Beam Spin Asymmetry of SIDIS pions with CLAS 12

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Introduction

- Physics motivation
- Particle identification
- Preliminary results

- run 3432 (~ 1400 files)
  - 10.6 GeV
  - solenoid -100%, torus -100%
  - cooked with coatjava v. 5b.3.3
Physics Motivation

- The 3D nucleon structure can be described with GPDs and TMDs
- The SIDIS cross section can be expressed in terms of model independent structure functions:

\[
\frac{d\sigma}{dx_B\, dQ^2\, dz\, d\phi\, dp_{h\perp}^2} = K(x, y, Q^2)\left\{ F_{UU,T} + \varepsilon F_{UU,L} \right\} \\
+ \sqrt{2\varepsilon(1+\varepsilon)} \cos\phi_h F_{UU}^{\cos\phi_h} + \varepsilon \cos(2\phi_h) F_{UU}^{\cos2\phi_h} + \lambda_e \sqrt{2\varepsilon(1-\varepsilon)} \sin\phi_h F_{LU}^{\sin\phi_h}
\]

\[
F_{LU}^{\sin\phi} = \frac{2M}{Q} C \left( -\hat{h} \cdot k_T \frac{H}{M} + \frac{M}{M} f_1 \frac{\tilde{G}}{z} \right) + \hat{h} \cdot p_T \left( xg^{\perp}D_1 + \frac{M}{M} h_1 \frac{\tilde{E}}{z} \right)
\]

Mulders, Tangerman (1995)
Physics Motivation

\[ BSA = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{A_{LU}^{\sin \phi} \sin \phi}{1 + A_{UU}^{\cos \phi} \cos \phi + A_{UU}^{\cos (2\phi)} \cos (2\phi)} \approx A_{LU}^{\sin \phi} \sin \phi \]

- BSA is a good tool to extract the „moments“

**Experimentally:**

\[ BSA_i = \frac{1}{P_e} \frac{N_i^+ - N_i^-}{N_i^+ + N_i^-} \]

- Helicity independent acceptance terms cancel out in the ratio!
Particle ID

- A clean particle ID is the key for all SIDIS analyses
  - There is no additional event selection criterion
  - Each particle should have a clear ID
  - It may be better to reject a particle than to assign it a wrong PID

a) Electron ID
   - Based on eventbuilder PID
     + fiducial cuts for PCAL
     + fiducial cuts for DC
     + Calorimeter sampling fraction cut limited to real $3\sigma$ region
     + $E > 1.5$ GeV @ 10.6 GeV
     + relatively wide $z$ vertex cut

b) Photon ID
   - Based on standard PID + fiducial cuts for PCAL + $\beta > 0.95$
c) Hadron Particle ID

i) Fiducial cuts on the 3 Driftchamber regions

ii) Particle selection based on $\beta$ vs $p$ correlation

100 MeV $p$ slices for each sector

- proton
- $\pi^+$
Mean and 3 sigma region

\[ q > 0 \]

\[ q > 0 \]
sector 1

\[ q > 0 \]
sector 2

\[ q > 0 \]
sector 3

\[ q < 0 \]

\[ q < 0 \]
sector 1

\[ q < 0 \]
sector 2

\[ q < 0 \]
sector 3
• Simple $\beta$ vs $p$ cut: particles are double assigned in the overlap region

$\Rightarrow$ Assignment of each particle based on statistical probabilities

\[
P(\beta') = \frac{1}{\sqrt{2\pi}\sigma} \cdot \exp\left(-\frac{1}{2}\left(\frac{\beta - \mu}{\sigma}\right)^2\right)
\]

**Consider**: Particles have momentum dependent population fractions

\[
n_{\pi^+}(p) = \frac{N_{\pi^+}(p)}{N_{\pi^+}(p) + N_p(p) + N_{K^+}(p)}
\]

\[
p_{\pi^+} = n_{\pi^+}(p) \cdot P(\beta', p)
\]

$\Rightarrow$ Calculate $p(\beta)$ for each particle species

$\Rightarrow$ Assign particle to species with the highest probability

$\Rightarrow$ Calculate the confidence level for the particle species

$\Rightarrow$ Check if particle is within the 3 sigma region (conf. lev. > 0.27%)
Population ratio for detected particles (outbending)

Proton population ratio

\[ \frac{\pi^-}{\pi^+} = 0.497 \]

\( p_0 = -0.481 \pm 0.024 \)
\( p_1 = 1.514 \pm 0.076 \)
\( p_2 = -0.2118 \pm 0.0118 \)
\( p_3 = -1.07 \pm 0.00 \)
\( p_4 = 0.5649 \pm 0.0002 \)
\( p_5 = -0.3671 \pm 0.0000 \)
\( p_6 = 0.0856 \pm 0.0000 \)
\( p_7 = -0.03688 \pm 0.00000 \)
\( p_8 = 0.30132 \pm 0.00000 \)
\( p_9 = 0.000107 \pm 0.00000 \)
\( p_{10} = -1.3956 - 2.919 - 10 \)
\( p_{11} = 7.545 - 0.7213 \)
\( p_{12} = -1.550 - 1.786 - 12 \)

Pip population ratio

\[ \frac{\pi^+}{\pi^-} = 0.0763 \]

\( p_0 = 0.0003 \pm 0.0472 \)
\( p_1 = -0.7255 \pm 1.525 \)
\( p_2 = 0.4145 \pm 0.9542 \)
\( p_3 = 0.1149 \pm 0.9765 \)
\( p_4 = -0.0172 \pm 0.16279 \)
\( p_5 = -0.00133 \pm 0.01287 \)
\( p_6 = 4.008e-05 \pm 4.157e-04 \)

Kp population ratio

\[ \frac{K^+}{\pi^-} = 0.163 \]

\( p_0 = 0.1718 \pm 0.0969 \)
\( p_1 = -0.1994 \pm 0.0386 \)
\( p_2 = 0.1145 \pm 0.0053 \)
\( p_3 = -0.0192 \pm 0.00082 \)
\( p_4 = 0.0004097 \pm 0.00000077 \)
\( p_5 = 0.0001238 \pm 0.0000069 \)
\( p_6 = -7.066e-06 \pm 6.054e-07 \)

Pim population ratio

\[ \frac{\pi^-}{\pi^+} = 0.7892 \]

\( p_0 = 0.9595 \pm 1.0850 \)
\( p_1 = 0.0063 \pm 1.2719 \)
\( p_2 = -0.03089 \pm 0.4431 \)
\( p_3 = 0.005294 \pm 0.061207 \)
\( p_4 = -0.0002486 \pm 0.00020566 \)

Km population ratio

\[ \frac{K^-}{\pi^-} = 0.2545 \]

\( p_0 = 0.2474 \pm 0.29114 \)
\( p_1 = 0.2435 \pm 0.42020 \)
\( p_2 = 0.2424 \pm 0.17150 \)
\( p_3 = -0.00456 \pm 0.02571 \)
\( p_4 = 0.0002215 \pm 0.0012682 \)

Based on SIDIS simulations
Maximum Likelihood Particle ID

no population weighting

population weighting

positive charge

negative charge
π⁰ Selection and kinematic coverage

π⁰ selection:
$E_γ > 1 \text{ GeV}$

cut on opening angle vs energy of π⁰ candidate

inv. mass of π⁰

3σ cut
$\sigma \sim 11 \text{ MeV}$

DIS cut:
$Q^2 > 1 \text{ GeV}^2$, $W > 2 \text{ GeV}$

kinematic coverage significantly extended compared to CLAS6

CLAS6:
$Q^2 < 4 \text{ GeV}^2$, $p_T < 1 \text{ GeV}$
BSA for a single detected pion

binned in z, x, pt and $Q^2$

$\pi^0 \ x = 0.15$

$\chi^2 / \text{ndf} \quad 10.16 / 11$

$p0 \quad 0.03609 \pm 0.01509$

$\pi^0 \ z = 0.45$

$\chi^2 / \text{ndf} \quad 8.339 / 11$

$p0 \quad 0.04493 \pm 0.02400$

$\pi^+ \ x = 0.25$

$\chi^2 / \text{ndf} \quad 16.13 / 11$

$p0 \quad 0.023 \pm 0.007$

$\pi^+ \ z = 0.45$

$\chi^2 / \text{ndf} \quad 5.883 / 11$

$p0 \quad 0.03398 \pm 0.01014$
CLAS 12
10.6 GeV

π^0 + π^-

π^+ outbending

π^- inbending

π^- outbending

π^+ inbending

W. Gohn et al., CLAS collaboration, PHYSICAL REVIEW D 89, 072011 (2014)
CLAS 12
10.6 GeV
no z cut!

CLAS 6 - 5.498 GeV

π⁺

π⁻

π⁰
CLAS 12
10.6 GeV

no z cut!
CLAS 12
10.6 GeV
no z cut!

CLAS 12:
• extension to 8 GeV² with more statistics

CLAS 6 - 5.498 GeV

\[ Q^2 / \text{GeV}^2 \]

\[ A_{LU} \]

inbending

\[ \pi^- \]

\[ \pi^+ \]

outbending

\[ \pi^- \]

\[ \pi^+ \]

\[ \pi^0 \]

\[ Q^2 / \text{GeV}^2 \]

\[ A_{LU} \]

downward slope ???

upward slope ???

downward slope ???
Summary and Outlook

- SIDIS BSA at 10.6 GeV shows a similar behaviour as at 5.5 GeV (CLAS 6)

- Cuts on $z > 0.3$ and $z < 0.7$ have to be added for the $Q^2$, $p_T$ and $x$ binning
  - $z > 0.3$ removes the "target fragmentation region"
  - $z < 0.7$ removes contamination by pions from exclusive channels

- Expected kinematic coverage:

<table>
<thead>
<tr>
<th></th>
<th>CLAS 6</th>
<th>CLAS 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_B$</td>
<td>0.1 - 0.6</td>
<td>0.1 - 0.7</td>
</tr>
<tr>
<td>$p_T$</td>
<td>0 - 1 GeV</td>
<td>0 - 3 GeV</td>
</tr>
<tr>
<td>$Q^2$</td>
<td>1 - 4 GeV$^2$</td>
<td>1 (1.5) - 8 GeV$^2$</td>
</tr>
</tbody>
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- ~ 1440 files of run 3432 have been used (0.3 % of spring run)
  - 5%/ 10%/ 25%/ 100% of spring run will reduce errors by a factor 4/6/9/18

- LTCC can provide better Pion/Kaon separation from 3.5 GeV to 9 GeV
  - Only 4 sectors available (only 1 filled with $C_4F_{10}$)

- Theoretical modells will be provided by Peter Schweitzer (UCONN)