Measurement of $\pi^+\pi^-$ Photoproduction in Double Polarization Experiments using the CLAS Spectrometer

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Abstract. Spectroscopic predictions based on first principles are not possible in the non-perturbative regime of Quantum Chromodynamics (QCD) where the strong coupling constant is large. For this reason, effective theories and models have been developed to determine the masses, couplings, and decay widths of resonances. Various constituent quark models (CQMs) based on three quark degrees of freedom predict numerous baryon resonances that have not been experimentally verified and are thus “missing”. The persistent non-observation of these states would present a big problem as the models would have failed to describe physical reality. CQMs predict strong couplings of these unobserved or missing states to γN as well as to $N\eta$, $N\eta'$ or $\Delta\pi$ ($\Delta \rightarrow p\pi$) making photoproduction experiments a promising method to find these missing resonances. Previous analyses of unpolarized data show the importance of polarization observables because some resonances reveal themselves more clearly in the interference with more dominant amplitudes. In addition, the determination of resonant contributions based on unpolarized data is not unique and requires further constraints provided by single- and double- polarization observables in the Partial Wave Analysis (PWA). A linearly- and circularly-polarized photon beam will be incident on a frozen-spin butanol target in Jefferson Lab’s Hall B CLAS detector located in Newport News, Va. This detector allows the target to be polarized both longitudinally as well as transversely giving rise to measurable polarization observables in $\pi^+\pi^-$ photoproduction. This experiment (FROST) will shed some light on the problem of the missing baryon resonances serving to better understand the properties of these states.

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INTRODUCTION

A problem encountered in hadron spectroscopy is the fact that the excited states of the nucleon are not seen as cleanly separated spectral lines. Instead the spectrum contains resonance states that are both broad and overlapping. The prediction of these states is also difficult as the QCD Lagrangian is not solvable at low energies because of the large value of the strong coupling constant and as of yet we have no usable lattice-QCD calculations derived from a fundamental theory. Constituent Quark Models (CQM) and corresponding predictions are based on three quark degrees of freedom and show good agreement with measured resonance properties in the low-energy regime [1]. The experimental motivation is not to test these models, but rather to use them as guides for finding the regions containing the most interesting physics. The region of interest for this experiment is the region around 1.8 GeV and above in which the majority of these “missing” resonances lie as predicted by the CQMs [2].

There are several reasons as to why these states have not yet been observed. First

of all, the bulk of the data regarding baryon resonance production has come from πN scattering experiments. These missing baryon resonances, as suggested by CQM's, may not couple strongly to πN but rather to γN . Photoproduction data (πN scattering) has just been taken fairly recently by the CLAS Collaboration and the CB-ELSA Collaboration in Bonn, Germany. Channels with more than one meson in the final state have not fully been explored (such as $\pi^+ \pi^- N$, $\pi^0 \pi^0 N$, $\pi \eta N$). Furthermore, polarization constraints have only been available at low energies (and usually only either the beam or target is polarized) and as one moves higher in energy, these resonances become more broad and overlapping making polarization even more crucial in identifying these “missing” resonances.

For a two-meson final state, the cross section is given by :

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

Where I is the reaction rate I_0 is the unpolarized reaction rate, $\vec{P}$ represents the polarization asymmetry that arises if at least the target nucleon is polarized and $\vec{\Lambda}_i$ denotes the polarization of the initial nucleon. The degree of circular polarization of the photon beam is denoted by $\delta_{\odot}$, the degree of linear polarization is denoted by δ_l and β denotes the orientation of the linear polarization with respect to the reaction plane. The $\mathbf{I}^s$ and $\mathbf{I}^c$ are the sine and cosine contributions of the observables arising from the use of a polarized photon beam. All of these polarization observables can be isolated through the use of different polarization settings. In the following $\rightarrow$ and $\leftarrow$ indicate circular polarization of the beam in its two possible settings, $\Rightarrow$ and $\Leftarrow$ indicate long. target polarization parallel or anti-parallel to the beam. Then (1) yields:

$$(\rightarrow\Rightarrow - \leftarrow\Leftarrow) := \frac{d\sigma(\rightarrow\Rightarrow)}{dx_i} - \frac{d\sigma(\leftarrow\Leftarrow)}{dx_i} = 2 \cdot \sigma_0 \{ \delta_{\odot} (\mathbf{I}^{\odot} + \Lambda_z \cdot \mathbf{P}_z^{\odot}) \} \quad (2)$$

$$(\leftarrow\Leftarrow - \rightarrow\Rightarrow) := \frac{d\sigma(\leftarrow\Leftarrow)}{dx_i} - \frac{d\sigma(\rightarrow\Rightarrow)}{dx_i} = 2 \cdot \sigma_0 \{ \delta_{\odot} (-\mathbf{I}^{\odot} + \Lambda_z \cdot \mathbf{P}_z^{\odot}) \} \quad (3)$$

The above shows the result of flipping only the polarization of the beam. It is obvious that only changing the beam polarization is not sufficient to isolate and extract the polarization observable $\mathbf{P}_z^{\odot}$. Therefore it is necessary to have all four polarization configurations such that $\mathbf{P}_z^{\odot}$ can be determined:

$$(\rightarrow\Rightarrow - \leftarrow\Leftarrow) + (\leftarrow\Leftarrow - \rightarrow\Rightarrow) := \frac{d\sigma_{3/2}}{dx_i} - \frac{d\sigma_{1/2}}{dx_i} = 4 \cdot \sigma_0 \cdot \delta_{\odot} \cdot (\Lambda_z \cdot \mathbf{P}_z^{\odot}). \quad (4)$$

By measuring and studying these observables, we will be able to disentangle these resonances and be able to “peer” inside this baryon spectrum.

EXPERIMENTAL SETUP

The FROST experiment will be carried out at the Thomas Jefferson National Accelerator Facility (JLab). This lab is home to the Continuous Electron Beam Accelerator

FIGURE 1. JLab's CLAS detector. Shown here with its detector components "open".

Facility (CEBAF) as well as three experimental halls : Hall A, Hall B, Hall C. Inside of Hall B, there is the CEBAF Large Acceptance Spectrometer (CLAS) (Fig. 1). The CLAS spectrometer is divided into six sectors by a superconducting, toroidal magnet. Immediately surrounding the target area a set of start counters made up of 24 scintillators arranged in six sectors. Moving from the inside of CLAS to the outside, there is another set of scintillators following the drift chambers. These scintillators are the time-of-flight scintillators which provide timing information to be used with the particle tracks and the start counter in order to find the velocities and energies of the outgoing particles. Finally, in the forward region of CLAS are the calorimeters which have been used primarily to detect the electron in ep-scattering experiments.

The broad-range tagging facility in Hall B at JLab has reliably provided two kinds of tagged-photon beams. A well oriented diamond radiator is used for production of a linearly-polarized photon beam by means of coherent bremsstrahlung radiation. The degree of photon polarization is a function of the fractional photon beam energy and collimation, with the ability to reach values of 80% to 90%. A circularly-polarized photon beam is produced using a beam of longitudinally polarized electrons incident on a bremsstrahlung radiator made of gold plated on a thin carbon foil. The values of photon polarization range from 60% to 99% of the incident electron beam polarization for photon energies between 50% and 95% of the incident electron energy.

The current polarized NH_3 target for use with the CLAS spectrometer is a dynamically polarized target and was used mainly for electroproduction experiments. The polarizing magnet utilizes a pair of 5 T Helmholtz coils resulting in longitudinal polarization. This magnet, however, is large and requires the target to sit inside of the magnet limiting the available opening to 55 degrees in the forward direction, blocking a significant portion of outgoing particles.

The FROST target uses butanol ($\text{C}_4\text{H}_9\text{OH}$) as the target material to produce both longitudinal as well as transverse polarization with a minimum amount of material between the target and CLAS. This FROST target will operate in a position such that the target cell will be in the geometrical center of CLAS. It will be polarized outside of CLAS and during data-taking, will reside in a low magnetic holding field. The target material will be polarized through microwave irradiation in a strong magnetic field of

5 T in an environment of 0.5 K. In the process of dynamic polarization, free electrons are polarized by a strong magnetic field and then microwaves are used to transfer that polarization to the nucleon. When maximum polarization is attained and the dilution unit is turned on, the spin of the protons remains frozen in a 0.5 T magnetic field at a temperature of 50 mK. A butanol target with an initial proton polarization of 90% has a relaxing time of several days under this procedure giving sufficient time for a useful polarized target experiment. Repolarization is required once the target's polarization has decomposed down to about 50-60%.

The process of dilution refrigeration freezes the spin of the proton at temperatures of about 50 mK (which cannot be obtained through the normal use of liquid helium). Dilution refrigeration works on the principle that when a mixture of the two stable isotopes of helium, He_3 and He_4 , is cooled below a critical temperature, it separates into two phases. The lighter "concentrated phase" is rich in He_3 , and the heavier "dilute phase" is rich in He_4 . Since the enthalpy of the He_3 in the two phases is different, the "evaporation" of He_3 from the concentrated phase into the dilute phase provides highly effective cooling. This process works even at the lowest temperatures because the equilibrium concentration of He_3 in the dilute phase is finite even at zero temperature.

For longitudinal target polarization, the holding magnet is a solenoid in design. Three layers of NbTi superconducting wire will provide a central field intensity of up to 0.5 T with a homogeneity over the entire target of less than 0.5%. The design for the transverse holding magnet is a dipole magnet with racetrack shaped coils. There are two coils, one on top of the supporting cylinder and one on the bottom with both coils being made from one continuous NbTi superconducting wire. This holding coil will produce a field of 0.5 T with a homogeneity of better than 0.8% using three layers of superconducting wire. The determination of polarization observables using FROST is a crucial step toward shedding some light on the missing resonance problem. The testing and final modifications of the FROST target will be completed by the end of summer 2007. Data taking is scheduled to begin October 2007.

REFERENCES

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