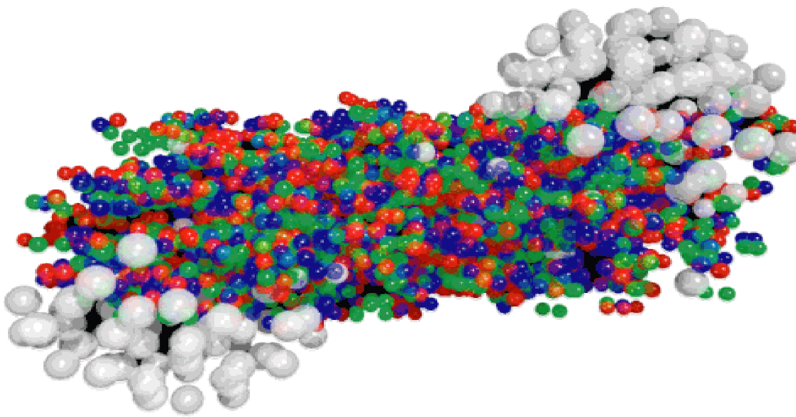
What do we really know about cold nuclear matter effects?

(for heavy quarkonia)

L. A. Linden Levy
for the PHENIX collaboration
lindenle@colorado.edu
Department of Physics
390 UCB
University of Colorado
Boulder, CO 80309-0390

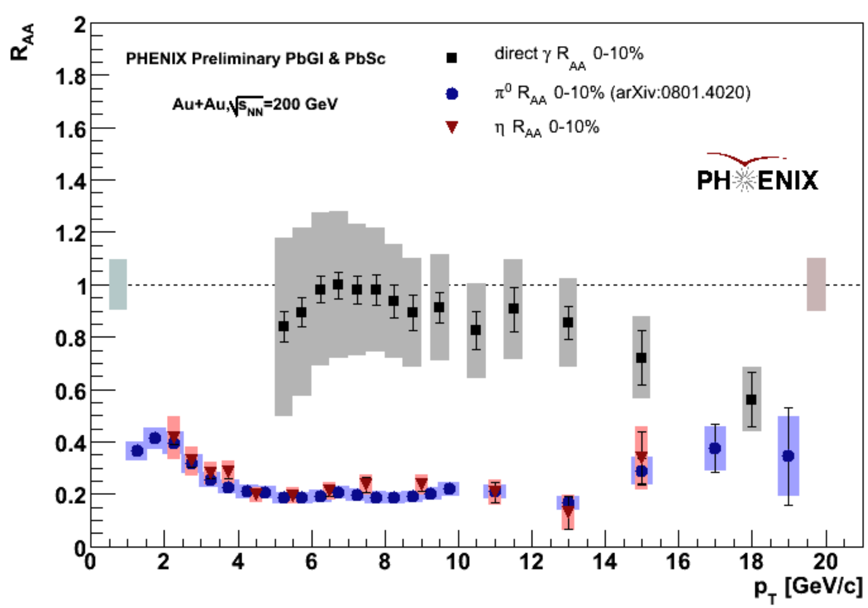
New state of matter at RHIC.

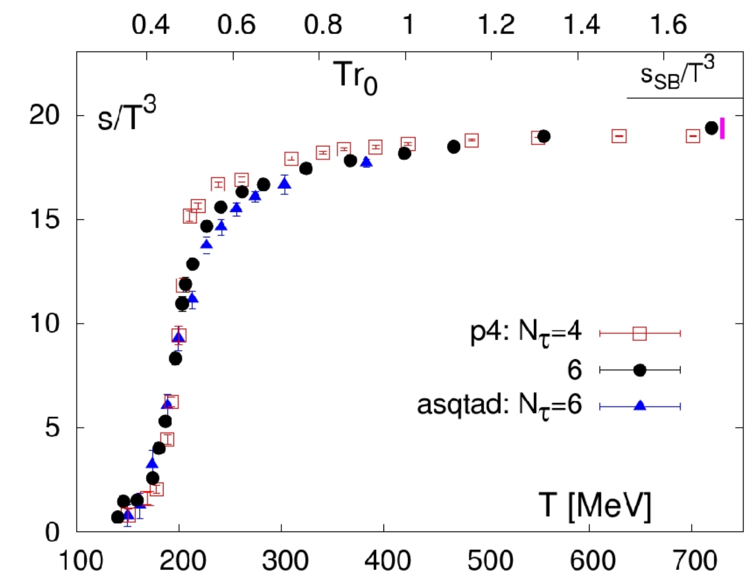
- Definitely created something different:
  - R_{AA} suppression of hadrons
    →but not photons
  - I_{AA} jet suppression → Energy loss
    - Very dense medium
  - Collective behavior → flow



Are we seeing de-confined partons?

→ LQCD seems to predict ↑d.o.f. above T_C~170MeV

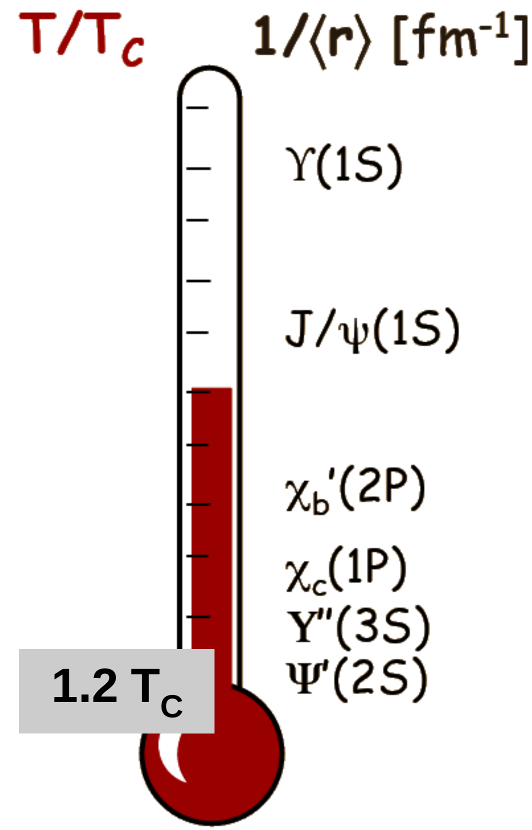




Why heavy quarkonia?

- J/ψ was predicted as an excellent QCD thermometer.
  - Heavy quark anti-quark pairs allow potential models.
  - Different states have different binding energies (radii) as the pair is screened they dissociate.
    → Color Debye screening. (Matsui and Satz).
- Corollary: The picture of sQGP has become even more complicated

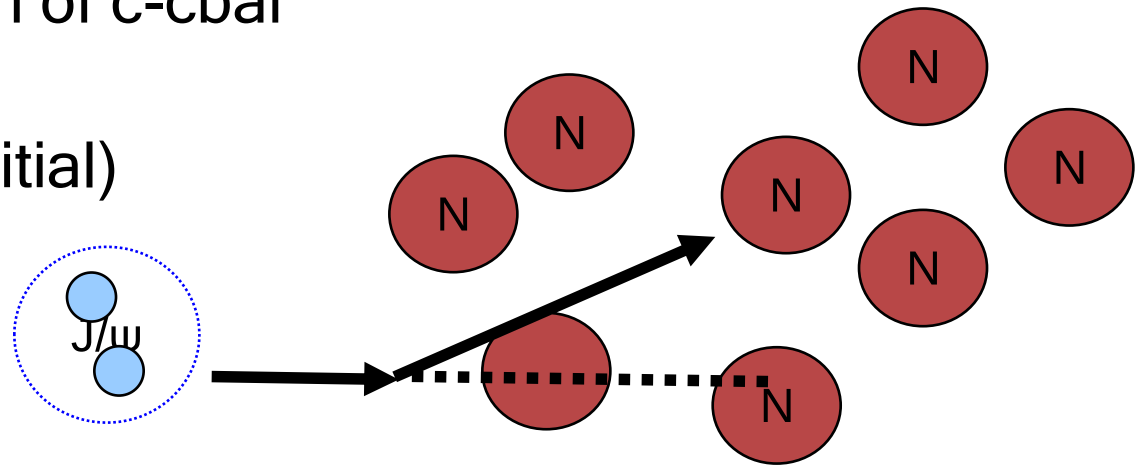
  (c.f. Talk by M. Wysocki)
  - Recombination of uncorrelated heavy flavor.
  - LQCD predictions of correlations $T>T_C$.
  - Gluo-disassociation
  - Detailed balance of J/ψ depletion and restoration is necessary.



WWND A. Mocsy

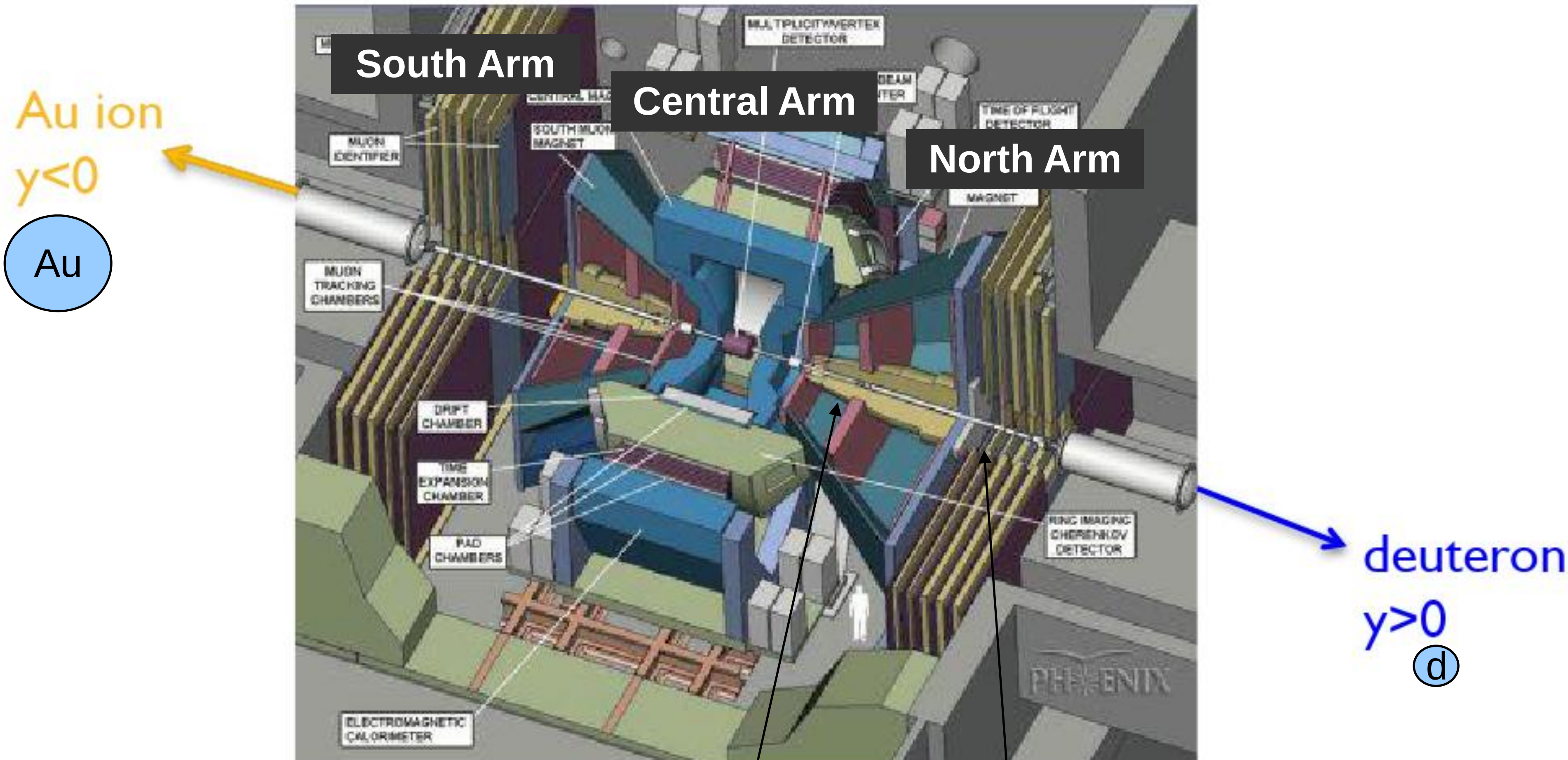
Cold Nuclear Matter (CNM) Effects

- $T << T_{C}$; $n \backsim n_0 = 3/4\pi r_0^{3} \sim 1N/10fm^3$
- J/ψ formed through by gluon fusion.
- "Normal" effects modify the J/ψ spectrum
  - Cronin effect (p_T broadening, initial).
  - Nuclear PDF modification (nPDF, initial).
  - Gluon saturation (initial).
  - Breakup cross section of c-cbar in the nucleus (final).
  - Gluon energy loss (initial)



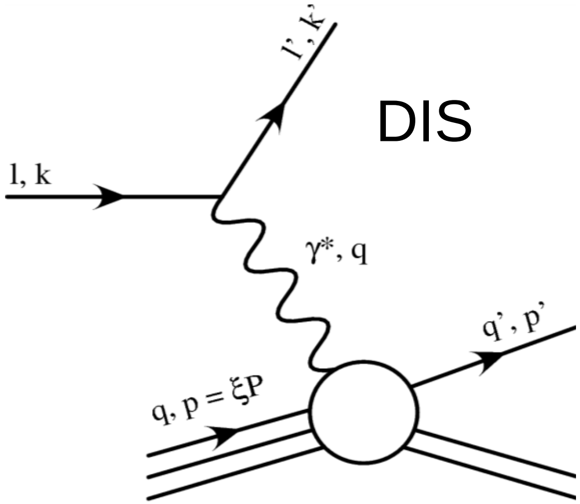
→ We need to quantify these CNM effects to truly understand the J/ψ suppression in RHIC matter.

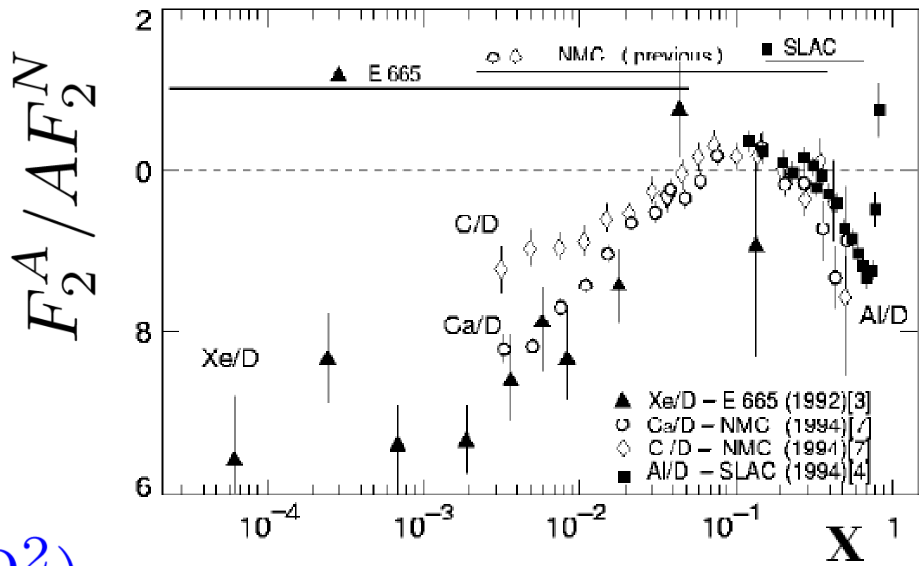
PHENIX Coordinate System



- 200GeV d+Au collisions.
- Di-Muons recorded via MuTr and MuID in N. & S. arm.
- Di-Electrons from Central arm PC, DC, EMCal and RICH.

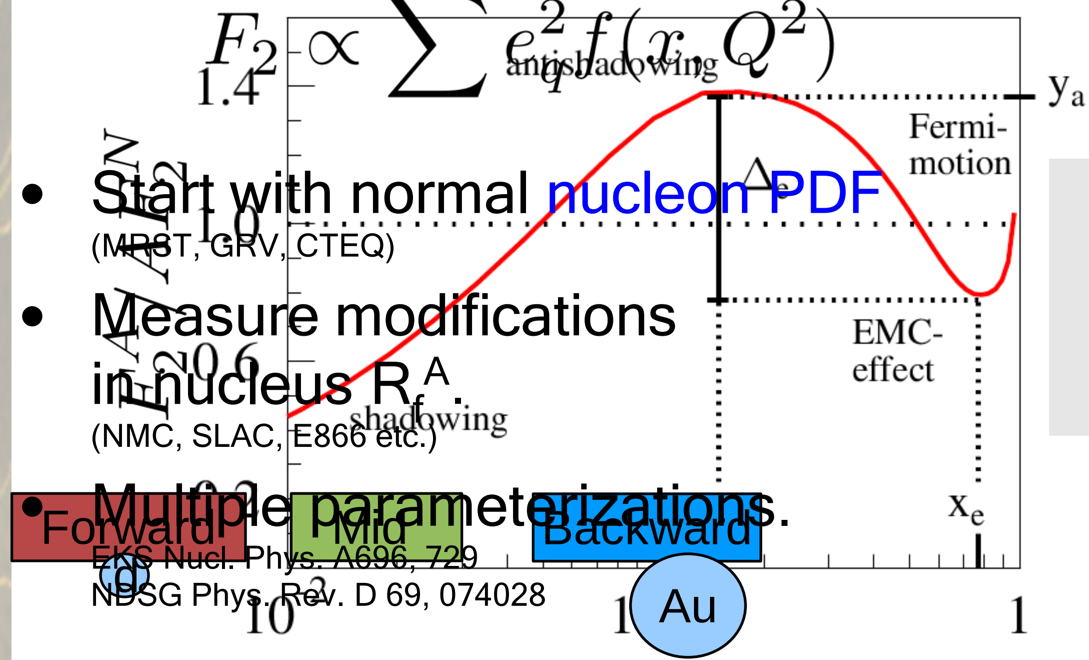
Nuclear modification of PDFs (nPDFs)





$$f^A(x,Q^2) = R_f^A(x,Q^2)\,f^N(x,Q^2)$$

$$F_2 \propto \sum e_q^2 f(x,Q^2)$$



- Start with normal nucleon PDF (MRST, GRV, CTEQ)
- Measure modifications in nucleus R_f^A. (NMC, SLAC, E866 etc.)
- Multiple parameterizations. EKS Nucl. Phys. A696, 729; nDSG Phys. Rev. D 69, 074028

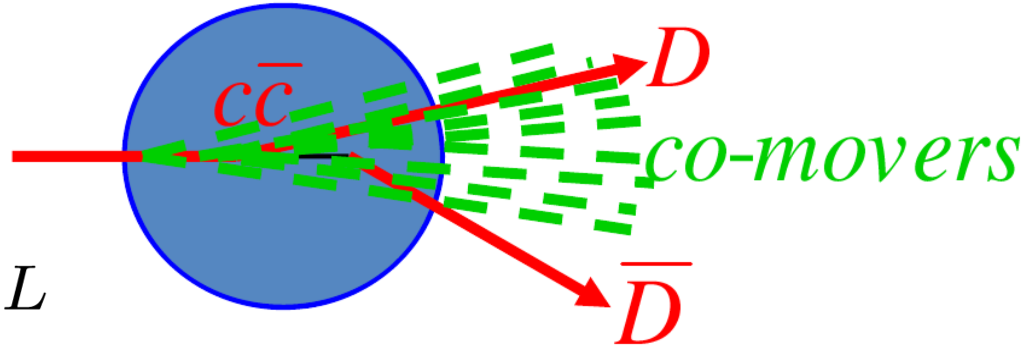
3 regions probed in dAu:

→ x_{Au} = 0.002-0.005
0.011-0.022
0.051-0.140

Absorption or Breakup cross section

- During hadronization/propagation the c-cbar pair broken up due to inelastic scattering in the nuclear medium.

$$J/\psi N \rightarrow D\bar{D}X$$



$$\sigma_{pA}^{J/\psi} = \sigma_{pN}^{J/\psi} A e^{-\sigma_{abs}\rho L}$$

- For instance NA50 |y|<0.5; <x>~0.18:
  - σ_{abs}=4.6 mb or 7.0 mb (with shadowing).
- Singlet versus Octet production for J/ψ.
  - Energy dependence of cross section very different.
  - Other unknown kinematic dependencies?

CURRENT PHENIX MEASUREMENTS

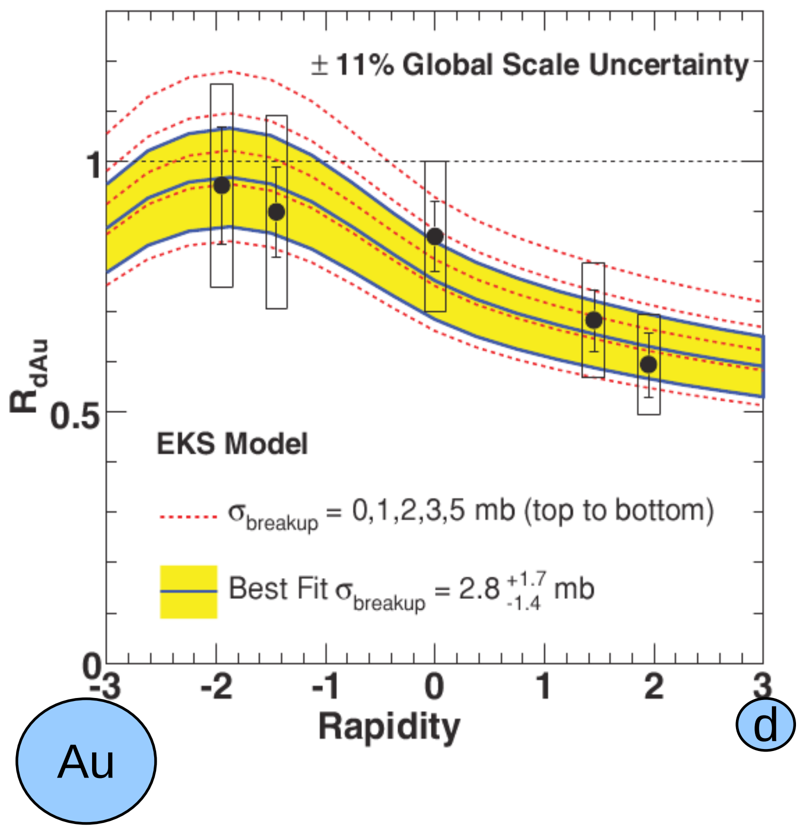
Quantitative comparison vs. rapidity.

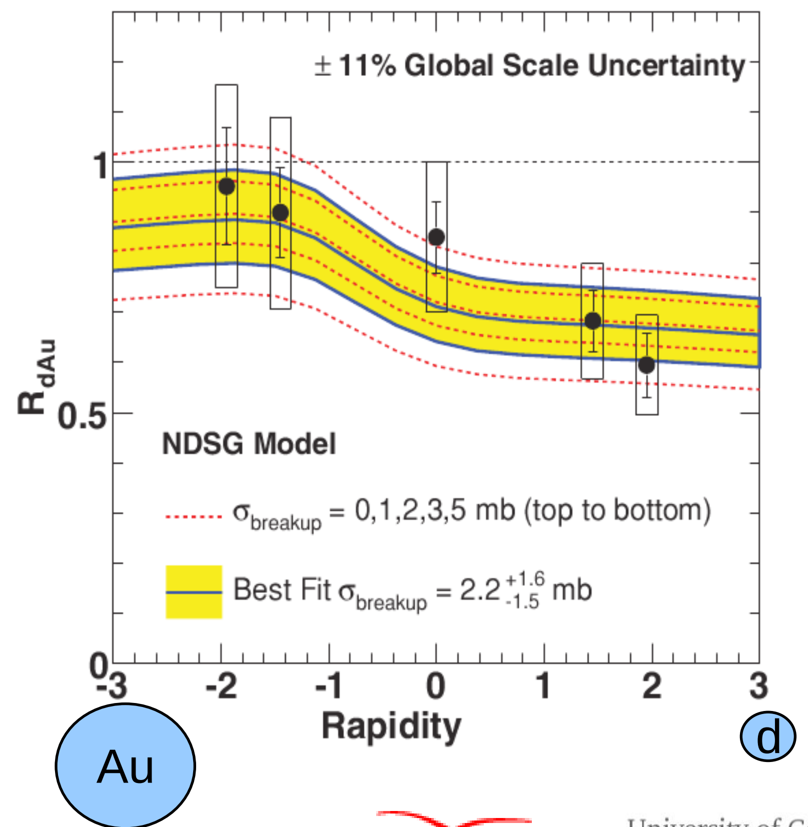
- Log Likelihood calc. accounting for all experimental errors:
  A Point to point uncorrelated
  B Point to point correlated
  C Global

Phys Rev C 77, 024912

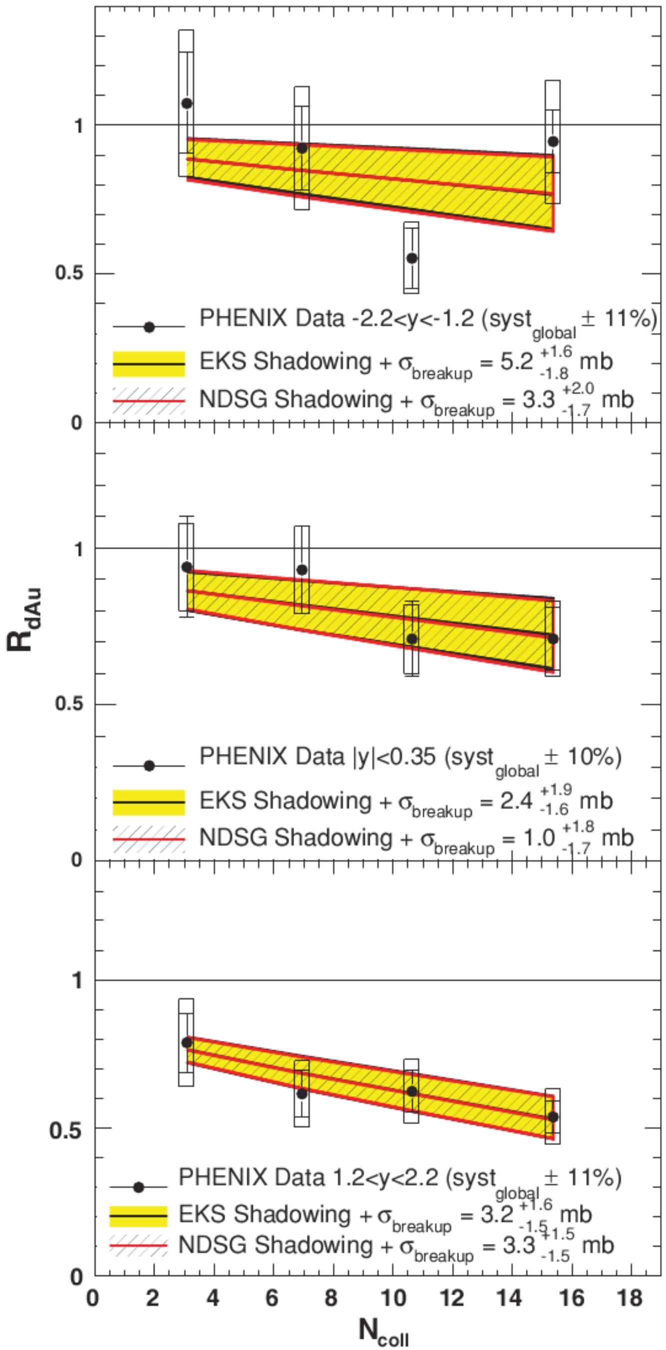
- One sigma error band shown for each model versus rapidity.

EKS: $\sigma_{abs}=2.8^{+1.7}_{-1.4}$mb NDSG: $\sigma_{abs}=2.2^{+1.6}_{-1.5}$mb





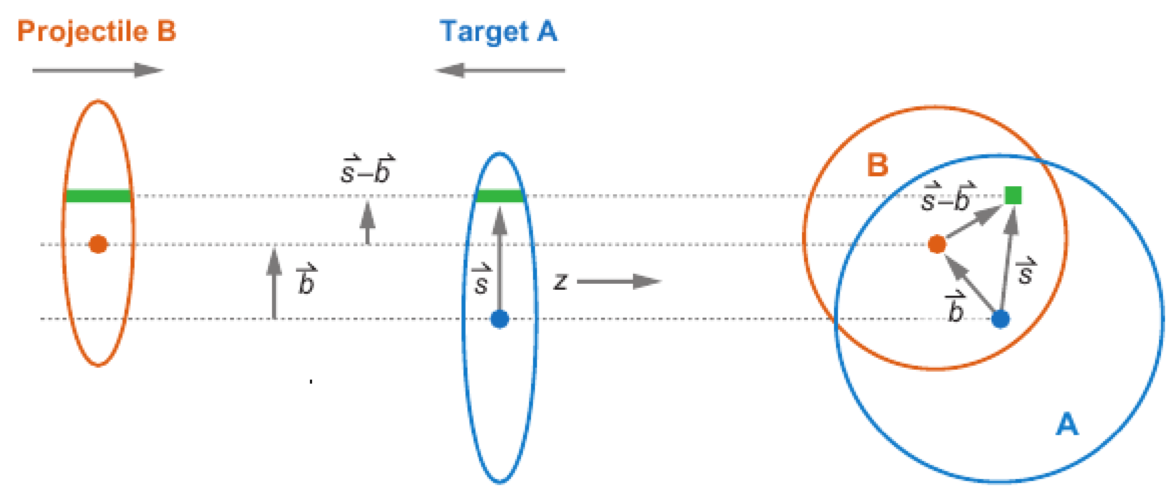
Quantitative comparison vs. centrality.



- N_{coll} dependence of the model from a Glauber inspired geometric model.
  (R. Vogt hep-ph 0411378)
- Breakup cross section is a free param.
- Woods-Saxon density profile for Au.

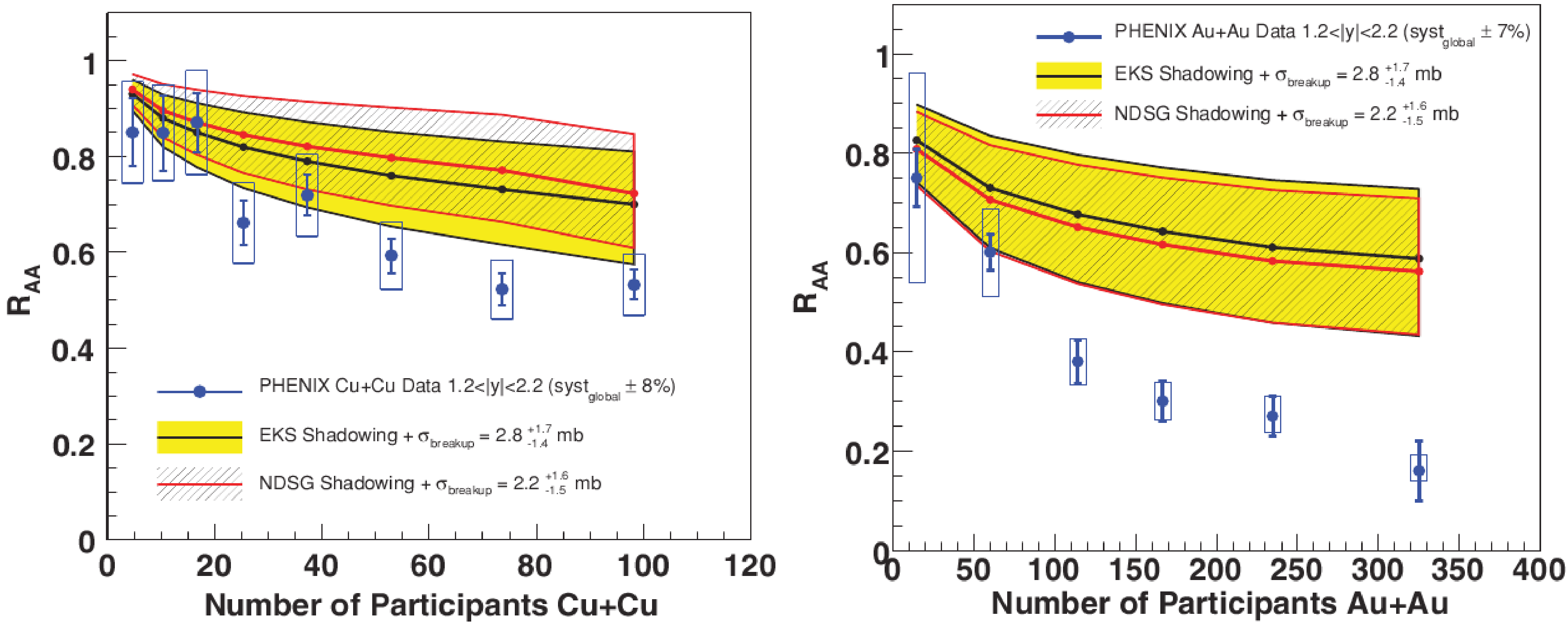
$$F_2^A = \rho_A(\vec{s}) S^J_{P,S}(A, x, Q^2, \vec{s}) f_j^N(x, Q^2)$$

$$S_{P,S}(A, x, Q^2, \vec{s}) \propto R(x, Q^2)\rho/\rho_0$$



PHENIX University of Colorado Nuclear Physics

Making Predictions for Au+Au & Cu+Cu.



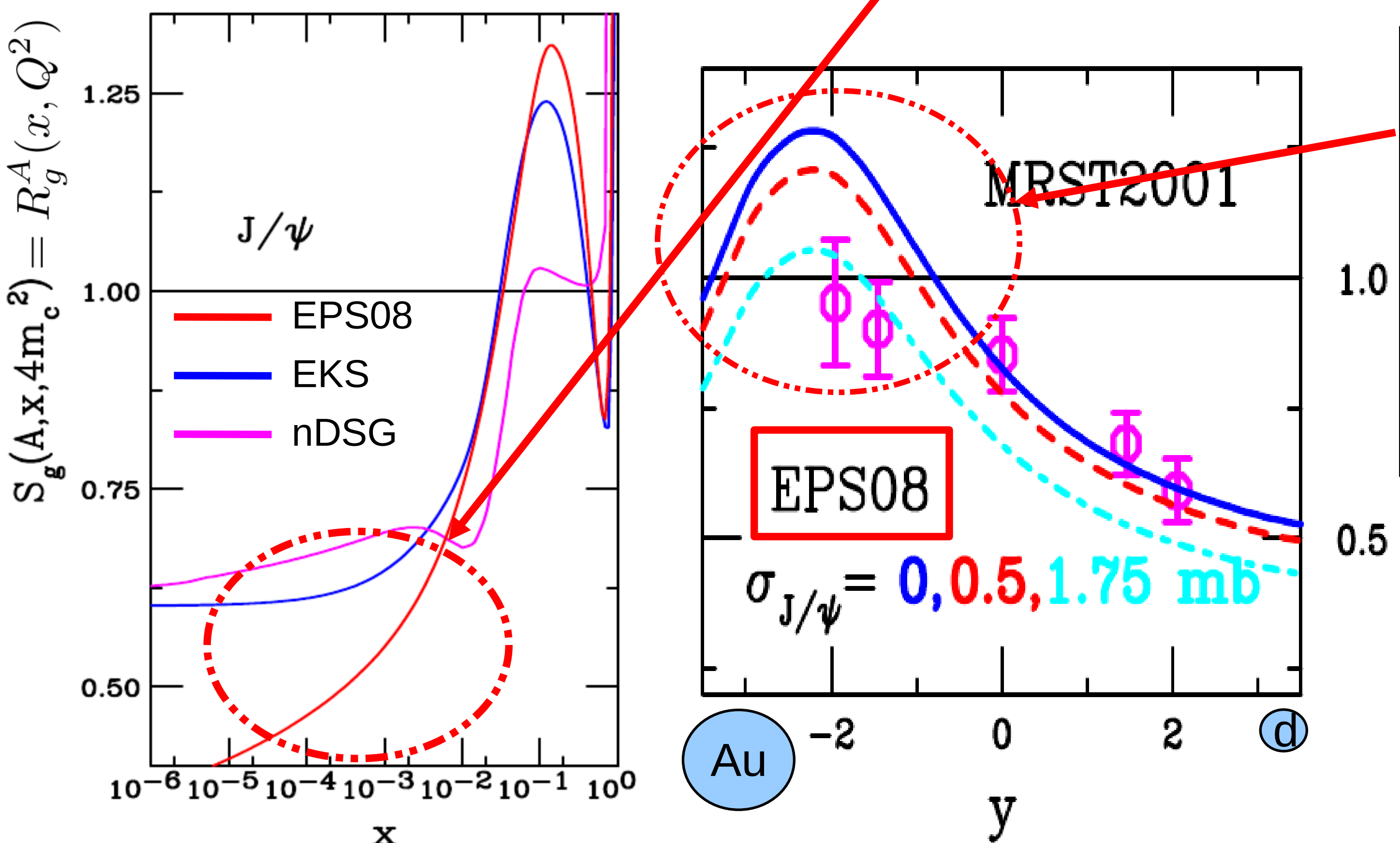
- Forward rapidity suppression apparent at 1σ level beyond that expected from CNM alone.
- However these are model dependent results, one has assumed that the nuclear modified PDFs are correct.
- Also strongly dependent on geometric model.
- Publication includes a data driven prediction.

PHENIX University of Colorado Nuclear Physics

New nPDF set to confront: EPS08

- Inclusion of RHIC data (PHENIX, STAR, BRAHMS).
- Large weight factor (40) given to the very forward negative hadron production data from BRAHMS.
- Resulting in much larger shadowing in the gluon nPDF.

(R. Vogt RHIC Users Mtg.)



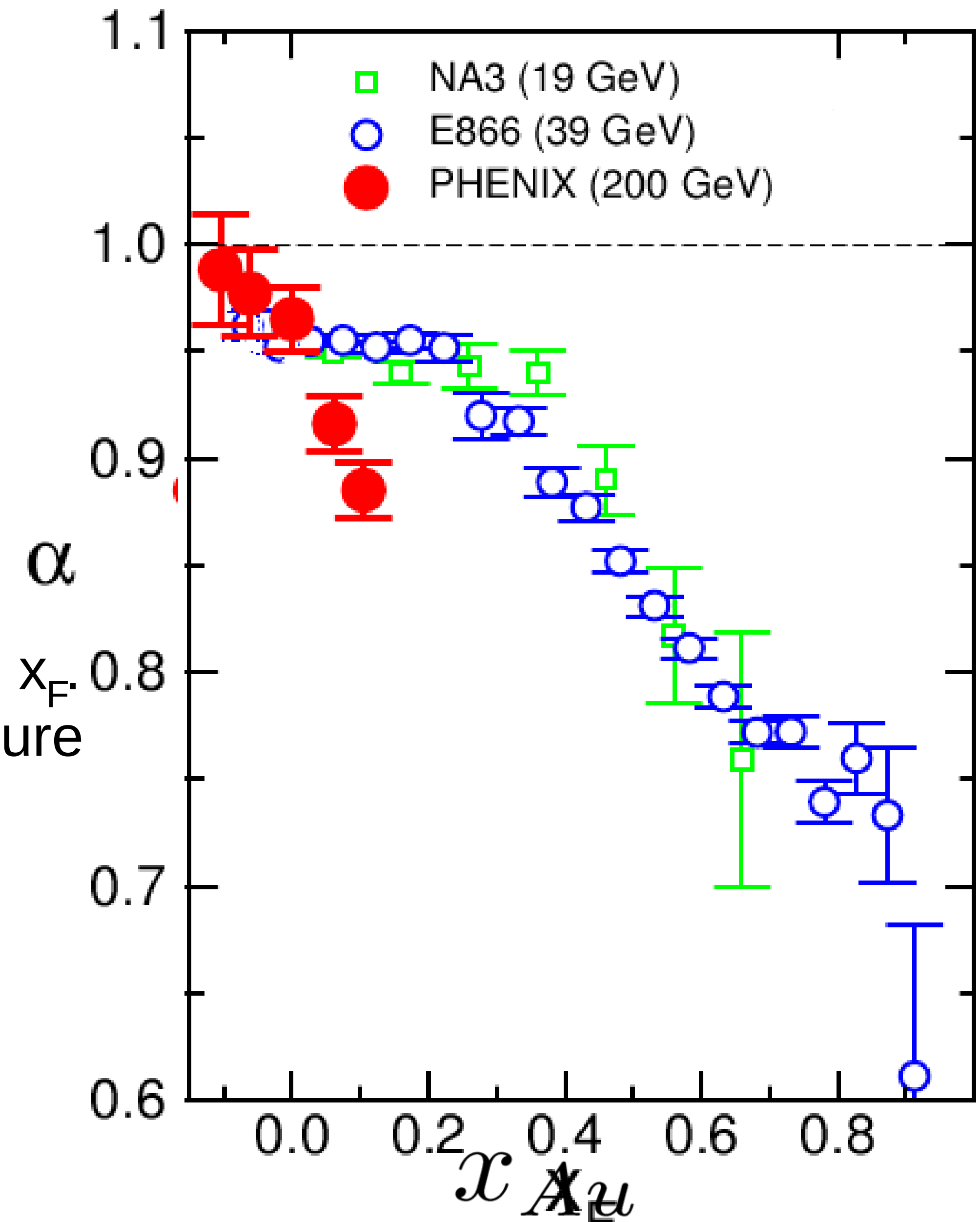
No constant (with rapidity) break up cross section allows for the mid and forward PHENIX data within 1 sigma.

Comparison to other measurements.

$$\sigma_{pAu} = \sigma_{pN} A^{\alpha}$$

$$\alpha = 1 - \sigma_{abs} \frac{\langle \rho L \rangle}{lnA}$$

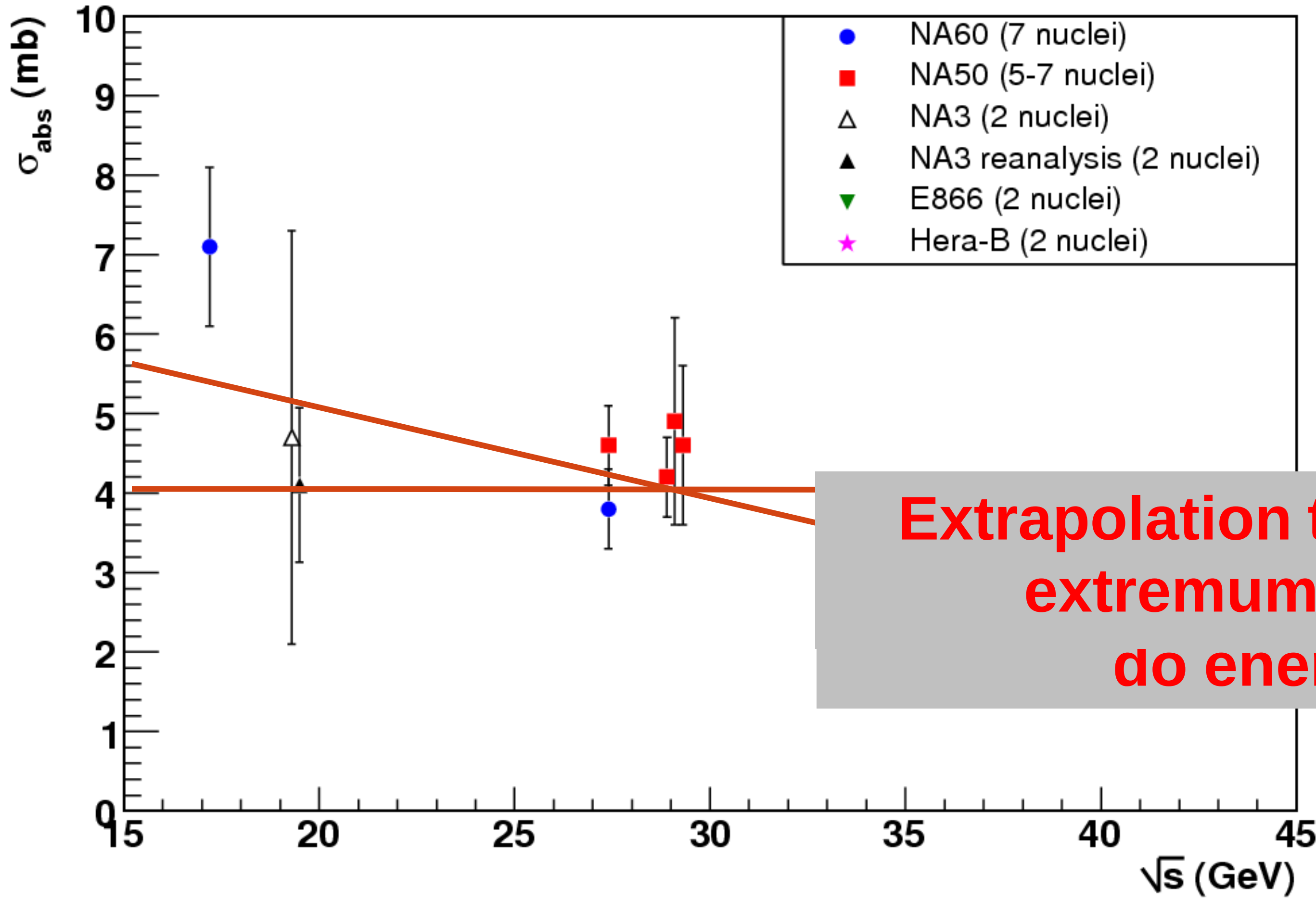
- α does not scale with x_{Au} as expected.
- Approximate energy scaling with x_F.
- Another hint that we cannot capture all of the physics in the nPDF.



PHENIX University of Colorado Nuclear Physics

Energy Dependant absorption cross section

- Data favors decreasing σ_{abs} with increasing energy? (RGdC)



Extrapolation to PHENIX is near extremum of σ_{abs} result do energy scans.

- Also theoretical motivation.

M. A. Braun et al., Nucl. Phys. B 509 (1998) 357

A. Capella and E. G. Ferreiro (hep-ph/0610313)]

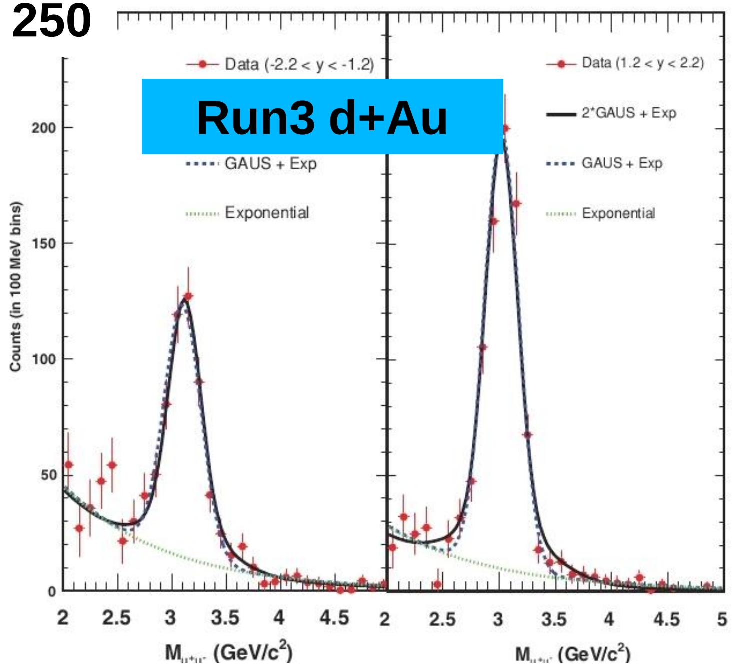
$$\sigma_{abs} = 0$$

FUTURE PHENIX MEASUREMENTS

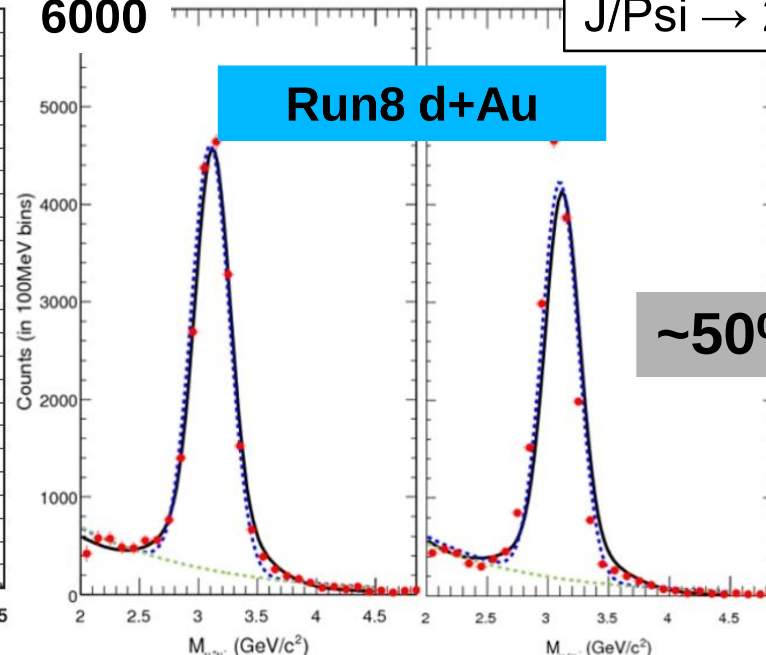
Improving the statistical error.

J/Psi → 2μ

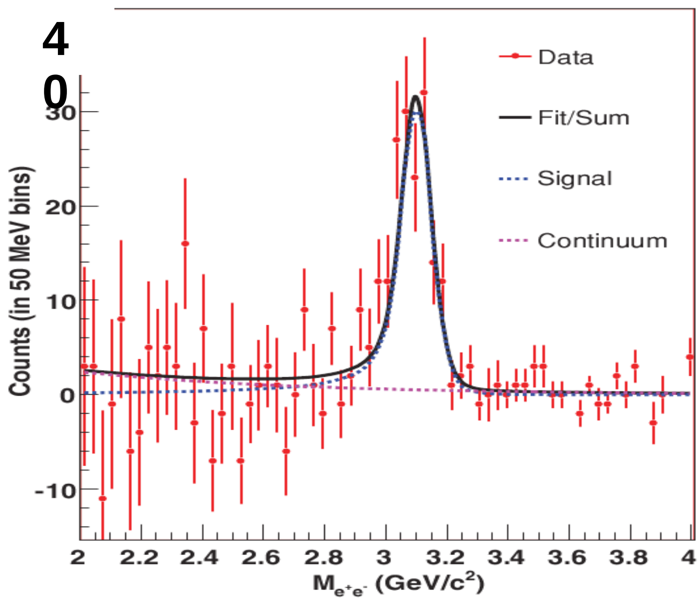
Run3 d+Au



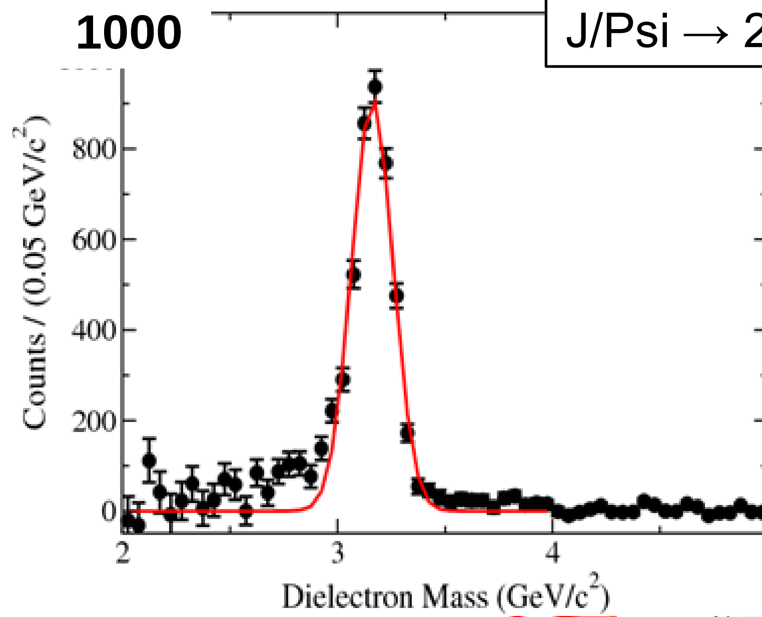
Run8 d+Au



~50% of data



J/Psi → 2e

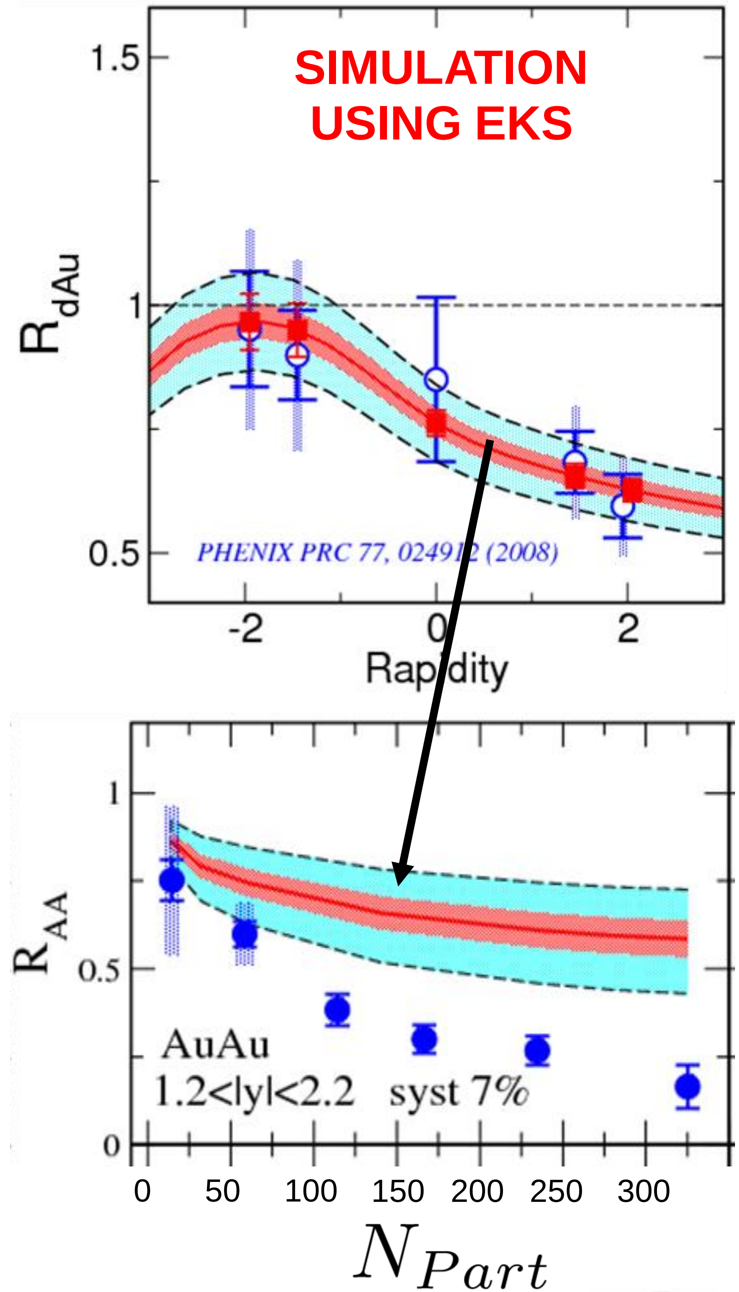


PHENIX University of Colorado Nuclear Physics

PHENIX CNM future results.

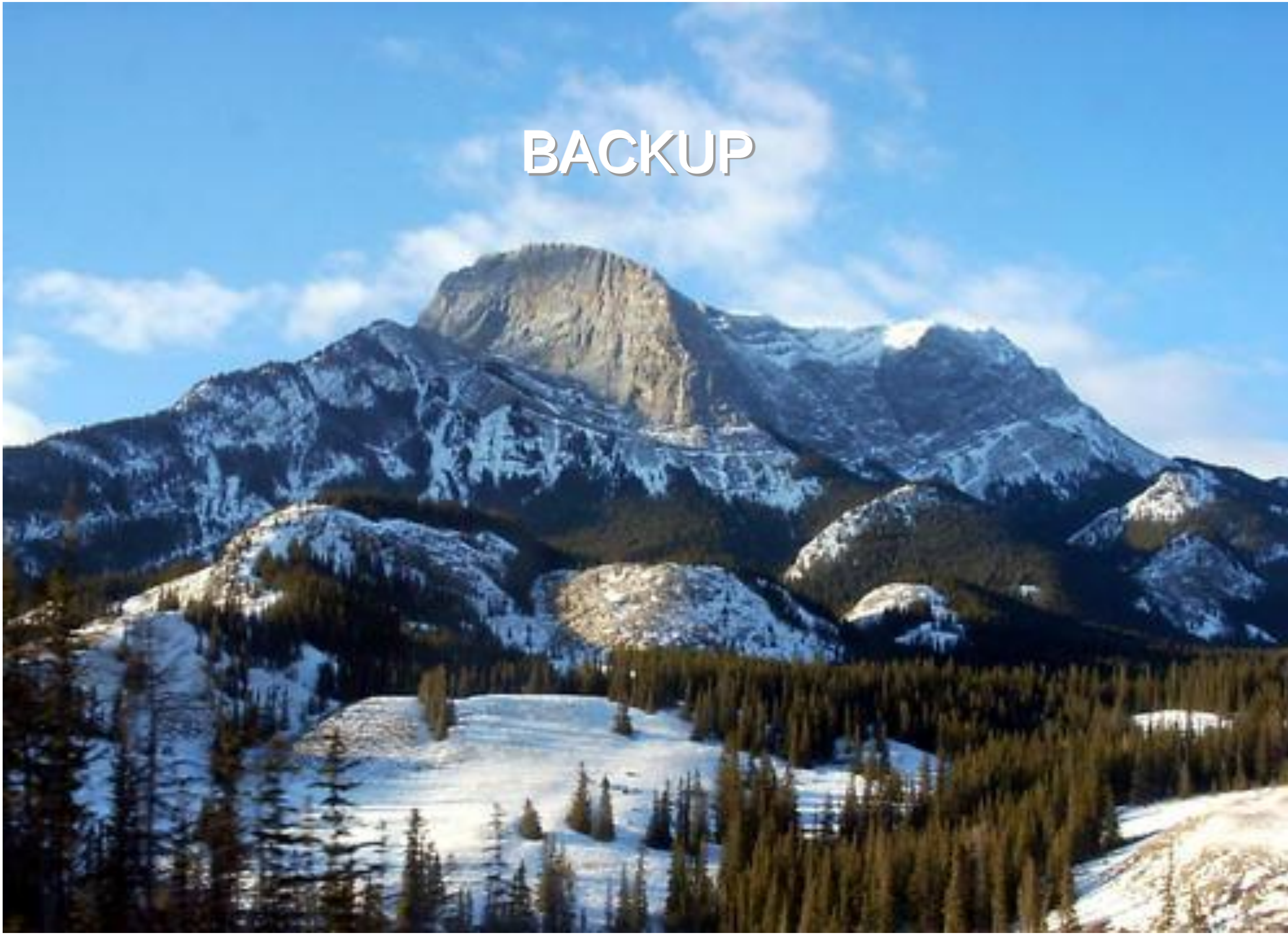
- Improved statistical precision:
  - 2008 RHIC d+Au Run ×30 J/ψ increase over 2003.
  - 2006 RHIC p+p Run ×3 J/ψ increase over 2005.
- Improve systematic uncertainty:
  - Better understanding of the PHENIX detector acceptance.
  - Improved estimate of line shape error.
- Extend p_T for both CNM and HNM
  → new p+p baseline
  → Ability to bin in p_T and N_{coll}

→ Tighter constraint for Au+Au predictions.

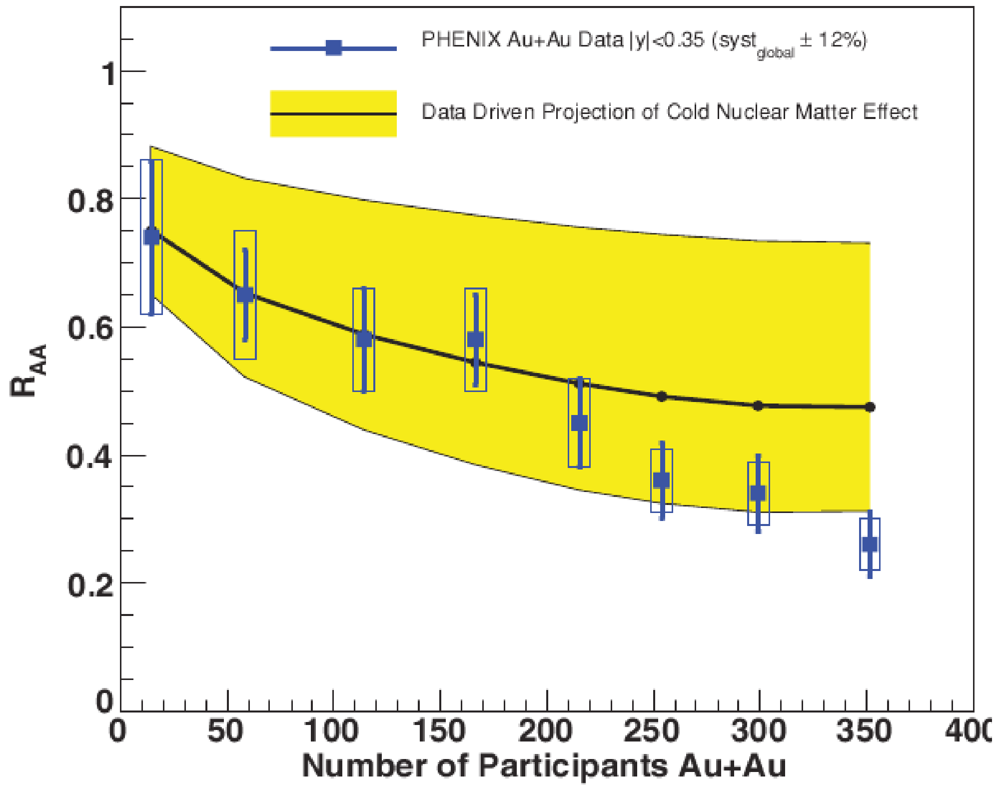


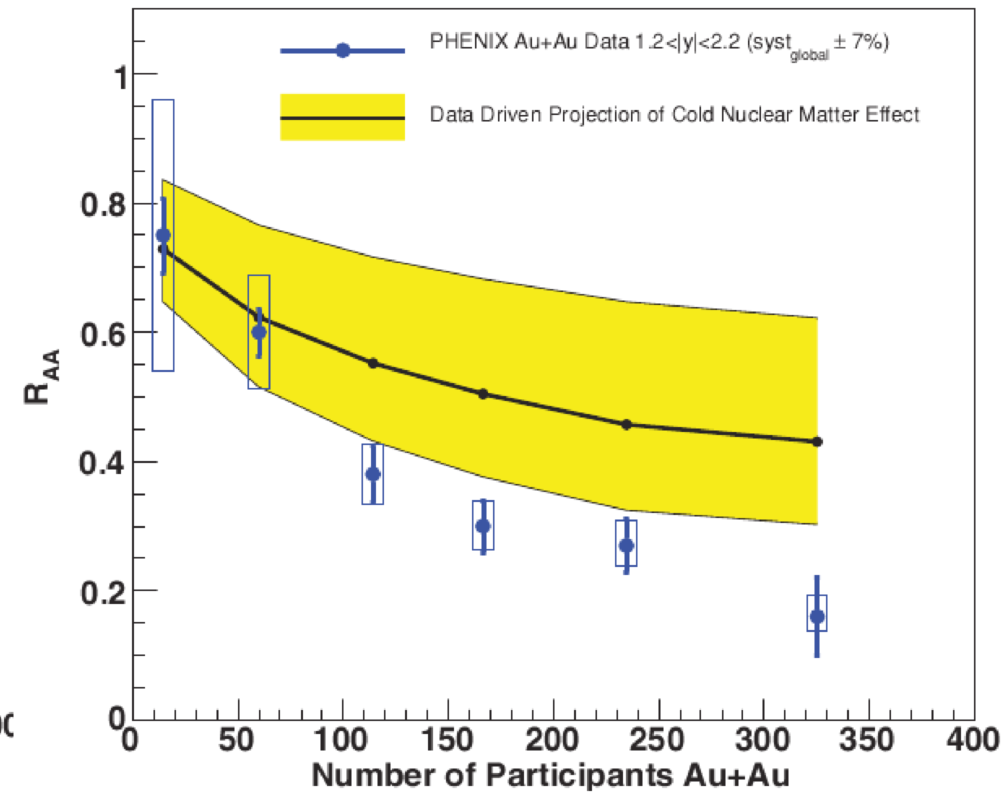
We know how much we don't know.

- Cold nuclear matter effects are a requirement to interpret anomalous J/ψ suppression in the sQGP.
  - However, still many puzzles in the CNM alone.
- New dAu results from PHENIX in the pipeline
  - Improved statistics and systematics.
- NPDF can not account for the CNM suppression alone.
  - Using Glauber inspired geometry.
  - No systematic errors for parameterizations
- Breakup cross section puzzle
  - Energy dependent absorption cross section (or other hidden kinematic dependencies).
  - Must also measure CNM (d+Au) effects to interpret J/ψ signal at lower energy.


BACKUP

Data driven extrapolation.



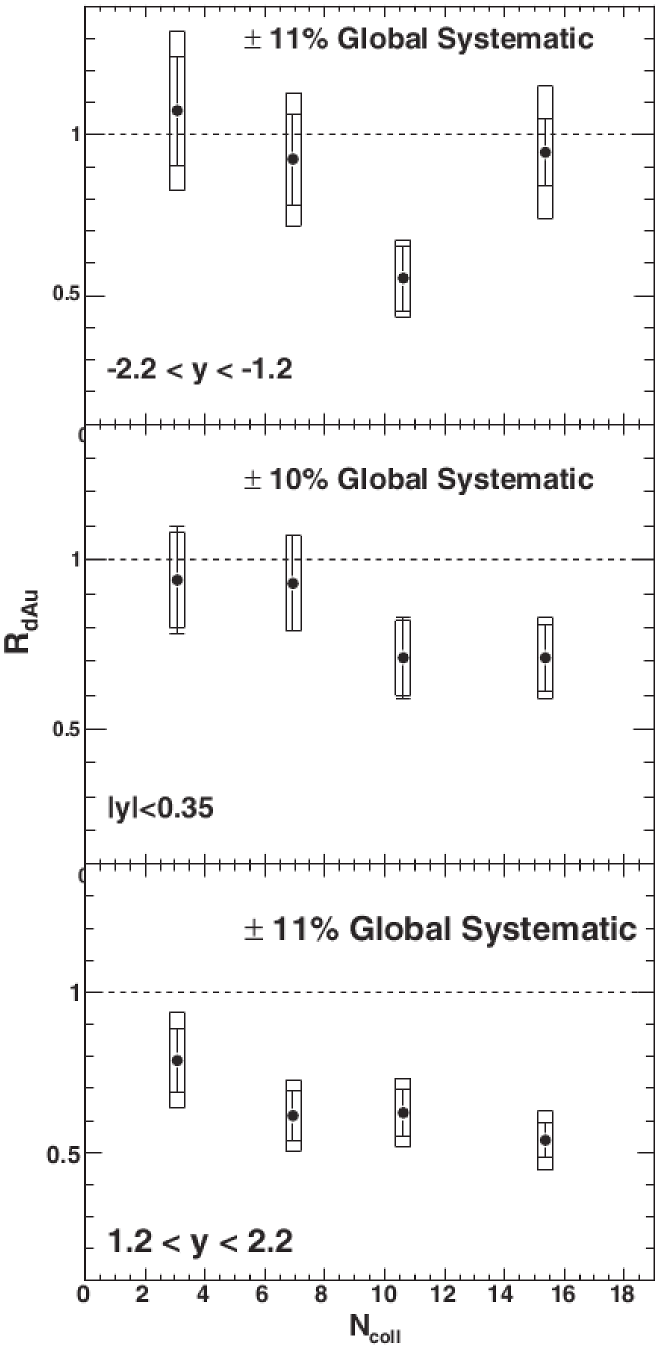


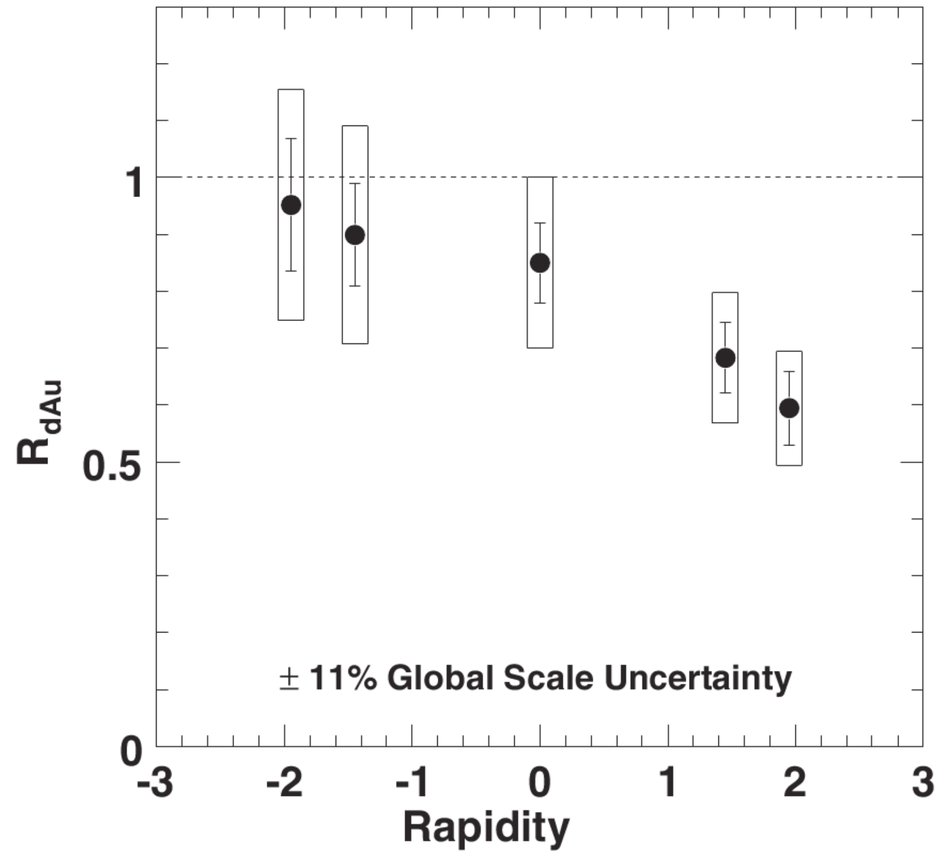
- Data driven method with no model assumptions. J.Phys.G34:S955

- Assumes the suppression factor goes to 1 once you reach the nuclear radius

- Not clear in this case that the mid rapidity suppression is significant beyond what is expected from CNM.

R_{dA} from PHENIX





Improving the systematic Error.

- Low mass and p_T acceptance
  - Limited acceptance due to small opening angle for low mass pairs at low p_T.
  - Outside of the mass window for the J/Psi but it can have effect on the systematic error.
  - Three fits used in the past and the variation between them taken as systematic.
  - One line shape with multiple fit windows is more stable and describes the J/Psi line shape well.