

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

Jeongsu Bok (New Mexico State University, USA)  
for the PHENIX Collaboration  
Moriond QCD 2017

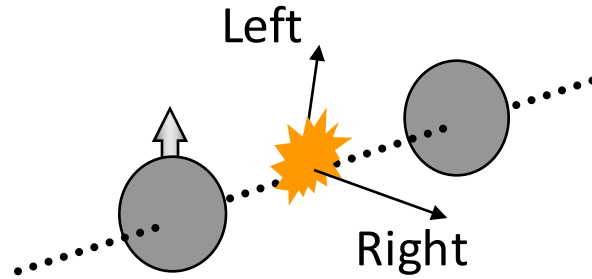
# Outline

- 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 $A_N$

$$A_N = \frac{\sigma_L^\uparrow - \sigma_R^\uparrow}{\sigma_L^\uparrow + \sigma_R^\uparrow}$$



### Theory Expectation:

Small asymmetries at high energies

(Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978))

$$A_N \propto \frac{m_q}{\sqrt{s}}$$

$A_N \sim \mathcal{O}(10^{-4})$   
theory

### Experiments:

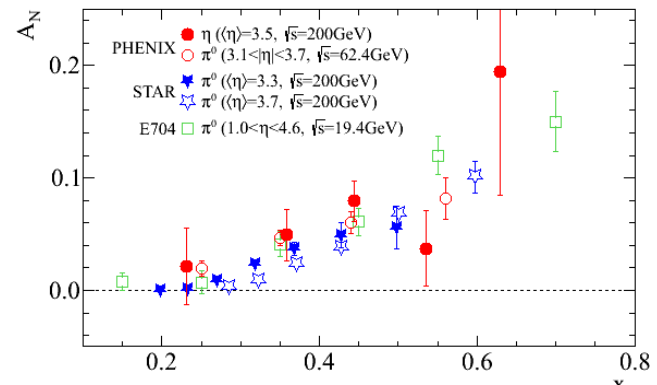
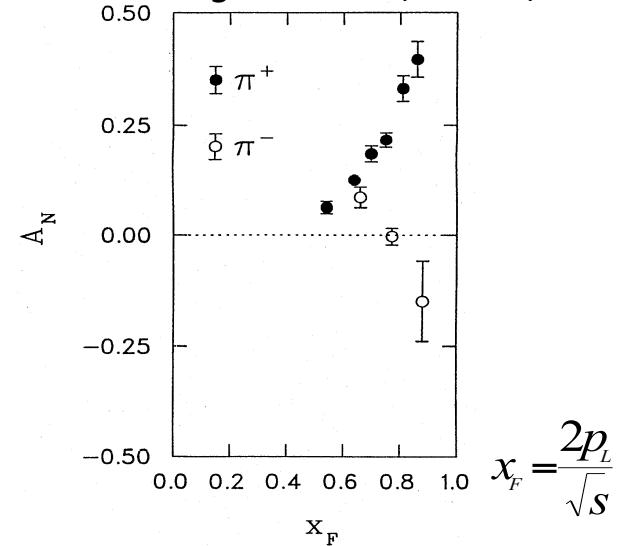
ZGS, AGS, FERMILAB to RHIC

$A_N \sim \mathcal{O}(10^{-1})$  observed at forward rapidity

$\sqrt{s} = 5 \sim 500$  GeV

Argonne ZGS,  $p_{\text{beam}} = 12$  GeV/c

W.H. Dragoset et al., PRL36, 929 (1976)



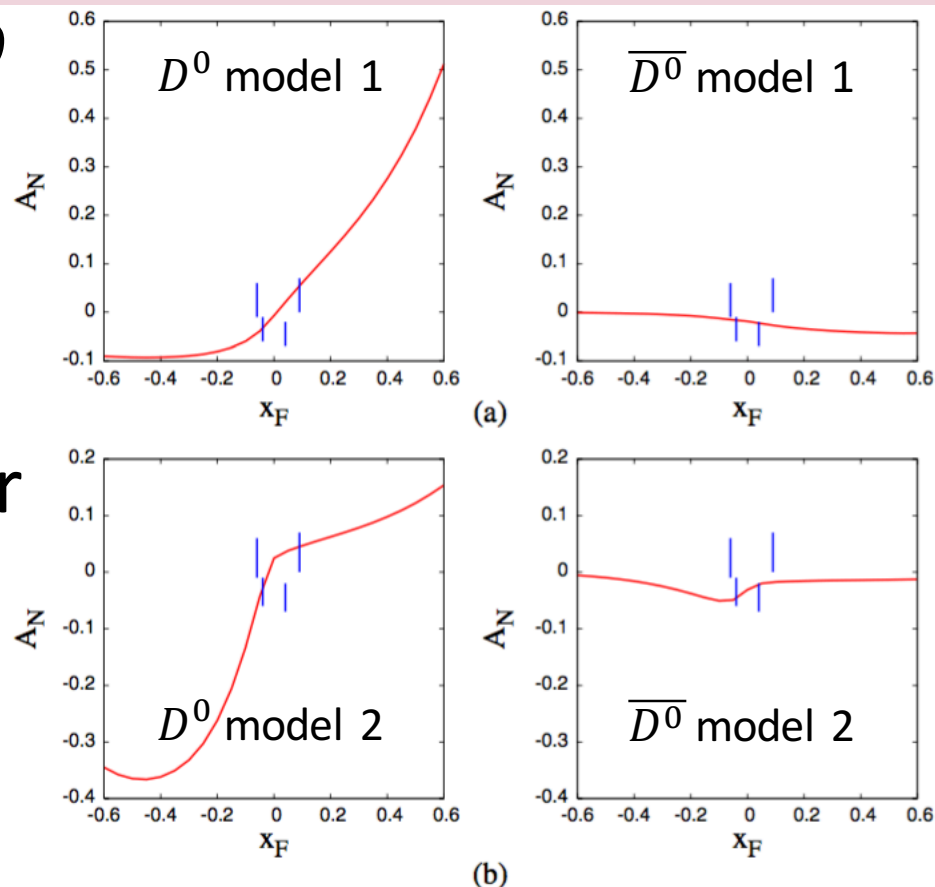
A. Adare et al. PRD 90, 072008 (2014)

# Mechanisms for $A_N$

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

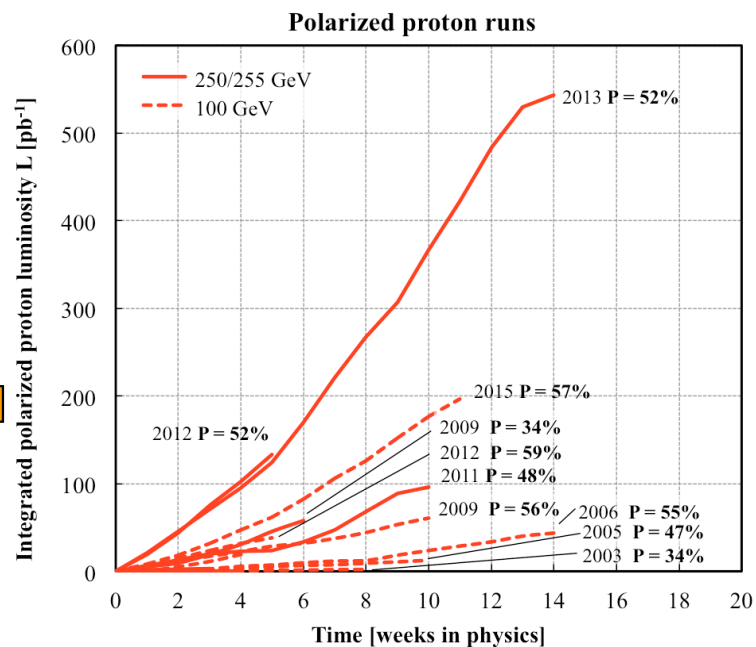
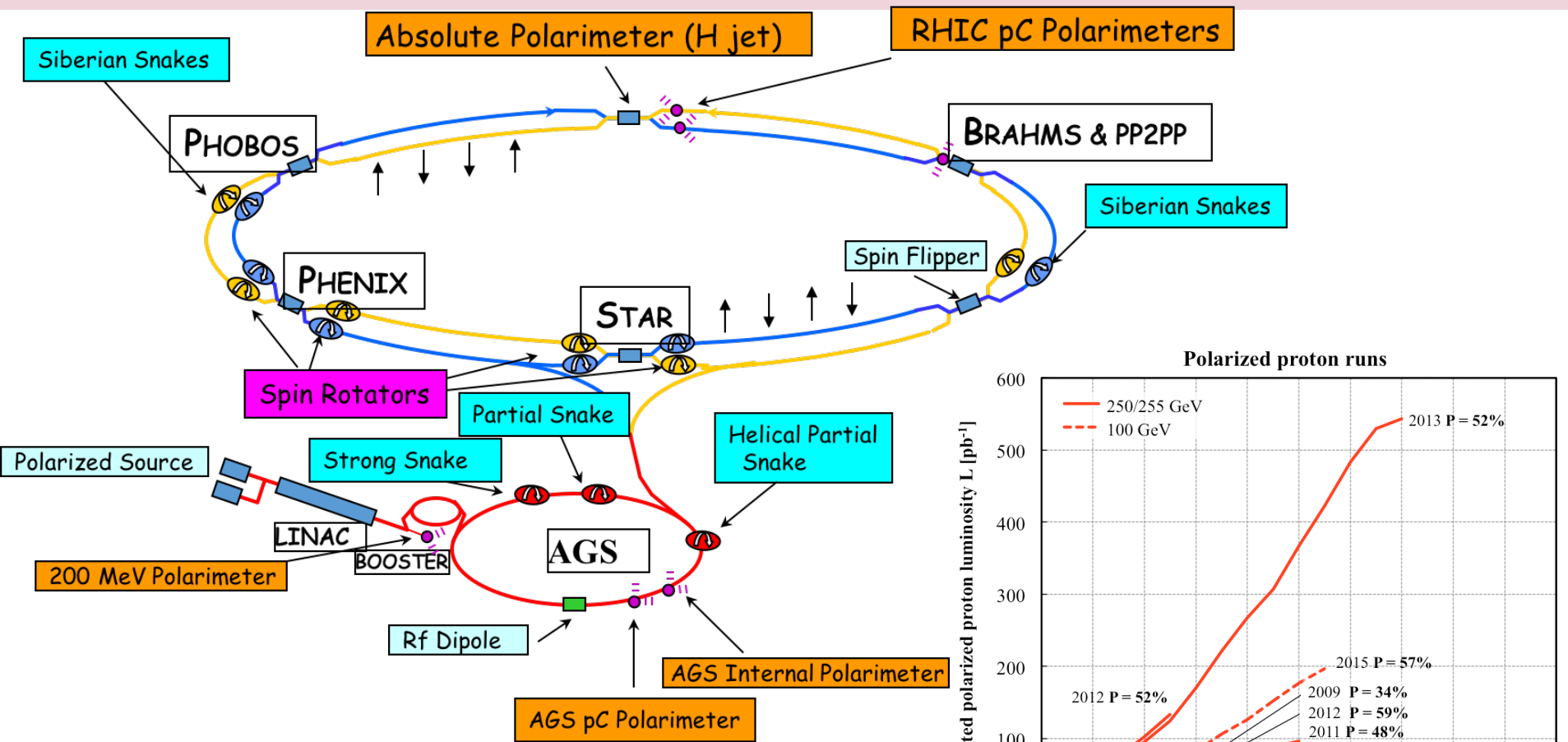
# Theory prediction for heavy flavor $A_N$

- Heavy Flavor (especially  $D$  meson) production is an ideal tool to investigate gluon distribution.
- Twist-3 three-gluon correlation in the collinear factorization framework
- $A_N(D^0, \overline{D^0})$  by gluon-fusion ( $gg \rightarrow c\bar{c}$ )



Y. Koike, S. Yoshida PRD84:014026 (2011)

# Polarized $p+p$ collision at RHIC

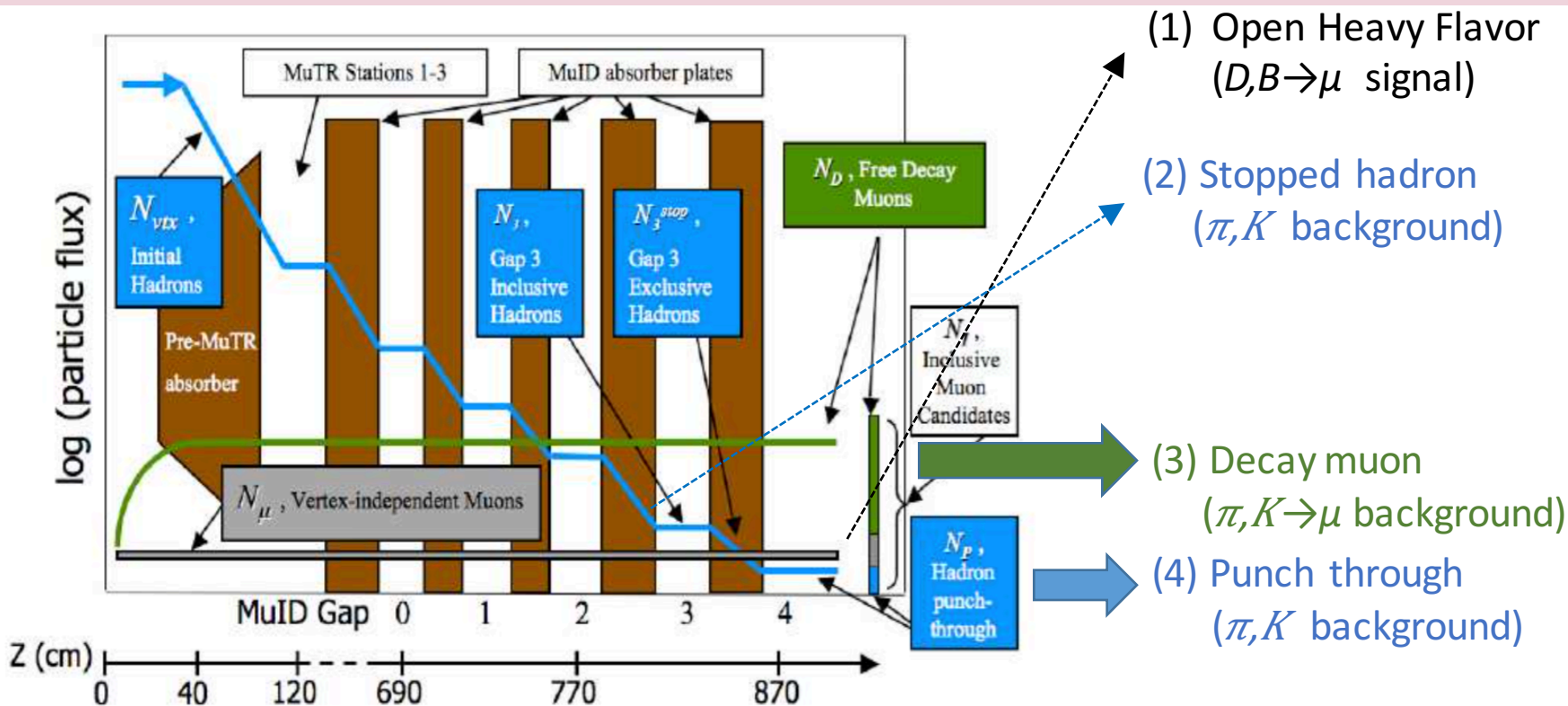


- Helicity controllable up to 510 GeV
  - Transverse, Longitudinal
- 2012  $p+p$  200 GeV run
  - Transversely polarized  $\overline{P}_B=0.64, \overline{P}_Y=0.59, \mathcal{L}_{int}=9.2\text{pb}^{-1}$



# Open Heavy Flavor $A_N$

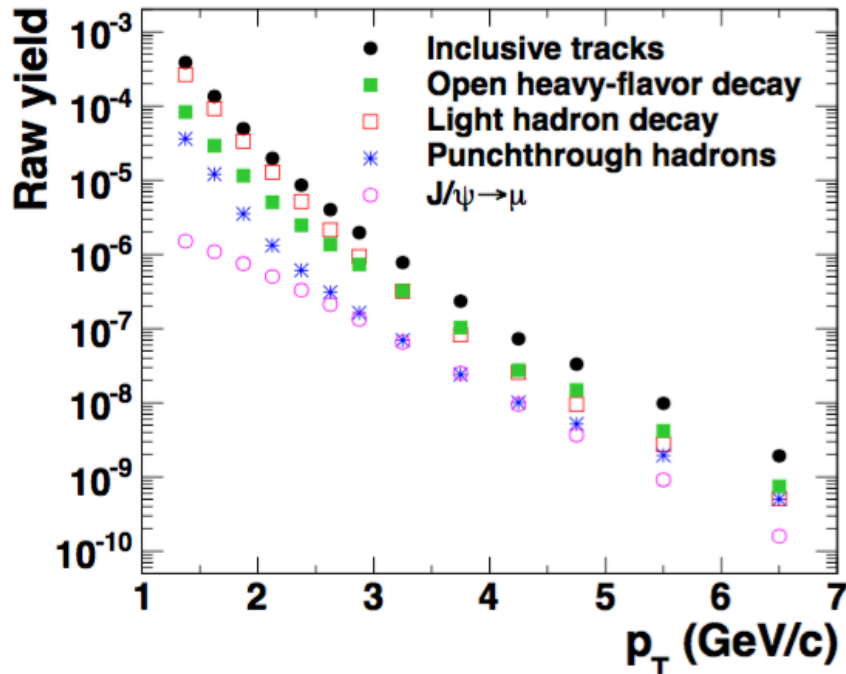
Relative contributions of signal and backgrounds



- 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

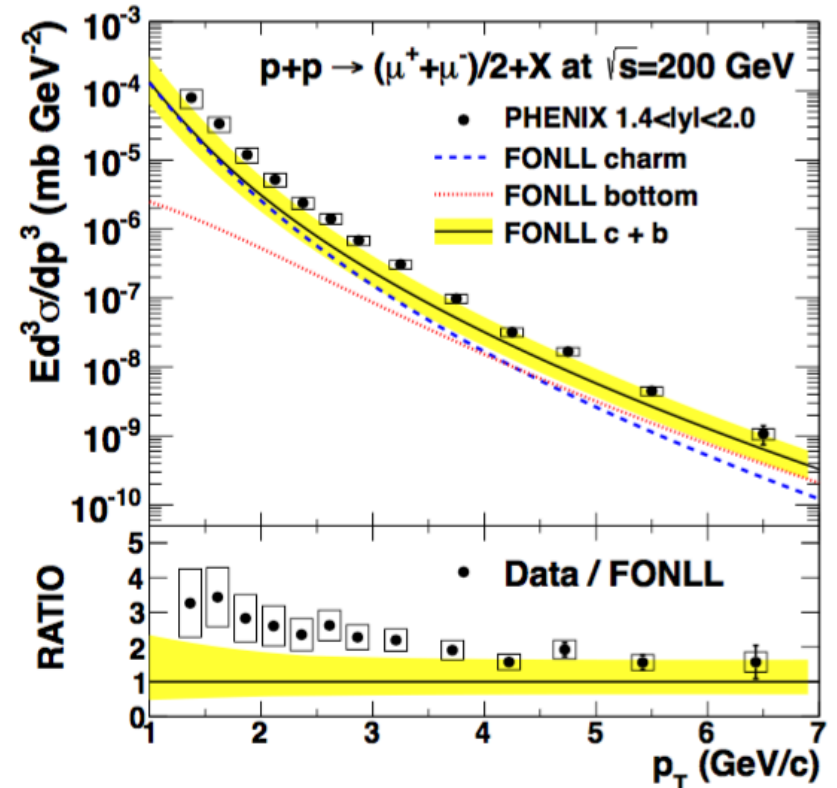


# Open Heavy Flavor Cross Section



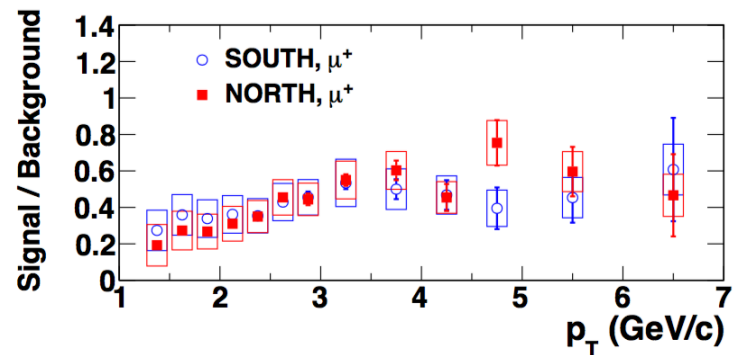
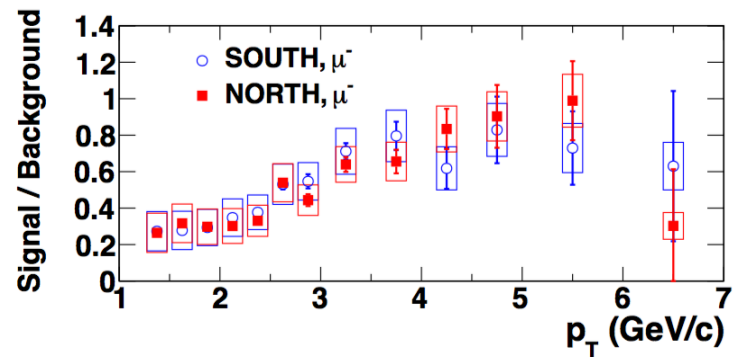
$p_T$  spectra of inclusive muon candidates and background sources from the hadron cocktail simulation

- [arXiv:1703.09333](https://arxiv.org/abs/1703.09333)



Invariant cross section of muons from open heavy flavor decays at forward rapidity, compared to FONLL calculation

# Open Heavy Flavor $A_N$



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

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

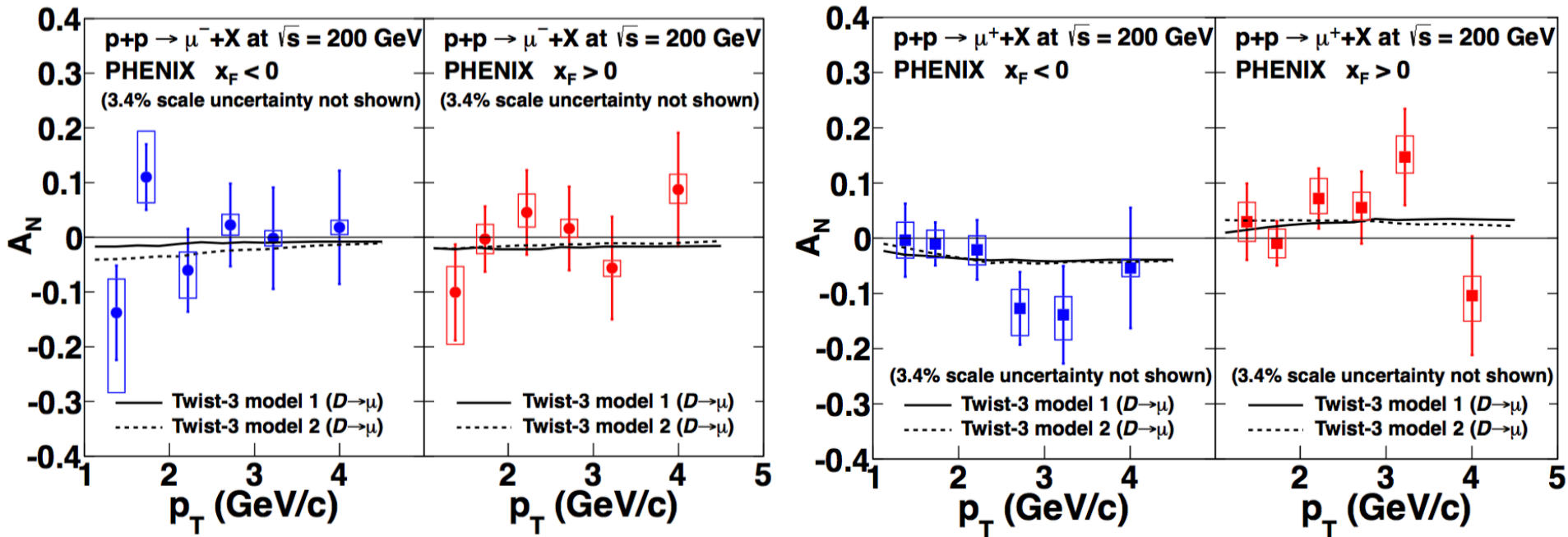
$$A_N^{Phys} = \frac{A_N^{incl} - r \cdot A_N^{BG}}{1 - r}$$

$$r = N^{BG} / N^{incl}$$

$$= (N^{incl} - N^{signal}) / N^{incl}$$

- $A_N^{Incl}$  : Inclusive MUID gap4 tracks
- $A_N^{BG}$  : 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

# Open Heavy Flavor $A_N$

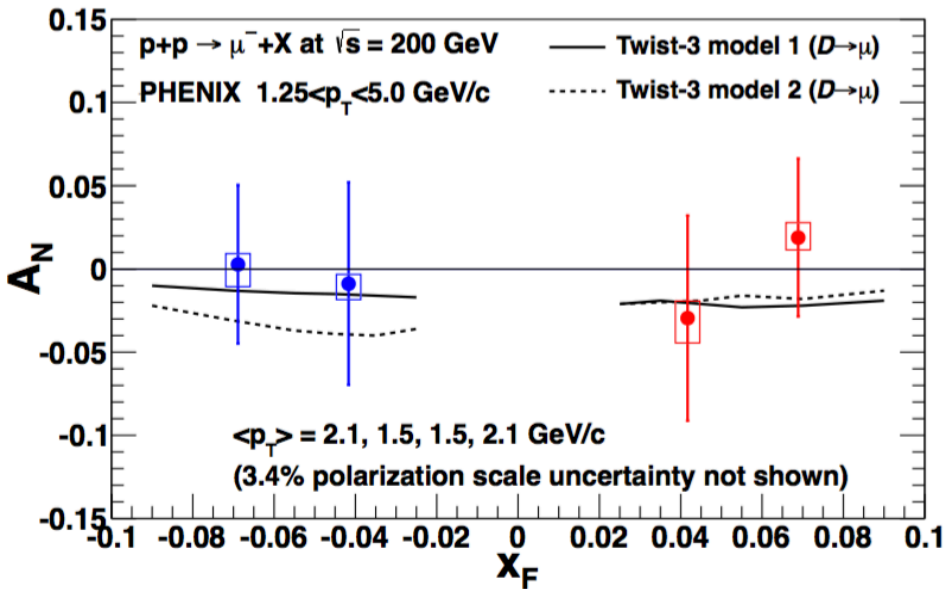


(-) charge • [arXiv:1703.09333](https://arxiv.org/abs/1703.09333)

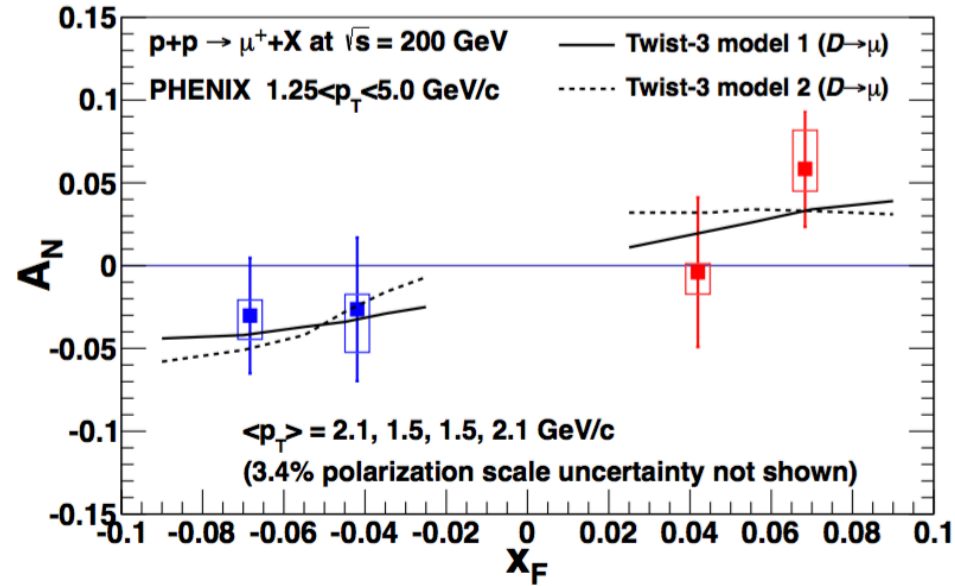
(+) charge

- Open heavy flavor  $A_N$  as a function of  $p_T$
- Twist-3 model curves are for muons using PYTHIA simulation ( $D \rightarrow \mu$ )
  - 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)

# Open Heavy Flavor $A_N$



(-) charge • [arXiv:1703.09333](https://arxiv.org/abs/1703.09333)



(+) charge

- 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.

# Summary and Outlook

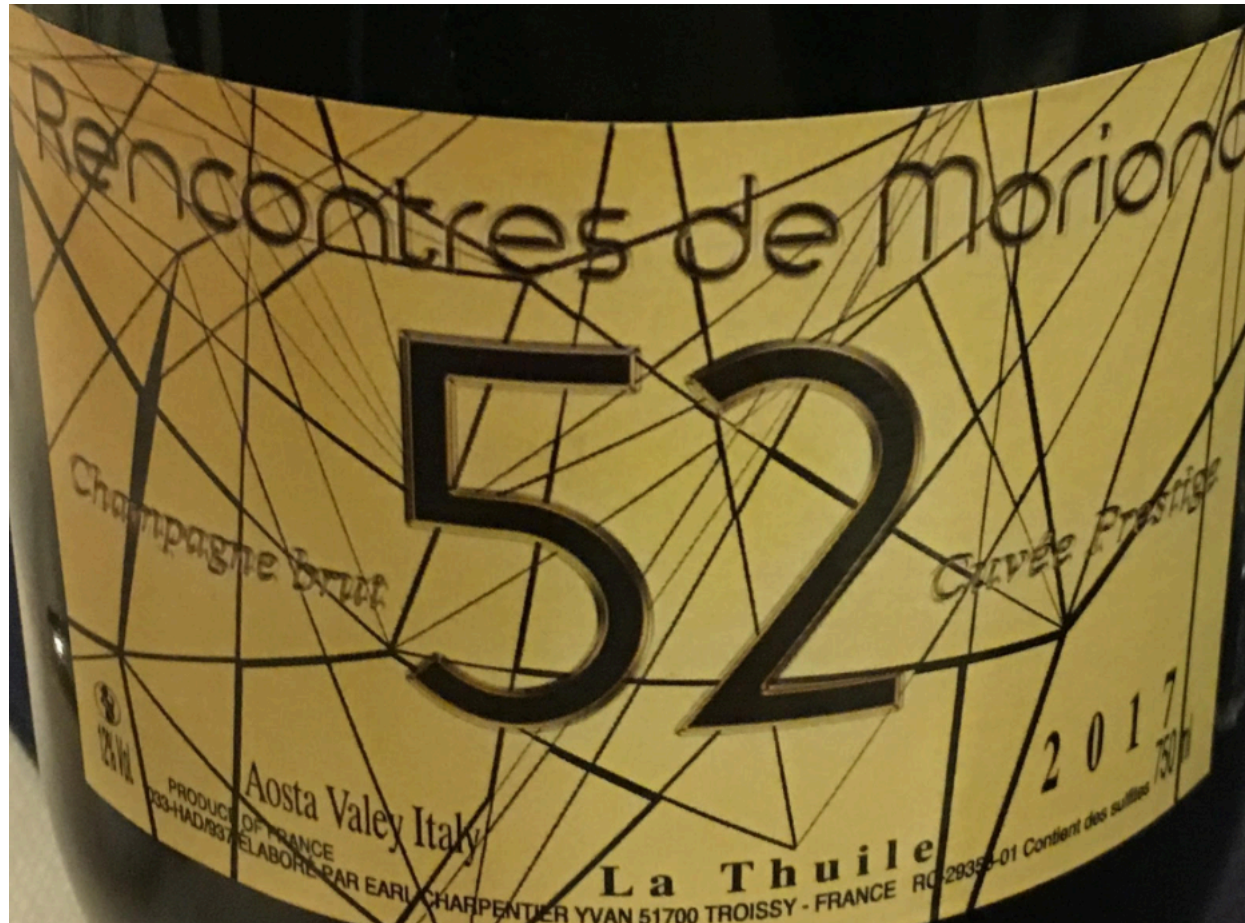
- Summary

- 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.

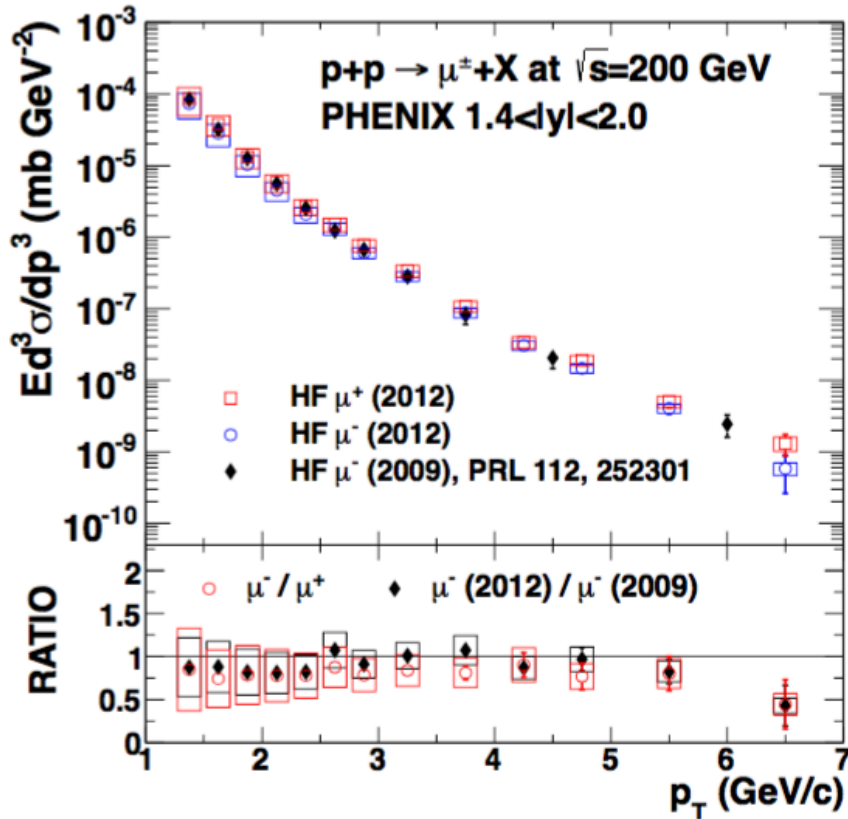
- Outlook

- 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.

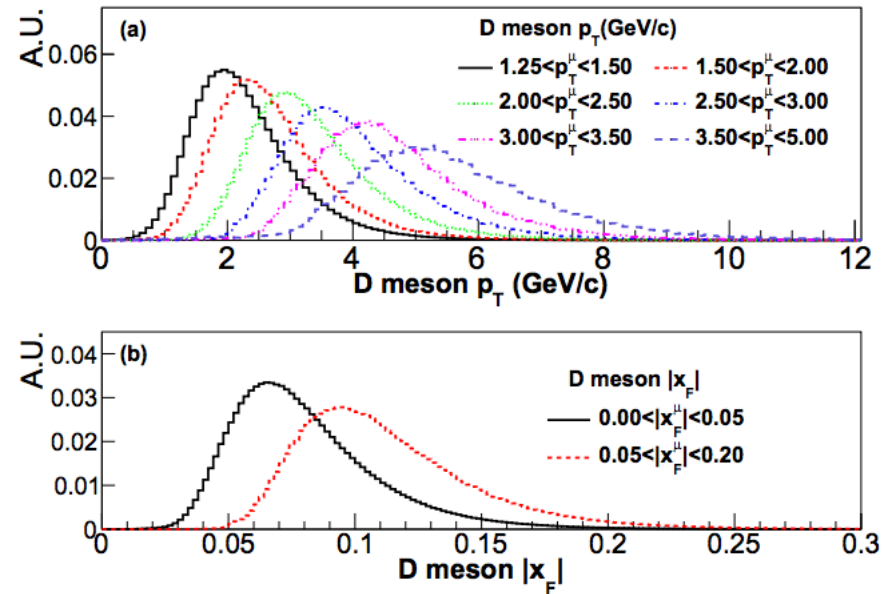
# Thank you!



# backup : more plots in the paper



charge separated invariant cross section of muons from open heavy flavor decays at forward rapidity



$p_T$ ,  $x_F$  distribution of parent D mesons for each 'muon'  $p_T$ ,  $x_F$  bin by PYTHIA simulation

- [arXiv:1703.09333](https://arxiv.org/abs/1703.09333)