PHENIX Measurements of Heavy Flavor Production and Spin Asymmetries in $p+p$ Collisions at RHIC

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Moriond QCD 2017
Outline

• Transverse Single Spin Asymmetries
• Open Heavy Flavor studies using muon spectrometers in PHENIX
• Cross section and Transverse Single Spin Asymmetry of heavy flavor in $p+p$ collisions in PHENIX
• Summary and outlook
Transverse Single Spin Asymmetry $A_N$

Transverse Single Spin Asymmetries $A_N$

$$A_N = \frac{\sigma^\uparrow_L - \sigma^\uparrow_R}{\sigma^\uparrow_L + \sigma^\uparrow_R}$$

**Theory Expectation:**
Small asymmetries at high energies
(Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978))

$$A_N \propto \frac{m_q}{\sqrt{s}}$$
$A_N \sim O(10^{-4})$

**Experiments:**
ZGS, AGS, FERMILAB to RHIC

$A_N \sim O(10^{-1})$ observed at forward rapidity
$\sqrt{s} = 5 \sim 500$ GeV
## Mechanisms for $A_N$

<table>
<thead>
<tr>
<th>Transverse-momentum-dependent (TMD) Factorization</th>
<th>Collinear Factorization</th>
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</thead>
<tbody>
<tr>
<td><strong>Applicable</strong></td>
<td></td>
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<tr>
<td>works at $Q \gg Q_T \geq \lambda_{\text{QCD}}$ needs 2 scales ($Q^2$ and $p_T$)</td>
<td>works at $Q, Q_T \gg \lambda_{\text{QCD}}$ needs 1 scale ($Q^2$ or $p_T$)</td>
</tr>
<tr>
<td><strong>$p+p$ observables</strong></td>
<td></td>
</tr>
<tr>
<td>$DY, W, Z$</td>
<td>$\pi^0, \gamma$, jet, Heavy Flavor, ...</td>
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<tr>
<td><strong>Initial state</strong></td>
<td></td>
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<tr>
<td>Sivers mechanism – proton spin and quark $k_T$ correlation</td>
<td>Twist-3 multi-parton correlation functions</td>
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<tr>
<td><strong>Final state</strong></td>
<td></td>
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<tr>
<td>Collins mechanism – proton spin and quark spin correlation, quark spin and hadron $k_T$ correlation</td>
<td>Twist-3 fragmentation functions</td>
</tr>
</tbody>
</table>
Theory prediction for heavy flavor $A_N$

- Heavy Flavor (especially $D$ meson) production is an ideal tool to investigate gluon distribution.

- Twist-3 three-gluon correlation in the collinear factorization framework

- $A_N(D^0, \bar{D}^0)$ by gluon-fusion ($gg \rightarrow c \bar{c}$)

Y. Koike, S. Yoshida PRD84:014026 (2011)
Polarized $p+p$ collision at RHIC

- Helicity controllable up to 510 GeV
  - Transverse, Longitudinal
- 2012 $p+p$ 200 GeV run
  - Transversely polarized $P_B=0.64$, $P_Y=0.59$, $L_{int}=9.2\,pb^{-1}$
PHENIX Detectors

- **Philosophy**
  - high resolution & high-rate
  - trigger for rare events

- **Central Arms**
  - $|\eta| < 0.35$, $\Delta\phi \sim \pi$
  - Momentum, EM Energy

- **Muon Arms**
  - $1.2 < |\eta| < 2.4$
  - Momentum
  - High $p_T$ muons

- **Muon piston calorimeter**
  - $3.1 < |\eta| < 3.9$
  - EM Energy
  - $\pi^0$ and $\eta$
Open Heavy Flavor $A_N$

Relative contributions of signal and backgrounds

- Signal at MuID Gap 4: (1) Open Heavy Flavor
- Background measured at MuID Gap 2,3: (2) Stopped Hadron
- Background at MuID Gap 4: (3) Decay Muon, (4) Punch Through

(1) Open Heavy Flavor ($D,B\to\mu$ signal)

(2) Stopped hadron ($\pi,K$ background)

(3) Decay muon ($\pi,K\to\mu$ background)

(4) Punch through ($\pi,K$ background)
Open Heavy Flavor Cross Section

\( p_T \) spectra of inclusive muon candidates and background sources from the hadron cocktail simulation

- \textit{arXiv:1703.09333}

Invariant cross section of muons from open heavy flavor decays at forward rapidity, compared to FONLL calculation.
Open Heavy Flavor $A_N$

\[ A^{Phys}_N = \frac{A^{incl}_N - r \cdot A^{BG}_N}{1 - r} \]

\[ r = \frac{N^{BG}}{N^{incl}} = \frac{(N^{incl} - N^{signal})}{N^{incl}} \]

- $A^{incl}_N$: Inclusive MUID gap4 tracks
- $A^{BG}_N$: Background (gap2,3 stopped hadron, $J/\psi$)
- $r$: non-distinguishable remaining background fraction in gap4 inclusive tracks
  - Each $A_N$ is calculated by Maximum Likelihood Method
  - $P$: polarization
  - $\phi_{pol}$: beam polarization direction
  - $\phi_i$: azimuthal angle of each track

signal-to-background ratio
Run12 $p+p$ 200 GeV

\[ \mathcal{L} = \prod (1 + P \cdot A_N \sin(\phi_{pol} - \phi_i)) \]
Open Heavy Flavor $A_N$

- Open heavy flavor $A_N$ as a function of $p_T$
- Twist-3 model curves are for muons using PYTHIA simulation ($D \to \mu$)
  - Y. Koike, S. Yoshida PRD84:014026 (2011)
  - $A_N$ calculations for $D$ mesons ($D^0$, $\bar{D}^0$, $D^+$, $D^-$) are provided by S. Yoshida (LANL)

• $arXiv:1703.09333$
Open heavy flavor $A_N$ as a function of $x_F$

- Results are consistent with zero within uncertainties, agree with the twist-3 model calculations.

• arXiv:1703.09333
Summary and Outlook

• Summary
  • Cross section and Transverse Single Spin Asymmetry of muons from open heavy flavor decay are measured in transversely polarized $p+p$ 200 GeV collisions in PHENIX experiment at RHIC.
  • Transverse Single Spin Asymmetry is consistent with zero within uncertainties, agrees with the twist-3 model calculation in the collinear factorization framework.

• Outlook
  • Improved statistics $p+p$ data in 2015 could provide constraints on the three-gluon correlation functions.
  • Polarized $p+A(Au,Al)$ data in 2015 are also interesting.
Thank you!
charge separated invariant cross section of muons from open heavy flavor decays at forward rapidity

• arXiv:1703.09333