Helicity Asymmetry Measurement for π^0 Photoproduction on the CLAS Frozen Spin Target

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Abstract. The measurement was performed with circularly polarized photons incident on longitudinally polarized target in Hall B at the Thomas Jefferson National Accelerator Facility. The helicity asymmetry E for $\vec{\gamma}\vec{p} \to \pi^0 p$ was determined at CM energies between 1450 MeV and 2050 MeV and compared to the SAID, MAID, and BnGa partial-wave analyses.

Intoduction

The second generation of CEBAF Large Acceptance Spectrometer (CLAS) photoproduction experiments used the FROzen Spin Target (FROST), which allowed double-polarization measurements on proton. With the FROST, we measure all beam-target double-polarization observables for single pseudoscalar meson photoproduction and for two charged pion production as well. This makes possible the complete experiment, which measures enough observables for unambiguous and direct reconstruction of the reaction amplitude [1]. CLAS collected data with linearly and circularly polarized photons and longitudinally and transverse polarized target. Many of the observables in this experiment were measured for the first time.

The entire data set is invaluable for a multi-channel analysis. The value of these data is more than just its broad coverage for different reaction channels and observables. The real strength of this program is its measurement of everything under the same controlled conditions with the same systematic uncertainty. This provides much stronger constraints for subsequent analyses of the properties of contributing nucleon resonances. With this greater understanding of these observables, effects of higher spin resonances can be investigated [2].

In this contribution, we present a measurement of the double-polarization observable E in the $\vec{\gamma}\vec{p} \to \pi^0 p$ reaction of circularly polarized photons with longitudinally polarized protons [3]. The full energy coverage is $E_\gamma = 466 - 1825$ MeV ($W = 1325 - 2075$ MeV).

Experiment

The experiment was performed at the Thomas Jefferson National Accelerator Facility (JLab). Data were taken within CLAS *G9A* run group, November 2007 through February 2008. Longitudinally polarized electrons from the CEBAF accelerator with energies of $E_e = 1.465$ GeV and 2.478 GeV were incident on the thin bremsstrahlung radiator of the Hall-B Photon Tagger [8] and producing circularly polarized tagged photons in the energy range between $E_\gamma = 466 - 1825$ MeV.

The degree of circular polarization of the photon beam, $P_\odot$, depends on the ratio $x = E_\gamma/E_e$ and increases from zero to the degree of incident electron-beam polarization, P_e, monotonically with photon energy [9]

$$P_\odot = P_e \frac{4x - x^2}{4 - 4x + 3x^2}. \tag{1}$$

Measurements of the electron-beam polarization were made routinely with the Hall-B Moeller polarimeter. The average value of the electron-beam polarization was found to be $P_e = 0.84 \pm 0.04$. The electron-beam helicity was pseudo-randomly flipped between $+1$ and -1 with a 30 Hz flip rate.

The collimated photon beam irradiated the FROST [10] at the center of the CLAS [11]. Frozen beads of butanol (C_4H_9OH) inside a 50 mm long target cup were used as target material. The protons of the hydrogen atoms in this material were dynamically polarized along the photon-beam direction and polarization was frozen. The degree of polarization on average was $P_z = 0.82 \pm 0.05$. The proton polarization was routinely changed from being aligned along the beam axis to being anti-aligned. Quasi-free photoproduction off the unpolarized, bound protons in the butanol target constituted a background. Data were taken simultaneously from an additional carbon target down-stream of the butanol target to allow for the determination of the bound-nucleon background.

The missing mass technique $\gamma p \rightarrow pX$, where X is π^0 was used to identify the reaction. Final-state protons were detected in CLAS. The particle detectors used in this experiment were a set of plastic scintillation counters close to the target to measure event start times (Start Counter) [12], drift chambers [13] to determine charged-particle trajectories in the magnetic field within CLAS, and scintillation counters for flight-time measurements [14]. Coincident signals from the photon tagger, start-, and time-of-flight counters constituted the event trigger. Data from this experiment were taken in seven groups of runs with various electron-beam energies and beam/target polarization orientations. Events with one and only one positively charged particle and no other charged particles detected in CLAS were considered. The protons were identified by their charge (from the curvature of the particle track) and by using the time-of-flight technique. Kinematics of $\vec{\gamma}\vec{p} \rightarrow \pi^0 p$ is given in Fig. 1. The polarized cross section is in $\vec{\gamma}\vec{p} \rightarrow \pi^0 p$ case given by [4].
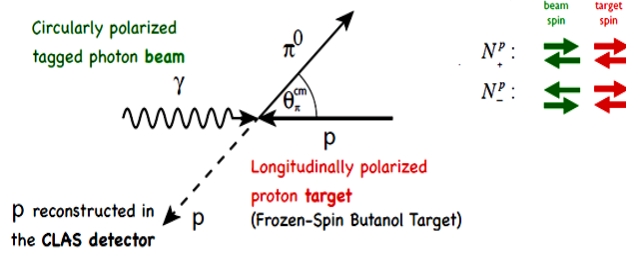

FIGURE 1. Kinematics for $\vec{\gamma}\vec{p} \rightarrow \pi^0 p$.

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_0}(1 - P_z P_\odot E), \tag{2}$$

where $\frac{d\sigma}{d\Omega_0}$ is the unpolarized cross section, P_z and $P_\odot$ are the target and beam polarizations, respectively. The observable E is the helicity asymmetry of the cross section,

$$E = \frac{d\sigma_{1/2} - d\sigma_{3/2}}{d\sigma_{1/2} + d\sigma_{3/2}} \tag{3}$$

for aligned, total helicity $h = 3/2$ and anti-aligned, $h = 1/2$ photon and proton spins. These data are fitted using three different PWA approaches - SAID [5], MAID [6], and BnGa [7]. The resulting consistency of helicity amplitudes for the dominant resonances demonstrates that the PWA results are largely driven by the data alone; the modest differences gauge the model-dependence. This consistency provides an excellent starting point to search for new resonances ("missed resonance" problem).

Experimental Data

The asymmetry E was determined in 256 kinematic bins of W ($\Delta W = 50~MeV$) and $\cos\theta$ ($\Delta(\cos\theta) = 0.1$), where W is the CM energy and θ is the pion CM angle with respect to the incident photon momentum direction.

The asymmetry E was extracted from the polarized yields, N_+^p and N_-^p (Fig. 1), of $\vec{\gamma}\vec{p} \rightarrow \pi^0 p$ events for total helicities $h = 3/2$ and $h = 1/2$, respectively, and the average beam and target polarizations,

$$E = -\frac{1}{P_z P_\odot} \frac{N_+^p - N_-^p}{N_+^p - N_-^p}. \tag{4}$$

Yields were determined using Gaussian plus polynomial to fit peak within $2\,\sigma$ (Fig. 2).
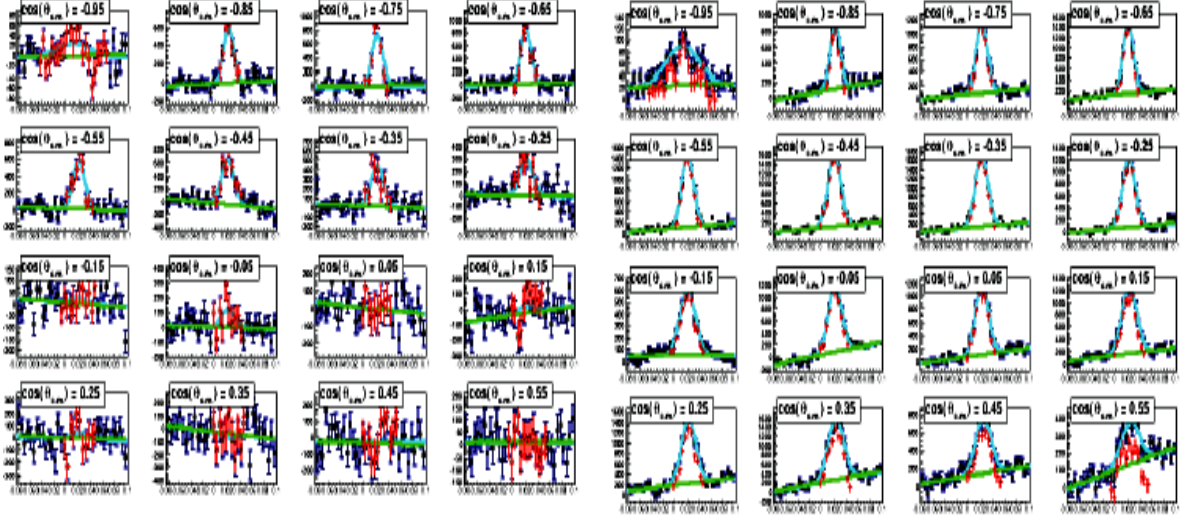

FIGURE 2. Sample for yield determination at W = 1475 MeV. Numerator (left) and denominator (right) for Eq. (4).

The preliminary results for asymmetry E were compared with PWA predictions from SAID, MAID and BnGa groups (Figs. 3). They are in agreement at low energies but start to deviate at higher energies.
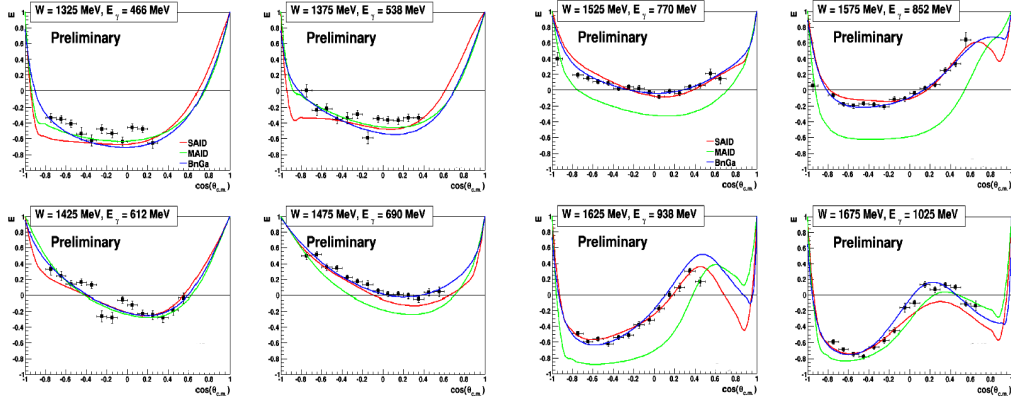

FIGURE 3. Preliminary double polarization asymmetry E for $\vec{\gamma}\vec{p} \to \pi^0 p$ at $E_\gamma = 466 - 1025$ MeV versus pion cos CM production angle. Photon energy is indicated by asymmetry E, while the CM total energy is indicated by W. Red solid (green solid) lines correspond to the SAID CM12 [5] (MAID07 [6]) predictions. Black solid lines give the BG2011-02 BnGa [7] predictions.

Beyond the SAID PWA, we plan the Legendre analysis for CLAS E measurements for both $\vec{\gamma}\vec{p} \to \pi^+ n$ [15] and new $\vec{\gamma}\vec{p} \to \pi^0 p$ as we did recently for the CLAS $\vec{\gamma}\vec{p} \to \pi^+ n$ and $\vec{\gamma}\vec{p} \to \pi^0 p$ Σ asymmetry measurements [16]. Unfortunately, recent CBELSA asymmetry E for $\vec{\gamma}\vec{p} \to \pi^0 p$ [17] is insufficient for that study because of so broad energy binning ($\Delta W = 300 - 500\ MeV$) (Fig. 5).

Conclusion

In summary, we have presented measurements of the double-polarization observable E in the $\vec{\gamma}\vec{p} \to \pi^0 p$ up to W = 2075 MeV over a broad angular range. The data for E asymmetry is the part of the FROST program at JLab. Results are consistent with PWA predictions (SAID, MAID, and BnGa PWA groups) at lower energies and will offer more
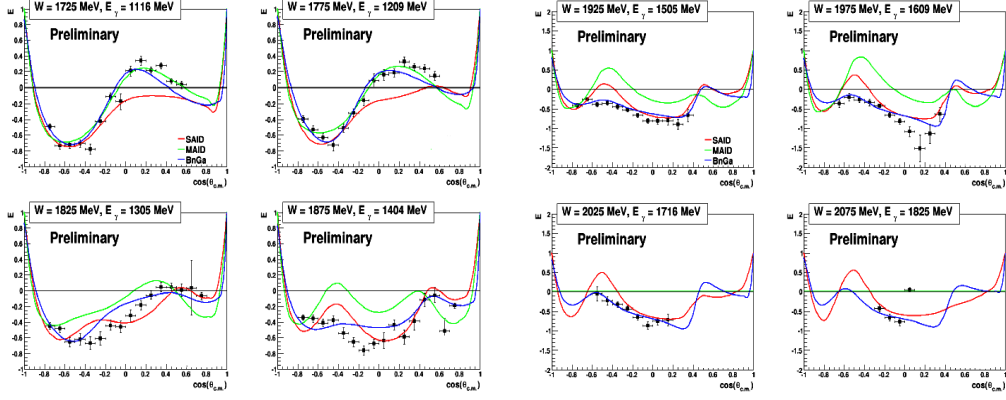
FIGURE 4. Preliminary double polarization asymmetry E for $\vec{\gamma}\vec{p} \to \pi^0 p$ at $E_\gamma = 1116 - 1825$ MeV versus pion cos CM production angle. Notation as in Fig. 3.

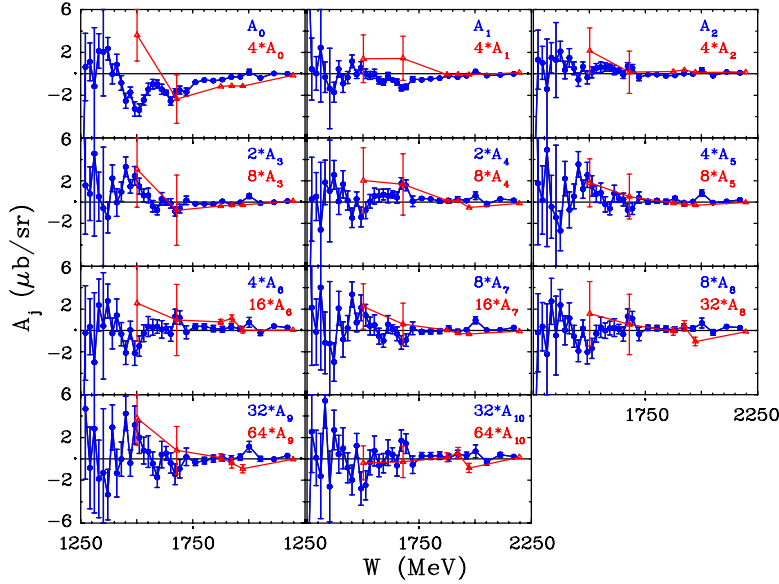**FIGURE 5.** Coefficients obtained from fitting the recent asymmetry E for $\vec{\gamma}\vec{p} \to \pi^+ n$, came from CLAS [15] (blue filled circles) and $\vec{\gamma}\vec{p} \to \pi^0 p$, came from CBELSA [17] (red filled triangles) with Legendre polynomials. The error bars of all values represent A_j uncertainties from the fits in which the statistical uncertainties were only used.

results to be fit in the higher energy ranges. The fine binning and unprecedented quantity of the data impose tight constraints on PWA, especially at high$-L$ multipoles and at high CM energies where new resonances are expected to exist.

The three light quarks can be arranged in 6 baryonic families, the N^*, Δ^*, Λ^*, Σ^*, Ξ^*, and Ω^*. The number of family members that can exists is not arbitrary. Rather, the following proportionality is expected when the $SU(3)$-flavor symmetry of QCD is controlling symmetry [18]

$$2\,N^* : 1\,\Delta^* : 3\,\Lambda^* : 3\,\Sigma^* : 3\,\Xi^* : 1\,\Omega^*. \tag{5}$$

Constituent quark models predict the existence of no less than 64 N^* and 22 Δ^* states with mass $< 3\,GeV^2$ [20]. Based on flavor $SU(3)$ symmetry, we expect to have twice as many N^* ($I = 1/2$) and Δ^* ($I = 3/2$) resonances. The number of experimentally identified resonances of each non-strange baryon family is 26 N^* and 22 Δ^* [19]. The seriousness of the "missing-states" problem is obvious from these numbers. The hypothesis of a very small πN coupling of missing states has received support from a quark-model calculations [20]. We should stress that the standard πN PWA (most

of our current knowledge about the bound states of three light quarks [19]) reveals resonances with widths of order $\Gamma \sim 100$ MeV, but not too wide ($\Gamma > 500$ MeV) or possessing too small a branching ratio ($BR < 4\%$), tending (by construction) to miss narrow resonances with $\Gamma < 30$ MeV [21]. However, conclusions on missing states should await the results of more realistic, coupled-channel calculations in which rescattering of the mesons, η, η', ω, and ρ, is considered.

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REFERENCES

[1]   A.M. Sandorfi *et al.*, AIP Conf. Proc. **1432**, 219 (2012); K. Nakayama, private communication, 2014.
[2]   B. Saghai and F. Tabakin, Phys. Rev. C **53**, 66 (1996).
[3]   *Pion photoproduction from a polarized target*, Spokespersons: N. Benmouna, W.J. Briscoe, I.I. Strakovsky, S. Strauch, and G.V. O'Rially (CLAS Collaborations), JLab Proposal E–03–105, Newport News, VA, USA, 2003.
[4]   I.S. Barker, A. Donnachie, J.K. Storrow, Nucl. Phys. B **95**, 347 (1975).
[5]   R.L. Workman, M.W. Paris, W.J. Briscoe, and I.I. Strakovsky, Phys. Rev. C **86**, 015202 (2012).
[6]   D. Drechsel, S.S. Kamalov, and L. Tiator, Eur. Phys. J. A **34**, 69 (2007).
[7]   A.V. Anisovich *et al.*, Eur. Phys. J. A **47**, 153 (2011); **48**, 15 (2012).
[8]   D. Sober *et al.*, Nucl. Instrum. Methods A **440**, 263 (2000).
[9]   H. Olsen, L.C. Maximon, Phys. Rev. **114**, 887 (1959).
[10]   C. Keith *et al.*, Nucl. Instrum. Methods A **684**, 27 (2012).
[11]   B.A. Mecking *et al.*, Nucl. Instrum. Methods A **503**, 513 (2003).
[12]   Y. Sharabian *et al.*, Nucl. Instrum. Methods A **556**, 246 (2006).
[13]   M. Mestayer *et al.*, Nucl. Instrum. Methods A **449**, 81 (2000).
[14]   E. Smith *et al.*, Nucl. Instrum. Methods A **432**, 265 (1999).
[15]   S. Strauch *et al.* (CLAS Collaboration), Phys. Lett. B **750**, 53 (2015).
[16]   M. Dugger *et al.* (CLAS Collaboration), Phys. Rev. C **88**, 065203 (2013).
[17]   M. Gottschall *et al.* (CBELSA/TAPS), Phys. Rev. Lett. **112**, 012003 (2014).
[18]   B.M.K. Nefkens, *Proceedings of 8th Intern. Symposium on Meson-Nucleon Physics and the Structure of the Nucleon*, Zuoz, Switzerland, Aug. 1999, πN Newsletter, **14**, 150 (1997).
[19]   K.A. Olive *et al.* (Particle Data Group Collaboration), Chin. Phys. C **38**, 090001 (2014).
[20]   S. Capstick and W. Roberts, Phys. Rev. D **49**, 4570 (1994).
[21]   R.A. Arndt, W.J. Briscoe, M.W. Paris, I.I. Strakovsky, and R.L. Workman, Chin. Phys. C **33**, 1063 (2009).