Measurements of J/ψ yields at forward-rapidity and mid-rapidity in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV by PHENIX at RHIC

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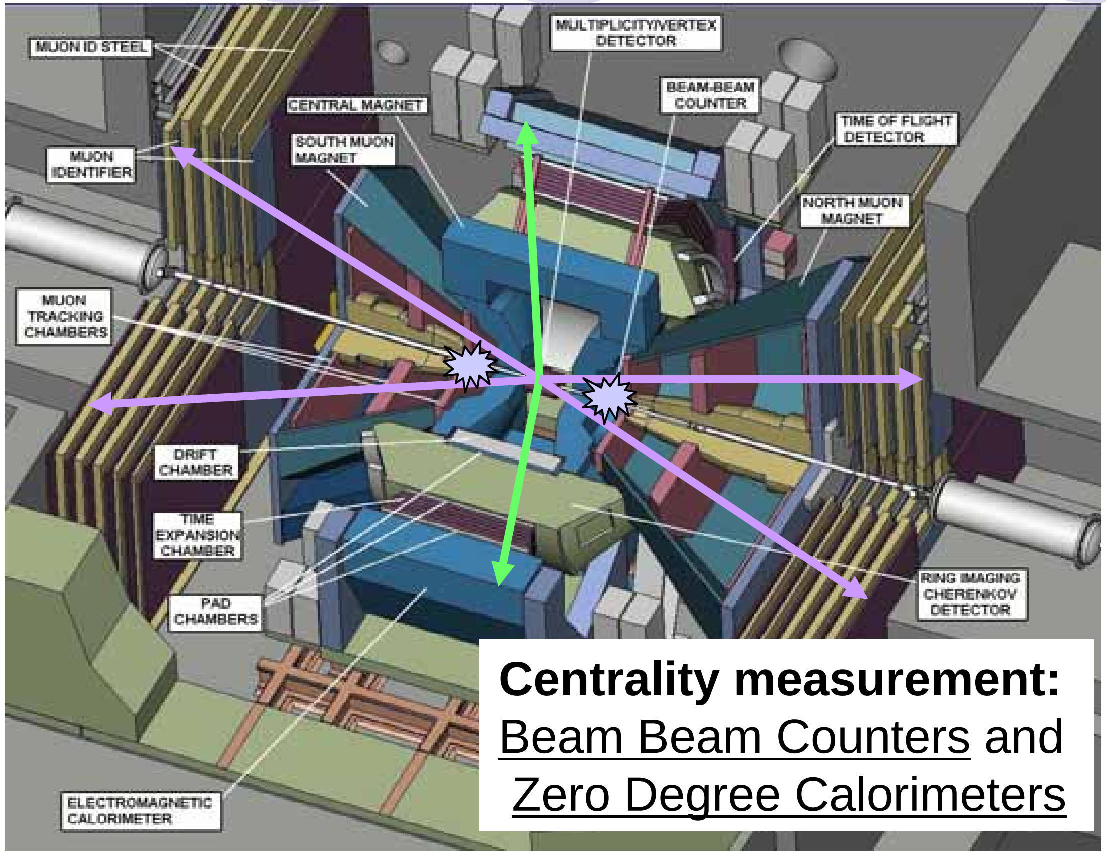
Outline

- Physics Motivation
- PHENIX Experiment
- Results and Comparison to the theoretical models
  - Nuclear Modification Factor
  - Invariant p_T distribution
  - $\langle p_T^2 \rangle$ vs. Number of collisions (Ncol)
  - Invariant Yield (BdN/dy) vs. Rapidity
- Summary

Physics Motivation

- J/ψ is one of the most important probes to study hot and dense medium created by heavy ion collisions.
  - J/ψ is supposed to be created at initial stage of collisions and interacts with the surrounding medium.
- Competing effects of J/ψ production in the medium
  - Suppression of the J/ψ yield by Color Debye Screening
  - Enhancement of the J/ψ yield by the recombination of uncorrelated $c\bar{c}$ pairs
  - Cold matter effects (Nuclear absorption, Gluon Shadowing)
- Therefore, Need to do the systematic study.
  - Collision Geometry and Rapidity dependence
  - Different nuclear species (p+p, d+Au, Cu+Cu, **Au+Au**)
    - Base line to understand the cold matter effects.
  - Different beam energy (62.4,130 and **200 GeV**)

PHENIX Experiment



Centrality measurement:
Beam Beam Counters and
Zero Degree Calorimeters

Central Arms:
Hadrons, photons, electrons

- $J/\psi \rightarrow e^+e^-$
- $|\eta|<0.35$
- $P_e > 0.2$ GeV/c
- $\Delta\phi = \pi$ (2 arms x $\pi/2$)

Muon Arms:
Muons at forward rapidity

- $J/\psi \rightarrow \mu^+\mu^-$
- $1.2< |\eta| < 2.4$
- $P\mu > 2$ GeV/c
- $\Delta\phi = 2\pi$

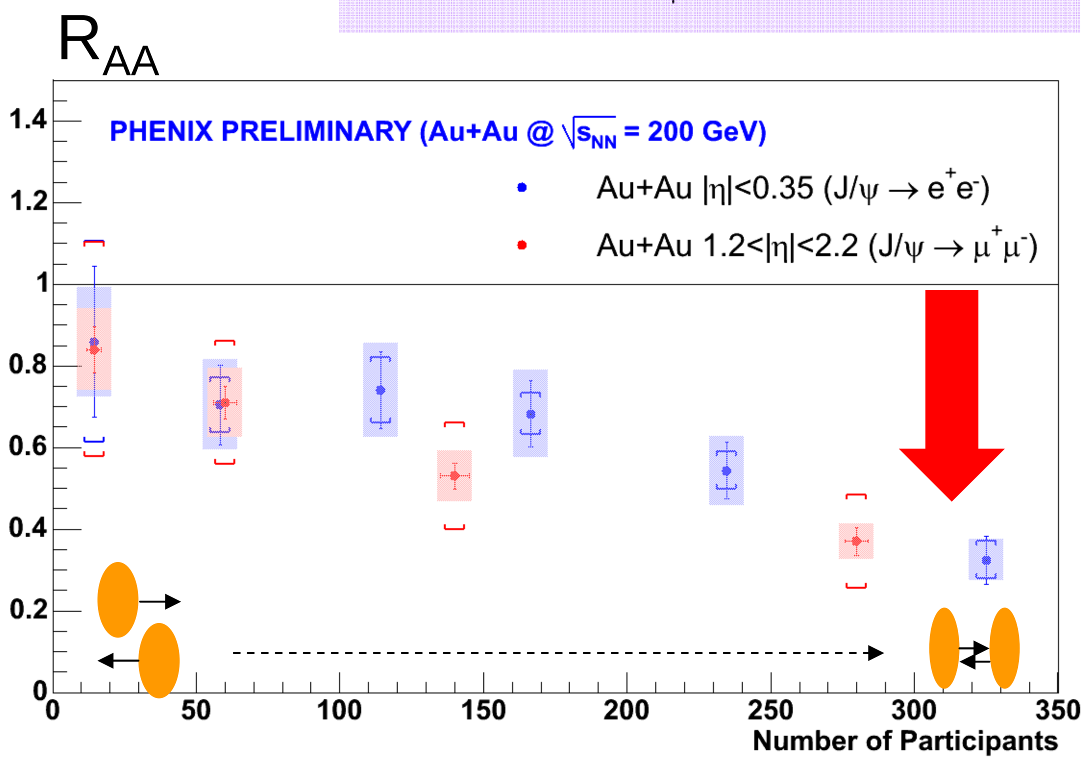
PHENIX recorded 1.5B (total) events (~ 241 μb^{-1}) in 2004 run

- 10 times larger statistics compared to 2002 run
- reconstructed ~ 600 $J/\psi \rightarrow e^+e^-$ and ~ 5000 $J/\psi \rightarrow \mu^+\mu^-$

Nuclear Modification Factor

- Nuclear Modification Factor : $R_{AA} = \dfrac{dN_{J/\psi}^{AuAu}/dy}{dN_{J/\psi}^{pp}/dy \times \langle N_{coll} \rangle}$

- N_{col} = Number of binary N-N collisions.
- R_{AA} =1
  - Yield is scaled by $N_{col.}$ (same as p+p)
  - No medium effects.
- R_{AA} < 1
  - Suppression



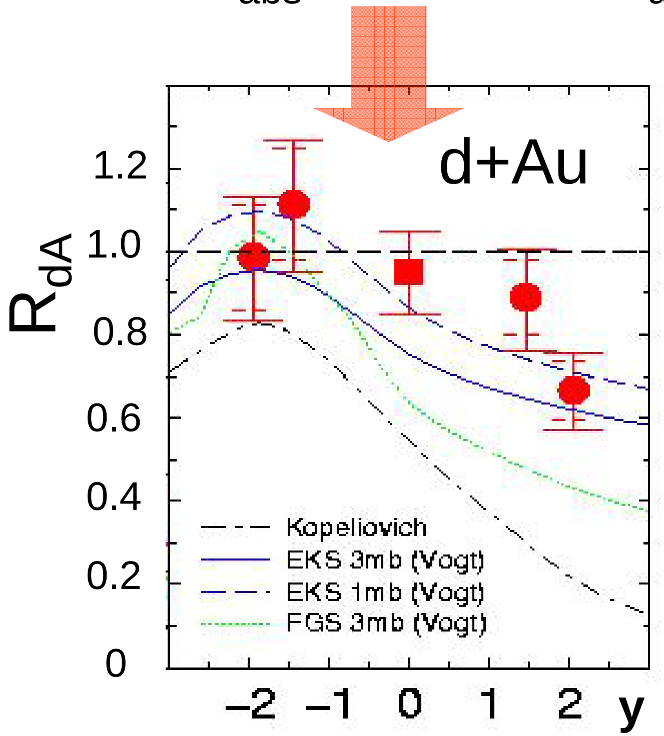
bar : stat. error
bracket : point-by-point sys. error
box : common sys. error

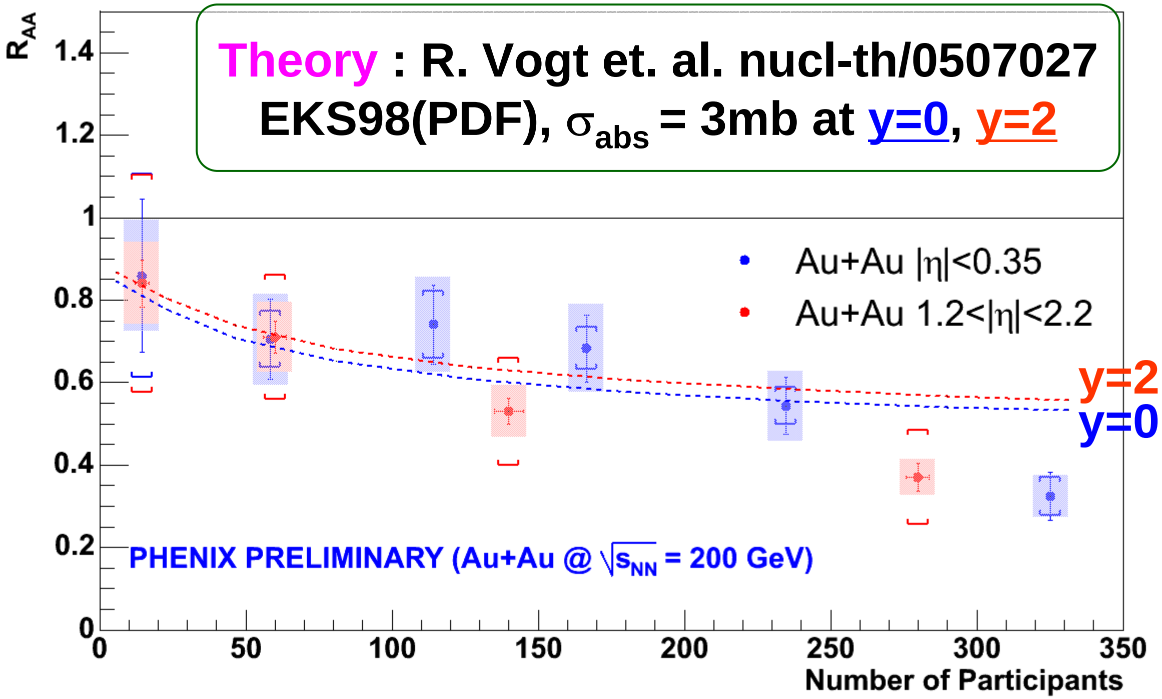
J/ψ yield is suppressed compared to that in p+p collisions.

- Suppression is larger for more central collisions.
- Factor of 3 suppression at most central collisions.

Cold Nuclear Matter Effects

- Nuclear Absorption and Gluon Shadowing
- Evaluated from PHENIX d+Au results (nucl-ex/0507032)
  - σ_{abs}< 3mb and σ_{abs} of 1 mb is the best fit result.

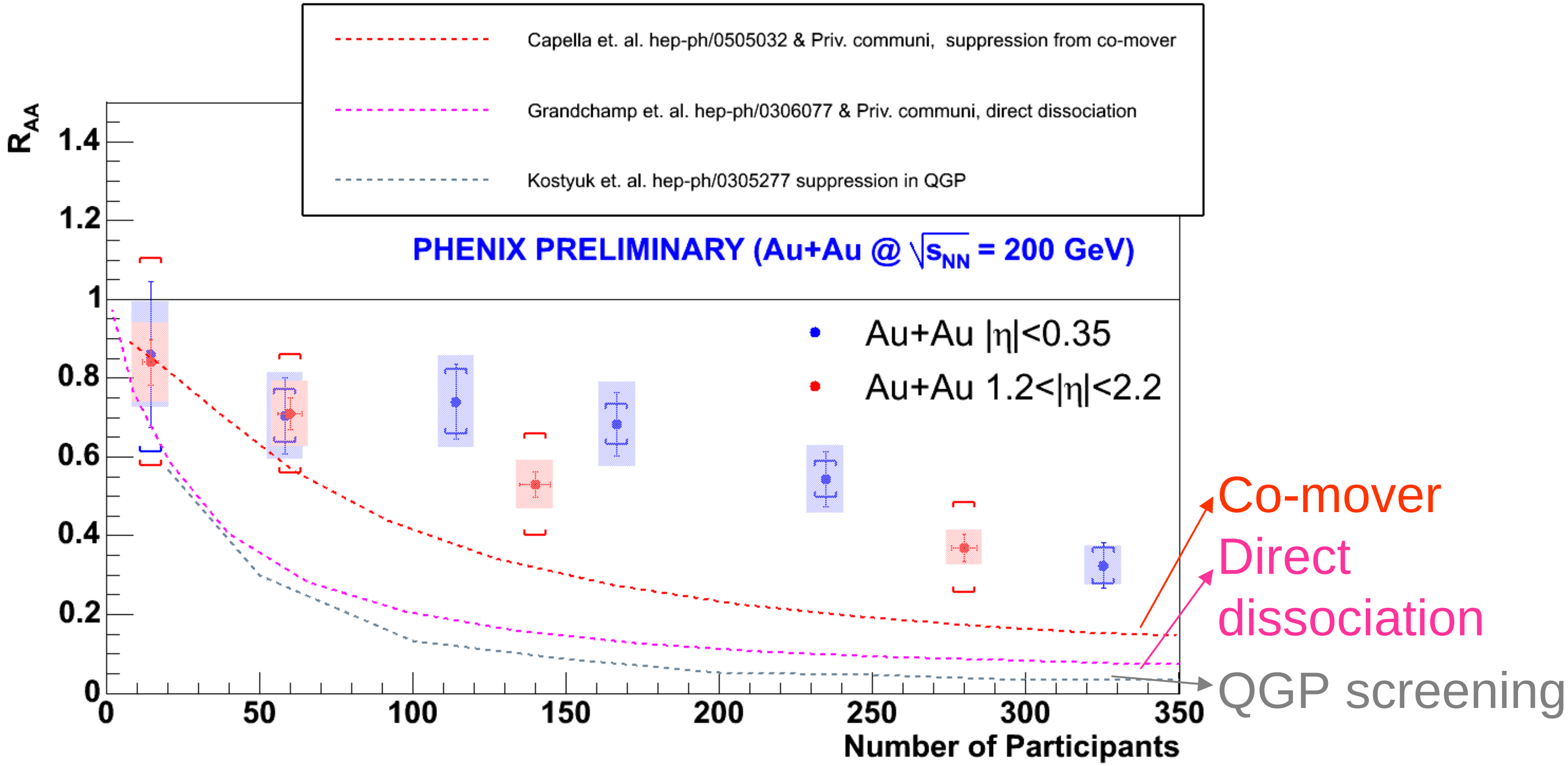




Beyond the suppression from cold nuclear matter effects for most central collisions even if σ_{abs} ~ 3 mb.

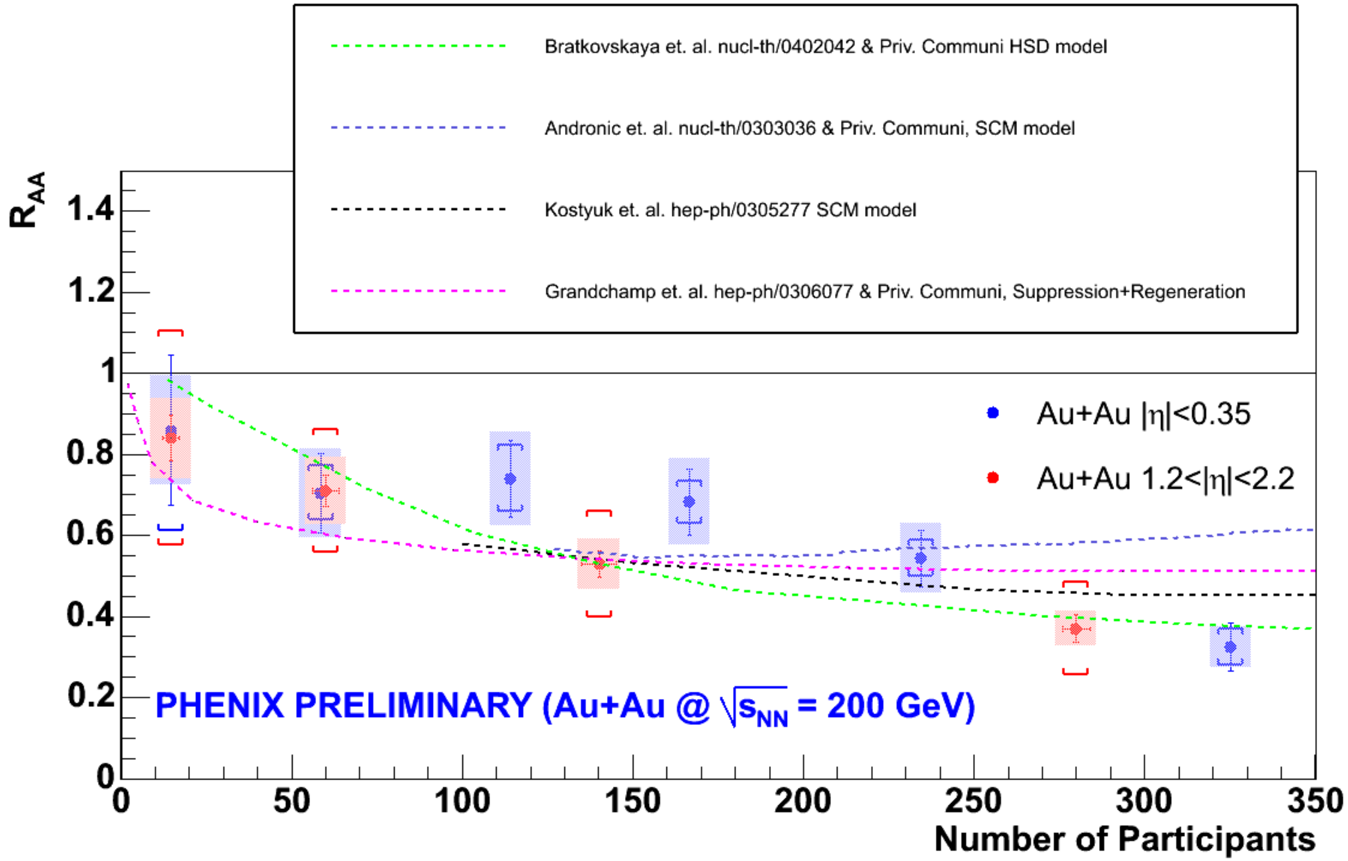
Suppression Models

- Color screening, direct dissociation, co-mover scattering



J/ψ suppression at RHIC is over-predicted by the suppression models that described SPS data successfully.

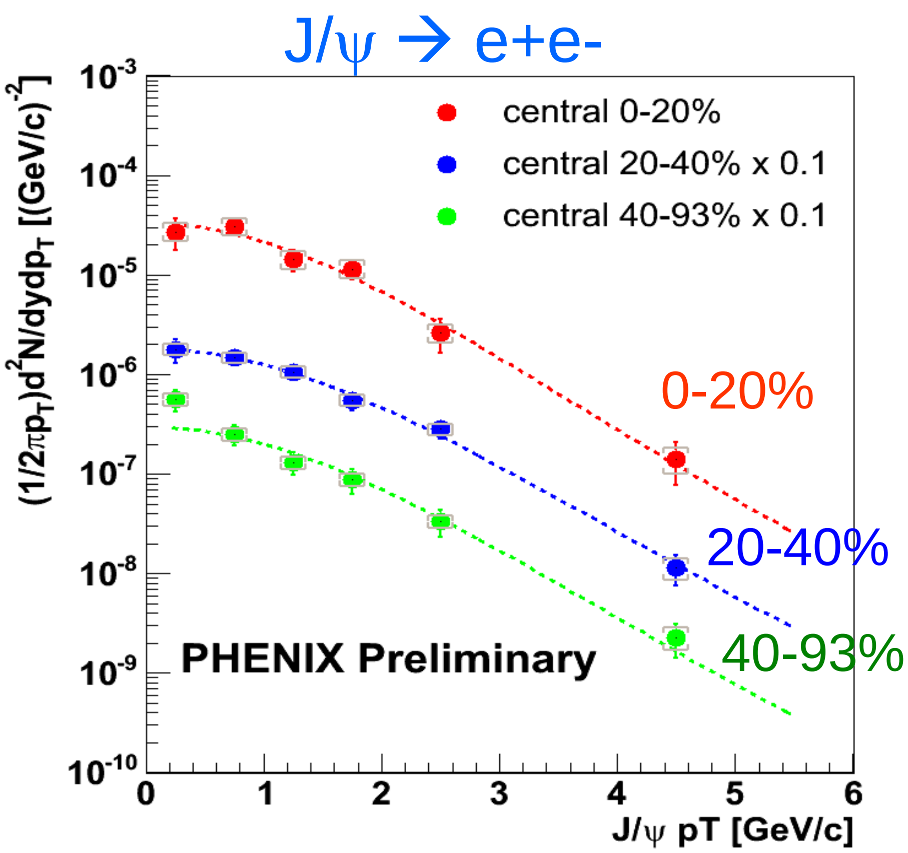
Suppression + Recombination Models

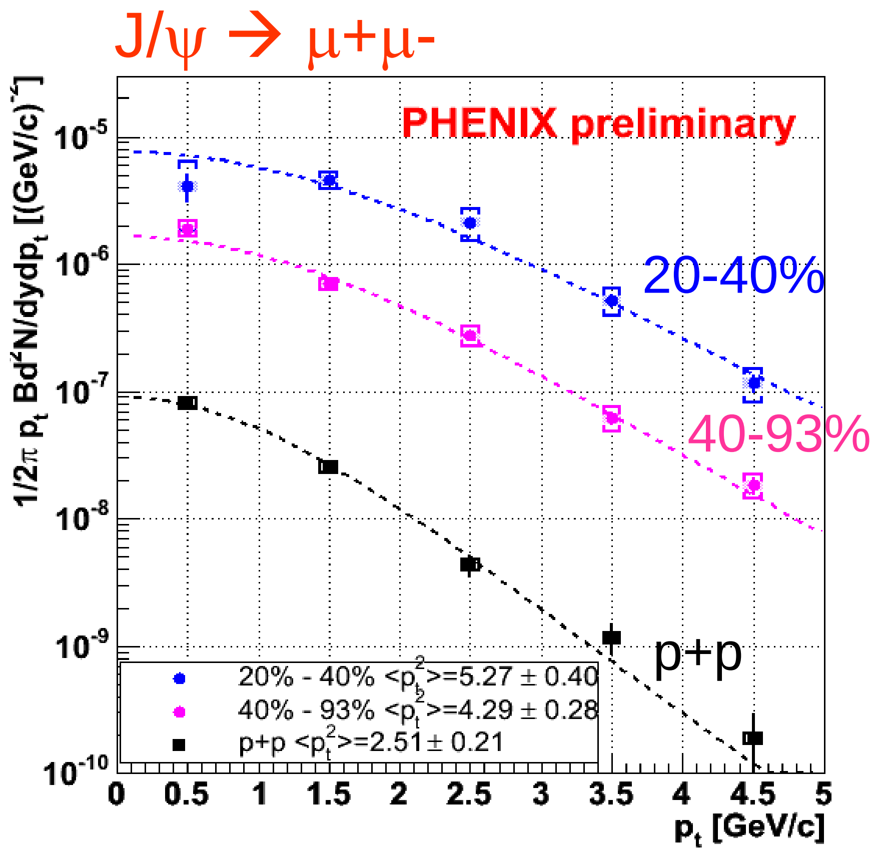


Better matching with results compared to suppression models.
At RHIC (energy): Recombination compensates stronger suppression?

Invariant p_T distribution

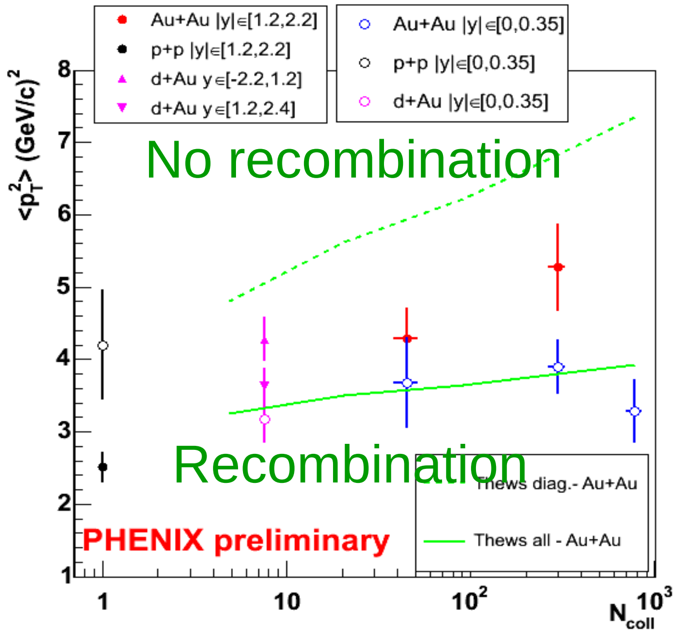
- Prediction of J/ψ yield at low p_T :
  - Enhancement (Recombination) / Suppression (QGP suppression)
- Extraction of $\langle p_T^2 \rangle$ by fitting with $A(1+(p_T/B)^2)^{-6}$

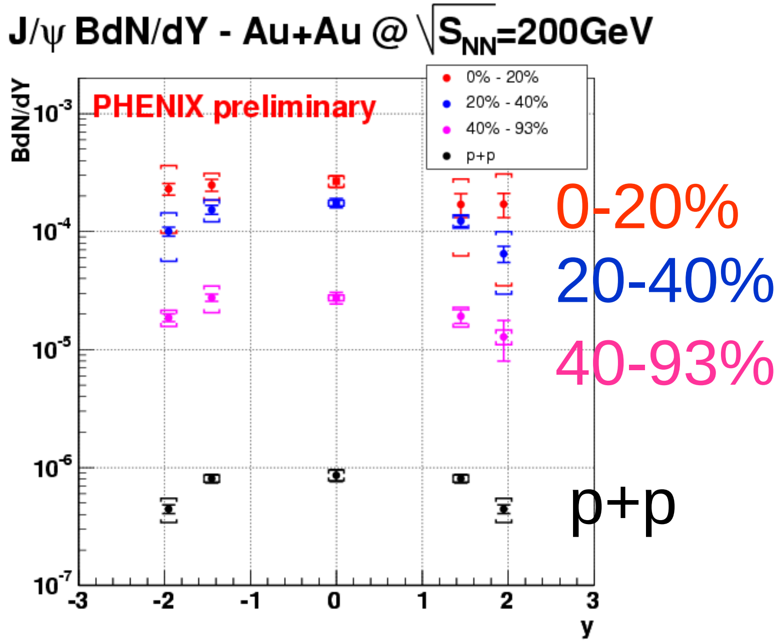




$<p_T^2>$ vs. Ncol, BdN/dy vs. Rapidity

- Recombination predicts narrower p_T and rapidity distribution.
  - $<p_T^2>$ vs. Ncol
    - Predictions of recombination model matches better.
  - BdN/dy vs. Rapidity
    - No significant change in rapidity shape compared to p+p result.
- But charm p_T and rapidity distributions at RHIC is open question.





Summary

- PHENIX measured the J/ψ yield and invariant p_T distribution at mid-rapidity and forward rapidity.
  - Suppression of J/ψ yield can be seen.
    - Suppression is larger for more central collisions.
    - Factor of 3 suppression at most central collisions.
  - Cold matter effects under-predict the suppression.
  - Suppression models over-predict the suppression.
  - Suppression + Recombination models match better.
  - $\langle p_T^2 \rangle$ shows better matching to recombination model.
  - No significant change in the Rapidity shape.
    - Need to understand our data with charm p_T and rapidity distributions at RHIC.

12 Countries; 58 Institutions; 480 Participants*

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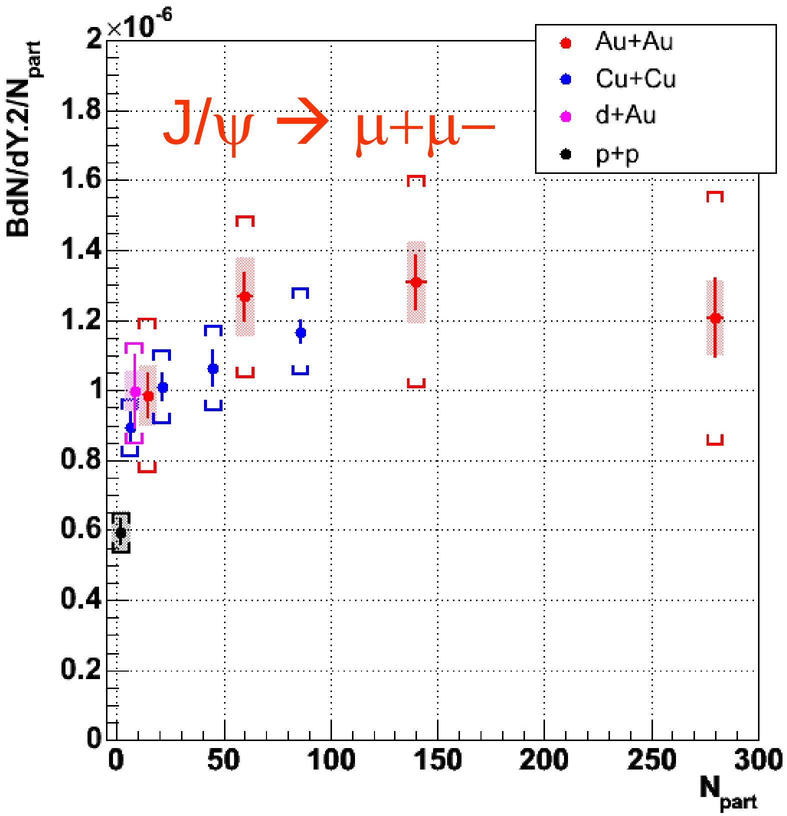
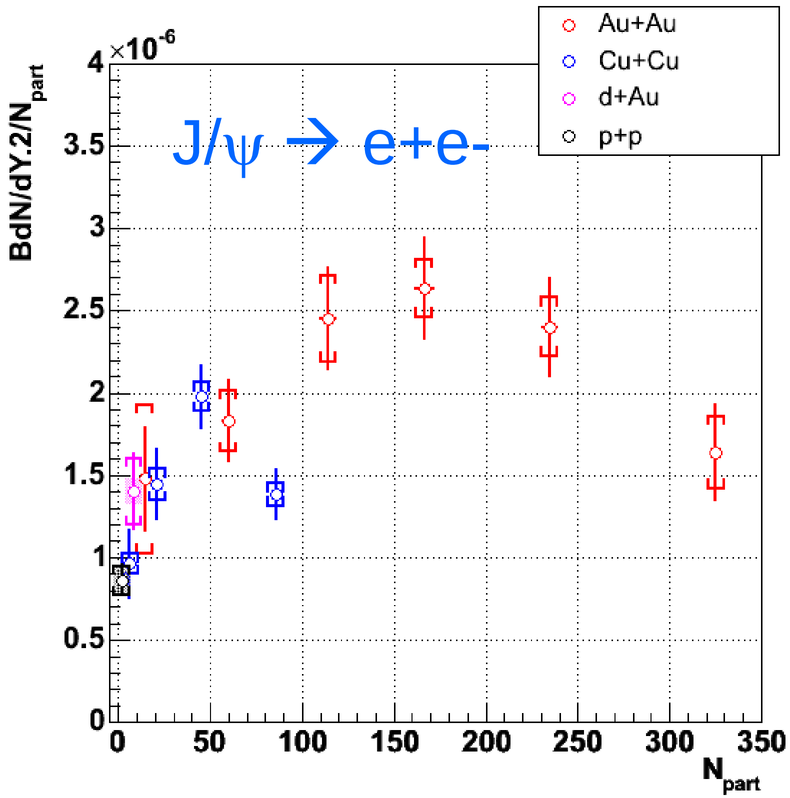
*as of January 2004

Back up slides

N_{part} scaling

$$\frac{dN^{AA}/dy}{0.5 \times \langle N_{part} \rangle}$$

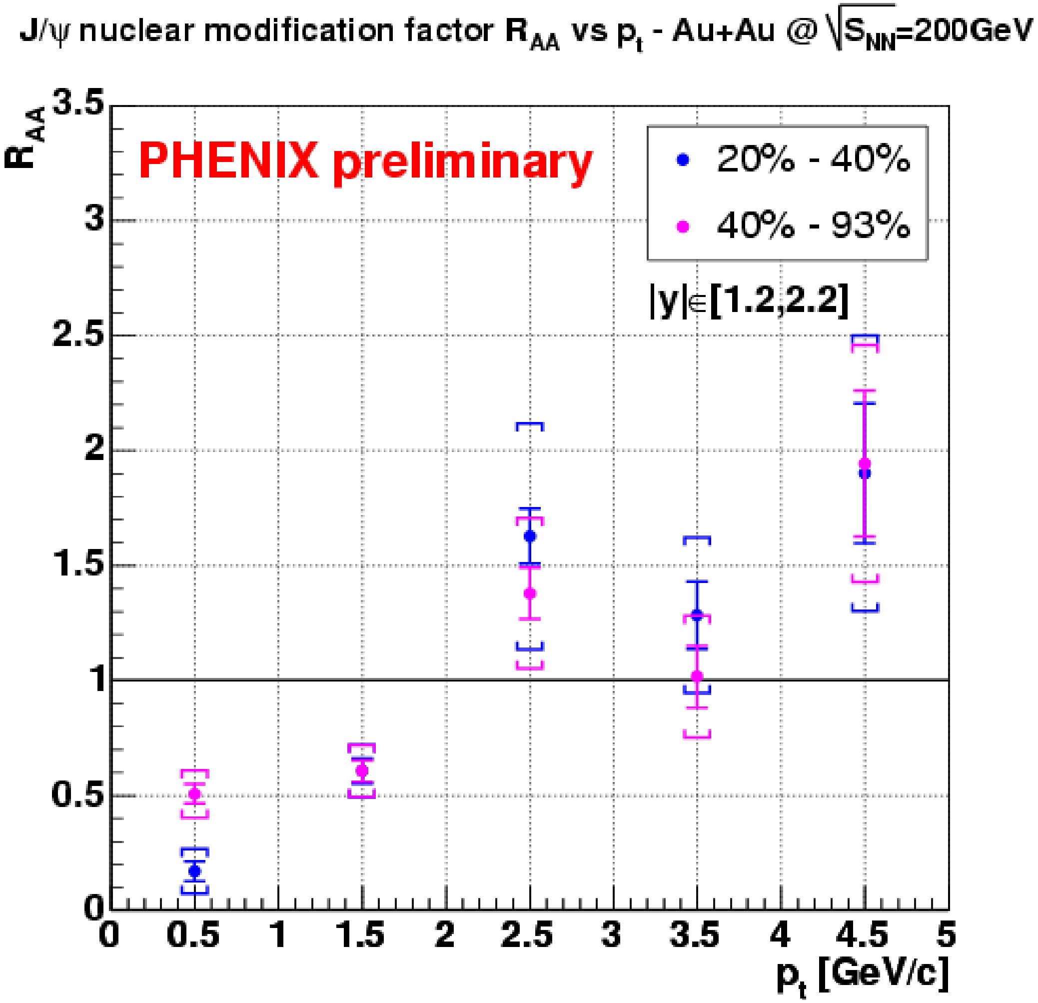




Could be flat in the forward region, but not in the central region

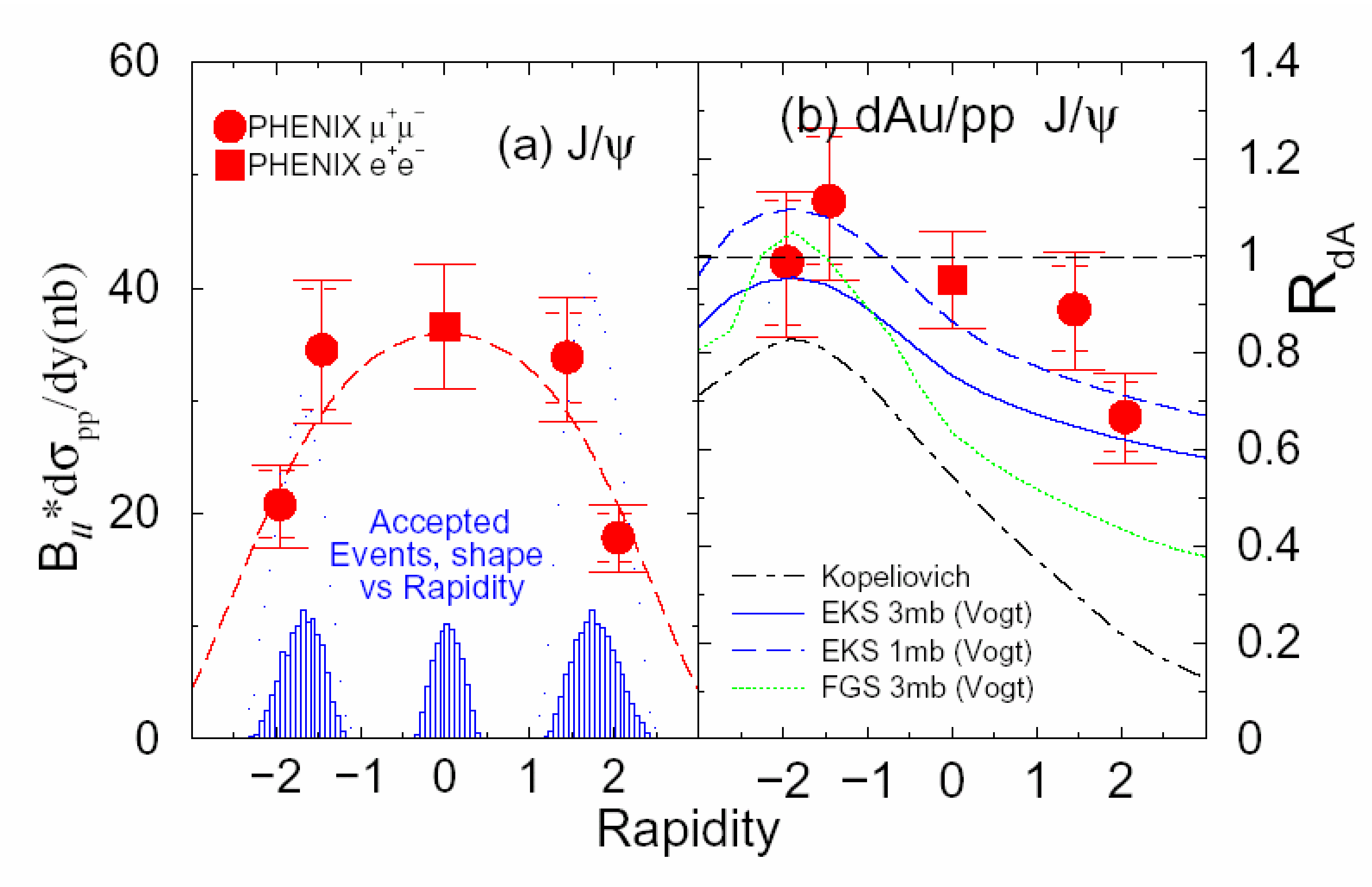
R_{AA} as a function of p_T

- R_{AA} vs. p_T
  - Results from forward rapidity region
  - low p_T points are Significantly lower than 1
  - Suppression can be seen for low p_T J/ψ.

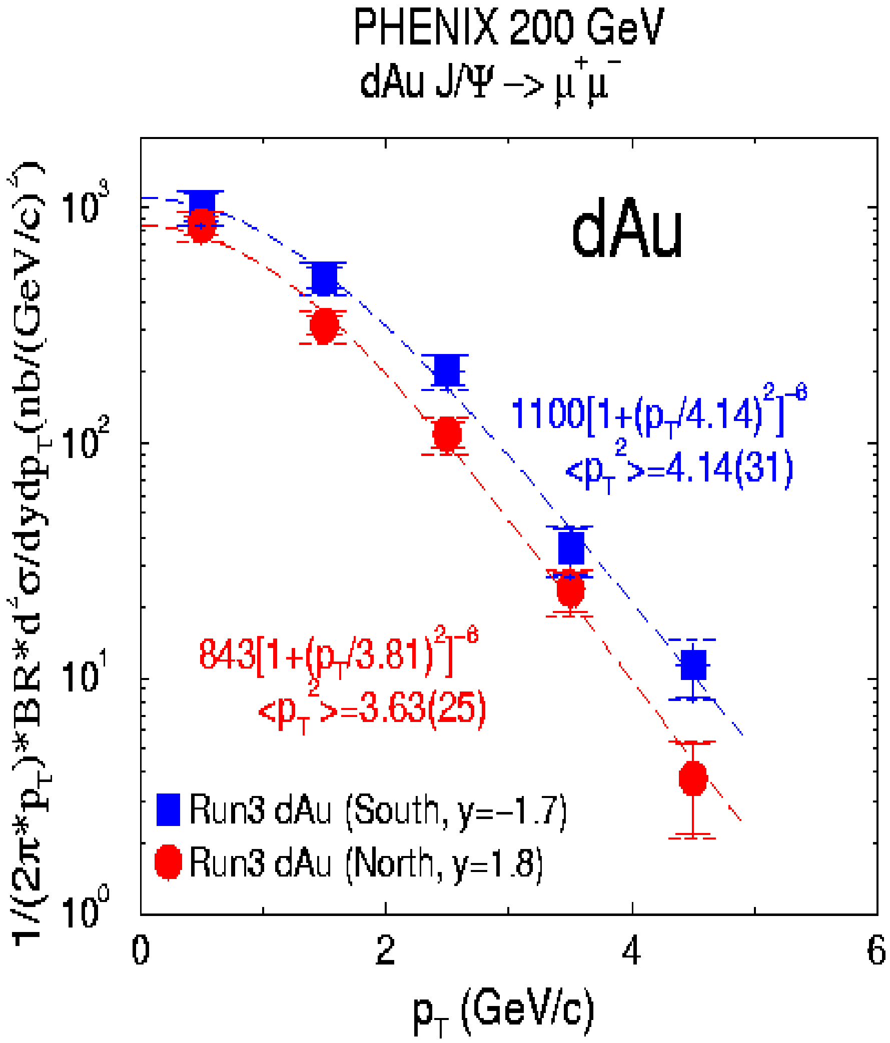


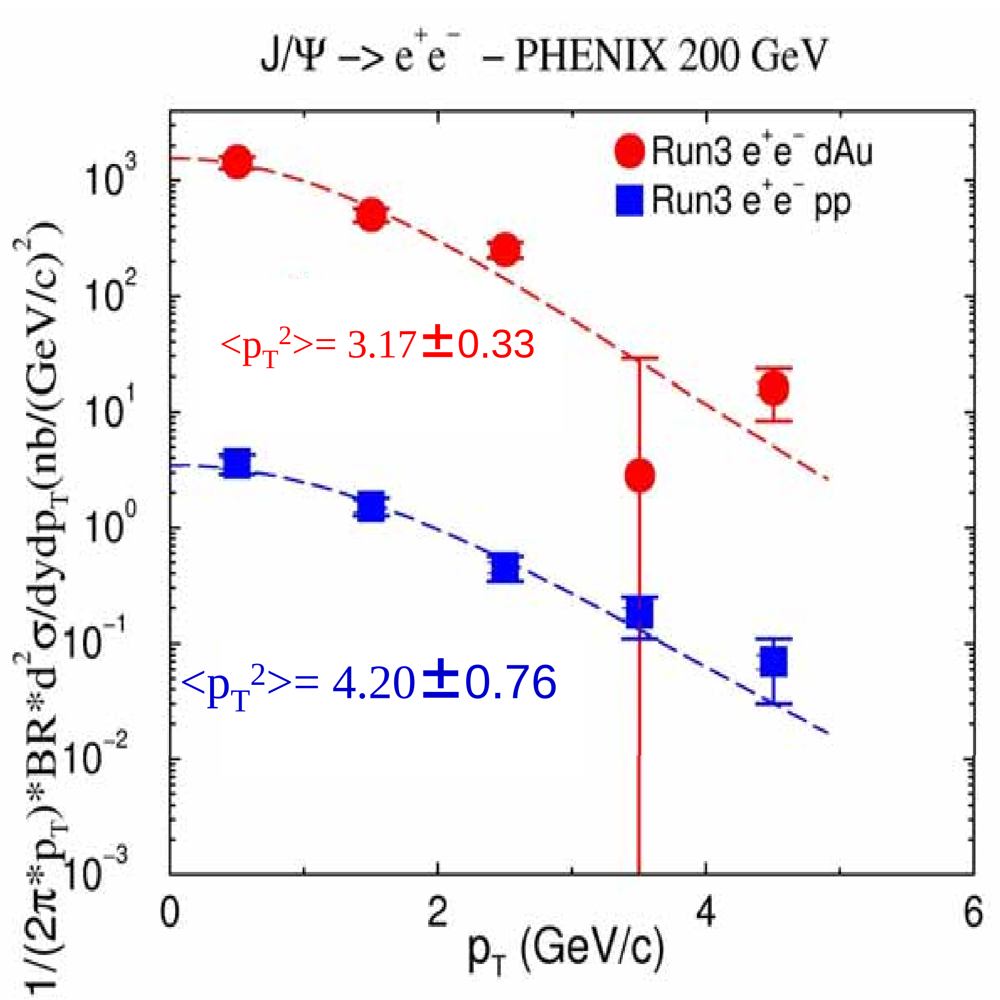
J/ψ from d+Au collisions

- Invariant cross section and R_{AA}



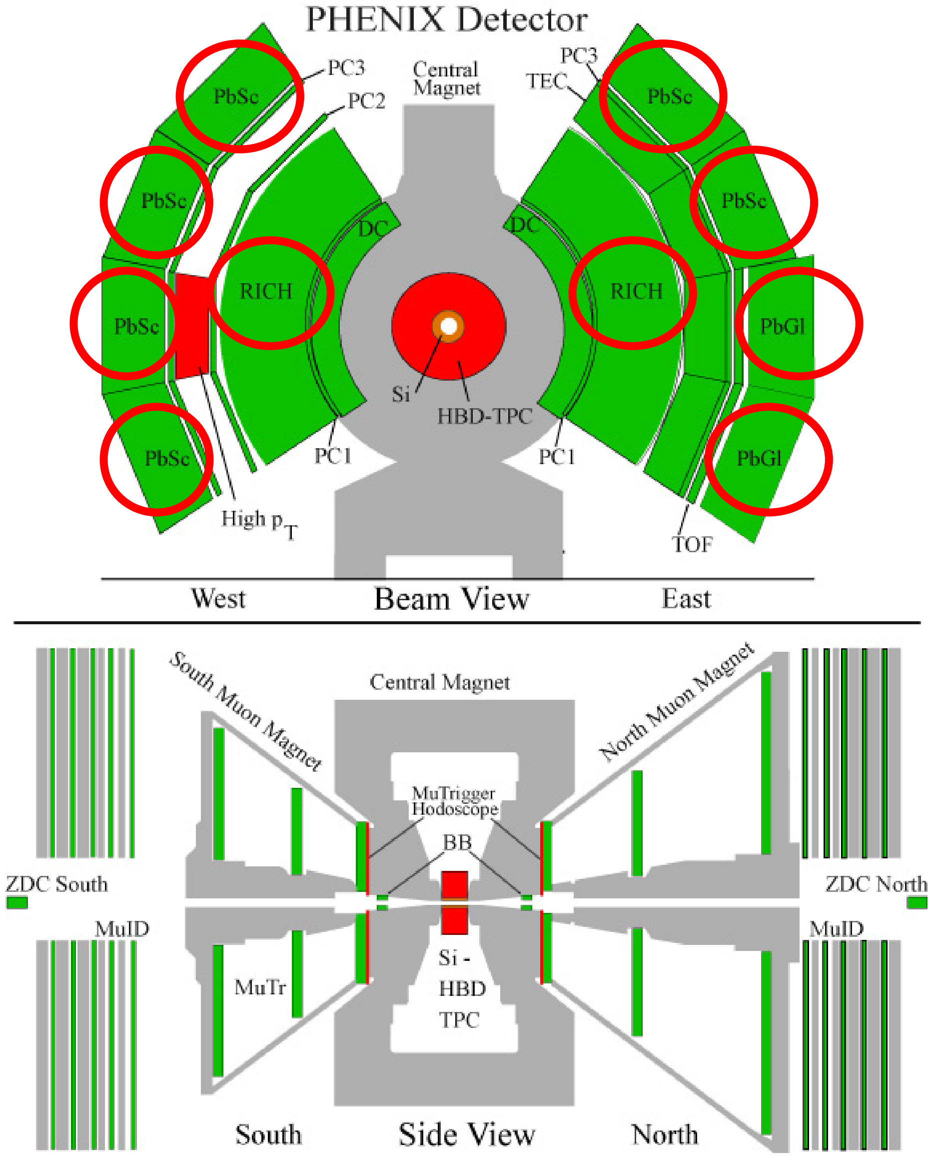
Invariant p_T distribution (d+Au and p+p)





PHENIX Experiment

- BBC, ZDC
  - centrality
  - z-vertex
- DC, PC1
  - momentum
- RICH
  - Electron ID
- EMCal (PbGl, PbSc)
  - Energy
  - Track Matching



Data analysis

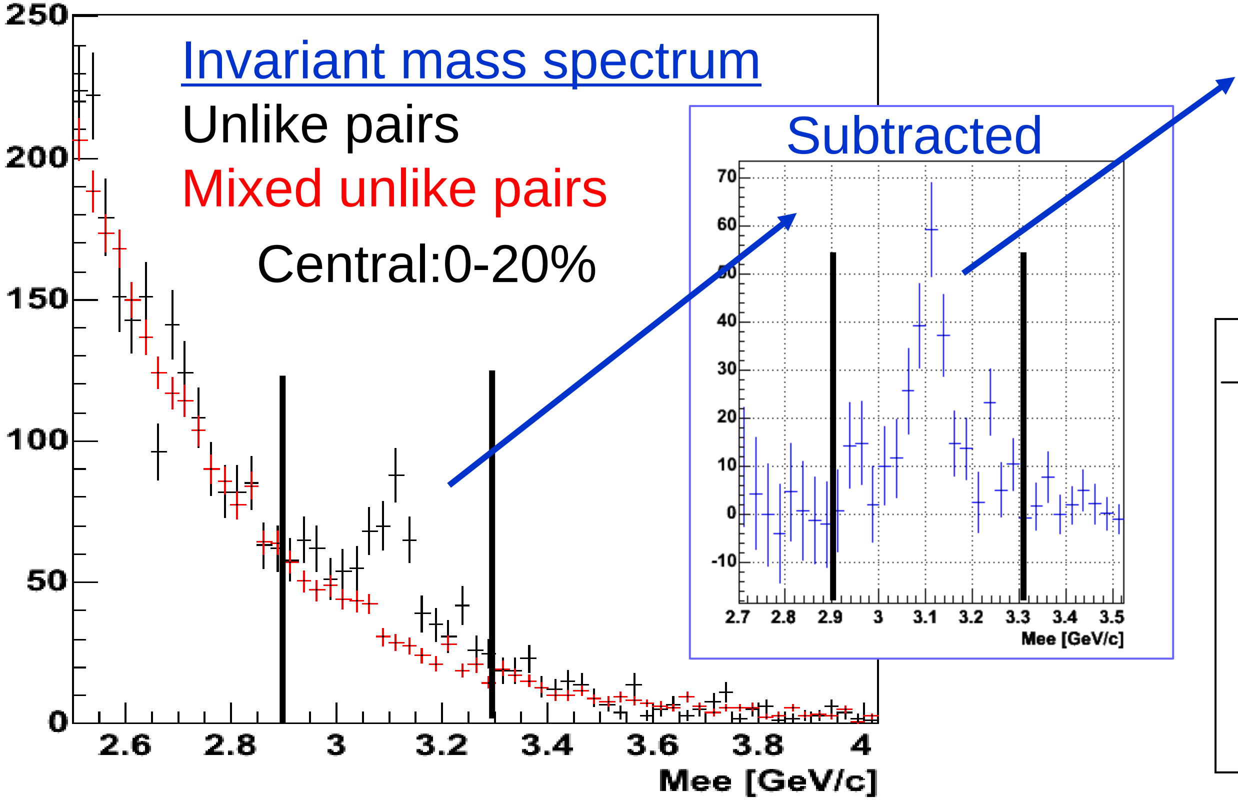
- Invariant Yield

$$B\frac{dN}{dy} = \frac{N_{J/\psi}}{N_{evt}} \times \frac{1}{\Delta y} \times \frac{1}{\epsilon_{acc} \times \epsilon_{eff} \times \epsilon_{run-by-run} \times \epsilon_{embed}}$$

- Centrality selection → N_{evt}
- Signal Counting of J/ψ → $N_{J/\psi}$
  - $e^+ e^-$ Invariant mass
  - subtract combinatorial background
- Correction factors
  - single J/ψ detection efficiency → $\varepsilon_{acc} \times \varepsilon_{eff}$
  - centrality dependence → ε_{embed}
  - Run-by-Run fluctuation of detector acceptance → $\varepsilon_{run\text{-}by\text{-}run}$

Signal counting of J/ψ

- Analyzed ~ 760 M Minimum Bias Data
- $N_{J/\psi} = N_{ee} – N_{mixed\_ee}$ (2.9 <Mee<3.3 GeV)
  - Event mixing method was used.



$N_{J/\psi}$ is counted in this mass range.

Centrality vs. $N_{J/\psi}$

Centrality	$N_{J/\psi}$
0-10%	145.4 +- 25.3
10-20%	155.1 +- 19.2
20-30%	124.2 +- 14.7
30-40%	87.9 +- 11.1
40-60%	70.1 +- 9.6
60-92%	26.7 +- 5.4

How do we get J/Ψ yield ?

Invariant yield :

$$B_{\mu\mu}\frac{dN}{dy}(AA \rightarrow J/\psi \rightarrow \mu^{+}\mu^{-}) = \frac{N_{J/\psi}}{\Delta y \;\; A\varepsilon_{J/\psi}\varepsilon_{BBC}^{J/\psi}} / \frac{N_{MB}}{\varepsilon_{BBC}^{MB}}$$

$N_{J/\psi}$: number of J/ψ 's reconstructed

$A\varepsilon^{J/\psi}$: probability for a J/ψ thrown and embeded into real data to be found (considering reconstruction and trigger efficiency)

N_{MB} : total number of events

$\varepsilon_{BBC}^{J/\psi}$: BBC trigger efficiency for events with a J/ψ

ε_{BBC}^{MB} : BBC trigger efficiency for minimum bias events

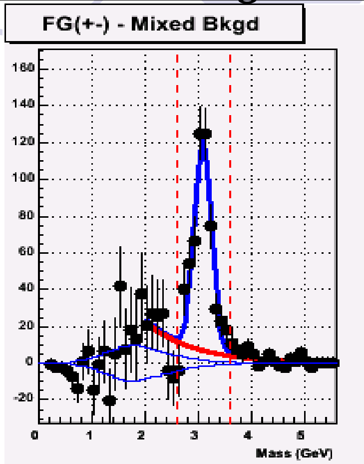
For Au+Au collision : $\varepsilon_{BBC}^{MB} \sim \varepsilon_{BBC}^{J/\psi}$

Analysis procedure

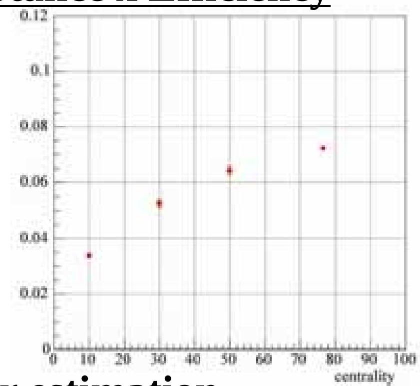
1. **Get momentum of tracks**
   - Muon tracker
2. **Identify muons**
   - Depth in Muon Identifier (MUID)
3. **Get di-muon invariant mass spectra**
4. **Extract J/ψ signal**
   - Event mixing technique
5. **Correct for acceptance and efficiencies**
   - Realistic detector simulation
6. **Calculate corresponding luminosity**
   - run4AuAu Level-2 filtered at *CCF* (70%) - 170 mb^{-1}
7. **Estimate systematic errors**

→ **Cross section**

Extract signal with event mixing method



Calculate Acceptance x Efficiency



Systematic error estimation

Acceptance **x** efficiency (considered various factors)	12 %
Luminosity	2 %
Signal extraction	Different (bin by