Helicity difference in $\vec{\gamma}\vec{p} \rightarrow p\pi^+\pi^-$ production with CLAS spectrometer at the JLab

Sungkyun Park
on behalf of CLAS collaboration

Florida State University

NStar 2011
May 19, 2011
Supported by Department of Energy
Outline

1 Motivation
- The motivation for the $\pi^+\pi^-$ photoproduction
- Polarization observables

2 FROST Experiment
- The CLAS at JLab
- The FROzen-Spin Target (FROST)
- The FROST-g9a run Period

3 Parameter
- Particle identification
- Dilution factor

4 The Preliminary results
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4 The Preliminary results
The motivation for the $\pi^+\pi^-$ photoproduction

- The cross section of the $\pi^+\pi^-$ photoproduction dominates above $W \approx 1.8$GeV.
- The excited states are found as broadly overlapping resonances.

$\rightarrow$ **The polarization observables** can isolate single resonances from other interference terms.
The differential cross section for $\gamma p \rightarrow p\pi^+\pi^-$

The differential cross section for $\gamma p \rightarrow p\pi^+\pi^-$

(without measuring the polarization of the recoiling nucleon)

$$\frac{d\sigma}{dx_i} = \sigma_0 \left\{ \left( 1 + \vec{\Lambda}_i \cdot \vec{P} \right) + \delta_\circ \left( I_\circ + \vec{\Lambda}_i \cdot \vec{P}_\circ \right) \right. \\
+ \delta_\iota \left[ \sin 2\beta \left( I_s + \vec{\Lambda}_i \cdot \vec{P}_s \right) + \cos 2\beta \left( I_c + \vec{\Lambda}_i \cdot \vec{P}_c \right) \right] \right\}$$

- $\sigma_0$: The unpolarized cross section
- $\beta$: The angle between the direction of polarization and the x-axis
- $\delta_\circ, I$: The degree of polarization of the photon beam $\Rightarrow \delta_\circ$, and $\delta_\iota$
- $\vec{\Lambda}_i$: The polarization of the initial nucleon $\Rightarrow (\Lambda_x, \Lambda_y, \Lambda_z)$
- $I_\circ, I_s, I_c$: The observable arising from use of polarized photons $\Rightarrow I_\circ, I_s, I_c$
- $\vec{P}$: The polarization observable $\Rightarrow (P_x, P_y, P_z)$ $\Rightarrow (P_x^\circ, P_y^\circ, P_z^\circ)$ $\Rightarrow (P_s, P_s, P_s)$ $\Rightarrow (P_x^c, P_y^c, P_z^c)$

15 Observables
Polarization observables

The circularly-polarized beam → \( \delta_1 = 0 \)

The longitudinally-polarized target → \( \Lambda_x = \Lambda_y = 0 \)

\[
\frac{d\sigma}{dx_i} = \sigma_0 \left\{ (1 + \Lambda_z \cdot P_z) + \delta_\odot (I^\odot + \Lambda_z \cdot P^\odot_z) \right\} \quad 3 \text{ Observables}
\]

\( I^\odot \) only is published and small and sensitive

The linearly-polarized beam → \( \delta_\odot = 0 \)

The longitudinally-polarized target → \( \Lambda_x = \Lambda_y = 0 \)

\[
\frac{d\sigma}{dx_i} = \sigma_0 \left\{ (1 + \vec{\Lambda}_z \cdot \vec{P}_z) \right. \\
\left. + \delta_1 \left[ \sin 2\beta (I^s + \vec{\Lambda}_z \cdot \vec{P}_z^s) + \cos 2\beta (I^c + \vec{\Lambda}_z \cdot \vec{P}_z^c) \right] \right\} \quad 5 \text{ Observables}
\]
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4. The Preliminary results
The continuous electron beam accelerator facility (CEBAF) can deliver a continuous electron beam up to 6 GeV.

Jefferson laboratory in Newport News, VA
CEBAF Large Acceptance Spectrometer (CLAS)

- **Torus magnet**: 6 superconducting coils
- **Electromagnetic calorimeters**: Lead/scintillator, 1296 photomultipliers
- **Drift chambers**: argon/CO₂ gas, 35,000 cells
- **Time-of-flight counters**: plastic scintillators, 684 photomultipliers
- **Gas Cherenkov counters**

**Motivation**
- The CLAS at JLab
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- The FROST-g9a run Period

**The Preliminary results**

**The FROST Experiment**

- The CEBAF Large Acceptance Spectrometer (CLAS)

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The FRozen-Spin Target (FROST)

28 mK (w/o beam) and 30mK (w/ beam)

The magnets in the FROST experiment

(a) The longitudinal holding magnet. (About 0.5 T)
(b) The transversal holding magnet. (March 2010 - August 2010)
(c) The polarizing magnet. (5 Tesla solenoid)

1. Polarized Butanol ($C_4H_9OH$) (L = 5.0 cm, $\phi$ = 1.5 cm) $\sim$ 5 g
2. Carbon ($^{12}C$) (L = 0.15 cm) (6 cm from CLAS center)
3. Polyethylene ($CH_2$) (L = 0.35 cm) (16 cm from CLAS center)

L: The length and $\phi$: The diameter
The FROST-g9a run Data

The FROST run period: Nov. 3, 2007 - Feb. 12, 2008
Data set: 35 TBytes

Production data

Target:
- Longitudinal polarized target
- Average target polarization
  \( \sim 82\% \) (+Pol) and 85 % (-Pol)

Photon beam:
- Circularly and linearly polarized photon beam
  0.5 - 4.5 GeV
- Electron beam polarization \( \sim 85\% \)

Trigger: - at least one charged particle in CLAS

10.5 Billion events
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Particle identification \( (\vec{\gamma}, p, \pi^+, \pi^-) \)

- Coincidence Time: \(|\Delta t| < 1.2 \text{ [ns]}\)
- Particle identification
  - Proton: \(|\Delta \beta| < 0.01882\)
  - \(\pi^+\): \(|\Delta \beta| < 0.0285\)
  - \(\pi^-\): \(|\Delta \beta| < 0.0264\)
The four different topologies of $\gamma p \rightarrow p\pi^+\pi^-$

- The topology: $\gamma p \rightarrow p\pi^+ (\pi^-)$
- The topology: $\gamma p \rightarrow p\pi^- (\pi^+)$
- The topology: $\gamma p \rightarrow \pi^+\pi^- (p)$
- The topology: $\gamma p \rightarrow p\pi^+\pi^-$
Three kinds of targets

Reaction Vertex

- **Butanol events** from Z ∈ [-6, 4] cm, r < 3 cm
- **Carbon events** from Z ∈ [4.5, 10] cm, r < 3 cm
- **CH$_2$ events** from Z ∈ [13, 19] cm, r < 3 cm

There is butanol background under carbon.

Motivation
FROST Experiment
Parameter
The Preliminary results

Particle identification
Dilution factor

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Motivation
FROST Experiment
Parameter
The Preliminary results

Dilution factor

Topology: $\gamma p \rightarrow \pi^+ \pi^- (p)$

$E_\gamma = 2.478 \text{ GeV}$

$E_\gamma = 0.9 - 1.0 \text{ GeV}$

- Butanol (data)

$M_{\text{M}} = [0.75, 0.8, 0.85, 0.9, 0.95, 1, 1.05, 1.1]$ GeV

$N_{\text{butanol}} - N_{\text{carbon}} \cdot S$

Dilution factor

Butanol ($C_4H_9OH$)
- Polarized Hydrogen
- Unpolarized Carbon
- Unpolarized Oxygen

$N_{\text{M}} = \frac{\sigma_H}{\sigma_{C_4H_9OH}} = \frac{N_{\text{butanol}} - N_{\text{carbon}} \cdot S}{N_{\text{butanol}}}$

(S: Scale Factor -> Normalization factor btw butanol and carbon target)

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**Dilution factor**

\[
\text{Dilution factor} = \frac{(\text{AREA}) \ of \ N_{\text{Hydrogen}}}{(\text{AREA}) \ of \ N_{\text{Butanol}}}
\]

\[E_\gamma = 2.478 \text{ GeV} \]
\[E_\gamma = 0.9 - 1.0 \text{ GeV} \]

- Hydrogen (data)
- Butanol (data)
- Carbon (scaled)

#events of Hydrogen (Topology: $\gamma \ p \to \pi^+ \pi^- (p)$)

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4 The Preliminary results
Photoproduction of $\pi^+\pi^-$ off the proton: Kinematics

The $\pi^+\pi^-$ in the final state require 5 independent variables!

$$\gamma p \rightarrow N^* \rightarrow p' \rho \rightarrow p'\pi^+\pi^-$$

ex: $E_\gamma$, $\theta_{c.m.}$, $\phi_{\pi^+}^*$, $\theta_{\pi^+}^*$, $M_{\pi^++\pi^-}$
Polarization observable $I^s$

\[
\frac{d\sigma(\Rightarrow)}{dx_i} + \frac{d\sigma(\Leftarrow)}{dx_i} = 2 \cdot \sigma_0 \left\{ 1 + \delta_1 \left[ \sin 2\beta (I^s) + \cos 2\beta (I^c) \right] \right\}
\]

- $\sigma_0$: The unpolarized cross section
- $\beta$: The angle between the direction of polarization and the x-axis
Comparison of observable $I^s$ with another data

$E_\gamma : 1250 - 1300$ MeV (comparison with g8b data)

- **g9a (FROST)**
  - polarized beam
  - polarized target
  - (butanol)

- **g8b**
  - polarized beam
  - unpolarized target
  - (liquid hydrogen)

- Previous presentation

- $\phi_{\pi^+}$: the $\pi^+$ azimuthal angle

- $\theta_{\pi^+}$: the $\pi^+$ polar angle

  - (in the rest frame of the $\pi^+ \pi^-$ system)
Polarization observable \( P_z \)

\[
P_z = \frac{1}{f \cdot \delta_\odot \cdot \Lambda_z} \left( \frac{N(\rightarrow\Rightarrow) + N(\leftarrow\leftarrow)}{N(\rightarrow\Rightarrow) + N(\leftarrow\leftarrow)} - \frac{N(\rightarrow\leftarrow) + N(\leftarrow\Rightarrow)}{N(\rightarrow\leftarrow) + N(\leftarrow\Rightarrow)} \right)
\]

- \( f \) - dilution factor \( \approx 0.56 \) (10%)
- \( \delta_\odot \) - beam polarization
- \( \Lambda_z \) - target polarization \( \approx 0.85 \) (5%)
- \( N(\rightarrow\Rightarrow) \) - the number of events with the circular beam polarization and longitudinal target polarization

\( \rightarrow \) and \( \leftarrow \): beam spin
\( \Rightarrow \) and \( \Leftarrow \): target spin
The asymmetry plot for $P_z$

$E_\gamma : 700 - 800$ MeV

Data used
- $E_e : 1.645$ GeV
- $E_e : 2.478$ GeV
- Average

Very preliminary

Difference btw average and data

Entries 4359
Constant 4.088e+05
Mean -0.0007202
Sigma 0.1313

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The asymmetry plot for $P_z$

$E_\gamma : 1000 - 1100$ MeV

Data used
- $E_e : 1.645$ GeV
- $E_e : 2.478$ GeV
- Average

Very preliminary data used
- $\Phi : 1000 - 1100$ MeV

Entries: 4359
Constant: $4.088 \times 10^5$
Mean: -0.0007202
Sigma: 0.1313

Difference between average and data

Entries: 4359
Constant: $4.088 \times 10^5$
Mean: -0.0007202
Sigma: 0.1313
The asymmetry plot for \( P_z \)

\[ E_\gamma : 1200 - 1300 \text{ MeV} \]

Data used

- \( E_e : 1.645 \text{ GeV} \)
- \( E_e : 2.478 \text{ GeV} \)
- Average

Difference
btw average and data

<table>
<thead>
<tr>
<th>Entries</th>
<th>4359</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>4.088e+05</td>
</tr>
<tr>
<td>Mean</td>
<td>-0.0007202</td>
</tr>
<tr>
<td>Sigma</td>
<td>0.1313</td>
</tr>
</tbody>
</table>
The asymmetry plot for $P_z$

$E_\gamma$ : 1500 - 1600 MeV

Data used
- $E_e$ : 1.645 GeV
- $E_e$ : 2.478 GeV
- Average

Difference between average and data

Very preliminary

Entries 4359
Constant 4.088e+05
Mean -0.0007202
Sigma 0.1313

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Polarization observable $P_z$

$$P_z = \frac{1}{f \cdot \Lambda_z} \frac{N(\Rightarrow) - N(\Leftarrow)}{N(\Rightarrow) + N(\Leftarrow)}$$

- $f$ - dilution factor $\approx 0.56 \ (10\%)$
- $\Lambda_z$ - target polarization $\approx 0.85 \ (5\%)$
- $N(\Rightarrow)$ - the number of events with the longitudinal target polarization

$\Rightarrow$ and $\Leftarrow$: target spin.
The asymmetry plot for $P_z$

$E_\gamma : 500 - 600$ MeV

Data used
- $E_e : 1.645$ GeV
- $E_e : 2.478$ GeV
- Average

Difference btw average and data

Entries 4400
Constant $1.043e+06$
Mean $0.0003413$
Sigma $0.05206$
The asymmetry plot for $P_z$

$E_{\gamma}$ : 700 - 800 MeV

Data used
- $E_e : 1.645$ GeV
- $E_e : 2.478$ GeV
- Average

Very preliminary

Difference
btw average and data

Entries  4400
Constant  1.043e+06
Mean      0.0003413
Sigma     0.05206

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The asymmetry plot for $P_z$

$E_\gamma : 800 - 900$ MeV

Data used
- $E_e : 1.645$ GeV
- $E_e : 2.478$ GeV
- Average

Difference btw average and data

Entries 4400
Constant 1.043e+06
Mean 0.0003413
Sigma 0.05206
The asymmetry plot for $P_z$

$E_\gamma : 900 - 1000 \text{ MeV}$

Data used
- $E_e : 1.645 \text{ GeV}$
- $E_e : 2.478 \text{ GeV}$
- Average

Difference btw average and data

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The asymmetry plot for $P_z$

$E_\gamma$ : 1000 - 1100 MeV

Data used
- $E_e : 1.645$ GeV
- $E_e : 2.478$ GeV
- Average

Difference btw average and data

Entries 4400
Constant 1.043e+06
Mean 0.0003413
Sigma 0.05206

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The asymmetry plot for $P_z$

$E_\gamma : 1100 - 1200 \text{ MeV}$

Data used
- $E_e : 1.645 \text{ GeV}$
- $E_e : 2.478 \text{ GeV}$
- Average

Very preliminary Data used
- Entries: 4400
- Constant: 1.043e+06
- Mean: 0.0003413
- Sigma: 0.05206

Sungkyun Park
NStar 2011, May 19, 2011
The asymmetry plot for $P_z$

$E_\gamma : 1200 - 1300$ MeV

**Data used**
- $E_e : 1.645$ GeV
- $E_e : 2.478$ GeV
- Average

**Difference**
btw average and data

Entries 4400
Constant 1.043e+06
Mean 0.0003413
Sigma 0.05206

Sungkyun Park
NStar 2011, May 19, 2011
The asymmetry plot for $P_z$

$E_\gamma : 1500 - 1600$ MeV

Data used
- $E_e : 1.645$ GeV
- $E_e : 2.478$ GeV
- Average

Very preliminary

Difference btw average and data

 Entries 4400
 Constant 1.043e+06
 Mean 0.0003413
 Sigma 0.05206
Summary

- Comparison of observable $I^s$ with another data
- Preliminary results for $P_z^\circ$ and $P_z$ in $\pi^+ \pi^-$ photoproduction

In future,
- Results for $I^\circ$ in $\pi^+ \pi^-$ photoproduction
- Comparison of observable $I^\circ$ with the published data
Back up
Motivation
FROST Experiment
Parameter
The Preliminary results

One of the Goals of the $N^*$ Program ...

Search for *missing* or yet unobserved resonances

Quark models predict many more baryons than have been observed

<table>
<thead>
<tr>
<th>N Spectrum</th>
<th>****</th>
<th>***</th>
<th>**</th>
<th>*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11</td>
<td>3</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Δ Spectrum</td>
<td>7</td>
<td>3</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

*according to PDG (Phys. Lett. B 667, 1 (2008))

little known (many open questions left)

Possible solutions:

1. Quark-diquark structure

one of the internal degrees of freedom is frozen

2. Have not been observed, yet

Nearly all existing data result from $\pi N$ scattering experiments

If the missing resonances did not couple to $N\pi$, they would not have been discovered!!
The excited states of the nucleon

Constituent quark models: $N^*$ resonances ($\text{Isospin } \frac{1}{2}$)

1. The some excited states suggested by models do not match accurately the states measured by experiment.

2. Many predicted states are missing.

---

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Expectation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base temperature:</td>
<td>50 mK</td>
<td>28 mK (w/o beam)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 mK (w/ beam)</td>
</tr>
<tr>
<td>Cooling Power:</td>
<td>10 $\mu$W (Frozen)</td>
<td>800 $\mu$W @ 50mK</td>
</tr>
<tr>
<td></td>
<td>20 mW (Polarizing)</td>
<td>60mW @ 300 mK</td>
</tr>
<tr>
<td>Polarization:</td>
<td>80 %</td>
<td>+ 82 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 85 %</td>
</tr>
<tr>
<td>1/e Relaxation Time:</td>
<td>500 hours</td>
<td>2700 hours (+ Pol.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1600 hours (-Pol.)</td>
</tr>
</tbody>
</table>
1. Selecting phase space with bound nucleon events in the butanol and carbon
2. Diving bound nucleon events from the butanol by the carbon.

Scale Factor = \( \frac{\text{phase\_space} (\text{Butanol})}{\text{phase\_space} (\text{Carbon})} \)
Motivation
FROST Experiment
Parameter
The Preliminary results

**Butanol/Carbon Normalization - Scale Factor**

![Graphs showing scale factors for different energy ranges](image_url)

- **0.5 \leq E(\gamma) \leq 0.6\,(GeV)**
- **0.6 \leq E(\gamma) \leq 0.7\,(GeV)**
- **0.8 \leq E(\gamma) \leq 0.9\,(GeV)**
- **0.9 \leq E(\gamma) \leq 1.0\,(GeV)**
- **1.0 \leq E(\gamma) \leq 1.1\,(GeV)**
- **1.1 \leq E(\gamma) \leq 1.2\,(GeV)**
- **1.2 \leq E(\gamma) \leq 1.3\,(GeV)**
- **1.3 \leq E(\gamma) \leq 1.4\,(GeV)**

**Phase Space Scale Factor (Target: Butanol)**

- **Average except Topology** $\gamma p \rightarrow \pi^+ \pi^- (p)$
- **Topology** $\gamma p \rightarrow \pi^+ \pi^- (p)$

**Check_PSSF_ABin_fsu_Per**

- **Entries** 25
- **Mean** 1.476
- **RMS** 0.5392

**Fitting (pol0)**

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Motivation

FROST Experiment

Parameter

The Preliminary results

the beam and target polarization

- Target polarization, $\Lambda_z \sim 0.85$
- Electron beam polarization, $P_e \sim 0.85$

$$P_\gamma = P_e \cdot \frac{(\frac{4}{E_e}) E_\gamma - (\frac{4}{E_e})^2 E_\gamma^2}{4 - (\frac{4}{E_e}) E_\gamma + 3 (\frac{4}{E_e})^2 E_\gamma^2}$$

![Graph showing the circular polarization of the photon beam as a function of photon energy, $E_e = 1.045$ GeV]

<table>
<thead>
<tr>
<th>The photon energy [GeV]</th>
<th>The photon polarization</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0.3,0.4]</td>
<td>0.209</td>
</tr>
<tr>
<td>[0.4,0.5]</td>
<td>0.277</td>
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<tr>
<td>[0.5,0.6]</td>
<td>0.348</td>
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<tr>
<td>[0.6,0.7]</td>
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<tr>
<td>[0.7,0.8]</td>
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<tr>
<td>[1.1,1.2]</td>
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<tr>
<td>[1.2,1.3]</td>
<td>0.777</td>
</tr>
<tr>
<td>[1.3,1.4]</td>
<td>0.810</td>
</tr>
<tr>
<td>[1.4,1.5]</td>
<td>0.833</td>
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<tr>
<td>[1.5,1.6]</td>
<td>0.846</td>
</tr>
</tbody>
</table>
Motivation
FROST Experiment
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The Preliminary results

Preliminary

\(-1.0 < \cos(\theta_{\pi^0}) < -0.9\)

\(-0.9 < \cos(\theta_{\pi^0}) < -0.8\)

\(-0.8 < \cos(\theta_{\pi^0}) < -0.7\)

\(-0.7 < \cos(\theta_{\pi^0}) < -0.6\)

\(-0.6 < \cos(\theta_{\pi^0}) < -0.5\)

\(-0.5 < \cos(\theta_{\pi^0}) < -0.4\)

\(-0.4 < \cos(\theta_{\pi^0}) < -0.3\)

\(-0.3 < \cos(\theta_{\pi^0}) < -0.2\)

\(-0.2 < \cos(\theta_{\pi^0}) < -0.1\)

\(-0.1 < \cos(\theta_{\pi^0}) < 0.0\)

\(0.0 < \cos(\theta_{\pi^0}) < 0.1\)

\(0.1 < \cos(\theta_{\pi^0}) < 0.2\)

\(0.2 < \cos(\theta_{\pi^0}) < 0.3\)

\(0.3 < \cos(\theta_{\pi^0}) < 0.4\)

\(0.4 < \cos(\theta_{\pi^0}) < 0.5\)

\(0.5 < \cos(\theta_{\pi^0}) < 0.6\)

\(0.6 < \cos(\theta_{\pi^0}) < 0.7\)

\(0.7 < \cos(\theta_{\pi^0}) < 0.8\)

\(0.8 < \cos(\theta_{\pi^0}) < 0.9\)

\(0.9 < \cos(\theta_{\pi^0}) < 1.0\)

\(\phi_{\pi^0}\)
FROST Experiment

Parameter

The Preliminary results

Motivation

Very preliminary

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