STUDY OF THE TOTAL NEUTRAL CROSS SECTION IN $\pi^- p$ INTERACTION IN THE MOMENTUM REGION 1.4-4.0 GeV/c*

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Partial cross sections for π^0 and η^0 production are measured at 12 energies. Pion multiplicities up to five are considered.

This paper reports the preliminary results of a study of $\pi^- p$ interactions, in the momentum range 1.4-4.0 GeV/c, leading to final states involving only neutral particles. This is the first experiment at these momenta in which it has been possible to determine the cross sections separately for the final states involving multiple π^0 production with multiplicities as high as five as well as single π^0 and η^0 production. A total of 20 energies were studied, and this report gives preliminary results on 12 of these.

The negative pion beam was produced at the alternating-gradient synchrotron by 30-BeV protons incident on an internal beryllium target. Particles coming out at 15 deg inside the ring were momentum analyzed and focused on the liquid-hydrogen target by a system of magnets. This system of magnets also raised the level of the beam so as to enter the equipment. The beam momentum at each magnet setting was calculated both from a Hall-probe measurement and from the magnet current. The beam composition was measured with a gas Cherenkov counter. The hydrogen target was surrounded by a system of counters and spark chambers. The trigger logic required a π^- to enter the region of the hydrogen target with no charged particle leaving the region.

The spark chamber arrays have been described in detail by Calvelli et al.[1] and Bulos et al.[2] previously. They consisted of four high-Z spark chambers arranged in a cubical array around a small liquid hydrogen target. Each chamber consisted of 50 2-mm-thick iron plates separated by 3-mm gaps. Effectively all γ's passing through the sides of the cube were detected while those passing out the top and bottom escaped undetected. The chambers cover approximately $\frac{2}{3}$ of the total solid angle. In addition to the large spark chambers, there were two thin-foil spark chambers in the beam which were used to define the beam direction and one after the target which was used to check the trigger. The liquid hydrogen was contained in a roughly spherical 4-cm-diam Mylar bulb. The bottom of the array was photographed directly together with mirrored side views by one camera. Since no energy estimates on the γ's were made in these chambers, the only information that was derived from the film was the direction of each γ relative to the incoming beam. Depending upon the event type and the beam energy, this direction was known to about 5 deg in the center of mass. The primary data basically consist of the number of γ's in each event and the direction of these γ's. The number of γ's seen in each event is not necessarily the true number of γ's in that event. There are two reasons for this. The first is that γ's, as mentioned above, can escape from the top and bottom of the system. The second is that the π^0's involved in the interaction can have a large opening angle which implies that one of the γ's in the decay of the π^0 can have a low energy. From the information contained in the film itself, we have determined that the chambers have a low-energy cutoff, which is 60 ± 10 MeV on the average. Therefore, any γ that has an energy less than this value will, in general, be undetected in our system even if it enters the center of one of the chambers. As a result of this, a major problem in the experiment is the disentangling of events with unobserved γ's and the subsequent placing of all events into the following reaction categories:

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

$$\to n + \eta^0 \qquad (2)$$

$$\to n + (2,3,4,5)\pi^0. \qquad (3)\text{-}(6)$$

We have been able to achieve this disentanglement using the data in the film itself. The fundamental knowledge with which we start is the number of events at each energy that have multiplicities ranging from three to ten gamma rays. We also know the number in the sample that have two γ's, one γ, and zero γ's. In addition, we have events that contain neutron stars, but since the cross section of iron for the energy neutron involved in this experiment is low, the number of such events is quite small. However, these few events enable us to make internal consistency checks of the data. In order to take the total neutral cross section as measured by the electronic counting rate and break it down into its component parts, one must have an angular and momentum distribution for parent events of each π^0 multiplicity from $2\pi^0$ to $5\pi^0$. We explicitly note that the contributions to our sample from sources that create three γ's or sources other than π^0's are small. The neutral decay of the ω^0 is such a small fraction of the total cross section that it can safely be neglected. This is also true of the rare electromagnetic decays such as the $\pi^0\gamma\gamma$ mode of the η^0. We consider later in the paper the possible presence of a large, unknown, 3γ source.

If one has for each multiple-π^0 final state known angular and energy distributions for each π^0, one can by Monte Carlo techniques use the known geometry of the experiment and predict the measured γ distribution. These distributions of parent π^0's also predict opening-angle distributions and single-γ's distributions.

The technique applied to this experiment uses the angular distribution of the γ's of the observed events themselves. We pair these γ's into π^0's, and then by Monte Carlo techniques take these π^0's and the chamber geometry and produce the parent samples of $5\pi^0$, $4\pi^0$, $3\pi^0$, and $2\pi^0$ distributions. One can do this since, given a π^0 that decays into two γ's and the knowledge of the direction of these two gammas, one can reconstruct statistically both the direction of the parent π^0 and the momentum of that π^0. A detailed description of the Monte Carlo techniques that perform this separation will be given in a later paper. As an example of the power of this technique, we show in Fig. 1 an opening-angle distribution derived from taking our three-γ events two gammas at a time and plotting their opening-angle distribution. This opening-angle distribution was not used anywhere in the analysis that produced our multiple-π^0 distributions. The multiple-π^0 distribution makes an absolute prediction as to magnitude and shape of the opening-angle distribution of our experimental three-γ sample taken two

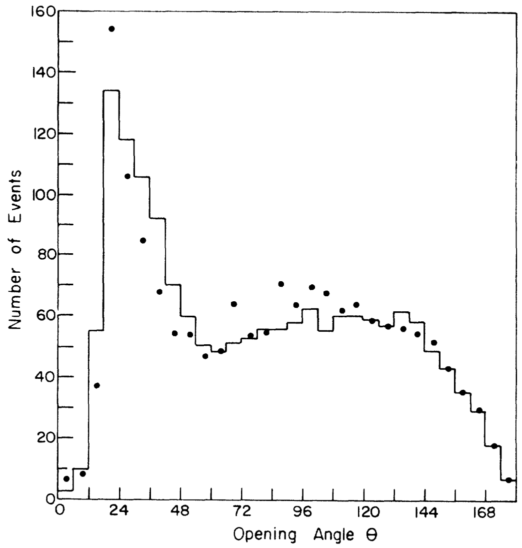

FIG. 1. Opening angle distribution of gamma-ray pairs from the observed three-γ sample (solid line) and that from Monte Carlo predictions based on the angular distributions and relative cross sections for $2\pi^0$ through $5\pi^0$ channels (points). The confidence of the fit is 90%.

gammas at a time. That prediction is plotted with the actual measured distribution. The probability of the measured distribution being the same as the predicted distribution is 90%; for the 12 energies presented in this paper similar fits were obtained for this distribution. These distributions varied greatly both in magnitude and in shape as one went from energy to energy, but in all 12 cases this distribution was faithfully reproduced by the prediction of our parent π^0 family.

With respect to a possible unknown three-γ source, it would likely contribute gamma-ray pairings which populate the broad right-hand maximum of Fig. 1. The left-hand peak is due to the gamma pairs from the high-momentum π^0 in $2\pi^0$ production. The difference between the observed sample and the cascaded-down prediction represents the extent that this unknown source may contribute. As can be seen, this possible source must be small.

From the found parent multiple-π^0 sample, the contamination into the two-γ sample (which contains mostly $1\pi^0$ and η^0) is calculated. The solid lines in Fig. 2 show the opening angle distribu-

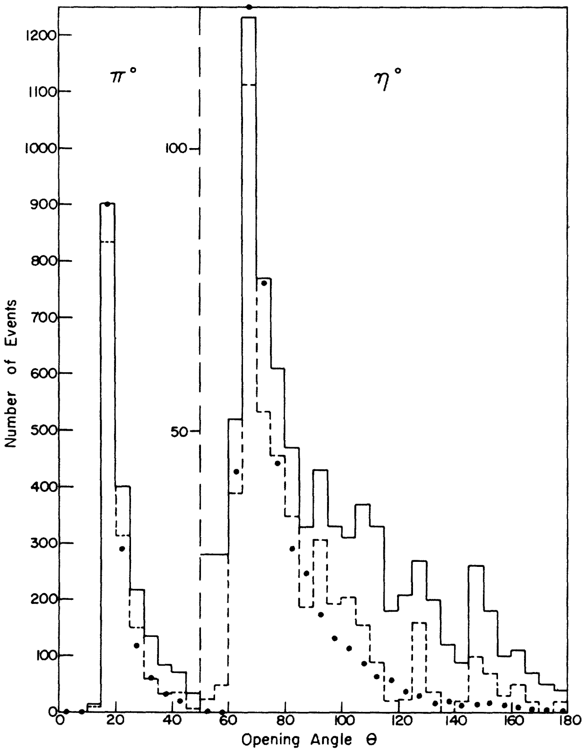

FIG. 2. Opening angle distributions for two-γ sample. Solid lines show original data. Dashed lines show data after subtraction of background from multiple π^0 production. Points show the values predicted for the π^0 and η. The values predicted for the π^0 fit the subtracted sample with a confidence level of 78% and for the η, 94%.

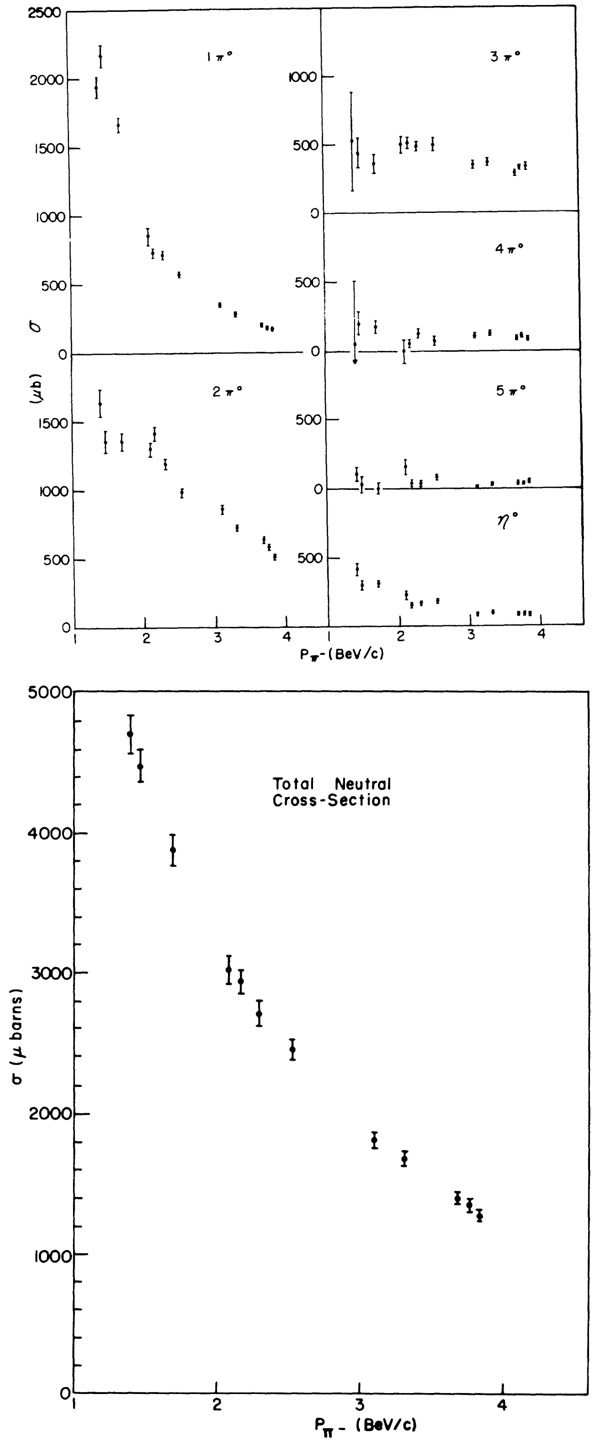

FIG. 3. Total neutral cross section as a function of π^- momentum and partial cross sections as a function of π^- momentum. The η cross section is for the two-γ decay mode only.

tion of our two-γ events while the dashed lines show the same distribution after subtraction of the background predicted from the multiple-π^0 sample. On the same figure is also plotted the theoretical opening-angle distribution that would be obtained for the π^0 and the η as detected by our spark chambers taking into account their efficiencies and angular acceptances. The probabilities for the fits are 78 and 94%. Similar probabilities are found for all energies in this paper. This is again an excellent confirmation that the magnitude of the multiple-π^0 events and their angle and energy distributions are reasonably approximated by our calculations.

Figure 3 is our total neutral cross section. The basic information for the total neutral cross section came from our electronic counting rates. Our counting rate was corrected for the loss of events due to gamma rays converting in the anticoincidence counters, neutrons, Dalitz pairs, and for the electron and muon contamination in the beam. The correction for all sources to the neutral cross section is approximately 17%. Figure 3 contains all of the partial cross sections for π^0 and η^0 (two-gamma mode only) production.

The errors on the curve represent not only the statistical errors but also our estimate of the systematic errors. In particular, scanning for zero-γ events and one-γ events is difficult. Hence, the numbers of zero-γ and one-γ events have a large systematic error. This error is estimated from a rescan which determined the scanning systematics and was included in the errors in Fig. 3. The number of zero-γ events included here is consistent, within our errors, with the known strange-particle production,[3] the major component detectable in this experiment being those reactions with two K_L^0's in the final state.

The general features of Fig. 3 can be summed up as follows: The total cross section drops rapidly as a function of bombarding momentum in the 1-4 GeV/c region. The $1\pi^0$ total cross section in the region 1-3 BeV drops much more rapidly than the total cross section and thereafter seems to drop more slowly. The η^0 cross section, although starting out at smaller values than the $1\pi^0$, does not seem to drop as rapidly. The $2\pi^0$ cross section seems to drop in about the same manner as the total cross section itself. The $3\pi^0$ cross section seems to have a more or less constant value, perhaps decreasing very slowly from a maximum of 500 μb in the interval 2-4 BeV/c. It should be noted that the η decays into $3\pi^0$ with about the same rate as it decays into 2γ; hence the $3\pi^0$ cross section must contain also a number of events equivalent to that of the two-γ mode of decay of the η. The uncertainties of the $5\pi^0$ and the $4\pi^0$ cross sections are large, but the data suggest for the $5\pi^0$'s a more or less uniform cross section in the neighborhood of 25 μb in the region 2-4 BeV, while those for the $4\pi^0$'s suggest a slightly larger cross section that increases to as much as 100 μb in this interval.

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