PHENIX

Spin2014

J/ψ Longitudinal Double Spin Asymmetry Measurements at Forward Rapidity in p+p Collisions at PHENIX

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Outline:

- Introduction
- PHENIX experiment and recent measurements
- Summary

Introduction

J/ψ production in p+p at RHIC

At RHIC energies J/ψ's are predominantly produced through gluon-gluon interaction

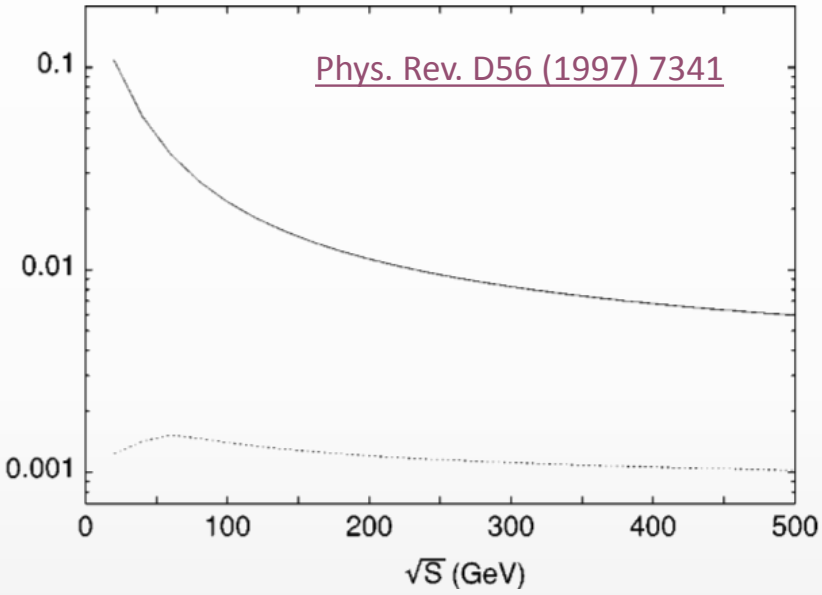
Factorization for J/ψ production (LO)

$$\sigma(pp \to J/\psi X) = g(x_1)g(x_2) \otimes \hat{\sigma}^{gg\to c\bar{c}}(\hat{s}) \otimes \mathcal{D}_{c\bar{c}}^{J/\psi} + \ldots$$

Thus, the asymmetry in production is sensitive to gluon polarzation

A_{LL} for J/Ψ production (LO)

$$A_{LL} = \frac{\Delta\sigma}{\sigma} \sim \frac{\Delta g(x_1)}{g(x_1)} \frac{\Delta g(x_2)}{g(x_2)} \otimes \hat{a}_{LL}^{gg\to c\bar{c}}$$



$q\bar{q}$ to gg ratios of unpolarized (solid) and polarized (dashed) processes

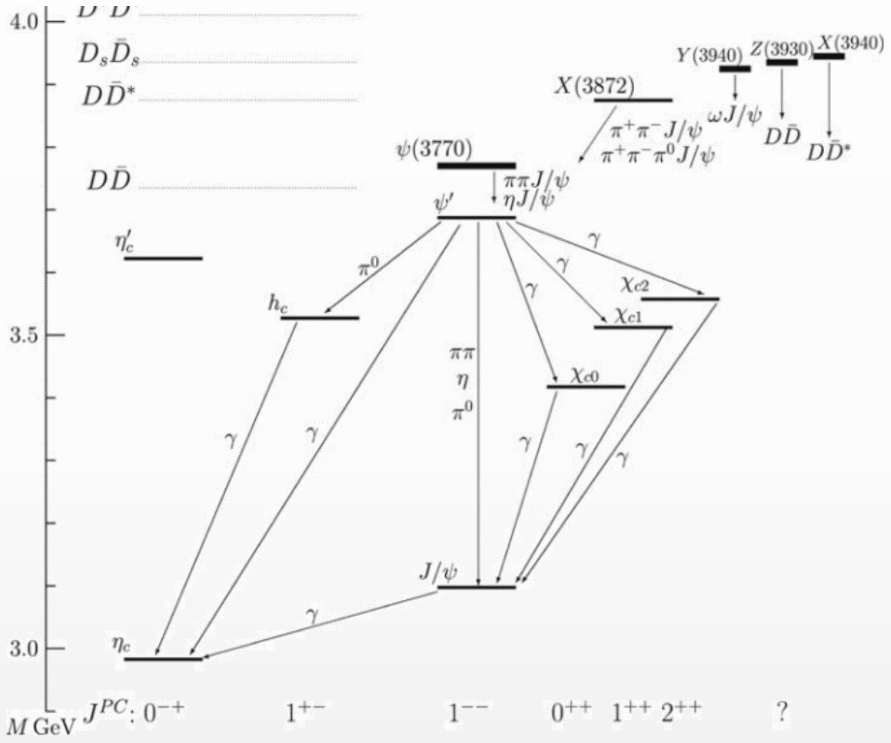
Introduction

Excited states feed-down fraction of J/ψ

Charmonium

- Except for J/ψ's, excited charmonium states are also generated in RHIC p+p collisions
- χ_c feed-down forms a sizable portion
  - Phys. Rev. D 85, 092004 (2012)
- ψ' overlaps J/ψ
- Fortunately:

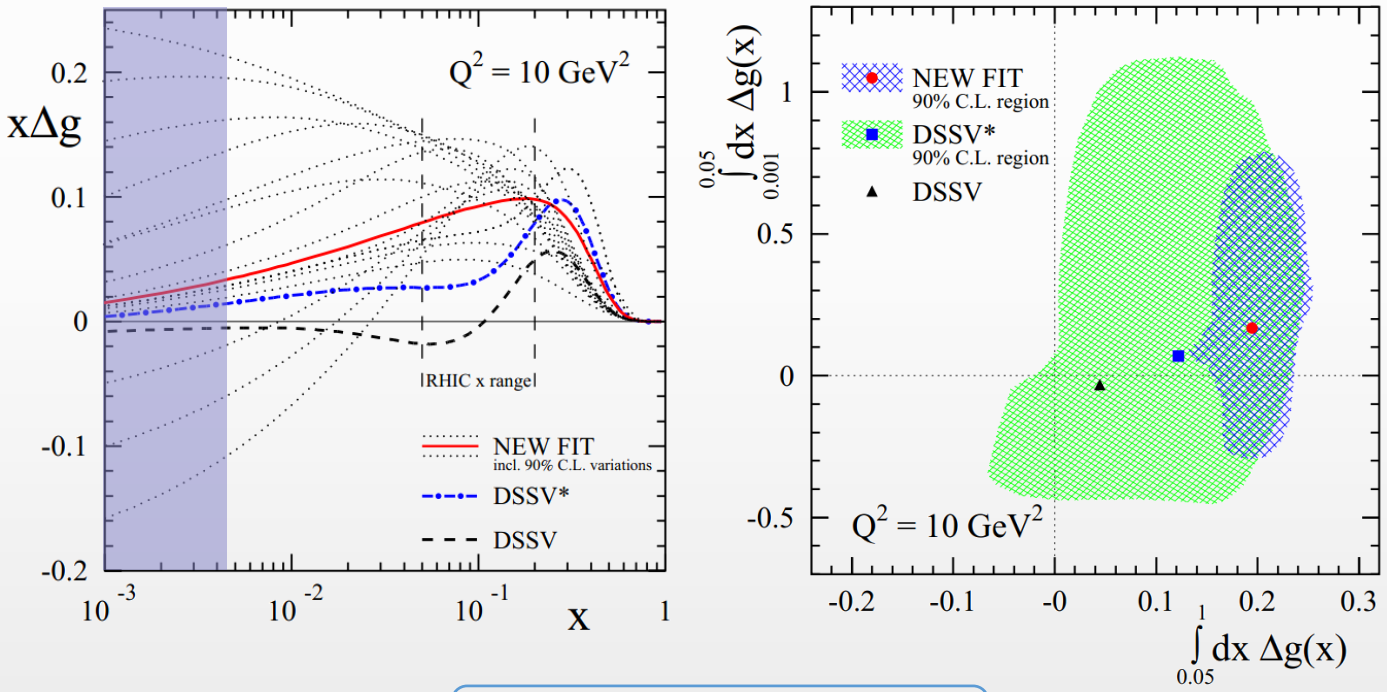
$$A_{LL}^{J/\psi} \approx A_{LL}^{\chi_c} \approx A_{LL}^{\psi'} \propto \frac{\Delta g(x1)}{g(x1)} \frac{\Delta g(x2)}{g(x2)}$$



Introduction

2014 DSSV Global Fit

- Including 2009 RHIC data sets, the 2014 DSSV global fit suggests non zero polarization of gluons in the proton at intermediate x range (0.05~1).
- Yet at low x range, the errors of DSSV are still poorly constrained



Phys. Rev. Lett. 113, 012001 (2014)

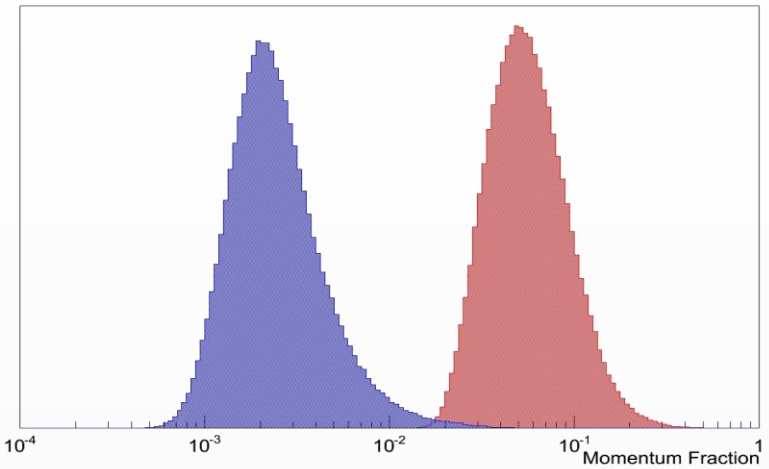
Introduction

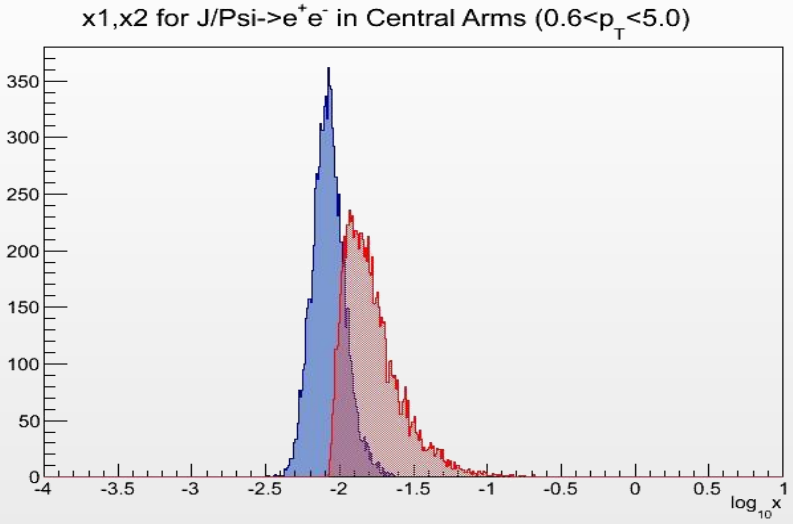
x range of $gg \to J/\psi \to \mu^+\mu^-$ at forward rapidity

Benefits of Forward Rapidity

- At forward rapidity the x distributions of the two gluons are at very different region
- Instead of probing $\sim(\Delta g/g)^2$ we are probing $\frac{\Delta g(x1)}{g(x1)}\frac{\Delta g(x2)}{g(x2)}$
- High-x gluon sits in the x-range where RHIC Run9 data already has constraints on the Δg
- Therefore, this forward $J/\psi \to \mu^+\mu^-$ A_{LL} gives sensitivity to possible sign change in Δg and cleanly accesses down to $x \sim 2 \times 10^{-3}$

$gg \to J/\psi + X \to \mu^+\mu^- + X$ @ $forward\ rapidity$



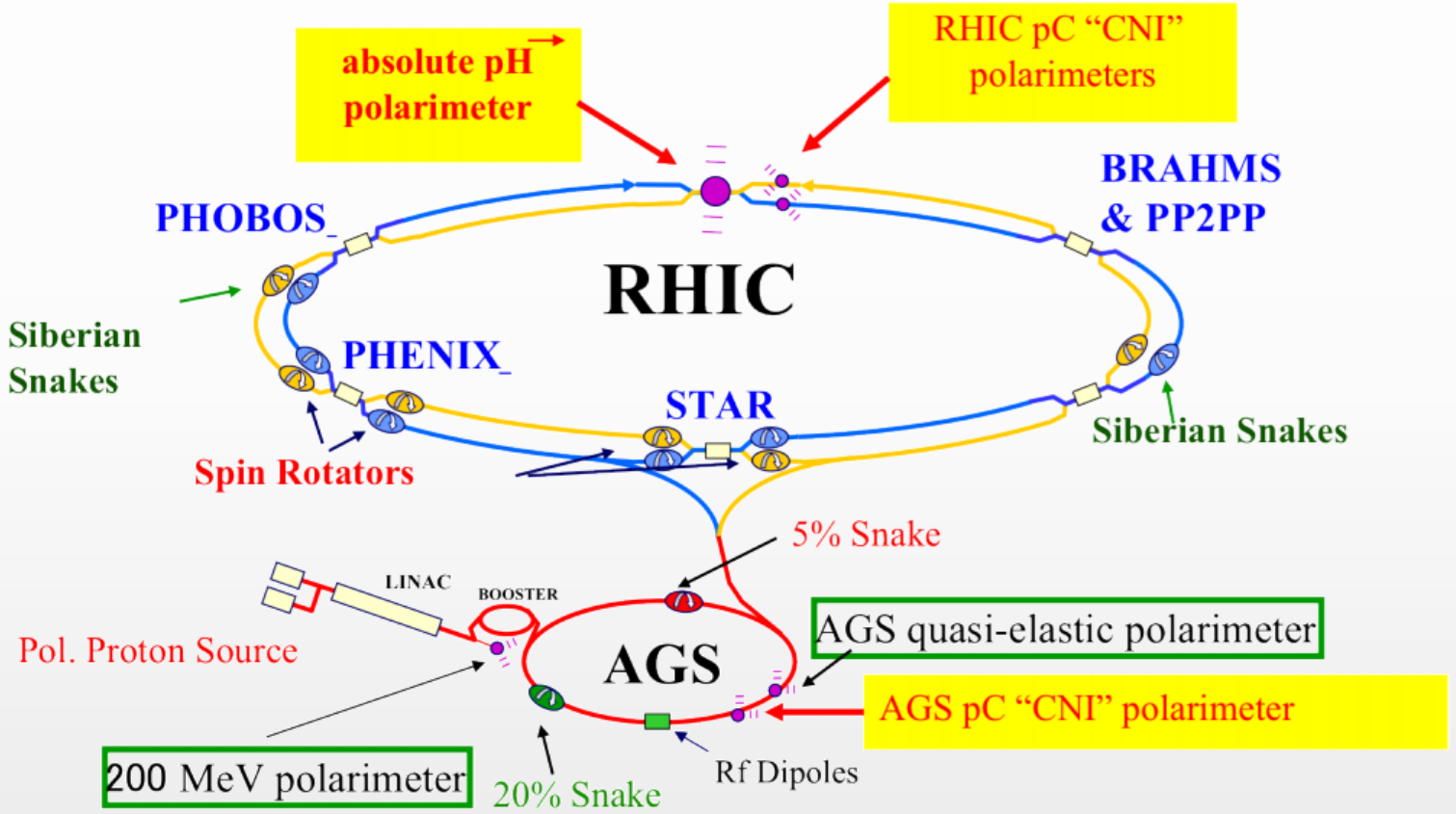


from Pythia simulation

RHIC

Brookhaven National Laboratory

World's only polarized pp collider



Up to $\sqrt{s} = 510$ GeV with $P \sim 60\%$ in transverse or longitudinal orientation

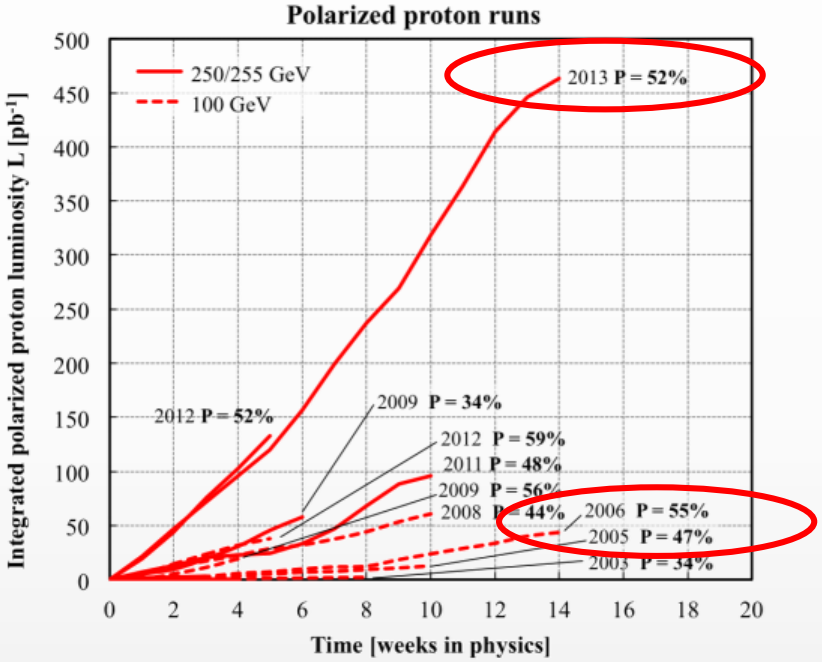
RHIC Spin

Recent Runs

Recent Spin Runs

- 2009: First 500 GeV longitudinal
- 2011: 500 GeV longitudinal
- 2012: 200 GeV transverse and 510 GeV longitudinal
- 2013: 510 GeV longitudinal run

Combined data from 2009-2013 longitudinal runs provide a high statistics, high polarization sample for sea quark and gluon polarization studies

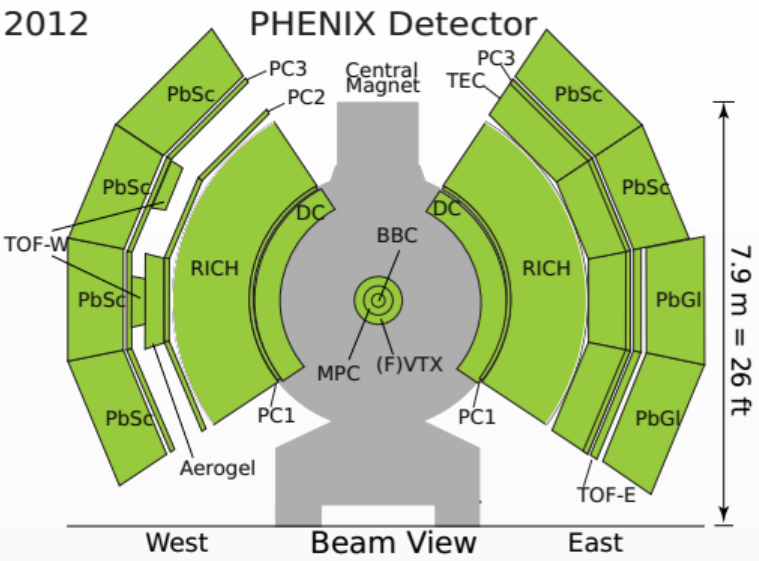


Figures of Merit

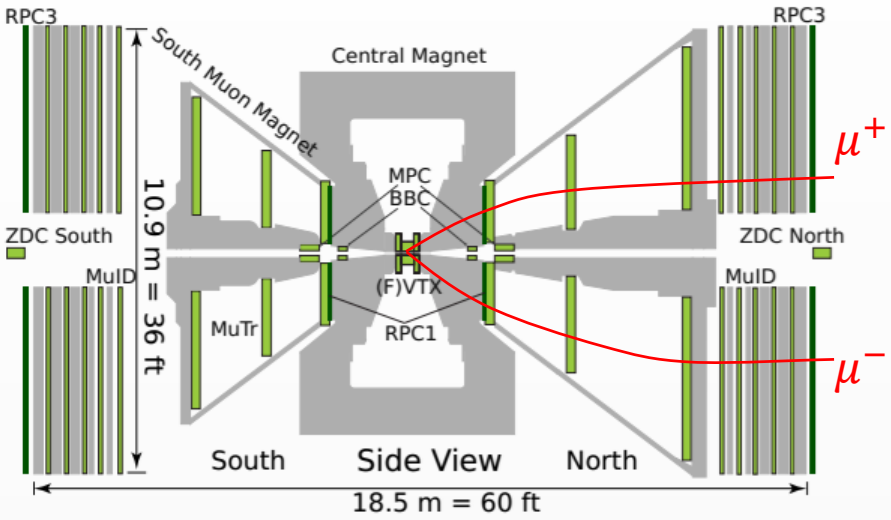
- Single Spin Asymmetry FOM: $L\langle P\rangle^2$
- Double Spin Asymmetry FOM: $L\langle P\rangle^4$

High polarization is essential for an effective measurement of A_{LL}

PHENIX Central Arm



Forward Muon Spectrometer

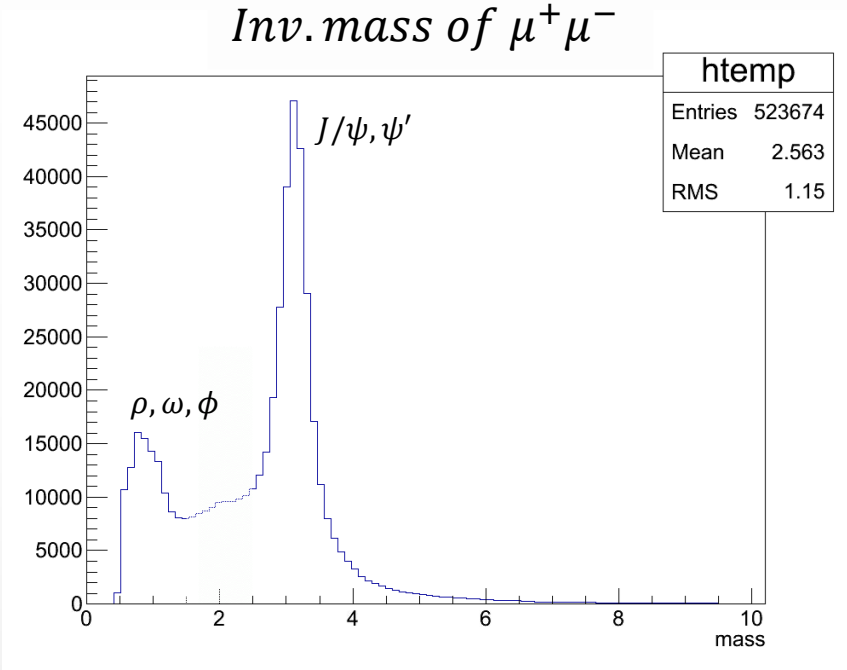


- Energy measured in EM Calorimeter (PbSc + PbGl)
- Momentum/Tracking in Drift Chamber (DC) + Silicon Barrel (VTX)
- PID with Ring Imaging Cherenkov Counter (RICH)
- $|\eta| < 0.35$, $\Delta\phi = 2 \times \frac{\pi}{2}$

- Silicon strip tracking and vertexing (FVTX)
- Momentum measured in cathode strip tracking chambers (MuTr)
- $\mu^{\pm}$ ID from Iarocci tubes interleaved with steel absorbers (MuID)
- $1.2 < |\eta| < 2.2$, $\Delta\phi = 2\pi$

Event and track selection

- *Vertex selection: |BBC_Z|<30 cm*
- *common PHENIX muon tracks quality cuts including:*
  - *from same arm*
  - *track matching between muon tracker and identifier*
  - *penetrating muon candidates cuts*
  - *etc.*
- *RPC timing cut are applied to guarantee J/ψ's are from the right bunch crossing*



$\mu^+\mu^-$ *inv. mass spectrum* after event and μ track selection
sideband region is used to estimate background asymmetry

J/ψ A_{LL}
measurement procedure

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{1}{P_B P_Y} \frac{N^{++} - R\,N^{+-}}{N^{++} + RN^{+-}}, (R = \frac{L^{++}}{L^{+-}})$$

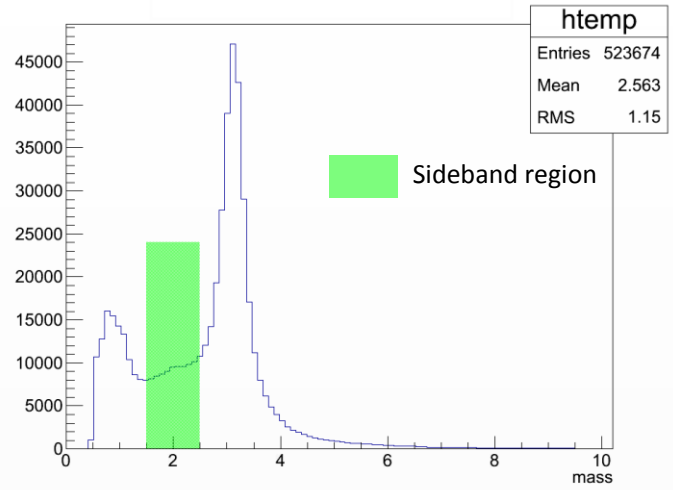
Outline

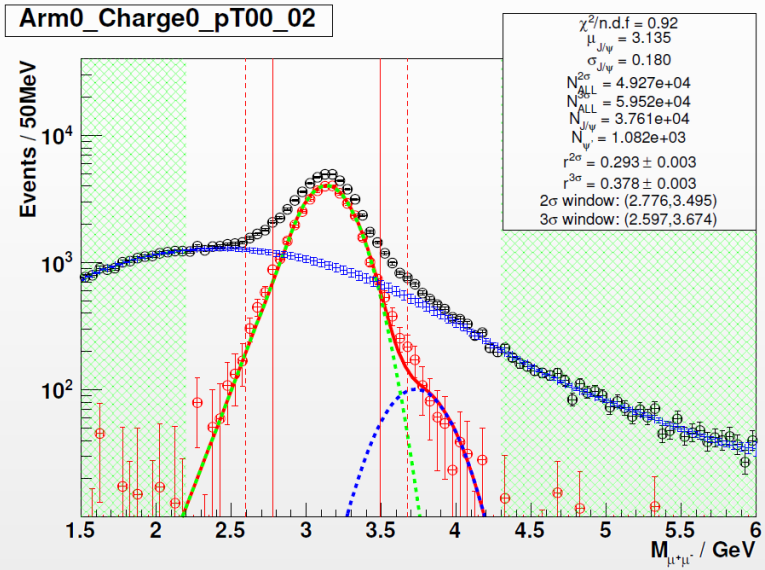
- Analyze south and north arm separately, and divide data from each arm into 3 p_T bins. So 6 subsets total.
- Fit each subsets for 2σ J/ψ mass window and background fraction "r".
  - CB shape for J/ψ, Gaussian for ψ'
  - Gaussian Process Regression (GPR) for background shape
- Sideband region is defined as $M_{\mu\mu} \in [1.5GeV, 2.5GeV]$
- Calculate $A_{LL}^{incl.}$ in the 2σ J/ψ mass window
- Estimate the background asymmetry from a sideband

$$A_{LL}^{J/\psi} = \frac{A_{LL}^{incl.} - r * A_{LL}^{BKG.}}{1 - r}$$

statistical uncertainty: $\Delta A_{LL}^{J/\psi} = \frac{\sqrt{(\Delta A_{LL}^{incl.})^2 + r^2 * (\Delta A_{LL}^{BKG.})^2}}{1-r}$

$Inv.mass\ of\ \mu^+\mu^-$



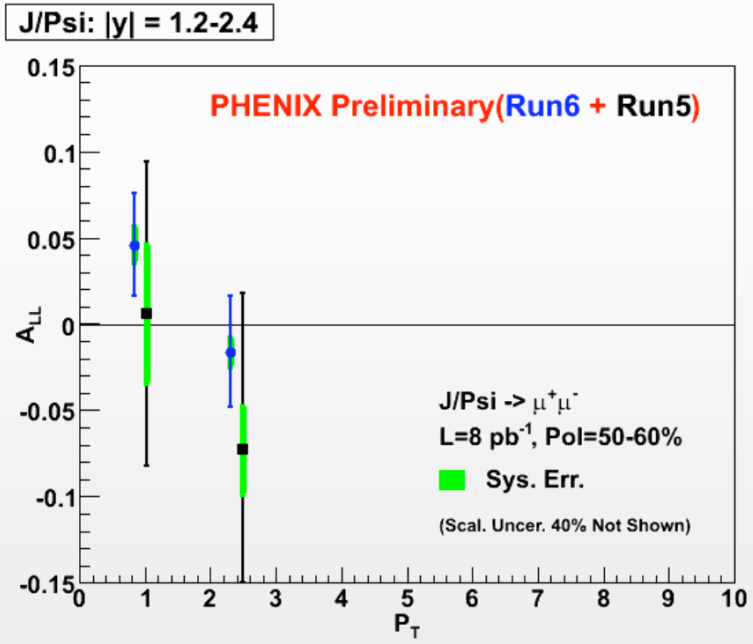


Gaussian Process Regression (GPR) background fraction extraction:
1 of the 6 subsets: north arm, $p_T \in [0,2GeV/c]$, and $r^{2\sigma} = 0.293 \pm 0.003$ for this subset

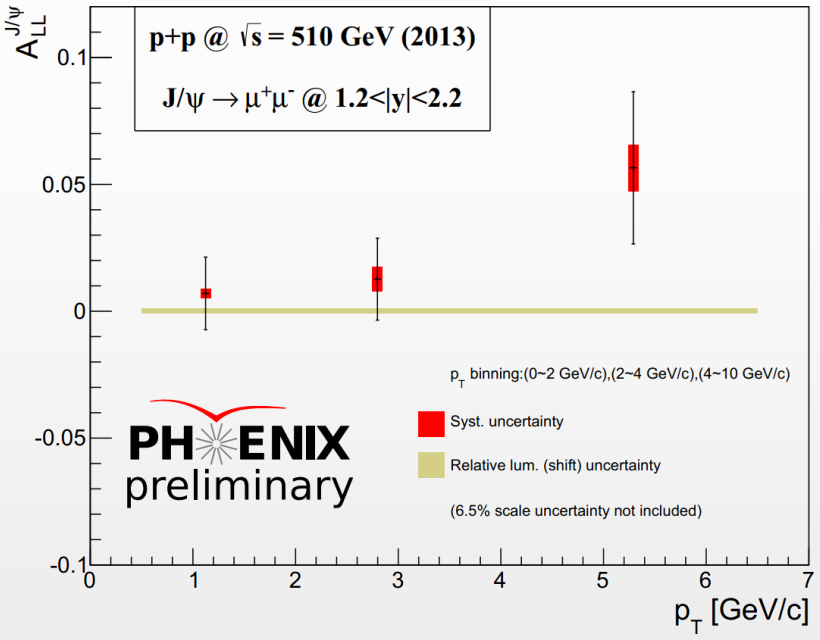
J/ψ A_{LL} @ forward rapidity

recent results

$$pp \to J/\psi + \mathrm{X} \to \mu^+ + \mu^- + X$$
$$@\ \sqrt{s} = 200GeV$$



$$pp \to J/\psi + \mathrm{X} \to \mu^+ + \mu^- + X$$
$$@\ \sqrt{s} = 510GeV$$



Summary & outlook

- The J/ψ A_{LL} measurements at forward rapidity provide access to the small-x region (~10^{-3}) where the gluon polarization is poorly constrained

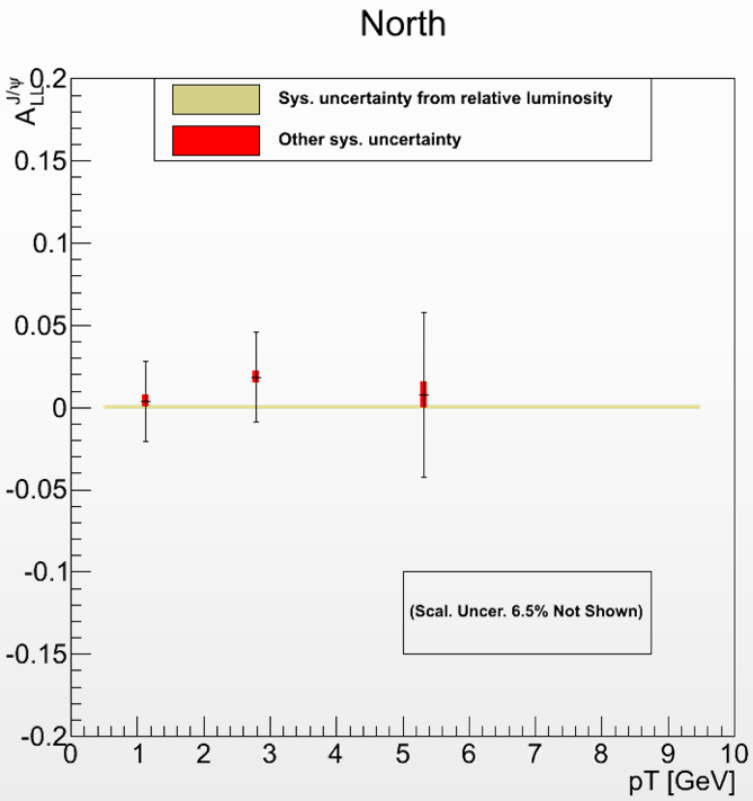
- With the large statistics longitudinal p+p data collected at RHIC in 2013, we measured $A_{LL}^{J/\psi}$ at forward rapidity with smaller uncertainty compared with similar prior RHIC measurements

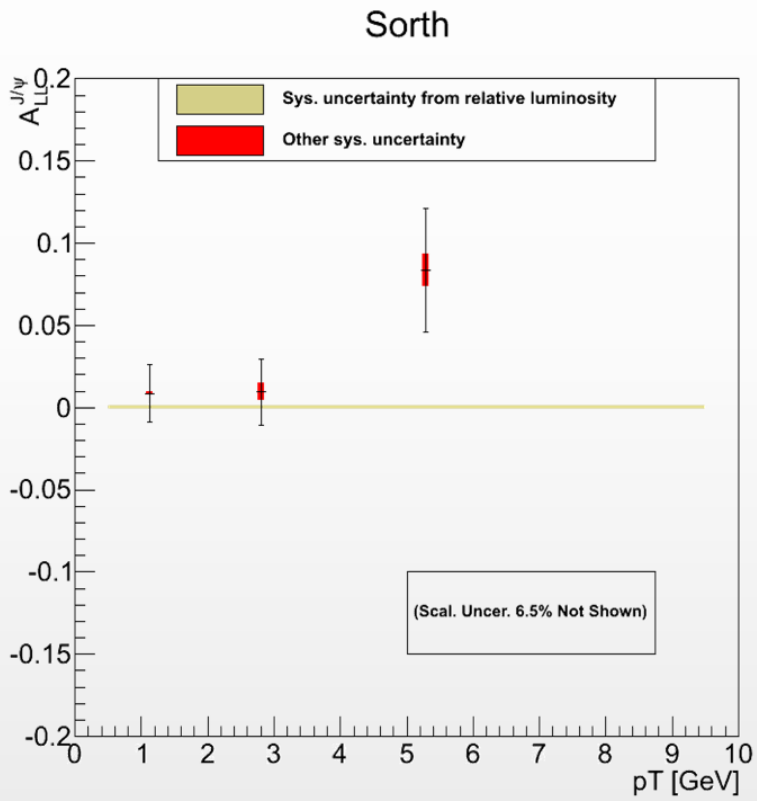
- We encourage theory community to incorporate this data in future NLO fits.

Backup slides

J/ψ A_{LL} result for North and South Muon arm separately

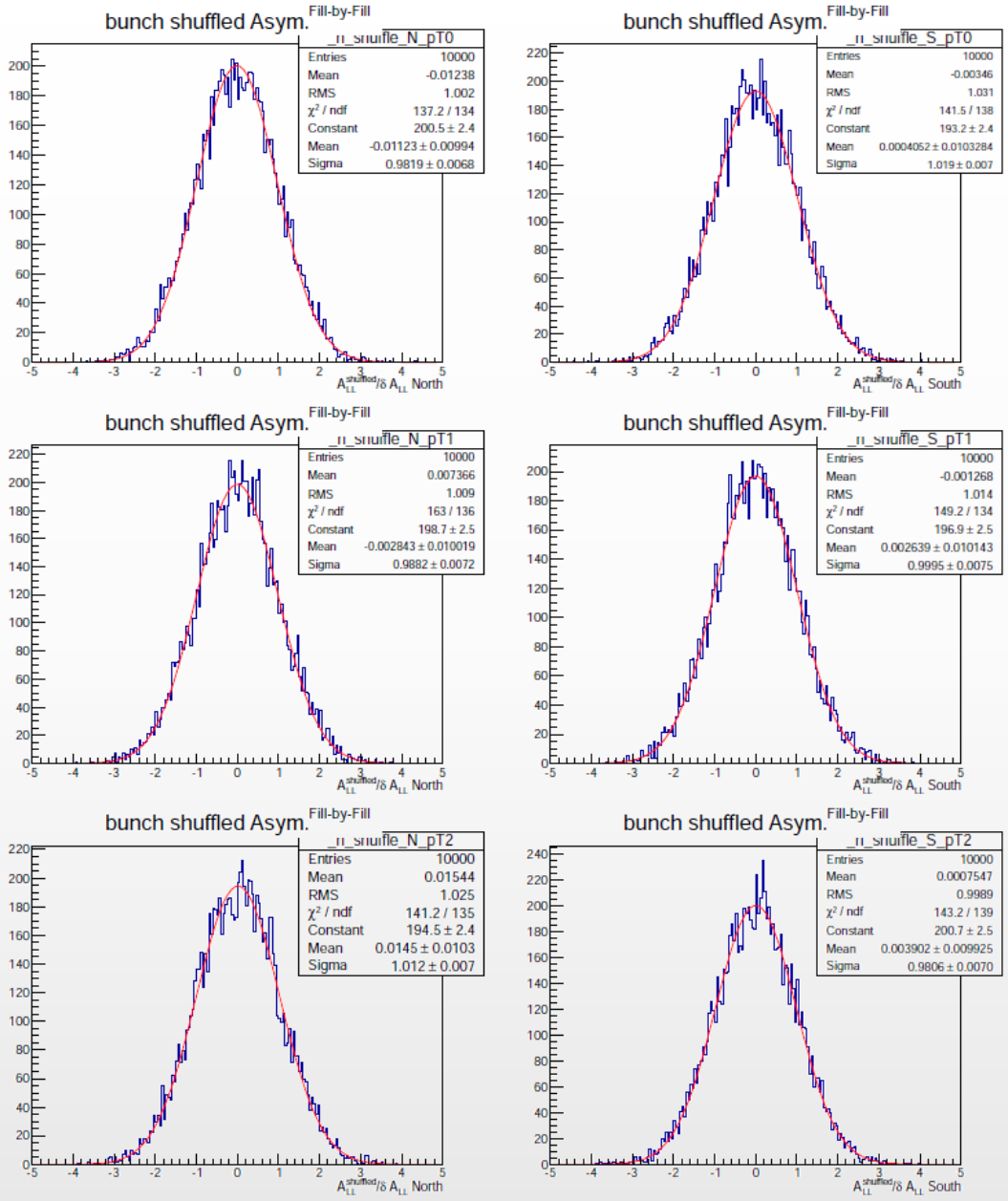
result based on 2013 RHIC 500GeV p+p run data set





bunch shuffling

The fact that the normalized RMS close to 1, indicates that all other non correlated bunch-to-bunch and fill-to-fill systematic errors are much smaller than the statistical errors.



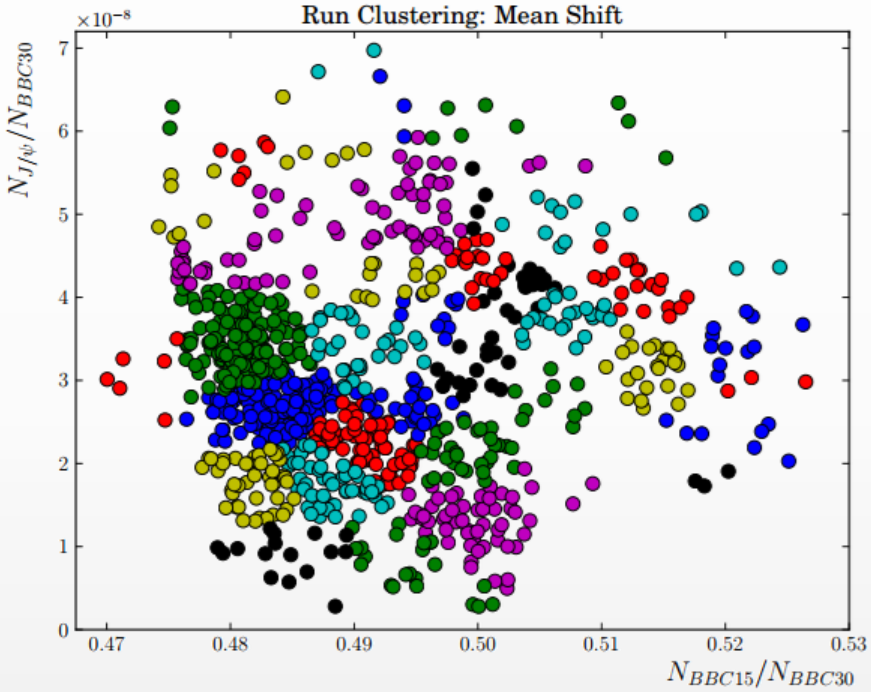
Run Clustering

Quantifying Stability

- Trigger: number of J/ψ candidates per minimum bias trigger
- Vertex: ratio of BBC15 and BBC30

Clustering

- Mean Shift algorithm
- Estimates number of feature sets and populations
- Use luminosity weighted average polarization for subset asymmetries



More information

D. Comaniciu, V. Ramesh, and P. Meer. Mean shift: A robust approach towards feature space analysis. IEEE Trans. on Pattern Analysis and Machine Intelligence, 24(5):603–619, 2002.

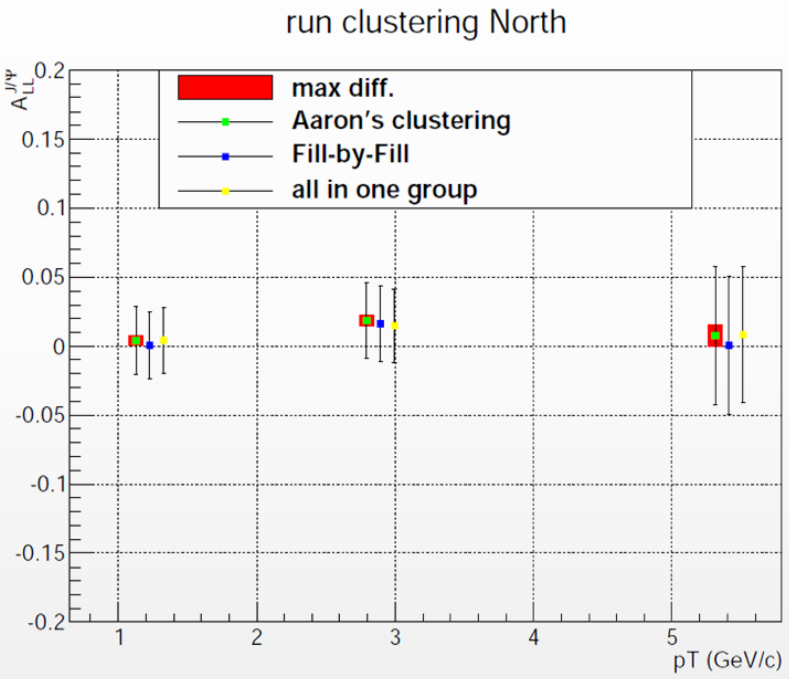
Ground and excited state charmonium production in p+p collisions at √s=200 GeV

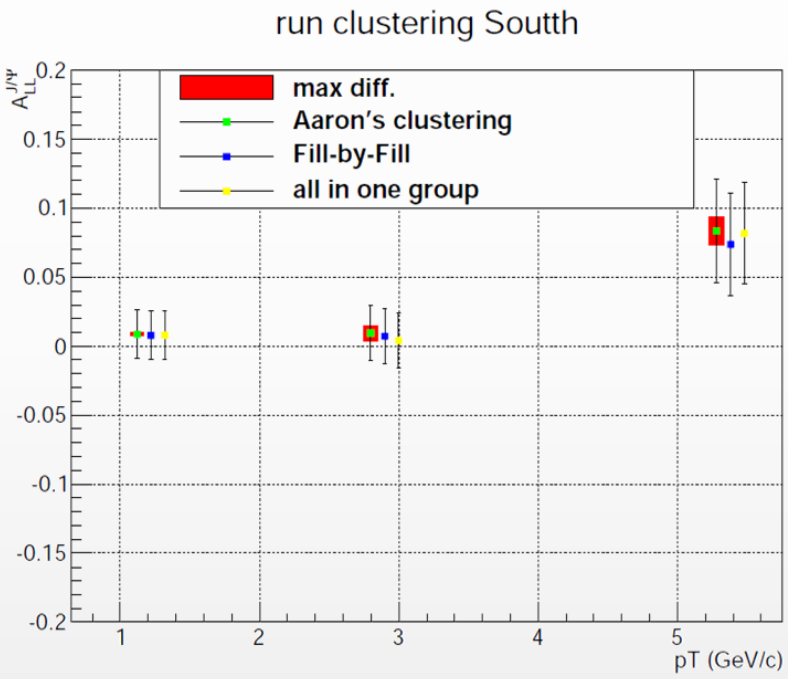
Phys. Rev. D 85, 092004 (2012)

VII. SUMMARY AND CONCLUSIONS

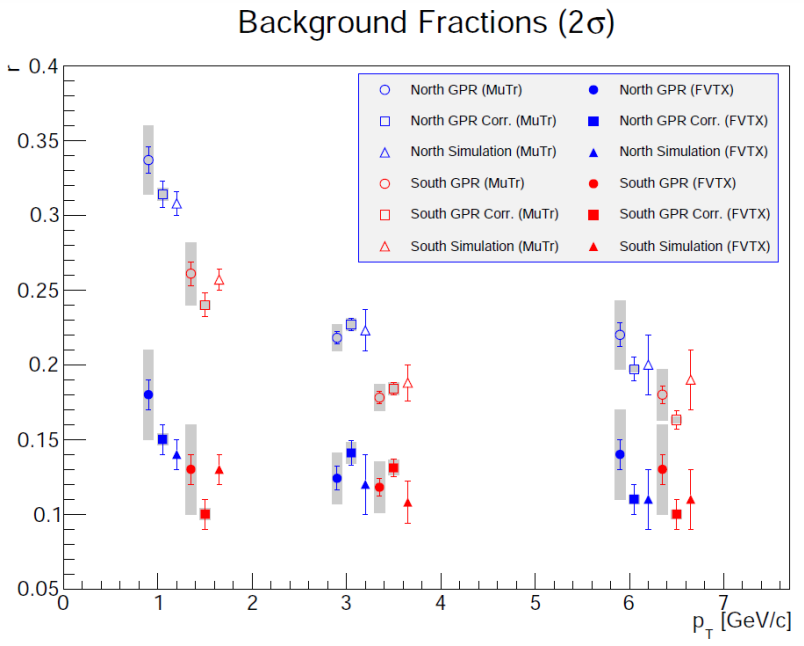
In conclusion, we have measured the yields of the three most important charmonium states in p+p collisions at $\sqrt{s} = 200$ GeV, where gluon fusion is expected to be the dominant production process. The rapidity dependence of J/ψ supports the use of CTEQ6M to describe the gluon distribution in protons. The inclusive J/ψ yield is in agreement with current models which involve a initial formation of colored charmonium states, as in the CEM or the color octet states of the NRQCD models. The inclusive J/ψ yield observed at midrapidity is composed of $9.6 \pm 2.4\%$ of ψ' decays and $32 \pm 9\%$ of χ_c decays. This result is in agreement with what was observed in other experiments. Given the current large statistical uncertainties, no conclusion can be made about collision energy or p_T dependence of these fractions. Finally, this J/ψ cross section measurement and feed-down fractions will play an important role in current studies of cold nuclear matter and the hot, dense matter formed in heavy ion collisions.

Systematics Uncertainty from run clustering

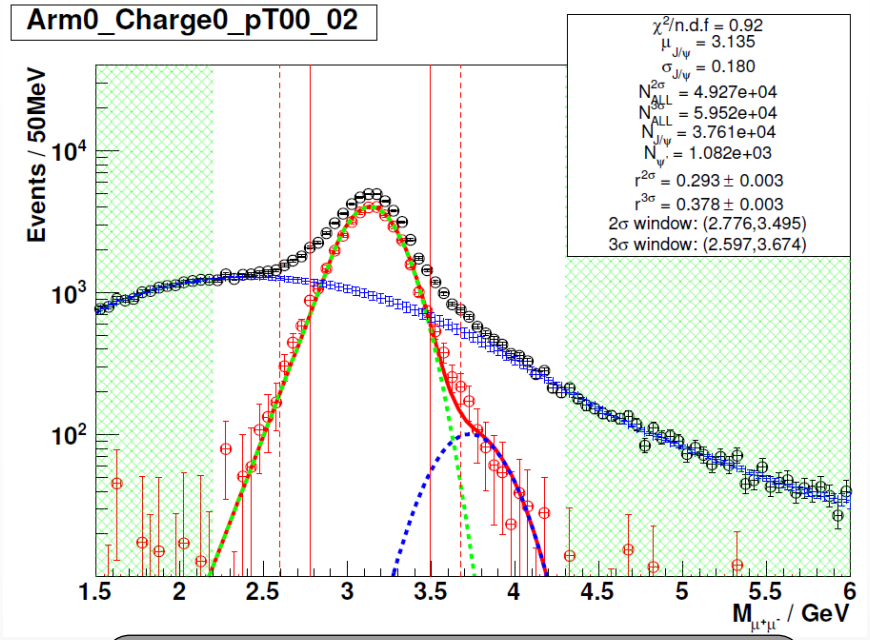




background fraction "r"



showing different fitting methods

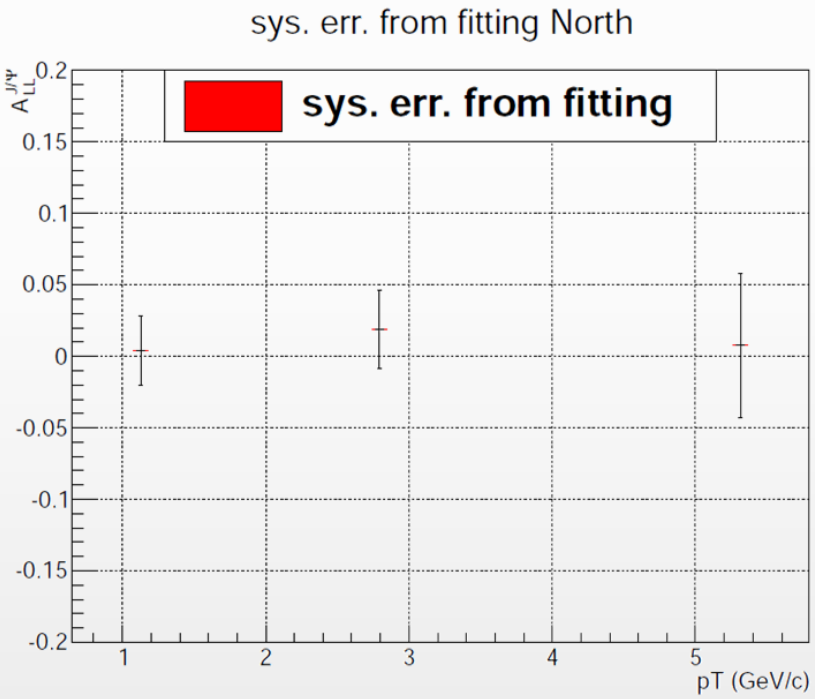


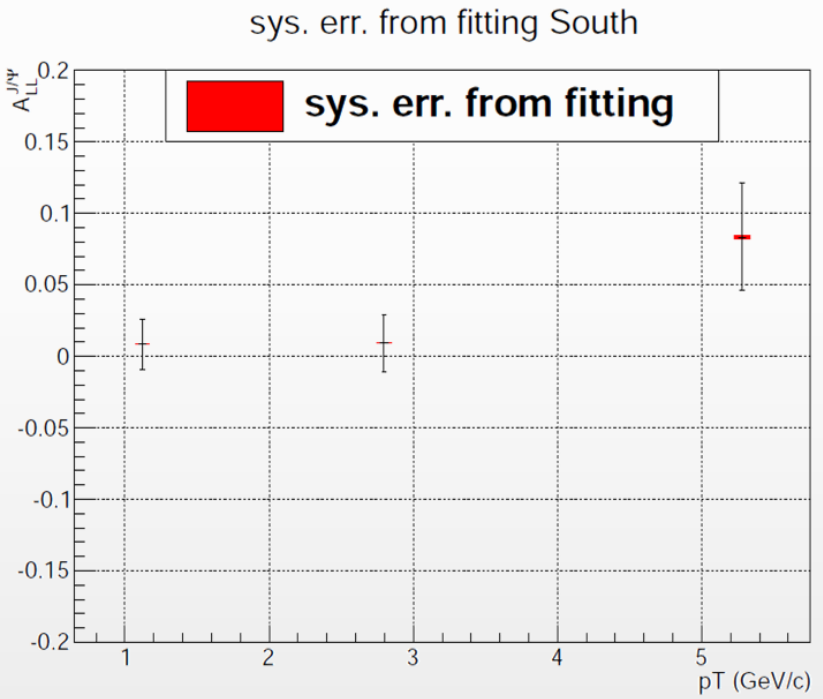
Showing one arm, one pT bin fitting for the Final result

The extraction of "r" has been done using several methods: GPR for the background, simulation driven, and the old fashion polynomial.

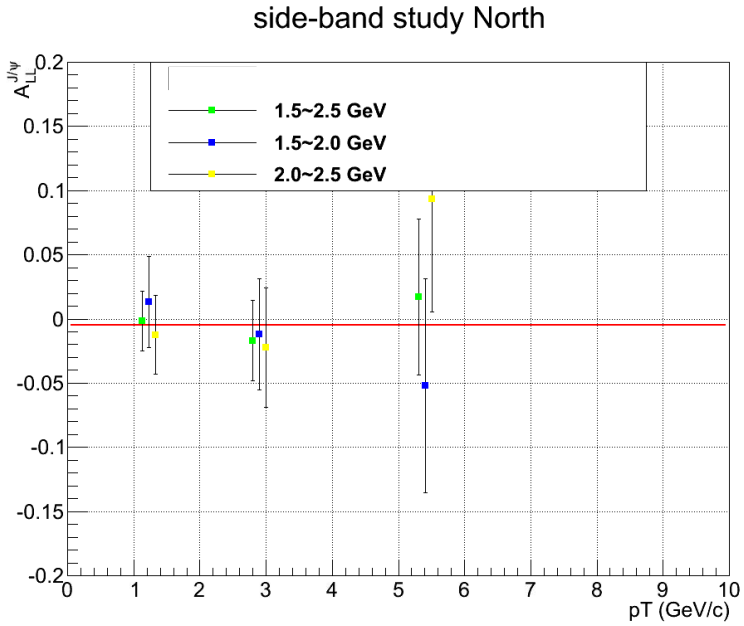
At the end, we took the GPR method as the central value and the difference as one systematic error.

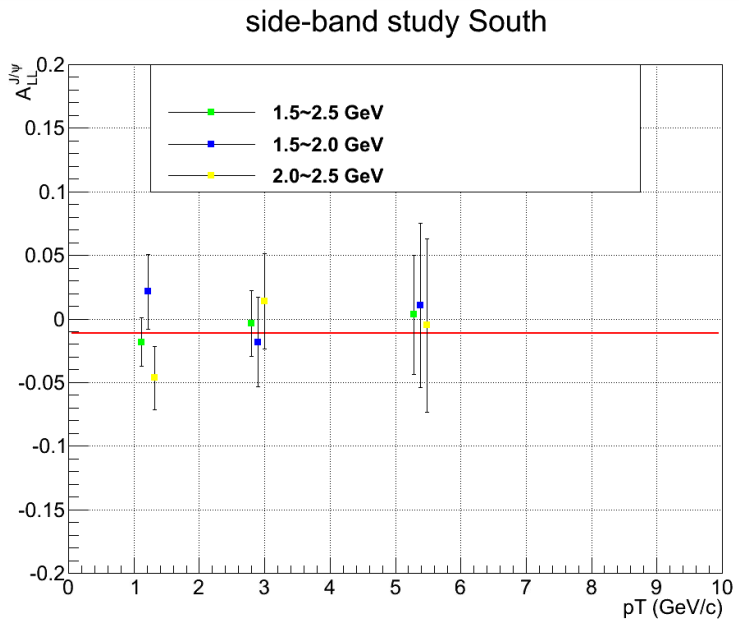
Systematics Uncertainty from background fraction extraction





background Asymmetry $A_{LL}^{BKG.}$ Estimation

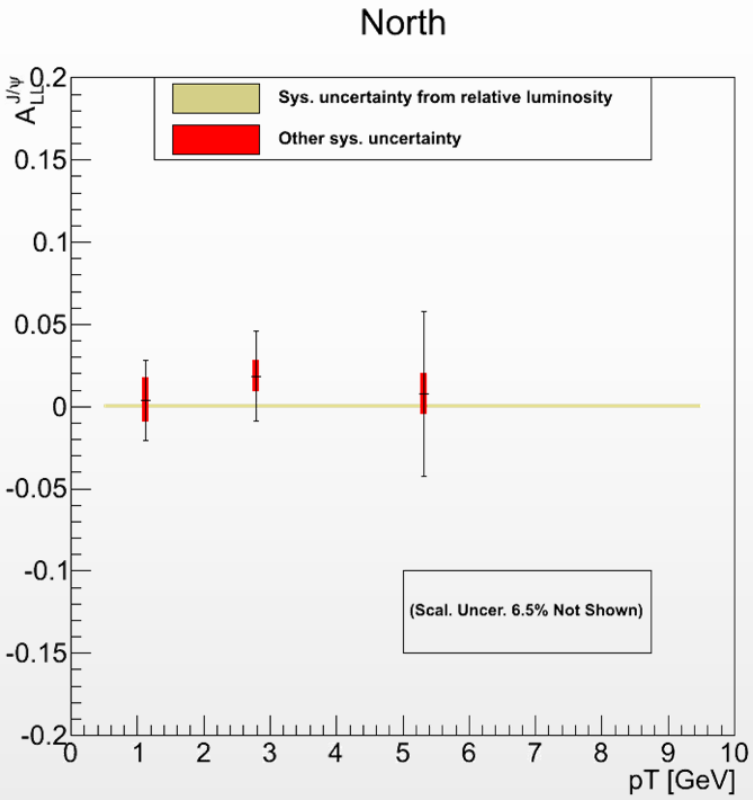


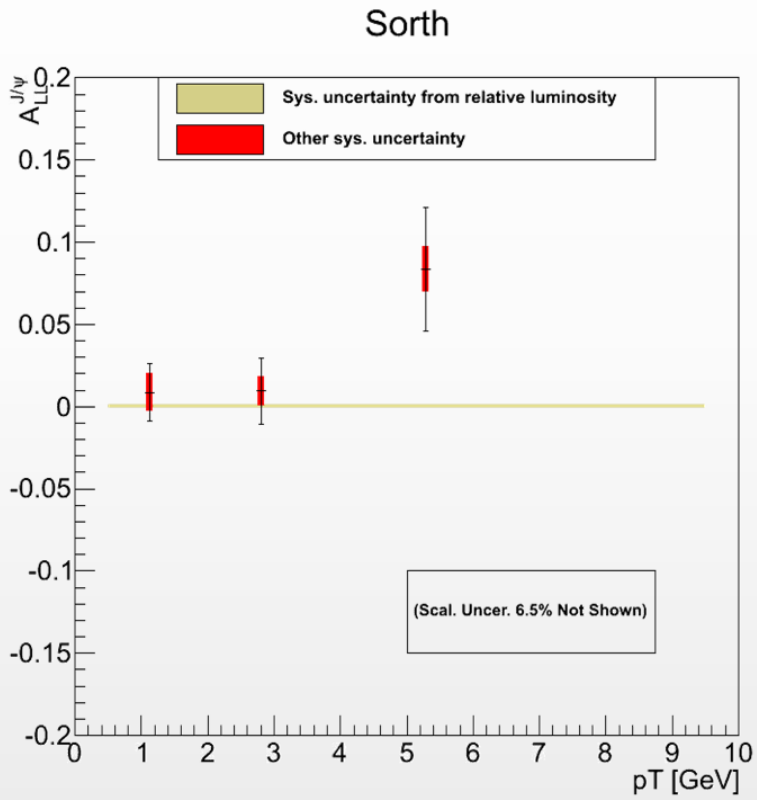


- AN1194 Figure 9:
  - showing the side-band asymmetry for different mass window

- We try to justify there is no obvious mass dependence of the asymmetry of the side band beyond the stat. err. can tell. So as we already assigned relatively large stat. err. to the background asymmetry, we ignored the sys. err. from this estimation method.

if use this very conservative sys. err. from side band estimation method:





Motivation

Gluon Polarization

For an A_{LL} measurement to be meaningful partonic level asymmetry must be reproduced at NLO accuracy

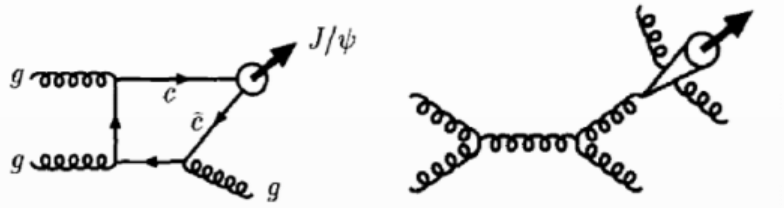
A_{LL} for J/Ψ production (LO)

$$A_{LL} = \frac{\Delta\sigma}{\sigma} \sim \frac{\Delta g(x_1)}{g(x_1)} \frac{\Delta g(x_2)}{g(x_2)} \otimes \hat{a}_{LL}^{gg\to c\bar{c}}$$

The production mechanism for the J/ψ from the $c\bar{c}$ pair remains an open question

Bottom Line

- None of the models completely describe the data
- Measurement of J/ψ cross section at 510 GeV is an important intermediate data point in the production mechanism search

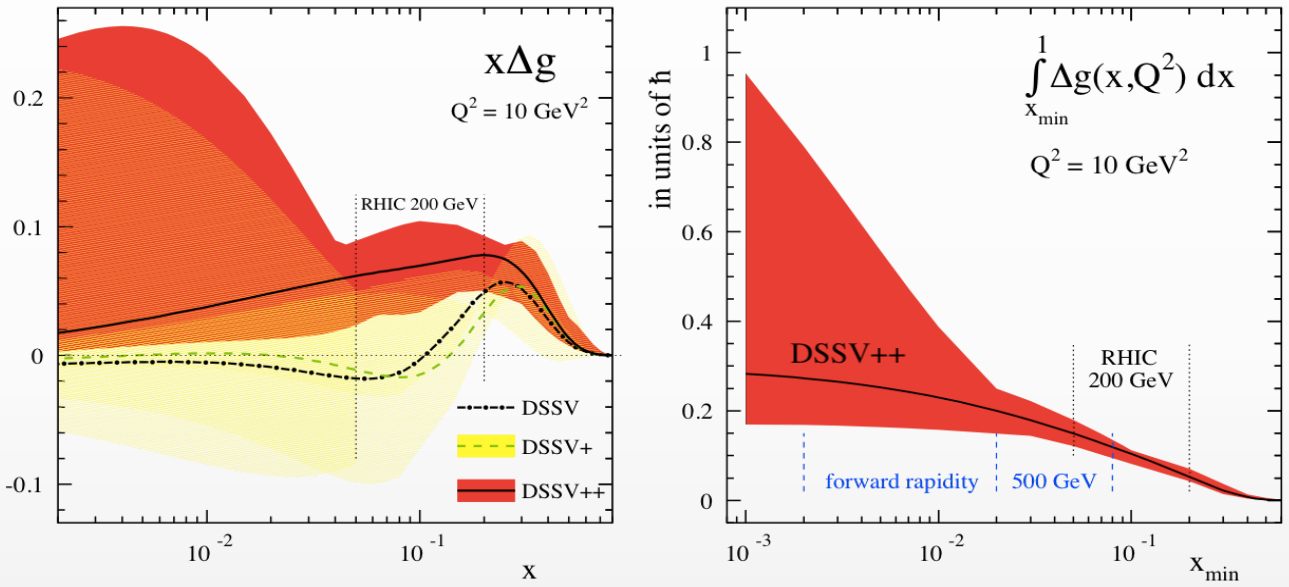


Color singlet diagrams for J/ψ production at LO (left) and from fragmentation (right)

Color octet diagrams for J/ψ production at LO (left) and from fragmentation (right)

Recent Results

Global Fit: DSSV++



Outlook:

- Large uncertainties remain in both the shape and integral of Δg(x)
- Unconstrained in the low x range where currently no data is available
- Improvements forthcoming from ALL measurements at 510 GeV and forward rapidity