# J/Ψ Production in *pp*, *dAu* and *CuCu* Collisions at RHIC

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# Color Screening and the QGP

- Matsui and Satz first articulated the consequences of color screening on quarkonium production:

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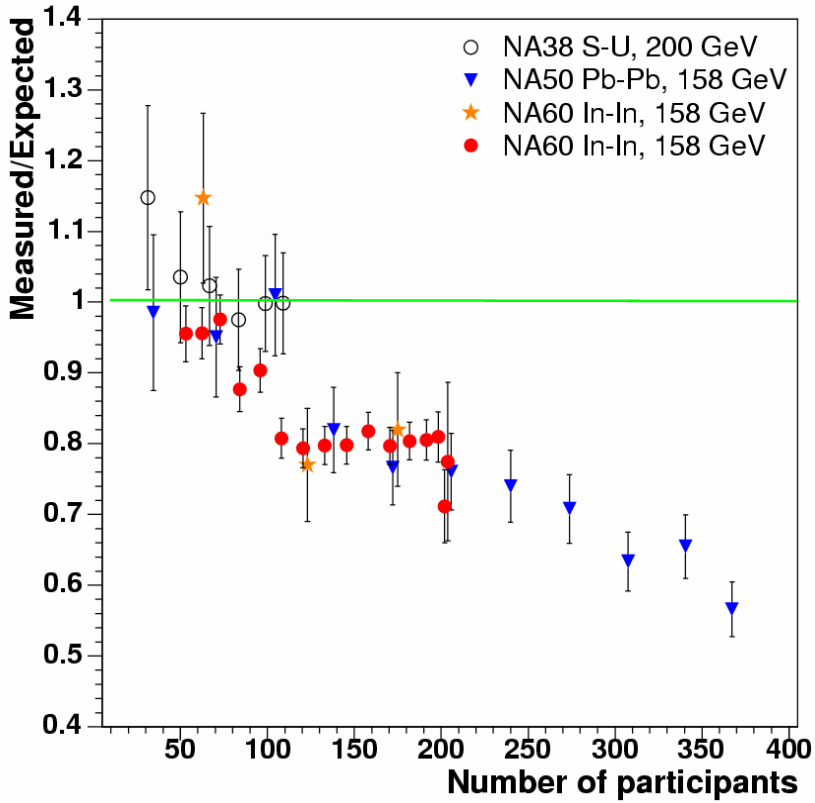
  - If the bound state is formed in, or passes through, a QGP, the free color charges will screen that potential (in a manner completely analogous to Debye screening in a Coulomb plasma).
  - In this case the J/Ψ will melt (or never form in the first place) and the c and c-bar quarks will again leave the system as D-mesons, having found a ubiquitous light quark.




Previous talk by Gianluca Usai

# An Unambiguous Signature?

- They carefully outlined the conditions that needed to be met for an observed suppression to be an unambiguous signature of QGP formation.
- We will see that two of these assumptions may well be violated.

To assure that this $J/\psi$ suppression in nuclear collisions indeed constitutes an observable signature of plasma formation, we must answer a number of questions:

(i) Can the $J/\psi$ escape from the production region before plasma formation?

(ii) At what temperature does $r_D(T)$ fall below $r_{J/\psi}(T)$, and how does $r_{J/\psi}(T)$ behave as function of $T$? The large mass gives the $J/\psi$ a smaller radius than that of conventional mesons, and sufficiently small hadrons could survive deconfinement as Coulombic bound states until much higher temperatures.

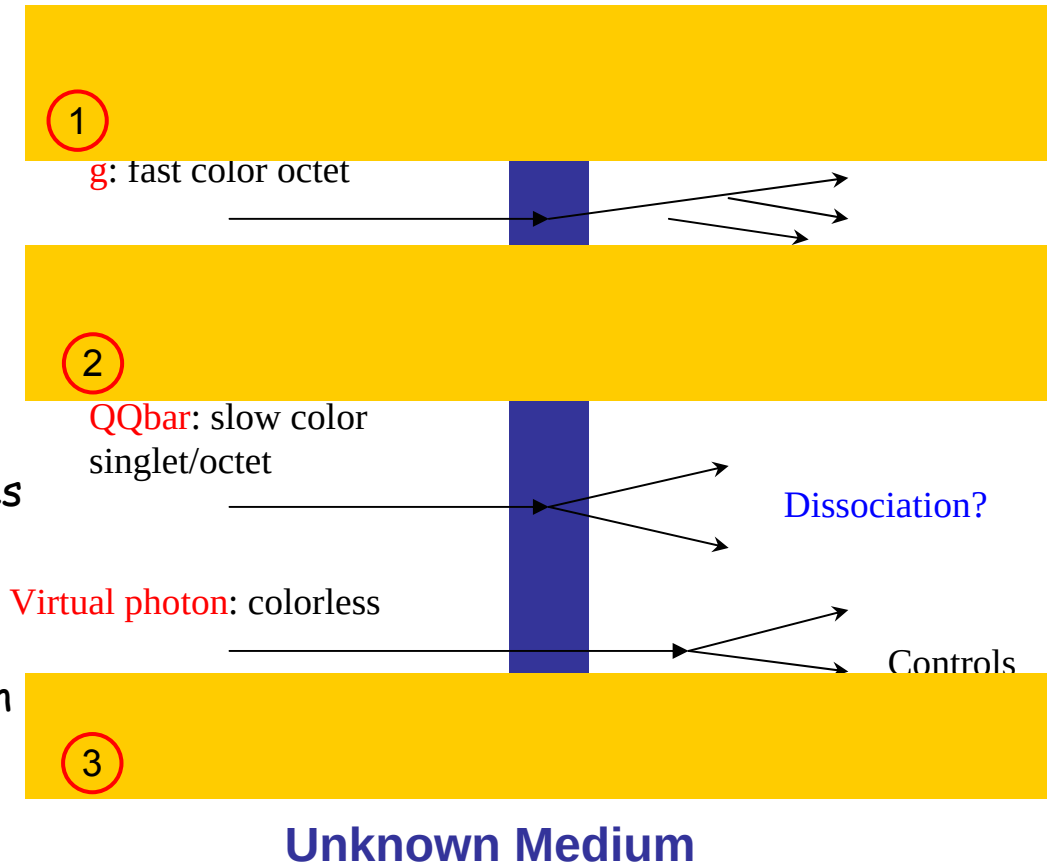
(iii) Are there competitive non-plasma $J/\psi$ suppression mechanisms?

(iv) Could the $J/\psi$ suppression in the plasma be compensated in the transition or hadronization stage?

(v) Could enhanced non-resonant production of lepton pairs ("thermal dileptons") prevent the observation of the $J/\psi$? In this case, we could not study deconfinement directly, although plasma formation would still be the cause for not seeing $J/\psi$'s. We will now take up these questions.

# Generic Advantages of Hard Probes

- Produced early
  - Sample medium
- Scale w/ $N_{binary}$ (in the absence of medium effects)
  - *pp* reactions calibrate probes, allowing detection of medium effects

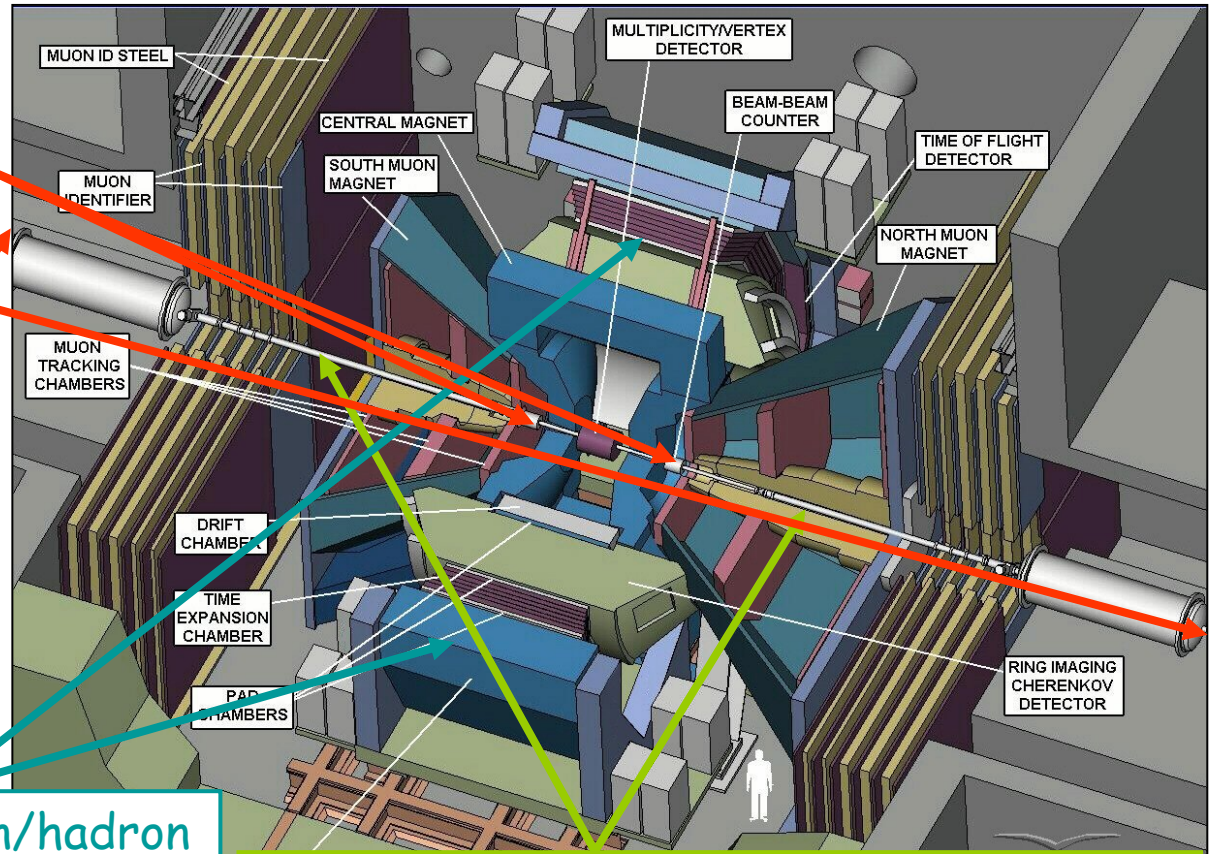



1. Suppression of high-pt single particles and jets (many talks).
2. Suppression of charm at high-pt (see talk I.3.B, by Xiaorong Wang).
3. Non-suppression of photon production (see talk I.9.A, by Takao Sakaguchi).

# PHENIX

**Two sets of forward-rapidity detectors for event characterization**

- Beam-beam counters measure particle production in $3.0<|\eta|<3.9$. Luminosity monitor + vertex determination.
- Zero-degree calorimeters measure forward-going neutrons.
- Correlation gives centrality




**Two central electron/photon/hadron spectrometers:**

- Tracking, momentum measurement with drift chamber, pixel pad chambers
- e ID with E/p ratio in EmCAL + good ring in RICH counter.

**Two forward muon spectrometers**

- Tracking, momentum measurement with cathode strip chambers
- $\mu$ ID with penetration depth / momentum match

# What Would We Like To Measure?

- Collision species dependence
- $y$, $p_T$ dependence
- $\sqrt{s}$ dependence
- Centrality dependence
- Polarization
- Reaction plane dependence
- $J/\Psi$ - hadron correlations
- $\Psi'$, $\chi_c$ and $B$ contributions
- Compare to $\Psi'$, $\Upsilon$

# What have we measured?

- Collision species dependence ✓e
- $y$, $p_T$ dependence ✓e
- $\sqrt{s}$ dependence ✓e
- Centrality dependence ✓e
- Polarization ✓e
- Reaction plane dependence No
- $J/\Psi$ - hadron correlations No
- $\Psi'$, $\chi_c$ and $B$ contributions No
- Compare to $\Psi'$, $\Upsilon$ No

✓e – Good start on exploratory measurements

| | |
|---|---|
| Species : | *pp, dAu, CuCu, AuAu* |
| $y$ : | $\lvert y\rvert < 0.35$ (central arm), $1.2 < \lvert y\rvert < 2.4$ (muon arms) |
| $p_T$ : | $0 < p_T < 5$ GeV/c |
| $\sqrt{s}$ : | 200 GeV (and 62 GeV/c CuCu) |
| Polarization : | preliminary measurement in dAu |
| Statistics : | More is always better (allows reduction in statistical and systematic errors) |

# J/Ψ in *pp* – Measuring Initial Production

- In *pp* we've measured the J/Ψ close to $p_T$ = 0 and over much of the rapidity range.

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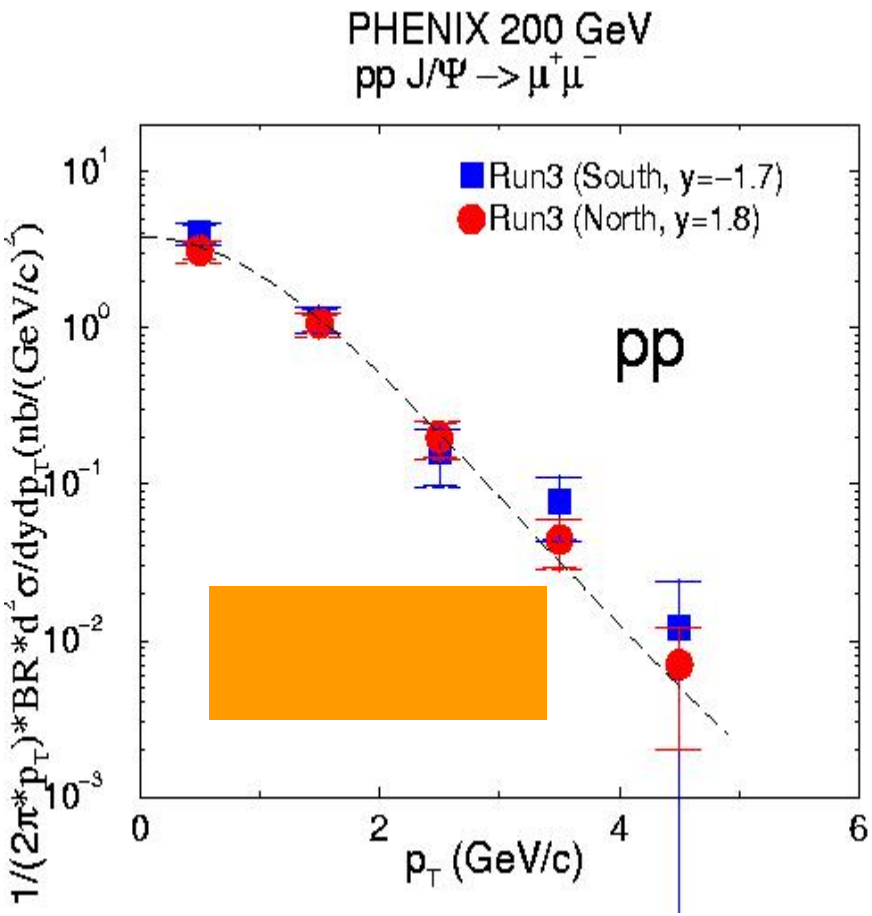
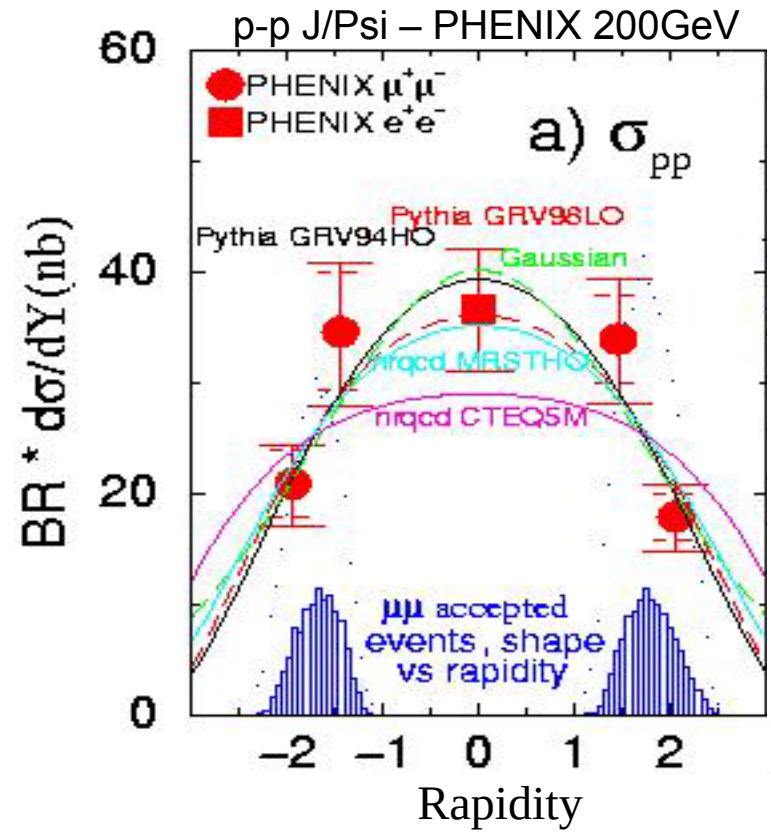
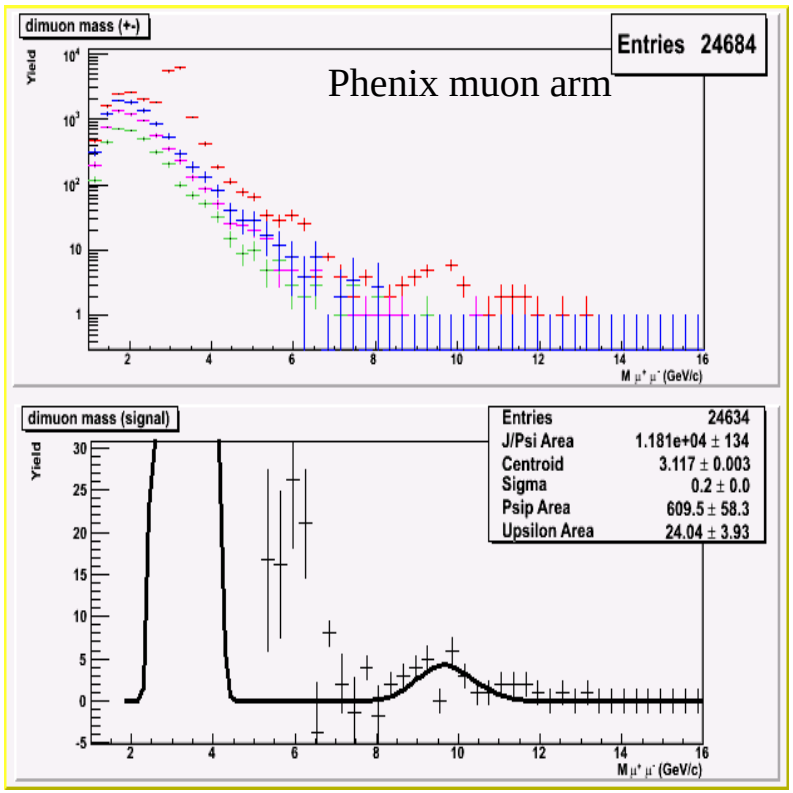
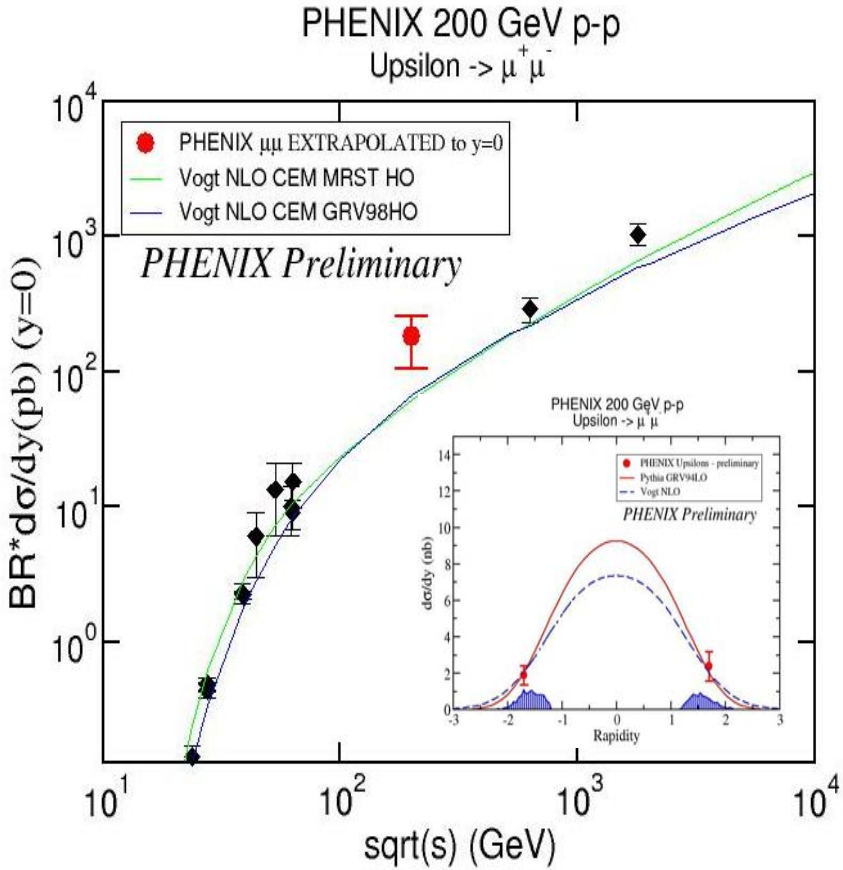



σ = 2.61+/-0.20(fit)+/-0.26(abs) μb



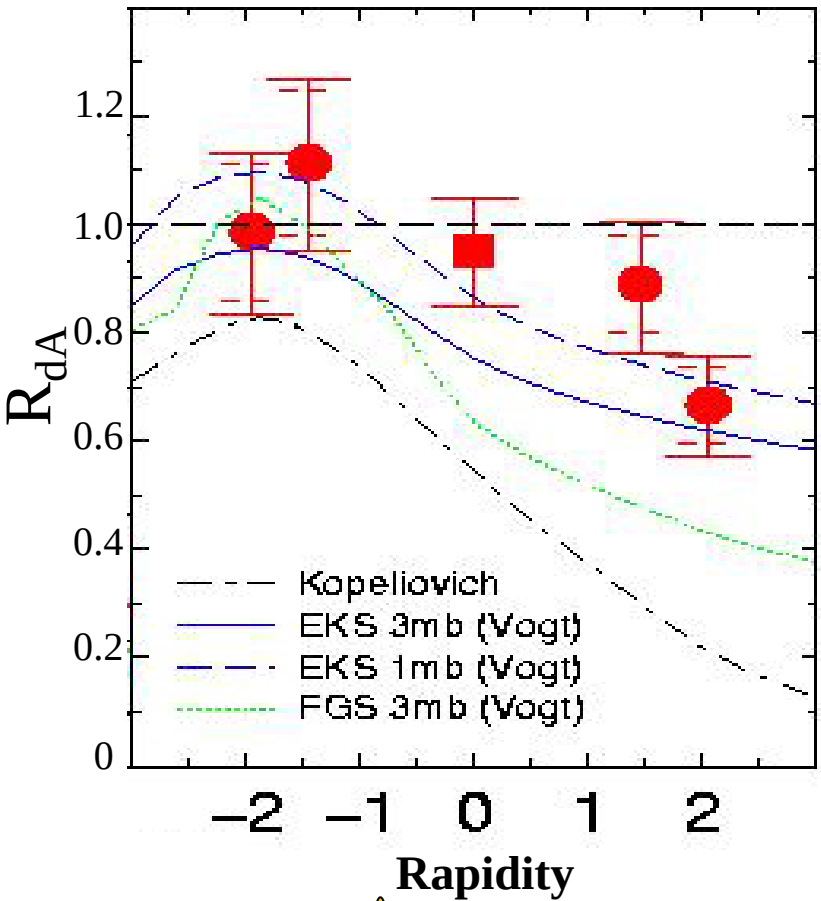
# J/Ψ in *pp* – Much More to Come!

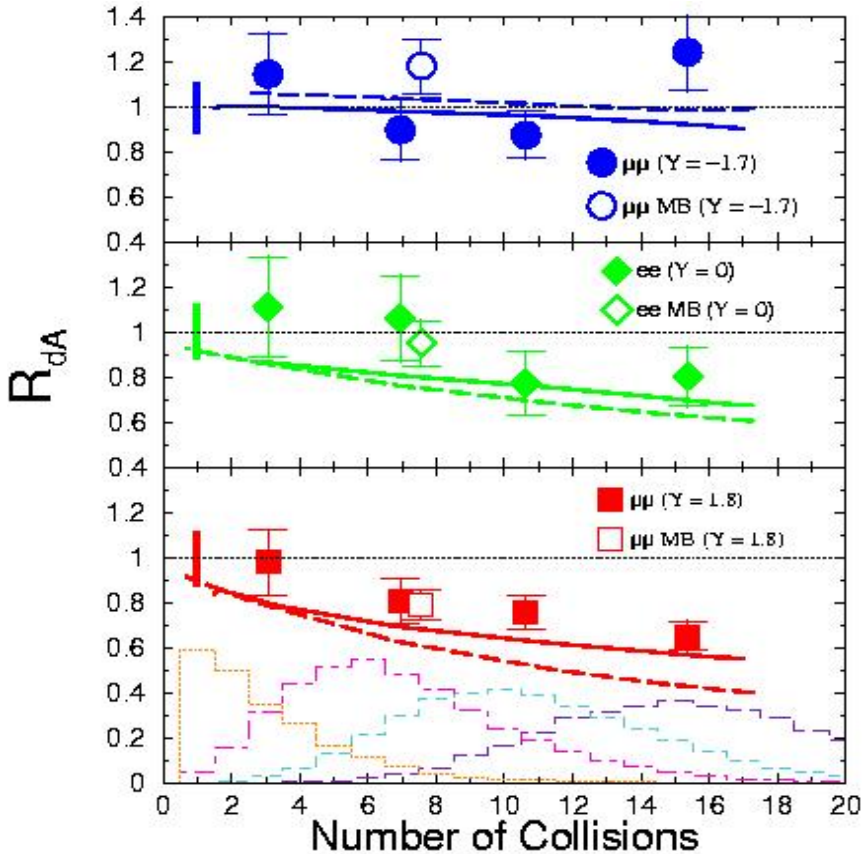


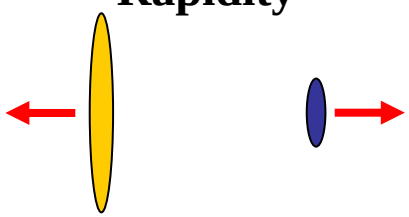




First Upsilons at RHIC from ~3pb$^{-1}$ collected during the 2005 run.

# J/Ψ in *dAu* – Calibrating Cold Nuclear Matter Effects I



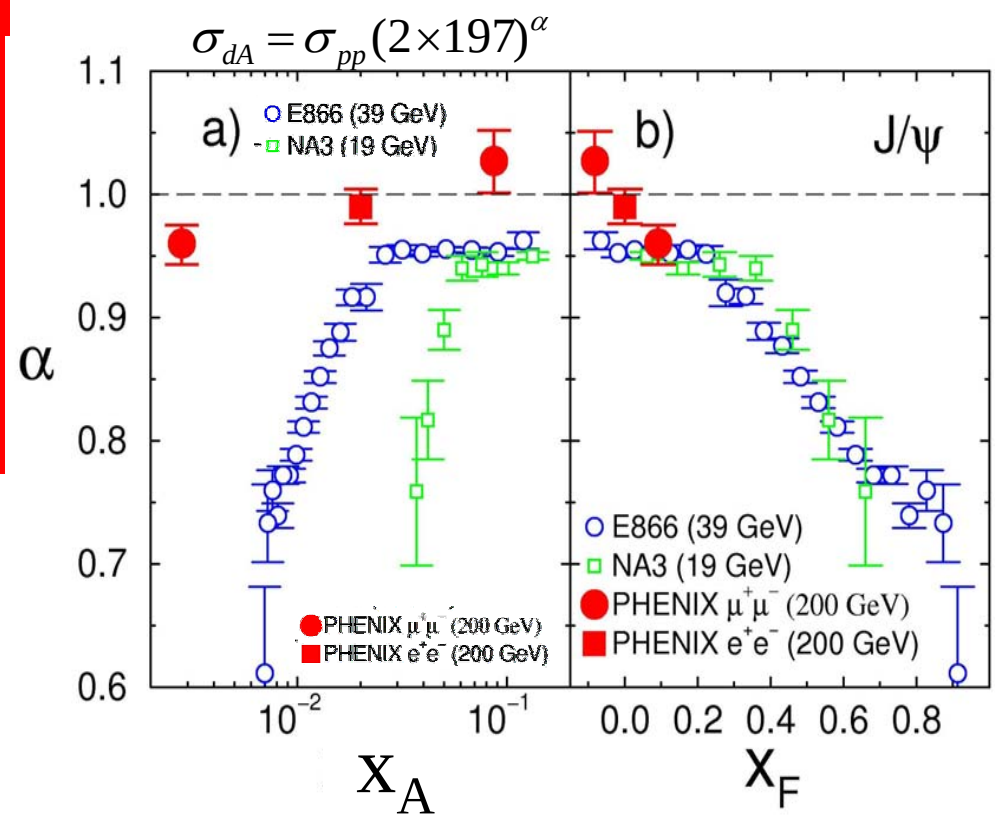



- Data favor weak shadowing and weak nuclear absorption.
- More suppression for more central events.

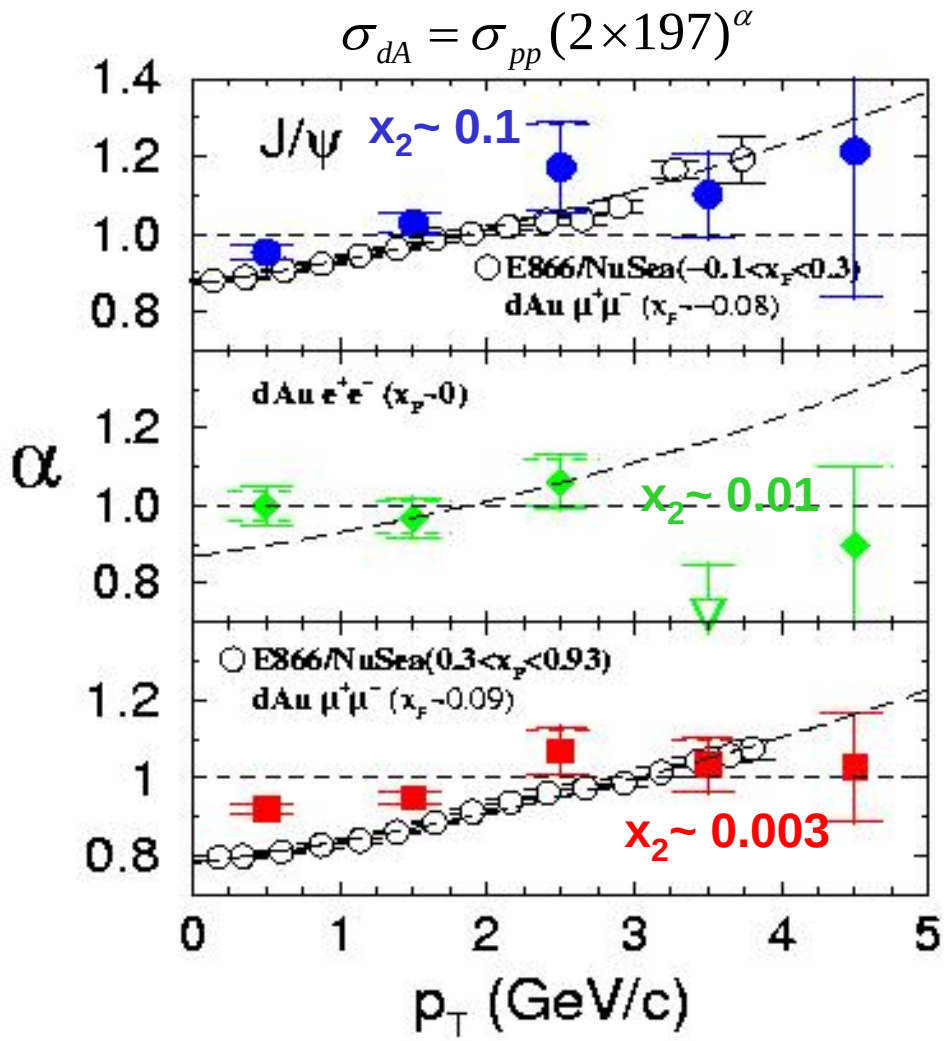
# J/Ψ in *dAu* – Calibrating Cold Nuclear Matter Effects II

- However, we observe strong violation of scaling with the momentum fraction of the nucleus, $x_A$, which one would not expect for shadowing effects.



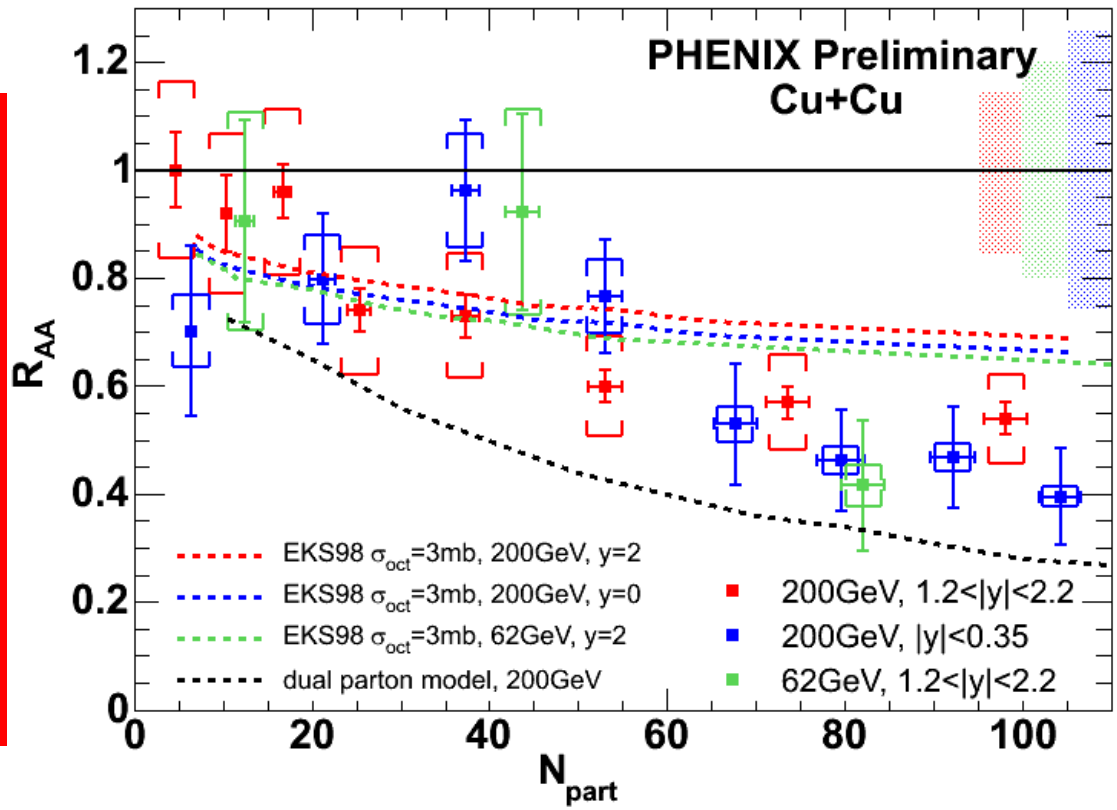
# J/Ψ in *dAu* – Calibrating Cold Nuclear Matter Effects III

- Distributions are broader in $p_T$, consistent with measurements by E866 at $\sqrt{s}$ = 39 GeV.



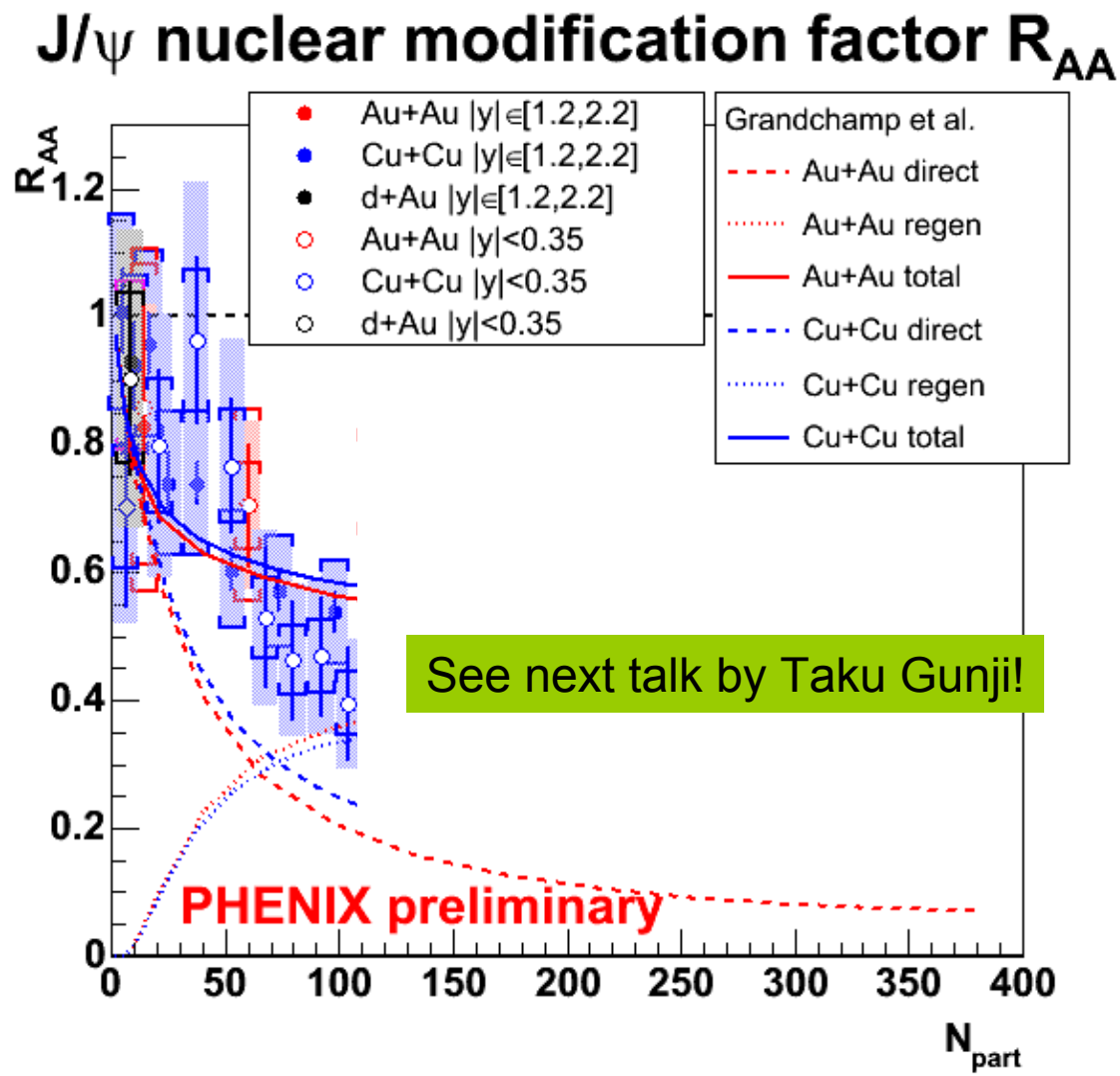
# J/Ψ in *CuCu* – $N_{part}$ Dependence

- Results similar in all rapidity bins.
- Results similar for $\sqrt{s}$ = 62 and 200 GeV.
- Smooth factor of two suppression as collisions get more central.
- Models with only cold nuclear matter effects somewhat underpredict the suppression, although they have the correct $\sqrt{s}$ and $y$ behavior.



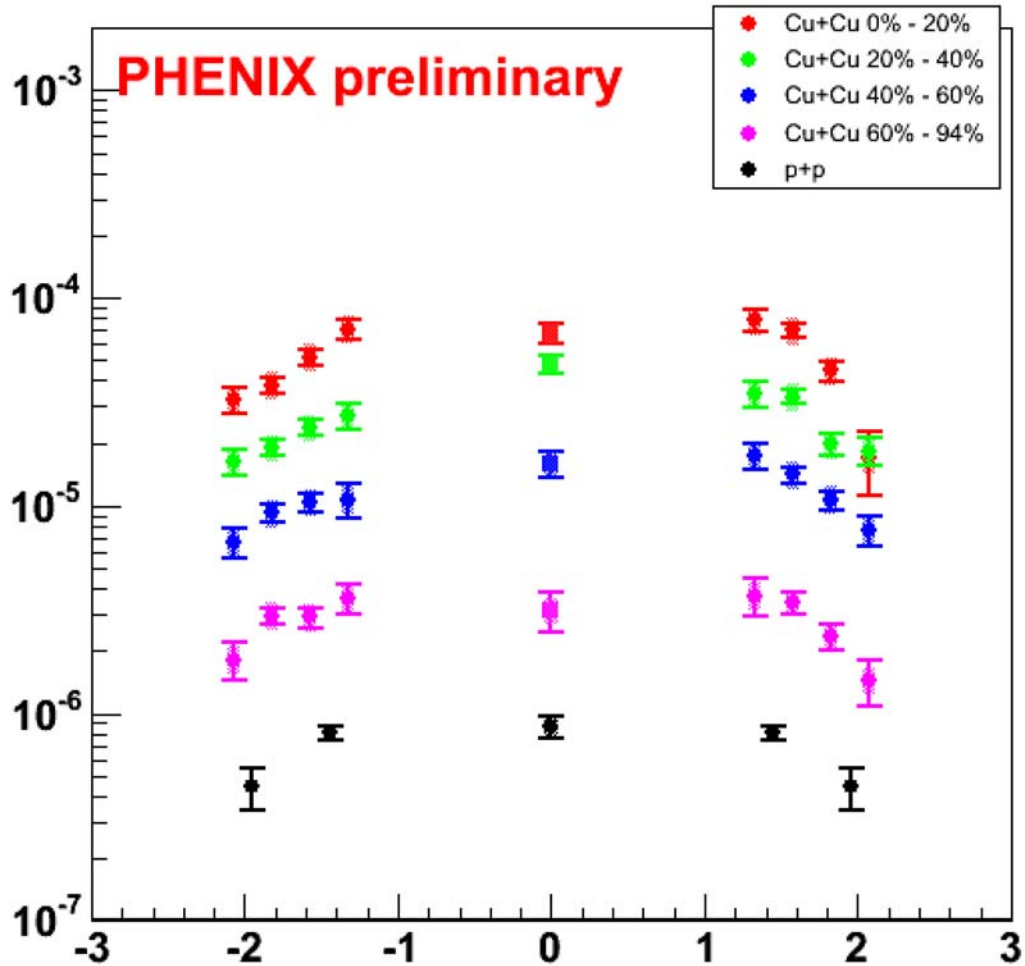
# J/Ψ in *CuCu* – Recombination Effects?

- In fact, models that explain NA50 results via hot nuclear matter effects significantly overpredict the suppression at RHIC.
  - Unless they include recombination.

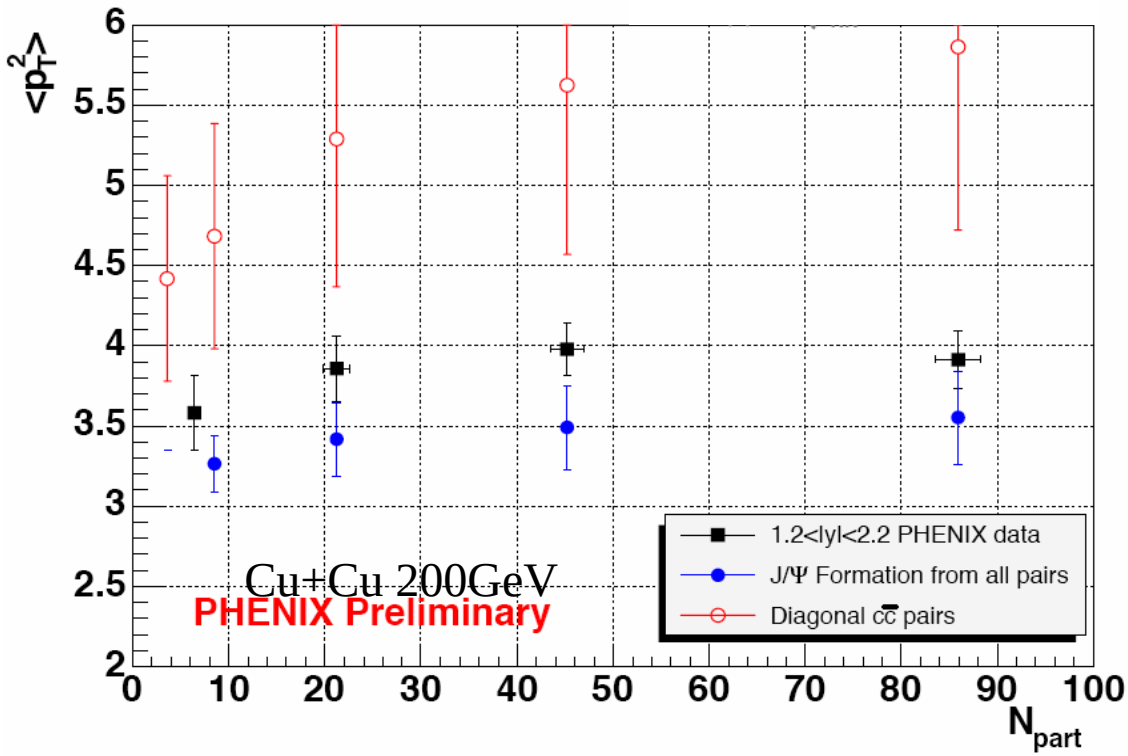


# J/Ψ in *CuCu* – Rapidity Dependence

- However, rapidity distributions not strongly peaked at $y = 0$ as expected from current recombination models.



# J/Ψ in *CuCu* – $p_T$ Dependence




- On the other hand…
- $\langle p_T^2 \rangle$ is consistent with flat as a function of centrality
  - Red* shows NLO calculation without recombination.
  - Blue* shows effect of including J/Ψ's produced via recombination.

* R.L. Thews, Quarkonium Formation from Heavy Quark Recombination", PHENIX Muon Workshop, June 13, 2005.

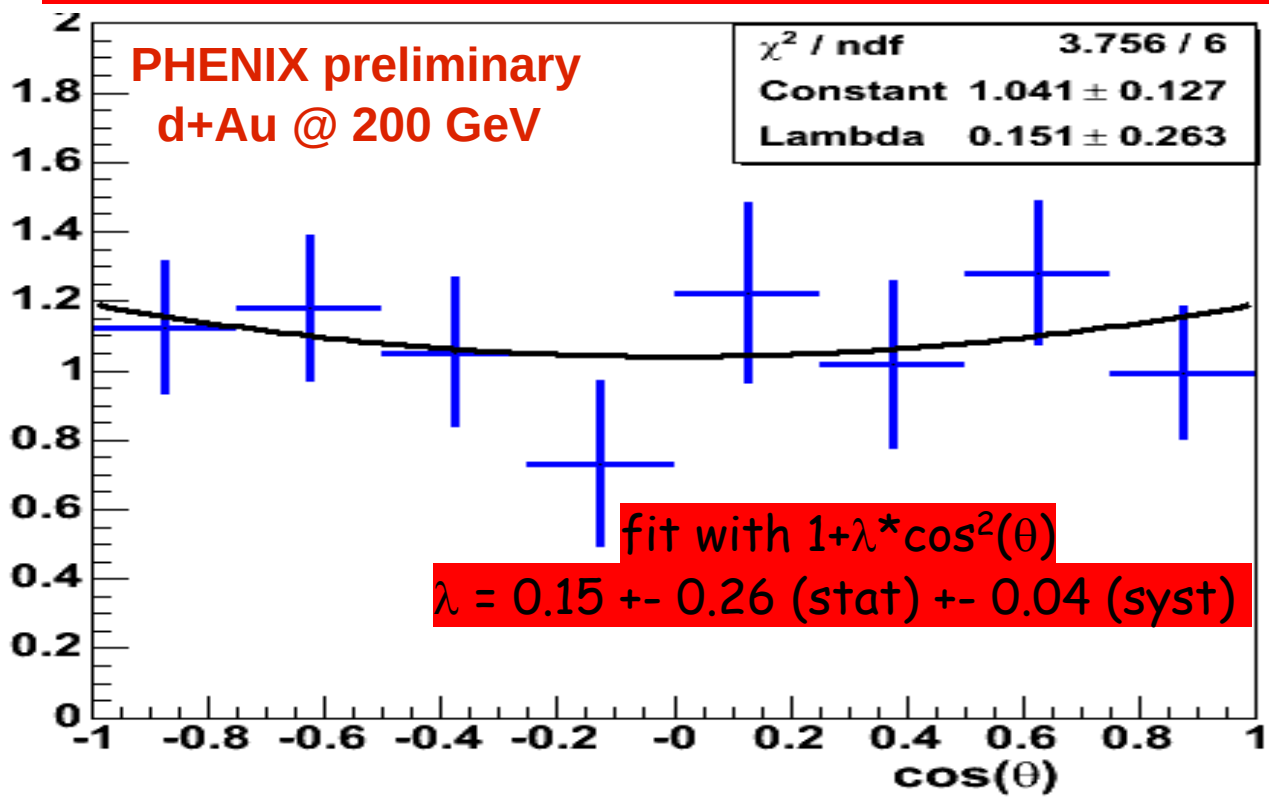
# Conclusions

- PHENIX has measured J/Ψ production as a function of several independent variables.
  - Really just starting on a systematic measurement program.
- J/Ψ's are not simple.
  - Cold nuclear matter effects are present and although they appear to be relatively modest they are not understood.
  - It may be that not all J/Ψ's come from initial production (*i.e.*, recombination may be important).
- Patience may be rewarded though, because J/Ψ's are sensitive to so much more than simple screening.

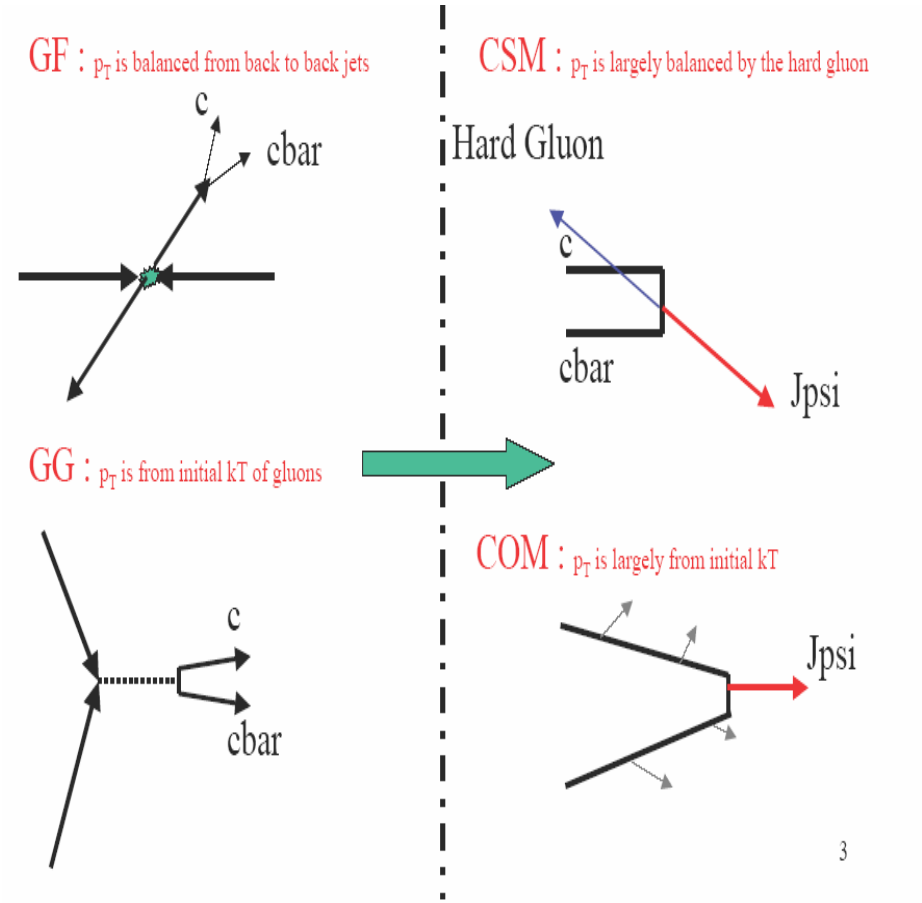
# Backup Slides

# J/Ψ Polarization – Understanding the Production Mechanism

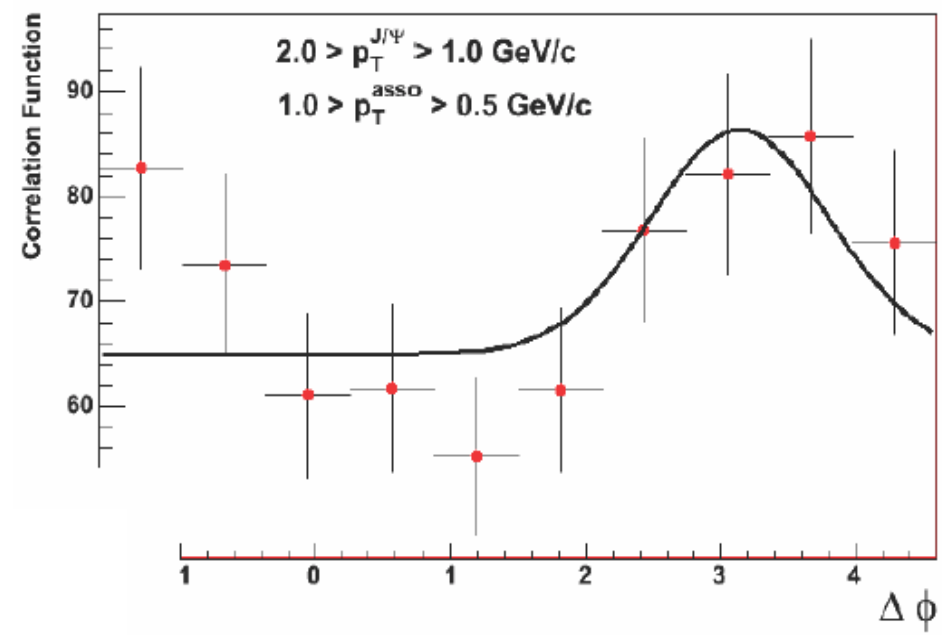
- J/Ψ cross section measured by CDF exceeds color-singlet predictions by a large factor.
- Color octet model predicts cross section in agreement with the data, but is in apparent disagreement with polarization measurement.
- We have a low-statistics measurement that should improve significantly with Run-5 data.



# Azimuthal Correlations Between J/Ψ's in the Muon Arms and Hadrons in the Central Arm – Understanding the Production Mechanism




- By looking at angular correlations between J/Ψ's and associated particles one may shed light on production mechanisms.



# Charm Energy Loss

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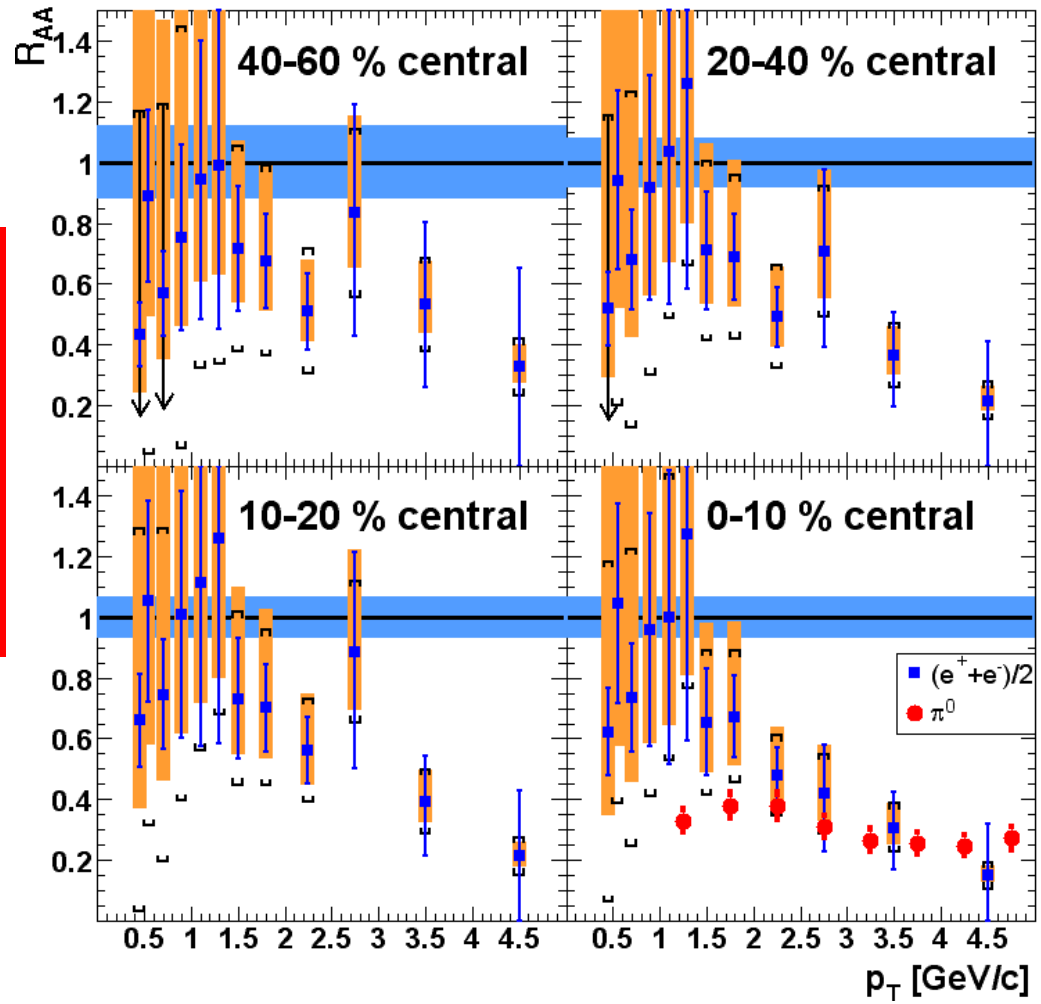
- Charm quarks appear to lose energy and flow in the medium.
- This may have a significant impact on our understanding of J/Ψ production.