The Meson Physics Laboratory enters the international collaboration performing the Program entitled "Baryon and Hyperon Spectroscopy with the Crystal Ball". This collaboration was formed finally in 1995–1997, at present it includes 14 institutions from 5 countries: Abilene Christian University, Argonne National Laboratory, Arizona State University, Brookhaven National Laboratory, University of California at Los Angeles, University of Colorado, The George Washington University, Kent State University, University of Maryland, Valparaiso University (USA), Petersburg Nuclear Physics Institute (Russia), University of Regina (Canada), Universität Karlsruhe (Germany), Rudjer Bošković Institute (Croatia). Experiments E913/914/953/958 were carried out in the C6 line of the Alternating Gradient Synchrotron at Brookhaven National Laboratory and involves following items:

1. Measurement of differential cross sections of $\pi^- p$ reactions with neutral particles in the final state ($\pi^- p \to \gamma n$, $\pi^- p \to \pi^0 n$, $\pi^- p \to \eta n$, $\pi^- p \to \pi^0\pi^0 n$, $\pi^- p \to \pi^0\eta n$ and so on at energies from 65 to 625 MeV – experiments E913/958.

2. Measurement of differential cross sections of $K^- p$ reactions with neutral particles in the final state: $K^- p \to \gamma\Lambda$, $K^- p \to \pi^0\Lambda$, $K^- p \to \eta\Lambda$ and similar reactions with the Σ^0 production – experiments E914/953.

3. Study of rare and forbidden η meson decays.

Owing to the use of a multi-photon 4π total absorption spectrometer Crystal Ball, the cross sections of all $\pi^- p$ reactions (or $K^- p$ reactions) with neutral particles in the final state are measured simultaneously by detecting gammas arisen directly in the reactions or after the decay of produced neutral mesons or hyperons. The ball proper is a sphere with an entrance and exit opening for the beam and an inside cavity for the target. It is constructed of 672 optically isolated NaI(Tl) crystals which are shaped like a truncated triangular pyramid. An external diameter of the Crystal Ball is 132 cm, an inner diameter of the NaI(Tl) crystals layer is 50 cm. The thickness of individual NaI(Tl) crystal is 15.7 radiation lengths. The energy resolution of the Crystal Ball is $\sigma_E/E = 2.7\% \cdot E^{-1/4}$ (E in GeV), the angular resolution $\sigma_\theta = 2^\circ - 3^\circ$, $\sigma_\phi = 2^\circ/\sin\theta$.

a. Study of $\pi^- p$ reactions with neutral mesons in the final state

In the Fall 1998, rather big run was performed using a liquid hydrogen target. During this running period, we collected over 42×10^6 triggers for $\pi^- p \to neutrals$ at 22 incident pions energies over a range of 65–625 MeV (the corresponding momenta are from 150 to 750 MeV/c). This energy range includes the Δ $P_{33}(1232)$ resonance and three N^* resonances: the $P_{11}(1440)$, the $D_{13}(1520)$ and the $S_{11}(1535)$. Preliminary results for $\pi^- p \to \pi^0 n$ reaction are obtained for eight energies in the range from 65 to 180 MeV.

At the incident pions momenta higher than the η-production threshold accumulated data were used to obtain cross sections of reaction $\pi^- p \to \eta n$. Until now existing experimental information on the cross sections of this reaction has been very scarce and contradictory, especially near the threshold. At the same time, obtaining accurate experimental data in the near-threshold region is very important for verifying theoretical models of η-meson production. Such data will also be useful for extracting the ηN scattering length and understanding properties of $S_{11}(1535)$ resonance. Total and differential cross sections of the reaction $\pi^- p \to \eta n$ were determined in the momentum range from the threshold (560 MeV) up to 585 MeV. The absolute beam momentum of incident pions was known with an accuracy of 0.5%. Events attributed to the reaction $\pi^- p \to \eta n$ were selected by detecting photons from the η-meson decays $\eta \to 2\gamma$ or $\eta \to 3\pi^0 \to 6\gamma$. Obtained new results are in a good agreement with those of earlier experiments but exceed significantly all existing experimental data in a statistical accuracy. These results do not contradict the predictions of the K-matrix model of pion-nucleon scattering, which takes into account S- and P-wave contributions to the η production.

In 2002, another run was performed using a CH_2 target. Experiment was carried out at ten energies covering the range from 60 to 625 MeV. To exclude a background due to π^- interactions with carbon nuclei of this target, at every energy an additional measurement was made using a carbon (graphite) target of corresponding thickness. In a subsequent off-line analysis, data obtained with the carbon target were subtracted from CH_2 data – after the appropriate renormalization of monitor counts. An analysis of data obtained is underway now with the aim to extract differential cross sections of reactions $\pi^- p \to \pi^0 n$ and $\pi^- p \to \eta n$ (in the near-threshold region).

b. Study of $K^- p$ reactions with neutral particles in the final state

In experiments on studying $K^- p$ reactions, negative kaons were separated from pions, muons and electrons using two $\vec{E} \times \vec{B}$ separators and the time-of-flight technique. Experimental data on $K^- p$ reactions were taken in the Fall 1998 at two different beam momenta. The low- and high-momentum beams had central momenta of 720 MeV/c and 750 MeV/c, respectively.The beam wire chambers were used to measure the momentum difference of every K^- with respect to the central value. The accuracy of the absolute K^- momentum is ± 2.5 MeV/c. Both the low- and high-momentum beam were tuned to optimize the K-to-π ratio and the beam position on the liquid hydrogen target. We obtained about 8×10^4 kaons in an AGS beam spill of 2.8 s duration every 5 s with the K-to-π ratio about 1:10.

When studying the $K^- p \to \eta \Lambda$ reaction, the final state was identified in two ways: (i) *via* the $\eta \to \gamma\gamma$ and $\Lambda \to \pi^0 n$ decays (four-cluster events); (ii) *via* $\eta \to 3\pi^0$ and $\Lambda \to \pi^0 n$ decays (eight-cluster events). Our new data have much better precision than previous measurements which were very scarce and contradictory and did not allow to determine even a shape of momentum dependence.

There are many similarities between the $K^- p \to \eta \Lambda$ reaction and the $\pi^- p \to \eta n$ reaction near threshold, which is dominated by the $N(1535)\frac{1}{2}^-$ resonance. These include:
1. The steep rise in σ_{tot} at the opening of the η channel.
2. s-wave dominance with similar slope parameters of the σ_{tot} dependence on η c.m. momentum:

$$\sigma_{tot}(K^- p \to \eta \Lambda) = (17 \pm 3)(\mu\mathrm{b}/(\mathrm{MeV/c})) \times p^*_\eta,$$

$$\sigma_{tot}(\pi^- p \to \eta n) = (15 \pm 1)(\mu\mathrm{b}/(\mathrm{MeV/c})) \times p^*_\eta.$$

3. Large values for σ_{tot} far from the opening of the η channel; the maximum value for $\sigma_{tot}(K^- p \to \eta\Lambda)$ is 1.5 ± 0.1 mb with $p^*_\eta = 81$ MeV/c, while for $\sigma_{tot}(\pi^- p \to \eta n)$ the maximum value is 2.6 ± 0.3 mb with $p^*_\eta = 182$ MeV/c.

To understand the near-threshold η production, we assumed that it is dominated by the excitation of the intermediate $\Lambda(1670)\frac{1}{2}^-$ resonance with very minor contribution from the $\Lambda(1600)\frac{1}{2}^+$ and $\Lambda(1690)\frac{3}{2}^-$ states. To fit the total cross section, a unitarity multi-channel parametrization was applied. The fitted mass of the $\Lambda(1670)\frac{1}{2}^-$ resonance, $M = 1673 \pm 2$ MeV.

This new value of mass is consistent with the most recent results listed in the Review of Particle Physics.

c. Study of rare and forbidden η-meson decays

The Crystal Ball collected ~ 30 million η mesons from the reaction $\pi^- p \to \eta n$ using a liquid hydrogen target at a beam momentum of 720 MeV/c. Data are in processing in USA and at PNPI.

An important goal of this experiment was to improve the present values of branching ratios for rare and forbidden decays of the η meson. Besides the most intense neutral decays $\eta \to 2\gamma$ and $\eta \to 3\pi^0$ having branching ratios of $39.3 \pm 0.3\%$ and $32.2 \pm 0.3\%$, accordingly, the following neutral decay modes can be investigated using the Crystal Ball: $\eta \to 3\gamma$; $\eta \to 2\pi^0\gamma$; $\eta \to 3\pi^0\gamma$; $\eta \to 2\pi^0$; $\eta \to 4\pi^0$; $\eta \to \pi^0\gamma\gamma$; $\eta \to \pi^0\pi^0\gamma\gamma$.

The decay mode $\eta \to 4\pi^0$ is forbidden by CP conservation so it provides a test for strong CP-violating amplitudes down to a level of about 10^{-7} where weak interactions come into play. This decay mode requires 8 neutral clusters in the CB which must be reconstructed to $4\pi^0$ mesons which together have the invariant mass of the η meson. With no 8-cluster event (from $\eta \to 4\pi^0$) found, the upper limit becomes $\mathrm{BR}(\eta \to 4\pi^0) \leq 6.9 \cdot 10^{-7}$ for 90% CL This upper limit can be expressed as $\Gamma(\eta \to 4\pi^0) \leq 8.3 \cdot 10^{-4}$ eV. Systematic errors have been estimated to be less then 2% and have not been included in the determination of the upper limit.

The decay $\eta \to 3\pi^0$ violates G parity and, ignoring a small electromagnetic contribution, occurs because of the u-d quark mass difference. And low-energy theory must predict both the rate and the spectrum of the pions correctly. Besides the decay rate, one must also consider the spectrum of the pions in the final state. Experimentally, the Dalitz plot for the neutral final state is usually expressed as a linear parametrization in which the quadratic slope parameter α describes the difference of the $\eta \to 3\pi^0$ decay from the pure phase space. The α value measured in the experiment was $\alpha = -0.031 \pm 0.004$ This result in several time more precise than the present world data and disagrees with current chiral perturbation theory calculations by about four standard deviations.