data flows, choice of hardware equipment and software tools. On this basis a pilot project of the high-voltage control subsystem was realized. In the framework of this project technical documentation was worked out, a data base structure, control algorithms and a graphical user interface were developed.

In 2000 the ATLAS Muon Group has done the following amount of work within the framework of the muon part of the project ATLAS:

1. Equipment of the work bay for assembly and test of muon detectors is manufactured, installed and adjusted. The equipment includes:
(i) a facility to measure outer diameters and ellipticity of aluminium tubes before assembling detectors (accuracy 2 μm);
(ii) a semiautomatic detector assembly line with a capacity up to 20 detectors an hour (Fig. 7);
(iii) a tension meter for the anode wire in an assembled detector (accuracy 1%);
(iv) a meter based on X-ray tubes and X-ray-sensitive CCD to measure the position of the wire in relation to the tube axis with an accuracy of 3 μm (Fig. 8);
(v) a fast meter (measuring time 5 min) to measure leakage of the assembled detector to within 10^{-8} bar·l/s (Fig. 9).
(vi) a unit for high-voltage training of assembled detectors filled with the working gas mixture and their dark current level checking (to an accuracy of 1 nA).

2. Mounting and adjustment of machining attachments are accomplished in the work bay for assembly of BMS-type muon chambers. The attachments include:
(i) a highly accurately cut granite plate $2.7\times3.6\times0.6$ m^3 in size;
(ii) a set of seven highly accurate reference "rulers" 2.2 m long each for precisely placing the horizontal layer of detectors;
(iii) an optical system for adjustment of the "rulers" on the granite table to within 0.3 mrad;
(iv) a set of devices (towers) for vertical and horizontal positioning of glued detector layers;
(v) a pneumatic feed-back system to accommodate sagging of the chamber in the course of assembly;

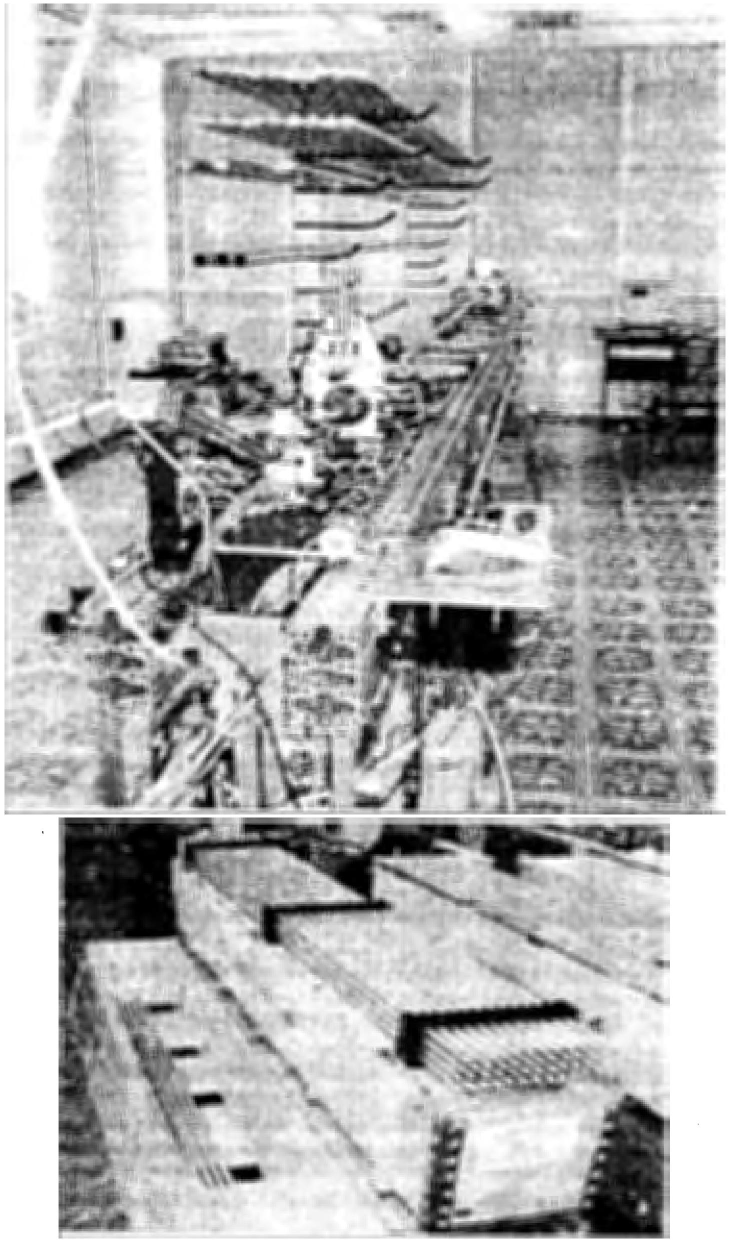


Figure 7: ATLAS Muon Group semiautomatic detector assembly line with a capacity up to 20 detectors an hour.

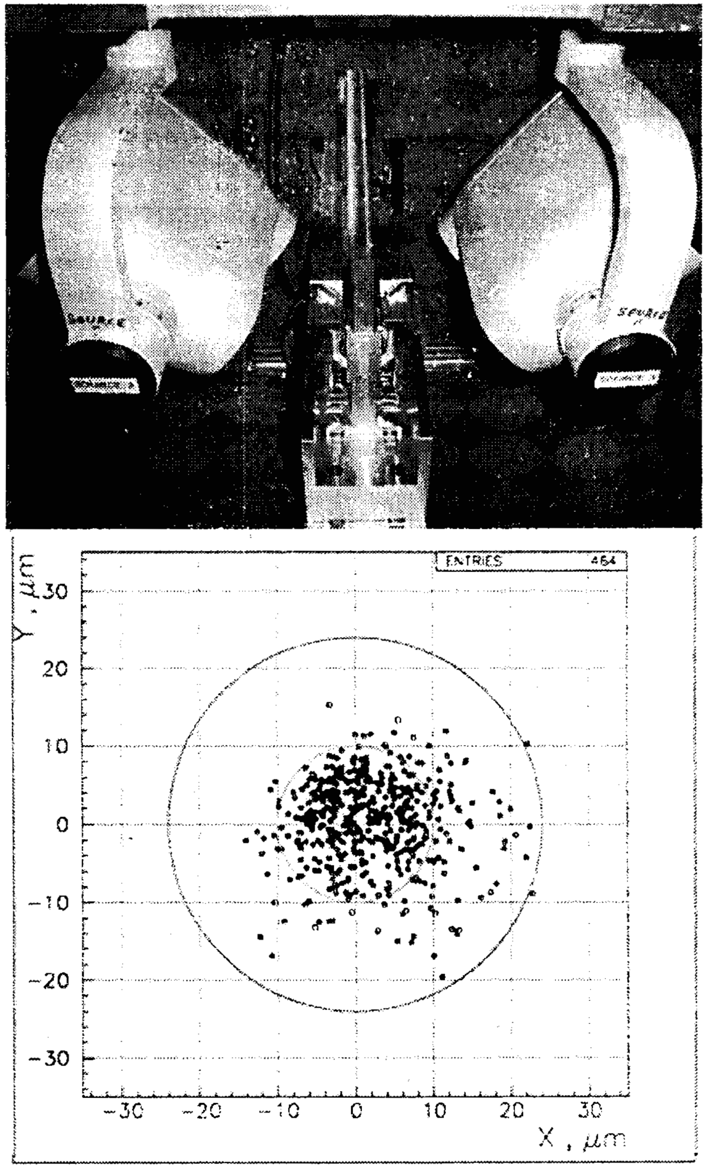


Figure 8: The measuring unit of the meter and the results of measuring the coordinates (position) of the anode wire in the assembled detector.

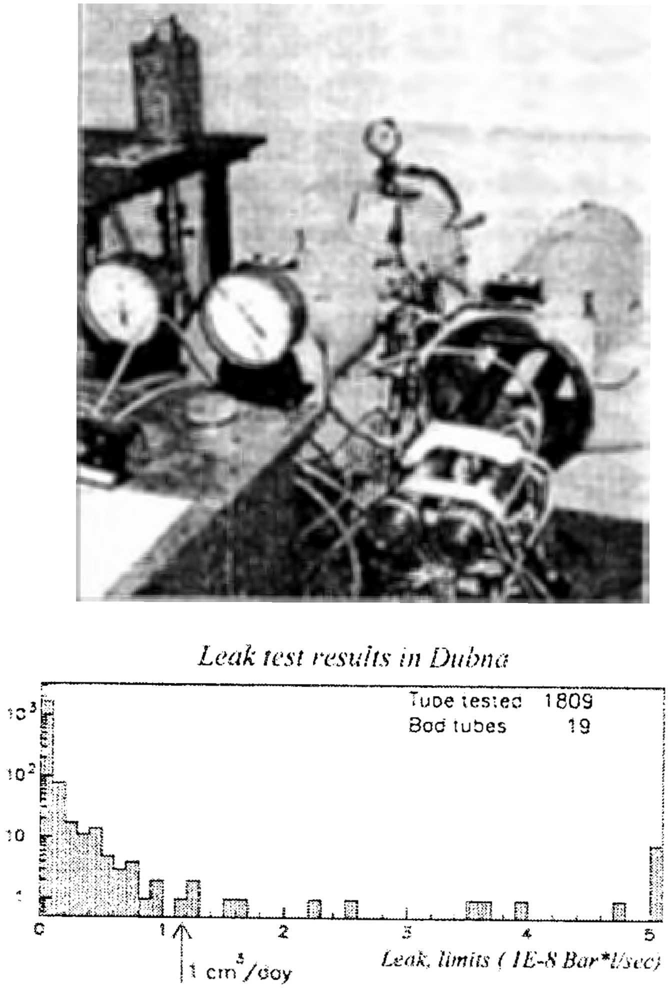


Figure 9: Leakage meter and the measurement results.

(vi) an electron-optical system to check accuracy (within 5 μm) of mutual arrangement of chamber elements in the course of assembly; (vii) an automaton to apply epoxy glue during the assembly of detector layers.

3. Both work bays (for detector assembly and test and for chamber assembly) were accepted by the collaboration acceptance commission in June 2000.

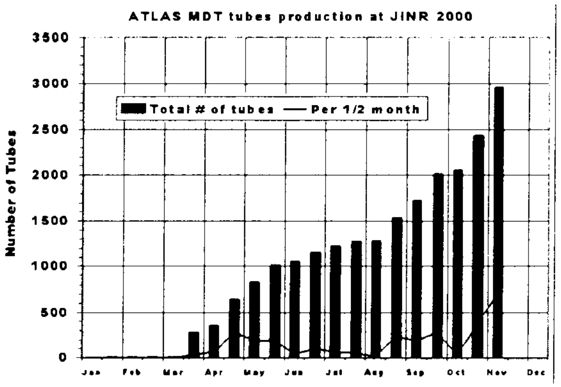


Figure 10: Detector assembly and test rates and the total number of assembled detector.

4. Mass production and tests of the detectors began. The design work bay capacity of 500 detectors was attained in two weeks. Over 2700 detectors were produced up to November 2000 inclusive. The current main problem of the mass production is delay in delivery of aluminium tubes and components by the collaboration. Figure 10 displays detector assembly and test rates and the total number of assembled detector up to November 2000 inclusive according to the work bay data base.

5. The zero module of the BMS chamber is to be assembled by the end of 2000. A four-month delay is due to late delivery of alignment system elements by the Saclay group.

In 2001, according to the muon collaboration plan, the Dubna group is to produce 26 BMS chambers, which requires 4,150,000 roubles.

The **D0** experiment is located at the high-energy accelerator, the Tevatron Collider, at the Fermi National Accelerator Laboratory (USA). The research is focused on precise studies of interactions of protons and antiprotons at the highest available energies. The main themes of the upgrade physics programme are to seek the mechanism of electroweak symmetry breaking through the study of large samples of the top quark and precision measurements of the parameters of the standard model; to make precision tests of the colour force using a variety of probes and measurements in a new region of phase space; to carry out a broad study of *b*-quark hadrons; to search for physics beyond the standard model, etc.

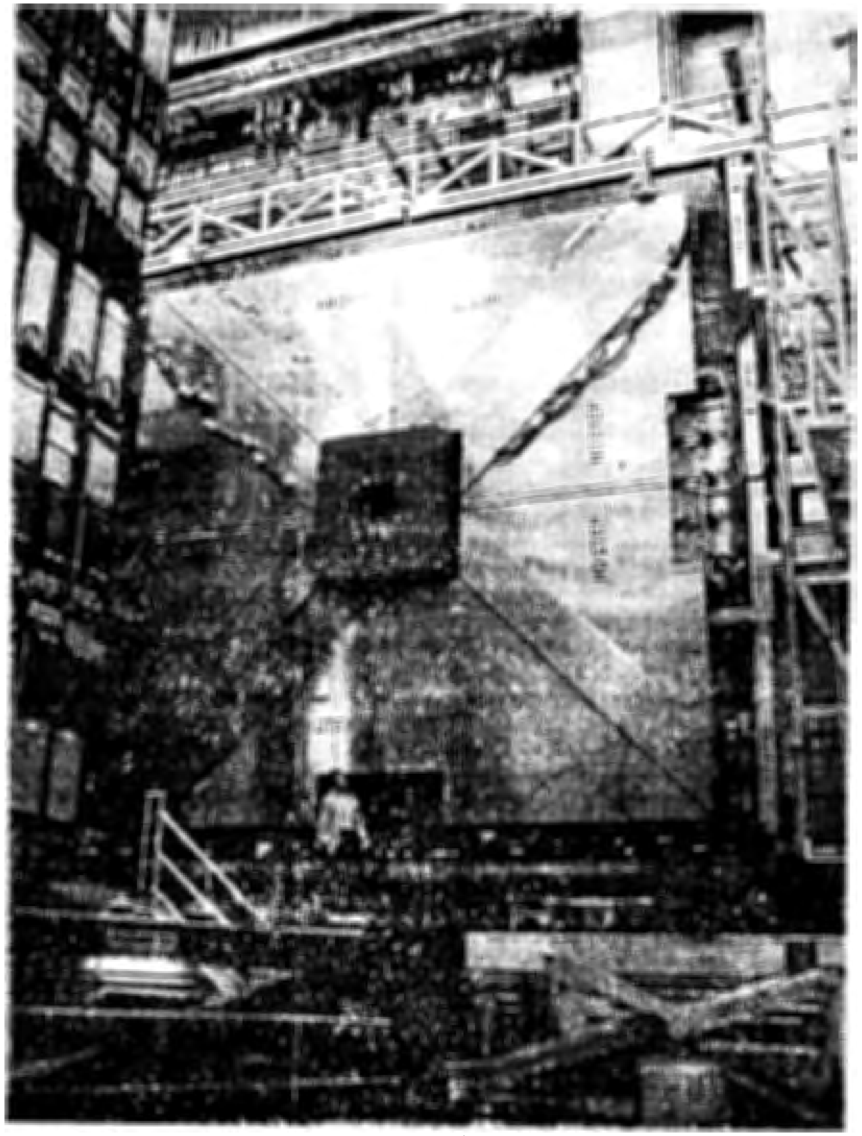


Figure 11: One layer with 8 octants of the forward muon spectrometer installed at the magnit on the D0 setup in summer 2000.

The basic JINR commitments in the D0 project — design and mass production of Mini-Drift Tubes (MDTs) and the corresponding front-end electronics based on ASIC chips for the D0 forward muon system — were completely executed by the DLNP JINR D0 group.

The main purpose of the forward muon system, which comprises about 6500 MDTs and 50000 electronic channels in total, is to measure the muon track with a high accuracy as well as to give coordinate information for the trigger system.

In 2000 the JINR D0 group has finished mass tests of 6500 MDTs in FNAL. Full assembly of forward muon tracker modules (48 octants in total) (Fig. 11) and their tests with cosmic rays were carried out. Commissioning of the entire system started. On-line, off-line and trigger software for forward muon system is developed. The JINR group started participating in development of software the physical analysis of future data.

A new JINR-FNAL Memorandum of Understanding, which covers next period of Tevatron operation (2001–2006), is being prepared for signing. This MoU stipulates new commitments of the D0 group in running the forward muon tracker system, development of on-line and off-line software, participation in data taking and analysis.

In 2001 the forward muon tracker system will be done fully assembled and movied into the working position at the Tevatron collision hall. The full system commissioning will be finished. The system will start to operate at colliding beams up to the highest design Tevatron Run II luminosity of 2×10^{32} cm$^{-2}\times$s^{-1}. The development and support of on-line, off-line and trigger software will take place. Run 2 data taking and analysis will start. In all these activites the JINR D0 group will participate.

In 2000 the **CDF** group of JINR contributed both to software and hardware development of the Silicon Vertex Tracker (SVT), aimed at efficiently tagging b-flavoured events at the trigger level with the Collider detector at Fermilab (CDF). The SVT gives access to physics phenomena where the bottom quark is involved (heavy flavour parameter measurements, CP violation, top quark related measurements)

and possible new physics can be observed. In 2000 the Dubna group participated in:

- software development for data "patterns" to download into the Associative Memory (AM) of the SVT and for generation of the optimal pattern set for the AM;
- estimation of the execution time of the track finding and fitting process;
- development of software tools for testing AM and Hit Buffer boards during the commissioning run on the CDF. Participation in the start of the SVT at FNAL. The beam profile reconstructed by the SVT is shown in Fig. 12;

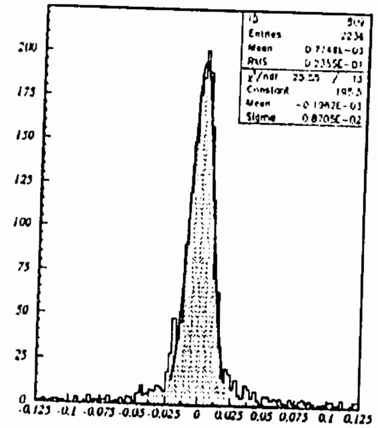


Figure 12: Beam profile reconstructed by the SVT: $\sigma = 87 \mu$m.

- development of the software and hardware tools for testing AM boards during mass production.

In 2000 a set of long (1.6–3.2 m) Scintillating Counters (607 units) for the new muon trigger of the Upgraded CDF were assembled, tested and delivered to FNAL. The counters weigh 5285 kg and cover an area of 271 m^2 around the CDF. These counters were tested with cosmic muons and radioactive sources. The yield of photoelectrons (Fig. 13) is sufficient for CDF needs (30 in average) and guarantees a high efficiency of the μ-trigger for the long Run II data taking period.

For more efficient π/K separation (important for B-physics investigations) the simulations were performed for the proposed Time-of-Flight (ToF) system based on the scintillating fiber bundle.

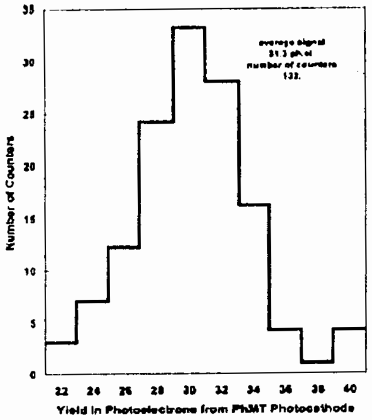


Figure 13: Yield of photoelectrons from scintillator counters for the new muon trigger of the Upgraded CDF

In 2001 the JINR CDF group plans to obtain new data on b and t quark physics, to search for CP-violation in the B-decays, to study B_s-mixing, to search for Higgs particles and new phenomena beyond the standard model and to study processes with ultrahigh multiplicity ($n \gg \bar{n}$). Data analysis will be started parallel to data taking at Run II (2001–2004).

JINR physicists will maintain the SVT and MUON systems during Run II; carry out R&D for the ToF system to separate π/K from B decays with the resolution $\tau(\text{ToF}) < 100\,\text{ps}$, and develop hardware and software for the SVT to increase its efficiency and to reduce the SVT decision time.

The main goal of the **COMPASS** experiment (NA58, CERN) is investigation of the hadron structure and hadron spectroscopy, which are both manifestations of non-perturbative QCD. With hadron beams three main issues are addressed: studies of charmed hadrons, spectroscopy of light quark systems and glueballs, and investigation of the hadronic structure of unstable particles with the use of Primakoff reactions. Measurement of the cross section asymmetry for open charm production in deep inelastic scattering of polarized muons on polarized nucleons will allow the gluon polarization ΔG to be determined.

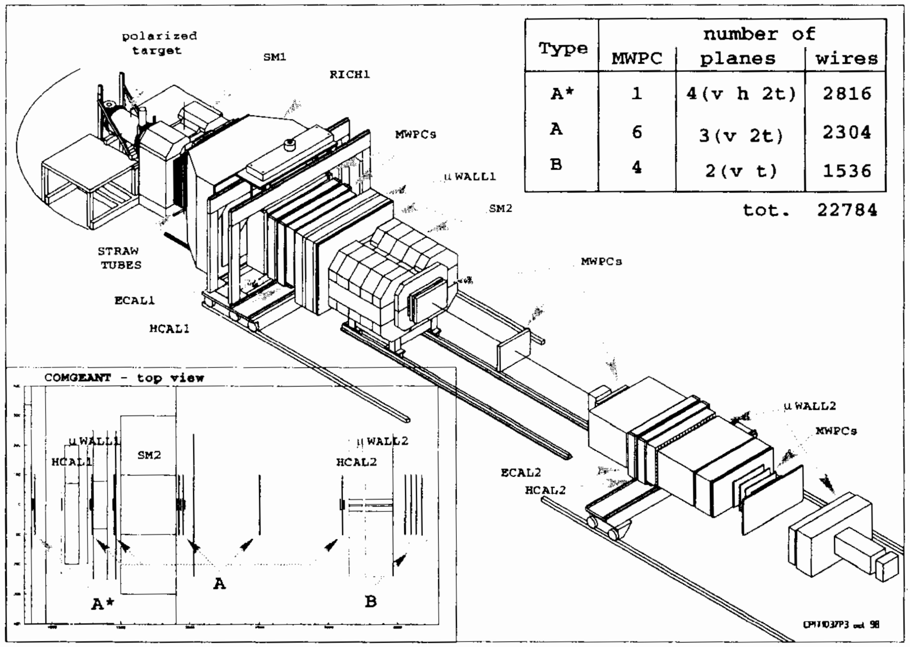
To perform these measurements a new state-of-the-art spectrometer with excellent particle identification and calorimetry is proposed. It

will be capable of standing beam intensities up to $2 \cdot 10^8$ particles/spill. Dedicated triggers and fast read-out complement the outstanding performance of the spectrometer.

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 systems.

The first runs for physics with the COMPASS spectrometer are scheduled for 2001–2002 at CERN.

The common DLNP-Torino responsibility (O.Denisov (chambers) and A.Maggiora (electronics)) in the COMPASS collaboration is construction of a system of miltiwire proportional chambers (MWPC). A total of 13 chambers are to be intalled (Fig. 14) in the initial setup



Type	MWPC	number of planes	wires
A*	1	4(v h 2t)	2816
A	6	3(v 2t)	2304
B	4	2(v t)	1536
		tot.	22784

Figure 14: Multiwire proportional chambers in the COMPASS initial setup.

(25.000 channels of electronics). Another DLNP responsibility is construction of the muon filter of the first spectrometer (μ-wall 1) — 16 chamber planes consisting of 1200 Proportional Tubes equipped with front-end electronics. The DLNP group is also participating in development of the reconstruction programme for the COMPASS apparatus and simulation of physics processes for optimization of triggers and detector design.

In 2000 the first COMPASS test beam run was completed with the impressive results obtained by the joint Dubna-Torino group: 6 proportional chambers (provided by Dubna) and instrumented with 1500 channels of front-end electronics (Torino) were successfully brought into operation complying with the nominal COMPASS spectrometer running conditions (high beam rate up to 2×10^8 muons per spill); above 50 million events were recorded with the Dubna-Torino system of MWPCs serving as the basis system to fulfill two main COMPASS collaboration obligations in 2000: COMPASS muon trigger test and the test of the First spectrometer.

In 2001 8 more chambers should be prepared for inatallation into the COMPASS initial setup.

In 2000 the COMPASS Muon Wall-1 group (leader G.Alexeev) obtained the following main results. All MW1 detectors (about 1100 proportional tubes, 8 wires per each tube) are produced in JINR, shipped to CERN and tested there. All analog front-end electronics (300 Amplifier-Discriminator Boards comprising about 10000 channels) is made and tested in JINR. Detector support frames are designed, the workshop for their production is prepared in DLNP, and the first two real-size frames are produced and shipped to CERN for tests. The MW1 prototype was investigated with M2 test beam at CERN and the working gas mixture was fixed (Fig. 15).

In 2001 the COMPASS Muon Wall-1 group plans to finish mass production of MW1 support frames; to assemble the whole MW1 (detectors, frames, electronics) at CERN; to commission the MW1 subsystem (high voltage, low voltage, gas system, front-end electronics, readout); to develop software for the on-line monitoring and control as well as for muon track reconstruction. The group will also participate in data taking and further data analysis.

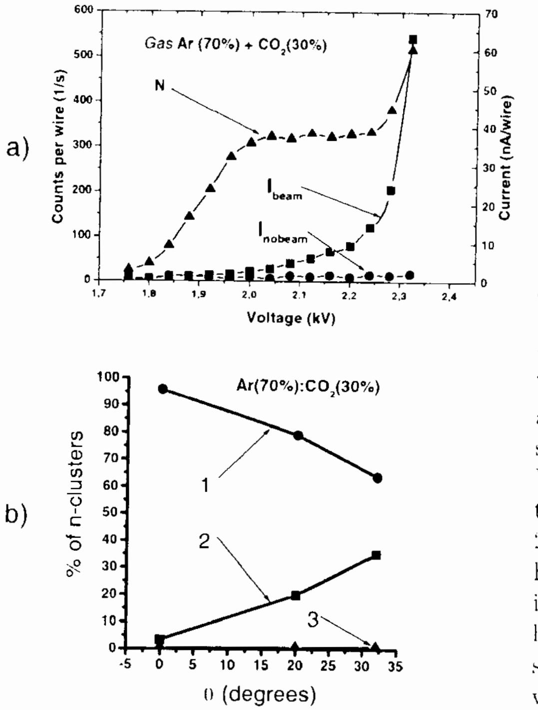


Figure 15: COMPASS proportional tubes characteristics for working gas mixture: a) dependence of singles counting rate with beam "on" (N) and currents through a detector (I) with beam "on" and "off" versus high voltage on detector: the plateau of stable performance equals to 250 V (starts at 2.0 kV, when detector is fully efficient and stops at 2.25 kV at abrupt current rise); b) hit clusterization versus particle incoming angle average number of fired wires (1.2 and 3 respectively) per detector plane at working voltage 2.1 kV.

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). The goal of the experiment is to study nucleon-nucleon interactions and in particular their tensor component, which can reveal the nature of the triton binding energy. To this end, in 1998 the polarized target was modernized and the first test run was successfully carried out. The new polarized target has radically new opportunities for production and measurement of polarization for different nuclei. In 2000 a new device for ultralow temperature measurements based on a 4-wire automatic bridge was constructed [16]. 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)". To speed up the data collection and to improve the signal/background ratio it is planned in 2001 to modify the neutron detectors of the existing setup and to introduce the technique of n/γ separation using pulse shape. In 2000 the containers for liquid scintillator and monitor counters were developed and their production is organized at the workshops of the Institute of Particle and Nuclear Physics (Prague). All registration systems were tested with fast neutrons and the coefficient of the background suppression was in the range 300–400.

In 2001 the electronics for a few channels ($5 \div 10$) will be constructed and the design of new detectors will be improved to increase the efficiency of registration.

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 aJINR member state untill recently.

In 2000 the analysis of the data on K-meson decays earlier obtained at the Serpukhov accelerator with the **HYPERON** spectrometer (SERP-167) was continued.

The very accurate investigations of the charged and neutral decays of kaons provide important fundamental information about violation of the CP-symmetry, properties of the effective (chiral) QCD Lagrangian and new physics phenomena (supersymmentry, techicolour, extra dimensions, etc).

At the end of 1999 a tentative value of the vector form factor slope parameter $\lambda_+ = 0.0277 \pm 0.040$ was obtained for the $K^+ \to \pi^o e^+ \nu$ (K_{e3}-decay). It is based on 14000 events, which account for only 1/4 of all experimental data selected on processing. It is necessary to point out that this result was obtained at the HYPERON-2 setup with the analyzing magnet, which was absent in the preceding setup. The result is in good agreement with the world average value $\lambda_+ = 0.0286 \pm 0.0022$. The data analysis is continued to check the presence of non-zero values of the scalar and tensor terms in the K_{e3} matrix element, which were found by the HYPERON collaboration a few years ago.

In 2000 the analysis of the K_{e3}-decay was carried out with the same setup but with a new trigger condition (so-called "soft" trigger) to exclude the possible "bias" for the earlier data. The result is $\lambda_+ = 0.0295 \pm 0.0045$ for 7000 events. This result shows that the old trigger condition does not bring in any bias and therefore all collected data samples can be summarized in the new data analysis [17].

In 2001 the investigation of the decays K^+_{e3}, $K^+ \to \pi^0\pi^{0+}\nu$ (K_{e4}-decay), $K^+ \to \pi^+\pi^0\gamma$ and $K^+ \to \pi^0 e^+\nu\gamma$ will be carried out. The new data taking is not planned so far.

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 to accumulate statistics for precise measurement of the pion beta-decay rate was continued in 2000. Statistics obtained allows the decay rate to be determined with about 0.7% accuracy. The PIBETA setup worked steadily in the almost automatic mode. All current parameters and operation of the setup are remotely controlled via Internet. Full information about data taking (counting rates, detector histograms, event display etc.) is available in real time via Internet. During the whole year 2000 filtering and analysis of the experimental data were continued [18].

The preparation to a precise measurement of radiative pion decay ($\pi \to e\nu\gamma$) was started. It was noticed [19] that a tensor interaction (forbidden in the standard model) could contribute to this decay. A new trigger was suggested which allow the $\pi \to e\nu\gamma$ events to be collected simultaneously with the data taking for the study of the pion beta-decay. A Monte-Carlo simulation performed in DLNP shows a good efficiency for $\pi \to e\nu\gamma$ decay registration with the new trigger. This allows one to increase the sensitivity of the experiment to possible tensor interaction by a factor of 10 in comparison with the earlier

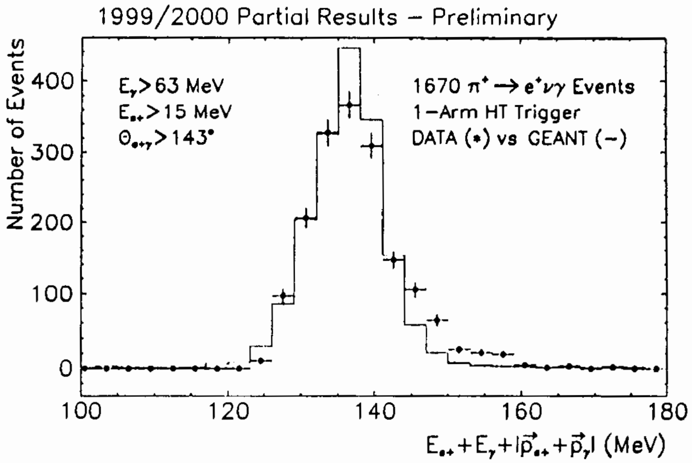


Figure 16: Pion invariant mass of the decay$\pi \to e\nu\gamma$.

experiment. This new trigger was accepted by the collaboration and included in the combined trigger of the setup. Data filtering of the available statistics for radiative pion decay study is started (Fig. 16).

In 2001 the data taking and analysis of the experimental data for pion beta-decay will be continued. New anode wire electronics and a new cylindrical proportional chamber will be manufactured for the PIBETA setup. The intermediate result of precise measurement of the pion beta-decay rate (to an accuracy of 1%) is expected to be published.

The *muon-catalyzed fusion* is an interesting and unique process having neutron yield of nuclear fusion dependent on the macroscopic parameters of a medium (temperature, density and medium content). In particular, the study of the processes of the muon catalyzed fusion allows one to solve the fundamental three-body problem with Coulomb interaction with relativistic corrections.

The investigations of the parameters of muon-catalyzed fusion in double (Deuteruim/Tritium) and triple (Protium/Deuterium/Tritium) mixtures of hydrogen isotopes at high temperature and density are under way at the Dzhelepov Laboratory of Nuclear Problems in col-

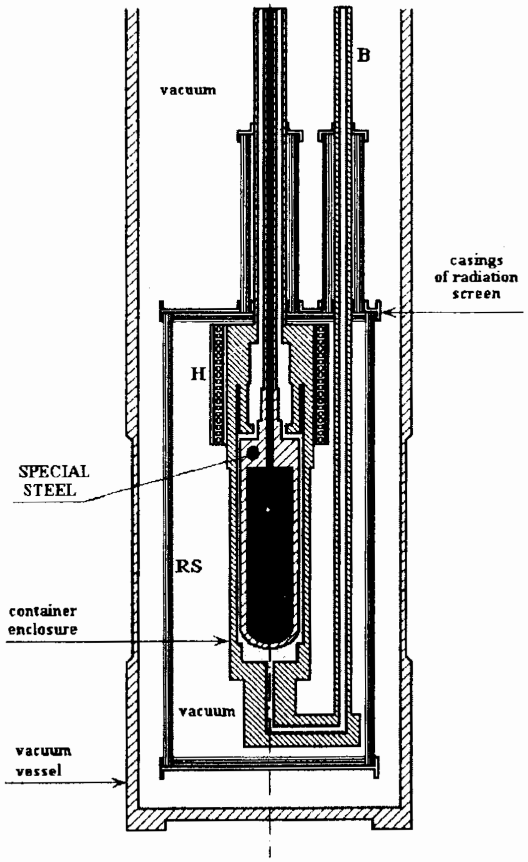


Figure 17: Schematic view of the Tritium High Pressure Target. A target container, B tube for the cooling agent (hydrogen) and the path for pumping the diffusing tritium. H heater, RS radiation screen.

laboration with the Russian Federal Nuclear Centre, (Sarov), St. Petersburg Nuclear Physics Institute (Gatchina), Russian Research Centre Kurchatov Institute (Moscow) and Delft University of Technology (The Netherlands).

The study is being conducted with the **TRITON** setup at the muon beam channel of the JINR phasotron. Measurement of the so-called effective parameters (cycling rate λ_c, neutron yield Y_n and muon loss ω) of the muon catalyzed processes in the mixtures of hydrogen isotopes is the main aim of the experiment.

The unique Tritium High Pressure Target (THPT) (Fig. 17) with the volume 16.5 cm^3, working temperature range $300 \div 800$ K and pressure $P \leq 1600$ atm was designed, constructed and used in the experiments. The purity of hydrogen isotopes at a level of 10^{-7} was provided by the original Gas Mix Preparation System. The molecular composition of the mixtures was checked with the aid of chromatography.

In 2000 with the Tritium High Pressure Target the above-mentioned effective parameters (cycling rate λ_c, neutron yield Y_n and muon loss ω) were measured [20] in the double D/T mixture (at temperature 300–800 K and density 1.275–$2.55 \cdot 10^{22}$ nuclei/cm^3) and in the triple H/D/T mixture of hydrogen isotopes (with dependence on protium concentration at temperature 300 K and fixed density of D/T fraction in H/D/T mixture).

The preliminary analysis of the dependence of the cycling rate λ_c on the tritium concentration C_t was performed (Fig. 18). The results for the $dt\mu$-mesomolecule formation rates on DD and DT molecules were obtained. Considering the results for the dependence of cycling rates on the tritium concentration one should conclude that the theoretical resonant mesomolecule formation rates (see Fig. 18) are far greater than the experimental ones. The same conclusion was made in [21].

In 2001 the collaboration plans to conduct a more thorough analysis and take additional measurements in the double D/T mixture at higher tritium concentrations (up to 90%). For the determination of the $dt\mu$-molecule formation rate on HD molecules (which is not yet measured) the collabortion plans to perform new systematic investigations with triple mixtures at the highest available temperatures (up to 800 K).

In 2000 the **DUBTO** self-shunted streamer chamber in a magnetic field, equipped with two CCD videocameras for studying pion interactions with light nuclei at the JINR phasotron, operated during several runs of data taking. The chamber was filled with ^{4}He at the atmospheric pressure. The technique of CCD videocameras has never been applied in experiments for visualization of particle tracks, so special software was developed for measuring digitized CCD images of nuclear events in the streamer chamber volume and for reconstruction of the reactions in space.

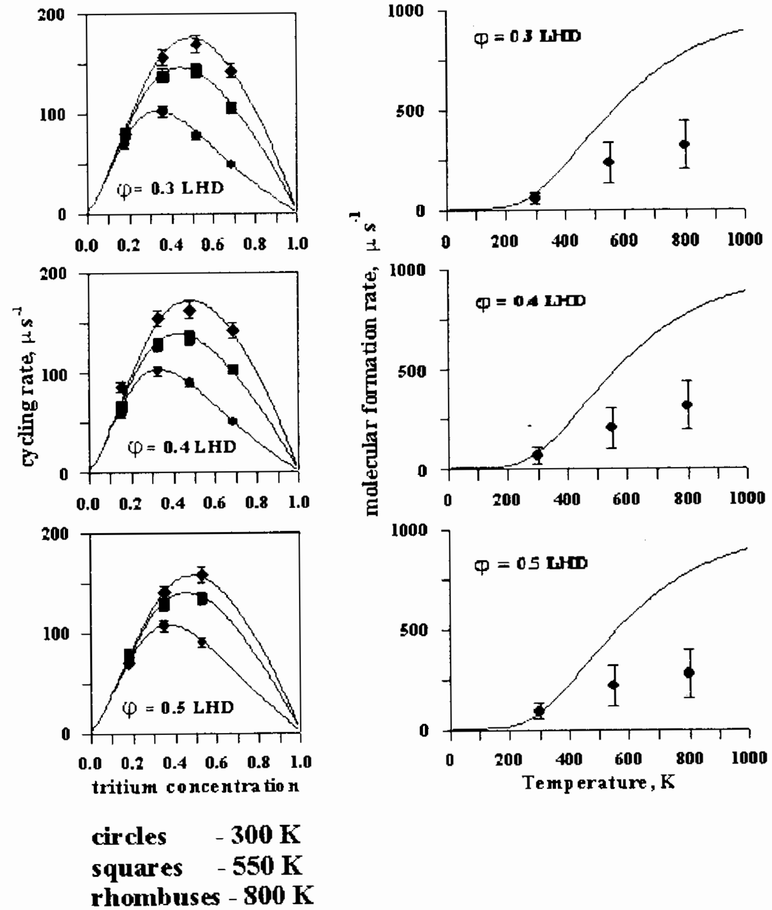


Figure 18: Dependence of the cycling rate on the tritium concentration $\lambda_c(C_t)$. Left: experimental data (points) and the best fit (curves) for $\lambda_c(C_t)$ at the density of the mixture 0.3–0.5 LHD (1 LHD $= 4.25 \cdot 10^{22}$ nuclei/cm^3). Right: $dt\mu$-mesomolecule formation rates $\lambda_{dt\mu-t}$ versus temperature (points) and theoretical expectations for the temperature dependence of $\lambda_{dt\mu-t}$ (curves, from P. Ackerbauer et al., Hyp. Int. 101/102 (1996) 67; M.P. Faifman et al., ibid., 179]).

Particle identification is based on kinematic relationships and on analysis of the luminosity of particle tracks, which is proportional to the ionization losses in the gas target. The brightness of the CCD image of a particle track is proportional to the actual amount of light reaching the pixels of the CCD matrix, unlike the case in photographic registration, where the track brightness is logarithmically proportional to the light incident upon the film.

Figure 19: The CCD stereo images of a ^{4}He breakup event.

Figure 19 shows the CCD stereo images of a ^{4}He breakup event, in which the pion, proton and tritium tracks in the reaction $\pi^+ + ^4\mathrm{He} \to \pi^+ + p + ^3\mathrm{H}$ are clearly identifiable.

The plots in Fig. 20 demonstrate the radial distributions of brightness for different tracks. Unambiguous identification of the charged particles and measurement of invariant masses involving strongly ionizing particles seems to make possible an analysis of the energy spectrum of excited nuclear states of the ^{4}He nucleus, and also of other quantities involving heavy secondary particles produced in the pion-helium reactions.

In 2001 the measurements and analysis of the obtained physical information will be continued.

With the spectrometer **ANKE** at the proton synchrotron COSY (Jülich) the A-dependence of the double differential cross section of the K^+-meson production in proton-nucleus collisions was measured at the proton energy above the threshold of the kaon production in proton-nucleon collisions (1.58 GeV) and in the subthreshold region [22]. The goal of the experiment is to distinguish (in the threshold energy region) two main reaction mechanisms, direct kaon production on a single nucleon with a high Fermi momentum (one-step mecha-

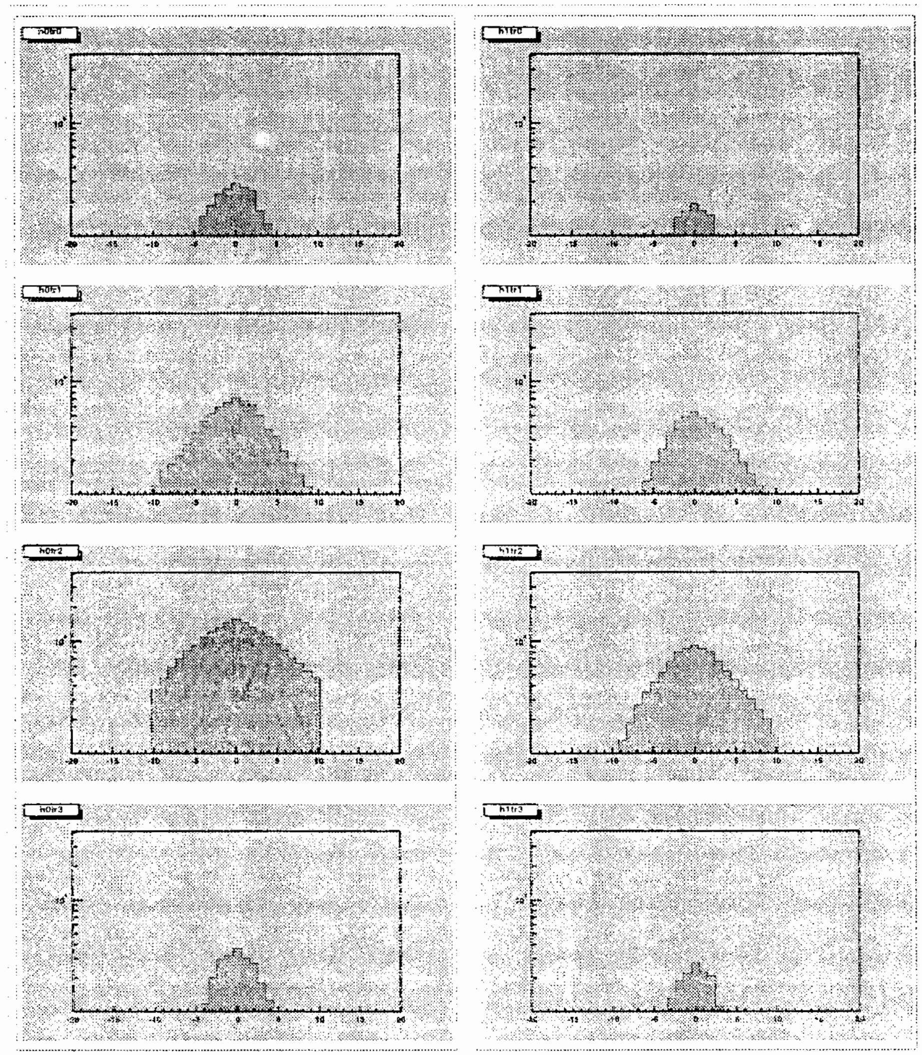


Figure 20: Radial distributions of brightness for different tracks. Top to bottom: incoming pion, proton, tritium, outgoing pion.

nism) and intermediate pion production followed by the $\pi N \to K^+\Lambda$ reaction in the same nucleus (two-step mechanism). At 2.3 GeV the dependence is close to $A^{2/3}$, which corresponds to the mechanism of direct production by the projectile on a nucleus proton. At the subthreshold energy a considerable deviation from $A^{2/3}$-dependence is observed, which indicates the cumulative nature (two-step mechanism) of the process.

Experimental data on ω-meson production on the neutron are obtained for the first time with the spectrometer ANKE in the reaction $pd \rightarrow d\omega p$ at 2 GeV.

The ANKE detector systems for studying the cumulative breakup of the deuteron by the proton (COSY Project 20, spokesman V.I.Komarov) are commissioned at the beam. The knockout of proton pairs with a small relative momentum at very small angles $p + d \rightarrow (pp)(0^o) + n(180^o)$ [23] was observed in exposure of the deuterium cluster target to a 0.5-GeV proton beam.

The lifetime of the negative muon in the ^{129}Xe isotope was measured for the first time at the DLNP JINR phasotron under the project **MUON** (Investigation of the muon properties and the muon interactions with matter). This value was compared with that obtained for the ^{132,136}Xe isotopes. The noticeable dependence of the nuclear muon capture rate on the mass number for the isotopes in question is observed (the isotopic effect in the nuclear capture of the negative muon in xenon) [24].

Preliminary measurements of the magnetic moment of the negative muon in the 1S-state of different atoms were performed at the μE4 beamline of the Paul Sherrer Institute accelerator (Switzerland). The negative muon in the bound state should possess a magnetic moment different from that of the free muon due to relativistic motion. Up to now there have only been three measurements of the magnetic moment of the negative muon in the 1S-state of different atoms and for light atoms there is a discrepancy in the results for Mg, Si and S atoms. The measurements of the muon magnetic moment in carbon, oxygen, magnesium, and silicon confirm that the magnetic moment of the negative muon bound in the Coulomb field of the nucleus differs from the one of the free muon [25].

In 2000 the study of condensed matter by the μSR-technique was continued under the project MUON. The μSR experiments with silicon

carried out in 2000 were aimed at investigating the effect of impurities on the relaxation rate of the magnetic moment of the shallow acceptor centre. The measurements were carried out on several silicon samples with phosphorous and aluminium impurities of different concentrations. The temperature dependence of the relaxation rate of the Al shallow acceptor centre in undeformed silicon is determined for the first time. The constant of the hyperfine interaction between the magnetic moment of the muon and that of the electron shell of the muonic atom and the coefficient for capture of free electrons by a neutral aluminium atom in silicon are estimated [26].

The study of the $Ce_3Pd_{20}Si_6$ compound, one of the heaviest electron system, was carried out in 2000. Below 0.4 K the increase of the muon spin depolarization rate represents development of quasi-static ordering of magnetic moments of electronic origin supposedly random oriented. The clear frequency shift of muon spin precession at the external transverse field was seen. This fact may be attributed to the increasing total moments of the superparamagnetic cube containing 8 Ce atoms and their ferromagnetic ordering with decreasing temperature [27]. The investigation of the system $Ce_3Pd_{20}Ge_6$ is also started.

The feasibility experiments were performed to investigate the properties of a liquid crystal whose molecule contains iron atoms. The compounds of this type are of interest from the point of view of obtaining liquid crystals with magnetic properties. The results obtained do not contradict the suggestion that the iron ions form an antiferromagnetically ordered structure in this liquid crystal at the temperature below 80 K [28].

The JINR-PNPI collaboration prepares a setup for searching for the two-particle muon decay on an electron and Goldstone's massless boson (**FAMILON** porject). This decay violates the lepton number conservation law and therefore is forbidden in the standard model.

In 2000 the assembling of the proportional chambers for the spectrometer was finished and the methodological tests were performed in PNPI. The new data acquisition system was also tested. The equipment was transported to Dubna and was assembled on the surface muon beam of the JINR phasotron. The adjustment of the chambers was performed. The data acquisition was tested in the actual conditions, the tests with radioactive sources were performed.

The Monte-Carlo calculations demonstrated that with the present configuration of the FAMILON setup the energy resolution for the muon decay positrons at a level of 10^{-3} can be reached. The resolution allows one to achieve 3-fold improvement of the TRIUMF results. In the present experimental conditions (when 10^5 muons stop per second in the target and the angle aperture is equal to $\pm 5^o$) the resolution can be obtained during 300 hours of data taking.

In 2001 progress in the study of the two-body decay of the muon would be provided by the use of the "active target" consisting of foils and thin drift chambers in the magnet. A prototype of the "active target" is prepared at PNPI.

Precision measurement of the 277-keV γ-ray produced by capturing muons in gaseous oxygen $\mu^- + {}^{16}\mathrm{O} \rightarrow \nu + {}^{16}\mathrm{N}^{**} \rightarrow {}^{16}\mathrm{N}^{*} + \gamma$ was performed with high-resolution HPGe detectors at the PSI $\mu E4$ channel (**AC/μC** project). The Doppler-broadened shape of this line is sensitive to the possible admixture of genuine scalar interaction to muon capture. This experiment complements, in the muon sector, similar ones undertaken recently in nuclear β-decay.

Although V–A interaction is postulated in the standard model, the modern extensions of this model (like R-parity violating supersymmetry, leptoquarks, etc) allow a possible admixture of fundamental S-coupling. The genuine scalar interaction C_S would contribute to various observable quantities in ordinary muon capture summed with the induced scalar coupling g_S which is expected to be small. A fit (Fig. 21) to the experimental line shape allowed one to obtain the recoil-gamma correlation coefficient value $a_2^1 = 0.096 \pm 0.041$ (95% C.L.).

In evaluation of the contributing nuclear matrix elements this value constrains the range of the scalar coupling constants to $-0.25 < C_S < -0.07$ (95% C.L.). The inaccuracy is dominated by the range of possi-

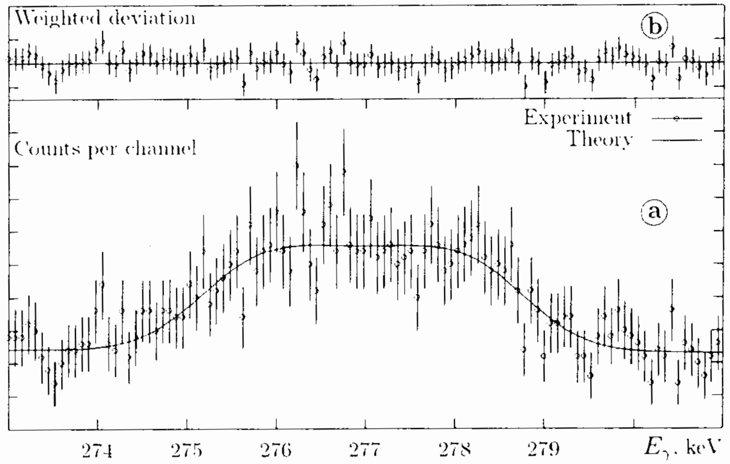


Figure 21: Result of the elementary fit: experimental and adjusted line shapes.

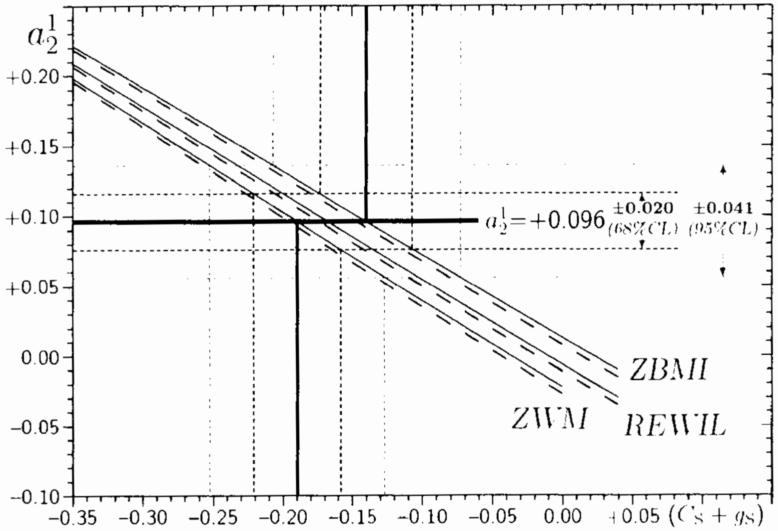


Figure 22: Transformation of the correlation coefficient a_2^1 to the $C_S + g_S$ value with different theoretical models.

ble variations of the nuclear matrix elements and thus could be reduced in the future (Fig. 22). This constraint is independent of the PCAC-prediction for the induced pseudoscalar coupling questioned recently in radiative muon-capture [30].

The β-decay of ^{32}Ar accompanied by proton emission is the goal of the next experiment under the **AnCor** project (Investigation of beta-neutrino angular correlation in superallowed beta-decay of short-lived nuclei). The fundamental aim of the project is accurate measurement of the couplings of scalar and tensor weak interactions, forbidden in the standard model.

The β-p coincidence technique used in the experiment allows one to measure a *shift* rather than a *spread* of protons following the β-decay. As the Doppler effect in β-p correlations ($\sim 1/v_p$) is essentially larger than in β-γ correlation ($\sim 1/c$), one should expect a greater sensitivity of the ^{32}Ar experiment in comparison with the previous ^{18}Ne measurements of the AnCor collaboration.

A successful test run was carried out at GANIL (Caen, France) in 2000. The quality of the ^{32}Ar beam, the experimental conditions and the characteristics of the detector prototypes were found to meet the requirements. The main experiment is scheduled for 2001–2002. The experimental setup is under construction.

The international experiment **NEMO-3** is aimed at studying nuclear double beta decays with the potential to measure a Majorana neutrino mass at the level of 0.1 eV. About 50 scientists from Russia, France, USA, Finland and Czech Republic take part in this project. A total of 10 kg of isotopically enriched samples (^{100}Mo, ^{130}Te, ^{82}Se, ^{150}Nd, ^{96}Zr, ^{48}Ca) will be measured simultaneously with the NEMO-3 setup to investigate both neutrinoless and two-neutrino modes of double beta decay.

During 2000 the main part of the NEMO-3 detector was assembled in the Frejus underground laboratory (France) at the depth of 4800 metres of water equivalent. The detector consists of 6180 Geiger counters and 1940 plastic scintillators assembled into 20 segmented sectors. In 2000 eight sectors were mounted with isotopically enriched ^{100}Mo, ^{130}Te and control non-enriched samples. The first test runs were carried out with three totally equipped sectors. The test runs showed perfect capability of the setup with expected background counting rate. Several calibration measurements with the ^{60}Co and ^{207}Bi sources were

performed and gave the first useful information about the real energy and time resolution of the detector [31]. Special computer programs are developed for data taking and analysis.

In 2001 the collaboration plans to assemble all 20 sectors of the NEMO-3 detector, to construct the iron shield around the detector, to develop and construct the neutron shielding. In November 2001 the detector will start the long-term data collection with 10 kg of isotopically enriched samples.

Search for the Double Beta Decay of ^{48}Ca was fulfilled in the Radiochemical departrent of DLNP with the **TGV** setup. The TGV collaboration has studied the double beta decay of ^{48}Ca with a low-background and high-sensitivity Ge multidetector spectrometer TGV (Telescope Germanium Vertical). The results $T_{1/2}^{2\nu\beta\beta} = (4.2\ ^{+3.3}_{-1.3}) \times 10^{19}$ years and $T_{1/2}^{0\nu\beta\beta} > 1.5 \times 10^{21}$ years (90% C.L.) for double beta decay of ^{48}Ca were obtained after the processing of the experimental data collected within 8700 hours of measurement with approximately 1 gramme of ^{48}Ca [32].

In 2000 the International Germanium EXperiment (**IGEX**), on investigation of the double beta decay modes of germanium, analysed about 10 kg-years of data from isotopically enriched (86% in ^{76}Ge) germanium detectors. During 2000 the experiment was conducted simultaneously in Canfranc (Spain) and Baksan (Russia) for collection of data for double beta decay with three 2-kg detectors at Canfranc (2450 metres of water equivalent) and with four 1-kg detectors in the underground laboratory (660 m w.e.) at Baksan. The average background level of about 0.15 counts per keV$\times$kg$\times$yr was achieved for all detectors. With Pulse Shape Discrimination applied to the recent data, the lower bound on the half-life for neutrinoless double beta decay of ^{76}Ge was deduced: 1.57×10^{25} yr (90% C.L.). This corresponds to the upper bound on the Majorana neutrino mass between 0.33 eV and 1.35 eV depending on the choice of theoretical nuclear matrix elements used in the analysis.

In 2001 construction of the fourth 2-kg detector will be completed and the detector will start to operate. Data collection aimed at searching for dark matter and the neutrinoless and two-neutrino double beta decays with four 2-kg detectors at Canfranc (with Pulse-Shape Discrimination) will be continued.

In 2001 the Baksan group will continue data collection with four 1-kg detectors aimed at searching for both dark matter and double beta decay in the old underground laboratory (660 m w.e.) and will make its best to begin measurements in the new deep underground laboratory (5000 m w.e.) at Baksan.

The behaviour of the basic characteristics of the *silicon and germanium detectors* in the temperature range 1–77 K is thoroughly studied [34]. A device varying the detector temperature in various steps and maintaining it to 0.1 K for a long time (over 24 hours) is developed. Limits of using the most popular types of semiconductor detectors as spectrometric instruments at ultralow temperatures are investigated with a view to requirements of some physical problems, such as search for dark matter, study of oriented radioactive nuclei, etc. It is shown

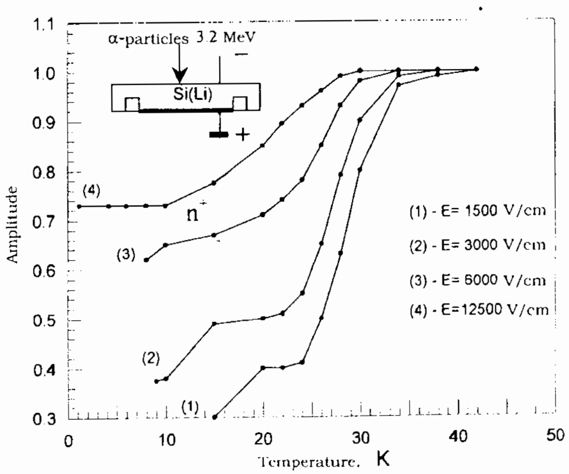


Figure 23: Signal amplitude as a function of the temperature for various bias voltages applied to the detector.

that silicon and germanium detectors can retain spectrometric properties down to 1 K under certain conditions. The investigated detectors of each type (surface-barrier, implanted, and lithium-drift ones) have specific features of their own to be taken into account under cryogenic conditions. It is shown for the first time that Si(Li) detectors

of secondary particles can be used in the temperature range 1–10 K (that the effect of their "polarizations" can be eliminated) if high (over 12500 V/cm) electric fields are generated (23).

Contribution of the R-parity violating *supersymmetry* to the muon-to-electron conversion is studied, new stringent constraints on the R-parity violating parameters are obtained from the the experimental data. The significant contribution from the strange nucleon sea is found. Effect of resonant enhancement of Majorana neutrino contribution to the semileptonic K-meson decays is predicted and studied. Stringent constraints on masses and mixings of heavy neutrinos are derived. Generic properties of lepton number violating processes and their relation to different entries of the Majorana neutrino mass matrix are studied. New phenomenological, astrophysical and cosmological issues of sterile neutrinos are investigated. Their impact on the accelerator neutrino counting experiments, big bang nuclear synthesis and supernova explosion are analysed [35]. New single spin CP-odd asymmetries in polarized proton-proton scattering are proposed. Mechanisms beyond the standard model generating these asymmetries are found and possible size of CP-violating effects is predicted [36].

In 2001 under the supersymmetry phenomenology project in DLNP, the sterile neutrinos in SUSY models will be studied; the formalism for the muon-to-(anti)muon, electron, positron conversion will be developed; general properties of the lepton number/flavour violation and relation between neutrino oscillations and rare decays will be investigated. The CP-violation in meson decays as well as SUSY mechanisms of CP-violation will also be considered. The role of the large extra dimensions in the rare processes will be studied.

Relativistic nuclear physics

The **FASA** project studies the mechanism of the "nuclear thermal multifragmentation" induced in heavy targets by light relativistic ions. The FASA collaboration includes scientists from Dubna, Kurchatov Institute, Institute for Nuclear Research (Moscow), H.Niewodnicz-

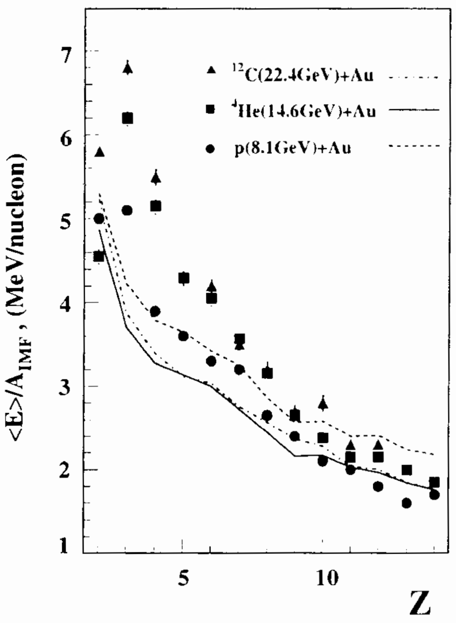


Figure 24: Mean kinetic energies per nucleon of outgoing fragments with charge Z measured at $\theta = 89^o$ for p (8.1 GeV), ^{4}He (14.6 GeV) and ^{12}C (22.4 GeV) collisions with Au. The lines are calculated within a combined approach which includes the Intranuclear Cascade Code followed by the Statistical Multifragmentation Model (INC* + SMM), assuming no flow.

anski Institute of Nuclear Physics (Cracow), TU-Darmstdt (Darmstadt), Iowa State University. In 1994 the FASA group proved for the first time through fine angular correlation measurements for the intermediate mass fragments (IMF, $2 < Z < 20$) that this process is a new multibody decay of very hot nuclei, governed mainly by the thermal excitation energy.

In 2000 the IMF energy spectra were studied. These spectra reflect (due to the Coulomb law) geometry and dynamics of the expansion of sources of the emitted IMF. By comparing the data from p+Au collisions with the data from reactions induced by heavier projectiles (^{4}He and ^{12}C) a transition from pure statistical process to a more complex (dynamical) process with a collective IMF flow was observed. The spatial distribution of the fragments can be deduced from the observed collective component of the IMF kinetic energy.

The experiments were performed with the modified 4π-setup FASA installed at the external beam of the JINR Synchrophasotron (Nuclotron). Figure 24 shows the mean kinetic energies per nucleon of fragments emitted in collisions of p (8.1 GeV), ^{4}He (14.6 GeV) and ^{12}C (22.4 GeV) collisions with Au. The calculated values of the mean

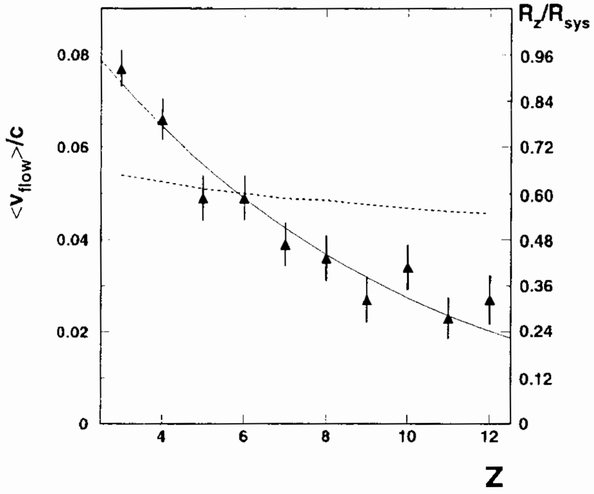


Figure 25: Experimentally deduced mean flow velocities (triangles) for ^{12}C+Au collisions as a function of the fragment charge (left scale), and the mean relative radial coordinates of fragments (right scale), obtained under the assumption of a linear radial profile for the expansion velocity. The dashed line shows the mean radial coordinates of fragments according to the SMM.

kinetic energy per nucleon $\langle E\rangle/A_{\mathrm{IMF}}$ (lines) are obtained with the combined approach, which includes the empirically modified Intranuclear Cascade Code (INC*) followed by the Statistical Multifragmentation Model (SMM) [37]. For the proton-induced reactions the measured energies are close to the calculated energies, but the experimental data for ^{4}He and ^{12}C exceed remarkably both the calculated and measured values for pAu interaction. This enhancement is connected with the radial collective flow (due to the thermal pressure) in the system of the target spectator which is hotter in the case of heavier projectiles. The flow energy of fragments is estimated [37, 38] as a difference between the measured IMF-energy and the energy calculated without any flow (see lines in Fig. 24). The corresponding mean flow velocities for different fragments are given in Fig. 25. The right scale gives the relative mean radial coordinates of the fragments. It is obtained under the assumption of self-similar radial expansion when the local velocities are linearly dependent on the distance of the particle from the centre of mass. The dashed line shows the mean radial coordinate of fragments according to the Statistical Multifragmentataion Model. The remarkable deviation of the data from the model prediction can be caused by the uniform density distribution used and therefore by a rather constant probability of fragment formation at any point of the available volume. The data indicate that heavy fragments are predominantely located in the interior of a nucleus.

The present study shows that in spite of the success of the statistical multifragmentation models, the description of the break-up condition might be still too simplified. The fragment energy spectra (and their correlations with the fragment multiplicity [39]) provide sensitive probes for the source configuration and emission dynamics.

In 2001 the programme of investigations will be realized with a modified FASA setup. The new counter array was developed. It includes 25 $\Delta E - E$ telescopes for correlation measurements and gives a better possibility for measuring IMF-IMF angular (and relative velocity) correlations, which are important for the time scale study. The triggering efficiency will be improved by a factor of 6. In 2001 the new data concerning the dependence of the decay time of the system on the excitation energy and the projectile mass will be obtained. The collaboration also expects the data on the evolution of the decay mechanism of very hot nuclei from pure thermal multifragmentation to that influenced by the dynamic effects. 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 programme.

Applied scientific research

The project Low-Energy Particle Toroidal Accumulator (**LEPTA**) (Fig. 26) is aimed at constructing of a small positron storage ring with electron cooling of circulating positrons. The goal of this device is generation of intense streams of electron-positron bound states, known as positronium, and (together with low-energy antiprotons) for the synthesis of antihydrogen atoms copiously.

Design of the storage ring elements is accomplished. The solenoid of the electron cooling section is constructed, tested and adjusted. The magnetic field inhomogeneity is less than 10^{-3}, which corresponds to the design value. Other elements of the magnetic system are un-

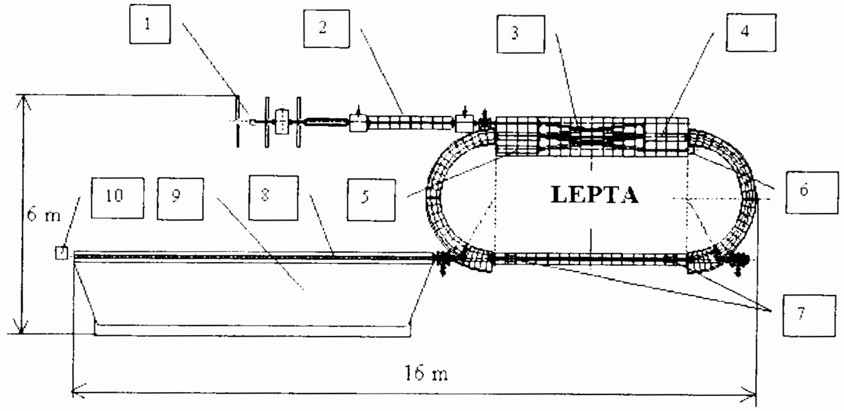


Figure 26: LEPTA layout: 1 — positron source, 2 — positron trap, 3 — septum coils, 4 — kicker, 5 — electron gun, 6 — electron collector, 7 — pick-up stations, 8 — decay channel, 9 — dipole magnet, 10 — Ps detector.

der construction. The vacuum chamber of the ring is designed, constructed and tested. The minimum residual gas pressure obtained is 10^{-7} Torr. The preparation of the baking procedure is in the final stage. The conceptual design of the positron injector is ready. The positron injector based on radioactive isotopes and the intermediate penning-type trap provides an injected beam intensity of 108 positrons, which permits an ortho-positronium flux of about 104 s^{-1}. Elements of the electron cooling system are designed on the basis of DLNP test bench. A method of the cooling process investigation is elaborated and required diagnostics is designed.

The conceptual design of the first experiments with positronium in flight is ready. It includes direct comparison of the electron and positron electric charges and ortho-positronium lifetime measurements. The expected experimental resolution is 5×10^{-10} for the charge difference and 10^{-5} for the positronium lifetime, which exceeds the present level by two and one order of magnitude respectively.

Based on the *Medico-technical complex* and medical hadron beams from the JINR Phasotron, medico-biological and clinical research on treatment of tumour patients, improvement of equipment, and development of new radiotherapy methods and accompanying diagnosis are carried out at the Dzhelepov Laboratory of Nuclear Problems.

In 2000 the clinical investigations on proton treatment of tumour patients at the Phasotron were extended. A total of 36 patients were given a course of fractionated radiation treatment with the medical 150-MeV proton beam (together with subsequent gamma therapy). The total number of proton sessions was 409. Another 17 tumour patients were given radiation treatment only on the Rokus-M gamma facility.

Special devices for modification of the Bragg peak of the proton beam have been developed, manufactured and tested. They allow a beam with a flat-top Bragg peak 2.5, 3.5, and 4.5 g/cm^2 long to be formed in treatment room 1, which makes radiation treatment of malignant tumours more effective.

In 2000 thermoluminescent and track detectors were exposed to the medical proton beam from the JINR Phasotron to determine their radiotherapeutic proton beam characteristics and to measure LET spectra and thus to find the contribution to the dose from secondary particles. Dosimetric calibration of the therapeutic gamma facility Rokus-M and clinical dosimeters used for dose supply in proton therapy sessions was carried out together with the specialists from the Institute of Nuclear Physics (Prague) [40].

The molecular and radiation genetics group continued experimental investigation of the nature of inherited radiation-induced recessive mutations and their locations on the gene map using the polymerase chain reaction (PCR) method [41].

At the exhibition "Moscow region on the threshold of the new century" the Joint Institute for Nuclear Research was awarded a gold medal for its medico-technical complex for hadron therapy.

A new-generation *cryogenic surgical apparatus* which deeply freezes biological tissues with a two-phase jet of liquid nitrogen is developed at the Dzelepov Laboratory of Nuclear Problem [42]. It allows a surgeon to select and regulate a cooling power, to cool tissues directly by a cryogen jet, to freeze tissue through replaceable tips of various shapes and size, to select cooling time, etc. The neighbouring normal tissues are highly protected against the direct effect of the cryogen.

References

[1] NOMAD Collaboration (Astier P. et al.), "Updated results from ν_τ appearence search in NOMAD", Phys. Lett. B 483 (2000) p.387.

[2] NOMAD Collaboration (Astier P. et al.), "Measurement of the Λ^0-polarization in ν_μ charged current interactions in the NOMAD experiment", Nucl. Phys. B 588 (2000) p.3.

[3] DELPHI Collaboration (Abreu P. et al.), Phys. Lett. B 485, (2000) p.45; Eur. Phys. J. C 16 (2000) p.371.

[4] DELPHI Collaboration (Abreu P. et al.), Phys. Lett. B 491 (2000) p.67.

[5] DELPHI Collaboration (Abreu P. et al.), Phys. Lett. B 479 (2000) p.89.

[6] DELPHI Collaboration (Abreu P. et al.), Eur. Phys. J., C 16 (2000) p.229.

[7] Olshevsky, V.G., Trusov S.V., JINR preprint, E10-2000-150, Submitted to NIM.

[8] Adeva B. et al., "First observation of pi K atom and its lifetime measurement", CERN-SPSC-2000-032, CERN-SPSC-P-284-ADD-1, Aug 2000, 74pp.

[9] Kulchitsky Y.A., "Hadron Energy Reconstruction for ATLAS Barrel Combined Calorimeter Using Non-parametrical Method", JINR-E1-2000-260, JINR, Dubna; Akhmadaliev S. et al., "Hadron Energy Reconstruction for the Atlas Calorimetry in the Framework of the Non-parametrical Method", Will be Published in NIMA (2000); Kulchitsky Yu.A. et al., "Hadron Energy Reconstruction for the Atlas Barrel Prototype Combined Calorimeter in the Framework of the Non-parametrical Method", JINR-E1-2000-073, JINR, Dubna.

[10] Kulchitsky Yu.A., "Hadronic Shower Development in Tile Iron-Scintillator Calorimetry", JINR-E1-2000-5, JINR, Dubna; Amaral P. et al., "Hadronic Shower Development in Iron-Scintillator Tile Calorimetry", NIMA 443 (2000) p.51.

[11] Kulchitsky, Yu.A., "Atlas Calorimeter Performance for Charged Pion", Particle and Nuclei, Letters; 2 [99], JINR, 2000. Bosman M., Kulchitsky Yu.A., Nessi M., "Charged Pion Energy Reconstruction in the ATLAS Barrel Calorimeter", JINR-E1-2000-031, JINR, Dubna, Russia.k

[12] Alexeev G.D. et al., "Eight-Channel ASIC Bipolar Transresistance Amplifier D0M Ampl-8.3", to be published in Nucl. Instr. and Methods A.

[13] CDF Collaboration (Ashmanskas W. et al.), "Silicon Vertex Tracker: a Fast Precise Tracking Trigger for CDF", Nucl. Instrum. Meth. A447 (2000) p.218.

[14] Budagov J. et al., "Test of Long Scintillating Counter Prototypes for CDF-II", JINR E13-2000-127, Dubna, 2000.

[15] CDF Collaboration (Ashmanskas W. et al.), "The CDF Silicon Vertex Tracker", FERMILAB-CONF-00-238-E, Oct 2000, 7pp.

[16] Borisov N.S. et al., in Proc. of the Int. Workshop "Symmetry and Spin", Prague, 1999, Czech. J. Phys. 50, Suppl. S1 (2000) 401.

[17] Batusov V.Yu. at al., "Processing of Experimental Data Collected by the "Soft" Trigger on the "Hyperon-2" Setup, Submitted to publication in 2000.

[18] Frlež E. et al., PSI Scientific Report 1999, Vol. I, Particles and Matter. Villigen PSI, March 2000.

[19] Bolotov V.N. et al., Phys. Lett. B243 (1990) p.308.

[20] Dremin D.L. et al., "The investigation of the dependence of the parameters of muon catalyzed fusion on the protium concentration in triple H/D/T mixture at high tempereture and density", JINR Communication, E15-2000-156. Dubna. 2000; "The investigation of the parameters of muon catalyzed fusion in double D/T mixture at high tempereture and density". JINR Communication. E15-2000-157. Dubna, 2000.

[21] Ackerbauer P. et.al., Nucl. Phys. A652 (1999) p.311.

[22] Barsov S. et al, "First results from subthreshold K^+-production measurements with ANKE", Nucl. Phys. A675 (2000) p.230; Proc.of Intern. Workshop "Meson 2000", Cracow, Poland, May 2000.

[23] Uzikov Yu., "Deuteron breakup $pd \to pnp$ in specific kinematics and short-range NN-interaction", JINR E2-2000-149, Dubna, 2000.

[24] Mamedov T.N. et al., "The isotopic effect in the nuclear capture of negative muons in xenon", JETP Lett, 2000, V.71, p.663.

[25] Mamedov T.N. et al., "Measurement of the magnetic moment of the negative muon in the 1S-state of different atoms", JINR Communication, E14-2000-158, Dubna, 2000,

[26] Mamedov T.N. et al., "μ^-SR investigations in silicon", Physica B, V.289-290, (2000) p.574; Gorelkin V.N. et al. "Theoretical analysis of muon spin polarization behaviour in acceptor centres formed by μ^- in Si", Physica B v.289-290 (2000) p.585; Mamedov T.N. et. al., "Investigation of the temperature dependence of the acceptor center relaxation rate in silicon by the μ^-SR-method", JETP Lett, 2000, V.71, p.637.

[27] Duginov V.N. et al. "Study of the magnetic properties of $Ce_3Pd_{20}Si_6$ compound", Physica B, V.289-290 (2000) p.43; See also http://nuweb.jinr.ru/~duginov/cepdsi.

[28] Mamedov T.N. et al. "μSR investigation of a liquid crystal containing Iron atoms", JINR Communication, E14-2000-99, Dubna, 2000,

[29] Gordeev V.A. et al., "Search for neutrinoless decay of muon. Project of experiment", Preprint PNPI NP-37-2000 2380, Gatchina, 2000.

[30] Shitov Yu. et al., "Doppler-broadening of gamma-rays follwing muon capture: search for scalar coupling", Submitted to Nucl. Phys. B.

[31] Arnold R. et al., Nucl. Phys. A678 (2000) p.341.

[32] Burdanin V.B. et al., To be printed in Phys. Lett. B.

[33] Aalseth C.E. et al., "Recent Results of the IGEX Ge-76 Double Beta Decay Experiment", Phys. of Atom. Nuclei, 63 (2000) p. 1299; Aalseth C.E. et al., "New Results of the WIMP search with the first IGEX Ge detectors", Phys. of Atom. Nuclei, 63 (2000) p.1268; Klimenko A.A. et al., "Results of the Pilot Experiment to search for Inelastic interactions of WIMPs with Ge-73", Phys. of Atom. Nuclei. 63 (2000), p.1264.

[34] Gusev K.N. et al, "The behaviour of the basic characteristics of the silicon and germanium detectors in the temperature range 1 77 K", Submitted to Nucl. Instr. and Methods.

[35] Faessler A., Kosmas T.S., Kovalenko S.G. , Vergados J.D., "Exotic $\mu - e$ conversion in nuclei and R-parity violating supersymmetry". Nucl. Phys. B587 (2000) p.25; Dib C., Gribanov V., Kovalenko S., Schmidt I., "K-meson neutrinoless double muon decay as a probe of neutrino masses and mixings:, to appear in Phys.Lett., B (2000), hep-ph/0006277; "Lepton number violating processes and Majorana neutrinos". To appear in the Proceedings of the Int. Workshop on Neutrino physics. NANPino'2000, JINR, Dubna, Russia, July 19-22, 2000, hep-ph/0011213.

[36] Kovalenko S., Schmidt I., Soffer J., "CP-violation in high-energy collisions of polarized protons", hep-ph/9912529.

[37] Avdeyev S.P. et al., "Multifragmentation of Gold Nuclei by Light Relativistic Ions Thermal Break-up versus Dynamic Disintegration". Preprint JINR, E1-2000-152, Dubna, 2000; Yad. Fiz., in press.

[38] Avdeyev S.P. et al., "Collective Flow in Multifragmentation Induced by Relativistic Helium and Carbon Ions". Paricles and Nuclei, Letter, 2000, 2[99]-2000, p. 62.

[39] Avdeyev S.P. et al., "Variation of the Coulomb Repulsion in Multifragmentation". Particles and Nuclei, Letters, 2000, 2[99]-2000, p.70.

[40] Vagner R. et al., "Dosimetric calibration of the therapeutic gamma facility Rokus-M and clinical dosimeters", JINR Communication, R16-2000-186, Dubna, 2000; Spurny F. et al., "The spectrometry of linear energy transfer with track etched detectors", Int. Symposium on Radiation Physics (ISPR-8), Prague, June 2000, p.304; Spurny F. et al., "Experimental Microdosimetry in High Energy Radiation Fields", Int. Congress of the International Radiation Protection Association (IRPA-10), Hiroshima, May 2000, p.203; Spurny F. et al., "Dosimetric and Microdosimetric Characteristics of High Energy Proton Beams", Int. Conference on Nuclear Track in Solids, Portoroz, Slovenia, 2000, p.105; Kostjuchenko V.I. et al., "Dosimetric and Microdosimetric Characteristics of Clinical Proton Beams", JINR Communication, E16-2000-165, Dubna, 2000.

[41] Alexandrov I.D., Alexandrova M.V., "Basic and locus-specific patterns of gene radiomutability in D. melanogaster", Int. Conf. "The Problems of Radiation Genetics at the Turn of the Century", Moscow, 20-24 Nov. 2000, Publ.House of Russian Peoples', Friendship, Moscow, p.6; Lapidus I.L. et al., "PCR-assay of gamma- and neutron-induced point mutations at the vestigial gene in D. melanogaster", ibid., p.42;

[42] Pavlov, V.N., "Cryogenic surgical apparatus", Preprint JINR, D8-2000-87, Dubna, 2000, Submitted to "Cryogenics".

Received by Publishing Department on December 26, 2000.