Measurement of the Helicity Difference in $\vec{\gamma}\vec{p} \rightarrow p\pi^+\pi^-$ with the CLAS Spectrometer at Jefferson Laboratory

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Abstract. The study of the properties of baryon resonances can provide us with hints to help us understand the structure of non-perturbative QCD and the effect of a particular resonance on polarization observables. The investigation of double-pion photoproduction data is needed to discover higher-lying states and their properties at and above W $\approx$ 1.8 GeV. Therefore, the analysis of the helicity difference in $\gamma p \rightarrow p\pi^+\pi^-$ will help us in our understanding of QCD.

The CLAS g9a (FROST) experiment, as part of the $N^\star$ spectroscopy program at Jefferson Laboratory, has accumulated photoproduction data using linearly and circularly polarized photons incident on a longitudinally-polarized butanol target in the photon energy range 0.3 to 2.4 GeV. The FROST experiment provides an important step toward a “complete” experiment for the reaction $\gamma N \rightarrow KY$. In this contribution, the method to calculate the helicity difference for the reaction $\gamma p \rightarrow p\pi^+\pi^-$ will be described and preliminary results will be discussed.

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INTRODUCTION

The Quantum Chromodynamics (QCD) is the theory of how quarks and gluons interact with themselves and each other. Strictly speaking, in the area of quark confinement, the methods of perturbative QCD break down. Although much information on these excitations has been researched already in πN scattering experiments, many of the baryon resonances are still not well established, and their parameters (i.e., masses, widths, and couplings to various decay modes) are poorly known because the excited states of the nucleon usually do not exist as cleanly separated spectral lines. In real measurements, they are found as broadly overlapping resonances which may decay into a multitude of final states involving mesons and baryons.

To better understand the properties of baryon resonances states, effective theories and models have been developed. Various Constituent Quark Models (CQMs) are currently the best approach to make predictions for parameters of the baryon ground and excited states. However, the excited states suggested by these models do not match accurately the states measured by experiment, especially at high energies. These models predict many more resonances than have been observed, leading to the so-called “missing resonance” problem. There are several reasons why the predicted excited baryon states may not be realized in nature. First of all, the unobserved resonances may have small couplings to πN. At the same time, they may have strong couplings to other final states like γN, ηN, $\eta' N$, KY, $2\pi N$. Secondly, photoproduction data have been accumulated in recent years, but mainly have covered masses up to 1.8 GeV. The additional resonances are predicted to exist in the mass region at and above this value. Finally, most channels explored until now include only one meson in the final state. However, many high-mass resonances do not decay directly into the ground state via single-meson emission but via a sequential decay populating higher-lying intermediate states.

The latest results in baryon spectroscopy suggest that 3-body final states are very likely to be the key for discovery of the higher-lying unobserved resonances. Especially, the photoproduction of double-pion final states [1] may give us very useful data to investigate many high-mass resonances because their cross sections dominate above 1.8 GeV. Quark models predict $\gamma N \rightarrow N^\star \rightarrow \Delta\pi \rightarrow N\pi^+\pi^-$ and $\gamma N \rightarrow N^\star \rightarrow N\rho \rightarrow N\pi^+\pi^-$ as dominant resonant decay modes leading to $\gamma p \rightarrow p\pi^+\pi^-$. However, these modes are difficult to detect because detectors with a large angular acceptance are needed and a large non-resonant background contributes to these decay modes. It is very effective to use data taken with the CLAS spectrometer at Jefferson Lab (JLab), utilizing circularly and linearly polarized photons, and longitudinally polarized targets. - FROST experiment.

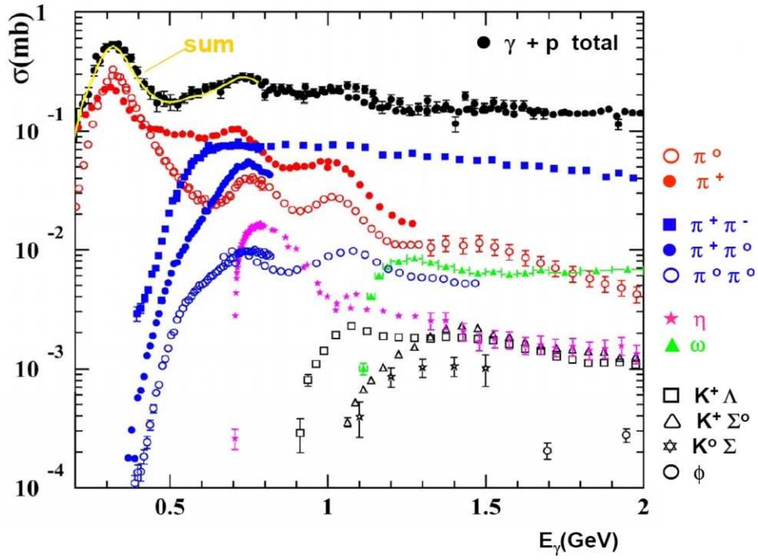

FIGURE 1. A summary of photoproduction cross section

FROST EXPERIMENT AT JLAB

The experimental Hall-B at JLab provides a unique set of experimental devices for the FROST experiment. Firstly, the CLAS spectrometer [2] housed in Hall B is a nearly-4π detector. This means that the sensitive region covers a range of polar angles from 10° to 150° and the azimuthal range covers approximately 90 % at large angles and 50 % at forward angles. Secondly, there is a broad range photon tagging facility [3]. The bremsstrahlung tagging technique, which is used by the tagging system at JLab, can tag photon energies over a range from 20 % to 95 % of the incident electron energy and is capable of operation with beam energies up to 6.0 GeV. The FROST experiment uses both a linearly-polarized beam and a circularly-polarized beam in the energy range from 1.645 GeV to 4.599 GeV. A thin, well oriented diamond radiator is used for the production of a linearly-polarized photon beam and circularly-polarized photon beam is produced using a beam of polarized electrons incident on the bremsstrahlung radiator.

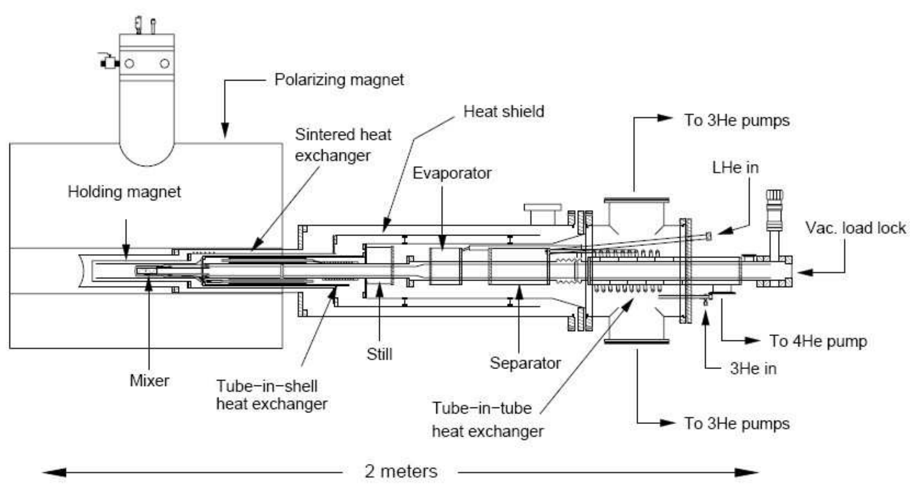

FIGURE 2. Schematic drawing of the CLAS Frozen Spin Target located inside a 5 T polarizing magnet.

The remaining element which is indispensable for the double polarization experiment is a frozen-spin polarized target (FROST) shown in Fig. 2. This polarized target [4] is capable of being polarized longitudinally with a minimal amount of material in the path of outgoing charged particles. The FROST target uses butanol (C_4H_9OH) as the target material with a dilution factor of approximately 13.5 %x. This material is cooled to approximately 0.5 K and dynamically polarized outside the spectrometer using a homogeneous magnetic field of about 5.0 T. Once polarized, the target is then cooled to a low temperature of 30 mK, enough to preserve the nuclear polarization in a more moderate holding field of about 0.5 T. The target is then moved back into the spectrometer, and data acquisition with the tagged photon beam can commence.

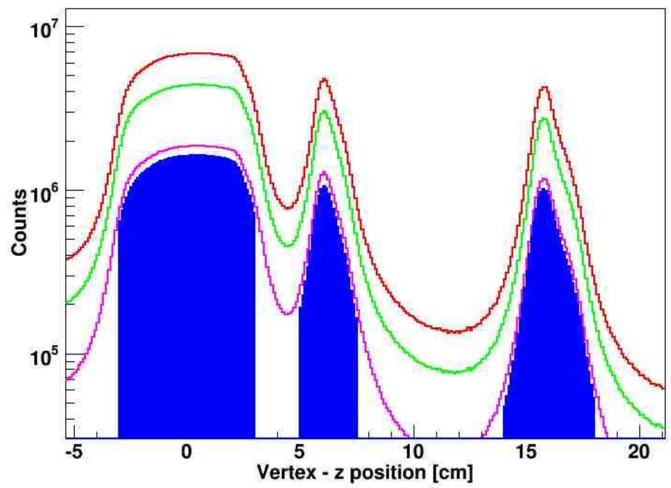

FIGURE 3. The vertex distribution of targets in the FROST experiment. The x axis means the beam direction and the y axis is made as the log scale. The red line is from the raw data. The green line is made after comparing the difference between the calculated velocities and the measured velocities. The violet line is composed of the data included in $\pi^+ \pi^-$ photoproduction. The first peak of the blue line is the butanol and the second is the carbon. The last one is the polyethylene.

The experiment was conducted from November 2007 to February 2008. In this experiment, target polarization was longitudinal with linearly and circularly polarized photons. The trigger required at least one charged particle in CLAS. In addition to the polarized butanol target, we also had a carbon and a polyethylene target further downstream. The corresponding vertex distribution for this experiment is shown in Fig. 3. The additional targets are useful for various systematics checks and for the determination of the shape of the background from bound nucleons in butanol.

PREVIEW OF THE DATA

For the reaction $\gamma p \rightarrow p\pi^+\pi^-$ without measuring the polarization of the recoiling nucleon, the differential cross section is given by:

$$\frac{d\sigma}{d\Omega} = \sigma_0 \left\{ \left(1 + \overrightarrow{\Lambda_i} \cdot \overrightarrow{P}\right) + \delta_\odot \left(I^\odot + \overrightarrow{\Lambda_i} \cdot \overrightarrow{P^\odot}\right) + \delta_l \left[sin2\beta \left(I^s + \overrightarrow{\Lambda_i} \cdot \overrightarrow{P^s}\right) + cos2\beta \left(I^c + \overrightarrow{\Lambda_i} \cdot \overrightarrow{P^c}\right) \right] \right\} \quad (1)$$

Where $\overrightarrow{P}$ and I represent the polarization observables arising from use of polarized targets and beams, respectively. $\overrightarrow{\Lambda_i}$ denotes the polarization of the initial nucleon, $\delta_\odot$ is the degree of circular polarization in the photon beam, while δ_l is the degree of linear polarization, with the direction of polarization being at an angle β to the x-axis. There are 15 observables which can be measured in the experiment. The combination of a circularly polarized beam and a longitudinal polarized target allows us to measure the 5-fold differential observable $P_z^\odot$ corresponding to the known observable E in single-meson production.

A preliminary analysis of the helicity asymmetry in the reaction $\gamma p \rightarrow p\pi^+\pi^-$ was performed. As the first step, the background events are excluded by comparing the measured velocities with calculated velocities. The effect of this is indicated by the green line in Fig. 3. And then events with π^+, π^-, and p detected are selected. Since the data have

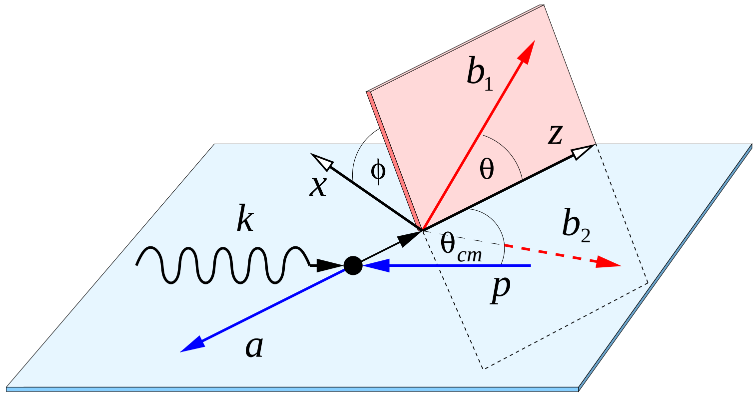

FIGURE 4. Decay angles in a 3-particle final state: a means the recoil proton. b_1 and b_2 denote π^+ and π^- made after the double-pion photoproduction. ϕ indicates the angle between the production plane and the plane formed by two of the final-state particles. θ represents the angle between one of the final-state particles and z-axis on the production plane.

more than one charged particle required by the trigger of the FROST experiment, the reaction $\gamma p \to p\pi^+\pi^-$ can have four kinds of topologies : the reaction $\gamma p \to p\pi^+(\pi^-)$, the reaction $\gamma p \to p\pi^-(\pi^+)$, the reaction $\gamma p \to \pi^+\pi^-(p)$, and the reaction $\gamma p \to p\pi^+\pi^-$. For those events, the missing particle can be calculated via missing mass for these topologies. Selected events were binned in photon energy, $cos\theta^*_{\pi^+}$, and $\phi^*_{\pi^+}$ shown in Fig. 4. $\theta^*_{\pi^+}$ and $\phi^*_{\pi^+}$ are defined as the π^+ polar and azimuthal angles in the rest frame of the π^+ π^- system with the z direction along the total momentum of the π^+ π^- system.

In each bin of $(E_\gamma, cos\theta^*_{\pi^+}, \phi^*_{\pi^+})$, the measured asymmetry is determined by:

$$A = \frac{N(\rightarrow\Rightarrow)+N(\leftarrow\Leftarrow)-N(\leftarrow\Rightarrow)-N(\rightarrow\Leftarrow)}{N(\rightarrow\Rightarrow)+N(\leftarrow\Leftarrow)+N(\leftarrow\Rightarrow)+N(\rightarrow\Leftarrow)} \qquad (2)$$

Where N($\rightarrow\Rightarrow$) indicates the number of events with the circular beam polarization and longitudinal target polarization parallel to the beam, $\rightarrow$ and $\leftarrow$ denote circular polarization of the beam in its two possible settings, $\Rightarrow$ and $\Leftarrow$ represent longitudinal target polarization parallel or anti-parallel to the beam. To get the helicity asymmetry $P_z^\odot$, the raw asymmetry was corrected by beam polarization ($\delta_\odot$), target polarization (Λ_z), and effective dilution factor (f) [5]. The equation is given by:

$$P_z^\odot = \frac{1}{\delta_\odot \cdot \Lambda_z \cdot f} \cdot A \qquad (3)$$

In FROST, only the hydrogen atoms are polarized longitudinally. That is, the atoms of carbon and oxygen in the butanol (C_4H_9OH) target remain unpolarized. The dilution factor is defined as the ratio between the polarizable hydrogen and the full butanol contribution to the cross section. At this stage of the analysis, very rough estimates of polarizations and the dilution factor (f = 0.578) are used for correction. Very preliminary results for the helicity asymmetry for π^+ π^- photoproduction are presented in Fig. 5. For $E_\gamma \in$ [0.8, 0.9] GeV, the asymmetry shows a sinusoidal shape for $-0.8 < cos\,\theta^*_{\pi^+} < -0.7$, but as $\theta^*_{\pi^+}$ decreases, this shape disappears, and then reappears in a reversed form once $cos\,\theta^*_{\pi^+} > 0.5$. Even in this early stage of this analysis, the behavior of the asymmetries can be seen.

SUMMARY

The first part of FROST with a longitudinally polarized target has been completed. The experimental data on the double pion photoproduction are being analyzed. The second round of the experiment is scheduled to run from March 2010 to July 2010 and will use a transversely polarized target. After this second series of experiments, FROST can almost satisfy the condition for a “complete” experiment.

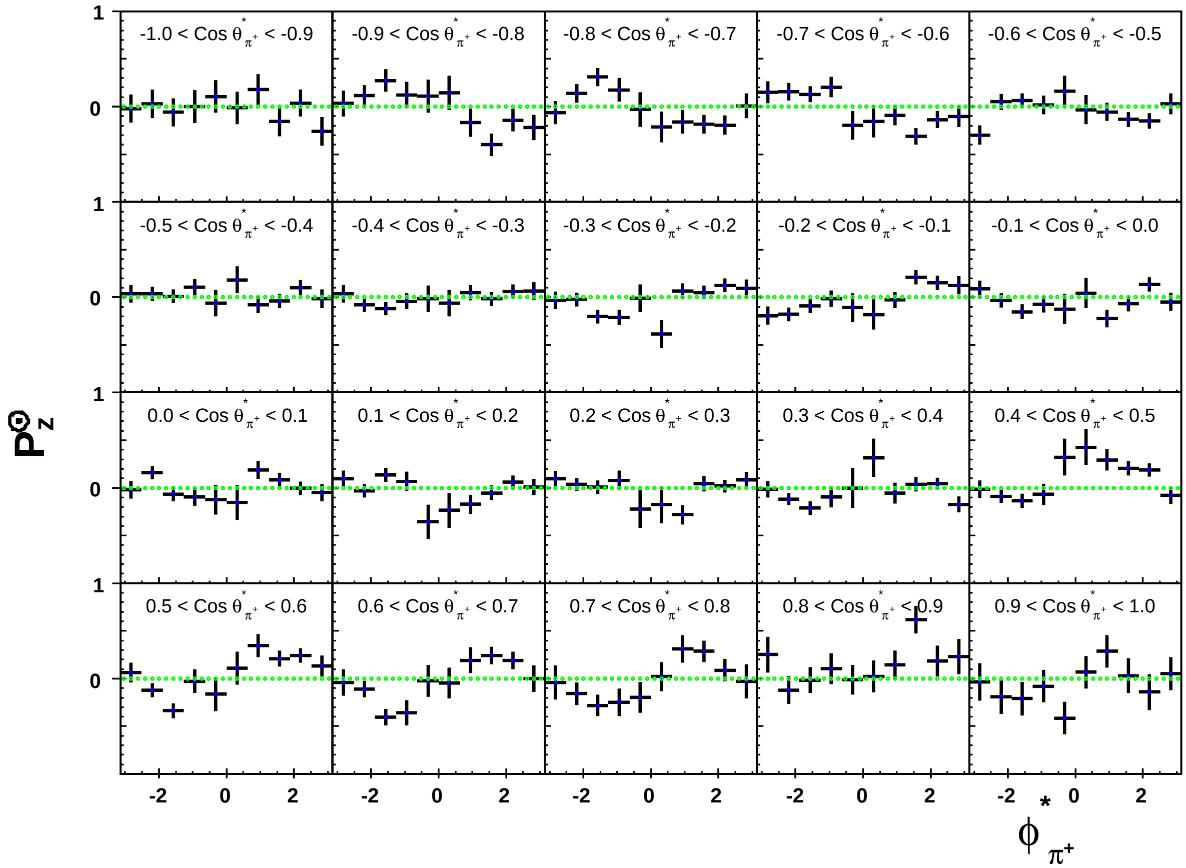

FIGURE 5. Helicity asymmetry for the reaction $\gamma p \to \pi^+\pi^-(p)$ for E_γ = 0.8 - 0.9 GeV

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