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Study of the Decay $A_2 \to \eta\pi$ via the Reaction $\pi^- p \to \eta\pi^- p$ at 6.0 GeV/c*†

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The reaction $\pi^- p \to \eta\pi^- p$ at 6.0 GeV/c has been studied at the Argonne zero-gradient synchrotron using optical spark chambers. About 1400 events have been obtained in the range $0.80 < M_{\eta\pi} < 1.55$ GeV/c^2, yielding approximately 1000 events of the type $A_2^- \to \eta\pi^-$, with $0.27 < |t| < 0.42$ (GeV/c)^2. No structure is discernible within the A_2 mass spectrum with an experimental resolution of 7.1 MeV/c^2 [full width at half-maximum (FWHM) $= 16.7$ MeV/c^2]. A single D-wave Breit-Wigner distribution fits the data with a high confidence level yielding the parameters $M_0 = 1.323 \pm 0.003$ GeV/c^2 and $\Gamma_0 = 0.108 \pm 0.009$ GeV/c^2 for the A_2.

An optical spark-chamber experiment has been performed at the Argonne zero-gradient synchrotron to study the reaction

$$\pi^- p \to X^- p; \quad X^- \to \eta\pi^-; \quad \eta \to \gamma\gamma \qquad (1)$$

for an X^- mass in the range from threshold to 1.5 GeV/c^2. This paper presents the analysis of the mass range $0.80 < M_x < 1.55$ GeV/c^2. For this mass range, a beam momentum of 6 GeV/c and a range in t (the four-momentum squared to the

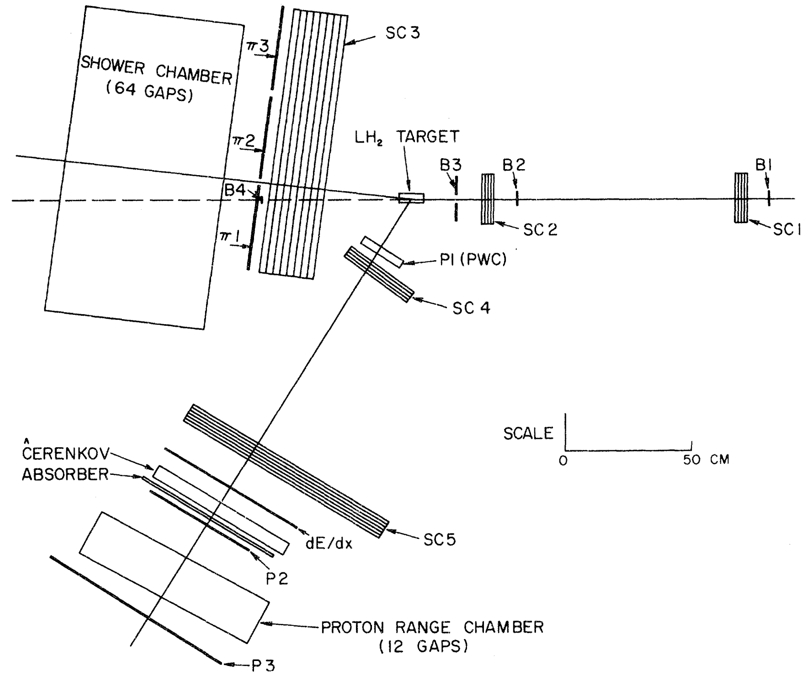

FIG. 1. Schematic plan view of the optical spark-chamber spectrometer. The beam is incident from the right. B_1, B_2, B_3, B_4, π_1, π_2, π_3, dE/dX, P_2, and P_3 denote scintillation counters. P_1 is a proportional wire chamber (PWC). C is a Lucite Cherenkov counter. SC_1, SC_2, SC_3, SC_4, and SC_5 denote thin-foil spark chambers. The proton range chamber and the γ shower chamber are thick plate chambers.

proton) of $0.27 < -t < 0.42$ $(\mathrm{GeV}/c)^2$ ensured that the X^- was produced in the Jacobian peak region. The resulting mass spectrum provides an extremely clean sample of the decay $A_2^- \to \eta\pi^-$. Approximately 1000 out of 1400 events corresponding to Reaction (1) are A_2 mesons. No experiment of comparable statistics has been previously reported for this decay mode of the A_2.[1]

The optical spark-chamber system is shown in Fig. 1. Two thin-foil spark chambers SC_1 and SC_2 were used to determine the incident π^- direction, and the thin-foil chambers SC_4 and SC_5 determined the recoil-proton direction. The proton range was measured in a twelve-gap aluminum-plate range chamber. The outgoing pion direction was determined using the thin-foil chamber SC_3 and the first few gaps of the shower chamber. The γ rays were converted in the shower chamber which consisted of sixty-four 1.59-mm-thick steel plates (approximately $5\frac{1}{2}$ radiation lengths).

A beam interaction in the 10-cm-long hydrogen target was defined by the electronic trigger signal $B_1B_2B_3B_4$. B_1 and B_2 were small beam scintillation counters in anticoincidence with a hole counter (B_3) directly in front of the hydrogen target and a small counter (B_4) downstream from the hydrogen target. A recoil proton was defined by a signal $P_1(dE/dX)P_2\overline{P}_3\overline{C}$ together with a selection on the pulse height in the dE/dX counter. The dE/dX counter pulse height was also recorded for each trigger. P_1 was chosen to be a wire proportional chamber in order to minimize multiple scattering. The Lucite Cherenkov counter, C, vetoed pions in the proton arm. The proton momentum was restricted to the interval 0.54 to 0.68 GeV/c by the absorber and P_3 in anticoincidence. The horizontal projection of the angle between the proton and the beam was restricted by counter P_2 to 49° to 64°, and the azimuthal acceptance of the proton arm was approximately 8%. These criteria correspond to a uniform efficiency for detecting the proton in the ranges $0.27 < -t < 0.42$ $(\mathrm{GeV}/c)^2$ and $1.05 < M_X < 1.45$ GeV/c^2. Most of the reactions leading to more than one charged pion in the final state were excluded by demanding a signal from one and only one of the three counters placed behind spark chamber SC_3. A full trigger signal for pulsing the spark chambers thus consisted of an incident π^- interacting in the hydrogen target, a single forward charged particle, and a recoil proton in the correct angular and momentum interval as defined by the coincidence signal $(B_1B_2\overline{B}_3\overline{B}_4)$ $\cdot[P_1P_2(dE/dX)\overline{P}_3\overline{C}]\cdot(\pi_1 \text{ or } \pi_2 \text{ or } \pi_3)$.

The beam spot size at the hydrogen target was typically 1.5 cm and the hydrogen-target cell position was carefully adjusted to minimize the amount of hydrogen traversed by the recoil protons. A beam flux of typically 10^5 pions/pulse produced a trigger rate of approximately 0.7 event/pulse.

For each of the 360 000 triggers two views of each spark chamber were photographed in approximately 90° stereo. The photographs were scanned for final states with a good proton, a single outgoing pion, and two photon showers with a projected opening angle of greater than 7° in at least one view. This latter cut reduced the number of $\eta\pi$ candidates due to single and multiple π^0 production by a factor of between 2 and 3. Approximately 20 000 candidates for full analysis were obtained.

A successful spatial reconstruction of an event required a unique vertex for the beam, the proton, and the outgoing pion using a method based on that of Zacharov.[3] The kinematic fitting was done using a modified version of the bubble chamber program SQUAW. The trial hypotheses were

$$\pi^- p \to \pi^- p\gamma\gamma, \qquad (2)$$

which gives a fit with one constraint (1C), and a 2C fit,

$$\pi^- p \to \pi^- p\eta; \quad \eta \to \gamma\gamma. \qquad (3)$$

This procedure yielded approximately 1400 $\eta\pi^-$ events fitting Reaction (3) with a χ^2 probability of greater than 1% in the mass range $0.80 < M_X < 1.55$ GeV/c^2. The invariant-mass plot of the two photons, $M_{\gamma\gamma}$, for events which satisfy Reaction (2) shows a clean π^0/η separation, with a background of approximately 3% under the η peak.

The mass resolution $\sigma(M_X)$ is mainly dependent on errors in the following quantities (unless otherwise stated the errors presented in this paper correspond to 1 standard deviation): (a) *The beam momentum.* The 6-GeV/c beam had a momentum spread of ±0.4%, and the absolute momentum was determined to ±0.15% by wire orbit measurements. An NMR probe was used to monitor continuously the momentum-defining magnet which was stable to within 0.02% throughout the experiment. (b) *The recoil proton momentum.* This error is determined from a knowledge of the stopping power of the plates in the range chamber and an analysis of πp elastic scattering at 1.1 GeV/c (see below) to be ±6 MeV/c. (c) *The angle between the beam and the recoil proton.* The mass resolution is dominated by this error, which itself is dominated by the multiple scattering of the proton. An experimental estimate of the average multiple-scattering error was obtained by measuring πp elastic scattering at 1.1 GeV/c in the same apparatus. At this beam momentum, the recoil protons are produced in the same angle and momentum interval as those which give an X^- mass centered around the A_2 for a beam momentum of 6 GeV/c. Since these events are kinematically overconstrained, it is possible to extract the multiple-scattering contribution to the error in the projected proton angle.

It is to be expected that the constrained fit of Reaction (3) will improve the resolution in the $\eta\pi$ invariant mass. The input error to the geometric reconstruction fit is the matrix of the errors in the reconstructed points. In the kinematic fitting procedure the multiple scattering error of the proton and the outgoing pion is calculated for each event using the method of Gluckstern[4] which includes contributions from small-angle single and plural scattering, scattering from the atomic electrons, and small-angle nuclear scattering. These errors are included in the full error matrix which is used in the minimum-χ^2 fitting method.[5] The resultant mass resolution is $\sigma(M_X) = 7.1$ MeV/c^2 (16.7 MeV/c^2 FWHM).

This procedure has been checked in two ways: (a) The elastic scattering events were processed through the fitting programs using the same error estimates and assuming that the mass of the outgoing pion was unknown. The calculated mass spectrum fitted to a Gaussian distribution gives a mean value of 139.0 MeV/c^2 with a standard deviation of 18.0±1.0 MeV/c^2 for the resultant 2C fits. The calculated rms error is 18.2 MeV/c^2, in good agreement. (b) The $M_{\gamma\gamma}$ mass spectrum from Reaction (2) for events satisfying the 2C fit of Reaction (3) gives a central mass value of 549.6 MeV/c^2 with a standard deviation of 10±1 MeV/c^2, again in good agreement with the calculated rms error of 12 MeV/c^2.

The $\eta\pi$ mass spectrum for events giving a 2C fit with a χ^2 probability of greater than 1% is shown in Fig. 2. The overall efficiency of the apparatus for detection of Reaction (1) has been calculated by standard Monte-Carlo techniques and the results incorporated in a Breit-Wigner fit to the data of Fig. 2. This fit[6] yields a mass $M_0 = 1.323 \pm 0.003$ GeV/c^2 and a width (corrected for resolution) of $\Gamma_0 = 0.108 \pm 0.009$ GeV/c^2 for the A_2, with a χ^2 of 38 for 36 degrees of freedom.

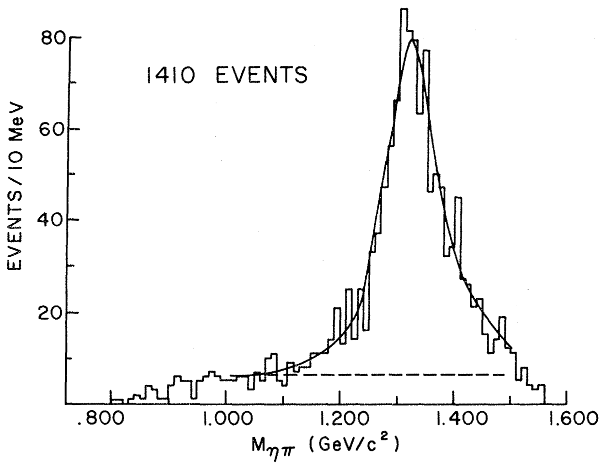

FIG. 2. Invariant mass of $\eta\pi^-$ from events fitting the reaction of Eq. (3). The solid curve shows the result of the single D-wave Breit-Wigner fit with parameters described in the text. The dashed curve indicates the fitted background.

The errors quoted are statistical only. The systematic mass error is estimated to be approximately ± 5 MeV/c^2. It should be emphasized that the spectrum shown has no background subtraction and includes a background of about 7 events per 10-MeV/c^2 bin. If the A_2 mass spectrum exhibited the "dipole" structure suggested by Chikovani *et al.*,[7] a mass resolution of 7.1 MeV/c^2 would give an observable valley-to-peak ratio of about 0.5. It is clear that the mass spectrum of Fig. 2 is inconsistent with such a structure. The result of no structure is in agreement with the recent missing-mass experiment of Bowen *et al.*[8]

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[5]The χ^2 probability plot for the 2C fit of Eq. (3) is flat above 1%, confirming the correctness of the errors used in the fitting procedure.

[6]The $(\eta\pi)$ mass spectrum was fitted from 1.05 to 1.45 GeV/c^2 to the functional form $F_{ps}[af_0(M)+bf_2(M)F_{BW}]$. F_{ps} is the phase space for the production of two out of three bodies ($\eta\pi$ in the final state $p\eta\pi$) at a mass M, corrected for the t acceptance $0.27 < -t < 0.42$ (GeV/c)^2. $f_l(M)$ is the detection efficiency for an $\eta\pi$ system in a relative angular momentum state l, calculated using Monte Carlo methods. The only sizable bias arises from the incomplete efficiency of the apparatus for the detection of the two γ's from η decay. The Breit-Wigner form used was

$$F_{BW} = \frac{MM_0\Gamma}{(M^2-M_0^2)^2+(M_0\Gamma)^2}$$

with

$$\Gamma = \Gamma_0\left(\frac{q}{q_0}\right)^{2l+1}\frac{\rho(q)}{\rho(q_0)}.$$

q (q_0) is the three-momentum of the η and π in the A_2 rest frame, for a mass of M (M_0), l is the relative angular momentum between the η and π ($l=2$), and $\rho(q) = (9+3R^2q^2+R^4q^4)^{-1}$ with R, the radius of interaction, chosen to be $R^2 = 12$ GeV^{-2}. a, b, M_0, and Γ_0 are free parameters found by the minimum-χ^2 fitting procedure, which also includes the effect of a mass resolution of 7.1 MeV/c^2.

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