Heavy flavor and quarkonia production in PHENIX

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Introduction

The PHENIX experiment recorded data through the 2016 RHIC run, before being removed in preparation for the installation of the sPHENIX experiment.

The collaboration is still actively analyzing data.

I will report here on several recent heavy flavor results:

- Modification of charm and bottom decay electron yields in Au+Au collisions.
- J/ψ elliptic flow in Au+Au collisions.
- Modification of J/ψ and ψ(2S) in p+Au collisions.
- Event multiplicity dependence of J/ψ production in p+p collisions.

PHENIX

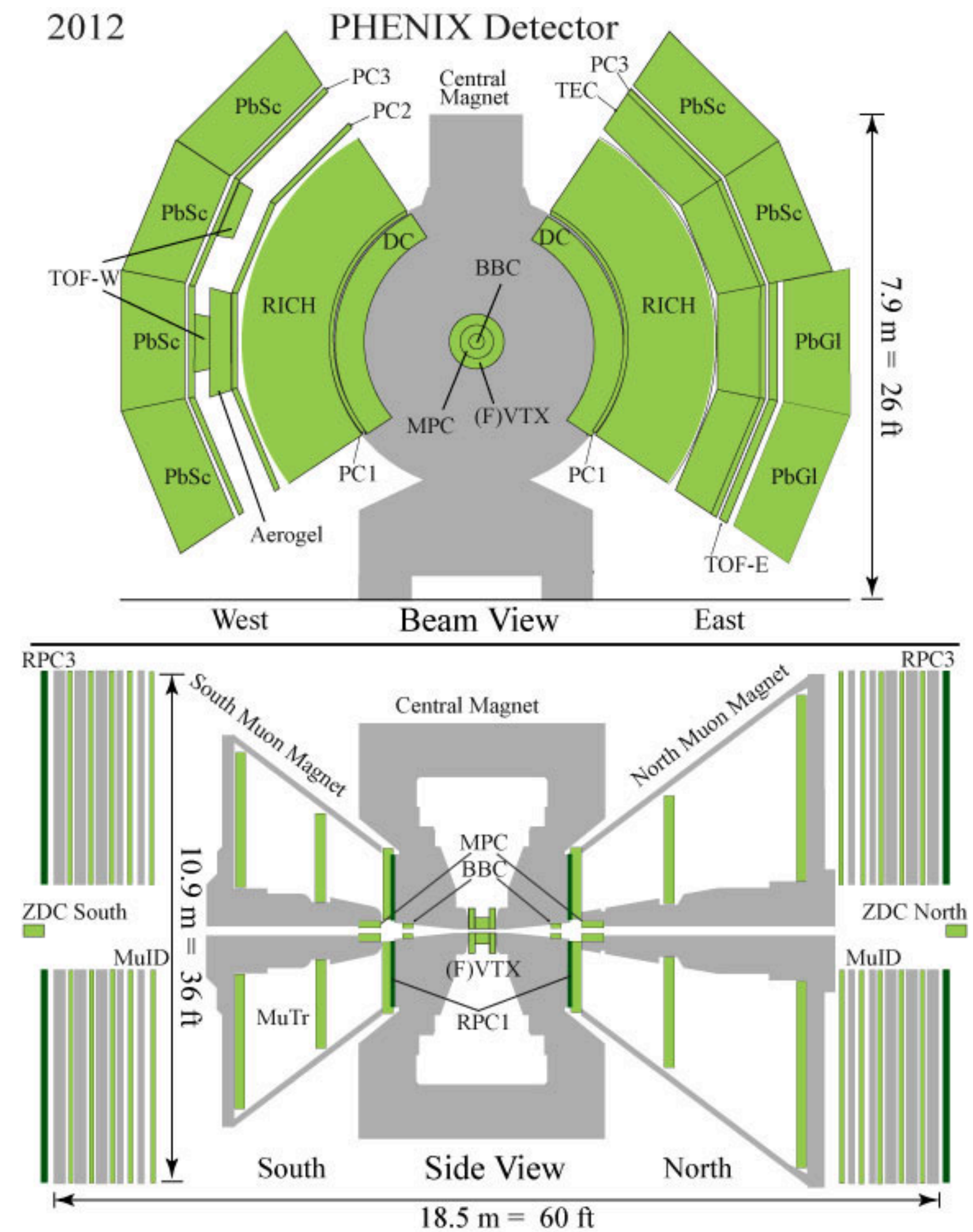
Central detector |η| < 0.35

Tracking + RICH + EMCal
- Excellent electron ID

Displaced vertex from VTX pixels
- Enables charm and bottom separation

Muon detector 1.2 < |η| < 2.2

Unidentified hadrons
Single muons
Quarkonia through dimuons
Forward Vertex detector (FVTX) before magnet
- improves muon momentum resolution
- Enables mass separation of J/ψ & ψ(2S)



Heavy flavor modification in AuAu

Mid-rapidity electron measurement:

- Start with all electrons after hadron rejection
- Subtract non-photonic sources (J/ψ, Y, kaon decays)
- Remainder is HF + photonic (Dalitz, conversions)
- Get fraction of HF/photonic electrons from data driven method
- Model photonic electron yield based on measured π^0, η invariant yields
- HF = photonic x HF / photonic

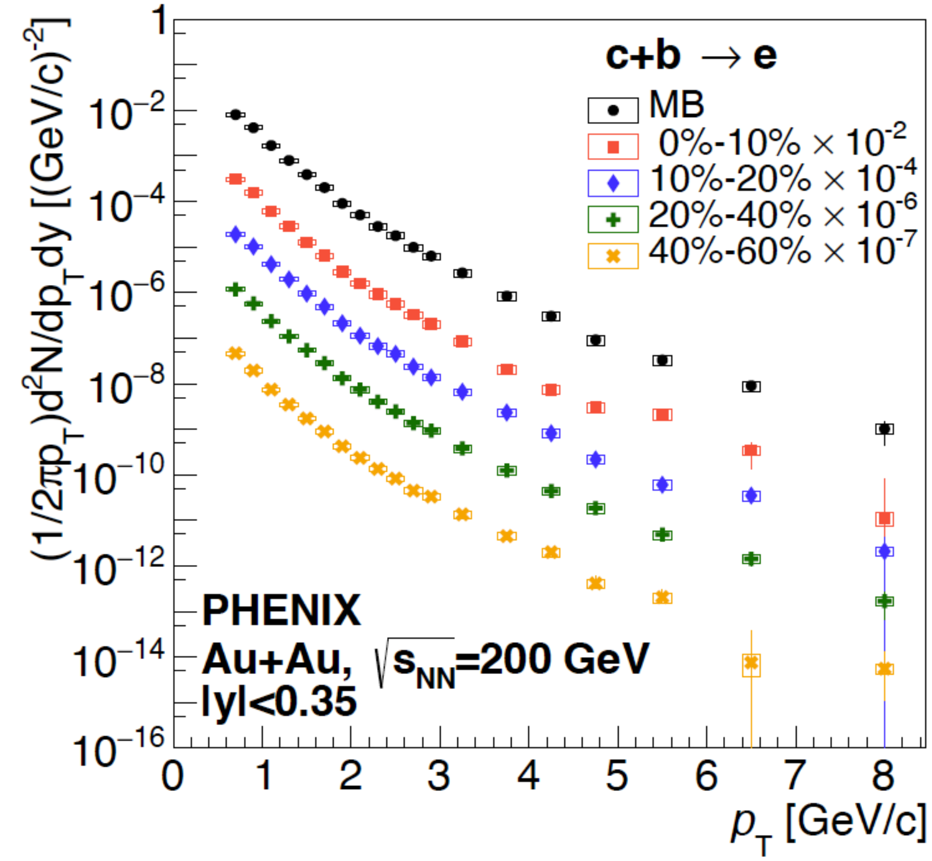
Displaced vertex analysis enables determination of the fraction of charm/bottom decays

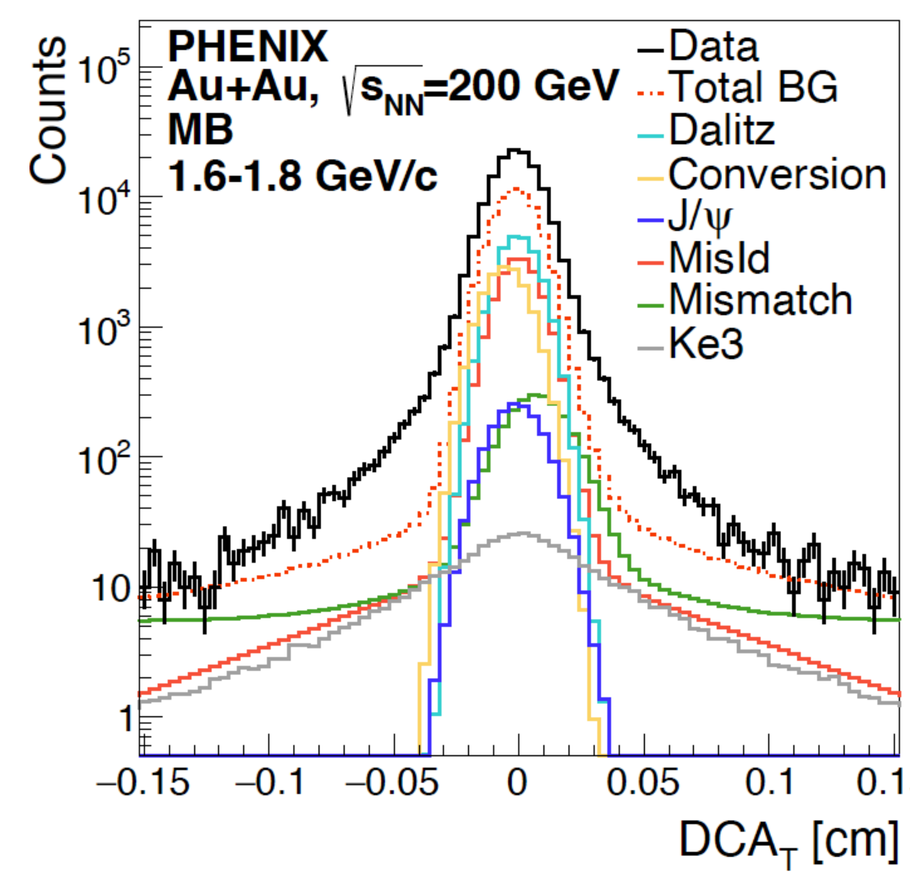
- Get background DCA_T distributions from GEANT 3
  - based on input distributions determined from data
- Simultaneous fits to p_T and DCA_T distributions
  - => c and b separately

Distributions of electrons from c and b depend on **unmeasured** p_T spectra of the parent hadrons

- To get invariant yield of **parent** charm and bottom hadrons, use Bayesian inference unfolding method
- Pythia6 is used to model the decay matrices

arXiv:2203.1708

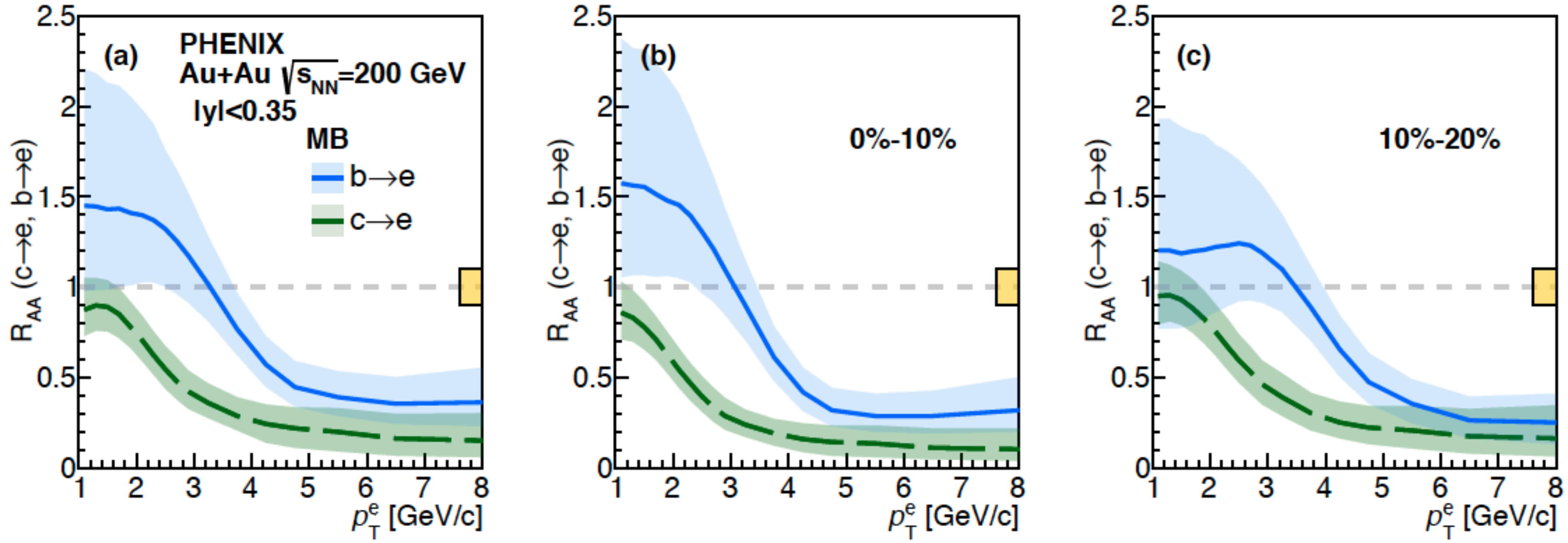


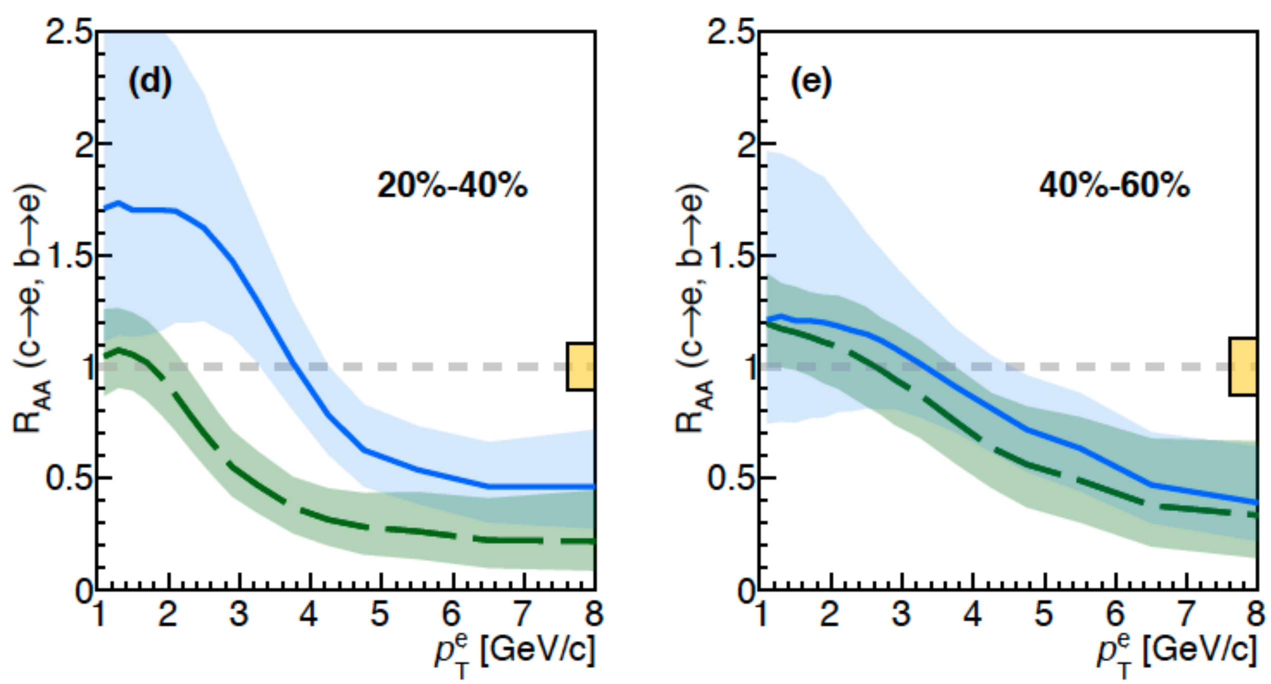


HF decay electron modification

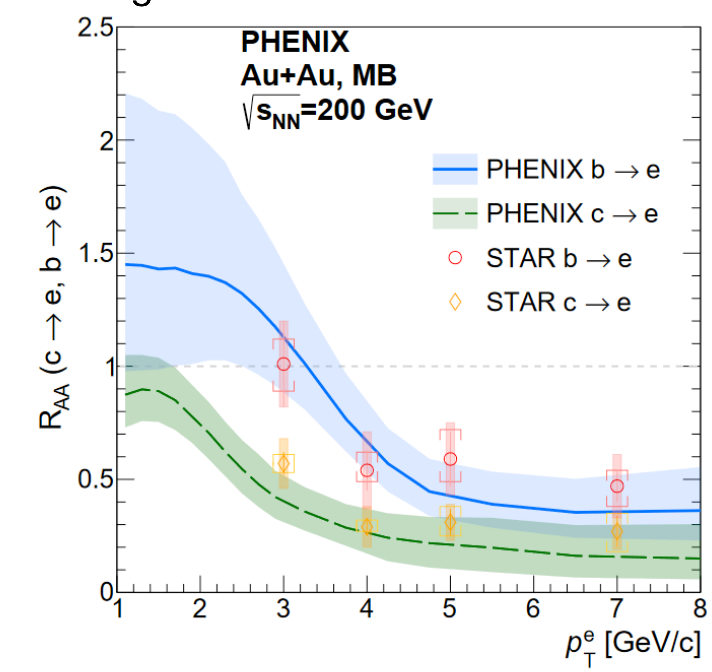
R_{AA} of electrons resulting from charm and bottom decays.

arXiv:2203.1708





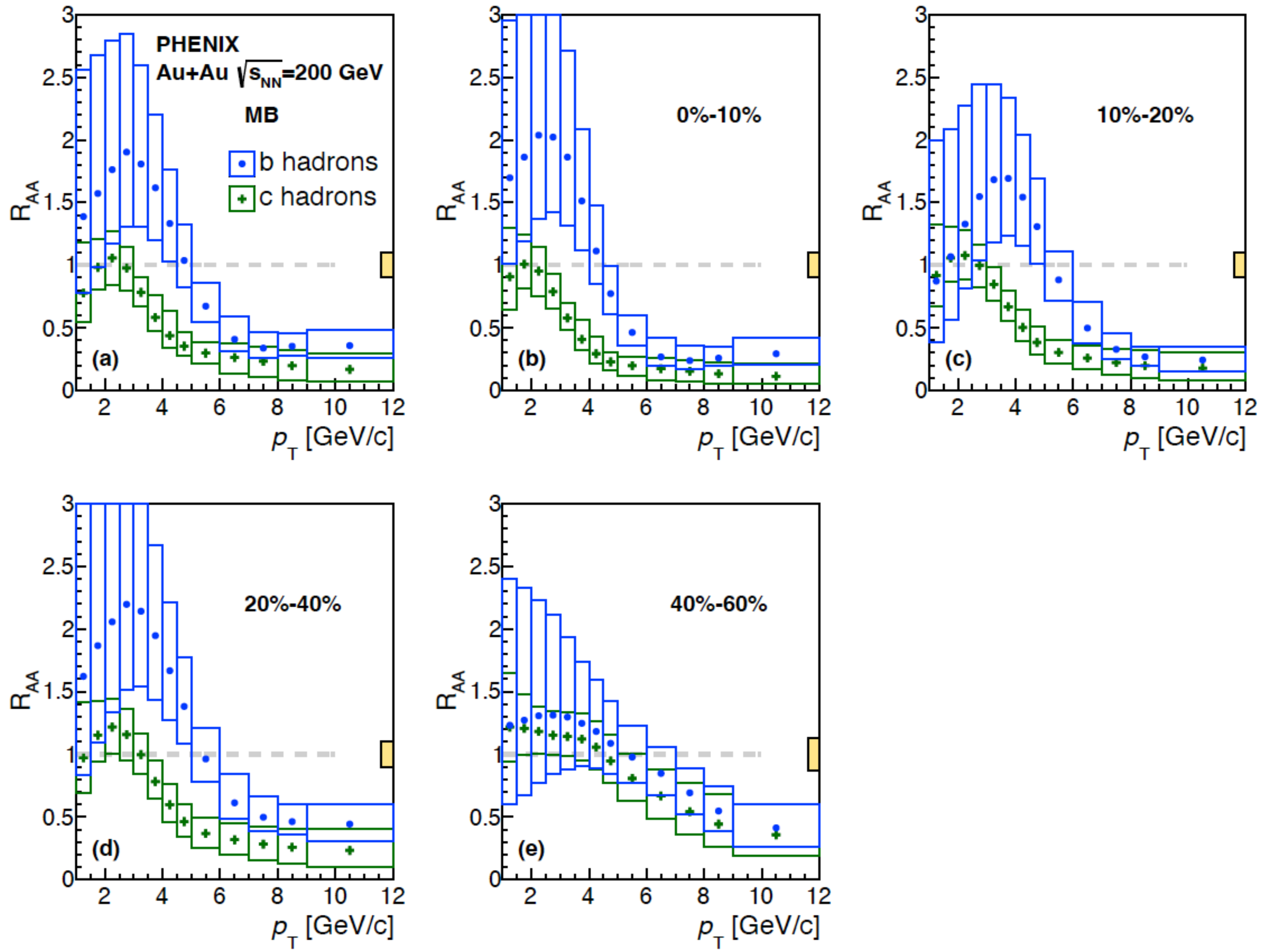
Good agreement with STAR results for MB



HF hadron modification

Charm and bottom hadron R_{AA} from a Bayesian unfolding of electron p_T and transverse DCA distributions.

arXiv:2203.1708



Model comparisons

T-Matrix model assumes formation of hadronic resonance by a heavy quark in the QGP based on lattice QCD

- van Hees et al., PRL 100, 192301 (2008)

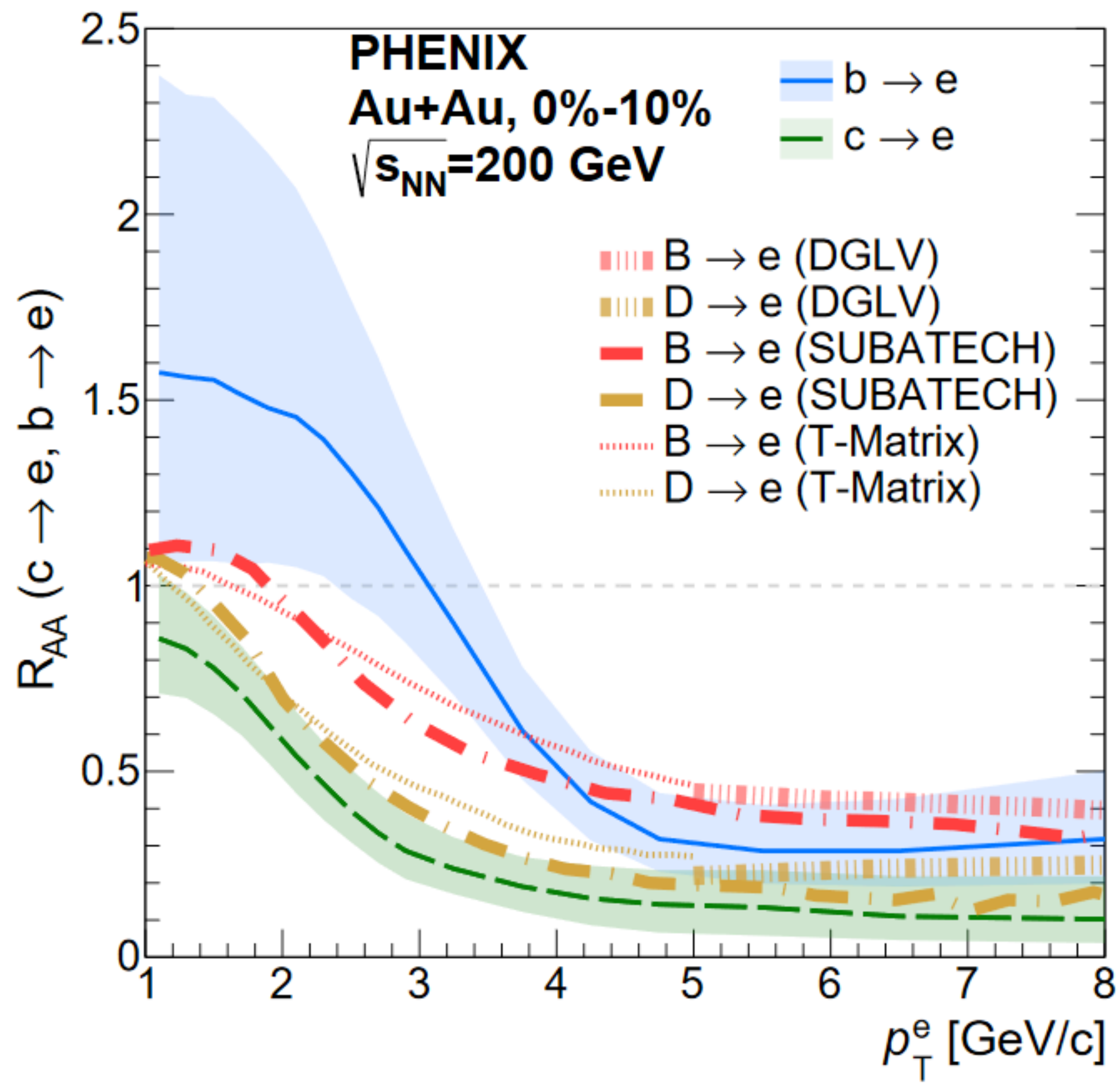
SUBATECH model with hard thermal loop calculation for the collisional energy loss

- Gossiaux and Aichelin, Phys. Rev. C 78, 014904 (2008)

DGLV model calculates both collisional and radiative energy loss assuming an effectively static medium

- Djordevic and Djordevic, Phys. Rev. C 90, 034910 (2014)

arXiv:2203.1708



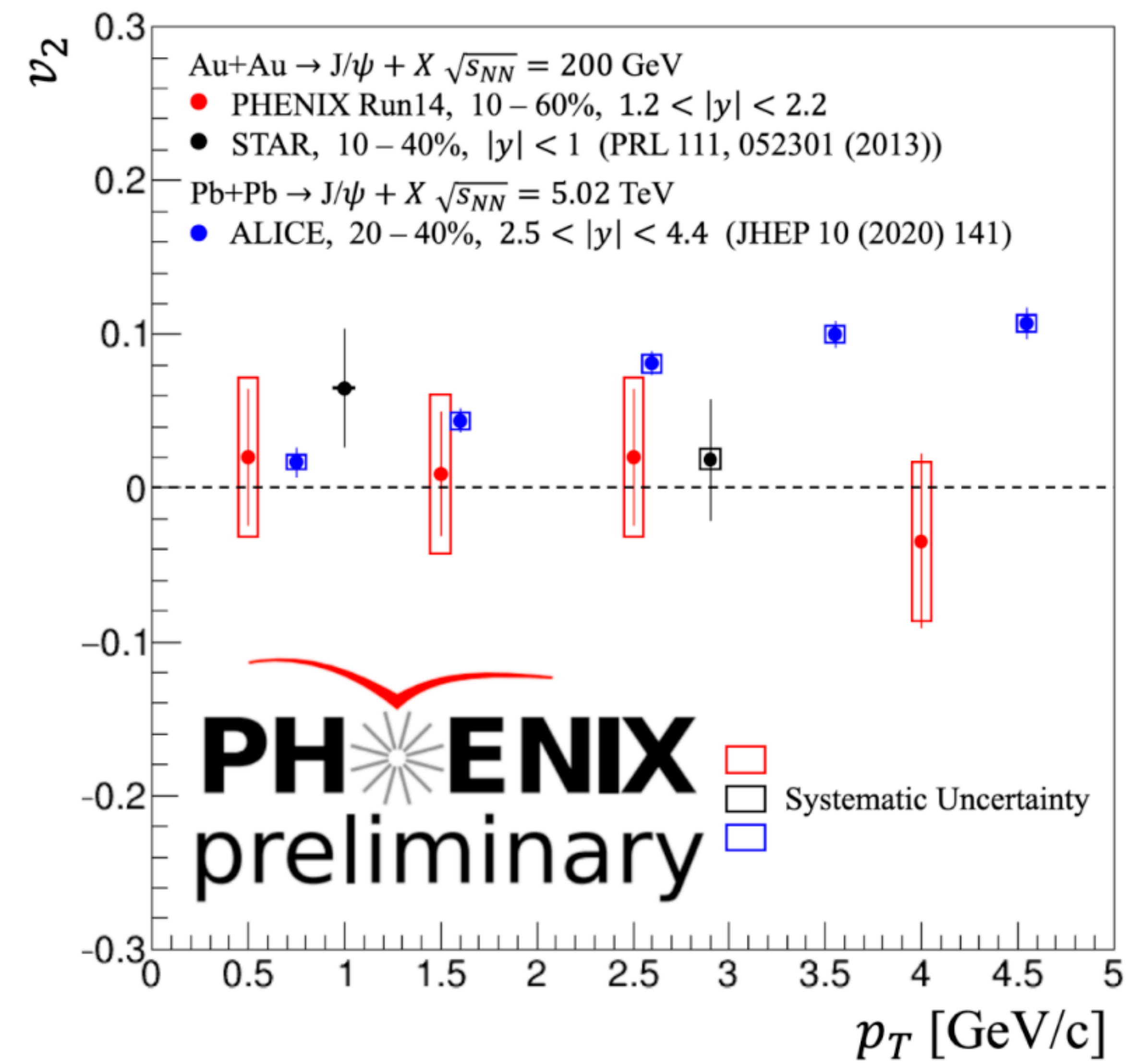
J/ψ elliptic flow in AuAu collisions

PHENIX J/ψ elliptic flow data from the RHIC 2014 run at forward rapidity

- 10-60% centrality v_2 is consistent with zero

Differs from the ALICE nonzero result

Au+Au data from Run 16 will be added next



J/ψ event multiplicity dependence in p+p

Study event multiplicity dependence of J/ψ production in p+p collisions using PHENIX forward / backward muon arms

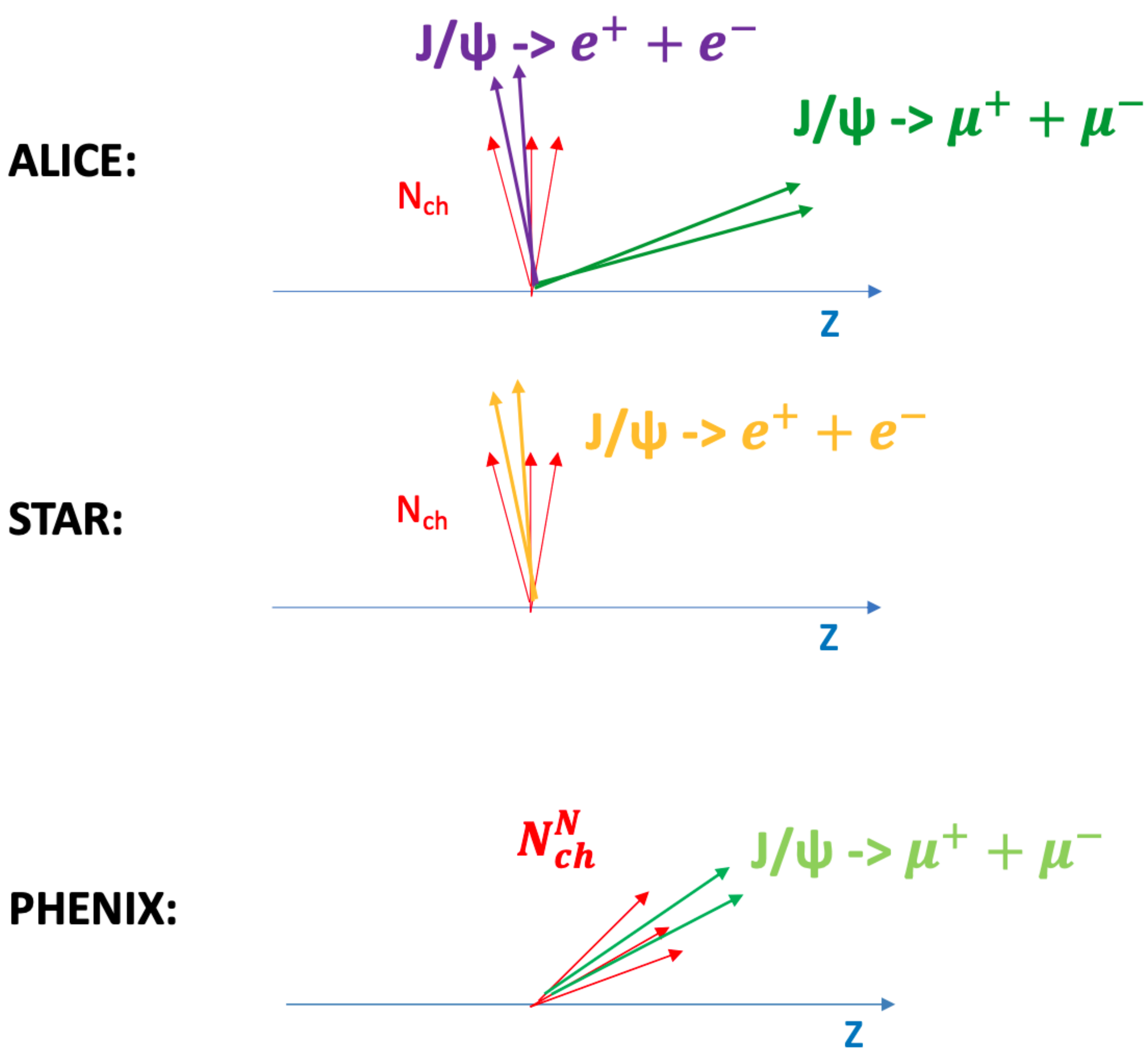
Data from 2015 RHIC run

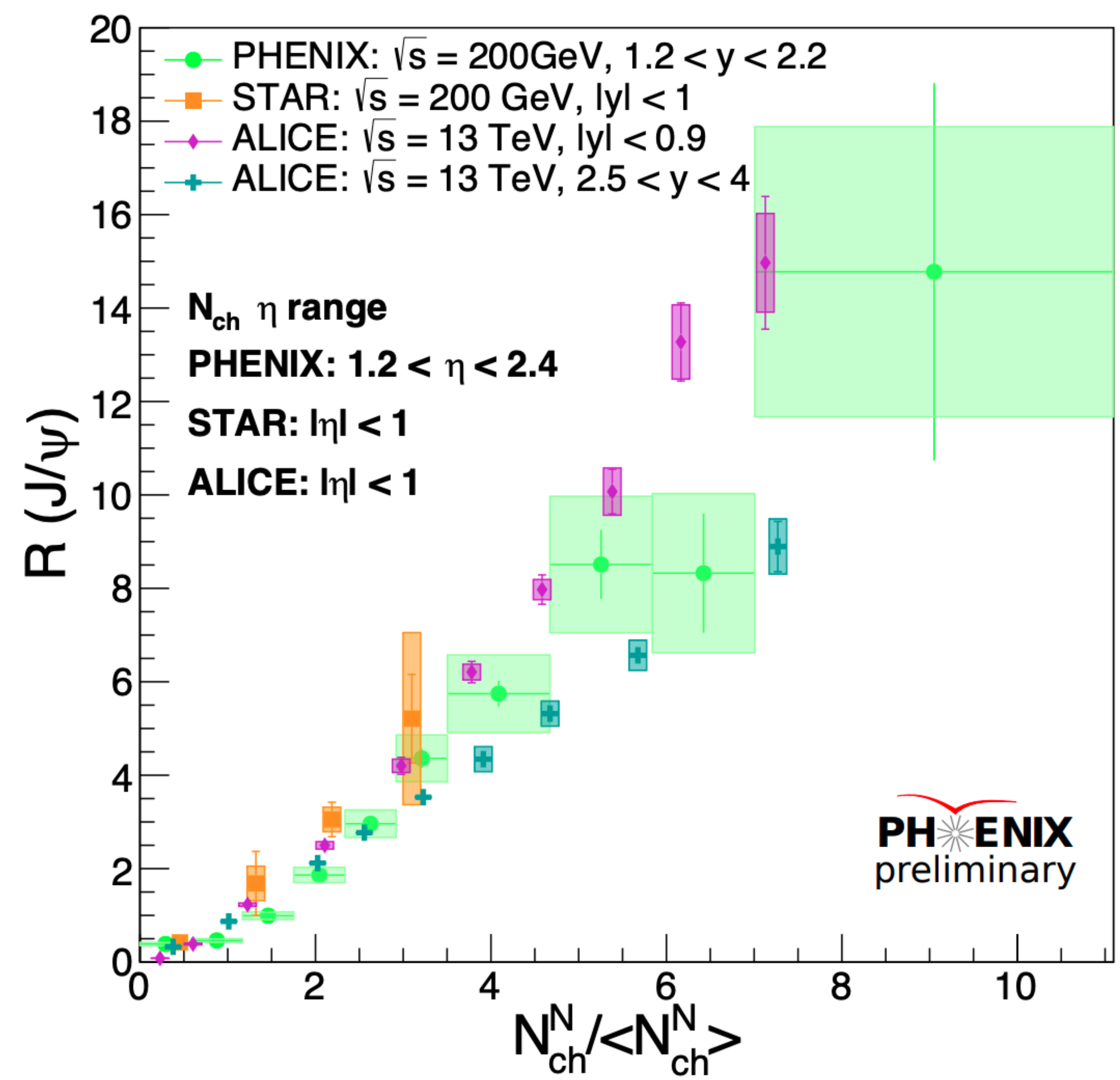
The muon arms can also detect unidentified hadrons

- Measure charged particle yields at $1.2 < \eta < 2.2$
- Measure J/ψ in same event at $1.2 < \eta < 2.2$ **or** $-1.2 < \eta < -2.2$

J/ψ production vs event multiplicity in p+p collisions

- Strong dependence on local track multiplicity
- Result consistent with observations at ALICE and STAR
- Large slope attributed to multi-parton interactions in p+p collisions





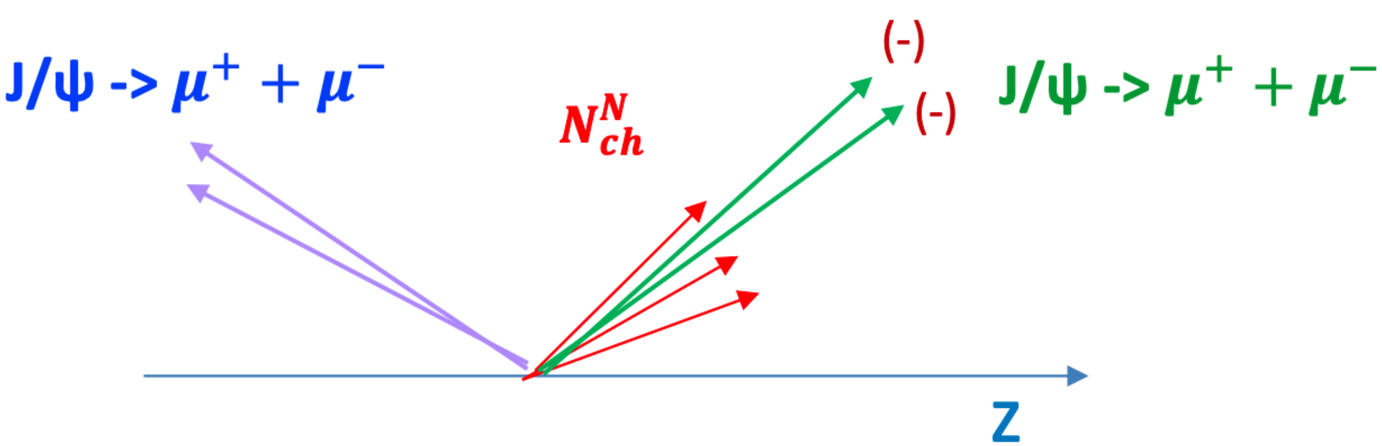
J/ψ production vs event multiplicity in p+p collisions

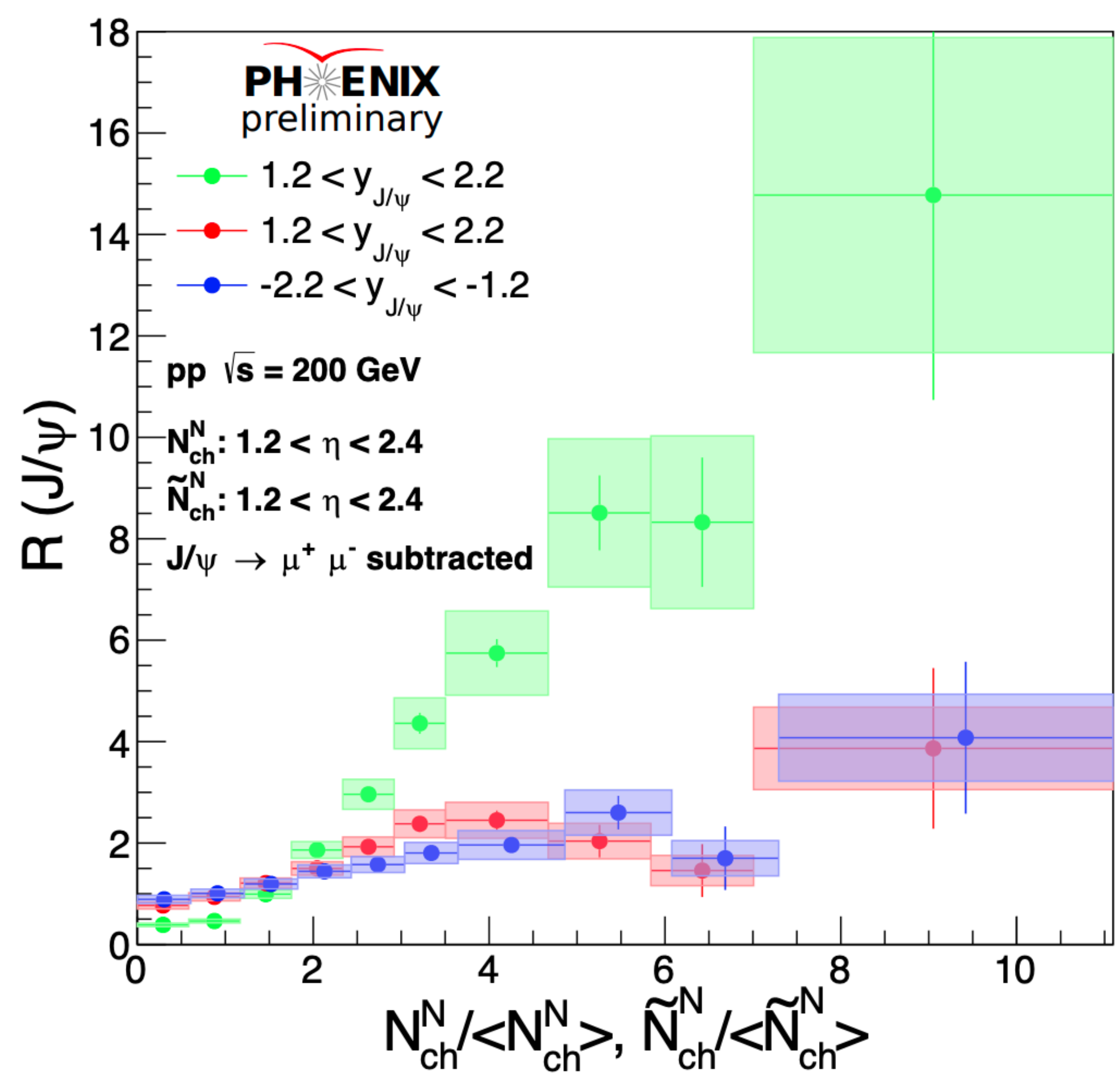
- Large dependence significantly reduced when
  - Removing tracks belonging to J/ψ or
  - Using non-local track multiplicity
- Is there still room for Multi-Parton Interactions ?

RED = Tracklets $N_{ch}^{N}(1.2 < \eta < 2.4)$ [inclusive, dimuon subtracted]

Green = J/ψ (1.2 < y < 2.2)

Blue = J/ψ (-2.2 < y < -1.2)





- Less MPI contribution to the forward J/ψ production?

Summary of observations

Strong N_{ch} dependence observed when signal and N_{ch} in the same kinematics

N_{ch} dependence reduced significantly if the dimuon contribution is removed

Dimuon subtracted N_{ch} dependence similar to the ones from N_{ch} determined in a far kinematic region from the signal

Final state effects on charmonia in p+Au

Final state effects on quarkonia production in light systems have received a lot of interest since:

- The observation of flow-like effects in p+A collisions at LHC and RHIC
- The observation of strong differential suppression of the ψ(2S) relative to the J/ψ in light systems at RHIC and LHC
  - Cold nuclear matter effects can not explain this

Recent work by PHENIX on two fronts:

Compare J/ψ modification in p+Au and ^{3}He+Au

- To look for differences due to final state effects

Measure ψ(2S) production vs centrality in p+Au collisions at forward/backward rapidity

- Previously had only midrapidity measurements vs centrality at RHIC

^{3}He+Au to p+Au J/ψ ratio (0-20%centrality)

Backward rapidity ratio 0.89 ±0.03 ± 0.08

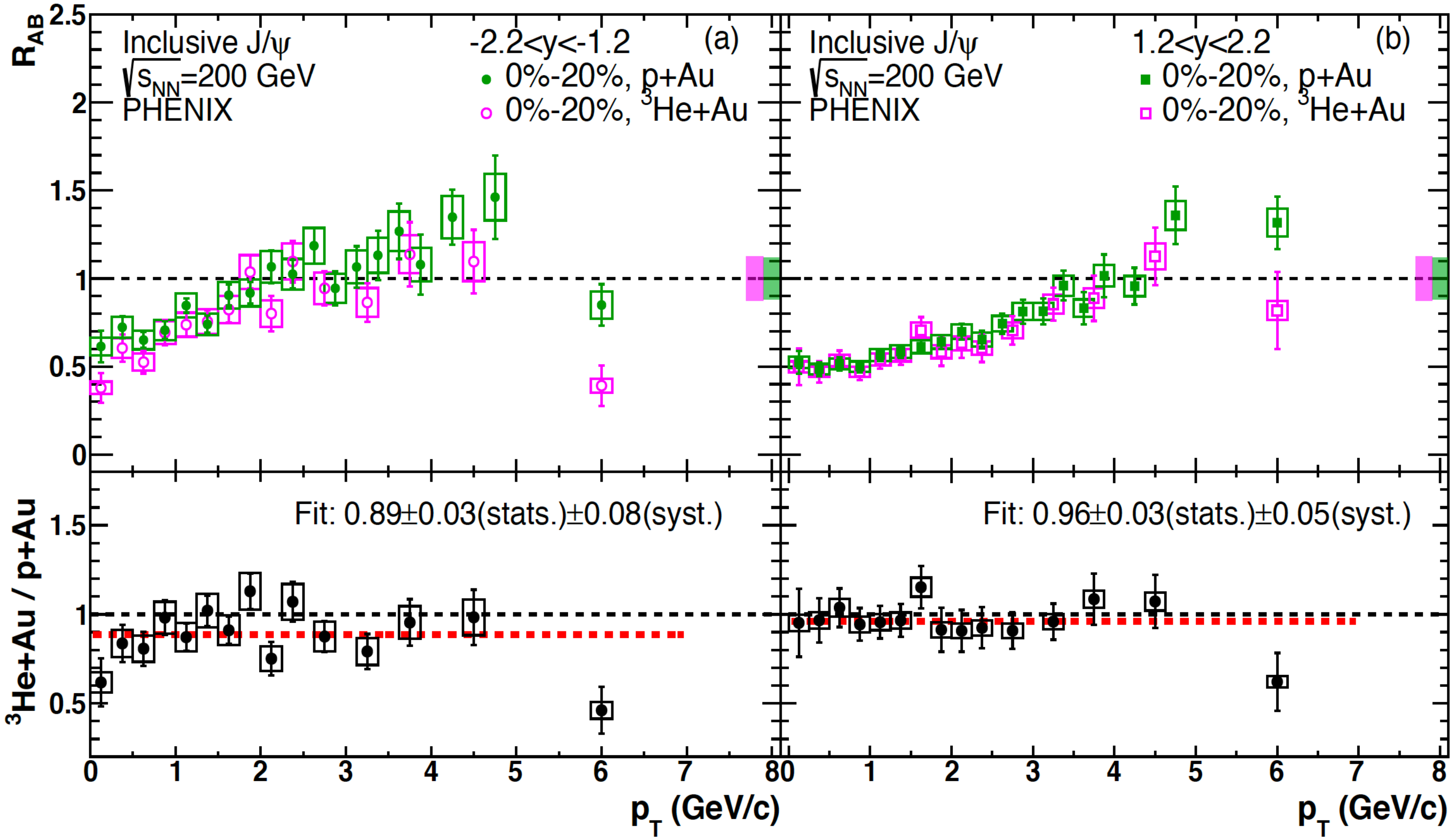
- Consistent with some additional suppression (90% probability).
- But not far outside the systematic uncertainty.

Forward rapidity ratio 0.96 ± 0.03 ± 0.05

- Consistent with 1

Little evidence for strong suppression of J/ψ in final state

Phys.Rev.C 102 (2020) 1, 014902



Extracting ψ(2S) yields

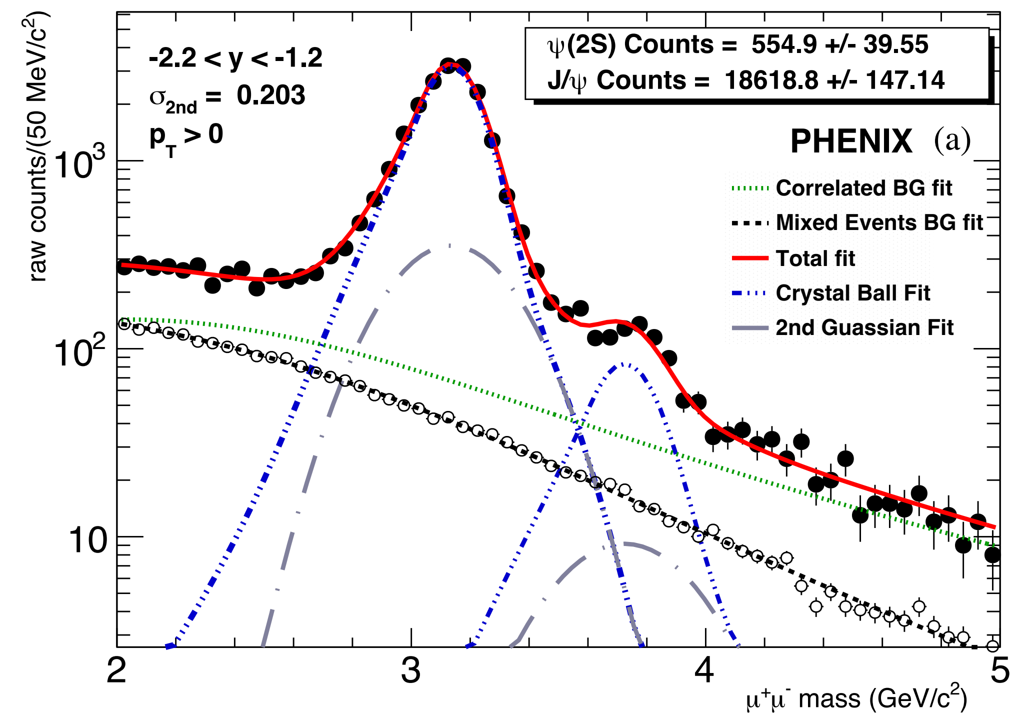
Phys.Rev.C 105 (2022) 064912

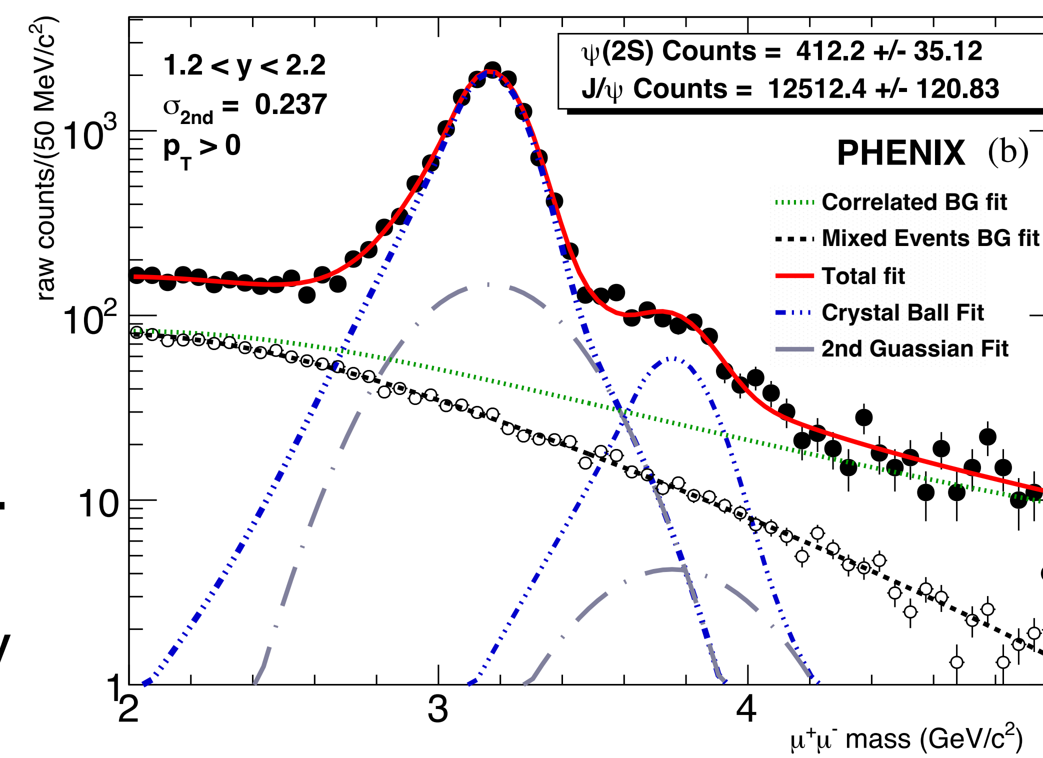
Crystal Ball line-shapes used for quarkonia.
- J/ψ mass and width fixed from MB data.
- ψ(2S) mass & width **ratio** to J/ψ from simulations.
- Tail parameters from simulations.

ψ(2S) yield is very sensitive to high mass tail of J/ψ.
- Caused by mis-association of MuTr and FVTX hits.
- Included in fit using second gaussian.
  - Parameters determined from simulation.

Combinatorial background estimated from event mixing.

Correlated background.
- Open HF, Drell Yan, charged hadron muon decays.
- Poorly constrained by the data.
- Use a modified Hagedorn function, constrained by detailed simulations of all components.





$\psi(2S)$ R_{pAu} - centrality dependence

Nuclear modification in p+Au collisions for J/ψ and ψ(2S) as a function of $\langle N_{coll} \rangle$.

Du and Rapp transport model somewhat under-predicts the suppression, but gets the suppression **ratios** about right.

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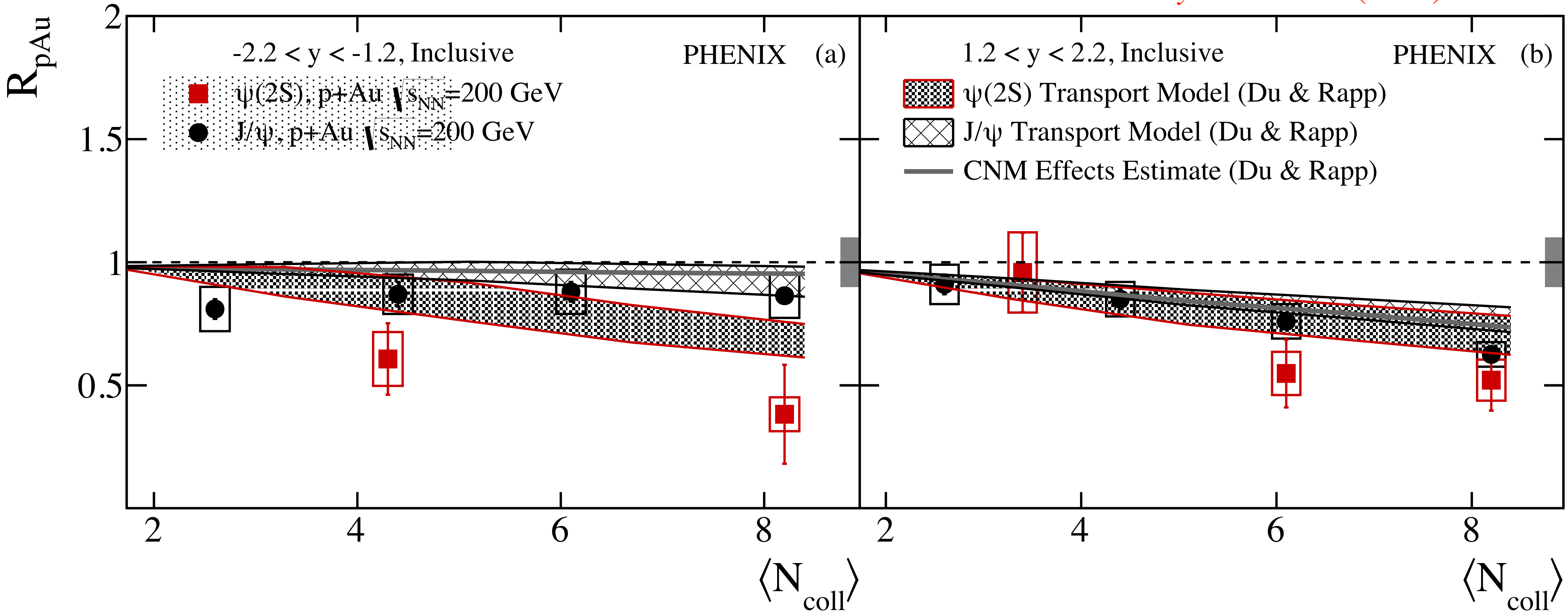

$\psi(2S)$ R_{pAu} centrality dependence - compare with shadowing alone

Add re-weighted shadowing comparison to plot.

Forward rapidity:

Modification consistent with shadowing alone.

Backward rapidity:

Require addition of strong absorption + differential $\psi(2S)$ suppression.

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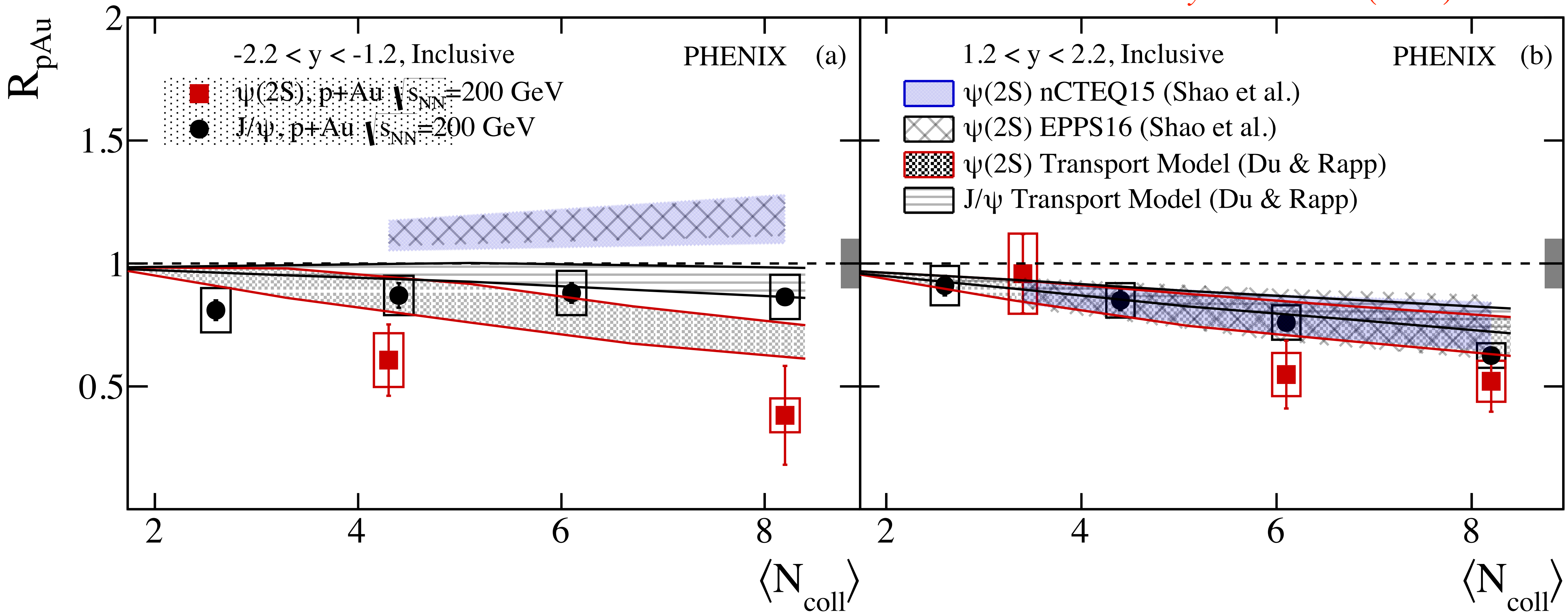

ψ(2S) R_{pAu} vs N_{coll} - PHENIX/ALICE

Simultaneous comparison of PHENIX and ALICE ψ(2S) modification data with Du & Rapp transport model.

- Similar suppression at backward rapidity
  - **Combination** of anti-shadowing, absorption, final state effects.
- The different model suppression at forward rapidity is due to differences in shadowing.

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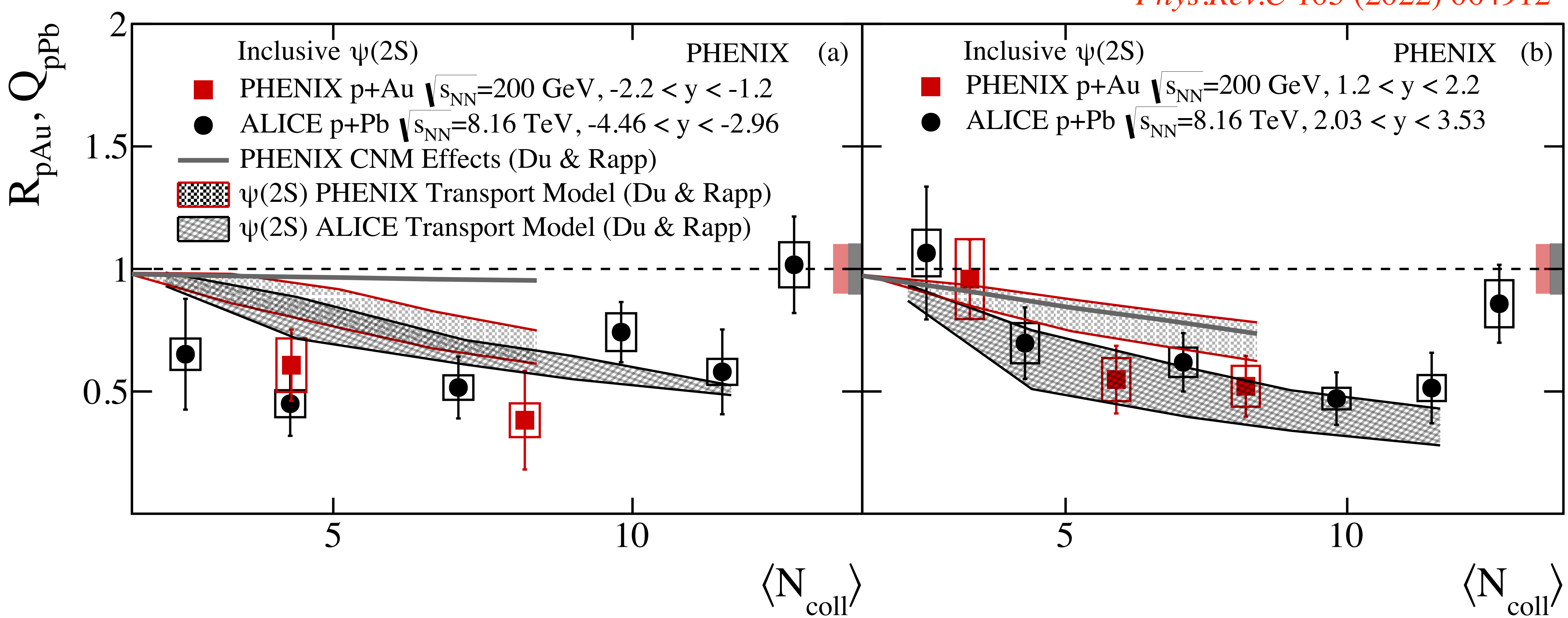

ψ(2S) R_{pAu} vs rapidity - trend in world data

PHENIX, ALICE and LHCb modification for J/ψ and ψ(2S) vs rapidity.

Clear trend of increasing differential suppression from forward to backward rapidity.

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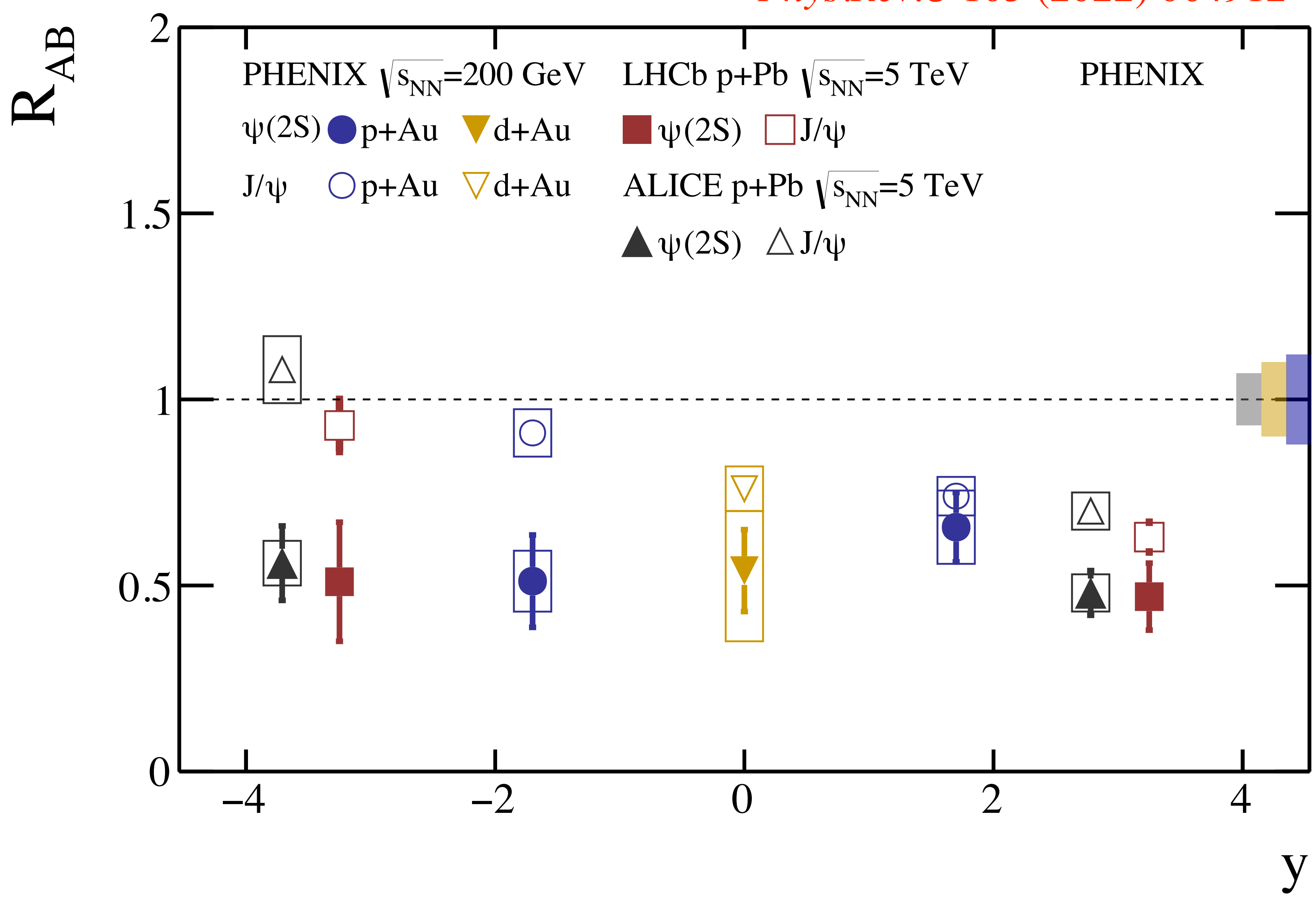

Summary

HF modification in Au+Au collisions

- Extracted c -> e and b-> e modification separately
- Charm and bottom hadron modifications from Bayesian analysis
- Charm more strongly suppressed than bottom

J/ψ elliptic flow in Au+Au collisions

- Consistent with zero, but with limited precision
- More data coming from Run 16

J/ψ event multiplicity dependence in p+p collisions

- Large dependence of J/ψ yield on track multiplicity reduced when
  - Using track multiplicity from the other muon arm
  - Removing J/ψ decay muon tracks from the same arm

Final state effects on quarkonia in light systems

- Final state effects on J/ψ production are small
  - From comparison of p+Au with ^{3}He+Au at backward rapidity
- Strong differential suppression of ψ(2S) at backward rapidity
  - But not at forward rapidity
- These ψ(2S) data at forward/backward rapidity complete systematic picture

Backup