


# Measurement of Double Longitudinal Spin Asymmetry in Heavy Flavor Production at PHENIX



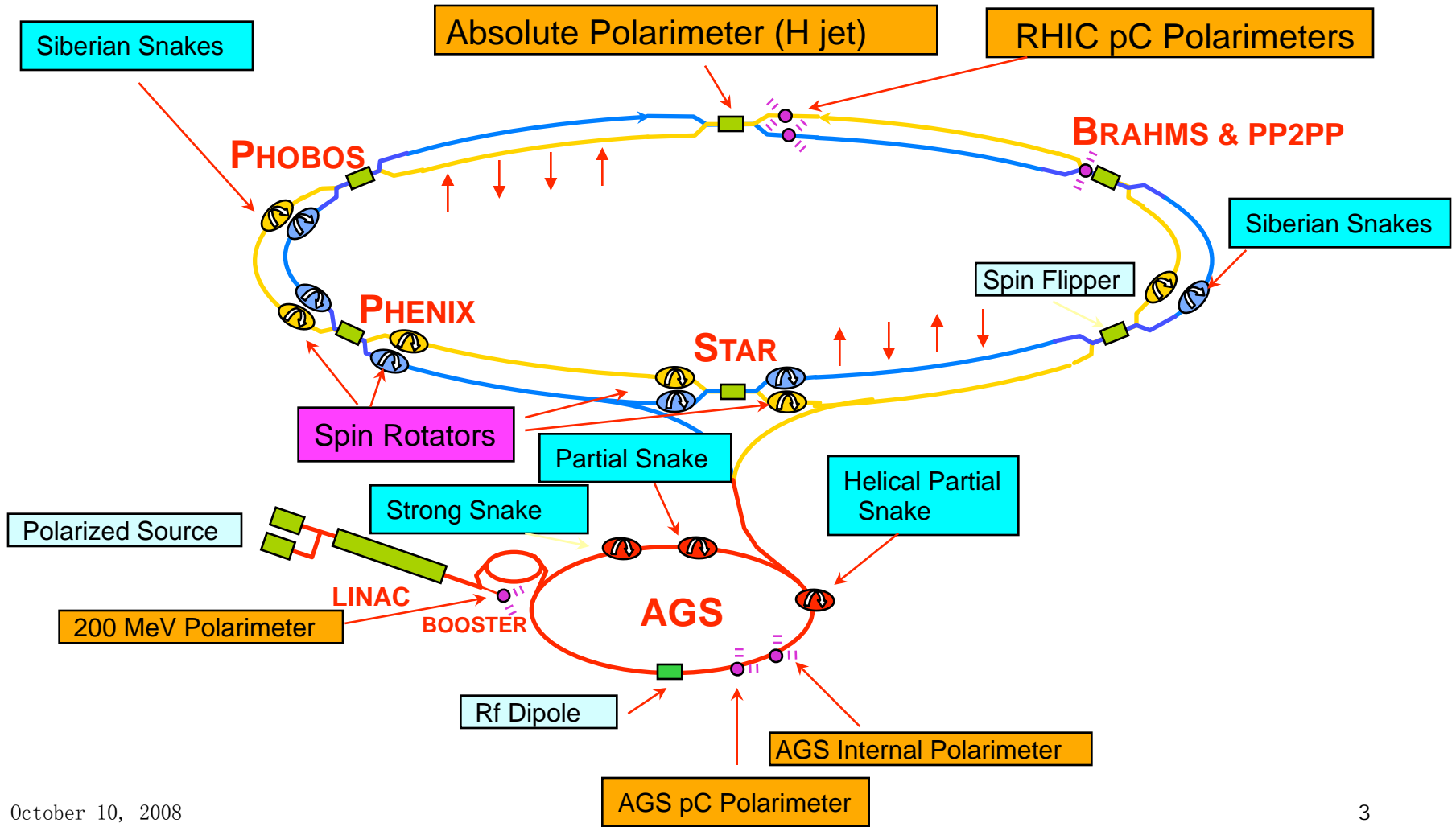
Xiaorong Wang  
New Mexico State University

# Outline

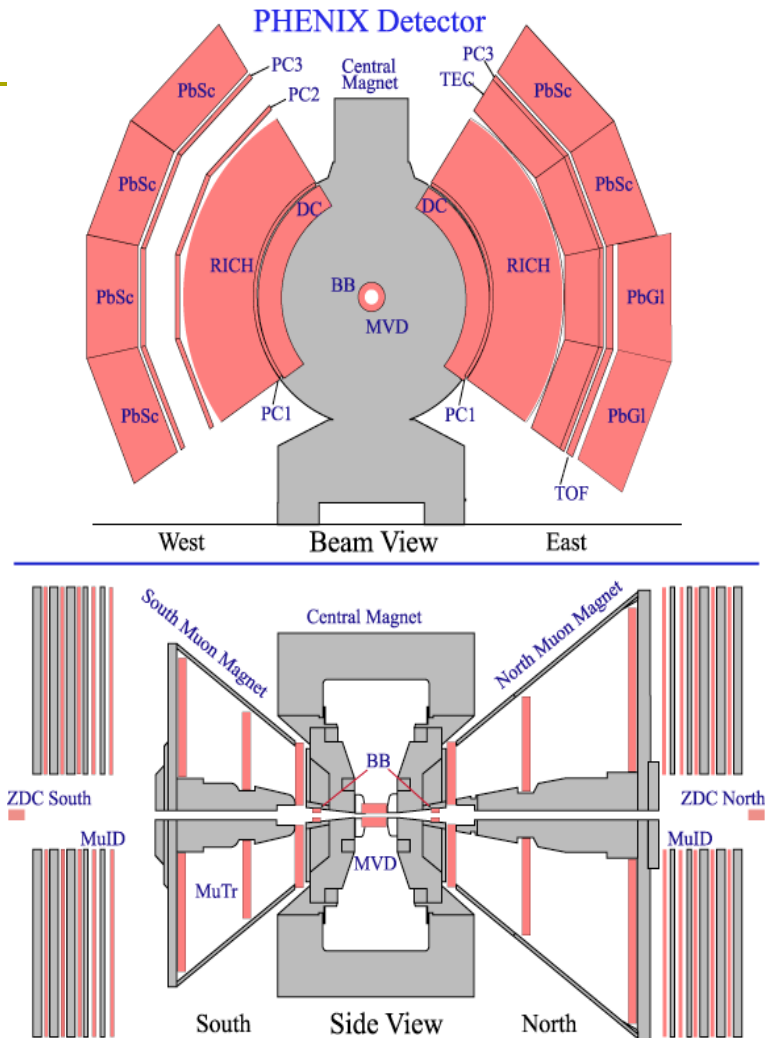
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- Introduction
- The PHENIX Experiment
- Heavy Flavor  $A_{LL}$  at 200GeV
  - $J/\psi$
  - $\mu^-$  from heavy flavor decay
- Summary and Outlook

# 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  $\Delta\phi\Delta\eta \sim 0.01 \times 0.01$
    - Trigger
- **Central Arm Particle Id**
  - RICH
    - electron/hadron separation
  - TOF
    - $\pi/K/p$  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
    - $\text{PbWO}_4$  Crystal
- **Forward Muon Arms**
  - South arm:  $-2.2 < \eta < -1.2$
  - North arm:  $1.2 < \eta < 2.4$

# Heavy Quark Production at PHENIX

➤ Sensitive to gluon polarization:  $\Delta g(x)$

➤ Gluon Fusion dominates at LO

PYTHIA estimate:

$$\sigma(gg \rightarrow Q\bar{Q}) : \sigma(q\bar{q} \rightarrow Q\bar{Q})$$

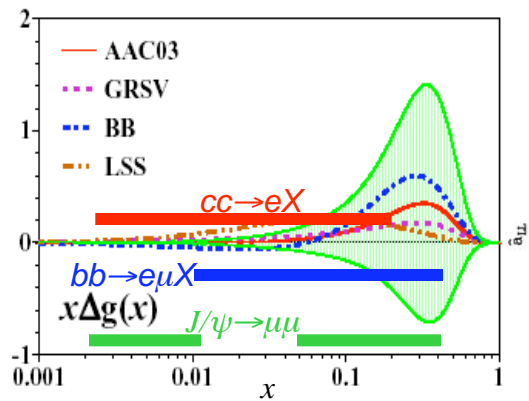
GeV	Charm	Beauty
200	95:5	85:15
500	97:3	92:8

Double spin asymmetry:

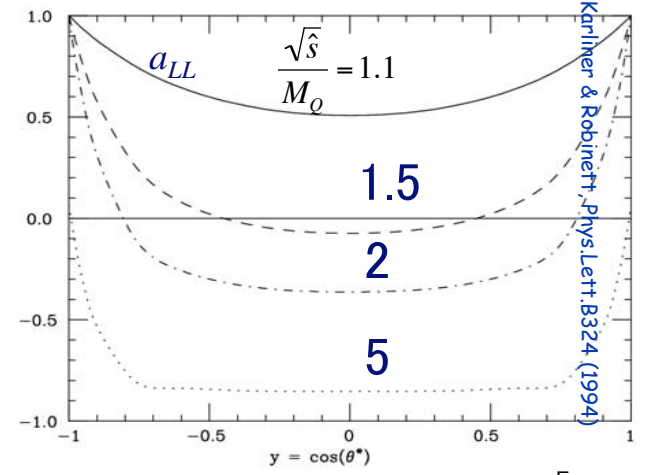
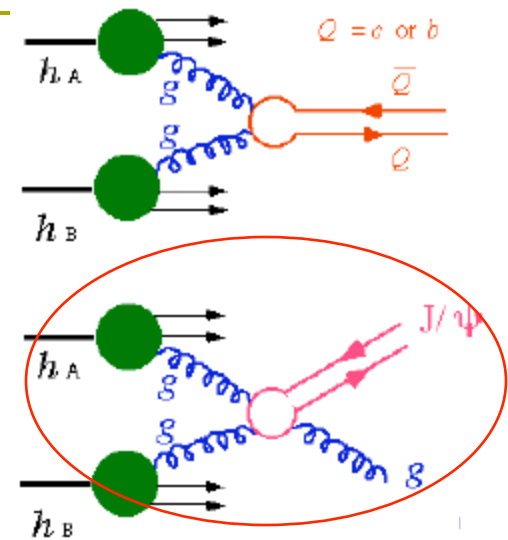
$$A_{LL} \approx \frac{\Delta g(x_1)}{g(x_1)} \frac{\Delta g(x_2)}{g(x_2)} a_{LL}^{gg \rightarrow Q\bar{Q}}$$

Decay modes:

$e^+e^-$ ,  $\mu^+\mu^-$ ,  $e\mu$ ,  $eX$ ,  $\mu X$



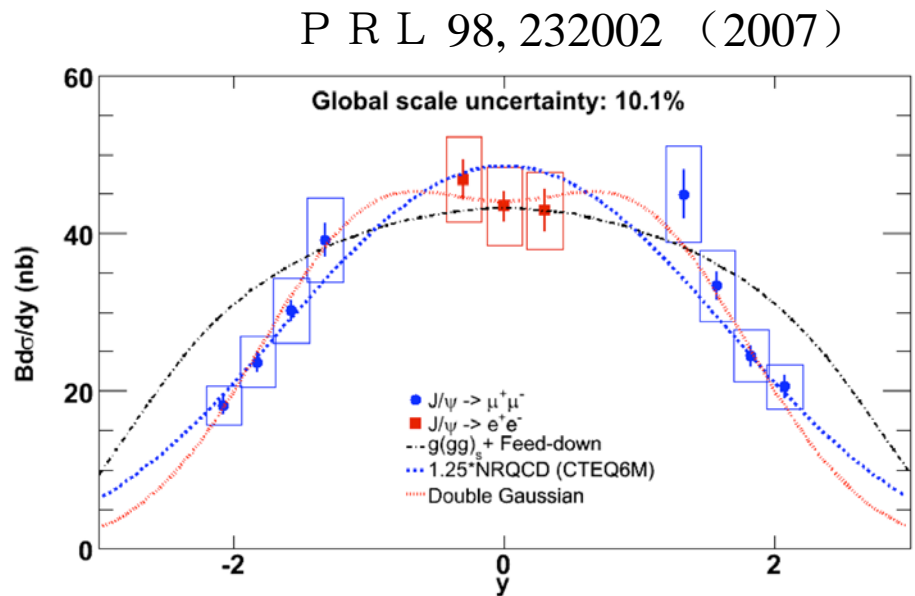
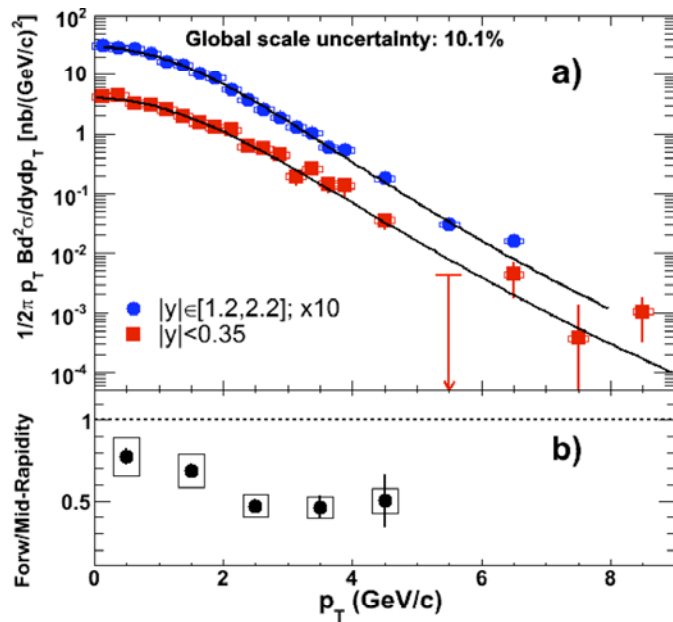
Gluon Fusion



# J/Psi

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# J/Psi: NRQCD and PHENIX data



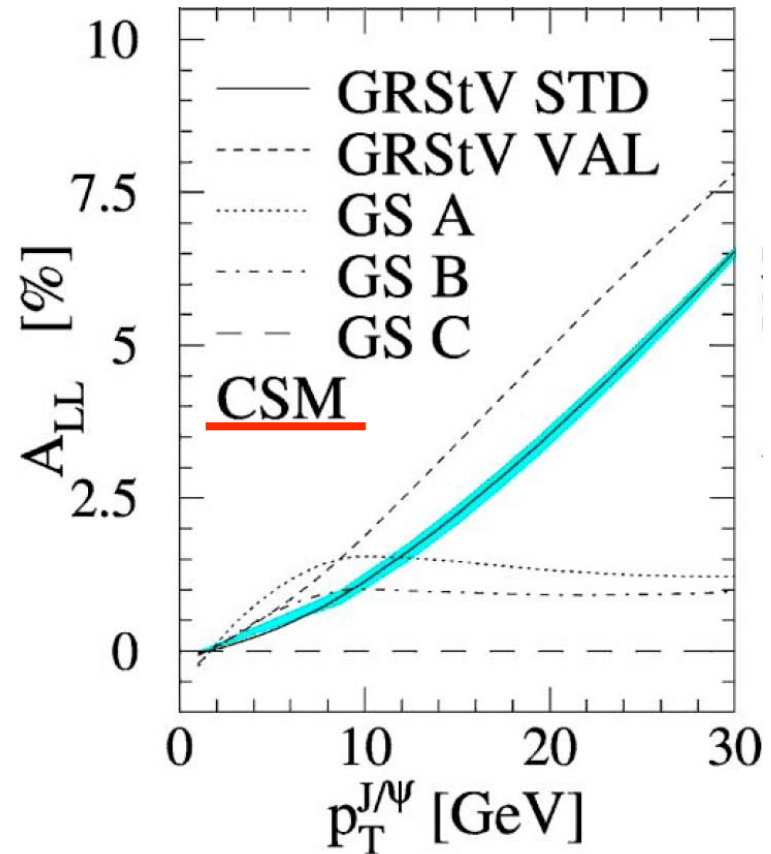
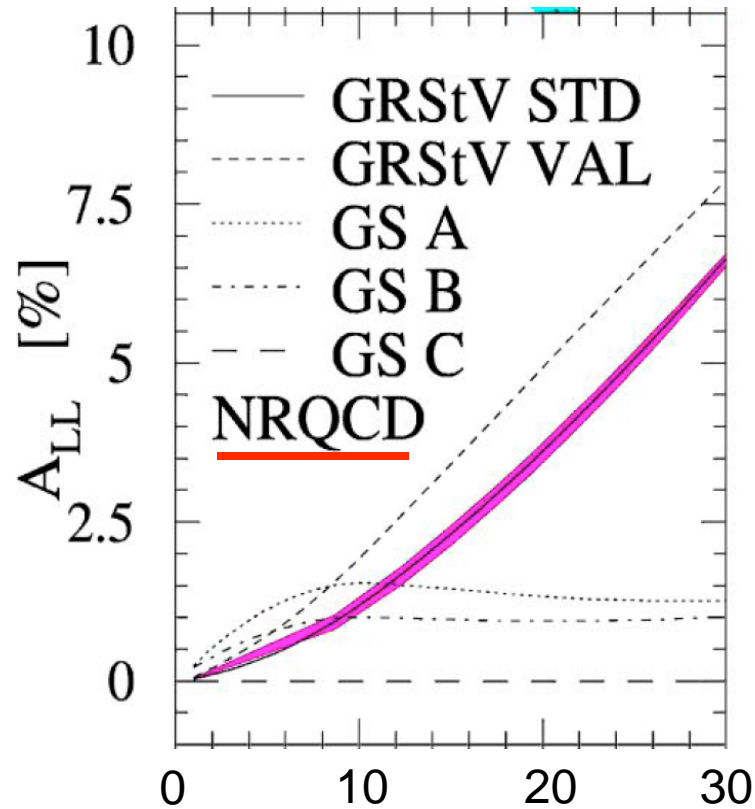
Theoretical predictions of  $J/\Psi$  production at RHIC are in good agreement with the PHENIX data: **COM process dominant**

- 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

# $A_{LL}$ : NRQCD and CSM

PRD 68, 034017(2003)



Not very sensitive to “fragmentation” processes



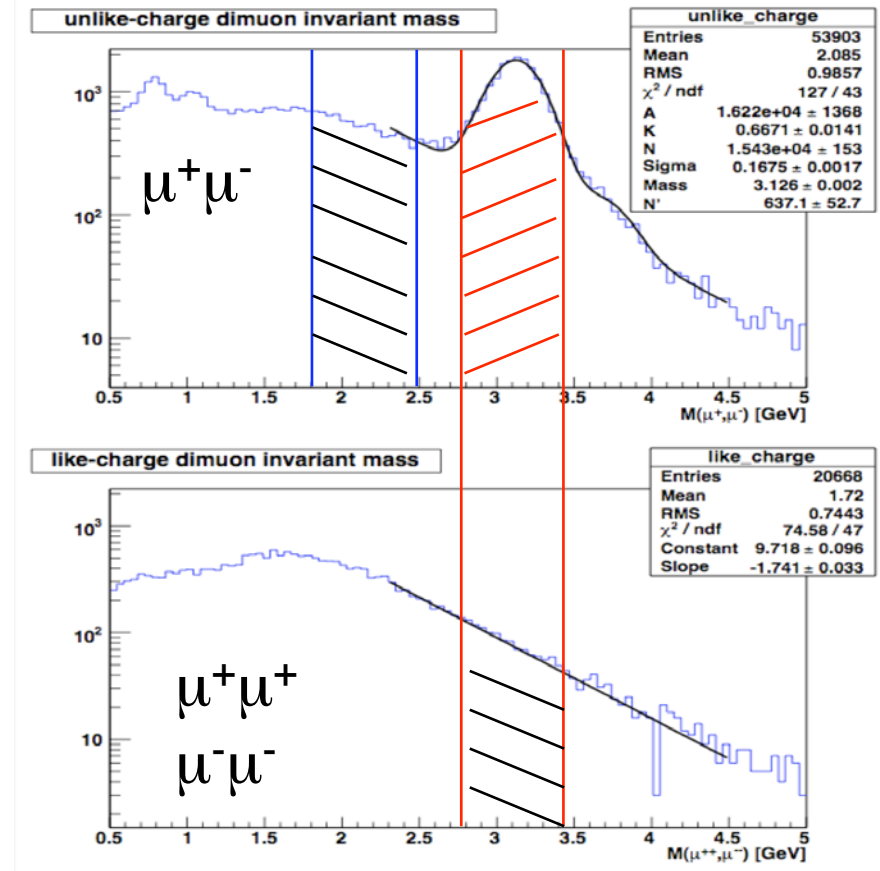
# J/Psi $A_{LL}$ Measurement

- Inclusive J/Psi events
- Background estimation
  - S/B ~ 6
- Fill-by-fill, beam pol from CNI
- GL1P scalers for ReLumi
  - BBC\_in

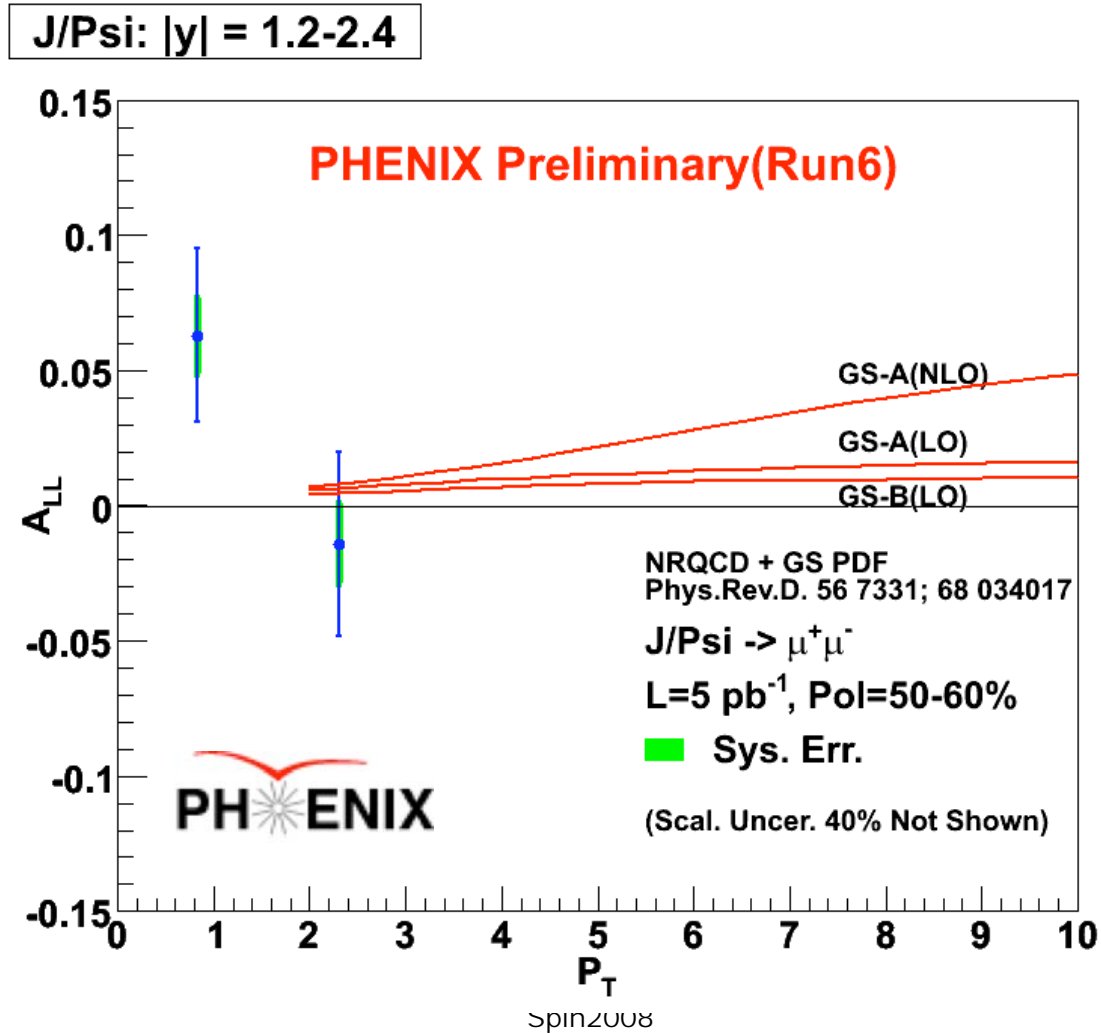
$$A_{LL}^{incl(BG)} = \frac{1}{\langle P_B \rangle \langle P_Y \rangle} \frac{N^{++} - R \cdot N^{+-}}{N^{++} + R \cdot N^{+-}}$$

$$A_{LL}^{J/Psi} = \frac{A_{LL}^{incl} - f_{BG} \cdot A_{LL}^{BG}}{1 - f_{BG}}$$

$$\delta A_{LL}^{J/Psi} = \frac{\sqrt{(\delta A_{LL}^{incl})^2 + f_{BG}^2 \cdot (\delta A_{LL}^{BG})^2}}{1 - f_{BG}}$$

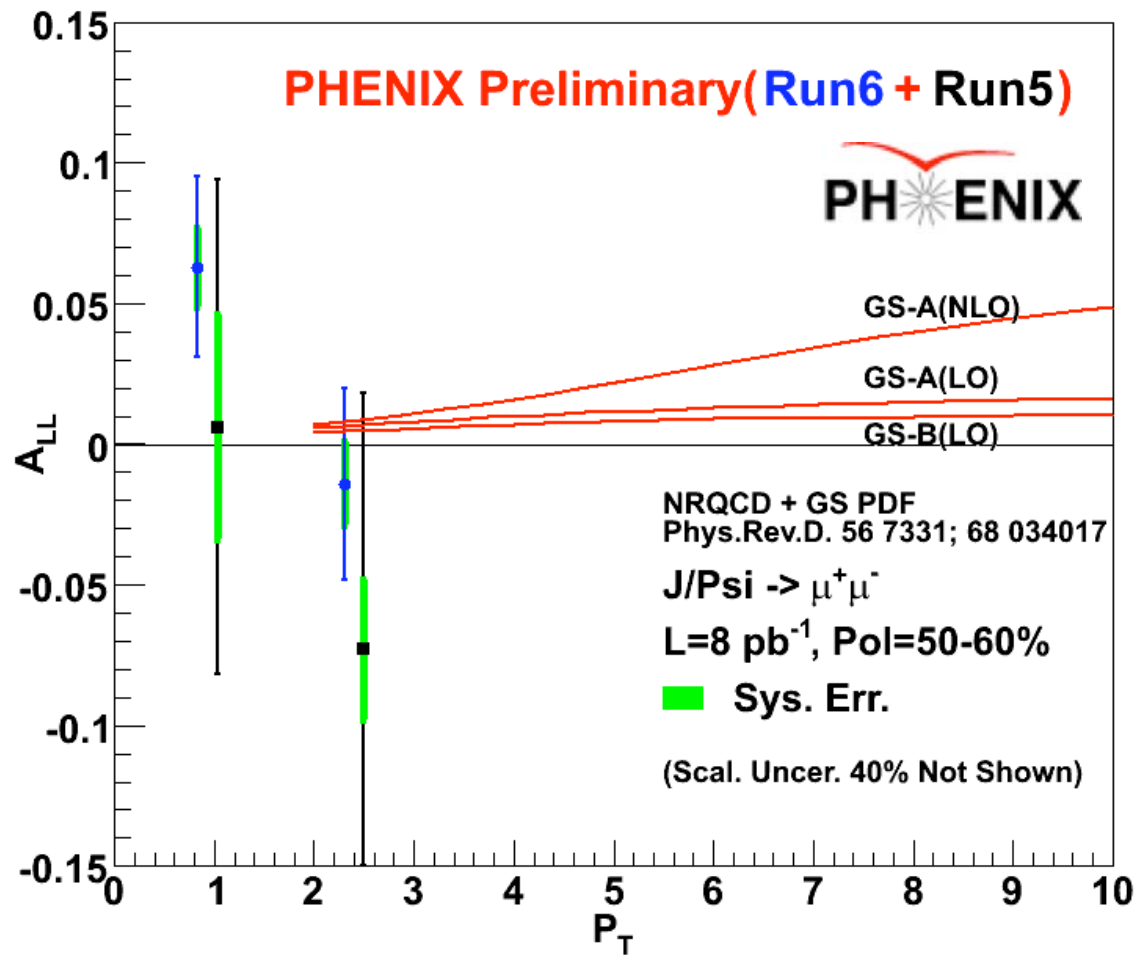


# J/ $\Psi$ $A_{LL}$ from Run6



# J/ $\Psi$ $A_{LL}$ from Run5+6

J/Psi:  $|y| = 1.2-2.4$



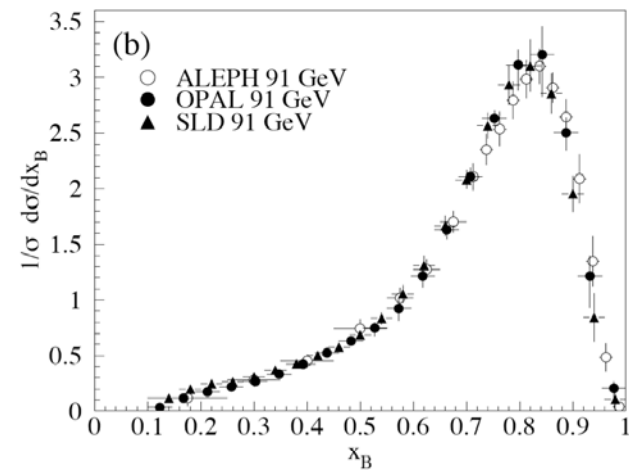
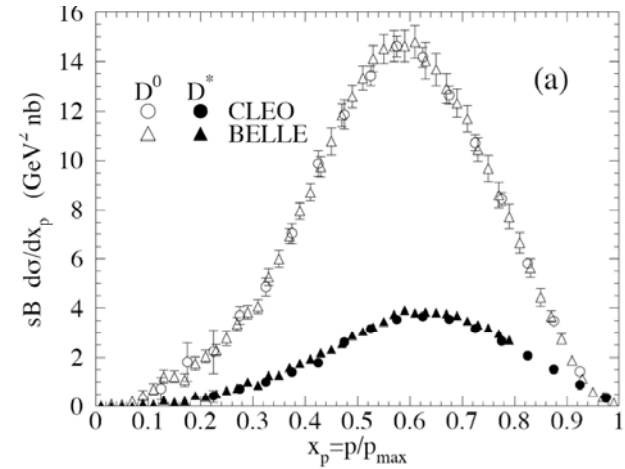
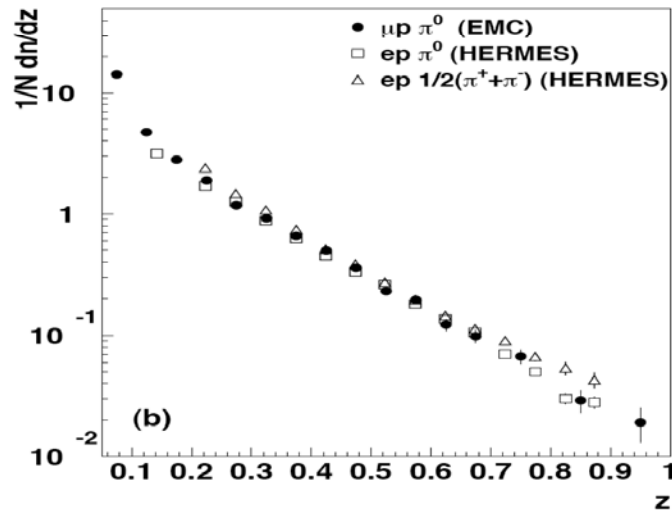
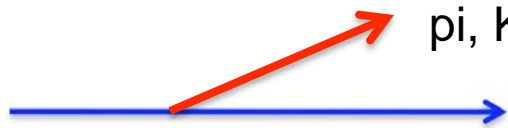
# Open Heavy Flavor

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# Open Heavy Quark Production: hard fragmentation function

- very different from Light hadrons  
Carry most of initial quark's energy,

$$E_B \sim 80\% \cdot E_{b-jet}$$



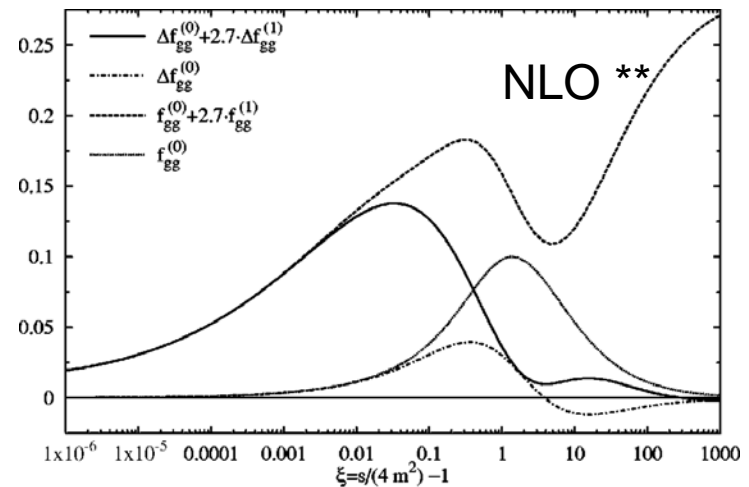
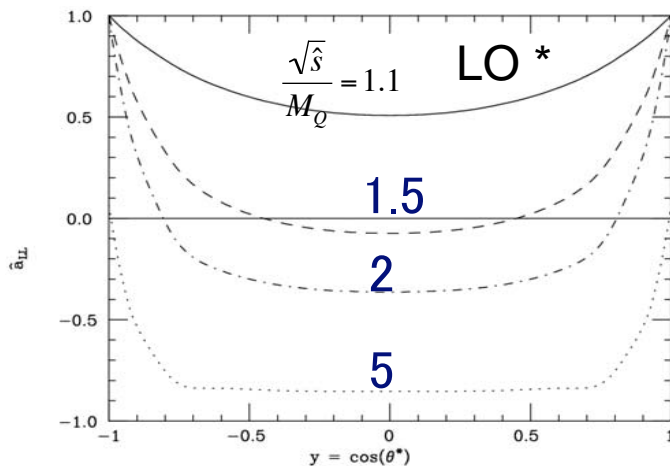
# Open Heavy Quark $A_{LL}$ Calculations

## □ LO calculations

- Phys. Lett. B 246, 523 (1990) A.P. Contogouris et al.
- Phys. Lett. B 324, 209 (1994) M. Karliner and R.W. Robinet(\*)

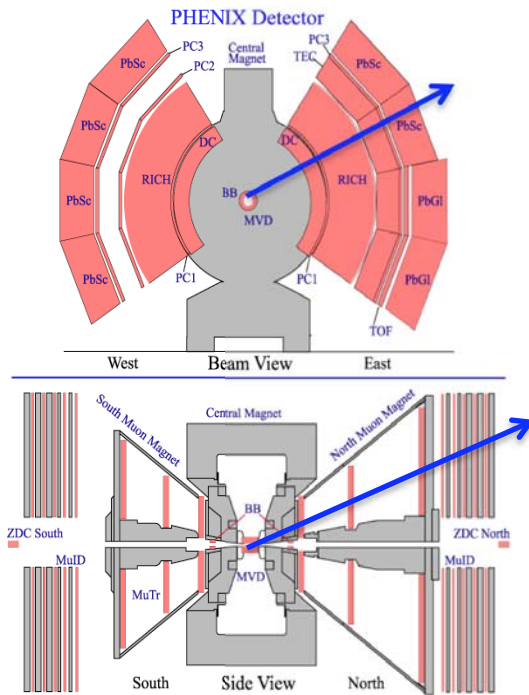
## □ NLO calculations

- PRD 67, 034010 (2003) I.Bojak and M. Stratmann(\*\*)



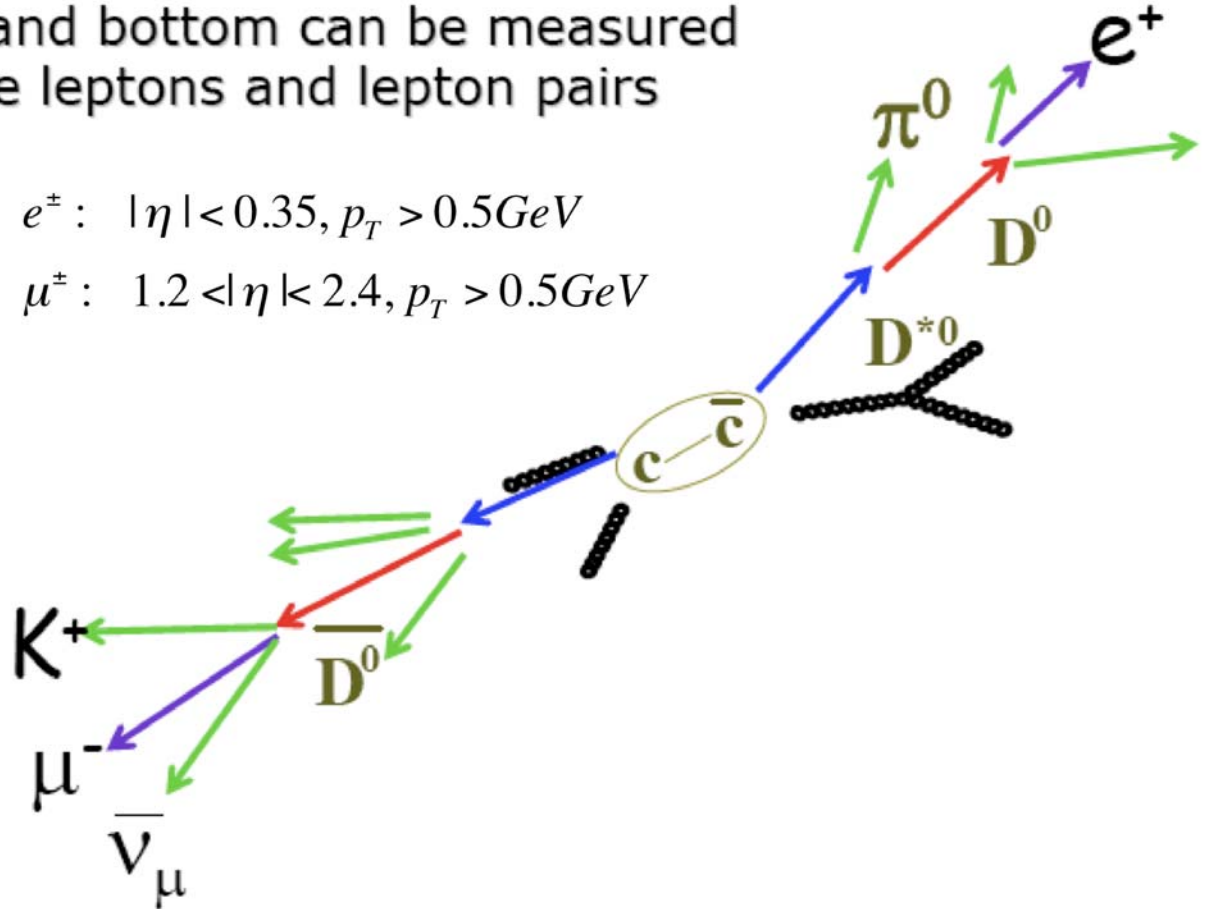
# Open heavy flavor via semi-leptonic decays

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

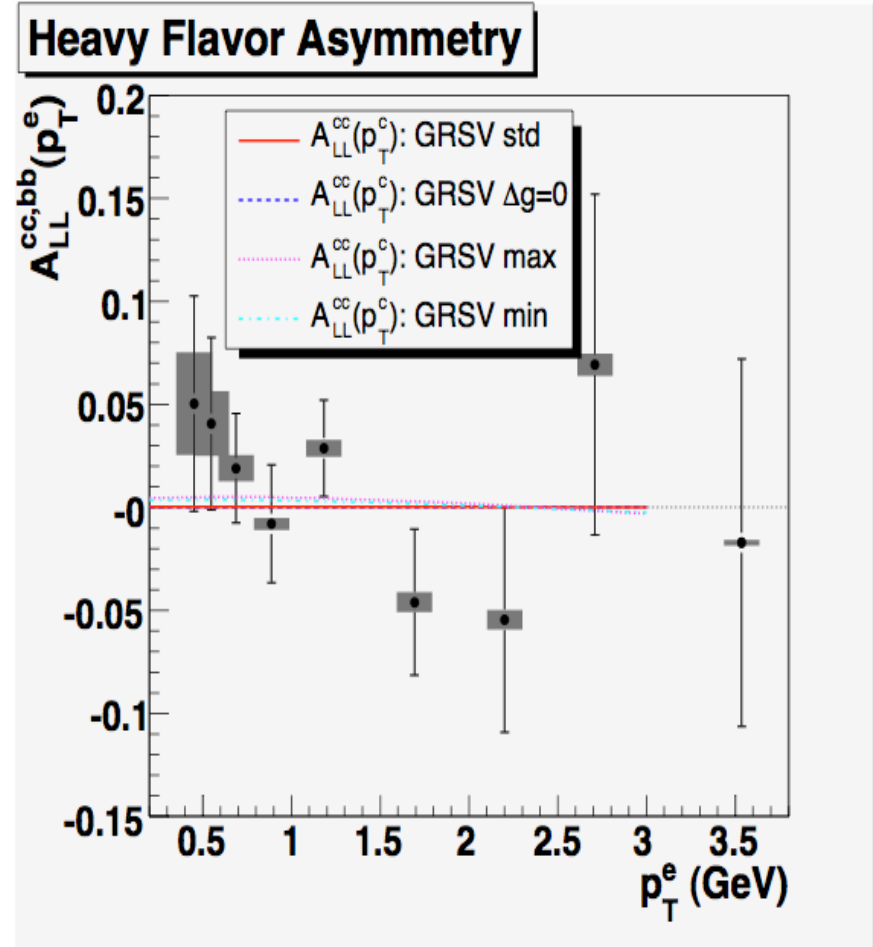
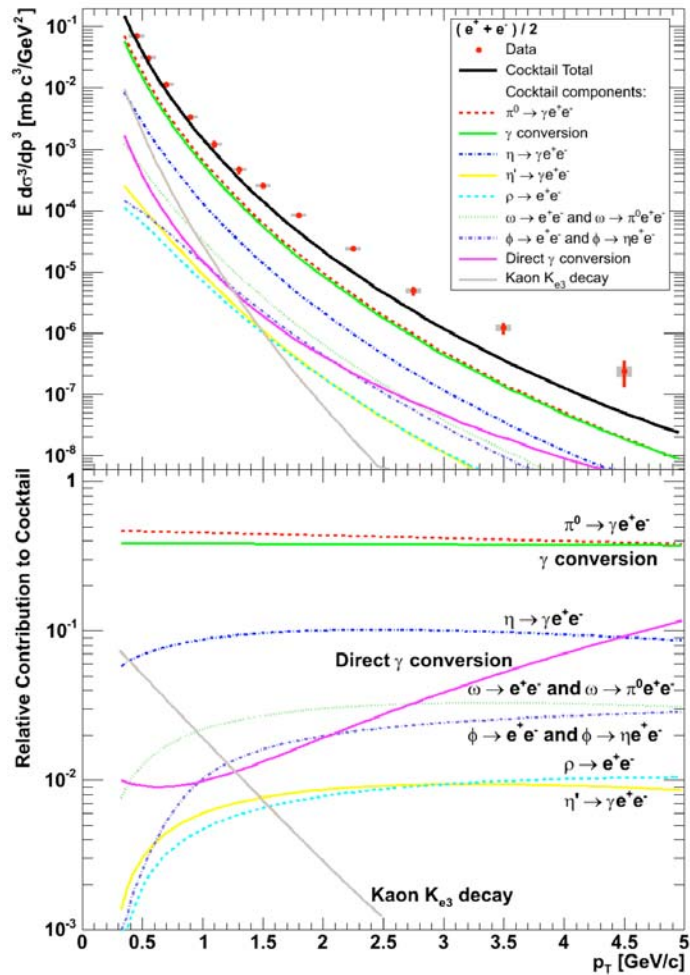


$$e^\pm : |\eta| < 0.35, p_T > 0.5 \text{ GeV}$$

$$\mu^\pm : 1.2 < |\eta| < 2.4, p_T > 0.5 \text{ GeV}$$



# $A_{LL}$ vs. $p_T$ through electron channel





# Muon Track Candidates in the Muon Spectrometer

$$1.2 < |\eta| < 2.4$$

$$\Delta\phi = 2\pi$$

$$P > 2\text{GeV}/c$$

Candidate Tracks:

Prompt Muons

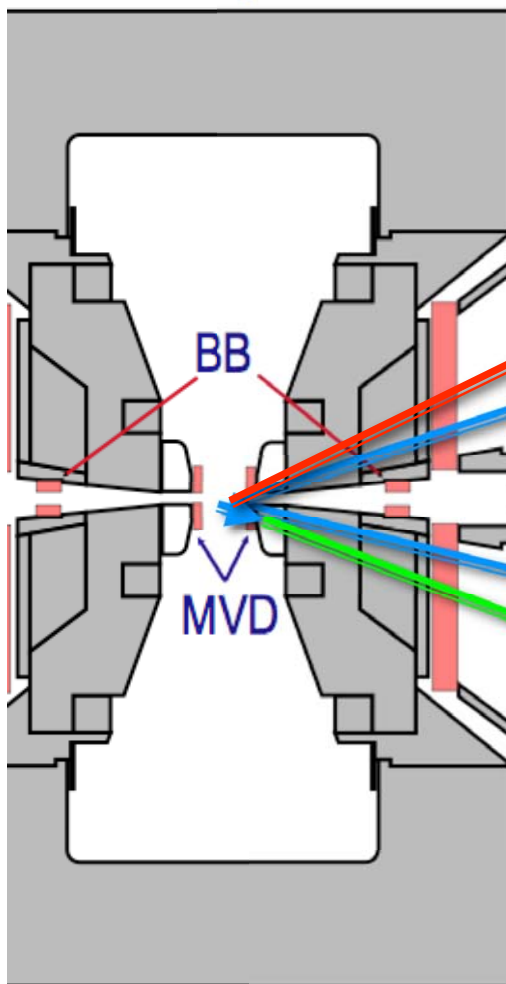
Punch-through hadrons

Stopped hadrons

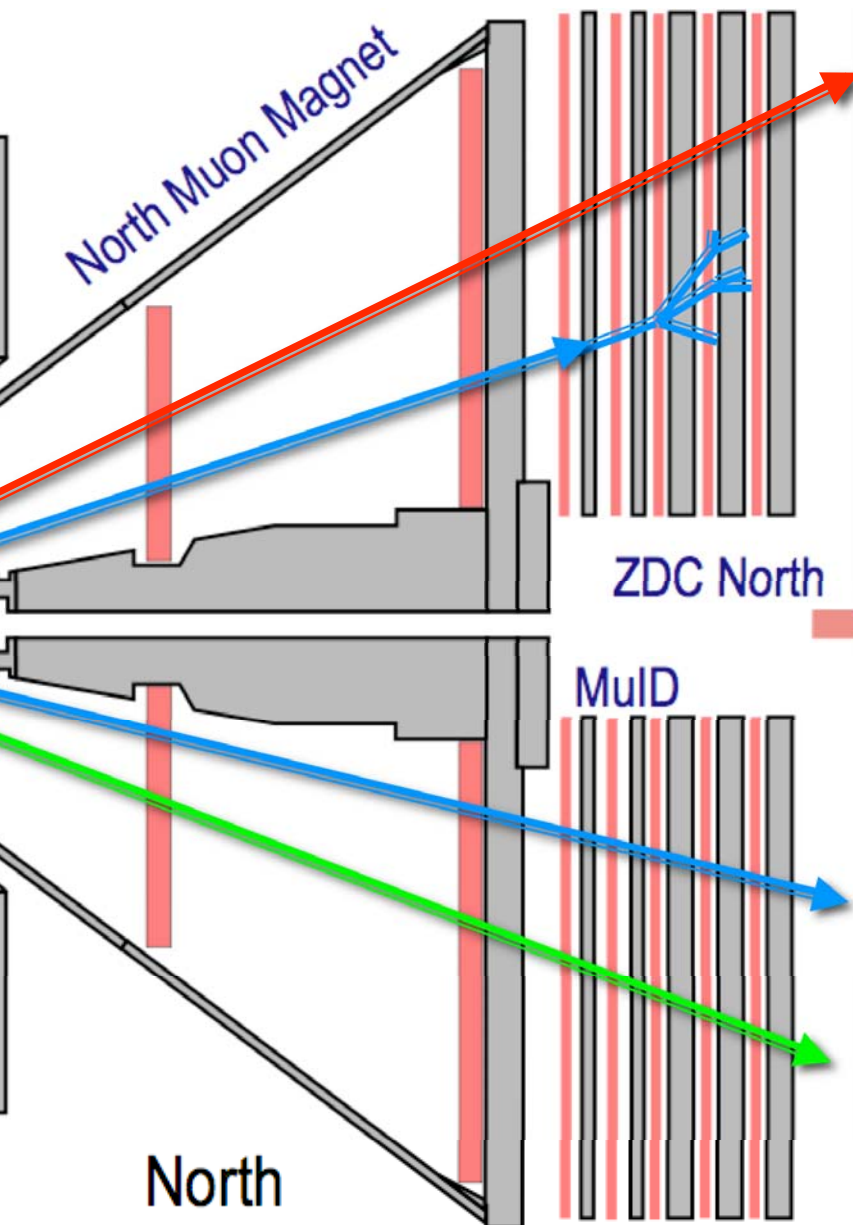
Decay muons

Central Magnet

North Muon Magnet



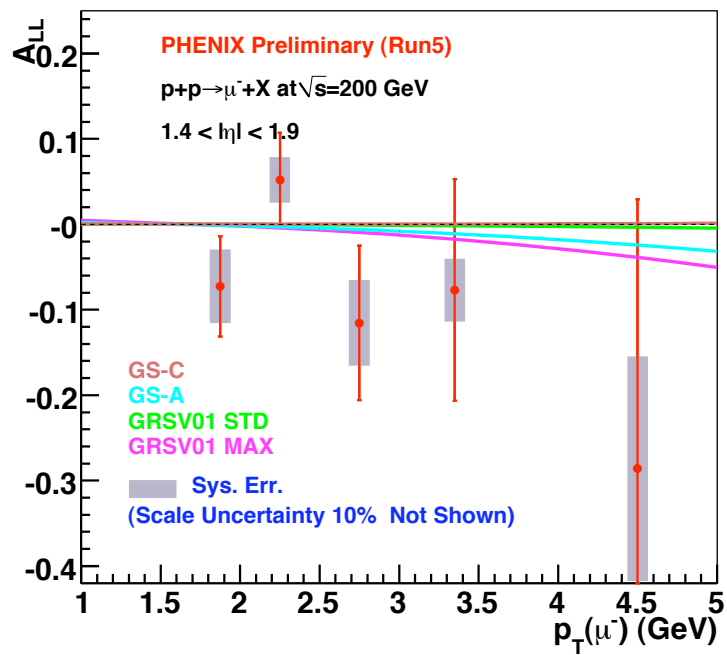
Side View



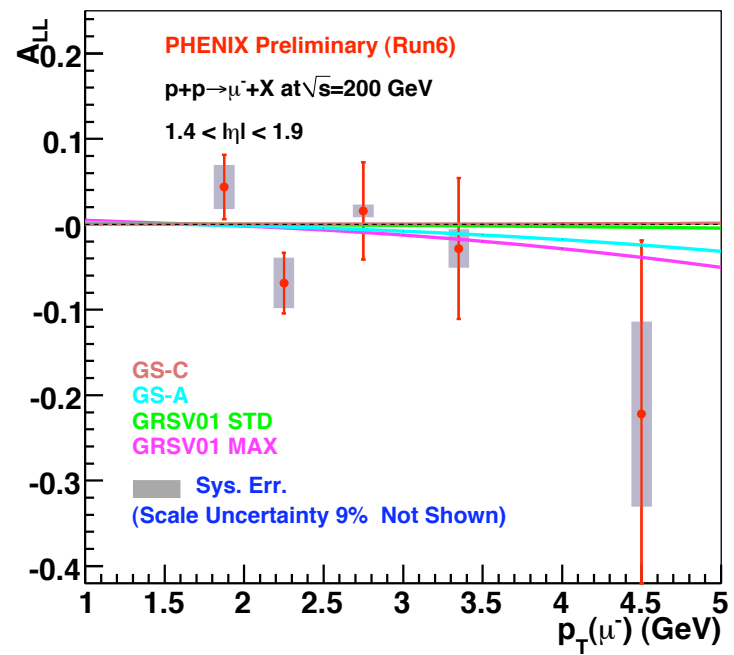
North

# $A_{LL}$ vs. $p_T$

$A_{LL}$  vs  $p_T$  (Prompt  $\mu^-$ )



$A_{LL}$  vs  $p_T$  (Prompt  $\mu^-$ )



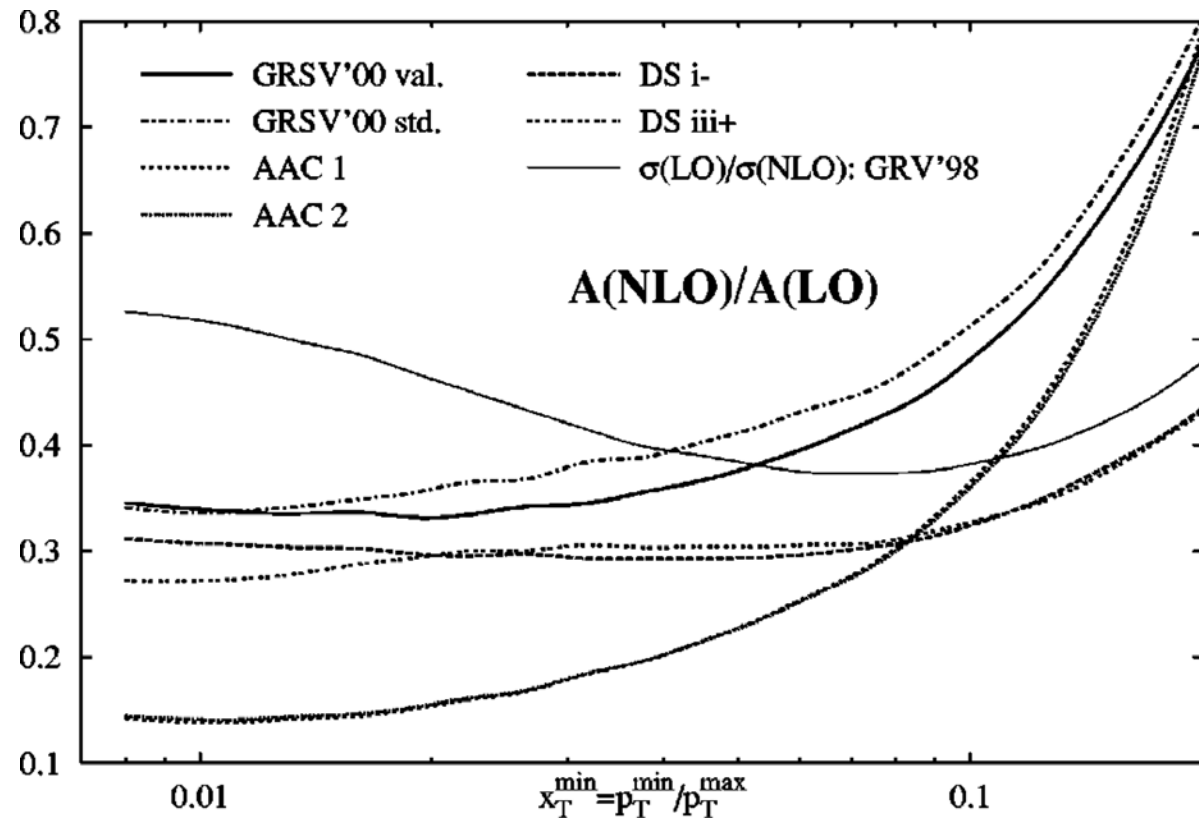
Current measurements are statistically limited. The can not constrain the gluon polarization.

# About $A_{LL}$ NLO/LO

□ At central arm  $y = 0$

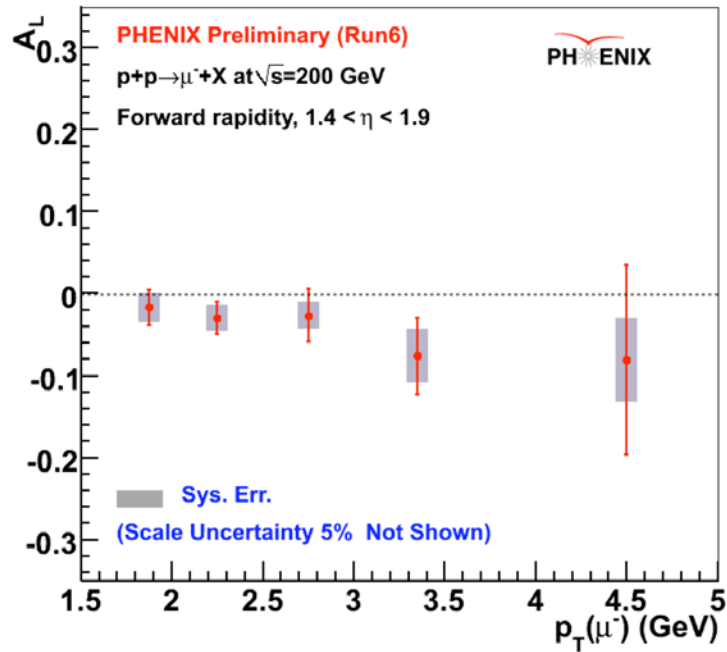
PRD 67 034010 (2003) Bojak & Stratmann

$$A_{LL} = \frac{\Delta\sigma}{\sigma}$$

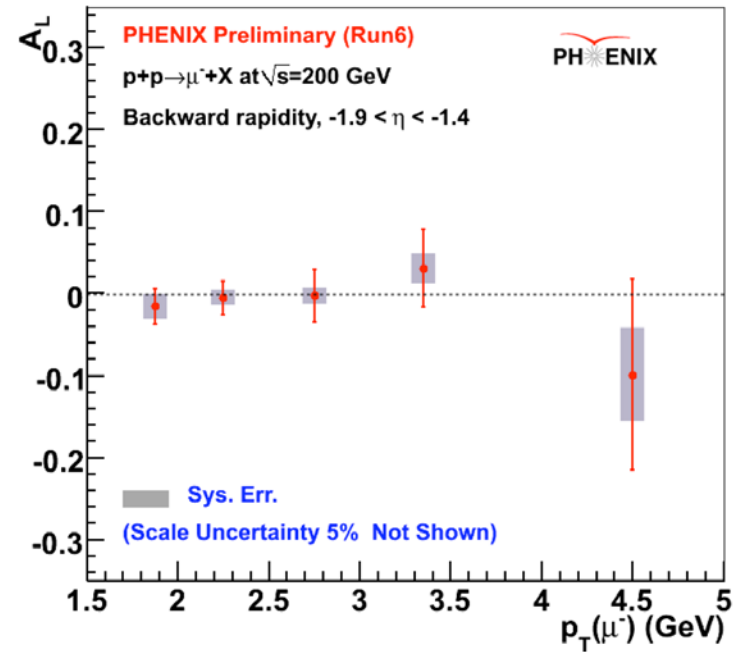


# $A_L$ vs. $p_T$ in the forward and backward rapidities

$A_L$  vs  $p_T$  (Prompt  $\mu^-$ )

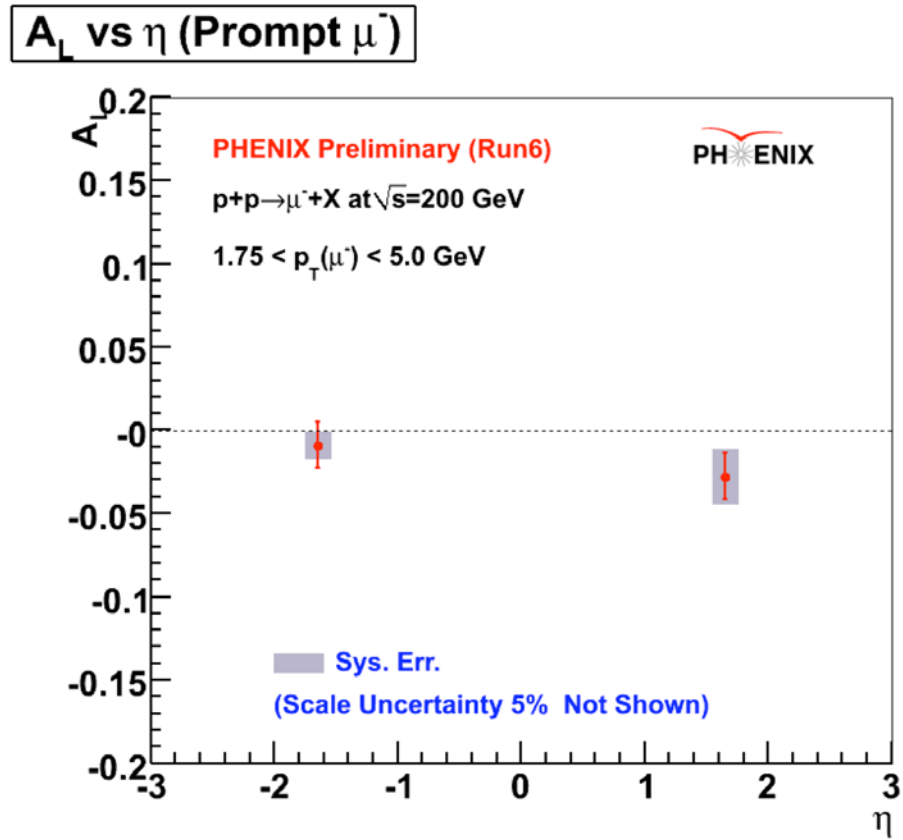


$A_L$  vs  $p_T$  (Prompt  $\mu^-$ )

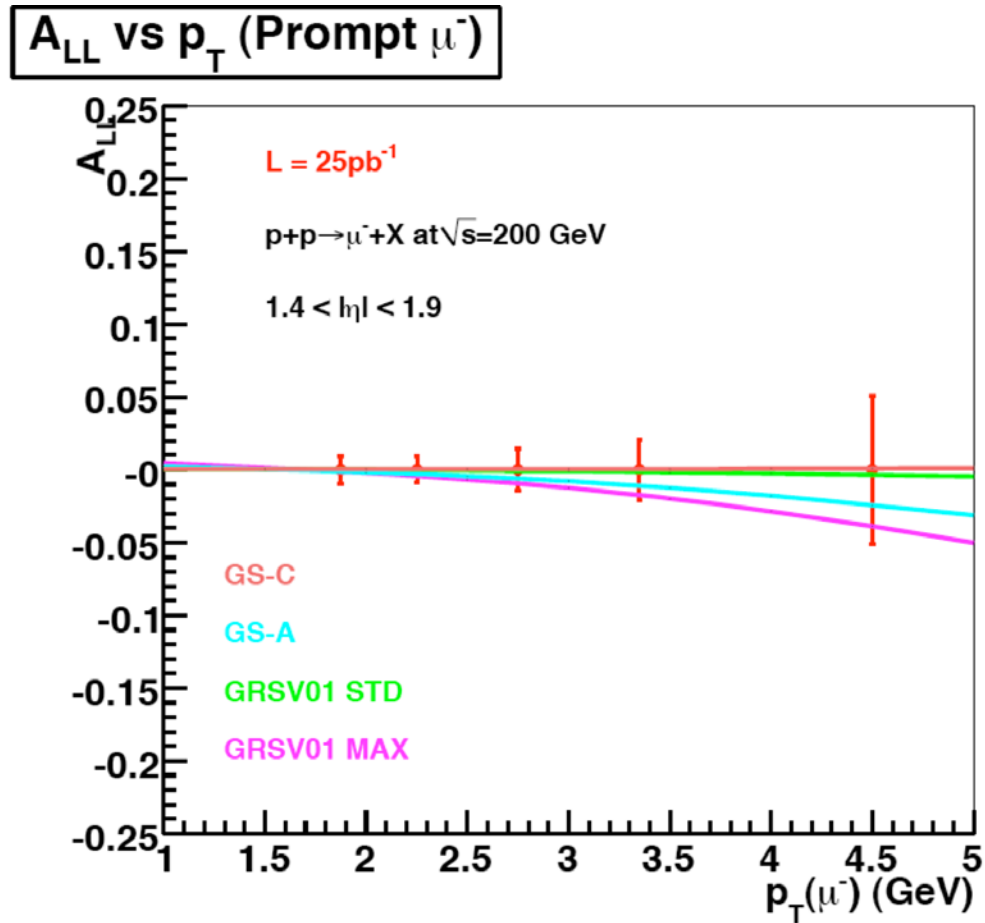


Import for future W measurements

# $A_L$ vs. $\eta$



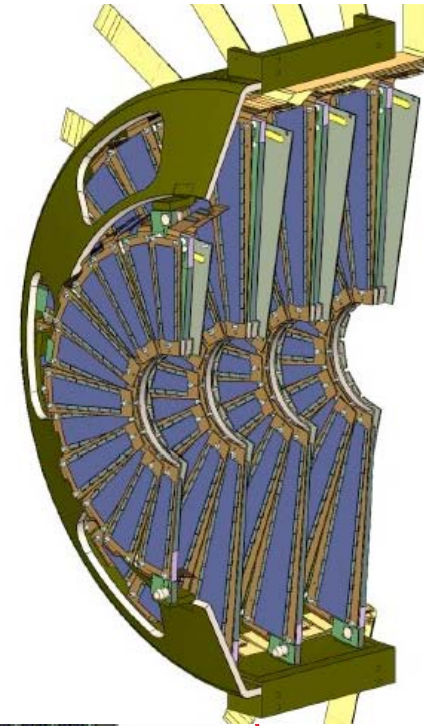
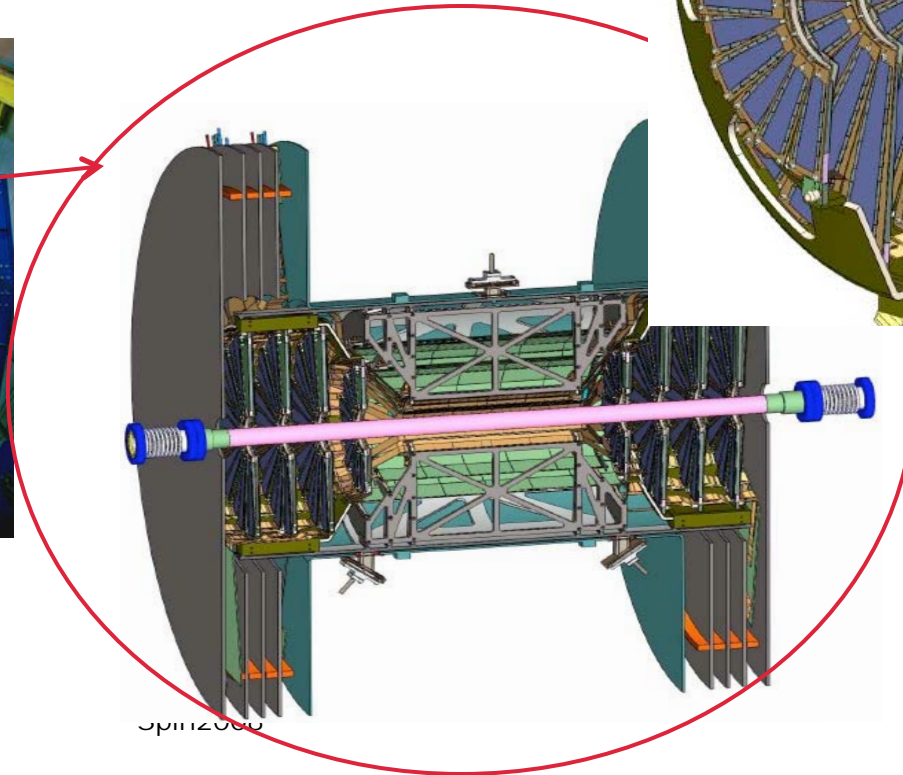
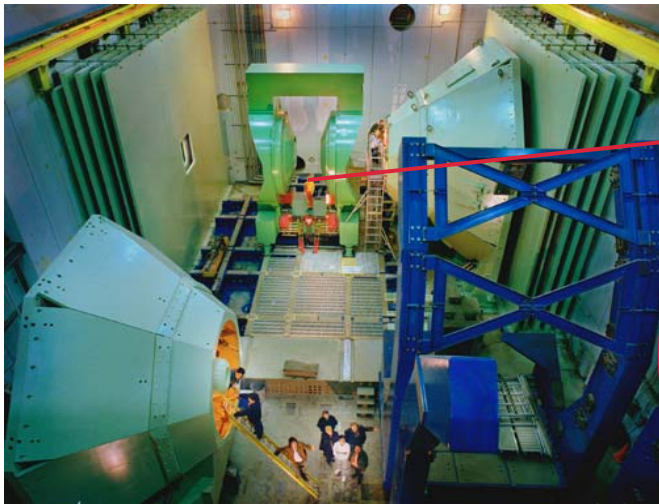
# Projection for Run9



# Forward Silicon VerTeX Detector for PHENIX

Four Layers of silicon mini-strips, covering Muon Arms

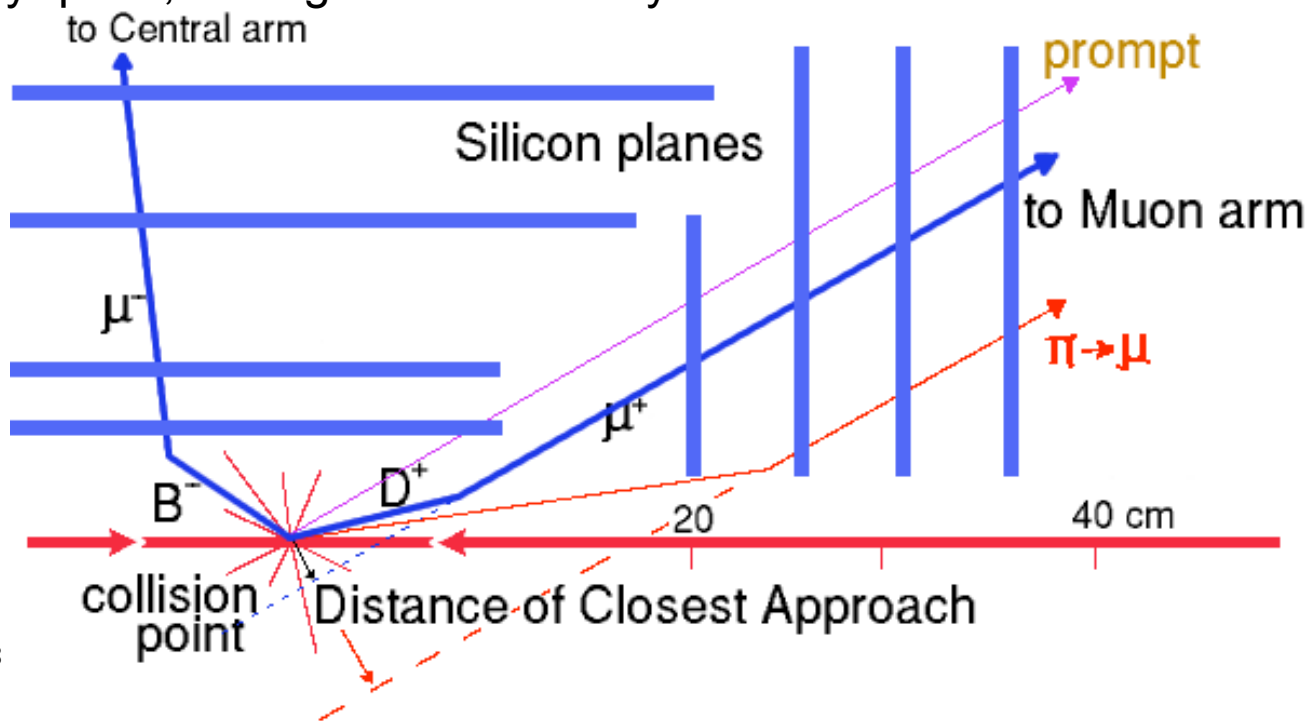
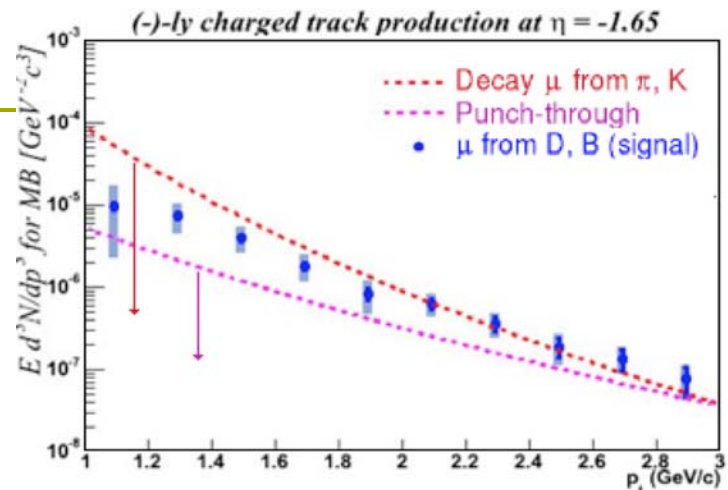
- $1.2 < \eta < 2.2$
- 1.1 million mini-strips
- **Strip size:  $75 \mu\text{m}$  in  $r$  and  $3.75^\circ$  in  $\phi$**



# FVTX detector performance

**The problem:** backgrounds ( $\pi \rightarrow \mu, e$  and  $K \rightarrow \mu, e$ ) overwhelm the signal

**Solution:** Average  $\sim 100 \mu\text{m}$  resolution in  $r$  and  $\sim 300 \mu\text{m}$  resolution in  $\phi$ , sufficient resolution to separate prompt, heavy quark, and light meson decays.

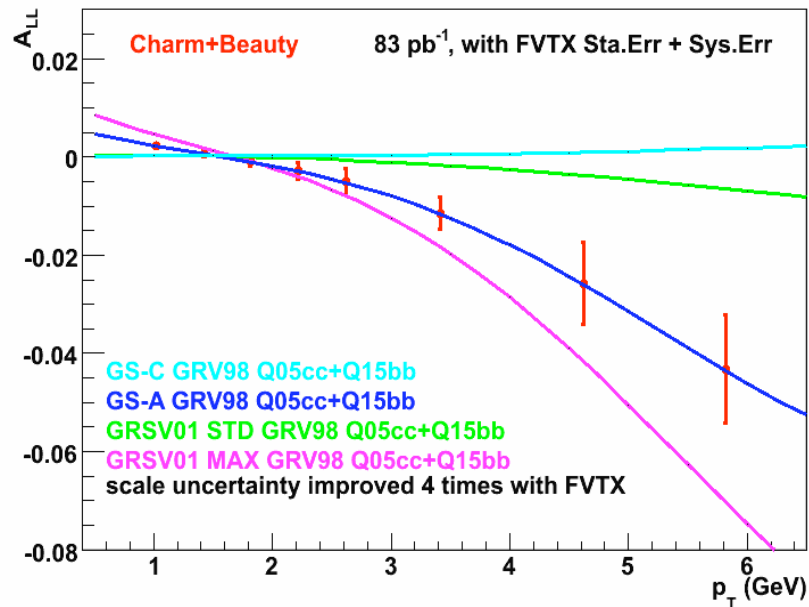




# $A_{LL}$ with FVTX

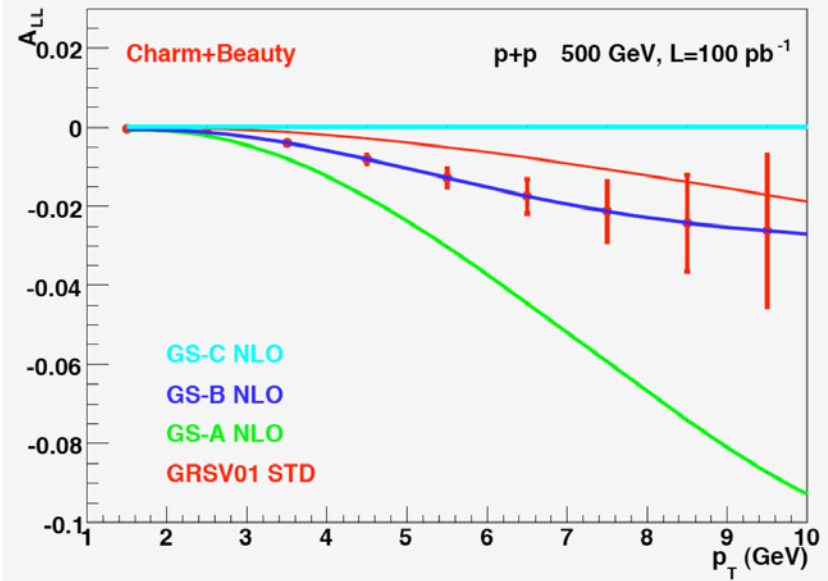
200GeV

$A_{LL}^{H^-}$  Tot. Err. with FVTX



500GeV

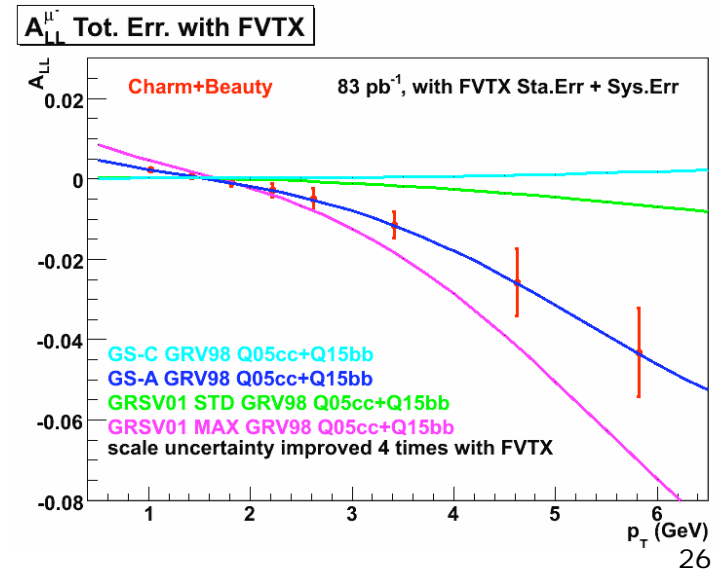
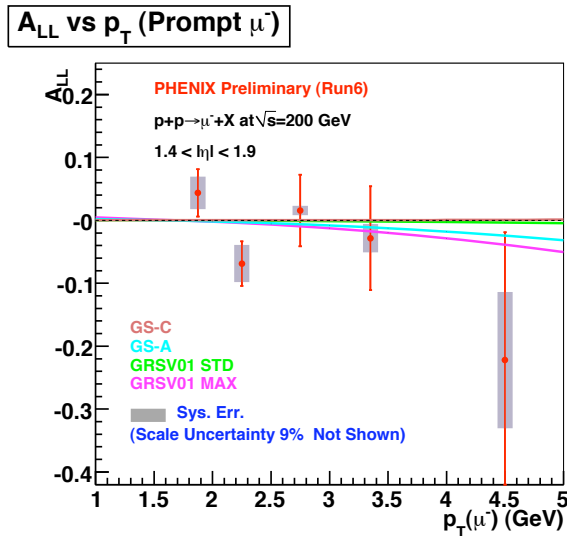
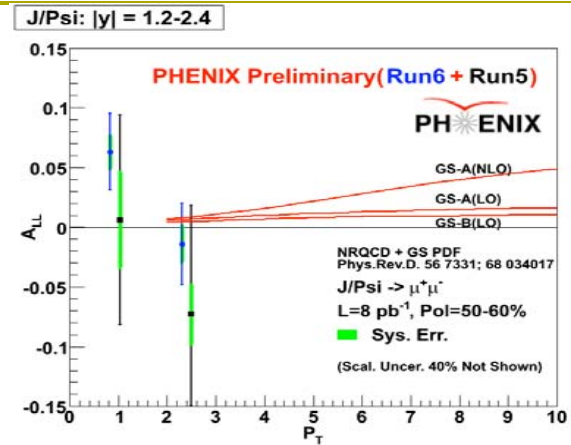
$A_{LL}^{H^-}$  Sta Err.



With FVTX, measurements will put constrain on the gluon polarization

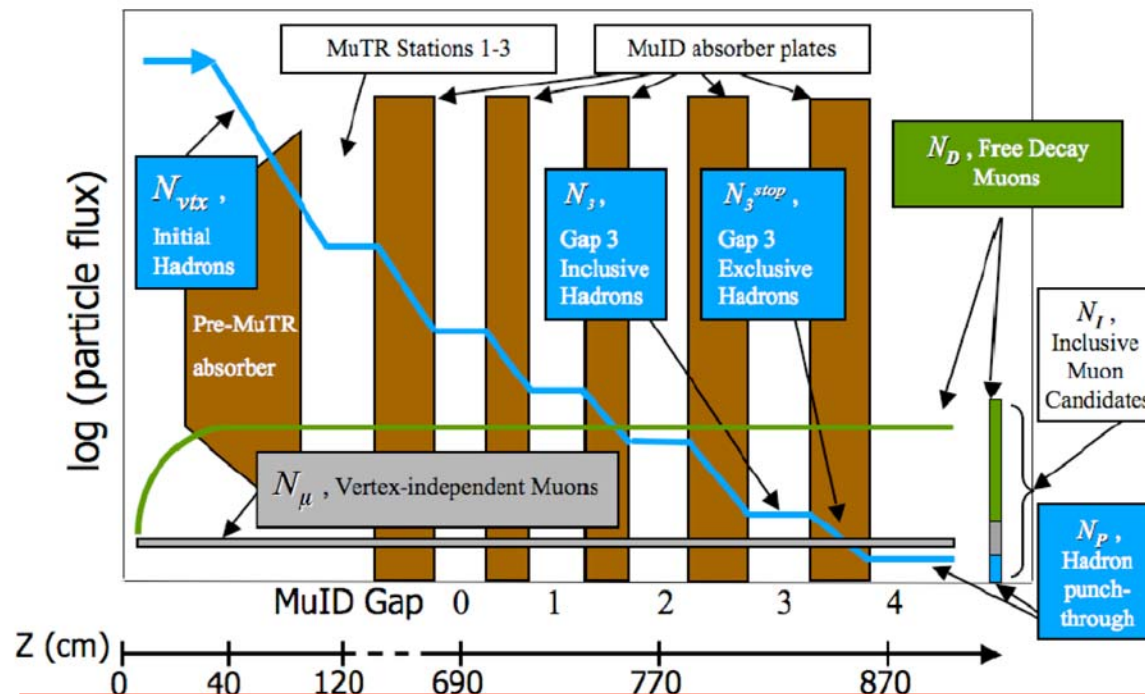
# Summary and Outlook

- First measurement of gluon polarization with  $J/\Psi$  and high  $p_T$  single muons and electrons in polarized  $p+p$  collisions at 200GeV
- Promising heavy flavor spin measurement with FVTX upgrade
- NLO calculations needed for PHENIX acqpt.



# Prompt muons from open heavy flavor decay

Cartoon depiction of the relative flux of particles in the PHENIX muon arm



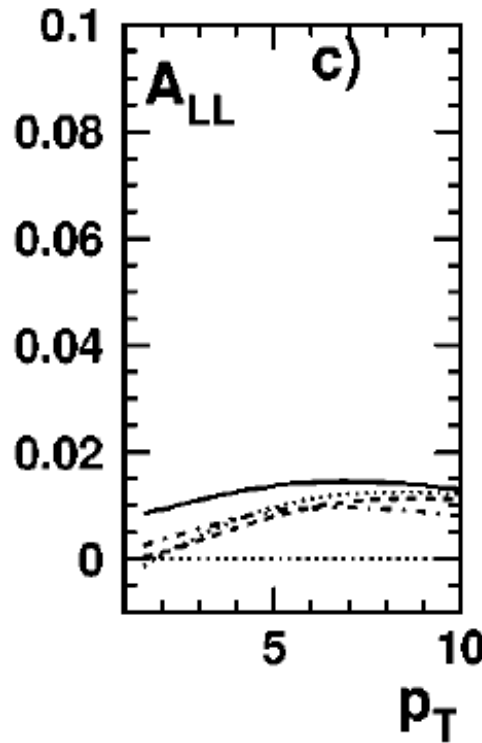
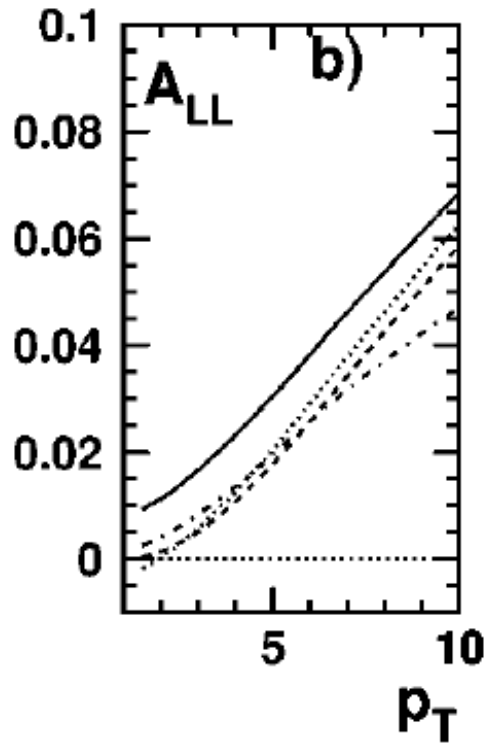
- $p_T < 3\text{GeV}$ , decay muons dominant and exhibit a well known linear z-vertex dependence
- $p_T > 3\text{GeV}$ , punch through hadrons dominate and can not be directly distinguished from prompt muons

# $A_{LL}$ and J/Psi Production @RHIC

GS-A(NLO)

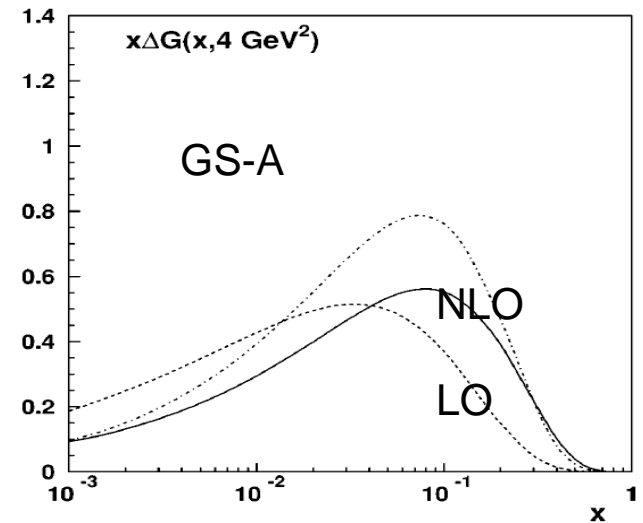
GS-A(LO)

PRD 56,7331(1997)



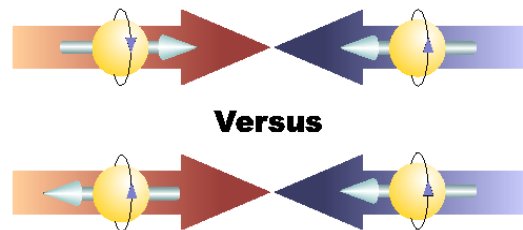
Solid =  $^1S_0^{(8)}$   
 Dashed =  $^3P_J^{(8)}$   
 Dash-dot =  $^3S_1^{(8)}$   
 Dotted = CSM

- Sensitive to gluon polarization distr.
- Good "x" measurement
- Weak process-dependence

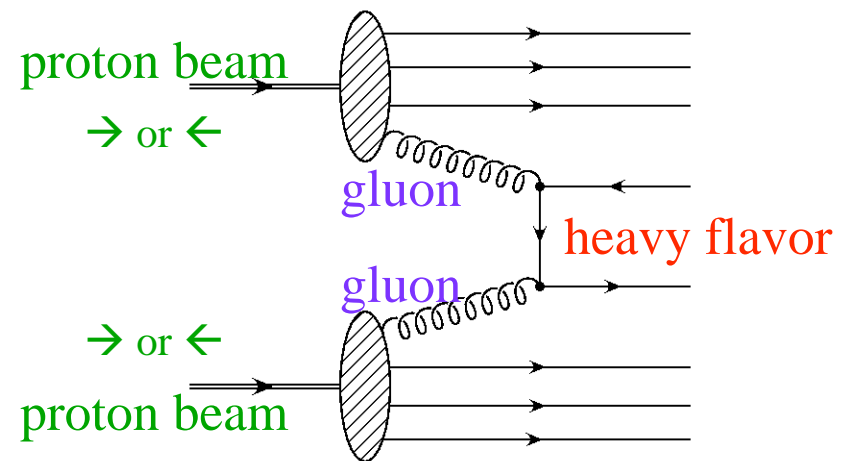


# Gluon polarization

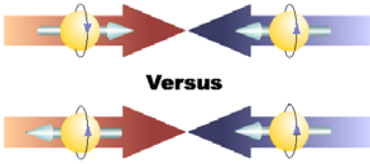
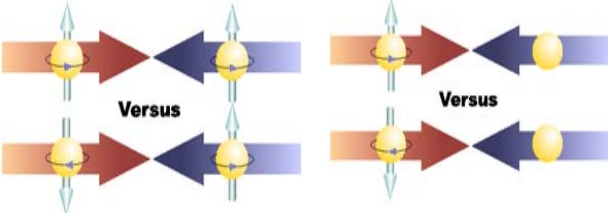
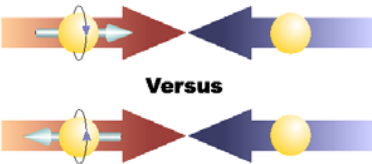
- Polarized hadron collision
  - double longitudinal spin asymmetry



- leading-order gluon measurement
  - direct-photon production
  - heavy-flavor production

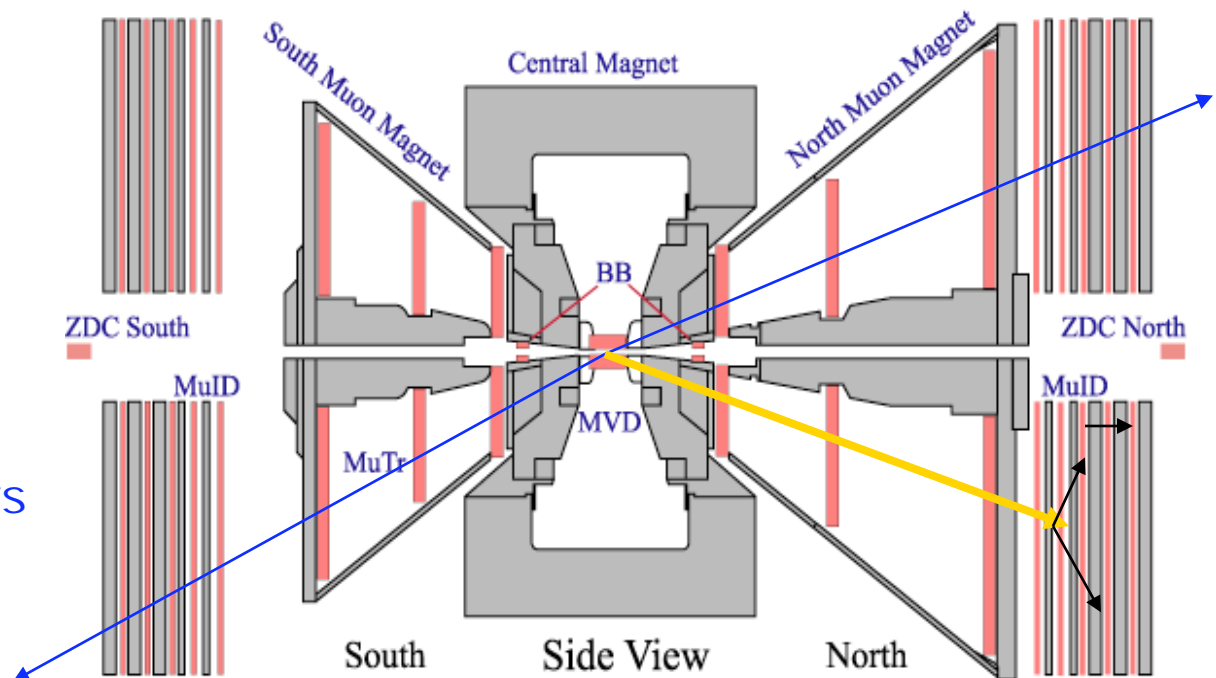


# Proton Spin Structure at PHENIX

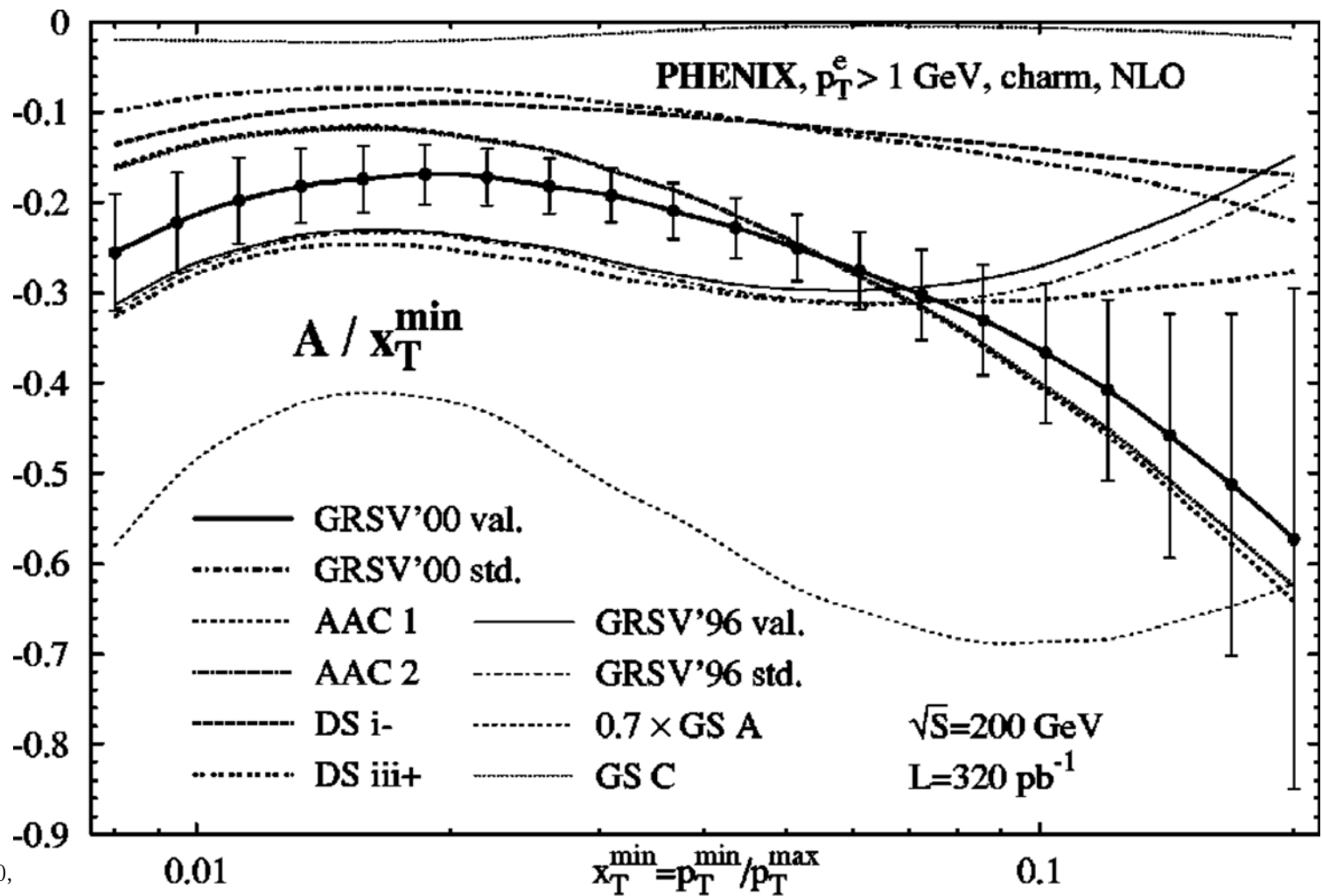
<p>First moment of the Spin dependent Gluon distribution <math>\Delta G</math></p>	<p>Transverse spin physics</p>	<p>Flavor separation of the quark and anti-quark sea</p>
<p>Inclusive Hadron Production <math>A_{LL}(gg, gq \rightarrow h + X)</math></p> <p>Prompt Photon <math>A_{LL}(gq \rightarrow \gamma + X)</math></p> <p>Heavy Flavors <math>A_{LL}(gg \rightarrow c\bar{c}, b\bar{b} + X)</math></p>	<p>Single Spin Asymmetries <math>A_N</math></p> <p>Transversity <math>\delta q</math></p> <p><math>\pi^+, \pi^-</math> Interference fragmentation : <math>A_T(p_\perp p \rightarrow (\pi^+, \pi^-) + X)</math></p> <p>Drell Yan <math>A_{TT}</math></p>	<p>W Production</p> <p><math>A_L(u + \bar{d} \rightarrow W^+ \rightarrow \ell^+ + \nu_\ell)</math></p> <p><math>A_L(\bar{u} + d \rightarrow W^- \rightarrow \ell^- + \bar{\nu}_\ell)</math></p>
		

# PHENIX Muon Detectors

- Muon arms
  - $1.2 < |\eta| < 2.4$
  - $\Delta\phi = 2\pi$
  - $P > 2\text{GeV}/c$
  - Triggers
- "Muons"
  - Stopped hadrons
  - Light meson decays
  - Heavy decays
    - J/Psi
    - Open charm



# NLO aLL

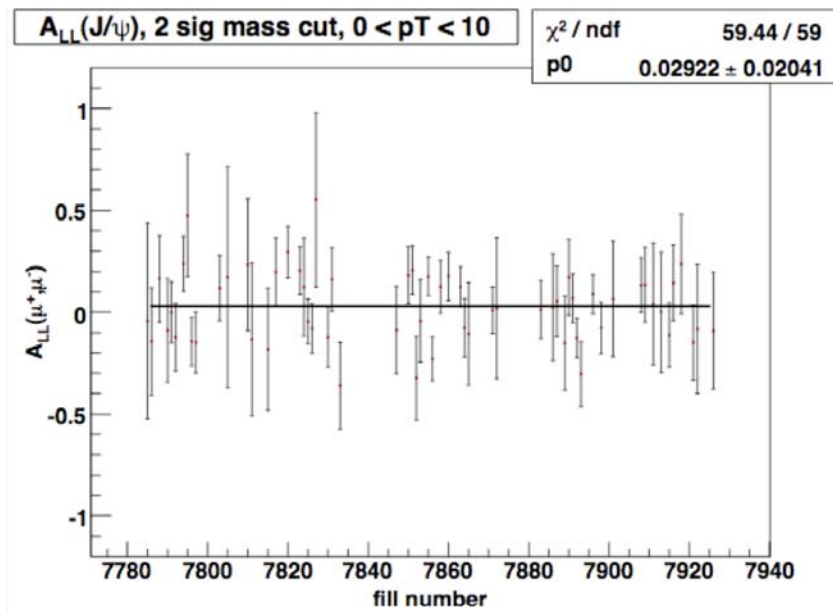




# Raw Asymmetries fill-by-fill

## □ Inclusive J/Psi

- $|M - M_{J\psi}| < 2$  sigma



## □ Background ( $\mu^+\mu^-$ )

- $1.8 < M < 2.5$

