PHOTOPRODUCTION OF NEGATIVE PIONS FROM HYDROGEN AT FORWARD ANGLES*

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(Received November 3, 1960)

The recent theoretical investigation by Drell[1] of the photoproduction of very high energy particles at small angles predicts a large peak in the differential cross section in this region. In particular, if one applies his results to the photoproduction of negative pions from hydrogen one obtains a value for the differential cross section that is several times larger than the value measured in pair production experiments at larger angles and lower energies. This interesting result has prompted the experimental investigation reported here.

The bremsstrahlung beam from the CalTech synchrotron was used to produce negative pions in a liquid hydrogen target predominantly through the process

$$\gamma + p \to \pi^- + \pi^+ + p. \qquad (1)$$

This is the only process kinematically possible for Q less than 140 Mev, where Q is the total kinetic energy in the p - π^+ center-of-momentum system. Above $Q = 140$ Mev, the π^- may be produced by

$$\gamma + p \to \pi^- + \begin{cases} \pi^+ + p + \pi^0 \\ \pi^+ + n + \pi^+; \end{cases} \qquad (2)$$

however, Chasan et al.[2] indicate that the cross section for this process is small, especially near the threshold.

Since there are three or more particles in the final state it was necessary to perform a "synchrotron subtraction" to determine the energy, k, of the photon initiating the reaction. An interval of approximately 100 Mev centered at 1230 Mev was obtained by taking the difference in normalized counting rates at peak bremsstrahlung energies of 1300 and 1200 Mev.

The negative pions were analyzed with a wedge-type magnetic spectrometer and detected with a counter telescope system consisting of one Čerenkov and three scintillation counters with a fifth "aperture-defining" counter located at the magnet exit. Pole-face veto counters were used to eliminate particles scattering from the magnet. Accidental and cosmic-ray counting rates were negligible. Brody et al.[3] give a more complete description of the apparatus except that we used the same magnet in the "high-energy" position as described by Vette.[4]

Data were taken at laboratory angles ranging from five to thirty degrees and π^- laboratory momenta ranging from approximately 600 to 1000 Mev/c. At laboratory angles less than about ten degrees appreciable numbers of electrons traversed the system and were rejected using the fact that they produce showers in matter. A one-half inch lead converter was placed in front of each of the last two counters, and the "electron biases" on the pulses from these counters were adjusted so that about 95% of the electrons and only 8% of the pions would give a pulse above this bias. Although there were approximately three times as many electrons as pions at the most forward points measured, the largest resulting electron contaminations were only on the order of 20% because of the high electron detection efficiency.

The data were further corrected for empty target backgrounds, pion decay in flight,[5] μ contamination from the π - μ decay,[5] and absorption in the system.[5] The photon beam was monitored by ionization chambers calibrated with an energy-independent Quantameter.[6] The error in this calibration and all other systematic errors (amounting to perhaps 5%) are not included in the graphs where only the statistical counting errors are shown.

The experimental differential cross sections, $\sigma(\theta, \omega)$, for $k = 1230$ Mev, are shown in Fig. 1 as a function of π^- center-of-momentum total energy (and also of Q) for several angles.[7] Not shown are four points for $\omega = 370$ Mev ($Q = 293$ Mev) with very large statistical errors, which gave values of $\sigma(\theta, \omega)$ consistent with other values near the lower energy end. Figure 2 gives the angular distribution for the average value of the data points at $\omega = 464$, $\omega = 505$, and $\omega = 519$ Mev. The peak value of the cross section is approximately five times larger than the pair production cross sections at lower energies and backward angles.[8] However, the peak is rather narrow in both energy and angle so that it contributes only about 25% of the total cross section. Specifically, the region of the peak, $10° \leq \theta \leq 55°$ and $420 \leq \omega \leq 573$ Mev in the center-of-momentum system, contributes 13 μb to the total cross section of about 50 μb.[2,8]

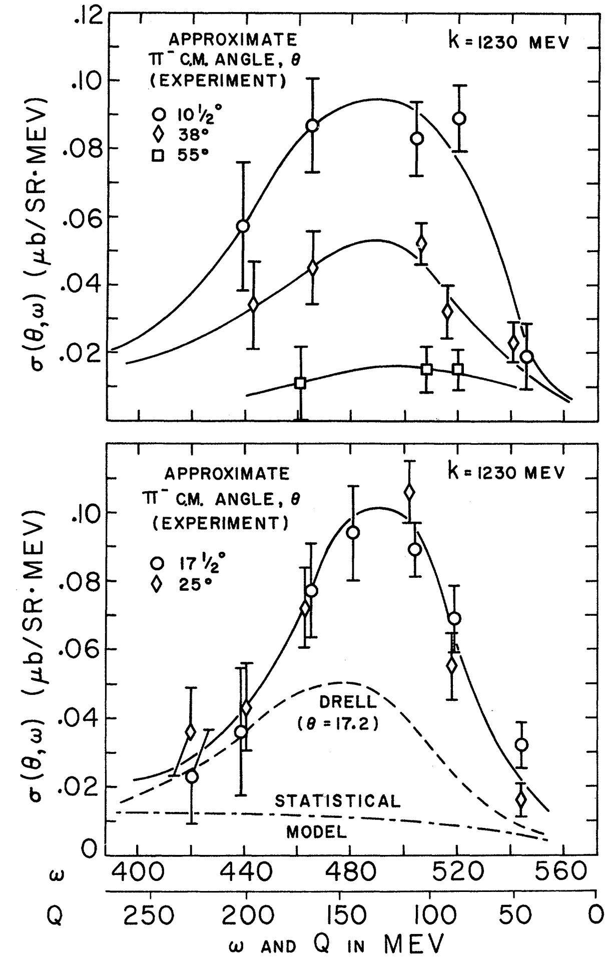

FIG. 1. The differential cross section as a function of ω (or Q) for several fixed angles. $\sigma(\theta,\omega)d\Omega\,d\omega$ is the cross section for producing a π^- at angle θ within $d\Omega$ and total energy ω within $d\omega$, all in the center-of-momentum system. The solid curves are drawn to fit the experimental points. The dashed curves are calculated from Drell's model (for $\theta = 17.2$ degrees) and for an isotropic statistical model, which are described in the text. Experimental resolutions have been folded in.

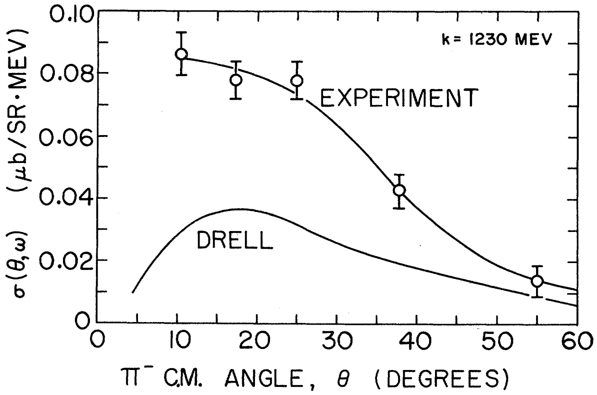

FIG. 2. The angular distribution for the average value of points at $\omega = 464$, $\omega = 505$, and $\omega = 519$ Mev. The prediction of the Drell model averaged in the same manner is also shown with the experimental resolutions folded in.

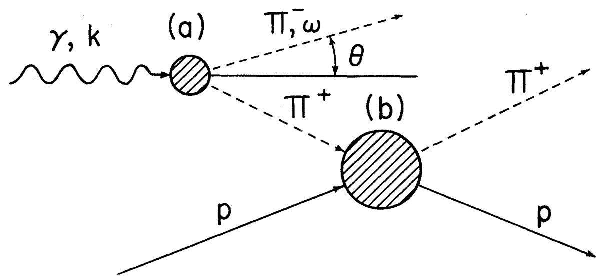

FIG. 3. The diagram for the photoproduction of negative pions which gives a large contribution at high energy and forward angles. Equation (3) gives the cross section from this diagram.

Drell[1] gives the diagram shown in Fig. 3 as the main contributor at forward angles for high-energy π^- photoproduction. The differential cross section is given by[9]

$$\sigma(\theta,\omega)d\Omega\,d\omega = \frac{\alpha}{2\pi}\frac{\sin^2\theta}{(1-\beta\cos\theta)^2}\frac{d\Omega}{4\pi}\frac{\omega(k-\omega)d\omega}{k^3}\sigma_{\pi^+ + p}(Q). \tag{3}$$

The case when more than one pion emerges from vertex (b) of Fig. 3 is included since this is contained in the total cross section,[10] $\sigma_{\pi^+ + p}(Q)$. Drell's process may be particularly easy to recognize in hydrogen where it should show not only the characteristic forward angle peak, but also a strongly peaked energy dependence arising from the 3-3 resonance in $\sigma_{\pi^+ + p}(Q)$.

The cross section calculated from Eq. (3) is shown in Fig. 1 for $\theta = 17.2$ degrees and in Fig. 2 where the same average used for the data points is plotted. Both of these curves have the photon distribution and magnet resolutions folded in. The data show the expected effect of the pion-nucleon scattering resonance which has a peak at $Q \approx 145$ Mev. Of course, any "isobar model" would give a similar dependence of $\sigma(\theta,\omega)$ on ω, but the fact that the angular distribution decreases so rapidly with angle is probably more specific to Drell's process. The distribution predicted by an isotropic statistical model[11] normalized to a total cross section[2,8] of 50 μb is also shown in Fig. 1.

Qualitatively, our results agree rather well with Drell's model, although the experimental cross sections are in general considerably larger than those calculated from Eq. (3), and do not show any decrease at the smallest angle measured. One should perhaps not expect a better quantitative agreement since Drell's diagram of Fig. 3 is not the only one leading to pion pair production, and other relatively small amplitudes may produce appreciable effects by interference with the Drell term.

*This work was supported in part by the U. S. Atomic Energy Commission.

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[7]$\sigma(\theta,\omega)d\Omega\,d\omega$ is the cross section for producting a π^- at an angle θ and an energy ω within the intervals $d\Omega$ and $d\omega$.

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[9]This is Eq. (2) of reference 1 with $\sigma_{\pi^++p}(k-\omega)$ replaced by $\sigma_{\pi^++p}(Q)$.

[10]$\sigma_{\pi^++p}(Q)$ is from S. J. Lindenbaum and L. C. L. Yuan, Phys. Rev. 100, 306 (1955), and Phys. Rev. 111, 1380 (1958); R. Cool, O. Piccioni, and D. Clark, Phys. Rev. 103, 1082 (1956); S. W. Barnes, B. Rose, G. Giacomelli, J. Ring, K. Miyake, and K. Kinsey, Phys. Rev. 117, 226 (1960).

[11]Extrapolated from curves given in reference 8.

RESONANCE IN THE $\Lambda\pi$ SYSTEM*

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(Received October 31, 1960)

We report a study of the reaction

$$K^- + p \to \Lambda^0 + \pi^+ + \pi^- \qquad (1)$$

produced by 1.15-Bev/c K^- mesons and observed in the Lawrence Radiation Laboratory's 15-in. hydrogen bubble chamber. A preliminary report of these results was presented at the 1960 Rochester Conference.[1] The beam was purified by two velocity spectrometers.[2] A Ξ^0 hyperon observed during the run[3] and the preliminary cross sections[4] for various K^- reactions at 1.15 Bev/c have been reported previously. Reaction (1) was the first one selected for detailed study, because it appeared to take place with relatively large probability and because the event, a 2-prong interaction accompanied by a V, was easily identified. In a volume of the chamber sufficiently restricted so that the scanning efficiency was near 100%, 255 such events were found. These events were measured, and the track data supplied to a computer which tested each event for goodness of fit to various kinematic hypotheses. The possible reactions, the distribution of events, and the corresponding cross sections are given in Table I. An event was placed in a given category of Table I if the χ^2 probability for the other hypotheses was <1%. It appears likely that the majority of the events in group (e) are also reactions of type (1). This belief is based on the following arguments:

1. Since the kinematics of a $\Lambda\pi\pi$ fit (four constraints) are more overdetermined than those of a $\Sigma^0\pi\pi$ fit (two constraints), it is relatively easy for a $\Lambda\pi\pi$ reaction to fit a $\Sigma^0\pi\pi$ reaction, but only

Table I. Distribution of events among different reactions.

Reaction	No. of events	Cross section (mb)
(a) $K^-+p\to\bar{K}^0+p+\pi^-$	48	2.0 ±0.3
(b) $K^-+p\to(\Lambda \text{ or } \Sigma^0)+\pi^++\pi^-+\pi^0$	39	1.1 ±0.2
(c) $K^-+p\to\Sigma^0+\pi^++\pi^-$	27	
(d) $K^-+p\to\Lambda+\pi^++\pi^-$	49	4.1 ±0.4
(e) $K^-+p\to(\Lambda \text{ or } \Sigma^0)+\pi^++\pi^-$	92	
Total	255	7.2 ±0.5