Recent Results of Transverse Spin Physics in PHENIX

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Transverse Asymmetries

\[ A_N = \frac{1}{P} \frac{d\sigma_L - d\sigma_R}{d\sigma_L + d\sigma_R} \]

\[ x_F = 2 \frac{p_{long}}{\sqrt{s}} \]
Three major questions

What are the origins of transverse-spin phenomena in QCD?
- Transversity
- Connections to orbital angular momentum
Transversity & Collins fragmentation correlation between proton spin & quark spin + spin dependant fragmentation function


\[ \propto \delta q(x) \cdot H_1^\perp(z_2, \bar{k}_\perp^2) \]
RHIC

- Two transversely polarized beams
- Two single spin asymmetry measurements in PHENIX at the same time
## Luminosity & Polarization

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<td>2002</td>
<td>200</td>
<td>15</td>
<td>-</td>
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<td>0.15</td>
<td>3.4 x 10$^{-3}$</td>
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<td>2003</td>
<td>200</td>
<td>27</td>
<td>0.35</td>
<td>1.9 x 10$^{-3}$</td>
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<tr>
<td>2004</td>
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<td>40</td>
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<tr>
<td>2005</td>
<td>200</td>
<td>49 (47)</td>
<td>3.4</td>
<td>2 x 10$^{-1}$</td>
<td>0.16</td>
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<td>62</td>
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<td>-</td>
<td>-</td>
<td>5.2</td>
<td>1.1 x 10$^0$</td>
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<td>14</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>2009</td>
<td>200</td>
<td>55</td>
<td>16</td>
<td>1.5 x 10$^0$</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* integrated luminosity for PHENIX central arm
Central Arms  \( |\eta| < 0.35 \)
- charged hadrons
- \( \pi^0, \eta \)
- direct photon
- \( J/\Psi \)
- heavy flavor

Muon Arms  \( 1.2 < |\eta| < 2.4 \)
- \( J/\Psi \)
- charged hadrons
- heavy flavor

MPC  \( 3.1 < |\eta| < 3.9 \)
- \( \pi^0, \eta \)
$A_N$: mid-rapidity $\pi^0$

PHENIX Preliminary, $\sqrt{s}=200$ GeV, $|\eta|<0.38$

Vertical Scale Uncertainty: 4.8%

less than 0.2%
$A_N$: mid-rapidity $\pi^0$ and $\eta$

PHENIX Preliminary, $\sqrt{s}=200$ GeV, $|\eta|<0.38$

Vertical Scale Uncertainty: 4.8%
$A_N$: mid-rapidity $\pi^0$

PHENIX Preliminary, $\sqrt{s}=200$ GeV, $|\eta|<0.38$

Vertical Scale Uncertainty: 4.8%

$|x_F| > 0.01$

$\pi^0 \ x_F < -0.01$

$\pi^0 \ x_F > 0.01$
$A_N$: mid-rapidity $\eta$

PHENIX Preliminary, $\sqrt{s}=200$ GeV, $|\eta|<0.38$

Vertical Scale Uncertainty: 4.8%

$|x_F|>0.01$

- $\eta x_F < -0.01$
- $\eta x_F > 0.01$

Transverse Spin Physics in PHENIX
Limit on Gluon Sivers Function

- gluon Sivers at positivity bound no sea quark Sivers
- gluon Sivers parameterized to be 1 sigma from PHENIX $\pi^0 A_N$
- sea quark maximized plus valence quarks
- gluon contribution

LO model-dependent constraints on gluon Sivers function from PHENIX data at SMALL x
Forward $A_N$ Charged Hadrons

- Unidentified charged hadron asymmetry
- Mid-rapidity results from 2002 & 2005
  - Increased statistics in 2008 data

Transverse Spin Physics in PHENIX
Forward $A_N \ @ 62.4 \ GeV$

- **Neutral pions**
- **quark-gluon dominated**

\[ p^+p \rightarrow \pi^0 + X \text{ at } \sqrt{s} = 62.4 \ GeV \]

Process contribution to $\pi^0$, $\eta = 3.3$, $\sqrt{s} = 200 \ GeV$


- **global analysis needed!**
Forward $A_N$ for Clusters

- in the Muon Piston Calorimeter clusters from pion decay photons merge at high energies (> 20 GeV)
- tower size $2.25^2 \text{ cm}^2$
- 220 cm from vertex

$\sqrt{s} = 200 \text{ GeV}$
Forward $A_N$ for Clusters

$\sqrt{s} = 200$ GeV

PHENIX Preliminary
Single Clusters, $p+p \sqrt{s}=200$ GeV
Vertical Scale Uncertainty: 4.8%

$A_N$ vs $p_T$ (GeV/c)

Cluster contribution
- decay photon
- $\pi^0$
- direct photon

Transverse Spin Physics in PHENIX
Heavy Flavor

$p^+ p \rightarrow DX$

- dominated by gluon gluon fusion
- No gluon transversity
- Sensitive to gluon Sivers effect

- Twist-3 gluon correlators $T_G^{(d)}, T_G^{(f)}$
- Disentangle effects in $x_F$ range
Heavy Flavor

**single leptons**

*no full D-meson reconstruction*

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Transverse Spin Physics in PHENIX
Back-to-back jets

The Sivers effect can manifest itself as an azimuthal asymmetry in back-to-back jets in polarized p+p collisions.

\[ \vec{S}_T \cdot (\vec{p} \times \vec{k}_T) \]

Boer, Vogelsang
Phys. Rev. D 69, 094025

Bomhof, Mulder, Vogelsang and Yuan
PRD 75, 074019
Di-hadrons in PHENIX

- Sivers asymmetry ($q_T \perp$)
- No asymmetry expected for $q_T \parallel$
- Improved statistics for 2008 data set!

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| $\eta_{\text{min}}$ | -3.7 | -2.4 | -0.35 | 1.2 | 3.1 |
| $\eta_{\text{max}}$ | -3.1 | -1.2 | +0.35 | 2.4 | 3.9 |
```

Similar analysis possible in different combinations of rapidity.

Transverse Spin Physics in PHENIX

Works in progress...
Transverse Spin Physics in PHENIX
Outlook

- Non zero asymmetries in forward direction
  - asymmetry for $\eta$-meson soon
- Sivers constraint possible with mid-rapidity data
- Di-hadron correlations for rapidity separated pairs
- Heavy flavor tagging with vertex detector upgrades
  - charm/bottom separation
Backup
Forward $A_N$ Charged Hadrons

- Unidentified charged hadron $A_N$
- Asymmetries corrected for bin sharing and interactions in magnet/absorber
- Non-zero $A_N$ persists to moderate pseudorapidity

Transverse Spin Physics in PHENIX

$p+p, \sqrt{s}=200\text{GeV}$

PHENIX Preliminary
Forward $A_N$ for clusters

- $0.25 < |x_F| < 0.30$
- $0.30 < |x_F| < 0.35$
- $0.35 < |x_F| < 0.40$
- $0.40 < |x_F| < 0.47$

**Decay photon $\pi^0$**
**Direct photon**

Transverse Spin Physics in PHENIX
Heavy Flavor

$pp \rightarrow DX \, @ \, LO$

Transverse Spin Physics in PHENIX
Heavy Flavor

- J/Psi single spin asymmetry
- production mechanism
- gluon dynamics
- larger $x_F$ lever arm?

Transverse Spin Physics in PHENIX