A Menu for Spin Physics at RHIC II

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Main focus of this talk:

What will (likely) be the compelling questions in spin physics in the RHIC II era?

What could be the corresponding key measurements at RHIC II?

What would it take to do those?

*Disclaimer: this talk will not have complete answers …
Cornerstones of present RHIC spin program:

- **Gluon polarization**  
  \[ \Delta g(x) = \text{gluons key contributors to the proton spin?} \]

- **u, \bar{u}, d, \bar{d} polarizations from W production**  
  important insights into dynamics in nucleon sea

- **Transverse-spin phenomena in QCD**  
  transversity, single-spin asymmetries, orbital ang. mom., …

- **Elastic pp scattering**  
  cross sections and spin asymmetries in new kinematic domain
The “baseline” RHIC spin program will provide important information on each of these topics, advancing our understanding of QCD and Nucleon structure.

Sustained running at high polarization and luminosity will be beneficial:

→ Increased statistics
  • rare probes
  • more detailed measurements / wider kinematics
  • can exploit the detector upgrades expected over next few years
  • can explore other “genuinely new things”
Gluon polarization
• a particular strength of RHIC: can probe $\Delta g(x)$ in various channels

• typically, high-$p_T$ photons, hadrons, jets, heavy fl.

$$x_g \sim 2 p_T/\sqrt{s}$$

0.025 < $x_g$ < 0.3 @ $\sqrt{s} = 200$ GeV

0.01 < $x_g$ < 0.1 @ $\sqrt{s} = 500$ GeV

• perhaps, determine unpolarized gluon distrib.?
$A_{LL}^\gamma$

P = 0.7  \  L = 1000/\text{pb}

GRSV $\Delta g = g$

GRSV std

GRSV $\Delta g = 0$

GRSV $\Delta g = -g$

$p_T / \text{GeV}$

$\sqrt{s} = 200 \text{ GeV}$ \quad |\eta| < 0.38
• how well are we going to get the integral?

• \[ \langle S_g \rangle = \int_0^1 dx \Delta g(x, Q^2) \propto \frac{1}{\alpha_s(Q^2)} \] in QCD

is that testable?

• may gain more information at small x with the help of planned forward detector upgrades

• this will require good statistics
\[ L = \frac{7}{\text{pb}}, \quad P = 0.4 \]
(Sea) Quark polarizations
Current status

(HERMES)

( large theoretical uncertainties )
• can one determine strange quark polarization?

• remember, deviation from Ellis-Jaffe sum rule is related to strange quarks

• associated $W^+$charm production a possibility?

\[ W^- \quad \text{“D-tagged W’s”} \]

\[ s \quad \text{vs.} \quad \bar{s} \quad ? \]

Ji, Kretzer, Saito, Soffer, Ming, Sudoh, Yokoya

• total cross section $\sim$ few pb:
  again a question of statistics (& energy ?)

• complementary to $\nu p$ elastic scattering?
• associated $W$+jet production?

• opportunities for unpolarized physics?
PDF uncertainty in total cross section

\( \sigma_{PDF} / \sigma \)

\( S_{1/2}, \text{GeV} \)

\( W^+ \) production
\( W^- \) production
\( Z^0 \) production

→ Sea quarks at large x

( courtesy B. Surrow )
Transversity
Helicity:
\[ \Delta q(x) = \begin{array}{c} \text{image} \end{array} - \begin{array}{c} \text{image} \end{array} \]

Transversity:
\[ \delta q(x) = \begin{array}{c} \text{image} \end{array} - \begin{array}{c} \text{image} \end{array} \]

- the unknown “leading-twist” distribution functions
- the physics involved: relativistic / dynamical effects, helicity-flip, \( \chi_{SB} \), nucleon tensor charge \( \langle P | \bar{q} i \sigma^{\mu \nu} \gamma^5 q | P \rangle \), …
• **Hard to measure:**

  * not in inclusive DIS:

    ![Diagram of q_R and q_L with p_ and p_-]

  * helicity-flip from final-state effect:

    ![Diagram of π and q_R and q_L with p_ and p_-]

  * initial studies done by **HERMES** and **COMPASS**, limited inform.
• The most straightforward (and clear-cut) probe:

\[ A_{TT} = \frac{d\sigma_{p^\uparrow p^\uparrow} - d\sigma_{p^\uparrow p^\downarrow}}{d\sigma_{p^\uparrow p^\uparrow} + d\sigma_{p^\uparrow p^\downarrow}} \]

• In particular: Drell-Yan
• note, dedicated program on Drell-Yan in $p^+p^-$ is proposed at GSI

• expectations for RHIC:

\[ \sqrt{S} = 200 \text{ GeV} \]
\[ L = 320/\text{pb} \]
\[ P = 0.7 \]

O. Martin et al.

• detector coverage and statistics important

• also: $A_{TT}$ for prompt photons, jets, …
Single-spin asymmetries
$A_N = \frac{L - R}{L + R} \sim \text{Im}$

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

$\langle \eta \rangle = 4.1$ (preliminary)

$\langle \eta \rangle = 3.8$ (PRL 92(2004)171801)

$\langle p_T \rangle (\text{GeV}/c) = 1.1 \rightarrow 2.1$

$\langle p_T \rangle (\text{GeV}/c) = 1.1 \rightarrow 2.4$
Related effects in lepton scattering \( e p^\uparrow \rightarrow e \pi X \)

\[
A_N \sim \sin(\phi - \phi_S), \sin(\phi + \phi_S)
\]

SMC, HERMES, COMPASS
Possible mechanisms:

- "Collins effect"
- Transversity
- Ordinary fragmentation
- "Sivers effect"

• Both could be involved in $A_N$ for $pp \rightarrow \pi X$
The physics of the Sivers function:

- **access to orbital angular momentum:**

  Probes overlap of proton wave fcts. with $J_z = \pm 1/2$

  requires quark transverse momentum

- **in fact, connected to GPD’s & spatial distributions of partons**

  Burkardt

- **origin of the phase:**

  from Wilson lines in gauge-invariant definition of function

  Brodsky, Hwang, Schmidt; Collins; Belitsky, Ji, Yuan; Boer, Mulders, Pijlman
Sivers functions in DIS and DY come with opposite sign leads to predictions that are **testable at RHIC**
Possibilities for RHIC: the physics of correlations

• single-spin azimuthal asymmetries in Drell-Yan

• back-to-back jet correlations

• description of $A_N$ for $pp \rightarrow \pi X$ is somewhat more involved and offers further insights

• we are likely only in early stages of this area

Boer, WV

Qiu, Sterman, …
From polarized Hadron colliders to “polarized Parton colliders” ...
• polarization is a valued tool in searches for New Physics: linear collider, parity violation in $\bar{e}e \rightarrow ee$, $\bar{e}p \rightarrow ep$

• ideas have been around for RHIC for a long time
  Tannenbaum; Craigie, Hidaka, Ratcliffe; Bourrely, Guillet, Soffer; Taxil, Virey

• possibilities at RHIC need to be seen in LHC context

• potential benefits of polarization are
  * “elimination” of (QCD) backgrounds
  * sensitivity to couplings that violate symmetries (parity)
**PV at the shortest distances at RHIC:**

\[ pp \rightarrow \text{jet } X \]

\[ A_{L}^{PV} \equiv \frac{(d\sigma^{+}/dE_{T}) - (d\sigma^{-}/dE_{T})}{(d\sigma^{+}/dE_{T}) + (d\sigma^{-}/dE_{T})} \]

generic contact interaction:

\[ \sim g^{2} \frac{\Lambda}{\Lambda^{2}} \bar{\Psi} \Gamma_{\mu} \Psi \bar{\Psi} \Gamma^{\mu} \Psi \]

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Bourrely, Guillet, Soffer; Tannenbaum; Taxil, Virey
Non-MSSM Squark and Gluino production
Elastic scattering
• in some sense, the most fundamental hadronic reactions, but among the most difficult to understand

• an exciting beginning now at RHIC

• topics for the future?

• generally, reach out to larger \(-t\)?
Spin Physics at RHIC $\neq$ polarized pp
• example: polarization as probe of dynamics in dA scattering

\[ pp \rightarrow \Lambda^\uparrow X \]

Anselmino, Boer, d’Alesio, Murgia: explain in terms of

\[ D_{1T}^\perp = \Lambda k_T \quad - \quad \Lambda k_T \sim \vec{S}_T \cdot (\vec{q} \times \vec{k}_T) \]

odd in \( k_T \)
Do this in pA collisions. $\Lambda$ polarization will be proportional to

$$\hat{\sigma} \left( p_T^\Lambda + k_T \right) - \hat{\sigma} \left( p_T^\Lambda - k_T \right)$$

$\sim$ derivative of partonic cross section in quark transv. mom.

LT: peaked at small $q_T$
CGC: peaked at $q_T \sim Q_s$

Boer, Dumitru
Instead of Conclusions:
Some questions (of many...)
• how well can one get the gluon spin contribution?
• is there an independent way of determining strange quark polarization?
• how large is transversity in the nucleon?
• can we learn about parton orbital angular momentum from the Sivers functions?
• can one verify the non-universality of the function?
• can one use polarized pp to find New Physics? Which?
• can one use polarization to probe high-density effects?