J. P. Schiffer, R. H. Bassel, R. M. Drisko, and G. R. Satchler, Phys. Rev. Letters 14, 261 (1965).
[3]T. Yamazaki, M. Kondo, and S. Yamabe, J. Phys. Soc. Japan 18, 620 (1963).
[4]R. M. Drisko, unpublished.
[5]G. R. Satchler, Nucl. Phys. A92, 273 (1967).
[6]L. McFadden and G. R. Satchler, Nucl. Phys. 84, 177 (1966).
[7]R. Stock, R. Bock, P. David, H. H. Duhm, and T. Tamura, Nucl. Phys. A104, 136 (1967).
[8]G. R. Satchler, Nucl. Phys. 70, 177 (1965).
[9]E. H. Auerbach, unpublished.

PHOTOPRODUCTION OF π^0 WITH PLANE POLARIZED 3-GeV PHOTONS*

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The cross section for photoproduction of π^0 mesons was measured at a photon energy of 3 GeV and squared four-momentum transfer (t) of -0.1 to -1.2 (GeV/c)^2 using plane-polarized photons. The asymmetry was found to be consistent with +1.0 for t values above -0.4 and below -1.1. For $-0.4 \leq t \leq -1.0$ there is a dip in the asymmetry and at $t = -0.6$ it drops to 0.55 ± 0.15. This result precludes a simple Regge model with ω^0 and B; a theoretical description requires Regge cuts or an ω' exchange.

The methods of obtaining polarized photons by electrons impinging on a suitably oriented crystal are described in the literature.[1,2] We used a diamond crystal mounted on a goniometer in the doughnut of the Cambridge Electron Accelerator. When struck by a circulating beam of 6-GeV electrons, a suitable crystal orientation produces a "spike" of photons at 3 GeV above the normal bremsstrahlung spectrum; a photon polarization $(N_\perp - N_\|)/(N_\perp + N_\|)$ of ± 0.6 is obtained in the spike region.

The reaction

$$\gamma + p \rightarrow \pi^0 + p, \quad \pi^0 \rightarrow \gamma + \gamma \tag{1}$$

is measured by detecting the protons (angle and momentum) in a magnetic spectrometer[3] and each of the two γ rays in two lead-glass hodoscopes (energy and angle).[4] Since the kinematics are overdetermined we can check that the event corresponds to Reaction (1). Between π^0 runs we measured the photon spectrum from the crystal by means of a 30 (15×2)-counter electron-positron pair spectrometer; the coincidence rates are converted to visually displayed spectra with an on-line computer. Runs were also taken with an amorphous electron target to give an unpolarized photon beam. The experimental layout is shown in Fig. 1.

The coherent crystal bremsstrahlung spectrum depends critically on the angle between bombarding electrons and the crystal axis. Since there may be an indeterminate angular spread in the electron beam we assumed such a smear in angle plus a central angle to give computed spectra to fit the measured spectra. The theory then gave us computed photon polarizations as a function of photon energy. From these spectra and the quantameter reading[5] $d\sigma_\perp/dt$ and $d\sigma_\|/dt$ could be computed. We checked this procedure by seeing that $d\sigma/dt = \frac{1}{2}(d\sigma_\|/dt + d\sigma_\perp/dt)$, where $d\sigma/dt$ was measured from the runs with unpolarized photons. From these cross sections the asymmetry parameter α is calculated:

$$\alpha = (d\sigma_\perp - d\sigma_\|)/(d\sigma_\perp + d\sigma_\|).$$

The results for our runs are shown in Fig. 2. This parameter is an average over cross sections taken at a photon energy of 3.0 ± 0.2 GeV. The errors shown are statistical; systematic errors in efficiency cancel in this ratio. A systematic error in α due to inaccurate measurement of the photon spectrum from run to run should be less than ± 0.1 in α.

We made a further check of our polarization calculations by measuring the coherent photoproduction of ρ^0 from lead:

$$\gamma + \text{Pb nucleus} \rightarrow \rho^0 + \text{Pb nucleus}, \quad \rho^0 \rightarrow \pi^+ + \pi^-.$$

A charged-particle telescope was placed at 14° with respect to the photon beam and the spectrometer was set for a π^- coming off at 14° on the other side. This setup is then sensitive to

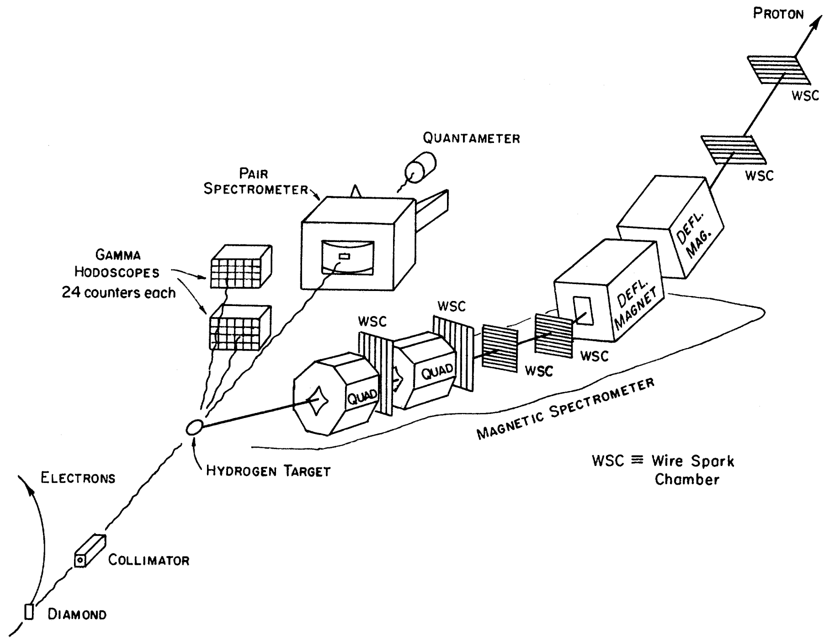

FIG. 1. Schematized layout of this experiment showing diamond crystal, proton spectrometer, gamma-ray hodoscopes, and the pair spectrometer. *WSC* denotes wire spark chambers.

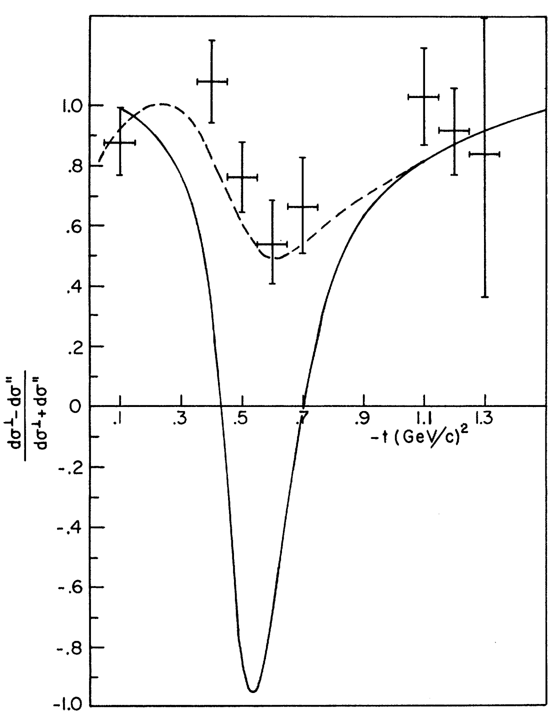

FIG. 2. A plot of polarization asymmetry α (see text) versus t for π^0 photoproduction at a photon bombarding energy of 3.0 ± 0.3 GeV. Also shown are theoretical models with ω^0 and B exchange (solid line) [J. P. Ader, M. Capdeville, and P. Salin, Nucl. Phys. B3, 407 (1967)] and ω^0 cut exchange (dotted line) [J. Frøyland, Nucl. Phys. B11, 204 (1969)].

ρ^0's produced coherently near 0° by (3.0 ± 0.3)-GeV photons. Parity conservation dictates that the $\pi^+\pi^-$ decay along the ρ^0 "electric field" vector which is aligned with the photon field vector. We assume that the $\pi^+\pi^-$ counts observed come predominantly from coherent production. We obtained $\alpha = -0.92 \pm 0.19$ which is in agreement with the theoretical number, $\alpha = -1.0$.

Initial attempts to explain π^0 photoproduction relied on ω^0-exchange Regge-pole models.[6] These predict $\alpha = +1.0$ by virtue of the J parity of the ω^0 (or ρ^0)[7] and this is in general agreement with experiment. However, the dip in cross section at $-t \cong 0.6$ GeV/c^2 was explained by the ω (or ρ) trajectory going through an $\alpha = 0$ nonsense pole and thereby vanishing. However an additional contribution was required because the cross section did not go to zero. At this point the B meson was used, and since it alone contributes, the asymmetry (α) should go to -1.0. This is clearly not the case from our results. The general panacea for these problems (i.e., cuts) has now been brought in with the expected improved agreement shown in Fig. 2.

An apparent disagreement with vector dominance exists between $\pi^\pm$ polarized photoproduction experiments and ρ^0 production experiments.[8] The nub of the disagreement rests on the larger $d\sigma_\perp$ for photoproduction compared with $d\sigma$ for ρ^0's produced in the equivalent polarization state.

A similar comparison can be made with π^0 photoproduction from protons and neutrons. But given only $\pi^0 p$ without $\pi^0 n$ data one must make assumptions about the interference of the isoscalar and isovector photon amplitudes. We have attempted such a comparison with our data; the results are inconclusive. However the large π^0 asymmetry ($\alpha \cong 1.0$) and thereby the large $d\sigma_\perp$ for π^0 photoproduction suggest similar difficulties for the vector-dominance model.

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[1]Details of this experiment may be obtained from D. M. Bellenger, thesis, Massachusetts Institute of Technology, 1968 (unpublished).

[2]Besides Bellenger, Ref. 1, see G. Diambrini Palazzi, Rev. Mod. Phys. 40, 611 (1968), for a review of the subject.

[3]Z. Bar-Yam, V. Elings, D. Garelick, R. Lewis, W. Lobar, P. D. Luckey, L. Osborne, S. Tazzari, J. Uglum, and R. Fessel, Nucl. Instr. Methods 56, 1 (1967).

[4]S. B. Deutsch, thesis, Massachusetts Institute of Technology, 1968 (unpublished).

[5]The Cambridge Electron Accelerator quantameters are described by G. F. Dell and M. Fotino, Cambridge Electron Accelerator Report No. CEAL-1040, 1968 (unpublished).

[6]J. P. Ader, M. Capdeville, and P. Salin, Nucl. Phys. B3, 407 (1967).

[7]P. Stickel, Z. Physik 180, 170 (1964).

[8]R. Diebold and J. A. Poirier, Phys. Rev. Letters 22, 906 (1969).

STRUCTURE IN NEUTRON-PROTON CHARGE EXCHANGE*

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Neutron-proton charge-exchange differential cross sections for incident-neutron momenta between 600 and 2000 MeV/c show a sharp change in the slope of $d\sigma/dt$ vs $-u$ in the vicinity of $-u = 0.01$ (GeV/c)^2. Near the one-pion threshold the slope at $u=0$ shows a maximum which reaches a value of order 100 (GeV/c)$^{-2}$. Also presented, as a function of s, is the intercept at $u=0$ which shows a pronounced deviation from smoothness in the region above the inelastic threshold.

Differential cross sections for neutron-proton charge exchange,

$$np \to pn,$$

have been measured for incident-neutron momenta between 600 and 2000 MeV/c. The data near $u = 0$ [1] presented here are a portion of a larger work[2,3] and exhibit several significant features of nucleon-nucleon scattering. They show a sharp change in the slope of $d\sigma/dt$ vs $-u = 0.01$ (GeV/c)^2. The slope of $d\sigma/dt$ at $u=0$, as a function of s, shows a maximum in the region near the one-pion threshold. Also presented is $d\sigma/dt$ at $u=0$ as a function of s using the absolute normalization determined during the experiment. Our points between 750 and 1250 MeV/c show a pronounced departure from a smooth curve joining data at lower and higher momenta.

The experiment was performed at the 3-GeV Princeton-Pennsylvania Accelerator using neutrons produced at 34° with respect to the internal proton beam. The incident-neutron momentum was determined by measuring the time of flight over a 108-ft flight path. The technique used the rf structure of the beam spill and had a resolution better than 2 nsec.[4] The neutrons were scattered in a thin-walled liquid-hydrogen target, and the recoil protons were detected in a wire-spark-chamber magnetic spectrometer. The complete data set, including laboratory angles up to 60°, contains over 500 000 elastic events.

The spectrometer consisted of four wire-cham-