Polarization Observables in $\gamma p \rightarrow K^+ + \Lambda$ and $K^+ + \Sigma^0$ Using Circularly Polarized Photons on a Polarized Frozen Spin Target

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(Received December 15, 2015)

The search for undiscovered excited states of the nucleon continues to be a focus of experiments at the Thomas Jefferson National Accelerator Facility (JLab). A large effort using the CEBAF Large Acceptance Spectrometer (CLAS) detector has provided the database, which will allow nearly model-independent partial wave analyses (PWA) to be carried out in the search for such states. Polarization observables play a crucial role in the effort, as they are essential in disentangling the contributing resonant and non-resonant amplitudes. Recent coupled-channel analyses have found strong sensitivity of the K^++Λ channel to several higher mass nucleon resonances. In 2008 and 2010, double-polarization data were taken at JLab using circularly and linearly polarized tagged photons incident on a longitudinally and transversely polarized frozen spin butanol target (FROST), operated at the temperature of 30 mK. The reaction products were detected in CLAS. This work is based on the analysis of FROST data and the extraction of the T and F asymmetries of the $K^+\Lambda$ and $K^+\Sigma^0$ final states and their comparison to predictions of recent multipole analyses. There are very few published measurements of the T asymmetry and none for the F asymmetry for the $K^+\Lambda$ final state. The $K^+\Sigma^0$ final state has no published measurements for these asymmetries. Comparison of CLAS results with the phenomenological models MAID, Bonn Gatchina, and RPR-Ghent will be shown. This work is the first of its kind and will significantly broaden the world database for these reactions.

KEYWORDS: photoproduction reactions; meson production; baryon production; polarization in interactions and scattering.

1. Introduction

Quantum Chromodynamics (QCD) is the theory that describes the strong force acting between quarks, but is only solvable at very low energies and high energies where pertubative methods are applicable. The nucleon spectrum can lead to an understanding of the dynamics and relevant degrees of freedom with hadrons in the non-perturbative regime of QCD. At medium energies, such as experiments performed at JLab, non-pertubative approximation models are necessary to describe the behavior of quarks inside of hadrons. The Constituent Quark Model (CQM) describes the hadron spectrum by means of valence quarks and correlations of gluons and sea-quarks, which contribute to effective, or constituent quark masses of the valence quarks. For baryons, three constituent quarks are considered. Resonances can then be described from the radial or angular momentum excitations of these valence quarks in a harmonic oscillator potential. A discrepancy known as the 'missing resonance problem' exists between the number of states that have been predicted and those states that have been observed. [1] Those that have not been observed could be due to the fact that they do not exist or that they exist, but current experiments have not been able to detect them. Most data was found using pion beams and in recent years, real photon beams have been more readily accessible.

The interaction between photon beams and nucleons is described by four complex amplitudes, which are fully determined when a complete set of measurements is performed. These four complex amplitudes give rise to the cross-section, complemented by polarization observables including beam, target, and recoil asymmetries and combinations of beam-target, beam-recoil, and target-recoil polarization asymmetries. This work is specifically concerned with the measurements of the T and F polarization observables. Both are accessed with a transversely polarized target and an unpolarized photon beam (T asymmetry) or circularly polarized photon beam (F asymmetry).

T and F can be defined as follows:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}(1 + TP_T \sin\phi + FP_cP_T \cos\phi) \tag{1}$$

where P_T is the transverse polarization of the target, P_c is the circular polarization of the beam, and ϕ is the angle between the target spin and the reaction plane.

2. Experimental Setup

The FROST (FROzen Spin Target) experiment with transversely polarized target was performed at JLab in the spring and summer of 2010. The FROST target consists of butanol cooled to a temperature of approximately 30 mK by means of a ^{3}He/^{4}He dilution refrigerator in order to maintain polarization with long relaxation times. [2] The decay products of the $K^+\Lambda$ and $K^+\Sigma^0$ final states were detected in CLAS in Hall B of JLab [3] and data was gathered on all single and double polarization observables. The detector was built around a superconducting torus magnet, providing a field-free region around its center where the target was located. Thus, CLAS was exceptionally well suited for the use of a transversely polarized target, which could not be realized using a detector with a more conventional solenoidal field. The incident photon beam, from 0.5 to 2.4 GeV, was produced by means of bremsstrahlung from high-energy electrons; the interaction time and energy of the deflected electrons were measured in a high-resolution tagging system. [4] Circularly polarized photons with up to 80% polarization were produced from the longitudinally polarized electrons on an amorphous radiator.

3. Analysis and Results

Once events have been collected, the raw data was calibrated and four-vectors were reconstructed using the CLAS detector information. The desired events of the final states $K^+\Lambda$ and $K^+\Sigma^0$ were identified using cuts on β and cuts on the reaction vertex along with well-known missing mass technique. Using a plot of β versus momentum, the proton and kaon can be explicitly identified. The missing mass of the detected proton and kaon is deduced using the invariant mass of the initial incoming photon and target proton. A loose cut is made around the missing π^- from 0.05 to 0.30 GeV and the Λ and Σ^0 peaks are clearly identified. The extracted Λ and Σ^0 signals are both fit with Gaussians, the background fit with a cubic polynomial, and a global fit performed over the mass range (here, from 1.05 to 1.3 MeV) for each $\cos\theta$ bin in order to separate the background. An example of the background separation can be seen in Fig. 1. The isolated quantities of Λ and Σ^0 can then be used to determine the polarization observables using a Fourier moment method.

Using the Fourier moment method, the signs of the polarization terms (P_T, P_C) in Eq. 1 are explicitly written out, e.g. after summing over both photon helicity states:

$$\sigma^{(+)} = \sigma_0[1 + |P_T^{(+)}| sin\phi], \quad \sigma^{(-)} = \sigma_0[1 - |P_T^{(-)}| sin\phi] \tag{2}$$

such that

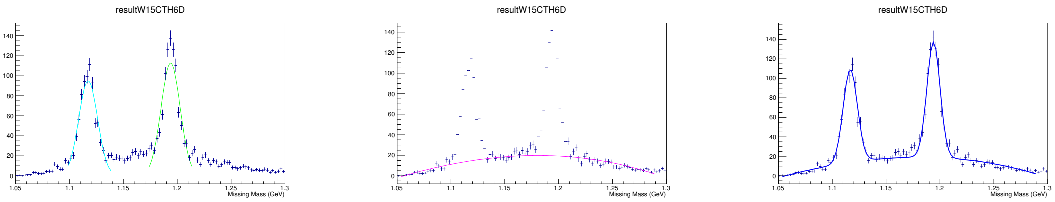

Fig. 1. Example fits for one selected bin $W = 1875$ MeV in $\cos\theta = 0.3$. Left figure shows the Gaussian fit, followed by the cubic polynomial fit (middle), and finishing with the global fit (right).

$$T = \frac{\sigma^{(+)} - \sigma^{(-)}}{\sigma^{(+)} + \sigma^{(-)}} = \frac{2(N^{(-)}Z_1^{(+)} - N^{(+)}Z_1^{(-)})}{N^{(-)}P_T^{(-)}(H_0^{(+)} - H_2^{(+)}) + N^{(+)}P_T^{(+)}(H_0^{(-)} - H_2^{(-)})} \tag{3}$$

where $N^{()}$ are the target polarization directions, $Z_n^{()}$ are the n-th sin moments and $H_n^{()}$ are the n-th cos moments for positive and negative target-polarization orientation, respectively. A similar expression can be obtained for the F asymmetry. [5]

The T asymmetry for $K^+\Lambda$ (left) and $K^+\Sigma^0$ (right) can be seen in Fig. 2. For $K^+\Lambda$, it can be seen that the data and model predictions appear to have a similar trend in energies up to $W = 2150$ MeV. At lower energies, the CLAS and GRAAL data are mostly in agreement. The GRAAL data is extracted using a combined fit of O_x, T, and O_z from double polarization data and not a polarized target, and the GRAAL data does not go as high in energy as the CLAS data. For $K^+\Sigma^0$, there is no previous published data. Here, none of the models appear to agree with the data, but has a similar trend as the Bonn-Gatchina model. At lower energies, the T asymmetry appears to start positive and end negative and around $W = 1950$ MeV, switches and starts negative and ends positive.

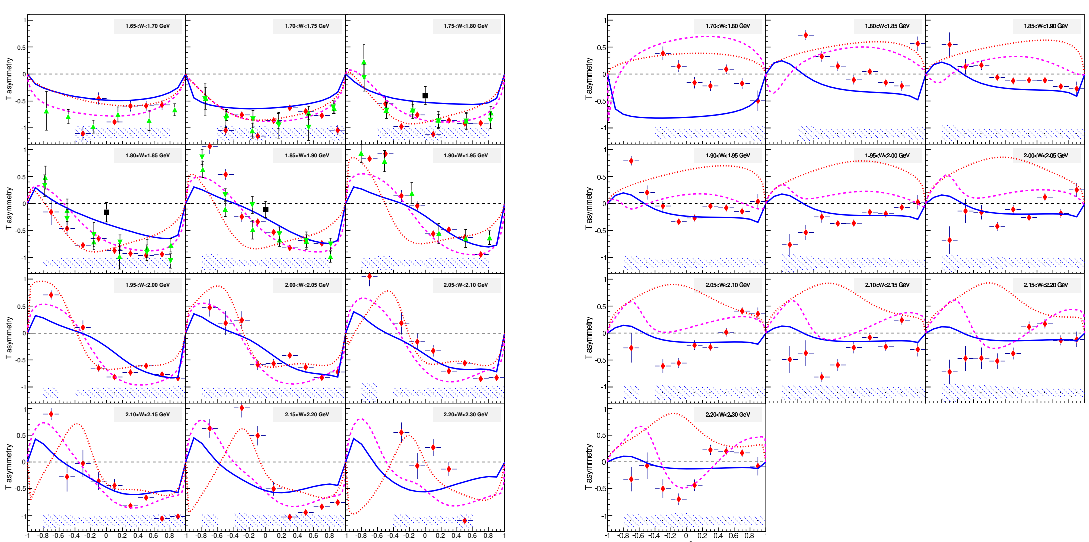

Fig. 2. Preliminary T asymmetry for $K^+\Lambda$ (left) and $K^+\Sigma^0$ (right). The red diamond data is CLAS g9b data, green triangles are GRAAL data (2009) [8], and the black circles are Bonn data (1978) [9]. The blue solid curve is the Kaon-MAID model [6], the red dotted curve is the RPR-Ghent model [10], and the magenta dashed curve is the Bonn-Gatchina model [7]. Results are mostly binned in 50 MeV and include statistical and systematic errors (indicated in blue shade).

The F asymmetry for $K^+\Lambda$ (left) and $K^+\Sigma^0$ (right) can be seen in Fig. 3. For both $K^+\Lambda$ and $K^+\Sigma^0$, there are no previously published results. For $K^+\Lambda$, the F asymmetry is around zero until $W = 1825$ and has changes in sign with increasing energies. None of the models agree with the data. Similarly, F for $K^+\Sigma^0$ hovers around zero as well and none of the models agree with the data here either.

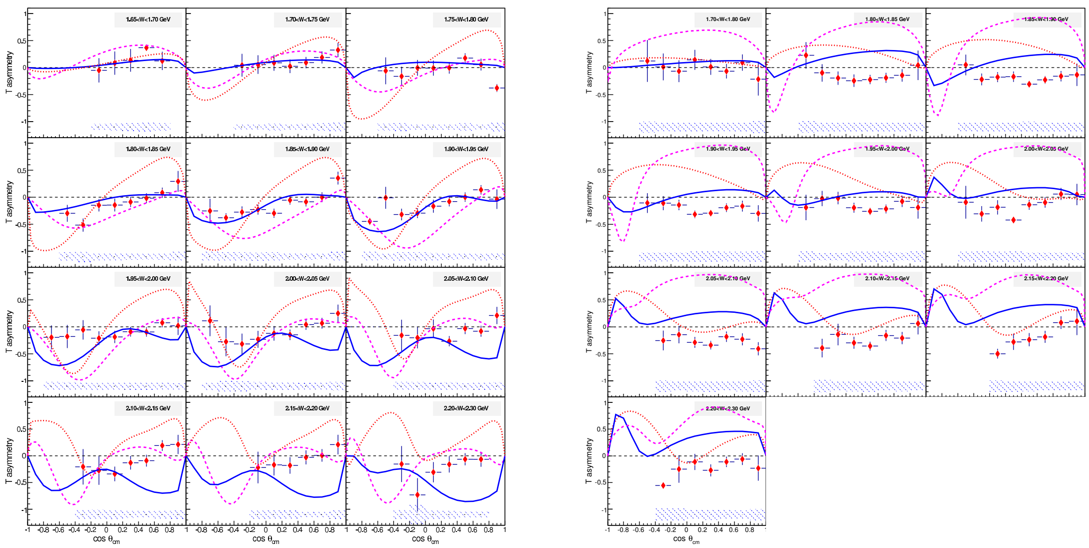

Fig. 3. Preliminary F asymmetry for $K^+\Lambda$ (left) and $K^+\Sigma^0$ (right). The red data is CLAS g9b data. The blue solid curve is the Kaon-MAID model [6], the red dotted curve is the RPR-Ghent model [10], and the magenta dashed curve is the Bonn-Gatchina model [7]. Results are mostly binned in 50 MeV and include statistical and systematic errors (indicated in blue shade).

In conclusion, measurements with kaons will help in accessing properties of N^* and Δ^* states. The results from CLAS range in energies never detected before, and due to the lack of kaon data in the world database, these results will provide answers in constraining the current PWA models and help to extract undiscovered states of the nucleon.

4. Acknowledgments

Our work at Jefferson Lab is supported in parts by the U.S. National Science Foundation: NSF PHY-0969434. Jefferson Science Associates operates the Thomas Jefferson National Accelerator Facility under DOE contract DE-AC05-84ER40150.

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