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NEUTRAL PION PRODUCTION BY 960-Mev NEGATIVE PIONS*

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Using a 1.14-Bev/c π^- beam from the Brookhaven Cosmotron, we are studying neutral pion production in the reactions

$$\pi^-+p\to\pi^0+n, \qquad (A)$$
$$\to 2\pi^0+n, \qquad (B)$$
$$\to 3\pi^0+n. \qquad (C)$$

We report here on the differential cross section of the elastic charge exchange reaction (A) based on the study of bubble chamber pictures containing 1.01×10^5 incident pions. Integral cross-section ratios for the reactions (A), (B), and (C) are also given. Differential cross sections for reaction (A) are necessary in order to analyze the $T=\frac{1}{2}$ pion-nucleon interaction. No such information has been available heretofore above 500 Mev.

The 15-inch diameter, 14-inch deep bubble chamber[1] located in a 19.5-kilogauss field is filled with a mixture of propane, ethane, and methyl iodide containing 0.061 g/cm^3 of H, 0.252 g/cm^3 of C, and 0.948 g/cm^3 of I. Under operating conditions the radiation length is 8.1 cm. At the entrance of the fiducial volume, the π^- beam has an energy of 990 ± 15 Mev (as determined by wire measurements), and events are accepted in an energy interval of 60 Mev. This places the present study on the high-energy side of the 900-Mev pion-nucleon resonance.

The film is scanned for events in which two or more electron pairs point to a π^- interaction with no visible secondaries (zero-prong endings). These two-pair events come from: (1) reaction (A) in free hydrogen, (2) $2\pi^0$ production in H, C, and I, in which only 2 gammas materialize in the chamber,[2] and (3) $1\pi^0$ production in C and I. Using the methods of analysis[3] to be described, we believe that it is possible to obtain a sample of events corresponding to reaction (A) which contains only a small contamination from the background (2) and (3).

The sample of two-pair events used to obtain the angular distribution of reaction (A) is limited to events in the interval $50°\leq\bar{\phi}\leq 90°$, where $\bar{\phi}$ is the angle between one of the π^0-decay gamma rays in the π^0 rest system and the π^0-flight direction. The two main advantages of this selection are:

(a) Since the energy of each gamma ray is unknown, there are two possible solutions for the direction of flight of the parent π^0. However, the bisector of the angle between the two decay gamma rays is a good approximation to the original π^0 direction. In the pion-nucleon center-of-mass system, a typical difference between either of the two possible solutions and the bisector direction is ±4°, the maximum difference being ±12°.

(b) The contamination from background events (2) and (3) is small. This is because at a given production angle, neutral mesons from the background events have substantially lower kinetic energies and therefore larger decay opening angles than elastic charge exchange events. The experimental evidence for this statement follows.

To make the $\bar{\phi}$ selection, each two-pair event is analyzed assuming that it originates from reaction (A) and that the π^0 travels along the bisector of the angle between pairs. Figure 1(a) shows the resulting $\bar{\phi}$ distribution in which $(39 \pm 3)\,\%$ of the two-pair events are in the acceptable $50° \leq \bar{\phi} \leq 90°$ region. (If no background events existed, this percentage would be 64%.) To measure the background (2), all possible two-pair combinations of three- and four-pair events are analyzed exactly like a two-pair event. The resulting $\bar{\phi}$ distribution is shown in Fig. 1(b) from which it is apparent that only $(7.1 \pm 1.3)\,\%$ of the two-pair combinations lie in the selected $\bar{\phi}$ interval. To estimate the background (3) from $1\pi^0$ production in zero-prong C and I interactions, about one half of the pictures have also been scanned for events in which two or more electron pairs point to π^- interactions with prongs. To obtain a star sample which is similar to the zero-prong background events, the visible energy of secondaries is limited to less than about 200 Mev by the requirement that all secondaries stop in the chamber. The star events with two associated pairs are analyzed like zero-prong events, and the resulting $\bar{\phi}$ distribution is shown in Fig. 1(c). $(8.7 \pm 2.4)\,\%$ of the star events have solutions in the acceptable $\bar{\phi}$ interval. Within statistics, this result is independent of the amount of visible energy.[4] This is the experimental justification for assuming that the distribution 1(c) is also valid for the zero-prong star background (3).

Using the $\bar{\phi}$ distributions of Fig. 1, the number of background events among 136 two-pair events in the $50° \leq \bar{\phi} \leq 90°$ region is calculated to be 13. Therefore $(90 \pm 3)\,\%$ of the two-pair events in the selected $\bar{\phi}$ sample are elastic charge exchange events. Figure 2 shows the angular distribution of reaction (A) based on 136 two-pair events in the $50° \leq \bar{\phi} \leq 90°$ region. $\bar{\theta}$ is the pion scattering angle in the pion-nucleon c.m. system. The sample used for the angular distribution includes the 10% background[5]; the cross-section scale has

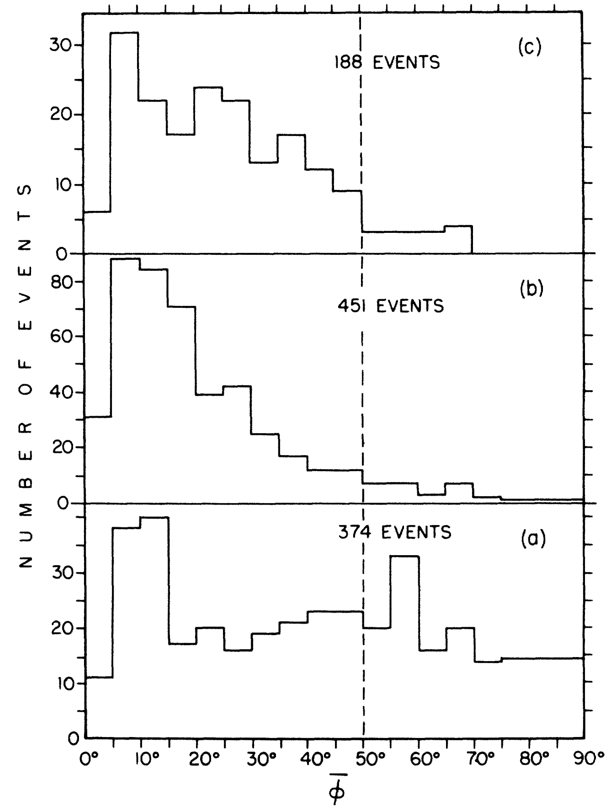

FIG. 1. π^0 center-of-mass decay angle distribution calculated from two-pair combinations of: (a) two-pair events from prongless π^- interactions; (b) three- and four-pair events from prongless π^- interactions; (c) two-pair events from π^- interactions with prongs. Events to the right of the dashed line lie in the acceptable $\bar{\phi}$ region.

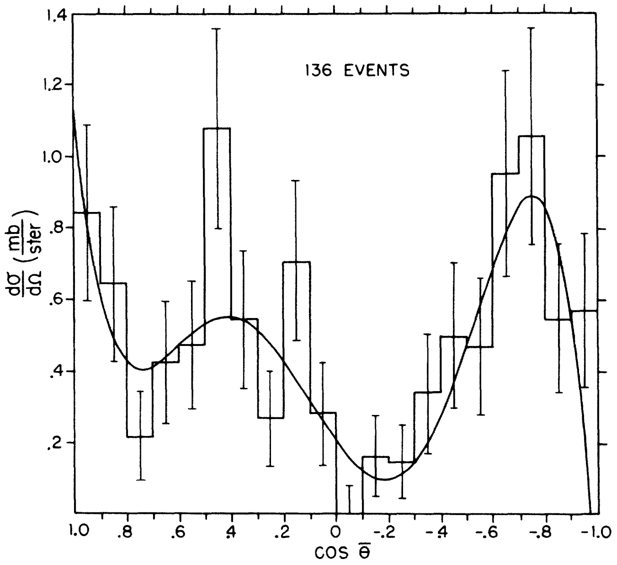

FIG. 2. Differential cross section of the reaction $\pi^- + p \rightarrow n + \pi^0$ in the pion-nucleon center-of-mass system. $\bar{\theta}$ is the pion scattering angle. The continuous curve represents expansion (1), given in the text.

this background subtracted. Each event has been corrected for its average detection efficiency[6] in the chamber.

The differential cross section has a forward peak, a minimum at 100°, and another maximum at 140°. There is an indication of fine structure in the forward hemisphere with a minimum at about 40° and a maximum at 65°. The cross section is represented by the following expansion in $x = \cos\bar{\theta}$ with a χ^2/f (f is the number of degrees of freedom) of 1.2 (probability 27%):

$$(d\sigma/d\Omega)(\mathrm{mb/sr}) = (0.21 \pm 0.06) + (1.03 \pm 0.29)x + (1.52 \pm 0.50)x^2 - (5.07 \pm 1.27)x^3 - (1.32 \pm 0.61)x^4 + (4.75 \pm 1.20)x^5. \tag{1}$$

The curve is fitted on the basis of equal $\bar{\theta}$ intervals and is shown as a solid line in Fig. 2.

The use of a series with no more than fourth-power cosine terms produces fits with a value of $\chi^2/f = 2.3$ (probability <1 %). The inclusion of fifth-power cosine terms has also been found necessary in elastic π^--p scattering in this energy region.[7] Another similarity with elastic π^--p scattering is the presence of the peak in the backward hemisphere. The optical theorem and dispersion relations[8] predict a forward scattering cross section of (2.4 ± 0.9) mb/sr. Using Eq. (1), we obtain a value of (1.13 ± 0.33) mb/sr. A sixth-power cosine expansion gives a value of (1.34 ± 0.39) mb/sr. Within the present accuracy, there appears to be no discrepancy. The differential cross section for reaction (A) satisfies the triangular inequalities required by charge independence.

The integrated cross section for the elastic charge exchange reaction (A) is found to be 6.4 ± 0.6 mb. The ratio of $1\pi^0$:$2\pi^0$:$3\pi^0$ production in zero-prong interactions is found to be

$$(1.00 \pm 0.07):(0.28 \pm 0.03):(0.050 \pm 0.012).$$

Assuming that the corresponding ratios for pronged stars are also valid for the zero-prong interactions with C and I, the cross-section ratios for reactions (A):(B):(C) with free protons are calculated to be

$$(1.00 \pm 0.14):(0.34 \pm 0.06):(0.07 \pm 0.02).$$

No event with more than 6 pairs pointing to a π^- interaction has been found. This places an upper limit of (0.002 ± 0.002) mb on the cross section for $4\pi^0$ production.

Brisson et al.[9] have obtained integrated reaction cross-section values for reaction (A), and an upper limit for reaction (B). Extrapolating between the energies at which their counter measurements were carried out, and using our cross-section value for reaction (C) to obtain[10] the cross sections for reactions (A) and (B), we calculate a value of 6.0 mb for reaction (A), and a $1\pi^0$:$2\pi^0$ ratio of 0.37 in very satisfactory agreement with our results.

This work would not have been possible without the help of all of our colleagues of the Cambridge Bubble Chamber Group in obtaining the pictures, and of the staff of the Cosmotron at Brookhaven National Laboratory in providing the pions. We wish to thank all of them, and also our efficient scanners.

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[4] In the star sample, 23 stars have prongs with a total projected length of less than 1 cm. Of these, one has a $\bar{\phi}$ solution in the acceptable region.

[5] The angular distribution of 16 background events is consistent with the distribution of Fig. 2 or isotropy.

[6] Each event defines the laboratory emission angle and energy of a π^0. The correct weight to be given to each event is the inverse of the two-gamma-ray conversion probability, averaged over all acceptable c.m. decay angles, all azimuthal angles, and all possible (properly weighted) interaction points in the chamber. For our chamber and beam distribution, it is sufficient to average only over the interaction position along the axis of the incident beam. Our sample was treated in this manner.

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