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ABSTRACT

We have measured the asymmetry in the cross section for the reaction $\gamma p \to \pi^+ n$ between the two states of polarization of the initial proton normal to the plane of scattering. The initial laboratory photon energies, k, were 5 GeV and 16 GeV, and the regions of momentum transfer, t, covered were $0.14 \leq \sqrt{-t} \leq 1.01$ GeV/c and $0.14 \leq \sqrt{-t} \leq 0.78$ GeV/c respectively. A butanol polarized target was used with the SLAC 20 GeV/c magnetic spectrometer. The data show a sizeable asymmetry at both 5 GeV and 16 GeV. The 16 GeV data peak at $\sqrt{-t} \sim 0.30$ GeV/c with an asymmetry of about -0.70, and the 5 GeV data peak at $\sqrt{-t} \sim 0.80$ GeV/c with an asymmetry of about -0.70. (The direction of our normal to the scattering plane is along (photon in) $\times$ (pion out)).

Single pion photoproduction at high energies has received much experimental and theoretical attention in the past several years.[1,2] In the forward direction (small momentum transfer to the pion) the differential cross section has been measured for $\gamma p \to \pi^+ n$, $\gamma p \to \pi^0 p$, and $\gamma n \to \pi^- p$ for γ energies up to 18 GeV. Theoretical models based on Regge poles only, Regge poles with absorptive cuts, vector meson dominance (VDM), electric Born approximation with and without absorption, and phenomenological fixed poles have been applied to these cross sections. Recently, beams of high-energy linearly polarized photons have allowed measurements of the production asymmetry by photons with states of polarization parallel and perpendicular to the plane of production. A different combination of amplitudes from that measured in the polarized photon experiments is measured by photoproducing from a polarized target (see ref. 11, for example). We report here a measurement of the asymmetry in the produced pions between two states of proton polarization in the reaction

$$\gamma p \to \pi^+ n \quad .$$

The experiment was performed at the Stanford Linear Accelerator Center, using the 20 GeV/c spectrometer to detect the π^+. The spectrometer system was similar to that used in previous photoproduction experiments of Boyarski, et al.[3,6] A butanol polarized proton target[4] was used in a vertical magnetic field with its proton spins (those of hydrogen nuclei) oriented parallel and anti-parallel to the normal of the production plane.

The photoproduction cross section of pions from polarized protons can be expressed as:

$$\frac{d\sigma}{dt}(t)_{\text{polarized}} = \frac{d\sigma}{dt}(t)_{\text{unpolarized}} \quad (1 + A(t)\vec{P}_T \cdot \hat{n})$$

where $\vec{P}_T$ is the target polarization, $\hat{n}$ is the normal to the production plane (positive in the direction $\vec{k}_\gamma \times \vec{p}_{\pi^+}$), t is the invariant momentum transfer squared, and A(t) is the asymmetry parameter we wish to measure. Experimentally we measure the quantity $\epsilon(t)$:

$$\epsilon(t) = \frac{N_\uparrow(t) - N_\downarrow(t)}{N_\uparrow(t) + N_\downarrow(t)}$$

where $N_\uparrow(N_\downarrow)$ is the number of pions produced per unit incident beam for the target polarized parallel (antiparallel) to $\hat{n}$. $\epsilon(t)$ and A(t) are related by:

$$A(t) = \frac{1}{|\vec{P}_T|} \mathcal{H}(t)\epsilon(t)$$

where $\mathcal{H}(t)$ is a factor to account for the fact that the target is not pure hydrogen. ($\epsilon(t)$ would equal A(t) for a pure hydrogen target that is 100% polarized.)

The photon beam causes radiation damage in the target, reducing its polarization. As the radiation damage, and thus the target polarization, is not uniform in the target along the beam direction, it was necessary to measure the target polarization with a nuclear-magnetic-resonance (NMR) system which would sample the whole target uniformly. This was achieved with a septum arrangement described in Ref. 4. Since the NMR system samples the entire target, it was important to illuminate uniformly the 2.5 cm × 2.5 cm target with the beam. To this end a beam sweeping technique used previously in the inelastic electron scattering experiment of Rock, et al.,[5] was employed to sweep the primary electron beam across a 0.03-radiation-length aluminum radiator at the rate of about once per second. The resulting bremsstrahlung beam passed through an adjustable collimator and a fixed beam scraper before striking the target. The various beam monitors were found to be affected slightly by this sweeping, but since this effect (< 5%) was present for both signs of target polarization, our results are not affected. The beam position on the target was observed by means of exposures of glass slides to the beam transmitted by the target. An exposure of about 5 minutes to the photon beam was adequate to fix images of the collimator and target outlines on the glass.

We recorded the target polarization about once per second and we estimate that its value was measured to better than one part in twenty. The target polarization was reversed about every five minutes in an attempt to reduce possible systematic errors due to changes in beam intensity, steering, etc. The beam intensity was adjusted to about 2×10^{11} equivalent quanta/sec, a limit set by counting rate and by target radiation-damage rate. Target radiation damage could be repaired to a large degree by an annealing process that took about 30 minutes.[4] We annealed each target about four times and changed the target completely once each day. We found that the average target polarization as a function of photon dose, Φ, followed roughly an exponential, $P = P_0 \exp(-\Phi/\Phi_0)$, where $\Phi_0 \sim 7 \times 10^{14}$ equivalent quanta/cm^2 for a target of 0.05 radiation lengths.[4] The target polarization was controlled and monitored by a PDP-5 computer which in turn was linked to an SDS-9300 computer, which monitored the counting asymmetry, $\epsilon(t)$, on-line.

The hydrogen correction factor, $\mathcal{H}(t)$, defined as the ratio of the total number of counts from the polarized target which satisfy $\gamma p \rightarrow \pi^+ n$ kinematics to the number of counts actually due to this reaction on polarizable protons, is needed to relate $\epsilon(t)$ to $A(t)$. The actual fraction, by mass, of hydrogen in our butanol target and nearby materials is about 0.10, but in the heavy nuclei only the protons can contribute to single π^+ photoproduction. Their contribution is reduced by exclusion-principle suppression as well as absorption of the π^+ produced inside a nucleus. In addition the Fermi motion of these bound protons further reduces their effectiveness in photoproducing pions in the momentum range acceptable to the spectrometer.[6] A typical value of $\mathfrak{H}(t)$ in our experiment is 4. This value for $\mathfrak{H}(t)$, together with the average target polarization of ~ 0.20 means that the maximum value of experimental asymmetry that we could observe is ~ 0.05. Typical values that we measured were $\epsilon(t) \sim 0.02$.

The procedure for determining the hydrogen correction, $\mathfrak{H}(t)$, involved calculating an effective differential cross section for the butanol targets, normalizing to the known number of free protons in the butanol. This quantity divided by the differential cross section for protons directly gives the hydrogen correction factor, $\mathfrak{H}(t)$. We could not use the previously measured hydrogen cross sections because in those measurements[3] the hydrogen target fully intercepted the photon beam, while we were intentionally sweeping the beam slightly beyond the limits of our butanol target in an attempt to uniformly illuminate it. Thus we had to measure the effective cross section for hydrogen in a manner similar to butanol-target running. This was done with a polyethylene block cut to the same cross section as the butanol target and matched to the butanol in radiation lengths. A similar block of carbon was prepared containing the same mass of carbon as the polyethylene block. Data were taken with the two blocks under beam conditions similar to the polarized butanol running. A subtraction of the "target empty" carbon rate from the polyethylene rate gave the needed effective hydrogen cross section and together with the effective cross section from the butanol targets, the hydrogen correction factor, $\mathcal{H}(t)$.

Data were taken at two incident photon energies, k = 5 and 16 GeV. The results are given in Table I and displayed in Fig. 1 as a function of $\sqrt{-t}$. The errors shown are statistical only and come from both the measurements of $\epsilon(t)$ and $\mathcal{H}(t)$. The statistical error in $\mathcal{H}(t)$ averages about ±7% of itself, which when combined in quadrature with the statistical errors in $\epsilon(t)$ give the errors shown. In addition to this statistical error, there is to be applied to all the data a systematic error of 12% (a factor of 1.00 ± 0.12), obtained from combination in quadrature of the systematic errors in the measurements of $\epsilon(t)$, P_T, and $\mathcal{H}(t)$. In $\epsilon(t)$ the contamination of the data with events from the process $\gamma p \to \pi^+\Delta^0$ was negligible except for the three forward points ($\sqrt{-t} \leq 0.40$ GeV) at 16 GeV, where there is a maximum shift of ±0.03 in A(t) from Δ^0 events (this maximum occurs if A = ± 1 in Δ^0 production). The systematic uncertainty in P_T is estimated to be less than 5%. The systematic error $\mathcal{H}(t)$ is 10%, due to monitor uncertainties and uncertainties in the matching of running conditions during polarized-target and background running.

The notable feature of the data is a large negative asymmetry at both energies out to the largest momentum transfer measured. The 5 GeV data is rather featureless for $\sqrt{-t} \leq 0.80$ GeV, a result seen recently in a np → pn asymmetry experiment with a polarized target.[7] The np → pn and $\gamma p \to \pi^+ n$ reactions have attracted attention recently as both show narrow peaks in the differential cross sections for

$\sqrt{-t} < 0.14$ GeV. When referred to the same normal, the signs of the asymmetries in $np \rightarrow pn$ and $\gamma p \rightarrow \pi^+ n$ are opposite, but the lack of structure of the asymmetries over a large range of t at similar energies lends further support to the similarity of the reactions. In addition to the magnitude of the photoproduction asymmetry there is a suggestion of energy dependence of the shape of the asymmetry from 5 GeV to 16 GeV. (It must be pointed out that an average curve can be constructed for the 5 and 16 GeV data that yields a total χ^2 of 10 for about 8 degrees of freedom. However a model with energy dependence could yield a better χ^2.)

The asymmetry can be expressed at high energies in terms of the Ball amplitudes[8] as[9]

$$A(t) = \frac{-2\sqrt{-t}\ \mathrm{Im}[A_1^* A_4 + A_3^*(A_1 + tA_2)]}{|A_1|^2 + |t|\,|A_4|^2 + |t|\,|A_3|^2 + |A_1 + tA_2|^2} .$$

The denominator is simply $32\pi\, d\sigma/dt$. In a pole-only model the first term in the numerator corresponds to an out-of-phase interference between natural parity exchanges in the t-channel while the second term in the numerator contains interferences between unnatural parity exchanges. The second term is thought to be small on the basis of polarized photon beam experiments (natural parity amplitudes dominate the cross section) and the fact that the A_3 amplitude receives contribution from GP = - t-channel exchange, the only candidate being $A_1(1070)$. (If the second term is indeed negligible, the recoil nucleon polarization from an unpolarized target will equal the asymmetry in this experiment.) Thus in order to reproduce the asymmetries observed, a model must have appreciable A_1 and A_4 amplitudes and they cannot be relatively real.

A Regge-pole model with absorption-generated cuts by Jackson and Quigg predicted the 16 GeV result.[10] However, Jackson and Quigg have since pointed out the flexibility of their model and have stressed its ability to accommodate a wide range of asymmetries including the values presented here.[11] Among other things the Regge cut models mix the simple quantum number assignments to the t-channel amplitudes and invalidate the simplified approach of the previous paragraph. Our results can be used with the vector dominance model to make predictions about the recoil nucleon polarization in $\pi^+ n \rightarrow \rho^0 p$. However experience has shown that VDM predictions are more reliable when summing π^+ and π^- photoproduction results[12] and since none of the experiments, $\gamma n \rightarrow \pi^- p$ asymmetry, $\pi^+ n \rightarrow \rho^0 p$ polarization, or $\pi^- p \rightarrow \rho^0 n$ polarization, have been done no check of VDM in nucleon asymmetries can be made at this time.

In addition to the $\gamma p \rightarrow \pi^+ n$ data, we have data of poor statistical quality on the reactions $\gamma p \rightarrow \pi^+ \Delta^0$, $\gamma p \rightarrow \pi^- \Delta^{++}$, and $\gamma p \rightarrow K^+(\Lambda, \Sigma^0)$. These results are shown in Table 2. The data involving Δ's is of such poor quality that no definite statements can be made about them. It would be interesting to investigate these asymmetries further, but it should be pointed out that the $\gamma p \rightarrow \pi^+ \Delta^0$ asymmetry is particularly difficult to measure in a bremsstrahlung beam as the asymmetric $\gamma p \rightarrow \pi^+ n$ reaction is present as background. We collected data on the reaction $\gamma p \rightarrow K^+(\Lambda, \Sigma^0)$ during the $\gamma p \rightarrow \pi^+ n$ running. (Lack of events prevented separating the processes $\gamma p \rightarrow K^+ \Lambda$ from $\gamma p \rightarrow K^+ \Sigma^0$.) The K^+ data suggests a negative asymmetry as in the $\gamma p \rightarrow \pi^+ n$ process and provides encouragement for further investigation of this process.

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FOOTNOTES AND REFERENCES

* Work done under the auspices of the United States Atomic Energy Commission.

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1. R. Diebold, Proceedings of the Boulder Conference on High Energy Physics, 1969, Boulder, Colorado.
2. K. Lübelsmeyer, Proceedings of the 4th International Symposium on Electron and Photon Interactions at High Energy, 1969, Daresbury Nuclear Physics Laboratory, Liverpool, England.
3. A. M. Boyarski, et al., Phys. Rev. Letters 20, 300 (1968).
4. Michel Borghini, et al., UCRL-19724 and to be published in Nucl. Instr. and Methods.
5. Stephen Rock, et al., Phys. Rev. Letters 24, 748 (1970).
6. A. M. Boyarski, et al., Phys. Rev. Letters 23, 1343 (1969).
7. Peter R. Robrish, et al., UCRL-19365 and to be published in Physics Letters. (Note that in this reference the definition of the normal to the scattering plane referred to the initial proton and final neutron momenta is opposite to that of ours.)
8. J. S. Ball, Phys. Rev. 124, 2014 (1961).
9. F. Henyey and G. Kane, private communication. See also ref. 11.
10. J. D. Jackson and C. Quigg, private communication.
11. J. D. Jackson and C. Quigg, UCRL-19410 and to be published in Nucl. Phys.
12. See for example ref. 1.

Table I. Asymmetry in $\gamma p \to \pi^+ n$ with a polarized proton target vs. $\sqrt{-t}$ at photon energies of 5 and 16 GeV. The errors shown are statistical only, and the data should include a systematic error in the form of a factor 1.00 ± 0.12.

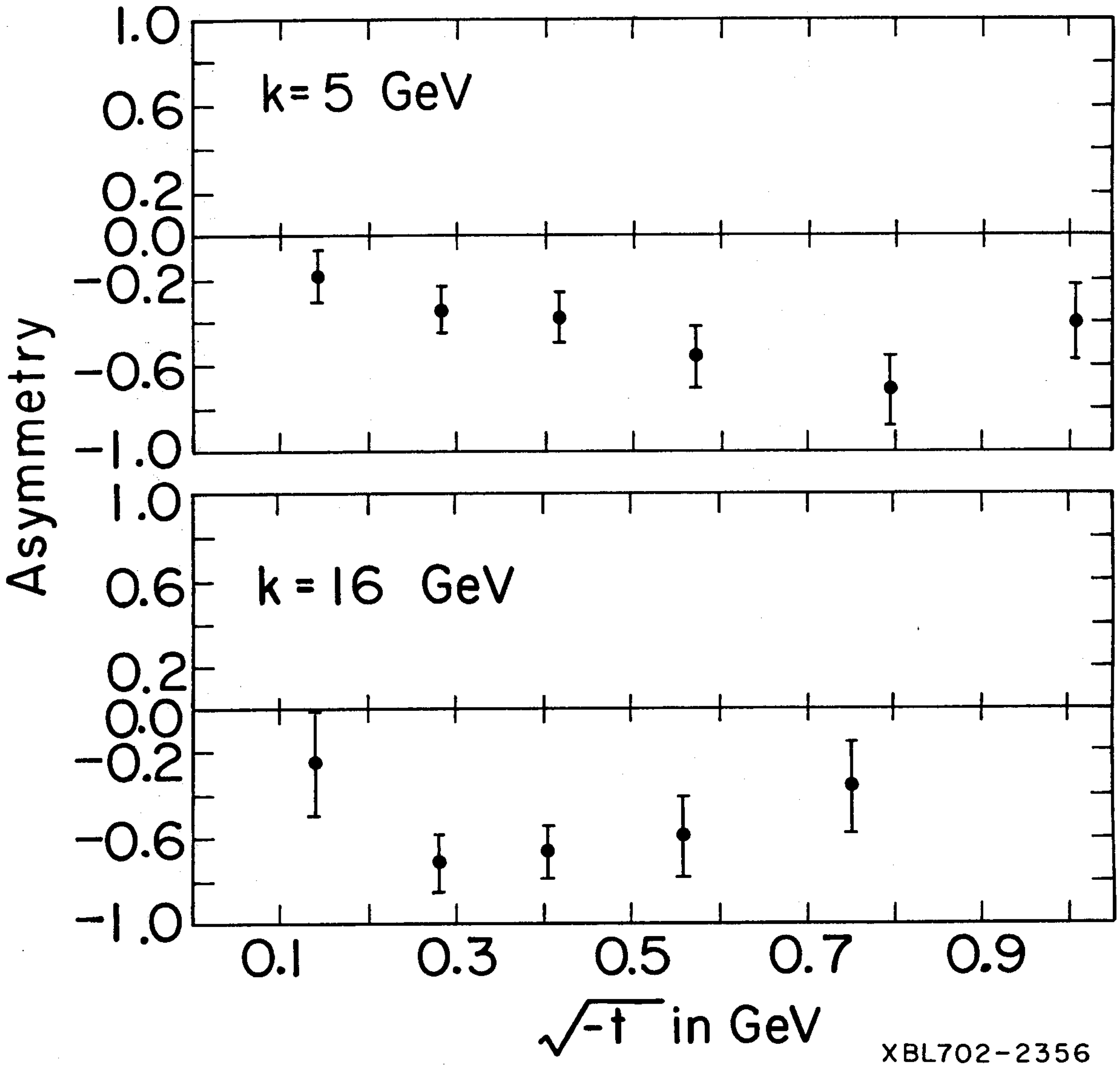
E_γ = 5 GeV		E_γ = 16 GeV	
$\sqrt{-t}$ (GeV)	A(t)	$\sqrt{-t}$ (GeV)	A(t)
0.14	-0.18±0.12	0.14	-0.25±0.24
0.28	-0.34±0.11	0.28	-0.72±0.13
0.42	-0.38±0.11	0.40	-0.66±0.12
0.57	-0.56±0.14	0.56	-0.59±0.19
0.79	-0.71±0.15	0.78	-0.36±0.20
1.01	-0.40±0.18		

Table II. Asymmetries from a polarized proton target in the processes $\gamma p \rightarrow \pi^+\Delta^0$, $\gamma p \rightarrow \pi^-\Delta^{++}$, and $\gamma p \rightarrow K^+(\Lambda, \Sigma^0)$ at photon energy of 16 GeV. Data were taken at the several momentum transfers shown and the errors are statistical only.

Process	$\sqrt{-t}$ (GeV)	A(t)
$\gamma p \rightarrow \pi^+\Delta^0$	0.28	-0.06±0.76
	0.56	-1.21±1.09
$\gamma p \rightarrow \pi^-\Delta^{++}$	0.40	+0.33±0.34
$\gamma p \rightarrow K^+(\Lambda,\Sigma^0)$	0.28	+0.05±0.18
	0.40	-0.83±0.33
	0.56	-0.29±0.15

FIGURE CAPTION

Fig. 1. Asymmetry in $\gamma p \to \pi^+ n$ with a polarized proton target vs. $\sqrt{-t}$ at photon energies of 5 and 16 GeV. Errors shown are statistical only.



1.0
0.6
0.2
0.0
−0.2
−0.6
−1.0
k= 5 GeV
k = 16 GeV
Asymmetry
0.1
0.3
0.5
0.7
0.9
√-t in GeV
XBL702-2356

Fig. 1