Quarkonia Results from PHENIX

Darren McGlinchey
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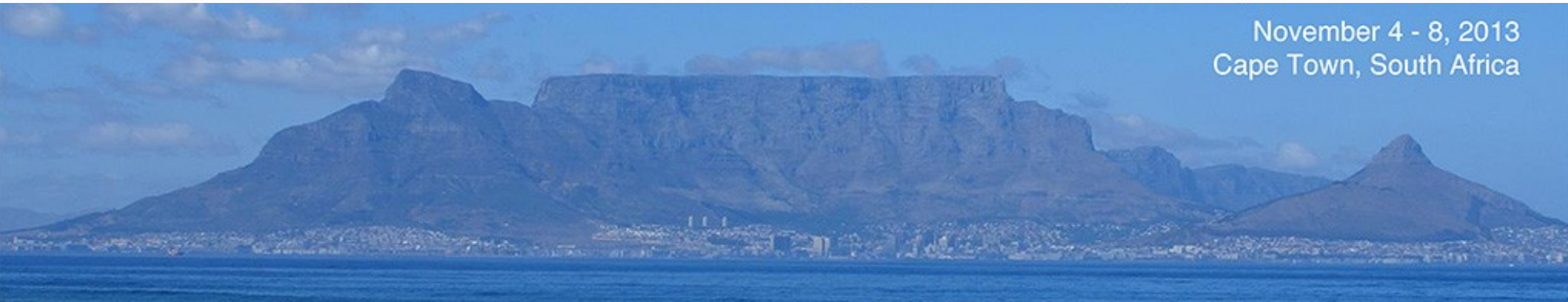
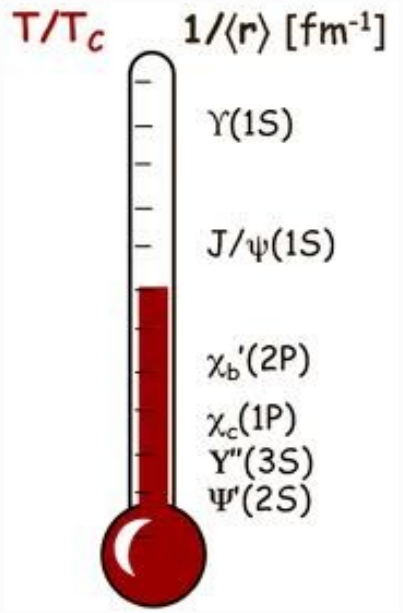
for the PHENIX collaboration
Hard Probes 2013



Heavy Quarkonia

Heavy Quarkonia have natural length & time scales.

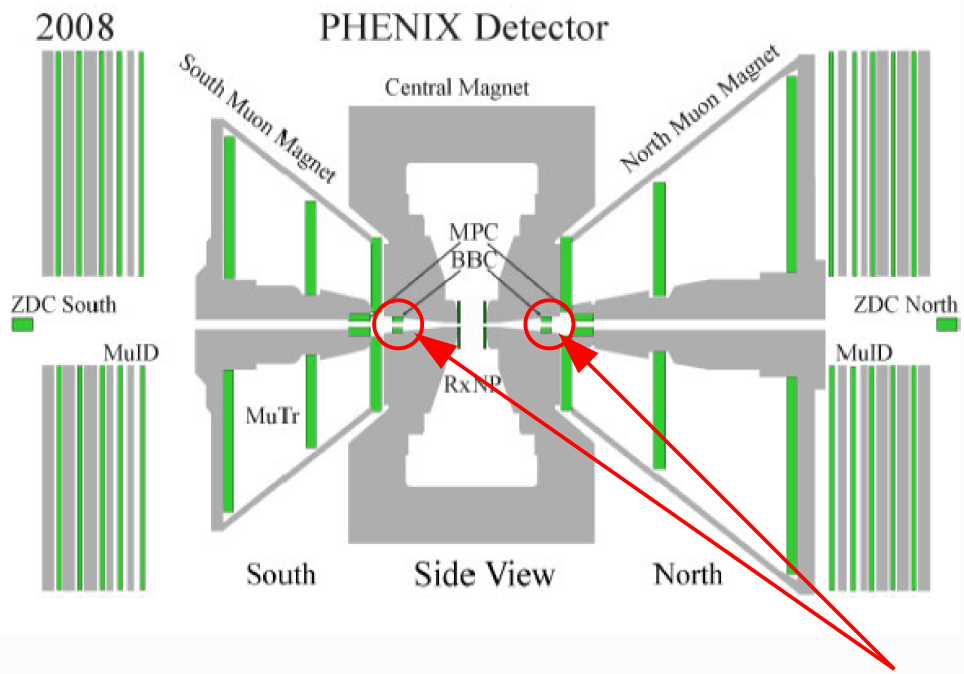


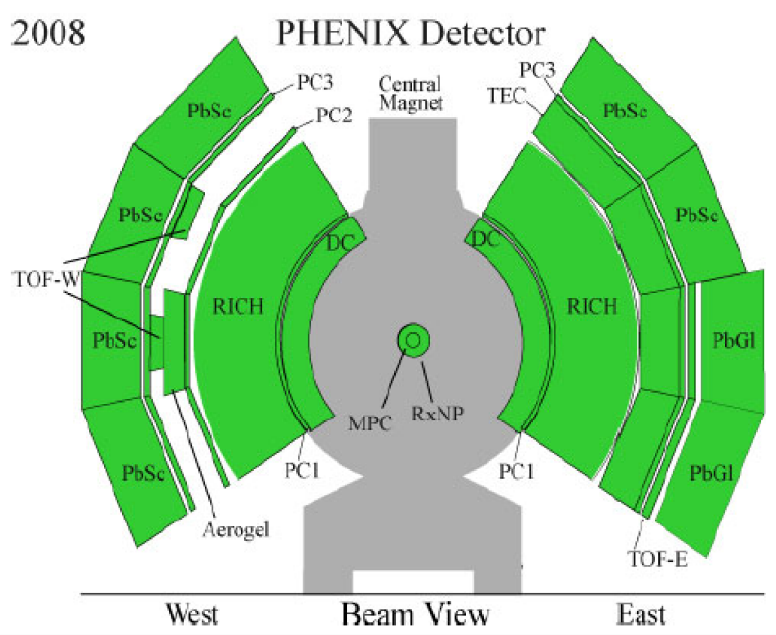
Allow us to probe effects at these scales

Leverage RHICs unique ability to measure over a wide range of energies & collision species.

state	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
mass [GeV]	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM [GeV]	0.02	-0.03	0.03	0.06	-0.06	-0.06	-0.08	-0.07
radius [fm]	0.25	0.36	0.45	0.14	0.22	0.28	0.34	0.39

PHENIX





Muon Arms

- $1.2<|\eta|<2.4$
- $J/\psi \rightarrow \mu^+\mu^-$

Beam-Beam Counters

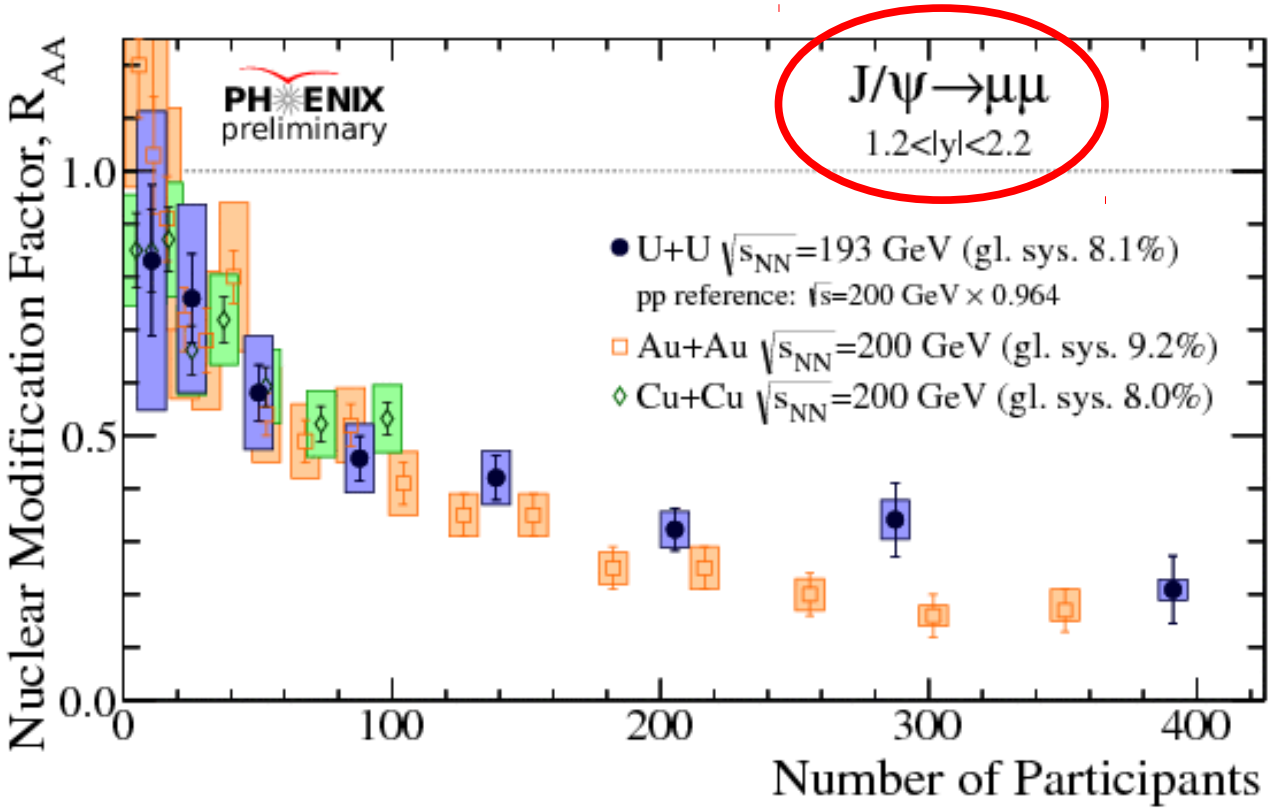
- Measure Centrality (impact parameter) as a percentage of BBC charge

Central Arms

- $\eta<|0.35|$
- $J/\psi \rightarrow e^+e^-$

J/ψ in A+A at RHIC

Cu+Cu at 200 GeV
Au+Au at 200 GeV
U+U at 193 GeV (new!)



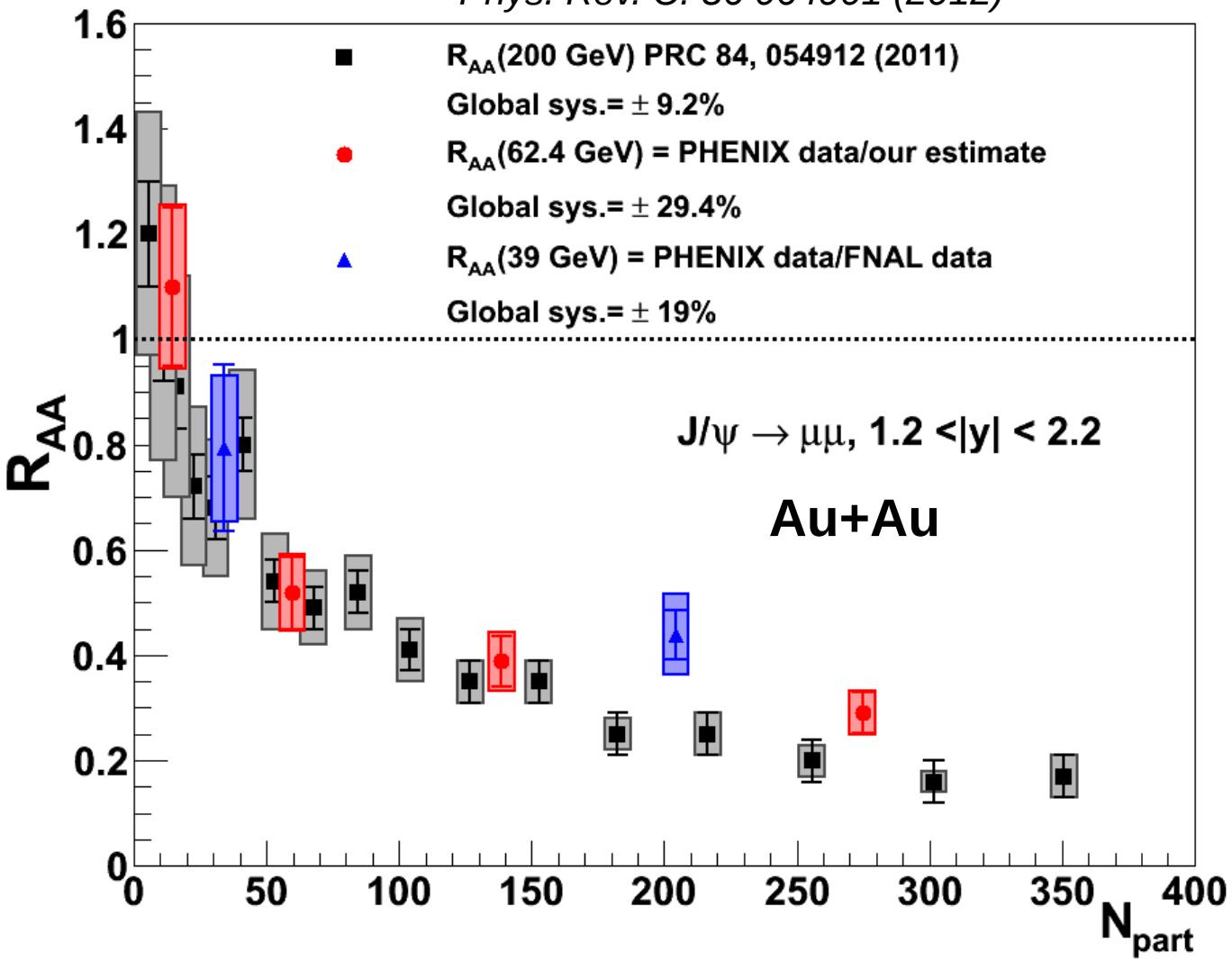
Observe suppression which is similar across species.

J/ψ in Au+Au at RHIC

Au+Au 39 GeV
Au+Au 62.4 GeV
Au+Au 200 GeV

Observe suppression which is similar across all energies.

Phys. Rev. C. 86 064901 (2012)



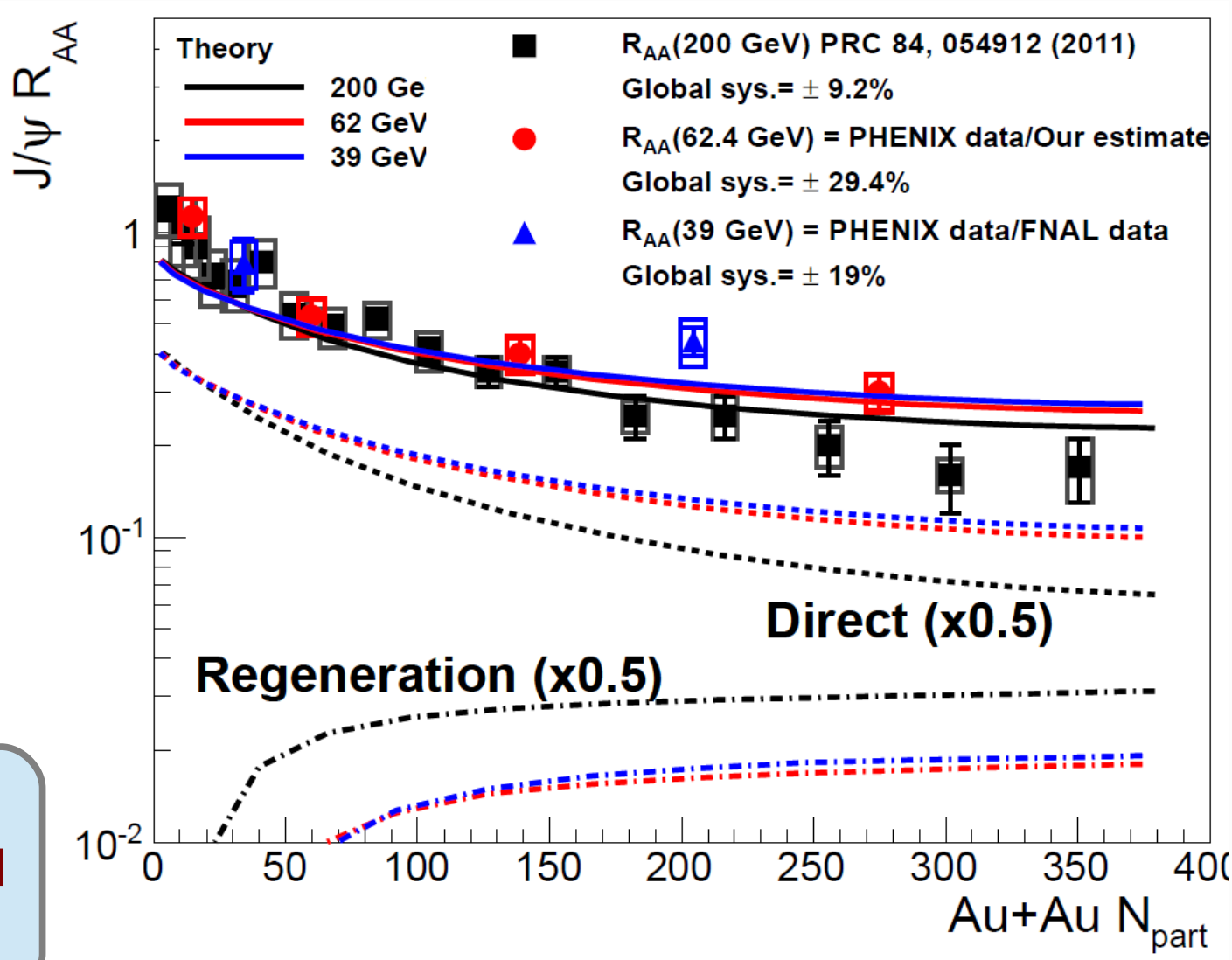
Shouldn't lower E have much less suppression?

Recombination?

Calculations by Zhao and Rapp. Include some CNM effects.

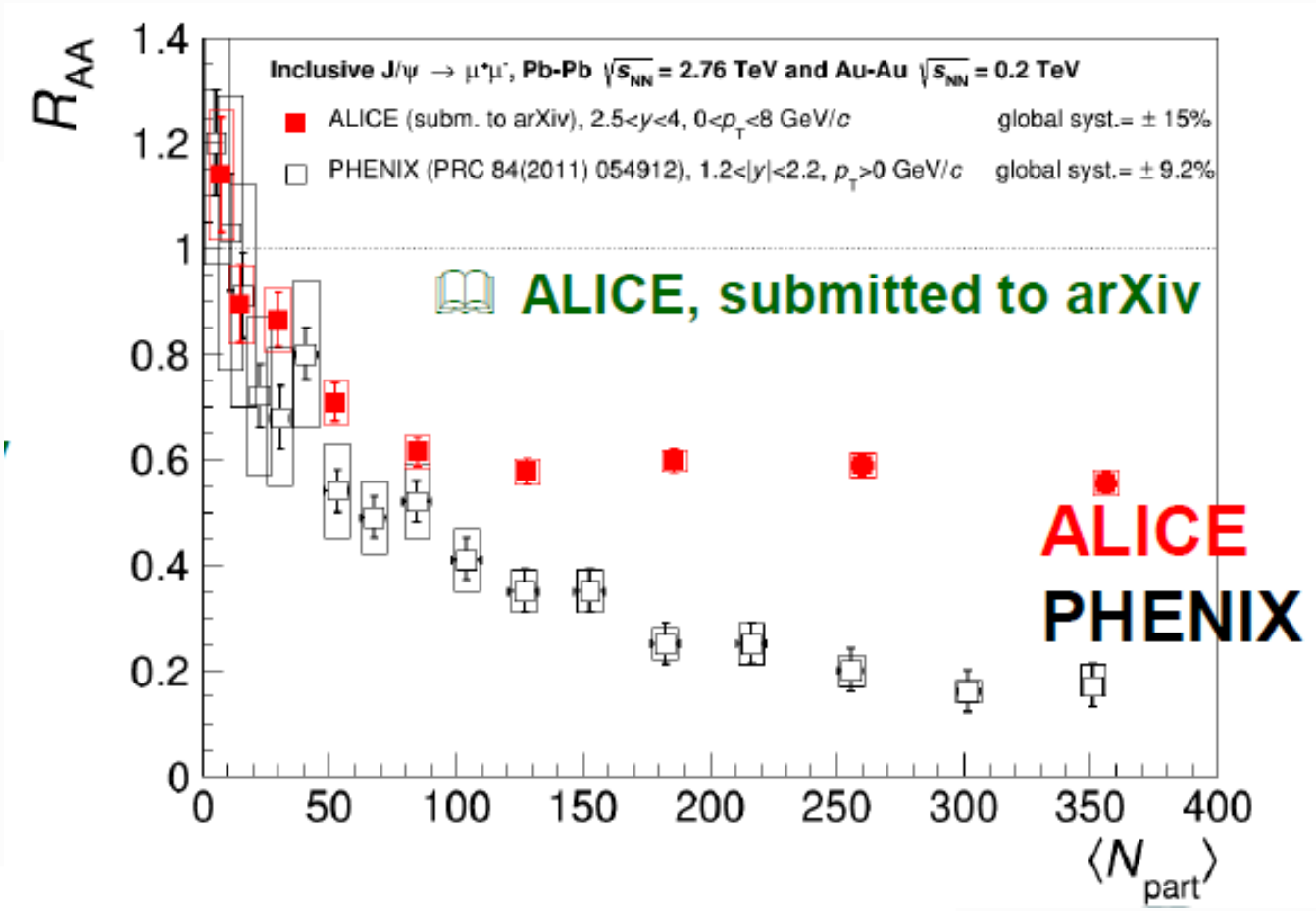
Direct suppression changes by ~50%

Lower suppression balanced by increased regeneration



J/ψ at the LHC

How does the similar suppression observed at RHIC compare to LHC results?

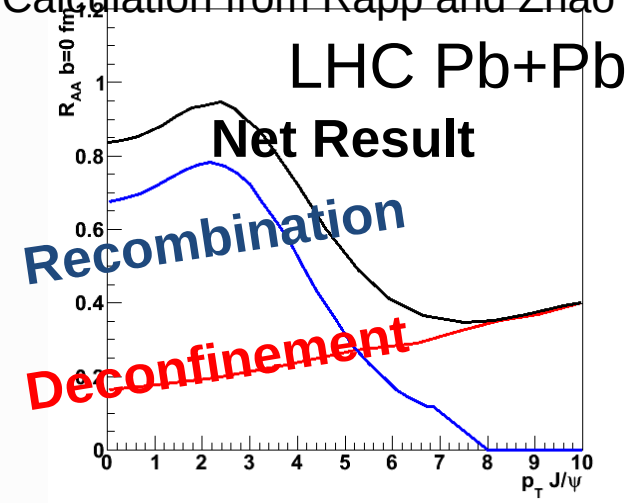


Less suppression at LHC an indication of larger recombination effect?

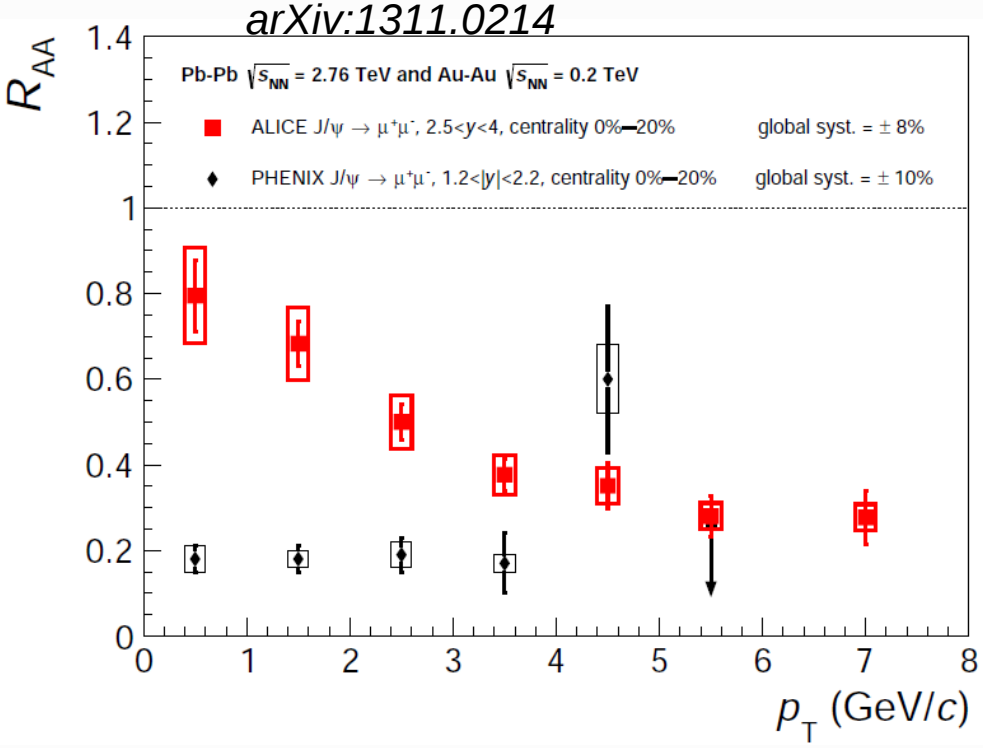
Recombination

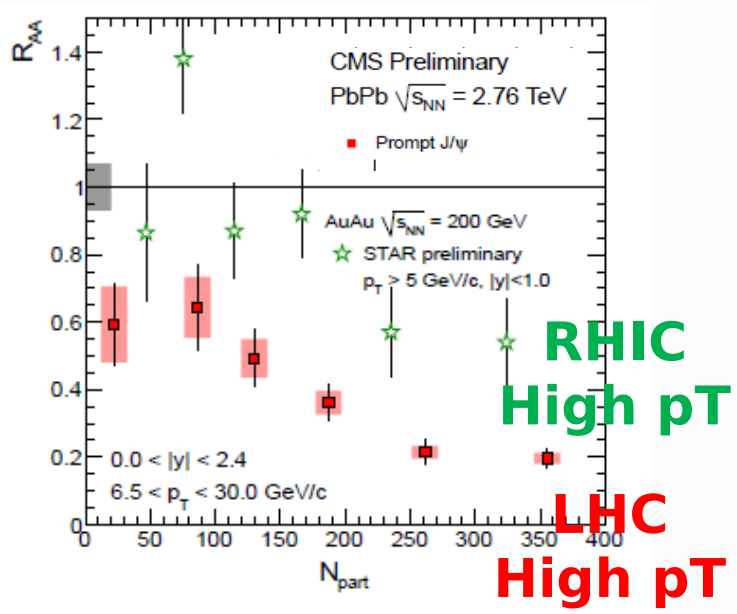
If recombination is the key, LHC results should be less suppressed at low p_T & more suppressed at high p_T compared to RHIC!

Calculation from Rapp and Zhao



arXiv:1311.0214



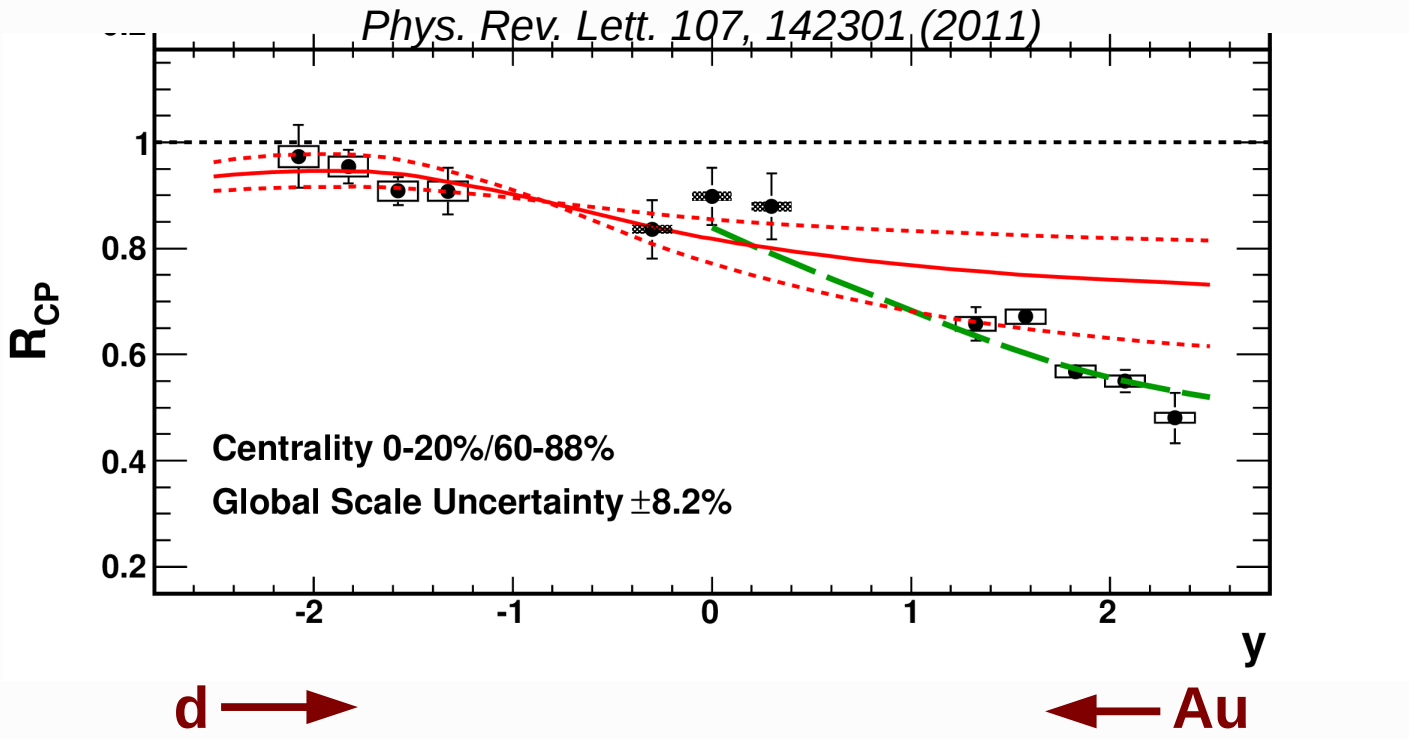


Combined results favor recombination

Quarkonia in small systems

- What about small systems, i.e p(d)+A?
  - Believed to probe differences in **Cold Nuclear Matter Effects**, as no medium should be formed.
  - However, new measurements in d+Au and p+Pb challenge the idea.

J/ψ in d+Au



- Strong centrality dependence of J/ψ R_{dAu} at forward rapidity.
- Centrality dependence at forward rapidity unexplained by EPS09 with linear dependence on the nuclear thickness plus nuclear breakup.
- First hint that something unexpected is occurring in small systems

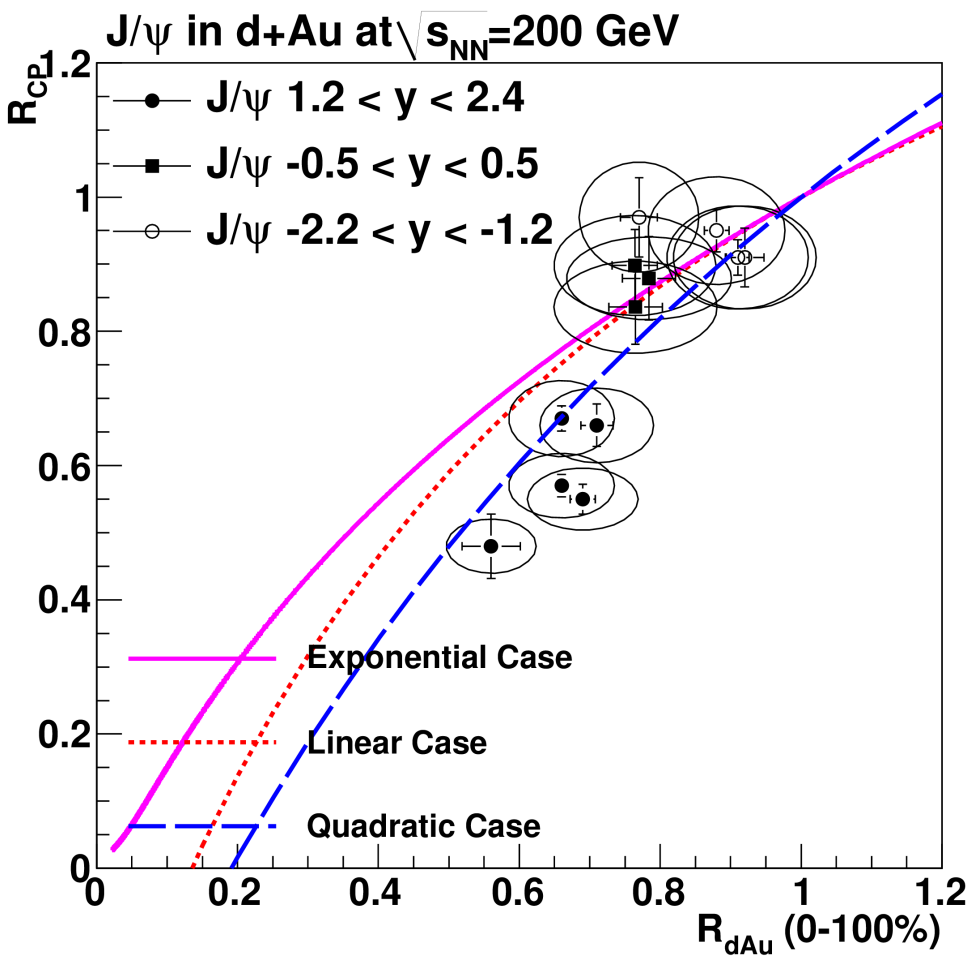
J/ψ in d+Au

R_{cp} – measure of the change in suppression over the Au nucleus

R_{dAu}**(0-100%)** - measure of the average suppression.

Curves indicate **exponential**, **linear**, and **quadratic** dependence on the **nuclear thickness**.

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

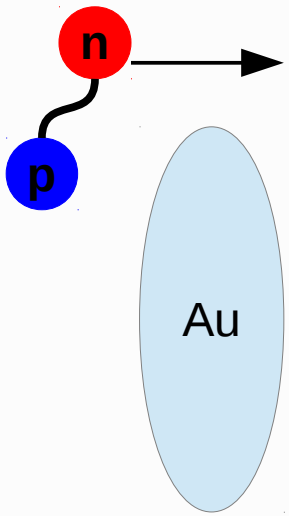


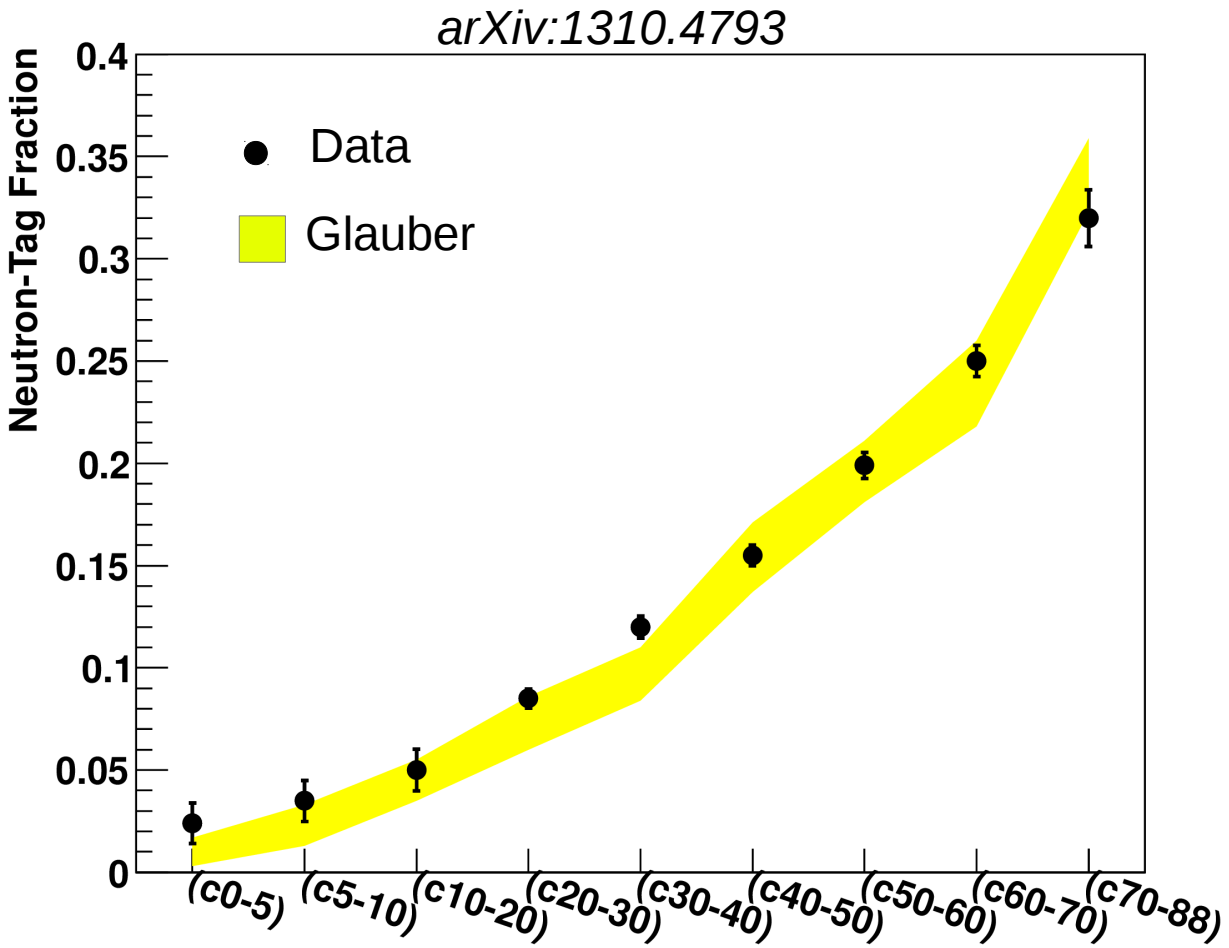
Non-linearity at forward rapidity is model independent!

Understanding Geometry in d+Au

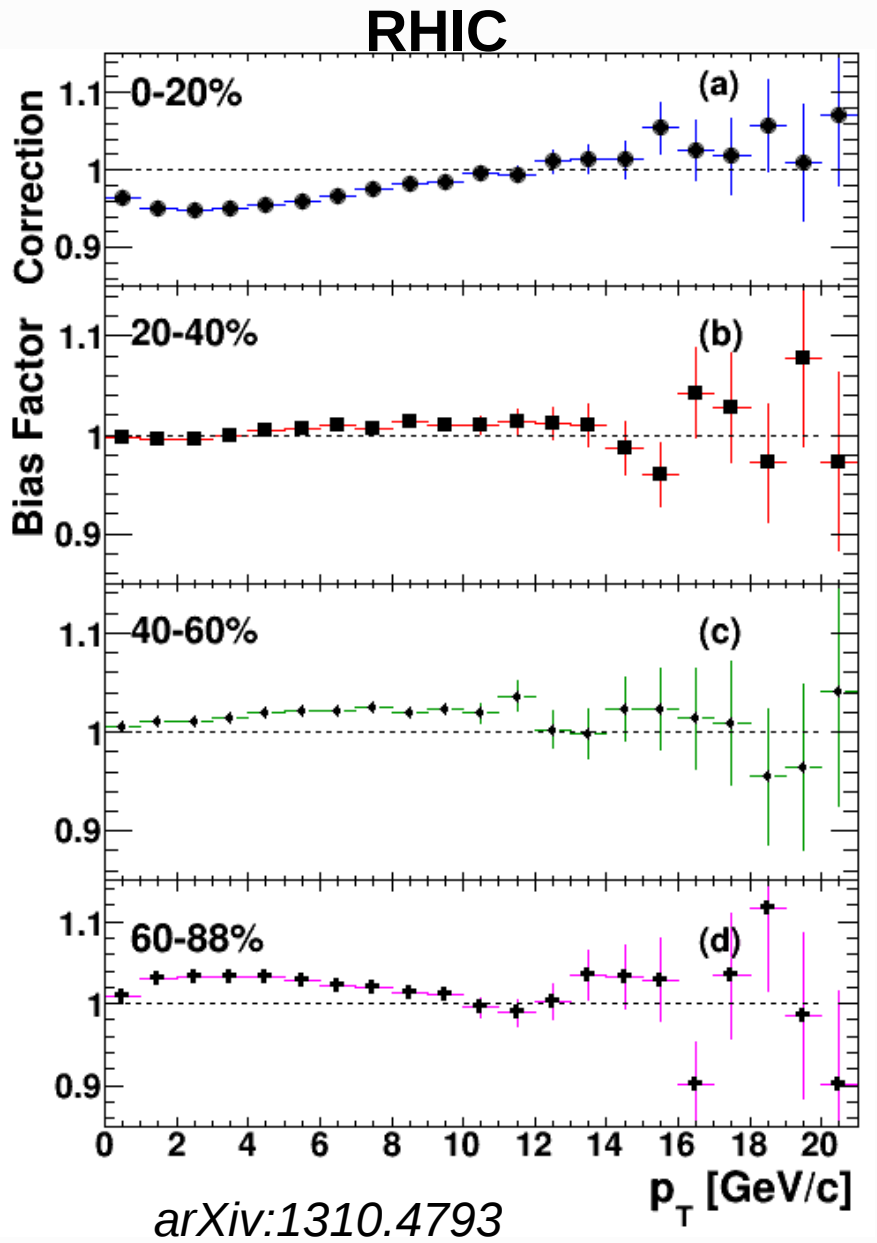
Measure fraction of events with a neutron in the ZDC.

Compares well with expectations from Glauber model.





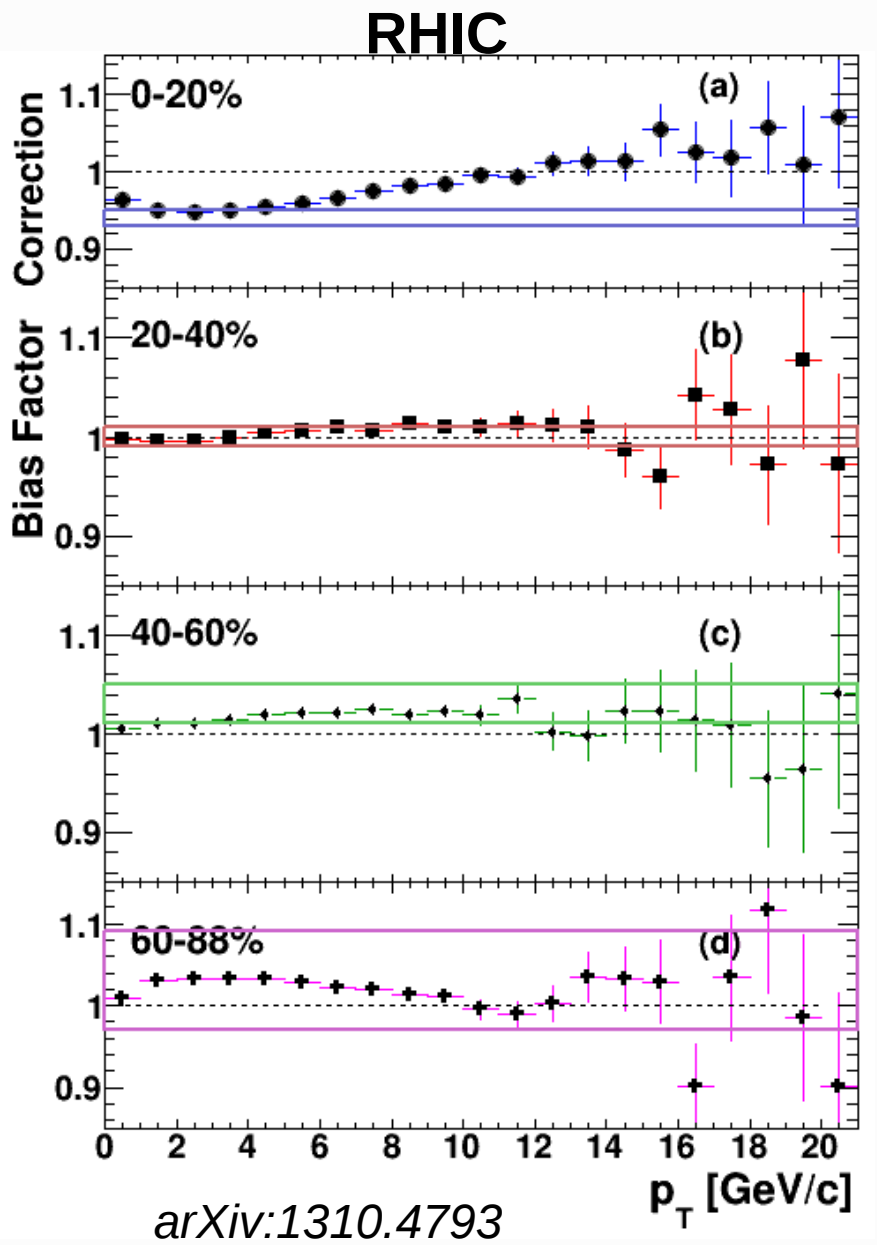
Understanding Geometry in d+Au



arXiv:1310.4793

- Large interest in correlations between the process of interest and the measured centrality (i.e. bias factors)
- Determined using data+Glauber model
- **Included in PHENIX 2003 & 2008 d+Au results.**
- Now test results using HIJING
- Minimal p_T dependence at RHIC for p_T<10 GeV.

Understanding Geometry in d+Au



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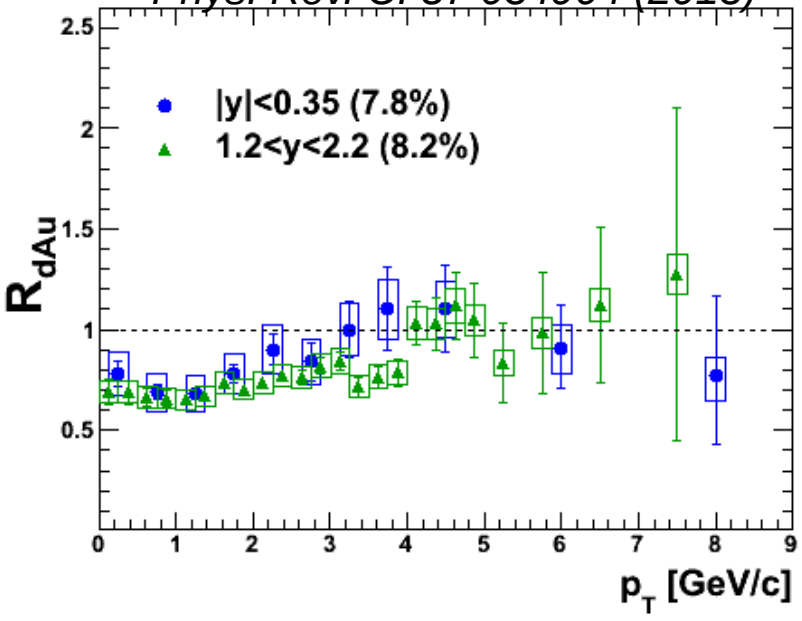
- Determined using data+Glauber model
- **Included in PHENIX 2003 & 2008 d+Au results.**
- Now test results using HIJING
- Minimal p_T dependence at RHIC for p_T<10 GeV.
- **Good agreement with Glauber results**.

~5% Effect at RHIC!

J/ψ p_T Dependence in d+Au

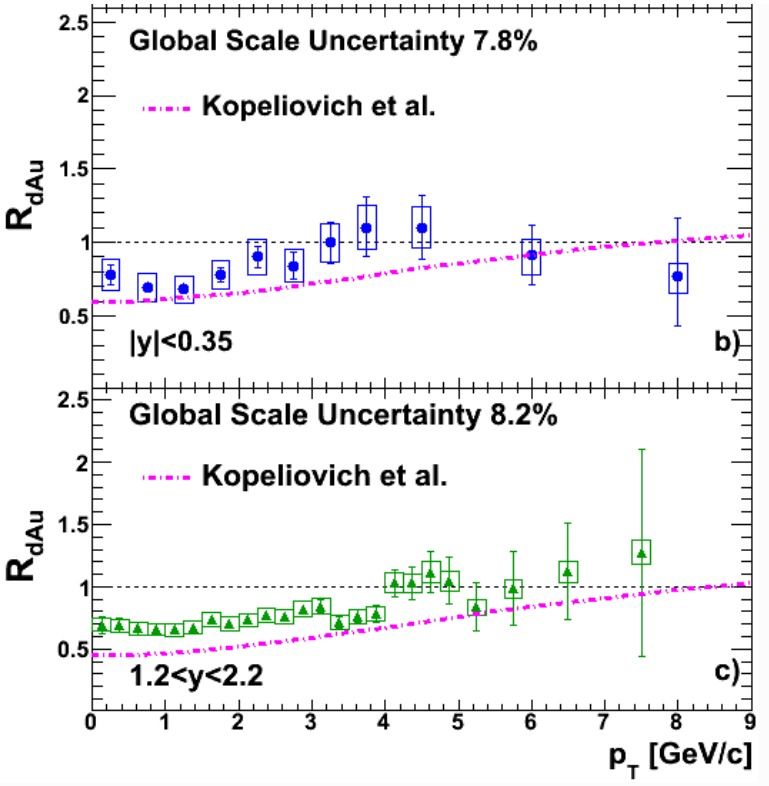
- Minimum Bias J/ψ R_{dAu} vs p_T
- Shape is similar at **forward** & **mid** rapidity.
  - $R_{dAu} < 1$ for $p_T < 4$ GeV/c
- Shape similar to calculations including shadowing, nuclear break-up, Cronin

Phys. Rev. C. 87 034904 (2013)



Vertical Error bars – uncorrelated uncertainties

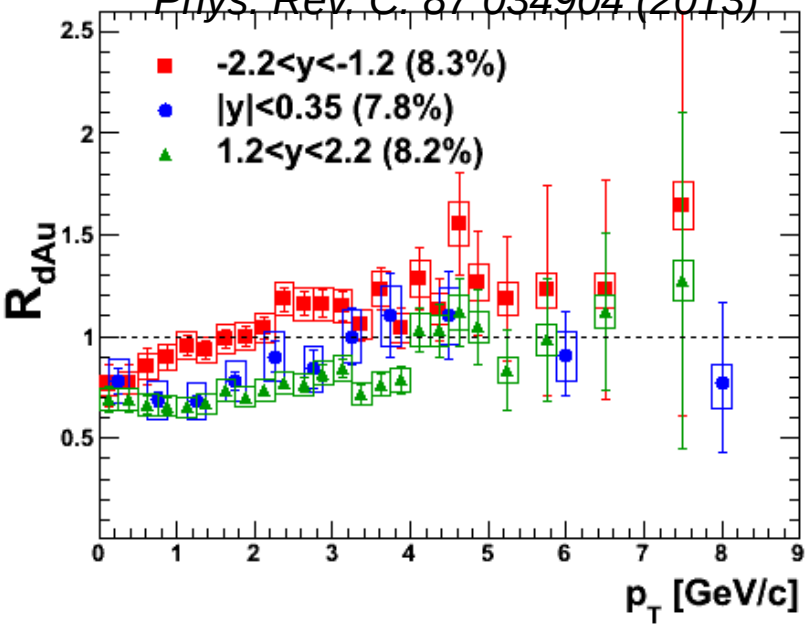
Boxes – point-to-point correlated uncertainties.



J/ψ p_T Dependence in d+Au

- Minimum Bias J/ψ R_{dAu} vs p_T
- Shape is different at **backward** rapidity.
  - $R_{dAu} > 1$ for $p_T > 2$ GeV/c.
- Unexplained by models.

Phys. Rev. C. 87 034904 (2013)



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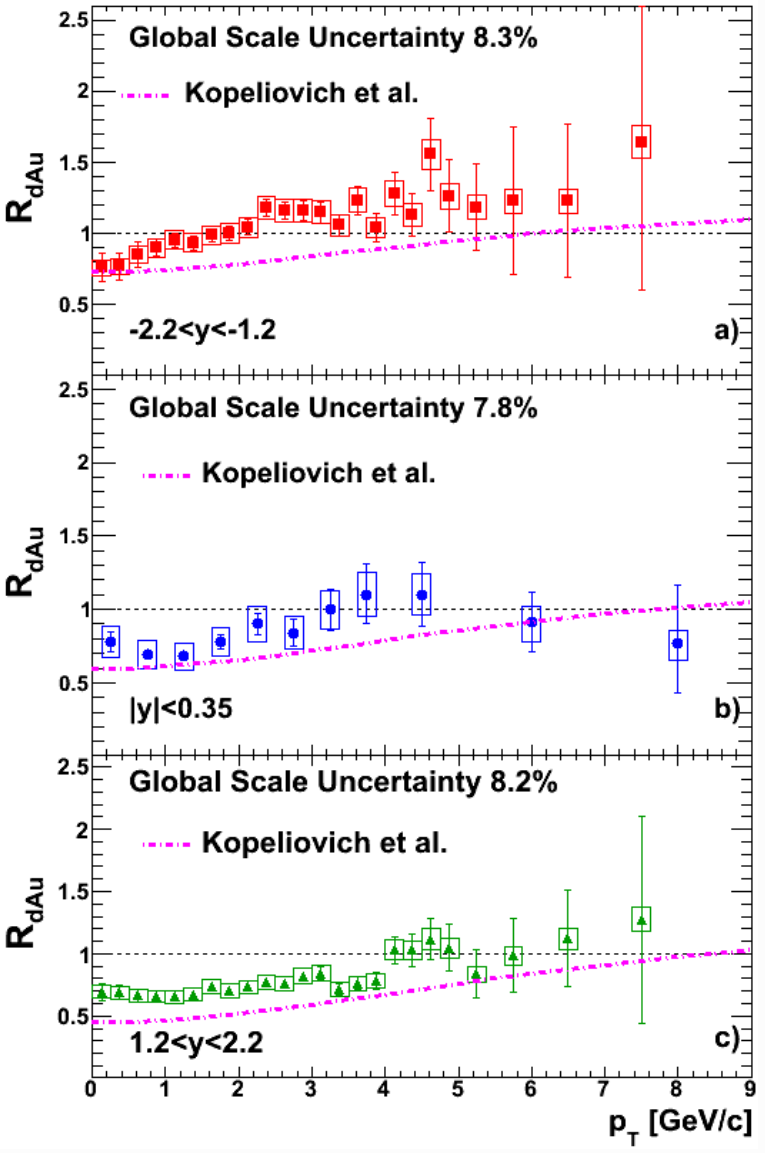
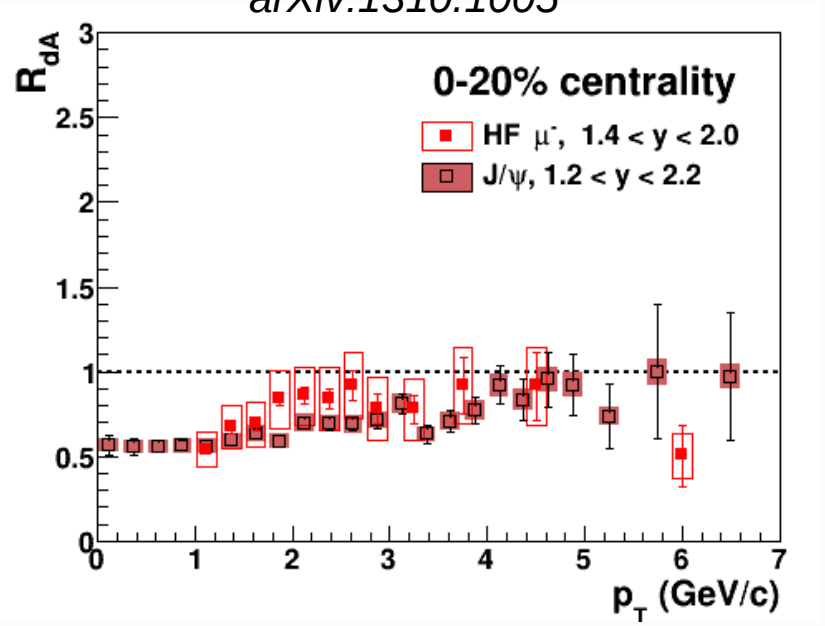


Comparing with Open HF

- Muons show a similar p_T dependence at forward rapidity.
  - Same underlying mechanism.

arXiv:1310.1005

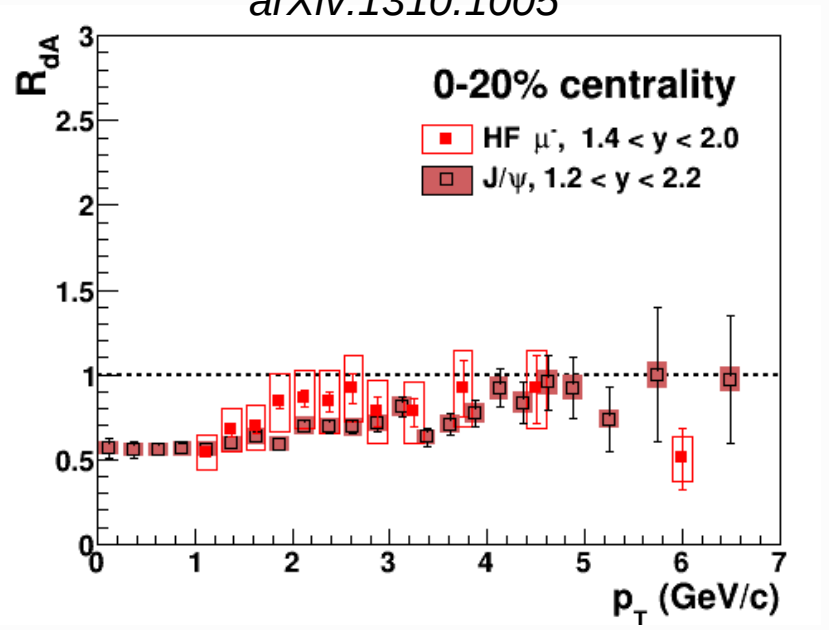


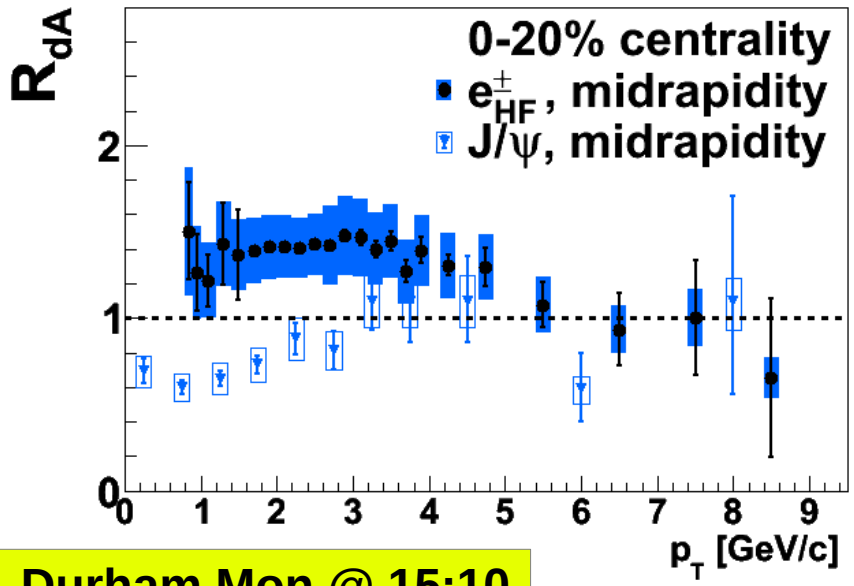
M. Durham Mon @ 15:10

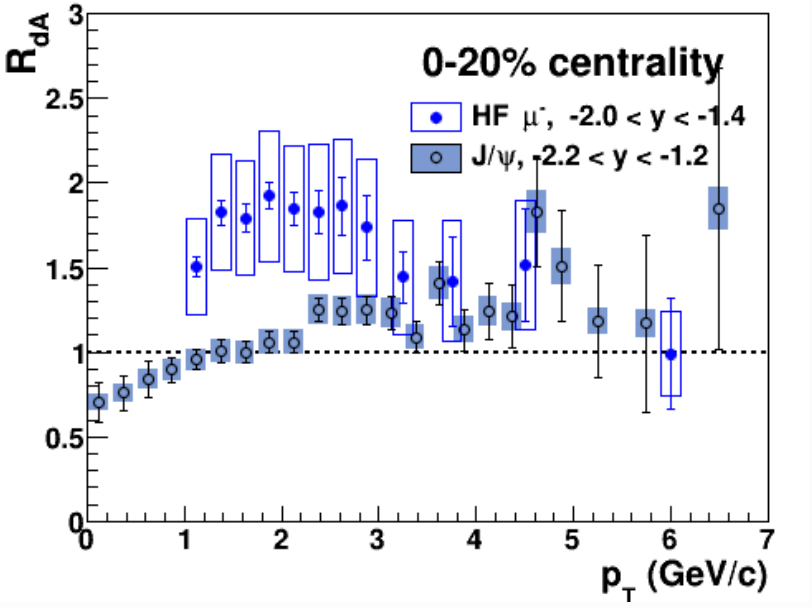
Comparing with Open HF

- Muons show a similar p_T dependence at backward rapidity.
  - Same underlying mechanism.
- Different low p_T behavior at mid/backward rapidity
  - J/ψ has an additional mechanism (nuclear break-up)

arXiv:1310.1005







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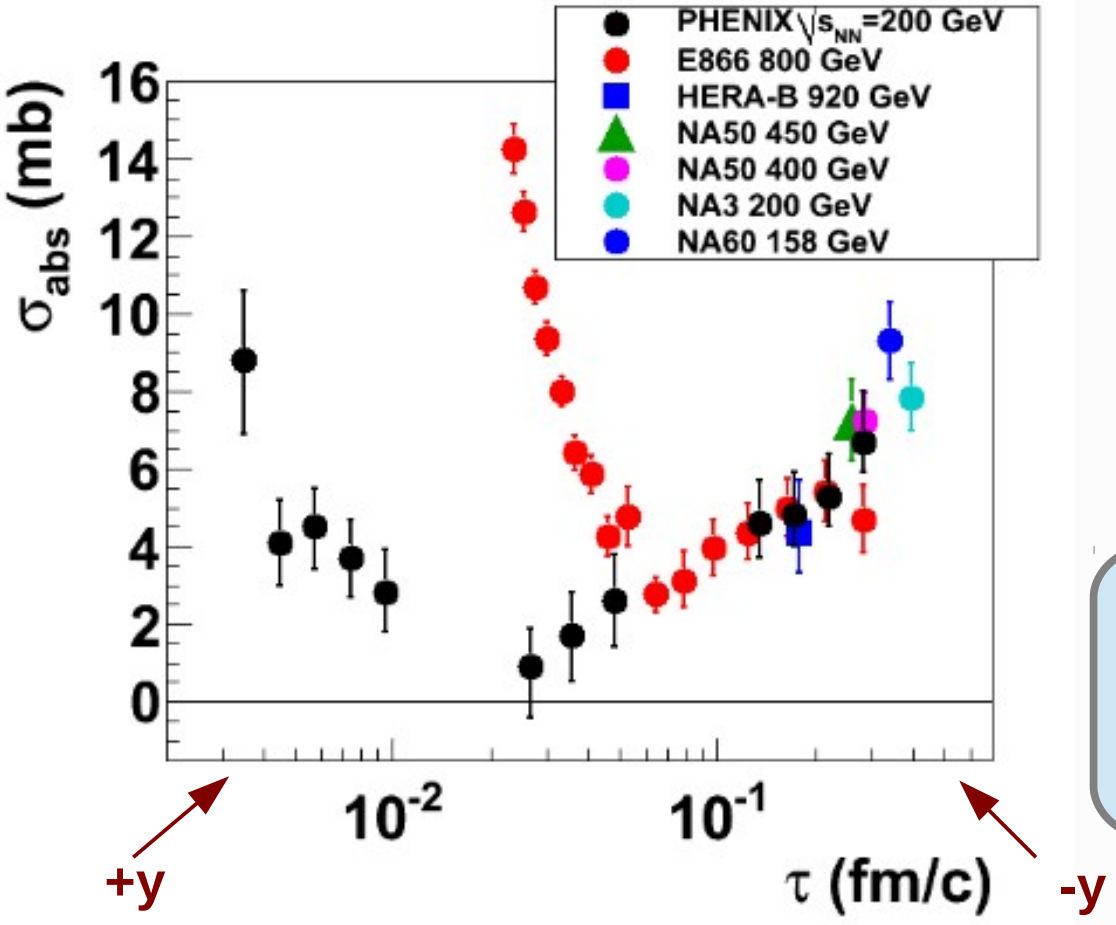
J/ψ Nuclear Break-up

Extract J/ψ break-up cross section (σ_{abs}) from shadowing corrected data



Observe τ scaling for RHIC backward rapidity.

Indication of increasing break-up due to expanding cc pair.

Breaks down at mid/forward rapidity.

Indication of different mechanisms at different rapidities

McGlinchey, et al. Phys. Rev. C. 87 (2013) 054910

J/ψ in d+Au

- PHENIX J/ψ results in d+Au presented a number of puzzles
  - No model simultaneously explains y, p_T, centrality dependence.
- Need to investigate modification of other quarkonium states
  - Different masses & binding energies may provide new insights

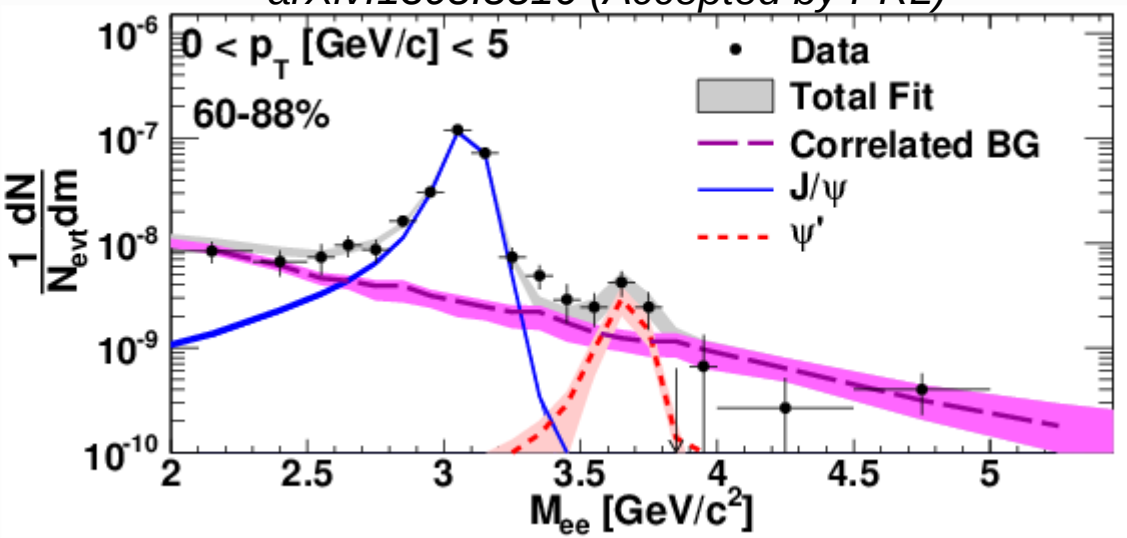
ψ' in d+Au

ψ' – most weakly bound quarkonia state

ΔE factor of 10 less than J/ψ!

Observe a clear ψ' peak in peripheral events.

arXiv:1305.5516 (Accepted by PRL)



ψ' in d+Au

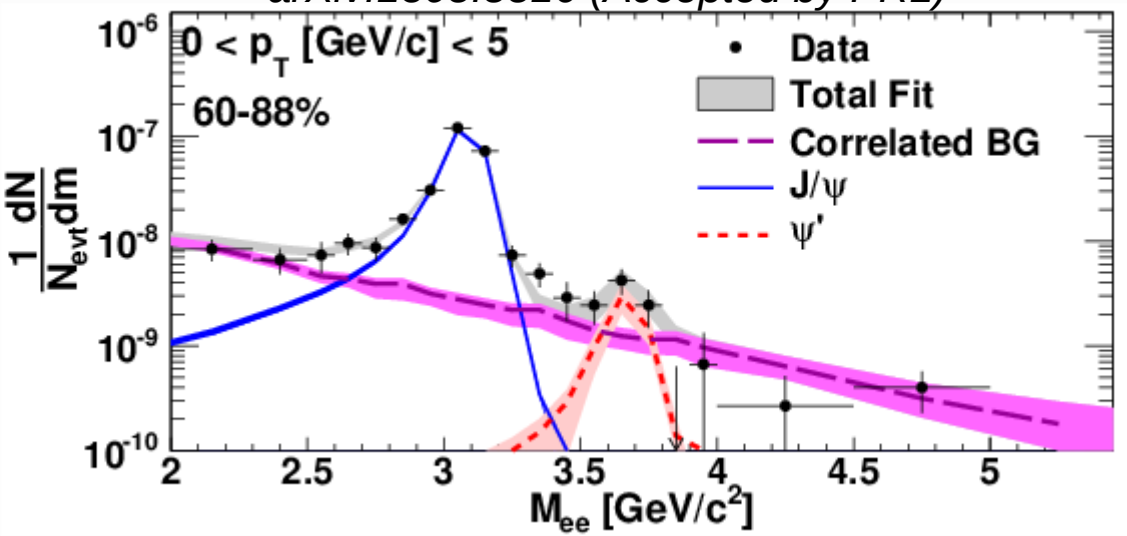
ψ' – most weakly bound quarkonia state

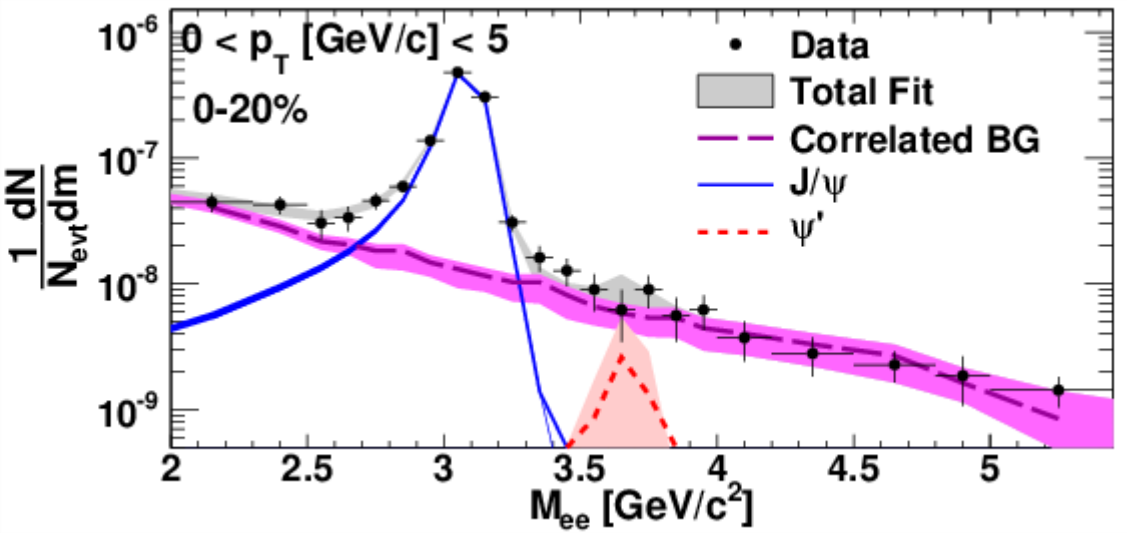
ΔE factor of 10 less than J/ψ!

Observe a clear ψ' peak in peripheral events.

Peak almost disappears in central events.

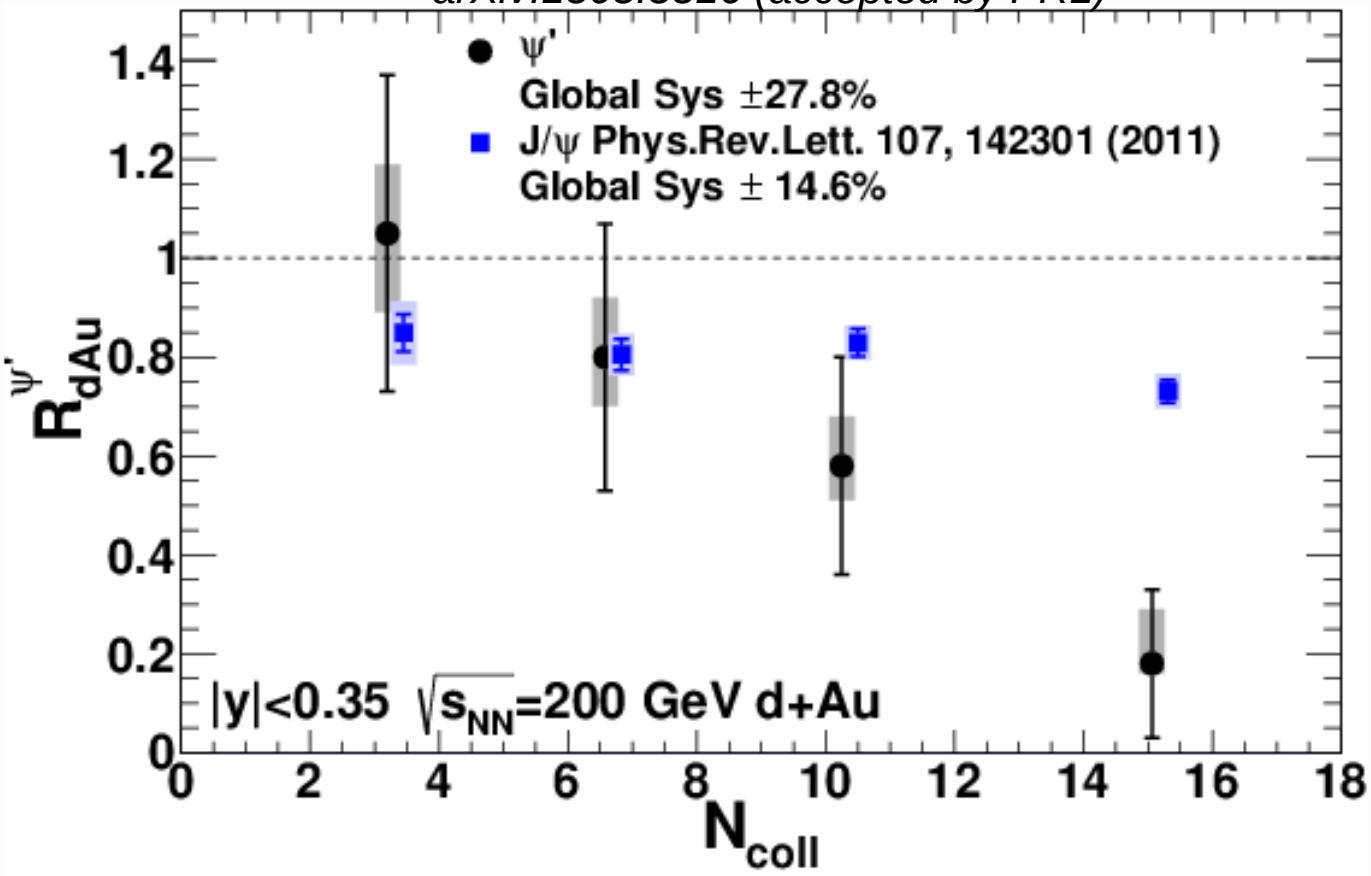
arXiv:1305.5516 (Accepted by PRL)





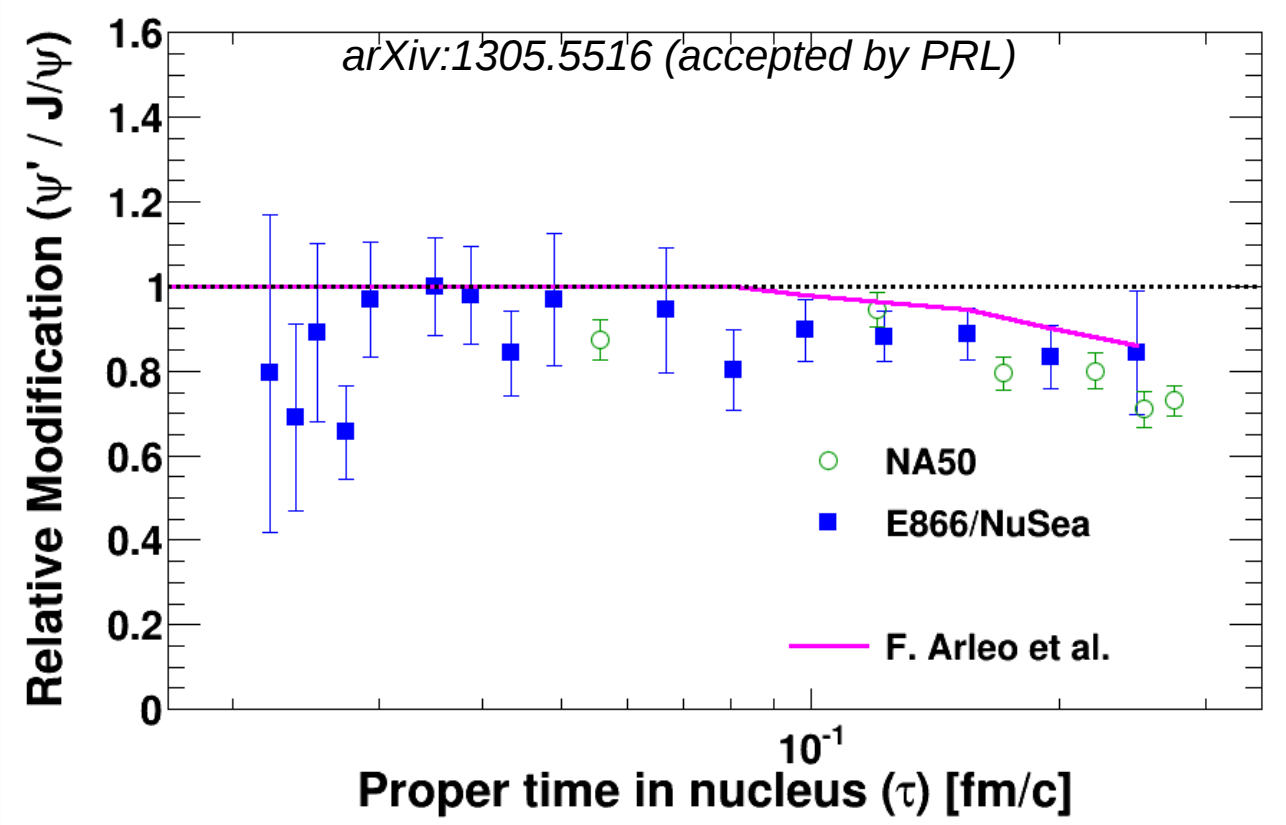
ψ' R_{dAu}

arXiv:1305.5516 (accepted by PRL)

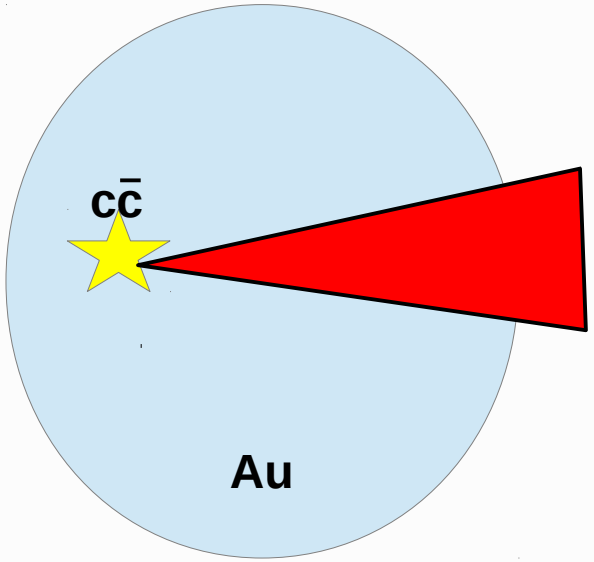


ψ' ~3 times more suppressed than J/ψ in central events!

τ Dependence of Suppression



Low energy results described by increased nuclear breakup due to expanding cc pair.



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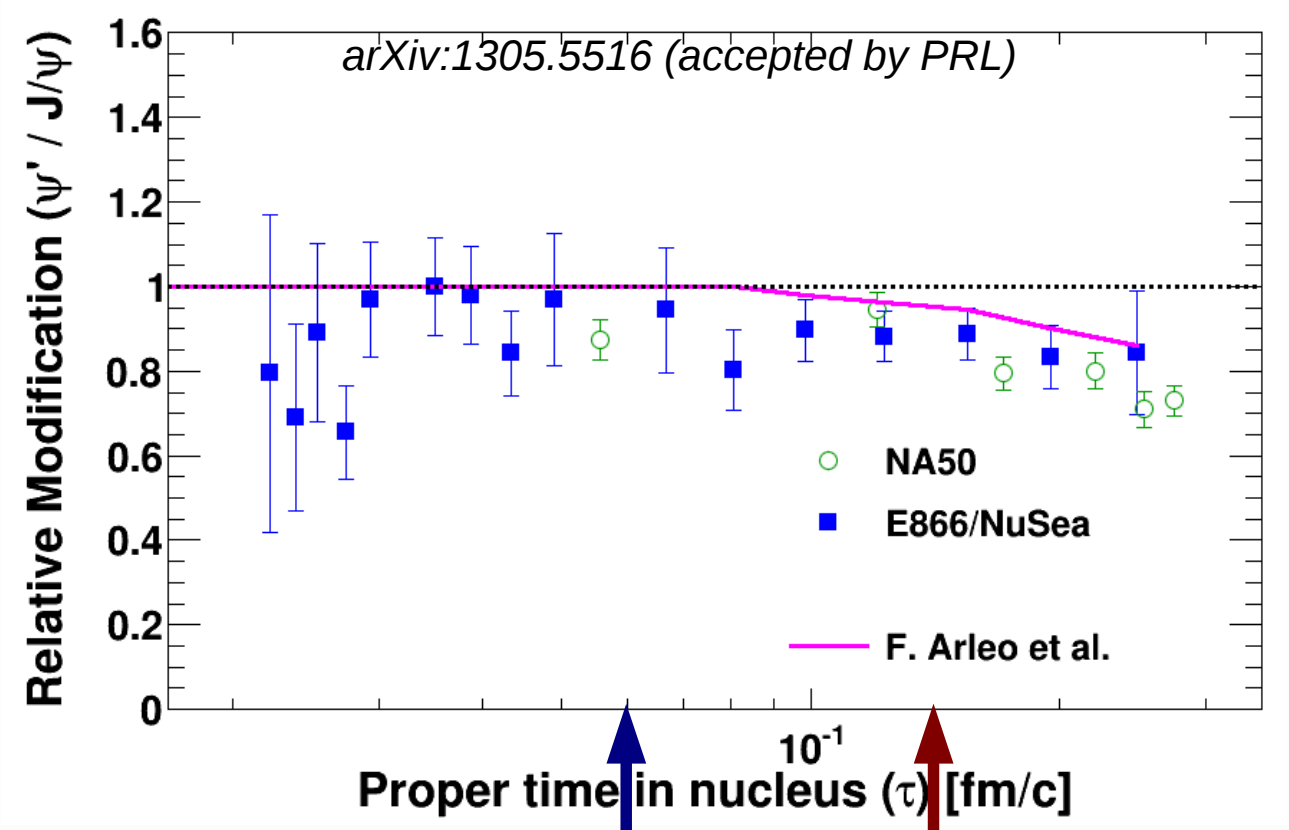
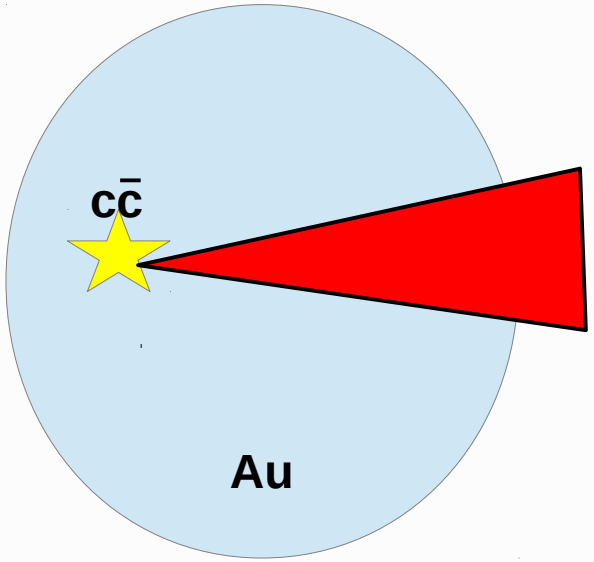


cc formation time
~ 0.05 fm/c

J/ψ formation time
~ 0.15 fm/c

Low energy results described by increased nuclear breakup due to expanding cc pair.



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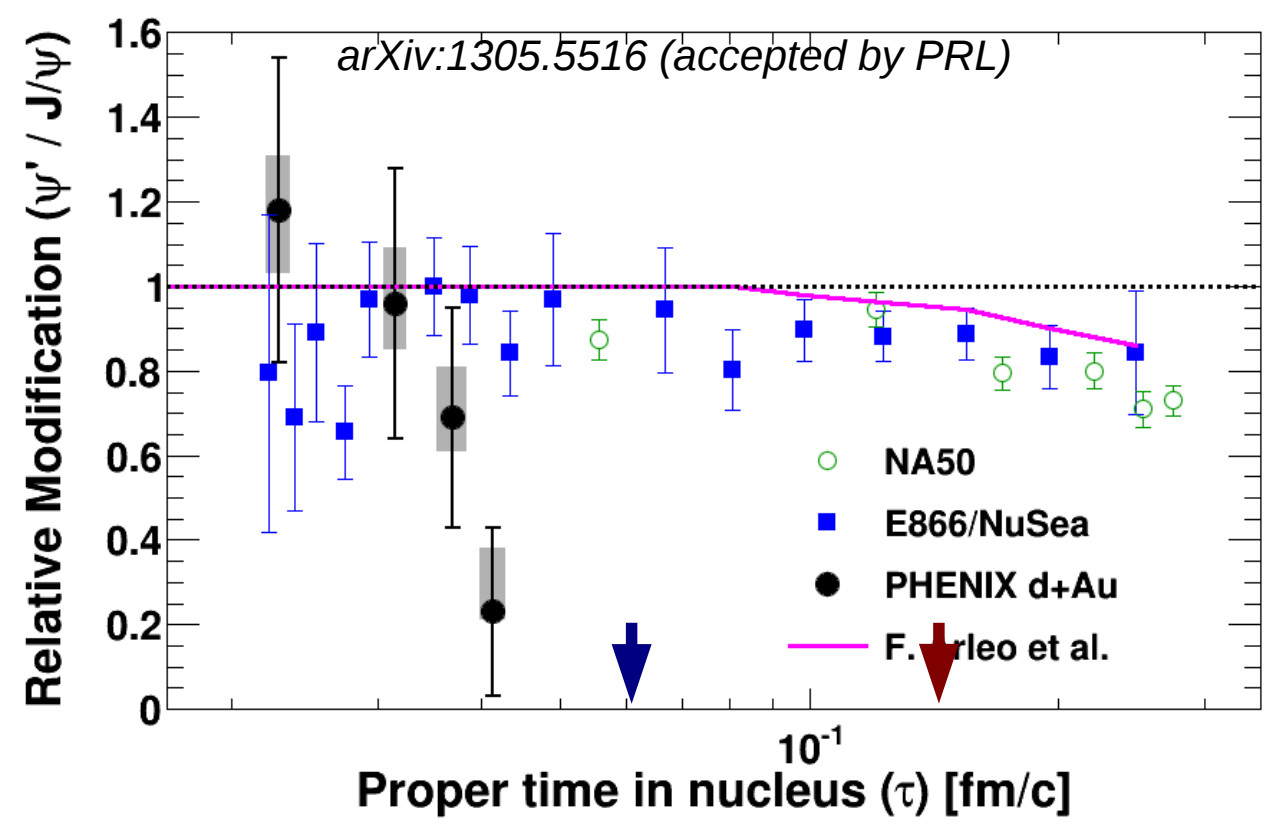


Low energy results described by increased nuclear breakup due to expanding cc pair.

cc formation time ~ 0.05 fm/c
J/ψ formation time ~ 0.15 fm/c

Increased nuclear breakup can not explain RHIC results, the cc crosses the nucleus too quickly!

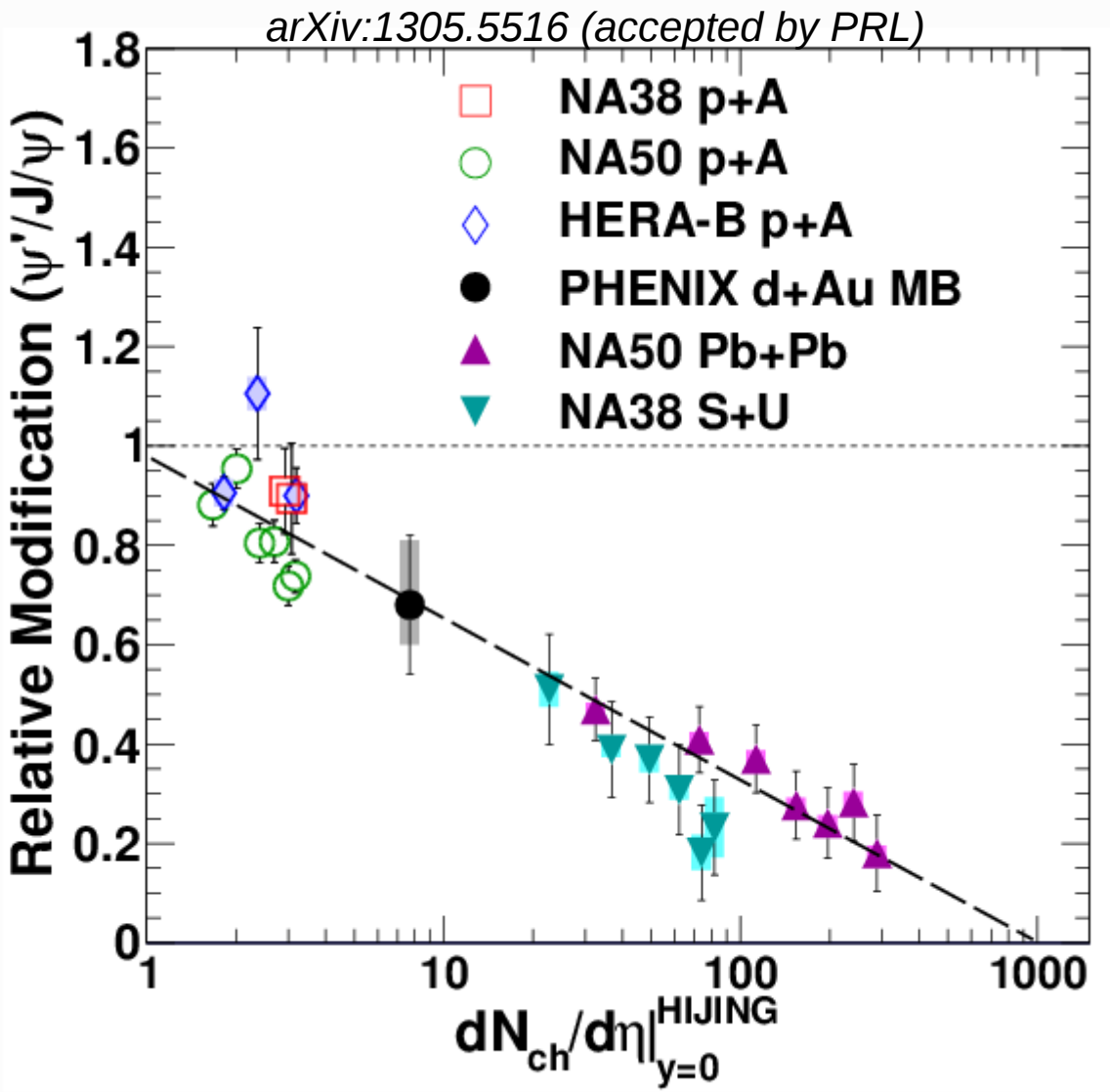
Need either an initial state effect that differs at very short time scales, or perhaps a long-range final state effect

Relative Modification

Relative modification ψ'/(J/ψ) vs midrapidity multiplicity for SPS p+A, RHIC d+Au and SPS A+A

Results seem to follow a common trend.

ψ' more effected by presence of a medium in d+Au?



Comparing to the LHC

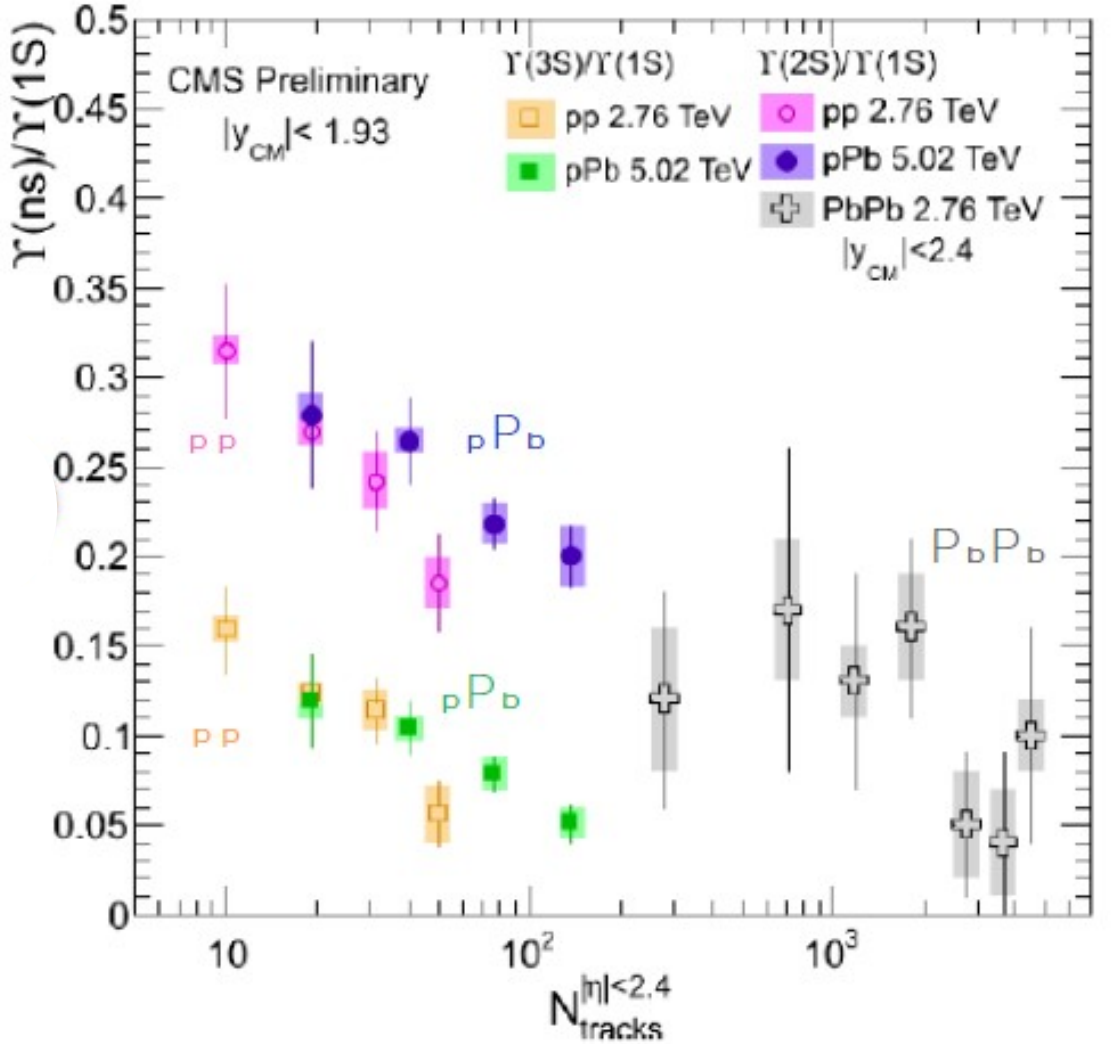
CMS has measured the relative modification for Upsilon states.

ΔE Y(2S) ~ ΔE J/ψ
ΔE Y(3S) ~ ΔE χ_c

Observe suppression of excited states in p+Pb @ 5.02 TeV

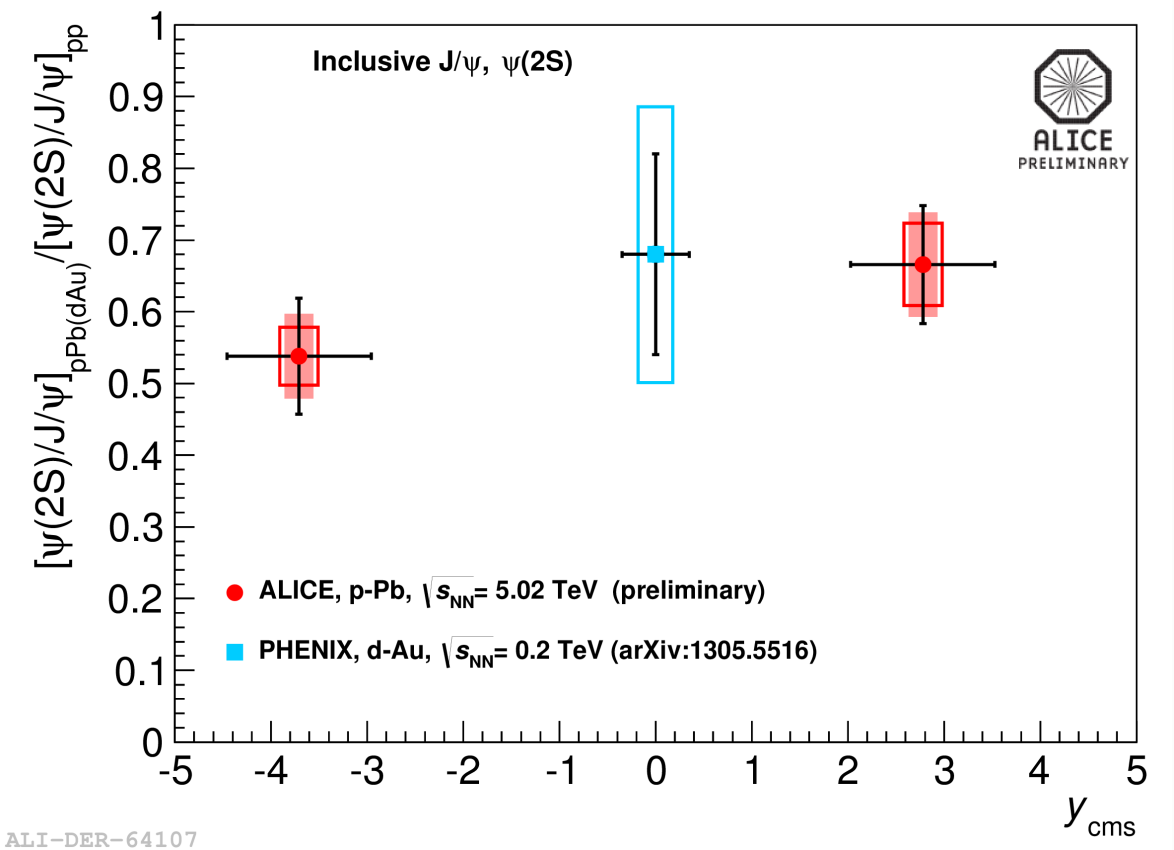
Weaker bound states are more suppressed.

Observe approximate multiplicity scaling.



Comparing to the LHC

M. Winn Thurs @ 16:20

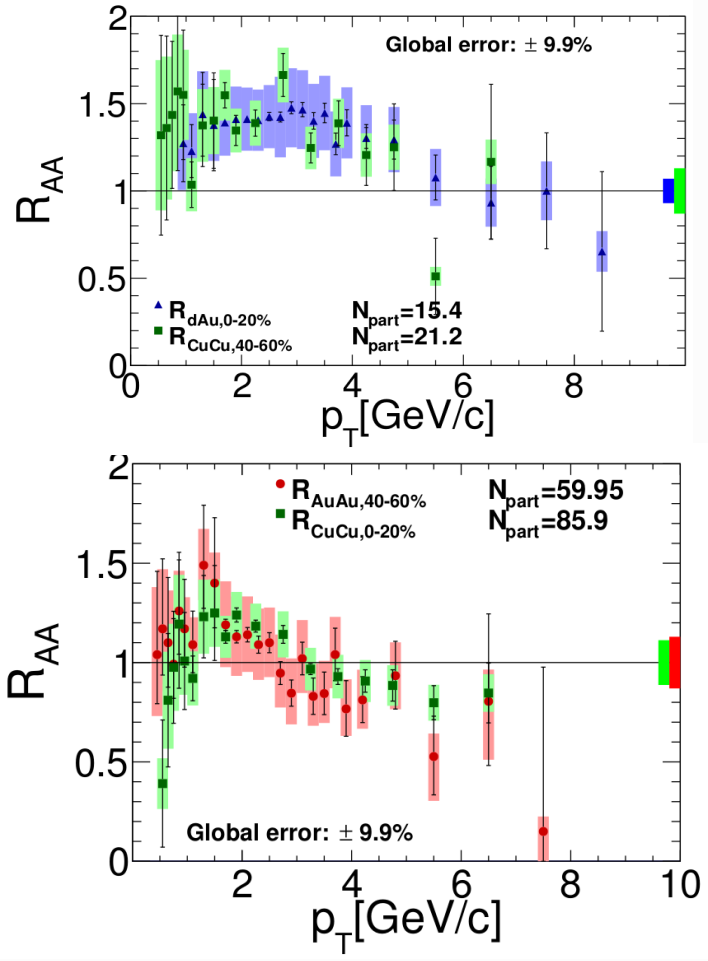


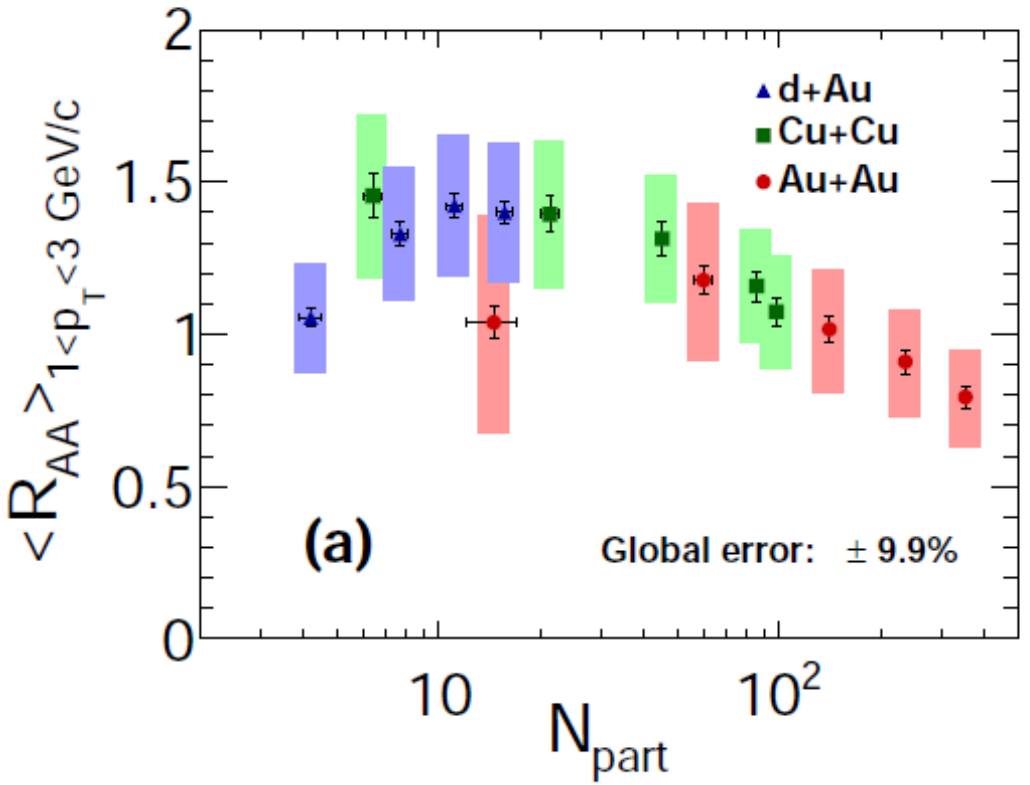
New ALICE results also show that the ψ'/J/ψ ratio in p+Pb@5 TeV is similar to d+Au@200 GeV!

Reconciling with other RHIC results

New results on heavy flavor electrons in Cu+Cu show a smooth transition from enhancement in small systems to suppression in large systems

arXiv:1310.8286

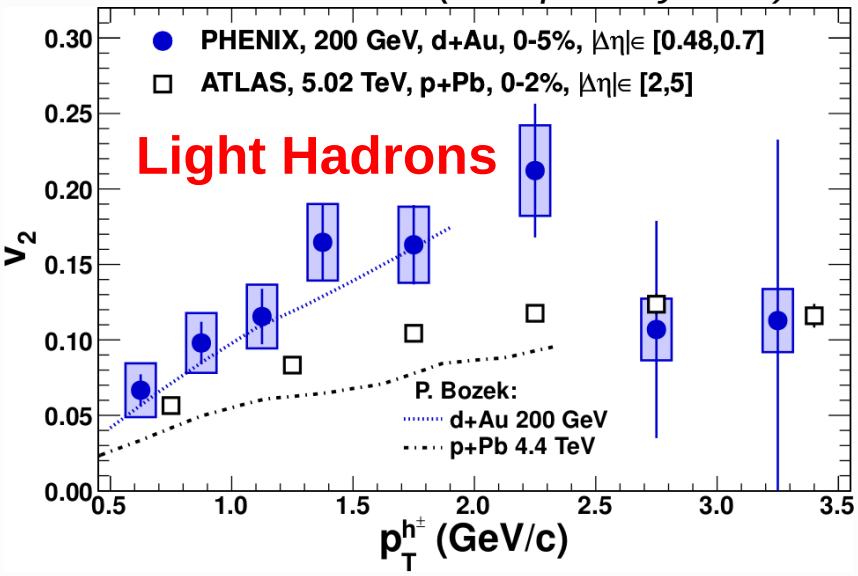




M. Durham Mon @ 15:10

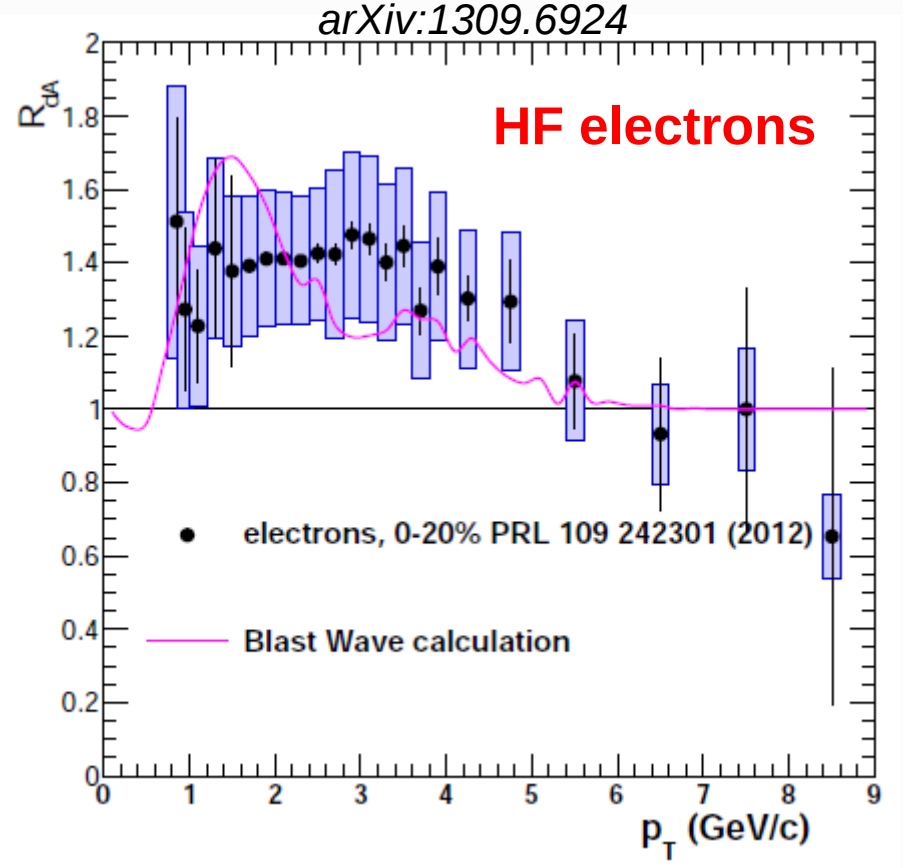
Open Heavy Flavor Flow?

arXiv:1303.1794 (accepted by PRL)



Possible flow effects at RHIC & LHC in p(d)+A

arXiv:1309.6924



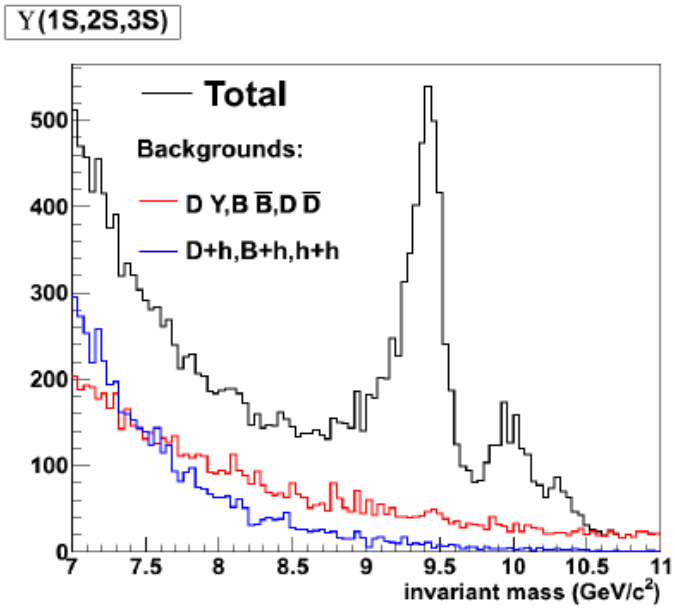
Blast wave calculation fits HF electron spectrum in d+Au, charm flow?

IF heavy flavor flows, how does that effect our interpretation of quarkonia results?

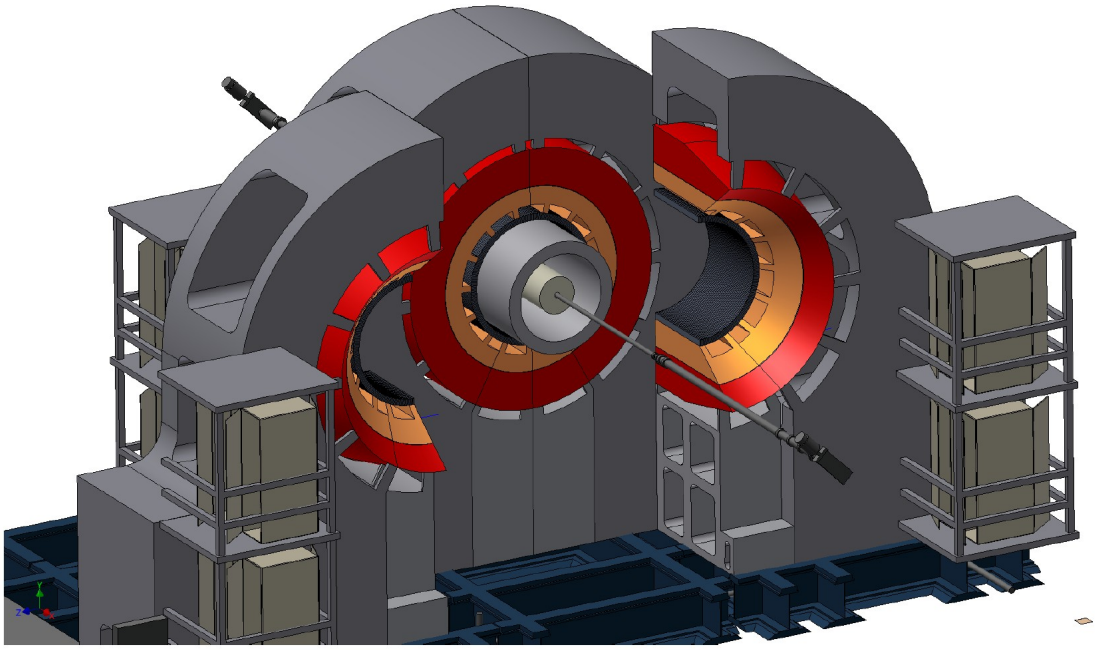
Future of Quarkonia at PHENIX

Near Future: p+Cu, p+Si, p+Au in **2015** at RHIC

sPHENIX



Another 7x Acceptance



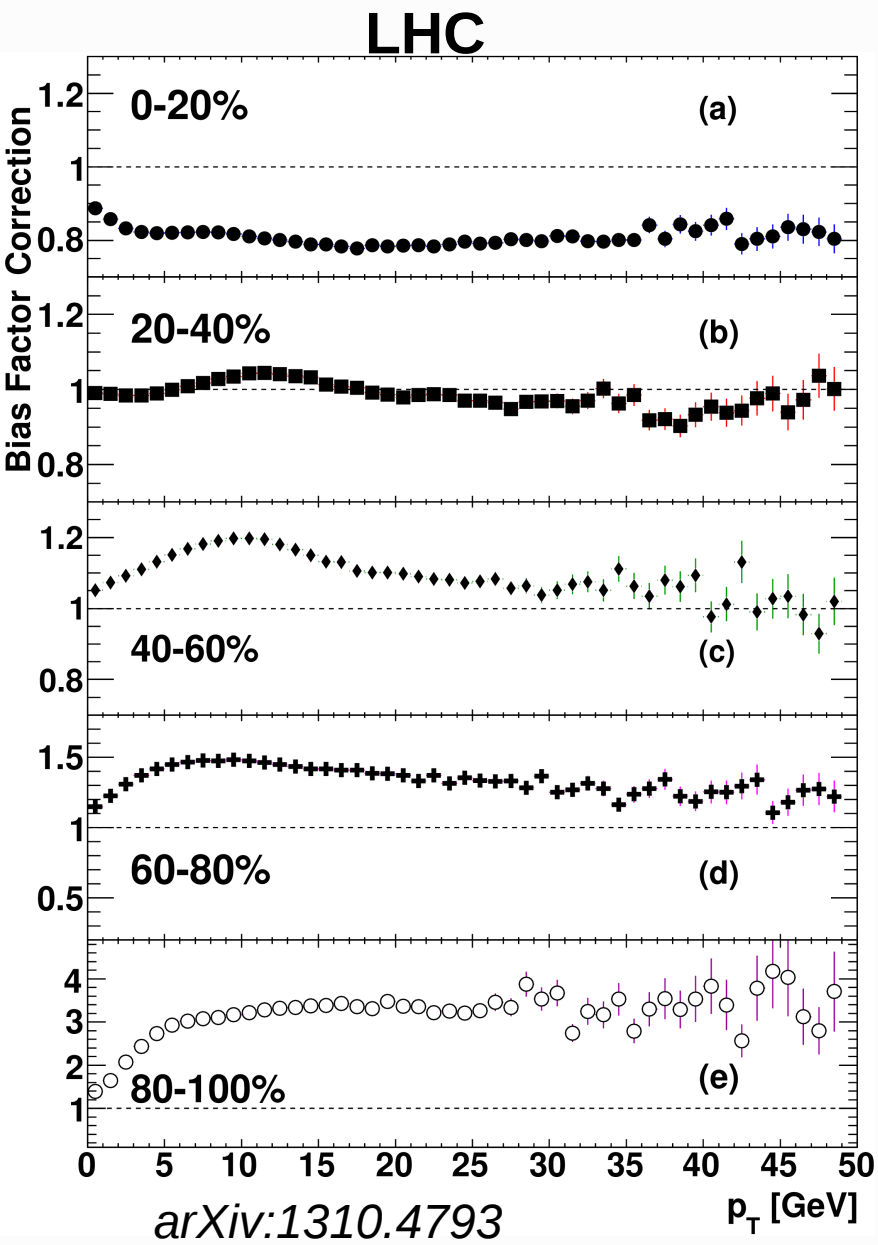
Long Term: Upsilons with sPHENIX!

Summary

- PHENIX has the capability to measure quarkonia in a wide range of collision species over a wide range in energies.
  - **Current:** p+p, d+Au, Cu+Cu, Cu+Au, Au+Au, U+U from 39 - 200 GeV
  - **Future:** p+A, d+A, H_3+A @ 200 GeV , sPHENIX
- Possible minimum in J/ψ R_{AA} @ 200 GeV.
- Larger suppression of the ψ' than J/ψ in d+Au.
  - Not explained by increased nuclear breakup.
  - possible “medium” effect?
- How does our evolving understanding of a possible medium in p(d)+A effect our interpretation of these results?

Thank You!

Understanding Geometry in d+Au

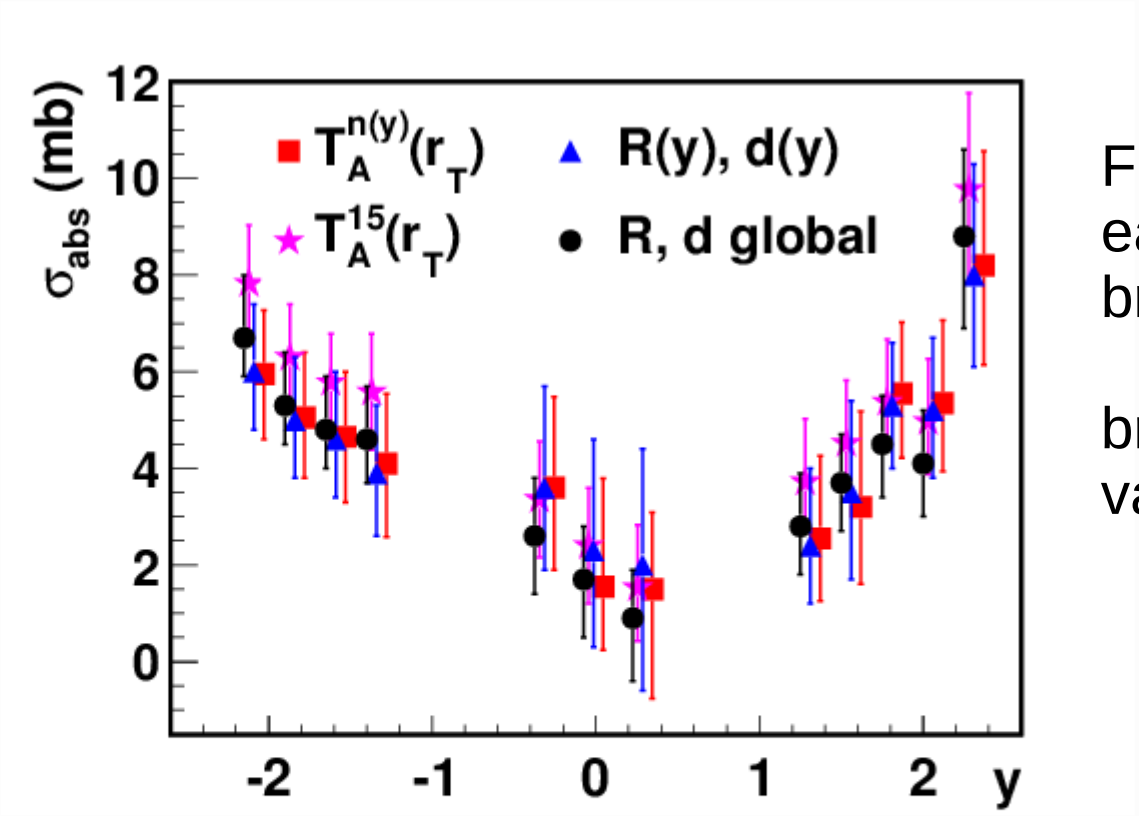


- Using same method, extract similar factors for LHC energies.
- Find larger bias factors with significant p_T dependence.
- Due to ~order of magnitude increase in Multi-Parton Interactions.
- Qualitatively similar to what has been shown by ALICE

~20-300% Effect at LHC!

J/ψ Nuclear Break-up

Extract J/ψ break-up cross section (σ_{abs}) from shadowing corrected data

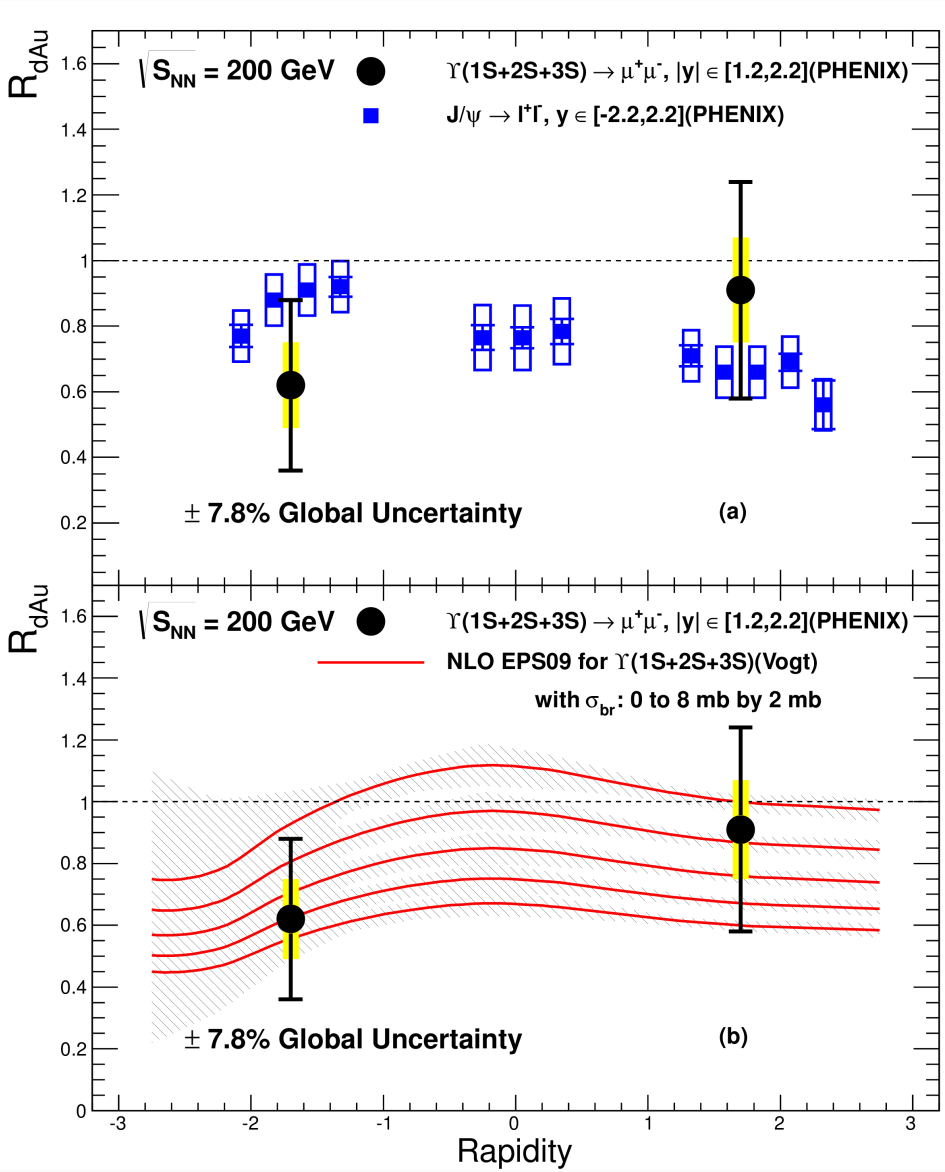


Fit the centrality dependence at each rapidity with EPS09 + nuclear break-up

break-up cross section allowed to vary at each rapidity!

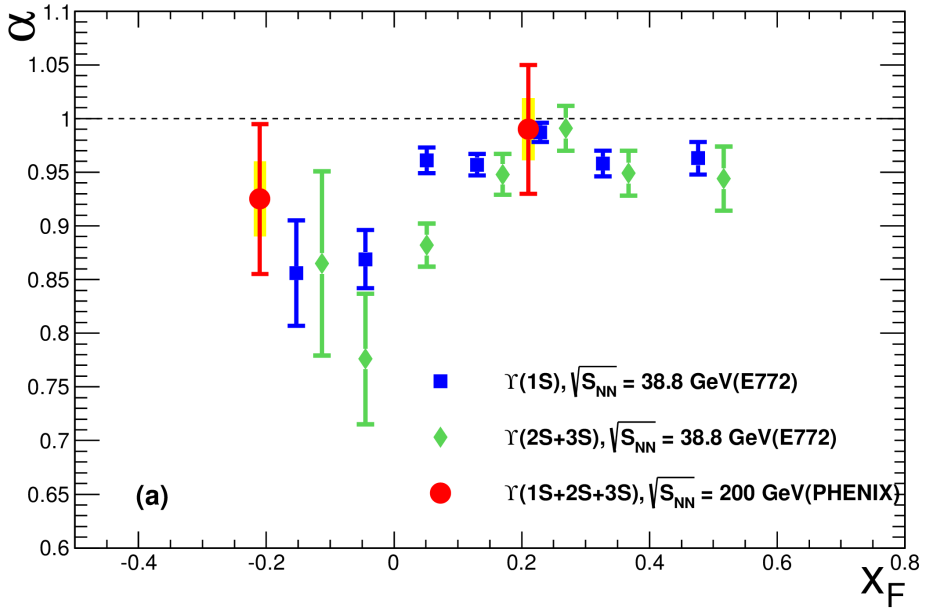
McGlinchey, et al. Phys. Rev. C. 87 (2013) 054910

Upsilon in d+Au



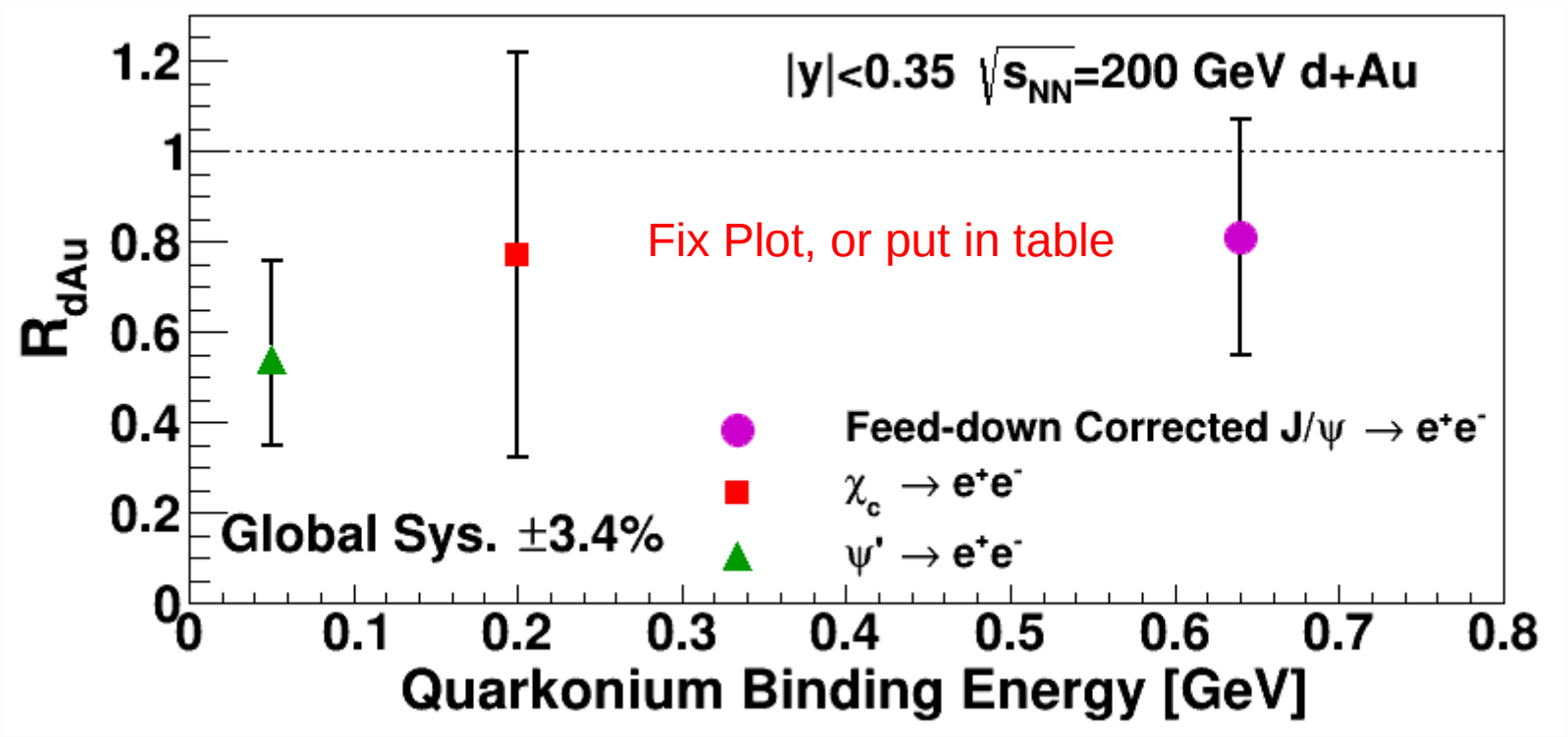
Upsilon R_{dAu} consistent with NLO EPS09

Upsilon modification consistent with lower energy results.



What about the χ_c?

J/ψ corrected for ψ' and χ_c feed-down effects!



Measuring χ_c is very challenging.

Currently, uncertainties are to large to draw any strong conclusions.