Quarkonia Updates from RHIC

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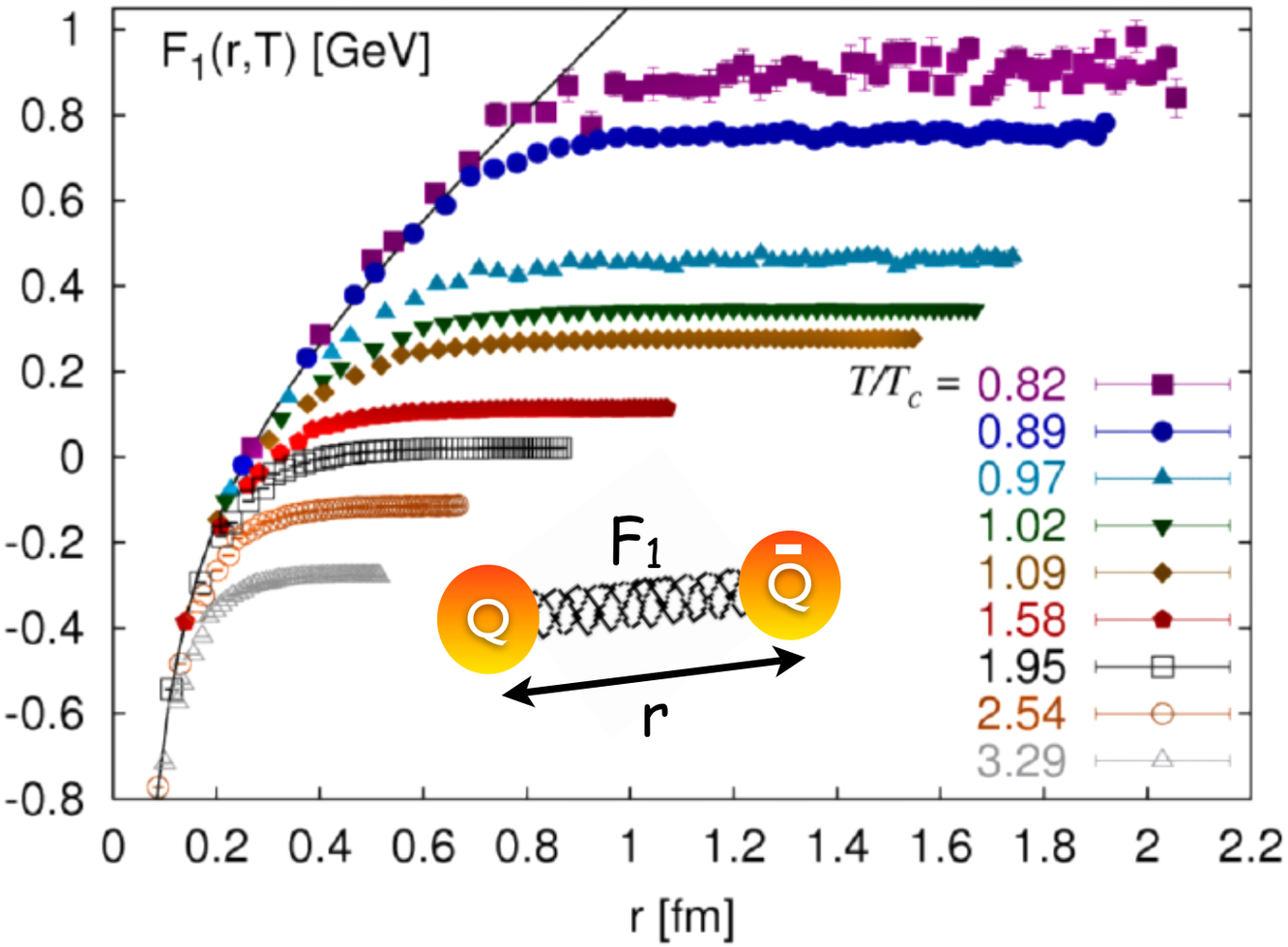
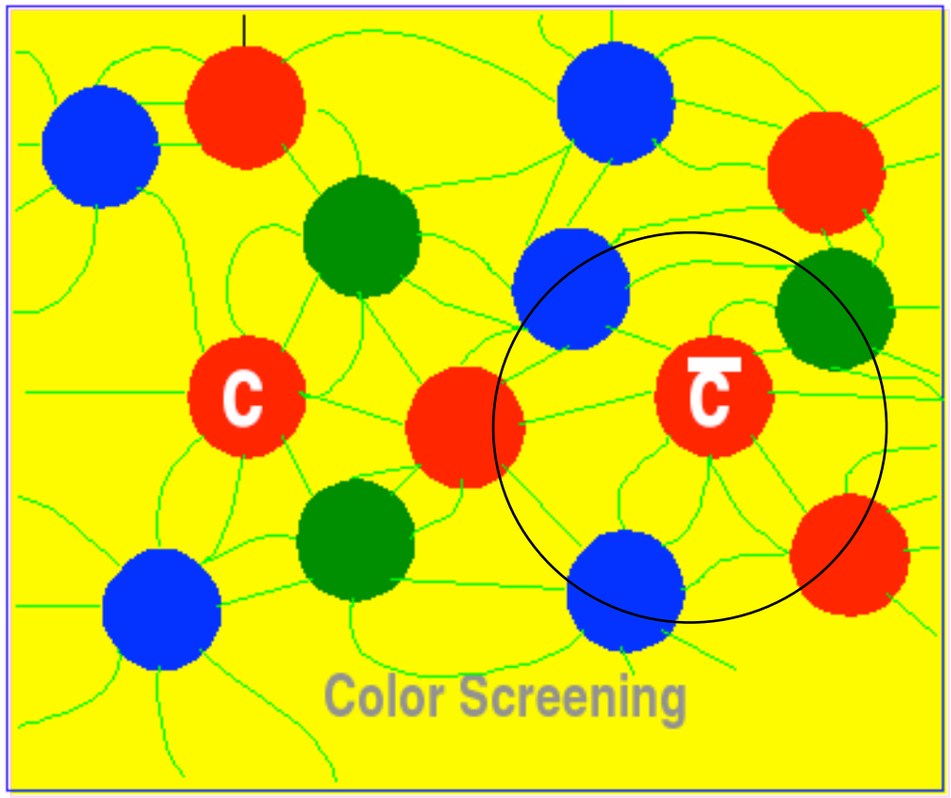
LOS ALAMOS NATIONAL LAB

RHIC/AGS Users Meeting 2013

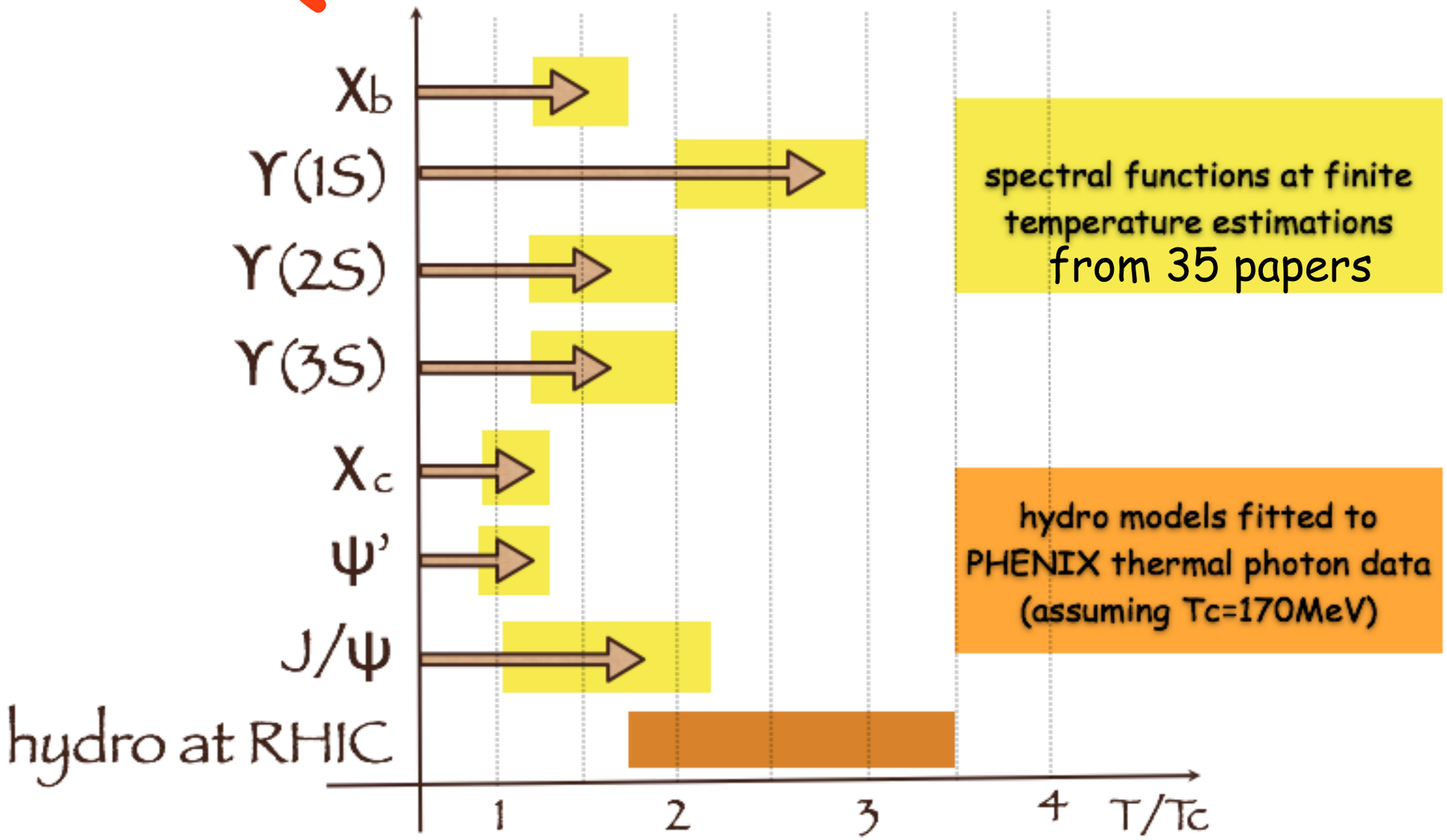
Color Screening





State	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
Mass (GeV)	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE (GeV)	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM (GeV)	0.02	−0.03	0.03	0.06	−0.06	−0.06	−0.08	−0.07
r_0 (fm)	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78

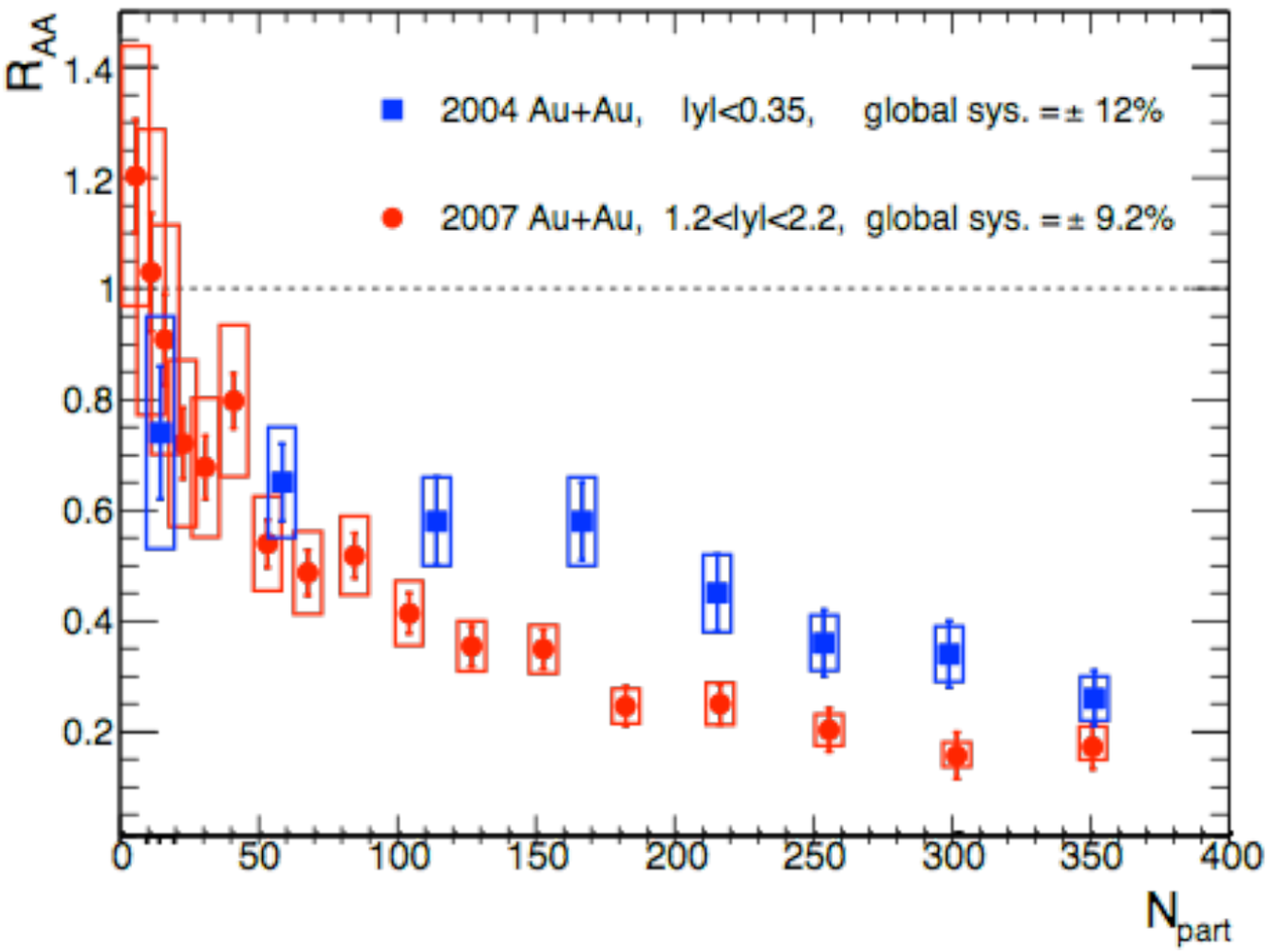
QGP Thermometer

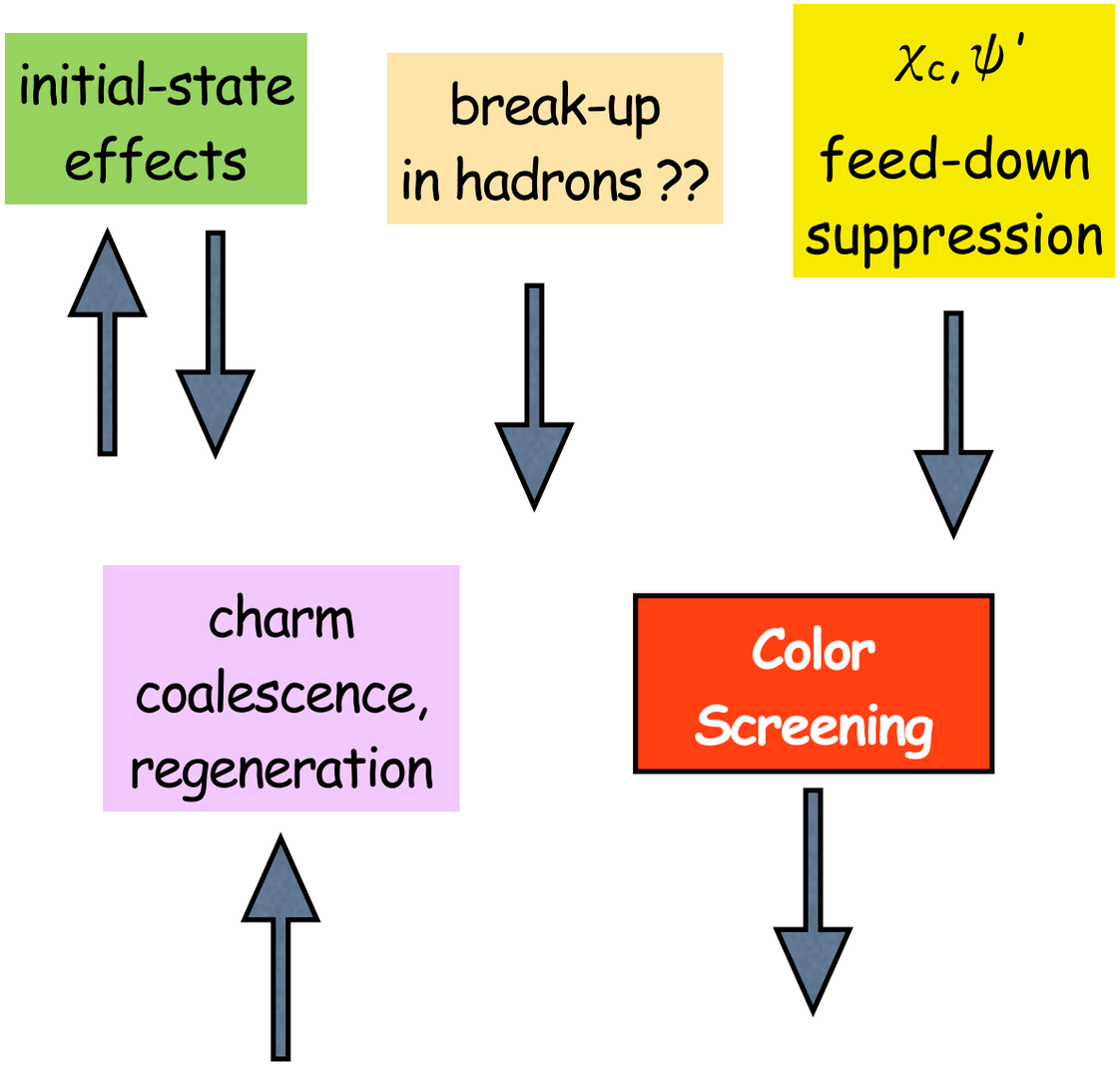


- quarkonia is much more than a QGP signature
- if color screening effect can be isolated quarkonia can be a more direct gauge for QGP temperature

J/ψ Suppression in Au+Au

Competing effects:

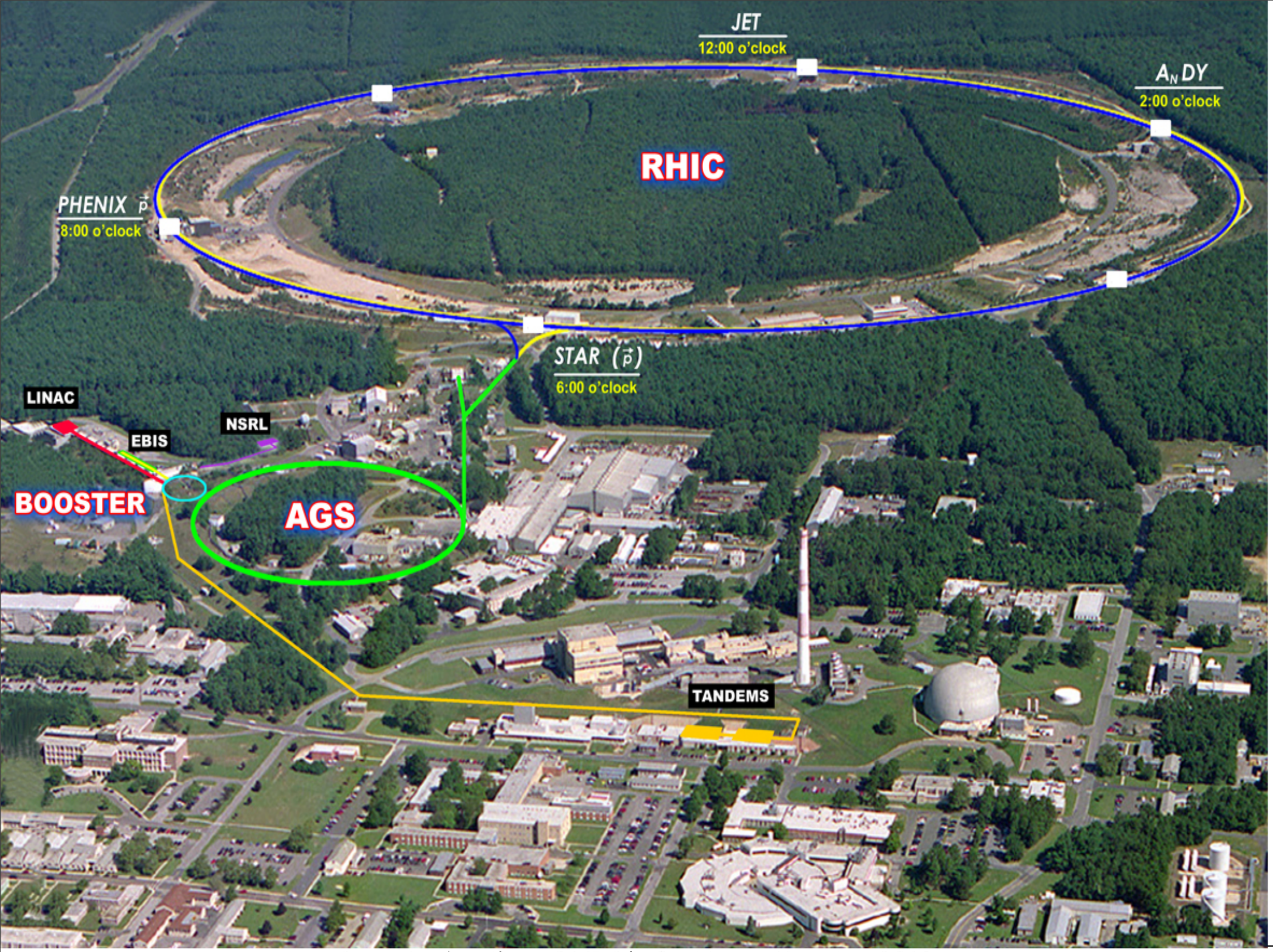




Isolating the color screening

Needs variation of:

- collision species to study the path length dependency of the quarkonia suppression
- collision energy where some of the suppression effects are reduced or enhanced
- rapidity which strongly depends on initial state effects


JET
12:00 o'clock
A_N DY
2:00 o'clock
RHIC
PHENIX $\vec{p}$
8:00 o'clock
STAR ($\vec{p}$)
6:00 o'clock
LINAC
NSRL
EBIS
BOOSTER
AGS
TANDEMS

RHIC ions – 6 species and 15 energies to date

$^{238}U^{92+}$–$^{238}U^{92+}$ → first time in 2012, 3 weeks physics

96.4 GeV/nucleon

$^{197}Au^{79+}$–$^{197}Au^{79+}$

3.85, 4.6, 5.75, 9.8, 13.5, 19.5, 27.9, 31.2, 65.2, 100.0 GeV/nucleon

$^{63}Cu^{29+}$–$^{197}Au^{79+}$ → first time in 2012, 5 weeks

99.9/100.0 GeV/nucleon

$^{63}Cu^{29+}$–$^{63}Cu^{29+}$

11.2, 31.2, 100.0 GeV/nucleon

d–$^{197}Au^{79+}$

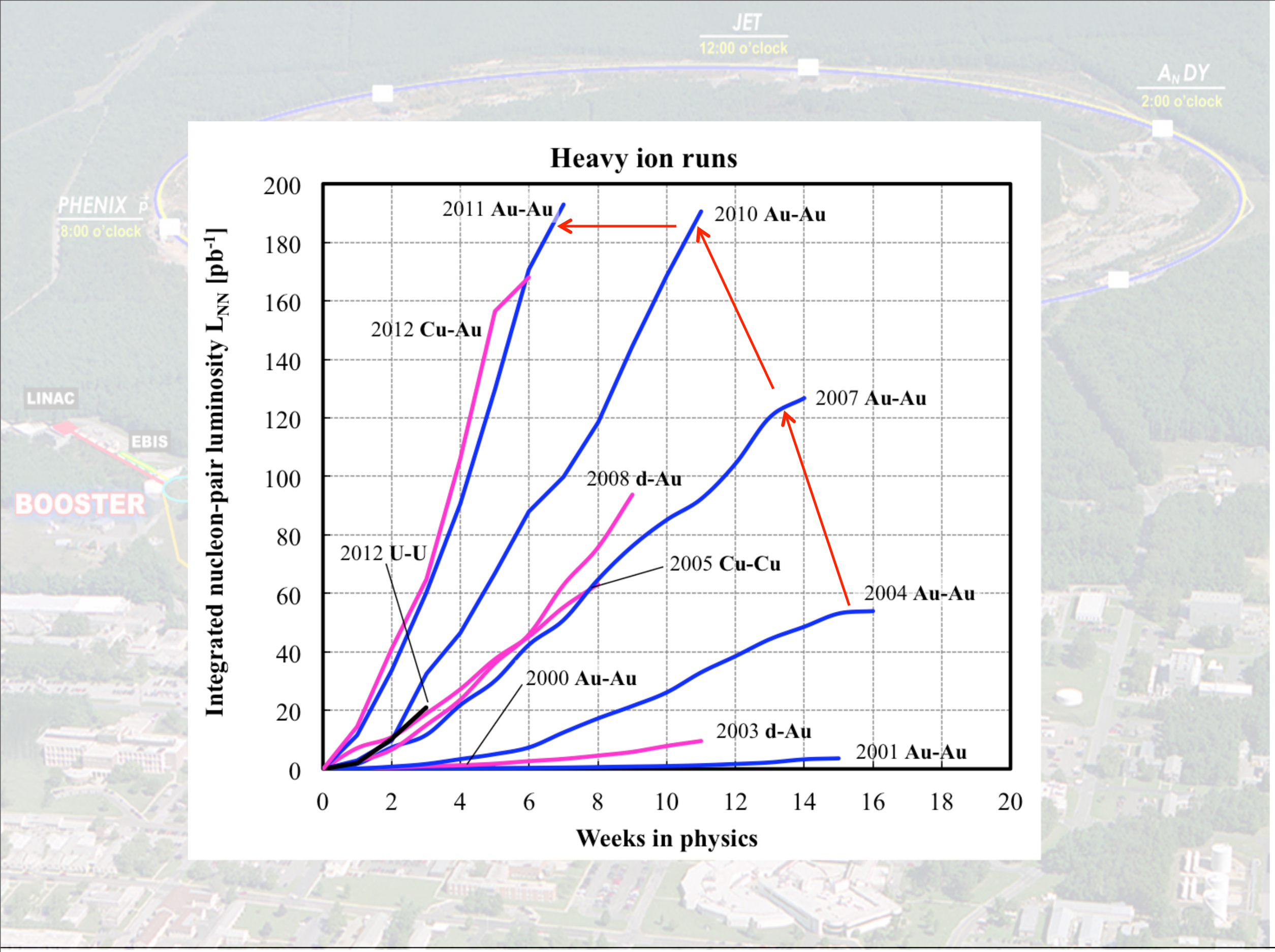
100.7/100.0 GeV/nucleon

p↑–p↑

31.2, 100.2, 204.9, 249.9, 254.9 GeV

Can collide any species from protons (polarized) to uranium
– with each other or with another species

from Wolfram Fischer talk in Forward Physics at RHIC,BNL - 07-31-2012


JET
12:00 o'clock
A_N DY
2:00 o'clock
PHENIX
8:00 o'clock
LINAC
EBIS
BOOSTER
Heavy ion runs
Integrated nucleon-pair luminosity L_NN [pb^-1]
Weeks in physics
2011 Au-Au
2010 Au-Au
2012 Cu-Au
2007 Au-Au
2008 d-Au
2012 U-U
2005 Cu-Cu
2004 Au-Au
2000 Au-Au
2003 d-Au
2001 Au-Au
0
20
40
60
80
100
120
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200
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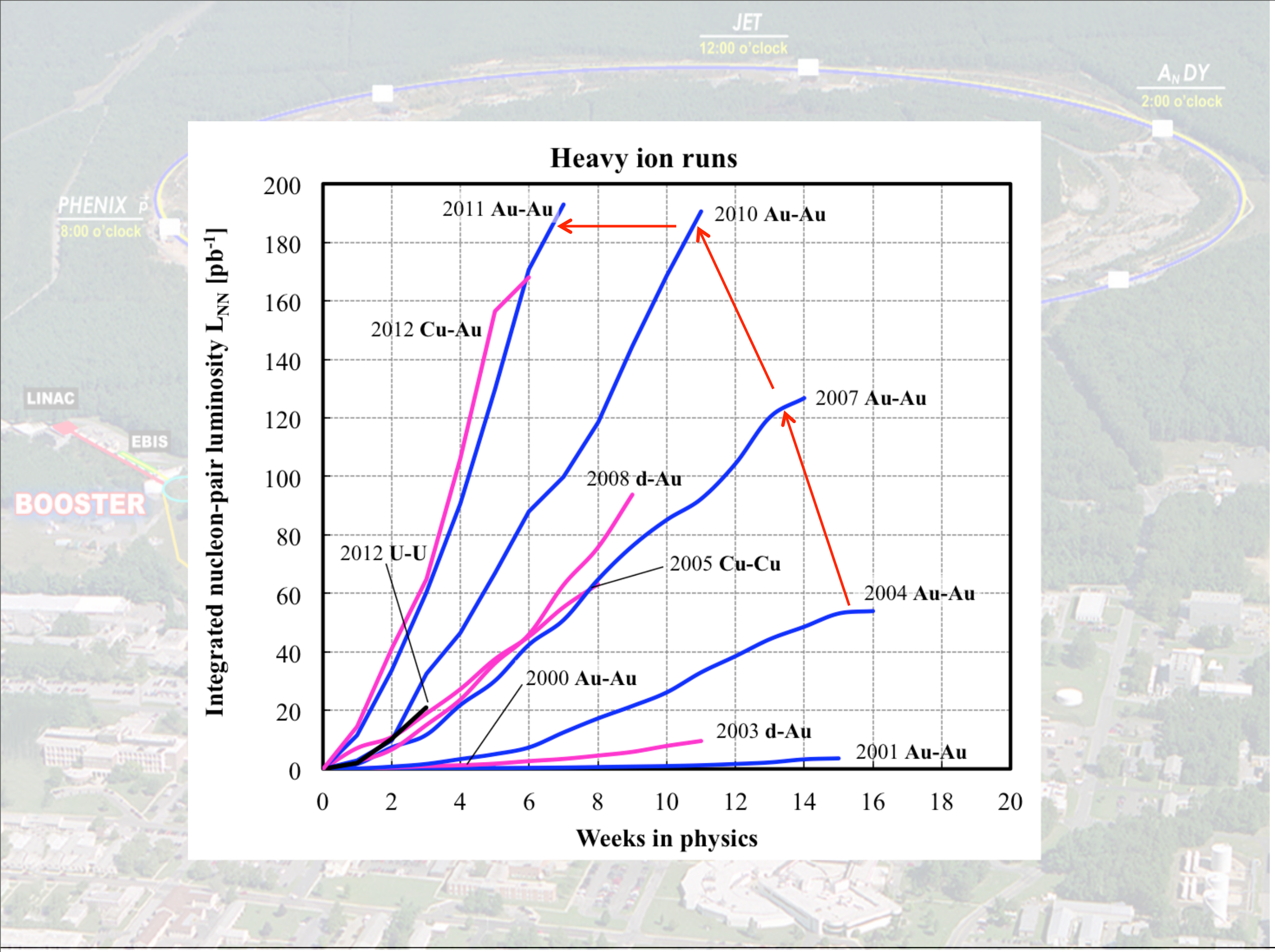
4
6
8
10
12
14
16
18
20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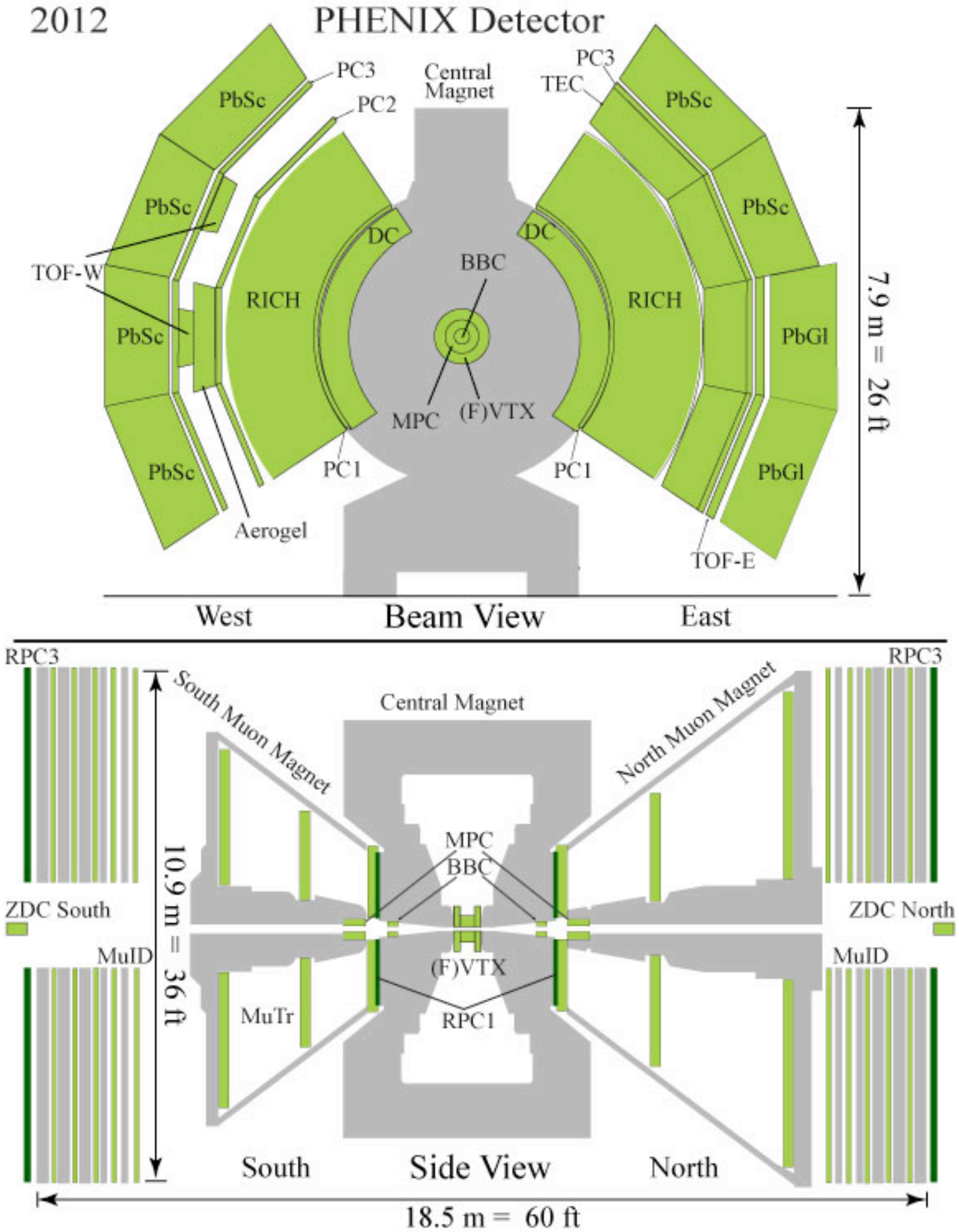
2004 Au-Au
2000 Au-Au
2003 d-Au
2001 Au-Au
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
14
16
18
20

$|y|<0.35$ $\Delta\Phi=2\times\pi/2$

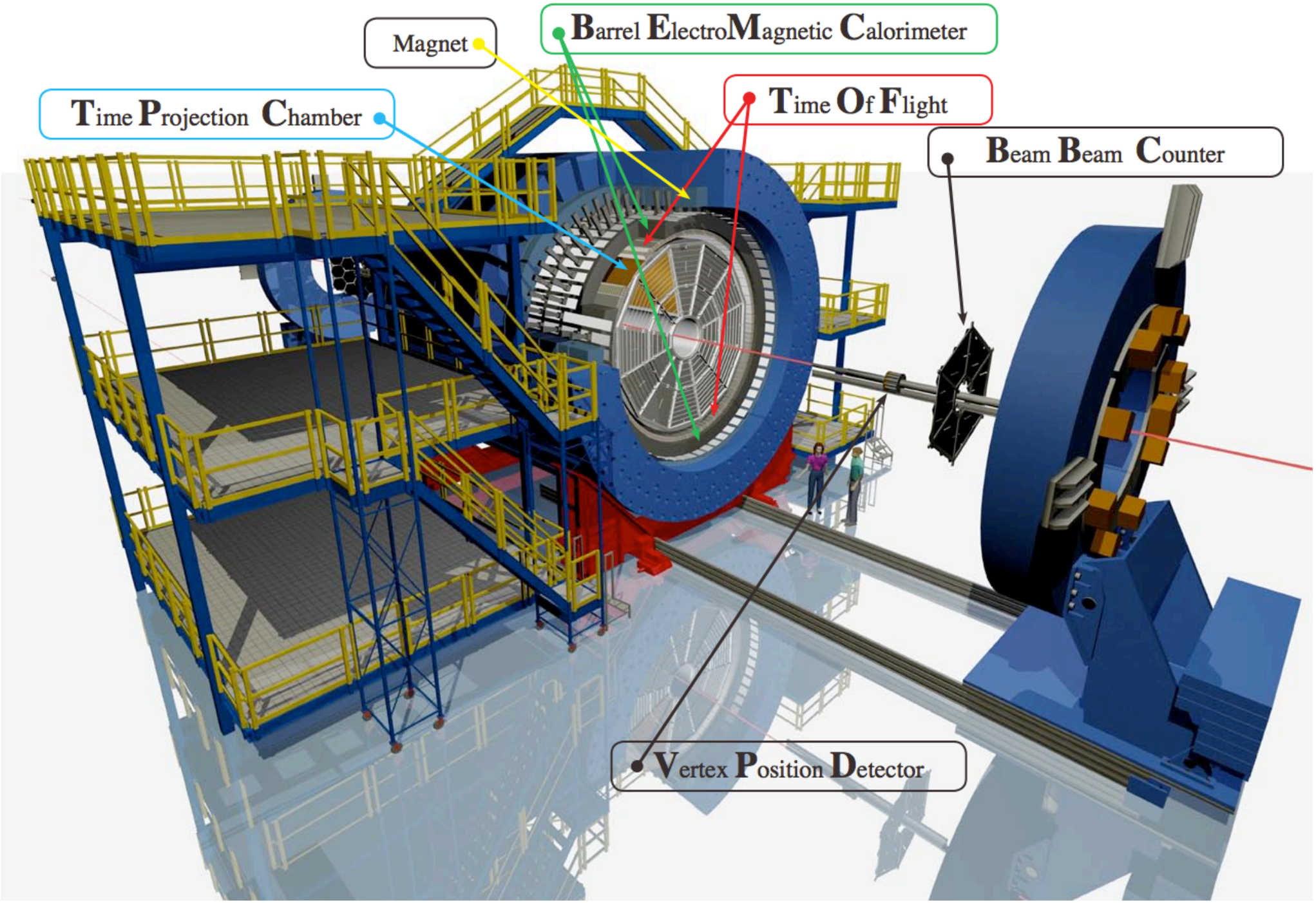
PHENIX can measure quarkonia from zero momentum

dilepton decays: J/ψ, ψ', Υ
radiative decays: $\chi_c \to e^+e^-\gamma$

$1.2<|y|<2.2$ $\Delta\Phi=2\pi$

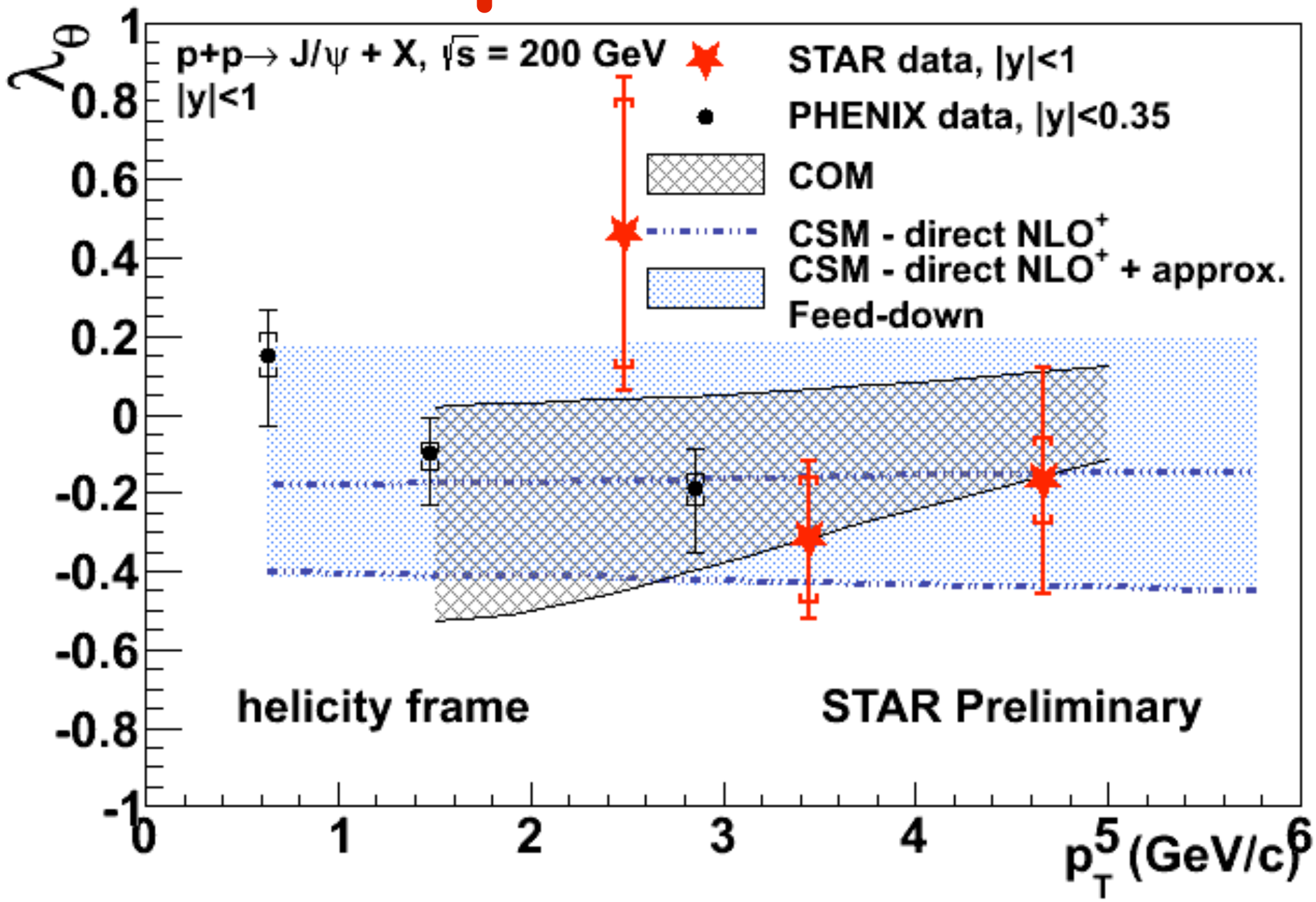


Solenoidal Tracker At RHIC : $-1 < \eta < 1, 0 < \phi < 2\pi$



p+p Collisions

Extended p_T J/ψ Polarization



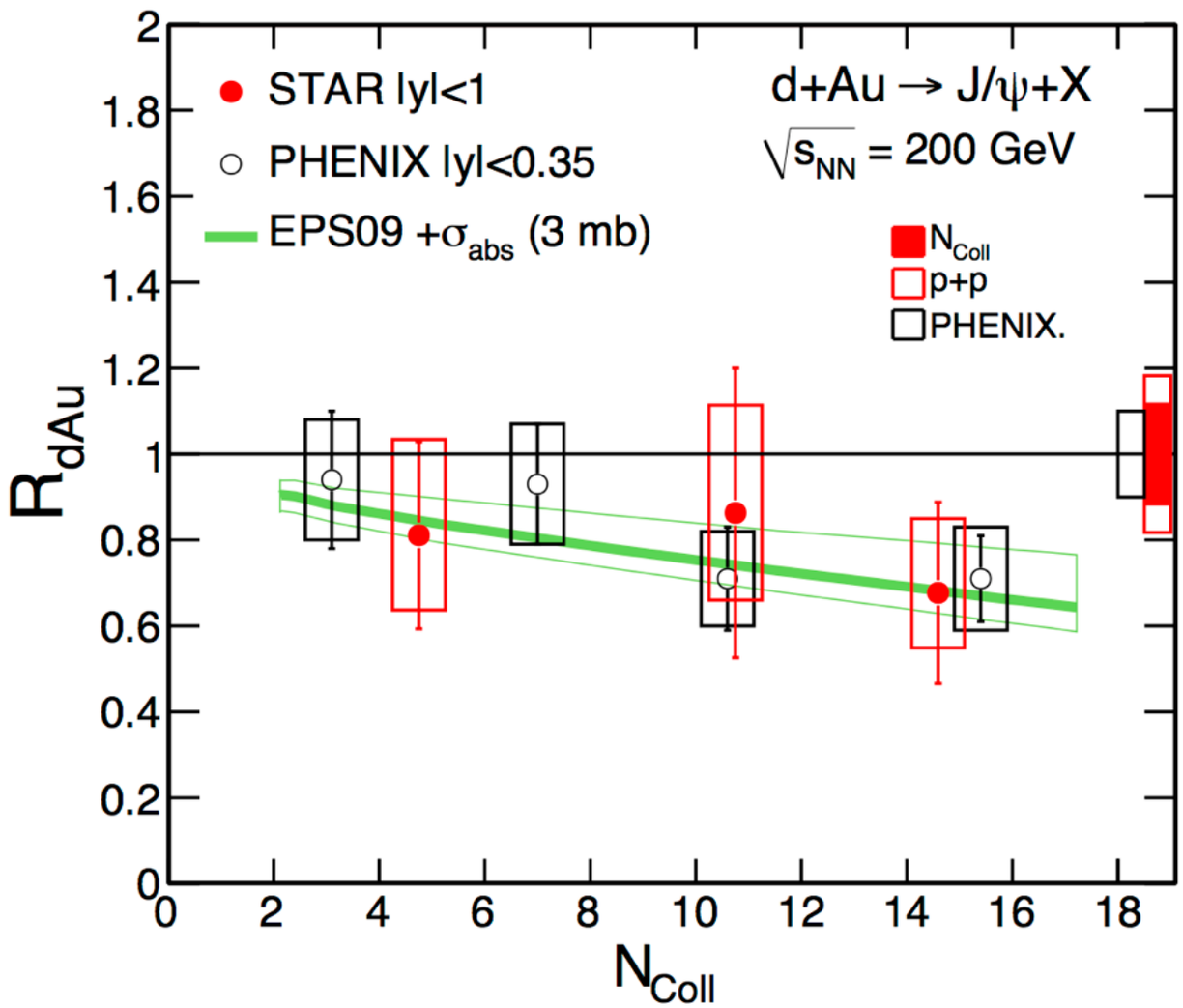
Big experimental and theoretical uncertainties.

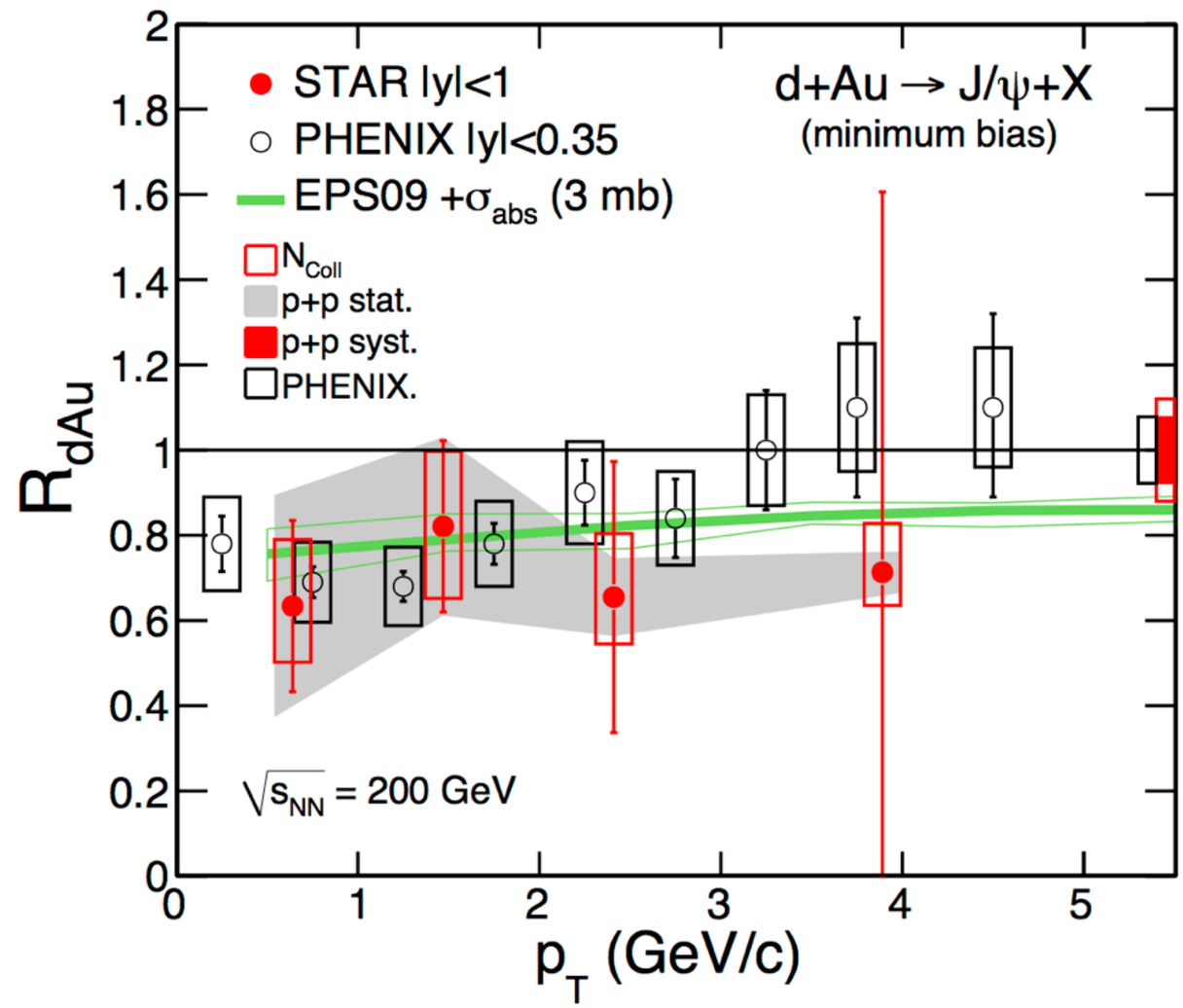
No conclusion about charmonium formation mechanism from polarization measurement

d+Au Collisions

Probing the initial state

$$d + Au \quad \sqrt{s_{NN}} = 200GeV$$

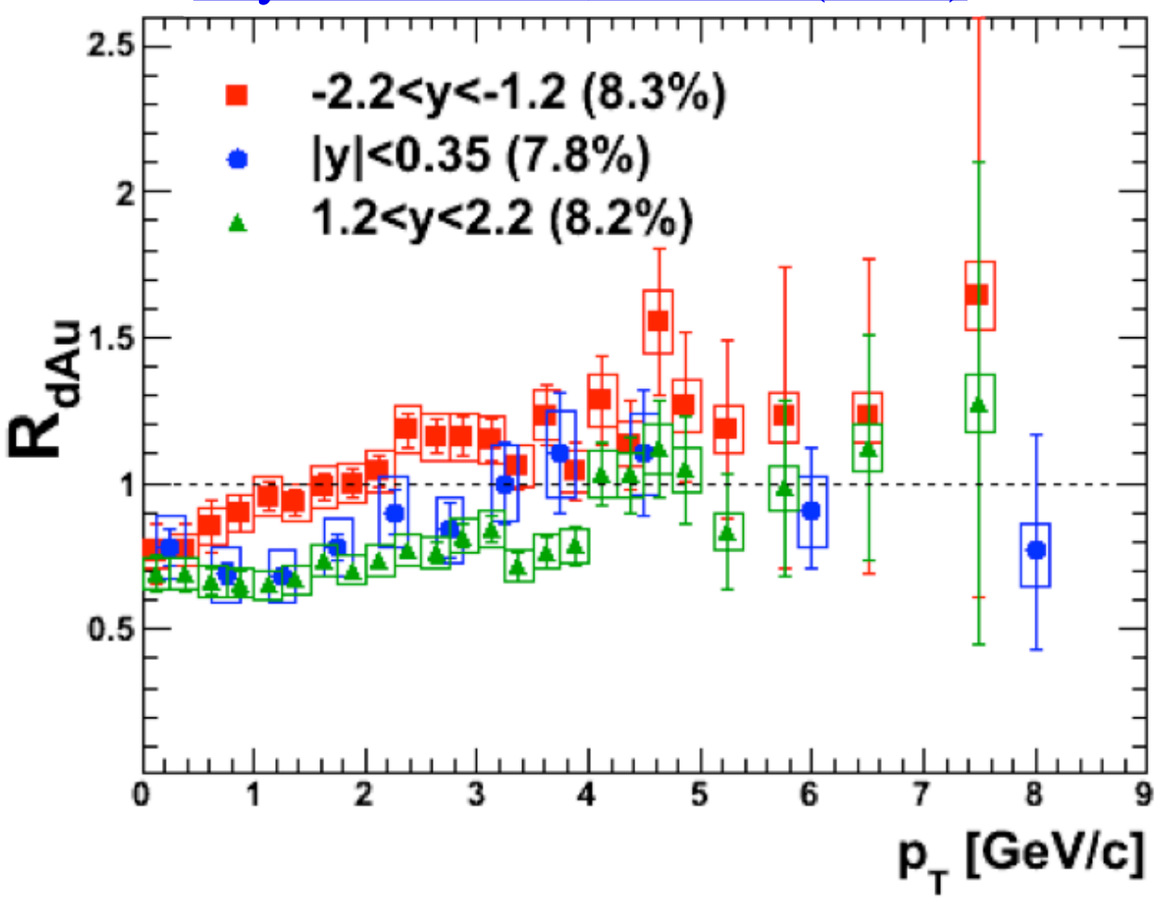


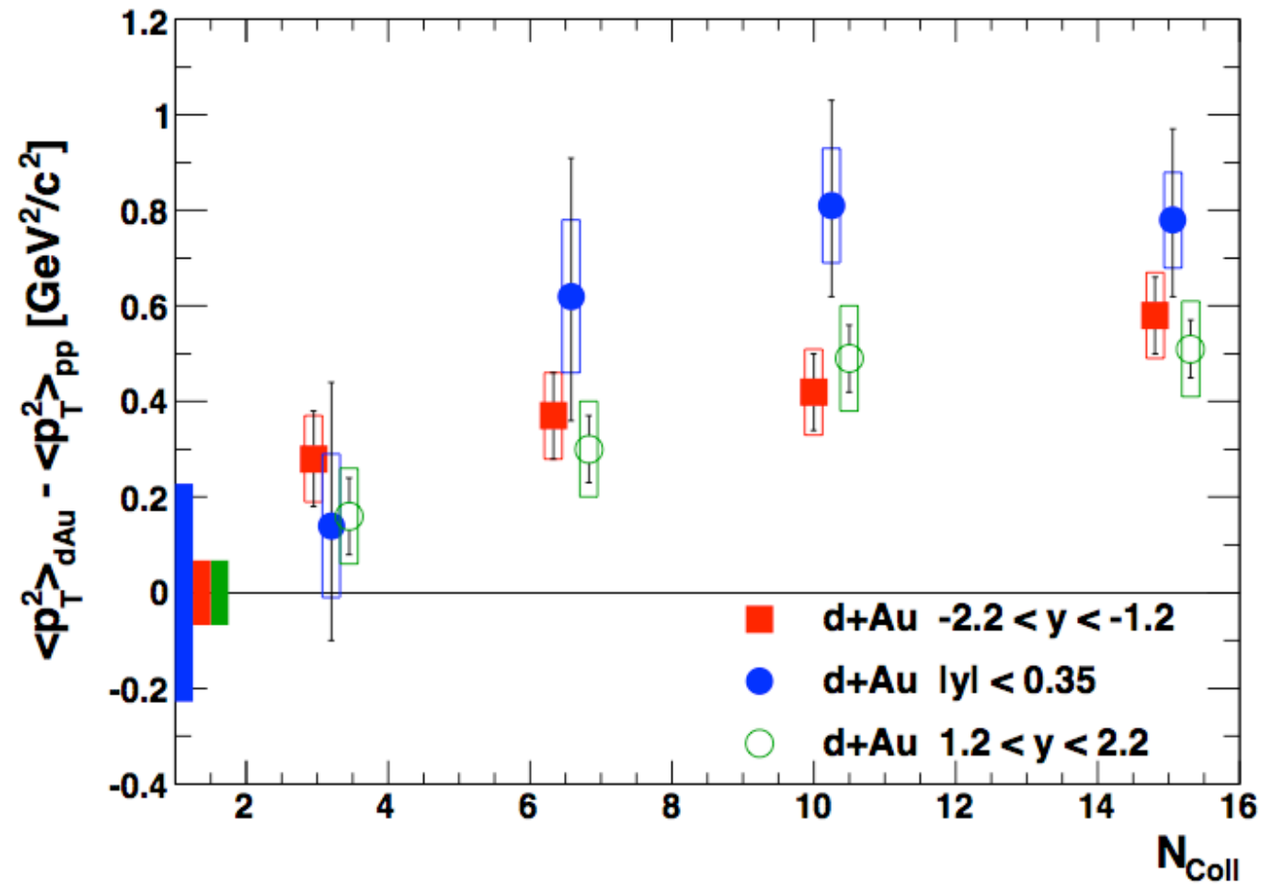


EPS09 + J/ψ breakup in hadronic matter qualitatively describes Minimum Bias R_{dAu} data

Final-state effects in cold nuclear matter

Phys. Rev. C 87, 034904 (2013)



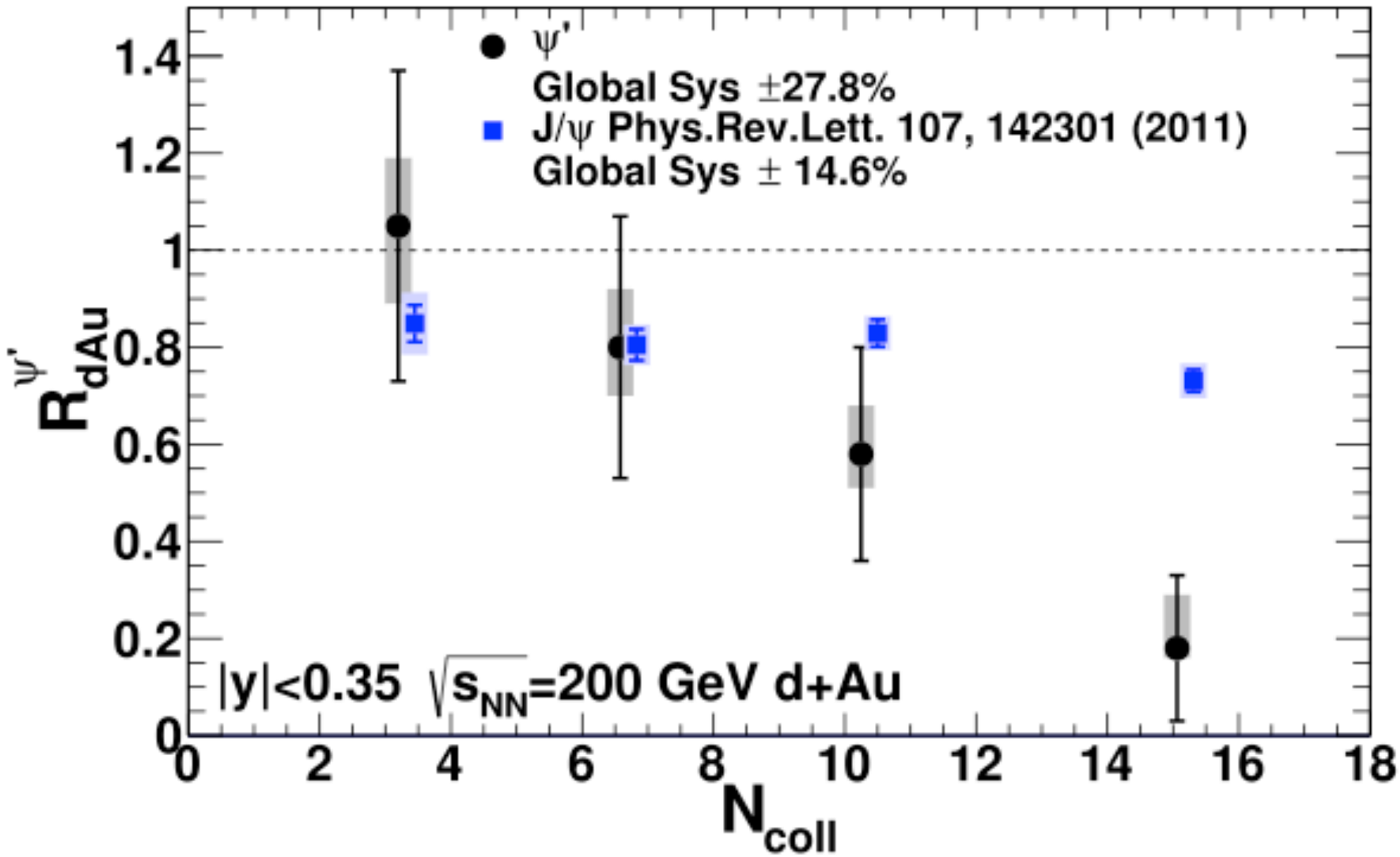


Significant Cronin effect

- R_{dA} increasing with p_T is larger than what is expected from shadowing/anti-shadowing

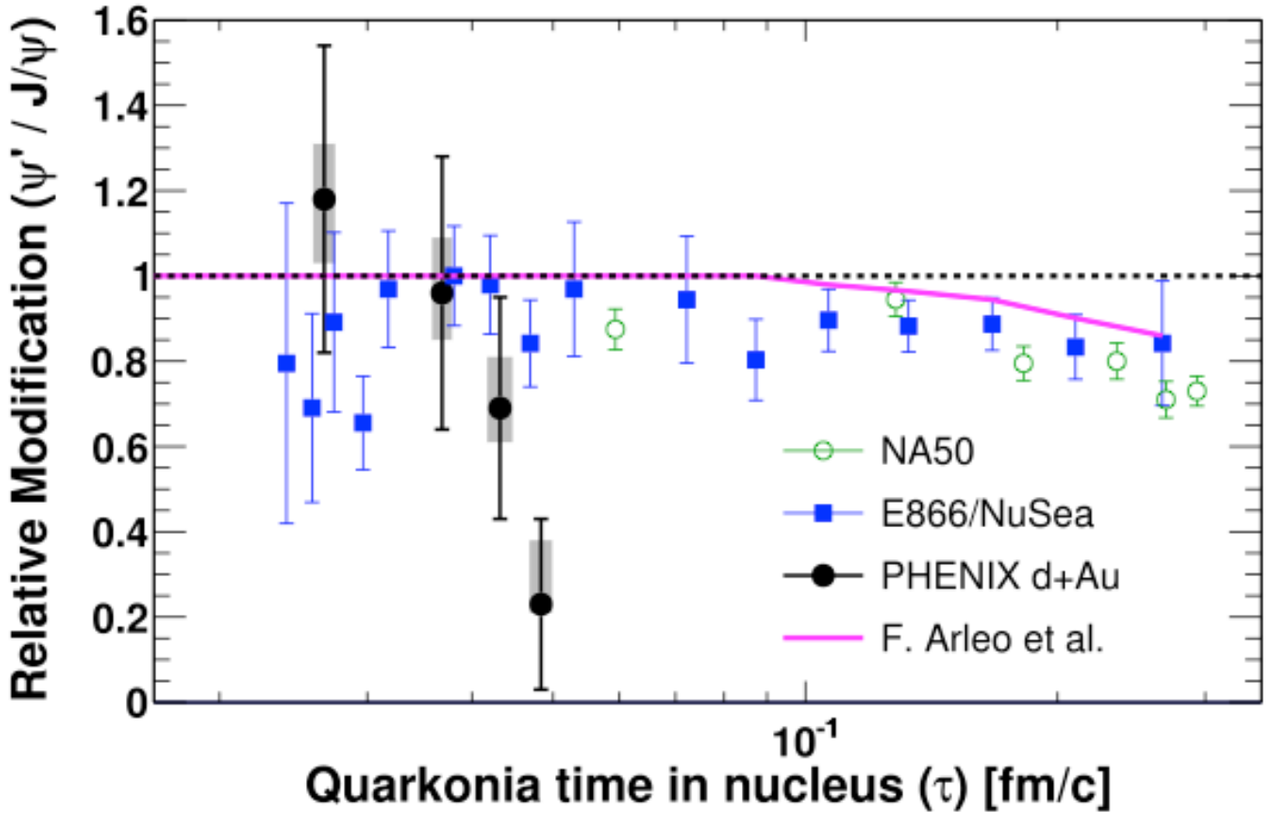
- result can explain the larger J/ψ R_{AA} at high p_T in A+A

Final-state effects in cold nuclear matter



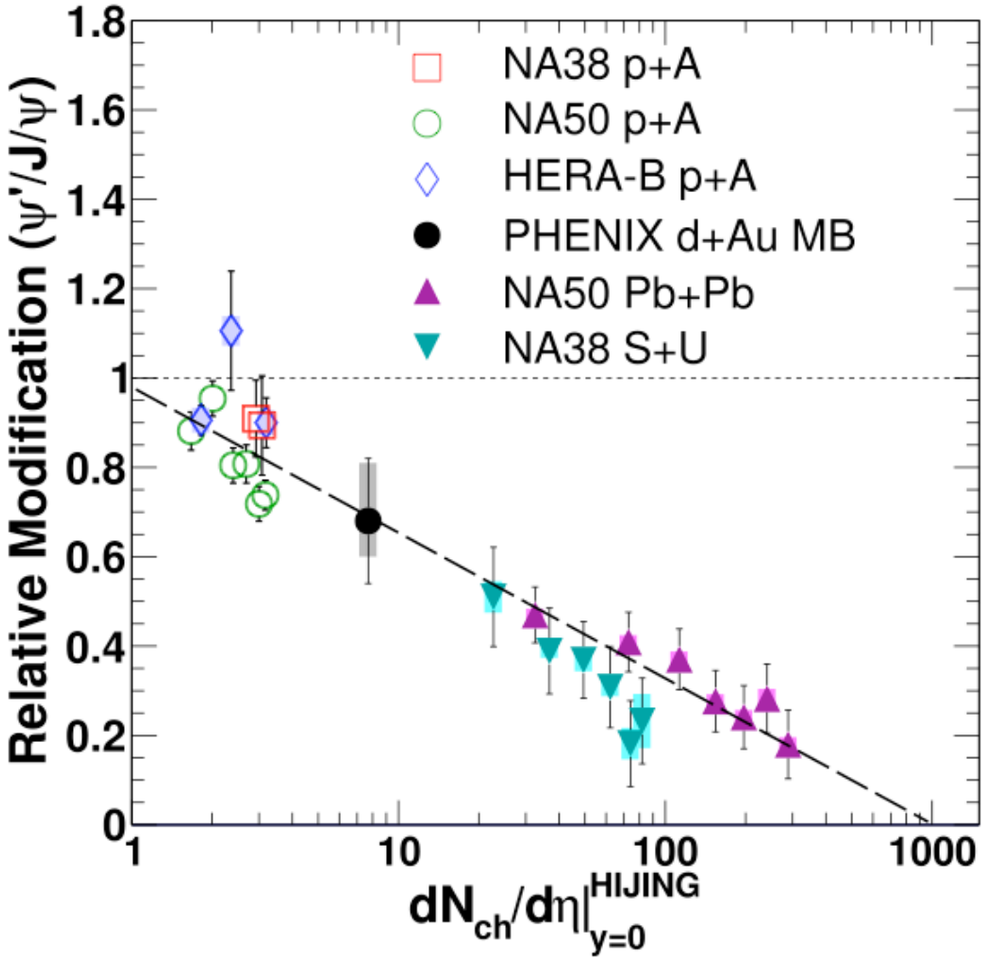
arXiv:1305.5516

- same initial-state effects for J/ψ and ψ'
- stronger suppression of ψ'



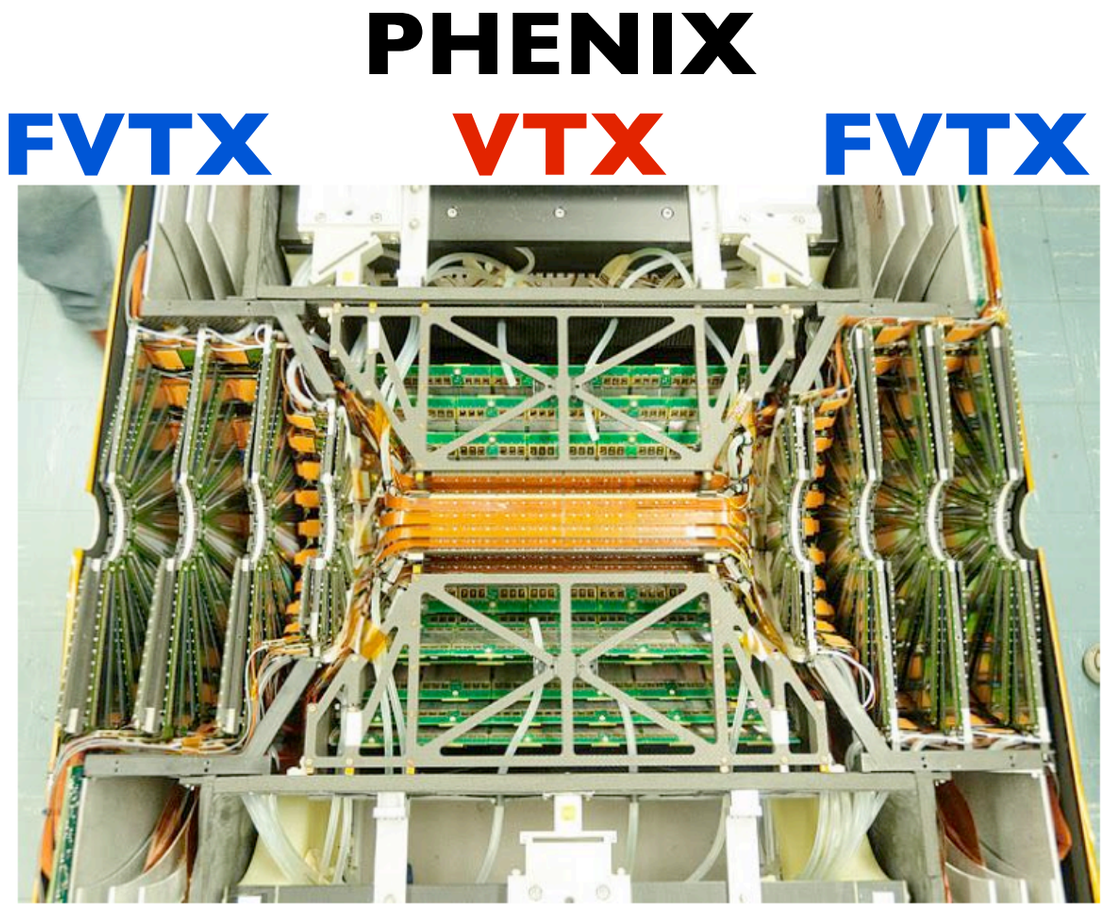
- crossing time is very short, there is no time for the formation of the final states J/ψ and ψ'

- data suggests J/ψ and ψ' can be formed differently at precursor $c\bar{c}$ stage

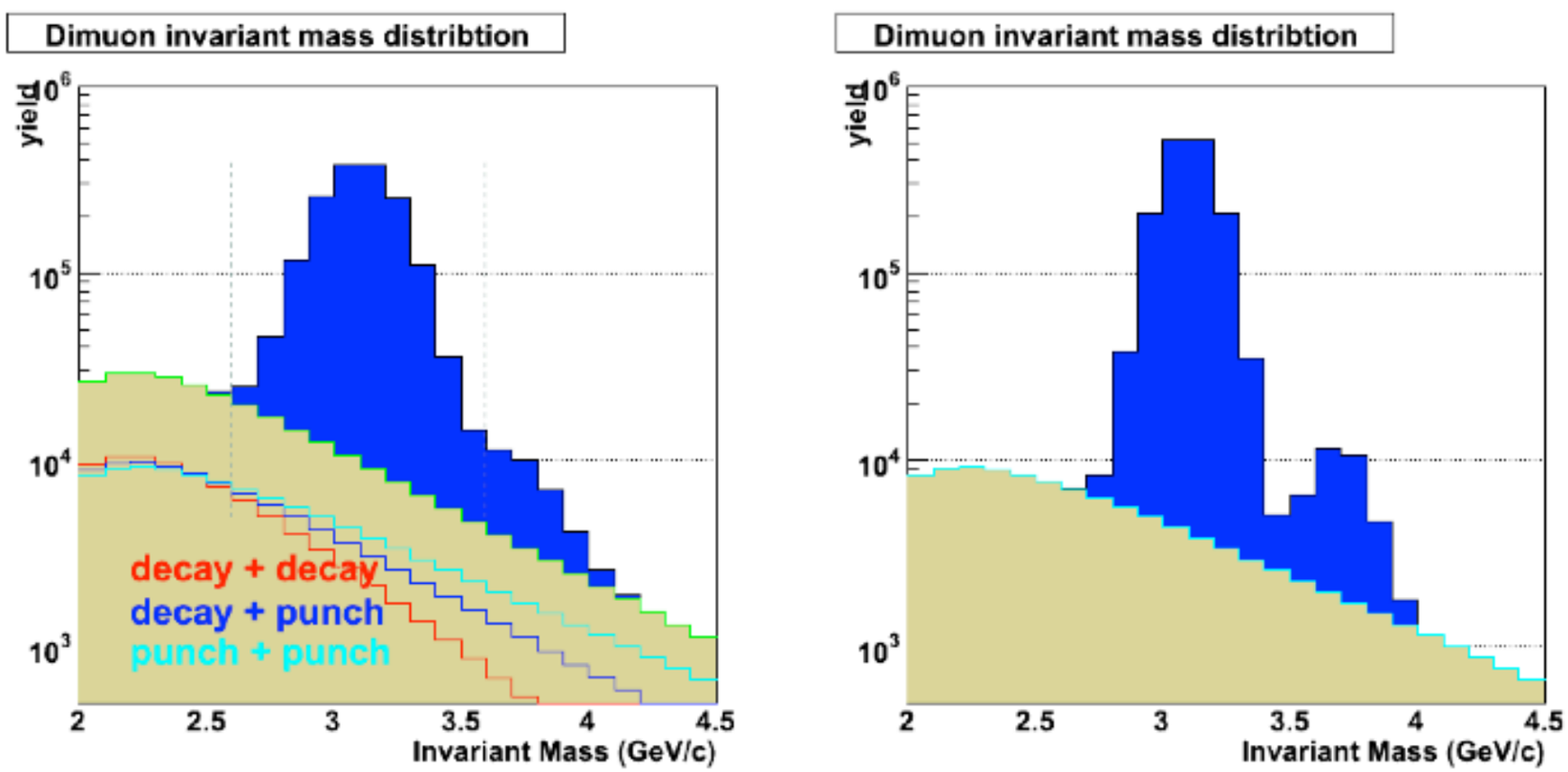


- breakup with final-state hadrons (comovers) ?

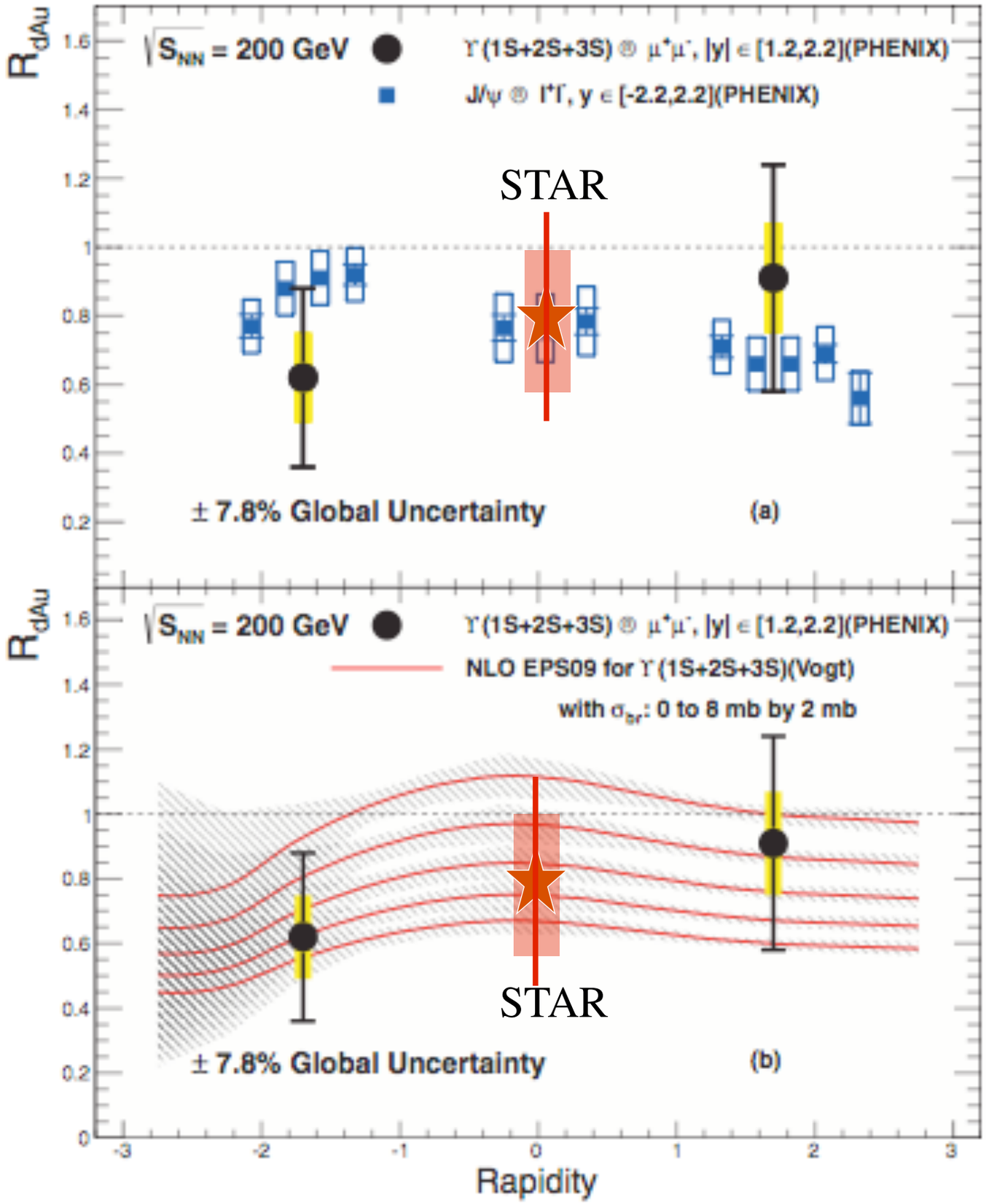
Future ψ' Measurements



Upcoming measurements at large rapidities will scan different charmonia crossing times



CNM effects on Upsilon Family

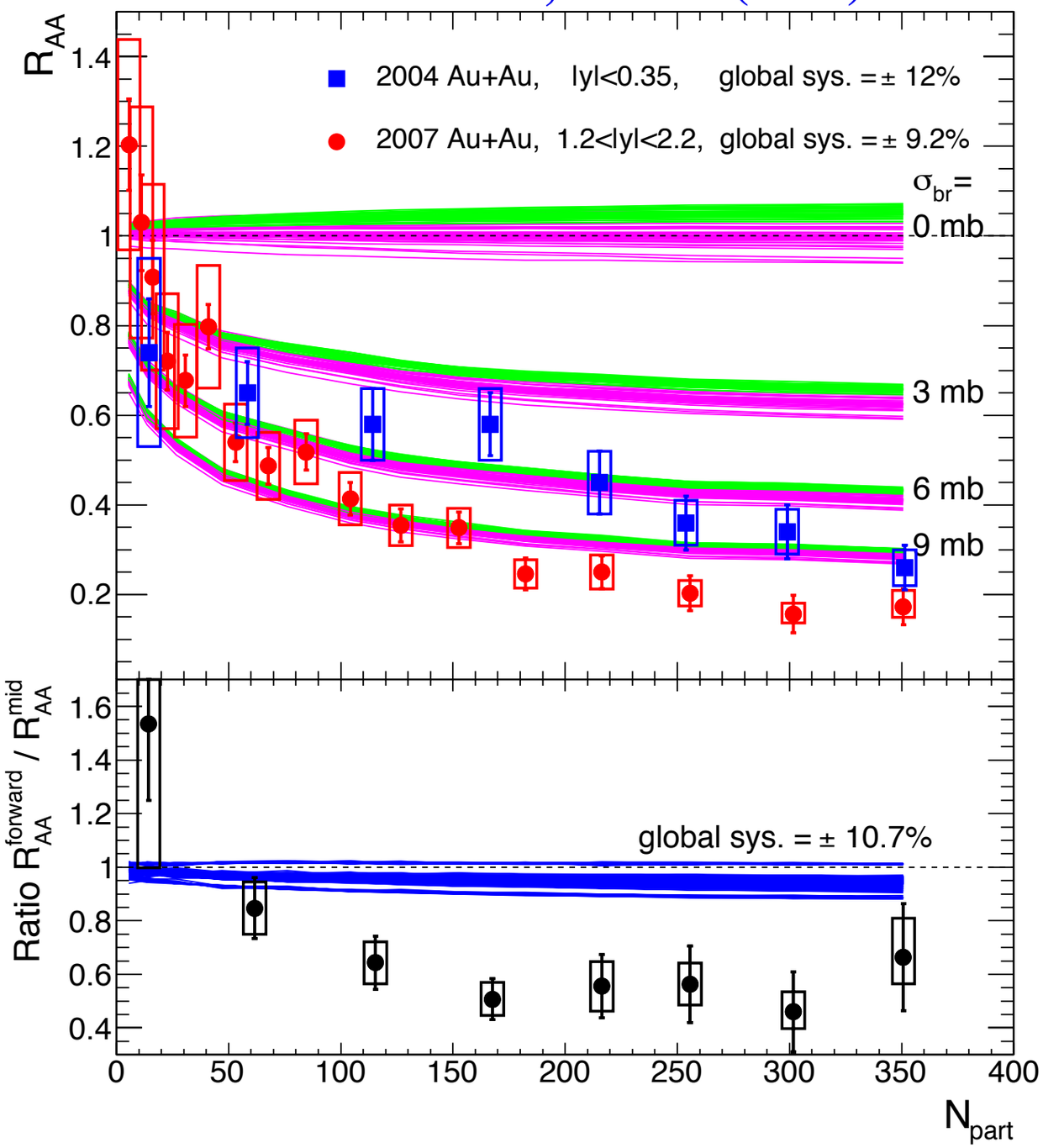


Phys. Rev. C 87, 044909 (2013)

A+A Collisions

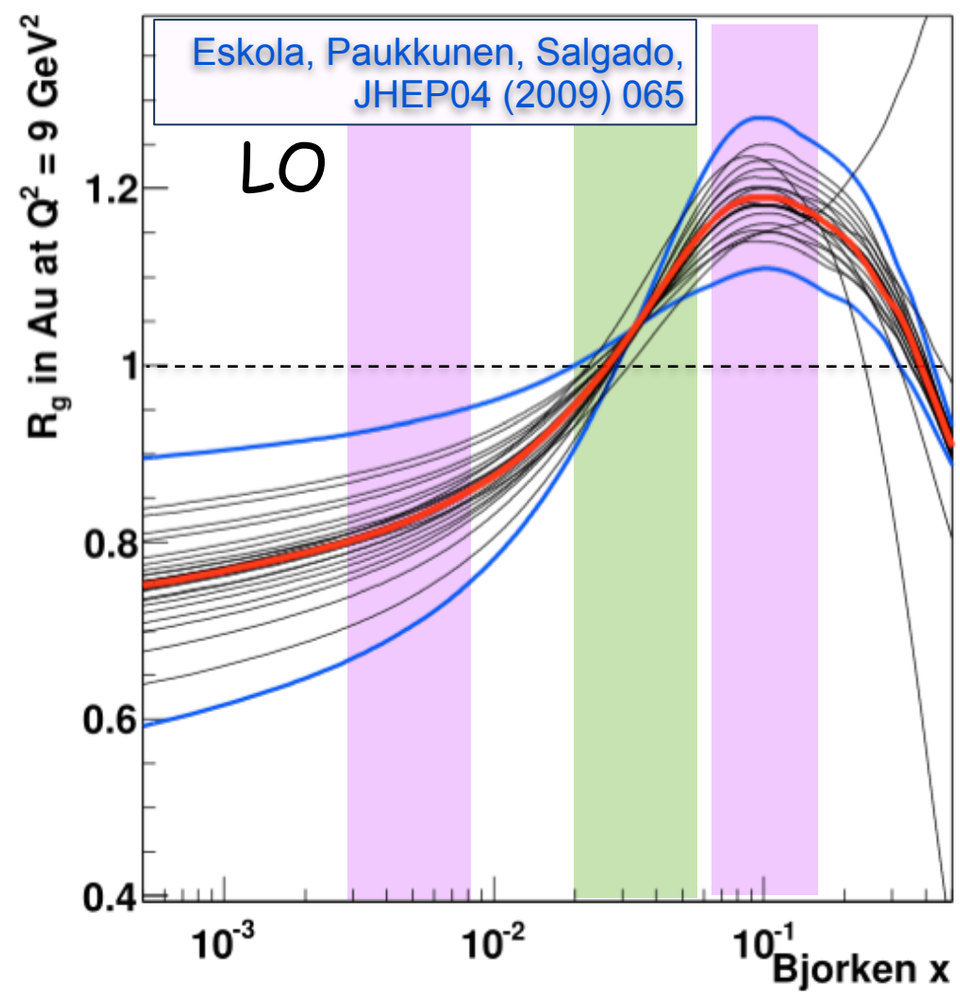
Propagation of nPDF+breakup to Au+Au

PRC84, 054912 (2011)



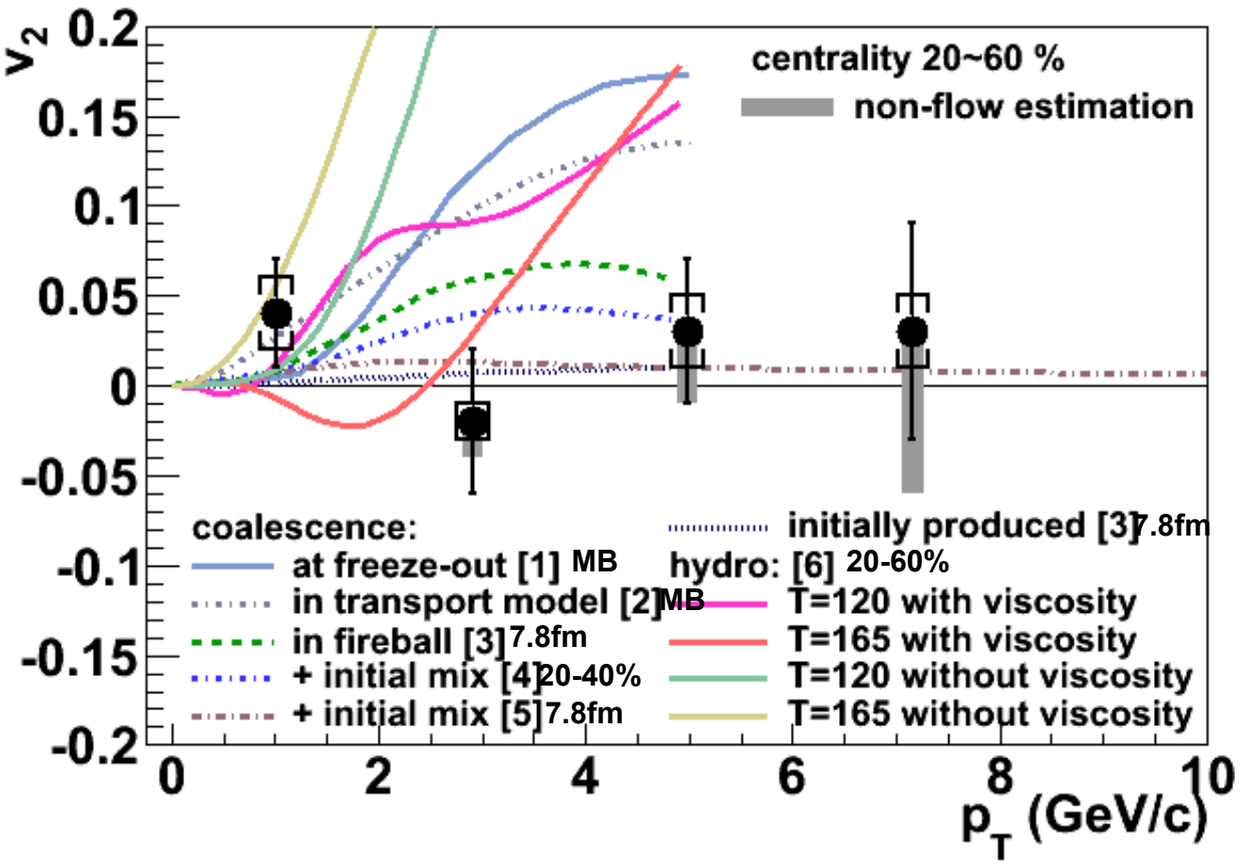
nPDF cannot describe the stronger suppression observed at forward rapidity in Au+Au collisions

Forward rapidity in Au+Au is a mix of small-x, large-x effects which cancel out

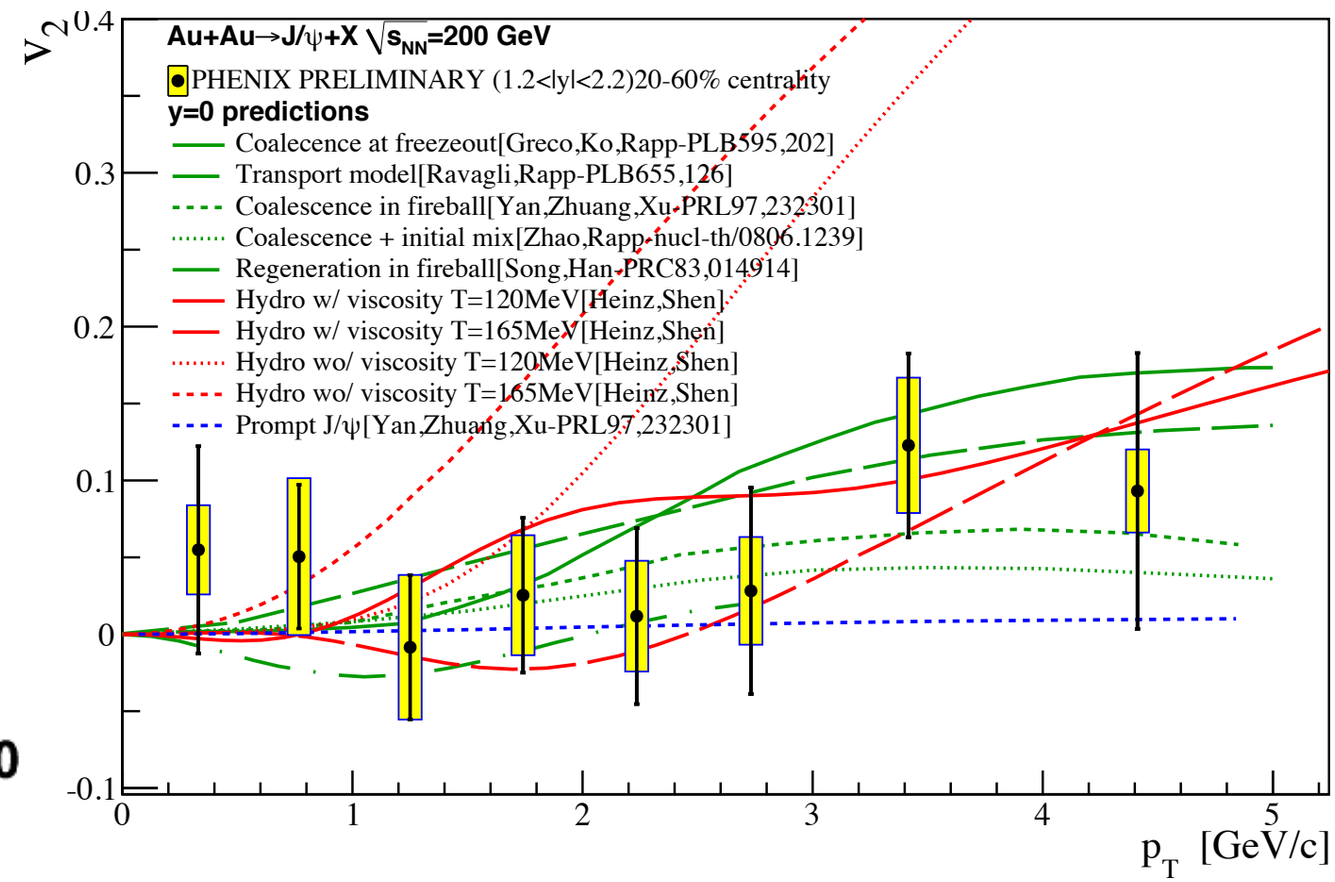


Coalescence and Regeneration

Mid-Rapidity



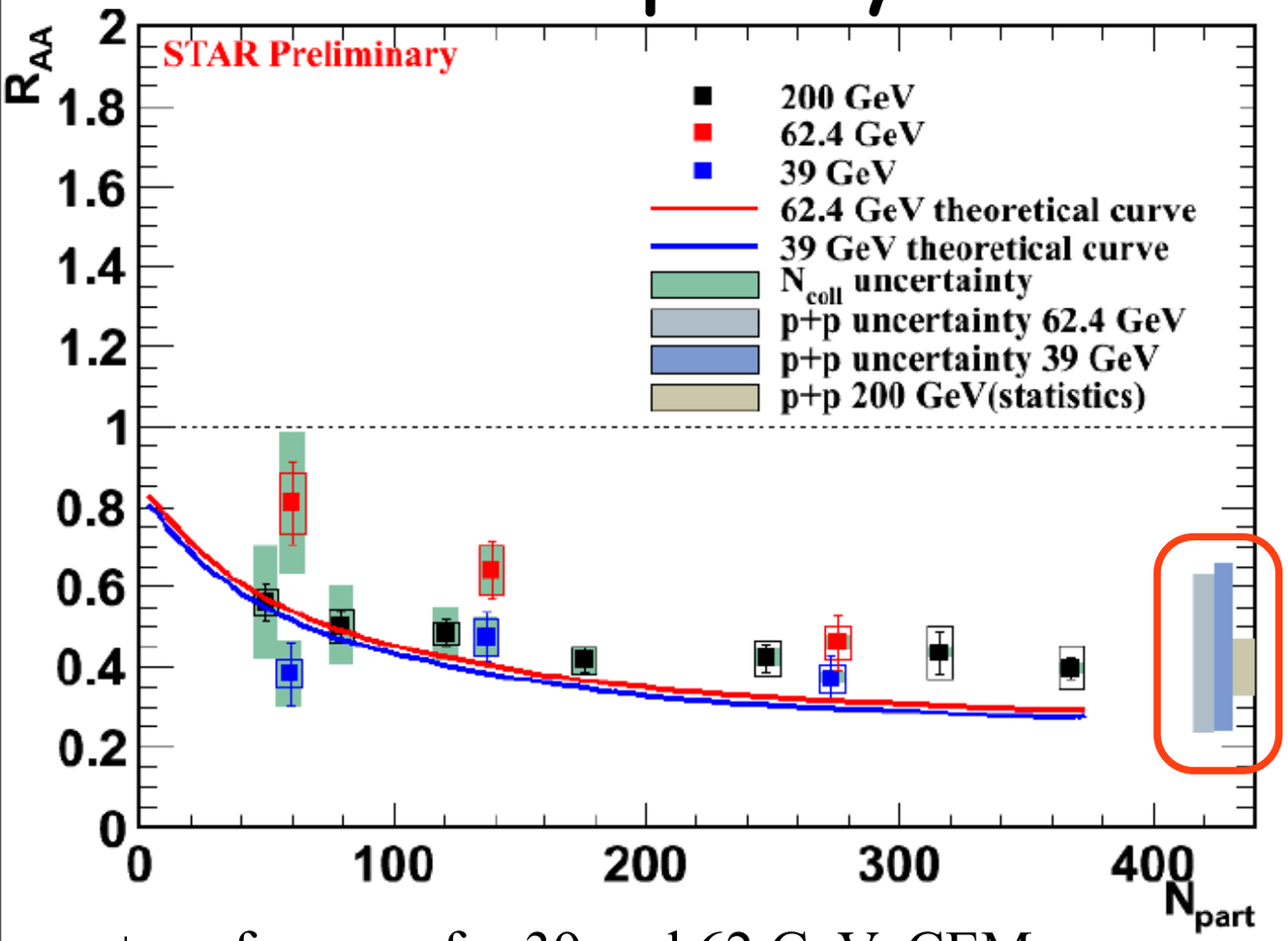
Forward-Rapidity



- data do not rule out all coalescence scenarios at RHIC
- Looking forward for theoretical estimations at forward rapidity...

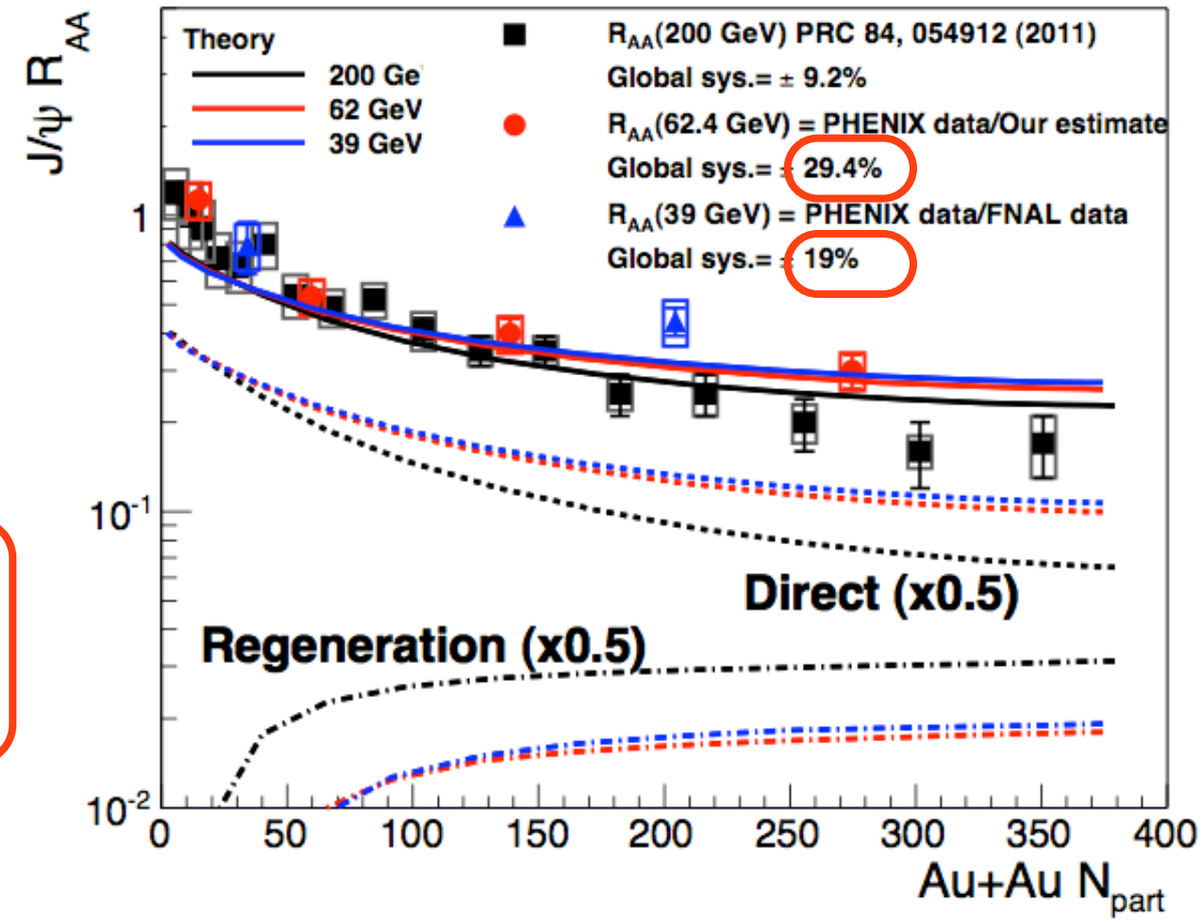
Collision Energy Dependence of J/ψ R_{AA}

Mid-Rapidity



p+p references for 39 and 62 GeV: CEM
R. Nelson, R. Vogt et al, arXiv:1210.4610

Forward-Rapidity

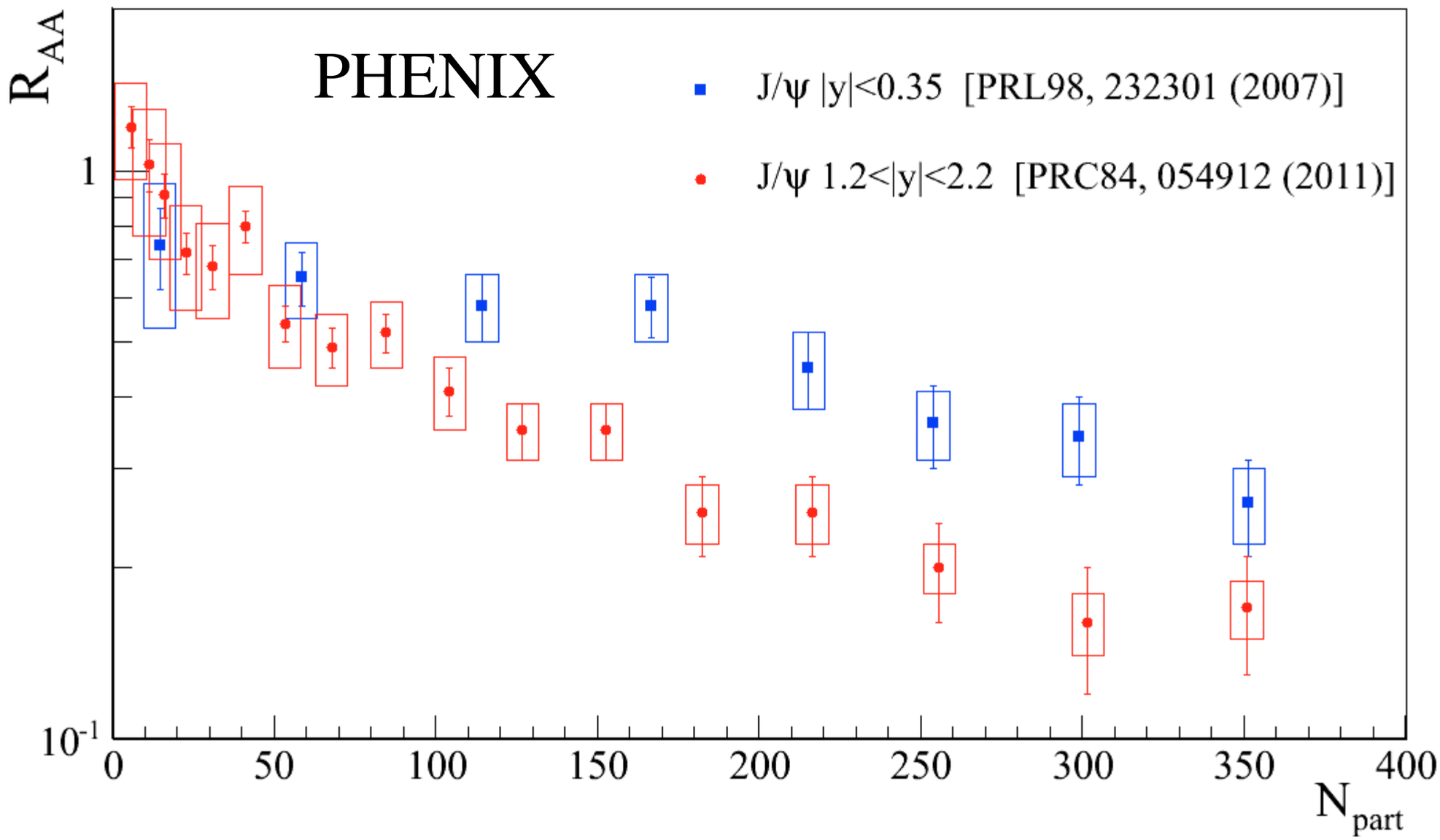


Using p+p reference from FERMILAB and ISR

Theoretical curves: Xingbo Zhao, Ralf Rapp PRC82, 064905 (2010)

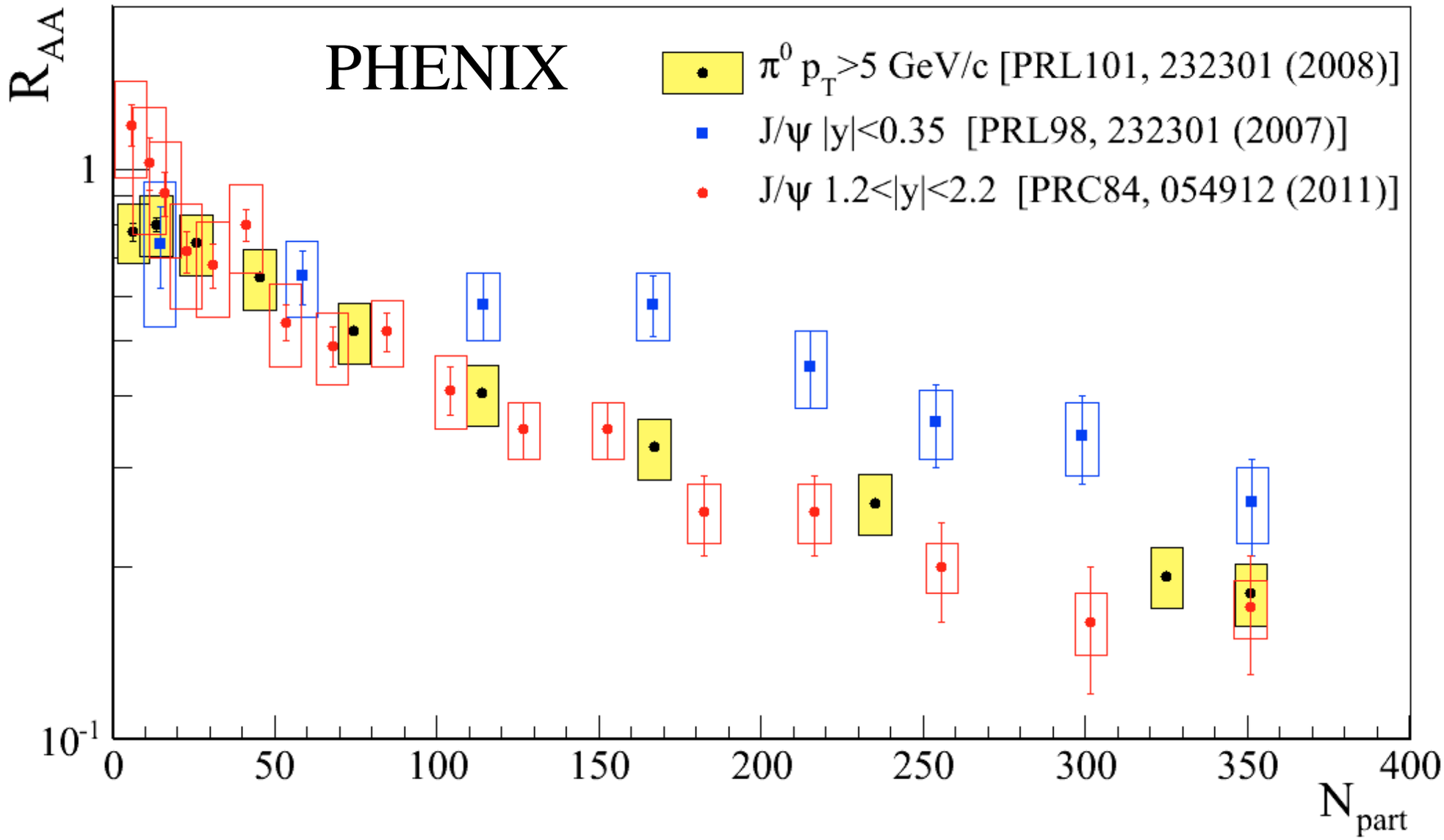
- no energy dependence on J/ψ R_{AA} given the current uncertainties
- needs a p+p reference at 39GeV and 62.4 GeV
- coalescence at high energy can reconcile R_{AA} at different energies

More Curiosities about J/ψ R_{AA}



Log-scale plot suggests more an additional source of J/ψ at mid-rapidity

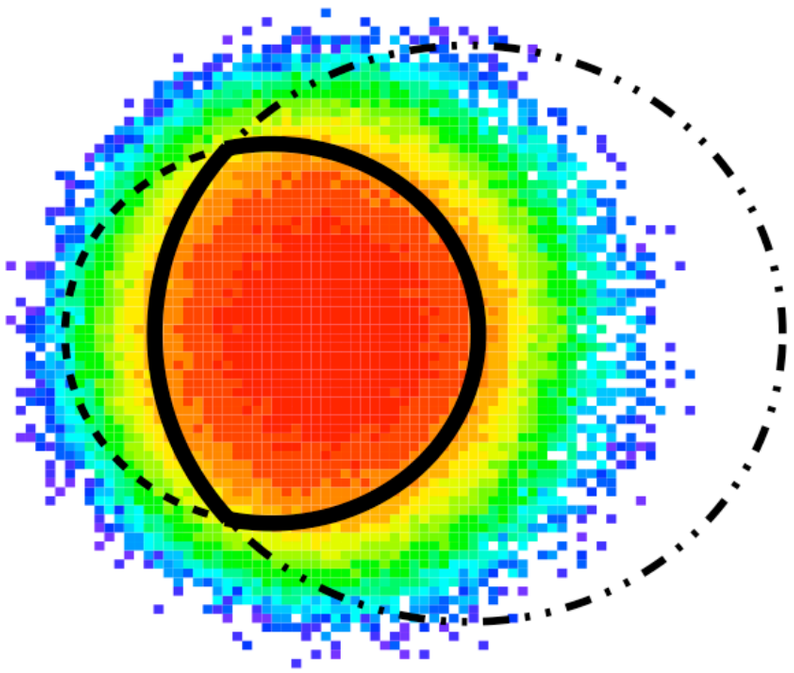
More Curiosities about J/ψ R_{AA}



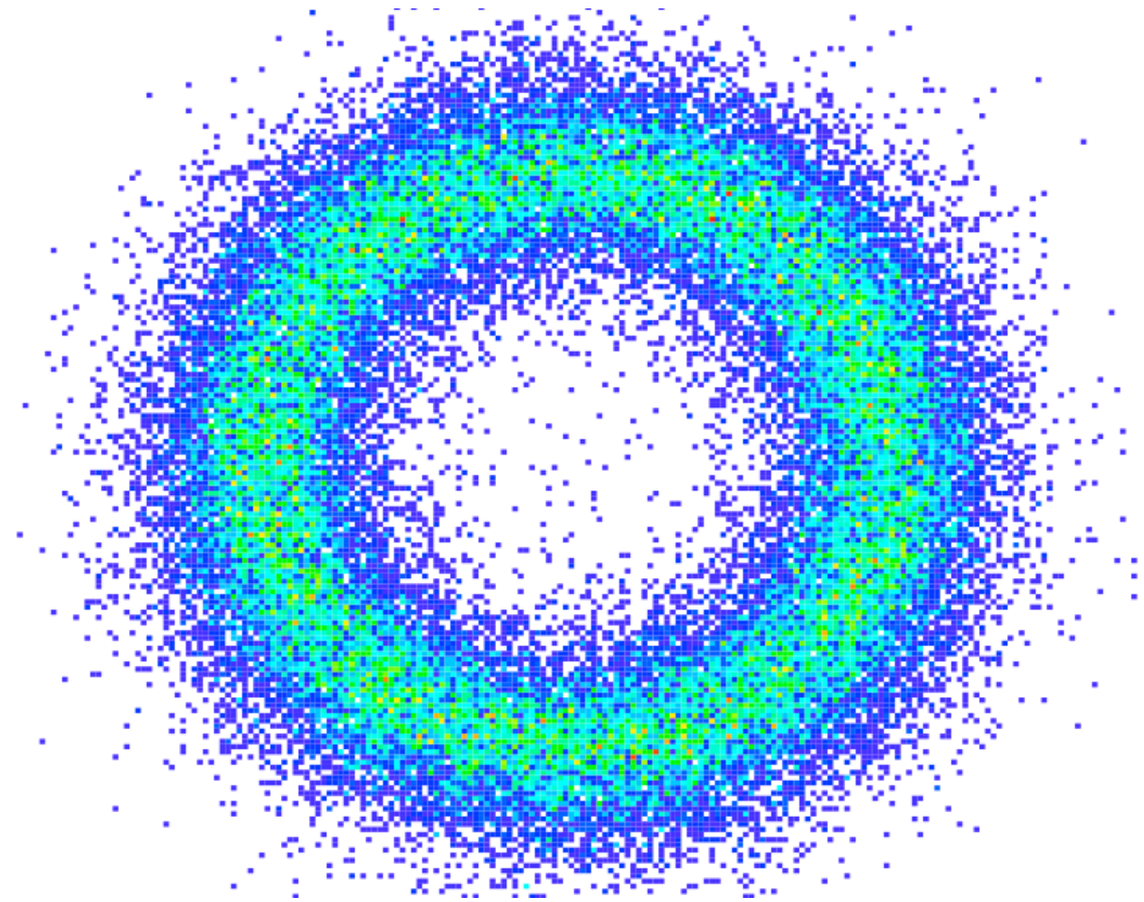
There is no final state effect which can explain such a similar R_{AA} pattern, unless this is a fantastic coincidence.

Gluon distribution modifications measured in p(d)+A does not factorize in Au+Au ?

Asymmetric Collisions: Cu+Au



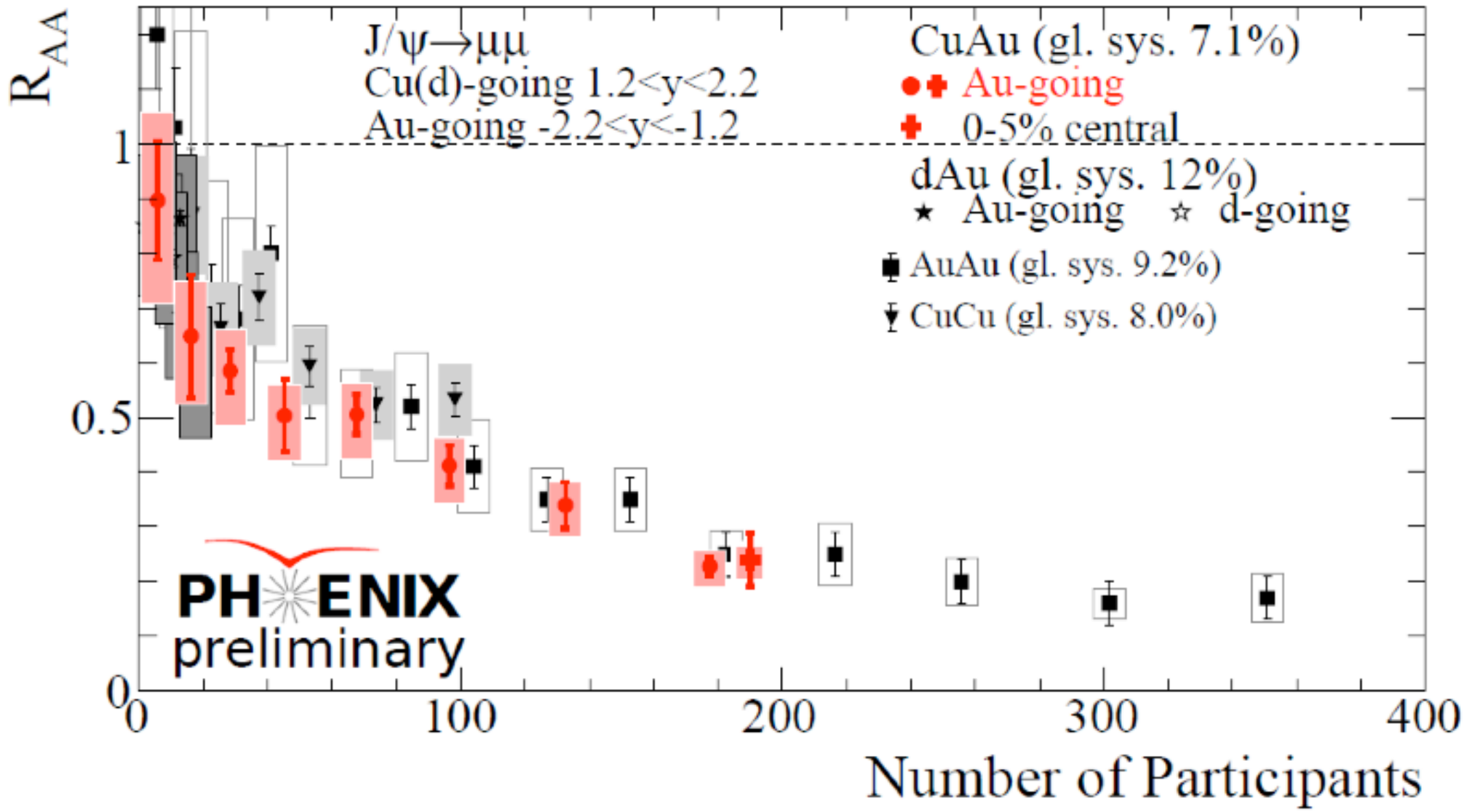
participant density
(log-scale)



spectator density

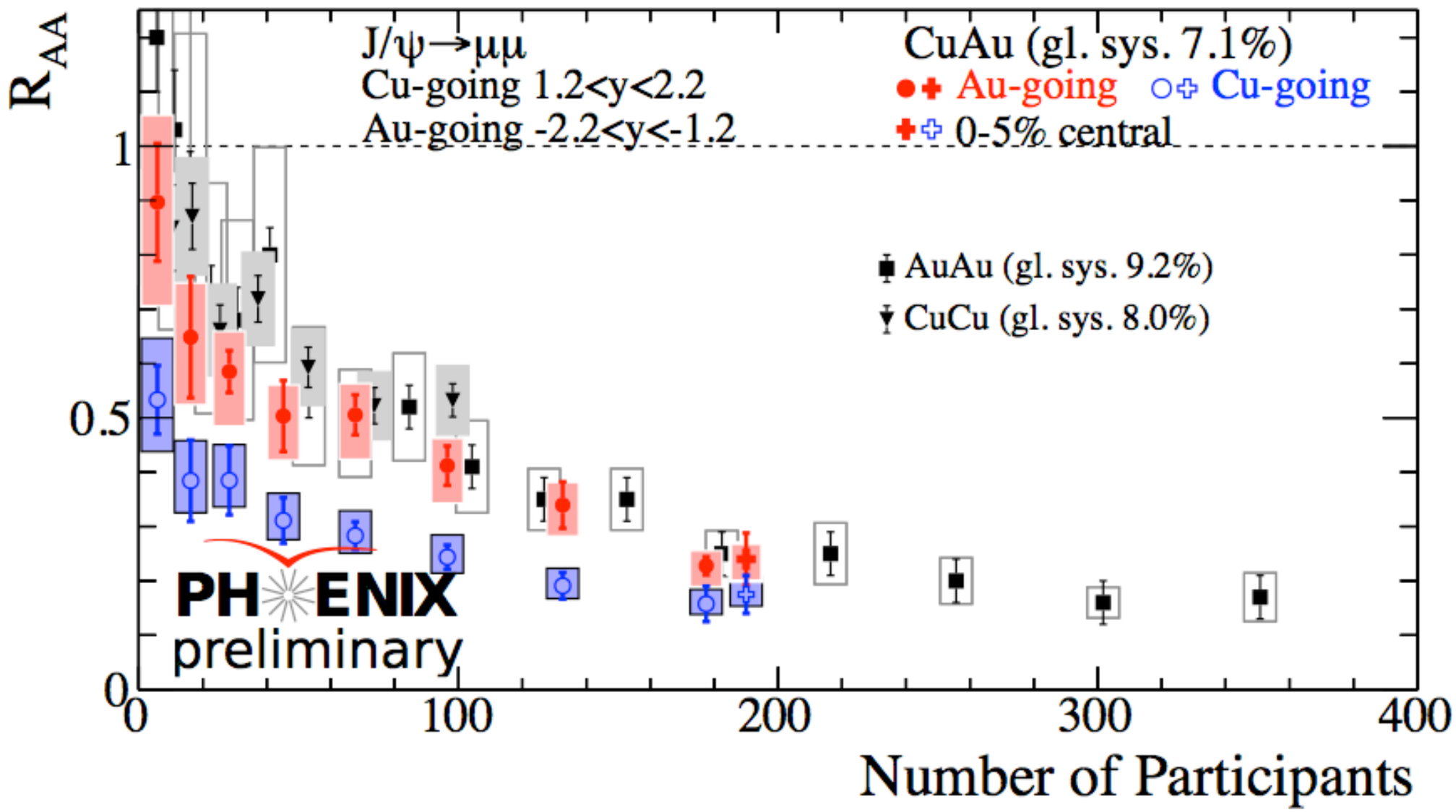
No room for corona effects in central Cu-going direction

Asymmetric Collisions: Cu+Au



Unmodified suppression in Au-going direction when compared to Au+Au

Asymmetric Collisions: Cu+Au



- stronger suppression in Cu-going direction
- but still not completely suppressed

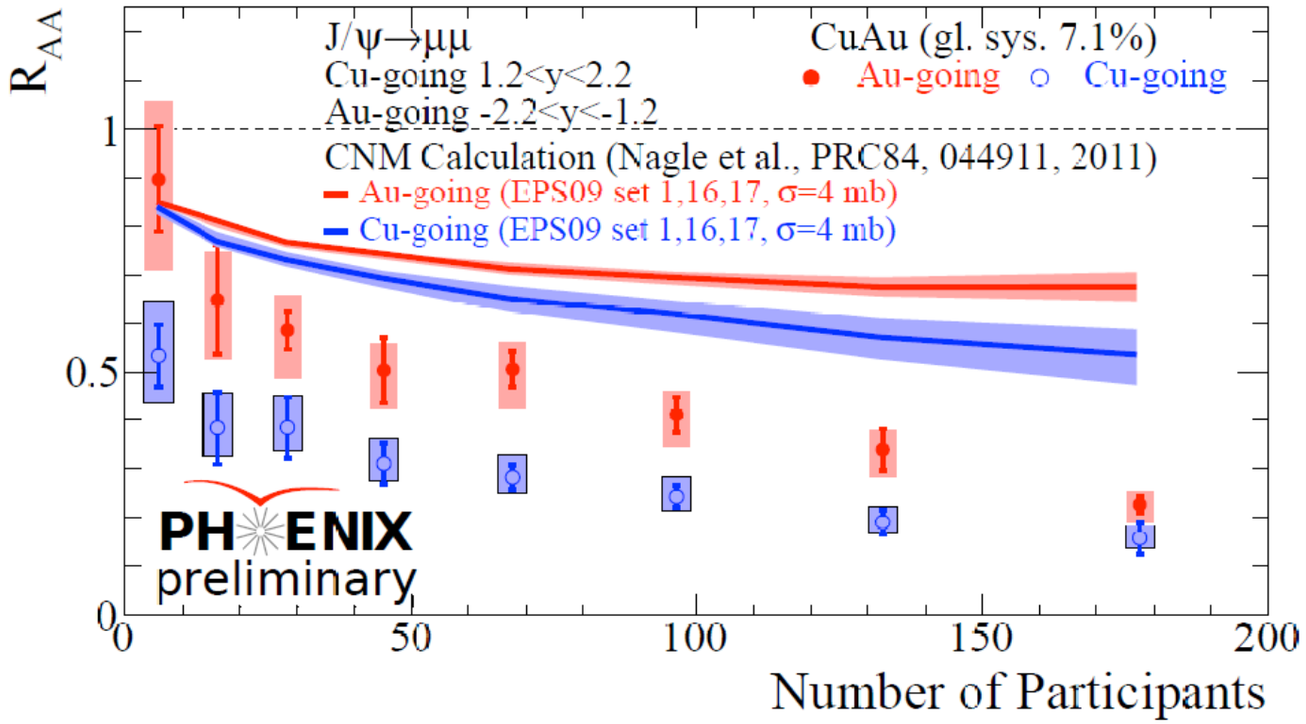
Asymmetric Collisions: Cu+Au

More thought about suppression in Cu-going direction:

Asymmetric Collisions: Cu+Au

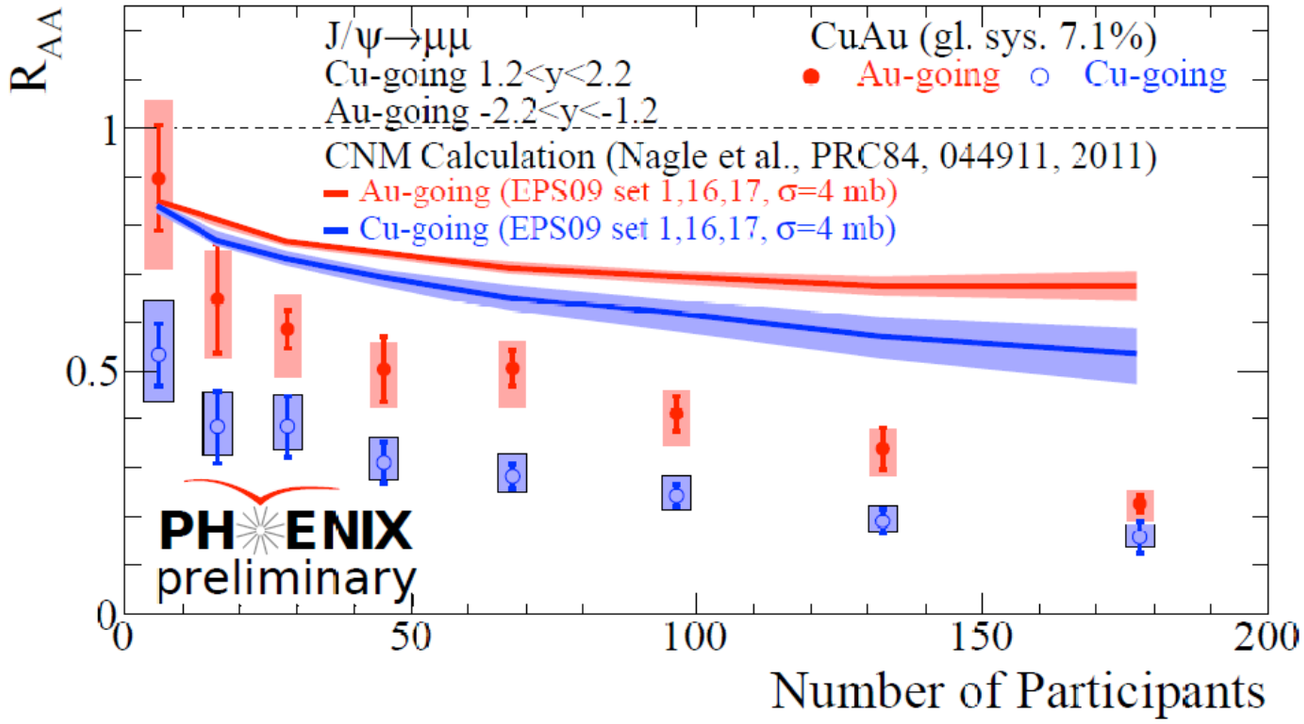
More thought about suppression in Cu-going direction:

- initial-state can partially describe difference

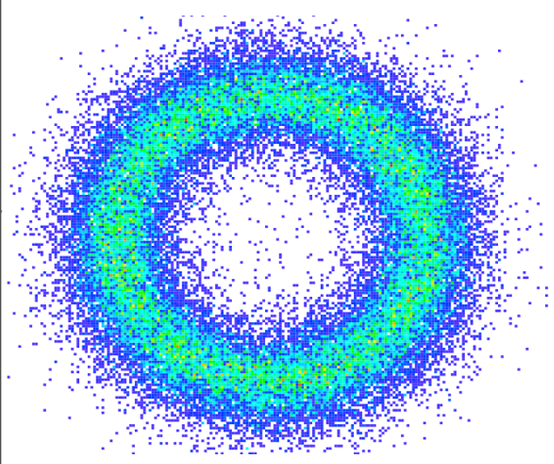


Asymmetric Collisions: Cu+Au

More thought about suppression in Cu-going direction:



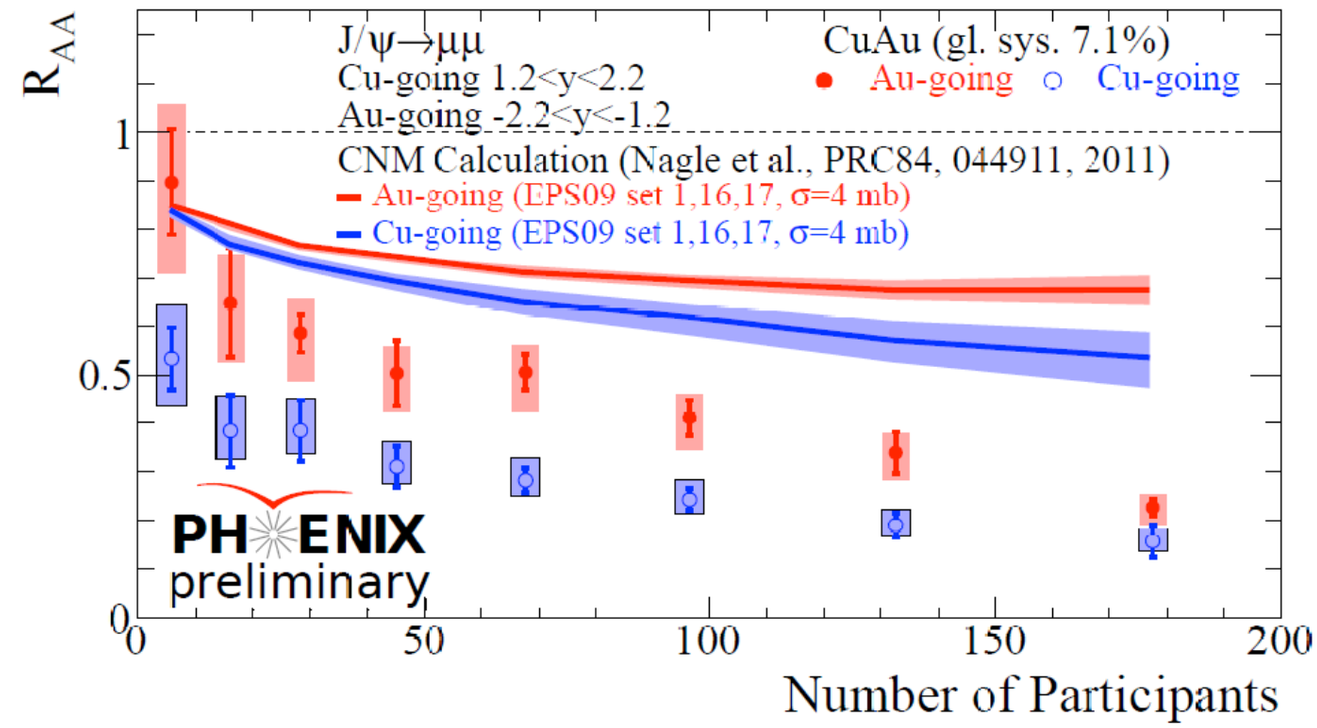
- initial-state can partially describe difference



- J/ψ formed has to cross some cold matter (halo in the picture)

Asymmetric Collisions: Cu+Au

More thought about suppression in Cu-going direction:



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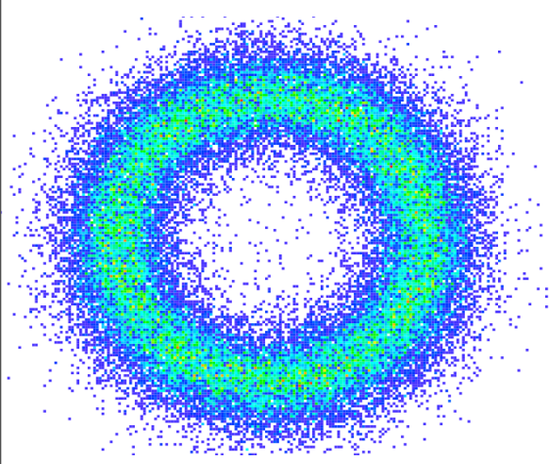
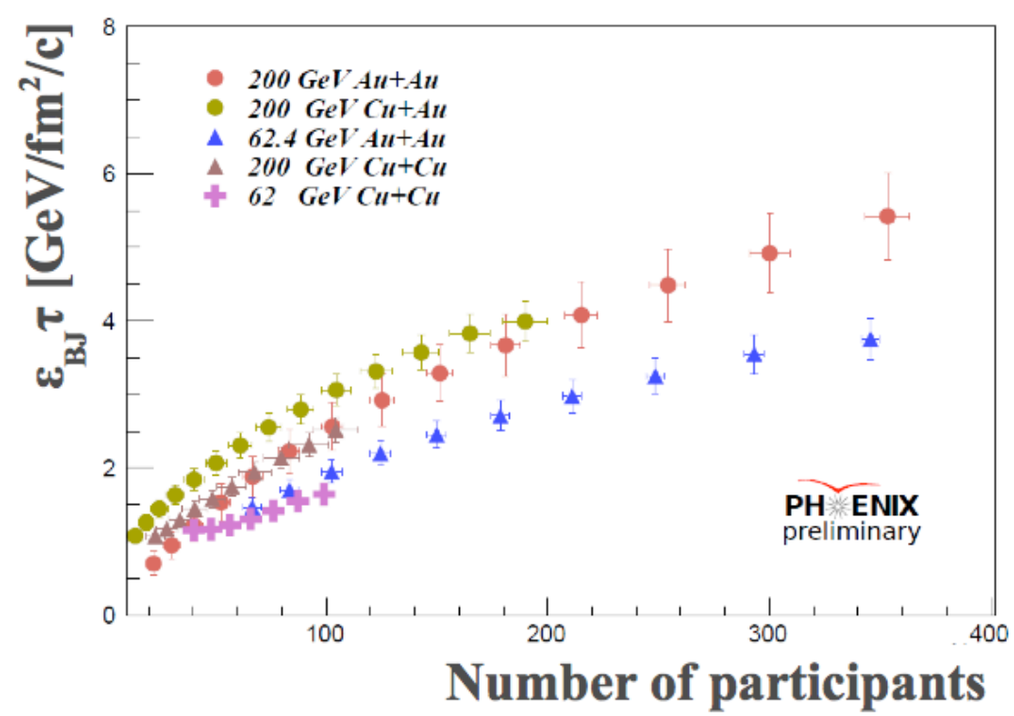
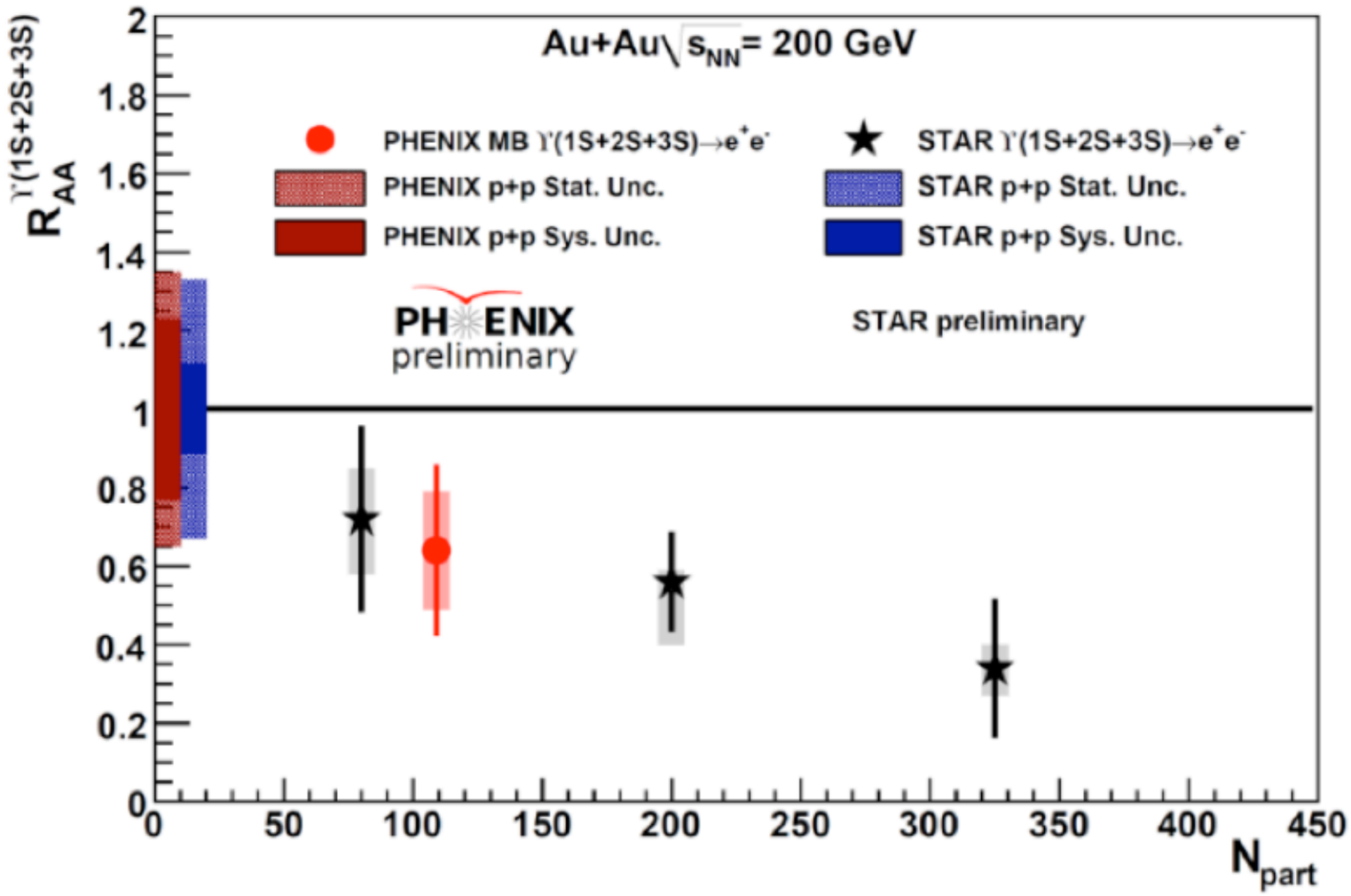


- J/ψ formed has to cross some cold matter (halo in the picture)



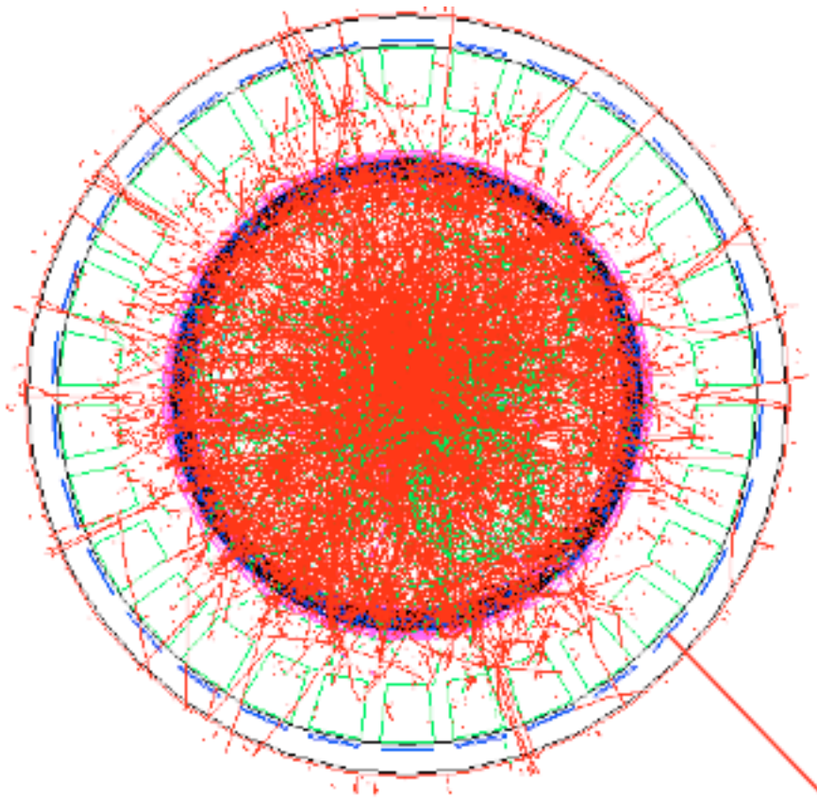
- energy density times crossing time slightly larger in Cu+Au than Au+Au

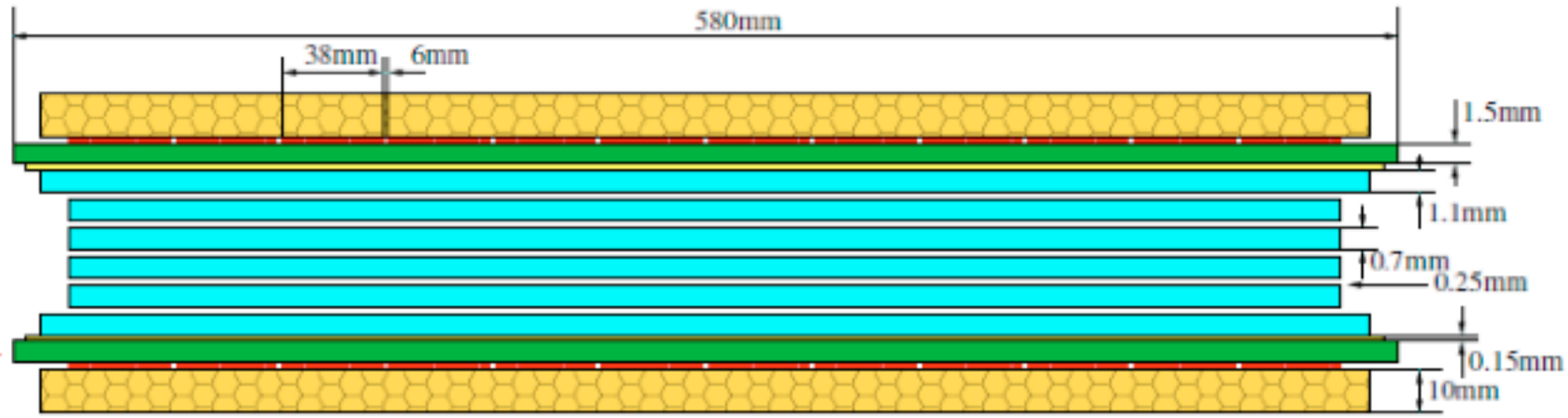
Upsilon Suppression

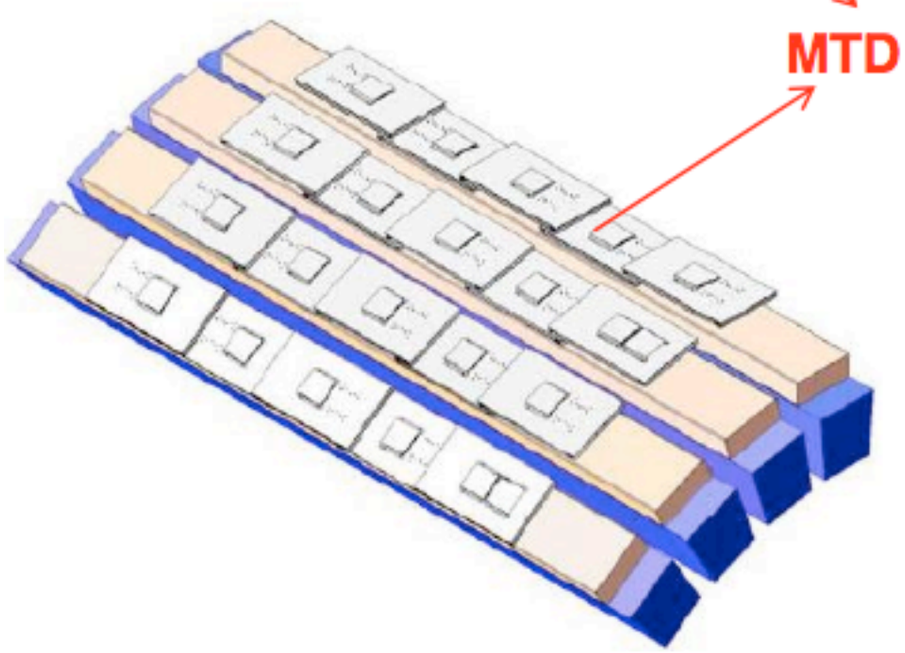


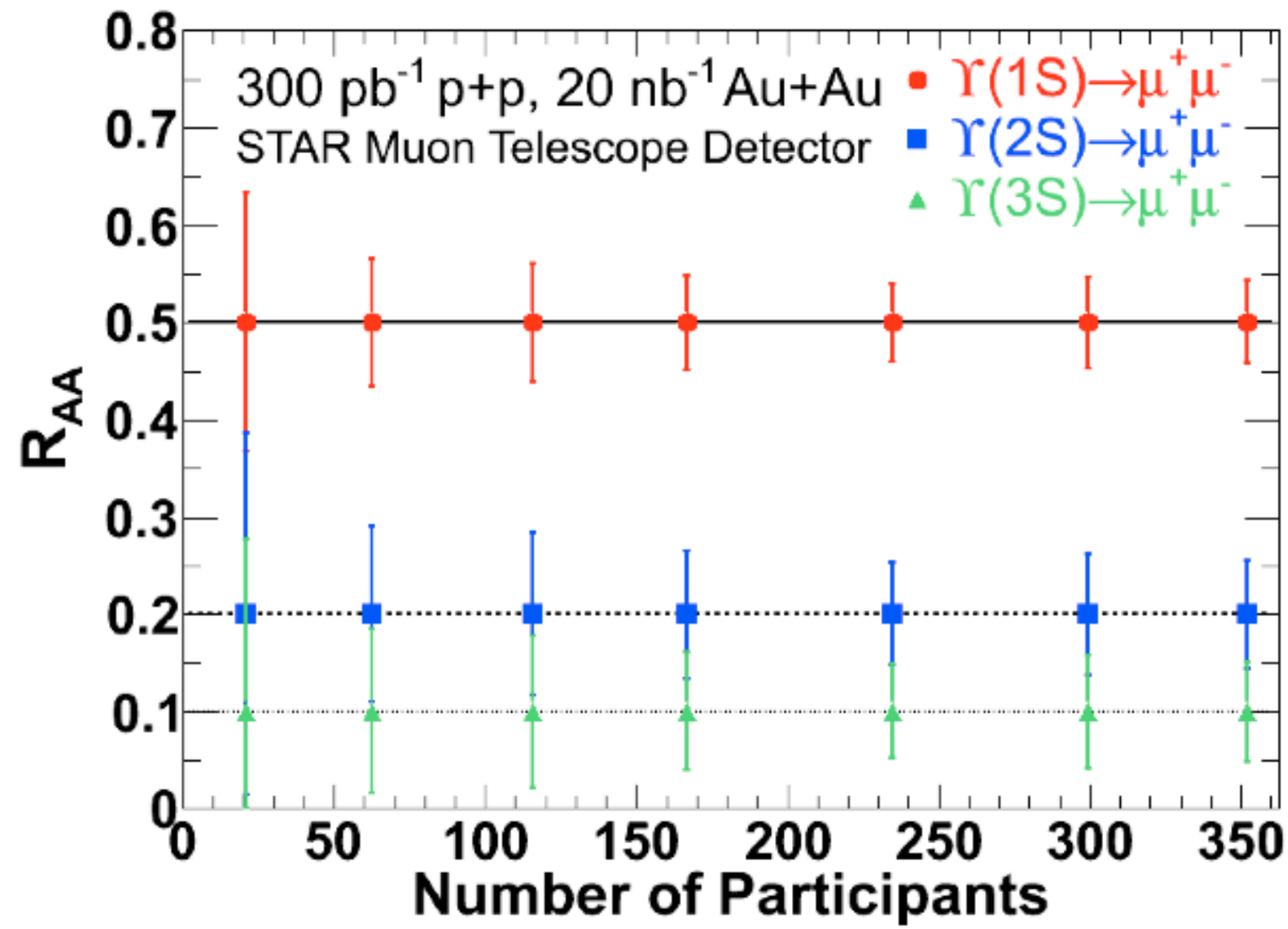
- scenarios
  - R_{AA}~0.64 if Υ(2S) and Υ(3S) melt (no CNM)
  - R_{AA}~0.37 if Υ(2S), Υ(3S) and χ_b (1P+2P) melt (no CNM)
- needs better handle of CNM and feed-down fractions

Upcoming Upsilons Measurements

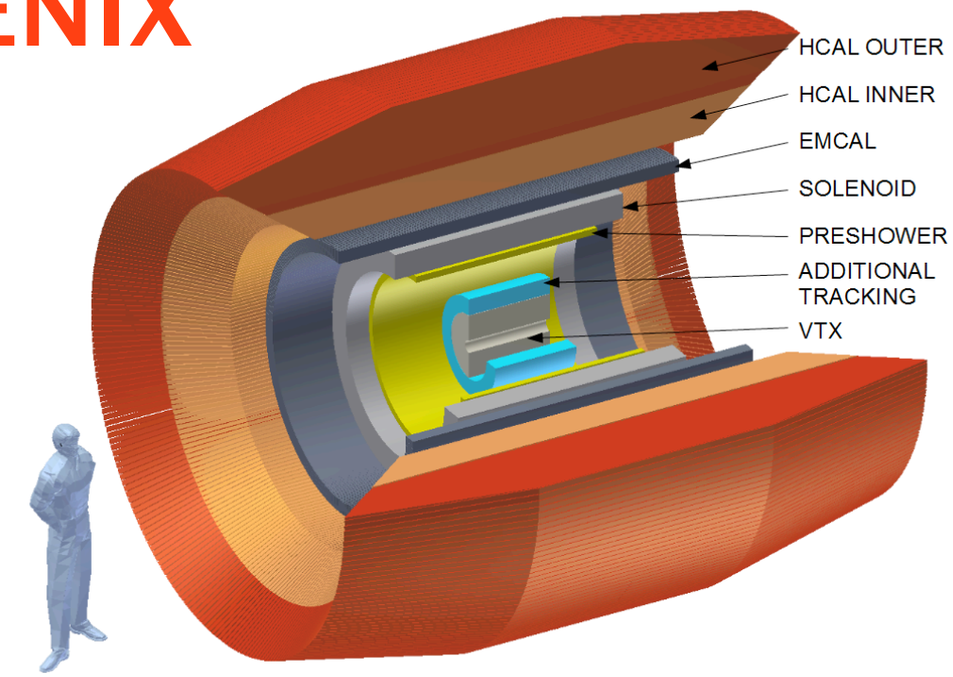




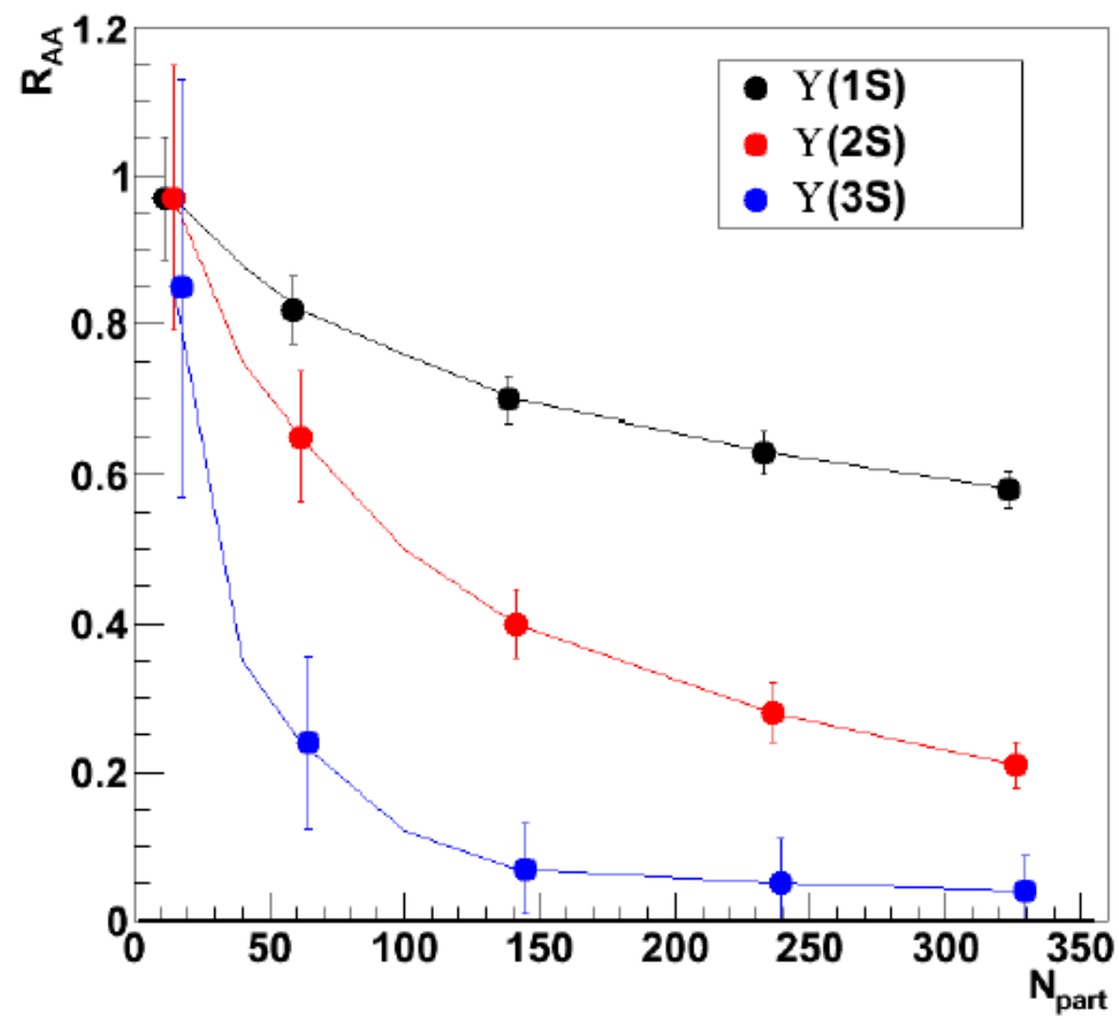




Upsilons in SPHENIX



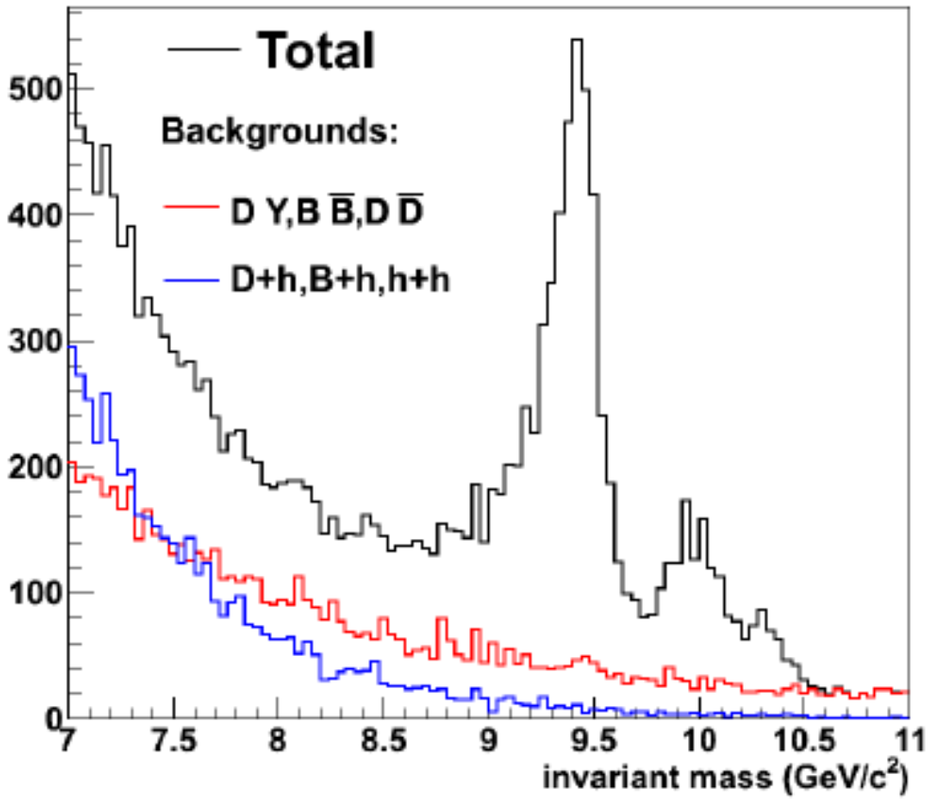
Species	$\int$ L dt	Events	$\langle N_{coll} \rangle$	Υ(1S)	Υ(2S)	Υ(3S)
$p+p$	18 pb^{-1}	756 B	1	805	202	106
Au+Au (MB)		50 B	240.4	12794	3217	1687
Au+Au (0–10%)		5 B	962	5121	1288	675

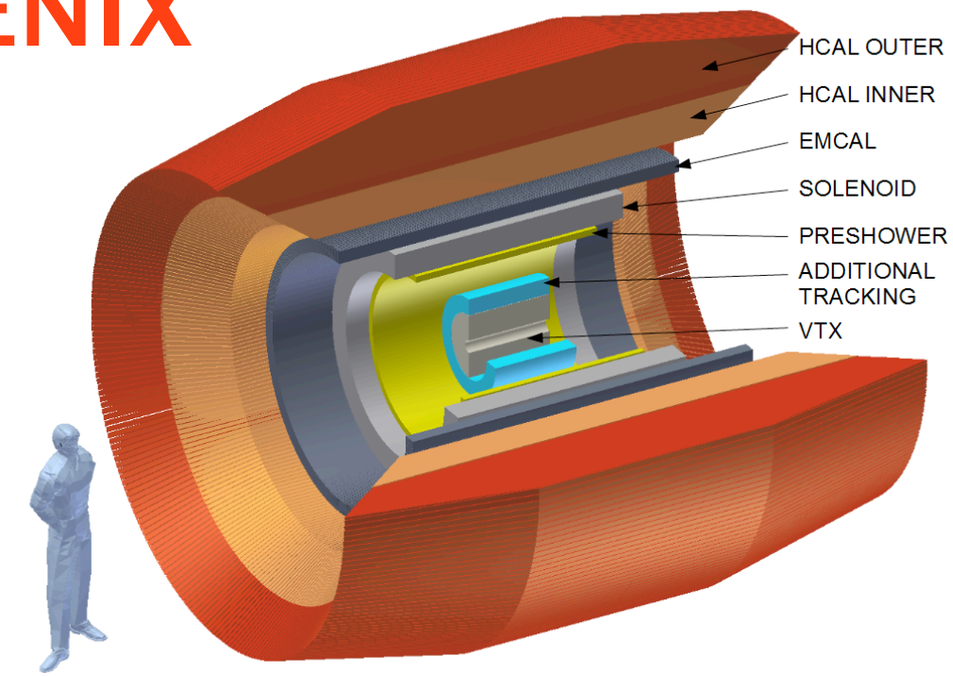


Clear separation of the three states
Large acceptance
Similar statistics to LHC

Upsilons in SPHENIX

Υ(1S,2S,3S)





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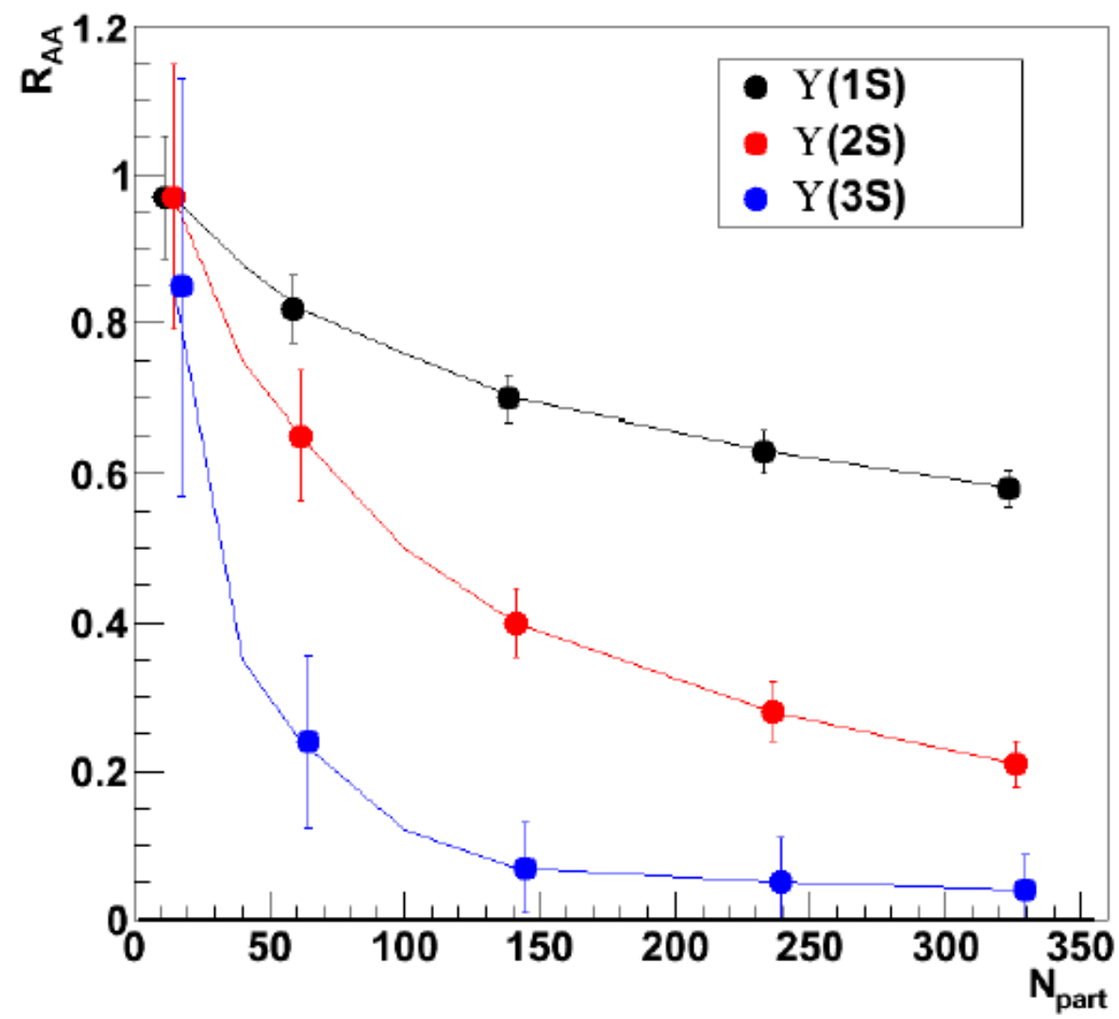

Clear separation of the three states
Large acceptance
Similar statistics to LHC

Conclusions

We have a machine which provide a large degree of freedom to study quarkonia in heavy ion collisions

Many complimentary/comparatively new data btw. STAR and PHENIX

Large effort to measure excited charmonia and bottomonia allowing the use of quarkonia as a QGP thermometer

Still needs a better understanding of initial state effects and coalescence

BACKUP SLIDES

List compiled by Kei Suzukia, Philipp Gublerb, Kenji Moritac, and Makoto Okaa - arXiv:1204.1173v1

Charmonium:
Lattice QCD [4, 5, 6, 7, 8, 9, 10, 11, 12, 13],
QCD sum rules [14, 15, 16, 17, 18],
AdS/QCD [19, 20, 21, 22],
resummed perturbation theory [23, 24],
effective field theories [25, 26]
potential models [11, 27, 28, 29, 30, 31, 32, 33].

Bottominum:
[12, 17, 27, 29, 33, 34,35]

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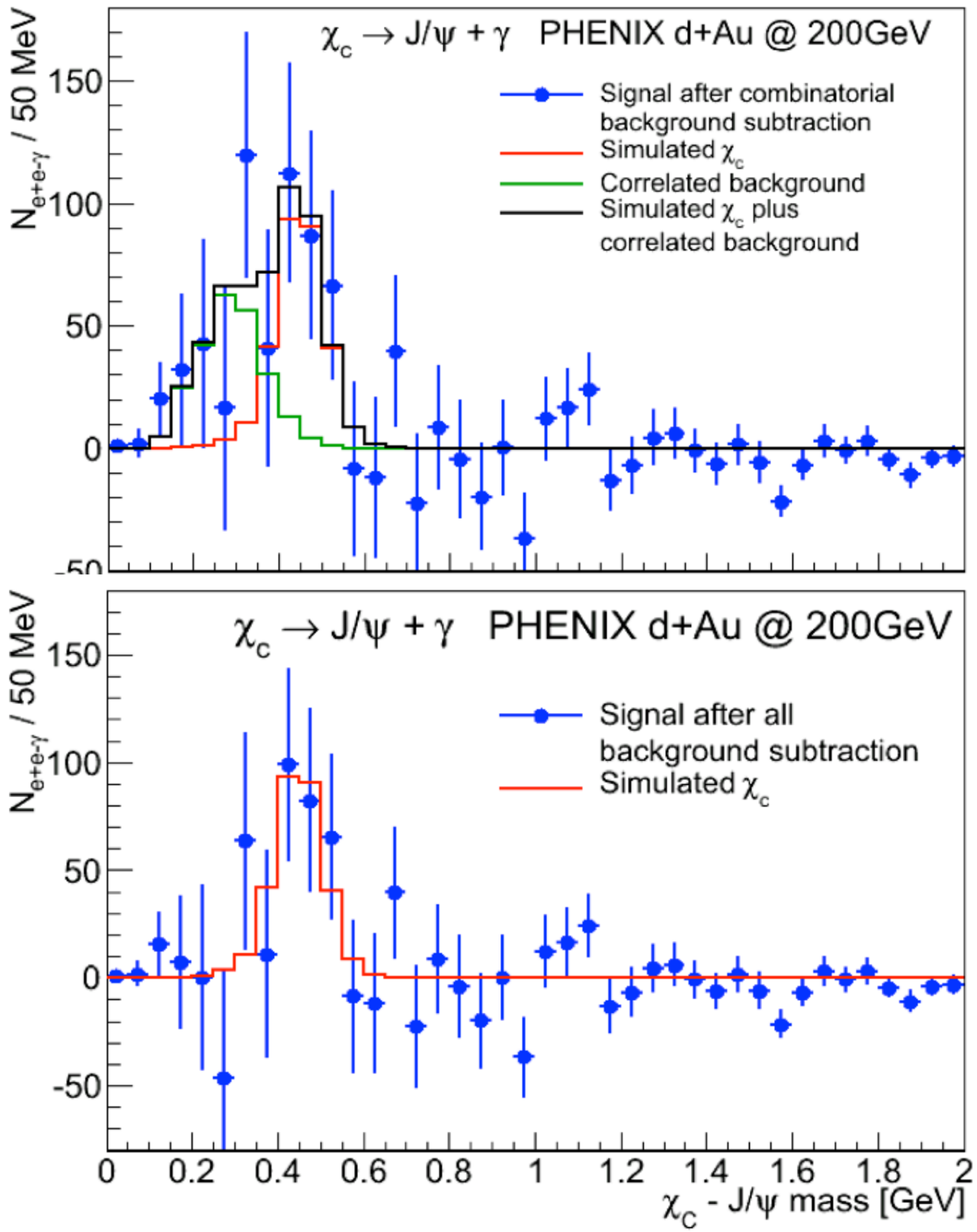
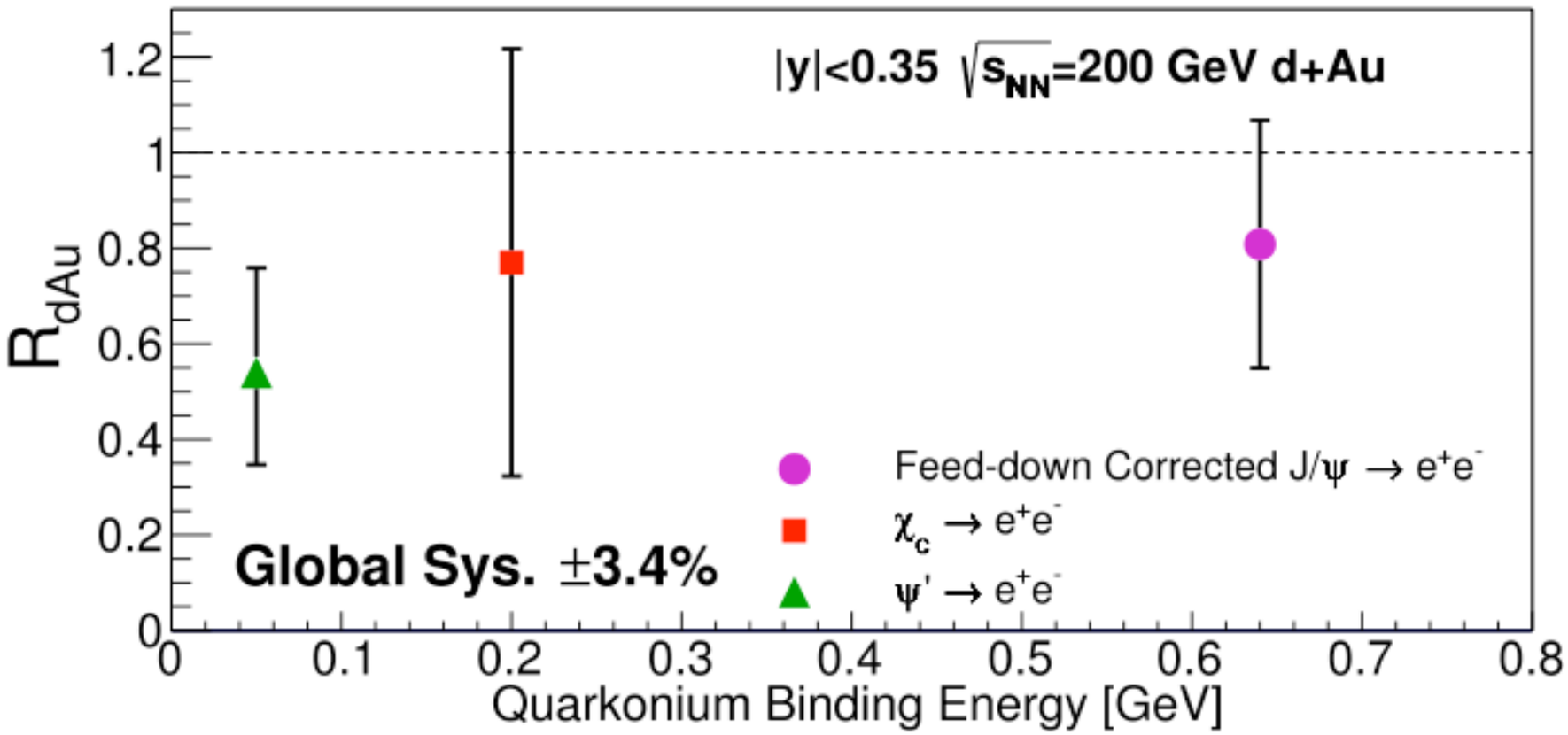
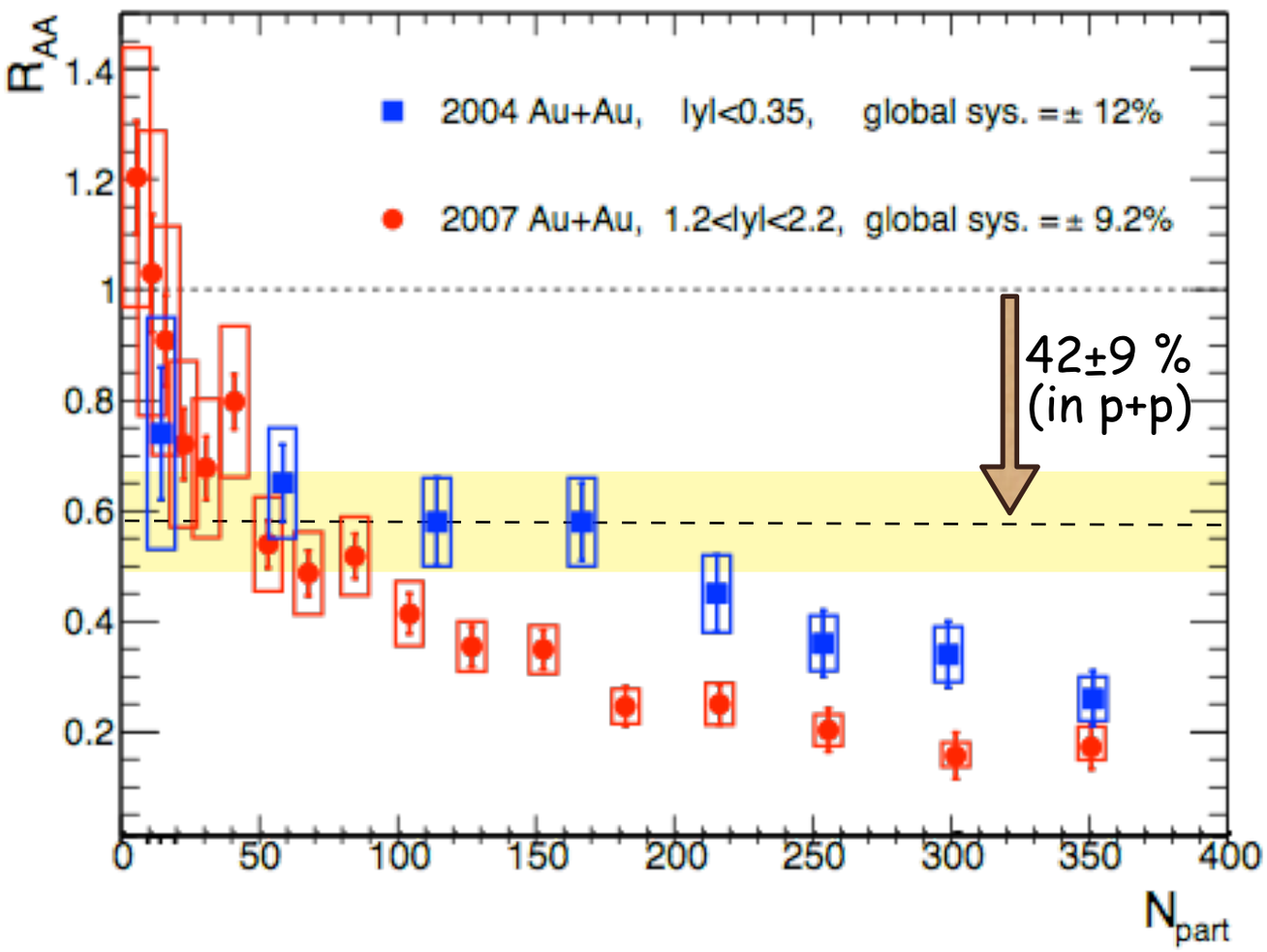

$\chi_c \rightarrow J/\psi + \gamma$ PHENIX d+Au @ 200GeV
Signal after combinatorial background subtraction
Simulated χ_c
Correlated background
Simulated χ_c plus correlated background
$N_{e+e-\gamma}$ / 50 MeV
$\chi_c \rightarrow J/\psi + \gamma$ PHENIX d+Au @ 200GeV
Signal after all background subtraction
Simulated χ_c
$N_{e+e-\gamma}$ / 50 MeV
χ_C - J/ψ mass [GeV]

Final-state effects in cold nuclear matter



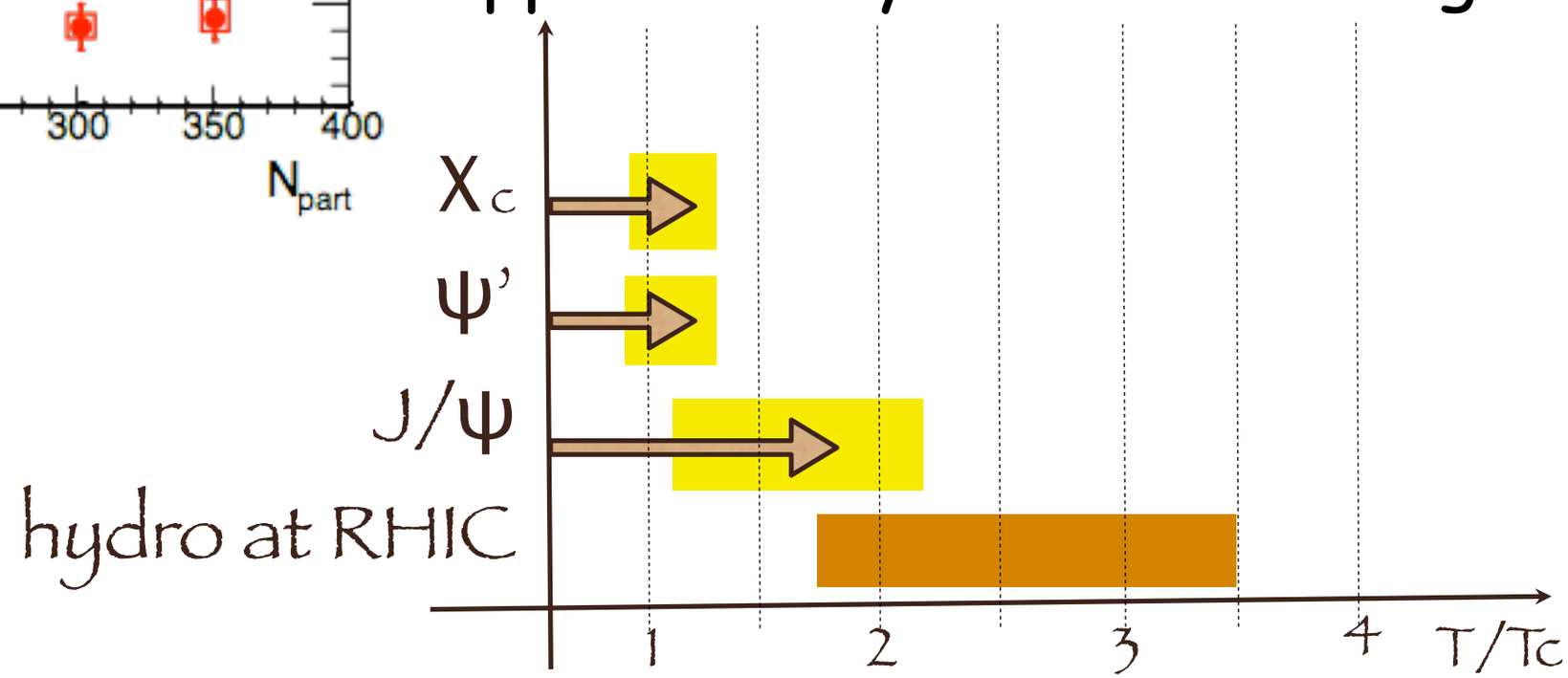
- charmonium breakup in confined matter depends on binding energy
- needs better measurement of χ_c

ψ' and χ_c feed-down suppression

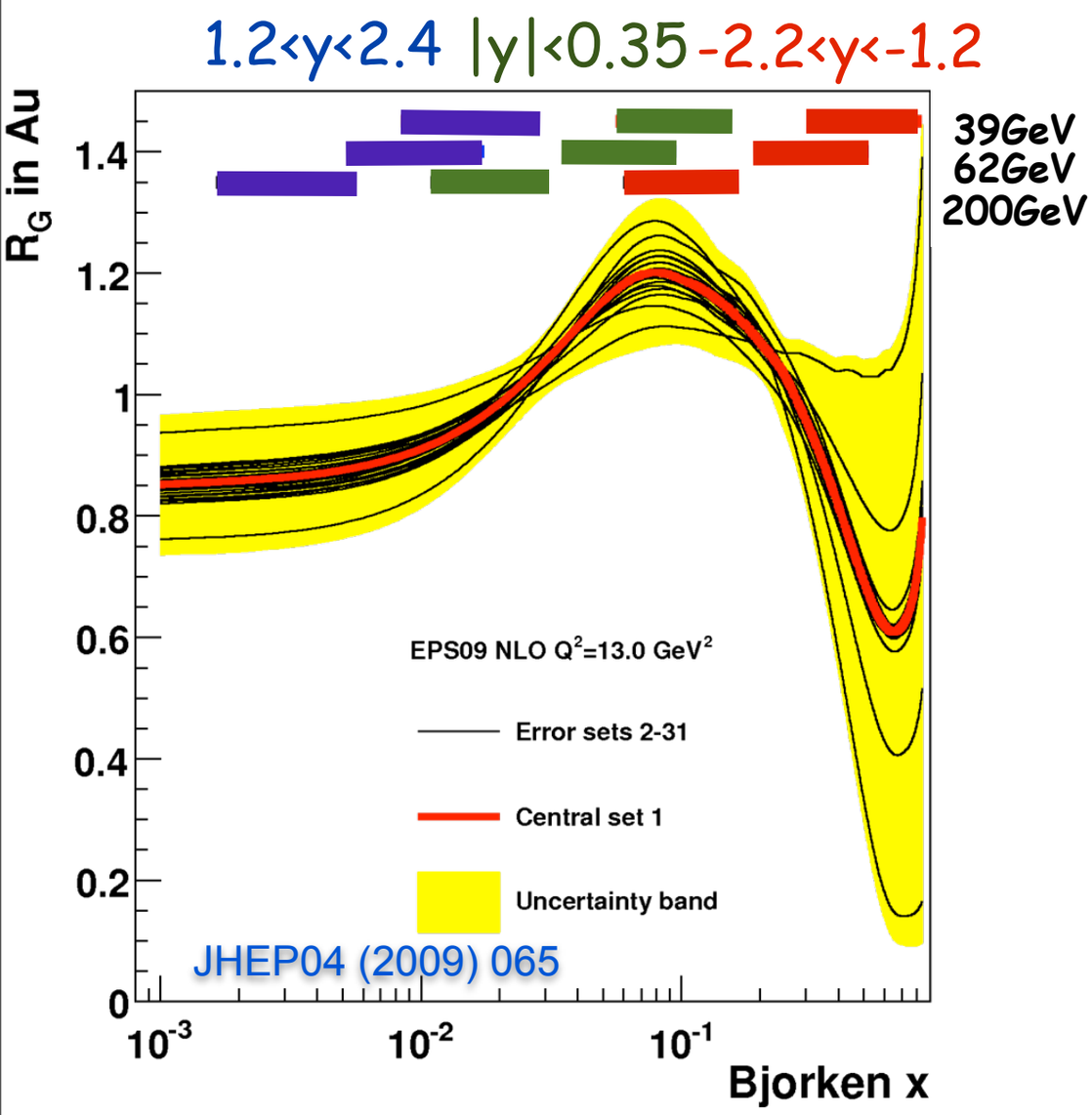


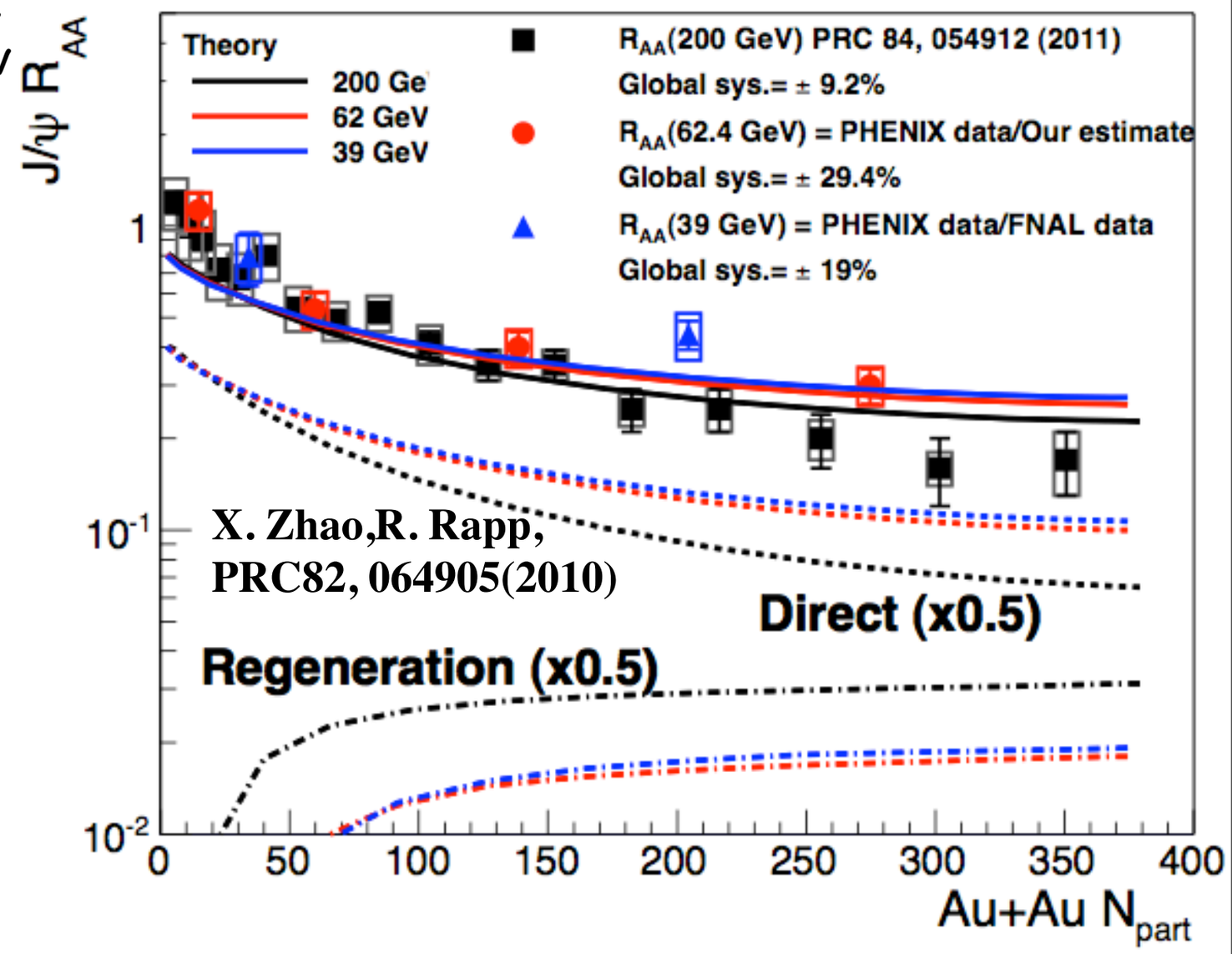
- not clear if there is any confined matter in A+A to break charmonium as in p(d)+A collisions

- but ψ' and χ_c can be totally suppressed by color screening



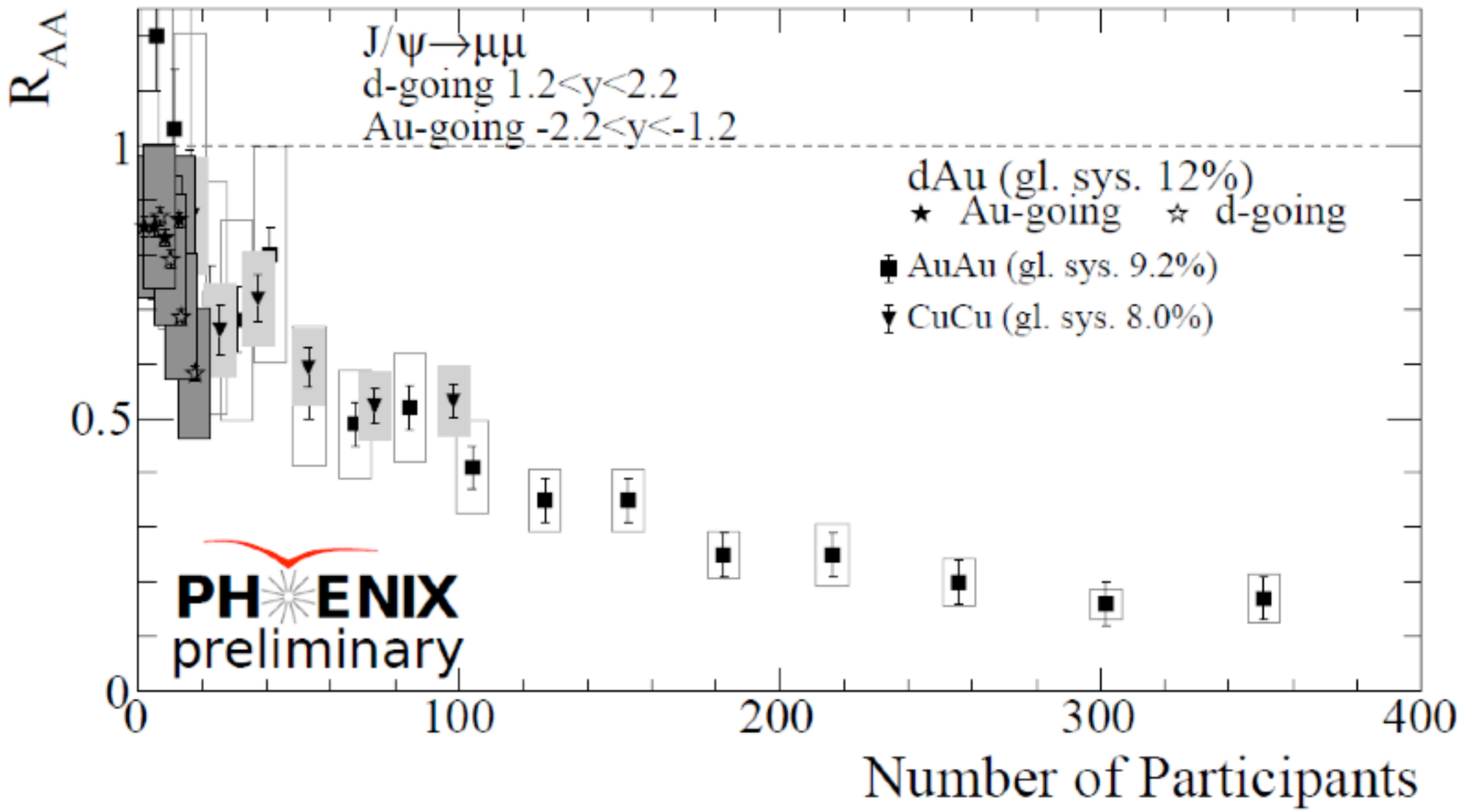
Collision Energy Dependence of J/ψ R_{AA}





- x-range coverage changes with energy
- balancing effects should make R_{AA} similar at different energies

System Size dependence



J/ψ suppression seems to scale with number of participants for different colliding species