

# Heavy Flavor $A_{LL}$ Study at RHIC

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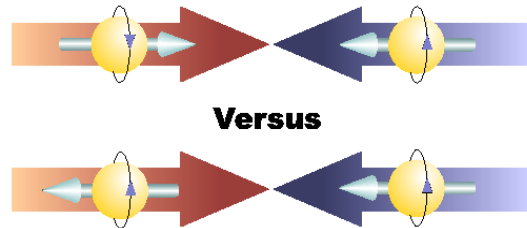
Los Alamos National Lab

(For the PHENIX Collaboration)

- Latest news from Run6
- Outlook

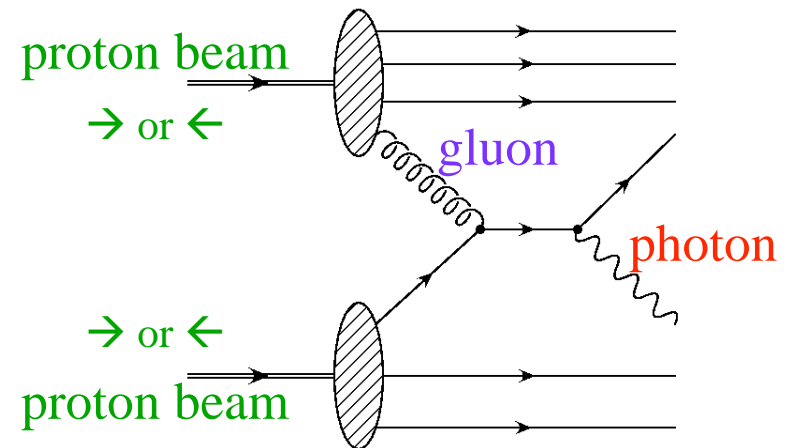
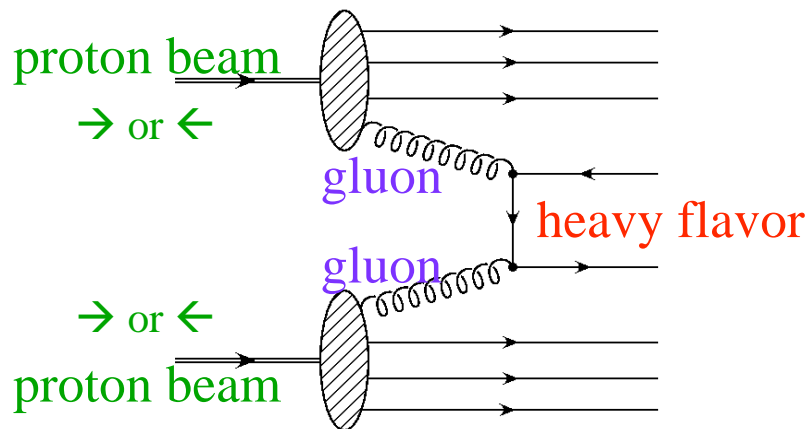
# $\Delta G$ Measurements @RHIC

- Polarized p+p collisions
  - double longitudinal spin asymmetry



$$A_{LL} \sim \frac{\Delta f(x_a)}{f(x_a)} \frac{\Delta f'(x_b)}{f'(x_b)} a_{LL}^{a+b \rightarrow X}$$

- leading-order gluon measurement
  - heavy-flavor production
  - Light hadrons, direct photons





# Heavy Quark Measurements @ PHENIX

- Sensitive to gluon polarization:  $\Delta g(x)$
- Gluon Fusion dominates at LO

PYTHIA estimate:

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

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

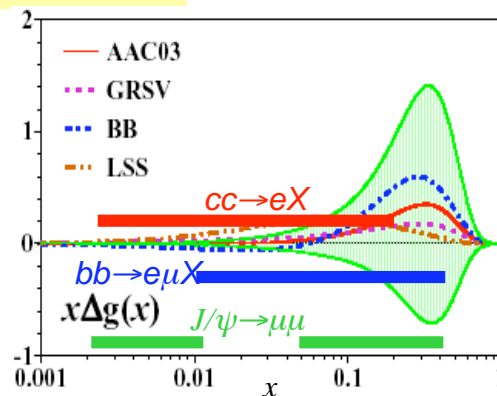
Double spin asymmetry:

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

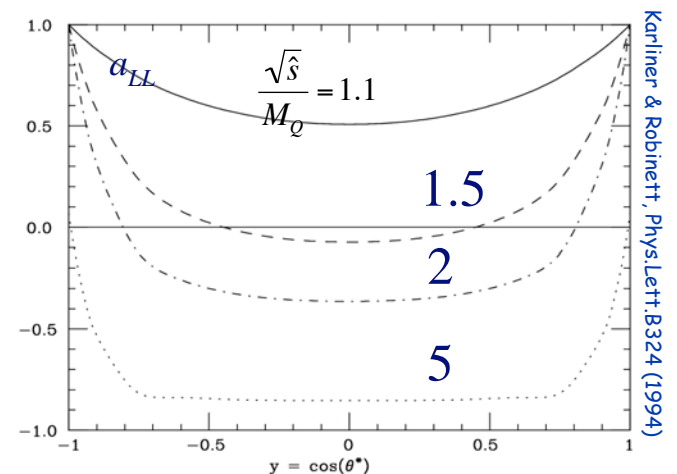
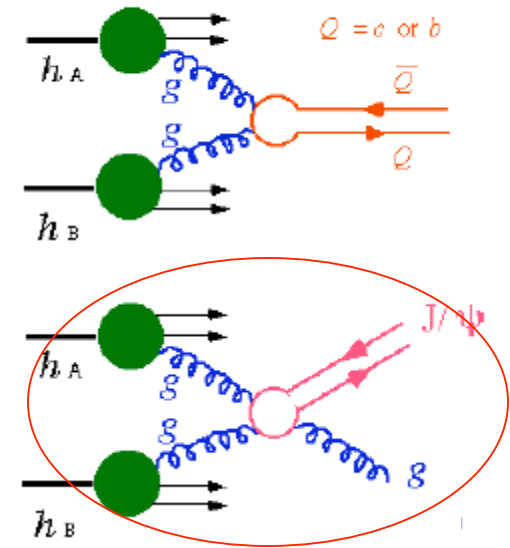
Decay modes:

$J/\psi$ :  $e^+e^-$ ,  $\mu^+\mu^-$

Charm:  $eX$ ,  $\mu X$ ,  $e\mu$  etc.

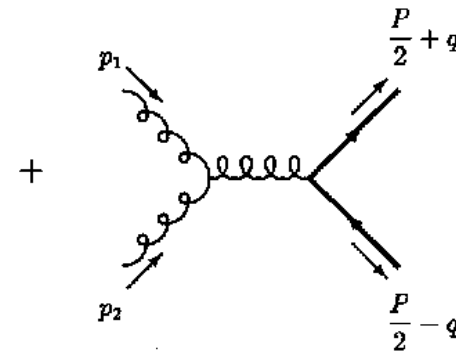
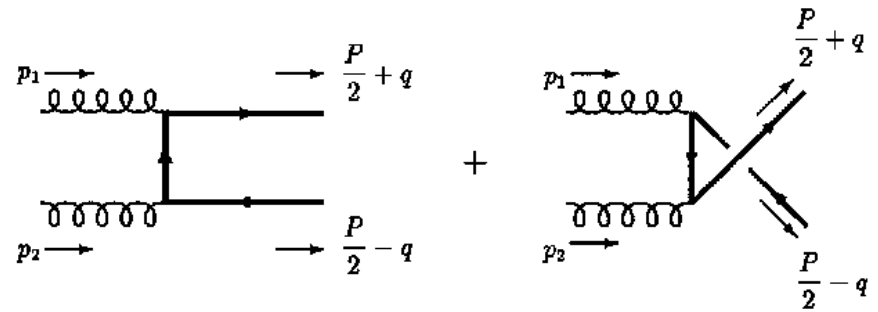
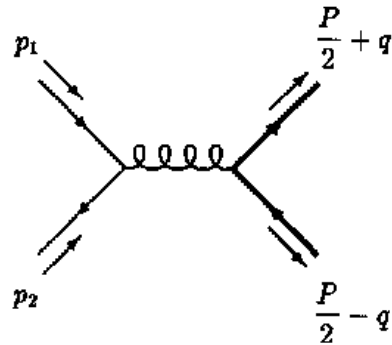


Gluon Fusion



# J/ψ Production in p+p Collisions

- LO NRQCD:  $\sim \alpha_s^2$



$$\Delta\sigma_{(pp \rightarrow J/\Psi(\lambda))} \approx \frac{\pi^3 \alpha_s^2}{27 \cdot s \cdot m^2} \int_{4m^2/s}^1 \frac{dx_1}{x_1} \{$$

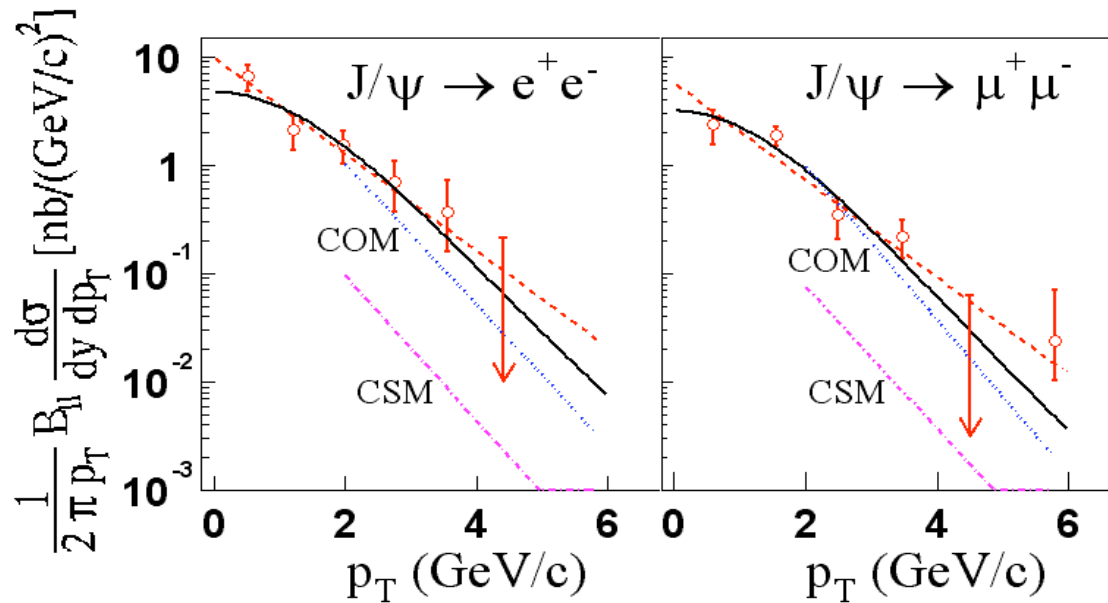
$$\Delta f_q(x_1, 2m) \cdot \Delta f_{\bar{q}}\left(\frac{4m^2}{x_1 \cdot s}, 2m\right) \times (\delta_{\lambda 0} - 1) \langle O_8^{J/\Psi(\lambda)}(^3S_1) \rangle$$

$$+ \frac{15}{32} \Delta f_g(x_1, 2m) \cdot \Delta f_{\bar{g}}\left(\frac{4m^2}{x_1 \cdot s}, 2m\right) \times \left[ \frac{9}{m^2} \left(1 - \frac{1}{2} \delta_{\lambda 0}\right) \langle O_8^{J/\Psi(\lambda)}(^3P_0) \rangle - \langle O_8^{J/\Psi(\lambda)}(^1S_0) \rangle \right]$$

mix of various processes

# NRQCD and PHENIX data: X-section

PHENIX, PRL 92, 051802 (2004)



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

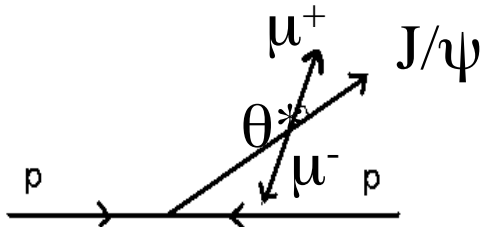
- PRD 68 (2003) 034003 G. Nayak, M. Liu, F. Cooper
- PRL 93 (2004) 171801 F. Cooper, M. Liu, G. Nayak

# More on J/ψ Production Mechanism

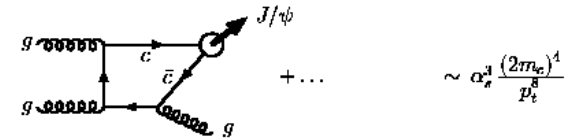
- J/Psi polarization - a key probe?
- Spin dynamics in pQCD

$$\frac{d\sigma}{d\cos\theta} \propto 1 + \alpha \cos^2 \theta *$$

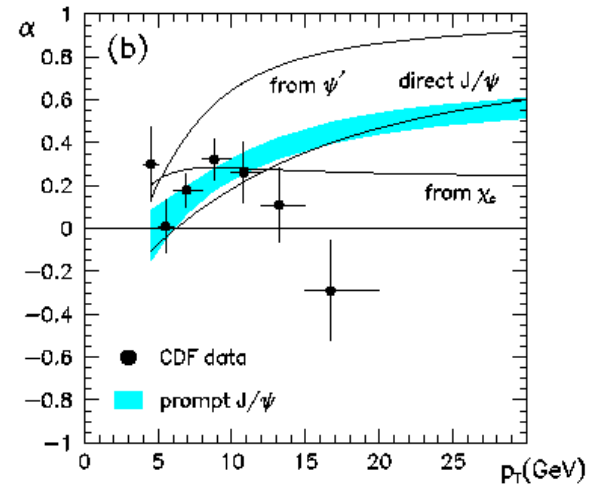
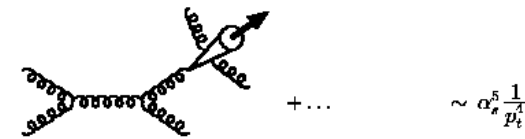
$\alpha = +1$ : transversely polarized  
 $\alpha = -1$ : longitudinally polarized  
 $\alpha = 0$ : no polarization



(a) leading-order colour-singlet:  $g + g \rightarrow c\bar{c}[^1S_1^{(1)}] + g$

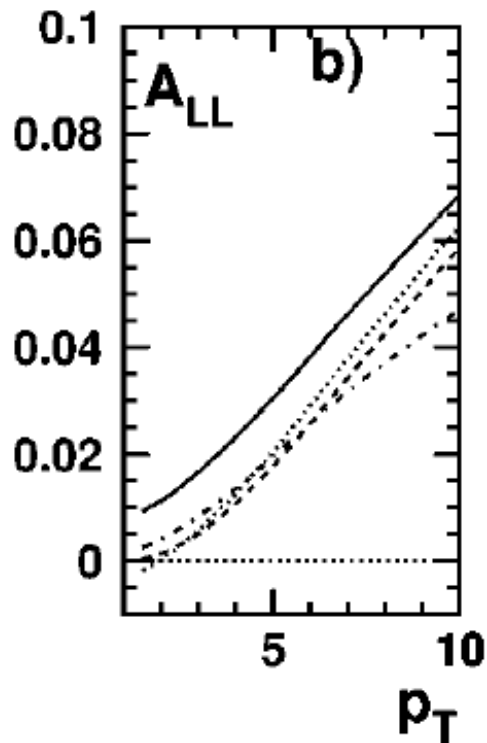


(b) colour-singlet fragmentation:  $g + g \rightarrow [c\bar{c}[^1S_1^{(1)}] + gg] + g$

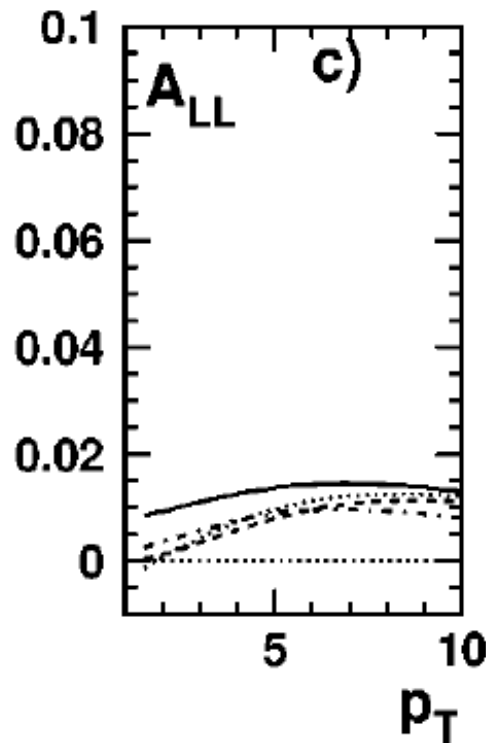


# $A_{LL}$ and J/Psi Production @RHIC

GS-A(NLO)



GS-A(LO)



PRD 56,7331(1997)

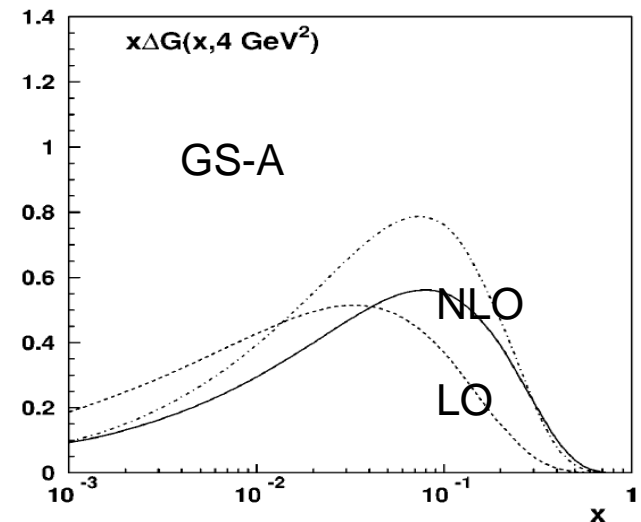
Solid =  $^1S_0^{(8)}$

Dashed =  $^3P_J^{(8)}$

Dash-dot =  $^3S_1^{(8)}$

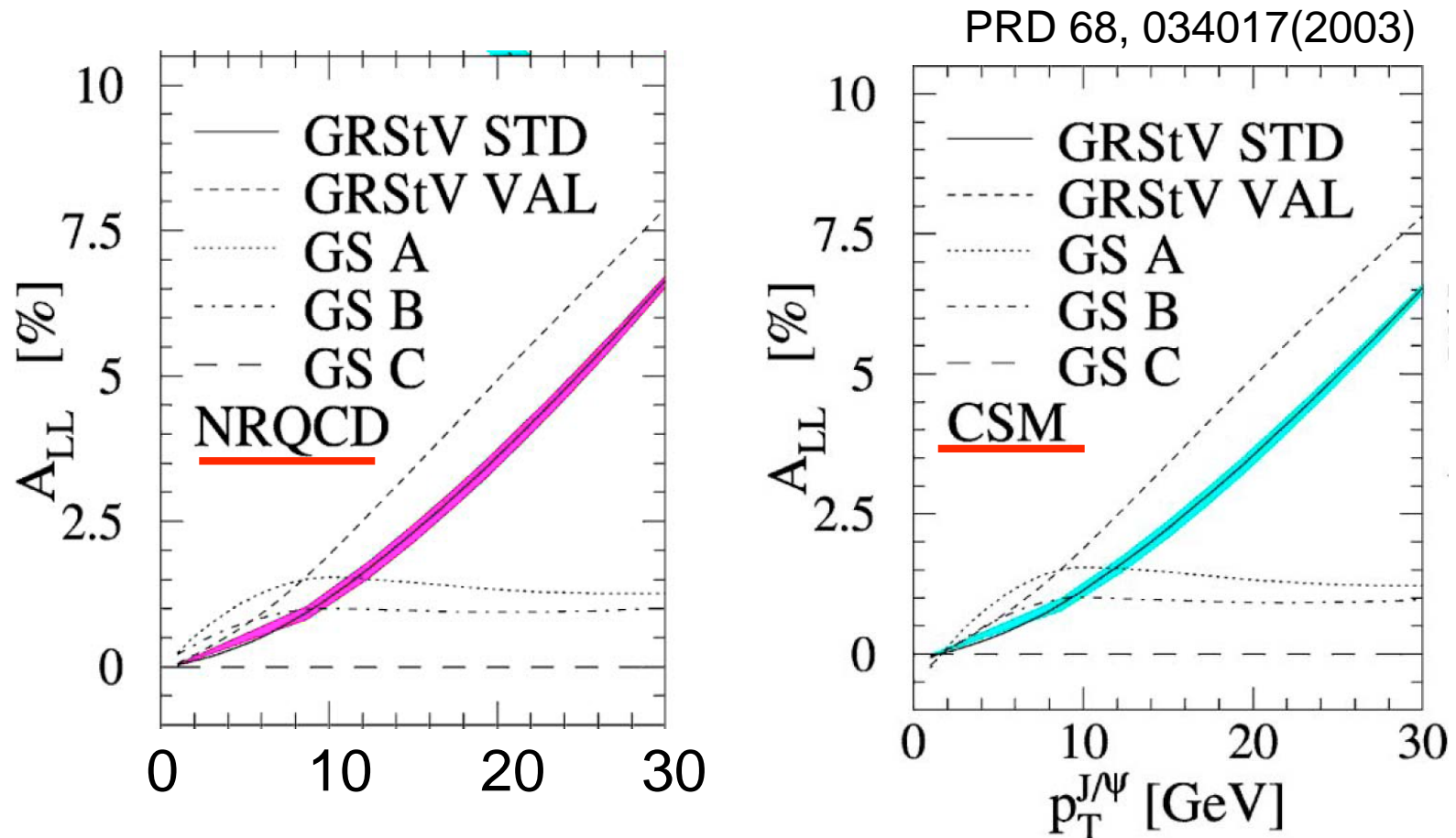
Dotted = CSM

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





# $A_{LL}$ : NRQCD and CSM

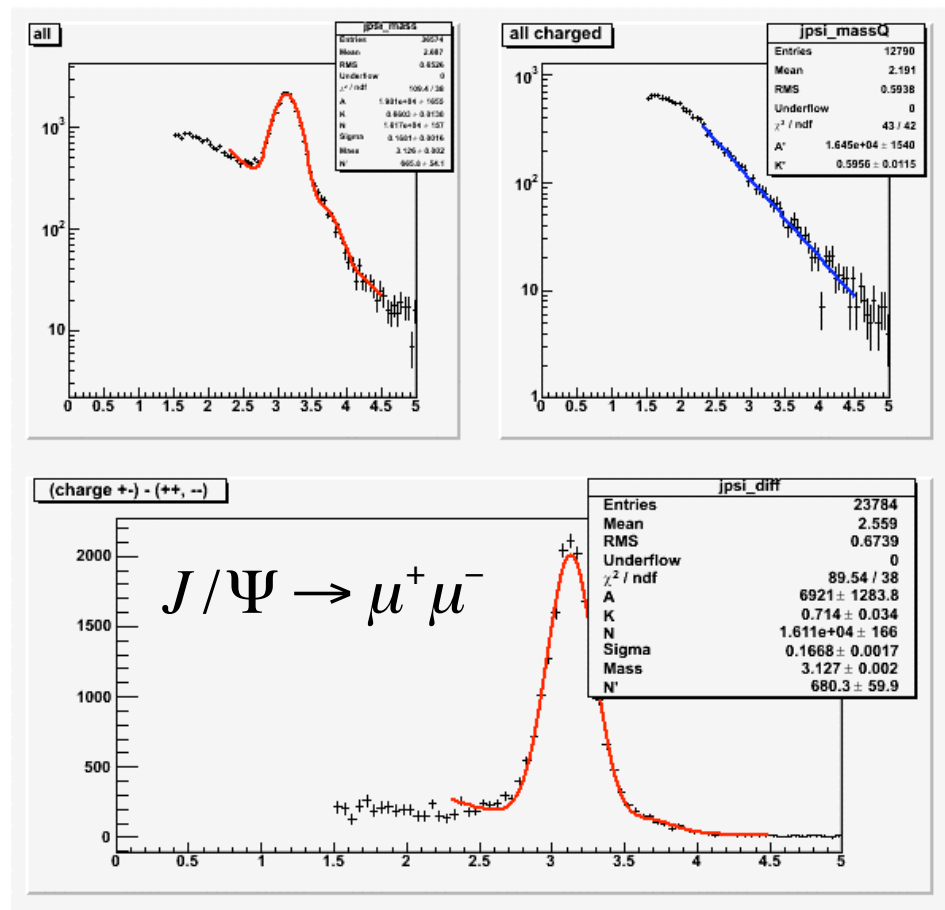


Not very sensitive to “fragmentation” processes

# J/Psi from Y06 Data

- Run6 pp dimuon events:
  - 5 pb<sup>-1</sup> from Level-2
  - 16K  $J/\Psi \rightarrow \mu^+ \mu^-$
- Fill-by-Fill analysis
  - Within a store, beam pol fixed

$$\begin{aligned}
 A_{LL} &= \frac{1}{P_B \cdot P_Y} \cdot \frac{\sigma^{+-} - \sigma^{++}}{\sigma^{+-} + \sigma^{++}} \\
 &= \frac{1}{P_B \cdot P_Y} \cdot \frac{\frac{N^{+-}}{L^{+-}} - \frac{N^{++}}{L^{++}}}{\frac{N^{+-}}{L^{+-}} + \frac{N^{++}}{L^{++}}} \\
 &= \frac{1}{P_B \cdot P_Y} \cdot \frac{N^{+-} - RN^{++}}{N^{+-} + RN^{++}}
 \end{aligned}$$



Dimuon mass

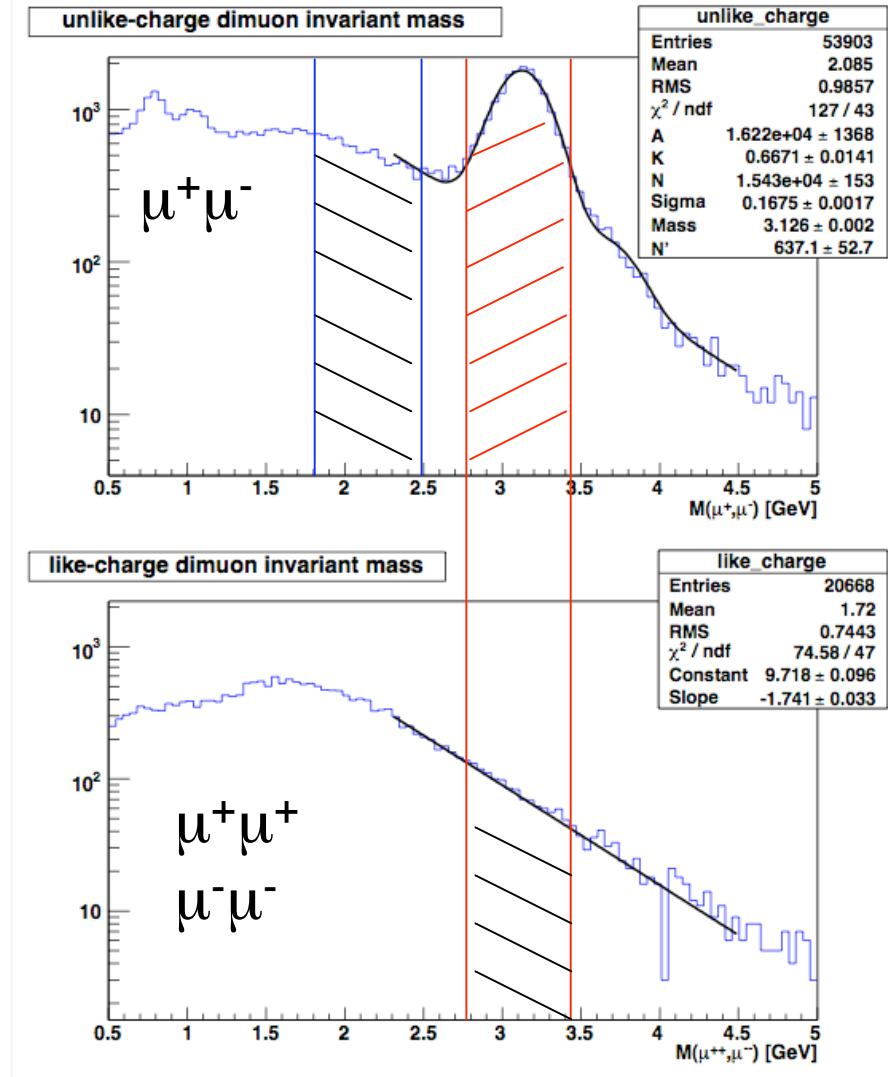
# Experimental Approach

- Inclusive J/Psi events
- Background estimation
  - S/B~10
- Fill-by-fill, beam pol from CNI
- Relative luminosity
  - BBC and ZDC trigger counts

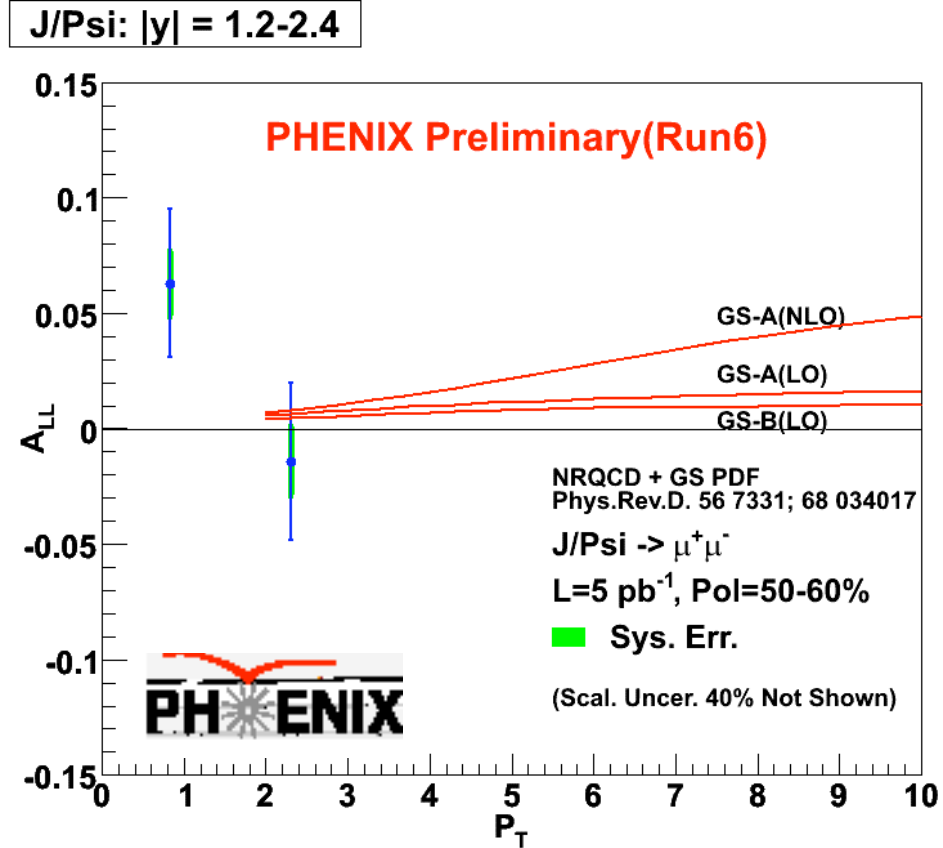
$$A_{LL}^{incl(BG)} = \frac{1}{\langle P_B \rangle \langle P_Y \rangle} \frac{N^{++} - R \cdot N^{+-}}{N^{++} + R \cdot N^{+-}}$$

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

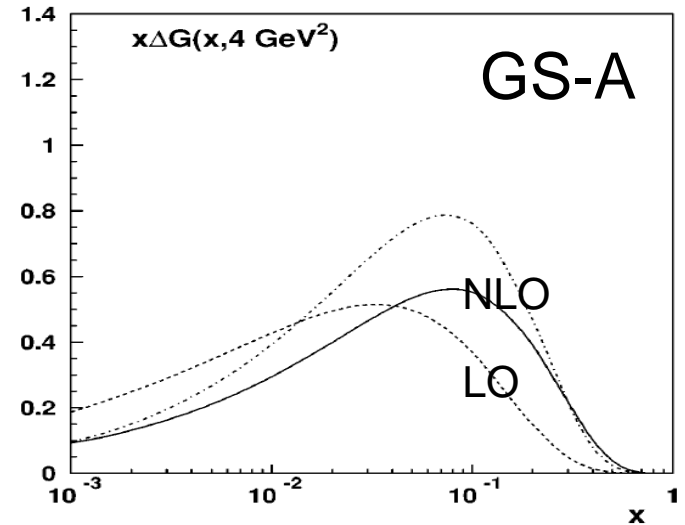
$$\delta A_{LL}^{J/Psi} = \frac{\sqrt{(\delta A_{LL}^{incl})^2 + f_{BG}^2 \cdot (\delta A_{LL}^{BG})^2}}{1 - f_{BG}}$$



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



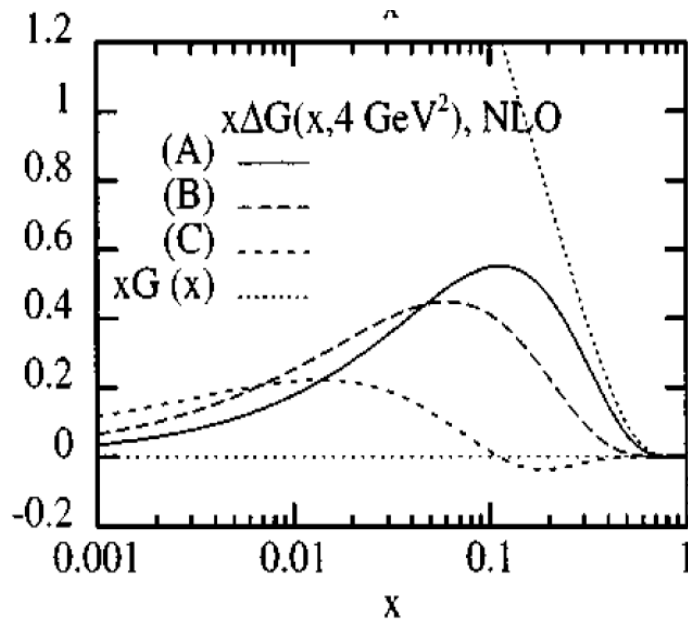
## Gluon Pol. Models



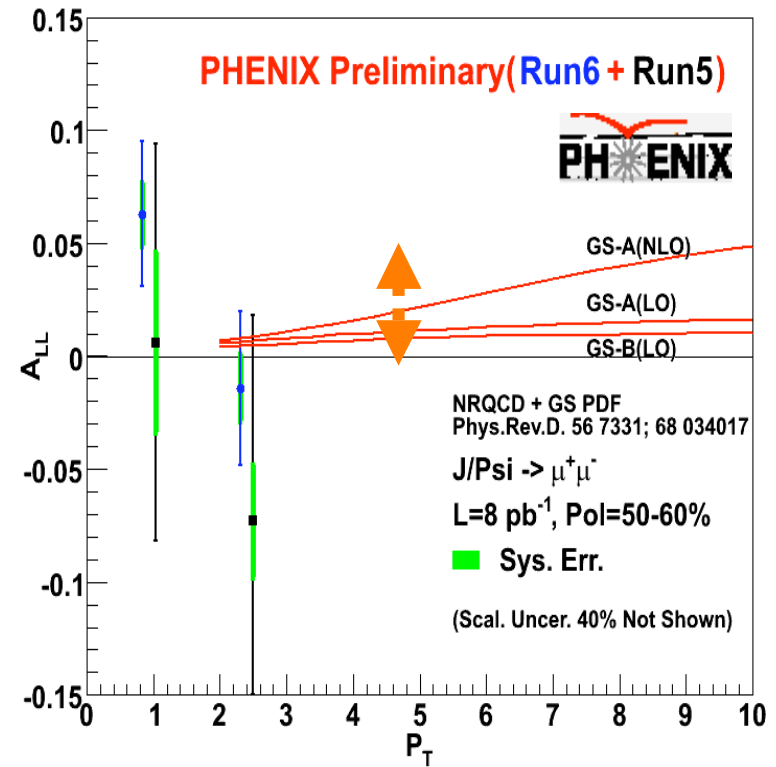
# J/ $\Psi$ $A_{LL}$ @RHIC - Outlook

- @ $p_T=5\text{GeV}$ , GS  $\Delta G(\text{NLO})$

- $1\sigma$  A-C:  $65\text{ pb}^{-1}$  (RHIC-I)
- $3\sigma$  A-C:  $10\times\text{RHIC-I}$  (RHIC-II)
- $3\sigma$  A-B:  $40\times\text{RHIC-I}$



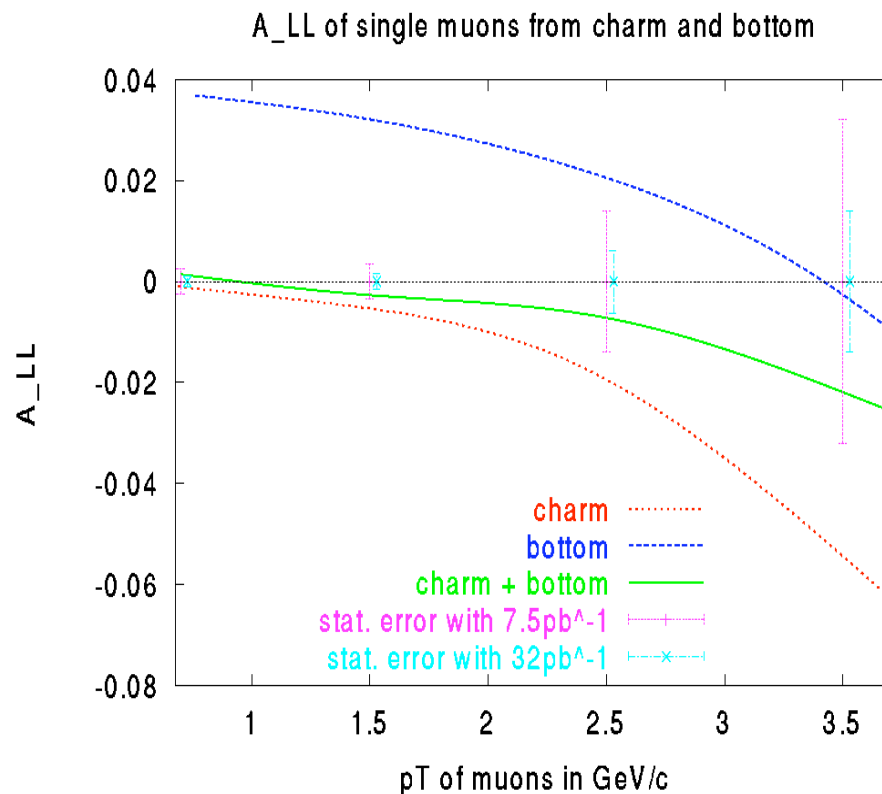
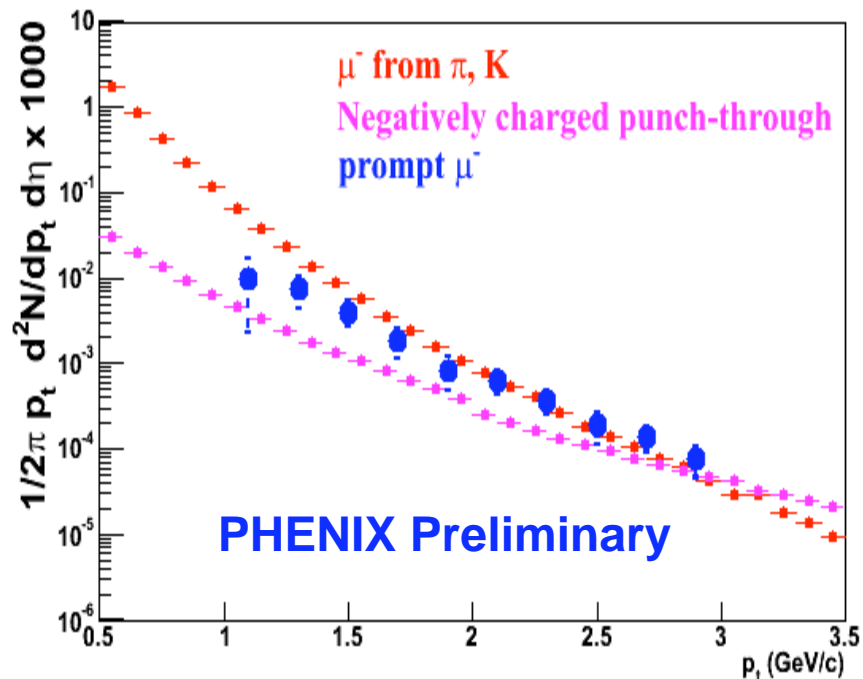
J/ $\Psi$ :  $|y| = 1.2-2.4$



Good for exploring large  $\Delta G$ ...

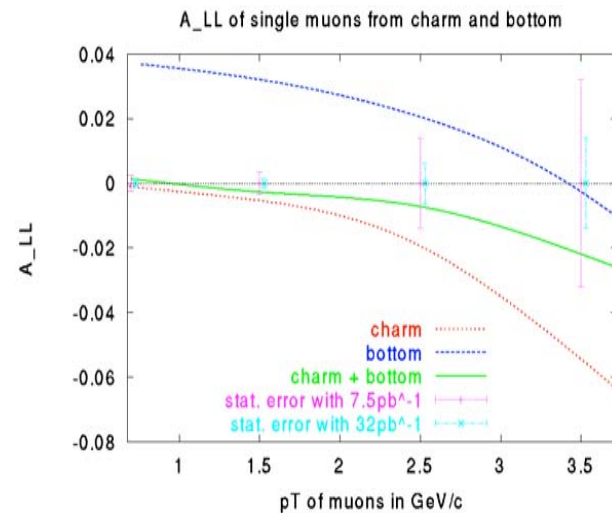
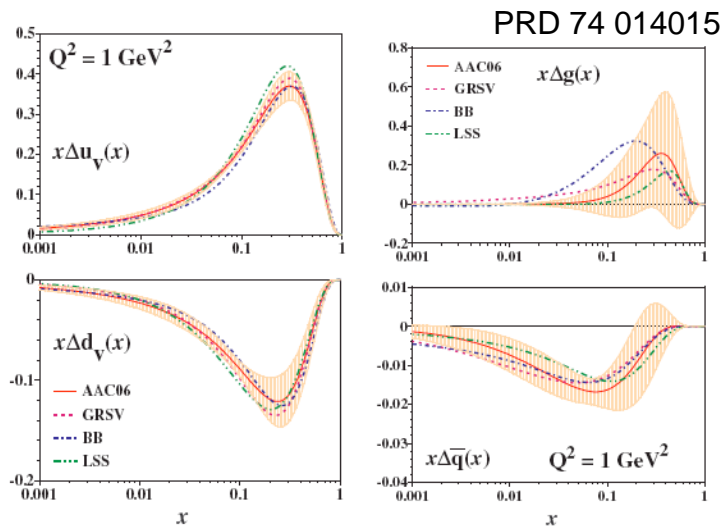
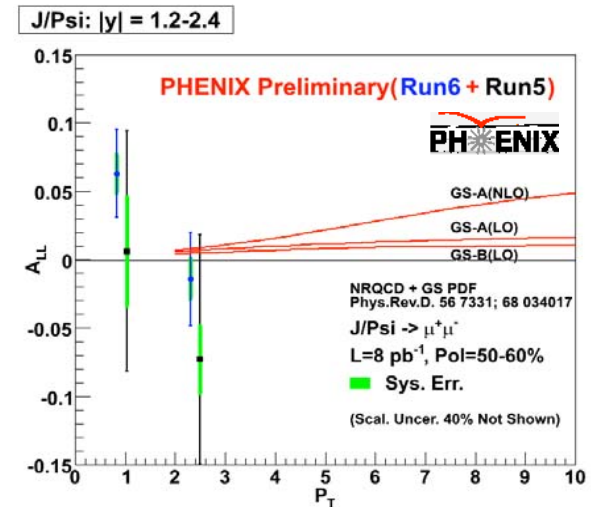
# Open Charm for Precision Measurements

- Open Charm via Muons and Electrons
  - A lot more statistics:  $\sim$  a few  $\times 10^2$  more
  - S/B  $\sim O(1)$  (S/B  $\gg O(1)$  with VTX upgrade)
  - Run5 full data production just finished



# Summary and Outlook

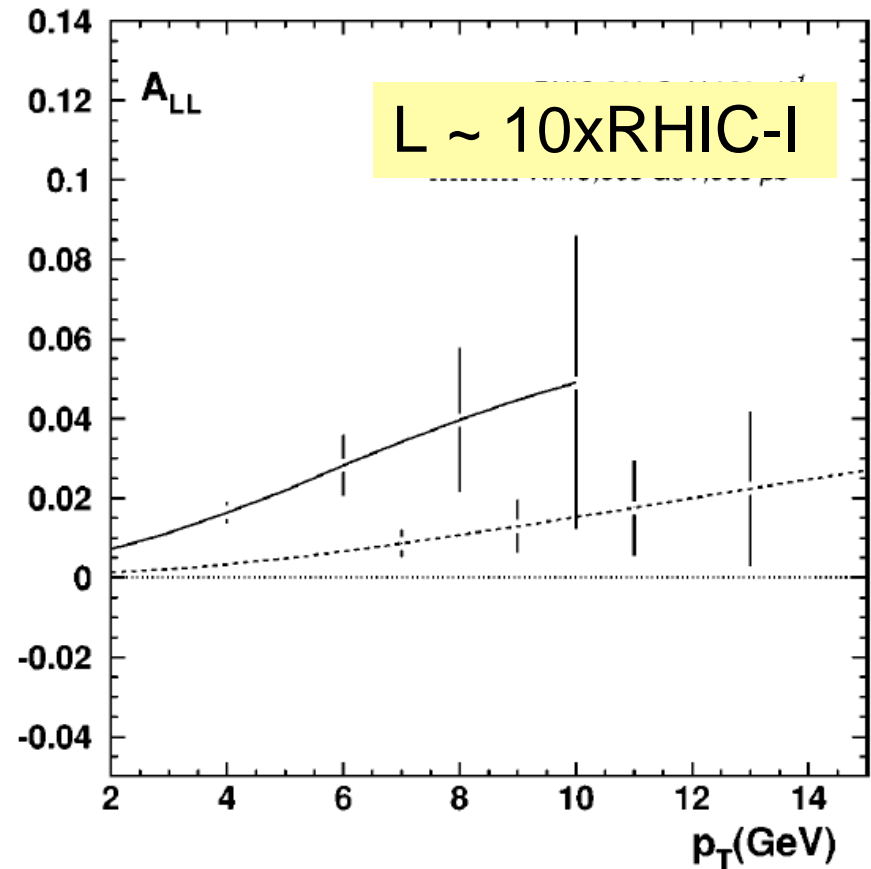
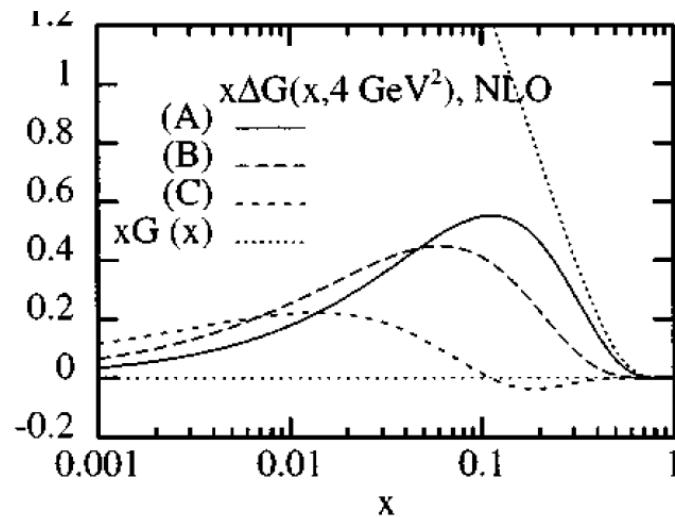
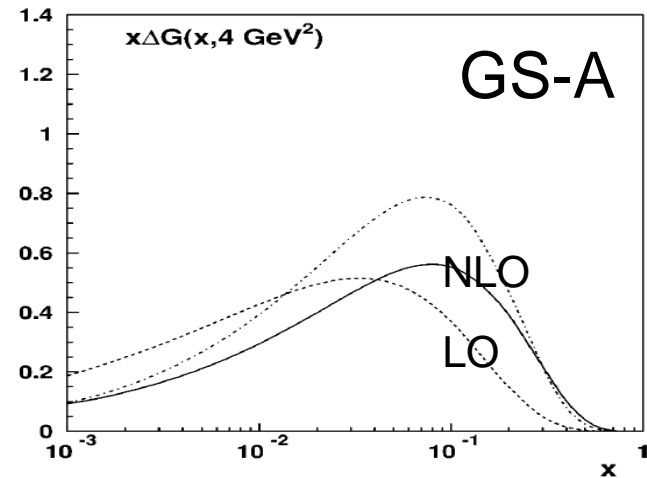
- Probe gluon polarization with heavy quarks
  - J/psi: |y|=2 filtered data (Run5+6)
  - Open charm: coming soon
- Need more theoretical calculations to study sensitivity



# backup



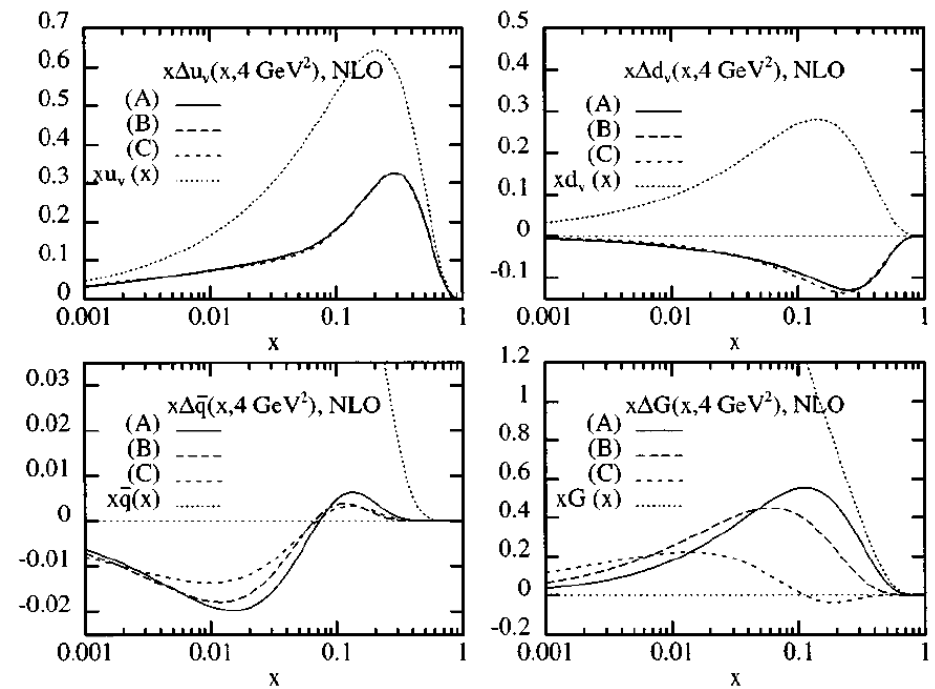
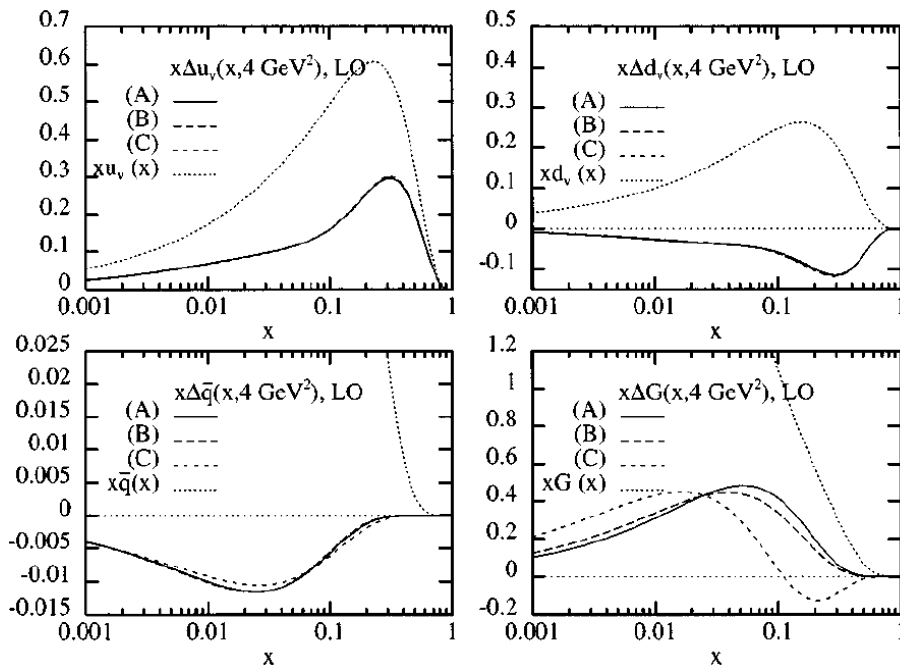
# $A_{LL}$ and Gluon Polarization



# GS PDF (PRD 1996)

LO

NLO



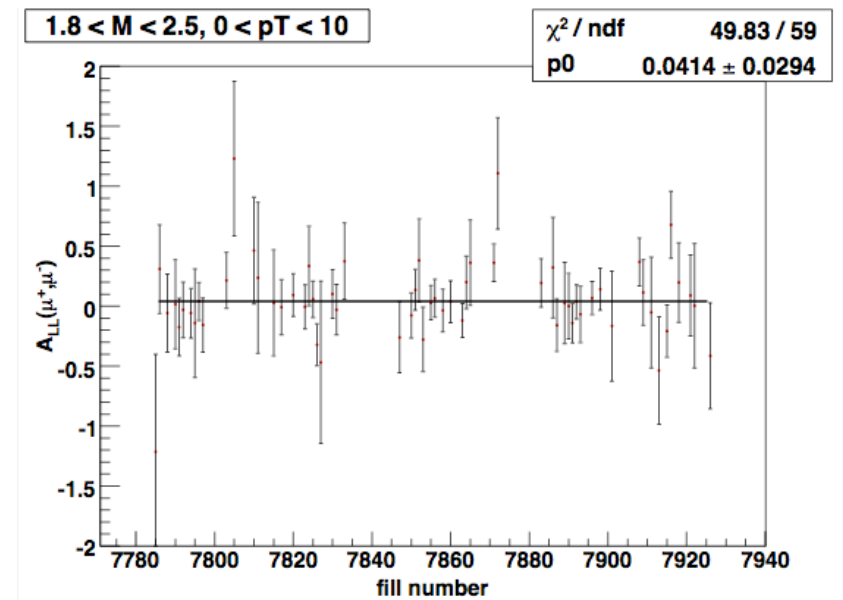
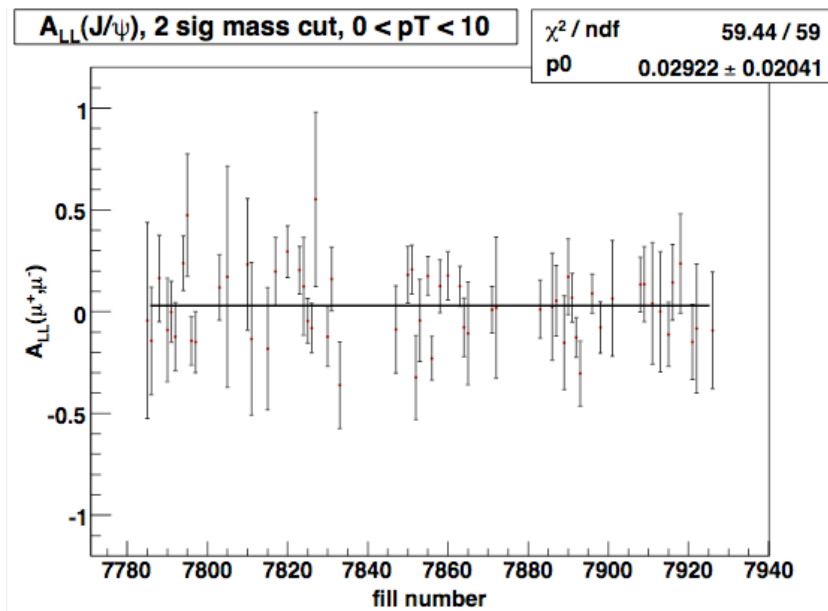
# Asymmetries fill-by-fill

- Inclusive J/Psi

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

- Background ( $\mu^+\mu^-$ )

- $1.8 < M < 2.5 \text{ GeV}$



# Systematic Checks

- Beam shuffling - random beam polarization

