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# HELICITY-DEPENDENT ANGULAR DISTRIBUTIONS IN DOUBLE-CHARGED-PION PHOTOPRODUCTION

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Two-pion photoproduction in the reaction $\boldsymbol{\gamma}\mathrm{p} \to \mathrm{p}\pi^+\pi^-$ has been studied at Jefferson Lab Hall B using a circularly polarized tagged-photon beam in the energy range between 0.6 GeV and 2.3 GeV. Owing to the large angular acceptance of the CLAS detector, complete beam-helicity-dependent angular distributions of the final-state particles were measured. The large cross-section asymmetries exhibit strong sensitivity to the kinematics of the reaction and provide valuable information on the reaction dynamics. Preliminary results are presented.

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## 1. Introduction

Many nucleon resonances in the mass region above 1.6 GeV decay predominantly through $\Delta\pi$ or N$\rho$ intermediate states into N$\pi\pi$ final states (see the Particle-Data Group review, [1]). This makes electromagnetic exclusive double-pion production an important tool in the investigation of N$^*$ structure and reaction dynamics, as well as in the search for "missing" baryon states. Unpolarized cross-section measurements of double-pion electroproduction have recently been reported in [2]. Further constraints are to be found in polarization observables.

Here, for the first time, a measurement of the $\boldsymbol{\gamma}\mathrm{p} \to \mathrm{p}\pi^+\pi^-$ reaction is reported, where the photon beam is circularly polarized and no nuclear polarization (target or recoil) is specified. The general form of the cross section can then be written as[1]

$$\sigma = \Sigma + P_{\odot}\Delta \, , \tag{1}$$

[1] See [3] for an overview of the more general case of exclusive-$n$ electron scattering, $A(\mathrm{e}, \mathrm{e}'\mathrm{x}_1 \ldots \mathrm{x}_n)$. The real-photon case, discussed here, results in a simpler formalism.

where $P_\odot$ is the degree of circular polarization of the photon and $\Sigma$ and $\Delta$ are the unpolarized and polarized cross sections, respectively. For this kind of study, a three-body final state is crucial, since reactions with two-body final states are always coplanar and have identical cross sections for unpolarized or circularly polarized photons [4], so that $\Delta = 0$.

The cross-section asymmetry, obtained by flipping the beam polarization, is defined by:

$$A = \frac{1}{P_\odot} \cdot \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta}{\Sigma}\,. \tag{2}$$

In this paper, we will discuss the double-charged-pion channel from a hydrogen target.

## 2. Data

The $\boldsymbol{\gamma}\mathrm{p} \to \mathrm{p}\pi^+\pi^-$ reaction was studied with the CEBAF Large Acceptance Spectrometer (CLAS) [5] at Jefferson Lab. Longitudinally polarized electrons with an energy of 2.4 GeV were incident on the thin radiator of the Hall-B Photon Tagger [6] and produced circularly polarized tagged photons in the energy range between 0.6 GeV and 2.3 GeV. The collimated photon beam irradiated a liquid-hydrogen target. The circular polarization of the photon beam can be determined from the electron beam polarization and the ratio of photon and incident electron energy [7].

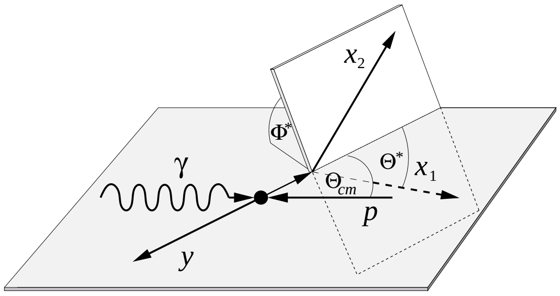


*Fig. 1. Angle definitions for the circular polarized real-photon reaction* $\mathrm{p}(\boldsymbol{\gamma}, \mathrm{x}_1\mathrm{x}_2)\mathrm{y}$*;* $\Theta_{\mathrm{cm}}$ *is defined in the center-of-mass frame of the* $\gamma\mathrm{p}$ *system,* $\Theta^*$ *is defined in the center-of-mass frame of the* $\mathrm{x}_1\mathrm{x}_2$ *system.*

To identify the reaction channel, the missing-mass technique was used, requiring the detection of at least two out of three final-state particles (p, $\pi^+$, and $\pi^-$) in the CLAS. Owing to the large angular acceptance of the CLAS, complete angular distributions of the cross-section asymmetries were observable. Figure 1 defines the azimuthal angle $\Phi^*$ between the scattering plane, containing the photon and the recoiling particle y, and the decay plane, containing the two particles $\mathrm{x}_1$ and $\mathrm{x}_2$. There are three different configurations relevant for the $\boldsymbol{\gamma}\mathrm{p} \to \mathrm{p}\pi^+\pi^-$ reaction channel: $\mathrm{y}[\mathrm{x}_1, \mathrm{x}_2] = \mathrm{p}[\pi^+, \pi^-], \pi^+[\mathrm{p}, \pi^-]$, and $\pi^-[\mathrm{p}, \pi^+]$.

## 3. *Results*

Preliminary analysis of the double-charged-pion channels has revealed large asymmetries in the helicity-dependent cross section. Figure 2 shows preliminary $\Phi^*$ angular distributions for different energy bins and for the $\mathrm{p}[\pi^+,\pi^-]$ and $\pi^-[\mathrm{p},\pi^+]$ configurations. The asymmetry was fitted with a series of sine functions:

$$A(\Phi^*) = \sum_{i=1}^{n} a_i \cdot \sin(i\Phi^*) \ . \tag{3}$$

No cosine terms were included in this series because the cosine is an even function. For example, when $\Phi^* = 0$ or $180°$, all particles are in one plane, and for this case, there is no helicity dependence of the cross section, due to parity conservation. The fits of Eq. (3) to the data are shown in Fig. 2 as the dotted curves. Preliminary calculations for these cross-section asymmetries were done by Oed and Roberts [8, 9] us-

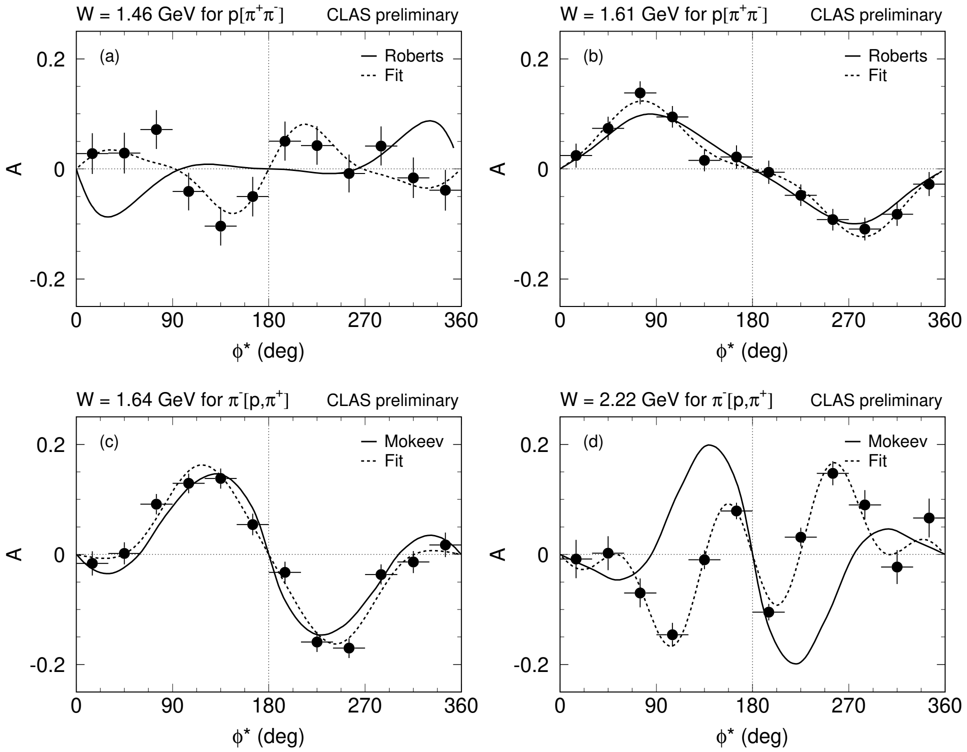


*Fig. 2. Preliminary angular distribution for four different center-of-mass energy bins* ($\Delta W \approx 15$ MeV) *of the cross-section asymmetry in the* $\gamma\mathrm{p} \to \mathrm{p}\pi^+\pi^-$ *reaction; (a) and (b) for the configuration* $\pi^-[\mathrm{p},\pi^+]$*, (c) and (d) for the configuration* $\mathrm{p}[\pi^+,\pi^-]$*. The solid curves are calculations by Roberts [8, 9] and Mokeev [10] as noted, and the dotted curves result from fitting the data with Eq. (3) up to order* $n = 4$.

ing a phenomenological Lagrangian approach and by Mokeev [10] in a phenomenological calculation using available information on N$^*$ and $\Delta$ states. It is important to note that the calculations performed to date have been integrated over $4\pi$, whereas the experimental data are integrated only over the CLAS acceptance. The results of the calculations are shown in Fig. 2 as solid curves. At about $W = 1.6$ GeV, an excellent description of the data is achieved by both calculations, whereas for the other energy bins there is clearly room for improvement in the model parameters.

The energy dependence of the $a_1$ and $a_2$ Fourier coefficients of the observed preliminary angular distributions for the p$[\pi^+, \pi^-]$ configuration is shown in Fig. 3. To demonstrate the strong dependence of the Fourier coefficients on the photon energy, reaction channel, and details of the kinematics, various cuts were applied to the data. Figure 3a shows the data where the invariant mass of the $\pi^+\pi^-$ pair is less than 0.7 GeV (open triangles) and more than 0.7 GeV (filled triangles); Fig. 3b shows different angular cuts, namely, for data with $\cos(\Theta^*) \leq -0.30$ (open circles) and for $\cos(\Theta^*) \geq 0.30$ (filled circles).

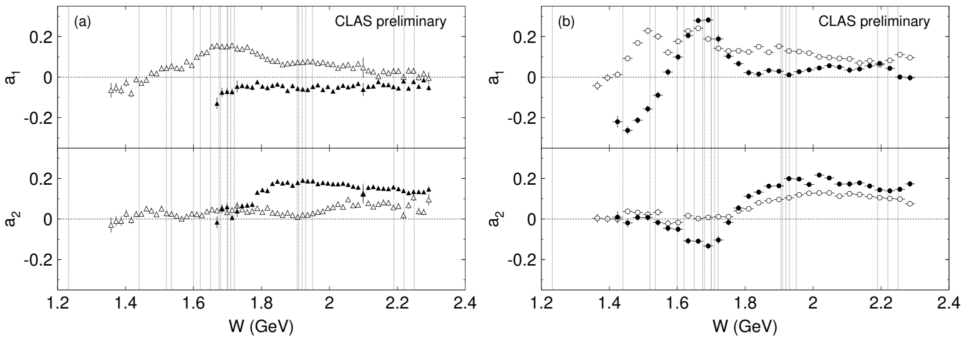


*Fig. 3. Fourier components of the preliminary* $\boldsymbol{\gamma}$p $\rightarrow$ p$\pi^+\pi^-$ *cross-section asymmetry as a function of the* $\gamma$N *center-of-mass energy. The data were integrated over the full CLAS acceptance constrained by the following cuts: panel (a)* $\pi^+\pi^-$ *invariant mass below 0.7* GeV *(open triangles) and above 0.7* GeV *(filled triangles); panel (b)* $\cos(\Theta^*)$ *less than* $-0.30$ *(open circles) and larger than* $+0.30$ *(filled circles). The vertical lines indicate the masses of 3- and 4-star resonances [1].*

It is desirable to examine the sensitivity of the asymmetry to various theoretical model parameters. In fact, current studies have indicated a strong sensitivity of the helicity asymmetries to relative contributions of various isobaric channels and interference among them. An example is shown in Fig. 4, where the preliminary $\boldsymbol{\gamma}$p $\rightarrow$ p$\pi^+\pi^-$ asymmetry data at $W = 1.84$ GeV for the configuration $\pi^-[\mathrm{p}, \pi^+]$ are compared with various calculations by Mokeev [11]. These calculations differ only in the amplitude and phase of the diffractive rho-production term. The helicity asymmetry shows strong sensitivity to this model parameter, whereas the differential cross section does not. This confirms the importance of the polarization observables for differentiating between model predictions.

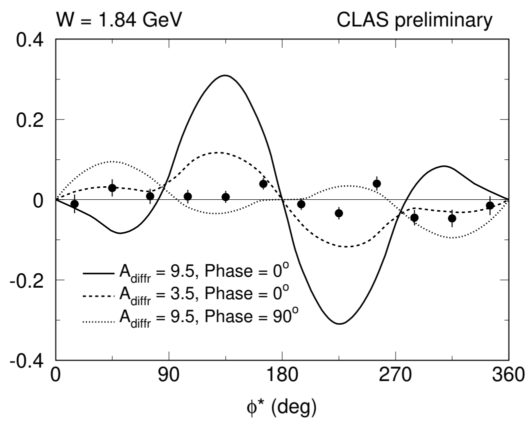


*Fig. 4. Preliminary* $\gamma$p $\rightarrow$ p$\pi^+\pi^-$ *angular distribution of the cross-section asymmetry at* $W = 1.84$ GeV *for the* $\pi^-[\mathrm{p}, \pi^+]$ *configuration, along with calculations of Mokeev with various choices for the diffractive rho-production amplitude [11].*

In summary, angular distributions of large helicity-dependent cross-section asymmetries in the $\gamma$p $\rightarrow$ p$\pi^+\pi^-$ reaction were observed for the first time, using the CLAS detector system. Our preliminary analysis has revealed the rich structure of these data, which are sensitive to details of the reaction dynamics. These data will prove to be an important tool in baryon spectroscopy, and similar data obtained using light nuclei ($^2$H, $^3$He, and $^4$He) will help us to understand the modification of baryonic parameters in the nuclear medium [12].

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## OVISNOST KUTNIH RASPODJELA O HELICITETU U FOTOTVORBI PAROVA NABIJENIH PIONA

Istraživali smo dvopionsku fototvorbu u reakciji $\gamma p \rightarrow p\pi^+\pi^-$ pomoću cirkularno polariziranog snopa obilježenih fotona na energijama između 0.6 GeV i 2.3 GeV u Hali B Jeffersonovog Laba. Zahvaljujući velikom prihvatnom kutu detektora CLAS, izmjerili smo potpune kutne raspodjele čestica u konačnom stanju u ovisnosti o helicitetu snopa. Velike asimetrije udarnih presjeka pokazuju jaku ovisnost o kinematici reakcije i pružaju važne podatke o njenoj dinamici. Predstavljaju se prethodni ishodi mjerenja.