

*Total and differential cross sections
for J/ψ production in $p+p$ collisions
at $\sqrt{s} = 200 \text{ GeV}$*

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References

hep-ex/0307019 (submitted to Phys. Rev. Lett.)

hep-ph/0305239

J/ψ Measurements at RHIC- PHENIX

- Better understanding of **Quantum Chromodynamics (QCD)**

charmonium production includes

- ✓ perturbative QCD aspects
- ✓ non-perturbative QCD aspects
(production mechanism)

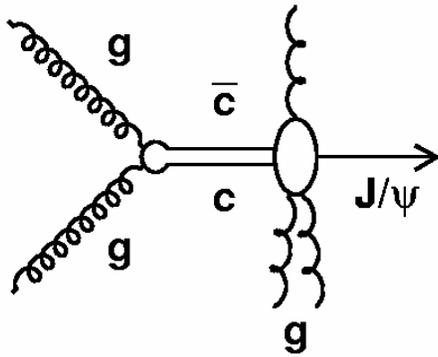
Cross sections
Polarization
Relative yields (χ/ψ etc)

In wide energy range

- Probe for new physics at RHIC
 - **QGP physics** with **heavy-ion collisions** at highest energy ($(\sqrt{s_{NN}})_{max} = 200$ GeV for Au+Au)
 - **Spin physics** with **polarized p+p collisions** at highest energy ($\sqrt{s_{max}} = 500$ GeV)

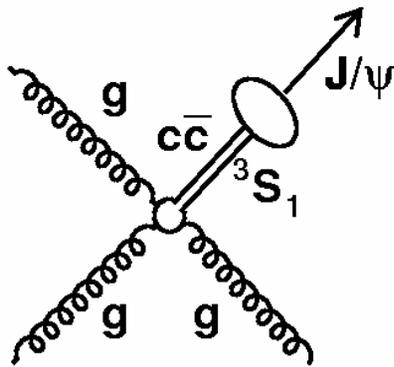
(Un-polarized) p+p data are important as reference

Charmonium Production Models



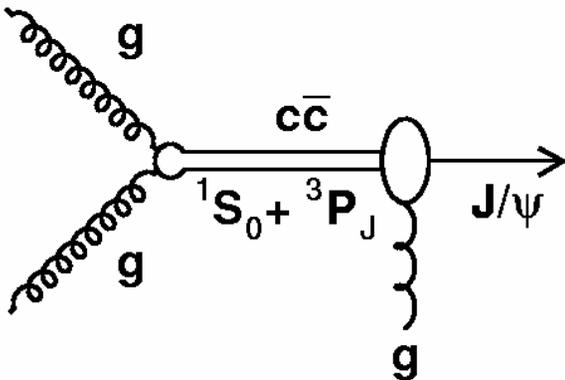
Color Evaporation Model (CEM)

Information of color-state and quantum numbers of $c\bar{c}$ pairs are destroyed by **multiple soft-gluon emissions**



Color Singlet Model (CSM)

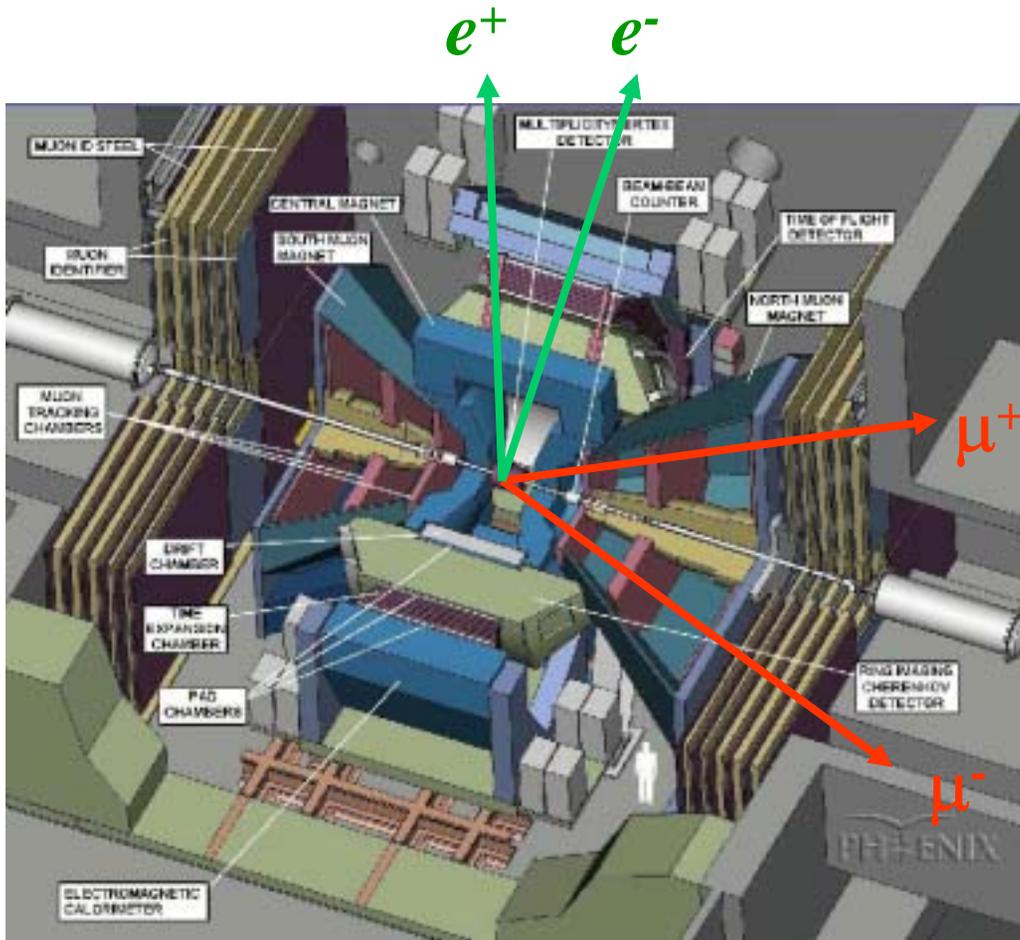
$c\bar{c}$ pairs should be in the color-singlet state and have the same quantum numbers as the charmonium to be formed → **no soft gluon emission**



Color Octet Model (COM)

Allow **one or some soft gluon emissions** to preserve the quantum numbers

The PHENIX Detector



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

- $|\eta| < 0.35, \Delta\phi = \pi$
- $p_T > 0.2 \text{ GeV}/c$

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

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

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

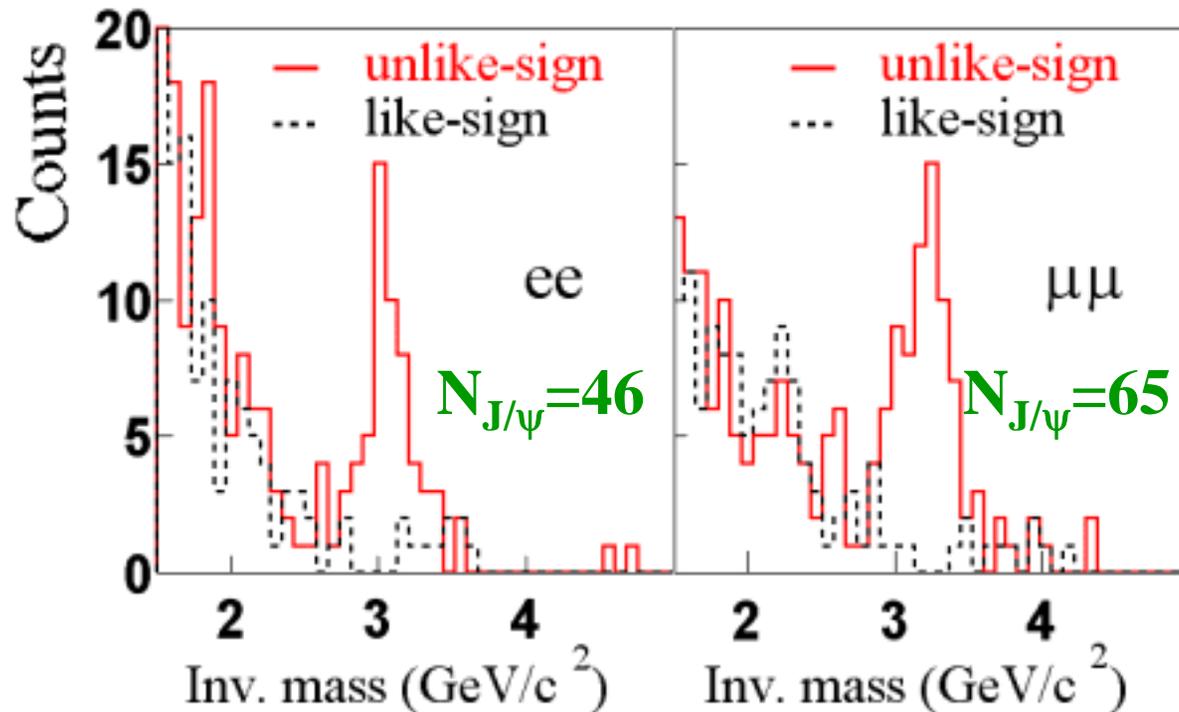
RHIC Run Summary

Run	Species	$\sqrt{s_{NN}}$ (GeV)	Integrated luminosity	Arms in operation
Run-1(2000)	Au+Au	130	1.0 mb ⁻¹	W+E
Run-2(2001- 2002)	Au+Au	200	24 mb ⁻¹	W+E+S
	p+p	200	150 nb⁻¹	
Run-3(2002- 2003)	d+Au	200	2.7 nb ⁻¹	W+E+S+
	p+p	200	350 nb ⁻¹	N

— — — — — **▶ This talk**

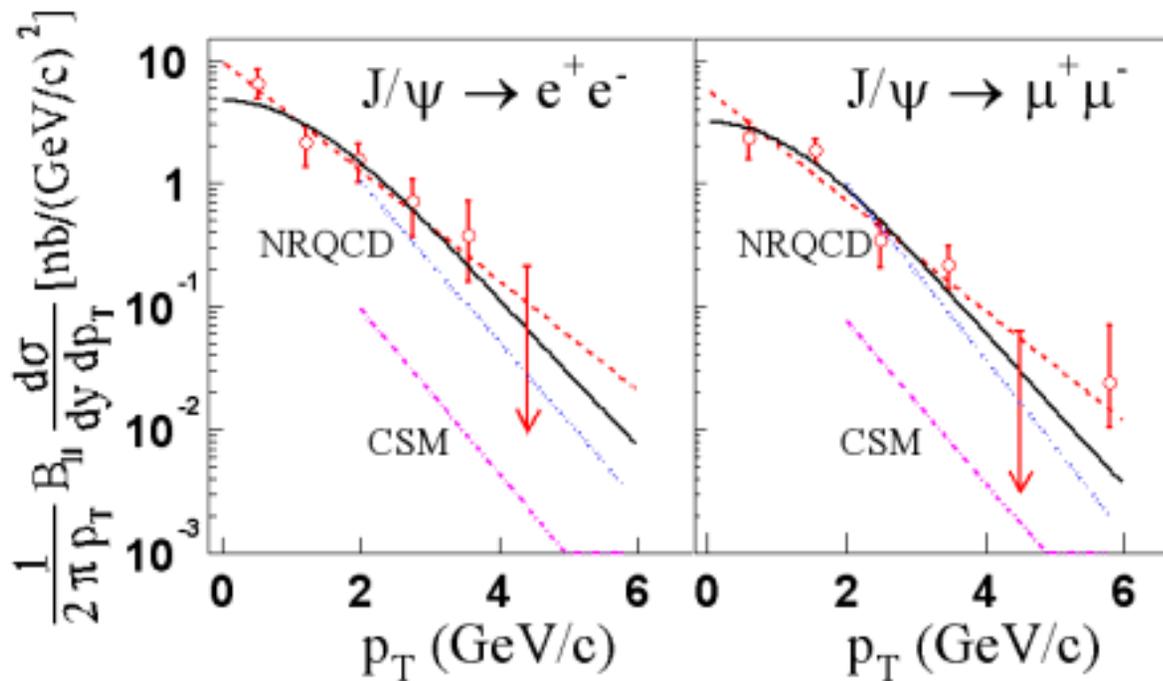
— — — — — **▶ Next talk**

Invariant Mass



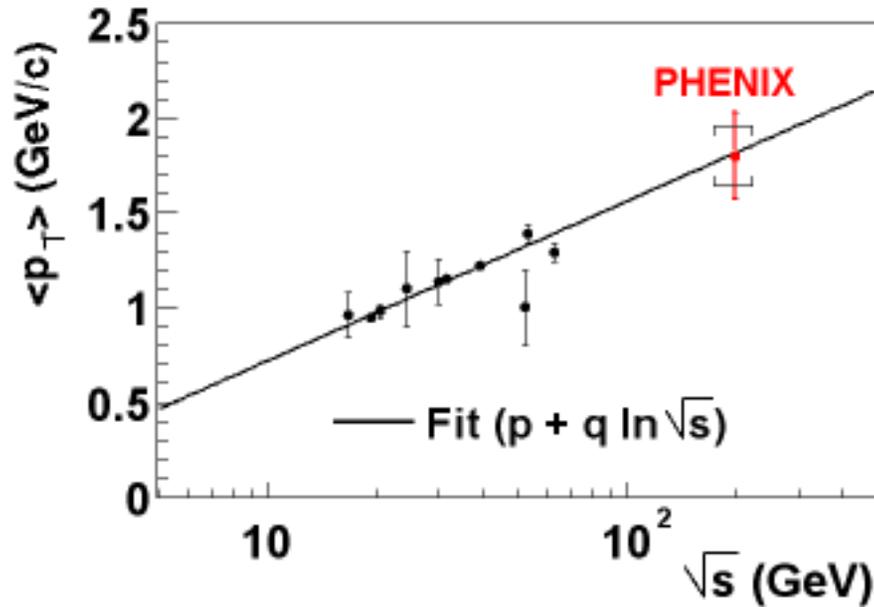
- Clear J/ψ peaks with small background in both e^+e^- and $\mu^+\mu^-$ pairs

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



- Reasonable agreement with NRQCD (COM) predictions
- Increased statistics in high- p_T is useful for more quantitative argument

$$\langle p_T \rangle$$

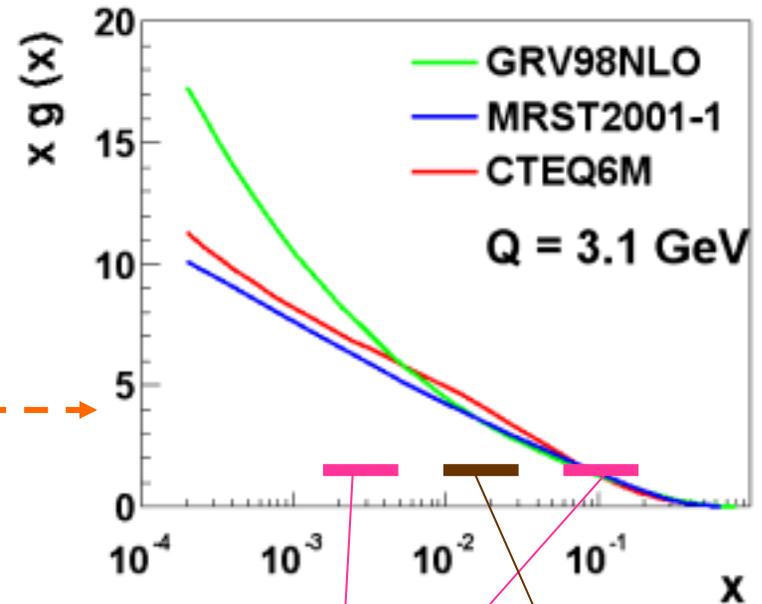
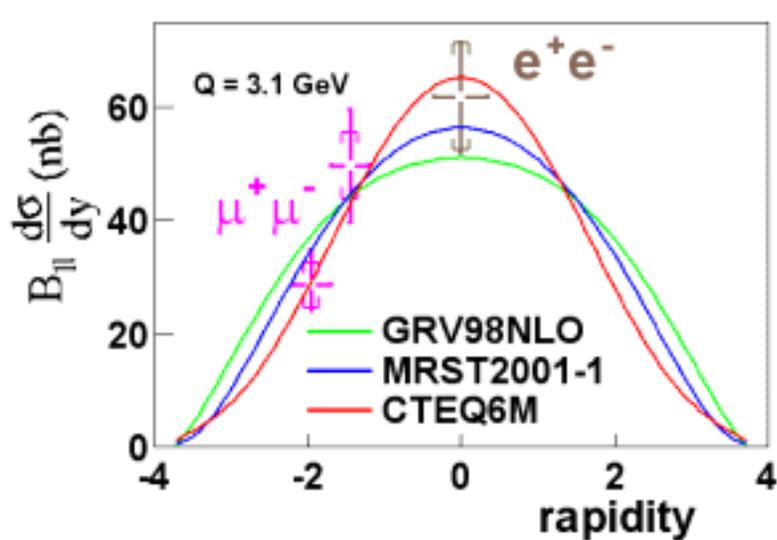


$$\langle p_T \rangle = 1.80 \pm 0.23 \text{ (stat.)} \pm 0.16 \text{ (syst.) GeV/c}$$

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

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

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



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

Muon Arms **Central Arms**

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

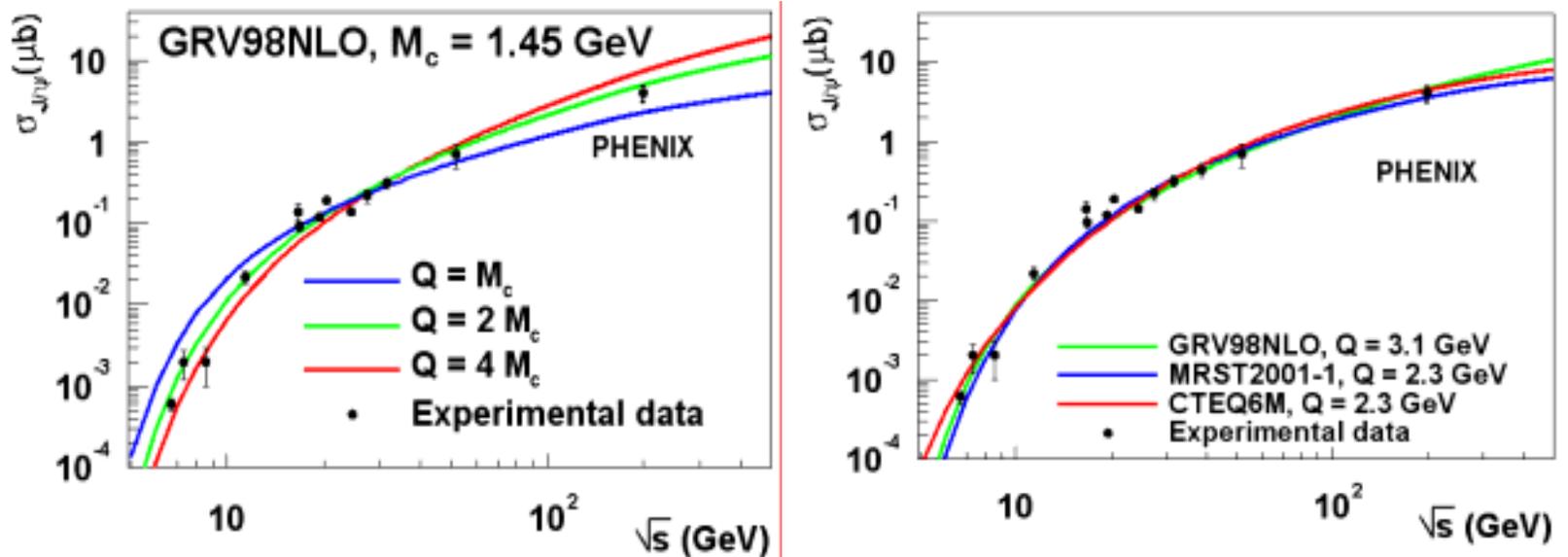
$$\sigma(\mathbf{p}+\mathbf{p} \rightarrow \mathbf{J}/\psi \mathbf{X}) = 3.99 \pm 0.61 \text{ (stat.)} \pm 0.58 \text{ (syst.)} \pm 0.40 \text{ (abs.) } \mu\text{b}$$

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

$\sigma_{J/\psi}$ (\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 $Q \rightarrow$ **confirms the gluon fusion picture of J/ψ production in hadron-hadron collisions in a wide energy range**

$\sigma_{J/\psi}$ (*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 $\langle O^{J/\psi}_8(^1S_0) \rangle + 7/M_c^2 \langle O^{J/\psi}_8(^3P_0) \rangle = 0.02 \text{ GeV}^3$ from photo-production data, but has large uncertainties from

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

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 $\sqrt{s} = \mathbf{200\ GeV}$
- p_T distribution is consistent with **Color-Octet Model** prediction. Average p_T , $\langle p_T \rangle_{y=1.7} = \mathbf{1.80 \pm 0.23 (stat.) \pm 0.16 (syst.)\ GeV/c}$ is slightly higher than lower energy results.
- Rapidity distribution is consistent with **gluon distribution function** and total cross section $\sigma_{J/\psi}(\sqrt{s} = \mathbf{200\ GeV}) = \mathbf{3.99 \pm 0.61 (stat.) \pm 0.58 (syst.) \pm 0.40 (abs.)\ \mu b}$ 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**.
- **These results are important as reference data for both Au+Au and polarized p+p data.**