PHENIX Transverse Spin Physics

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Outline

• An Overview

• Early transverse spin data

• Transverse spin program at PHENIX

• Summary
The RHIC Polarized Collider

- Absolute Polarimeter (H↑ jet)
- RHIC pC Polarimeters
- ANDY/BRAHMS
- E-Lens and Spin Flipper
- Siberian Snakes
- PHENIX
- SPIN Rotators (longitudinal polarization)
- AGS
- Pol. H− Source
- LINAC
- EBIS
- Booster
- 200 MeV Polarimeter
- AGS pC Polarimeter
- Strong AGS Snake
- Helical Partial Siberian Snake

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Measuring Asymmetries in a Collider

(N) Yield
\( \pi^0, \eta, \pi^\pm, h^\pm, \text{jets, } \gamma, \text{ e, } \mu \text{ etc.} \)

(R) Relative Luminosity

(P) Polarization
- RHIC Polarimeters (at 12 o’clock)
- Local Polarimeters (in experiments)

Bunch spin configuration alternates every 106 ns, at RHIC
Fill different bunch pattern every store
Data for all bunch spin configurations are collected at the same \( t \)

False asymmetries are greatly reduced
Transverse spin physics, the odd man out!

In this note we have pointed out that the asymmetry off a polarized target, and the transverse polarization of a produced quark in $e^+e^-\rightarrow qq$, or in $q\bar{q}-q\bar{q}$ at large $p_T$, or in leptoproduction, should all be calculable perturbatively in QCD. The result is zero for $m_q=0$ and is numerically small if we calculate $m_q/\sqrt{s}$ corrections for light quarks. We discuss how to test the predictions. At least for the cases when $P$ is small, tests should be available soon in large-$p_T$ production [where currently $P(\Lambda)=25\%$ for $p_T\approx 2$ GeV/c], and $e^+e^-$ reactions. While fragmentation effects could dilute polarizations, they cannot (by parity considerations) induce polarization. Consequently, observation of significant polarizations in the above reactions would contradict either QCD or its applicability.

Kane, Pumpkin and Repko  PRL 41 1978

Small quark masses, expected low asymmetries at GeV beam energies

Efremov countered one should use hardonic mass instead, thus some measureable asymmetries

Undeterred, the experiments proved otherwise!
\( p^+ + p \rightarrow h^\pm \) SSA before RHIC

- Hard scattering process expected very small asymmetries
- Large asymmetries seen over a large range

At RHIC we are in the partonic regime
Where factorization in hadronic collisions apply
Possible triggers

Initial State:
- Transversity
  - Correlation between proton and quark spin
  - Chiral-Odd, so must couple with another Chiral-Odd function
  - *Does not generate L-R asymmetries by itself*
- Sivers
  - Correlation between proton spin and parton $k_T$
  - *Could generate L-R asymmetries*

Final State
- Collins
  - Correlation between scattered quark spin and fragmenting hadron $k_T$.
  - Chiral-Odd
  - *Coupled with transversity could generate L-R asymmetries*
Forward charged asymmetries adding RHIC

- Asymmetries from the BRAHMS experiment at RHIC are similar
- This covers a wide center of mass range
- Could these be attributed to initial or final state effects?
An overall picture?

Collinear QCD factorization vs. TMD parton distribution functions

Phenomenological approach in overlap region

软 $p_T$ 破坏

软 $p_T$ 独立化

$1/p_T$ 形状

$\Lambda_{QCD} \ll q_T < Q$

$q_T \sim Q$ 联合事实

TF
The PHENIX detector

**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**
\[ 3.1 < |\eta| < 3.9 \]
- \( \pi^0, \eta \)
Cross sections @ $\sqrt{s}=200$ & 62 GeV

Good agreement between NLO pQCD calculations and data $\Rightarrow$ pQCD can be used to extract spin dependent pdf's from RHIC data.
Asymmetries at Midrapidity

$\pi^0$ and $\eta$
$\sqrt{s}=200$ GeV

Partonic Cross Sections
- quark-gluon dominated in our $p_T$ range
- gluon-gluon at low $p_T$ (Sivers)
- quark-quark at large $p_T$ (Sivers+Collins)
- Rules out a gluon Sivers??

Little or no Asymmetries observed over a wide $p_T$ range
Asymmetries: forward region $\pi^0 \ 3.1 < |\eta| < 3.9$

- significant asymmetries similar to $\pi^+/-$ (Brahms)
- quark-gluon is the dominant partonic component
Isospin Dependence

\[ \sqrt{s} = 62.4 \text{ GeV} \]

**Transversity**

\[ \pi^+ (u\bar{d}) \]

**Sivers**

\[ \pi^0 (u\bar{u} + d\bar{d}) \]

\[ \pi^- (u\bar{d}) \]

\[ A_N(\pi^0) \sim 2A_N(\pi^+) + A_N(\pi^-) \]
Asymmetries Forward Region: $\eta$ @ 200 GeV

Significant asymmetries observed similar to pizero

Different fragmentation, strangeness, and isospin
Cluster analysis $\pi^0$ measurement

Clustering:
1. Groups towers together above an energy threshold
2. Fit energy and position of incident photon

If two photons are separated by ~1 tower, they are reconstructed as a single cluster.

Physics Impact:
Photon merging effects prevent two-photon $\pi^0$ analysis:
for $E_{\pi^0} > 20$ GeV ($p_T > 2$ GeV/c)
• At $\sqrt{s} = 62$ GeV
  $20$ GeV $\rightarrow 0.65$ $x_F$: Two-photon $\pi^0$ analysis
• At $\sqrt{s} = 200$ GeV
  $20$ GeV $\rightarrow 0.20$ $x_F$ for two-photon $\pi^0$ analysis
Use merged Single clusters as proxy for $\pi^0$

Yields dominated by $\pi^0$'s but subject to backgrounds

Decay photon impact positions for low and high energy $\pi^0$'s
Asymmetries: forward region $\pi^0$ clusters

Cluster contribution
- decay photon
- $\pi^0$
- direct photon
- Estimated using Pythia
What about the $p_T$ Dependence?

Trend in $A_N$ data described by theory as an expected fall off at high $p_T$

Is there any evidence from earlier data?

A turnover around 1 GeV and a flat dependence? At RHIC we should be able to access higher $p_T$. 

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Lambda polarization

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

$P_T$ GeV/c
PHENIX Pt dependence

No evidence of 1/pt fall off yet w/ 8 pb-1 so far
Projected statistical errors are indicated from Run 12 & 13 with expected 33 pb-1
IFF in Dihardons access Transversity

PHENIX Good acceptance – no effect of jet axis reconstruction
Independent from Collins Asymmetries
Favorable in pp: no Sivers
Transverse momentum is integrated
Collinear factorization
No assumption about $k_t$ in evolution
Evolution known, collinear scheme can be used
Universal function: directly applicable to semi-inclusive DIS and pp
First experimental results from HERMES, COMPASS and Belle
Dihadrons in pursuit of Collins

- Probe transversity (Collins) using Jets?
- Phenix we will use high pt di-hadrons
- Will pair the central and forward regions using the MPC.
- Taking data in the current running period

F. Yuan, PLB 666 (2008) 44-47
Summary

- Transverse physics forms a significant component of the RHIC spin physics program
- We strive to add more inclusive channels to shed an additional light on potential transverse spin phenomena.
- Large asymmetries have been observed in the forward rapidity similar to lower energy results
- The expected fall off at high pt is not observed
- Current and future runs for better statistics at higher momenta
- Early look at transverse asymmetries in dihardon production yielded null results. New effort will combine the central detectors and and the forward MPCs.
- Drell-Yan measurements will require a future upgrade

(Kieran Boyle’s)
Backup
Asymmetry in Forward Production

At RHIC, we have measured forward SSA for many hadrons

- $\pi^0$, $\pi^\pm$, K, p, $\eta$

![Graph showing asymmetry in forward production for different hadrons at 200 GeV and 62.4 GeV.]
Forward asymmetries

\[ A_N = 0.075 \pm 0.004 \]

\[ A_N = 0.058 \pm 0.008 \]