Previous Main Results

The "Elementary Particle Physics Laboratory" named in the past as "The Nuclear Structure Laboratory" was formed in 1963 in PNPI (at that time PNPI being a branch-institute of the Leningrad Physico-Technical Institute). Up to 2002, this laboratory was headed by Prof. A.A. Vorobyov. Among the most important directions of investigation carried out in this laboratory were the following (see PNPI report of the High Energy Physics Division "Main Scientific Activities 1971-1996").

1. Proton diffraction scattering on nuclei and nuclear matter distributions

The 1 GeV proton scattering from nuclei has been proven to be a very useful tool for studying the nuclear structure. The first high precision measurements of the differential cross sections for elastic scattering of the 1 GeV protons on nuclei were performed at PNPI (LNPI) in 1972. It was demonstrated that with this method one can obtain information on the nuclear matter distributions with the accuracy comparable to that reached in studying nuclear charge distributions by the method of electron scattering. A number of nuclei, from ^{3}He to ^{208}Pb, including all doubly magic nuclei, were studied at PNPI. Starting from 1973, similar investigations were performed in joint PNPI-Saclay experiments (E_p=1 GeV), and later (from 1977) at Los-Alamos (E_p=0.8 GeV). Thus, the study of diffraction scattering of ~1 GeV protons on nuclei became a new branch of experimental research in nuclear physics, and it is due to these studies that the most accurate information on nuclear matter distributions has been obtained by present.

2. Small-angle diffraction scattering of hadrons on the lightest nuclei

A serious of experiments at Gatchina, Saclay, Serpukhov and CERN have been performed where small-angle scattering of pions and nucleons on hydrogen, deuterium, and helium nuclei were studied at intermediate and high energy. A dedicated ionization chamber recoil detector IKAR developed at PNPI was the main part of the experimental setup. The advantage of the applied method was a possibility to measure differential cross sections at small momentum transfers with high absolute accuracy of 1-2%. The differential cross sections of elastic scattering and the analyzing powers have been measured. The total cross sections and the ratios of the real to the imaginary parts for the scalar amplitudes of the studied processes have been found. Experimental upper bounds for the nucleon-nucleon (NN) spin-spin amplitudes have been determined. The obtained experimental data are useful in the NN-scattering phase-shift analyses, and in many cases clarify the problem of the dibaryon resonances which are a matter of interest up to now. Also, the measured hadron-nucleus total cross sections permit to get information on the inelastic shadowing corrections to the cross sections calculated in the framework of the Glauber theory.

3. Study of Nuclear Structure with Quasielastic Proton Scattering at 1 GeV

The shell structure of nuclei was studied at PNPI by (p, 2p) and (p, np) reactions using the 1 GeV proton beam of the PNPI syncrocyclotron . Both reactions were studied in identical kinematical conditions. The scattered proton was detected with a magnetic spectrometer, while the knocked out nucleon (p or n) was detected

with a time-of-flight spectrometer. A number of nuclei (more than 20, from ^{6}Li to ^{208}Pb) were studied, and detailed information on the proton- and neutron-shell energies was obtained. Prior these measurements, the neutron shell energies were in most cases unknown. An important result of these studies was the observation of the $1s_{1/2}$ and $1p_{1/2}$ proton and neutron shells in heavy nuclei including ^{90}Zr and ^{208}Pb. The shell splitting was observed in many of the studied nuclei. This shell spliting was explained in terms of the spatial deformation of the self-consistent nuclear field. It has been shown that the data on the proton and neutron shell energies allow one to study the deformation parameters of the nuclear density distributions both for protons and neutrons. Also, the measured spectra show high sensitivity to the differences between the proton and neutron root-mean square radii. The obtained data can serve as a solid basis for testing the existing nuclear models and for developing new theoretical approaches to microscopic descriptions of the nuclear structure.

4. Muon Catalized dd- and dt-Fusion
(See "Muon capture group"(?))

5. Ternary Fission

A serious of experiments on ternary nuclear fission were performed at the Gatchina WWR-M neutron reactor. Two alternative approaches in description of the nuclear fission process were discussed in the 60s. Within the framework of the statistical fission model, descending from the saddle point was considered to be adiabatically slow, so that formation of the fragments occurs just before the scission point. On the contrary, in the dynamical model of fission the formation takes place at the barrier, and further separation of the fragments goes so rapidly that no significant redistribution of the fragment masses occurs. The ternary fission has occurred to be useful to tell between these two fission models.

The inclusive spectra of light nuclei (^{2,3}H, ^{4,6,8,}He, ^{7,8,9}Li, ^{9,10,11}Be, ^{11,12,13,14}B, ^{14,15,16}C, ^{20}O) formed in the ternary fission were measured with a magnetic time-of-flight mass-spectrometer. The experiments were carried out with the ^{233}U, ^{235}U, ^{239}Pu, and ^{242m}Am targets exposed to thermal neutron fluxes. The next stage was the correlation experiment with a special setup which enabled simultaneous detection of the heavy fragments and the light nuclei ^{3}H, ^{4}He, ^{6}He, ^{10}Be. Detailed studies of the ^{235}U and ^{239}Pu thermal neutron induced fission, as well as spontaneous fission of ^{252}Cf, were performed. As a result of these studies, the experimental data were obtained which created the basis for a detailed kinematics analysis aimed at determination of the initial conditions of the fragment separation. Such an analysis resulted in a rather large value ($\approx$30 MeV) of the fragments initial energy. This value excludes the statistical model of nuclear fission.

6. Diffraction scattering of high energy hadrons

In the end of 60s, the study of the global characteristics of the hadron interactions was of common interest. The behaviour of the total cross sections for the hadron interactions and the shrinkage of the diffraction cone with the energy increasing were hot topics at that time. In particular, the theory of Regge poles predicted constancy of the total cross sections in the asymptotic region of high energies accompanied by the logarithmic shrinkage of the diffraction cone. Also, it was a question whether the dispersion relations between the real part of the forward scattering amplitude and the

total cross section remain valid. In 1969, a new experimental method was suggested and worked out at PNPI for studies of the small-angle scattering of high energy hadrons. A hydrogen-filled ionization chamber (IKAR) used as a recoil detector was the base of the method. This method provided precise measurements of the differential cross sections for small-angle scattering of various hadrons with the absolute normalization at the 1% precision level.

First experiments using this method were carried out at PNPI in 1972. The pp scattering in the energy internal from 600 to 1000 MeV was investigated. In these experiments, the "puzzle of Dutton" was solved, and the validity of the dispersion relations in pp scattering at this energy was restored. Then, πp scattering at the energy of 40 GeV was studied at IHEP (Serpukhov). Later, πp scattering was studied at the energy up to 140 GeV (CERN, WA9 experiment), and at the energy to 400 GeV (CERN, NA8 experiment). These experiments yielded important results concerning the hadron interaction at available at that time energies. The most important results are the observation of the universal rise of the total cross sections and the universal shrinkage of the diffraction cone with the energy increasing. The obtained results agree with the conclusions of the general theorems formulated on the basis of the local quantum theory axioms.

7. Study of Rare Hyperon decays

PNPI was an active participant in the study of rare hyperon decays at the FNAL hyperon beams. The beginning of the PNPI – FNAL collaboration goes back to the year 1981. The basis of the collaboration was the PNPI suggestion of an experiment for studying the Σ^--hyperon β-decay in view of a strange situation in investigation of this process. The existing at that time experimental information on the asymmetry in the decay of polarized Σ^--hyperons was in contradiction with the Cabibbo model prediction while the β-decay of the other baryon octet members were well described by this model. The most difficult task in the study of the reaction $\Sigma^- \rightarrow n e \widetilde{\nu}_e$ was the separation from the 10^3 times more intense reaction $\Sigma^- \rightarrow n\pi^-$. To overcome this difficulty, the PNPI group proposed to use a Transition Radiation Detector sensitive to electrons and less sensitive to π mesons. This detector occurred to be a very important part of the E715 experiment dedicated to the study of the Σ^--hyperon β-decay. The measured electron asymmetry in the β-decay of polarized Σ^- proved to be in good agreement with the Cabibbo model prediction. So, the long time contradiction between experiment and theory was settled in favour of the Cabibbo model.

Following the PNPI initiative, in 1986 a new experiment (E761) was proposed. Existing at that time experimental data revealed a strong asymmetry in the radiative decay $\Sigma^+ \rightarrow p\gamma$, and none of the theoretical attempts succeeded in explanation of this fact. In the E761 experiments, the data on the radiative decay of $\Sigma^+ \rightarrow p\gamma$ were obtained with high statistical accuracy. A possible admixture of the more intensive background reaction $\Sigma^+ \rightarrow p\pi^0 \rightarrow p2\gamma$ was suppressed with a new specially developed Transition Radiation Detector. The E761 data demonstrated that the asymmetry in the Σ^+-hyperon radiative decay was indeed large and negative, the observed decay rate being in agreement with the world data. In the E761 experiment, the data on the radiative decays $\Xi^- \rightarrow \Sigma^-\gamma$ and $\Omega^- \rightarrow \Xi^-\gamma$ were also obtained and the polarization of Σ^+ and Σ^- produced in the interaction of high energy protons with nuclei was measured.

In addition to the main program of the E715 and E761 experiments, the magnetic moments of Σ^-, Σ^+, $\overline{\Sigma}^+$, and Ξ^- hyperons were also measured.

8.   Participation in L3 experiment

   The L3 experiment at the Large Electron-Positron collider at CERN was one of the largest in the high energy physics. PNPI made a significant contribution to the L3 experimental complex. A half of the electromagnetic calorimeter crystals were fabricated by joint efforts using the material supplied by PNPI, the muon spectrometer high-voltage monitor was designed, produced and installed by the PNPI group. All the L3 data taking and experimental control electronics (about 1000 CAMAC and FASTBUS crates) were installed in the water-cooled racks (250 racks) designed (jointly with CERN) and fabricated at PNPI. Finally, the forward-backward FTC detectors, together with the electronics, have been designed and produced at PNPI. The PNPI physicists performed the FTC exploitation, including its calibration and alignment. The PNPI group participated in the data taking and the analysis of the data collected. More than 100 papers were published by the L3 collaboration. One of the main results of the L3 experiment was the high precision confirmation of the validity of the Standard Model.
   See also L3.

9.   Precision measurement of nuclear muon capture by ^{3}He
(See "Muon capture group").

10.   Meson spectroscopy
(The identification of resonances in the mass region 1.9-2.4 GeVin the reaction $\overline{p}p$ annihilation in flight)

   The search for the tensor glueball is one of primary objectives of the meson spectroscopy in the mass region 1900-2400 MeV. There are rather strong proofs that the scalar glueball exists with mass 1500-1650 MeV. It mixes with nearby $q\overline{q}$ states and physical resonances carry a large content of this state. The lattice QCD calculations give the ratio of tensor and scalar glueball masses ~ 1.4 with rather small errors. It corresponds to a mass for the tensor glueball 2150-2350 MeV. The first step in the tensor glueball search is to locate meson resonances in this mass region. The indication of an exotic state could be an appreciable deviation of the pole positions from the linear trajectories or the presence of a state which does not match linear trajectories at all. The real progress was made in the analysis of new data on $\overline{p}p$ annihilation in flight taken by Crystal Barrel collaboration at LEAR over the momentum range of antiproton 600-1940 MeV/c. The neutral particle production channels were analyzed by PNPI (Theoretical Physics Division and High Energy Physics one) group in collaboration with D.V.Bugg (Queen Mary and Wiestfield college, London), B.S.Zou (IHEP, Beijing) and group of C.Batty from Rutherford Appleton Laboratory (England). The following final neutral channels have been processed: $p\overline{p} \rightarrow \pi^0\pi^0, \eta\eta, \eta\eta^{'}, \pi^0\eta, \pi^0\eta^{'}$; $\pi^0\omega, \eta\omega, \eta^{'}\omega$; $3\pi^0, 2\pi^0\eta$; $\pi^02\eta, \pi^0\eta\eta^{'}$; $4\pi^0, 3\pi^0\eta, 2\pi^02\eta$.
   The first stage was a separate partial wave analysis of two body and three body final states. At the next stage all relevant data production channels were investigated in the framework of a combined analysis. The analysis allows us to determine a considerable number of meson states over the range 1900-2400 MeV that makes it possible to carry out the systematics of $q\overline{q}$ states in the (n, M^2) and (J, M^2) planes.