Preliminary results of the helicity asymmetry $E$ for $\eta$ photoproduction on the proton

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Motivation for $\eta$ photoproduction experiments

- $\eta$ is an isospin zero meson, which limits possible resonance couplings to $N^*$'s effectively working as an isospin filter.

- $\eta$ is one of the lightest non-strange pseudoscalar mesons.

- Very little current data available on double polarization observables.

- Predictions for observables for incident photon energies at and above threshold are available from different theoretical approaches, for example:
  - Effective Lagrangian theories (e.g. Nakayama and Haberzettl)
  - Partial wave analysis (e.g. SAID and Bonn-Gatchina)
  - Isobar analysis (e.g. eta-MAID)
Polarization observables

<table>
<thead>
<tr>
<th>Photon</th>
<th>Target</th>
<th>Recoil</th>
<th>Target + Recoil</th>
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</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>x'</td>
</tr>
<tr>
<td>-</td>
<td>x</td>
<td>y</td>
<td>z'</td>
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<tr>
<td>-</td>
<td>x</td>
<td>y</td>
<td>z'</td>
</tr>
</tbody>
</table>

- \( \sigma_0 \)
- \( T \)
- \( 0 \)
- \( 0 \)
- \( P \)
- \( 0 \)
- \( T_{x'} \)
- \( -L_{x'} \)
- \( T_{z'} \)
- \( L_{z'} \)
- \( -\Sigma \)
- \( H \)
- \( (-P) \)
- \( -G \)
- \( O_{x'} \)
- \( (-T) \)
- \( O_{z'} \)
- \( (-L_{z'} ) \)
- \( (T_{z'} ) \)
- \( (-L_{x'} ) \)
- \( (-T_{x'} ) \)
- \( 0 \)
- \( 0 \)
- \( -E \)
- \( -C_{x'} \)
- \( 0 \)
- \( -C_{z'} \)
- \( 0 \)
- \( 0 \)
- \( 0 \)
- \( 0 \)
- \( 0 \)

Observables possible with beam-target polarization experiments

Observable of interest in this talk

Polarization observable \( E \):

\[
E = \frac{\sigma_{\frac{1}{2}} - \sigma_{\frac{3}{2}}}{\sigma_{\frac{1}{2}} + \sigma_{\frac{3}{2}}}
\]

By convention we take \( 1/2 \) state minus the \( 3/2 \) state
Helicity asymmetry $E$

Raw asymmetry equation in terms of yield (N):

$$R = \frac{N^{1/2} - N^{3/2}}{N^{1/2} + N^{3/2}}$$

Equation for the observable $E$ accounting for polarizations:

$$x = E_{\gamma} / E_e$$

$$P_{\text{photon}} = P_{\text{electron}} \cdot \frac{4x - x^2}{4 - 4x + 3x^4}$$

$$P_o = P_{\text{target}} \cdot P_{\text{photon}}$$

$$E = \frac{1}{P_o \cdot f_{\text{(Dilution)}}} \cdot \frac{N^{1/2} - N^{3/2}}{N^{1/2} + N^{3/2}}$$
Constraints on $E$

• $S_{11}(1535)$ dominates $\eta$ photoproduction at threshold energies ($W = 1500-1550$ MeV)
  – Since the $S_{11}(1535)$ is a spin $= \frac{1}{2}, L = 0$ resonance, the resonance can only couple to a helicity $\frac{1}{2}$ initial states.

• This dominance forces $E \approx 1$ at and near threshold for all scattering angles.

• This constraint of $E \approx 1$ provides an analysis check near threshold.

• For all energies, $E$ must have a value of 1 at 0 and 180° due to conservation laws.
Running conditions

• The data for this analysis was collected during the g9a running period of FroST using the CLAS detector at the Thomas Jefferson National Laboratory.

• Target:
  – Longitudinal polarized target
  – Average target polarization:
    • ∼82% (+Pol) and 90% (-Pol)

• Photon beam:
  – Circularly and linearly polarized photon beam
  – 0.5 - 4.5 GeV
  – Electron beam polarization ∼85%

• Trigger:
  – At least one charged particle in CLAS

• 10.5 billion events taken
FroST (Frozen Spin Target)

The FroST target and its components:
A: Primary heat exchanger
B: 1 K heat shield
C: Holding coil
D: 20 K heat shield
E: Outer vacuum can (Rohacell extension)
F: CH2 target
G: Carbon target
H: Butanol target
J: Target insert
K: Mixing chamber
L: Microwave waveguide
M: Kapton coldseal

Butanol Composition:
$C_4H_9OH + \text{liquid He}$

Performance Specs:
Base Temp: 28 mK w/o beam, 30 mK with
Cooling Power: 800 $\mu$W @ 50 mK, 10 mW @ 100 mK, and 60 mW @ 300 mK
Polarization: +82%, -90%
1/e Relaxation Time: 2800 hours (+Pol), 1600 hours (-Pol)
Roughly 1% polarization loss per day.
Particle identification

- Particle identification used GPID.
- GPID compares measured velocity to known particles given the measured momentum.
- A cut of $|\beta_{\text{measured}} - \beta_{\text{calculated}}| \leq 0.08$ was enforced for pions.
Vertex resolution

Counts

-10 -5 0 5 10 15 20 25 30
Z position (cm)

Butanol Target
Carbon Target
CH2 Target

Butanol Composition:
$C_4H_9OH + \text{liquid He}$
Potential topologies:

\[ \gamma + p \rightarrow p + X \ (\text{full CLAS acceptance}) \]

\[ W = 1500 \text{ to } 1550 \text{ MeV} \]
Potential topologies:

\[ \gamma + p \rightarrow p + X \text{ (no charged particles other than the proton detected)} \]

\[ W = 1500 \text{ to } 1550 \text{ MeV} \]
Potential topologies:
\[ \gamma + p \rightarrow p + \pi^{\pm/-} + X \]

\[ W = 1500 \text{ to } 1550 \text{ MeV} \]

Counts vs. \( M_X (\text{GeV}) \)
Potential topologies:

\[ \gamma + p \rightarrow p + \pi^+ + \pi^- + \pi^0 \]

\[ W = 1500 \text{ to } 1550 \text{ MeV} \]
Potential topologies:

\[ \gamma + p \rightarrow p + X \ (photon \ detected) \]

\[ W = 1500 \text{ to } 1550 \ MeV \]
Fits for $\gamma + p \rightarrow p + X$ (no charged particles other than the proton detected)

- $W = 1500$ to $1550$ MeV
- $\cos(\theta_{\text{c.m.}}) = -0.4$ to $-0.2$

Denominator
- $N_{\frac{1}{2}} + N_{\frac{3}{2}}$

Numerator
- $N_{\frac{1}{2}} - N_{\frac{3}{2}}$

Scaled Carbon
$E$ at threshold

\begin{align*}
\text{Observable } E \text{ for } \eta: W &= 1525 \text{ MeV} \\
\gamma + p &\rightarrow p + X \\
p_0 &= 1.00 \pm 0.04 \\
\gamma + p &\rightarrow p + X (n.c.) \\
p_0 &= 1.02 \pm 0.04 \\
\gamma + p &\rightarrow p + X (\gamma \text{ det.}) \\
p_0 &= 0.99 \pm 0.04 \\
\gamma + p &\rightarrow p + X (\gamma \text{ det., n.c.}) \\
p_0 &= 0.98 \pm 0.04 \\
\end{align*}

*\text{n.c. implies no charged particles other than the proton.}
$E$ for $\eta$: $\gamma + p \rightarrow p + X \ (n.c.)$

**Observable $E$ for $\eta$: $W = 1525$ MeV**

SAID

$\eta$-MAID

Bonn-Gatchina

VERY PRELIMINARY
$E$ for $\eta$: $\gamma + p \rightarrow p + X$ (n.c.)

Observable $E$ for $\eta$: $W = 1575$ MeV

SAID

$\eta$-MAID

Bonn-Gatchina

VERY PRELIMINARY
$E$ for $\eta: \gamma + p \rightarrow p + X \ (n.c.)$

Observable $E$ for $\eta$: $W = 1625$ MeV

SAID  
$\eta$-MAID  
Bonn-Gatchina

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**SAID**

**$\eta$-MAID**

**Bonn-Gatchina**

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$E$ for $\eta$: $\gamma + p \rightarrow p + X$ (n.c.)

**SAID**

**$\eta$-MAID**

Bonn-Gatchina

**Observable $E$ for $\eta$: $W = 1925$ MeV**

**VERY PRELIMINARY**
$E$ vs $W$

Topology: $\gamma + p \rightarrow p + X$ (n.c.)
Conclusions

• Preliminary measurements for $E$ near threshold demonstrate proper behavior. Very preliminary measurements for $E$ have been obtained up to 1925 MeV in W.

• Polarization observables from $\eta$ photoproduction will help constrain theoretical models.

• All other beam-target double polarization observables are accessible through FroST and will be analyzed.
Acknowledgements

• The CLAS collaboration
• The ASU working group:
  – Barry Ritchie
  – Michael Dugger
  – Eugene Pasyuk (now at Jlab)
Polarization systematics

• Beam polarization: < 4%

• Target polarization: < 4%