MEASUREMENTS OF SINGLE π^- AND π^+ PHOTOPRODUCTION AT SMALL MOMENTUM TRANSFERS*

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Single π^- and π^+ photoproduction from deuterium has been measured at gamma energies of 3.4 and 5 GeV and momentum transfers between 0.005 and 0.6 $(\mathrm{GeV}/c)^2$. The π^-/π^+ ratio is found to be unity near the forward direction and drops to about 0.3 at larger angles. The data support the existence of a forward peak in π^- photoproduction on neutrons.

In this paper we present the results of an experiment on π^- and π^+ photoproduction on deuterium and hydrogen. We have measured the reactions $\gamma d \to \pi^- 2p$, $\gamma d \to \pi^+ 2n$, and in addition $\gamma p \to \pi^+ n$ in order to have a check on the validity of the spectator model. The experiment was performed using a bremstrahlung beam from the Deutsches Elektronen-Synchrotron (DESY) facility and detecting only the pion with a magnetic spectrometer. Details of the apparatus and experimental procedure are given by Heide et al.[1]

In our calculations of the photoproduction kinematics on deuterons we assumed the spectator model to be valid. At small momentum transfers the relation between incident gamma energy and pion momentum is nearly the same as in photoproduction on free nucleons. Therefore, a one-arm spectrometer was adequate to identify the single-pion production reaction. The Fermi motion in the deuteron leads to an uncertainty of about ±100 MeV in the center-of-mass energy, but has negligible influence on the momentum transfer t.

A Monte Carlo calculation was performed to simulate the photoproduction process caused by a bremsstrahlung beam in a deuterium target. The spectator momentum distribution was computed from the Hulthén deuteron wave function.[2] We found good agreement between calculated and measured pion-momentum spectra. With increasing momentum transfer, an increasing smearing of the pion-momentum profile was observed which is due to the Fermi motion of the target nucleon. However, the energetic separation between single and multiple pion production was still good enough to have a di-pion contamination in elastic yields of at most a few per cent.

Single-pion photoporduction cross sections were calculated using a photon energy interval $E_{\gamma\max} - 200\ \mathrm{MeV} < E_\gamma < E_{\gamma\max}$. The cross sections have been corrected for empty target (3-13 %), nuclear absorption (6 %), pion decay in flight (7-13 %), and ambiguous events (3 %). Multiple Coulomb scattering and dE/dx losses were taken into account in the solid angle calculation. The contamination of the pion rate due to electrons, muons, and protons is estimated to be less than 1 %.

The errors given with the cross sections are statistical only. For the deuterium cross sections the smearing in the momentum spectrum probably causes a systematic uncertainty which smoothly increases with angle (<5 %). An overall normalization uncertainty is estimated to be less than ±7 %. The π^-/π^+ ratios should not be affected by the systematic errors, since the π^+ and π^- data were taken under identical conditions except for reversed magnet polarities.

In Figs. 1 and 2 we show the pion cross sections for hydrogen and deuterium at $E_\gamma = 3.4$ and GeV together with previous hydrogen data[3,4] and deuterium data.[5] The π^-/π^+ ratios calculated from the deuterium cross sections are shown in Fig. 3. Numerical values are given in Ref. 1. The striking feature is that the π^- cross sections have the same magnitude near the forward direction, but drop more rapidly with increasing momentum transfers than the π^+ cross sections.

At momentum transfers $|t| \gtrsim 0.3\ (\mathrm{GeV}/c)^2$ the π^+ cross sections on deuterium and hydrogen are roughly equal, which is found also by Bar-Yam et al.[5] However, there is a clear difference at smaller momentum transfers which may be qualitatively understood from spin and isospin restrictions in the spectator model.[6] A similar suppression of the π^+ yields from deuterium at small angles was observed in lower energy experiments by Neugebauer, Wales, and Walker.[7] Assuming that the corrections are the same for the π^- (d) and the π^+ (d) reactions, one can obtain the π^- cross section on free neutrons by multiplying the π^-/π^+ ratio from deuterium with

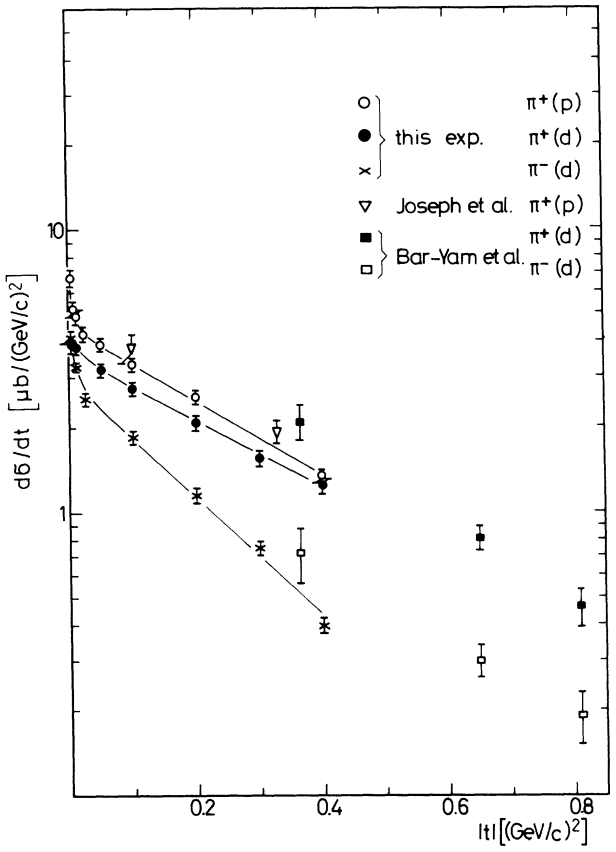

FIG. 1. Differential cross sections for the reactions $\gamma p \to \pi^+ n$, $\gamma d \to \pi^+ nn$, and $\gamma d \to \pi^- pp$ at $E_\gamma = 3.4$ GeV as functions of momentum transfer $|t|$. The curves are drawn to guide the reader.

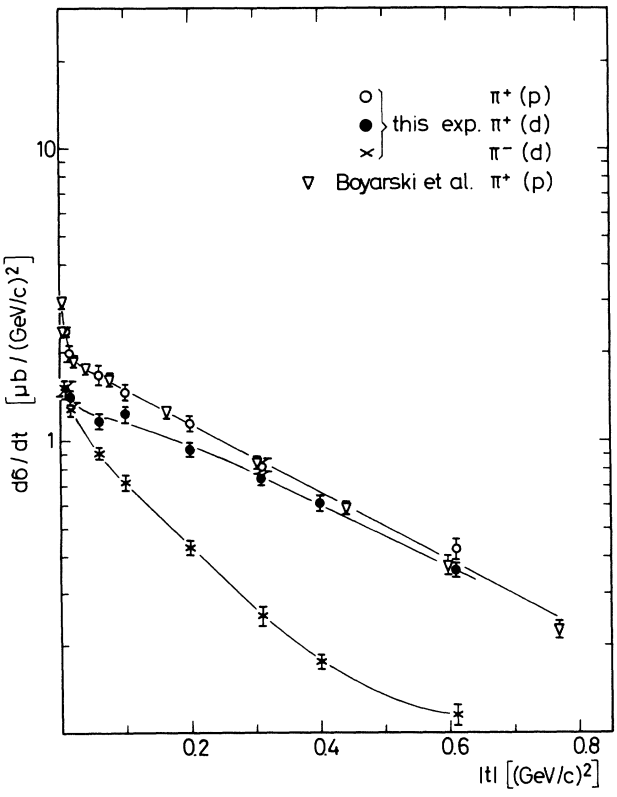

FIG. 2. Differential cross sections for the reactions $\gamma p \to \pi^+ n$, $\gamma d \to \pi^+ nn$, and $\gamma d \to \pi^- pp$ at $E_\gamma = 5$ GeV as functions of momentum transfer $|t|$. The curves are drawn to guide the reader.

the π^+ cross section from hydrogen. We suspect that this simple relation needs some modification at very small momentum transfers, because the additional Coulomb interaction between the two final-state protons should suppress the π^- (d) cross section relative to the π^+ (d) cross section.[6] The data most likely imply that there is a forward peak in π^- photoproduction on free neutrons, and furthermore, that $d\sigma(\gamma n \to \pi^- p) \geq d\sigma(\gamma p \to \pi^+ n)$ at the smallest momentum transfer covered in this experiment.

That the π^-/π^+ ratio drops to $\simeq 0.3$ (Fig. 2) indicates that there has to be considerable interference between the isovector and isoscalar amplitudes of the photon. In the vector-dominance model this implies that not only the intermediate ρ^0 state but also the ω (and possibly the φ) state of the photon is required. A π^-/π^+ ratio 0.3 is not inconsistent with experimental data on ρ^0 and ω production in πN interactions.[8] Dar et al.[9] have made vector-dominance predictions for the sum

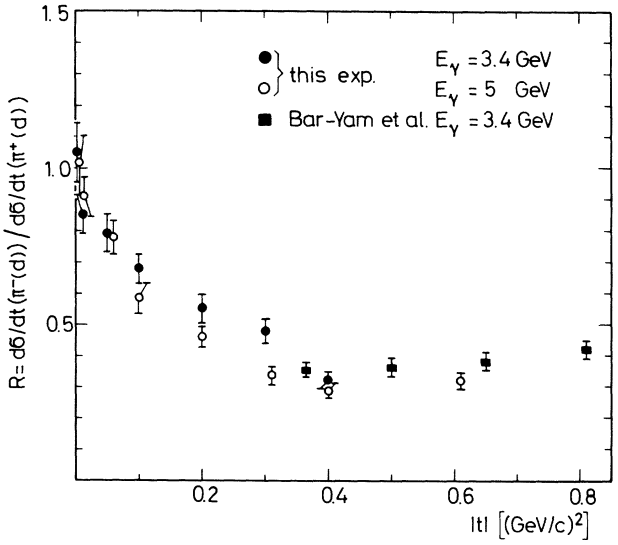

FIG. 3. π^-/π^+ ratios at $E_\gamma = 3.4$ and 5 GeV from deuterium as a function of $|t|$.

of π^+ and π^- photoproduction cross sections and have found good agreement with previous data. Also the data presented in this paper agree well with their predictions.

Several authors have fitted the forward peak in π^+ photoproduction using conspiring trajectories, cuts, or a phenomenological background term.[10] Frøyland and Gordon[10] also make predictions for π^- photoproduction. They describe the π^-/π^+ ratio correctly for large momentum transfers; however, they do not find the rise to unity near the forward direction.

We would like to comment on a quark-model prediction by Bialas et al.[11] relating the difference between π^+ and π^- photoproduction to a difference of K^{*0} production cross sections. These authors use a π^-/π^+ ratio of 0.4 and find the quark-model relation to be violated. With our new results which give roughly equal π^+ and π^- cross sections in the forward direction and a smaller difference of the integrated cross sections, the violation is not so evident.

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LORENTZ INVARIANCE IN REGGEIZATION OF PION PHOTOPRODUCTION AMPLITUDES*

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We study the implications of Lorentz and gauge invariance for Reggeization of the pion trajectory in charged pion photoproduction and find that the pion pole need not be introduced as a kinematical singularity. As a consequence of having a dynamical Regge pion pole, we find that effects characteristic of an s-channel nucleon pole appear automatically.

Charged-pion photoproduction $\gamma p \to \pi^+ n$ has recently received considerable attention[1-4] because of the experimental observation[5] of a sharp peak in the forward direction. In the past, forward peaking of many reactions had been explained very nicely in the peripheral model with pion exchange. Whereas a natural pion exchange mechanism exists also in photoproduction, the contribution from this particular single process vanishes in the forward direction; in the usual scheme for Reggeization of helicity amplitudes there is no dynamical pole on the pion trajectory at the position of the pion mass and spin; it is introduced through a kinematical factor.[1,6] This is at least esthetically dissatisfying since this same kinematical factor also occurs in the perturba-