CLAS+FROST: new generation of photoproduction experiments at Jefferson Lab.*

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Abstract A large part of the experimental program in Hall B of the Jefferson Lab is dedicated to baryon spectroscopy. Photoproduction experiments are essential part of this program. CEBAF Large Acceptance Spectrometer (CLAS) and availability of circularly and linearly polarized tagged photon beams provide unique conditions for this type of experiments. Recent addition of the Frozen Spin Target (FROST) gives a remarkable opportunity to measure double and triple polarization observables for different pseudo-scalar meson photoproduction processes. For the first time, a complete or nearly complete experiment becomes possible and will allow model independent extraction of the reaction amplitude. An overview of the experiment and its current status is presented.

Key words photoproduction, double polarization, baryon resonance

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1 Introduction

Among the most exciting and challenging topics in sub-nuclear physics today is the study of the structure of the nucleon and its different modes of excitation, the baryon resonances. Initially, most of the information on these excitations came primarily from partial wave analysis of data from πN scattering. Recently, these data have been supplemented by a large amount of information from pion electro- and photoproduction experiments. Yet, in spite of extensive studies spanning decades, many of the baryon resonances are still not well established and their parameters (i.e., mass, width, and couplings to various decay modes) are poorly known. Much of this is due to the complexity of the nucleon resonance spectrum, with many broad, overlapping resonances. While traditional theoretical approaches have highlighted a semi-empirical approach to understanding the process as proceeding through a multitude of *s*-channel resonances, *t*-channel processes, and non-resonant background, more recently attention has turned to approaches based on the underlying constituent quarks. An extensive review of the quark models of baryon masses and decays can be found in Ref. [1]. Most recently lattice QCD is making significant progress in calculations of baryon spectrum. While these quark approaches are more fundamental and hold great promise, all of them predict many more resonances than have been observed, leading to the so-called “missing resonance” problem. One possible reason why they were not observed because they may have small coupling to the πN. At the same time they may have strong coupling to other final states ηN, η′N, KY, 2πN.x

There are three objects in pseudo-scalar meson photoproduction which can be polarized: photon beam, target nucleon and recoil baryon. There are 16 observables which can be measured. Table 1 lists all of them in three groups: beam-target, beam recoil and target-recoil. The photoproduction reactions can be described in terms of four complex amplitudes. Therefore, in order to be able to perform full recon-

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struction of the amplitude one need to measure at least eight carefully chosen observables from at least two different groups. This implies requirement of having polarized beam, polarized target and recoil polarimetry. Hyperons have a remarkable feature: their weak decay is self-analyzing. This gift of nature allows us to measure their polarization without polarimeter.

Table 1. Polarization observables in pseudo-scalar meson photoproduction. The entries in parentheses signify that the same polarization observables also appear elsewhere in the table.

beam	target				recoil			target + recoil			
	–	–	–	–	x'	y'	z'	x'	x'	z'	z'
	–	x	y	z	–	–	–	x	z	x	z
unpolarized	σ_0	0	T	0	0	P	0	$T_{x'}$	$-L_{x'}$	$T_{z'}$	$L_{z'}$
linear pol.	$-\Sigma$	H	$(-P)$	$-G$	$O_{x'}$	$(-T)$	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	$(-L_{x'})$	$(-T_{x'})$
circular pol.	0	F	0	$-E$	$-C_{x'}$	0	$-C_{z'}$	0	0	0	0

A large part of the experimental program of Jefferson Lab and CLAS in particular is dedicated to baryon spectroscopy. There were several CLAS running periods with circularly and linearly polarized photon beams. High quality data for the cross sections of π^0[2], π^+[3], η[4], η'[5] and kaon photoproduction were obtained. In addition to the cross sections[6] for $K^+\Lambda$ and $K^+\Sigma^0$ final states the polarization of hyperons P[7] and polarization transfer C_x/C_z were measured[8]. The beam asymmetry Σ was measured with linearly polarized beam. Significant amount of data for cross sections and beam asymmetries was also accumulated at ELSA, MAMI, GRAAL and LEPS. However, without double polarization measurement it is still impossible to resolve all ambiguities in the reaction amplitude. Several experiments[9] were proposed to measure double polarization observables in all reaction channels π^0p, π^+n, ηp, η'p, KY, $\pi^+\pi^-$p with CLAS, circularly and linearly polarized photons and longitudinally and transversely polarized target.

2 Experimental Hall-B

Experimetal Hall-B at Jefferson Lab provides a unique set of instruments for these experiments. One instrument is the CLAS[10], a large acceptance spectrometer which allows detection of particles in a wide range of θ and ϕ. The other instrument is a broad-range photon tagging facility [11] with the recent addition of the ability to produce linearly-polarized photon beams through coherent bremsstrahlung. The remaining component essential for the double polarization experiments is a frozen-spin polarized target (FROST) .

2.1 Tagged photon beams

The Hall B photon tagger[11] covers a range in photon energies from 20 to 95% of the incident electron beam energy. Unpolarized, circularly polarized and linearly polarized tagged photon beams are presently available.

2.1.1 Circularly-polarized photon beam

With a polarized electron beam incident on the bremsstrahlung radiator, a circularly polarized photon beam can be produced. The degree of circular polarization of the photon beam depends on the ratio $k = E_\gamma/E_e$, and is given by[12]

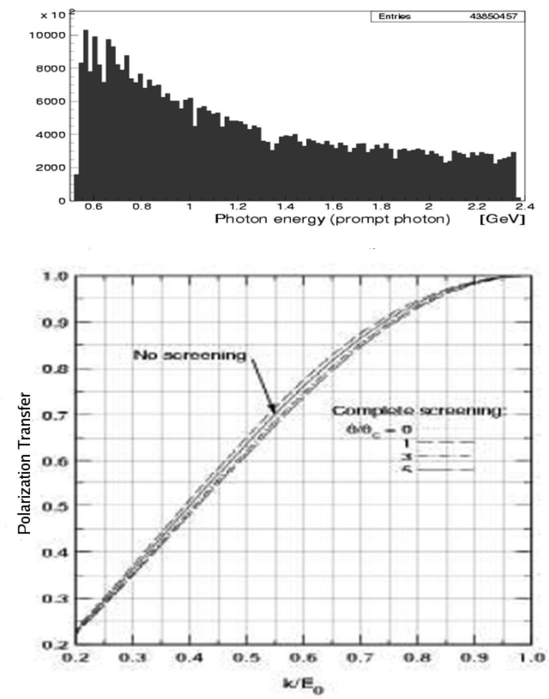

Fig. 1. An example of tagged bremsstrahlung photon spectrum (top) and polarization transfer from electron to photon (bottom).

$$P_\odot = P_e \cdot \frac{4k-k^2}{4-4k+3k^2} \ . \qquad (1)$$

The magnitude of $P_\odot$ ranges from 60% to 99% of the incident electron beam polarization P_e for photon energies E_γ between 50% and 95% of the incident electron energy. CEBAF accelerator routinely delivers electron beam with polarization of 85% and higher. An example of tagged circularly polarized photon spectrum and its degree of polarization is shown in Fig. 1.

2.1.2 Linearly polarized photon beam

A linearly polarized photon beam is produced by the coherent bremsstrahlung technique, using an oriented diamond crystal as a radiator. Fig. 2 shows an example of collimated linearly polarized tagged photon spectrum obtained in Hall-B. The degree of polarization is a function of the fractional photon beam energy and collimation and can reach 80% to 90%. With linearly polarized photons, over 80% of the photon flux is confined to a 200 MeV wide energy interval.

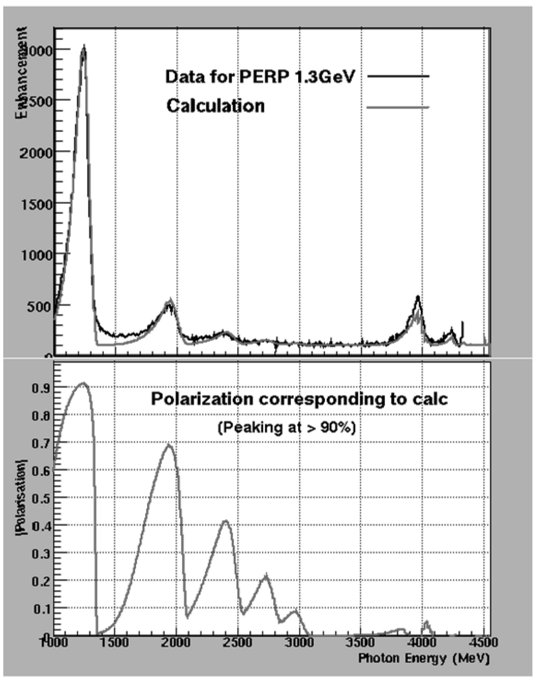

Fig. 2. Coherent bremsstrahlung spectrum and calculated photon polarization as a function of energy.

2.2 Frozen spin polarized target (FROST)

An essential piece of the hardware for this experiment is a polarized target capable of being polarized transversely and longitudinally with a minimal amount of material in the path of outgoing charged particles. The Hall-B polarized target[13] used in electron beam experiments is a dynamically polarized target. The target is longitudinally polarized with a pair of 5 Tesla Helmholtz coils. These massive coils limit available aperture to 55 degrees in forward direction. For photon beam experiments, a frozen-spin target is a much more attractive choice.

In frozen-spin mode, the target material is dynamically polarized in a strong magnetic field of 5 Tesla at the temperature of about 1K outside of CLAS. After maximal polarization is reached the cryostat is turned to the "holding" mode with much lower magnetic field of 0.5 Tesla at a temperature of 50 mK or less, and then moved in CLAS. A photon beam does not induce noticeable radiation damage and does not produce significant heat load on the target material. Under these conditions the target can hold its polarization with a relaxation time on the order of several days before re-polarization is required. Since the holding field is relatively low, it is possible to design a "transparent" holding magnet with a minimal amount of material for the charged particles to traverse on their way into CLAS. The target system uses an external polarizing magnet located outside of CLAS, and an internal holding magnet inside the cryostat. Butanol was chosen as target material. The operation cycle is following.

Dynamically polarize target with microwaves outside of CLAS in external polarizing magnet.

Turn off microwave and freeze polarization and switch to holding mode with internal holding magnet. Do spin rotation in case of transverse polarization.

Take data for several days.

Repeat the cycle and flip polarization if required.

Figure 3 shows two configurations of the target. On the top panel the target is pulled out from the CLAS and inserted in the polarizing magnet. The bottom panels shows the target inside the CLAS in it normal configuration for data taking.

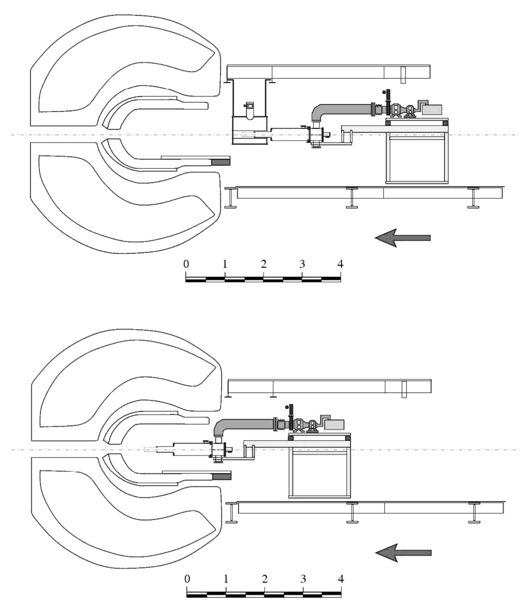

Fig. 3. The target is pulled out from the CLAS and inserted in the polarizing magnet (top panel). The target is inside the CLAS in its normal configuration for data taking (bottom panel).

The frozen spin target has been built by the JLab polarized target group. Table 2 summarizes main parameters of the target. There are two holding magnets available an the target can be configured either for longitudinal or transverse polarization. During the first round of experiments the target demonstrated excellent performance running continuously for three and a half months.

Table 2. Parameters of the FROST.

	expectation	result
base	50 mK	28 mK no beam
temperature		30 mK beam
cooling	10 μW	800 μW@50 mK
power	(frozen)	
	20 mW	60 mW@300 mK
	(polarizing)	
polarization	±85%	+82%
		−85%
relaxation	500 hours	2700 h (+Pol)
time	(5% per day)	1400 h (−Pol)
		(<1.5% per day)

3 Experiment

The first round of experiment with FROST was conducted in November 2007 — February 2008. In this set of experiments target polarization was longitudinal. We used both, linearly and circularly polarized photons. Photon energy range covered 0.5—2.3 GeV. Trigger required at least one charged particle in CLAS. In addition to the polarized butanol target we also had carbon and polyethylene target downstream. They are useful for various systematics checks and for determination of the shape of the background form bound nucleons in butanol. Target polarization was reversed at each re-polarization cycle. Combination of circularly polarized beam and longitudinally polarized target allows us to measure helicity asymmetry E. With linearly polarized photons incident on longitudinal target we have access to the observable G.

4 Preview of the data

In this section we present the first look at the data collected. A preliminary analysis of the helicity asymmetry in the reaction $\gamma p \to \pi^+ n$ was done. We used standard CLAS particle identification procedure to select events with π^+ detected. For those events we calculated missing mass assuming reaction $\gamma p \to \pi^+ X$. The missing particle was required to have a mass of neutron. Selected events were binned in

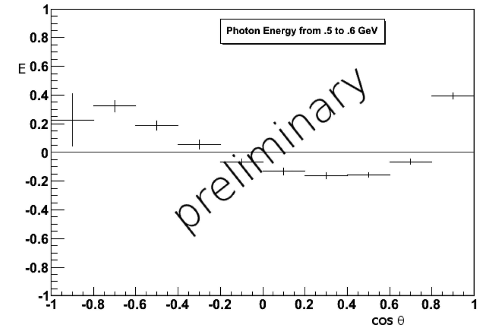

Fig. 4. Helicity asymmetry for $\gamma p \to \pi^+ n$. $E_\gamma = 0.5$—0.6 GeV.

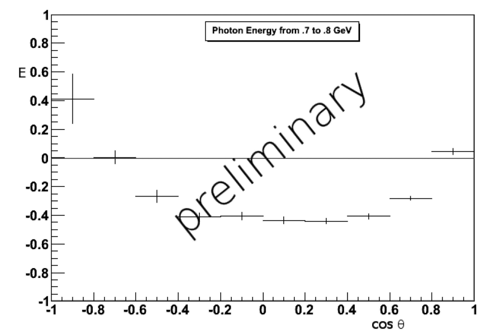

Fig. 5. Helicity asymmetry for $\gamma p \to \pi^+ n$. $E_\gamma = 0.7$—0.8 GeV.

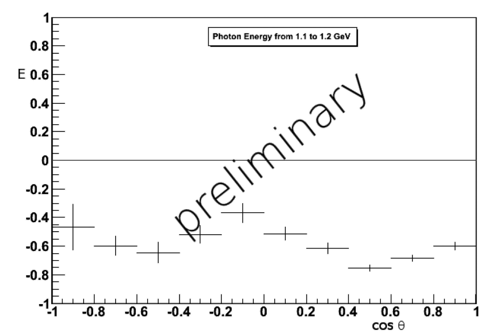

Fig. 6. Helicity asymmetry for $\gamma p \to \pi^+ n$. $E_\gamma = 1.1$—1.2 GeV.

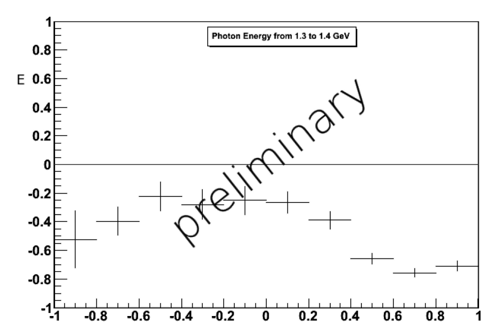

Fig. 7. Helicity asymmetry for $\gamma p \to \pi^+ n$. $E_\gamma = 1.3$—1.4 GeV.

photon energy and $\cos\theta_{c.m.}$. In each bin we determined measured asymmetry

$$A = \frac{N_{\rightrightarrows} - N_{\rightleftarrows}}{N_{\rightrightarrows} + N_{\rightleftarrows}}, \quad (2)$$

where $N_{\rightrightarrows}$ and $N_{\rightleftarrows}$ is number of events beam and target polarization is parallel and anti-parallel respectively. Then, to get helicity asymmetry, E, this raw asymmetry was corrected for beam and target polarization and effective dilution factor. At this stage of the analysis we used very rough estimate of these corrections A very preliminary results for helicity asymmetry for π^+ photoproduction are presented in Figs. 4—7. This represents about 10% of available statistics.

One can see that asymmetry is large and energy evolution displays various structures in angular dependence. This is just one example of what is coming in near future. The analysis of all other final states is underway.

5 Summary

The addition of Frozen Spin Target, with both, longitudinal and transverse polarization significantly advances our experimental capabilities. The first round of the double polarization photoproduction experiments with longitudinally polarized target has been complete and experimental data are being analyzed. The second part of the experiment is scheduled to run in spring of 2010 and will use transversely polarized target.

Upon completion of the experiment it will be possible for the first time to perform complete experiment of KY photoproduction and nearly complete for other final states. Entire program is more than just a sum of several experiments, observables for all final states are measured simultaneously under the same experimental conditions and have the same systematic uncertainties. It can be considered as a "coupled channel experiment" ultimately providing data for coupled channel analysis and extraction of parameters of baryon resonances.

Another essential part of the program which was not described here involves photoproduction experiments on the deuteron target which allow to study different isospin states of the baryon resonances. Several CLAS experiments with polarized photons and unpolarized deuteron target were complete. Double polarization experiments with HD-Ice polarized target are in preparation.

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