Determination of the Polarization Observables $C_{x'}$, $C_{z'}$, and $P_{y'}$ for $\gamma d \rightarrow K^0\Lambda(p)$ From g13 Data

CLAS Collaboration Meeting

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October 22, 2015
Overview and g13 data set

Selection of $K^0 \Lambda$

Extraction of $C_{x'}$, $C_{z'}$, and $P_{y'}$

Very preliminary results

- 1d fits
- 2d fits
- Maximum likelihood method (addition of $P_{y'}$)
Understanding the N* spectrum is a major part of the research program at Jefferson Lab.

Recently, there has been significant work done on pseudo-scalar meson channels to understand the N* spectrum.

For KY, largest contribution is from the proton where progress has been made ($\gamma p \rightarrow K^+\Lambda\ N(1900)3/2^+$).

Main goal of the g13 proposal: provide 7 observables ($\frac{d\sigma}{d\Omega}$, $P_y$, $\Sigma$, $O_{x'/z'}$, $C_{x'/z'}$) on $\gamma n \rightarrow K^0\Lambda\ (\star\star\ N(2080)3/2^−)$.

Current $K^0\Lambda$ studies in g13: Charles Taylor and Nick Compton are working on cross-sections, Derek Glazier working on linearly polarized photon data (Neil Hassal’s PhD project).
g13 Experiment

- Data for experiment E06–103 (g13) was taken at Jefferson Lab in 2006–2007
- g13a: circularly–polarized, g13b: linearly–polarized
- Both used a 40-cm long unpolarized LD$_2$ target
- $e^-$ beam energies of 2.0 and 2.6 GeV for g13a

<table>
<thead>
<tr>
<th>Person</th>
<th>Channel</th>
<th>Observable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongtong Cao</td>
<td>$\tilde{\gamma} d \rightarrow K^+\Lambda n$</td>
<td>$C_x, C_z, P_y$</td>
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<tr>
<td>Nick Compton and Charles Taylor</td>
<td>$\gamma d \rightarrow K^0\Lambda(p)$</td>
<td>$d\sigma/d\Omega$</td>
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<td>Olga Cortes</td>
<td>$\tilde{\gamma} d \rightarrow \omega(n)$ and $\tilde{\gamma} d \rightarrow \omega(p)$</td>
<td>$\Sigma, \ldots$</td>
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<tr>
<td>Derek Glazier (Neil Hassal)</td>
<td>$\tilde{\gamma} d \rightarrow K^0\Lambda(p)$</td>
<td>$\Sigma$</td>
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<tr>
<td>Paul Mattione</td>
<td>$\gamma d \rightarrow K^*0\Lambda(p)$ and $\gamma d \rightarrow K^+\Sigma^-(p)$</td>
<td>$d\sigma/d\Omega$</td>
</tr>
<tr>
<td>Daria Sokhan</td>
<td>$\tilde{\gamma} d \rightarrow p\pi^-(p)$</td>
<td>$\Sigma$</td>
</tr>
<tr>
<td>Nicholas Zachariou</td>
<td>$\tilde{\gamma} d \rightarrow K^+\Lambda n$</td>
<td>$\Sigma, O_x, O_z$</td>
</tr>
</tbody>
</table>
Observables for $\vec{\gamma} d \rightarrow K^0 \vec{\Lambda}(p_s)$

$$\frac{d\sigma}{d\Omega}^\pm = \sigma_0 (1 \pm \alpha \cos \theta_{x'} P_{circ} C_{x'} \pm \alpha \cos \theta_{z'} P_{circ} C_{z'} + \alpha P_{y'} \cos \theta_{y'})$$
**Analysis Overview:** $\vec{\gamma}d \rightarrow K^0\bar{\Lambda}(p)$

- $K^0 \rightarrow \pi^+\pi^-$ and $\Lambda \rightarrow p\pi^-$
- Select events which have 2 positive and 2 negative tracks

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**Particle Identification**

**Photon Selection**

**$\beta$ vs. Momentum**

Particles were identified based on their velocity and momentum in CLAS ($\Delta\beta$ cut)

$\Delta t = t_v - t_\gamma$ where $t_v$ is the reconstructed event vertex time using the trajectory in CLAS of the fastest particle and $t_\gamma$ is the time that the photon arrived at the event location
Selection of $K^0 \Lambda$

**Kaon Selection**

1) Select $M(\pi^+\pi^-)=M(\Lambda)+0.005$ GeV/c$^2$
2) Draw $M(\pi^+\pi^-)$ events
3) Fit with Gaussian

**Lambda Selection**

1) Select $M(\pi^+\pi^-)=M(K)+0.01$ GeV/c$^2$
2) Draw $M(\pi^+\pi^-)$ events
3) Fit with Gaussian
Selection of $K^0$ and $\Lambda$

$M(\pi^+\pi^-)$ vs. $M(p\pi^-)$
Quasi-Free Event Selection: $\vec{\gamma}d \rightarrow K^0\vec{\Lambda}(p_s)$

- The reaction of interest is $\gamma(n_s) \rightarrow K^0\Lambda$
- QF events: the momentum of the final state proton should be small (consistent with the Fermi momentum of the $n_s$)
- For the reaction $\gamma d \rightarrow K^0\Lambda X$, we calculate the missing momentum, $\tilde{p}_X$

$$\tilde{p}_X = \tilde{p}_\gamma + \tilde{p}_d - \tilde{p}_p - \tilde{p}_{\pi^+} - \tilde{p}_{\pi^-} - \tilde{p}_{\pi^-}$$

### Missing Momentum $p_X$

- **Quasi-Free**
- **Final state interactions**
Selection of the $K^0\Lambda(p_s)$ Final State

The $K^0\Lambda$ final state was identified using the missing mass (MM) technique.

Two MM’s were calculated and used in cutting away large portion of background events:

1. $\text{MM}(K^0X): \gamma n \to K^0X$ where $M_X = \sqrt{(\tilde{p}_{\gamma} + \tilde{p}_n - \tilde{p}_{K^0})^2}$ and $X = \Lambda$ OR $X = \Sigma \to \Lambda\gamma \to \gamma p\pi^-$

2. $\text{MM}(K^0\Lambda X): \gamma d \to K^0\Lambda X$ where $M_X = \sqrt{(\tilde{p}_{\gamma} + \tilde{p}_d - \tilde{p}_{K^0} - \tilde{p}_\Lambda)^2}$ and $X = p$ OR $X = \gamma p$

[Graph showing MM($K^0X$) vs. MM($K^0\Lambda X$) with signal and background regions marked]

225,330 $K^0\Lambda(p_s)$ events

This is a preliminary cut
Beam Polarization

In order to determine the polarization observables, the polarization of the photon beam needs to be determined

- $e^-$ polarization ($P_e$) measured using a Moller polarimeter in Hall B

<table>
<thead>
<tr>
<th>Run Number</th>
<th>Average % $e^-$ Polarization</th>
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<tbody>
<tr>
<td>53164-53532</td>
<td>84.97 ± 0.28</td>
</tr>
<tr>
<td>53538-53547</td>
<td>80.60 ± 0.18</td>
</tr>
<tr>
<td>53550-53862</td>
<td>78.47 ± 0.18</td>
</tr>
<tr>
<td>53998-54035</td>
<td>84.11 ± 1.11</td>
</tr>
</tbody>
</table>

$P_{\text{circ}} = \frac{E_\gamma (E_e + \frac{1}{3} E')}{E_e^2 + E'^2 - \frac{2}{3} E_e E'} P_e$

$E' = E_e - E_\gamma$

Data in the table is from the work done by Tongtong Cao
Extraction of $C_{x'}$, $C_{z'}$, and $P_{y'}$

From the equation for the polarized cross section of $K\Lambda$ photoproduction, the experimental asymmetry, $A$, can be derived:

1. $A = \frac{N^+-N^-}{N^++N^-} = \alpha P_{circ} C_{z'} \cos \theta_{z'}$

2. $A = \alpha P_{circ} (C_{z'} \cos \theta_{z'} + C_{x'} \cos \theta_{x'}) \leftarrow$ Simultaneous fit to $\cos \theta_{z'}$ and $\cos \theta_{x'}$

3. PDF: $1 \pm \alpha P_{circ} C_{x'} \cos \theta_{x'} \pm \alpha P_{circ} C_{z'} \cos \theta_{z'} + \alpha P_{y'} \cos \theta_{y'}$

- $N^+ (N^-)$ is the number of events with $+$($-$) helicity
- $\alpha = 0.642 \pm 0.013$, is the self-analyzing power of $\Lambda$
$E_\gamma$ and $\cos\theta_K$ bins

- An $A$ is calculated for each kinematic bin
- 12 $E_\gamma$ bins, 9 $\cos\theta_K^*$ bins

![Graph of $E_\gamma$ vs. $\cos\theta_K$]

![Graph of asymmetry $A$ vs. $\cos\theta_K$]
Very preliminary results

Maximum likelihood method (addition of $P_{y'}$)

$C_{X'}$ Comparison for 1d, 2d, Maximum Likelihood

Colin Gleason (USC)
Very preliminary results

Maximum likelihood method (addition of $P_{y'}$)

$C_{z'}$, Comparison for 1d, 2d, Maximum Likelihood

$E_{\gamma} < 1.0 \text{ GeV}$

$1.0 < E_{\gamma} < 1.1 \text{ GeV}$

$1.1 < E_{\gamma} < 1.2 \text{ GeV}$

$1.2 < E_{\gamma} < 1.3$

$1.3 < E_{\gamma} < 1.4$

$1.4 < E_{\gamma} < 1.5$

$1.5 < E_{\gamma} < 1.6$

$1.6 < E_{\gamma} < 1.7$

$1.7 < E_{\gamma} < 1.8$

$1.8 < E_{\gamma} < 1.9$

$1.9 < E_{\gamma} < 2.0$

$E_{\gamma} > 2.0$
Maximum Likelihood Estimates for $C_{x'}$, $C_{z'}$, $P_{y'}$
Very preliminary results

Maximum likelihood method (addition of $P_y'$)

$$R = \sqrt{C^2_x + C^2_z + P^2_y}$$

$R$

$E_\gamma < 1.0$ GeV

$1.0 < E_\gamma < 1.1$ GeV

$1.1 < E_\gamma < 1.2$ GeV

$1.2 < E_\gamma < 1.3$

$1.3 < E_\gamma < 1.4$

$1.4 < E_\gamma < 1.5$

$1.5 < E_\gamma < 1.6$

$1.6 < E_\gamma < 1.7$

$1.7 < E_\gamma < 1.8$

$1.8 < E_\gamma < 1.9$

$1.9 < E_\gamma < 2.0$

$E_\gamma > 2.0$
Conclusions

- This work aims to provide polarization observables for $K\Lambda$ photoproduction off the bound neutron
- Preliminary estimates of $C_{x'}$, $C_{z'}$ were extracted with 3 different methods, and $P_{y'}$ with the maximum likelihood method
- As of now, all three methods provide similar estimates
- The maximum likelihood method will be used to extract final results
- Work is in progress to understand background contributions