Cold Nuclear Matter Effects on J/ψ as Constrained by d+Au Measurements at $\sqrt{s_{NN}}$ = 200 GeV in the PHENIX Experiment

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Introduction

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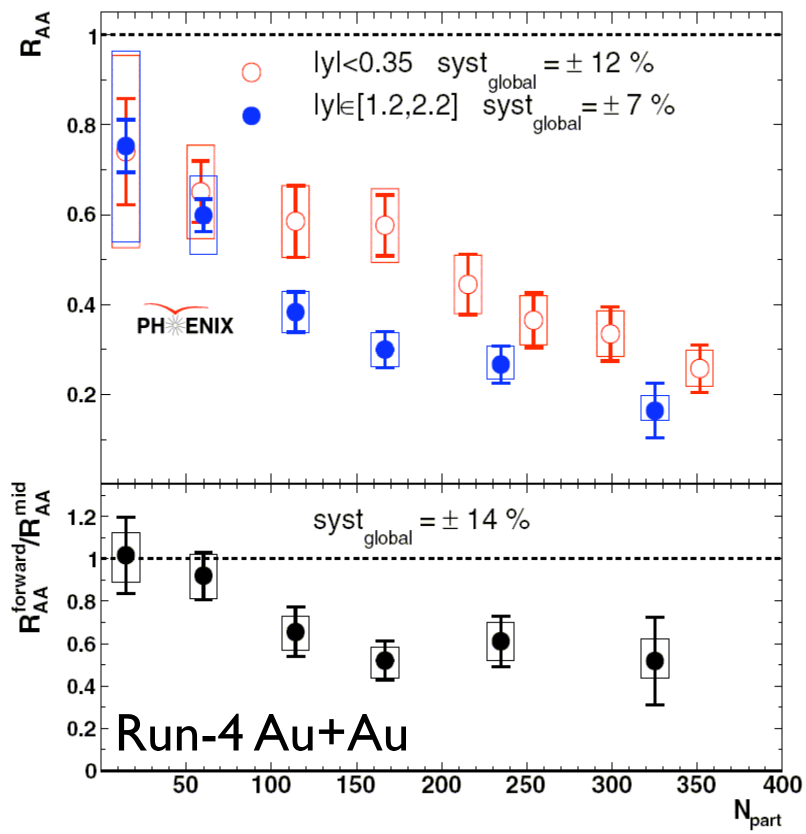


- There is much interest in J/ψ suppression in hot nuclear matter!
- For the latest PHENIX charmonia measurements, see:
  - Session XVIII: Susumu Oda and Catherine Silvestre
  - poster by Cesar Luiz da Silva
- Unfortunately, this is not sufficient to understand hot nuclear matter effects. We must also understand the cold nuclear matter effects on the J/ψ. That is our baseline.

Cold Nuclear Matter Effects on J/ψ Production

- Cold nuclear matter is a complicated place!
  - Shadowing, gluon saturation, anti-shadowing, EMC effect…
  - Initial and final state partonic multiple scattering…
  - Cronin effect…
- One way that we can study CNM is through high-energy p+A or d+A collisions.
- At RHIC we use $\sqrt{s_{NN}}$=200 *GeV* d+Au, which was first collided in Run-3 and now again in Run-8.

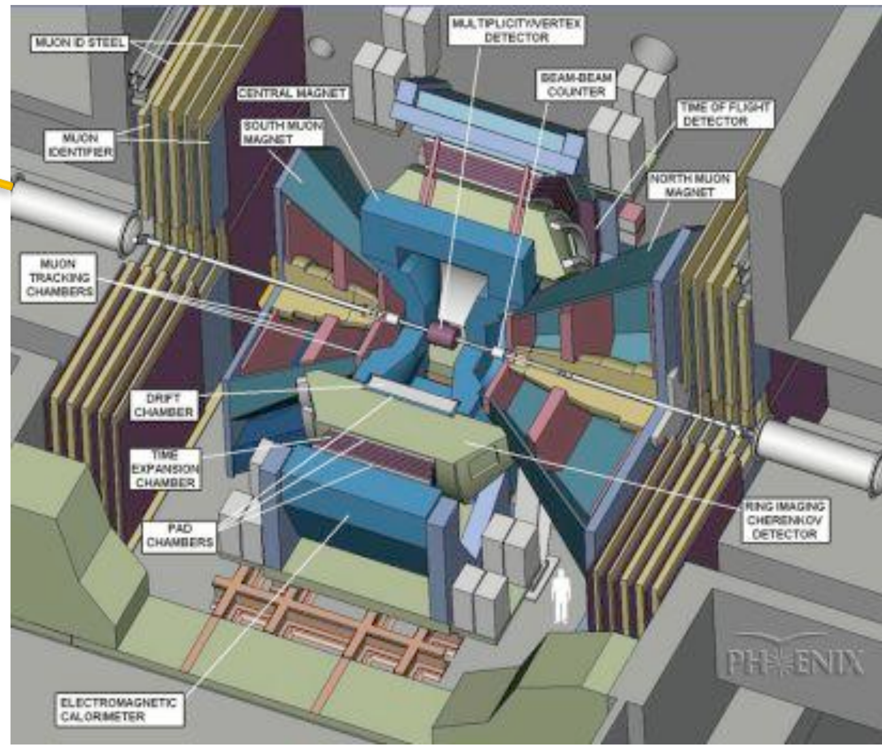
What Can We Do Now?

- New p+p data set in 2005 with an order of magnitude better statistics.
- Two years of improvements in:
  - Reconstruction software
  - Signal extraction
  - Understanding of detector
- Need d+Au analysis done using same method as the new p+p data, so we can do an apples-to-apples comparison.
  - Run-4 and Run-7 R_{AA} also use this p+p reference.
- For details of the analysis, see arXiv:0711.3917 (accepted for publication in Phys. Rev. C).

The PHENIX Experiment

Drift Chamber, Pad Chamber, EMCal & RICH detect $J/\psi \rightarrow ee$ at mid-rapidity.

Au ion
$y<0$



Beam-Beam Counter used to measure centrality and collision z-position.

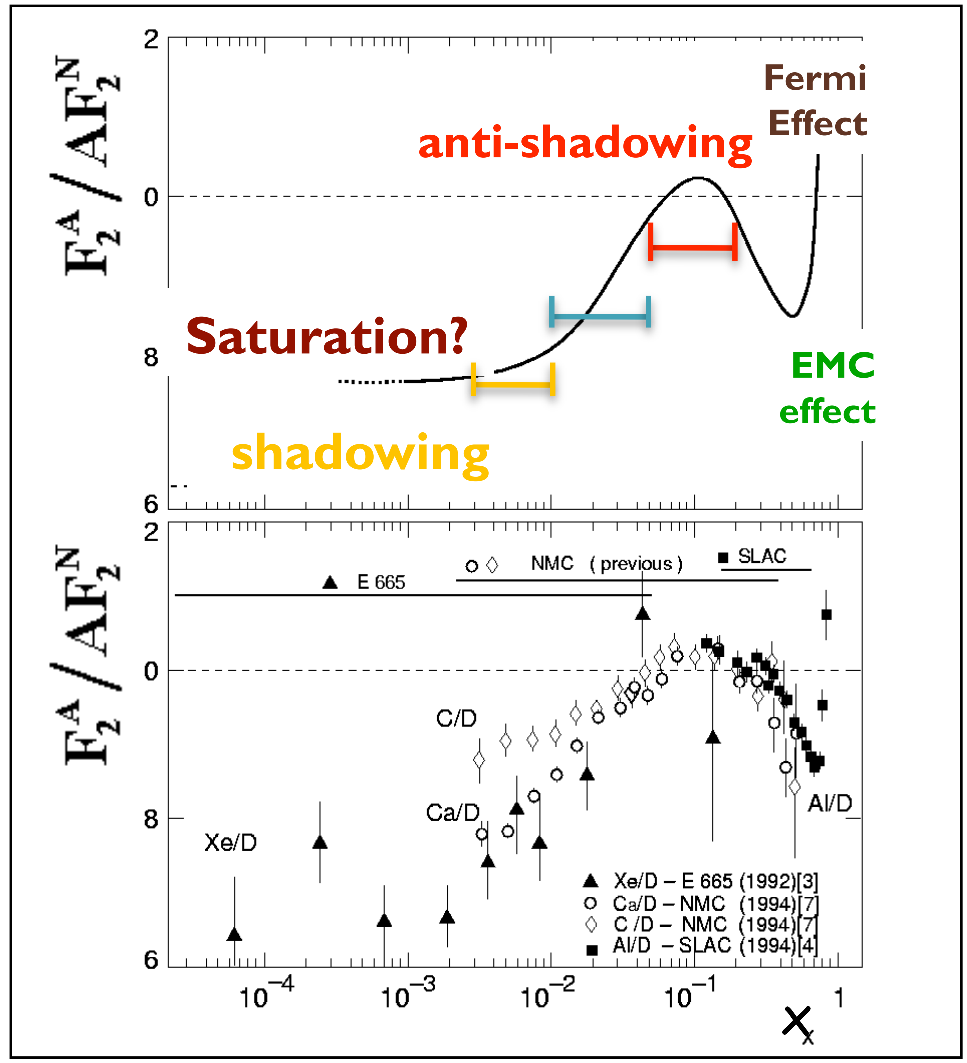
MuTr and MuID detect $J/\psi \rightarrow \mu\mu$ at forward & backward rapidities.

deuteron
$y>0$

Parton Momentum Cartography

- Nuclear PDFs are modified in various x-ranges.
  - Shadowing, anti-shadowing, EMC effect, etc.

- Here we probe 3 ranges of *x*, in both the shadowing and anti-shadowing regions, using PHENIX detectors at forward, x~0.002-0.01 backward, x~0.01-0.05 and mid-rapidity, x~0.05-0.2.



arXiv:0711.3917

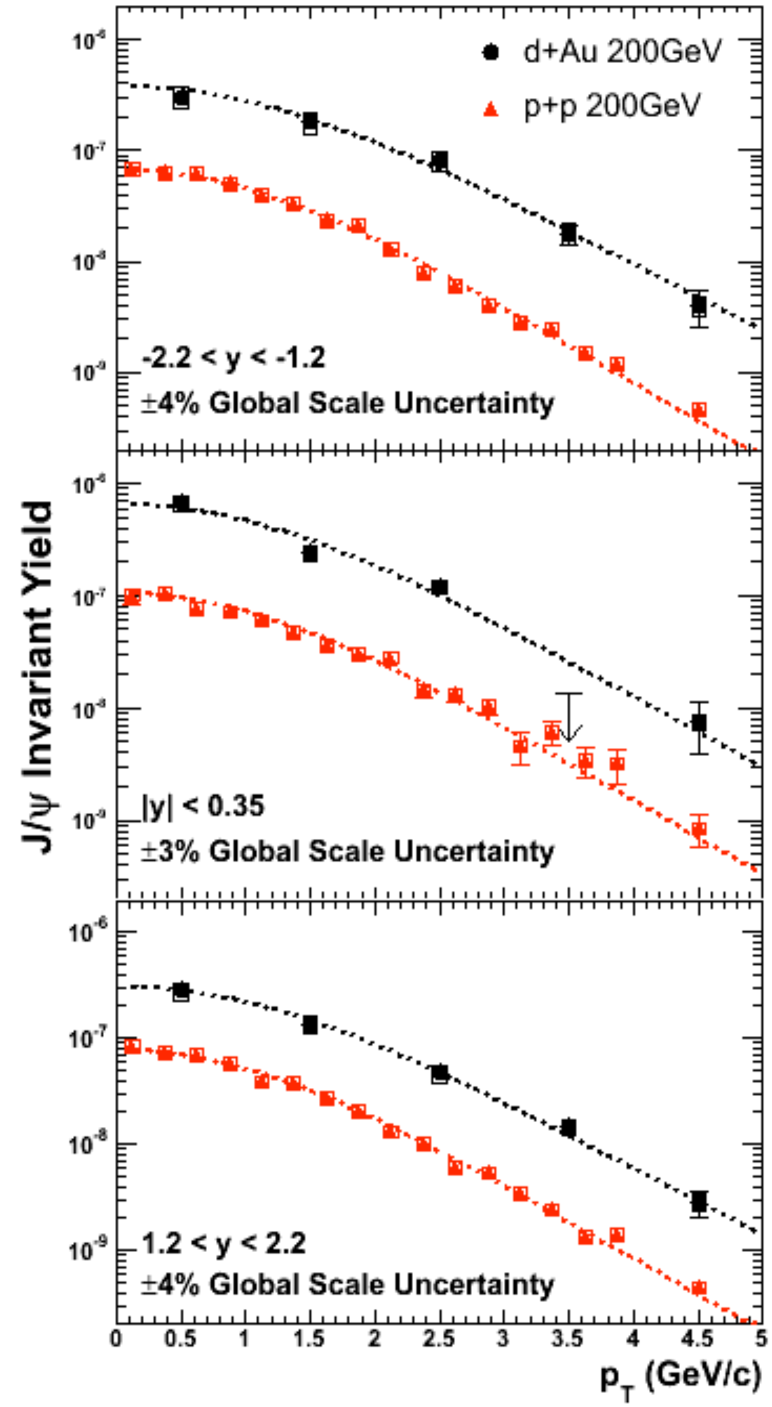
J/ψ p_T Spectra

d+Au data are from Run-3, p+p are from Run-5.

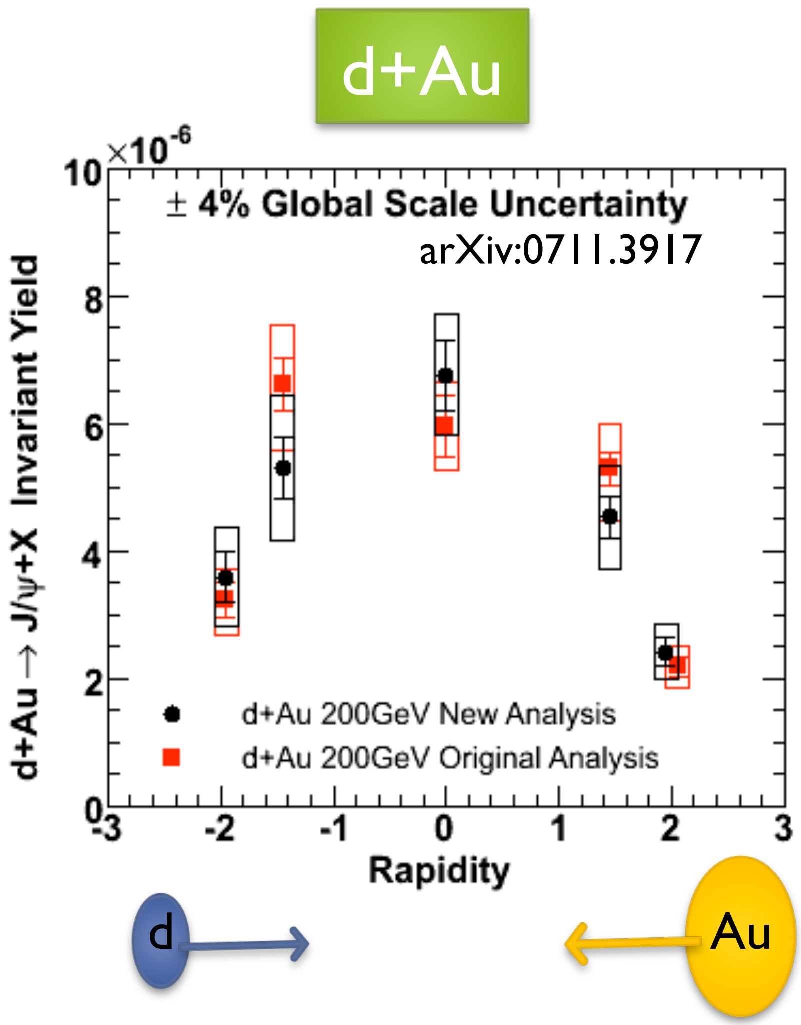
Fits are to a power law over $p_T \in [0,5]$ GeV/c, then integrated to get $\langle p_T^2 \rangle$.

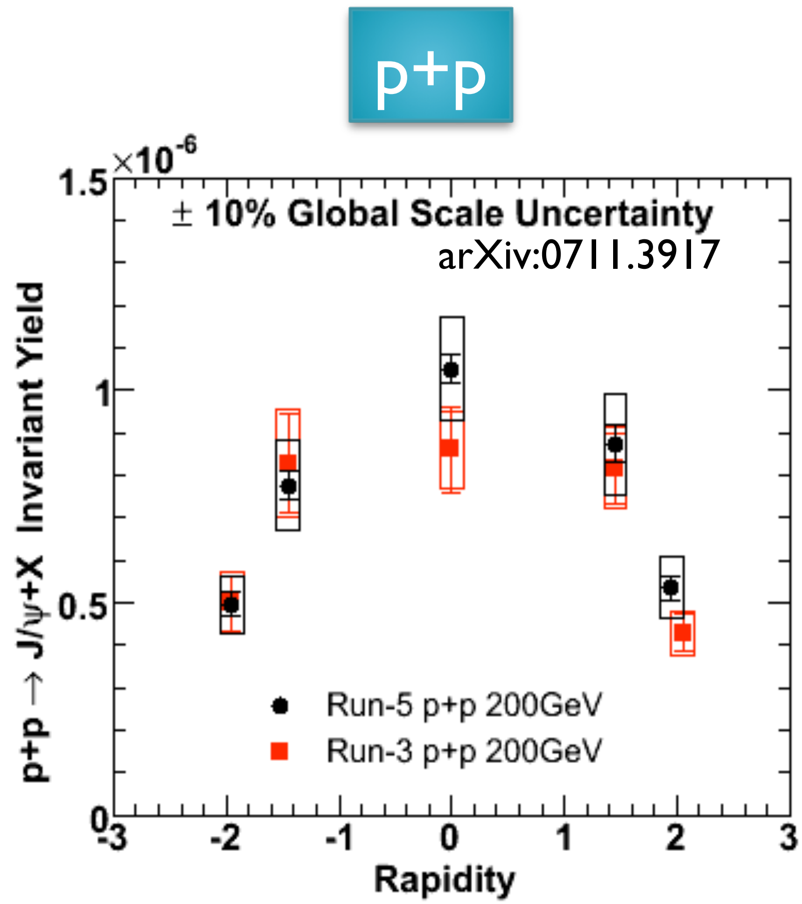
Can compare to other systems to study p_T-spectrum broadening from Cronin Effect/ multiple scattering.

- For discussion of this see the talk by Susumu Oda in XVIII.



J/ψ Invariant Yields



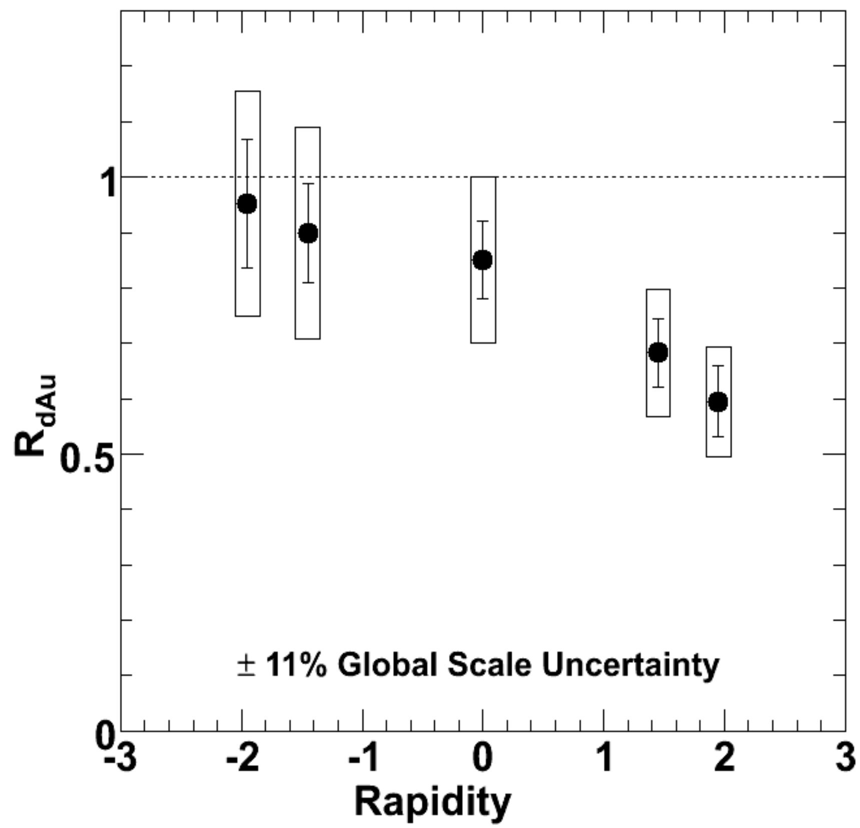


J/ ψ Nuclear Modification Factor

$$R_{\mathrm{dAu}} = \frac{1}{\langle N_{coll} \rangle} \frac{dN^{d+Au}/y}{dN^{p+p}/y}$$

- Calculate using new p+p data and new d+Au analysis.
- Suppression at forward rapidity (deuteron-going direction). This is sensitive to low-x partons in the Au nucleus.

arXiv:0711.3917

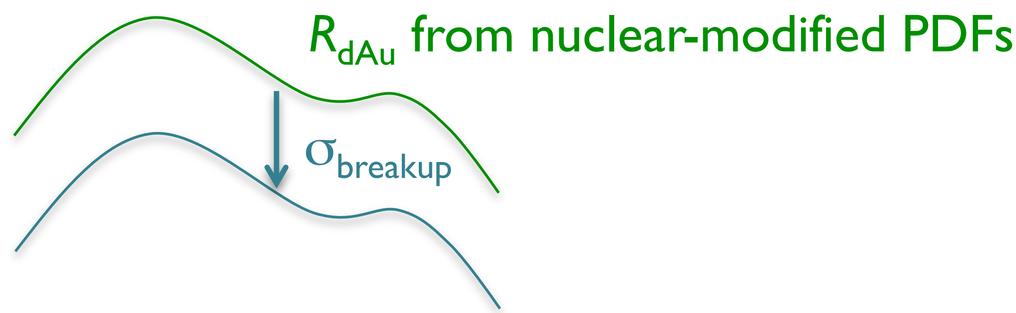


Comparison to Nuclear Models

One can use EKS[1] and NDSG[2] nuclear modified PDFs to calculate R_{dAu} as a function of rapidity.

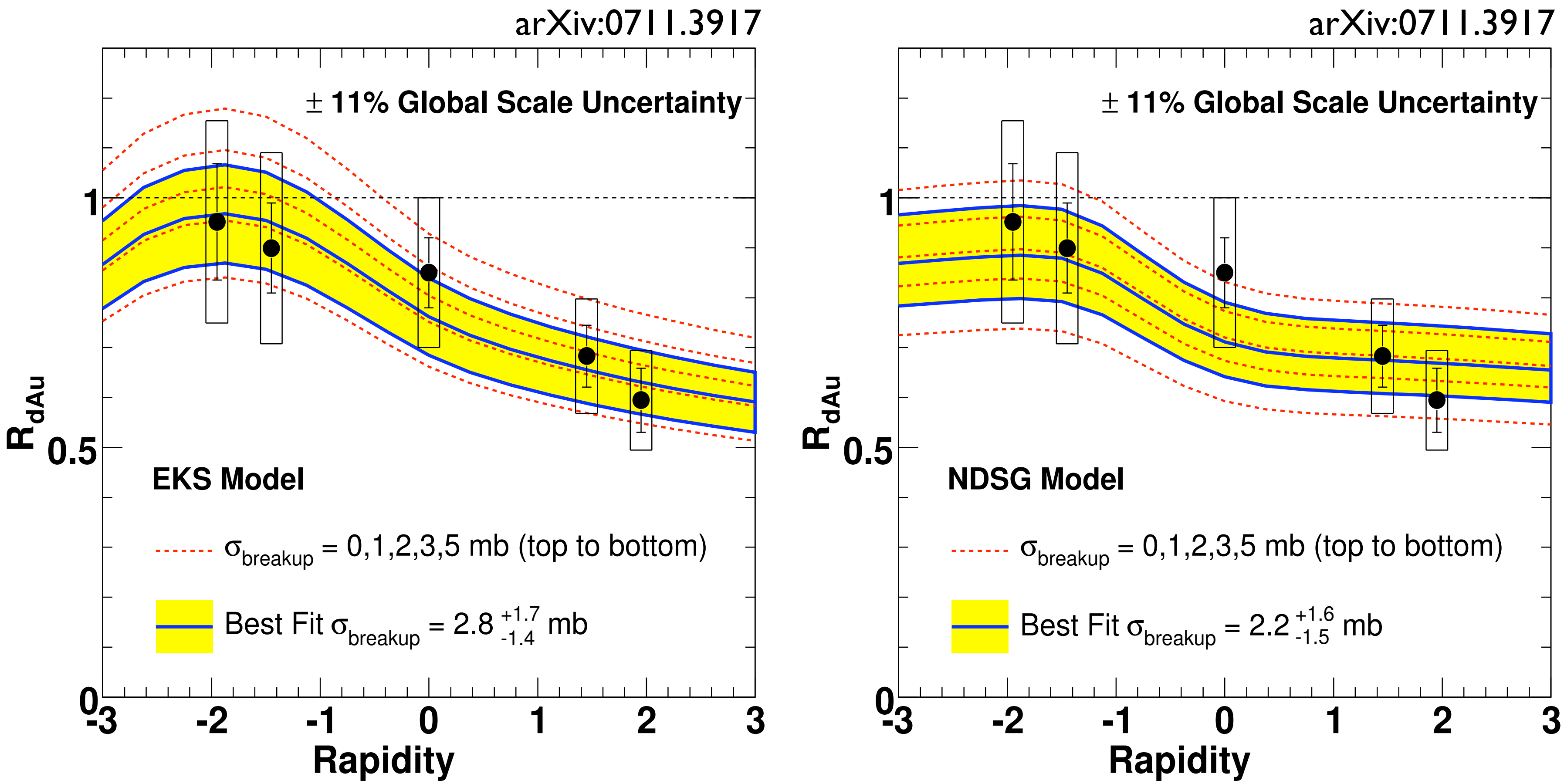
Assume that all additional J/ψ suppression can be accounted for by a single parameter due to interactions with the Au ion. Express this in terms of a breakup cross section, $\sigma_{breakup}$.

Then we can fit our measured R_{dAu} to extract $\sigma_{breakup}$.



[1]K. J. Eskola, V. J. Kolhinen, and R. Vogt, Nucl. Phys. A696, 729 (2001)
[2]D. de Florian and R. Sassot, Phys. Rev. D69, 074028 (2004)

Comparison to Nuclear Models



Using EKS (NDSG) model we get $\sigma_{breakup}$ **= 2.8$^{+1.7}_{-1.4}$ (2.2$^{+1.6}_{-1.5}$) mb.**

Both are compatible (within very large error bars) with $\sigma_{breakup}$ = 4.2±0.5 mb measured at the CERN SPS.

B. Alessandro et al., Euro. Phys. J. C48, 329 (2006), nucl-ex/0612012

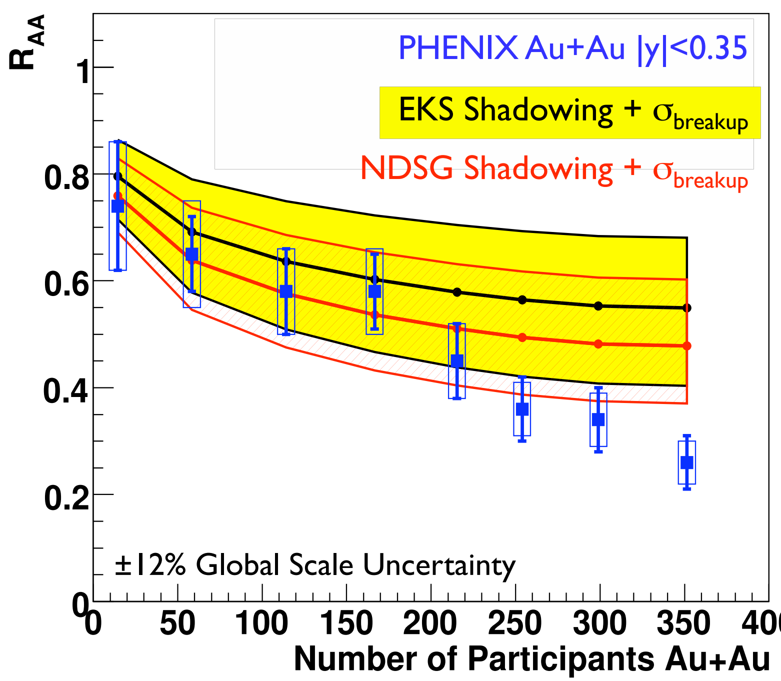
Extrapolation to Au+Au

We can use the calculated $\sigma_{breakup}$ due to CNM effects to extrapolate to CNM effects in Au+Au collisions.

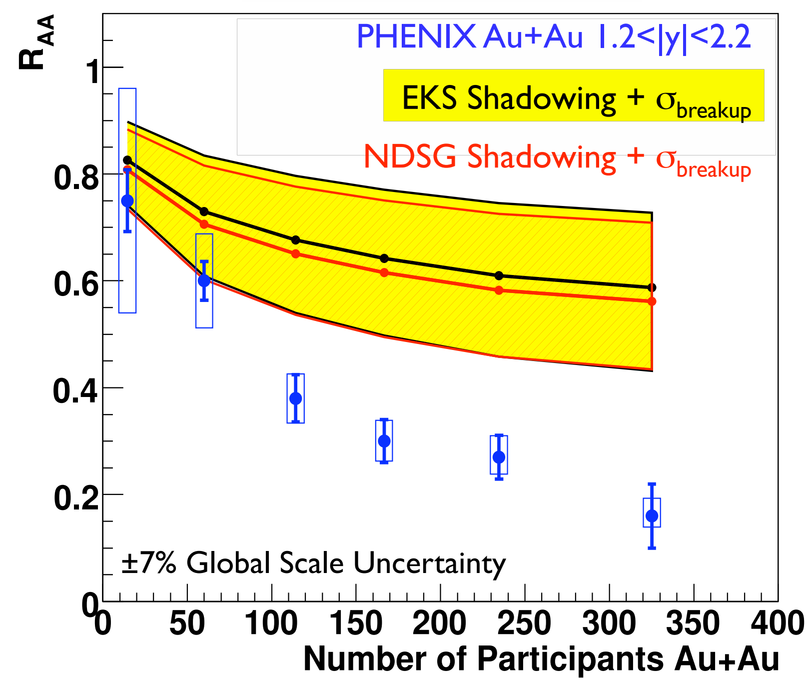
Assuming these nuclear modified PDFs are exactly correct, there is statistically significant J/ψ suppression beyond CNM effects at forward rapidity in Au+Au collisions.

It must be noted that the error bands are correlated between forward and mid-rapidity.

Mid-rapidity



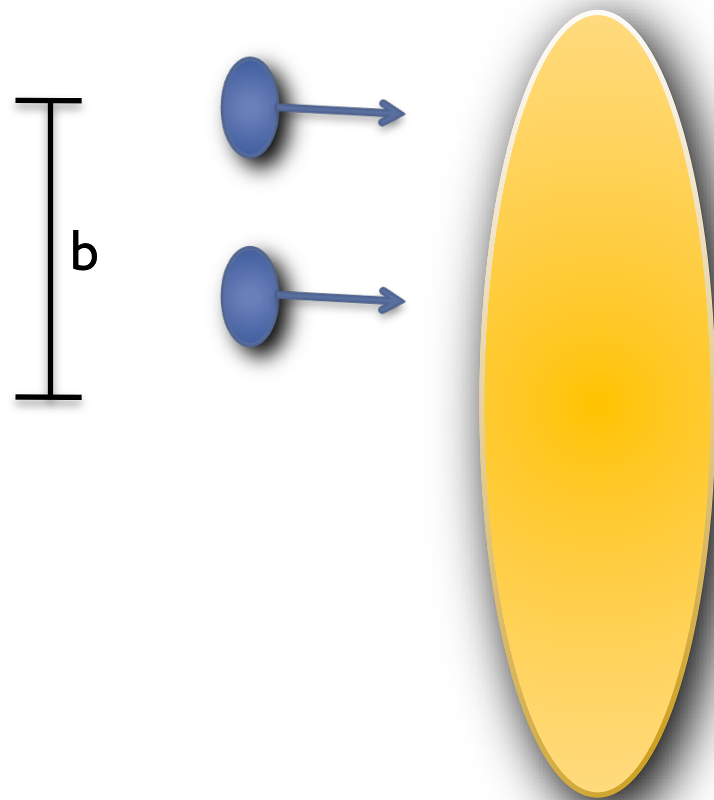
Forward rapidity



arXiv:0711.3917

Centrality in d+Au

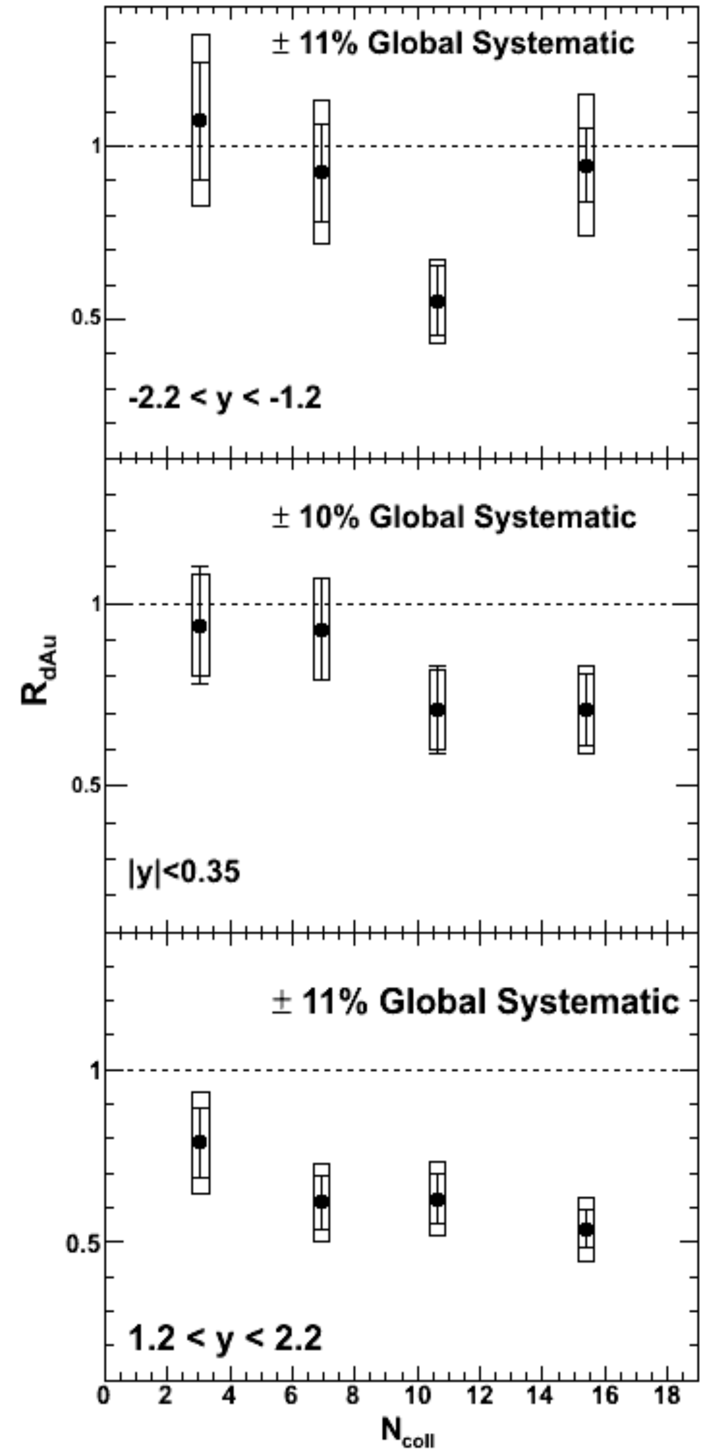
- At RHIC we are also able to make measurements vs. impact parameter.
- In Run-3 we use 4 centrality bins, each corresponding to a range of impact parameters.



J/ψ R_{dAu} vs. N_{coll}

Again, significant suppression only at forward rapidity.

Possible hint of a trend w.r.t. N_{coll}, at forward and mid-rapidity, but we are hitting the limits of our Run-3 statistics. Looking forward to Run-8 result (QM2009?).



A More Data-Driven Projection

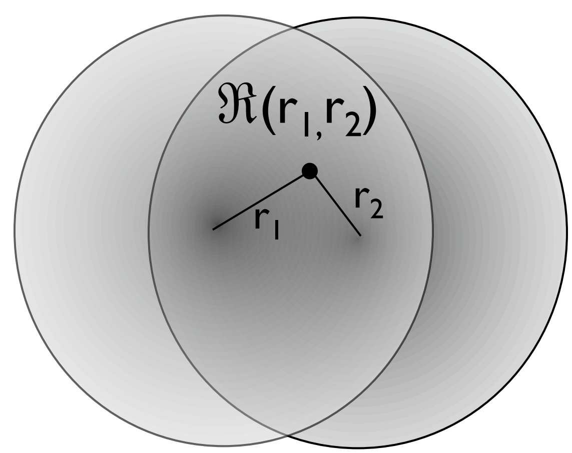
However, if we do not want to assume either of the previous models, then we may try a different approach.

In this case we assume that the modification factor depends only on the radial position in the nucleus. We can then use the measured R_{dAu} vs. impact parameter to constrain this $\Re$. We also appropriately incorporate the statistical and systematic errors on the data[1].

$\Re$ is the modification on J/ψ due to one Au nucleus, so we take $\Re(+y)*\Re(-y)$ for Au+Au collisions.

[1]For details of statistical analysis method, see poster by Jamie Nagle.

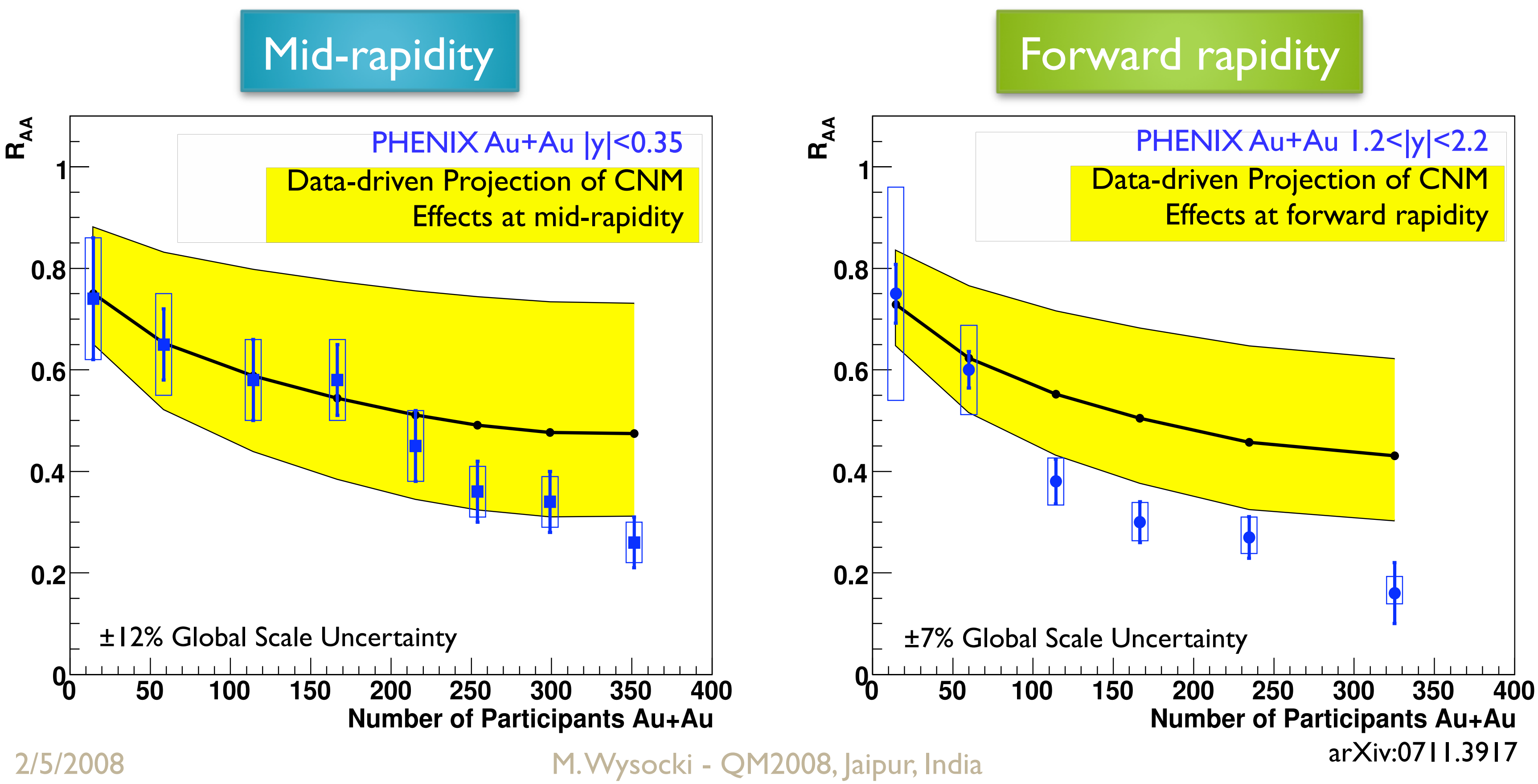
For more details see:
Proposal: R. Granier de Cassagnac, hep-ph/0701222.
Calculation: A. Adare et al., arXiv:0711.3917



Data-driven Projection to Au+Au

Larger uncertainty bands than those from nuclear-modified PDFs and $\sigma_{breakup}$. In this case we cannot rule out Au+Au suppression entirely from cold nuclear matter effects, within the statistical and systematic uncertainties.

It should be noted that contrary to the previous Au+Au projection, these uncertainty bands are *not* directly correlated between rapidities.



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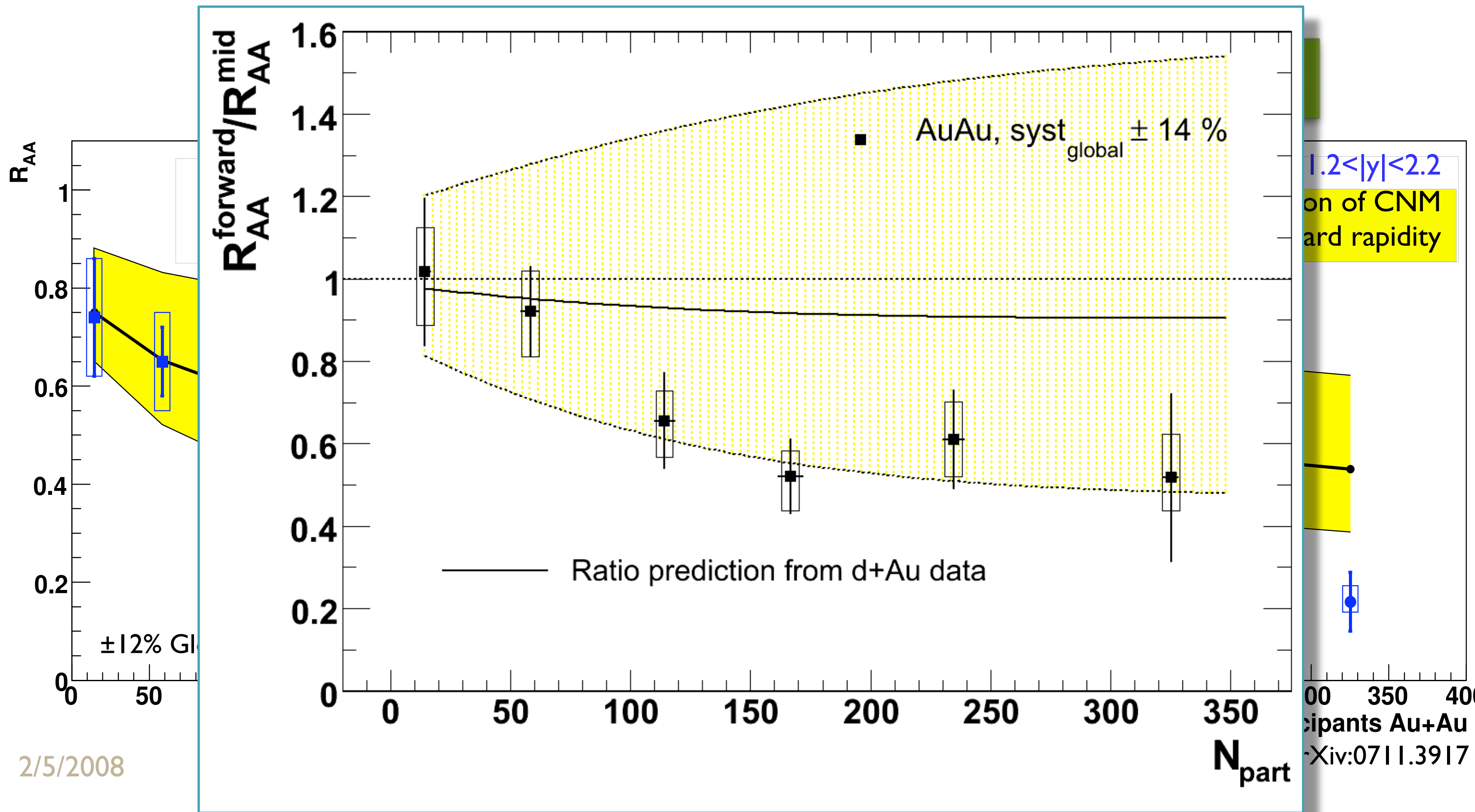
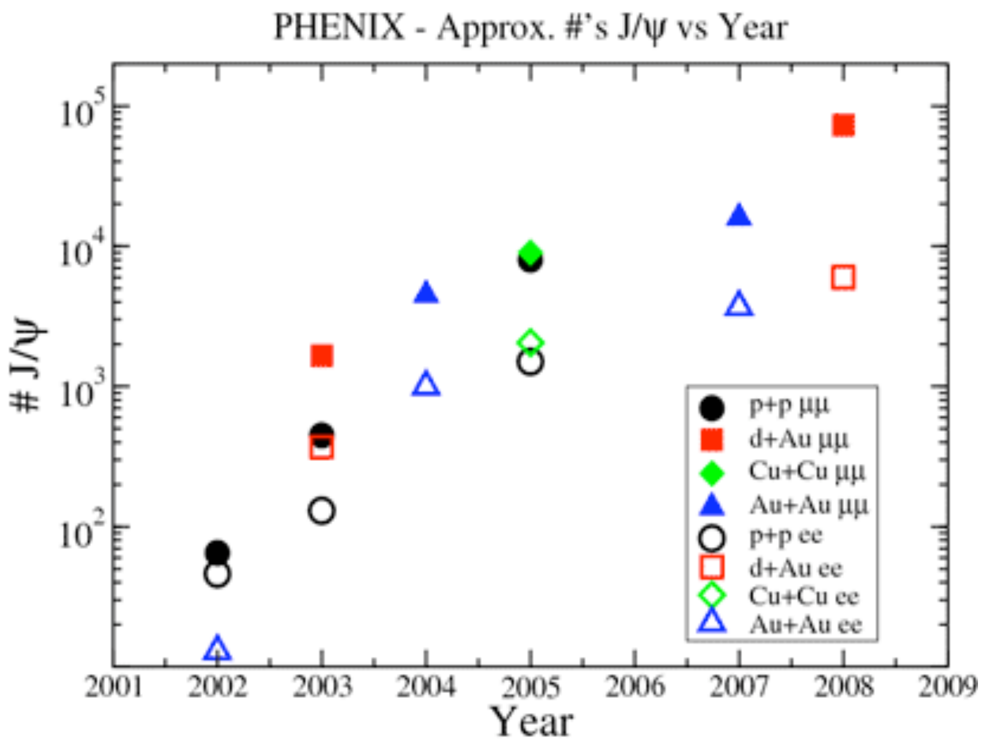
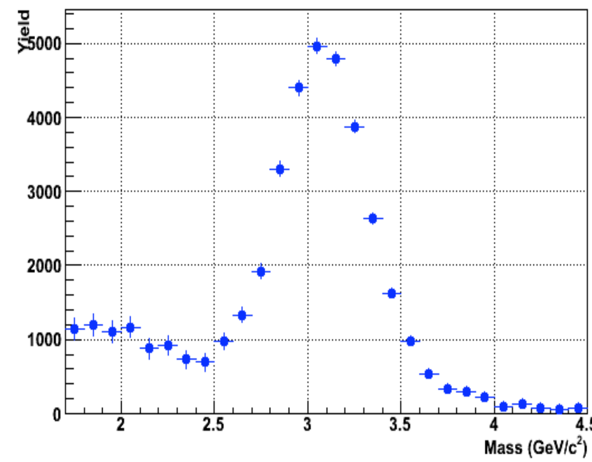


Run-8 d+Au J/ψ

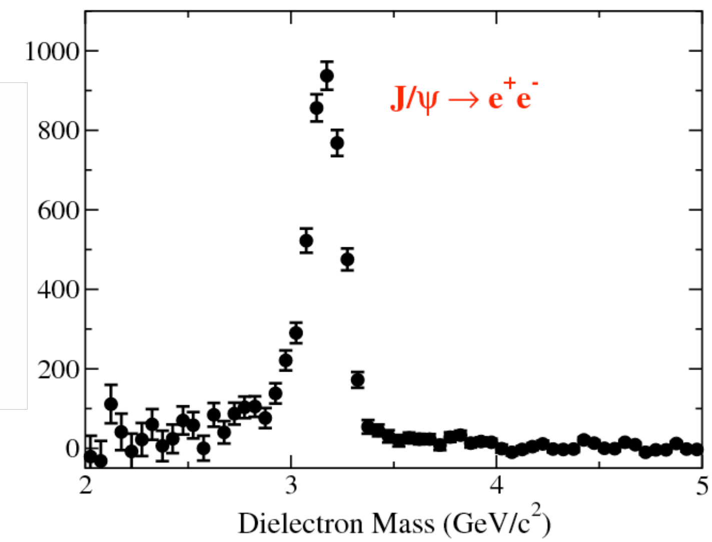


- Already many J/ψ recorded in Run-8 d+Au.
  - Over 50x as many J/ψ as Run-3!

South Arm Dimuon Mass



Central Arm Dielectron Mass



- Should allow for a much-improved R_{dAu} measurement in the near future, with smaller statistical errors as well as better constrained systematic uncertainties.

Summary

- R_{dAu} measured using new p+p data and a new analysis of d+Au data at forward, backward, and mid-rapidity, and in 4 centrality bins.
  - Statistically-significant suppression observed at forward rapidity.

- Comparison to EKS and NDSG nuclear shadowing calculations used to estimate $\sigma_{breakup}$. Extrapolation of these models to Au+Au do not reproduce the full J/ψ suppression at forward rapidity.

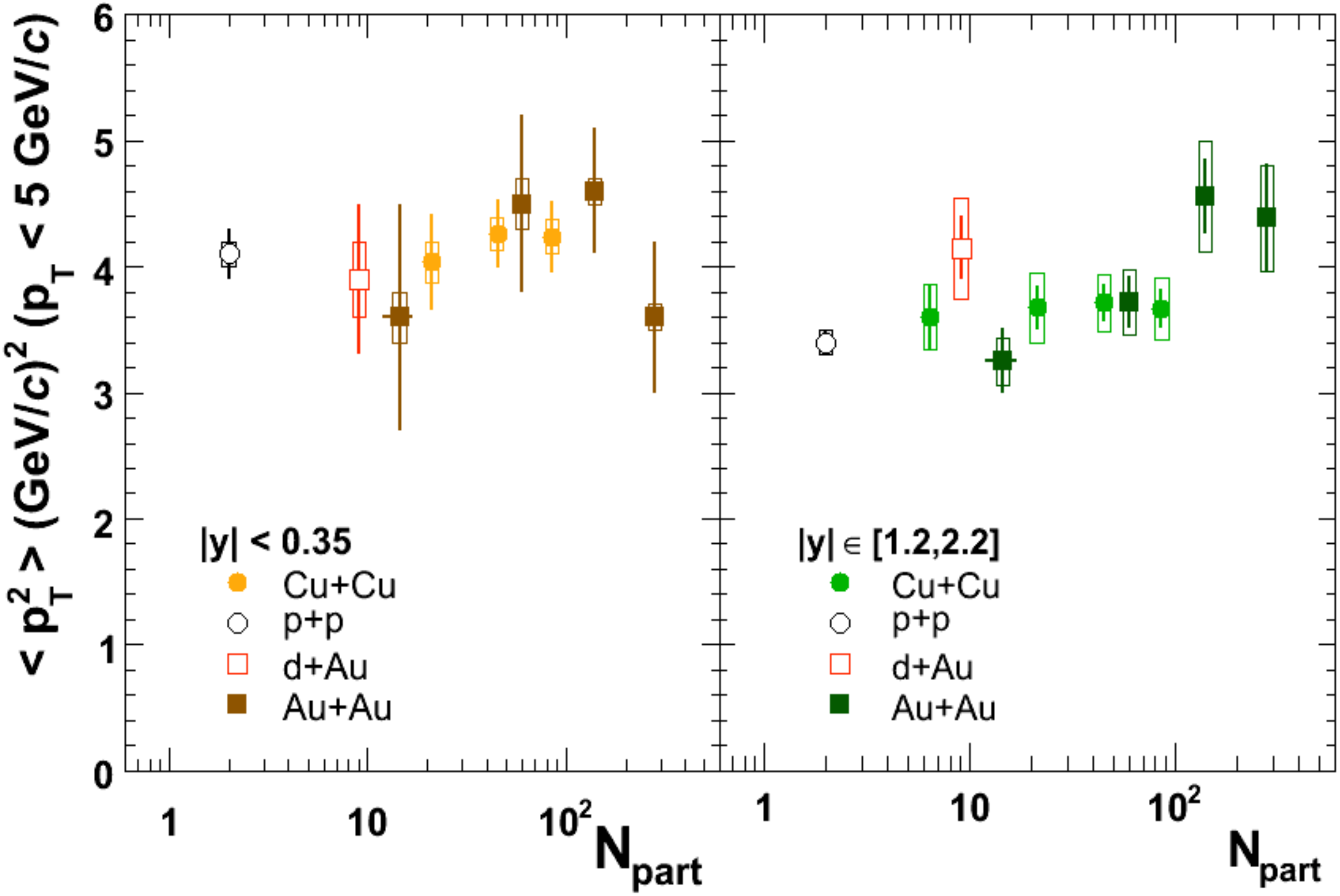
- A less model-dependent extrapolation from the measured R_{dAu} is unable to constrain the CNM contribution to the measured suppression in Au+Au.

- Looking forward to much better constraints on CNM effects in Run-8 results!

Backup

$\langle p_T^2 \rangle$ from All Runs

arXiv:0801.0220



Centrality in d+Au

- At RHIC we are also able to make measurements vs. impact parameter.
- In Run-3 we use 4 centrality bins, each corresponding to a range of impact parameters.
- We can also express the bins in terms of the average number of nucleon-nucleon collisions in that bin (N_{coll}).