Polarization Observables for Double Charged Pion and Vector Meson Photoproduction from Polarized HD Target at CLAS

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Constituent Quark Models and recent Lattice QCD calculations predict an excited baryon spectrum much richer than the one experimentally observed, the so-called *missing resonances problem*. These missing states may be revealed by partial wave analysis of not yet measured polarization observables. The CLAS g14/E06-101 (HDice) experiment is part of the N* spectroscopy program at Jefferson Laboratory: it has taken photoproduction data using both circularly- and linearly- polarized photons in the photon energy range up to 2.5 GeV. The beam impinged on a longitudinally-polarized Hydrogen-Deuteride (HD) frozen spin target, where both the proton and the deuteron are polarized. We present results on the beam-helicity asymmetry $\mathbf{I}^{\odot}$, for the double charged pion photoproduction on both proton and (bound) neutron targets and on the helicity difference $\mathbf{P}_z^{\odot}$ on the proton target. Preliminary results on the double polarization observable E for the photoproduction of the ρ^0 vector meson on the proton will be also discussed.

KEYWORDS: polarization observables, photoproduction, pseudoscalar meson, vector meson

1. Introduction

While perturbative methods can be used at high energies in the evaluation of QCD diagrams, in the low energy regime, corresponding to the scale typical of the nucleon masses and its excited states (~ 1 GeV), the perturbative approach is no more valid. In order to explain property of hadrons, a different theoretical approach is then needed.

The most recent and promising results are those coming from Lattice QCD calculations; in calculations carried out using pion masses as large as 400 MeV, a rich spectrum of excited states has been obtained [1], where the low-lying states have the same quantum numbers as the states in models based on three constituent quarks. These constituent quark models predict a number of excited states that are not experimentally observed, the so-called *missing resonances problem*.

From the experimental side Koniug and Isgur [2] already in 1960 tried to address the question, suggesting that the missing states may be weakly coupled to channels where the pion is both in the initial and final states, but they could be observed in other reactions where other initial and/or final states are investigated.

Their intuition is at the basis of the experimental world-wide program for the study of photon- and electro-induced reactions. The study of the photoproduction of double-pion final states, in particular, could be extremely useful to investigate many high-mass resonances, because this channel dominates the cross section above W=1.6 GeV.

In order to extract the contributing resonances in photoproduction experiments, partial wave analyses must be performed. A *complete* experiment [3], where all spin states of the involved particles are

disentangled, is required to determine the contributing amplitudes in a model-independent way; this involves the measurement of a *complete set* of polarization observables for a given reaction. The number of polarization observable it is necessary to measure, strictly depends on the reaction involved. In a single meson photoproduction out of a total of 16 possible spin-dependent observables, a well-chosen set of 8 measurements are sufficient for an unambiguous partial wave-analysis. In the case of double meson photoproduction, additional degrees of freedom arise from the fact that the reaction kinematic is not restricted to a plane (like in a two body reaction), but we have a production and a decay plane, as shown in Fig. 1; this leads to a total of 64 possible observables. By means of identities and relationships among the observables themselves, the number of independent measurements that are necessary to carry out the complete experiment reduces to 15.
The case of vector meson photoproduction [4] is even much more complicated as the spin of the vector meson contributes three additional degrees of freedom, leading to a total of 290 polarization observables, which makes a complete measurement out of reach.
In this note we present the results for the extraction of the single polarization observable $\mathbf{I}^{\odot}$ for the reactions $\gamma p \rightarrow \pi^+\pi^- p$ and $\gamma n(p) \rightarrow \pi^+\pi^- n(p)$ and of the double polarization observable $\mathbf{P}_z^{\odot}$ for the reaction $\gamma p \rightarrow \pi^+\pi^- p$. Finally we will also discuss a first attempt to isolate a subset of events from the reaction $\gamma p \rightarrow \rho^0 p \rightarrow \pi^+\pi^- p$, where the two pions are coming from the strong decay of the ρ^0 vector meson and show the result for the double polarization asymmetry E for that channel.

2. The HD-ice experiment at JLab

The dataset presented here has been obtained with the HD-ice (g14) experiment [5], which made possible to perform the measurement of several polarization observables both on the polarized proton and bound neutron targets. The experiment took data from November 2011 to May 2012 at the Thomas Jefferson National Accelerator Facility, also known as Jefferson Laboratory (JLab), Virginia, Newport News, USA. It made use of the CEBAF accelerator to produce the polarized photon beam: the electron beam from the CEBAF, with maximum energy of 6 GeV, impinged a radiator, a thin gold foil, to produce circularly-polarized photons; an oriented diamond was used to produce linearly-polarized photons. The energy of the produced polarized photons is measured through the photon tagging system; for the g14 run period the typical energy range was $E_\gamma \sim$ 0.9-2.5 GeV.
The target was a Hydrogen-Deuteride (HD) polarized frozen-spin target [5]. The ”frozen-spin mode” means that the target polarization, which was achieved by using high magnetic field (∼ 15 T) and very low temperatures (∼ 10 mk) (Brute Force conditions [7]), can be maintained for months under conditions compatible with the used experimental setup (B=1 T and T<50 mK). Another peculiar feature of the HDice target was that it contained only proton and deuterons which can be both polarized with a high degree of polarization (90% H and 60% D, in principle), reducing in this way the background due to non-polarizable nuclei, which is typical, for example, of ammonia (NH_3 or ND_3) and butanol targets.
The particle produced in photo-nuclear reactions are detected by CLAS (CEBAF Large Acceptance Spectrometer (CLAS)), a nearly 4π detector housed in Hall B, optimized for multi-particle final states.

3. Observables for double pion photoproduction on the polarized protons and neutrons

In the case of the $\gamma p \rightarrow \pi^+\pi^- p$ and $\gamma n(p) \rightarrow \pi^+\pi^- n(p)$ reactions, where the polarization of the recoiling nucleon is not measured and the analyzed dataset were taken with circularly-polarized photons and a longitudinally-polarized target, the differential cross section can be written as:

$$\frac{d\sigma}{dx_i} = \sigma_0\{(1 + \Lambda_z \cdot \mathbf{P_z}) + \delta_{\odot}(\mathbf{I}^{\odot} + \Lambda_z \cdot \mathbf{P}_z^{\odot})\} \quad (1)$$

where x_i are the kinematical variables of the reactions $\gamma N \rightarrow \pi^+\pi^- N$ (being N the nucleon), σ_0 is the unpolarized cross section, Λ_z is the longitudinal polarization degree of the initial nucleon, $\delta_\odot$ is the degree of circular polarization of the photon beam. The accessible polarization observables in this particular case are: two single polarization observables $\mathbf{I}^\odot$ (beam-helicity asymmetry) and $\mathbf{P_z}$ (target asymmetry) and a double polarization observable $\mathbf{P_z}^\odot$ (helicity difference).

3.1 Angles definition and bin choice

Before proceeding with the extraction of the polarization observables we describe the kinematic of the reaction $\gamma N \rightarrow \pi^+\pi^- N$, as shown in Figure 1. The grey shadowed plane represents the center-of-mass production plane, defined by the incident photon and the recoiling nucleon momenta; the white plane represents the decay plane formed by the two final state pions and the recoil nucleon (in the CM frame). The angle $\phi^{hel}_{\pi^+}$ (or $\phi^{'}_{\pi^+}$) is the azimuthal angle of the π^+ meson in the rest frame of the $\pi^+\pi^-$ system, also known as "*helicity frame*". It defines the orientation of the decay plane containing the two pions with respect to the production plane. The azimuthal angle $\phi^{'}_{\pi^+}$ can be determined from the positive charged pion momentum in the laboratory frame applying two boost and a rotation: a first boost along the beam line axis into the overall center-of-mass frame; a rotation around the direction perpendicular to the reaction plane transforms the z axis, formally aligned with the beam line, into the direction $z^{'}$, opposite to the recoil nucleon momentum. Finally, a second boost along $z^{'}$ results in the rest frame where the two pions are emitted back to back.

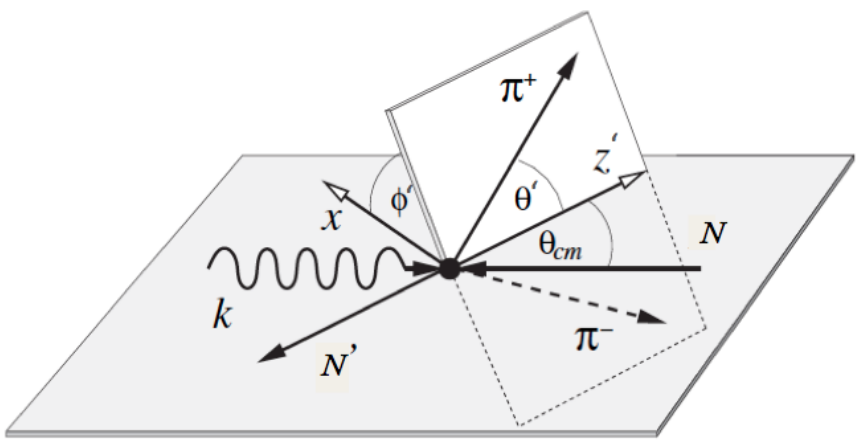

Fig. 1. The grey shadowed plane represents the center-of-mass production plane formed by the incident photon and initial nucleon; the white plane represents the decay plane of the two final state pions. K denotes the initial photon and N the polarized target nucleon. $N^{'}$ is the final state nucleon, π^+ and π^- are the two pions in the final state. θ_{cm} is the angle between the initial nucleon and the recoiling nucleon in the centre-of-mass system. $\phi^{hel}_{\pi^+}$ and $\theta^{hel}_{\pi^+}$ are the azimuthal and polar angle of the π^+ in the helicity frame of the two pions [8].

In this work the data are binned in two variables: E_γ, which is the incident photon energy in the Laboratory frame, and the azimuthal angle $\phi^{hel}_{\pi^+}$. E_γ is divided into 7 bins, 200 MeV wide, in the interval $E_\gamma \in [0.9,2.5]$ GeV, $\phi^{hel}_{\pi^+}$ is divided into 16 bins of $\pi/8$ width, covering a range $-\pi < \phi^{hel}_{\pi^+} < \pi$. We integrated over all the other independent kinematic variables.

4. Data analysis and preliminary results

The results of the polarization observable $\mathbf{I}^\odot$ for both the reactions $\gamma p \rightarrow \pi^+\pi^- p$ and $\gamma n(p) \rightarrow \pi^+\pi^- n(p)$ are shown in Fig. 2 and Fig. 3, respectively, for the first two photon energy bins. The results from the g14 experiment (*blue dots*) are compared with the previous works of S. Strauch (*red dots*), who used the CLAS-g1c data [8] and S. Park, who used the CLAS-g9a data [9] (*black dots*). The observable $\mathbf{I}^{\odot}$ measured from the g14 experiment shows the expected odd symmetry and is in overall agreement with the previously cited works.

The results from the g14 experiment are also compared to the calculation from the model of A. Fix [10]; while the predictions from A. Fix show the expected odd symmetry, the agreement with the data from the three cited experiments is not very good. Fig. 3 shows the observable $\mathbf{I}^{\odot}$ extracted from the analysis of the channel $\gamma n(p) \rightarrow \pi^{+}\pi^{-}n(p)$ and it is compared to the model of A. Fix [11]. As for the the previous case, the agreement is poor. These are the first results for the extraction of the observable $\mathbf{I}^{\odot}$ off a neutron target available in the world.

In Fig. 4 the results for the extraction of the double polarization observable $\mathbf{P_z}^{\odot}$, for the first two energy bins, are shown. The results from the g14 experiment are compared with the data from g9 and with the model of A. Fix [10]. The agreement with the previous experiment is good. The comparison with the model predictions shows an agreement which is good in shape but not in amplitude.

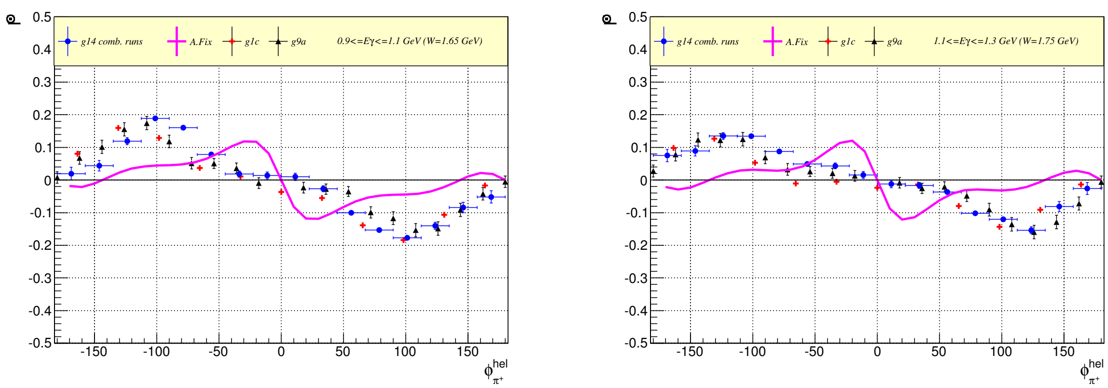

Fig. 2. Measured beam-helicity asymmetry $\mathbf{I}^{\odot}$ for the reaction $\gamma p \rightarrow \pi^{+}\pi^{-}p$, as a function of $\phi^{hel}_{\pi^{+}}$, for the first two energy bins out of the full photon energy range $E_{\gamma} \in [0.9, 2.3]$ GeV. Blue points are from g14 data, black points from g9a analysis [9], red points from g1c data [8]. The magenta curves are theoretical predictions from A. Fix [10].

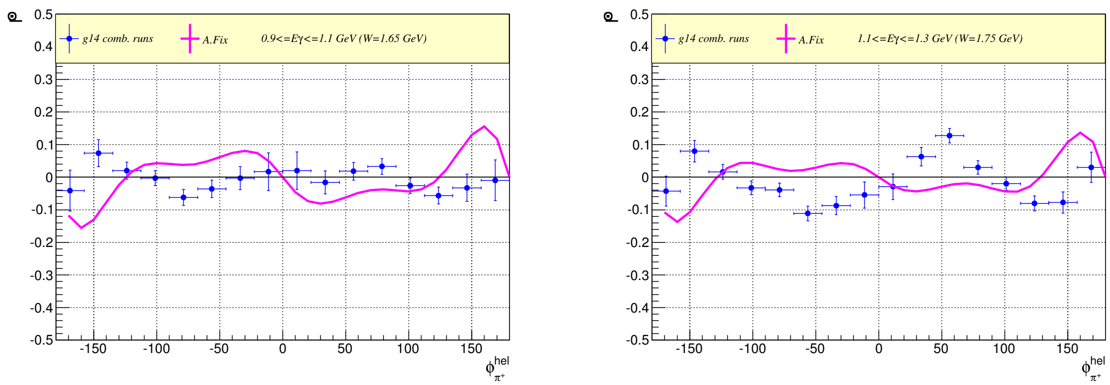

Fig. 3. Measured beam-helicity asymmetry $\mathbf{I}^{\odot}$ for the reaction $\gamma n(p) \to \pi^+\pi^- n(p)$, as a function of $\phi^{hel}_{\pi^+}$, for the first two energy bins out of the full photon energy range $E_\gamma \in [0.9, 2.3]$ GeV. Blue points are from g14 data,. The magenta curves are theoretical predictions from A. Fix [10].

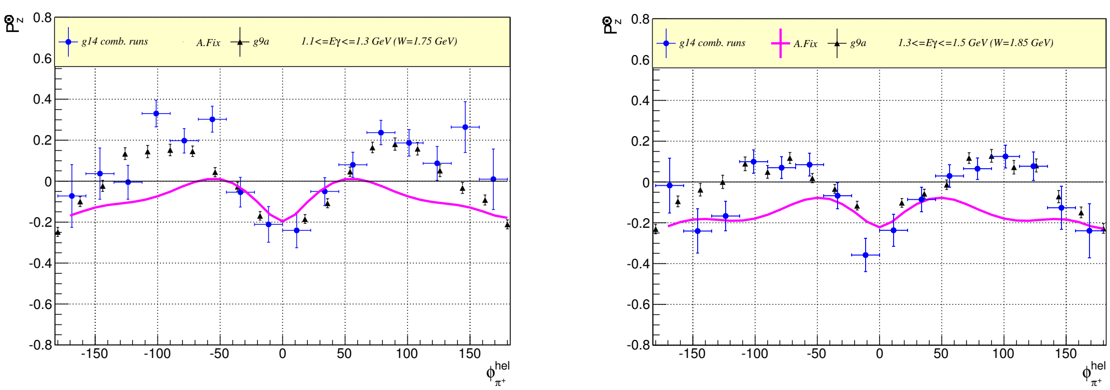

Fig. 4. Measured helicity difference $\mathbf{P}^{\odot}_z$ for the reaction $\gamma p \to \pi^+\pi^- p$, as a function of $\phi^{hel}_{\pi^+}$, for the two energy bins out of the full photon energy range $E_\gamma \in [0.9, 2.1]$ GeV. Blue points are from g14 data, black points from g9a analysis [9], red points from g1c data [8]. The magenta curves are theoretical predictions from A. Fix [10].

5. The reaction $\gamma p \to \rho^0 p$

Our final aim is to extract the double polarization asymmetry E for the reaction $\gamma p \to \rho^0 p$. In order to do that it is necessary to identify events where the two charged pions are coming from the strong decay of the ρ^0 vector meson and isolate them from the other production mechanism of two pions. The main background sources to the channel of out interest are:

- $\gamma p \to \Delta^{++}\pi^- \to \pi^+\pi^- p$
- $\gamma p \to \Delta^0\pi^+ \to \pi^+\pi^- p$
- $\gamma p \to \pi^+\pi^- p$ (non resonant)

The cuts applied to reject most of the background are:

- Cut on the invariant mass distributions of the couple $\pi^+ p$ and $\pi^- p$, respectively: $IM(\pi^+ p) > 1.3$ GeV and $IM(\pi^- p) > 1.3$ GeV

- Cut on the squared recoil momentum -t< 0.5 GeV/c
- Cut on the incident photon energy E_γ >1.3 GeV

The final invariant mass distribution of the couple $\pi^+\pi^-$ is shown in Fig. 5. It can be seen that, after the selection procedure, the distribution is well-centered around the nominal mass of the ρ vector meson and the remaining background is small (less than 10 %), mostly due to the non-resonant direct photoproduction of $\pi^+\pi^-$ pairs and residual interference contribution from the $\Delta\pi$ production. For the selected events is now possible to extract the double polarization observable E, as shown in Fig. 6.

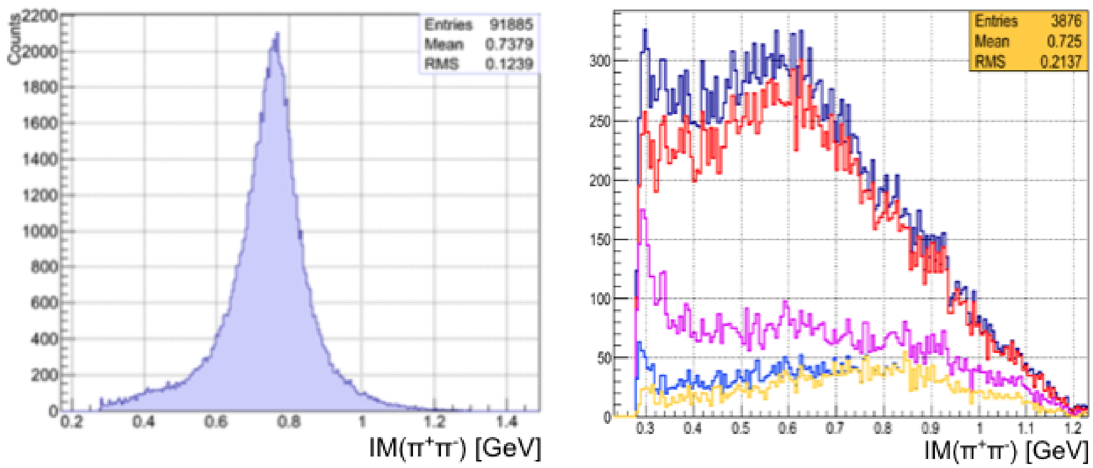

Fig. 5. Left: the final invariant mass distribution $IM(\pi^+\pi^-)$ after the selection procedure; right: the final invariant mass distribution $IM(\pi^+\pi^-)$ from simulated background data, for different cuts imposed in the analysis. The blue histogram is the $IM(\pi^+\pi^-)$ for all background events; the red histogram is the $IM(\pi^+\pi^-)$ after applying a cut on the $MM(\pi^+\pi^-)$ closing the $\gamma p \to \pi^+\pi^- p$ kinematics; the violet histogram is the $IM(\pi^+\pi^-)$ after applying a cut on the invariant masses $IM(\pi^+ p)$>1.3 GeV and $IM(\pi^- p)$>1.3 GeV; the azure histogram is the $IM(\pi^+\pi^-)$ after imposing a cut on t, and finally the yellow histogram is the $IM(\pi^+\pi^-)$ after imposing a cut on E_γ>1.3 GeV.

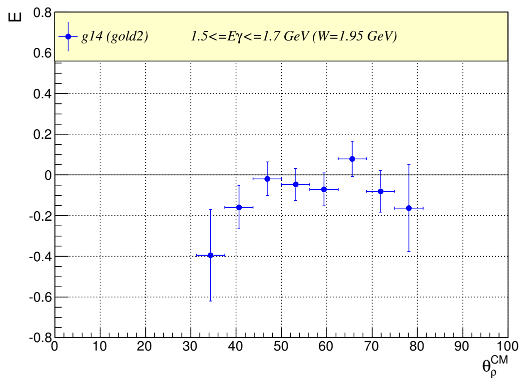

Fig. 6. Measured helicity difference $\mathbf{P}_z^{\odot}$ for the reaction $\gamma p \rightarrow \pi^+\pi^- p$, as a function of $\phi_{\pi^+}^{hel}$, for a single energy bin out of the full photon energy range $E_\gamma \in [0.9,2.1]$ GeV. Blue points are from g14 data, black points from g9a analysis [9], red points from g1c data [8]. The magenta curves are theoretical predictions from A. Fix [10].

6. Conclusions

Results on the beam-helicity asymmetry $\mathbf{I}^{\odot}$ and helicity-difference $\mathbf{P}_z^{\odot}$ on the proton have been obtained with the HD-ice polarized target and CLAS at JLab; data are in agreement with previous measurements (g1c and FROST) and show poor agreement with available theoretical predictions.
First results have been obtained on $\mathbf{I}^{\odot}$ for polarized quasi-free neutron target, showing a sensibly different trend, compared with the proton target and predictions on the neutron (which are characterized by an opposite sign).
Very preliminary attempt to disentangle events from ρ^0 photoproduction has been performed and first results on double polarization asymmetry E for the reaction $\gamma p \rightarrow \rho^0 p \rightarrow \pi^+\pi^- p$ have been obtained, showing non-negligible helicity-difference in a vector meson production reaction.

References

[1] Robert G. Edwards et al. Phys. Rev. D **84** (2011) 074508
[2] R. Koniuk, N. Isgur Phys. Rev. Lett. **44** (1980) 845
[3] W.-T. Chiang, F. Tabakin, Phys. Rev. C **55** (1997) 2054
[4] M. Pichowsky, C. Savkly and F. Tabakin Phys. Rev. C **53** (1996)
[5] F.J. Klein, A.M. Sandorfi et al. Jefferson Lab experiment proposal E06-101/g14
[6] H. Olsen and L.C Maximon Phys. Rev. **114** (1957) 887
[7] A. Honig Phys. Rev. Lett **19** (1967) 1009-10010
[8] S.Strauch, B.I Berman and the CLAS collaboration Phys. ReV. Lett **95** (2005) 162003-1-16203-5
[9] S. Park et al. CLAS NOTE 2013-012
[10] A. Fix et al. Eur. Phys. J. A **25** (2005) 115
[11] Private Communications