Measurement of the Induced Polarization of Electroproduced $\Lambda(1116)$ with CLAS

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- Motivation. Why study electromagnetic production of kaons?
- Formalism
- CLAS detector and particle ID.
- Polarization extraction.
- Analysis results.
- Current status and future work.
Motivation

- This study is part of a larger project that has a goal of measuring as many observables as possible for kaon-lambda electroproduction.

- Get a better understanding of the strange-quark production process by mapping out the kinematic dependencies for these observables.

- These data are needed in a coupled-channel analysis to identify previously unobserved s-channel resonances.

- The results will tell us which (if any) of the currently available models best describe the data.

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Kinematics Definitions

\[ e + p \rightarrow e' + K^+ + (\Lambda \rightarrow \pi^- + p) \]

\[ Q^2 = -q^2 = 4EE'\sin^2(\theta_e/2) \]

- Momentum of virtual photon.

\[ W^2 = M_p^2 + 2M_p\nu - Q^2 \]

- C.M. mass of intermediate state.
Cross Section for Electroproduction

\[
\frac{d^3\sigma}{dE'd\Omega_e d\Omega_K^*} = \Gamma \frac{d\sigma_v}{d\Omega_K^*}
\]

Polarized beam & recoil hyperon, unpolarized target.

\[
\frac{d\sigma_v}{d\Omega_K^*} = \sigma_0 (1 + h A_{LT'}) + P_x' \hat{x}' \cdot \hat{S}' + P_y' \hat{y}' \cdot \hat{S}' + P_z' \hat{z}' \cdot \hat{S}'
\]

Where:

\[
A_{LT'} = \frac{K_f}{\sigma_0} \sqrt{2\epsilon_L (1 - \epsilon)} R_{LT'}^{00} \sin \Phi
\]

\[
P_{i'} = P_{i'}^0 + h P_{i'}
\]

Transferred polarization

Induced polarization
Polarization Observables in \((x', y', z')\)

**Induced polarization**

\[
\begin{align*}
P_{x'}^0 &= \frac{K_f}{\sigma_0} \left( \sqrt{2\epsilon_L (1 + \epsilon)} R_{LT}^{x'0} \sin \Phi + \epsilon R_{TT}^{x'0} \sin 2\Phi \right) \\
P_{y'}^0 &= \frac{K_f}{\sigma_0} \left( R_{T}^{y'0} + \epsilon L R_{L}^{y'0} + \sqrt{2\epsilon_L (1 + \epsilon)} R_{LT}^{y'0} \cos \Phi + \epsilon R_{TT}^{y'0} \cos 2\Phi \right) \\
P_{z'}^0 &= \frac{K_f}{\sigma_0} \left( \sqrt{2\epsilon_L (1 + \epsilon)} R_{LT}^{z'0} \sin \Phi + \epsilon R_{TT}^{z'0} \sin 2\Phi \right),
\end{align*}
\]

**Transferred polarization**

\[
\begin{align*}
P_{x'}' &= \frac{K_f}{\sigma_0} \left( \sqrt{2\epsilon_L (1 - \epsilon)} R_{LT}^{x'0'} \cos \Phi + \sqrt{1 - \epsilon^2} R_{TT}^{x'0'} \right) \\
P_{y'}' &= \frac{K_f}{\sigma_0} \sqrt{2\epsilon_L (1 - \epsilon)} R_{LT}^{y'0'} \sin \Phi \\
P_{z'}' &= \frac{K_f}{\sigma_0} \left( \sqrt{2\epsilon_L (1 - \epsilon)} R_{LT}^{z'0'} \cos \Phi + \sqrt{1 - \epsilon^2} R_{TT}^{z'0'} \right).
\end{align*}
\]

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## Integrated Polarization Observables

ONLY normal component survive for induced polarization and ONLY in-plane components survive for transferred polarization.

\[
K_I = \frac{1}{R_T^{00} + \epsilon_L R_L^{00}}
\]

| \( \mathcal{P}_x^0 \) | \( 0 \) | \( \mathcal{P}_x^0 \) | \( \frac{1}{2} \sqrt{2\epsilon_L(1 + \epsilon)} K_I \left( R_{LT}^{0} \cos \theta_K^* + R_{LT}^{0} + R_{LT}^{0} \sin \theta_K^* \right) \) |
| \( \mathcal{P}_{y'} \) | \( K_I \sqrt{1 - \epsilon^2 R_{TT}^{00}} \) | \( \mathcal{P}_{y'} \) | \( \frac{1}{2} \sqrt{2\epsilon_L(1 - \epsilon)} K_I \left( R_{LT}^{0} \cos \theta_K^* - R_{LT}^{0} + R_{LT}^{0} \sin \theta_K^* \right) \) |
| \( \mathcal{P}_{z'} \) | \( K_I \sqrt{1 - \epsilon^2 R_{TT}^{00}} \) | \( \mathcal{P}_{z'} \) | \( \sqrt{1 - \epsilon^2} K_I \left( -R_{TT}^{00} \sin \theta_K^* + R_{TT}^{00} \cos \theta_K^* \right) \) |

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CEBAF Large Acceptance Spectrometer

- Torroidal magnetic field in region 2
- 3 regions of drift chambers located spherically around target provide charge particle tracking for angle and momentum reconstruction.
- Cherenkov detectors provide $e/\pi$ separation
- Electromagnetic calorimeter gives total energy measurement for electrons and neutrals and also $e/\pi$ separation
- Time of flight scintillators $\rightarrow \beta \rightarrow$ particle ID

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Analysis Method Summary

- Electron identification
  - Good EC fiducial cut
  - Good trace back to target
  - Fiducial cuts (flat acceptance region)
  - Momentum corrections
- Hadron ($K, \rho$) identification
  - Timing cut
  - Fiducial cuts
  - Momentum corrections
- Hyperon ($\Lambda, \Sigma^0$) identification
  - Reconstructed missing mass for $e+p \rightarrow e'K^+(Y)$
  - For recoil polarization observables $e+p \rightarrow e'K^+p(\pi^-)$
    include $\pi^-$ missing-mass cut

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Hadron Identification

Timing cut to minimize $\Delta t = t_1 - t_2$

$\Delta t$ - Difference between the time $t_1$ it takes for hadron with momentum $p$ to travel from vertex to SC and the time $t_2$ it takes for assumed particle with the same momentum to travel the same distance.

$t_1 = \frac{d}{\beta_1 c}, \quad m_1 = \frac{p}{\beta_1 \gamma c}$, \hspace{1cm} d - distance from vertex to SC system

$t_2 = \frac{d}{\beta_2 c}, \quad \beta_2 = \frac{p}{\sqrt{(m_2 c)^2 + p^2}}$, \hspace{1cm} m_2 - is the assumed particle mass.

$\Delta t = t_1 \left( 1 - \sqrt{\frac{p^2 + (m_2 c)^2}{p^2 + (m_1 c)^2}} \right)$

Minimum $\Delta t$ identifies the hadron.

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**Hadron Identification**

*Minimum $\Delta t$ identifies the hadron.*

**ALL $p$ and $K$ (NO $\Lambda$ or $\pi$ missing mass cuts)**

After $\Lambda$ and $\pi$ missing mass cuts

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Minimum $\Delta t$ vs $p$
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```
Minimum $\Delta t$ vs $p$
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Minimum $\Delta t$ vs $p$
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Minimum $\Delta t$ vs $p$
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Hadron Identification

Minimum $\Delta t$ identifies the hadron.

ALL $p$ and $K$ (NO $\Lambda$ or $\pi$ missing mass cuts)

After $\Lambda$ and $\pi$ missing mass cuts

$p$ given $K$ mass

$\pi$ given $K$ mass
Hyperon Identification

Background in the $\Lambda$ missing mass spectrum is due to MOSTLY misidentified $\pi$’s, some misidentified $p$’s and $\Sigma$’s.

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Λ Polarization Extraction

Parity non-conservation in weak decay allows to extract recoil polarization from $p$ angular distribution.

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

where: $\alpha = 0.642 \pm 0.013$ (PDG)

Two ways to extract polarization:

1. Calculating $P_\Lambda \sim (N_F - N_B) / (N_F + N_B)$
2. Fitting a line to angular distribution.

The presented polarization results are CALCULATED via forward-backward asymmetry.

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Polarization vs $Q^2$, Sum over $\cos(\theta_{K^{CM}})$, $\Phi$
Induced Polarization vs $\cos(\theta_K^{CM})$

**Preliminary Results**

- $1.6 < W < 1.65$ GeV
- $1.65 < W < 1.7$ GeV
- $1.7 < W < 1.75$ GeV
- $1.75 < W < 1.8$ GeV
- $1.8 < W < 1.85$ GeV
- $1.85 < W < 1.9$ GeV
- $1.95 < W < 2.0$ GeV
- $2.0 < W < 2.05$ GeV
- $2.05 < W < 2.1$ GeV
- $2.1 < W < 2.15$ GeV
- $2.15 < W < 2.2$ GeV
- $2.2 < W < 2.25$ GeV

$1.71 < W < 1.87$ (GeV)  
SUM over $Q^2, \Phi$

$W$: $1.6-2.2$ (GeV), 50 MeV bins  
SUM over $Q^2, \Phi$

$1.873 < W < 2.152$ (GeV)  
SUM over $Q^2, \Phi$
Induced Polarization vs $W$

### Preliminary Results

$\text{SUM over } Q^2, \Phi$

-1.0 < $\cos(\theta_{K^{CM}})$ < -0.5
-0.5 < $\cos(\theta_{K^{CM}})$ < 0.0
0.0 < $\cos(\theta_{K^{CM}})$ < 0.2
0.2 < $\cos(\theta_{K^{CM}})$ < 0.4
0.4 < $\cos(\theta_{K^{CM}})$ < 0.6
0.6 < $\cos(\theta_{K^{CM}})$ < 0.8
0.8 < $\cos(\theta_{K^{CM}})$ < 1.0

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Induced Polarization vs $W$ (photoproduction)

Figure from M. McCracken Dissertation

FIG 12: (Color On-line) $P_A$ vs $\sqrt{s}$ (GeV) in bins of $\cos \theta_W$. Results of this analysis are represented by red circles, previous CLAS (McNab, et al. [102]) results by blue triangles, SAPHIR 2004 (Chauwen, et al. [3]) by green triangles, and GRAAL 2007 (Leray et al. [20]) by black squares. Physical limits on $P_A$ are indicated by dashed horizontal lines.
Polarization vs W: E1F and E1-6

$W$: 1.6-2.8 (GeV), 50 MeV bins
$SUM$ over $Q^2$, $\Phi$

- $-1.0 < \cos(\theta_K^{CM}) < -0.5$
- $-0.5 < \cos(\theta_K^{CM}) < 0.0$
- $0.0 < \cos(\theta_K^{CM}) < 0.2$
- $0.2 < \cos(\theta_K^{CM}) < 0.4$
- $0.4 < \cos(\theta_K^{CM}) < 0.6$
- $0.6 < \cos(\theta_K^{CM}) < 0.8$
- $0.8 < \cos(\theta_K^{CM}) < 1.0$
Polarization vs $\cos(\theta_K^{CM})$: E1F and E1-6

- $1.6 < W < 1.85 \text{ GeV}$
- $1.65 < W < 1.7 \text{ GeV}$
- $1.95 < W < 2.0 \text{ GeV}$
- $2.0 < W < 2.05 \text{ GeV}$
- $1.65 < W < 1.7 \text{ GeV}$
- $1.7 < W < 1.75 \text{ GeV}$
- $1.75 < W < 1.8 \text{ GeV}$
- $2.05 < W < 2.1 \text{ GeV}$
- $2.1 < W < 2.15 \text{ GeV}$
- $1.8 < W < 1.85 \text{ GeV}$
- $1.85 < W < 1.9 \text{ GeV}$
- $2.15 < W < 2.2 \text{ GeV}$
- $2.2 < W < 2.25 \text{ GeV}$
Current Status

- e\(^-\) and hadron cuts are finalized.
- Final state identification cuts are finalized.
- Currently working on background subtraction using MC templates for fitting and acceptance corrections.

Although the \(\pi\) and \(\rho\) backgrounds are unpolarized, they still have some dilution effect on polarization results. Polarized \(\Sigma\) contribution must be properly subtracted.

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Future Work

It is necessary to repeat induced polarization measurement by Simeon McAleer (FSU). Previous measurement combines data from 4 different data sets with different energies and torus currents.

<table>
<thead>
<tr>
<th>$E_{beam}$(GeV)</th>
<th>$W$(GeV)</th>
<th>$Q^2$(GeV$^2$)</th>
<th>$N_\Lambda$</th>
<th>$N_\Sigma$</th>
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<td>0.8-3.5</td>
<td>367000</td>
<td>?</td>
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**NEXT...**

• Determine acceptance corrections.
• Acceptance corrected polarization extraction.

Strong systematic check of our results is to show that the $P_L$ and $P_T$ components are consistent with 0.
• Systematic error analysis.
• Comparison to theory.

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$P_L$ and $P_T$ vs $\cos(\theta_K^{CM})$

No acceptance corrections. No background subtraction.
π Background Polarization vs W

Preliminary Results

SUM over Q^2, Φ
<table>
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<tr>
<th>Pol.</th>
<th>Response Functions</th>
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<tr>
<td>$z'$</td>
<td>$z$</td>
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</table>

Response functions for pseudo-scalar meson production.


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Cross Section for Electroproduction

\[ \frac{d^5 \sigma}{dE' d\Omega_e d\Omega^*_K} = \Gamma \frac{d^2 \sigma_v}{d\Omega^*_K} \]

**Unpolarized beam/target/recoil**

\[ \sigma_0 \equiv \left( \frac{d\sigma_v}{d\Omega^*_K} \right)^{00} = K_f \left[ R_{TT}^{00} + \epsilon_L R_{LL}^{00} + \sqrt{2\epsilon_L(1+\epsilon)} R_{LT}^{00} \cos \Phi + \epsilon R_{TT}^{00} \cos 2\Phi \right] \]

\[ \Gamma = \frac{\alpha}{8\pi^2} \frac{W}{M_p^2 E^2 (W^2 - M_p^2)} \left[ \frac{1}{Q^2 (1 - \epsilon)} \right] \]

\[ \epsilon = \frac{1}{1 + \frac{2\sigma^2}{Q^2} \tan^2 \frac{\theta_e}{2}} , \quad \epsilon_L = \frac{Q^2}{\nu^2} \epsilon . \]

M. Gabrielyan, Florida International University, HUGS 2008