Transverse Single Spin Asymmetry in Heavy Flavor Production in Polarized p+p Collisions at PHENIX

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Outline

- Introduction
- The PHENIX Experiment
- SSA in Heavy Flavor Production at 200GeV
  - -- J/Ψ
  - -- Muons(μ^-) from heavy flavor decay
- Summary and Outlook

A brief history…

-- Kane, Pumplin, Repko '78

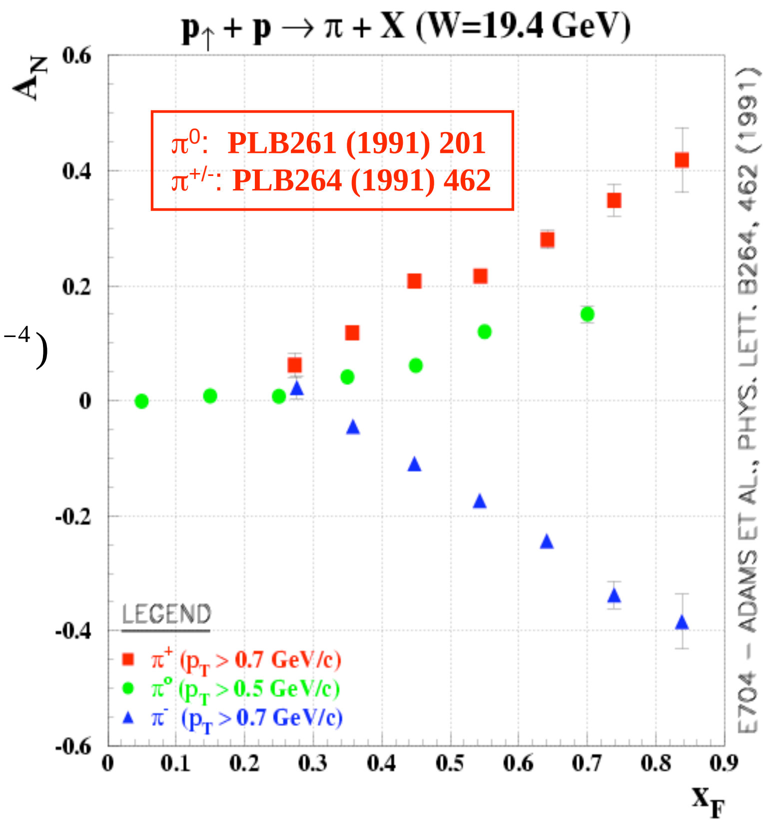
At leading twist and with collinear factorization, pQCD predicts small analyzing powers in transversely polarized p+p collisions

$$A_N \propto \frac{m_q}{\sqrt{s}} \text{ (for example, } m_q = 3MeV, \sqrt{s} = 20GeV, A_N \approx 10^{-4})$$

-- FermiLab E704 experiment

Found strikingly large transverse single-spin effects in p↑+p fixed-target collisions with 200 GeV polarized proton beam

-- Persists at RHIC energies



Theoretical Models

Different mechanisms have been proposed to explain these asymmetries

- Sivers effect
  -- Transverse momentum dependent quark and gluon distributions give rise to correlation between transverse proton spin and the transverse momentum k_T of quarks and gluons

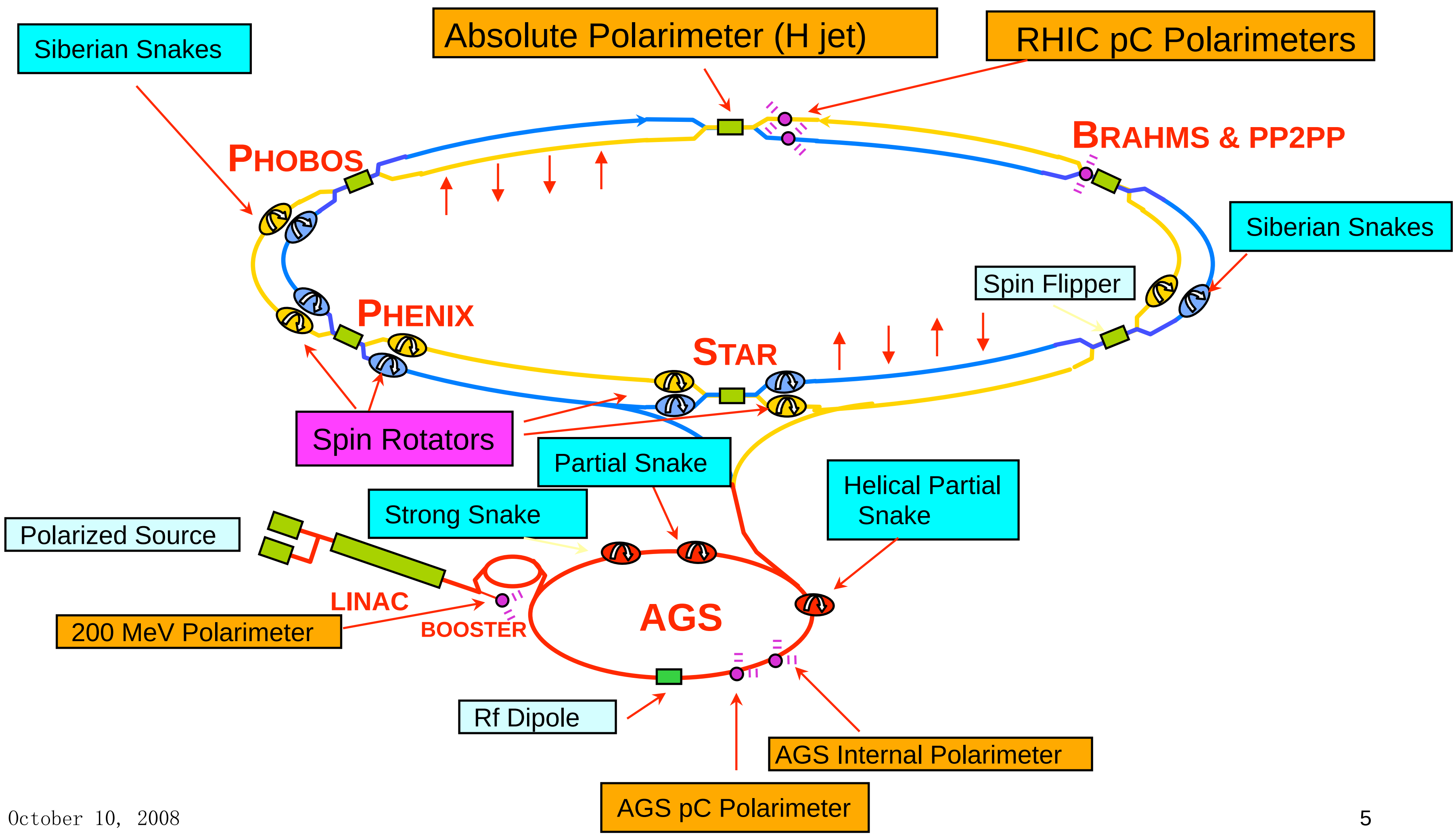
- Collins effect
  -- Transversity distributions + spin dependent fragmentation functions

- Higher-twist effects
  -- Quark gluon field interference
  * Sterman and Qiu → Initial State Twist 3
  * Koike → Final State Twist 3

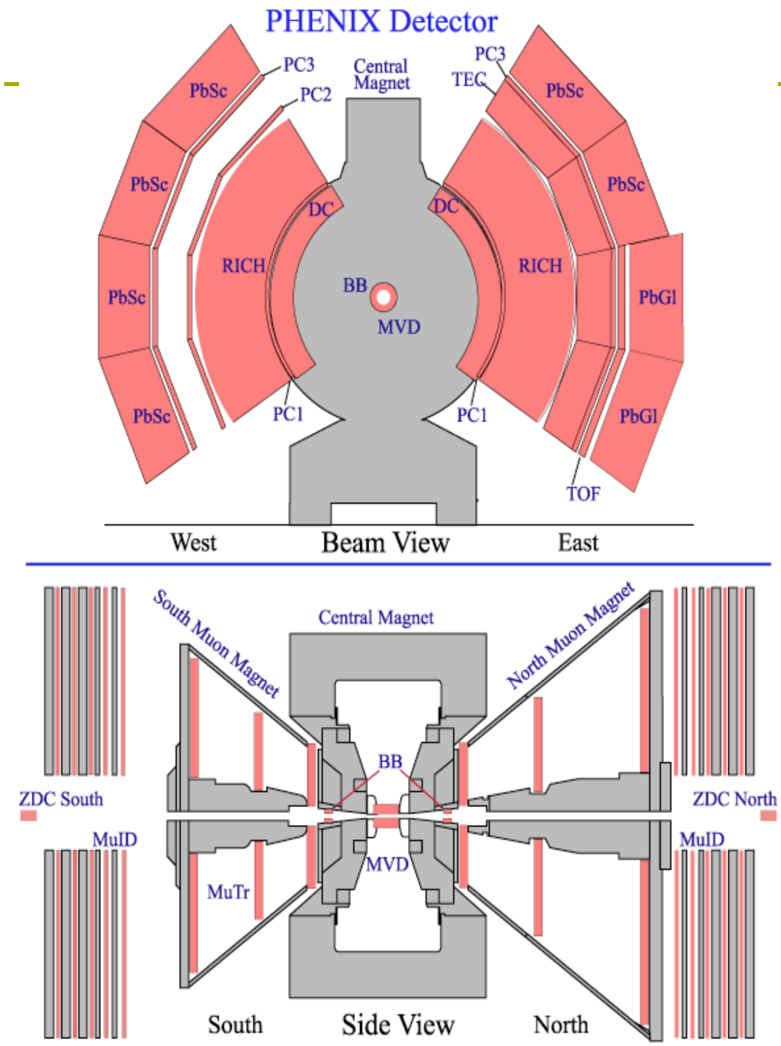
A coherent treatment of the Sivers effect and quark gluon correlations at higher twist has been provided by Ji, Qiu, Vogelsang and Yuan (**PRL97**:082002,2006)

- Or some combination of above

RHIC as a polarized p+p collider



The PHENIX detectors



- **Central Arm Tracking** $|\eta| < 0.35$, $x_F \sim 0$
  - Drift Chamber (DC)
    - momentum measurement
  - Pad Chambers (PC)
    - pattern recognition, 3d space point
  - Time Expansion Chamber (TEC)
    - additional resolution at high pt
- **Central Arm Calorimetry**
  - PbGl and PbSc
    - Very Fine Granularity
      - Tower $\Delta\phi \times \Delta\eta \sim 0.01 \times 0.01$
    - Trigger
- **Central Arm Particle Id**
  - RICH
    - electron/hadron separation
  - TOF
    - π/K/p identification
- **Global Detectors (Luminosity,Trigger)**
  - BBC **$3.0 < |\eta| < 3.9$**
    - Quartz Cherenkov Radiators
  - ZDC/SMD (**Local Polarimeter)**
    - Forward Hadron Calorimeter
- **Forward Calorimetry** **$3.1 < |\eta| < 3.7$**
  - MPC
    - $PbWO_4$ Crystal
- **Forward Muon Arms**

  South arm: $-2.2 < \eta < -1.2$

  North arm: $1.2 < \eta < 2.4$

Transverse spin running at PHENIX

Year	√s [GeV]	Recorded L	Pol [%]	FOM (P^2L)
2001 (Run 2)	200	.15 pb^{-1}	15	3.4 nb^{-1}
2005 (Run 5)	200	.16 pb^{-1}	47	38 nb^{-1}
2006 (Run 6)	200	2.7 pb^{-1}	51	700 nb^{-1}
2006 (Run 6)	62.4	.02 pb^{-1}	48	4.6 nb^{-1}
2008 (Run 8)	200	5.2 pb^{-1}	46	1100 nb^{-1}

Heavy flavor A_N at forward rapidity with muon spectrometers

Why heavy flavor?

- Eliminate Collins' effects
  * heavy flavor production dominated by gluon gluon fusion at RHIC energy

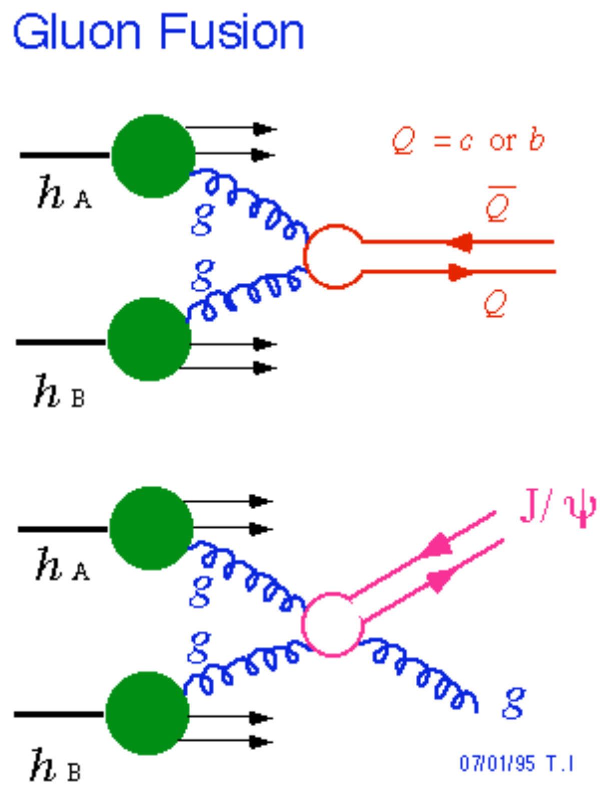
  Pythia 6.1 simulation

$c\bar{c}:$	$gg \rightarrow c\bar{c}$	95%
$b\bar{b}:$	$gg \rightarrow b\bar{b}$	85%

  * gluon has zero transversity

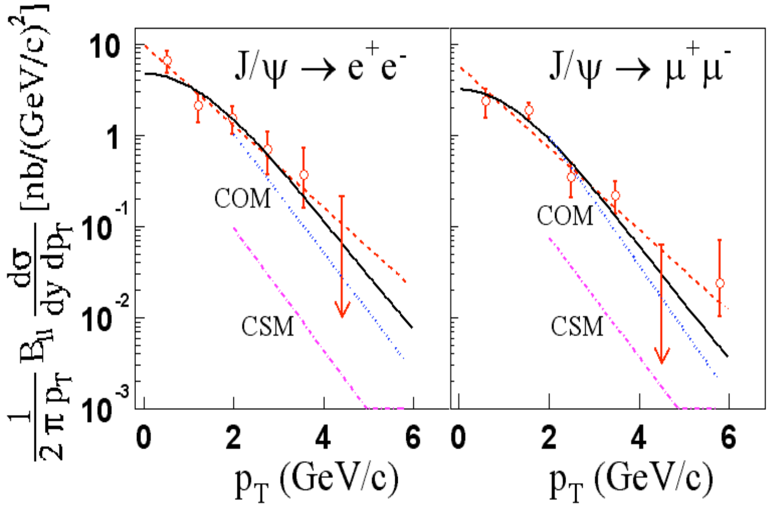
- A perfect channel for gluon Sivers function
  * Gluon's orbital angular momentum?

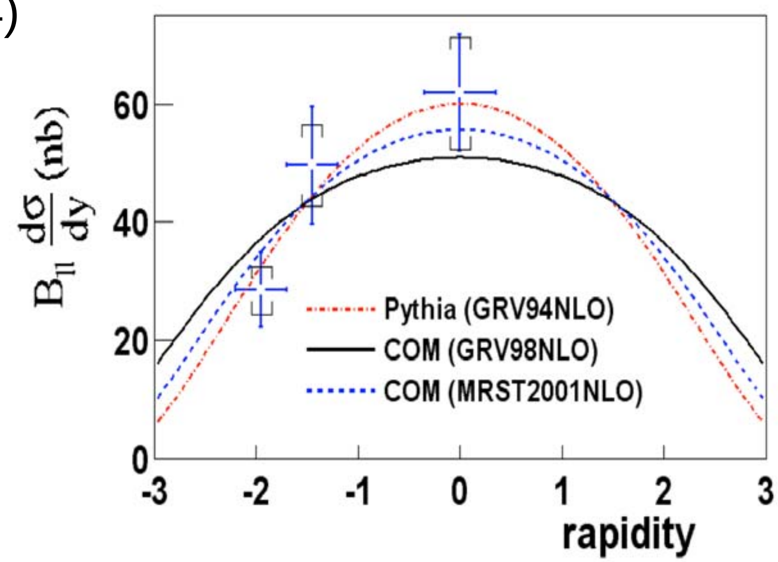
- Important to understand the origin of observed large A_N at large x_F



J/Psi: NRQCD and PHENIX data

PHENIX, PRL 92, 051802 (2004)





Theoretical predictions of J/Ψ production at RHIC are in good agreement with the PHENIX data: COM process dominant

- PRD 68 (2003) 034003 G. Nayak, M. Liu, F. Cooper
- PRL 93 (2004) 171801 F. Cooper, M. Liu, G. Nayak

kT factorization & CSM ... PRD 77 (2008) 05416 S.Baranov,A.Szczurek

How does J/Ψ production affect asymmetry prediction?

Very sensitive to the production mechanism

(Feng Yuan, Phys. Rev. D 78, 014024)

- NRQCD (non-relativistic QCD) can describe some experimental observations

  -- the heavy quark pairs are produced at short distance in a color-singlet or color-octet configurations

- Two cases:

  -- ep scattering: (only final state interaction)

  SSA vanishes if the pair are produced in a color-singlet model but survives in the color-octet model

  -- pp scattering: (both initial and final state interactions)

  SSA vanishes if the pair are produced in a color-octet model but survives in the color-singlet model

Shall shed light on the production mechanism for the heavy quarkonium production

J/Ψ measurement via dimuon channel

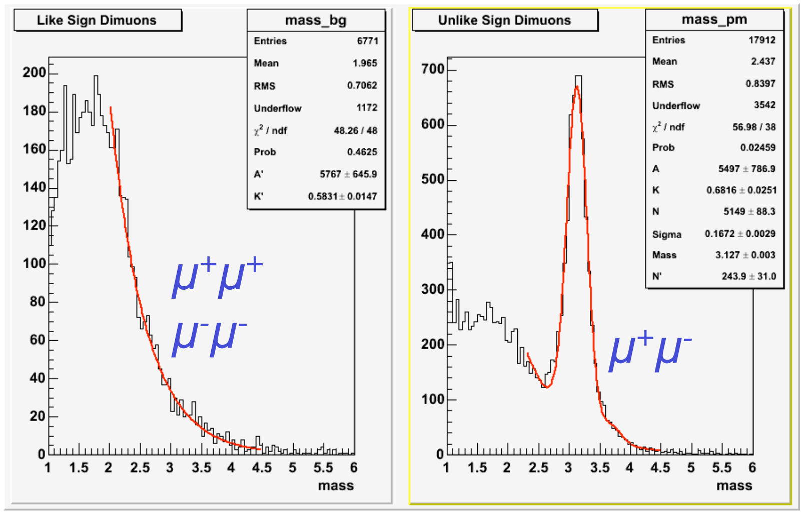
Fill-by-Fill

- No need for fill by fill muon efficiency correction
- Fix mass range to extract the number of J/Ψ (2σ)

Gaussian + Exponential background

- Good fit
- Used to estimate the background fraction under the J/Ψ peak

Like/Unlike charge signed dimuon mass spectra



$$\frac{dN}{dM} = A\cdot e^{-K\cdot M} + N\cdot\frac{1}{2\pi\sqrt{\sigma}}e^{-\frac{(M-M_{J/\psi})^2}{2\sigma^2}} + N^{'}\cdot\frac{1}{2\pi\sqrt{\sigma}}e^{-\frac{(M-M_{\psi^{'}})^2}{2\sigma^2}}$$

A: Total background
K: Slope
N: Number of J/Ψ
σ: J/ψ mass resolution
M: J/Ψ mass
N’: Number of Ψ’

Background estimation

- From Drell-Yan, Open charm, Light hadrons, etc.
- Three methods:

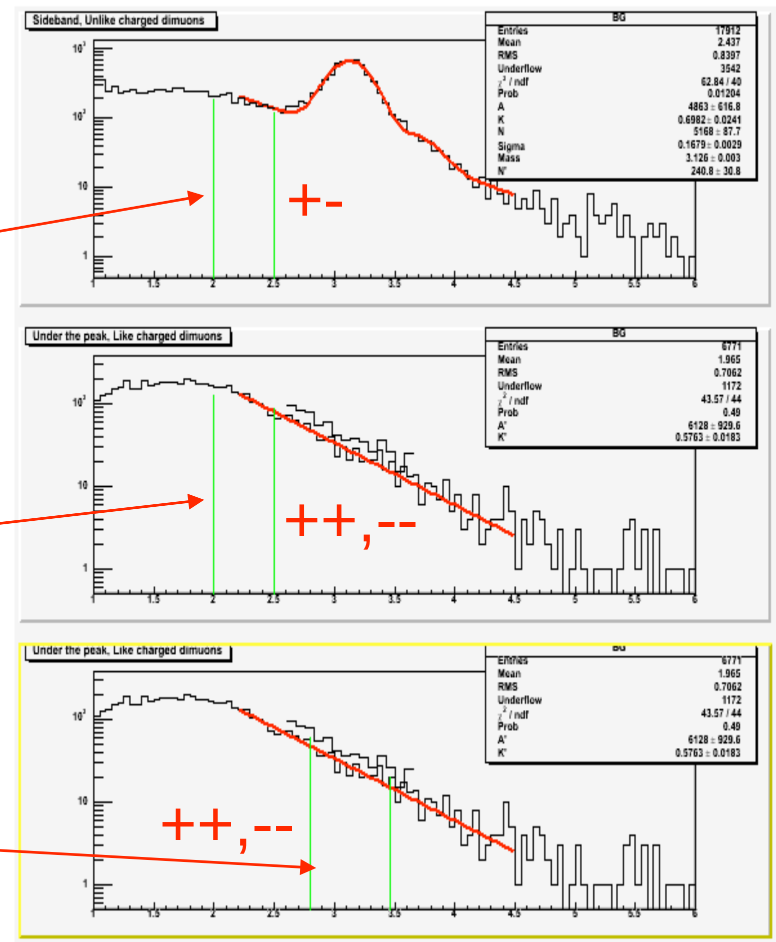
-- Sideband from unlike sign dimuon pairs:

$2.0 < m < 2.5$

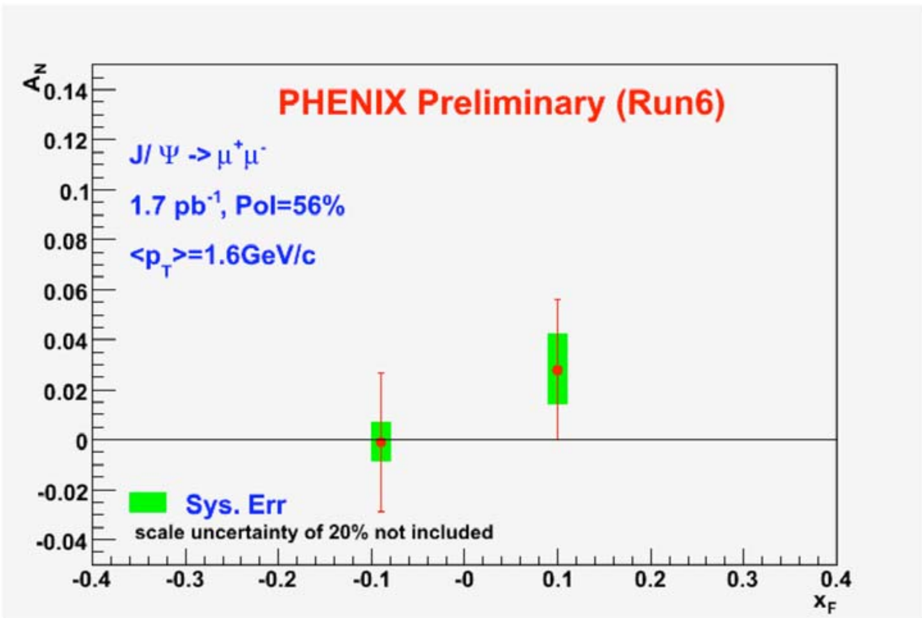
-- Sideband from like sign dimuon pairs:

$2.0 < m < 2.5$

-- Like sign dimuon pairs under the J/Ψ peak

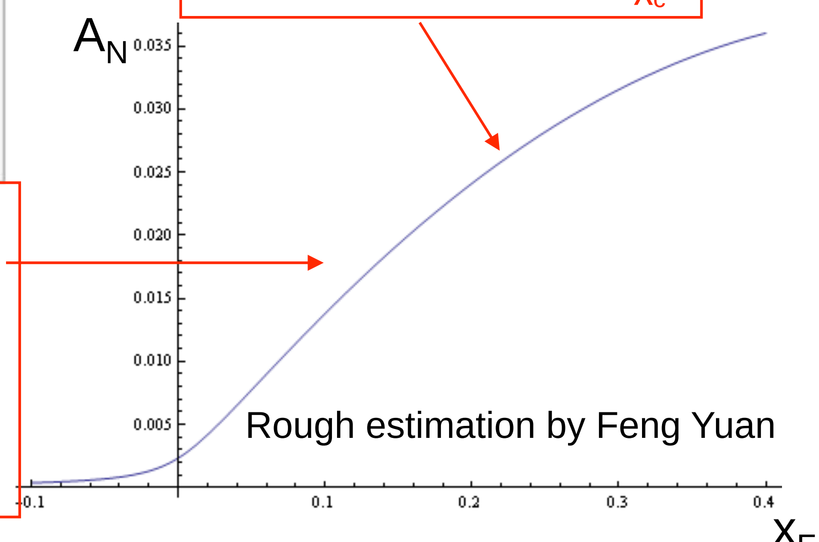


A Sivers Model Calculation for RHIC



- At RHIC, color-octet dominate the production cross section
- 30%-40% J/Ψ comes from Ψ′ and χ_c feeddown

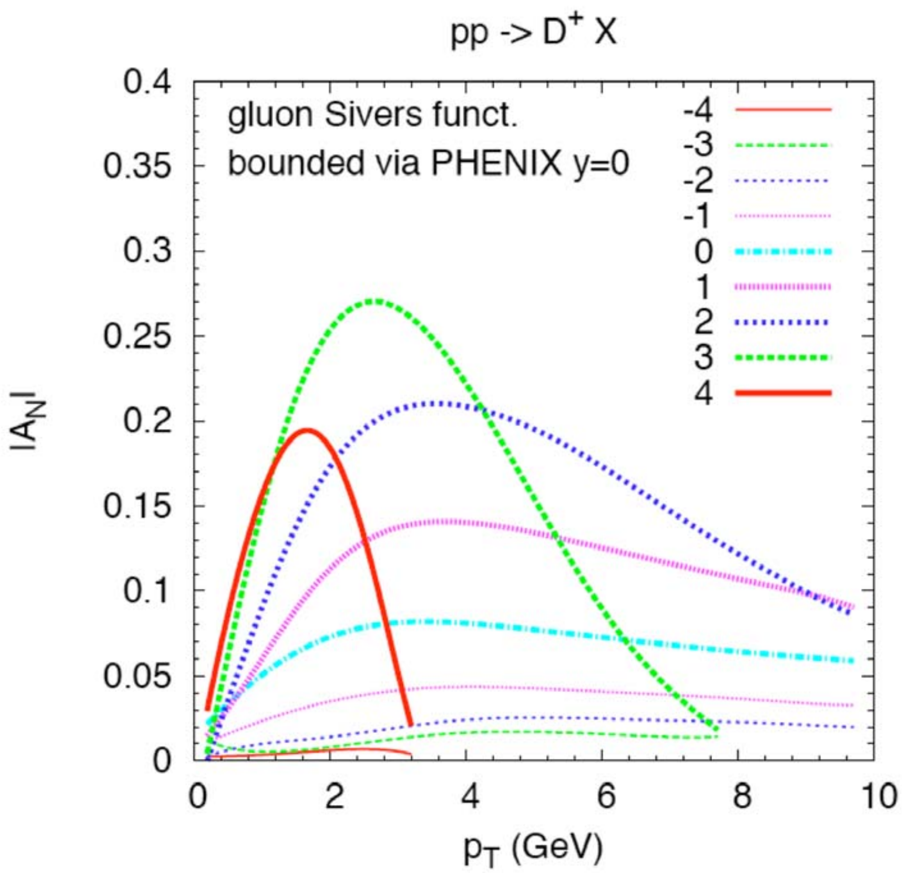
Non-zero AN is entirely due to feeddown from the χ_c



Assume:
--Gluon Sivers function ~ 0.5 x(1-x) times unpolarized gluon distribution (expect large-x and small-x suppression of the Sivers function as compared to the unpolarized one)

-- 30% J/Ψ comes from χ_c feeddown

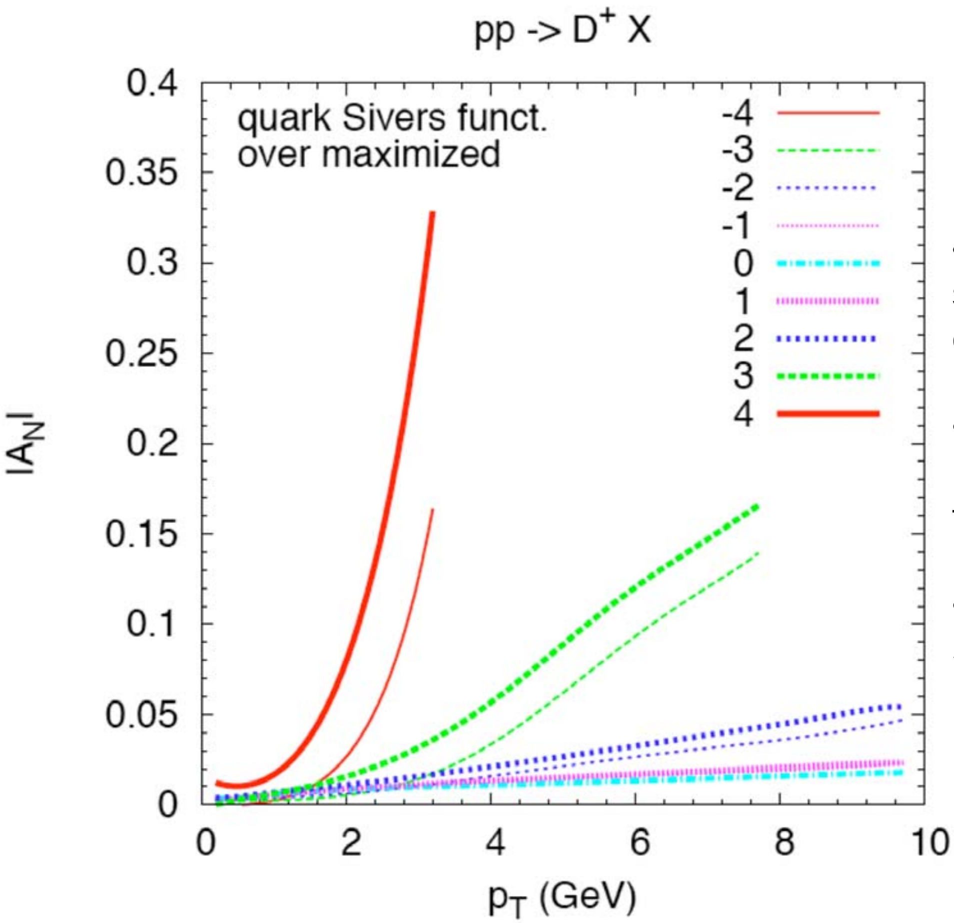
Gluon Sivers Function and Open Charm A_N



contribution to open charm A_N from the gluon Sivers function "bounded" via PHENIX data at y=0

Phys. Rev. D 74 (2006) 094011

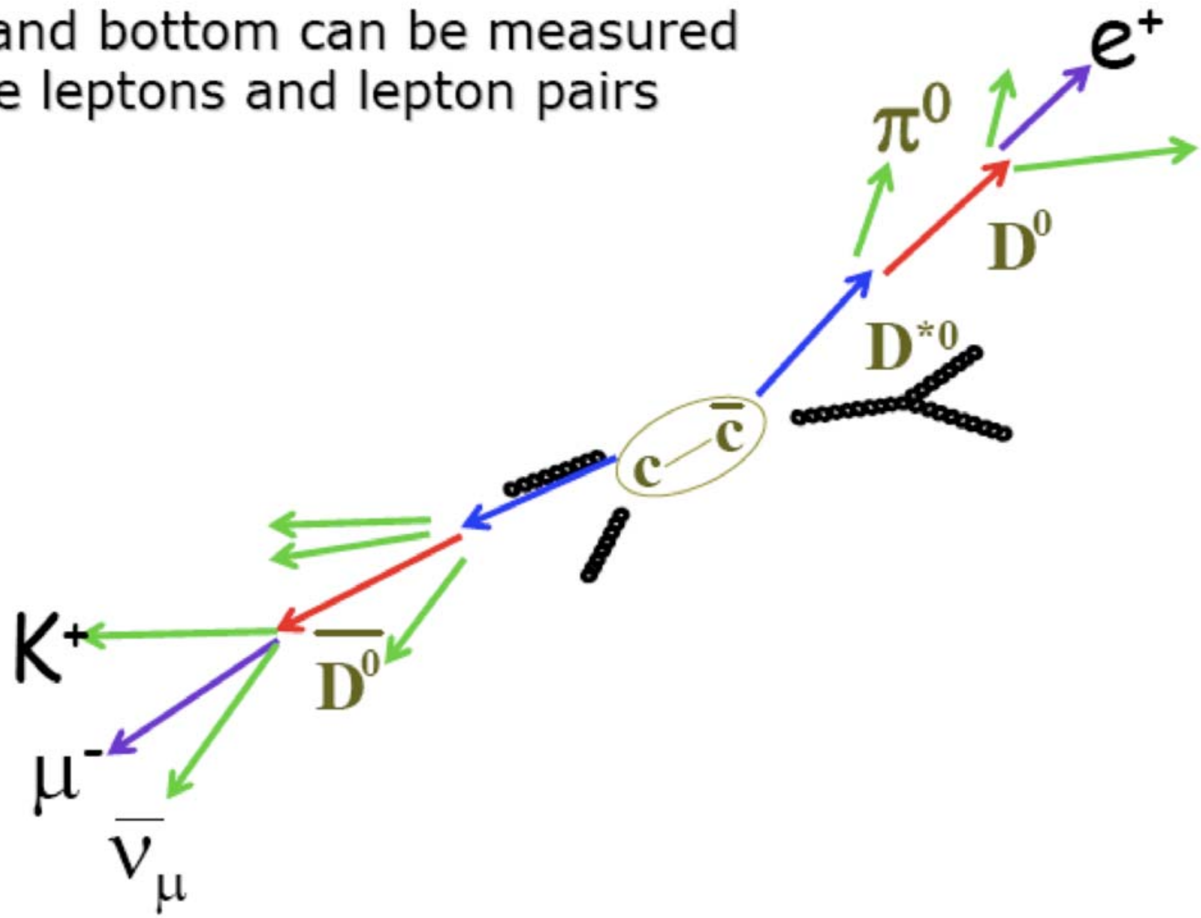
Open charm A_N from Quark's Sivers Function



- The Sivers functions for up and down quark are set to be equal to their positivity bounds (twice the corresponding unpolarized PDF)
- They both have the same sign (against the present phenomenological evidence) and therefore their contribution add up constructively.
- Any physical parametrization (extracted from SIDIS and/or pp) would give a smaller A_N

Open heavy flavor via semi-leptonic decays

Open charm and bottom can be measured through single leptons and lepton pairs



Muon Track Candidates in the Muon Spectrometer

$1.2 < |\eta| < 2.4$

$\Delta\varphi = 2\pi$

$P > 2GeV/c$

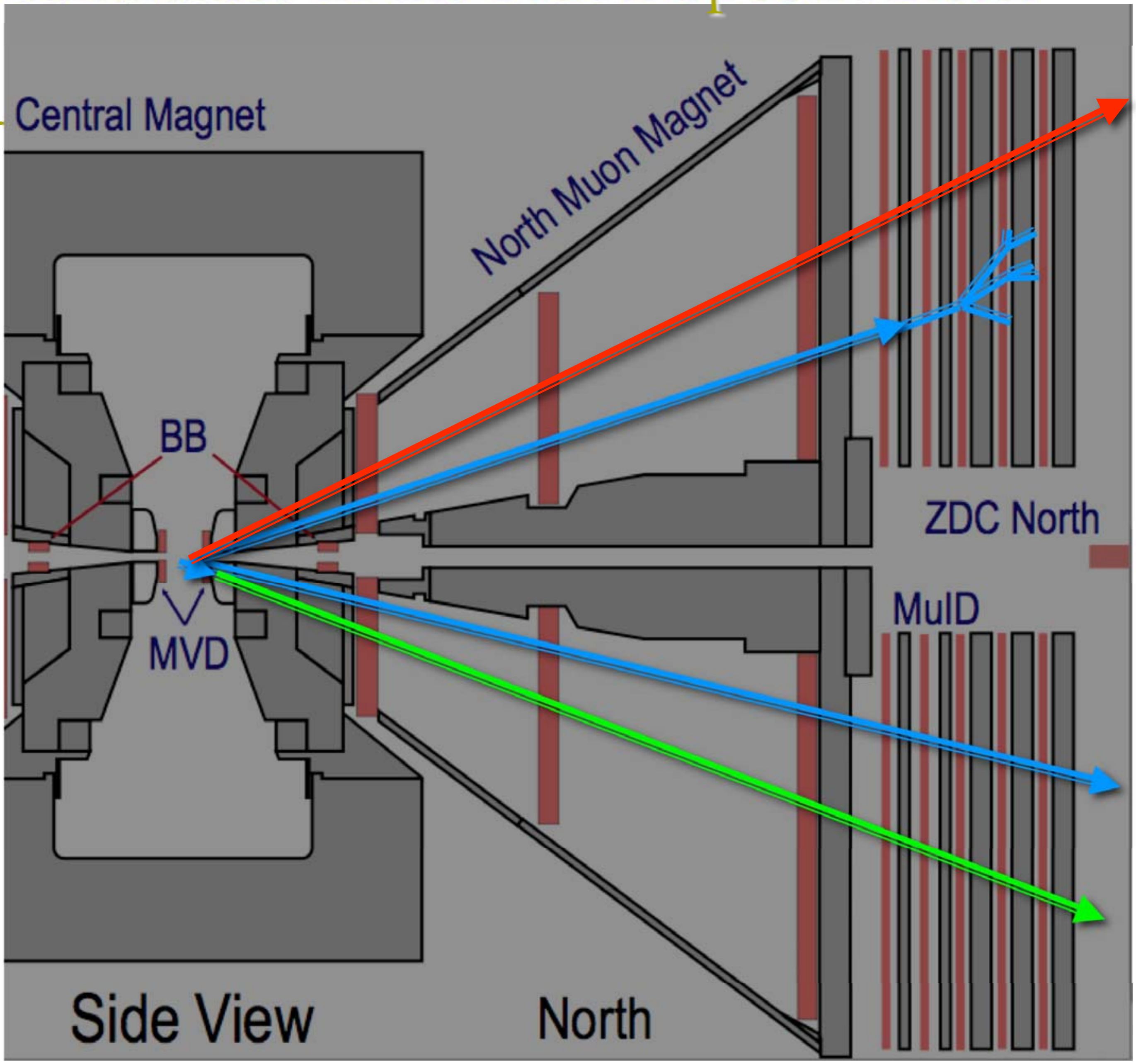
Candidate Tracks:

Prompt Muons

Punch-through hadrons

Stopped hadrons

Decay muons

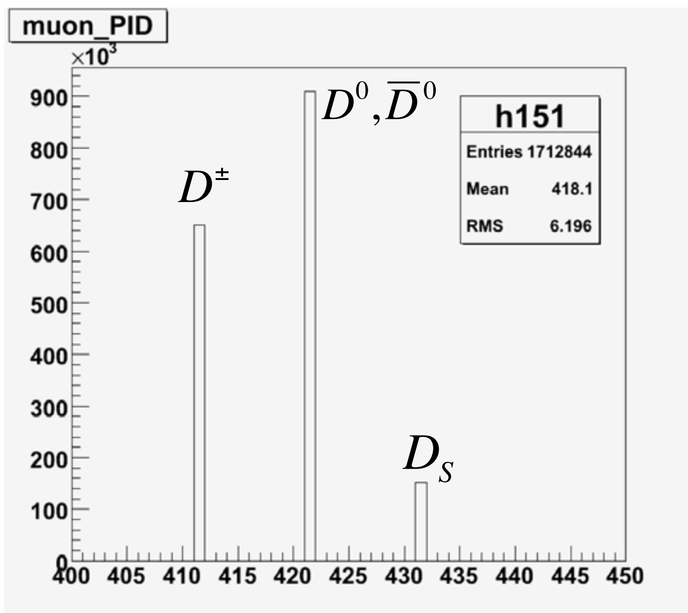


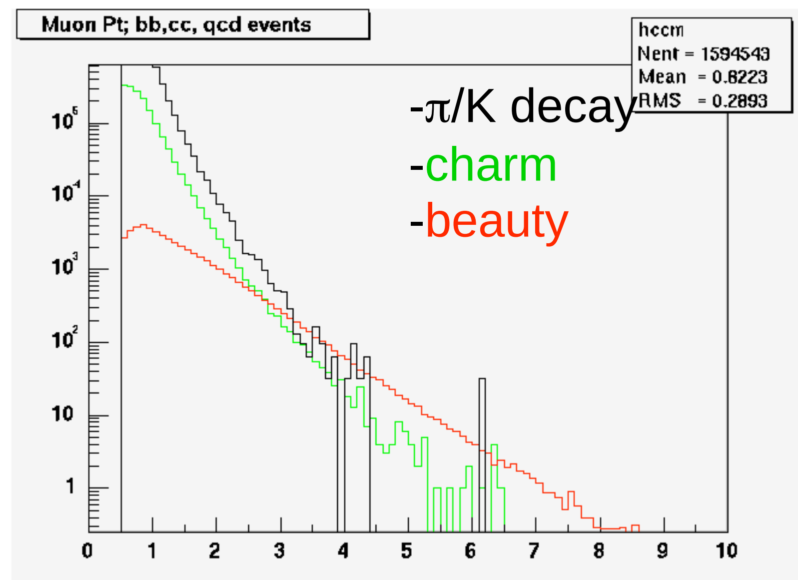
Muons from D and B Hadron Decay

- Get muon kinematics from PYTHIA simulation @200GeV

-- D^0, $D^{+/-}$ hadron relative fraction

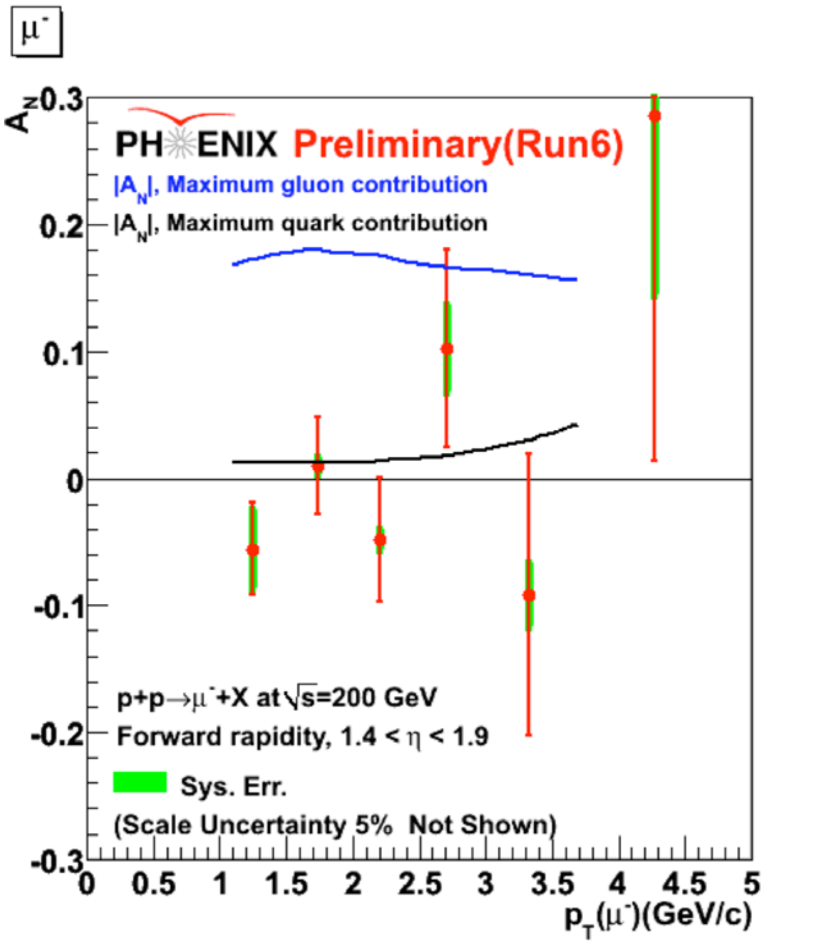
-- D/B fractions

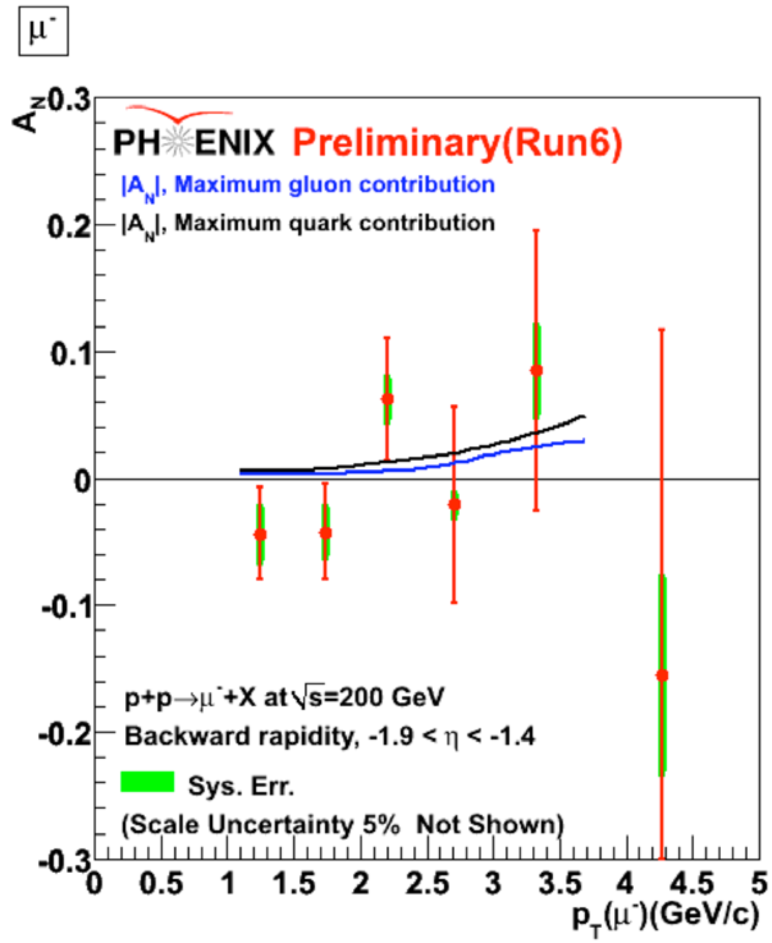




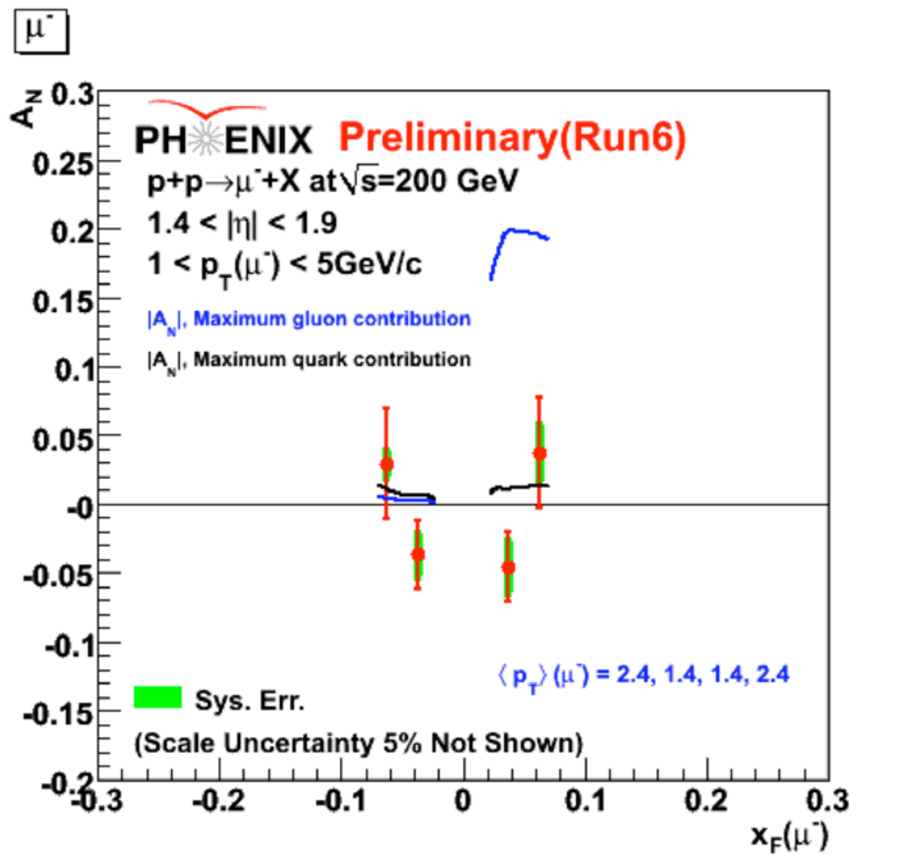
$p_T(\mu)$

Prompt muons: A_N vs. p_T





Prompt muons: A_N vs. x_F



Data constrain the gluon Sivers function to be significantly smaller than the maximal allowed

Charm production at forward rapidity

- Two component model
  - Leading particle effects and coalescence
    - R.Vogt and S.J. Brodsky, NP B 478 (1996) 311-332

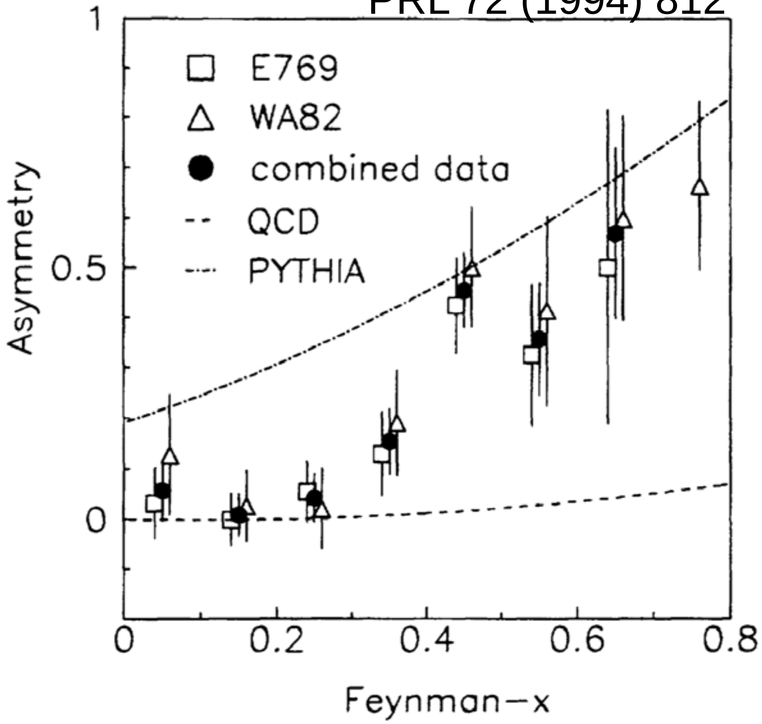
$$\pi^- + A \rightarrow D^{\pm} X$$

$$\pi^- \sim (\bar{u}d)$$

$$D^- \sim (\bar{c}d), \quad D^+ \sim (c\bar{d})$$

$$A(D^-/D^+) = \frac{d\sigma(D^-) - d\sigma(D^+)}{d\sigma(D^-) + d\sigma(D^+)}$$

PRL 72 (1994) 812



Theoretical effort on open charm A_N

G.D. Zacarias et. al., EPJC 51(2007)619

- Two component model (has been used to describe the production asymmetry of charm productions successfully)

$$\frac{d\sigma^D}{dx_F dp_T} = \frac{d\sigma^D_{rec}}{dx_F dp_T} + \frac{d\sigma^D_{frag}}{dx_F dp_T}$$

-- Recombination process: a quark from the sea joins a valence quark in the initial state

$$\overline{D}^0 : u\overline{c} \qquad D^- : d\overline{c}$$

-- Fragmentation process: assume particles created by the fragmentation process lose information about the spin polarization of the proton in the initial state

$$\frac{d\sigma^{\uparrow}_{frag}}{dx_F dp_T} = \frac{d\sigma^{\downarrow}_{frag}}{dx_F dp_T}$$

Fit the π^0 A_N at different collision energy

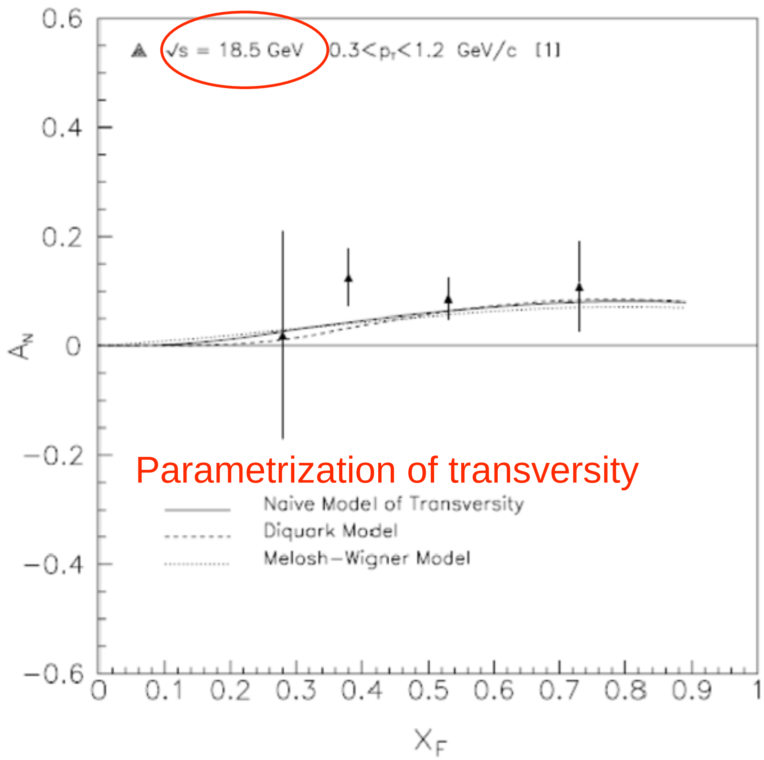


Fig. 3. Single spin asymmetry for π^0 [2–4] in the framework of the two component model with three different transversity parametrizations [15–18, 31–40]. The center of mass energy of the reaction is $\sqrt{s} = 18.5$ GeV

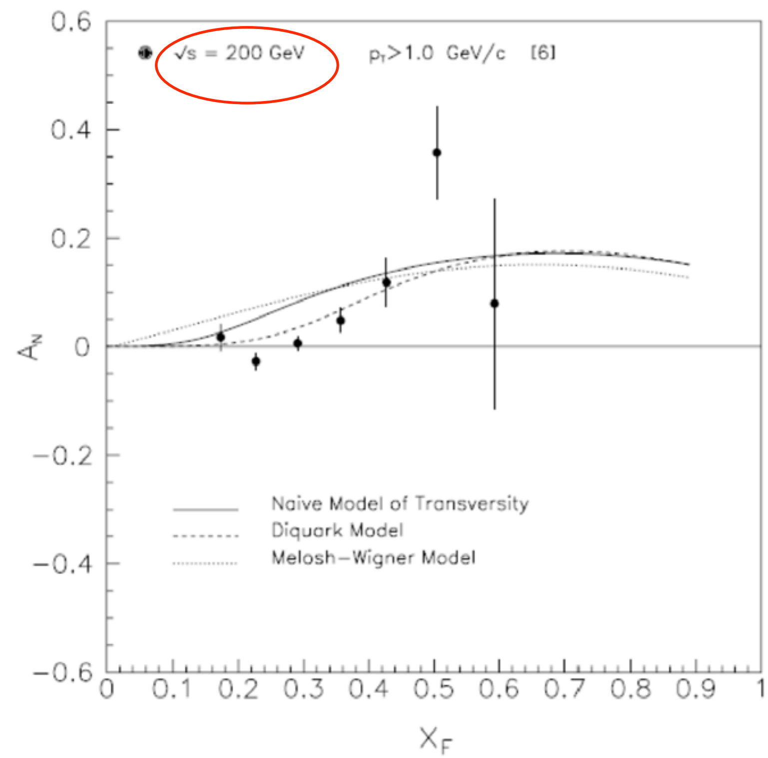


Fig. 4. Single spin asymmetry for π^0 [20] in the framework of the two component model with three different transversity parametrizations [15–18, 31–40]. The center of mass energy of the reaction is $\sqrt{s} = 200$ GeV

Prediction of two component model

Anselmino's model

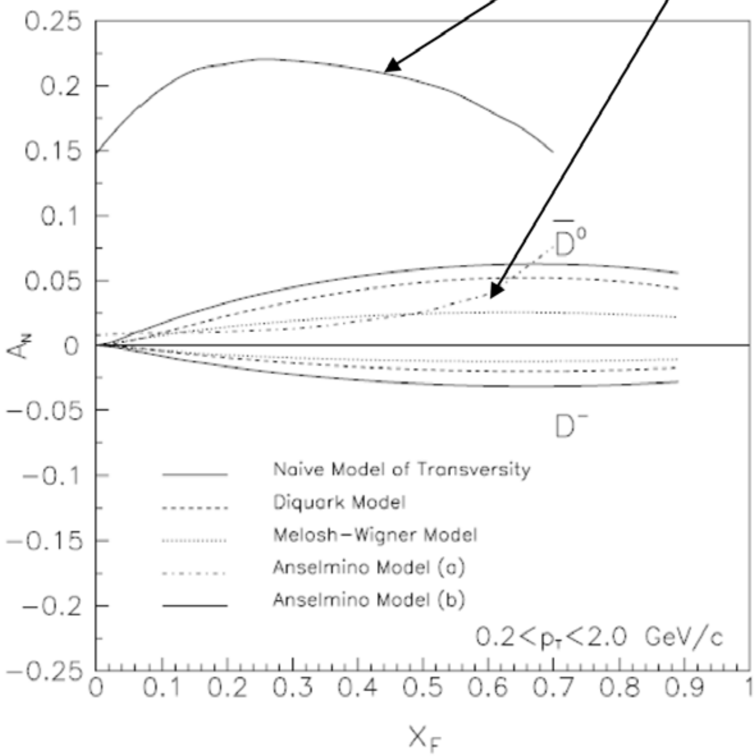
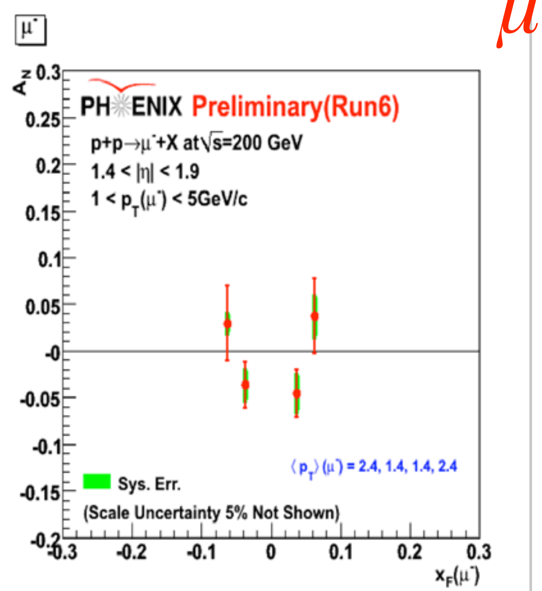


Fig. 6. Comparison of the single spin asymmetries obtained with the model presented here (*solid*, *dash* and *dotted curves*) with those obtained by Anselmino et al. [19] (*solid* in the upper part and *dot dashed curve*)

Prediction:

$\bar{D}^0(u\bar{c}), D^-(d\bar{c})$ → Sizable A_N → μ^-

$D^0(\bar{u}c), D^+(\bar{d}c)$ → $A_N = 0$ → μ^+



Summary and Outlook

- PHENIX has measured the transverse single spin asymmetries in heavy flavor production at 200GeV. At RHIC energy, Open Heavy flavor and J/Ψ production are dominated by gluon-gluon fusion, so the A_N in heavy flavor production are prefect channel to study gluon's Sivers effect.

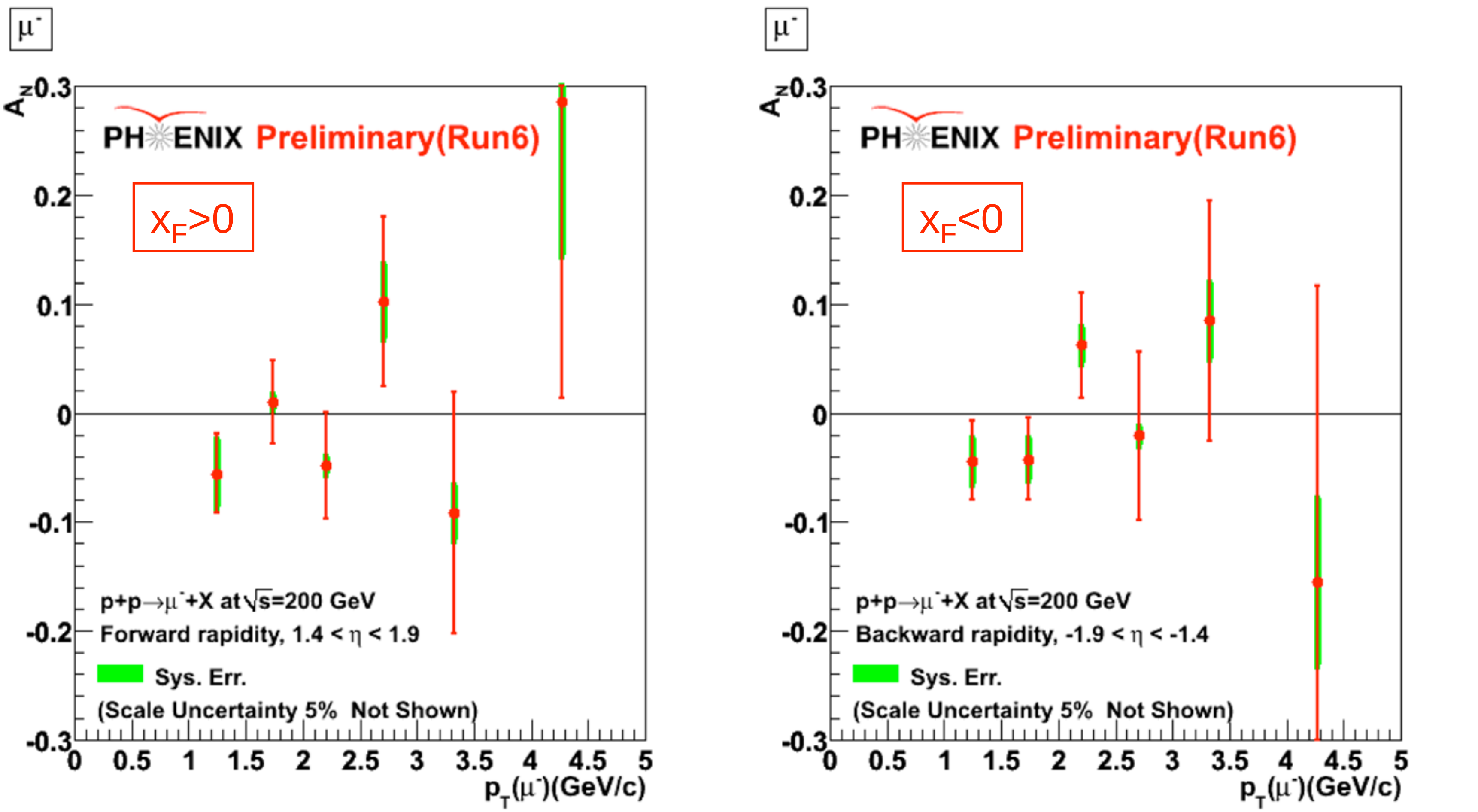
  -- First measurement in J/Ψ production at $x_F \approx \pm 0.1$
  -- First measurement in open heavy flavor production at forward rapidity

- With Run6 and Run8 data sets,

  -- Open heavy flavor through μ^+ channel at forward rapidity
  -- J/Ψ --> di-electron channel at $x_F=0$
  -- open heavy flavor through electron channel at $x_F=0$

- New upgrade detectors should significantly enhance physics reach
  -- Silicon Detectors (SVTX and FVTX)
  Heavy flavor measurement (Ψ', open heavy flavor)

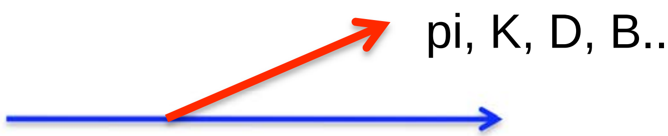
A_N vs. p_T in forward and backward rapidities

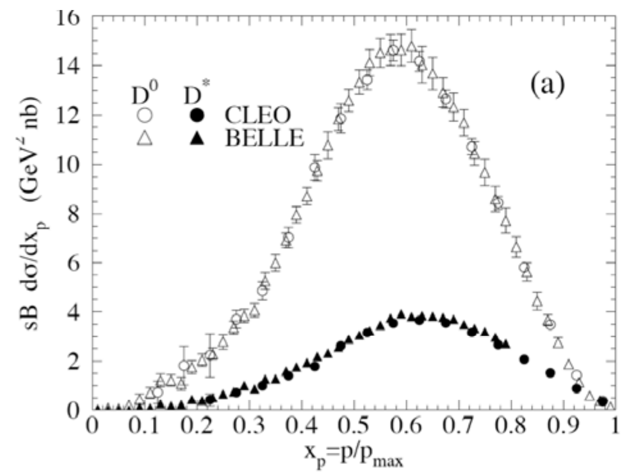


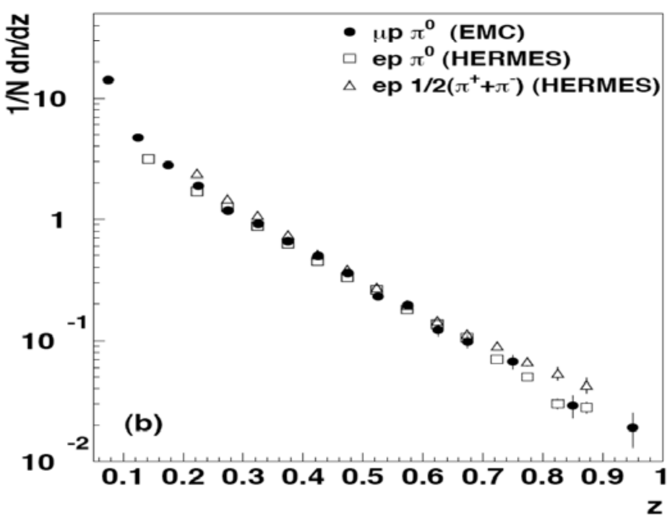
Fragmentation function for light hadrons and heavy flavors

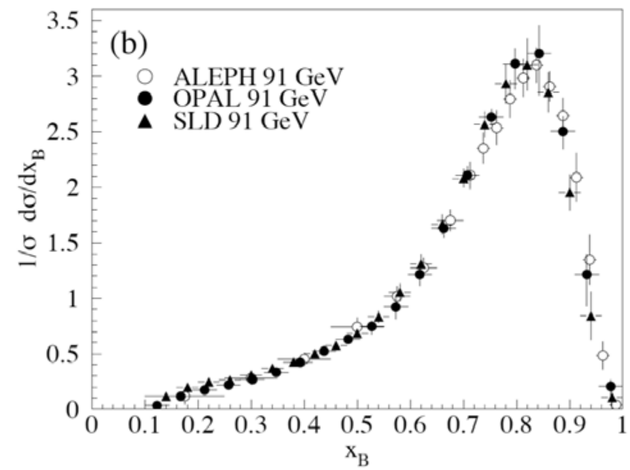
- Light hadrons - soft frag.
- Heavy hadrons - hard frag.

  Carry most of initial quark's energy

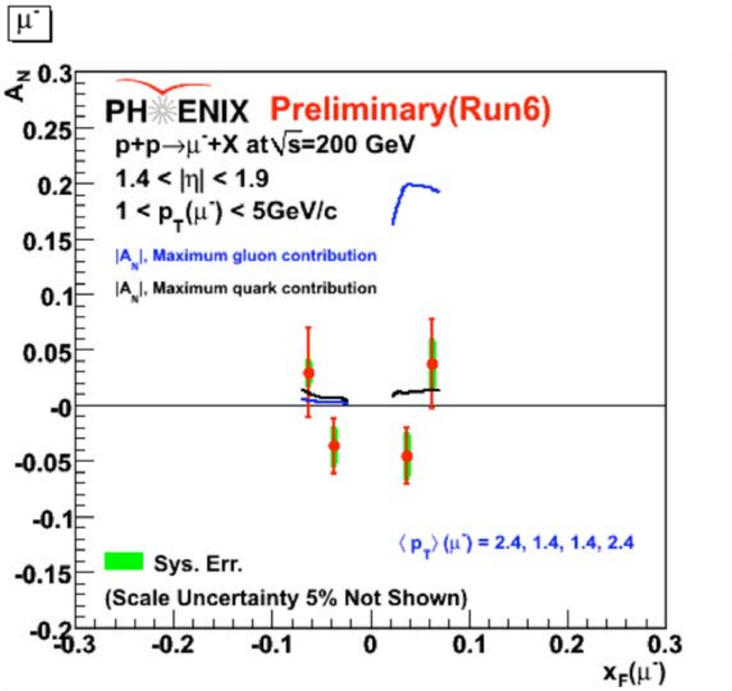


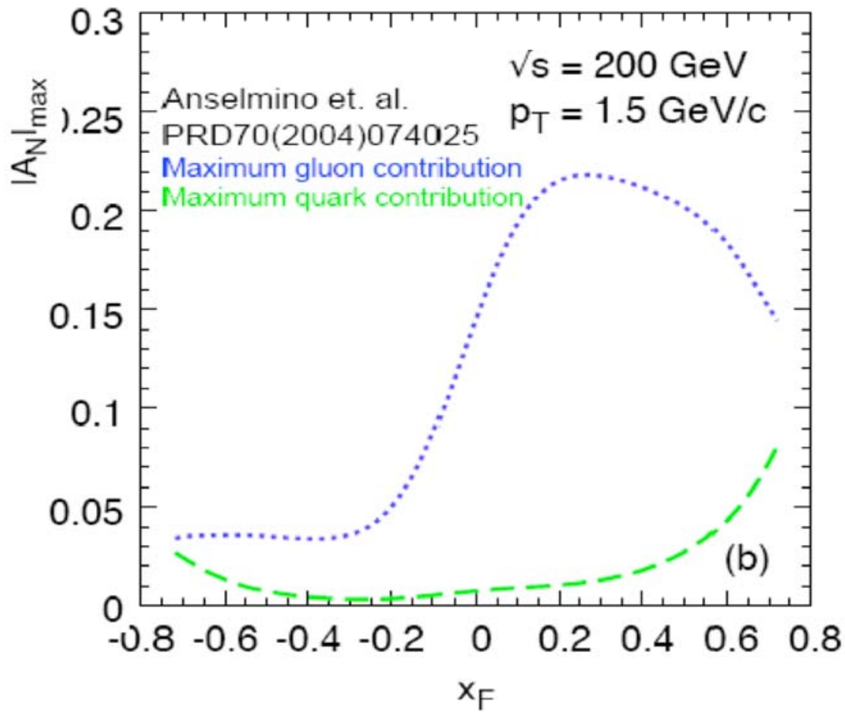






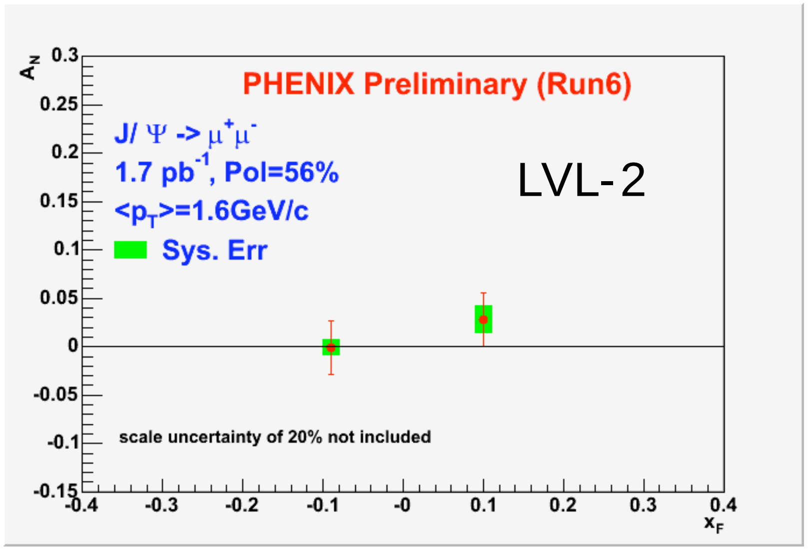
Prompt muons: A_N vs. x_F





Data constrain the gluon Sivers function to be significantly smaller than the maximal allowed

J/Ψ A_N vs. x_F

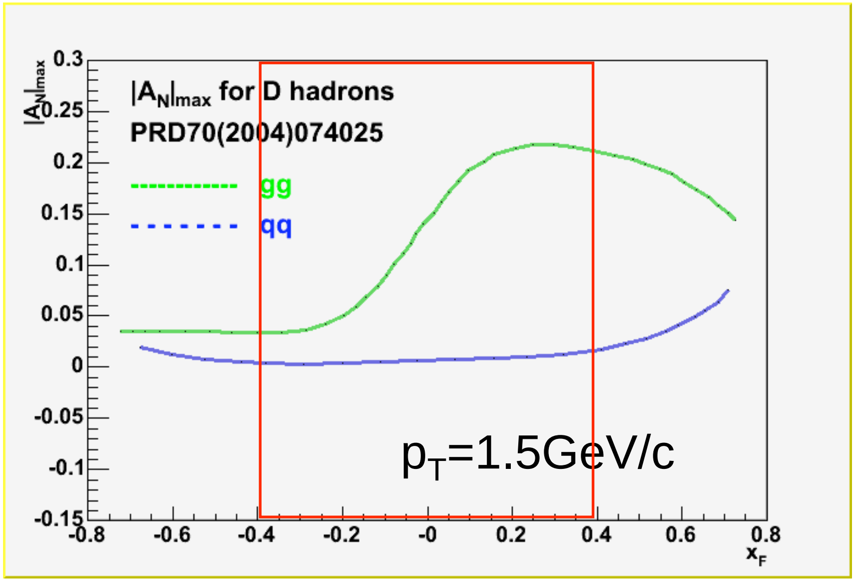


Theoretical prediction:

For open charm production

--quark Sivers function set to its maximum
gluon Sivers function set to 0

--gluon Sivers function set to its maximum
quark Sivers function set to 0



How does J/Ψ production affect prediction?