Single Transverse Spin Asymmetries in Drell Yan at RHIC

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White paper: “Transverse Spin Drell-Yan Physics at RHIC”

Initial predictions for SSA in  DY at RHIC
Single Transverse Spin Asymmetries: $A_N$ in pp

(I) “Transversity” quark-distributions and Collins fragmentation

Correlation between proton- und quark-spin and spin dependent fragmentation

$$\delta q(x) \cdot H_1^c(z_2, k^2)$$

Quark transverse spin distribution

Collins FF

(II) Sivers quark-distribution

Correlation between proton-spin and transverse quark momentum

$$\bar{F}_T^c(x, k^2) \cdot D_q^h(z)$$

Sivers distribution

(III) Qiu Sterman

Quark-gluon correlations at sub-leading twist

Unification of formalisms:

Ji, Qiu, Vogelsang, Yuan

Single Transverse Spin Asymmetries $A_N$ persist at $\sqrt{s}=62.4$ GeV and 200 GeV

Large single spin asymmetries persist at higher $\sqrt{s}=62.4$ and 200 GeV
Semi-Inclusive Deep Inelastic Scattering: Sivers Asymmetries from HERMES

\[ \langle \sin(\varphi - \varphi_S) \rangle_{UT}^h \]

\[ f_1^{qT} (x) \otimes D_1^{qT} (z) \]

\( \Rightarrow \) isolate Sivers contribution!

COMPASS results with deuteron and proton (?) targets appear consistent with 0.
### Transverse spin program at RHIC

#### Physics channel

<table>
<thead>
<tr>
<th>Physics channel</th>
<th>Luminosity?</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_N$ (hadrons, jets)</td>
<td>++</td>
</tr>
<tr>
<td>$A_N$ (back-to-back)</td>
<td>+</td>
</tr>
<tr>
<td>$A_T$ (Collins FF)</td>
<td>not studied yet</td>
</tr>
<tr>
<td>$A_T$ (Interference FF)</td>
<td>ok</td>
</tr>
<tr>
<td>$A_T$ (photon-jet)</td>
<td>ok</td>
</tr>
<tr>
<td>$A_T$ (Drell Yan)</td>
<td>+</td>
</tr>
<tr>
<td>$A_{TT}$ (Drell Yan)</td>
<td>---</td>
</tr>
</tbody>
</table>

#### Luminosity?

- $\int L dt \sim 50 \text{pb}^{-1}$
- $\int L dt \sim 250 \text{pb}^{-1}$

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Next 5 years

$\int L dt \sim 50 \text{pb}^{-1}$

> 5 years

$\int L dt \sim 250 \text{pb}^{-1}$

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May 29th
Theory: Sivers Effect from Initial or Final State Soft Gluon Interactions → Gauge Link Formalism

\[ \sigma \sim \sum_{\mu \ldots \nu} C_t(Q^2) \langle p | O^{\mu \ldots \nu} | p \rangle \]

Integrate initial state gluon radiation: gauge link and insert gauge link in hard scattering matrix element

Integrate final state gluon radiation: gauge link and insert gauge link in hard scattering matrix element

Prediction: Sign Change between SIDIS and Drell Yan
• Prediction from gauge link formalism: Sivers function is non-universal. Sign change for the Sivers function between Drell Yan and SIDIS

• Can be tested at RHIC with high luminosity (\(\sim 250 \text{ pb}^{-1}\) at \(\sqrt{s} = 200\text{GeV}\)) in either STAR or PHENIX. [For comparison we expect \(\sim 950 \text{ pb}^{-1}\) delivered for operations at \(\sqrt{s} = 500\text{GeV}\).]
Non-universality of Sivers Asymmetries:
Unique Prediction of Gauge Theory!

Simple QED example:

DIS: attractive
Drell-Yan: repulsive

Same in QCD:

As a result:

\[ \text{Sivers}_{\text{DIS}} = -\text{Sivers}_{\text{DY}} \]
Drell Yan at RHIC

Large $x \rightarrow$ forward rapidity

Example: Drell Yan with the PHENIX muon spectrometers and a new forward silicon detector (FVTX).

\[ p + p \rightarrow e^+e^- + X, \int L dt = 200 \text{ pb}^{-1} \]

All events with $M_{\mu\mu} > 4.0$ GeV

Also require $x > 0.3$

$\sqrt{s} = 500$ GeV
$\sqrt{s} = 200$ GeV
$\sqrt{s} = 62$ GeV

FVTX enables DY measurement by rejecting heavy flavor background:

Measurement: $4 \text{ GeV} < Q < 10 \text{ GeV}$

\[ y_\gamma \]

\[ \text{yield in arbitrary units} \]

$\Upsilon$-states

Drell Yan

$J/\Psi$

charm

bottom

\[ \psi' \]

SG dimuons

\[ \mu \]

\[ \text{Mass (GeV)} \]

**STAR**: endcap EMC + FMS

**PHENIX**: muon spectrometers
Experiment SIDIS vs Drell Yan: $Sivers|_{\text{DIS}} = -Sivers|_{\text{DY}}$

*** Test QCD Prediction of Non-Universality ***

HERMES Sivers Results

Markus Diefenthaler
DIS Workshop
München, April 2007

RHIC II Drell Yan Projections

RHIC II, 250 pb$^{-1}$
Drell Yan Sivers $A_N$

- * not benchmarked
  - stat. errors only
- # partially benchmarked
  - statistical errors
  - and uncertainty
  - with background

- PHENIX
- STAR
Unique Sensitivity at RHIC to Sivers Effect for Anti-Quarks


Sensitive to valence quark Sivers at large $x$ and sea quark Sivers distributions at small $x$.

$$f_{1T_{DY}}^{\perp(1)q}(x) = \epsilon(x) f_{1T_{DY}}^{\perp(1)\bar{q}}(x),$$

$$\epsilon(x) = \pm \left\{ \begin{array}{ll}
0.25 = \text{const} & \text{model I} \\
\frac{(f_{1u} + f_{1d})(x)}{(f_{1u} + f_{1d})(x)} & \text{model II}
\end{array} \right.$$
Other Channels will be also interesting with $\int L dt = 250 \text{pb}^{-1}$ Transverse p-p

Example: Interference Fragmentation projections from Ruizhe Yang based on PHENIX run 6 analysis

$A_{UL} \sin(\delta)$

$m_{NN}$ (GeV/c$^2$)

$250 \text{ pb}^{-1}$

Jaffe, Tang (updated)

$5 \times 10^{-4}$ present systematic error: relative luminosity $\rightarrow$ reduce with spin flipper
Increasing experimental evidence that the Sivers effect plays an important role in accounting for single transverse spin asymmetries observed in hard scattering.

Gauge link formalism makes it possible to account for the presence of Sivers asymmetries. Fundamental test possible in Drell Yan at RHIC. Unique possibility to constrain the Sivers function for sea quarks.

Experimental capabilities exist to carry out $A_T$ measurement in Drell Yan at RHIC. Ongoing upgrades will further improve the measurement.