Transverse Spin Drell-Yan @PHENIX

a hard probe for soft physics

Ming X. Liu
Los Alamos National Lab

\[
p \uparrow \rightarrow \mu^+ - M^2
\]

\[
p \rightarrow \mu^- - k_T
\]
Experiment SIDIS vs Drell Yan: \( Sivers|_{\text{DIS}} = - Sivers|_{\text{DY}} \)

*** Probes QCD attraction and QCD repulsion ***
More of DY Sivers SSA Predictions...

Anselmino et. al. PRD 79, 054010 (2009)

Kang and Qiu, PRD81 054020 (2010)

Vogelsang and Yuan PRD72 054028 (2005)

Z^0 @ 500GeV

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Figure 5: PYTHIA simulation of the rapidity distribution of $e^+ e^-$ dileptons produced through the Drell-Yan process. The importance of large rapidity to probe the valence region is illustrated by selecting events with $x_1 > 0.3$.

\[
\frac{d^2 \sigma}{dx_1 dx_2} = \frac{4 \pi \alpha^2}{9 x_1 x_2 s} \sum_i e_i^2 [q_i(x_1)\bar{q}_i(x_2) + \bar{q}_i(x_1)q_i(x_2)]
\]

\[
= \frac{\pi \alpha^2}{9 M^2} \sum_i e_i^2 [q_i(x_1)\bar{q}_i(x_2) + \bar{q}_i(x_1)q_i(x_2)]
\]

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The Physics case is compelling, can we do it?

Experimental challenges:
- Luminosity (CAD/RSC ... )
- Detectors (PHENIX, STAR ...)

- Di-electrons
- $|\eta|<0.35$

- Di-muons
- $1.2<|\eta|<2.4$

Also later today:
- Oleg Eyser
- Anselm Vossen
Forward Muon Measurement @PHENIX

The normalized muon event vertex distribution

Muon detector

absorber

\(\pi, K\)

\(\mu\)

Decay muons

Punch-through hadrons

Prompt muons

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Dimuon Measurement @PHENIX

- Forward rapidity  $1.2 < |\eta| < 2.4$
- $P > 2.5$ GeV

1. $\pi^\pm, K^\pm \rightarrow \mu^\pm + X$
2. $D, B \rightarrow \mu^\pm + X$
3. $J/\Psi \ldots \rightarrow \mu^+\mu^-$
4. $DY \rightarrow \mu^+\mu^-$

...
Drell-Yan/Dimuon PYTHIA Simulations

- **Drell-Yan**
  - LO needs $K=1.3$ , $\sim$NLO, reliable pQCD calculation exists
  - PYTHIA describes DY well at Mass > 4GeV
- **Open Charm and Beauty to di-leptons**
  - Not well known, very limited data from low energy Exp’s
  - Tuned to p+p non-photonic single electron $p_T$ spectrum
- **Heavy quarkonia**
  - Reasonably known, lots of data from RHIC
- **Muon with Forward VTX**
  - PYTHIA charm, beauty, and p+p QCD background events
PYTHIA Parameters (I)

- **Open Charm:**
  - Tuned to PHENIX single electron pT spectrum at y=0
  - Charm mass and intrinsic kT
- **Open Beauty:** similar to charm
- **Open Charm/Beauty Ratio:**
  - Fixed to FONLL
- **Heavy quarkonia relative ratios** expect not dependent on collision energy so fixed to low energy experimental data:
PYHIHTA (6.2) Parameters (II)

<table>
<thead>
<tr>
<th>Physics meaning</th>
<th>Pythia parameter</th>
<th>Drell-Yan</th>
<th>open charm</th>
<th>open beauty</th>
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<tbody>
<tr>
<td>QCD scale: $Q^2$</td>
<td>MSTP(32)</td>
<td>4 ($Q^2 = \hat{s}$)</td>
<td>4 ($Q^2 = \hat{s}$)</td>
<td>2 ($Q^2 = \hat{p}_T^2 + m_Q^2$)</td>
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<tr>
<td>minimum $Q^2$ value</td>
<td>CKIN(1)</td>
<td>1.3 GeV</td>
<td>1.3 GeV</td>
<td>1.3 GeV</td>
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<td>PDF</td>
<td>MSTP(51)</td>
<td>CTEQ5M1</td>
<td>CTEQ5M1</td>
<td>CTEQ5M1</td>
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<tr>
<td>$k_T$ width</td>
<td>PARP(91)</td>
<td>1.5 GeV/c</td>
<td>1.5 GeV/c</td>
<td>2 GeV/C</td>
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<tr>
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<td>PARP(93)</td>
<td>-</td>
<td>-</td>
<td>5 GeV/c</td>
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<td>global process selected</td>
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<td>0</td>
<td>4</td>
<td>5</td>
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<tr>
<td>individual process selected</td>
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<td>-</td>
<td>-</td>
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<td>virtual photon consideration</td>
<td>MSTP(43)</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>$c$ quark mass</td>
<td>PMAS(4,1)</td>
<td>-</td>
<td>1.25 GeV/c$^2$</td>
<td>-</td>
</tr>
<tr>
<td>$b$ quark mass</td>
<td>PMAS(5,1)</td>
<td>-</td>
<td>-</td>
<td>4.75 GeV/c$^2$</td>
</tr>
</tbody>
</table>

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PYTHIA, NLO and PDFs

Dimuon physics continuum simulation (2)

Drell-Yan: reproduction as best as possible of theoretical predictions from R. Vogt (NLO calculation with CTEQ6M)

Comparison:
\[
\frac{(dN/dm)_{\text{Pythia}}}{(dN/dm)_{R.\text{Vogt}}}
\]

This is due to a different behaviour of the two PDFs at low x (R. Vogt)

Good agreement between Pythia and QCD@NLO Prediction with same PDF
Accepted Drell-Yan Kinematics

- $p_T$ (GeV)

- Rapidity

$4 < \text{Mass} < 8 \text{ GeV}$

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Dimuon Cocktails @200GeV

(PYTHIA Simulations, DY~NLO)
The Experimental Challenge of $A_N$ Measurement

- Need to measure both open heavy and DY
  - Background fraction
  - Background asymmetry
- Silicon VTX - a critical tool

\[
A_N^{DY} = \frac{1}{P} \frac{A_N^{incl} - r \cdot A_N^{BG}}{1 - r} \\
\delta A_N^{DY} \approx \frac{1}{P} \sqrt{\delta^2 A_N^{incl} + r^2 \cdot \delta^2 A_N^{BG}} \\
\]

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The Benchmarked Values

- NLO Drell-Yan with 250 pb\(^{-1}\) (K=1.3)
- Full PHENIX detector simulations

If Drell-Yan only w/o background

\[ DY : \quad \delta A_N^{DY} \approx \frac{1}{\sqrt{P^2 \cdot 2 \cdot N_{DY}}} ; \quad P = 0.7, \quad N_{DY} = 21100 \]
\[ \approx 0.7\% \]

If Drell-Yan w/ background, S/B\~{}1

\[ DY : \quad with \quad r \sim 0.5 : \]
\[ \delta A_N^{DY} \approx \frac{1}{1 - r} \cdot \frac{1}{\sqrt{P^2 \cdot 2 \cdot N_{incl}}} ; \quad N_{incl} \approx 2N_{DY} \]
\[ \approx 1\% \]
PHENIX Silicon VTX Upgrades – 2010-2011

- Precision Charm/Beauty Measurements
- $B \rightarrow J/\psi$, Drell-Yan, $\psi'$
Impact Parameters for muons from D,B and DY

Measuring Charm, Beauty and Drell-Yan

- D, B mesons travel ~1 mm (with boost) before semi-leptonic decay to muons
- By measuring DCA to primary vertex, can separate D and B from prompt particles and long-lived decays like π, K
Heavy Quark Background Suppression
- Work in progress

DCA < 1 $\sigma$ cut:
Increase DY/\(bb\) $\sim$ 5

DCA < 2 $\sigma$
Increase DY/\(bb\) $\sim$ 3
Silicon VTX, Heavy Quark and Drell-Yan

- Tracking muons with MuTr+FVTX
  - Prompt muons from DY
  - Displaced tracks from π/K and heavy quark decays

\[ \text{DCA} < 1 \sigma \text{ cut:} \]
\[ \text{Increase DY}/bb \sim 5 \]
Luminosity and $Z_{\text{VTX}}$

- Collision Vertex Distribution
  - $|Z_{\text{VTX}}| < 15$ cm desired
  - Simulation Sig = 10 cm
Outlook (I)

- Luminosity, luminosity, luminosity...
- With upgrade VTX detectors, it is feasible @PHENIX
  - Drell-Yan
  - Heavy quarks
- Let’s do it!
Outlook (II)

**W^+/- & Z^0** Transverse SSA @500GeV ?

Kang & Qiu PRL 103, 172001 (2009)

- **Latest theoretical progress**
  - Test time-reversal universality of Sivers functions with W/Z
  - Expect large asymmetry (from DIS fit)

- **Flavor-identified Sivers Funs**
  - Very large $Q^2$

- **Expected Statistics @1fb^{-1} 500GeV**
  - $W^+/- \rightarrow \mu^+/- \sim 20K$
  - $Z^0 \rightarrow \mu^+\mu^- \sim 1K$

$$W^+/- : \delta A_N \approx \frac{1}{\sqrt{P^2 \cdot 2 \cdot N}} ; \ P = 0.6, \ N = 6300(6900)$$

$$= 1.5\% (1.4\%)$$

$$Z^0 : \delta A_N \approx \frac{1}{\sqrt{P^2 \cdot 2 \cdot N}} ; \ P = 0.6, \ N = 380$$

$$= 6.0\%$$

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FIG. 3. $A_N$ as a function of lepton rapidity.

Kang & Qiu arX 0912.1319

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FIG. 3: Left: SSA of lepton pair production as a function of the pair’s invariant mass $Q$. Right: SSA of lepton pair accumulated over several values of rapidity.
Backup slides
QCD Correction
K factor collection

\[ d\sigma_{NLO}^{DY} = K(s, M^2) d\sigma_{LO}^{DY} \]

<table>
<thead>
<tr>
<th>Group</th>
<th>Beam/target</th>
<th>cm Energy</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>E288</td>
<td>p/Pt</td>
<td>27.4</td>
<td>1.7</td>
</tr>
<tr>
<td>E439</td>
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<tr>
<td>CHFMNP</td>
<td>p/p</td>
<td>44.63</td>
<td>1.6±0.2</td>
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<tr>
<td>AABCSY</td>
<td>p/p</td>
<td>44.63</td>
<td>1.7</td>
</tr>
<tr>
<td>NA3</td>
<td>p/Pt</td>
<td>27.4</td>
<td>3.1±0.5±0.3</td>
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<tr>
<td>E537</td>
<td>p/W</td>
<td>15.3</td>
<td>2.45±0.12±0.20</td>
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<td>NA3</td>
<td>(p-\bar{p})/Pt</td>
<td>16.8</td>
<td>2.3±0.4</td>
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<tr>
<td>NA3</td>
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<td>20.6</td>
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<td>NA10</td>
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<td>2.8±0.1</td>
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<td>Goliath</td>
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<td>16.8,18.1</td>
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<tr>
<td>Omega</td>
<td>\pi/W</td>
<td>8.7</td>
<td>2.6±0.5</td>
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</tbody>
</table>

Table VII.2. K Factors for dilepton experiments (Grosso-Pilcher and Shochet, 1986).
Drell-Yan Dimuon Kinematics
**Twist-3 Tri-gluon Correlation Functions vs TMD**

A unique opportunity @RHIC to study charm physics!

\[ A_N(c) \neq A_N(\bar{c}) \]


- **D meson**: Largest \( A_N \) happens when \( T_G^{(d)} = T_G^{(f)} \)
- **D̄ meson**: Largest \( A_N \) happens when \( T_G^{(d)} = -T_G^{(f)} \)

- **Solid**: \( \lambda_f = \lambda_d = 0.07 \) GeV, \( T_G^{(d)} = T_G^{(f)} \)
- **Dotted**: \( \lambda_f = -\lambda_d = 0.07 \) GeV, \( T_G^{(d)} = -T_G^{(f)} \)
- **Dashed**: \( \lambda_f = \lambda_d = 0 \), \( T_G^{(d)} = T_G^{(f)} = 0 \)

\( D^0 \rightarrow \mu^+ + X \)

\( \bar{D}^0 \rightarrow \mu^- + X \)