Double-spin observables in charged pion photo-production from polarized neutrons in solid HD using the CLAS at Jefferson Lab

@SPIN 2016
Sept. 27, 2016; Champaign, USA

Tsuneo Kageya

Thomas Jefferson National Accelerator Facility,
Newport News, USA
(On behalf of the g14 Analysis Team and CLAS collaboration)
1. Experimental conditions and our objective

g14 experiments: Dec. 2011 – May. 2012

* Circularly polarized photon beams: $0.85 < E_\gamma < 2.4$ GeV

$\overrightarrow{D}$: 27 days $\rightarrow$ 4.5 B events (Dpol. $\sim + 25\%$)

Used for this analysis

Extract E asymmetry from $\gamma + n(p) \rightarrow \pi^- + p (p)$
2. Experimental apparatus

Circularly and linearly polarized photon beams

CLAS detectors and electron tagging system

Polarized deuteron target (Solid HD)
3. Independent analyses of this $E$ asymmetry with three methods

(a) Background subtraction (1D-Bsub)
(b) BDT (Boosted Decision Trees) : $K^0\Lambda$ analysis
(c) Kinematical fitting

(a): Background from target cell can be subtracted completely

(b) & (c): could be applied to low statistics channels.

Compare and combine the results from three analysis methods

1) from Dao Ho PhD. thesis; “Measurements of the $E$ Polarization Observable for $\gamma d \rightarrow \pi-p(p_s)$, $\gamma d \rightarrow K^0\Lambda(p_s)$, and $\gamma d \rightarrow \pi+\pi-d(o)$ using CLAS g14 data at Jefferson Lab”

2) from Peng Peng PhD thesis; “Polarization observables for single and double charged pion photo-production with polarized HD target”
CLAS detector side view (reconstruct and identify $\pi^-$ & proton )
Common corrections for $E$ asymmetry on $\gamma + n(p) \rightarrow \pi^- + p (p)$

(a) Energy loss correction
(b) Momentum correction
(c) Tagger photon beam energy correction
Target Cell

(a) Background subtraction method (No.1)

Reconstructed vertex (beam direction) for $\pi^-$ and proton

HD and target cell

HD ice

Thin Al wire

$\gamma$ beam

PCTFE walls

Al wires

Target cell

23%

HD 77%
(a) Background subtraction method (No.2); Major cuts

**Coplanarity cut**

\[ |\Phi_{\pi^-} - \Phi_p| < 20 \]

**Missing Mass Squared cut**

\[ 0 < \text{M.M. squared} < 1.1 \text{ GeV}^2 \]

**Target cell background subtraction & vertex cut**

-13 < Z < 2 cm
(b) Kinematic fitting method (No. 1)

- Apply a hypothesis to the fitter; $\gamma + (n) \rightarrow \pi^- + p$;
- Assume a moving target neutron with unknown Fermi momentum

This method removes the events from

* high-momentum neutrons in the deuteron (automatically)
* Target cell background
* Background from 2 pion productions
(b) Kinematic fitting method (No.2) : $\gamma + (n) \rightarrow \pi^- + p$

Good events pass the CL
Background to be removed
**BDT (Multivariate analysis, Boosted Decision Trees) Method (No.1)**

* To reject two backgrounds

- Target cell
- Other channels (2 Π productions)

* Train data with

- Signals from Monte Carlo (CLAS geometry and performances)
- Background from target cell data
(c) BDT (Multivariate analysis, Boosted Decision Trees) Method (No.2)

* Before (Blue) and after (Red) BDT applied

**Missing Momentum**

**Missing Mass**
* Common cut for Missing momentum to the three methods

T. Kageya, SPIN 2016, Sept. 27 2016

Cut

$$0 \leq M_{\text{M.}} \leq 1.1 \text{ GeV}^2$$

Missing momentum of proton (GeV/c)
E asymmetry dependence on the missing momentum ranges (all energy and integrated to $\cos \theta_{CM}$ of $\pi^-$)

(BDT method)

$3^{rd}$ order polynomial $\chi^2$/d.o.f=0.75

Used for the analysis
4. Preliminary results; $E$ asymmetries from 3 methods for $\gamma + n(p) \rightarrow \pi^- + p(p)$ ($\cos \theta_{CM}$ of $\pi^-$)

$1.48 < W < 1.52$ GeV

$1.76 < W < 1.8$ GeV

$2.04 < W < 2.08$ GeV

$2.28 < W < 2.32$ GeV

BDT, Kinematical fit, BG subtraction

T. Kageya, SPIN 2016, Sept. 27 2016
E asymmetries for $\gamma+n(p) \rightarrow \pi^- + p + (p)$

Comparisons of three methods

(as a function of $\cos \theta_{\text{CM}}$)

**BDT**

**Kinematic Fitting**

**Background Subtraction**
asymmetries for combining 3 methods with PWA analysis for $\gamma + n\ (p) \rightarrow \pi^- + p(p)\ (\cos \theta_{CM\, \pi^-})$

Errors: statistical only

Red: SAID[CM12]
Black: BG2011-02
Blue: $g_{14}$ data
E asymmetries for $\gamma+n(p) \rightarrow \pi^-+p+(p)$ (3 methods combined)

All energy bins from this experiment (as a function of $\cos \theta_{CM}$)

Red: SAID[CM12]
Black: BG2011-02
Blue: g14 data

T. Kageya, SPIN 2016, Sept. 27 2016
### Combined systematic errors (relative) for the three analysis methods

<table>
<thead>
<tr>
<th>Contributions to $\sigma_{\text{sys}}$</th>
<th>$\sigma_{\text{sys}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1D-Bsub</td>
</tr>
<tr>
<td><strong>z-vertex cut / Kel-F suppression:</strong></td>
<td>2.6 %</td>
</tr>
<tr>
<td><strong>Confidence level cut / BDT cut:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Missing momentum cut:</strong></td>
<td>1.7 %</td>
</tr>
<tr>
<td><strong>PID cut:</strong></td>
<td>1.3 %</td>
</tr>
<tr>
<td><strong>Missing mass cut:</strong></td>
<td>1.4 %</td>
</tr>
<tr>
<td><strong>Coplanarity cut:</strong></td>
<td>0.4 %</td>
</tr>
<tr>
<td><strong>Monte Carlo (DC resolution):</strong></td>
<td></td>
</tr>
<tr>
<td>**Extrapolation to $</td>
<td>p_{\text{missing}}</td>
</tr>
<tr>
<td><strong>$\sigma$ (cuts):</strong></td>
<td>4.3 %</td>
</tr>
<tr>
<td><strong>Photon beam polarization:</strong></td>
<td>3.4 %</td>
</tr>
<tr>
<td><strong>Target polarization:</strong></td>
<td>6.0 %</td>
</tr>
<tr>
<td><strong>$\sigma$ (polarization):</strong></td>
<td>6.9 %</td>
</tr>
<tr>
<td><strong>$\sigma$ (total):</strong></td>
<td>8.1 %</td>
</tr>
</tbody>
</table>
5. Summary

a. Completed experiments for pseudoscalar-meson photo-production from longitudinally polarized HD at CLAS for 64 days of circularly and 30 days of linearly polarized photon beams.

b. Preliminary results for $E$ asymmetry for $\gamma + n(p) \rightarrow \pi^- p (p)$ were shown. Systematic errors are estimated.

c. Study of $\Sigma$ and $G$ asymmetries for $\gamma + n(p) \rightarrow \pi^- p (p)$ is ongoing

d. Analyses for other channels, like $\gamma + p(n) \rightarrow p \pi^+ \pi^- (n)$, $\gamma + n(p) \rightarrow n \pi^+ \pi^- (p)$, $K^0\Lambda$ and $K^+\Sigma^-$ are in progress.

e. For vector meson production, $\gamma + p(n) \rightarrow p \rho (n)$, analyses are ongoing.
Backup slides
(c) BDT (Multivariate analysis, Boosted Decision Trees) Method (No.2)

* Build up distinct decision trees in multi dimensional (10 in this case)
(c) BDT (Multivariate analysis, Boosted Decision Trees) Method (No.3)

* BDT output $\rightarrow$ -1 (background) to 1 (Signal)
1. Physics motivation: for missing resonances issue, measure more spin observables for neutron (little known) from HD

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

<table>
<thead>
<tr>
<th>un polarized</th>
<th>σ₀</th>
<th>T</th>
<th>P</th>
<th>Tₓ'</th>
<th>Lₓ'</th>
<th>Σ</th>
<th>Tₚ'</th>
<th>Lₚ'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pₑ sin(2φₑ)</td>
<td>H</td>
<td>G</td>
<td>Ox'</td>
<td>Os'</td>
<td>Cz'</td>
<td>E</td>
<td>F</td>
<td>-Cx'</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pₑ cos(2φₑ)</th>
<th>Σ</th>
<th>-P</th>
<th>-T</th>
<th>-Lz'</th>
<th>Tz'</th>
<th>-σ₀</th>
<th>Lz'</th>
<th>-Tz'</th>
</tr>
</thead>
<tbody>
<tr>
<td>circular Pₑ</td>
<td>F</td>
<td>-E</td>
<td>Cₓ'</td>
<td>Cz'</td>
<td>-Oz'</td>
<td>G</td>
<td>-H</td>
<td>Ox'</td>
</tr>
</tbody>
</table>

This talk

<table>
<thead>
<tr>
<th>status</th>
<th>CLAS run period</th>
<th>beam</th>
<th>target</th>
</tr>
</thead>
<tbody>
<tr>
<td>complete</td>
<td>g13</td>
<td>Γₓ , Γₓ</td>
<td>LD₂</td>
</tr>
<tr>
<td>complete</td>
<td>g14</td>
<td>Γₓ , Γₓ</td>
<td>H₀Ice (Longitudinally polarized)</td>
</tr>
</tbody>
</table>

Sandorfi, Hoblit, Kumano, Lee, J.PHYS, G38 (2011)053001

T. Kageya, SPIN 2016, Sept. 27 2016
New longitudinally polarized target for this experiment

Frozen Spin Polarized solid HD target  
Relaxation time of D > 1 year @ ~ 50 mK and 0.9 Tesla

* Horizontal Dilution Fridge (designed and constructed by HDice group at Jlab)
* 1 Tesla main Solenoid for longitudinal holding field
* Transverse field of 750 Gauss for field rotation (spin flip)
* NMR coil: polarization monitor during the run and spin transfer and H-spin flip, Birdcage coil
Definitions of axes and angles

- $\gamma$: Beam
- $\pi^{-}$
- $\theta$: Polar angle
- $\Phi$: Azimuthal angle
- $X$
- $Z$
- Target
Pseudoscalar meson reactions and observables measured in this experiment (try Neutron reactions using Deuteron)

<table>
<thead>
<tr>
<th>reaction</th>
<th>observable</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma + n \ (p) \rightarrow \pi^- \ p \ (p)$</td>
<td>$\sigma_0, \Sigma, E, G$</td>
</tr>
<tr>
<td>$\gamma + n \ (p) \rightarrow \pi^+ \pi^- \ n \ (p)$</td>
<td>$\sigma_0, I^c (\Sigma), I^s, I^o, P_z, P^o_z (E), P^s_z (G), P^c_z$</td>
</tr>
</tbody>
</table>
| $\gamma + n \ (p) \rightarrow K^0 \ \Lambda \ (p)$ | $\sigma_0, \Sigma, E, G$  
$O_{x'}, O_{z'}, C_{x'}, C_{z'}, P, T=(-O_{y'})$  
$L_{x'}, L_{z'}, T_{x'}, T_{z'}$ |
| $\gamma + n \ (p) \rightarrow K^0 \ \Sigma^0 \ (p)$ | $\sigma_0, \Sigma, P, E, G$ |
| $\gamma + n \ (p) \rightarrow K^+ \ \Sigma^- \ (p)$ | $\sigma_0, \Sigma, E, G$ |

From proposal E06-101

T. Kageya, 4th Joint DNP Meeting, October 11, 2014
3. Experimental conditions and data reduction

**g14 experiments: Dec. 2011 – May. 2012**

* Circularly polarized photon beams: $0.85 < E_\gamma < 2.4$ GeV
  \[ \rightarrow \] 27 days $\rightarrow$ 4.5 B events (Dpol. $\sim + 25\%$)

Dpol : Preliminary

* Linearly polarized photon beams: $1.6 < E_\gamma < 2.2$ GeV
  \[ \rightarrow \] 21 days $\rightarrow$ 2.5 B events (Dpol. $\sim + 25\%$)
  \[ \leftarrow \] 9 days $\rightarrow$ 1.2 B events (Dpol. $\sim - 17\%$)
(a) Select events; only \( \pi^\pm \) and Proton detected in CLAS.

Particle Identification using \( \beta = \nu/c \) vs \( P \) (\( \nu \): from TOF)

Thanks to Peng Peng.