# Probing the Gluon Polarization with $A_{LL}$ of $J/\Psi$ at RHIC

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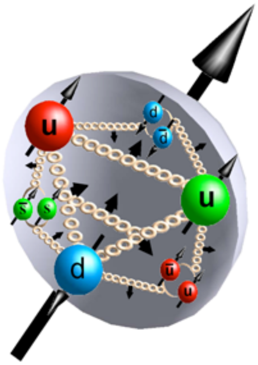
# Spin Crisis and Gluon Polarization

- Proton Spin Puzzle:

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \Delta L_{G+q}$$
$$= J_q + J_G$$




$$\Delta\Sigma \approx 0.3 \quad vs \quad \Delta\Sigma^{QCD} \approx 0.6$$

- Asymptotic limit $Q^2 \to \infty$

$$J_q(Q^2) = \frac{1}{2}\Delta\Sigma + \Delta L_q \to \frac{1}{2}\frac{3n_f}{16+3n_f}$$
$$J_G(Q^2) = \Delta G + \Delta L_G \to \frac{1}{2}\frac{16}{16+3n_f}$$

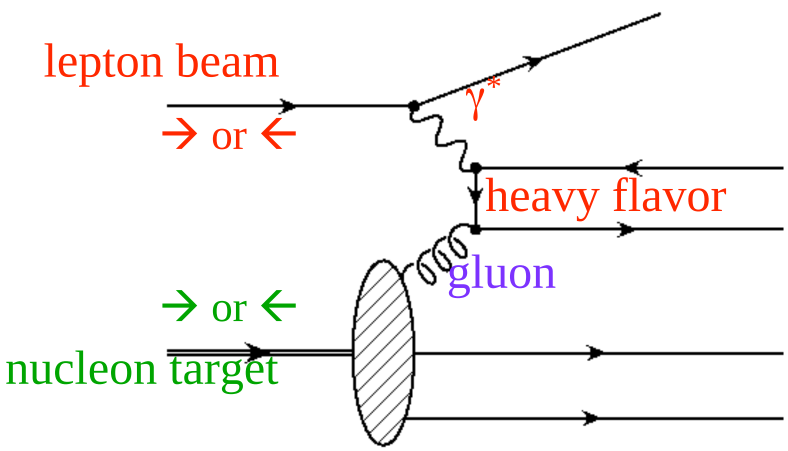
- PCAC

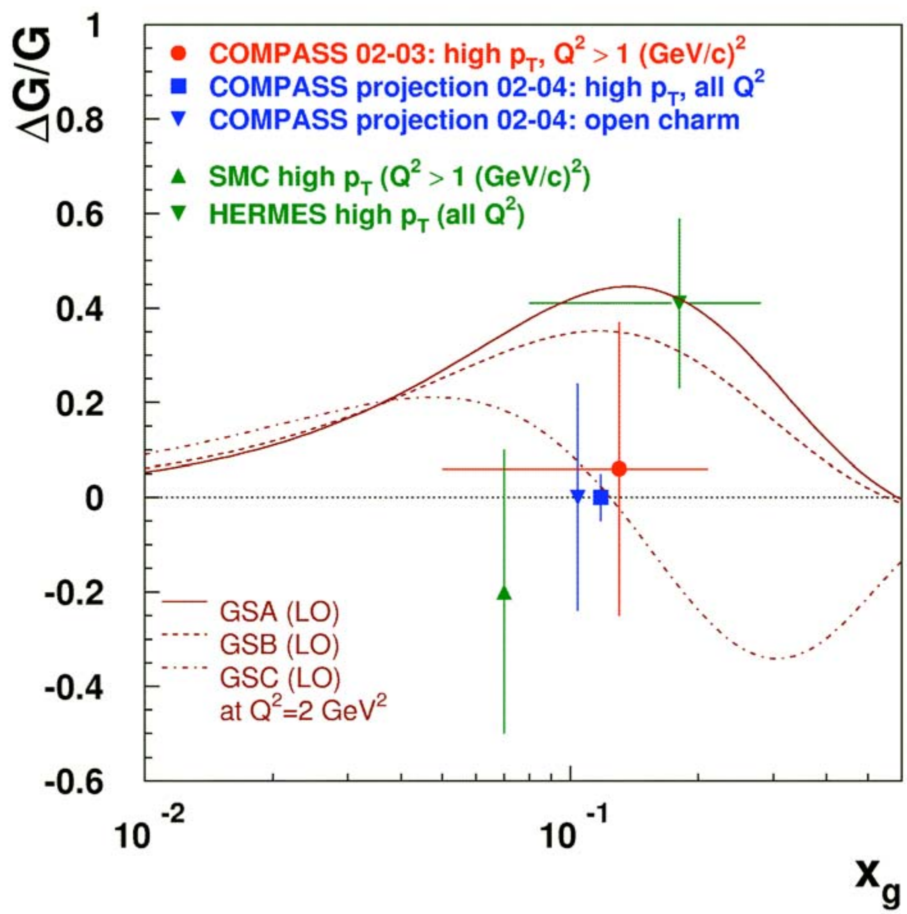
$$\Delta\tilde{\Sigma}^{\exp} = \Delta\Sigma - N_f \frac{\alpha_s}{2\pi}\Delta g$$
$$\Delta\Sigma = 0.6 \to \Delta g \sim 3$$

Gluons may play a significant role !

# Gluon Polarization Measurements: (SI)DIS

- 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

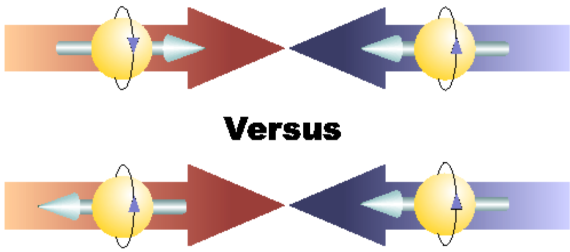


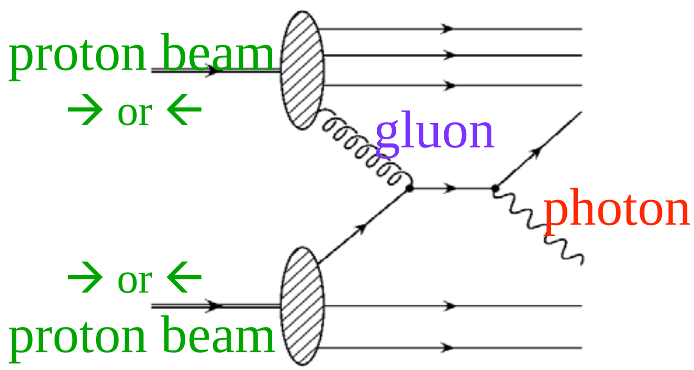
# @RHIC-SPIN

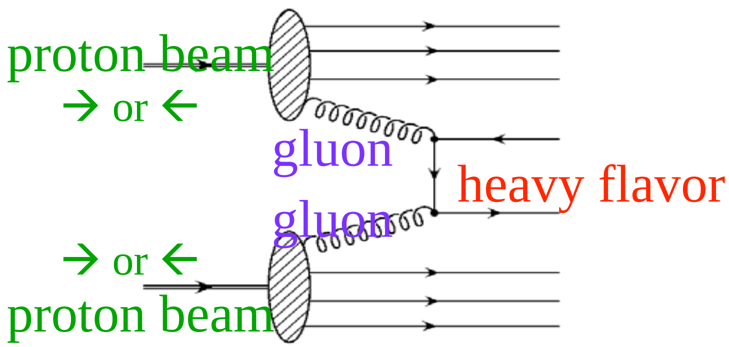
- Polarized hadron collisions
  - double longitudinal spin asymmetry

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

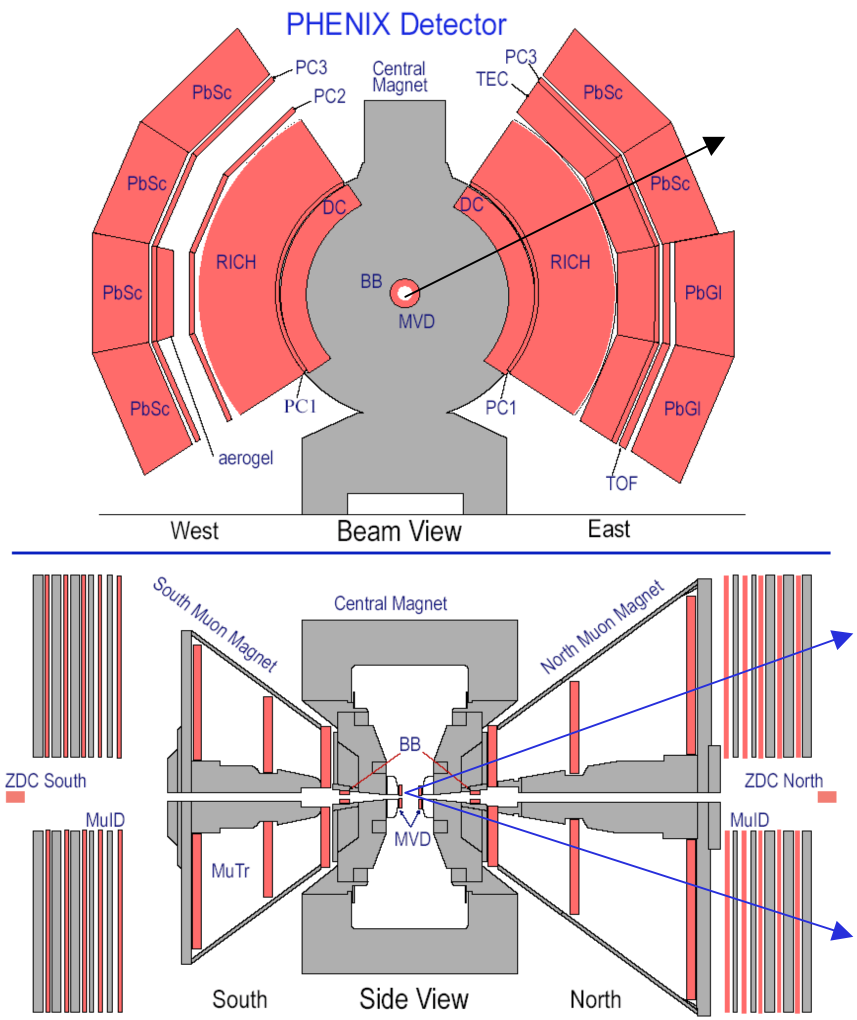



  - leading-order gluon interactions
    - direct-photon production
    - heavy-flavor production



# The PHENIX Detectors




- Central Arms
  - $|\eta| < 0.35$, $\Delta\phi \sim \pi$
  - $\gamma$, $\pi^0$, e, $\pi^{+-}$, ... – Identified
  - Momentum, Energy
- Muon Arms
  - $1.2 < |\eta| < 2.4$
  - Momentum (MuTr)
  - Open charm, $J/\psi$ etc

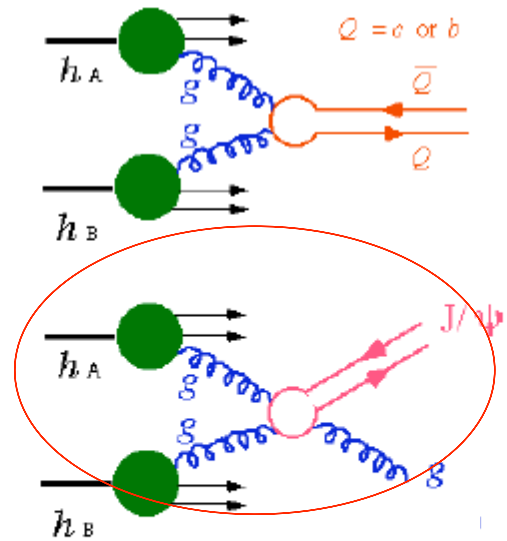
# A New Probe: Heavy Quarks

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

PHYTHA estimate:

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

Gluon Fusion

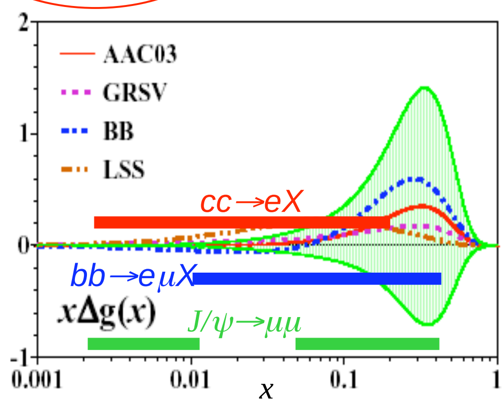


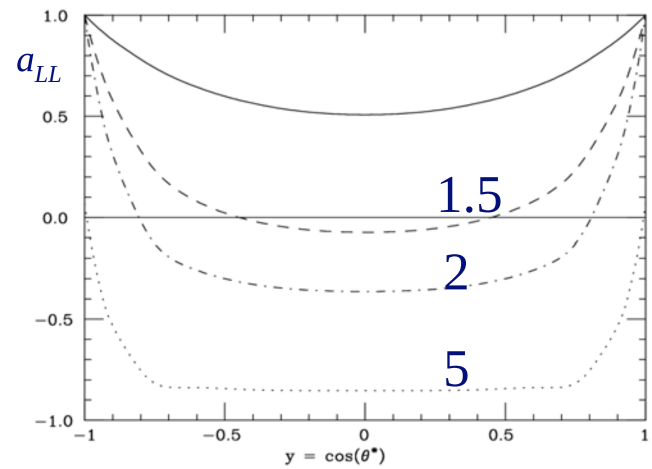

## Double spin asymmetry:

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

*Decay modes:*

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

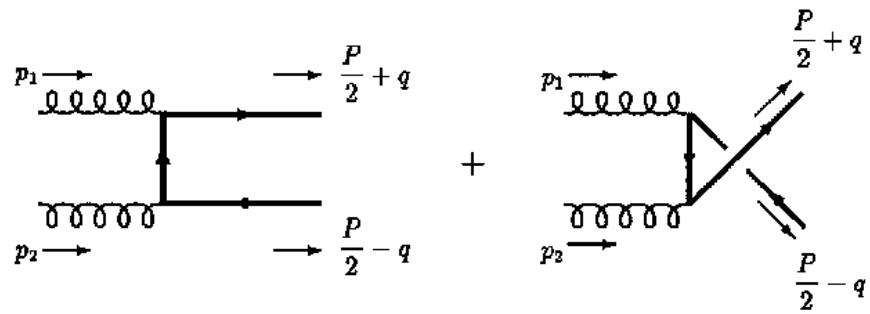


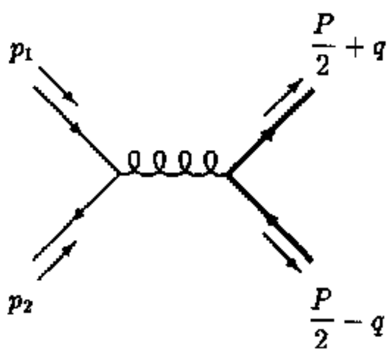



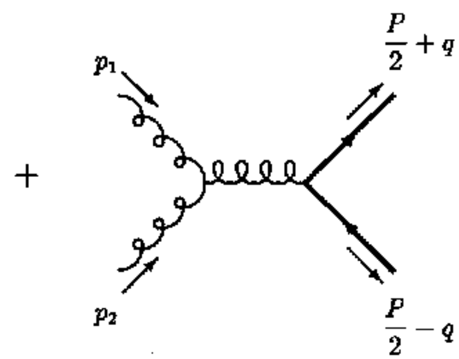

Karliner & Robinett, Phys.Lett.B324 (1994)

# J/ψ production mechanism

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




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

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

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

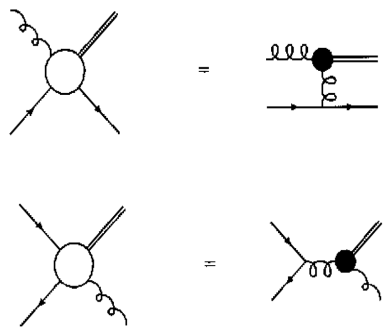
mix of various processes

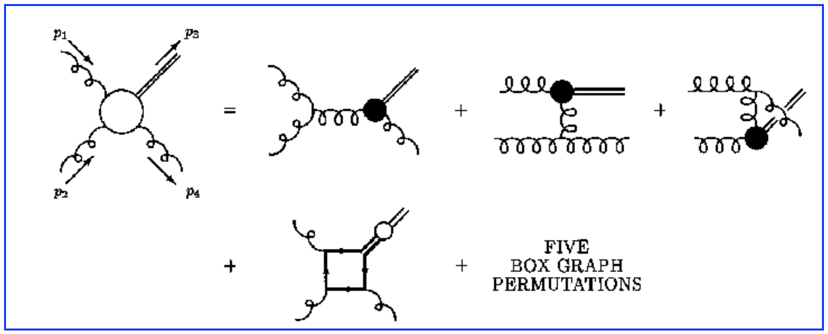
hep-ph/0509335 G. Nayak et al.

# J/ψ production mechanism (cont.)

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

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



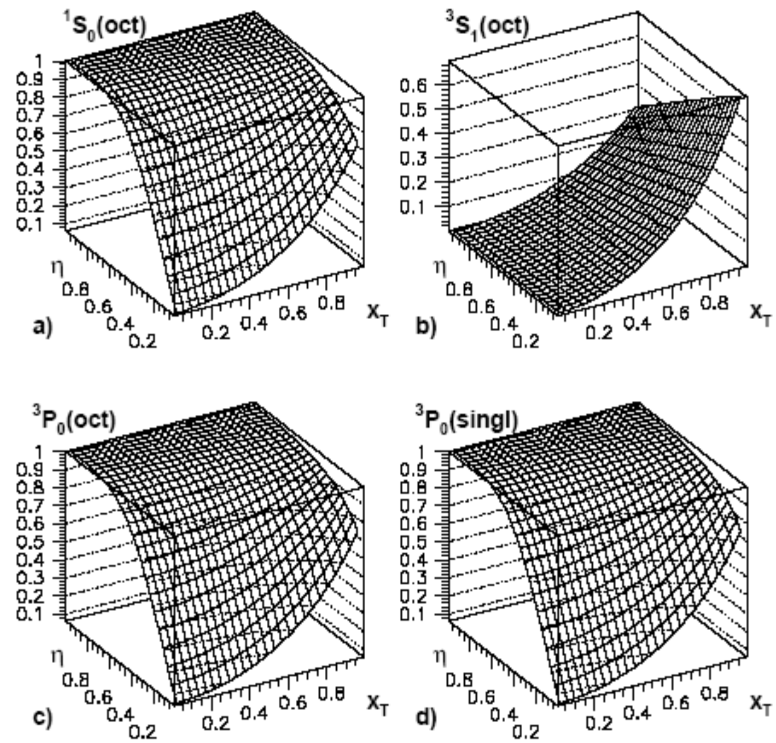




"final state" mixture ratios: fixed from other data

Teryaev and Tkabladze PRD56(97)7331

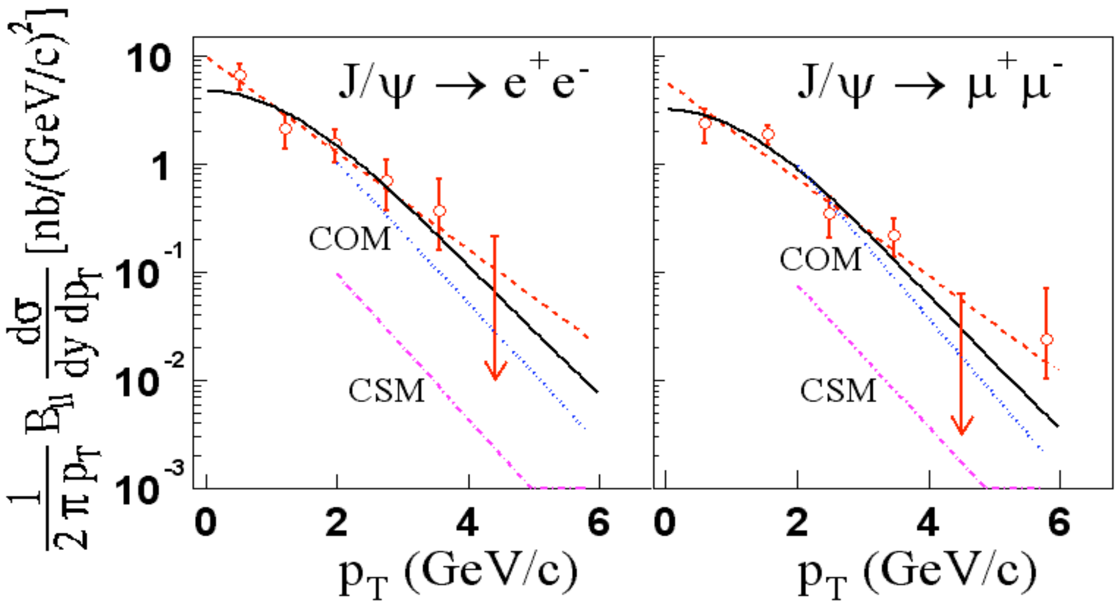
Partonic asymmetry for $gg \rightarrow J/\psi\, X$

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



# 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

# $A_{LL}$ Measurement with $J/\psi \rightarrow \mu^+\mu^-$

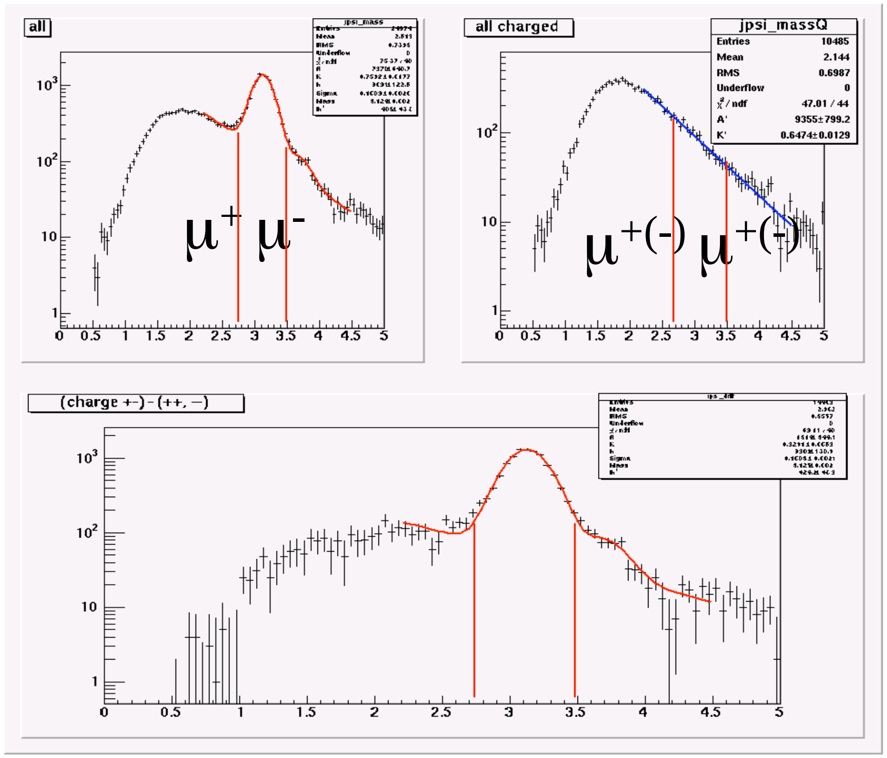
- Experimental approach
  - Polarization=47% (average)
  - R is from Beam-Beam-Counter scalers
  - N_Jpsi Yield

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

$$A_{LL}(raw) = \frac{N_{J/Psi}^{++} - R \cdot N_{J/Psi}^{+-}}{N_{J/Psi}^{++} + R \cdot N_{J/Psi}^{+-}}$$

# J/ψ Yield Measurements

- Fill by fill: ($N^{+-}$ - $N^{++,--}$)
  - Detector efficiency variation canceled out
  - Have Open charm, DY and other background (<10%)
- Gaussian+Exponential background
  - Used to estimate the background under J/Psi peak




Dimuon mass distributions

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

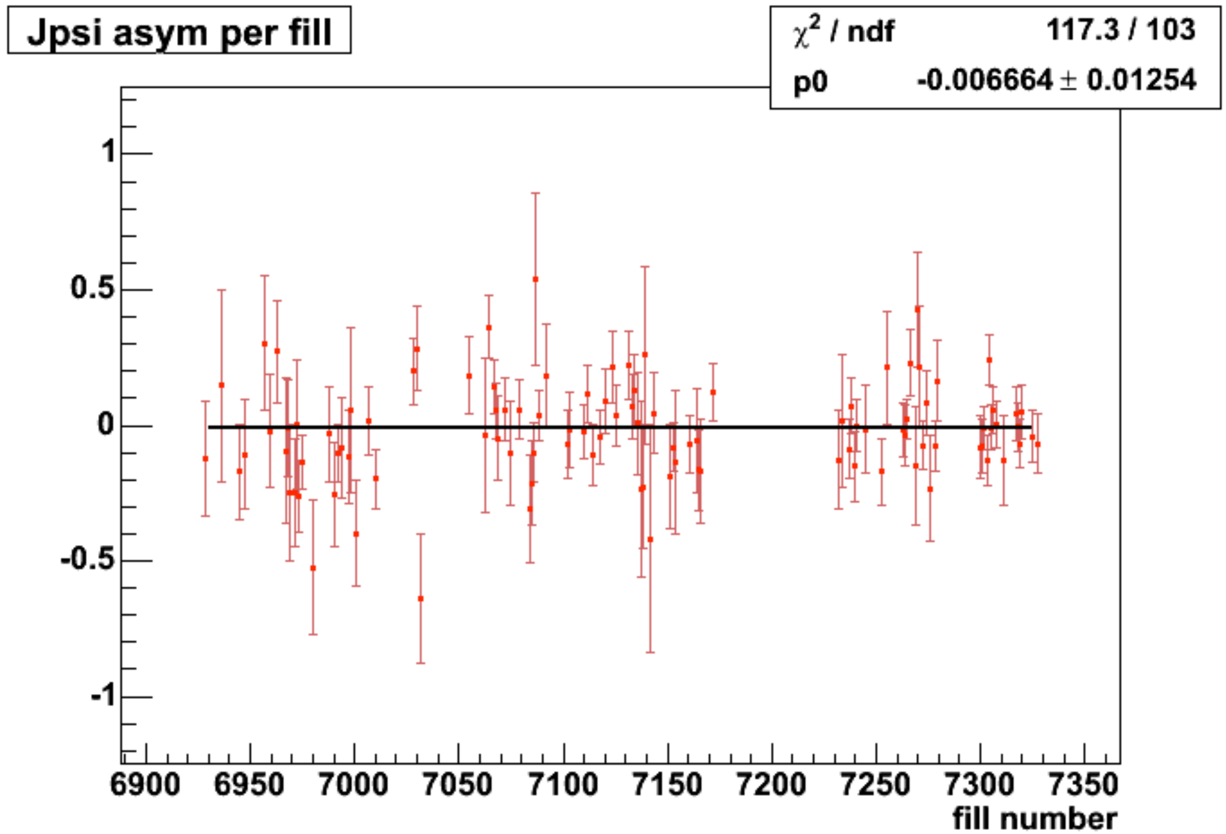
# Raw Asymmetries Fill by Fill:

$N_{J/\Psi} > 10$ per fill

**2 sigma cut:**

**2.78 < *Mass* < 3.42**

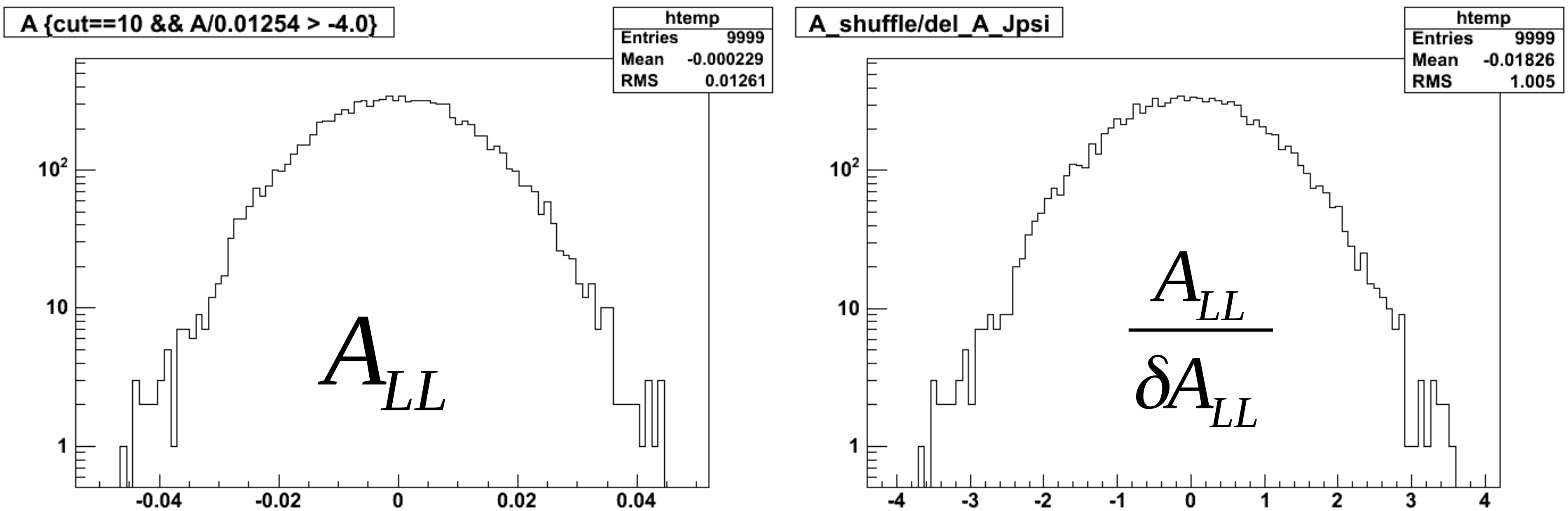
**<*RL*> = 1.0089(3)**




$$A_{LL}(raw) = \frac{N^{++}_{J/Psi} - R \cdot N^{+-}_{J/Psi}}{N^{++}_{J/Psi} + R \cdot N^{+-}_{J/Psi}} = -0.007 \pm 0.013$$

# Statistical Test

- Beam polarization shuffling
  - random beam polarization values
  - repeat 10,000 times



# Background Estimation

## Background Raw Asymmetry

Left of the peak: 2.0 < Mass < 2.5

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

Under the peak:

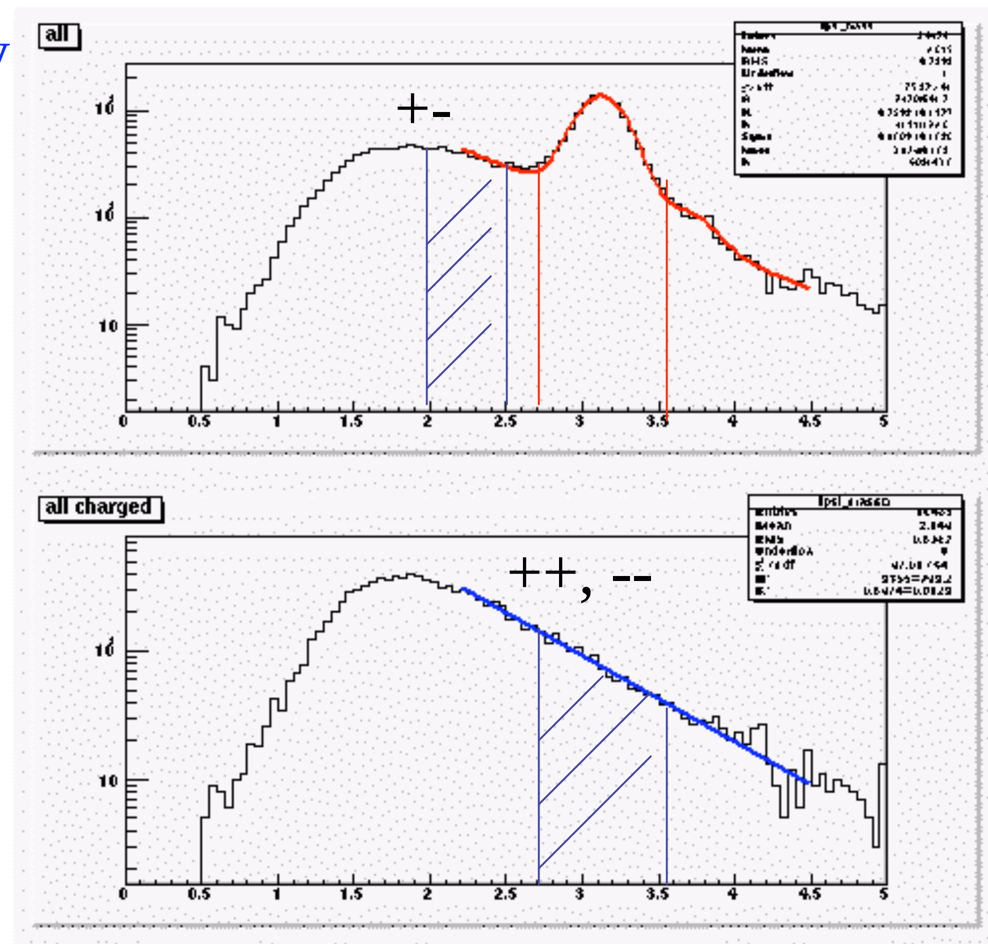
$A_{LL}(raw) = -0.0351 \pm 0.0318$

$N = 988 \pm 31$

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

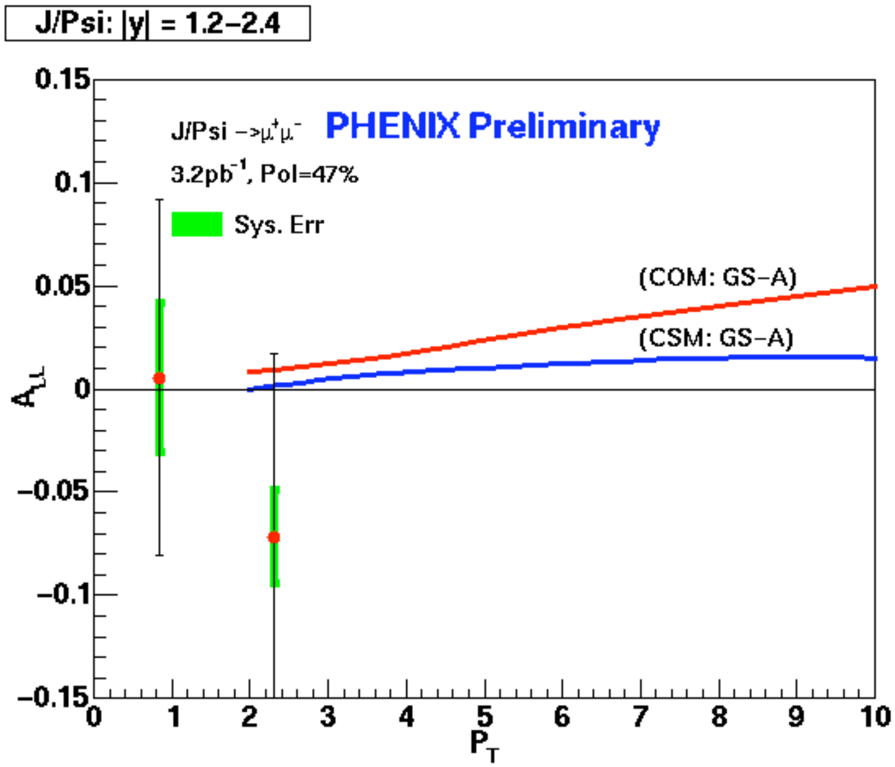
$$A_{LL}^{J/Psi} = \frac{A_{LL}^{incl} - r \cdot A_{LL}^{BG}}{1-r}$$

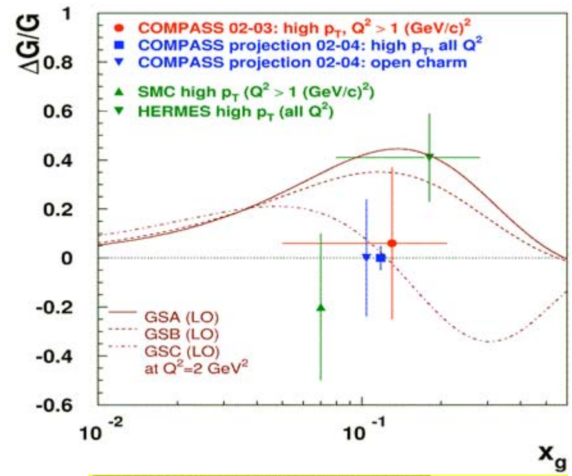
$$\delta A_{LL}^{J/Psi} = \frac{\sqrt{(\delta A_{LL}^{incl})^2 + r^2 \cdot (\delta A_{LL}^{BG})^2}}{1-r}$$

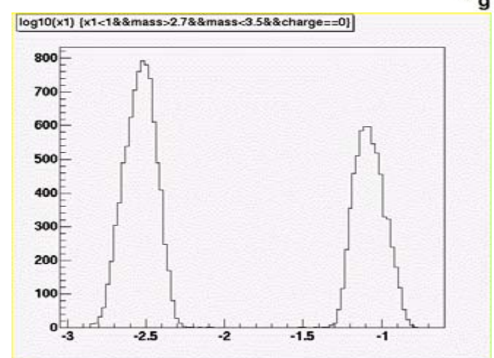



Dimuon mass distributions

# $A_{LL}$ vs pT




Log(x)

## First spin physics result from J/Ψ

- J/ψ: produced via almost pure gluon fusion
- sensitive to gluon polarization

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

# Summary and Outlook

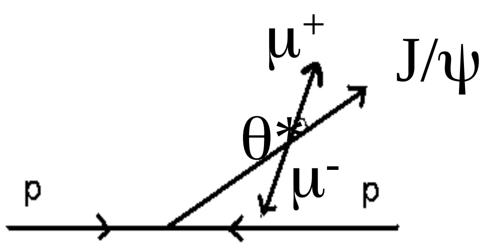
- First measurement of double spin asymmetry with J/Psi from longitudinally polarized p-p collisions
  - Almost pure gluon fusion
  - 10k J/psi, statistically limited
  - Expect x100 more statistics in the future
- Work in progress
  - J/Psi polarization measurement
  - Open charm - much larger statistics from run5 and will tell us more about gluon polarization
- Need more theoretical work
  - $J/\Psi$ production mechanism
  - Polarized gluon PDFs
  - Excellent QCD test ground with polarization
- Where does the nucleon get its spin?
  - Still don't know … but RHIC-SPIN will help us to find the answer
  - and we will learn a lot more about the nature of strong interactions

# More on J/ψ Production Mechanism

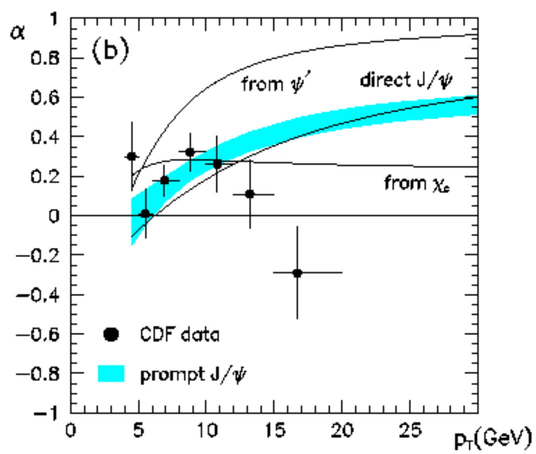
- J/Psi polarization - a key probe?
- Spin dynamics in pQCD

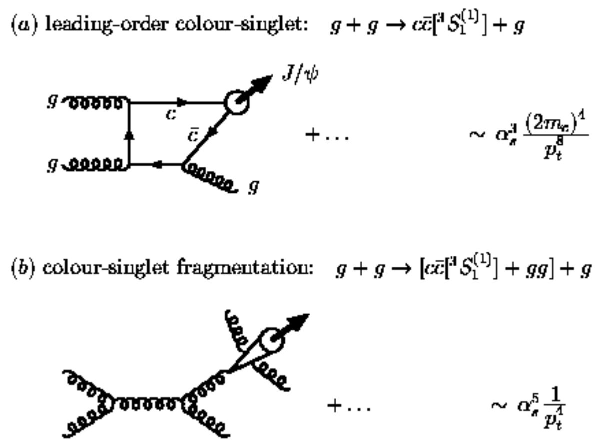
$$\frac{d\sigma}{d\cos\theta^*} \propto 1+\alpha\cos^2\theta^*$$

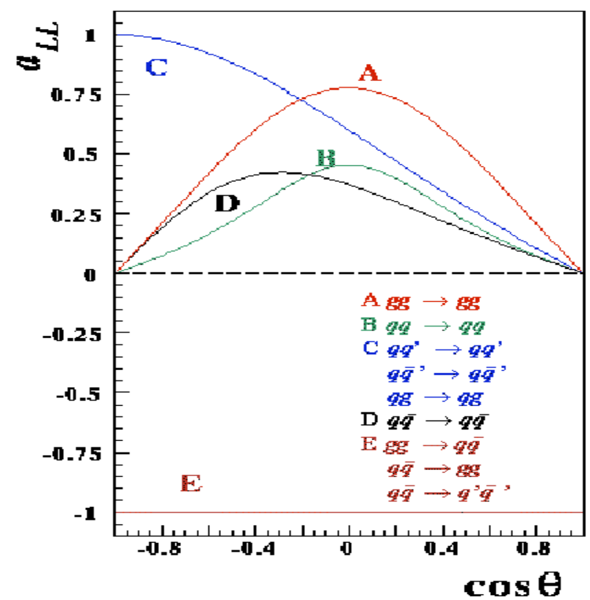
α= +1: transversely polarized
α= -1: longitudinally polarized
α= 0: no polarization




hep-ph/0106120 M. Kramer



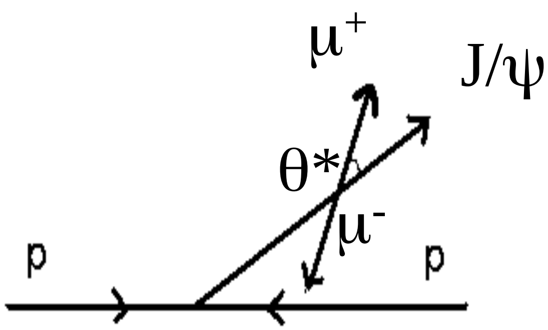



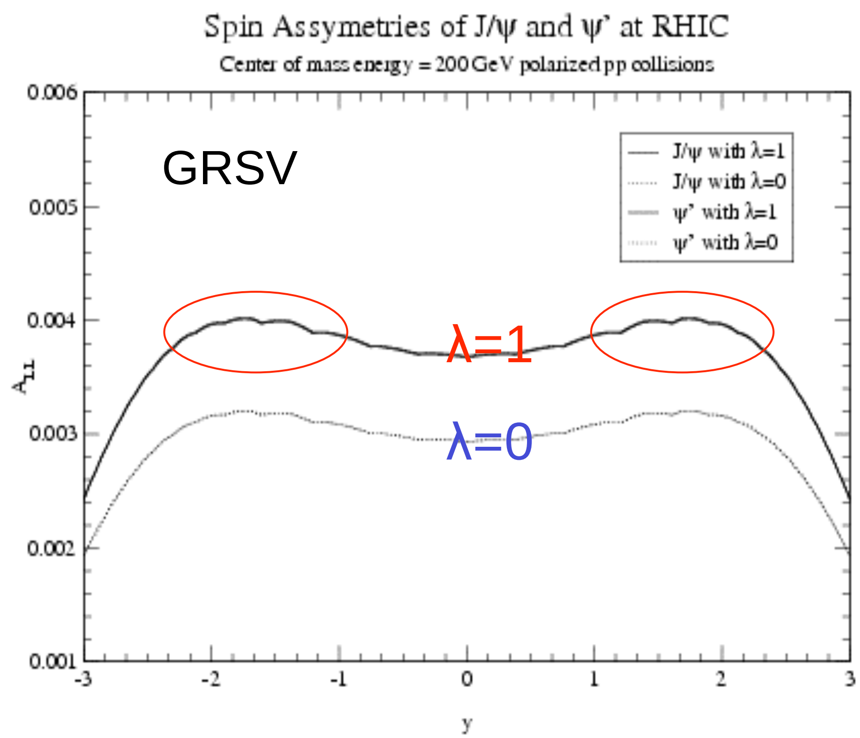
# NRQCD Calculations of $A_{LL}$

- NRQCD LO

Helicity dependent double-spin asymmetry




hep-ph/0509335 G. Nayak et al.




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

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

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