sPHENIX Heavy Flavor

Xiaochun He
Georgia State University

July 30, 2013

Quarkonia

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A fundamental problem

- QCD is a successful theory to describe strong interaction, but its fundamental ingredients, the quarks and gluons, are not observed freely and must hadronize eventually. This fact makes it impossible to calculate any processes involving detected hadrons in the final to initial state directly. Therefore, a suitable factorization scheme to divide problems into perturbative calculable and nonperturbative parts is very important.
- QCD in vacuum - baseline measurement (p+p collisions)
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Systematic measurements of heavy flavors come to rescue !!!

A 27-year-young theory

Quarkonia melt in QGP - Matsui & Satz 1986.

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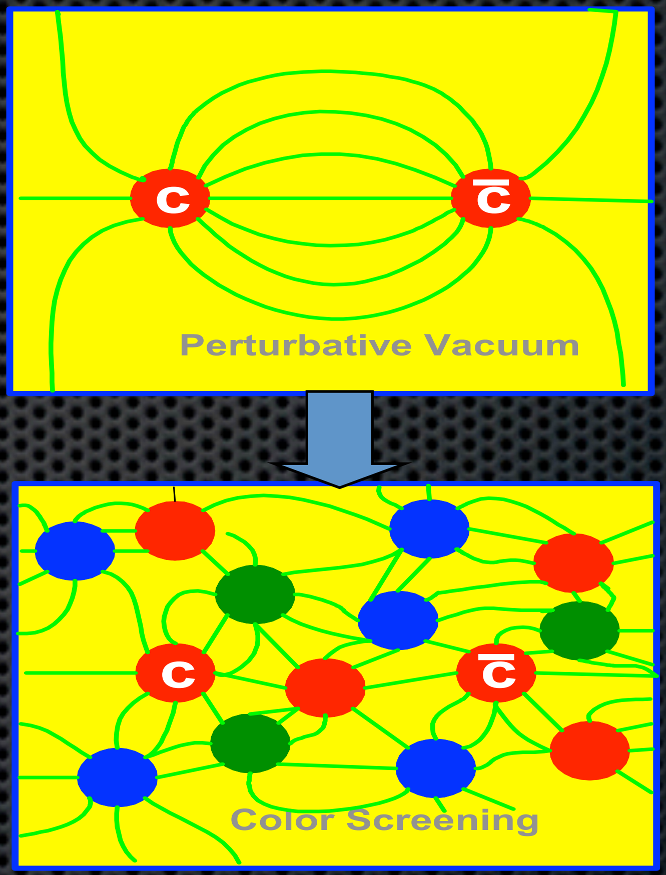
" ... If high energy heavy ion collisions lead to the formation of a hot quark-gluon plasma, then color screening prevents c-cbar binding in the deconfined interior of the interaction region ... It is concluded that J/Ψ suppression in nuclear collisions should provide an unambiguous signature of quark-gluon plasma formation."

Melting quarkonia

- Binging of a q-qbar pair is subject to color screening in QGP
- Temperature of QGP can be probed by measurement of heavy quarkonia
- Each quarkonium has different binding radius

state	J/ψ	χ_c	Ψ'	Υ_{1S}	Υ_{2S}	Υ_{3S}
mass [GeV]	3.10	3.53	3.68	9.46	10.02	10.36
radius [fm]	0.25	0.36	0.45	0.14	0.28	0.39



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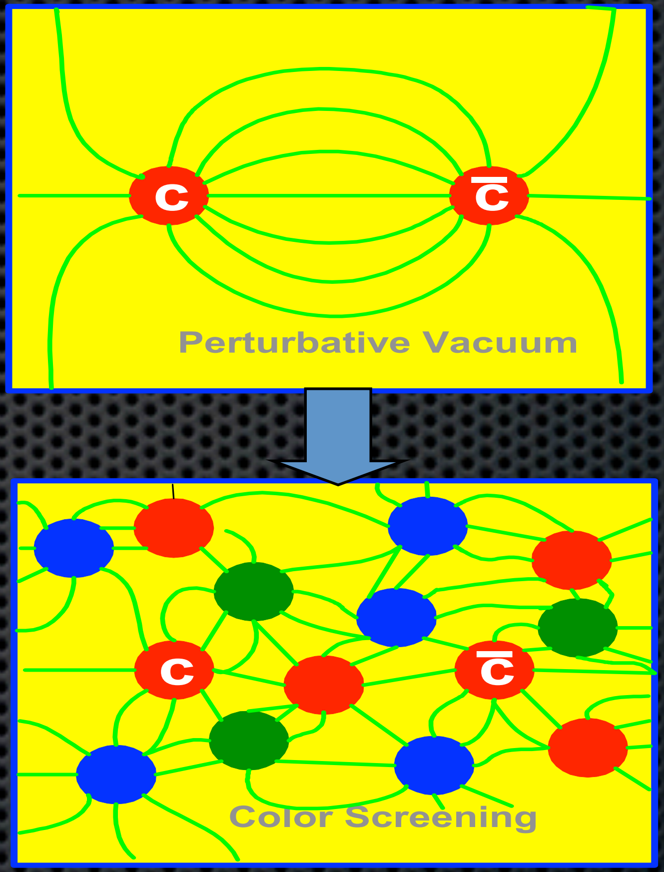

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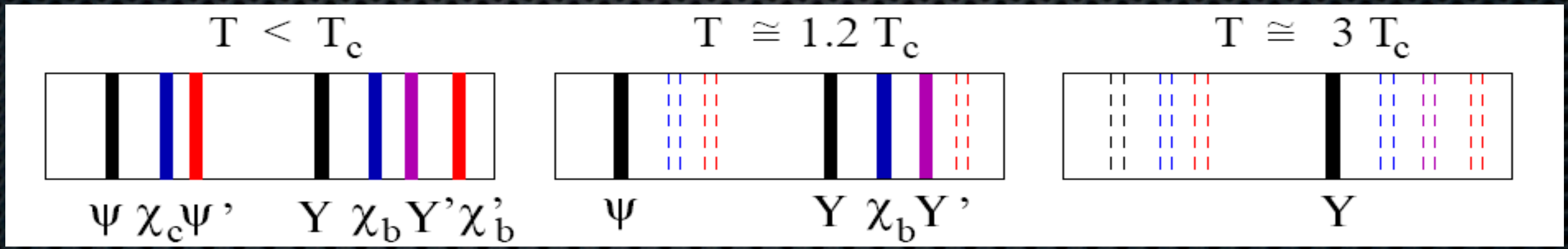
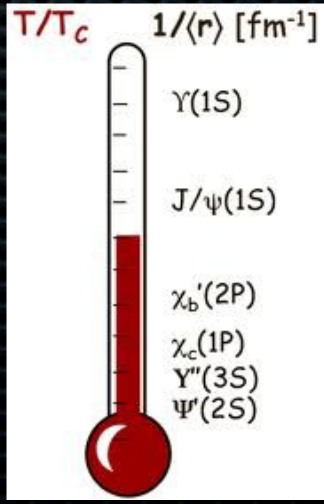




Disentangle the interplay among the competing effects on quarkonia production

Disentangle the interplay among the competing effects on quarkonia production

- Quarkonium production mechanism is not well understood:
  - Color-singlet vs color-octet?
- Observed yields are a mixture of direct production and feedown:
  - E.g. J/psi ~ 0.6 J/psi (direct) + 0.1 psi' + 0.3 chi_c
- Cold nuclear effects: nuclear absorption, gluon shadowing, initial state energy loss, Cronin effect and gluon saturation.
- Hot/dense medium effect: recombination of uncorrelated charm pairs.

RHIC run summary

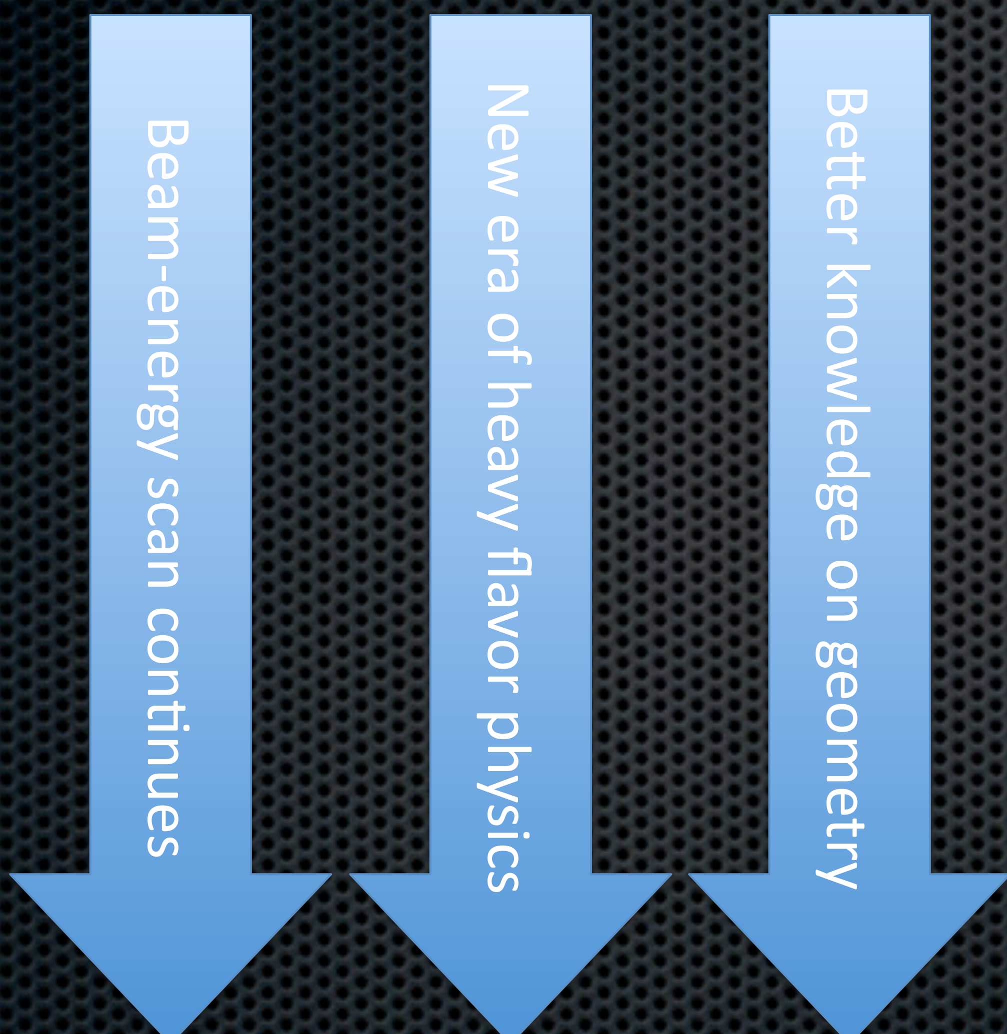
- RHIC has run with many colliding species which range from p+p, d+Au, Au+Au, Cu+Cu, Cu+Au and U+U.
- RHIC has run at variety center of mass energies.
- RHIC beam scan has started and will continue for years to come.

RHIC-Run	Year	Species	Energy	Ldt
Run-1	2000	Au+Au	130 GeV	1 μb^{-1}
Run-2	2001/2	Au+Au	200 GeV	24 μb^{-1}
		p+p	200 GeV	150 nb^{-1}
Run-3	2002/3	d+Au	200 GeV	2.74 nb^{-1}
		p+p	200 GeV	0.35 nb^{-1}
Run-4	2003/4	Au+Au	200 GeV	241 μb^{-1}
		Au+Au	62.4 GeV	9 μb^{-1}
Run-5	2005	Cu+Cu	200 GeV	3 nb^{-1}
		Cu+Cu	62.4 GeV	0.19 nb^{-1}
		Cu+Cu	22.4 GeV	2.7 μb^{-1}
Run-6	2006	p+p	200 GeV	10.7 pb^{-1}
		p+p	62.4 GeV	100 nb^{-1}
Run-7	2007	Au+Au	200 GeV	813 μb^{-1}
Run-8	2007/8	d+Au	200 GeV	80 nb^{-1}
		p+p	200 GeV	5.2 pb^{-1}
Run-9	2009	p+p	200 GeV	16 pb^{-1}
		p+p	500 GeV	14 pb^{-1}
Run-10	2010	Au+Au	200 GeV	1.3 nb^{-1}
		Au+Au	62.4 GeV	100 μb^{-1}
		Au+Au	39 GeV	40 μb^{-1}
		Au+Au	7.7 GeV	260 mb^{-1}
Run-11	2011	p+p	500 GeV	27 pb^{-1}
		Au+Au	200 GeV	915 μb^{-1}
		Au+Au	27 GeV	5.2 μb^{-1}
		Au+Au	19.6 GeV	13.7 M
Run-12	2012	p+p	200 GeV	9.2 pb^{-1}
		p+p	510 GeV	30 pb^{-1}
		U+U	193 GeV	171 μb^{-1}
		Cu+Au	200 GeV	4.96 nb^{-1}

Run-13 p+p at 500 GeV completed a few months ago

RHIC run summary

Discovery and Diagnostic Period



Medium Characterization Started

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Yield in nucleus-nucleus collisions divided by p+p yield and scaled by the appropriate number of binary collisions N_{coll}, which is calculated using Glauber model.

$$R_{AA} = \frac{dN_{AA}^{J/\psi}/dy}{N_{coll}\, dN_{pp}^{J/\psi}/dy}$$

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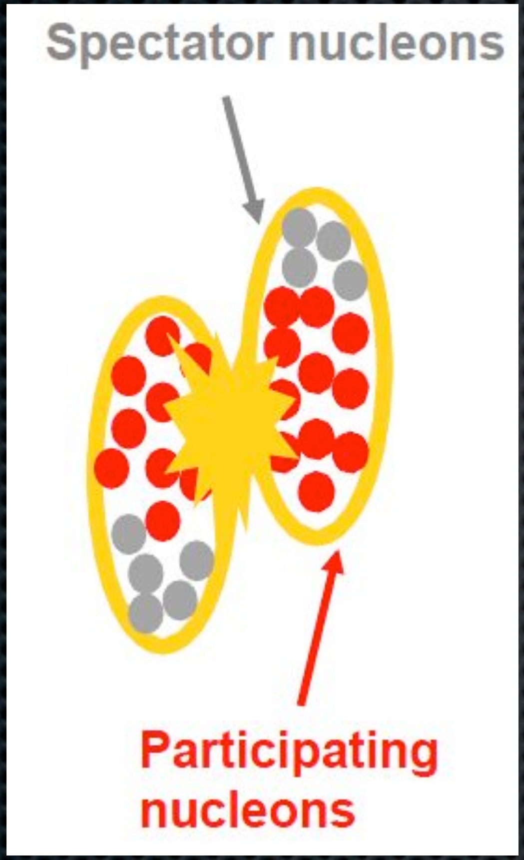
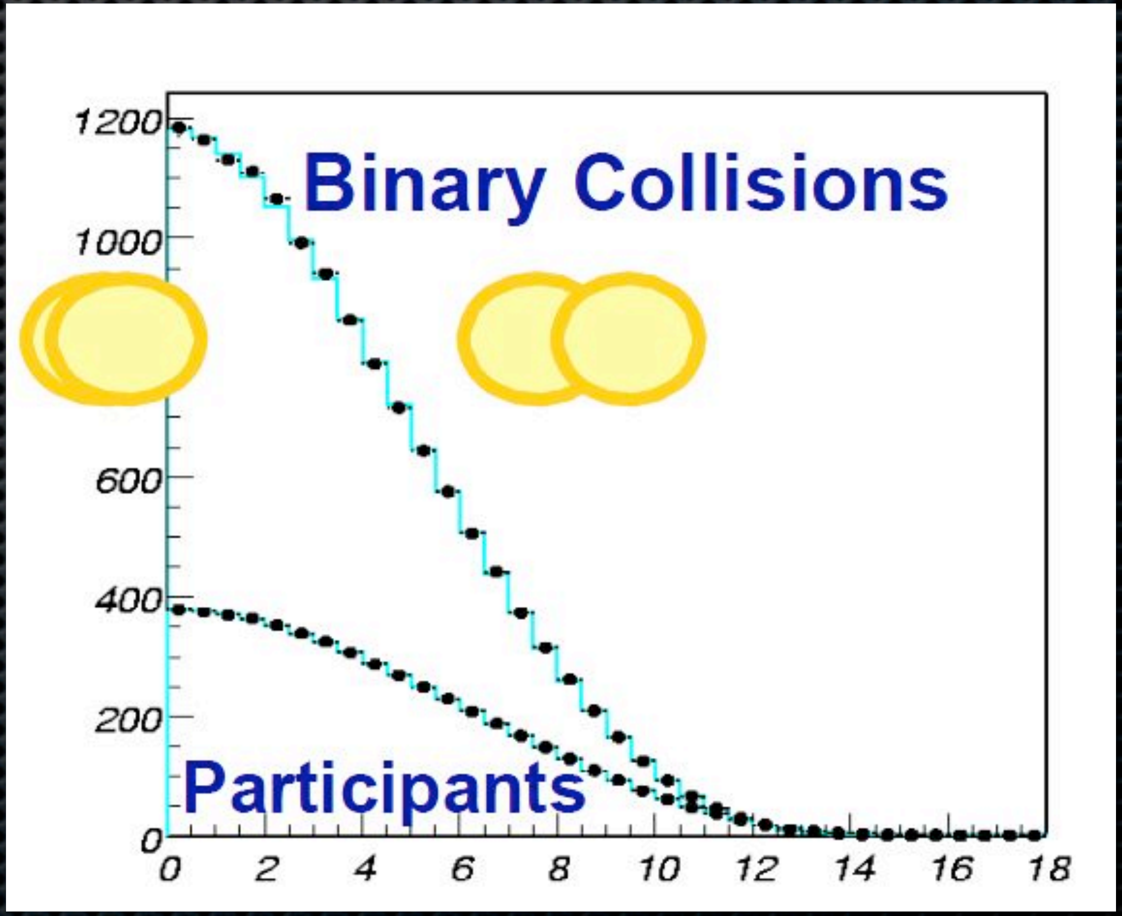


Centrality of collision is described by number of participant nucleons, N_{part}.



Impact parameter [fm]

PHENIX Facts

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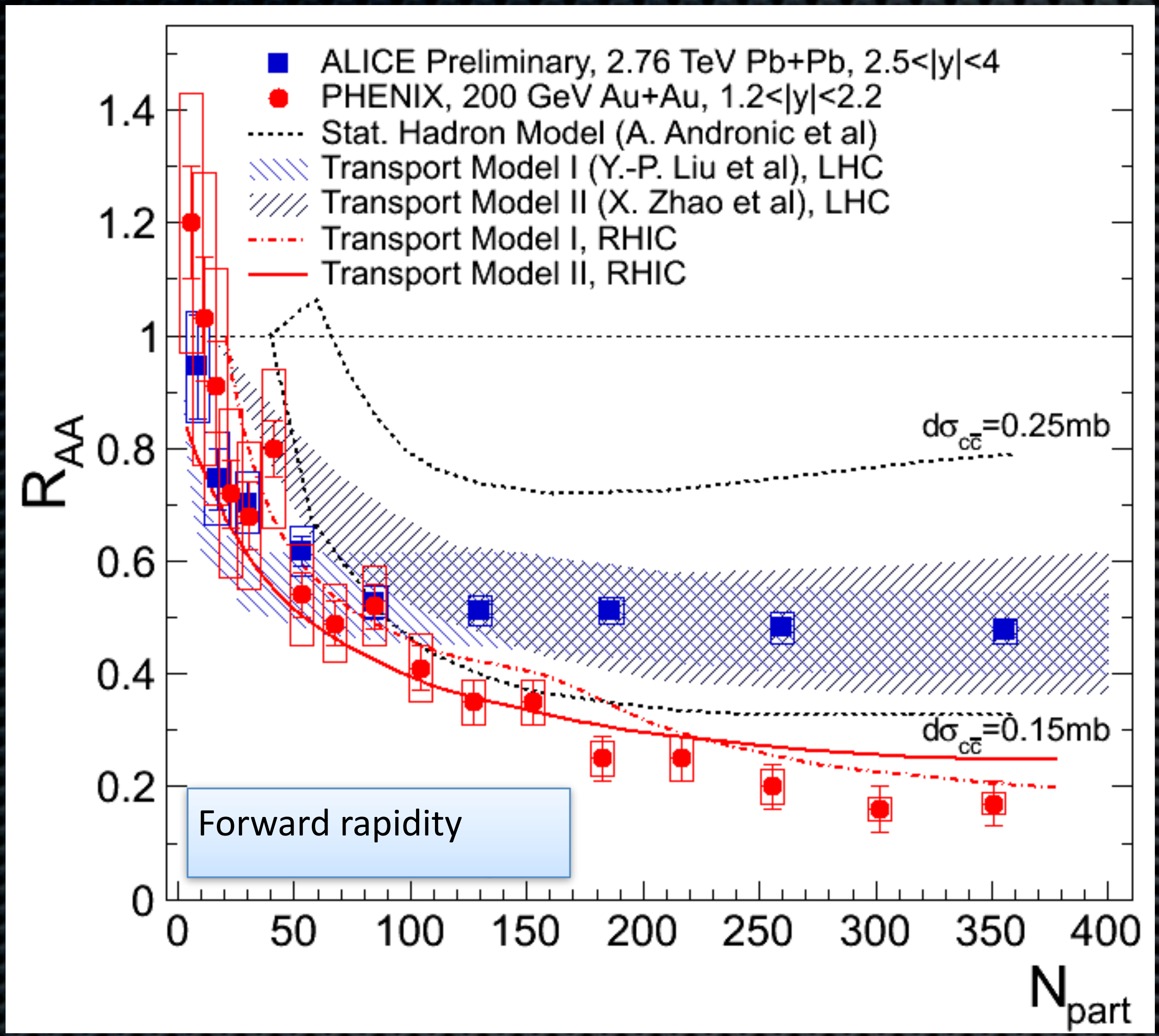
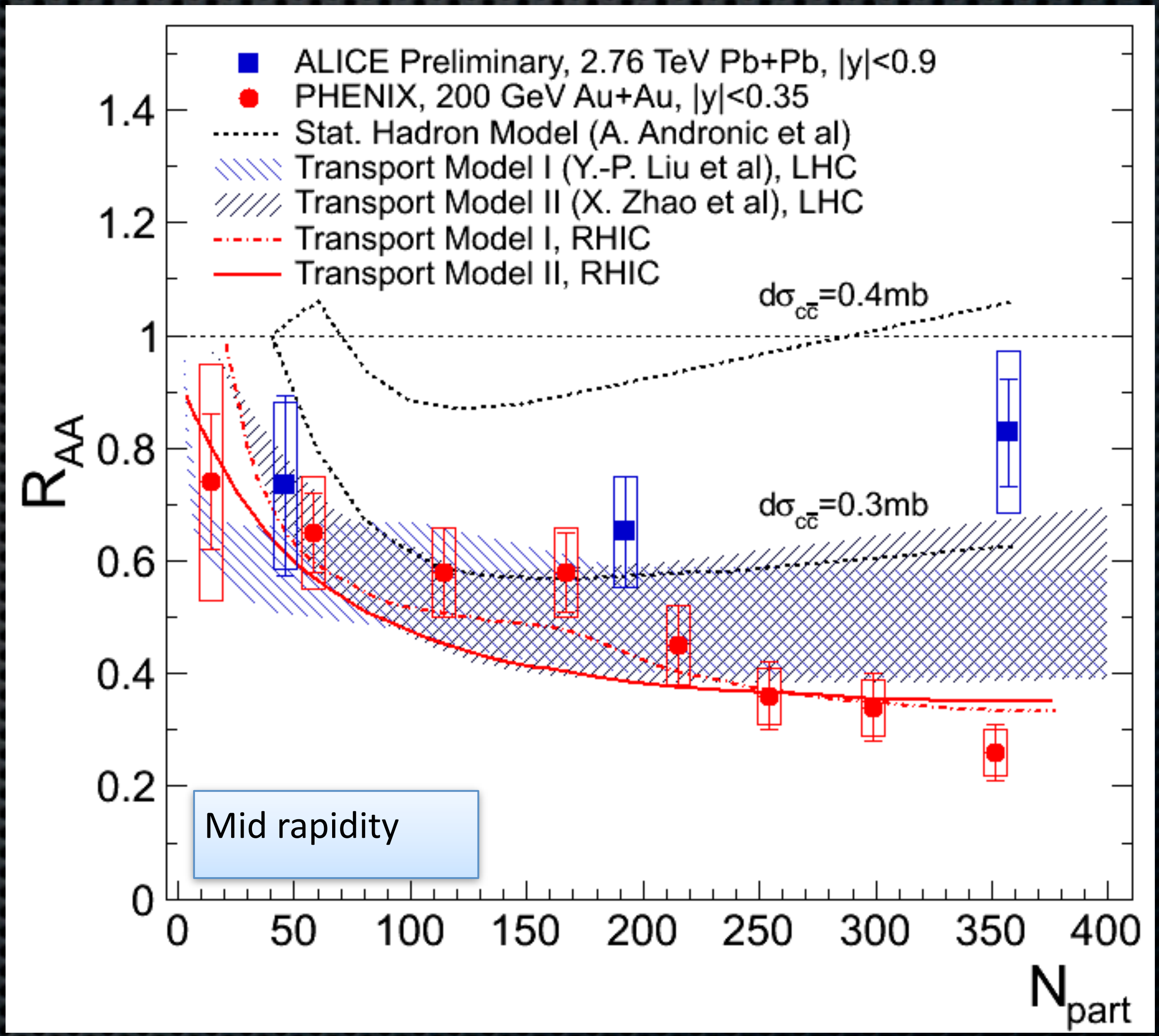
- The pending heavy flavor physics data analysis and publications. This will not change the landscape of our knowledge about heavy flavors significantly.
- The issues: lack of precision measurement. Most of our measurements are inclusive.

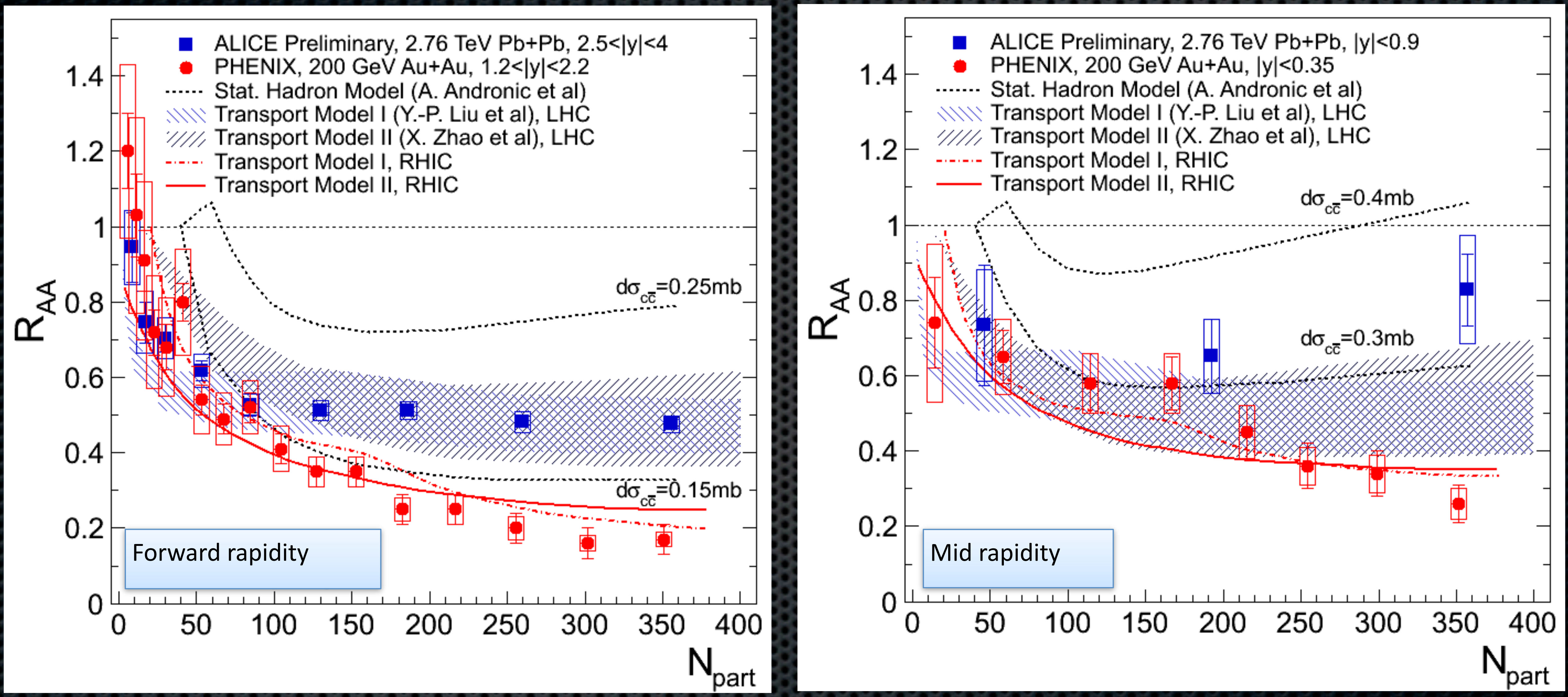
J/ψ Puzzles

J/ψ Production vs Centrality





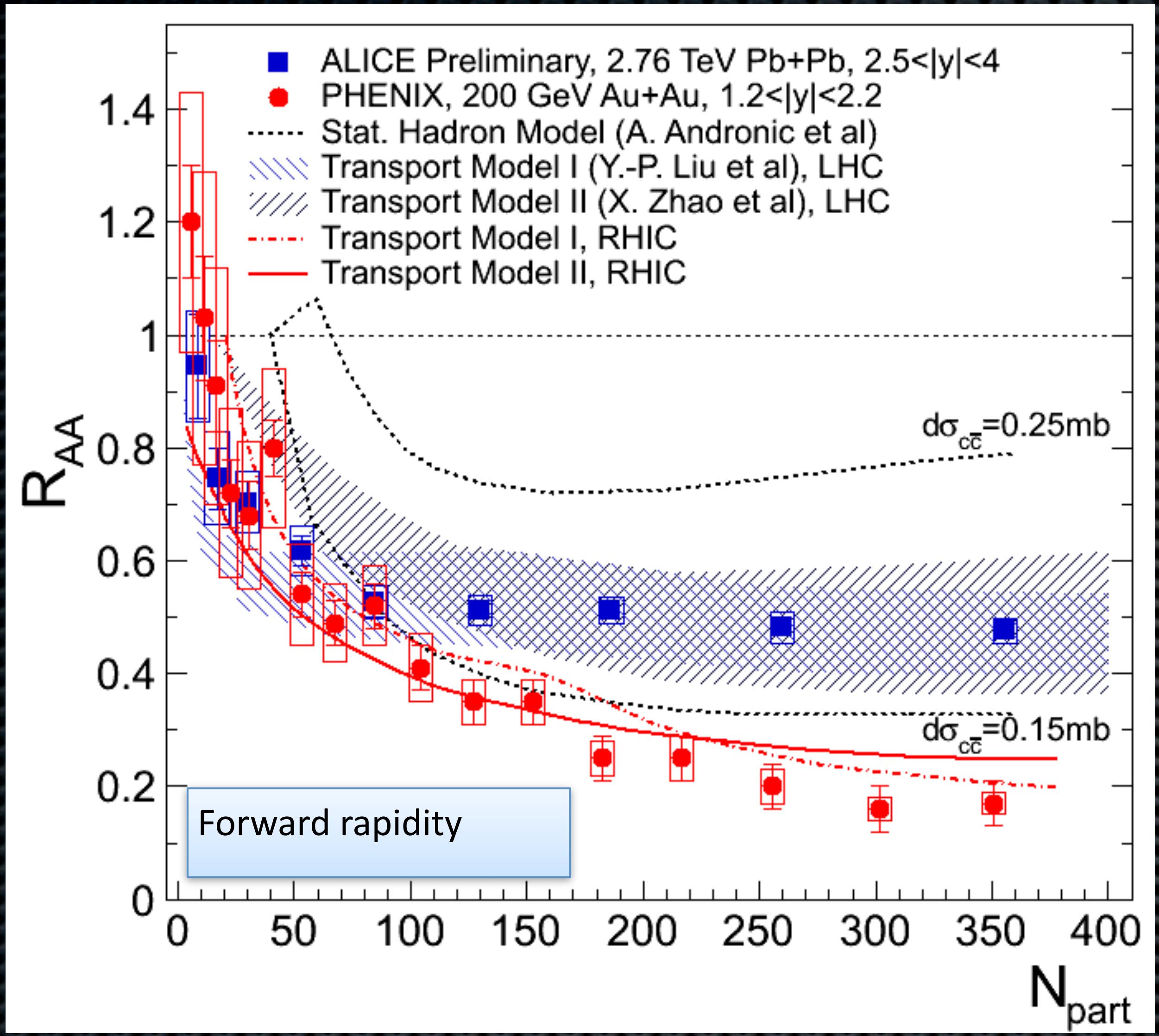
J/ψ Production vs Centrality

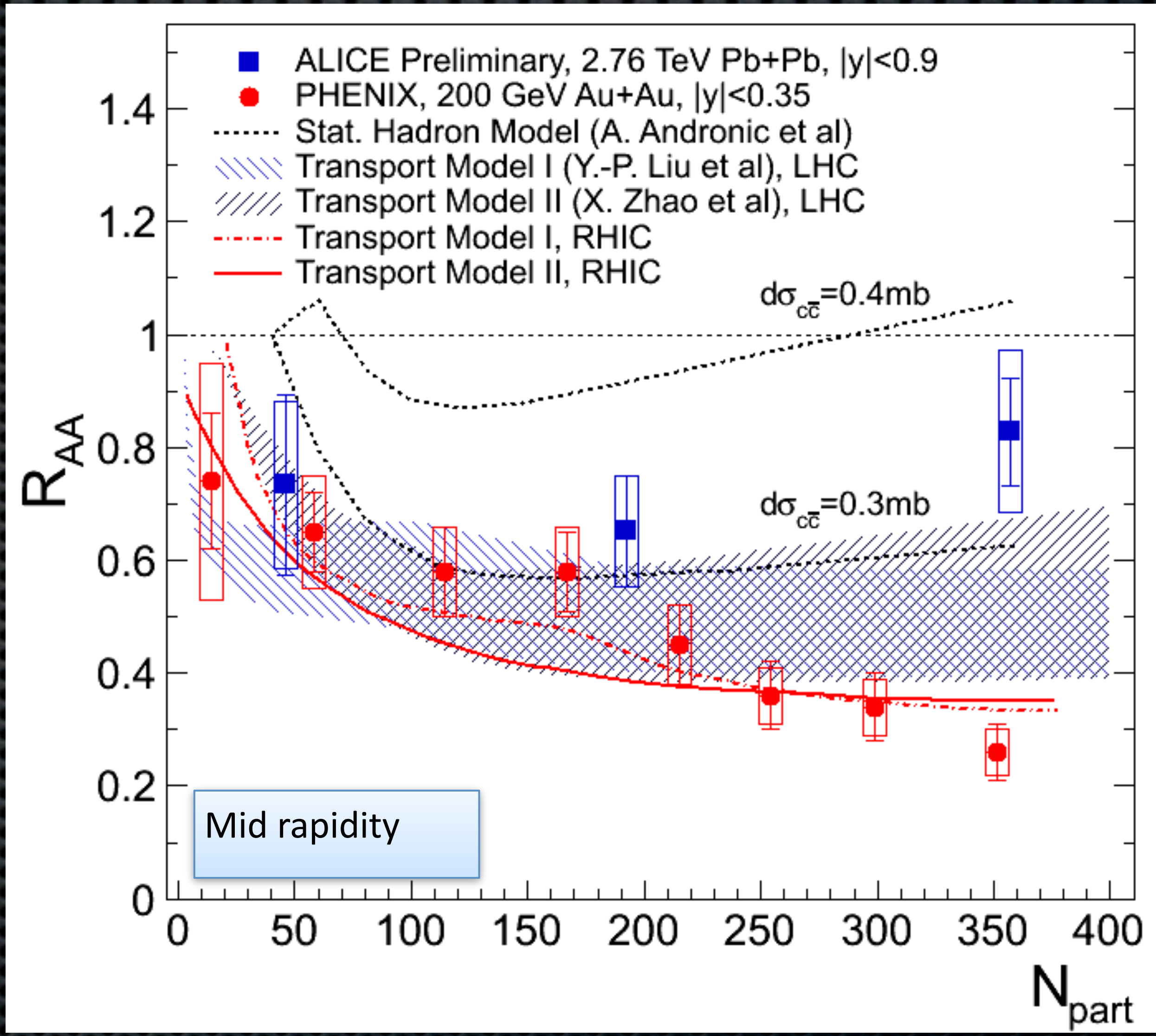


N_{part} dependence of J/ψ R_{AA}: less suppression at LHC compared to at RHIC in central collisions.

J/ψ Production vs Centrality

Puzzle #1





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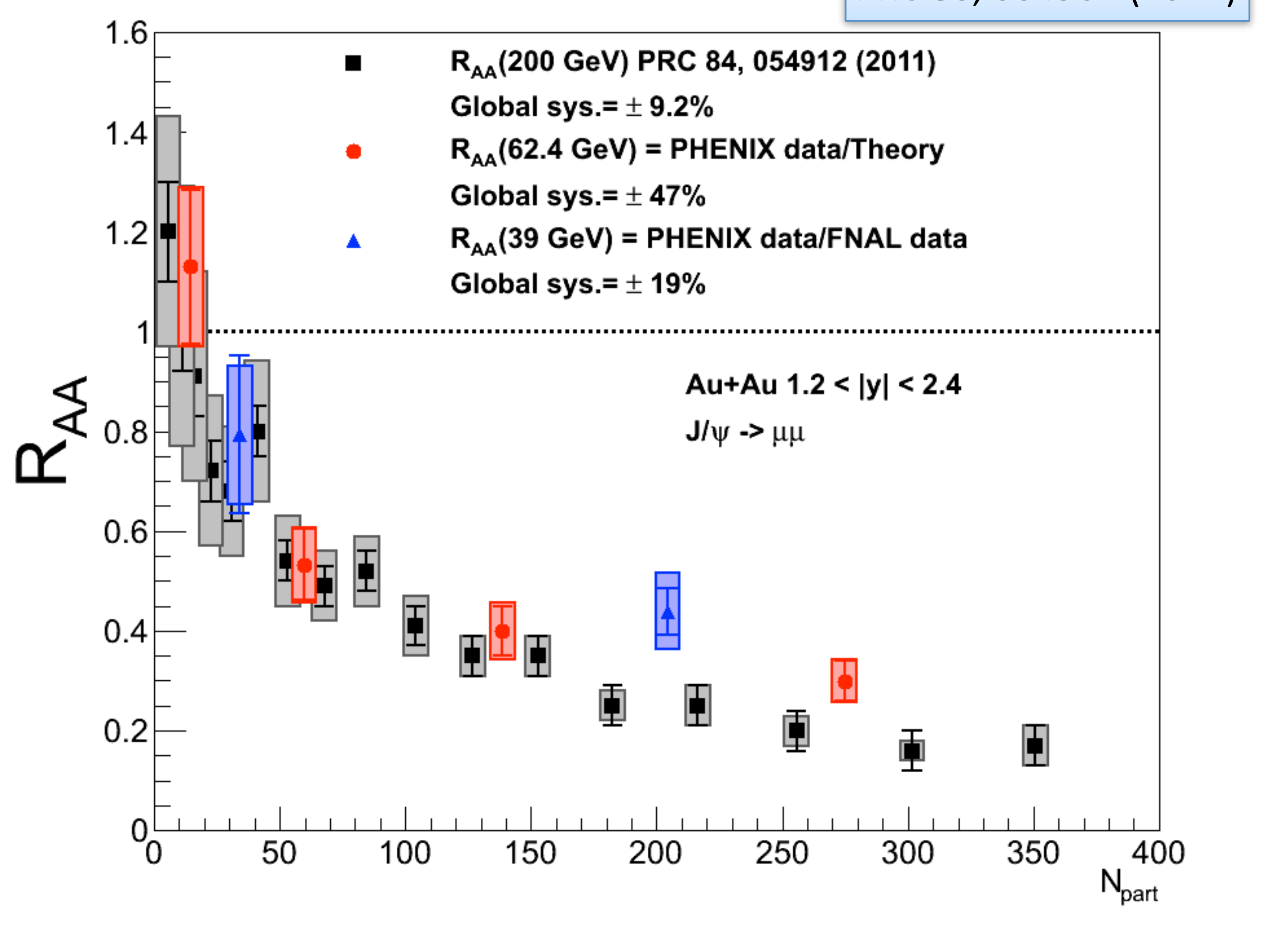
J/ψ Production vs Energy

PRC 86, 064901 (2012)



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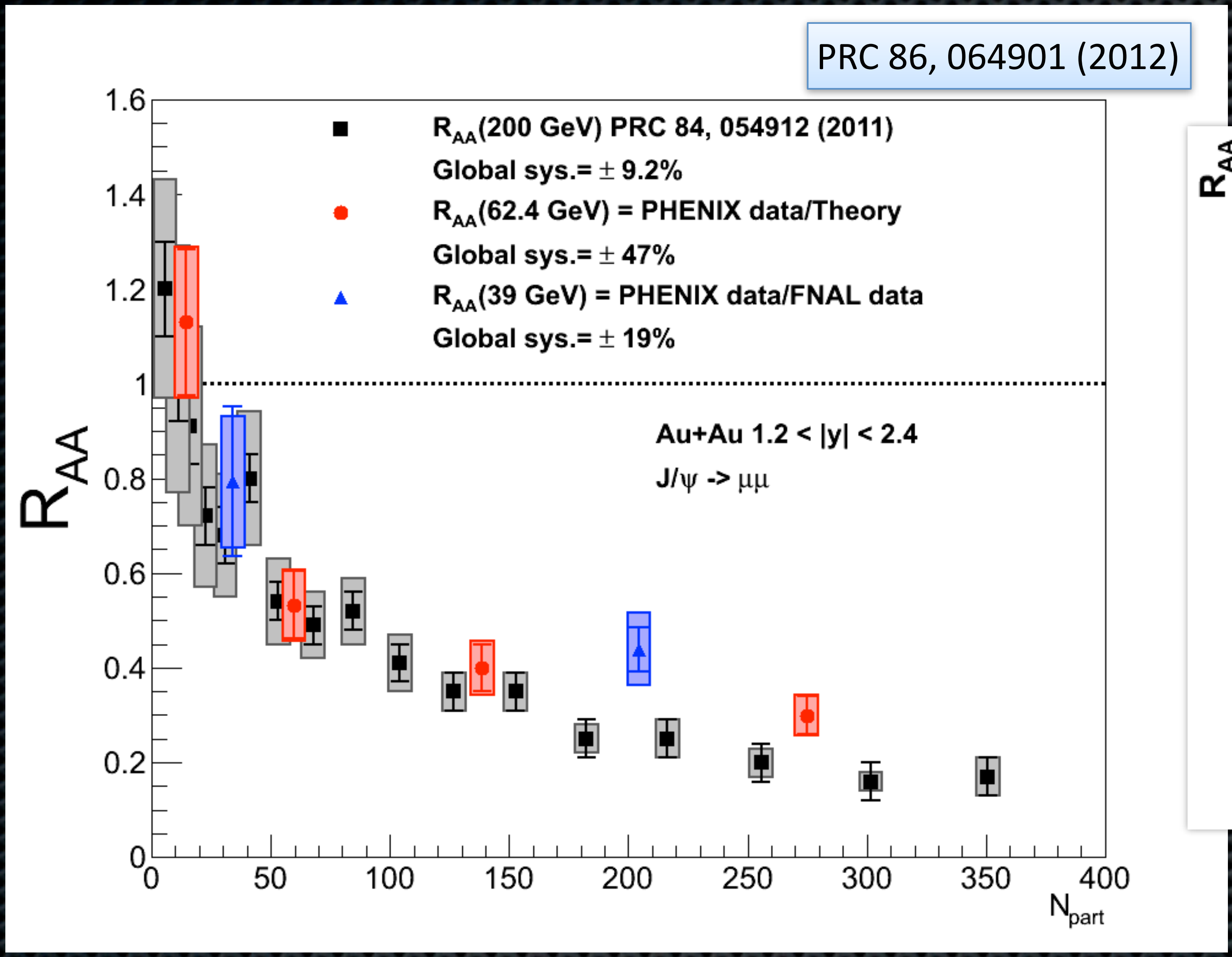

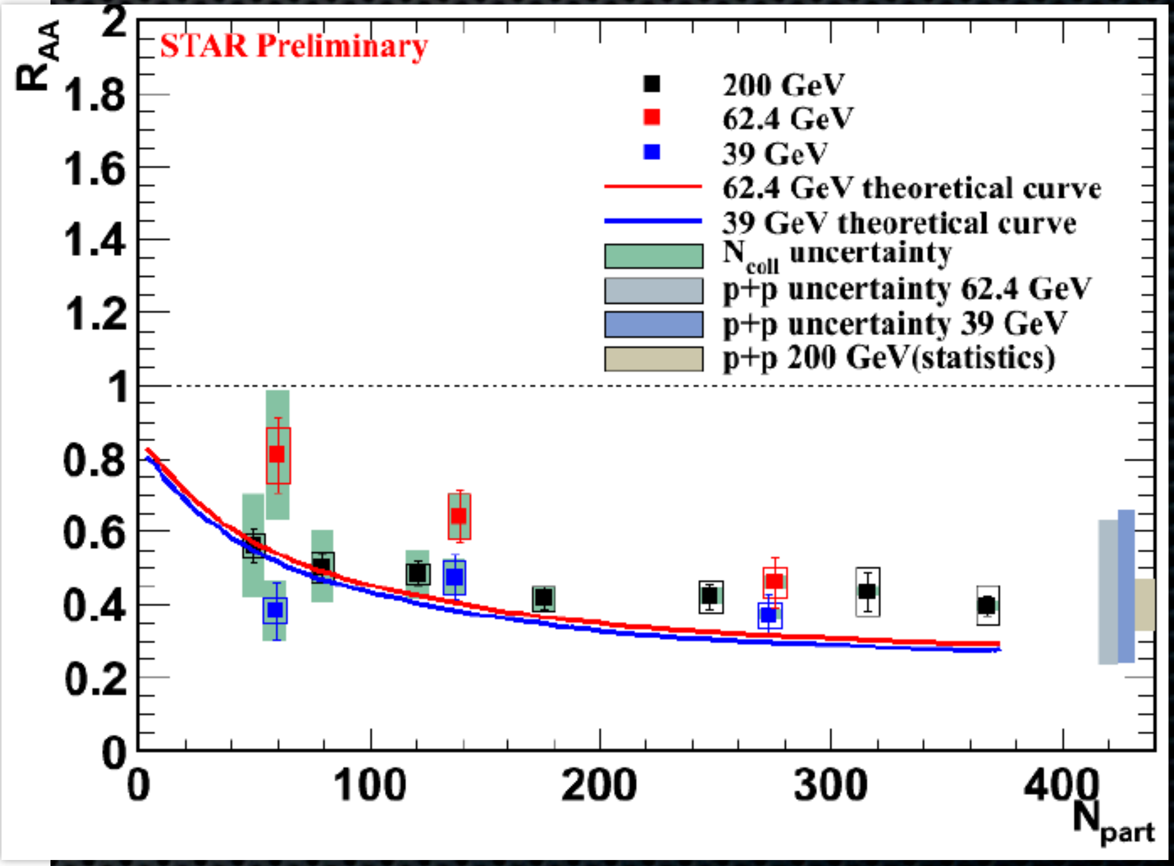

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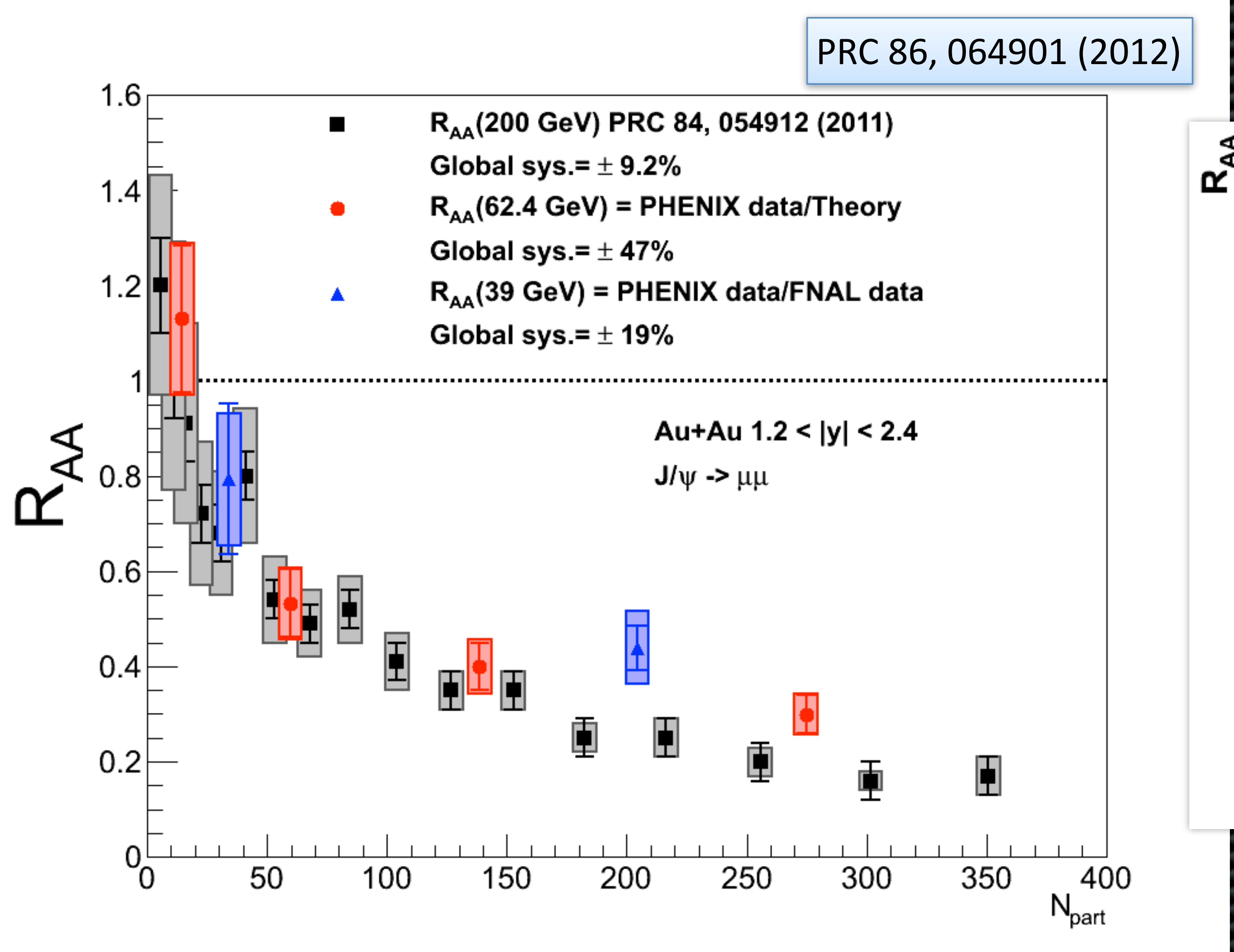
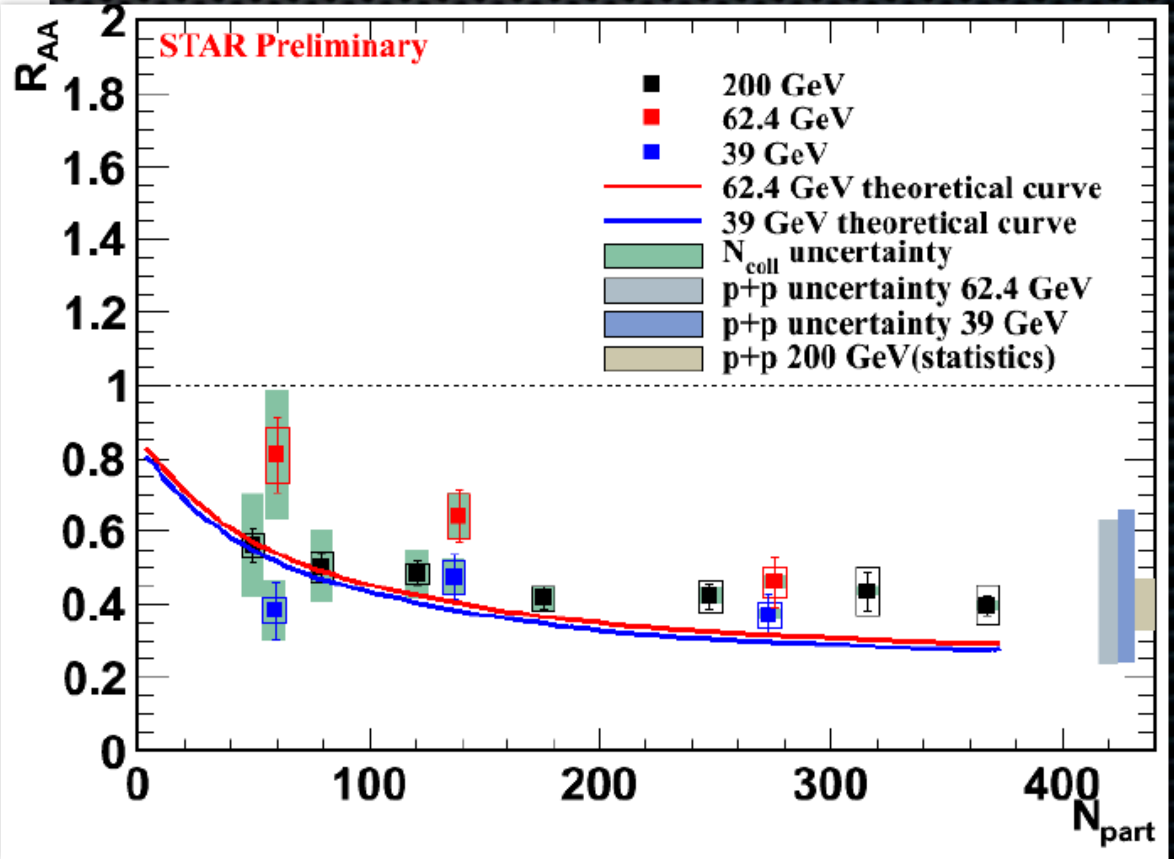
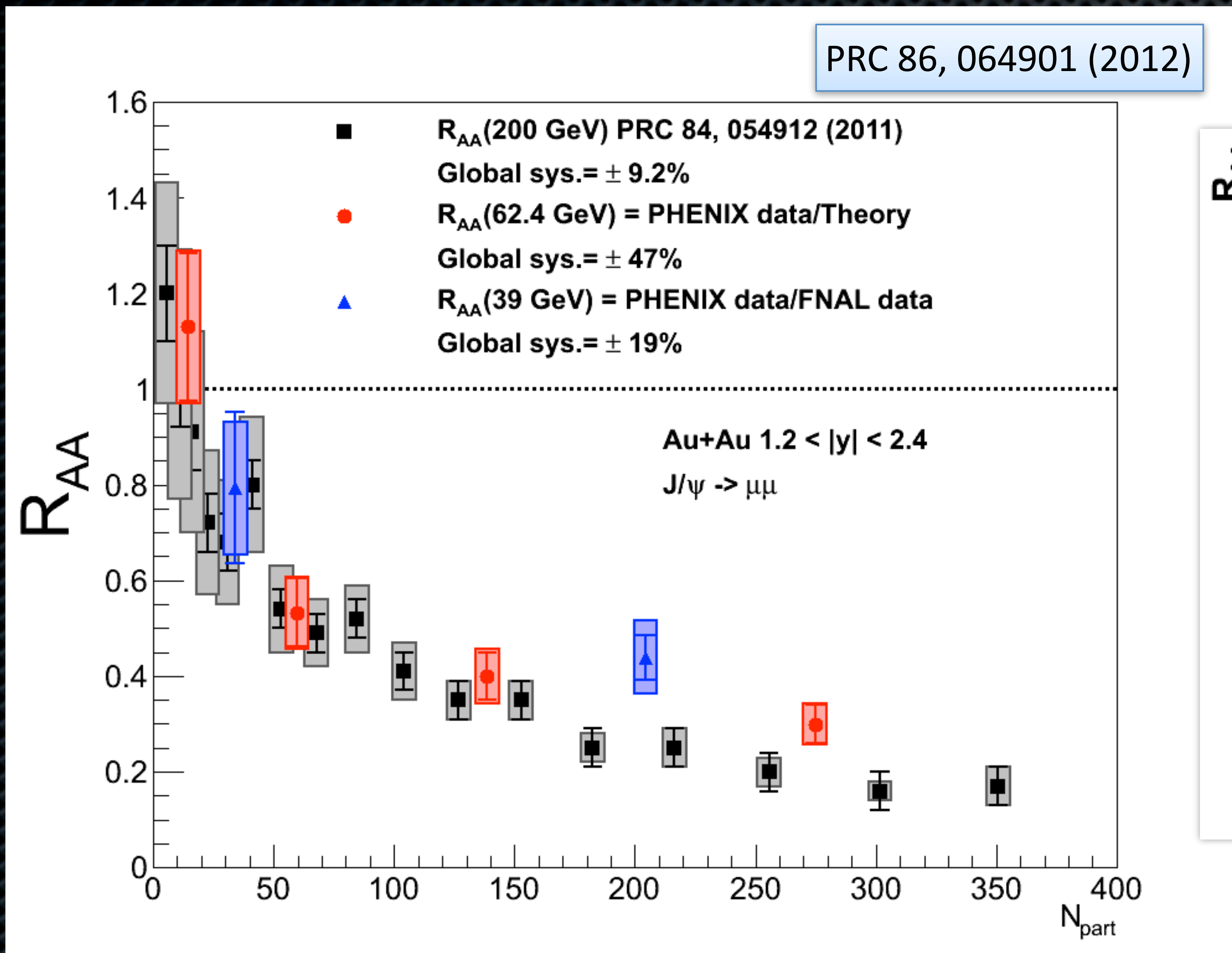


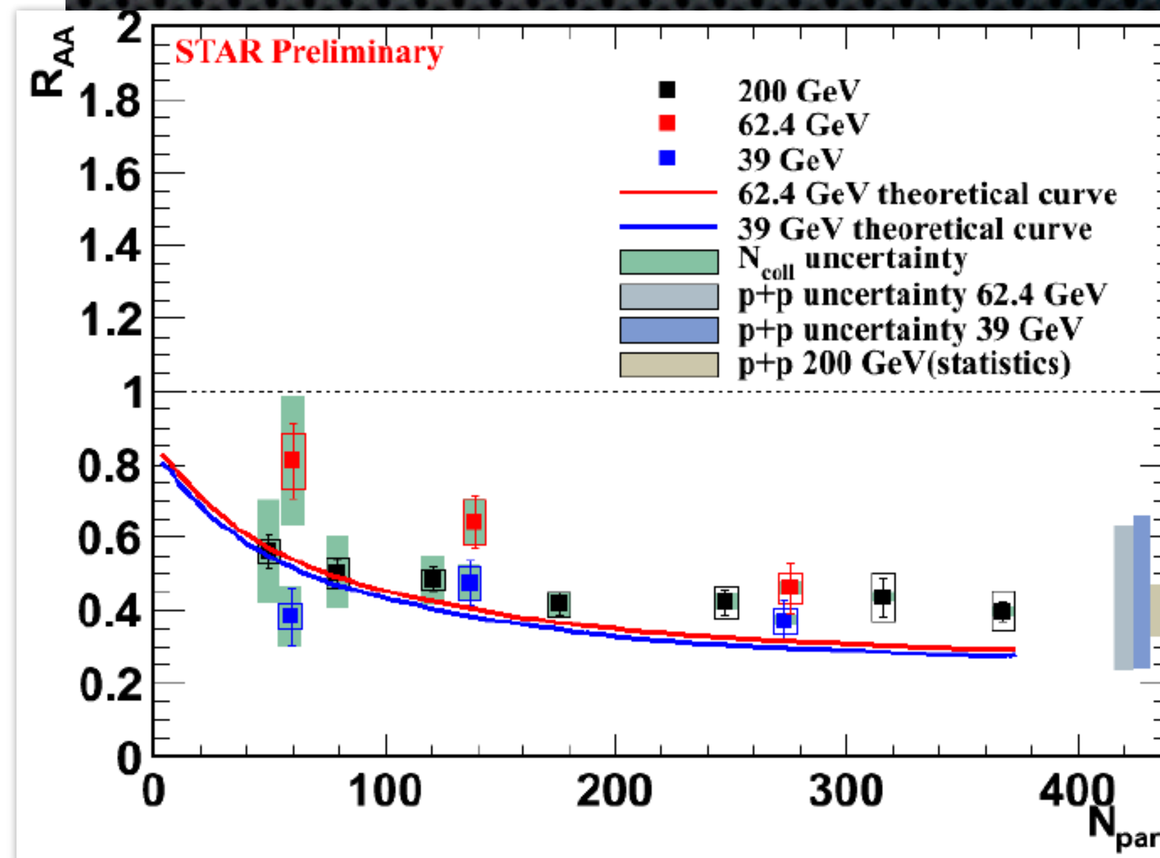


Similar suppression level !!! Still lack of baseline measurement at lower energies

J/ψ Production vs Energy

Puzzle #2





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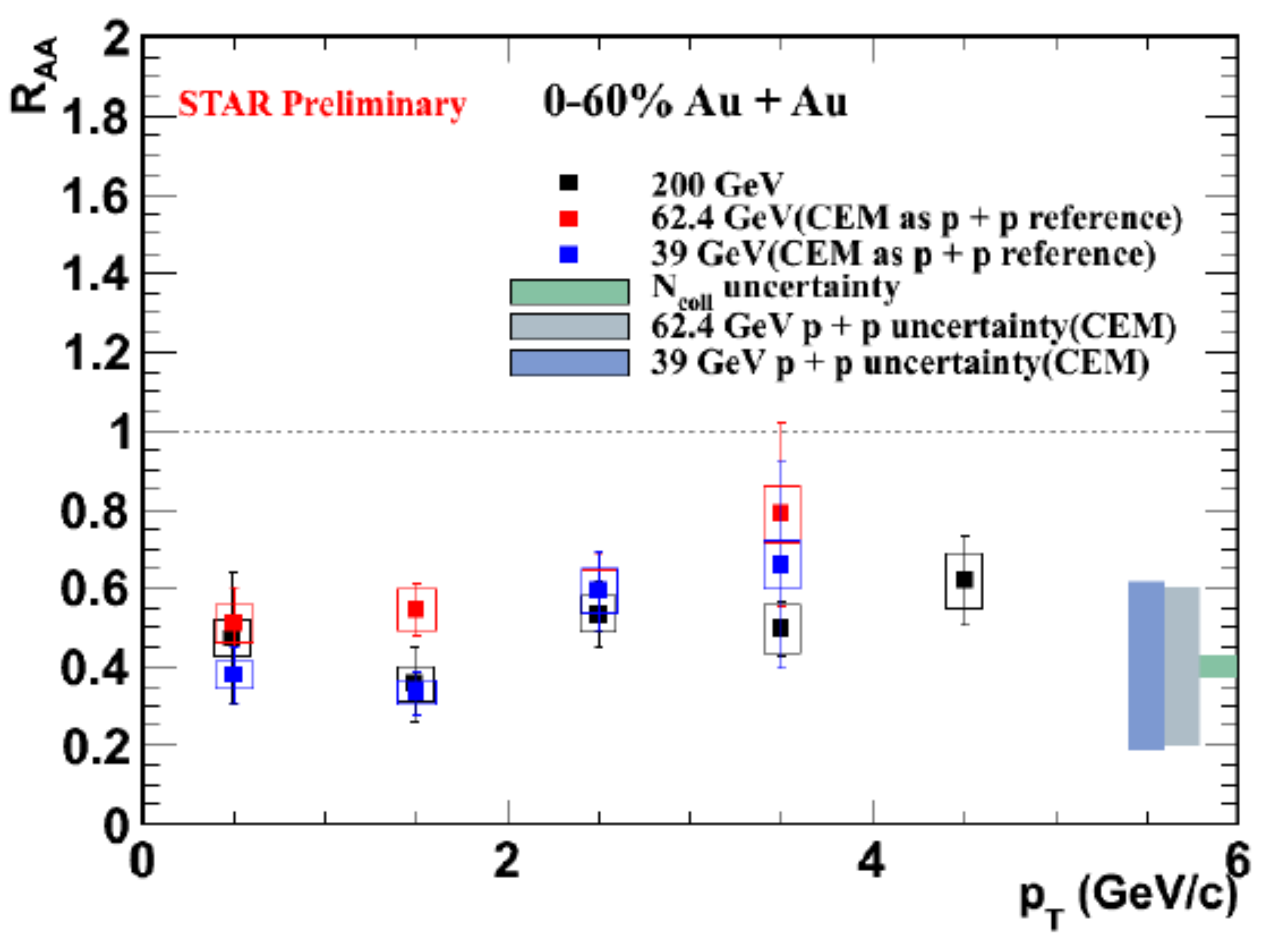
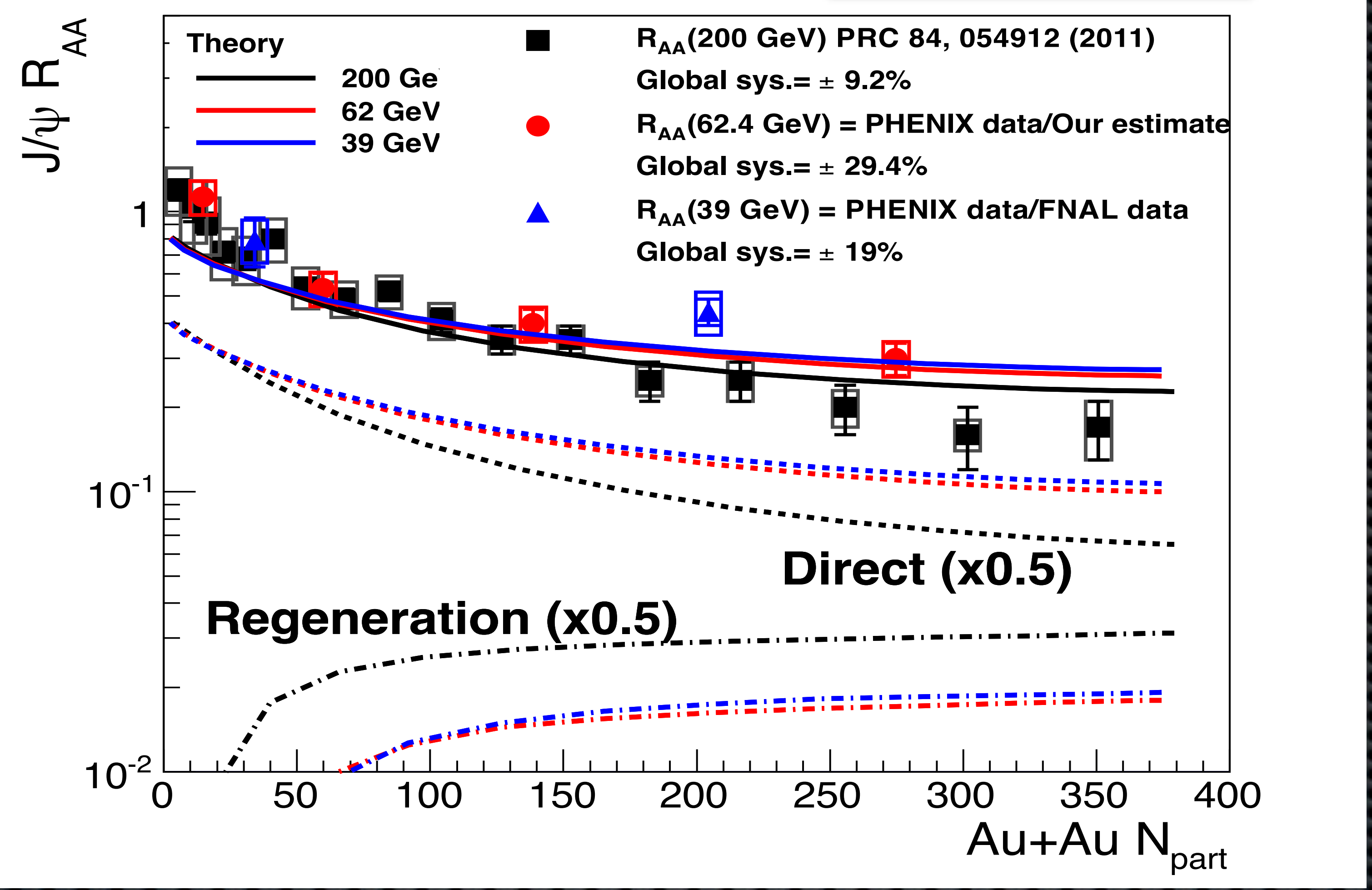
Another STAR Result



Stronger suppression at lower pT
No significant energy dependence

Theory Comparison

PRC 86, 064901 (2012)



Regeneration compensates for suppression in QGP. Calculations are done by X. Zhao and R. Rapp [Phys. Rev. C 82, 064905 (2010)].

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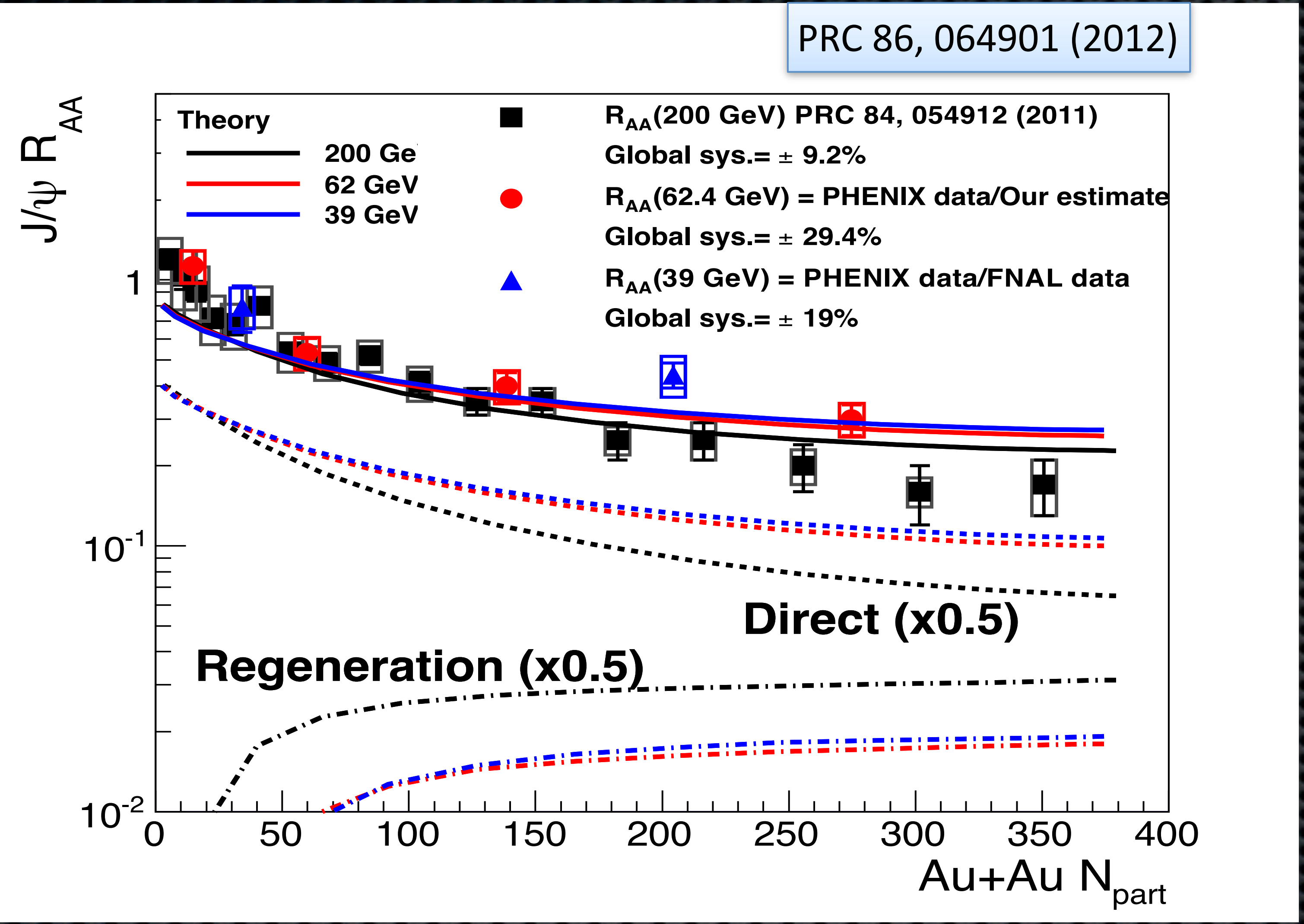

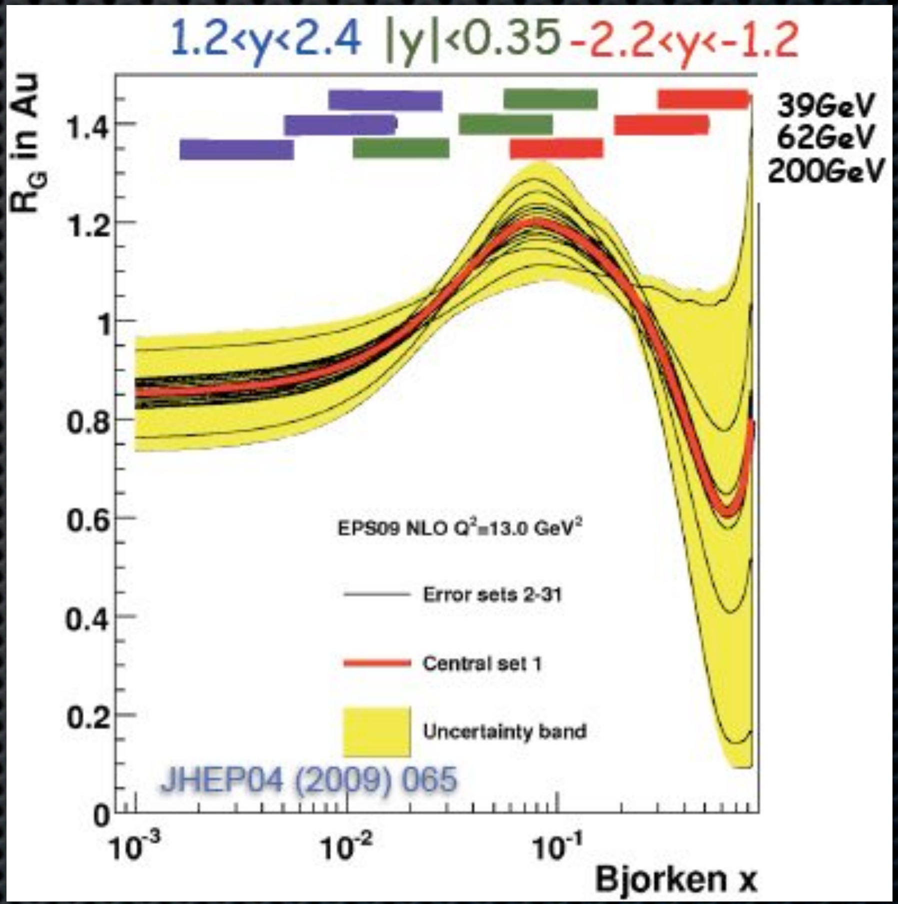

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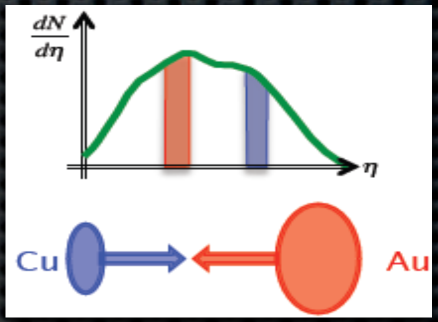
But cold nuclear matter effects should be different!

J/ψ Production vs Coll. Geom.

Controlled Geometry



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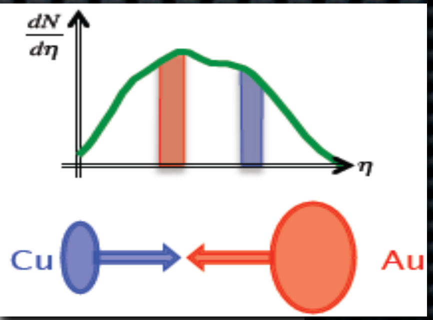
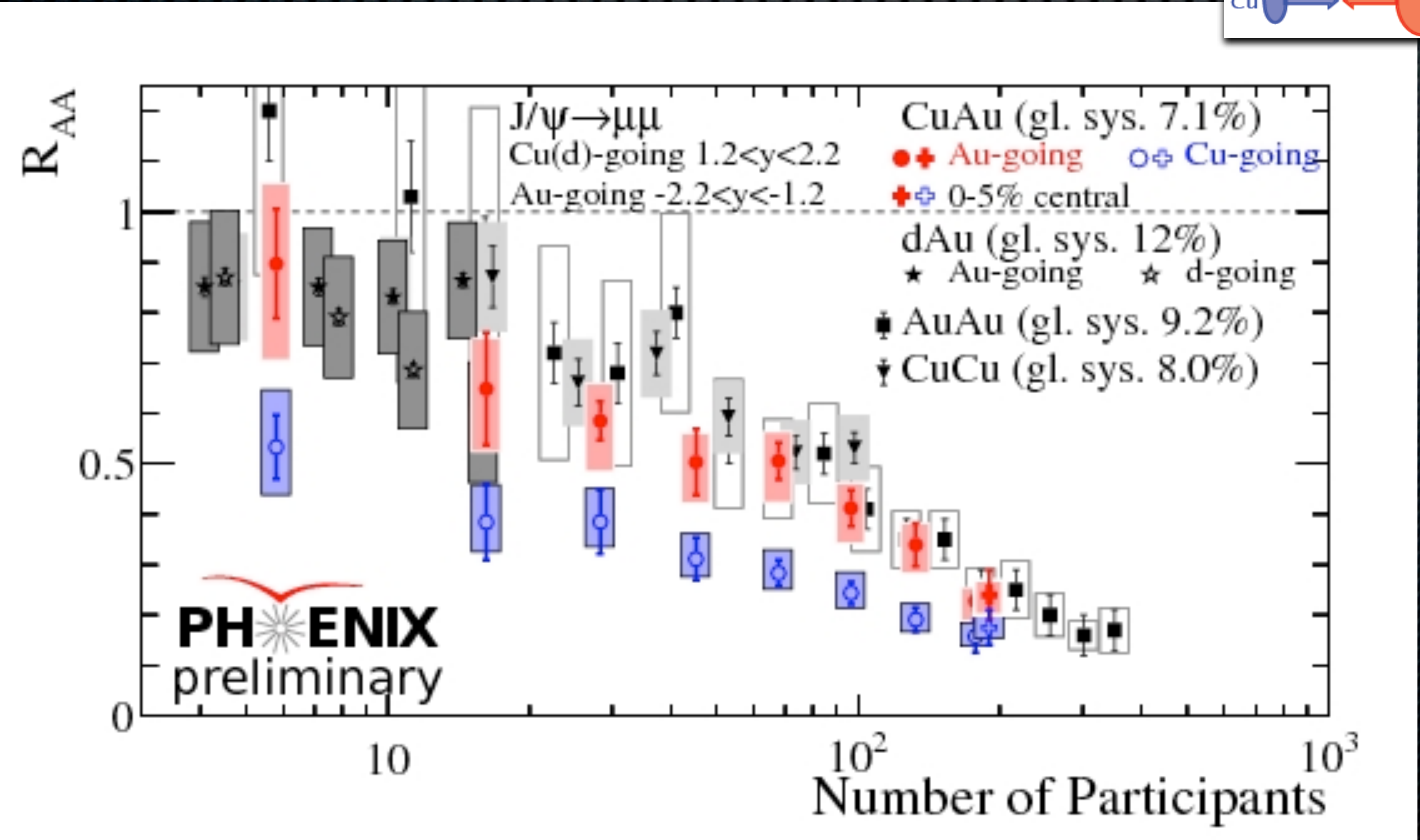
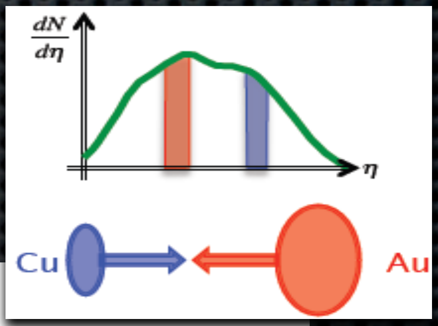
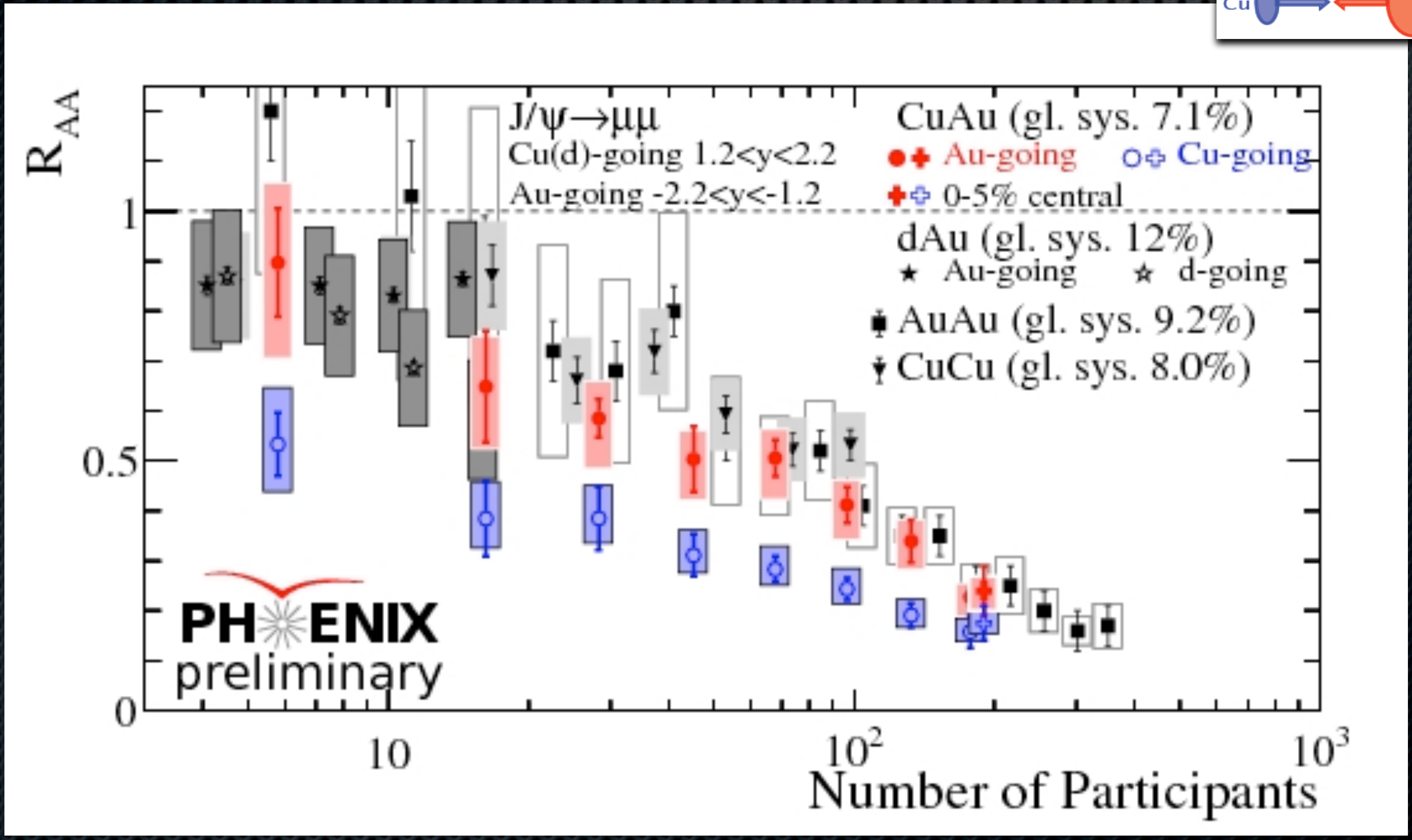




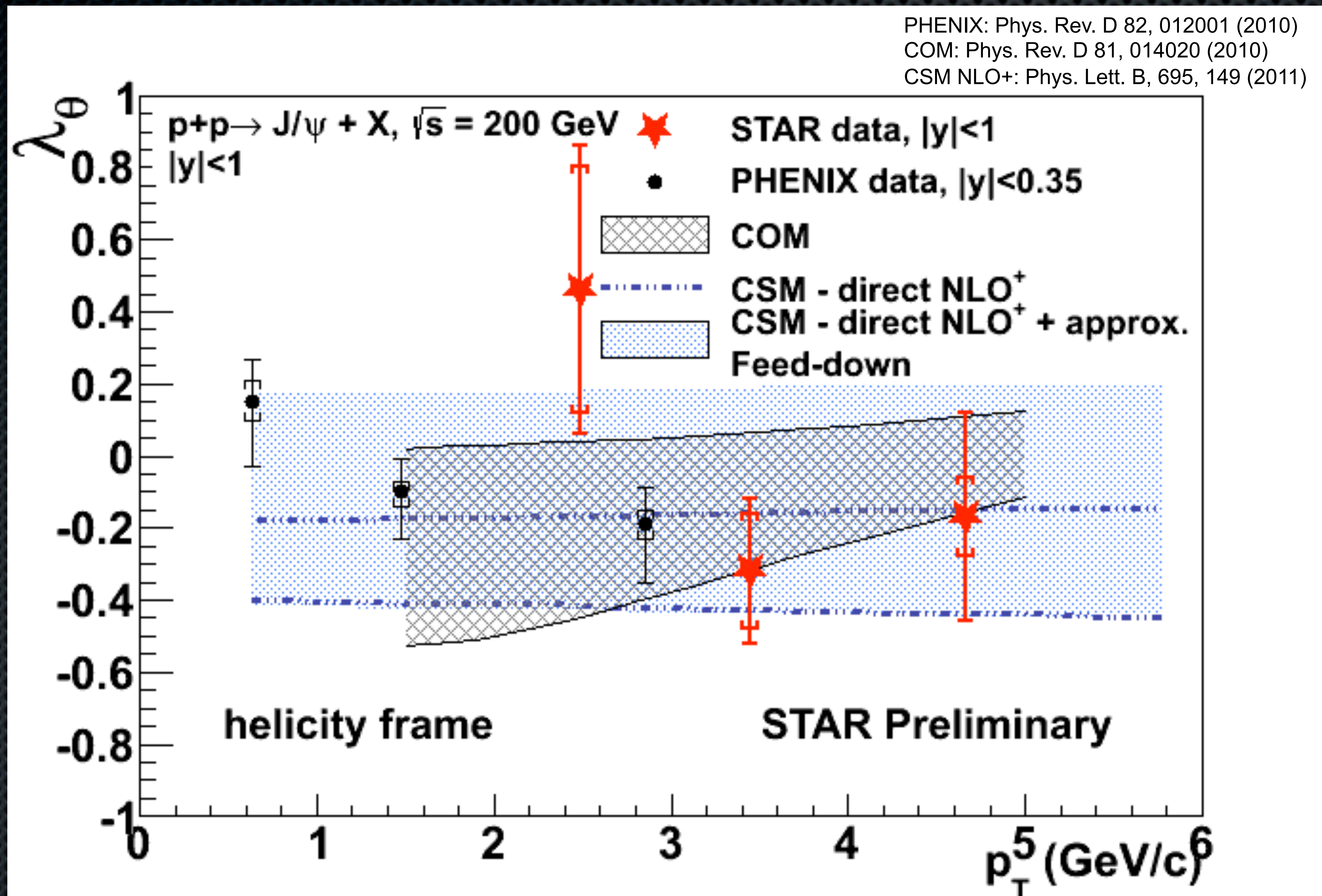
J/ψ Production vs Coll. Geom.

Puzzle #3 Controlled Geometry



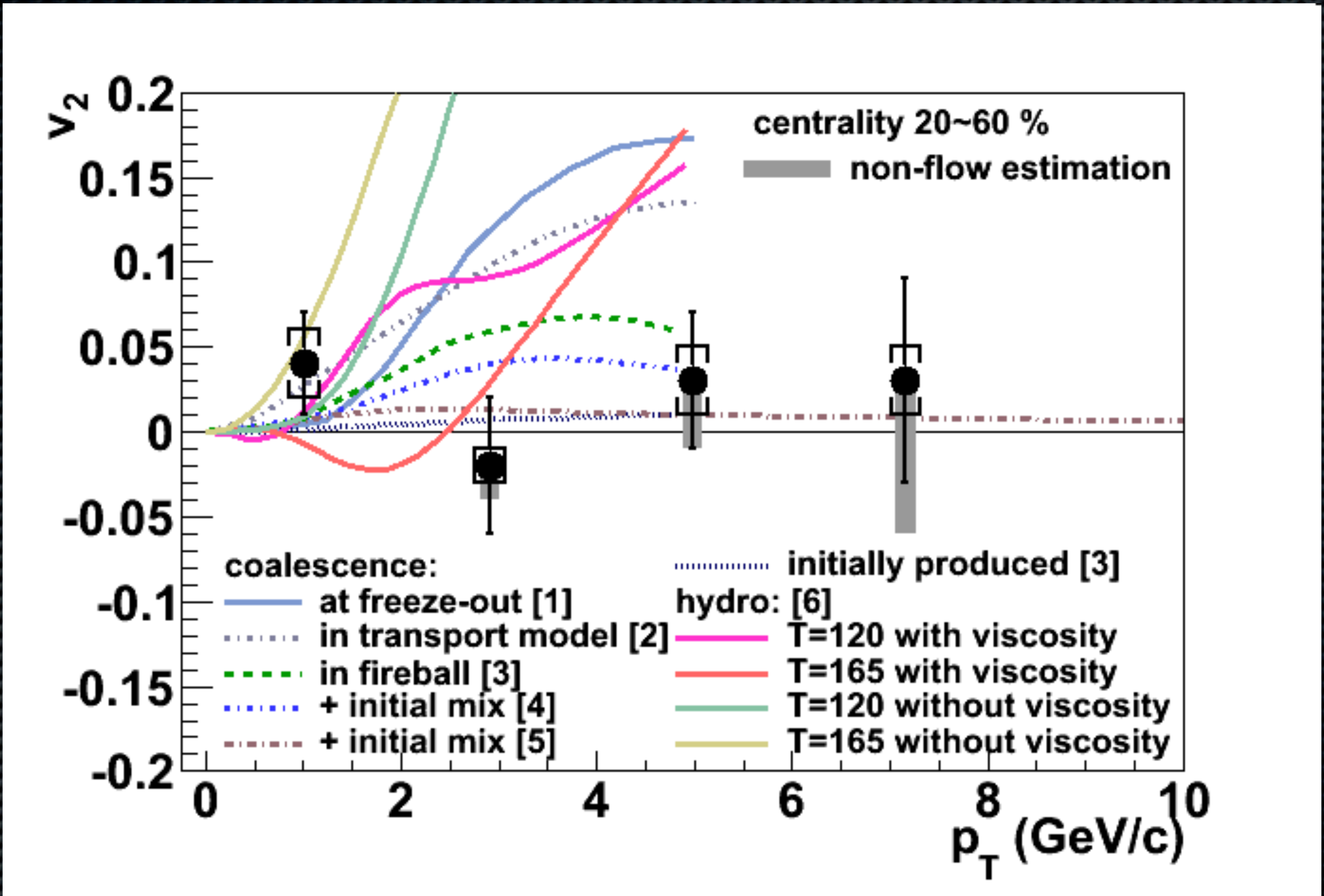


J/ψ Polarization vs Production Models



λ_θ is consistent with NLO+ CSM and COM and with no polarization within current uncertainties.

Does J/ψ Flow?

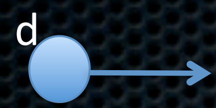


Consistent with non-flow, disfavor the recombination model from thermalized charm quarks at high p_T.

Quantify Cold Nuclear Matter Effects

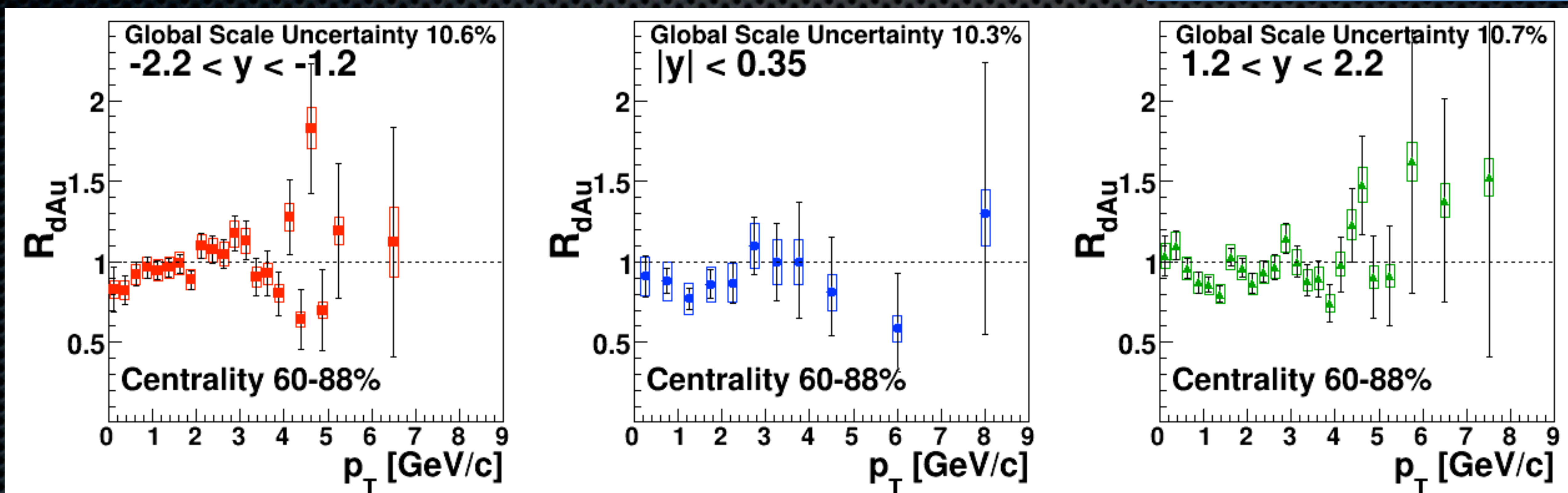
- **High statistics d+Au data set taken in 2008**
  - **J/ψ production at 200 GeV at backward, mid, and forward rapidities as a function of centrality, y, and (new) p_T.**
  - **ψ' at midrapidity as a function of centrality.**
  - **χ_c at midrapidity**

Centrality Dependence



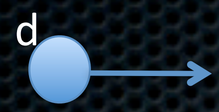
60-88%

Phys. Rev. D 86, 092006 (2012)



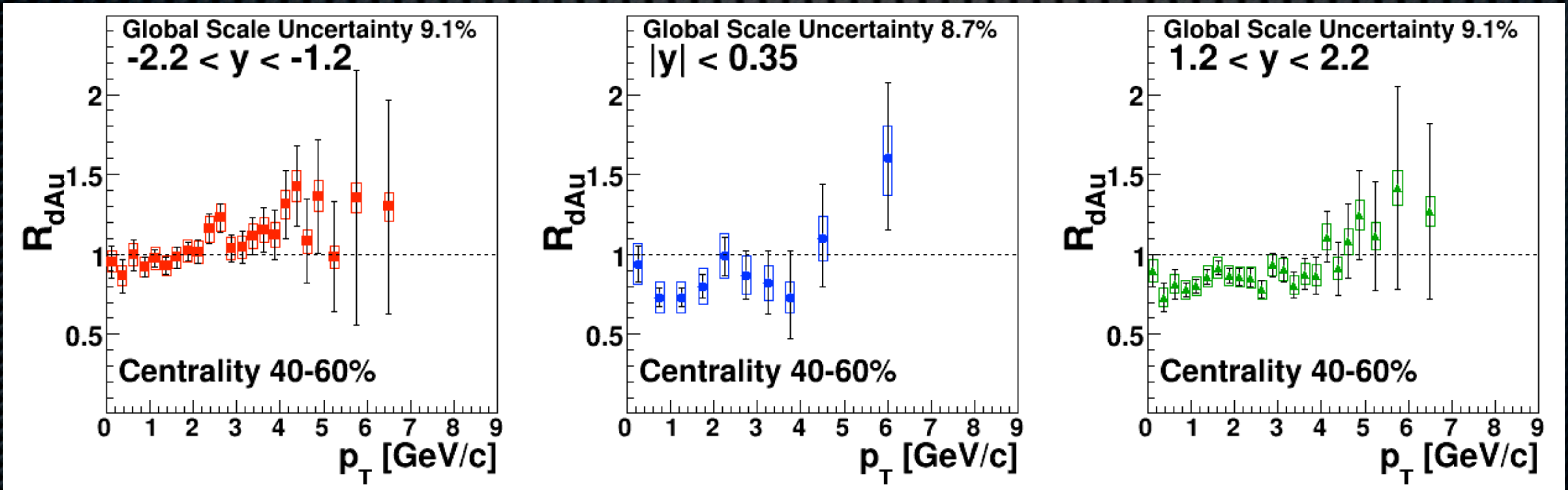
R_{dAu} consistent with 1 at all p_T for peripheral collisions

Centrality Dependence



40-60%

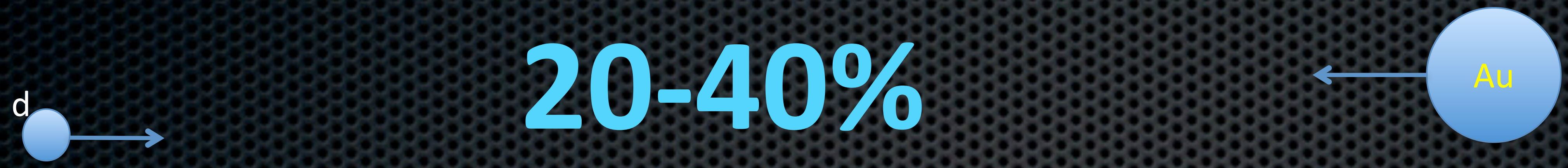
Phys. Rev. D 86, 092006 (2012)



Increasing suppression at low pT when moving to more central events

Centrality Dependence

20-40%



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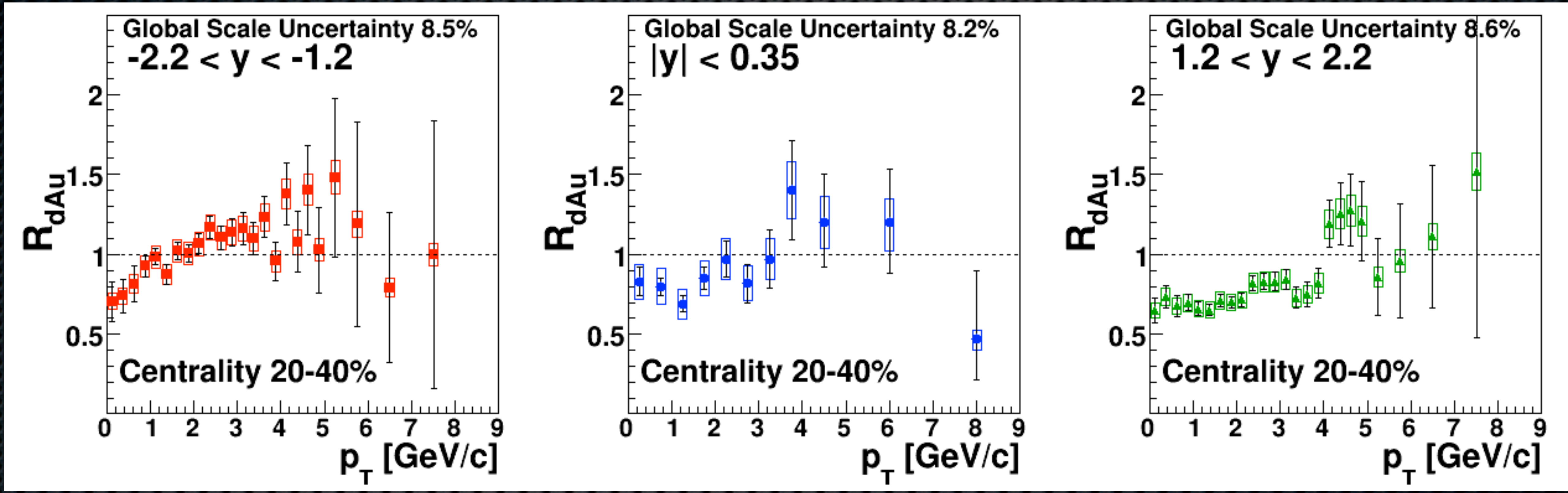

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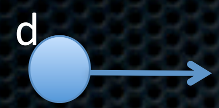
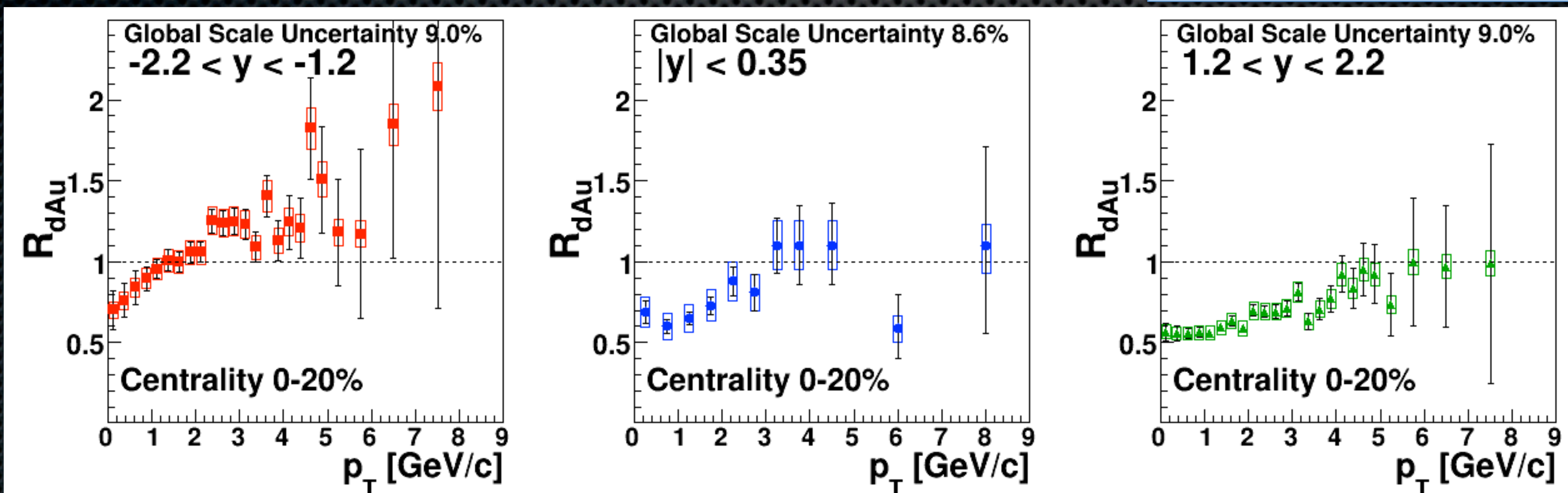


0-20%

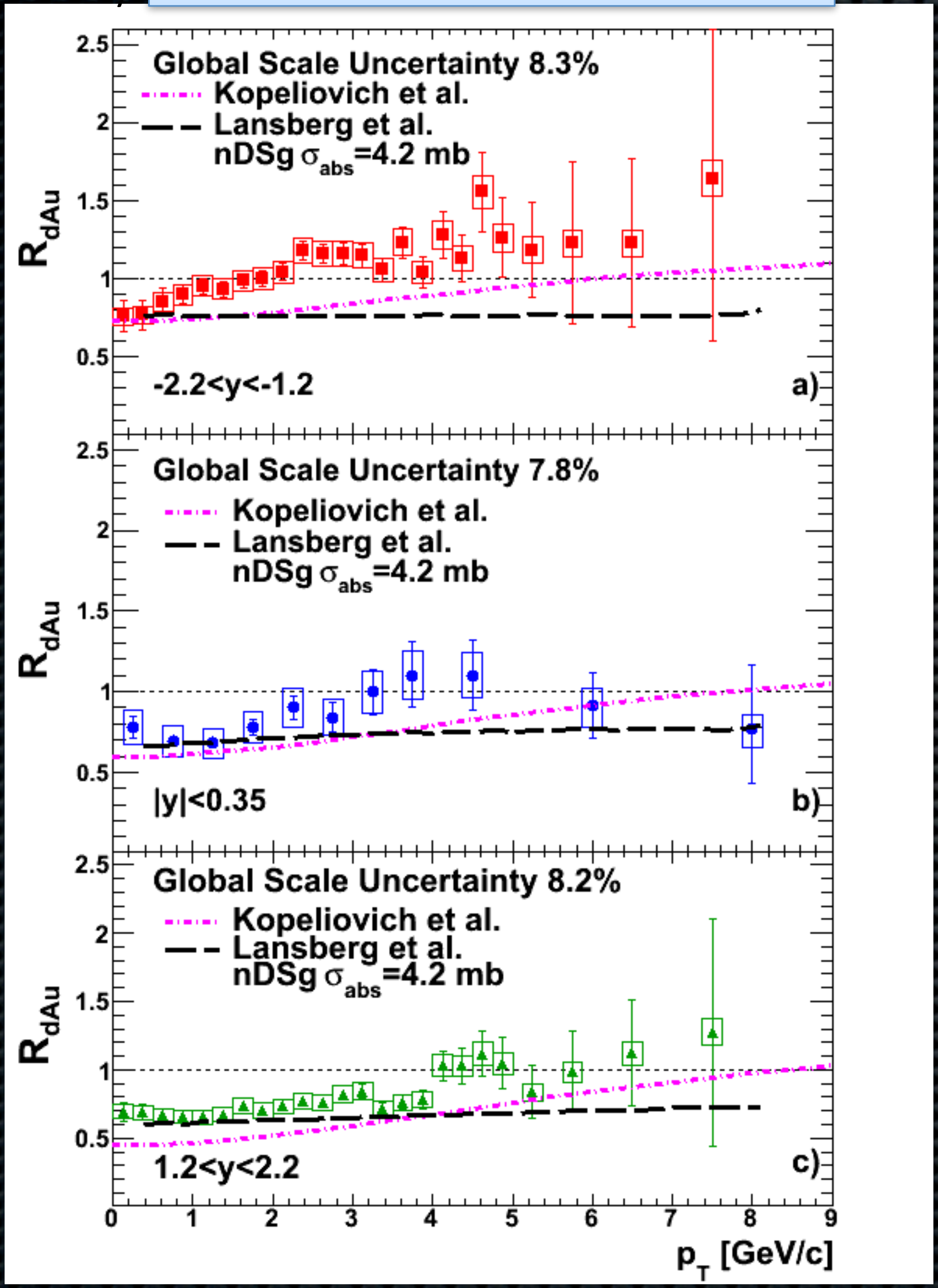
Phys. Rev. D 86, 092006 (2012)



Increasing suppression at low pT when moving to more central events. Enhancement at high pT at backward rapidity (Au going direction)

J/ψ R_{dAu} vs (p_T, y) in d+Au Collisions

Phys. Rev. D 86, 092006 (2012)



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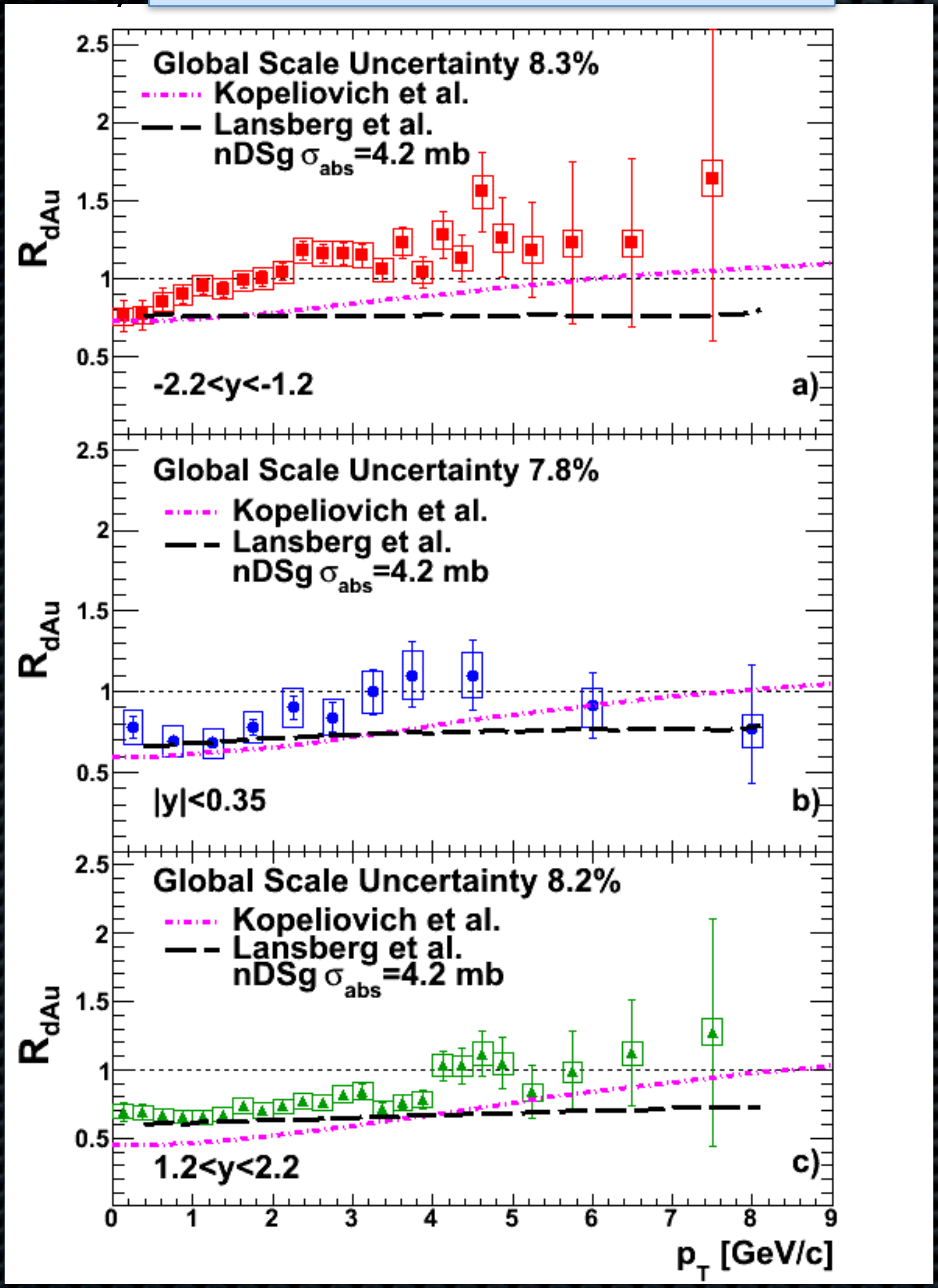
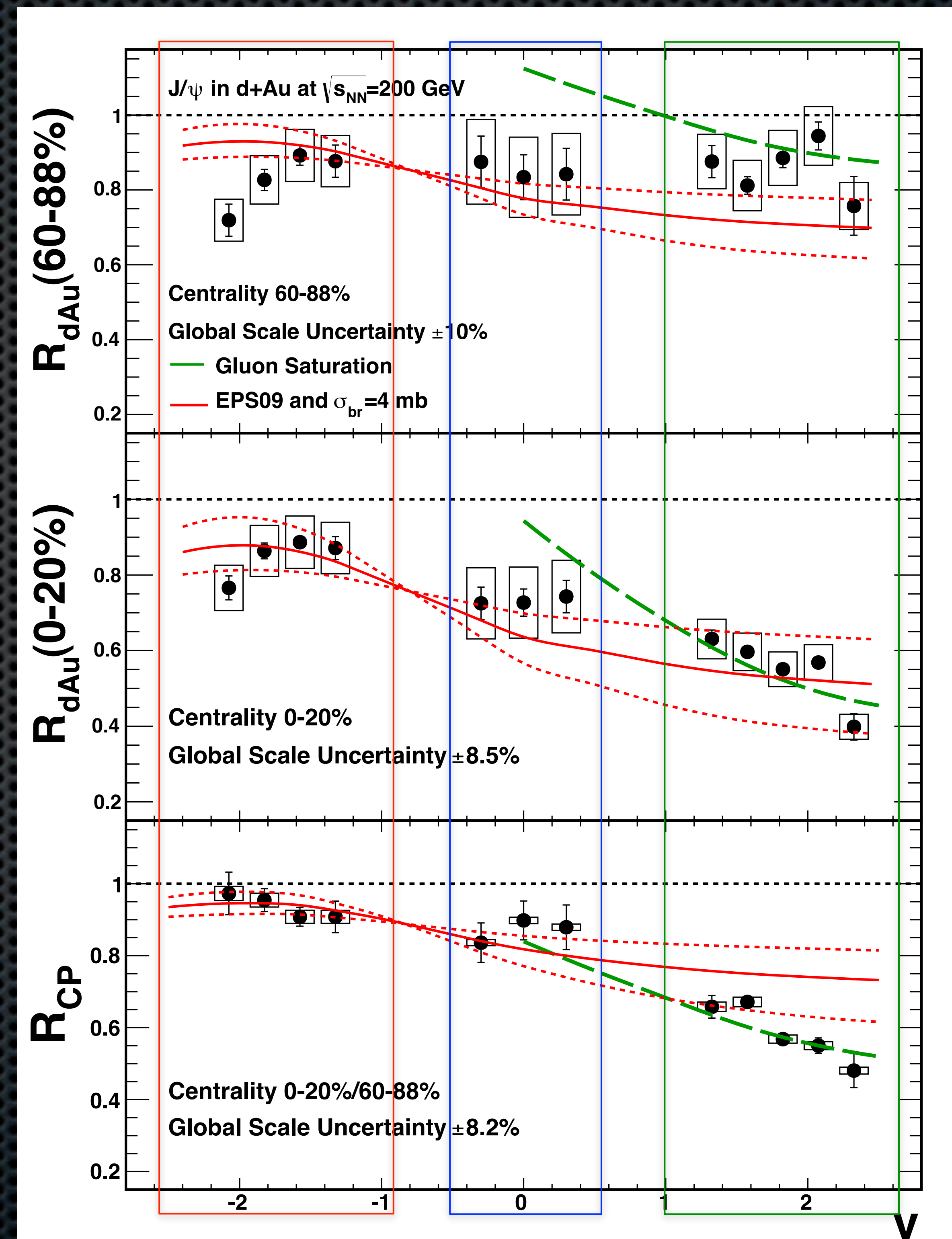


- Minimum bias results
- Similar suppression at mid-rapidity and forward (d-going) rapidity. Suppression below 4 GeV. R_{dAu} ~1 above 4 GeV
- Different R_{dAu} pT dependence at forward (Au-going) rapidity. Enhancement above 1 GeV
- No clear explanation from theory for the forward results.

J/ψ R_{dAu} vs ($p_{T,}$ y) in d+Au Collisions

Phys. Rev. Lett. 107 (2011) 142301

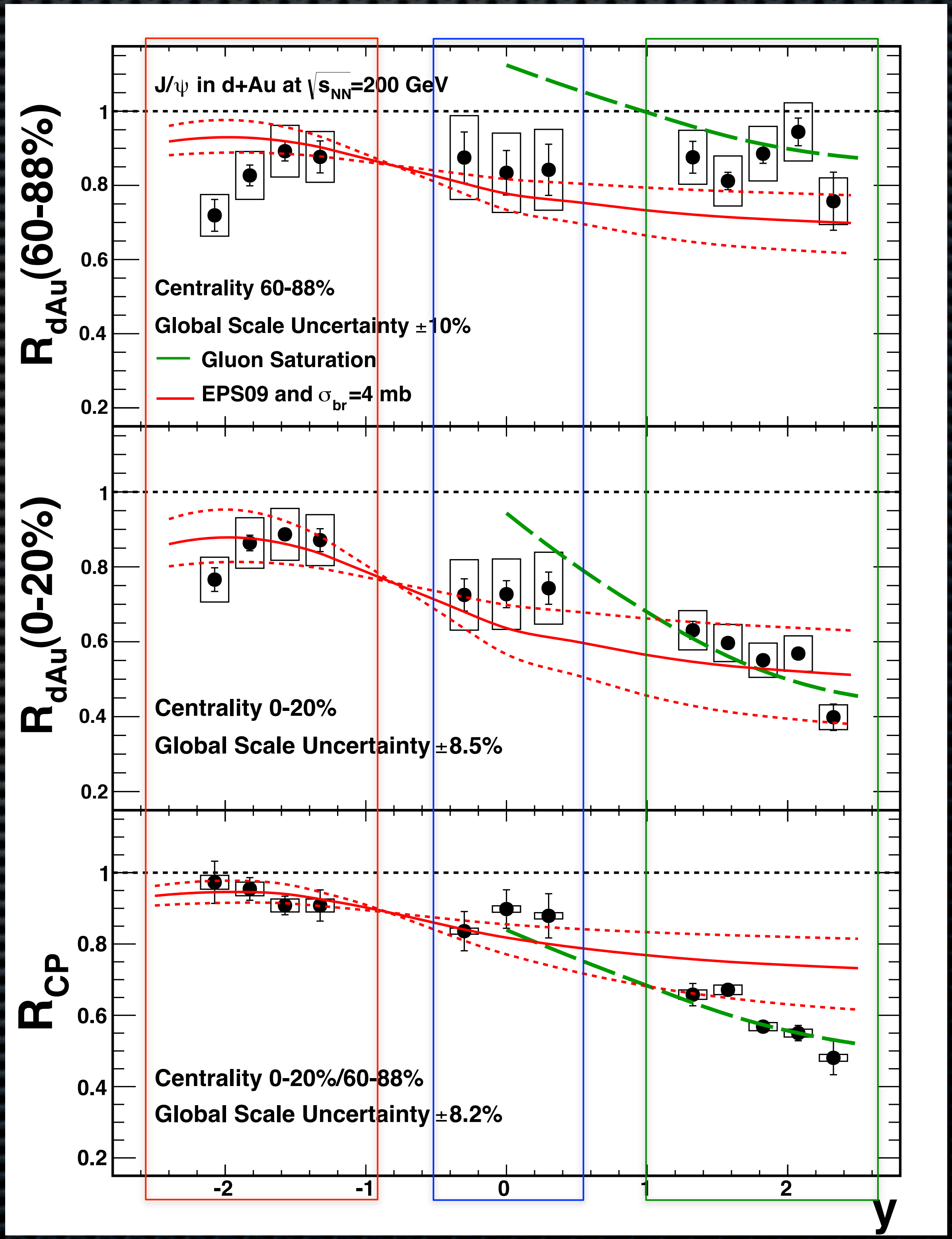
Phys. Rev. D 86, 092006 (2012)



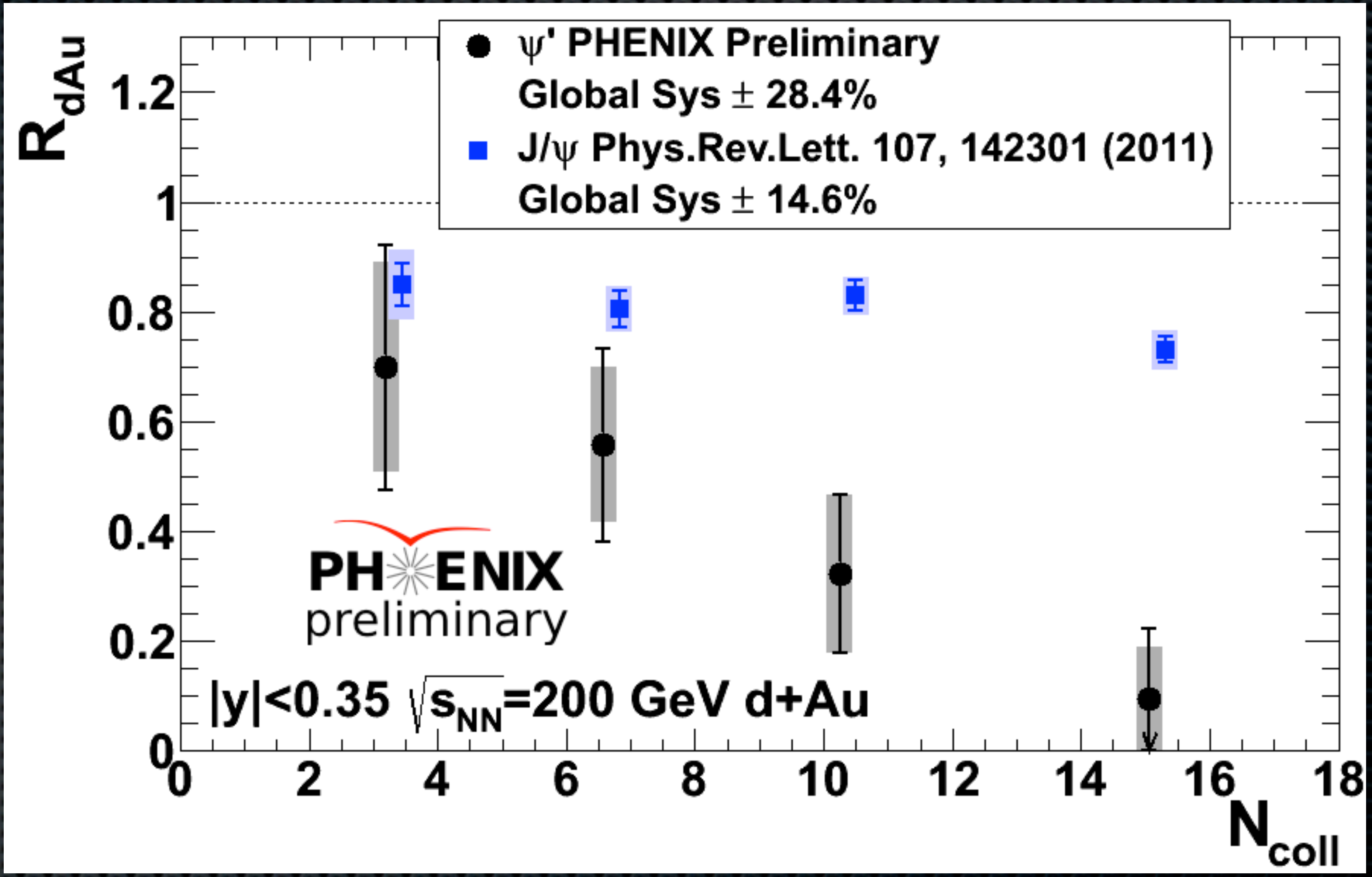
J/ψ R_{dAu} vs (p_T, y) in d+Au Collisions

Phys. Rev. Lett. 107 (2011) 142301

- J/ψ (integrated over pT) are suppressed at all rapidities, in all centralities.
- The model, using shadowing (EPS09) + breakup x-section qualitatively matches what we see, but cannot simultaneously capture the rapidity and centrality dependences.

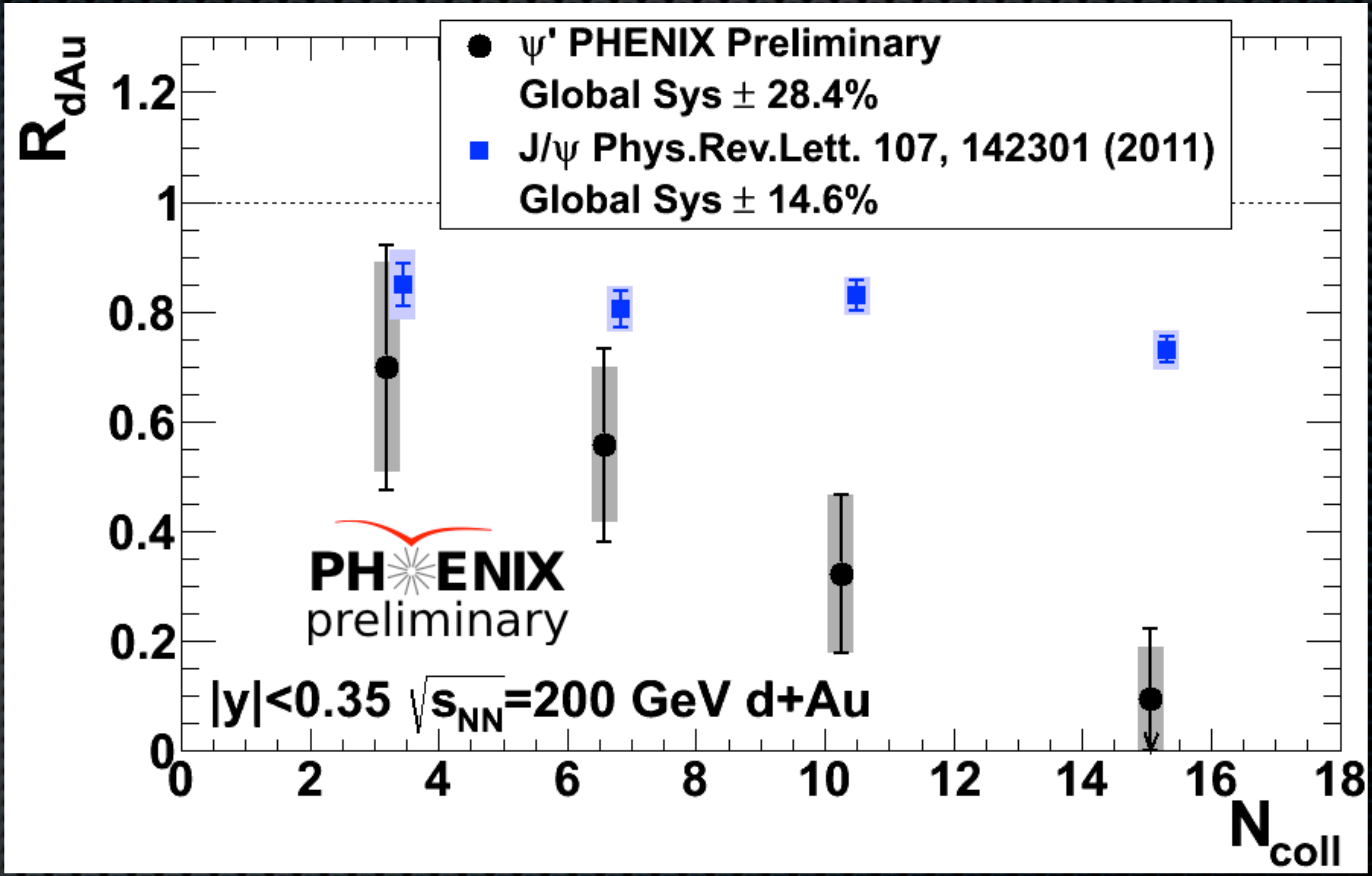


Brief on ψ' R_{dAu}

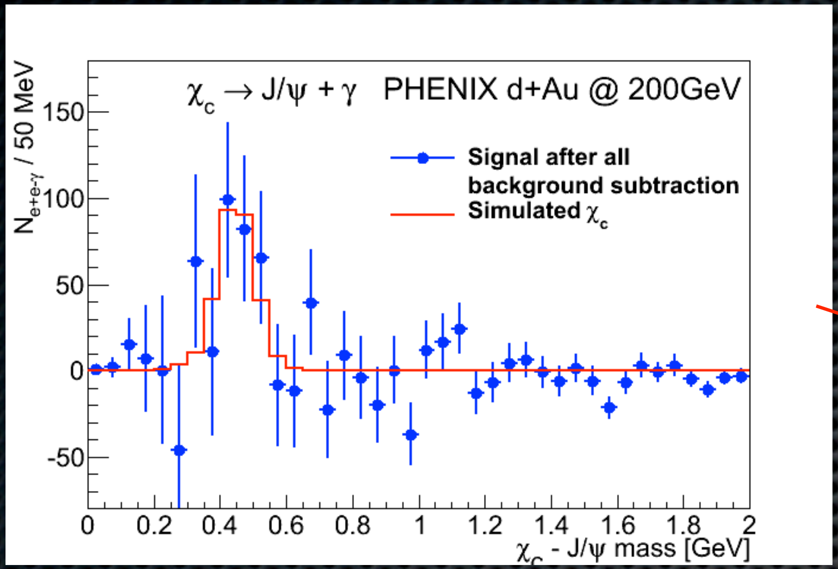


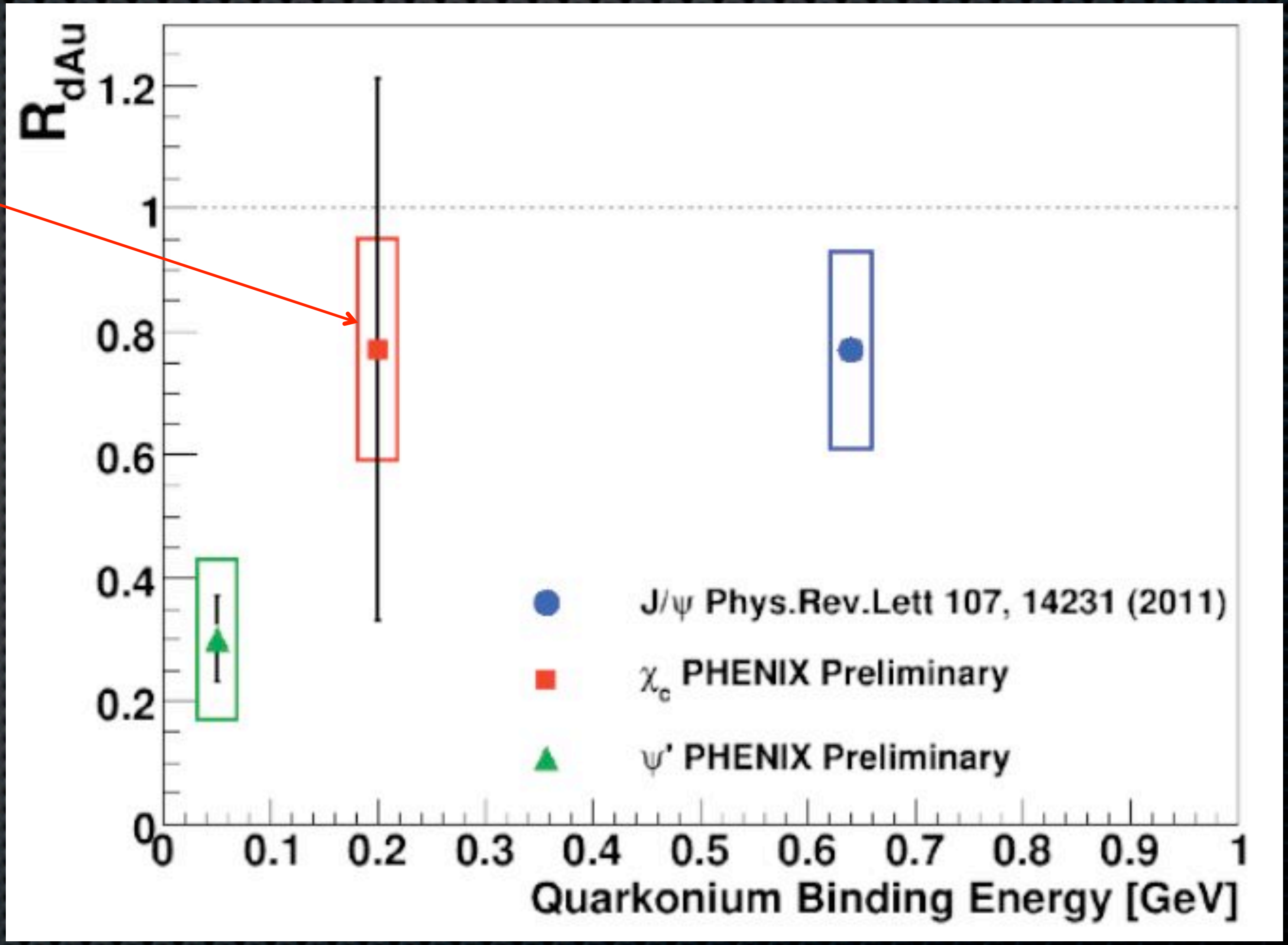
Brief on ψ' R_{dAu}

- Strong suppression with increasing Ncoll
- Centrality dependence of the suppression is even stronger at the mid-rapidity.

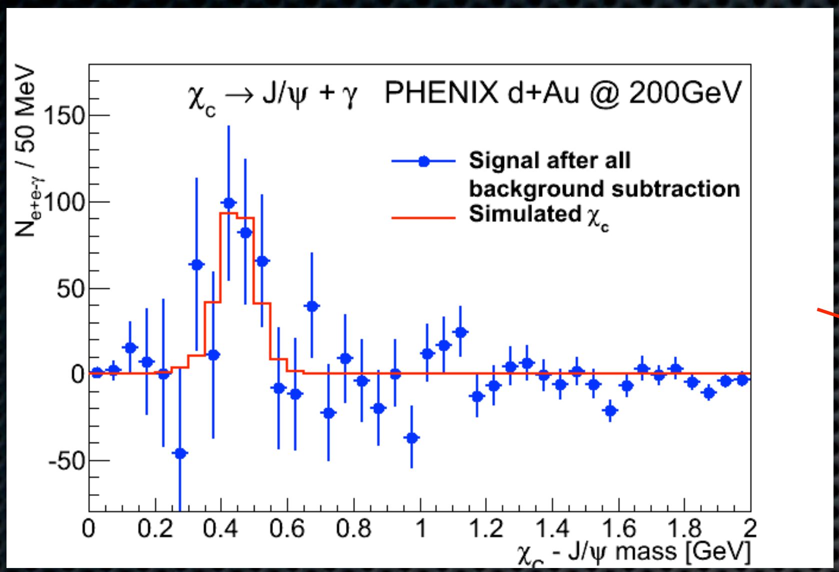


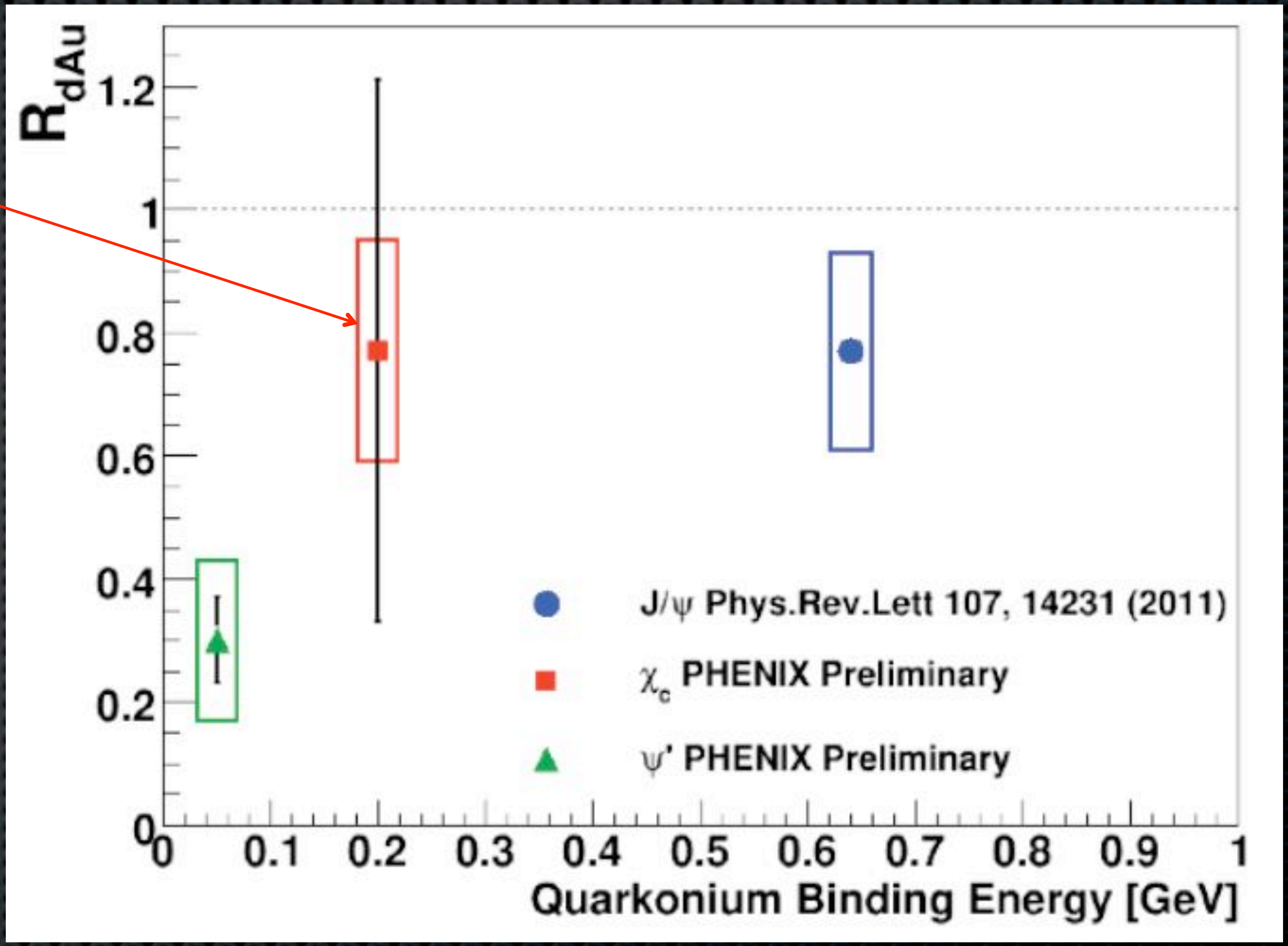
Brief on χ_c R_{dAu}





Brief on χ_c R_{dAu}





- Charmonium RdAu seems to depend on binding energy. Better (high statistics) measurement is needed though.

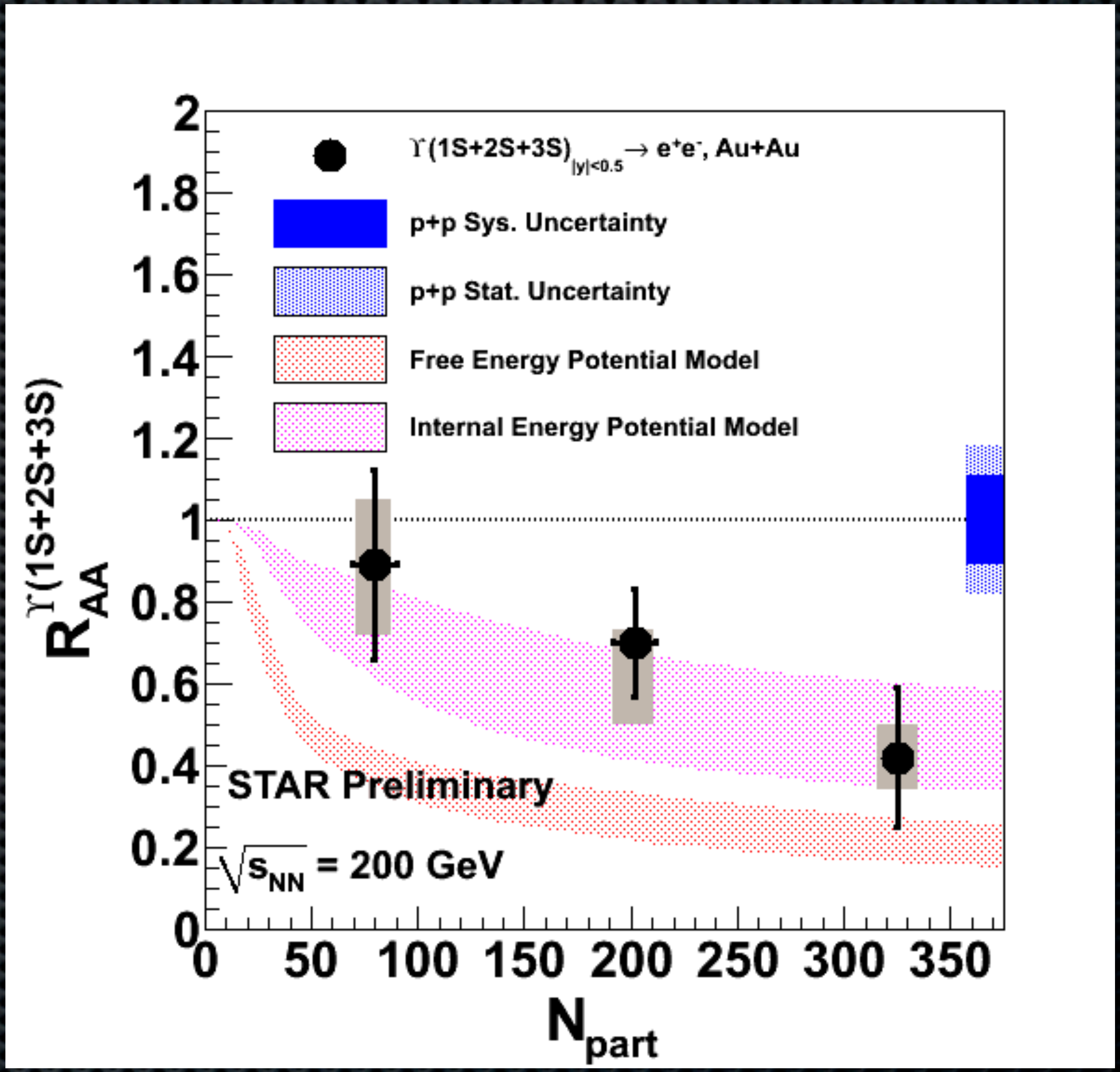
Upsilons - A cleaner probe of QGP

Upsilon results from RHIC

- At RHIC, upsilon measurements have been hampered by a combination of low x-section and acceptance, and insufficient momentum resolution to resolve the three states. So far, there are preliminary measurements of the three states combined by PHENIX and STAR, including in the STAR case a measurement for Au+Au.

Preliminary results from STAR

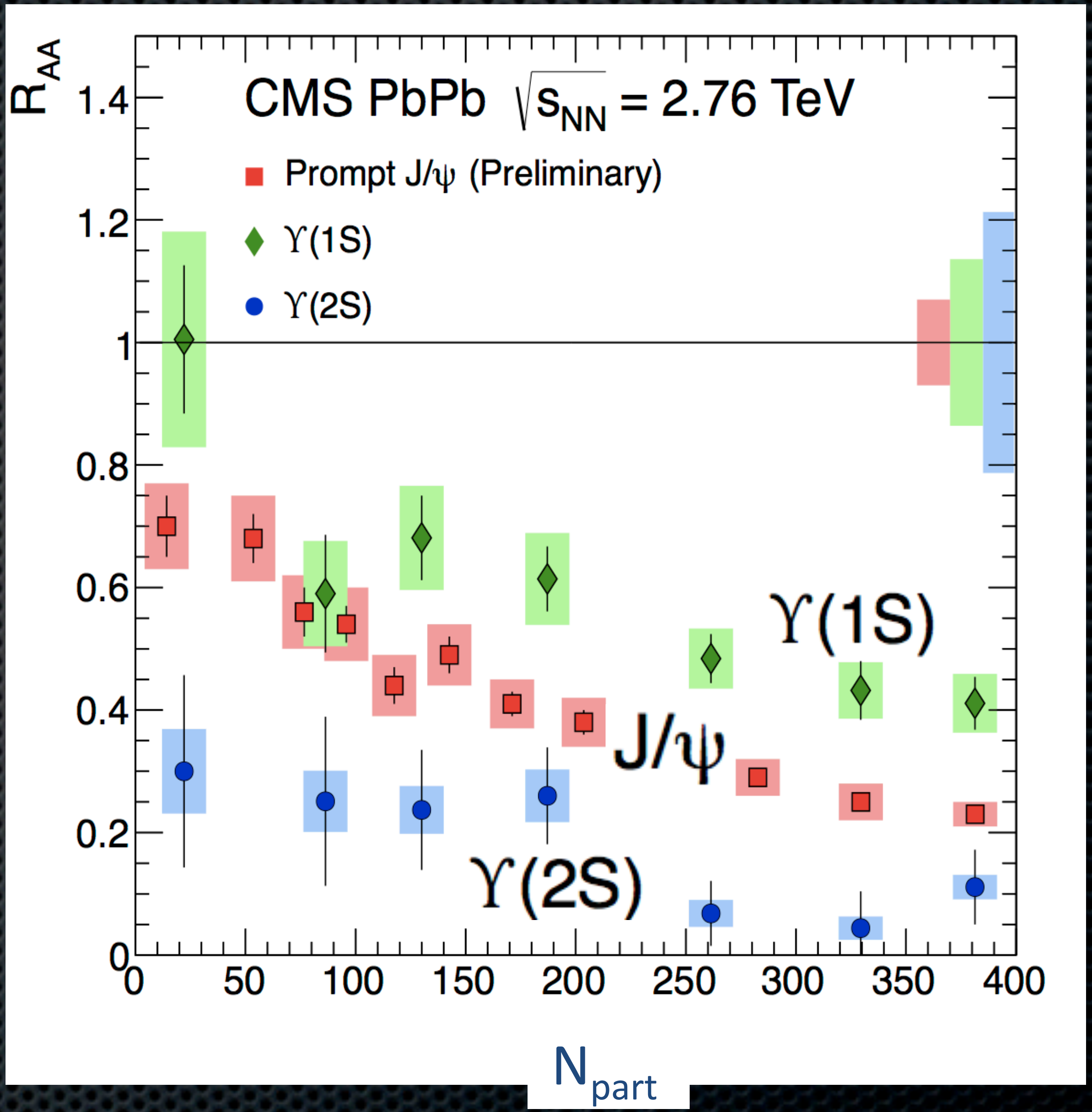
- Suppression of the mixed states in central collision is observed.
- Inclusive measurements including 50% feeddown contributions.



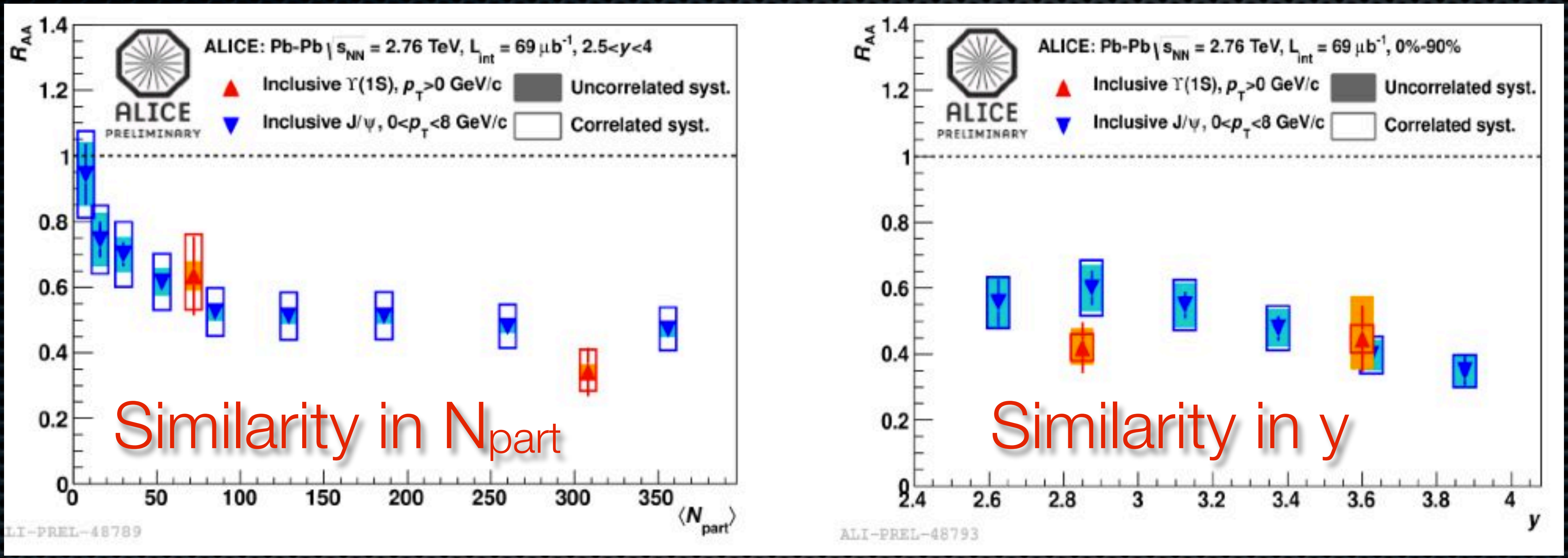
Model: M. Strickland, PRL 107, 132301 (2011).

Upsilon R_{AA} from CMS

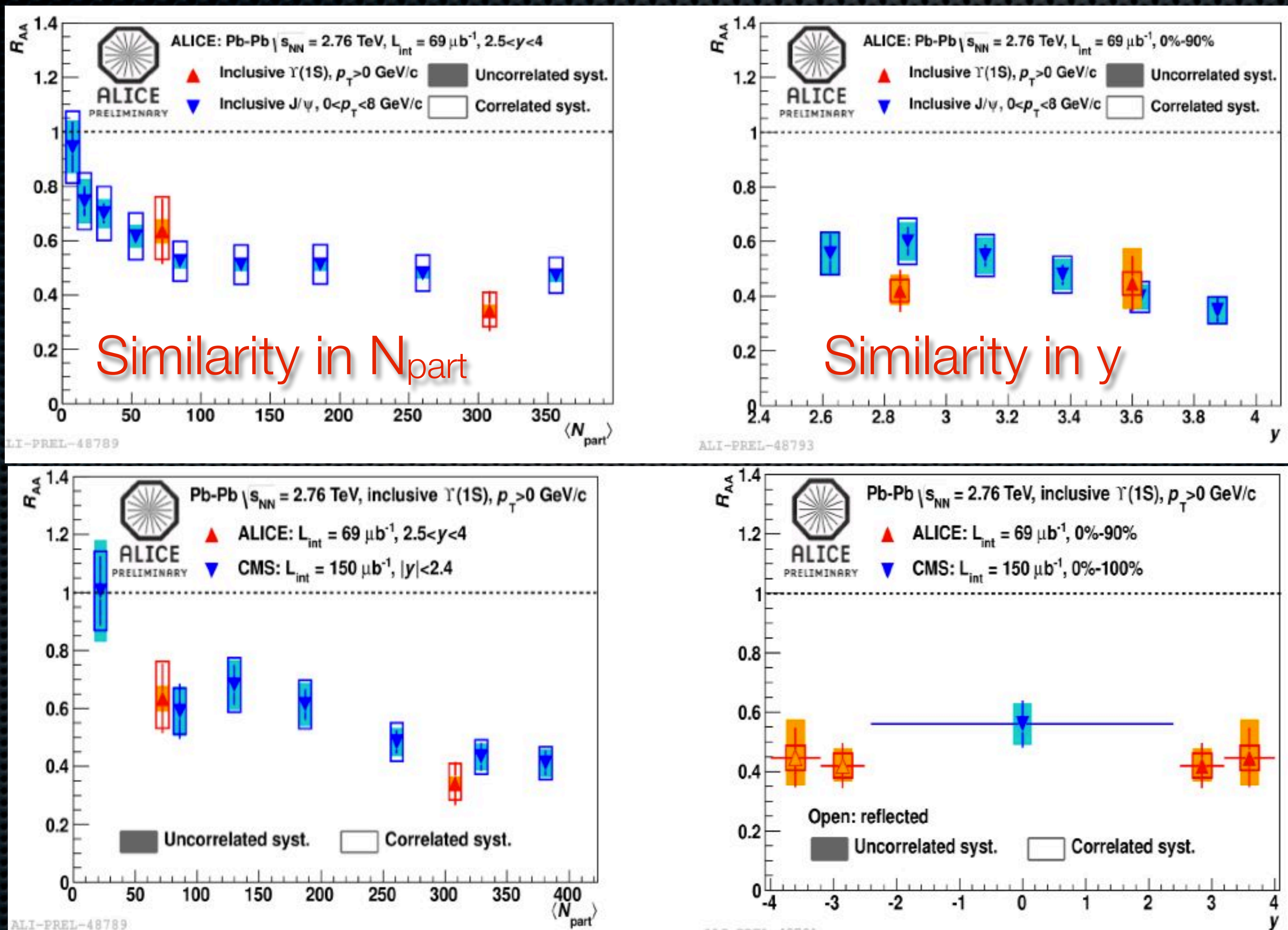
- Suppression of the Υ(1S) and Υ(2S) states in central collision is observed.
- Suppression for Υ(2S) is larger than Υ(1S).



Upsilon R_{AA} from CMS/ALICE



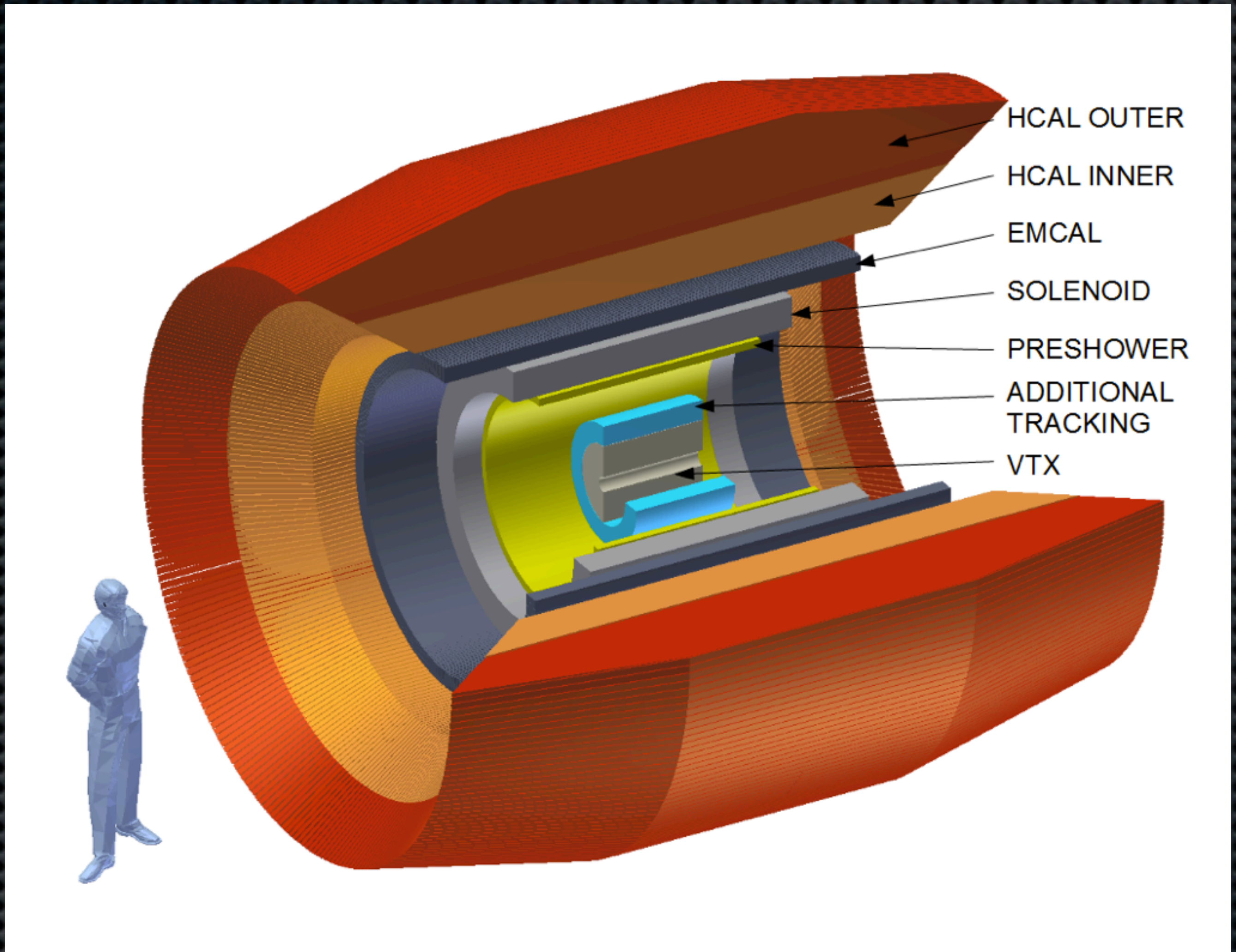
Upsilon R_{AA} from CMS/ALICE



What are proposed for sPHENIX

- In the sPHENIX proposed in this document with only the VTX for tracking, one will be limited to charged particle tracks with pT < 5 GeV/c and without heavy flavor tagging via displaced vertices (the VTX by itself will not be able to discriminate sufficiently against fake tracks).
- Thus, the sPHENIX future upgrade will need to incorporates additional precision tracking in the radial space from 15-65 cm (inside the new magnetic solenoid). The technology and exact number of layers or space-points has not been determined at this time.
- This will give us a world class upsilon measurement with separation of the three states and statistical precision comparable with that of the LHC experiment. Therefore it is possible to compare the effects of medium simultaneously on three bottomonium states - all of which have quite radii and binding energies.

Engineering drawing

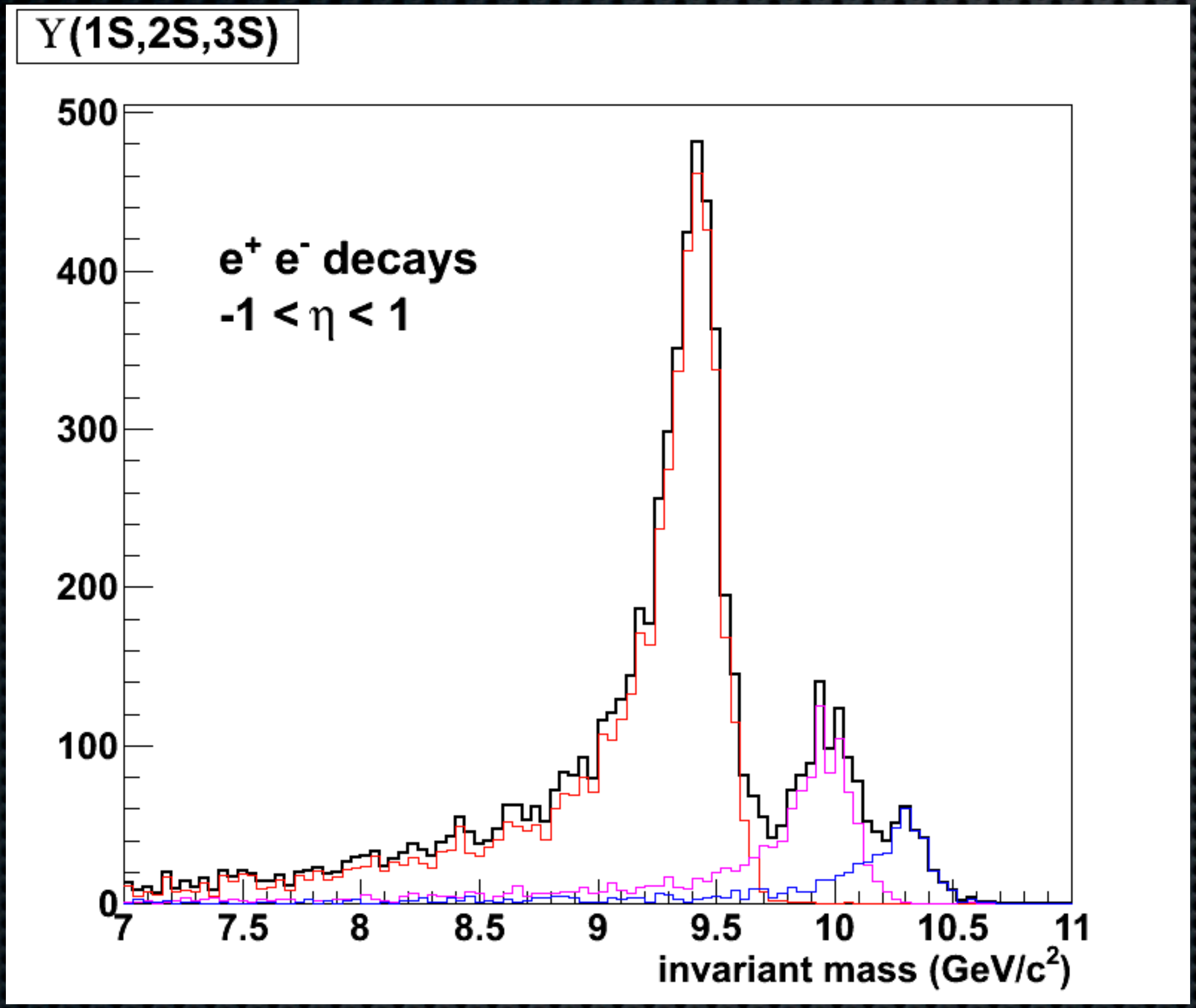


It seems likely that we will be using Babar solenoid which is larger in radius than the solenoid described in the MIE proposal, as we learned from Jamie and John yesterday.

Earlier work on Υ in sPHENIX

- A Geant4 simulation with VTX + two additional tracking layers (at 40 and 60 cm radius) was performed in sPHENIX with single simulated upsilon events. The magnetic field was 2 tesla. The sPHENIX acceptance times tracking efficiency for Υ(1S+2S+3S) ->e^+e^- decays was found to be 0.34 in the mass window 7-11 GeV/c^2.
- A critical question is whether the proposed tracking system, with a magnetic field of 2 tesla, is capable of adequately resolving the Υ(1S) from the Υ(2S) and Υ (3S) states.

Upsilon mass spectra



- The mass spectra from reconstructed electron decay tracks for the three upsilon states combined. The yield corresponds roughly to that for the 0-10% centrality bin from 50B minimum bias events, assuming no suppression in Au+Au collisions.'
- The background under the Upsilon peaks consists of an irreducible (physics) background due to deletions from correlated charms, bottoms and Drell Yan. There is also combinatorial background from misidentified charges pions.

Summary

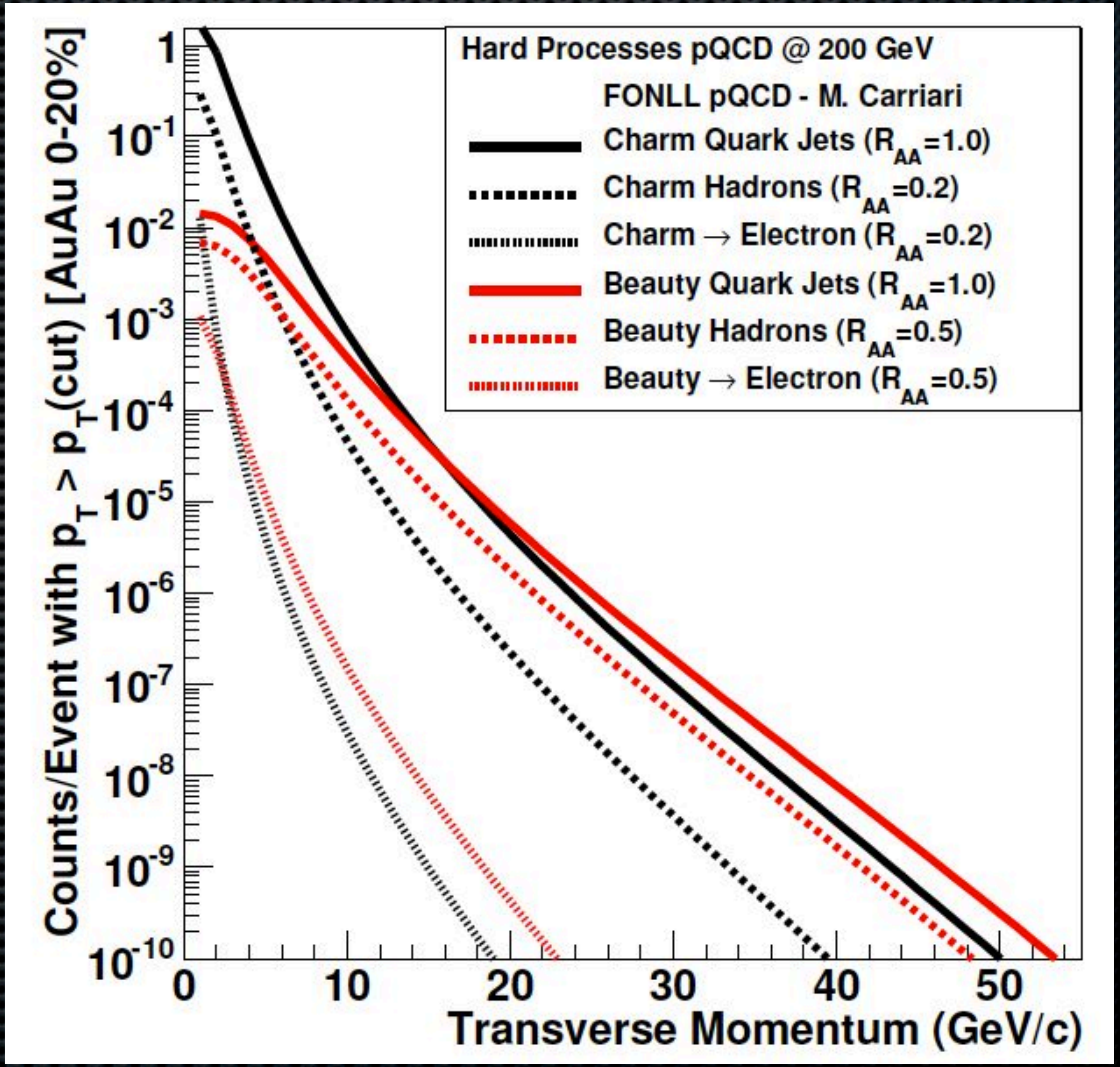
- Showed three puzzles about J/ψ production at 200 GeV Au+Au collisions in comparison with the results from LHC Alice experiment and at RHIC low energy runs.
- All signs indicate that one has to carefully disentangle the cold nuclear matter effects on J/ψ production in order to exclusively extract color screen effects from a QGP medium.
- PHENIX has made measurement of J/ψ production from d+Au collisions at 200 GeV in 2008. This data set allows us to study the J/ψ production as a function of collision centrality, pT, and rapidity, which provides important constraints on theoretical modeling of cold nuclear effects on quarkonium production.
- Single leptons from heavy flavor decays, charm/bottom tagged jets, heavy flows are intentionally omitted in this talk.
- sPHENIX provides a unique opportunity for studying upsilon states which is a much cleaner probe for QGP medium. In the meantime, we need to plan on disentangling CNM effects from hot/dense medium for upsilons as we have been doing for J/ψ study at RHIC.

Tagging charm/bottom jets

- A main motivation for studying heavy flavor jets in heavy ion collisions is to understand the mechanism for patron-medium interactions and to further explore the issues of strong versus weak coupling.

Heavy flavor production rates

- FONLL calculations for heavy flavor jets, fragmentation hadrons (D, B mesons primarily), and decay electrons as a function of transverse momentum.



J/ψ R_{AA} Comparison