The Future of RHIC Spin

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Outline

• Quick Overview of RHIC
• Helicity Structure
  – What we’ve learned
  – What’s next
• Transverse Spin physics
  – Understanding large forward asymmetries
  – Near term plans
  – Longer term detector upgrade plans
• Transverse Spin as a tool to understand QCD
  – Saturation effects in polarized p+A:
  – Factorization:
    • Drell Yan, W
• $\sqrt{s}=62.4-500\,(510)\;\text{GeV}$
• Experiments choose Transverse or Longitudinal polarization
• Achieved 60% (55%) polarization at $\sqrt{s}=200\,(500)\;\text{GeV}$
Experiments

**PHOENIX**

- High rate capability
- Limited acceptance
- High $p_T$ photon trigger
- Forward muon arms

**STAR**

- Large acceptance
- Azimuthal symmetry
- Jet patch trigger
- Forward EMcal
RHIC Spin Program

Three Main Programs:

• Gluon Helicity

\[ S_p = \frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L_q + L_g \]

• Flavor-separated Sea Quark Helicity

• Transverse Spin Phenomena
Helicity Program
Sea Quark Polarization ($\Delta \bar{u}$, $\Delta \bar{d}$)

- Unique access to sea quarks through weak interactions
- Complimentary approach with SIDIS
- Huge 2013 data set will further constrain sea quark helicities
Gluon Polarization ($\Delta G$)

\[ A_{LL} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \quad R = \frac{L_{++}}{L_{+-}} \]

• 2009 results indicate positive asymmetries.
• Used in global analyses
• positive $\Delta G$, similar to quark contribution
Gluon Polarization ($\Delta G$)

- Large uncertainty at low $x$
  - RHIC can get to lower $x$ two ways:
    - higher $\sqrt{s}$ (510 GeV)
    - forward measurements
- Additional data at $\sqrt{s}=200$ GeV in 2015

Spin 2014--Oct. 23, 2014
Transverse Spin Physics
Transverse Spin Conundrum

- Very large asymmetries seen over wide range in scattering energy
- Survive up to $\sqrt{s} = 500$ GeV

\[ x_F = 2p_{long} / \sqrt{s} \]
Transverse Spin Conundrum

- Very large asymmetries seen over wide range in scattering energy
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\[ x_F = \frac{2p_{long}}{\sqrt{s}} \]
But what is the cause?

• Some possibilities:
  – Transverse Momentum Dependent (TMD) effect (and there twist three counterparts)
    • Sivers: Initial state effect with quark $k_T$ correlated with proton spin
    • Transversity $\otimes$ Collins: Correlation between quark and proton spin, coupled with pin dependent fragmentation function
  – Something else, like diffractive physics.
Results

• RHIC has measured many single hadron transverse spin asymmetries

• To understand the mechanism generating these asymmetries, we must move beyond single hadrons
The problem with hadrons

• Hadron asymmetries could be caused by
  – asymmetries in the parent Jet, like for Sivers
  – asymmetries within a parent Jet, like for Collins

• Therefore, event level information, like jet structure is needed to separate the two
Solution 1: Look at direct photons

- Direct Photon is sensitive to Siver’s
  - small contribution from fragmentation photons
- PHENIX and STAR installing preshowers for forward calorimetry
- 2015 run will allow for test of Siver’s type asymmetry source
Solution 2: Look at Jets

- If we can look at jet containing hadrons, can start to separate effects
- Measurements by AnDY found small jet asymmetries
  - possible that Siver’s effect for up and down quarks cancel
• STAR has looked at how the measured $A_N$ for $\pi^0$ depend on other activity in the forward calorimeter, i.e. proxy for jet
• Find that with more activity, asymmetries are reduced

Why?
• $z$ dependence? could be Collin’s
• Some suggestions that could be effect of diffractive physics
Study diffractive events

- For 2015 run, STAR will have installed Roman Pots.
- Will allow tagging of diffractive events, testing the idea that diffractive processes could be the source of large hadron $A_N$. 

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### Phase I RPs

- $Q4$, $Q3$, $D0$ 
- $DX$ 

### Phase II* RPs

- $15.8$, $17.6$m 
- $55.5$, $58.5$m 

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Spin 2014--Oct. 23, 2014
Limitations of current detectors

• Both PHENIX and STAR forward detectors for measuring hadrons are limited to EM Calorimeters
  – This limits how well we can distinguish Sivers from Collins effects

• For real jet measurements, need at a minimum hadronic calorimetry and/or tracking in the forward direction

• Both STAR and PHENIX plan long term upgrades to allow forward jet measurements at the start of the next decade.
PHENIX is planning an significant upgrade (sPHENIX) which will use the BABAR magnet and wider calorimetry coverage

This will open up the forward direction, allowing for a forward spectrometer to be added

Such a spectrometer could form the basis for and EIC detector at eRHIC
Forward sPHENIX

- Tag hadron charge with tracking
- Determine z with hadronic calorimeter
- Separation of jets by leading hadron can isolate jets from up and down quarks, testing whether Sivers generate hadron $A_N$
- Can also look at Collins asymmetry of hadrons in jets
STAR Forward Upgrades

ECal:
- Tungsten-Powder-Scintillating-fiber
- 2.3 cm Moliere Radius, Tower-size: 2.5x2.5x17 cm³, 23 $X_0$

HCal:
- Lead and Scintillator tiles, Tower size of 10x10x81 cm³
- 4 interaction length

Tracking:
- Silicon mini-strip detector 3-4 disks at $z \sim 70$ to 140 cm
- Each disk has wedges covering full $2\pi$ range in $\phi$
- and 2.5-4 in $\eta$ (other options still under study)

Part of a coordinated upgrade path that can lead to an EIC detector.
 Upgrade allows very precise measurements of:
 - Forward jets for Sivers
 - Hadrons in jets for Collins
 - Hadron pairs for Interference fragmentation functions (IFF)
  • allow access to transversity
Transverse Spin Asymmetries as a Tool
The nucleus is an *amplifier* of high gluon densities.

\[
\left( Q_s^A \right)^2 \approx c Q_0^2 \left( \frac{A}{x} \right)^{1/3}
\]

The gluon density grows to the point where recombination tames the growth of the gluon distribution at small x.
Polarized p+A Collisions at RHIC

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

Left

\[ \frac{A_{pA \rightarrow h}^{N}}{A_{pp \rightarrow h}^{N}} \approx \frac{Q_{sp}^2}{Q_{sA}^2} e^{p_{h}^2 \delta^2 / Q_{sp}^2} \]

Right

\( Q_{sp}^2 = (1.0 \text{ GeV})^2 \)
\( Q_{sA}^2 = (2.5 \text{ GeV})^2 \)
\( \delta = 0.16 \text{ GeV} \)

Single spin asymmetries can act as a probe of the saturation scale – the p+p reference will also be better understood with new instruments.

A unique capability of RHIC!

- Dependence of \( Q_{sA} \) on \( A \)
- \( p_T (\text{GeV/c}) \)
- Combined with other measurements this can estimate \( Q_{sp} \)

Y. Kovchegov & M.D. Sievert: PRD 86, 034028 (2012)
Kang, Yuan: PRD 84, 034019 (2011)
Plan for 2015 RHIC Run

First p+A Run at RHIC

1. 5 weeks of p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with transverse polarization of the proton

2. 2 weeks of p+Al collisions at $\sqrt{s_{NN}} = 200$ GeV with transverse polarization of the proton
Testing Factorization in TMDs

• TMD factorization predicts the sign of the Sivers effect is flipped between SIDIS and Drell Yan
  – Due to difference in the color interaction between the proton remnant and the initial (Drell-Yan) or final (SIDIS) state hadron.
W boson production

- Similar effect is possible in W-boson production

2012: small proof of principle
W boson production

- Similar effect is possible in W-boson production

This method to test Sivers sign flip with uniquely available to RHIC
Conclusions

• Over the next several years, RHIC will be used to make measurements that are uniquely available in a flexible polarized hadron collider

• Large transverse spin asymmetries:
  – Asymmetries are quite consistently sizable over very wide range in center of mass energy ($\sqrt{s}=5$-500 GeV)
  – With upgraded forward capabilities, RHIC should allow a final understanding of their source

• Exploring Saturation effects in Nuclei
  – With it’s polarized proton and Heavy ion capabilities, RHIC is the only collider in the world that can run polarized p+A
  – Measurements of simple forward hadron asymmetries while varying A can tell us about the saturation scale in Nuclei

• Testing Factorization of TMDs
  – RHIC can extend the reach of Drell-Yan measurements to explore the expected sign flip
  – With transverse spin asymmetry in W production, RHIC can add a second unique test of this sign flip in the next few years
BACKUPS
Limitations of Current Data

• Current mid-rapidity inclusive measurements ($\pi^0$, jet, etc.) at $\sqrt{s}=200$ GeV have two drawbacks
  – They cover a limited range in $x$ (approx. $0.02 < x < 0.3$)
  – Each $p_T$ bin integrates over a wide range in $x$

• We can extend $x$ range by
  – Measuring at larger rapidity (low $x$ gluon)
  – Measuring at larger $\sqrt{s}$ (smaller $x$ at same $p_T$)

• We can more precisely determine $x$ through correlation measurements

• And we can do both

\[ x_1 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{n3} + p_{T4}e^{n4}\right) \]
\[ x_2 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{-n3} + p_{T4}e^{-n4}\right) \]
Future plans

- More precise determination of ΔG(x) over wider range in x

Single particle

Correlations

Better x determination

Forward-Central correlation measurements at both STAR and PHENIX