Open and Hidden Heavy Flavor Measurements at PHENIX

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Quarkonia in HI collisions

Volume 178, number 4 PHYSICS LETTERS B 9 October 1986

>2500 citations

J/ψ SUPPRESSION BY QUARK–GLUON PLASMA FORMATION ☆

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and

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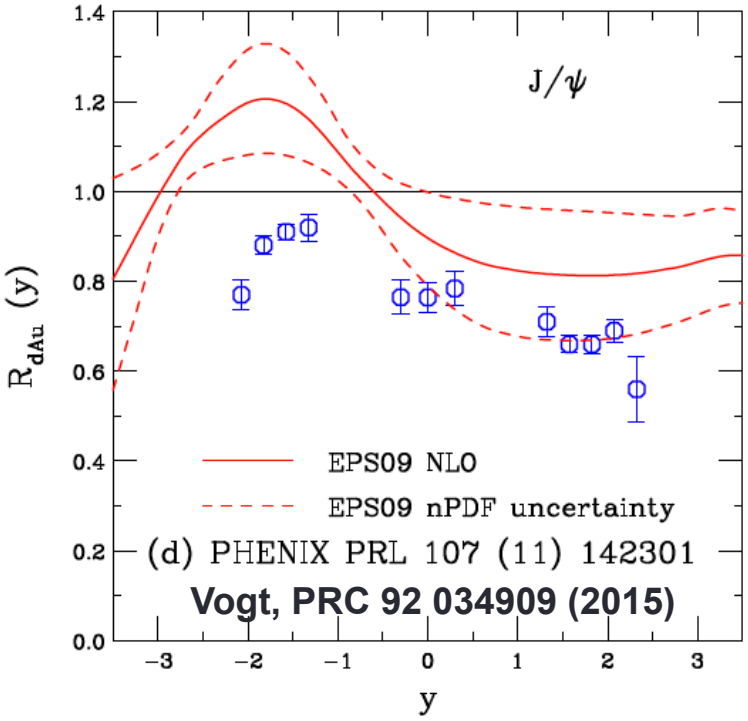
Received 17 July 1986

If high energy heavy ion collisions lead to the formation of a hot quark–gluon plasma, then colour screening prevents $c\bar{c}$ binding in the deconfined interior of the interaction region. To study this effect, the temperature dependence of the screening radius, as obtained from lattice QCD, is compared with the J/ψ radius calculated in charmonium models. The feasibility to detect this effect clearly in the dilepton mass spectrum is examined. It is concluded that J/ψ suppression in nuclear collisions should provide an unambiguous signature of quark–gluon plasma formation.

“unambiguous signature of QGP formation”

Quarkonia in HI collisions

PDF Modifications



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ratory, Upton, NY 11973, USA

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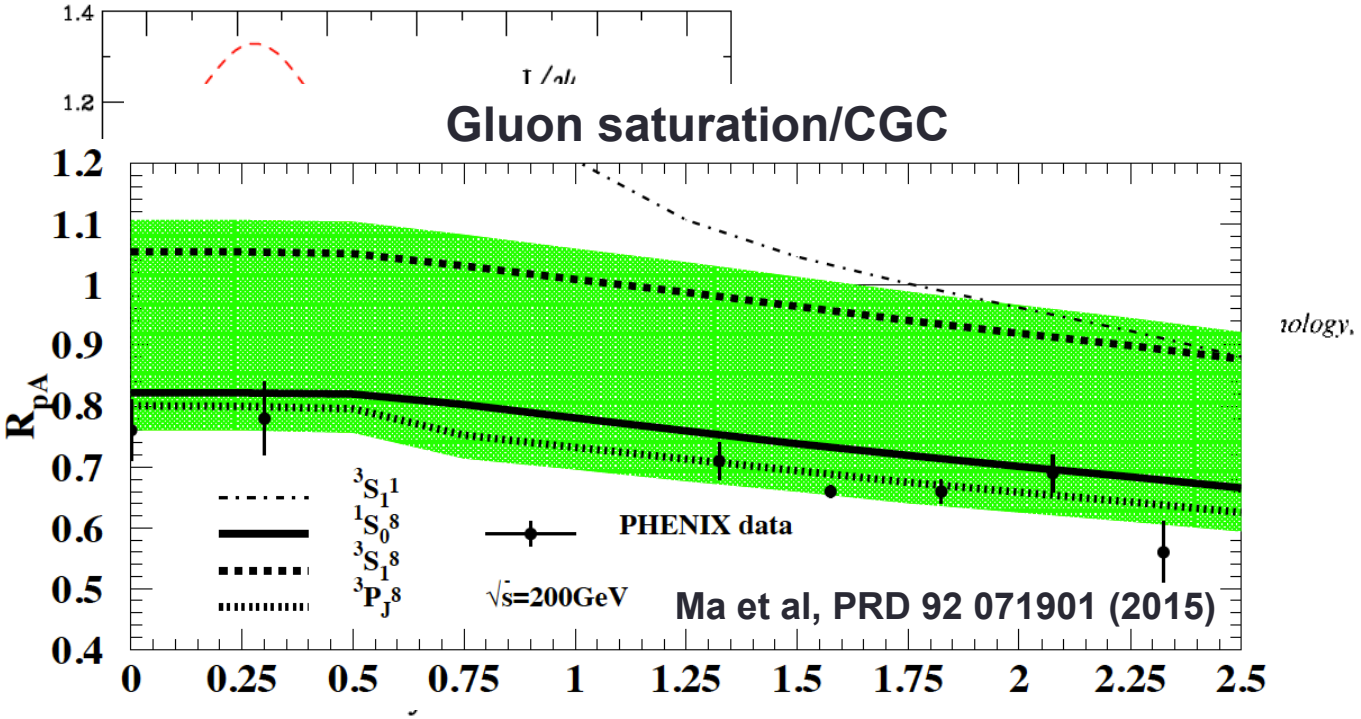

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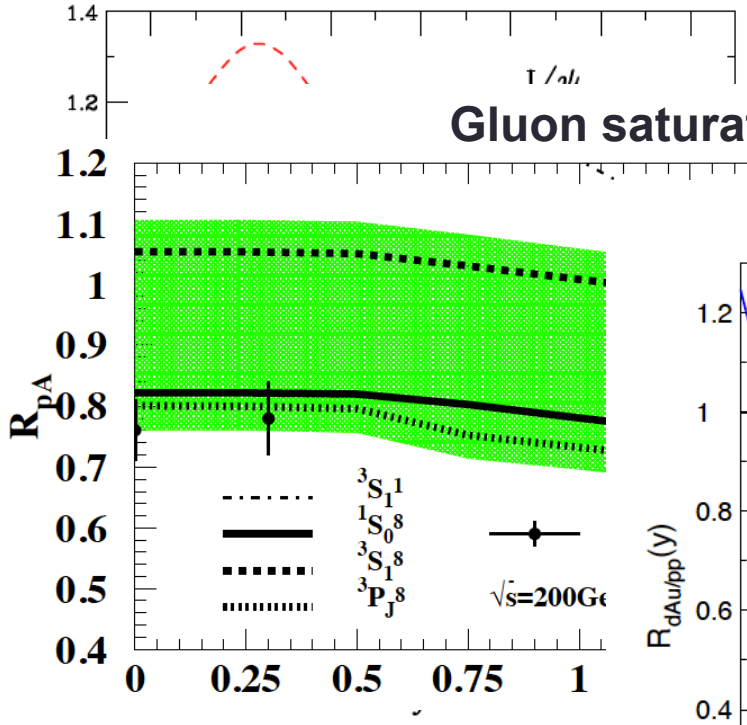
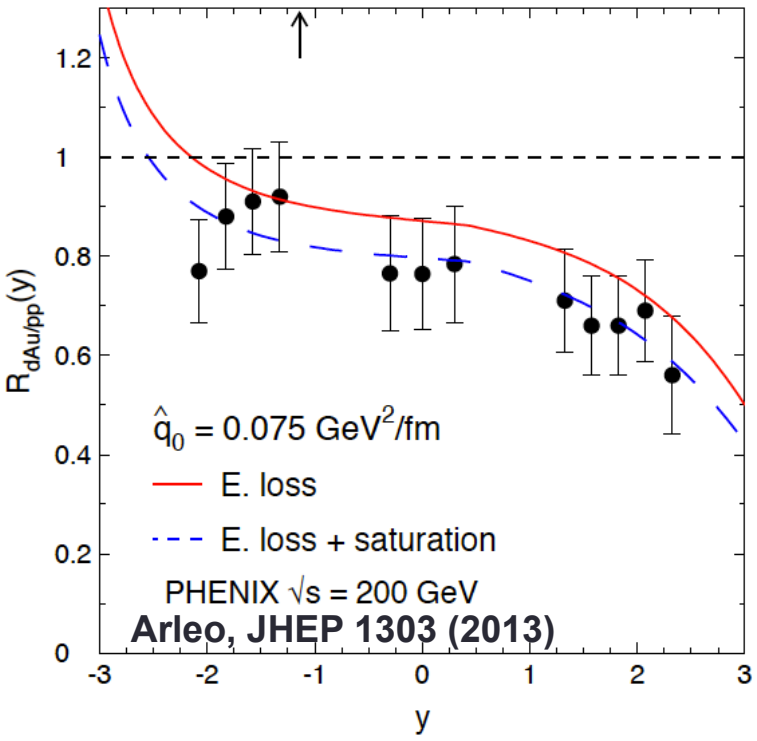


Gluon saturation/CGC



Energy Loss

HYSICS LETTERS B

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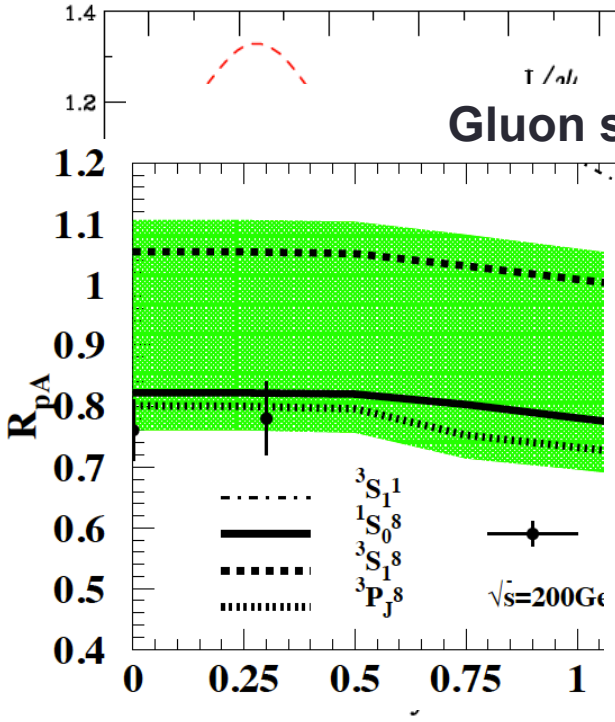

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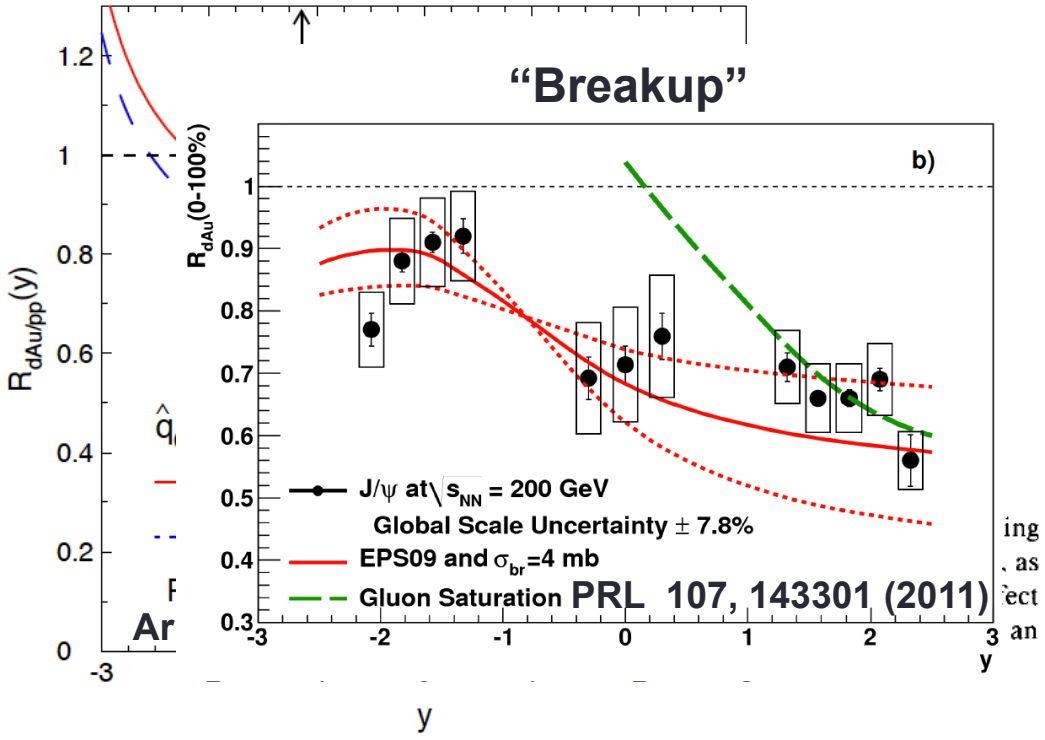
"Breakup"



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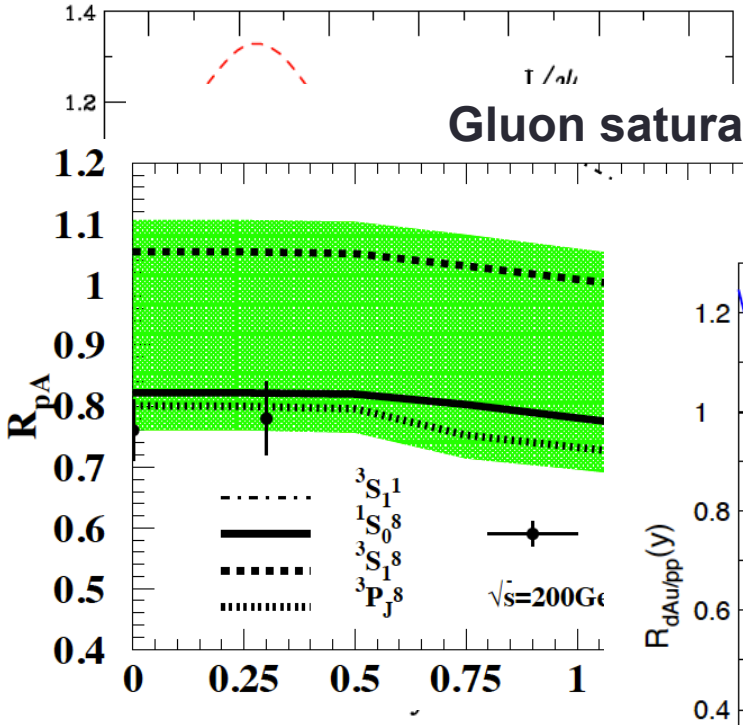

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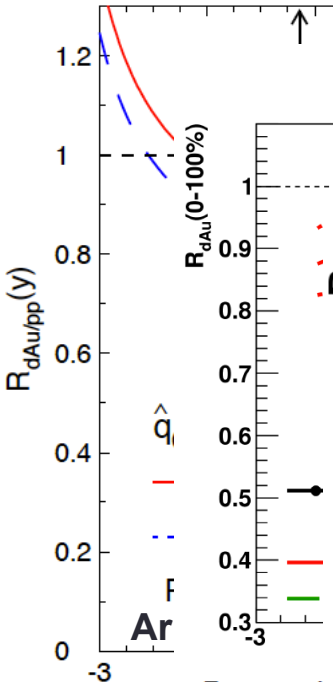
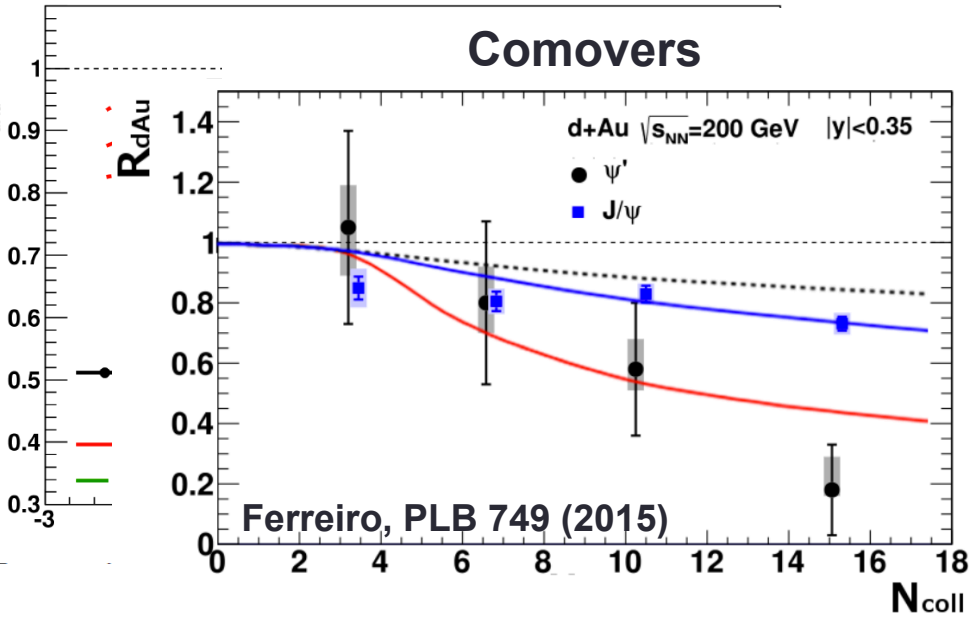


"Breakup"

Comovers



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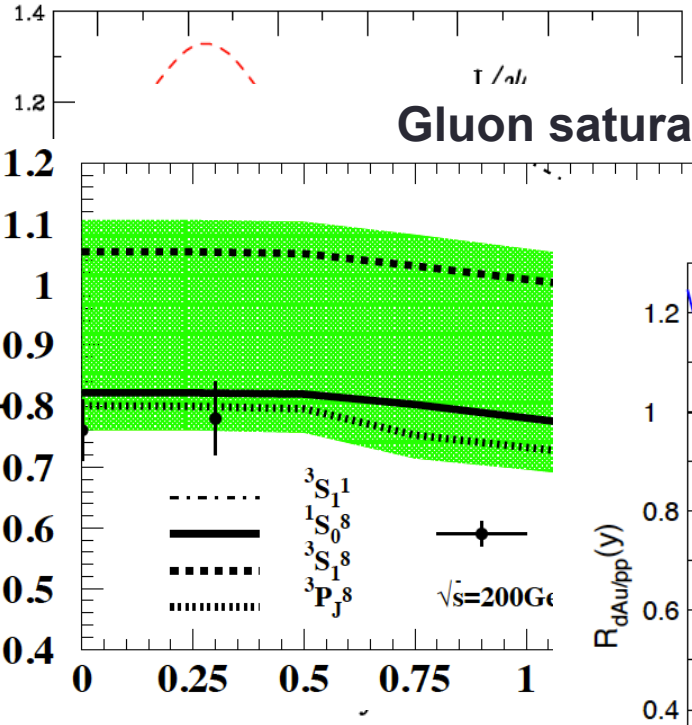

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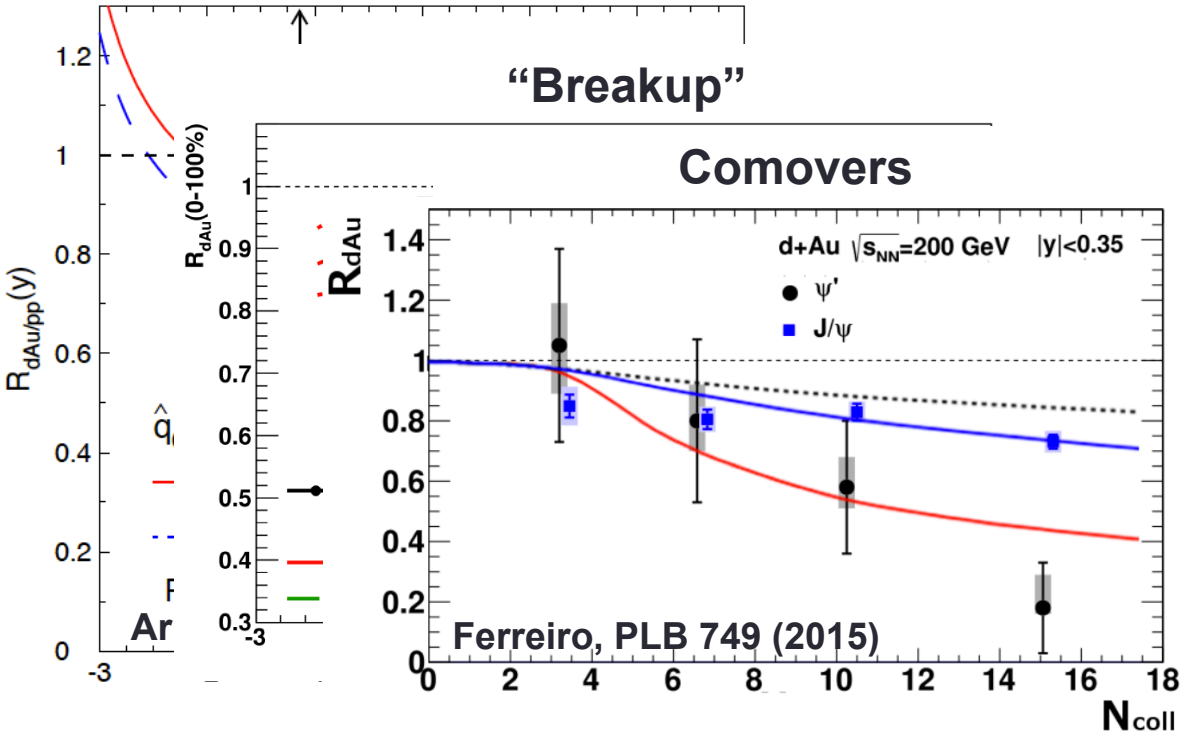


~~"Unambiguous signature of QGP formation"~~

PHENIX Detector

Designed to measure quarkonia down to pT = 0 through dilepton decays at mid and forward rapidity, and open HF through semileptonic decays

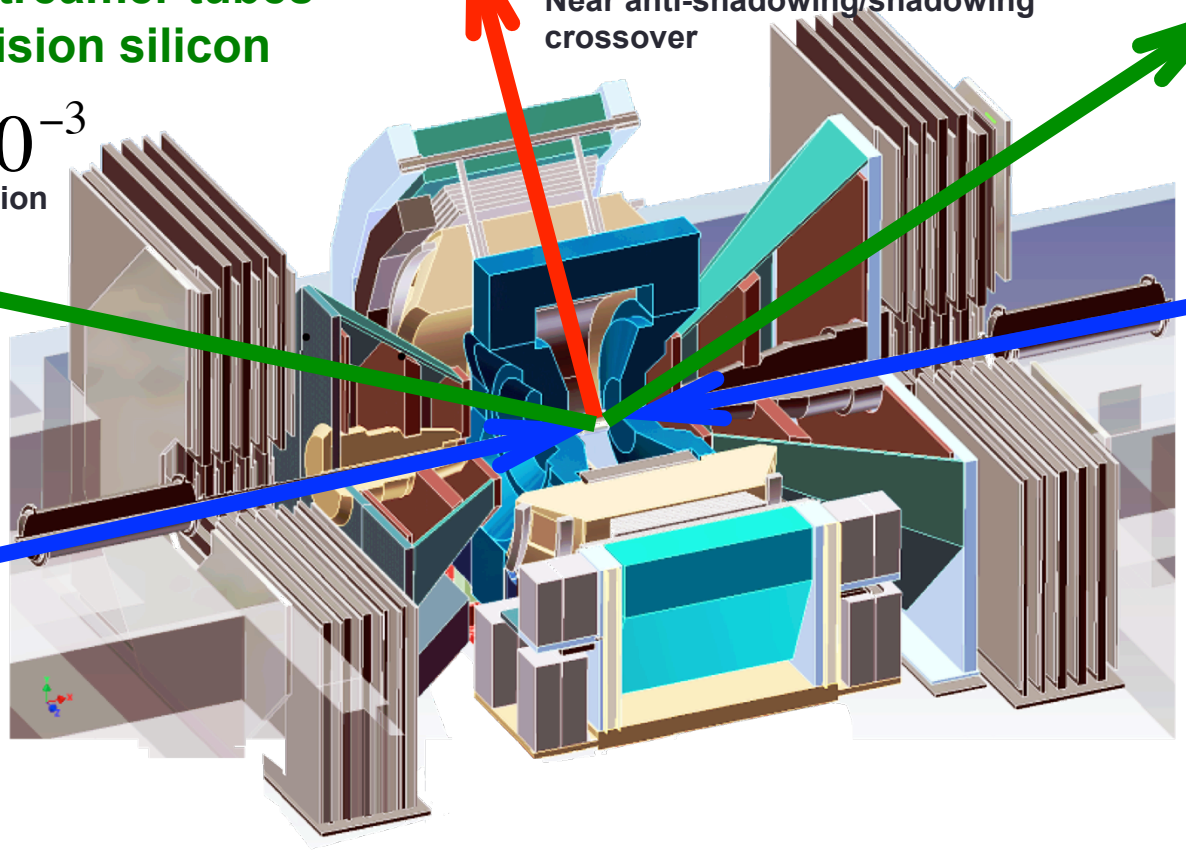
Muons: 1.2 < |y| < 2.2,
-Tracked with wire chambers
-Further muon ID with layers of steel and streamer tubes
NEW: Precision silicon tracking

$x \approx 5 \times 10^{-3}$
Shadowing region

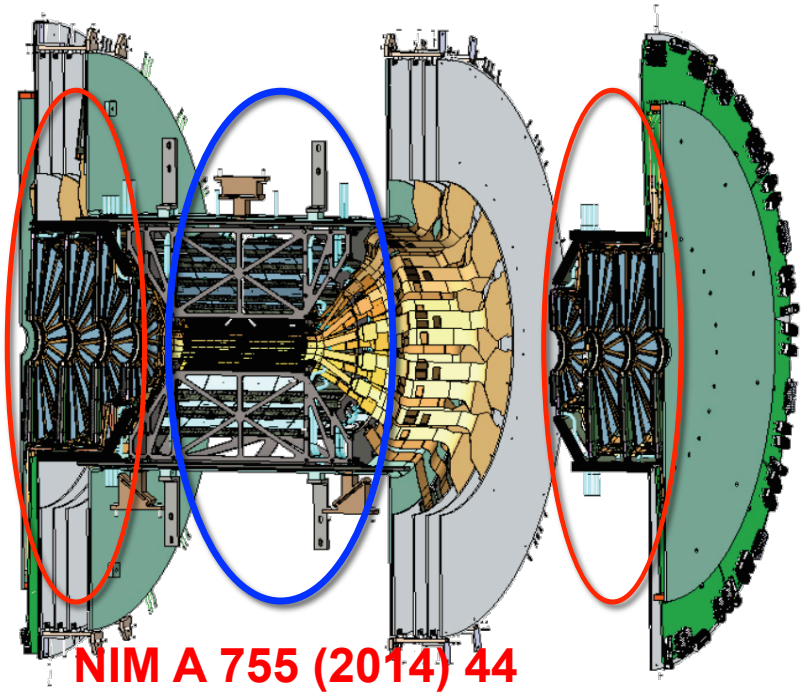
Electrons: |y| <0.35,
-Tracked with DC,PC
-ID with RICH, EmCal

$x \approx 3 \times 10^{-2}$
Near anti-shadowing/shadowing crossover

$x \approx 8 \times 10^{-2}$
Anti-shadowing region



Precision tracking with silicon



NIM A 755 (2014) 44

Midrapidity, 2011 - on: VTX provides precision DCA and vertex measurements

Forward, 2012 - on: FVTX gives precision tracking in front of absorber

- Improved dimuon mass resolution, precision DCA measurements

Data recorded: p+p, p+Al, p+Au, ^{3}He+Au, Cu+Au, Au+Au, d+Au energy scan

- **Separated b,c suppression (PRC 93 034904, 2016)**
- **forward/backward ψ(2s) (this presentation)**
- **B->J/ψ (Xuan Li)**
- **improved rxn plane (Javier, Shengli)**
- **Drell-Yan (hard at work)**

Charm initial state

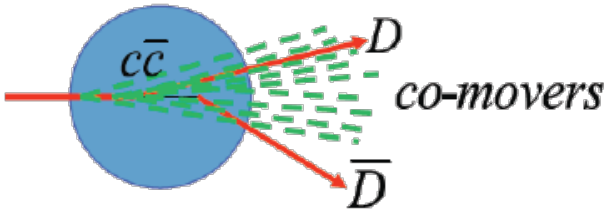
Open charm is the proper reference for evaluating effects on J/ψ

- **Sensitive to same initial state effects: gluon shadowing, kT broadening, partonic energy loss in nucleus**

$$d\sigma(Q^2,\sqrt{s})_{pA\to a+X} = \sum_{i,j=q,\bar{q},g} f_i^p(x_1,Q^2) \otimes A f_i^A(x_2,Q^2) \otimes d\hat{\sigma}(Q^2,x_1,x_2)_{i,j\to a+X}$$

At RHIC/LHC energies, charm projection onto final state happens *outside nucleus*

- **Species with same quark content but different radii and binding energy are more/less sensitive to final state disruption**



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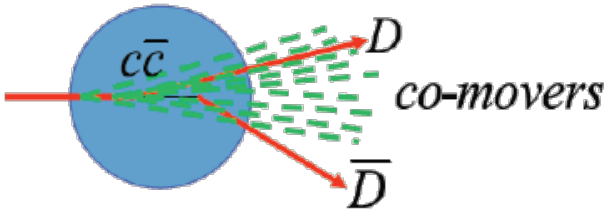

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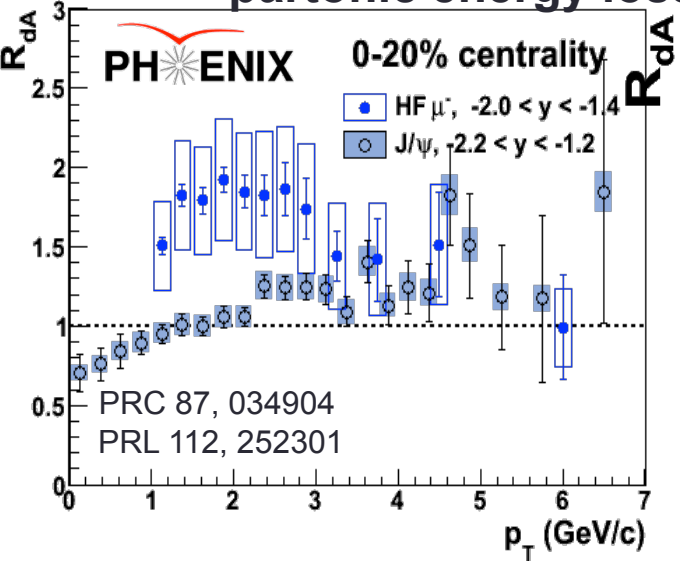
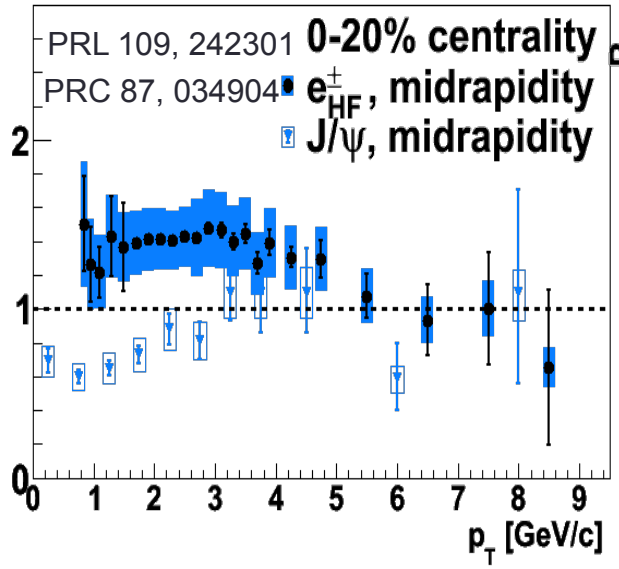
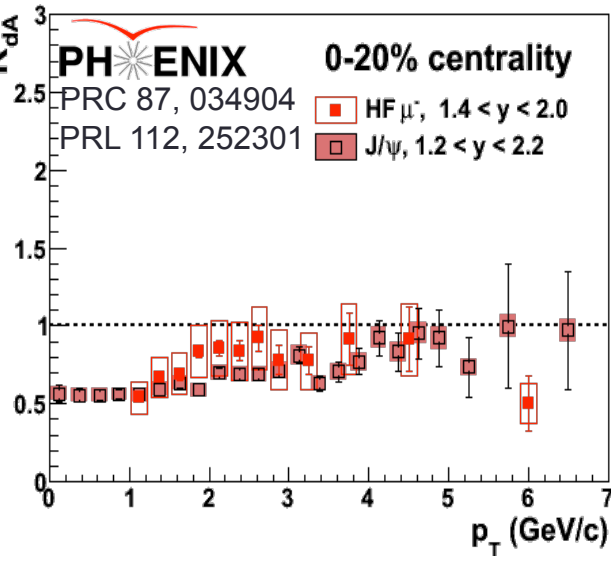




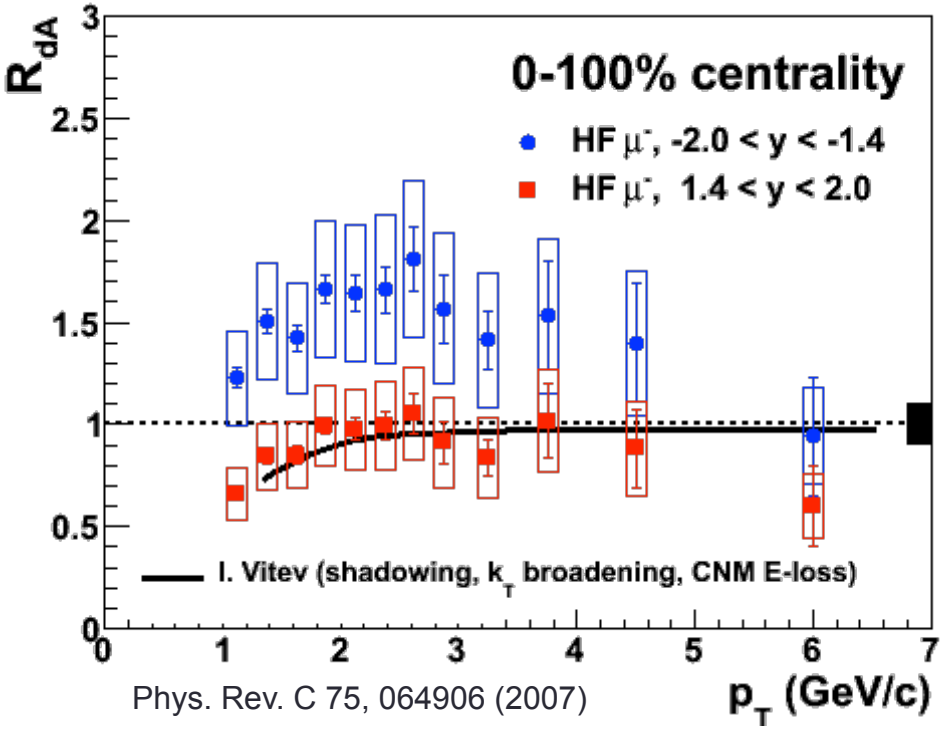


Mid- and backwards rapidity: DIFFERENT behavior
***enhanced* open HF versus *suppressed* J/ψ**

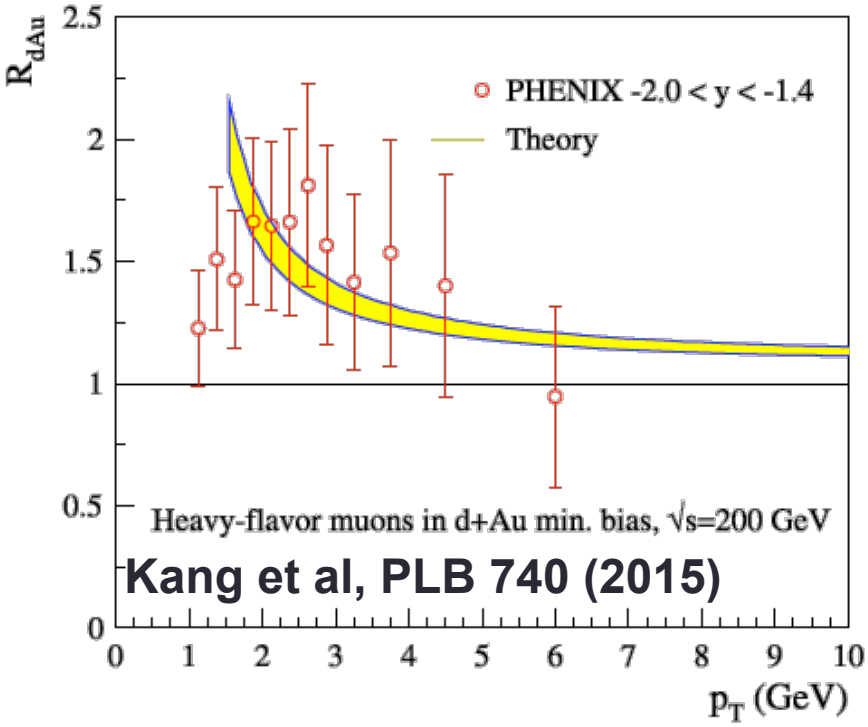
Forward: similar behavior
-Short time in nucleus
-Low co-mover density
-Shadowing region of nPDF

Evidence for significant *cc* breakup

CNM Models



Phys. Rev. C 75, 064906 (2007)

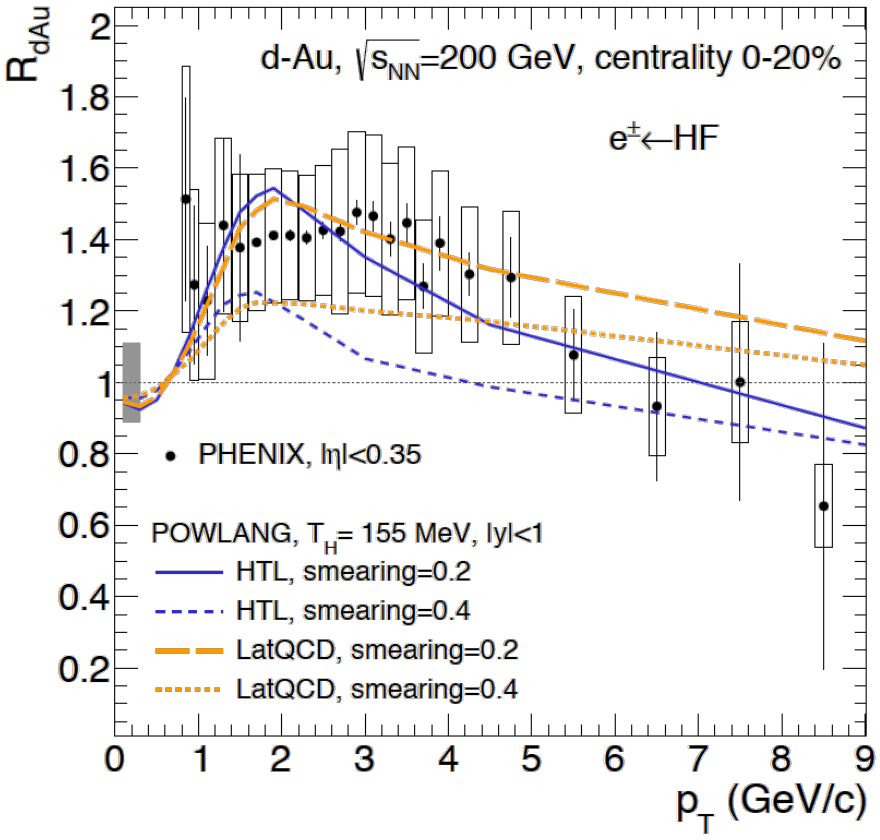


Calculation includes Cronin broadening via parton scattering, shadowing, energy loss in cold nuclear matter

Calculation at backward rapidity also includes incoherent multiple parton scattering in nuclear medium. ->AFAIK, the only calculation that can reproduce backwards rapidity data.

d+A Flow Model

Beraudo et al, JHEP03 (2016) 123



EPS09 + kT broadening, Langevin transport in short-lived medium, with different transport coefficients.

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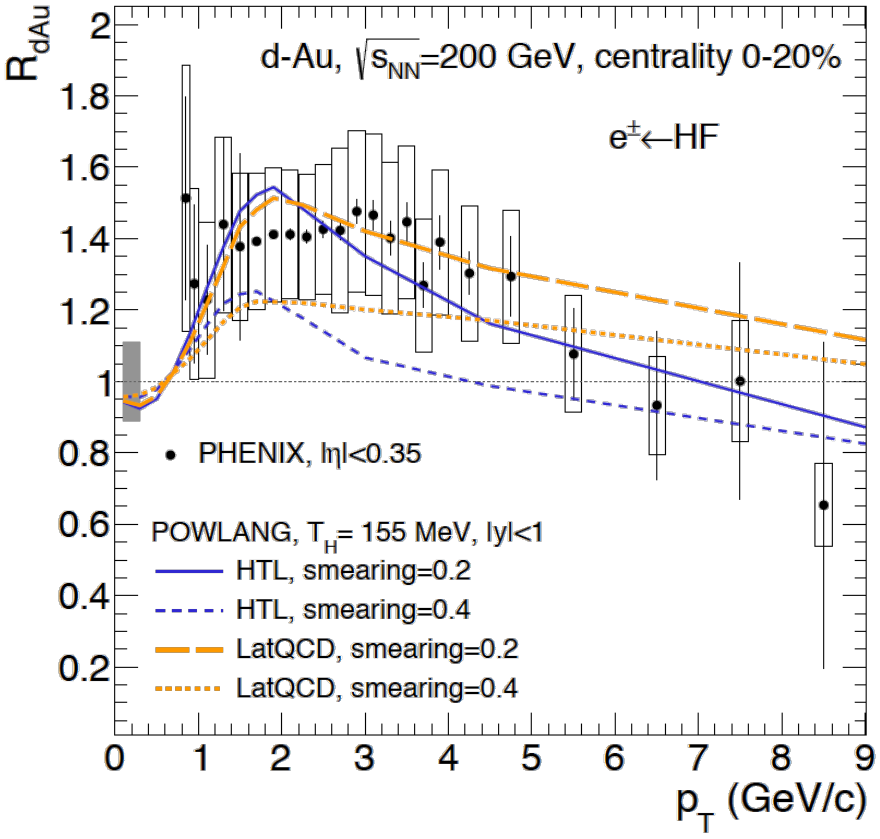
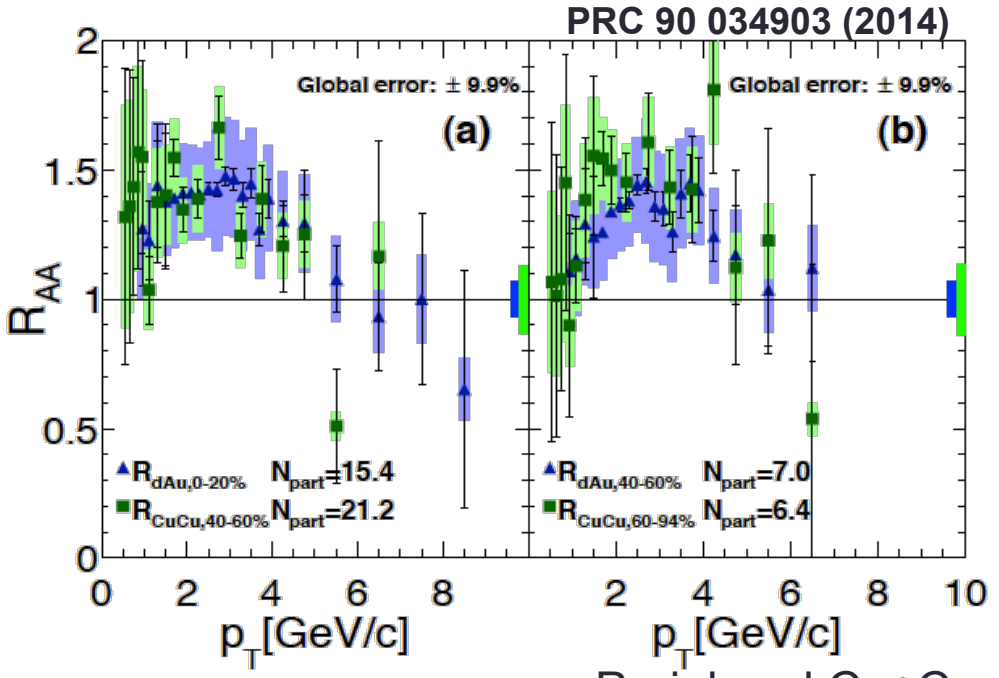
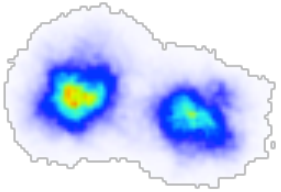
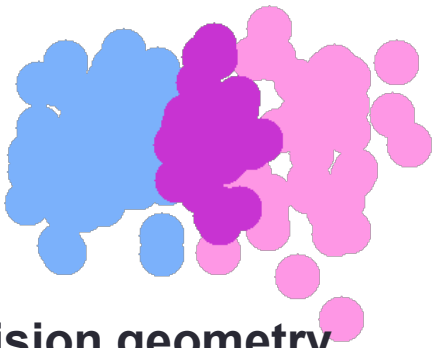




Central d+Au



Peripheral Cu+Cu



EPS09 + kT broadening, Langevin transport in short-lived medium, with different transport coefficients.

This different collision geometry could be an interesting test for flow models.

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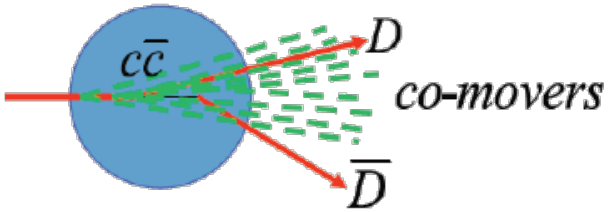
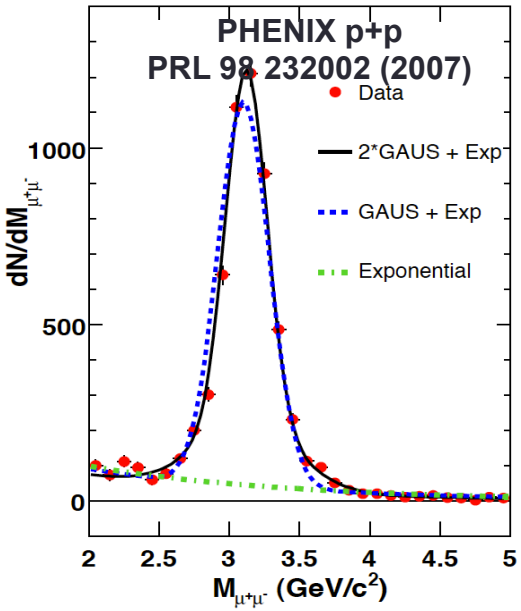
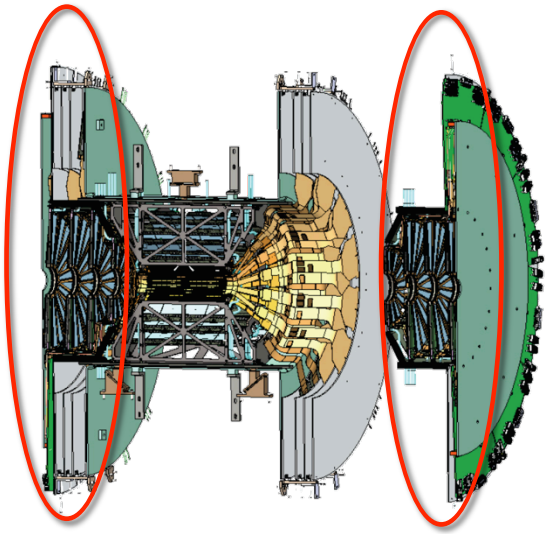


New capabilities



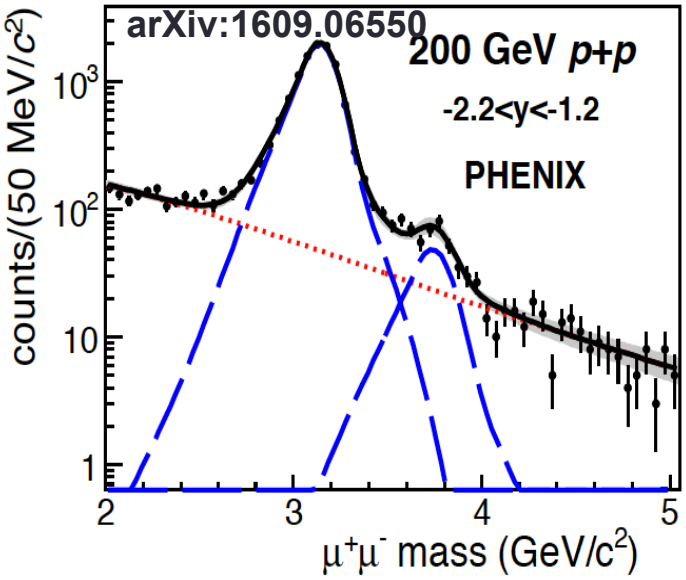
Measure pair opening angle in front of absorber

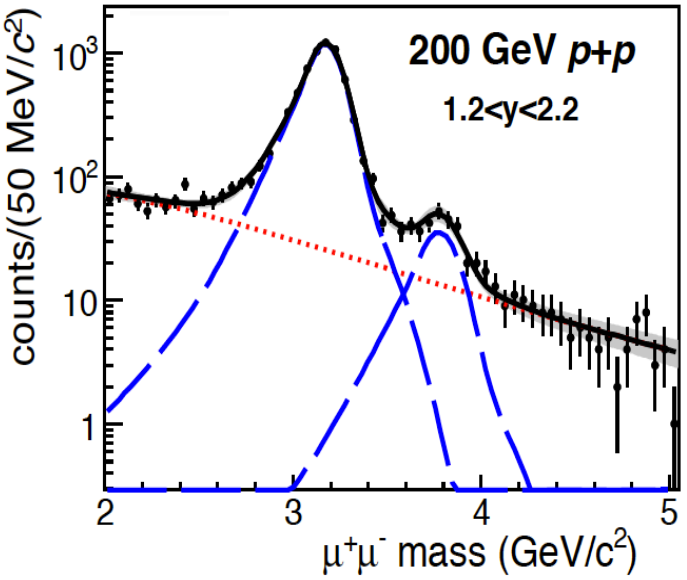
FVTX



Resolve ψ(2s) state in dimuon continuum at forward/backward rapidity:

Differences in 2S and 1S production must come in final state





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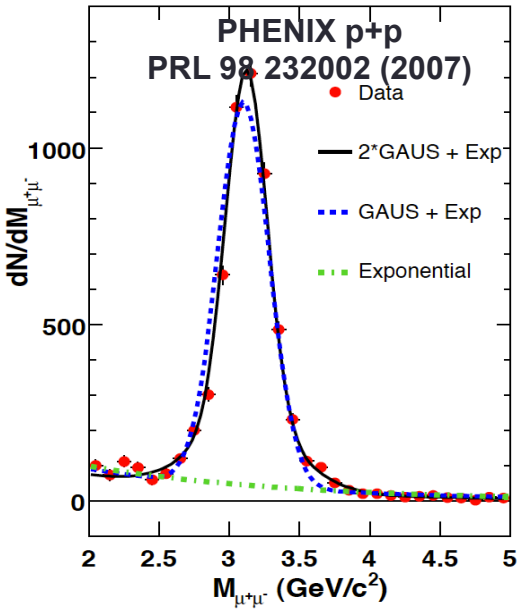

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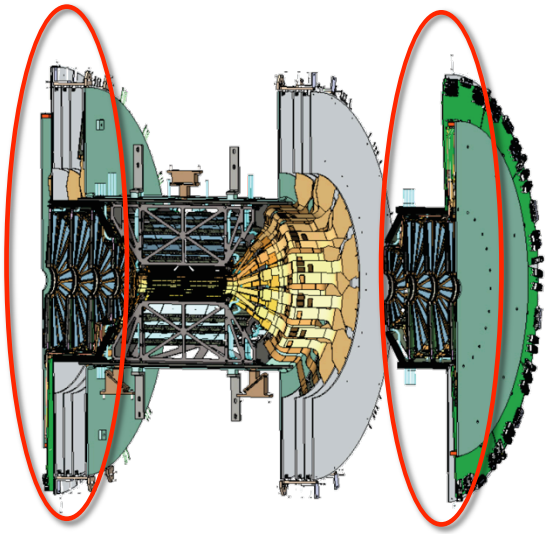
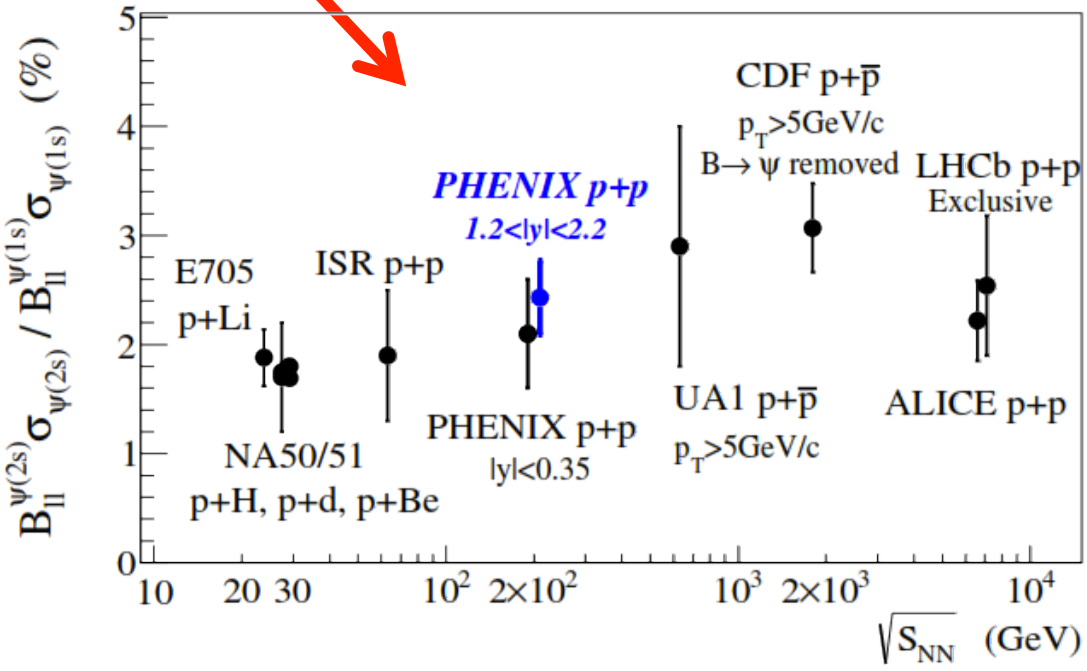
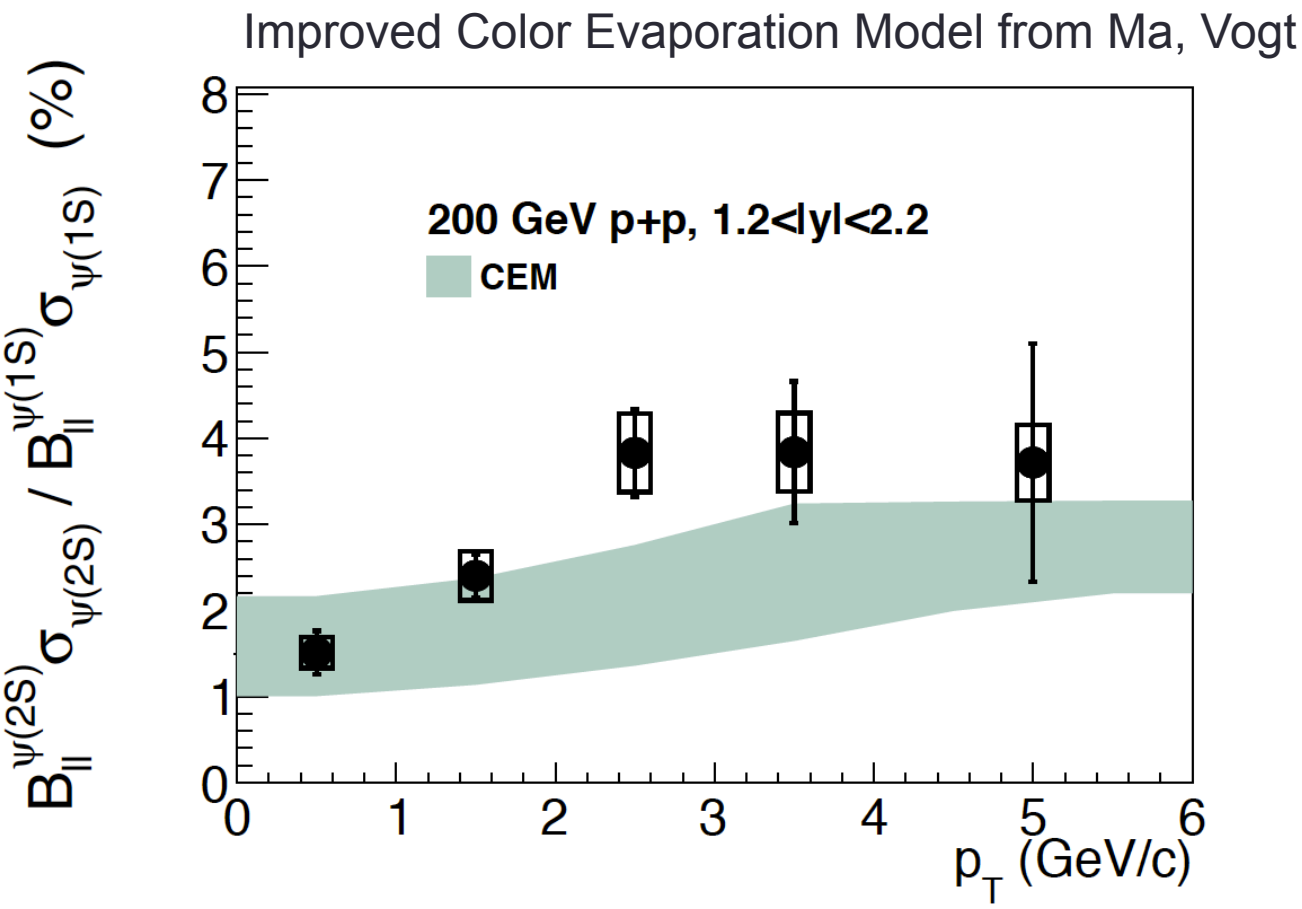




Forward ψ(2s) measurements



200 GeV p+p

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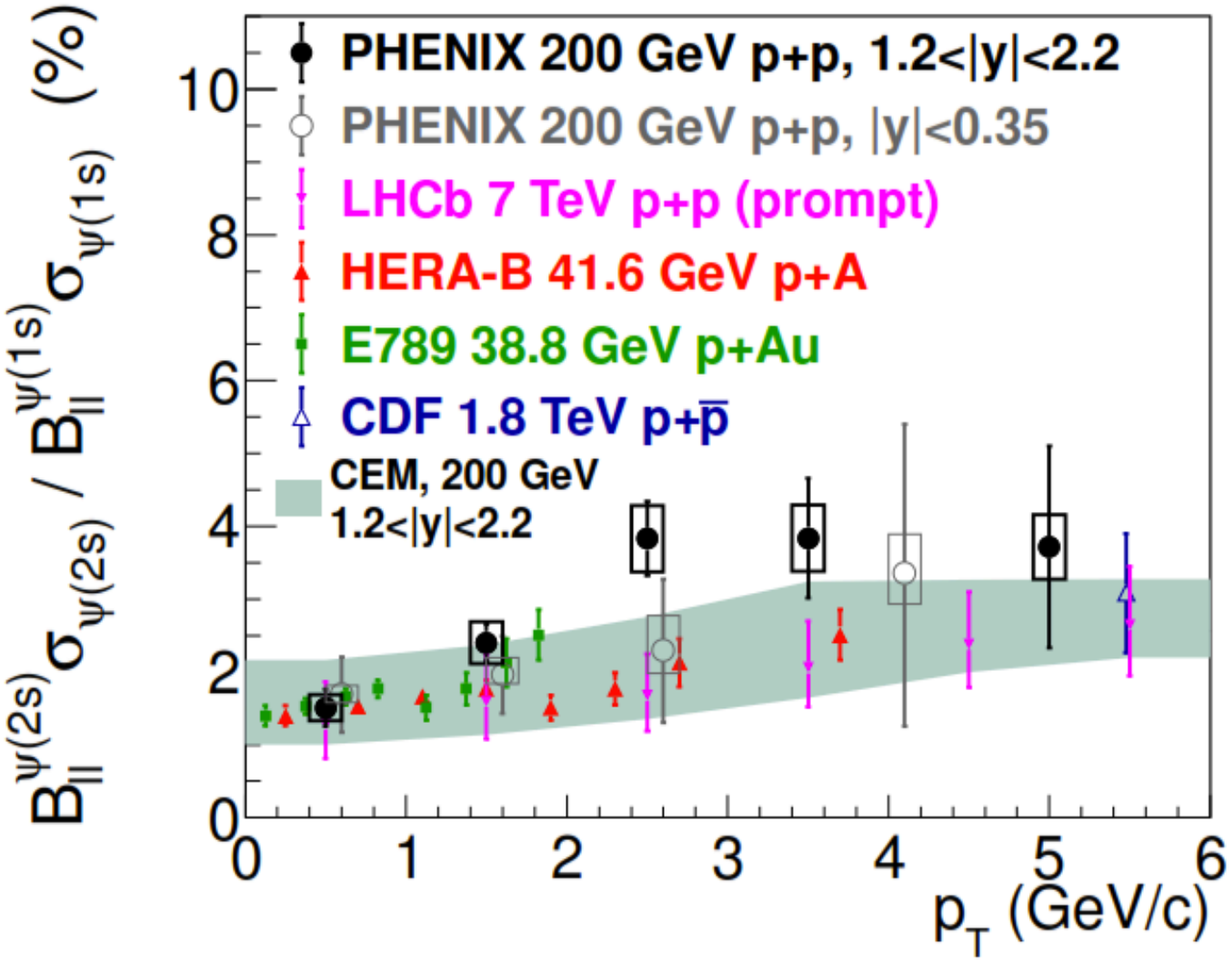

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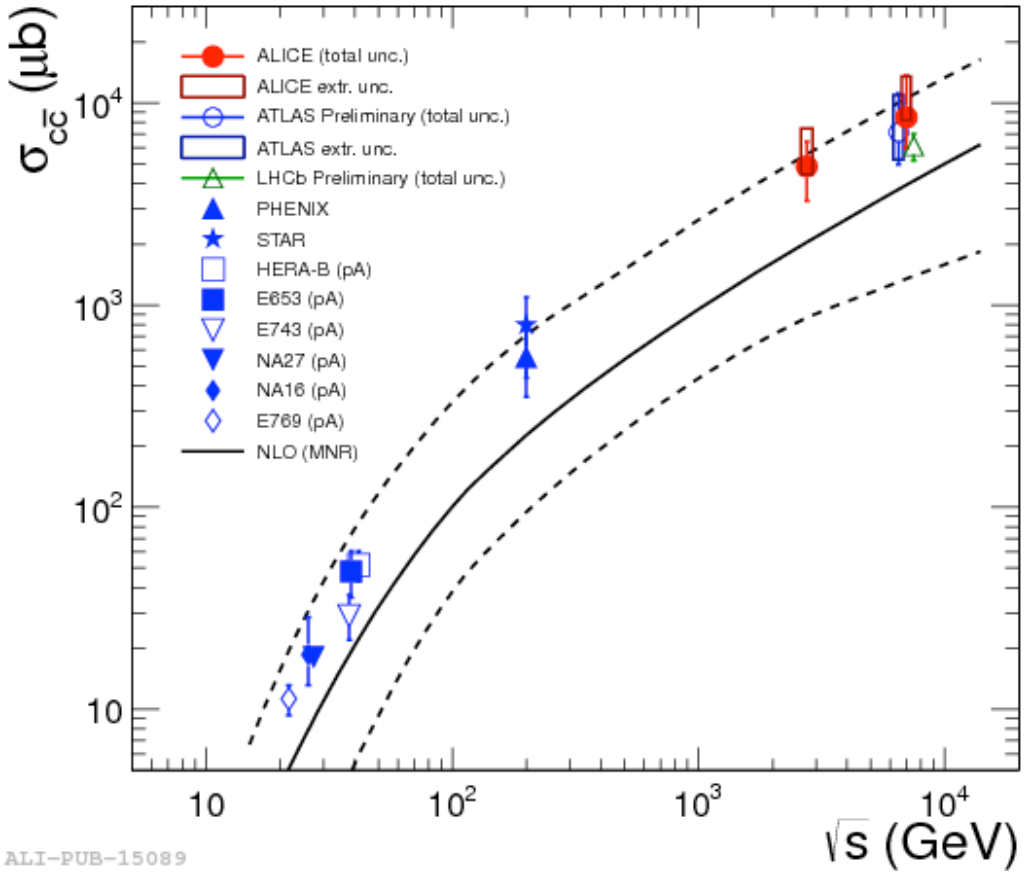
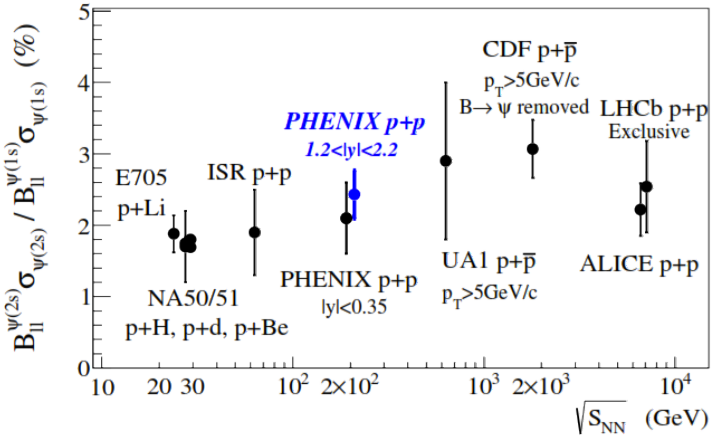
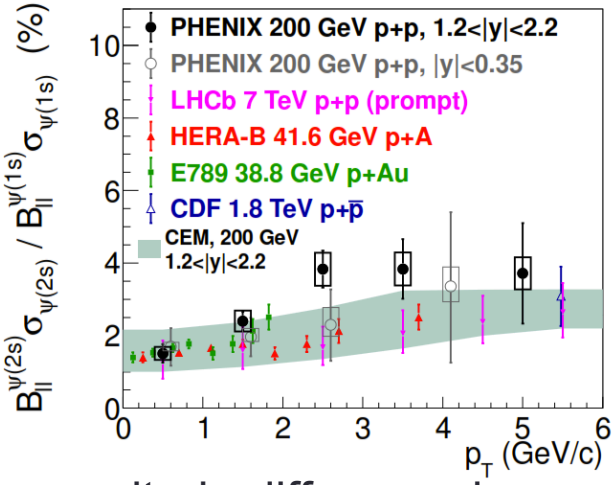


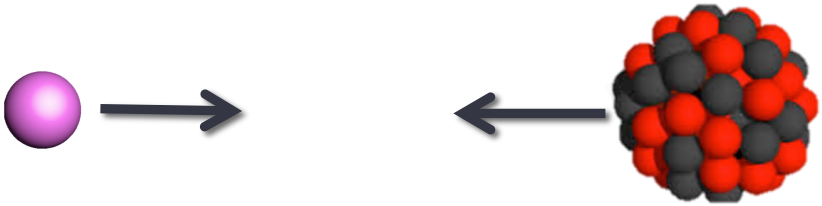


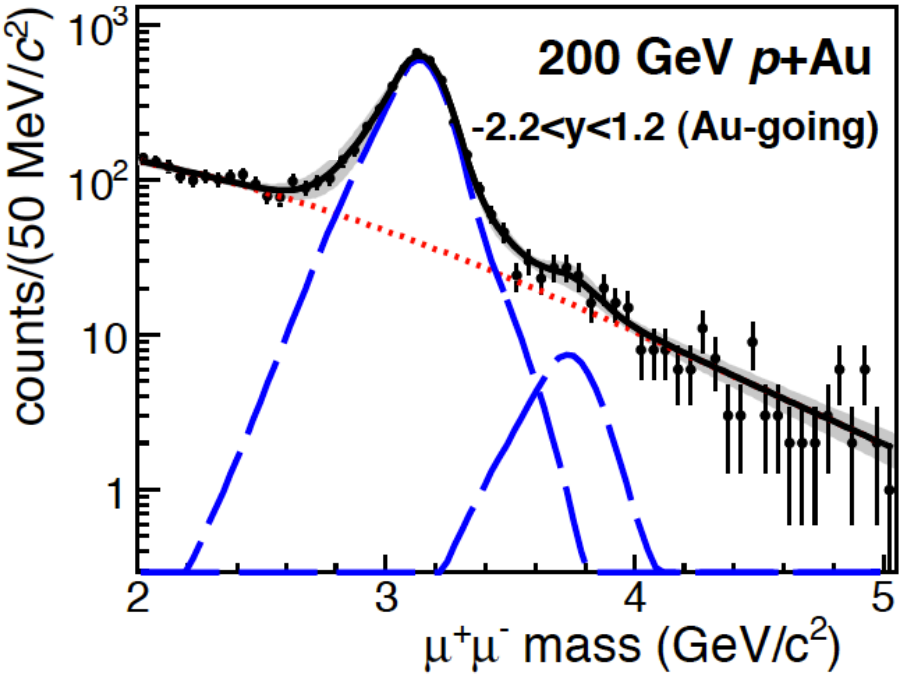


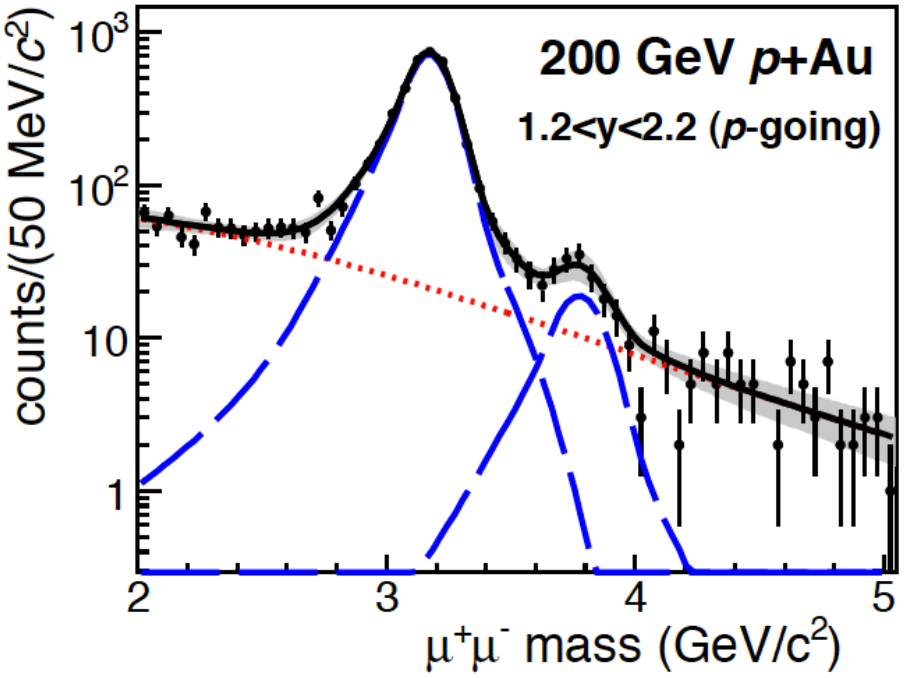
Little difference in 2S/1S ratio despite order of magnitude difference in σ_{cc}

Quarkonia formation ~factorizes from precursor formation

p+Au dimuon mass

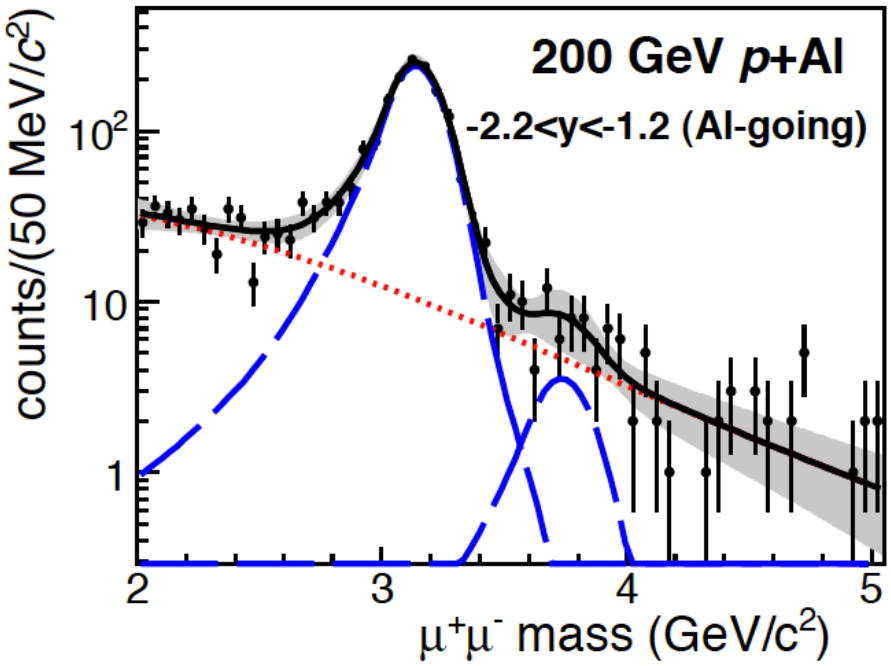


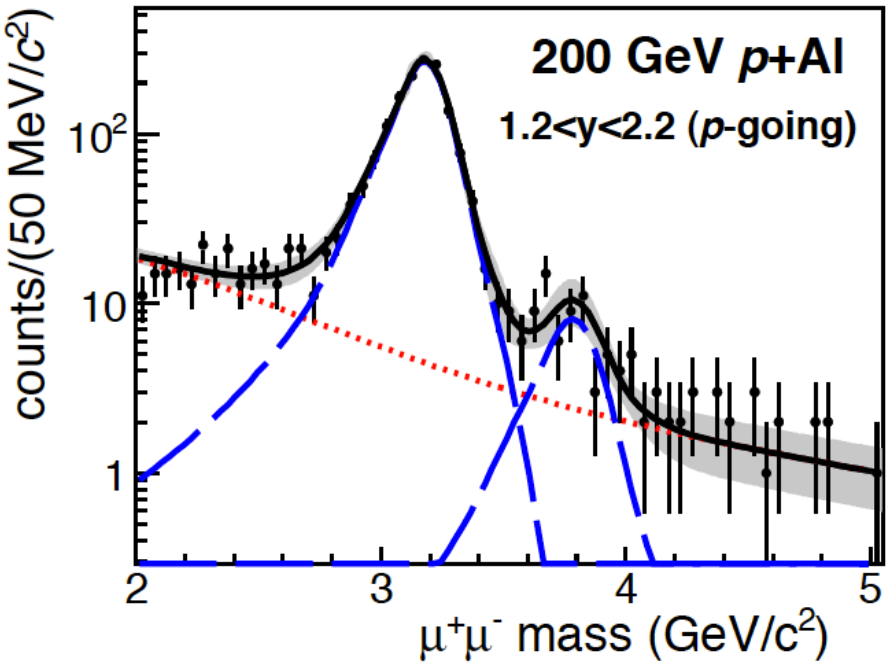




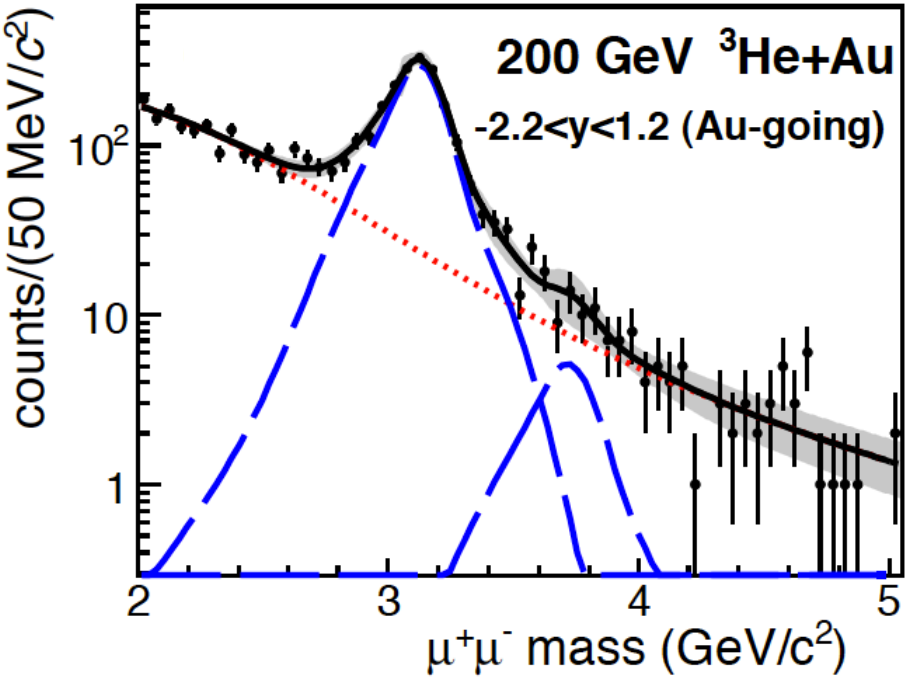
Immediately apparent that ψ(2s) yields are preferentially suppressed in Au-going direction.

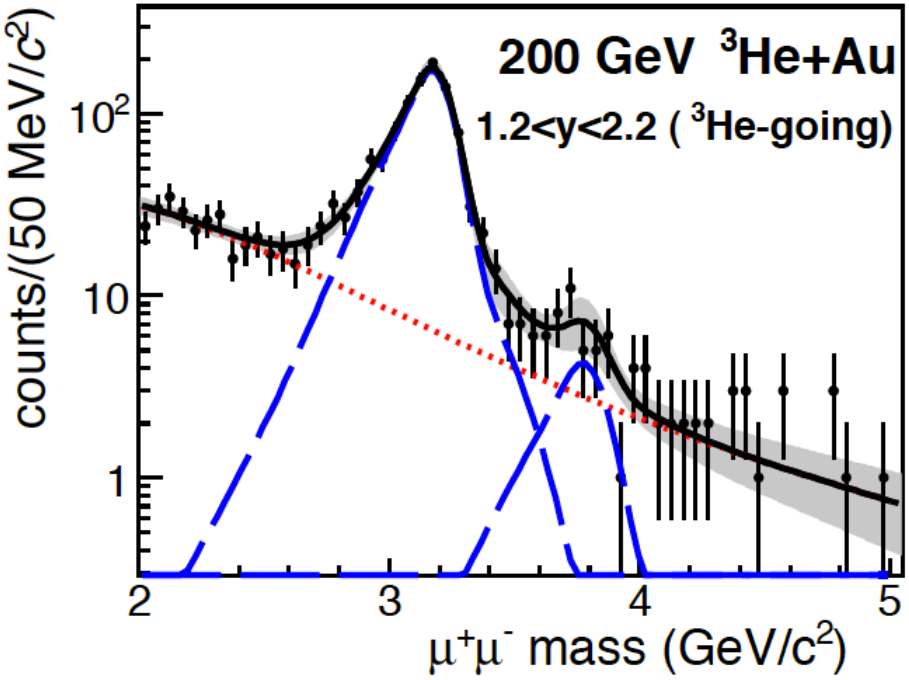
p+Al dimuon mass



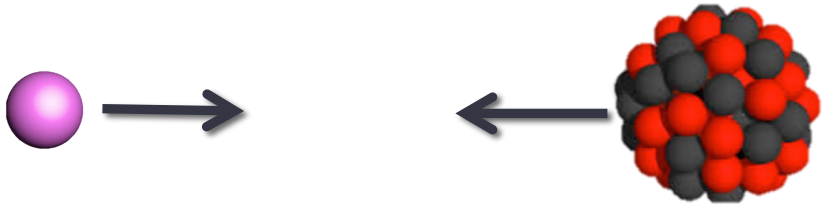


^{3}He+Au dimuon mass





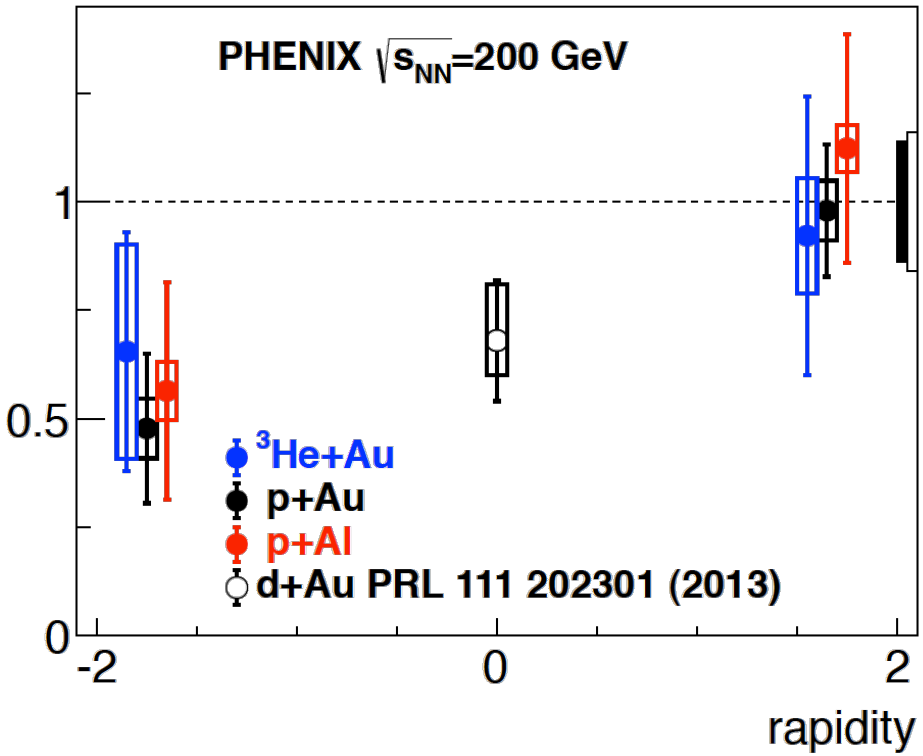
Relative suppression in p+A



Moderate J/ψ suppression.

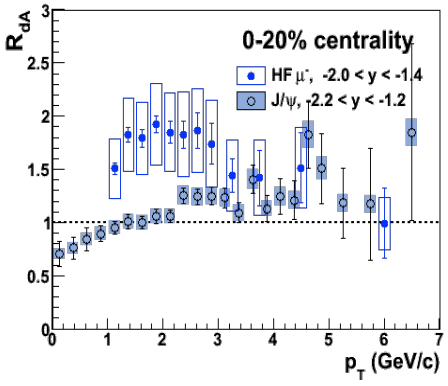
STRONG ψ(2s) suppression.

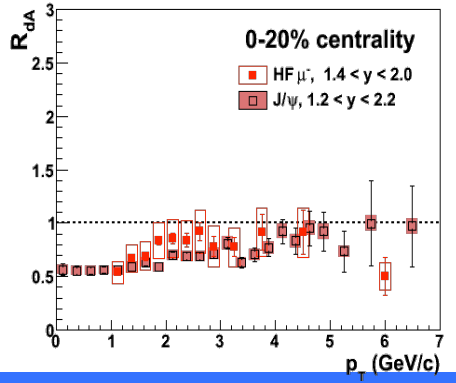
$$\left[\frac{\sigma_{\psi(2S)}}{\sigma_{\psi(1S)}}\right]^{p/^3He+A} \Big/ \left[\frac{\sigma_{\psi(2S)}}{\sigma_{\psi(1S)}}\right]^{p+p}$$



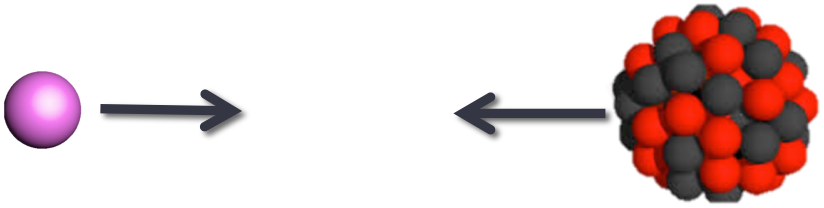
STRONG J/ψ suppression.

Equivalent ψ(2s) suppression.





Relative suppression in p+A



Moderate J/ψ suppression.

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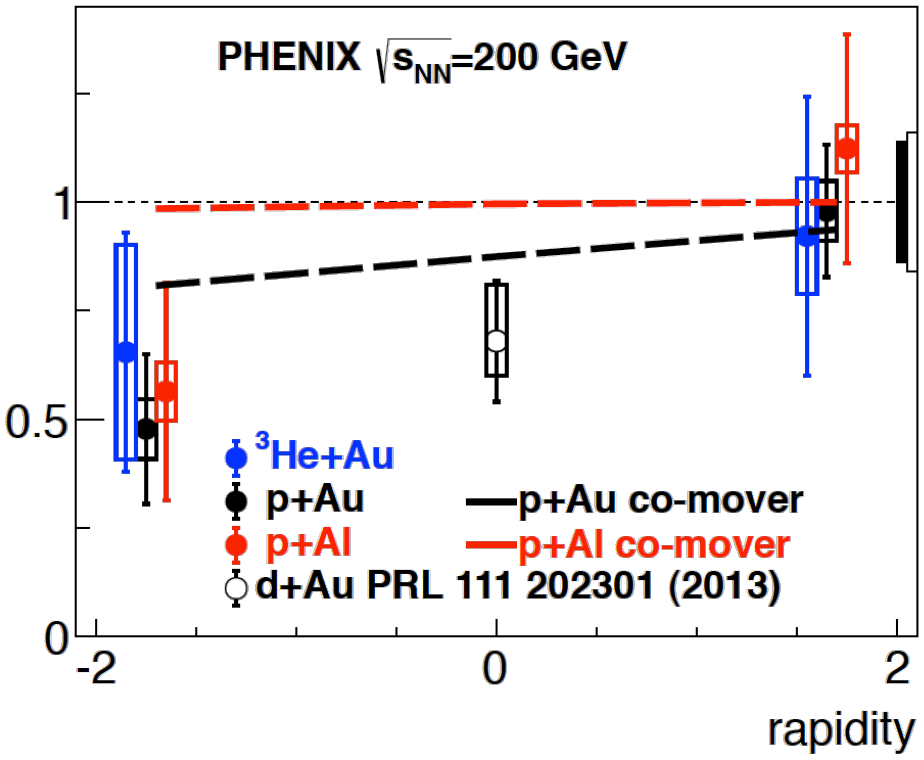
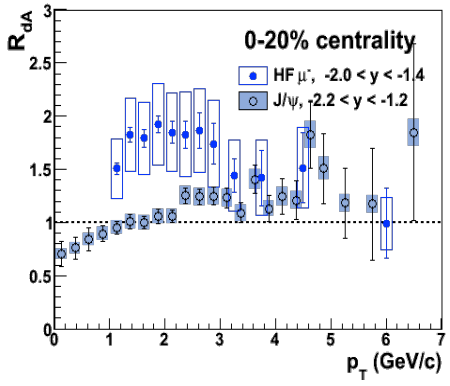
$$\left[\frac{\sigma_{\psi(2S)}}{\sigma_{\psi(1S)}}\right]^{p/^3He+A} \Big/ \left[\frac{\sigma_{\psi(2S)}}{\sigma_{\psi(1S)}}\right]^{p+p}$$

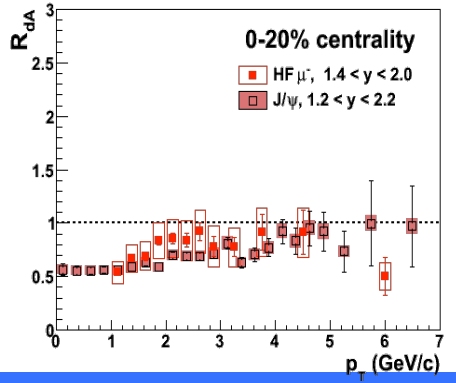


STRONG J/ψ suppression.

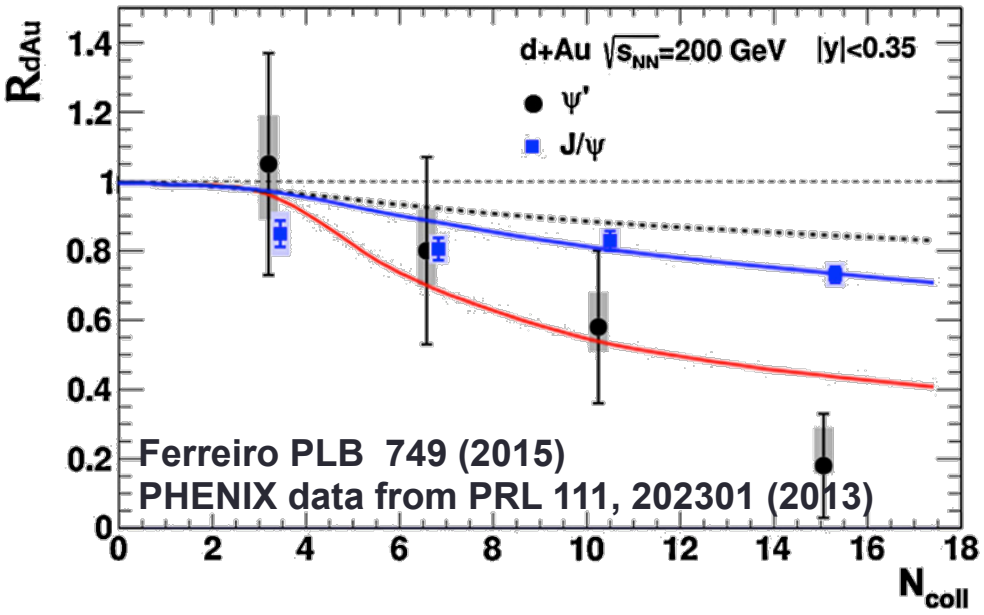
Equivalent ψ(2s) suppression.



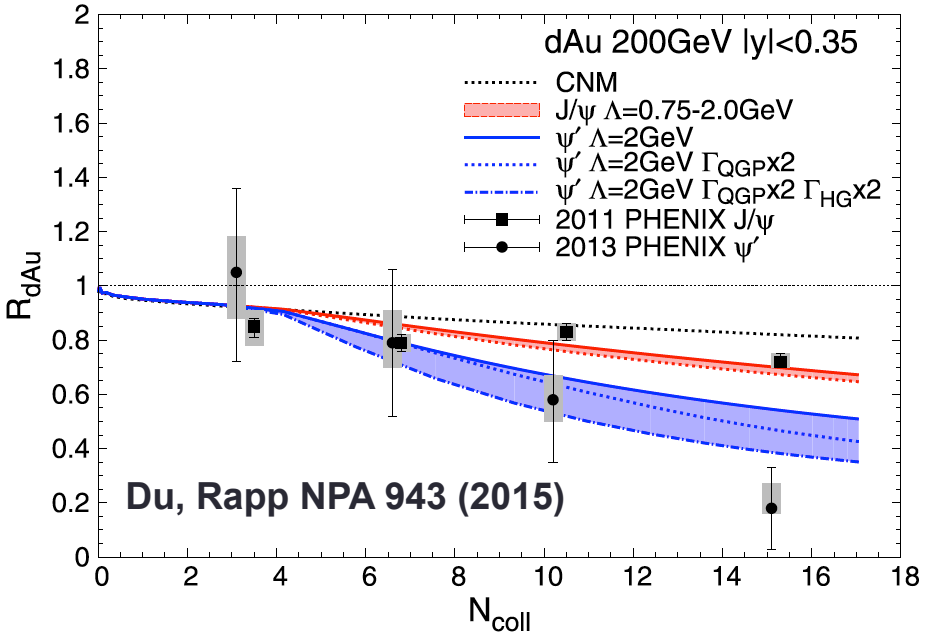
E. Ferreiro, PLB 749 (2015) ~consistent within significant statistical uncertainties with comover dissociation model



Model comparisons (midrapidity data)

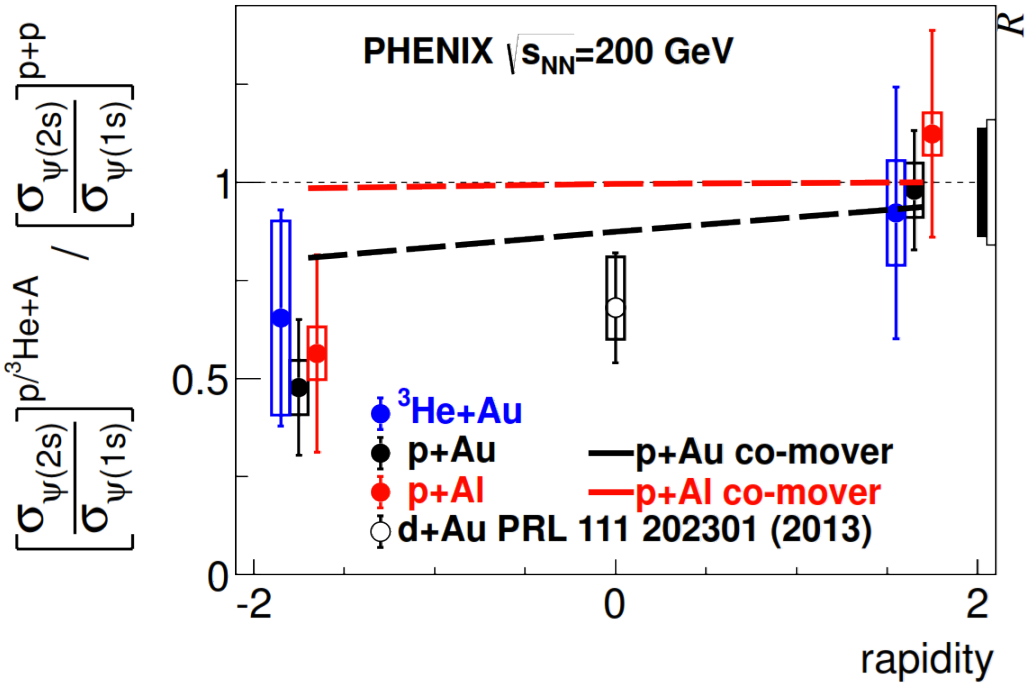


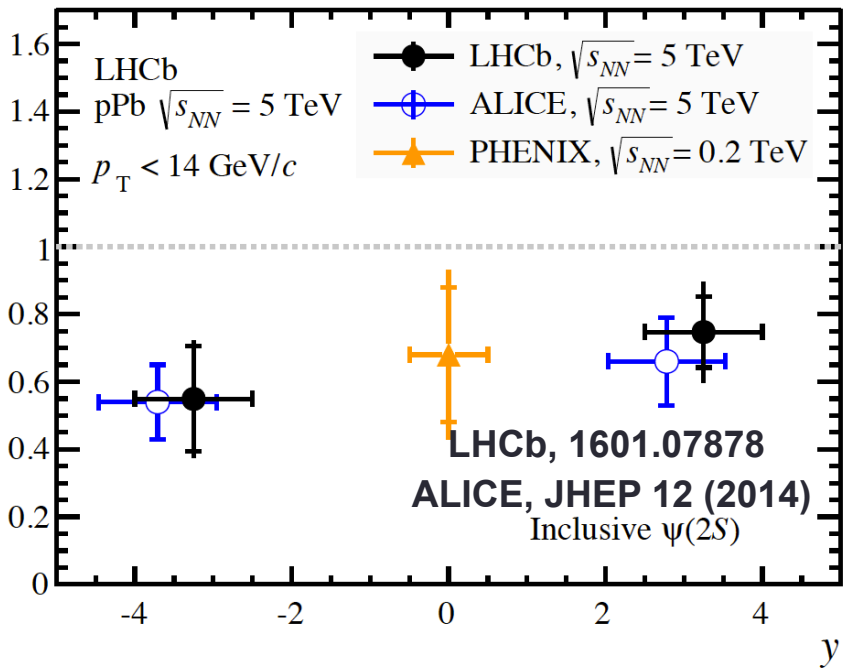
Ferreiro co-mover model ~consistent with mid, backward, and forward rapidity p(d)+Au data.



Calculation allows for short QGP phase in central d+Au collisions + hadron resonance gas.

Comparison with LHC

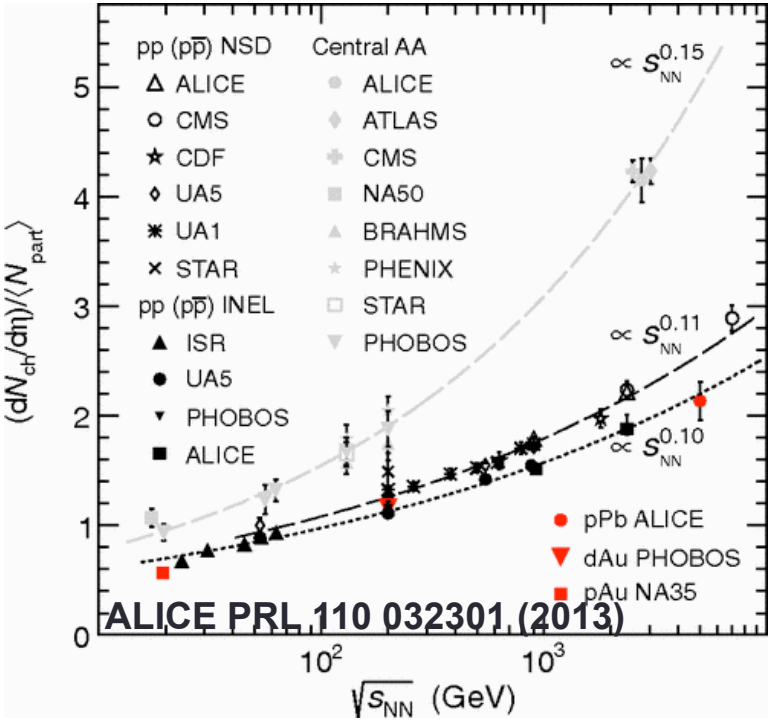




Similar suppression at forward and backward rapidities at LHC.

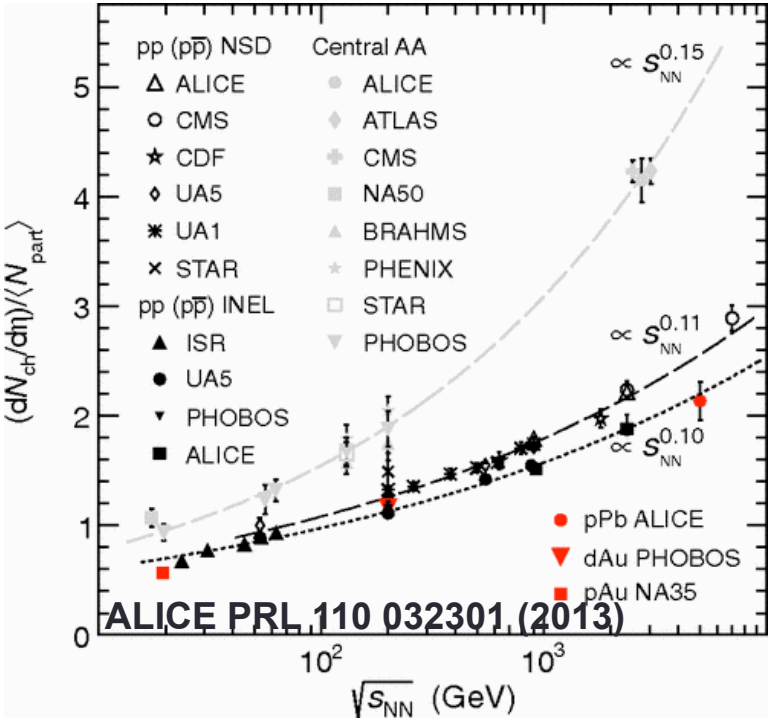
Is there an additional breakup effect? Color screening in p+A at LHC?

Comparison with LHC

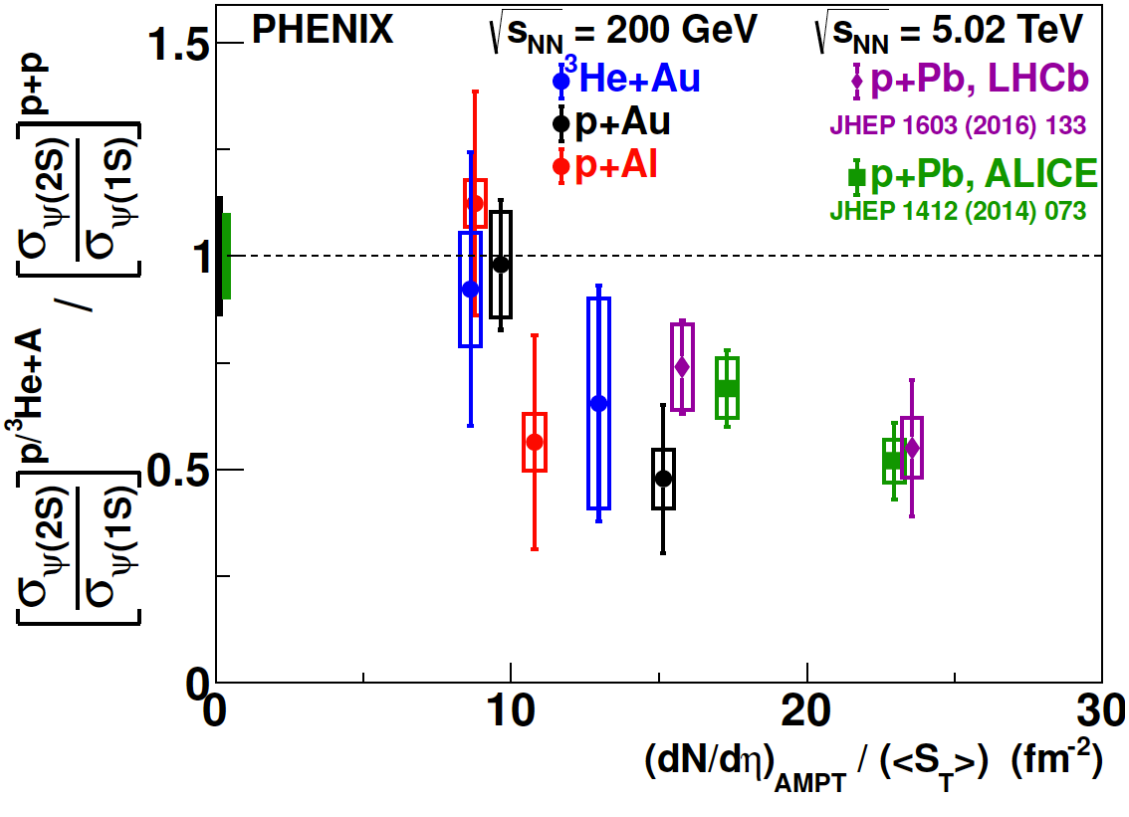


ALICE PRL 110 032301 (2013)

Comparison with LHC



Direct comparison with LHC data as function of comoving particle density



Measurements not available for all rapidity ranges for all species

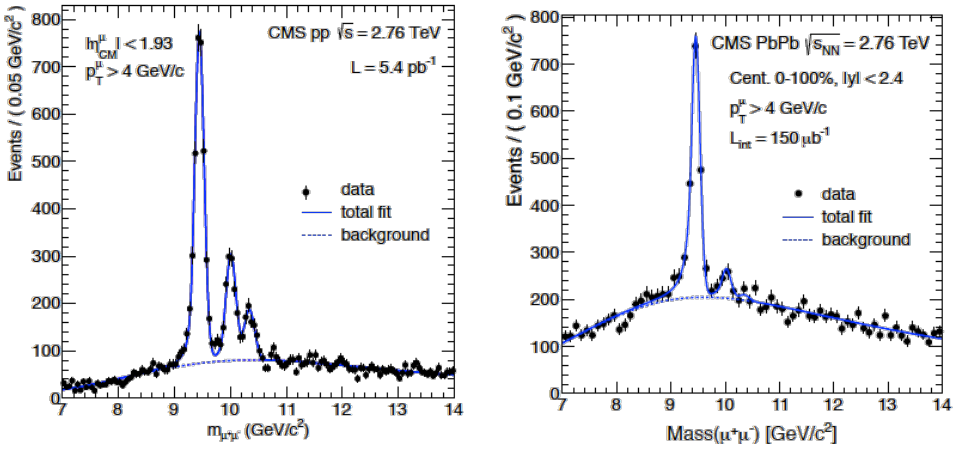
- **use AMPT simulation for dN/dη**

$$< S_T >= 4\pi\sqrt{< x^2 >< y^2 > - < xy >^2}$$

from Glauber model

Effects on bottomonia

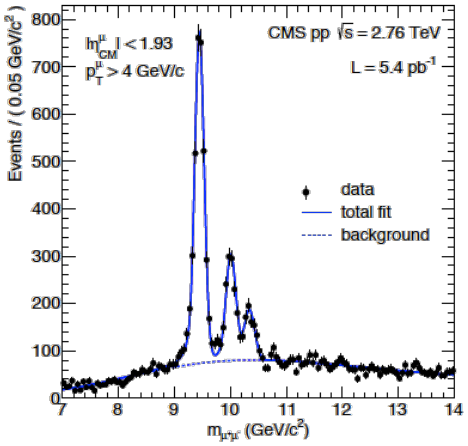
CMS PRL 109 222301 (2012), JHEP04(2014)103

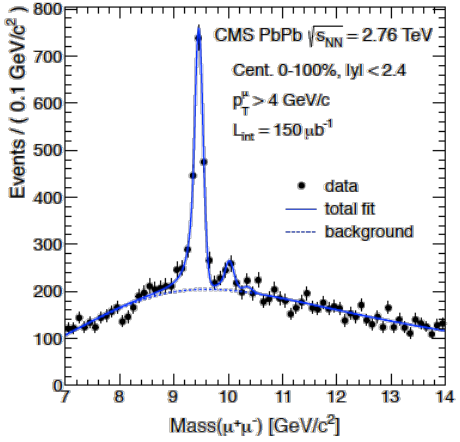


Comover Interaction Model:
JP Lansberg, Hard Probes 2016
E Ferreiro, ECT Trento 2016

Effects on bottomonia

CMS PRL 109 222301 (2012), JHEP04(2014)103

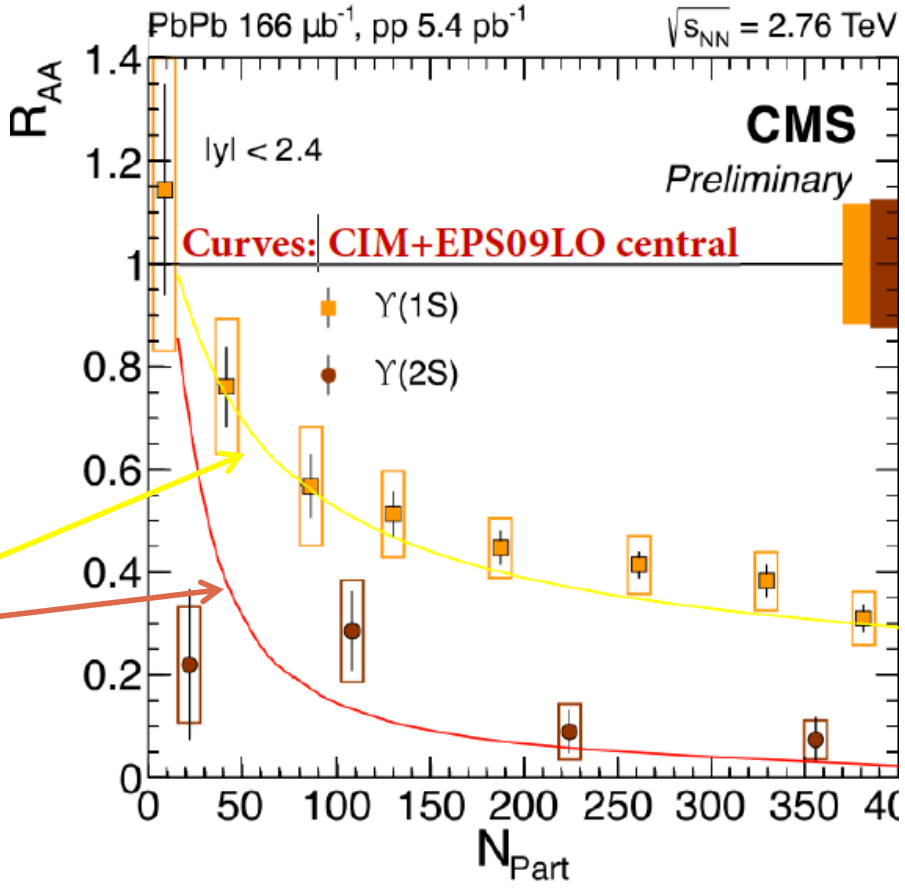




$$\sigma^{co-\mathcal{Q}_{b\bar{b}}} = \sigma_{\text{geom}}\left(1 - \frac{E_{\text{Binding}}}{\langle E_{co}\rangle}\right)^{n}$$

<E_{co}>, n determined by fit to p+Pb data

Comover Interaction Model:
JP Lansberg, Hard Probes 2016
E Ferreiro, ECT Trento 2016



Comover interactions expected to be significant (dominant?) in A+A

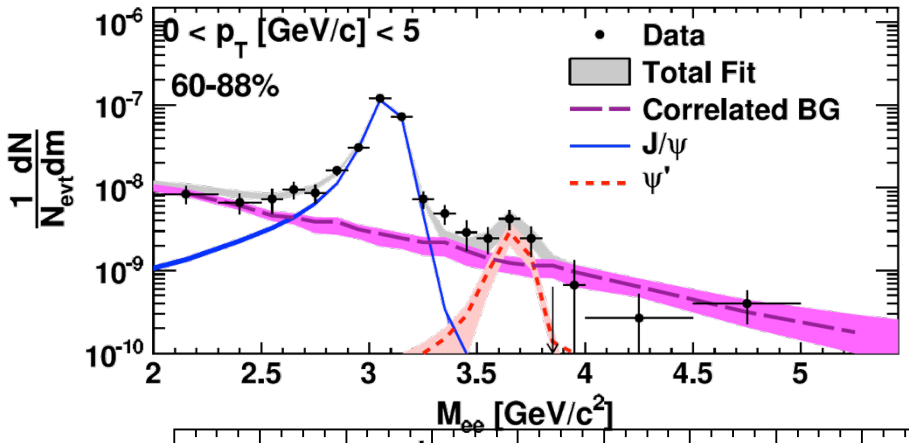
Conclusions

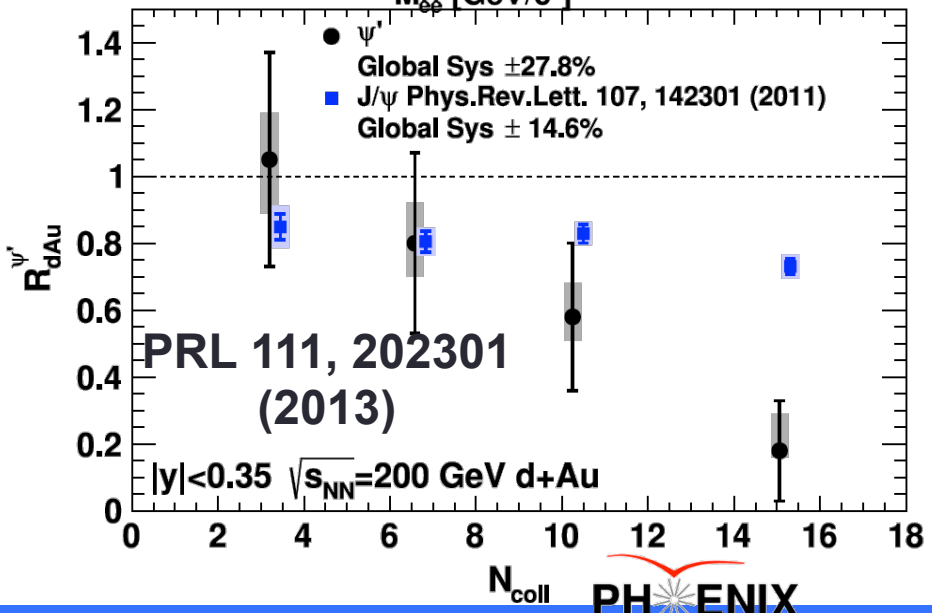
- Many mechanisms beyond color screening can contribute to quarkonia suppression.
- Some of these can be disentangled through comparisons of hadrons with similar quark content but different masses.
- Comover dissociation likely plays a significant role in quarkonia suppression.
- Extrapolations suggest this is also a significant effect in A+A collisions

BACKUPS

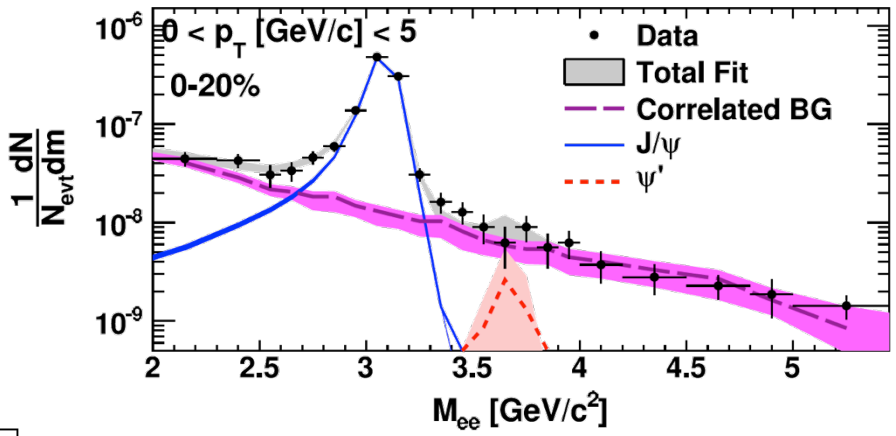
ψ(2s) at midrapidity

Peripheral d+Au





Central d+Au



VERY similar effects: ~identical shadowing, energy loss, etc on cc precursor pair in nucleus

Different tend and magnitude of suppression with increasing N_{coll} ->Something happening in later stages