THE REACTION $\pi^- p \rightarrow n\pi^0$ IN THE BACKWARD HEMISPHERE AT 6 GeV/c *

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The angular distribution for the charge-exchange reaction $\pi^- p \rightarrow n\pi^0$ has been measured for an incident pion momentum of 6 GeV/c. The cross sections are presented for a range of crossed four-momentum transfer from $u = 0.06$ (GeV)^2 (180°) to $u = -1.4$ (GeV)^2 (66° lab). These data are compared with the predictions of Barger and Cline and are found to be in qualitative but not quantitative agreement.

We present cross sections for the charge-exchange reaction

$$\pi^- + p \rightarrow n + \pi^0$$

in the backward hemisphere at 6-GeV/c incident pion momentum. These data were taken at the alternating gradient synchrotron (AGS) at Brookhaven National Laboratory. The measurements were designed to complement those already published[1] on the elastic-scattering cross section for both positively and negatively charged pions on protons. In Fig. 1 we show schematically the experimental layout. The pion beam was incident from the left and was monitored by the counters B_1 and B_2. Not shown in the diagram is a threshold gas Cherenkov counter that was used to discriminate against the kaons and antiprotons in the beam. The halo counter ensured that there were no particles outside B_1 nearly coincident with the beam particle. The hydrogen target H_2 was approximately 50 cm long and contained 3.56 g/cm^2. The triggering logic excluded any reaction with charged particles in the final state, or any neutral reaction with photons in the forward cone of approximately 40° half angle. The counter labeled "box veto" excluded charged particles emitted at all but the smallest angles; the veto counters B_3, B_4 and the "plug veto" counter removed the rest. The wall veto and plug counters were constructed as lead-scintillator sandwich counters approximately 6 radiation lengths thick. This combination of counters gave a triggering rate of 3.4×10^{-5}; the contribution of the charge-exchange reaction, using our measured cross sections, was 2×10^{-6}.

The identification of the charge-exchange reaction was accomplished by the spark chambers numbered 1 through 5 in Fig. 1. In this diagram, chamber 5 is shown upstrean of its actual position for clarity; during the experiment, chamber 5 fitted closely onto the ends of chambers 1 through 4. These spark chambers had plates built of an aluminum-lead laminate[2] containing approximately 0.1 radiation length of lead per plate. Each spark chamber had a total of 5 radiation lengths for photons traversing the plates normally. The combination of these spark chambers and the forward veto counters gave a 4π solid angle detector except for some small cracks between the chambers. Chamber 5 had holes cut in the plates to admit the beam; these holes were covered by thin foil so that the beam track was visible. The chambers were photographed: chamber 5 in 90° stereo, the other 4 chambers in 35° stereo. An instantaneous beam rate of 2×10^5 pions/sec was used; events with

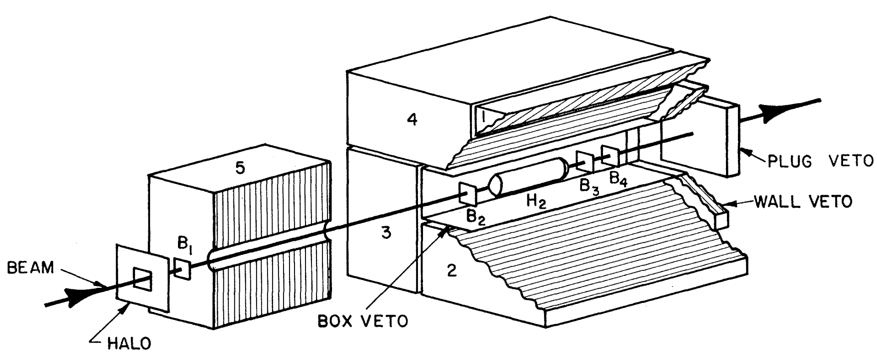

FIG. 1. Counter and spark-chamber assembly. Spark chamber 5 is pulled upstream for clarity.

two beam tracks were excluded from the analysis and a small correction made.

For each shower two points were measured: the point of conversion and a point along the shower to estimate the direction of the photon. The line formed by these points was extrapolated toward the beam track and the position on the beam track that was the point of closest approach was calculated. For two-shower events a weighted mean of these two points was taken as the event vertex. Using this vertex and the initial points of the showers, the photon directions were calculated. Since the photon velocities are known it is possible to transform to the c.m. system without a knowledge of the photon energies. This has been done, and the opening-angle distribution for the two-photon events is plotted in Fig. 2. The charge-exchange reaction produces a π^0 of constant momentum in the center-of-mass system independent of angle, so that the opening angles cluster near the minimum opening angle of 9.6° at 6-GeV/c incident momentum. In Fig. 2 the peak is associated with the charge-exchange reaction and the background is spread over all angles. It remains to calculate the fraction of the events that are included in the peak and the necessary background subtraction.

The cross section in the backward direction is very strongly dependent on the crossed four-momentum–transfer squared u, so that it is necessary to understand the angular dependence of the background also. We plot in Fig. 2 the measured opening angle distribution for several intervals of the apparent u value. This apparent u value is calculated by taking the bisector of the two photon directions as the pion direction. This value is close to the correct u for charge-exchange events. The background subtraction is made by extrapolating the shape from beyond 20° in the opening angle distribution, where the charge-exchange contribution is very small, into the charge-exchange region.

We have also made a Monte Carlo estimate of the background, assuming that the main contributors are the following reactions:

$$\pi^- + p \to K^0 + \Lambda^0 \to K_2^{\,0} + n + \gamma + \gamma,$$

$$\pi^- + p \to K + \Sigma^0 \to K_2^{\,0} + n + \gamma + \gamma + \gamma,$$

$$\pi^- + p \to n + \eta^0 \to n + \gamma + \gamma,$$

$$\pi^- + p \to n + \omega^0 \to n + \gamma + \gamma + \gamma.$$

The first three reactions are approximately known[3]; we have an estimate for the fourth from low-energy data. This method of calculating the

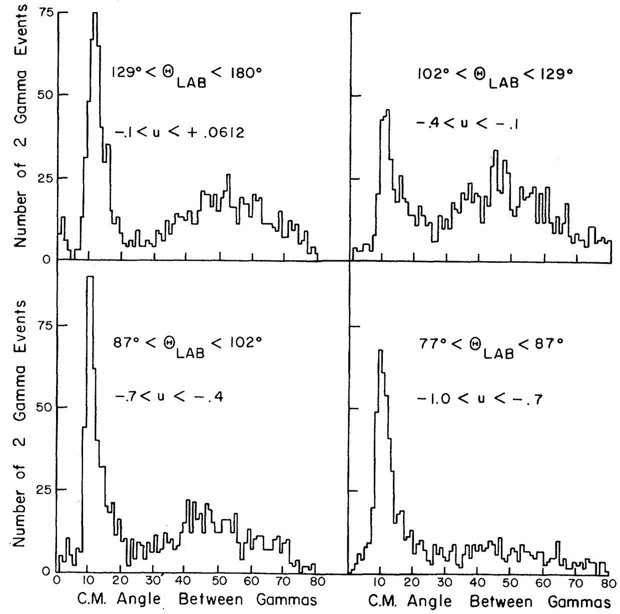

FIG. 2. Distribution of c.m. angle between gamma rays for various intervals of u, for two-gamma events.

subtraction is consistent with the extrapolation method. The subtraction is small everywhere except near the dip at $u = -0.2$, where it is 35% of the total number of events.

The charge-exchange cross sections are obtained from the number of events after background subtraction which have an opening angle from 6° to 18°. For a backward π^0, in over 80% of the decays within this interval, both photons have more than 100-MeV laboratory energy. At $u = -1.0$, the corresponding fraction is 96%. We take the angle bisector of the two photons as the π^0 direction. This raw u distribution, corrected for background, but not for efficiency or resolution, is shown in Fig. 3(a). Due to our 3π geometry, we do not expect any strong u dependence of the efficiency within the u range shown, so that the main distortion of the shape is due to resolution smearing. The u resolution arises mainly, we believe, from the bisector approximation for the π^0 direction, and from measuring error, with smaller contributions from multiple scattering and shower development. This u resolution varies with u and, for $u \sim -0.2$, has an rms half width $\Delta u = 0.1$, consistent with the width of the dip in our uncorrected data. For this reason alone it is clear that the dip is deeper than our raw data shows.

We have unfolded the effects of efficiency and resolution using a Monte Carlo event generator, which simulates all details of our apparatus.

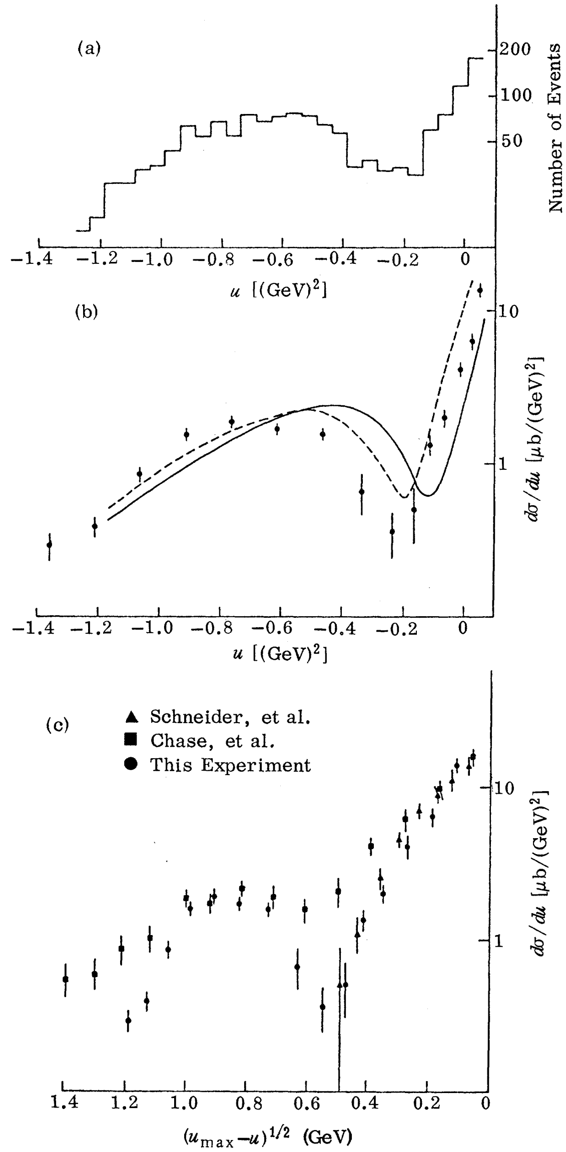

FIG. 3. (a) Raw event u distribution after background subtraction. (b) Differential cross sections $d\sigma/du$ for the reaction $\pi^- p \rightarrow n\pi^0$ at 6-GeV/c lab momentum. The curves shown are the predictions of Barger and Cline based on their Regge pole fit to the elastic-scattering data. The solid line is for $\beta_\Delta/\beta_N > 0$; the dashed line for for $\beta_\Delta/\beta_N < 0$ [V. Barger and D. Cline, Phys. Rev. Letters 19, 1504 (1967), and V. Barger, private communication]. (c) Differential cross sections $d\sigma/du$ for the reaction $\pi^- p \rightarrow n\pi^0$ at 6-GeV/c lab momentum. The data shown are from Ref. 5 (Schneider *et al.*), Ref. 6 (Chase *et al.*), and this experiment. The cross sections are plotted against $(u_{max}-u)^{1/2}$ to spread out the cluster of points near $u=0$.

Since the cross section changes significantly within our resolution width, the corrections are somewhat sensitive to the input u distribution

Table I. Charge-exchange cross sections at 6 GeV/c are given in column 3. $\Delta\sigma/\Delta u$ is the charge-exchange cross section averaged over the u range Δu in the second column, centered at the u value in column 1. The fourth column lists the 1-standard-deviation relative error between adjacent points. In addition, there is a 20% normalization error.

u [(GeV)^2]	Δu (bin width) [(GeV)^2]	$\Delta\sigma/\Delta u$ [μb/(GeV)^2]	$\Delta(\Delta\sigma/\Delta u)$ [μb/(GeV)^2]
+0.049	0.025	13.88	1.46
+0.024	0.025	6.37	0.85
−0.014	0.050	4.14	0.43
−0.064	0.050	1.99	0.27
−0.114	0.050	1.33	0.22
−0.164	0.050	0.50	0.20
−0.239	0.100	0.36	0.12
−0.339	0.100	0.66	0.20
−0.464	0.150	1.57	0.14
−0.614	0.150	1.70	0.14
−0.764	0.150	1.89	0.16
−0.914	0.150	1.56	0.15
−1.064	0.150	0.85	0.10
−1.214	0.150	0.39	0.06
−1.364	0.150	0.29	0.05

assumed. The input-to-output ratio of the Monte Carlo events is used to correct the real events, bin by bin. In practice, only two or three iterations are required, and the cross sections obtained in this manner are not very sensitive to the input shape used for the last iteration. The Monte Carlo events generated in this manner also have an opening-angle distribution, an apparent interaction-location distribution, and a distribution of photon-conversion points identical, within statistics, to the corresponding distributions for real events. Figure 3(b) shows our resulting cross sections based on 1500 events with the resolution unfolded. The cross sections and errors are also listed in Table I. The errors are statistical, increased by appropriate factors where the results are most sensitive to the unfolding procedure. In addition we estimate an overall normalization uncertainty of 20%, essentially independent of u. Corrections have been made for muons and electrons in the beam, accidental veto of beam particles, forward neutron interactions (particularly in the plug veto), scanning efficiency, attenuation of the beam before and in the target, photon conversion before the box veto counters, Dalitz conversion of π^0's, and the resolution effects mentioned above. Target-empty corrections are so small that they have not been made. Also shown in

Fig. 3(b) are the predictions of Barger and Cline[4] based on their Regge pole fits to the elastic-scattering data.

We have analyzed a sample of events using additional information. Downstream of the apparatus shown in Fig. 1 is an array of spark chambers in which the forward neutron interacts, allowing a measurement of its position. Using this information and the photon-conversion points, but not the apparent photon directions, and constraining the event to satisfy charge-exchange kinematics, the event can be reconstructed without using the bisector approximation. The photon laboratory energies can be calculated and checked for consistency by spark counting. The results of this analysis are that events in the 6° to 18° opening-angle range have energies consistent with the charge-exchange hypothesis, have solutions close to those found by using the photon directions alone, and have neutron positions close to those predicted by the charge-exchange hypothesis. In addition, the neutron analysis has better u resolution, and the corrections to the cross sections predicted by the Monte Carlo procedure are qualitatively corroborated. We have not used the neutron analysis in producing these cross sections, however, because the measurements are not finished.

Previous to this experiment there have been two measurements of the angular distribution of this reaction.[5,6] We are in agreement with the experiment of Schneider et al. who measured in the region $u>-0.2$. We are not in agreement with the experiment of Chase et al. in the regions $u\sim-0.2$ and $u<-1.0$; in particular our cross sections have an appreciably lower dip value near $u=-0.2$. The cross sections for all three experiments are shown in Fig. 3(c) as a function of $(u_{\max}-u)^{1/2}$, to spread out the cluster of points near $u=0$.

A least-squares fit of the backward peak by the form $Ae^{B(u-u_{\max})}$, using the first six points, gives $A=(14.4\pm1.4)\ \mu\text{b}/(\text{GeV})^2$ and $B=(15.7\pm1.4)$ $(\text{GeV})^{-2}$, in agreement with the Schneider et al. fit and with a preliminary, unpublished point of Kistiakowsky et al.[7]

Similar exposures were made at 10- and 14-GeV/c incident momentum and are now being analyzed. In addition, the neutron analysis is being continued to improve resolution, and also as an aid in extracting the backward η^0 and ω^0 cross sections.

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