# Probing Gluon Polarization with J/Psi in Longitudinally Polarized pp Collisions

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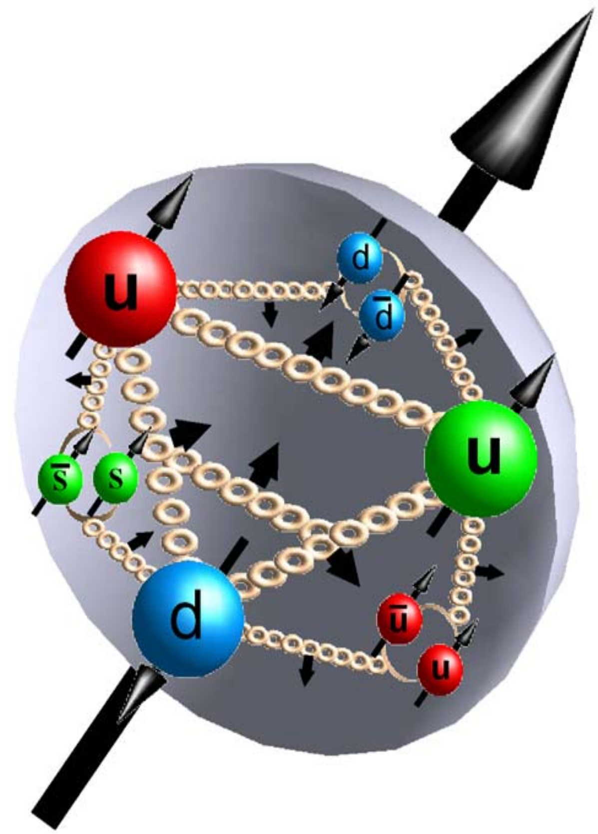
# The Challenge: the spin “crisis”

- Understanding the nucleon sub-structure

$$\frac{1}{2} = \int_0^1 dx\left[\tfrac{1}{2}\,\Delta\Sigma(x) + \Delta g(x)\right] + L_Z$$

$$= \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

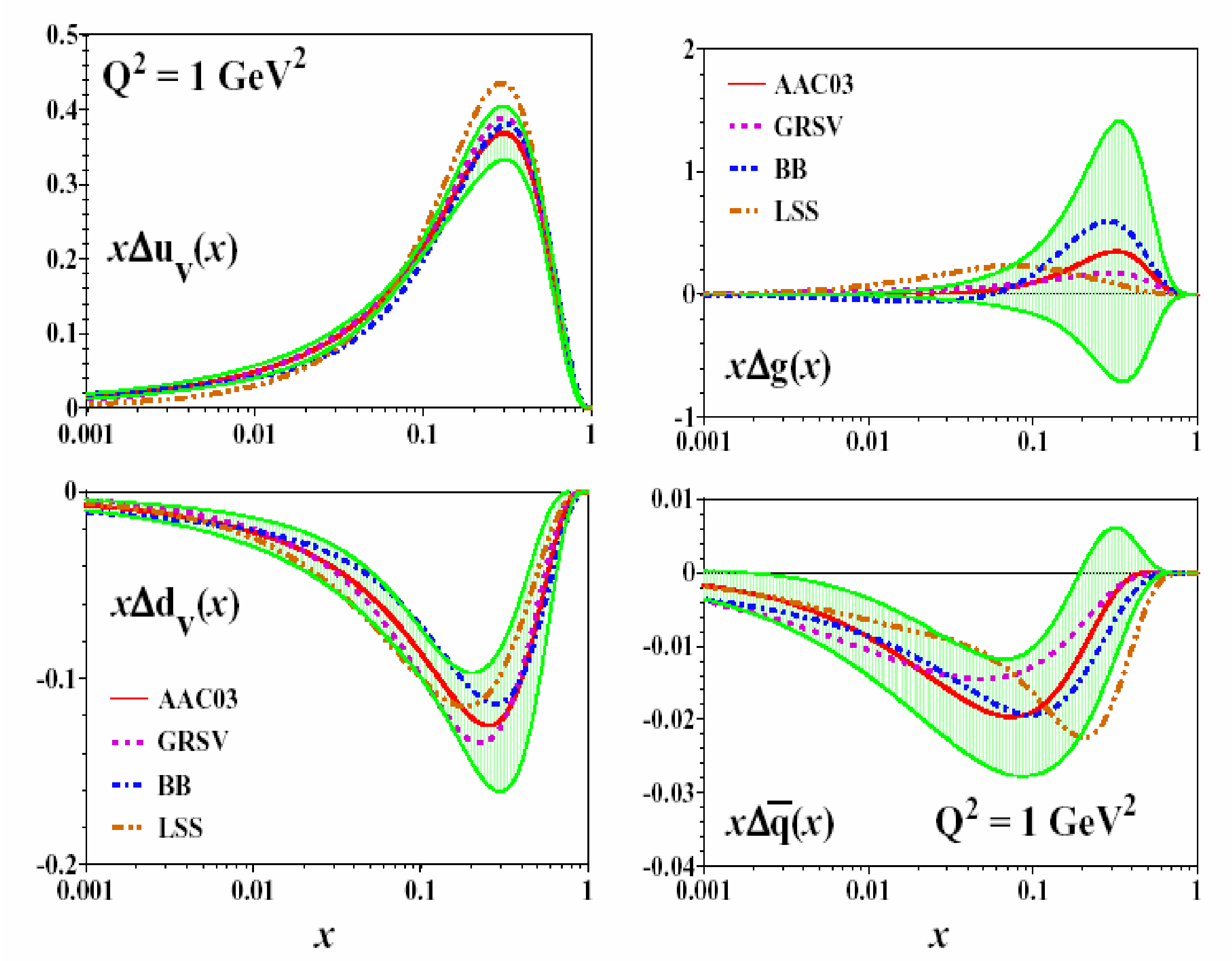


# Polarized PDFs

Asymmetry Analysis Collaboration

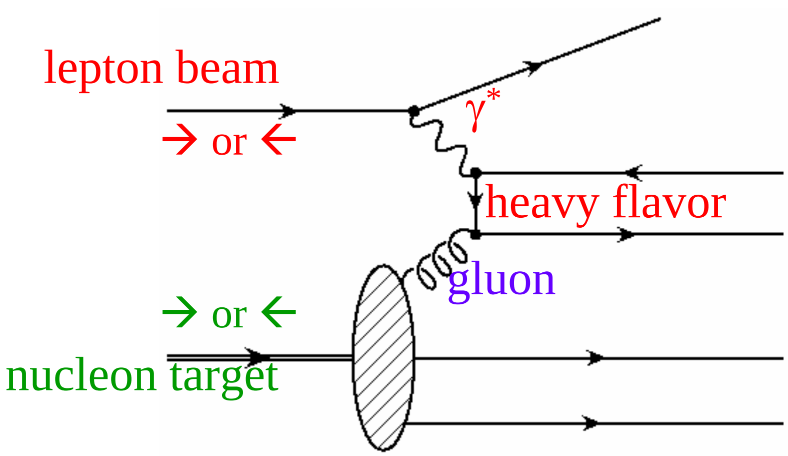
M. Hirai, S. Kumano and N. Saito, PRD (2004)

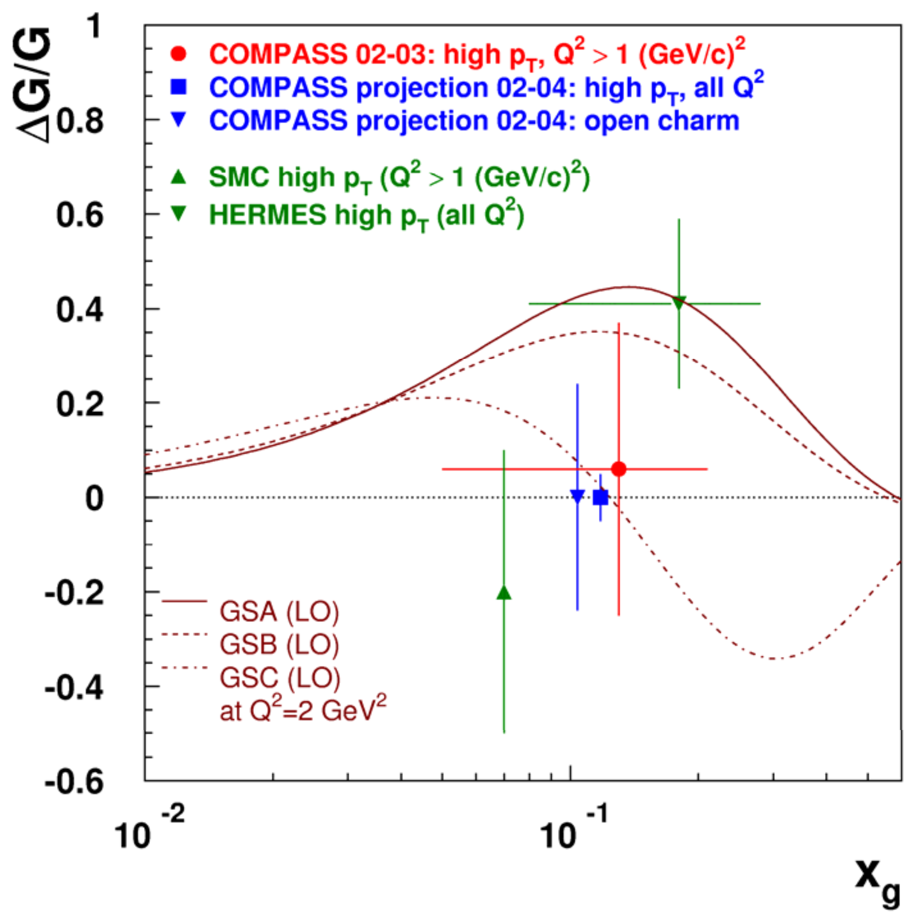
*Gluon polarization ($\Delta G$) remains poorly constrained*



# SIDIS and Gluon Polarization Measurements

- Semi-inclusive DIS
  - HERMES @ DESY
    - high-$p_T$ hadron pairs
  - SMC @ CERN
    - high-$p_T$ hadron pairs
  - COMPASS @ CERN
    - high-$p_T$ hadron pairs
    - open charm (projection)

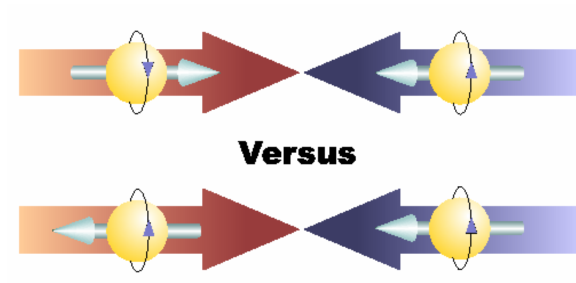


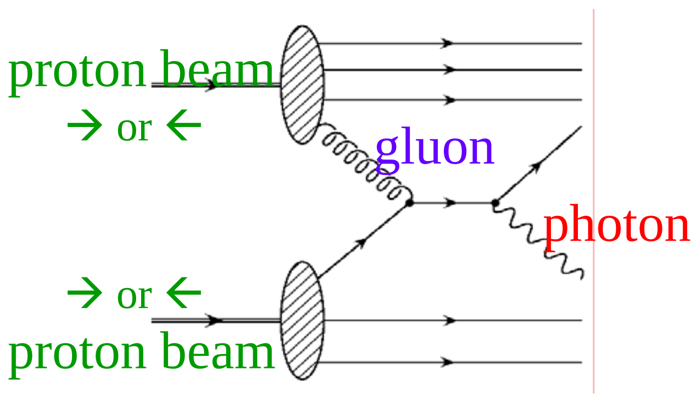
# @RHIC-SPIN

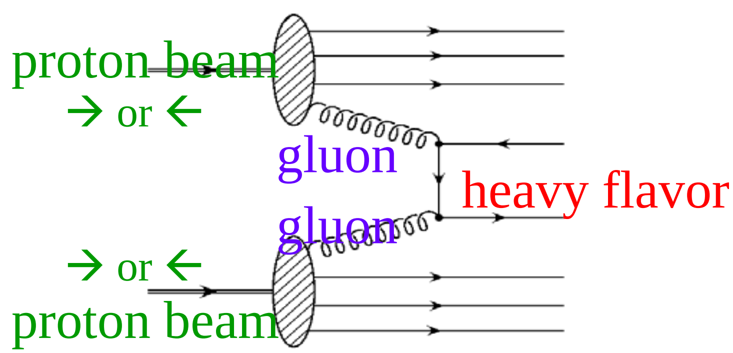
- Polarized hadron collisions
  - double longitudinal spin asymmetry

$$A_{LL} = \frac{d\sigma_{++} - d\sigma_{+-}}{d\sigma_{++} + d\sigma_{+-}}$$




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



# Advantage of Heavy Quarks

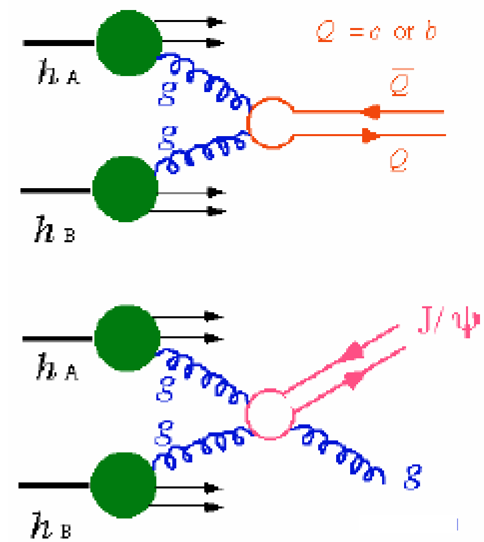
- Sensitive to gluon polarization: $\Delta g(x)$
- Gluon Fusion dominates at LO

PHYTHA estimate:

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

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

Gluon Fusion

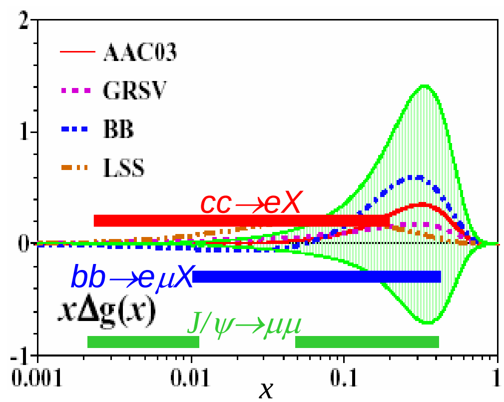


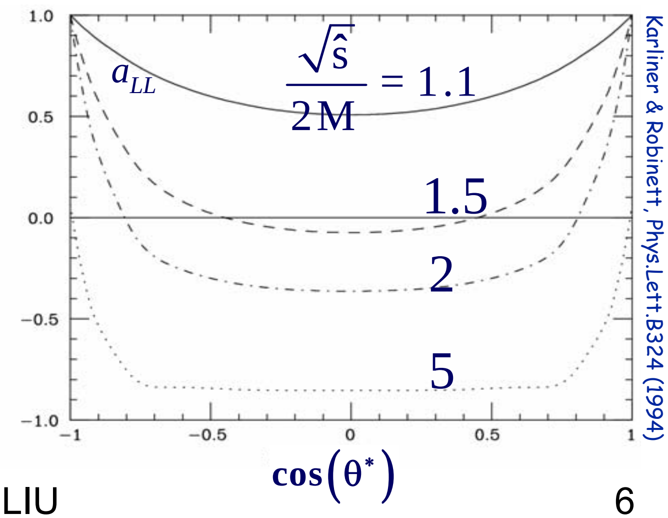

## For open charm production

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

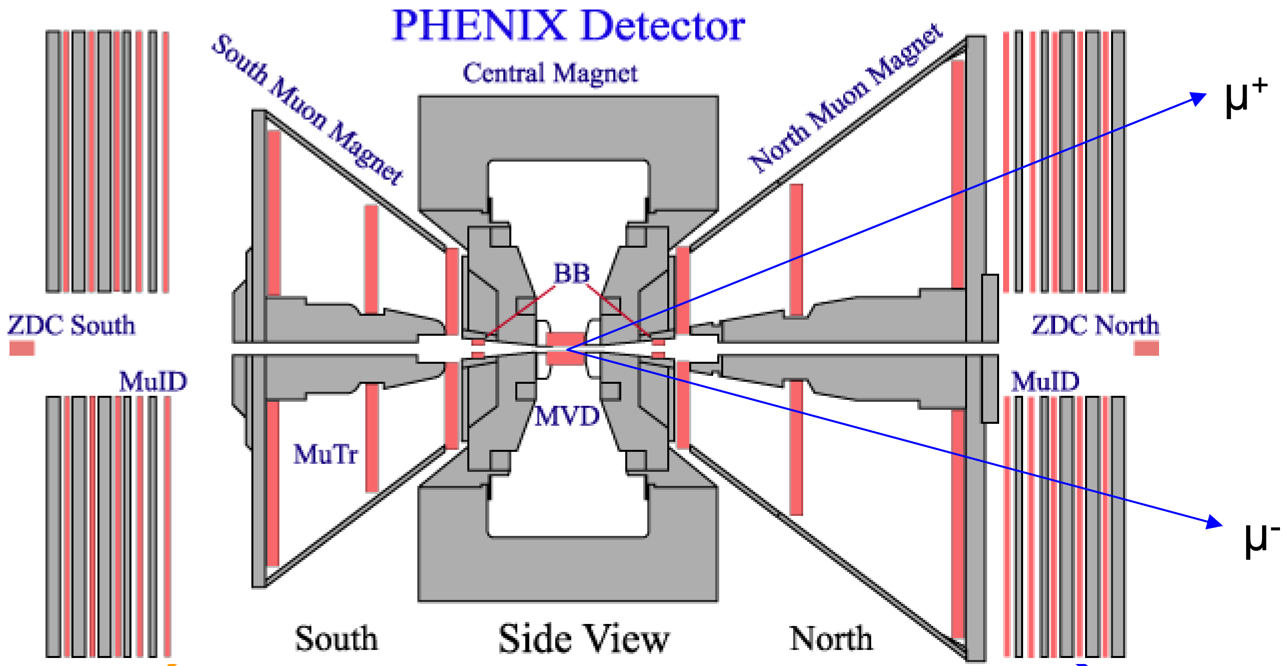
*Decay modes:*

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



# The PHENIX Muon Arms




South Muon arm : $-1.2 > \eta > -2.0$

North Muon arm : $2.4 > \eta > 1.2$

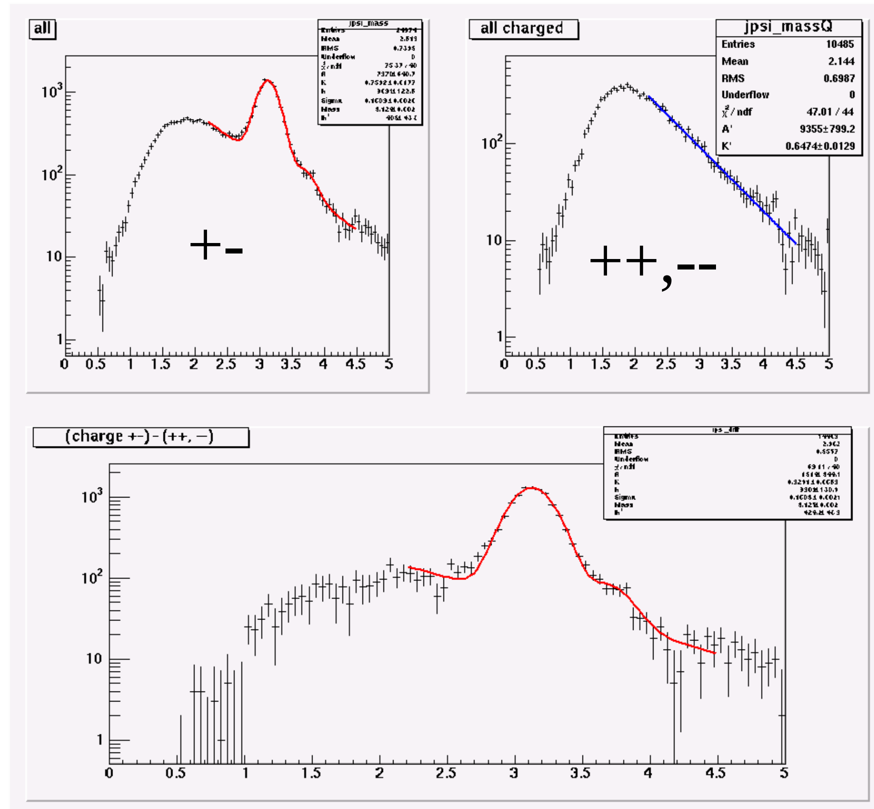
# $A_{LL}$ from J/$\psi\rightarrow\mu+\mu-$

- Analysis approach
  - Polarization=47% (average)
  - R is from BBC_in (GL1P)
  - N_Jpsi Yield

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} - \sigma^{+-}} = \frac{1}{P_B \cdot P_Y} \frac{N_{J/Psi}^{++} - R \cdot N_{J/Psi}^{+-}}{N_{J/Psi}^{++} + R \cdot N_{J/Psi}^{+-}}$$

# J/psi Yield Measurements

1. Fill by fill {Charge(+-) – charge(++,--)}
   - No need fill by fill muon efficiency correction
   - Have Open charm, DY and other background
   - Fix mass range to extract N_Jpsi
   - We used this one for the final results.
2. Gaussian+Exponential background
   - Used to estimate the background under J/Psi peak




Dimuon mass distributions

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

# Raw asymmetry per Fill:

**N_J/Psi > 10 per fill**

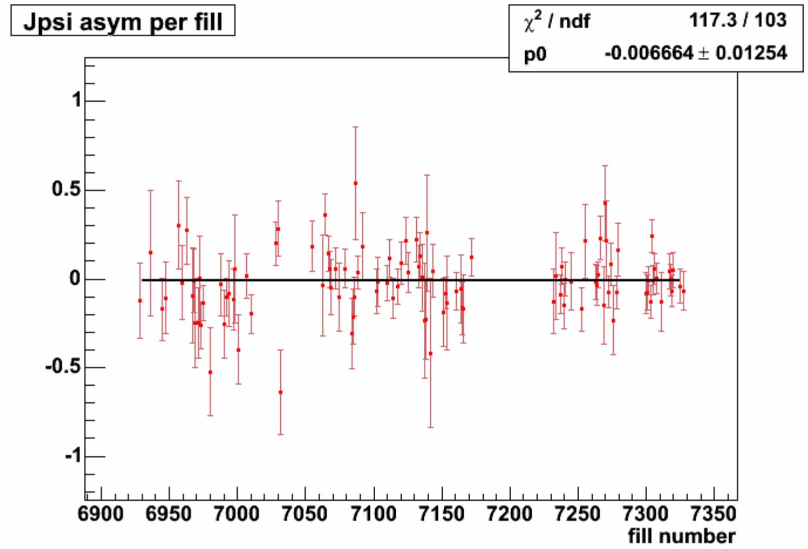
**2 sigma cut:**

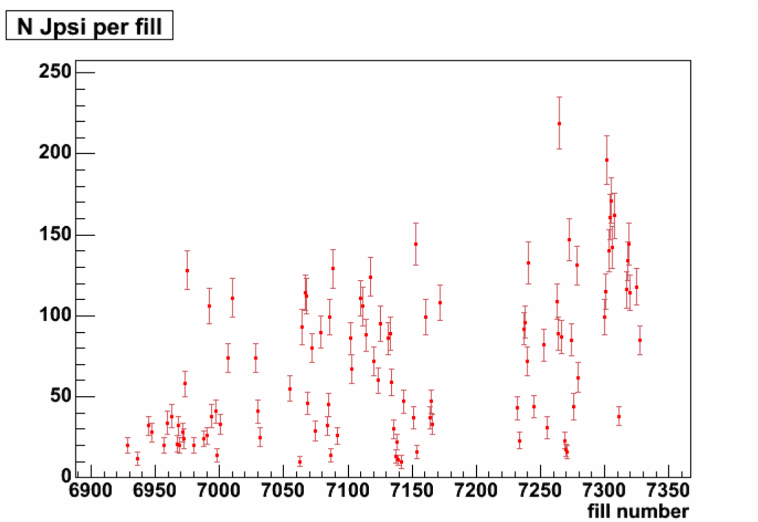
**2.80 < *Mass* < 3.44**

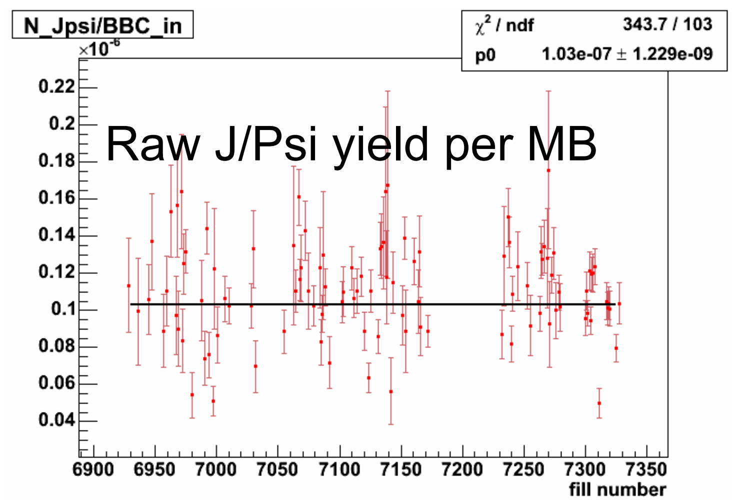
***N* = 7373 ± 86**

**<*RL*> = 1.00892**

**$A_{LL}$ (raw)= -0.007 ± 0.013**



# Signals

## Raw Asymmetry Per Fill:

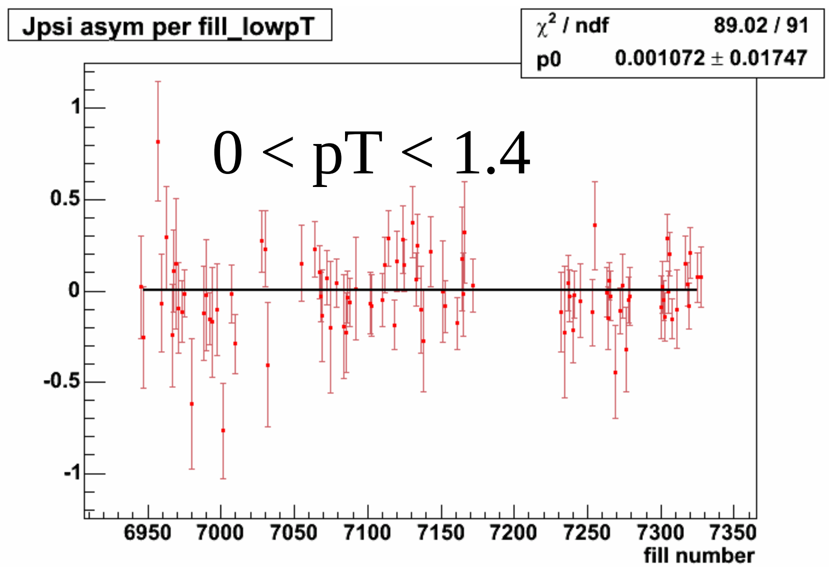
N_Jpsi > 10

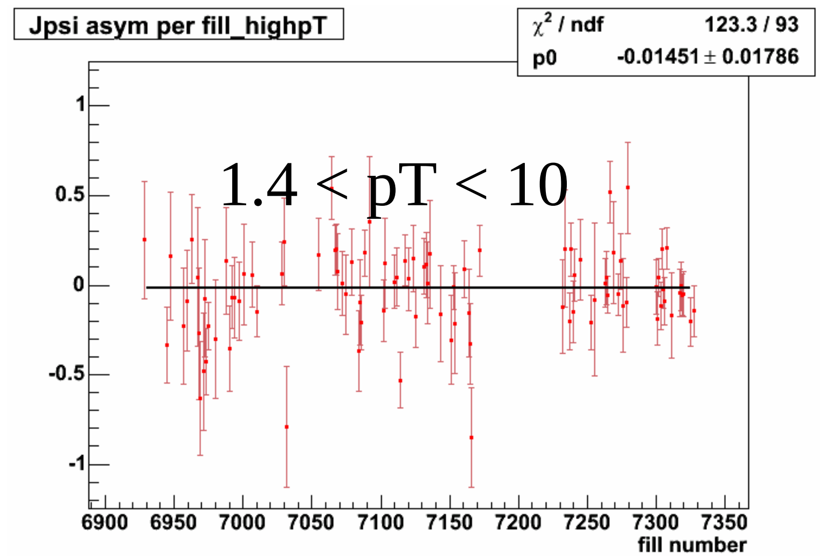
Two pT bins: 0.0-1.4 GeV and 1.4 – 10 GeV

**2.80 < *Mass* < 3.44, 2 sigma cut**

**$A_{LL}$(raw) = +0.0011 ± 0.0175**

**$A_{LL}$(raw) = -0.0145 ± 0.0179**



# Background

## Background Raw Asymmetry

Left of the peak: 2.0 < Mass < 2.5

$A_{LL}(raw) = 0.0107 \pm 0.0220$

$N = 2068 \pm 45.5$

Under the peak:

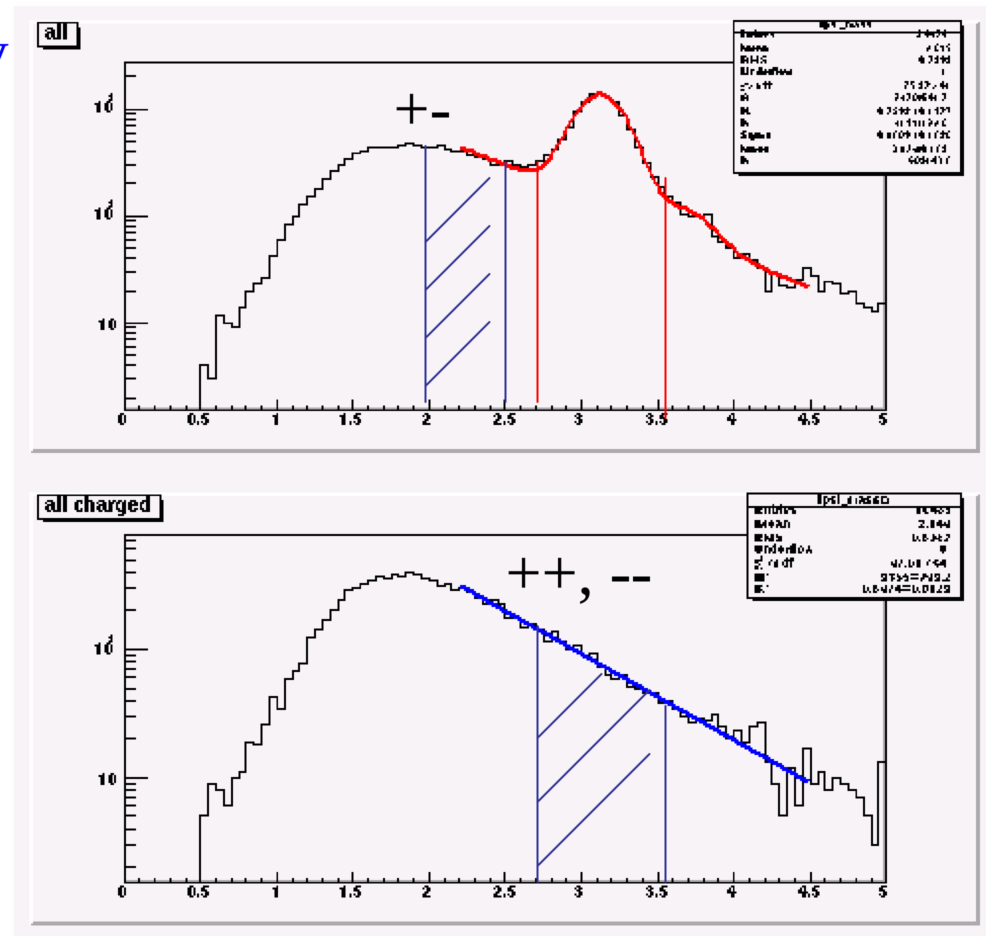
$A_{LL}(raw) = -0.0351 \pm 0.0318$

$N = 988 \pm 31$

$$A_{LL}^{BG}(RAW) = -0.0041 \pm 0.018$$

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

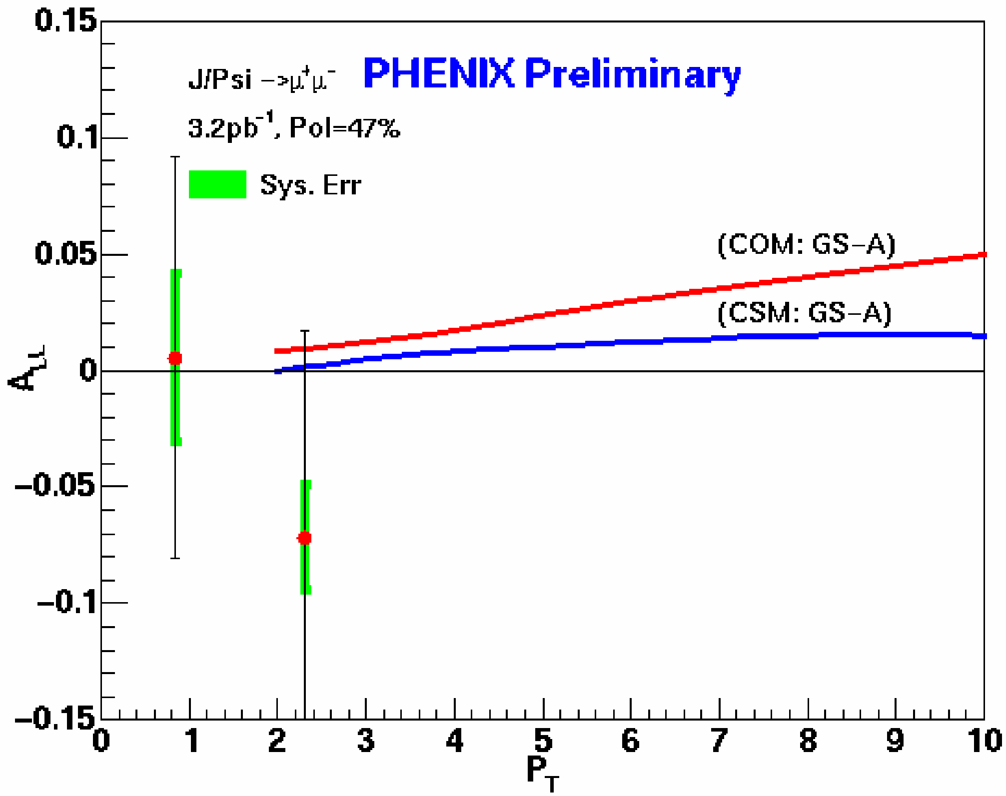
$$\delta A_{LL}^{J/Psi} = \frac{\sqrt{(\delta A_{LL}^{incl})^2 + r^2 \cdot (\delta A_{LL}^{BG})^2}}{1-r}$$

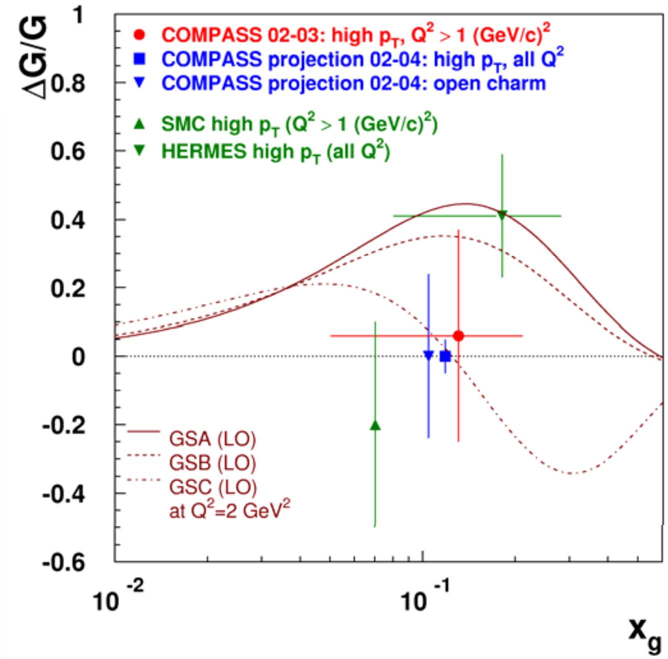


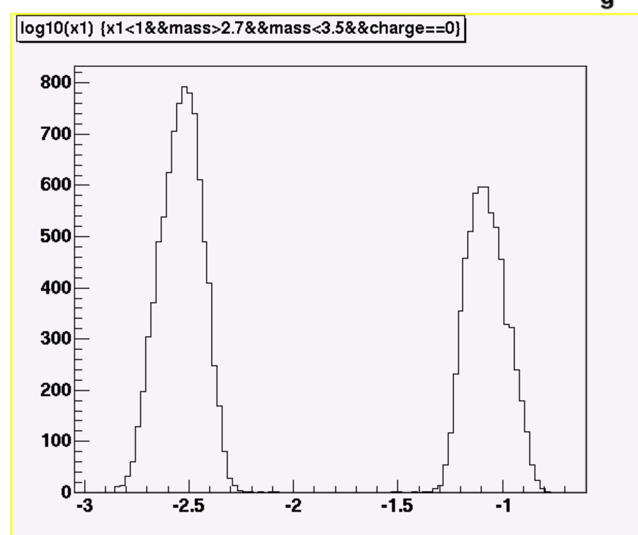

Dimuon mass distributions

# $A_{LL}$ vs pT

J/Psi: |y| = 1.2–2.4



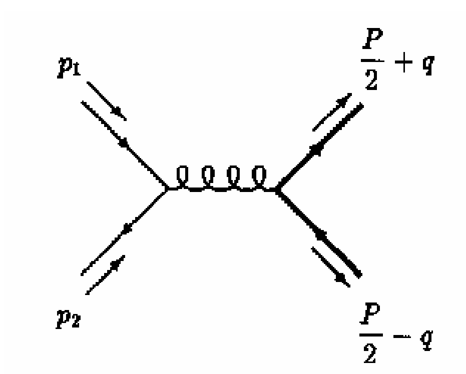



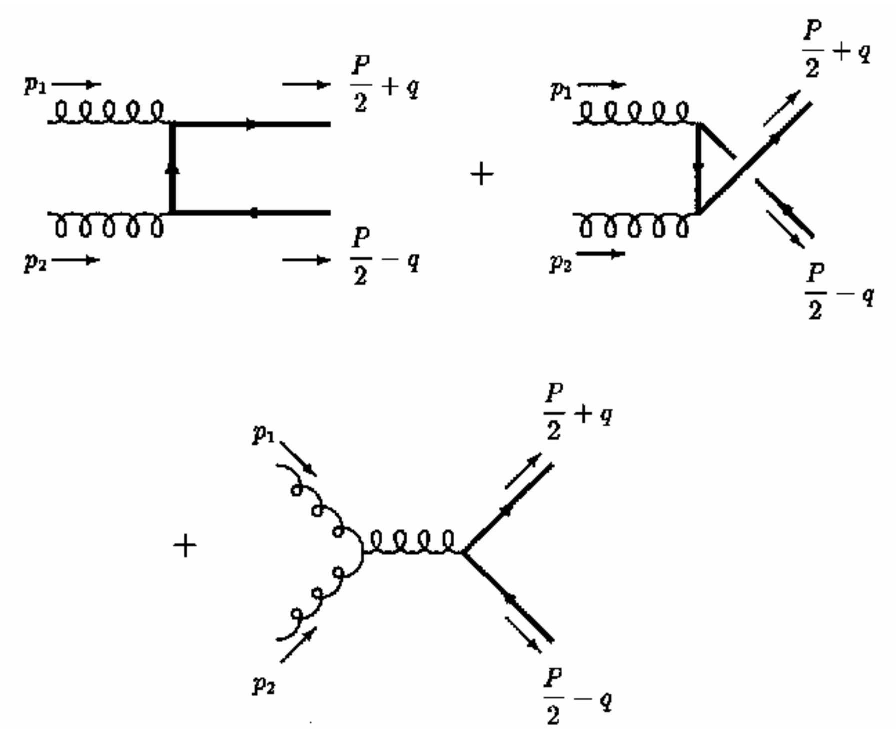

$$A_{LL} \approx \frac{\Delta g(x_1)}{g(x_1)} \frac{\Delta g(x_2)}{g(x_2)} a_{LL}^{gg \to J/\Psi + X}$$

Log(x)

# About Theoretical Calculations

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




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

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

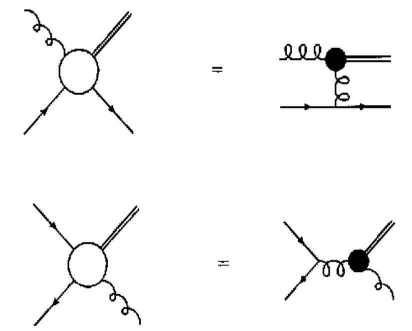
$$+\frac{15}{32}\Delta f_g(x_1,2m)\cdot\Delta f_g(\frac{4m^2}{x_1\cdot s},2m)\times[\frac{9}{m^2}(1-\frac{1}{2}\delta_{\lambda 0})<O_8^{J/\Psi(\lambda)}({}^3P_0)>-<O_8^{J/\Psi(\lambda)}({}^1S_0)>]\}$$

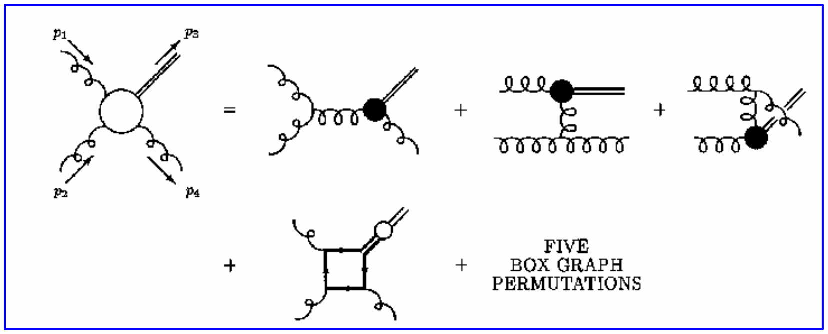
mix of various processes

# Theoretical Calculations (cont.)

- NLO RNQCD: $\sim \alpha_s^3$

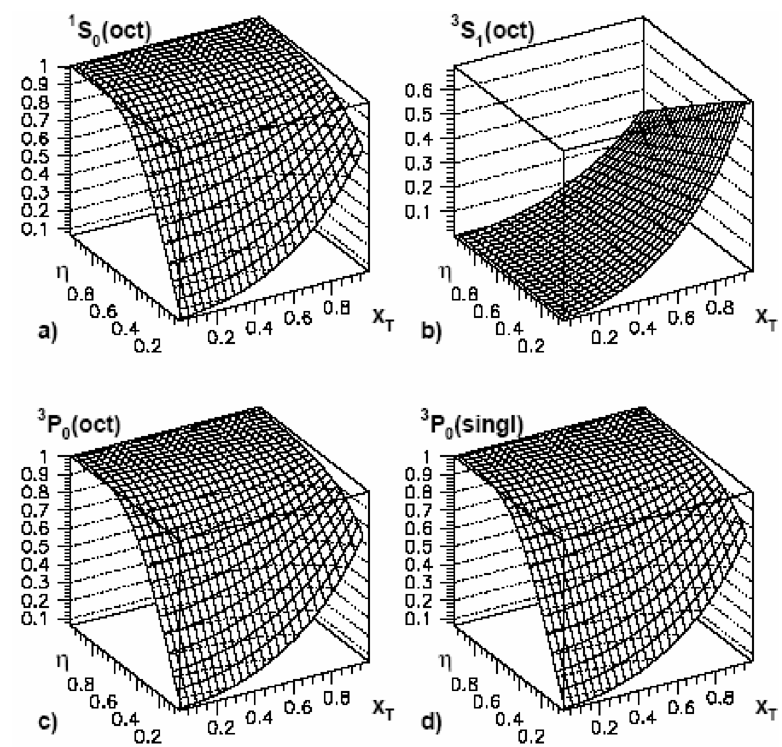
$$g + q \rightarrow \{c, \bar{c}\} + q$$
$$q + \bar{q} \rightarrow \{c, \bar{c}\} + g$$
$$g + g \rightarrow \{c, \bar{c}\} + g$$






Partonic asymmetry for $gg \rightarrow J/\psi\, X$

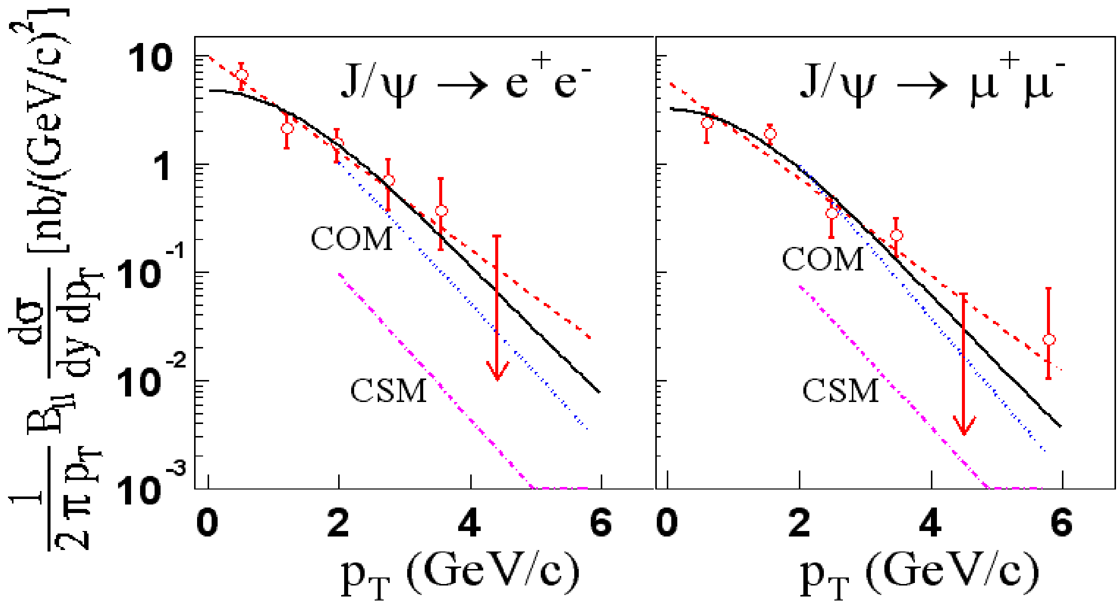
$$a_{LL}^{gg \rightarrow J/\psi X}(\eta = 4m_c^2 / s^2, x_T = p_T / p_{\max})$$




“final state” mixture ratios: fixed from other data

# NLO NRQCD and PHENIX data

PHENIX, PRL 92, 051802 (2004)

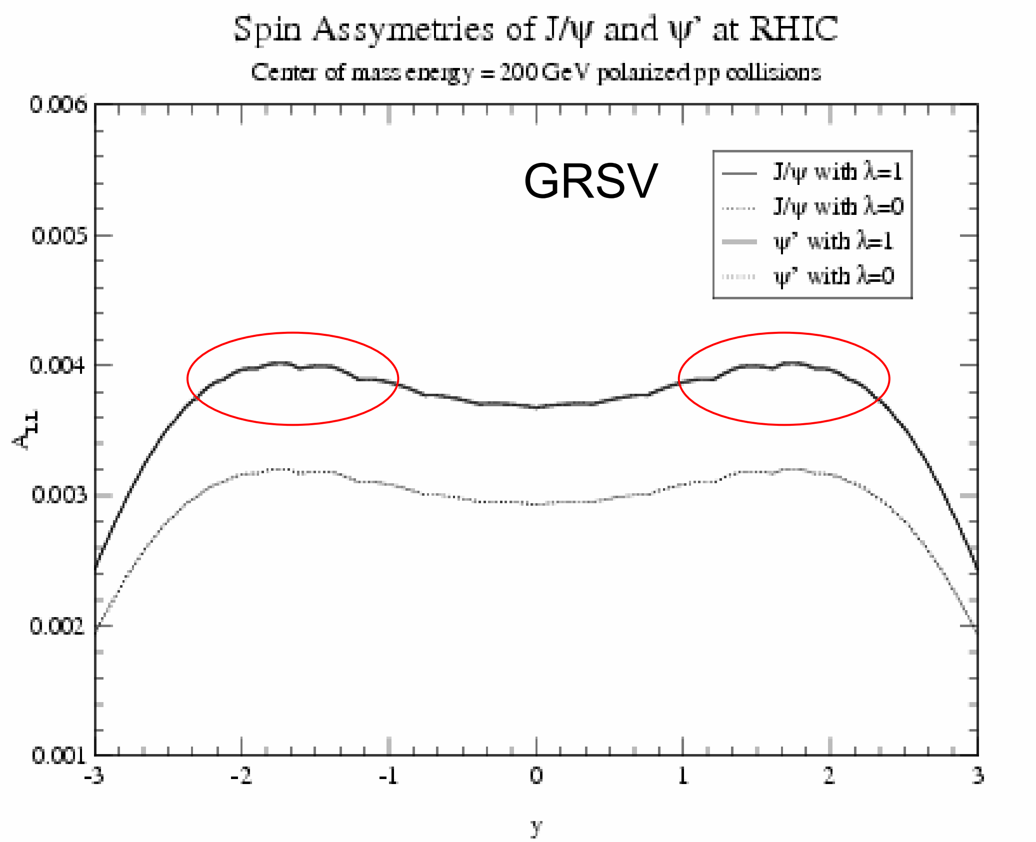



Theoretical predictions of J/Ψ production at RHIC are in good agreement with the PHENIX data: COM process dominant

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

# NRQCD Calculations of $A_{LL}$

- NRQCD LO (hep-ph/0509335 G. Nayak et al.)



# Summary and Outlook

- First measurement of double spin asymmetry with J/Psi from longitudinally polarized p-p collisions
  - Almost pure gluon fusion
  - 10k J/psi, statistically limited
- Theoretical work in progress (G. Nayak et al)
  - No gluon polarization
  - Maximum(+,-) polarization
  - Excellent QCD test ground
- Open charm with prompt muons with a much larger statistics from run5