J/ψ production in p+p collisions at PHENIX and gluon distribution

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for the PHENIX collaboration

QWG meeting at FNAL

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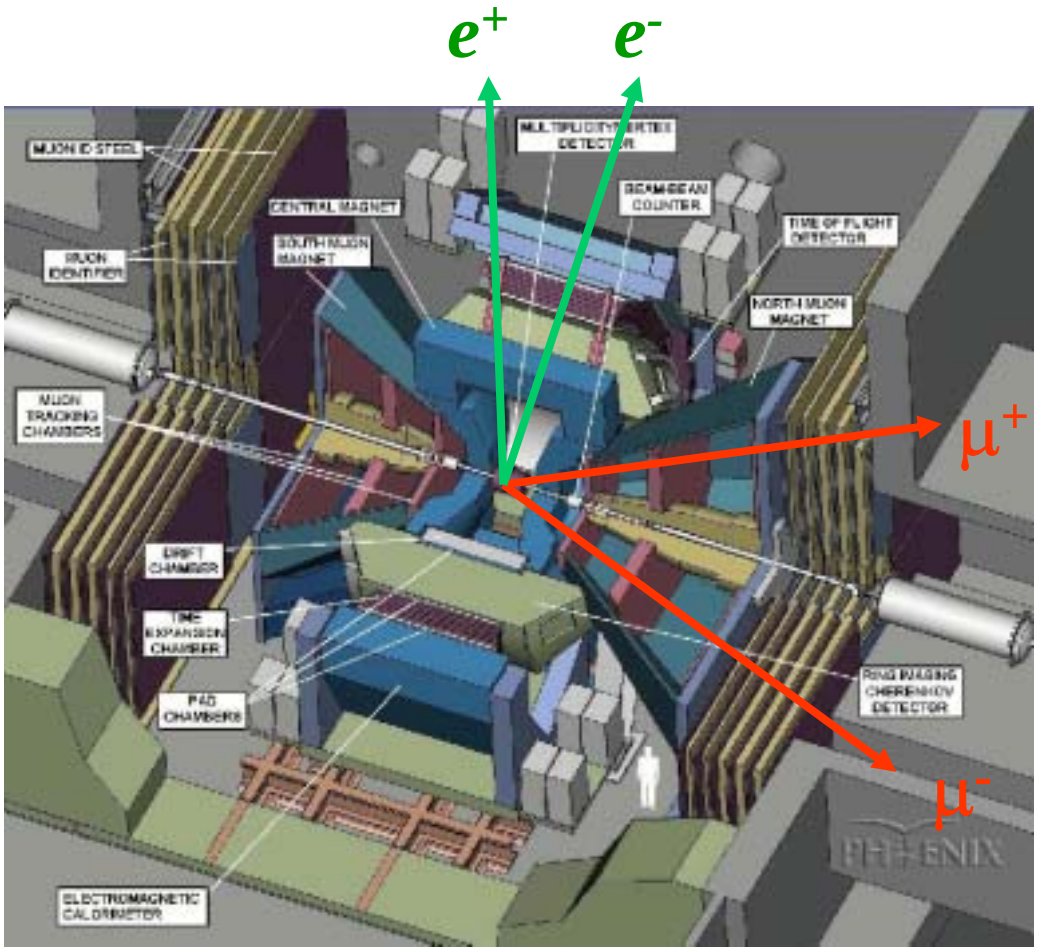
- **Total and differential cross section results and gluon distribution**
- **Prospects for spin asymmetry (A_{LL}) measurements and polarized gluon distribution**

The PHENIX Detector



e, γ, $h \rightarrow$ Central Arms (West + East)

- $|\eta| < 0.35$, $\Delta\varphi = \pi$
- $p_T > 0.2$ GeV/c

$\mu \rightarrow$ Muon Arms (North + South)

- $1.2 < |\eta| < 2.4$, $\Delta\varphi = 2\pi$
- $p_{tot} > 2$ GeV/c

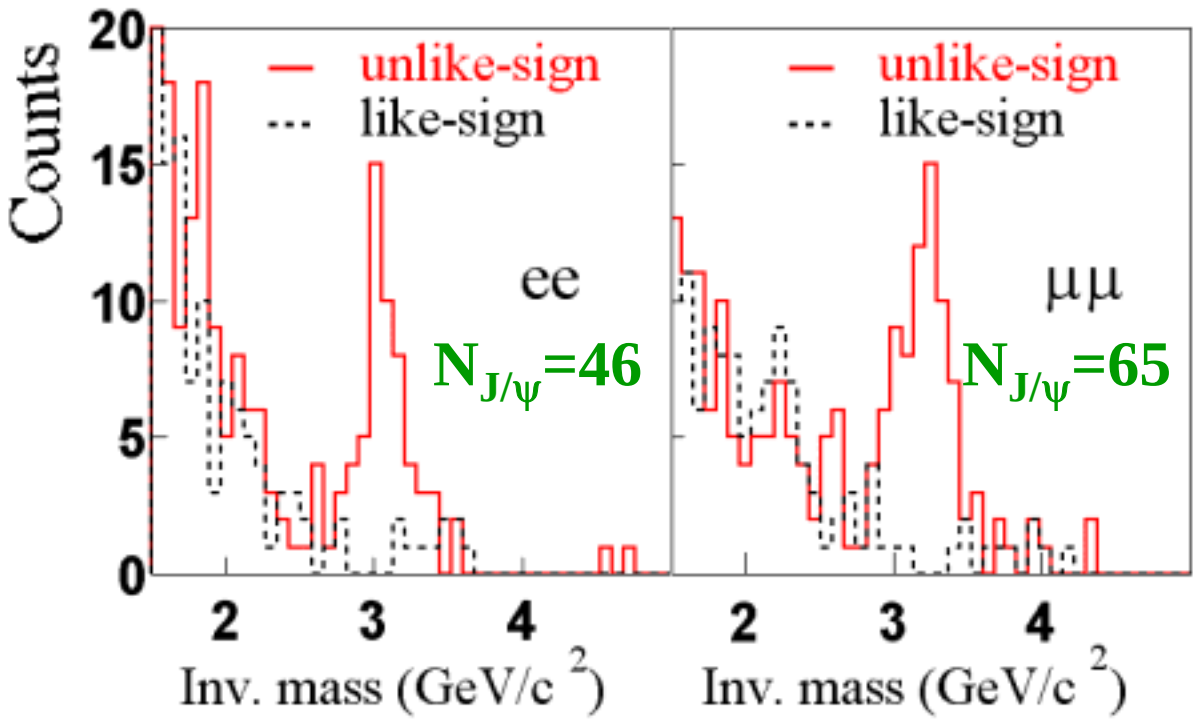
Interaction-trigger and vertex detectors

Independent measurements of J/ψ using both e^+e^- channel and $\mu^+\mu^-$ channel

Low momentum (p_T) cut* and *wide rapidity coverage* $\rightarrow$ *enables the extraction of the total cross section at the highest energy

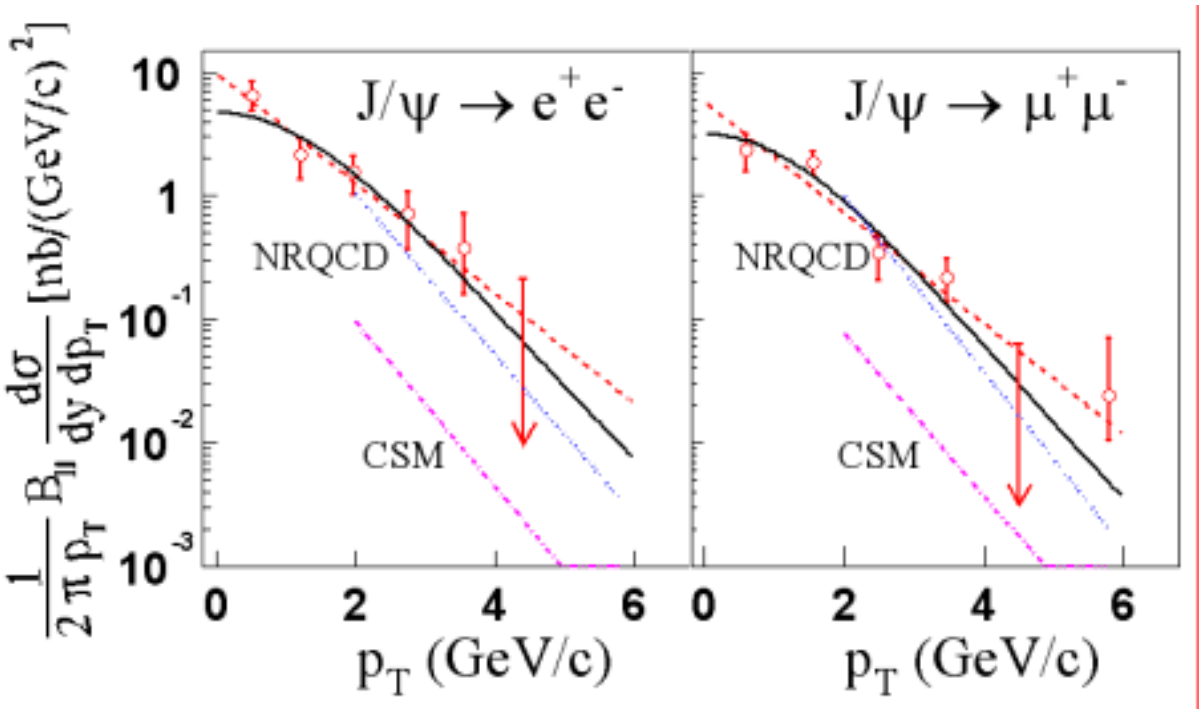
Invariant Mass

PHENIX Run2(2001-2002) p+p at √s=200 GeV



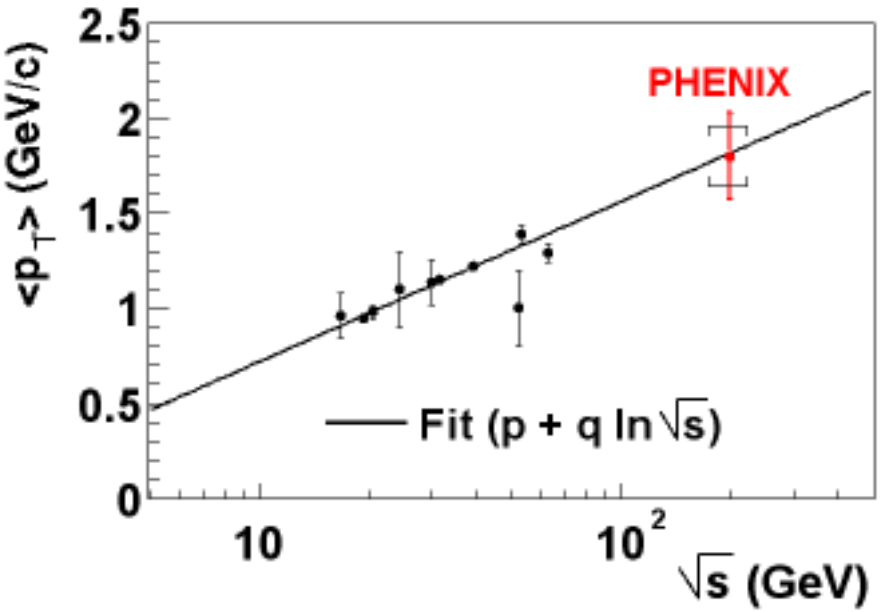
- Clear J/ψ peaks with small background in both e^+e^- and $\mu^+\mu^-$ pairs

$d\sigma_{J/\psi}/dp_T$



- Reasonable agreement with NRQCD (COM) predictions
- Increased statistics in high-p_T is useful for more quantitative argument → Run-3 (~10 times statistics) and later

$<p_T>$



$<p_T>$ = 1.80 ± 0.23 (stat.) ± 0.16 (syst.) GeV/*c*

- Average transverse momentum ($<p_T>$) is slightly higher than lower energy results.
- Energy dependence can well be fitted with a logarithmic function.

J/ψ rapidity distribution and gluon distribution function

- In hadron-hadron collisions at moderate energy ($\sqrt{s} \geq 20$GeV), p_T-integrated yield should be dominated by g+g $\rightarrow$ J/ψ. Neglecting other contributions (q+q_bar, gluon fragmentation and *b*-decay), rapidity (or x_F) distribution and energy dependence of total cross section can be simply written by gluon distribution function $g(x)$

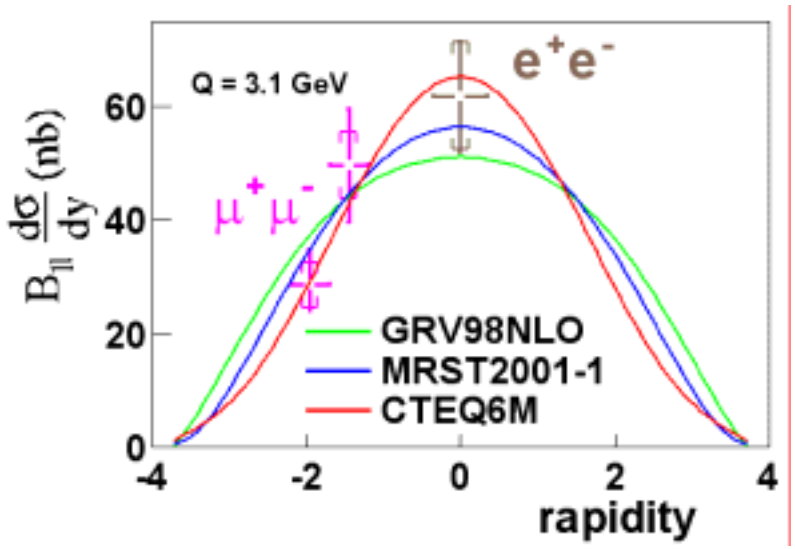
$$\frac{d\sigma}{dy} \propto g(x_1)g(x_2),\ x_{1,2} = (2m_c/\sqrt{s})\exp(\pm y)$$

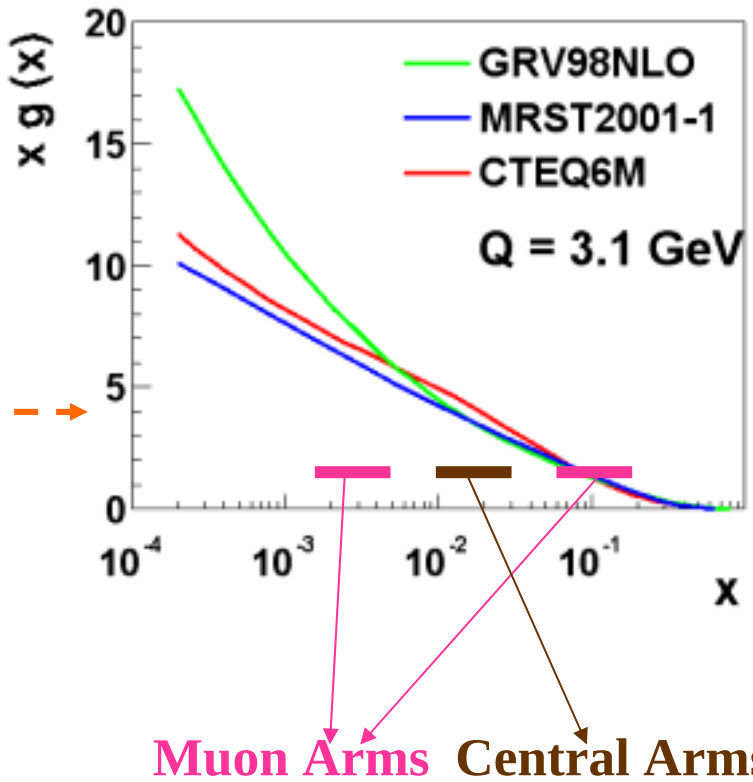
$$\sigma_{J/\psi}(\sqrt{s}) \propto \int_{\sqrt{\tau}}^{1} \frac{dx}{x} g(x)g(\tau/x)$$

$$\sqrt{\tau} = 2m_c/\sqrt{s}$$

$d\sigma_{J/\psi}/dy$ and $\sigma_{J/\psi}$

$$\frac{d\sigma}{dy} \propto g(x_1)g(x_2),\ x_{1,2} = (2m_c/\sqrt{s})\exp(\pm y)$$





Rapidity shape is mainly sensitive to **gluon distribution function g(*x*,*Q*)** in the proton and consistent with most of typical PDF sets

Using the curve which fits our data best, total cross section was obtained

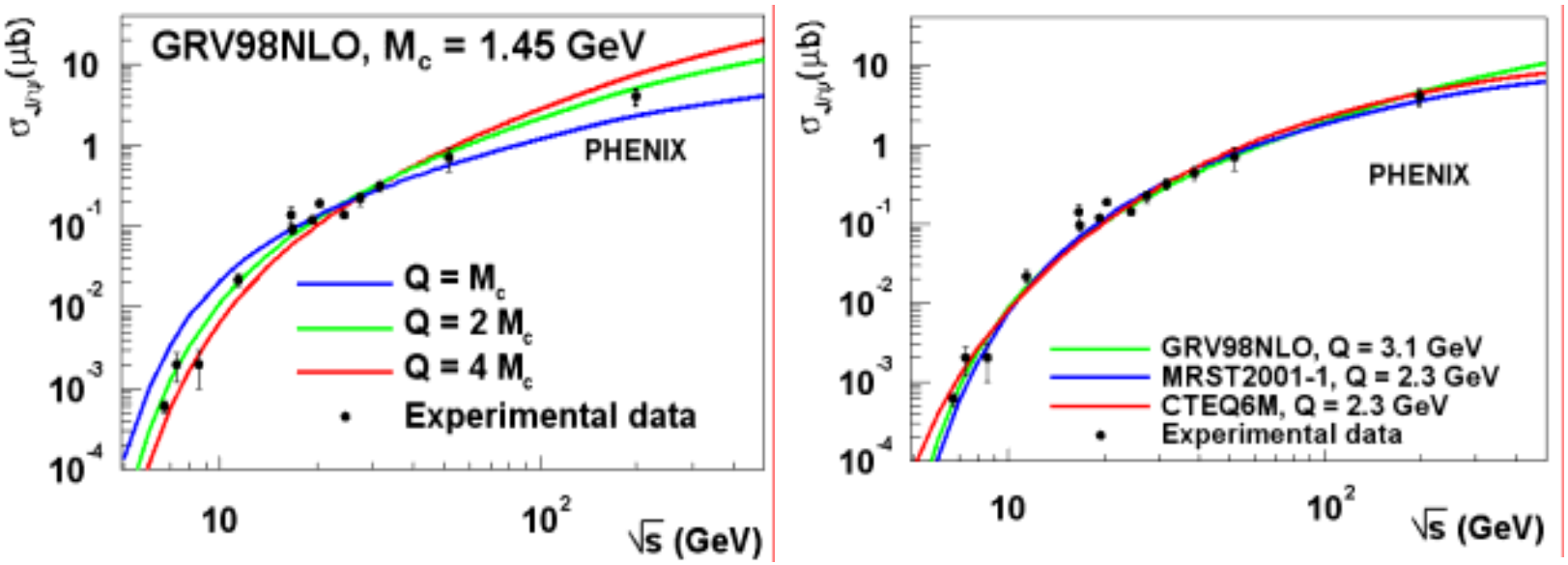
$\sigma(p+p \rightarrow J/\psi X) = 4.0 \pm 0.6\ (stat.) \pm 0.6\ (syst.) \pm 0.4\ (abs.)\ \mu b$

using Br ($J/\psi \rightarrow l^+l^-$) = 0.059

$\sigma_{J/\psi}$ ($\sqrt{s}$ dependence)

$$\sigma_{J/\psi}(\sqrt{s}) \propto \int_{\sqrt{\tau}}^{1} \frac{dx}{x} g(x) g(\tau / x)$$

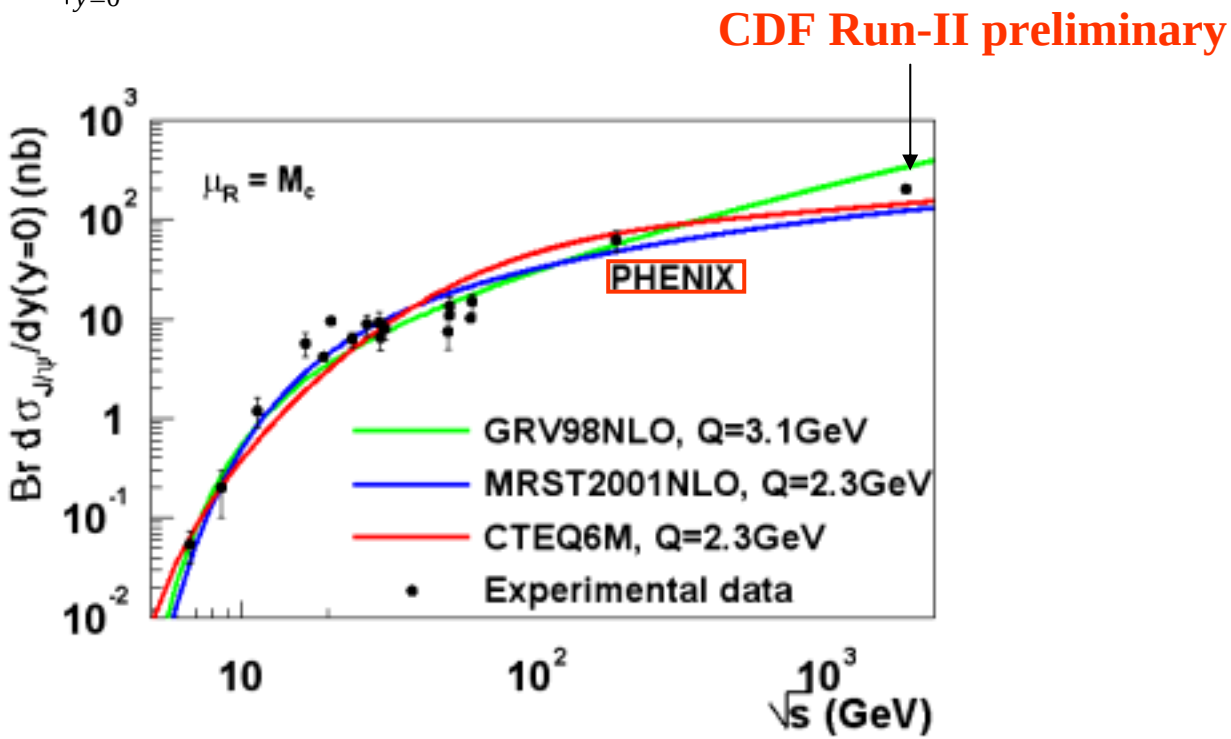
$$\sqrt{\tau} = 2m_c / \sqrt{s}$$



- Energy dependence of $\sigma_{J/\psi}$ is sensitive to **gluon distribution function** and its scale Q
- Our new result and lower-energy results are consistent with typical gluon distribution functions with a reasonable choice of Q → confirms the gluon fusion picture of J/ψ production in hadron-hadron collisions in a wide energy range

$\sqrt{s}$ dependence of $d\sigma_{J/\psi}/dy|_{y=0}$

$$\left.\frac{d\sigma}{dy}\right|_{y=0}(\sqrt{s}) \propto [g(2m_c/\sqrt{s})]^2$$



- New Tevatron data ($\sqrt{s}$ = 2TeV) will further constrain gluon distribution ?

$\sigma_{J/\psi}$ *(absolute value)*

Absolute normalization for $\sigma_{J/\psi}$ is sensitive to production model

- Color-evaporation model (CEM)

  can explain $\sigma_{J/\psi}$ using $\rho_{J/\psi}$ (fraction of J/ψ to all produced $c\bar{c}$ pairs) ~ 0.06 determined by photo-production data

- Color-singlet model (CSM)

  Color singlet production underestimate $\sigma_{J/\psi}$ by a large (~10) factor

- Color-octet model (COM)

  Consistent using the color octet matrix element $\langle O^{J/\psi}_8(^1S_0)\rangle + 7/M_c^2 \langle O^{J/\psi}_8(^3P_0)\rangle = 0.02\ GeV^3$ from photo-production data, but has large uncertainties from

  - Extraction of color-octet matrix element
  - Charm quark mass
  - Factorization and renormalization scales

Measurement of polarized gluon distribution in polarized p+p collisions

We have confirmed that J/ψ production is dominated by gluon fusion -> ready to measure polarized gluon distribution (ΔG(x)) in longitudinally polarized p+p collisions at RHIC

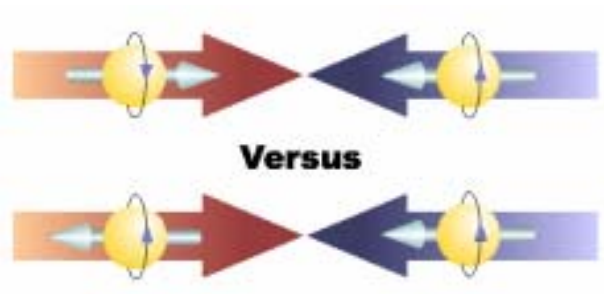
$$A_{LL}^{p+p\to J/\psi+X} \equiv \frac{\sigma^{++}-\sigma^{+-}}{\sigma^{++}+\sigma^{+-}} = \frac{\Delta G(x_1)}{G(x_1)}\frac{\Delta G(x_2)}{G(x_2)} a_{LL}^{g+g\to J/\psi+X}$$

$\Delta G(x)$: polarized gluon density

$a_{LL}^{g+g\to J/\psi+X}$: partonic subprocess asymmetry

~+1 (CEM)
~ -1 (CSM)
-0.3 ~ +0.7 (COM)

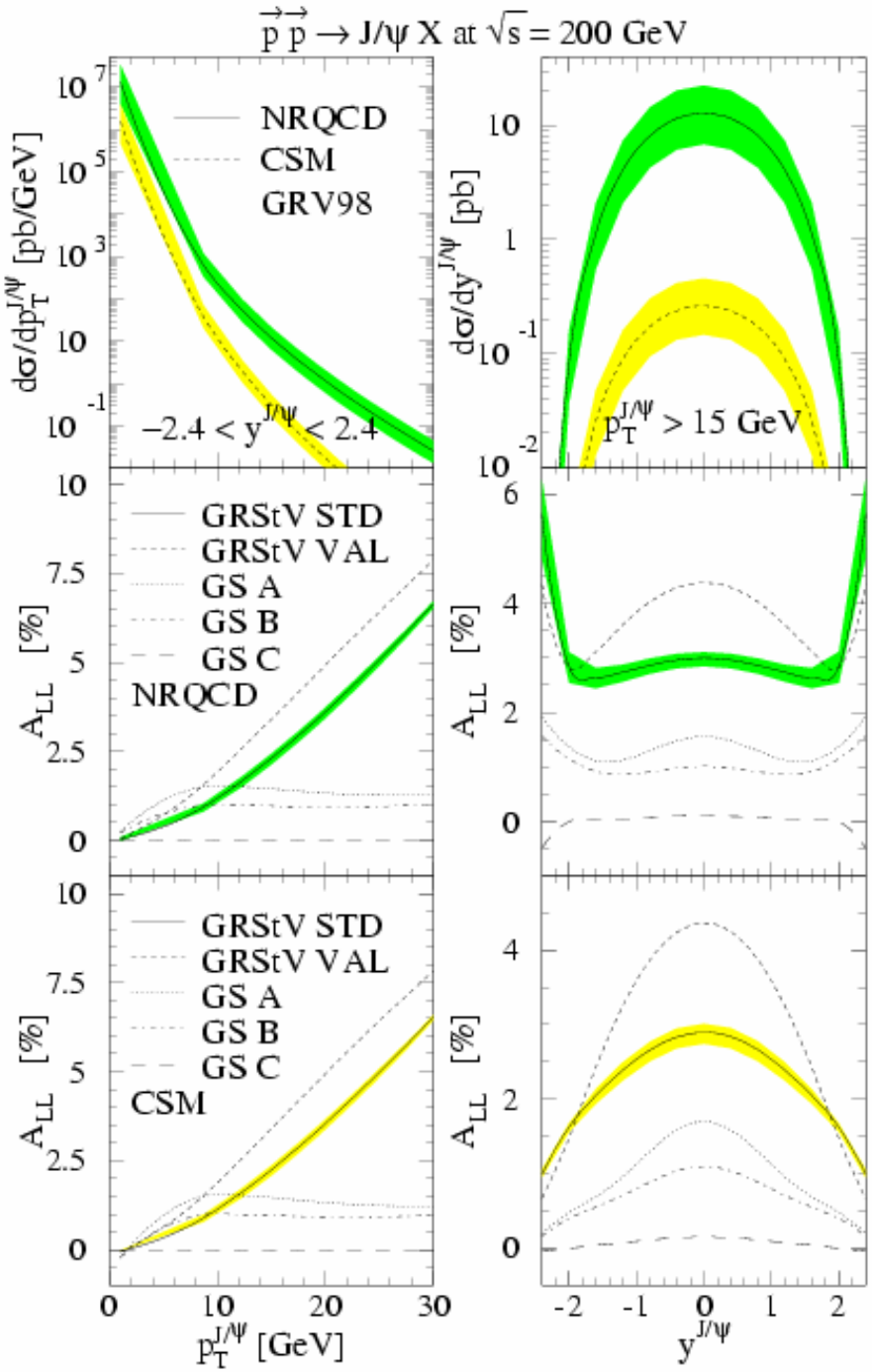
Gupta and Mathews, Phys. Rev. D55, 7144



σ_{++}

σ_{+-}

δA_{LL}(stat.) ~ 1% with 1-year full luminosity (32pb^{-1})



NRQCD calculation of A_{LL}

M. Klasen et al.
Phys. Rev. D68, 034017 (2003)

Conclusion

- **J/ψ** particles are clearly identified with **PHENIX** with a small background via e^+e^- and $\mu^+\mu^-$ decays in the first **p+p** Run at RHIC (Run-2) at $\sqrt{s}$ **= 200 GeV**
- p_T distribution is consistent with Color-Octet Model prediction. Average p_T, $\langle p_T \rangle_{y=1.7} = 1.80 \pm 0.23$ (stat.) $\pm$ 0.16 (syst.) GeV/c is slightly higher than lower energy results.
- Rapidity distribution is consistent with gluon distribution function and total cross section $\sigma_{J/\psi}(\sqrt{s} = 200\ \text{GeV}) = 4.0 \pm 0.6$ (stat.) $\pm$ 0.6 (syst.) $\pm$ 0.4 (abs.) μb was extracted.
- Energy dependence of $\sigma_{J/\psi}$ can be well reproduced by gluon distribution function.
- The absolute normalization for $\sigma_{J/\psi}$ can be reproduced well by the Color-Evaporation Model and the Color-Octet Model.
- We plan to measure double-longitudinal spin asymmetries (A_{LL}) which are sensitive to polarized gluon distribution at leading order.

References

- hep-ex/0307019 (submitted to Phys. Rev. Lett.)
- hep-ph/0305239 (My Ph.D thesis)