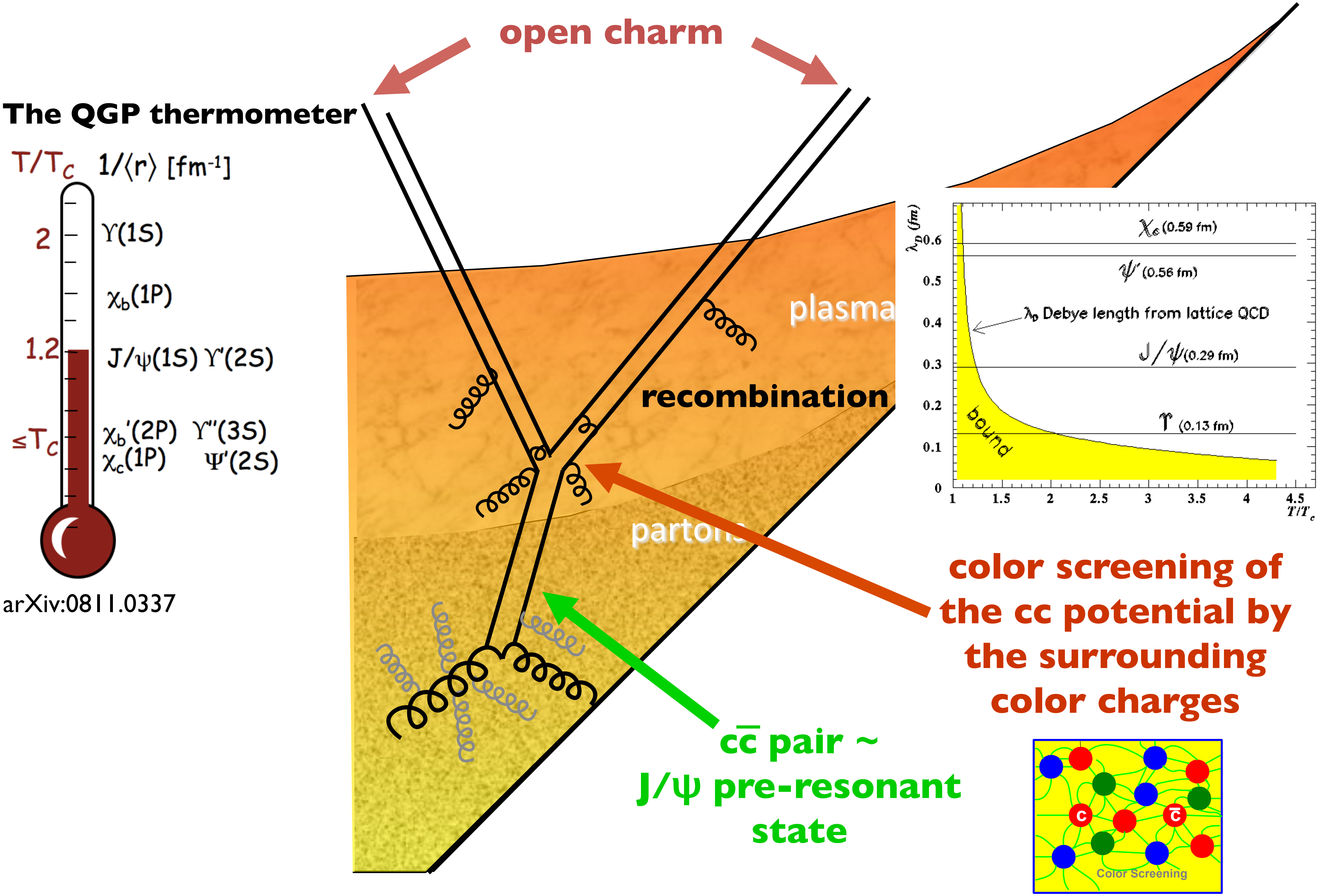
Quarkonia Results from PHENIX

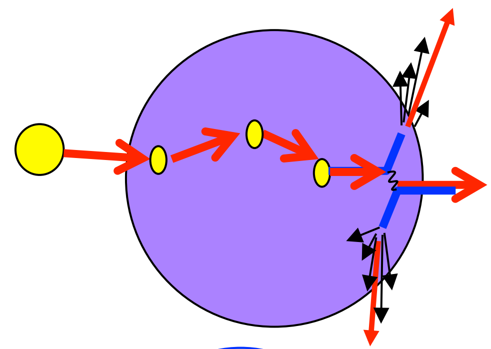
Sanghoon Lim
Los Alamos National Lab

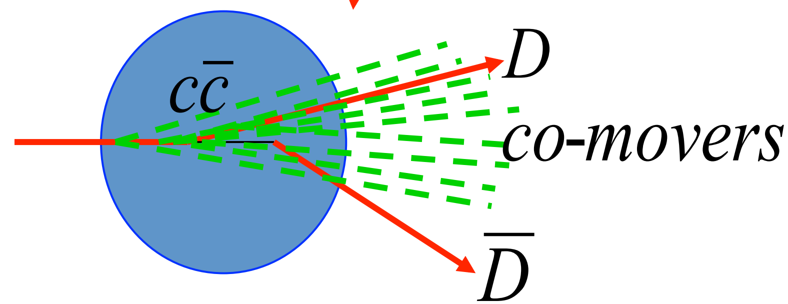
RHIC&AGS Users' meeting
June/7/2016

Quarkonia in the QGP



Scattering with nuclear matter





Initial-state (before hard scattering) interaction or final-state (after hard scattering) interaction can cause **energy loss, transverse momentum broadening, and break-up of bound states**

Quarkonia in small collision system

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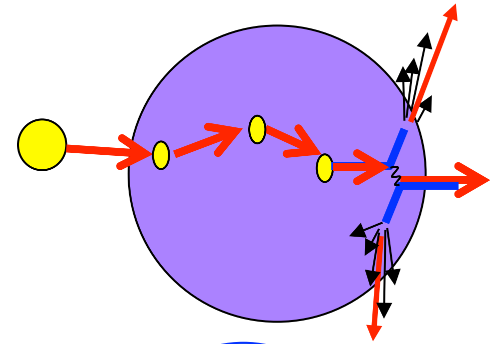
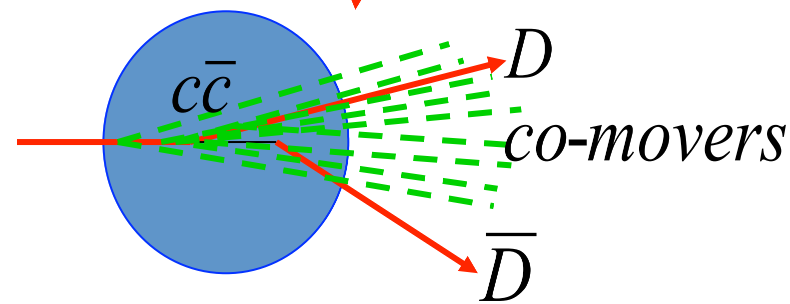
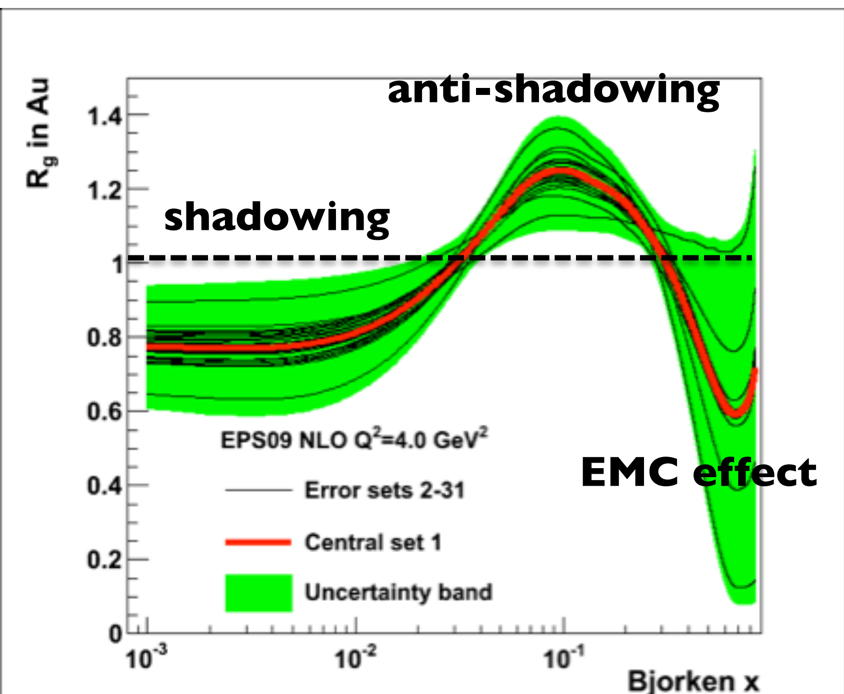






Modification of parton's distribution

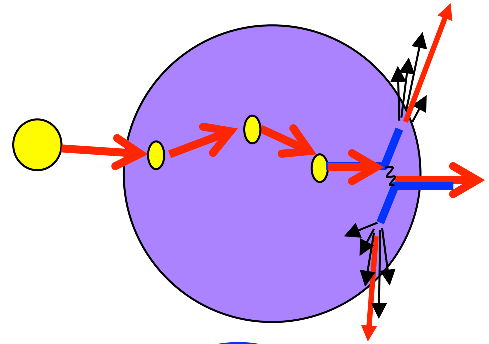
Parton distribution functions (PDF) in nucleus are modified from those in nucleon depends on **x (longitudinal momentum fraction)** and **Q^2 (energy scale)**

$$R^A(x, Q^2) = \frac{f^A(x, Q^2)}{Af^p(x, Q^2)}$$

EPS09 model for gluon modification

Quarkonia in small collision system

Scattering with nuclear matter



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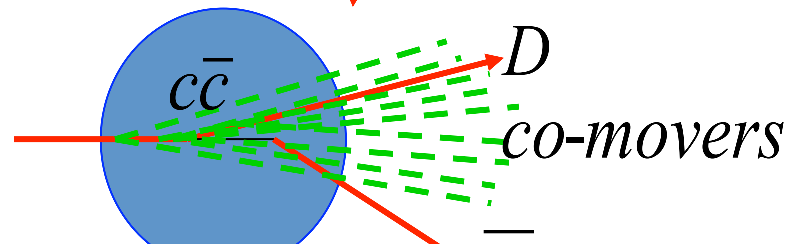
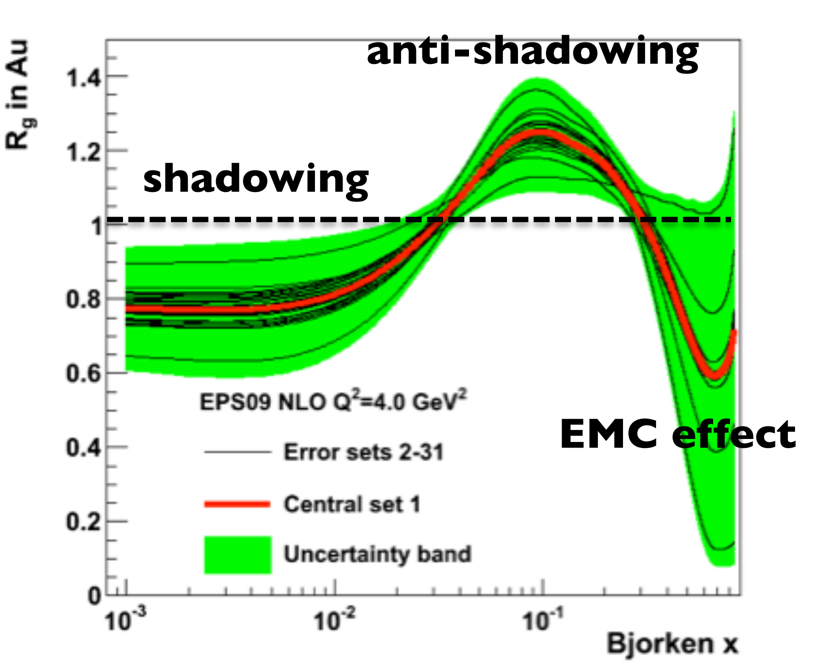


Need various measurements at wide kinematic range!!



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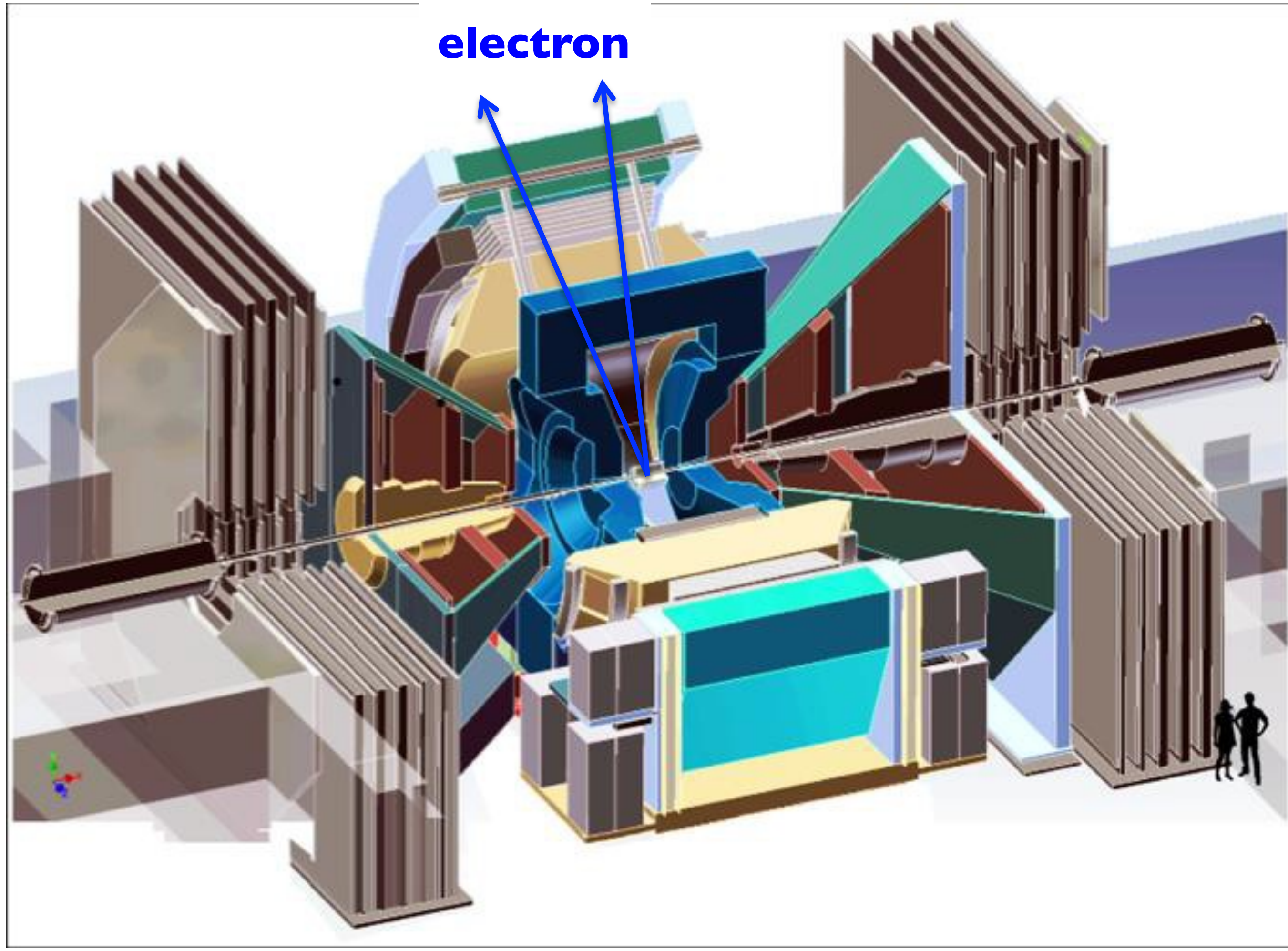
Quarkonia measurements at PHENIX

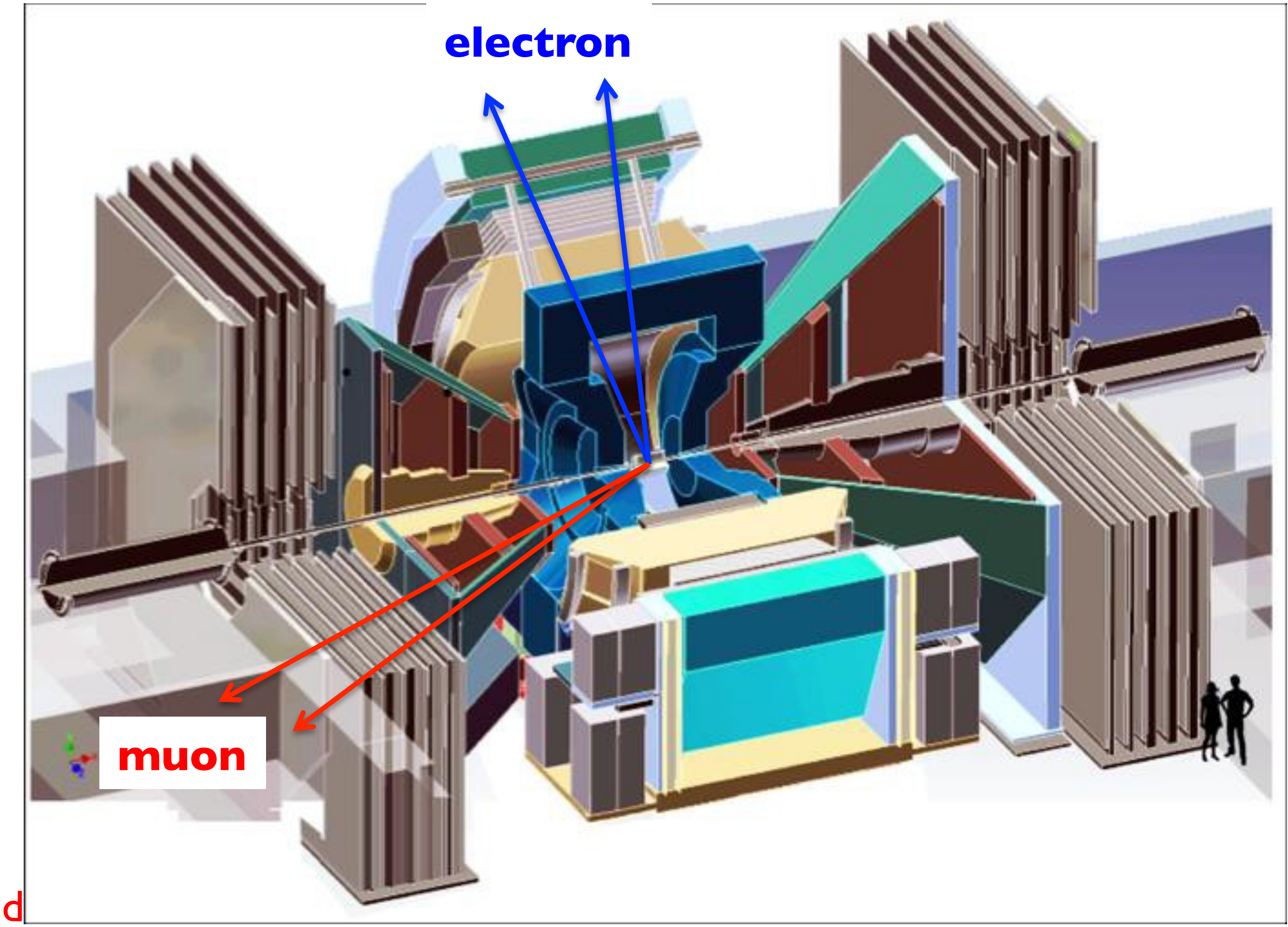
- **Central arm**
  - $|\eta|<0.35$
  - $\Delta\phi=\pi$
  - Tracking w/ DC, PC
  - eID w/ RICH, EMcal



Quarkonia measurements at PHENIX

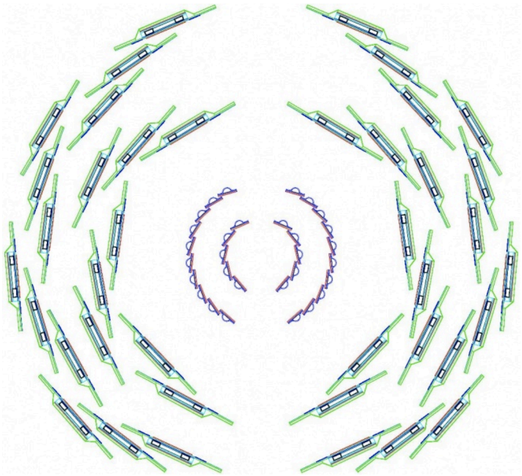
- **Central arm**
  - $|\eta|<0.35$
  - $\Delta\phi=\pi$
  - Tracking w/ DC, PC
  - eID w/ RICH, EMcal

- **Muon arm**
  - $1.2<|\eta|<2.2$
  - $\Delta\phi=2\pi$
  - $\sim 10\lambda$ absorber
  - Tracking w/ wire chamber
  - muID w/ 5 layers of steel and Iarocci tube plane

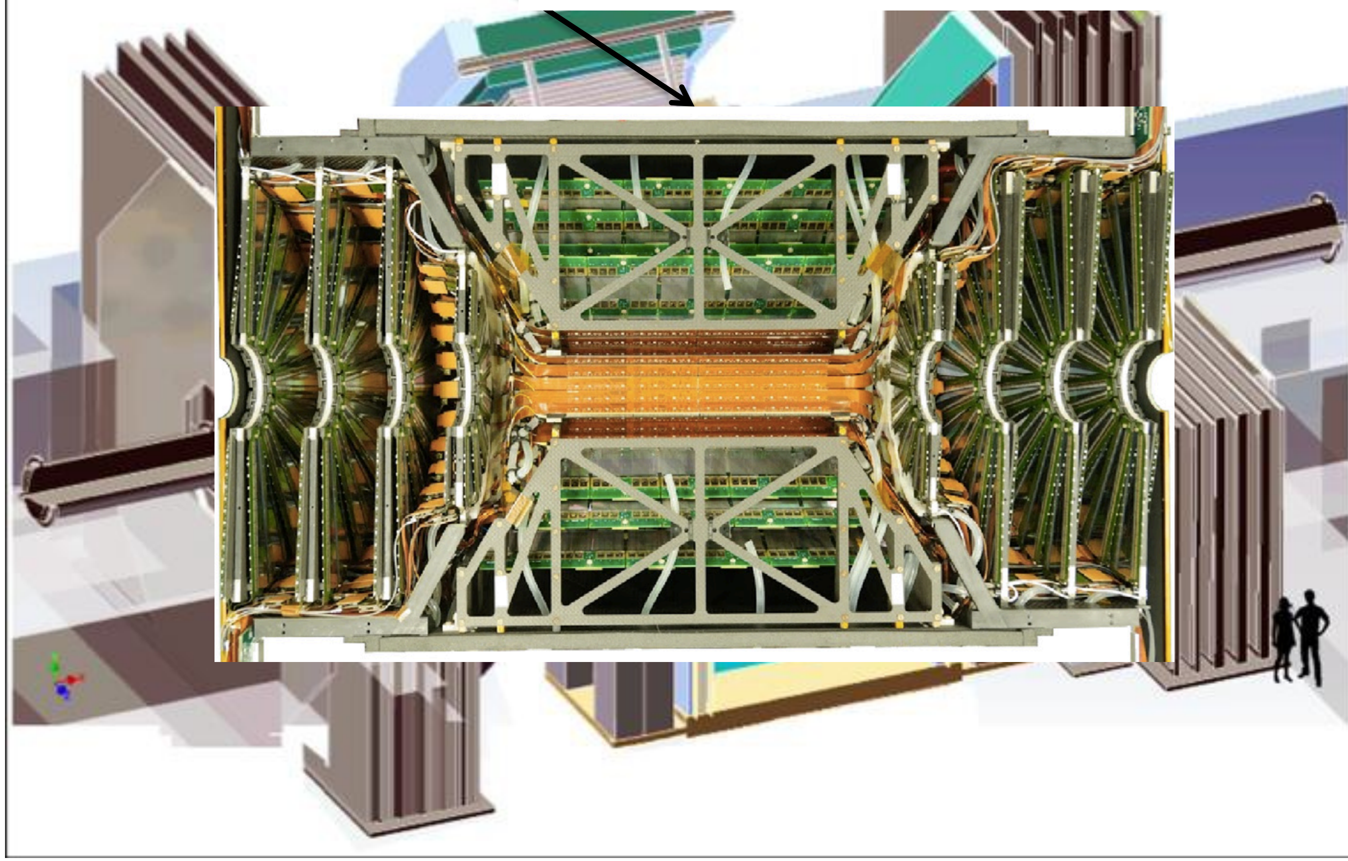


Silicon Vertex Tracking System

- **VTX at mid-rapidity 2011**



2 layers of pixel (R = 2.5, 5 cm)
→50 um x 450 um
2 layers of strips (R = ~10, ~15 cm)



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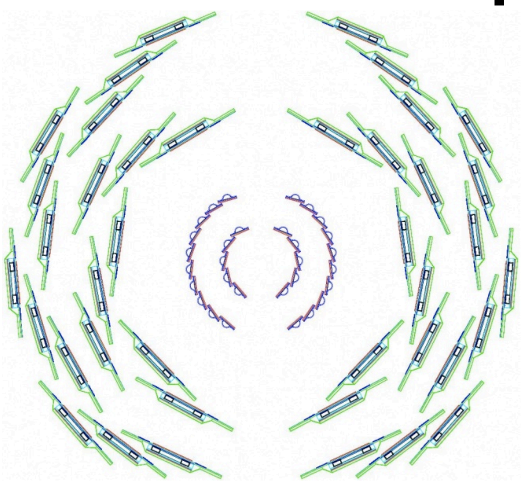

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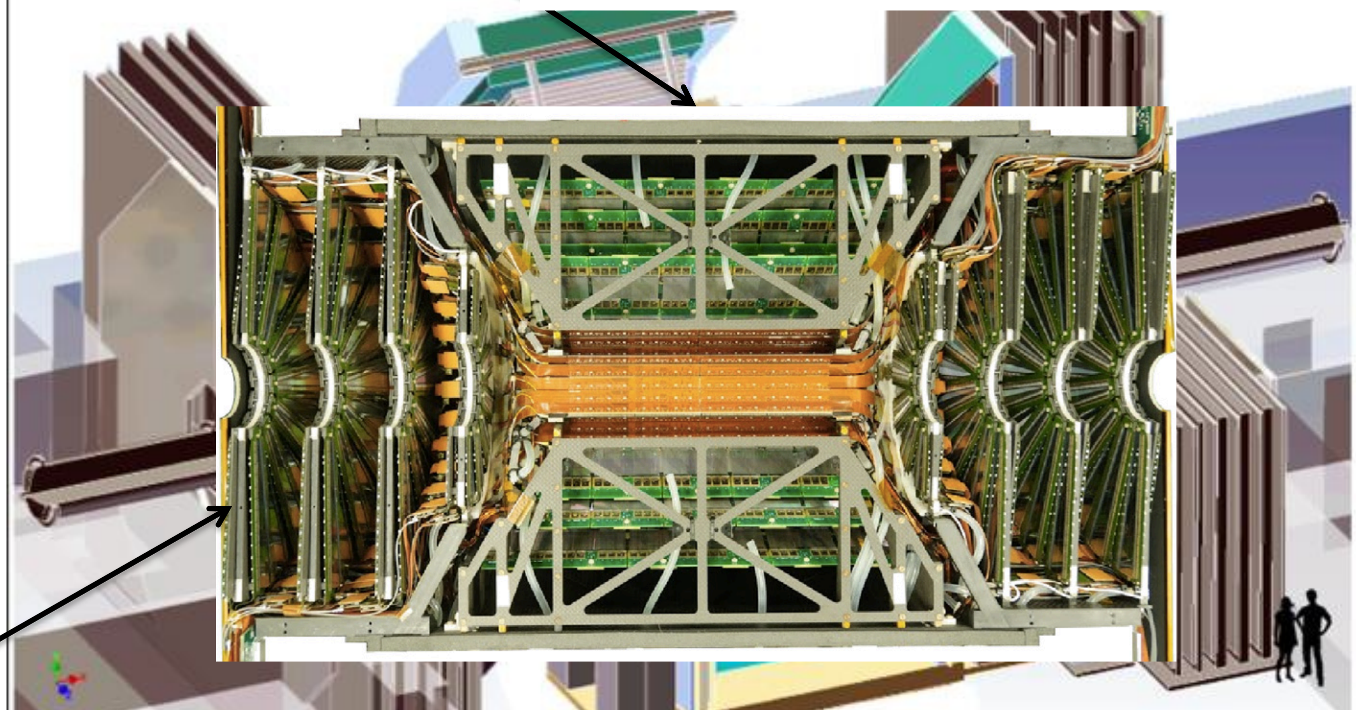
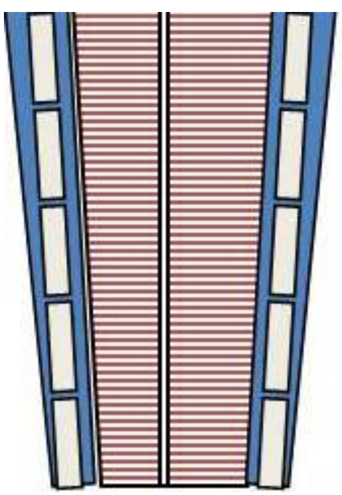


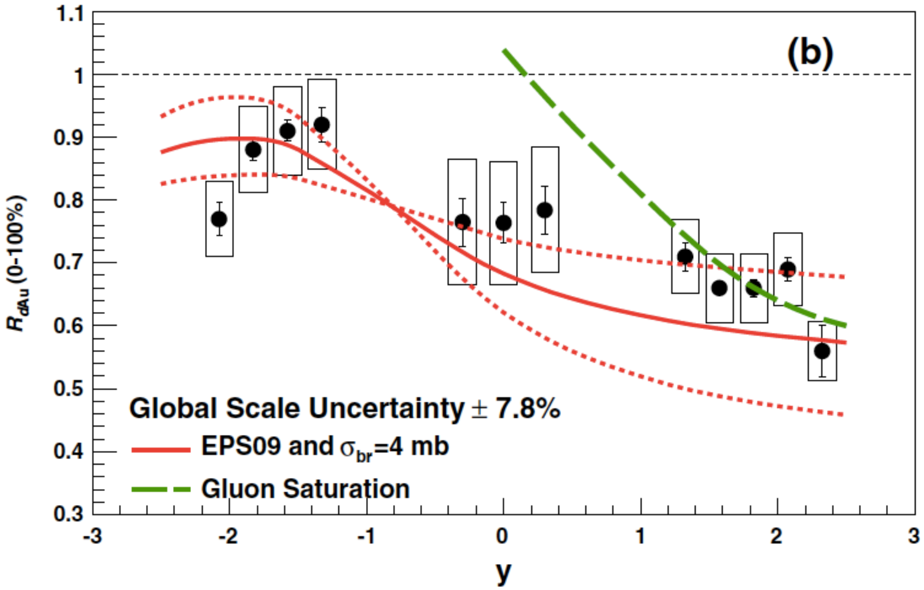
- **FVTX at forward 2012**



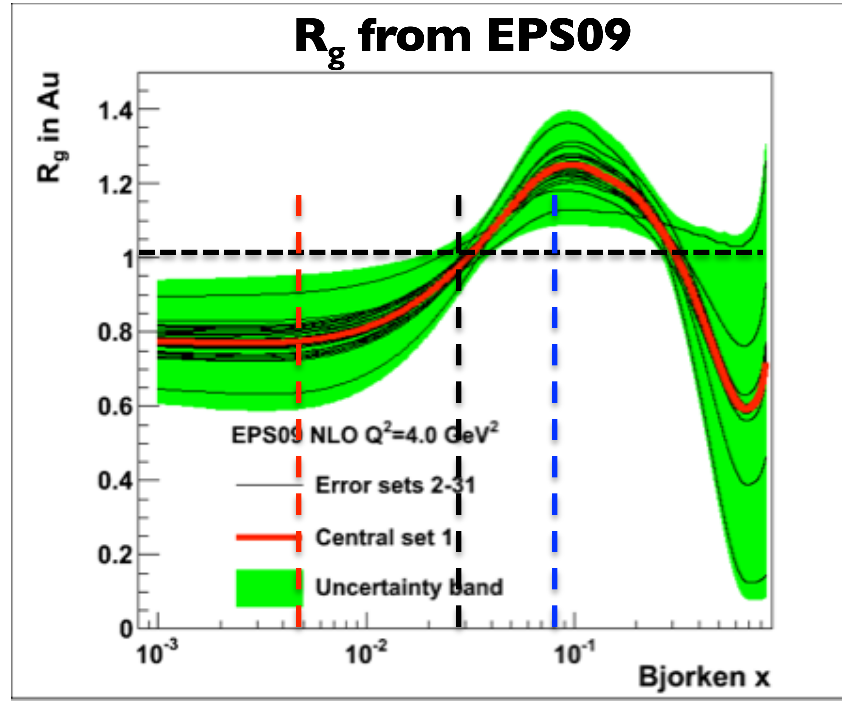
2 columns of strips
75 micron spacing
4 disks per arm (z= ~20, ~25, ~31, ~38 cm)

Quarkonia production in small systems

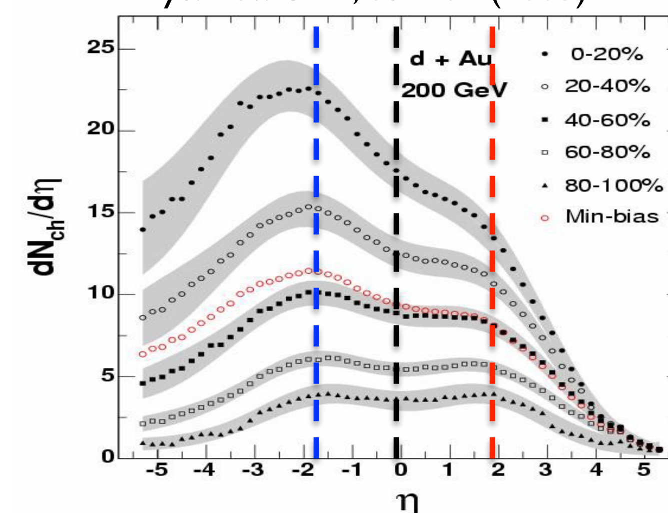
J/ψ production in d+Au collisions



Phys. Rev. Lett. 107, 142301 (2011)

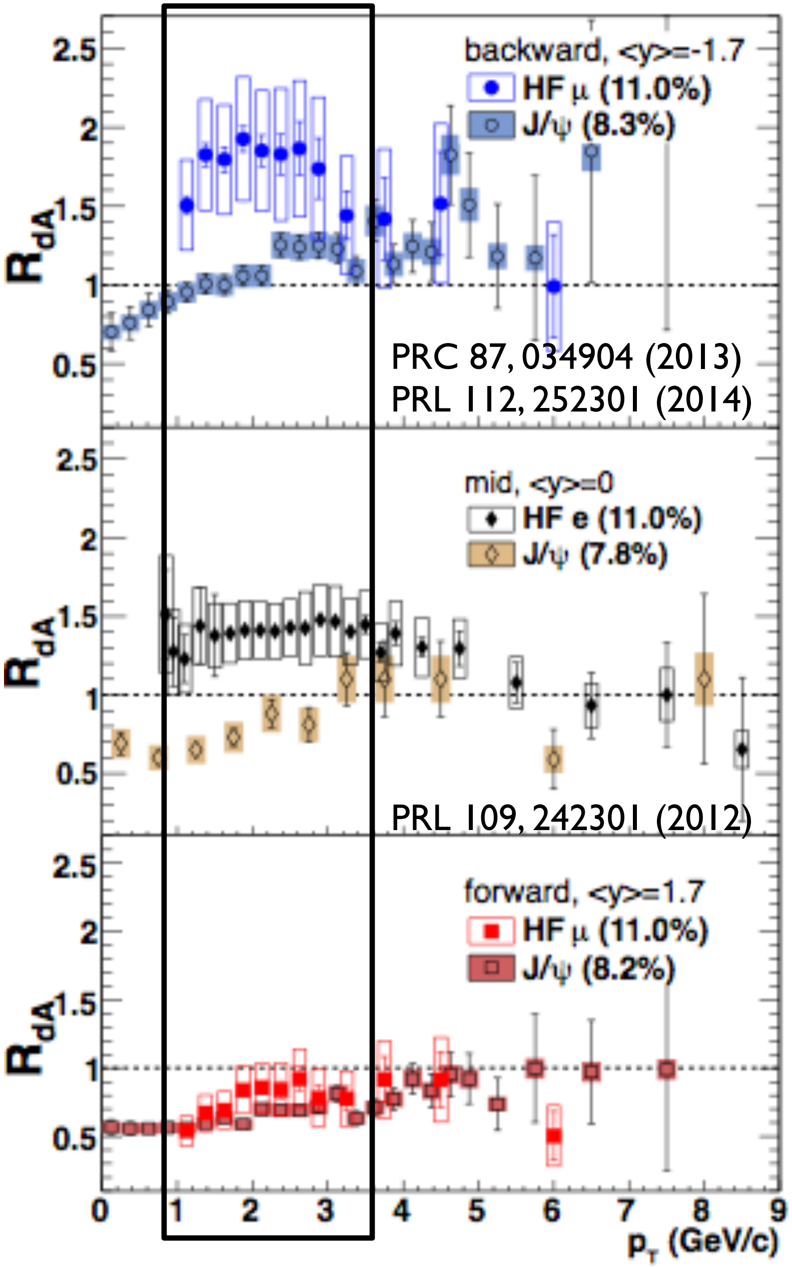


Phys. Rev. C 72, 031901 (2005)



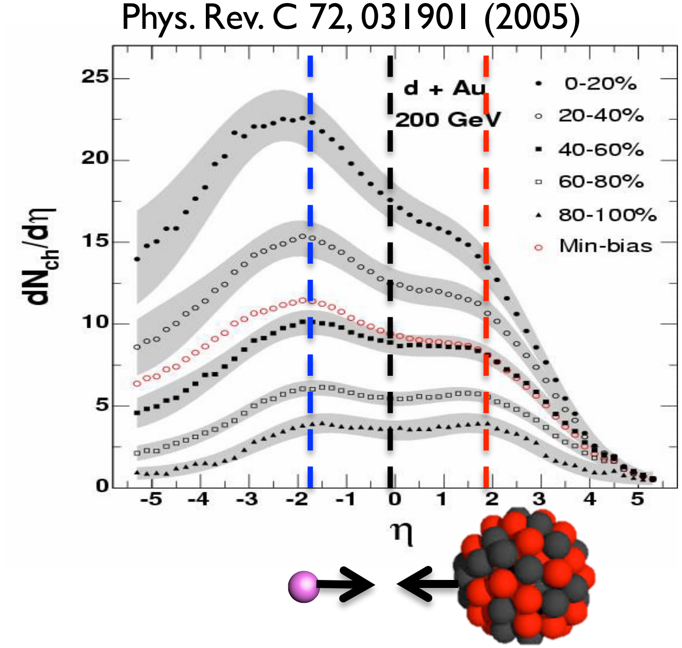
- Suppression of J/ψ compared to p+p collisions at the entire rapidity region
  - Not expected from PDF modification →something beyond the PDF modification
  - Model including 4 mb of breakup shows a good agreement with the data

Comparison between open and closed heavy-flavor

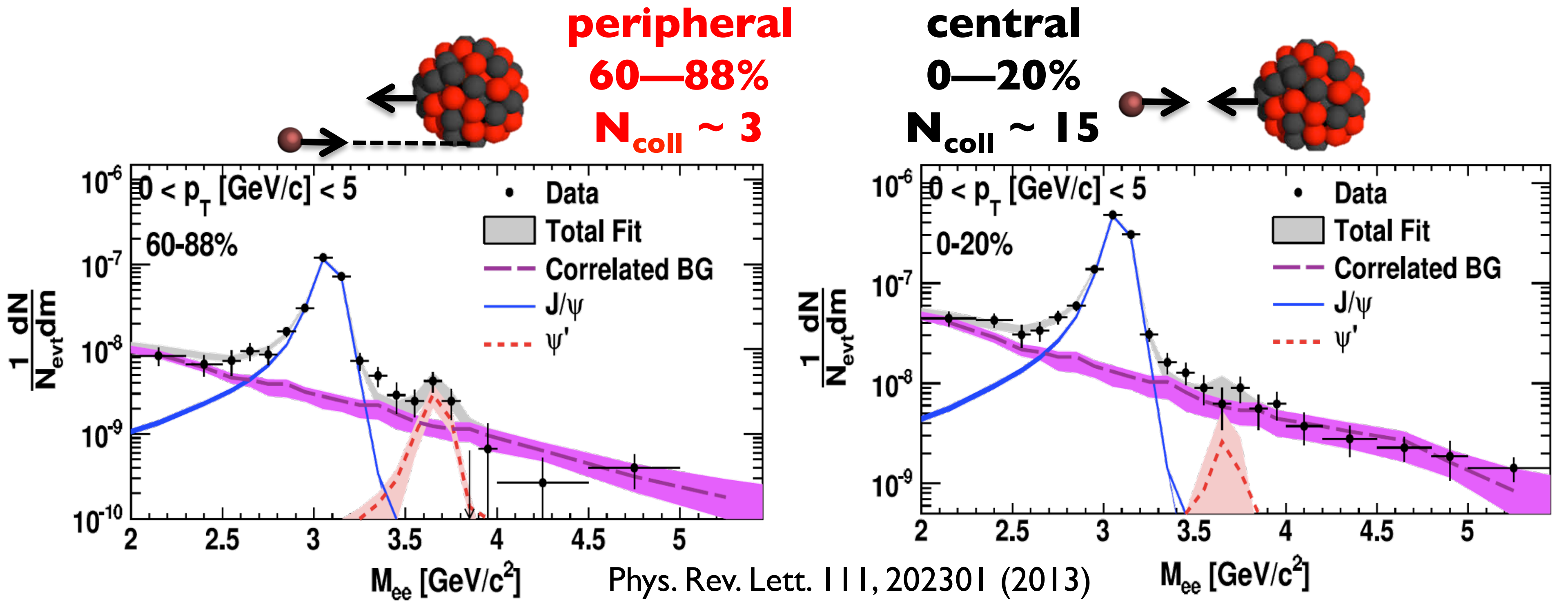


- In the most central collision
  - RdA of HF muon and J/psi are still consistent at forward rapidity
  - however, clearly different at backward rapidity
  - **charm production is enhanced but J/psi production is significantly suppressed** due to nuclear breakup inside dense co-movers at backward rapidity

Phys. Rev. C 72, 031901 (2005)



Suppression of ψ(2S) in central d+Au collisions



Phys. Rev. Lett. 111, 202301 (2013)

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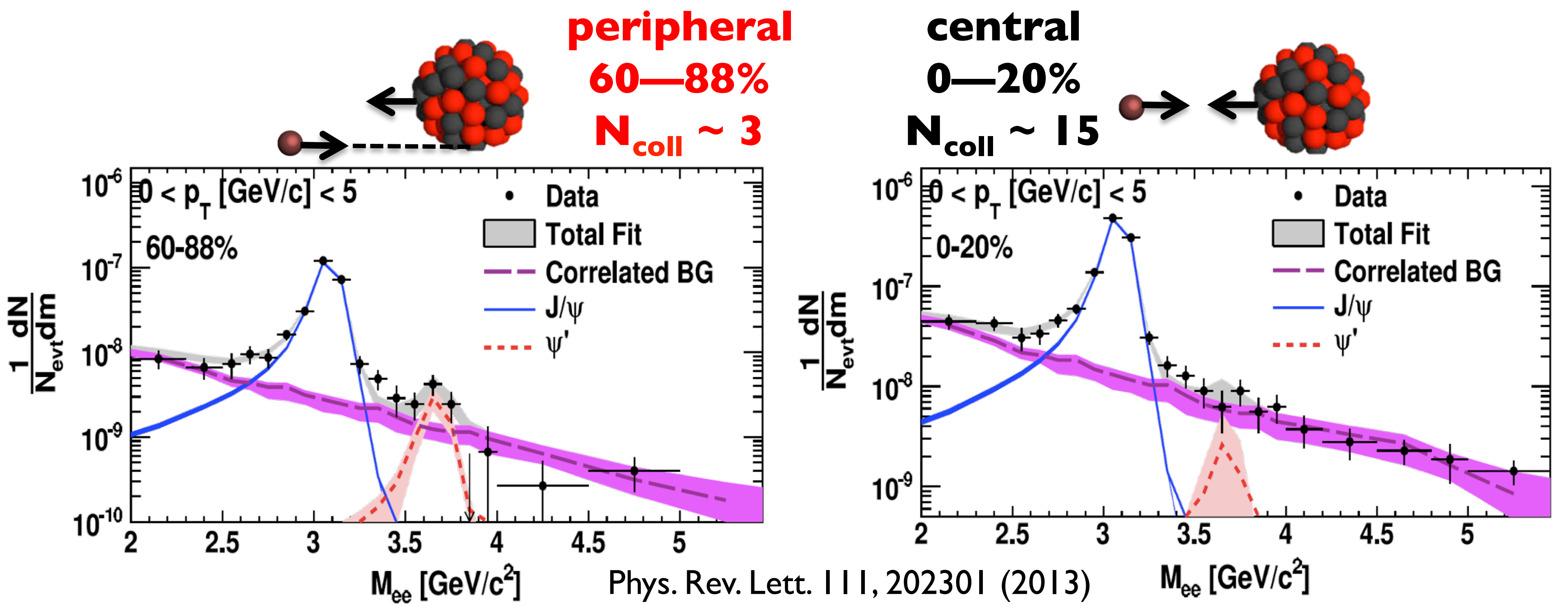
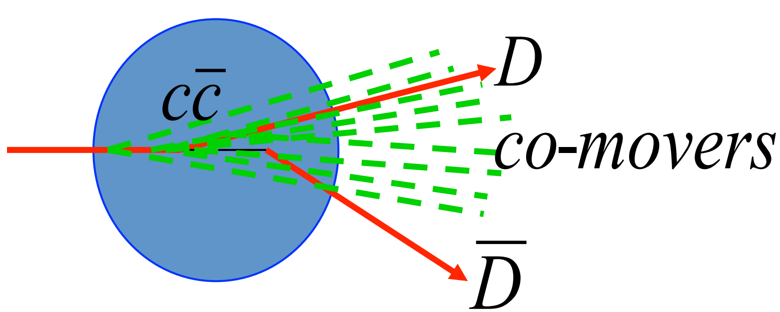
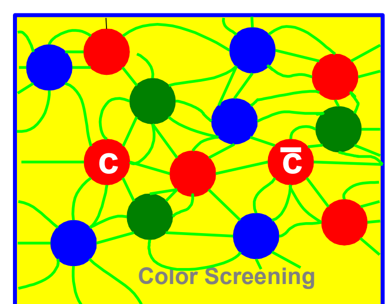


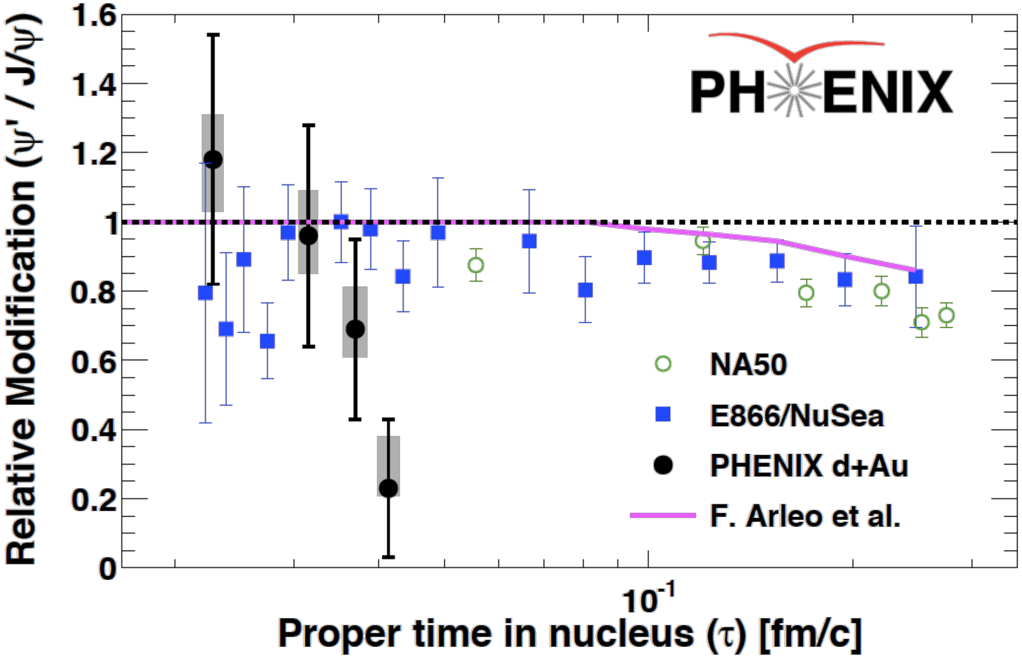
Phys. Rev. Lett. 111, 202301 (2013)

- **Breakup of quarkonia due to interaction with nuclear matters**
  - **Large suppression of the weakly bounded state ψ(2S)**
  - **Interaction with nucleus? co-movers? or medium?**





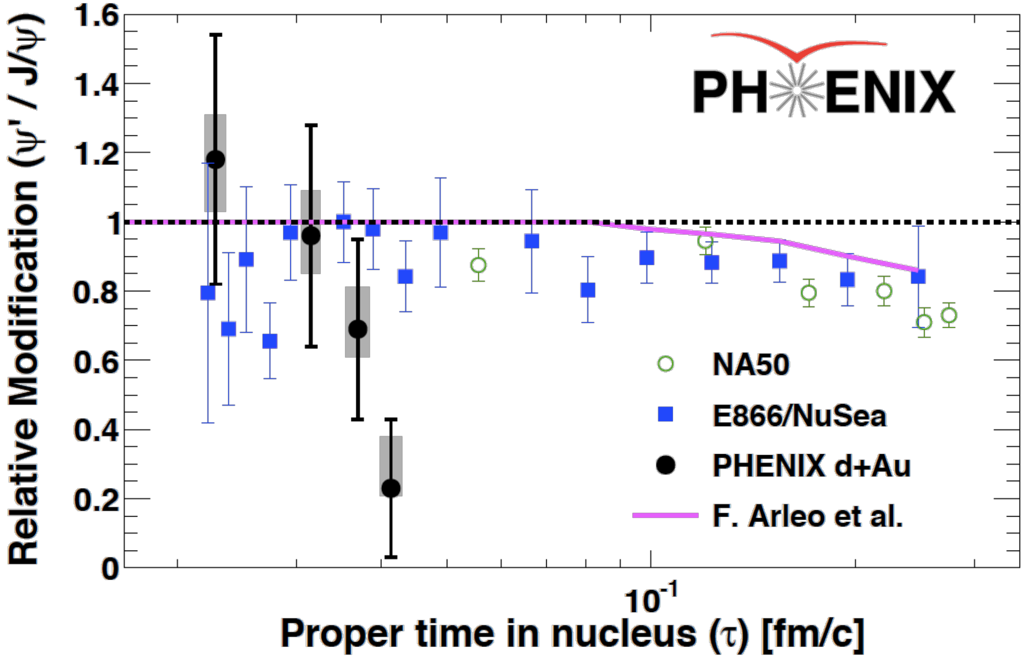
Modification inside/outside nucleus?

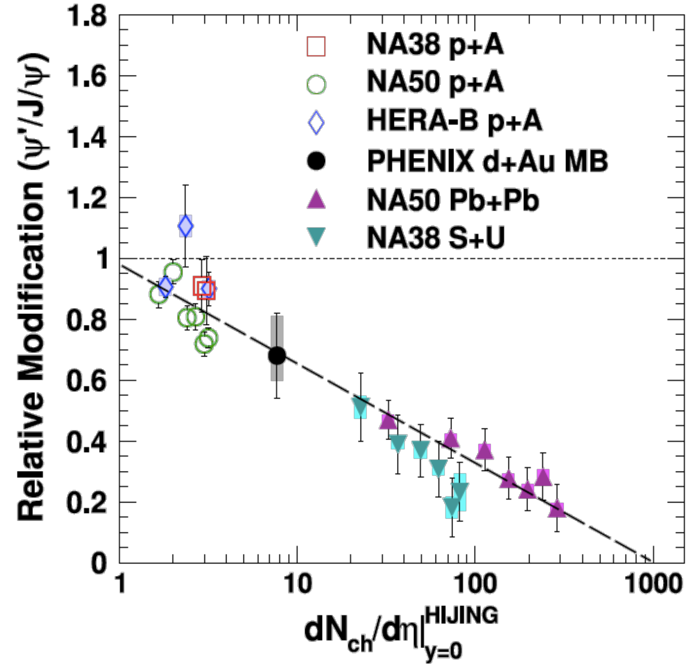


Phys. Rev. Lett. 111, 202301 (2013)

- Larger relative modification of ψ(2S) than the estimation of breakup in nucleus →at RHIC, formation time of J/ψ (~0.15 fm) is longer than and proper time in nucleus (~0.05 fm)

Modification inside/outside nucleus?



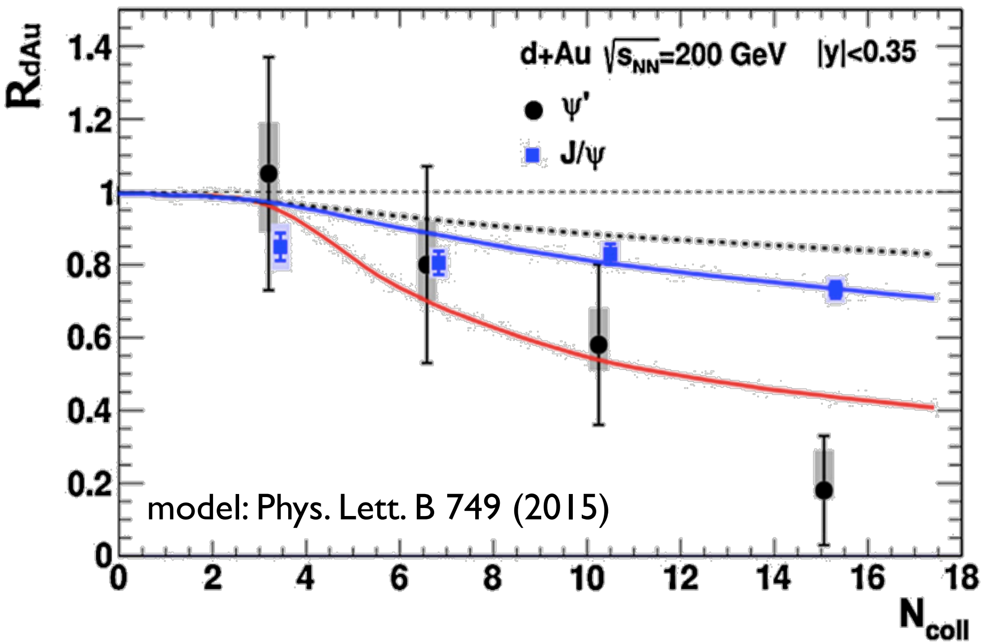


Phys. Rev. Lett. 111, 202301 (2013)

- Larger relative modification of ψ(2S) than the estimation of breakup in nucleus →at RHIC, formation time of J/ψ (~0.15 fm) is longer than and proper time in nucleus (~0.05 fm)

- Follow the trend of produced particle density →breakup due to interaction with co-movers? or medium?

Nuclear modification factors of J/ψ and ψ(2S) in d+Au collisions at mid-rapidity



Model including **interaction with co-moving particles** reasonably well describes the suppression of J/ψ and ψ(2S) in d+Au collisions

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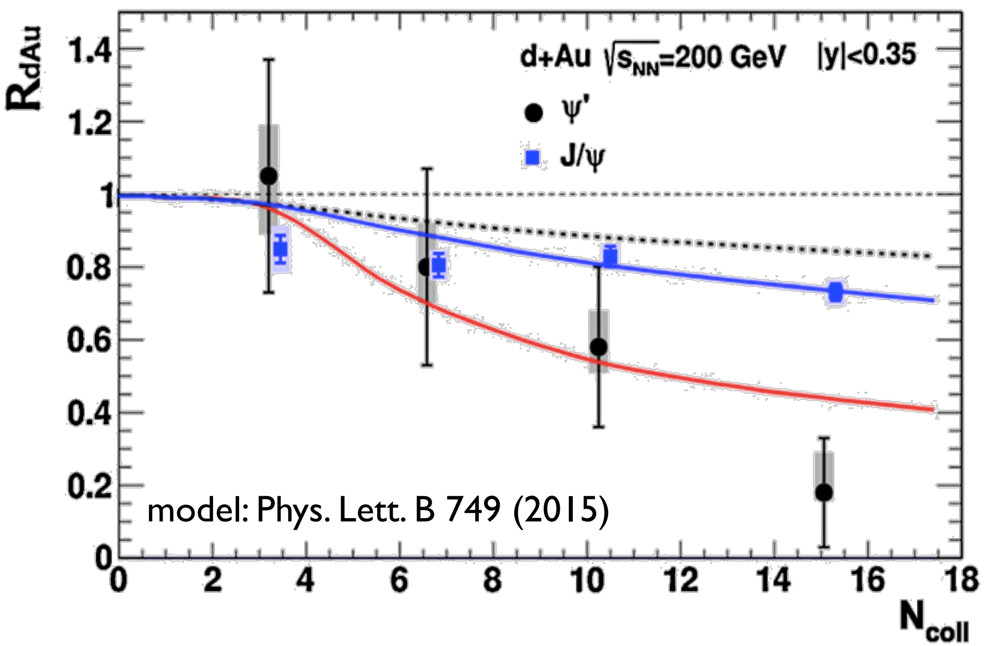
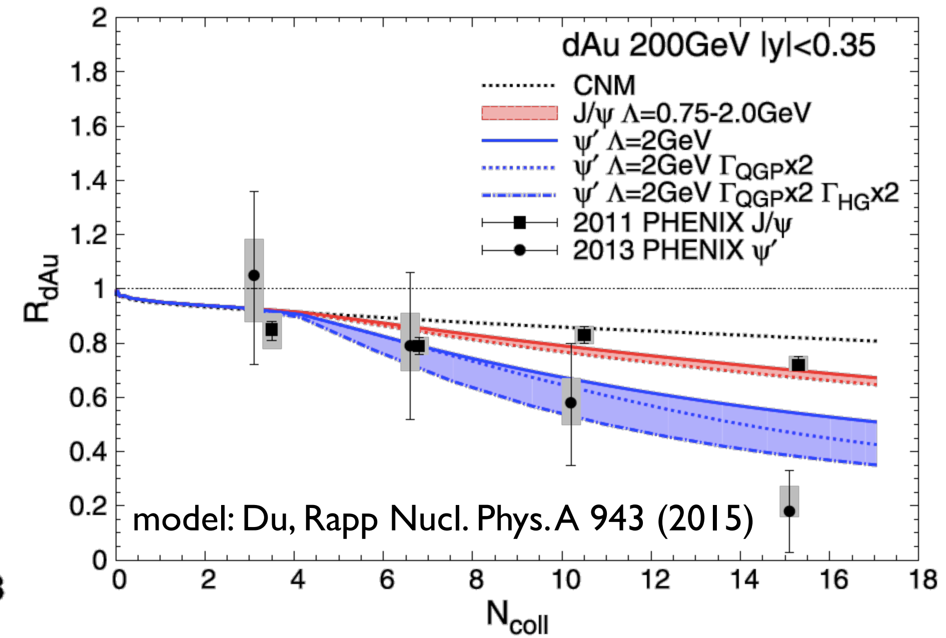
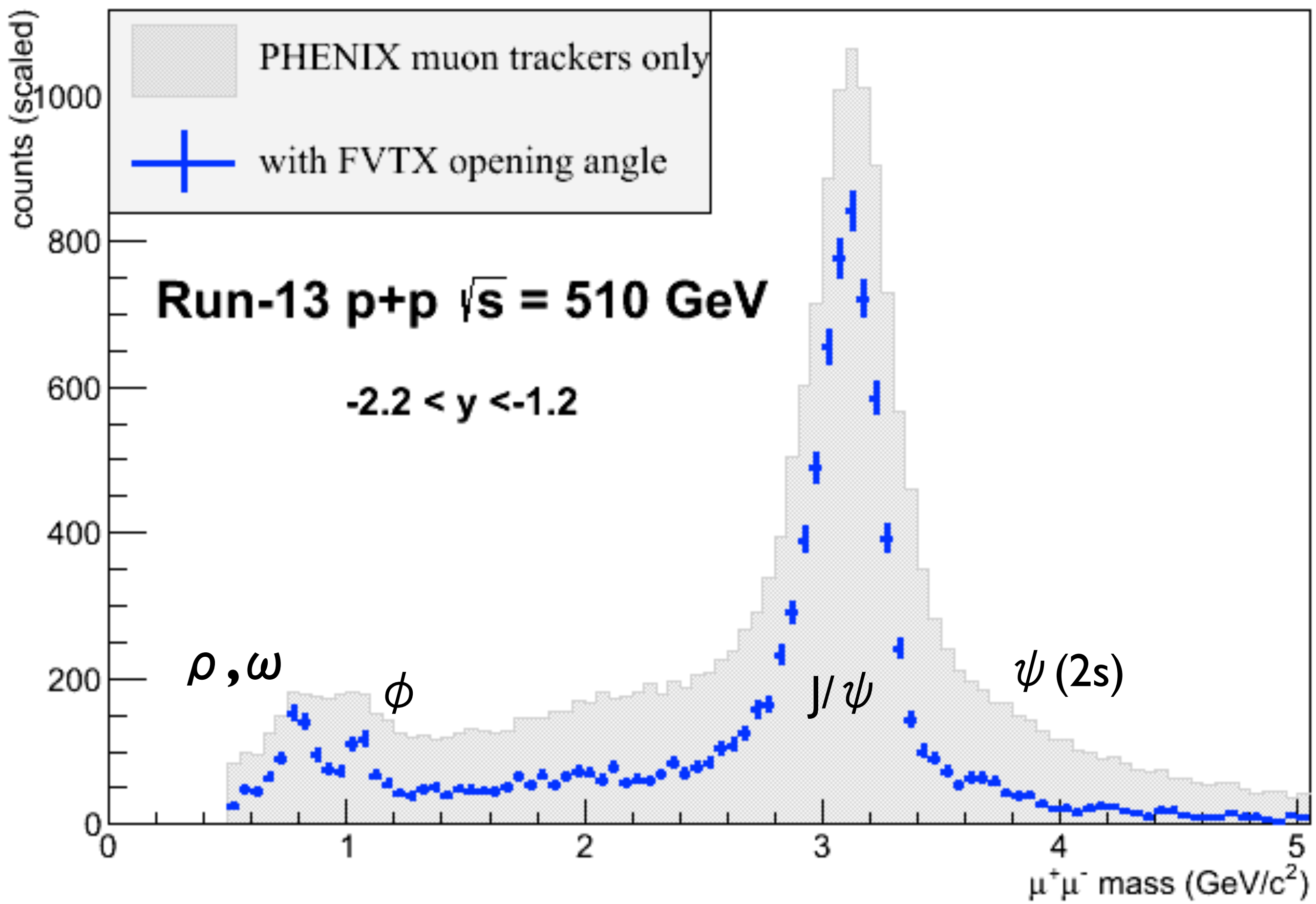




Model including **interaction with co-moving particles** reasonably well describes the suppression of J/ψ and ψ(2S) in d+Au collisions

Model considering **QGP formation in central d+Au collisions** and evolution to a hadronic gas state also show an agreement with the data

ψ(2S) at forward rapidity with FVTX



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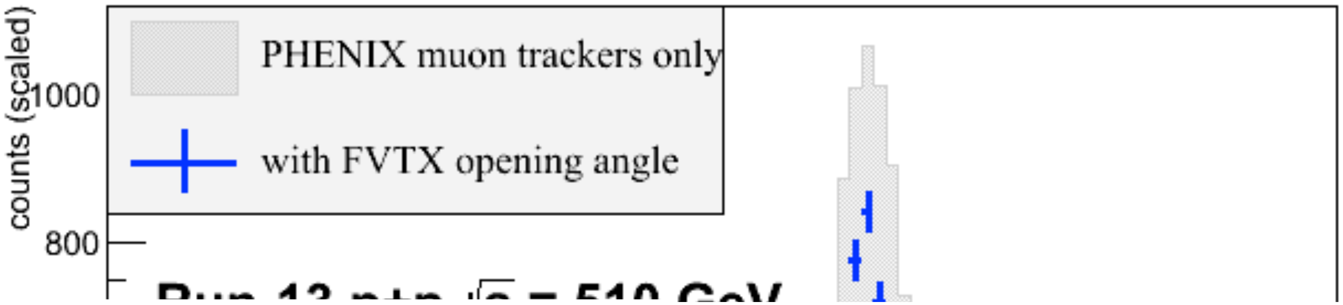
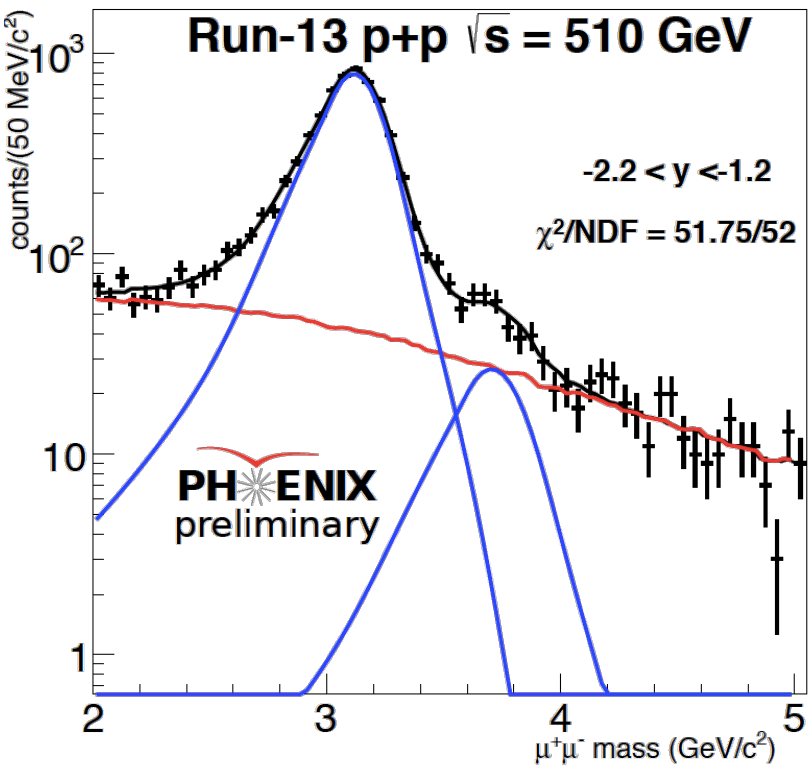
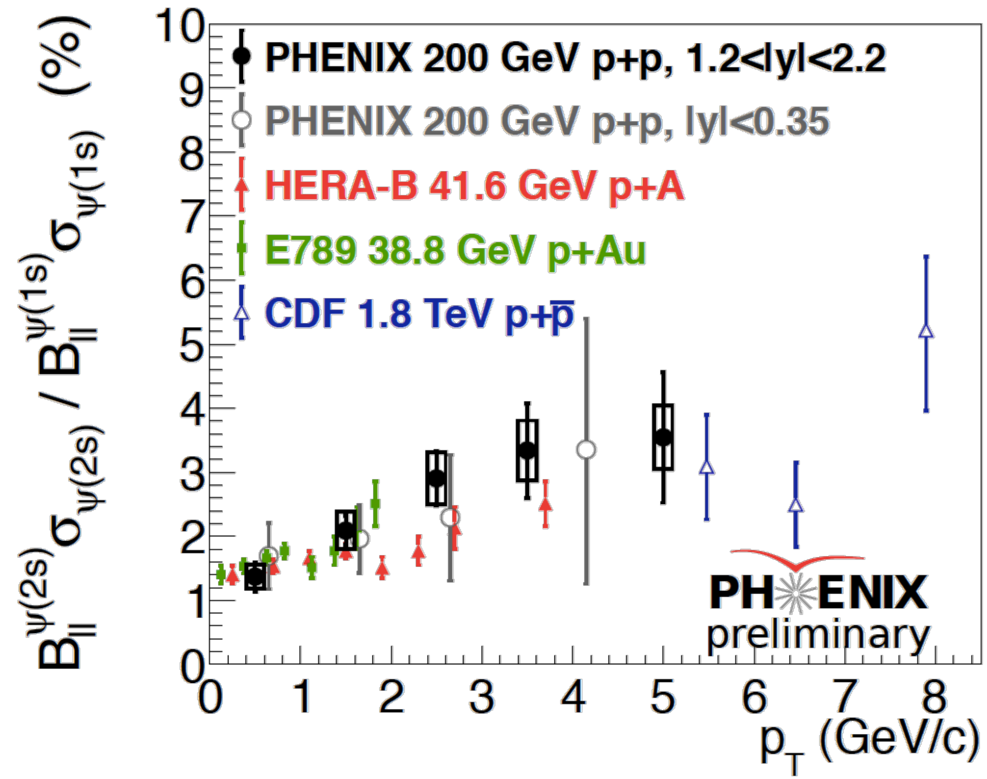


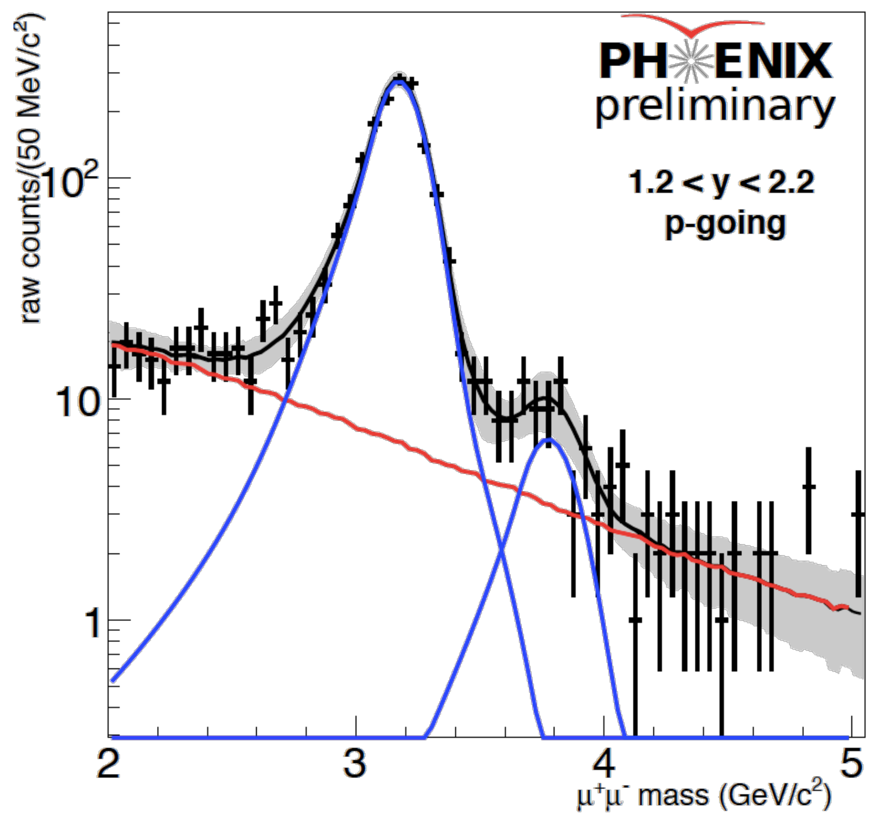




ψ(2S) at forward/backward in central p+Al collision

Forward
p-going direction

Run-15 p+Al $\sqrt{s}$ = 200 GeV

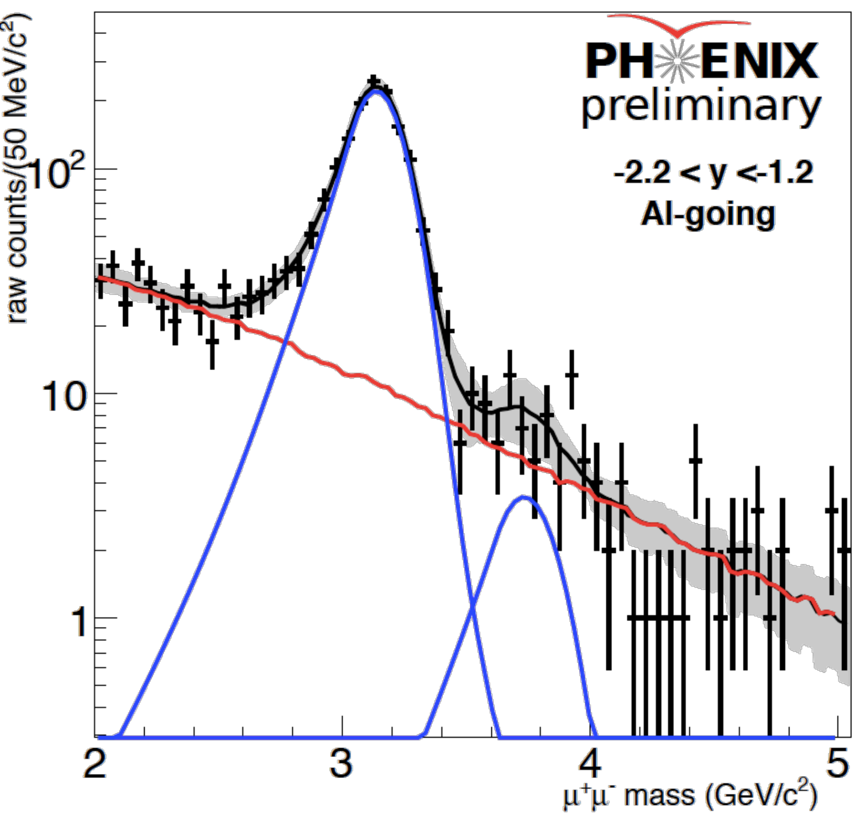


ψ(2S) at forward/backward in central p+Al collision

Backward
Au-going direction

Forward
p-going direction

Run-15 p+Al $\sqrt{s}$ = 200 GeV



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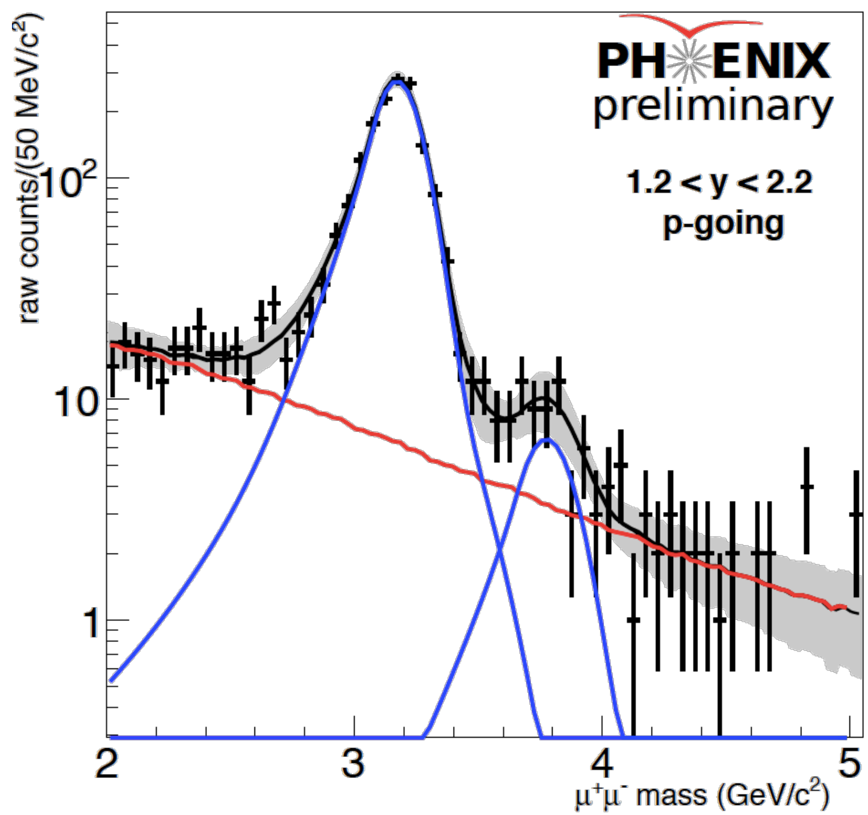

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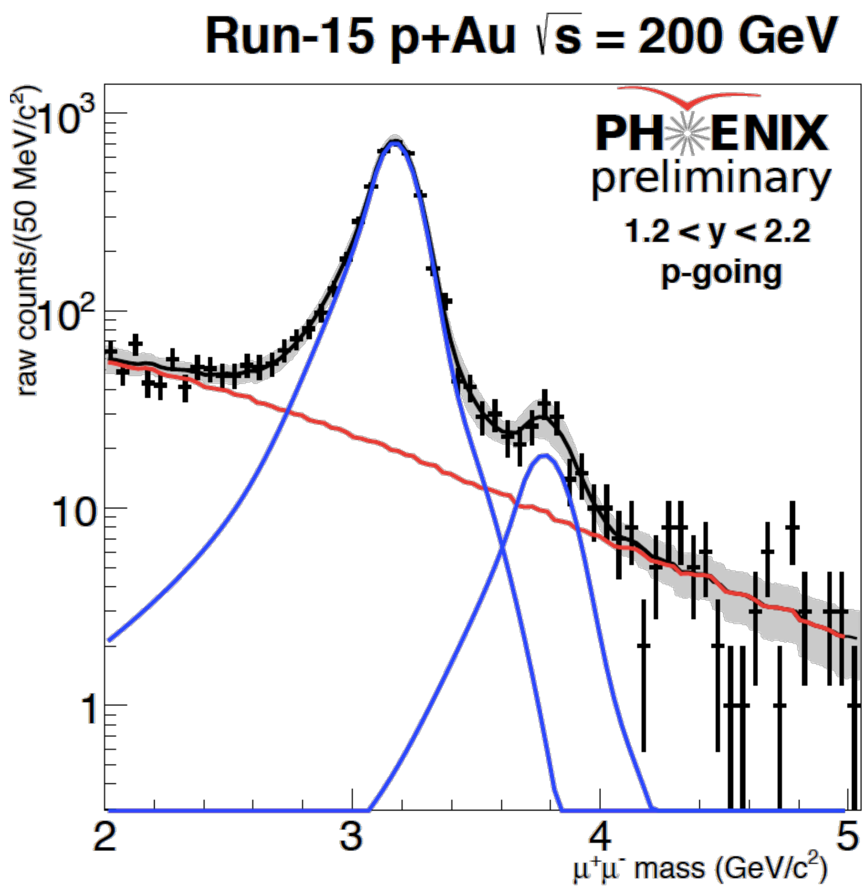

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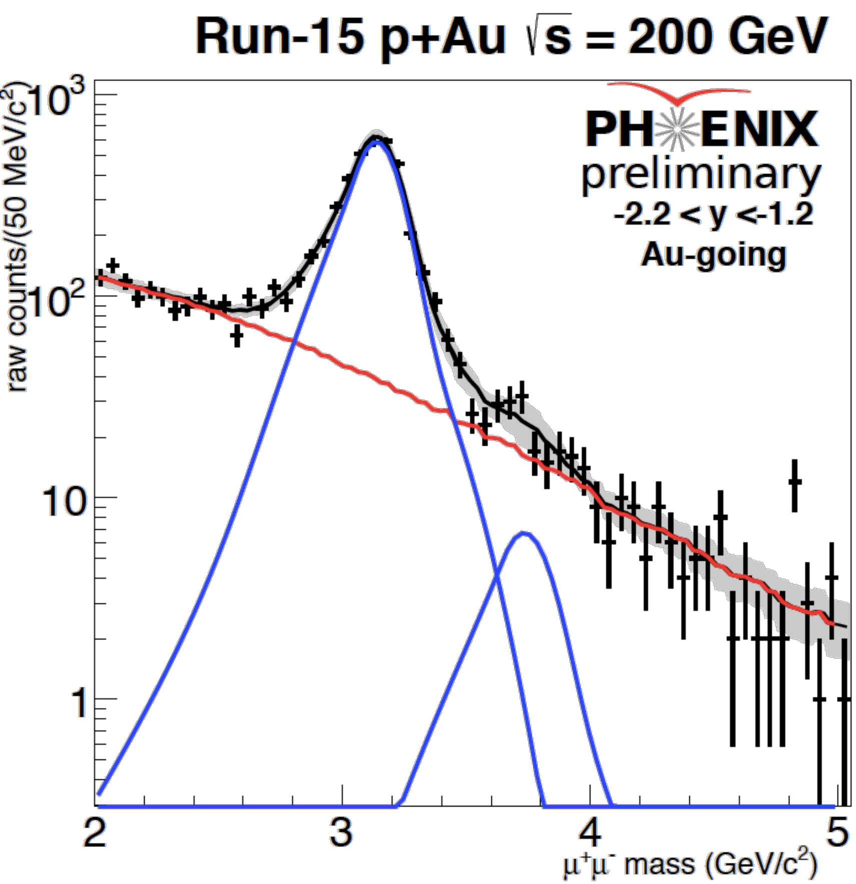
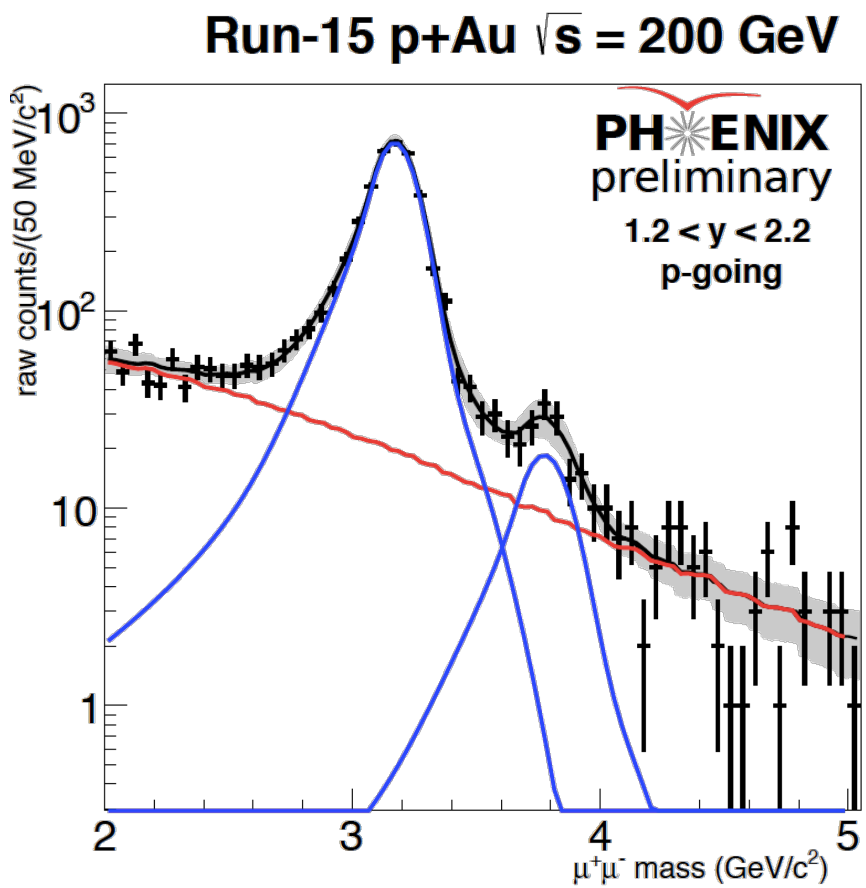
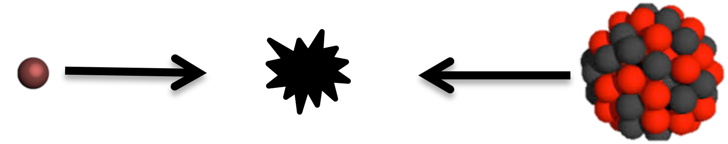
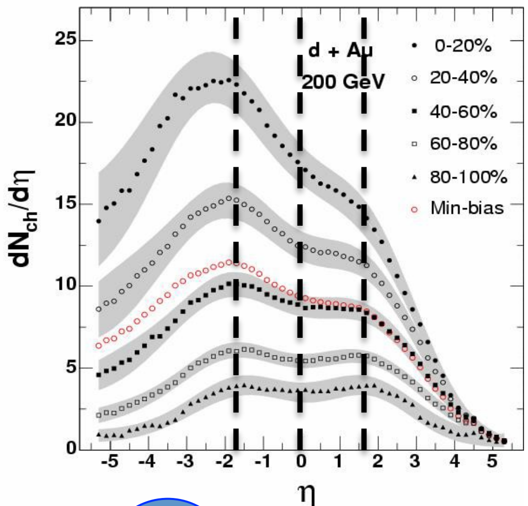


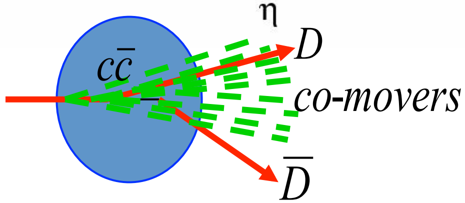


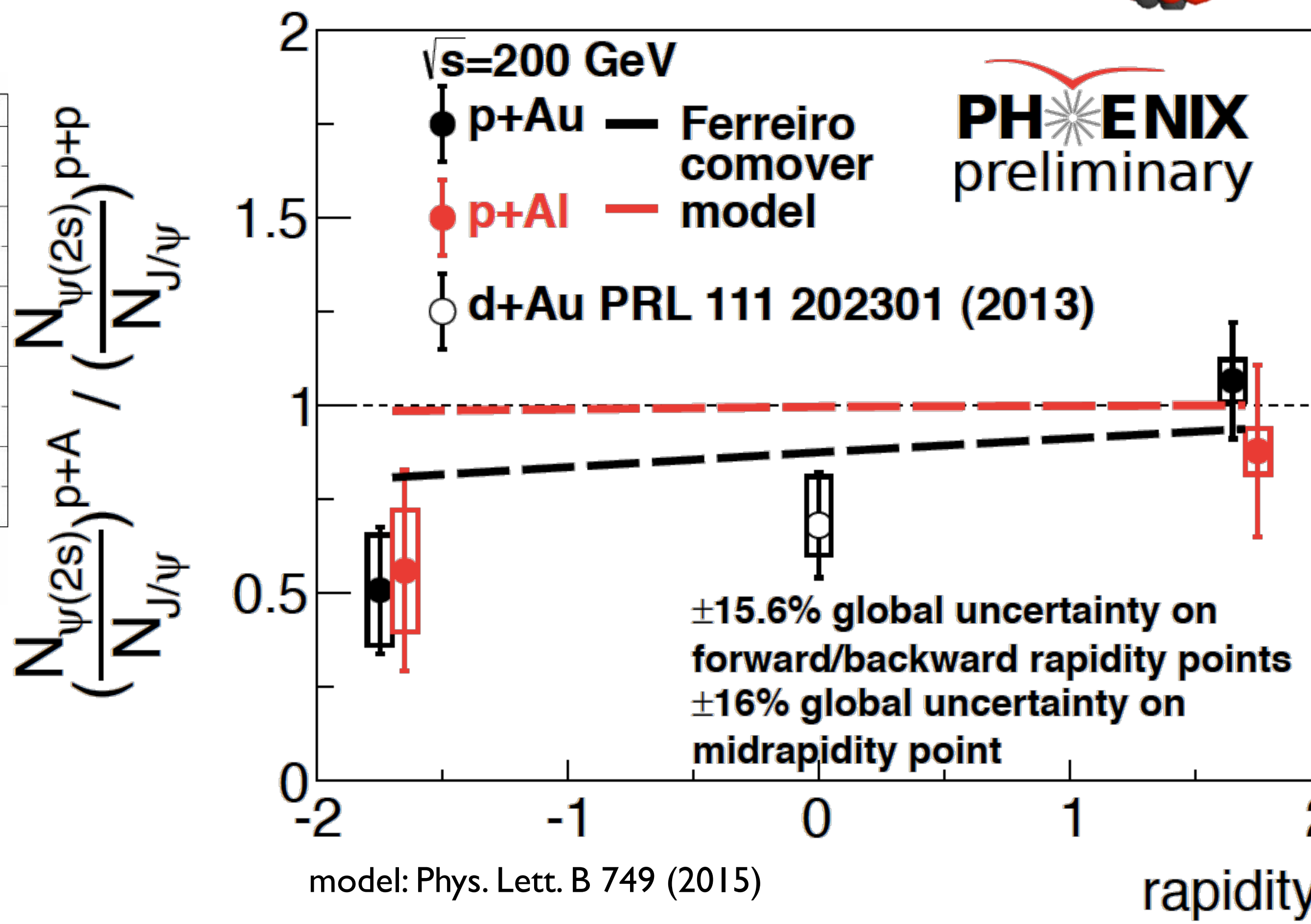
ψ(2S), easily broken up



Phys. Rev. C 72, 031901 (2005)

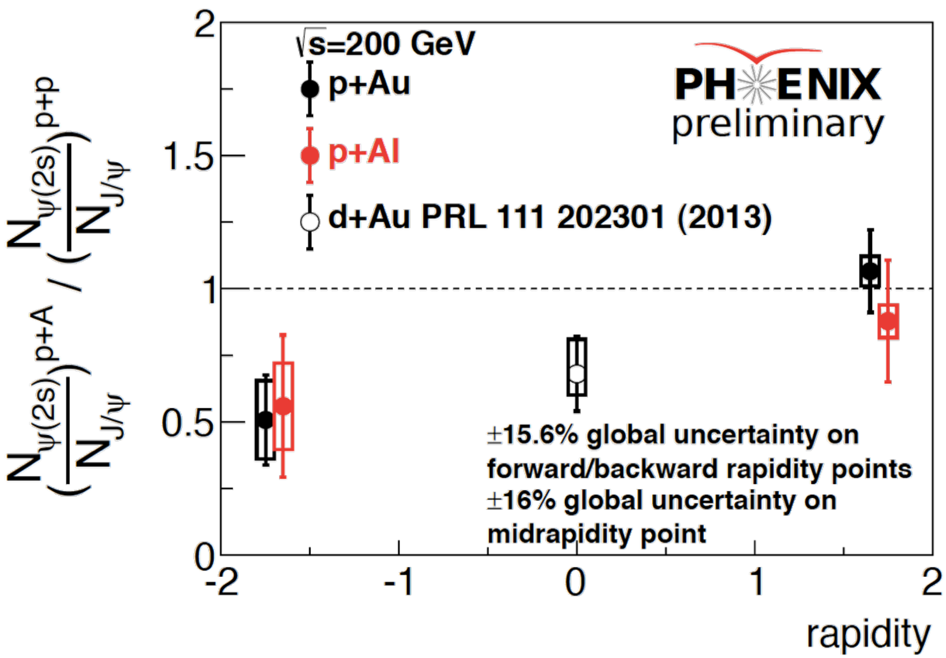


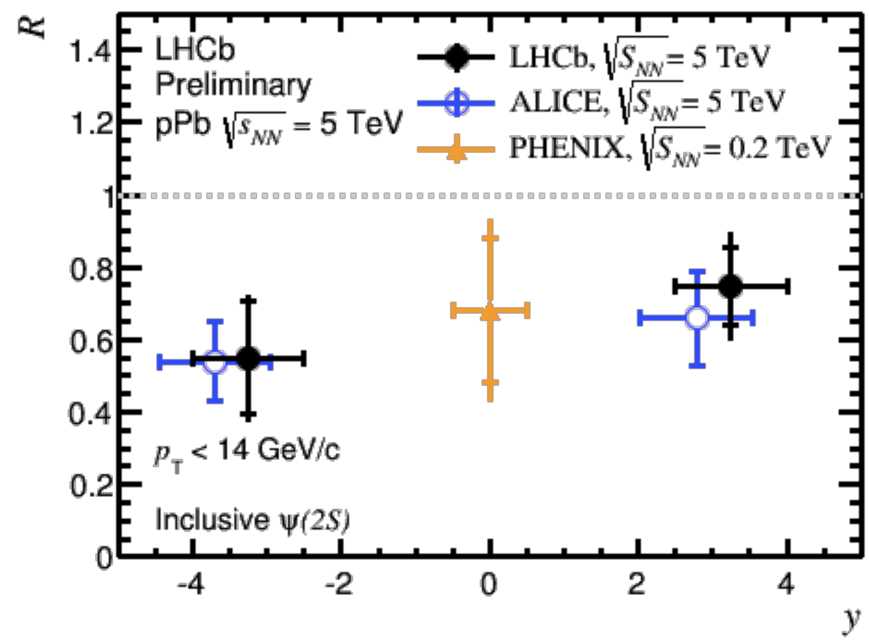




model: Phys. Lett. B 749 (2015)

Qualitatively agrees with the co-mover dissociation model
Comparison with the QGP model will be updated



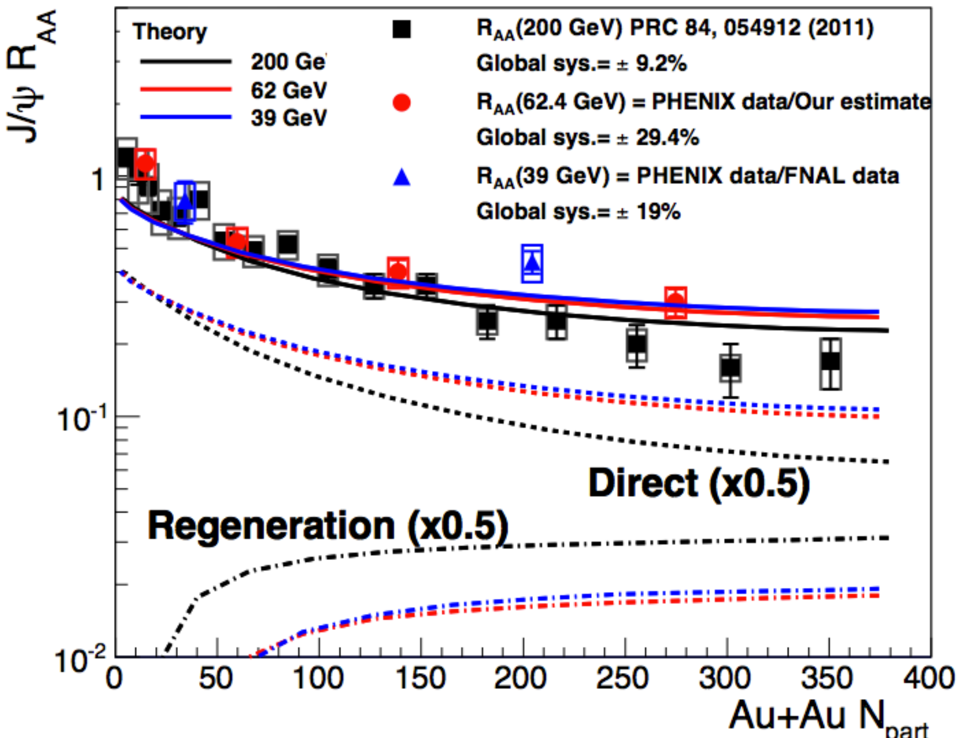


Similar relative suppression of ψ(2S) at backward rapidity, but larger relative suppression of ψ(2S) at forward rapidity at LHC

New results from heavy-ion collisions

Not a large effect of coalescence at RHIC?

similar suppression of J/ψ at forward in Au+Au collisions at 39, 62, and 200 GeV

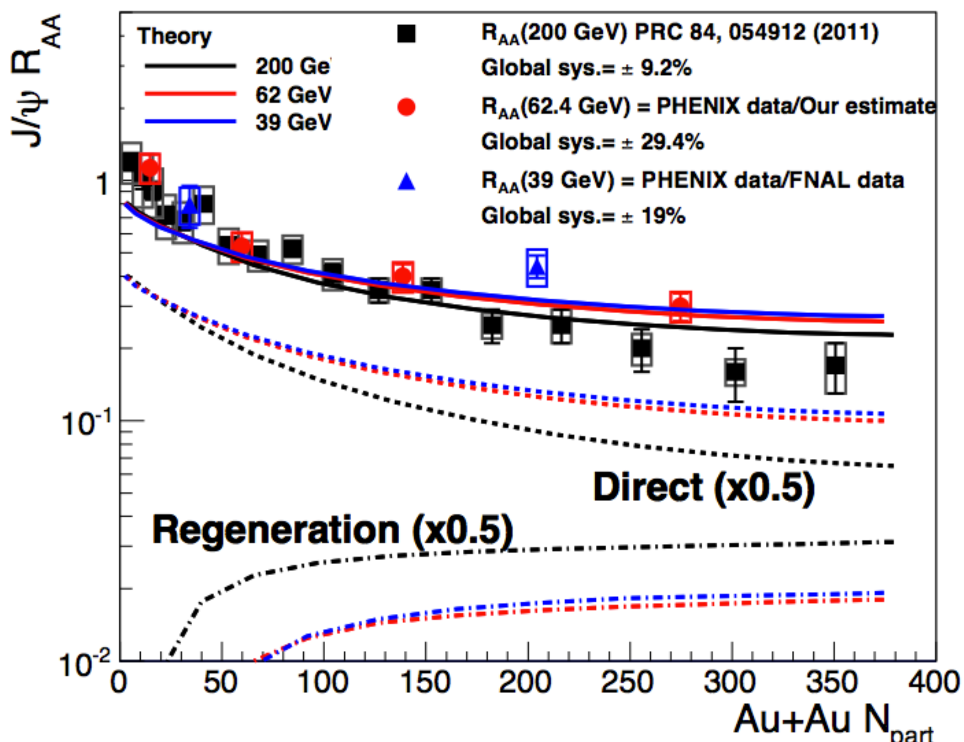


Phys. Rev. C 86, 064901 (2012)

Not a large effect of coalescence at RHIC?

similar suppression of J/ψ at forward in Au+Au collisions at 39, 62, and 200 GeV

less suppression at 2.76 TeV →strong coalescence at LHC



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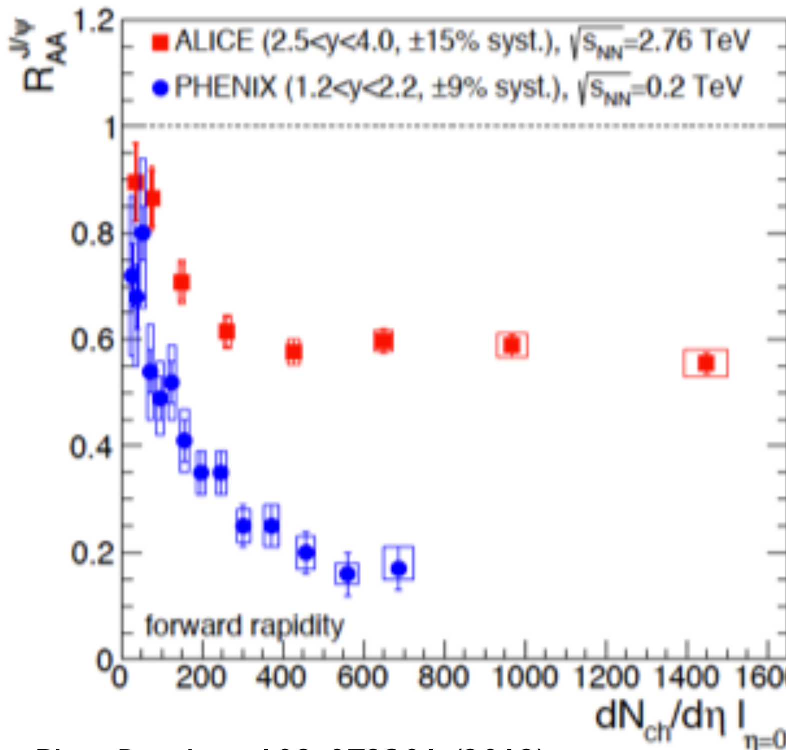
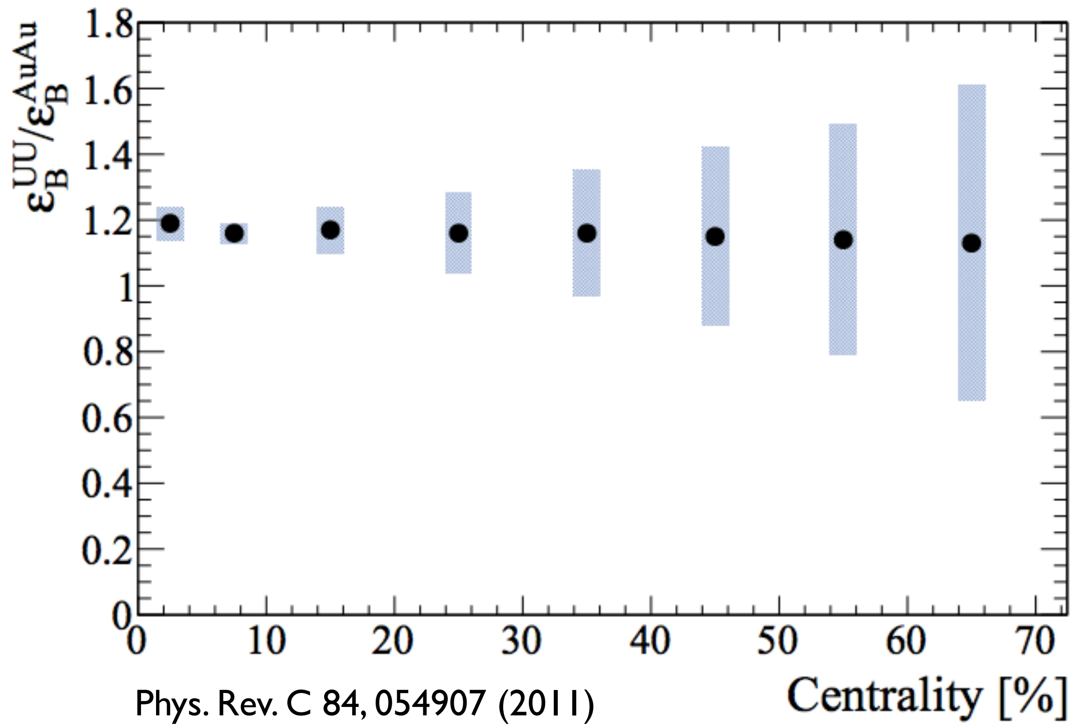


Phys. Rev. Lett 109, 072301 (2012)

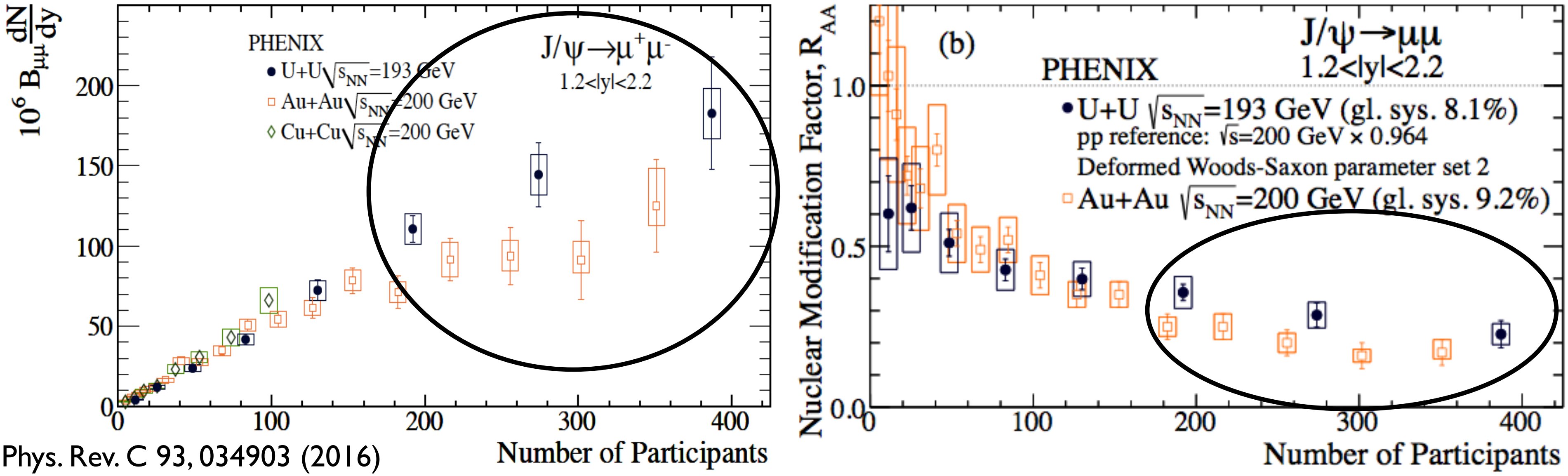
J/ψ production in U+U collisions

- U+U collisions provide highest density of matters at RHIC
  - ~20% higher energy density than Au+Au collisions
    →expect **stronger color screening**
  - ~25% larger binary collisions (N_{coll})
    →expect **more coalescence**



Phys. Rev. C 84, 054907 (2011)

J/ψ measurements in U+U collisions

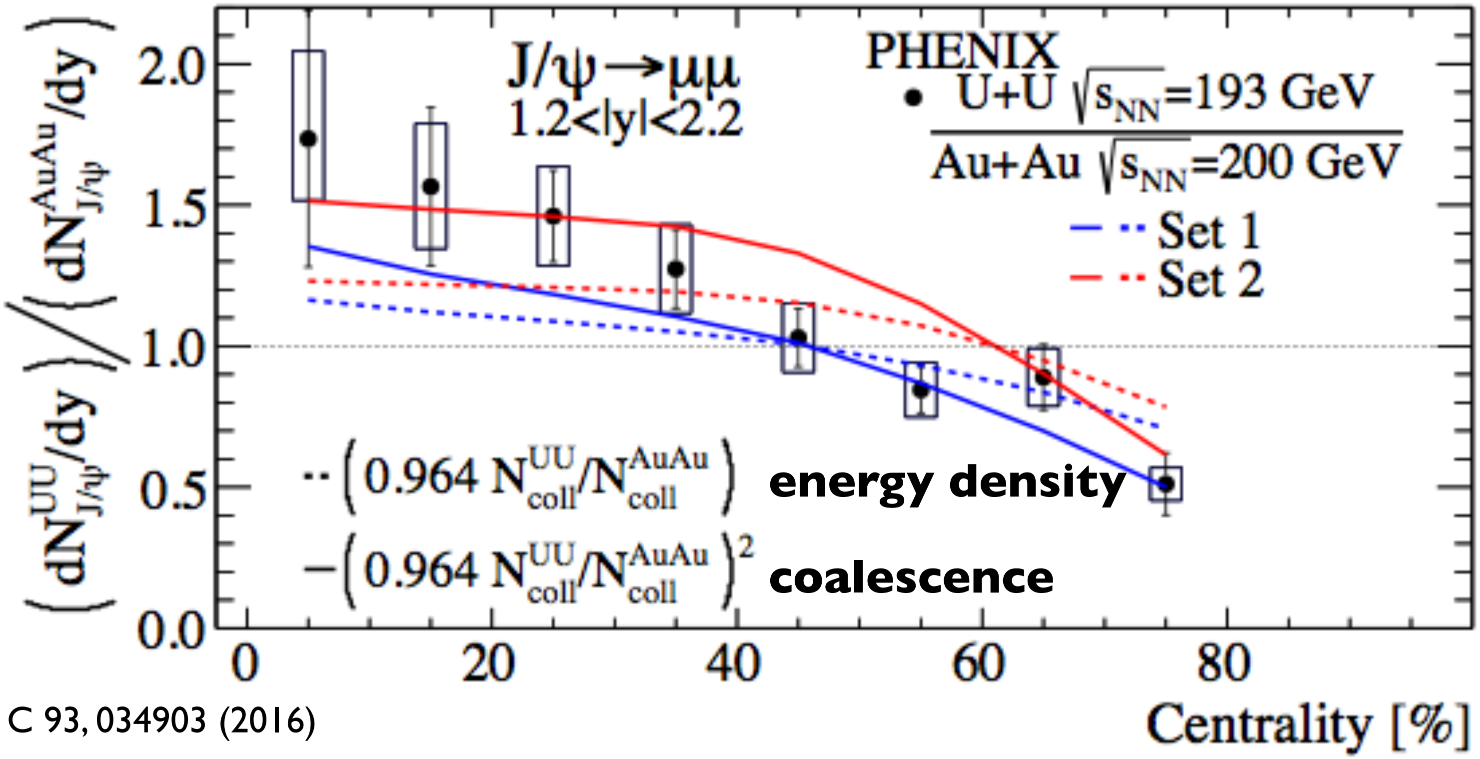


Phys. Rev. C 93, 034903 (2016)

more J/ψ production (less suppression)
in central U+U collisions than central Au+Au collisions

coalescence becomes important in central U+U collisions

J/ψ measurements in U+U collisions



Phys. Rev. C 93, 034903 (2016)

The J/ψ yield ratio between U+U and Au+Au shows a slight preference for N_{coll}^2 scaling in central collisions

Summary & Outlook

- ψ(2S) measurements at small system
  - Larger suppression than J/ψ at mid and backward rapidity
    →break-up due to co-mover? color screening?

- J/ψ measurements at U+U collisions
  - Less suppression in central U+U collisions than central Au+Au collisions
    →coalescence becomes important in central U+U collisions

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    →coalescence becomes important in central U+U collisions

- Quarkonia measurements in the future
  - J/ψ measurements in small systems
    results in all p+Al, p+Au, d+Au, and He+Au will give a comprehensive picture
  - ϒ/ψ(2S) measurements in Au+Au collisions
    results from large statistics of data (Run-14/Run-16) will be obtained

BACK UP