The target asymmetry $P_z$ in $\gamma \bar{p} \rightarrow p \pi^+ \pi^-$ with CLAS spectrometer at the JLab (Ph.D. Student Annual Review)

Sungkyun Park

Florida State University

Sep. 01, 2011
Outline

1. The FROzen-Spin Target (FROST)
   - The FROzen-Spin Target (FROST)
   - The FROST-g9a run Period
   - Polarization observables

2. The current status of the analysis
   - Dilution factor
   - Target Polarization
   - Normalization Factor

3. The Preliminary results
Outline

1. The FROzen-Spin Target (FROST)
   - The FROzen-Spin Target (FROST)
   - The FROST-g9a run Period
   - Polarization observables

2. The current status of the analysis
   - Dilution factor
   - Target Polarization
   - Normalization Factor

3. The Preliminary results
The FROzen-Spin Target (FROST)

The current status of the analysis

The Preliminary results

The FROST-g9a run Period

Polarization observables

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

L: The length and \(\phi\): The diameter

28 mK (w/o beam) and 30mK (w/ beam)
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
The differential cross section for $\gamma p \rightarrow p\pi^+\pi^-$

(without measuring the polarization of the recoiling nucleon)

$$\frac{d\sigma}{dx_i} = \sigma_0 \left\{ (1 + \vec{\Lambda}_i \cdot \vec{P}) + \delta_\circ (I^\circ + \vec{\Lambda}_i \cdot \vec{P}^\circ) \right.$$ 

$$+ \delta_\perp [\sin 2\beta (I^s + \vec{\Lambda}_i \cdot \vec{P}^s) + \cos 2\beta (I^c + \vec{\Lambda}_i \cdot \vec{P}^c)] \right\}$$

- $\sigma_0$: The unpolarized cross section
- $\beta$: The angle between the direction of polarization and the x-axis
- $\delta_\circ, \delta_\perp$: The degree of polarization of the photon beam $\Rightarrow \delta_\circ$, and $\delta_\perp$
- $\vec{\Lambda}_i$: 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 $\Rightarrow (P_x, P_y, P_z) (P_x^\circ, P_y^\circ, P_z^\circ) (P_x^s, P_y^s, P_z^s) (P_x^c, P_y^c, P_z^c)$

15 Observables
Polarization observables

1. The circularly-polarized beam → $\delta_l = 0$

2. The longitudinally-polarized target → $\Lambda_x = \Lambda_y = 0$

$$\frac{d\sigma}{dx_i} = \sigma_0 \left\{ (1 + \Lambda_z \cdot P_z) + \delta_\odot (I_\odot + \Lambda_z \cdot P_{z_\odot}) \right\}$$

3 Observables

$I_\odot$ only is published and small and sensitive

$$P_z(E_\gamma, \theta^*, \phi^*) = \frac{1}{D(E_\gamma,top) \cdot \Lambda_z} \left\{ \frac{N(\Rightarrow)_{but.} - N(\Leftarrow)_{but.}}{N(\Rightarrow)_{but.} + N(\Leftarrow)_{but.}} \right\}$$
Polarization observable, $P_z$

$$P_z(E_\gamma, \theta^*, \phi^*) = \frac{1}{D(E_\gamma, \text{topology}) \cdot \bar{\Lambda}_z} \left\{ \begin{array}{c} N(\Rightarrow)_{but.} - N(\Leftarrow)_{but.} \\ N(\Rightarrow)_{but.} + N(\Leftarrow)_{but.} \end{array} \right\}$$

$$N(\Rightarrow)_{but.} = N(\rightarrow\Rightarrow; E_\gamma, \theta^*, \phi^*) + N(\leftarrow\Rightarrow; E_\gamma, \theta^*, \phi^*)$$

$$N(\Leftarrow)_{but.} = \frac{N(\leftarrow\Leftarrow; E_\gamma, \theta^*, \phi^*)}{A(\Leftarrow) / A(\Rightarrow)} + \frac{N(\Leftarrow\Leftarrow; E_\gamma, \theta^*, \phi^*)}{A(\Leftarrow) / A(\Rightarrow)}$$

Three important parameters for polarization observable, $P_z$

- $D(E_\gamma, \text{topology})$: Dilution Factor
- $\bar{\Lambda}_z$: The average of the target polarizations
- $A(\Leftarrow) / A(\Rightarrow)$: The normalization factors
- $N$ terms: the number of events for the different polarization configuration

$\Rightarrow$ (or $\Leftarrow$): The target polarization direction is parallel (or antiparallel) to the beam
Outline

1. The FROzen-Spin Target (FROST)
   - The FROzen-Spin Target (FROST)
   - The FROST-g9a run Period
   - Polarization observables

2. The current status of the analysis
   - Dilution factor
   - Target Polarization
   - Normalization Factor

3. The Preliminary results
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: $\gamma p \rightarrow p\pi^+\pi^-$
The FROzen-Spin Target (FROST)
The current status of the analysis
The Preliminary results

Dilution factor, \( D(E_\gamma, \text{topology}) \)

**Topoji : \( \gamma p \rightarrow \pi^+ \pi^- (p) \)**

- \( E_\gamma = 2.478 \text{ GeV} \)
- \( E_\gamma = 0.9 - 1.0 \text{ GeV} \)

**Signal**

**bound nucleons events**

**background**

\[
\text{Dilution factor} = \frac{\sigma_H}{\sigma_{C_4H_9OH}} = \frac{N_{\text{butanol}} - N_{\text{carbon}}}{N_{\text{butanol}}} \cdot S = \frac{(\text{AREA}) \text{ of } N_{\text{Hydrogen}}}{(\text{AREA}) \text{ of } N_{\text{Butanol}}} \]

(\( S \) : Scale Factor -> Normalization factor btw butanol and carbon target)
The angle dependence of the dilution factor

diamond θ angle-00 : 0 < θ < 180
diamond θ angle-01 : 0 < θ < 18
diamond θ angle-02 : 18 < θ < 36 ...

Average from θ angle-01 to θ angle-10

Error : statistic error + systematic error (10 %)

θ angle : The π⁺ polar angle in the rest frame of the π⁺ π⁻ system
Target Polarization, $\bar{\Lambda}_z$

Target Polarization at periods

- Period 01: 0.800 (⇐)
- Period 02: 0.787 (⇐)
- Period 03: 0.876 (⇒)
- Period 04: 0.843 (⇒)
- Period 05: 0.834 (⇐)
- Period 06: 0.796 (⇒)
- Period 07: 0.800 (⇐)

$E_e$: 1.6 GeV

$E_e$: 2.4 GeV

- Target polarization, ⇒ (or ⇐): The direction is parallel (or antiparallel) to the beam
- There are groups of runs with similar conditions in data with circularly polarized beam

These are defined as periods

Sungkyun Park

Annual Review 2011
Normalization Factor, \( A(\leftarrow) \) or \( A(\Rightarrow) \)

- From \( gflux \): use the number of total photons as the normalization factor.
- From Total events: use the number of total events.

\[ E_{\gamma} = 1.645 \text{ GeV} \]
\[ E_{\gamma} = 2.478 \text{ GeV} \]
Outline

1. The FROzen-Spin Target (FROST)
   - The FROsten-Spin Target (FROST)
   - The FROST-g9a run Period
   - Polarization observables

2. The current status of the analysis
   - Dilution factor
   - Target Polarization
   - Normalization Factor

3. The Preliminary results
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, $P_z$

$$P_z(E_\gamma, \theta^*, \phi^*) = \frac{1}{D(E_\gamma, \text{topology}) \cdot \Lambda_z} \left\{ \begin{array}{c} N(\Rightarrow)_{\text{but.}} - N(\Leftarrow)_{\text{but.}} \\ N(\Rightarrow)_{\text{but.}} + N(\Leftarrow)_{\text{but.}} \end{array} \right\}$$

Target Polarization

- $N(\Rightarrow)_{\text{but.}}$: Period 3, 4, and 6
- $N(\Leftarrow)_{\text{but.}}$: Period 1, 2, 5, and 7

There are 6 combinations for Polarization observable, $P_z$

- [1, 3], [2, 3], [4, 5], [4, 7], [6, 5], [6, 7]
The FROzen-Spin Target (FROST)
The current status of the analysis
The Preliminary results

Target asymmetry for $P_z$

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

Data used
- Per-13
- Per-23
- Per-67
- Per-45
- Per-47
- Per-65
- All-Ave

- $\phi_{\pi^+}$: the $\pi^+$ azimuthal angle
- $\theta_{\pi^+}$: the $\pi^+$ polar angle
  
  (in the rest frame of the $\pi^+ \pi^-$ system)
The FROzen-Spin Target (FROST)
The current status of the analysis
The Preliminary results

Target asymmetry for $P_z$

$E_\gamma : 800 - 900$ MeV

Data used
- Per-13
- Per-23
- Per-67
- Per-45
- Per-47
- Per-65
- All-Ave

Very preliminary

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

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

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

Sungkyun Park Annual Review 2011
The FROzen-Spin Target (FROST)
The current status of the analysis
The Preliminary results

Target asymmetry for $P_z$

$E_\gamma : 900 - 1000$ MeV

Data used
- Per-13
- Per-23
- Per-67
- Per-45
- Per-47
- Per-65
- All-Ave

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

( in the rest frame of the $\pi^+\pi^-$ system )
Summary

- Polarization observables $P_z$ made in the different periods have very nice agreement.
- The sinusoidal structure of the asymmetries can be observed.
- The proper normalization factors are not existed now.

In future,
- Results for $I$ and $P_z$ in $\pi^+$ $\pi^-$ photoproduction.
<table>
<thead>
<tr>
<th>Expectation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base temperature:</strong></td>
<td></td>
</tr>
<tr>
<td>50 mK</td>
<td>28 mK (w/o beam)</td>
</tr>
<tr>
<td></td>
<td>30 mK (w/ beam)</td>
</tr>
<tr>
<td><strong>Cooling Power:</strong></td>
<td></td>
</tr>
<tr>
<td>10 $\mu$W (Frozen)</td>
<td>800 $\mu$W @ 50mK</td>
</tr>
<tr>
<td>20 mW (Polarizing)</td>
<td>60mW @ 300 mK</td>
</tr>
<tr>
<td><strong>Polarization:</strong></td>
<td></td>
</tr>
<tr>
<td>80 %</td>
<td>+ 82 %</td>
</tr>
<tr>
<td></td>
<td>- 85 %</td>
</tr>
<tr>
<td><strong>1/e Relaxation Time:</strong></td>
<td></td>
</tr>
<tr>
<td>500 hours</td>
<td>2700 hours (+ Pol.)</td>
</tr>
<tr>
<td></td>
<td>1600 hours (-Pol.)</td>
</tr>
</tbody>
</table>
Systematic error in the dilution factor

- **Topology:** $\gamma p \rightarrow p \pi^+ \pi^-$
- The ratio of values made by the different methods is about 1.1
- **Systematic error:** 10 %