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ANNUAL REPORT OF THE LABORATORY OF NUCLEAR PROBLEMS FOR 1997

Report to the 83rd Session
of the Scientific Council of JINR
January 15–16, 1998

Dubna 1997

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Preface

The staff of the Laboratory of Nuclear Problems includes 330 scientists involved in about 30 projects, essentially in the fields of particle and nuclear physics as well as in experimental technology.

In this brief report we touch upon only the most significant results achieved during the last year. For a more comprehensive picture of the Laboratory life one can be referred, for example, to the "JINR annual report" and Recommendations of the PAC's for Nuclear and Particle Physics in JINR.

Low and Intermediate Energy Physics

The main results obtained within the domain of Low and Intermediate Energy Physics in 1997 are as follows.

- Project NEMO. The half-lives of the double two-neutrino β decay of ^{100}Mo, ^{116}Gd, ^{82}Se, and ^{96}Zr were measured at the set-up NEMO-2 and found to be at the level of 10^{19} years. The upper limit at the level of 10^{23} years was obtained for the half-life of the double neutrinoless β decay. Now NEMO-2 in the Modane underground laboratory (France) is dismounted and a new large spectrometer NEMO-3 is being assembled in its place. Greater part of the NEMO-3 units (a large copper foundation of the spectrometer, 50% of plastic scintillators, iron shield) have already been made in Dubna. Development of software based on the elastic neuron network method is well under way.

- Project TGV. Test measurements of the background conditions were carried out at the prototype TGV spectrometer, consisting of 16 HPGe detectors and installed at LSM in Modane (France). The half-life of the double neutrinoless β decay of ^{48}Ca was also measured and the upper limit was tentatively estimated to be $T_{1/2}^{2\beta0\nu} > 1.2\cdot10^{21}$ years (90% C.L.). Now the designing of the cryostat is under way and detectors for the TGV spectrometer are being made.

- Project ANCOR. The electron–neutrino angular correlation in the β decay of ^{18}Ne, formed in the ^{16}O(^{3}He, n)^{18}Ne reaction, was investigated with the multidetector set-up (14 Si(Li) positron detectors and 2 HPGe γ detectors) at the tandem accelerator of IPN (Orsay, France). The upper limit for the scalar coupling constant $C_S/C_V \le 0.26$ (95% C.L.) was obtained. To choose the best candidates for new correlation experiments, μ-capture in different targets (^{10}B, ^{4}B, B_40, H_20, Ne, Mg, Al, Si, S, Ca, Sn and some structural materials) was investigated. Rates of partial muon capture were found for some materials.

- In 1997 new data on the *muonium-antimuonium conversion*, forbidden within the Standard Model by the lepton number conservation law, were obtained in the joint LNP–PSI experiment. About 10^{13} muons stopped in the target were analyzed. No unit events of antimuonium decay were found. As a result, a new upper limit for the conversion probability $P_{\mathrm{M\overline{M}}} \le 8 \cdot 10^{-11}$ (90% C.L.) was established, which improves the previous world data by a factor of about 100. The corresponding value of the conversion binding constant is $G_{\mathrm{M\overline{M}}} \le 1.8 \cdot 10^{-3}\, G_{\mathrm{F}}$, where G_{F} is the Fermi constant. These values appreciably limit the parameters of the available models.

- The most interesting result obtained by the LNP group together with the colleagues from the OBELIX collaboration is the first observation of the Pontecorvo reaction $\bar{p}d \to \phi n$ in annihilation of stopped antiprotons in gaseous deuterium. Pontecorvo reactions are processes forbidden for annihilation on a free nucleon. Their probability is very small: about 8 million trigger events were collected to observe the reaction $\bar{p}d \to \phi n$. The ratio between the yields of this channel and the $\bar{p}d \to \phi\pi^0 n$ channel was measured:

$$\frac{Y(\bar{p}d \to \phi\pi^0 n)}{Y(\bar{p}d \to \phi n)} = 58 \pm 7$$

This allowed evaluating the yield of the Pontecorvo reaction

$$Y(\bar{p}d \to \phi n) = (7.3 \pm 1.1) \cdot 10^{-6}$$

and the ratio that characterizes the degree of violation of the OZI rule

$$\frac{Y(\bar{p}d \to \phi n)}{Y(\bar{p}d \to \omega n)} = (321 \pm 74) \cdot 10^{-3}.$$

This value considerably exceeds the predicted value $4.2 \cdot 10^{-3}$ and is noticeably larger than the value $Y(\bar{p}p \to \phi\pi^0)/Y(\bar{p}p \to \omega\pi^0) = (96 \pm 15) \cdot 10^{-3}$ for annihilation on a free nucleon.

- A new and important advancement in μ-catalyzed fusion research in 1997 is a set-up with a liquid-tritium target and a gas supply system, designed for measurement of mesomolecular formation rate in double and triple mixtures of hydrogen isotopes. It was constructed in cooperation with the Institute of Experimental Physics (Sarov) and mounted in the low-background laboratory of the Phasotron. The accelerator runs in June and September were very effective (Fig. 1).

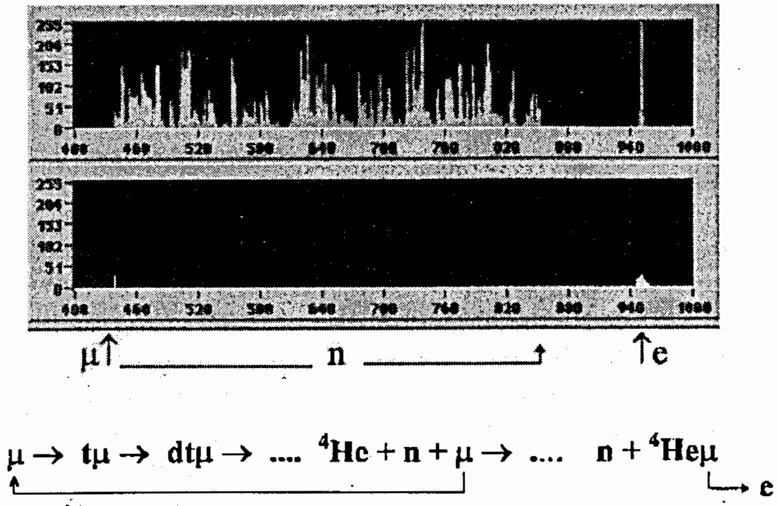

Figure 1: Process of μ-catalyzed fusion in the d-t-mixture. The first pulse in the lower panel corresponds to the time, when the muon enters the set-up. The second pulse marks the time of the muon decay. The cycles of the creation of ^{4}He accompanied with neutron emission are depicted in the upper panel. A total number of 400 neutrons was emitted. The termination of the neutron emission before the muon decay is a result of sticking of the muon to helium.

Successfully operating were the system for separation of muon stops in the target and of decay electrons, based on uniquely designed proportional chambers, the highly effective system for recording neutrons in the 4π geometry, the liquid-tritium target of volume 30 cm^3 with two radiation safety lines, the highly efficient system for thorough (10^{-7}) purification of large amounts of tritium (up to 10 kCi) from admixtures, based on a palladium filter, and the multichannel fast spectrometric system.

The main purpose of the experiment is direct measurement of the neutron yield and the muon-to-helium sticking coefficient in the mixture of tritium, deuterium, and hydrogen.

- The most promising models of the physics beyond the Standard Model are based on the supersymmetry (SUSY). Accelerators provide us with the most unambiguous test of the hypothetical physics beyond the standard model — they either discover or do not discover the new particles by direct observation and thus either explicitly prove or disprove certain theoretical expectations. Another approach intensively developed at present is based on the indirect search for new physics and is connected mainly with the non-accelerator experiments. They are searching for thin effects produced by the new physics at the virtual level via the heavy exotic particle exchange between particles of ordinary matter. These experiments are not limited by any energy threshold unlike the accelerator ones. The sensitivity of the non-accelerator experiment to new physics extends to extremely large scales. Among these non-accelerator experiments, the neutrinoless double beta decay ($0\nu\beta\beta$) has long been recognized as a sensitive probe of the new physics. A new SUSY mechanism of $0\nu\beta\beta$ based on the pion exchange between decaying neutrons was proposed. Pions couple to the final state electrons via the R-parity violating ($\not{R}_p$) SUSY interactions. This pion-exchange mechanism (Fig. 2, right) dominates over the conventional two-nucleon one (Fig. 2, left). The latter corresponds to direct interaction between quarks from two decaying neutrons without any light hadronic mediator like the π-meson.

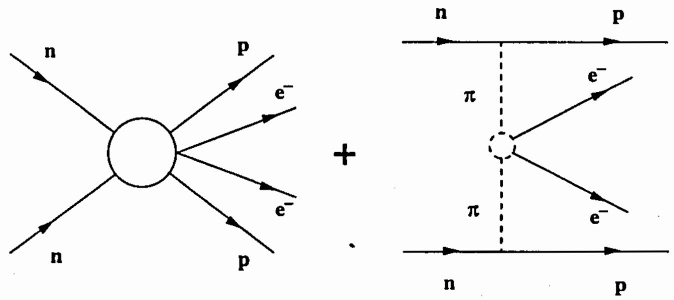

Figure 2: Conventional two-nucleon mode (left) and new π-exchange (right) contributions to $0\nu\beta\beta$ decay.

The constraints on the $\not{R}_p$ SUSY parameters extracted from the current experimental $0\nu\beta\beta$-decay half-life limit are significantly stronger than those previously known or expected from the ongoing accelerator and non-accelerator experiments (Fig. 3).

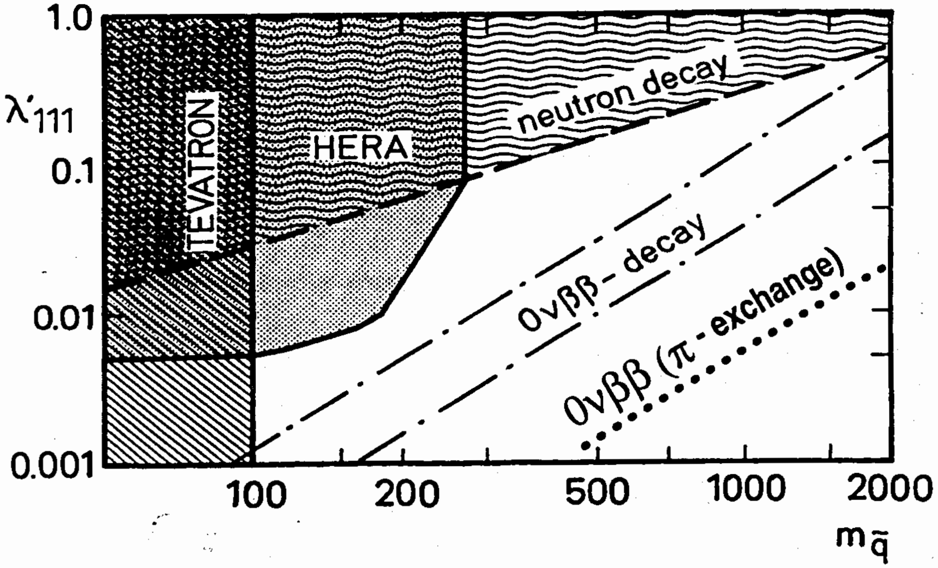

Figure 3: Limits from neutrinoless double beta decay on the SUSY $\not{R}_p$ parity violating parameter λ'_{111} as a function of the squark mass (dot-dashed lines), under two assumptions of the the gluino mass (1 TeV and 100 GeV). Also given are the limits obtained from Tevatron and HERA, as well from neutron decay. The new (dotted) line presents the π-exchange constraint obtained from $0\nu\beta\beta$. The regions above and to the left of the lines are forbidden.

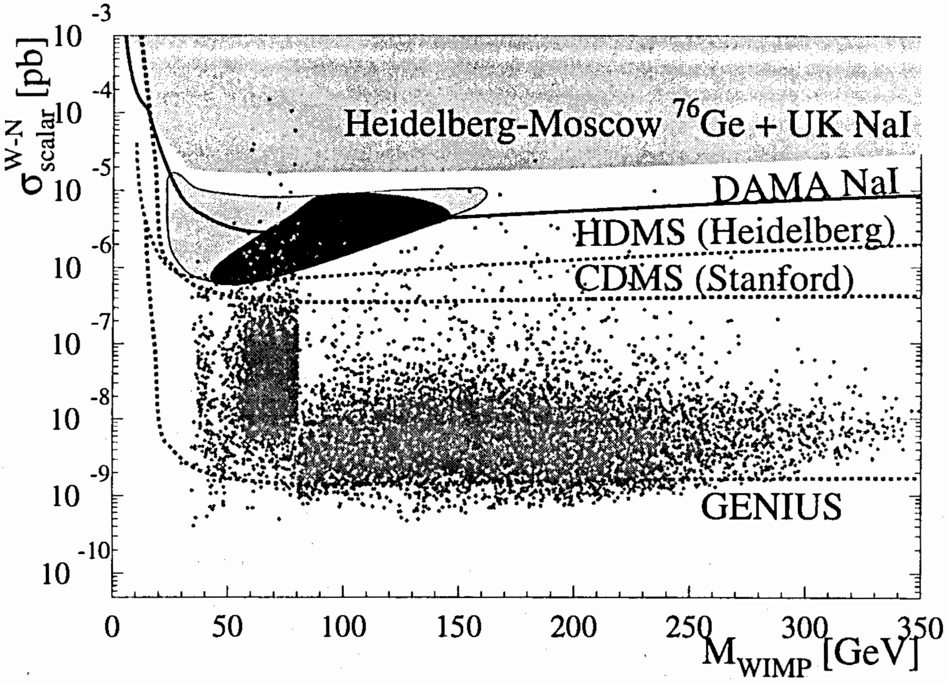

Figure 4: Best present experimental limits for neutralinos as cold dark matter and perspectives of future experiments (solid and dotted curves). Masses of the neutralino ($M_{\rm WIMP}$) and cross sections of the neutralino scattering on nuclei ($\sigma^{\rm W-N}_{\rm scalar}$) beyond the contour lines are excluded. The present best limits are from the DAMA experiment. The proposed GENUIS experiment (Heidelberg) will be able to cover the full parameter space of the SUSY predictions for neutralinos (scattered dots).

- The SUSY offers the cold dark matter particle candidate, neutralino, and thus solves the long-standing cold dark matter problem related to the age of the universe and the structure formation. The neutralino is a stable lightest supersymmetric particle (LSP). The prospects of the LSP direct detection by means of elastic and inelastic scattering of the LSP on nuclei are now under comprehensive investigation both from the theoretical and experimental points of view. The breakthrough in the direct dark matter detection is expected with new-generation detectors like GENIUS (Germanium in Nitrogen Underground Set-up, Heidelberg)[1]. The fact became clear after comparison of the GENIUS sensitivity with the detector-counting-rate calculations (scattered dots in Fig. 4), performed at LNP.

[1]CERN Courier, vol. 37, 1997, p. 18.

Elementary Particle Physics

During the LEP running period in 1997, statistics was collected at the energy 183 GeV, i.e., well above the threshold of the W-boson pair production. About 80 pb^{-1} of integrated luminosity were provided in total by LEP. New results were obtained from the analysis of the **DELPHI** data. Many of them were presented at Jerusâlem 1997 International Conference on High Energy Physics.

In particular, the following should be pointed out:

- The search for $B^0_s \leftrightarrow \bar{B}^0_s$ oscillations in events with large transverse momenta was carried out. A new limit for the mass difference of physical B^0_s states $\Delta m_s > 4.3 \times 10^{-3}$ eV, 90% C.L., was established.
- Neutral and charged Higgs bosons were searched for. The analysis within the Standard Model allowed a new limit $m_h > 66.2$ GeV/c^2, 95% C.L., to be established for the mass of this boson.

In 1997 the LNP scientists continued participating in the experiment on the search for $\nu_\mu \leftrightarrow \nu_\tau$ and $\nu_\mu \leftrightarrow \nu_e$ oscillations (**NOMAD**, SPS, CERN). About 1 million $\nu_\mu N \to \mu + X$ events were recorded. The following new limits for the oscillation probability amplitudes were established from the analysis of $\sim$ 15% of the statistics:

- $\nu_\mu \leftrightarrow \nu_\tau$, in the region $\Delta m^2 > 10$ eV^2, $\sin^2 2\theta < 3.4 \times 10^{-3}$, 90% C.L., which is below the best world result (Fig. 5);
- $\nu_\mu \leftrightarrow \nu_e$, in the region $\Delta m^2 > 10$ eV^2, $\sin^2 2\theta < 2 \times 10^{-3}$, 90% C.L..

The latter result argues against the "observation" of $\bar{\nu}_\mu \leftrightarrow \bar{\nu}_e$ oscillations in the region $\Delta m^2 > 10$ eV^2 in the experiment LSND (Liquid Scintillation Neutrino Detector, Los Alamos, 1996).

New data on charm production in proton–nucleon interactions at 70 GeV are obtained in the joint beam-dump experiment at the IHEP–JINR **Neutrino Detector**. The yield cross section, evaluated by four independent methods, is $0.9^{+1.1}_{-0.9}$ μb/nucleon and agrees with the prediction of α_s^3 order perturbative QCD.

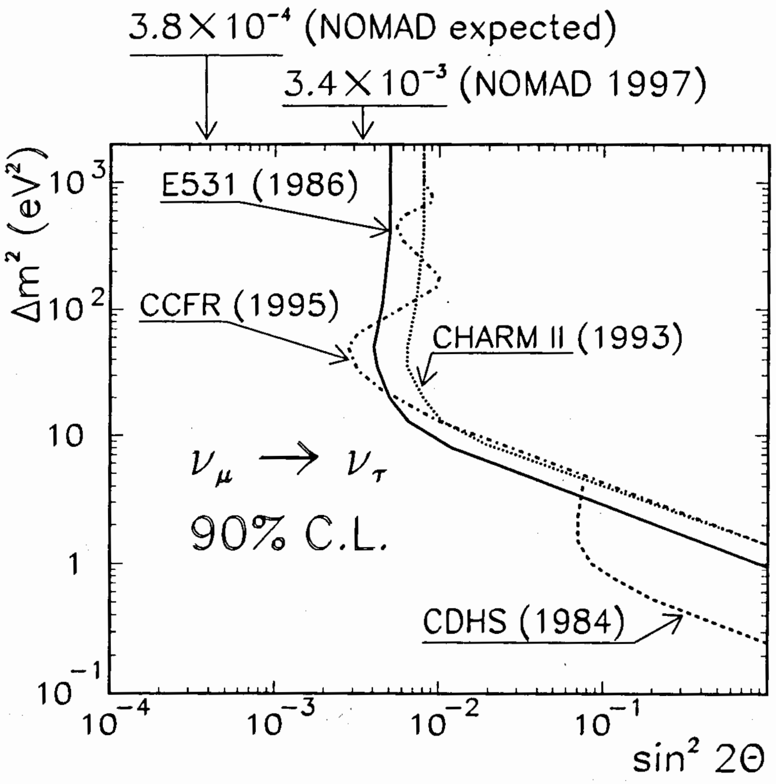

Figure 5: The vertical axis is the difference in mass squared between neutrino types. The horizontal axis is the neutrino mixing angle. The area to the right of the curves is excluded.

The LNP group, which participate in the **DØ** (Tevatron, FNAL) upgrading programme, is responsible for construction of the forward-angle muon system for DØ. The following results were obtained in 1997:

- the design and development for mini-drift tubes (MDT) are accomplished;
- the assembly and test areas are prepared for MDT mass production in the JINR Central Workshop;
- the prototype front-end fast discriminator electronics chip is designed and produced in co-operation with Byelorussian State University.

One of the main tasks of the LNP group participating in the upgrading of the **CDF** set-up (Tevatron, FNAL) is to develop a new system of muon scintillation trigger counters (Muon Scintillator counters Upgrade, MSU).

- The LNP scientists (together with the colleagues from Pisa, Kharkov, Bratislava, and Udine) proposed and designed a new light-collecting system for large (1.8–3.3 m long) scintillation counters. The new design is free of traditional light guides, which are extremely difficult to use under the CDF conditions. The CDF collaboration adopted the proposal as a working version.

In the frame of the **ATLAS** project the TILECAL group has obtained a number of important results, of which the following are noteworthy:

- substantial preparatory work for mass production of absorber plates for the Barrel Tile Calorimeter Modules is completed (Fig. 6);
- the TileCal performance is investigated through the off-line analysis of the experimental data from the test runs with the SPS beam. New results concerning the e/h ratios for different rapidities, the longitudinal and lateral profiles of the hadron shower are obtained;
- considerable work is done to determine the magnetic fields and magnetic forces affecting ATLAS elements;

The main result of the **ATLAS** muon group is the construction of the first full-scale $3.2\times2.0\times0.5$ m^3 prototype ATLAS muon chamber. For fulfilling this task a lot of work was done before:

- full chamber design, including Finite Elements Analysis calculation, was carried out;
- spacer structure was produced and assembled;
- in-plane alignment system (RASMIK) was produced, tested, calibrated with the accuracy about 1 μm and mounted in the spacer structure;

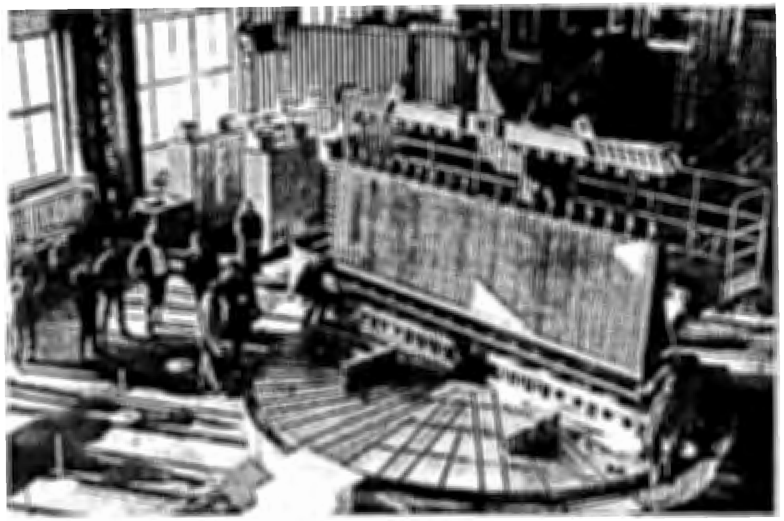

Figure 6: Full-scale Module 0 of the Hadron Barrel Tile Calorimeter on the assembly platform of LNP JINR.

- a 3200 mm long by 30 mm diameter detector of 384 single drift tubes was assembled and tested in compliance with the ATLAS Muon project Quality Control requirements.

The aim of the **DIRAC** project (PS, CERN) is to measure the lifetime of $\pi^+\pi^-$-atoms with a 10% accuracy. This will allow one to verify the chiral perturbation theory — the lower energy limit of QCD — in a model-independent way at a precision level of 5%.

In 1997 the following phases of the project were successfully realized:

- a set of three drift chambers (DC) with the sensitive area 128×40 cm^2 in size (12 signal planes) was tested in the test beam at PS CERN;
- a prototype of the advanced data taking system for DCs is developed, manufactured and tested. This system includes time-to-digital converters, readout controllers and service modules;
- the DAQ software is developed and tested.

Meetings and workshops organized by LNP

The first International Workshop on **Non-Accelerator New Physics (NANP-97)** took place in Dubna on July 7-11, 1997.

The main purpose of the Workshop was to highlight the present status and prospects of searching for new physics beyond the Standard Model in non-accelerator experiments. Complementarity of accelerator and non-accelerator searches was also within the scope of the NANP-97. Various extensions of the Standard Model including the supersymmetry and grand unification ideas were considered by the Organizing Committee as a central point of the NANP-97 to attract both theoretical and experimental talks and discussions.

The scientific programme included: present status of new physics beyond the Standard Model; non-baryonic dark matter; possible manifestations of new physics in neutrinoless double beta decay and some other rare processes; new physics implications for the neutrino mass problem; nucleon and nuclear structure as a background in searching for new physics; experimental facilities to probe new physics.

About 90 scientists participated in the workshop.

The key persons in the fields of scientific interest of the workshop gave their invited review talks. Among them one should mention well-known professors F.T.Avignone (South Carolina), V.S.Berezinsky (Gran Sasso), A.Dar (Tel-Aviv), G.V.Domogatsky (Moscow), E.Fiorini (Milan), P.Herczeg (LANL), S.Jullian (Orsay), H.V.Klapdor-Kleingrothaus (Heidelberg), V.A.Kuzmin (Moscow), V.M.Lobashev (Moscow), R.Mohapatra (Maryland), L.Roszkowski (Lancaster), J.F.W.Valle (Valencia), H.C. Walter (PSI), etc.

The JINR Local Organizing Committee was headed by V.B.Brudanin and S.G.Kovalenko (Co-Chairmen).

The International School-Seminar **"Actual Problems of Particle and Nuclear Physics"** was organized by JINR (on the basis of the Laboratory of Nuclear Problems) together with the National Centre of Particle and High Energy Physics (Minsk, Belarus). This school took place in the hotel "Golden sands" located near Gomel, the Republic of

Belarus, August 8–17, 1997. The school was managed by the International Advisory Committee led by JINR Director prof. V.G.Kadyshevsky.

The scientific programme of the school–seminar included the following topics: status of main recent experimental results from accelerators (LEP, HERA, TEVATRON, etc); program of the LHC and future experiments ATLAS, CMS, etc; physics of the Standard Model and beyond; soft and hard QCD processes (perturbative and non-perturbative approaches, jets, hard diffraction, etc); new directions in quantum field theory and relativistic nuclear physics.

About 120 participants took part in the School.

The 19th workshop on the JINR–IHEP **Neutrino Detector** and **NOMAD** experiment (WA-96, CERN) took place in the Laboratory of Nuclear Problems, January 29–31, 1997.

The Organizing Committee was headed by the well-known leader of the projects from JINR and permanent chairman of all these workshops prof. S.A.Bunyatov.

Twenty-eight scientists participated in the workshop. The current status of the experiments with the Neutrino Detector and NOMAD was reported. The main goal of the experiments is searching for the new phenomenon – neutrino oscillations in the fluxes of muon and electron neutrinos.

New data on the nucleon structure functions and their QCD analysis were discussed. A new proposal concerning the investigation of the strange-quark component in the nucleon with the Neutrino Detector was presented for the first time and discussed.

The NOMAD drift chamber reconstruction programme, the programmes for extraction of the muon and electron neutrino charged-current interaction, etc, the status of the new project NOMAD-STAR were considered. The future prospects for neutrino physics at accelerators were presented by a guest from CERN G.Conforto.

Finances

One can get the general impression of the last year's financial situation of LNP looking at Fig. 7. For two leading fields of activity (Low and Intermediate Energy Physics and High Energy Physics) the actual and planned expenditures for Equipment and International Scientific Cooperation are also compared (Fig. 8 and 9).

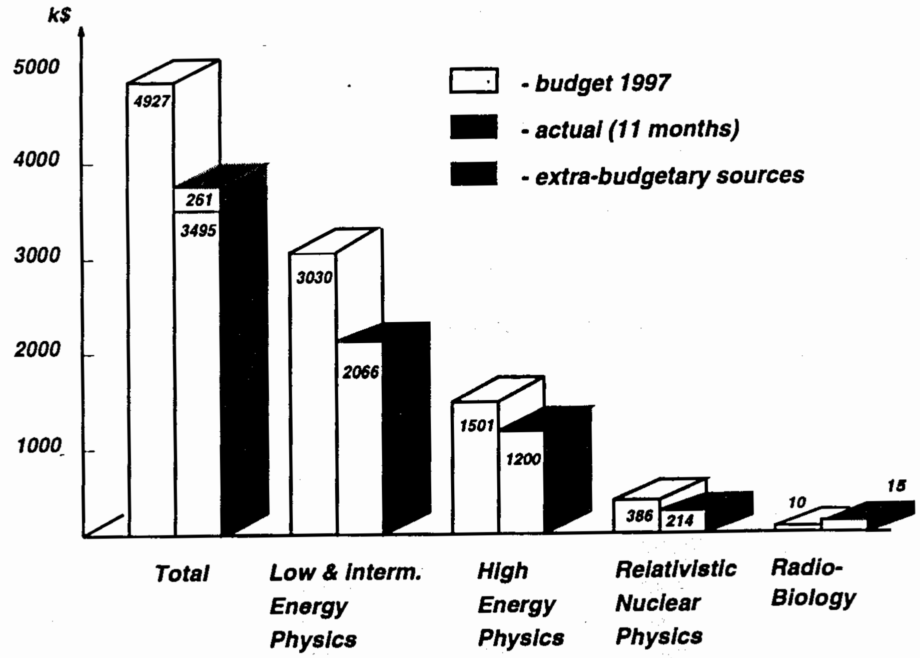

Figure 7: Budget of the Laboratory of Nuclear Problem in 1997.

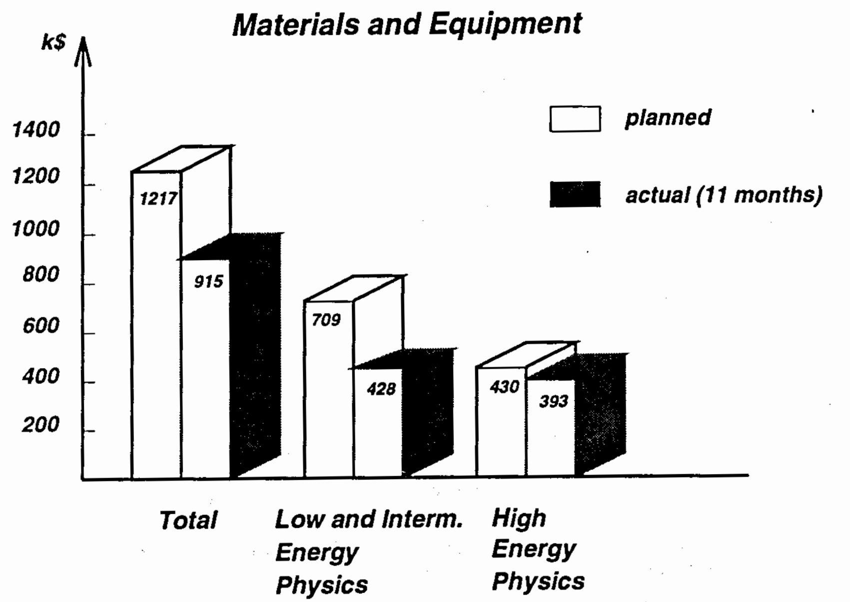

Figure 8: Expenditures of the Laboratory of Nuclear Problem on equipment in 1997.

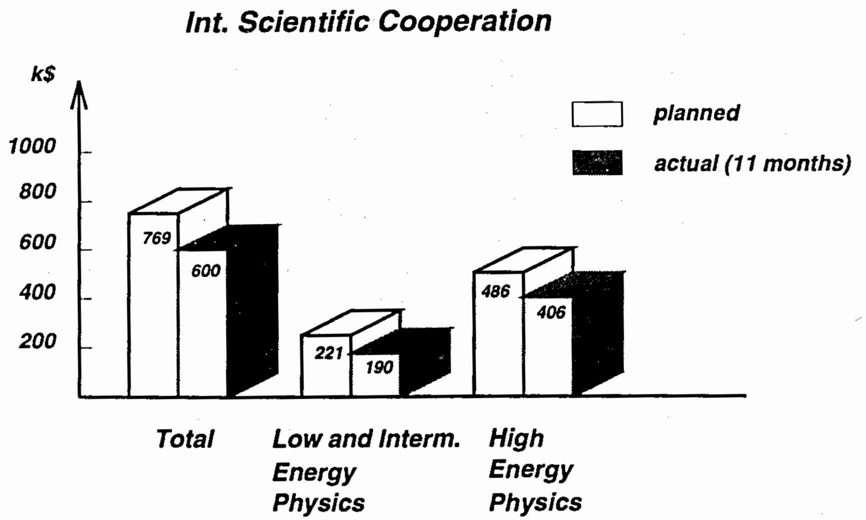

Figure 9: Expenditures of the Laboratory of Nuclear Problem on international scientific cooperation in 1997.

General notes

In the time being the Laboratory of Nuclear Problems does not have a modern powerful home facility. We understand well that it is the serious obstacle in maintaining our attractiveness for the JINR Member States.

Keeping this in mind we always encourage ideas concerning new facilities for intermediate energy and nuclear physics at JINR. Examples are the concepts of the $c\tau$-factory and the accelerator complex on the basis of upgraded SATURNE-II.

Unfortunately, these activities have been terminated because today they are not considered realistic.

Under the present conditions we consider the Phasotron to be a still useful facility which provides, at least in some particular cases, possibility of doing good physics (e.g. μ-catalyzed fusion, DUBTO project). One should also keep in mind the specific role of the project on nuclear spectroscopy (YASNAPP), which has not only physical but also educational importance.

We do believe as well that the developed techniques for the proton therapy with the Phasotron beam will be intensively used in the coming years.

With respect to experiments on external facilities, our strategy is as follows. We regard as priority the participation in such projects where our contribution is well identified in terms of physical ideas, advanced software, and unique equipment, developed and produced at JINR.