Recent heavy flavor measurements by PHENIX experiment

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PHENIX

Outline

- Brief introduction
  - studying open heavy flavor
  - PHENIX detector
- Heavy flavor measurements by PHENIX
  - remind of HI results
  - d+Au results
- Highlighting the PHENIX results finalized soon
- Summary

Studying open heavy flavor

- p+p collisions
  - test pQCD calculations
  - baseline for heavy ion collisions

- Heavy ion collisions
  - probe effects of the strongly interacting hot medium

- d(p)+A collisions
  - quantify cold nuclear matter effects

Studying open heavy flavor

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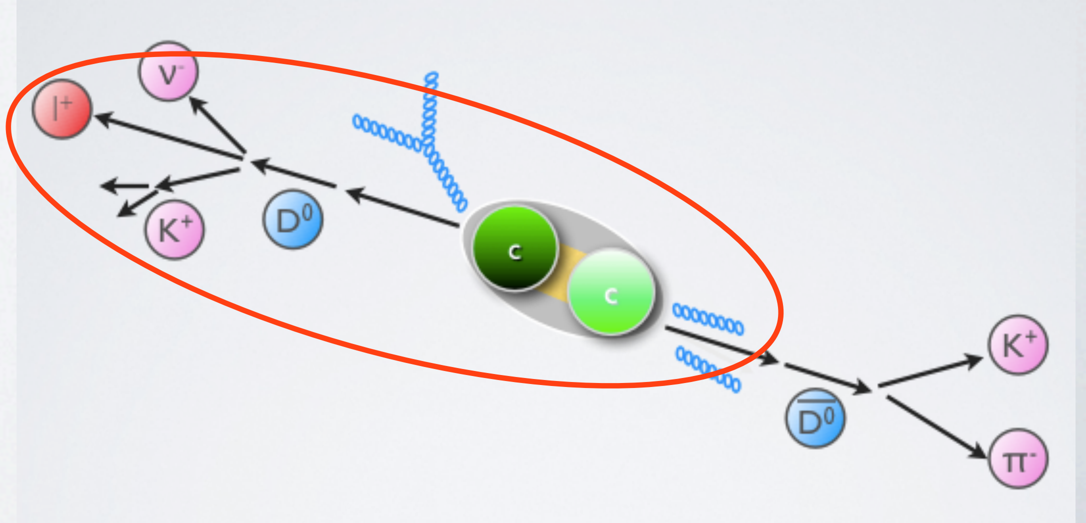
  - probe effects of the strongly interacting hot medium

- d(p)+A collisions
  - quantify cold nuclear matter effects

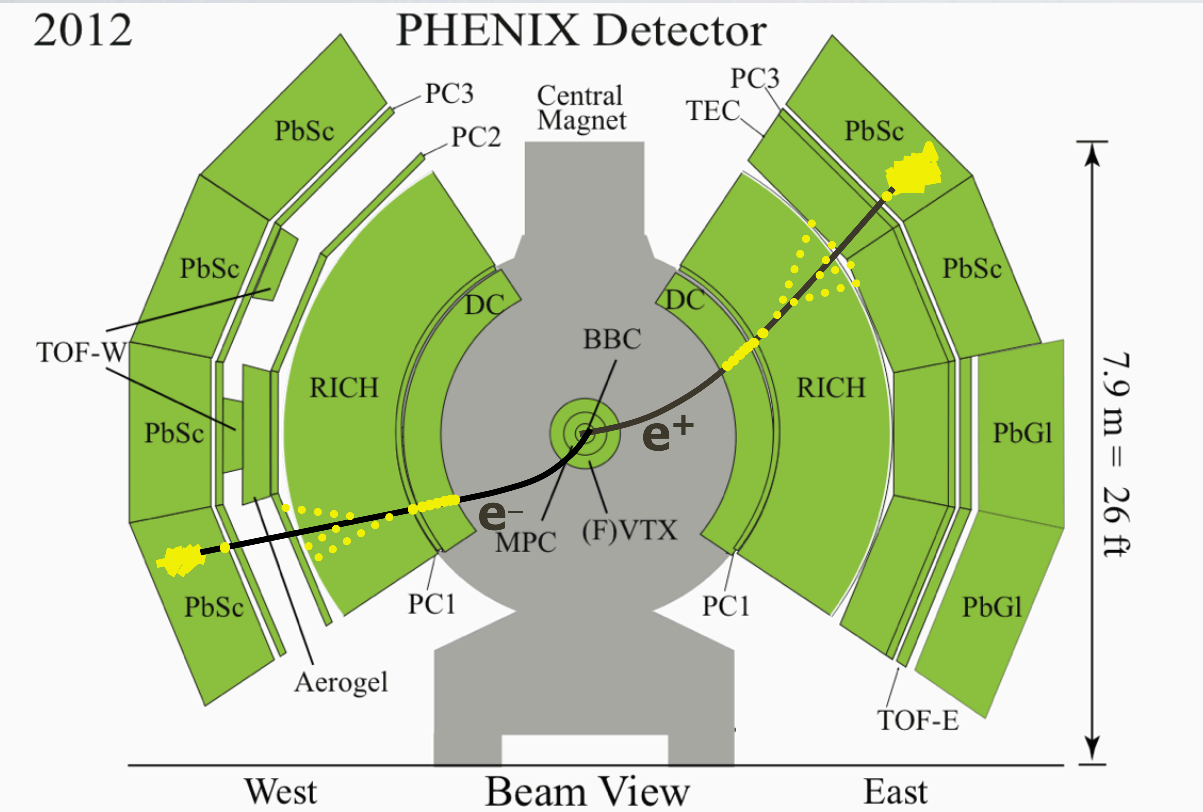
- PHENIX has suitable design for lepton measurements
  - single leptons from open heavy flavor
  - lepton pairs from quarkonia

Semi-leptonic decay

- lepton triggered measurement(e, μ)
(statistical background subtraction)

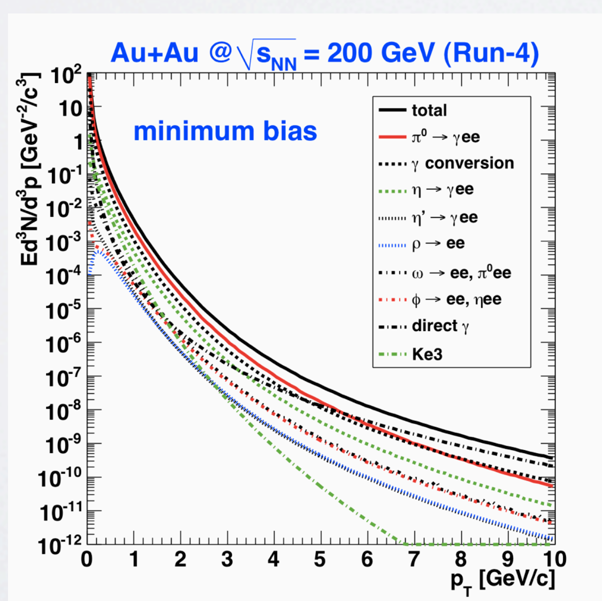


e measurement @ PHENIX central arm



- kinematic range
  - |η| < 0.35
  - Δφ = π
- Detectors
  - DC & PC for tracking
  - RICH for electron ID
  - EMcal for energy of electron

- Cocktail method
  - simulate photonic background with measured spectra of hadrons
  - large systematics
  - π0 Dalitz
  - conversion γ
  - direct γ & Ke3
  - J/Ψ, ϒ, DY



- Converter method
  - using photon converter (1.68% X_0)
  - increase photonic background and statistically limited

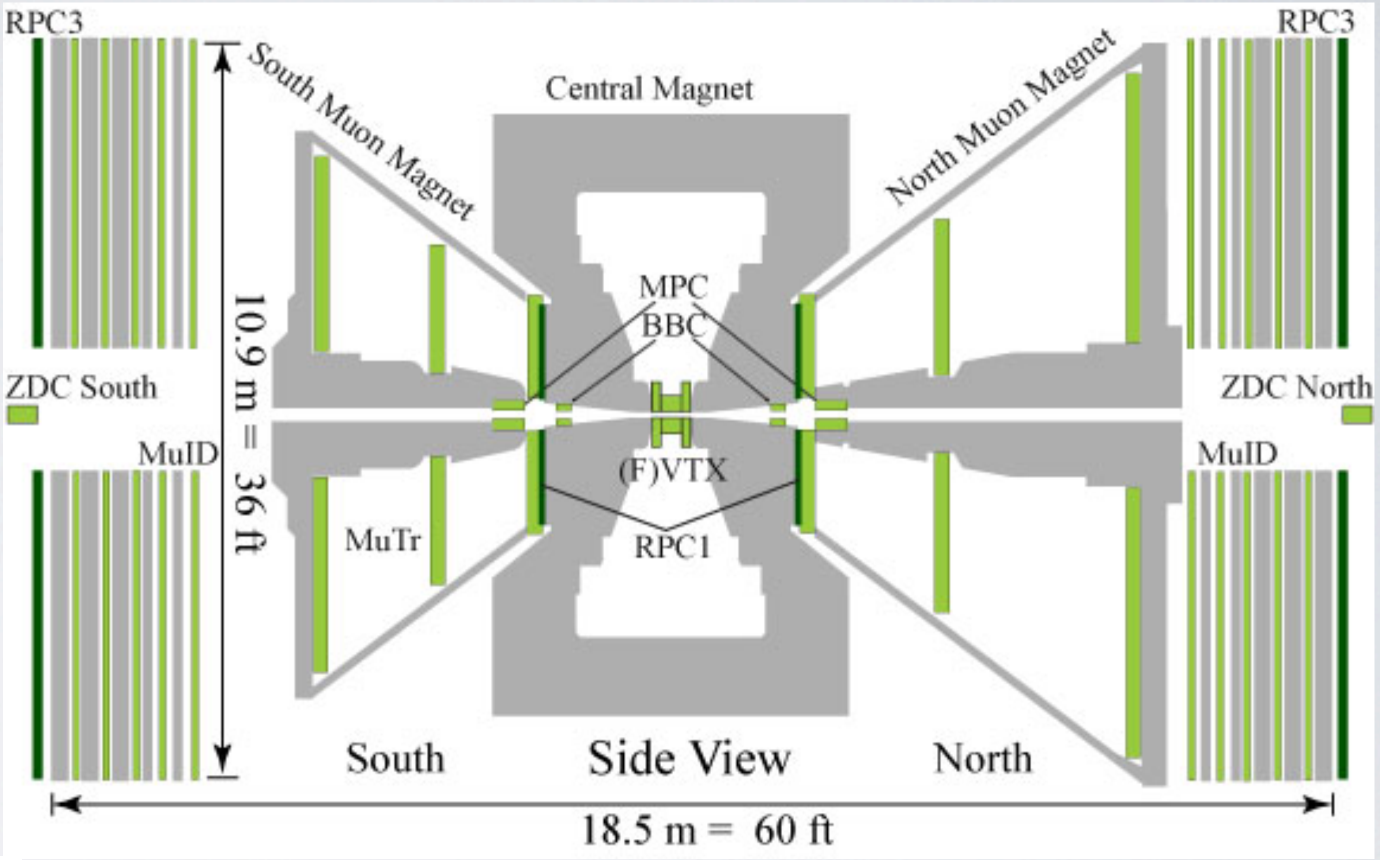
$$N_e^{conv-out} = N_e^{\gamma} + N_e^{non-\gamma}$$

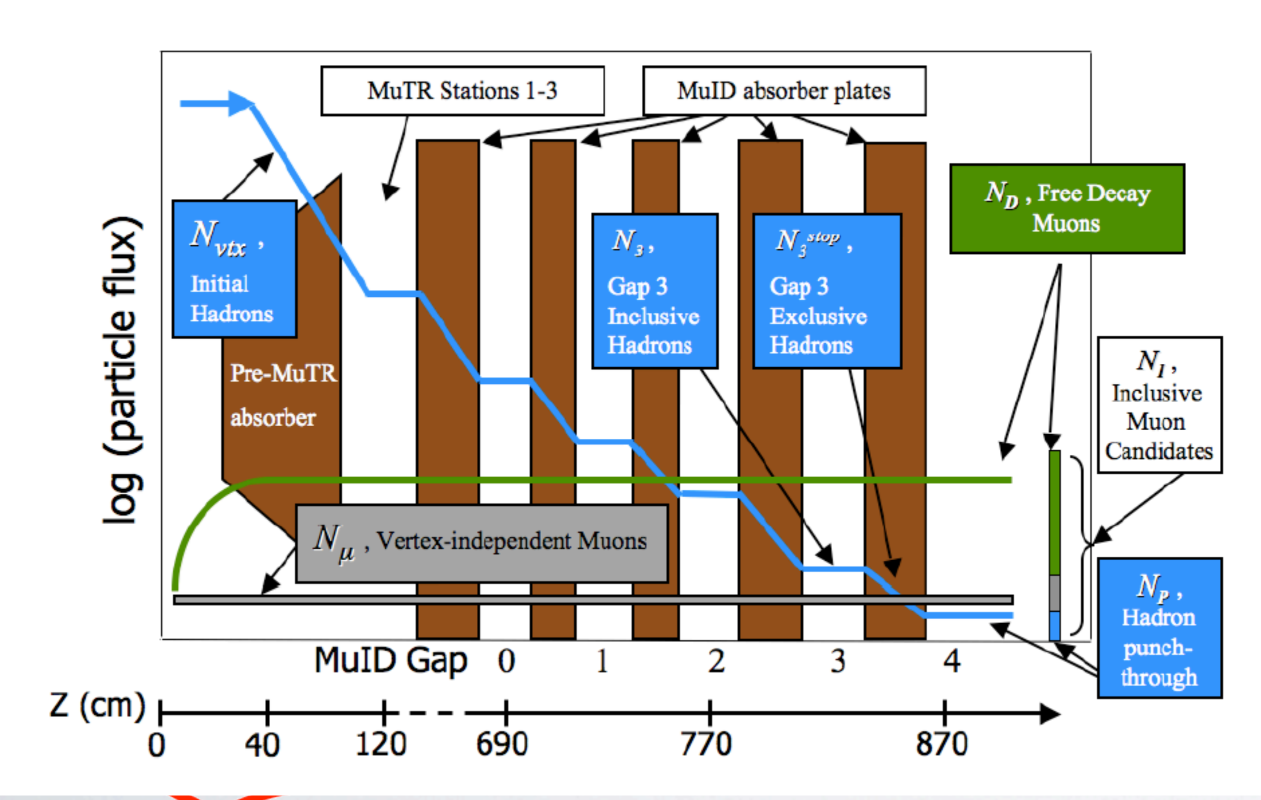
$$N_e^{conv-in} = R_{\gamma} N_e^{\gamma} + (1-\epsilon) N_e^{non-\gamma}$$

μ measurement @ PHENIX muon arm

- kinematic range
  - 1.2 < |η| < 2.2 at forward
  - Δφ = 2π

  - ~10λ absorber to reject hadrons
  - Muon Tracker for momentum
  - Muon identifier for hadron/muon separation



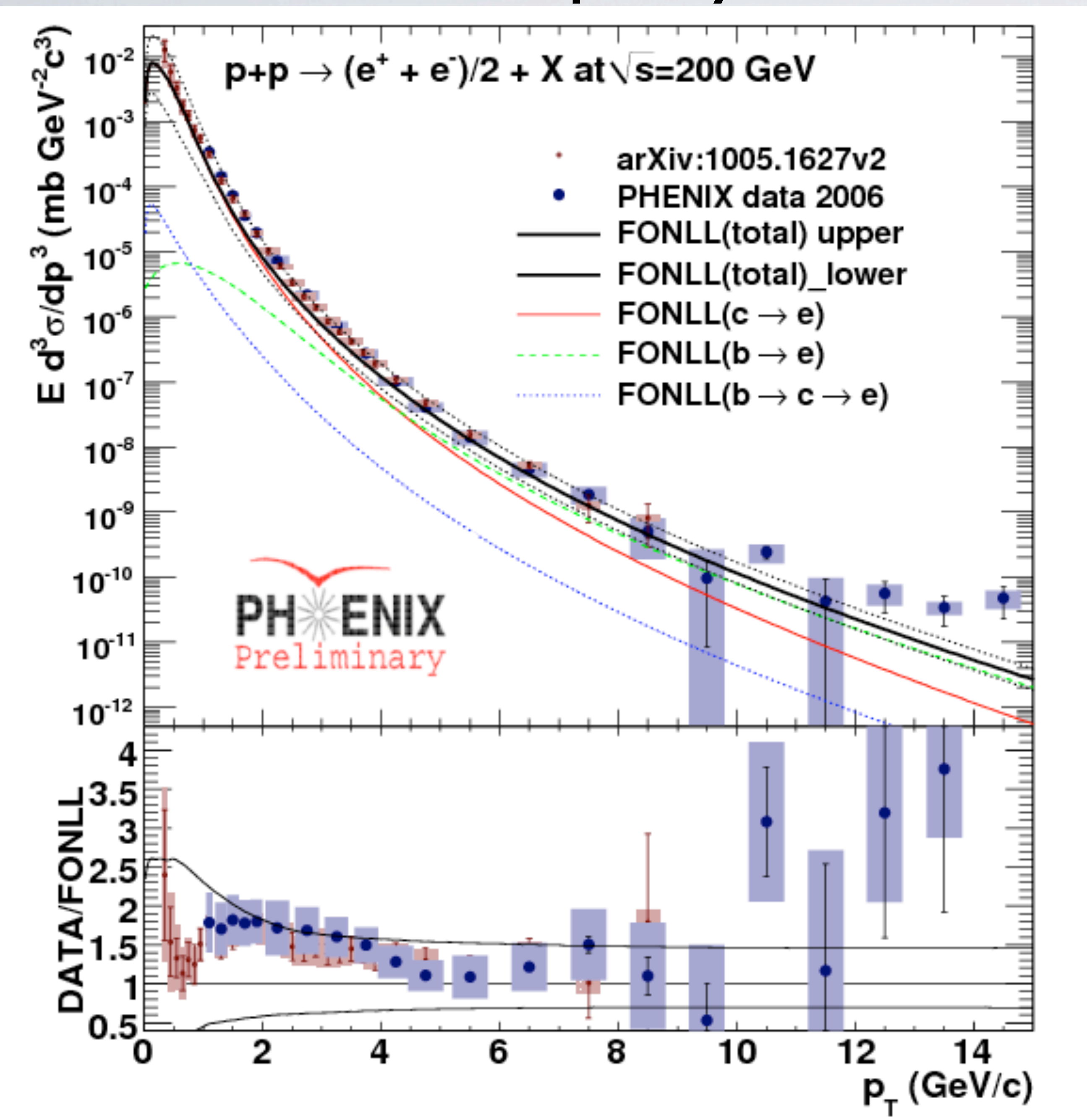


- Main background sources are decay muons from light hadrons and punch-through hadrons.

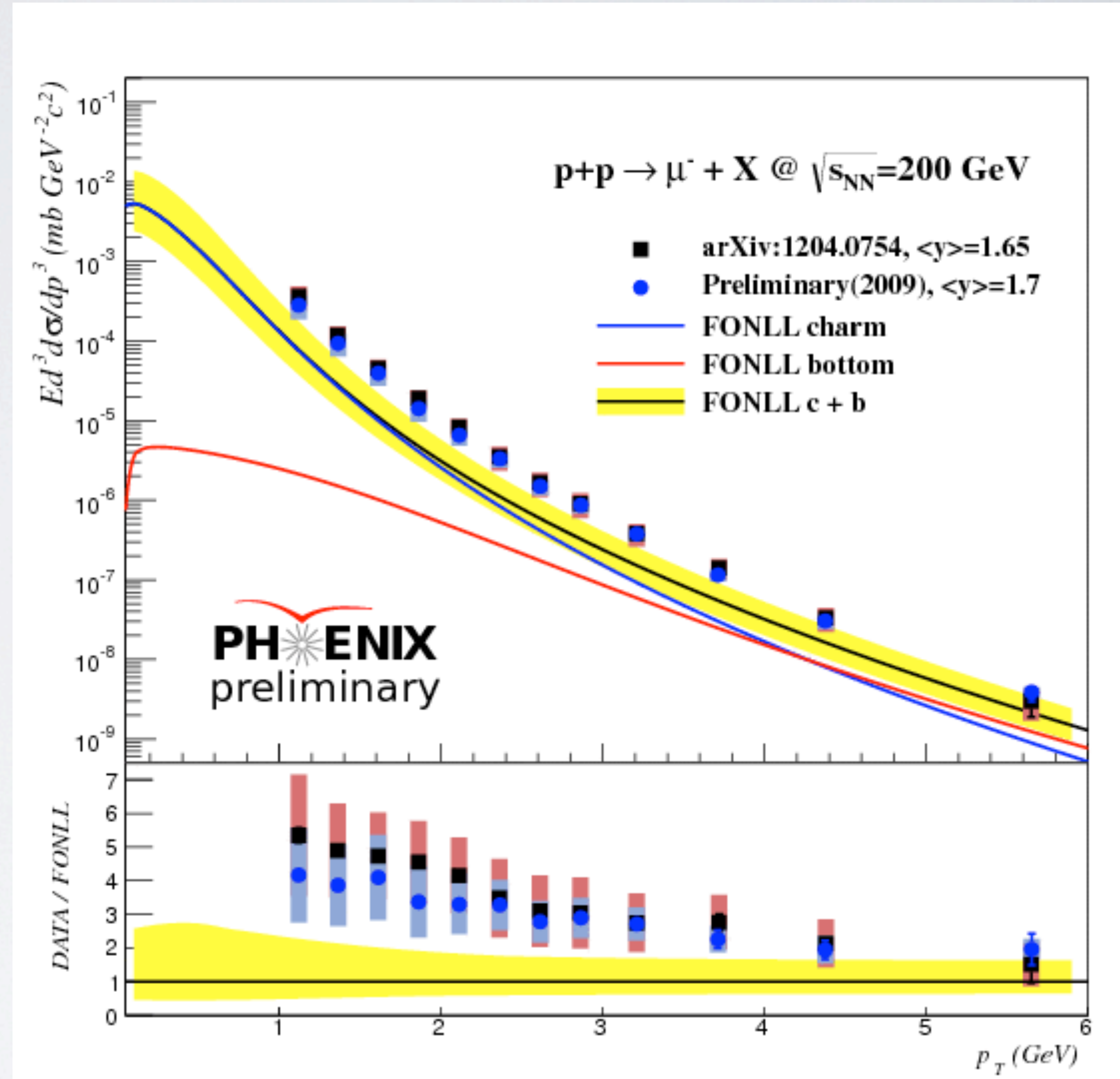
- Full MC simulation of hadron cocktail(π, K, p)
  - Tune to data by using z-vertex dependence of decay muons at MuID Gap 4 and yields of stopped hadrons at MuID Gap 2 and 3

Heavy flavor in p+p collisions

mid-rapidity



forward rapidity



- Extend kinematic range and reduce uncertainties with enhanced statistics and improved analysis techniques

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Quantifying medium effects

- Nuclear modification factor
  - $R_{AA} = 1$: No overall modification
  - $R_{AA} < 1$: Suppression
  - $R_{AA} > 1$: Enhancement

$$R_{AA} = \frac{dN_{AA}}{\langle N_{coll} \rangle \times dN_{pp}}$$

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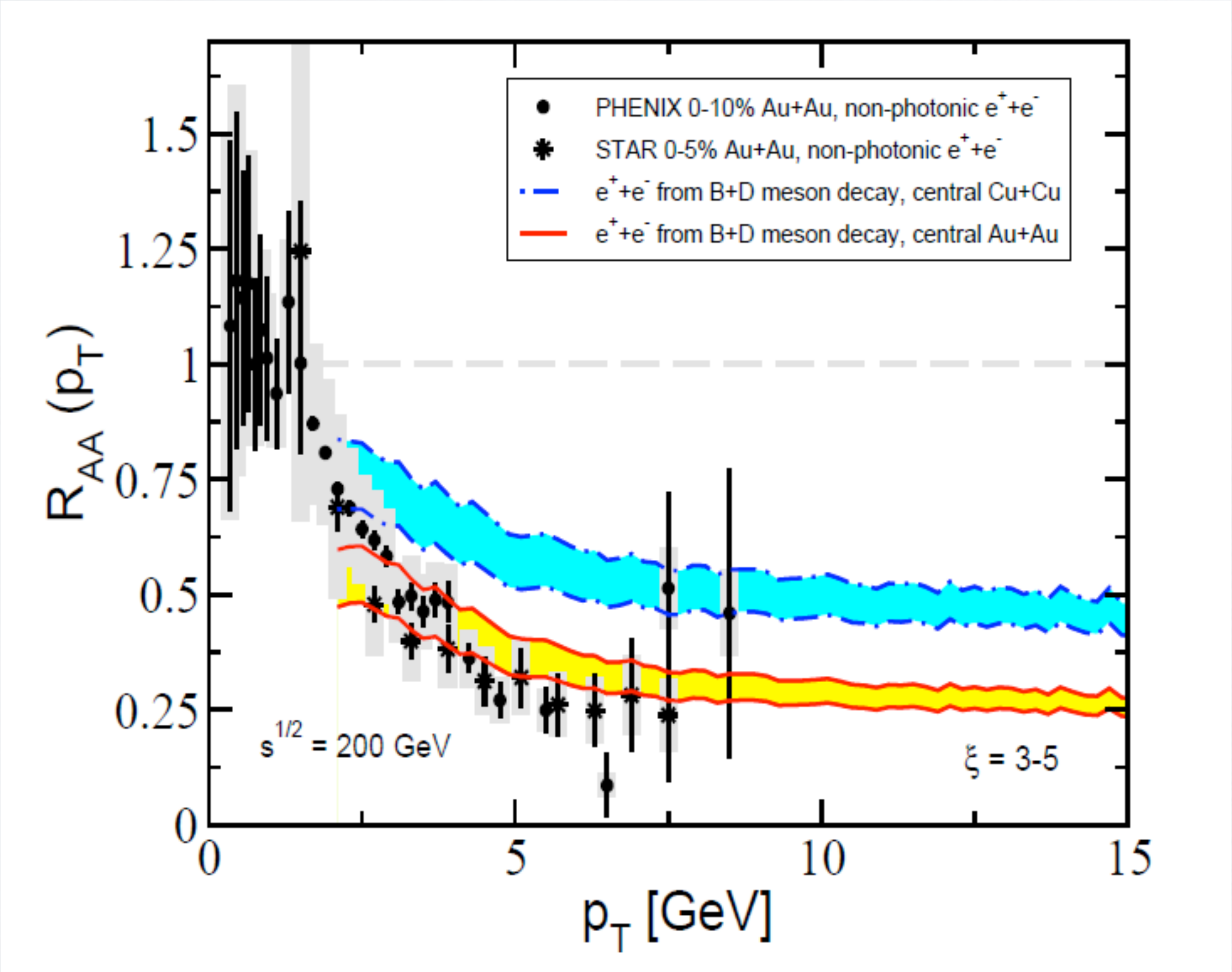
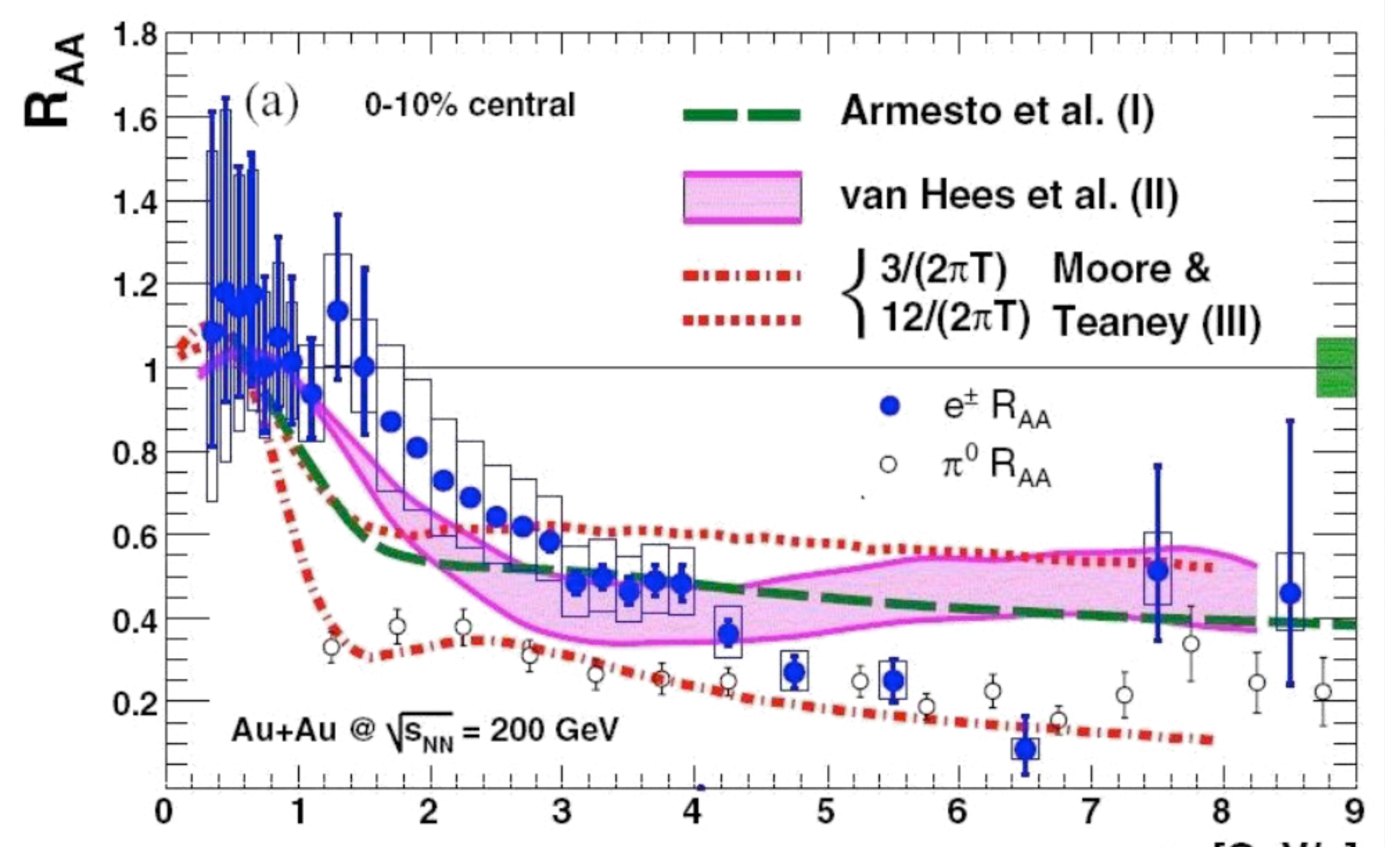


Phys. Rev. C 80, 054902 (2009)

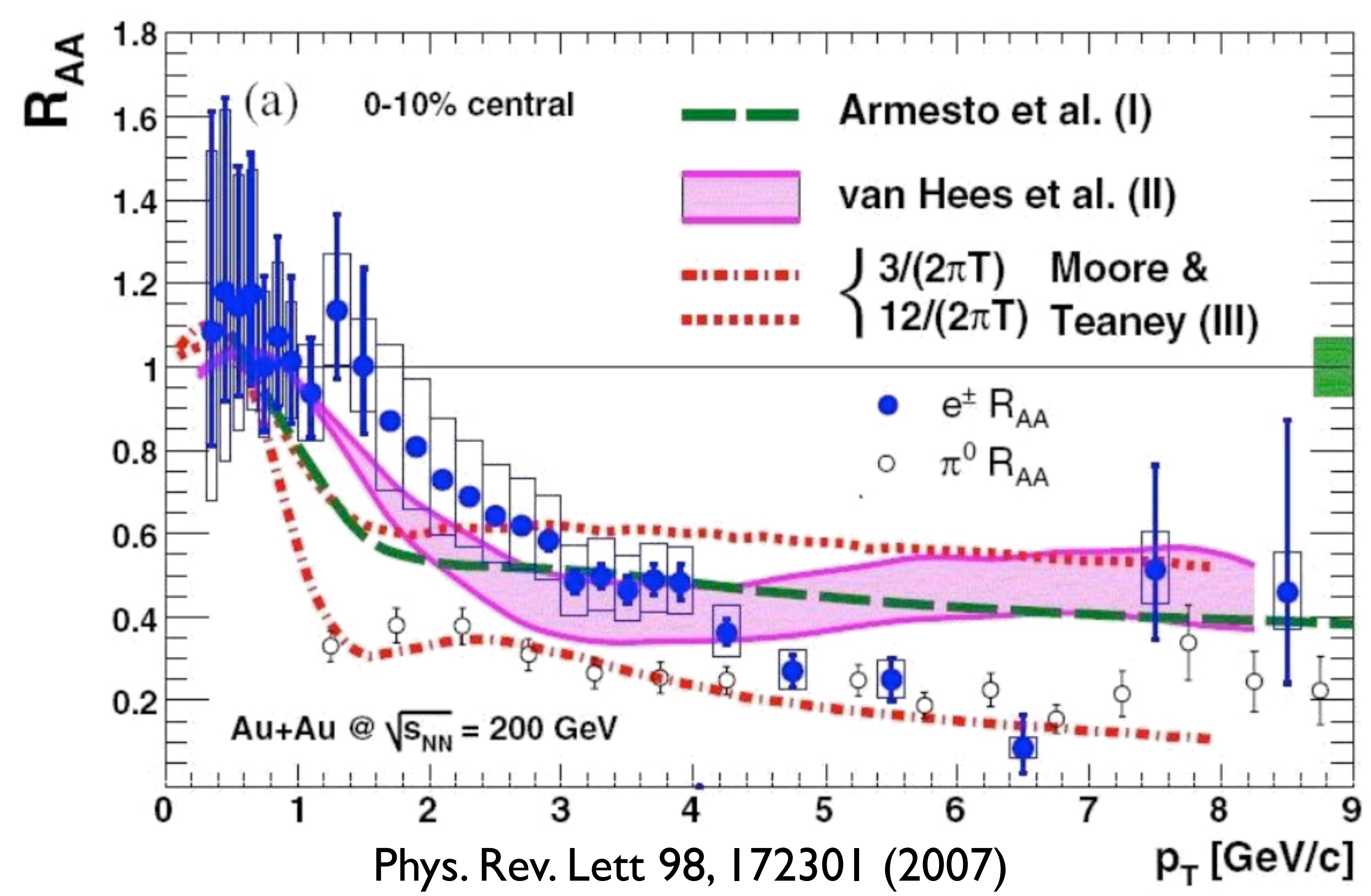
- Theoretical model (Sharma, Vitev and Zhang)
  - radiative energy loss not enough to describe large suppression
  - includes partonic energy loss and collisional dissociation
  - CNM effects such as shadowing, Cronin effect and initial energy loss

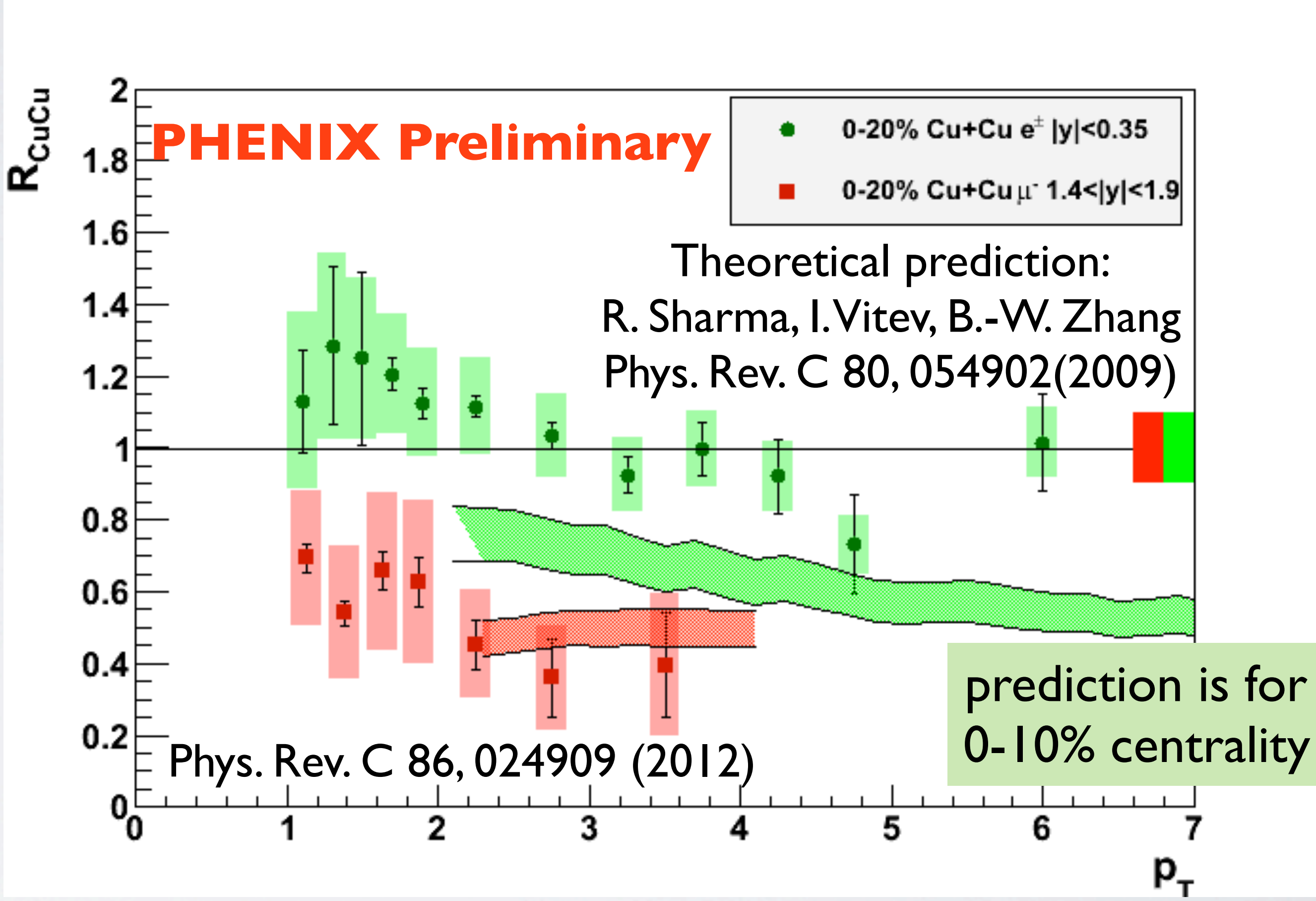


Phys. Rev. Lett 98, 172301 (2007)

- Large suppression in central Au+Au collisions at mid-rapidity

Heavy flavor in HI collisions

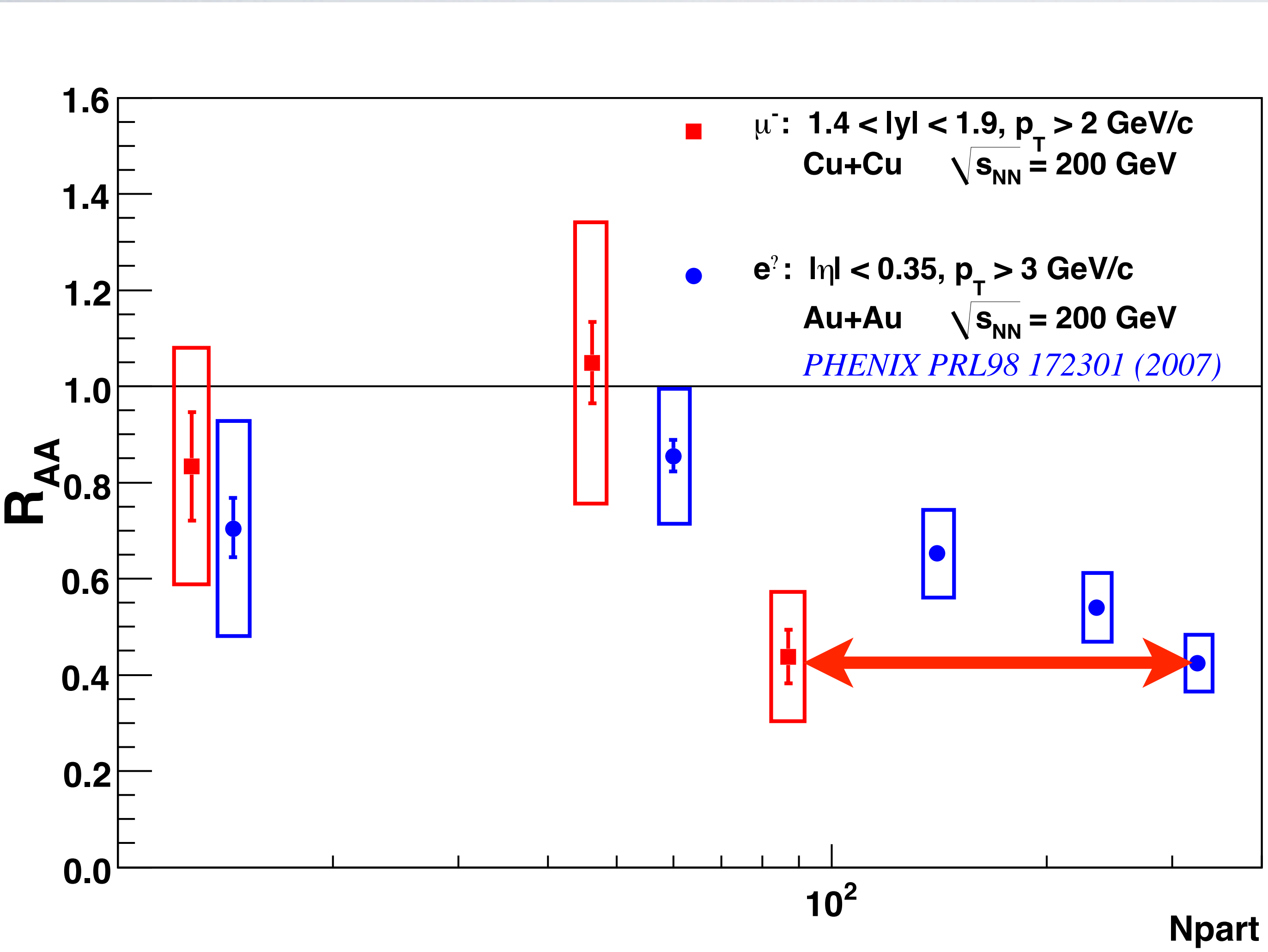


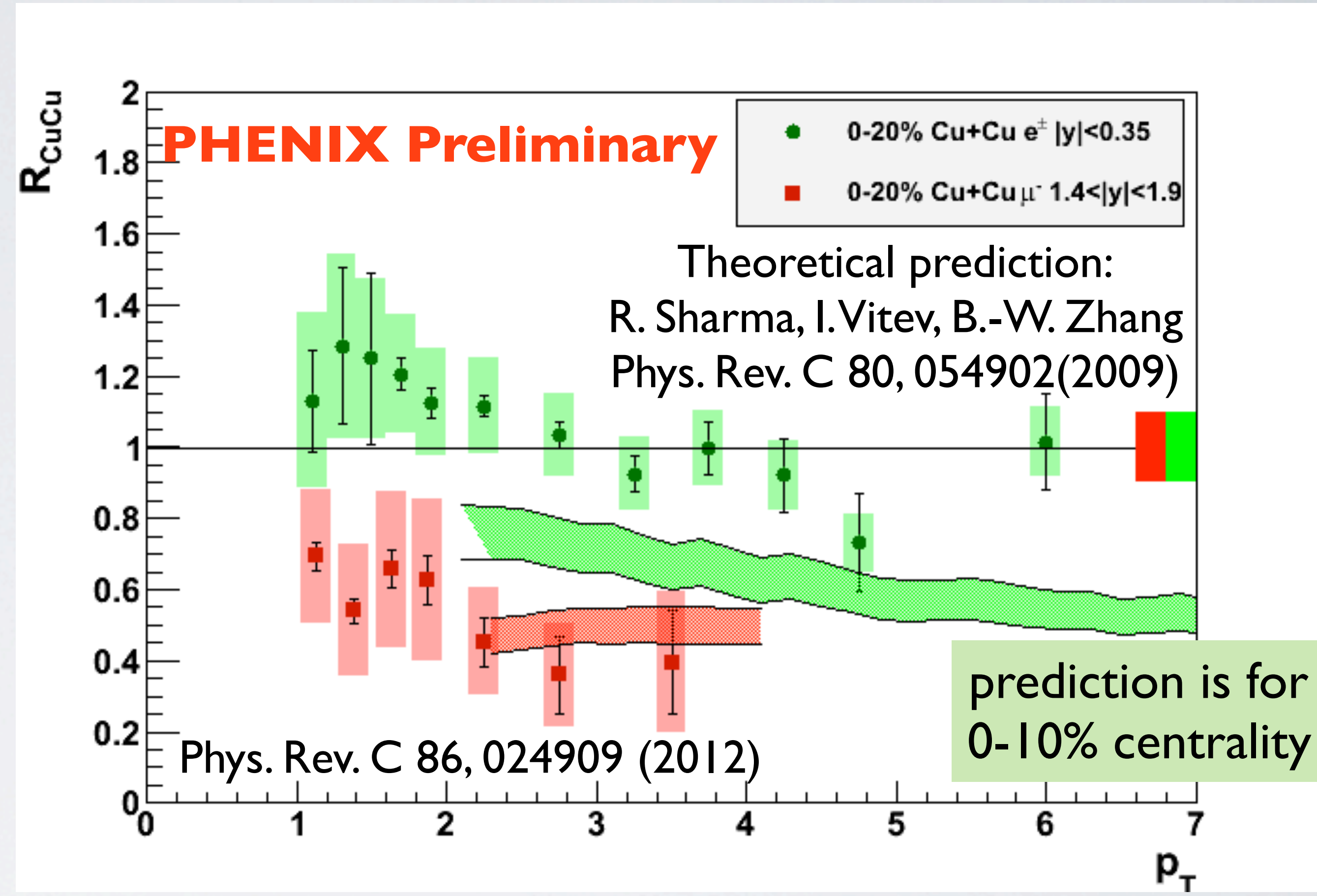


- Large suppression in central Au+Au collisions at mid-rapidity

- The most central (0-20%) Cu+Cu collisions
  - not much suppression at mid, but large suppression at forward
  - well describe suppression at forward rapidity with additional CNM effects (shadowing, initial energy loss)

Heavy flavor in HI collisions





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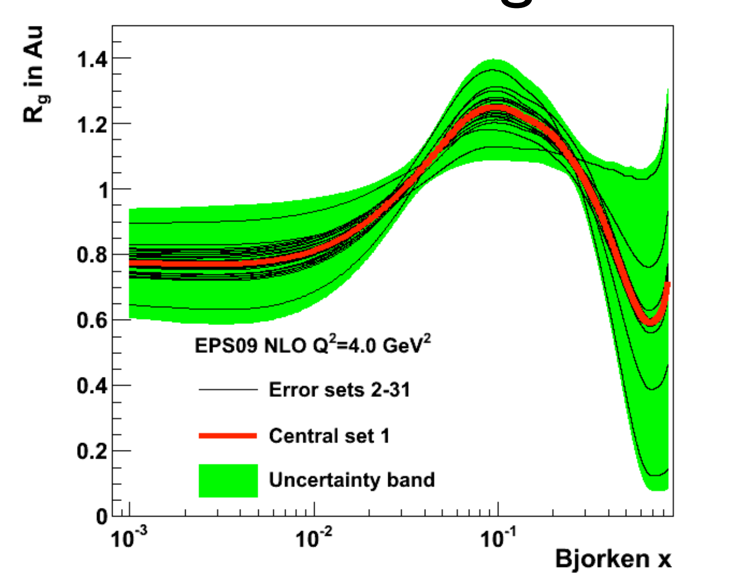
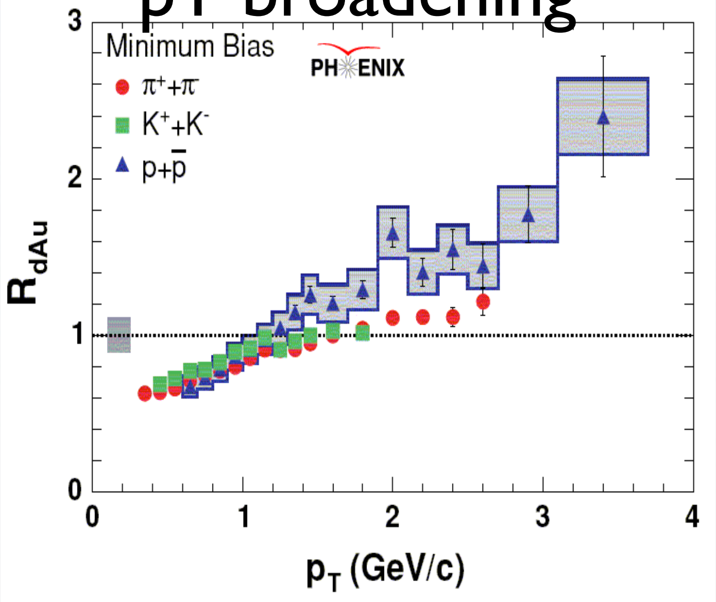
Cold Nuclear Matter in d+Au collisions

- d+Au collision as a control experiment
  - In heavy ion collision, CNM & HNM effects are mixed
  - baseline measurements with minimal hot nuclear medium

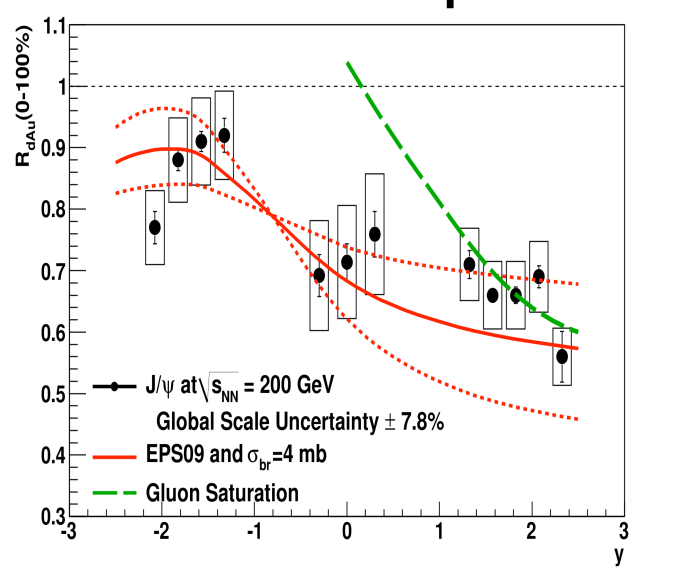
Shadowing



pT broadening



Break up



Cold Nuclear Matter in d+Au collisions

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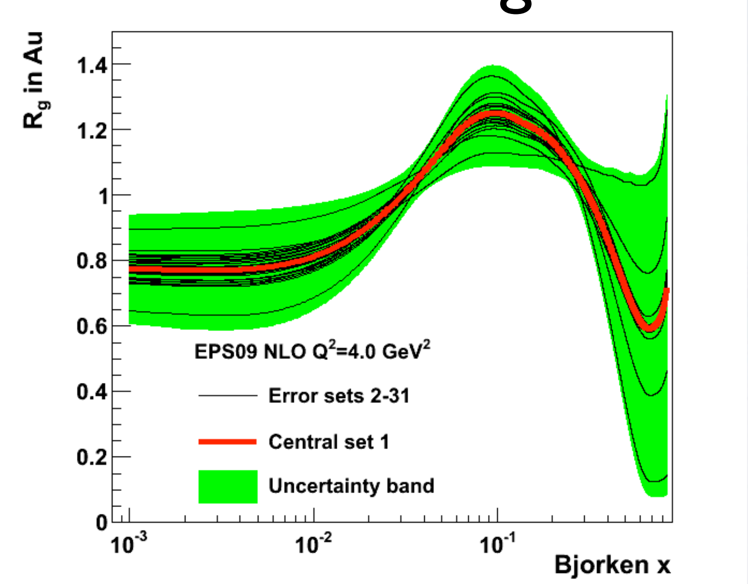

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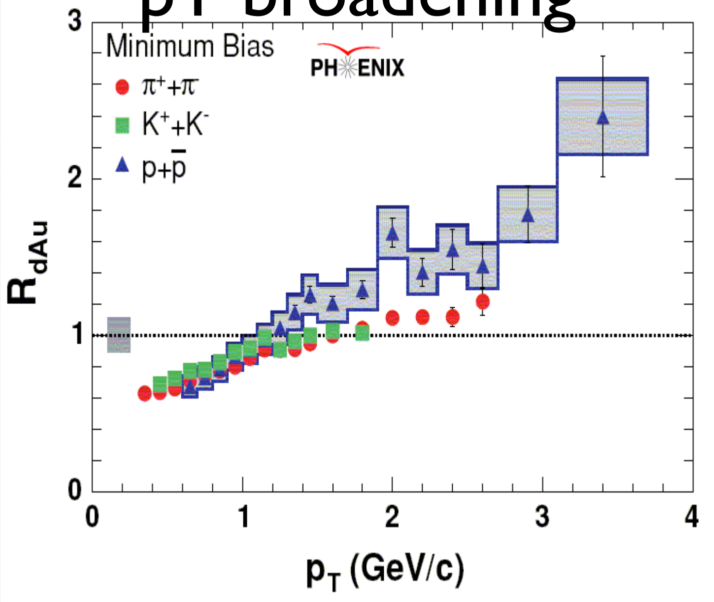

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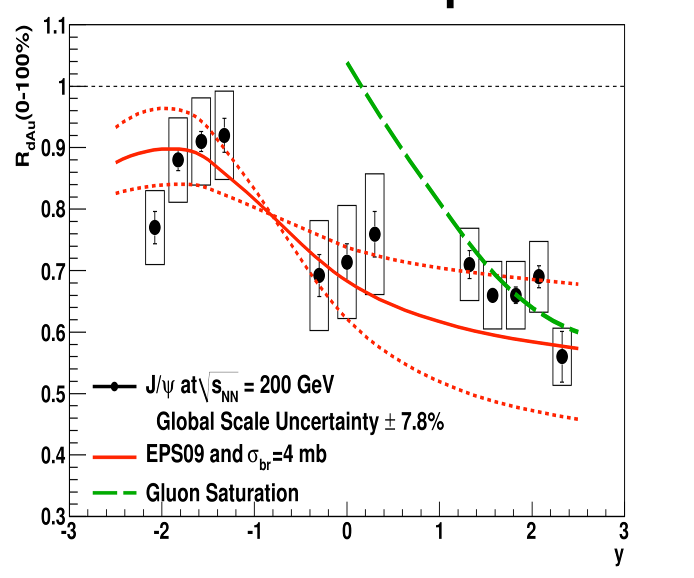
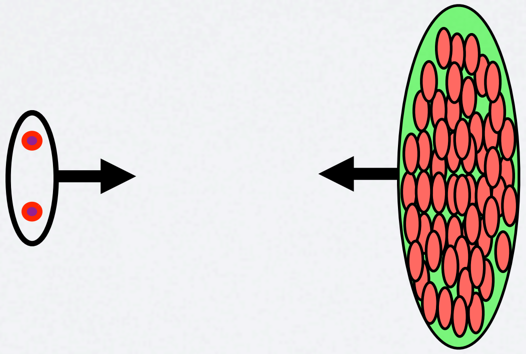


Backward rapidity
*Au-going side
*$x_1 < x_2$



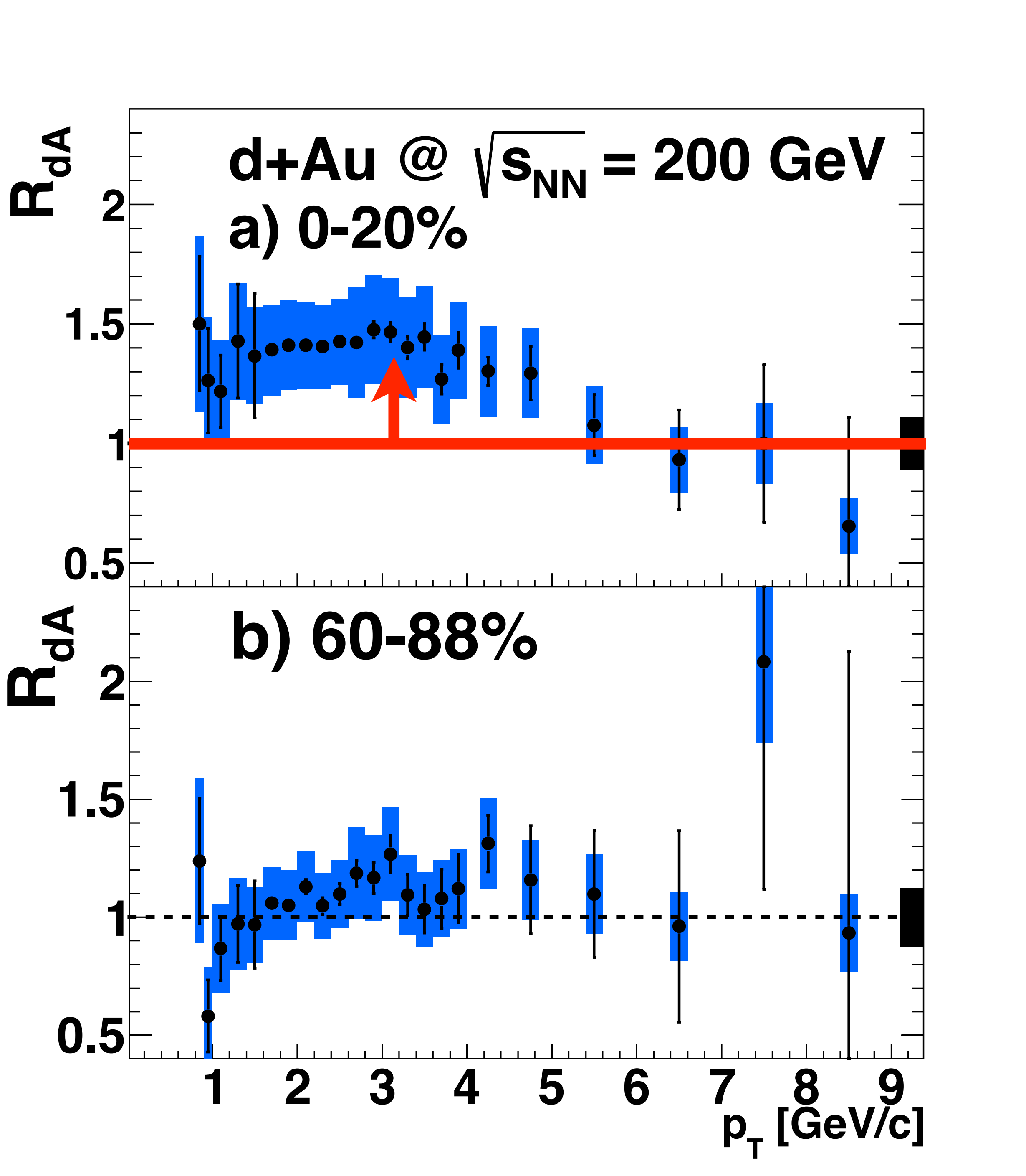
parton of x_1 in d

parton of x_2 in Au

Forward rapidity
*d-going side
*$x_1 > x_2$

$$x_2 = \frac{Q}{\sqrt{s_{NN}}} e^{-y}$$

HF electrons @ mid-rapidity



Phys. Rev. Lett. 109, 242301 (2012)

- R_{dA} ~ 1 in the peripheral collisions
- Large enhancement in the central collision

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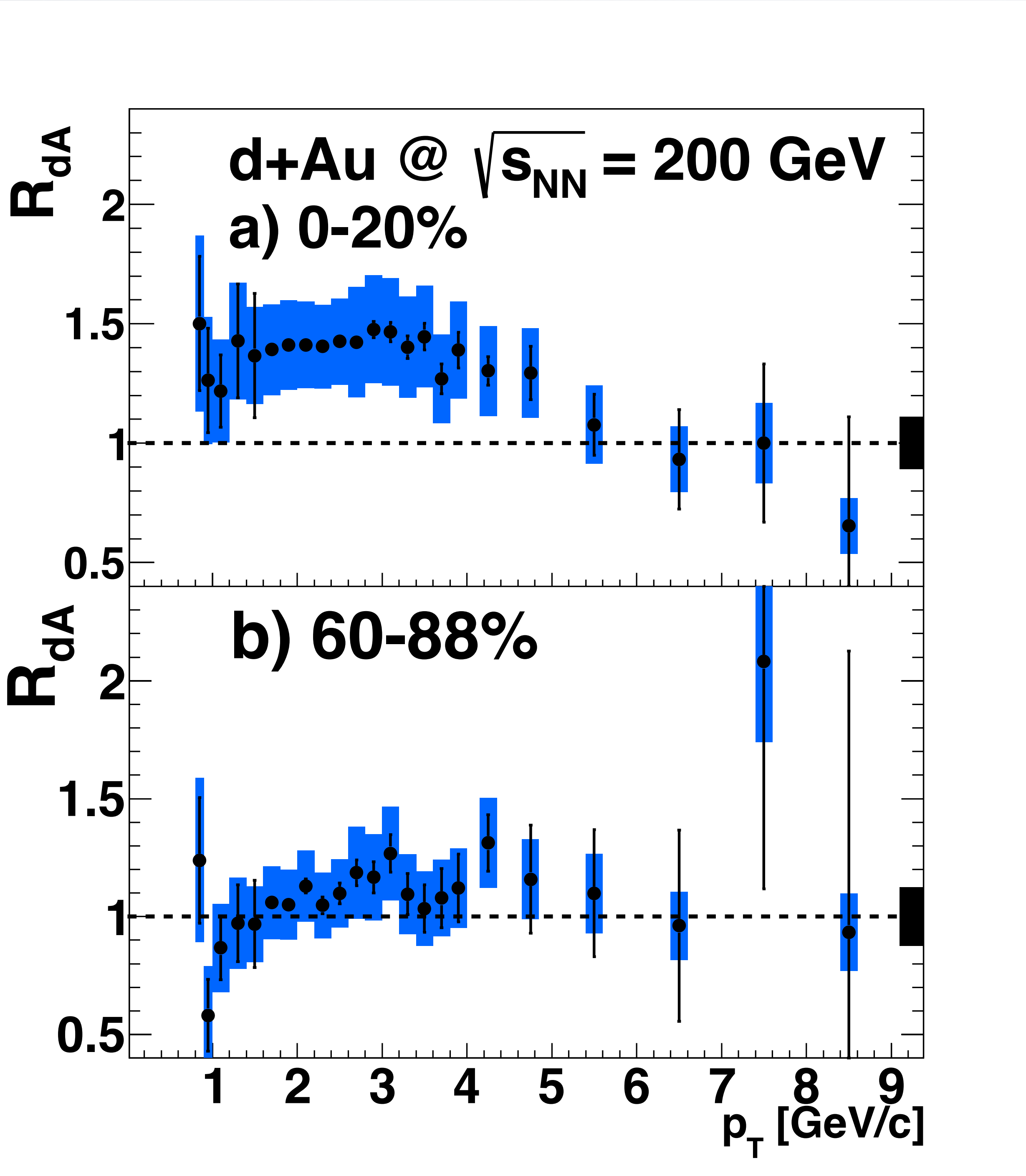
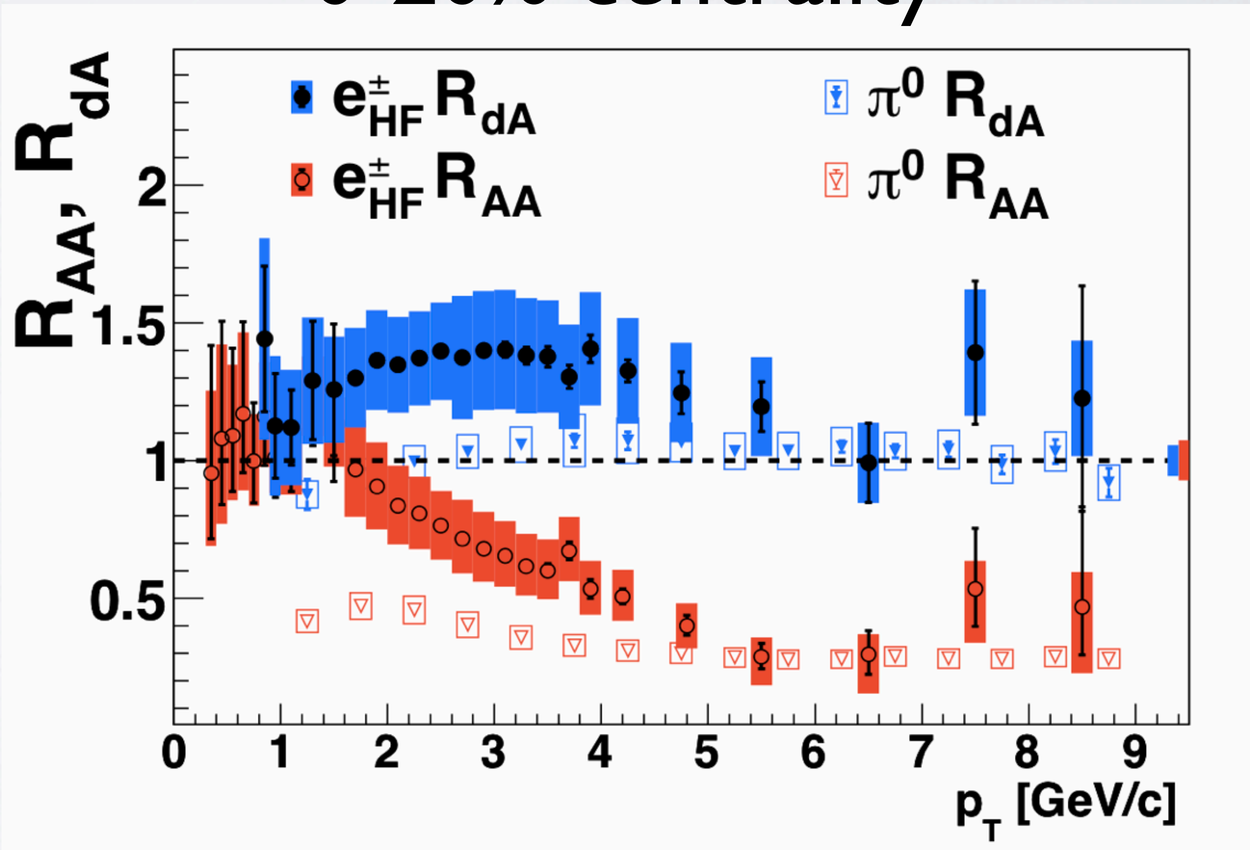


Phys. Rev. Lett. 109, 242301 (2012)

- R_{dA} ~ 1 in the peripheral collisions
- Large enhancement in the central collision
  - HF R_{dA} is larger than π^0 R_{dA}
  - HF suppression in Au+Au is due to the HNM effects

0-20% centrality



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HF electrons @ mid-rapidity

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- Large enhancement in the central collision

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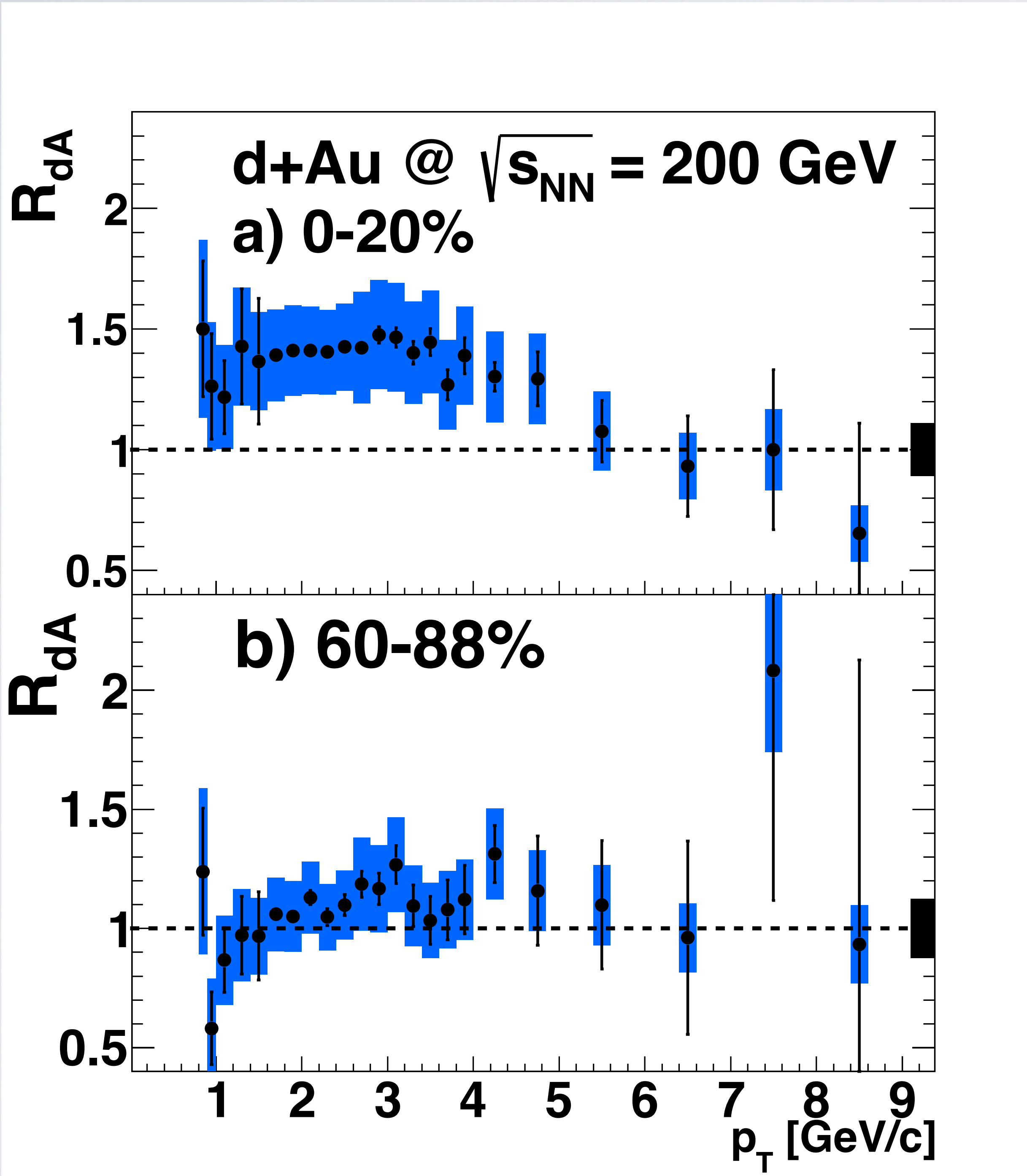
ALICE preliminary in SQM 13'



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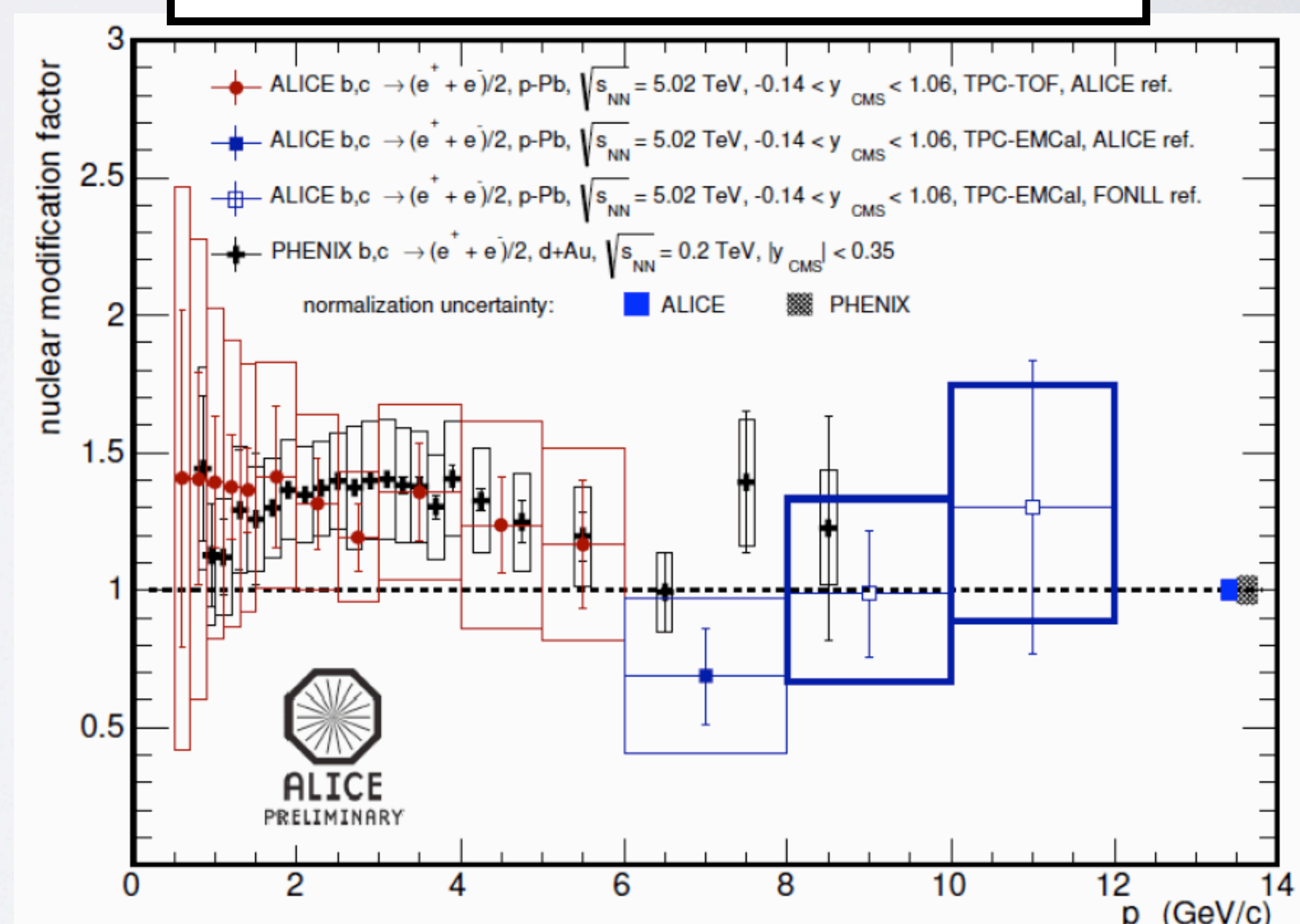
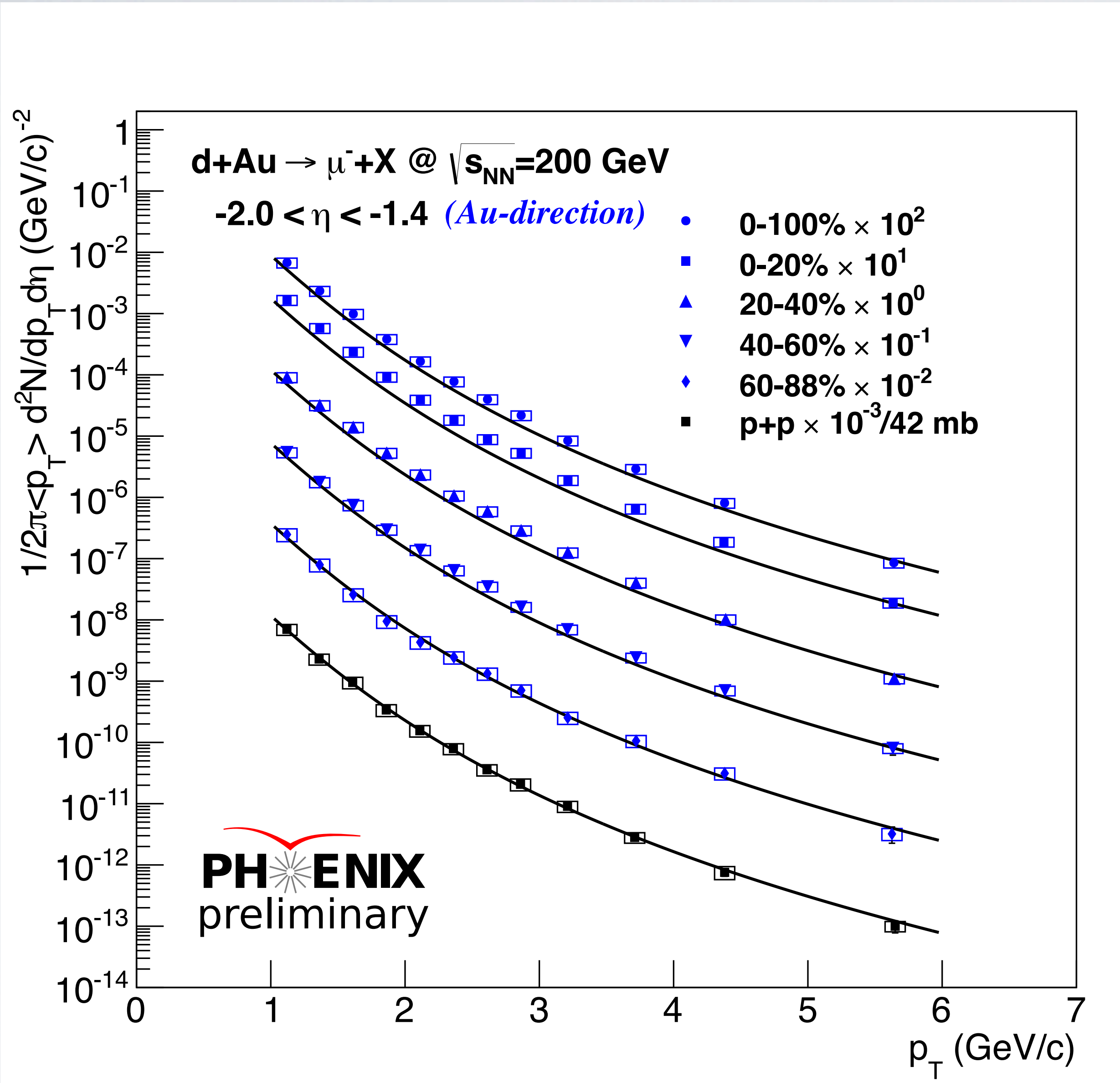
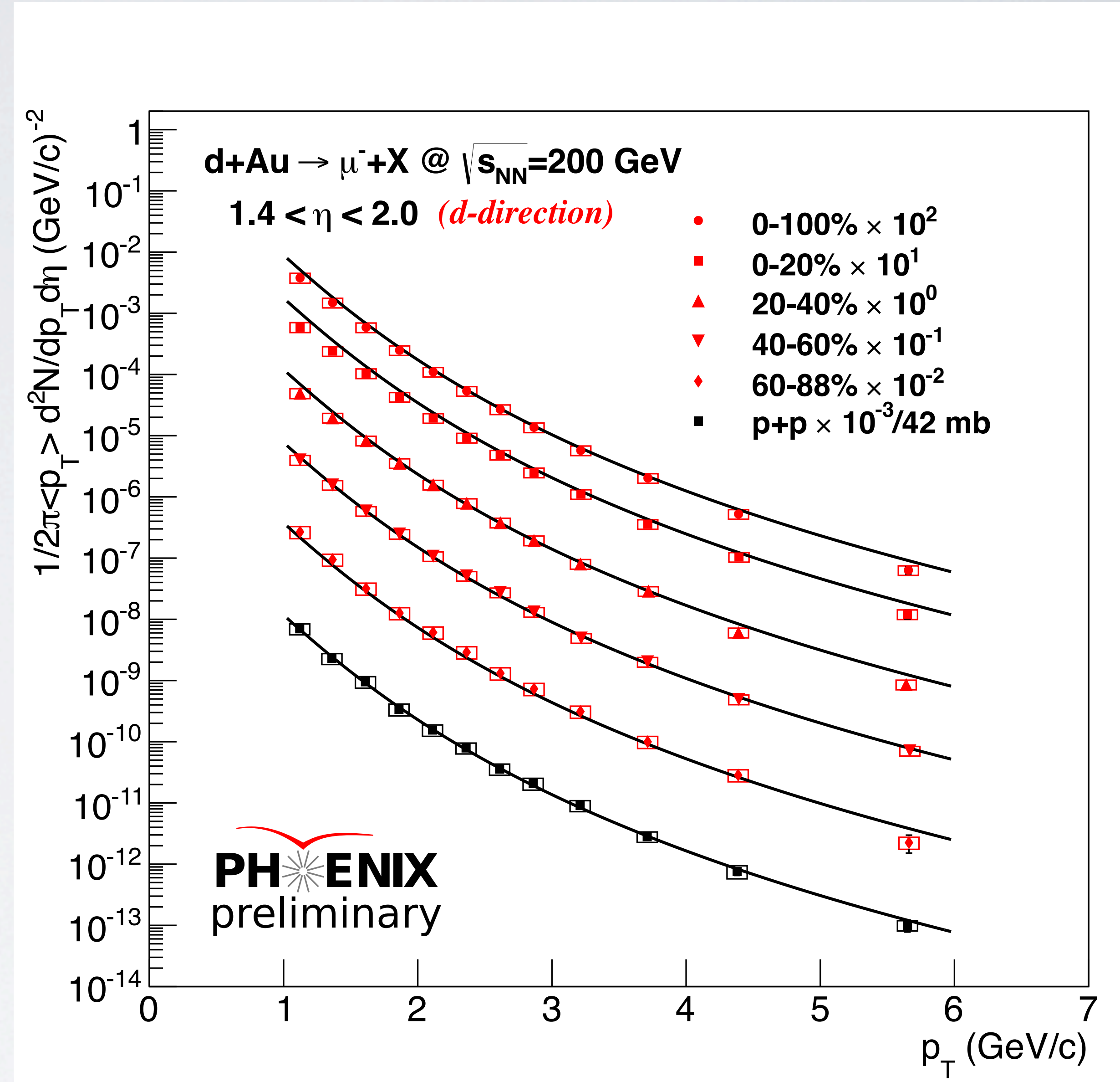


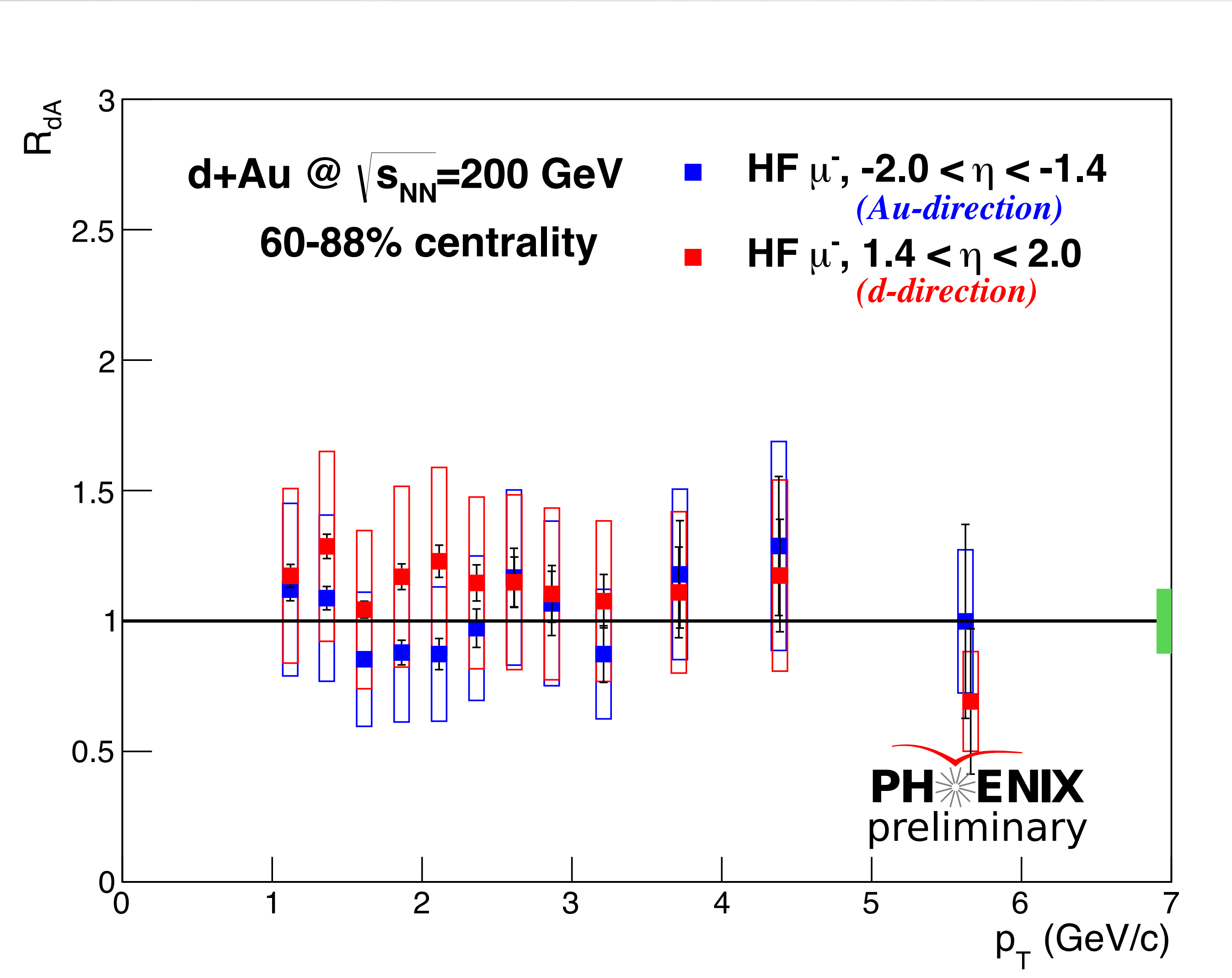
HF muons @ forward & backward rapidity





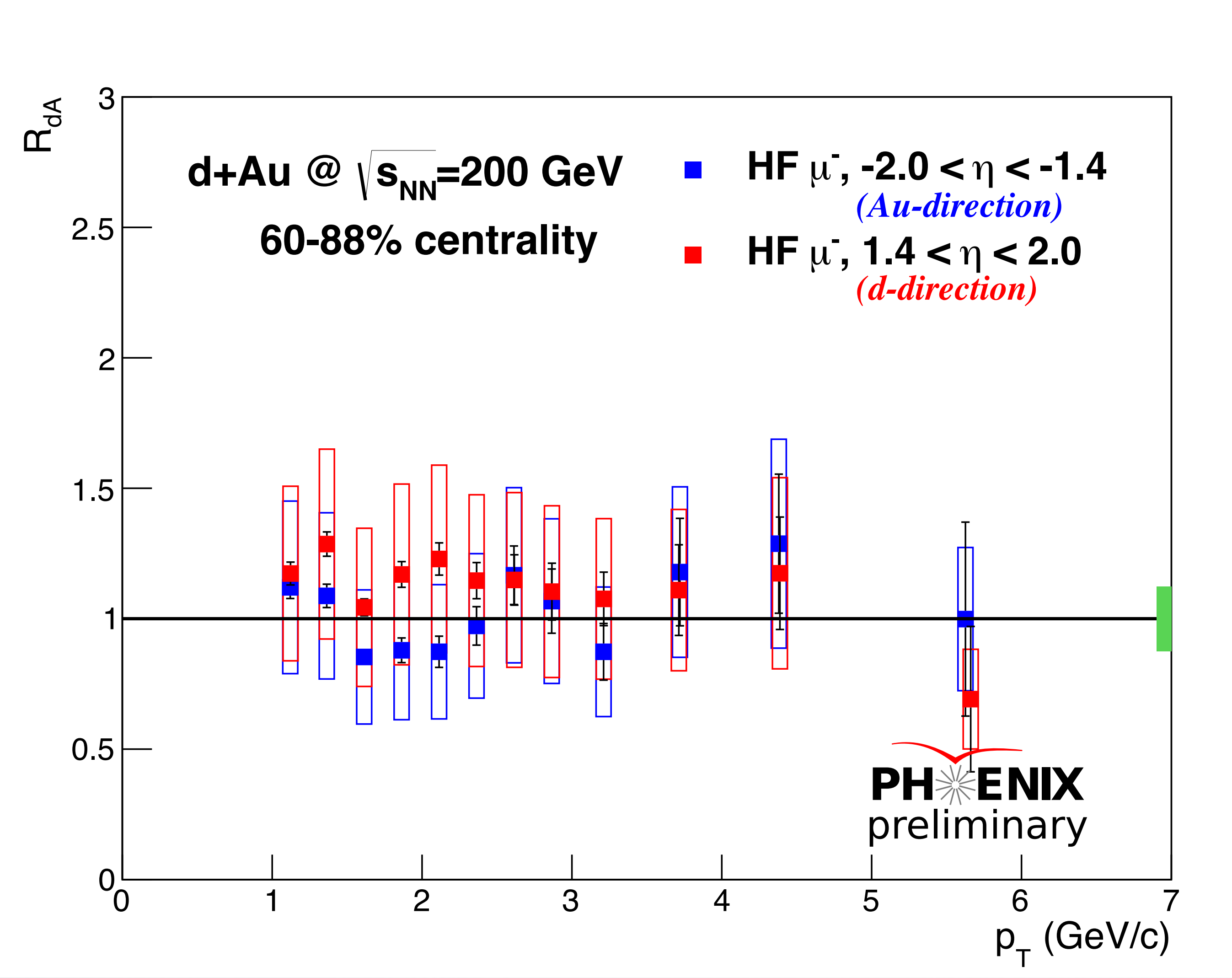
- HF single muons p_T spectra at **backward(Au-direction, left)** and at **forward(d-direction, right)** in d+Au collisions
  - lines are $\langle T_{AB} \rangle$ scaled fit function of spectra in p+p collisions

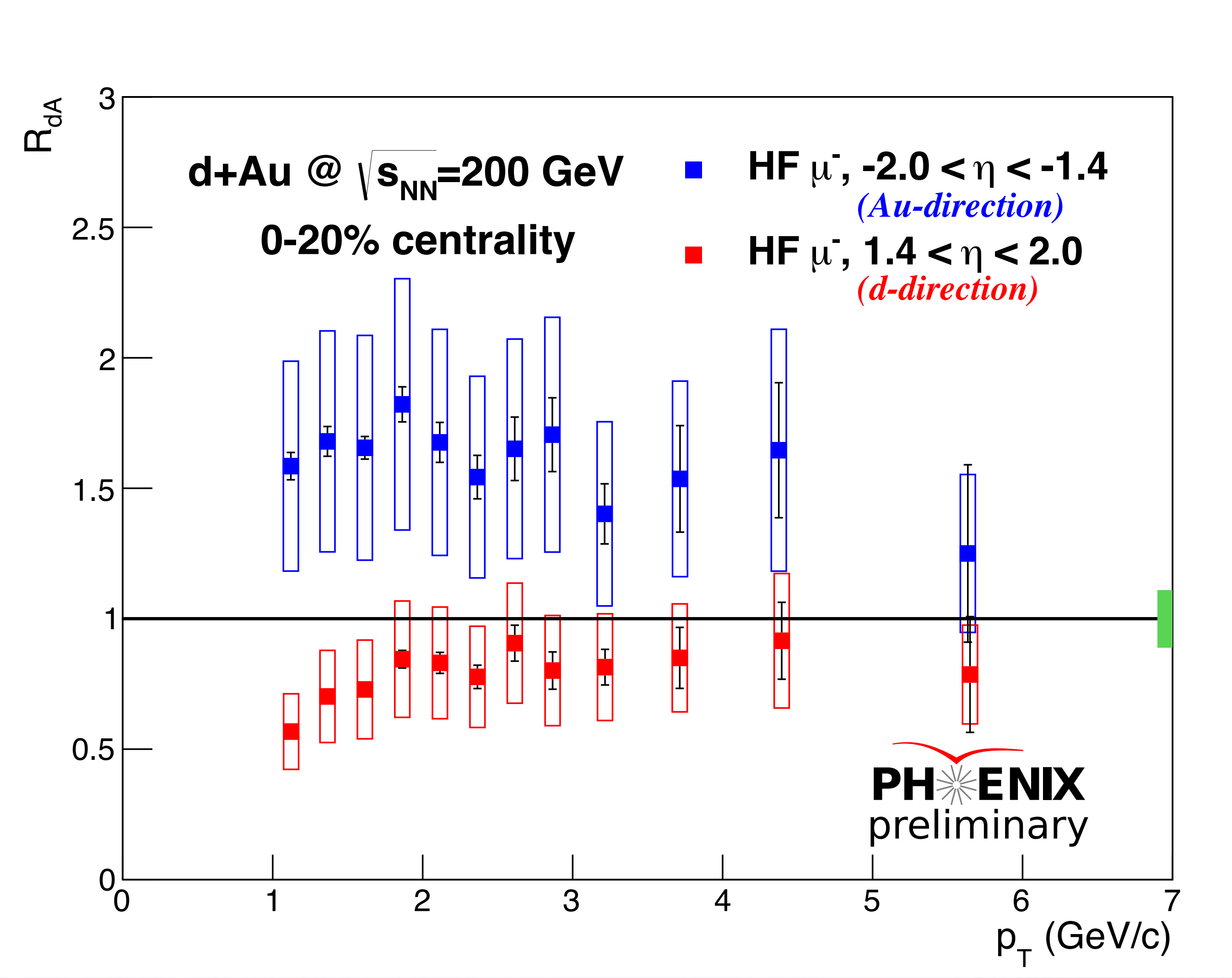
HF muons R_{dA}, peripheral (60-88%)



- No modification at both rapidity ranges in most peripheral collisions

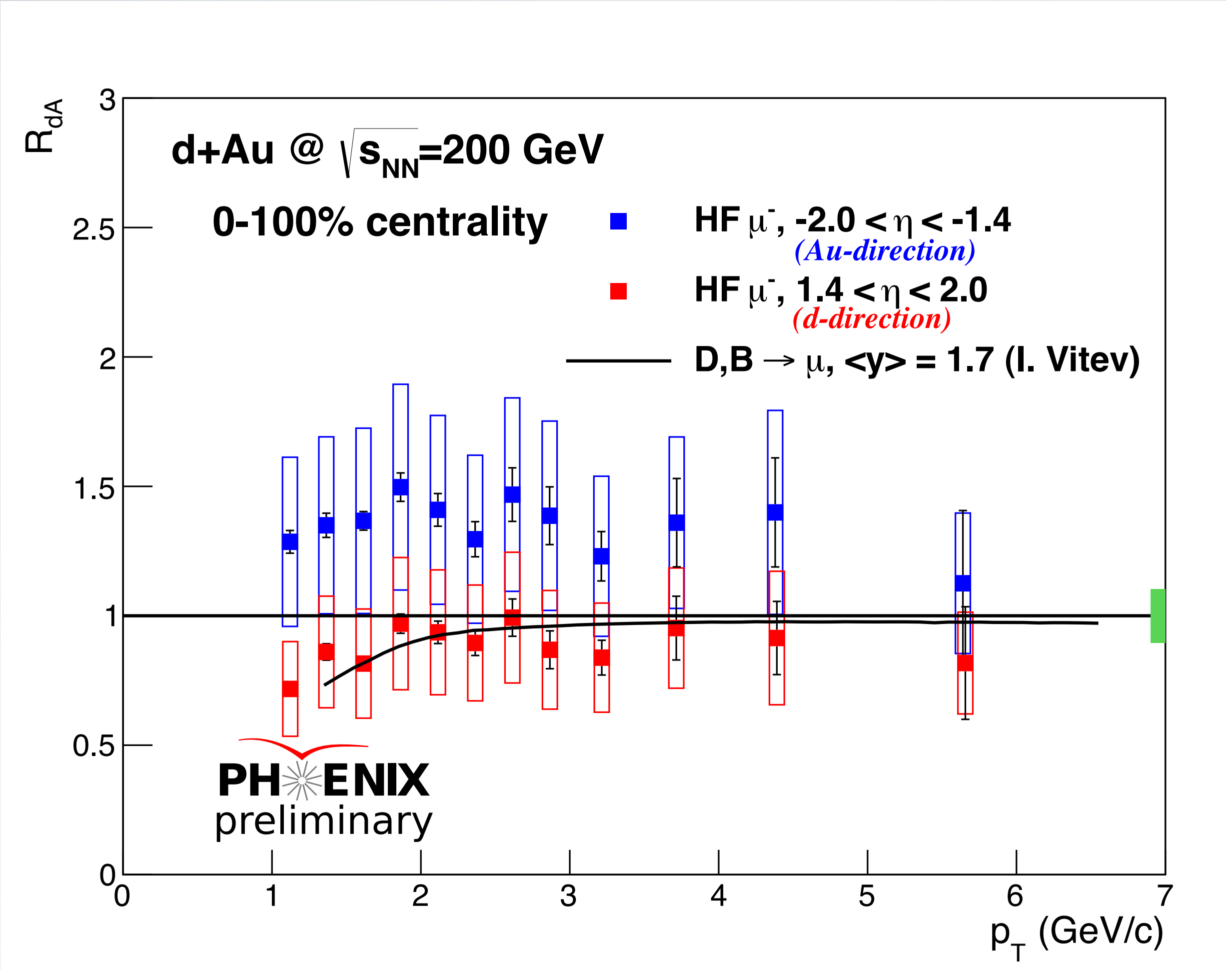
HF muons R_{dA}, peripheral (60-88%) vs. central (0-20%)





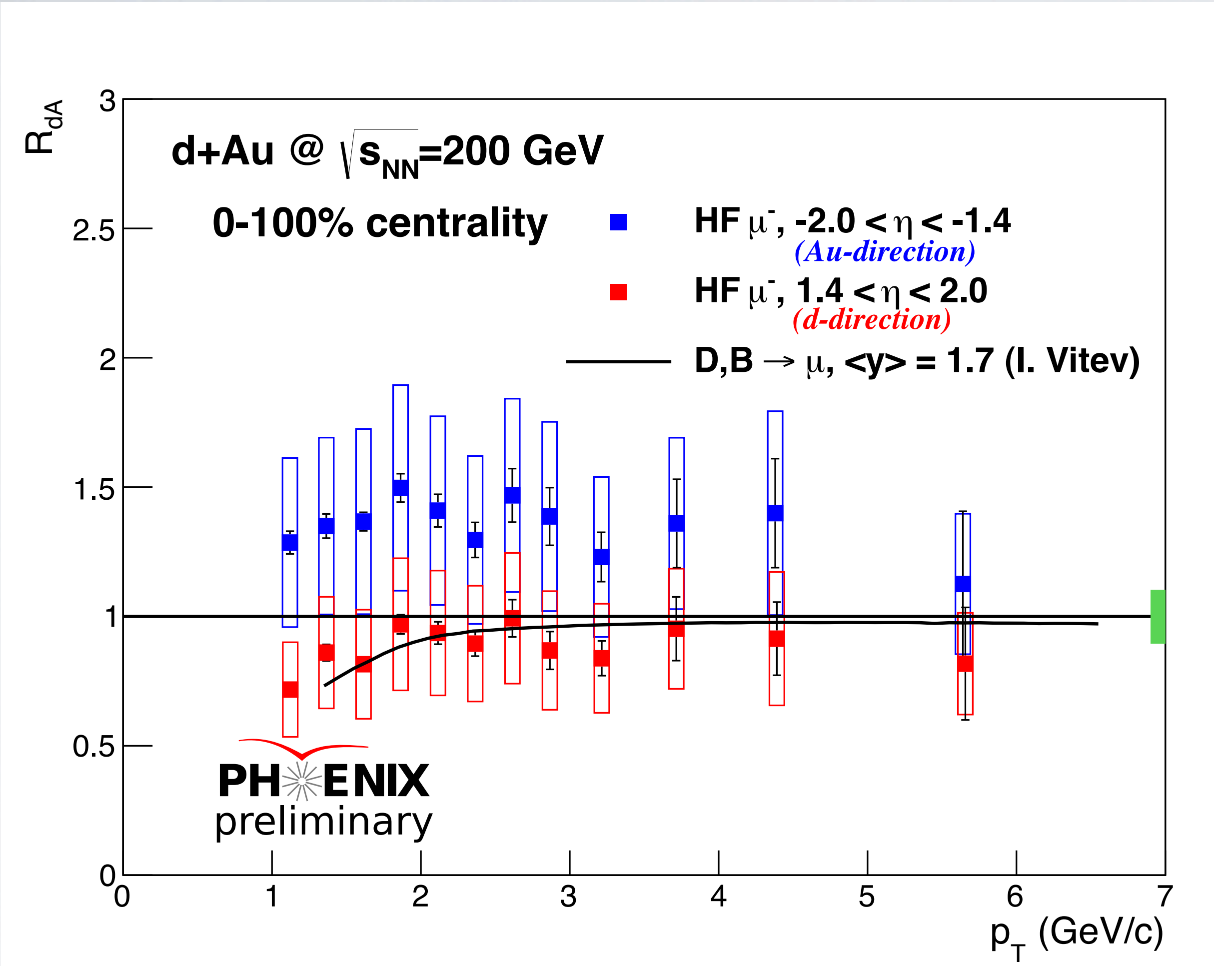
- No modification at both rapidity ranges in most peripheral collisions
- **Enhancement at backward** rapidity and **suppression at forward rapidity** in most central collisions
  - Strong CNM effects in the most central d+Au collisions!

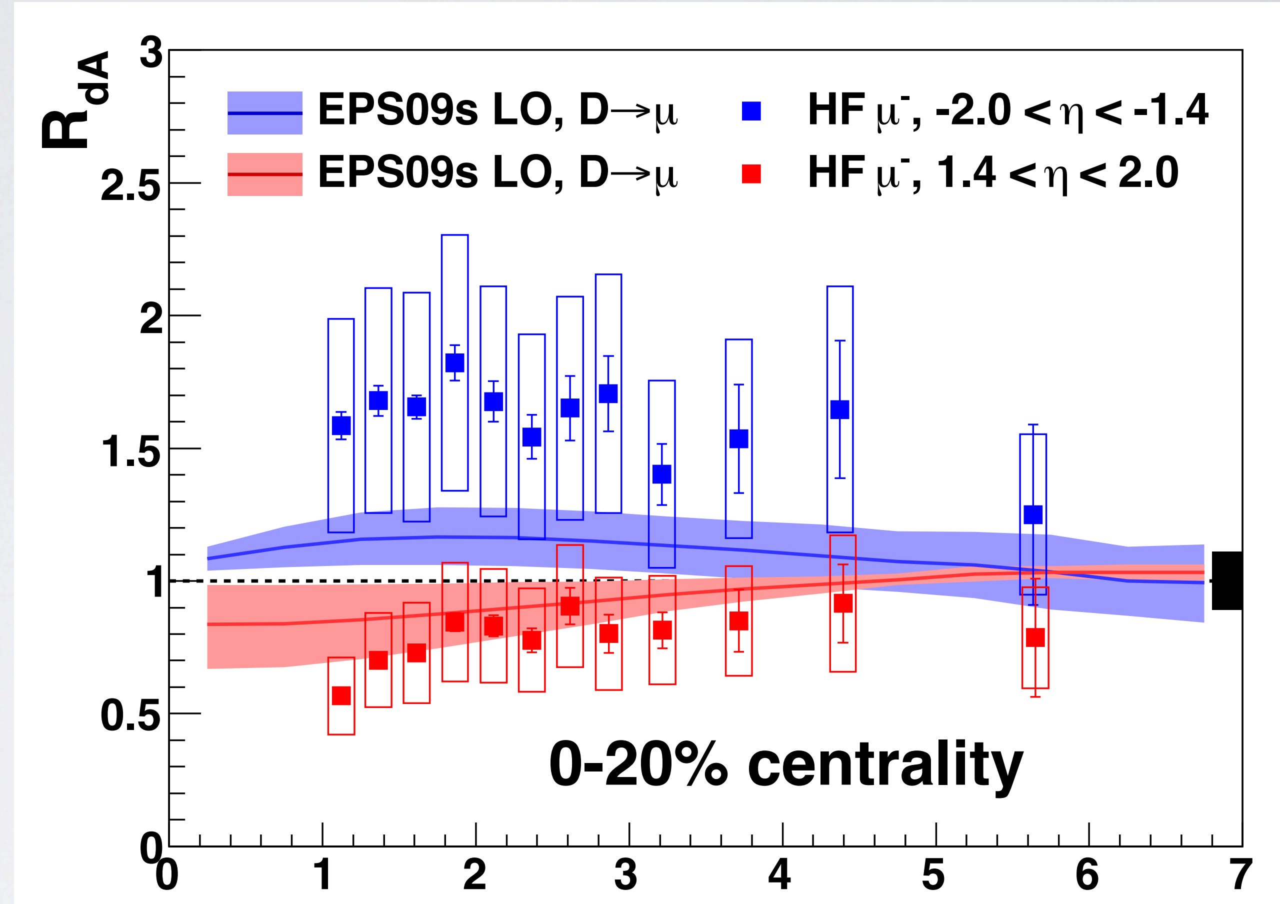
Comparison to models



- good agreement with the prediction from I. Vitev
  - muon production from D and B meson at <y>=1.7
  - considering shadowing, Cronin effect and initial parton energy loss

Comparison to models



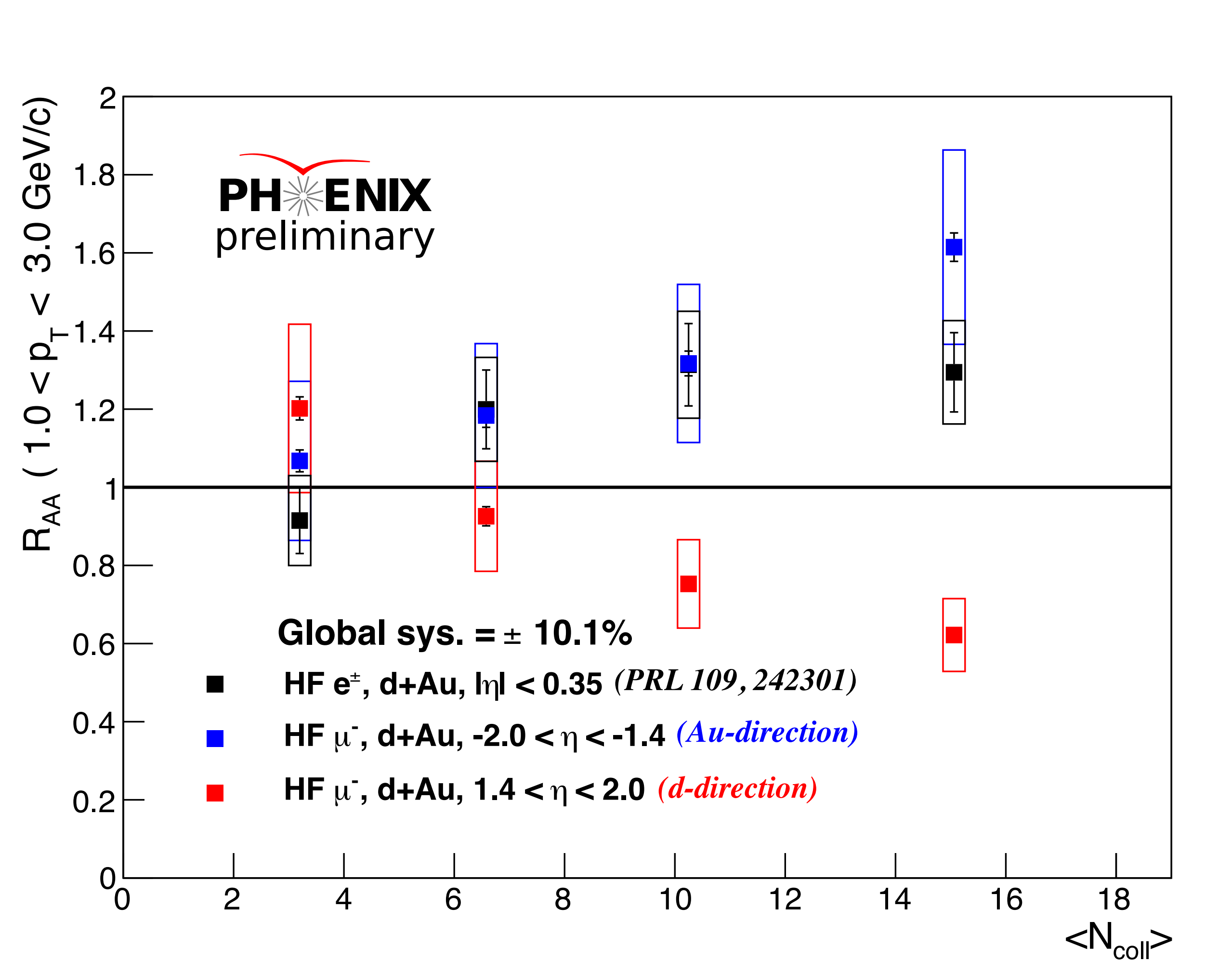


EPS09s : JHEP 1207, 073 (2012)

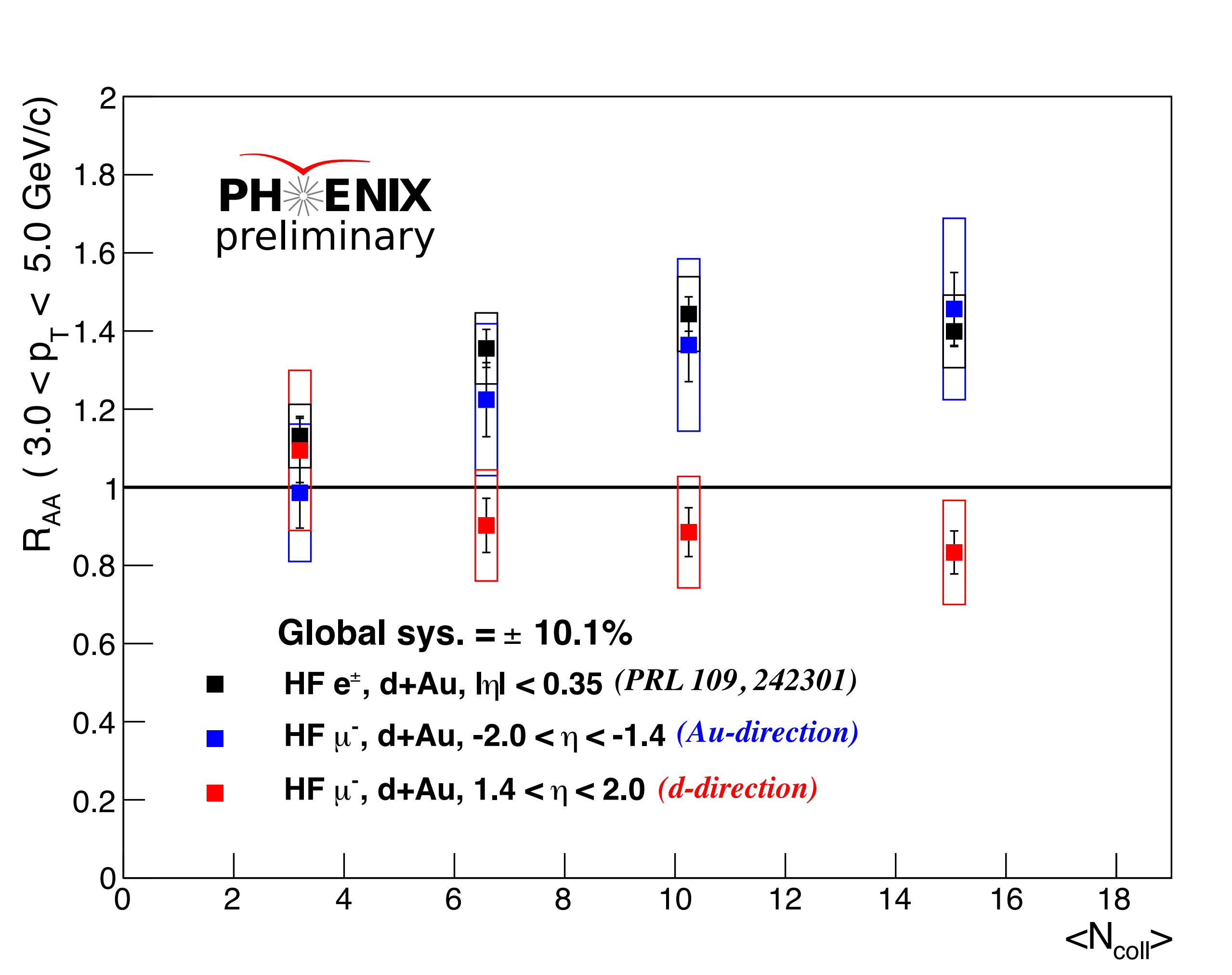
- good agreement with the prediction from I. Vitev
  - muon production from D and B meson at <y>=1.7
  - considering shadowing, Cronin effect and initial parton energy loss
- EPS09s nPDF evaluation with PYTHIA
  - consistent with data at forward rapidity as well

Rapidity evolution of R_{dA} vs. N_{coll}

$1.0 < p_T < 3.0$ GeV/c

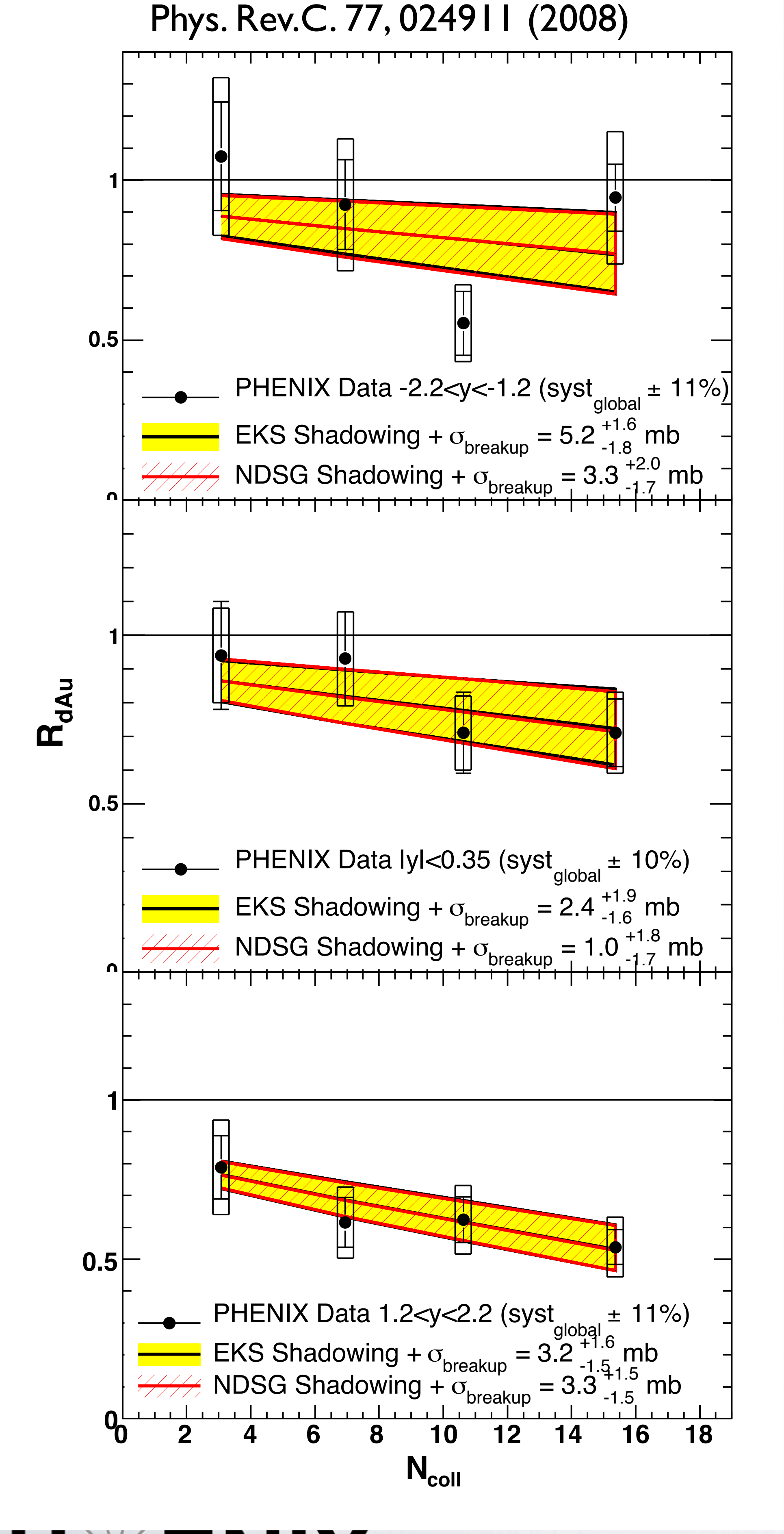


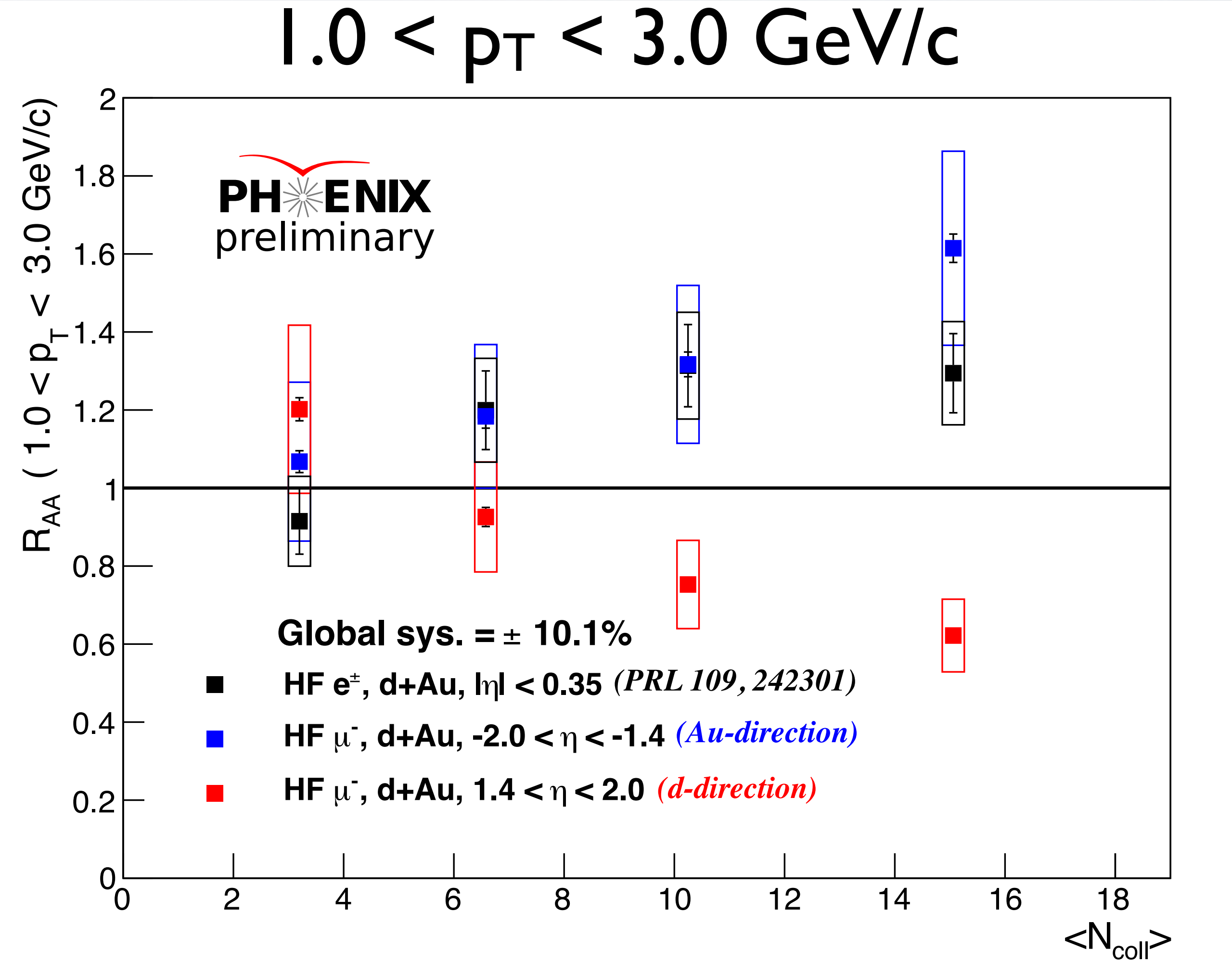
$3.0 < p_T < 5.0$ GeV/c



- Stronger centrality dependence at low p_T region
  - similar trends at backward and mid-rapidity
  - opposite trend at forward, more suppression as larger N_{coll}

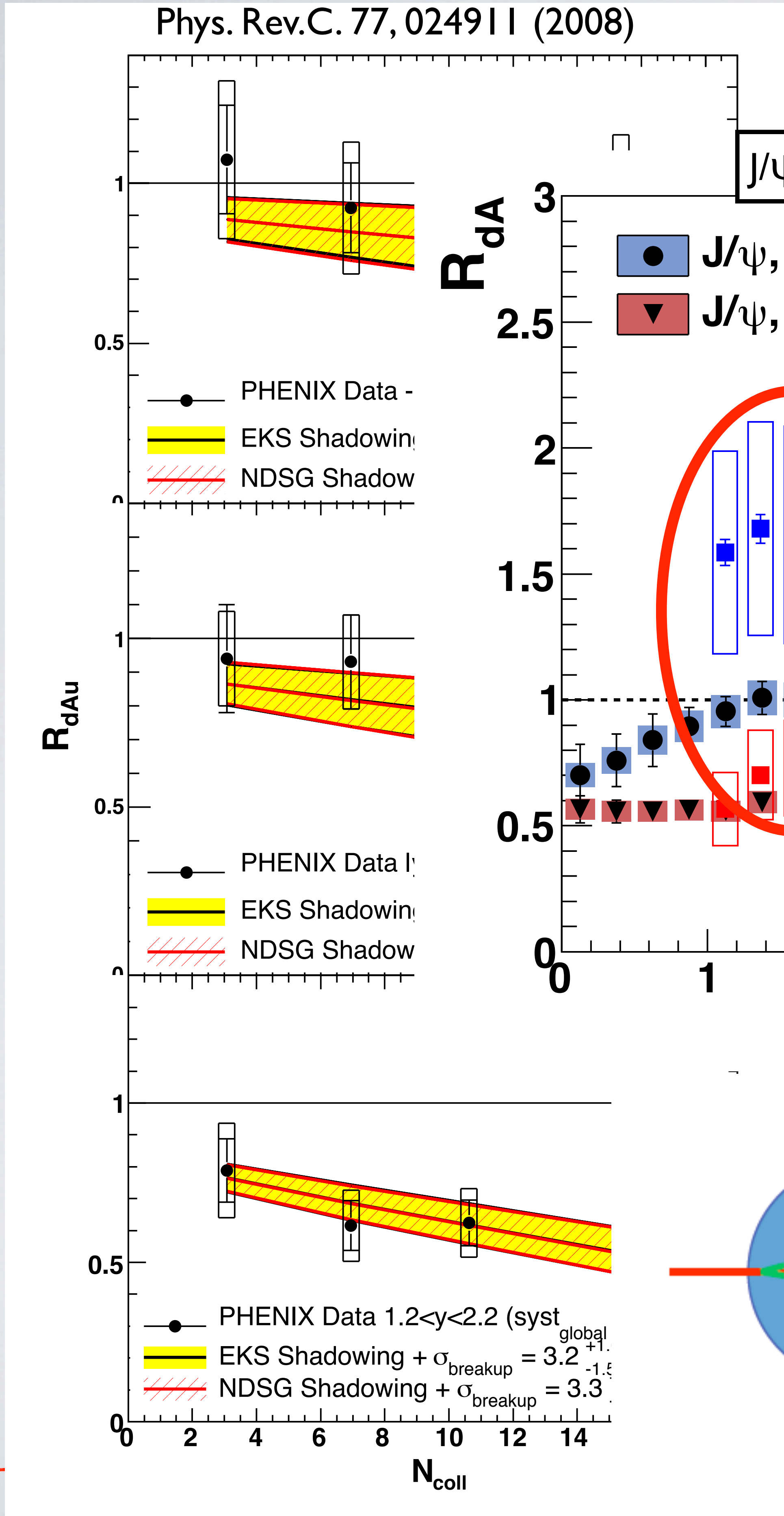
Comparison to J/ψ

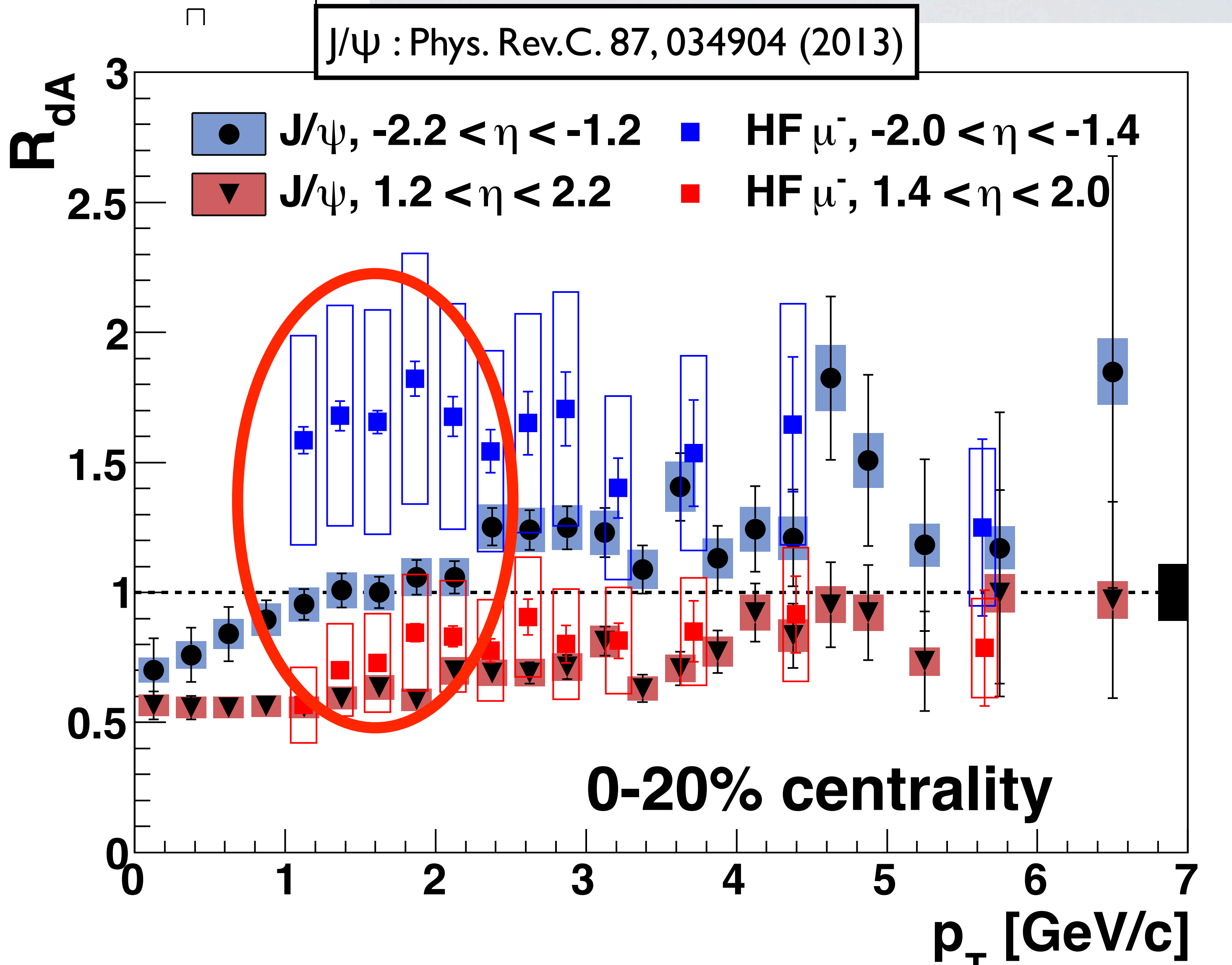


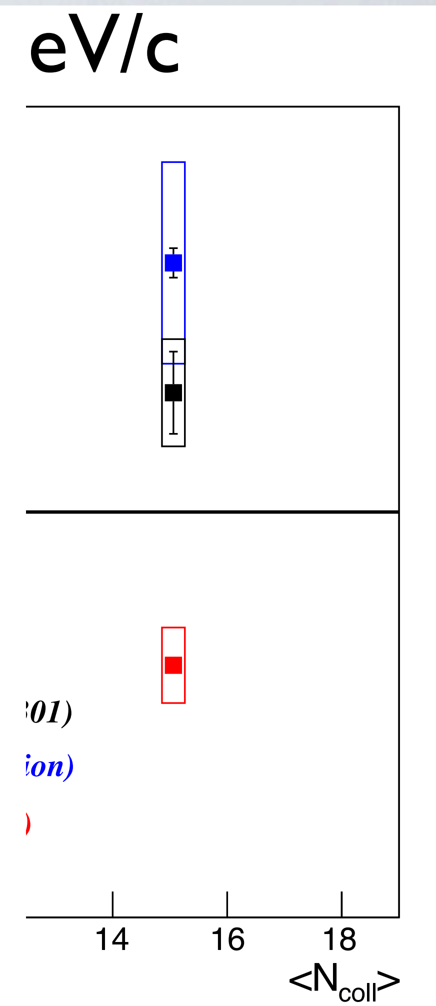


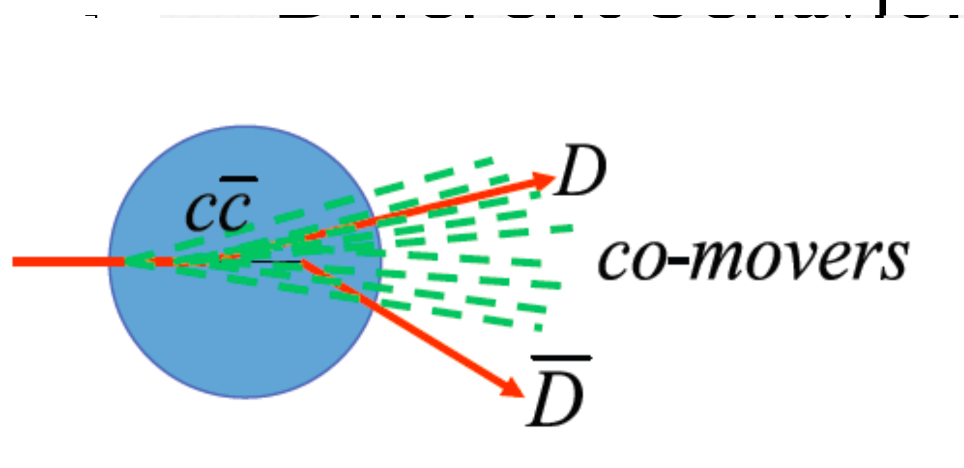
- Different behavior at mid- and backward rapidity depending on centrality
  - significant role of break-up in quarkonia production?

Comparison to J/ψ



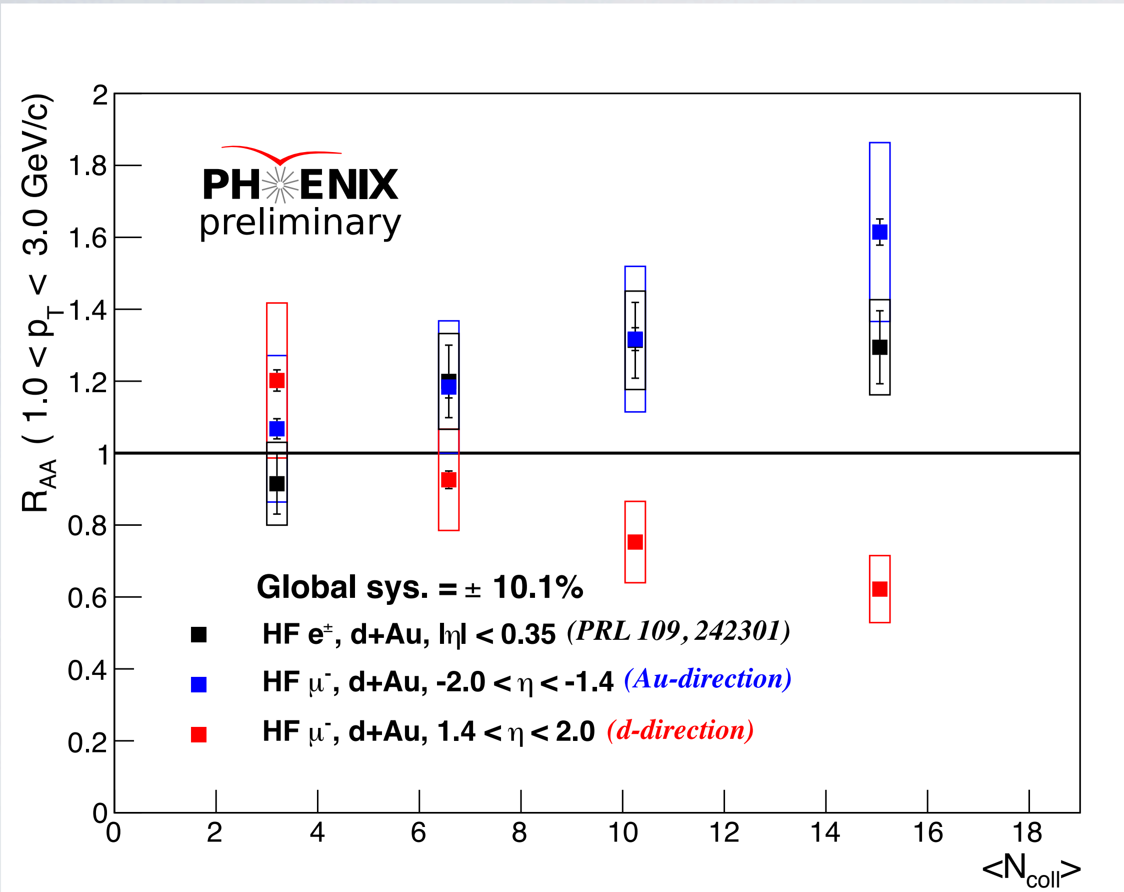


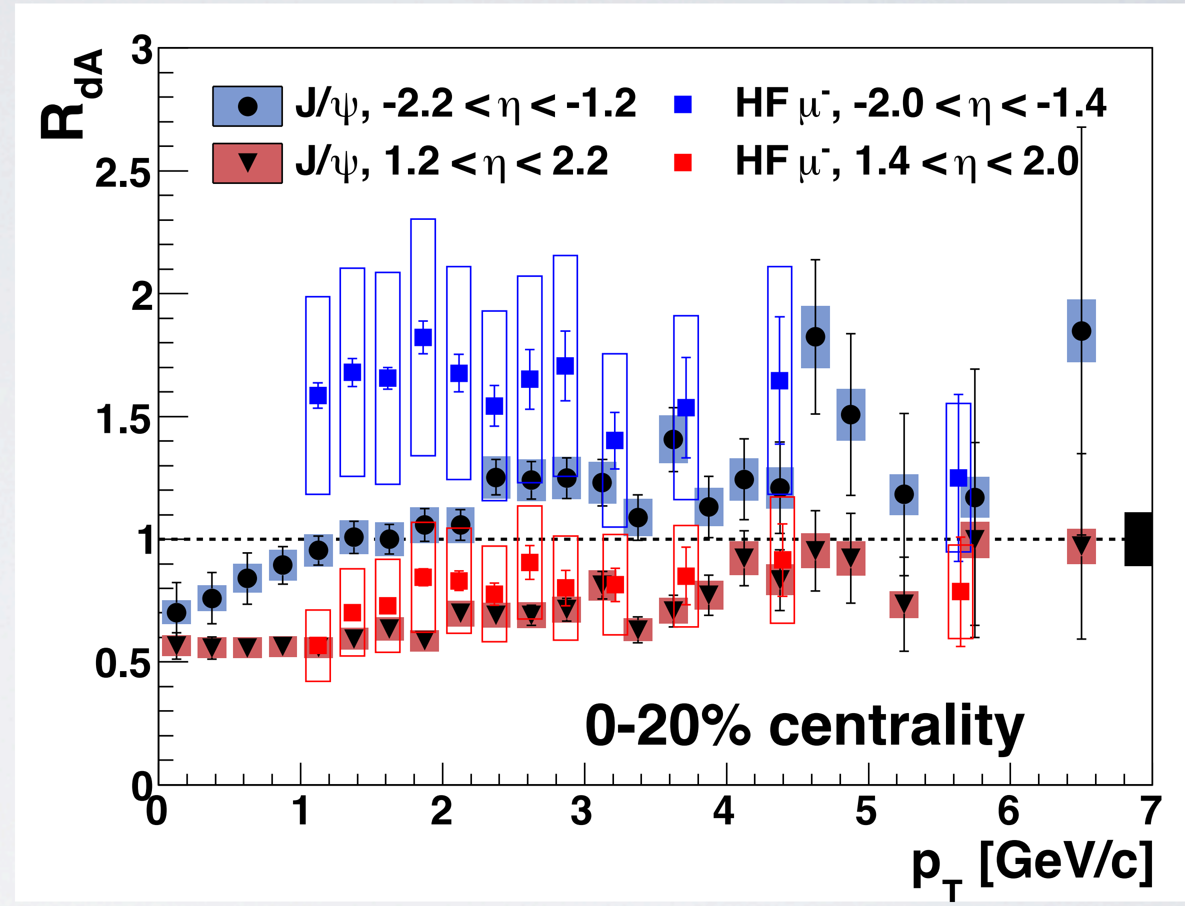




d- and
depending on
f break-up in
tion?

Finalized soon I: HF μ in d+Au (200 GeV) at forward





- HF μ production in central d+Au collisions at forward (backward) rapidity is suppressed (enhanced).
  - backward results are consistent with the results mid-rapidity

- Comparison to J/ψ results
  - highlight the role of nuclear break-up cross section in quarkonia production

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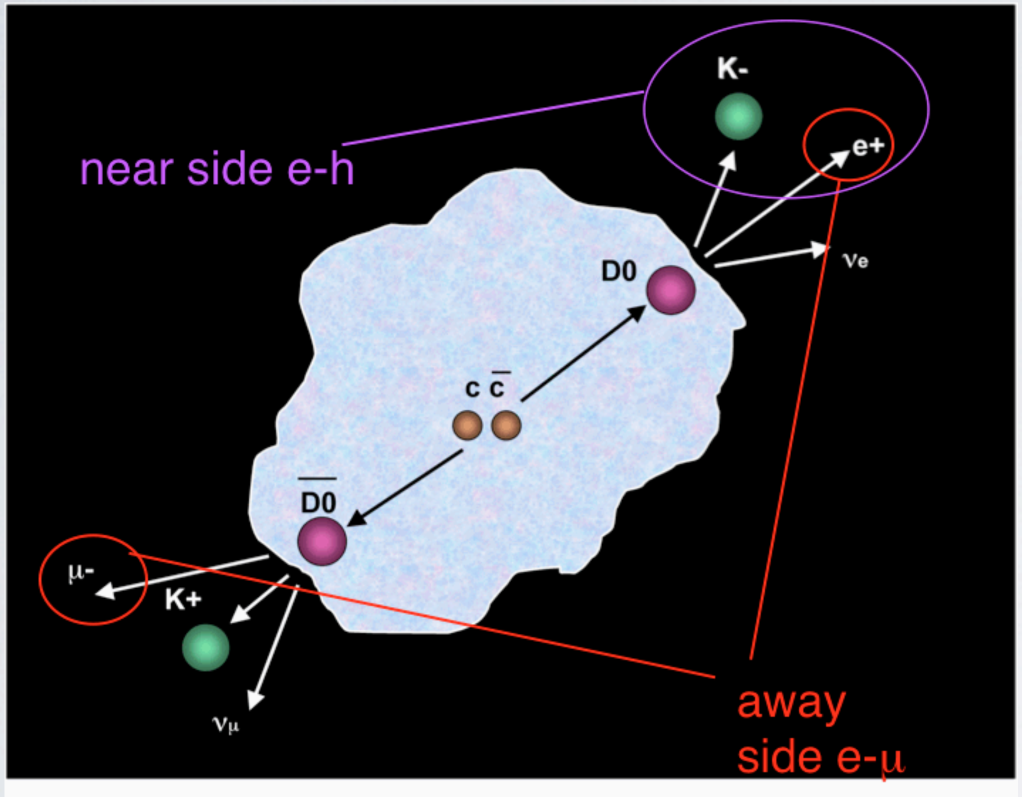
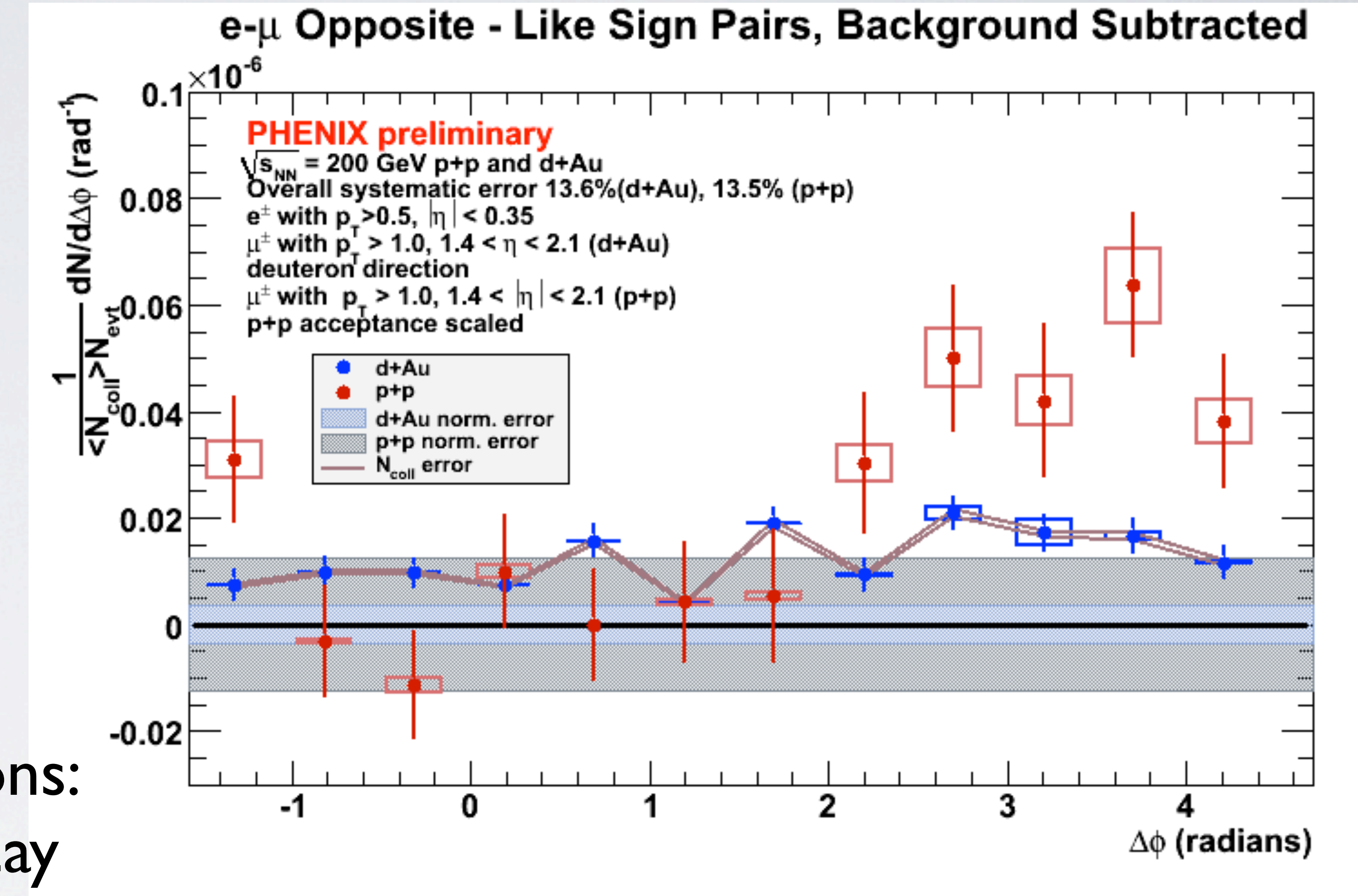
Finalized soon II: HF e-μ correlation in d+Au at 200 GeV

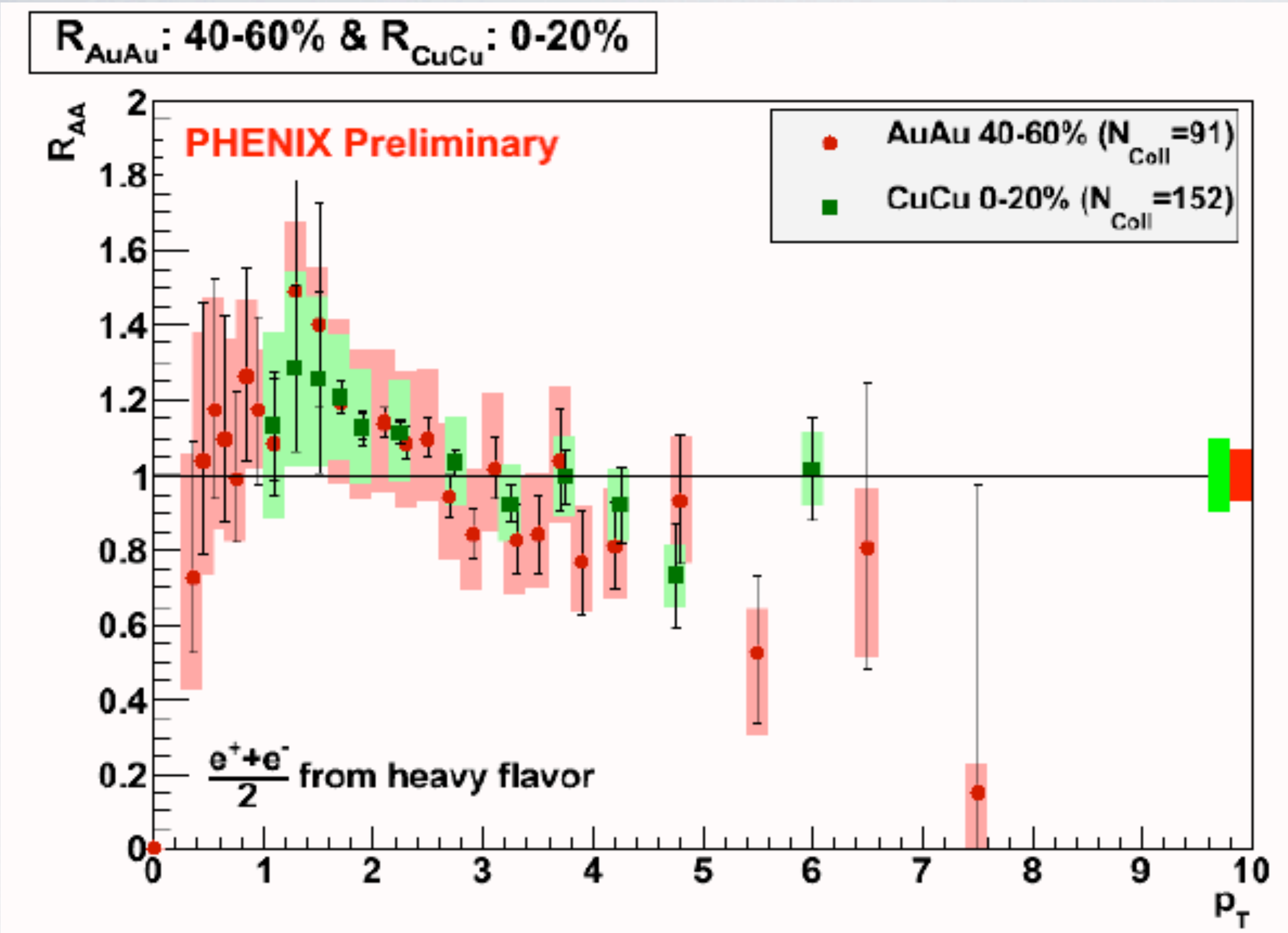


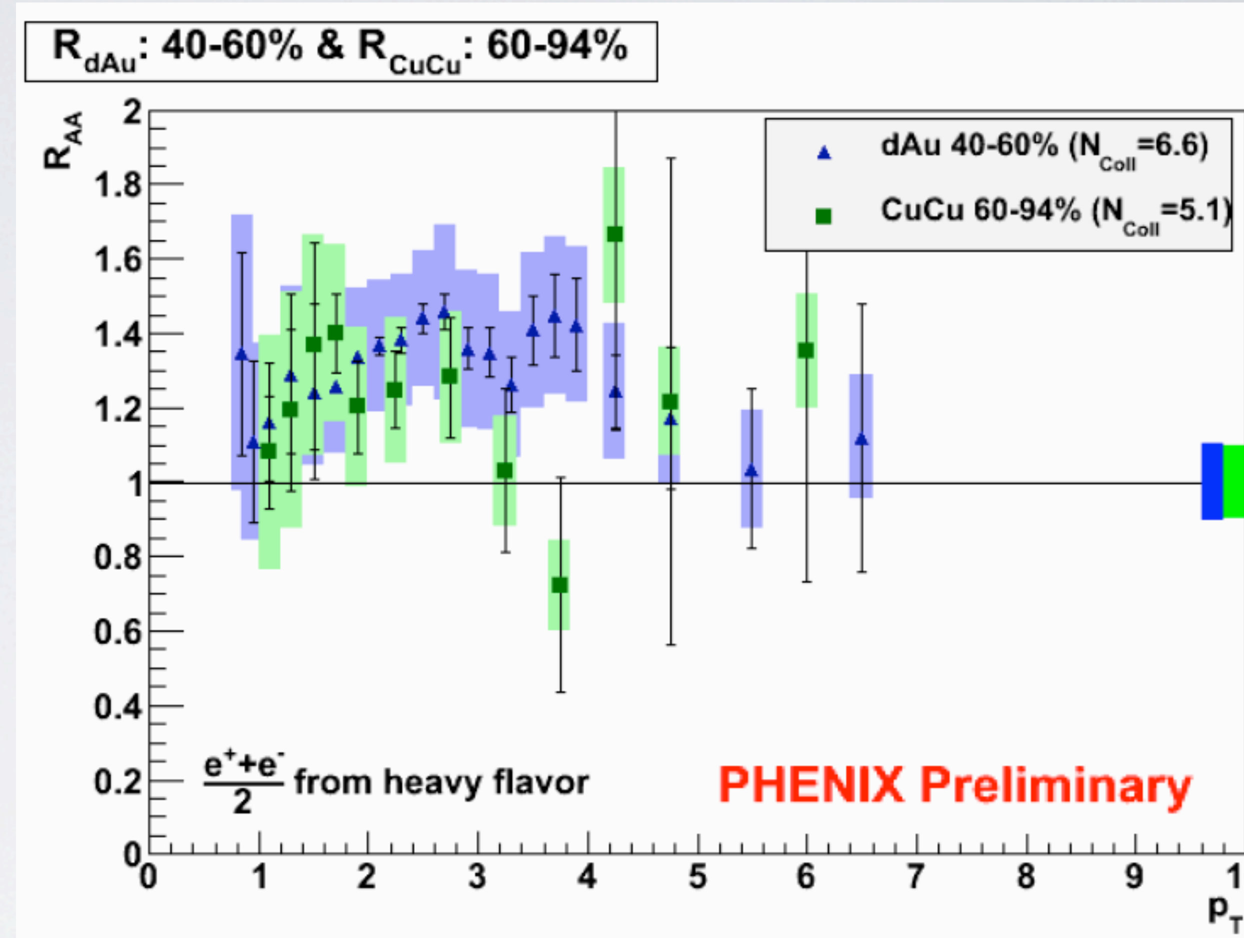
Opposite sign e-μ azimuthal correlations:
double semi-leptonic heavy-flavor decay



- Correlation between HF e (mid) and HF μ (forward)
  - In d+Au results at forward rapidity, suppression/de-correlation is shown relative to p+p results.

Finalized soon III: HF e in Cu+Cu (200 GeV) at mid



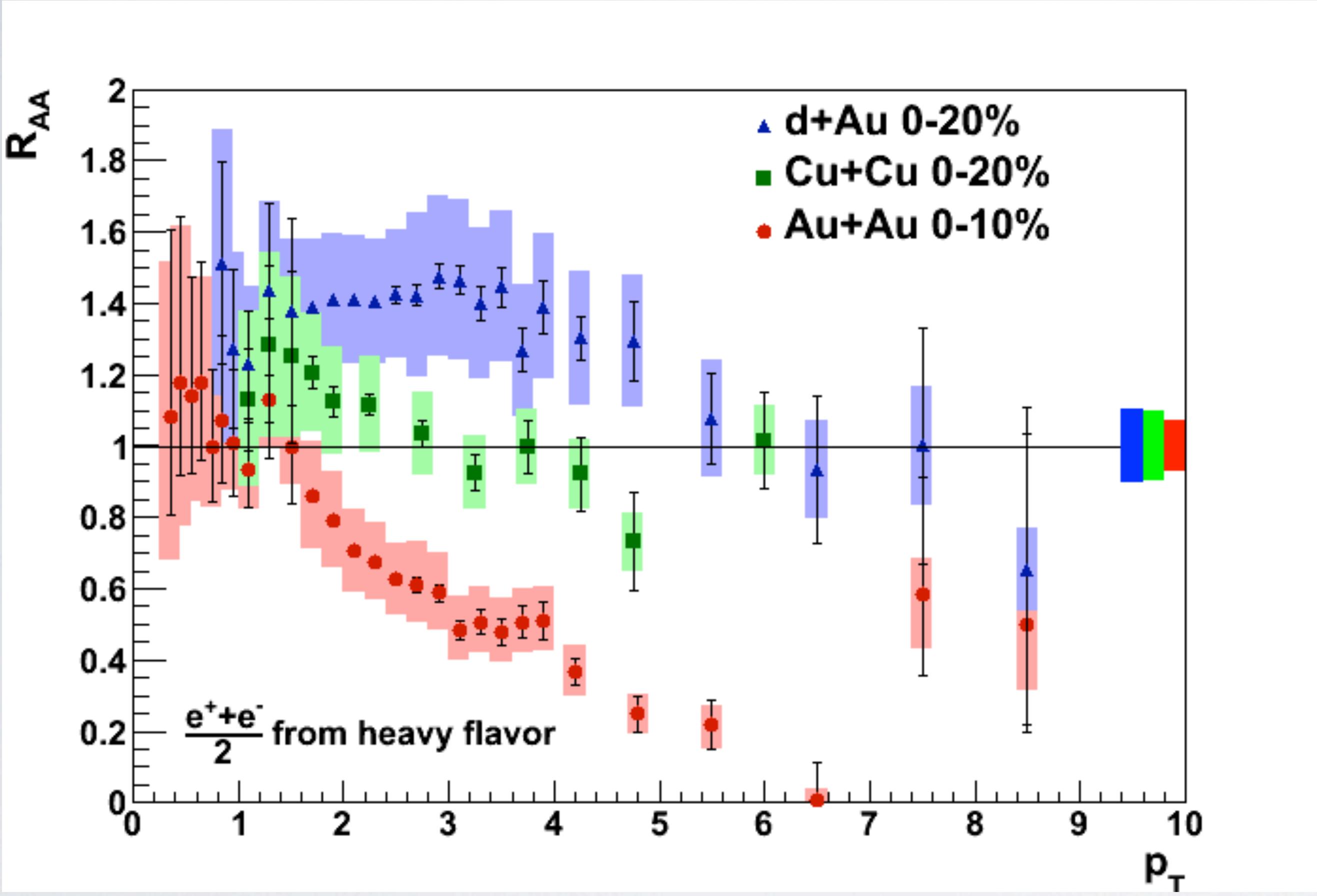


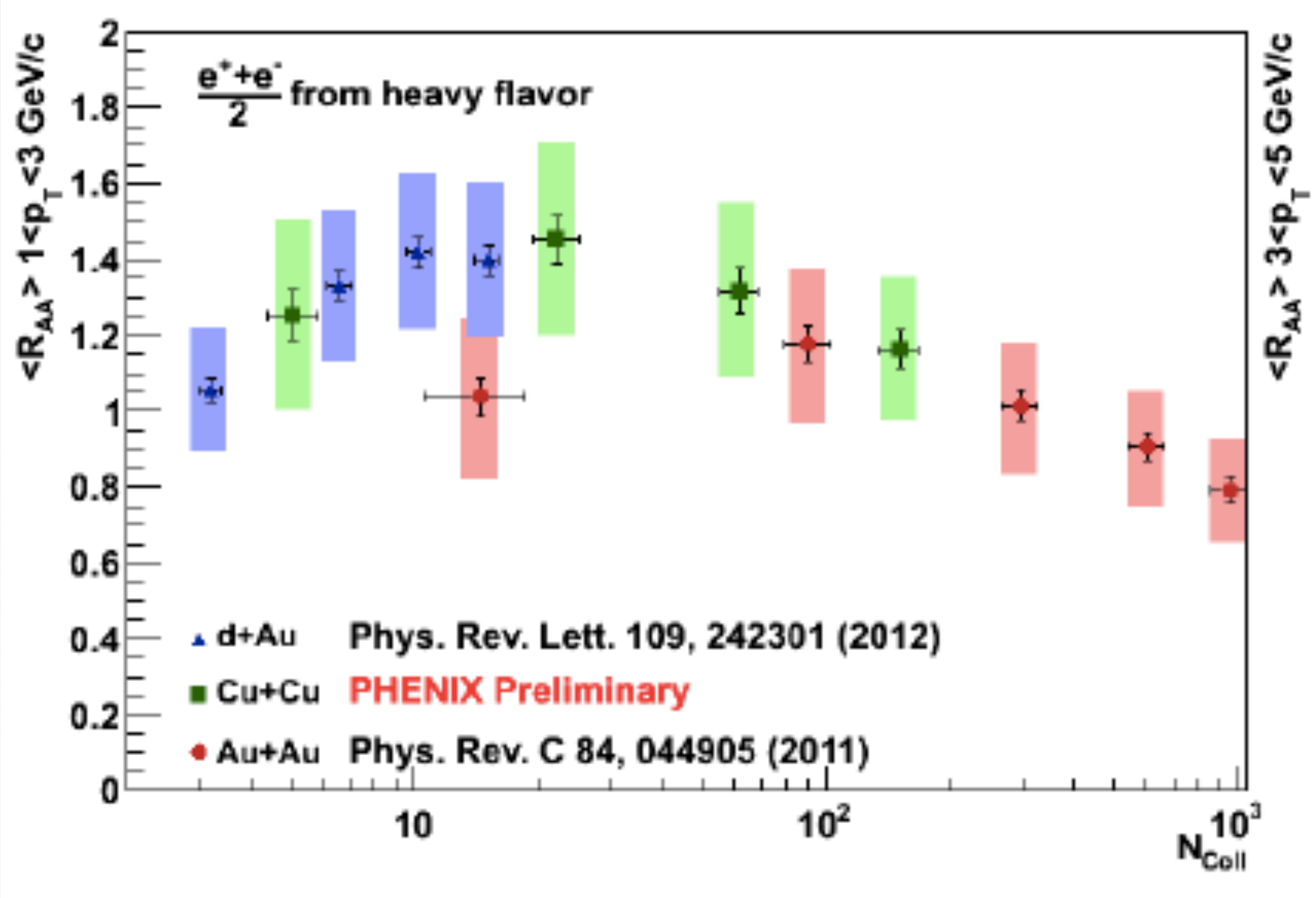
$<N_{coll}>$AuAu = 91, $<N_{coll}>$CuCu = 152
$<N_{part}>$AuAu = 60, $<N_{part}>$CuCu = 86

$<N_{coll}>$dAu = 6.6, $<N_{coll}>$CuCu = 5.1
$<N_{part}>$dAu = 7.7, $<N_{part}>$CuCu = 6.4

- Cu+Cu results are consistent with Au+Au and d+Au results in similar $<N_{coll}>$ regioin

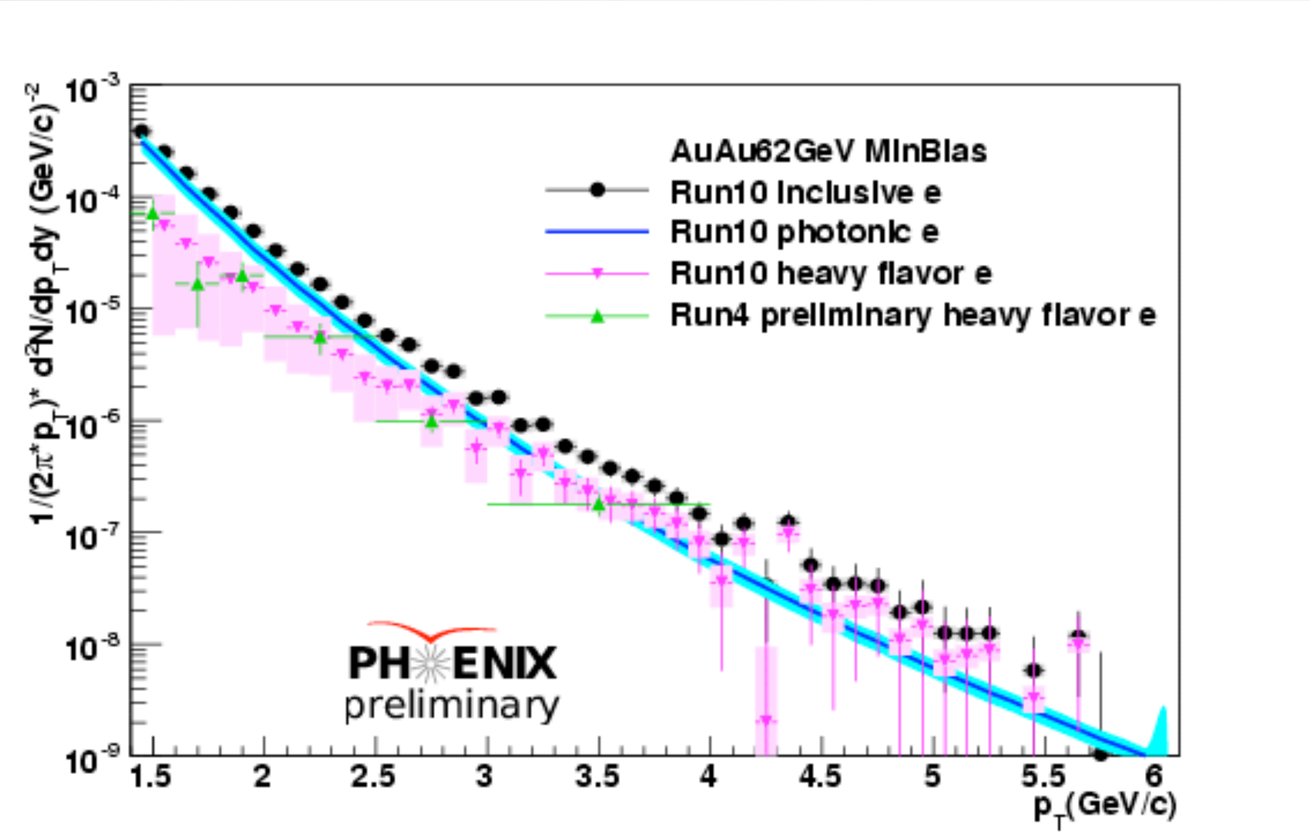
Finalized soon III: HF e in Cu+Cu (200 GeV) at mid

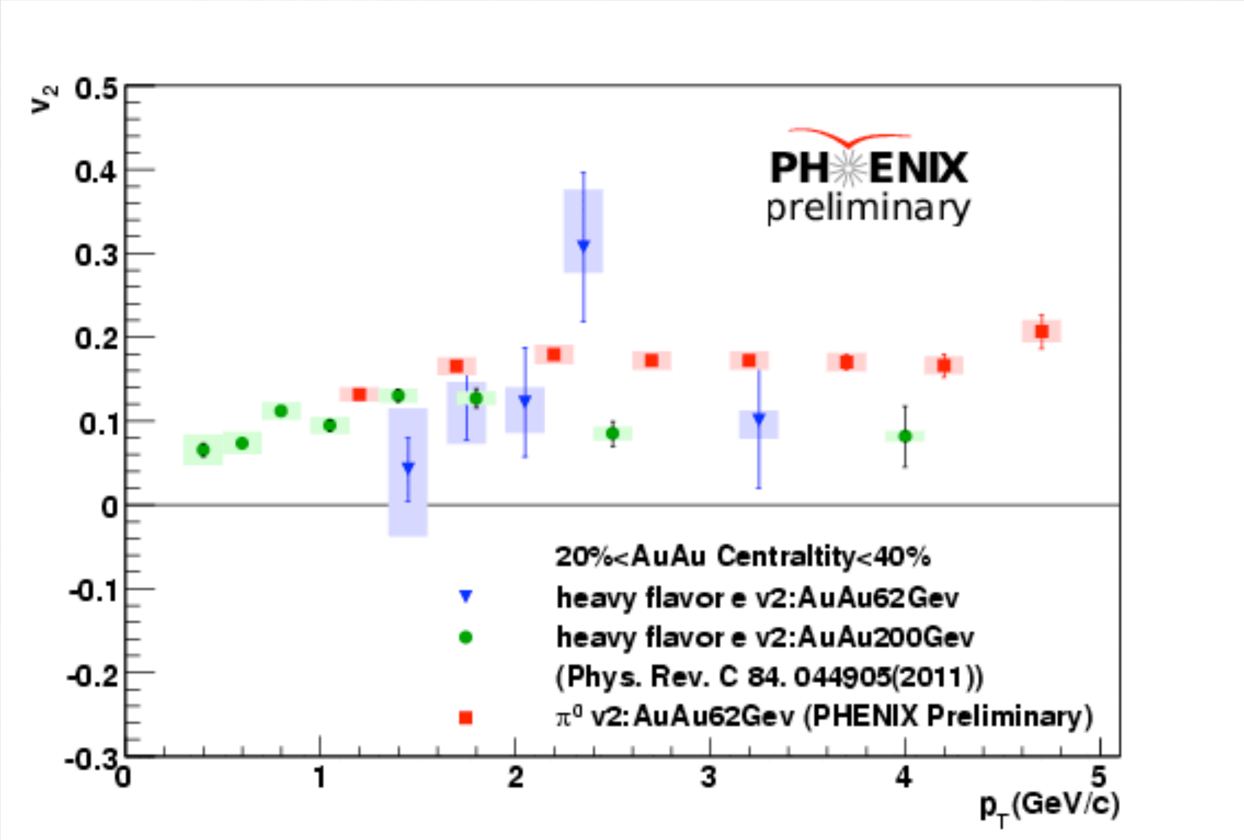




- Cu+Cu R_{AA} is located between R_{dA} and Au+Au R_{AA}.
- Smooth take over from CNM effect in d+Au/peripheral Cu+Cu systems to central Cu+Cu/Au+Au systems as collision size increase.

Finalized soon IIII: HF e in Au+Au (62.4 GeV) at mid



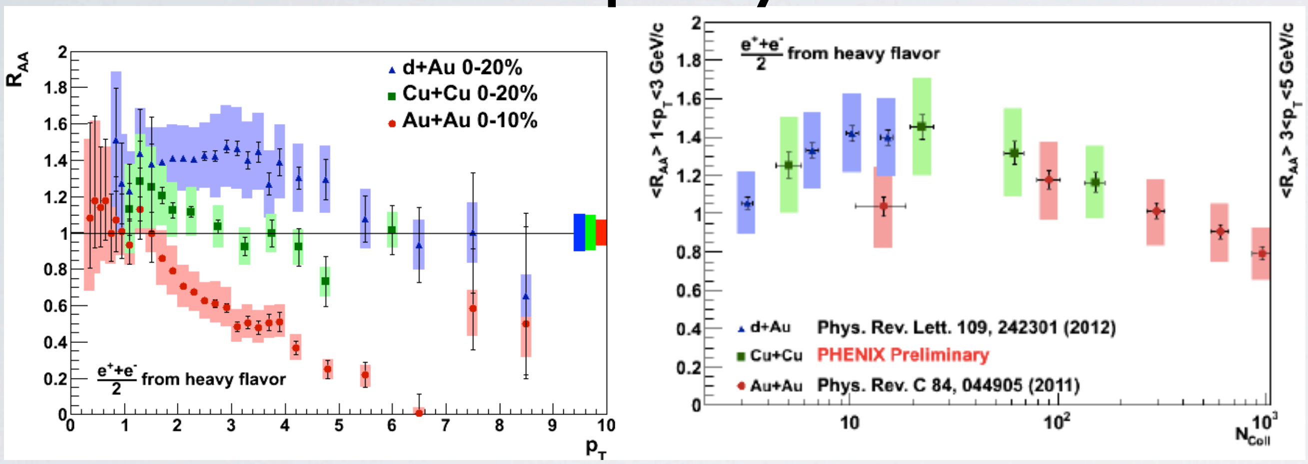


- Non-zero v_2 component of HF e in Au+Au collisions at 62.4 GeV
  - consistent with v_2 in Au+Au collisions at 200 GeV

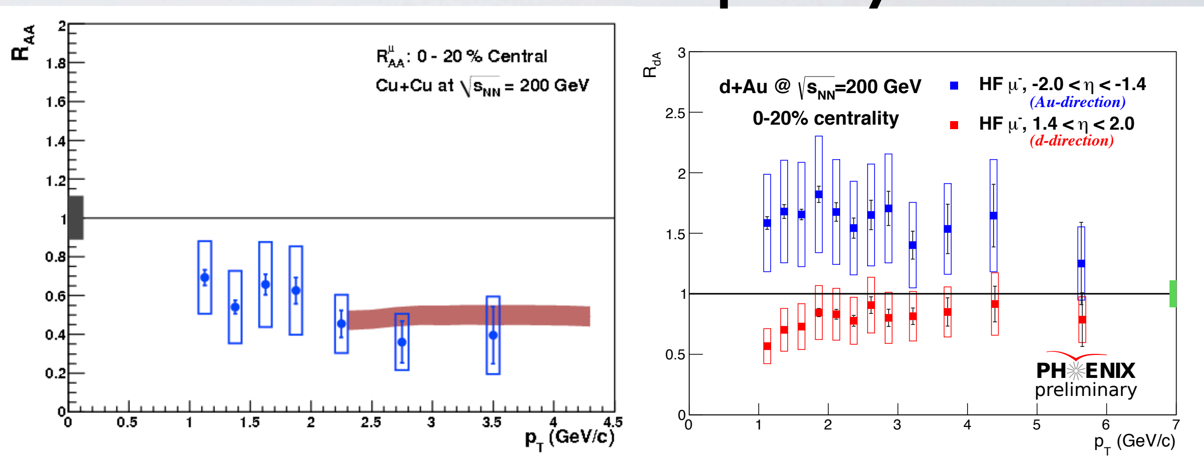
Summary

- PHENIX measured open heavy flavors in various collision system
  - many interesting results will be finalized soon

mid-rapidity



forward-rapidity

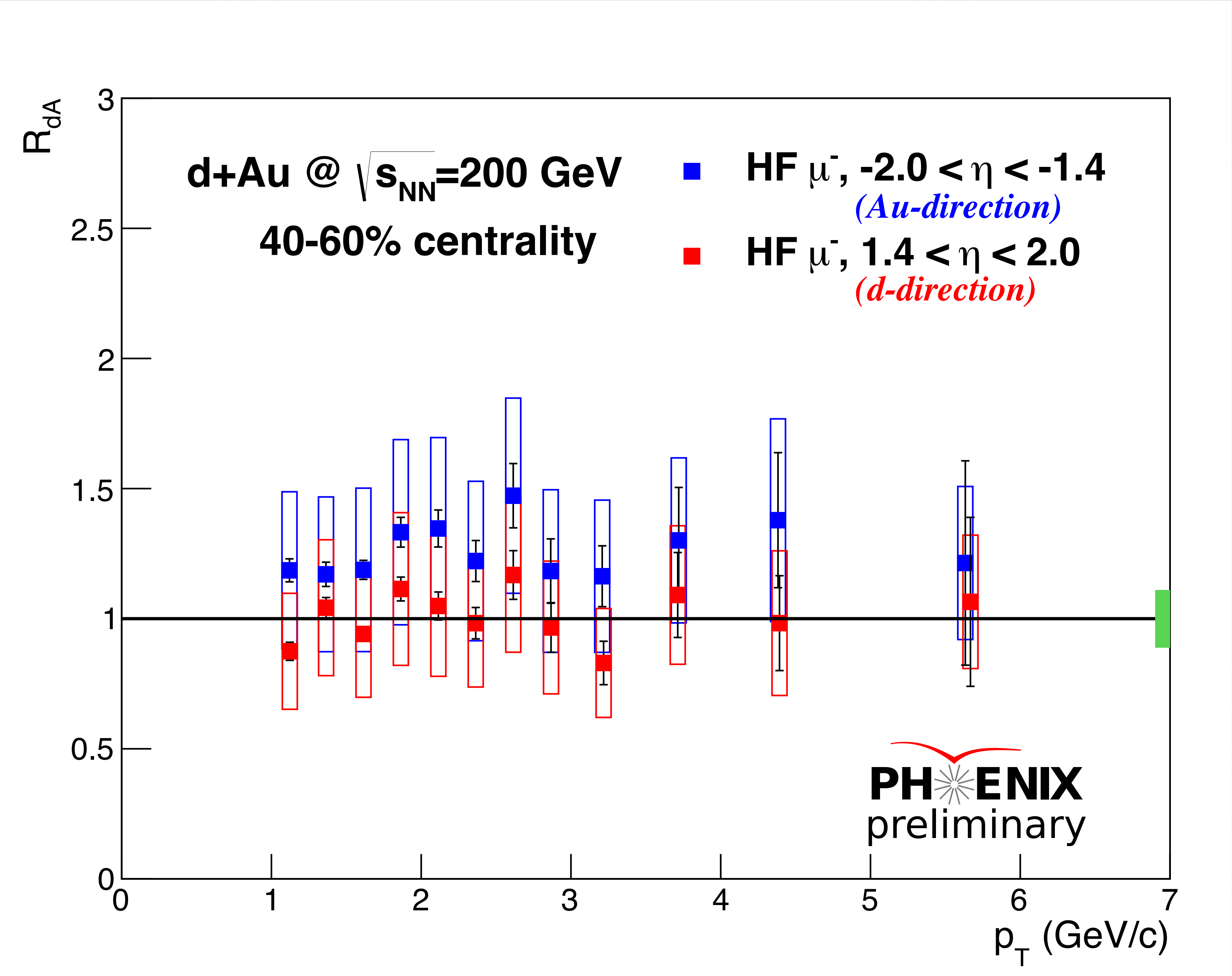


- Theoretical prediction works well!
  - consistent with Au+Au and over predicts suppression in Cu+Cu at mid-rapidity
  - consistent with d+Au and Cu+Cu at forward rapidity

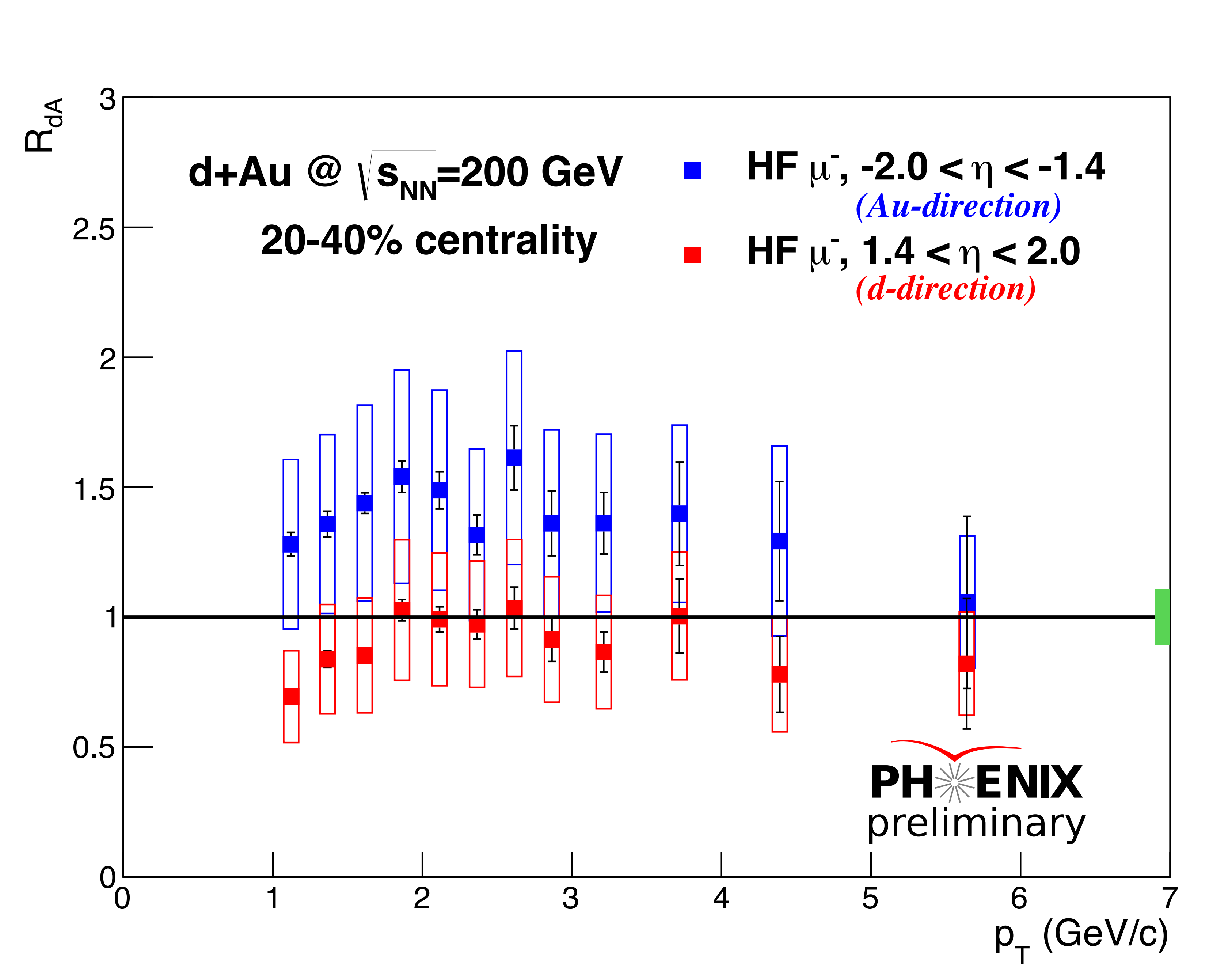
- New PHENIX inner silicon vertex tracker system (VTX & FVTX) provides precise vertex position and allows to separate charm and bottom meson.

Back up

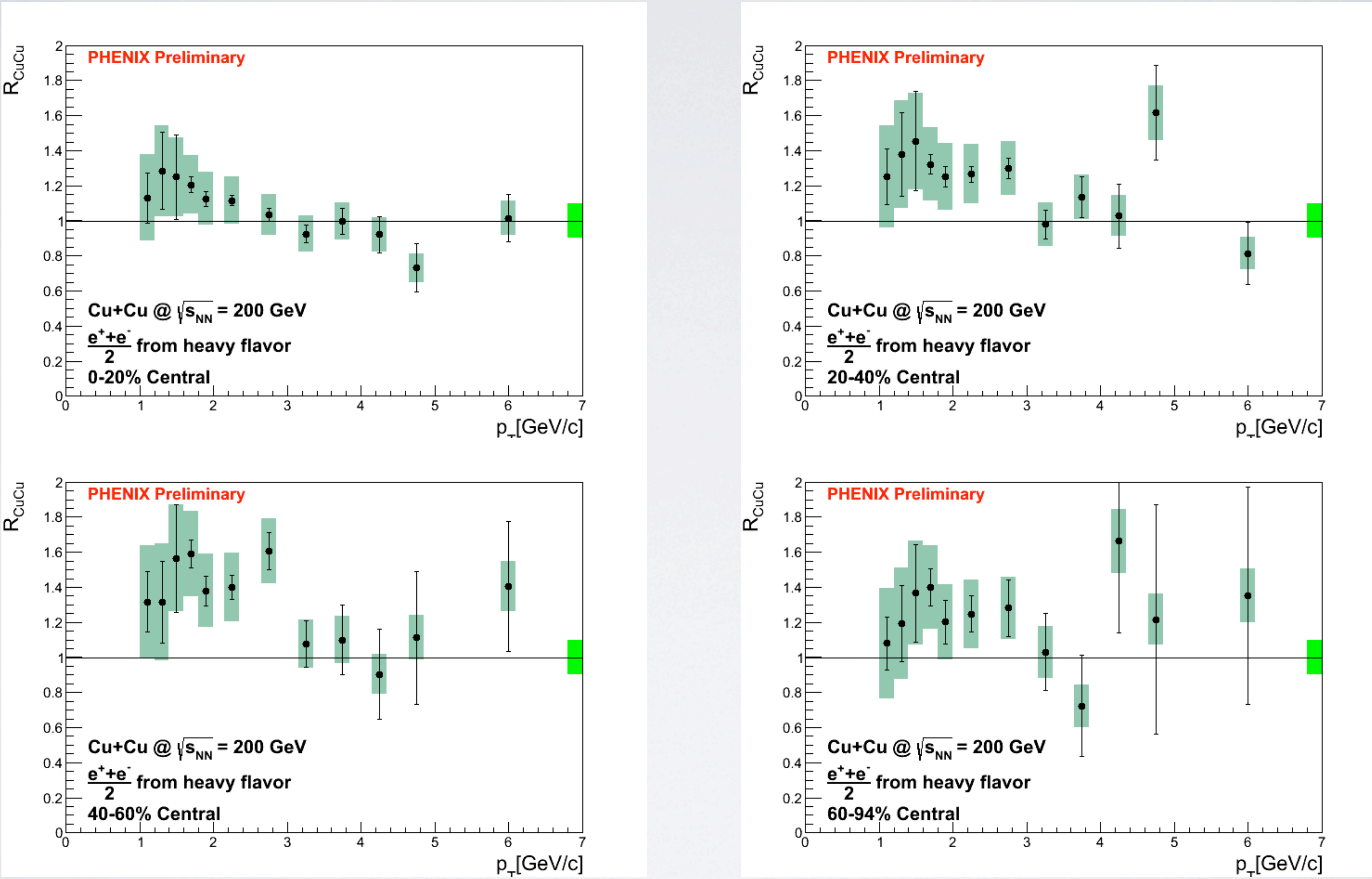
Heavy flavor muons R_{dA}, 40 - 60%



Heavy flavor muons R_{dA}, 20 - 40%



Heavy flavor electrons R_{AA} at mid-rapidity



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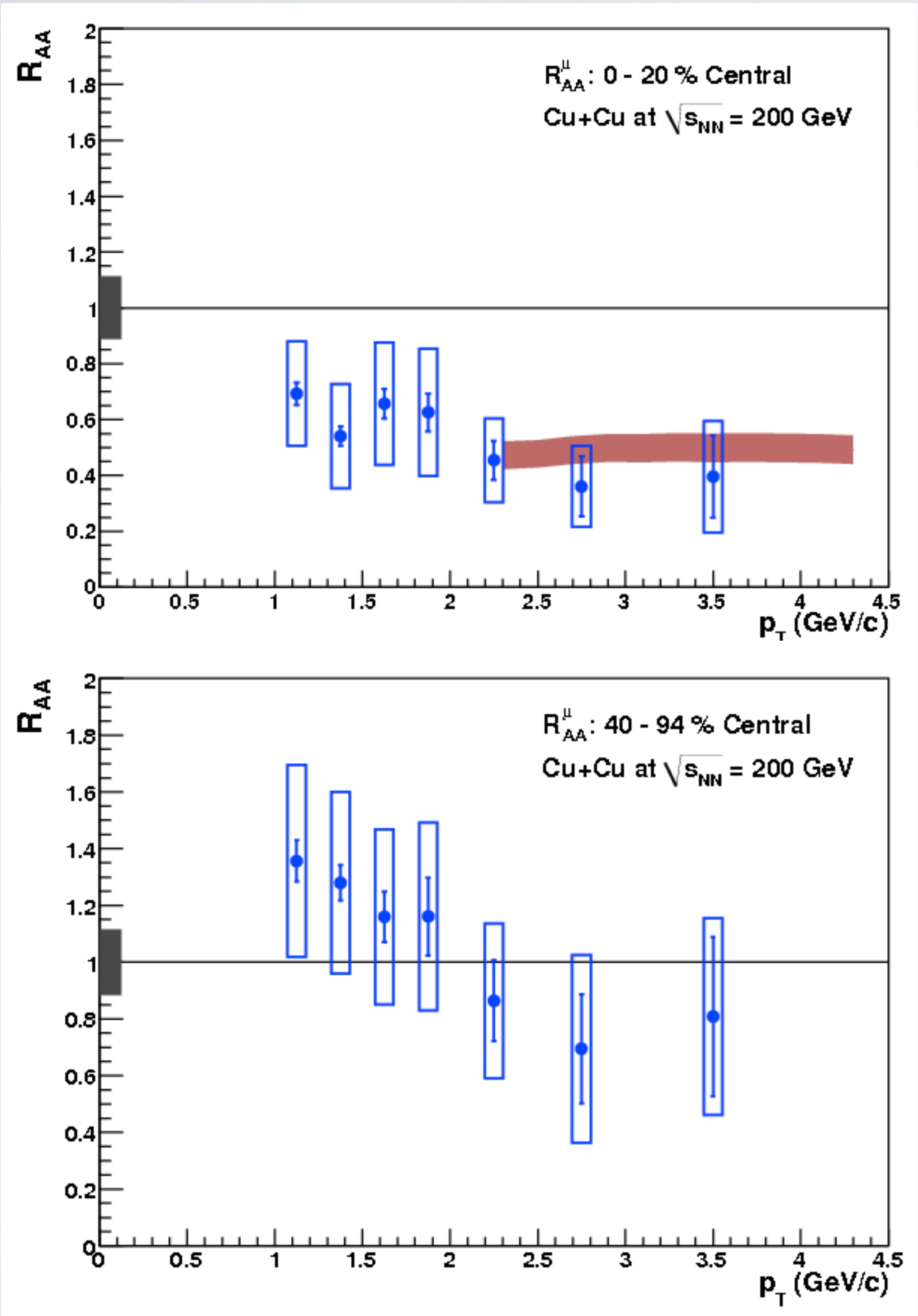
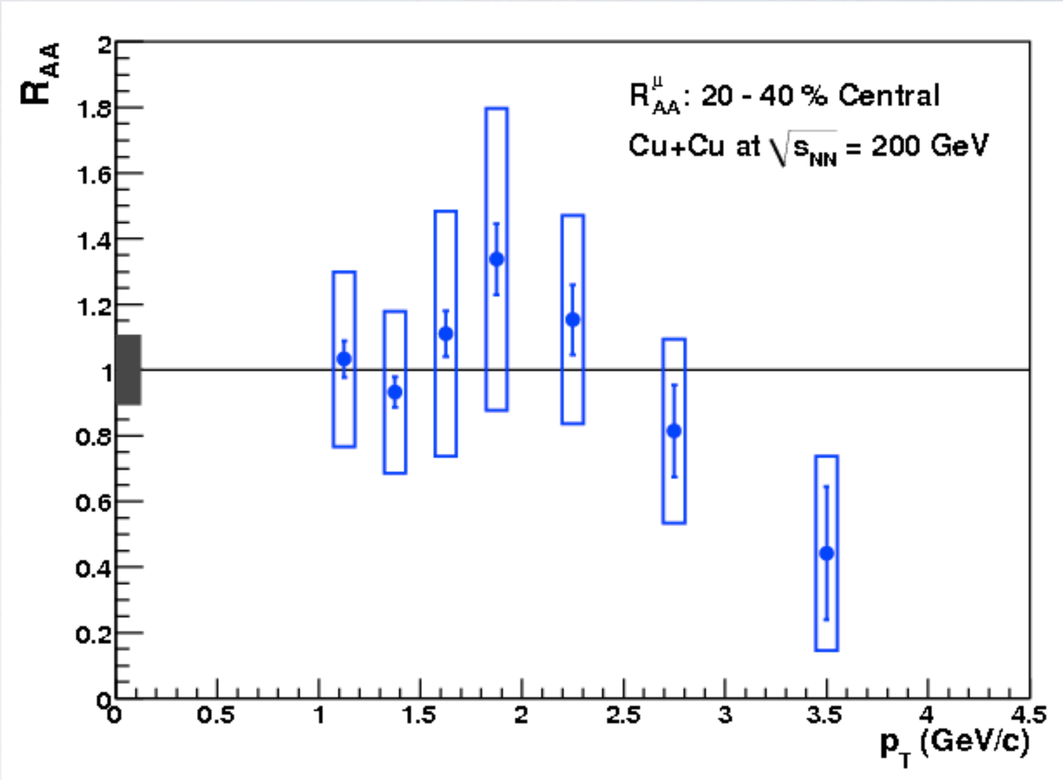
Heavy flavor μ R_{AA} at forward-rapidity





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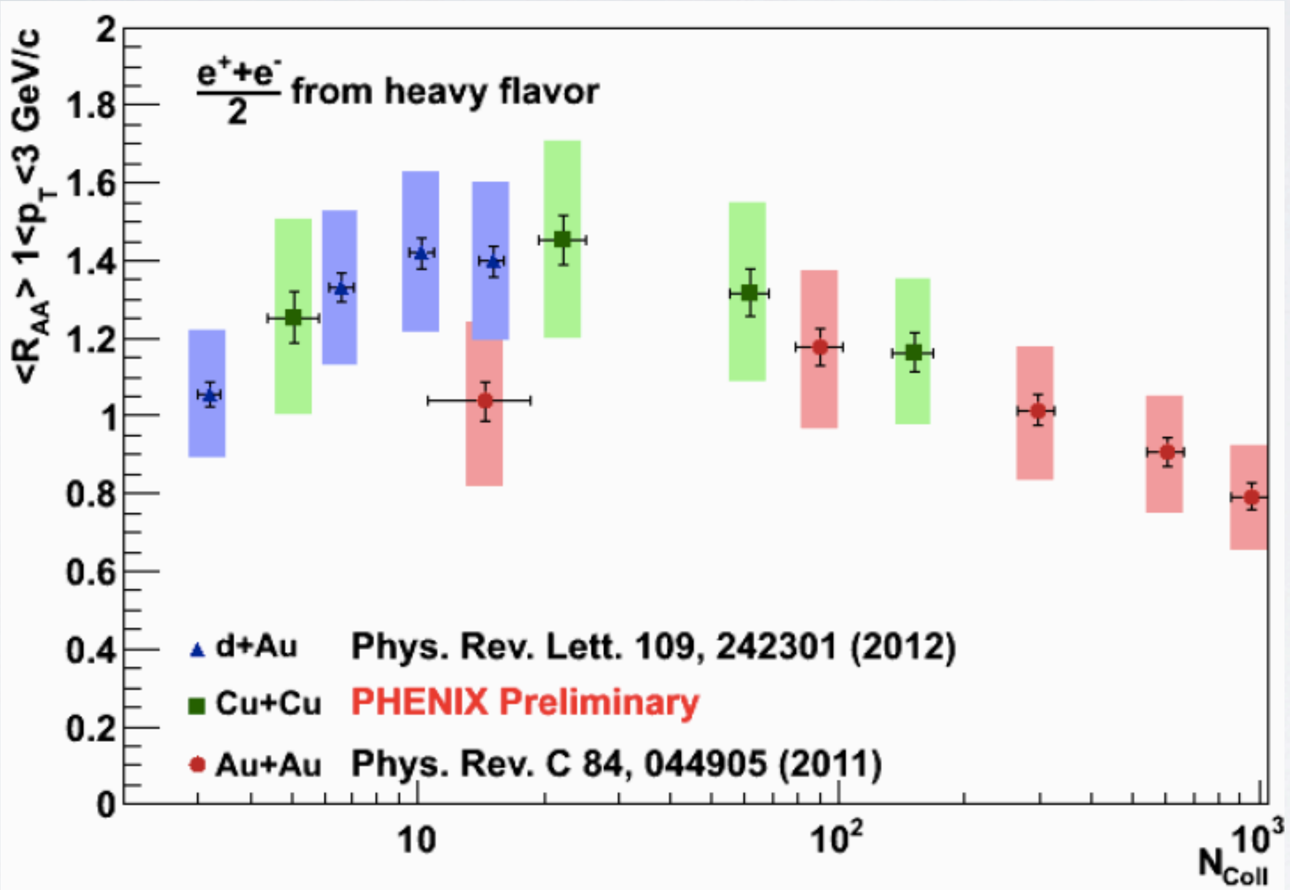
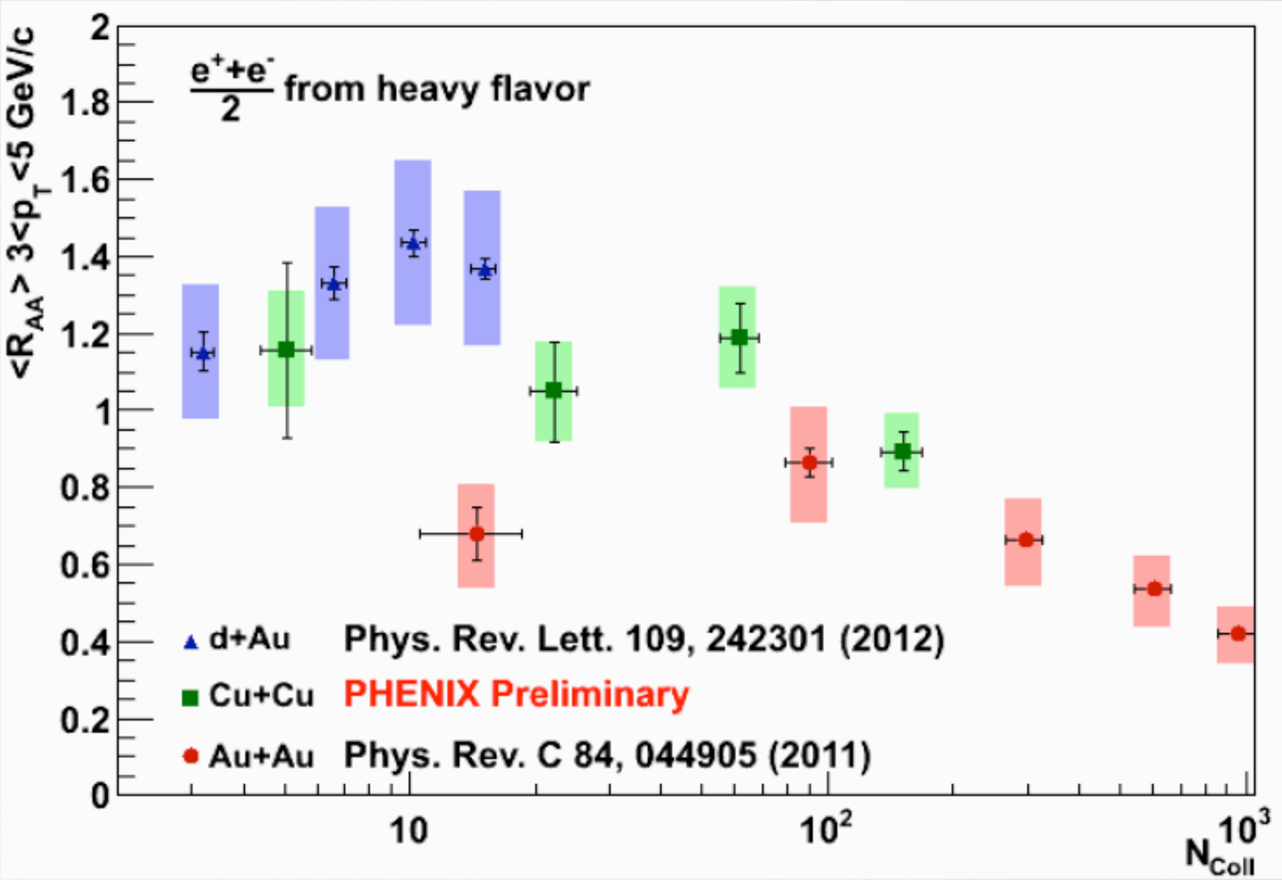
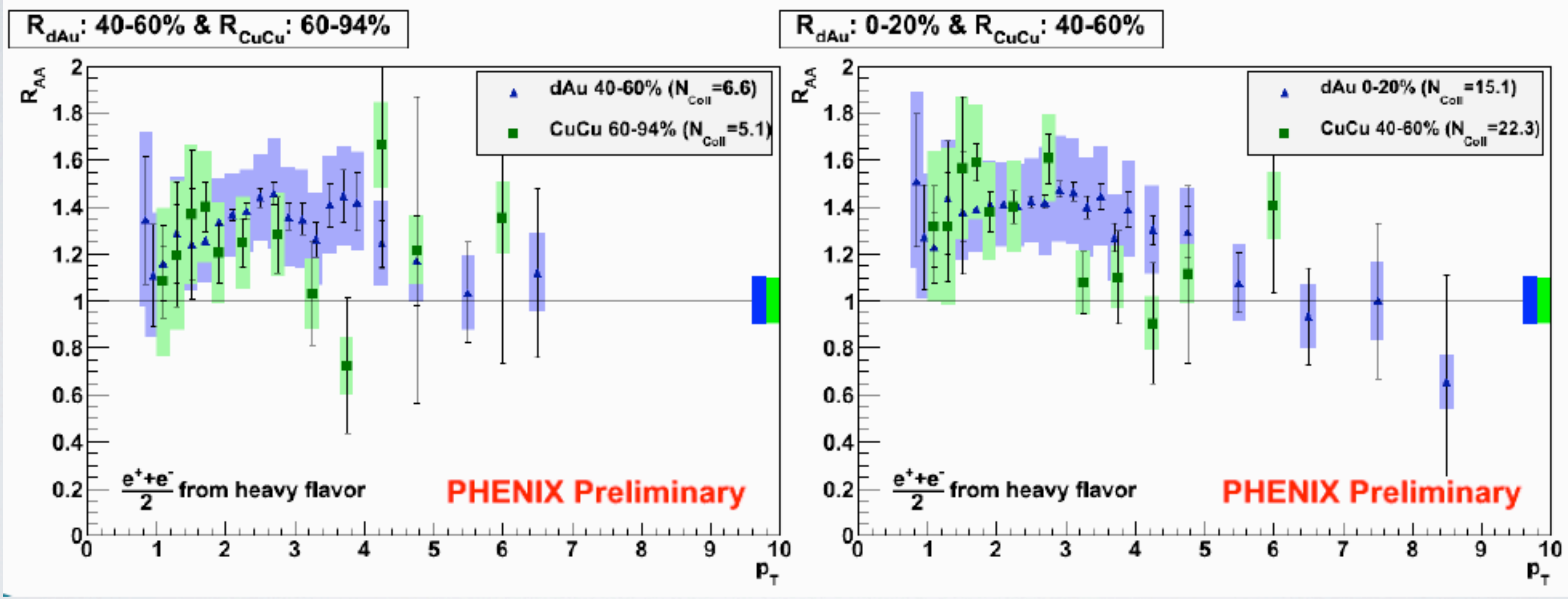
R_{AA} vs. N_{coll} at mid-rapidity





comparison between d+Au and Cu+Cu



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