Cross Sections of \( \gamma d \rightarrow K^0 \Lambda(p) \) with g13 Data

N. Compton, C.E. Taylor, K. Hicks, P. Cole, and others

11/3/2016

CLAS Collaboration
Motivation

• A complete experiment in several reaction channels will improve our understanding of nucleon resonances

• $K^0\Lambda$ provides constraint on resonances found in $K^+\Lambda$ channels through PWA

• This reaction has t-channel suppression
  • Neutrality and spin of the $K^0$
  • Ideal for resonance studies (s-channel)
  • Cross section is likely lower than $K^+\Lambda$
\[ \gamma d \rightarrow K^0 \Lambda(p) \]

• Detected with the topology:
  • \[ \gamma d \rightarrow K^0 \Lambda p \rightarrow K_S^0 \Lambda p \rightarrow \pi^- \pi^+ \pi^- p(p) \]

• Backgrounds contributing to this topology:
  • \[ \gamma d \rightarrow X \rightarrow \pi^- \pi^+ \pi^- p(p) \]
    • \(X \neq K^0 \Lambda\), but could be \(\rho \Delta\)
    • Minimized, but not excluded with invariant mass cuts
  • \[ \gamma d \rightarrow K^0 \Sigma^0 p \rightarrow K_S^0 \Lambda \gamma p \rightarrow \pi^- \pi^+ \pi^- p(\gamma p) \]

• Cuts and Corrections:
  • removal of problematic tagger bins, removal of junk runs, eloss corrections, momentum corrections, invariant mass cuts, pairing of \(\pi^-\), fiducial cuts, and reaction vertex cut
Invariant Mass of $\Lambda$

- Shown is $M(\pi^- p)$
- The pairing of the $\pi^- p$ was determined based on reproducibility of the $\Lambda$
- Gaussian fit is applied to the peak
  - Only used for determining a cut location
  - Systematics of this cut were investigated (typically on the order of 1%)
Invariant Mass of $K^0$

- Shown is $M(\pi^-\pi^+)$
- The $\pi^-$ from the $K^0$ decay typically has more momentum
- Gaussian fit is applied to this peak as well
  - Only used for determining a cut location
  - Systematics of this cut were investigated (typically on the order of 1%)
Missing Mass Spectra

• Possible topologies
  • $\gamma d \rightarrow X \rightarrow \pi^- \pi^+ \pi^- p(p)$
    • Non-strange background
    • $K^0 \Lambda$
  • $\gamma d \rightarrow X \rightarrow \pi^- \pi^+ \pi^- p(\gamma p)$
    • $K^0 \Sigma^0$
    • Non-strange background (minimal)
  • $\gamma d \rightarrow X \rightarrow \pi^- \pi^+ \pi^- p(\pi p Y)$
    • $K^0 \Sigma^*$
    • $K^* \Sigma^0$
    • Non-strange background
  • Where $X$ and $Y$ could be anything

• Higher mass resonances
  • Assuming an on shell neutron
  • Assuming zero momentum

11/3/2016
Simulation Weighting

- Comparison to Data
  - Extracted Yield (top right)
  - Proton Momentum (bottom left)
  - \( \pi^- \) Momentum (bottom mid.)
  - \( \pi^+ \) Momentum (bottom right)

**Legend**
- Scaled simulation uniform in \( \cos \theta_{CM}^{K^0} \)
- Scaled simulation weighted in \( \cos \theta_{CM}^{K^0} \)
- Data Points

11/3/2016

![Graphs showing comparison to data, extracted yield, and momentum distributions for protons and pions.](image)
Comparison of Missing Momenta

• Missing momentum (of the assumed spectator proton) can only be compared from data to simulation with a strict missing mass cut

• A missing particle will result in more missing momentum

• A missing momentum cut of 300 MeV was employed (typically ~1-2%)
Comparison of Missing Masses

- The reconstructed missing mass
- Peak at the proton mass
- Non-Strange background
- Signal
- Shoulder to that peak
- $\Sigma^0$ contribution
Yield Extraction (Fits)

Steps Taken to Fit the Data
1. Fit the $K^0\Lambda$ Simulation (Gaussian)
2. Fit the $K^0\Sigma^0$ Simulation (Sigmoidal Shape)
3. Use these parameters to constrain fit to Data
   a) Shape fit the $\Sigma^0$
4. Subtract Non-Strange Background (next slide)
Background Subtraction

1. Cut on the $K^0$
2. Estimate the background in region 2 from region 1 and 3
3. Subtract background from previously obtained yield

Background contribution ranged from 0-20% of the total counts depending on the kinematic bin
Differential Cross Section of $\gamma d \rightarrow K^0 \Lambda(p)$
Differential Cross Section

1. Comparison to g10 results

2. BoGa Fit including $K^0\Lambda \ (\chi^2_v \sim 1)$
   a) Two Solutions
   b) $z = \cos (\theta_{CM}^{K^0})$

3. Comparison to KaonMaid w/o $K^*$ or $K_1$ exchange
   a) Accessed via website
   b) NOT A FIT
Total Cross Section Estimation

- Fit differential cross section
- Multiple functions
- Utilize $1\sigma$ error bands
- Integral represents the total cross section
- Each integral has an uncertainty
- Systematic Uncertainty
- Calculated standard deviation

Energy = 1.65 GeV

![Graph of $d\sigma/d\cos\theta_{CM}$ vs $\cos\theta_{CM}$ at 1.65 GeV](image1)

![Graph of Total Cross Section vs Energy (GeV)](image2)
Total Cross Section
w/ BoGa, KaonMaid, and $K^+\Lambda$

- Left Figure
  - Kaon Maid is shown as a comparison with two different options
- Right Figure
  - Comparison between $\gamma p \rightarrow K^+\Lambda (g11)$ and its BoGa solution (web)
  - No “bump” is seen in $\gamma d \rightarrow K^0\Lambda(p)$ at 1900 MeV
  - Preliminary $K^0\Lambda$ BoGa solutions shown
    - Minor changes in fit parameters
Summary

• $\gamma d \rightarrow K^0 \Lambda(p)$ cross sections were measured with g13 data
• These data agree with previous g10 measurements
• These cross sections appear to be missing a "bump" at 1900 MeV
  • Contribute valuable information on complex amplitudes
• Preliminary PWA fits were provided by BoGa
  • These fits are very close to a "predicted" value
• Analysis review is complete
• Ad-Hoc started
Back-Up Slides
Total Cross Section
BoGa Estimation and Fit Compared to K+Lambda
BoGa Coupled Channel Fits

- Neutron coupled channels listed
- References not given here, but will be reported in the paper
- Most chi-squares improved

<table>
<thead>
<tr>
<th>$d \to \pi^- p(p)$</th>
<th>Observ.</th>
<th>$N_{\text{data}}$</th>
<th>$\chi^2_{\text{old}}$</th>
<th>$\chi^2_{\text{new}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[19, 20]$</td>
<td>$d\sigma/d\Omega$</td>
<td>529</td>
<td>3.08</td>
<td>3.10</td>
</tr>
<tr>
<td>$[21-27]$</td>
<td>$d\sigma/d\Omega$</td>
<td>1298</td>
<td>2.32</td>
<td>2.92</td>
</tr>
<tr>
<td>$[28-36]$</td>
<td>$\Sigma$</td>
<td>316</td>
<td>3.08</td>
<td>2.99</td>
</tr>
<tr>
<td>$[37-40]$</td>
<td>$T$</td>
<td>105</td>
<td>3.18</td>
<td>1.88</td>
</tr>
<tr>
<td>$[41-43]$</td>
<td>$P$</td>
<td>20</td>
<td>3.17</td>
<td>1.55</td>
</tr>
</tbody>
</table>

- $\pi^- p \to \gamma n$

| $[44-50]$         | $d\sigma/d\Omega$ | 495               | 1.53                   | 1.60                   |
| $[51-53]$         | $P$              | 55                | 3.11                   | 1.96                   |

- $\gamma d \to \pi^0 n(p)$

| $[54-57]$         | $d\sigma/d\Omega$ | 147               | 2.98                   | 2.97                   |
| $[58]$            | $\Sigma$         | 216               | 1.90                   | 1.85                   |
| $[16]$            | $d\sigma/d\Omega$ | 969               | —                      | 3.38                   |

- $\gamma d \to \eta n(p)$

| $[59]$            | $d\sigma/d\Omega$ | 330               | 1.40                   | 6.59                   |
| $[60]$            | $\Sigma$         | 88                | 2.17                   | 1.85                   |
| $[11, 12]$        | $d\sigma/d\Omega$ | 880               | —                      | 1.01                   |

- $\gamma d \to K^0 \Lambda(p)$

| $[13]$            | $d\sigma/d\Omega$ | 364               | —                      | 0.96                   |

- $\gamma d \to K^+ \Sigma^-(p)$

| $[14]$            | $d\sigma/d\Omega$ | 229               | —                      | 0.72                   |
# Neutron Helicity Amplitude

**Table 2:** The $\gamma N$ helicity couplings of nucleon states (GeV$^{-1/2}$10$^{-3}$) calculated as residues in the pole position and corresponding Breit-Wigner couplings.

<table>
<thead>
<tr>
<th>State</th>
<th>$E$</th>
<th>Phase</th>
<th>$E_{(BW)}$</th>
<th>$M$</th>
<th>Phase</th>
<th>$M_{(BW)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N(1535)1/2^-$</td>
<td>88±4</td>
<td>5±4°</td>
<td>81±6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N(1650)1/2^-$</td>
<td>-16±4</td>
<td>-28±10°</td>
<td>-16±5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N(1895)1/2^-$</td>
<td>15±10</td>
<td>60±25°</td>
<td>14±10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N(1440)1/2^+$</td>
<td></td>
<td></td>
<td></td>
<td>41±5</td>
<td>23±10°</td>
<td>53±7</td>
</tr>
<tr>
<td>$N(1710)1/2^+$</td>
<td></td>
<td></td>
<td></td>
<td>29±7</td>
<td>80±20°</td>
<td>±(30±7)</td>
</tr>
<tr>
<td>$N(1880)1/2^+$</td>
<td></td>
<td></td>
<td></td>
<td>72±24</td>
<td>-30±30°</td>
<td>70±22</td>
</tr>
<tr>
<td>$N(2100)1/2^+$</td>
<td></td>
<td></td>
<td></td>
<td>29±9</td>
<td>35±20°</td>
<td>29±10</td>
</tr>
<tr>
<td>$N(1520)3/2^-$</td>
<td>126±5</td>
<td>5±5°</td>
<td>125±6</td>
<td>13±3</td>
<td>26±3°</td>
<td>13±3</td>
</tr>
<tr>
<td>$N(1875)3/2^-$</td>
<td>3±2</td>
<td>-50±40°</td>
<td>3±2</td>
<td>3±2</td>
<td>-80±40°</td>
<td>±(3±2)</td>
</tr>
<tr>
<td>$N(2120)3/2^-$</td>
<td>-33±15</td>
<td>75±40°</td>
<td>-33±15</td>
<td>43±20</td>
<td>5±20°</td>
<td>43±20</td>
</tr>
<tr>
<td>$N(1720)3/2^+$</td>
<td>(20$^{+30}_{-10}$)</td>
<td>-75±30°</td>
<td>(20$^{+30}_{-10}$)</td>
<td>-85±30</td>
<td>-80±30°</td>
<td>±(85±30)</td>
</tr>
<tr>
<td>$N(1900)3/2^+$</td>
<td>70±17</td>
<td>-8±20°</td>
<td>71±17</td>
<td>-22±12</td>
<td>40±40°</td>
<td>-21±11</td>
</tr>
<tr>
<td>$N(1975)3/2^+$</td>
<td>-12±10</td>
<td>-10±35°</td>
<td>-12±9</td>
<td>80±15</td>
<td>5±20°</td>
<td>79±14</td>
</tr>
<tr>
<td>$N(1675)5/2^-$</td>
<td>3±2</td>
<td>60±30°</td>
<td>3±2</td>
<td>52±5</td>
<td>-10±5°</td>
<td>51±4</td>
</tr>
<tr>
<td>$N(2060)5/2^-$</td>
<td>-20±10</td>
<td>5±15°</td>
<td>-20±9</td>
<td>-27±9</td>
<td>5±20°</td>
<td>-26±9</td>
</tr>
<tr>
<td>$N(1680)5/2^+$</td>
<td>19±2</td>
<td>-13±7°</td>
<td>19±2</td>
<td>25±2</td>
<td>-9±4°</td>
<td>26±2</td>
</tr>
<tr>
<td>$N(2000)5/2^+$</td>
<td>-3±4</td>
<td>not defined</td>
<td>-3±4</td>
<td>8±4</td>
<td>-86±30°</td>
<td>±(8±4)</td>
</tr>
<tr>
<td>$N(1990)7/2^+$</td>
<td>-7±4</td>
<td>-12±20°</td>
<td>-5±4</td>
<td>30±15</td>
<td>-5±25°</td>
<td>30±15</td>
</tr>
<tr>
<td>$N(2190)7/2^-$</td>
<td>-5±2</td>
<td>-5±10°</td>
<td>-5±2</td>
<td>7±2</td>
<td>5±10°</td>
<td>7±2</td>
</tr>
</tbody>
</table>