Quarkonium Production at RHIC

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Florida State University

12th Conference on Quark Confinement and the Hadron Spectrum
Thessaloniki, Greece
August 28 - September 4, 2016

In-medium Program

Study the screening length in hot matter via:

- Modifications to quarkonia production in A+A collisions
- Relative to the baseline production in p+p collisions
- Correcting for modifications due to production in a nucleus (p,d+A)
  - Traditionally called cold nuclear matter (CNM) effects

Physics is extracted from comparison with theory - so ideally, we would like to:

Vary the temperature of the medium in A+A

- Collision energy (RHIC vs LHC gives wide lever arm)
- Mass of colliding ions
- Collision centrality (but not easy to model)

Vary the type and strength of underlying CNM effects

- Depends on collision energy
- Depends on rapidity

Quarkonia - PHENIX

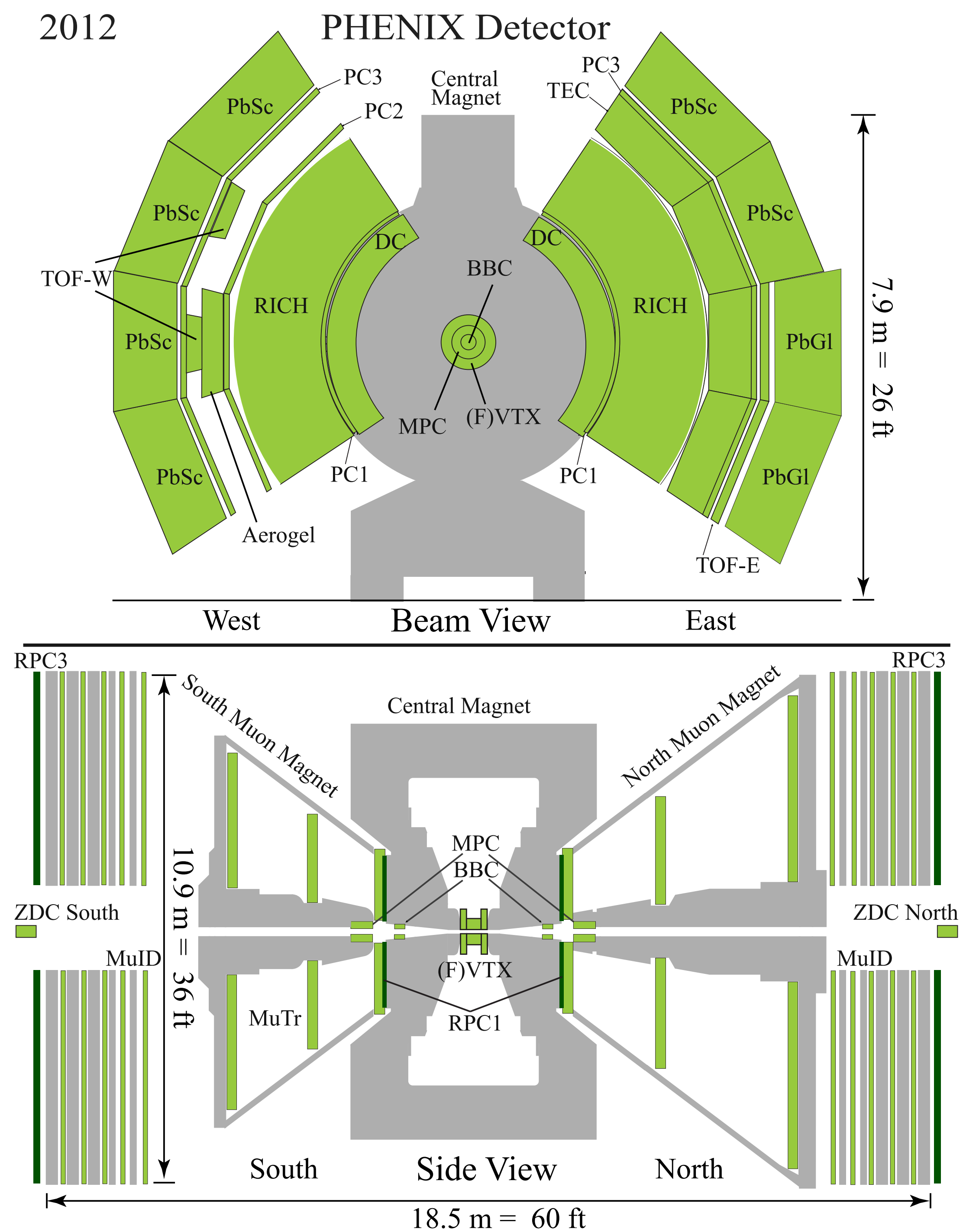
Central arms (|η| < 0.35)

D, B ➔ $e^{\pm}$
J/ψ ➔ $e^{+}e^{-}$
$-0.35 < y < 0.35$
$\Delta\Phi = \pi$

Muon arms (1.2 < |η| < 2.2 (2.4))

D, B ➔ $\mu^{\pm}$
J/ψ ➔ $\mu^{+}\mu^{-}$
$-2.2 < y < -1.2$
$1.2<y<2.4$
$\Delta\Phi = 2\pi$

High data rate, no triggering in Au+Au
Good triggers in p+p, d,p+A
Smaller dielectron acceptance than STAR



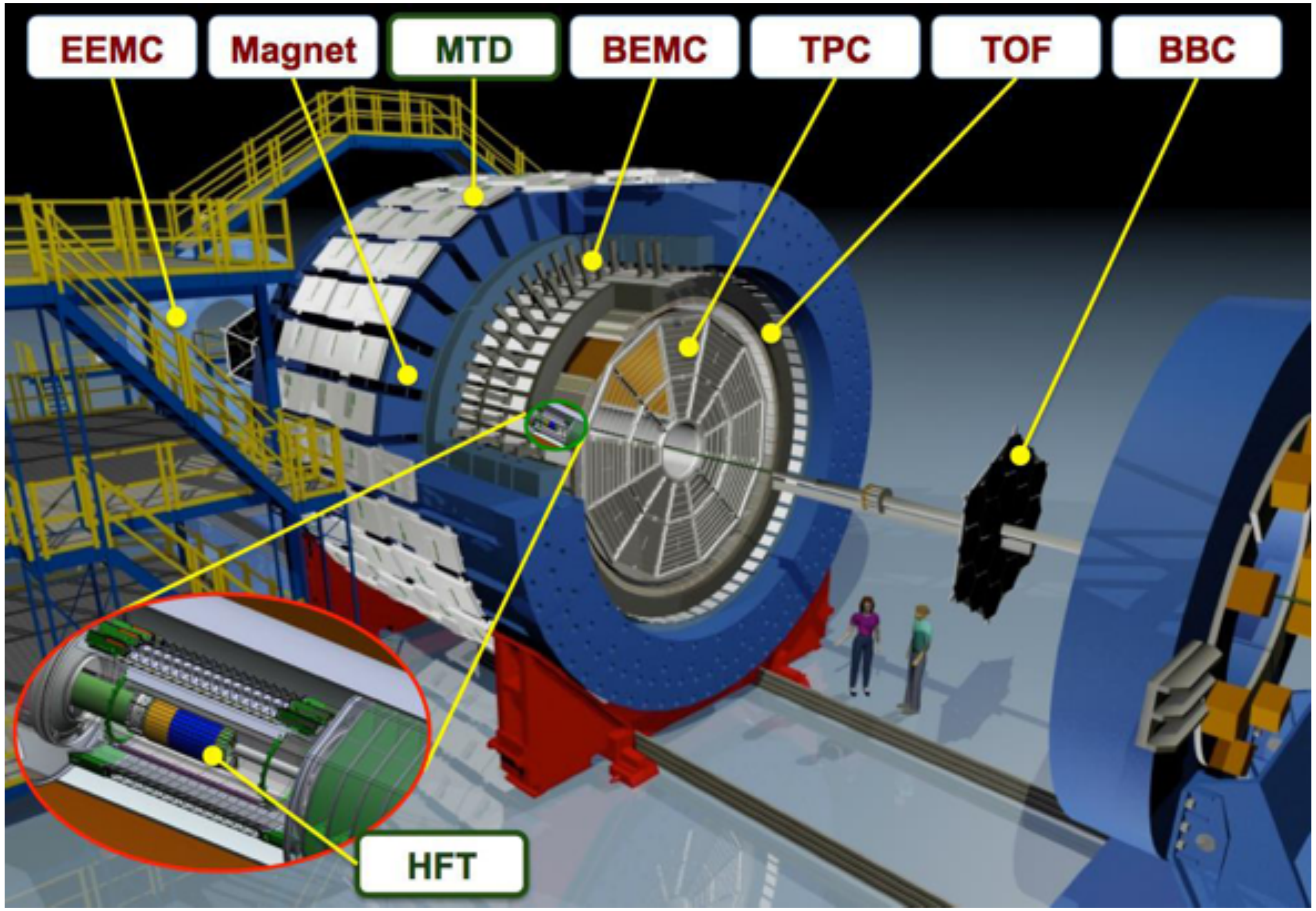
Quarkonia - STAR

$J/\psi \rightarrow e^+e^-$
$\Upsilon \rightarrow e^+e^-$
$|y| < 1.0$
$\Delta\Phi = 2\pi$

Large dielectron acceptance
Trigger difficult at low p_T

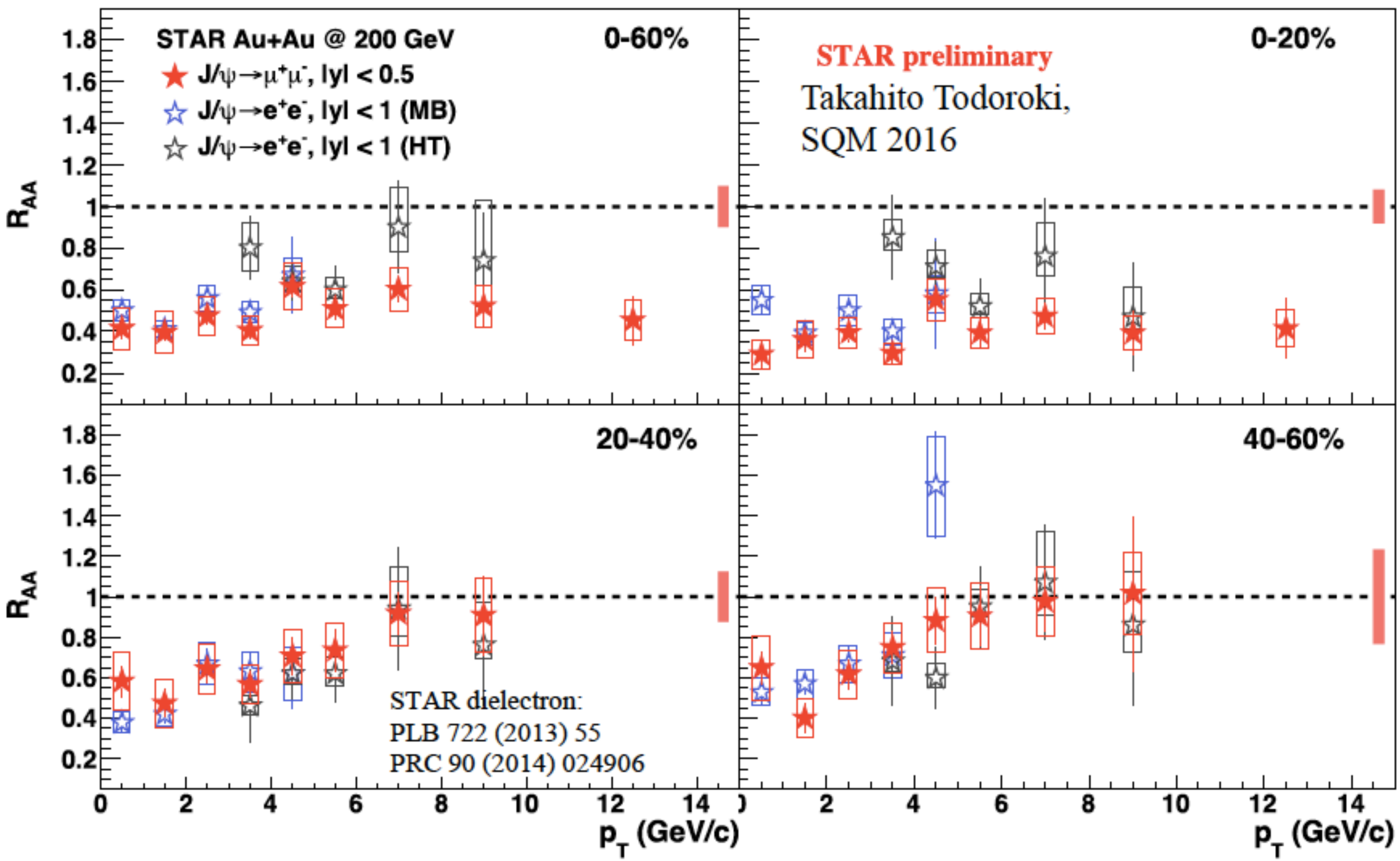
$J/\psi \rightarrow \mu^+\mu^-$
$\Upsilon \rightarrow \mu^+\mu^-$
$|y| < 0.5$
$\Delta\Phi = 2\pi$

MTD: smaller dimuon acceptance
But easy trigger, good S/B



Recent: STAR Au+Au J/ψ p_T dependence - from dimuons

First (preliminary) results for J/ψ from the MTD, shown earlier this year.
Good precision and p_T reach!



PHENIX, STAR, ALICE J/ψ centrality dependence

midrapidity, integrated over all p_T

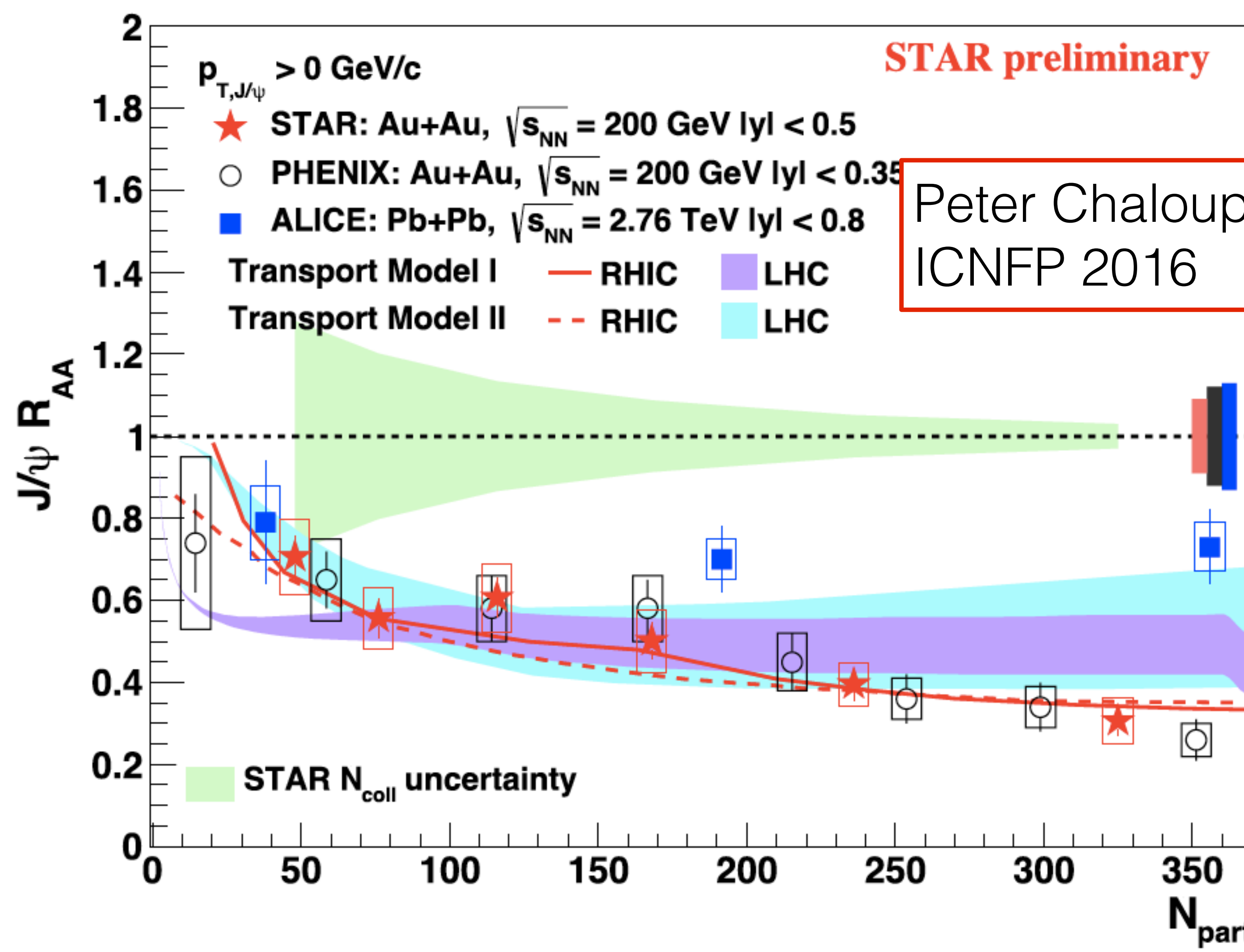
Transport models:

Liu et. al.
Model I at RHIC: PLB 678 (2009) 72
Model I at LHC: PRC 89 (2014) 054911

Zhao et. al.
Model II at RHIC: PRC 82 (2010) 064905
Model II at LHC: NPA 859 (2011) 114

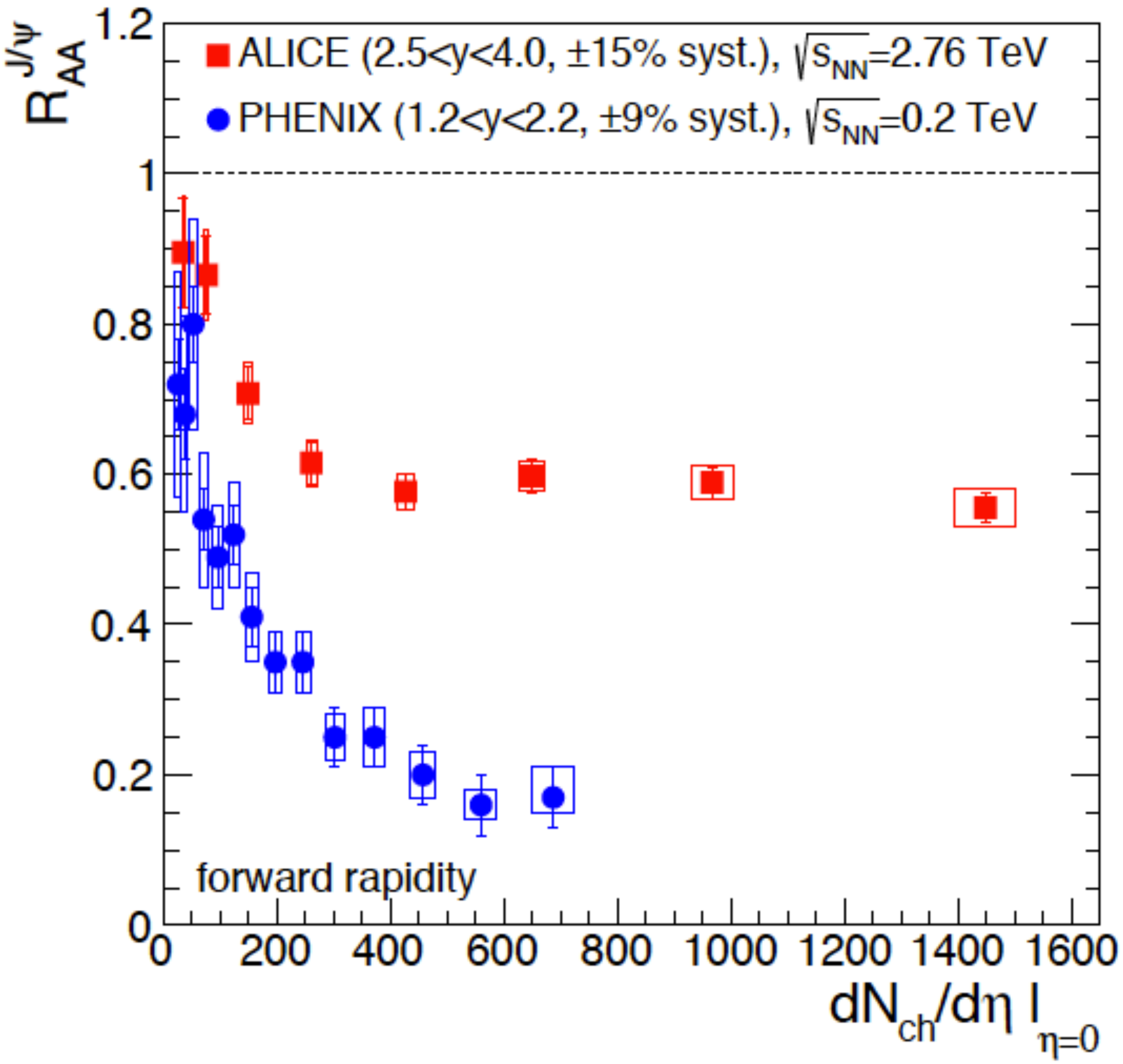
Very nice agreement between PHENIX and STAR.

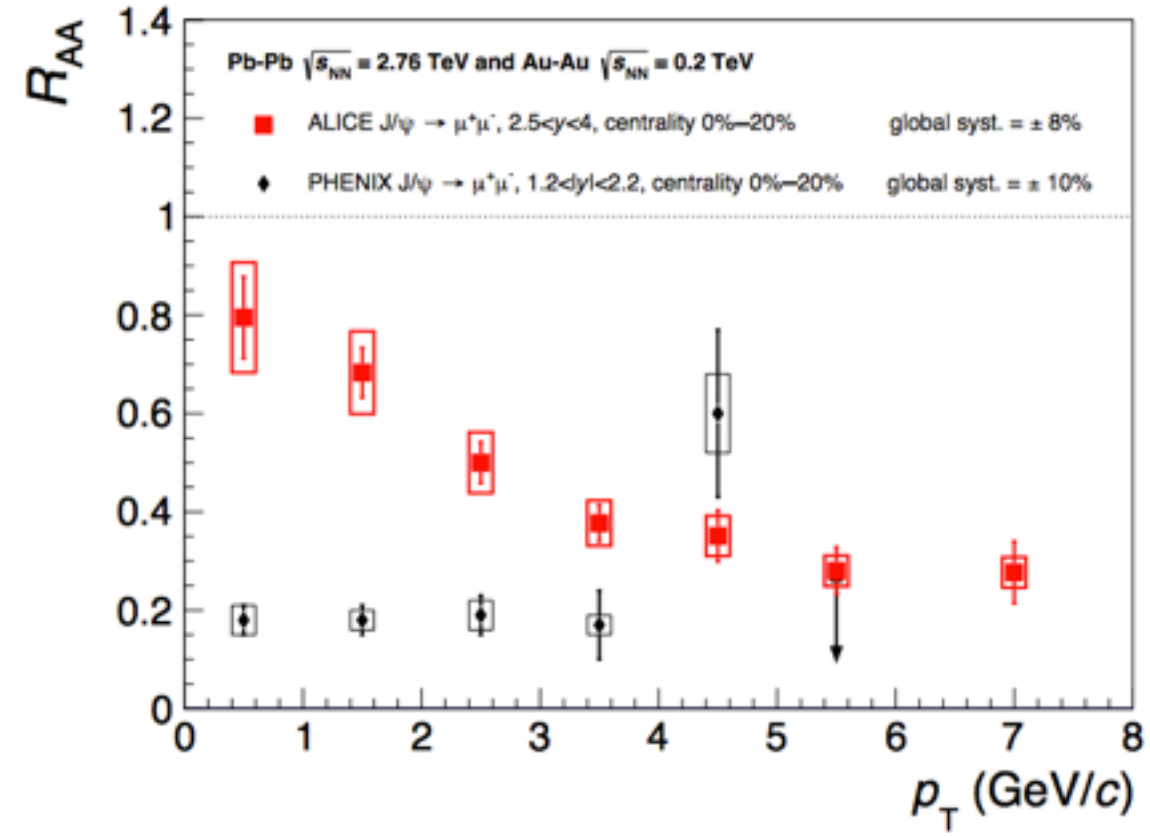
Coalescence is dominant at LHC for p_T integrated data.

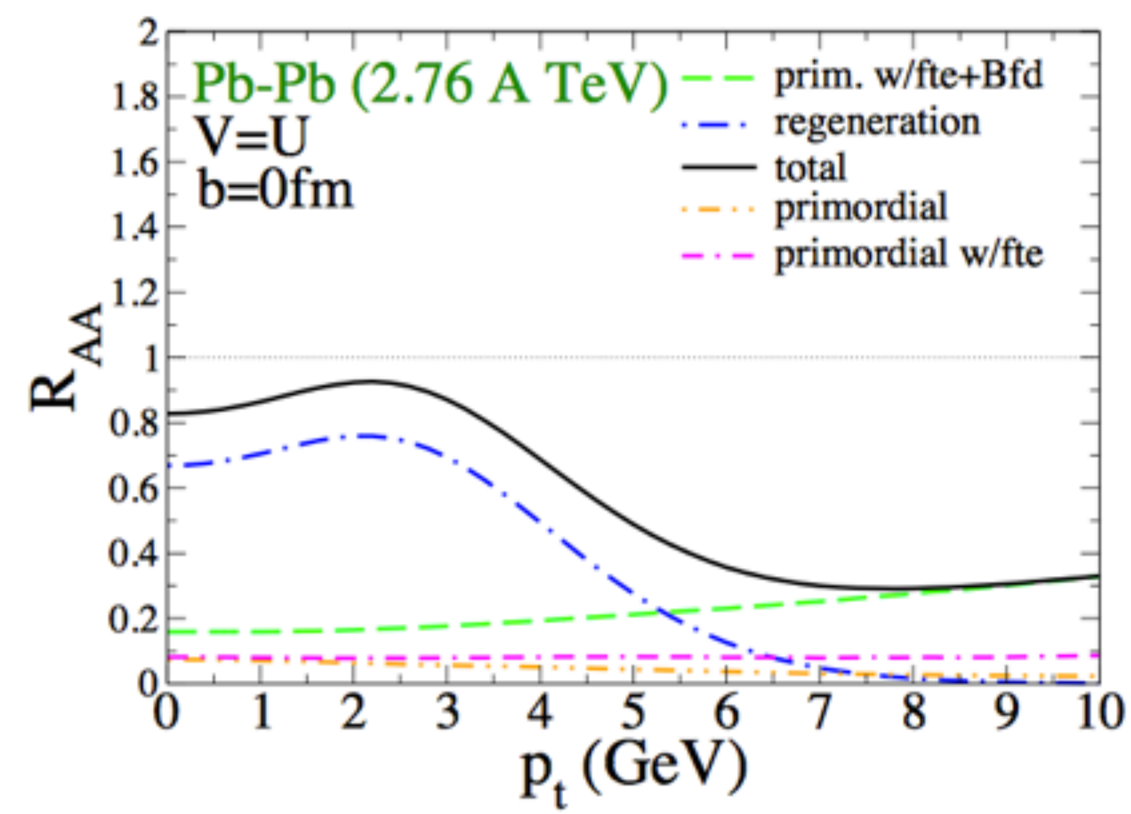


Peter Chaloupka
ICNFP 2016

PHENIX, ALICE J/ψ - forward rapidity







The striking difference in suppression is partly due to coalescence, partly due to stronger CNM effects at forward rapidity at RHIC energy.

STAR, CMS J/ψ - high p_T

Transport models:

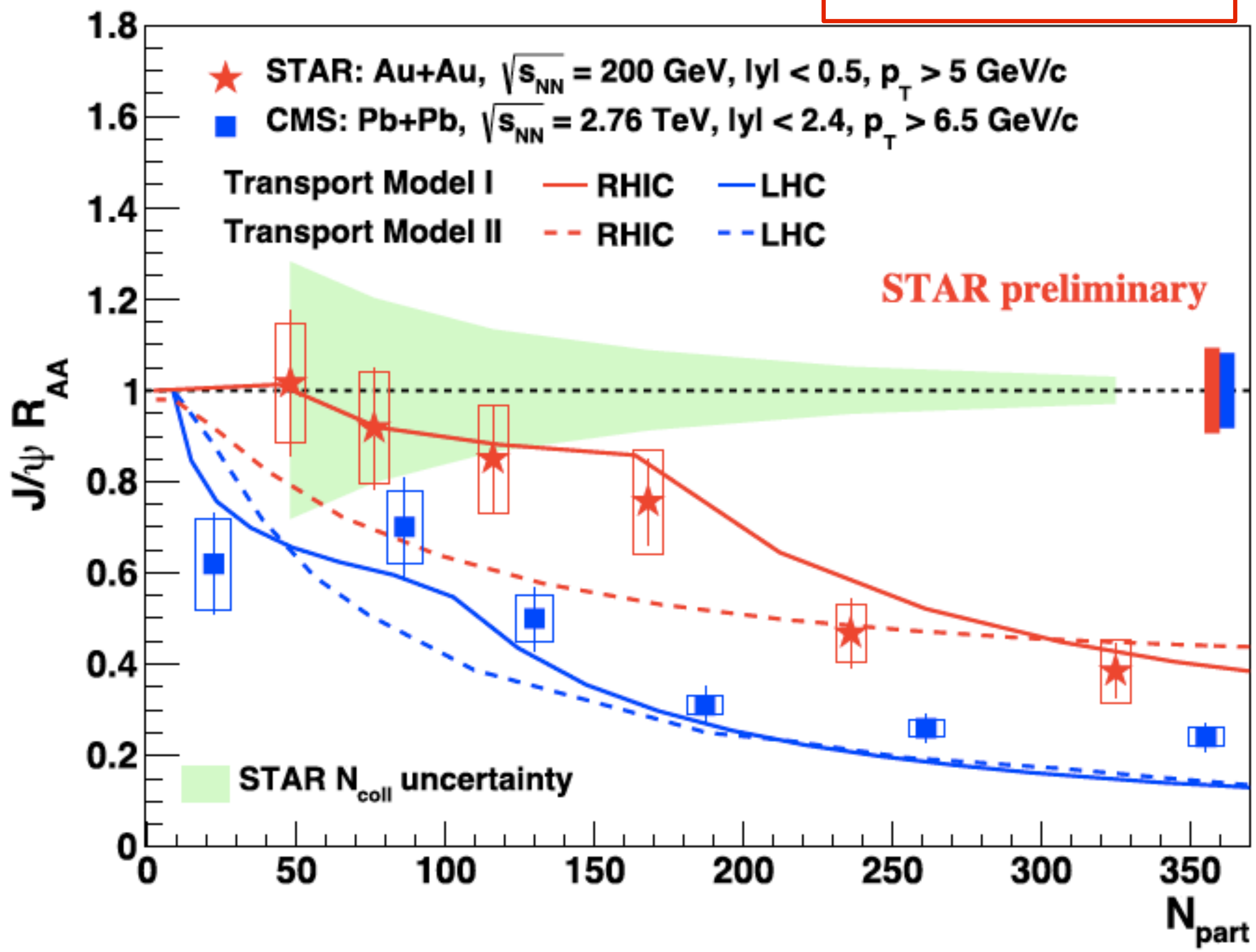
Liu et. al.
Model I at RHIC: PLB 678 (2009) 72
Model I at LHC: PRC 89 (2014) 054911

Zhao et. al.
Model II at RHIC: PRC 82 (2010) 064905
Model II at LHC: NPA 859 (2011) 114

Peter Chaloupka
ICNFP 2016

Contrast: high p_T J/ψ show much stronger suppression at LHC energies

Higher energy density wins over coalescence at high p_T.



Au+Au J/ψ Energy scan at RHIC

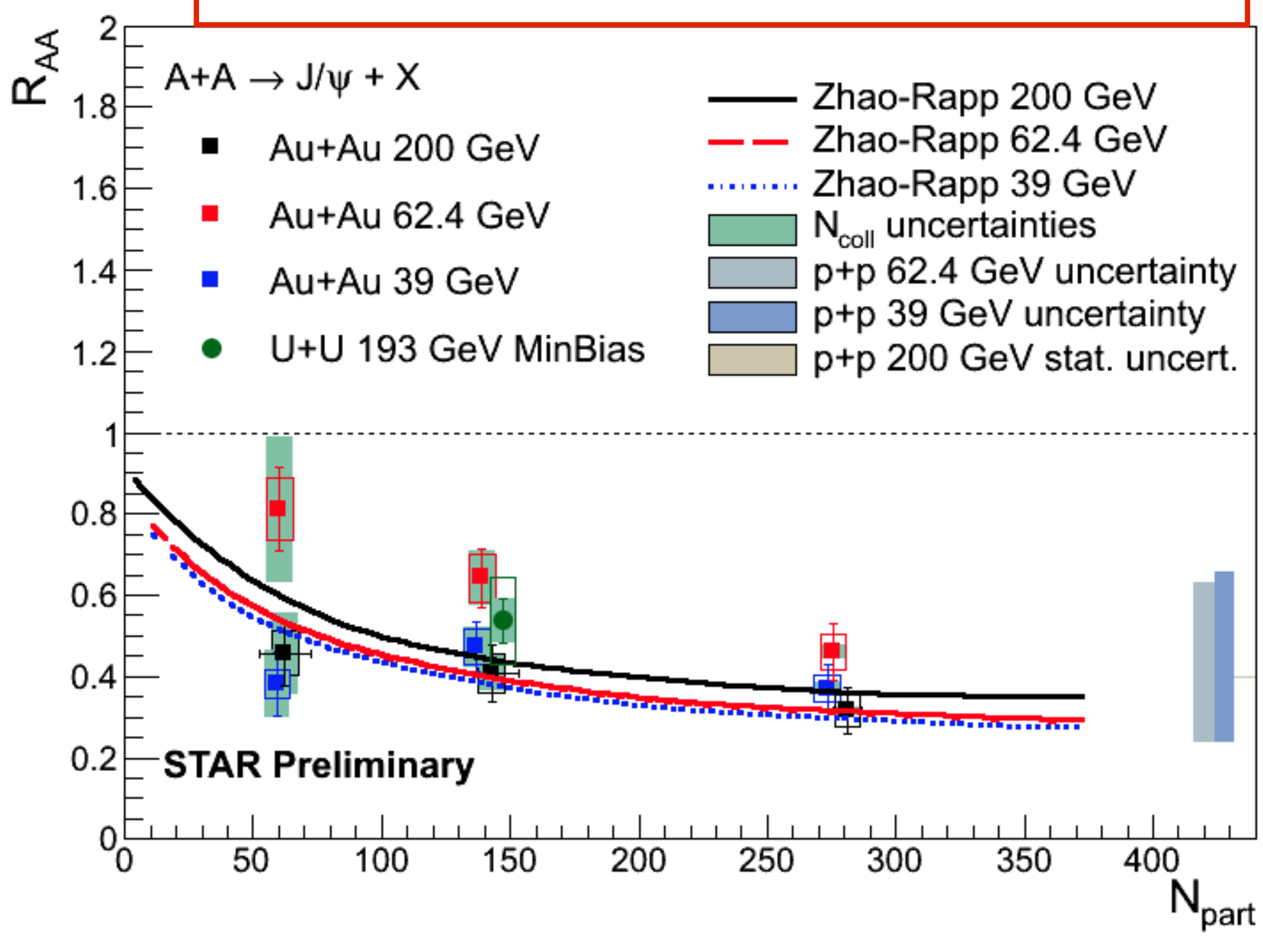
PHENIX data at 39, 64 and 200 GeV.
The suppression seems to be:

- Strongest at 200 GeV
- Weaker at 64 GeV
- Weaker again at 39 GeV

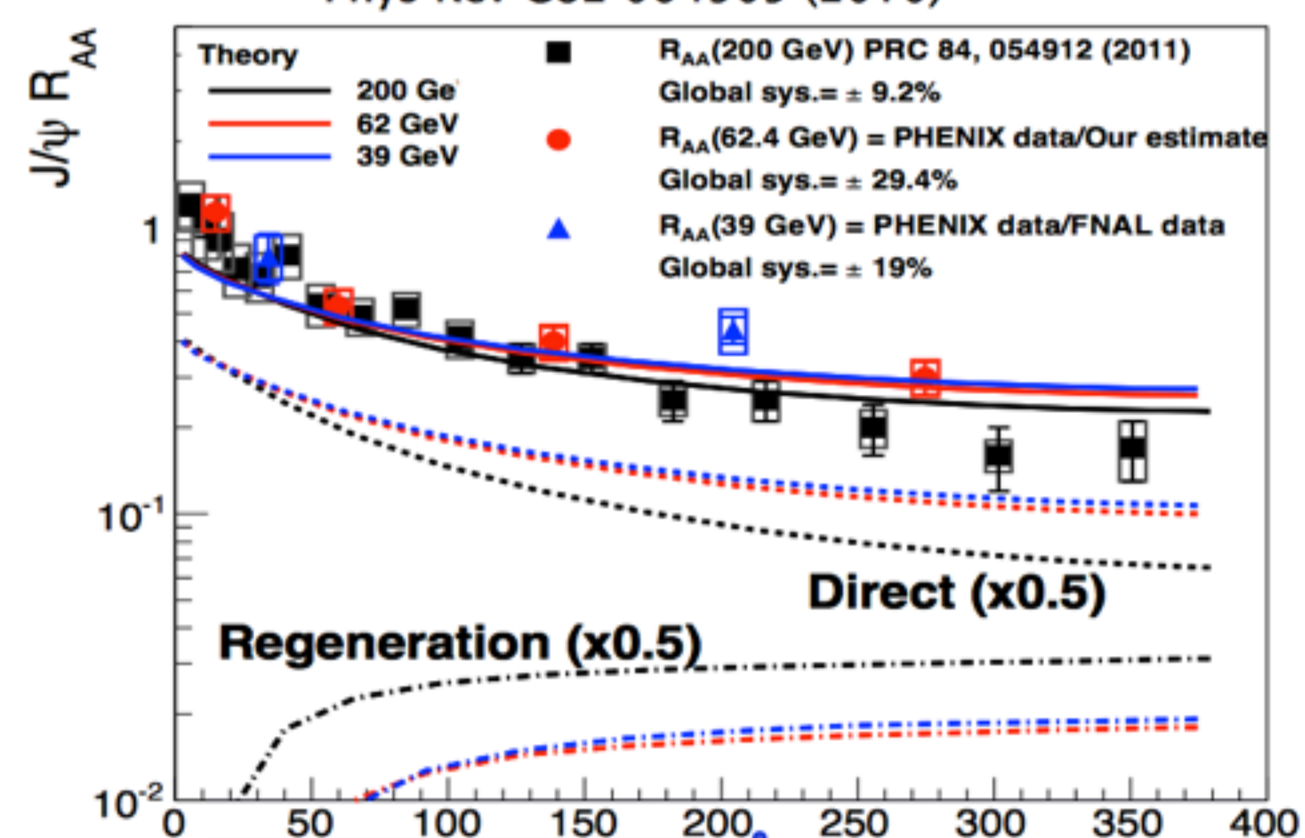
Model (Zhao & Rapp): the suppression is similar at the three energies:

- As the energy increases, suppression increases
- **But** increased suppression is compensated by increased regeneration.

STAR final data - arXiv:1607.07517



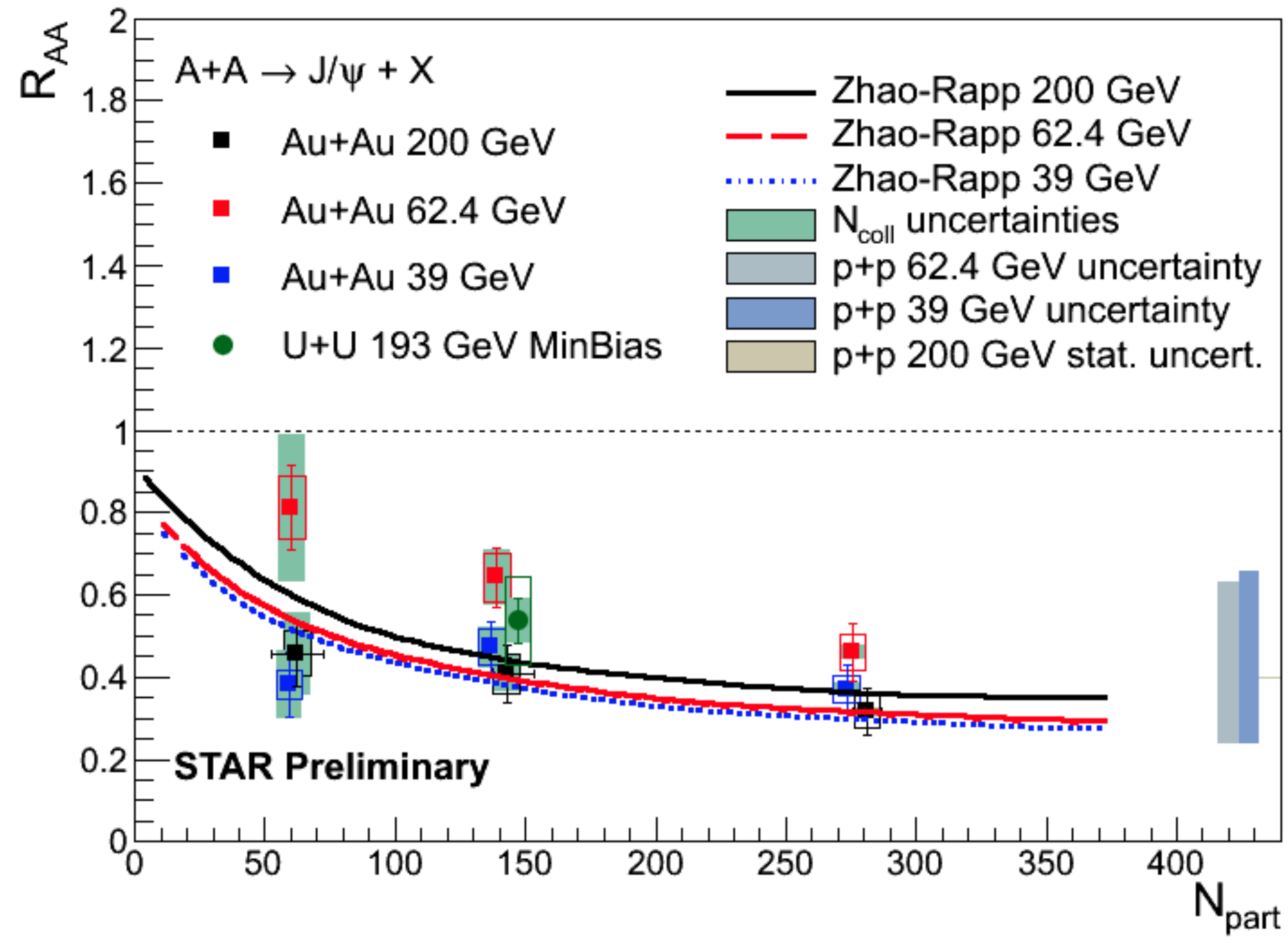
X. Zhao, R. Rapp
Phys Rev C82 064905 (2010)

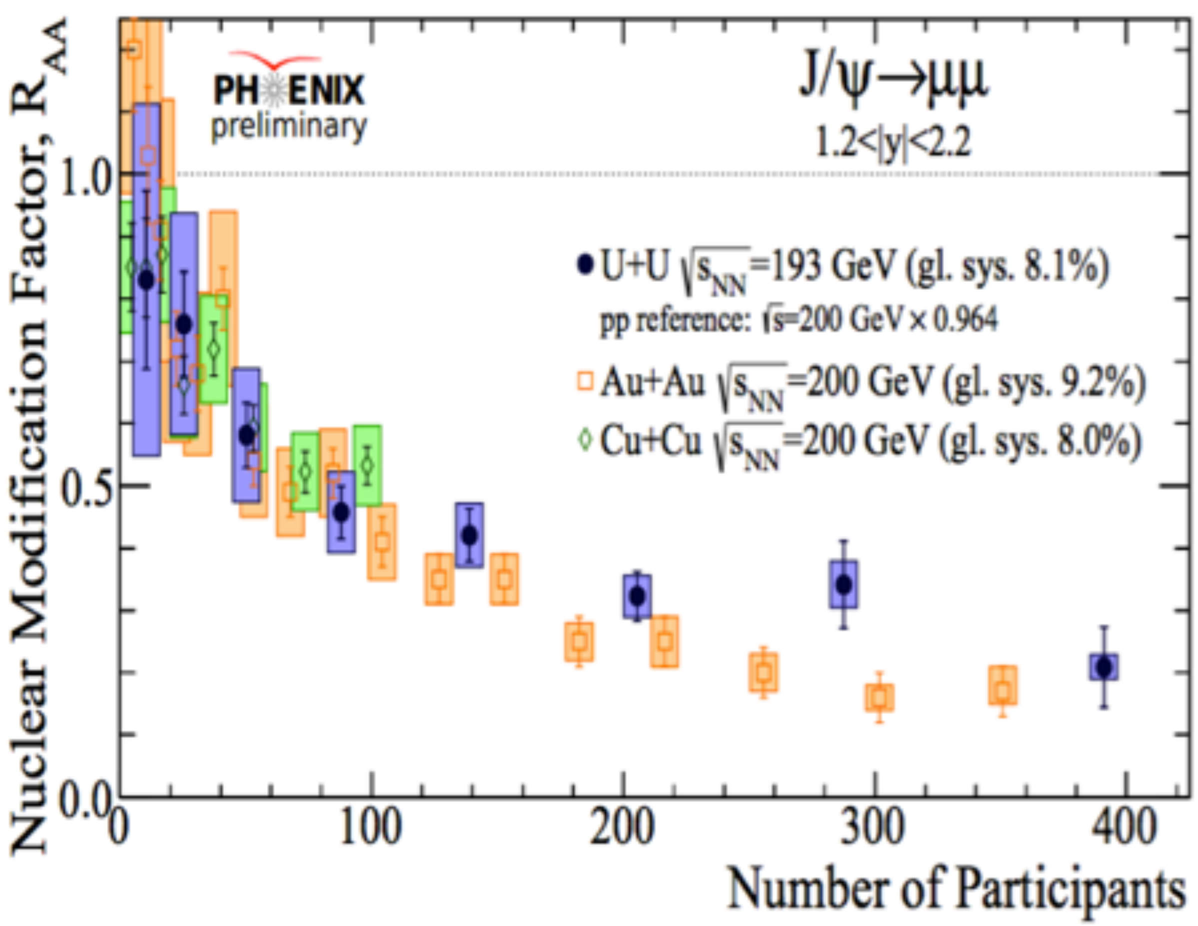


PRC86, 064901 (2012)

STAR, PHENIX U+U J/ψ

- Expect about 20% higher energy density (Kikola, Odyniec, Vogt, PRC 84, 054907 (2011))
- CNM effects are expected to be very similar
- Charm production is higher - N_{coll} increases





Both PHENIX and STAR observe weaker suppression for U+U

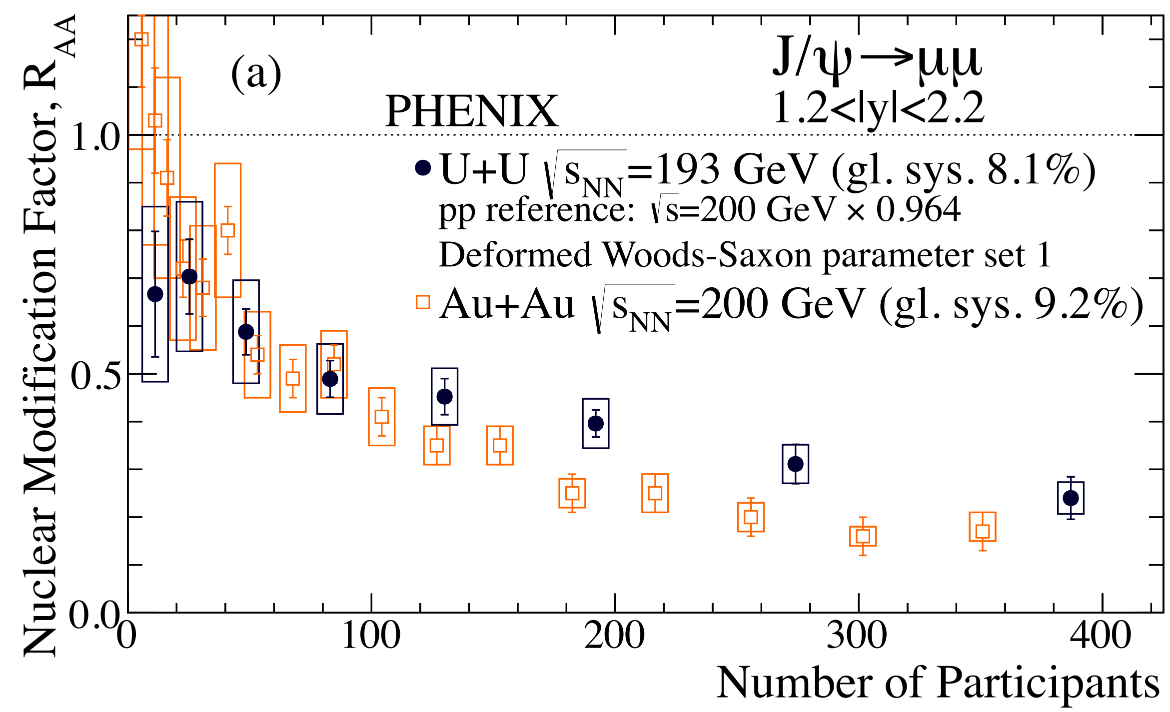
Charm coalescence wins?
PRC 84, 054907 (2011)

U+U vs Au+Au J/ψ

Problem: competing models of U deformation:

- Set 1 has larger surface diffuseness
  - smaller N_{coll} values by 6-15%

Phys. Rev. C 93, 034903 (2016)



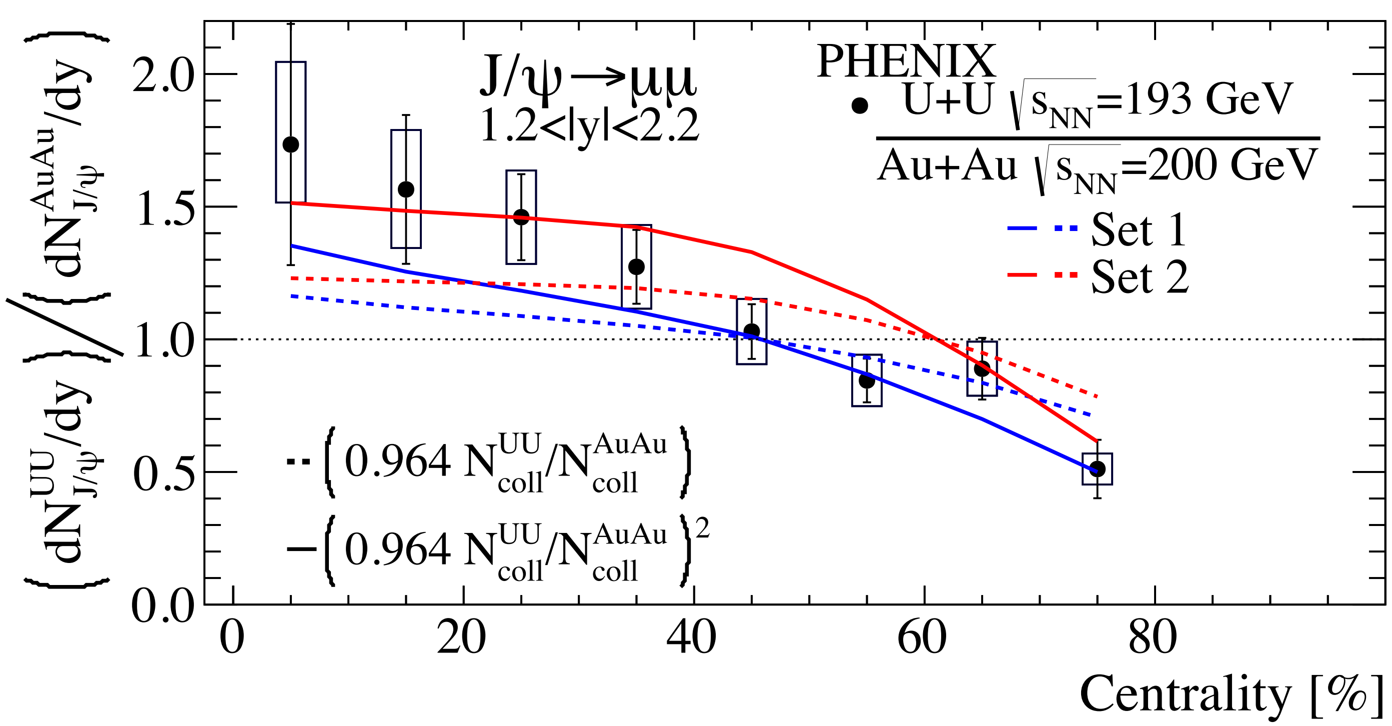
Take invariant yield ratio:

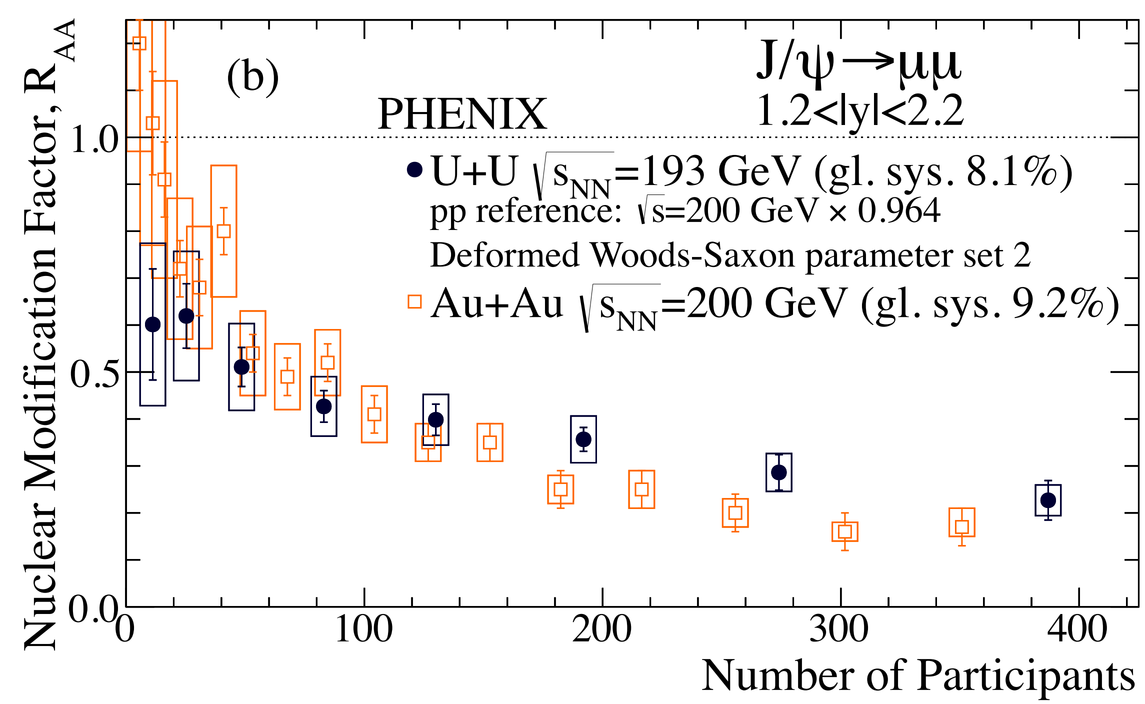
Curves show centrality dependence if J/ψ production scaled with

- N_{coll} (dashed lines)
- N_{coll}^2 (solid lines)

Set 1 (blue) Not much difference

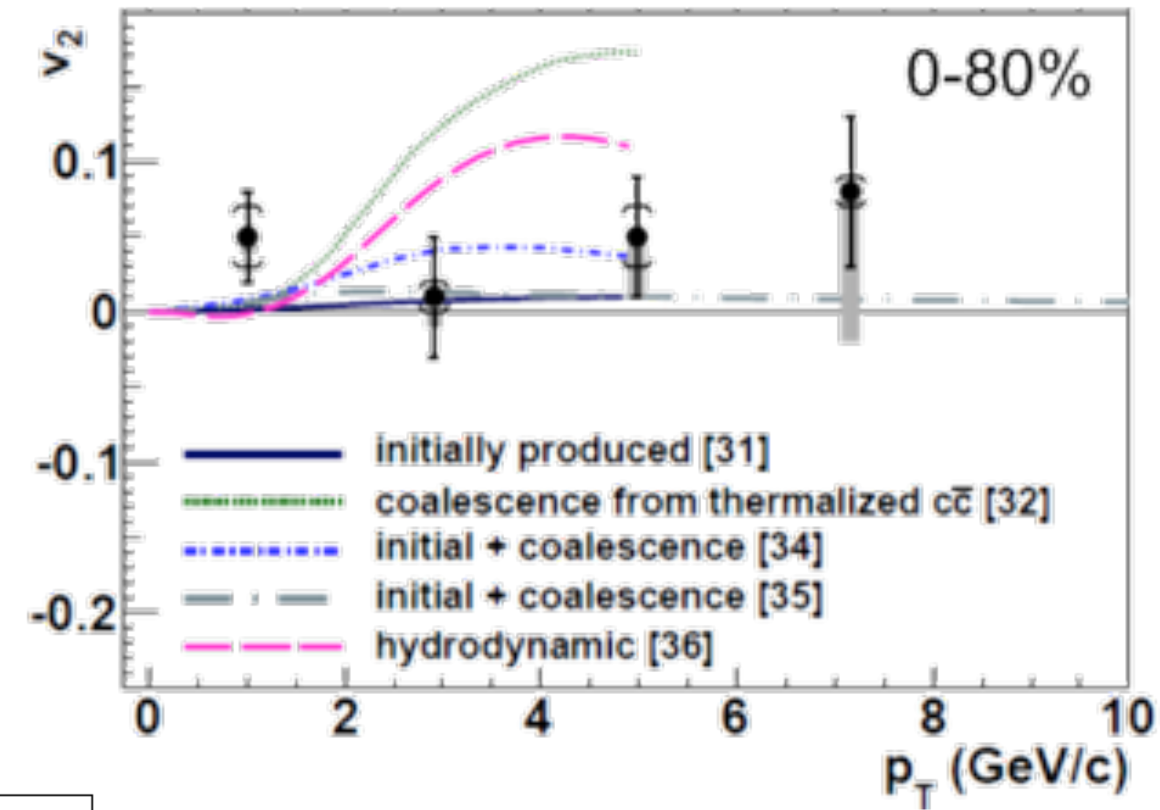
set 2 (red) Favors N_{coll}^2 for central

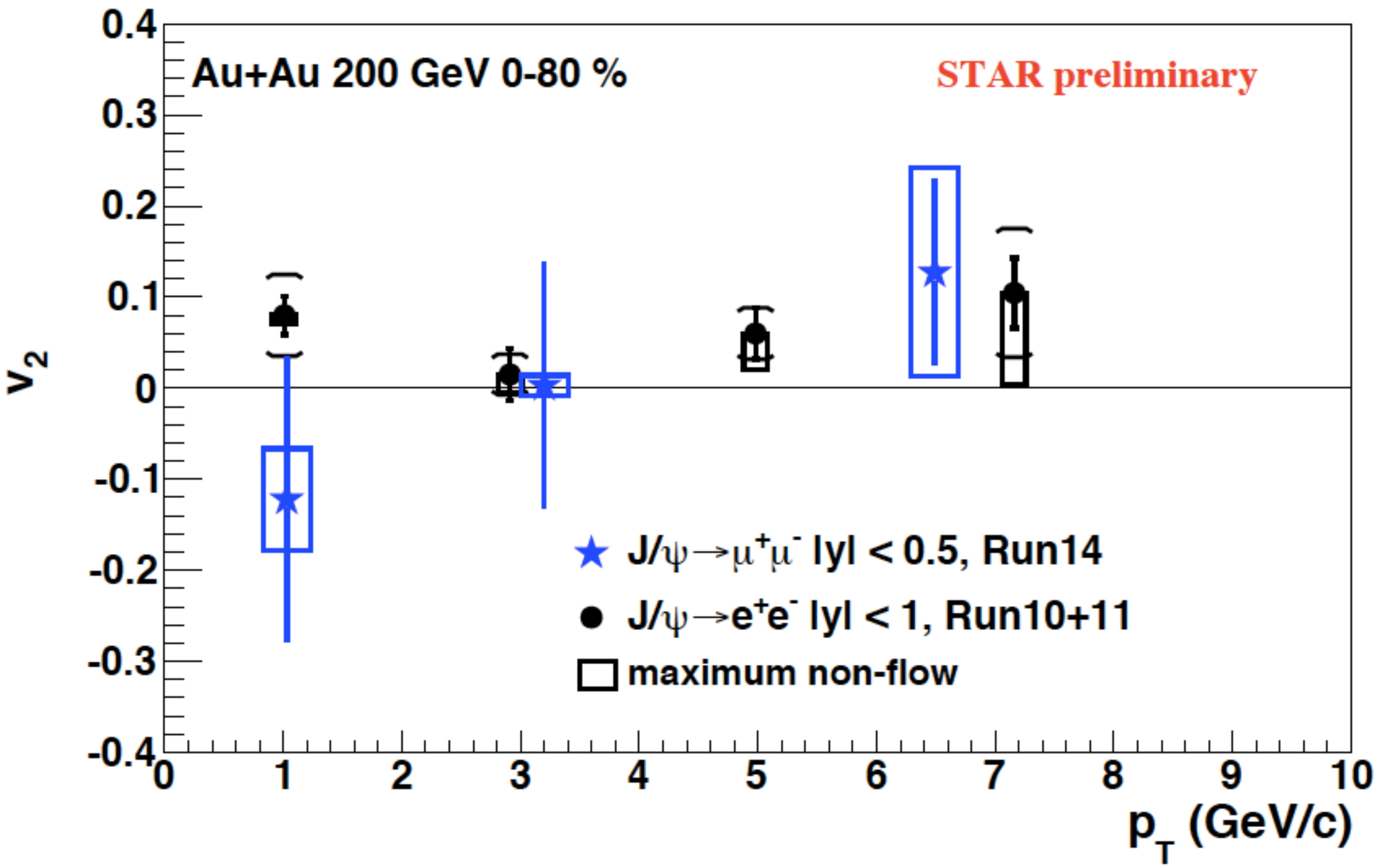




J/ψ Flow in Au+Au at 200 GeV

Old: STAR J/ψ flow measurements using dielectrons

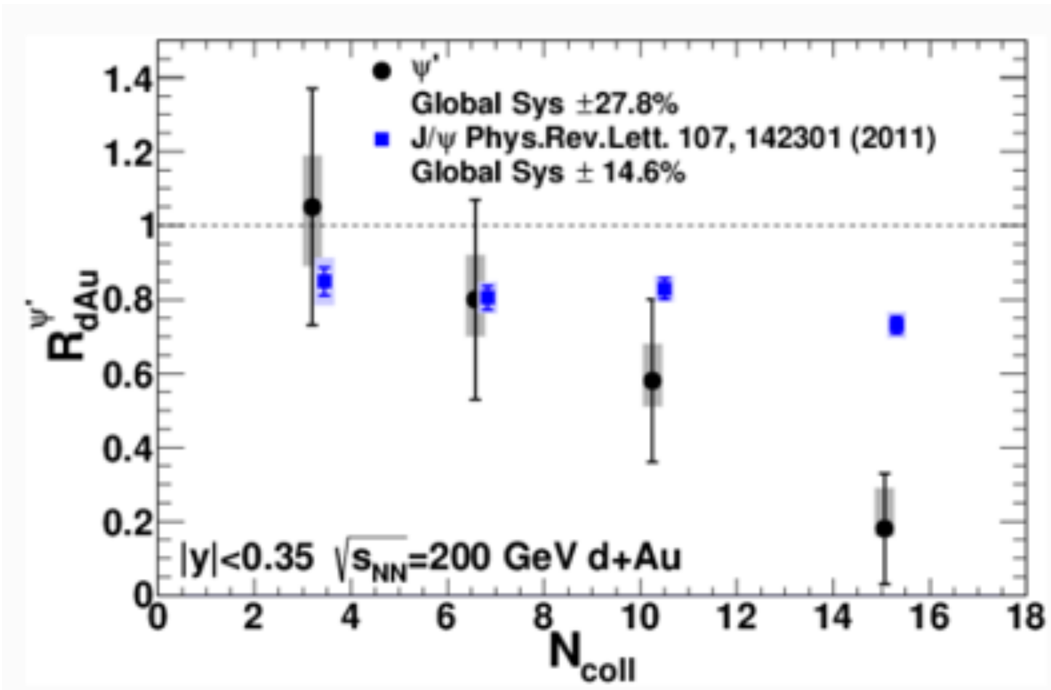




New: preliminary STAR dimuon measurements

this preliminary dimuon analysis uses only 1/7 of available data - more to come

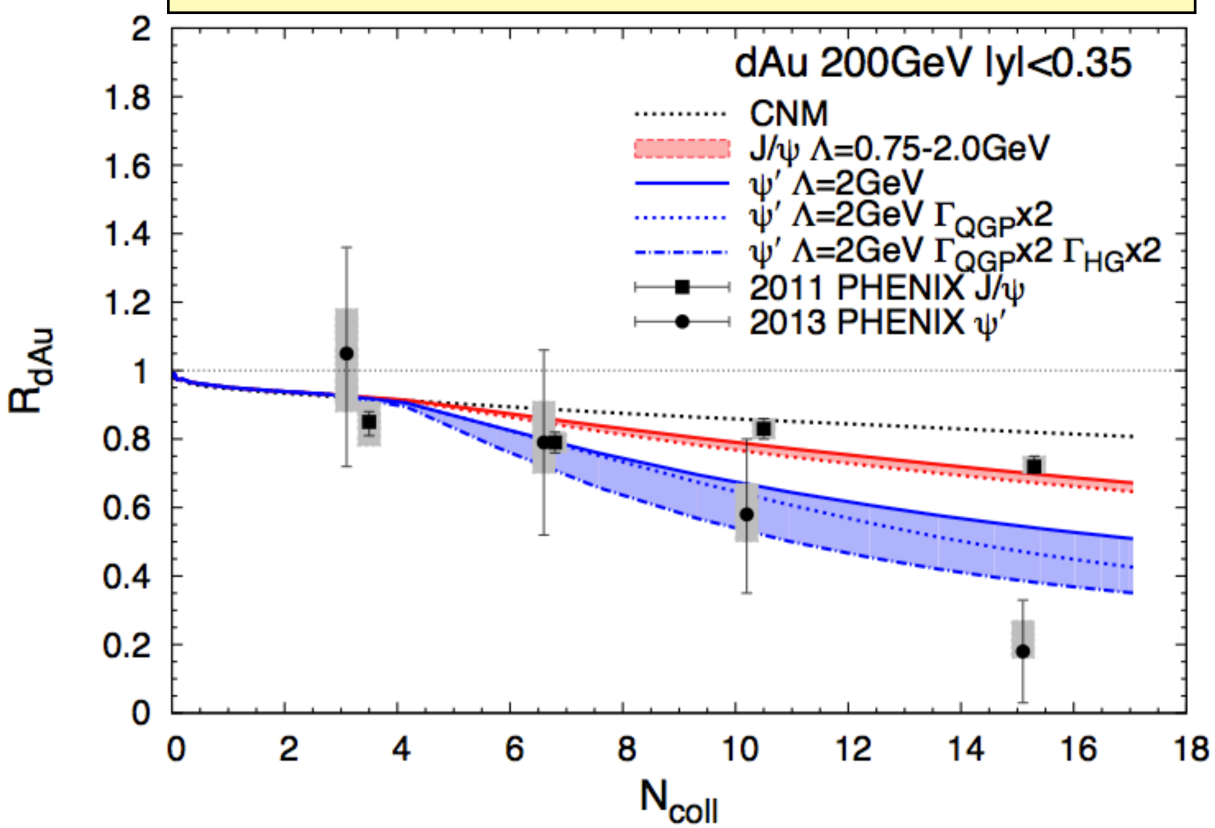
d+Au ψ' - mid rapidity



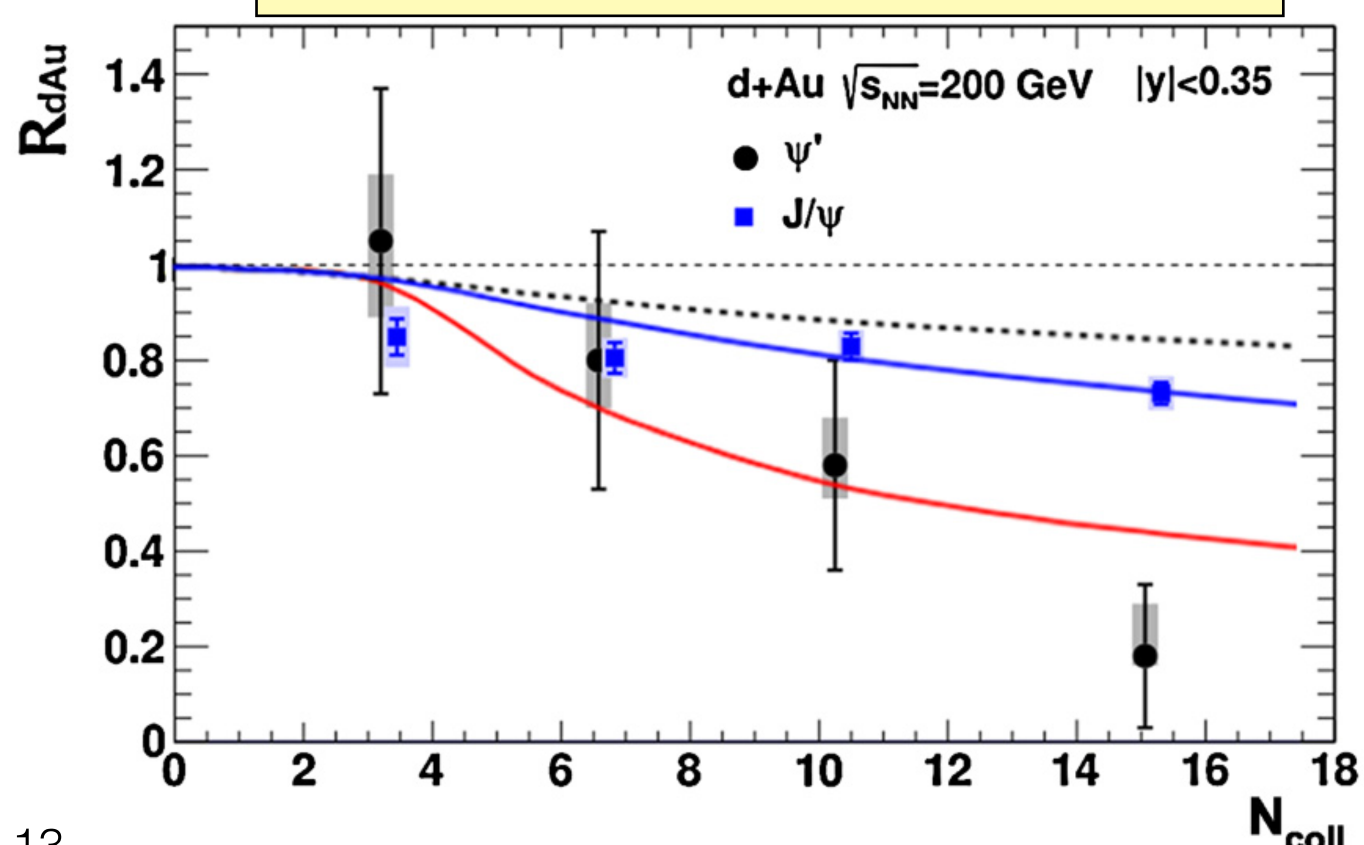
PHENIX R_{dAu} data
PRL111 (2013) 202301

Too strong for CNM effects:
Interpreted as final state suppression due to effects of co-moving matter on the weakly bound ψ' state

Du & Rapp arXiv:1504.00670
Hadronic gas + QGP in final state

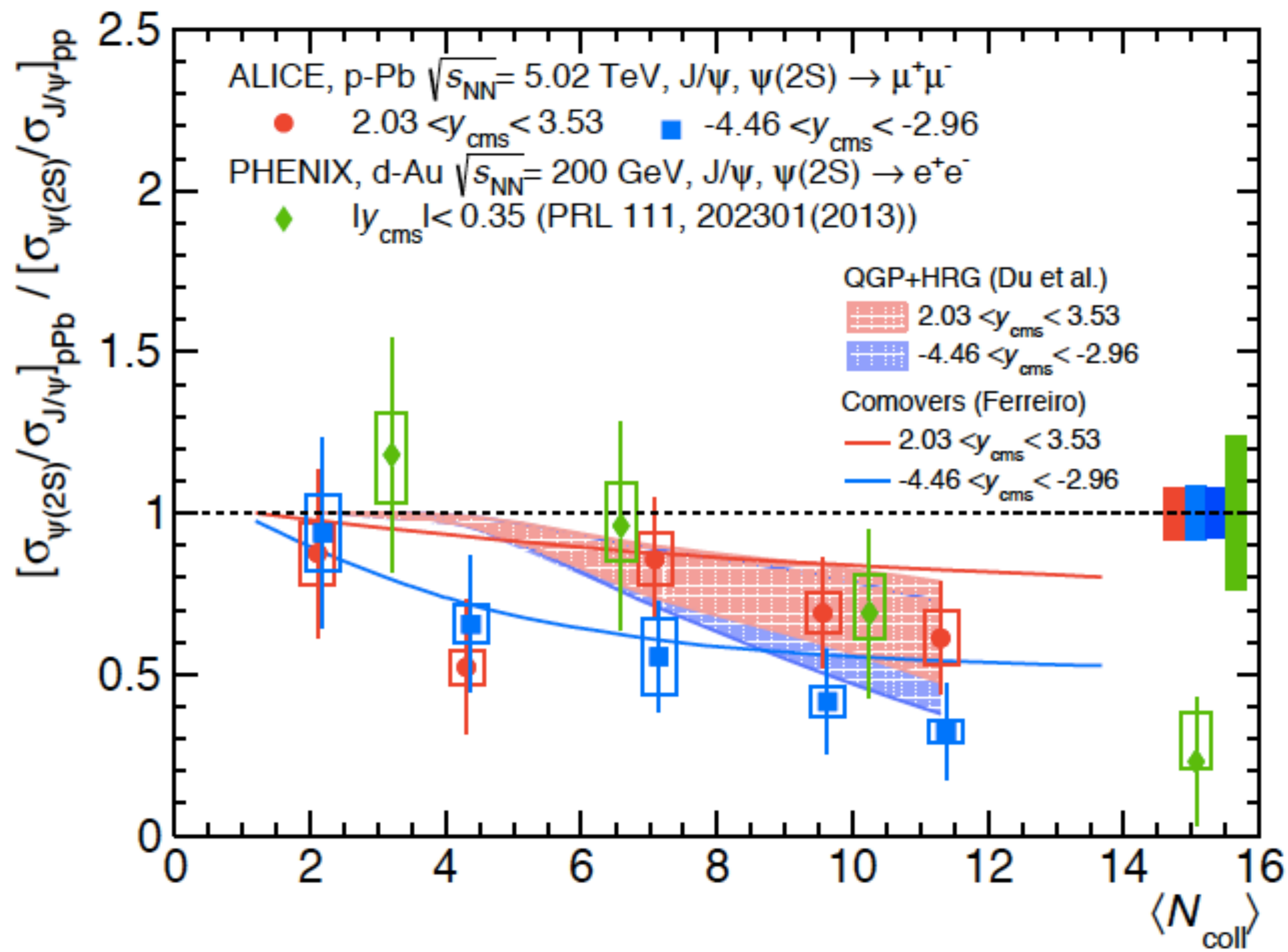


Ferreiro (PLB 749 (2015) 98)
"Comovers" in final state



d+Au ψ' - comparison with p+Pb from ALICE

Double ratio has similar dependence on collision centrality at the two very different collision energies
Seems to be explained well by final state models

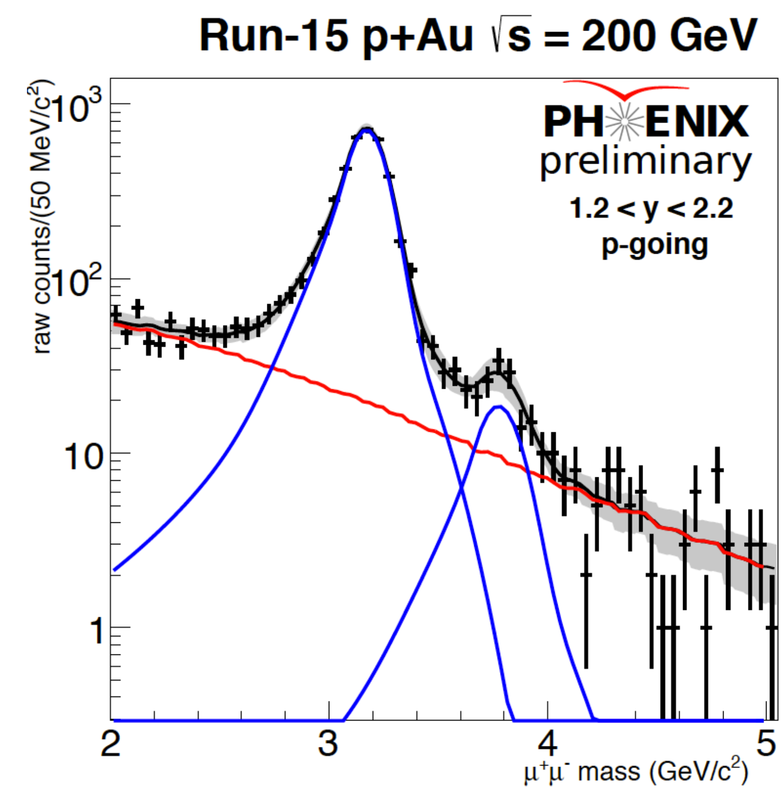


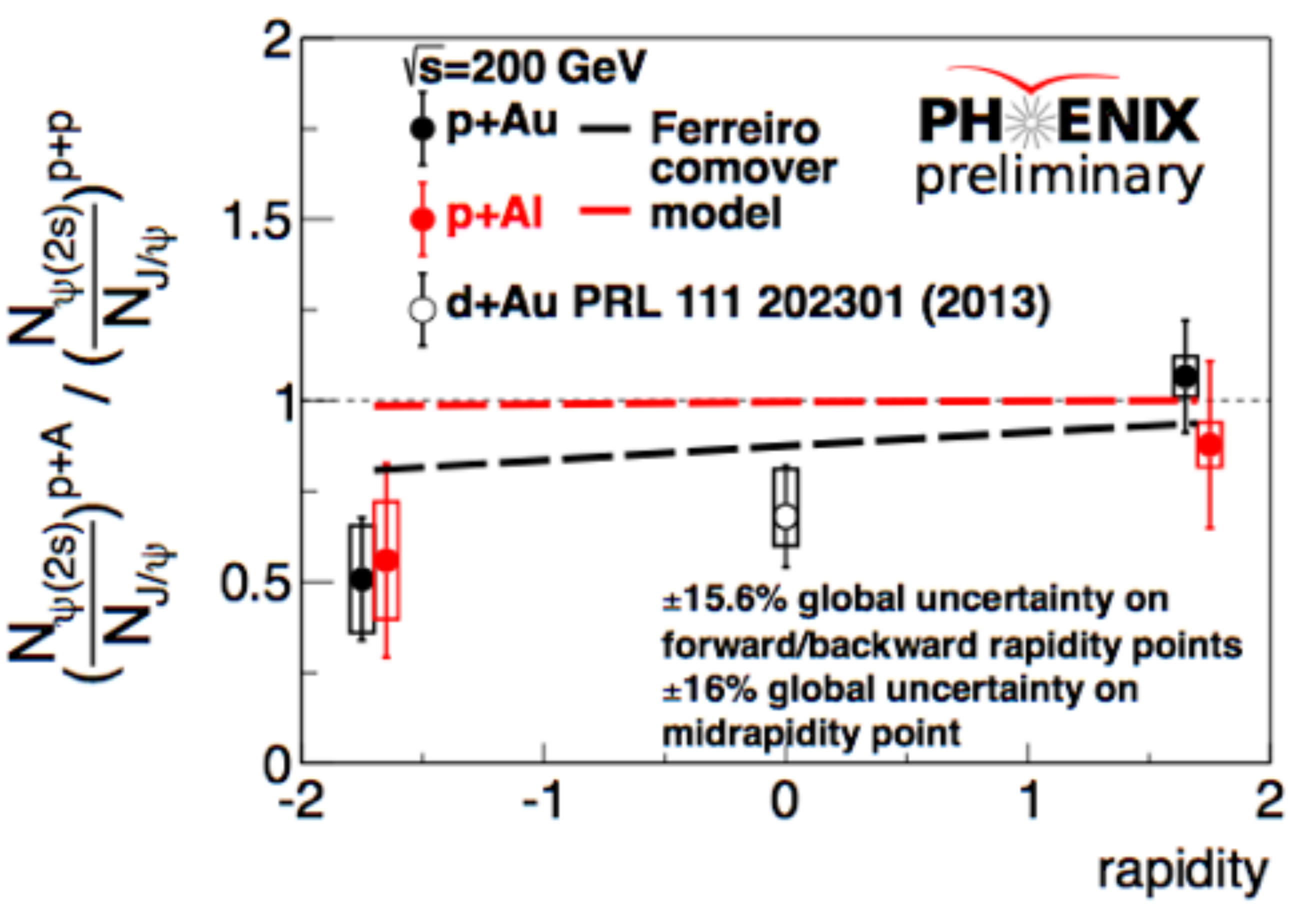
p+Al, p+Au ψ’

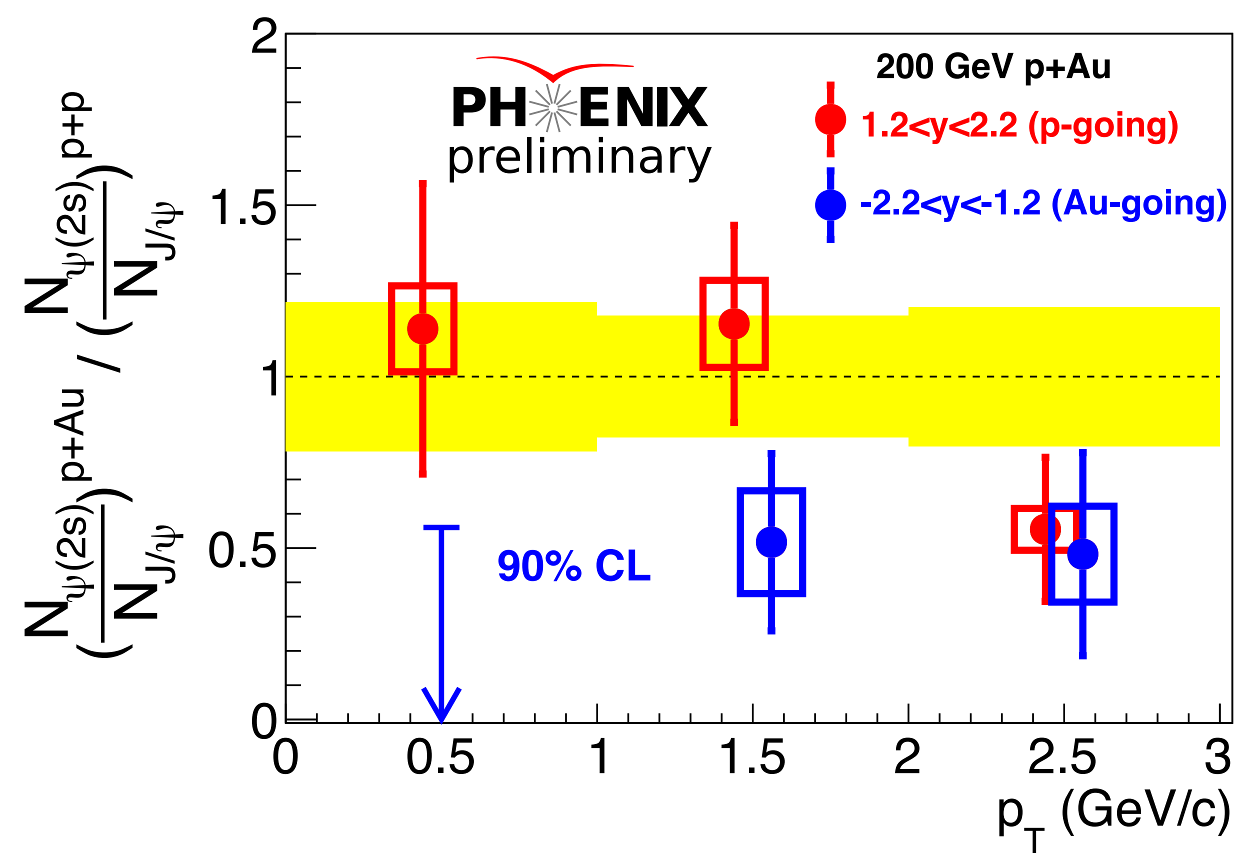
Add forward/backward rapidity p+Au and p+Al measurements from RHIC 2015 run - strong suppression at backward rapidity, consistent trend with midrapidity

Coming (very) soon: Final results for ψ(2S)/ψ(1S) ratios at forward/backward rapidity in

- p+p, p+Al, p+Au, ^{3}He+Au





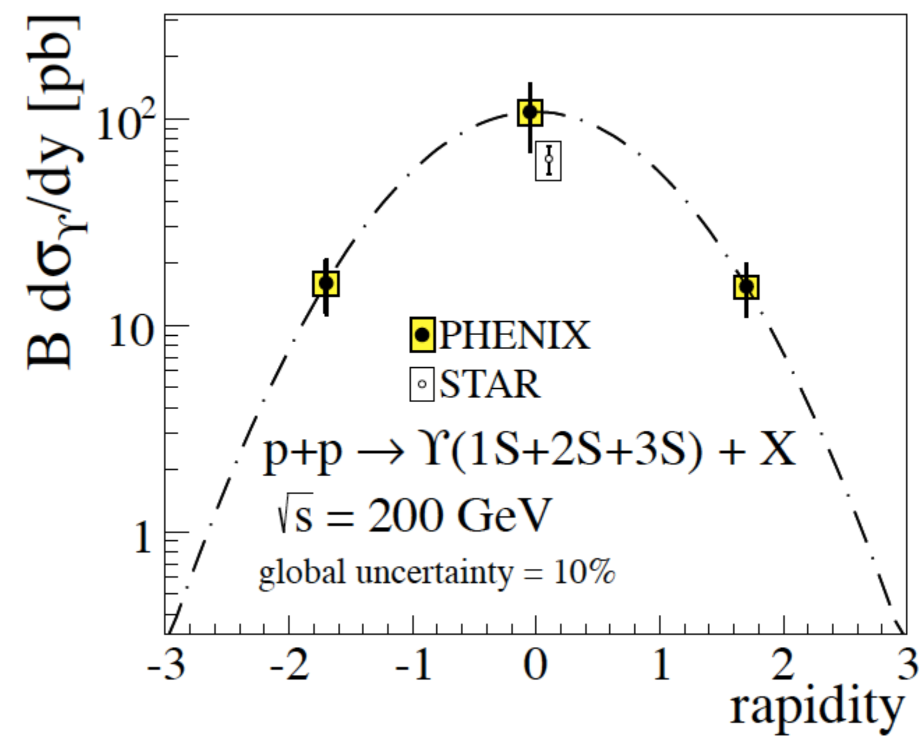


PHENIX Υ(1S+2S+3S) in Au+Au

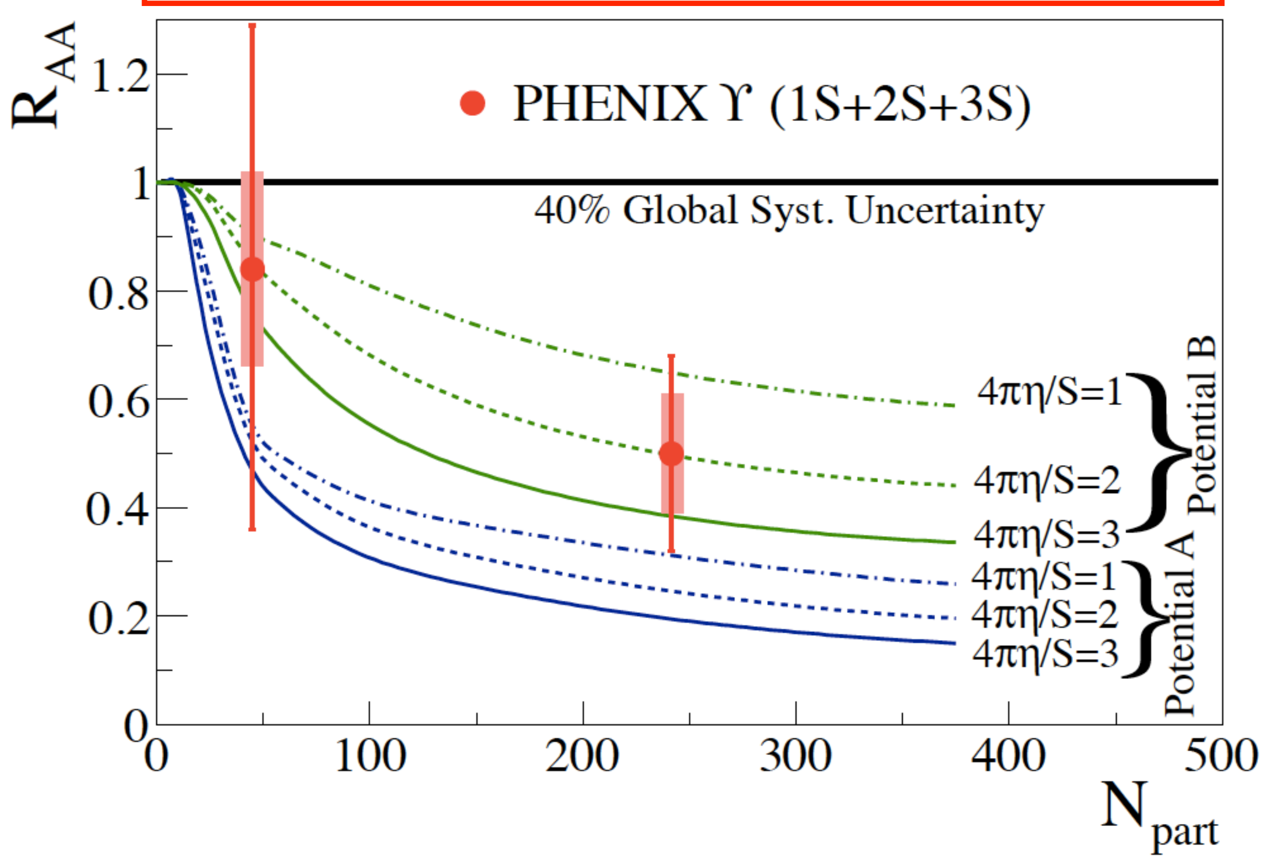
Statistics starved measurement for PHENIX due to

- small acceptance at midrapidity,
- small cross section at forward/backward rapidity

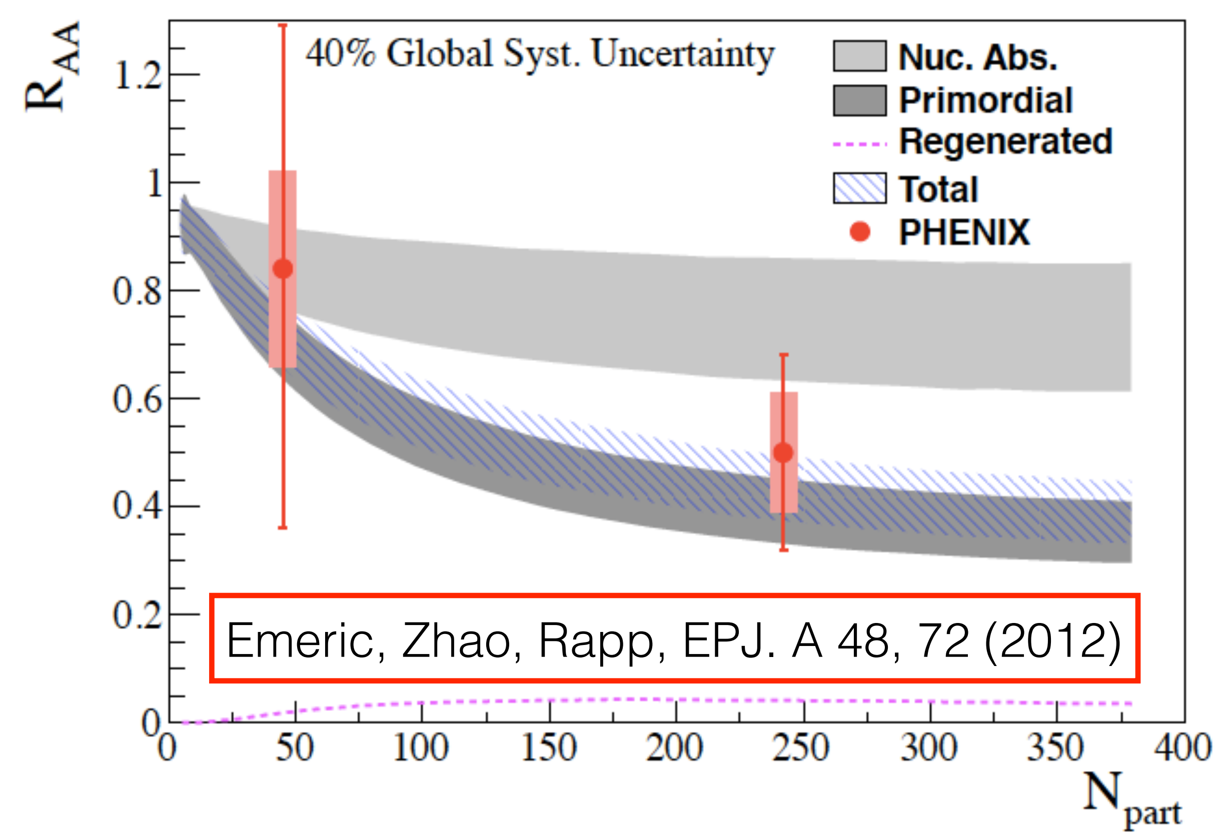
Described by the models, but the data do not provide a strong constraint



Strickland, Bazow, Nucl. Phys.A 879, 25 (2012).



PRC 91 (2015) 024913

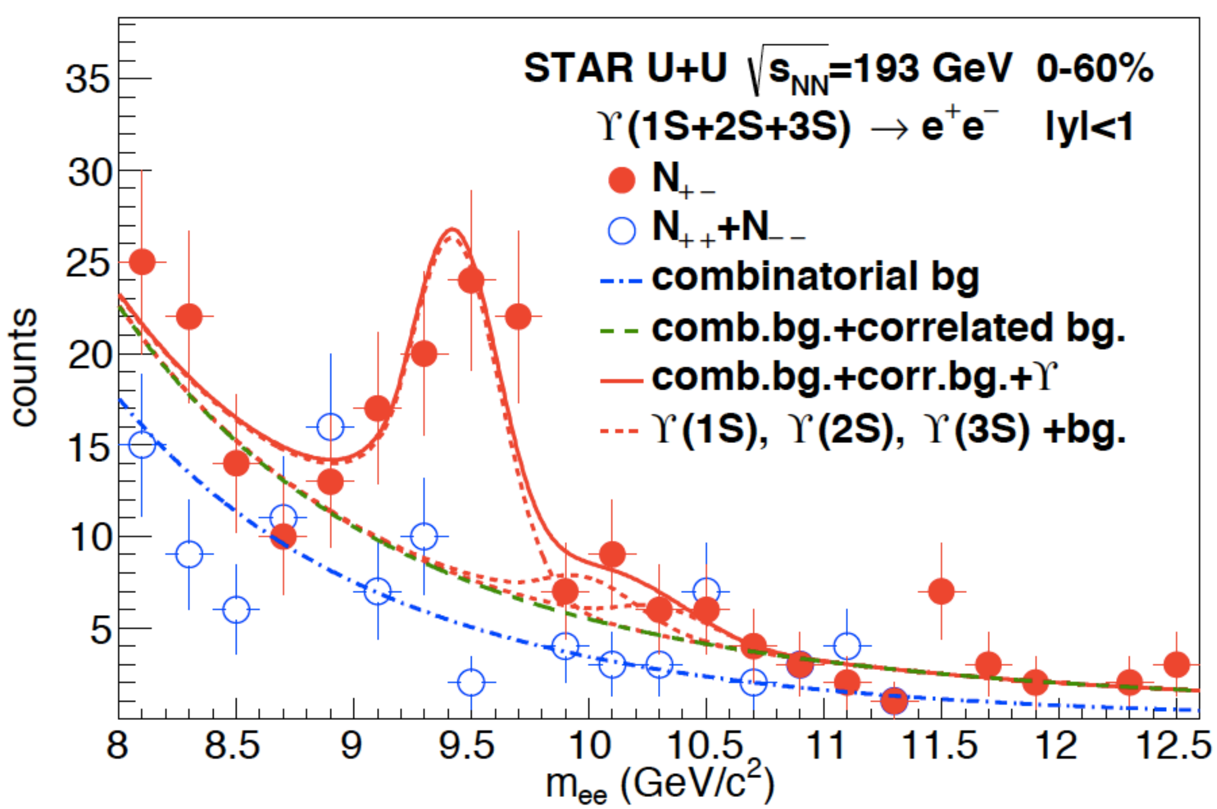


New: **STAR Υ production in U+U at 193 GeV/c**

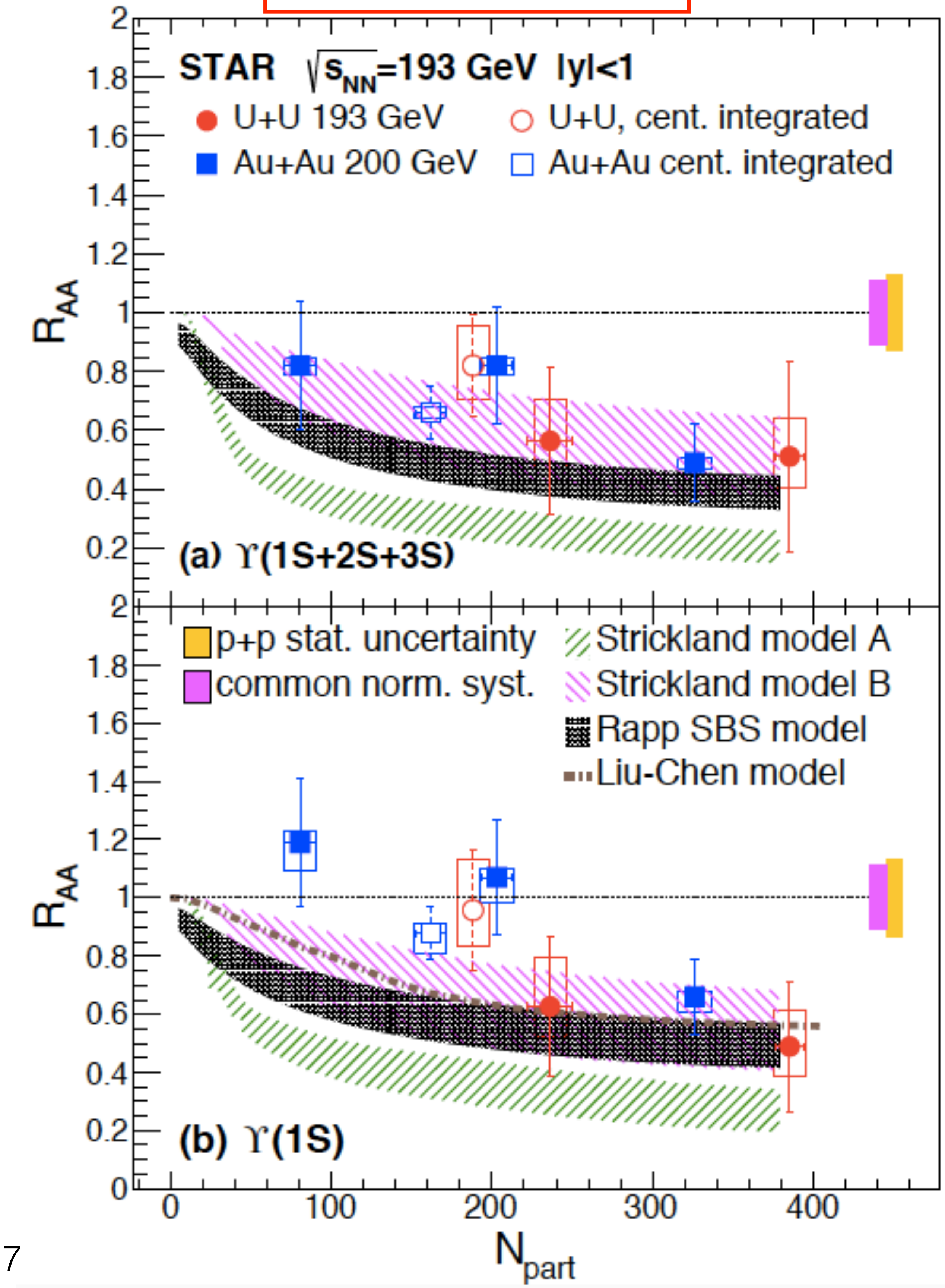
Fit dielectron mass spectrum with Crystal Ball lineshapes

Extract R_{AA} for
- Υ(1S+2S+3S)
- Υ(1S)

Well described by Strickland model B & the other models



arXiv:1608.06487

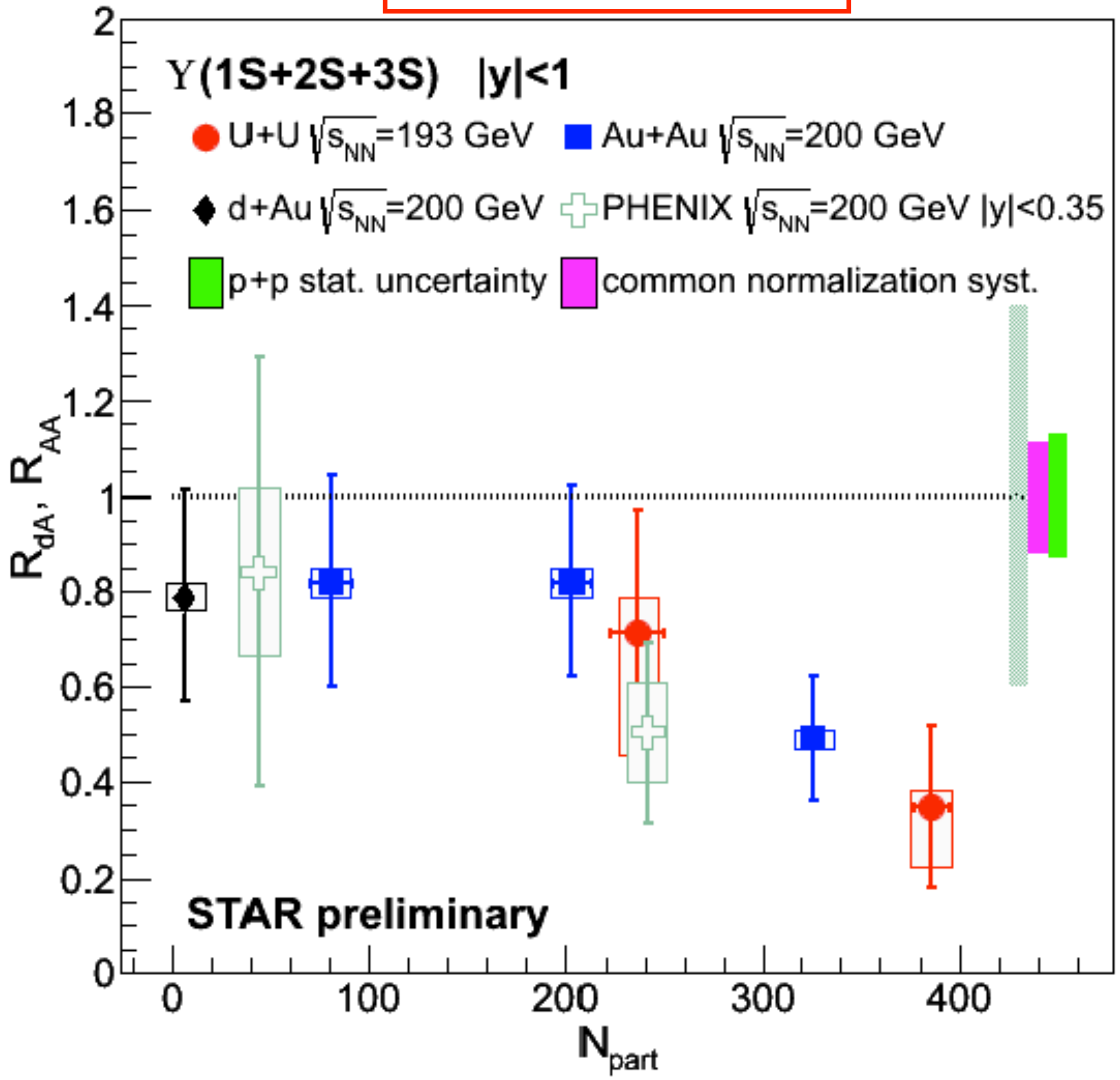


Υ(1S+2S+3S) comparisons at RHIC

Υ(1S+2S+3S) for d+Au, U+U and Au+Au

Common trend with N_{part} for suppression in Au+Au (200 GeV) and U+U (193 GeV).

arXiv:1608.06487

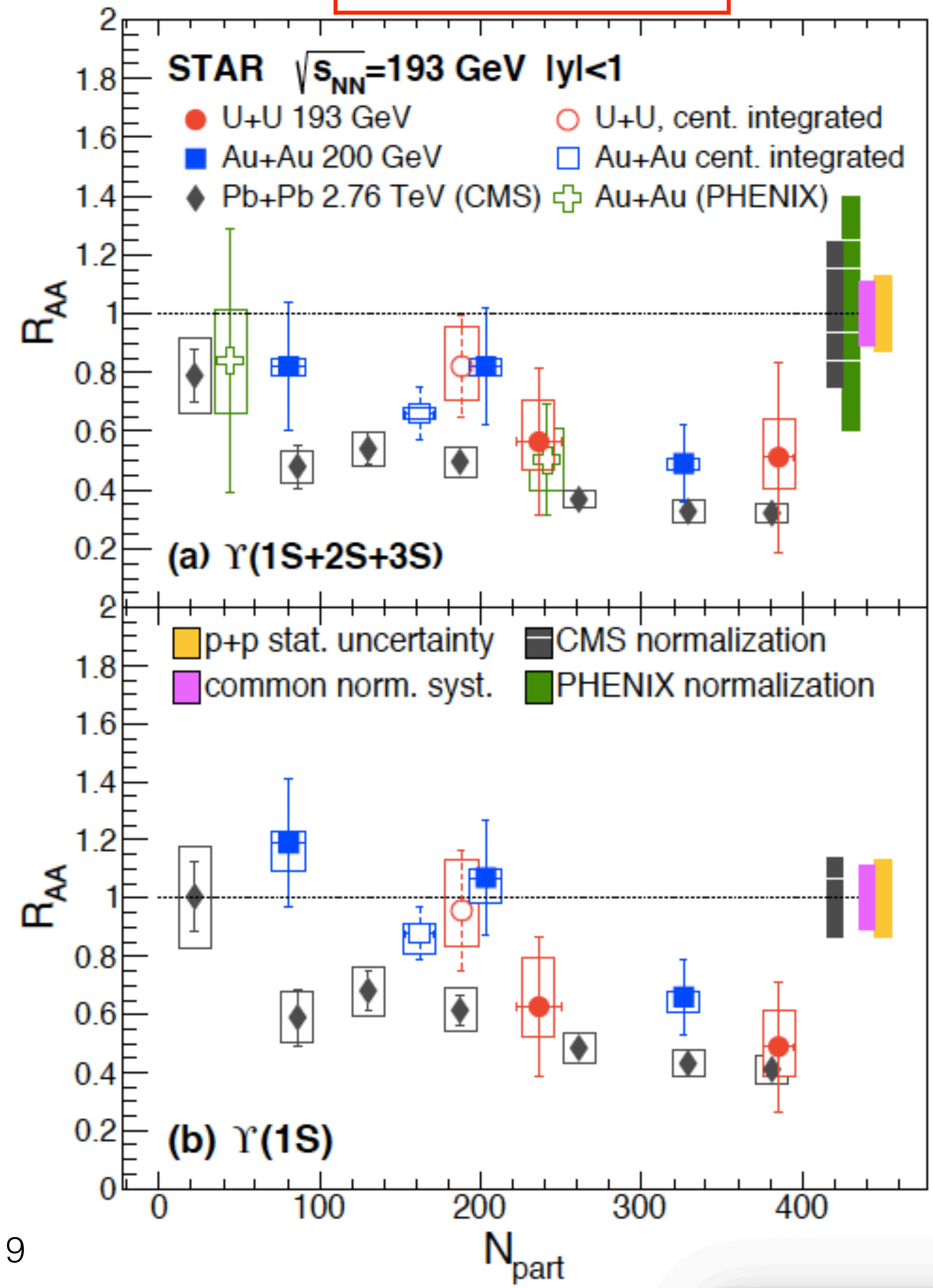


Υ(1S), Υ(1S+2S+3S) - comparison STAR/CMS

Υ(1S+2S+3S) for
U+U, Au+Au at RHIC from STAR
Pb+Pb at 2.76 TeV from CMS

Trend is for stronger suppression
at 2.76 GeV in both cases

arXiv:1608.06487

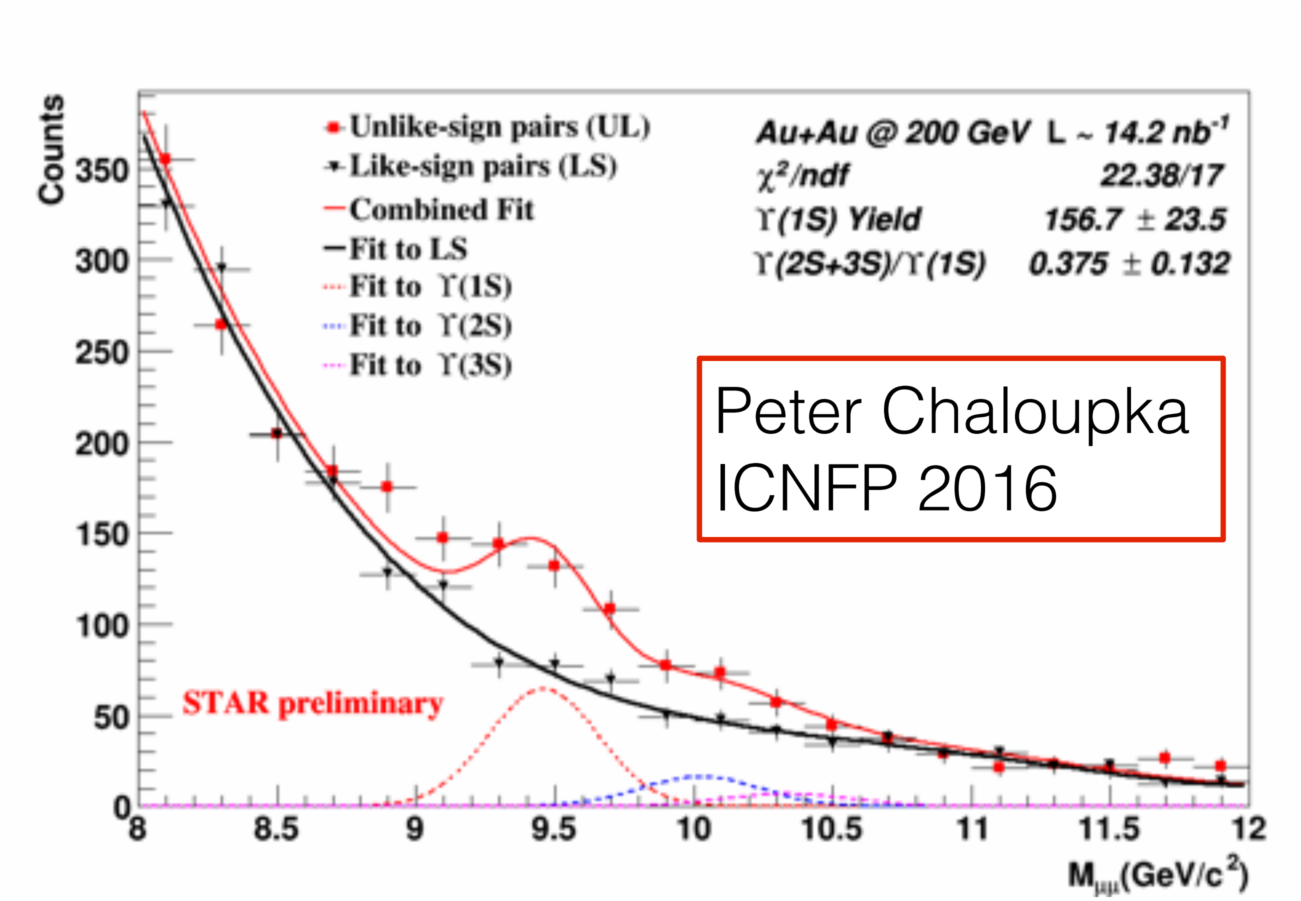


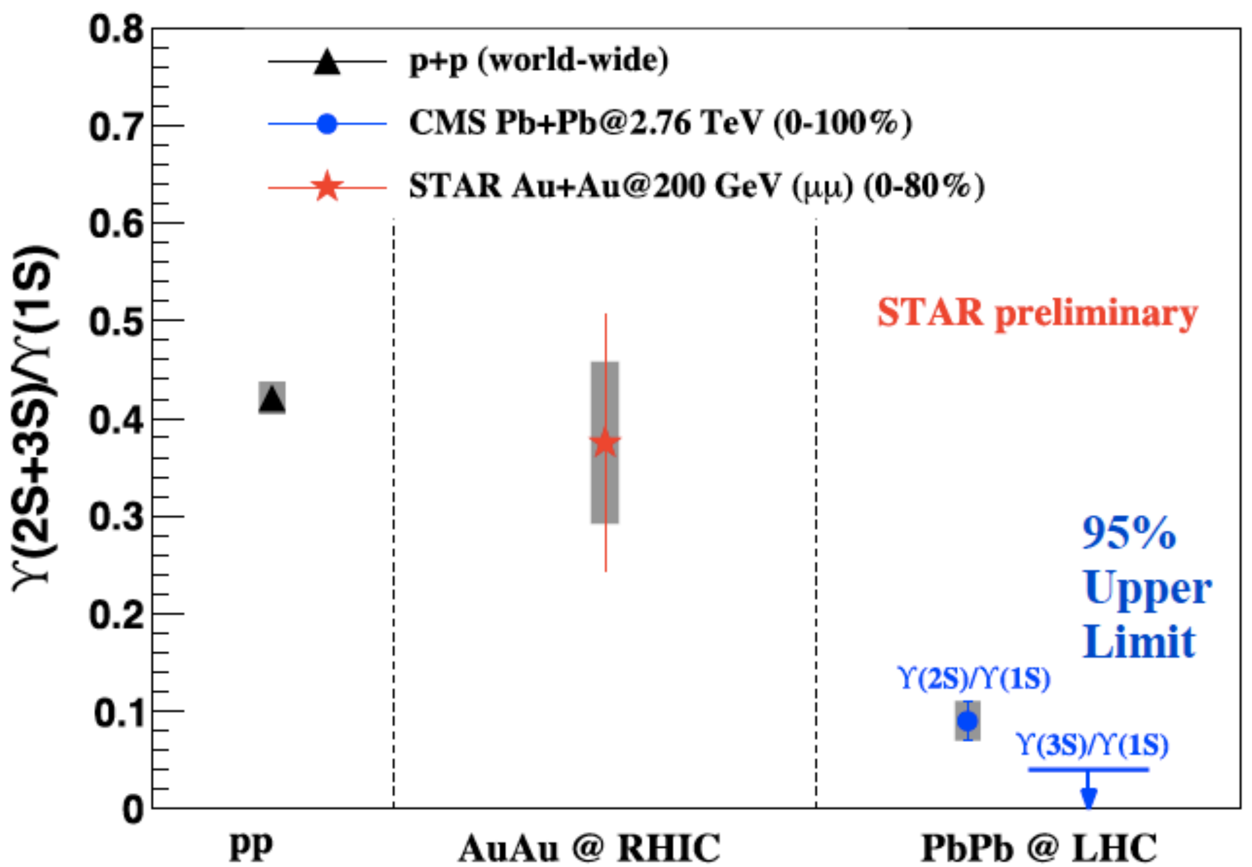
Recent: **STAR Υ's from dimuons**

First results using dimuons from the STAR MTD

Best Υ(2S+3S)/Υ(1S) ratio measurement so far

Indicates that Υ(2S+3S)/Υ(1S) ratio is larger at RHIC than at LHC





Future: **sPHENIX**

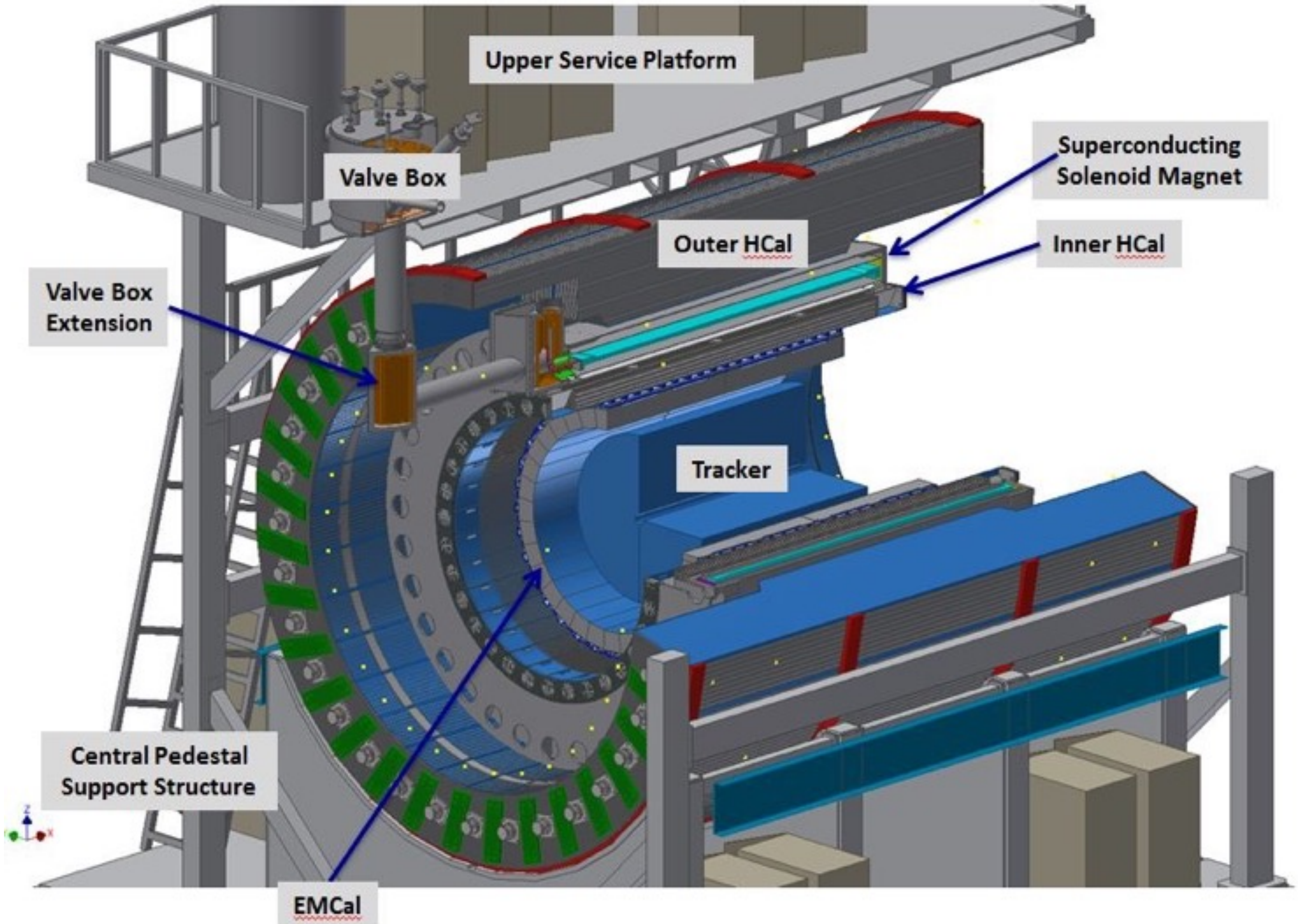
the PHENIX detector is no more (being dismantled this summer)

- Although we have a lot of data to analyze yet!

Next: sPHENIX

Designed for

- Jets
- HF tagged jets
- Upsilons

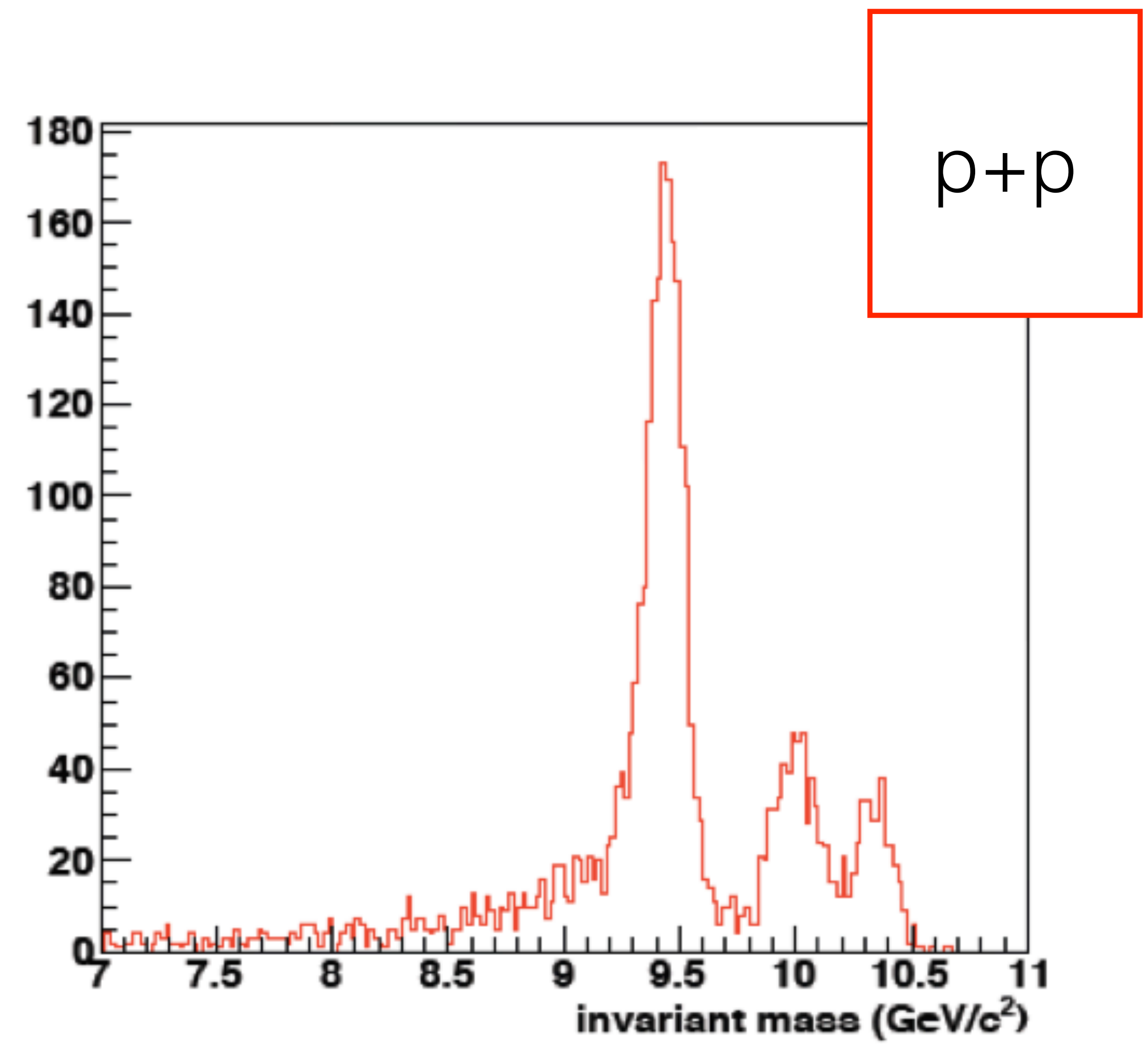


sPHENIX Upsilons

Proposed tracker:

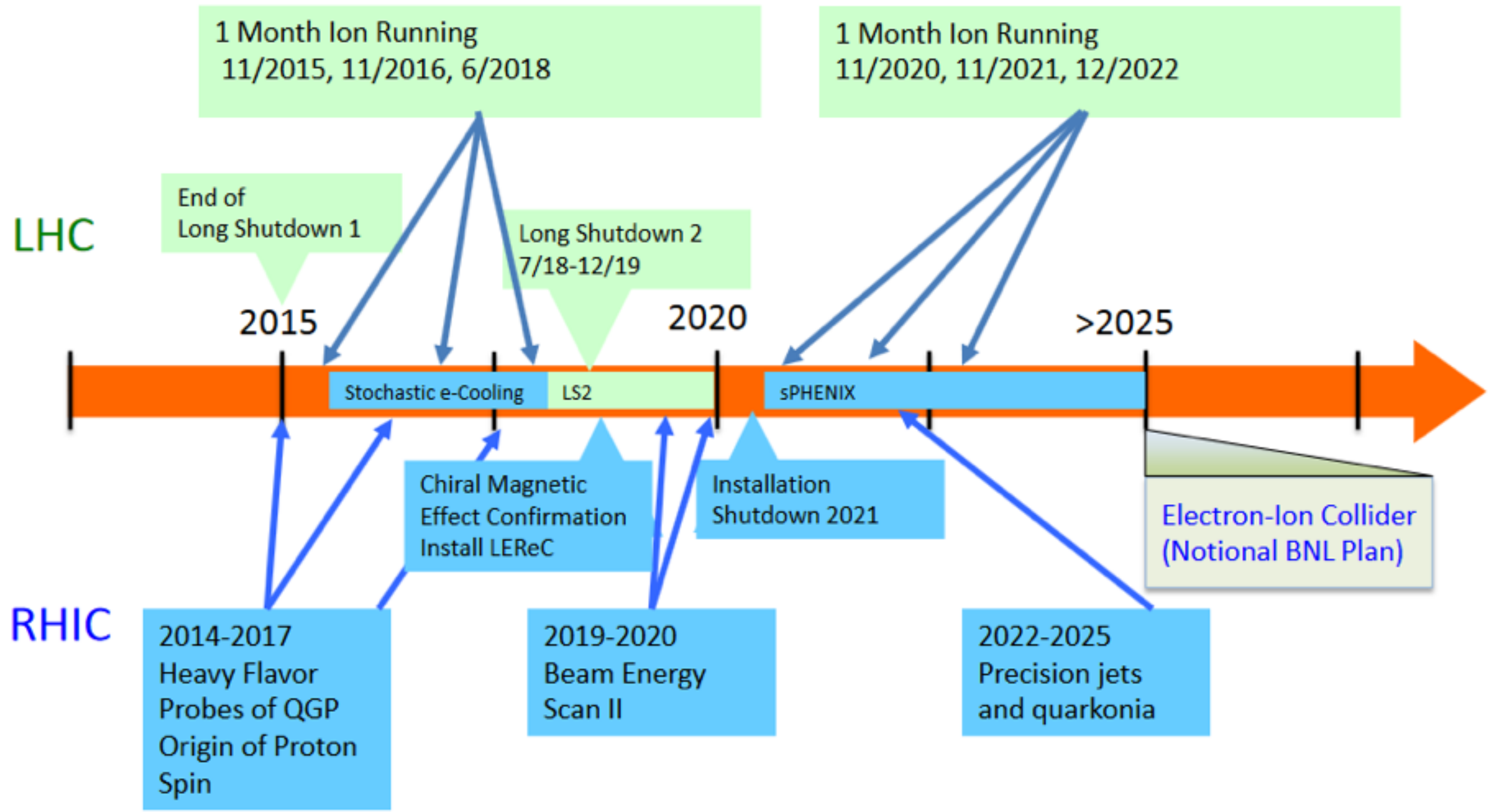
- Inner barrel: 3 MAPS pixel layers (copy of ALICE ITS upgrade IB)
- Intermediate tracker: 4 silicon strip layers
- Outer tracker: Compact TPC

Measure Upsilons with dielectrons
Anticipate ~ 80 MeV mass resolution



Tim Hallman, RHIC User's Meeting June 2016

RHIC / LHC Timeline



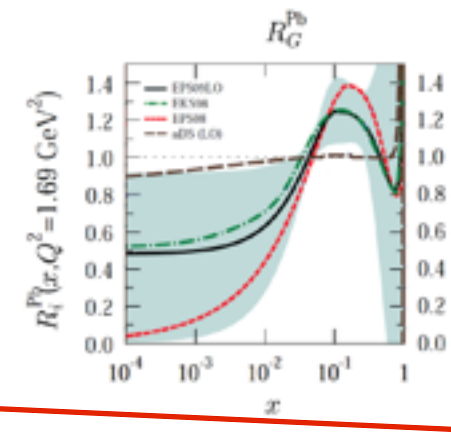
Backup

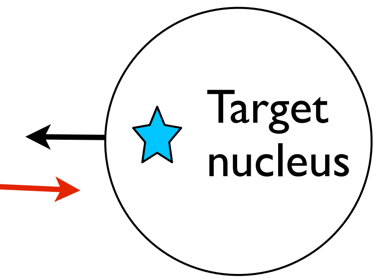
Cold nuclear matter effects

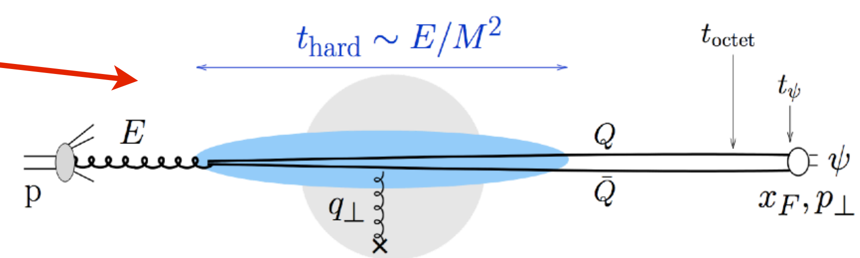
The lack of a pattern in the R_{AA} values is due to processes that modify the quarkonia yield in a nuclear target - cold nuclear matter (CNM) processes

CNM effects include

- Gluon shadowing – parton distributions modified in a nucleus
- Breakup of the precursor J/ψ by collisions with nucleons
- Initial state energy loss of partons in cold nuclear matter
- Cronin effect – multiple elastic scattering of partons







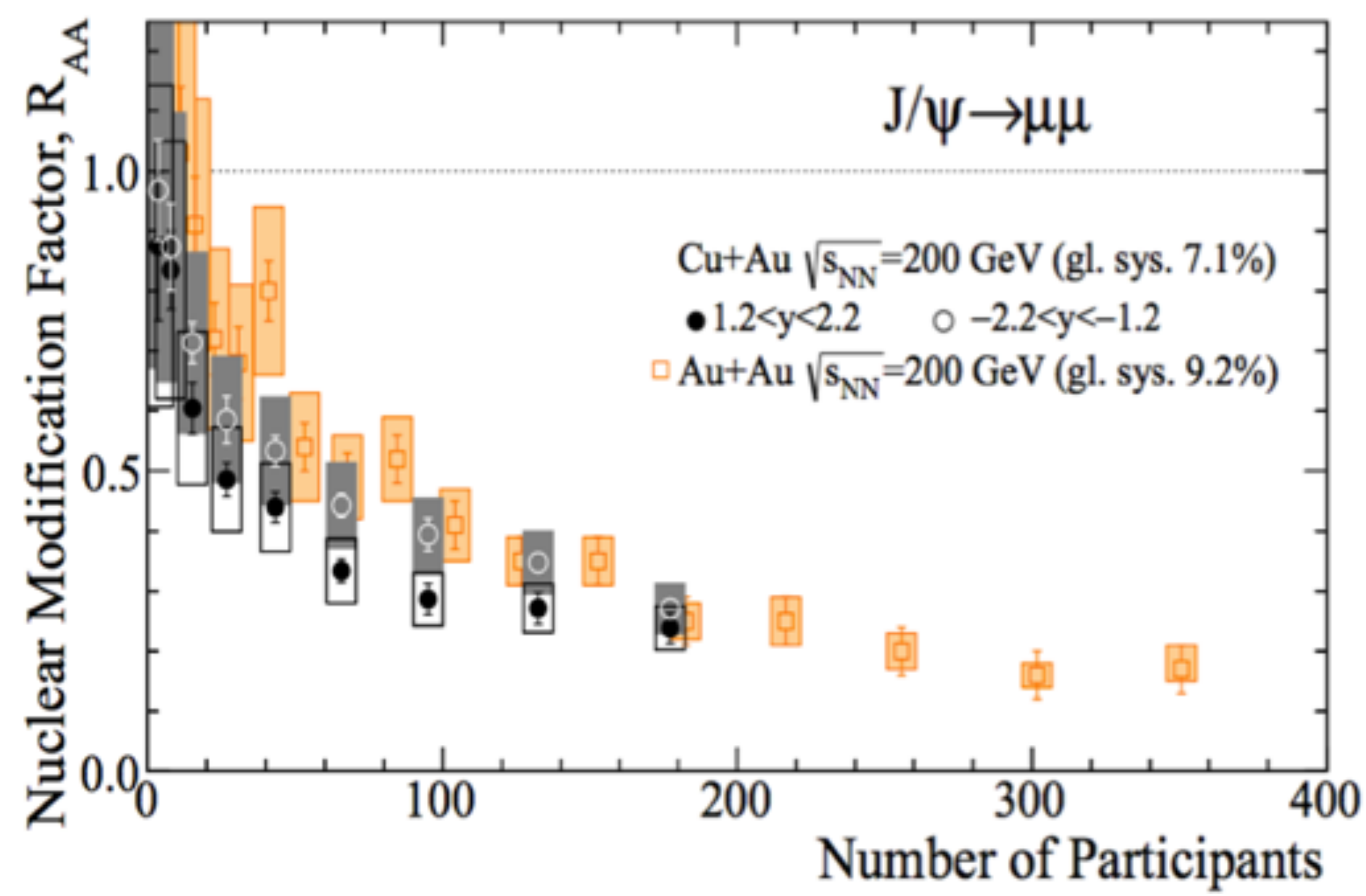
Notes:

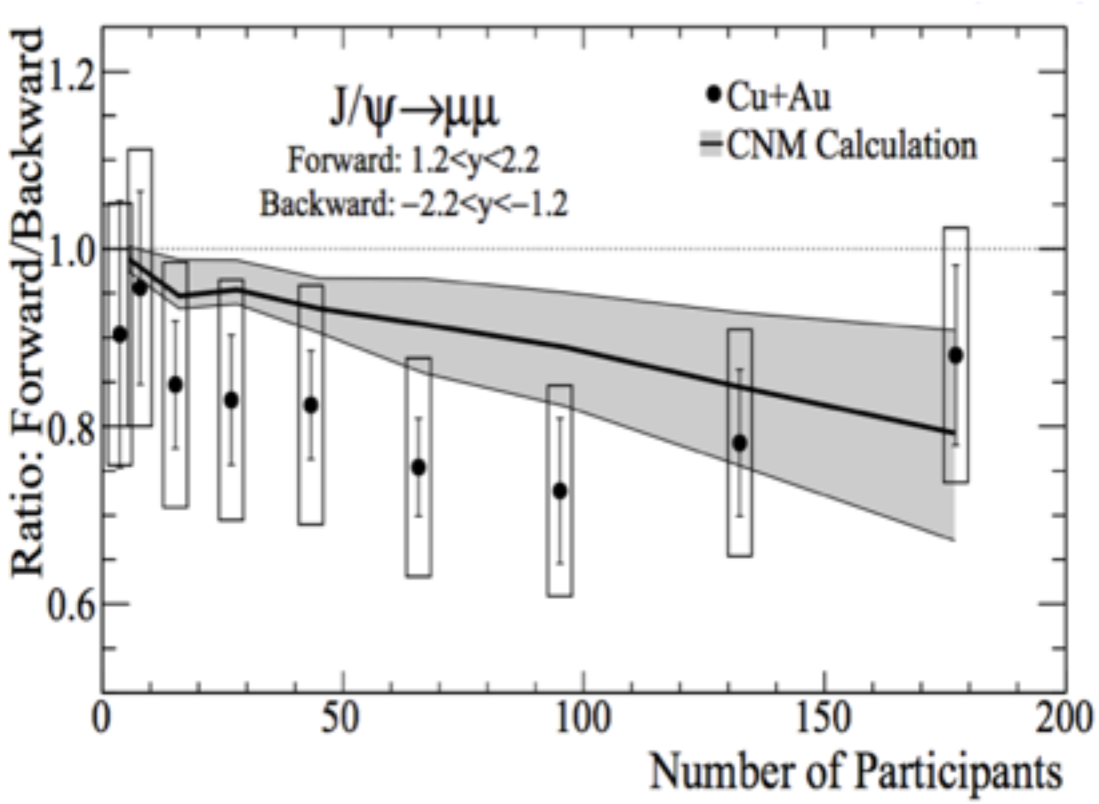
- Gluon shadowing affects the underlying charm yield.
- Breakup reduces the **fraction** of charm forming bound charmonium.
- Initial state energy loss changes the rapidity distribution
- Cronin effect modifies only the p_T distribution.

Cu+Au J/ψ

Asymmetric heavy beams
Compare forward backward
R_{AA} in the muon arms

arXiv:1404.1873

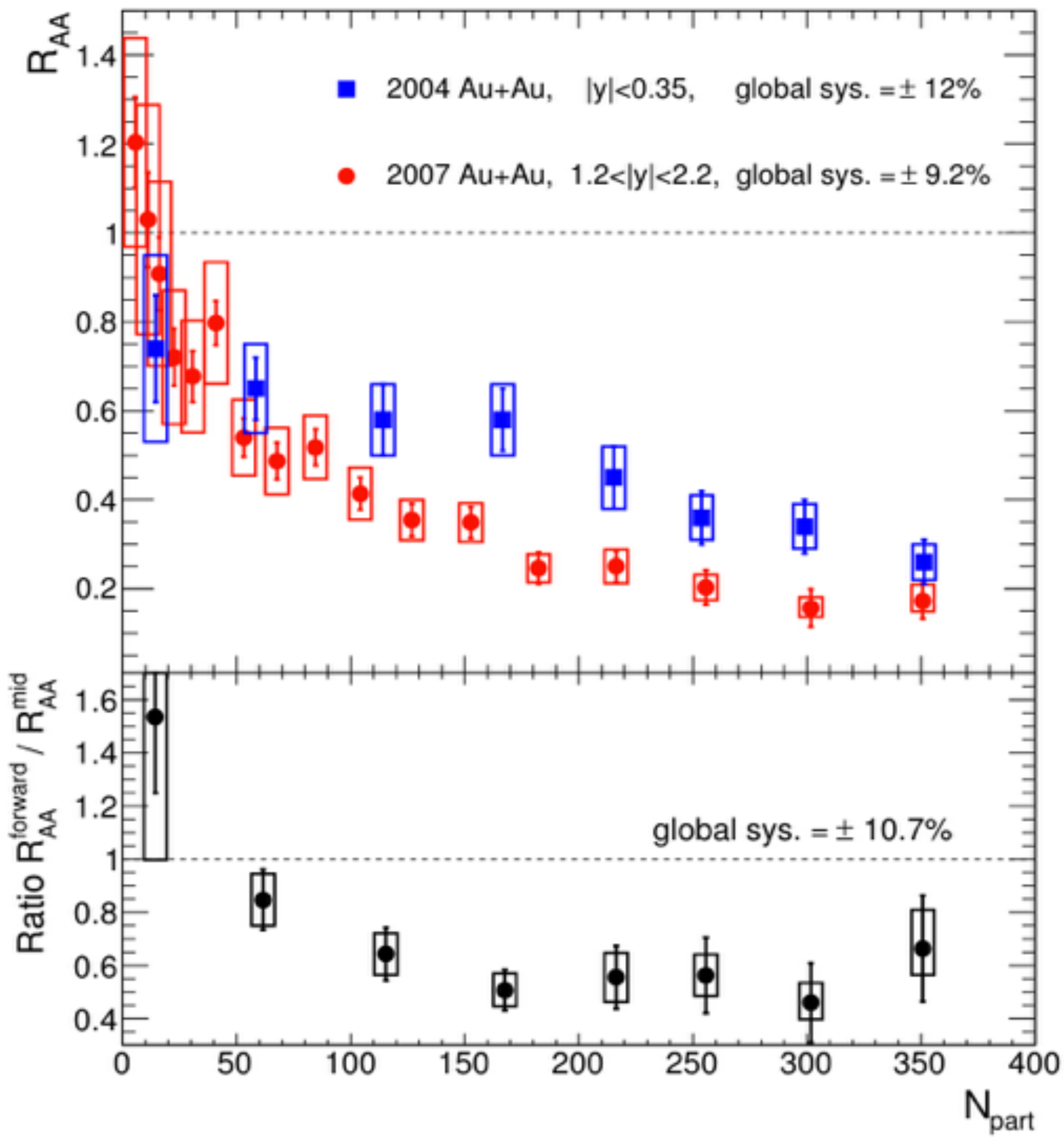




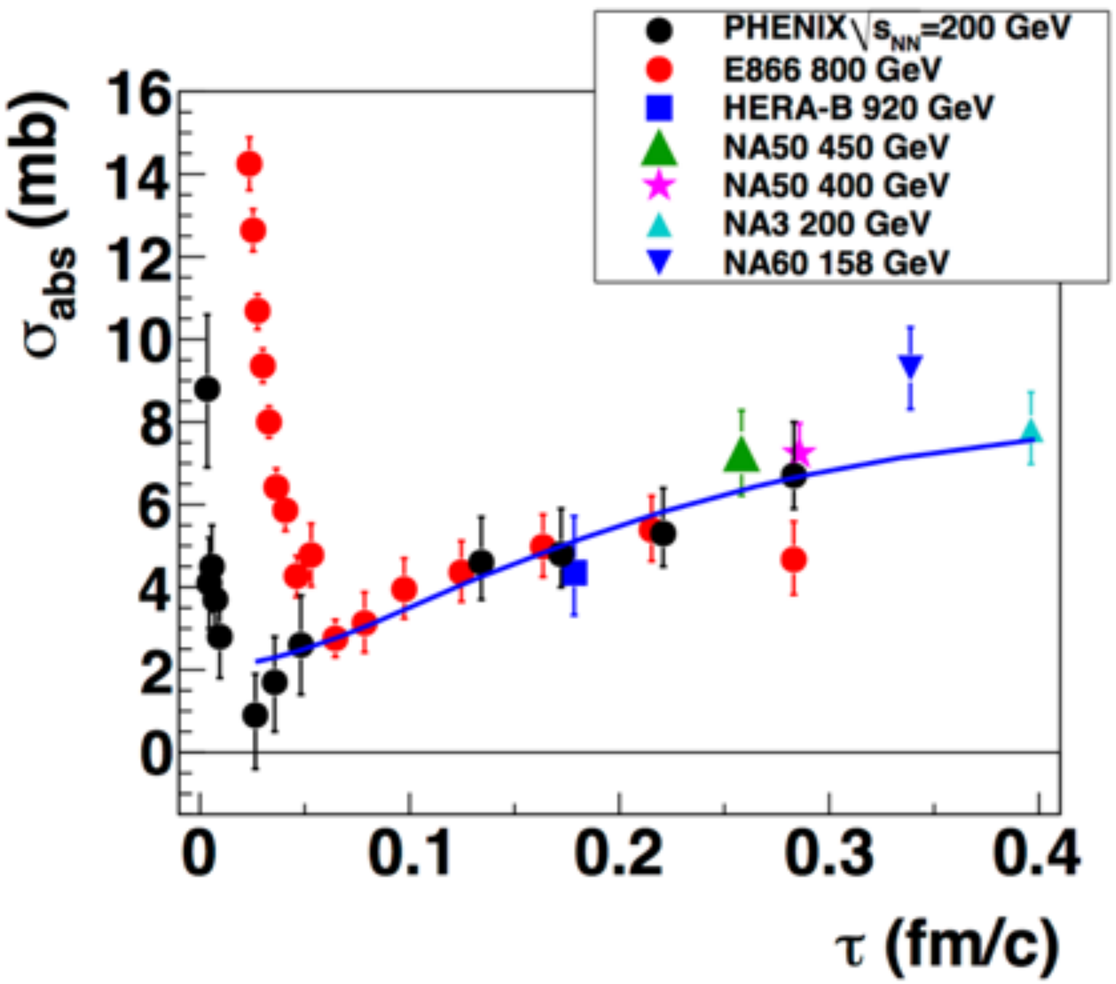
At backward rapidity, Cu+Au similar to Au+Au

The forward backward difference for Cu+Au is consistent with the expected effect of shadowing (EPS09)

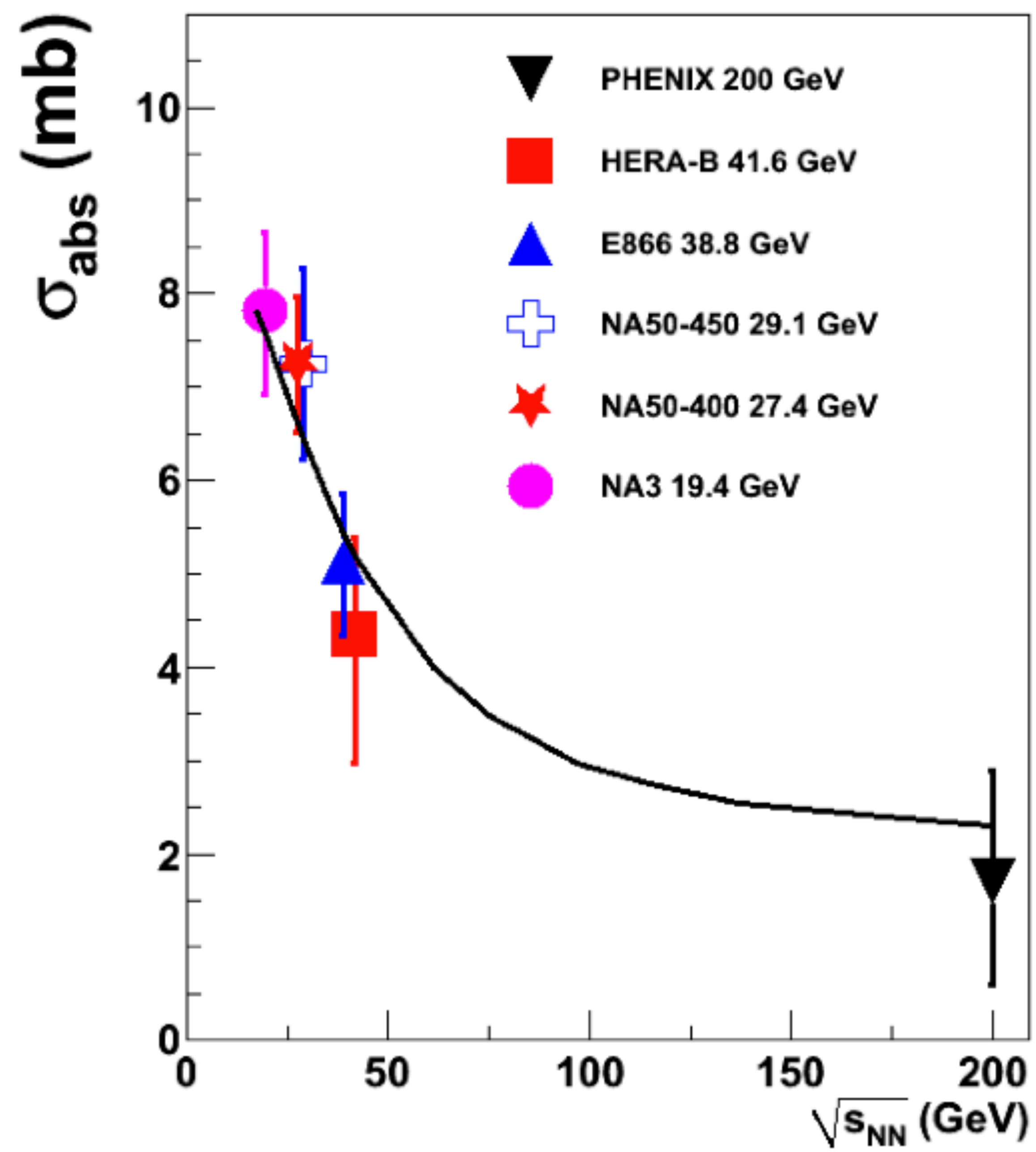
Au+Au J/ψ centrality dependence



J/ψ Data



PHENIX √s_NN=200 GeV
E866 800 GeV
HERA-B 920 GeV
NA50 450 GeV
NA50 400 GeV
NA3 200 GeV
NA60 158 GeV
σ_abs (mb)
τ (fm/c)
0
0.1
0.2
0.3
0.4
0
2
4
6
8
10
12
14
16



PHENIX 200 GeV
HERA-B 41.6 GeV
E866 38.8 GeV
NA50-450 29.1 GeV
NA50-400 27.4 GeV
NA3 19.4 GeV
σ_abs (mb)
√s_NN (GeV)
0
50
100
150
200
0
2
4
6
8
10