Polarization of the Cascade Hyperon in Photoproduction

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The weak decay of hyperons offers a valuable means of measuring their polarization, which provides insight into the mechanisms behind hyperon production. Jefferson Lab's CLAS collaboration has utilized this property of hyperons, publishing the most precise polarization measurements for the Λ to date in both photo and electroproduction [1, 2, 3]. In contrast, no such studies have been obtained for the Ξ^- in photoproduction due to a low production cross section and the resulting lack of data. However, CLAS data were collected in 2008 with a luminosity of $68pb^{-1}$ using a circularly polarized photon beam with energies up to 5.45 GeV and a liquid hydrogen target. This dataset is, at present, the world's largest for photoproduction in this energy range and provides a first time opportunity to study the polarization of the Ξ^- in photoproduction. Preliminary results displaying polarization in bins of beam energy and center of mass Ξ^- angle are shown along with basic features of the data. A comparison with upcoming polarization predictions from various theoretical production models and experimental results will help constrain the production mechanism.

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1. Introduction

1.1 Motivation

Despite extensive and successful research into the production of baryons with strangeness quantum number $S = -1$ like the Λ and Σ, little is understood about the production of $S = -2$ cascade states. Since the discovery of the Ξ ground state in the 1950's, the spectrum of excited states have remained experimentally elusive. So far, only six cascade states are considered to be well established [4]. While the Ξ^- production mechanism is still unclear, recent CLAS measurements of the differential cross sections [5], together with some existing models [6], suggests the leading contribution comes through intermediate $S = -1$ high-mass hyperon resonances. However, the results of [5] did not include any polarization measurements, though it was pointed out that the contributions from various hyperons states can be differentiated using the Ξ^- spin observables [7]. The model of $\gamma p \rightarrow K^+ K^+ \Xi^-$ production, as outlined in Ref. [7], is based on a relativistic meson-exchange of hadronic interactions where the production amplitudes are calculated from the relevant effective Lagrangian in the tree-level approximation [6]. Ultimately, measurement of the Ξ^- spin observables will help shed light on the mechanisms behind the production of strangeness and the hadronic processes that give rise to hyperon polarization, which should be different for the $S = -2$ cascades from the $S = -1$ baryons, due to their different di-quark configurations.
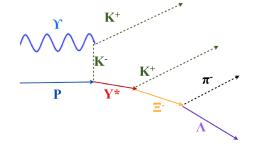
1.2 Method

Figure 1: A t-channel model for the $\gamma p \rightarrow K^+ K^+ (\Xi^-) \rightarrow K^+ K^+ \pi^- (\Lambda)$ reaction.

The production channel of interest for this analysis is $\gamma p \rightarrow K^+ K^+ \Xi^-$, which is shown as a t-channel process in Fig. 1. Experimentally, the polarization of the Ξ^- can be accessed through measuring the angular distribution of its emerging decay products in the $\Xi^- \rightarrow \pi^- \Lambda$ decay. The appropriate reaction to be studied is then, $\gamma p \rightarrow K^+ K^+ (\Xi^-) \rightarrow K^+ K^+ \pi^- (\Lambda)$, which requires the detection of two positive kaons and one negative pion in the final state. The angular distribution of the decay π^- as measured in the rest frame of the Ξ^- is related to the Ξ^-'s polarization by,

$$I(\theta_\pi^{\hat{i}}) = \frac{N}{2}(1 + P_{\Xi_i}\alpha\cos\theta_\pi^{\hat{i}}). \tag{1.1}$$

where,

- $\theta_\pi^{\hat{i}}$ is the pion angle across the i-axis in the Ξ^- rest frame,

- $I(\theta_\pi^{\hat{i}})$ is the yield or number of events in the bin centered around $\theta_\pi^{\hat{i}}$,

- N is the total number of events in the sample,

- P_{Ξ_i} is the i-component of the Ξ^- polarization $\vec{P}_\Xi$, and

- α is the Ξ^- decay asymmetry or analyzing power with α = -0.458 [4].

Thus, the parameters of a first-degree polynomial fit to the acceptance corrected yield vs θ_π plots can provide a measurement of the Ξ^- polarization. The polarization can be measured across three coordinates, x,y and z corresponding to polarization observables C_x, P and C_z respectively. The axes are defined in the Ξ^- rest-frame according to.

$$\hat{z} = \hat{p}_\gamma,$$
$$\hat{y} = \hat{z} \times \hat{p}_\Xi, \qquad (1.2)$$
$$\hat{x} = \hat{y} \times \hat{z},$$

The spin observables P, C_x and C_z are connected to the recoil polarization $\vec{P}$ through,

$$P_{\Xi_x} = P_\odot C_x,$$
$$P_{\Xi_y} = P, \qquad (1.3)$$
$$P_{\Xi_z} = P_\odot C_z.$$

Where $P_\odot$ is the degree of photon-beam polarization. Experimentally, the induced polarization P, is extracted from the acceptance corrected angular distributions for the π^- directly. As for the polarization transfer observables $C_{x,z}$, they are extracted from the helicity asymmetry

$$A(\cos\theta_\pi^{\hat{i}}) = \frac{N^+ - N^-}{N^+ + N^-} = |P_\odot|\alpha C_i \cos(\theta_\pi^{\hat{i}}) \qquad (1.4)$$

where $N^\pm$ is the yield for positive (negative) photon-beam helicity. The asymmetry method has the benefit that efficiency of the detector cancels to first order and therefore no acceptance corrections need be applied for the calculation of C_x, C_z.

2. Signal

The $K^+ K^+ \pi^-(\Lambda)$ final state allows for not one, but four constraints on the Lorentz-invariant masses in the reaction, which are:

1. Require the invariant mass of $(\gamma + p) - (K^+ + K^+)$ to be the known mass of the Ξ^-.

2. Require the invariant mass of $(\gamma + p) - (K^+ + K^+ + \pi^-)$ to be equal to the known mass of the Λ.

3. Require the invariant mass of $\pi^- + \Lambda$ to be equal to the known mass of Ξ^-

4. Require the invariant mass of $\pi^- - \Xi^-$ to be equal to the known mass of Λ

Figures 2a - 2b show the data after passing all kinematic and timing cuts. After all cuts a nearly background free signal with approximately 5000 events is attained, a globally unprecedented yield for detecting $\Xi^- \to \pi^-(\Lambda)$ in photoproduction.

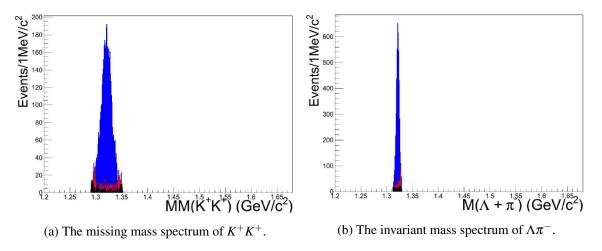The 5000 events shown in the mass plots were used to determinate the Ξ^- polarization observables.

(a) The missing mass spectrum of K^+K^+.

(b) The invariant mass spectrum of $\Lambda\pi^-$.

Figure 2: Shows the Ξ^- signal after a three-sigma cut (blue) over a six and nine-sigma background (red and black respectively)

3. Preliminary Results

Statistics allow for the data to be binned into three photon-beam energy (E_γ) bins and three center-of-mass Ξ^- polar angle (θ_Ξ^{cm}) bins (where the angle is measured relative to the photon beam direction). Fig. 3 shows the acceptance corrected pion angular distribution across the $\hat{y}$ axis with a linear fit that yields the measurement of induced polarization observable P. Figs. 4 and 5 show the asymmetry as a function of pion angle across the x- and z-axis respectively. Superimposed is a linear fit that yields the double polarization observables C_x and C_z.
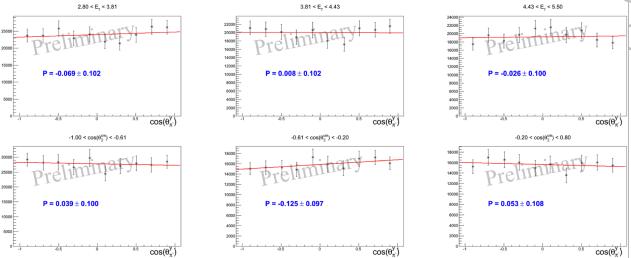

Figure 3: The fitted acceptance corrected angular distribution of the π^- off the $\hat{y}$-axis. The measured value of P in each kinematic bin is given in blue with its associated error. The beam energy and center of mass Ξ^- polar angle binning is given above the plots.
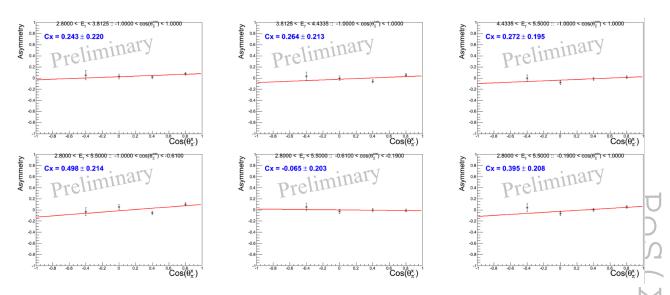
4

Figure 4: The fitted asymmetry as a function $\cos\theta_\pi^{\hat{x}}$. The measured value of C_x in each kinematic bin is given in blue with its associated error. The beam energy and center of mass Ξ^- polar angle binning is given above the plots.
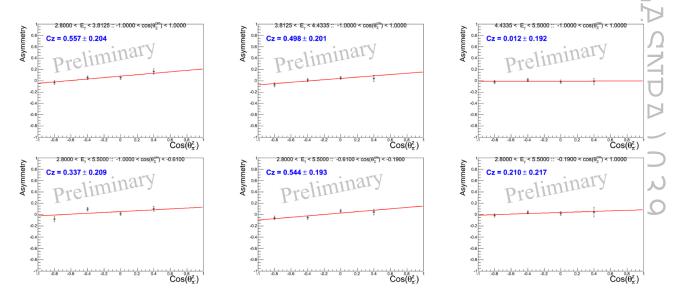

Figure 5: The fitted asymmetry as a function $\cos\theta_\pi^{\hat{z}}$. The measured value of C_z in each kinematic bin is given in blue with its associated error. The beam energy and center of mass Ξ^- polar angle binning is given above the plots.

4. Discussion

Preliminary results show a positive transfered polarization and an induced polarization consistent with zero in most kinematic bins. The three polarization observables should also satisfy the unitary condition of $C_x^2 + C_z^2 + P^2 \leq 1$ [8], and our results are consistent with this constraint. Results will be compared with predictions from theory so that models of production can be constrained.

5. Conclusion

Preliminary results of the induced polarization,*P*, are consistent with zero for all kinematic regions. The measurement of C_x and C_z are also mostly positive or consistent with zero. These results are a first time measurement for the Ξ^- polarization in photoproduction. The final results will be compared with prediction from at least one detailed theoretical model of Ξ photoproduction. Future high statistics data at CLAS12 and GlueX are needed in order to obtain the kinematic evolution of polarization observables.

References

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