J/ψ measurements in p+Al, p+Au and ^{3}He+Au collisions

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Quark Matter 2019

Inclusive J/ψ Results in Small Systems

- 2003, 2008 d+Au at $\sqrt{S_{NN}} = 200$ GeV

  PHENIX added 3 new small systems data sets

- 2014 ^{3}He+Au at $\sqrt{S_{NN}} = 200$ GeV
- 2015 p+p, p+Al, p+Au at $\sqrt{S_{NN}} = 200$ GeV

PHENIX has measured the inclusive J/ψ $\rightarrow$ $\mu^+\mu^-$ nuclear modification across three collision systems. The systems, which have different projectile and target sizes, are compared at the same collision energy.

*Paper submitted (**arXiv:1910.14487**)*

J/ψ Final State Effects in p+A Collisions?

PHENIX

d+Au and p+Pb

- Strong suppression observed for ψ(2s) with respect to J/ψ
  - Not expected if only CNM effects present
  - Reproduced by Co-Movers model

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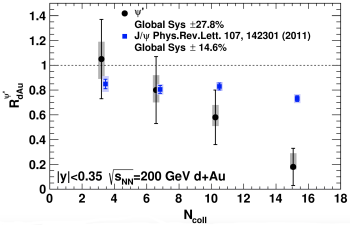
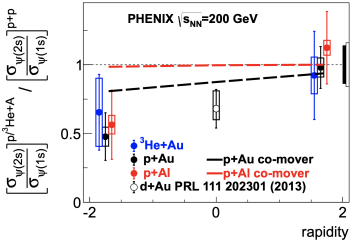


Phys. Rev. Letters 111, 202301



Phys. Rev. C 95, 034904

J/ψ Final State Effects in p+A Collisions?

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Flow in Small Systems at LHC and RHIC

- Consistent with QGP production in most central collisions

J/ψ Final State Effects in p+A Collisions?

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Flow in Sm

- Consis
  - T preferential
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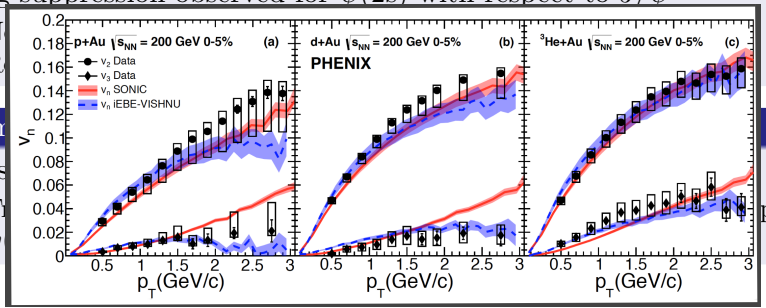


Nature Physics volume 15 (2019)

J/ψ Final State Effects in p+A Collisions?

PHENIX

d+Au and p+Pb

- Strong suppression observed for ψ(2s) wrt J/ψ
  - Would not be expected if only CNM effects are present
  - Reproduced by Co-Movers model

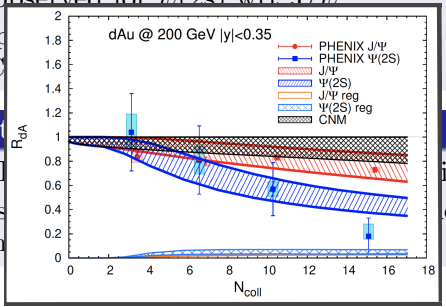
Flow in Small Systems at LHC and RHIC

- Consistent with QGP production in most central collisions
  - Transport models extended to small systems and can describe the preferential ψ(2s) suppression

J/ψ Final State Effects in p+A Collisions?

d+Au and p+Pb

- Strong suppression observed for $\psi(2s)$ wrt. J/ψ
  - Would not be exp
  - Reproduced by C



JHEP 03, 015

Flow in Small Systems at

- Consistent with QGI ions
  - Transport models escribe the preferential $\psi(2s)$ suppression

J/ψ Final State Effects in p+A Collisions?

PHENIX

d+Au and p+Pb

- Strong suppression observed for ψ(2s) wrt J/ψ
  - Would not be expected if only CNM effects are present
  - Reproduced by Co-Movers model

Flow in Small Systems at LHC and RHIC

- Consistent with QGP production in most central collisions
  - Transport models can describe the preferential ψ(2s) suppression

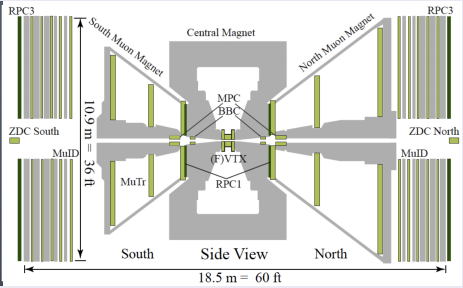
Question

- Evidence of final state effects on the J/ψ by comparing p+Au with ^{3}He+Au?

PHENIX Detector: Muon Arms

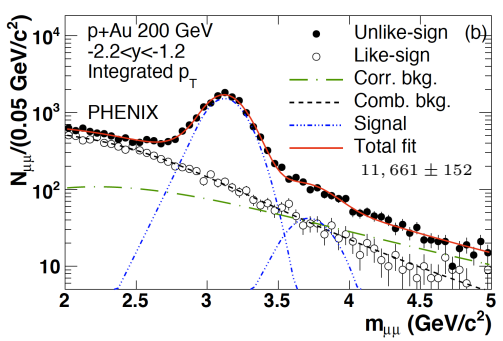
Muon Arms

- rapidity coverage: $1.2 < |y| < 2.2$
- Muon Tracking followed by Muon Identifier
  - Iron and copper absorbers for hadron rejection
- BBC measures collision vertex along beam axis



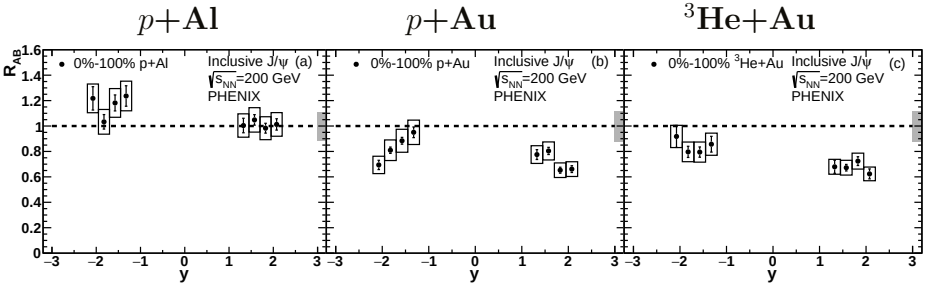
- Centrality is measured using the BBC detector in the A-going direction

Dimuon Reconstructed Mass Distribution



- Unlike-sign reconstructed muon pairs
- Like-sign reconstructed muon pairs
- Correlated background
- Fit to the combinatorial background
- J/ψ, $\psi(2s)$ Crystal Ball fits
- Total fit (sum of all fits)

J/ψ Modification vs. Rapidity (0-100%)



- Suppression at forward rapidity for Au target
- Little modification at forward rapidity for Al target, as expected

Model Overview

PHENIX

nCTEQ15 and EPPS16 NLO (Shao, et. al.) — PRL 121, 052004

- Reweighted using LHC p+Pb data
  - Gives tighter J/ψ constraints

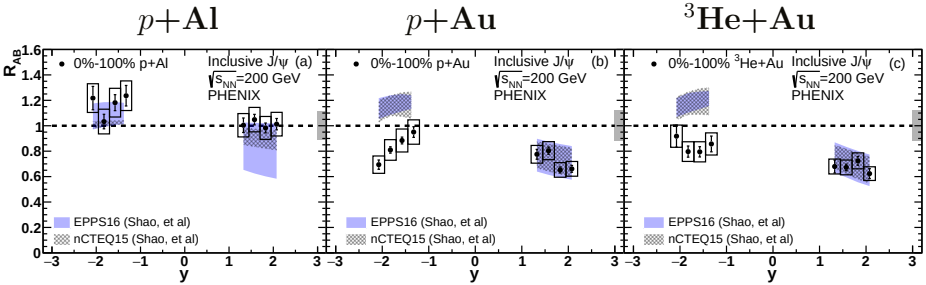
Nuclear Absorption Model — PRC 87, 054910 2013

- Estimated from global fit to world data
- Added to Shao, et. al. at backward rapidity only

EPS09 NLO + Transport Model (Du & Rapp) — JHEP 03, 015

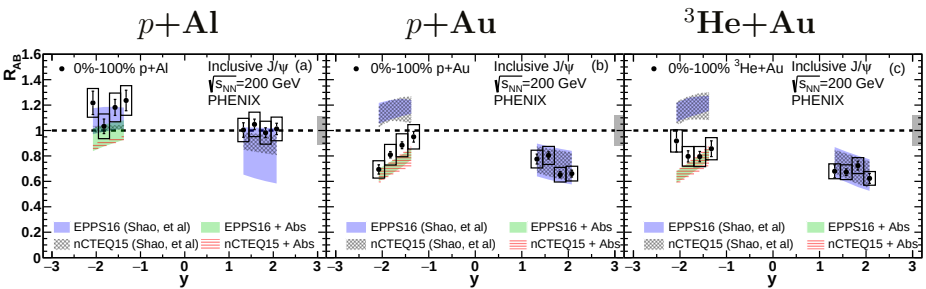
- Includes fireball, MC Glauber for initial conditions
- p_T broadening included
- Backward rapidity: Nuclear absorption added

J/ψ Modification vs. Rapidity (0-100%)



- Reweighted nCTEQ15 and EPPS16 predictions (NLO)
  - Agree well with data at forward rapidity
  - Do not agree at backward rapidity for Au target
    - Shadowing only - no nuclear absorption

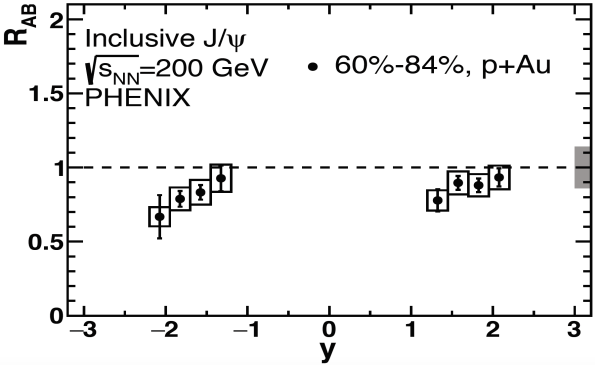
J/ψ Modification vs. Rapidity (0-100%)



- Reweighted nCTEQ15 and EPPS16 predictions
  - Added PHENIX nuclear absorption estimate at backward rapidity
    - Describe data reasonably well

Centrality Dependence

p+**Au**



Centrality Dependence

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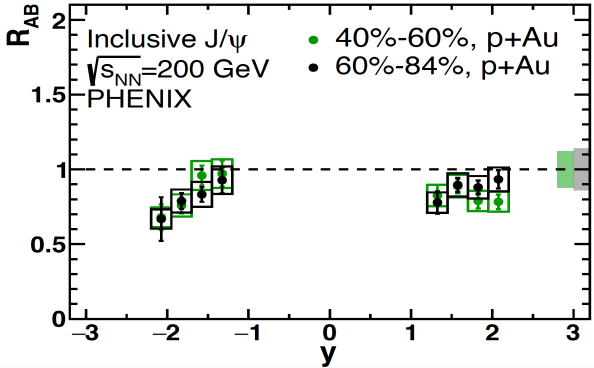
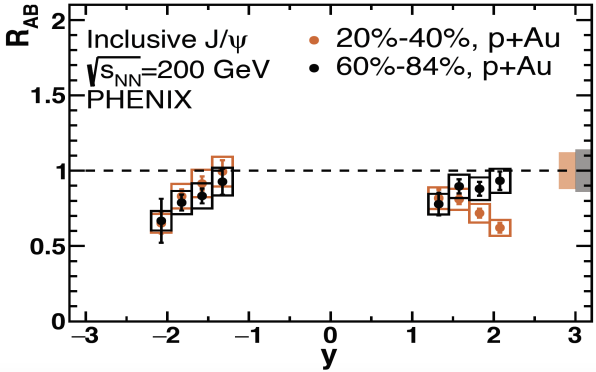


Centrality Dependence

p+Au



Centrality Dependence

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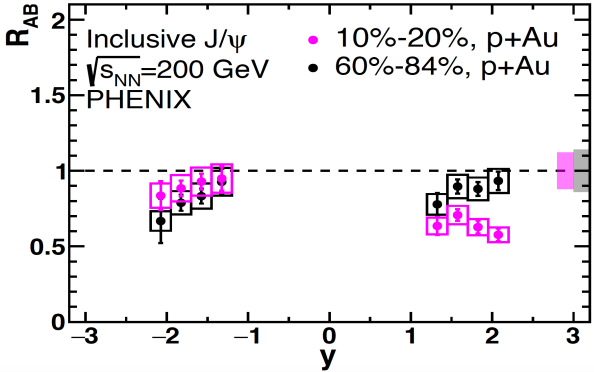

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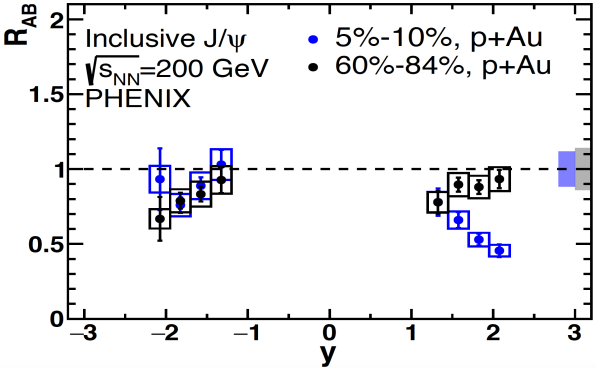

Centrality Dependence

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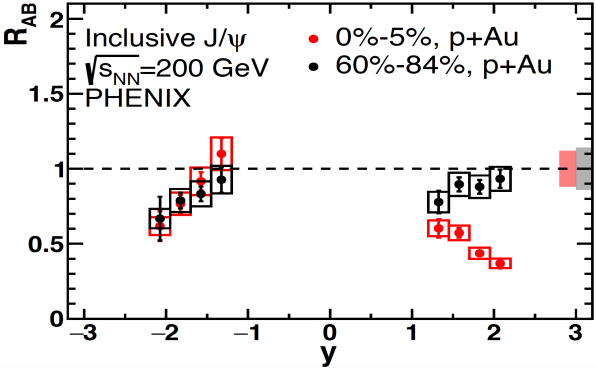
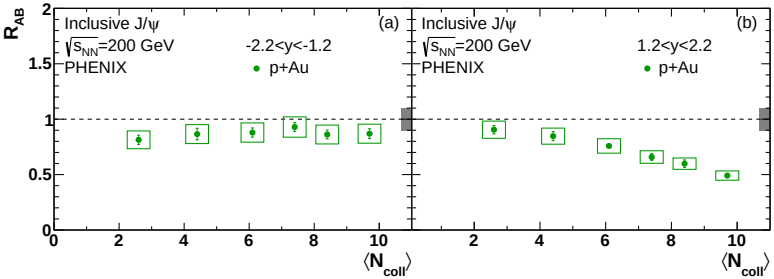
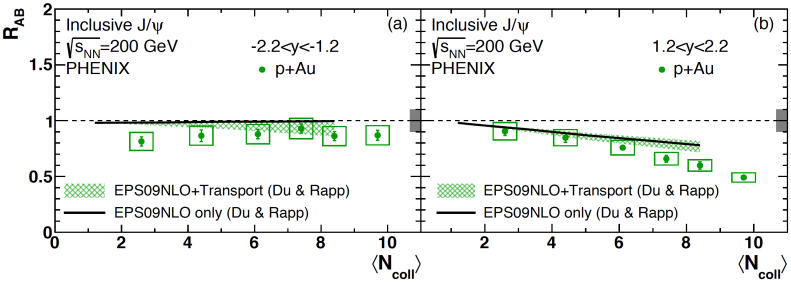


p+Au Dependence on $\langle N_{coll} \rangle$



- Little centrality dependence at backward rapidity
  - Consistent with trade off between anti-shadowing and nuclear absorption
- Strong centrality dependence at forward rapidity

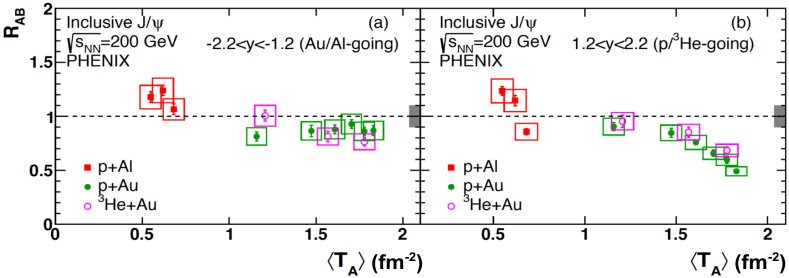
p+Au Dependence on $\langle N_{coll} \rangle$



- EPS09 NLO+transport model
  - Includes nuclear absorption at backward rapidity
- Little effect from transport model at forward rapidity
  - CNM suppression dominant

$\langle T_A \rangle$ Dependence

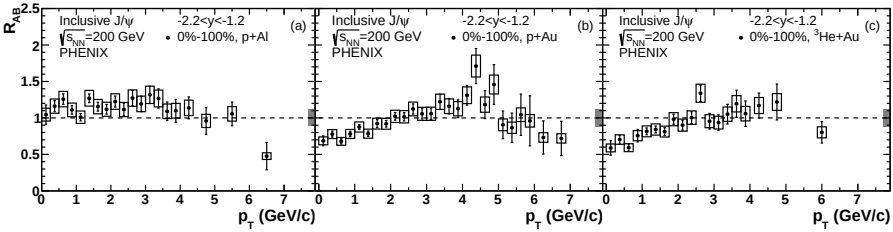
p+Al p+Au ^{3}He+Au



- Is modification determined only by target thickness?
  - Plot data vs. mean target thickness for hard processes
  - Data consistent with no projectile dependence

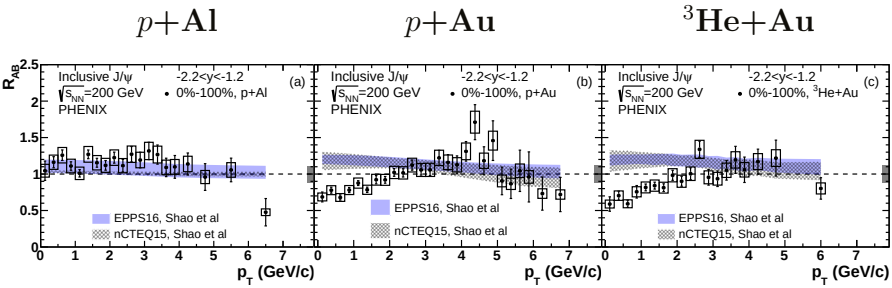
p_T Dependence, Backward Rapidity

p+Al | p+Au | ^{3}He+Au



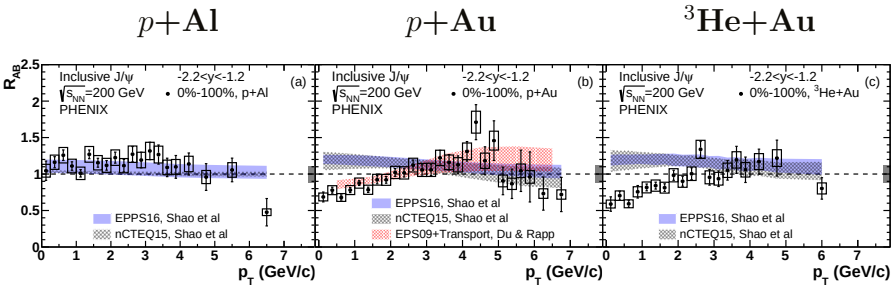
- Little modification in p+Al
- Similar modification between p+Au and ^{3}He+Au

p_T Dependence, Backward Rapidity



- Reweighted shadowing only - no nuclear absorption

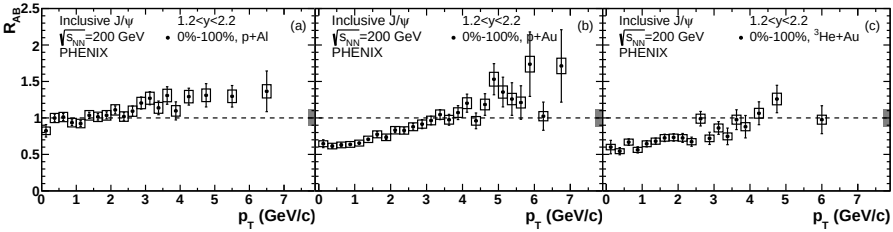
p_T Dependence, Backward Rapidity



- Transport model with nuclear absorption and p_T broadening

p_T Dependence, Forward Rapidity

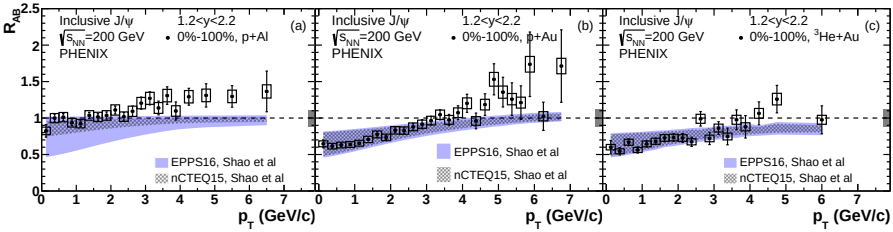
p+Al | p+Au | ^{3}He+Au



- No modification for p+Al
- Similar modification between p+Au and ^{3}He+Au

p_T Dependence, Forward Rapidity

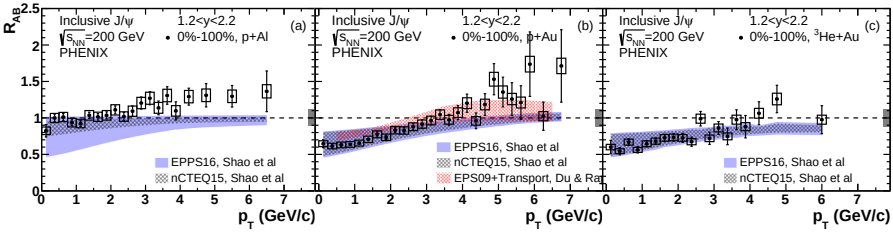
p+Al | p+Au | ^{3}He+Au



- Reweighted shadowing alone does well at low p_T

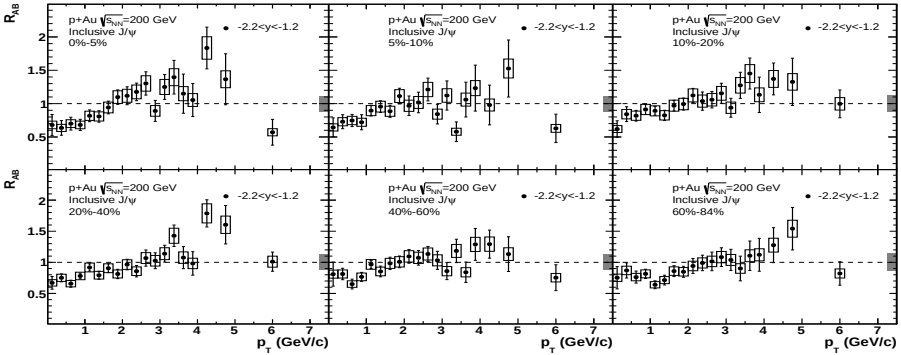
p_T Dependence, Forward Rapidity

p+Al | p+Au | ^{3}He+Au



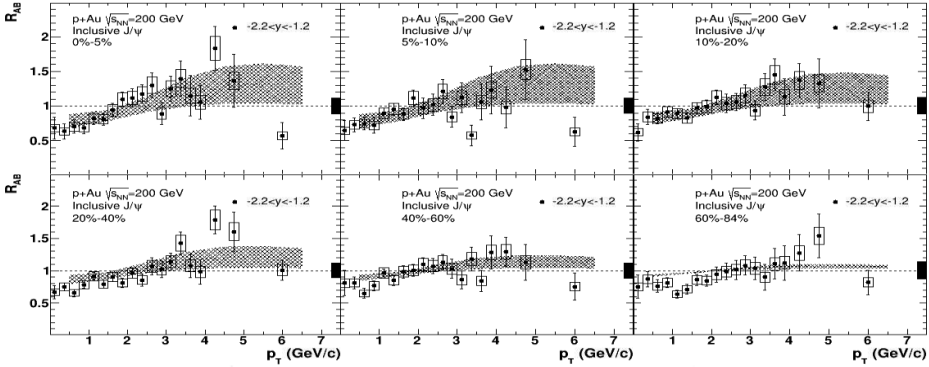
- Transport model with EPS09 + p_T broadening
- EPS09 shows weaker suppression due to shadowing than data

p+Au Centrality Dependence, Bkwd Rapidity



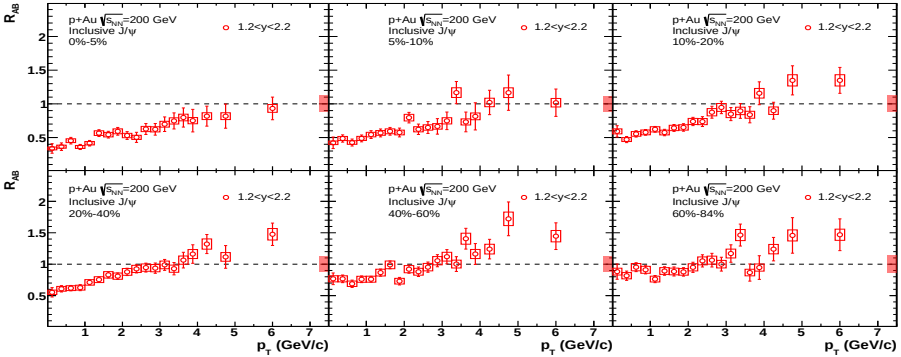
- Suppression at low p_T for most central collisions
  - Competition between nuclear absorption and anti-shadowing

p+Au Centrality Dependence, Bwd Rapidity



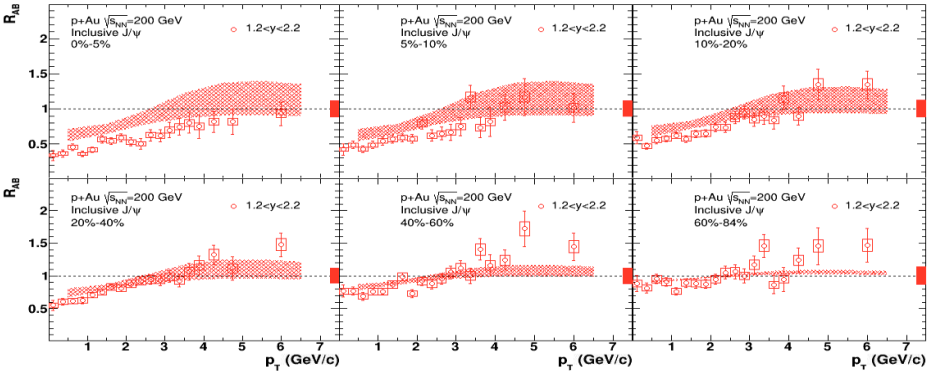
- Transport model includes nuclear absorption and p_T broadening
- Describes data well across full p_T range

p+Au Centrality Dependence, Fwd Rapidity



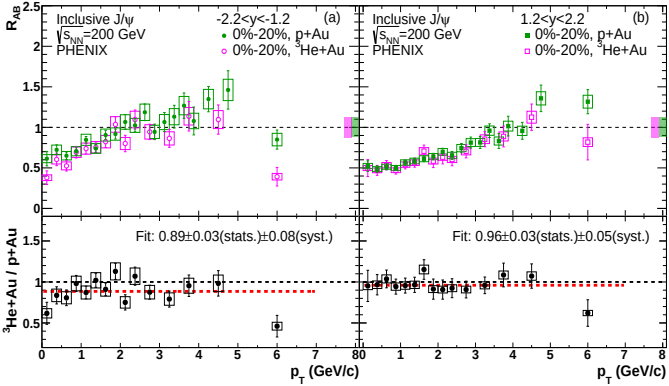
- Very strong suppression in most central collisions

p+Au Centrality Dependence, Fwd Rapidity



- Transport effects small at forward rapidity
  - EPS09 shadowing dominates model calculations
  - Shadowing not strong enough in central collisions

^{3}He+Au to p+Au Ratio (0-20%)



- ^{3}He+Au shows 11% stronger suppression than p+Au at backward rapidity

Conclusion

- Very strong forward rapidity suppression for most central collisions
  - Reweighted EPPS16 and nCTEQ15 shadowing describe 0-100% forward rapidity suppression
  - EPS09 centrality dependence (linear) assumed in transport model gives much weaker suppression than observed for most central collisions
- Small increase in suppression for ^{3}He+Au over p+Au
  - Consistent with small final state effect
- Absorption is significant at RHIC energies at backward rapidity
- Data suggest p_T broadening is needed in model calculations

Theory References

[1] Kusina, Aleksander and Lansberg, Jean-Philippe and Schienbein, Ingo and Shao, Hua-Sheng
Gluon Shadowing in Heavy-Flavor Production at the LHC
Phys. Rev. Lett 121, 052004

[2] Lansberg, Jean-Philippe and Shao, Hua-Sheng
Towards an automated tool to evaluate the impact of the nuclear modification of the gluon density on quarkonium, D and B meson production in protonnucleus collisions
Eur. Phys. J. C77, 2017

[3] Du, Xiaojian and Rapp, Ralf
In-Medium Charmonium Production in Proton-Nucleus Collisions
JHEP 03, 015

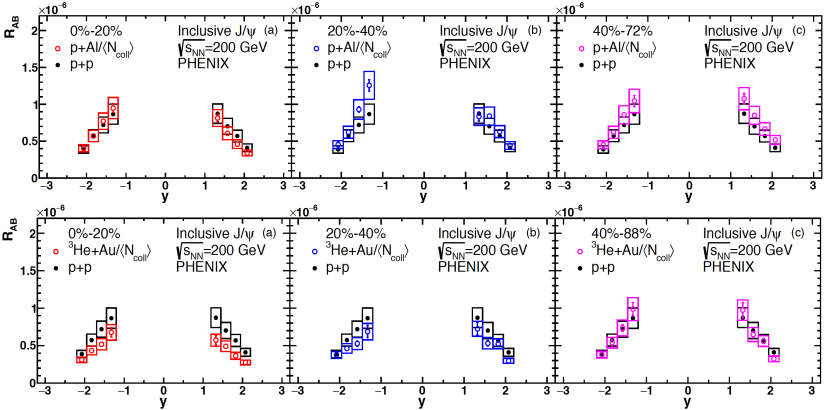
[4] Du, Xiaojian and Rapp, Ralf
Sequential Regeneration of Charmonia in Heavy-Ion Collisions
Nucl. Phys. A943, 2015

[5] D. McGlinchey, A.D. Frawley and R. Vogt
Impact-parameter dependence of the nuclear modification of J/ψ production in d+Au collisions at $\sqrt{s_{NN}}$ =200 GeV
Phys. Rev. C 87, 054910 (2013)

Back-Up

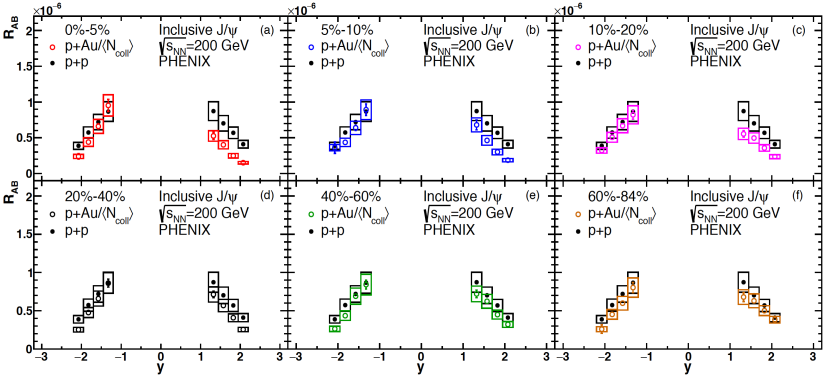
Invariant Yields as a function of y and Centrality

p+Al and ^{3}He+Au

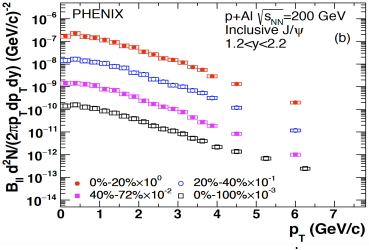


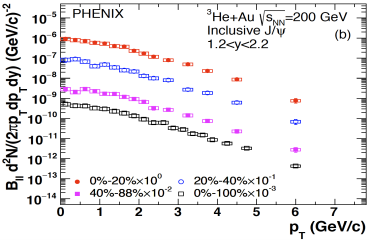
Invariant Yields as a function of y with Centrality

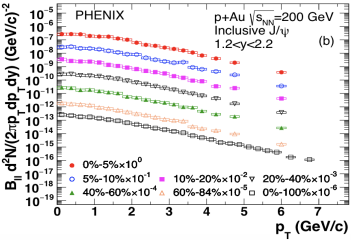
p+Au

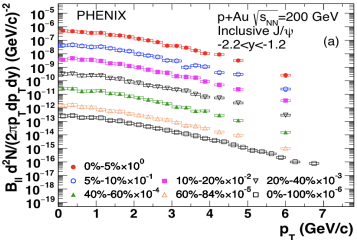


Invariant Yields as a function of p_T





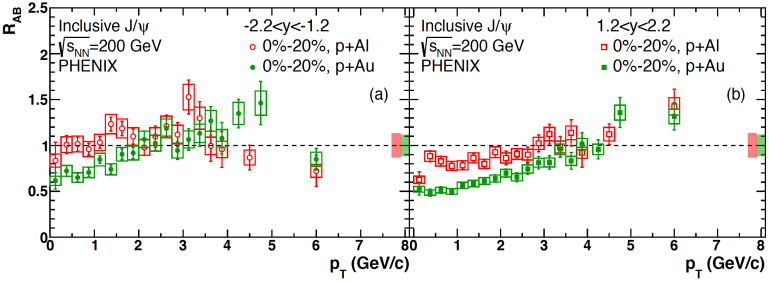




J/ψ Nuclear Modification (0–20% Centrality)

R_{AB} as a function of p_T for 0–20% centrality for p+Al and p+Au

p+Al and p+Au



- At forward rapidity with same projectile, quite different suppression
- At backward rapidity, expect trade off between absorption and shadowing