Forward Single Spin Asymmetries in Transversely Polarized Proton Collisions at STAR

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OUTLINE

- Transverse Single Spin Asymmetries
- STAR Forward Meson Spectrometer
- $\sqrt{s} = 500$ GeV data overview and production asymmetries of $\pi^0$
- Summary & Outlook
Transverse SSA in hadronic collisions

- Production asymmetry of hadron/jet/direct photon.
  \[ A_N = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \]

- A promising tool to reveal spin-correlated parton transverse motion and/or parton transversity.

- Test QCD in non-perturbative regime
Transverse SSA in hadronic collisions

FNAL E704 $\sqrt{s} = 20$ GeV

$\rho+p \rightarrow \pi^0+X$ at $\sqrt{s}=200$ GeV

STAR,
Transverse SSA beyond collinear scheme


J. Collins, Nuclear Physics B396 (1993) 161
Transverse SSA beyond leading twist

- **Low $p_T$ region**--
  TMD factorization, non-zero $A_N$ at leading twist.
  Intrinsic $k_T$ in initial or final state

- **High $p_T$ ($p_T \geq Q$) region**--
  Collinear factorization, $A_N$ generated by higher twist effects, e.g. initial state quark-gluon correlation

Transition region--
If both factorization schemes work, they should predict the same $A_N$
Transverse SSA measurement at STAR

FMS
(Forward Meson Calorimeter)
2.5<\eta<4.0
Transverse SSA measurement at STAR

- **Forward Meson Spectrometer**
  Pb-glass EMCal, collects Cherenkov light

Greatly extends STAR EM coverage

Capable of measuring $\pi^0, \eta, \text{jets, etc.}$

788 large cells / 476 small cells
Data overview

FY2011 Run

- Data taken at $\sqrt{s} = 500$ GeV with transversely polarized proton collisions.
- Online analysis performed during commissioning run.
- 22.4 pb$^{-1}$ of data were retained after QA. Pol. $\sim (40\%, 50\%)$.
- Jet Patch triggered data were analyzed with preliminary calibrations.
  
  More data can be restored...
Data overview — single/double $\gamma$ separation

log(Energy) weighted cluster moments provides $\pi^0/\gamma$ separation up to $\sim 80$ GeV

$\sigma_{\text{max}} \equiv \text{Max Eigenvector of}$

\[
\begin{bmatrix}
\sigma_x^2 & \sigma_{xy} \\
\sigma_{yx} & \sigma_y^2
\end{bmatrix}
\]

$\sigma_x = \sqrt{\frac{\sum_i \log(E_i + E_{\text{offset}}) \cdot (\bar{x} - x_i)^2}{\sum_i \log(E_i + E_{\text{offset}})}}$

$\sigma_y = \sqrt{\frac{\sum_i \log(E_i + E_{\text{offset}}) \cdot (\bar{y} - y_i)^2}{\sum_i \log(E_i + E_{\text{offset}})}}$

$\sigma_{xy} = \sigma_{yx} = \sqrt{\frac{\sum_i \log(E_i + E_{\text{offset}}) \cdot (\bar{x} - x_i)(\bar{y} - y_i)}{\sum_i \log(E_i + E_{\text{offset}})}}$

10/28/2011 1-photon clusters 2011 DNP Fall meeting, MSU

Old algorithm with Energy weighted moments

Improved algorithm with log energy weighted moments

Provides clearer separation Between $\pi^0$ and single photon. Clusters up to $\sim 80$ GeV.
Data overview — kinematic acceptance

2-photon pair mass
$0.07 \text{GeV} < m_{\gamma\gamma} < 0.27 \text{GeV}$

Pseudorapidity (2.6, 4.0)

$\mathbf{STAR \ 2006 \ FPD}$

$\mathbf{Phys.Rev.Lett.} \ 101,222001 \ (2008)$

$\mathbf{x_F \approx E/250 = \ 0.2 \ 0.3 \ 0.4}$
Data overview – 2-photon invariant mass

FMS 2011 data @35 GeV
Pseudorapidity (3.0,3.4)
Data overview — estimate \( \pi^0 \) candidate yield

\[ \begin{array}{c}
\text{Energy / GeV} \\
0 & 20 & 40 & 60 & 80 & 100 & 120 \\
\hline
x_F \approx 0.2 & 0.3 \\
\end{array} \]

\[ \begin{array}{c}
\text{# of pions} \\
10^7 & 10^6 & 10^5 & 10^4 \\
\hline
\end{array} \]

\[ p + p \rightarrow \pi^0 + X \text{ at } \sqrt{s} = 200 \text{ GeV} \]

\[ \begin{array}{c}
< x_F > \approx 0.28 \\
\text{FPD data} \\
< x_F > \approx 0.32 \\
\text{twist-3} \\
\end{array} \]

\[ \begin{array}{c}
< x_F > \approx 0.37 \\
< x_F > \approx 0.43 \\
\end{array} \]

STAR 2006 FPD data from {
{Phys.Rev.Lett.}
101, 222001 (2008)\]
Raw asymmetry — $\pi^0$ candidates

Yield asym. = \frac{[N(\text{up}) - N(\text{down})]}{[N(\text{up}) + N(\text{down})]} = R_{\text{lumi}} + \text{Pol.} * A_N \cos(\phi)

R_{\text{lumi}} = \frac{L_{\text{up}} - L_{\text{down}}}{L_{\text{up}} + L_{\text{down}}}

A_N \text{ calculated by assuming 50% beam polarization}

@75 \text{ GeV} (x_F = 0.3)

blue beam (positive $x_F$) $A_N = 0.026 \pm 0.001$

yellow beam (negative $x_F$) $A_N = 0.0007 \pm 0.001$

0.1 \text{ GeV mass window, } A_N \text{ reported for di-photon events within the window}
Summary & Outlook

- $p_T$ dependence of SSA provides critical test of TMD factorization and Twist-3 scheme in transition region.

- STAR has taken a large data sample @500 GeV polarized pp collisions, with large detector acceptance.

- Nonzero single spin asymmetries of $\pi^0$ candidates have been observed.

- Further efforts in calibration and background study are needed to investigate $x_F$ and $p_T$ dependence of SSA.