Near-threshold η-meson production of the reaction $\pi^- p \to \eta n$ using the Crystal Ball detector*

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Preliminary results of the measurement of the reaction $\pi^- p \to \eta n$, obtained in 1998 by the Crystal Ball Collaboration, are presented. These new experimental results do not contradict the predictions of the model of pion-nucleon scattering in the K-matrix approach.

PACS numbers:

Until now experimental information on the cross sections of the reaction $\pi^- p \to \eta n$ is very scarce and contradictory, especially near the threshold (685 MeV/c). 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.

For measuring $\pi^- p \to \eta n$ cross sections it is necessary to detect either the neutron or the photons from the η-meson decay modes $\eta \to 2\gamma$ or $\eta \to 3\pi^0 \to 6\gamma$. An ideal detector for these purposes is a 4π gamma detector such as the Crystal Ball (CB) [1] which is now on the C6 beam line at

* Supported in part by US DOE, NSF, NSERC, Volkswagen Stiftung, Russian Fund Basic Research and Russian Ministry of Sciences.

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BNL. Shown in Fig. 1 is the floor layout of the C6 beam line including the Crystal Ball detector. Not shown in Fig. 1 is a gas Čerenkov counter used

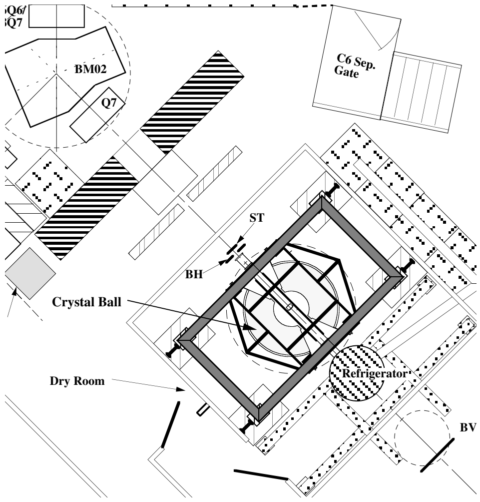

Fig. 1. Floor layout of C6 beam line.

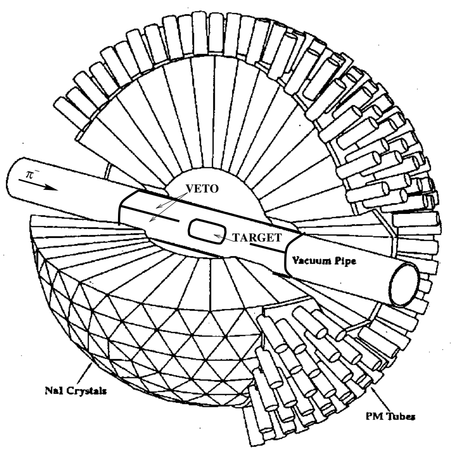

Fig. 2. Crystal Ball schematic view.

for determining of the electron contamination of the beam. The Crystal Ball detector is shown in Fig. 2. It consists of 672 separate NaI(Tl) crystals covering 93% of 4π steradians, each crystal being 16 radiation lengths thick.

Measurements of the reaction yield were performed in the near-threshold region in the momentum range up to 720 MeV/c. The absolut beam momentum of the incident pion was known with accuracy 0.5%. The invariant mass of the η meson (for the case when 2γ were detected in the CB) was calculated as $M_{2\gamma}^{inv} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1-\cos\theta_{\gamma_1\gamma_2})}$. A typical invariant mass distribution for 2γ events is shown in Fig. 3. The background under the η

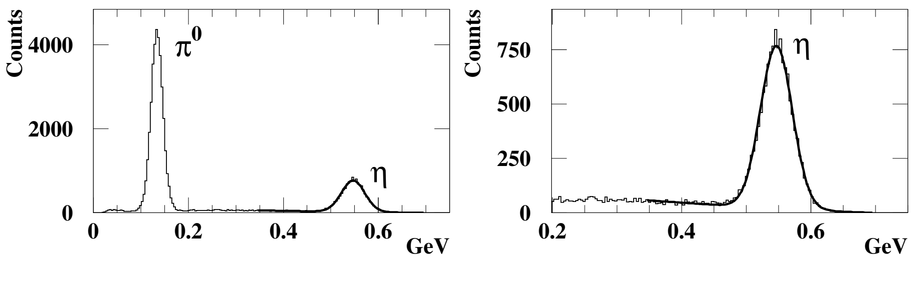

Fig. 3. Invariant mass spectrum for 2γ. The second histogram is enlarged version of the first in the vicinity of the eta.

peak (in Fig. 3) is less than 6% and was subtracted in order to calculate the yield. The background from an empty target was about 2%.

The total cross section σ^{tot} is defined by the formula:

$$\sigma^{tot} \propto \frac{N_\eta}{N_{\pi^-}\ N_p\ \ A}, \quad \text{where} \quad N_{\pi^-} = N_{tot}\ \ (1-n_e)\ (1-n_\mu),$$

N_η	–	number of events under the peak of $M_{2\gamma}^{inv}$;
N_{π^-}	–	number of incident pions;
N_p	–	number of protons in the target (1/cm^2);
A	–	acceptance of the Crystal Ball for detection of 2γ, (includes analysis efficiency) and ≈ 0.45 for 720MeV/c;
N_{tot}	–	beam monitor (total number of particles including e, μ, π);
n_e, n_μ	–	fraction of electron and muon contamination correspondingly.

The veto barrel efficiency was taken in to account by Monte-Carlo calculation and included into acceptance. Uncertanty in knowledge of the hardware threshold of the veto barrel give error 1% for the value of the total cross section.

Since the statistical errors of this experiment were very small, the main problem consists of detection and elimination of the possible sources of systematic errors. The main source of systematic errors in the experiment was the uncertainty determining the electron contamination in the incident beam. Therefore, in the present work, the influence of the inaccuracy in determining this contamination on the magnitude of cross section was investigated. The influence of the energy threshold in the Crystal Ball was also investigated.

Data were taken in July and September 1998 with various experimental conditions shown in Table 1 below. The Table lists the run number along with the corresponding electron contamination. Each run in the Table was taken at a beam momentum of 720 MeV/c. The maximum electron contamination of 61% was found in run 336. In runs 339, 340 and 341 a 3 mm thick lead plate was placed at the intermediate focus of the C6 channel. The electrons lost a considerable part of energy due to radiative losses in the lead and were removed from the beam by the second bending magnet (**BM02**). This reduced the electron contamination of these runs to about 7.7%. In runs 387–517 the content of electrons was from 25% to 32%. The muon contamination in the beam was almost constant for the momentum range 685-750 MeV/c and was about 2%.

In Table 1 the energy thresholds in the Crystal Ball are given as well: 0.258 V (100 MeV), 1.50 V (350 MeV) and 2.26 V (450 MeV). As Monte Carlo (GEANT code) calculations show, the acceptance A for detection $\pi^- p \to \eta n$ practically does not depend on this threshold.

The cross section was calculated for each run. Figure 4 shows a plot of σ^{tot} versus run number. The average cross section was found to be 2.03±0.01

mb (the solid line in Fig. 4). The maximum diversion from the average is about 4%(systematic error).

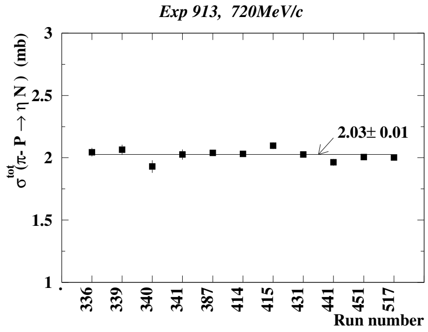

Fig. 4. Comparison of total cross section values obtained at different experimental conditions (see Table 1). The solid line is the Least-Squares Fit.

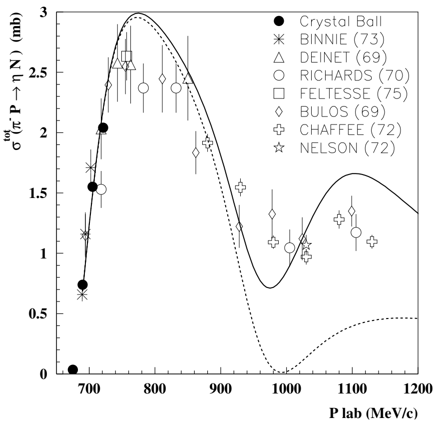

Fig. 5. Total cross section of $\pi^- p \to \eta n$. The solid line corresponds to calculations [2] including S and P waves. The dashed line corresponds to only S wave contributions.

Month	Run	Electrons	Threshold	
July	336	61%	0.26 V	
	339	7.5%	0.26 V	Lead (3 mm)
	340	7.7%	1.50 V	Lead (3 mm)
	341	7.7%	2.26 V	Lead (3 mm)
Sept.	387	30%	2.26 V	
	415	31%	2.26 V	
	431	29%	2.26 V	
	451	32%	2.26 V	
	517	25%	2.26 V	

Table 1. Different run experimental conditions.

The total cross section obtained in this work are in a good agreement with previous experiments but exceed significantly all existing experimental data in statistical accuracy – see Fig. 5. Our results do not contradict the predictions of the K-matrix model of pion-nucleon scattering [2], which takes into account S- and P-wave contributions to the η-production.

REFERENCES

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