Search for N^* Resonances in Double-Polarization Experiments using CLAS

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Abstract. At medium energies where the strong coupling constant is very large and perturbative methods can no longer be applied, the nature of confinement remains one of the key challenges in our present understanding of QCD. A necessary step is undoubtedly to identify the relevant degrees of freedom in this energy regime and the effective forces between them. Thus, a precise knowledge of the spectrum of baryon resonances and their properties is needed. A large number of states has been found in different analyses. However, only a few of them are well established and confirmed by different experiments. It has been shown that particular resonances have large effects on polarization observables. At Jefferson Laboratory, a major program has been proposed to perform a large set of photoproduction experiments using linearly- and circularly-polarized tagged photon beams as well as longitudinally and transversely-polarized targets. In double-pion production, a major obstacle in the determination of the couplings of baryon resonances are the considerable contributions from non-resonant mechanisms. In this case, polarization observables, which are sensitive to very small resonance contributions, will be helpful in the evaluation of N^* properties.

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INTRODUCTION

The excited states of the nucleon cannot simply be inferred from cleanly separated spectral lines as known from atomic physics. Quite the contrary, a *spectral analysis* in nucleon resonance physics is complicated by the fact that the resonances are broadly overlapping states which decay into a multitude of final states involving mesons and baryons. To provide a consistent and complete picture of an individual nucleon resonance, the various possible production and decay channels must be treated in a multi-channel framework that permits separating resonance from background contributions. Very often, resonances reveal themselves more clearly through interference with dominant amplitudes. These interference terms can be isolated via polarization observables. However, in the absence of experimental data on polarization observables, in particular for multi-meson final states, the predictive power of currently used theoretical models is unclear.

The upcoming FROST program at Jefferson Laboratory (JLab) anticipates to take data for all four combinations of beam and target polarization, thus providing (almost) complete sets of measurements for π^0 , π^+ , η , η' , and $\pi^+\pi^-$ photoproduction. The additional determination of the recoil polarization in hyperon production, completes polarization measurements for the reactions $\gamma p \rightarrow K\Sigma$ and $\gamma p \rightarrow K\Lambda$. The program was awarded beam time to determine all observables over a large range in production angle and energy with anticipated statistical errors between ± 0.05 and ± 0.07 .

FIGURE 1. Photograph of the precooling unit. The direction of the photon beam is from left to right.

EXPERIMENTAL SETUP AT JEFFERSON LAB

The experiments to measure single- and double-polarization observables at Jefferson Lab [1, 2, 3, 4, 5] will make use of the large-acceptance spectrometer (CLAS [6]) and the photon-beam facility [7] in Hall-B, providing circularly-polarized photons from highly polarized electrons and linearly-polarized photons via coherent bremsstrahlung.

The FROzen-Spin Target (FROST)

A new frozen-spin (butanol) target, which is currently under construction, will be positioned in the geometrical center of CLAS with a minimum amount of material in the path of outgoing particles (Fig. 1). The target cryostat is of horizontal type with a pipe of about 200 cm in length and 25 cm in diameter. Since CLAS is a magnetic spectrometer, its operational characteristics are very sensitive to the additional magnetic field produced by the target. For this reason, the target material will be dynamically polarized by microwave irradiation in a strong magnetic field of 5 T at a temperature of about 1 K outside of CLAS. After maximum polarization is reached, the cryostat will be switched to *holding* (or *frozen-spin*) mode using a much lower magnetic field of 0.5 T at a temperature of ≈ 50 mK and moved back into CLAS. For a butanol target, the proton polarization of initially about 90 % generally decreases slowly with a relaxation time of typically several days under the conditions outlined above. This is sufficiently long for a useful polarized-target experiment.

The target cell is 50 mm long and 15 mm in diameter. The length is a compromise between conflicting demands for count rate and cooling requirements. Butanol has a dilution factor (fraction of polarizable nucleons) of $10/74 \approx 13.5\%$ and an effective density of 0.611 g/cm^3 . We anticipate an average degree of polarization for both longitudinal and transverse polarization of about 80 %.

For the cylindrical target volume in question, approximately 20 mW of microwave power will be necessary for the polarization process at 0.5 K considering a polarization build-up time of about 30 minutes. Under experimental run conditions the heat load from

the photon beam will be about $1 \mu\text{W}$. This implies that in *frozen-spin* mode at 0.5 T and 50 mK, the refrigerator should provide a cooling power of a few μW . The only technique that satisfies these conditions is a $^3\text{He}/^4\text{He}$ dilution refrigerator.

POLARIZATION OBSERVABLES IN $\pi^+\pi^-$ PRODUCTION

Differential cross section data, though helpful, provide little information about small resonance contributions. However, these states should reveal themselves more clearly through the interference with dominant amplitudes. These interference terms can be isolated via polarization observables. A typical example for such an effect is the $N(1520)\text{D}_{13}$ resonance revealing itself in the beam-asymmetry data of η photoproduction, due to its interference with the dominant $N(1535)\text{S}_{11}$.

In the past, the $p\pi^+\pi^-$ final state has been treated often as arising from either of the quasi two-body states $\Delta\pi$ or $\text{N}\rho$, followed by the decay of the Δ or the ρ . This Isobar Approach has been reasonably successful. However, it is considered important that the polarization observables for such processes be measured and elucidated in a more general framework, one that goes beyond the quasi two-body assumption. The formalism and terminology for the various polarization observables of interest in double-meson photoproduction can be found in Ref. [8].

For $\gamma p \rightarrow p\pi\pi$ without measuring the polarization of the recoiling nucleon, the reaction rate I can be written as:

$$I = I_0 \{ (1 + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}) + \delta_\odot (\mathbf{I}^\odot + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^\odot) + \delta_l [\sin 2\beta (\mathbf{I}^s + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^s) + \cos 2\beta (\mathbf{I}^c + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^c)] \} , \quad (1)$$

where $\vec{\mathbf{P}}$ represents the polarization asymmetry that arises if the target nucleon is polarized and $\vec{\Lambda}_i$ denotes the polarization of the initial nucleon. Here $\delta_\odot$ 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. Note that all observables in Eq. 1 are 5-fold differential and that there are 15 polarization observables in

FIGURE 2. Model predictions of $\mathbf{P}_x^\odot$ (left) and $\mathbf{P}_y^\odot$ (right) plotted versus the invariant mass of the two pions (circularly-polarized beam and transverse target polarization) at different values of ϕ , which denotes the π^+ azimuthal angle in the rest frame of the $\pi^+\pi^-$ system [8]. The anticipated statistical errors of 0.05 are shown for values of $\phi = \pi$ (left) and $\phi = 3/2\pi$ (right). The total center-of-mass energy is $W = 2 \text{ GeV}$.

double-meson production as opposed to only 7 observables in single-meson production. The helicity difference $I^\odot$ has been measured by the CLAS Collaboration [9].

The sensitivity of some polarization observables has been studied to contributions from resonances in the 1900 MeV/ c^2 mass region, where the so-called *missing-resonance* problem begins. A plethora of states is considered *missing* because they are predicted by constituent quark models based on three quark degrees of freedom but haven't been observed experimentally, yet. In particular, Fig. 2 shows model predictions of the double-polarization observables $\mathbf{P}_x^\odot$ (left) and $\mathbf{P}_y^\odot$ (right) and how these differ from the full solution if for example the $\Delta(1900) S_{31}$ (dashed curves) or the $\Delta(1910) P_{31}$ (dot-dashed curves) are omitted from the calculation. Many observables that are functions of the invariant $p\pi^+$ or $p\pi^-$ mass, exhibit structures indicating the presence of the $\Delta(1232)$, but it has to be pointed out that much more than such a *visual* identification will be needed in the interpretation of any data obtained. For other observables that are functions of the $\pi^+\pi^-$ invariant mass, similar *structures* can be seen that identify the ρ meson. Note that in all these calculations no other $\pi^+\pi^-$ resonances are included, e.g. f_0 and σ contributions were omitted at this time. The plots are largely independent of the photocouplings of the excited baryons, indicating that contributions in which the excited baryon couples to the proton are small. Great sensitivity of the resonances to the $\Delta\pi$ channel is expected [10]. Particularly, the ratio of the decay angular momenta between Δ and π will be accessible. No baryons with spin greater than 3/2 have been included in the calculations, but all resonances below 1.94 GeV/ c^2 were considered.

The observables are very sensitive to particular kinematic variables and in some cases, exhibit large values. The anticipated statistical error of 0.05 will be sufficient to distinguish between the different resonant contributions in the model presented in Fig. 2.

SUMMARY

The measurement of single- and double-polarization observables in a variety of final states is required to disentangle broadly overlapping resonances in photoproduction. The FROST program at JLab is currently scheduled for data taking in 2007 using a polarized tagged-photon beams and longitudinally- as well as transversely-polarized protons.

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