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π^+ PHOTOPRODUCTION FROM HYDROGEN WITH POLARIZED PHOTONS*

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The reaction $\gamma_{\perp,\parallel}p\to\pi^+n$ has been studied with linearly polarized photons of energy 3.0 GeV at $-t$ values between 0.15 and 1.2 $(\mathrm{GeV}/c)^2$. The asymmetry $A^+=(d\sigma_\perp-d\sigma_\parallel)/(d\sigma_\perp+d\sigma_\parallel)$ is found to be positive throughout this four-momentum–transfer range, implying the dominance of natural parity exchange in the t channel. Comparison of $d\sigma_\perp(\gamma_\perp p\to\pi^+n)$ and $d\sigma_\perp p\to\pi^-p)$ from a previous experiment indicates strong interference between the isoscalar and isovector photon amplitudes for photons polarized perpendicular to the production plane.

We report the results of an experiment carried out at the Cambridge Electron Accelerator (CEA) on the reactions $\gamma_{\perp,\parallel}p\to\pi^+n$ and $\gamma_{\perp,\parallel}d\to\pi^+nn_s$ using photons of 3.0 GeV linearly polarized perpendicular ($\perp$) or parallel ($\parallel$) to the production plane.[1]

Polarized photons were produced from a diamond crystal via the Überall-Diambrini effect.[2] The photon energy was determined by a subtraction method identical to that used in a previous experiment on π^- production.[3] Briefly, a 6-GeV electron beam from the CEA impinged on a diamond crystal oriented so that the principal "spike" of coherently produced photons occurred at 3.15 and 2.85 GeV, respectively, in two consecutive runs with the same polarization direction. By taking the difference between the normalized pion yields from two such runs, the energy of the polarized photons contributing to the subtracted pion yield was determined to be $E=3.0\pm0.15$ GeV.

To ascertain the proper orientation of the diamond crystal and to be able to calculate the degree of polarization of the photon spike, the energy spectrum of the photon beam was measured periodically with a pair spectrometer and a multicounter system. The integrated photon flux and the total beam energy were monitored with the aid of a thin transmission-type ionization chamber and a total-absorption quantameter.

The experiment consisted of measuring coincidence yields between the pions and the recoil neutrons produced in a liquid-hydrogen or deuterium target. The momentum and production angle of the π^+ were measured in a magnetic spectrometer[4] equipped with scintillation trigger counters and digitized wire spark chambers. A threshold gas Cherenkov counter mounted on the spectrometer platform was used to discriminate pions from protons.

The recoil neutron was detected by means of a scintillation counter assembly consisting of 20 counters $3\times3\times12$ in. stacked in a 4×5 matrix. Two thin scintillation anticoincidence counters were placed in front of this matrix to reject charged particles entering the neutron counter.

The efficiency of the neutron counter had been measured in a previous experiment at CEA and found to be about 28 %.[5] The precise value of the efficiency is not critical, however, for the purpose of this experiment, since only cross-section ratios are used in the calculation of the polarization asymmetries. Systematic errors due to counter inefficiencies will therefore cancel out.

The coincidence requirement between pion and neutron and the subtraction of pion yields used for determining the photon energy permit the identification of the single-pion production process. This method not only substantially eliminates the contamination due to multipion

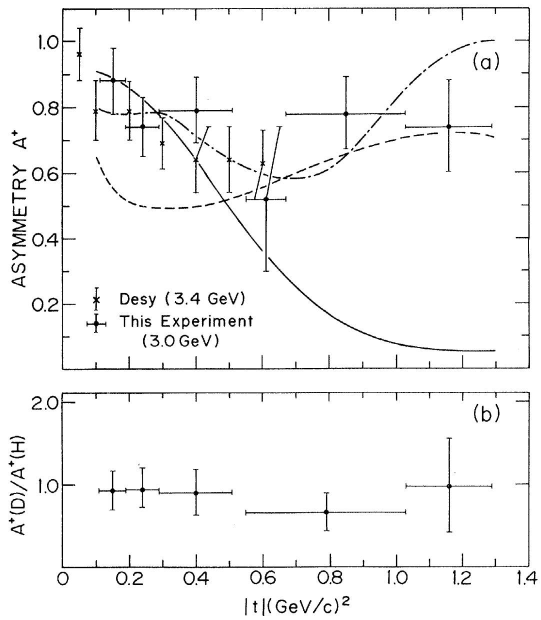

FIG. 1. (a) Polarization asymmetry for π^+ photoproduction at 3.0 GeV incident photon energy as a function of $-t$. The vertical error bars include statistical errors, the uncertainty in the number of photons in the subtracted photon-yield spectrum (10%), and the error in the degree of photon polarization (5%). Horizontal bars indicate the $-t$ range included in each point. The DESY points are from Geweniger *et al.* (Ref. 6). The dashed curves are from two different models due to Korth; the solid curve is the prediction of Frøyland and Gordon, Ref. 7. (b) Ratio of polarization asymmetries for π^+ photoproduction from deuterium, $A^+(\mathrm{D})$, and hydrogen, $A^+(\mathrm{H})$, as a function of $-t$.

events, but also reduces the contribution of incoherently produced unpolarized photons.

Our results for the asymmetry, $A^+ = (d\sigma_\perp - d\sigma_\parallel)/(d\sigma_\perp + d\sigma_\parallel)$, are shown in Fig. 1(a). We have included data from the reaction $\gamma_{\perp,\parallel} d \to \pi^+ n n_s$ in this figure since we expect no effects from the spectator neutron n_s at these t values. Figure 1(b) justifies this expectation; the asymmetry A^+ from proton and deuteron is the same within statistics. Data are also given for hydrogen and deuterium separately in Table I. We note agreement of our points with previous results[6] at small $-t$.

A physical interpretation of our results in terms of simple t-channel exchange amplitudes is that π^+ photoproduction occurs predominantly through natural parity exchange. Detailed Regge models[7] to explain photoproduction have required cuts. The predictions of the Frøyland-Gordon cut conspiracy model, which are in good agreement with the earlier data up to about $-t = 0.5$ $(\mathrm{GeV}/c)^2$ show large deviations from the data points above $-t = 0.6$ $(\mathrm{GeV}/c)^2$. Two fits based on other Regge models were attempted by Korth.[7] They are also included in Fig. 1(a).

We have combined the results of this experiment with previous results on π^- photoproduction[3] to obtain $R_\perp$ and $R_\parallel$ where, for example, $R_\perp = d\sigma_\perp(\pi^-)/d\sigma_\perp(\pi^+)$; the results are shown in Fig. 2. $R_\perp$ is seen to be appreciably smaller than 1 throughout the measured t range and has a dip at $-t = 0.4$ $(\mathrm{GeV}/c)^2$, reminiscent of the $-t$ behavior of the unpolarized π^-/π^+ ratio, R_0

Table I. Summary of experimental results. In order to obtain $R_\perp$, $R_\parallel$, $A(\pi^+ + \pi^-)$, and $\Sigma_\perp$ we have used interpolated values of R_0 from the combined data of Ref. 8. In calculation of $\Sigma_\perp$ we used in addition interpolated values of the unpolarized π^+ photoproduction cross section from the combined data of Refs. 8 and 18.

	$\lvert t \rvert$ Range $(\mathrm{GeV}/c)^2$					
	0.11↔0.19	0.19↔0.29	0.29↔0.51	0.55↔0.67	0.67↔1.03	1.03↔1.29
A^+(H+D)	0.88 ± 0.10	0.74 ± 0.09	0.79 ± 0.10	0.52 ± 0.22	0.78 ± 0.11	0.74 ± 0.14
A^+(D)	0.84 ± 0.19	0.70 ± 0.17	0.73 ± 0.20	0.55 ± 0.17		0.72 ± 0.39
A^+(H)	0.90 ± 0.11	0.75 ± 0.11	0.81 ± 0.12	0.65 ± 0.26	0.87 ± 0.13	0.74 ± 0.15
A^-	0.52 ± 0.22	0.19 ± 0.16	-0.30 ± 0.17	-0.10 ± 0.17	0.33 ± 0.20	0.14 ± 0.19
$R_\perp$	0.51 ± 0.06	0.36 ± 0.06	0.13 ± 0.04	0.21 ± 0.06	0.30 ± 0.07	0.30 ± 0.08
$R_\parallel$	2.6 ± 2.5	1.6 ± 0.7	2.1 ± 1.1	0.82 ± 0.41	1.2 ± 0.7	1.5 ± 0.9
$A(\pi^+ + \pi^-)$	0.74 ± 0.10	0.55 ± 0.08	0.52 ± 0.09	0.36 ± 0.17	0.65 ± 0.10	0.55 ± 0.12
$\Sigma_\perp \frac{\mu b}{(\mathrm{GeV}/c)^2}$	3.83 ± 0.46	2.52 ± 0.29	1.43 ± 0.16	0.77 ± 0.12	0.51 ± 0.06	0.19 ± 0.03

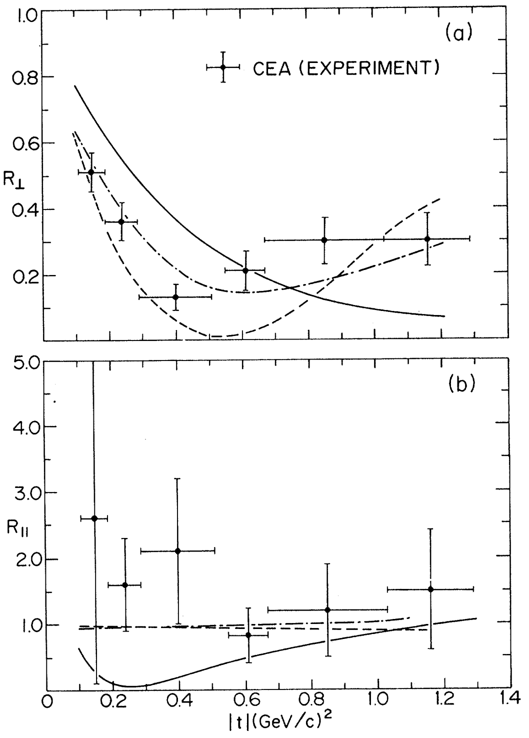

FIG. 2. The ratios $R_{\perp,\parallel}$ between π^- and π^+ photoproduction cross sections using photons (a) perpendicular, and (b) parallel to the production plane. $R_\perp = \sigma_\perp(\pi^-)/\sigma_\perp(\pi^+) = R_0(1+A^-)/(1+A^+)$; $R_\parallel = R_0(1-A^-)/(1-A^+)$; see Table I. The curves are from the same models as those in Fig. 1.

$= d\sigma(\pi^-)/d\sigma(\pi^+)$.[8] Since $d\sigma_\parallel(\pi^-)$ and $d\sigma_\parallel(\pi^+)$ are small and since $R_\parallel$, though measured with poor statistics, is consistent with 1.0 [see Fig. 2(b)], the source of the whole charge asymmetry in the unpolarized π^-/π^+ cross-section ratio appears to come from $d\sigma_\perp$. In simple terms, the isovector-isoscalar photon interference can be accounted for by the natural-parity particle exchange,[9] e.g., ρ-A_2 interference.[10] However, we note that the poor statistics of $R_\parallel$ do not allow a conclusive statement regarding the presence of the isovector-isoscalar photon interference terms in the unnatural parity exchange mode, e.g., B–π interference.

In order to compare the experimental results with the vector-dominance model (VDM) free from the uncertainty of the $\rho^0\omega$ interference term, one needs to sum corresponding π^+ and π^- data. Two expressions that have been used in this comparison are $\Sigma_\perp = \frac{1}{2}[d\sigma_\perp(\pi^+) + d\sigma_\perp(\pi^-)]$ and $A(\pi^+ + \pi^-) = [(d\sigma_\perp - d\sigma_\parallel)_{\pi^+} + (d\sigma_\perp - d\sigma_\parallel)_{\pi^-}]/[(d\sigma_\perp + d\sigma_\parallel)_{\pi^+} + (d\sigma_\perp + d\sigma_\parallel)_{\pi^-}]$.

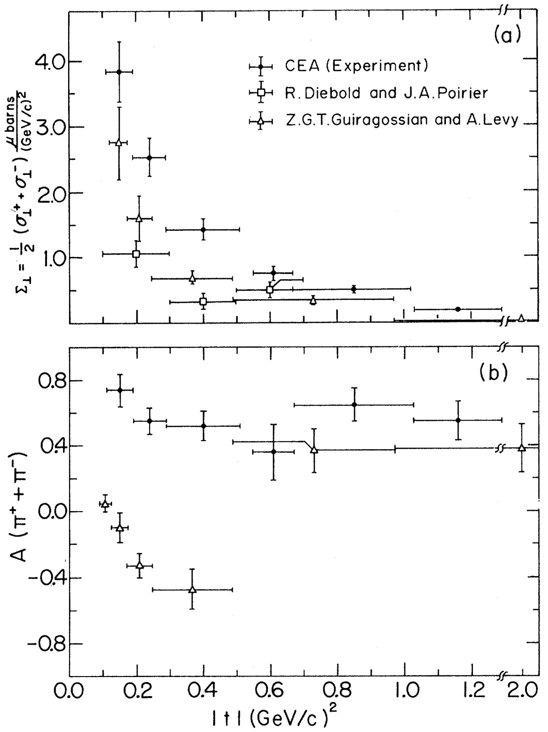

FIG. 3. Comparison of the photoproduction data and the VDM predictions. The VDM values are from Ref. 12 using for consistency the same coupling constant $\gamma_\rho^2/4\pi = 0.52 \pm 0.07$.

Assuming ω and φ contributions to be negligible,[11] VDM relates $\Sigma_\perp$ to ρ^0 production through the expression

$$\Sigma_\perp = (2\alpha\pi/\gamma_\rho^2)[(\rho_{11} + \rho_{1-1})d\sigma]_{\pi^- p \to \rho^0 n},$$

where the ρ_{ik} are the spin-density matrix elements of the ρ^0. $\Sigma_\perp$ is not only free of the $\rho^0\omega$ interference term, but also independent of rotations about the normal to the production plane of the frame in which the spin-density matrix is evaluated.[11]

The VDM relation for the asymmetry, $A(\pi^+ + \pi^-) = \rho_{1-1}/\rho_{11}$, on the other hand, is frame dependent and thus subject to the ambiguity associated with evaluating the spin-density matrix in different frames.

The VDM comparison between π photoproduction and ρ^0 production by pions has been done up to $-t = 0.6$ (GeV/c)^2 by several groups.[12] Our present data allow extension of this comparison to $-t = 1.2$ (GeV/c)^2. Figure 3(a) presents our data on $\Sigma_\perp$ together with the predictions from Ref. 12, using $\gamma_\rho^2/4\pi = 0.52 \pm 0.07$ for the coupling constant in both cases.[13] The deviations of the photoproduction data from the VDM predictions, particularly around $-t = 0.4$ (GeV/c)^2, are uncomfortably large. The data between 0.6 and 1.2 $(\text{GeV}/c)^2$ show deviations from VDM consistent with the earlier data at smaller $-t$ values, requiring coupling constants $\gamma_\rho^2/4\pi$ between 0.2 and 0.3 to reach better agreement. This is even lower than the value of 0.38 found from total cross section measurements on nuclei.[14]

Figure 3(b) presents our data for $A(\pi^+ + \pi^-)$ and VDM predictions evaluated in the helicity frame. There is strong disagreement between VDM and photoproduction data at small $-t$; for our new points at large $-t$, however, there is agreement. Past attempts to reconcile the disagreement at small $-t$ by using other frames[15] have been challenged on the basis of the violation of a smooth mass extrapolation.[16]

The VDM comparisons for both $\Sigma_\perp$ and $A(\pi^+ + \pi^-)$ may be unreliable because there appears to be a D-wave contamination of the ρ_{1-1} matrix element used in the comparison.[17]

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