Project «PION»

Realyzed in the framework of the Program of the Branch of General Physics and Astronomy of the Russian Academy of Sciences «Physics of Elementary Particles and Fundamental Nuclear Physics»

At the Meson Physics Laboratory PNPI investigations on the Program «Baryon spectroscopy at pion beams with the energy up to 2000 MeV» are underway. At earlier stages, in the framework of this Program at the pion channel of the PNPI synchrocyclotron a series of experiments was carried out, in which the differential cross sections and polarization parameters P, A, R in $\pi^{\pm}p$ elastic scattering were measured at many energies in the region of low-lying πN resonances. Obtained precision data have served as a base for performing a new phase-shift at PNPI. One of important results – for the first time on the ground of phase-shift analysis the charge splitting in P_{33} phase was discovered and masses and widths of the Δ^0 и Δ^{++} resonances were determined.

In spite of πN scattering is studying for a rather long time, several problems are unsolved till now. Even for well established resonances $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$ having the highest rating ****, the masses, widths and decay rates are known with an insufficient accuracy. At the same time, many physicists show big interest in these resonances. For example, there exists an opinion that the $P_{11}(1440)$ resonance is a superposition of the usual resonance and of the so called hybrid resonance consisting of three quarks and one gluon. As to the $S_{11}(1535)$ resonance, last time sharp discussions about its nature – if it is the "true" resonance or only a threshold anomaly connected with opening the ηN channel – are going on.

The situation with the existing data-base is as following – if elastic channels ($\pi^{+}p$ and $\pi^{-}p$ scattering) are studied well enough, data on inelastic channels ($\pi^{-}p$ charge exchange scattering, η-production process $\pi^{-}p \to \eta n$) are quite scarce and contradictory. And these project aimed at filling up this gap in the data-base by measurements with a high precision of the differential cross sections of above mentioned reactions using a liquid-hydrogen target and of the asymmetry values in an experiment using a polarized proton target.

For solving above described tasks, at PNPI the Neutral Meson Spectrometer (NMS) was designed and created. It is a two-arm setup each arm of which represent an electromagnetic total absorption calorimeter consisting of 24 CsI(Na) crystals. A mosaic structure of the calorimeters allows to measure not only the energy but also the emission angle of both photon entering the calorimeters and, hence, to reconstruct the kinematics of the decay $\pi^0 \to 2\gamma$ (or $\eta \to 2\gamma$) and to determine after that the energy of produced π^0 meson (η meson) and the angle at which this meson was produced

Using the NMS, at the pion channel of the PNPI synchrocyclotron there were measured differential cross sections of $\pi^{-}p$ charge exchange scattering $\pi^{-}p \to \pi^0 n$ in the range of incident pions momentum from 417 to 710 MeV/c (corresponding values of the energy of incident pions were from 300 to 580 MeV); the momentum spread of particles in the beam was $\Delta p/p$ = 6%. Measurements were made for forward scattering angles using a liquid-hydrogen target. As a result, we have obtained high-accuracy data on the cross sections of the charge exchange reaction just in that energy range in which no measurements were performed till now or their results were unreliable and contradictory. A comparison of obtained new results with the predictions of partial-wave analyses demonstrates the existence of essential discrepancies, especially in the energy range 300–400 MeV. In order to make sure in the significance these discrepancies (which can be an evidence of the isospin violation in πN scattering), it is planned to continue measurements at lower energies. The obtained results were reported at the 10th International Conference on Hadron Spectroscopy (Germany, 2003) and published in the journal "Yad. Fiz". (Phys. Atom. Nucl.) in 2004.

In the framework of the program of studying the η-production process in the near-threshold region, at the pion channel of the PNPI synchrocyclotron we have measured using the NMS the differential cross sections of the reaction $\pi^{-}p \to \eta n$ at momenta of the incident pions near the threshold of this reaction (685 MeV/c). Since in the near-threshold region the cross section of process under study rises sharply with the momentum of the incident pions, the momentum spread of beam particles was

reduced in carrying out this experiment down to 1.5% (full width in half maximum of corresponding distribution) by a narrow vertical slit placed at that part of the pion channel where the momentum dispersion is maximal.

The kinematics of the reaction $\pi^- p \to \eta n$ has some distinctive features. In the near-threshold region, the angular distribution of produced η mesons covering a wide angular range from 0° to 180° in the centre-of-mass system (c.m.s.) transfers to a small forward cone in the laboratory system. In the subsequent decay of η mesons $\eta \to 2\gamma$ photons are emitted in the angular range from 0° to 180° (relatively to the η-meson momentum) but their symmetrical emission has the maximal probability. These kinematical features allowed us to use the NMS, having rather limited angular acceptance, for measuring the differential cross sections of the reaction $\pi^- p \to \eta n$ in the full angular range in the c.m.s. The value of total cross section was determined then by the integration of the differential cross sections over c.m.s. angles.

In 2005–2006 cross sections of the reaction $\pi^- p \to \eta n$ were measured at the incident pion momenta of 700 and 710 MeV/c. The shape of the differential cross sections, obtained at momenta of 700 and 710 MeV/c, distinguish rather essentially – in the first case the cross section are practically isotropic by the angle, in the second case the angular dependence unisotropic but symmetric relatively $\cos\theta^{cm} = 0$ (it looks like the bowl profile). It may be considered as an evidence that at the momentum of 700 MeV/c only *S*-wave plays a role in the η-production process but at the momentum 710 МэВ/с the contribution of higher waves becomes apparent visibly. To estimate this effect quantitatively, measurement at higher momenta are needed.

At the pion channel of the ITEP synchrotron experiments on measurement of the spin rotation parameters *A* and *R* in elastic $\pi^{\pm} p$ scattering at the second resonance region of pion-nucleon scattering are under way – in collaboration with ITEP physicists. Just experiments of this kind give a principally new quality – they allow to cancel discrete ambiguities arising in the course of a partial-wave analysis (PWA) and provide a unique possibility to find the only correct PWA solution.

Till recently similar experiment were not carries out because their extreme complexity. The spin rotation parameters may be determined only with the help of pion scattering on a polarized proton target with the spin lying in the horizontal plane and subsequent measuring the polarization of the recoil protons by their secondary scattering on nuclei of substance-analyzer (carbon}. A container with a working substance was put into the cryostat which was located between two superconducting Helmholtz coils producing the magnetic field of 2.5 T. By the evaporation of helium-3 the temperature inside the cryostat was 0.6 K, that provided the value of protons' polarization in the target at a level of 70–80%. For determining trajectories of the incident and scattered pions as well as trajectories of the recoil protons before and after their secondary scattering on the analyzer (carbon) arrays of magnetostrictive spark chambers were used.

Results of measurement of the spin rotation parameters *A* and *R* obtained at the incident pions momenta of 1430 and 1620 MeV/c allowed to make the very important conclusion – the widely used analysis KH-80 (all characteristics of πN resonances given in Listings of Particle Data Group are based just on the results of this analysis) is incorrect in some energy regions.

Now the next stage of experiment is underway at the pion channel of the ITEP accelerator, namely – measurements of the polarization parameter *P*. Measurements have been performed already at momenta of 1780, 1940 and 2070 MeV/c in the angular range from 150° to 170° (in the centre-of-mass system); till now no measurements were done in this angular range because of the very small values of differential cross section. The obtained results are reported at the International Workshop SPIN-03.

A preparation of new experiment on the search for a narrow exotic nucleon resonance is underway. The experiment will be carried out by scanning of the $\pi^- p$-system invariant mass in the region 1610–1770 MeV with the detection of $\pi^- p$ and $K\Lambda$ decays. The scan is supposed to be done by the variation of the incident pions momentum and its measurement with an accuracy $\leq 0.1\%$ (better than 1 MeV in terms of the invariant mass in the whole energy range) with a set of multiwire proportional chambers located in the first focus of the pion channel. The secondary particles scattered on a liquid hydrogen target will be detected by sets of the wire drift chambers equipped with modern readout electronics.