Current and Near-term Transverse Spin Measurements at PHENIX

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PHENIX Detector at RHIC

Central Arms $|\eta| < 0.35$
- Identified charged hadrons
- $\pi^0, \eta$
- Direct Photon
- $J/\Psi$
- Heavy Flavor

Muon Arms $1.2 < |\eta| < 2.4$
- $J/\Psi$
- Unidentified charged hadrons
- Heavy Flavor

MPC $3.1 < |\eta| < 3.9$
- $\pi^0, \eta$
Single Transverse Spin Asymmetries in pp Collisions

Features:
- Forward non-zero asymmetries.
- Asymmetries consistent over an order of magnitude in \( \sqrt{s} \).
- Several theoretical frameworks to explain the results.
(I) Transversity quark distributions and Collins fragmentation function
Correlation between proton & quark spin + spin dependant fragmentation function

\[ \propto \delta q(x) \cdot H_1^\perp (z, \vec{k}_\perp^2) \]

Quark transverse spin distribution \hspace{1cm} Collins FF


(II) Sivers quark-distribution
Correlation between proton-spin and transverse quark momentum

\[ \propto \tilde{f}_{1T}^q (x, k_{\perp}^2) \cdot D_q^h (z) \]

Sivers distribution


(III) Higher-twist effects
 Twist-3 quark-gluon/gluon-gluon correlators
 Expectation: at large \( p_T \), \( A_N \sim 1/p_T \)

So far, fall-off with \( p_T \) has not been observed!
Neutral Pion Cross-Sections Experiment vs pQCD

New PHENIX Result with Forward Neutral Pions at $\sqrt{s}=200$ GeV

Close agreement with charged pions from BRAHMS.

More work needed to understand lower energies.
1. $A_N$ Measurements
   - Sensitive to combinations of all three effects
   - At forward and mid rapidity

2. Sivers Measurements
   - Heavy flavor
   - Back to back hadrons

3. Transversity Measurements
   - Interference Fragmentation Function
   - Collins in Jets

2012+2013 Runs are projected to produce 33 pb$^{-1}$ at 60% polarization. Projected error bars are interspersed throughout the talk.
Underlying Event Kinematics of p-p Scattering at √s=200 GeV

- Estimated with Pythia simulation package
- Mid-rapidity:
  Low $p_T$ dominated by gluon gluon scattering
- Forward-rapidity:
  High-$x$ + Low-$x$ scattering

![Graphs showing data in different rapidity regions](image_url)
Photon merging effects prevent two-photon $\pi^0$ analysis for $E>20$ GeV ($p_T>2$ GeV/c)

**62 GeV**
20 GeV $\rightarrow$ 0.65 $x_F$: Two-photon $\pi^0$ analysis

**200 GeV**
20 GeV $\rightarrow$ 0.20 $x_F$: “Single clusters”. Yields dominated by $\pi^0$’s but also get contributions from:

- **Electromagnetic**
  - Direct photons
  - Decay photons ($\eta$, etc)
  - Estimated using Pythia (TuneA)

- **Hadronic: ($\pi^{+/-}, K^{+/-}$, etc.)**
  - Estimated with Pythia+GEANT.
    Initial estimate is <10% contamination in lowest energy bin with decreasing fraction as deposited energy increases
  - Qualitatively consistent with expected detector behavior

Decay photon impact positions for low and high energy $\pi^0$’s
(i) Forward SSA $A_N \pi^0$ in MPC at $\sqrt{s}=62$ GeV

- PHENIX $\pi^0$ results available for $\sqrt{s}=62$ GeV
  - Production dominated by quark-gluon
  - Similar $x_F$ scaling to higher and lower center of masses
  - Asymmetries could enter a global analysis on transverse spin asymmetries

PHENIX Detector

$\sqrt{s}=200$ GeV

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

- $\eta > 3.5$
- $\eta < 3.5$

(i) Forward SSA $A_N$ Cluster in MPC at $\sqrt{s}=200$ GeV
(i) Mid-rapidity, |y|<0.38, $A_N \pi^0$, $\eta$ Analysis

Similar analysis to existing PHENIX $A_{LL}$

1. Measure $A_N$ in mass window of:
   - $\pi^0$ (Signal+Background)
   - $\eta$ (Signal+Background)
   - Background

2. Determine background fractions ($r$)

3. Asymmetries binned in $p_T$ for:
   - inclusive selection
   - with $x_F>0.01$, $x_F<-0.01$

$\begin{align*}
A_N^{\text{Signal}} &= \frac{A_N^{\text{Signal}+\text{Background}} - r A_N^{\text{Background}}}{1 - r}
\end{align*}$

Previous $\pi^0$ $A_N$ measurement done with 2002 dataset.
(i) Results for mid-rapidity $\pi^0 A_N$

- Previous result shown to be sensitive to gluon Sivers function.
- New result will be published with 20x smaller error bars.
(i) Mid-rapidity $\pi^0$ and $\eta A_N$

- $A_N$ consistent with zero
(i) Mid-rapidity $\pi^0 A_N |x_F| > 0.01$

- $A_N$ consistent with zero

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

Vertical Scale Uncertainty: 4.8%

- $\pi^0 x_F < -0.01$
- $\pi^0 x_F > 0.01$
(i) Mid-rapidity $\eta \ A_N \ |x_F| > 0.01$

- $A_N$ consistent with zero
1. $A_N$ Measurements
   – Sensitive to combinations of all three effects
   – At forward and mid rapidity
2. Sivers Measurements
   – Heavy flavor
   – Back to back hadrons
3. Transversity Measurements
   – Interference Fragmentation Function
   – Collins in Jets
(ii) Constraints on Sivers Function: Heavy Flavor

D meson $A_N$

- Production dominated by gluon-gluon fusion at RHIC energy

- Gluon transversity zero
  → Asymmetry cannot originate from Transversity x Collins
- Sensitive to gluon Sivers effect

**Theoretical prediction:**

$p^+p \rightarrow DX$

\[ Q = c \text{ or } b \]

\[ Q \]

Gluon Sivers=Max
Quark Sivers=0
Gluon Sivers=0
Quark Sivers=Max

(ii) Constraints on Sivers Function: Heavy Flavor

PHENIX: no reconstruction of D meson
Exploratory measurements of $A_N$ for single muons
Dominated by charm production in current kinematic range

- Predicted asymmetry smeared by decay kinematics
- Measurements will be enhanced significantly by the inclusion of precision tracking: VTX (installed) and FVTX (to be installed for next run).
Azimuthal distribution of Di-Jet production in pp
Suggested in: Boer, Vogelsang, Phys. Rev. D 69, 094025

Beam is in and out of page
Look at back-to-back jet opening angles

Sensitive to Sivers function only!
No Collins-type effects
(ii) Constraints on Sivers Function: DiHadron Production

**PHENIX Result from 2006 data:**
- Done with di-hadrons at $y_1 = y_2 \approx 0$
- Asymmetry consistent with zero

<table>
<thead>
<tr>
<th>$\eta_{\min}$</th>
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<td>1.4</td>
<td>2.0</td>
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<tr>
<td>3.4</td>
<td>3.9</td>
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</tbody>
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Similar analysis possible in different combinations of rapidity

Works in progress…
1. $A_N$ Measurements
   - Sensitive to combinations of all three effects
   - At forward and mid rapidity

2. Sivers Measurements
   - Heavy flavor
   - Back to back hadrons

3. Transversity Measurements
   - Interference Fragmentation Function
     Already covered in Anselm Vossen’s talk
   - Collins in Jets
(iii) Collins Jet+Hadron Measurements

- Measurement originally proposed in:
  F. Yuan, PLB 666 (2008) 44-47

- Measure:
  \[ p(P_A,S)+p(P_B) \rightarrow jet(P_j) \rightarrow H(P_H)+X \]

  Define two angles:
  - \( \phi_S \): proton spin direction
  - \( \phi_H \): hadron angle around jet axis

  Measure: azimuthal modulation of \( \sin(\phi_H - \phi_S) \)

Model dependent calculations show that Collins effect can produce large forward single spin asymmetries.
Planned measurement:

- Measure near-side jet axis using PHENIX central arm.
  - Central arm recently upgraded with large acceptance silicon tracker ($|\eta|<1.2$)
- Measure away side neutral pion in forward region using MPC.

Projected asymmetries:

- Added transverse spin processes in Pythia to predict the asymmetries for various transversity distributions.
- Collins function taken from analysis of SIDIS+BELLE data.
Transversity tuned to produce:

- 25% of PHENIX forward $A_N$
- 100% of PHENIX forward $A_N$
PHENIX has exciting measurements for the near-term of RHIC running. (Exciting long term opportunities covered in other talks!)

- Figure of merit ($P^2L$):
  - on disk: 2.3 pb$^{-1}$
  - projected: 11.9 pb$^{-1}$

Planned Measurements

- Inclusive $A_N$ asymmetries
  - High $p_T$ results at forward rapidity.
  - Precision results at mid rapidity for both $\pi^0$ and $\eta$ mesons

- Sivers asymmetries
  - Di-hadron correlations at mid rapidity
  - Heavy flavor asymmetries
    Results will be significantly enhanced by precision tracking upgrades.

- Collins asymmetries
  - Interference Fragmentation Function asymmetry at mid rapidity (covered in Anselm’s talk)
  - Jet+Hadron Collins measurement.