Study of medium effects on heavy-flavor production at RHIC

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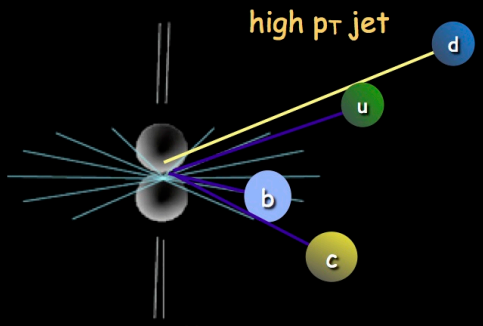
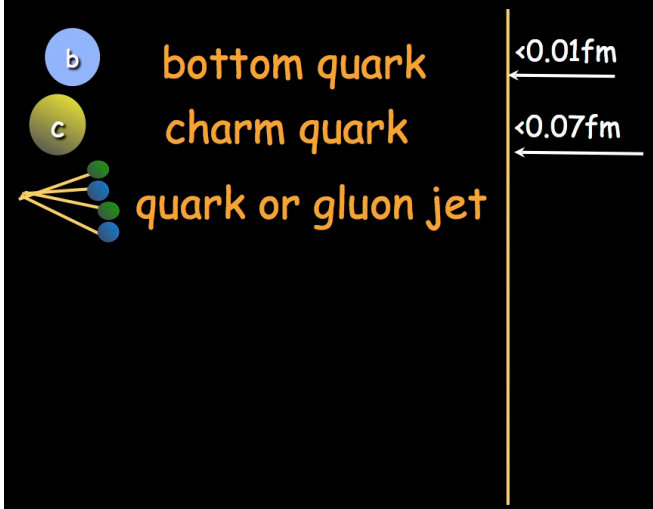
Quark Gluon Plasma in a minute

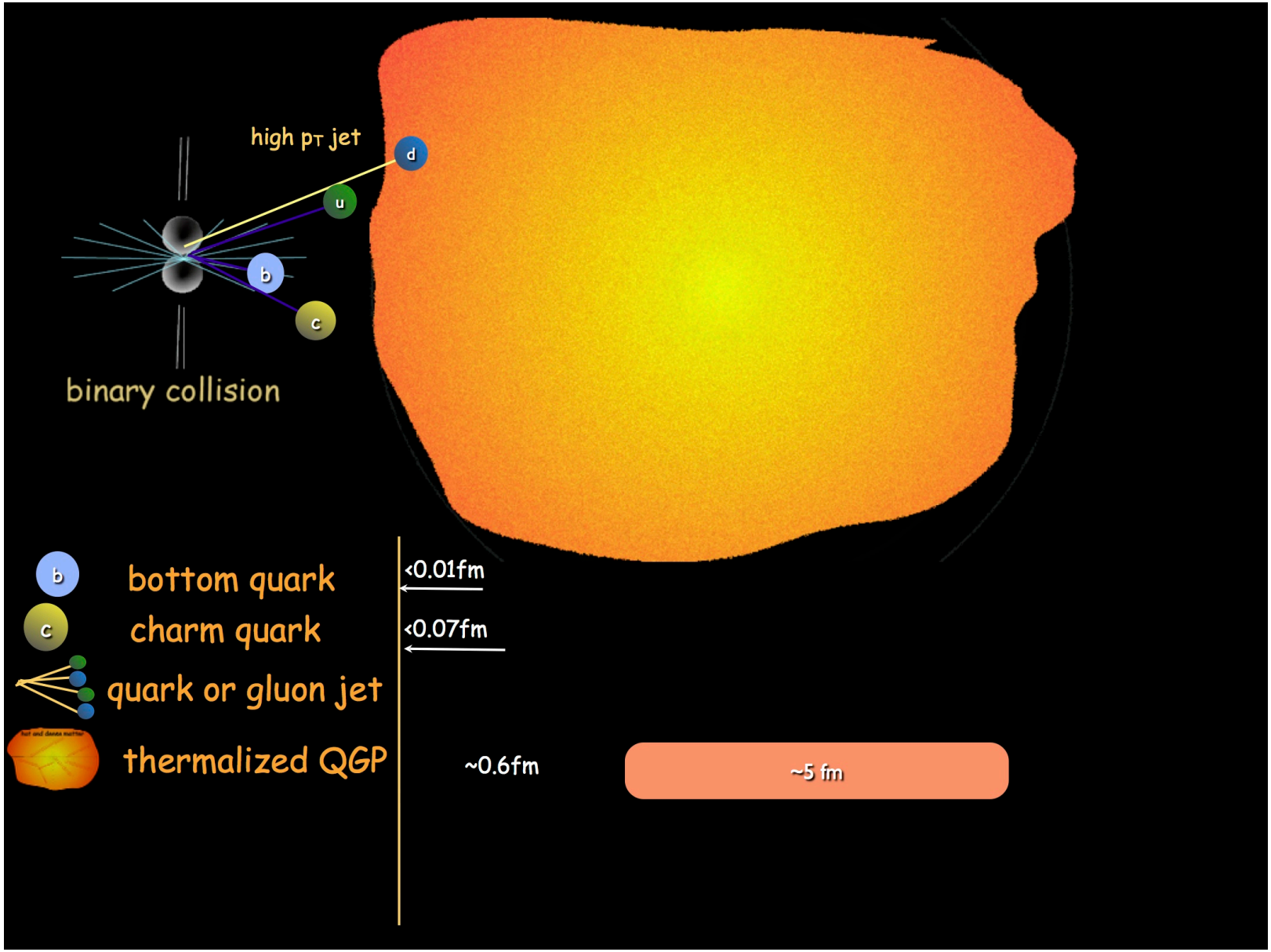
Heavy quarks in heavy-ion collisions



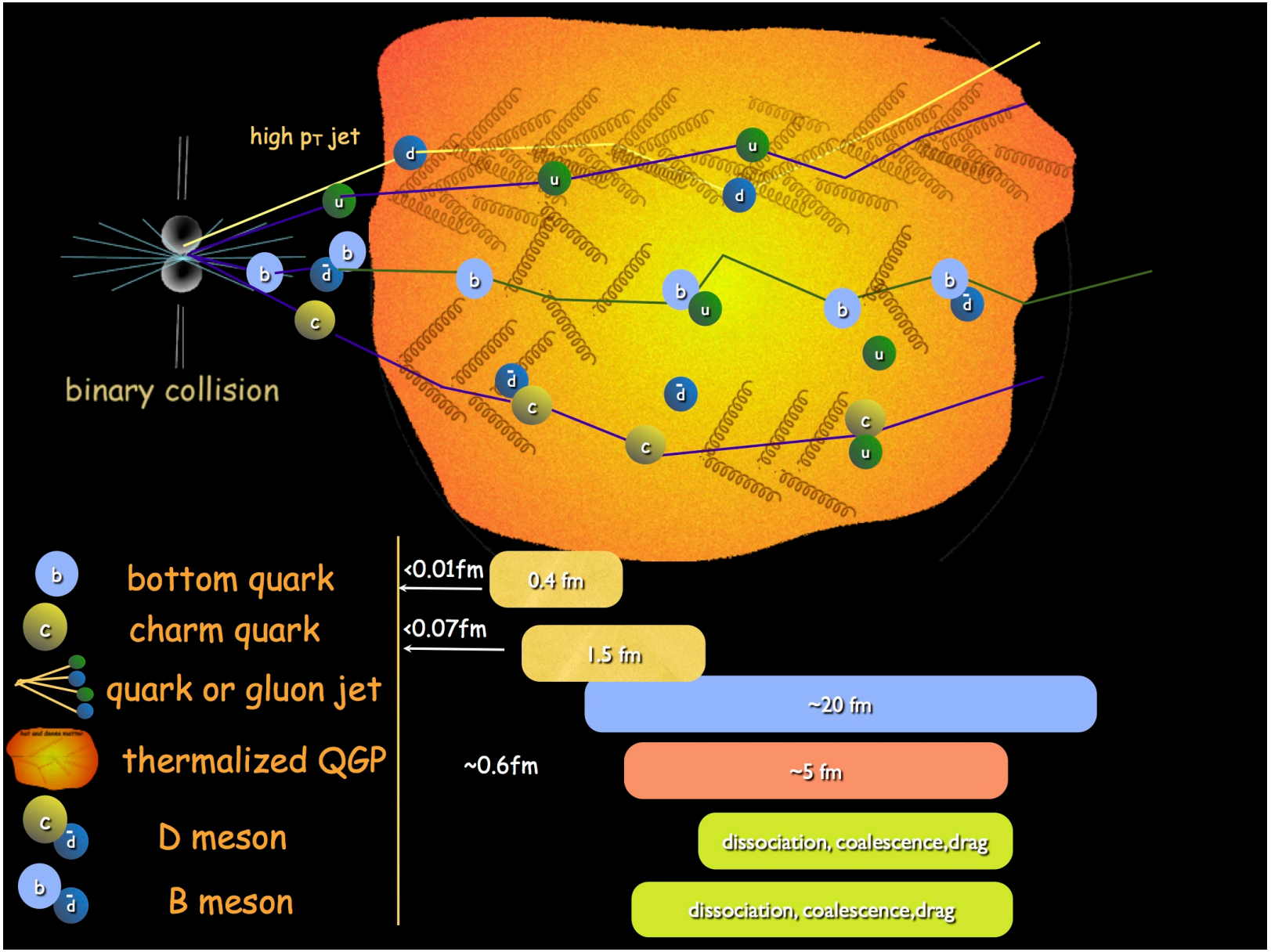


pictures from
Cesar Silva's slides
numbers from
A. Adil, I. Vitev, PLB649 (2007) 139

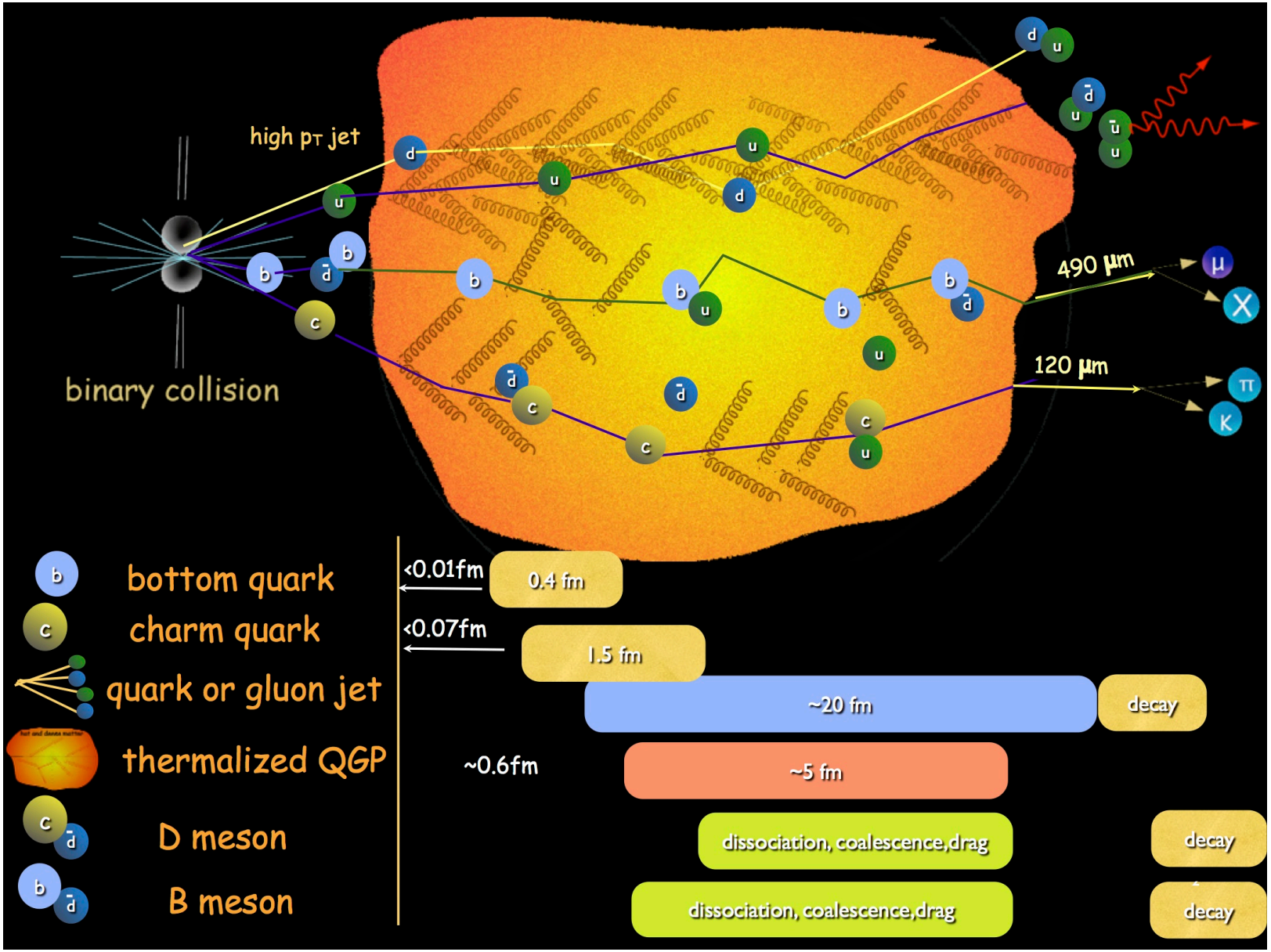
Heavy quarks in heavy-ion collisions



Heavy quarks in heavy-ion collisions



Heavy quarks in heavy-ion collisions



Relativistic Heavy Ion Collider (RHIC)

- Circumference 3.8 km
  - two counter-circulating rings (yellow and blue rings)
- Beam species : p, d, He, Cu, Au, U
  - bunch length : 20 cm, bunches per rung : 56
- Maximum energy for heavy-ion collisions: sqrt(s_{NN})=200 GeV
- Maximum energy for proton-proton collisions : sqrt(s)=510 GeV

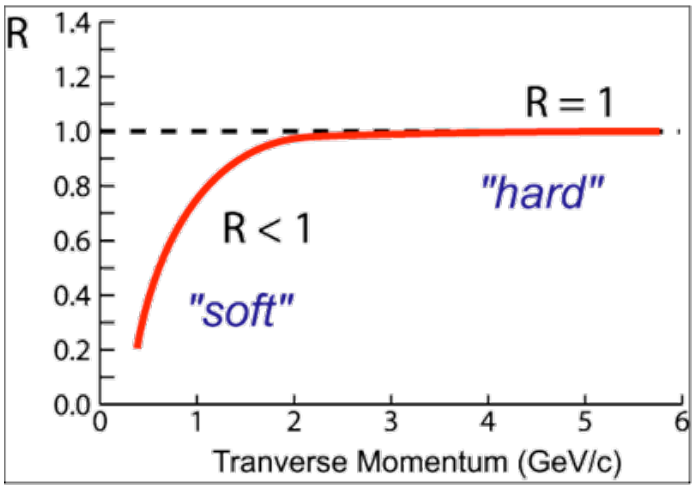
Study of heavy quark production

- Produced in the early stage of collisions
  - dominantly produced by gluon fusion at RHIC energy
  - experience full evolution of medium from heavy-ion collision

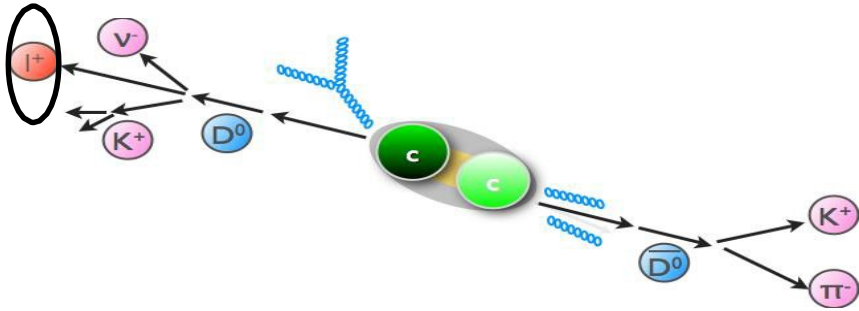
- Medium effects on heavy quark production can be studied from various collision systems

- Nuclear modification factor

$$R_{AB} = \frac{1}{\langle N_{coll} \rangle} \times \frac{Yield(A+B)}{Yield(p+p)}$$

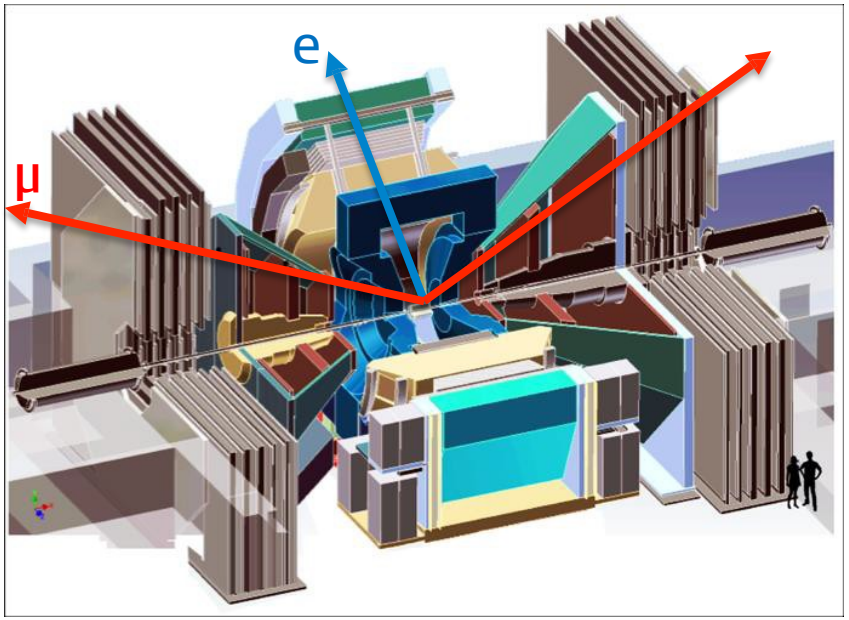


Heavy flavor in PHENIX



- Measurement of leptons from semi-leptonic decays of D/B mesons
  - easy to trigger
  - need to understand/subtract background from other lepton sources

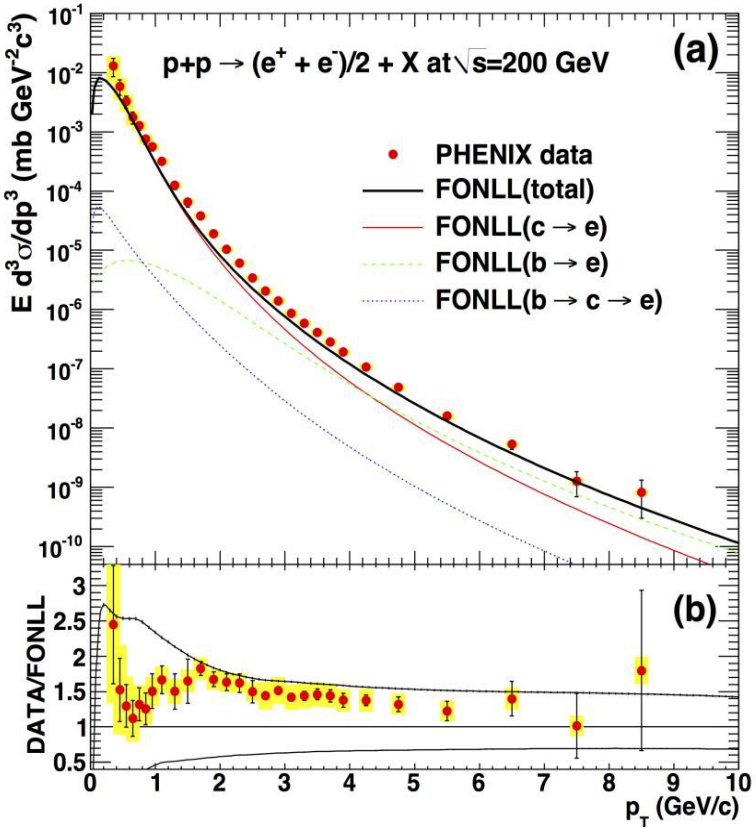
- Electrons at Central arm
  - $|\eta|<0.35$
  - $\Delta\phi=\pi$
  - Tracking w/ DC, PC
  - eID w/ RICH, EMcal

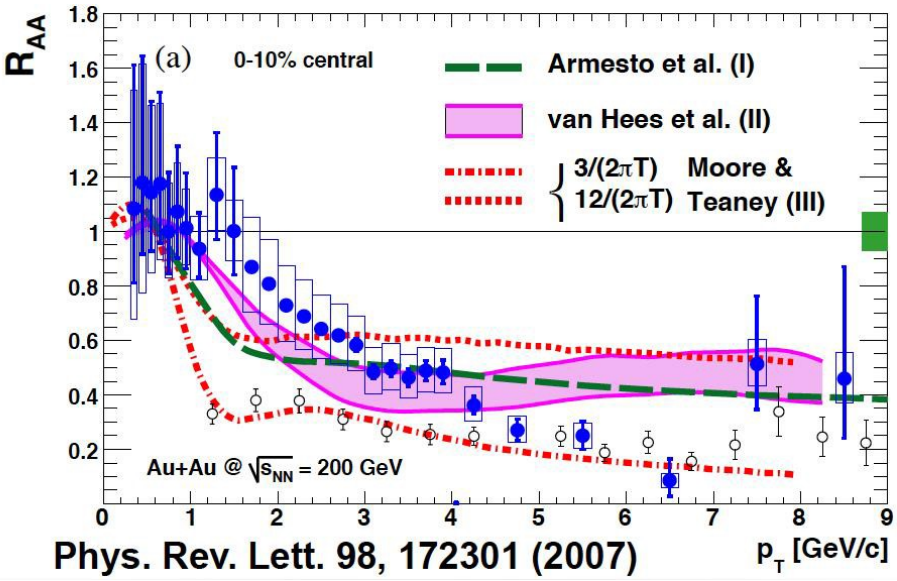


- Muons at Muon arm
  - $1.2<|\eta|<2.2$
  - $\Delta\phi=2\pi$
  - ~10 λ absorber
  - Tracking w/ wire chamber
  - muID w/ 5 layers of steel and larocci tube plane

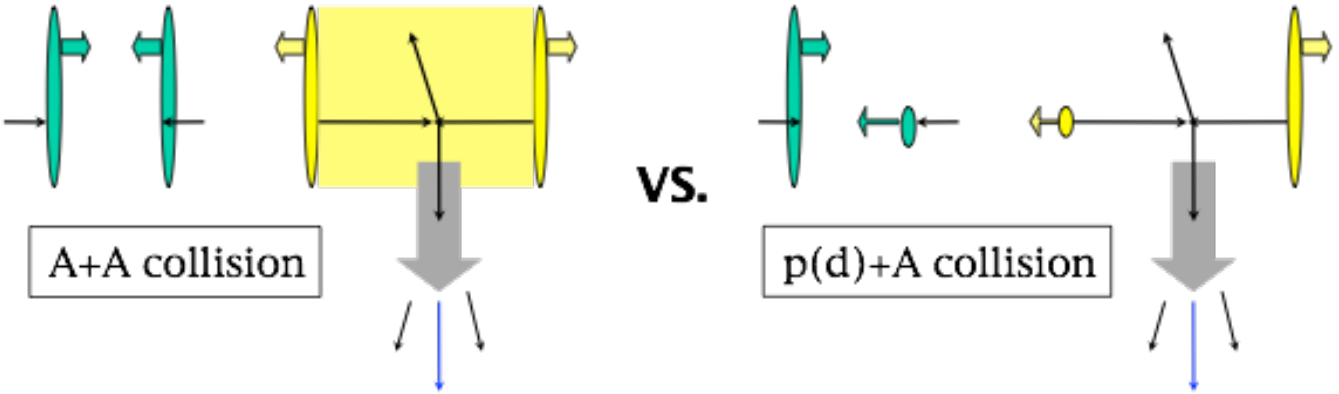
From N_{coll}=1 to N_{coll}=1000

- In p+p collisions
  - consistent with the FONLL calculation
  - reference for other collision systems
- In central Au+Au collisions
  - large suppression of high p_T HF e

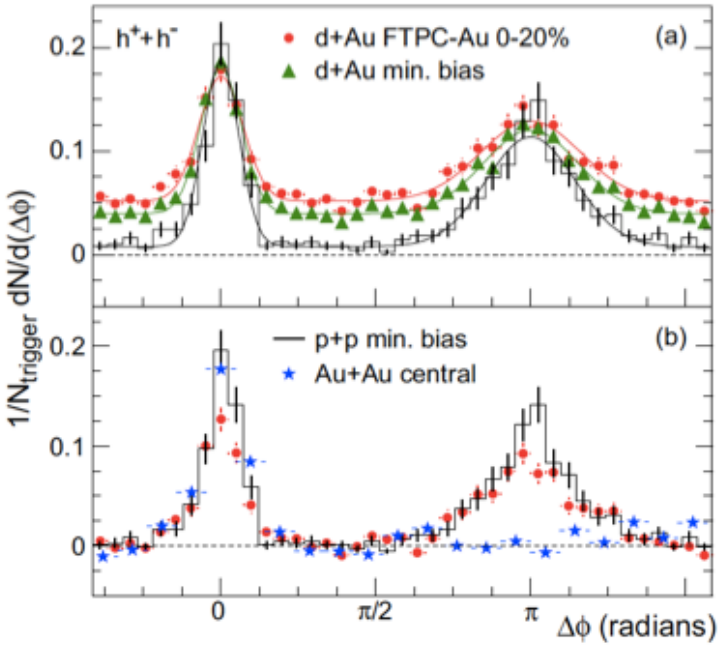




- Minimize the hot medium effects to study initial-state modification

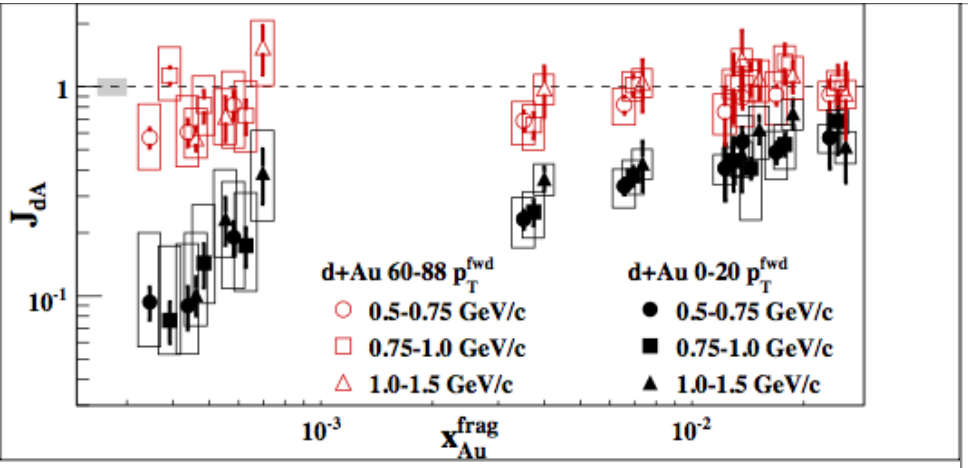


- Jet quenching is absent in d+Au collisions

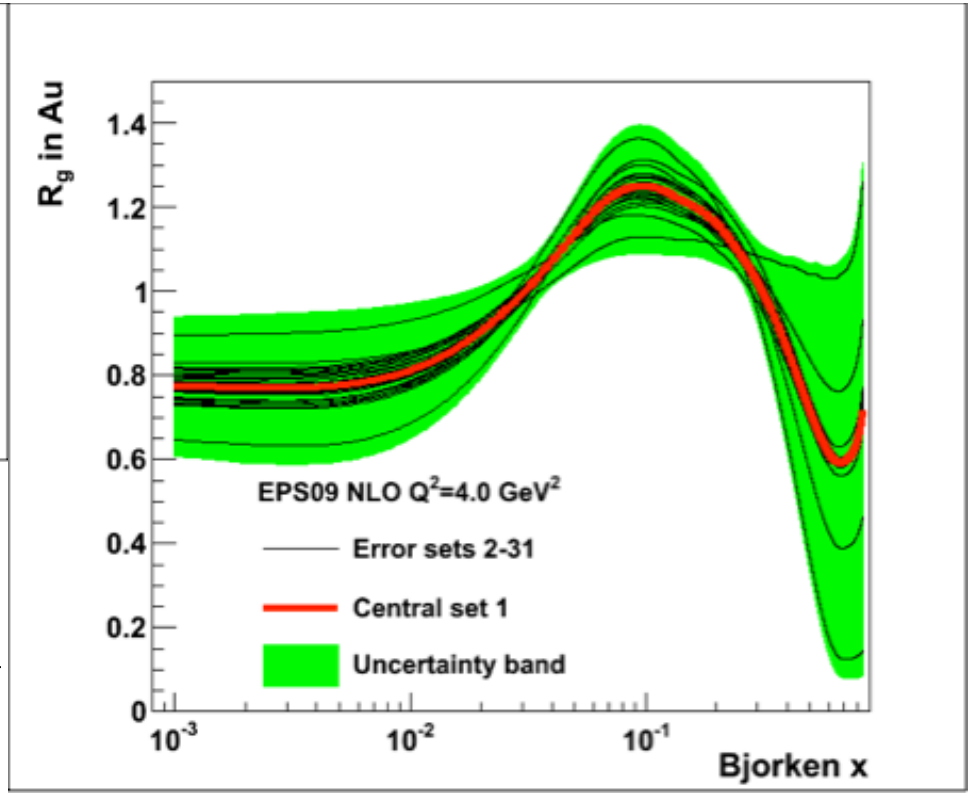


Phys. Rev. Lett. 91, 072304 (2003)

CNM effects – Nuclear shadowing



Phys. Rev. Lett. 107, 172301 (2011)



JHEP04 (2009) 065

$$J_{dA} = \frac{\sigma_{dA}^{pair} / \sigma_{dA}}{\langle N_{coll} \rangle \sigma_{pp}^{pair} / \sigma_{pp}} \propto \frac{f_d^a(x_d) \otimes f_A^b(x_A) \otimes \sigma^{ab \to cd} \otimes D(z_c, z_d)}{f_p^a(x_p) \otimes f_p^b(x_p) \otimes \sigma^{ab \to cd} \otimes D(z_c, z_d)}$$

High x in d
mostly valance quarks
weak modification expected

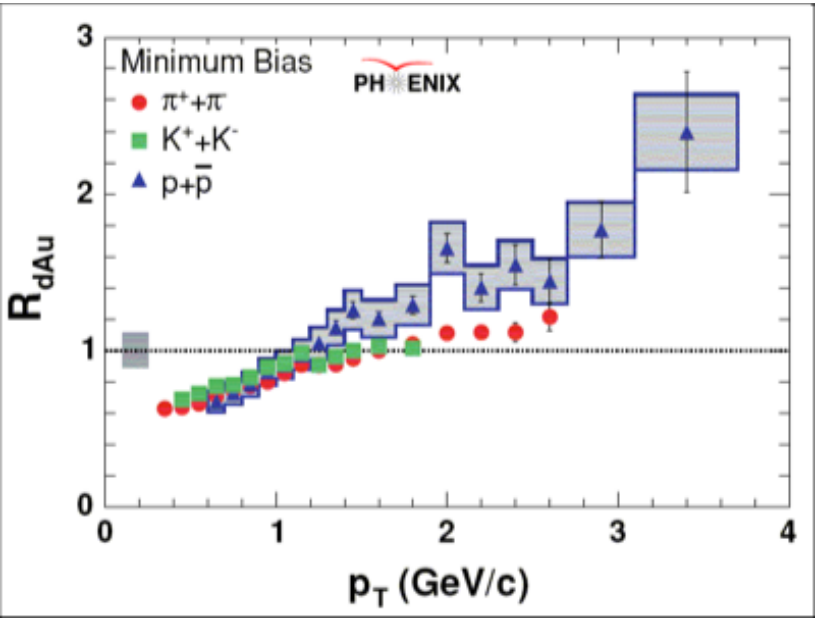
Low x in Au
mostly gluon
strong modification (suppression) expected

$$J_{dA} \sim R_G^A$$

- Modification of parton distribution in nuclei
  - shadowing
  - anti-shadowing
  - EMC

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

CNM effects – Cronin effect & nuclear absorption

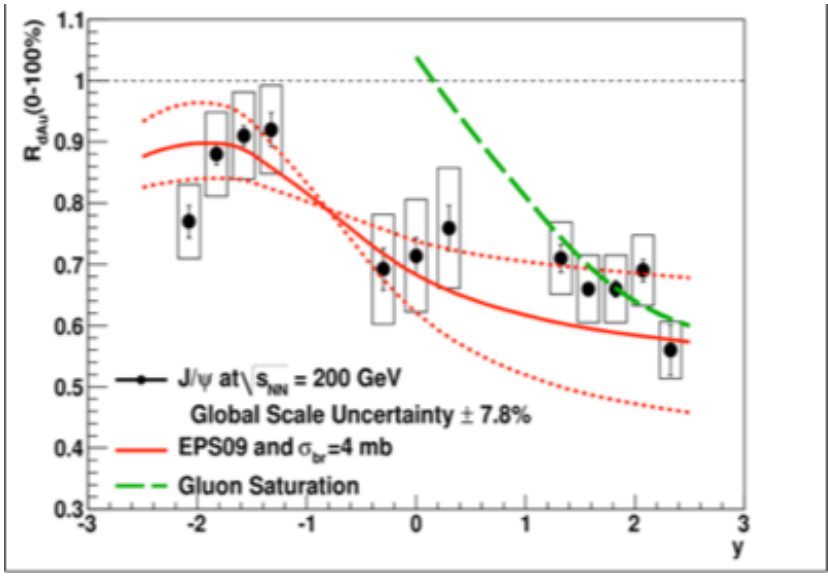


Phys. Rev. C 74, 024904 (2006)

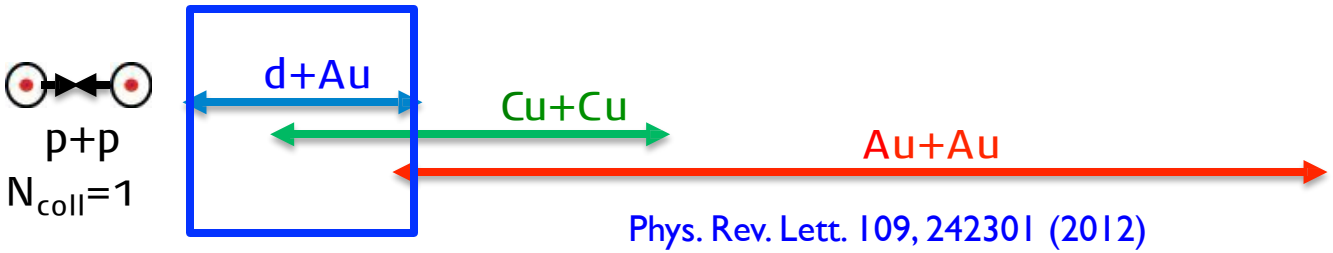
- Cronin effect
  - pT broadening due to multiple inelastic scattering of incoming parton before hard scattering
  - baryon enhancement can be explained by recombination model
    (R. Hwa et al. nucl-th/040466)

- Nuclear breakup (absorption)
  - breaking up quarkonia with CNM
    - nucleus during bunch crossing
    - co-mover
  - J/psi are suppressed at all rapidity and in all centrality ranges
  - large difference from open heavy flavor results

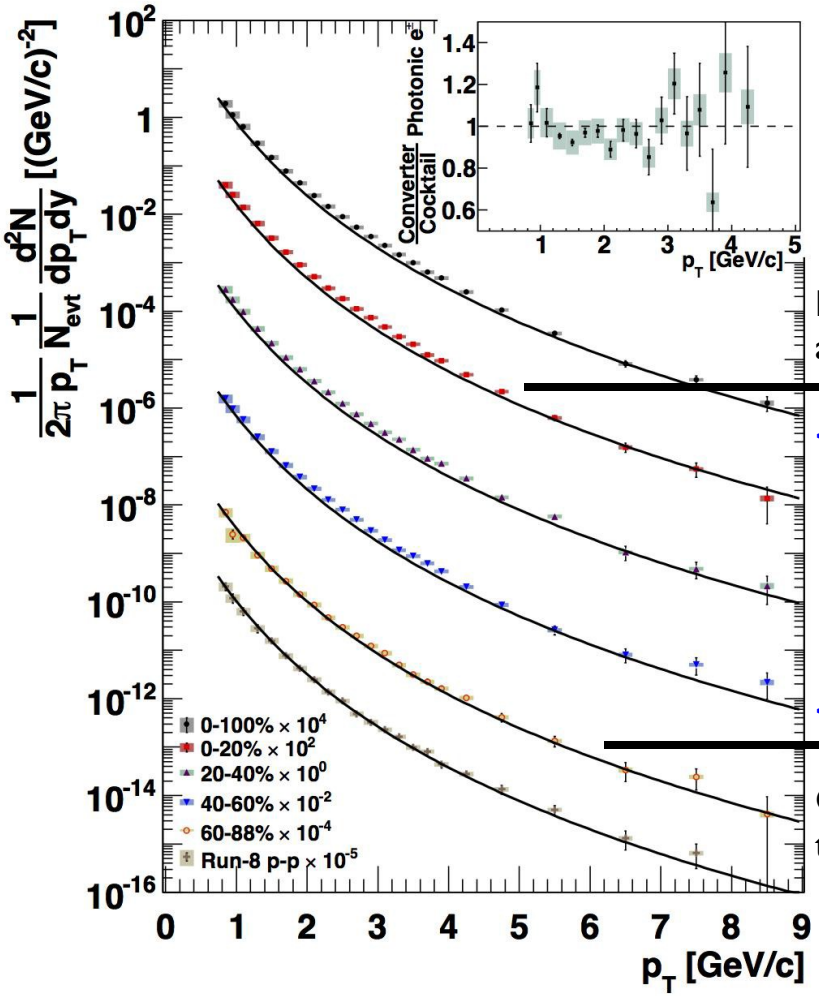
Phys. Rev. Lett. 107, 142301 (2011)



In d+Au collisions



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

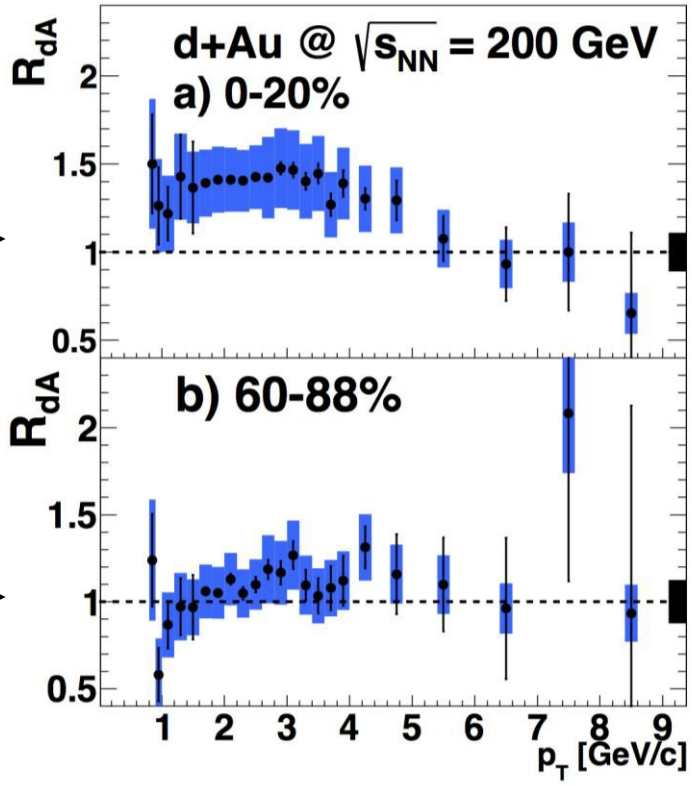


Enhancement at intermediate p_T

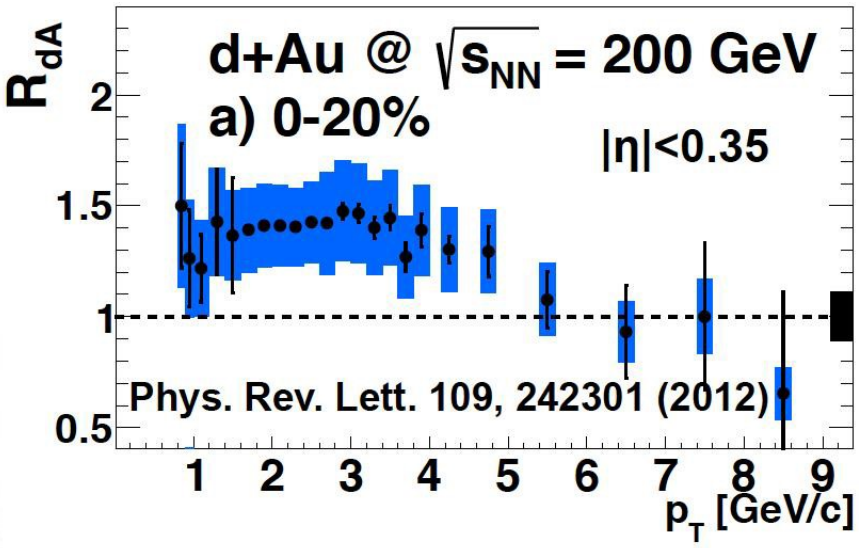
$\langle N_{coll}\rangle \approx 15.1$

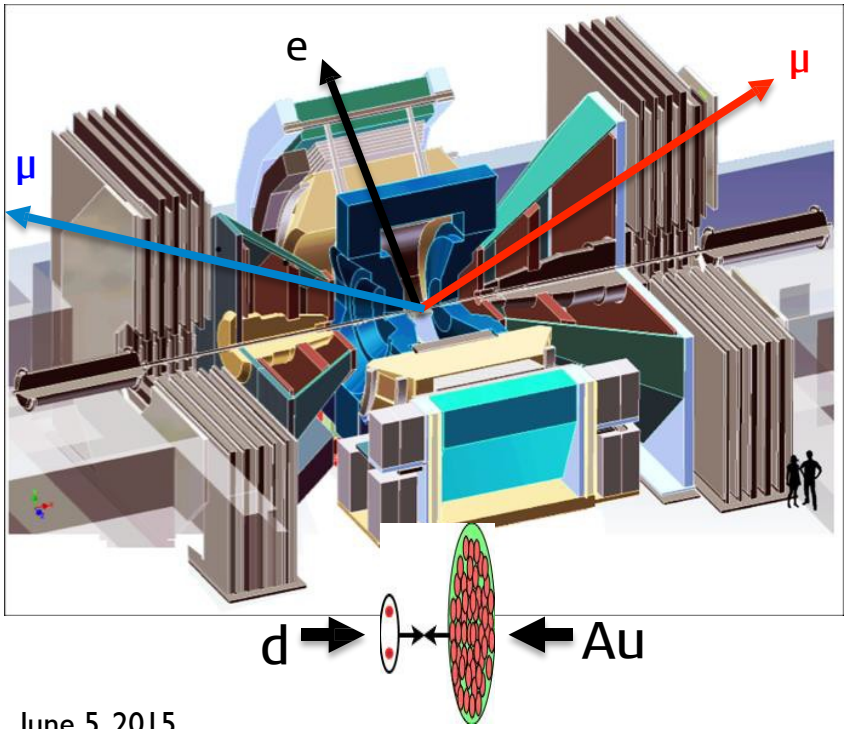
$\langle N_{coll}\rangle \approx 3.2$

Consistent with the scaled p+p results

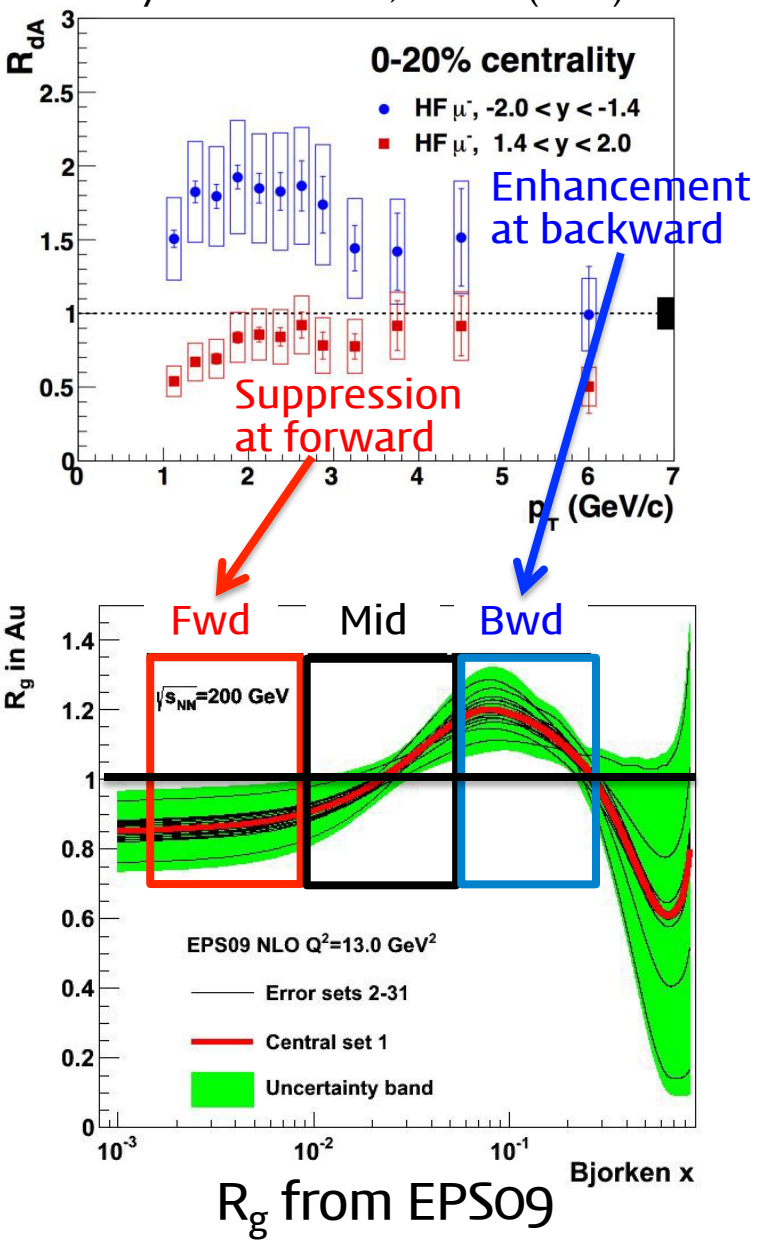


Rapidity expansion in d+Au



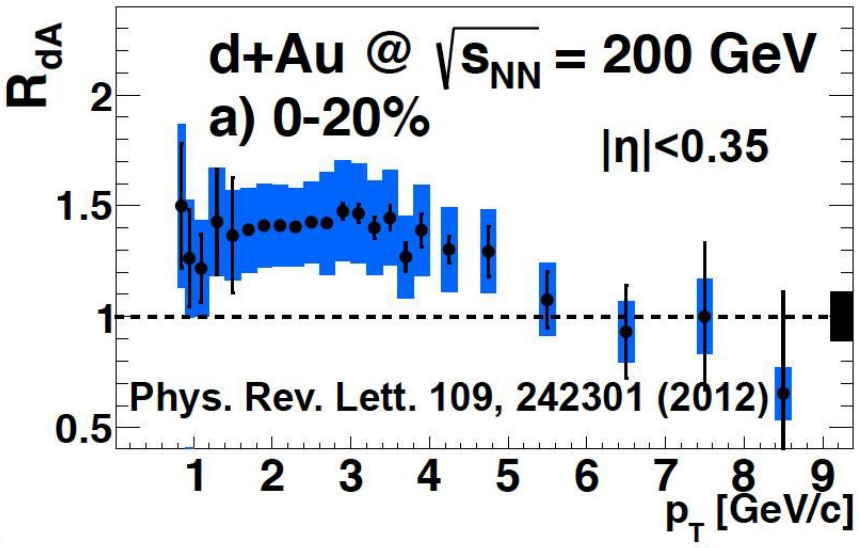


Phys. Rev. Lett. 112, 252301 (2014)

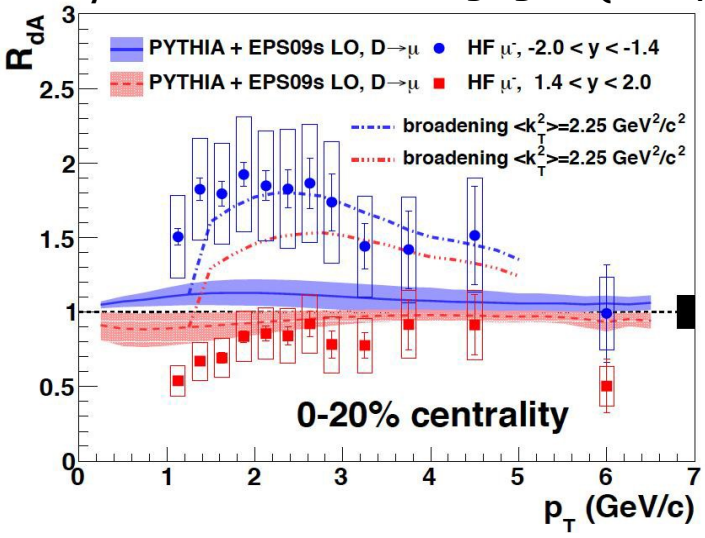


R_g from EPS09

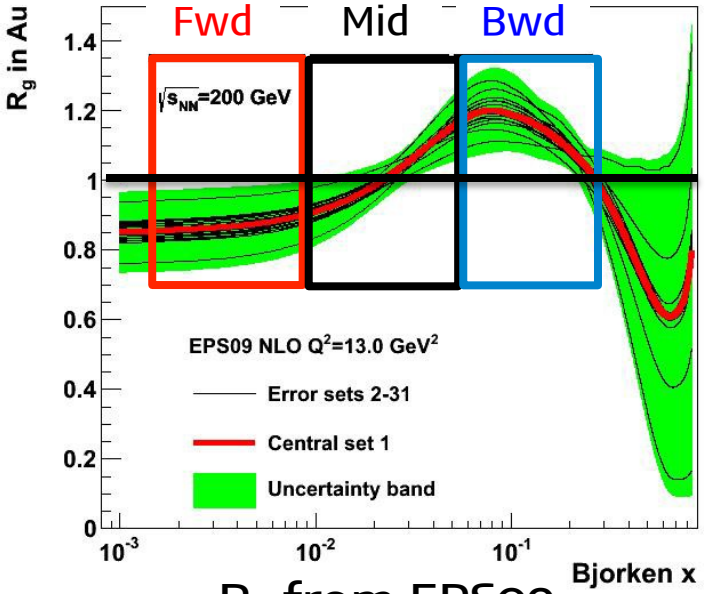
Rapidity expansion in d+Au



Phys. Rev. Lett. 112, 252301 (2014)

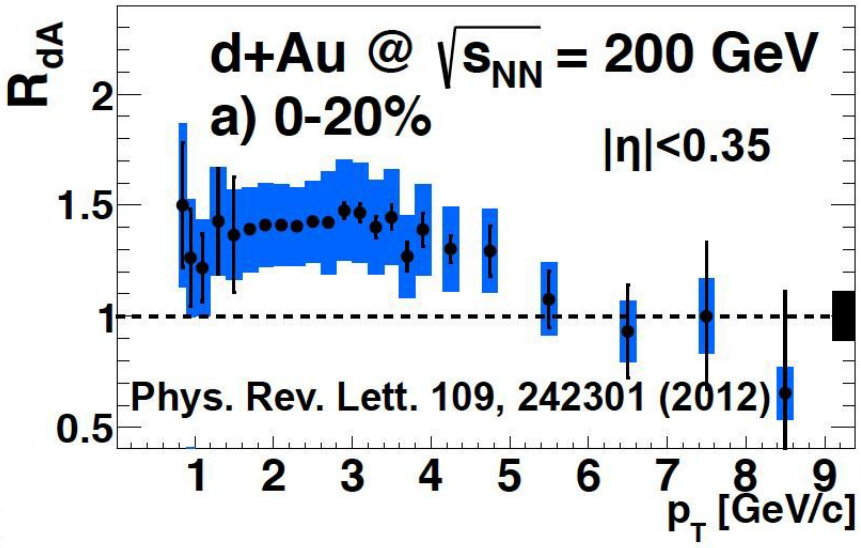


- Fail to reproduce the data at both rapidity simultaneously w/ combinations of initial-state effects
  - modification of nPDF
  - initial k_T broadening

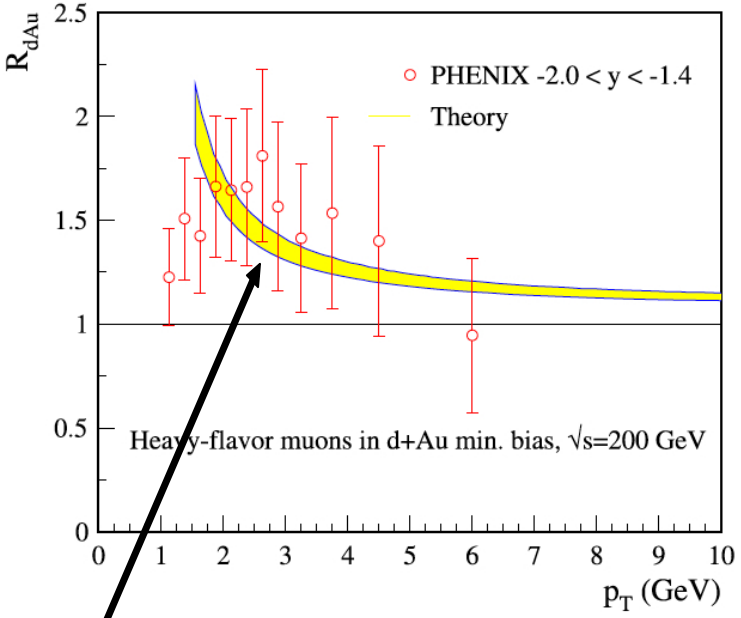


R_g from EPS09

Enhancement in central d+Au

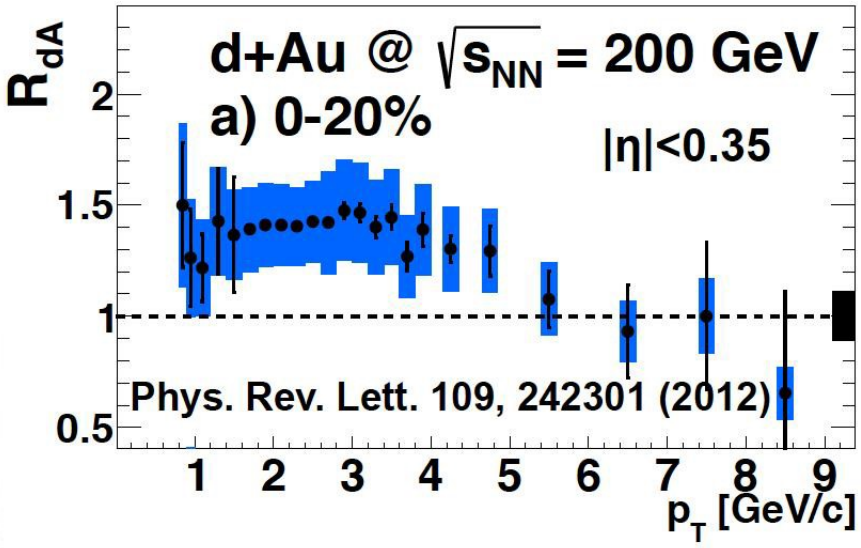


Phys. Lett. B740 (2015) 23

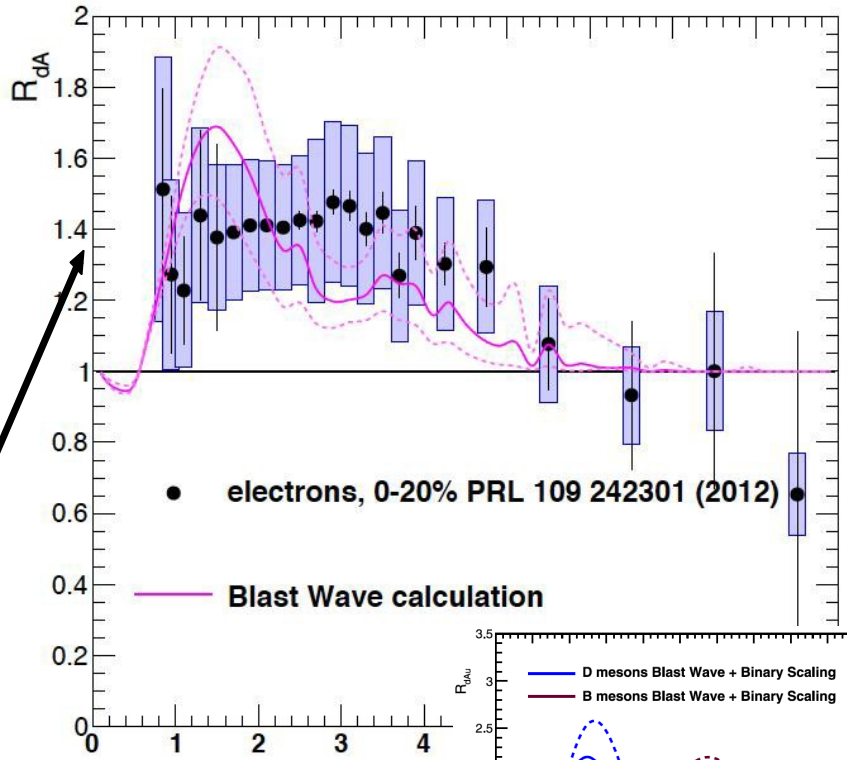


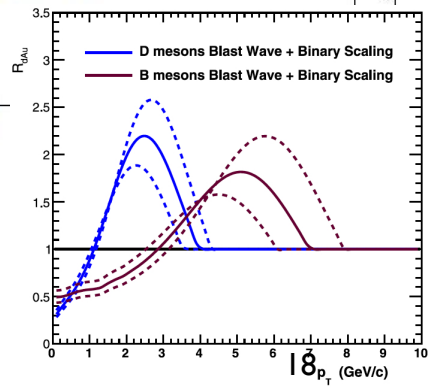
- Cronin enhancement?
  - initial pT component due to multiple scattering of incoming partons
- pQCD calculation considering multiple scattering effects reproduces the enhancement at backward rapidity!

Enhancement in central d+Au



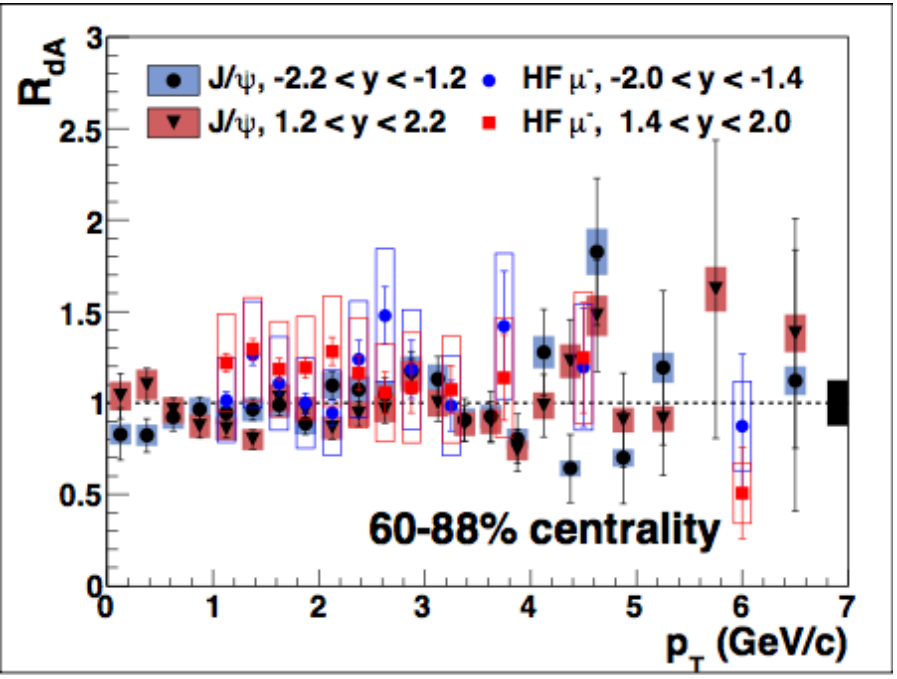
Phys. Lett. B731 (2014) 51

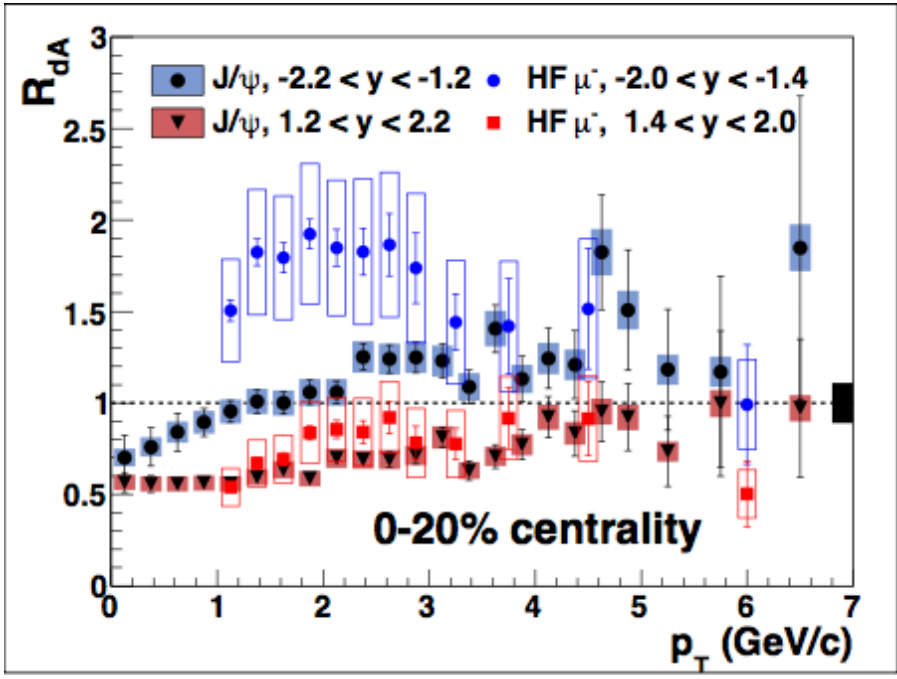




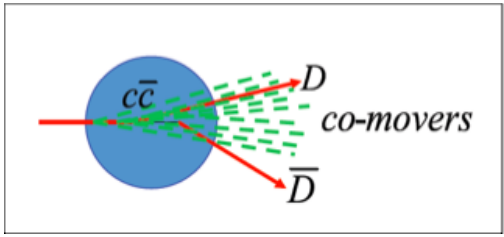
- Cronin enhancement?
  - initial pT component due to multiple scattering of incoming partons
- Radial flow also qualitatively reproduce the data!

HF mu vs. J/psi



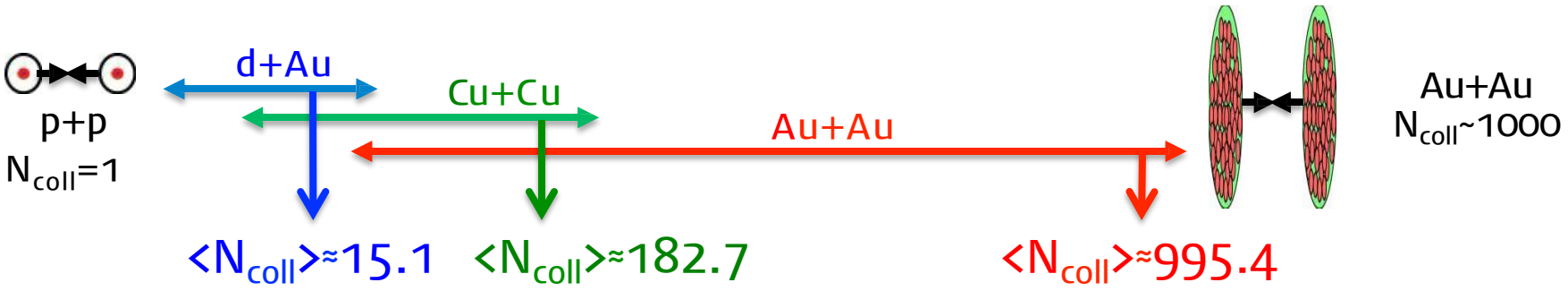


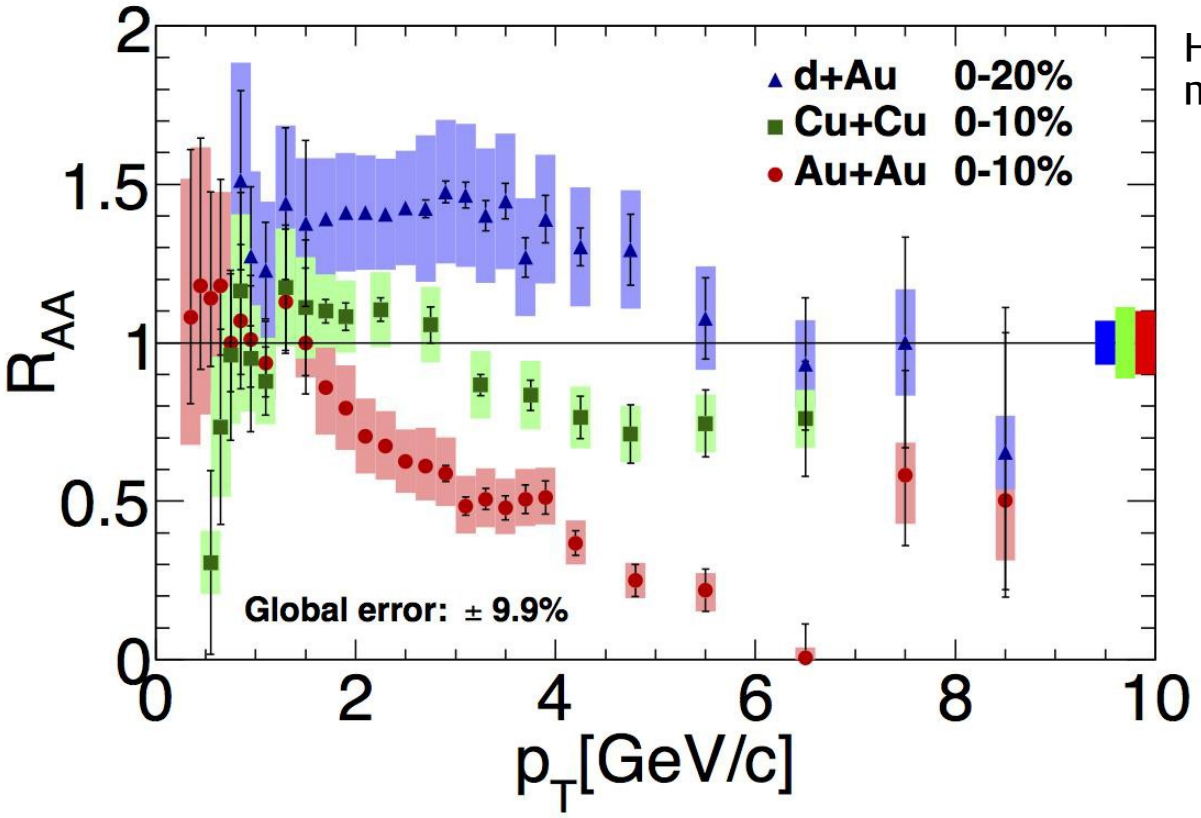
J/psi : Phys. Rev. C 87, 034904 (2013)



- In the most peripheral collision
  - all RdA ~ 1
- In the most central collision
  - RdA of HF muon and J/psi are still consistent at forward rapidity
  - however, clearly different at backward rapidity
  - charm production is enhanced but J/psi is significantly absorbed due to nuclear breakup inside dense co-movers at backward rapidity

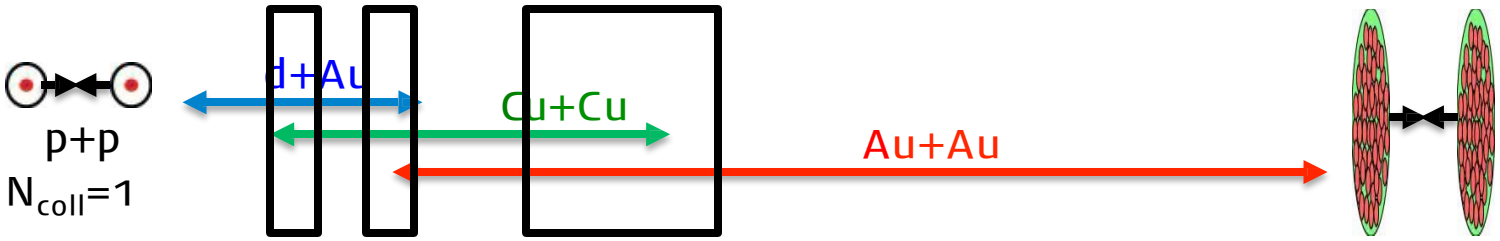
Most central collisions in d+Au, Cu+Cu, and Au+Au collisions

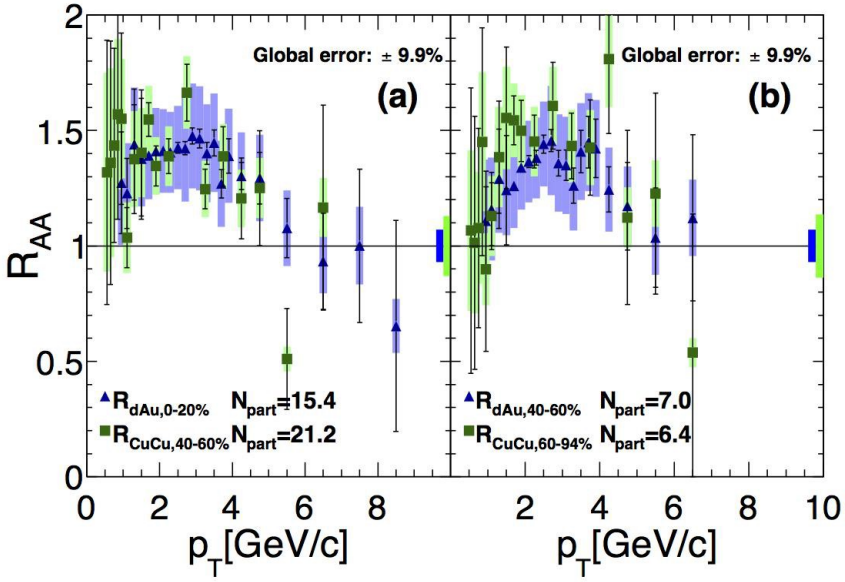




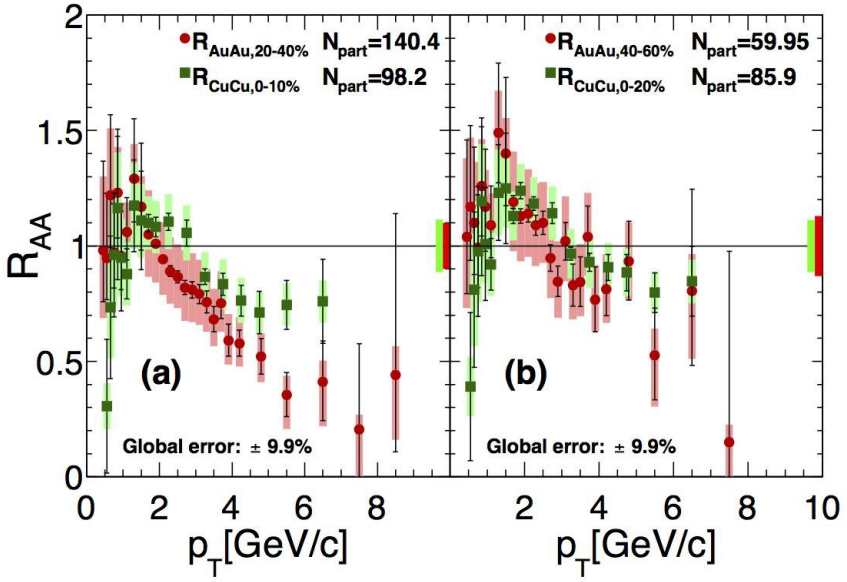
HF e, mid-rapidity

Similar system size



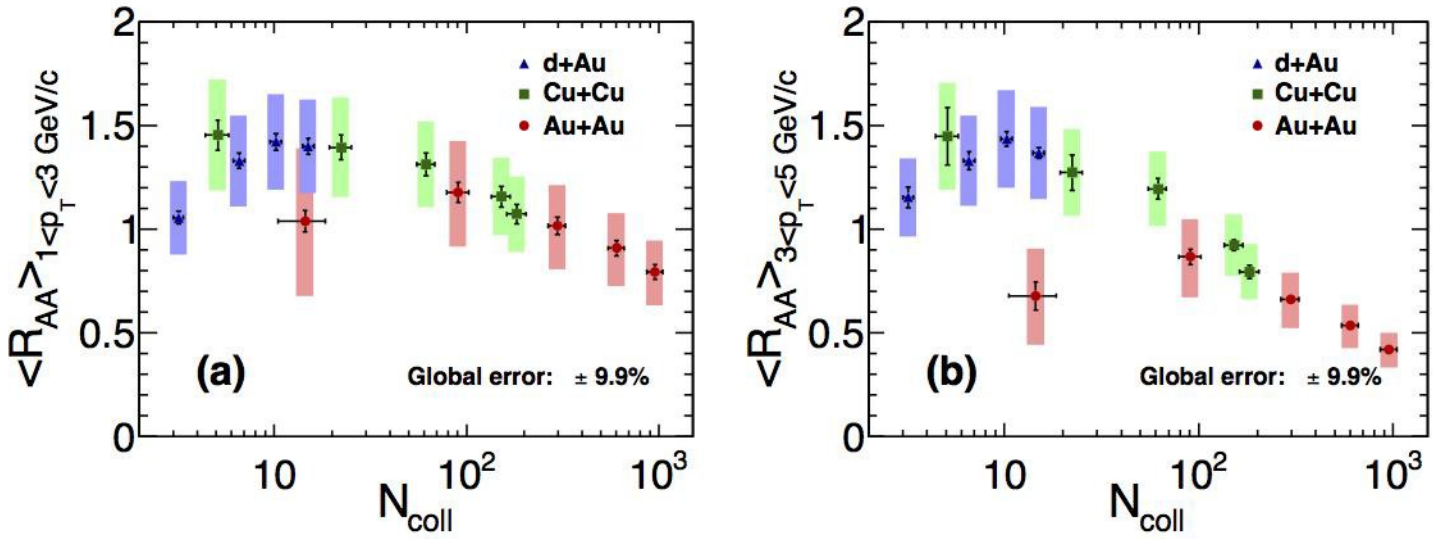


CENTRAL d+Au ≈ PERIPHERAL Cu+Cu



CENTRAL Cu+Cu ≈ MID Au+Au

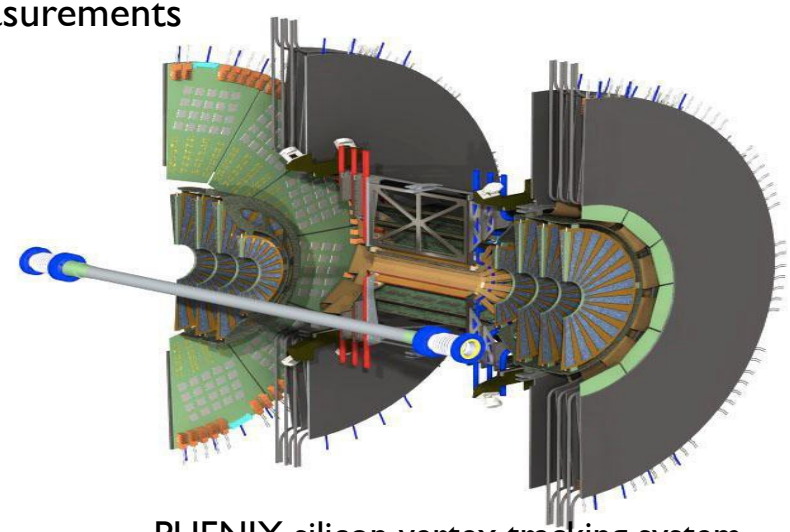
System size dependence



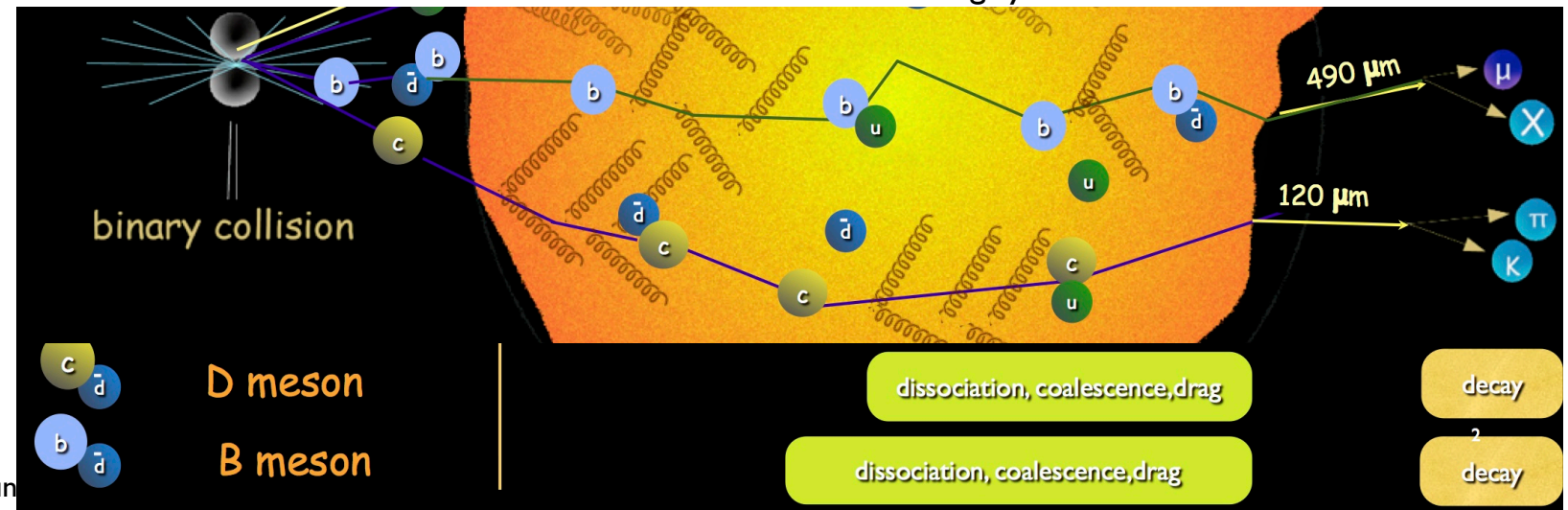
- Trend from d+Au and peripheral Cu+Cu collisions,
  where enhancement effects are dominating
- To central Cu+Cu and Au+Au collisions,
  where suppression effects take over

Next measurement!

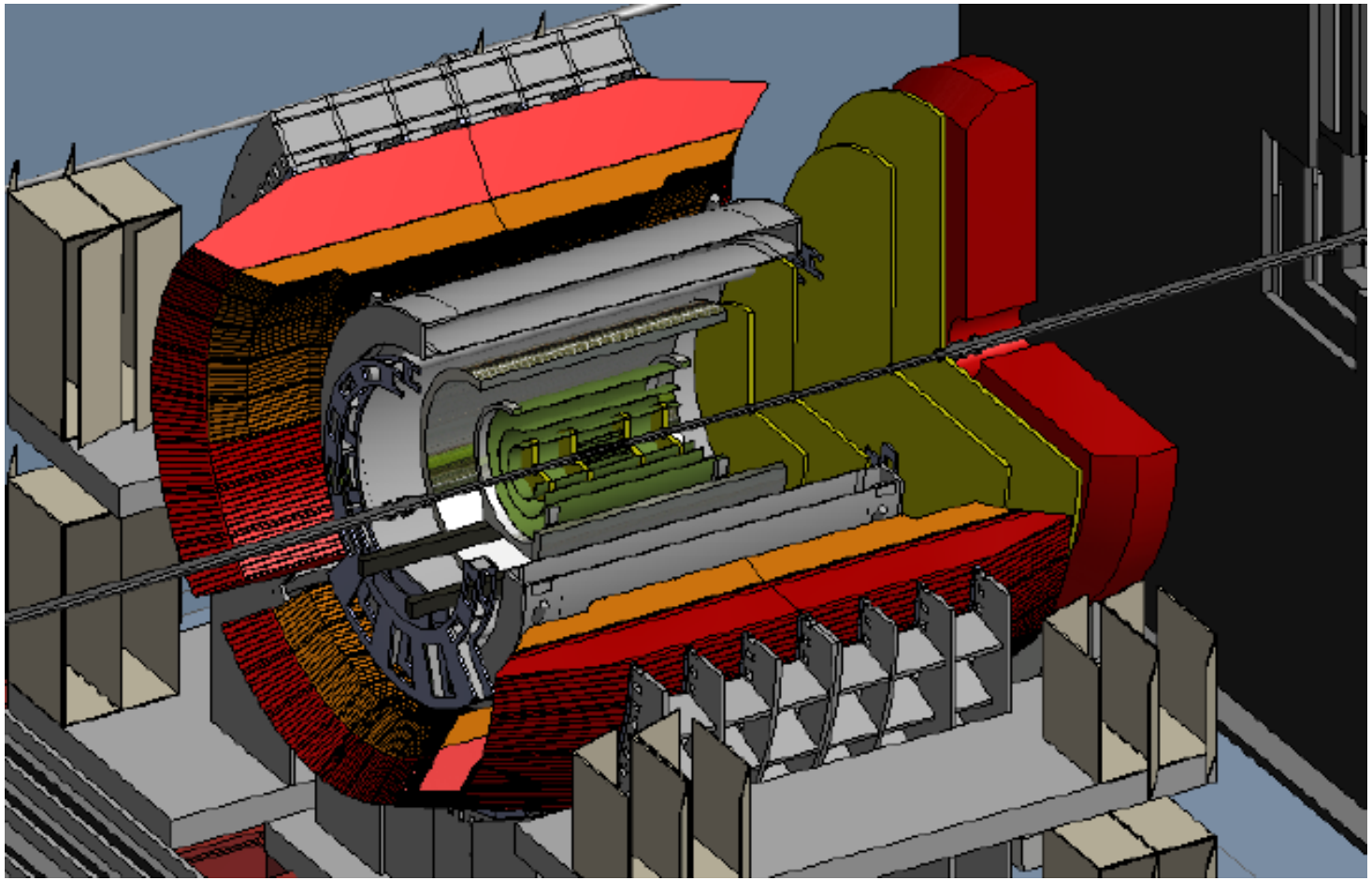
- Silicon vertex tracking system VTX and FVTX are successfully working now!
  - fine measurement will be achieved based on very precise vertex position information
    - separation of letpons from D and B mesons
    - B->J/Ψ, Ψ' measurements



PHENIX silicon vertex tracking system



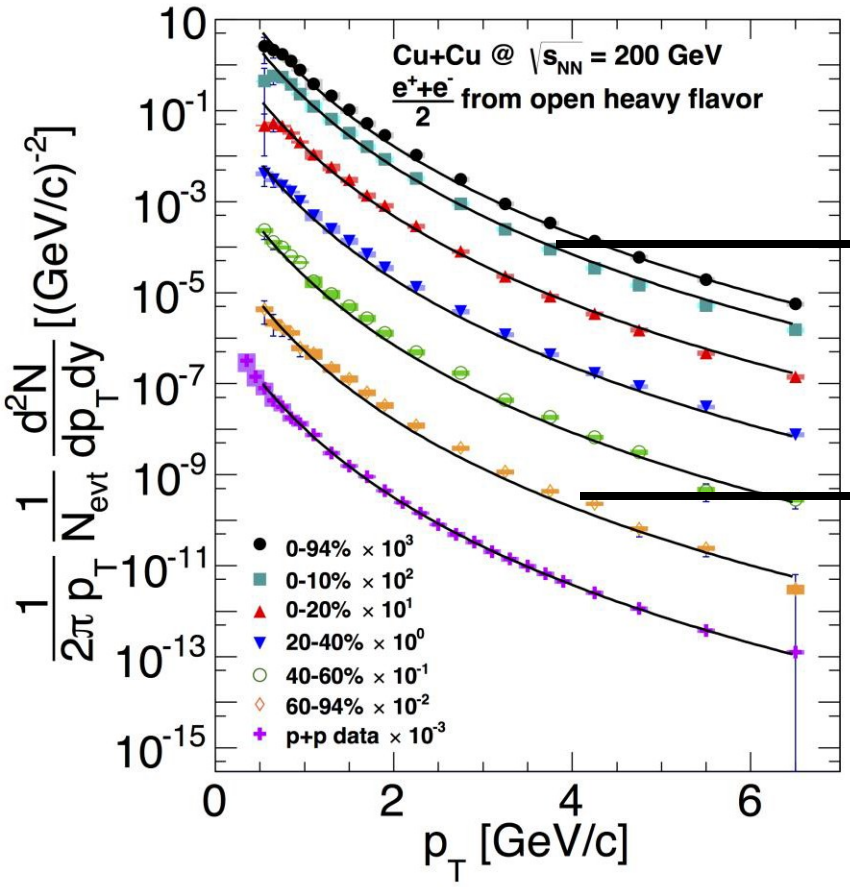
- For full jet and enhanced Υ measurements!
  - arXiv:1501.06197



BACK UP

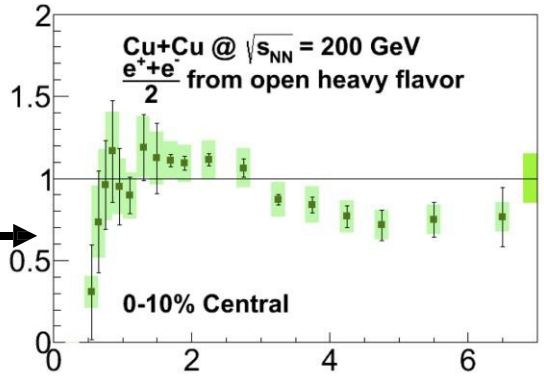
In Cu+Cu collisions

Phys. Rev. C 90, 034903 (2014)



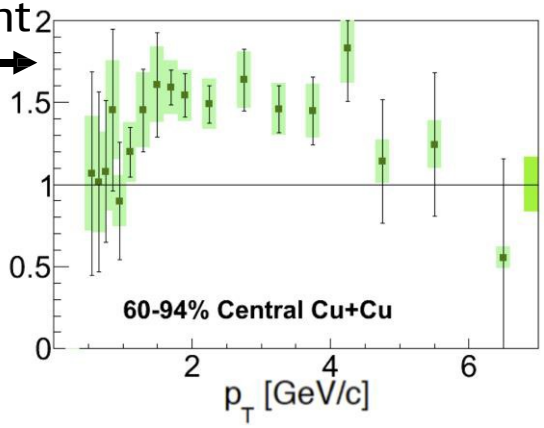
Slight suppression

<Ncoll>≈182.7

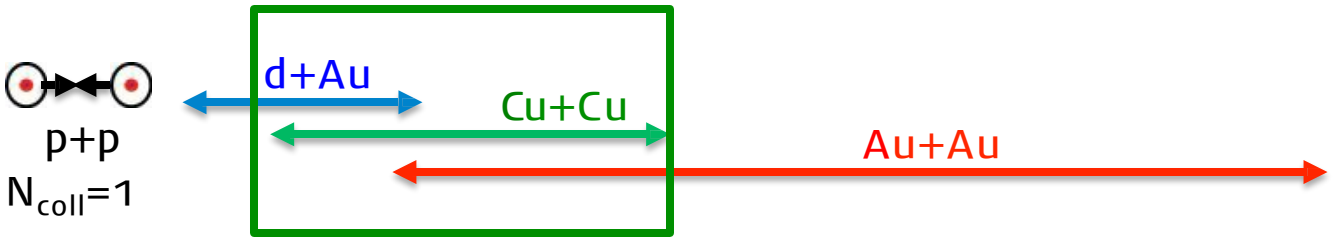


Significant enhancement

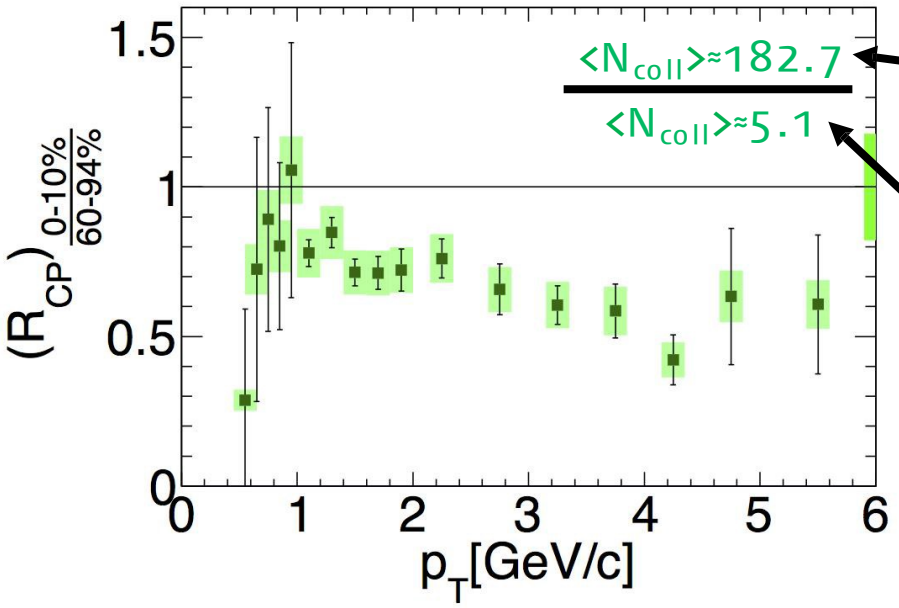
<Ncoll>≈5.1

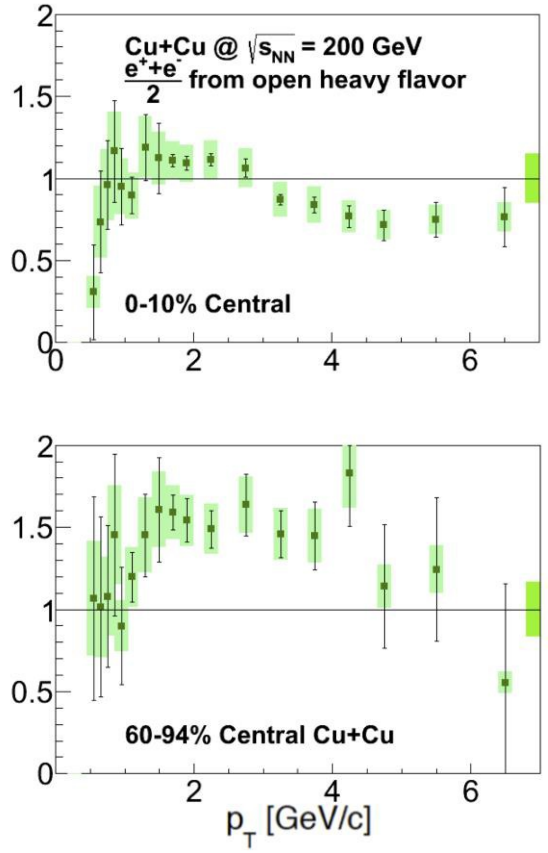


In Cu+Cu collisions



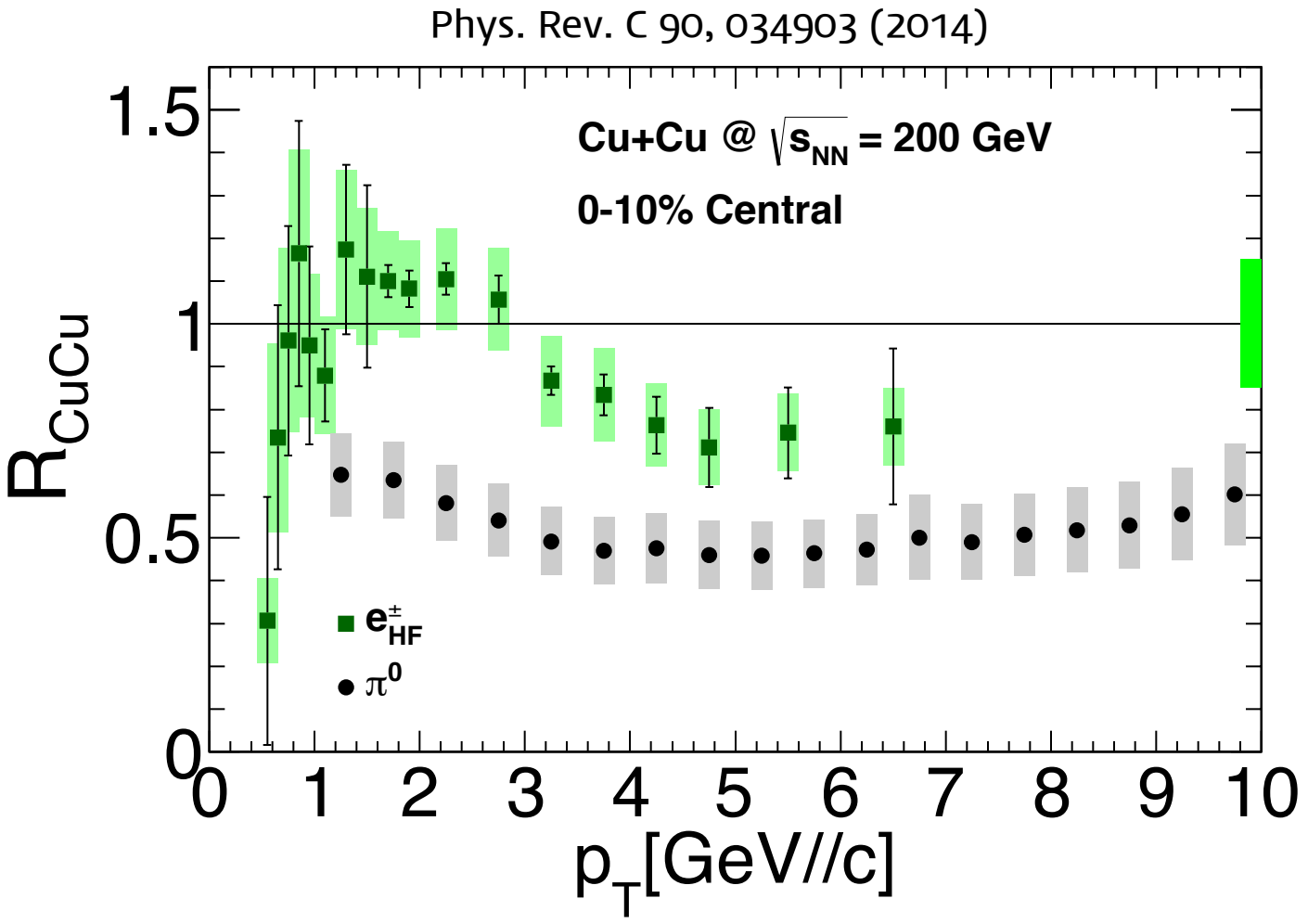
Phys. Rev. C 90, 034903 (2014)



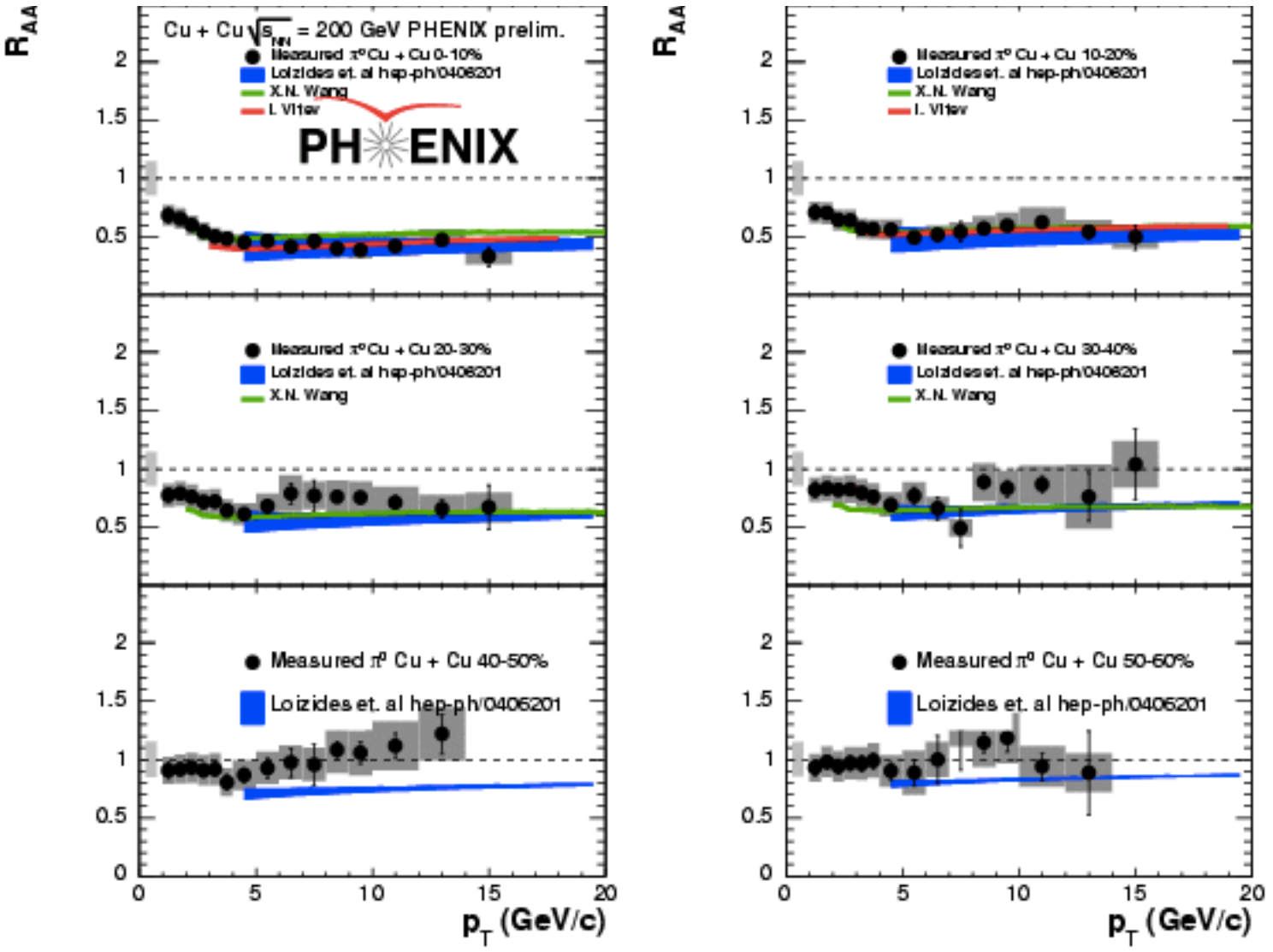


- R_{CP} shows a significant suppression
  - hot nuclear matter effects are dominating in central Cu+Cu collisions

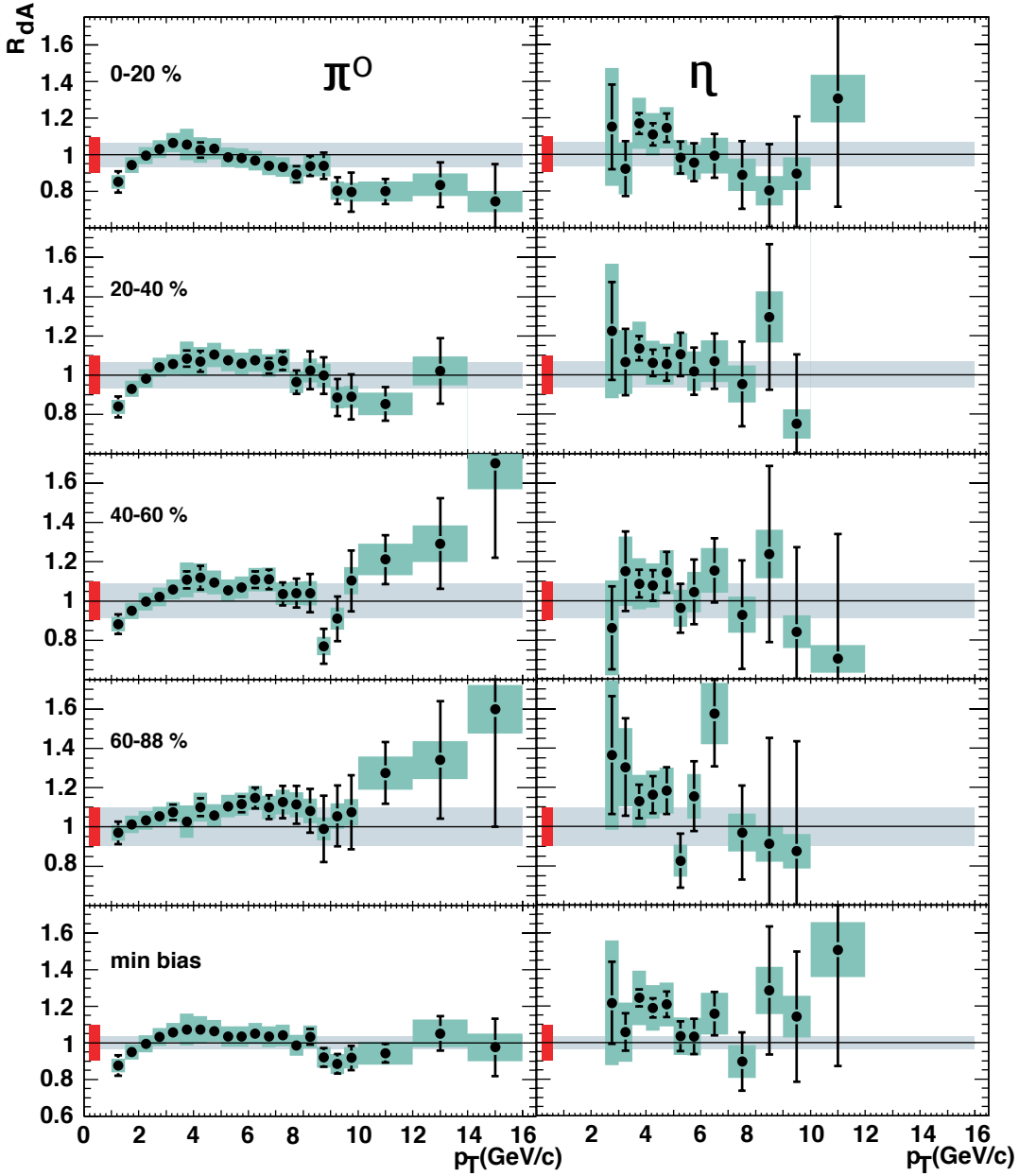
HF e and π^0 in central Cu+Cu collisions



π^0 production in Cu+Cu collisions at mid-rapidity



π^0 production in d+Au collisions at mid-rapidity



π^0 production in Au+Au collisions at mid-rapidity