Photoproduction of $\eta\pi^{\pm}$ resonances*

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The cross sections at 9.7 GeV for the reactions $\gamma n \to \delta^{\pm}(980)X$ and $\gamma N \to A_2^{\pm}X$, $M_N \leq m_X \leq 1.4$ GeV, are, respectively, $\lesssim 25$ nb and 1.46 ± 0.36 μb. Fitting the A_2 differential cross section with a one-pion-exchange model yields $\Gamma(A_2 \to \pi\gamma) = 0.46 \pm 0.11$ MeV.

Resonances with the quantum numbers $I^G J^P = 1^- 0^+$ can couple to $\eta\pi$, $\omega\rho$, ρA_2, and $K\bar{K}$. They cannot couple to pionic systems containing fewer than five pions. Because of the weak coupling of η to nucleons, π-N interactions are expected to have low production cross sections for these resonances, while K-N interactions should be more favorable. These expectations are borne out for $\delta(980)$.[1] The $\omega\rho$ and ρA_2 couplings, in conjunction with vector dominance ideas, suggest that γ-N interactions may be another promising way to produce $\delta(980)$, and any other as-yet-undiscovered $1^- 0^+$ resonances. We have therefore conducted a search for $1^- 0^+$ resonances photoproduced from nucleons, looking for such resonances via their $\eta\pi^{\pm}$ decay mode. Simultaneously we have observed A_2 through its $\eta\pi^{\pm}$ decay mode, and by fitting the A_2 photoproduction cross section with a pion-exchange model, obtained a measurement of the A_2 $\pi\gamma$ coupling.

The experimental layout, described previously,[2,3] consisted of a 8.8- to 10.4-GeV tagged photon beam, a hydrogen or deuterium target, and a multiparticle forward spectrometer capable of measuring the vector momenta of charged particles and γ rays. The trigger required one or more charged particles and two or more γ rays. Events with exactly two detected γ rays and one detected charged particle were analyzed as examples of the reaction $\gamma N \to \pi^{\pm}\gamma\gamma X$. The $\gamma\gamma$ mass spectrum for events with missing masses m_X below 1.41 GeV and $t' \equiv |t - t_{\min}| < 0.5$ GeV^2 is shown in Fig. 1. There is a dominant π^0 peak (considered elsewhere[3,4]), and also a clear η signal. We cut on the η signal, impose the η mass as a constraint, correct[5] for the non-η background within the η cut, and obtain the $\eta\pi^{\pm}$ mass spectrum shown in Fig. 2(a). Correcting for acceptance and other factors, we obtain the cross sections shown in Fig. 2(b). There is a clear A_2 signal and a suggestion of $\delta(980)$.

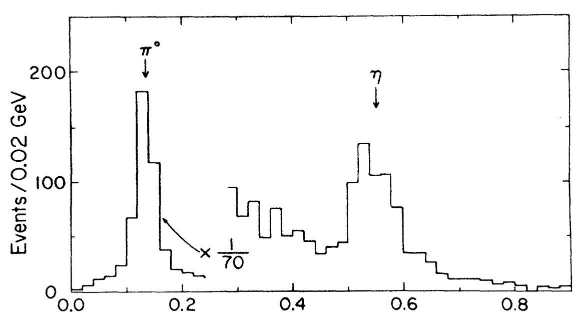

FIG. 1. $\gamma\gamma$ mass spectrum for topologically acceptable events with missing masses below 1.41 GeV and t' less than 0.5 GeV^2. The π^0 peak has been divided by a factor of 70 so that it can be shown on the graph.

We fit the cross-section distribution of Fig. 2(b) with three terms: (a) an A_2 of fixed mass and width,[6] but adjustable magnitude; (b) a δ of natural width[7] 55 MeV,[1] variable mass, and adjustable magnitude; and (c) a background term. For the background term we have tried three-body phase space, three-body peripheral phase space, three-body double peripheral phase space,[8] and a three-term polynomial. For each variety of phase space, sensitivity to the choice of the mass of the third body (m_X) was investigated. For all backgrounds tried, a δ signal persists, at a 2 standard-deviation level. Its mass is found to be 993 ± 20 MeV, in agreement with the recently obtained[1] value of 981 MeV. We find no evidence for resonances other than $\delta(980)$ and A_2. Using the value of 981 MeV for the δ mass, we obtain a cross section of 25 ± 9 nb for the reaction $\gamma N \to \delta^{\pm}X$, $m_X < 1.41$ GeV, $t' < 0.5$ GeV/c^2.[9] The error quoted is purely statistical. For the range of background parametrizations tried, the cross section varies by ± 4 nb, small compared to the statistical uncertainty. Although

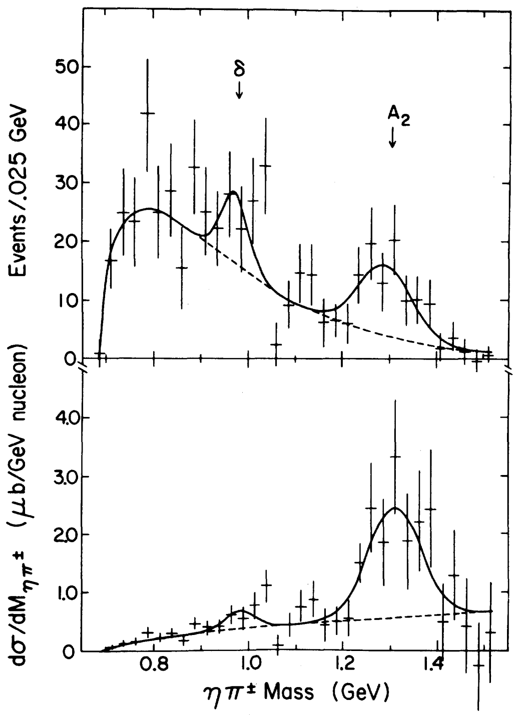

FIG. 2. $\eta\pi^\pm$ mass spectrum for events with missing masses below 1.41 GeV and t' less than 0.5 GeV^2: (a) uncorrected for acceptance; (b) corrected for acceptance, and expressed as a cross section.

these procedures all indicate the presence of a δ(980) signal, Fig. 2(b) leaves one unconvinced, and we feel more secure in quoting an upper limit, $\sigma(\gamma N\to\delta^\pm X)\lesssim 25$ nb.

The $\delta^\pm$ photoproduction cross section is compared with other photoproduction cross sections[4,10,11] in Table I. One notes that it is one to two orders of magnitude smaller than the cross sections for photoproduction of the charged nonstrange members of the 0^-, 1^-, and 2^+ nonets. Fox[12] has noted that with ρ-A_2 exchange-degeneracy arguments one can relate δ photoproduction (dominantly A_2 exchange) to η photoproduction (dominantly ρ exchange). One readily shows

$$\frac{d\sigma/dt(\gamma N\to\delta^\pm X)}{d\sigma/dt(\gamma N\to\eta X)}\approx 2\left(\frac{\gamma_\omega}{\gamma_\rho}\right)^2 y, \qquad (1)$$

where

$$y=\left|\frac{\langle\delta^+|J_\mu|\rho^+\rangle}{\langle\eta|J_\mu|\rho^0\rangle}\right|^2 .$$

The ratio of the $\delta^\pm$ photoproduction cross section obtained here and the η photoproduction cross section obtained in a companion experiment[10] gives $y\lesssim 0.015$. Since the ρ^+-δ^+ matrix element is an electric dipole transition, while the η-ρ^0 matrix element is magnetic dipole, one might have expected y to be large. However, calculating y with a nonrelativistic, naive quark model, we find that the contributions to $E1$ from quark charges and quark magnetic moments largely cancel each other, and a small value, $y=0.06(\bar{r})^2$, results. $\bar{r}$ is the δ-ρ overlap radius, expressed in fermis, and is expected to be 0.5 to 1.0 F. Thus the abnormally small cross section is consistent with the quark model.

TABLE I. Meson photoproduction cross sections at 9.7 GeV, summing over charge states and low-lying baryon resonances $m_N\leq m_X\leq 1.41$ GeV.

Process	σ_{tot}/nucleon (μb)	Reference
$\gamma N\to\pi^\pm X$	0.600	Ref. 11
$\gamma N\to\eta X$	0.090	Ref. 10
$\gamma N\to\rho^\pm X$	1.26	Ref. 4
$\gamma N\to A_2^\pm X$	1.46	This article
$\gamma N\to\delta^\pm X$	$\lesssim$0.025	This article

The A_2 signal in Fig. 2(b) is insensitive to the amount of δ signal assumed, and is readily extracted. Cutting on the A_2 signal, and correcting[13] for the non-A_2 background within the cut, we obtain the t' distribution for the reaction $\gamma N\to A_2^\pm X$, $m_X<1.41$, shown in Fig. 3. Error bars show statistical errors only. In addition, we estimate a systematic error of ±15%, which allows for the variation among the different background parametrizations, and the uncertainty in acceptance due to lack of knowledge of the decay distribution.

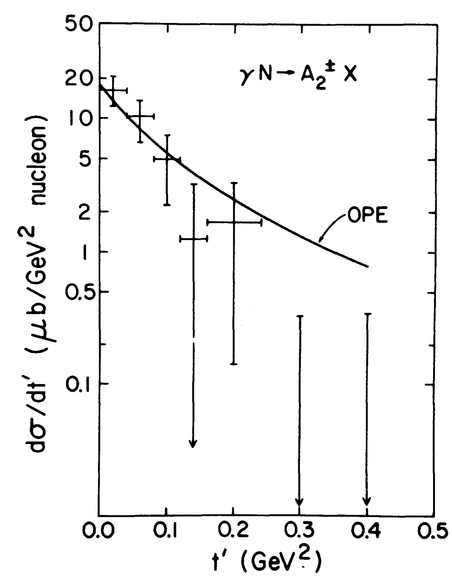

FIG. 3. Differential cross section for the reaction $\gamma N\to A_2^\pm X$, $m_X<1.41$ GeV. Not included in the error bars shown is a systematic error of ± 15%.

π exchange is expected to play an important role in A_2 photoproduction, and the sharp forward peaking seen in Fig. 3 suggests that it does. We therefore have taken a one-pion-exchange model[3] for ω photoproduction, which correctly describes the reaction $\gamma p \to \omega p$ (unnatural-parity exchange); $\gamma p \to \omega\Delta$; and $\gamma p \to \omega X$, $2.2 < m_X^2 < 4.5$; and modified it to be appropriate for A_2 photoproduction. The model has one free parameter, the partial decay width $\Gamma(A_2 \to \pi\gamma)$. A best fit to the cross sections in Fig. 3 (including the systematic error) yields $\Gamma(A_2 \to \pi\gamma) = 0.46 \pm 0.11$ MeV. This result compares well with one obtained in a similar fashion from a measurement of A_2 elastic photoproduction at SLAC,[14] and is a factor of two below the value of 1.0 MeV obtained from the $A_2 \to \pi\rho$ partial width by invoking vector dominance.

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[1]J. B. Gay, Phys. Lett. 63B, 220 (1976) and references therein.

[2]J. Abramson *et al.*, Phys. Rev. Lett. 36, 1428 (1976).

[3]C. A. Nelson, Jr. *et al.* (unpublished).

[4]J. Abramson *et al.*, Phys. Rev. Lett. 36, 1432 (1976).

[5]The η mass cut was the region 0.49 to 0.61 GeV. The non-η background within this cut was taken to be a fraction of the events in the control regions, 0.40 to 0.46 GeV and 0.62 to 0.70 GeV. The fraction was assumed independent of t' and the $\eta\pi^{\pm}$ mass, and was determined from Fig. 1.

[6]Particle Data Group, Rev. Mod. Phys. 48, S120 (1976).

[7]In fitting, the natural width was smeared with the $\eta\pi$ mass resolution of 25 MeV.

[8]Phase-space models are taken from *Particle Kinematics*, edited by E. Byckling and K. Kajantie (Wiley, New York, 1973).

[9]The two charge states of the δ have been summed; hydrogen and deuterium have been given equal weight; a 100% braching ratio of δ into $\eta\pi$ has been assumed.

[10]C. A. Nelson, Jr. *et al.* (unpublished).

[11]P. Joos, DESY Report No. DESY-Hera 70-1, 1970 (unpublished).

[12]G. C. Fox (private communication).

[13]The A_2 mass cut was the region 1.2 to 1.4 GeV. The non-A_2 background within this cut was taken to be a fraction of the events in the control region 1.05 to 1.175 GeV. The fraction was assumed independent of t', and was determined from the fit to Fig. 2.

[14]Y. Eisenberg *et al.*, Phys. Rev. D 5, 15 (1972).