Heavy quark production in d+Au collisions at forward rapidity in PHENIX

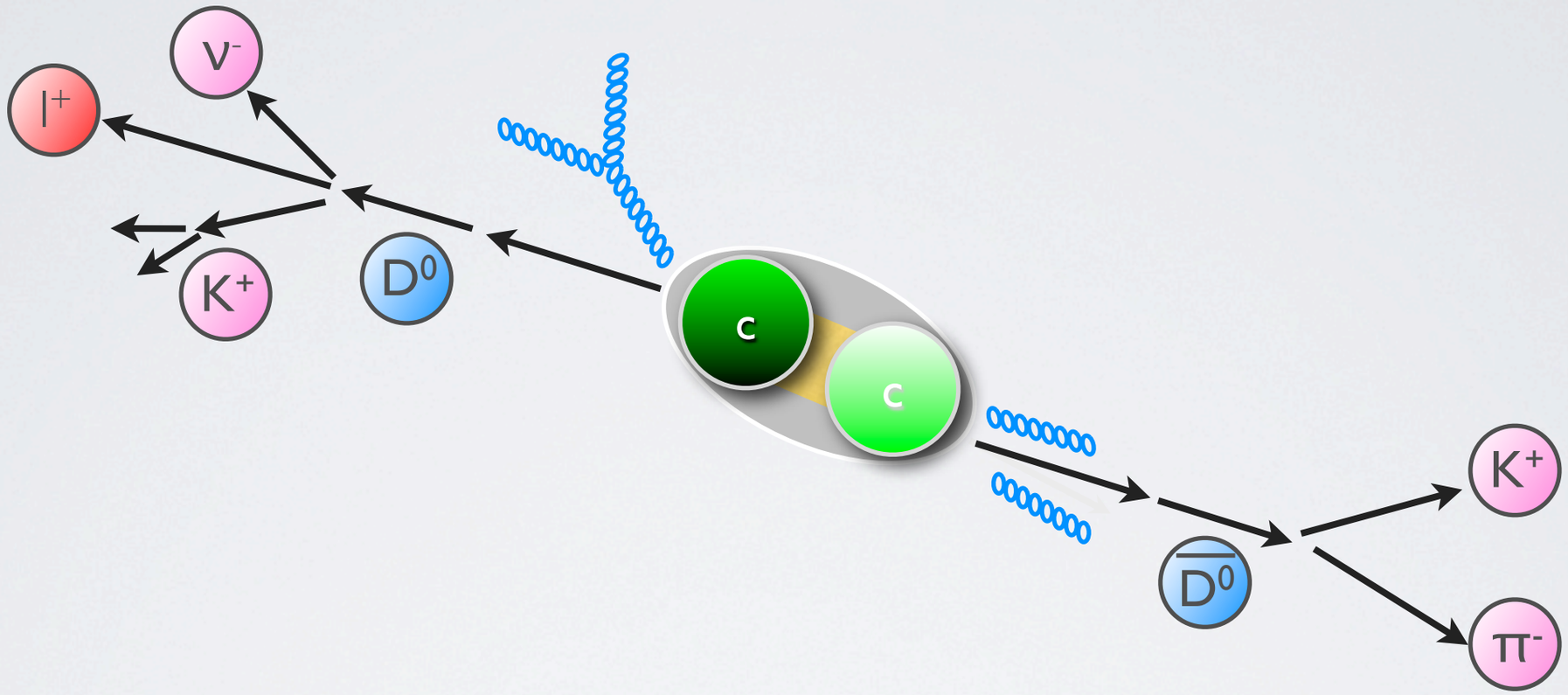
Sanghoon Lim
Yonsei University

Dec. 7th 2013
HIM / Andong Univ.

Introduction

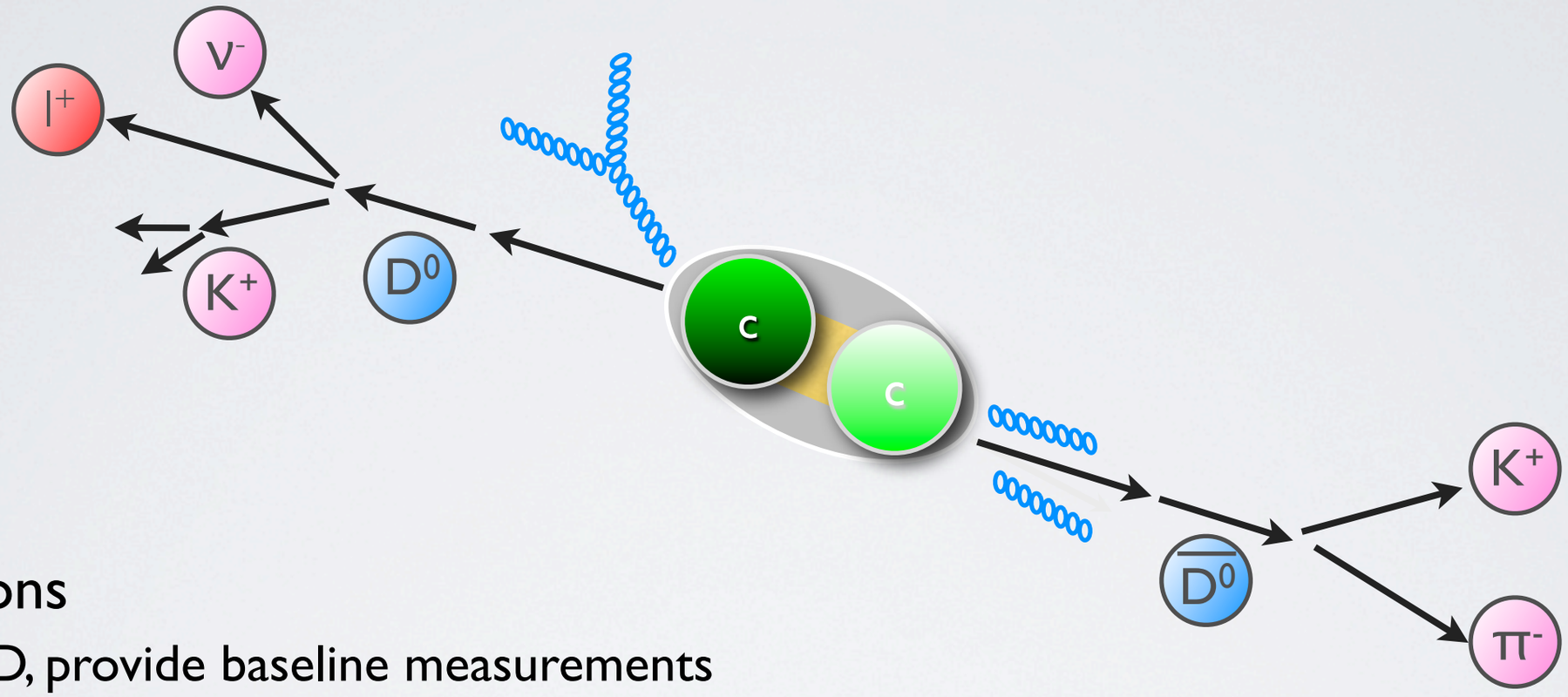
Heavy-quark production

- Heavy quark production is, by definition, "hard" probes due to their large masses
  - Produced in the early stage of the collision
  - Leading-order process is **gluon fusion**

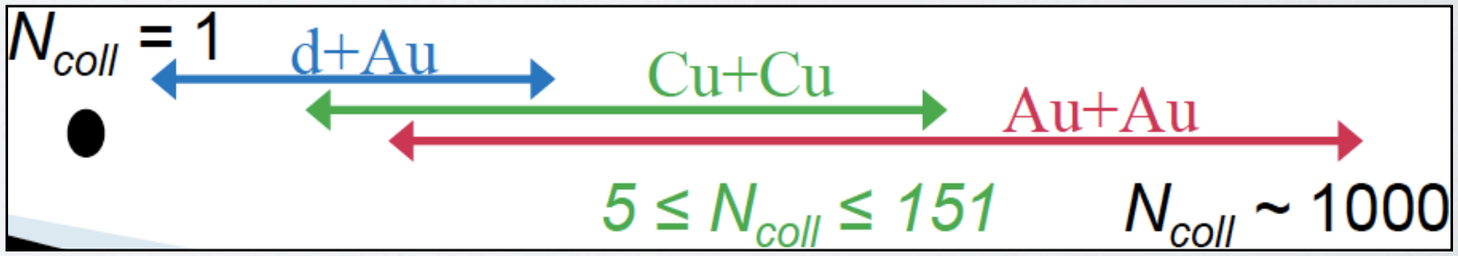


Heavy-quark production

- Heavy quark production is, by definition, "hard" probes due to their large masses
  - Produced in the early stage of the collision
  - Leading-order process is **gluon fusion**

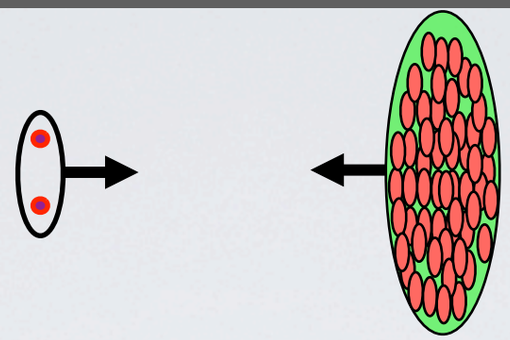


- p+p collisions
  - Test pQCD, provide baseline measurements
- d+Au collisions
  - Study cold nuclear matter effects
- Heavy-ion collisions
  - Probe effects of hot and dense medium



d+Au collisions

PHENIX backward rapidity
*Au-going side



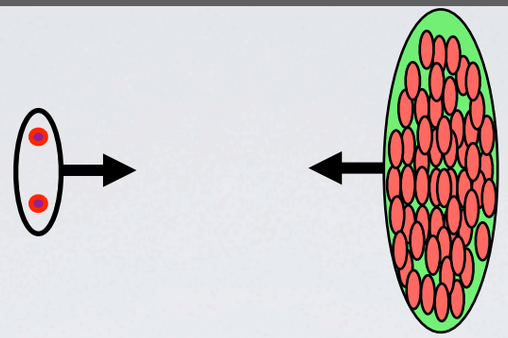
PHENIX forward rapidity
*d-going side

parton of x_1 in d parton of x_2 in Au $x_2 = \frac{Q}{\sqrt{s_{NN}}} e^{-y}$

- d+Au collisions as a **control experiment**
  - In heavy-ion collisions, both HNM & CNM effects are included
  - Another baseline to interpret and understand the heavy-ion results

d+Au collisions

PHENIX backward rapidity
*Au-going side

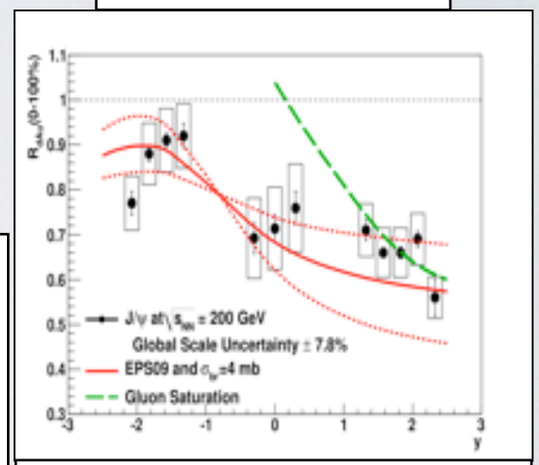


PHENIX forward rapidity
*d-going side

parton of x_1 in d parton of x_2 in Au $x_2 = \frac{Q}{\sqrt{s_{NN}}} e^{-y}$

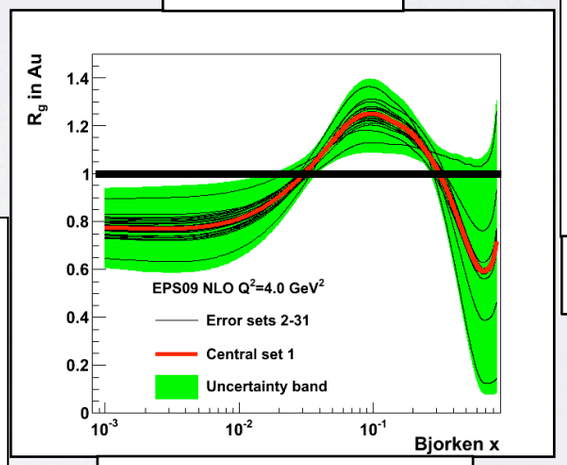
- d+Au collisions as a **control experiment**
  - In heavy-ion collisions, both HNM & CNM effects are included
  - Another baseline to interpret and understand the heavy-ion results
- Cold Nuclear Matter (CNM) effects
  - Modification of parton distribution function
  - p_T (k_T) broadening (Cronin effect)
  - Nuclear break-up (absorption)
  - Initial parton energy loss

nuclear breakup



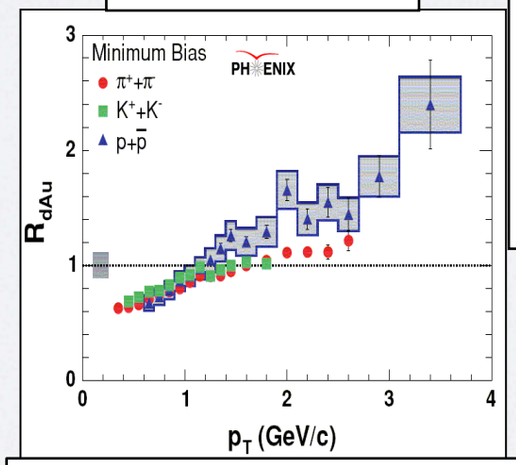
PRL 107, 142301 (2011)

shadowing



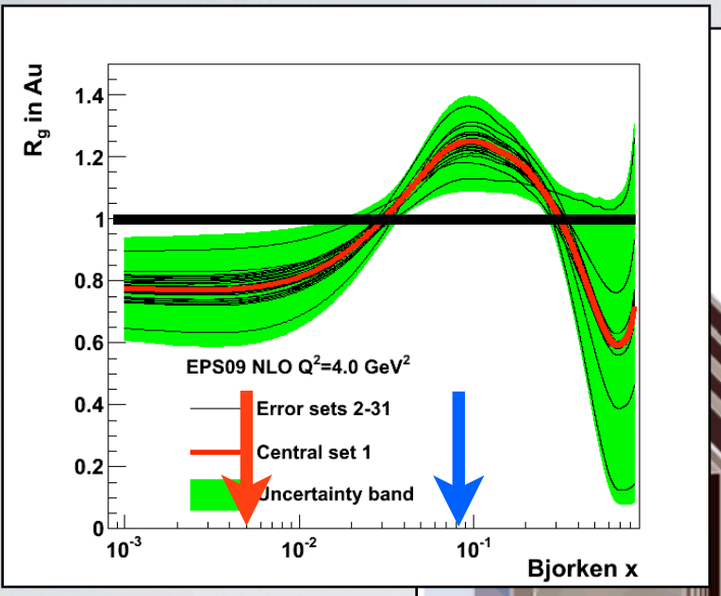
JHP04 (2009)065

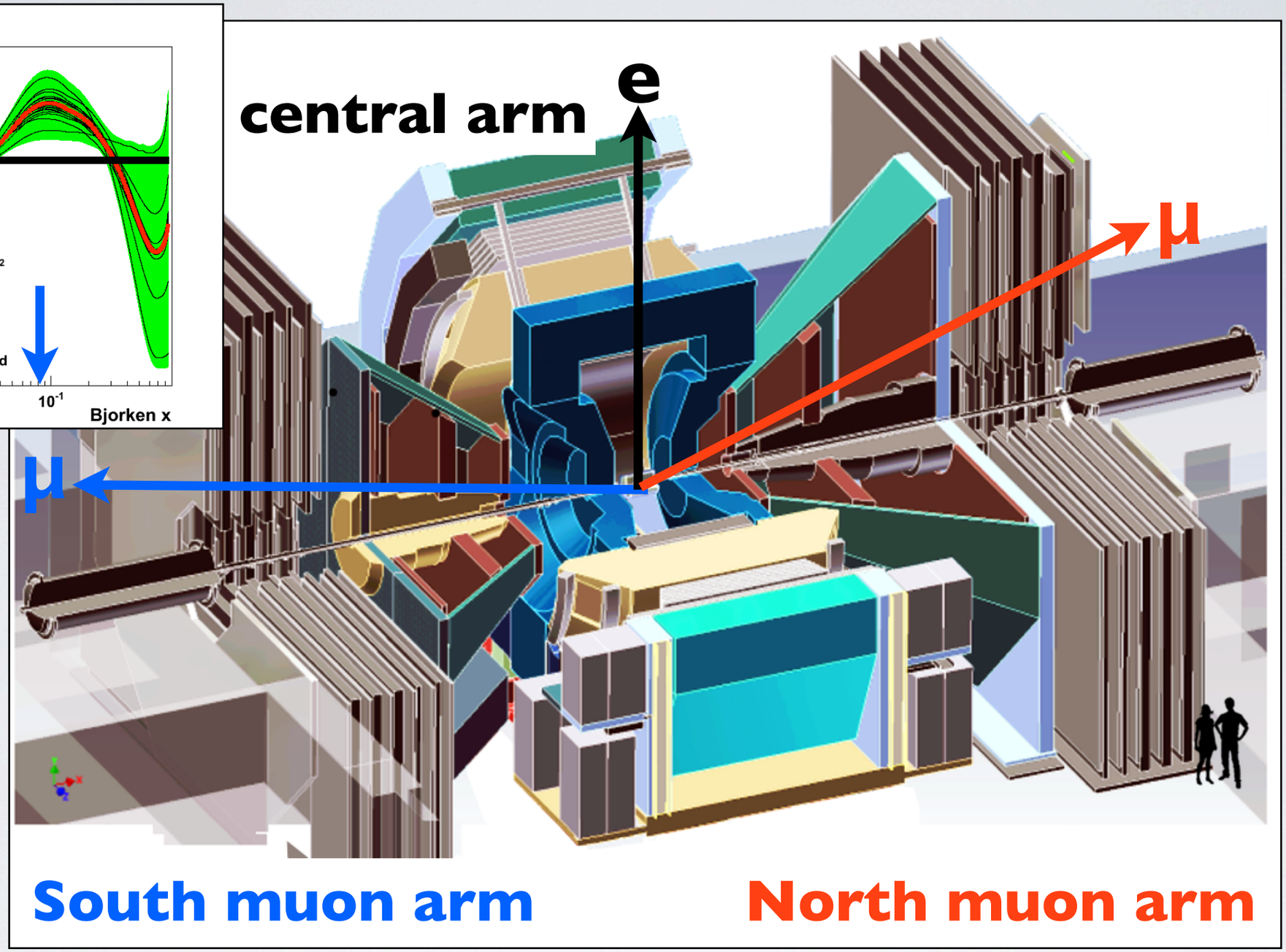
p_T broadening



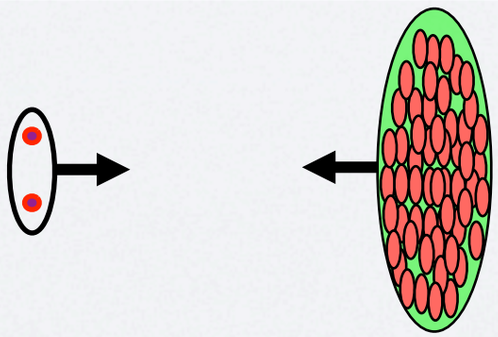
PRC 74, 024904 (2006)

Heavy-flavor in PHENIX





PHENIX backward rapidity
*Au-going side
*$x_2 \approx 8 \times 10^{-2}$ **(anti-shadowing)**

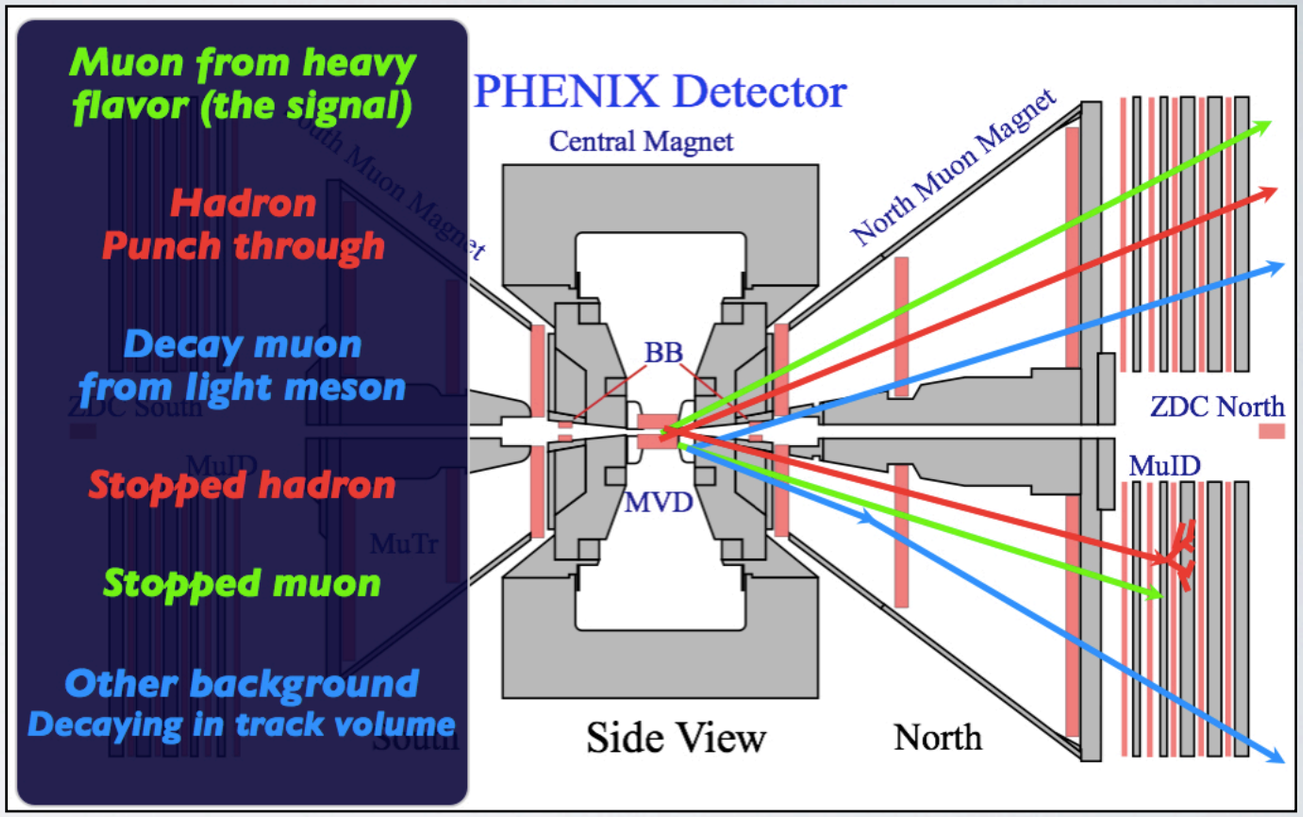


PHENIX forward rapidity
*d-going side
* $x_2 \approx 5 \times 10^{-3}$ **(shadowing)**

Heavy-flavor in PHENIX muon arm

- Kinematic range
  - $1.2 < |\eta| < 2.2$
  - $\Delta\phi = 2\pi$

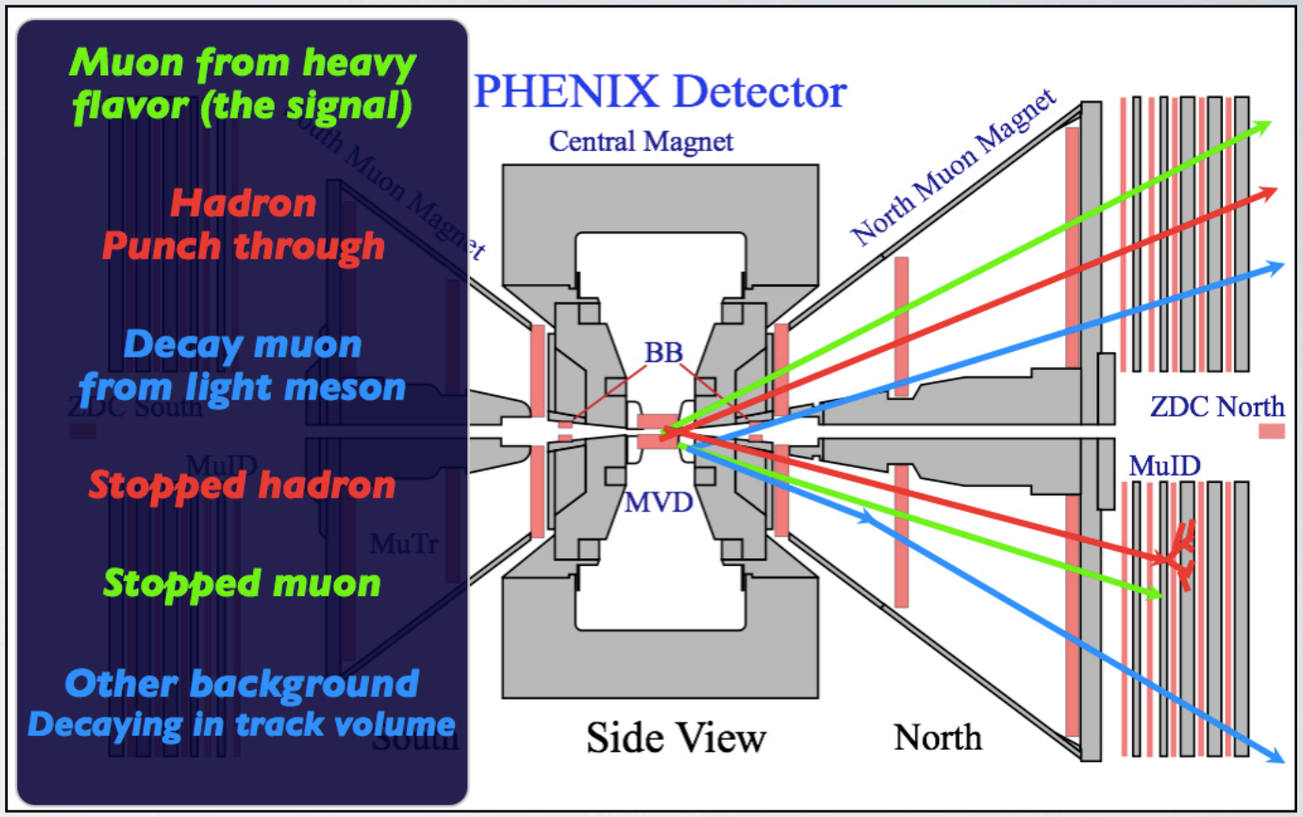
  - Absorber to reject hadrons
  - Muon tracker for momentum mesurement
    *3 stations inside magnet
  - Muon identifier for hadron/muon separation
    *5 gaps (layers) of absorber/multi-wire chamber



Heavy-flavor in PHENIX muon arm

- Kinematic range
  - $1.2 < |\eta| < 2.2$
  - $\Delta\phi = 2\pi$

  - Absorber to reject hadrons
  - Muon tracker for momentum mesurement
    *3 stations inside magnet
  - Muon identifier for hadron/muon separation
    *5 gaps (layers) of absorber/multi-wire chamber



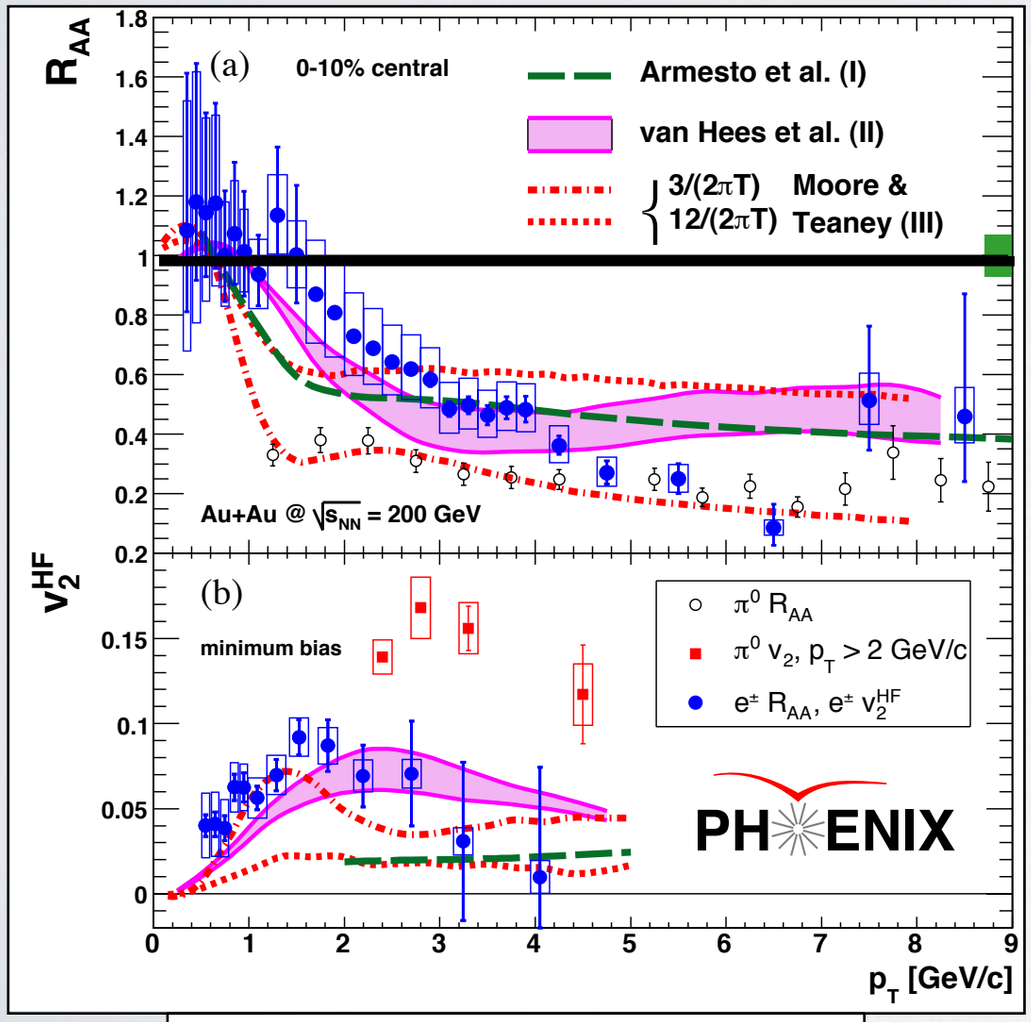
- Main background sources
  - **Decay muons** from light hadrons (π, K) and **punch-through hadrons**
- Background estimation
  - Hadron cocktail method - full MC simulation of light hadrons (π, K, p)
  - Muons from J/ψ are estimated based on the PHENIX J/ψ results

$$N_{prompt} = N_{inclusive} - N_{decay} - N_{punch\text{-}through} - N_{J/psi}$$

Review of heavy-quark results

- In central Au+Au collisions
  - **Large suppression** of high p_T heavy-flavor electron
  - **Significant v_2**

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

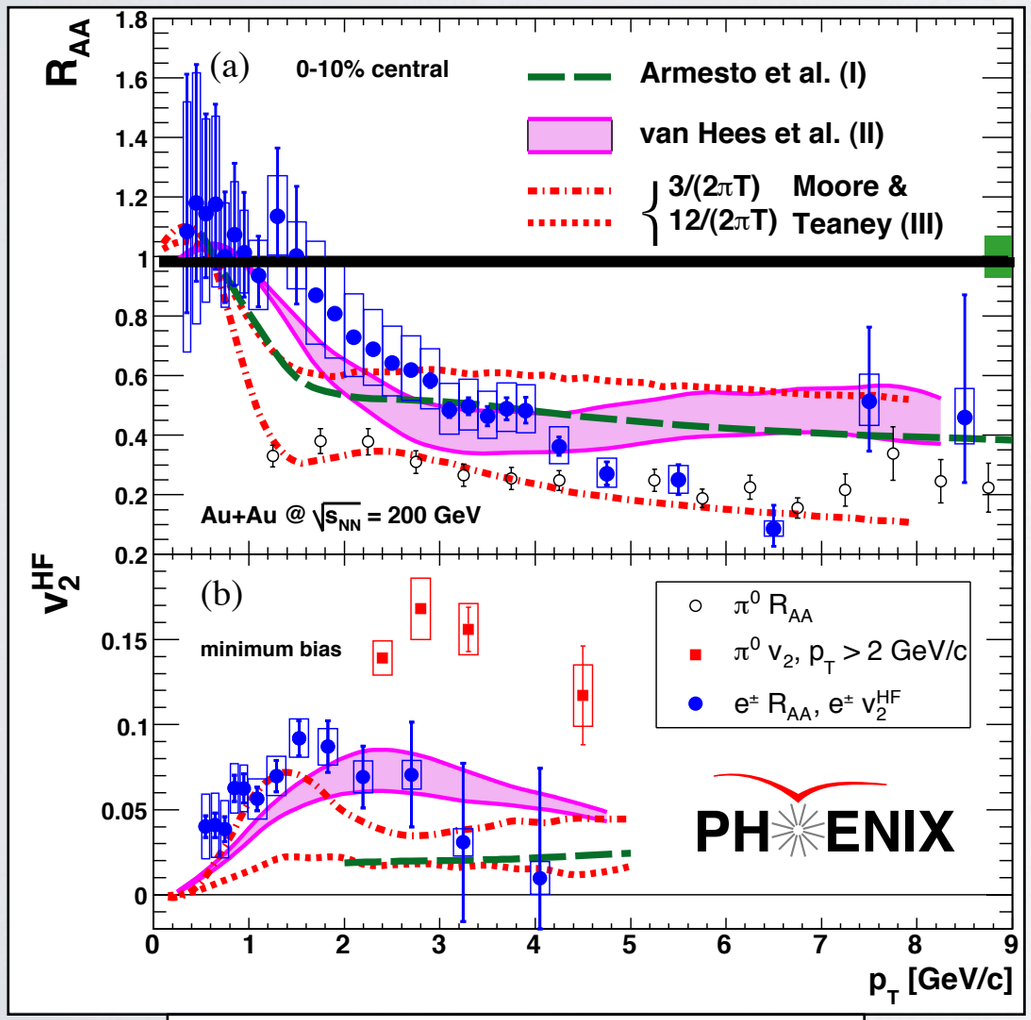


Phys. Rev. Lett. 98, 172301 (2007)

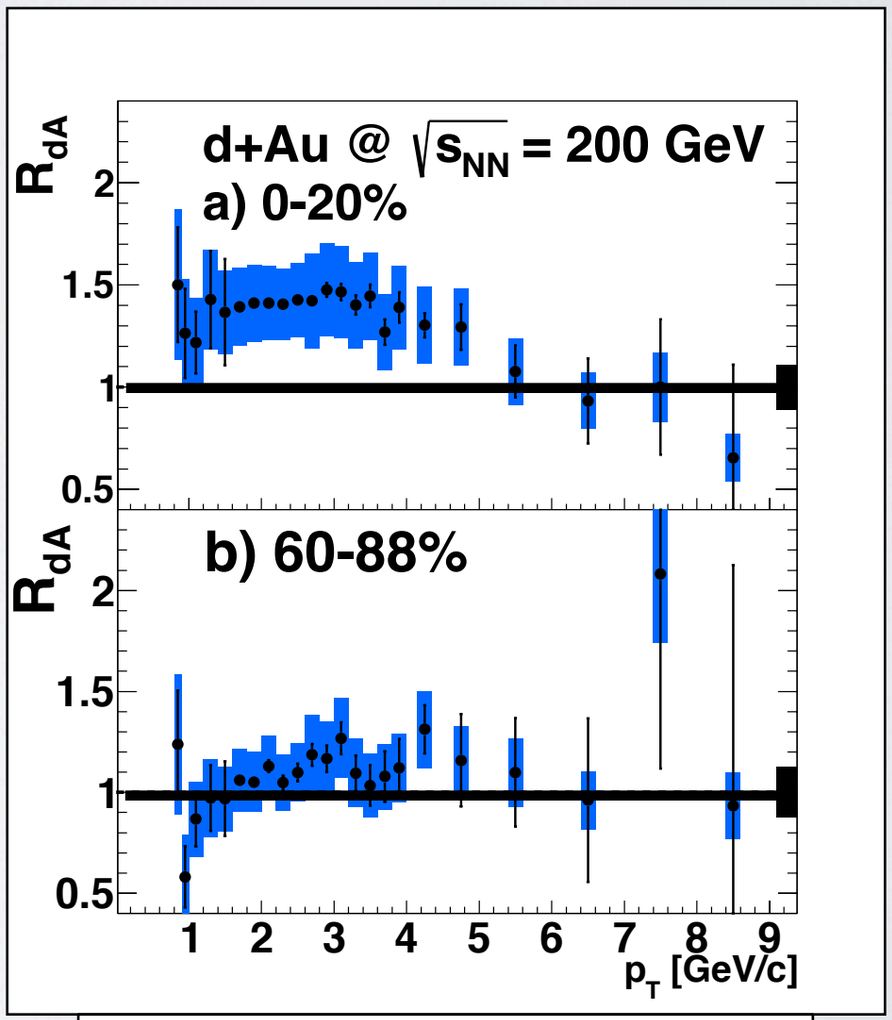
Review of heavy-quark results

- In central Au+Au collisions
  - **Large suppression** of high p_T heavy-flavor electron
  - **Significant v_2**
- In d+Au collisions
  - **Clear enhancement** in central d+Au collisions at mid-rapidity
    →suppression at mid-rapidity is due to HNM effects

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



Phys. Rev. Lett. 98, 172301 (2007)

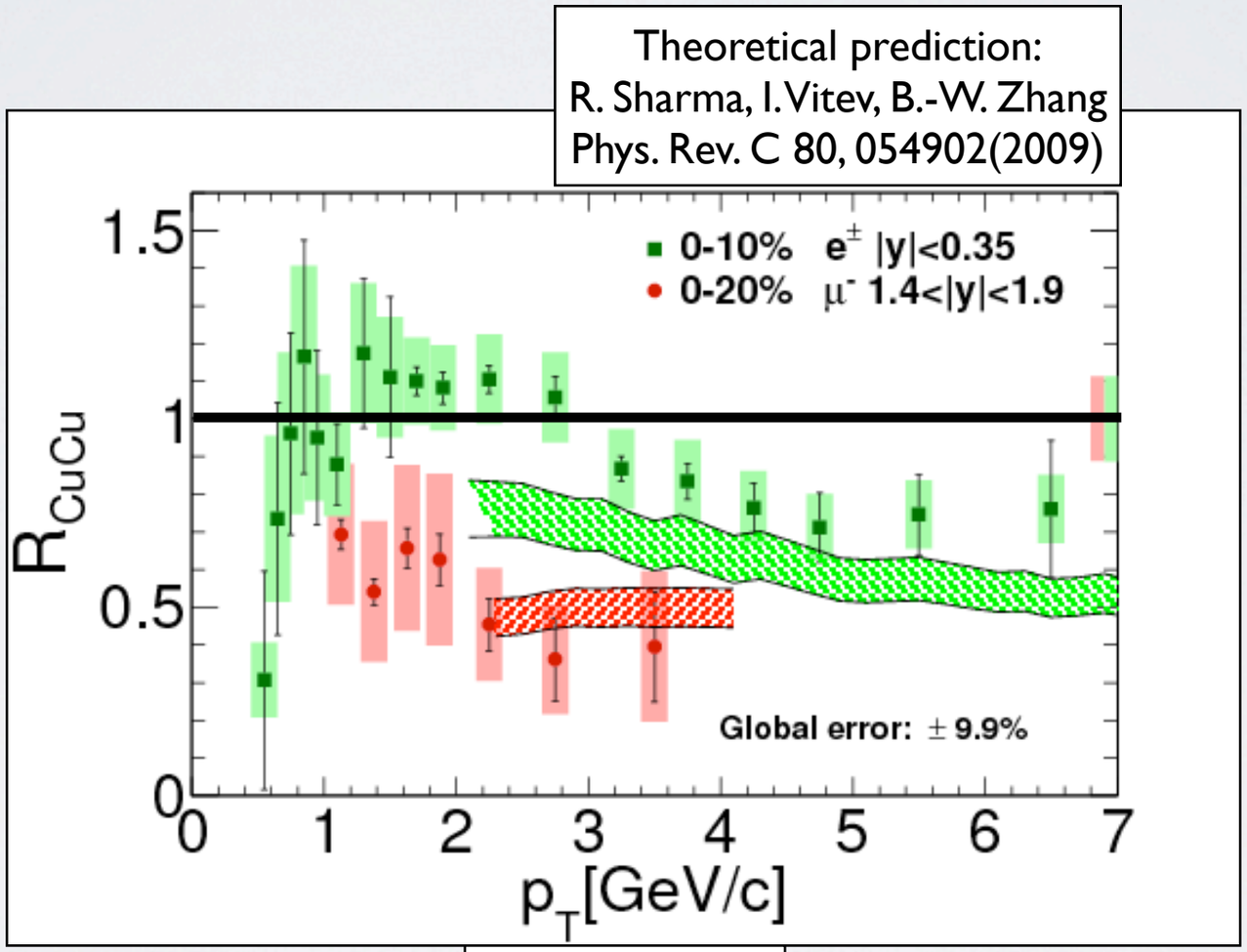


Phys. Rev. Lett. 100, 242301 (2012)

Review of heavy-quark results

- In central Cu+Cu collisions
  - **Small suppression** at mid-rapidity → **CNM & HNM are competing**
  - Whereas, **large suppression** at forward rapidity
    ⇒pQCD predictions including CNM effects shows good agreements both at mid- and forward

Theoretical prediction:
R. Sharma, I.Vitev, B.-W. Zhang
Phys. Rev. C 80, 054902(2009)



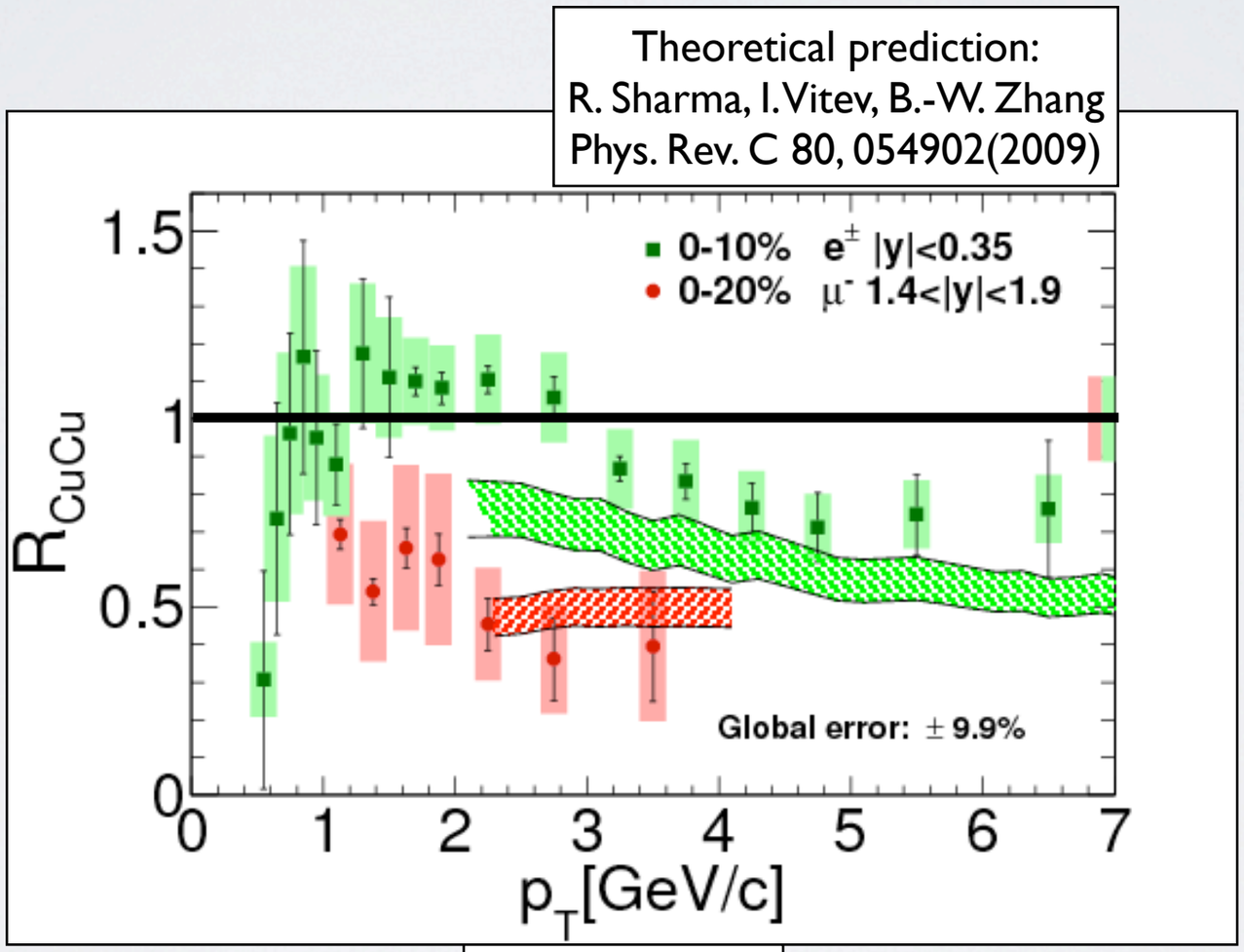
arXiv:1310.8286

Review of heavy-quark results

- In central Cu+Cu collisions
  - **Small suppression** at mid-rapidity → **CNM & HNM are competing**
  - Whereas, **large suppression** at forward rapidity
    ⇒pQCD predictions including CNM effects shows good agreements both at mid- and forward

large CNM effects at forward?

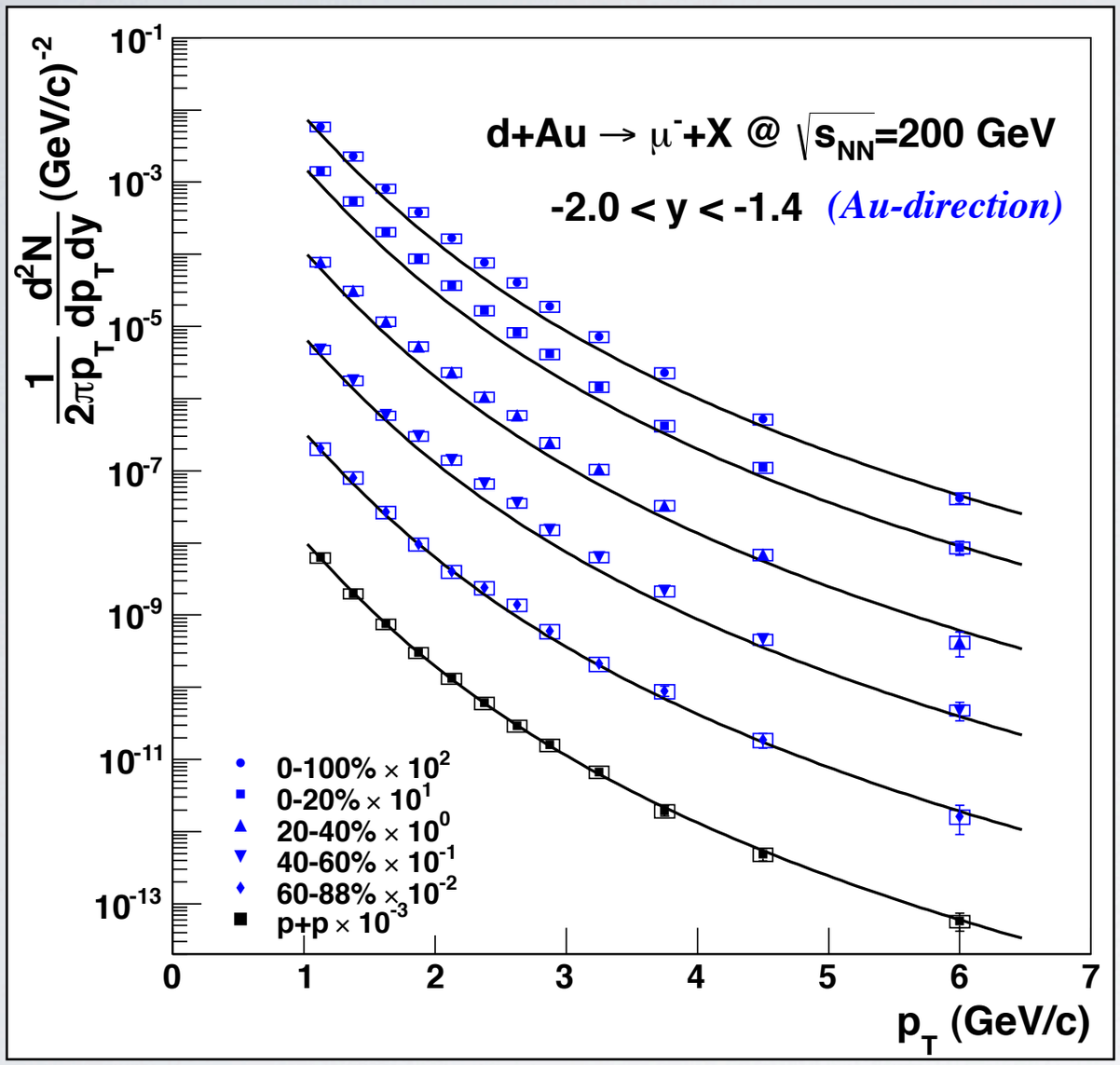
Theoretical prediction:
R. Sharma, I.Vitev, B.-W. Zhang
Phys. Rev. C 80, 054902(2009)

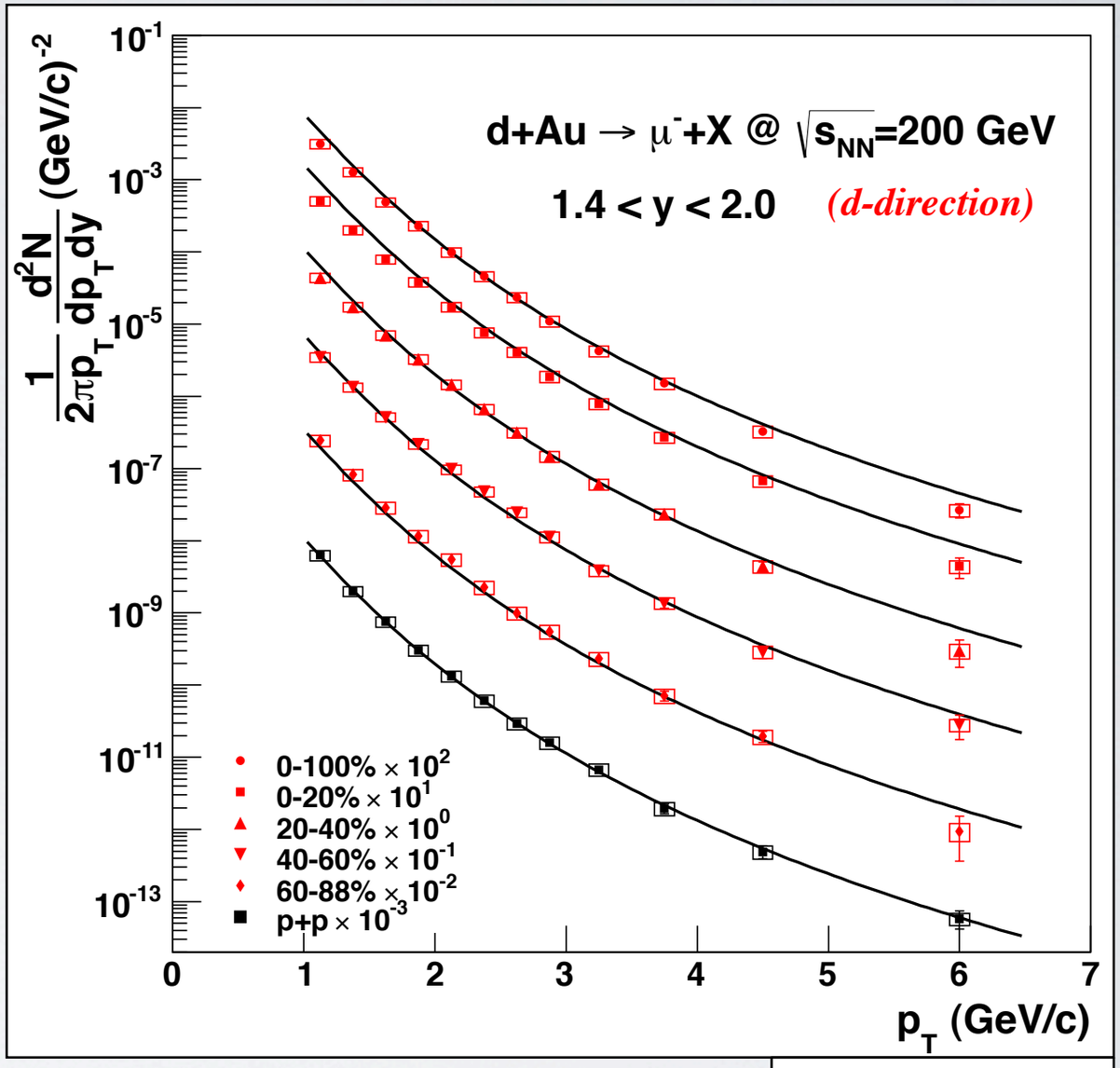


arXiv:1310.8286

Results

HF muon p_T spectra

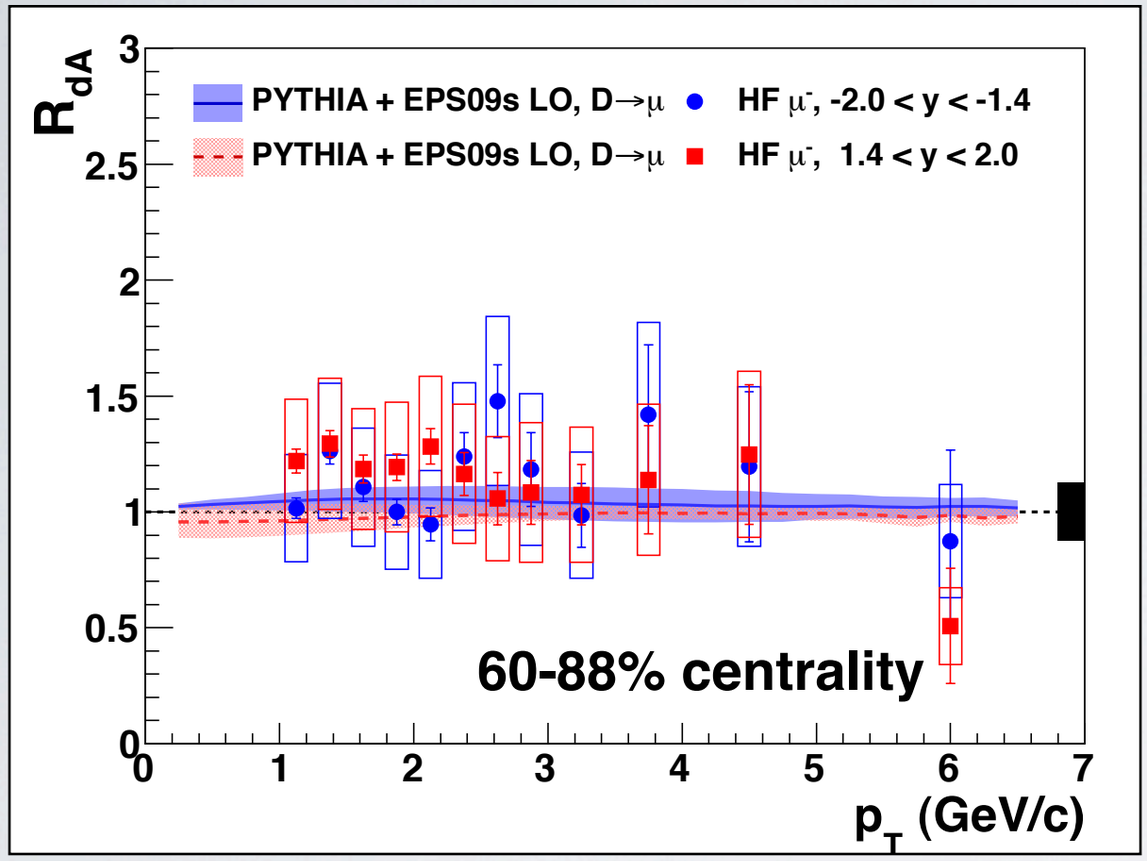




arXiv:1310.1005

- Invariant yield of heavy-flavor muon in d+Au collisions at sqrt(s_{NN})=200 GeV
  - lines are scaled fit functions of the p+p results by the average number of binary collision corresponding centrality class

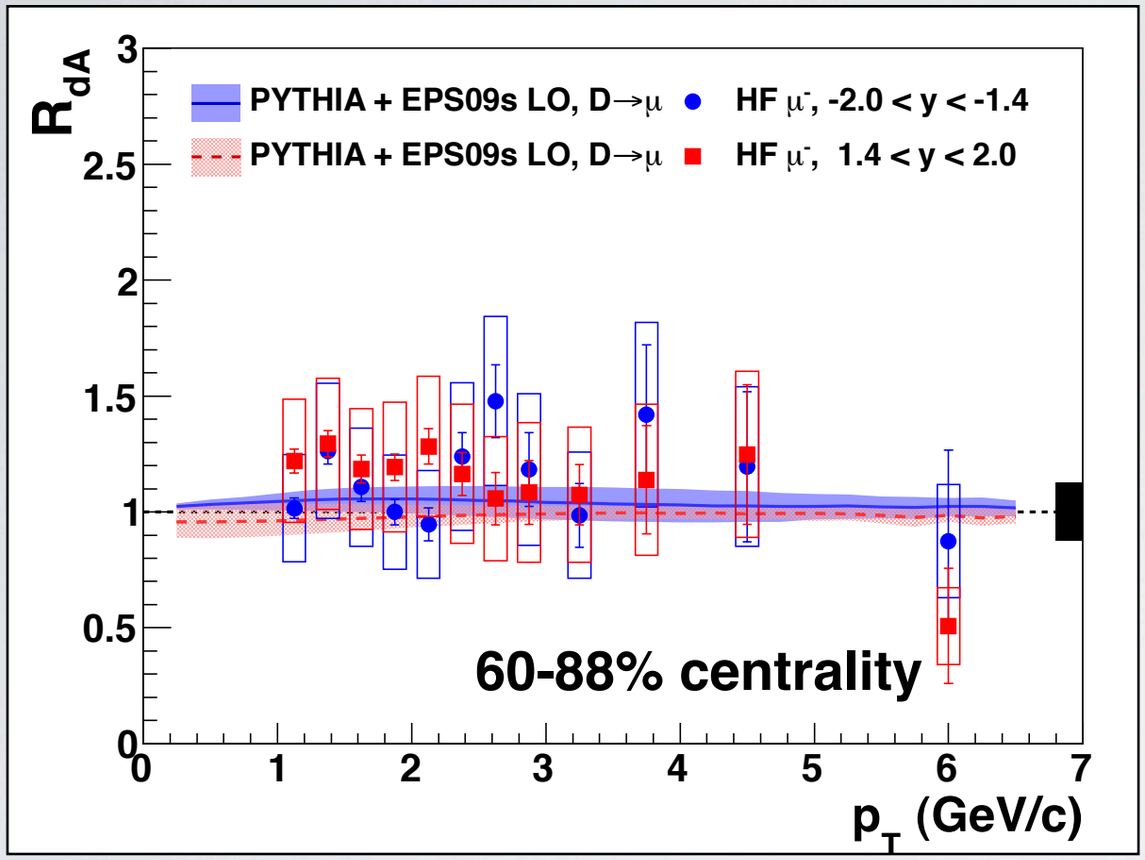
HF muon $R_{dA}(p_T)$

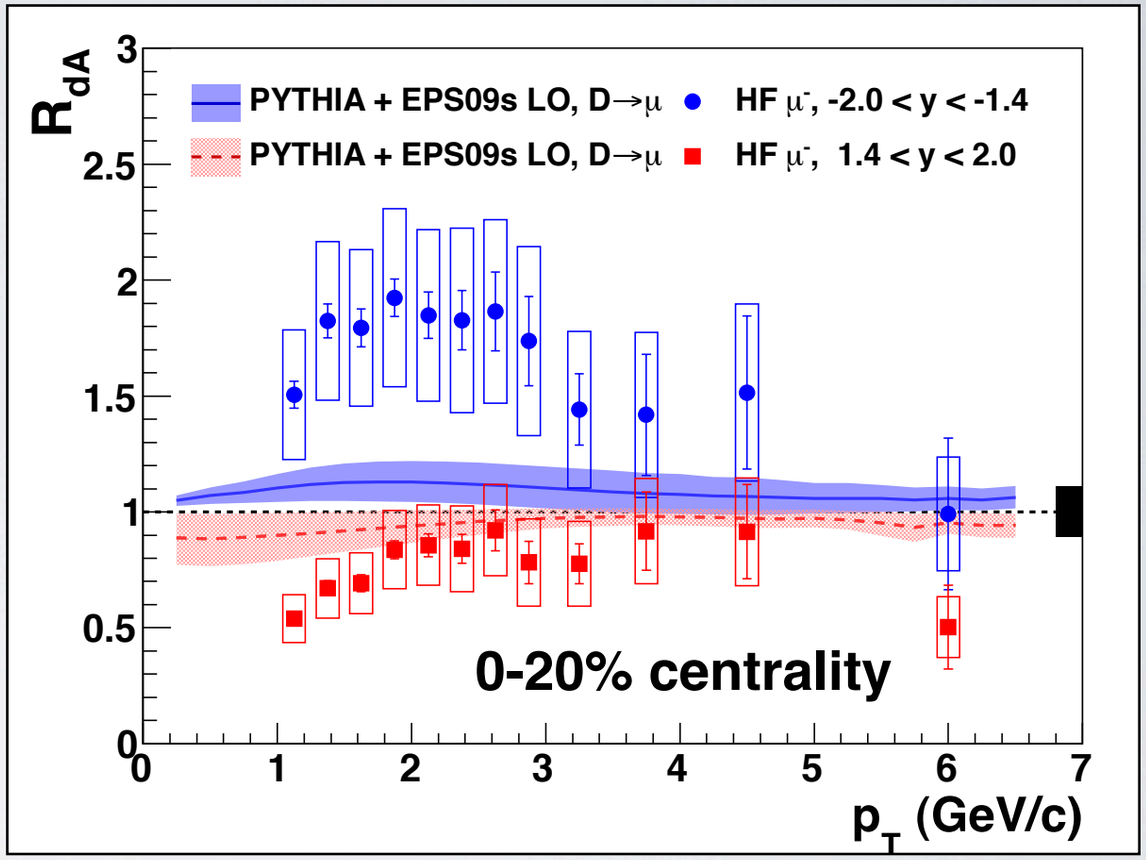


- No modification at both rapidity ranges in most peripheral collisions

$$R_{dA} = \frac{dN^{\mu}_{dAu}}{\langle N_{coll} \rangle dN^{\mu}_{pp}}$$

HF muon $R_{dA}(p_T)$

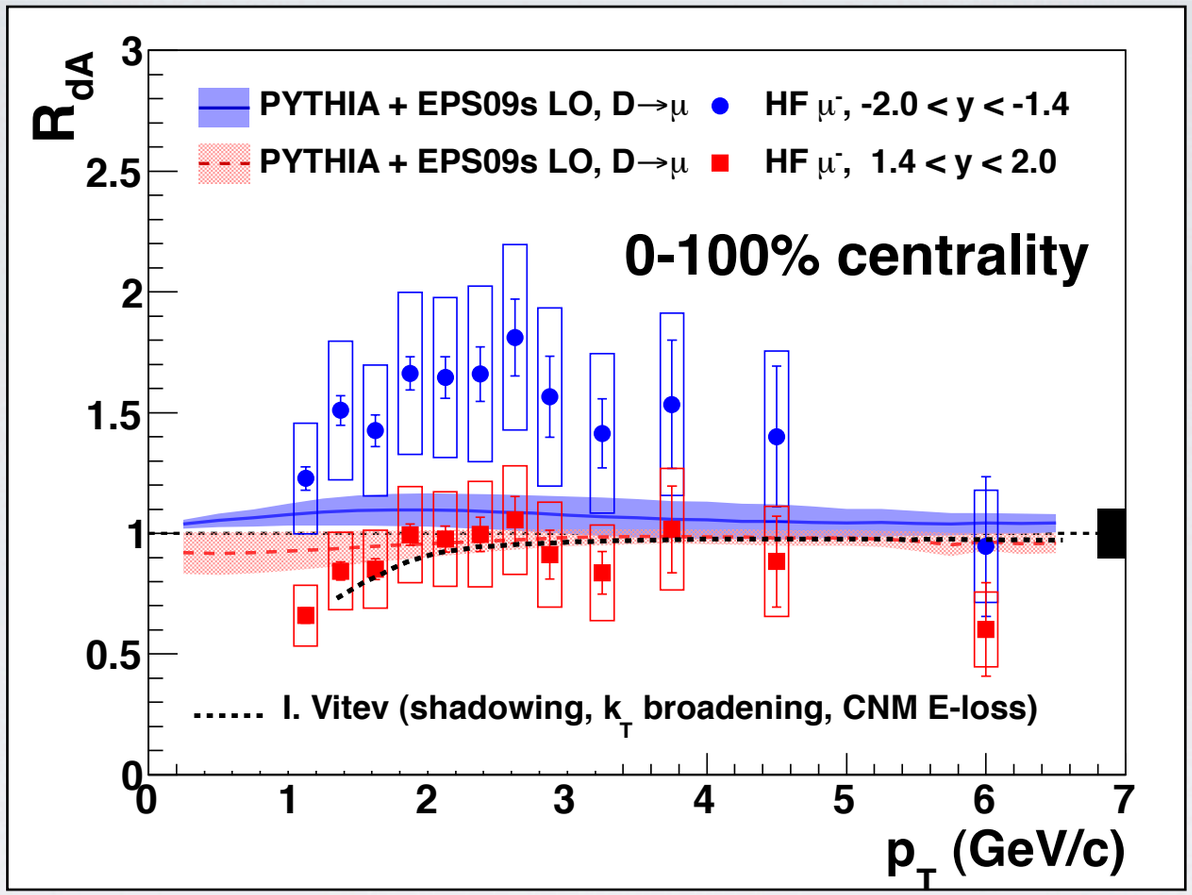




- No modification at both rapidity ranges in most peripheral collisions
- **Enhancement at backward** rapidity and **suppression at forward** rapidity in most central collisions
  - Anti-shadowing (shadowing) at backward (forward)?

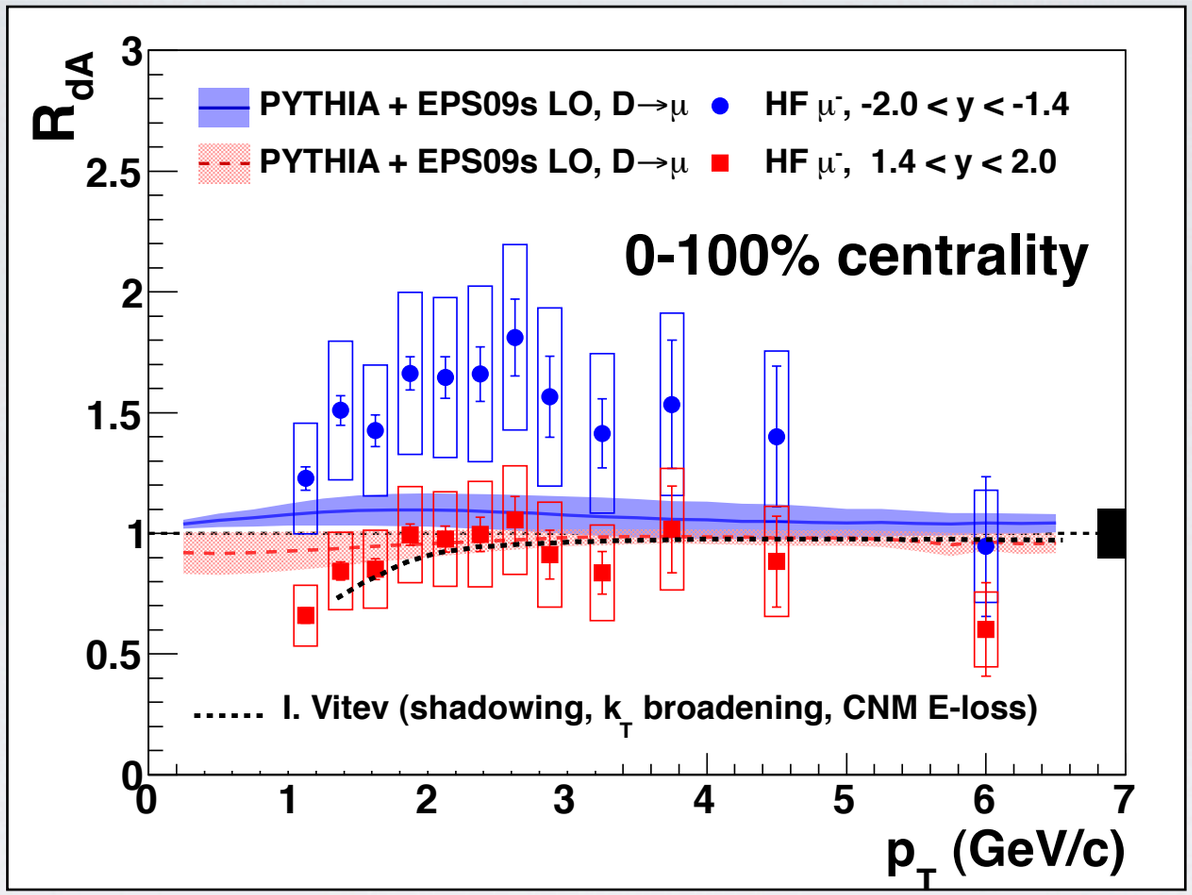
$$R_{dA} = \frac{dN^{\mu}_{dAu}}{\langle N_{coll} \rangle dN^{\mu}_{pp}}$$

Comparison to models



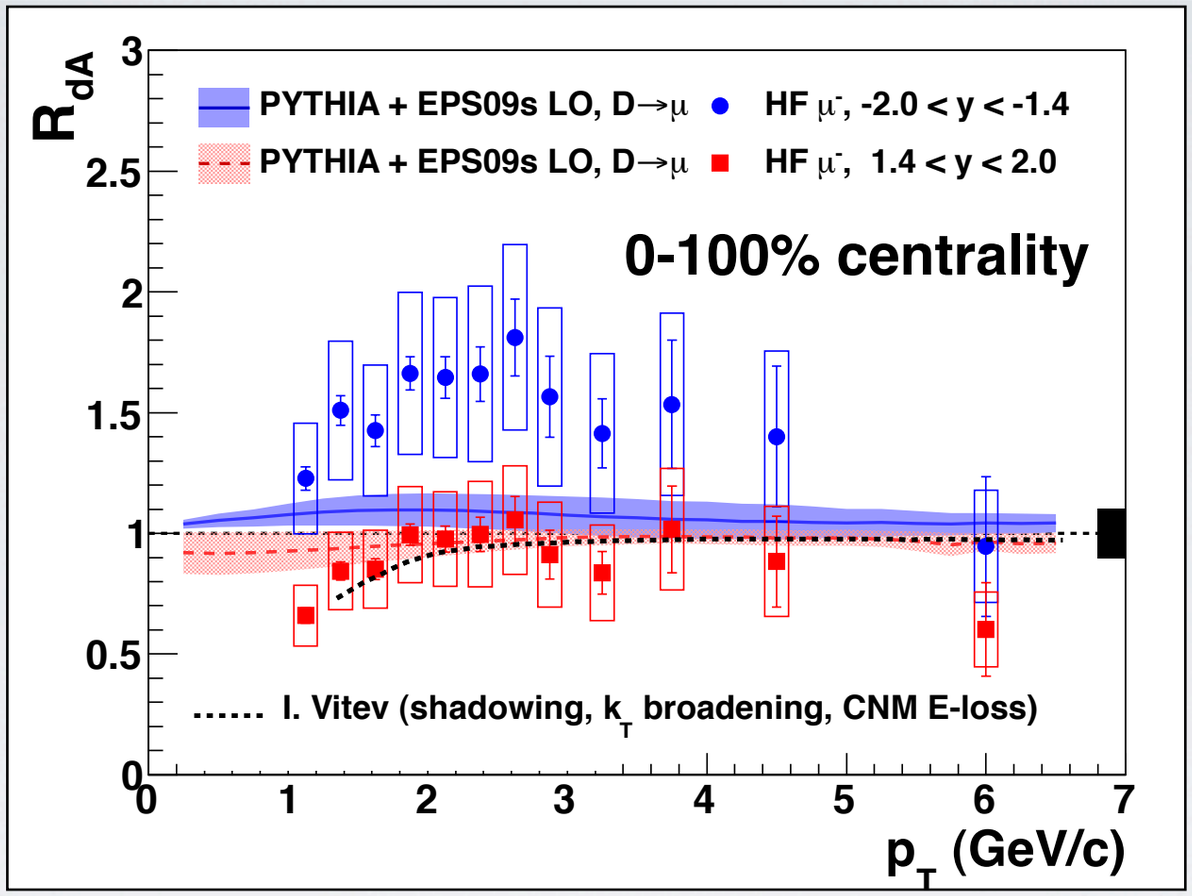
- pQCD calculation (I.Vitev)
  - CNM effects including shadowing, p_T broadening, and energy loss
  - Good agreement with the data at forward rapidity

Comparison to models



- pQCD calculation (I.Vitev)
  - CNM effects including shadowing, p_T broadening, and energy loss
  - Good agreement with the data at forward rapidity
- prediction based on EPS09s (spatial dependent) nPDF set
  - Calculate modification depending on x and Q^2 of $D \rightarrow \mu$ from PYTHIA
  - Well describe the data at forward rapidity
  - Whereas, underestimate the enhancement seen in backward rapidity

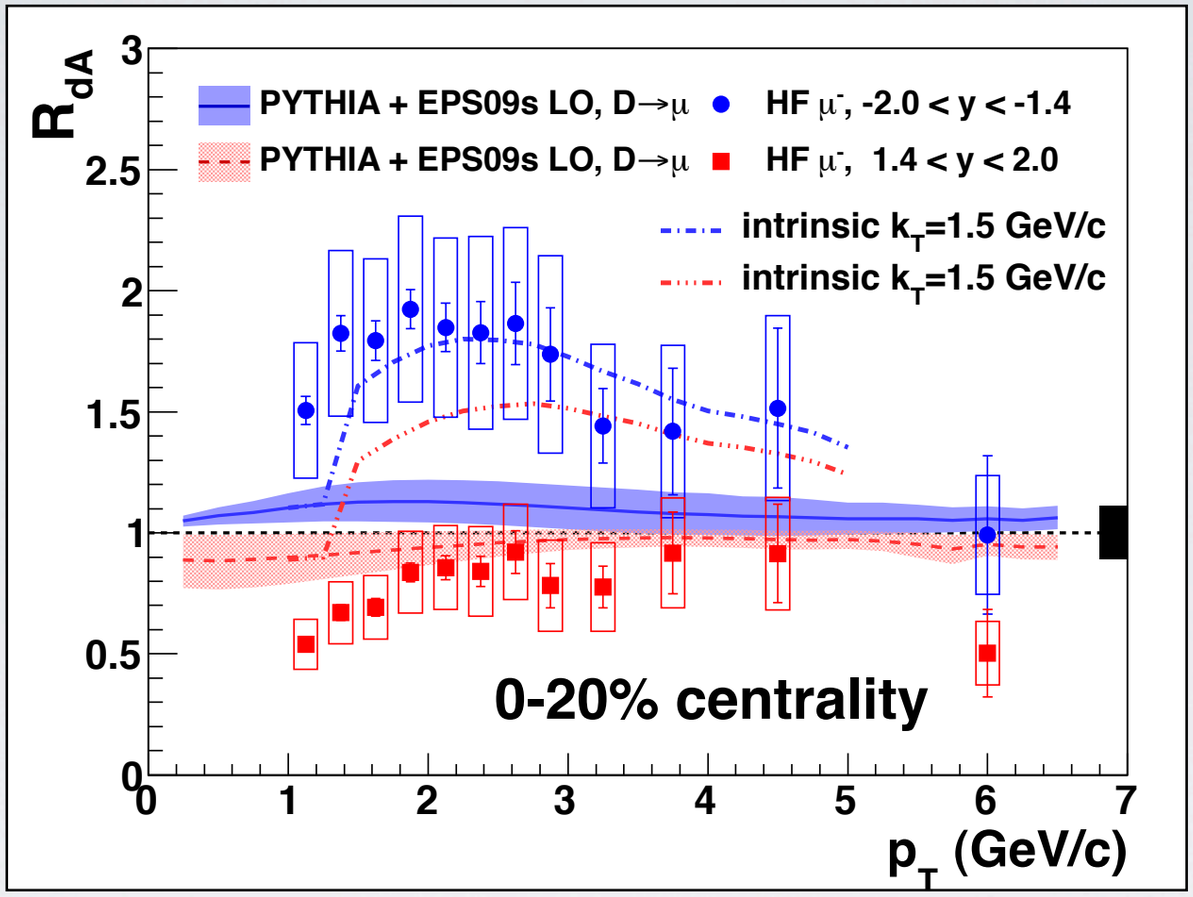
Comparison to models



- pQCD calculation (I.Vitev)
  - CNM effects including shadowing, p_T broadening, and energy loss
  - Good agreement with the data at forward rapidity
- prediction based on EPS09s (spatial dependent) nPDF set
  - Calculate modification depending on x and Q^2 of D→μ from PYTHIA
  - Well describe the data at forward rapidity
  - Whereas, underestimate the enhancement seen in backward rapidity

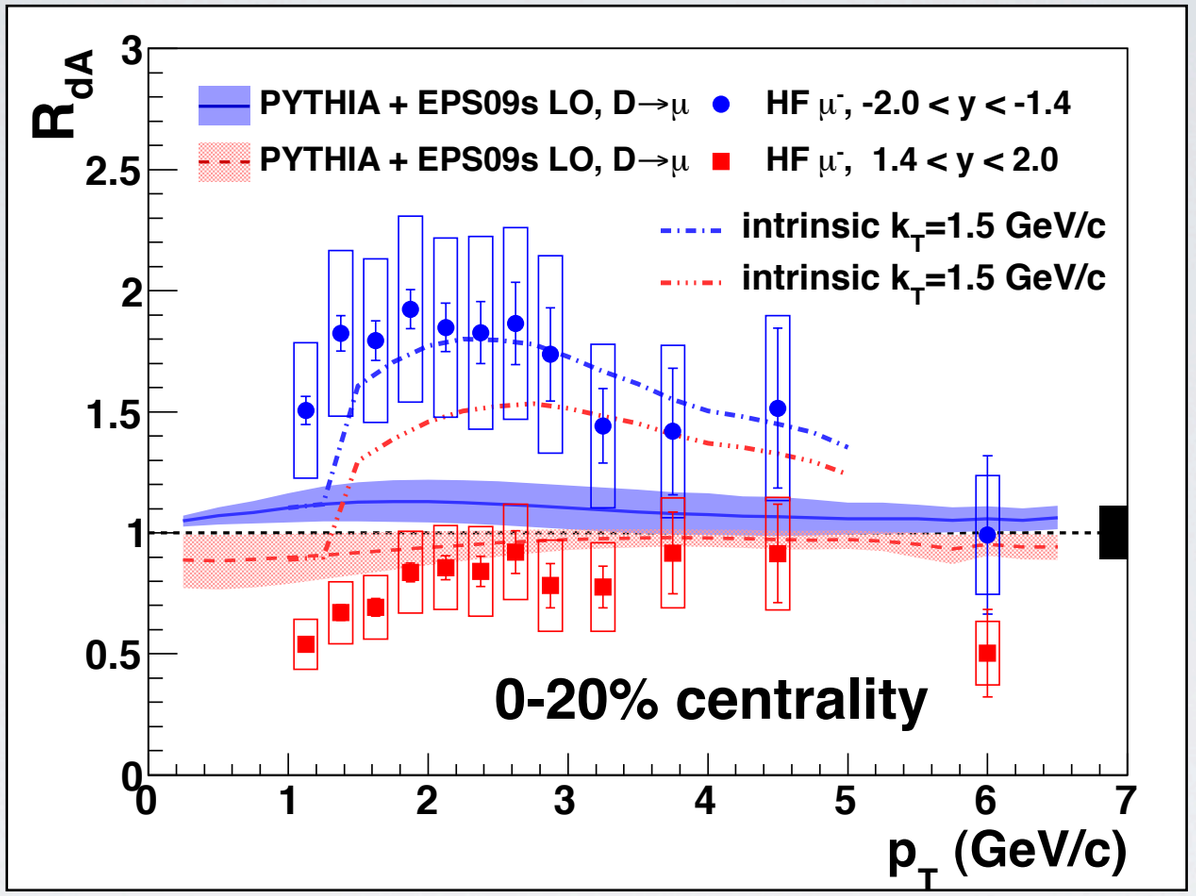
Predictions from both models can reproduce the forward data!!

Comparison to models

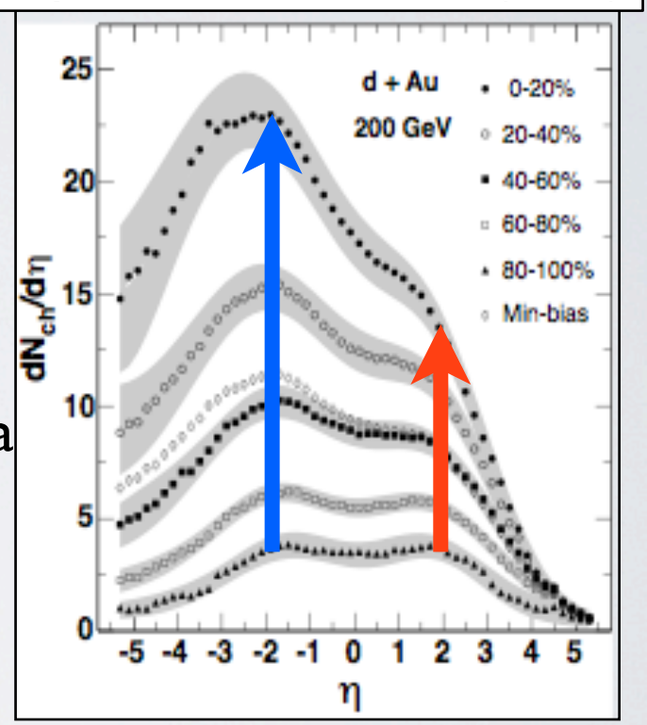


- Additional intrinsic k_T(1.5 GeV/c) + EPS09s nPDF
  - Reproduce the backward data pretty well, but overshoot the forward data
    ➔ hard to find the good combination, consistent with the data

Comparison to models

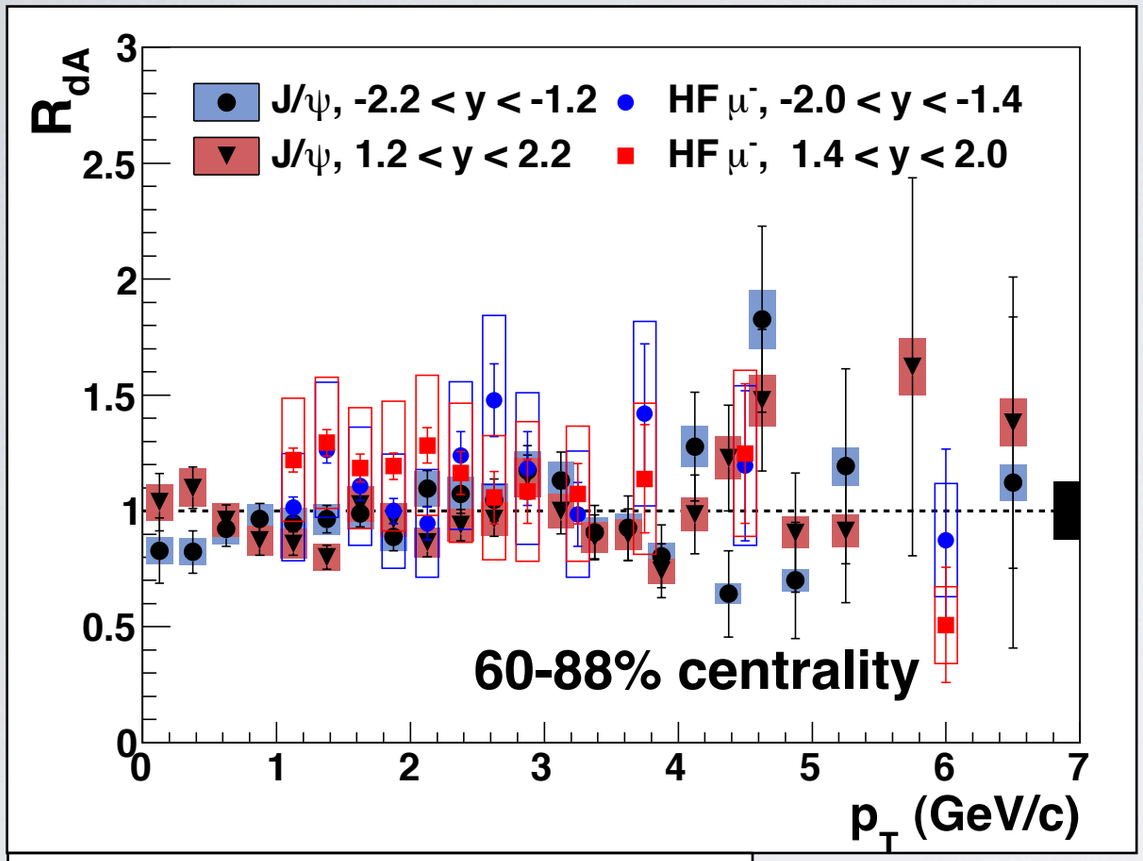


Phys. Rev. C 72, 031901 (2005)



- Additional intrinsic k_T(1.5 GeV/c) + EPS09s nPDF
  - Reproduce the backward data pretty well, but overshoot the forward data
    ➔ hard to find the good combination, consistent with the data
- Final state interaction?
  - Additional p_T kick due to multiple scattering with dense co-moving particles at backward rapidity

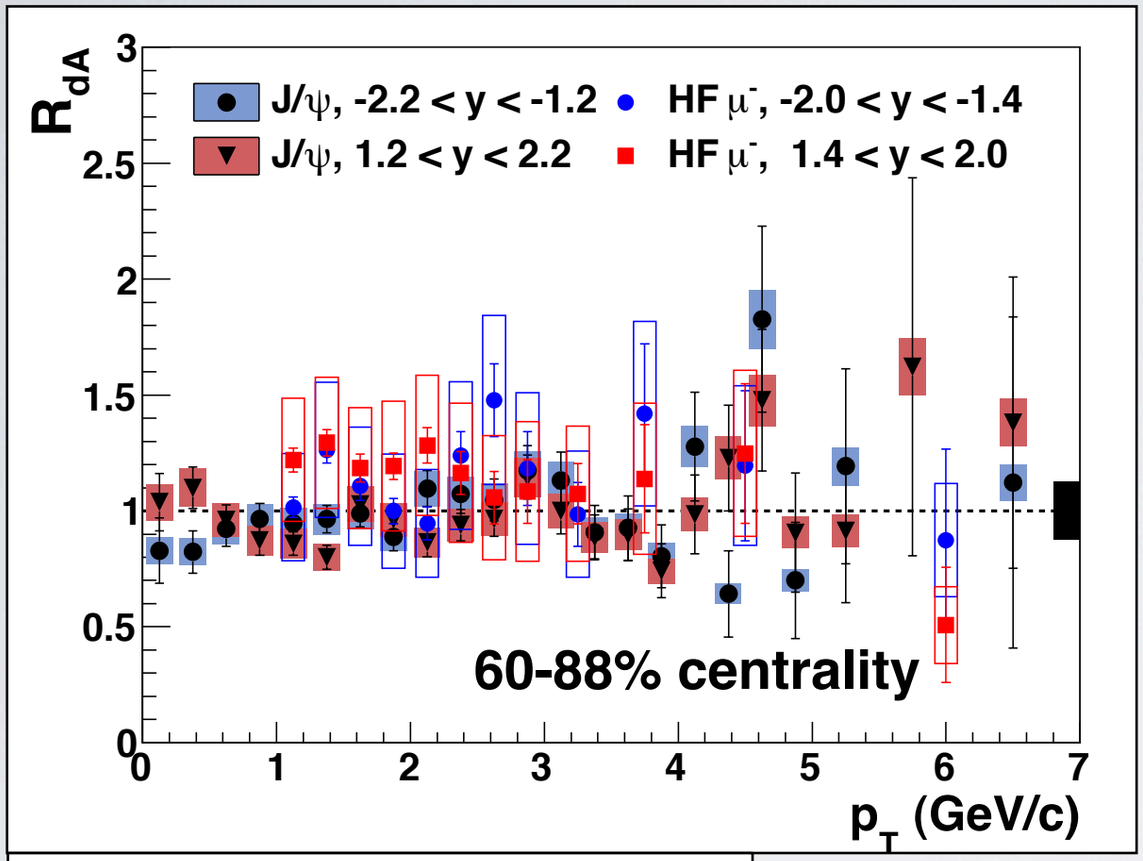
HF μ vs. J/ψ

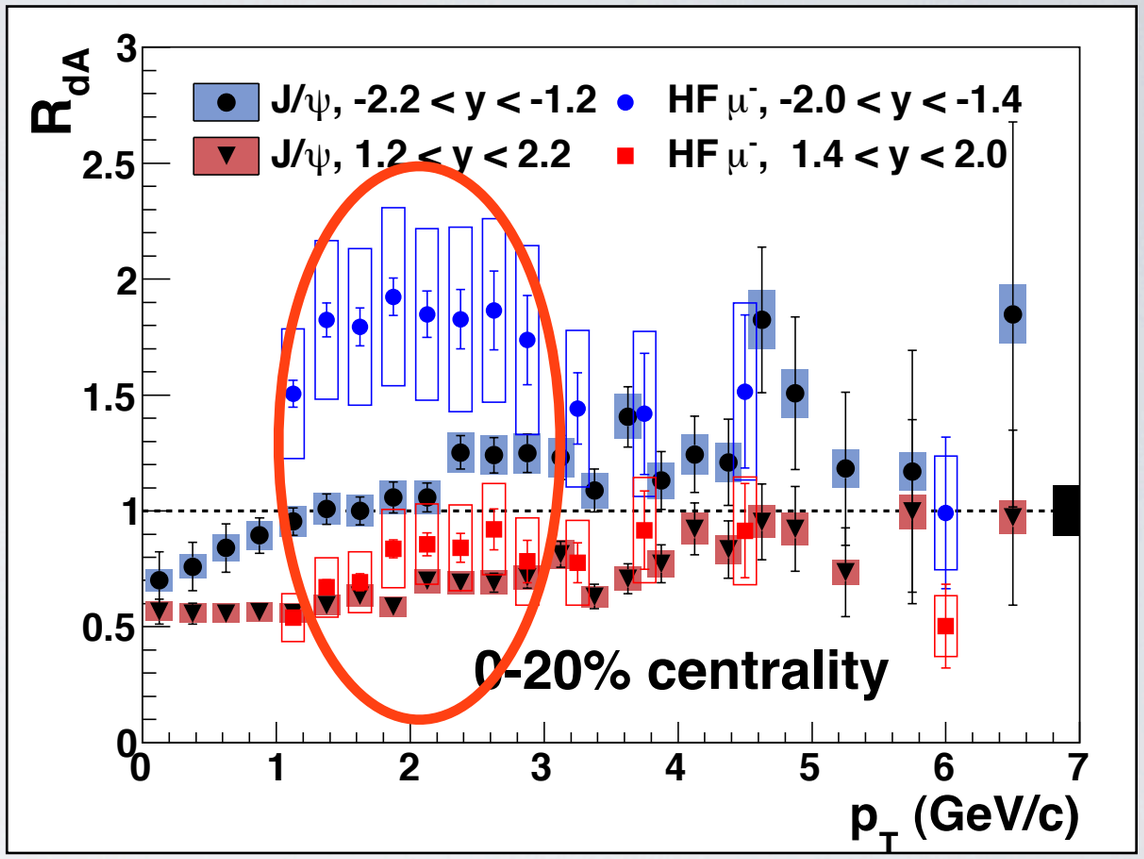


J/ψ : Phys. Rev. C 87, 034904 (2013)

- In the most peripheral collision
  - **all R_{dA} ~ 1**

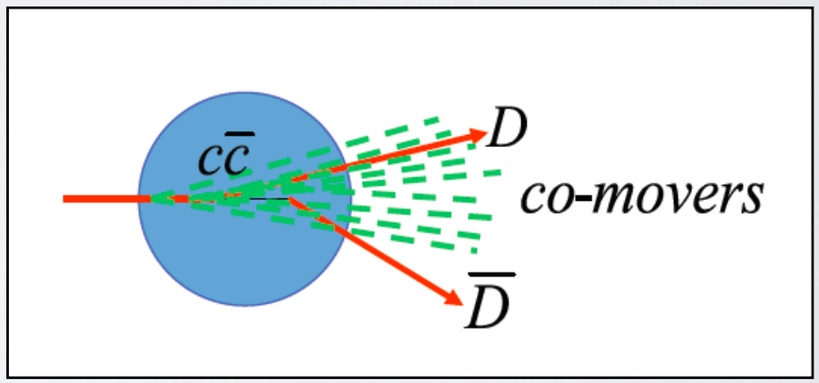
HF μ vs. J/ψ





J/ψ : Phys. Rev. C 87, 034904 (2013)

- In the most peripheral collision
  - **all R_{dA} ~ 1**
- In the most central collision
  - R_{dA} of HF muon and J/ψ are still consistent
  - However, **large difference at backward rapidity**
  - Charm production is enhanced but **J/ψ seems to be significantly absorbed due to nuclear breakup** inside dense co-movers at backward rapidity



Summary

- Heavy-flavor muon production in d+Au collisions
  - **suppression at forward** rapidity
  - **enhancement at backward** rapidity
  - indicate **important role of nuclear break-up in J/ψ** production
  - pQCD calculation well reproduce the forward data
  - EPS09s nPDF prediction underestimate the difference between forward and backward rapidity

- Outlook
  - D/B can be separated with **VTX/FVTX** (Run-14 Au+Au, Run-15 p+Au)
  - Comparison with the ALICE forward data would be interesting

Back up

Heavy-quark production

Heavy-quark production

$$\frac{d\sigma}{dp_T dy} \propto \sum_{abcd} \int dx_a dx_b f_a(x_a, Q^2) f_b(x_b, Q^2) \hat{\sigma}(ab \to cd) D_{h/c}$$

p+p collisions

parton distribution fucntion (pQCD)

partonic cross section

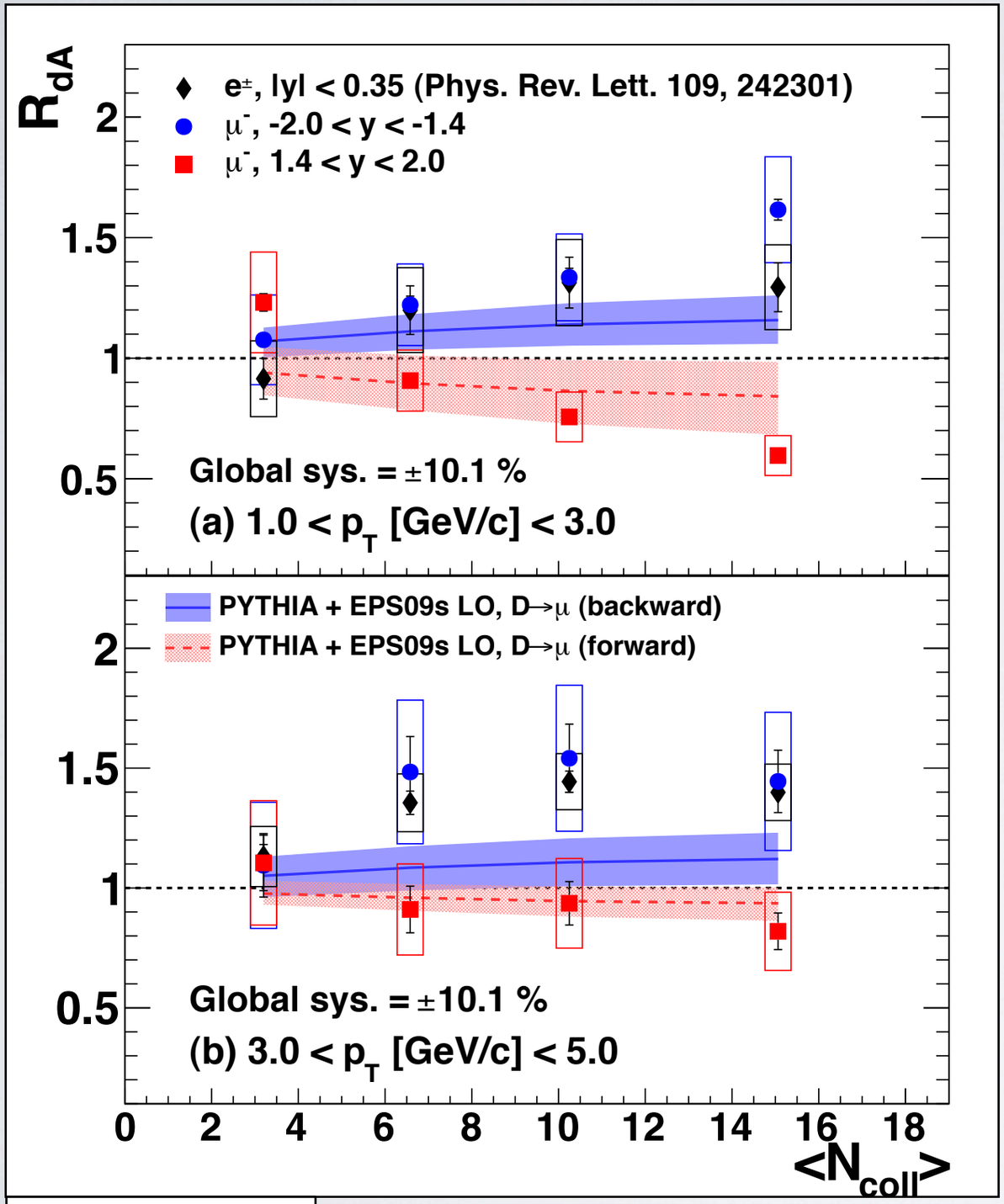
fragmentation function

Heavy-quark production

$$\frac{d\sigma}{dp_T dy} \propto \sum_{abcd} \int dx_a dx_b f_a(x_a, Q^2) f_b(x_b, Q^2) \hat{\sigma}(ab \to cd) D_{h/c}$$

	parton distribution fucntion	partonic cross section (pQCD)	fragmentation function
p+p collisions			
d+A collisions	initial-state modification		
A+A collisions	initial-state modification		final-state modification

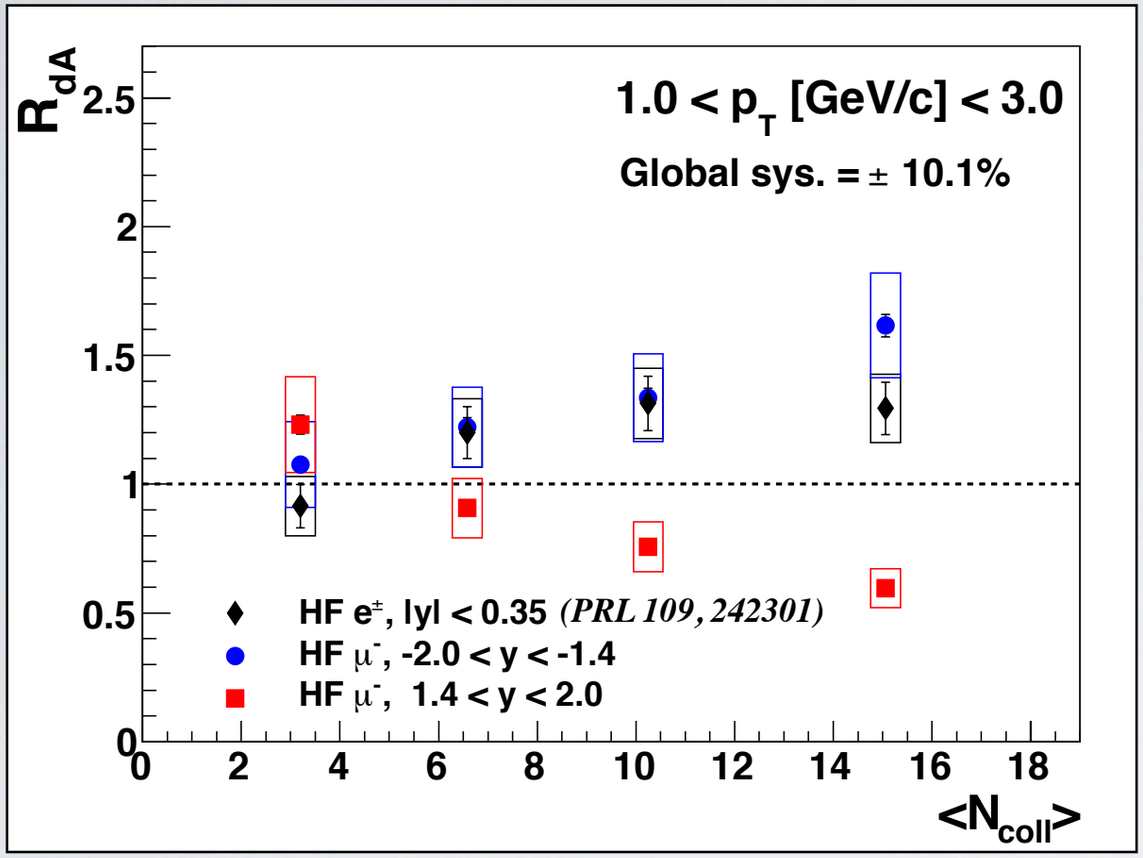
HF muon $R_{dA}(\langle N_{coll}\rangle)$

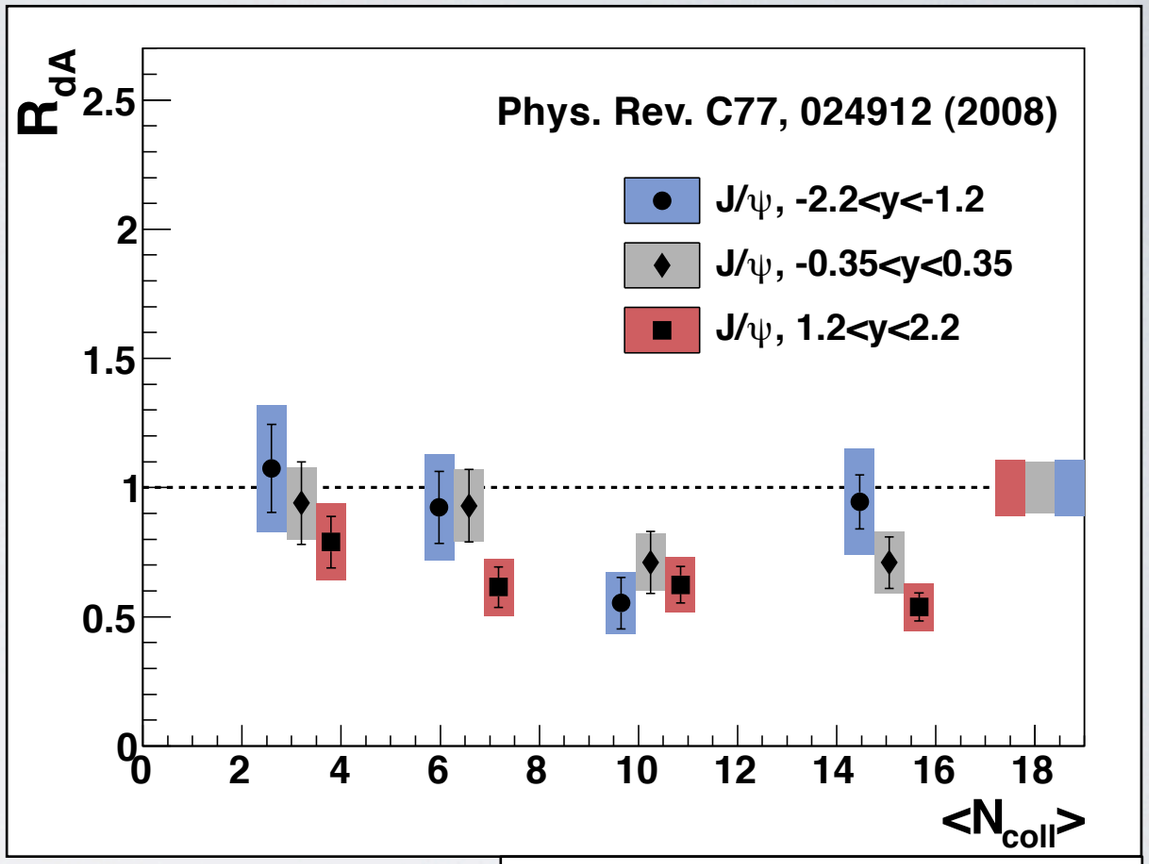


arXiv:1310.1005

- RdA as a function of $\langle N_{coll}\rangle$ in different p_T ranges
  - Stronger CNM effects with increasing centrality at both rapidity ranges
- Enhancement at backward rapidity is similar to that in HF electron at mid-rapidity
- EPS09s calculation shows similar trends, but underestimate the difference between forward and backward rapidity

HF μ vs. J/ψ I

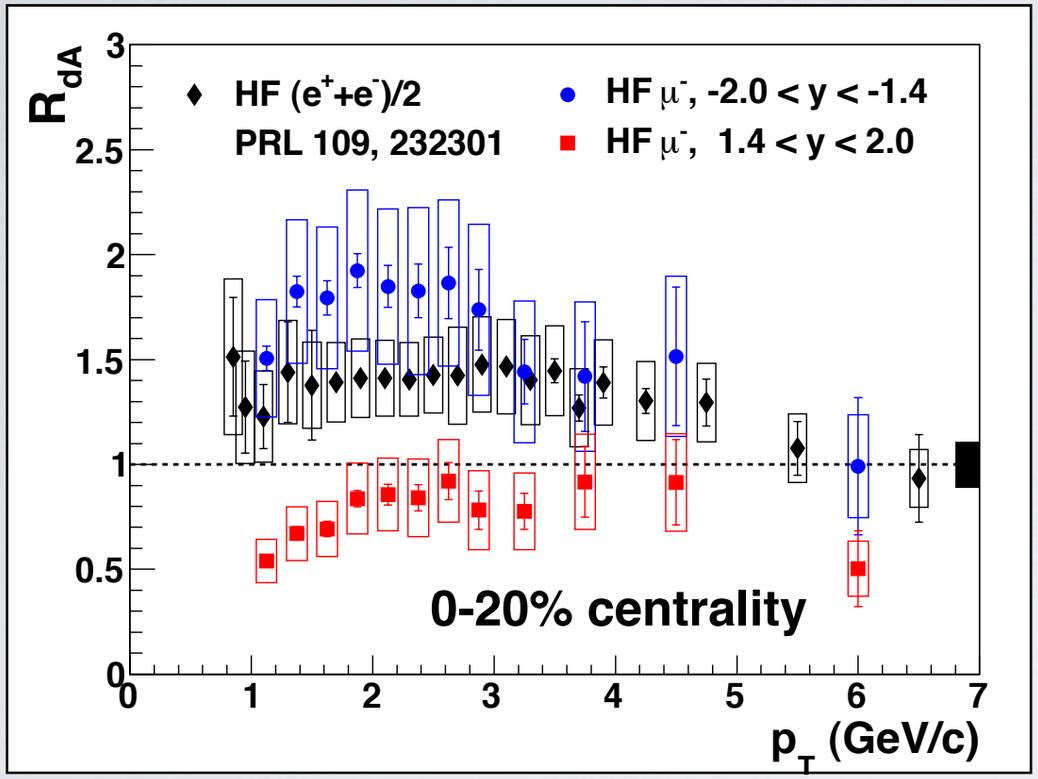


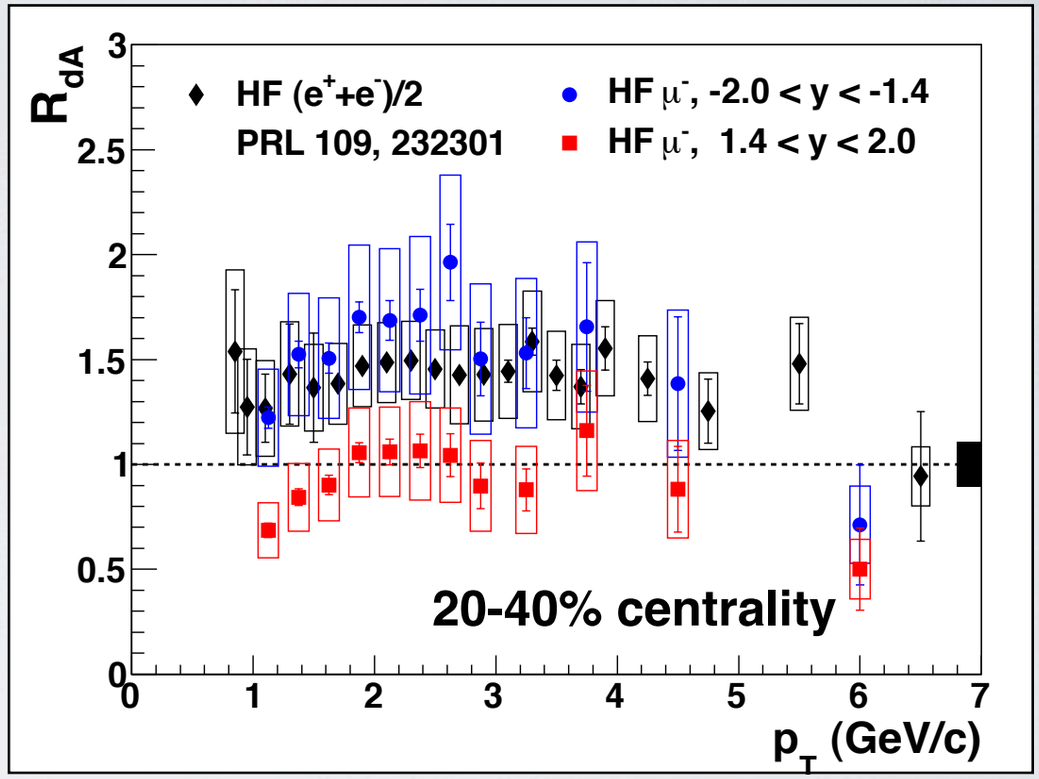


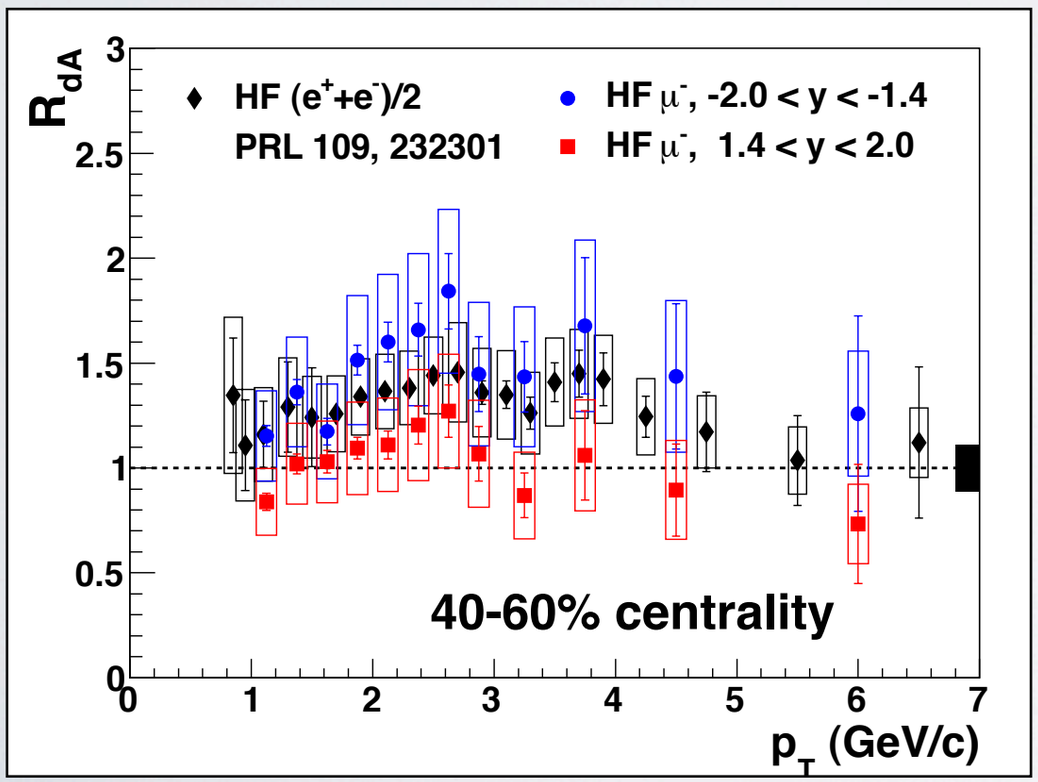
Phys. Rev. C 77, 024912 (2008)

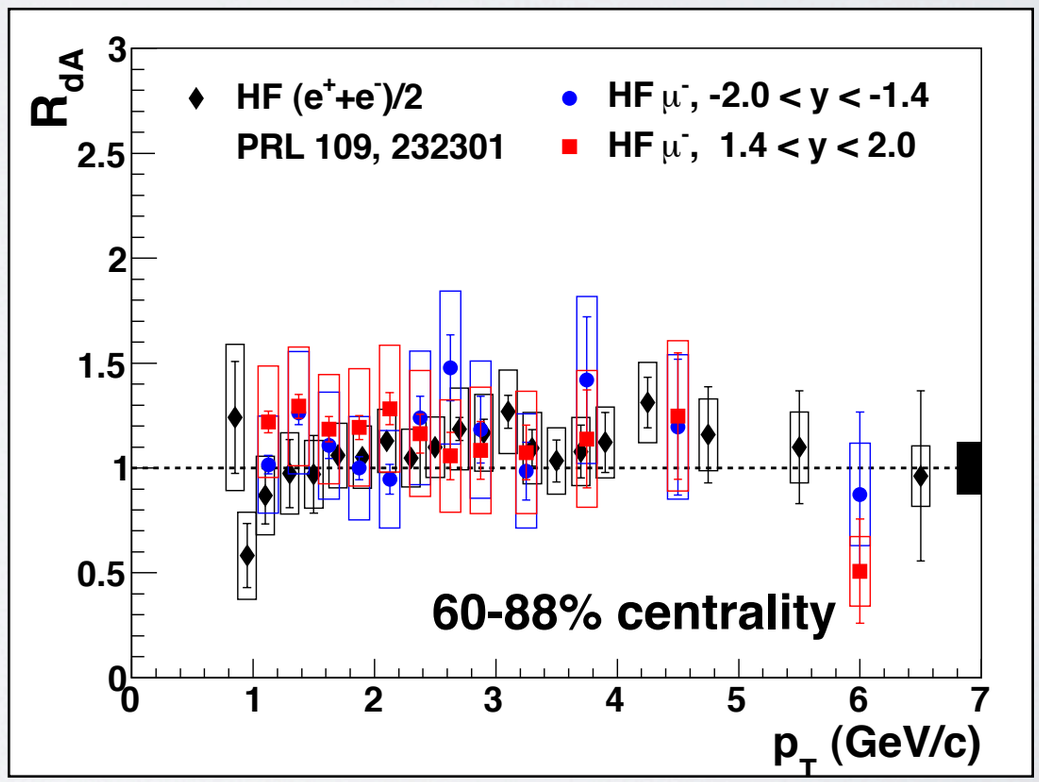
- R_{dA} as a function of $\langle N_{coll} \rangle$
  - R_{dA} of J/ψ are suppressed at all rapidity ranges
    ⇔ only R_{dA} at forward rapidity are suppressed in case of HF muon
    *caveat : J/ψ integrated over the entire p_T range
  - J/ψ suppression at forward probably is related to the suppression of charm production
  - Large nuclear break-up is implied at mid- and backward rapidity

Comparison of $R_{dA}(p_T)$ with HF e at y=0









Comparison to EPS09s calculations