Measurement of the Induced Polarization of $\Lambda$ (1116) in Kaon Electroproduction with CLAS

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Abstract. The CLAS Collaboration is using the $p(e,e'K'^+p)\pi^-$ reaction to measure the induced polarization of the electroproduced $\Lambda$(1116). In this experiment a 5.499-GeV electron beam was incident upon an unpolarized liquid-hydrogen target. The CEBAF Large Acceptance Spectrometer (CLAS) was used to detect the scattered electron, the kaon, and the decay proton from the $\Lambda$ hyperon. CLAS allowed for a large kinematic acceptance in $Q^2 (0.75 \leq Q^2 \leq 3.5 \text{ GeV}^2)$ and $W (1.6 \leq W \leq 3.0 \text{ GeV})$, as well as the kaon center-of-mass scattering angle. The goal is to map out the kinematic dependencies for the induced polarization in order to provide new constraints on models of $K$-hyperon production. Along with previously published photo- and electroproduction cross sections and polarization observables from CLAS, LEPS, SAPHIR, and GRAAL, these new induced polarization data are needed in coupled-channel analyses to search for previously unobserved $s$-channel resonances. Preliminary polarization results are presented.

Keywords: kaon, hyperon, electroproduction, polarization.

PACS: 13.40.-f, 13.60Rj, 13.88.+e, 14.20.Gk, 14.20Jn

INTRODUCTION

The strange quark plays an important role in understanding the strong interactions of the nucleons. The investigation of strangeness production in both photo- and electroproduction reactions has been carried out since the 1950s, but as of today, there is no comprehensive model describing the reaction mechanism. The present study is part of a larger program to determine cross sections and polarization observables in kaon photo- and electroproduction, with a final goal of developing a comprehensive model of the strangeness production process. The electroproduction cross sections and the polarization observables can be expressed in terms of response functions according to framework of Ref. [1]. A total of 36 independent response functions need to be measured for a complete, model-independent description of this process. Previous experimental work from CLAS has already provided measurements of the unpolarized cross section and corresponding separated structure functions [2], the polarized beam asymmetries [3], and transferred polarizations [4] for kaon electroproduction. Cross sections, along with both induced and transferred polarizations were also measured for kaon photoproduction [5,6,7].

In this work, we have measured the induced polarization of the $\Lambda$(1116) from $e + p \rightarrow e' + K' + \Lambda$. The $\Lambda$ is a strange unstable particle that decays via the weak interaction into either a $p\pi^-$ (64%) or $n\pi^0$ (36%) pair. Since parity is not conserved in the weak decay, the recoil $\Lambda$ polarization can be extracted by measuring the angular distribution of the decay proton in the $\Lambda$ rest frame. We will map out the dependence of the induced polarization as a function of the invariant energy $W$, the four-momentum transfer $Q^2$, and the center-of-momentum kaon scattering angle $\theta_{K^{\text{c.m.}}}$.

These data will ultimately lead to a better understanding of the strange-quark production process. Within the framework of available theoretical approaches, these data, when combined with other electro- and photoproduction data, have the potential to reveal the presence of previously unseen nucleon resonances that have been predicted by quark models [8]. Within the framework of recent coupled-channels approaches (see e.g. Refs.[9,10,11]), these new data should provide for valuable new constraints for future theoretical work.

This work is a continuation of previously unpublished CLAS efforts [12] to measure the induced polarization in the $K^{*}\Lambda$ channel. In the previous work, based on the first electron-beam run in Hall B, several data sets with different beam energies were combined in order to reduce statistical uncertainties. In doing so, data with different
Experimental Setup

The data for this experiment were taken using the CLAS [13] detector in Hall B of the Thomas Jefferson National Accelerator Facility in Newport News, VA. A 5.499-GeV polarized electron beam was incident upon an unpolarized liquid-hydrogen target. The scattered electrons and the reaction products were detected in CLAS. Different detector subsystems were used for energy and momentum reconstruction, as well as particle identification. Each of the six CLAS sectors contains three layers of drift chambers (DC), Cherenkov counters (CC), time-of-flight scintillation counters (SC), and electromagnetic calorimeters (EC). The DC provides charged-particle tracking for angle and momentum reconstruction. The momentum reconstruction is achieved by using the tracking information from the DC, which are located in and around the magnetic field of the CLAS superconducting torus. The CC is used for electron/pion separation. The SC provides the measurement of $\beta$, which, along with the reconstructed momentum from the DC, is used for particle identification. The EC measures the energy of the electrons and neutral particles. It is also used for electron/pion separation above 2.5 GeV.

The geometrical shape of the CLAS detector allows for a large kinematic acceptance in $Q^2$, $W$, and hadron scattering angles. This large acceptance is very important in studying the kinematical dependencies of cross sections and polarization observables. The data acquired with CLAS at 5.499-GeV, spanned a $Q^2$ range from 0.75 to 3.5 GeV$^2$, $W$ from 1.6 to 3.0 GeV, and covered nearly the full range of $\theta_{K}^{cm}$. 

Data Analysis

For the measurement of the $\Lambda$ polarization, the $p(e,e'K^+p)\pi^- \Lambda$ reaction was used. In principle, data from the neutral decay branch ($\Lambda \rightarrow n\pi^0$) could also be used in this analysis, but because of the relatively poor acceptance of CLAS for neutrals and because of the lower branching ratio, data from this branch are sparse. The scattered electron, kaon, and decay proton are detected by the CLAS spectrometer. The data acquisition system was triggered by a coincidence between the CC and the EC in a given CLAS sector. Electrons are identified as negatively charged tracks in the DC that match in time with an SC hit. Hadron identification is done by measuring the difference $\Delta t$ between the time $t_1$ it takes for a hadron with momentum $p$ to travel from the reaction vertex to the SC and the time $t_2$ it takes for an assumed particle with the same momentum to travel the same distance.

$$\Delta t = t_1 - t_2 = t_1 \left(1 - \sqrt{\frac{p^2 + (m_2c)^2}{p^2 + (m_1c)^2}}\right)$$

(1)

where $m_1$ is the hadron mass reconstructed from the momentum and the velocity measurements by the DC and the SC, and $m_2$ is the assumed particle mass. For each event, $\Delta t$ is calculated three times assuming a pion, kaon, and proton mass. The assumed mass that minimizes $\Delta t$ is assigned to the hadron. The minimum $\Delta t$ distributions vs. momentum for protons and kaons without any cuts are plotted in Fig. 1(a) and 1(c), respectively. The same distributions are plotted in Fig. 1(b) and 1(d) after the $\Lambda$ invariant mass cut and the pion missing-mass cut are applied. These cuts clean up the tails due to accidential and background events as can be seen. Even after applying all cuts, it is impossible to completely get rid of the pion and proton backgrounds. A background correction has yet to be applied to these data, and this work is now in progress.

The missing-mass from $e'K^-$ is used for hyperon identification. The final state proton comes from the $\Lambda$ decay, so to identify $\Lambda$’s, the presence of a good reconstructed proton is required on the missing-mass spectrum. In order to further clean up the background, an additional cut is applied on the $e'K^-p$ missing mass, requiring it to be around the pion mass. Fig. 2 shows the $e'K^-$ missing-mass spectrum with the requirement of a detected proton and the pion missing-mass cut.

Additional cuts are applied to further clean up the final state. These include a reaction vertex cut on the electrons and kaons to ensure that they originate from the target region and geometrical fiducial cuts to select the flat acceptance regions in CLAS. EC fiducial cuts are applied to the scattered electrons to ensure that the
electromagnetic shower is fully contained within the volume of the calorimeter. The main background in the $\Lambda$ missing-mass spectrum is due mostly to pions misidentified as kaons and $\Sigma^0$'s leaking into the $\Lambda$ peak (Fig. 2).

**FIGURE 1.** Minimum $\Delta t$ distributions vs. momentum $p$ (GeV) for protons (a), (b) and kaons (c), (d). (a) and (c) are before any cuts; (b) and (d) are after the $\Lambda$ invariant mass cut and pion missing mass cut are applied.

**FIGURE 2.** (a) $e'K^+$ missing mass vs. pion missing-mass squared. The yellow line shows the applied pion missing-mass cut, (b) $e'K^+$ missing-mass spectrum with a detected-proton requirement and pion missing-mass cut. (Units in GeV).
The angular distribution of the decay protons in the Λ rest frame is given by

\[
\frac{dN}{d \cos \theta_p^{RF}} = n(1 + \alpha \Lambda \cos \theta_p^{RF}),
\]

where \( n \) is a normalization factor, \( \alpha \) is the Λ weak decay asymmetry parameter, \( \Lambda \) is the average induced polarization, and \( \theta_p^{RF} \) is the proton angle in the Λ rest frame with respect to a given spin-quantization axis. For the induced polarization, the relevant spin-quantization axis is normal to \( K^+ \Lambda \) reaction plane. There are two ways to extract the polarization from the angular distributions: 1) by calculating the \( \Lambda \) forward-backward asymmetry (relative to \( \cos \theta_p^{RF} = 0 \) and 2) by fitting a line to the angular distribution. The presented polarization results are calculated via the forward-backward asymmetry. During the course of the analysis we found that the polarization was independent of \( Q^2 \), which allowed us to integrate over this variable. In order to increase the statistics in each kinematic bin, the results are also summed over \( \Phi \), the angle between the electron scattering and the hadron production planes in the c.m. system. With the \( \Phi \) integration, only the normal (to the \( K^+ \Lambda \) reaction plane) induced polarization component can be non-zero. As the longitudinal (along the Λ direction) and transverse components of the polarization must vanish, this provides a valuable check on our systematics.

The yields in one typical kinematic bin are plotted vs. \( \cos \theta_p^{RF} \) in Fig. 3. The acceptance corrections and background subtraction will be worked out and applied in later steps of the analysis. However, the effects of both acceptance and background on the extracted induced polarization components are expected to be quite small. Fig. 3 shows a sample fit to the data. Here a first-order polynomial is used. By comparing with the angular distribution formula from Eq.(2), we can see that the slope \( B \) is the product \( n\alpha \Lambda \) (where \( \alpha \) is 0.642±0.013 [14]).

![Fit = A + Bx](image)

**FIGURE 3,** Sample fit of the angular distribution of the decay protons in the rest frame of the Λ.

Preliminary polarization results vs. \( W \) are shown in Fig. 4 for seven \( \cos \theta_K^{c.m.} \) bins. The polarization shows a strong dependence on \( W \) up to about 2.0 GeV (Figs. 4(a)-4(f)) at all but the most forward-angle bin. This suggests sensitivity to s-channel processes. In the forward-angle bin, where t-channel processes dominate, the data are rather flat with \( W \) (Fig. 4(g)). Similar strong \( W \) dependence of the polarizations is observed at mid-range angles in the CLAS photoproduction data [7]. At forward angles the CLAS photoproduction polarization is again flat.

**Conclusion**

This work is part of a larger program to measure cross sections and polarization observables in kaon photo- and electroproduction, with our main goals of better understand which s-channel resonances couple to strangeness and to improve theoretical descriptions of the associated reaction mechanism. The induced Λ polarization gives access to several structure functions that cannot be accessed by other means. We expect that when the analysis is finalized,
these new polarization data, covering a broad kinematic range, will help to improve the constraints to ongoing coupled-channels analyses.

ACKNOWLEDGMENTS

This work is funded in part by the U.S. Dept. of Energy and the Graduate School at Florida International University.

REFERENCES