HARD PROBES 2018

International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions
30 September 2018 to 5 October 2018 • Aix-Les-Bains • France

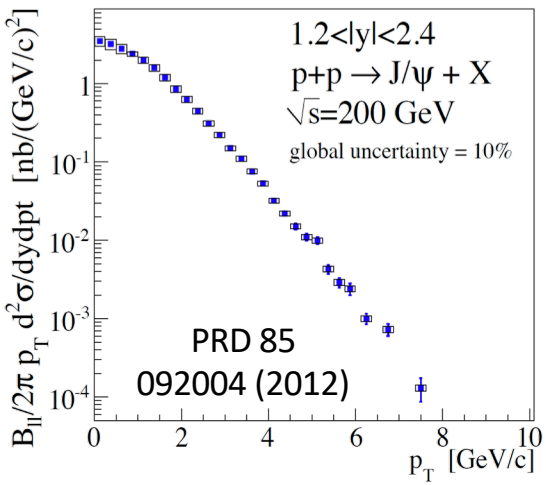
Los Alamos NATIONAL LABORATORY EST. 1943

# System size dependence of J/ψ nuclear modification from PHENIX

Matt Durham

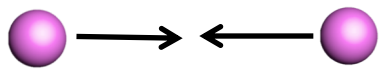
Los Alamos National Laboratory

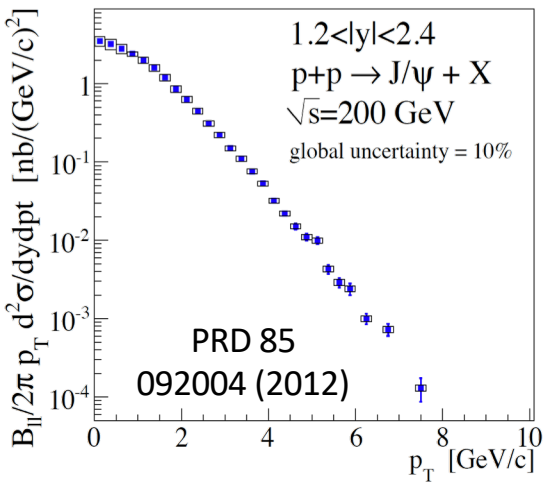
# Charmonium production in the nucleus



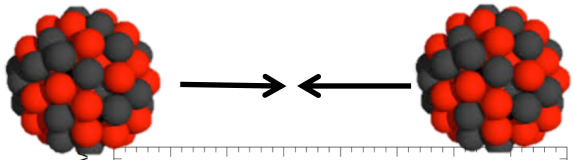

Charm production (pQCD) + hadronization

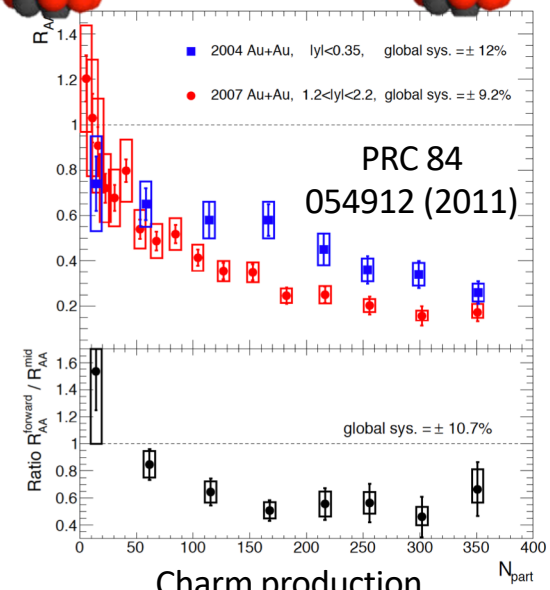
# Charmonium production in the nucleus





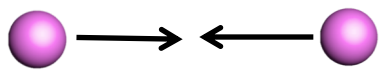

Charm production (pQCD) + hadronization

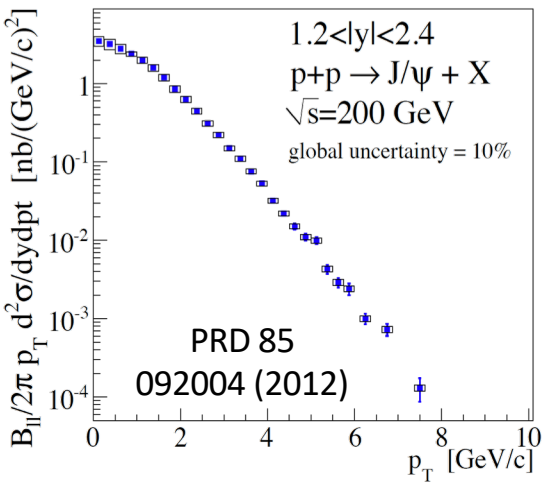




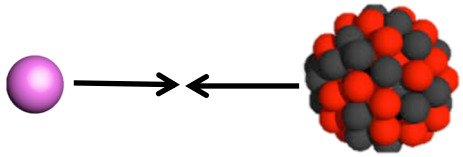

Charm production (pQCD) + hadronization
+color screening

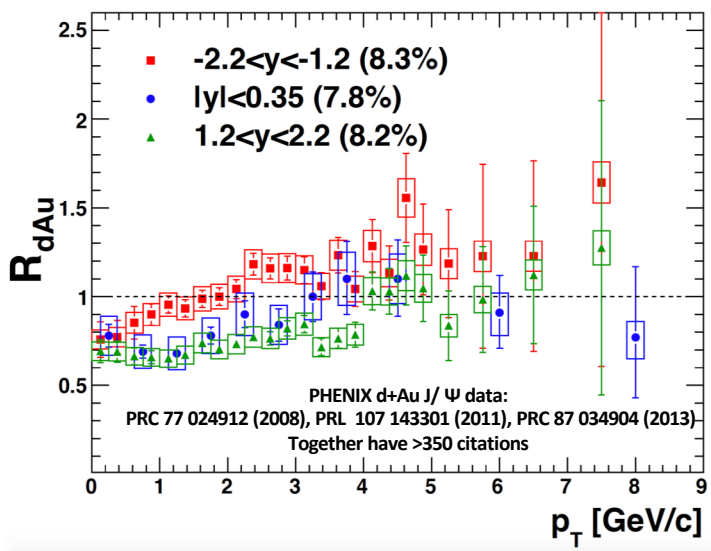
# Charmonium production in the nucleus

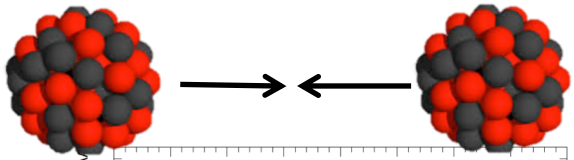


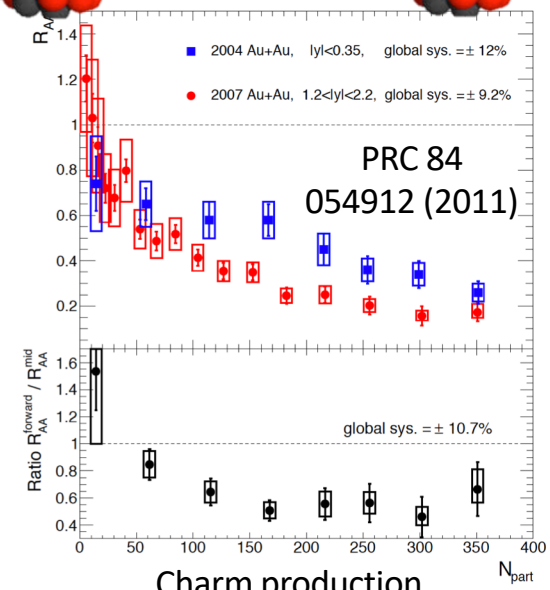



Charm production (pQCD) + hadronization



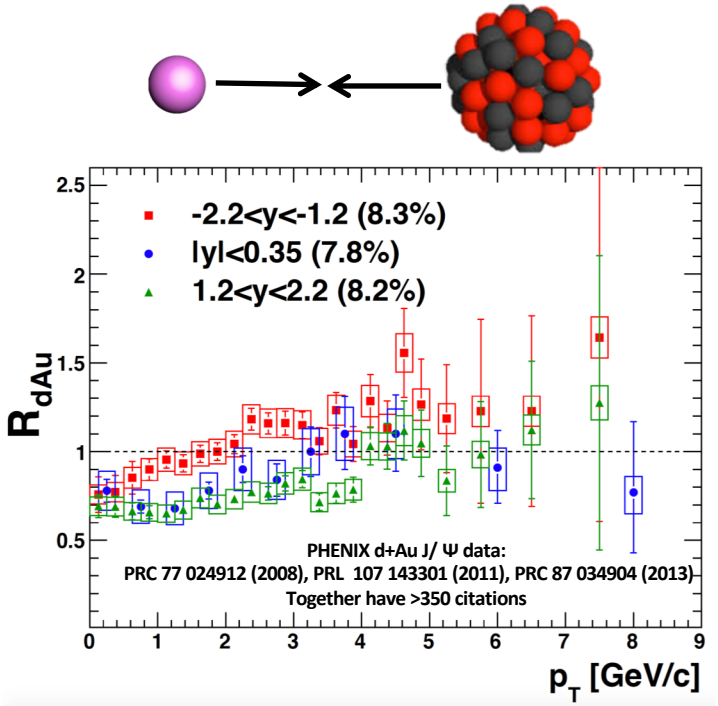




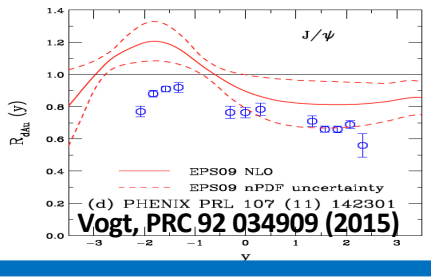

Charm production (pQCD) + hadronization
+color screening

# Charmonium production in the nucleus

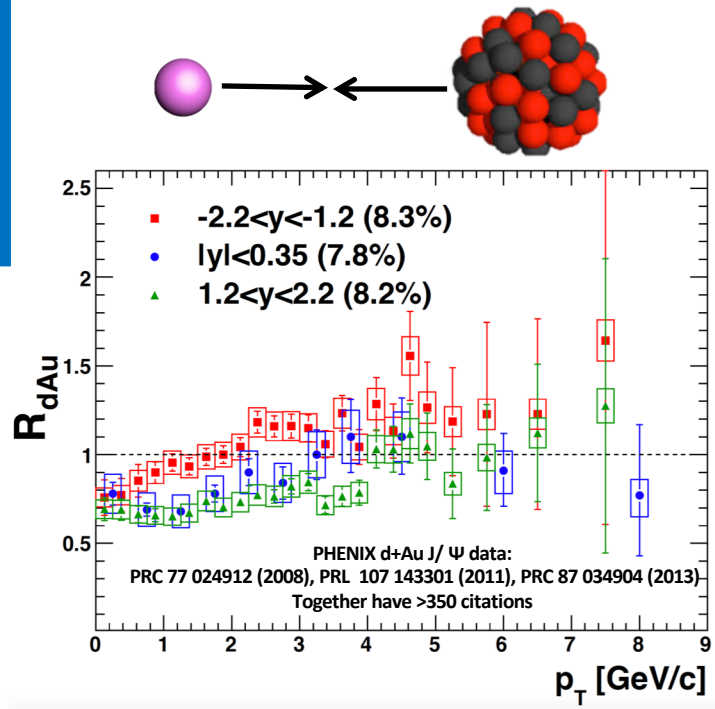


# Charmonium production in the nucleus

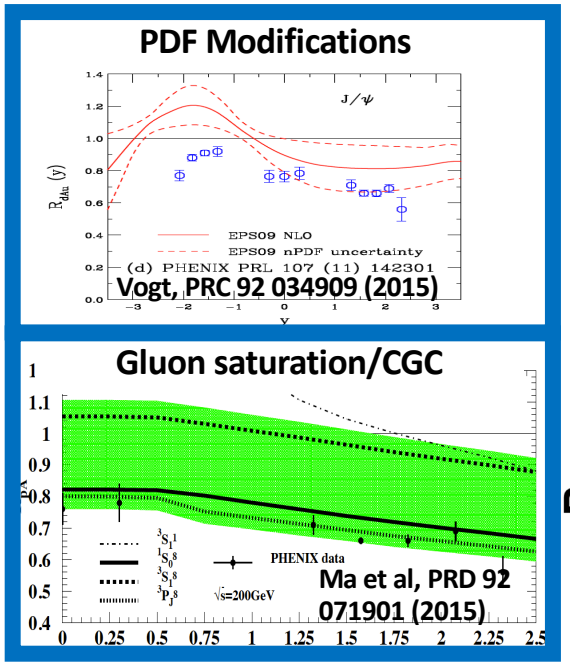
**PDF Modifications**

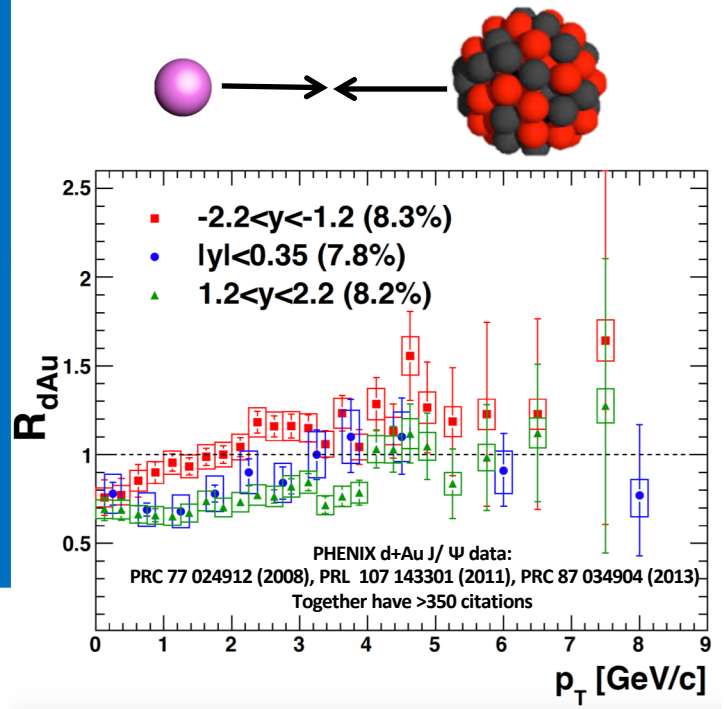



Vogt, PRC 92 034909 (2015)

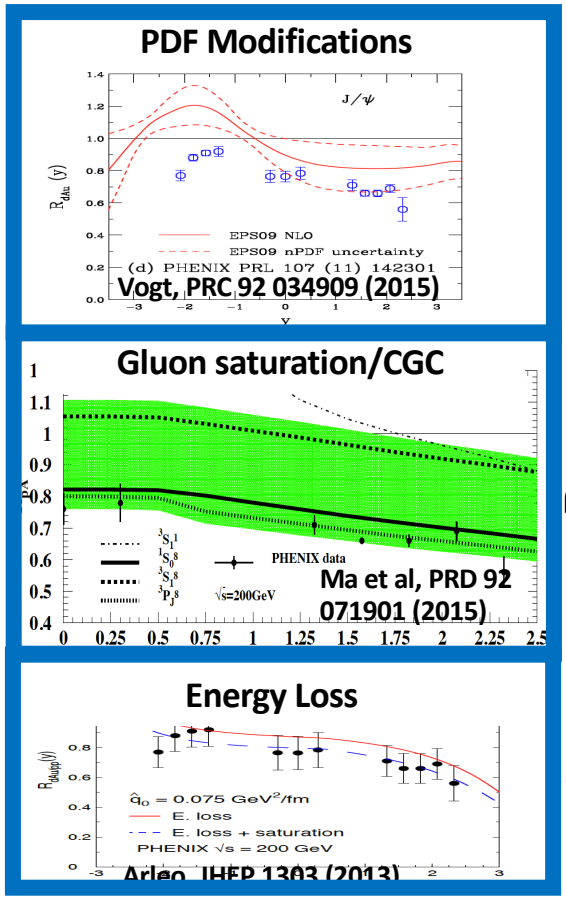


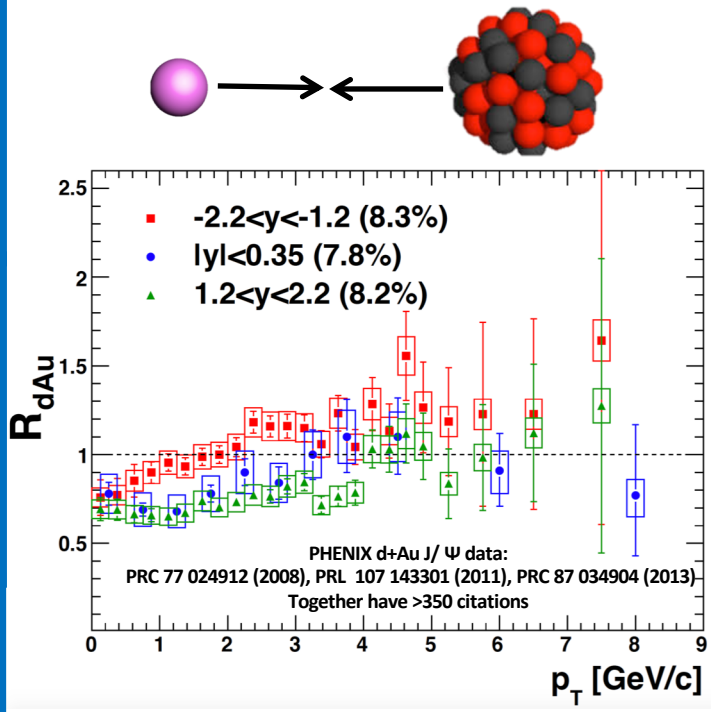
# Charmonium production in the nucleus



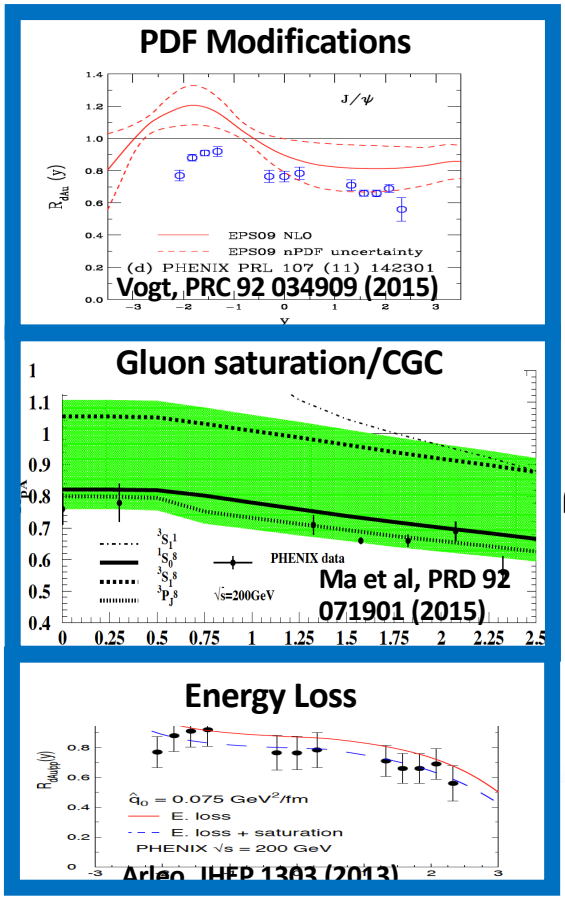



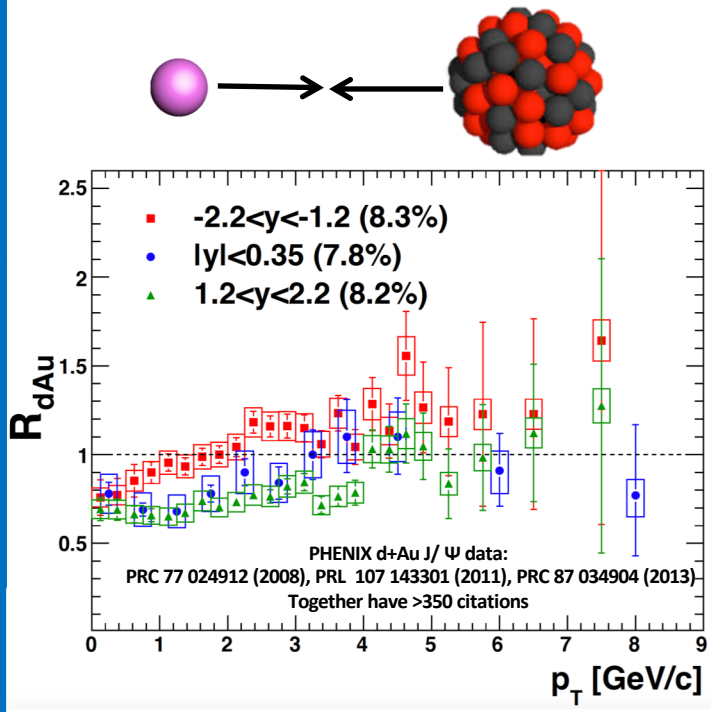
# Charmonium production in the nucleus

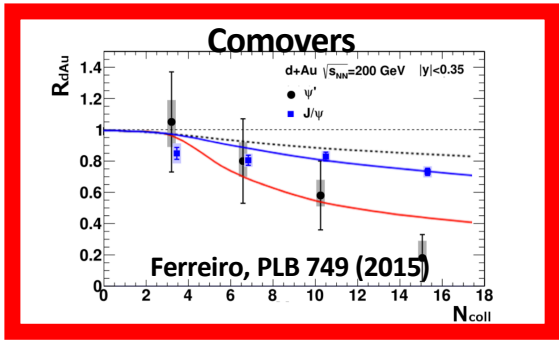


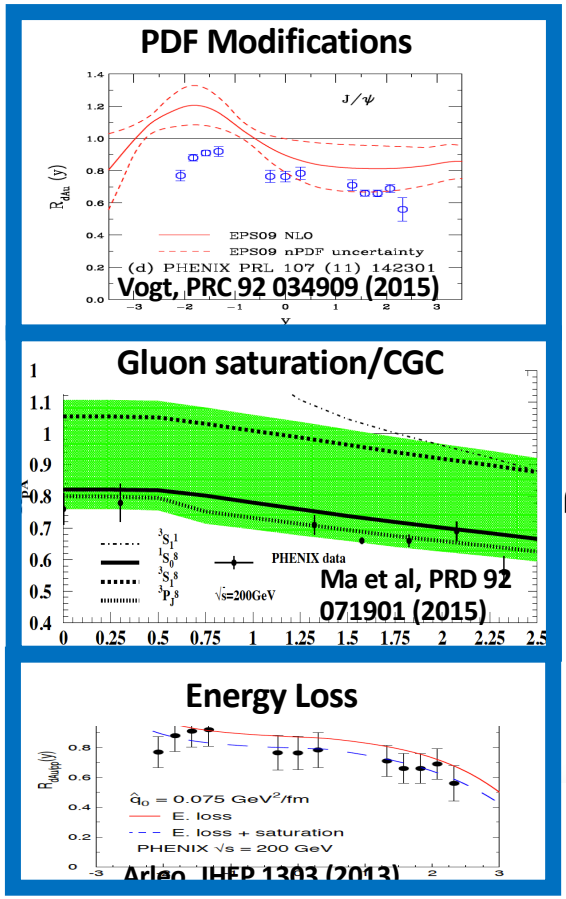
# Charmonium production in the nucleus

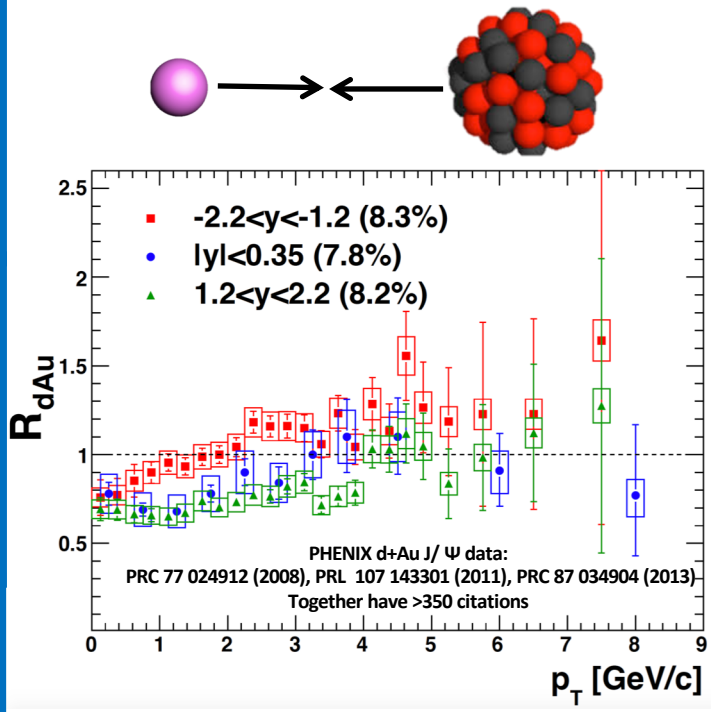


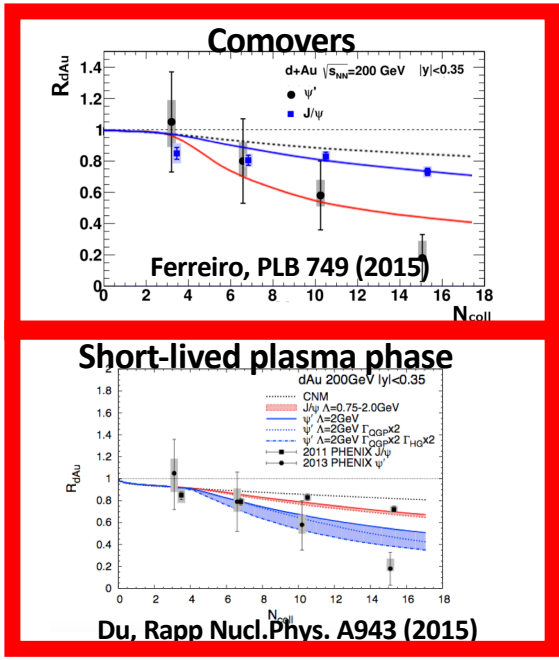



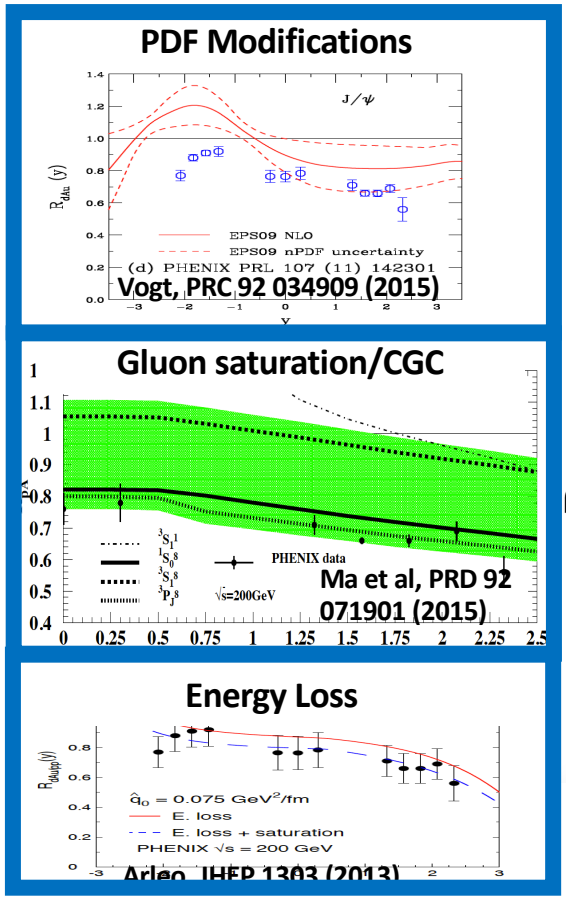
# Charmonium production in the nucleus

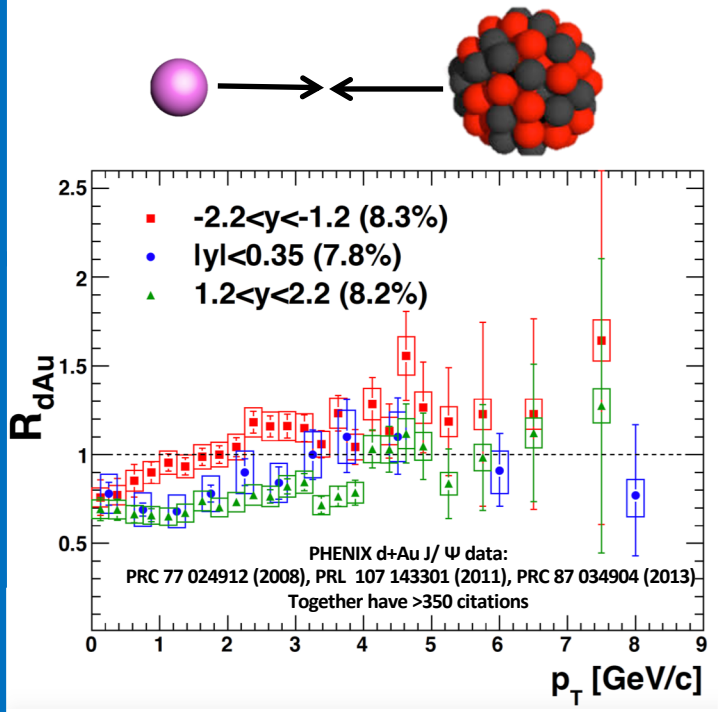


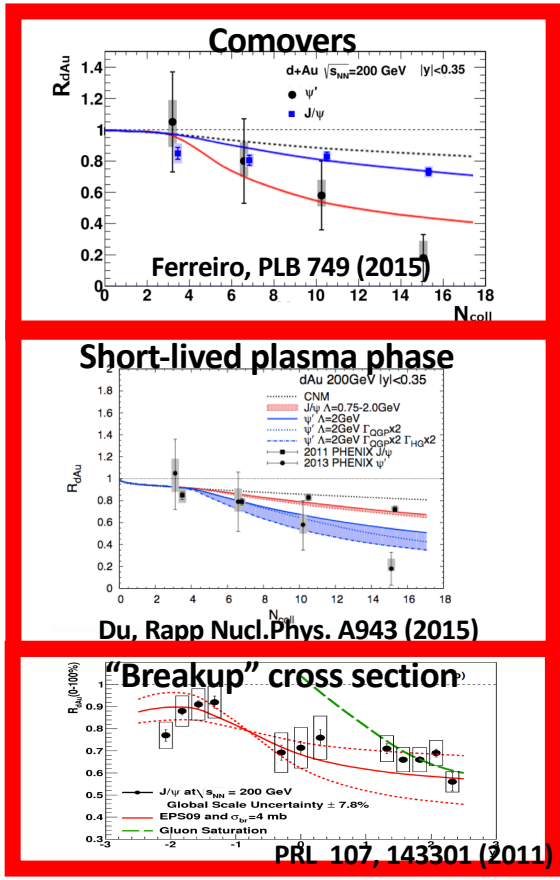



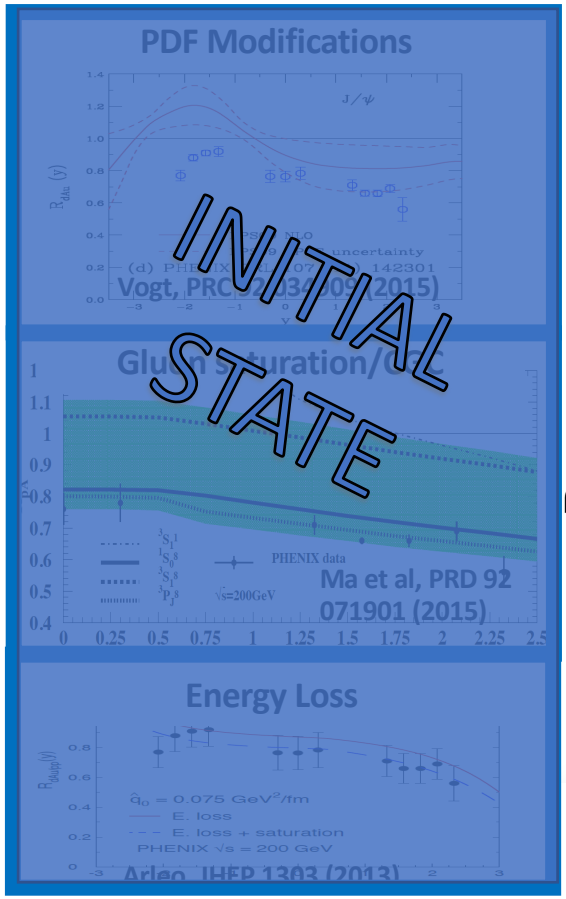
# Charmonium production in the nucleus

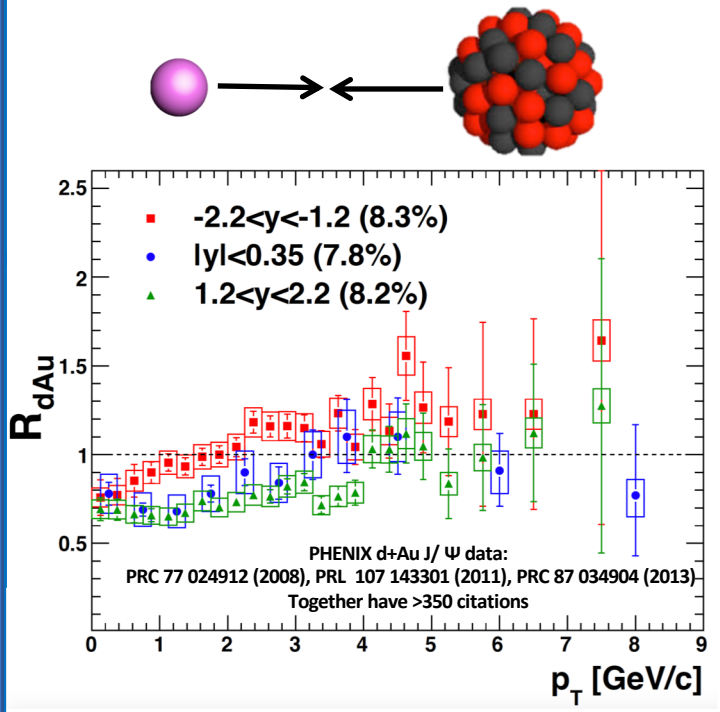


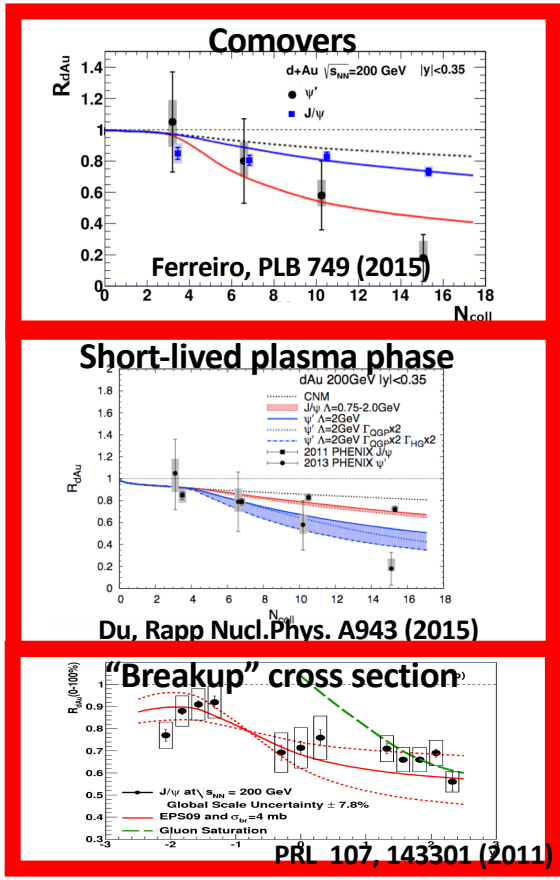



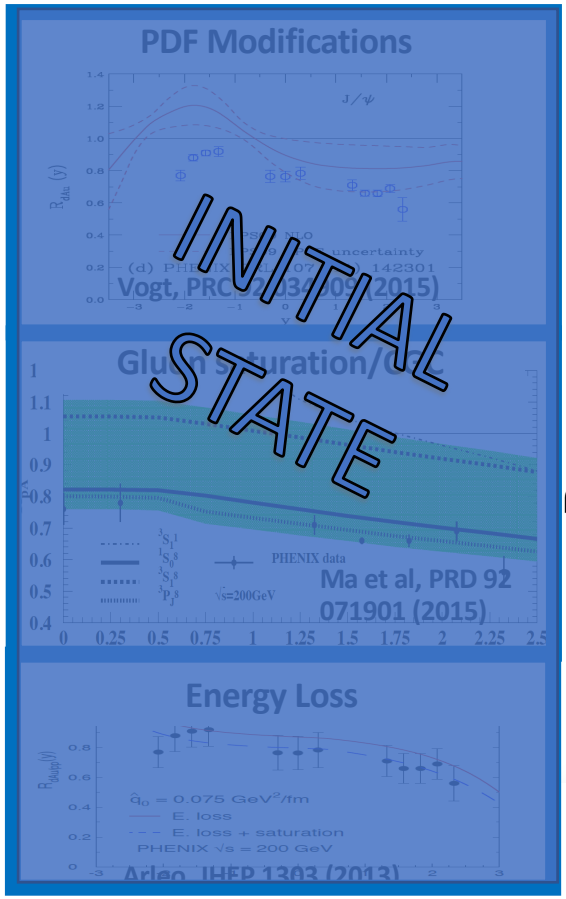
# Charmonium production in the nucleus

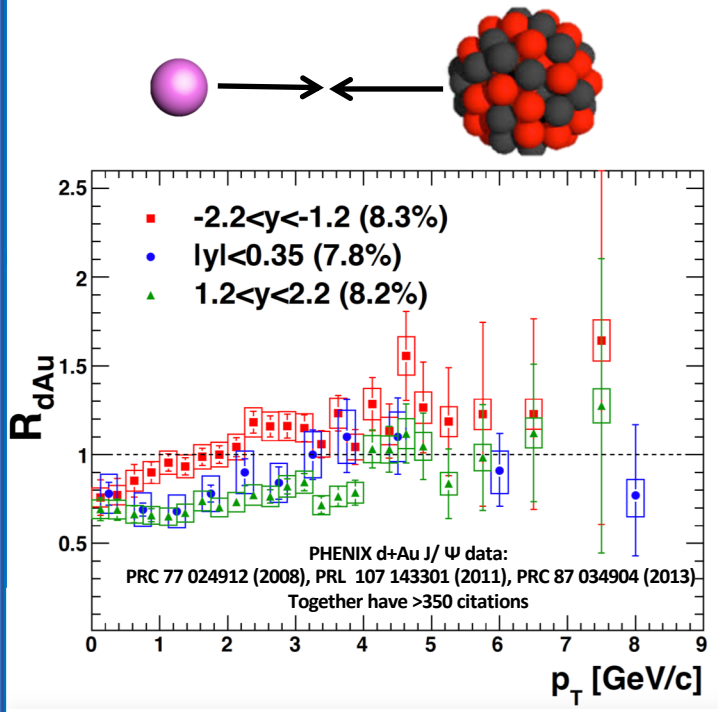


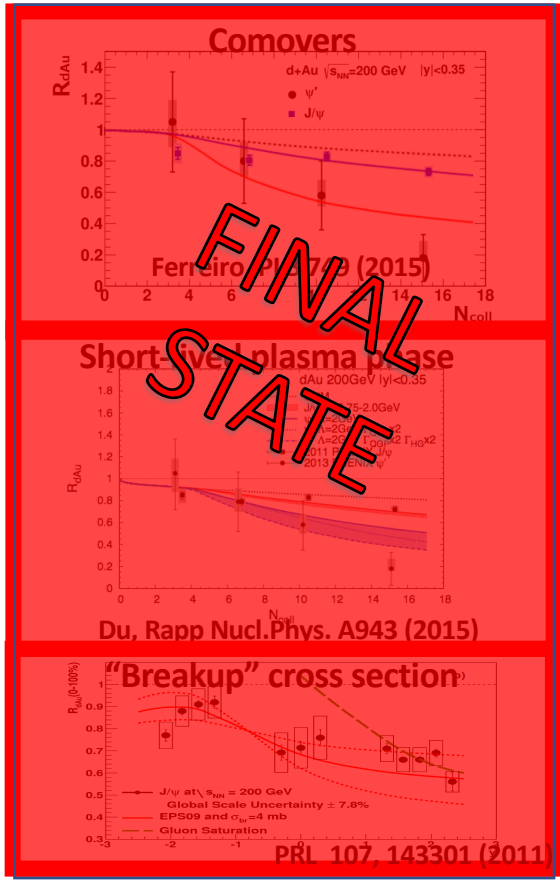



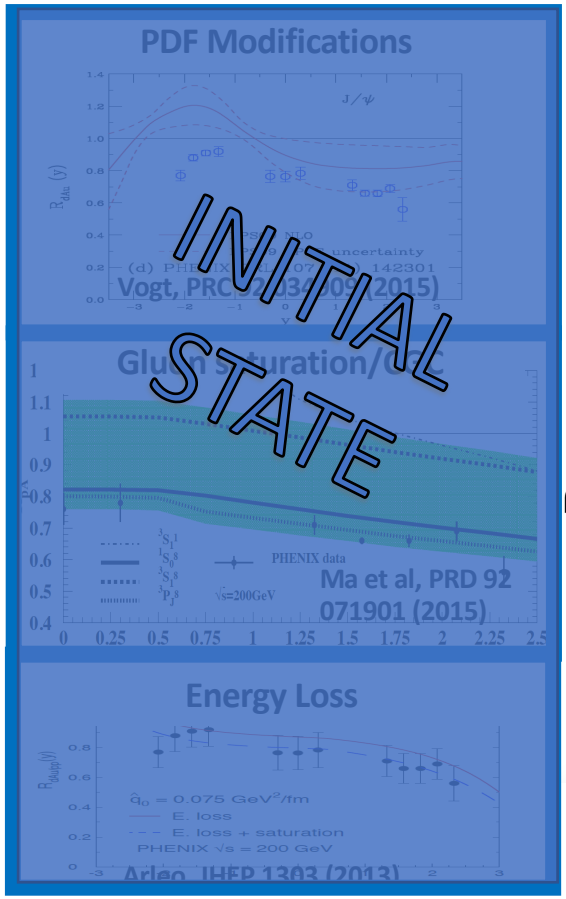
# Charmonium production in the nucleus

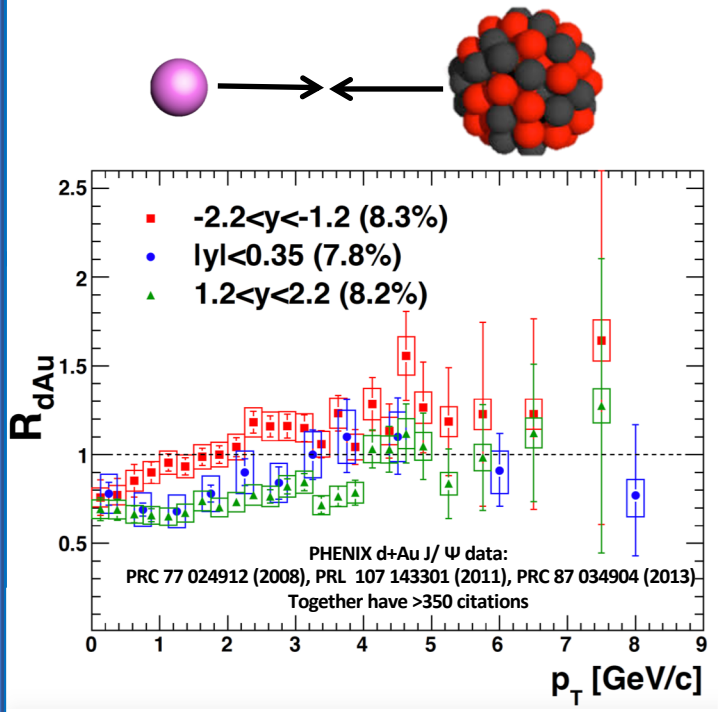


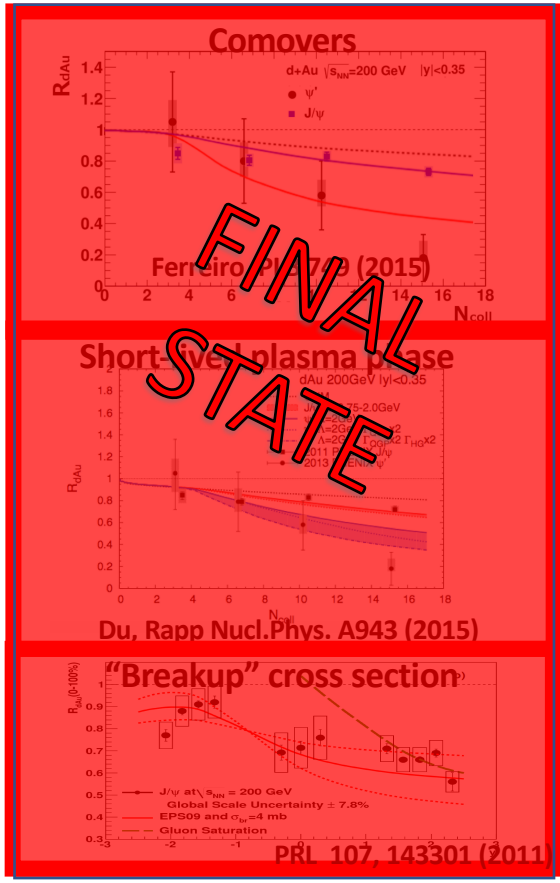



# Charmonium production in the nucleus

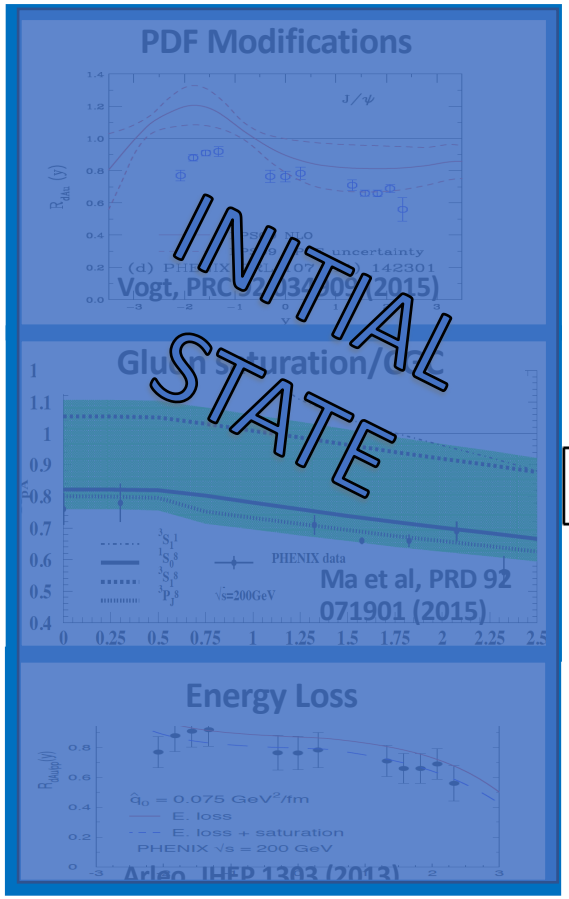


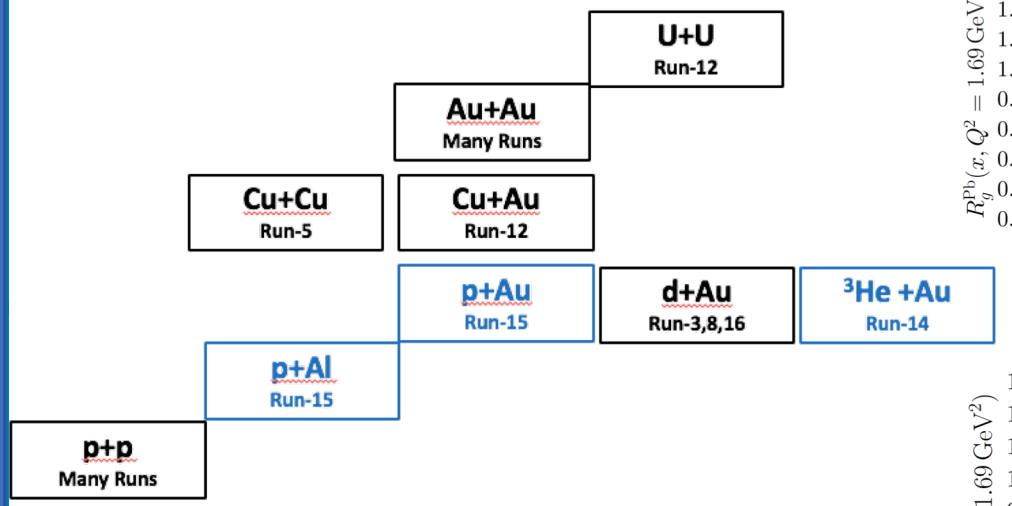



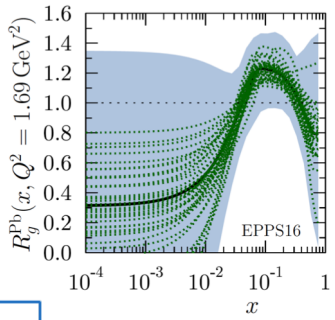

**Wide range of physical mechanisms all describe data.**

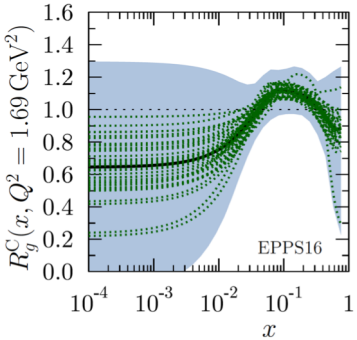
# Varying the initial state




Vary target nucleus:
Changes magnitude of PDF modifications



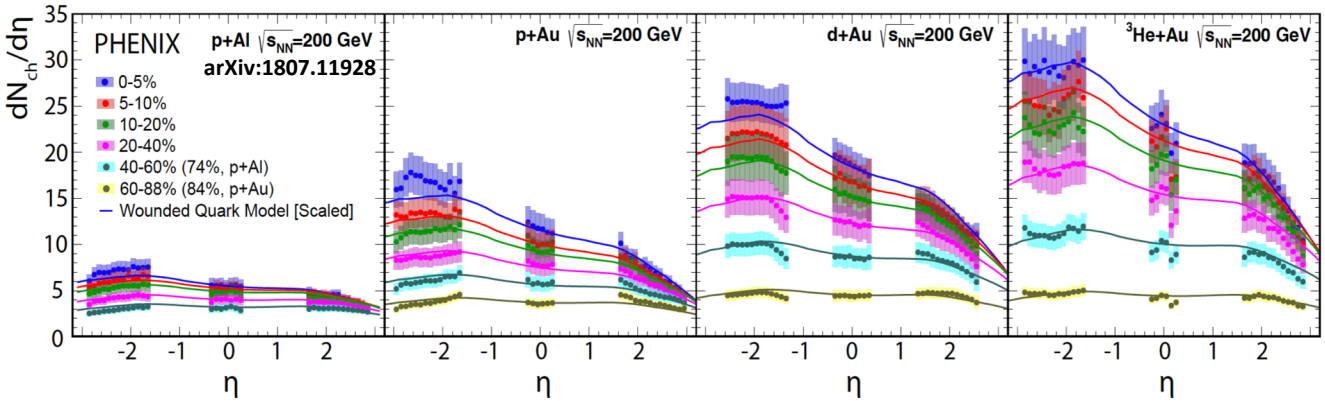




Vary path length charm precursor state travels inside nucleus
->Affects initial state energy loss

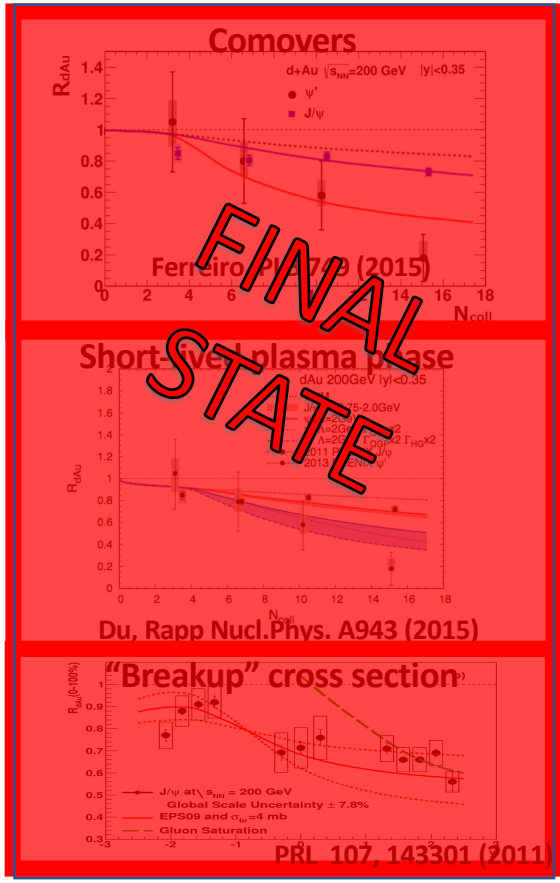
$$r = 1.2fm \cdot A^{1/3}$$

# Varying the final state

Vary projectile:
Changes density of final state particles,
especially in backward direction.




| p+p | p+Al | p+Au | d+Au | $^3$He +Au |
|---|---|---|---|---|
| Many Runs | Run-15 | Run-15 | Run-3,8,16 | Run-14 |

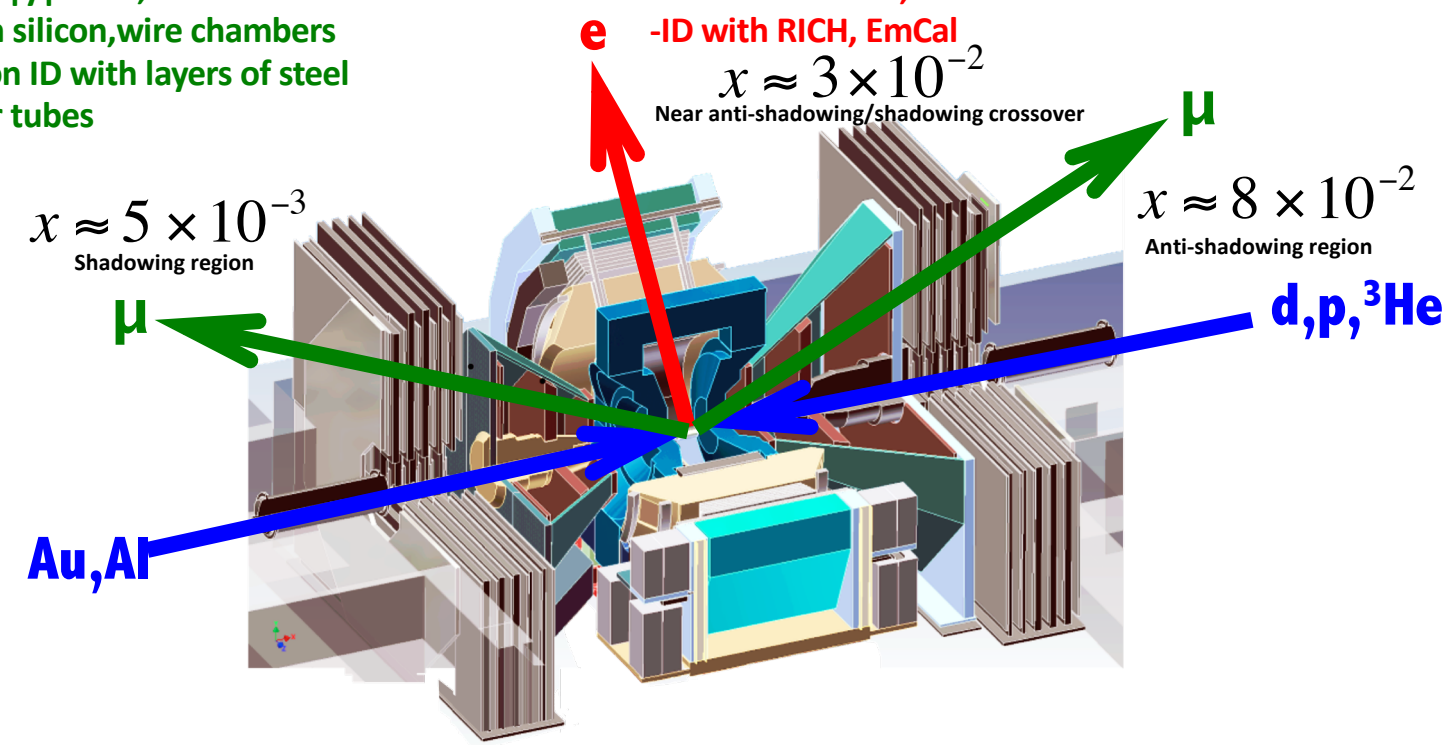


# PHENIX Detector

**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 silicon,wire chambers**
**-Further muon ID with layers of steel and streamer tubes**

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



# Quarkonia in *p*+*p* collisions – Run 15

**Total Fit:**

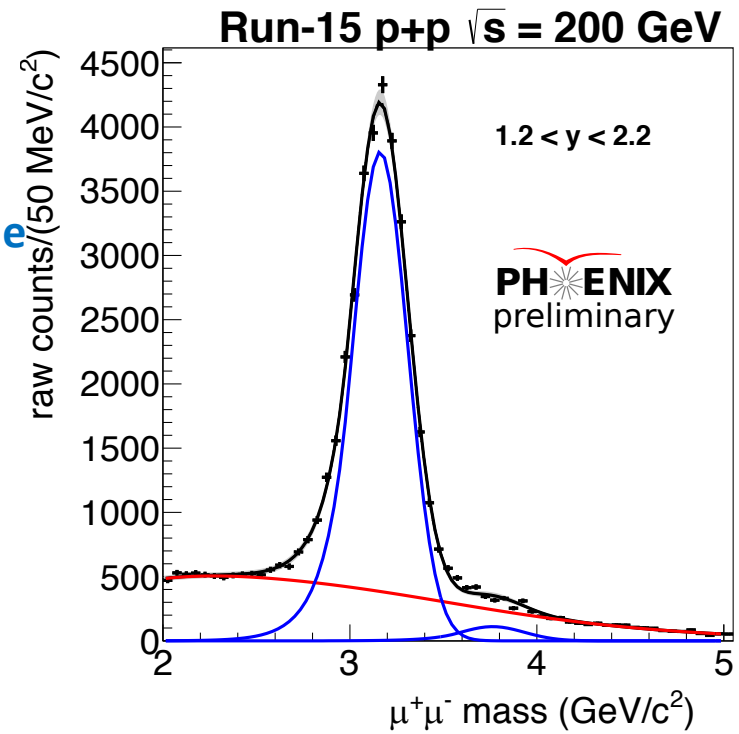
**Crystal Ball function for J/ψ(1S) and ψ(2S)**

**$M_{\psi(2S)} - M_{J/\psi}$ constrained to PDG value**

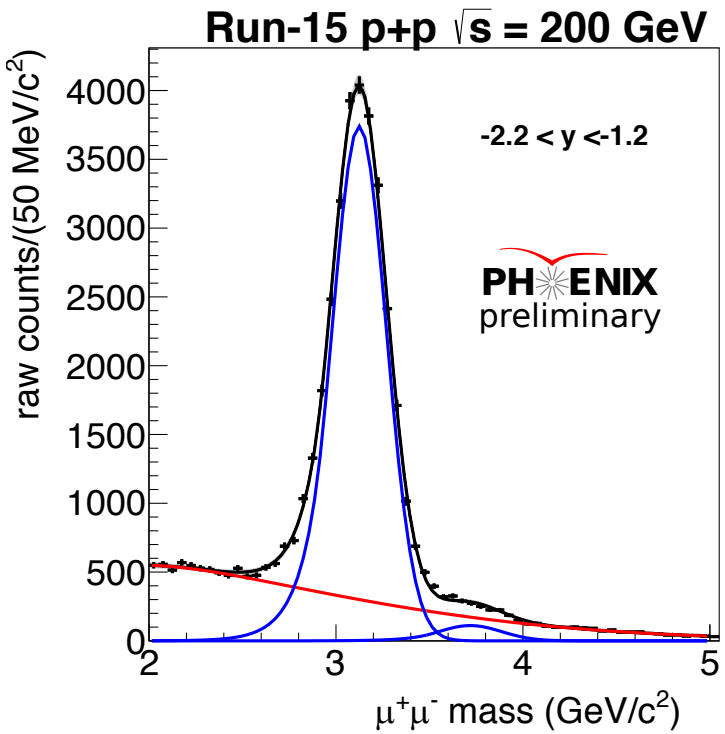
**Crystal Ball n, $\alpha$ parameters same**

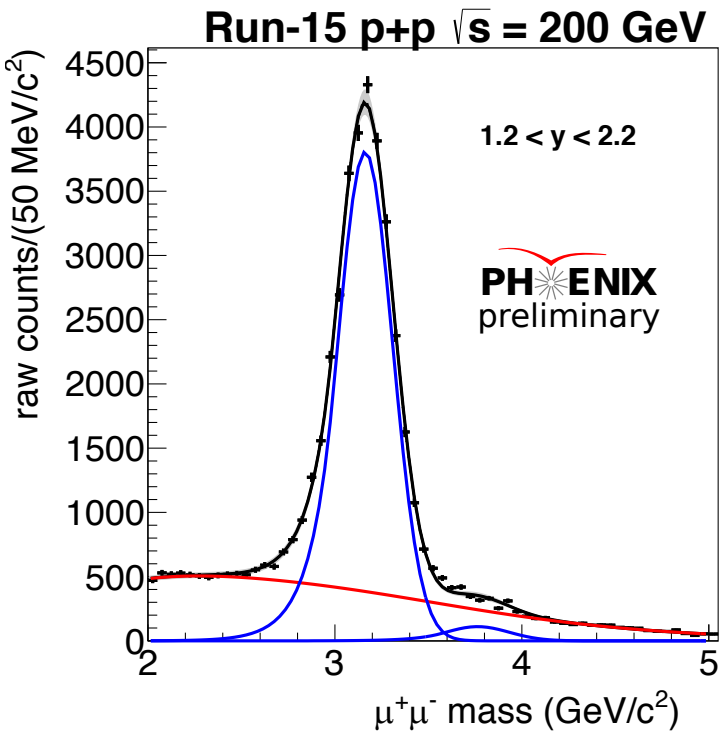
**Background is sum of like sign + exponential**

***FVTX silicon tracker not necessary for J/ψ, but is necessary to clearly separate ψ(2S) peak**

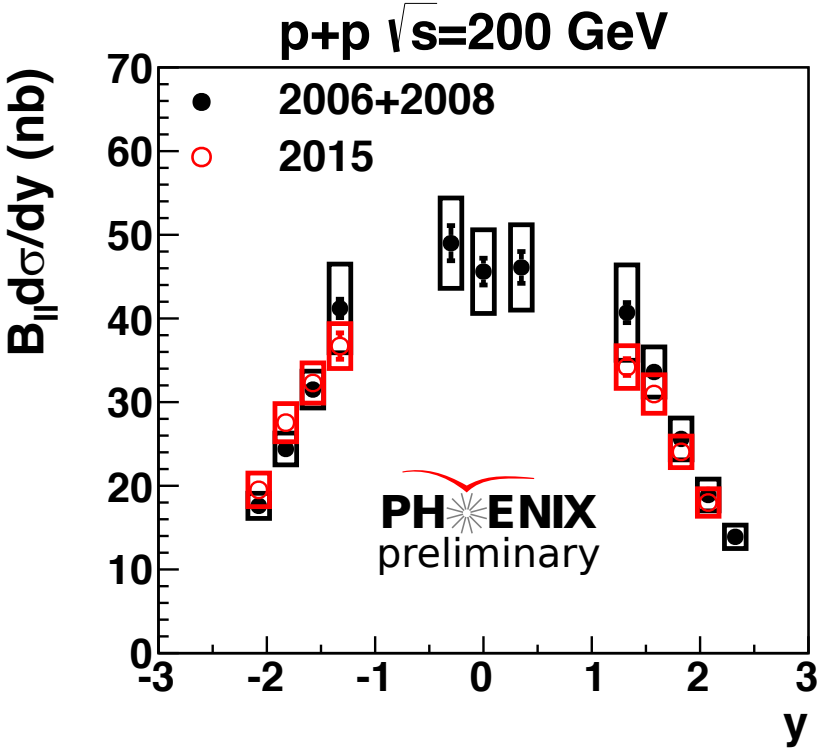


# Quarkonia in *p+p* collisions – Run 15



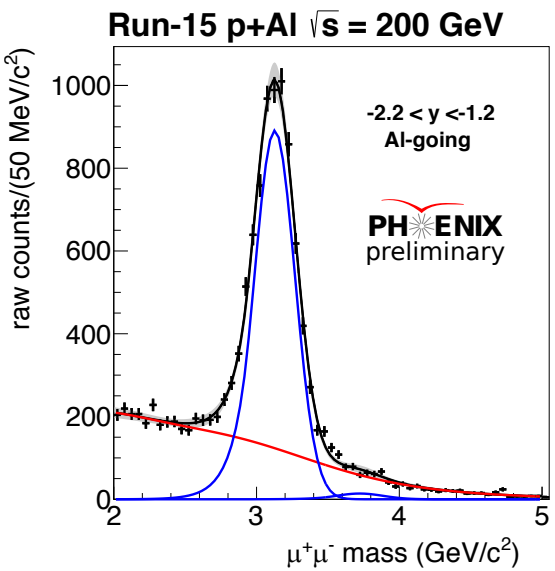



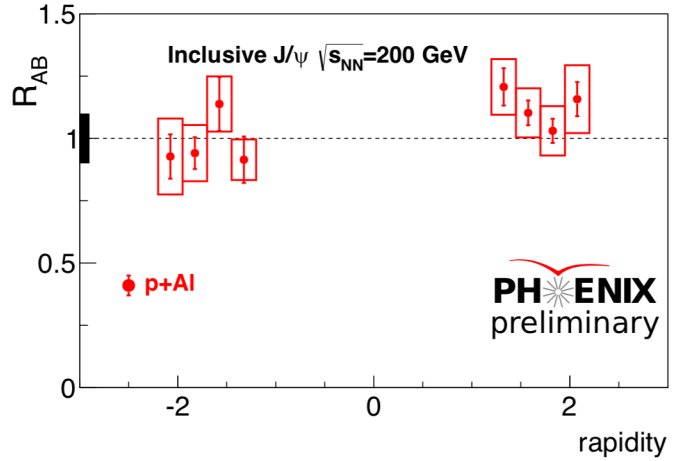
# Quarkonia in *p+p* collisions – Run 15

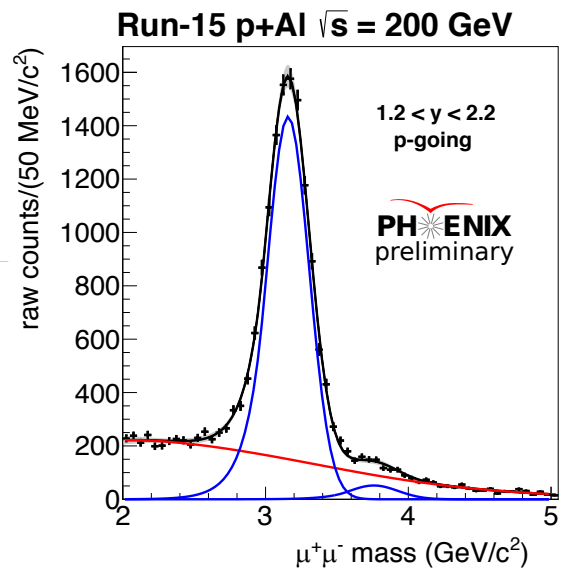



- **Consistent with older data that was recorded with thinner hadron absorber**
- **Consistent forward/backward**

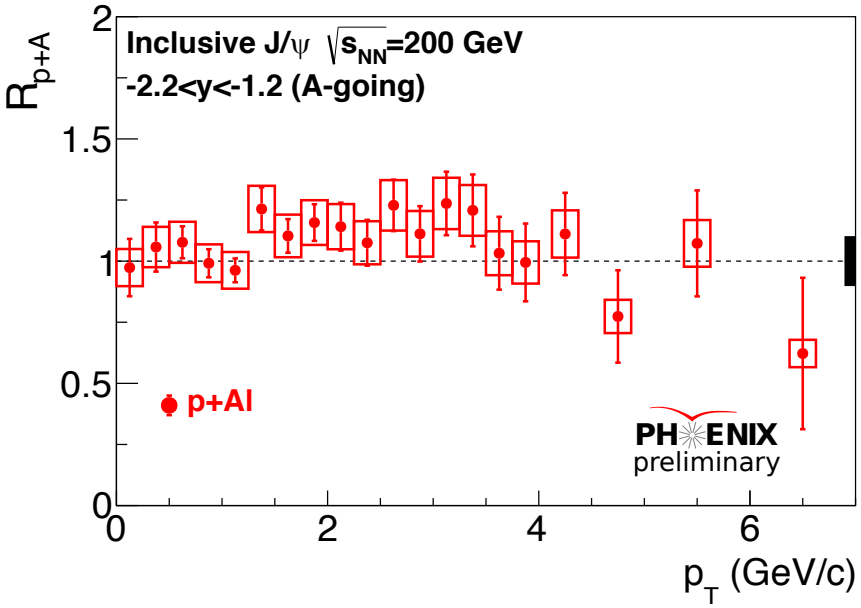
# Quarkonia in *p*+Al collisions – Run 15

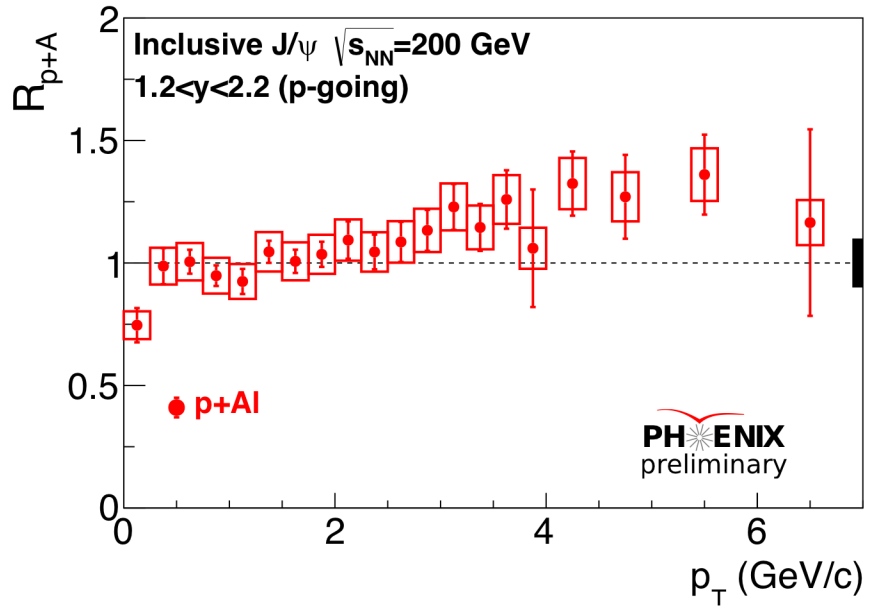


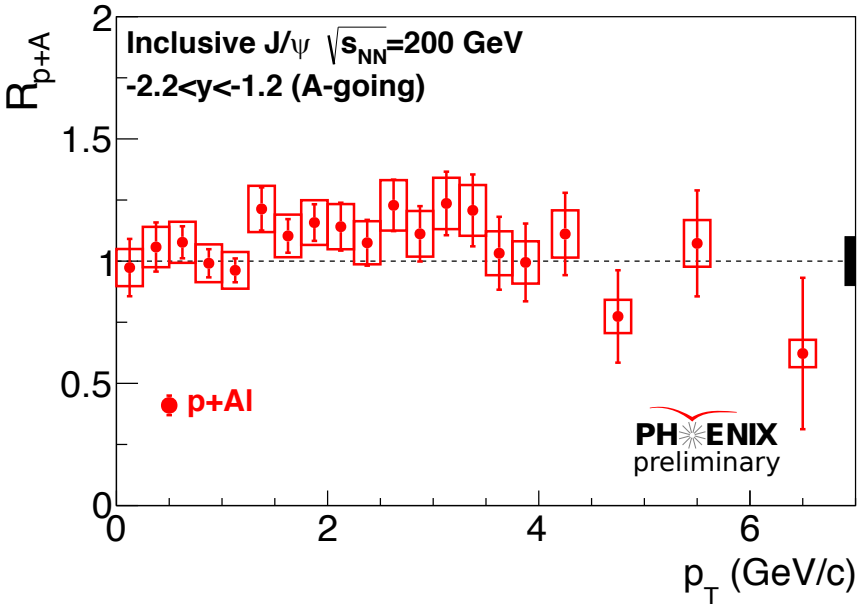



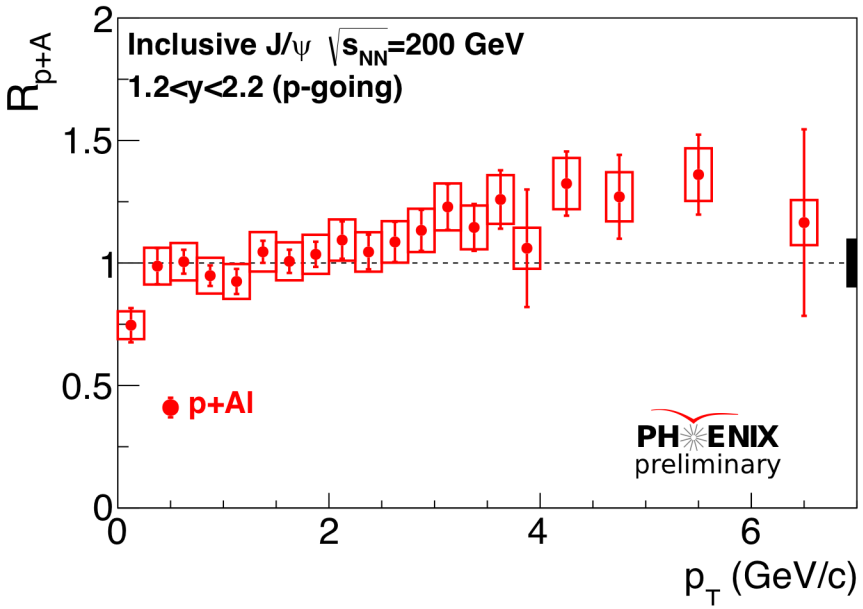
# New results: $p_T$ dependence



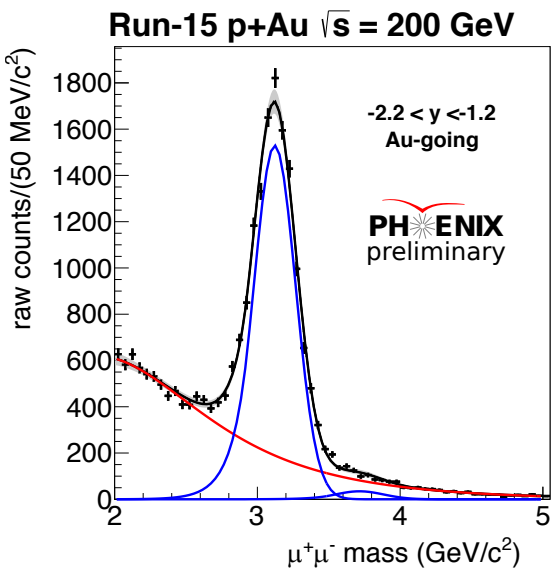
# New results: $p_T$ dependence

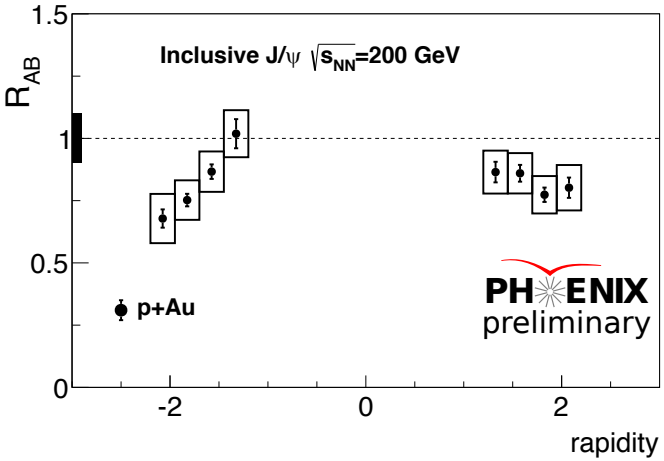


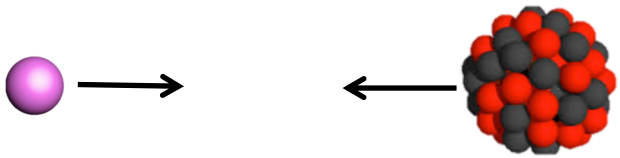



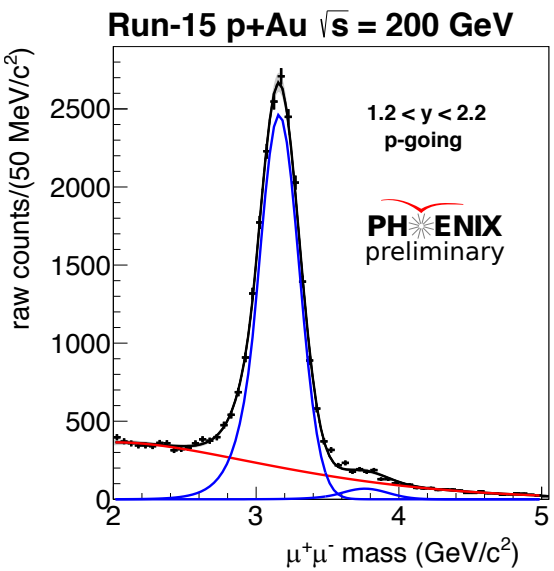

**Some evidence of Cronin broadening**
**Overall, effects are small.**

# Quarkonia in *p*+Au collisions – Run 15

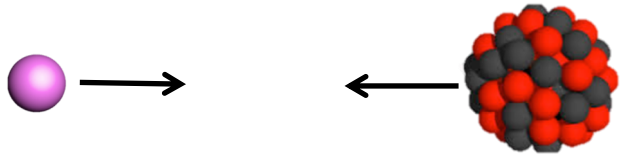


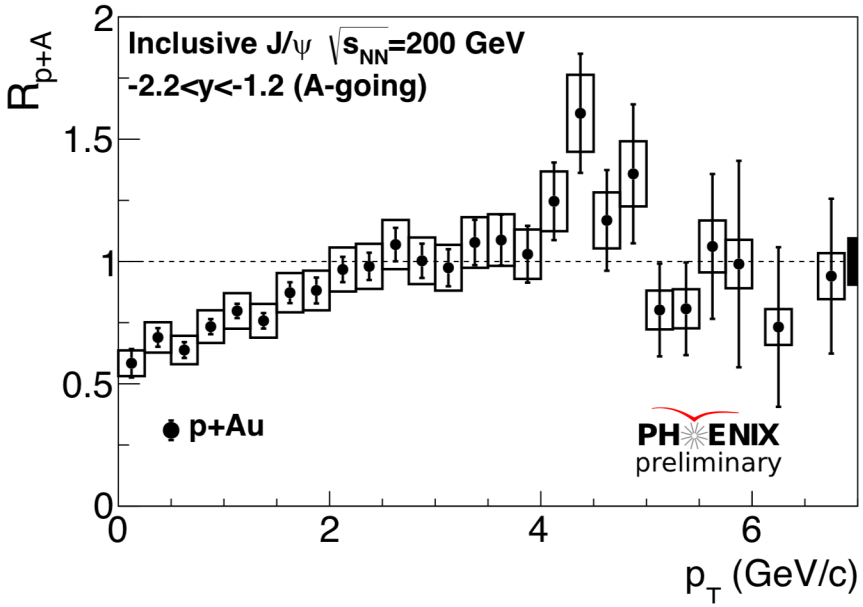



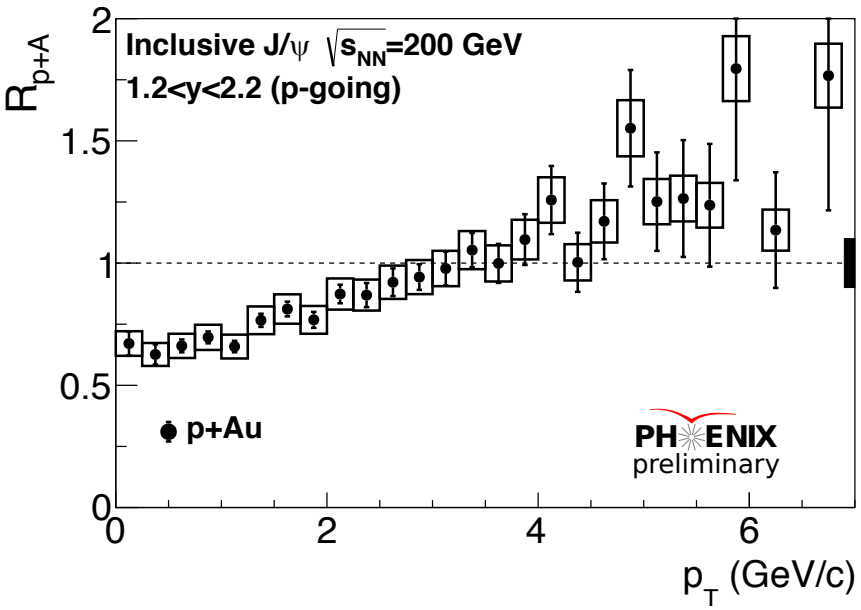





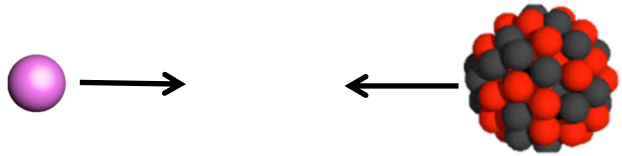
# New results: $p_T$ dependence

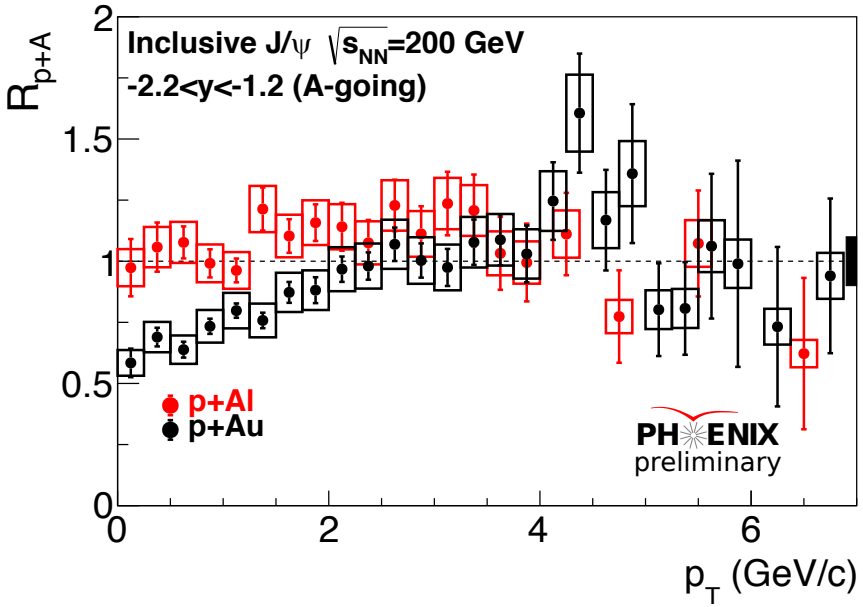


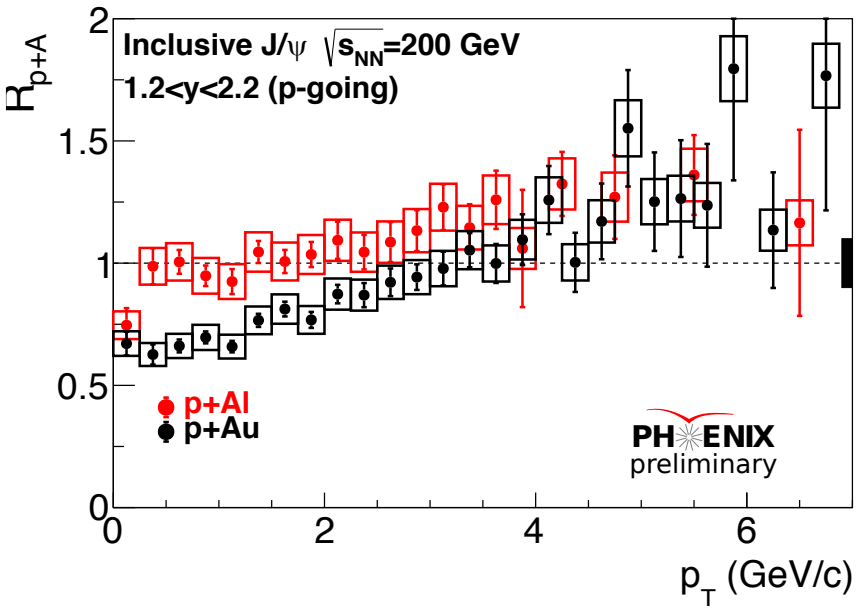


# New results: $p_T$ dependence

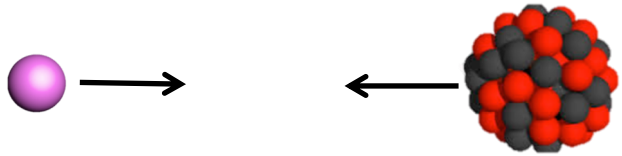


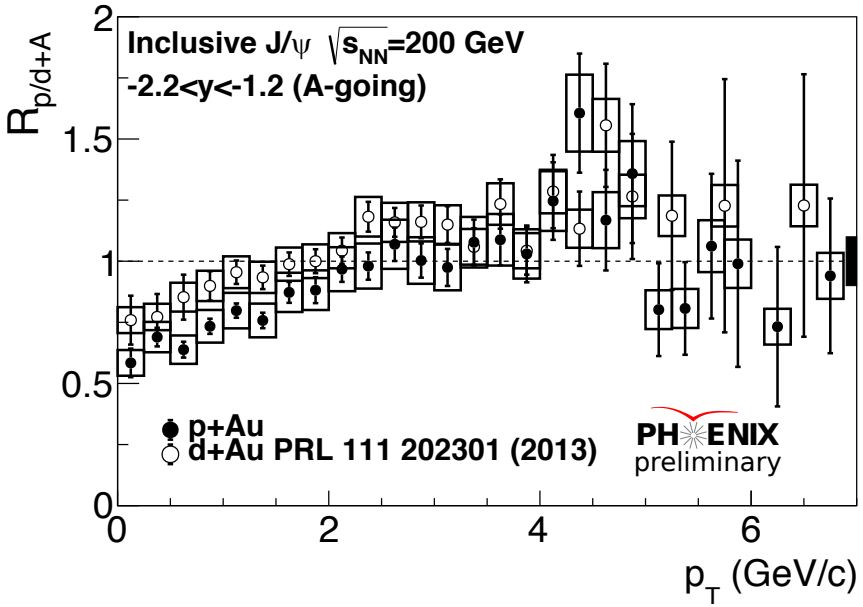


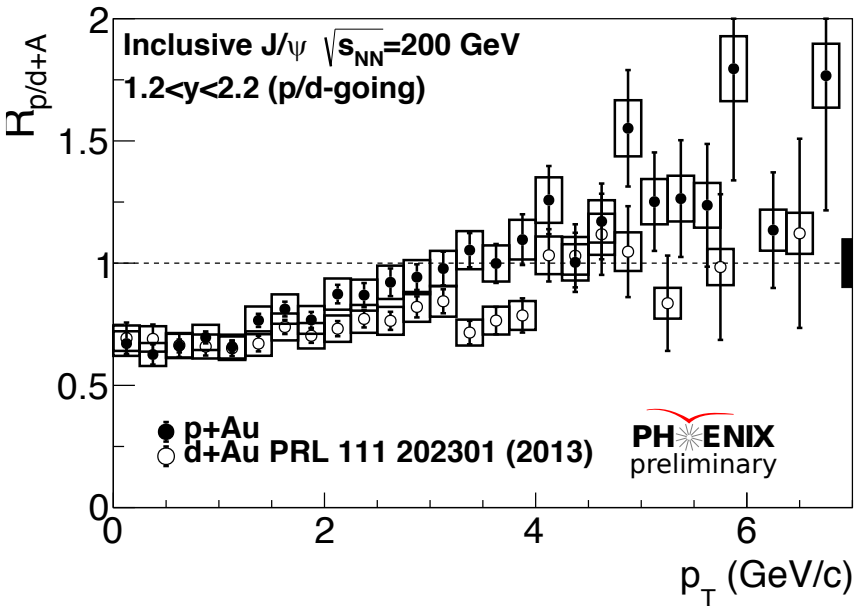




p+Al, p+Au differences at low $p_T$

# New results: $p_T$ dependence

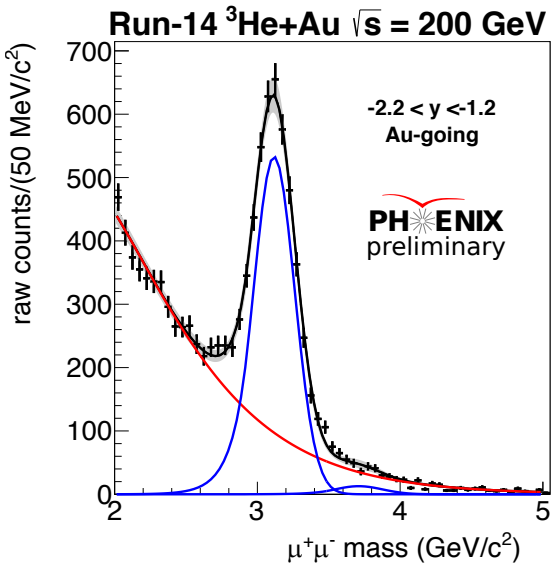


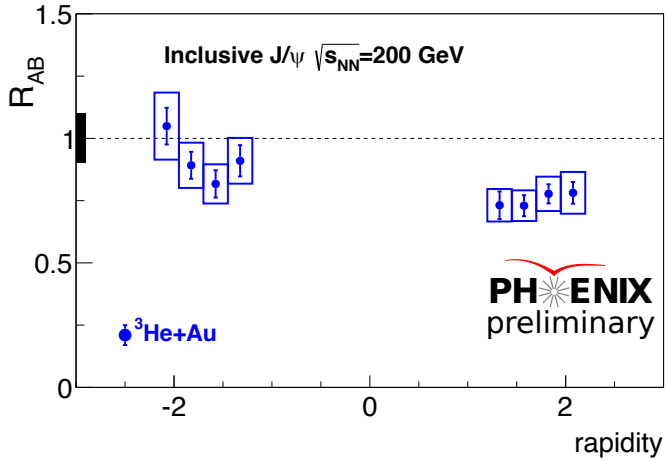


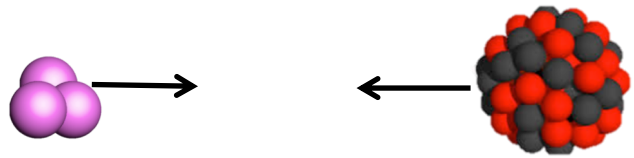



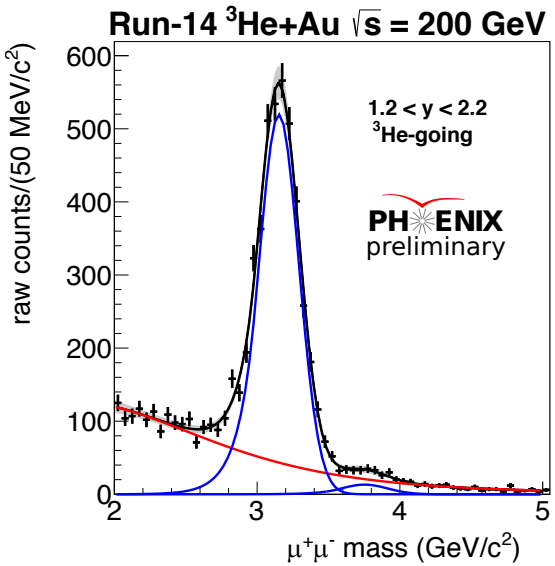

Consistent with d+Au within uncertainties.

# Quarkonia in $^3$He+Au collisions – Run 14

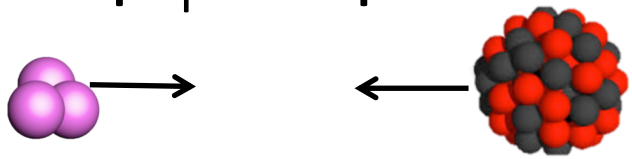


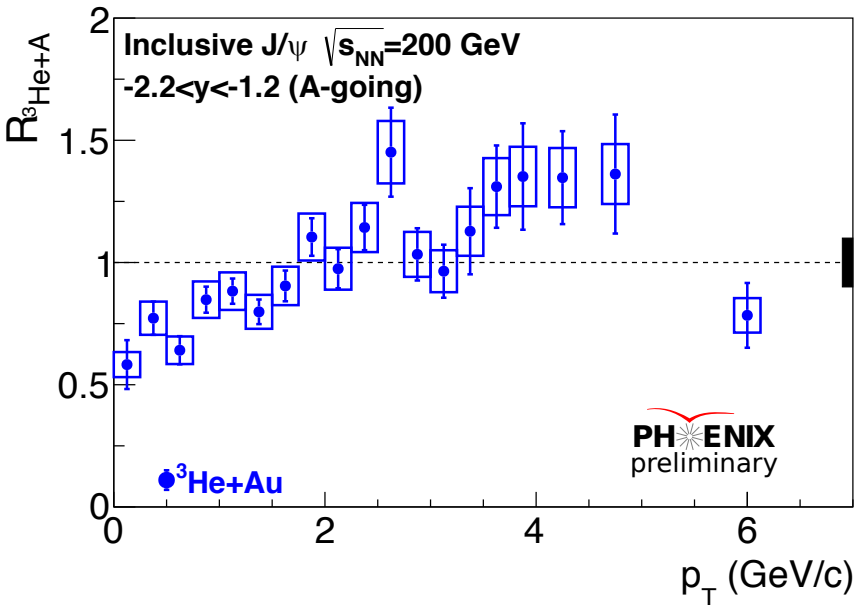



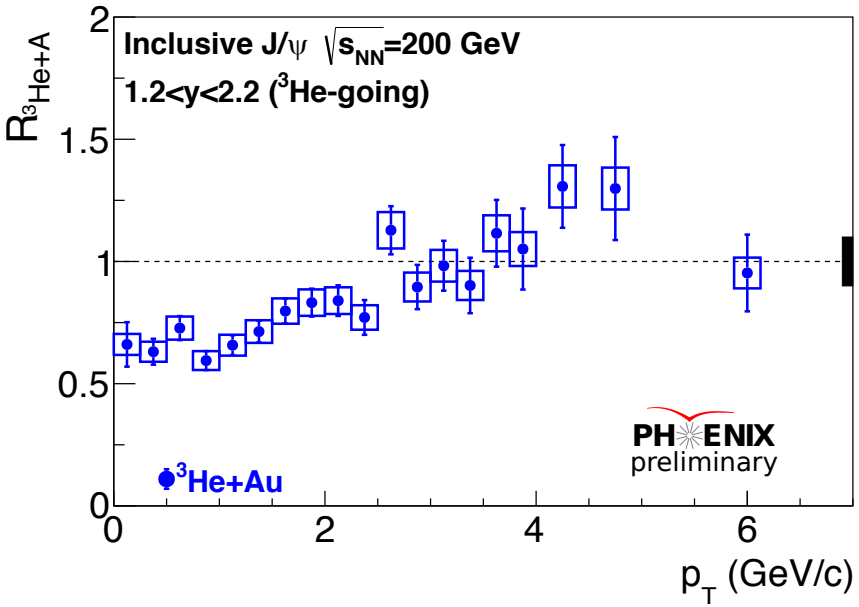





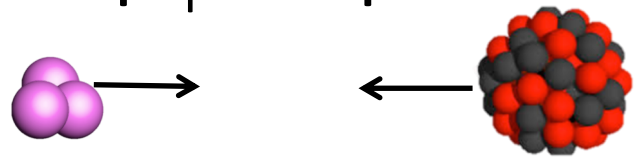
# New results: $p_T$ dependence

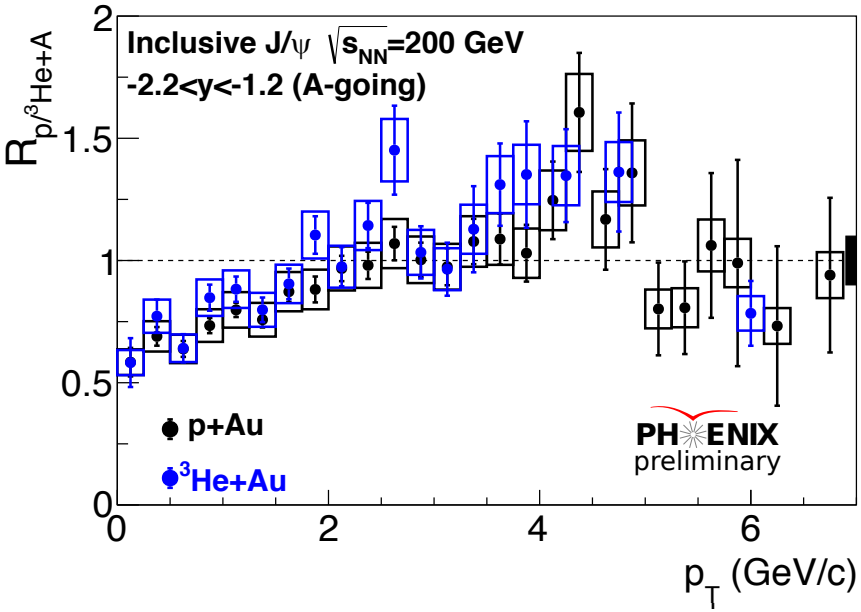


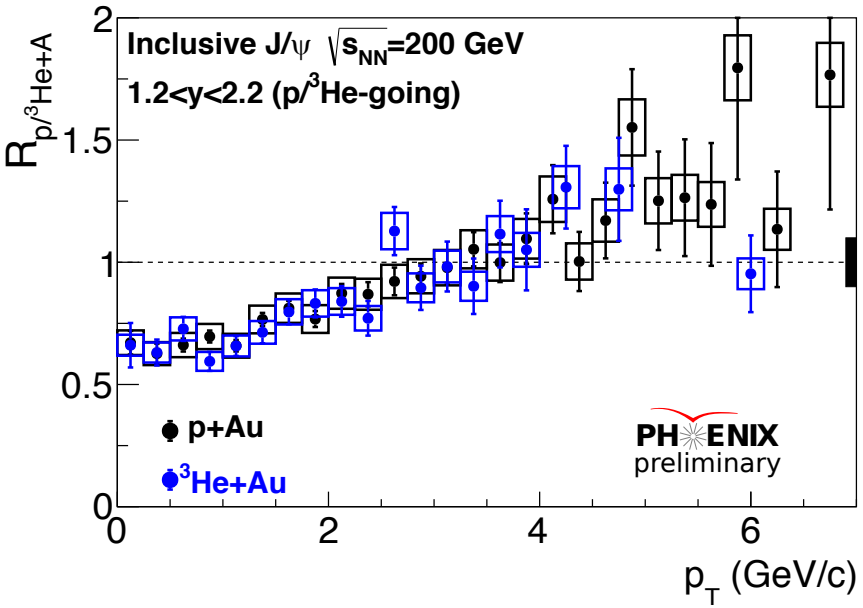


# New results: $p_T$ dependence

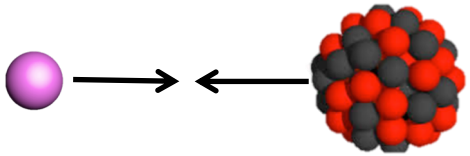


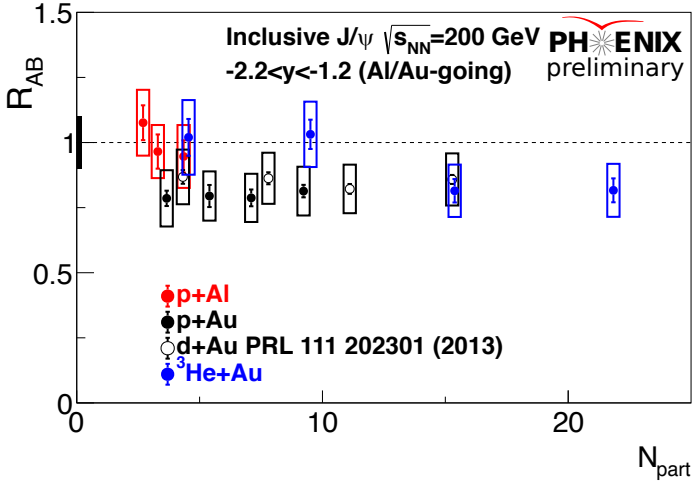


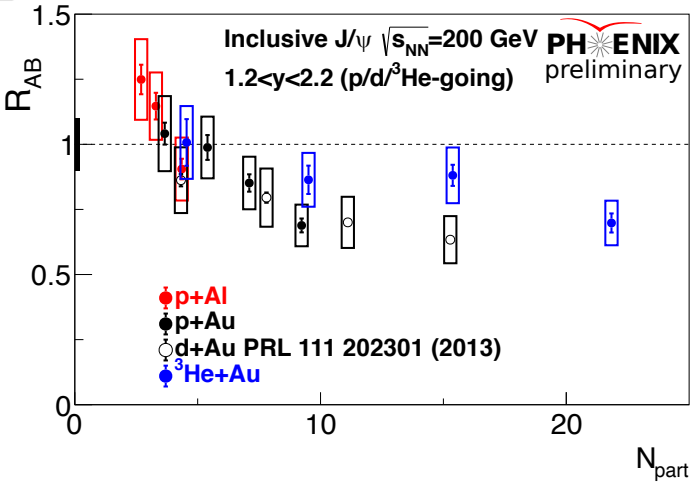




Consistent with p+Au within uncertainties.

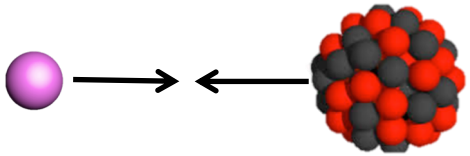
# $R_{AB}$ vs Npart in small systems

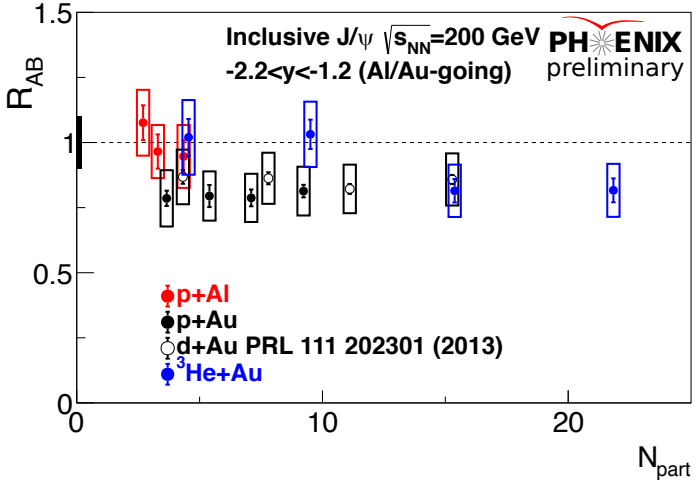


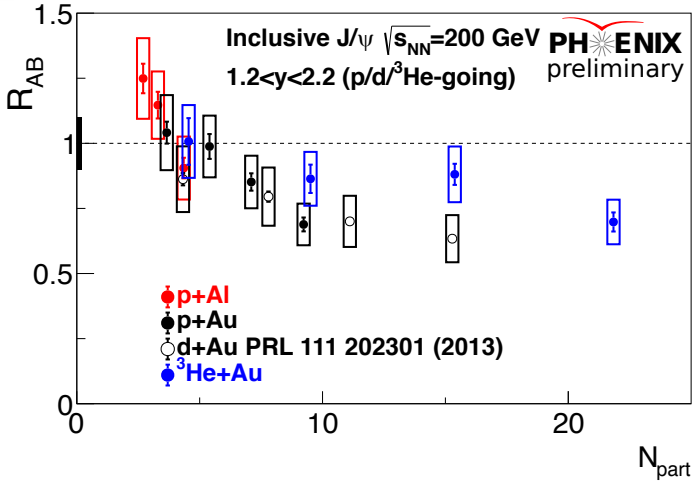


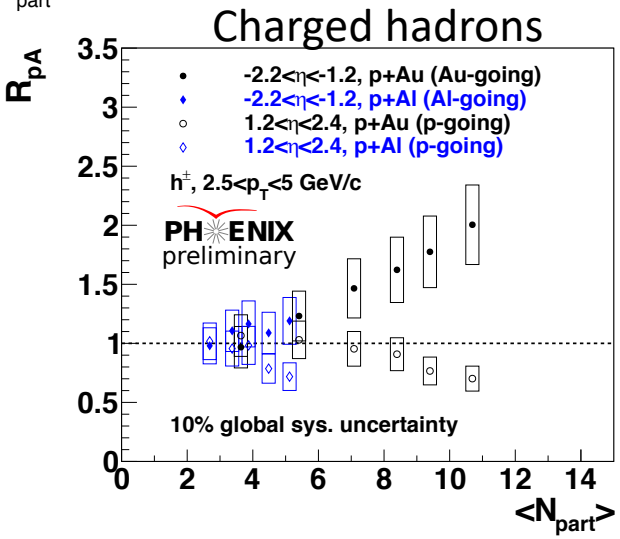



# $R_{AB}$ vs Npart in small systems

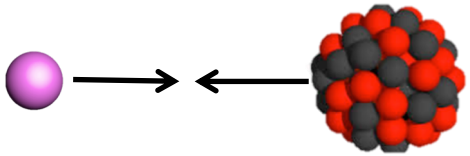


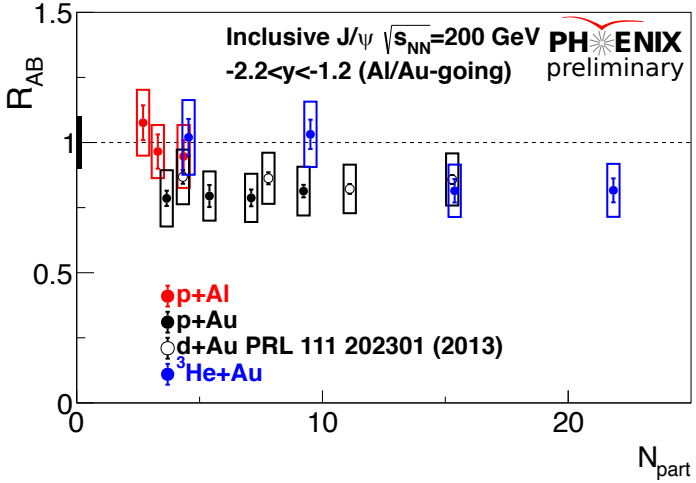


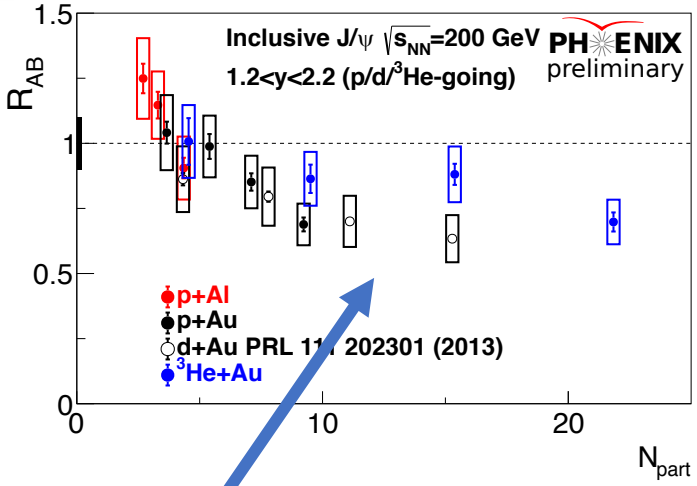



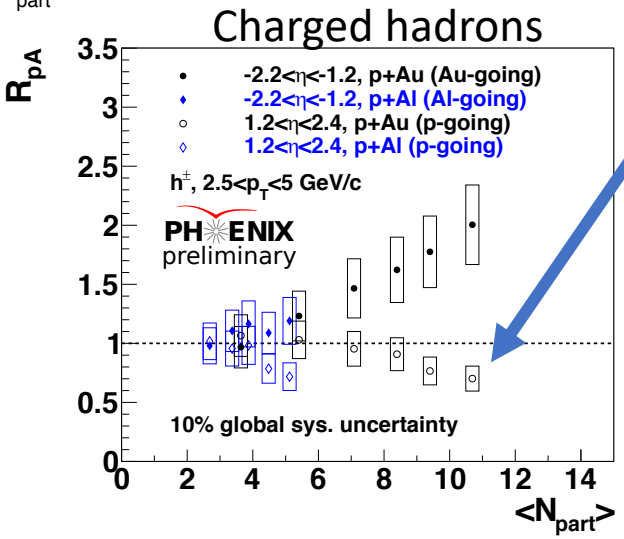



# $R_{AB}$ vs Npart in small systems





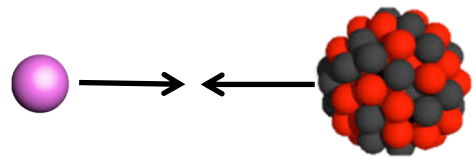



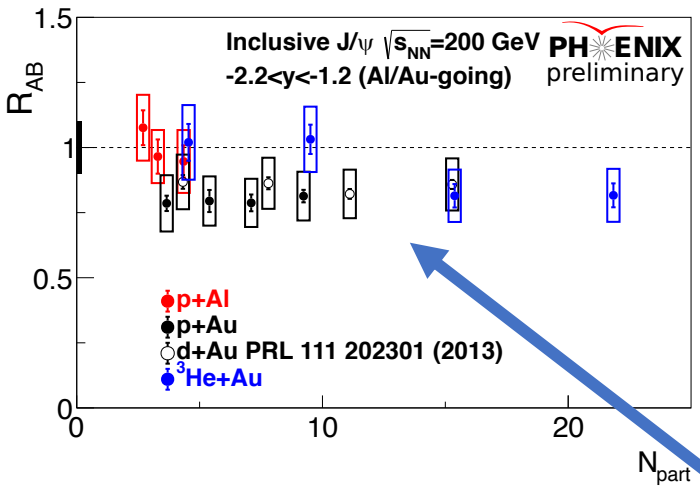



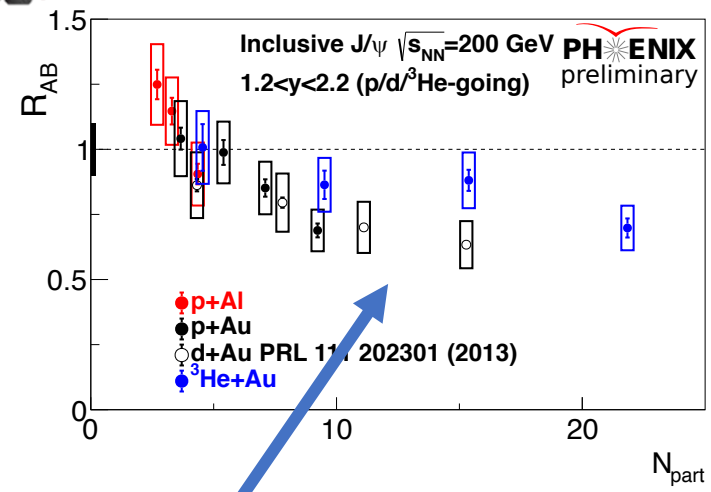

**Forward rapidity: relatively low hadron density**

**-Charged hadrons suppressed**
**-J/ψ suppressed**
**Suggests initial state effect *shadowing* may be dominant effect here**

# $R_{AB}$ vs Npart in small systems

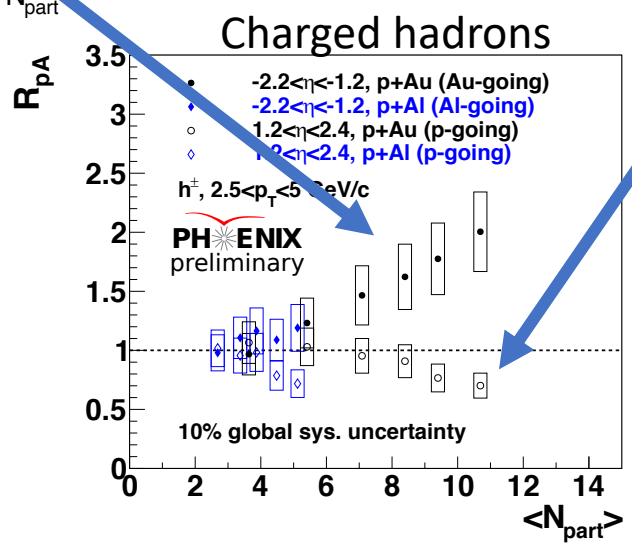





Backward rapidity: relatively high hadron density

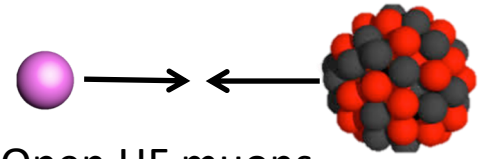
Charged hadrons enhanced
J/ψ suppressed
Suggests final state effect *"breakup"* may be dominant effect here



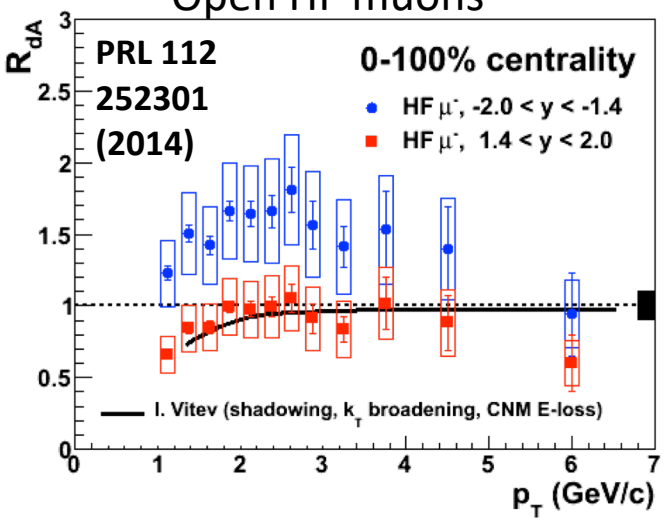

Forward rapidity: relatively low hadron density

-Charged hadrons suppressed
-J/ψ suppressed
Suggests initial state effect *shadowing* may be dominant effect here

# Comparing charm across small systems

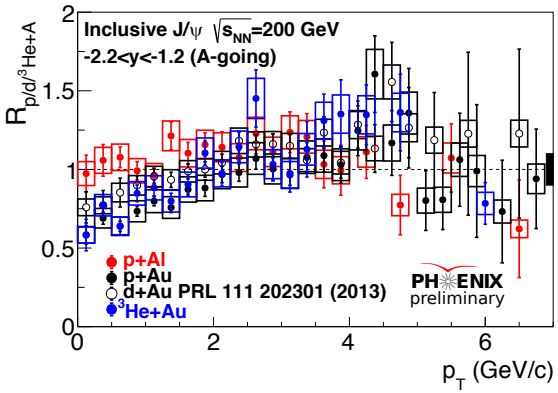


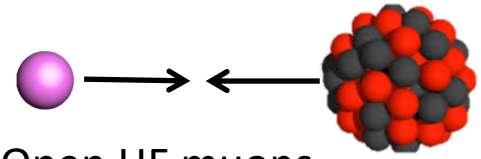
Open HF muons



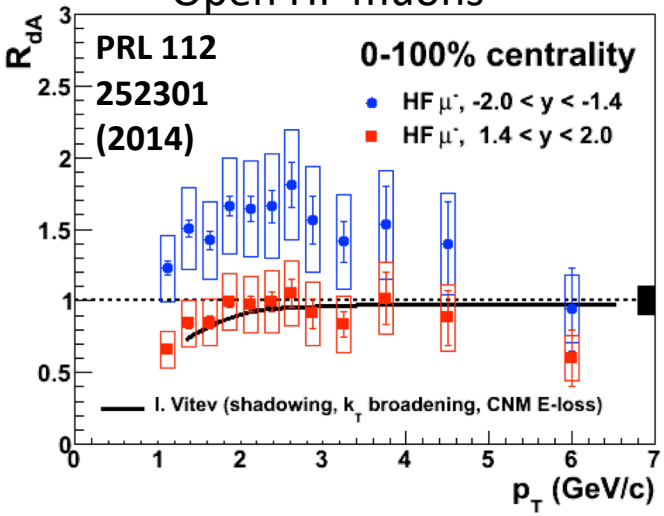

| Observable | -2.2<y<-1.2 | 1.2<y<2.2 |
|---|---|---|
| Open HF (muons) | enhanced | some suppression |

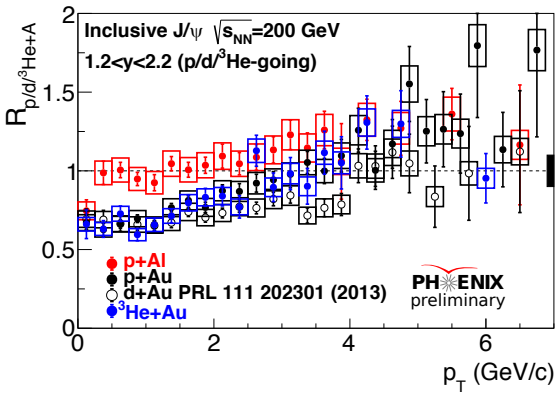
# Comparing charm across small systems



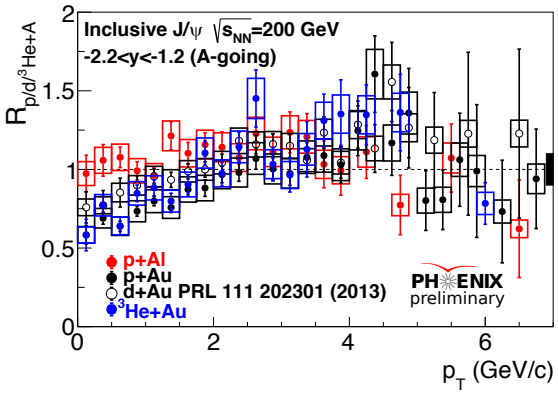
Open HF muons

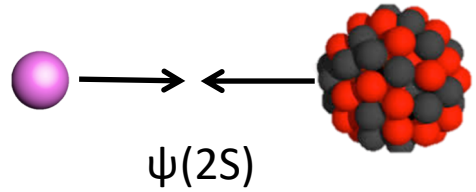


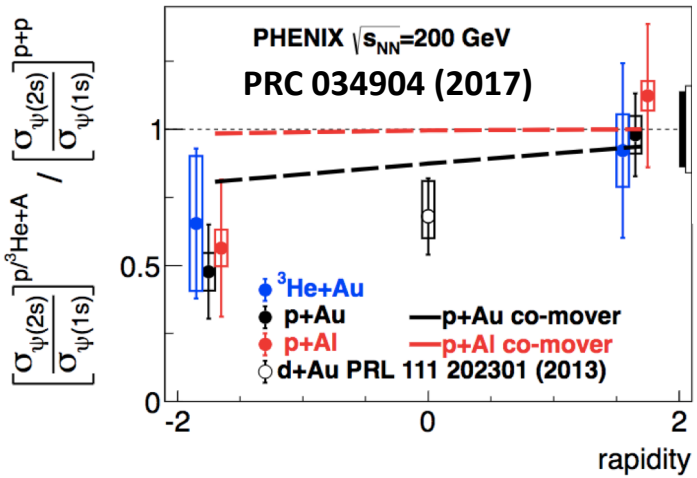

| Observable | -2.2<y<-1.2 | 1.2<y<2.2 |
|---|---|---|
| Open HF (muons) | enhanced | some suppression |
| J/ψ(1S) | suppressed | suppressed |

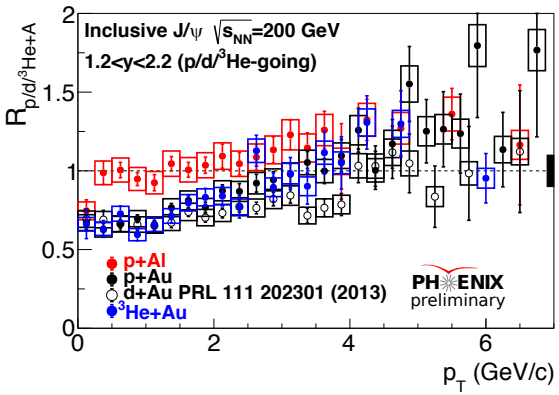
# Comparing charm across small systems



ψ(2S)

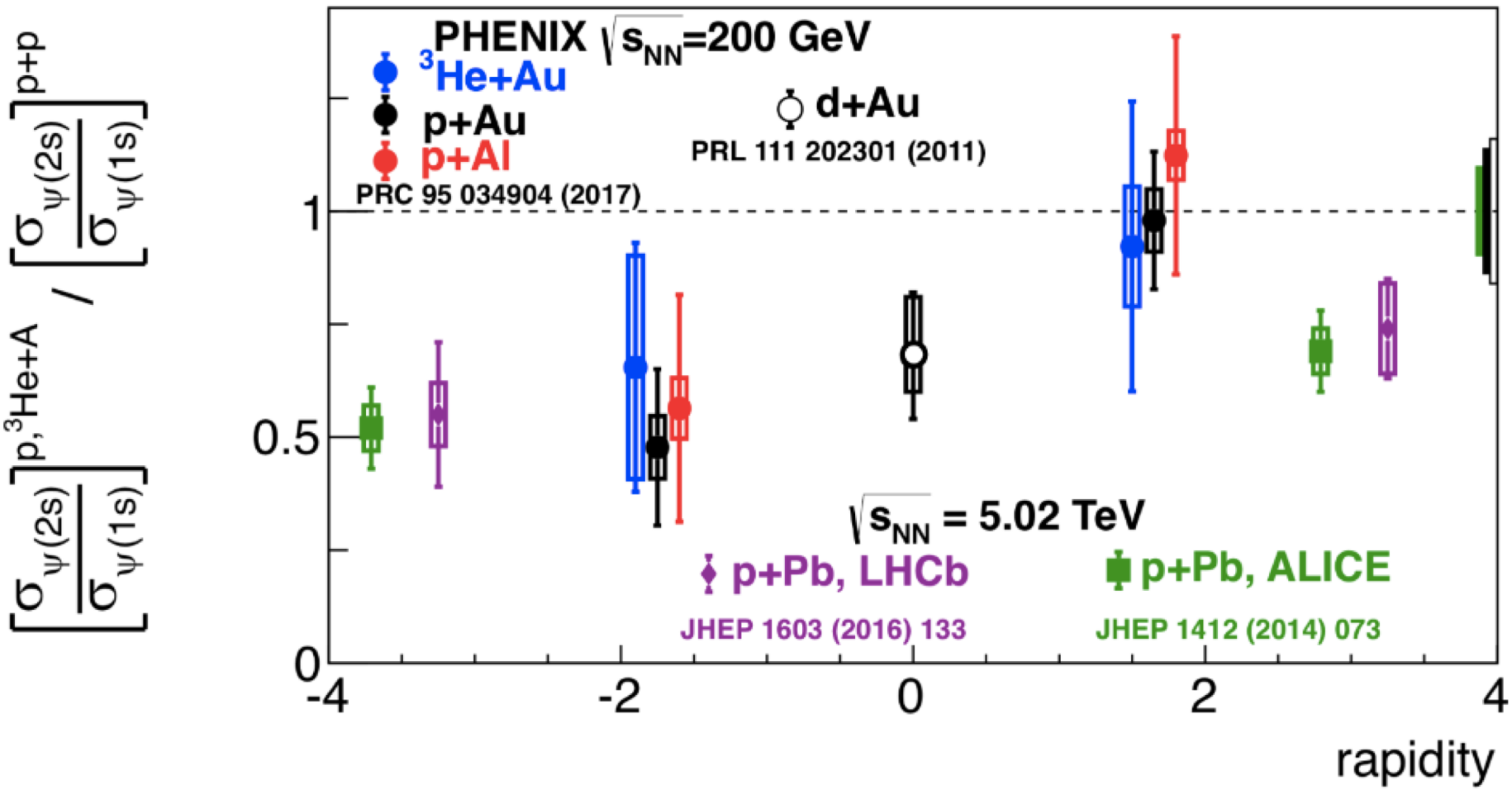


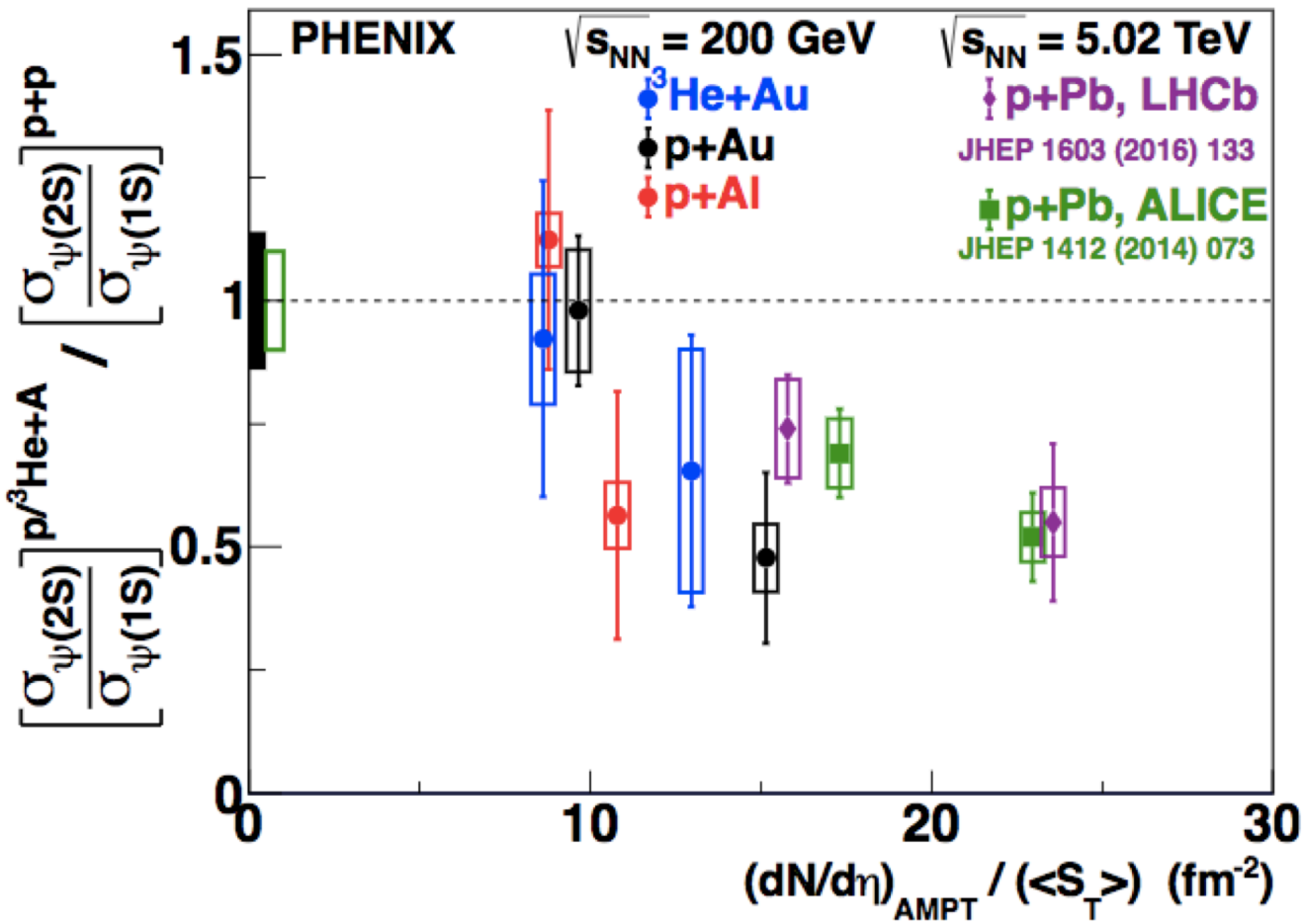



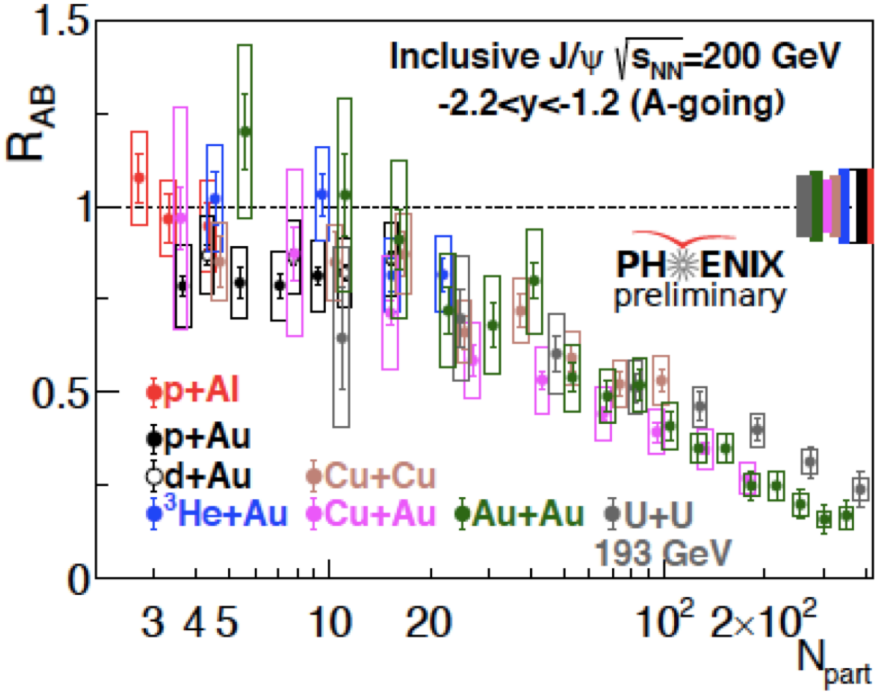

| Observable | -2.2<y<-1.2 | 1.2<y<2.2 |
|---|---|---|
| Open HF (muons) | enhanced | some suppression |
| J/ψ(1S) | suppressed | suppressed |
| ψ(2S) | highly suppressed | equal suppressed |

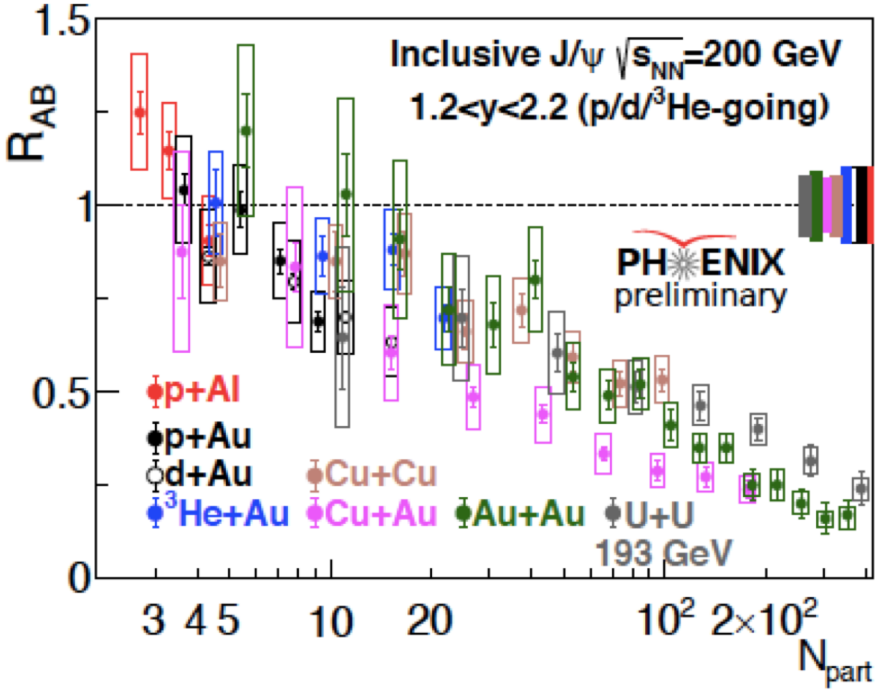
# Summary

- PHENIX has measured J/ψ production across a wide range of system size
- Similar effects are seen in forward direction for all small systems with the same nuclear target, suggesting initial state effects in nucleus dominate
    - Shadowing and/or energy loss are prime suspects
- Comparisons with open charm and hadron production suggests final state effects on J/ψ are significant at backwards rapidity, and very important for excited states
- Centrality dependence in small systems coming soon


PHENIX $\sqrt{s_{NN}}$=200 GeV
$^3$He+Au
p+Au
p+Al
PRC 95 034904 (2017)
d+Au
PRL 111 202301 (2011)
$\sqrt{s_{NN}}$ = 5.02 TeV
p+Pb, LHCb
JHEP 1603 (2016) 133
p+Pb, ALICE
JHEP 1412 (2014) 073
$\left[\frac{\sigma_{\psi(2s)}}{\sigma_{\psi(1s)}}\right]^{p,^3He+A} / \left[\frac{\sigma_{\psi(2s)}}{\sigma_{\psi(1s)}}\right]^{p+p}$
rapidity
0
0.5
1
-4
-2
0
2
4


PHENIX
$\sqrt{s_{NN}}$ = 200 GeV
$\sqrt{s_{NN}}$ = 5.02 TeV
$^3$He+Au
p+Au
p+Al
p+Pb, LHCb
JHEP 1603 (2016) 133
p+Pb, ALICE
JHEP 1412 (2014) 073
$\left[\frac{\sigma_{\psi(2S)}}{\sigma_{\psi(1S)}}\right]^{p/^3He+A} / \left[\frac{\sigma_{\psi(2S)}}{\sigma_{\psi(1S)}}\right]^{p+p}$
1.5
1
0.5
0
0
10
20
30
$(dN/d\eta)_{AMPT} / (\langle S_T \rangle)$ (fm$^{-2}$)


Inclusive J/ψ √sNN=200 GeV
-2.2<y<-1.2 (A-going)
PHENIX
preliminary
p+Al
p+Au
d+Au
3He+Au
Cu+Cu
Cu+Au
Au+Au
U+U
193 GeV
RAB
Npart


Inclusive J/ψ √sNN=200 GeV
1.2<y<2.2 (p/d/3He-going)
PHENIX
preliminary
p+Al
p+Au
d+Au
3He+Au
Cu+Cu
Cu+Au
Au+Au
U+U
193 GeV
RAB
Npart