Inclusive π^0 production in $\pi^- p$ interactions at 5 GeV/c

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We have measured the cross section for the reaction $\pi^- p \to \pi^0 +$ anything at an incident momentum of 5 GeV/c. The two γ rays from π^0 decays were detected using a 150-element lead-glass hodoscope array. A comparison is given of the inclusive π^0 spectrum from hydrogen (obtained through a subtraction of CH_2 and C target data) with π^0 production from C and Cu.

I. INTRODUCTION

Theoretical interest in the subject of inclusive reactions has served to stimulate extensive experimental investigations of these processes.[1] A considerable amount of data has recently become available concerning neutral- and charged-pion production in hadronic collisions; however, there is at present little information pertaining to inclusive π^0 production, particularly for the reaction[2]

$$\pi^- p \to \pi^0 + \text{anything} . \qquad (1)$$

Theoretically, this reaction is one of the simplest to analyze, especially from a t-channel point of view.[3]

In this report we present an analysis of data for reaction (1) obtained at an incident beam momentum of 5 GeV/c at the Argonne Zero Gradient Synchrotron (ZGS). We used three types of nuclear targets: natural copper (0.25 in. thick), carbon (2-in. and 6-in. blocks of graphite), and CH_2 (6-in.-thick polyethylene). The cross section for interactions on hydrogen was obtained through a CH_2-C subtraction. The limits in the kinematic variables to which we are sensitive are

$$p_T > 0.5 \text{ GeV}/c ,$$

$$E_{\text{lab}} > 1.5 \text{ GeV} ,$$

where p_T and E_{lab} are the transverse momentum and the energy of the π^0 in the laboratory, respectively. The data presented here represent a sample size of about 10^6 $\gamma\gamma$ pairs.

II. DESCRIPTION OF THE EXPERIMENT

The setup, shown schematically in Fig. 1, consisted of a solid target in the 17° beam of the ZGS about 140 in. upstream of a hodoscope of 150 lead-glass Čerenkov counters which detected the decay γ rays from the π^0. The distance from the target to the hodoscope was chosen so that photon pairs from 5-GeV/c π^0's would be separated by at least $2\frac{1}{2}$ counters at the hodoscope. The counters had a typical energy resolution of about 9% at 1 GeV/c (standard deviation), and a position resolution, for photon showers covering more than one counter, of $\sim\frac{3}{8}$ in., yielding a resolution in the square of the mass of the π^0 of $\sim\pm 20\%$. Directly in front of these counters was an array of 42 scintillation counters which tagged charged particles. Upstream of the target was a magnet used to bend the beam particle downward so as to change the acceptance in the angular range of the detected π^0's.

The trigger consisted of a signal from the beam counters indicating a π^- had entered the target, followed by a signal from the sum of the lead-glass hodoscope counters.[4] This provided a gate during which the pulse height from each lead-glass counter was latched into individual integrator circuits. All of the integrators were scanned by a special device to ensure that the event contained at least two discrete hits in the lead-glass hodoscope.[5] Three ADC's in parallel were used to

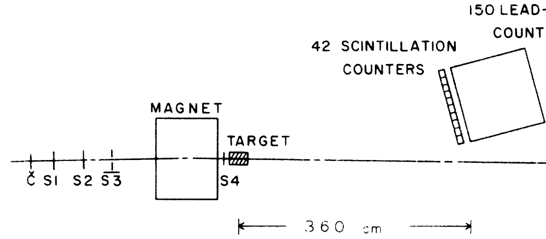

FIG. 1. Schematic of the experimental arrangement.

process the 150 integrators. This information, together with the tagged counter data, was transferred to an EMR-6050 on-line computer. The total dead time per event was 2 msec. The stability of all the electronics associated with the lead-glass counters was monitored periodically throughout the experiment by observing the pulse-height spectrum of each counter when muons were incident. Drifts of about 10% over the course of the experiment were typical.

The analysis of the data consisted of sorting the events to find those which had patterns consistent with the presence of two γ's, and calculating the invariant mass of the γ-γ system. (Information from the 42 scintillation counters was used in the off-line analysis to eliminate false γ triggers caused by charged particles in the lead-glass hodoscope.) A typical γ-γ mass distribution, displayed in Fig. 2, shows a large peak near the mass of the π^0. In order to resolve the minimum opening angle of the π^0 the lead glass had to be positioned so as to eliminate any detection efficiency of η^0's. Events in the peak region (defined by the arrows) were used to generate cross section distributions in various kinematical variables such as momentum transfer and missing mass, or longitudinal and transverse momentum in the center of mass, etc. Backgrounds were subtracted by using "target out" data. Corrections for detection efficiency were based on a Monte Carlo calculation.

In Fig. 3 we display the t distribution (t from π^- to π^0) for several ranges in the value of the mass (M) of the "anything" system recoiling from the π^0. The first region, $M^2 < 2$ GeV^2, represents events corresponding to the charge-exchange reaction ($\pi^- p \to \pi^0 n$) and $\Delta^0(1236)$ production. The solid curve shown on the figure corresponds to previous measurements of the charge-exchange cross section.[6] We observe the well-known minimum in the cross section at $-t \approx 0.6$ GeV.^{2}

It has recently been conjectured that the minimum at $-t \approx 0.6$ GeV^2, observed in the charge-exchange reaction and in $\Delta^0(1236)$ production, might also occur for larger M^2 values of reaction (1).[3] Our data in Fig. 3 do, in fact, show some evidence for such a minimum in the larger-M^2 range of 2–4 GeV^2. The peak observed at $-t \approx 0.5$ GeV^2 for the highest-mass range is due to our kinematic cutoffs in p_T and E_{lab}.

Figure 4 displays our data in terms of the invariant single-particle cross section, integrated over the acceptance in p_T; the horizontal axis is in units of Feynman's variable $x = p_l^*/p_{l\,max}^*$, where p_l^* is the longitudinal momentum of the π^0 and $p_{l\,max}^*$ is the momentum of the incident π^-, both

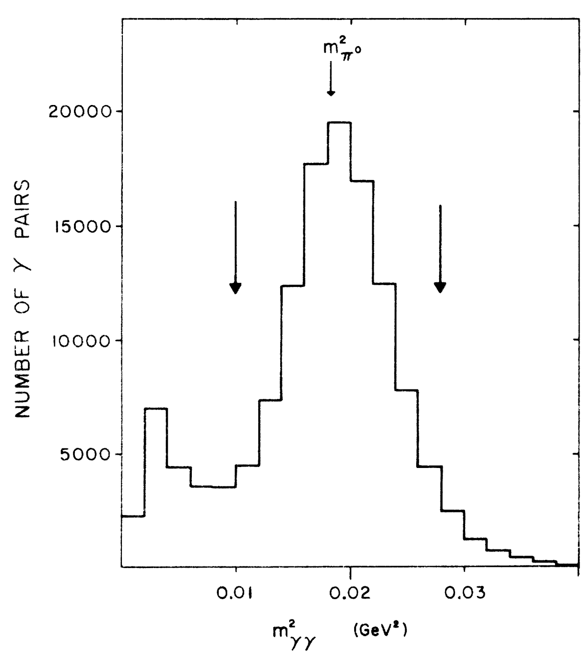

FIG. 2. Mass distribution of the γ-γ system for a typical data run.

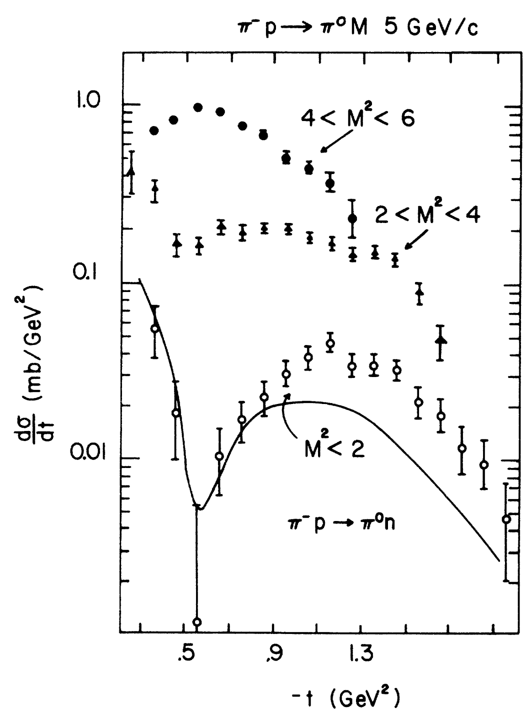

FIG. 3. Cross section as a function of the square of the four-momentum transfer for different values of mass produced in association with a π^0.

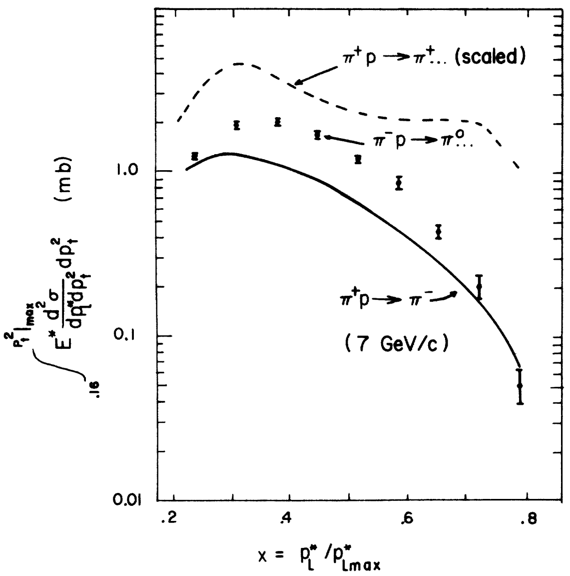

FIG. 4. Invariant cross section for π^0 production, integrated over p_T^2, as a function of x.

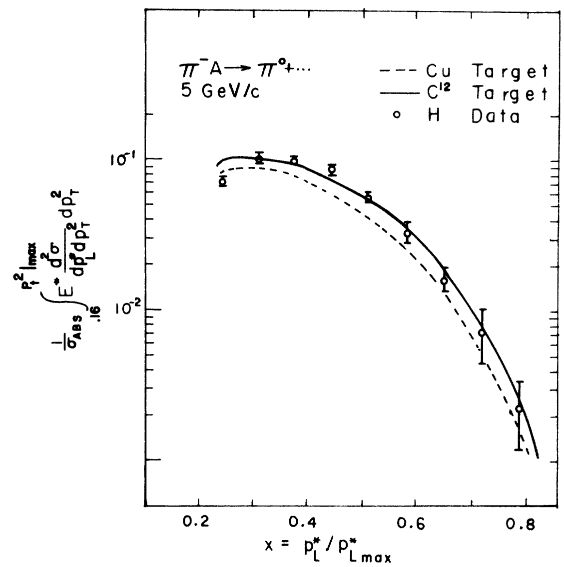

FIG. 5. Normalized invariant cross section for π^0 production on copper, carbon, and hydrogen, integrated over p_T^2, displayed as a function of x.

evaluated in the center-of-mass system. The falloff of the cross section at small values of x is due to our experimentally imposed cutoff on E_{lab}. For comparison, we also show in the same figure smoothed data from the reactions[7]

$$\pi^+ p \to \pi^- + \text{anything at } 7\ \text{GeV}/c\ , \tag{2}$$

$$\pi^+ p \to \pi^+ + \text{anything at } 8\ \text{GeV}/c\ . \tag{3}$$

Although a comparison of our data with the reactions

$$\pi^- p \to \pi^+ + \text{anything}\ , \tag{4}$$

$$\pi^- p \to \pi^- + \text{anything} \tag{5}$$

(particularly at the same energy of 5 GeV/c) would be more interesting, it is worth noting that the cross sections for $x > 0$ for reactions (2) and (3) do not differ substantially ($\lesssim 20\%$) from the cross sections for reactions (4) and (5), respectively.[8]

In Fig. 5 we display invariant cross sections for π^0 production on Cu, C, and H.[9] To facilitate comparison, we have normalized the distributions by their respective π^--nucleus total absorption cross sections.[10] Smooth curves were drawn through the Cu and C data; typical error bars are shown on the smoothed spectra. We note that the shapes of these cross sections for $x > 0.3$ do not depend on the nature of the target; there appears to be a small over-all shift of the normalization for the Cu data relative to C and H. This ~10% discrepancy could be due to the uncertainty in the π-Cu absorption cross section.

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[1]For a recent review of the status of inclusive reactions see M. Boggild and T. Ferbel, Annu. Rev. Nucl. Sci. 24, 451 (1974).

[2]The most extensive data have been presented by L. H. O' Neill *et al.* in *Experiments on High Energy Particle Collisions — 1973,* proceedings of the international conference on new results, Vanderbilt Univ.,

edited by Robert S. Panvini.

[3]See J. Finkelstein and R. Rajaraman, Phys. Lett. 36B, 459 (1971); G. Thomas, Phys. Rev. D 5, 2212 (1972). Also see the review of G. Thomas in the proceedings of the Symposium on Applications of Duality [ANL report, 1972 (unpublished)].

[4]The signal from the sum of the lead-glass counters was required to have a pulse height greater than some minimum threshold value V_{th}. Several settings of V_{th} were used during the course of the run, typically corresponding to an energy cutoff for the π^0 of ~ 1.5 GeV/c. Although the size of the background level changed somewhat with the value of the V_{th} setting, the background-subtracted data from the separate runs were in agreement with each other in regions of overlap.

[5]T. Droege, Argonne Lab. internal report (unpublished).

[6]G. Giacomelli *et al.*, CERN/HERA Report No. 69-1, 1969 (unpublished).

[7]The data from reaction (2) have the same $p_T(\pi^-)$ cutoff (0.4 GeV/c) as our π^0 data. The $E_{lab}(\pi^-)$ cutoff was scaled up to 2.1 GeV/c to account for the difference in energies between the two experiments. We thank Dr. S. Stone of Rochester for providing these distributions. Data for reaction (3) are derived from J. V. Beaupre *et al.*, Phys. Lett. 37B, 432 (1971). Here we assumed that the ratio of cross sections for reactions (2) and (3) is approximately independent of incident energy (between 7 and 8 GeV/c), as well as independent of the cutoffs on p_T and E_{lab}.

[8]Also, the energy dependence of these cross sections is quite weak. See, for example, the review by T. Ferbel, in *Proceedings of the Third International Colloquium on Multiparticle Reactions, Zakopane, Poland, 1972*, edited by O. Czyżewski and L. Michejda (Nuclear Energy Information Center of the Polish Government Commissioner, Warsaw, 1972).

[9]The copper data were taken at just one pulse-height threshold setting (Ref. 4). We consequently compare these data only with H and C data at the same threshold setting.

[10]We use 600 mb, 220 mb, and 23 mb for Cu, C, and H, respectively. See J. Ranft, CERN Report No. CERN/71/21 (unpublished) and E. Bracci *et al.*, CERN/HERA Report No. 72-1, 1972 (unpublished). See also W. Lakin *et al.*, Phys. Lett. 31B, 677 (1970).