Studies of Λn Interaction Through Polarization Observables For Final-State Interactions In The $\vec{\gamma}d \to K^+\vec{\Lambda}n$ Reaction

Yordanka Ilieva[1], Tongtong Cao[1], and Nicholas Zachariou[2], for The CLAS Collaboration

[1] *University of South Carolina, 712 Main St., Columbia, SC 29205, USA*
[2] *University of Edinburgh, Peter Guthrie Tait Road, Edinburgh EH9 3FD, Great Britain*

(Received December 13, 2015)

We present preliminary experimental estimates of the polarization observables Σ, O_x, O_z, C_x, and C_z for final-state interactions (FSI) in exclusive Λ photoproduction off the deuteron. The observables are predicted to be sensitive to the parameters of hyperon-nucleon potentials, which are important for the understanding of hypernuclear matter and neutron stars. The observables were obtained from data collected during the E06-103 (g13) experiment with the CEBAF Large Acceptance Spectrometer (CLAS) in Hall B at Jefferson Lab. The experiment ran with unpolarized deuteron target and both, circularly- and linearly-polarized photon beams with energies between 0.5 GeV and 2.5 GeV. The events of interest were selected by requiring that the kaon and the Λ decay products, a proton and a negative pion, were detected in CLAS and that the mass of the missing state was consistent with the neutron mass. Final-state-interaction events were selected by requesting that the reconstructed neutron had a momentum larger than 200 MeV/c. The large statistics of E06-103 provided statistically meaningful FSI event samples, which allow for the extraction of one- to four-fold differential single- and double-polarization observables. Our results are the very first estimates of polarization observables for FSI in hyperon photoproduction and will be used to constrain the free parameters of hyperon-nucleon potentials. This work is supported in part by the U.S. National Science Foundation under grant PHY-125782.

KEYWORDS: hyperon-nucleon scattering, photoproduction, polarization observables, final-state interactions

1. Introduction

Theoretical studies suggest that experimental observables for hyperon photoproduction reactions can be used to constrain the low-energy scattering parameters of hyperon-nucleon (YN) potentials [1–11].

In a simplified picture, the $\gamma d \to K^+\Lambda n$ reaction can be viewed in terms of elementary two-body-to-two-body mechanisms. The quasi-free (QF) production, in which the kaon and the hyperon are produced off the bound proton and the neutron acts as a spectator, dominates the cross section. Two-step mechanisms (or final-state interactions, FSI), in which one of the particles produced on one target nucleon then scatters off the other nucleon, have smaller contributions. Of all such FSI, the mechanism in which the Λ is first produced off the bound proton and then scatters elastically off the bound neutron, is of interest for YN studies as it allows access to the Λn elastic scattering amplitude. Other FSI include kaon rescattering, pion-mediated, and sigma-mediated production, which are all backgrounds for the YN study. Extracting information about the YN scattering amplitude from $\gamma d \to K^+\Lambda n$ data, therefore, requires theoretical modeling of the background mechanisms and experimental coverage of a broad kinematic range that can be explored in detail to identify kinematics where the Λ rescattering dominates. Estimates of the low-energy YN-potential parameters can be obtained from

model fits to the data. The theoretical uncertainties of these parameters can be significantly reduced if a large set of $\gamma d \to K^+\Lambda n$ observables is included in the fits. Here, we discuss only polarization observables.

At a given photon energy E_γ, the polarized differential cross section for KY photoproduction off an unpolarized free-nucleon target is

$$\begin{aligned}\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega_0}(1 \quad &- \quad P_{lin}\Sigma\cos 2\phi + \alpha\cos\theta_x(-P_{lin}O_x\sin 2\phi - P_{circ}C_x) - \alpha\cos\theta_y(-P + P_{lin}T\cos 2\phi) \\ &- \quad \alpha\cos\theta_z(P_{lin}O_z\sin 2\phi + P_{circ}C_z)), \qquad (1)\end{aligned}$$

where $d\sigma/d\Omega_0$ is the unpolarized cross section, P_{lin} and P_{circ} are the linear and the circular polarization of the photon beam, respectively; ϕ is the angle between the photon linear-polarization vector and the reaction plane (see Fig. 1); α is the self-analyzing power of the Λ; $\cos\theta_x$, $\cos\theta_y$, and $\cos\theta_z$ are the direction cosines of the three-momentum vector of the decay proton in the rest frame of Λ (see Fig. 1), and Σ, P, T, O_x, O_z C_x, and C_z denote the beam-spin asymmetry, the Λ induced polarization, the target asymmetry, and the polarization transfers from linearly- and circrularly-polarized photons to the hyperon, respectively. The expression of the polarized cross section for the $\gamma d \to K^+\Lambda n$ reac-

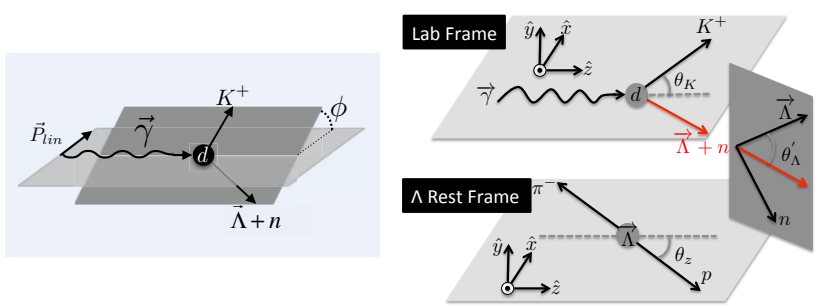

Fig. 1. Left: The azimutal angle ϕ used in Eq. (1) is the angle between the photon linear-polarization vector and the reaction plane. Right: Definition of a Cartesian Reference Plane for the extraction of the polarization observables described in Eq. (1). The Z axis points in the direction of the incoming photon. The Y axis is in the direction of the vector product of the photon and the kaon 3-vectors. The X axis complements Z and Y to a right-handed reference frame. The angles θ_x, θ_y, and θ_z are defined in the rest frame of Λ. The angle θ'_Λ is the angle between the 3-vector of Λ and the 3-momentum-vector transfer to the Λn system in the lab frame.

tion is more complicated than Eq. (1) as there are three particles in the final state. More observables, such as helicity asymmetries, can be estimated. Here, we focus only on the observables Σ, O_x, O_z, C_x, and C_z.

2. Experimental Data and Preliminary Results

The data were collected with the CLAS in Hall B at Jefferson Lab during the E06-103 (g13) experiment [12]. A tagged real-photon beam was incident on a 40-cm-long liquid deuterium target located 40 cm upstream from the center of the CLAS. Data were taken with both, circularly- and linearly-polarized photon beams. The energy and the polarization of the circularly-polarized photons were in the ranges 0.5 GeV – 2.5 GeV and 30% – 80%, respectively. The energy of the coherent edge for linearly-polarized photons was 1.1 GeV, 1.3 GeV, 1.5 GeV, 1.7 GeV, 1.9 GeV, 2.1 GeV, and 2.3 GeV, while the average photon polarization was 75%.

The events of interest were selected by requiring that the kaon and the Λ decay products, a proton and a negative pion, were detected in CLAS and that the mass of the missing state was consistent with

the neutron mass. Final-state-interaction events were selected by requesting that the reconstructed neutron has a momentum larger than 200 MeV/c. The latter constraint is very important as it significantly reduces the contribution of QF events to our data sample. To obtain the reaction yields, accidental and physics background events were removed on a bin-per-bin basis.

Our preliminary results for Σ, O_x, and O_z, as functions of E_γ, θ'_Λ, p_K, and $IM_{\Lambda n}$ are shown in Fig. 2. Here, $IM_{\Lambda n}$ denotes the invariant mass of the Λn system and p_K denotes the kaon momentum in lab system. One can see that the beam-spin asymmetry is relatively large and negative at all

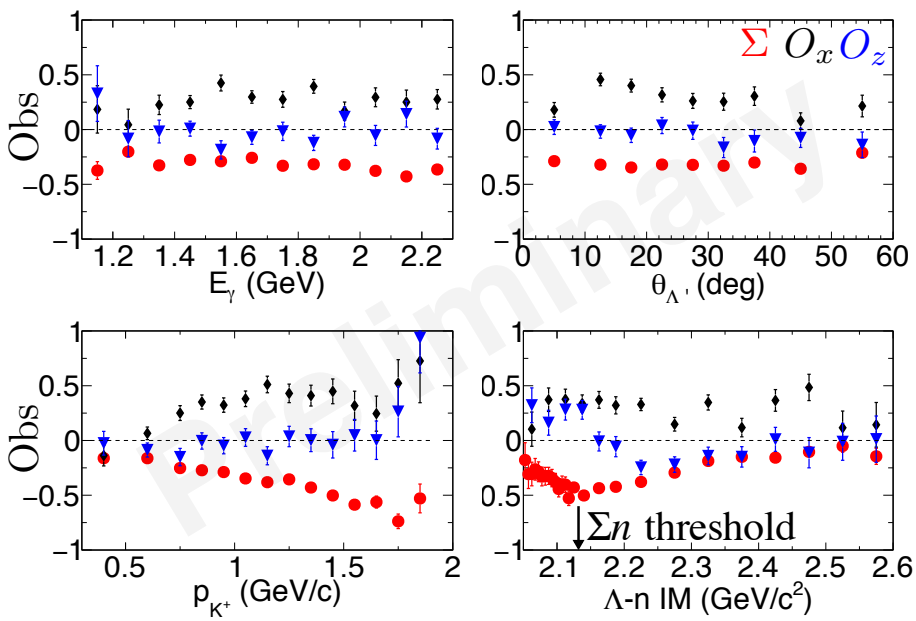

Fig. 2. Preliminary one-fold differential estimates of Σ, O_z, and O_x as functions of E_γ (top left), θ'_Λ (top right), p_K (bottom left), and $IM_{\Lambda n}$ (bottom right). The observables are integrated over all other kinematic variables. Only statistical uncertainties are shown. The Σ is binned very finely in $IM_{\Lambda n}$ in the range below the Σn threshold to demonstrate the statistical uncertainties of the data and the potential to apply the method of [10] to extract an estimate of a spin-averaged Λn scattering length.

kinematics, while the polarization transfer along the photon direction, O_z, seems to be almost zero. The polarization transfer O_x is mostly positive and significantly non-zero. Overall, the three observables show very little E_γ and θ'_Λ dependence when integrated over all other kinematic variables. The dependence of Σ on the Λn invariant mass suggests that the observable increases in magnitude up to the Σn threshold, where it reaches a value of -0.5, and decreases in magnitude at higher Λn invariant masses. Fits to the data below the Σn threshold will be done in order to extract an estimate of a spin-averaged Λn scattering length. For a separation of the $^1S_0$ and $^3S_1$ scattering lengths, data with polarized deuteron target are needed.

Our preliminary one-fold differential estimates for the polarization transfers C_x and C_z for both, QF production and FSI are shown in Fig. 3. Similarly to the beam-spin asymmetry, C_x and C_z for FSI show very weak dependence on E_γ when they are integrated over all other kinematic variables. To maximize statistics, we will focus on extracting the observables in bins of the other kinematic variables and will integrate over E_γ. These two observables can be used to probe in more detail the FSI dynamics, especially when the K^+ and Λ are produced in the second step through the pion-mediated mechanism. In this case, the expected values of C_x and C_z, in a proper reference frame, are zero since the pion beam is unpolarized. Figure 3 also shows four-fold estimates of C_x and C_z for

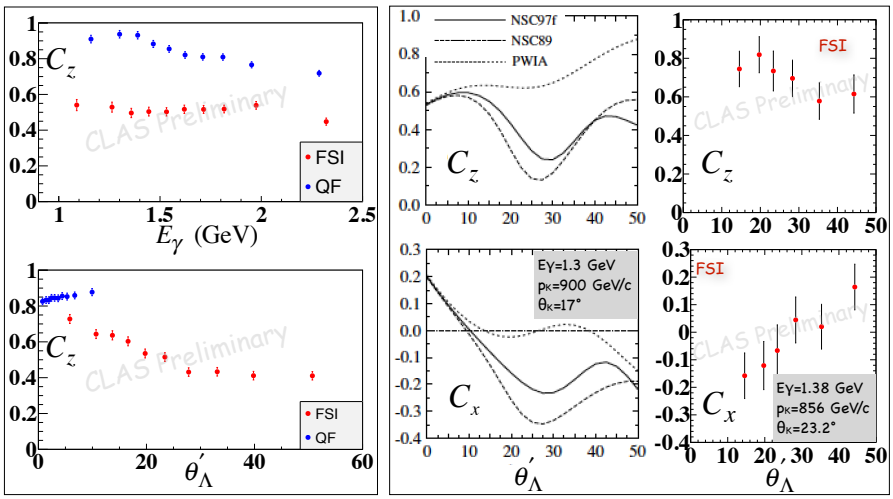

Fig. 3. Left panel: Preliminary one-fold differential estimates of C_z for QF production and FSI as functions of E_γ and θ'_Λ. One can clearly see a sizable effect of FSI. **Right panel:** Right column: Preliminary four-fold differential estimates of C_x and C_z for FSI. The observables are shown as a function of θ'_Λ for the kinematic bin (E_γ = 1.38 GeV, p_K = 856 GeV/c, θ_K = 23.2°). Left column: Model predictions of [6] for the observables in a very similar kinematic bin. The dotted curve shows predictions for QF only. The solid and dashed curves show predictions for QF and Λ rescattering with NSC97f and NSC89 YN potentials, respectively. The data and the model predictions are plotted in the same figure only to demonstrate the statistical uncertainties of the data and the predicted sensitivity to different YN potentials. Direct comparison should not be done. Data error bars include only statistical uncertainties.

kinematics very similar to the one of the model predictions of [6]. Our results show that the expected statistical uncertainties of four-fold differential estimates are reasonable for the YN study, especially in view of the fact that the full set of observables will be simultaneously fitted.

In summary, we have presented preliminary estimates for the observables Σ, O_x, O_z, C_x, and C_z for FSI in the reaction $\vec{\gamma}d \rightarrow K^+\vec{\Lambda}n$. One- to four-fold differential estimates are extracted with reasonable statistical uncertainties. Each of these observables can be used to identify kinematics where a specific FSI mechanism is dominant. The beam-spin asymmetry can be binned finely at low $IM_{\Lambda n}$ to be suitable for the extraction of a spin-averaged Λn scattering length. Work is in progress to estimate the systematic uncertainties of the observables and to establish reliable methods for their physics interpretation. Our data have sufficient coverage and statistical significance to impact the studies of the YN interaction.

References

[1] B.O. Kerbikov, B.L.G. Bekker, and R. Daling: Nucl. Phys. A **480** (1988) 585.
[2] R.A. Adelseck and L.E. Wright: Phys. Rev. C **39** (1989) 580.
[3] X. Li and L.E. Wright: Nucl. Part. Phys. **17** (1991) 1127 and references therein.
[4] H. Yamamura *et al.*: Phys. Rev. C **61** (1999) 014001.
[5] O.V. Maxwell: Phys. Rev. C **69** (2004) 0346705.
[6] K. Miyagawa *et al.*: Phys. Rev. C **74** (2006) 034002.
[7] A. Salam *et al.*: Phys. Rev. C **74** (2006) 044004.
[8] A. Salam and H. Arenhövel: Phys. Rev. C **70** (2004) 044008.
[9] J.M.-Laget: Phys. Rev. C **75** (2007) 014002.
[10] A. Gasparian *et al.*: Eur. Phys. J. A **32** (2007) 61.
[11] A. Gasparian *et al.*: Phys. Rev. C **69** (2004) 034006.
[12] P. N-Turonski, B.L. Berman, Y. Ilieva, D. Ireland, and A. Tkabladze, *Kaon Production on the Deuteron Using Polarized Photons*, JLab experiment E06-103 (2006).