System-size dependence of Quarkonia from PHENIX

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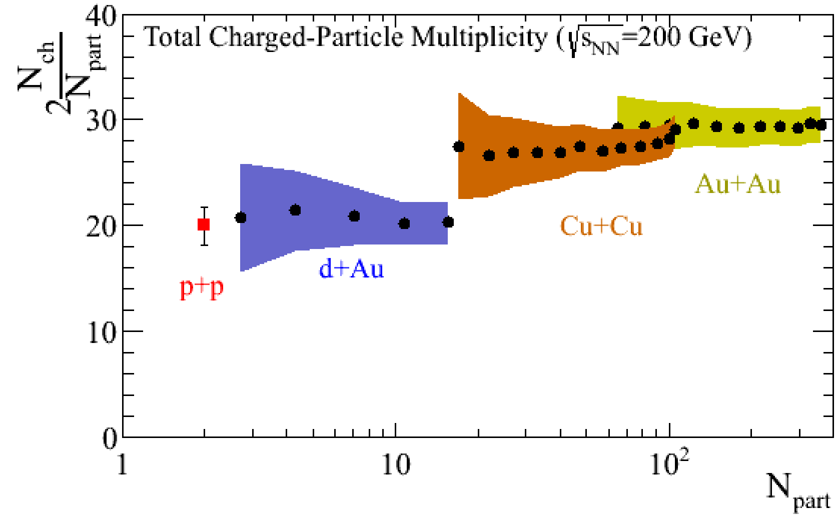
Outline

- Motivation
- PHENIX Detector
- Methods
- Results
- Summary

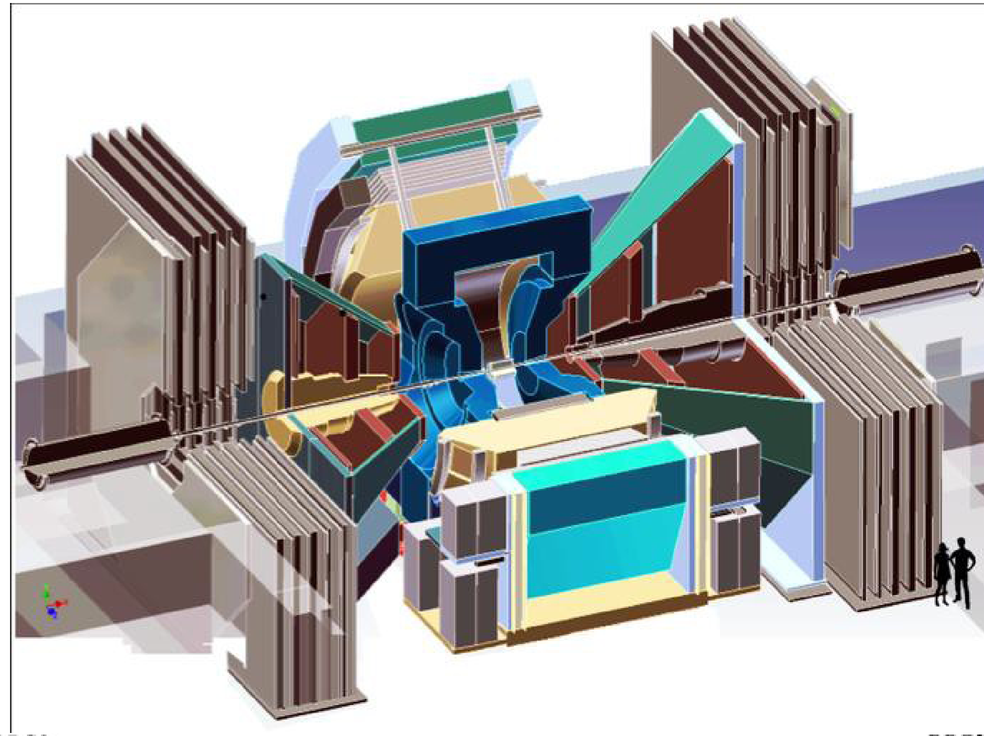
Motivation:
Why study the system-size dependences?

- In the early days we would have said:
  - "Turn on and turn off medium effects"
- From an analysis point of view:
  - "Can better measure central collisions, better control of systematic uncertainties"
- Probably now we might say:
  - "Subtle physics effects may be borne out of detailed comparisons..."

Phobos,Phys. Rev. C 83, 024913 (2011)

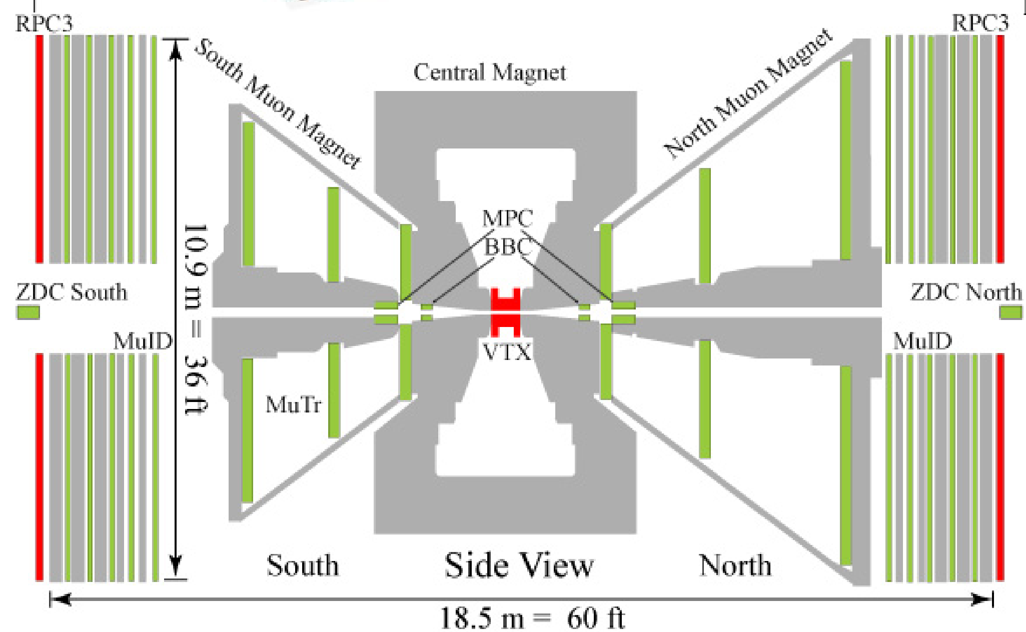


PHENIX Detector



Central arm: Focus on electrons
- EM Calorimeter (e^+/e^-)
- VTX – flavor separation (2011+ Upgrade)

Measure:
- J/ψ, ψ', $\Upsilon \rightarrow e^+ + e^-$
- Single electrons



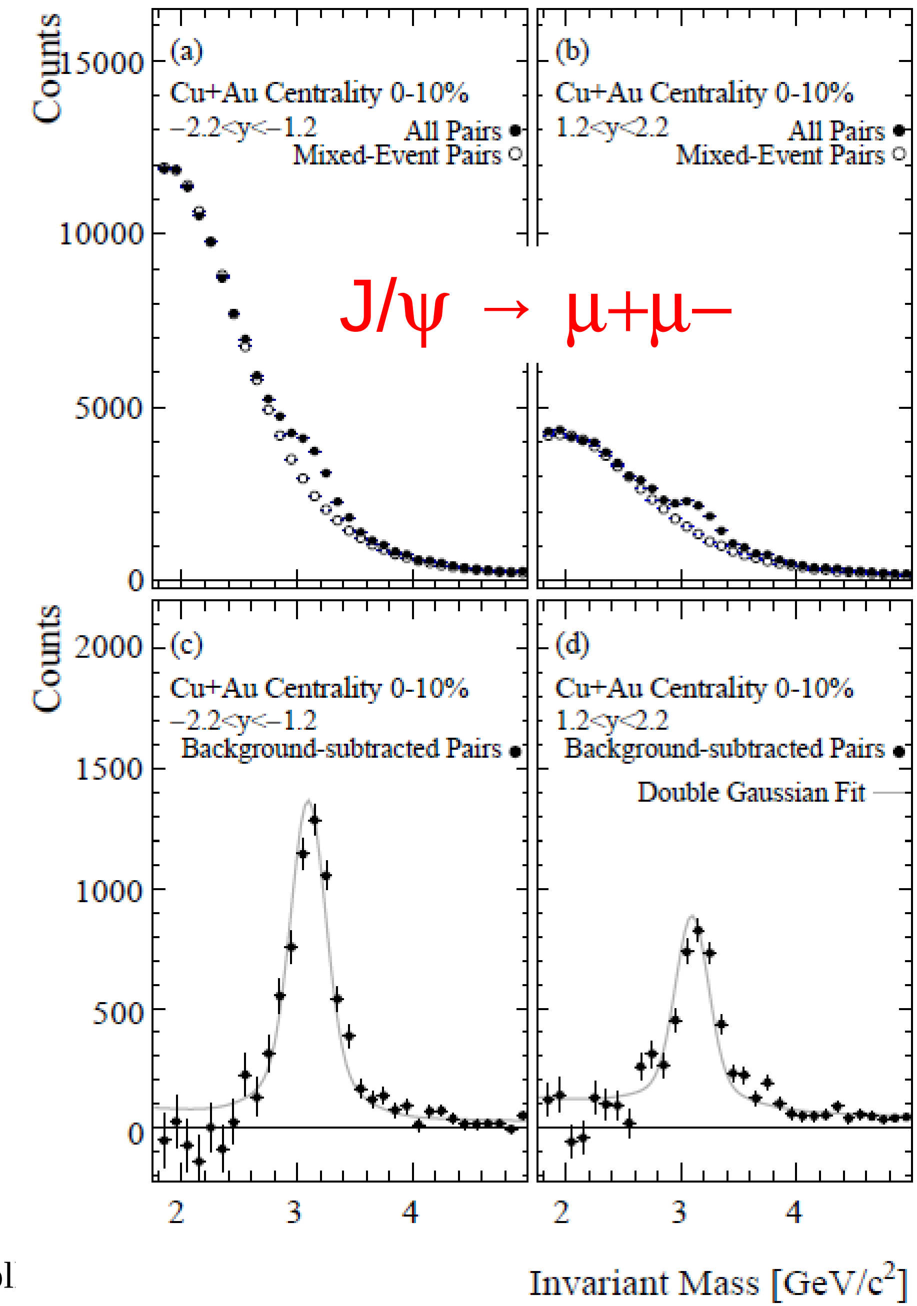
Forward arms: Focus on muons
- Muon Tracker/ID (μ^+/μ^-)
- fVTX – flavor separation (2012+ Upgrade)

Measure:
- J/ψ, ψ', $\Upsilon \rightarrow \mu^+ + \mu^-$
- Single muons

Measuring Quarkonia in PHENIX

Phys. Rev. C 90 064908 (2014)

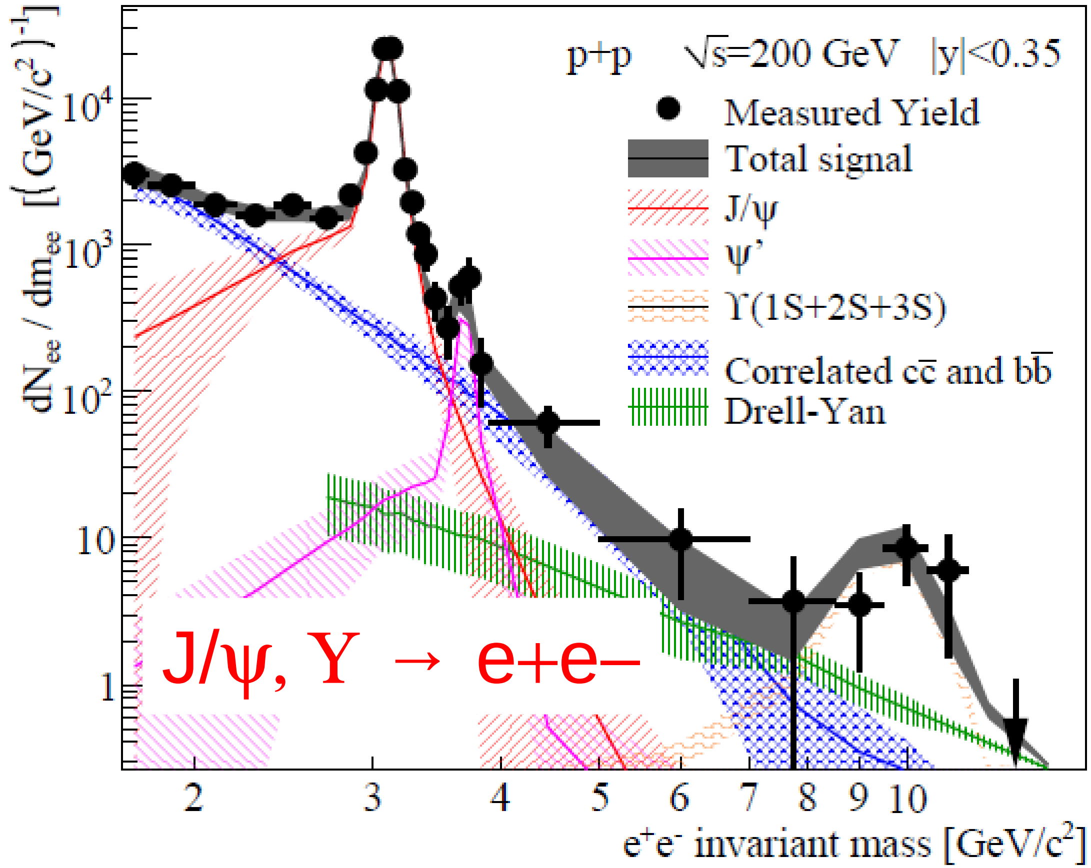
- Method:
  - Calculate invariant mass from decay leptons
    - J/ψ, (ψ'), Υ → μμ
    - Forward arms



Measuring Quarkonia in PHENIX

- Method:
  - Calculate invariant mass from decay leptons
    - J/ψ, ψ', Υ → ee
    - Central arms

Phys. Rev. C. 91 024913 (2015)



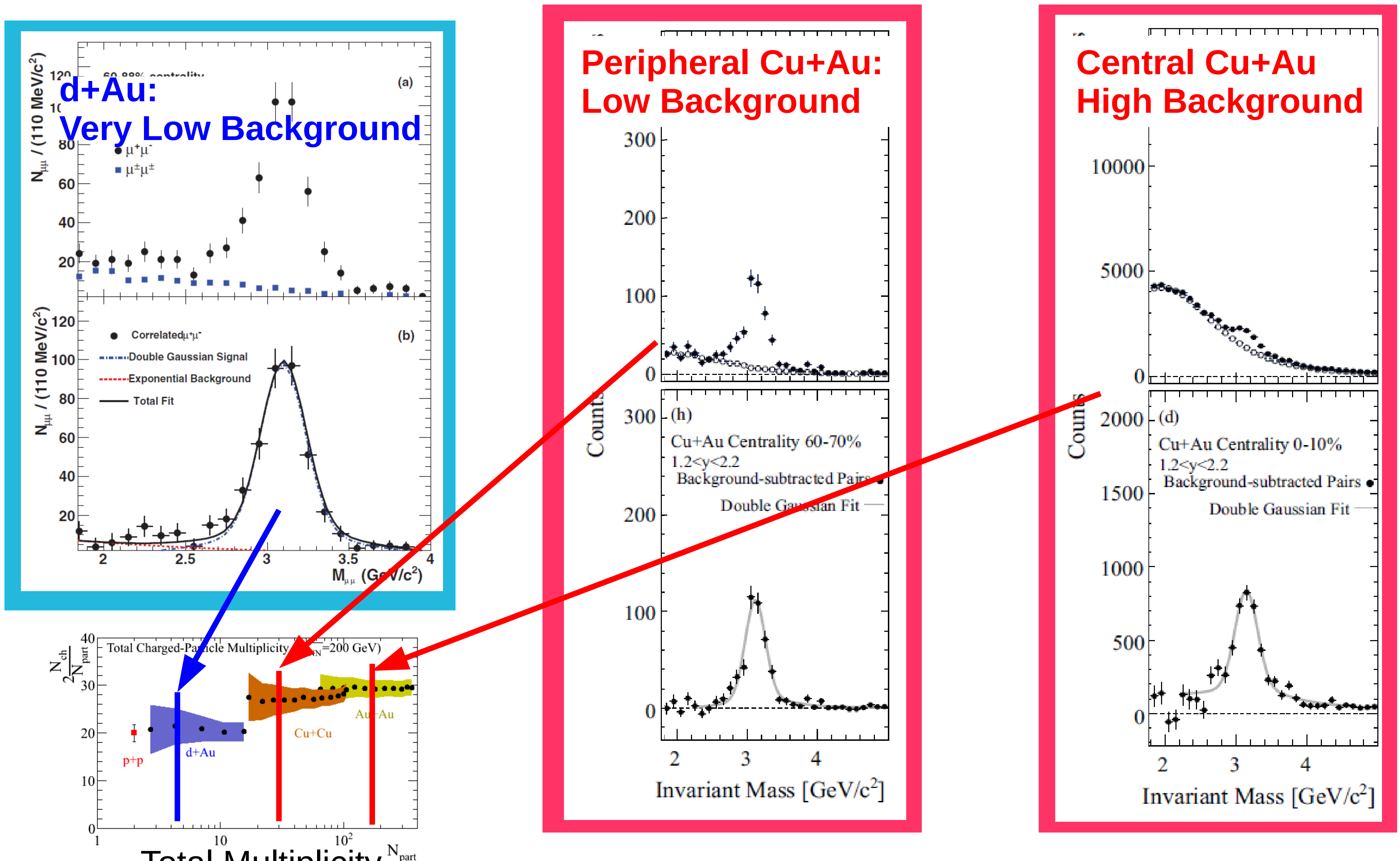
Collision species collected

- p+p baseline reference
- d+Au nuclear reference*
- Au+Au main dataset

- Systematic Studies:
  - Smaller system: Cu+Cu
  - Asymmetric system: Cu+Au
  - Larger system: U+U

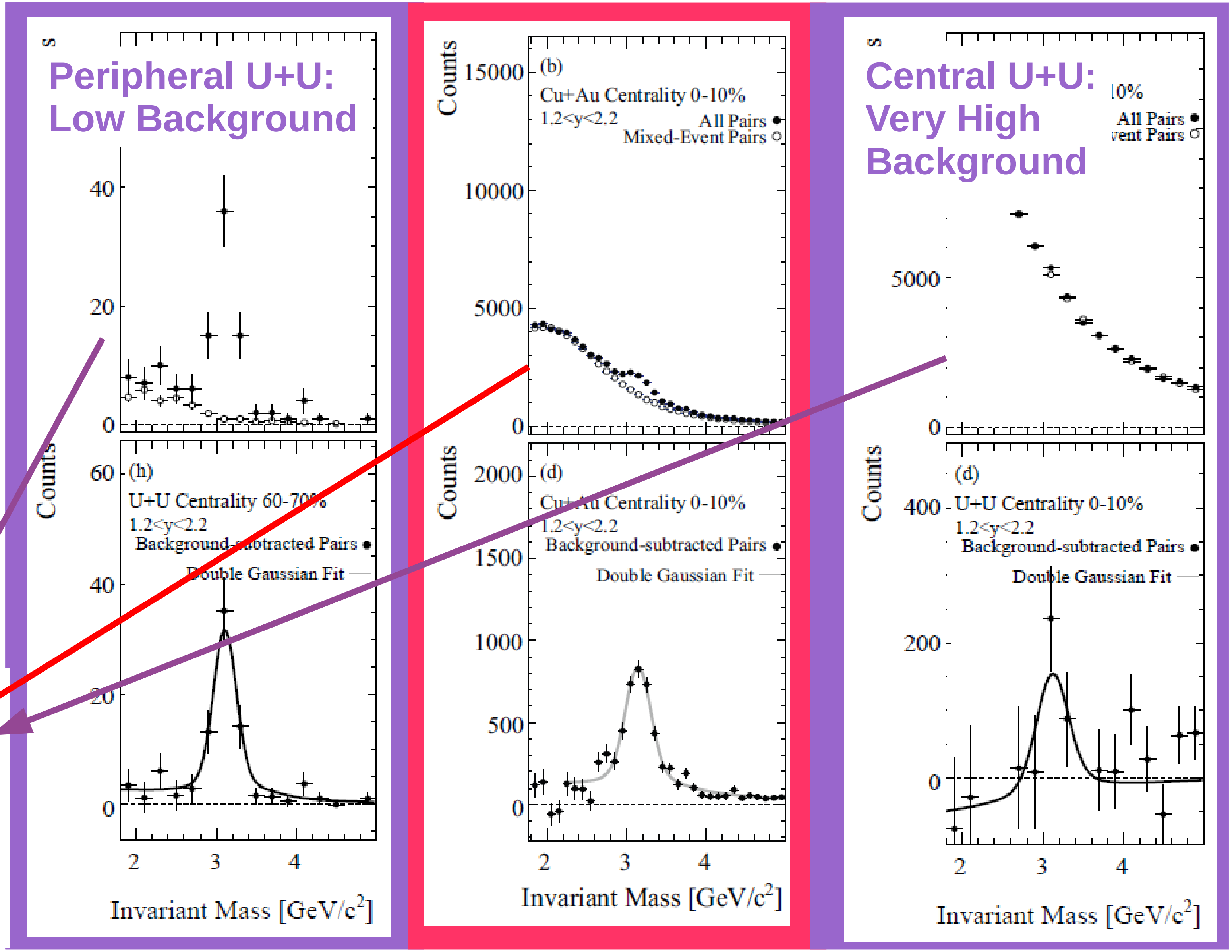
*d+Au is not to be considered a “reference” system as it has revealed its own swathe of interesting physics effects

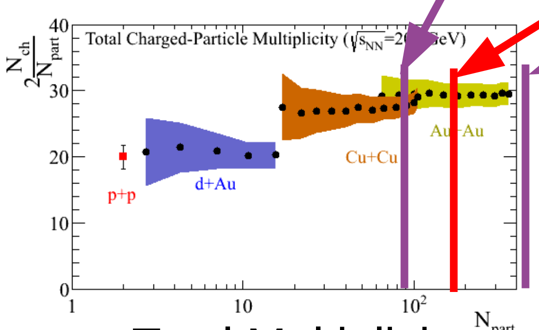
Measuring Quarkonia in PHENIX
Challenges at high-multiplicity



Measuring Quarkonia in PHENIX
Challenges at high-multiplicity

- Highest background observed in central U+U collisions
  - Signal is barely visible





Total Multiplicity

Nuclear Modification Effects

Competing effects from *HOT* and *COLD* nuclear matter

Color screening

Recombination

Coalescence

p_T Broadening

Collective Flow

Final State Energy loss

Gluon (anti) shadowing

Initial state energy loss

QQ-bar breakup in target nucleus

Gluon saturation

Separation of HOT and COLD effects not clearly established experimentally

PHENIX: Multiple Parameters

System Size/ Collision Asymmetry

Change the relative contributions of ***Cold*** and ***Hot*** nuclear matter effects

Centrality

Suppression vs path length

Collision Energy

Change system energy density

Momentum

Hard collision dynamics

Rapidity

Probes different gluon (anti)shadowing

Heavy/Light

Mass ordering of suppression

Particle Species

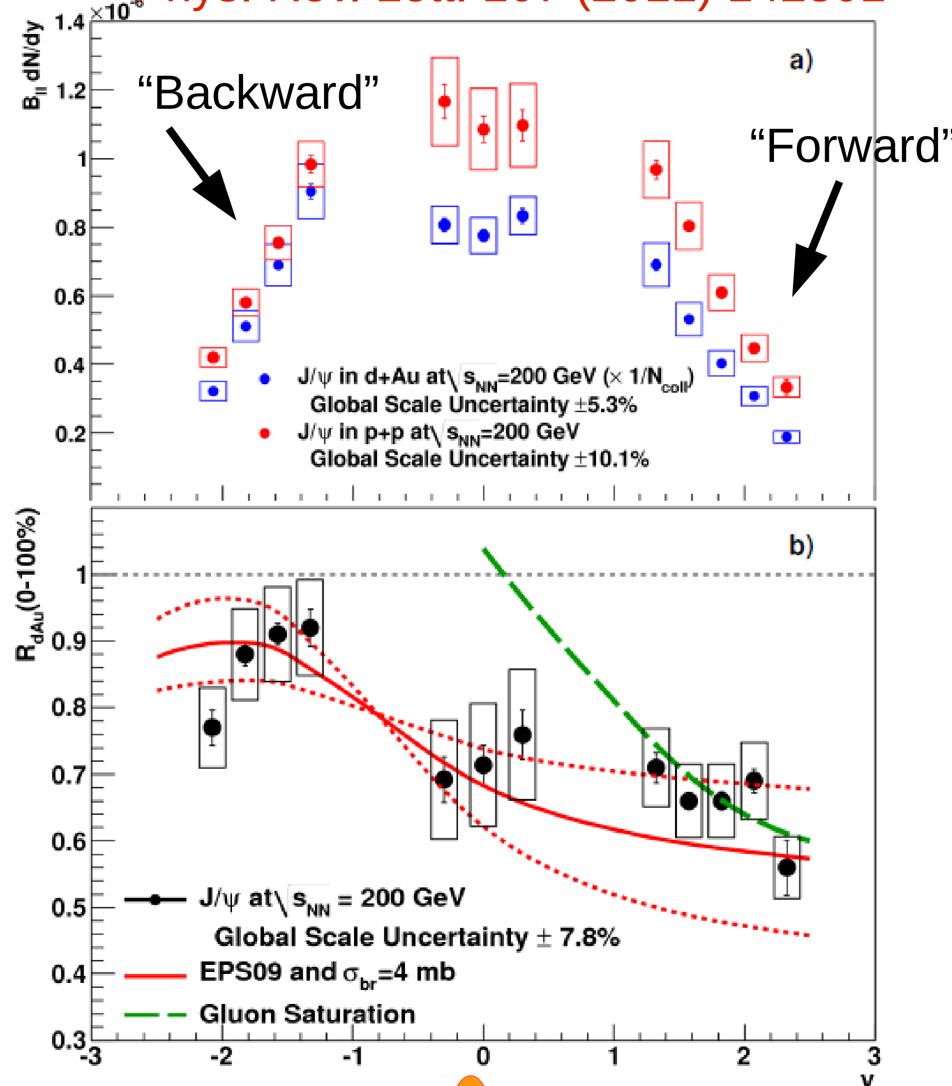
Break-up, Temperature?

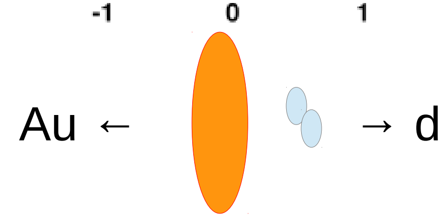
Each parameter probes different admixtures of nuclear modification

p+p and d+Au: J/ψ measurements

- p+p:
  - production cross-section baseline
- d+Au:
  - Nuclear effects baseline
- d+Au compared to p+p observations:
  - Forward/backward asymmetry
  - “suppression” at forward rapidity
- Cold Nuclear Matter only (?)
  - Nuclear shadowing and cc breakup describes the data well (favors σ_{br}~4mb)
  - Gluon saturation does not replicate the full rapidity distribution

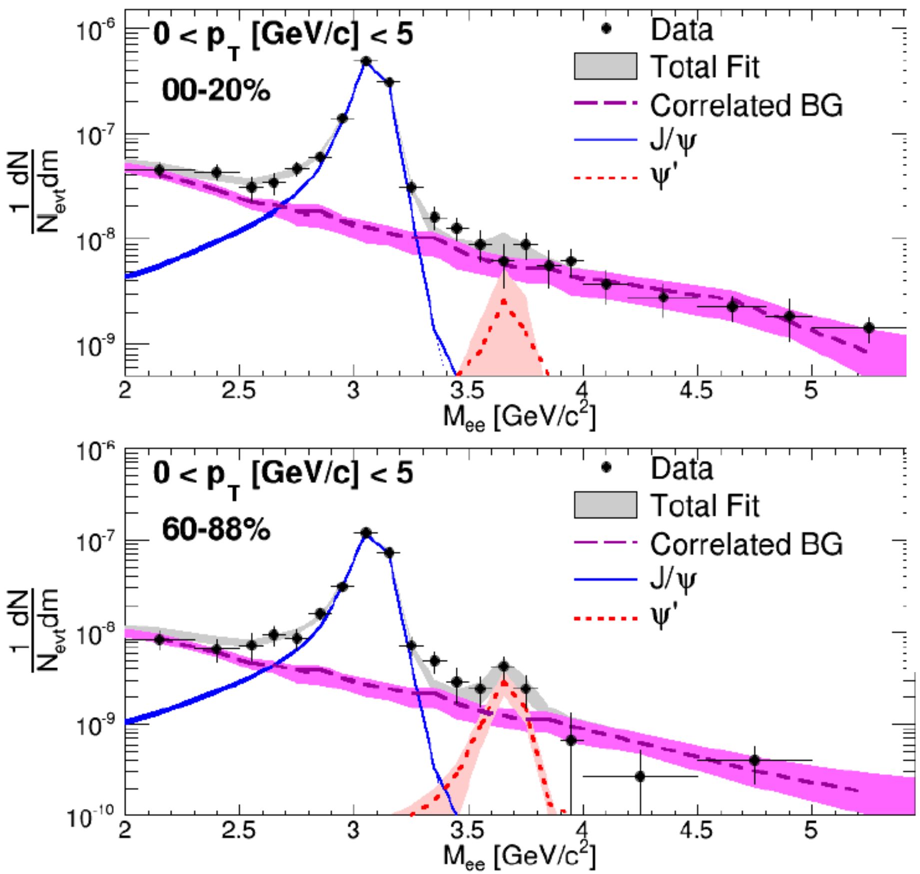
Phys. Rev. Lett. 107 (2011) 142301

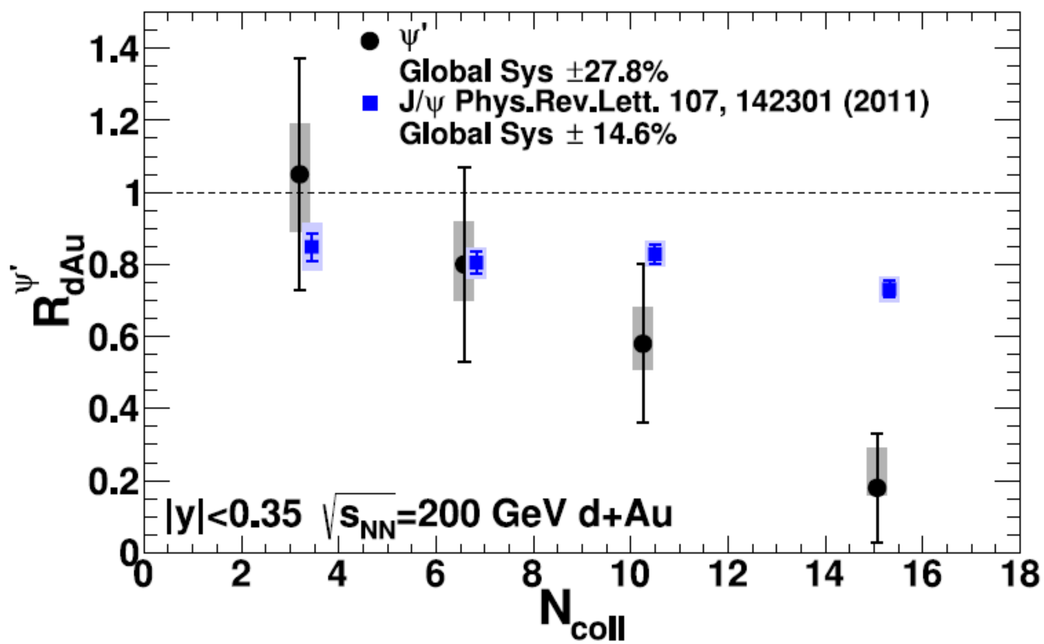




J/ψ versus ψ'

Central arms (electron channel)
Phys. Rev. Lett. 111 (2013) 202301





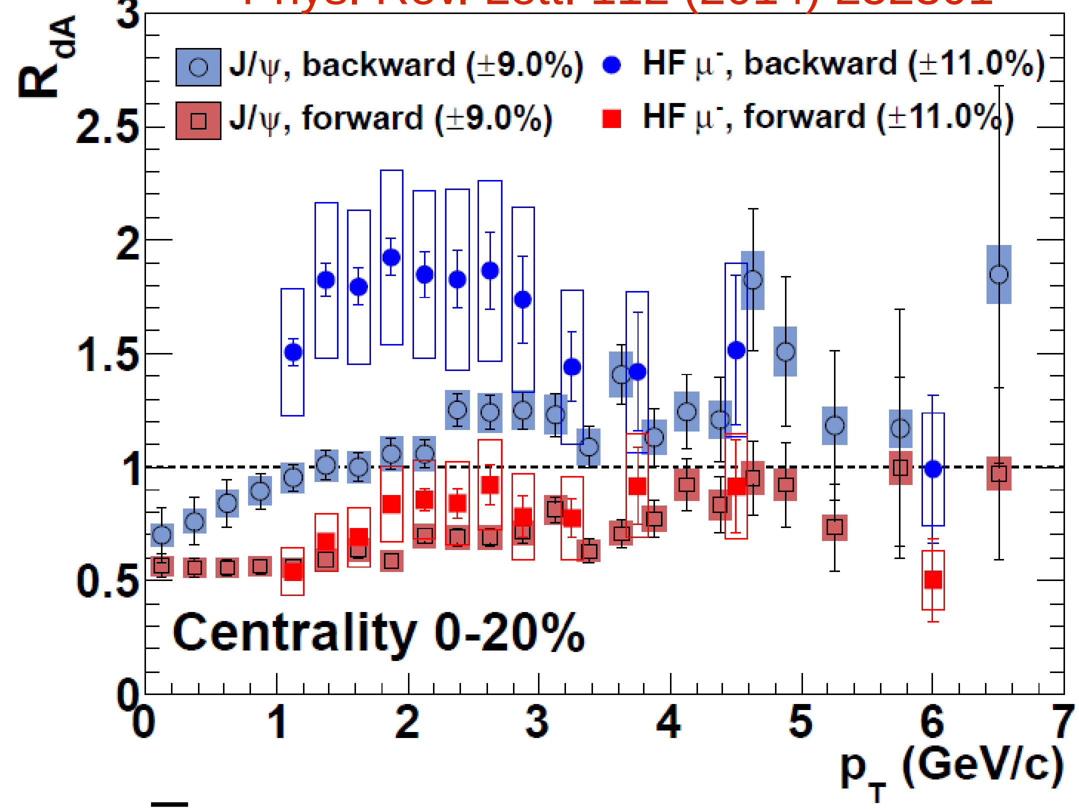
- ψ' more suppressed in central d+Au than J/ψ
- Smaller binding energy → more sensitive to final state effects

More systematic studies are possible in He+Au, p+Au, and p+Al datasets
at forward, backward, and central rapidities

J/ψ comparison to Heavy Flavor in d+Au

Forward arms (muon channel)

Phys. Rev. Lett. 112 (2014) 252301

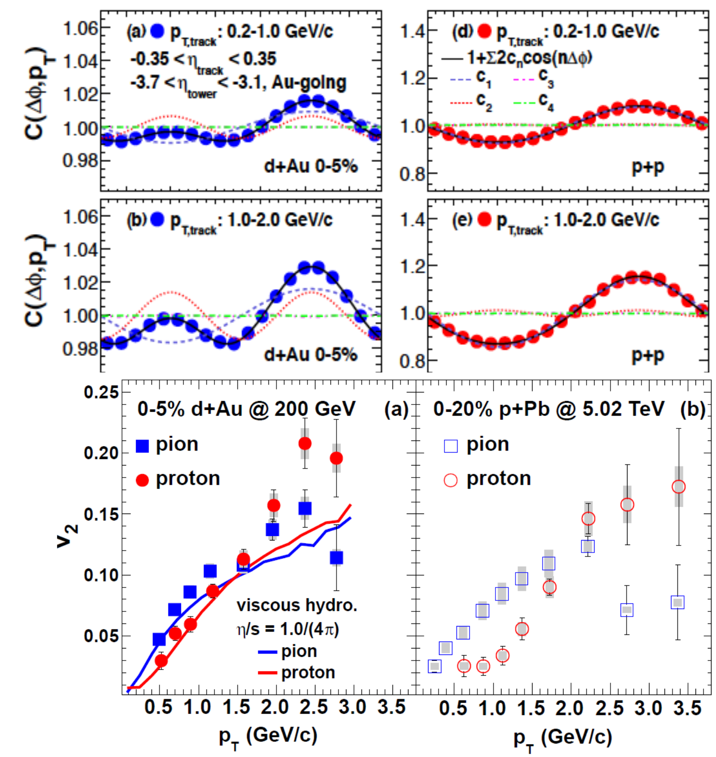


- Similar modification at forward rapidity
- Distinct difference at backward rapidity
  - p_T<2.5 GeV/c
    - Dominated by charm
- J/ψ additionally sensitive to $c\bar{c}$ breakup by the nuclear matter:
  - Longer crossing time in nucleus?
  - Higher co-mover density at backward rapidity?

We have a baseline!

- p+p and d+Au
  - Understood in terms of measurements
  - Not understood in terms of physics
  - Supposed to be “Cold-nuclear-matter” only
    - i.e. no “Hot-nuclear” effects
- More recent studies of bulk properties in d+Au indicate “medium-type” collective effects
  - Adds more questions than answers...

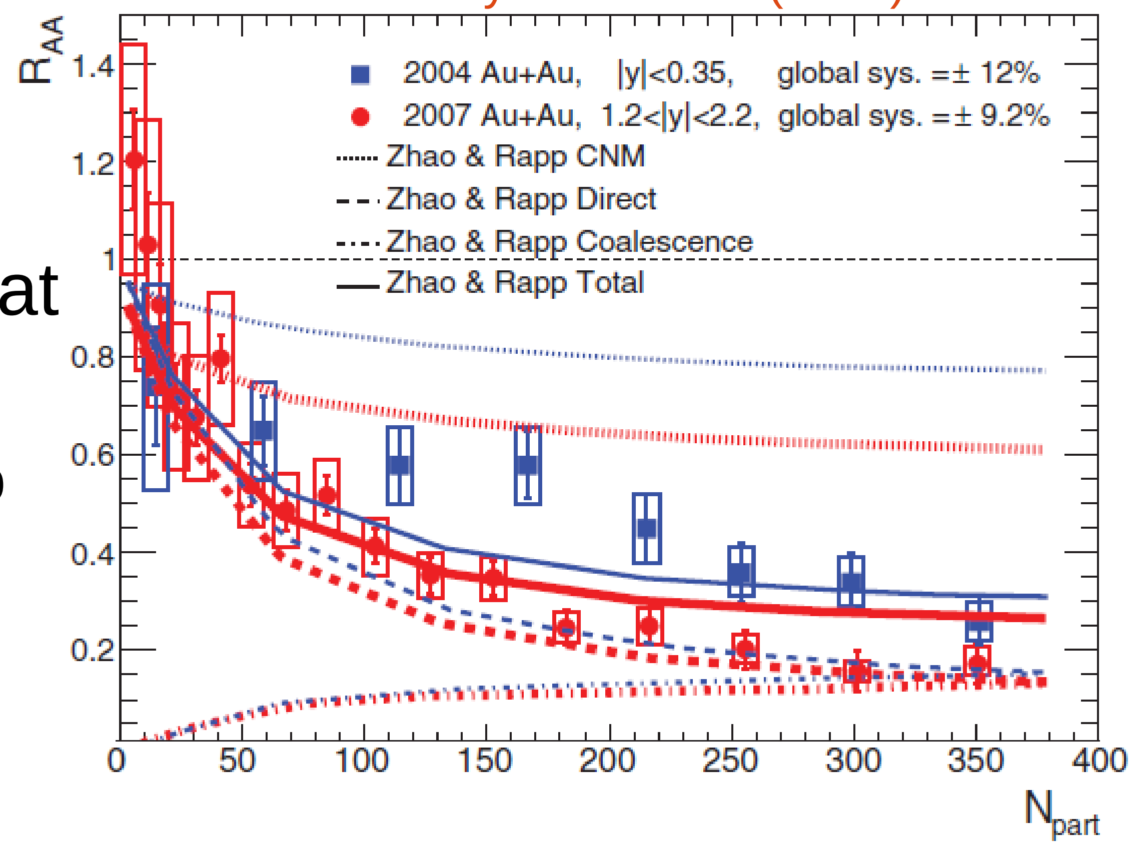
arXiv:1404.7461



J/ψ in Au+Au collisions

- Au+Au datasets: 200 GeV (62.4, 39.6 GeV not shown)

Phys. Rev. C84 (2011) 054912



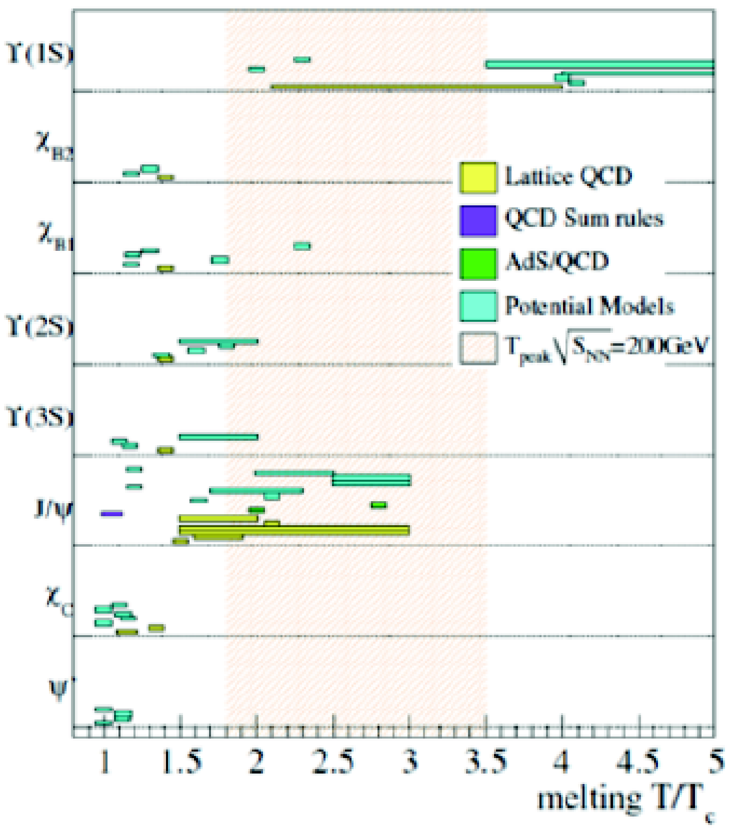
- Study R_{AA}:
  - Distinct suppression at different rapidities
    - Forward compared to central rapidities
  - Models:
    - Can reproduced data
    - Need a complex admixture of effects

Need to increase variety of collisions-systems to systematically vary the magnitude of physics effects

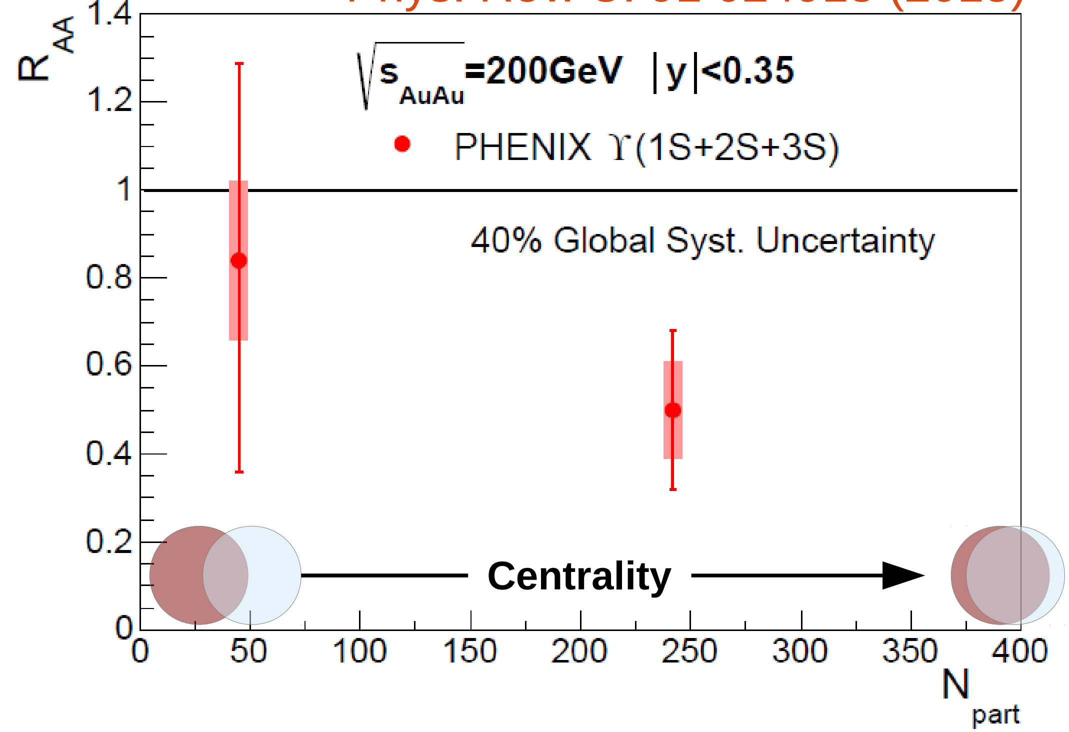
Υ family in Au+Au collisions

“Melting Temperature”
“Color Screening”

$$R_{AA} = \frac{1}{N_{coll}} \frac{Y(AA)}{Y(pp)}$$



Phys. Rev. C. 91 024913 (2015)



- Υ(1S+2S+3S) suppression in central collisions

Υ family in Au+Au collisions

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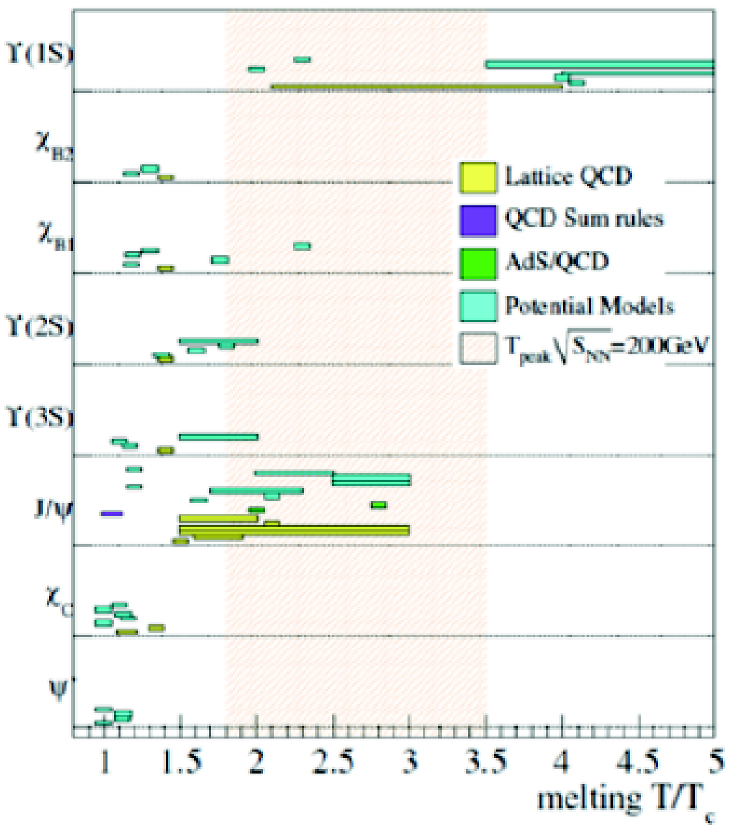
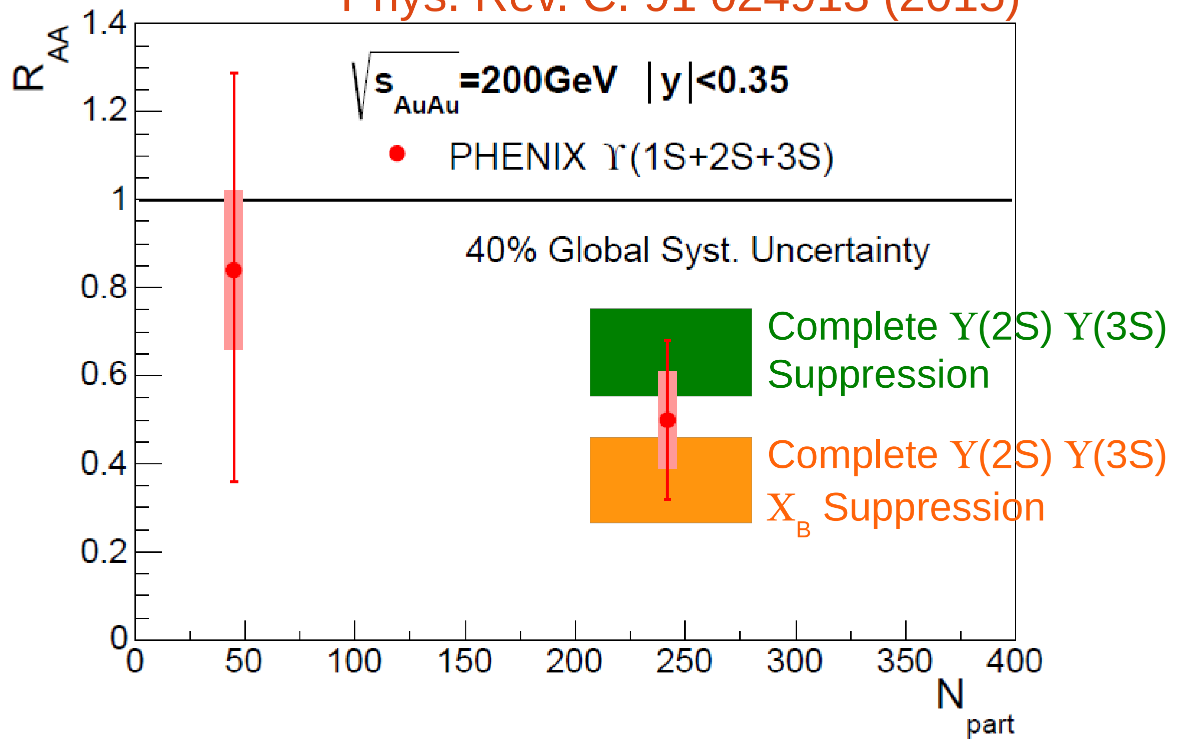


Phys. Rev. C. 91 024913 (2015)



- Υ(1S+2S+3S) suppression in central collisions
  - Consistent with complete suppression of Υ(2S+3S)

Υ family in Au+Au collisions

Phys. Rev. C. 91 024913 (2015)

"Melting Temperature"
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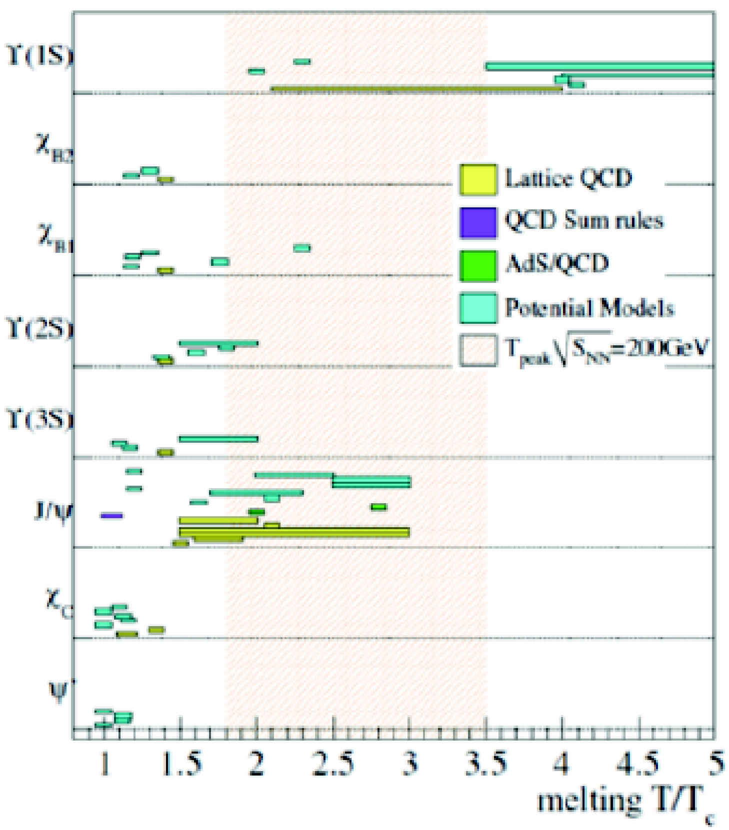
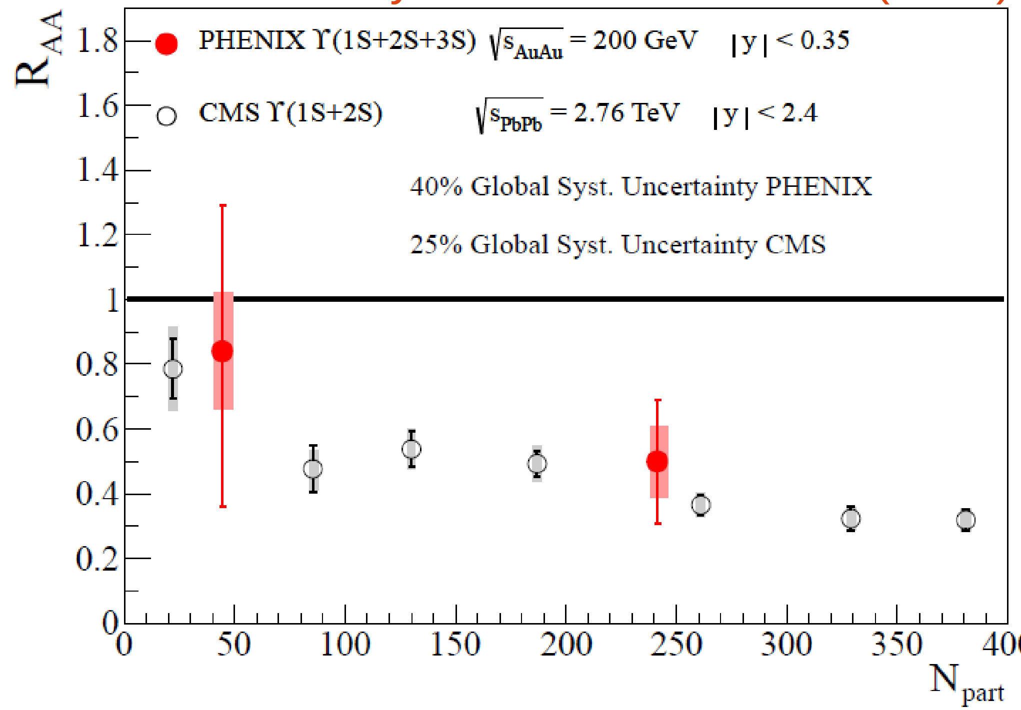
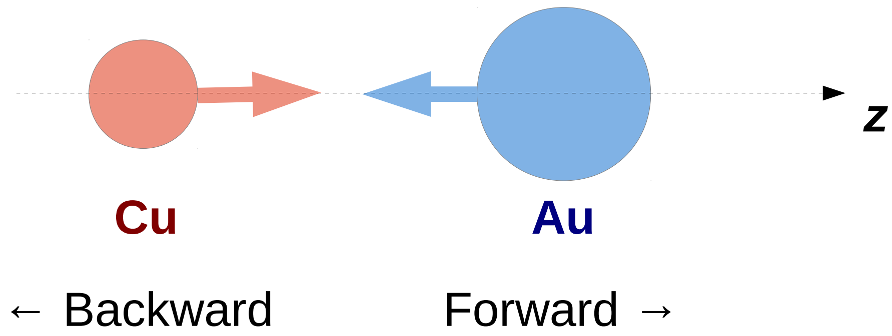
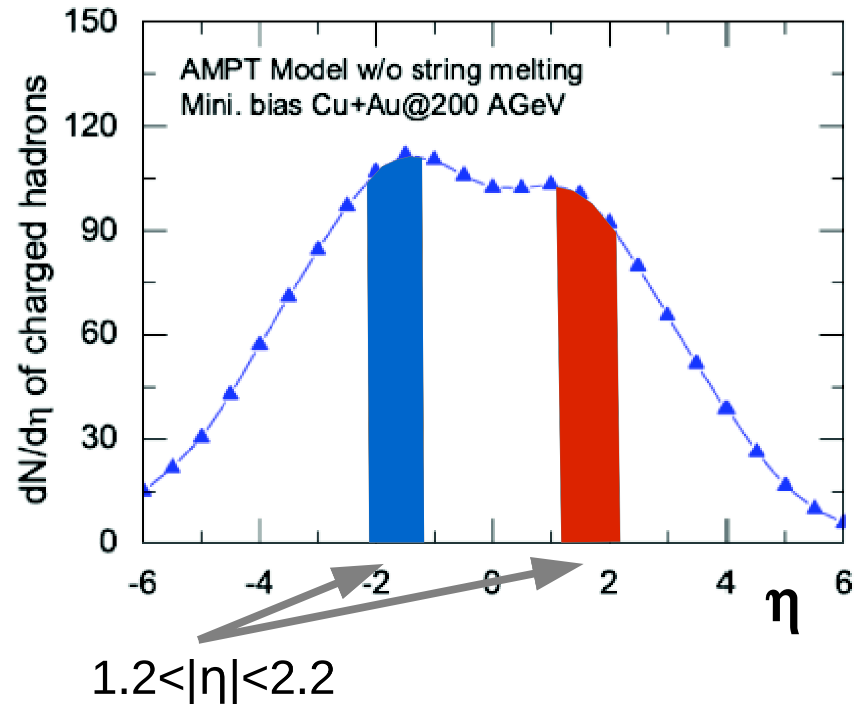




- Υ(1S+2S+3S) suppression in central collisions
  - Consistent with complete suppression of Υ(2S+3S)
  - Consistent with R_{AA} observed at LHC (CMS)

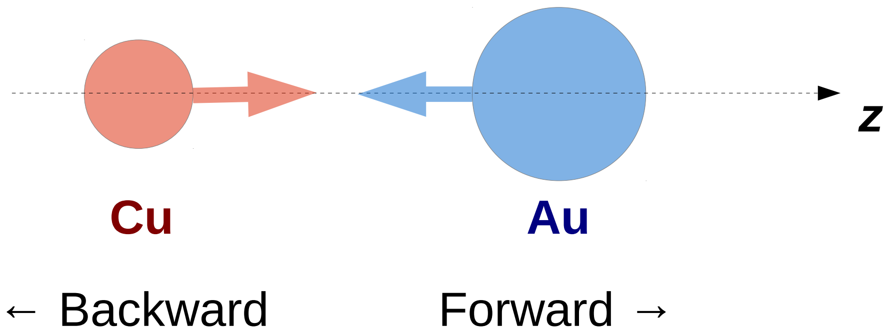
Collision System: Cu+Au

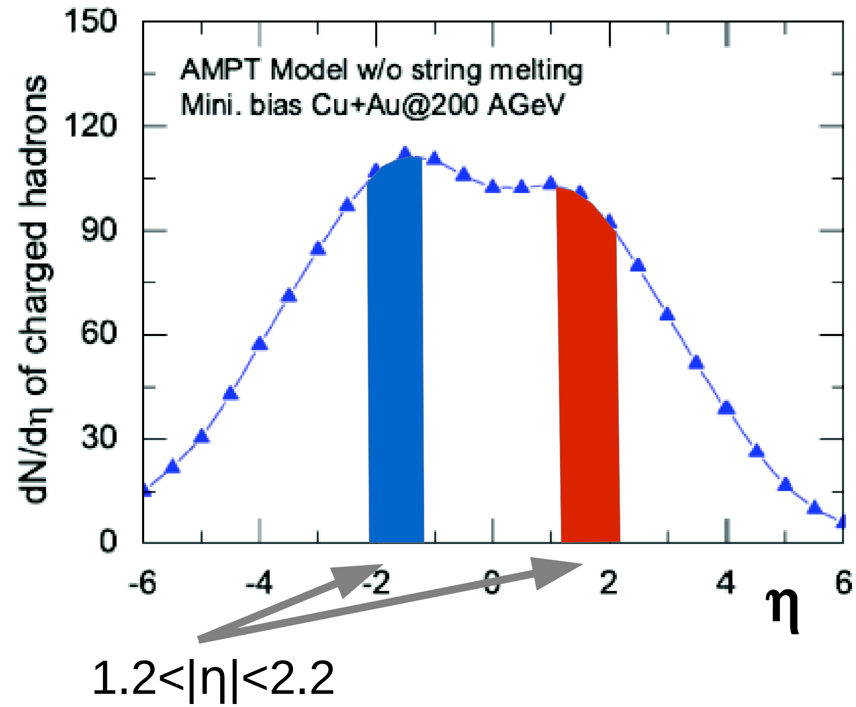




- Forward/Backward asymmetry
  - Along the beam axes
  - Initial asymmetry → asymmetric distribution of final particle density is expected
- J/ψ in Cu+Au
  - Asymmetric CNM effects
  - HNM effects – possibly asymmetric?

Collision System: Cu+Au





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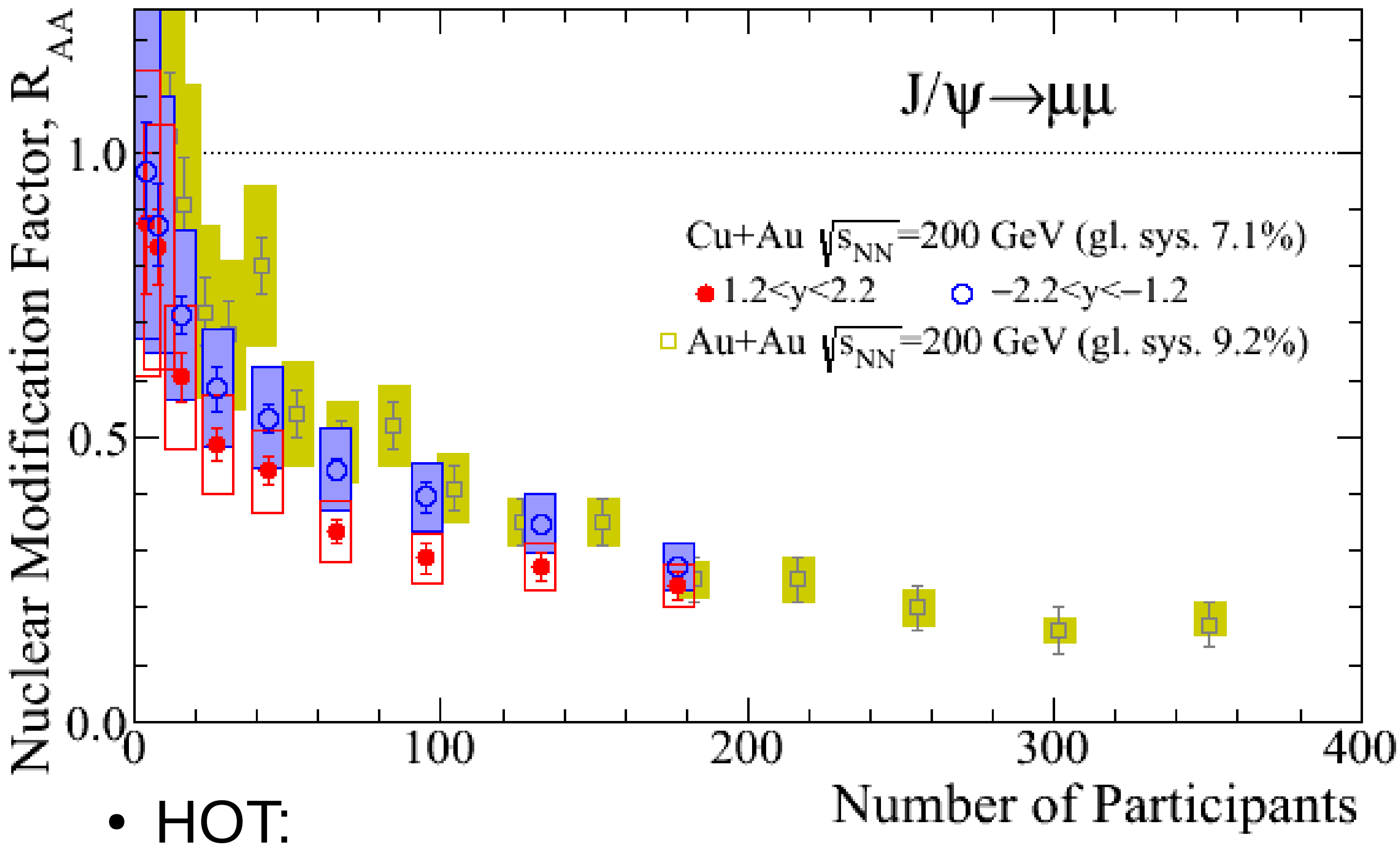
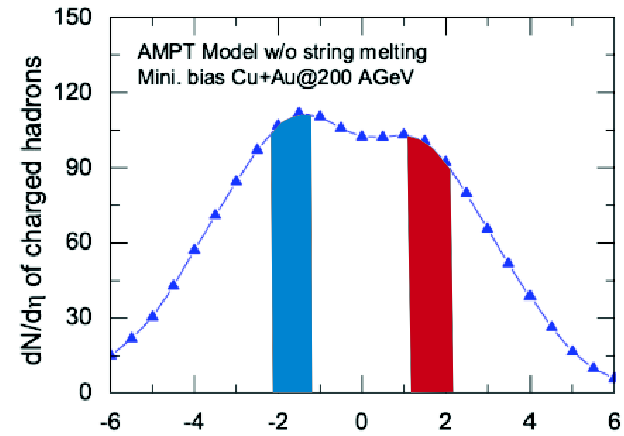
Probing Cold and Hot

Phys. Rev. C 90 064908 (2014)

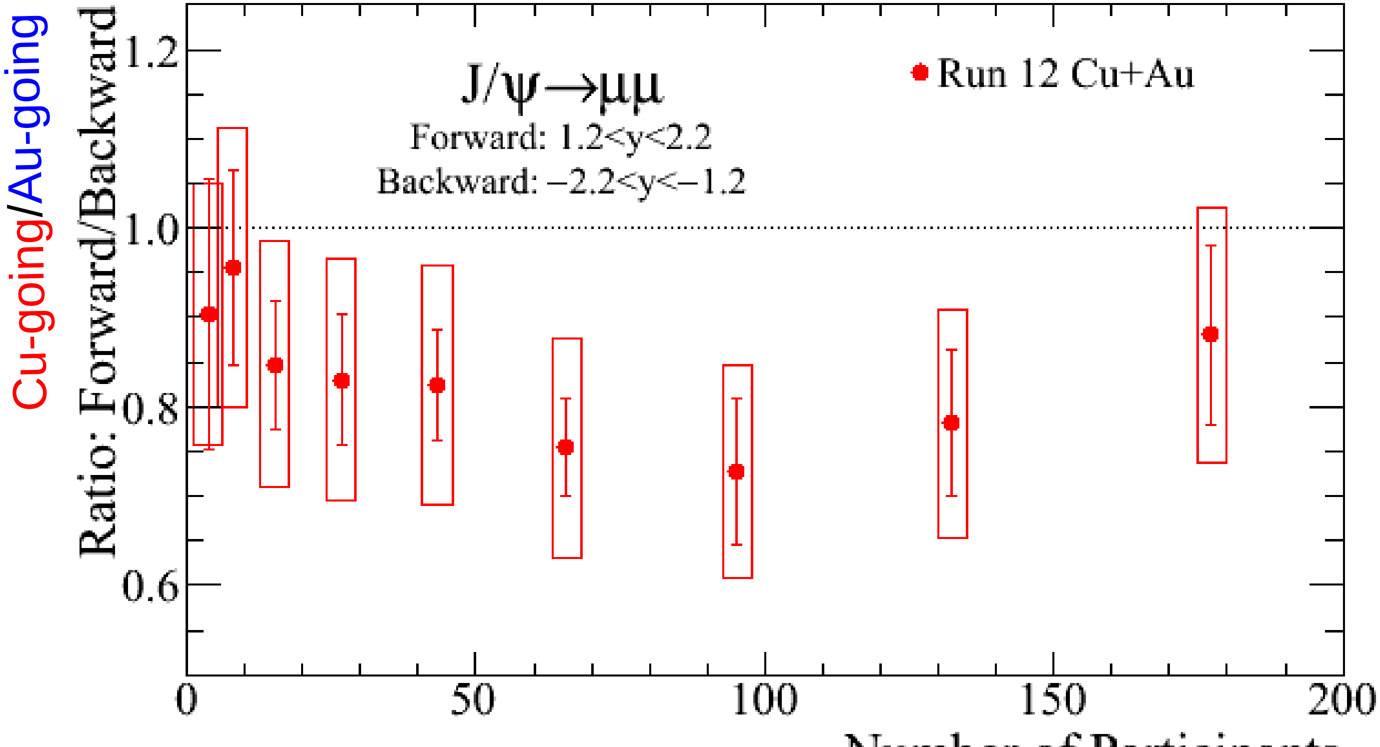


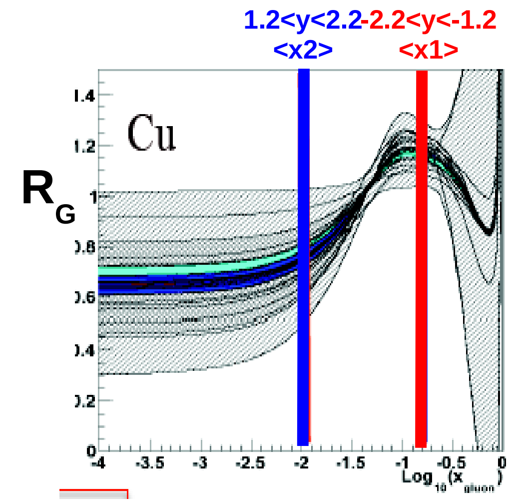


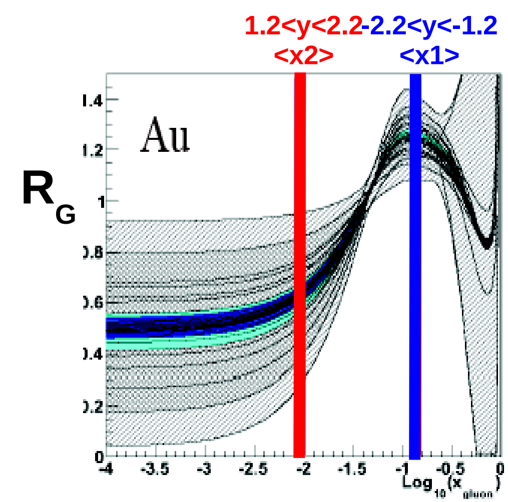
- HOT:
  - Similar suppression in Cu+Au compared to Au+Au (Au-going)
- COLD:
  - Forward (Cu-going) more suppressed than Backward

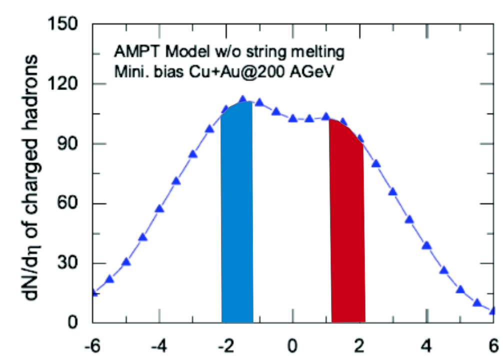
Disentangle Cold

Phys. Rev. C 90 064908 (2014)









CNM effects → asymmetric in rapidity

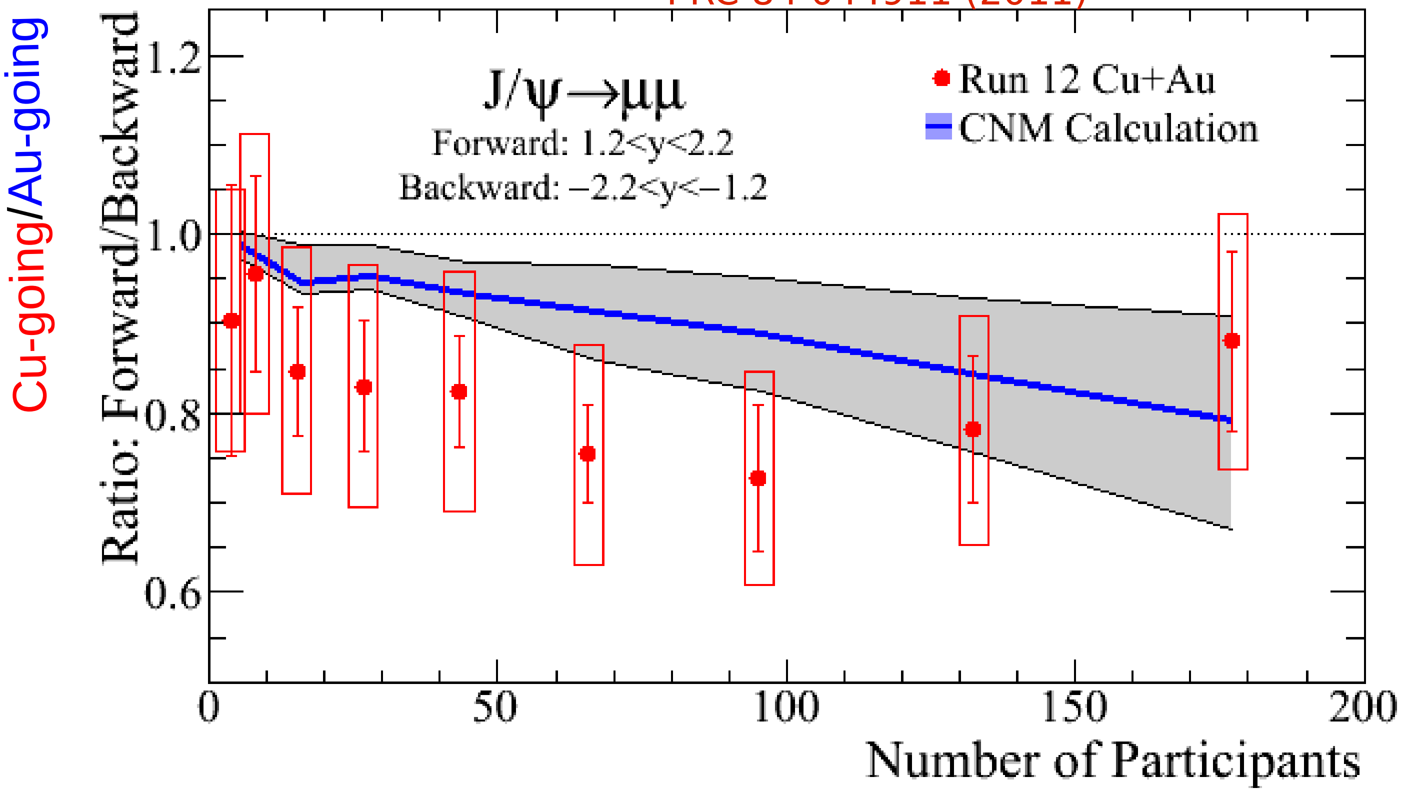
Forward CNM effects (Cu-going)

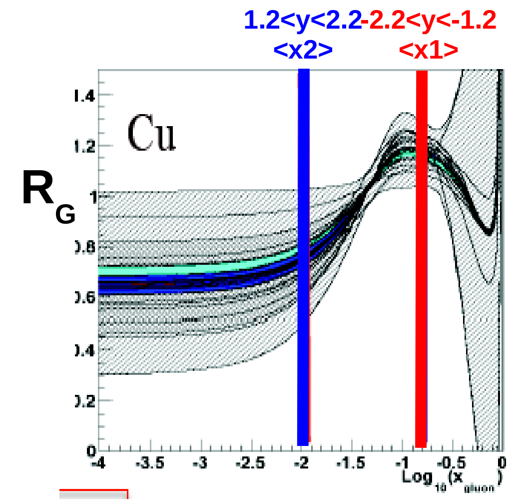
- gluon modification – J/ψ probes gluons at high-x in Cu, low -x in Au
- dynamical processes
  - J/ψ short crossing proper time in Au → probes Eloss
  - long crossing proper time in Cu → $c\bar{c}$ breakup by nucleon collisions

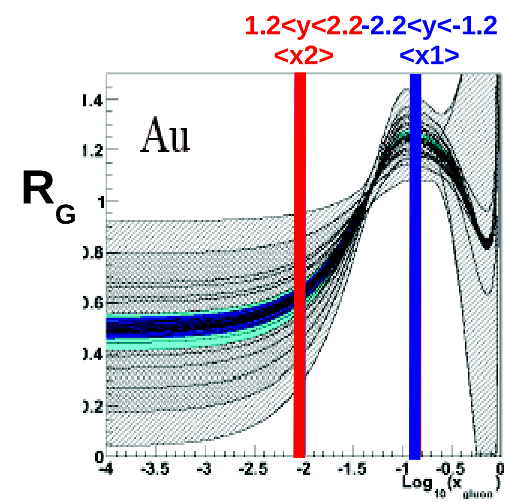
Backward (Au-going) → Reversed CNM effects

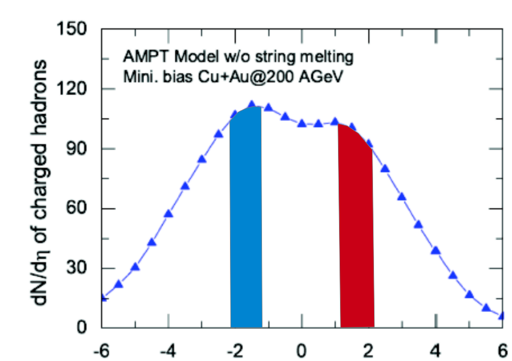
Disentangle Cold

J.Nagle, A.Frawley, L.Levy, M.Wysocki,
PRC 84 044911 (2011)





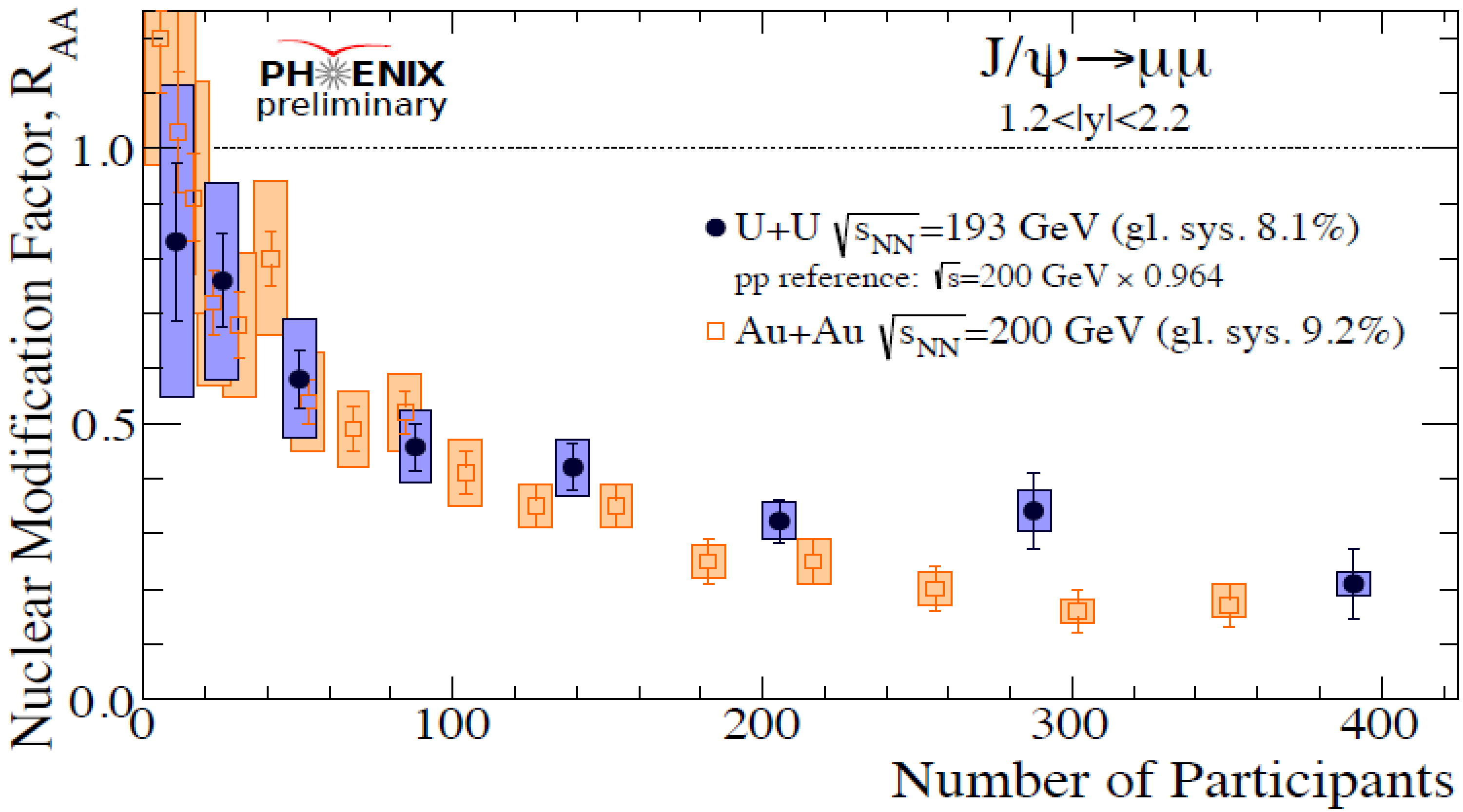




CNM effects → asymmetric in rapidity

- Shadowing effect comparable with data
- Not considering other mechanisms, e.g color screening (will increase the ratio)

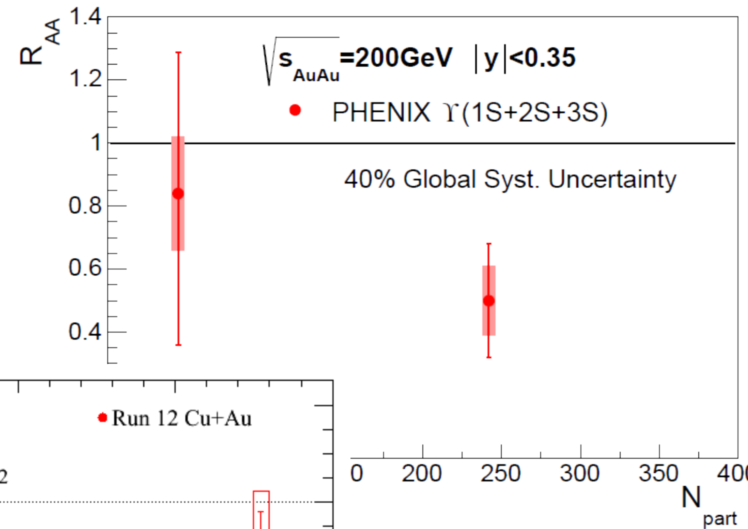
More Dense System:
U+U collisions



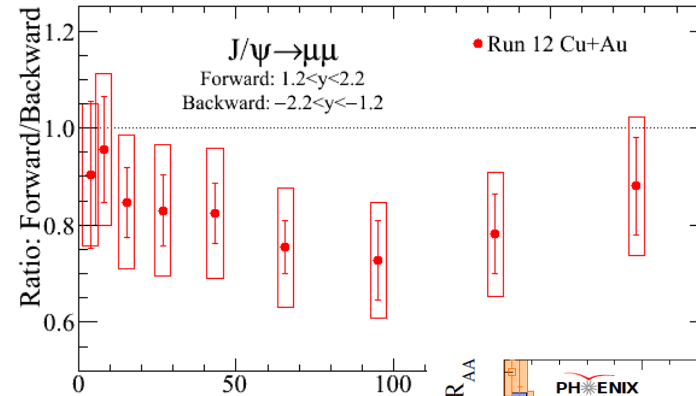
Observed weaker suppression in central collisions in U+U?
Higher coalescence? (PRC 84, 054907 (2011))

Manuscript currently under collaboration review.

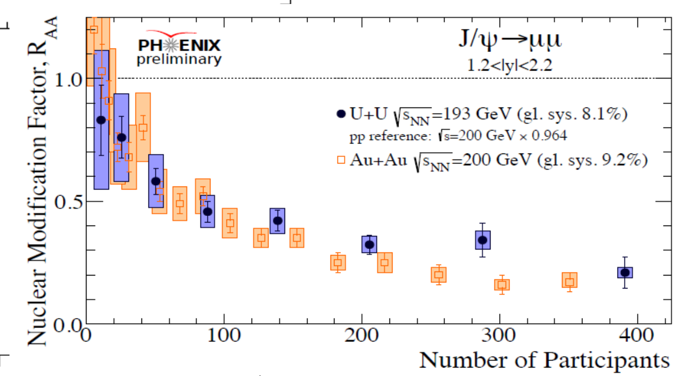
~~Conclusions~~ Story thus far...



- PHENIX continues to contribute to the World's Quarkonia data
  - Providing measurements at various energies and in diverse collision systems



- Au+Au, Cu+Au, U+U
  - J/ψ and ϒ are found to be suppressed in central collisions
  - Stronger suppressed at forward rapidity in Cu+Au collisions
  - U+U similar suppression to Au+Au
    - But more in the details ...



- d+Au
  - ψ' suppression dependent on N_{coll}