Helicity Asymmetries in the $\vec{\gamma}p \rightarrow p\pi^+\pi^-$ Reaction

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Abstract. Beam-helicity asymmetries in the $\vec{\gamma}p \rightarrow p\pi^+\pi^-$ reaction have been measured at Jefferson Lab with the CEBAF Large Acceptance Spectrometer using circularly polarized tagged photons incident on an unpolarized hydrogen target. The experiment covered the resonance region for center-of-mass energies between 1.35 GeV and 2.30 GeV. Here, we show a few examples out of the comprehensive data set and demonstrate the sensitivity of the helicity asymmetries to the dynamics of the reaction by comparing with the results of various phenomenological model calculations.

1. Introduction
Charged double-pion production by real and virtual photons is an important tool in the investigation of nucleon resonances and reaction dynamics, as many nucleon resonances in the mass region above 1.6 GeV decay predominantly through either $\Delta\pi$ or $N\rho$ intermediate states into $N\pi\pi$ final states (see the Particle-Data Group review [1]). One example of such an investigation is a recent electroproduction experiment of the CLAS Collaboration, which observed a structure in the differential cross section near $W = 1.7$ GeV [2]. The analysis of these data with a phenomenological model [3, 4, 5] hints at the existence of a new baryon state of mass 1.72 GeV and spin-parity of $3/2^+$. Polarization observables in the $\vec{\gamma}p \rightarrow p\pi^+\pi^-$ reaction allow for a more detailed study and are particularly promising in light of the large number of resonances located in the second and third resonance regions and the well known problem of the missing nucleon resonances, which decay readily into the $\pi\pi N$ channels but only weakly couple to the $\pi N$ and $\gamma N$ channels [6].

Here, we report some results of a first comprehensive measurement of the beam-helicity asymmetry\(^1\)

$$A = \frac{1}{P_\gamma} \cdot \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

in the $\vec{\gamma}p \rightarrow p\pi^+\pi^-$ reaction for center-of-mass energies $W$ between 1.35 GeV and 2.30 GeV, where the photon beam is circularly polarized and neither target nor recoil polarization is specified. $P_\gamma$ is the degree of circular polarization of the photon and $\sigma^\pm$ are the cross sections for the two photon-helicity states $\lambda_\gamma = \pm 1$. In the first step of the analysis of the data, we

\(^1\) Roberts and Oed [7] discuss the reaction in terms of eight transversity amplitudes $b_i^\pm$, $i = 1, \ldots, 4$. The beam-helicity asymmetry can then be written as the ratio $\sum_{i=1,4} (|b_i^+|^2 - |b_i^-|^2) / \sum_{i=1,4} (|b_i^+|^2 + |b_i^-|^2)$ and is one of the required measurements to obtain the absolute magnitudes of the transversity amplitudes.
demonstrate, by means of a phenomenological model, the sensitivity of this observable to the dynamics of the reaction.

2. Experiment
The experiment was performed in Hall B at Jefferson Lab. Longitudinally polarized electrons with an energy \( E_0 = 2.445 \) GeV from the CEBAF accelerator were incident on a thin radiator. The beam polarization was routinely monitored during data taking by a Möller polarimeter and was, on average, 0.67. A photon tagger system [8] was used to tag photons in the energy range between 0.6 GeV and 2.3 GeV. The degree of circular polarization of the photon beam varied from \( \approx 0.16 \) at the lowest photon energy up to \( \approx 0.66 \) at the highest energy. The photon-helicity state changes with the electron-beam helicity, which was flipped pseudorandomly at a rate of 30 Hz. The collimated photon beam irradiated an 18-cm thick liquid-hydrogen target. The final-state hadrons were detected in the CEBAF Large Acceptance Spectrometer (CLAS) [9]. The CLAS provides a large coverage for charged particles that includes particle momenta down to 0.25 GeV/c and polar angles in the range \( 8^\circ < \theta_{\text{lab}} < 145^\circ \). The \( \gamma p \rightarrow p\pi^+\pi^- \) reaction channel was identified by the missing-mass technique, requiring the detection of all three final-state particles or the detection of two out of the three particles. A schematic view of the reaction, together with angle definitions, is shown in Fig. 1.

3. Results
A typical angular distribution of the helicity asymmetry is shown in Fig. 2 for data at \( W = 1.65 \) GeV, integrated over the full CLAS acceptance. The distribution has the symmetry \( A(\phi) = -A(2\pi - \phi) \), which is expected from parity conservation [10]. Figure 3 shows (in another example) the helicity asymmetry as a function of the invariant mass \( M(p\pi^-) \) for two different values of \( W \) and a fixed value of \( \phi \). What is most interesting about these curves is the change that occurs as \( M(p\pi^-) \) traverses the \( \Delta(1232) \) resonance. At \( W = 1.55 \) GeV, a maximum is seen in the region of this resonance. We see a similar trend in the region of the higher-mass resonances around 1.60 GeV. This is by no means a rigorous analysis, but it hints at the way in which the helicity asymmetry (along with other polarization observables) could be used in studies of baryon spectroscopy.

The beam-helicity asymmetries are particularly sensitive to the various coupling constants as well as to the relative phases between various nonresonant mechanisms and between resonant-nonresonant mechanisms. At \( W = 1.5 \) GeV, Fig. 4 shows the helicity asymmetries for nine bins in the \( \pi^+\pi^- \) invariant mass. The data are compared with results of a phenomenological model by Mokeev et al. [3, 4, 5] (solid curves). This model was developed in studies of double-pion photo- and electroproduction with CLAS and is able to reproduce both CLAS and world cross-section data below \( W = 1.9 \) GeV and for \( Q^2 < 1.5 \) GeV\(^2 \). The polarization data of Fig. 4 is well reproduced for \( M(\pi^+\pi^-) < 0.4 \) GeV, but not for larger invariant masses.

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Figure 1. Angle definitions for the circularly polarized real-photon reaction \( \gamma p \rightarrow p\pi^+\pi^- \) in the helicity frame: \( \theta_{\text{cm}} \) is defined in the overall center-of-mass frame, and \( \theta \) and \( \phi \) are defined as the \( \pi^+ \) polar and azimuthal angles in the rest frame of the \( \pi^+\pi^- \) system.
Figure 2. Angular distribution of the helicity asymmetry in the $\vec{\gamma}p \rightarrow p\pi^+\pi^-$ reaction at $W = 1.65$ GeV. The data are integrated over the CLAS acceptance. The solid curve results from fitting the data with $A = \sum a_k \sin(k\phi)$, $k = 1, \ldots, 4$.

Figure 3. Helicity asymmetry as a function of $M(p\pi^-)$, for $W = 1.55$ GeV (filled circles) and 1.95 GeV (open triangles) and a $30^\circ$-wide $\phi$-angle range centered at $\phi = 105^\circ$. The vertical lines indicate the masses of the known $N$ and $\Delta$ resonances.

Figure 4. Helicity asymmetries at $W = 1.50$ GeV for nine bins of the $\pi^+\pi^-$ invariant mass. The dashed and dotted curves show results of two different calculations by Fix and Arenhövel with the signs of various $N(1440)P_{11}$ and $N(1520)D_{13}$ coupling constants flipped to negative values (see text). The solid curves are results of a calculation by Mokeev et al.
The data are also compared with results of calculations by Fix and Arenhövel [11]. The $\gamma p \rightarrow p\pi^+\pi^-$ reaction is described in this model with a limited set of tree-level diagrams. The model includes the nucleon, and the $\Delta(1232)P_{33}$, $N(1440)P_{11}$, $N(1520)D_{13}$, $N(1535)S_{11}$, $N(1680)F_{15}$, and $\Delta(1700)D_{33}$ resonances, as well as the $\pi$, $\sigma$, and $\rho$ mesons. The dashed curves show the results for the calculations with the nominal, positive values of the coupling constants. In order to demonstrate the sensitivity of the helicity asymmetry to the dynamics of the reaction, the signs of the coupling constants for the channels $N(1440) \rightarrow \Delta\pi$, $N(1520) \rightarrow N\rho$, $N(1520) \rightarrow \Delta\pi$, $(s \text{ wave})$ and $N(1520) \rightarrow \Delta\pi$ $(d \text{ wave})$ have been flipped. The curves resulting from this exercise are the dotted ones. Note that the results of the latter calculation give a significantly better description of the data below 0.45 GeV when compared to the original results (dashed curves). However, a worse description is produced for other cases; an overall good description has yet to be found.

Several quasi-two-body channels contribute to double-pion production [3, 4, 5]. The relative phases among the amplitudes of these processes are largely unknown. When combined with unpolarized data, these polarization data, being particularly sensitive to interference effects, might give one access for the first time to the relative phases between various nonresonant mechanisms and between resonant-nonresonant mechanisms in double-pion photoproduction. This information is vital for the understanding of nonresonant processes and for reliable extraction of $N^*$ photocouplings.

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References
[1] S. Eidelman et al., Phys. Lett. B592, 1 (2004).
[2] M. Ripani et al., Phys. Rev. Lett. 91, 022002 (2003).
[3] V. I. Mokeev et al., Yad. Fiz. 64, 1368 (2001), [Phys. At. Nucl. 64, 1292 (2001)].
[4] V. Burkert, Nucl. Phys. A737, 5231 (2004).
[5] V. I. Mokeev et al., to appear in Proc. NSTAR2004 Workshop (World Scientific).
[6] S. Capstick and W. Roberts, Phys. Rev. D 49, 4570 (1994).
[7] W. Roberts and T. Oed, nucl-th/0410012 (2004).
[8] D. I. Sober et al., Nucl. Instrum. Methods A440, 263 (2000).
[9] B. A. Mecking et al., Nucl. Instrum. Methods A503, 513 (2003).
[10] K. Schilling, P. Seyboth, and G. Wolf, Nucl. Phys. B15, 397 (1970).
[11] A. Fix and H. Arenhövel, in preparation.