Quarkonia Production in p+p, d+Au and A+A from PHENIX

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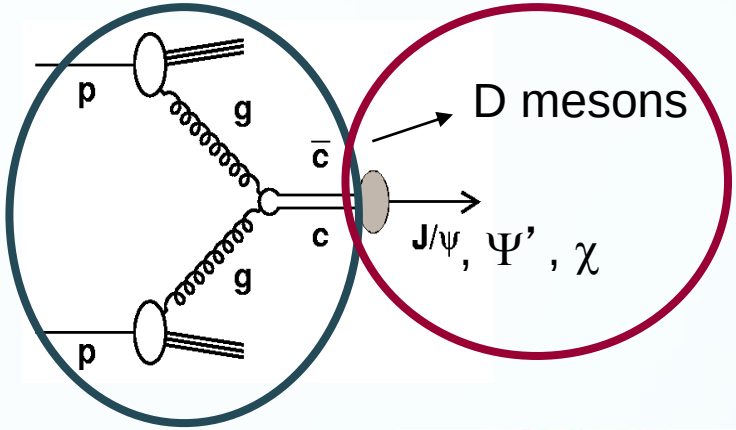
Heavy Flavor Production

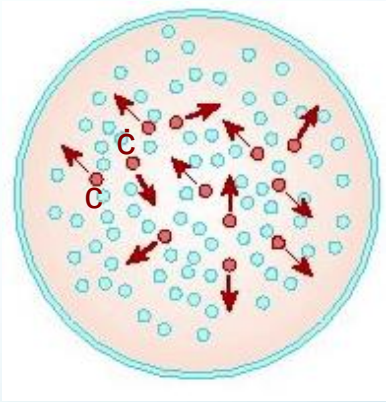


Factorize calculations:

- pQCD to calculate cc production
- $c\dot{c}$ propagation and hadronization

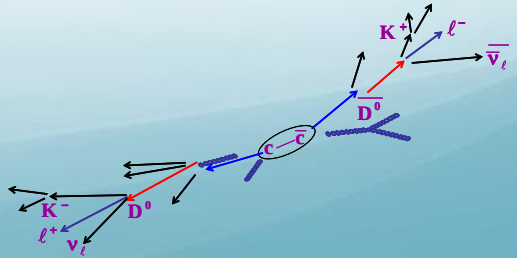
Note: much of J/Ψ production comes from feed-down from higher resonances, B

Possible Modifications beyond p+p production extrapolation:



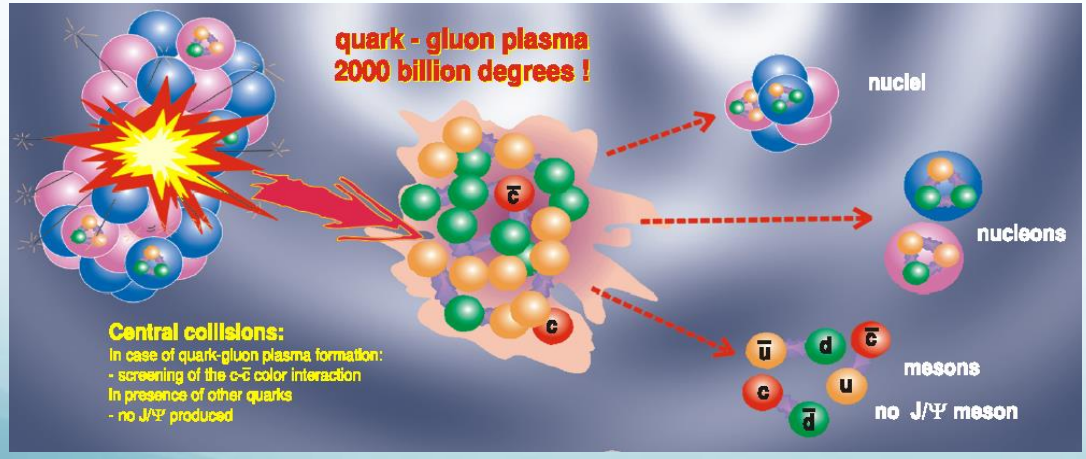
- Parton Distribution Functions modified in nucleus?
- Energy loss of partons traversing nucleus
- Cronin modification of p_T spectra
- Breakup of charmonium before exiting nucleus
- Energy loss of partons traversing QGP
- Debye screening of charmonia by QGP
- If enough cc, can have charmonium production through coalescence

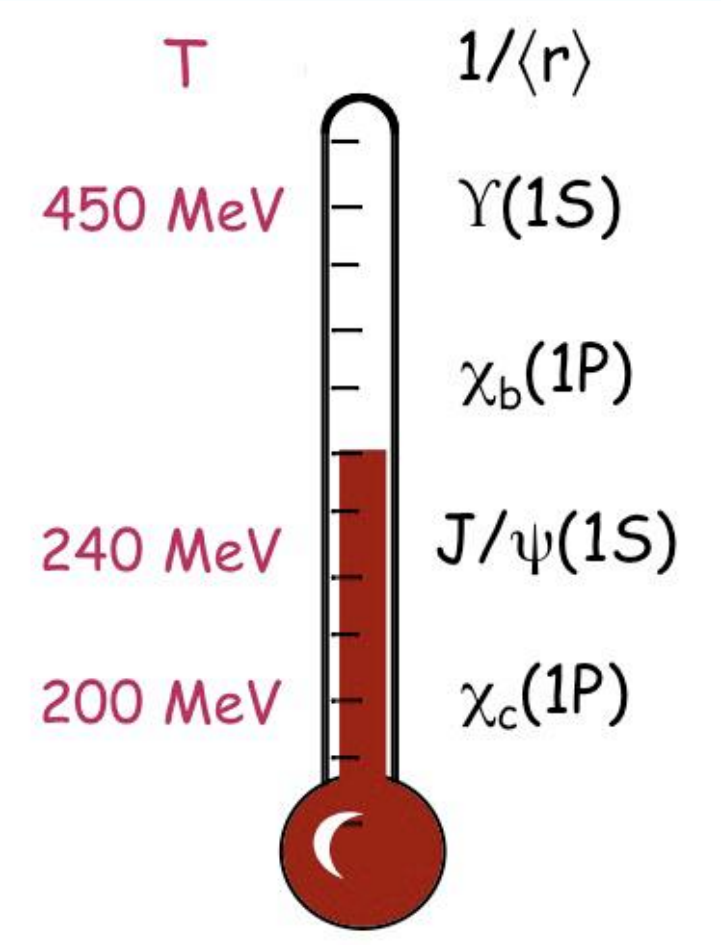
- Note heavy flavor kinematics differences



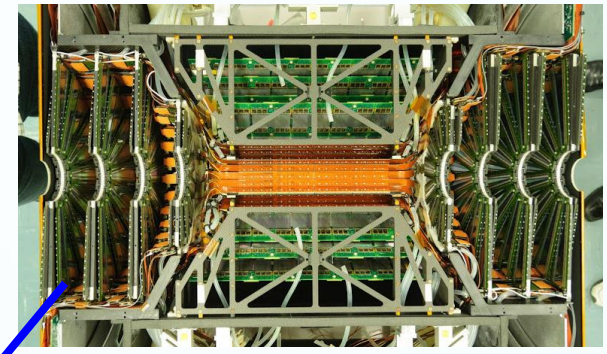
Upsilon

- Charmonia plus upsilon states covers large range of binding energies which can give indication of whether screening is occurring or not





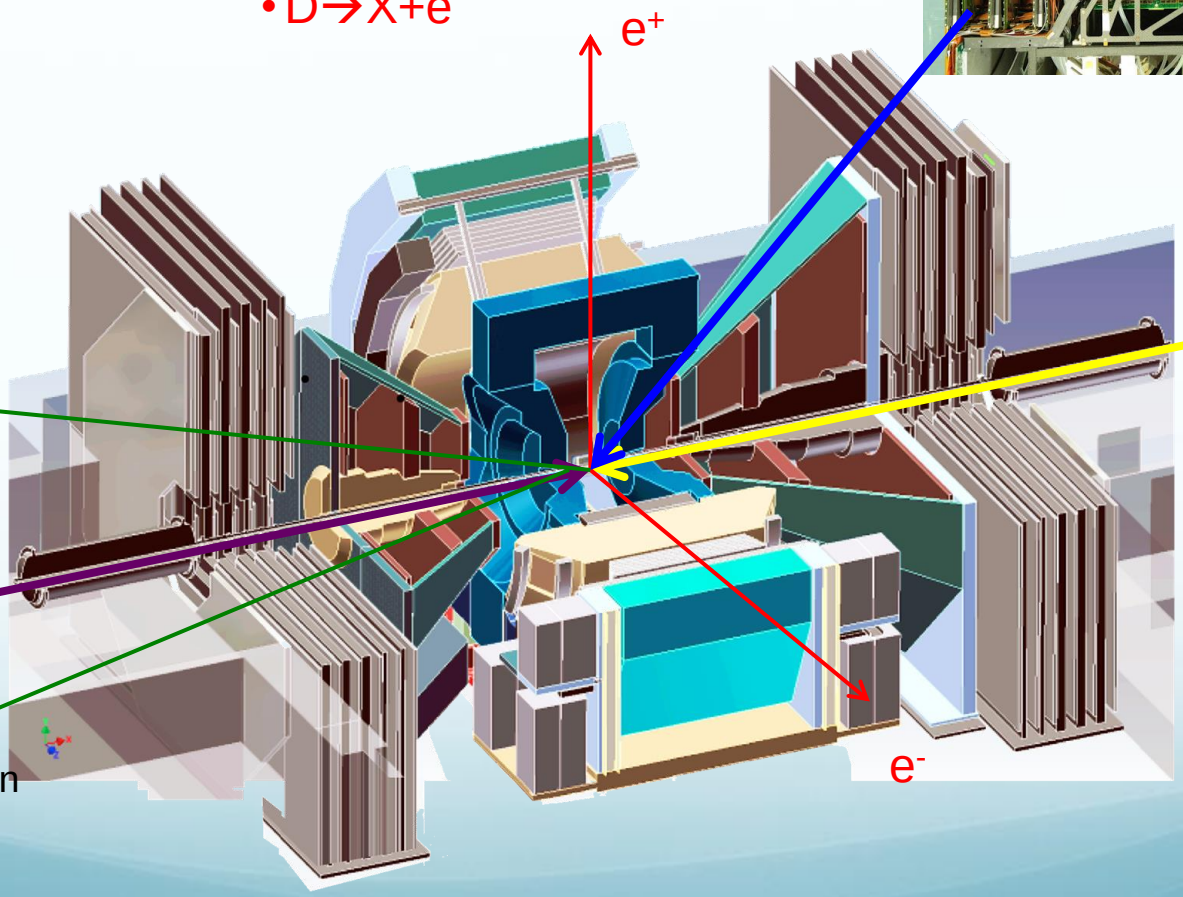
The PHENIX Detector



Central Arms:
- Υ, J/ψ, $\psi' \rightarrow e^+e^-$
- $D \rightarrow X+e$

Muon Arms:
- Υ, $J/\psi \rightarrow \mu^+\mu^-$
- $D \rightarrow X+\mu$

Adding FVTX:
- $\psi' \rightarrow \mu^+\mu^-$
- D, B



Au

$x \approx 5 \times 10^{-3}$
Shadowing region

$x \approx 8 \times 10^{-2}$
Anti-shadowing region

PHENIX Data Sets

p+p (200 and 510 GeV)

- J/ψ, ψ', Υ at central and forward rapidities

d+Au (200 GeV)

- J/ψ, ψ', χ_c, Υ at central rapidity
- J/ψ, Υ at forward/backward rapidities

Cu+Cu, Cu+Au, (200 GeV), Au+Au (39, 62, 200 GeV)

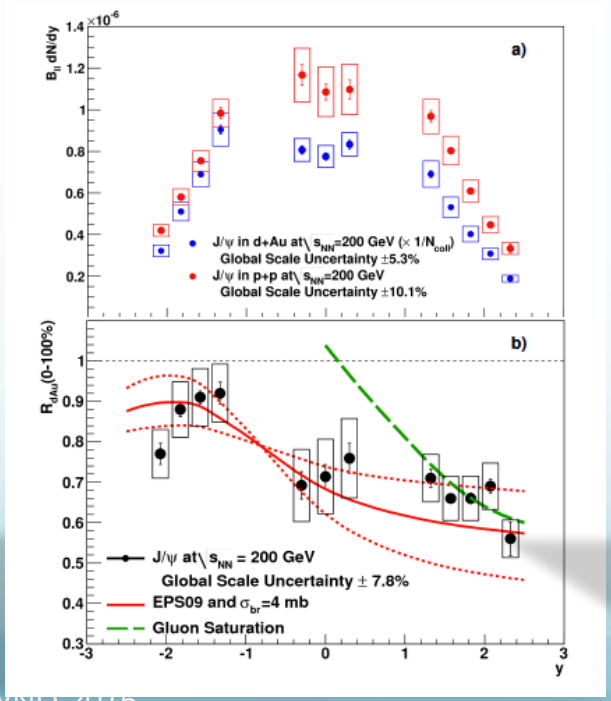
- CuCu J/ψ R_{AA} at forward/backward rapidities
- CuAu J/ψ R_{AA} at forward/backward rapidities
- AuAu J/ψ R_{AA} at central and forward rapidities
- AuAu J/ψ R_{cp} at 39, 62, 200 GeV, forward rapidities
- CuAu, AuAu ψ' at forward rapidities analysis underway
- AuAu Υ at central rapidity

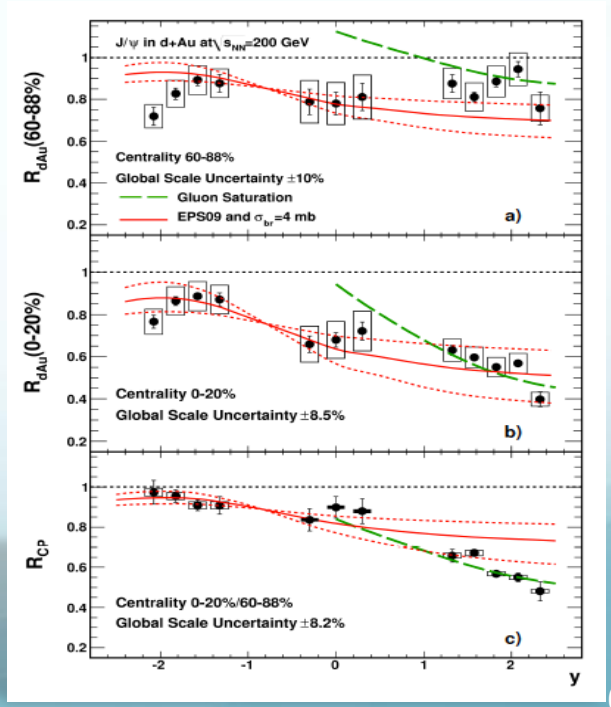
J/ψ in d+Au Collisions: Cold Nuclear Matter Effects

- In d+Au collisions, rapidity-dependent R_{dA}

$$R_{dA} = \frac{dN/dy_{dAu}}{dN/dy_{pp} * N_{coll}}$$

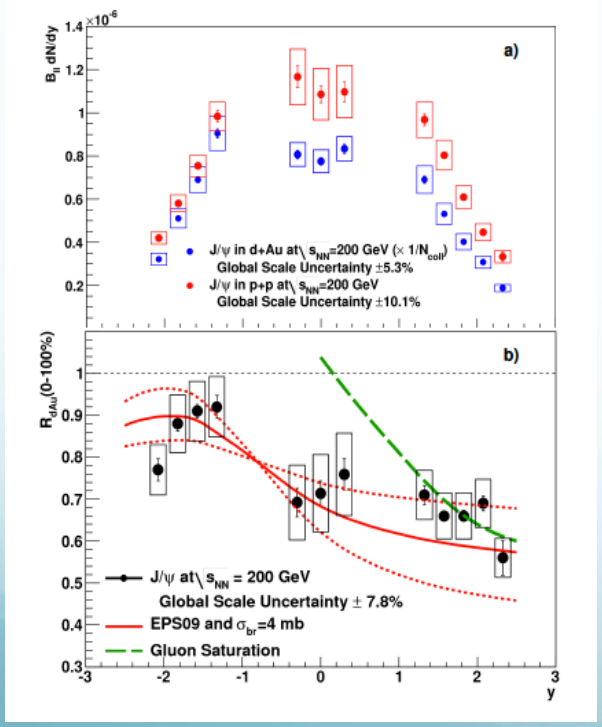
- Forward rapidity shows more suppression than central/backward rapidities. Centrality-dependent.
- Possible explanations: gluon shadowing, nuclear breakup, energy loss

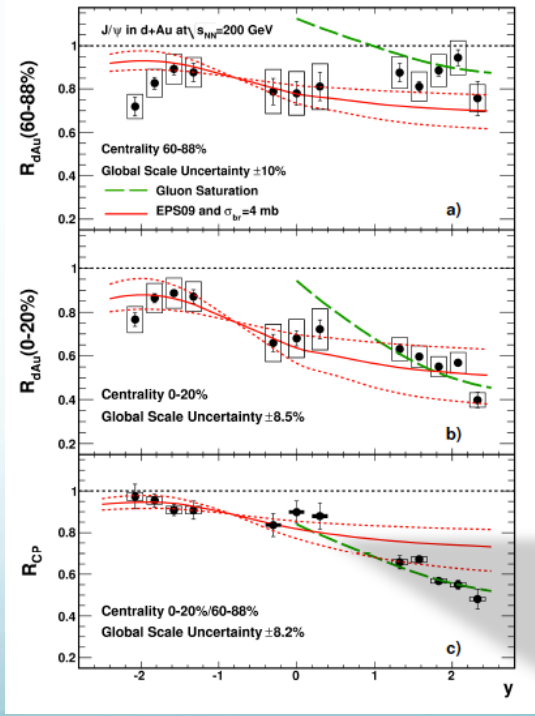


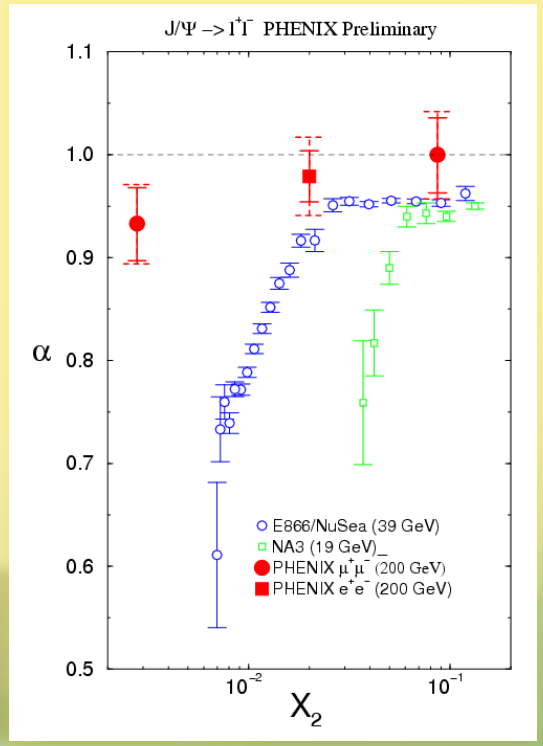


However,

- We do not see x_2 scaling, which would be indicative of gluon shadowing
- Initial-state energy loss and final-state effects?

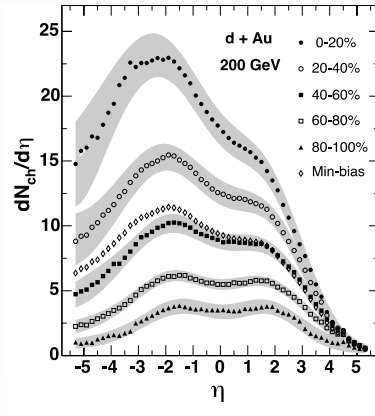


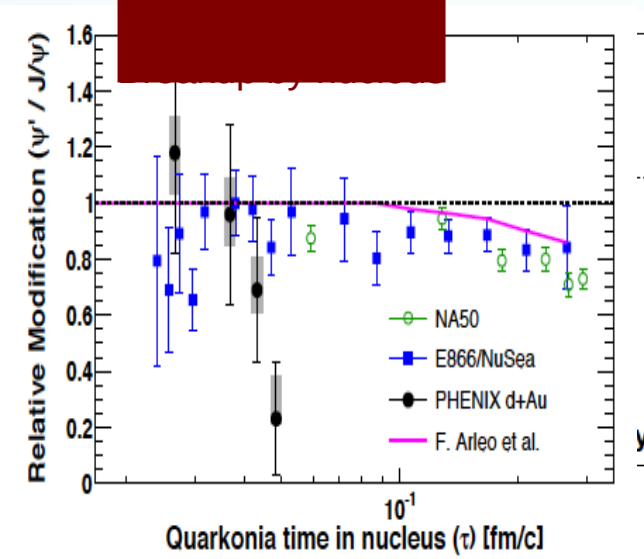


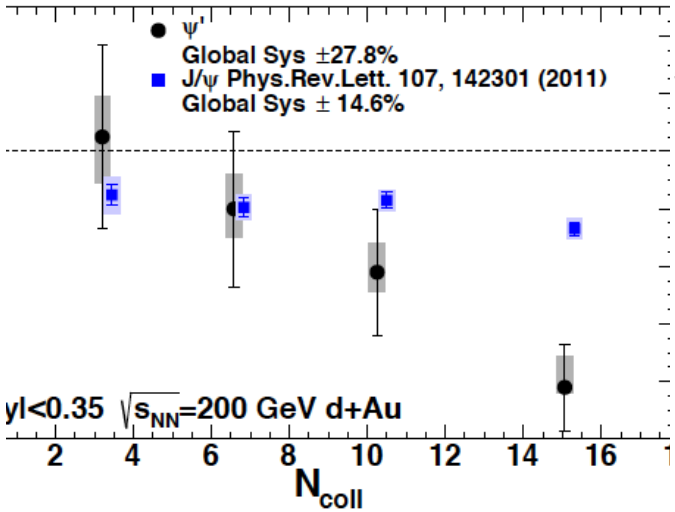


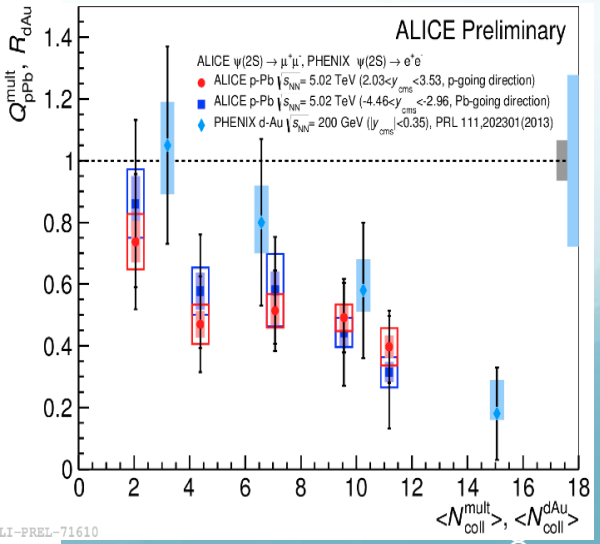
mparing CNM for J/ψ, ψ'

- P uppressed more than J/ψ at central rapidity, in c ent in nucleus (breakup) does not hold as e r PHENIX data.
- U d with $dN_{ch}/d\eta$ for several systems, up to 200 G
- A a also seems consistent with this trend



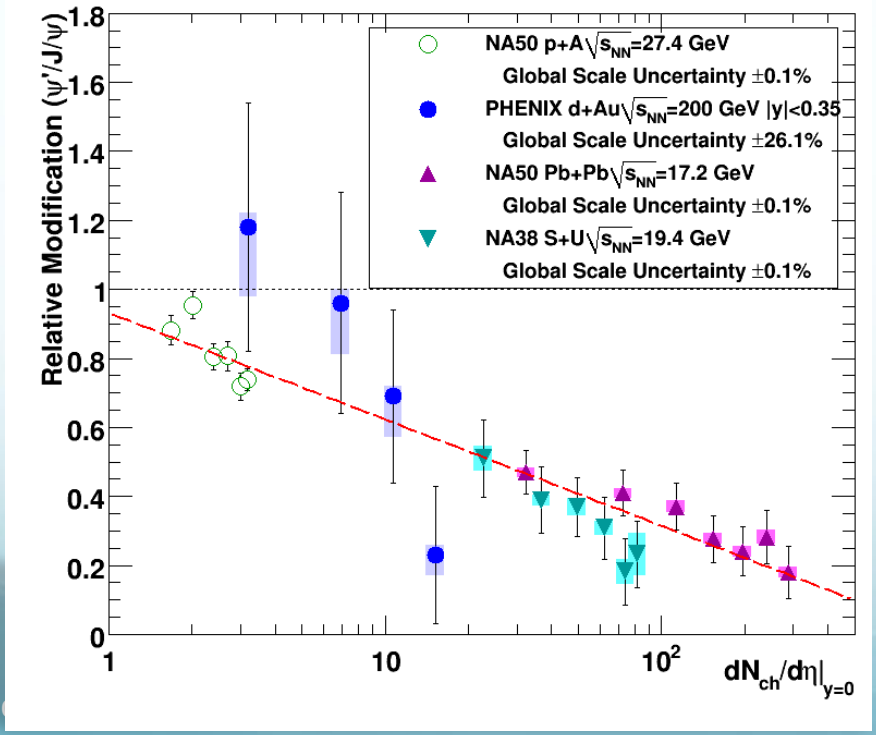


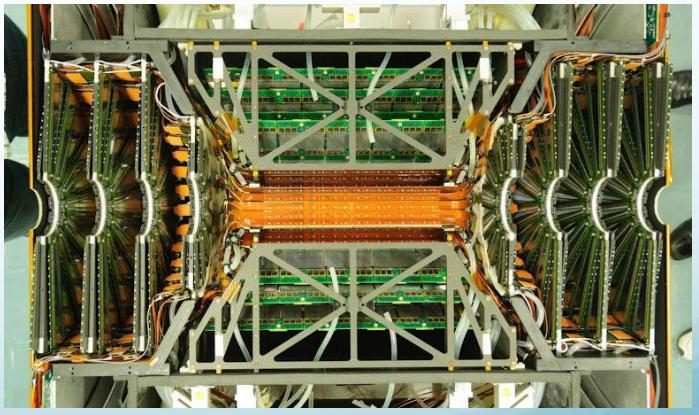




Comparing CNM for J/ψ, ψ'

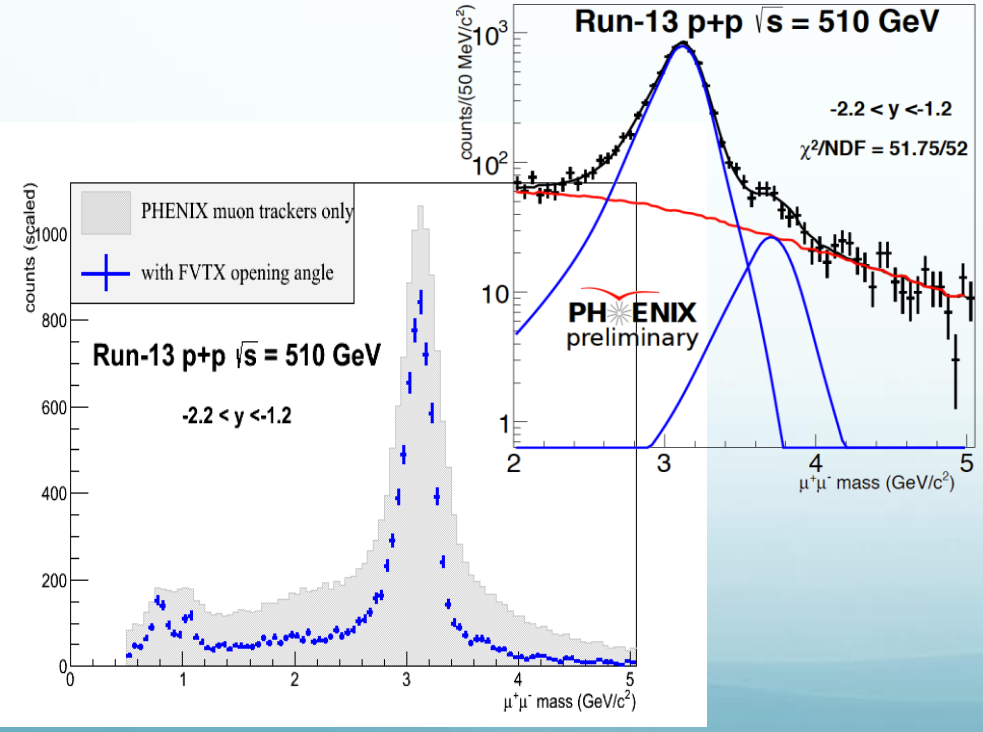
- Would like to more fully explore the trend with $dN_{ch}/d\eta$, but current data are limited (see below)
- New p+A and heavy ion data from forward rapidity will expand our coverage at RHIC
- Vertex Detectors allow us to explore trend versus event multiplicity

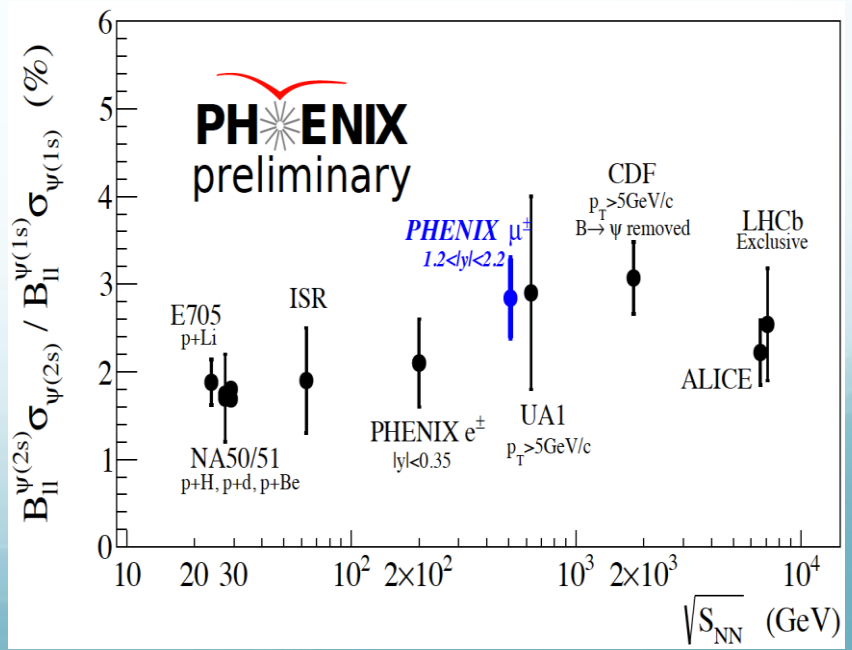




J/ψ:ψ' at Forward Rapidity

- PHENIX has a first J/ψ:ψ' result at forward rapidity from p+p 510 GeV
- FVTX detector allows separation of J/ψ and ψ'
- Heavy Ion analysis underway. p+A data set coming.

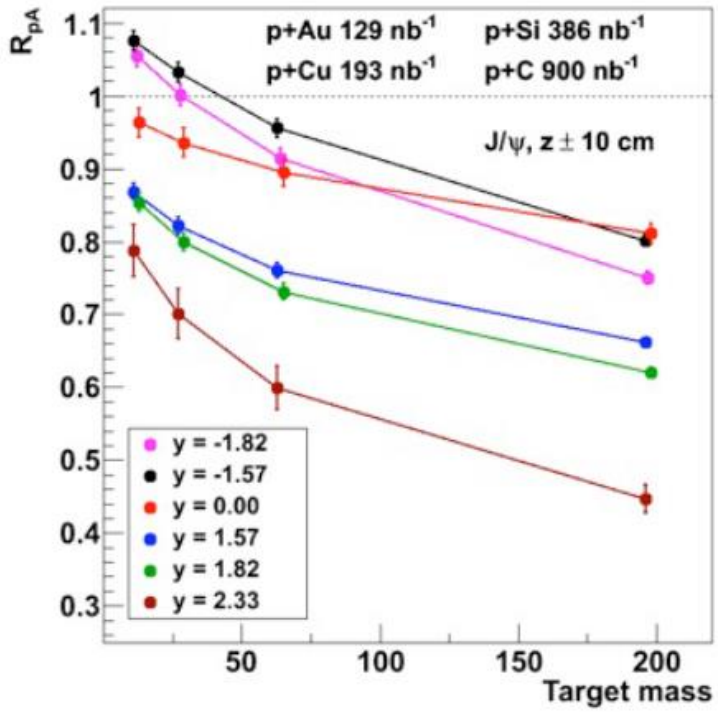


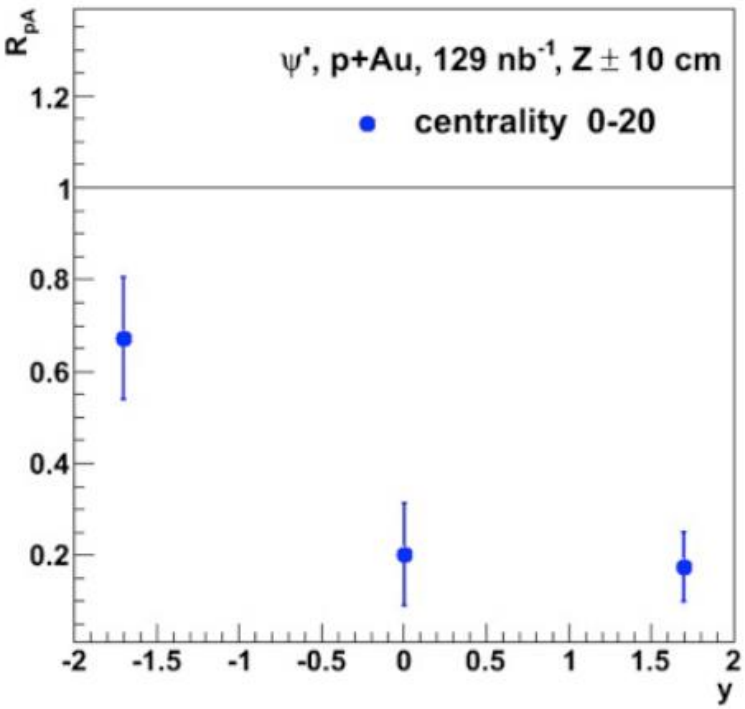


pA Projections for Quarkonia

- Expect J/ψ measurements of significance for several nuclei
- p+Au will provide a good statistical measurement of ψ'

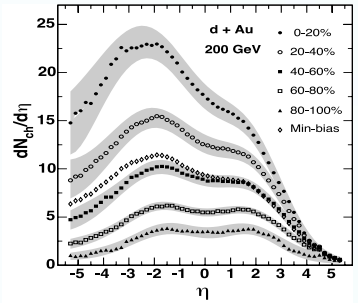
p+A projections for Run 15

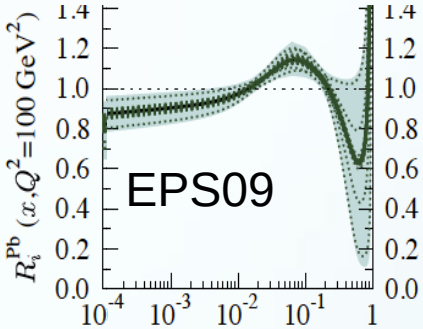


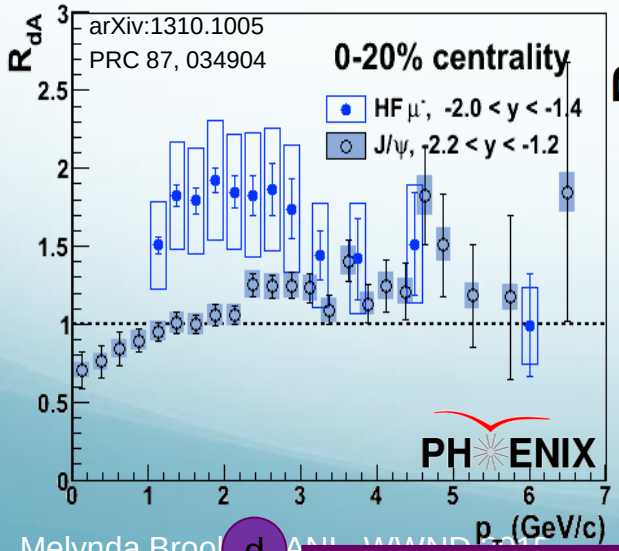


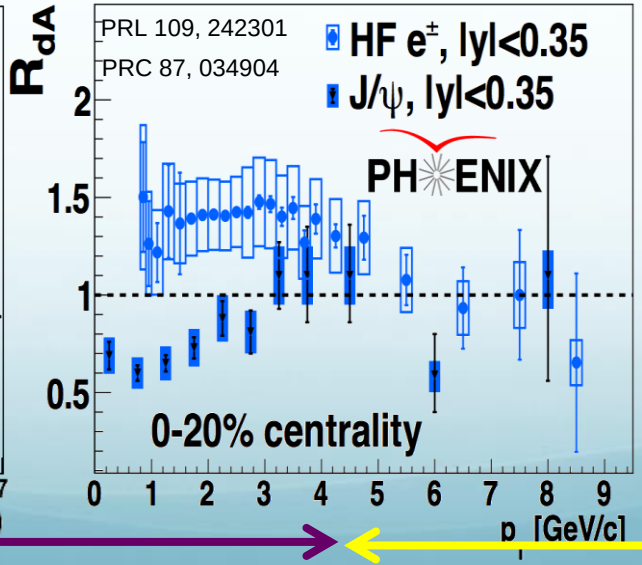
CNM for Open and Closed Heavy Flavor

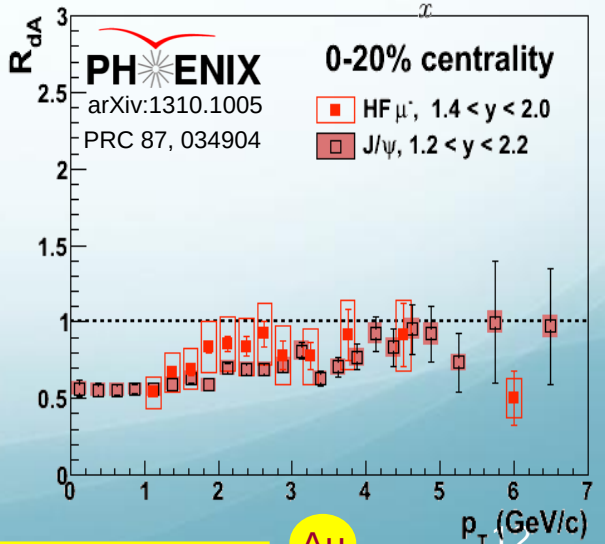
- Open heavy flavor shows a different rapidity dependence from J/ψ
- Combination of initial-state and final-state effects or primarily final-state?
- The FVTX will allow more precise measurement to better quantify differences from Run 15 p+A







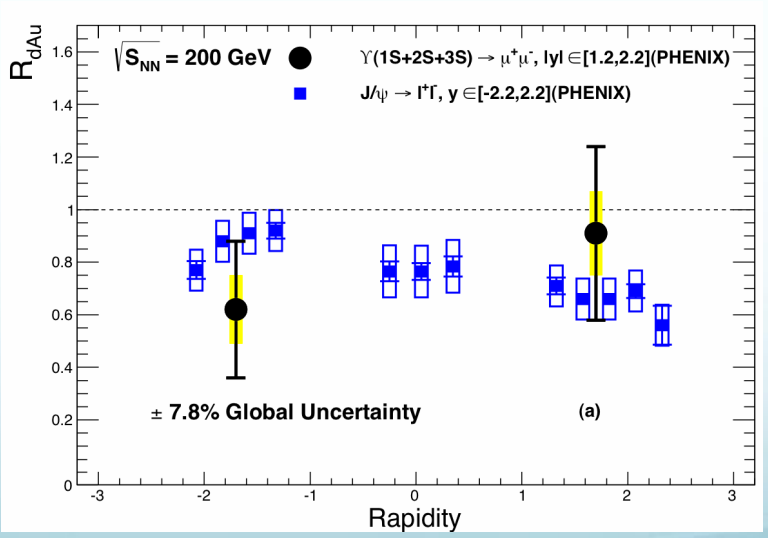




d → ← Au

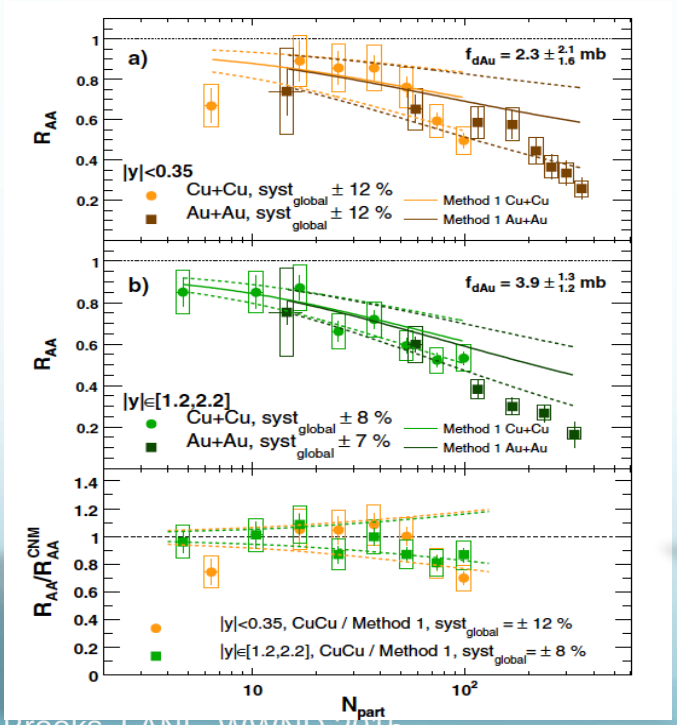
What About Upsilons?

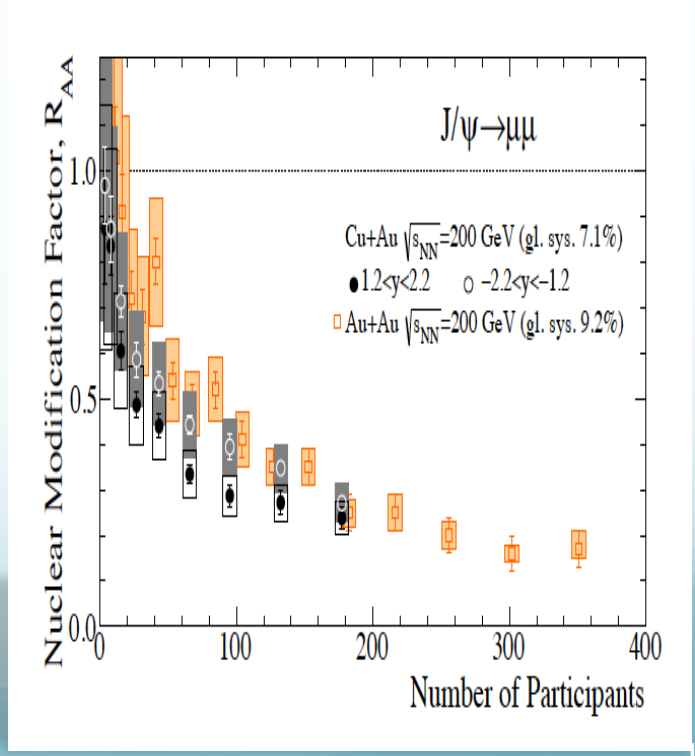
- Possible suppression at *backward* rapidity (but error bars large)
- Forward rapidity may or may not be suppressed
- Challenging to make significantly better measurements with PHENIX. sPHENIX proposes to continue upsilon program.



System Size and CNM

- Suppression similar for smaller systems (CuCu) and larger (AuAu). Close to value extrapolated from dAu (modified PDF and breakup)
- Small rapidity dependence in CuAu, more consistent with CNM effects than QGP





J/ψ Heavy Ion Measurements

- J/ψ suppression strikingly similar at SPS and RHIC despite different energies
- Rapidity dependence not initially expected: CNM effects bring forward down? Coalescence brings central up?
- p_T dependence does not show a strong effect

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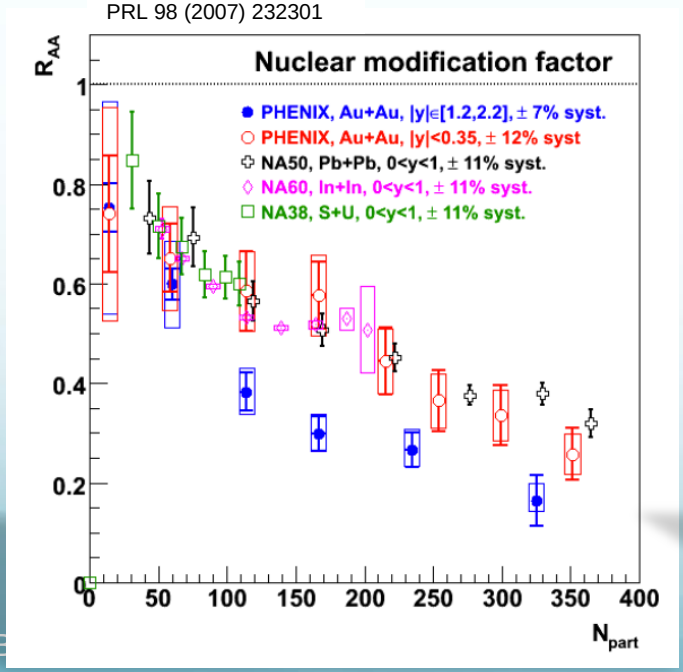
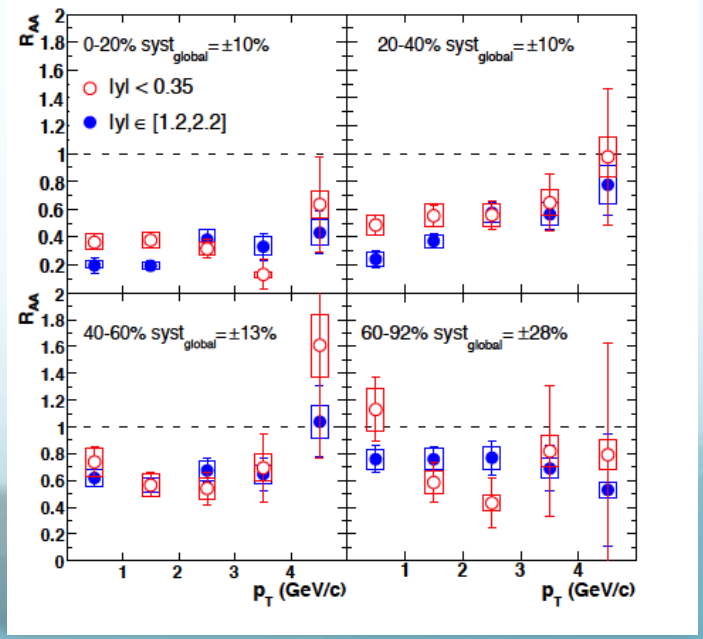
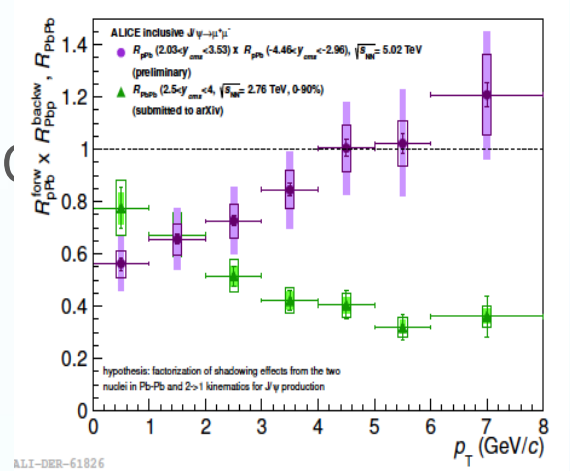
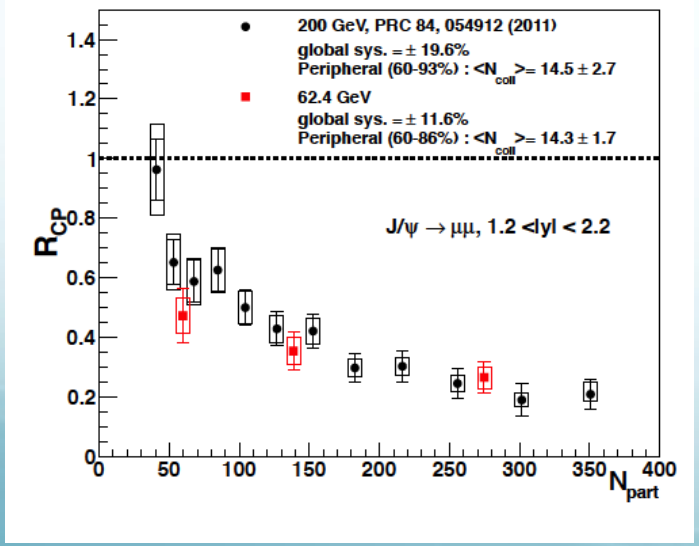


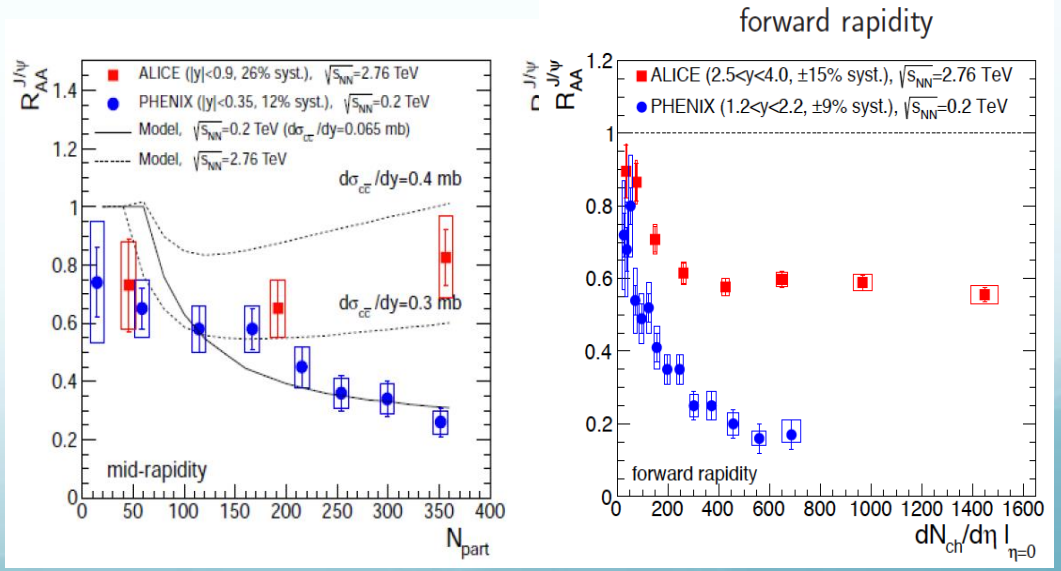


Energy Dependence Cont'd

- Explore energy dependence more at RHIC
- Don't see large change in suppression until LHC
- p_T dependence now looks consistent with coalescence picture

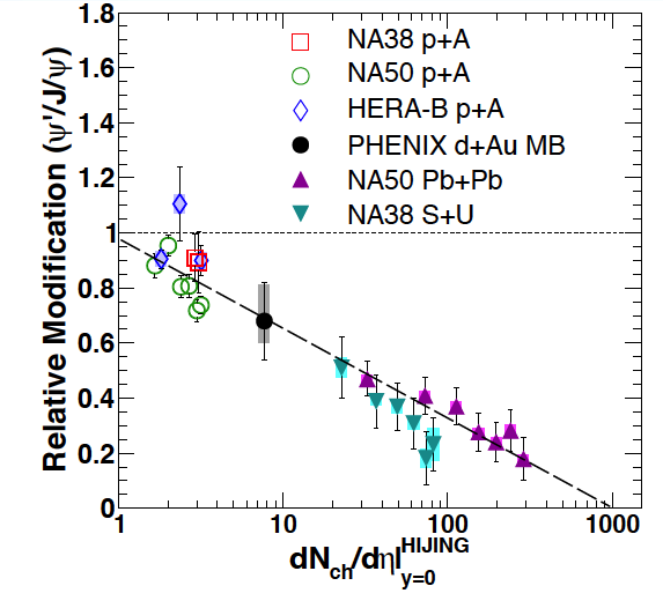


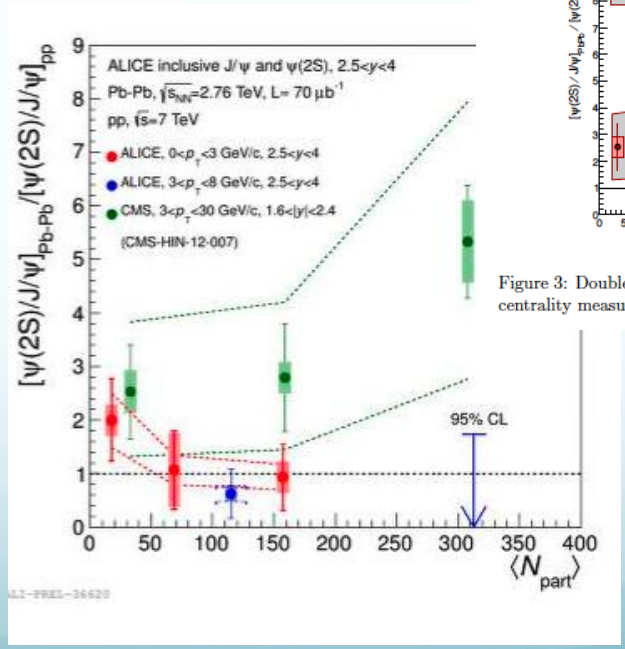




Heavy Ion ψ':J/ψ

- At LHC energies, the J/ψ:ψ' ratio also seems to now deviate from linear trend.
- Another indication of coalescence atLHC? What will we see in RHIC heavy ion?





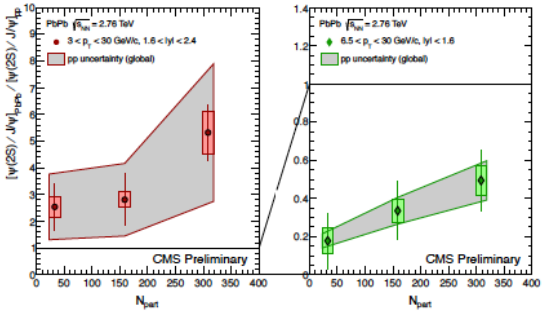
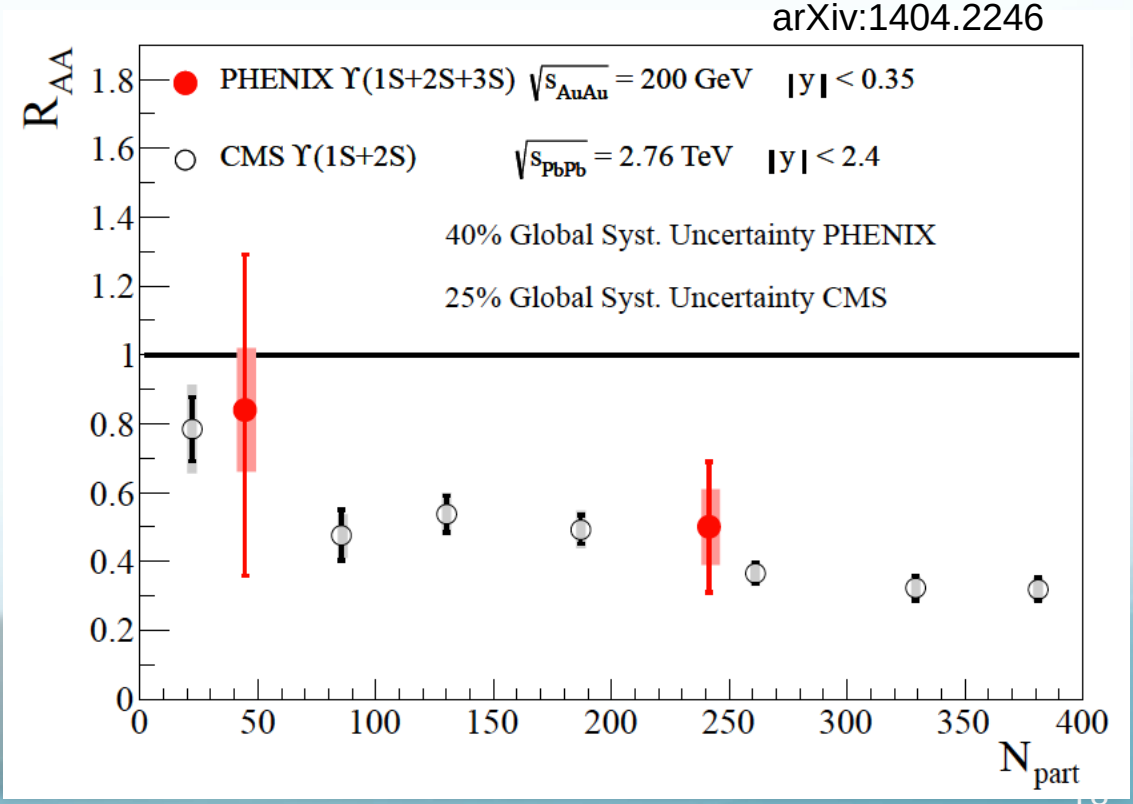


Figure 3: Double ratio (ratio of ratios in PbPb to pp) of $\psi(2S)$ and J/ψ as a function of centrality measured by CMS in two kinematic regions [19].

Upsilon Au-Au

- R_{AA} ~0.65 if no 2S, 3S
- R_{AA} ~0.37 if no 2S, 3S, χ_B
- PHENIX consistent with 2S, 3S states both melt, if no other suppression effects

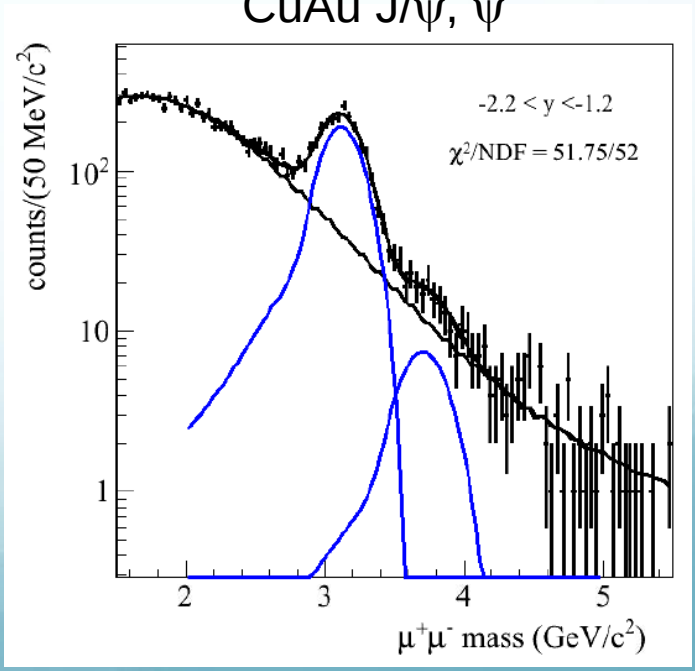
arXiv:1404.2246



What's Next at PHENIX?

- J/ψ:ψ' ratio in CuAu and AuAu at forward rapidity – will we see any ψ'?
- J/ψ:ψ' ratio in p+A at forward and backward rapidity – will it follow same $dN_{ch}/d\eta$ trend?
- J/ψ:ψ' ratio versus multiplicity
- Higher precision open heavy flavor, B/D separation

CuAu J/ψ, ψ'



Summary

- Significant suppression of J/ψ in d-Au; x_2 dependence → suppression not from gluon shadowing
- Extrapolation to heavy ion similar to what is measured except perhaps central AuAu → what might QGP suppression be? Can we reduce extrapolation errors?
- ψ' suppressed beyond J/ψ in d+Au, proportional to $dN_{ch}/d\eta$ independent of energy→co-mover type effect, not nuclear medium?
- J/ψ suppression in heavy ion: similar N_{part} trend across energies, system-size until LHC where suppression is reduced →recombination?
- How much of J/ψ suppression might be due to QGP effects? Does ψ' survive in heavy ion collisions at RHIC?