

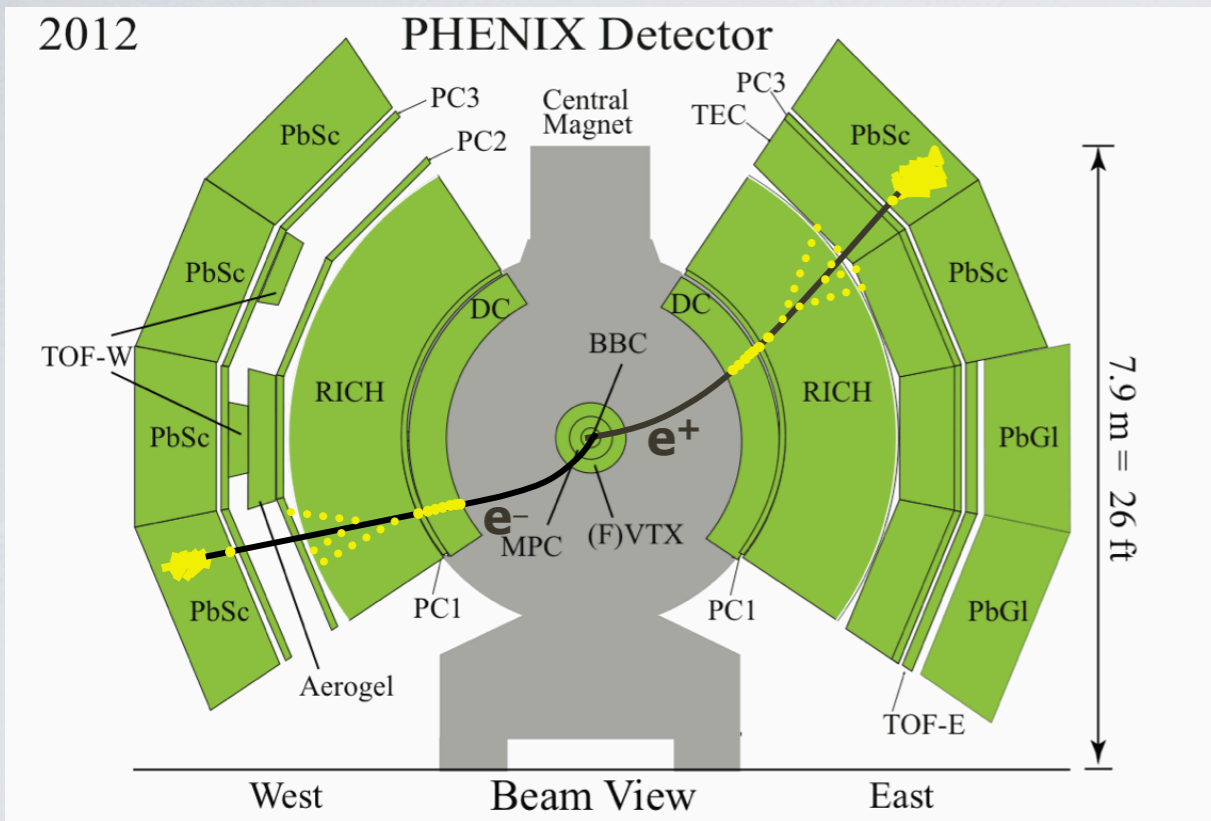
# Open heavy flavor measurements in d+Au collisions at PHENIX experiment

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ICNFP 2013  
Kolymbari, Crete, Greece

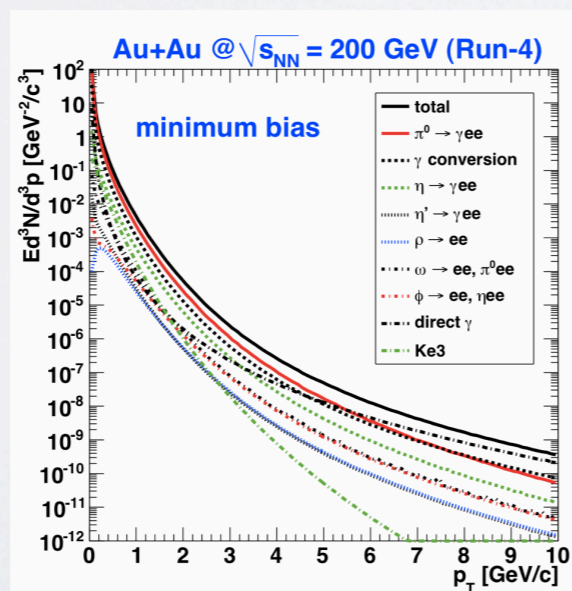


# e measurement @ PHENIX central arm



- kinematic range
  - $|\eta| < 0.35$
  - $\Delta\varphi = \pi$
- 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
  - $\pi^0$  Dalitz
  - conversion  $\gamma$
  - direct  $\gamma$  & Ke3
  - $J/\psi$ ,  $\Upsilon$ , DY



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

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

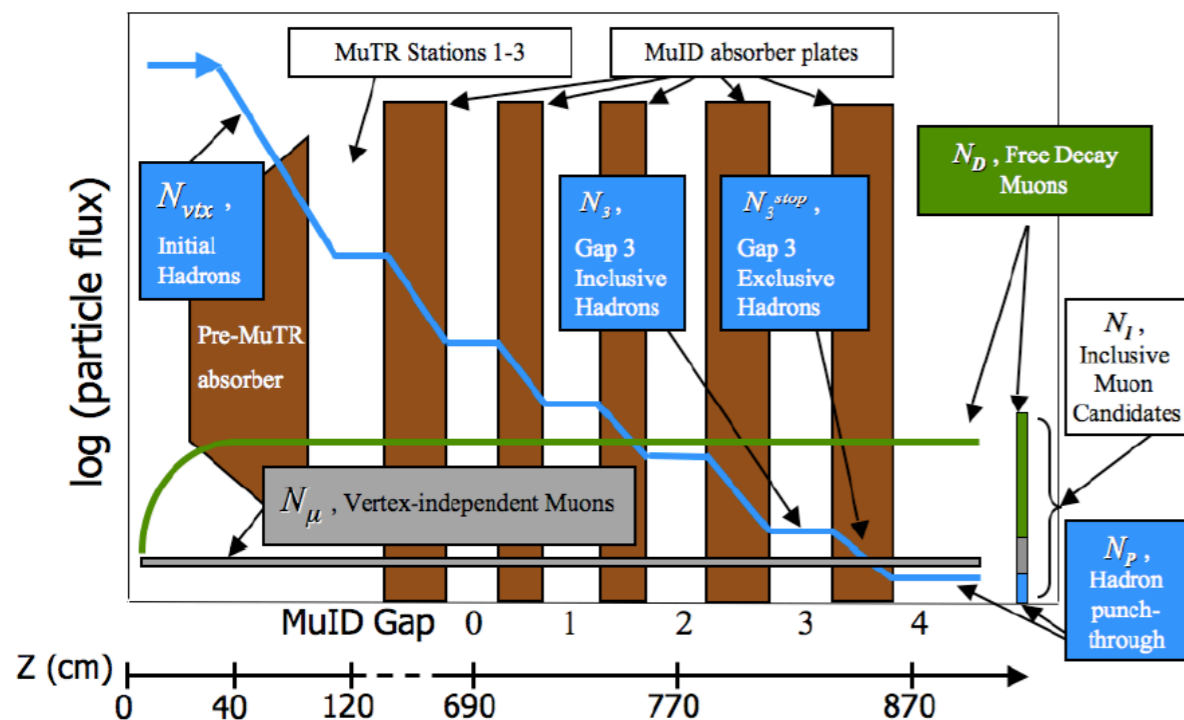
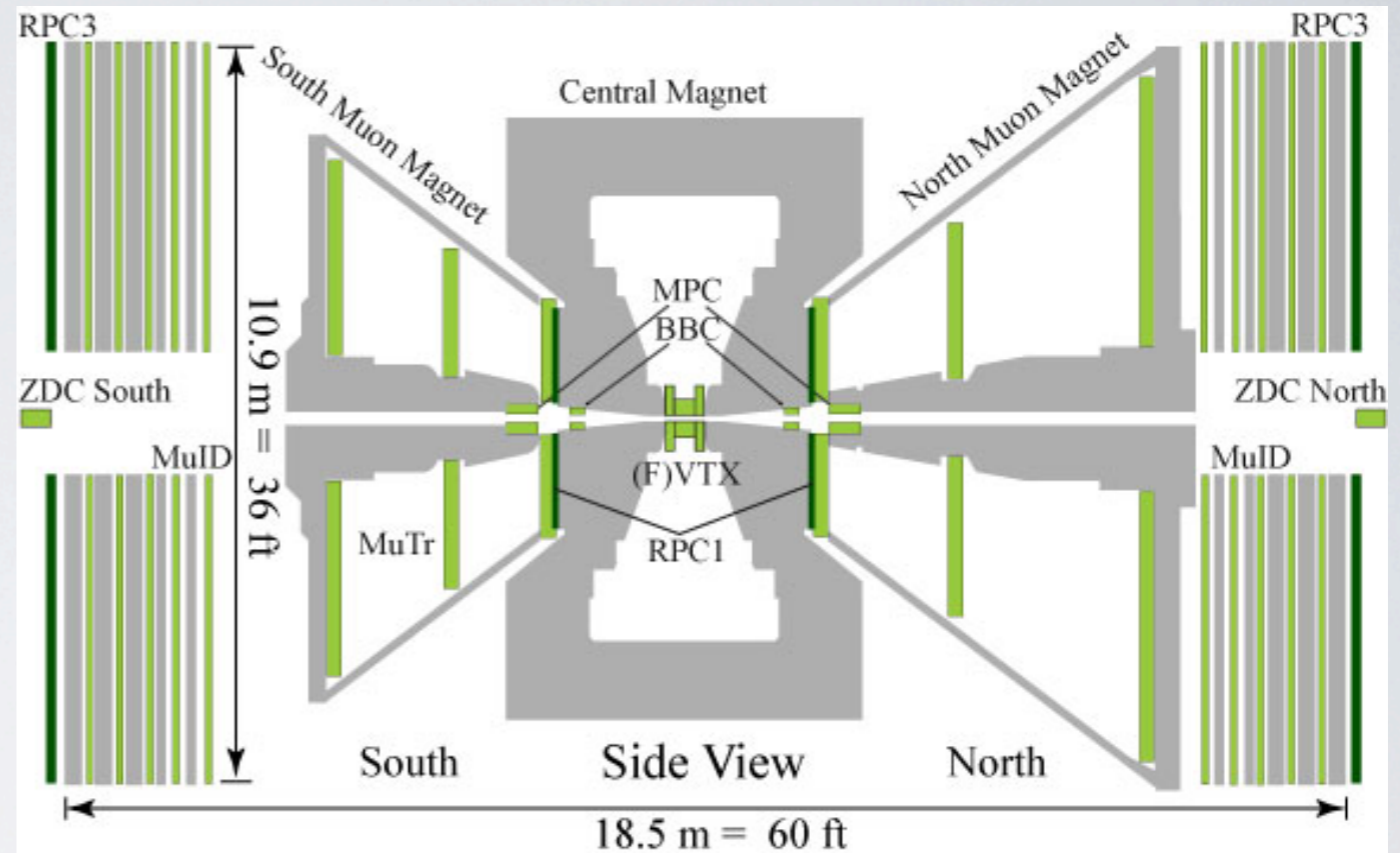
$$N_e^{conv-in} = R_\gamma N_e^\gamma + (1 - \epsilon) N_e^{non-\gamma}$$



S. H. Lim, ICNFP 2013

# $\mu$ measurement @ PHENIX central arm

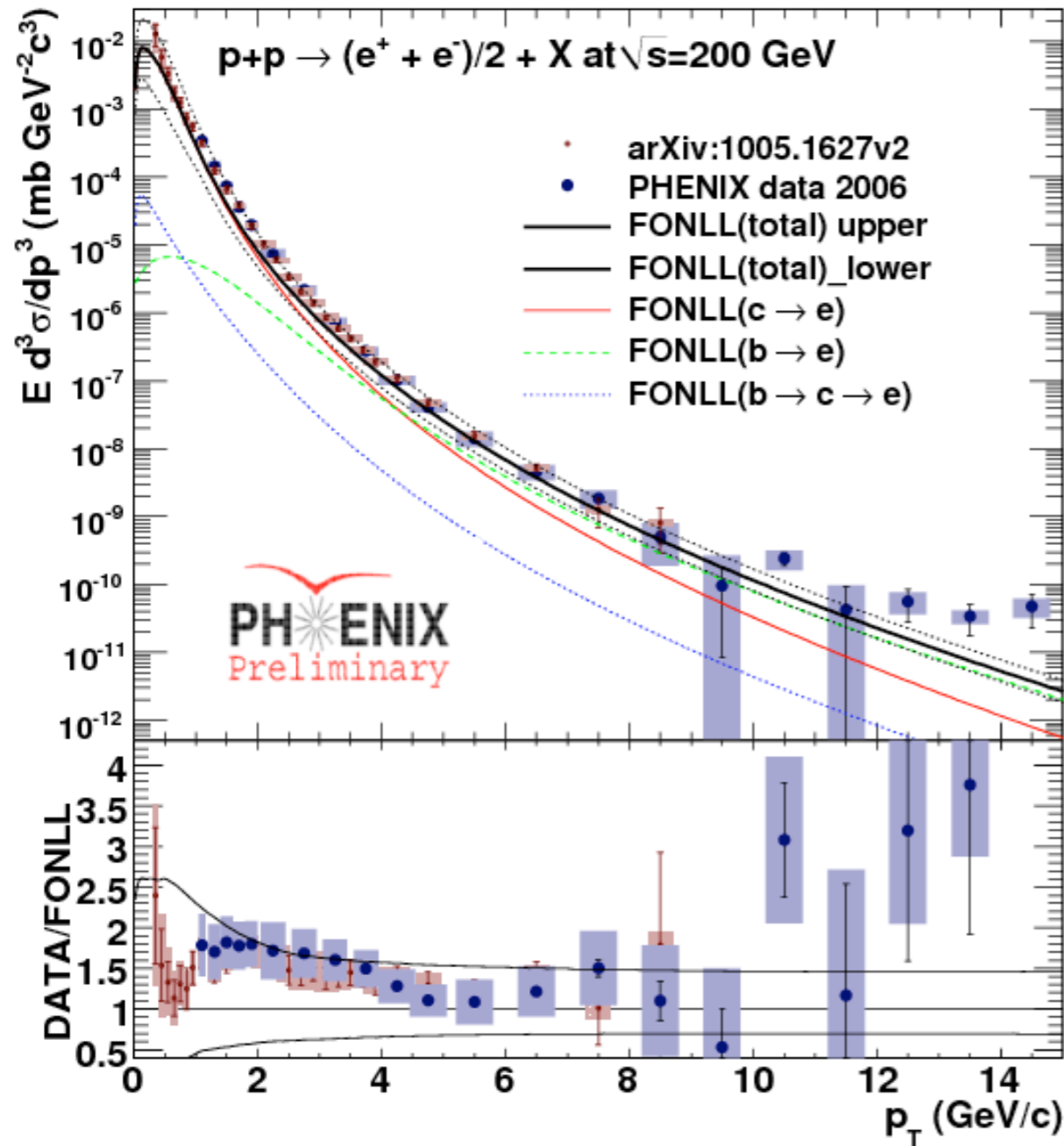
- kinematic range
  - $1.2 < |\eta| < 2.2$  at forward
  - $\Delta\varphi = 2\pi$
- $\sim 10\lambda$  absorber to reject hadrons
- Muon Tracker for momentum
- Muon identifier for hadron/muon separation



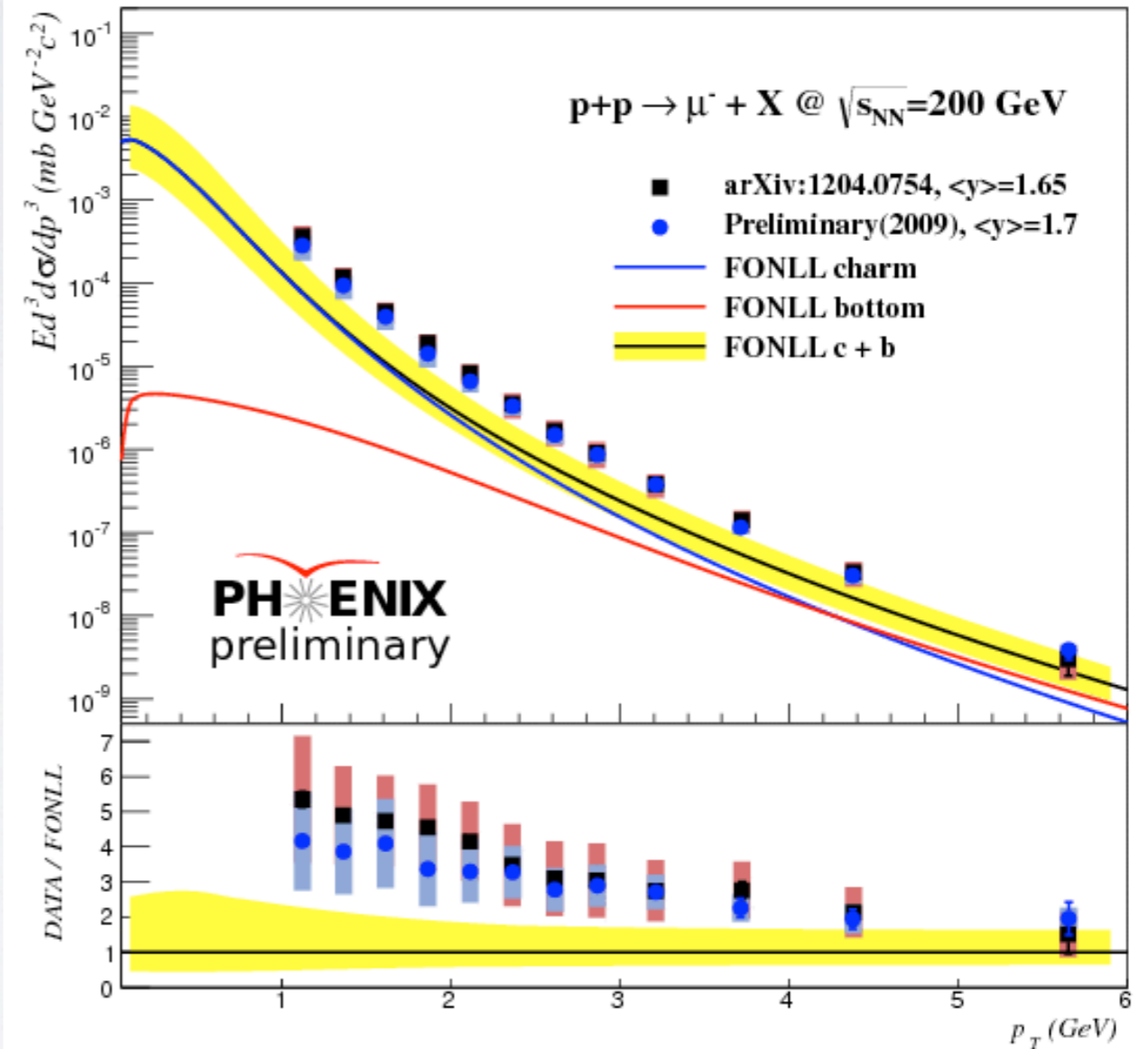
- Main background sources are decay muons from light hadrons and punch-through hadrons.
- Full MC simulation of hadron cocktail ( $\pi$ ,  $K$ ,  $p$ )
  - Tune to data by using z-vertex dependence of decay muons at MuID Gap 4 and yields of stopped hadrons at MuID Gap 2 and 3

# Heavy flavor in p+p collisions

mid-rapidity



forward rapidity

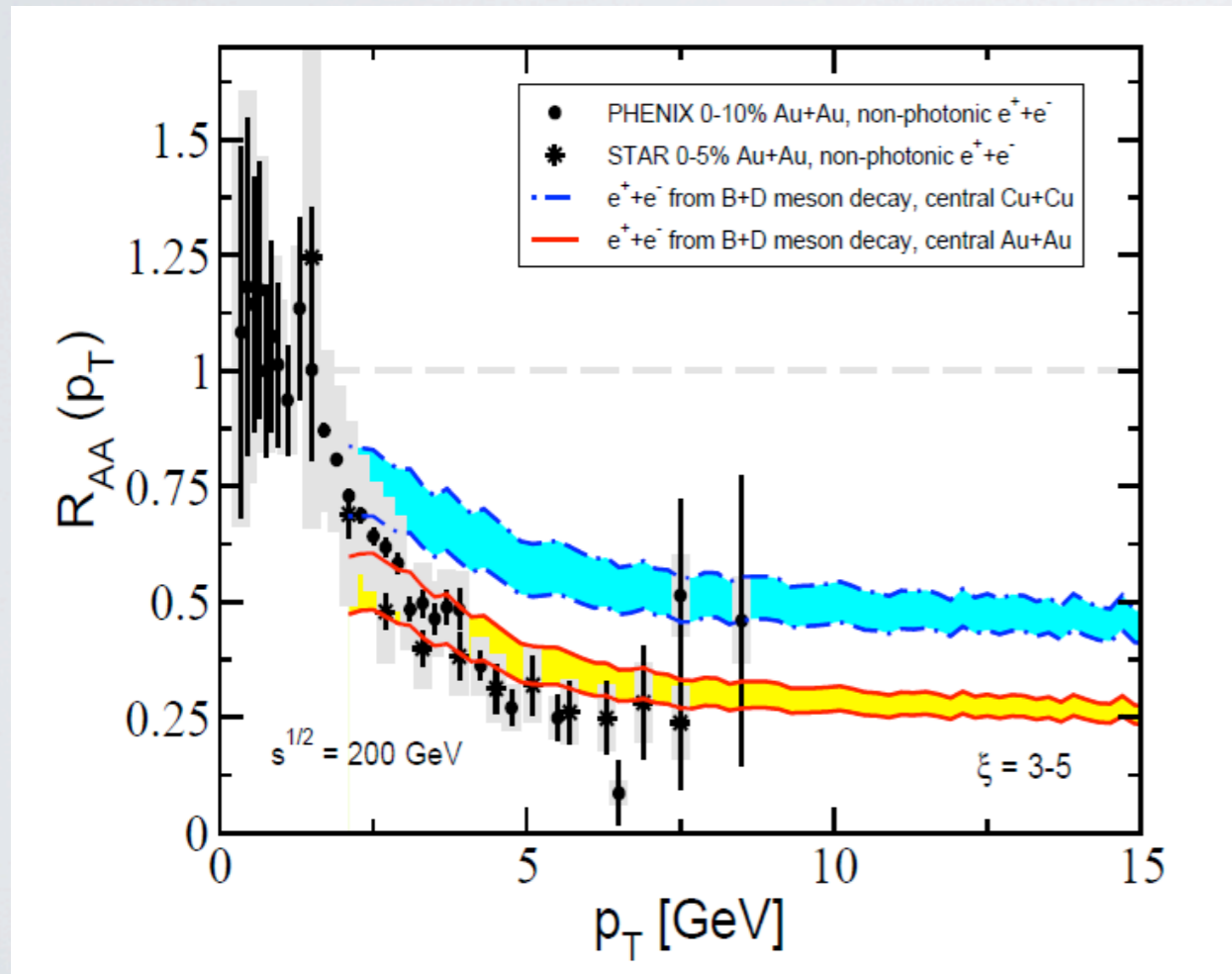


- Extend kinematic range and reduce uncertainties with enhanced statistics and improved analysis techniques

# Quantifying medium effects

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

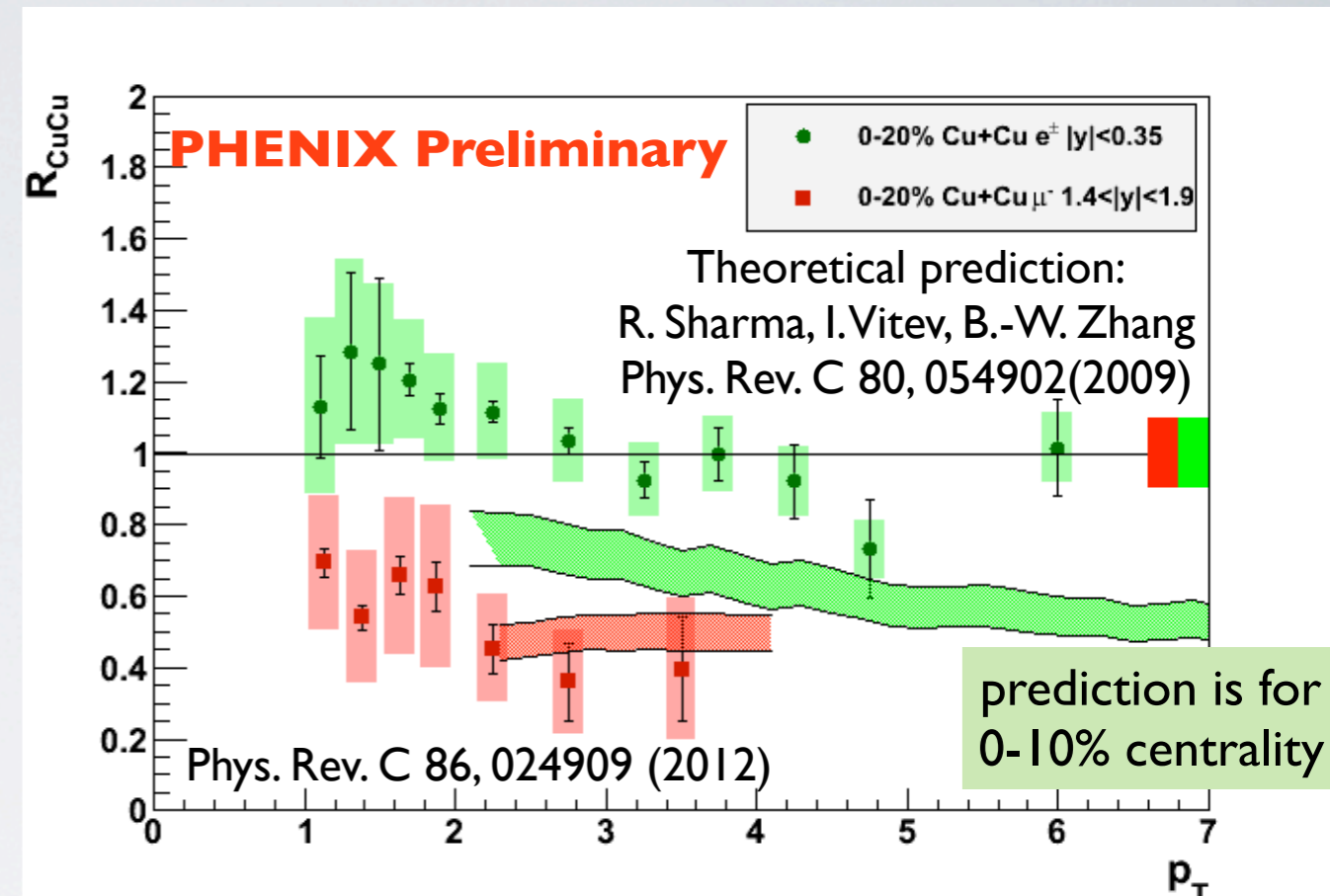
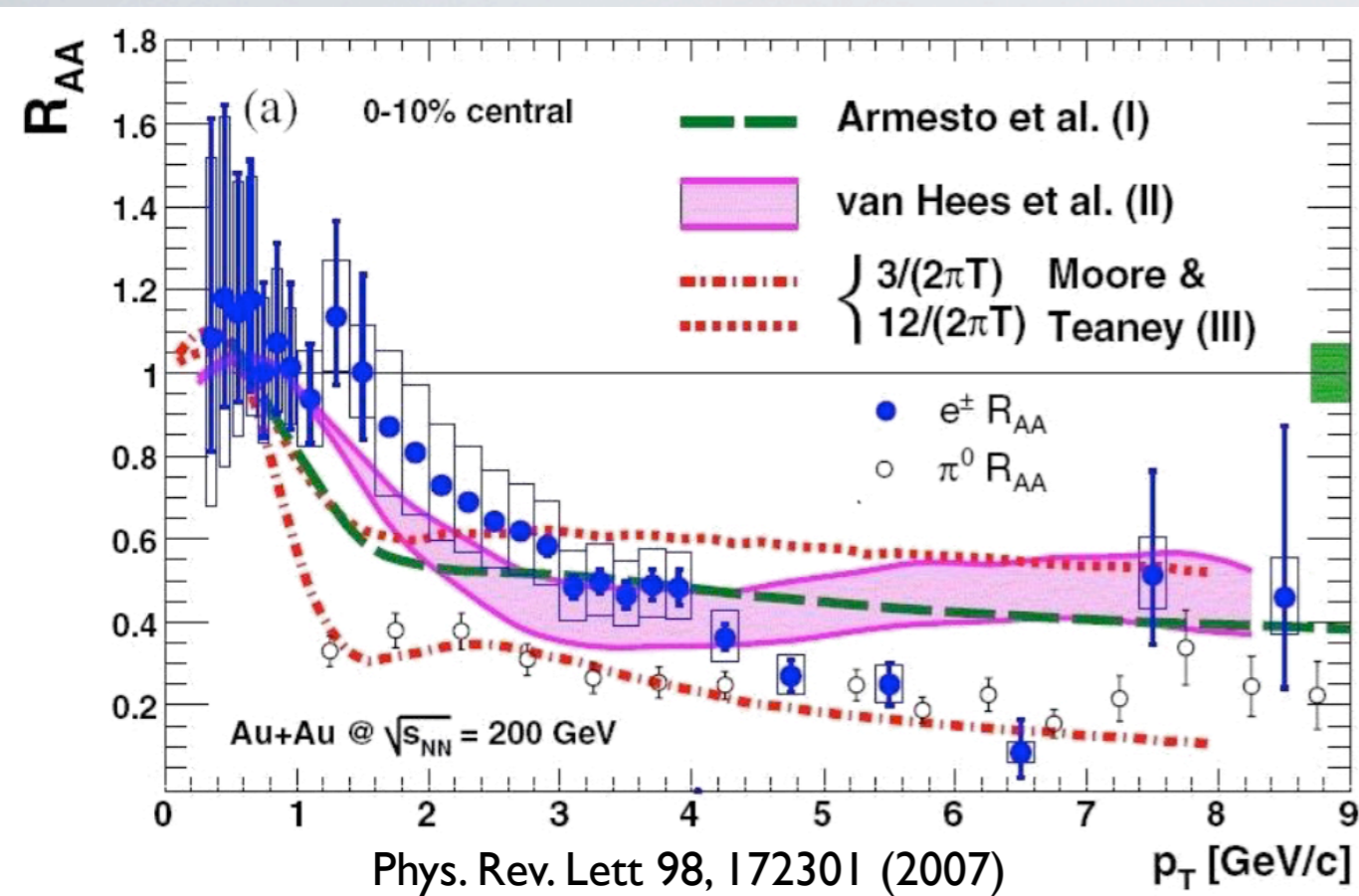
$$R_{AA} = \frac{dN_{AA}}{\langle N_{coll} \rangle \times dN_{pp}}$$



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

# Heavy flavor in HI collisions



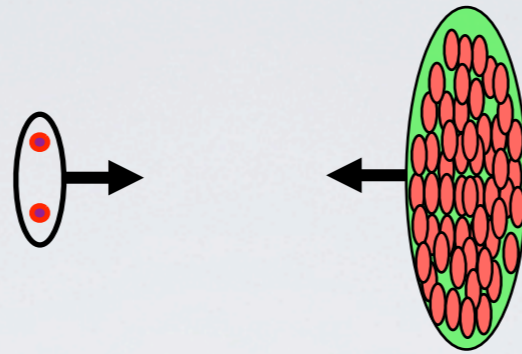
- Large suppression in central Au+Au collisions at mid-rapidity
- The most central (0-20%) Cu+Cu collisions
  - not much suppression at mid, but large suppression at forward
  - well describe suppression at forward rapidity with additional CNM effects (shadowing, initial energy loss)

# Cold Nuclear Matter in d(p)+A collisions

Backward rapidity

\*Au-going side

\* $x_1 < x_2$



parton of  $x_1$   
in d

parton of  $x_2$   
in Au

Forward rapidity

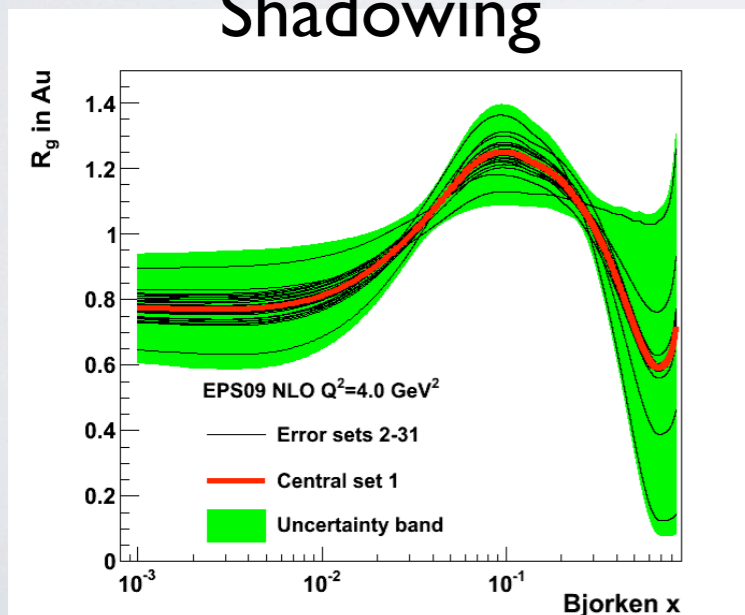
\*d-going side

\* $x_1 > x_2$

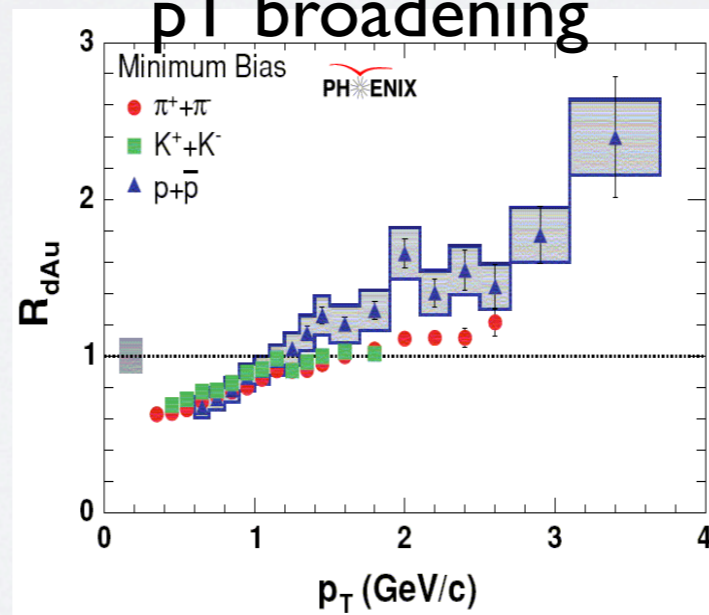
$$x_2 = \frac{Q}{\sqrt{s_{NN}}} e^{-y}$$

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

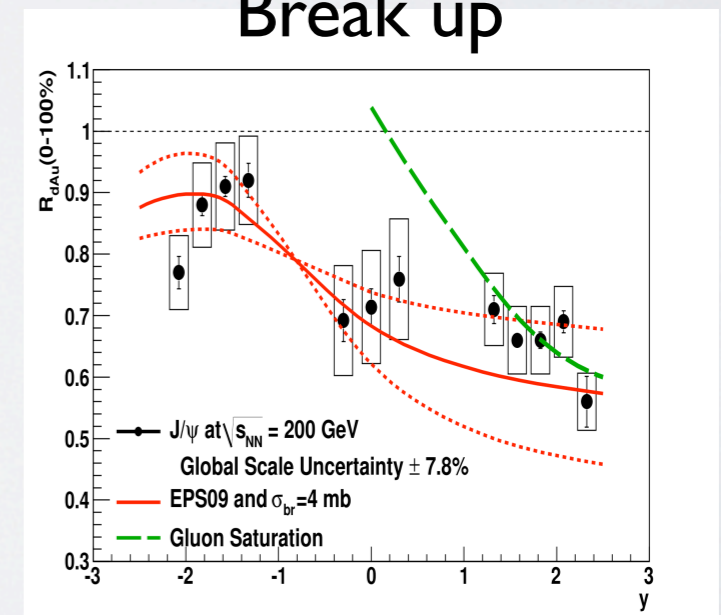
Shadowing



pT broadening

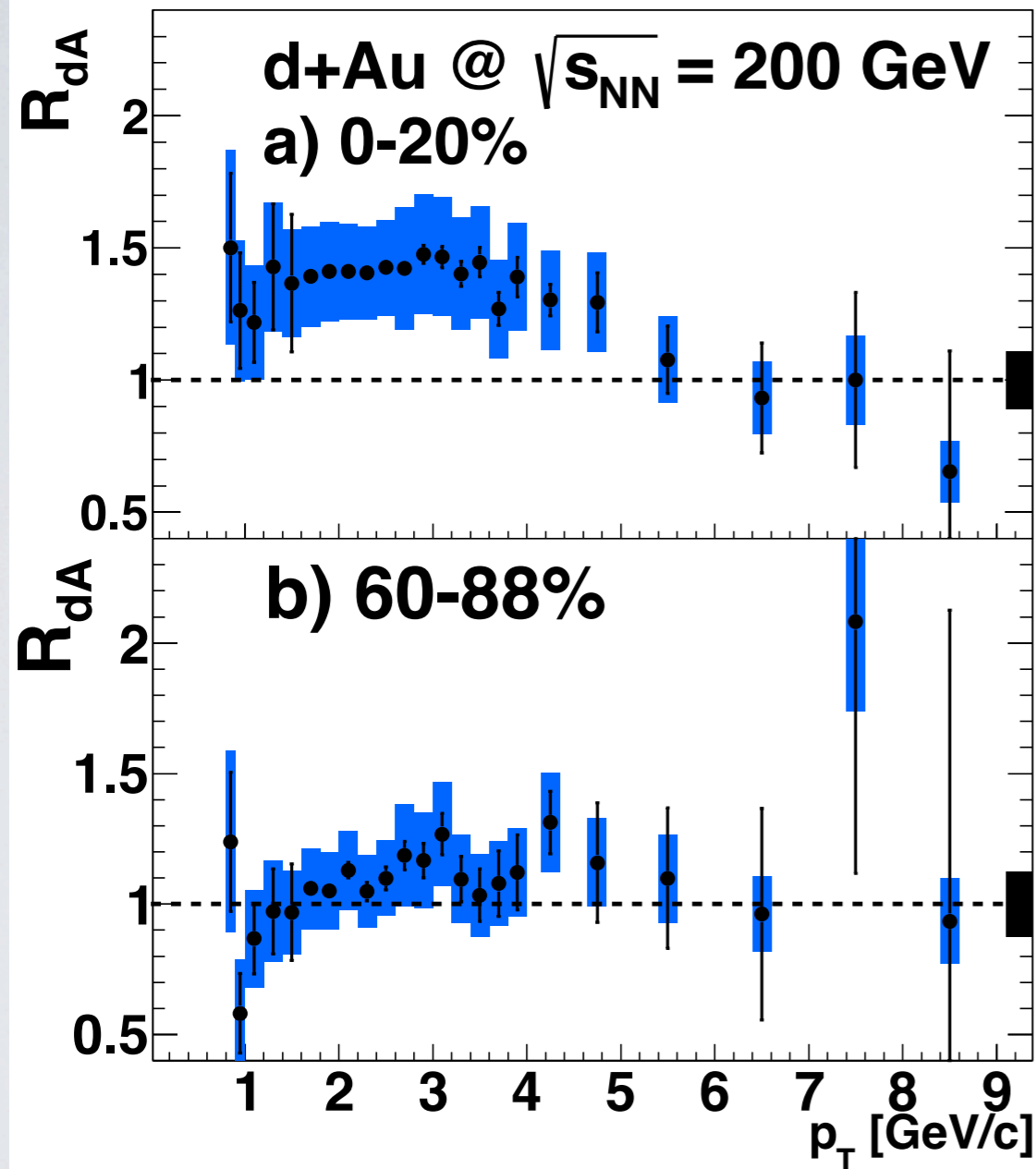


Break up



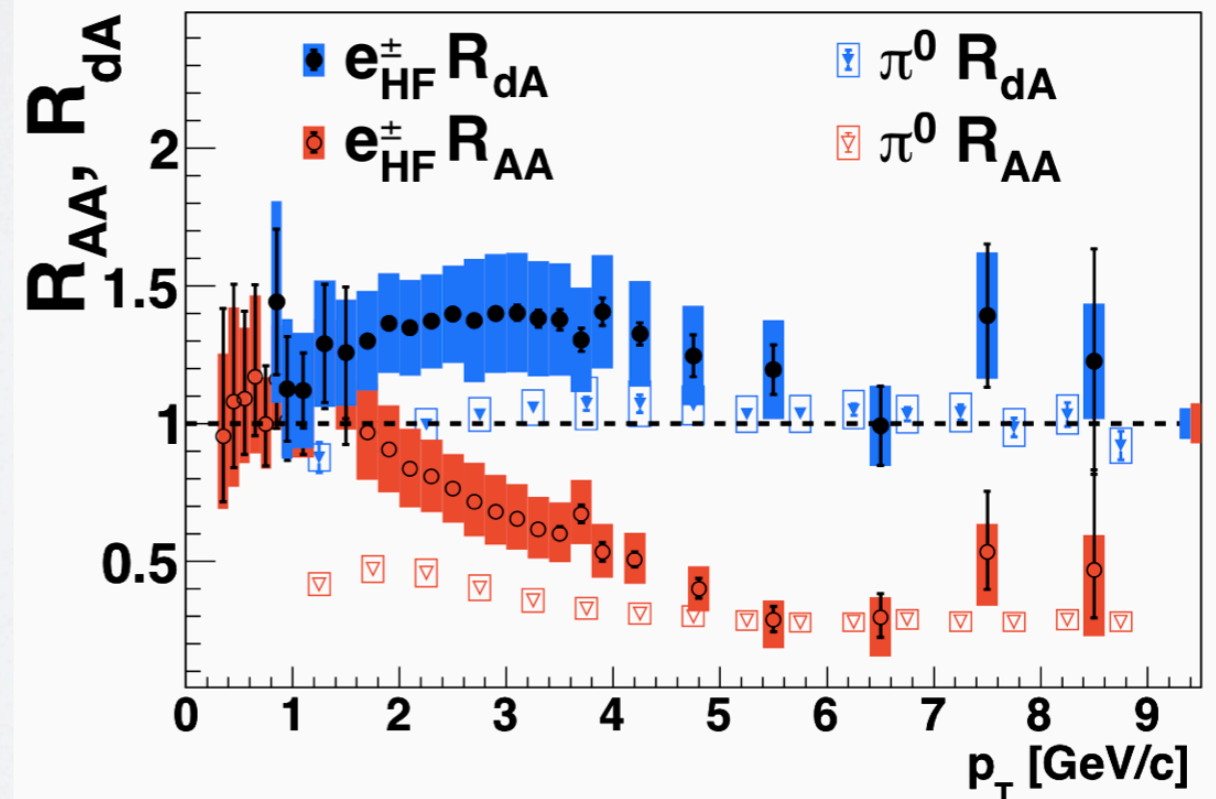
# HF electrons @ mid-rapidity

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



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

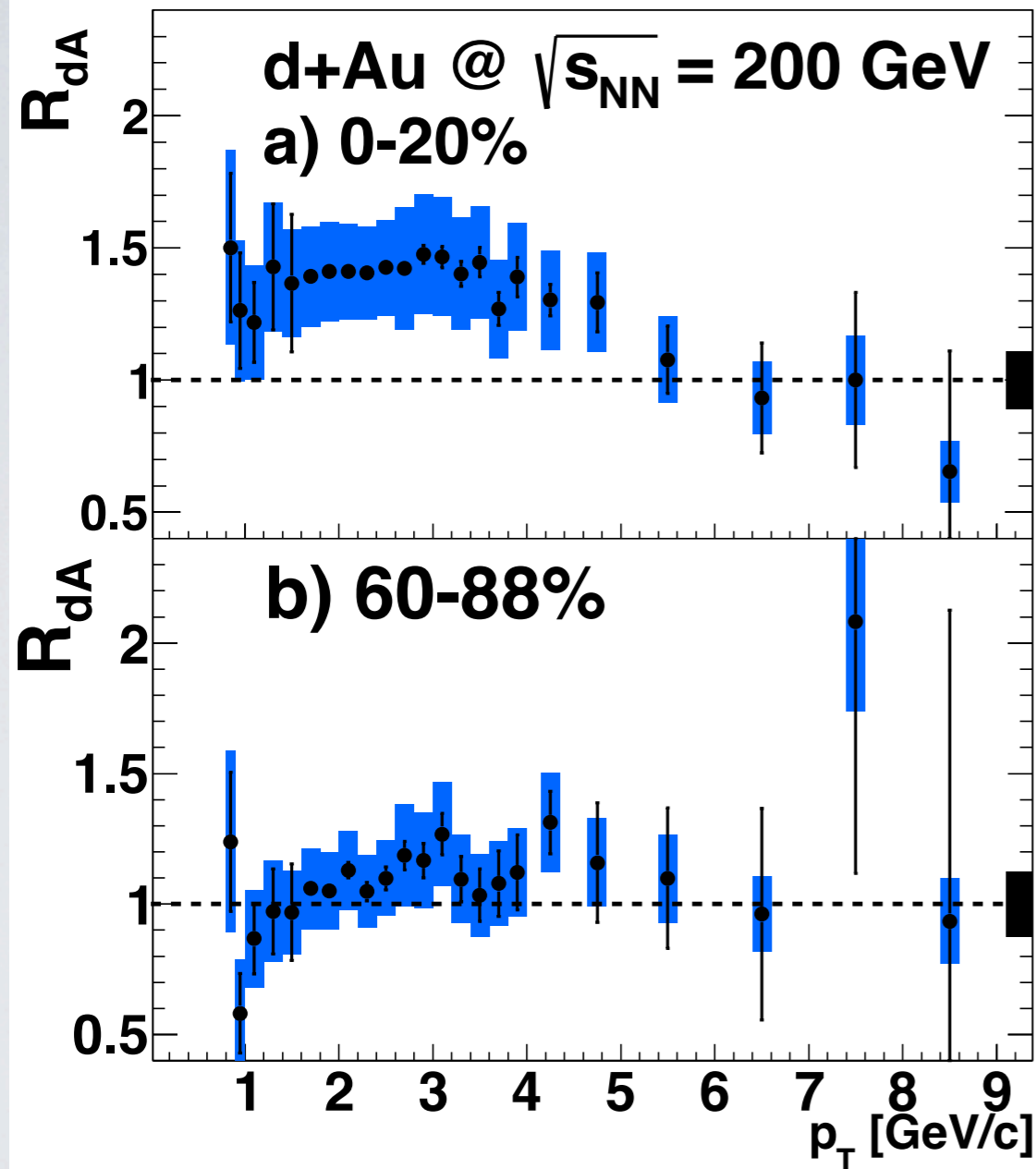
## 0-20% centrality



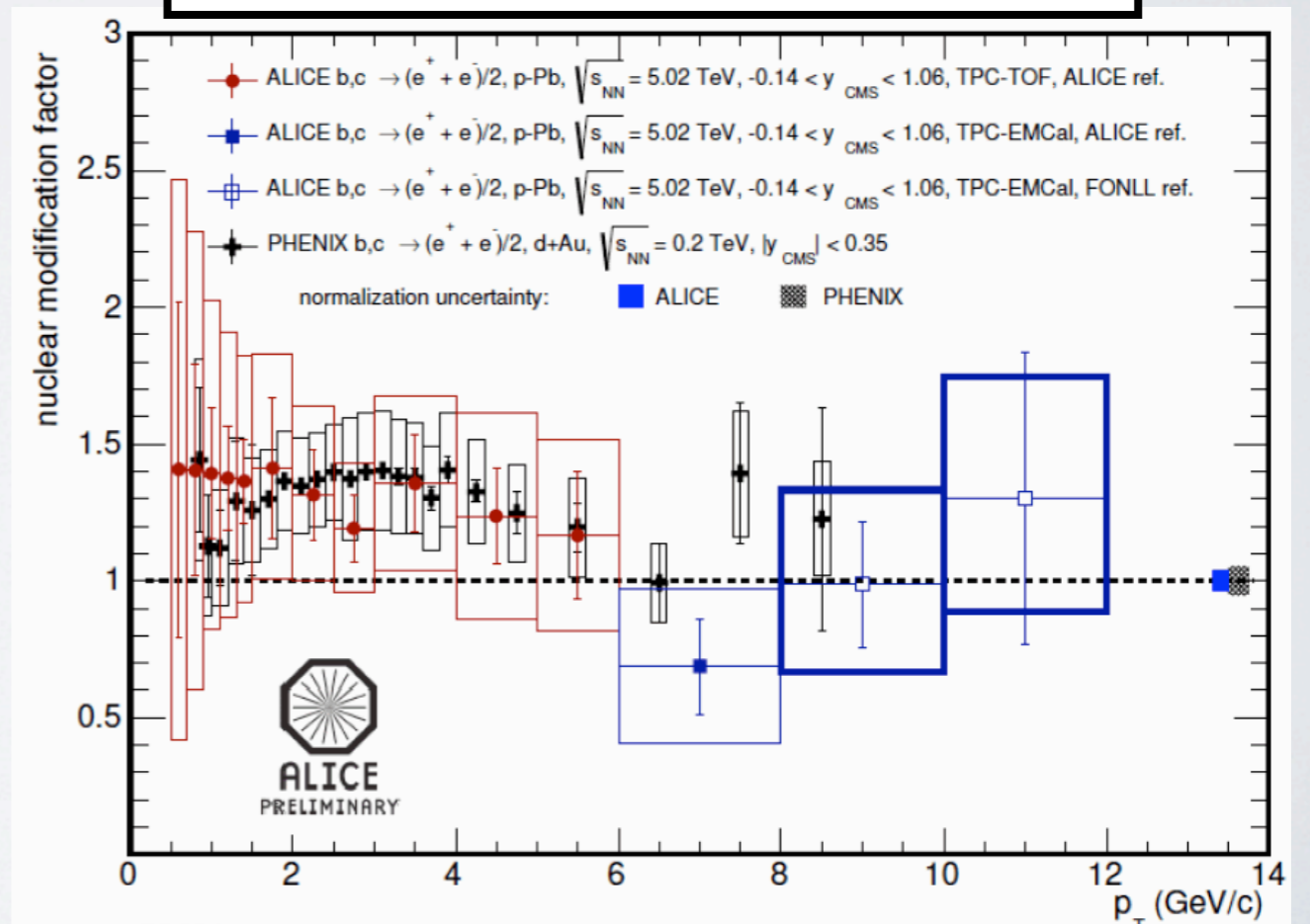
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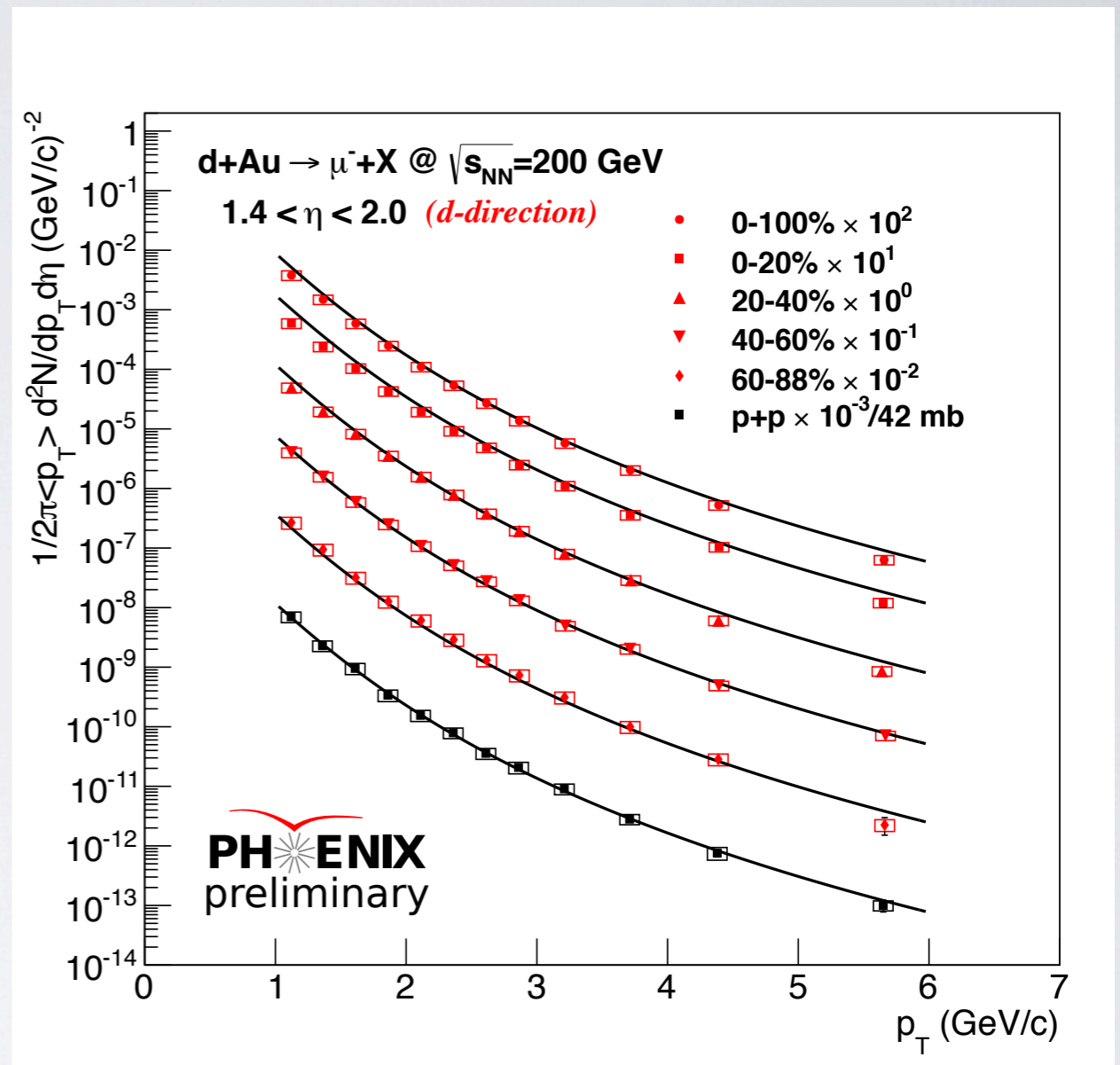
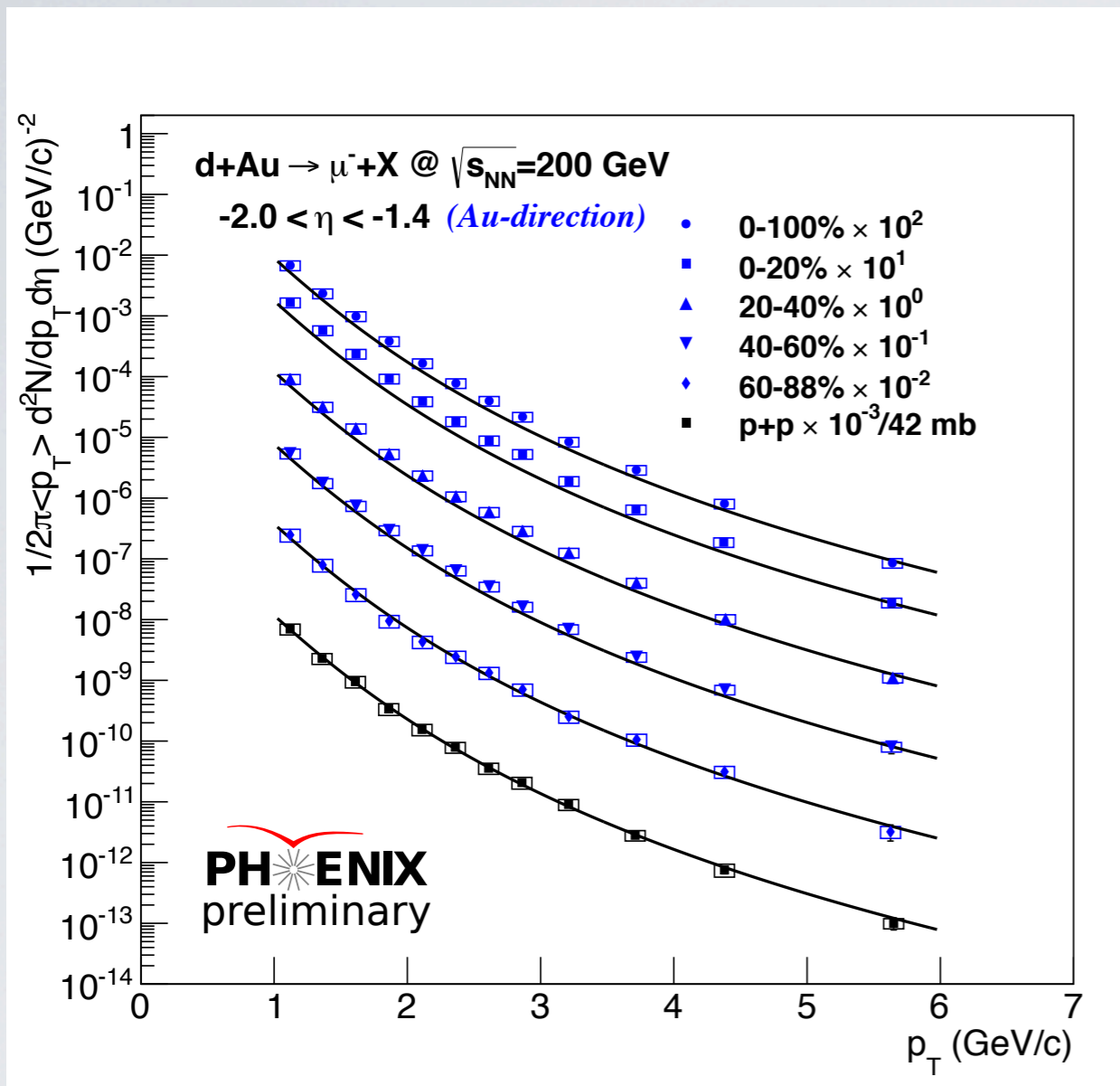
ALICE preliminary  
in SQM 13'



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

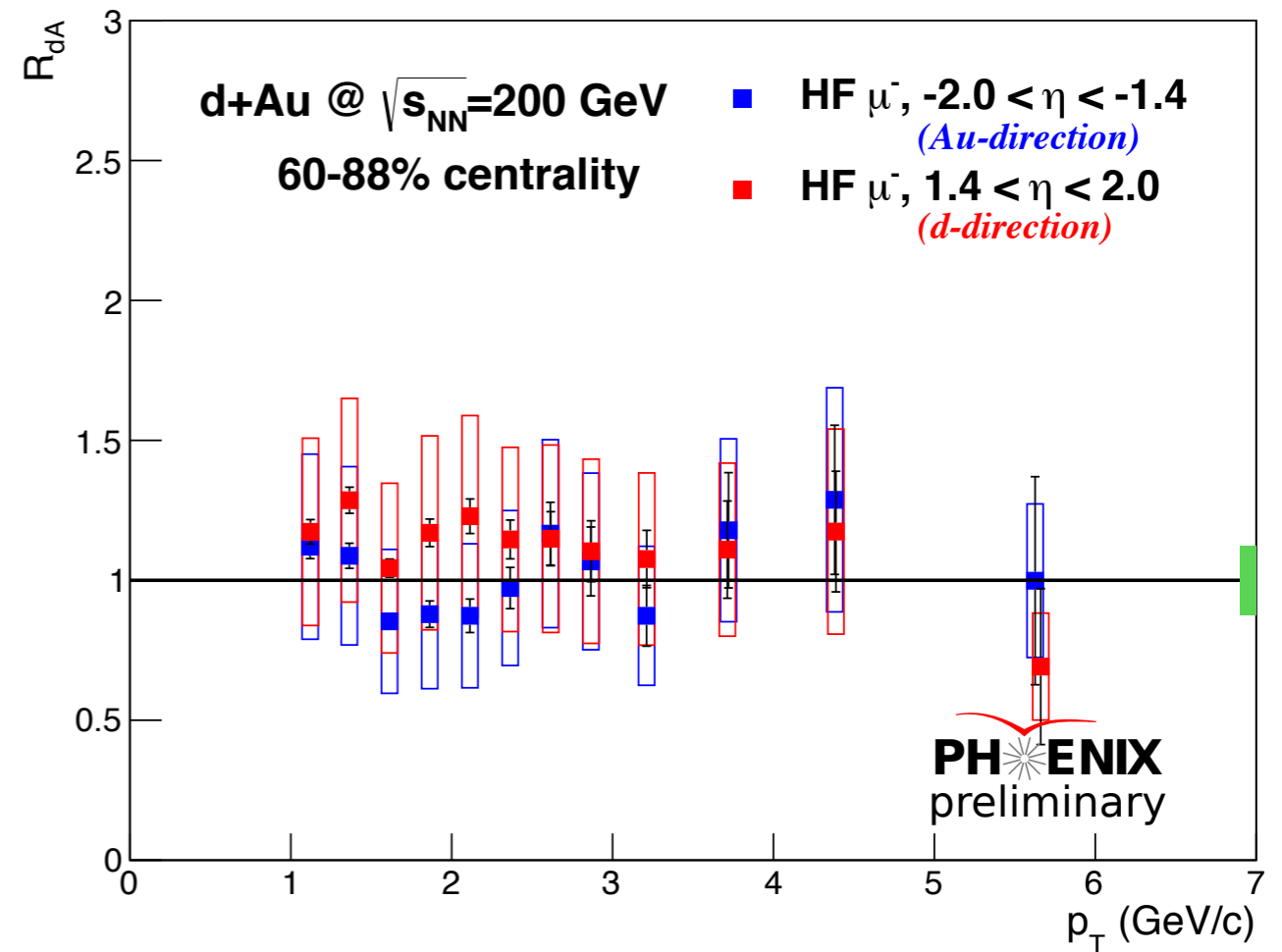
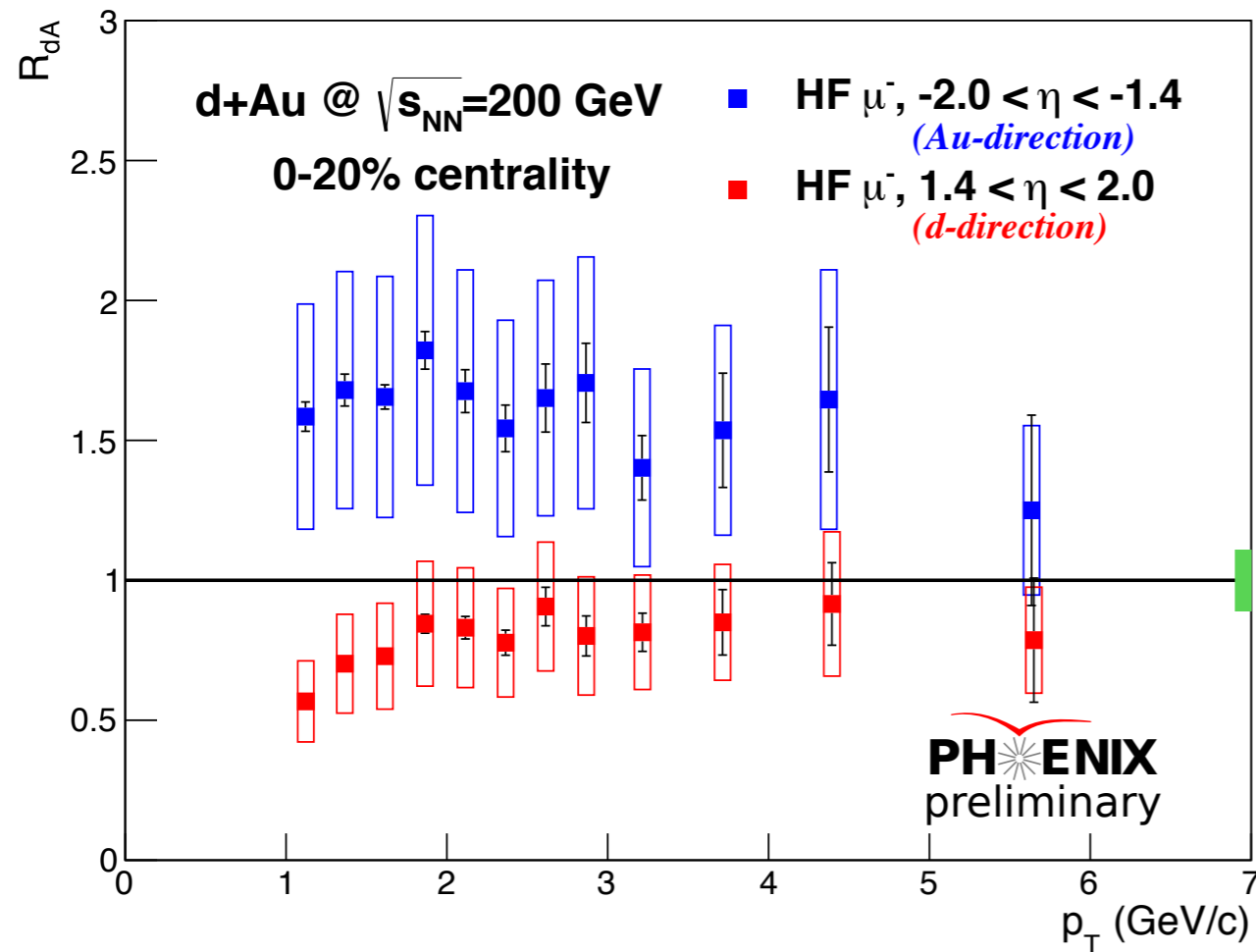


# HF muons @ forward & backward rapidity



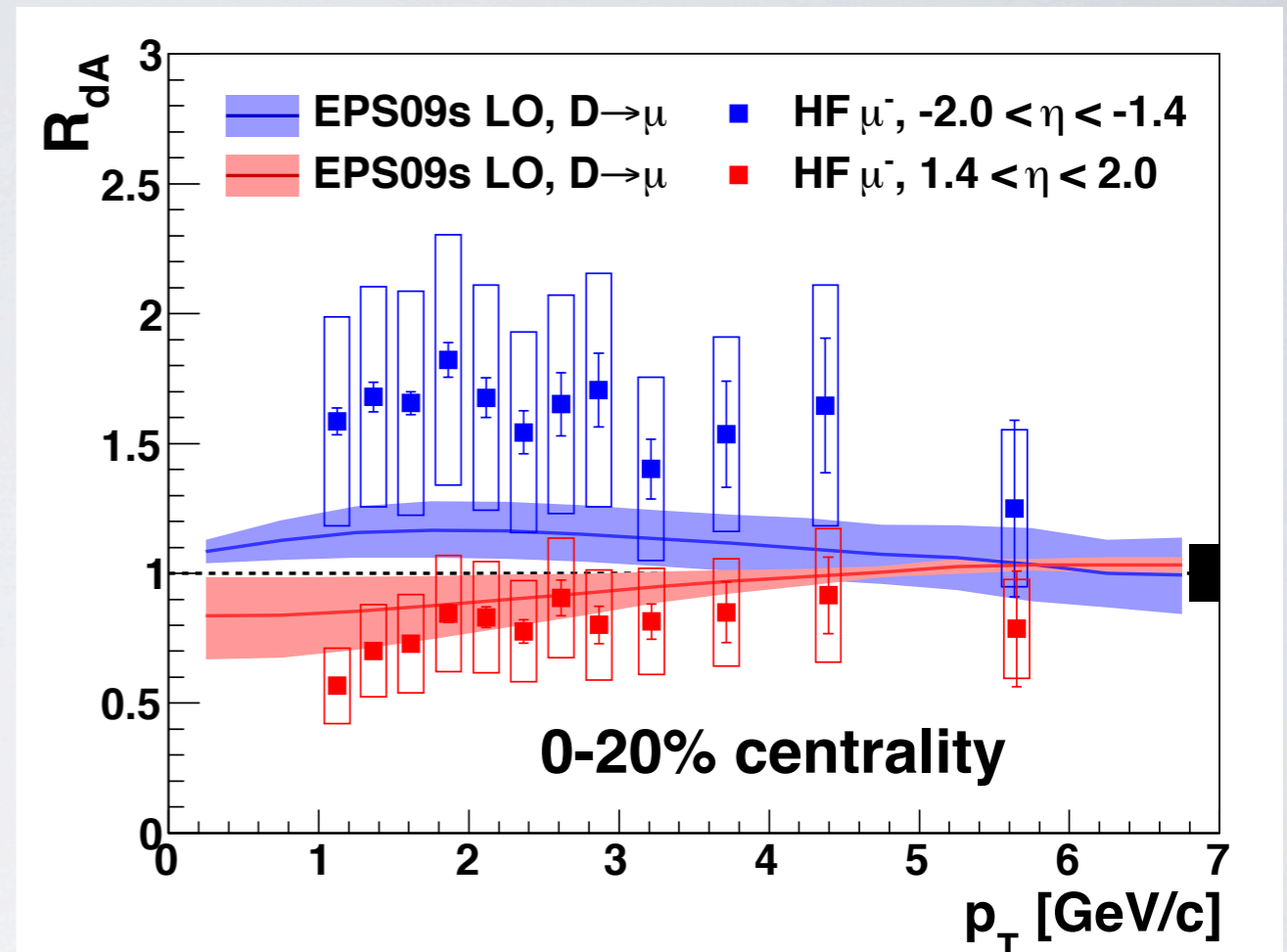
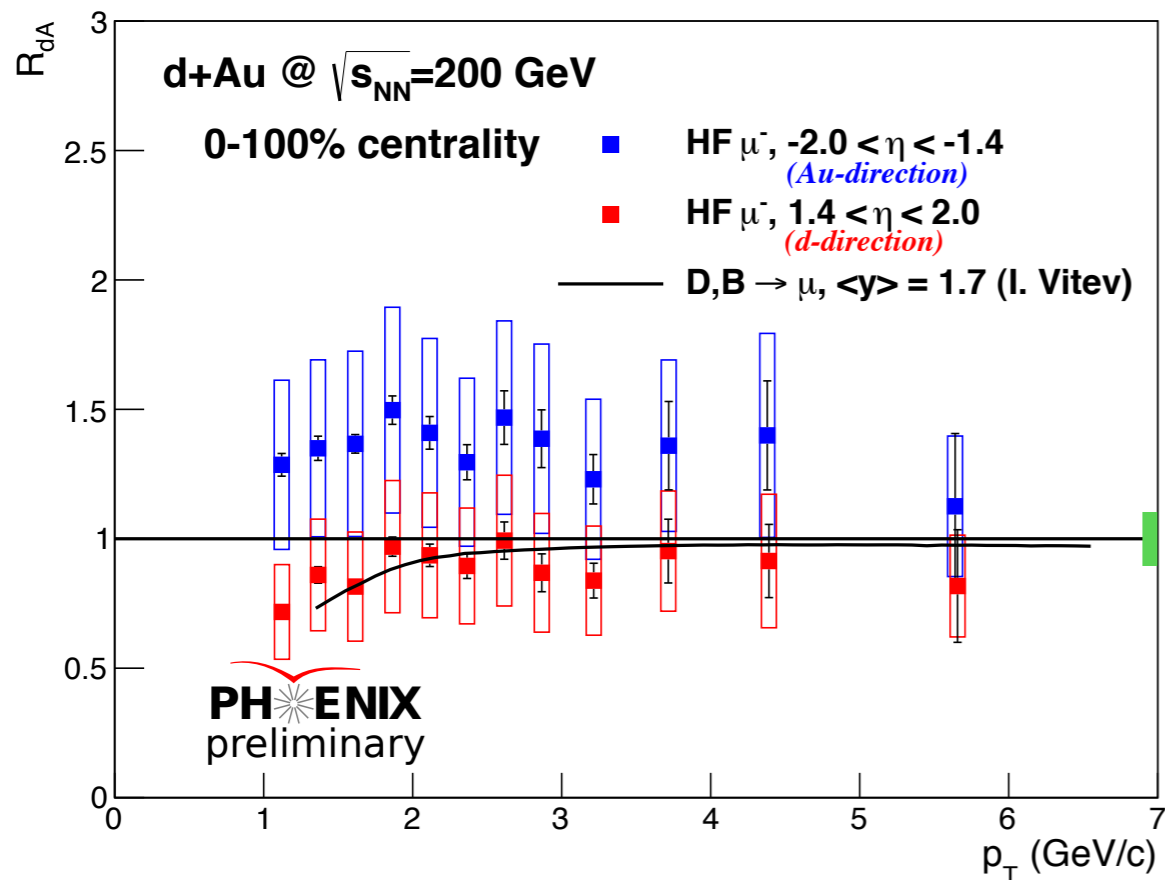
- HF single muons  $p_T$  spectra at **backward (Au-direction, left)** and at **forward (d-direction, right)** in d+Au collisions
  - lines are  $T_{AB}$  scaled fit function of spectra in p+p collisions

# HF muons $R_{dA}$ , central vs. peripheral



- 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!

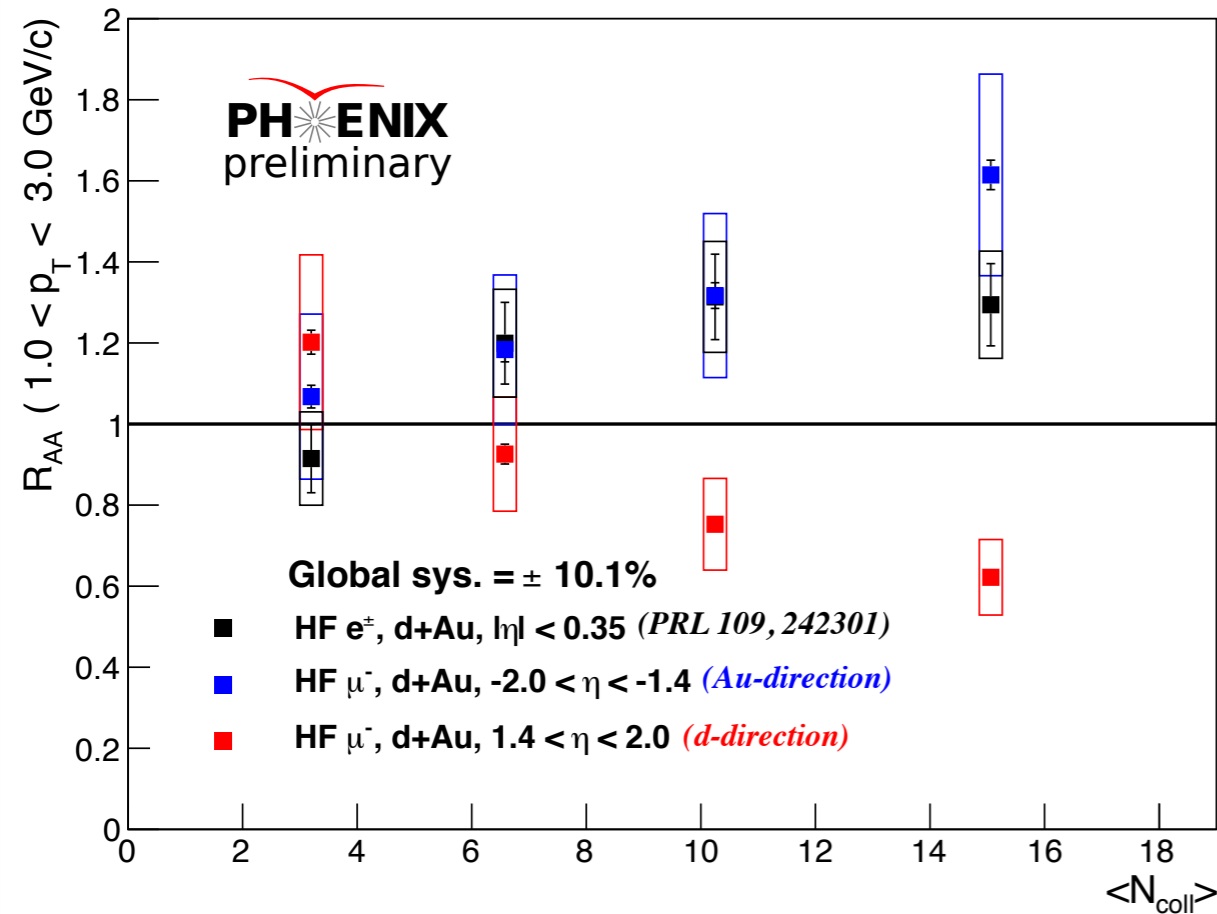
# Comparison to models



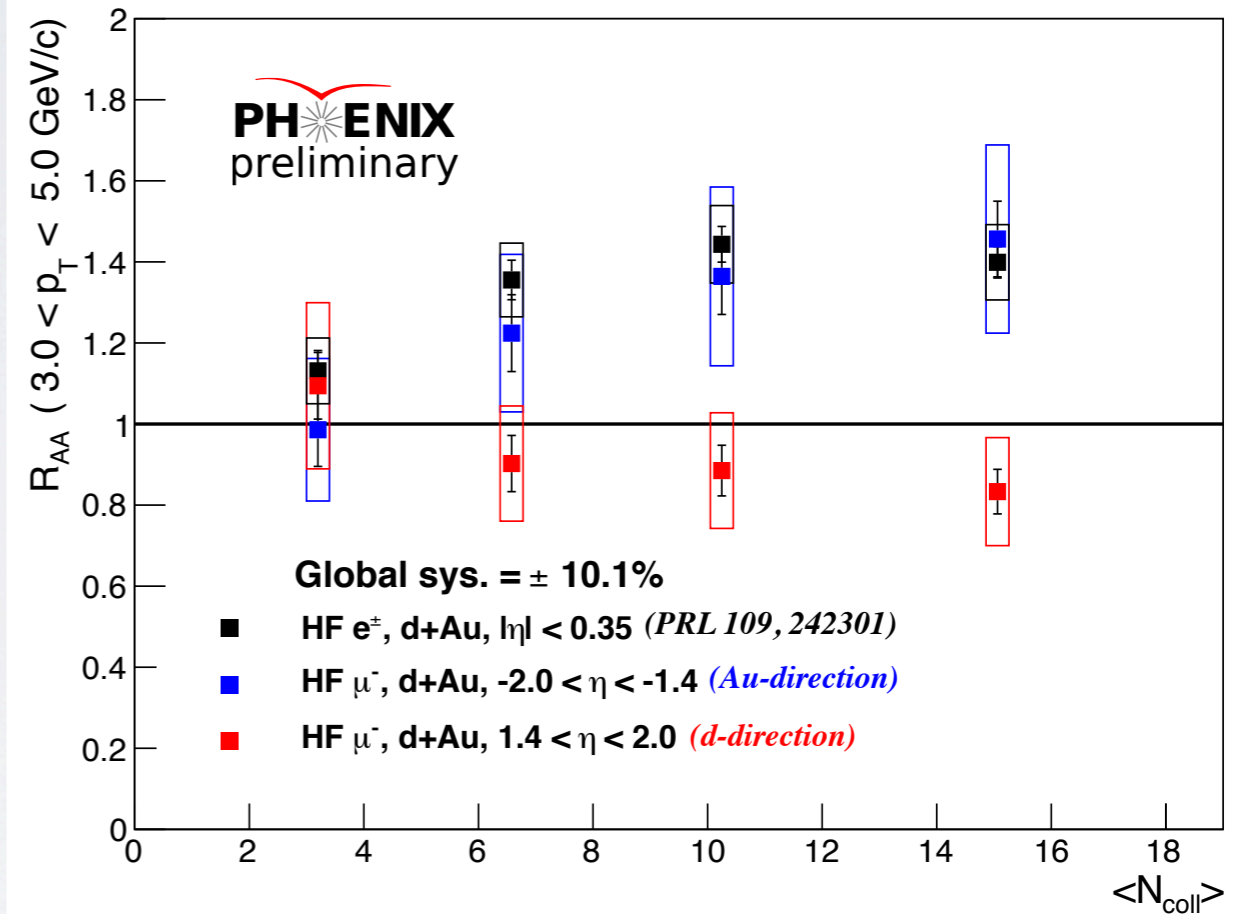
- good agreement with the prediction from I. Vitev
  - muon production from D and B meson at  $\langle y \rangle = 1.7$
  - considering shadowing, Cronin effect and initial parton energy loss
- EPS09s nPDF evaluation with PYTHIA
  - consistent with data at forward rapidity as well

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

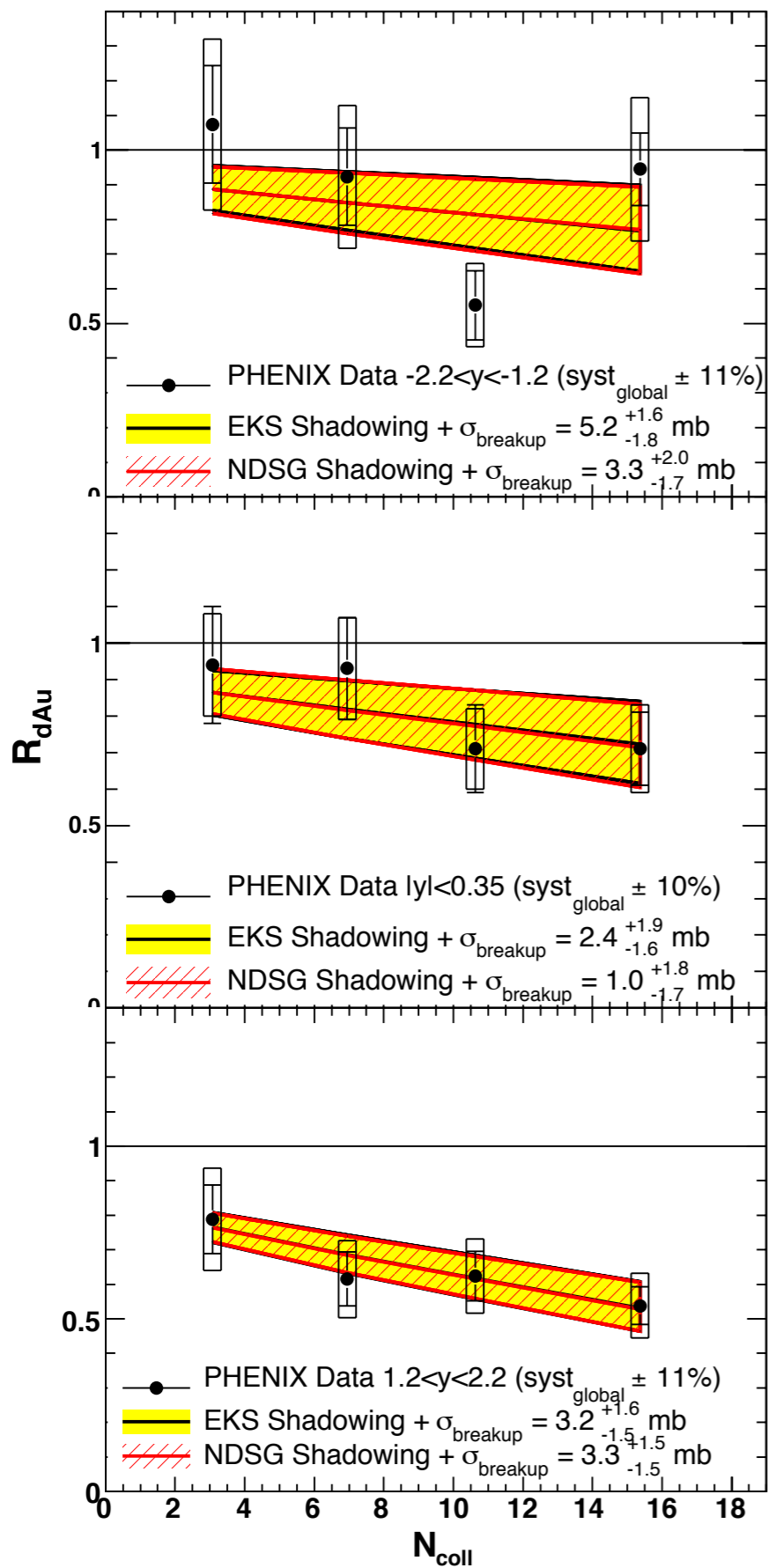
$1.0 < p_T < 3.0 \text{ GeV}/c$



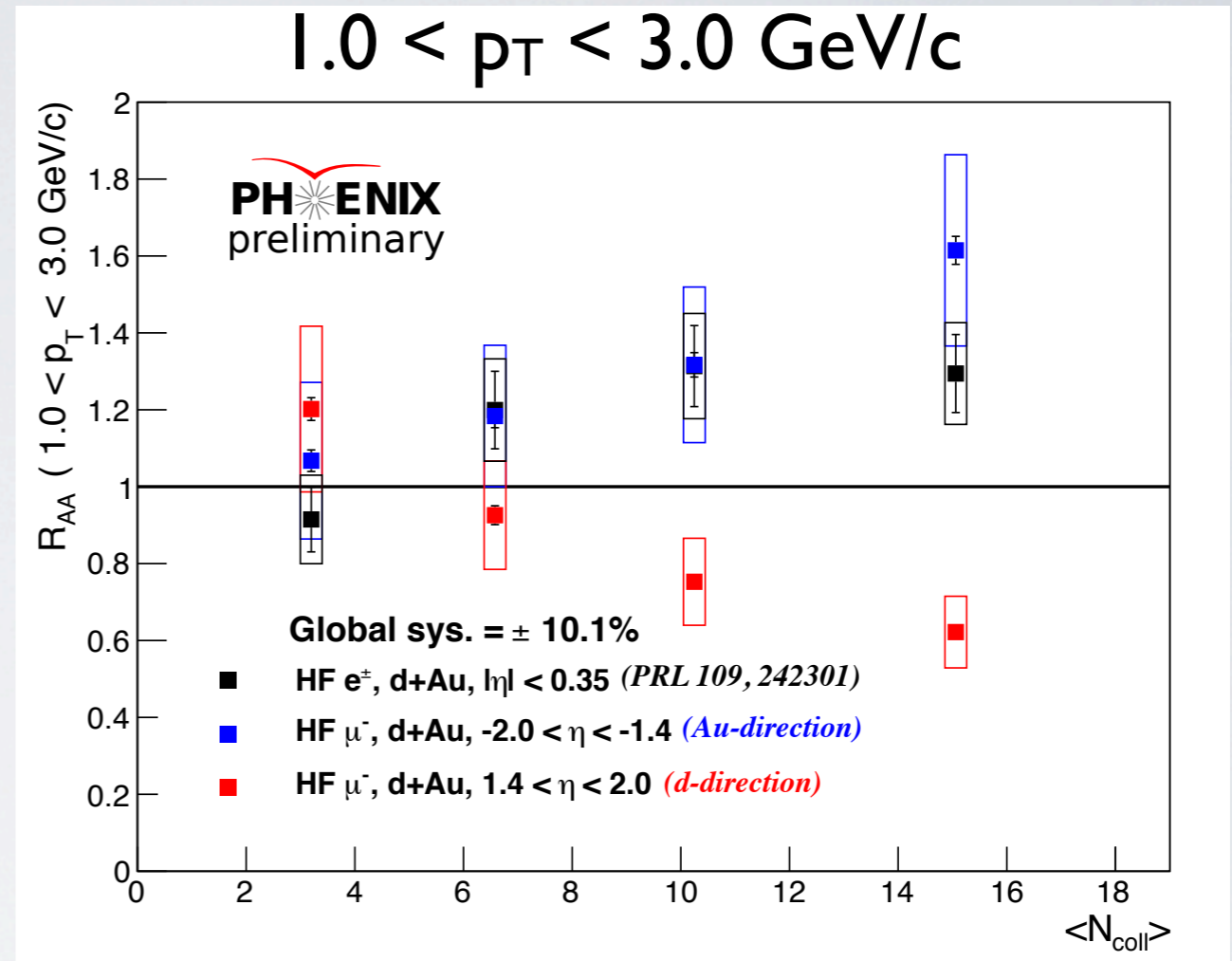
$3.0 < p_T < 5.0 \text{ GeV}/c$



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

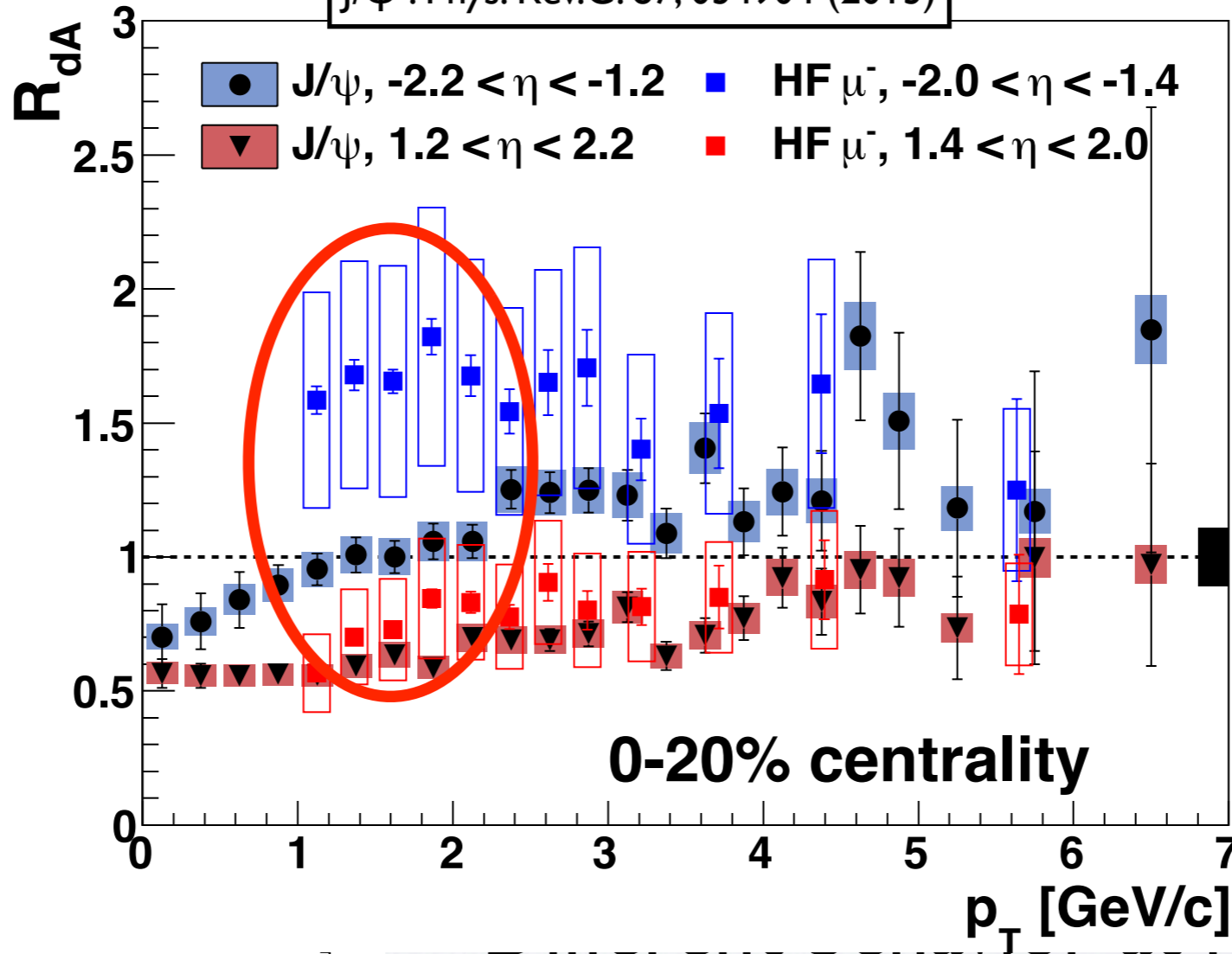
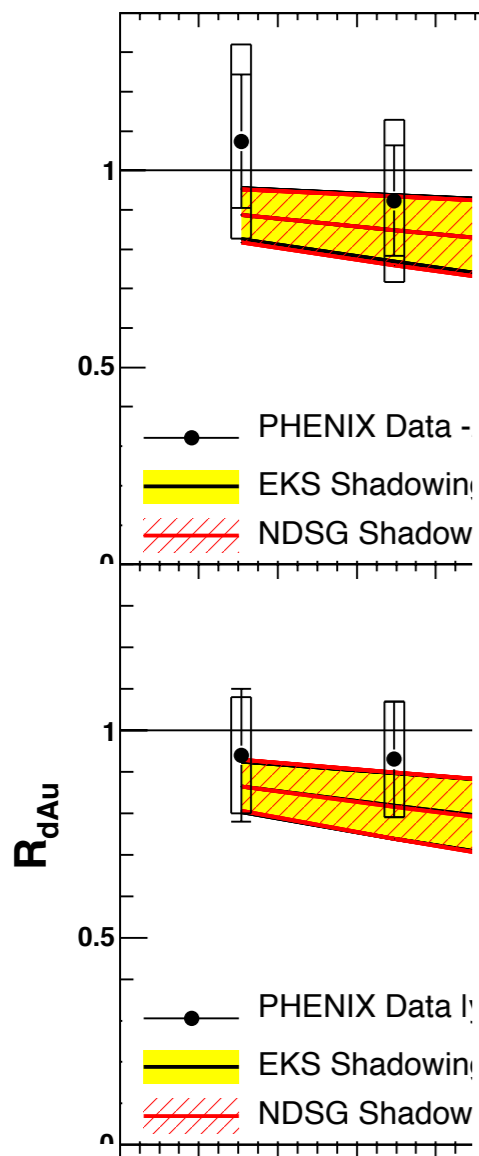


# Comparison to $J/\psi$

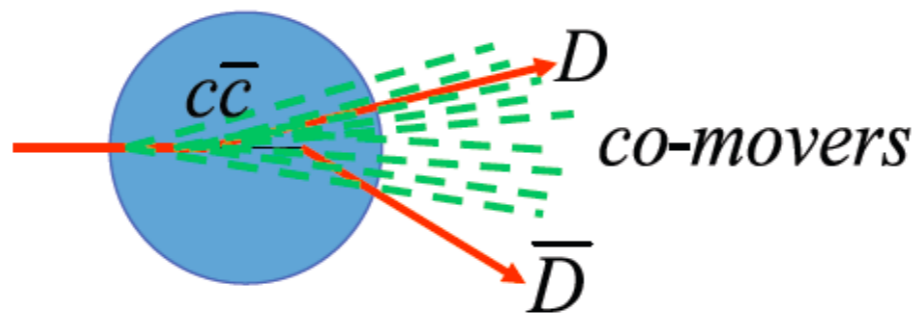
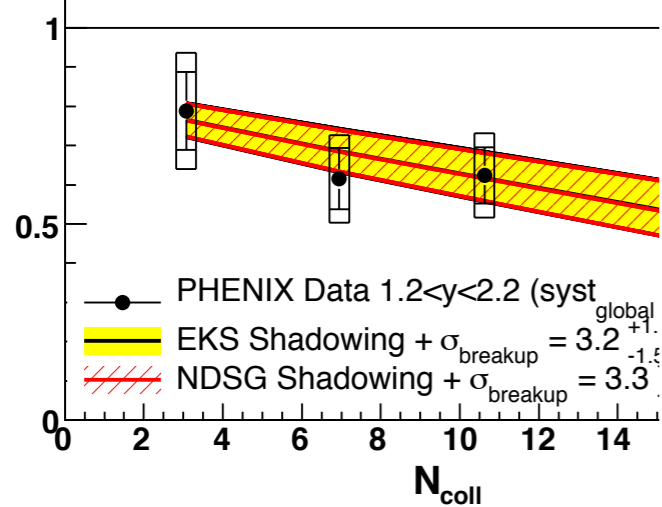
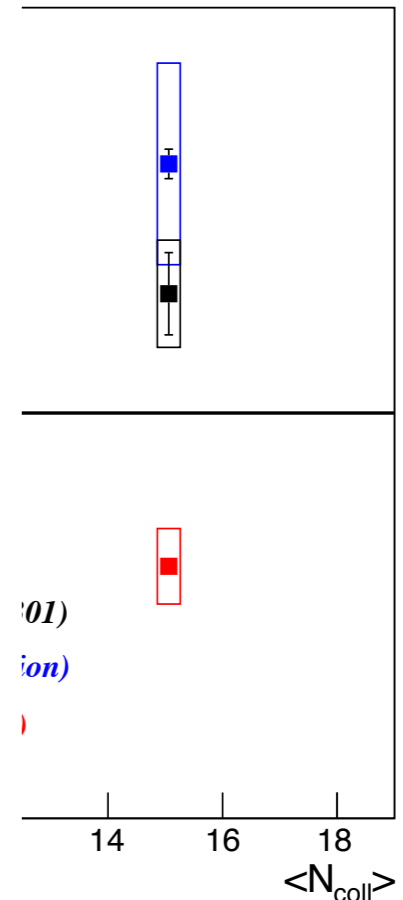


- Different behavior at mid- and backward rapidity depending on centrality
- significant role of break-up in quarkonia production?

$J/\psi$  : Phys. Rev.C. 87, 034904 (2013)



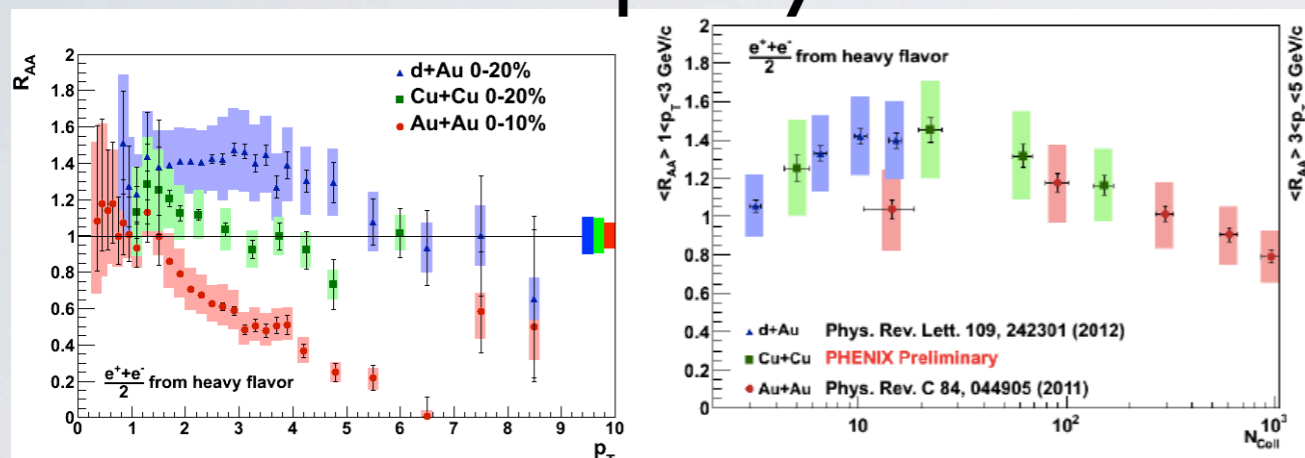
eV/c



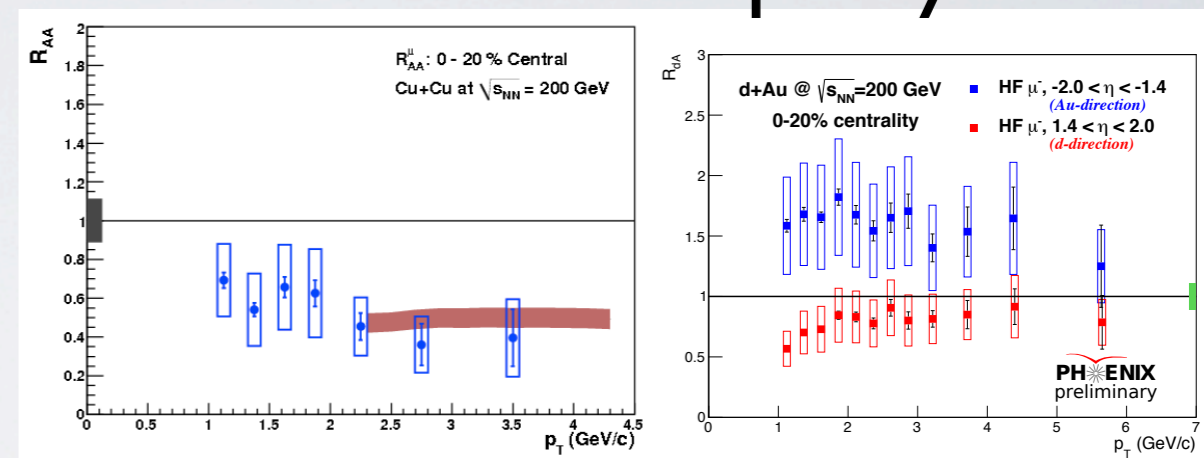
d- and  
 depending on  
 f break-up in  
 tion?

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

## mid-rapidity



## forward-rapidity

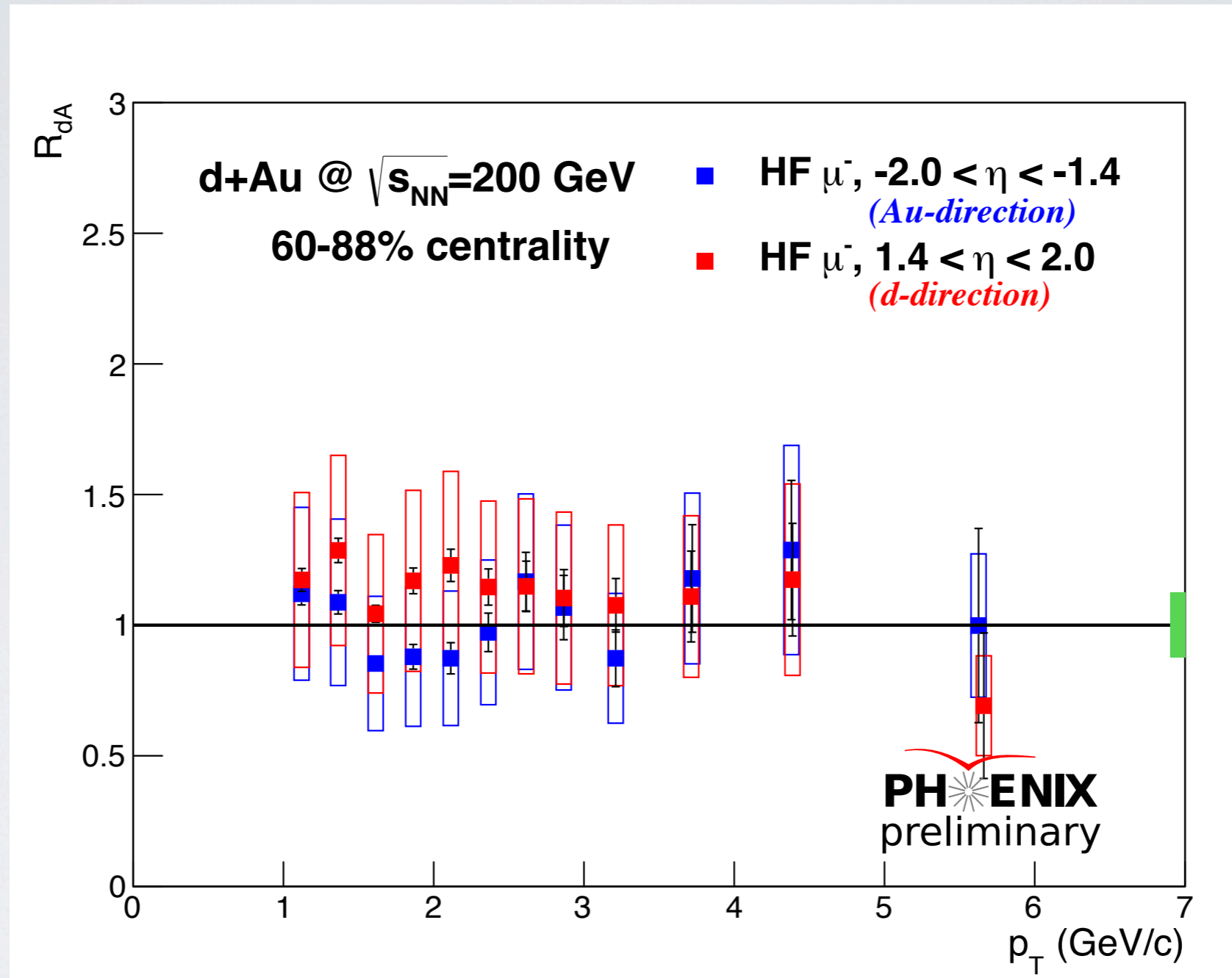


- Theoretical prediction works well!
  - consistent with Au+Au and over predicts suppression in Cu+Cu at mid-rapidity
  - consistent with d+Au and Cu+Cu at forward rapidity
- New PHENIX inner silicon vertex tracker system (VTX & FVTX) provides precise vertex position and allows to separate charm and bottom meson.

**Thank you!**

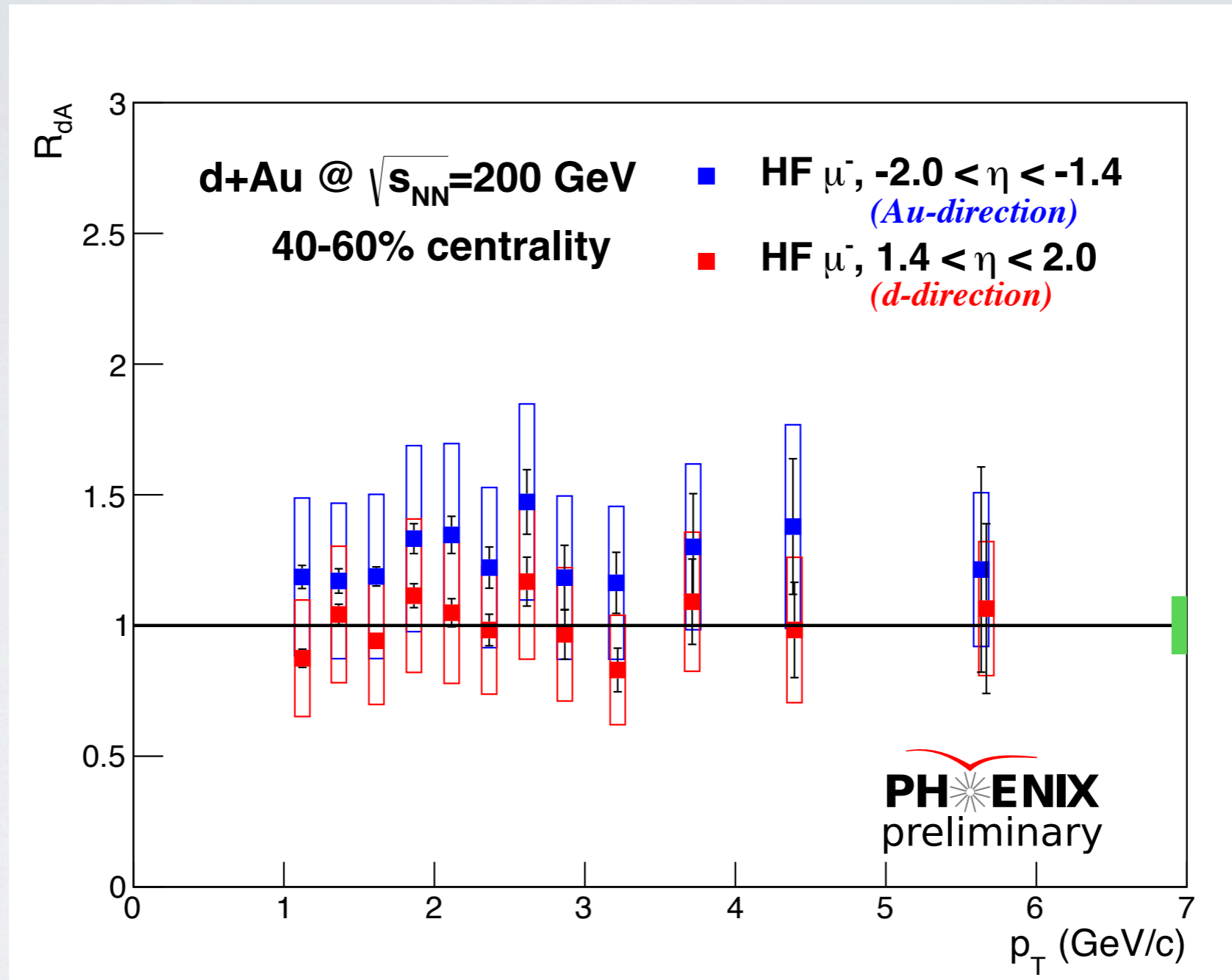
**Back up**

# Heavy flavor single muons $R_{dA}$ , 60 - 88%

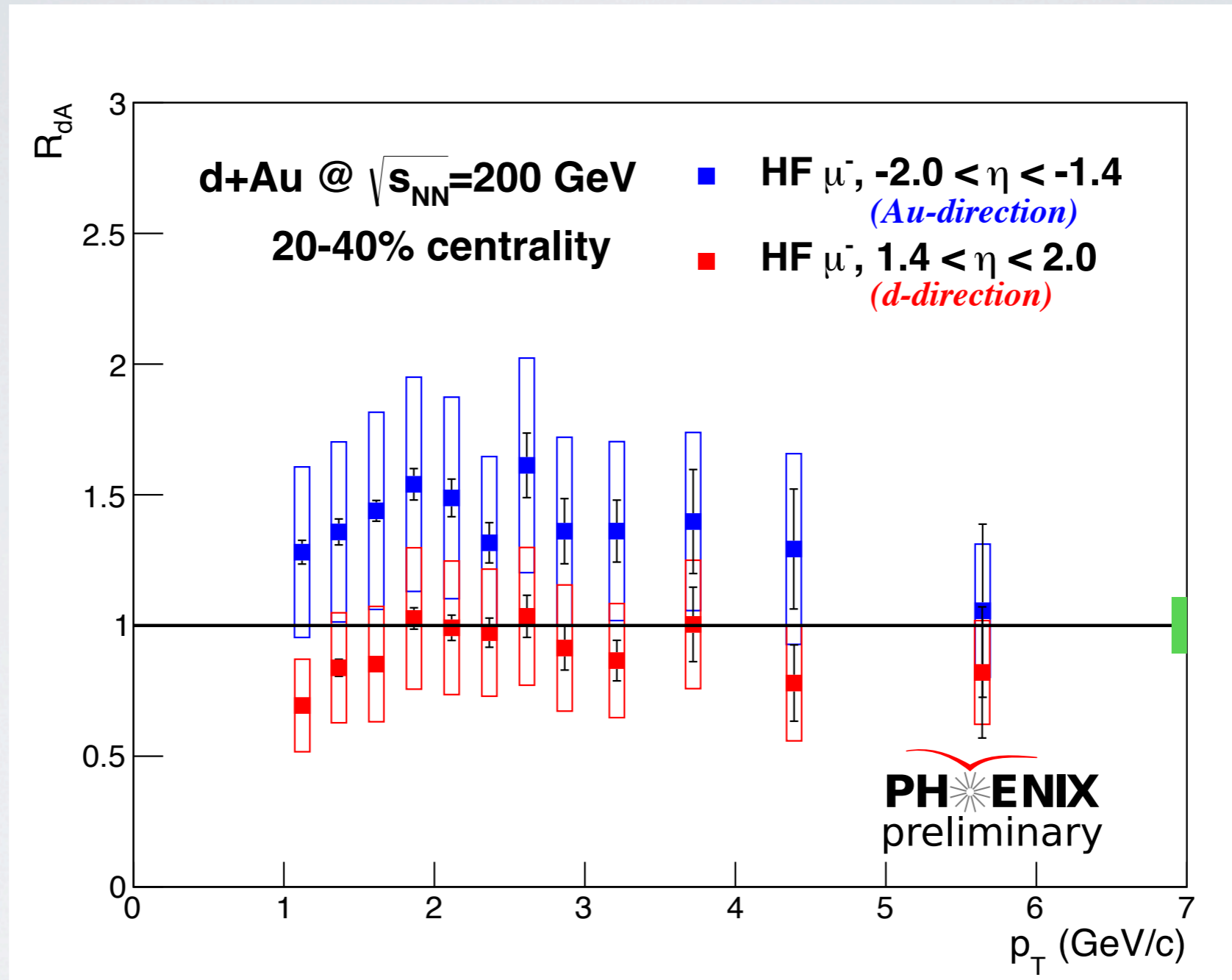


Consistent between forward and backward  
in the most peripheral d+Au collisions

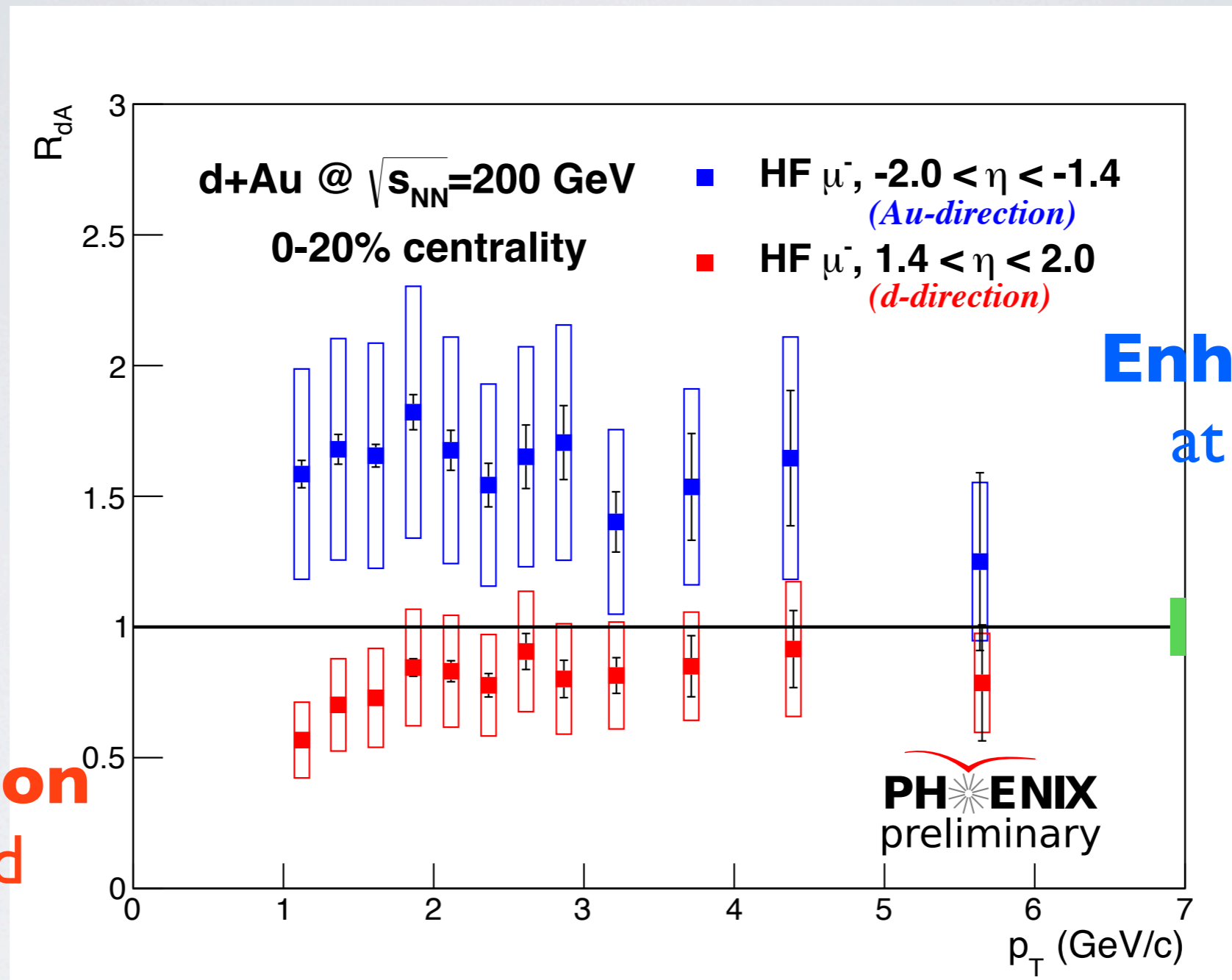
# Heavy flavor muons $R_{dA}$ , 40 - 60%



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



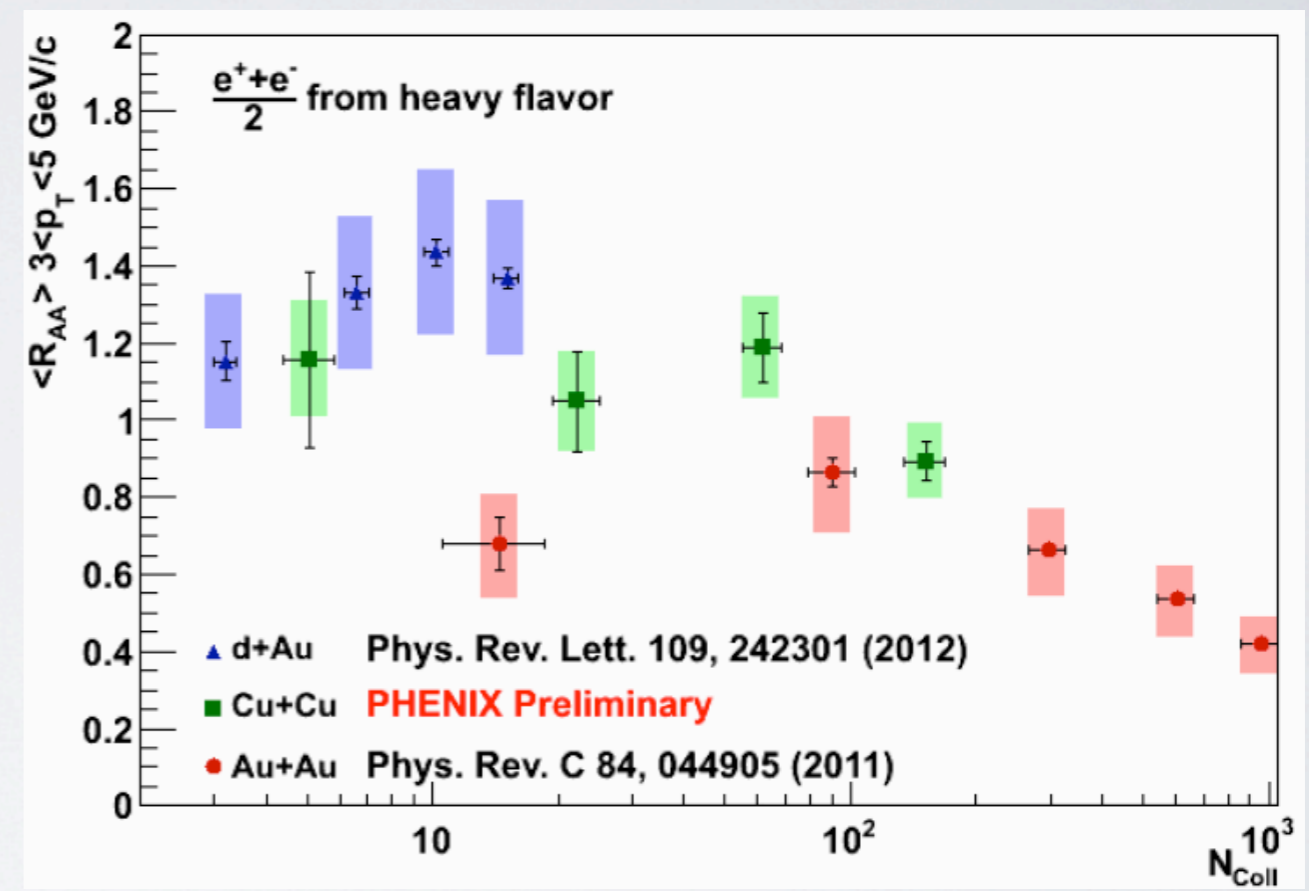
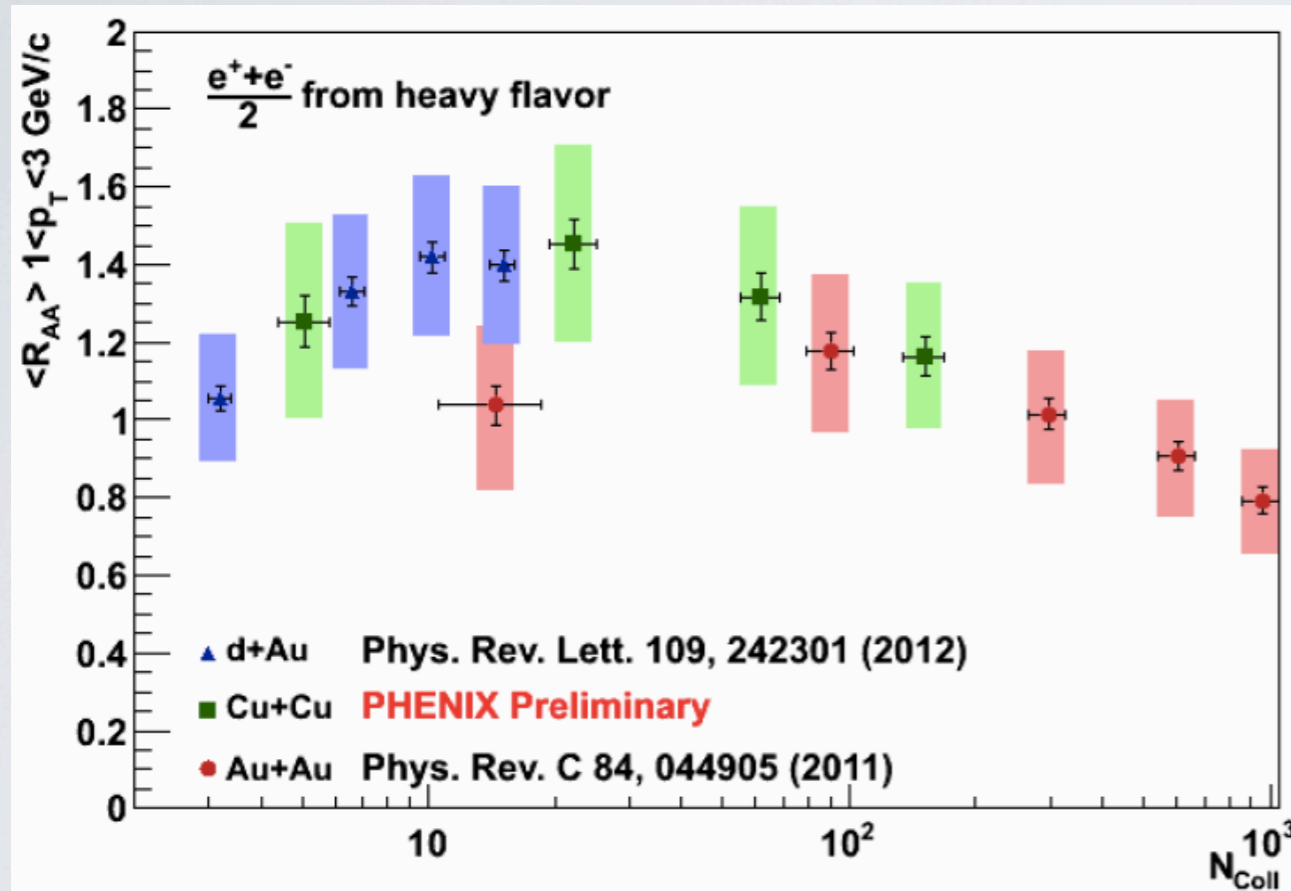
# Heavy flavor muons $R_{dA}$ , 0 - 20%



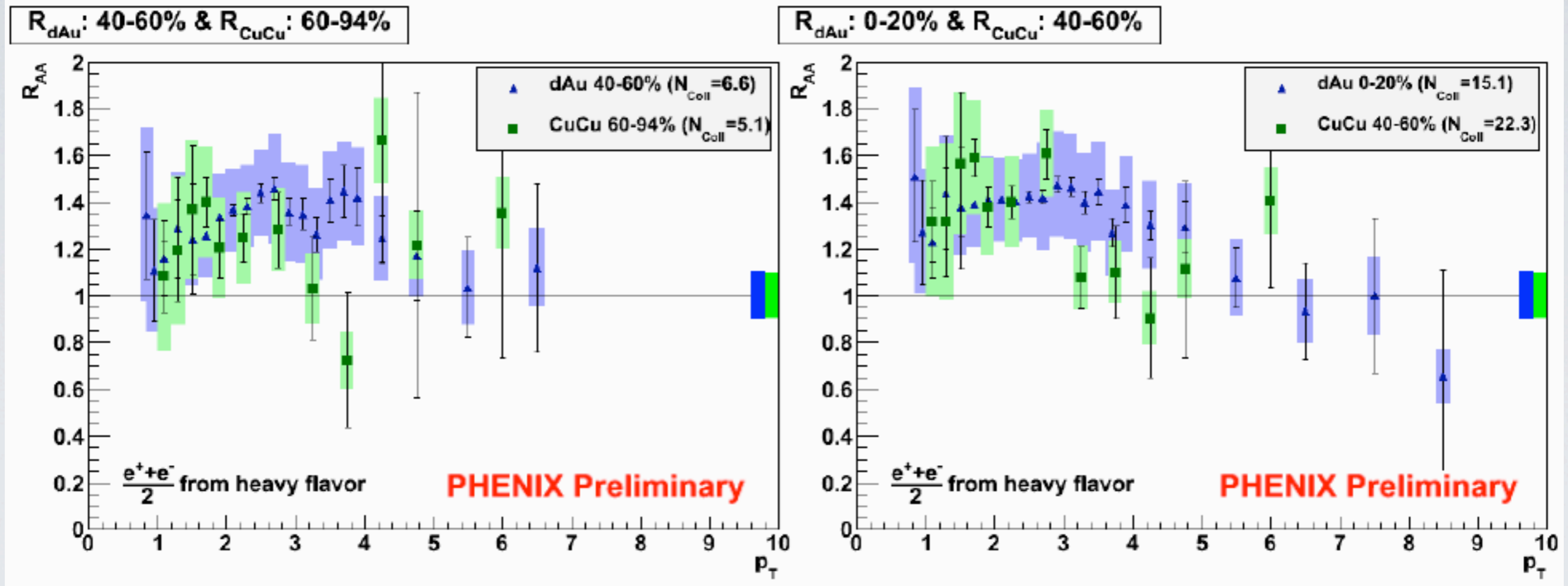
**Enhancement**  
at backward

**Suppression**  
at forward

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



# comparison between d+Au and Cu+Cu



consistent in similar  $N_{coll}$  region