Light Baryon Spectroscopy using the CLAS Spectrometer at Jefferson Laboratory

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Baryons are complex systems of confined quarks and gluons and exhibit the characteristic spectra of excited states. The systematics of the baryon excitation spectrum is important to our understanding of the effective degrees of freedom underlying nucleon matter. High-energy electrons and photons are a remarkably clean probe of hadronic matter, providing a microscope for examining the nucleon and the strong nuclear force. Current experimental efforts with the CLAS spectrometer at Jefferson Laboratory utilize highly-polarized frozen-spin targets in combination with polarized photon beams. The status of the recent double-polarization experiments and some preliminary results are discussed in this contribution.

1 Introduction

It is widely accepted that models based on three constituent-quark degrees of freedom still provide the most comprehensive predictions of the nucleon excitation spectrum. While many predicted properties of the lower-mass (excited) states (< 1.8 GeV$/c^2$) agree fairly well with experimental findings, discrepancies concerning the number and ordering of states emerge above this threshold, mostly due to missing experimental information. In recent years, lattice-QCD has made significant progress toward understanding the spectra of baryons, despite the (still) large pion masses of about 420 MeV$/c^2$ used in these calculations. Since baryon resonances are broad and overlapping, individual excited states usually cannot be observed directly. To extract resonance parameters, the observed angular distributions need to be decomposed into partial waves in a partial wave analysis (PWA). Examples of PWA formalisms are described in [1,2]. Moreover, dynamical coupled channel models have been developed successfully in recent years from a more theoretical side. The EBAC group at Jefferson Laboratory (JLab) has demonstrated that the low physical mass of the Roper resonance can be explained by such coupled channel effects [3].

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The Search for new Excited Baryons

Differential cross sections alone result in ambiguous sets of resonances contributing to a particular photoproduction channel since almost all information on interference effects is lost. For this reason, the FROST experiment at JLab aims at performing so-called complete or nearly-complete experiments for reactions like $\gamma p \to N\pi$, $p\eta$, $p\omega$, K^+Y, and $p\pi^+\pi^-$, which will significantly reduce and eventually eliminate the ambiguities in the extraction of the scattering amplitude. The photoproduction of a single pseudoscalar meson off the nucleon is fully described by four complex parity-conserving amplitudes, which may be determined from eight well-chosen combinations of the unpolarized cross section, three single-spin, and four double-spin observables [4].

In the hyperon channels, precise cross section and polarization data have been measured in recent years, e.g. [5–8]. The weak decay of the hyperon provides additional access to the polarization of the recoiling hyperon rendering a complete experiment feasible. If all combinations of beam, target, and recoil polarization are measured, 16 observables can be extracted providing highly redundant information on the production amplitude. In reactions involving non-strange mesons (without measuring the recoil polarization), seven independent observables can be directly determined. The recoil polarization can then be inferred from beam-target double-polarization measurements. In recent years, very precise differential cross section data were obtained for single $p\pi^0$, $n\pi^+$, $p\eta$, $p\eta'$, and $p\omega$ production, e.g. [1,2,9]. Analyses on beam asymmetries for these reactions are currently being finalized. In $\gamma p \to p\omega$, the ω decay to $\pi^+\pi^-\pi^0$ provides additional polarization information, which further constrains the partial wave analysis for this reaction [2]. The high-spin resonance, $N(2190)G_{17}$, decaying to $p\omega$ could be identified and confirmed in photoproduction as well as the weakly established nucleon state, $N(1950)F_{15}$.

2 Experimental Setup

The results from the JLab double-polarization (FROST) measurements discussed at this conference were obtained with the CEBAF Large Acceptance Spectrometer (CLAS) [10] at the Thomas Jefferson National Accelerator Facility. Longitudinally polarized electrons with energies of 1.65 and 2.48 GeV were incident on the thin radiator of the Hall B Photon Tagger [11] and produced circularly-polarized tagged photons in the energy range between 0.35 and 2.35 GeV with a polarization value of $\approx$ 85 % for the initial electron. The photon helicity was flipped at a rate of 30 Hz. The frozen-spin butanol target had an average proton spin state polarization of $\approx$ 82 % parallel to the beam axis and $\approx$ 85 % anti-parallel to the beam axis. The average target temperature was 30 mK with beam on target. Degradation of target polarization occurred at rates of $\approx$ 0.9 % (parallel) and $\approx$ 1.5 % (anti-parallel) per day. The target was typically repolarized once a week, usually with flips of the polarization direction. Data were collected simultaneously for the butanol target at the center of the

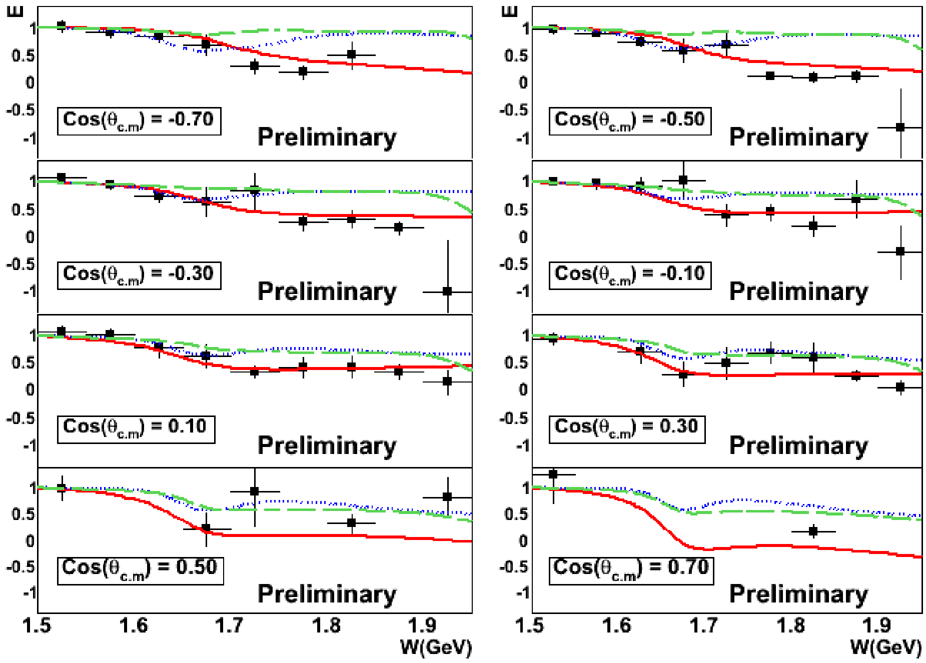

Figure 1: Preliminary results for E in $\vec{\gamma}\vec{p} \rightarrow p\eta$ for energies $W = 1.525 - 1.925$ GeV [12]. Curves: η-MAID (dotted line), Bonn-Gatchina PWA (dashed line), and SAID (solid line).

CLAS detector, and, slightly downstream for separate carbon and a polyethylene targets (to provide information on bound nucleon backgrounds in the butanol target).

3 The Helicity Asymmetry E for η Photoproduction on the Proton

Of particular importance are well-chosen decay channels that can help isolate contributions from individual excited states and clarify their importance. Photoproduction of η mesons offers the distinct advantage of serving as an *isospin filter* for the spectrum of nucleon resonances and, thus, simplifies data interpretations and theoretical efforts to predict the excited states contributing to these reactions. Since the η mesons have isospin $I = 0$, the $N\eta$ final states can only originate (in one-step processes) from intermediate $I = 1/2$ nucleon resonances.

The polarized cross section for the reaction $\vec{\gamma}\vec{p} \rightarrow p\eta$ of circularly-polarized photons on longitudinally-polarized protons is given by:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_0}\,(1 - \Lambda_z\,\delta_\odot\,E)\,, \qquad (1)$$

where $d\sigma/d\Omega_0$ is the unpolarized cross section. Λ_z and $\delta_\odot$ are the degrees of target and beam polarization, respectively. E denotes the helicity difference.

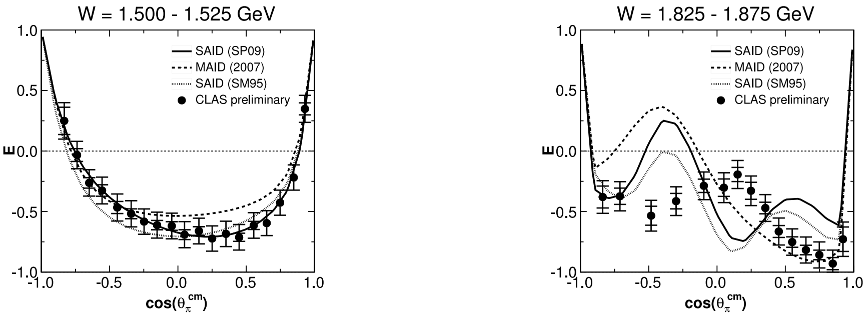

Figure 2: Preliminary results of the double-pololarization observable E (helicity difference) for $\vec{\gamma}\vec{p} \to n\pi^+$ [12]. The inner error bars indicate stat. uncertainties; the outer error bars include a 10 % sys. uncertainty, which is expected to be reduced in the final analysis. The curves show solutions of the SAID SP09 [1], MAID [13] and SAID SM95 PWA.

Preliminary results of the helicity difference E for $\vec{\gamma}\vec{p} \to p\eta$ are shown in Fig. 1. Since the η-threshold is dominated by the $N(1535)S_{11}$ resonance, the observable exhibits values close to unity for $W < 1.6$ GeV/c^2. The preliminary results indicate that the observable remains positive below about $W = 2$ GeV, shedding further light on contributing resonances.

4 The Helicity Asymmetry E for the Reaction $\vec{\gamma}\vec{p} \to n\pi^+$

Although many of the *unobserved* baryon resonances may have small couplings to πN, it is still important to study pion photoproduction. Polarization observables will help sift the several competing descriptions of the spectrum by more conclusively indicating which resonances are involved in elastic pion-nucleon scattering, as well as providing evidence for previously unidentified resonances. New resonances found in reactions like $\gamma N \to \pi N$ are expected to have masses larger than about 1.8 GeV/c^2, although the higher-mass resonance contributions are expected to be more important in double-meson photoproduction.

The current database for pion photoproduction is mainly populated by unpolarized cross section data and single-spin observables. Fig. 2 shows preliminary results of the double-polarization E for $\vec{\gamma}\vec{p} \to n\pi^+$ (Eqn. 1). While the predictions shown in the figure agree nicely with the new data at low energies (left side), discrepancies emerge at higher energies (right side) for $W \geqslant 1.7$ GeV/c^2. Single-pion photoproduction appears less well understood than previously expected. For this reason, the present data will greatly reduce model-dependent uncertainties.

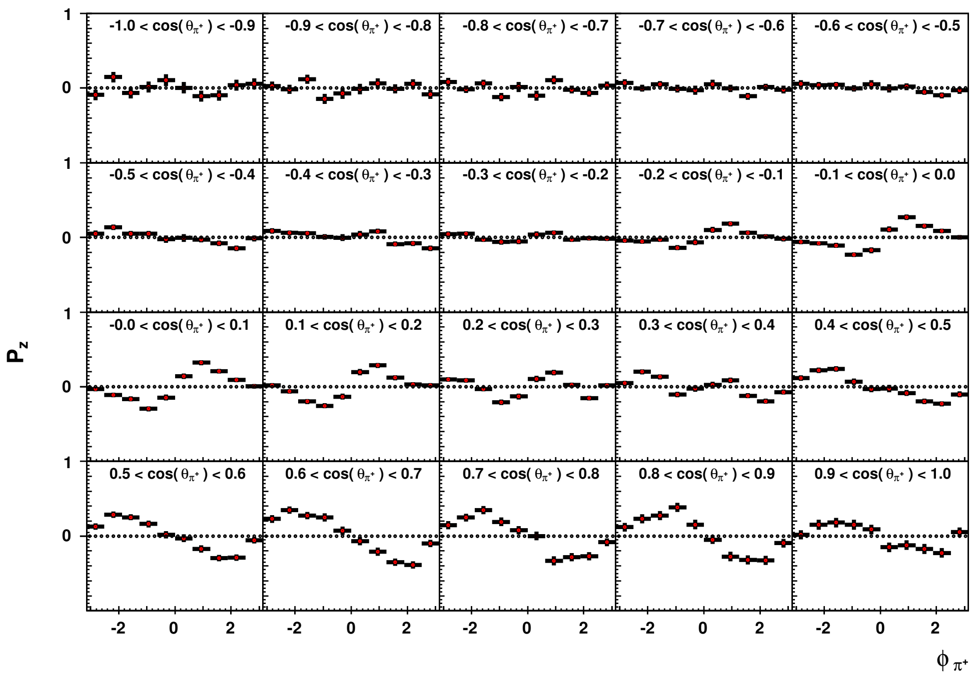

Figure 3: Preliminary target asymmetry, P_z, from FROST for the reaction $\gamma\vec{p} \to p\pi^+\pi^-$ for $E_\gamma \in [0.7, 0.8]$ GeV [12]. Error bars are statistical only.

5 Polarization Observables for $\pi^+\pi^-$ Production on the Proton

One of the key experiments in the search for yet unobserved states is the investigation of double-pion photoproduction. Quark models predict large couplings of those states to $\Delta\pi$, for instance. The five-dimensional cross section for the photoproduction of two pseudoscalar mesons using longitudinal target polarization and circularly-polarized (or unpolarized) beam can be written in the form [14]:

$$I = I_0 \{ (1 + \Lambda_z \cdot P_z) + \delta_\odot (I^\odot + \Lambda_z \cdot P_z^\odot) \},$$

where I_0 denotes the unpolarized cross section and $\delta_\odot$ and Λ_z denote the degree of beam and target polarization, respectively. The additional polarization observables, P_z and $I^\odot$, for the two-meson final state arise since the reaction is no longer restricted to a single plane. Fig. 3 shows an example for the observable P_z in $\gamma\vec{p} \to p\pi^+\pi^-$ [12]. The variables ϕ and θ denote the azimuthal and polar angle of the π^+ in the rest frame of the two mesons. The observable acquires surprisingly large values for $\cos\theta_{\pi^+} > 0$ with the statistical errors in some cases smaller than the symbol size. The expected odd behavior of the distribution is clearly visible.

6 Summary and Conclusion

The goal of measuring a sufficient number of polarization observables to unambiguously construct the scattering amplitude for a given channel is within reach. New resonance candidates have been proposed on the basis of recent high-quality photoproduction data, though a clear pattern of new states has not yet emerged. These efforts will soon shed light on the open questions concerning the spectrum of baryon resonances. A better understanding of QCD and the phenomenon of confinement appears on the horizon.

Acknowledgments

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