Recent Results in Heavy Flavor From PHENIX

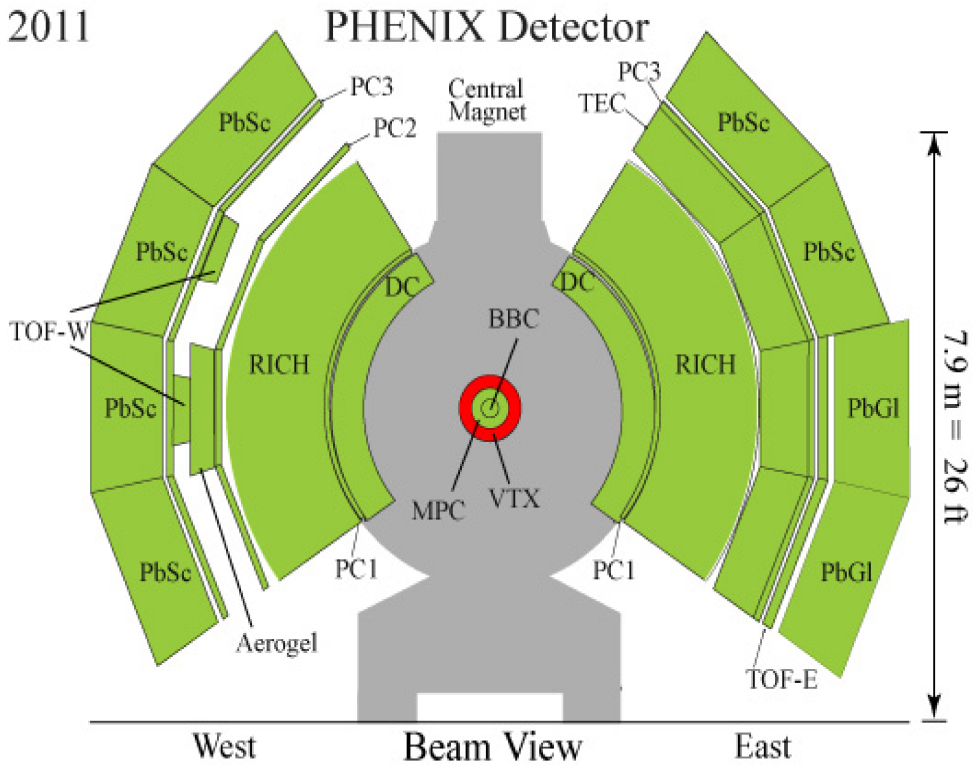
Richard Hollis
UC Riverside
(On behalf of the PHENIX collaboration)

Outline

- PHENIX Detector
- Methods
- Results
- Summary

ICHEP VALENCIA 2014
37th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS
2-9-JULY-2014-VALENCIA

PHENIX Detector

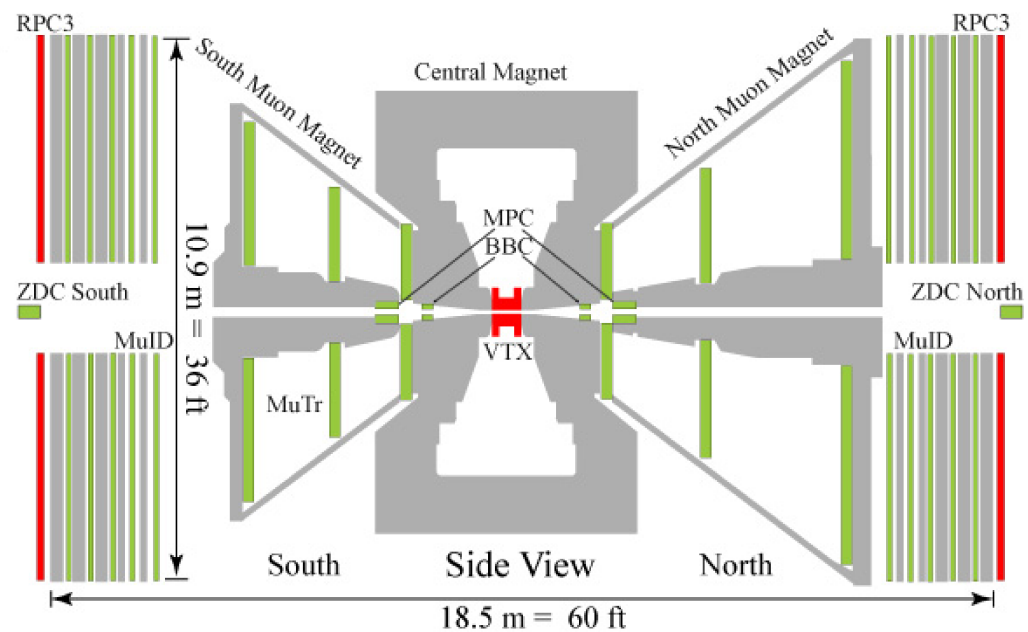


Central arm: Focus on electrons
- EM Calorimeter (e^+/e^-)
- VTX – flavor separation (2011+ Upgrade)

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

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

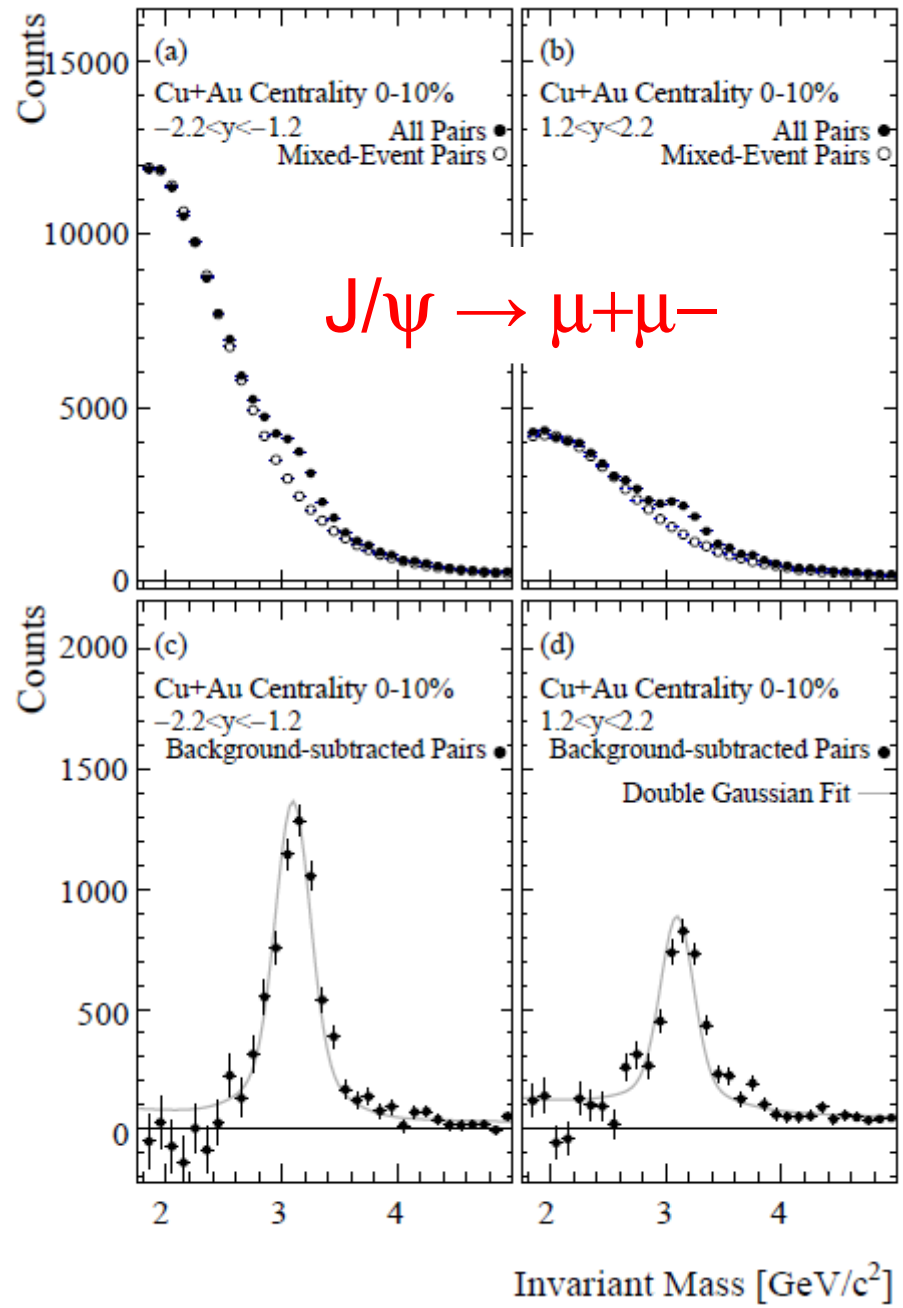
Measure:
- Single muons
- J/ψ, ψ', $\Upsilon \rightarrow \mu^+ + \mu^-$



Measuring Heavy Flavor and Quarkonia in PHENIX

arXiv:1404.1873

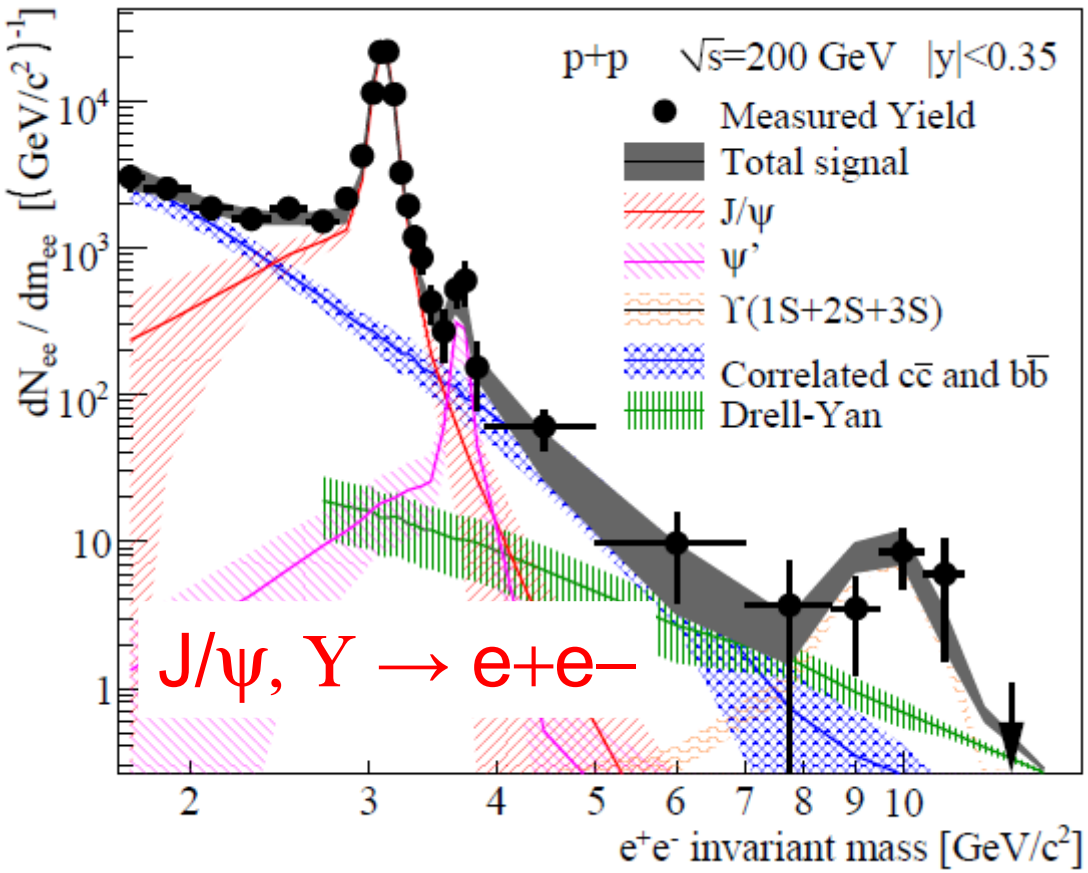
- Multiple methods:
  - Direct – Mass Peak
    - J/ψ



Measuring Heavy Flavor and Quarkonia in PHENIX

- Multiple methods:
  - Direct – Mass Peak
    - J/ψ
    - ψ', Υ

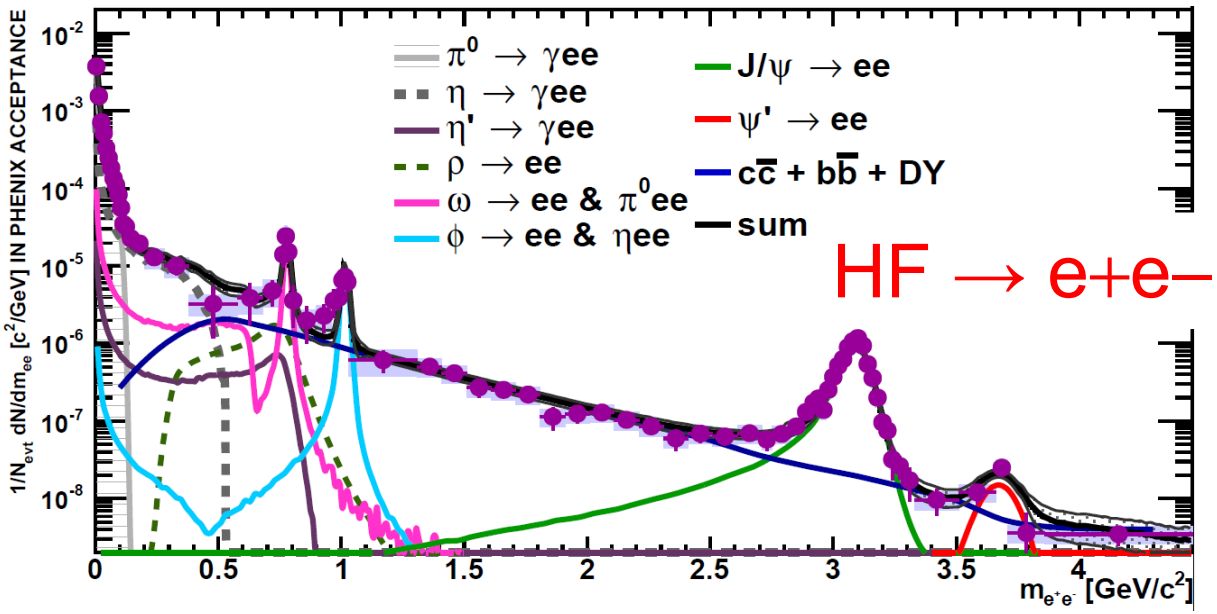
arXiv:1404.2246



Measuring Heavy Flavor and Quarkonia in PHENIX

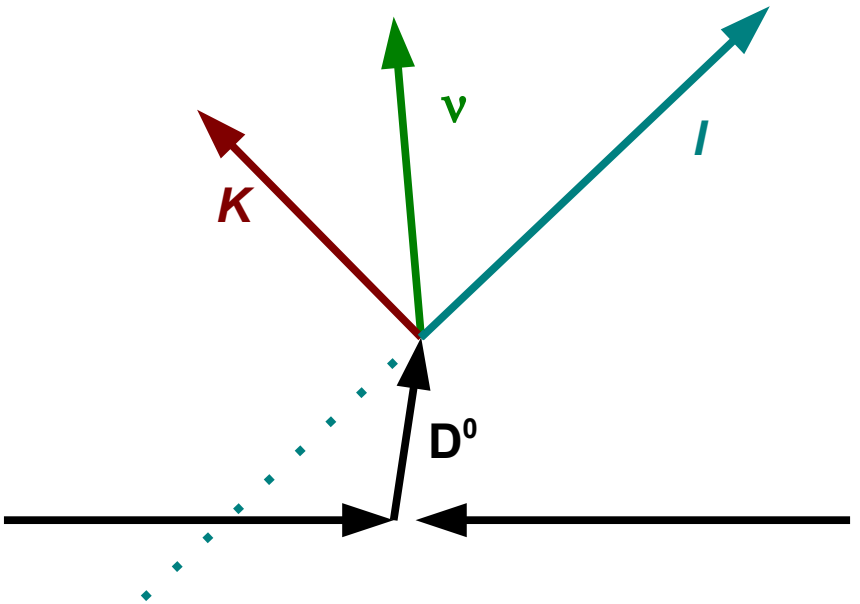
- Multiple methods:
  - Direct – Mass Peak
    - J/ψ
    - ψ', Υ
  - Indirect – Cocktail, converter
    - HF e,μ

arXiv:1405.4004



Measuring Heavy Flavor and Quarkonia in PHENIX

- Multiple methods:
  - Direct – Mass Peak
    - J/ψ
    - ψ', Υ
  - Indirect – Cocktail, converter
    - HF e,μ
  - Tagged – Displaced Vertex
    - c,b



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?

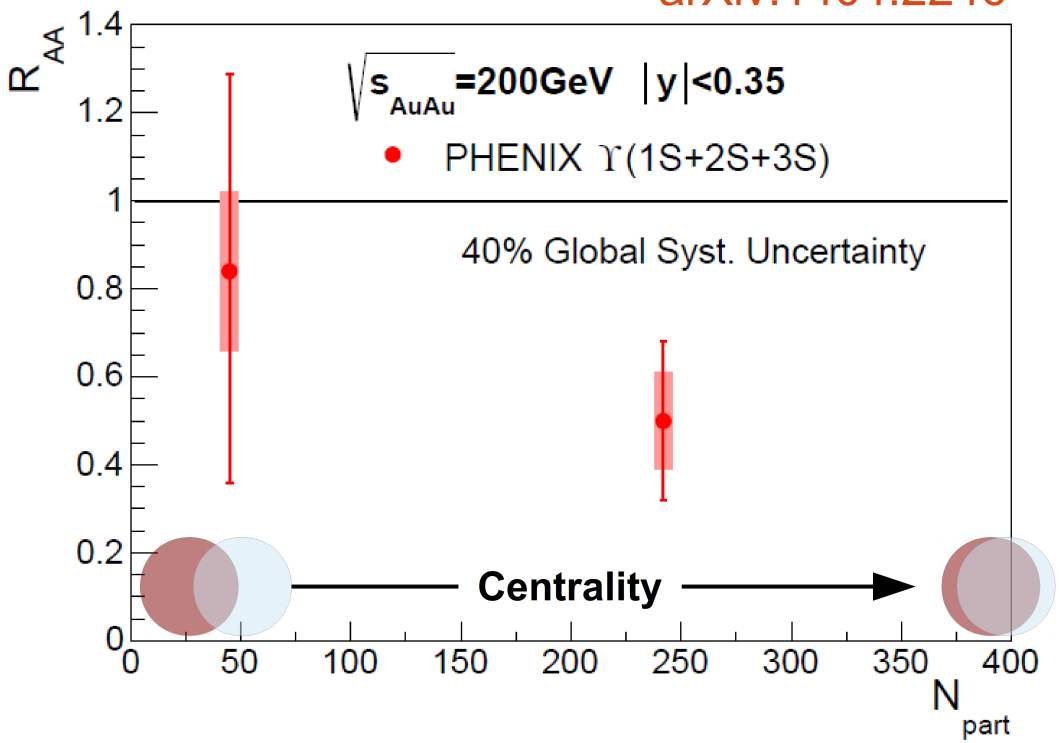
Each parameter probes different admixtures of nuclear modification

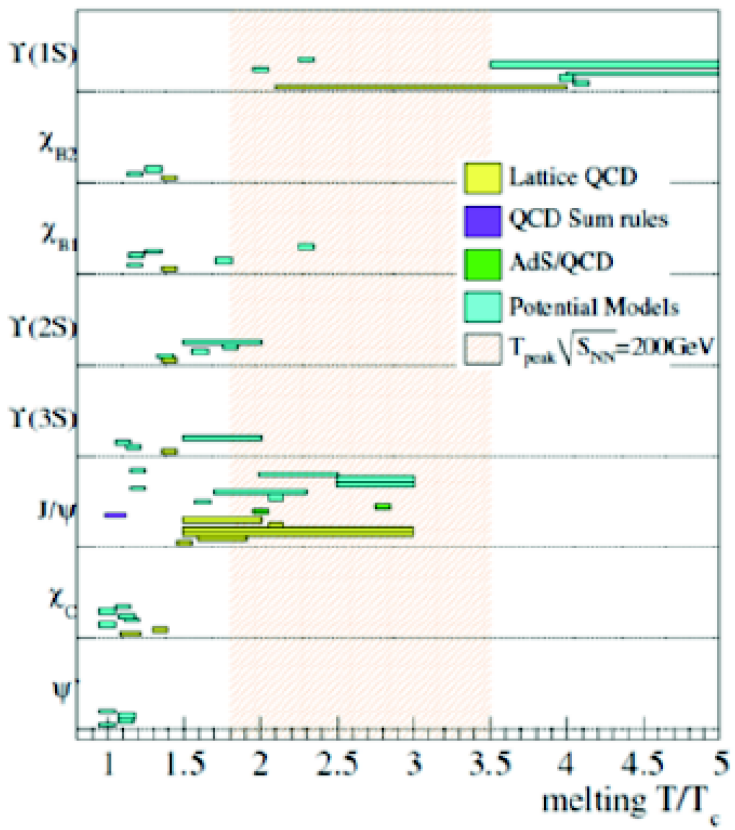
Particle Species: Υ family

arXiv:1404.2246

"Melting Temperature"
"Color Screening"

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



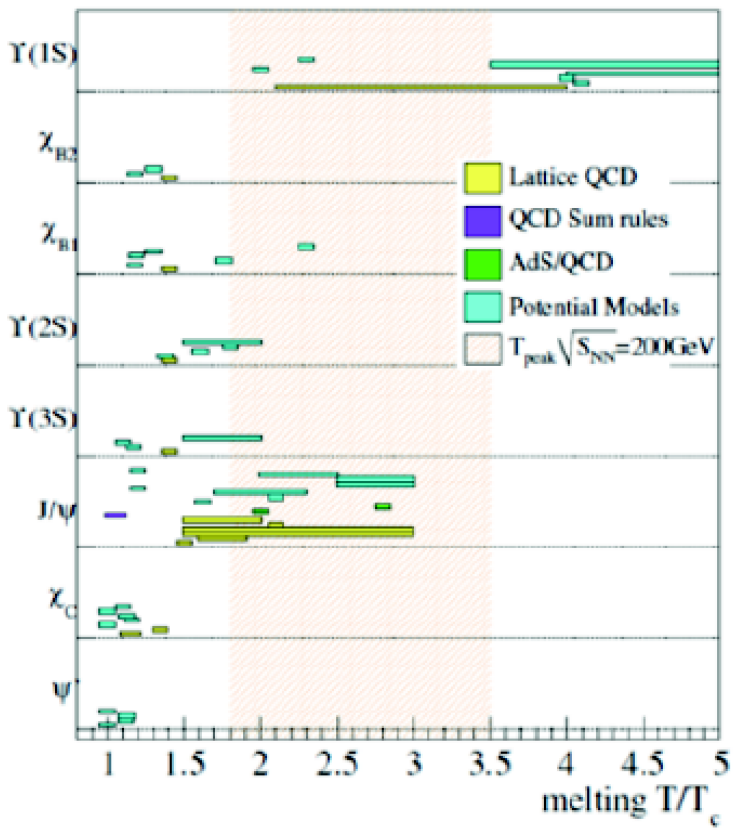


- Υ(1S+2S+3S) suppression in central collisions

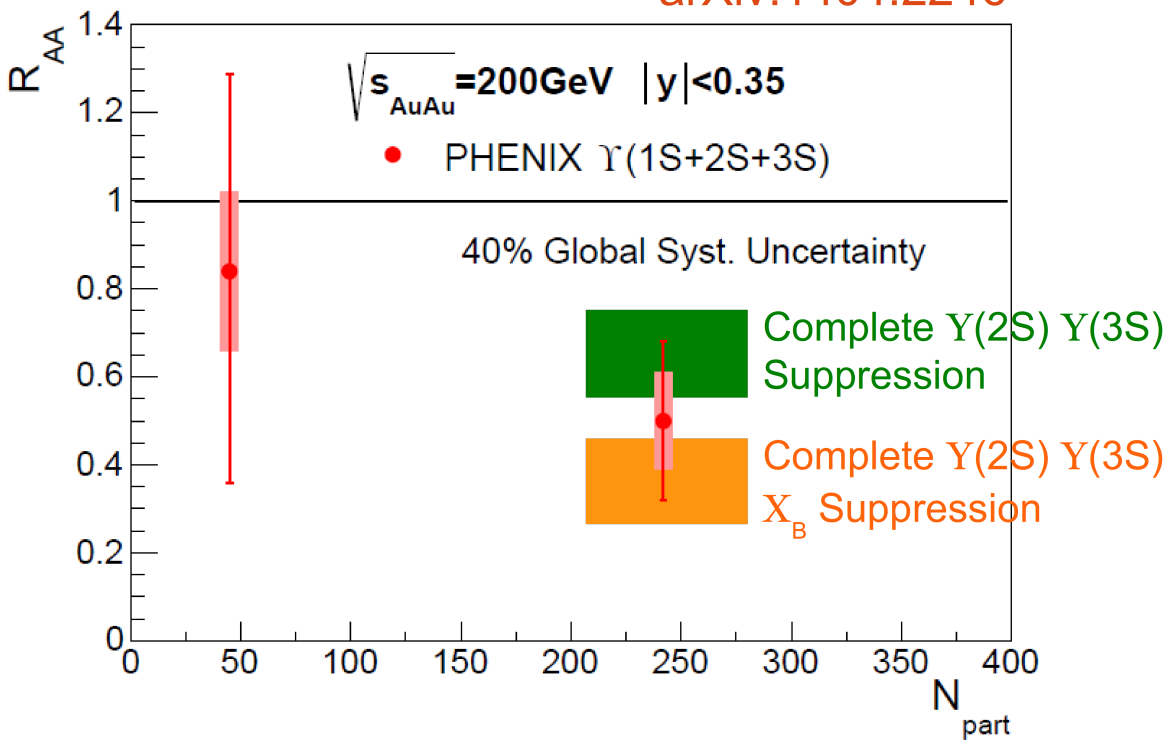
Particle Species: Υ family

"Melting Temperature"
"Color Screening"

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



arXiv:1404.2246



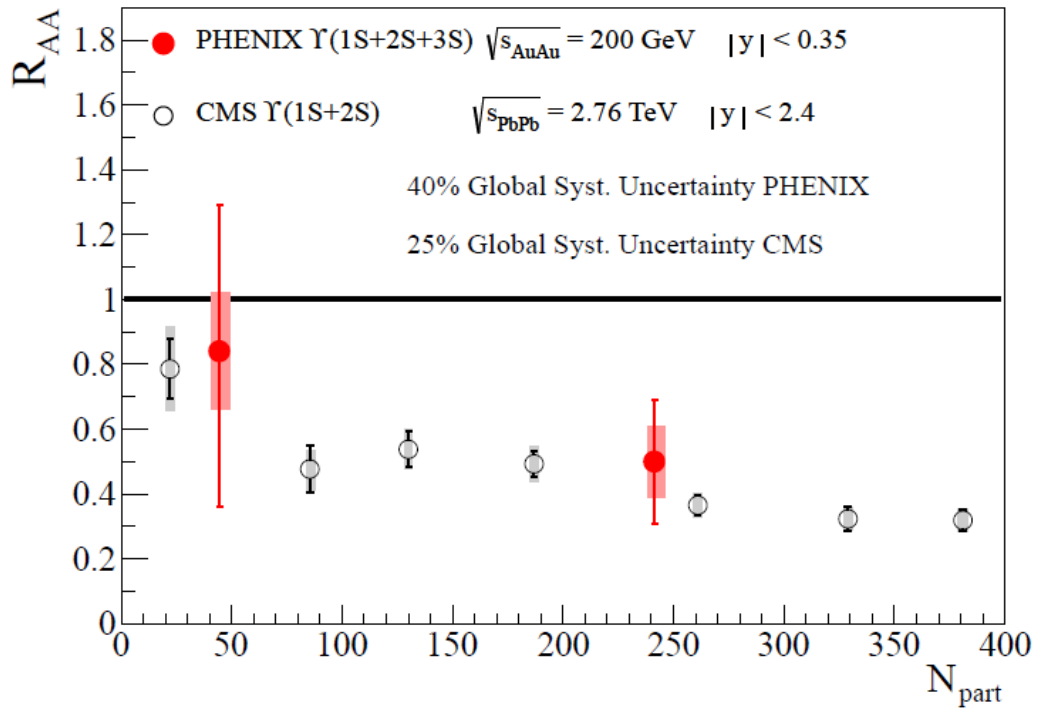
- Υ(1S+2S+3S) suppression in central collisions
  - Consistent with complete suppression of Υ(2S+3S)

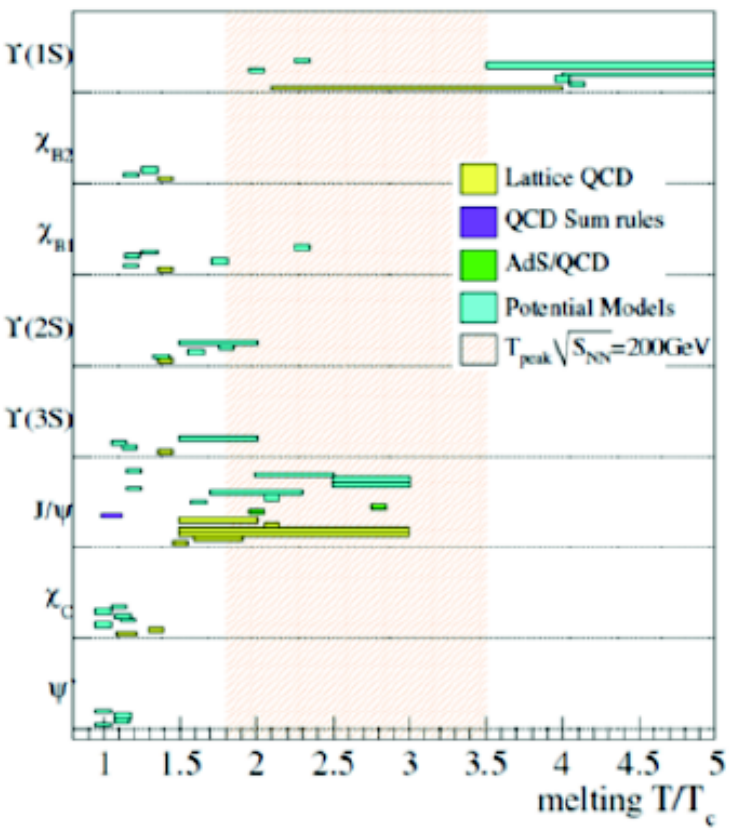
Particle Species: Υ family

arXiv:1404.2246

"Melting Temperature"
"Color Screening"

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





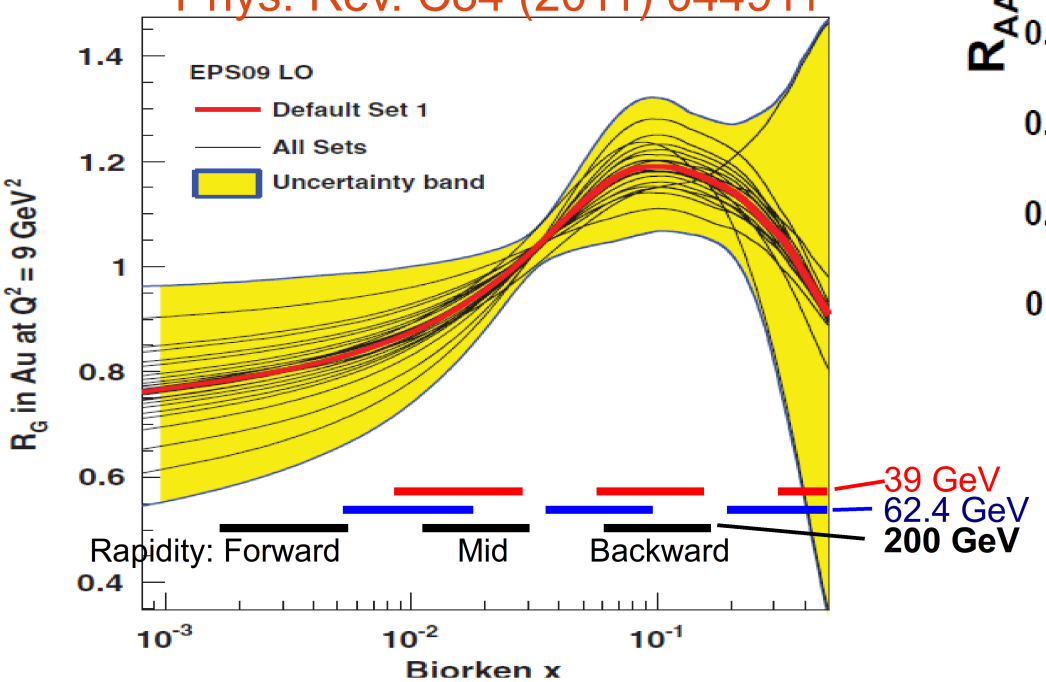
- Υ(1S+2S+3S) suppression in central collisions
  - Consistent with complete suppression of Υ(2S+3S)
  - Consistent with R_{AA} observed at LHC (CMS)

Particle Species: J/ψ

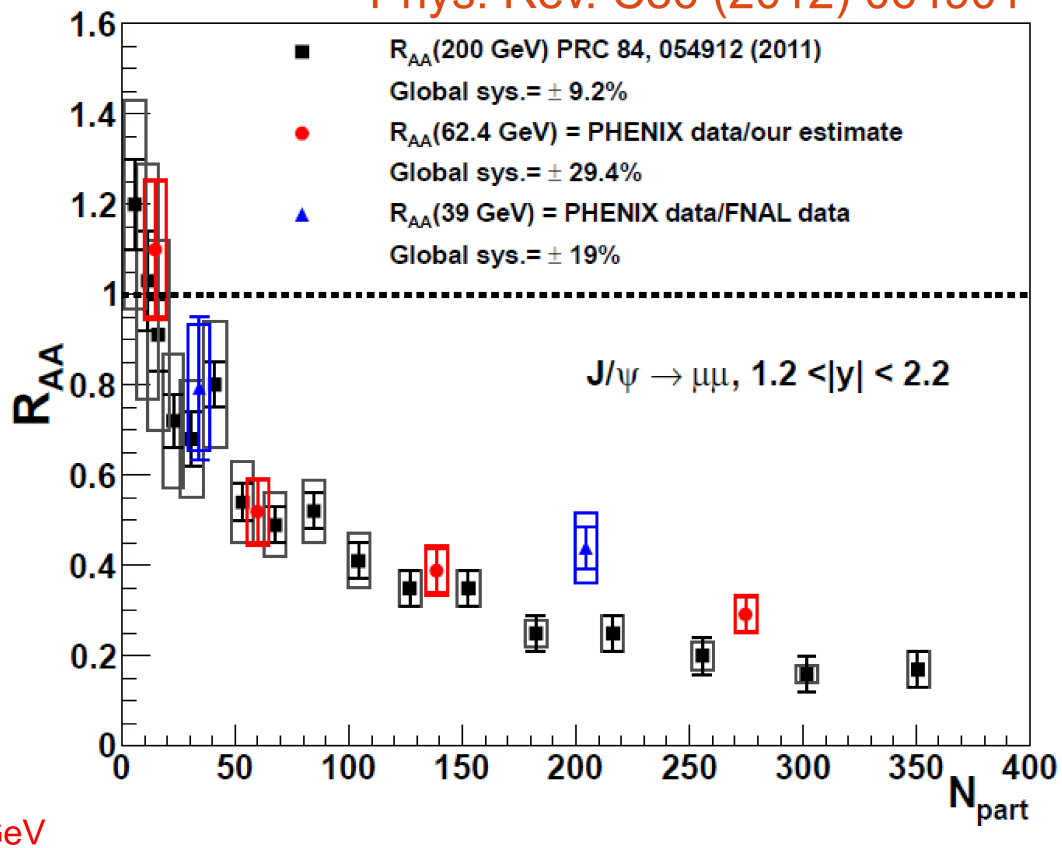
- Larger cross-section
  → Larger statistics
  → probe in more detail

- Study RAA:
  - Similar suppression at different collision energies
    - Forward rapidity

Phys. Rev. C84 (2011) 044911



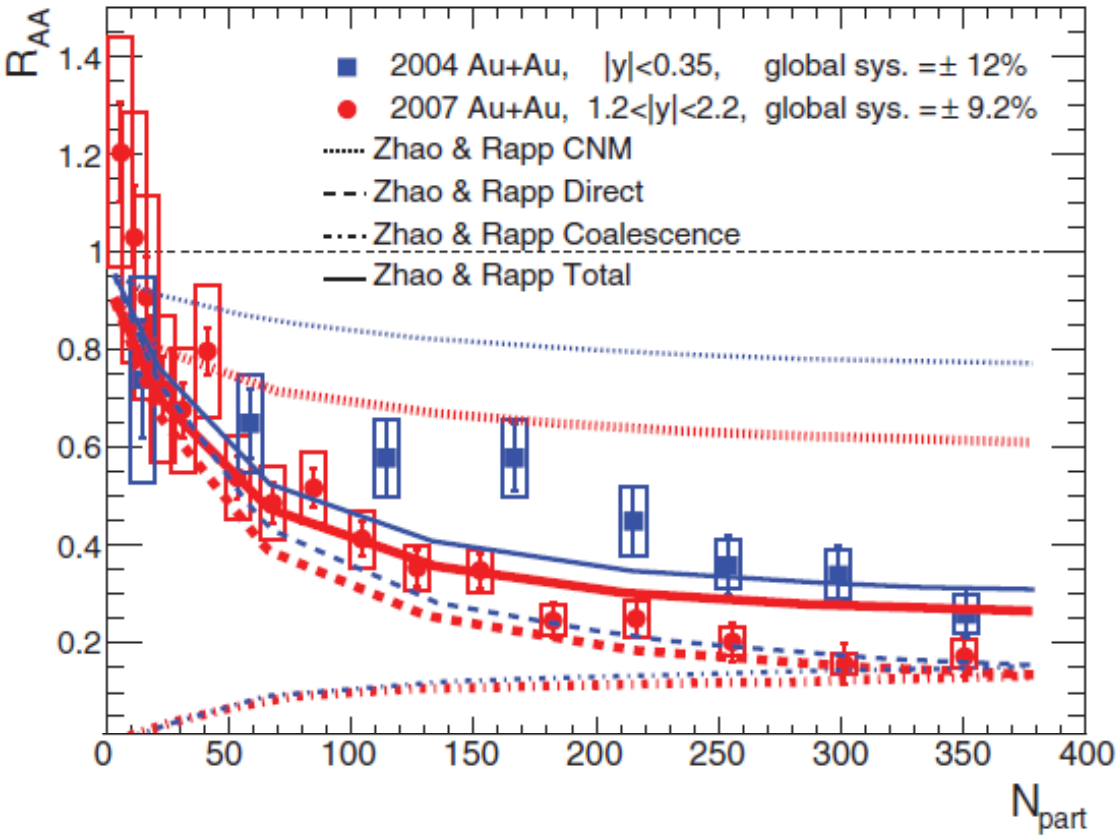
Phys. Rev. C86 (2012) 064901



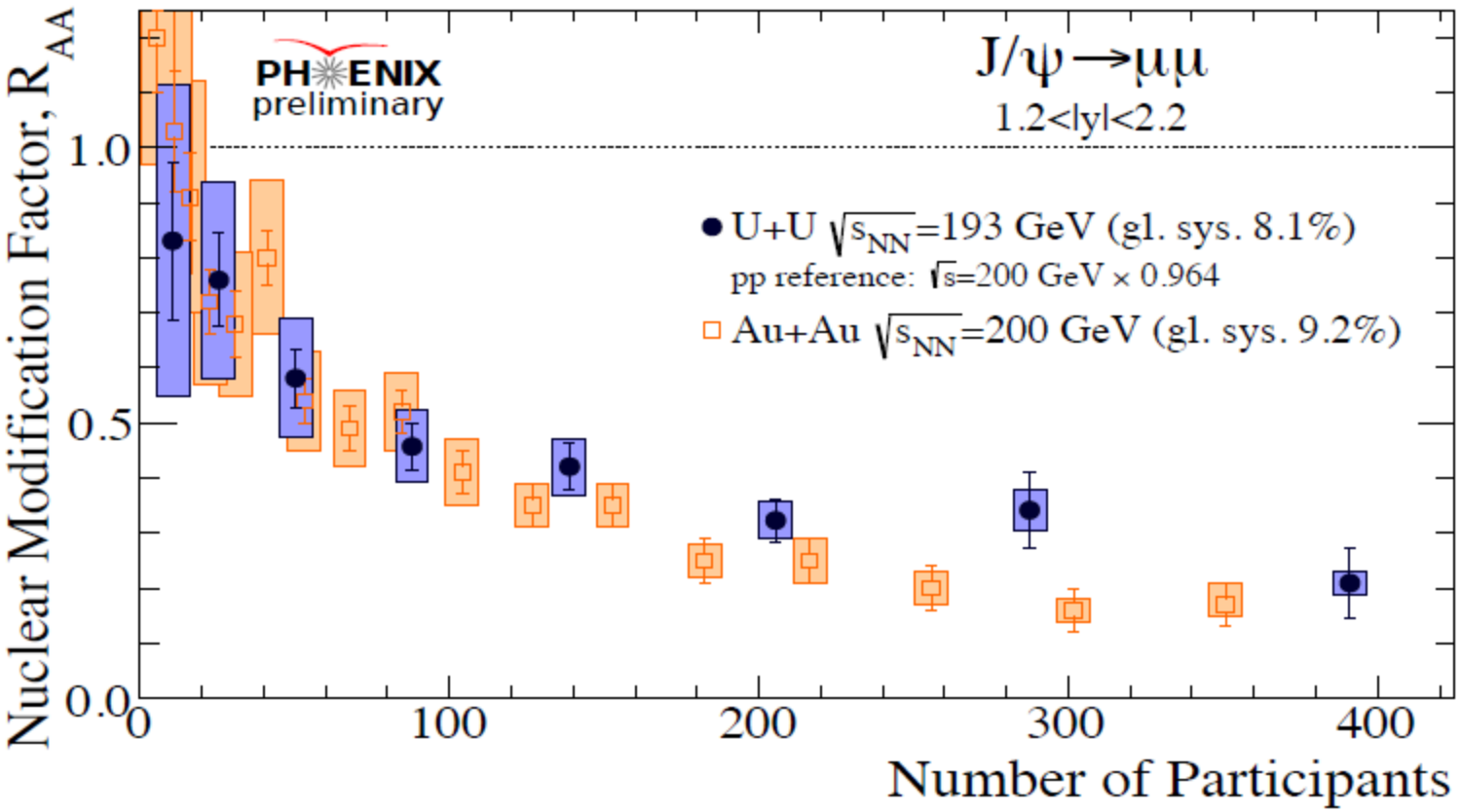
Particle Species: J/ψ

- Larger cross-section
  → Larger statistics
  → probe in more detail
- Study RAA:
  - Similar suppression at different collision energies
    - Forward rapidity

Phys. Rev. C84 (2011) 054912

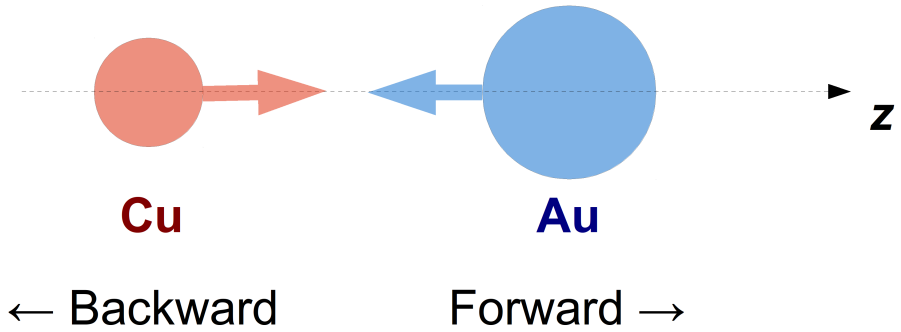


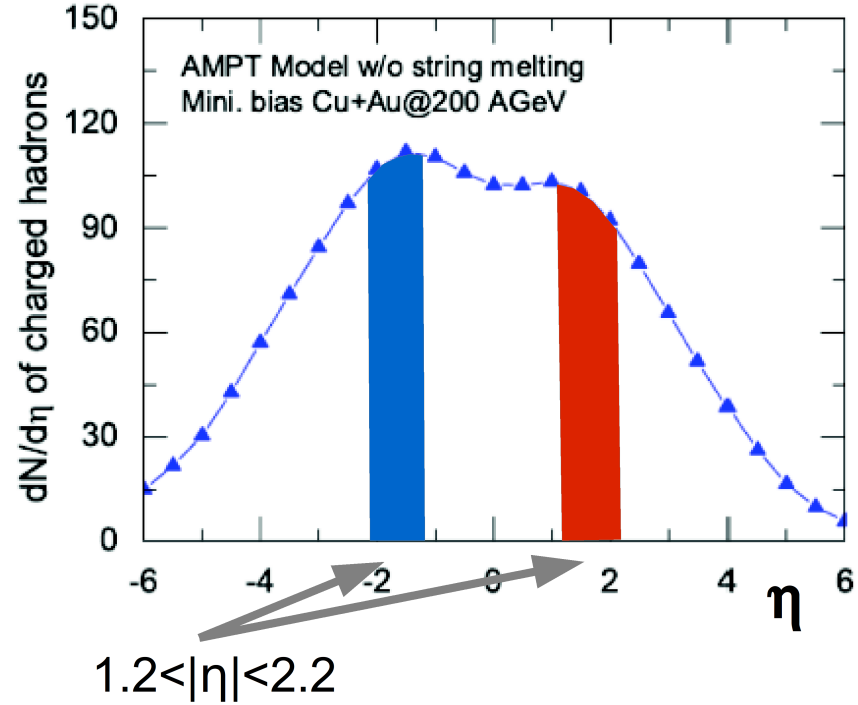
More Dense System: U+U collisions



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

Collision System: Cu+Au

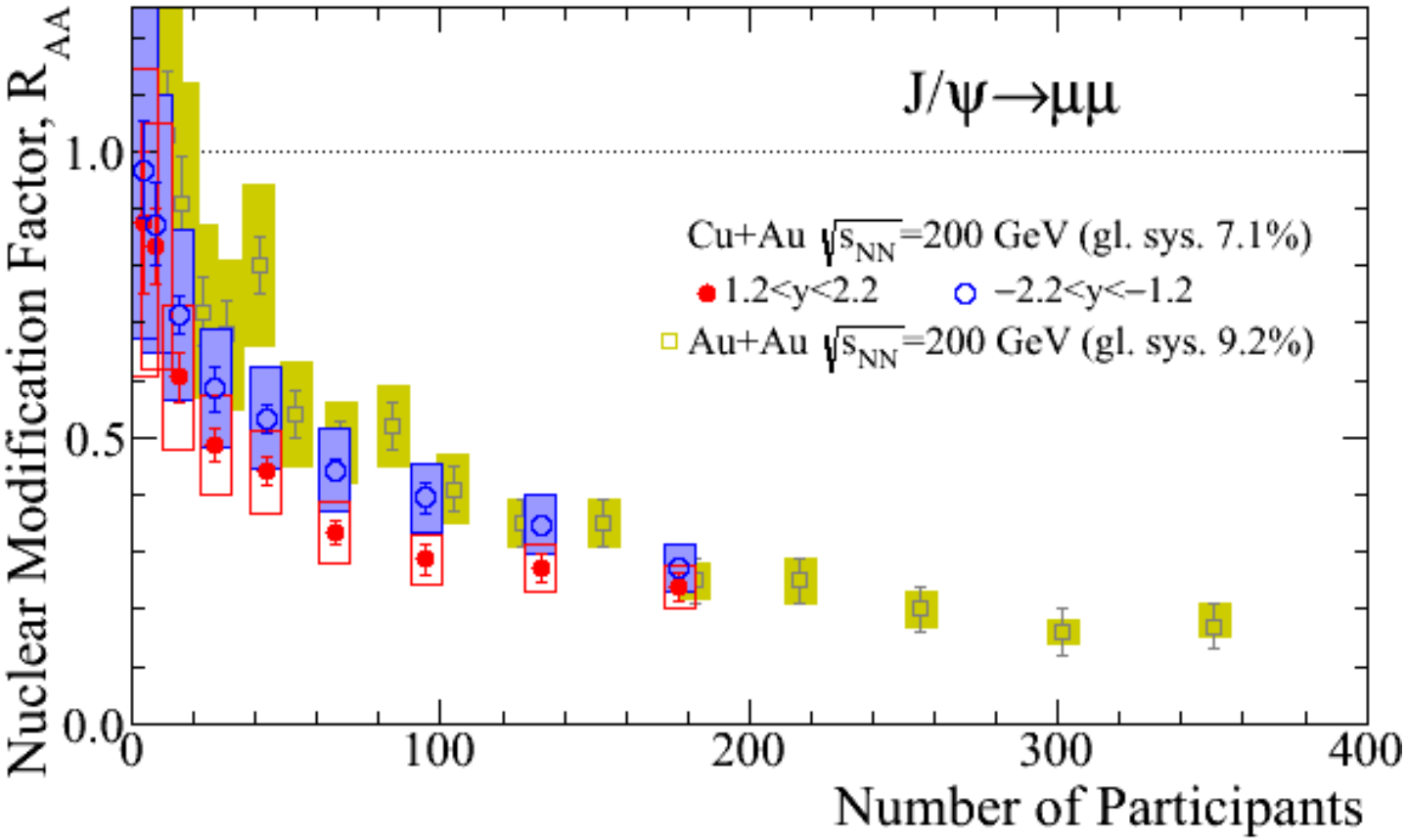


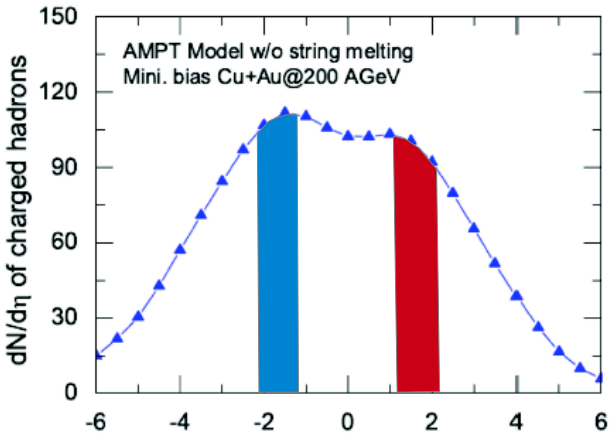


- Forward/Backward asymmetry
  - Along the beam axes
  - Initial asymmetry → asymmetric distribution of final particle density is expected
- J/ψ in Cu+Au
  - Asymmetric CNM effects
  - HNM effects – possibly asymmetric?

Probing Cold and Hot

arXiv:1404.1873

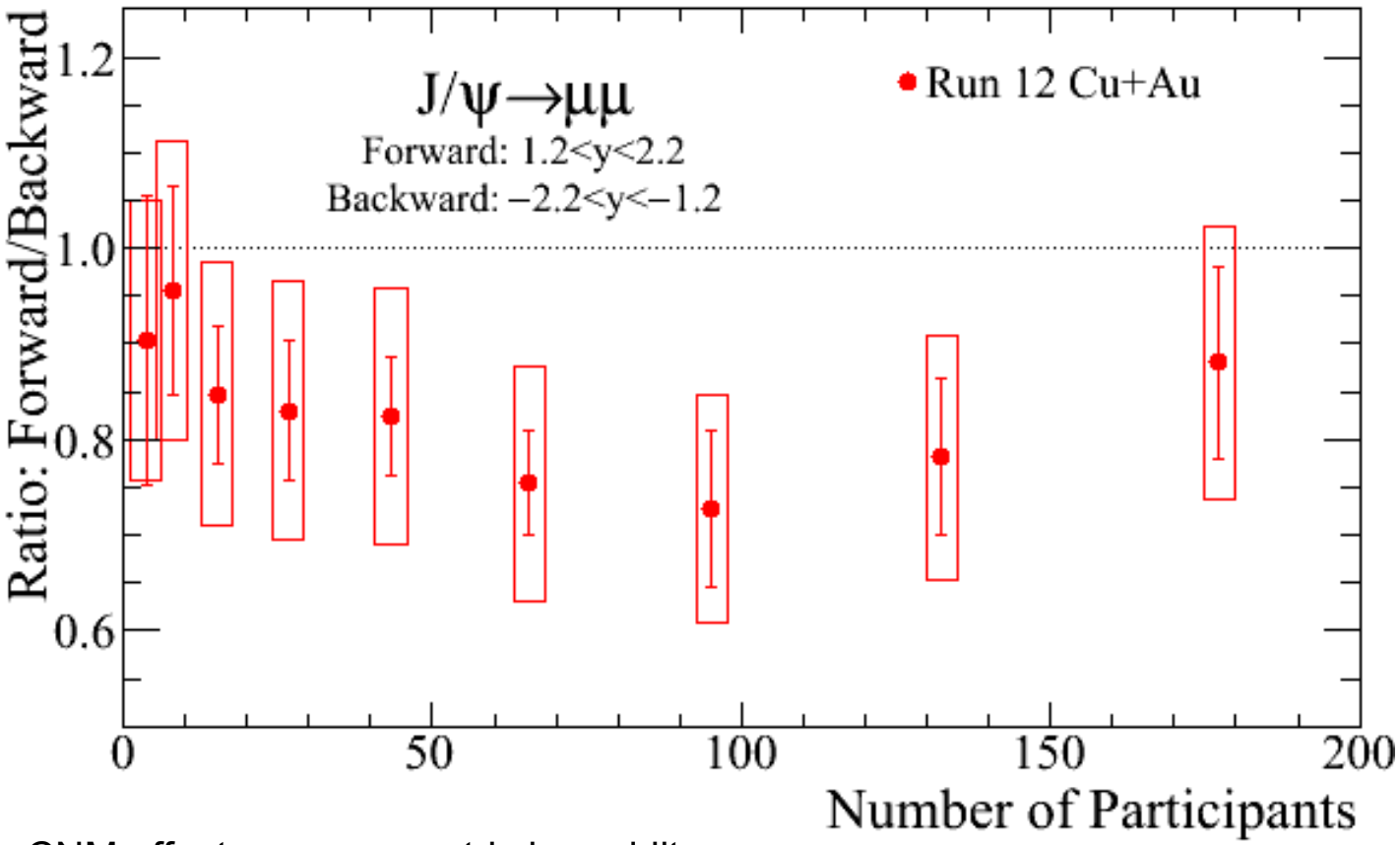


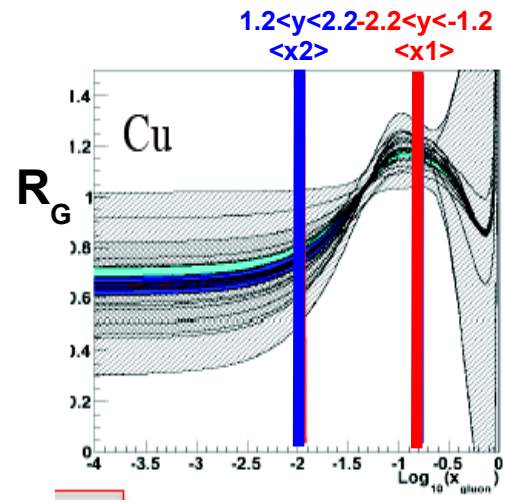


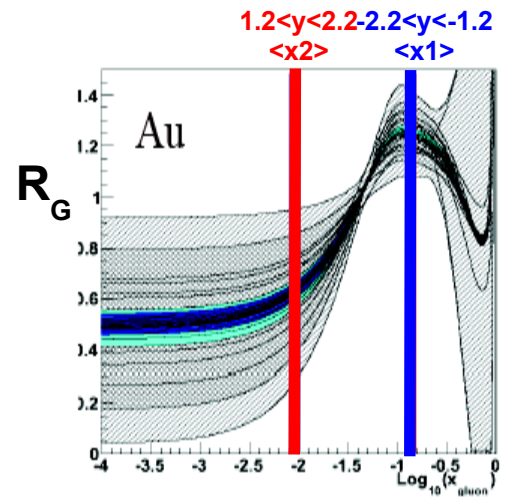
- HOT:
  - Similar suppression in Cu+Au compared to Au+Au
- COLD:
  - Forward (Cu-going) more suppressed than Backward

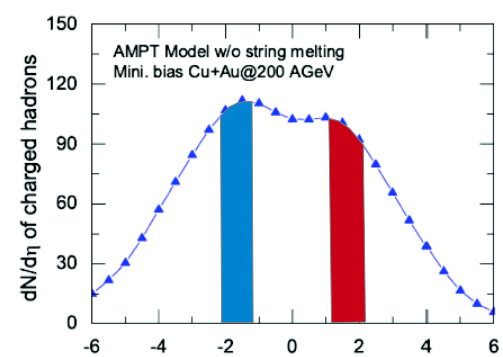
Probing Cold and Hot

arXiv:1404.1873









CNM effects → asymmetric in rapidity

Forward CNM effects (Cu-going)

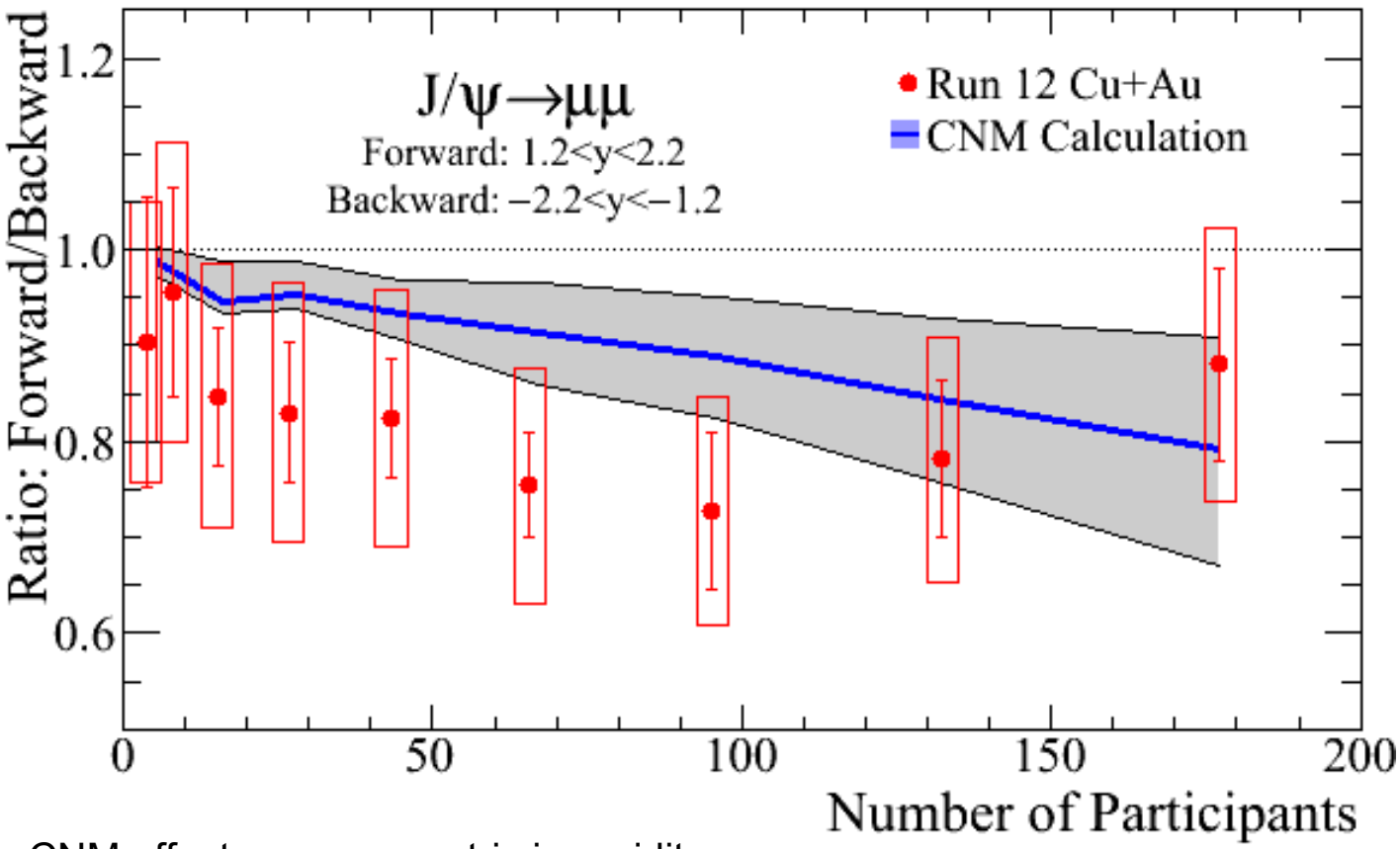
- gluon modification – J/ψ probes gluons at high-x in Cu, low -x in Au
- dynamical processes
  - Eloss, J/ψ short crossing proper time in Au
  - $c\bar{c}$ breakup by nucleon collisions, long crossing proper time in Cu

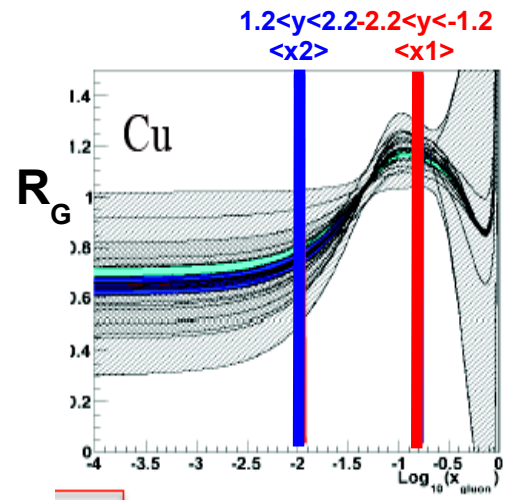
Backward (Au-going)

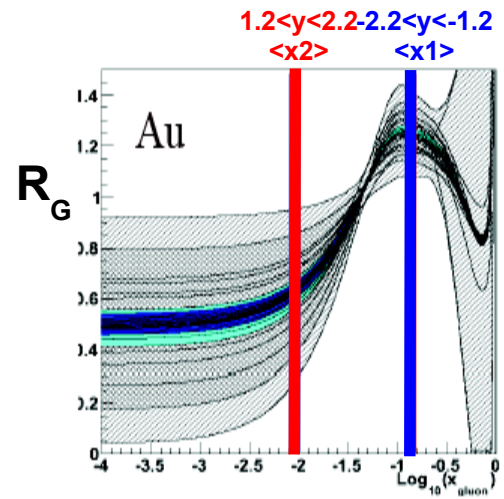
- Reversed CNM effects

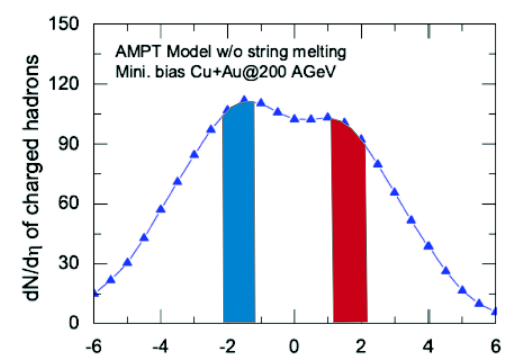
Probing Cold and Hot

arXiv:1404.1873









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
  - Eloss, J/ψ short crossing proper time in Au
  - $c\bar{c}$ breakup by nucleon collisions, long crossing proper time in Cu

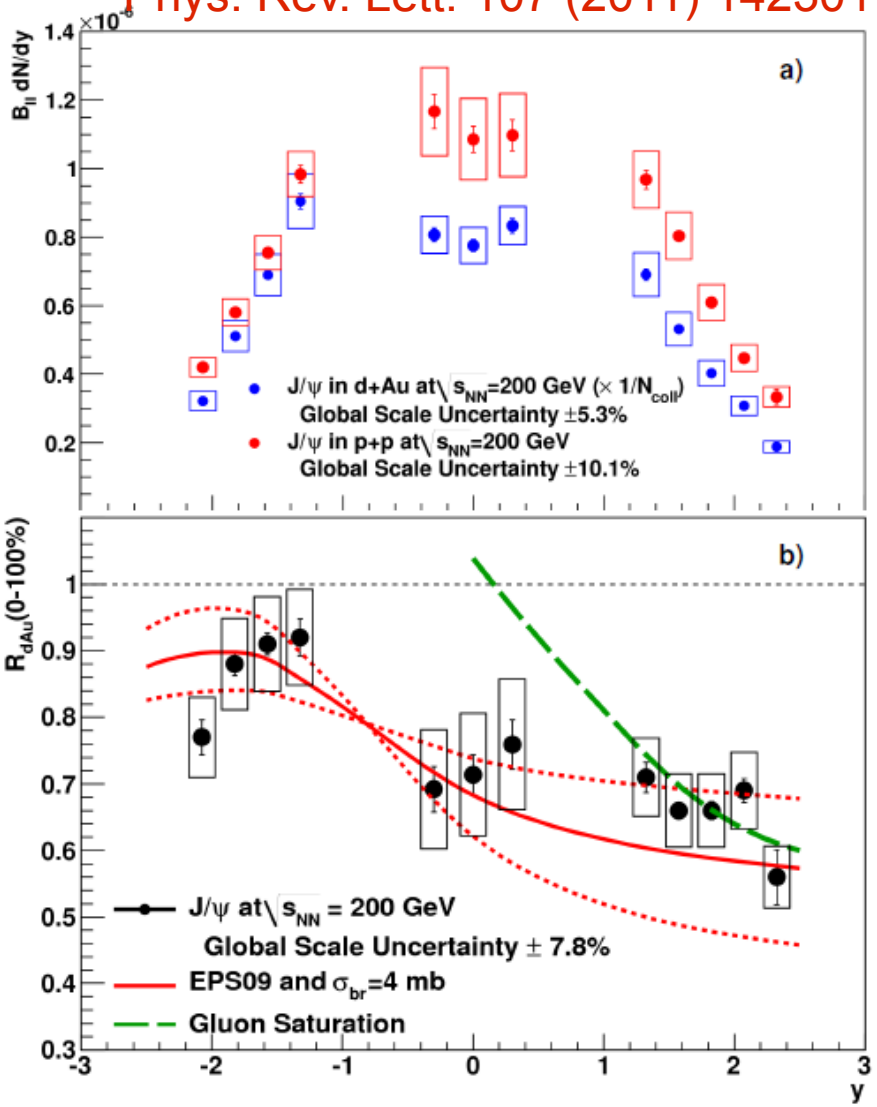
Backward (Au-going)

- Reversed CNM effects

Rapidity J/ψ

- d+Au
  - 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

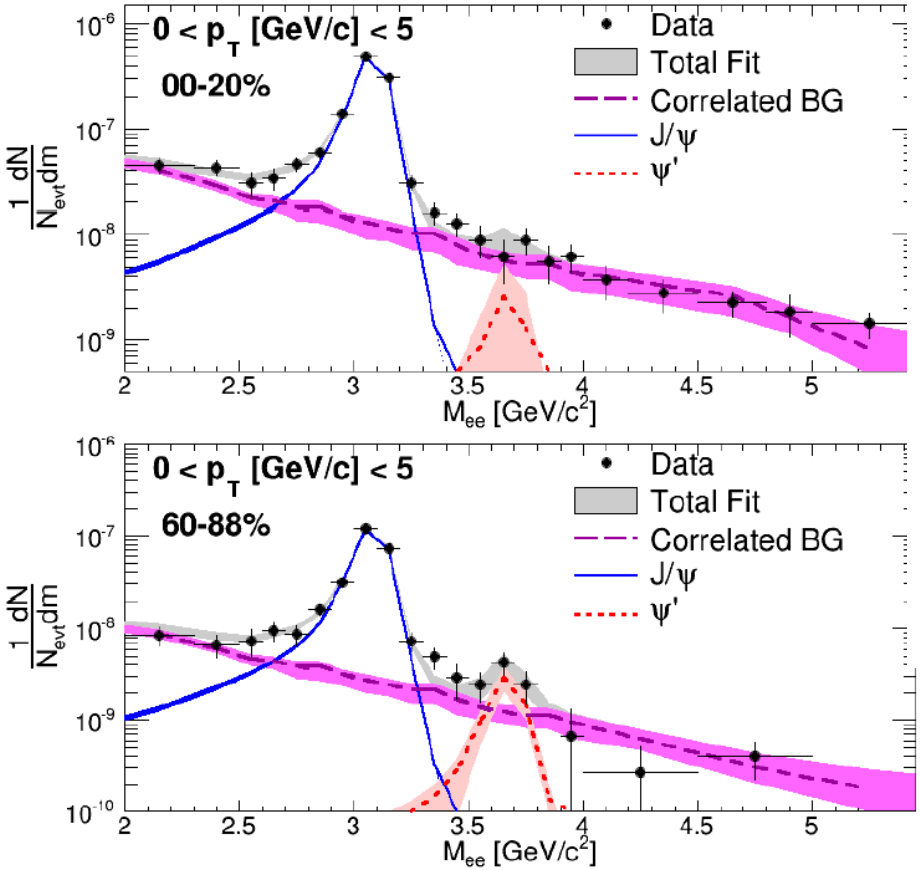
Phys. Rev. Lett. 107 (2011) 142301

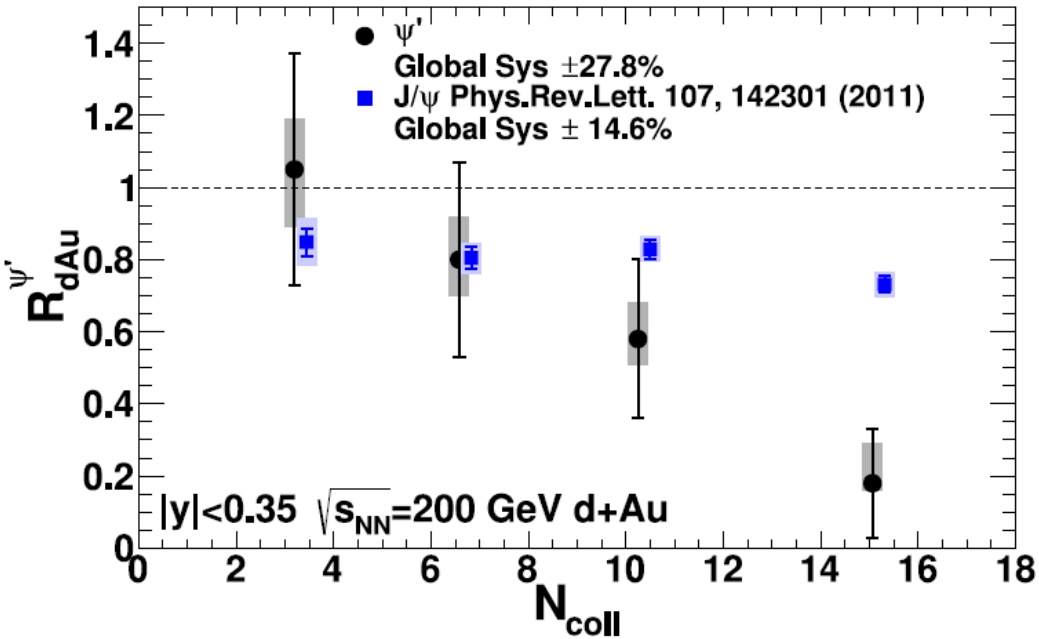


J/ψ versus ψ'

Central arms (electron channel)

Phys. Rev. Lett. 111 (2013) 202301





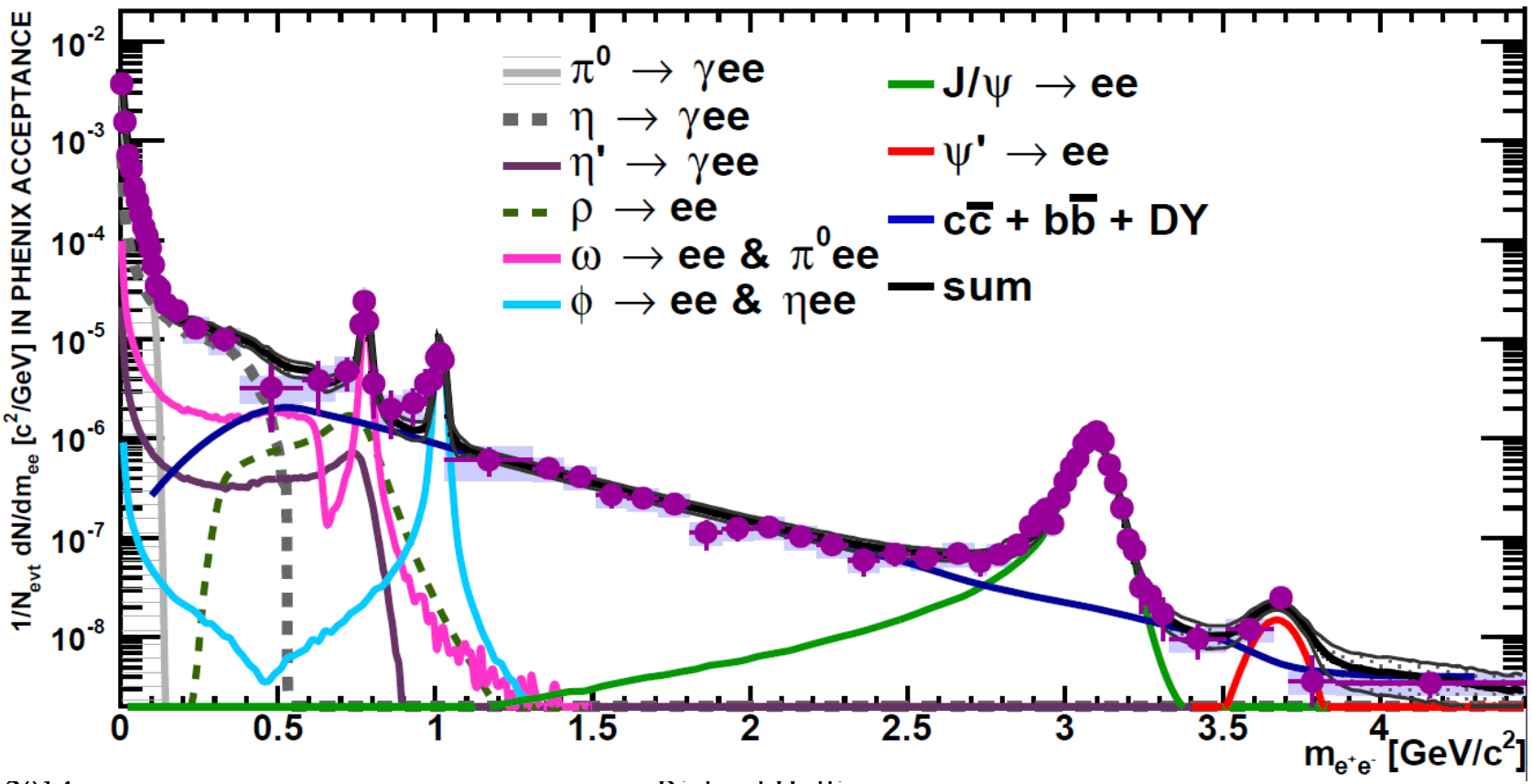
- ψ' more suppressed in central d+Au than J/ψ
- Smaller binding energy → more sensitive to final state effects

d+Au: Open Heavy Flavor

Central arms (electron channel)

- Minimum bias d+Au ($\sqrt{s_{NN}}$ = 200 GeV)
- Cocktail subtraction of feed-down electrons from mesons
  - Double differential in mass and p_T
  - Pairs from open flavor and DY (small contribution)

arXiv:1405.4004

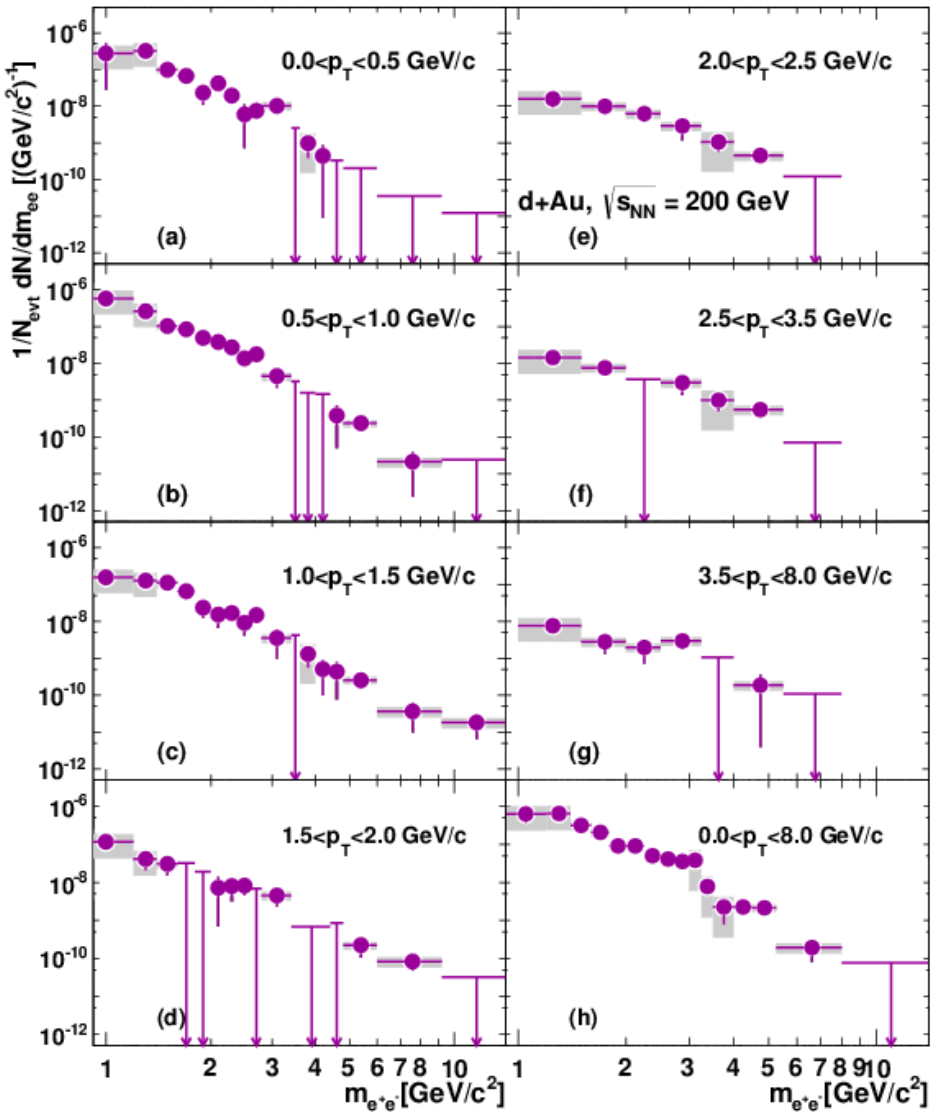


d+Au: Open Heavy Flavor

Central arms (electron channel)

- HF yields after subtracting all backgrounds

arXiv:1405.4004



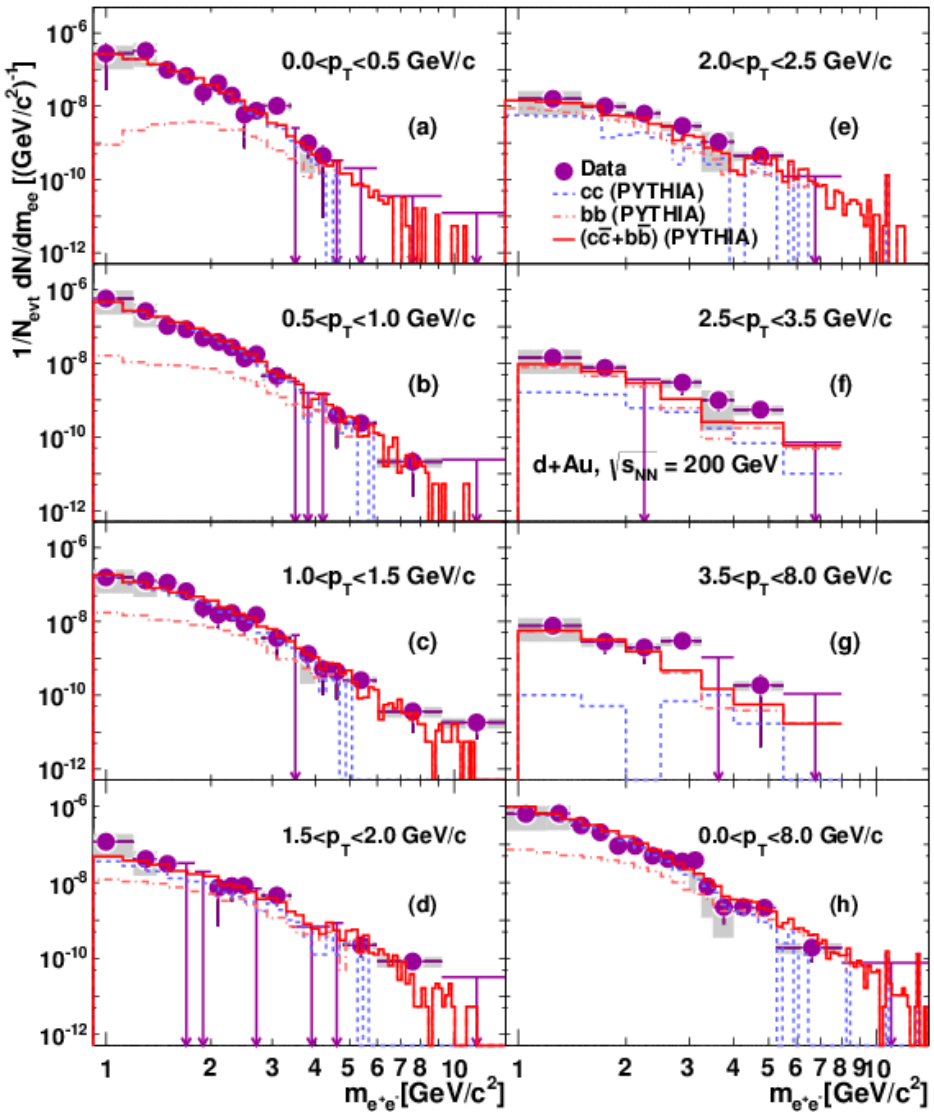
d+Au: Open Heavy Flavor

Central arms (electron channel)

- HF yields after subtracting all backgrounds

- $c\bar{c}$ and $b\bar{b}$ cross-section extraction:
  - Shape fixed from
    - PYTHIA (shown)
    - MC@NLO (similar)
  - Normalization floats

arXiv:1405.4004



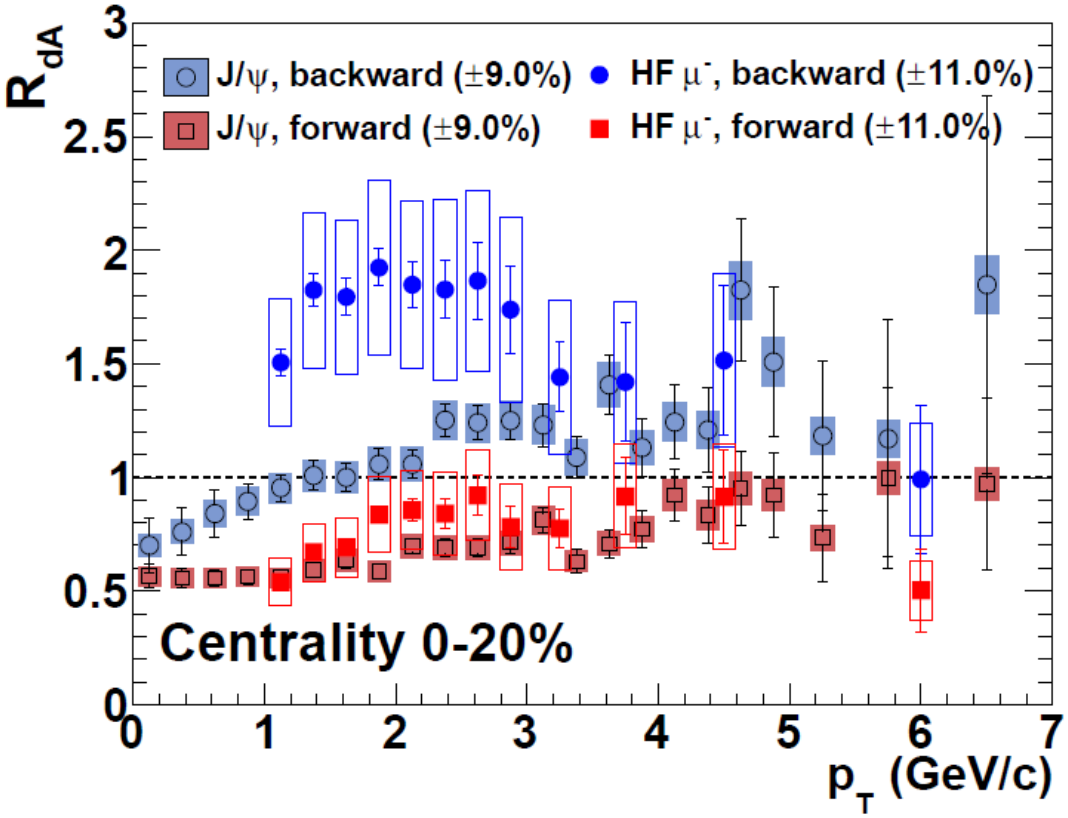
σ_{bb}(d+Au) = 1.37 ± 0.28(stat) ± 0.46(syst) mb

HF and J/ψ comparison in d+Au

Forward arms (muon channel)

- Similar yields at forward rapidity
- Distinct difference at backward rapidity
  - p_T<2.5 GeV/c
    - Dominated by charm

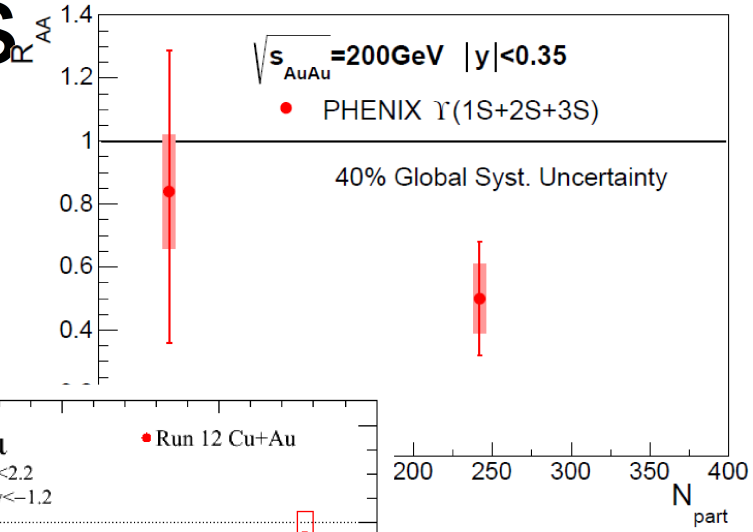
Phys. Rev. Lett. 112 (2014) 252301

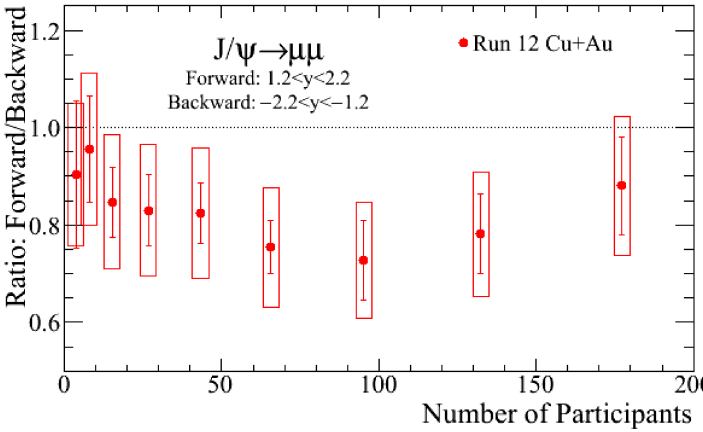


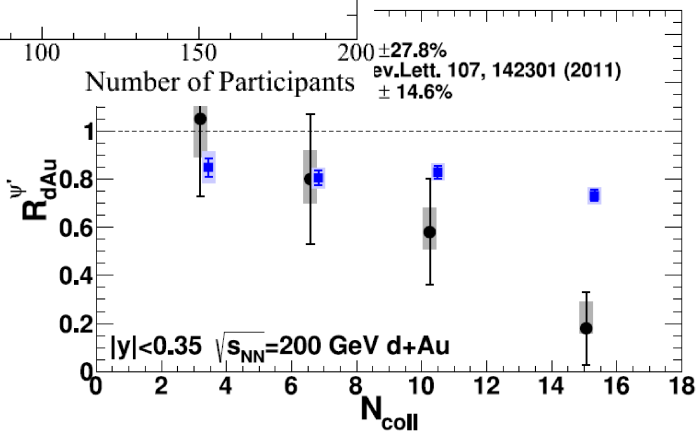
- J/ψ $c\bar{c}$ additional breakup
  - Longer time in nucleus?
- Higher co-mover density at backward rapidity?

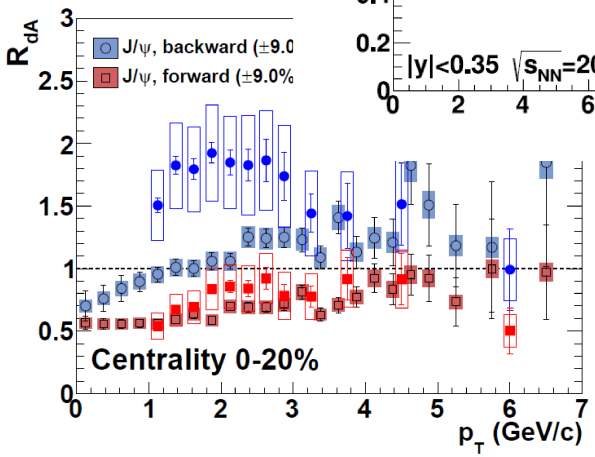
Conclusions

- PHENIX has contributed substantially to the World's Heavy Flavor data
  - Providing measurements at various energies and in diverse collision systems
- Au+Au and Cu+Au
  - J/ψ and ϒ are found to be suppressed in central collisions
  - Stronger suppressed at forward rapidity in Cu+Au collisions
- d+Au
  - ψ' suppression dependent on N_{coll}
  - HF enhancement at backward rapidity (compared to J/ψ)









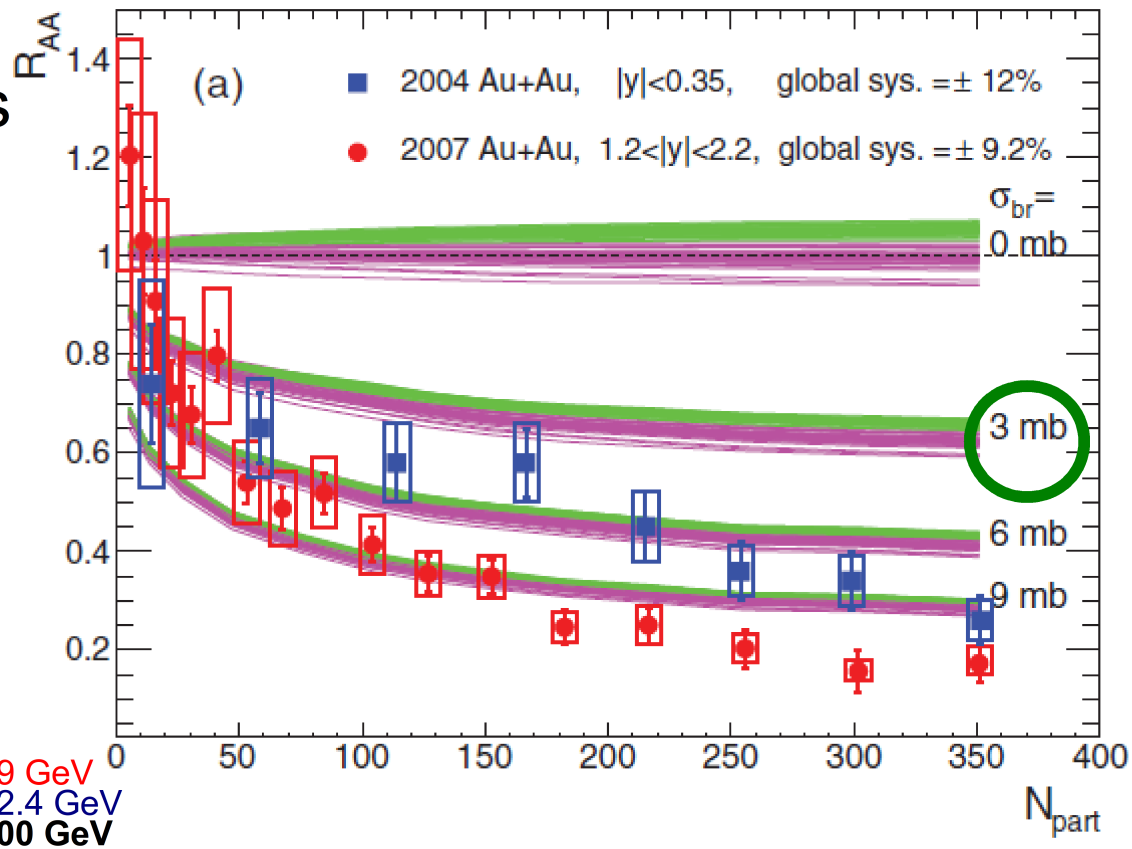
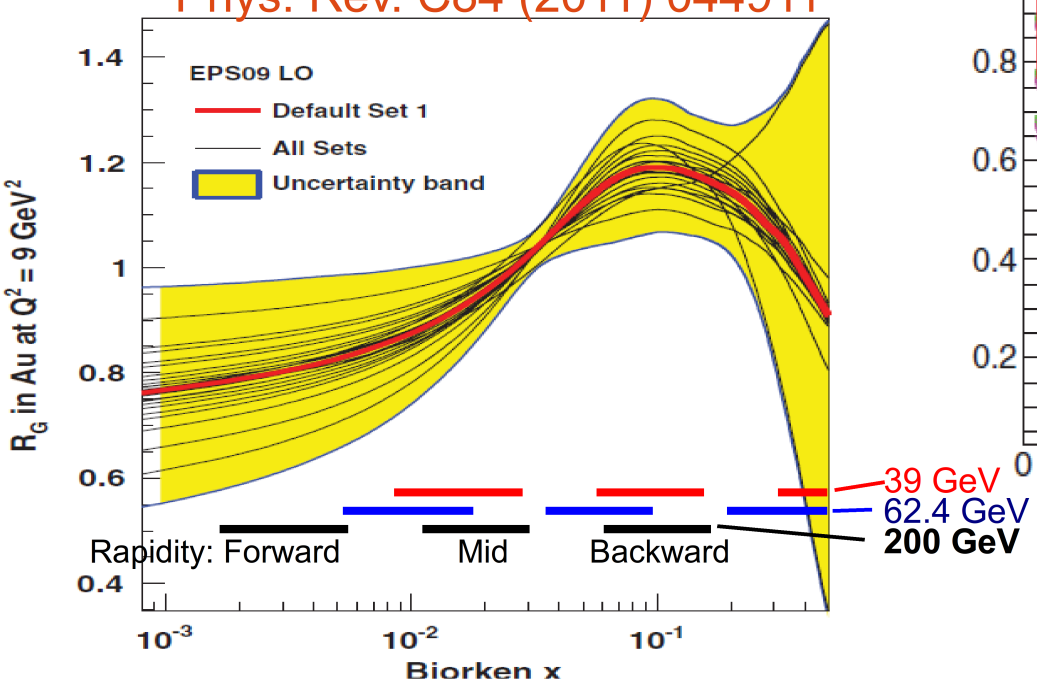
backup

Particle Species: J/ψ

- Larger cross-section
  → Larger statistics
  → probe in more detail

- Study RAA:
  - Similar suppression at different collision energies
    - Forward rapidity

Phys. Rev. C84 (2011) 054912



Phys. Rev. C84 (2011) 044911