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Asymmetries in Charged-Pion Photoproduction on Nucleons by 16-GeV Polarized Photons*

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Asymmetries in charged-pion photoproduction from hydrogen and deuterium have been measured with 16-GeV linearly polarized photons. Considerable energy dependence is seen in the natural-parity contribution to the π^-/π^+ ratio from deuterium, and in the unnatural-parity part of the cross section for $\gamma n \to \pi^- p$. The energy dependence of this latter cross section is consistent with the expected from a conventional pion Regge trajectory.

The use of linearly polarized photons to separate natural- and unnatural-parity exchanges in single-pion photoproduction has been discussed by several authors.[1] To leading order in t/s, photoproduction with photons polarized perpendicular (parallel) to the reaction plane proceeds by natural- (unnatural-) parity exchange in the t channel. The asymmetry

$$\Sigma = \frac{d\sigma_\perp/dt - d\sigma_\parallel/dt}{d\sigma_\perp/dt + d\sigma_\parallel/dt},$$

where $d\sigma_\perp/dt$ $(d\sigma_\parallel/dt)$ denotes the cross section for photons polarized perpendicular (parallel) to the reaction plane, is thus a measure of the relative importance of the two parity sequences exchanged.

Polarized-photon asymmetries have previously been measured[2] for $\gamma n \to \pi^- p$ at 3.0 and 3.4 GeV, and for $\gamma p \to \pi^+ n$ at several energies[3] between 2.5 and 12.0 GeV. The measured π^+ asymmetries were large and positive at all t values, and showed no significant s dependence. These results, coupled with the near constancy of $s^2 d\sigma/dt$, indicated that the dominant amplitudes in π^+ photoproduction came from natural-parity exchange, and had little s dependence other than the standard s^{-1}.

If this apparently simple behavior of the π^+ photoproduction cross section and asymmetry were taken as evidence that the amplitudes for the process were approaching some asymptotic limit, then, since the reactions $\gamma n \to \pi^- p$ and $\gamma p \to \pi^+ n$ are related by line reversal, one would expect the ratio $R \equiv [d\sigma(\gamma n \to \pi^- p)/dt]/[d\sigma(\gamma p \to \pi^+ n)/dt]$ to approach unity with increasing s.[4] However, measurements of R with unpolarized photons deviate considerably from this value, and show little s dependence.[5] Use of R and asymmetry data available at 3.4 GeV indicates that R does not equal 1 because of interference between the amplitudes for t-channel exchanges of natural parity and even G parity and those for exchanges of natural parity and odd G parity.

This interference is destructive in $\gamma n \to \pi^- p$; thus the unnatural-parity amplitudes are more prominent in this reaction than in $\gamma p \to \pi^+ n$. A study of the former reaction thus yields information about the s dependence of the unnatural-parity amplitudes. For this reason, and to study the s dependence of the interference in the natural-parity amplitudes, we have measured the polarized-photon asymmetry for both reactions at 16 GeV.

The polarized photon beam was produced through the selective absorption, by coherent pair production,[6] of one linear-polarization state from an unpolarized 16.05-GeV bremsstrahlung beam. The absorber was a 61-cm length of compression-annealed pyrolytic graphite, oriented to optimize the net linear polarization of the beam between 15 and 16 GeV. The energy spectrum of the beam was similar to bremsstrahlung in this region. A detailed description of the beam is to be published.[7]

The polarization of the beam from 15 to 16 GeV was measured to be 0.255 ± 0.020 by using a second graphite assembly, 30.5 cm long, as an analyzer and measuring the beam intensity as a function of the relative alignment of the polarizer and analyzer. The Stanford Linear Accelerator Center (SLAC) pair spectrometer was used for these measurements.[8] The beam was found to be constant in time to within ± 0.008 by measuring the asymmetry in $\gamma p \to \pi^+ n$ at $t = -0.15$ $(\mathrm{GeV}/c)^2$ several times during the experiment. The pair spectrometer, monitored by a gas-filled quantameter, was also used to measure the energy spectrum of the beam, allowing normalization of our cross-section data for comparison with other measurements. The energy spectrum was found to be independent of beam polarization direction.

The beam was incident on a 1-m-long hydrogen or deuterium target. Photoproduced pions and kaons were detected with the SLAC 20-GeV/c spectrometer, operated on line to an XDS 9300 computer. Particle identification was done with information from both threshold and differential Cherenkov counters, a lead-Lucite shower counter, and a range telescope. Scintillation-counter hodoscopes measured the particle momentum and both production angles. All beam monitoring was done with a small secondary-emission quantameter, which was calibrated against a precision silver calorimeter several times during the experiment.[9] Its response was independent of the beam polarization state, and remained constant for the $2\frac{1}{2}$-month data-taking period.

Measured yields were corrected for various counter inefficiencies, loss of events from cuts applied to the raw data, beam absorption in the target, hadron absorption in the target and detectors, decay in flight, and electronic and computer dead times. Only the dead-time corrections can influence the asymmetry measurements; other corrections affect only the overall normalization. The resulting cross sections were corrected for the azimuthal acceptance of the spectrometer in calculating the asymmetry.

An example of fully corrected and fitted data, obtained at a single angle setting of the 20-GeV/c spectrometer, is shown in Fig. 1. The unpolarized cross section is obtained by averaging the results with the photon polarization in and perpendicular to the reaction plane, and the measured asymmetry values have been divided by the beam polarization. The spectrometer momentum was scanned over a limited range to obtain these data.

Because the incident beam contains photons of

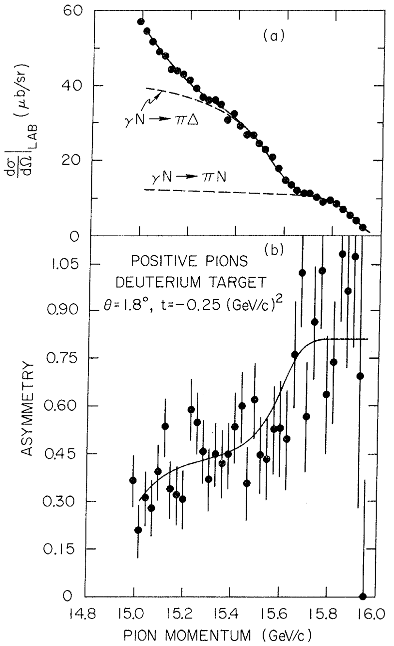

FIG. 1. An example of fits to fully analyzed data for (a) the unpolarized cross section, and (b) the asymmetry. The curves are discussed in the text.

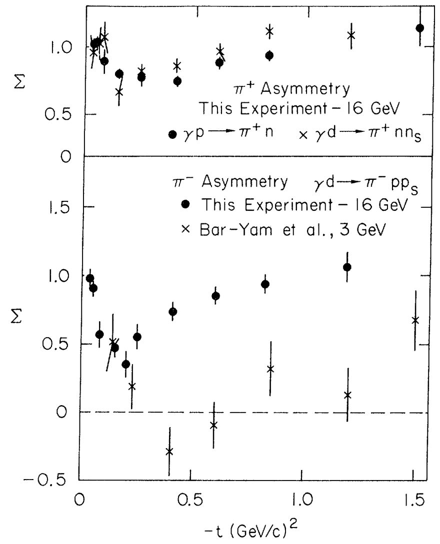

FIG. 2. Measured asymmetries in $\gamma p \to \pi^+ n$ and $\gamma n \to \pi^- p$ as a function of t. The 3-GeV π^- asymmetry data of Bar-Yam *et al.* (Ref. 2) are plotted to show the energy dependence of this asymmetry. Lower-energy π^+ asymmetry data have been omitted for clarity. Smaller momentum-transfer data, which show the asymmetry falling to zero as $-t$ decreases below $m_\pi{}^2$, are also omitted.

all energies up to the electron-beam energy, pions of a particular momentum may originate from any kinematically allowed reaction and photon energy. As the cross section for any particular process does not vary greatly over the spectrometer acceptance, the pion momentum spectrum from a particular two-body process mirrors the incident-photon intensity spectrum. Contributions to the measured cross sections from the reactions $\gamma d \to \pi^+ nn_s$ and the sum of $\gamma d \to \pi^+\Delta^0 n_s$ and $\gamma d \to \pi^+\Delta^- p_s$ are indicated in the figure. At a given momentum the asymmetry has contributions from all allowed processes. The contribution from a single process depends on both the asymmetry and the cross section of the process at that momentum.

The unpolarized cross section and the asymmetry were simultaneously fitted from a pion momentum above the π production threshold to a lower momentum where other processes dominate the yield. The fitted variables were the asymmetries and unpolarized cross sections for the reactions $\gamma N \to \pi N$, $\gamma N \to \pi\Delta$, and two assumed background processes, a resolution function, and an overall energy shift to accommodate differences between the spectrometer and electron-beam momentum calibrations. When fitting the deuterium data, account was taken of the Fermi momentum. Since all processes other than single-pion photoproduction have thresholds at lower pion momenta, our results are in no way sensitive to either the lower momentum used in the fit, or the detailed nature of the background processes employed.

Our asymmetry results are presented in Fig. 2. The uncertainty in the beam polarization leads to an overall t-independent error which is not included in the data of Fig. 2. Agreement between the π^+ asymmetries from hydrogen and deuterium indicates that the π^- asymmetry from deuterium may be taken as that from the reaction $\gamma n \to \pi^- p$. Calculations by Julius[10] show that any difficulties with such an interpretation should be small compared to the accuracy of our measurements. The ratio of our unpolarized cross sections to those of Boyarski *et al.*,[11] is 1.12 ± 0.07. We believe this slight normalization difference does not affect our asymmetry measurements in any meaningful way.

The π^+ asymmetry is found to be large and positive out to $t = -1.5$ (GeV/c)^2. The π^- asymmetry is significantly different from the asymmetry measured at lower energies. This is the first significant energy dependence observed in high-

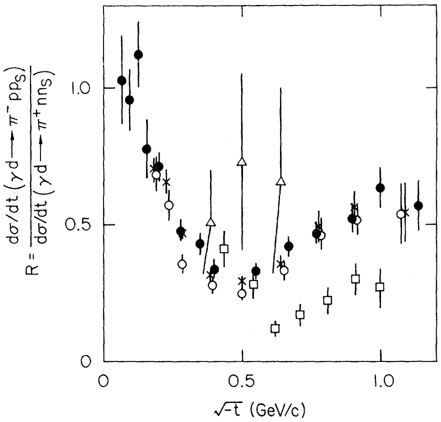

FIG. 3. The π^-/π^+ ratio in photoproduction from deuterium. The data of this experiment at 16 GeV with unpolarized (crosses), perpendicularly polarized (open circles), and parallel-polarized photons (triangles) are compared with the 16-GeV unpolarized-photon data of Boyarski *et al.* (Ref. 5) (filled circles) and to the 3-GeV perpendicularly polarized photon data of Bar-Yam *et al* . (Ref. 5) (squares).

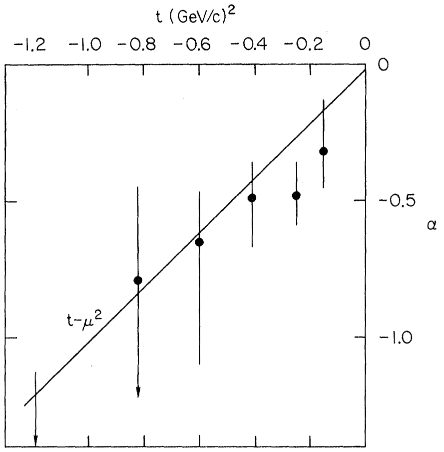

FIG. 4. The effective Regge α for $d\sigma_{\parallel}(\gamma n \to \pi^- p)/dt$. A Monte Carlo procedure was used to calculate the errors. The error bars indicate bounds within which 68.3% of the generated events were contained. The uncertainty in the beam polarization was included in this calculation.

energy pion photoproduction.

Our results for the π^-/π^+ ratio from deuterium are presented in Fig. 3 for unpolarized, parallel, and perpendicular photons. The unpolarized-photon results are in agreement with those of Boyarski *et al.*[5] From our result with parallel photons, we conclude there is some, not overly compelling, evidence for interference between the two *G* parities in the unnatural-parity amplitudes. Comparison of our perpendicular-photon results to those at 3 GeV (calculated using the 3.4-GeV unpolarized-photon π^-/π^+ ratio) shows a large energy dependence to the *G* parity interference in the natural-parity amplitudes, in contrast to the smaller energy dependence seen in the unpolarized-photon case.

By parametrizing the cross section with parallel or perpendicular photons as

$$d\sigma_{\perp,\parallel}(s,t)/dt = f_{\perp,\parallel}(t)\, s^{2\alpha_{\perp,\parallel}(t)-2},$$

one can calculate an effective Regge α. These results with parallel photons are shown in Fig. 4. The effective α for $d\sigma_{\parallel}(\gamma n \to \pi^- p)/dt$ is consistent with that expected of a conventional pion Regge trajectory. Other evidence for a conventional pion trajectory has been found recently in the closely related process $\pi^- p \to \rho^0 n$.[12]

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Σ^- Production in High-Energy Proton Interactions*

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Momentum spectra for forward Σ^- production on beryllium by protons of momentum 25.8 and 29.4 GeV/c are presented. Data for the two primary proton momenta are compared for scaling behavior in the invariant cross section. In addition, the observed single-particle momentum distributions are compared with single-particle spectra from other inclusive reactions initiated by protons.

Using the Yale University–National Accelerator Laboratory–Brookhaven National Laboratory hyperon beam at the Brookhaven alternating-gradient synchrotron, we have measured the momentum spectrum of Σ^- hyperons produced by 25.8- and 29.4-GeV/c protons on a beryllium target. We compare the Σ^- momentum distributions with the inclusive spectra of other particles produced in proton-initiated reactions and discuss these distributions in the light of the hypothesis of limiting fragmentation (HLF).[1]

Figure 1 is a schematic representation of the hyperon bean and detection apparatus. A slow extracted beam of about 10^{11} protons per pulse interacts in a 0.26×0.26 in.^{3} Be target. The target is viewed at 0° and is followed by a curved, shielded magnetic channel 172 in. long. This length is sufficient to shield the downstream detectors from hadronic backgrounds produced in the target while limiting decay losses of Σ^- and Ξ^- hyperons to an acceptable level.

The inside walls of the second half of the channel are aluminized and tapered. When filled with freon gas, the channel acts as a threshold Cherenkov counter. Light beam particles (π^-, K^-) which form the most serious potential background are thus tagged and rejected.

The position and direction of the hyperons are measured by novel high-resolution (100 μm) spark chambers[2] placed immediately after the channel exit. These chambers operate with small gaps (1.2 mm) and high pressures (up to 15 atm). They yield measurements of the hyperon momentum to $\pm1\%$ and direction to ±0.5 mrad with minimal decay loss in the spark chambers.

Downstream from the decay region are two magnet–spark-chamber spectrometers, the first for analyzing the light decay products (mesons or electrons) and the second for analyzing the high-momentum decay proton from hyperon decay with a Λ^0 in the final state. These momenta are measured to an accuracy of better than 1%. Magnetostrictive readout was used on all of the spark chambers.

A hydrogen-filled threshold Cherenkov counter is used to select electrons for an experiment to study leptonic decays. A total-absorption scintillation-counter calorimeter[3] with the appropriate charged-particle and γ vetoes is located after the second spectrometer magnet. A pulse-height re-