System Size, Energy and Rapidity Dependence of Quarkonia Production Measured by the PHENIX Detector

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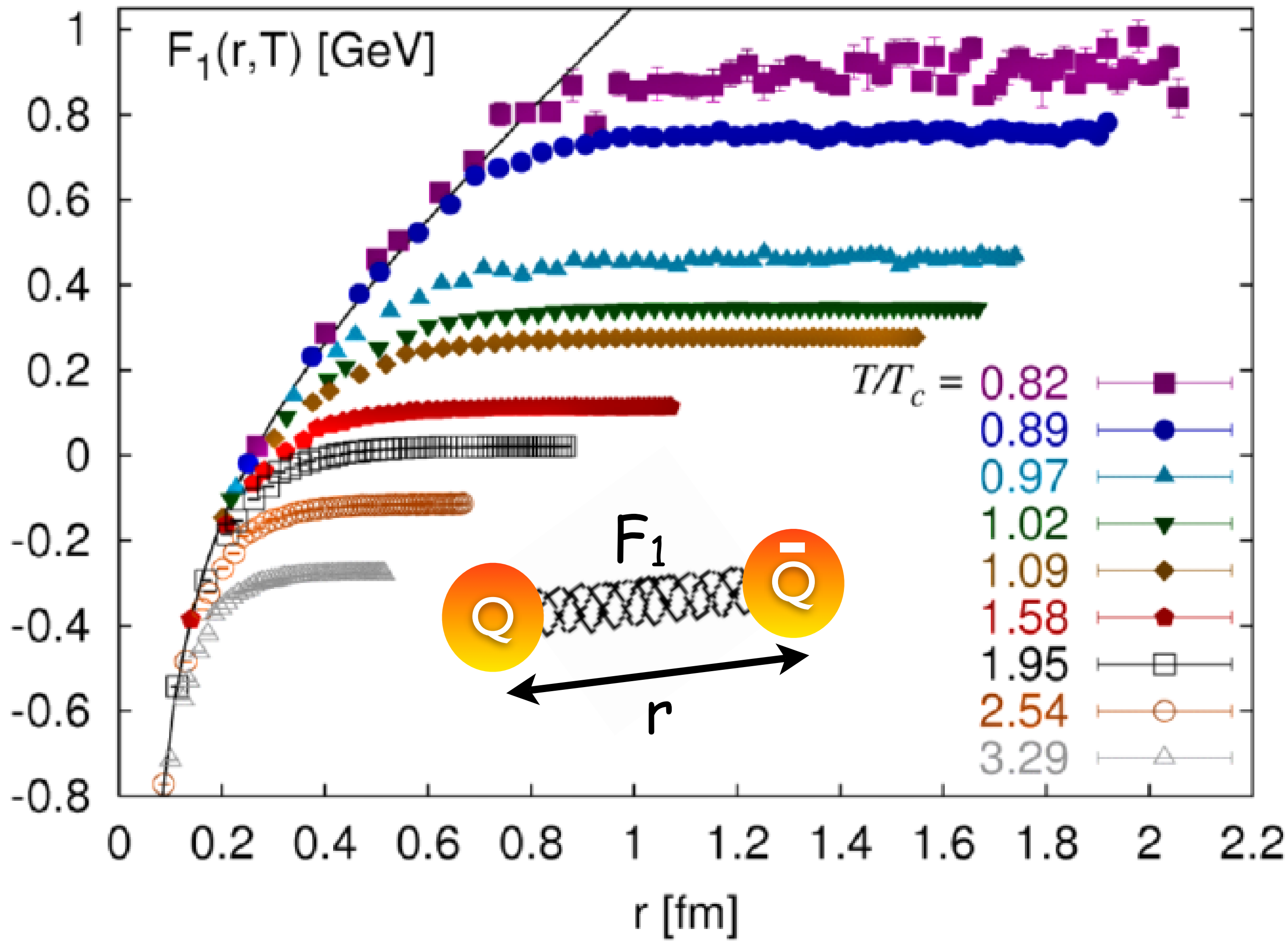
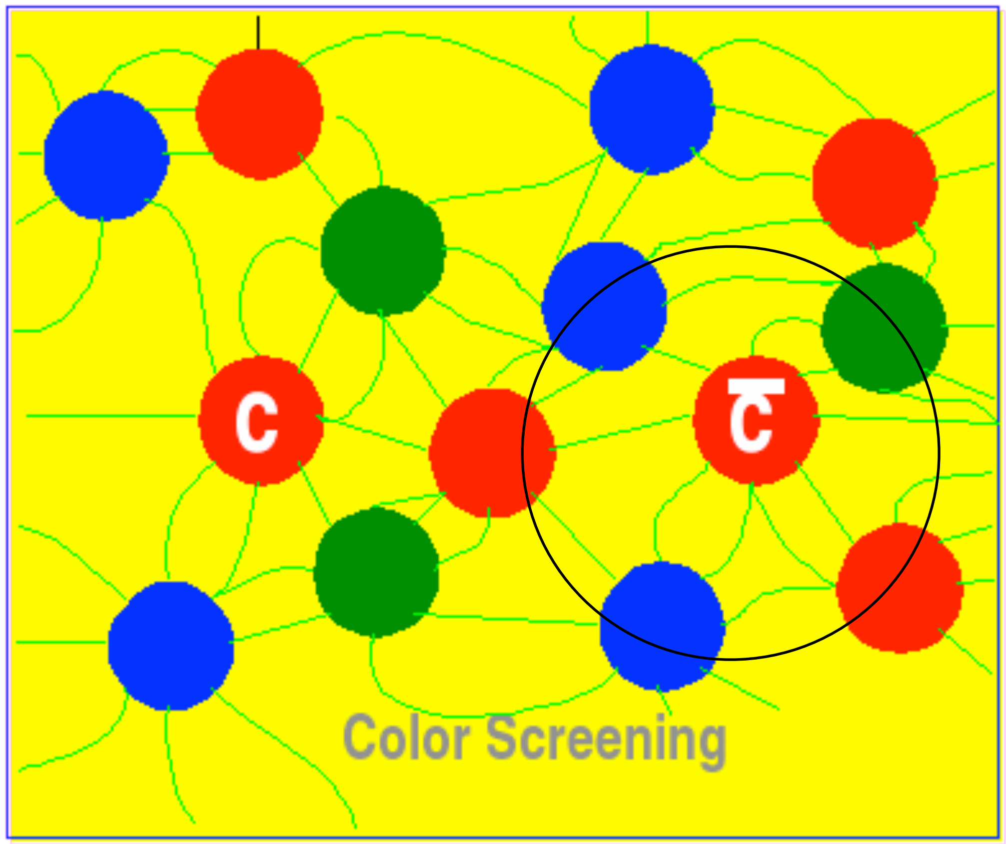
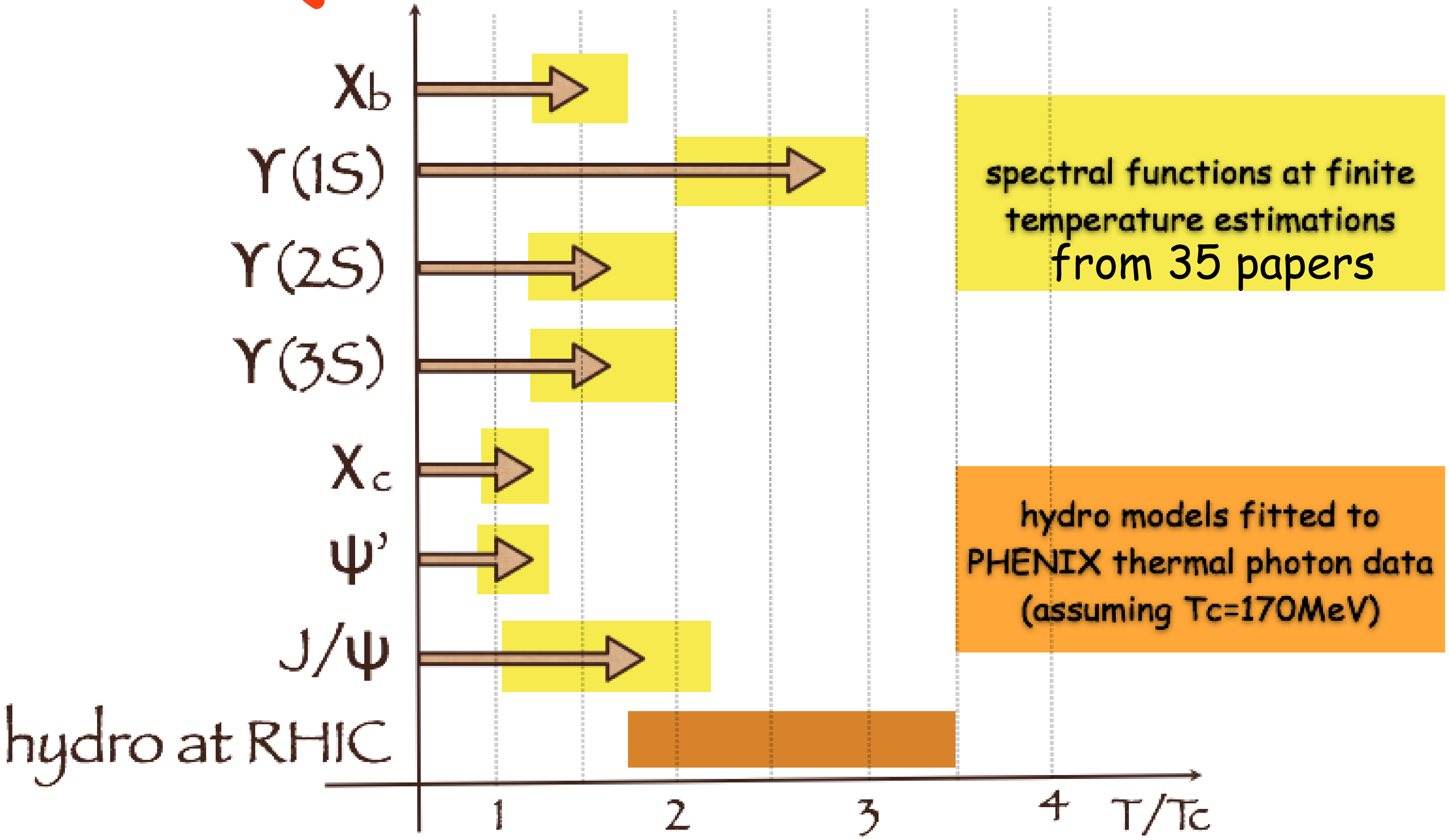
Color Screening





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

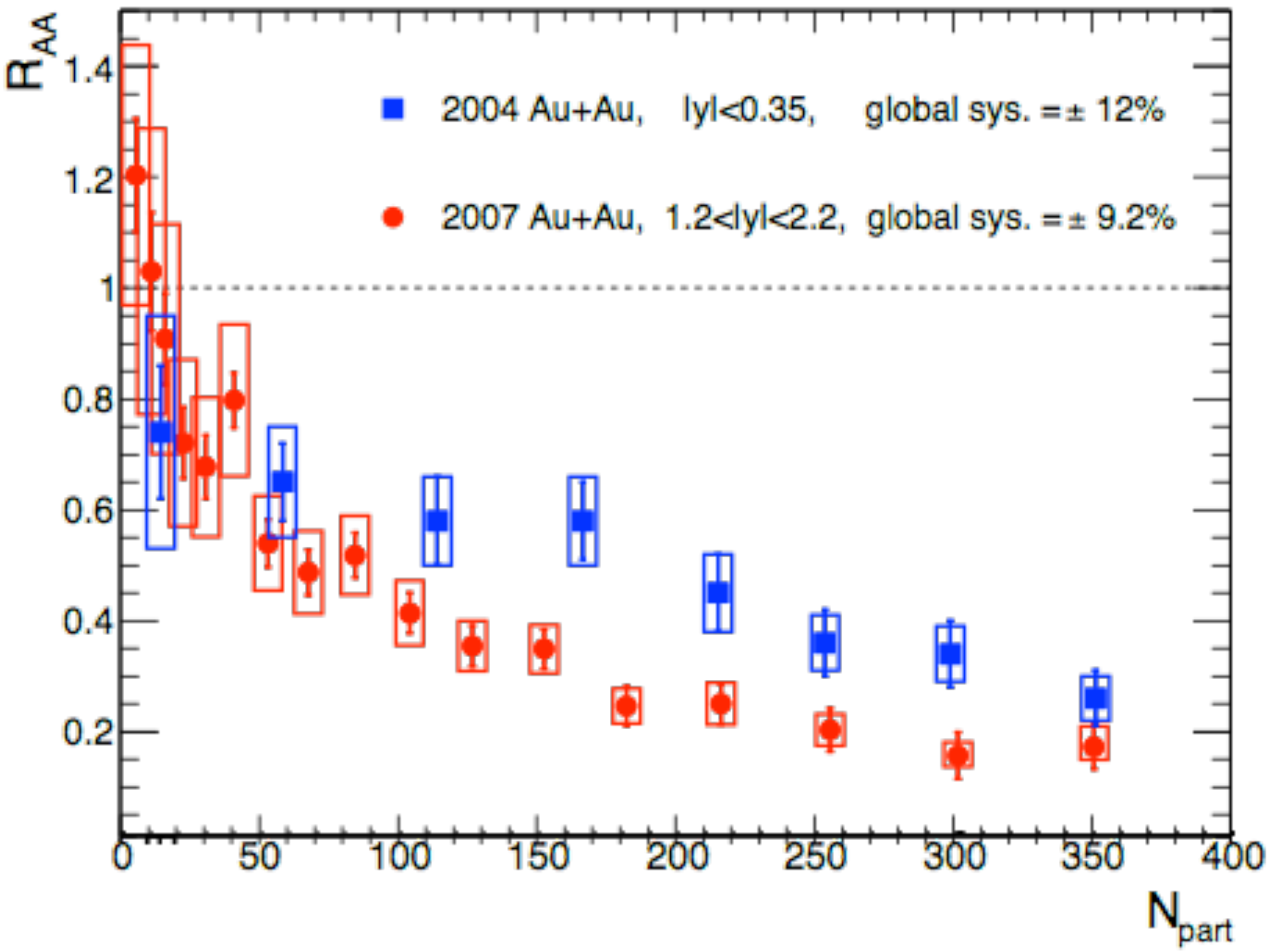
QGP Thermometer

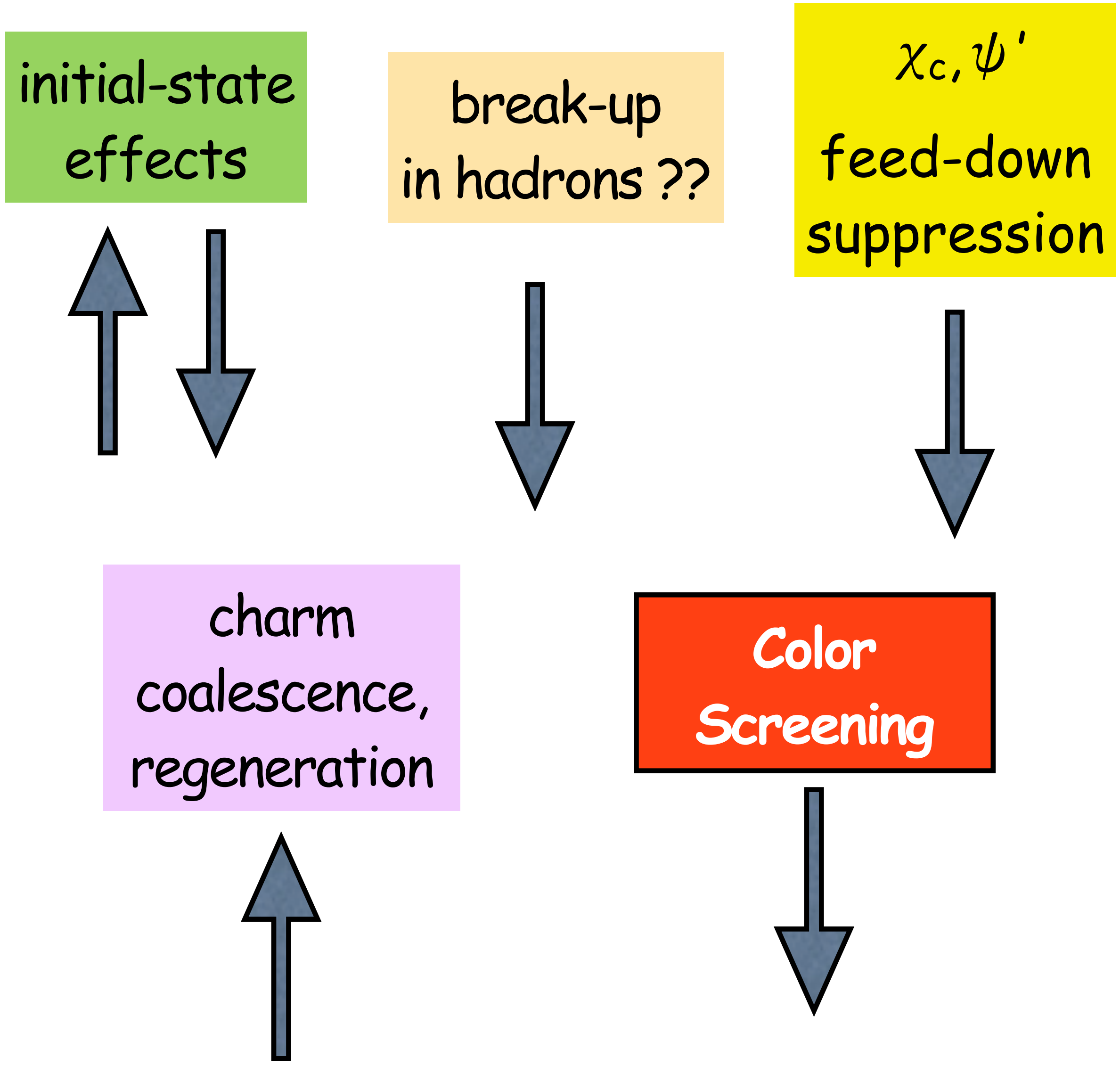


- quarkonia is much more than a QGP signature
- if color screening effect can be isolated quarkonia can be a
  - unique Gauge for screening length
  - more direct QGP temperature

J/ψ Suppression in Au+Au

Competing effects:





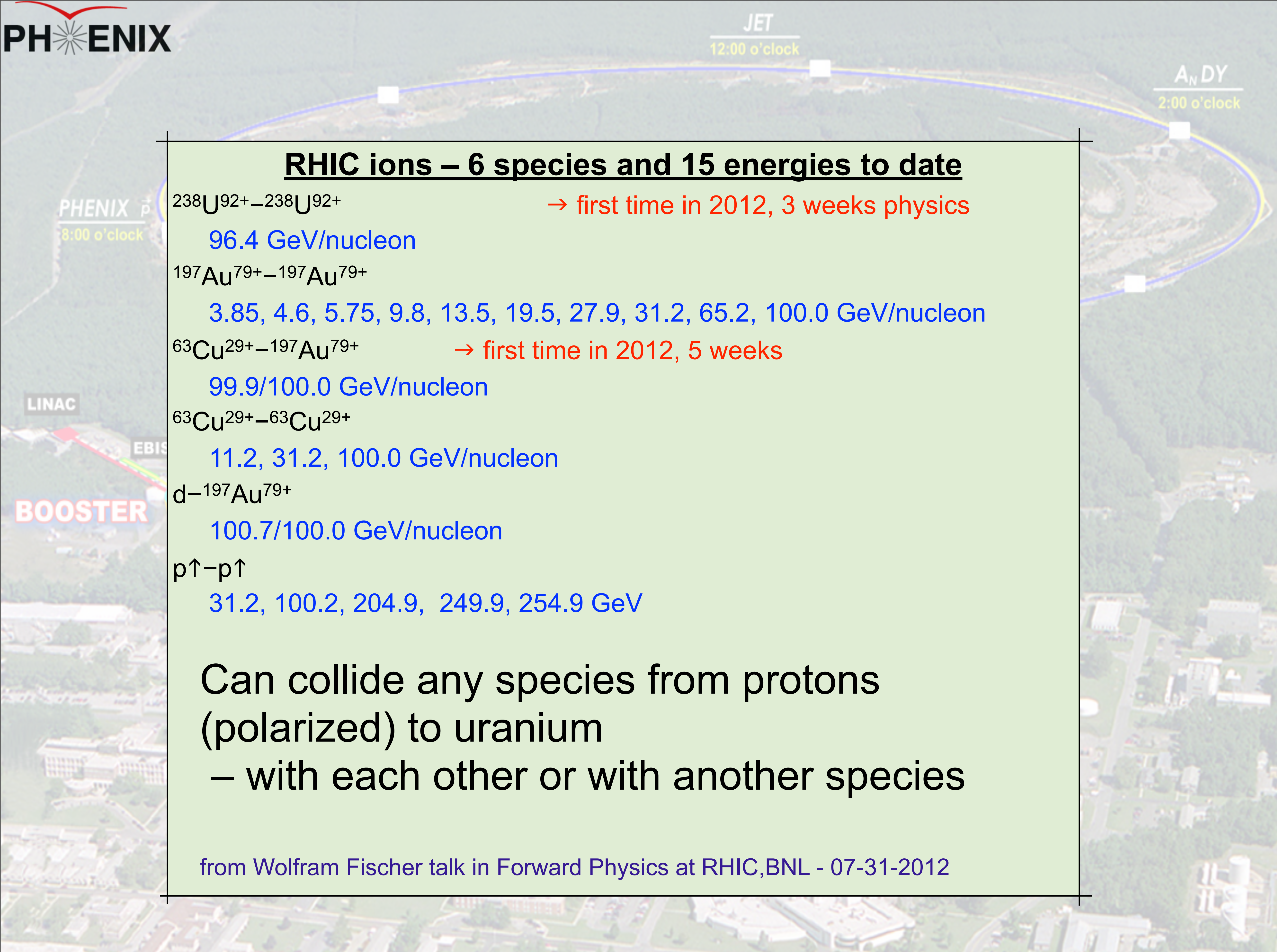
Isolating the color screening

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

PHENIX



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

$d-^{197}Au^{79+}$

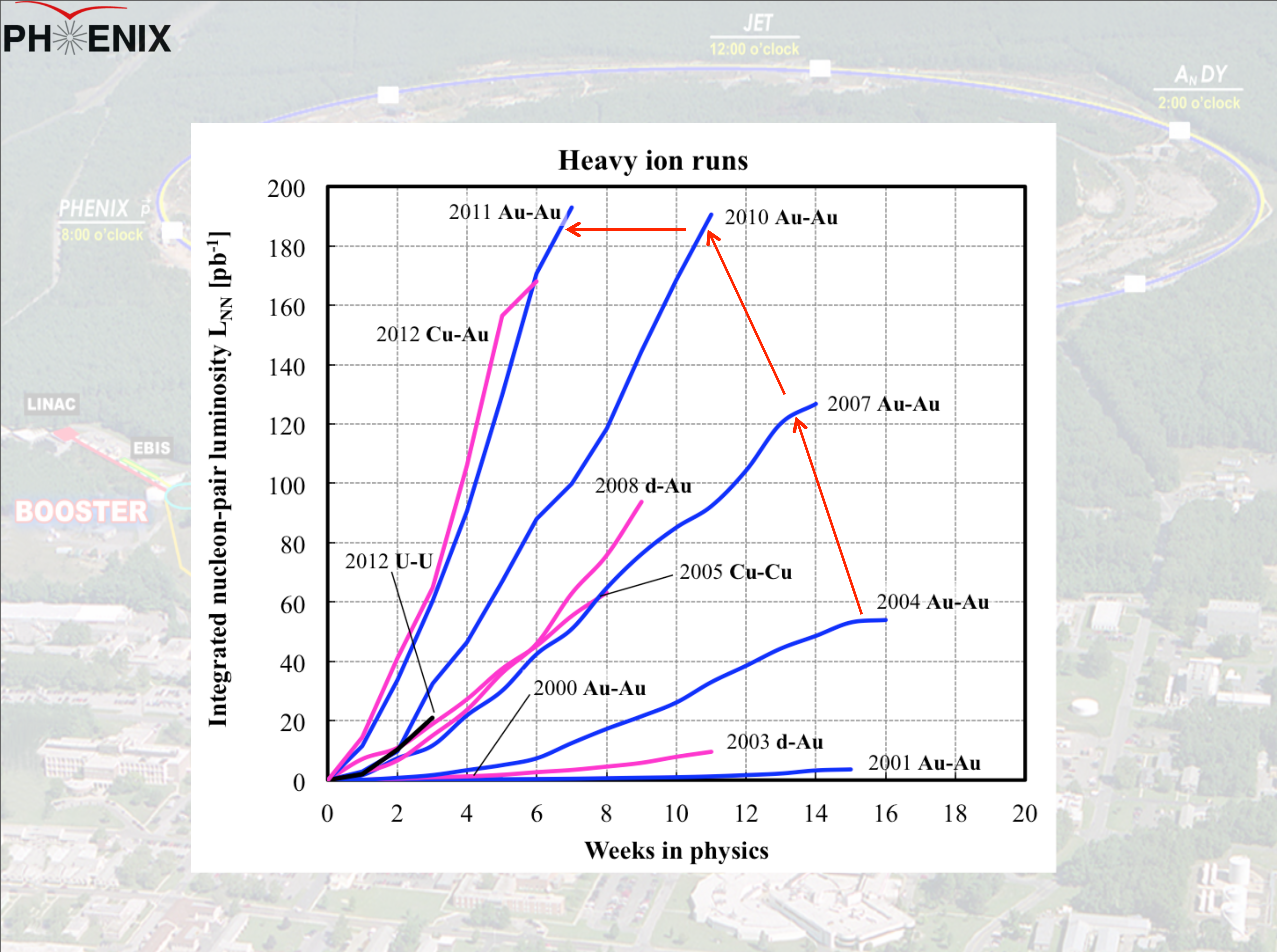
100.7/100.0 GeV/nucleon

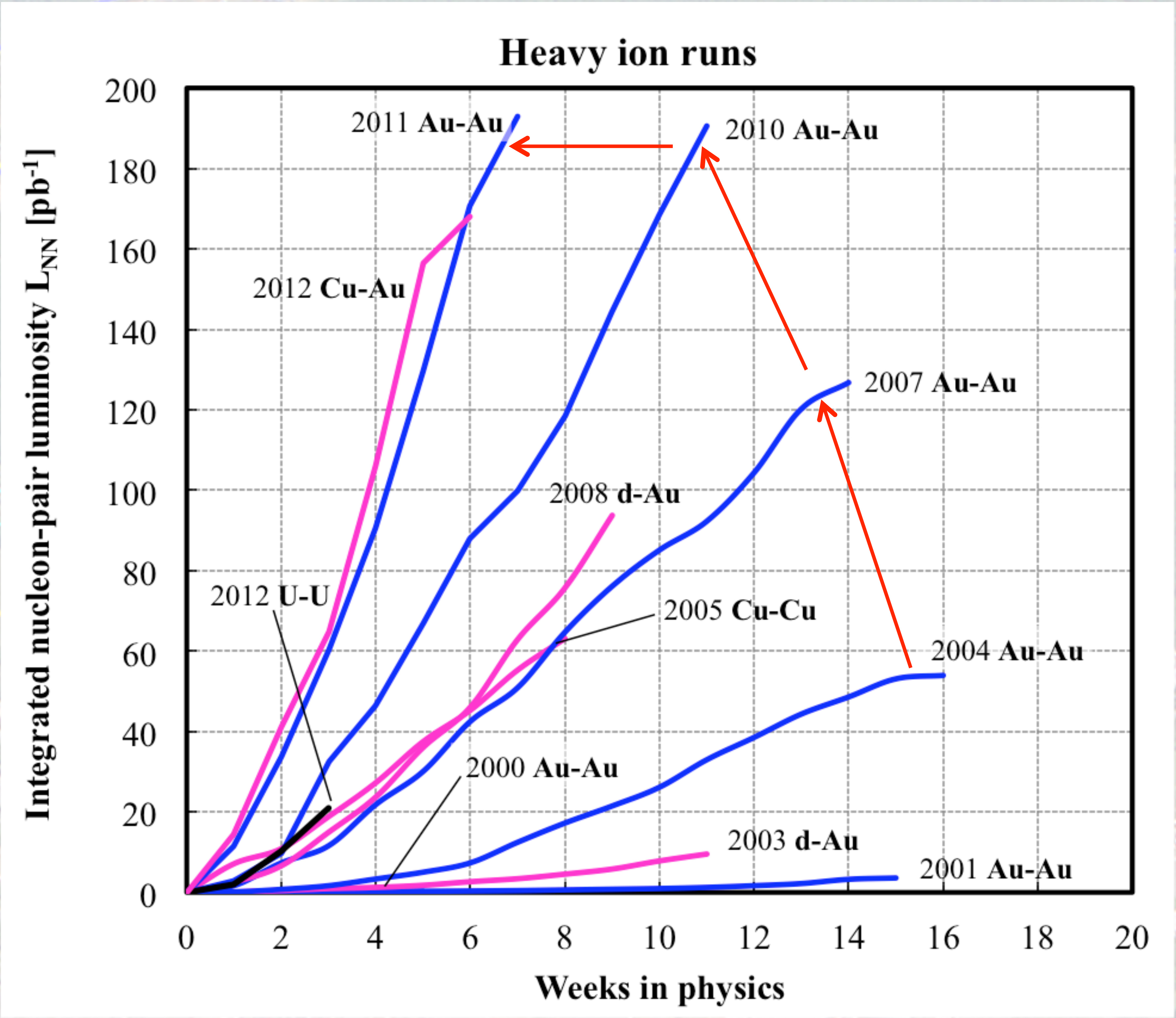
$p\uparrow-p\uparrow$

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


PHENIX
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
0
2
4
6
8
10
12
14
16
18
20
200
180
160
140
120
100
80
60
40
20
0
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


Heavy ion runs
Integrated nucleon-pair luminosity L_{NN} [pb^{-1}]
Weeks in physics
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2010 Au-Au
2012 Cu-Au
2007 Au-Au
2008 d-Au
2005 Cu-Cu
2012 U-U
2004 Au-Au
2000 Au-Au
2003 d-Au
2001 Au-Au
200
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
20

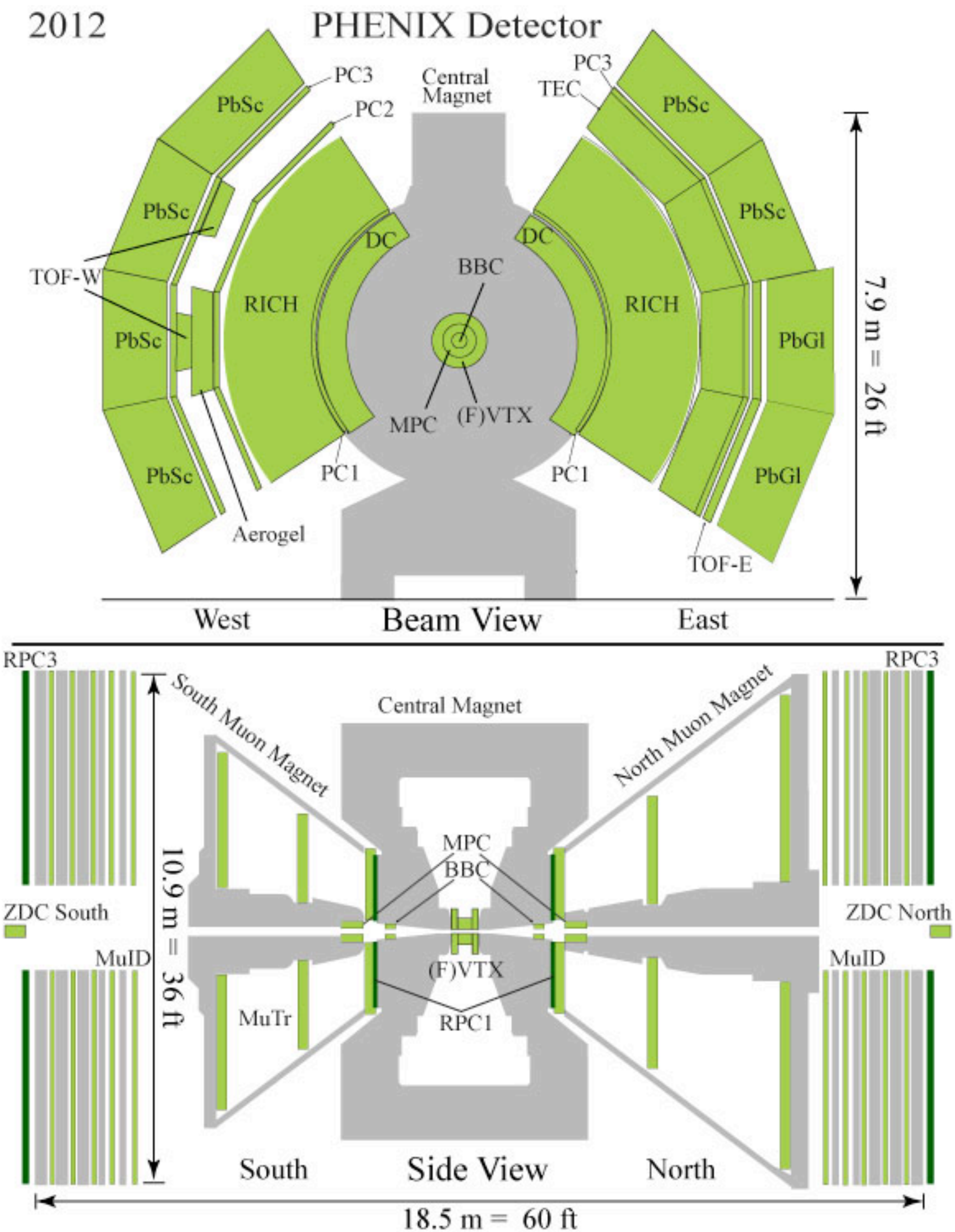
PHENIX

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

PHENIX can measure quarkonia from zero momentum

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

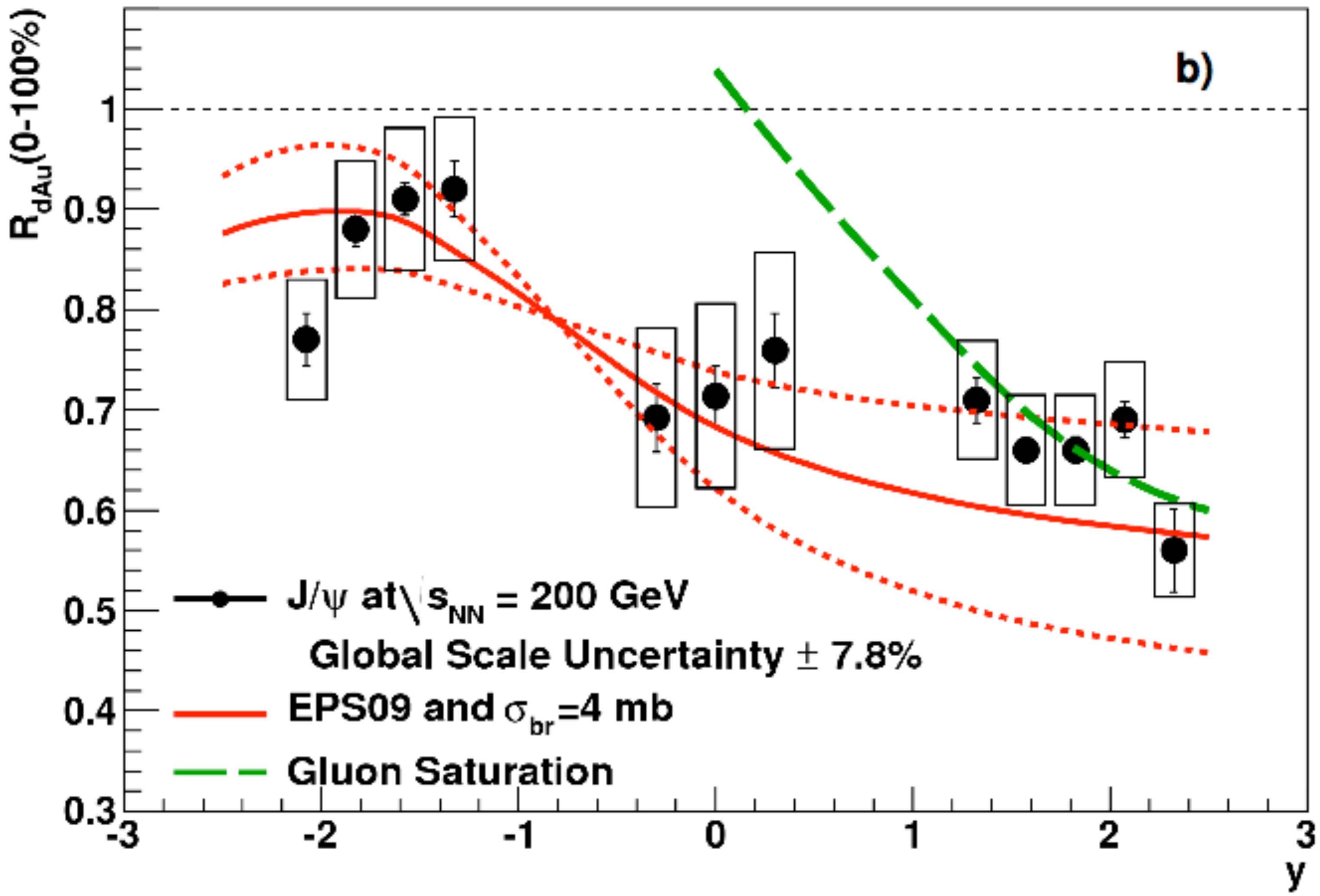
$1.2<|y|<2.2$ $\Delta\Phi = 2\pi$



Probing the initial state

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

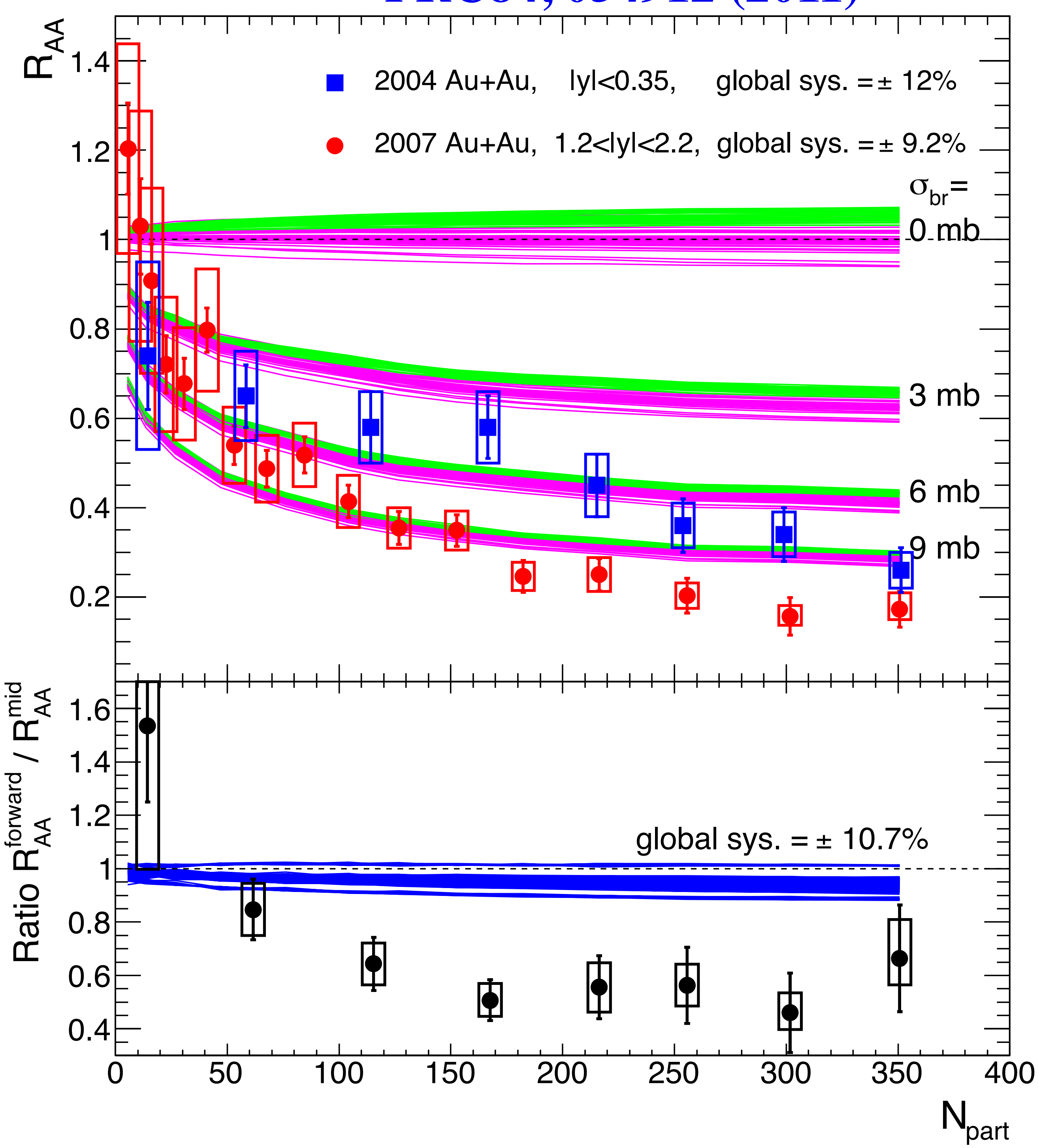
PRL107, 142301 (2011)



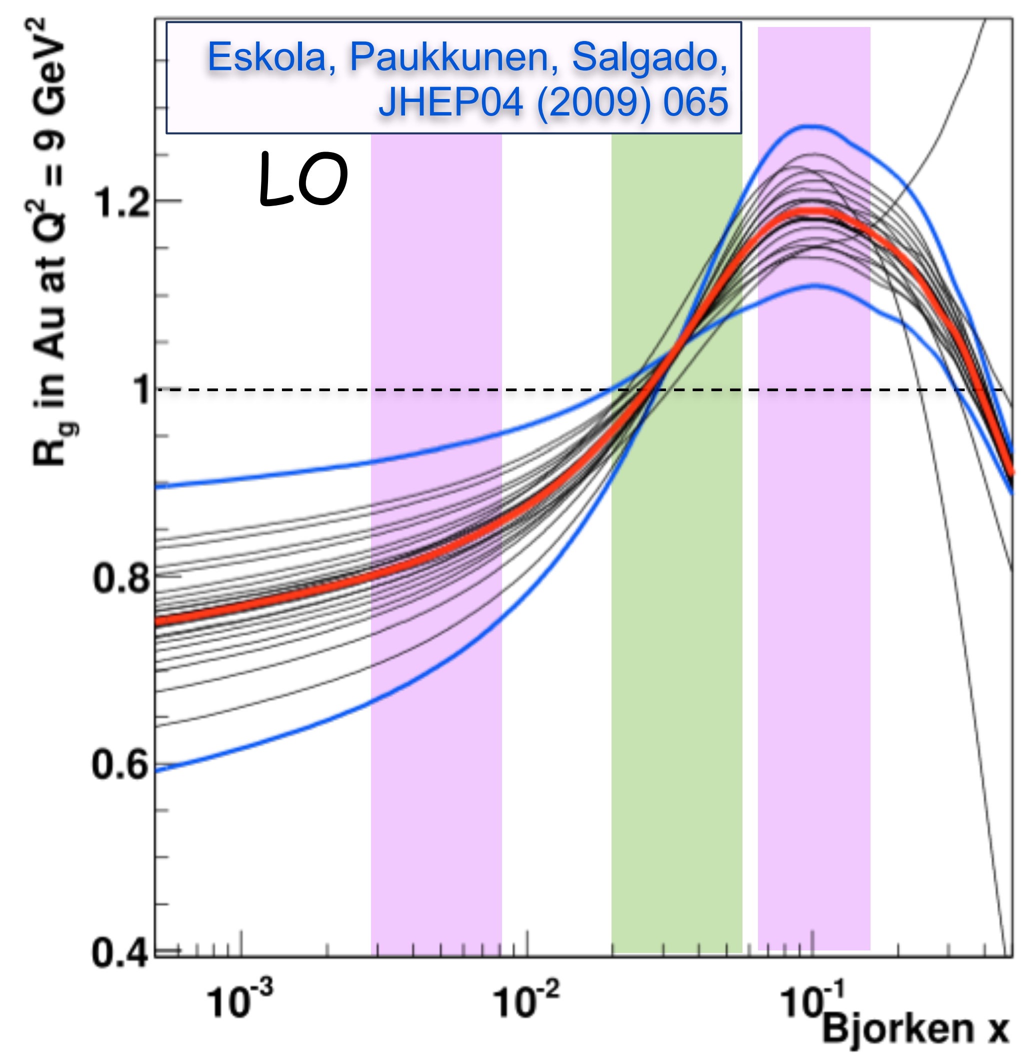
- EPS09 + J/ψ breakup in hadronic matter qualitatively describes Minimum Bias R_{dAu} data

Propagation of nPDF+breakup to Au+Au

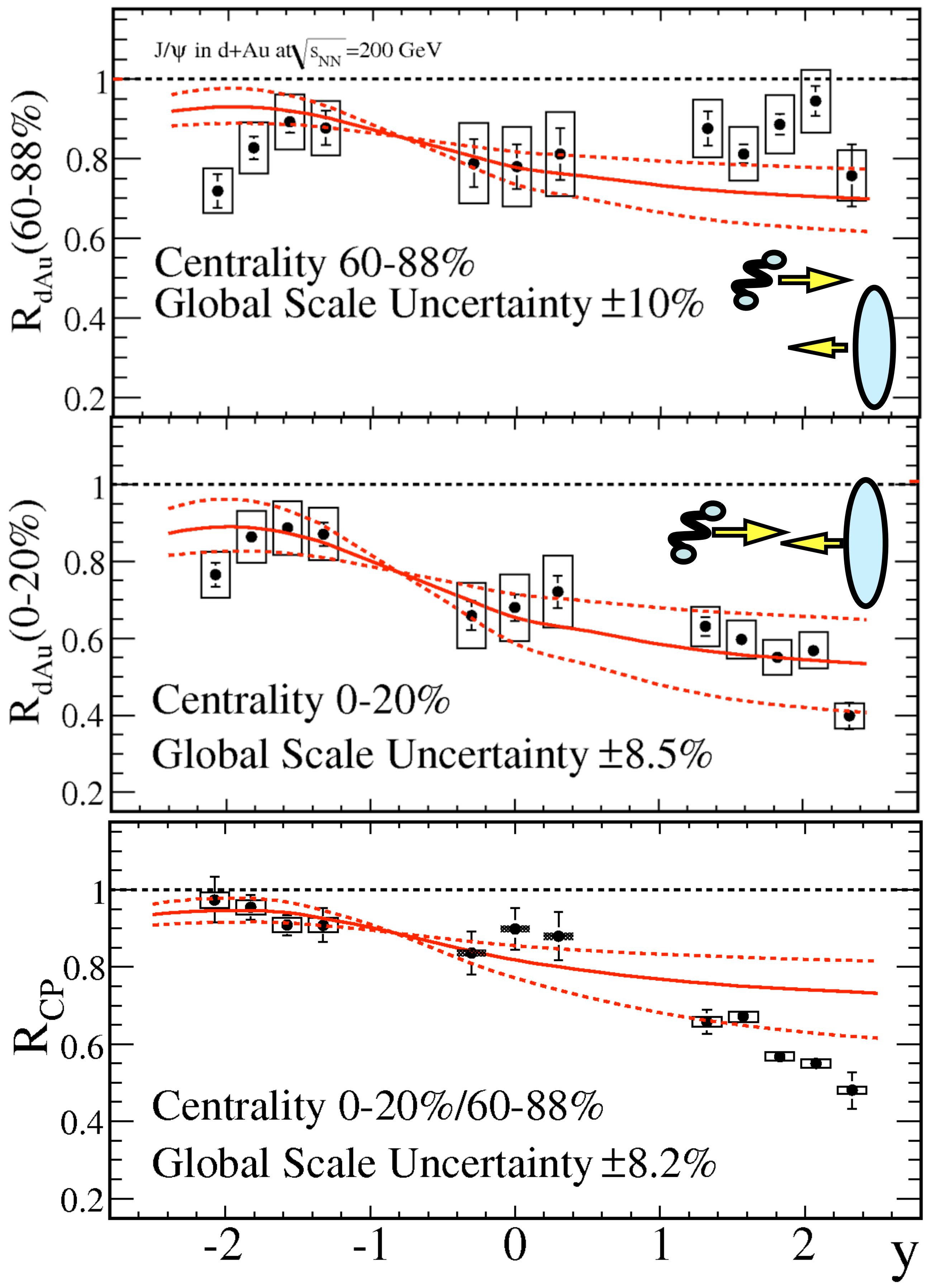
nPDF cannot describe the stronger suppression observed at forward rapidity in Au+Au collisions



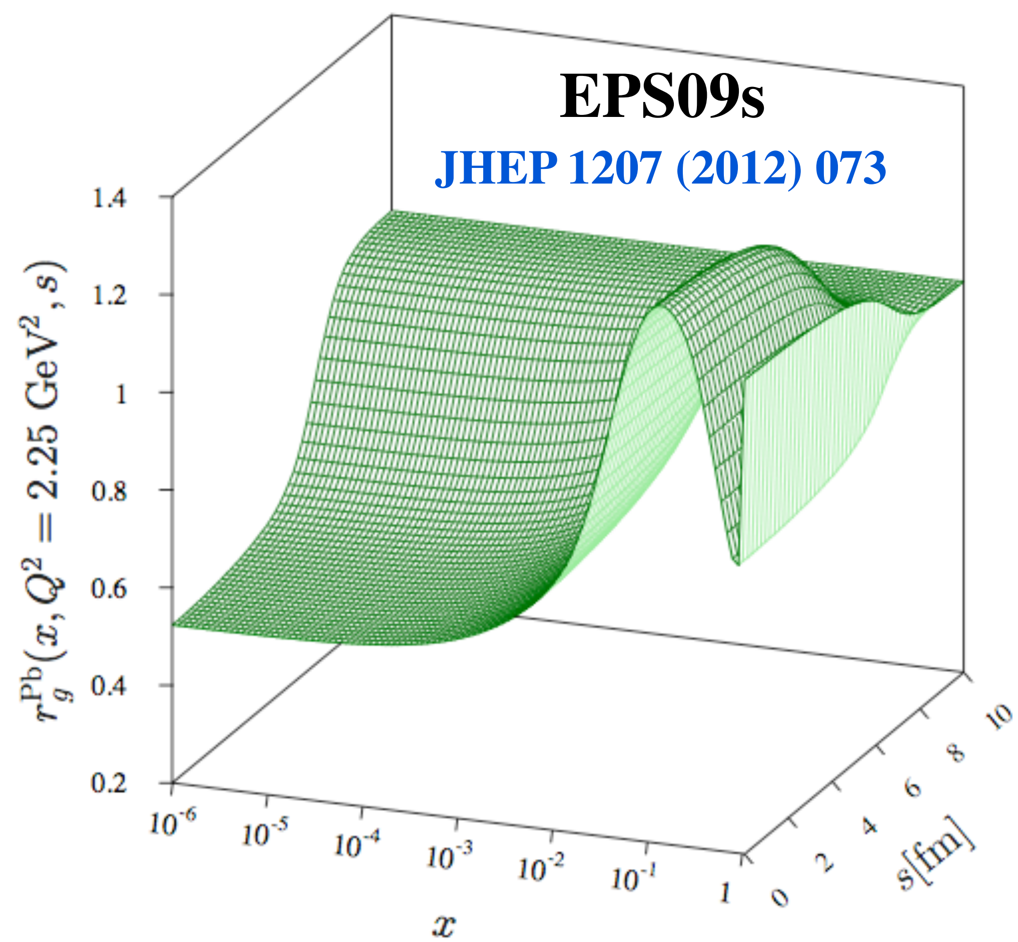
Forward rapidity in Au+Au is a mix of small-x, large-x effects which cancel out

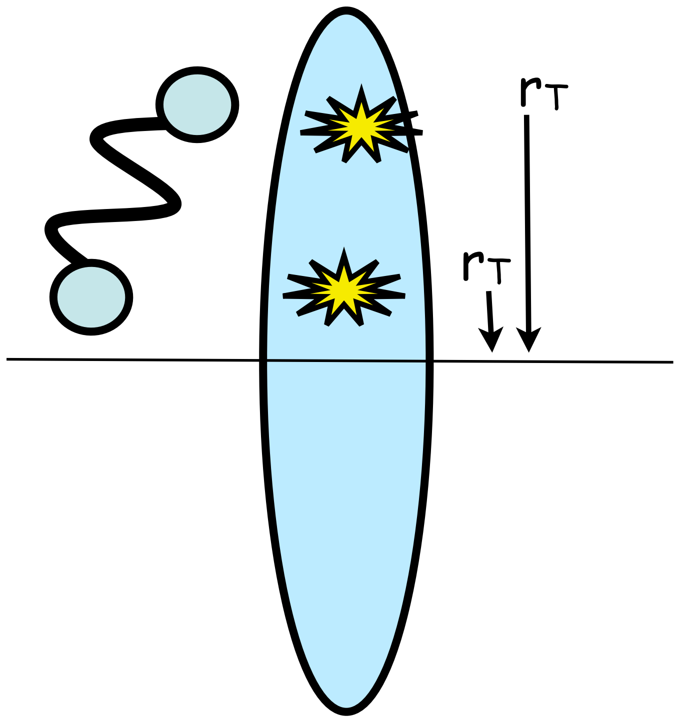


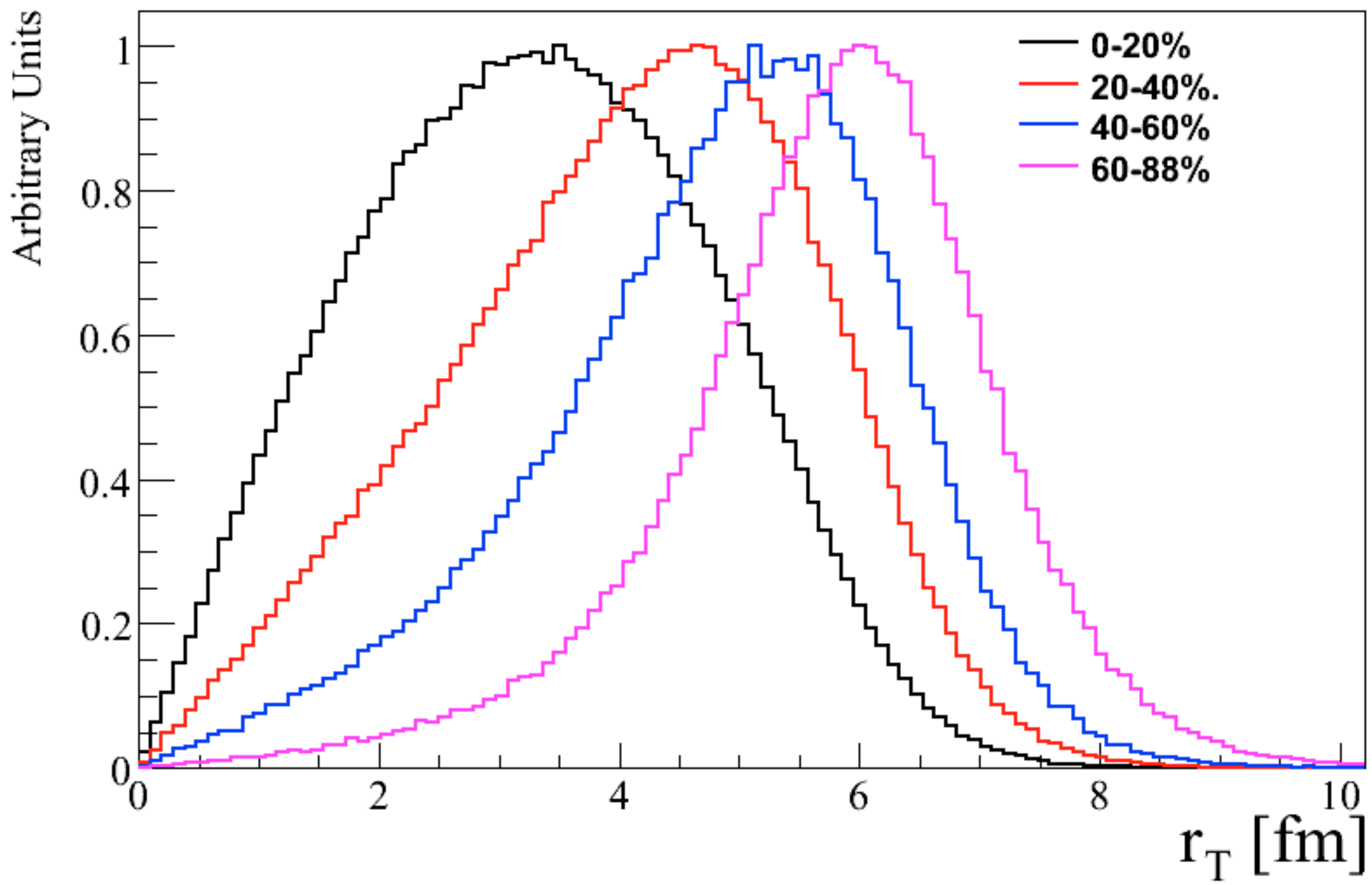
PHENIX PRL107, 142301 (2011)



- EPS09 cannot reproduce either RdA in peripheral events or Rcp
- one of the first indications of an impact parameter dependence of the nPDF







The impact parameter is still poorly determined in d+Au collisions

Future p+A collisions and additional centrality detectors can provide a better measurement of the impact parameter and how nPDFs can be extrapolated to A+A collisions

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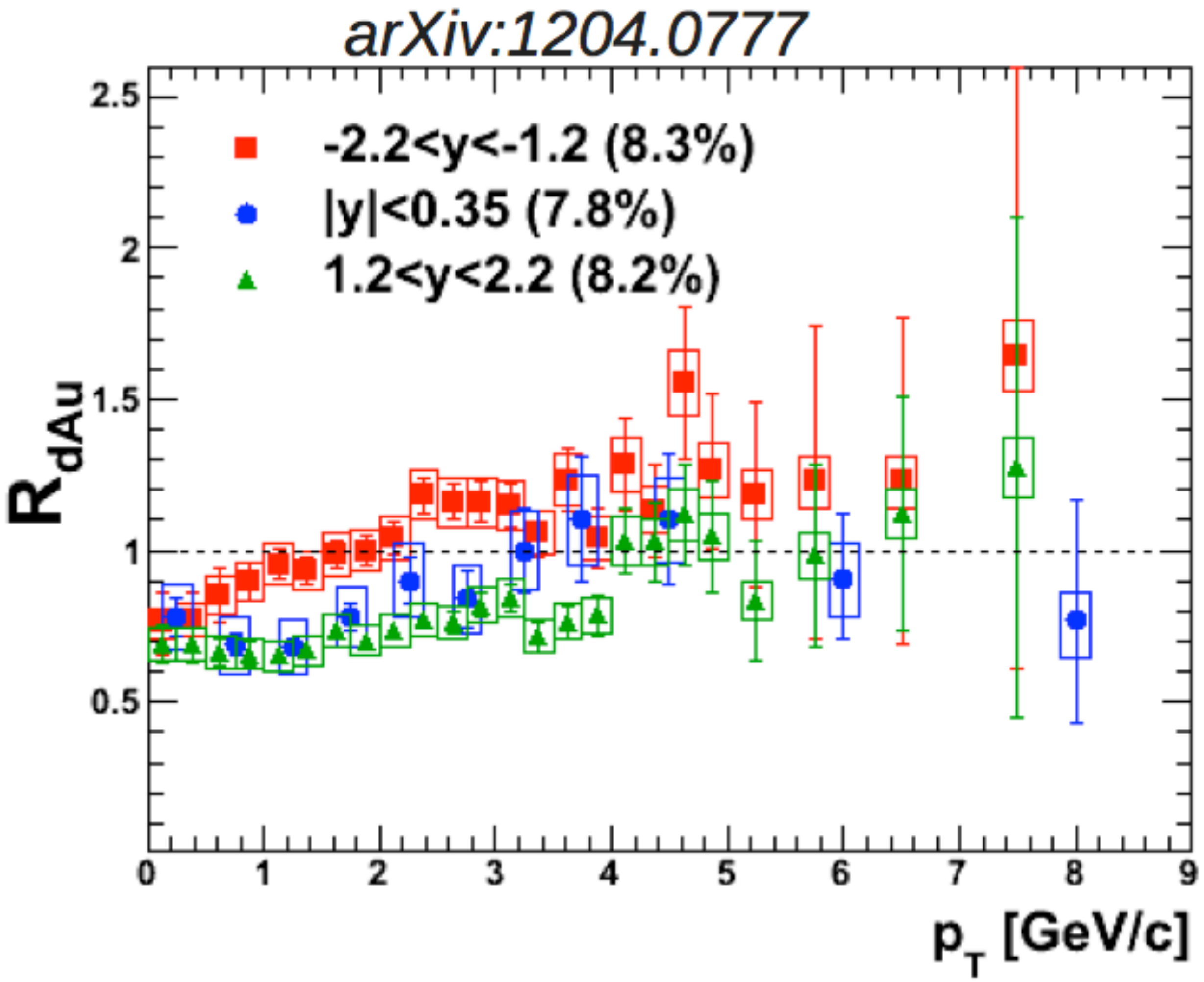
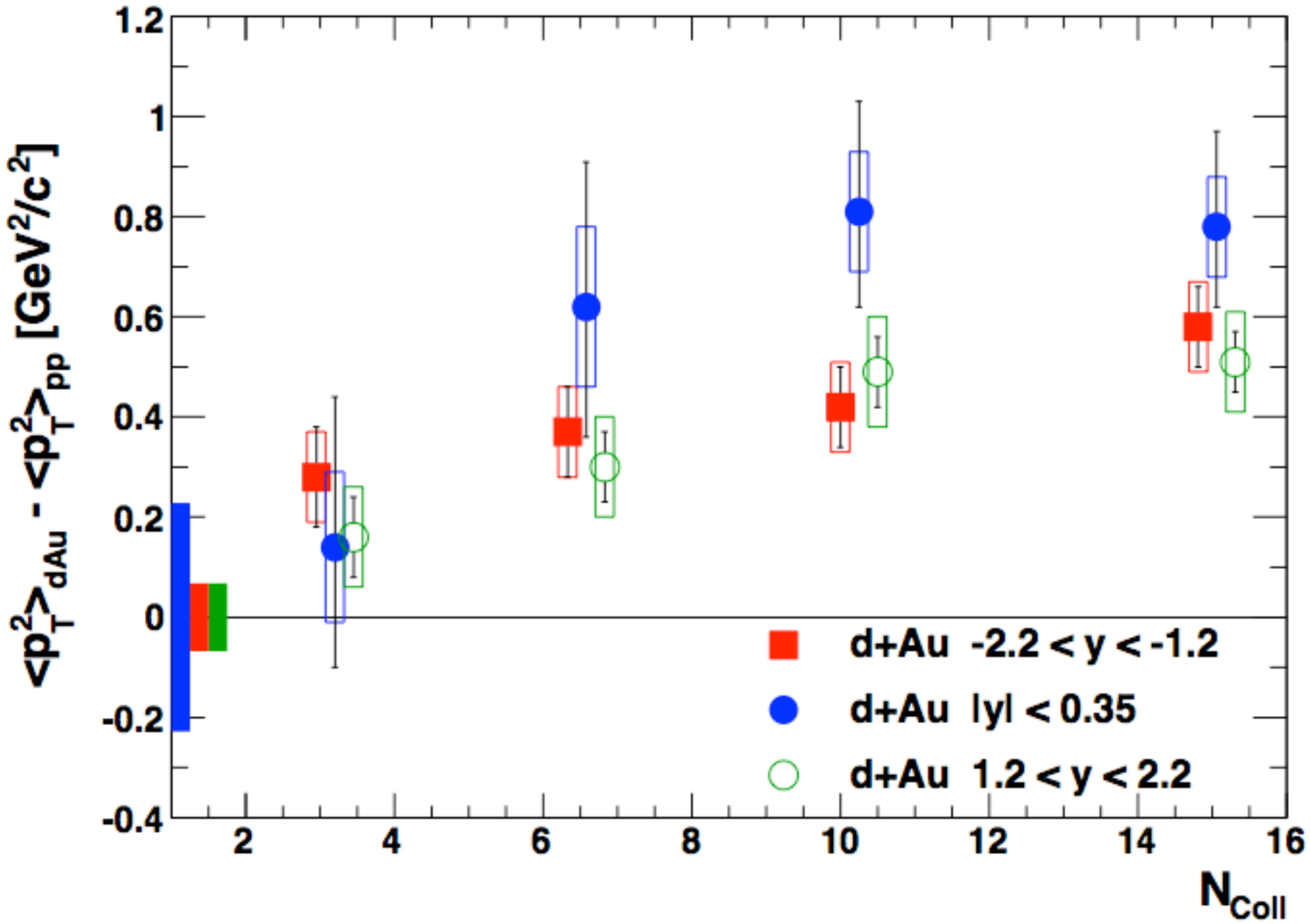


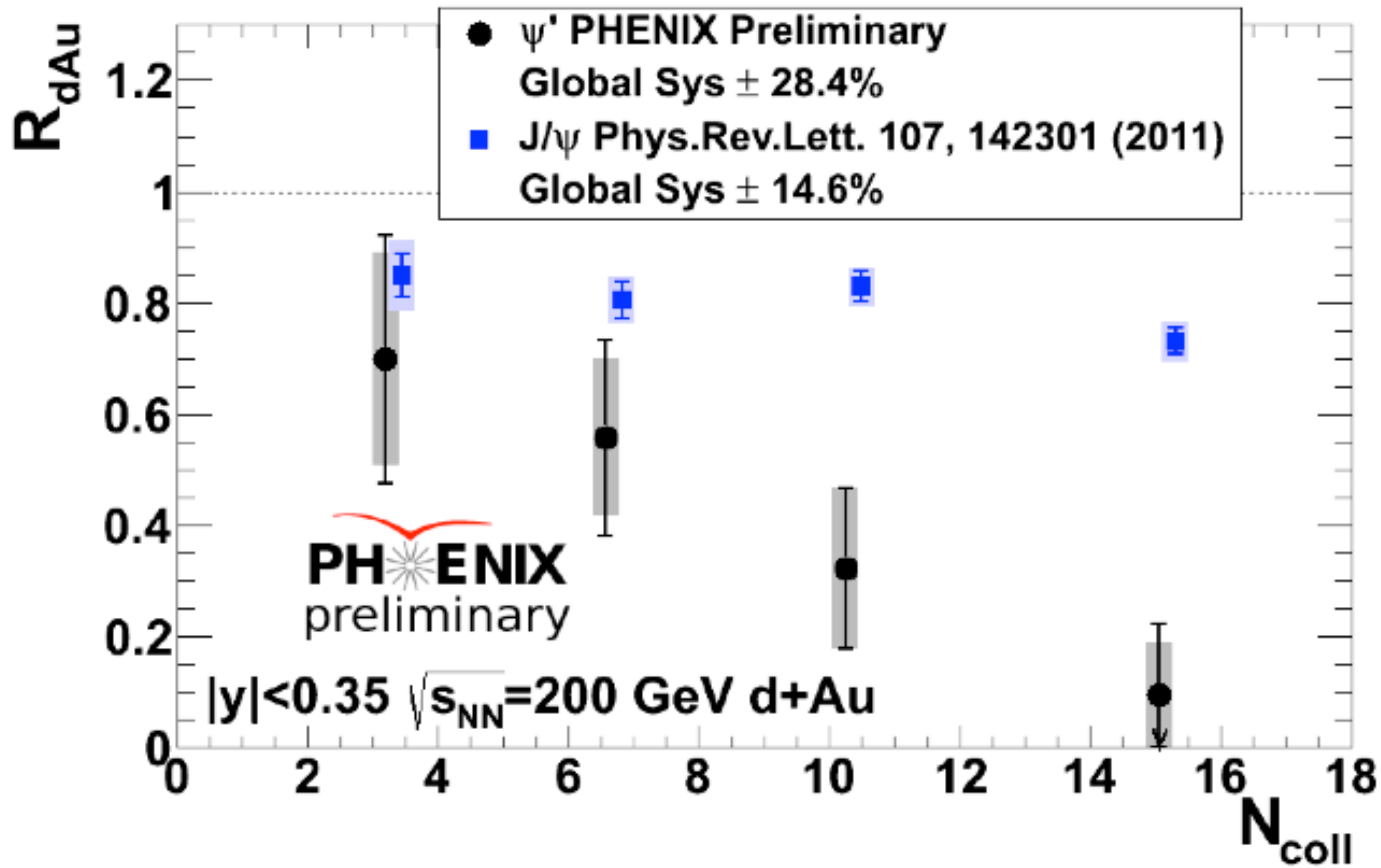


Significant Cronin effect

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

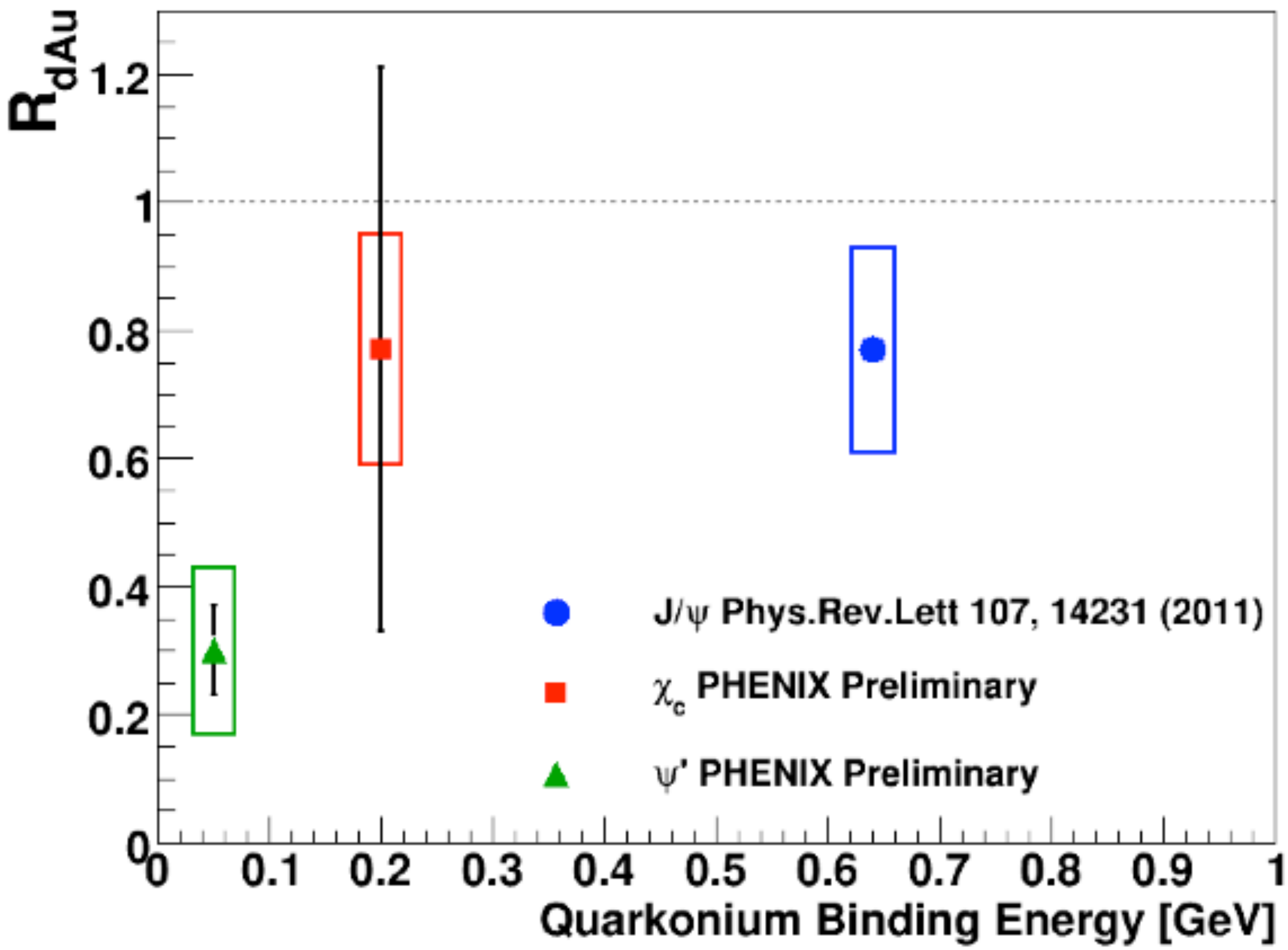
- result can explain the smaller J/ψ suppression at high p_T in A+A

Final-state effects in cold nuclear matter



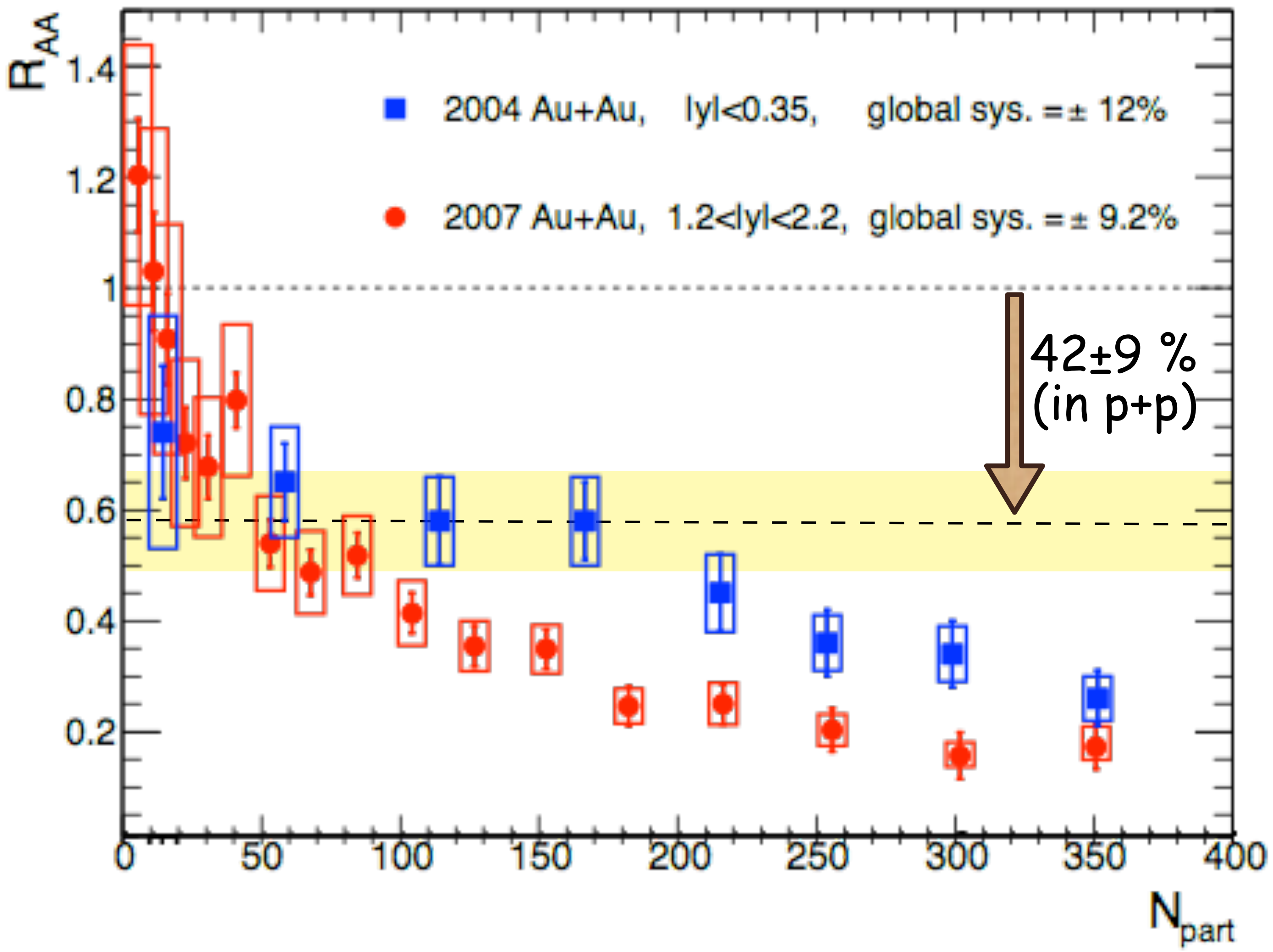
- same initial-state effects for J/ψ and ψ'
- stronger suppression of ψ' indicates charmonia cross the nucleus as final singlet states

Final-state effects in cold nuclear matter



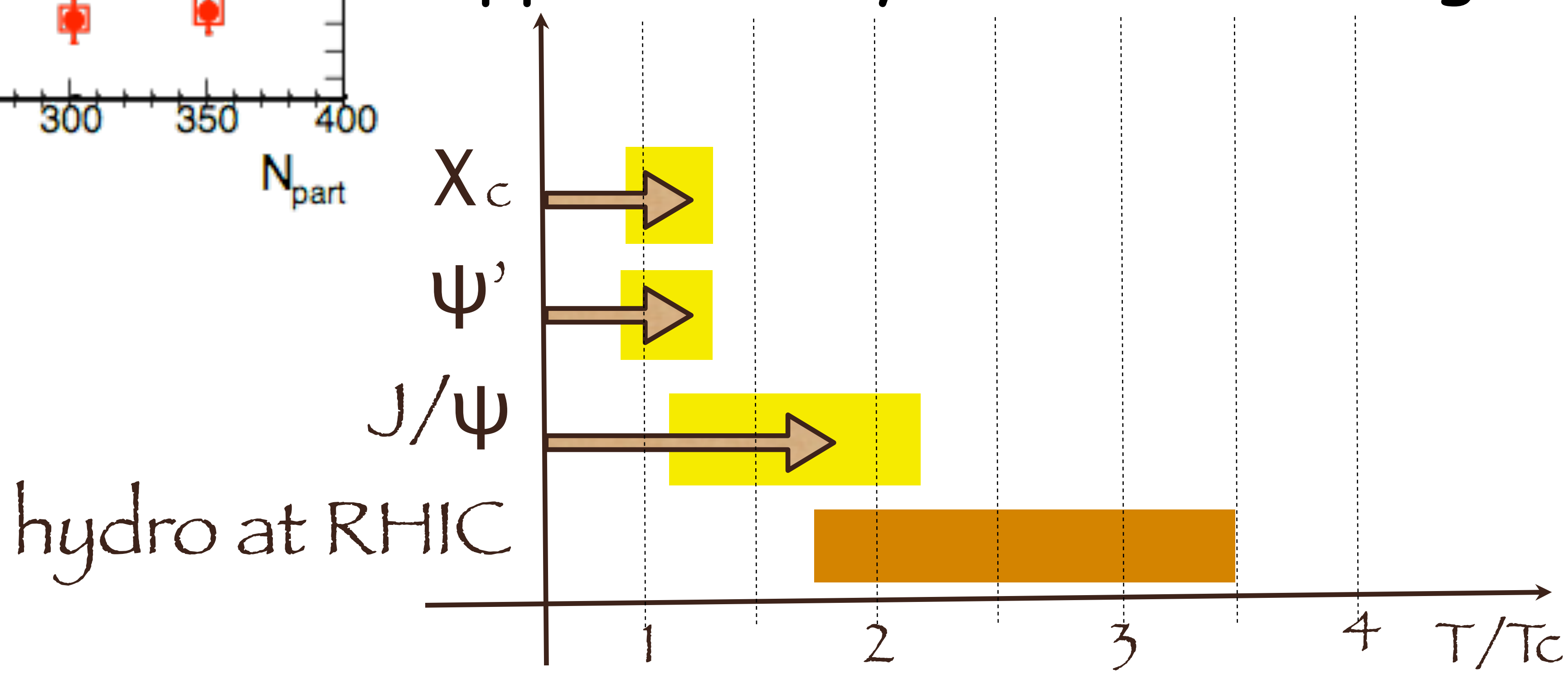
- charmonium breakup in confined matter depends on binding energy
- needs better measurement of χ_c

ψ' and χ_c feed-down suppression

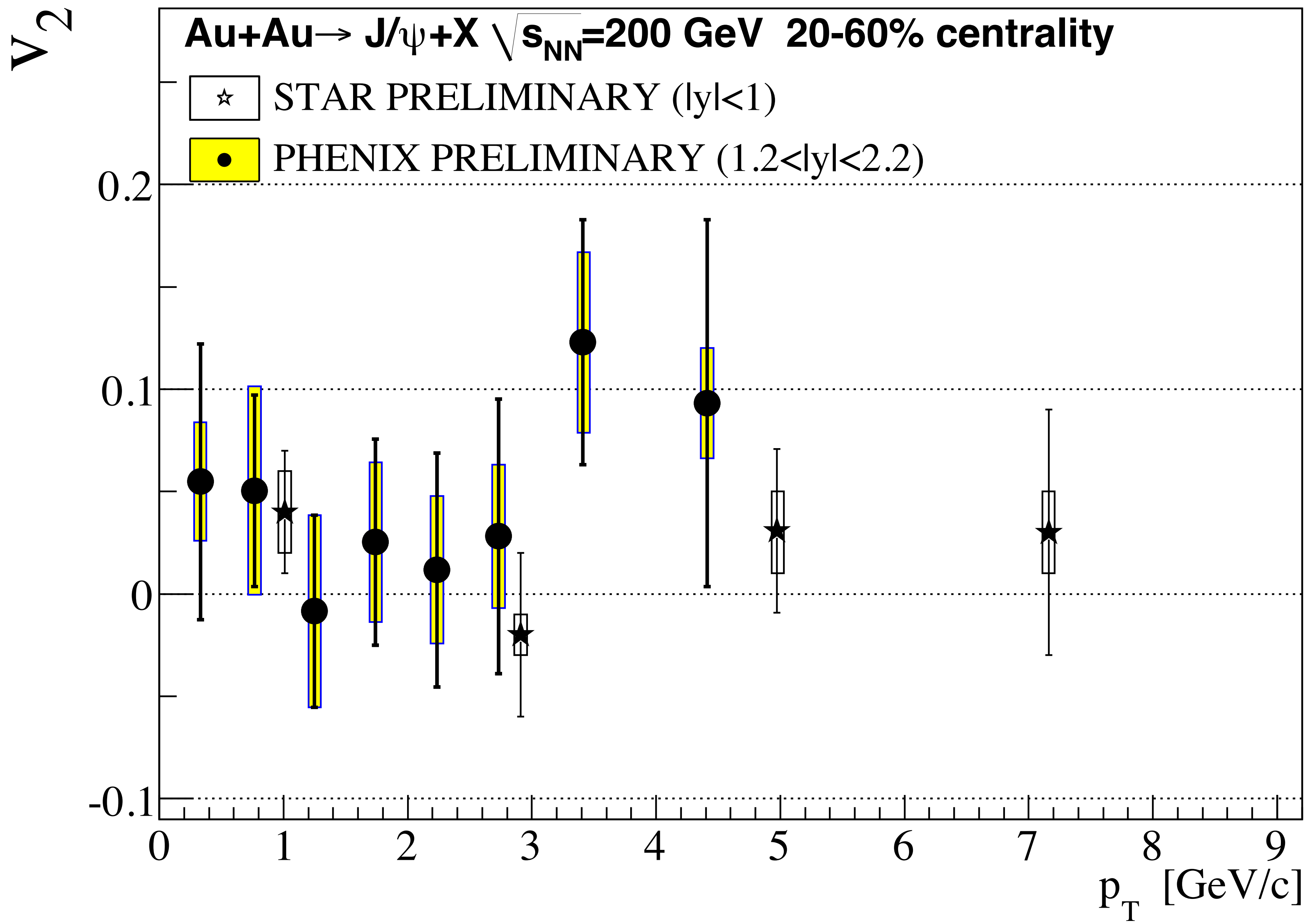


- not clear if there is any confined matter in A+A to break charmonium as in p(d)+A collisions

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

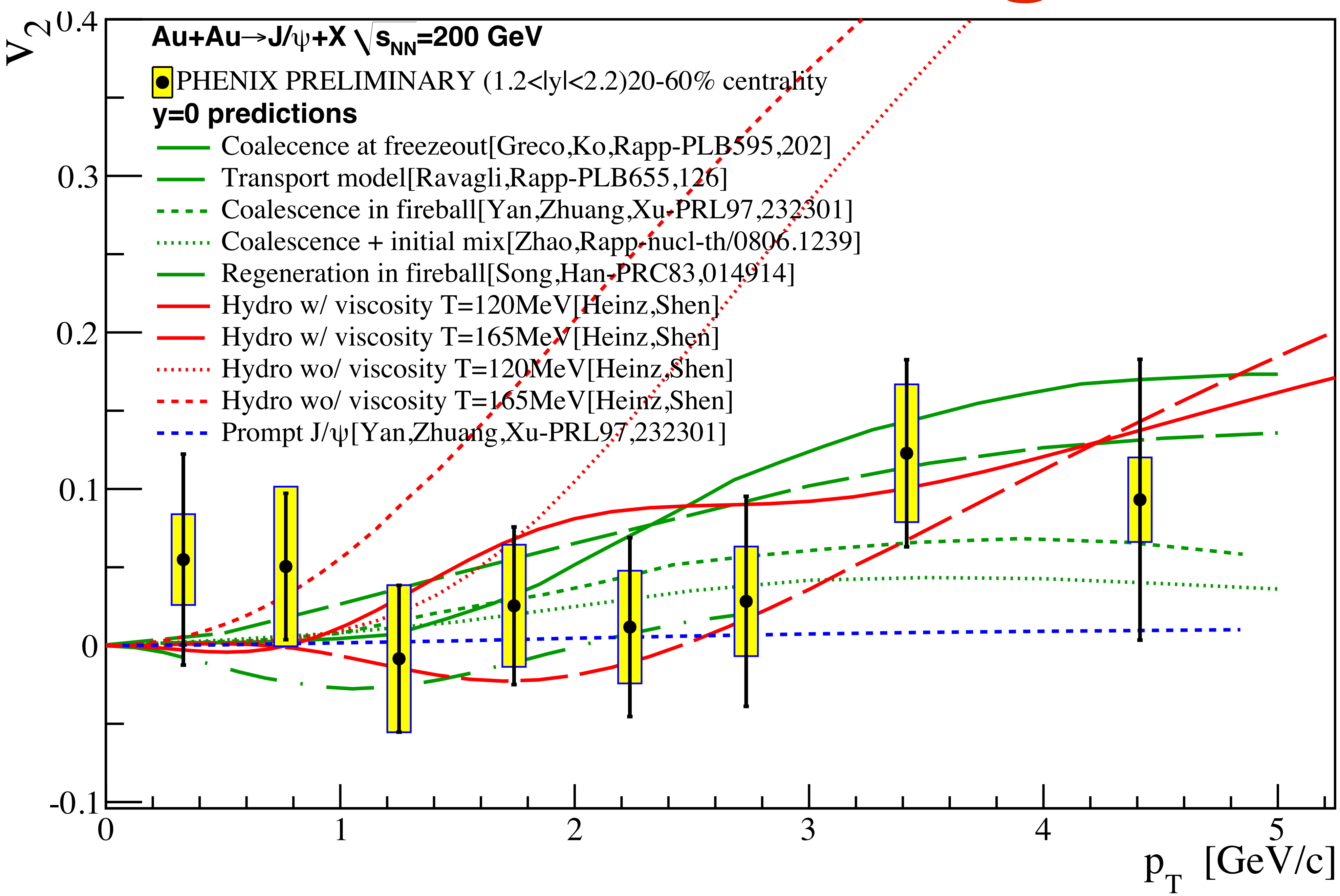


Coalescence and Regeneration



- J/ψ v_2 is a great tool to probe path length dependent suppression
- Forward rapidity consistent with mid-rapidity from STAR

Coalescence and Regeneration



- Can we really say there is no coalescence at RHIC ?
- Is there a hint for regeneration at 3-5 GeV/c ?
- Looking forward for theoretical estimations at forward rapidity...

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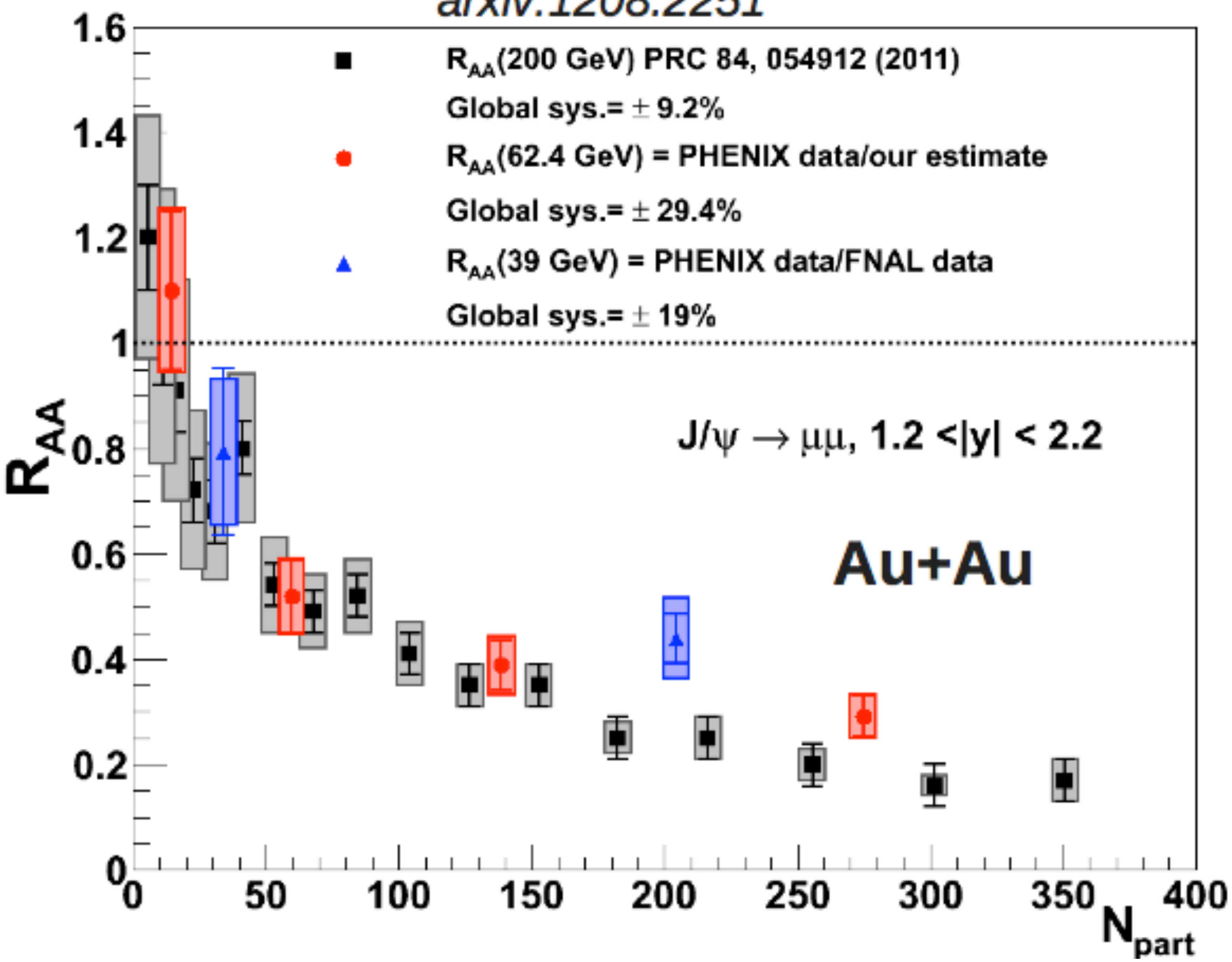
Collision Energy Dependence of J/ψ R_{AA}

arxiv:1208.2251



Using p+p reference from FERMILAB and ISR

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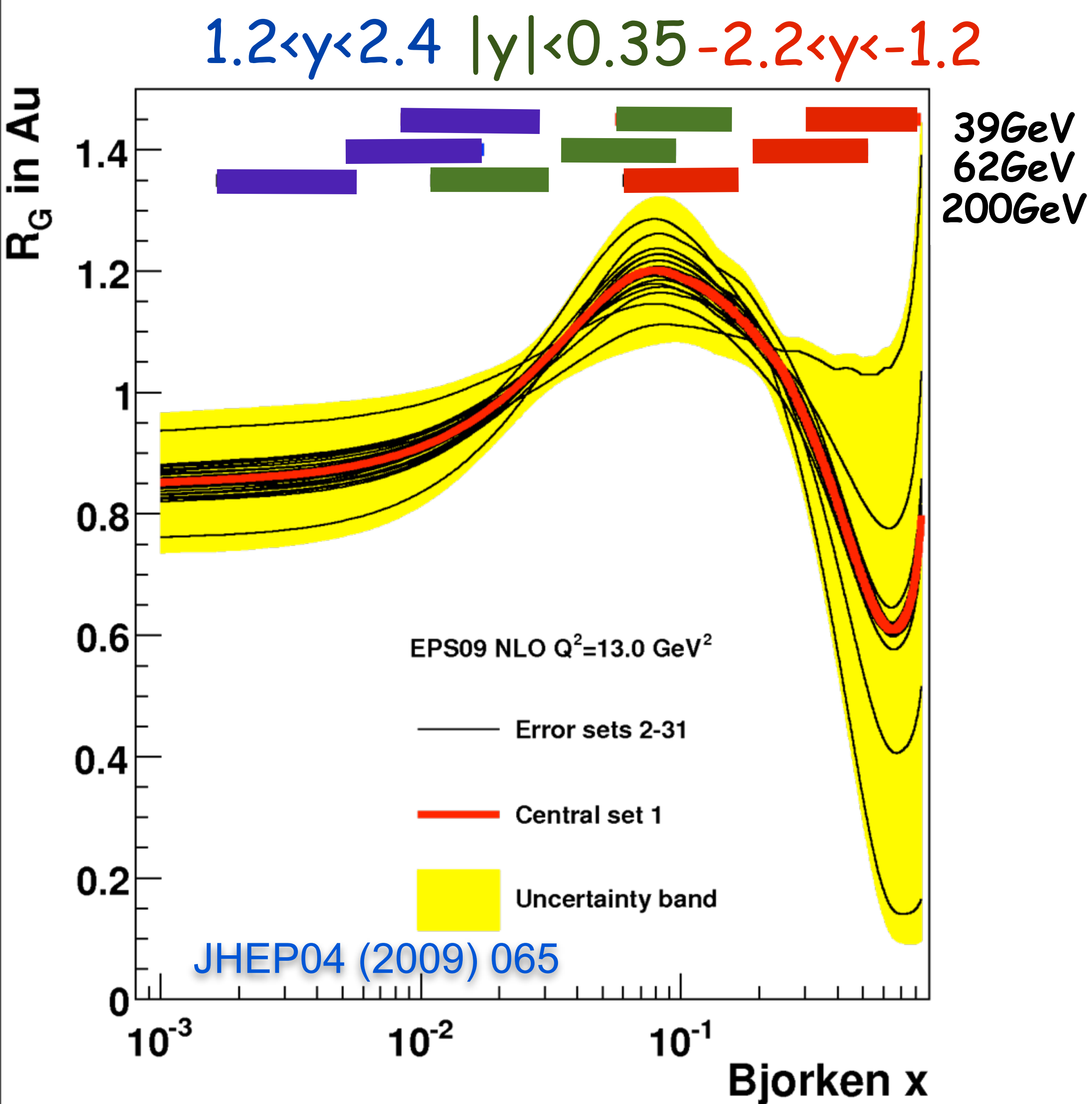
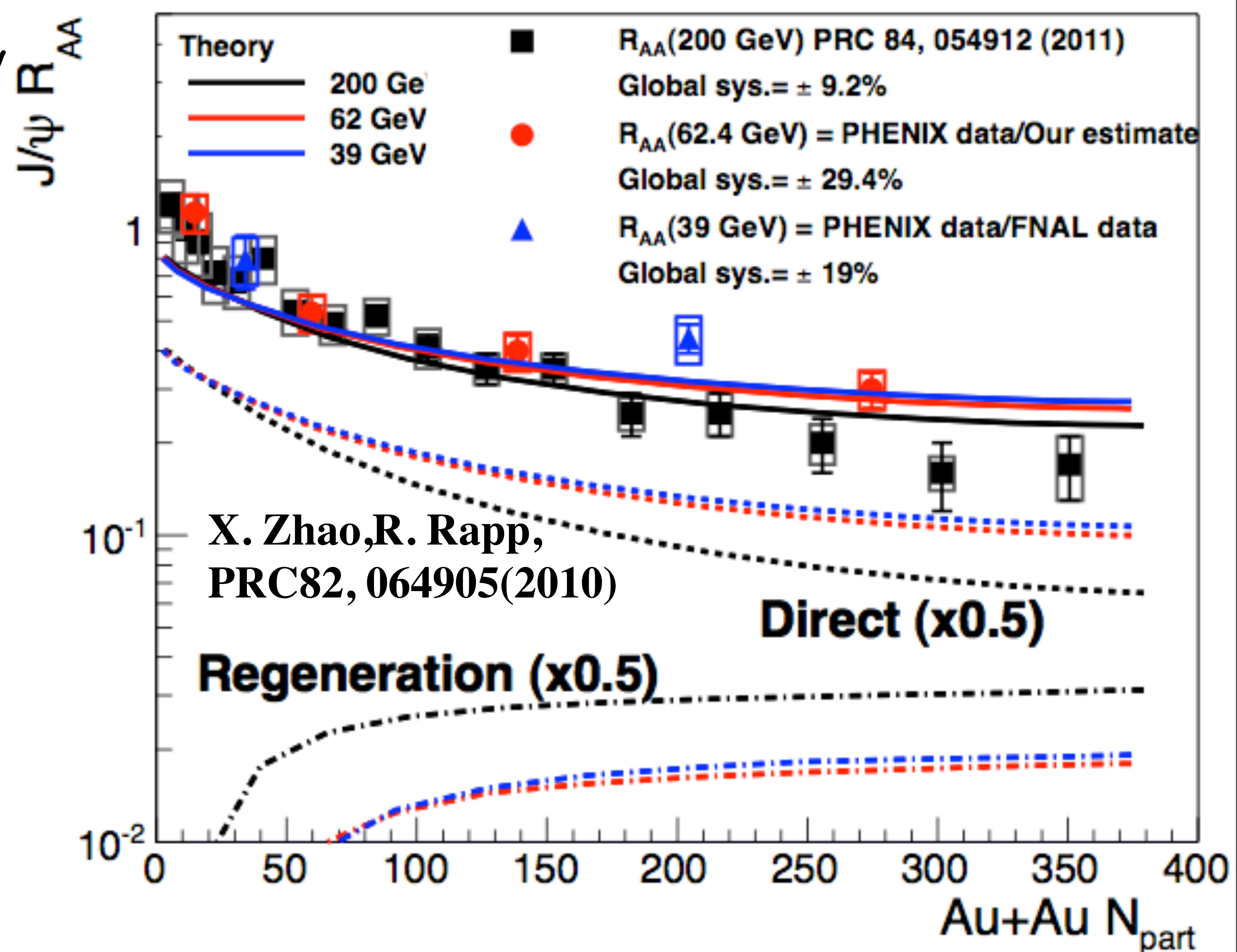
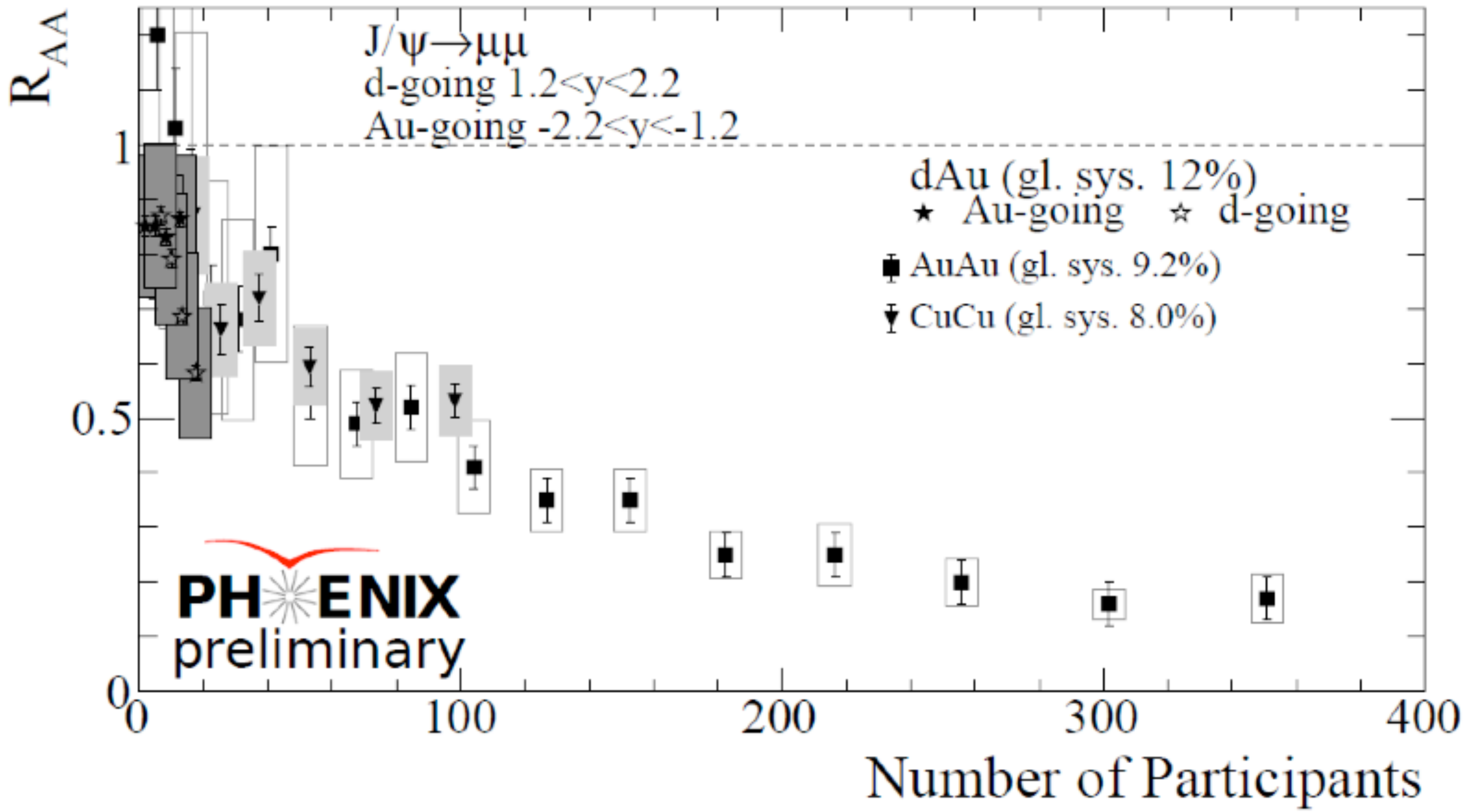
Collision Energy Dependence of J/ψ R_{AA}





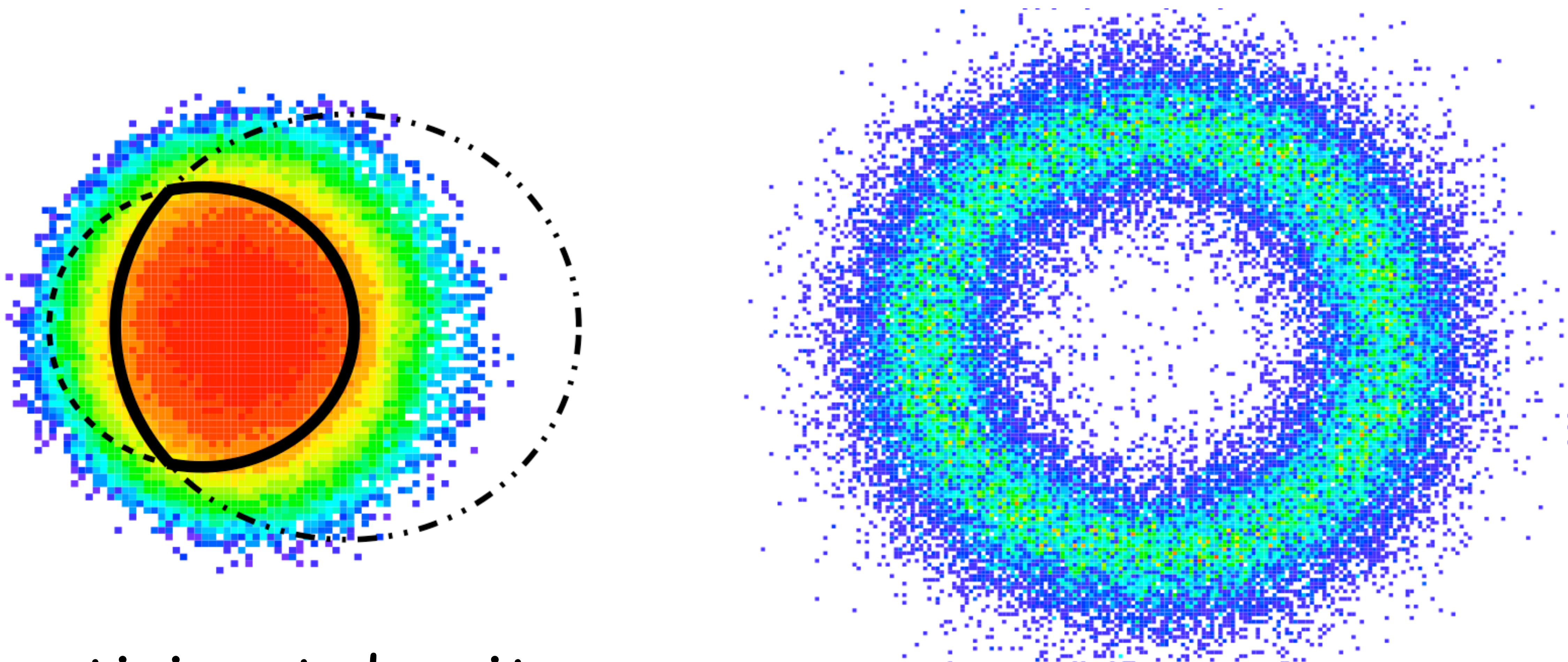
- x-range coverage changes with energy
- balancing effects makes R_{AA} similar at different energies

System Size dependence



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

Asymmetric Collisions: Cu+Au

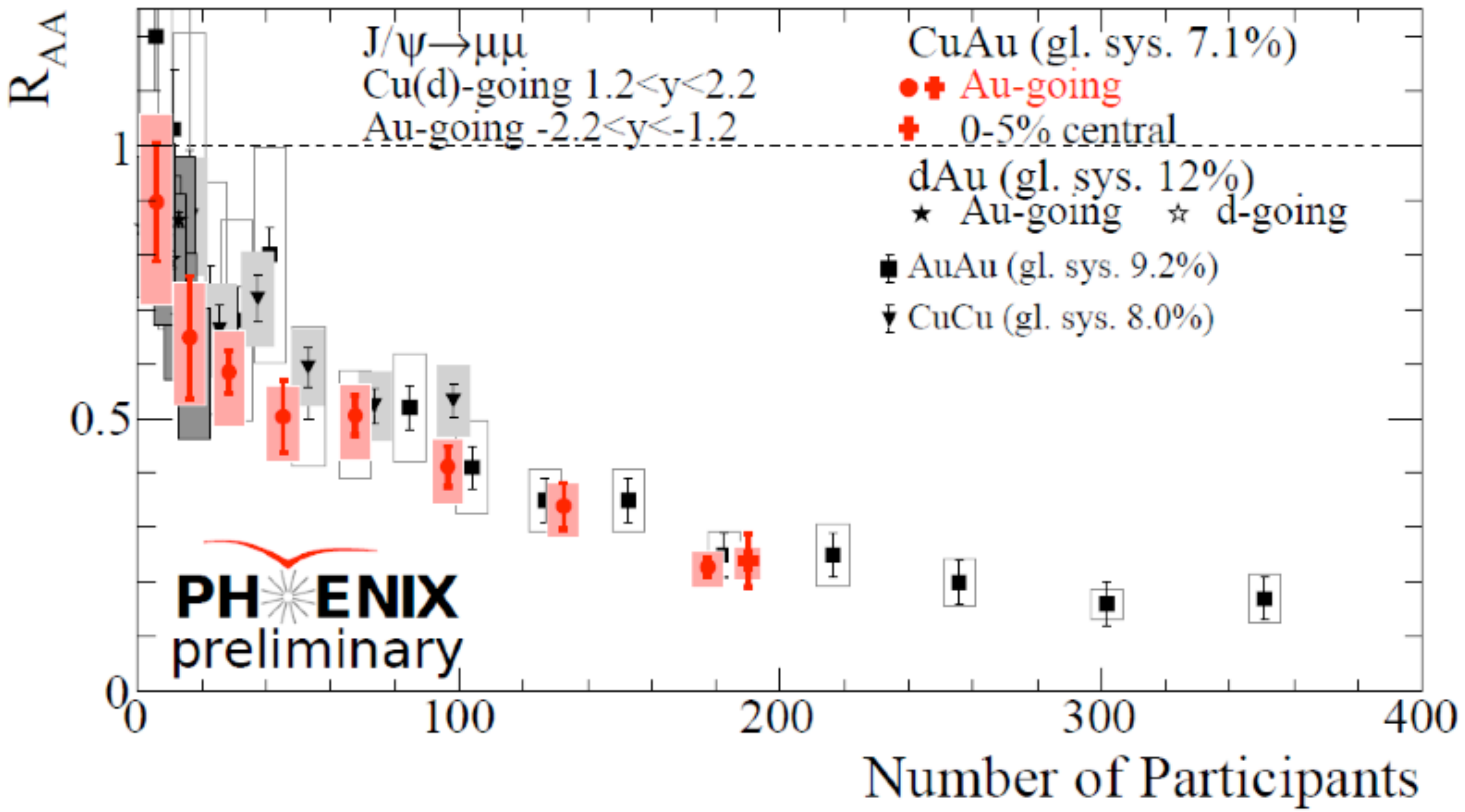


participant density
(log-scale)

spectator density

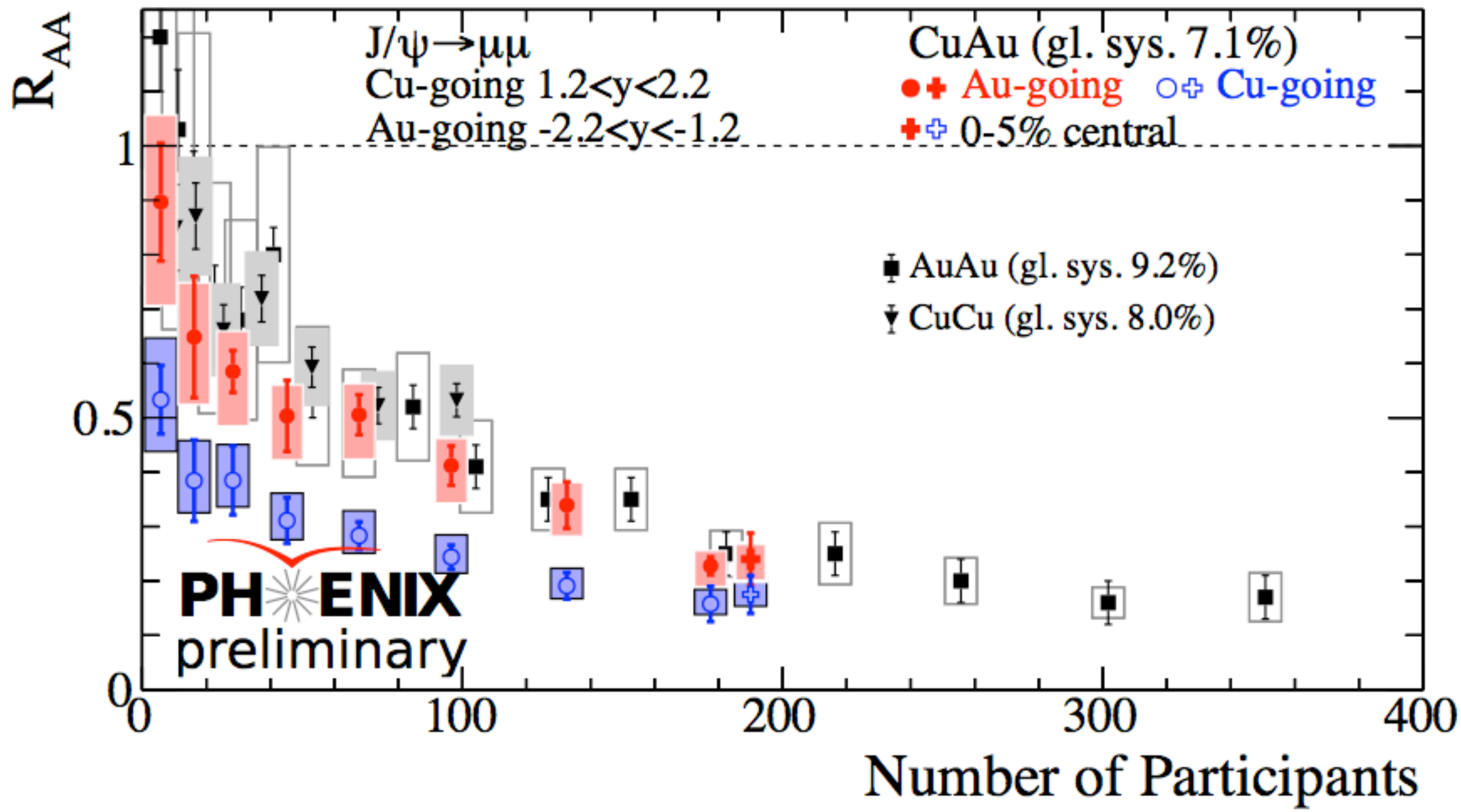
No room for corona effects in Cu-going direction
for central collisions

Asymmetric Collisions: Cu+Au



Unmodified suppression in Au-going direction

Asymmetric Collisions: Cu+Au



- stronger suppression in Cu-going direction
- but still not completely suppressed
  - J/ψ is not melted ?
  - contribution from regeneration ?

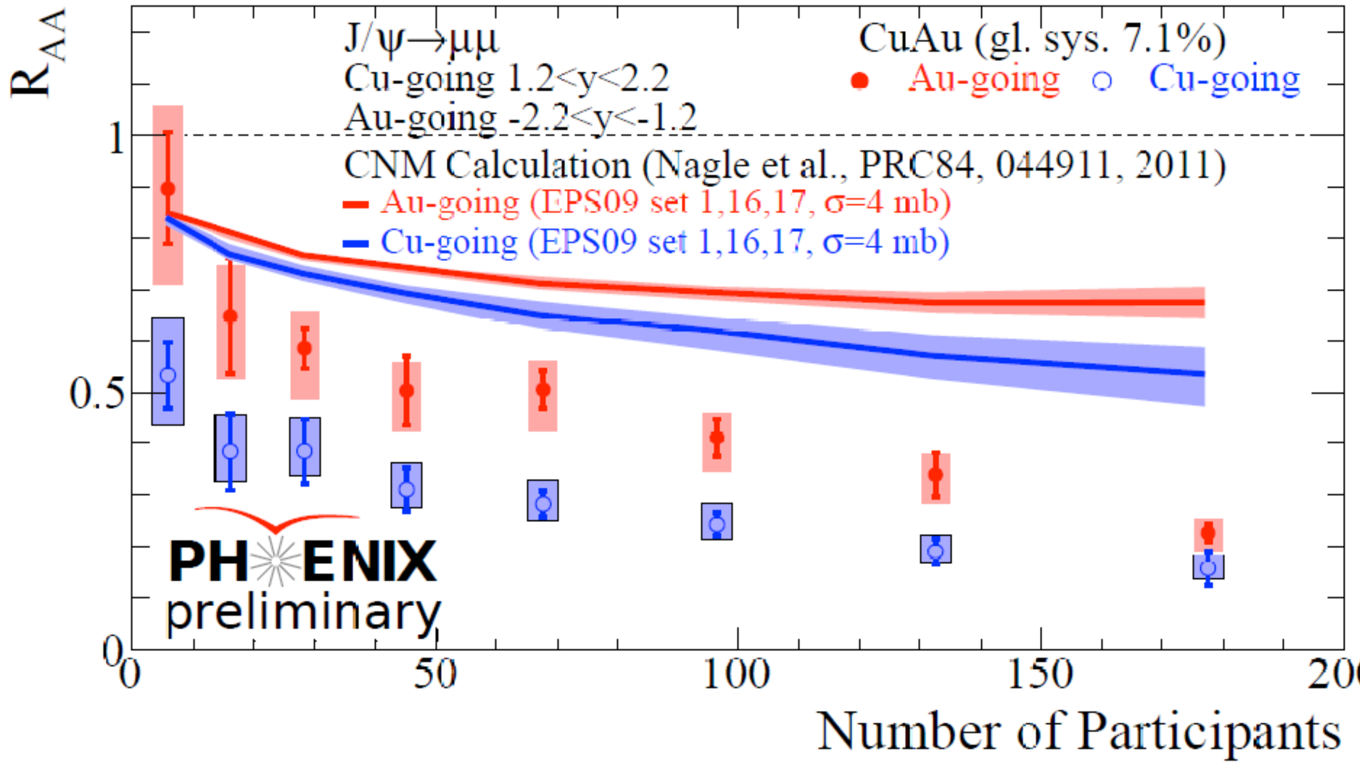
Asymmetric Collisions: Cu+Au

More thought about suppression in Cu-going direction:

Asymmetric Collisions: Cu+Au

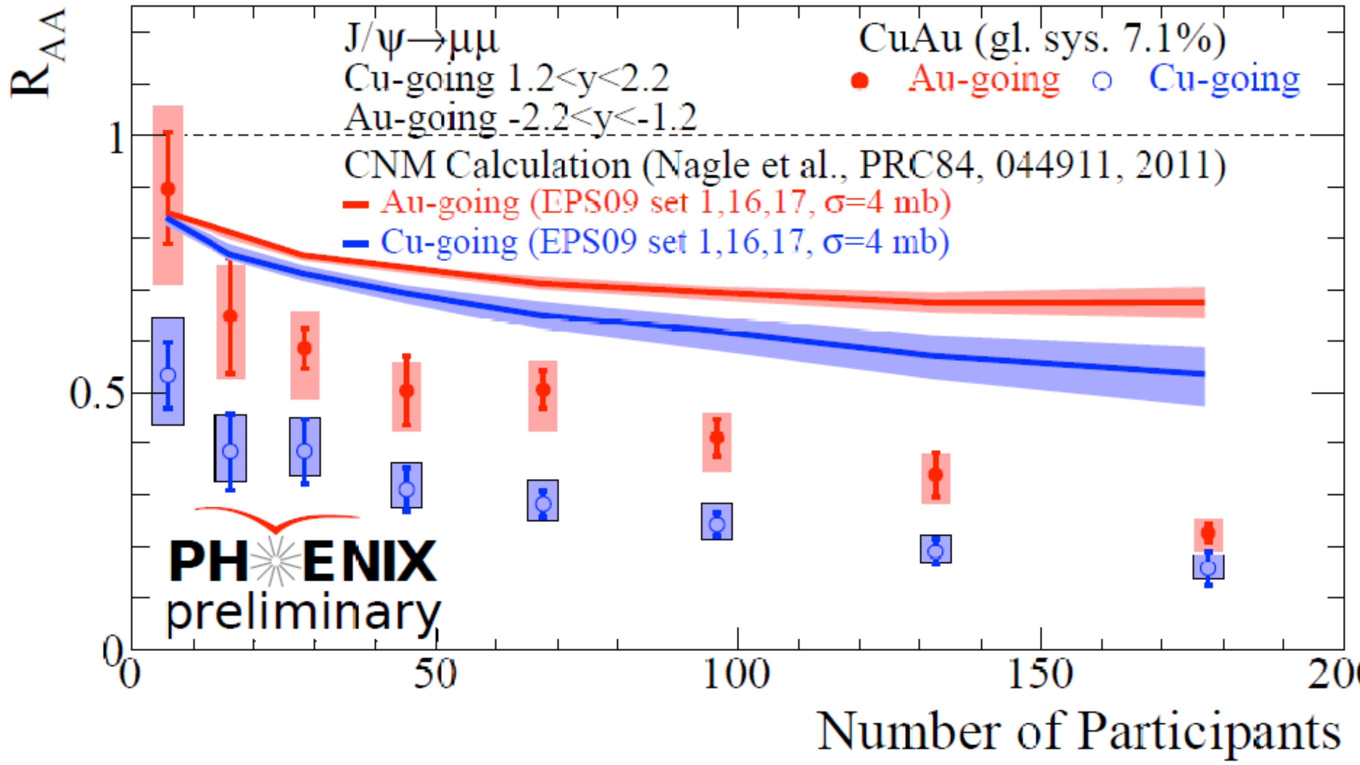
More thought about suppression in Cu-going direction:

- initial-state can partially describe difference

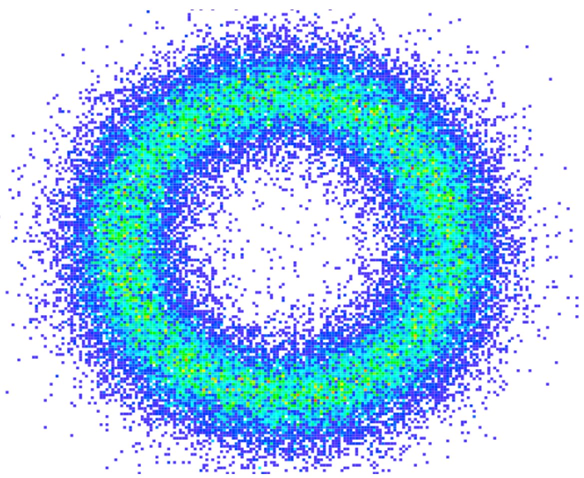


Asymmetric Collisions: Cu+Au

More thought about suppression in Cu-going direction:



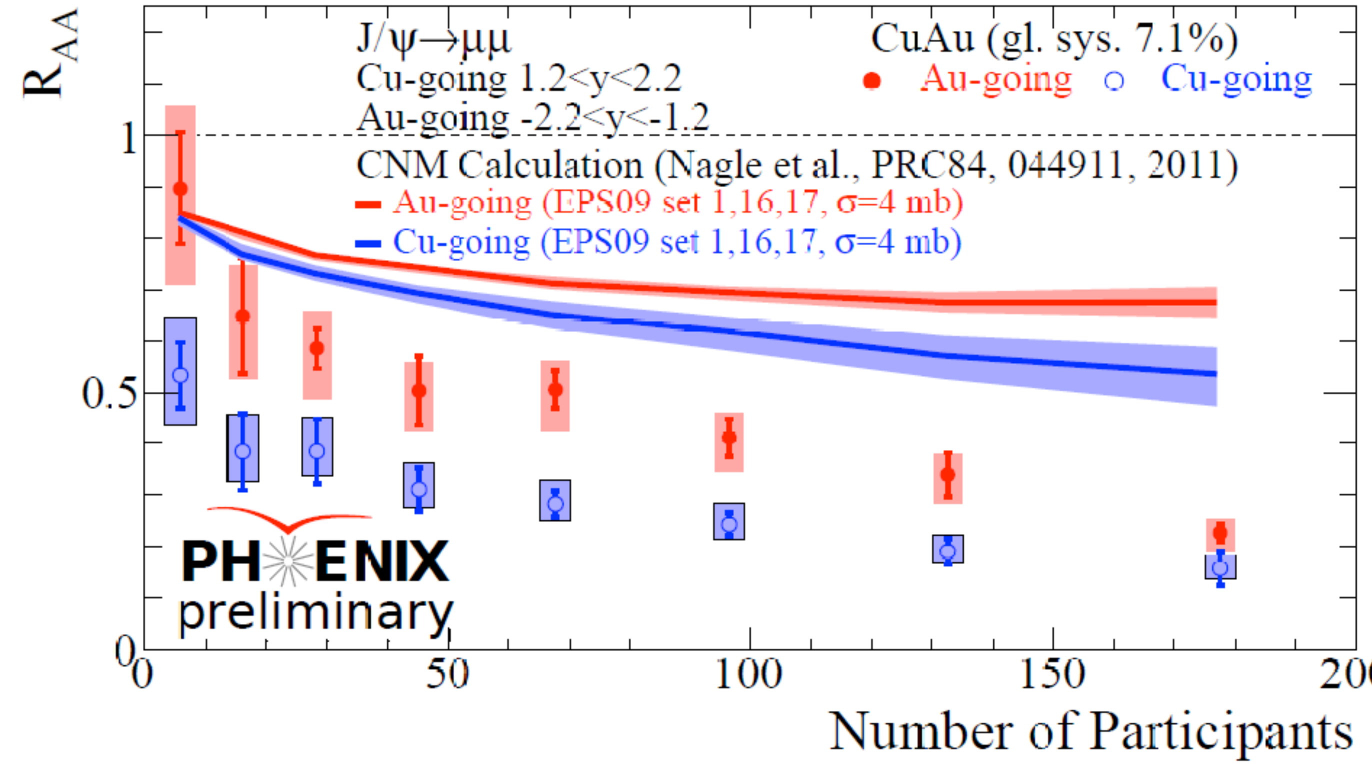
- initial-state can partially describe difference



- 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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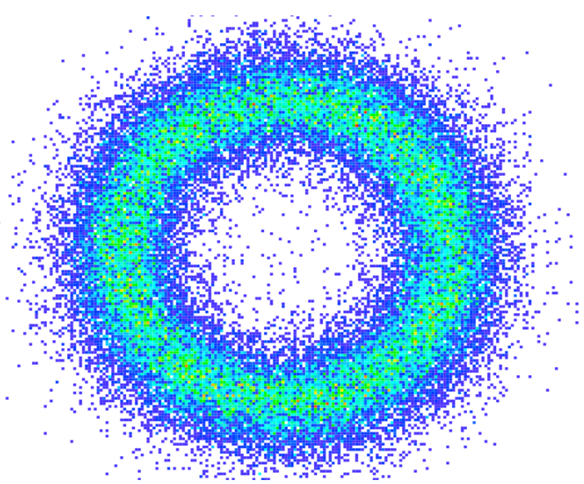
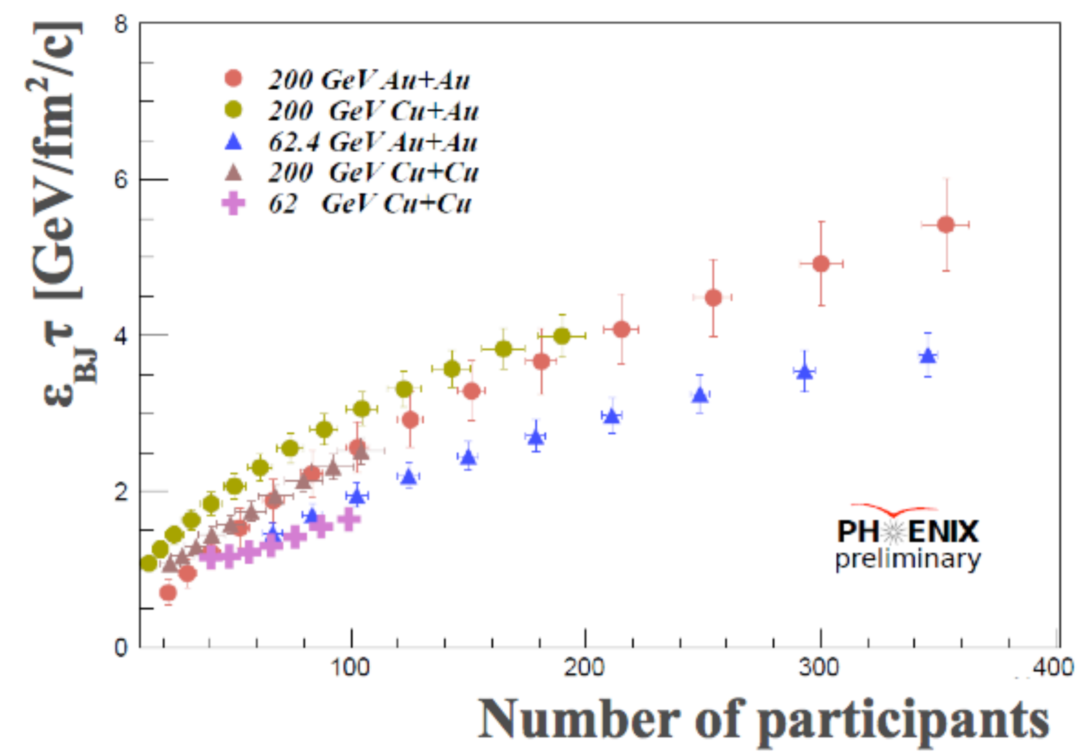


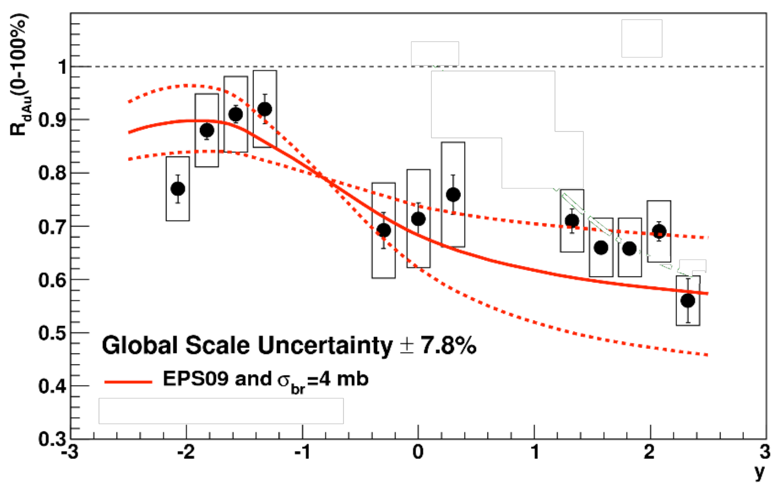
- J/ψ formed has to cross some cold matter (halo in the picture)

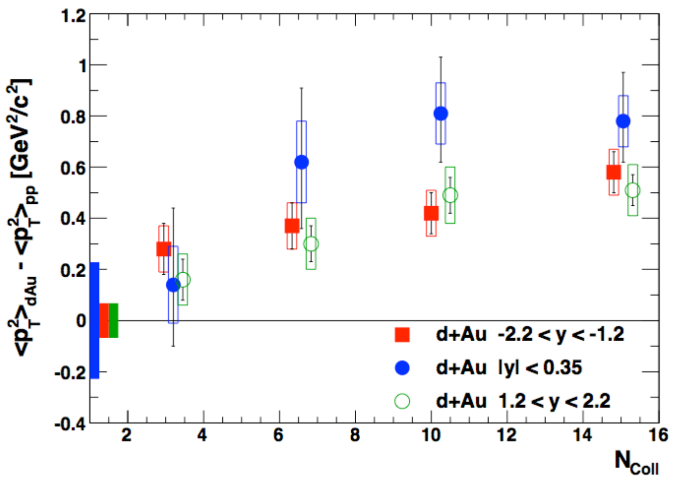


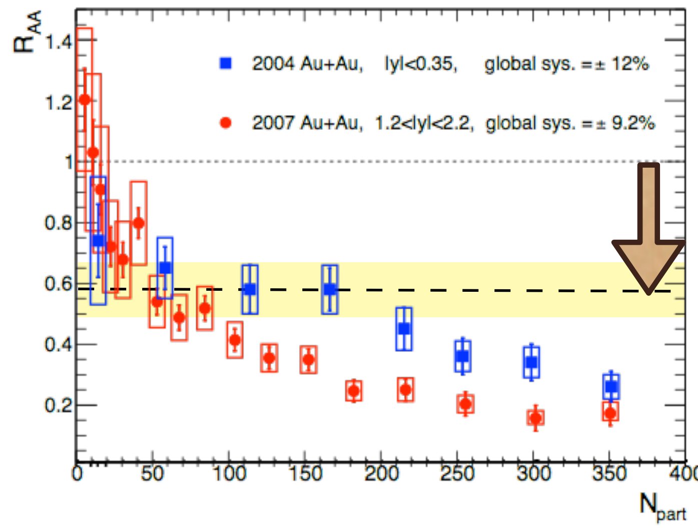
- energy density times crossing time slightly larger in Cu+Au than Au+Au

Conclusions

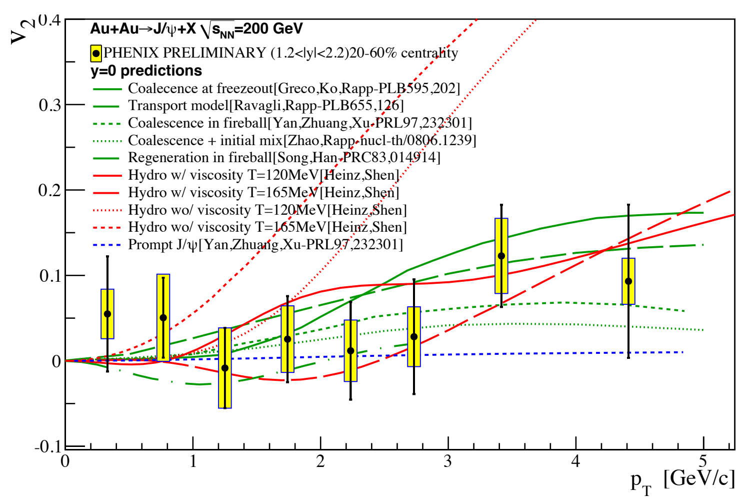
We have a machine which provide a large degree of freedom to study quarkonia in heavy ion collisions

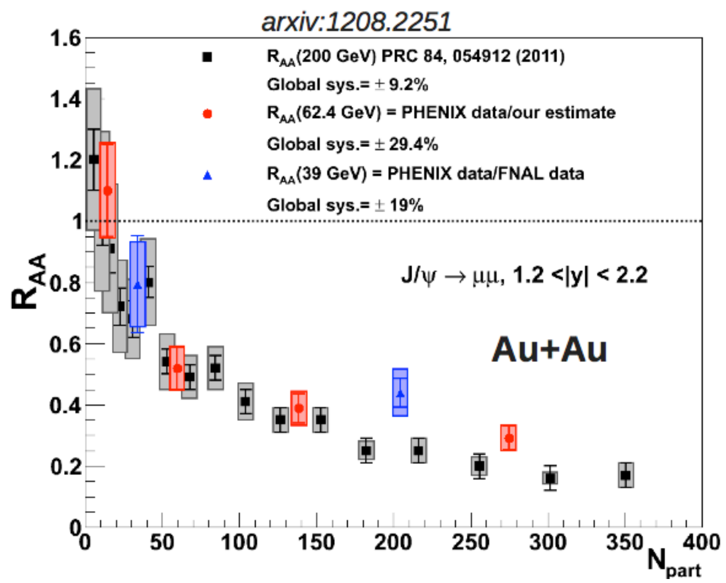


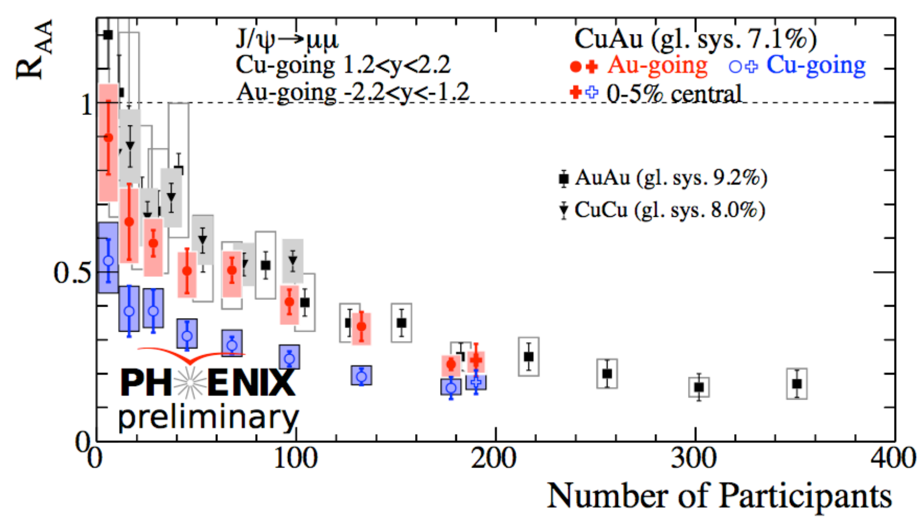




$\chi_c + \psi'$

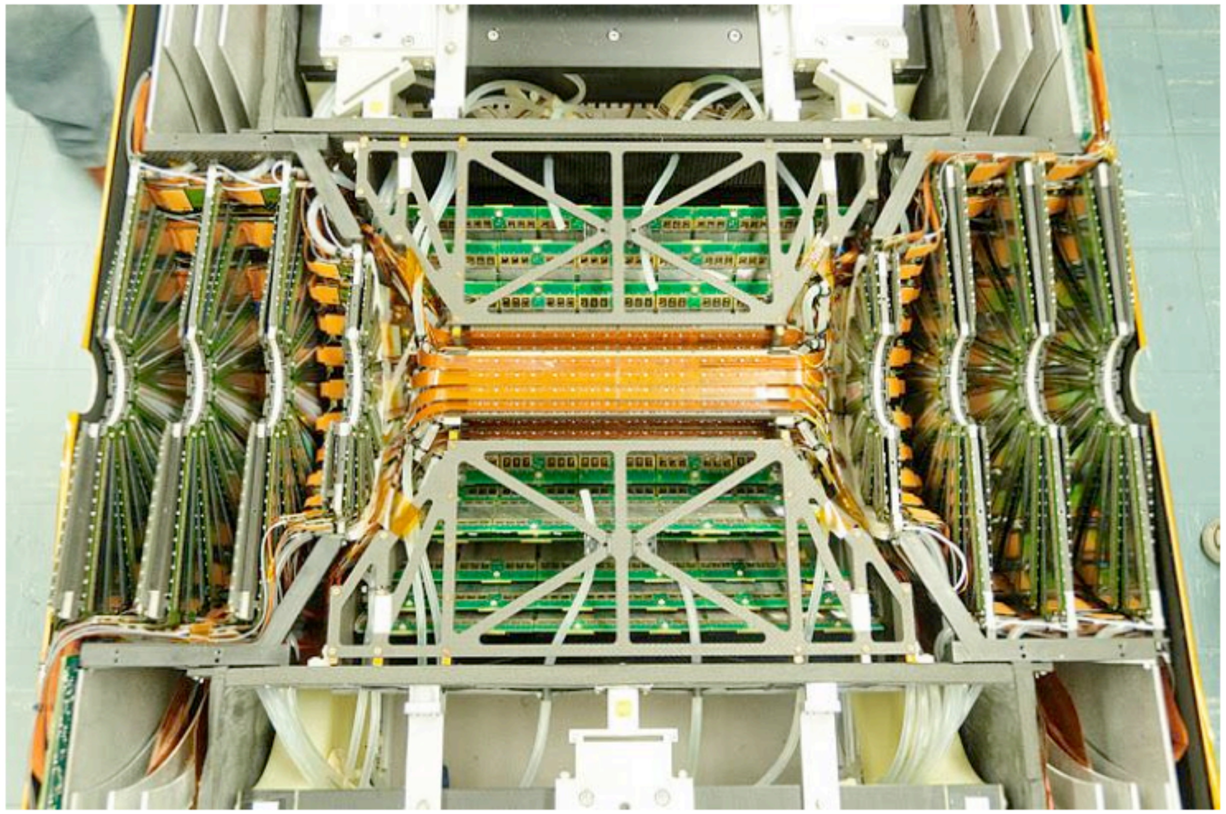


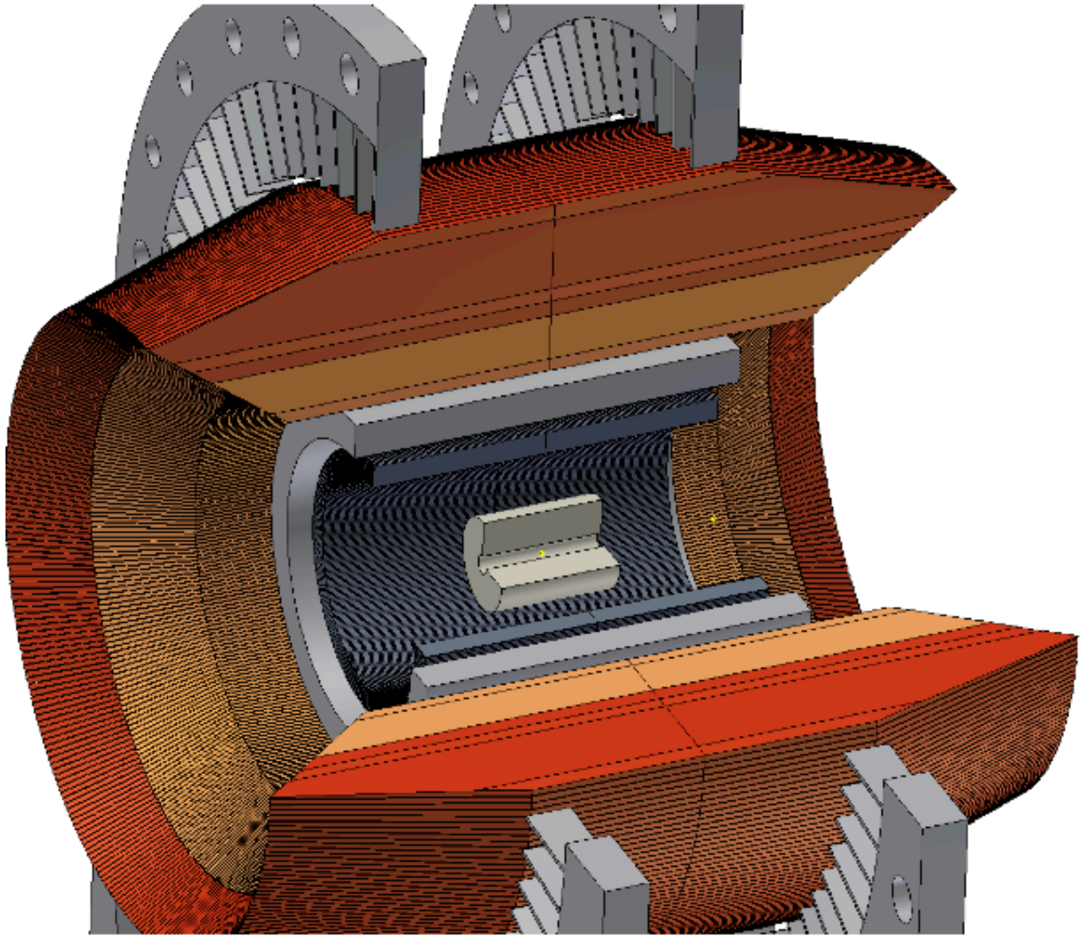




More studies and data can allows us to quantify the effects involved in charmonium suppression

More on Future Measurements talk on Saturday





Thanks for your attention!

BACKUP SLIDES

PHENIX

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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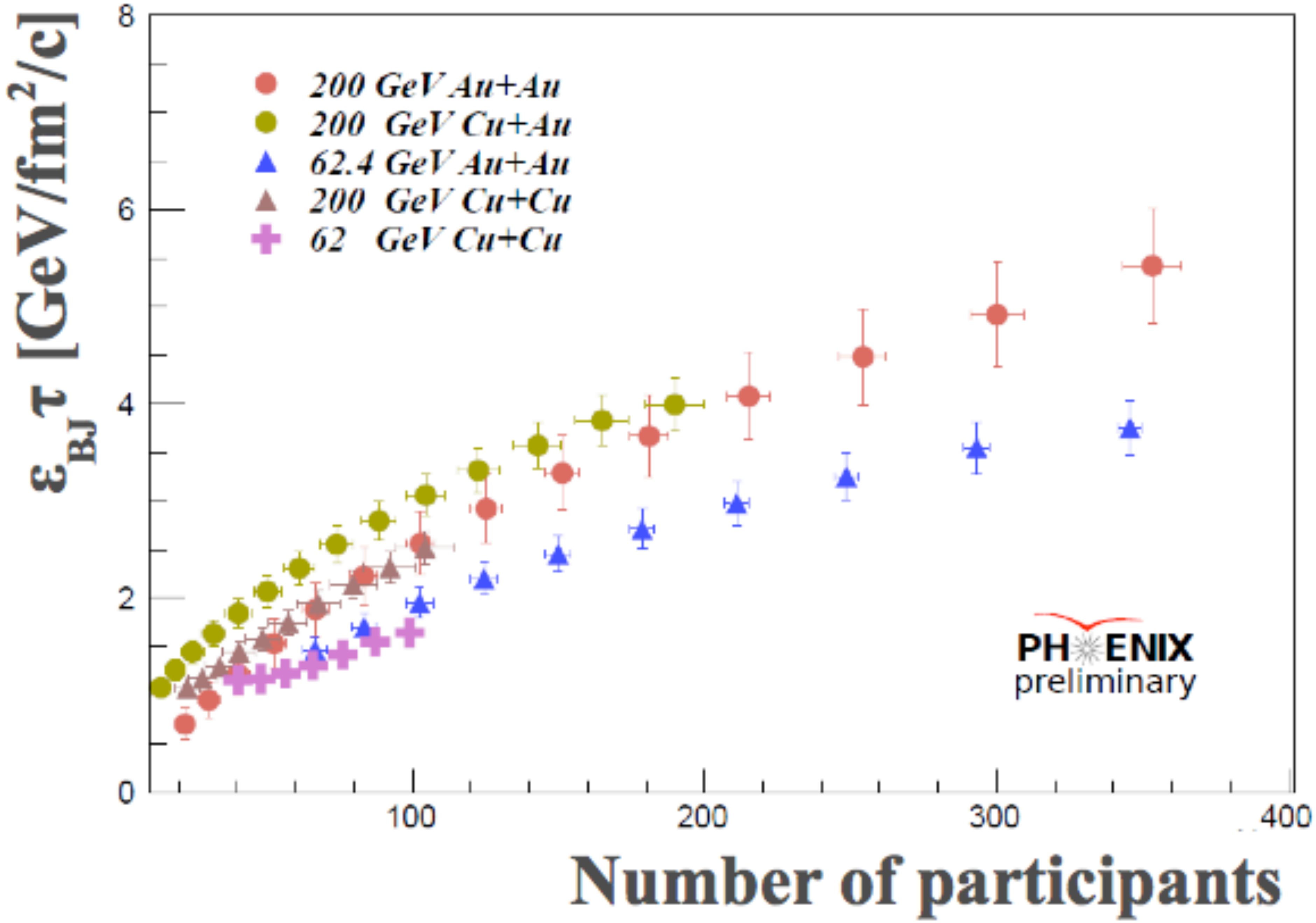
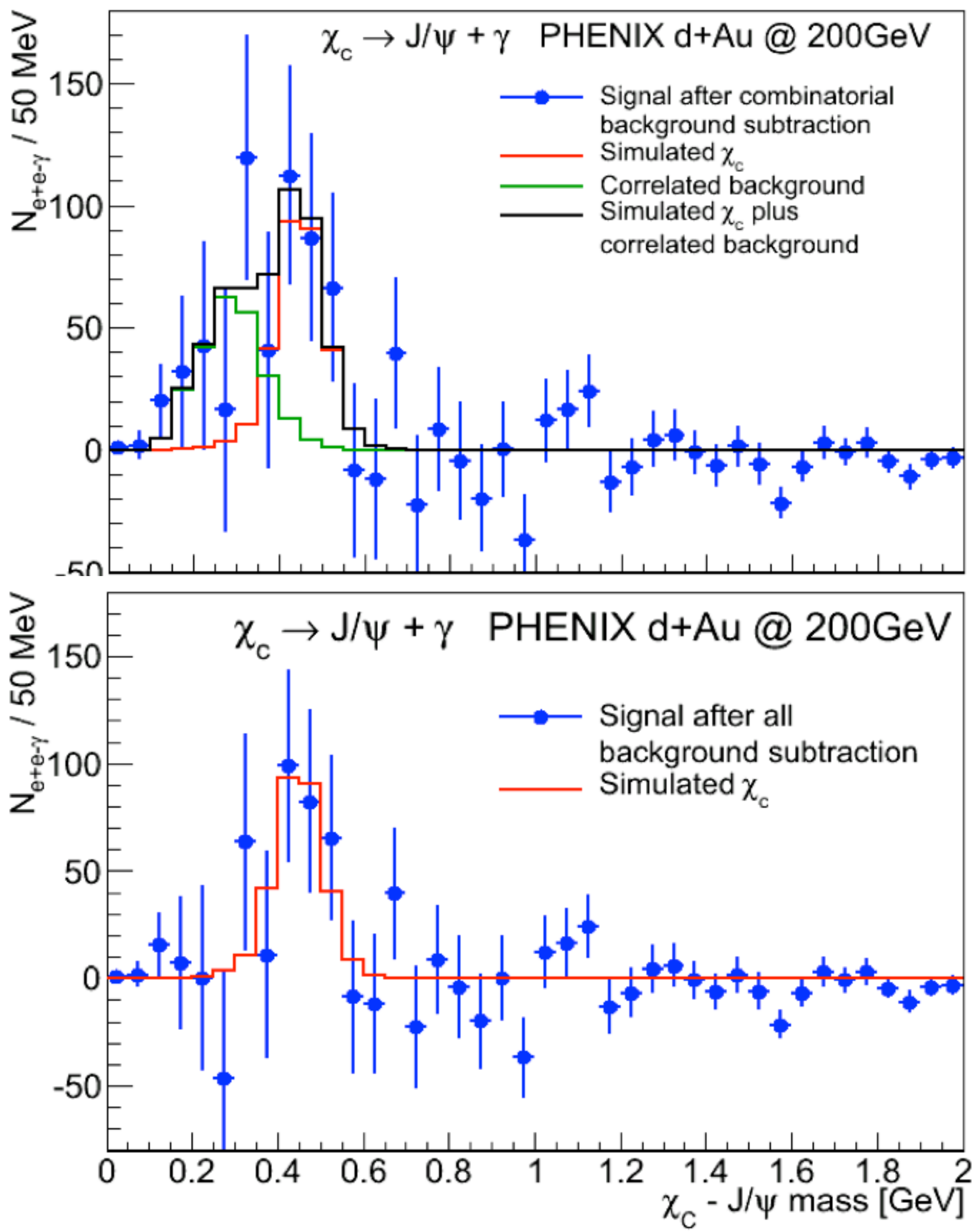
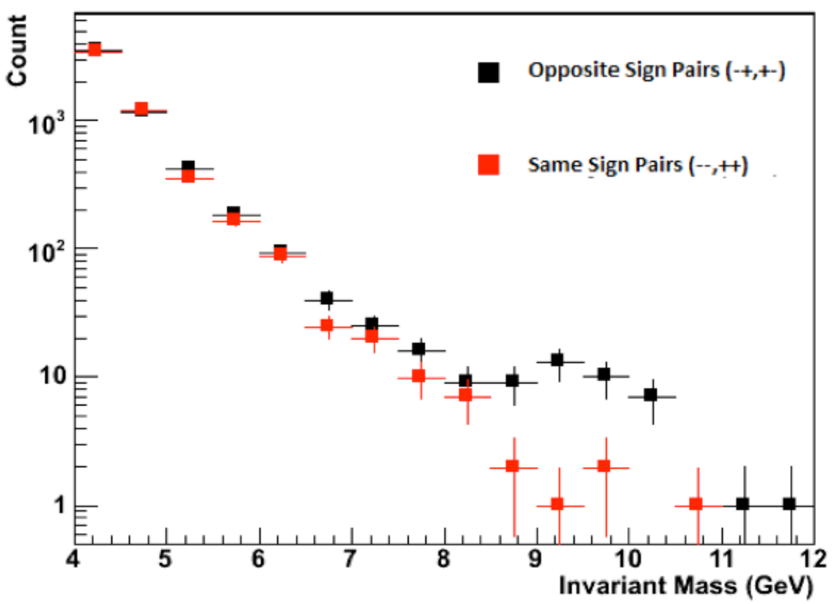


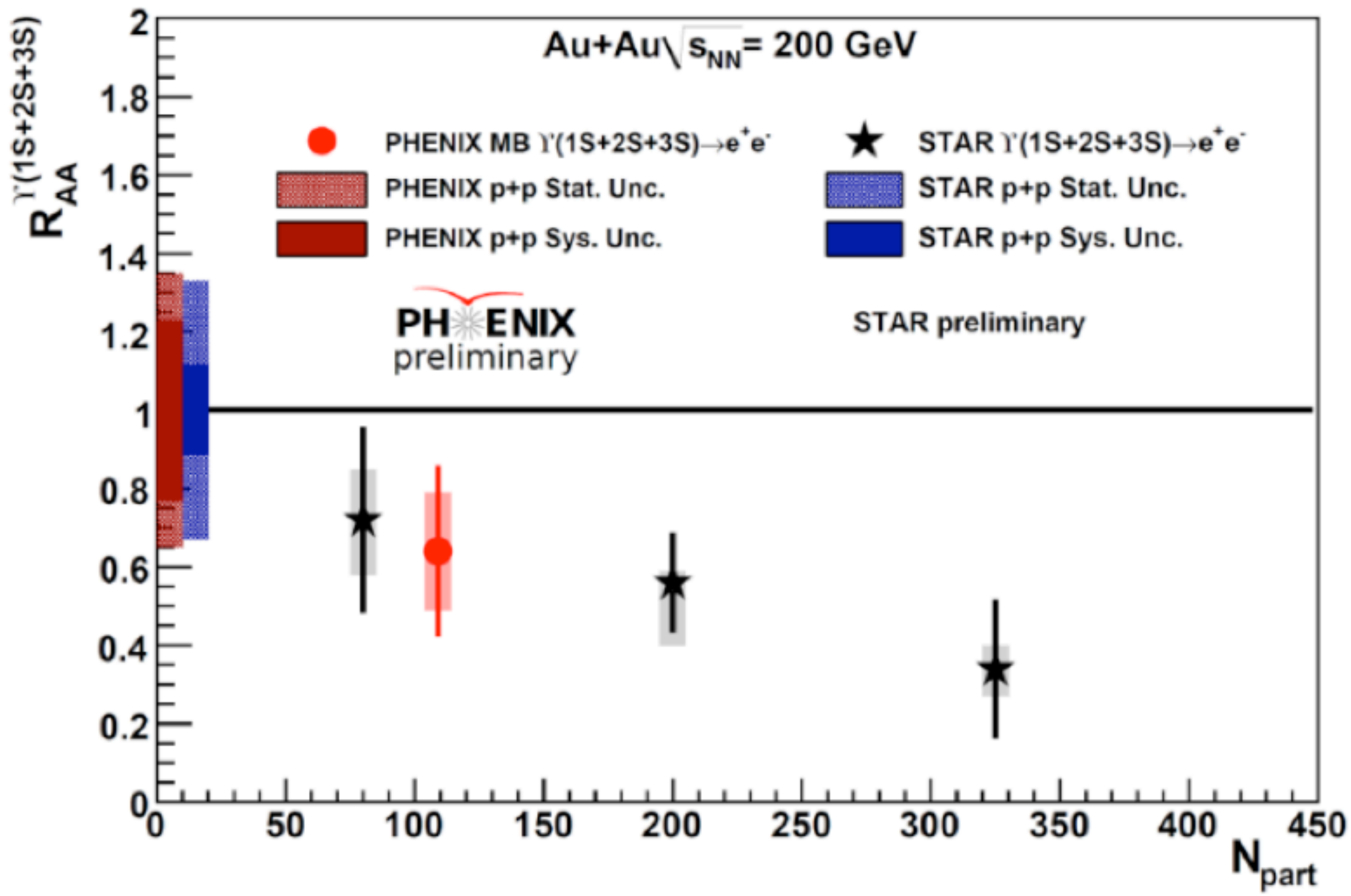
Broad range of energy density covered



$\chi_c \to J/\psi + \gamma$ 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
$\chi_c \to J/\psi + \gamma$ PHENIX d+Au @ 200GeV
Signal after all background subtraction
Simulated χ_c
χ_C - J/ψ mass [GeV]

CNM + QGP effects





- consistent with STAR result
- 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 for confirmations