

funds supported by the Wisconsin Alumni Research Foundation (COO-881).

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STRUCTURE IN FORWARD-DIRECTION π^-p CHARGE-EXCHANGE SCATTERING IN THE 3 GeV/c REGION*

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(Received 6 May 1964)

A survey of the forward-direction elastic charge-exchange scattering reaction $\pi^- + p \rightarrow \pi^0 + n$ has been made over the range $p_{\pi^-} = 2.4$ GeV/c through 18 GeV/c at the BNL AGS. We report here that strong energy dependence is evident in the lower part of that energy range.

On the assumption of charge independence, the amplitude for charge-exchange scattering (hereafter referred to as CEX) is proportional to the difference between the $I = \frac{3}{2}$ and $I = \frac{1}{2}$ amplitudes. Combined with the optical theorem, this yields the relationship

$$\frac{d\sigma}{d\Omega}(0^0)_{\text{CEX}} = \frac{1}{2}(D^- - D^+)^2 + \frac{1}{2}\left(\frac{k}{4\pi}\right)^2 (\sigma^- - \sigma^+)^2$$

for the forward direction cross section, where D^- and D^+ are real parts of the forward-scattering amplitudes for π^-p and π^+p , respectively, and σ^- and σ^+ are the total cross sections. Since above 2.4 GeV/c the difference between σ^- and σ^+ is much smaller than the magnitude of each, the forward CEX cross section should reflect resonances in this energy region with a much more favorable signal-to-noise ratio than would a total cross-section measurement, barring accidental cancellation by the variation of the term in the real parts. An $I = \frac{1}{2}$ resonance increases σ^- and not σ^+ , and since σ^- is already larger than σ^+ , $(d\sigma/d\Omega)(0^0)_{\text{CEX}}$ increases also. By contrast, an $I = \frac{3}{2}$ resonance increases σ^+ more than σ^- and results in a decrease in $(d\sigma/d\Omega)(0^0)_{\text{CEX}}$.

The data described here, from the low-energy part of the survey, were obtained with the apparatus shown in Fig. 1. A liquid hydrogen target was placed in a 2.4- to 6.0-GeV/c momentum-analyzed ($\pm 0.8\%$) beam of unseparated negative particles. The target was surrounded by alternate layers of scintillating plastic and lead in order to veto both charged particles and gammas

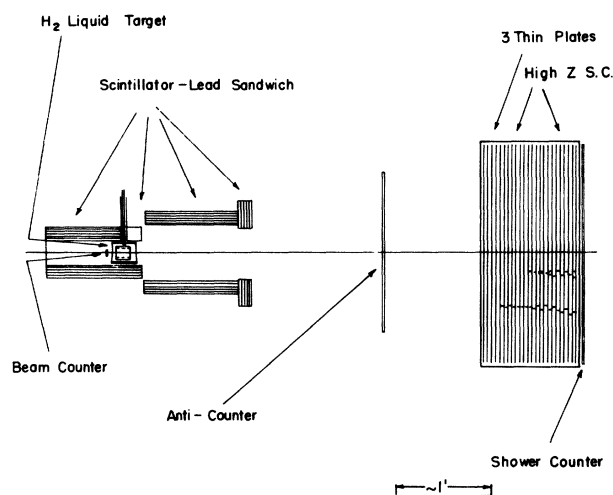


FIG. 1. Experimental apparatus. The π^- beam enters from the left.

produced in all but the downstream direction. A square opening in the downstream direction, subtending approximately $12^\circ \times 12^\circ$, was covered only by a $\frac{1}{2}$ -in. thick scintillator which vetoed only charged particles. Gammas passed through this scintillator and converted in a 14-plate brass spark chamber, 5 radiation lengths thick. The detection of one or more charged particles in a large scintillation counter directly downstream from the spark chamber completed the trigger. The spark chamber had an additional three plates of thin aluminum foil on the upstream side to provide a visual veto of any charged particles which escaped our veto system. Loss of events due to low-energy recoil neutrons triggering the veto counters have been estimated to be small compared with the counting errors.

There were typically less than 6×10^{-5} trigger per incident particle with the target empty, and

roughly double this rate with the target full. Approximately 5000 pictures were taken at each energy, of which half have been scanned to date. About half of these photographs contained measurable 2γ events, and a quarter contained a single γ . Roughly half of the measured 2γ events turned out to be elastic CEX events from the liquid hydrogen.

Only the starting point of each shower was measured. With the distance between the hydrogen target and spark chamber fixed at 60 in., the 1-in. width of the incident beam set the maximum error in the polar angle of a γ ray at $\sim\pm 0.5^\circ$ in the laboratory. The 2-in. length of the target set the maximum error in the opening angle $\theta_{\gamma\gamma}$ between the two γ 's as $\sim\pm 1.7\%$.

A typical 2γ opening-angle distribution is shown in Fig. 2, plotted in 5% intervals in the ratio of the observed opening angle in the π^-p c.m. system to the minimum angle expected ($\theta_{\gamma\gamma\min}^* \approx 2/\gamma^*$, where γ^* is the energy of the π^0 in the π^-p system in natural units). For the present analysis we have used only those events for which the normalized opening angle $\theta_{\gamma\gamma}^*/\theta_{\gamma\gamma\min}^*$

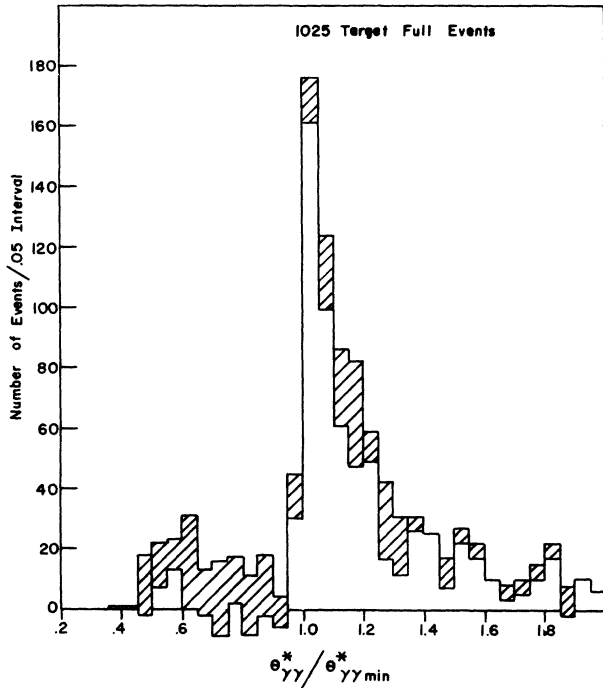


FIG. 2. Distribution in 5% intervals of the c.m. opening angle between the two γ 's in $\pi^0 \rightarrow 2\gamma$ decay, normalized to the expected minimum opening angle. The momentum is 3.0 GeV/c. The upper histogram is target-full data. The histogram below the cross-hatched area is what remains after subtracting the target-empty background.

is between 0.99 and 1.15, thus including $\sim 50\%$ of all the elastic charge-exchange events. This restriction limits the number of background events accepted, and also allows us to use the bisector of the two gamma rays, θ_b^* , as the direction of the π^0 . The error introduced by the use of the bisector varies between 0° and 4.6° in the c.m. system at the two extremes of the opening angle cut.

As an approximation to $(d\sigma/d\Omega)(0^\circ)_{\text{CEX}}$, we have used the events in the interval $1.00 \geq \cos\theta_b^* > 0.99$. (This approximation is good unless the differential cross section varies so rapidly near 0° that important structure is present within this $\cos\theta_b^*$ interval; such structure would be beyond the resolution of this experiment.) The variation of $(d\sigma/d\Omega)(0^\circ)_{\text{CEX}}$ thus estimated vs bombarding momentum is shown in Fig. 3. The errors shown are just the statistical errors.

The number of events per point in Fig. 3 varies between 40 and 75 for the full target data, except for the points at 4.0, 4.5, and 5.0 GeV/c, which consist of 15, 6, and 9 events, respectively. The number of events per point for the target empty data varies between 1 and 7, except that we have no empty target data at 4.0, 4.5, or 5.0 GeV/c.

In normalizing the differential cross sections, we have made corrections for scanning inefficiencies, events mismeasured by the scanners, muon contamination of the beam, events in which the two γ 's did not both convert in the spark chamber, and the fraction of elastic charge-exchange events rejected by our opening angle cut-off. An error of $\pm 30\%$ is tentatively assigned to the absolute normalization.

A similar resonant structure is observed also in the variation with momentum of the total number of CEX events detected in the spark chamber per incident pion. The interpretation of this result awaits a detailed calculation of the efficiency of the spark chamber as a function of π^0 angle, since even without the efficiency correction we can see that the angular dependence of the cross section changes markedly within this energy region. However, the spark-chamber efficiency is practically 100% for $\cos\theta_b^* \geq 0.96$, so that the results for $\cos\theta_b^* > 0.99$ shown in Fig. 3 are independent of it.

The strong structure evident in Fig. 3 can be interpreted most simply as an $I = \frac{1}{2}$ resonance at ~ 3.1 GeV/c ($E^* \sim 2.6$ GeV), or as two $I = \frac{3}{2}$ resonances at ~ 2.6 and 3.5 GeV/c ($E^* \sim 2.4$ and 2.7

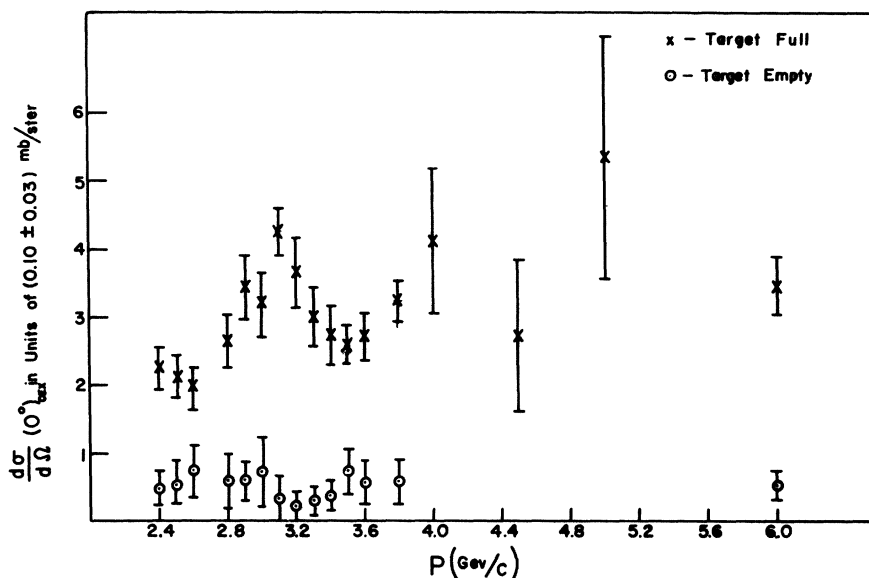


FIG. 3. The forward-direction elastic charge-exchange scattering cross section as a function of lab momentum. For these data, "forward" means $1.00 \geq \cos\theta_b^* > 0.99$, where θ_b^* is the angle of the bisector of the two γ rays in the c.m. system.

GeV), or as all three of these together. We have no well-defined off-resonance baseline in this energy region with which to compare the resonances.

An $I = \frac{3}{2}$ resonance has previously been observed at 2.51 GeV/c ($E^* = 2.36$ GeV) by Diddens et al.¹ in the total $\pi^\pm + p$ cross sections. More recently Alvarez et al.² have seen further structure in this energy region in π^+ and π^0 photoproduction at certain angles, which they interpret as a resonance at $E^* \sim 2.5$ GeV probably with $I = \frac{3}{2}$, and another resonance at $E^* \sim 2.7$ GeV with $I = \frac{1}{2}$.

We thank P. Mockett for help in planning this experiment; L. Osborne for discussion of new results; D. Frisch for advice and support throughout; and A. Buffington, G. Chen, J. Kasper, M. Poe, P. Kirk, S. Smith, L. Sompayrac,

S. Taub, the BNL AGS crew, and especially L. Stinson for great help in running the experiment.

*This work is supported in part through funds provided by the U. S. Atomic Energy Commission under Contract No. AT(30-1)-2098.

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