

PHENIX heavy-flavor results in d+Au collisions

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DIS @ SMU
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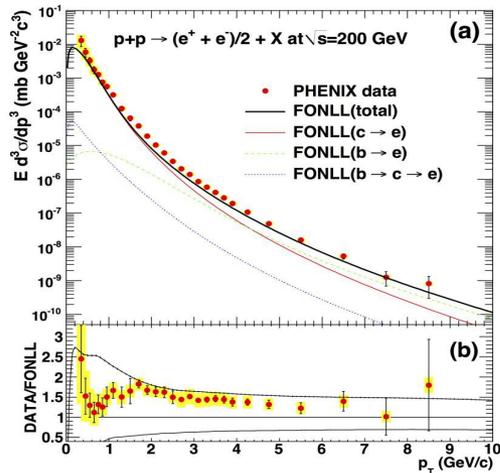
Study of heavy quark production

- 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



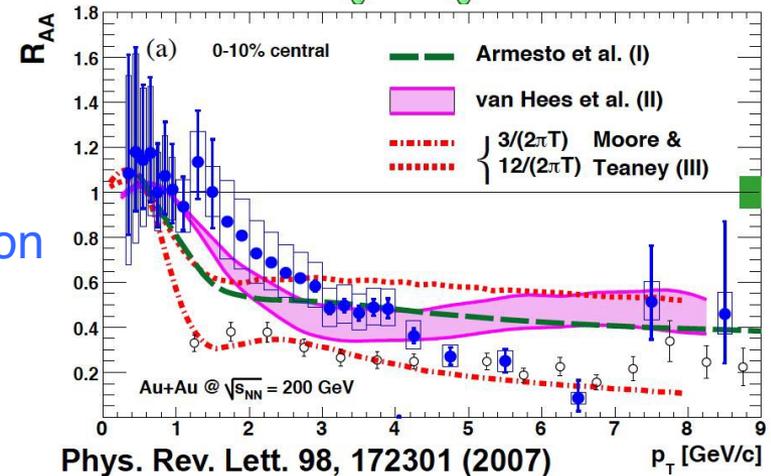
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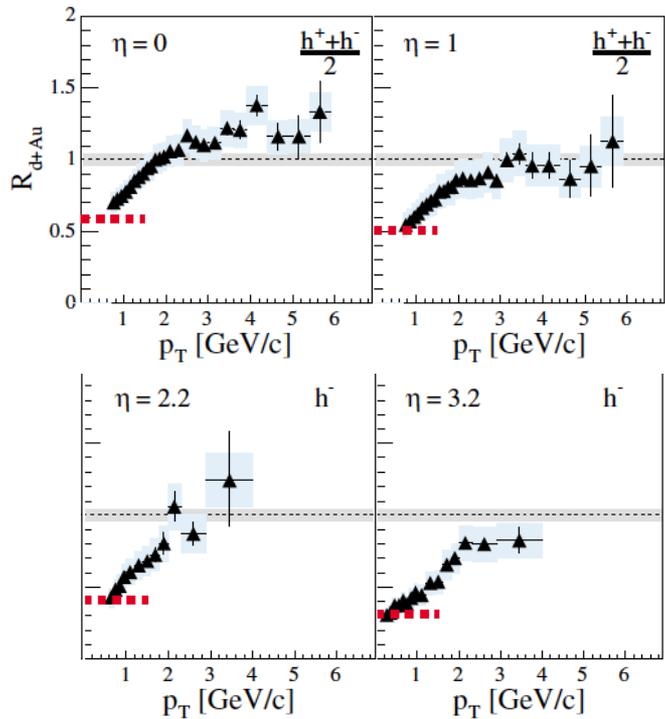
We can study evolution of medium effects/modification as system size increasing

$p+p$ results consistent with pQCD calculation



large suppression of high p_T HF e in central $Au+Au$ collisions

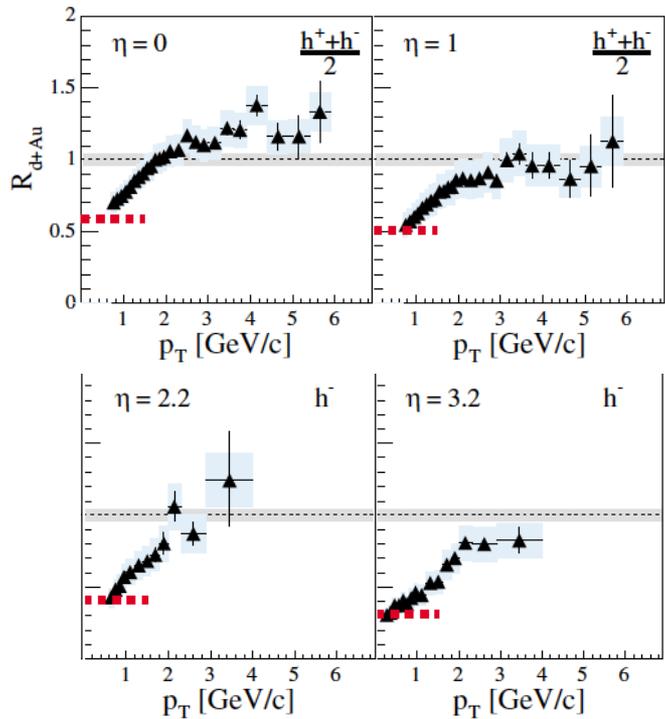
- Initial-state effects
 - nuclear PDF modification (shadowing, anti-shadowing, EMC)
 - initial k_T
 - energy loss in CNM



Phys. Rev. Lett. 93, 242303 (2004)

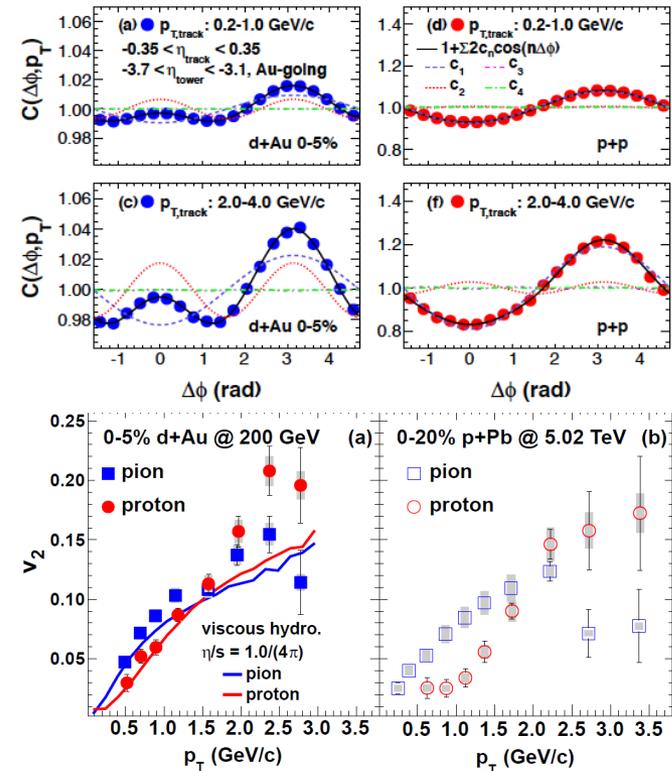
d+Au : small but surprising

- Initial-state effects
 - nuclear PDF modification (shadowing, anti-shadowing, EMC)
 - initial k_T
 - energy loss in CNM



Phys. Rev. Lett. 93, 242303 (2004)

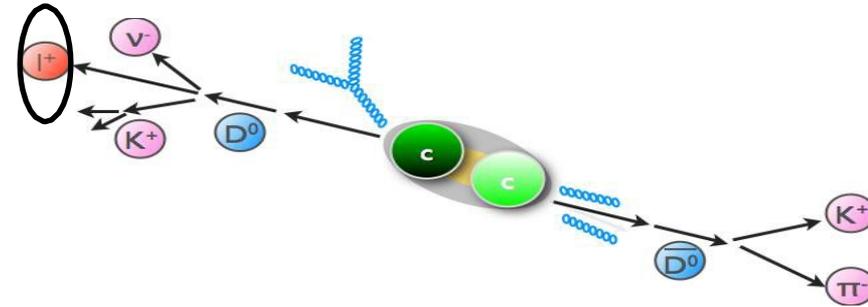
- medium in d+Au collisions?
 - long-range correlation
 - elliptic flow



arXiv:1404.7461

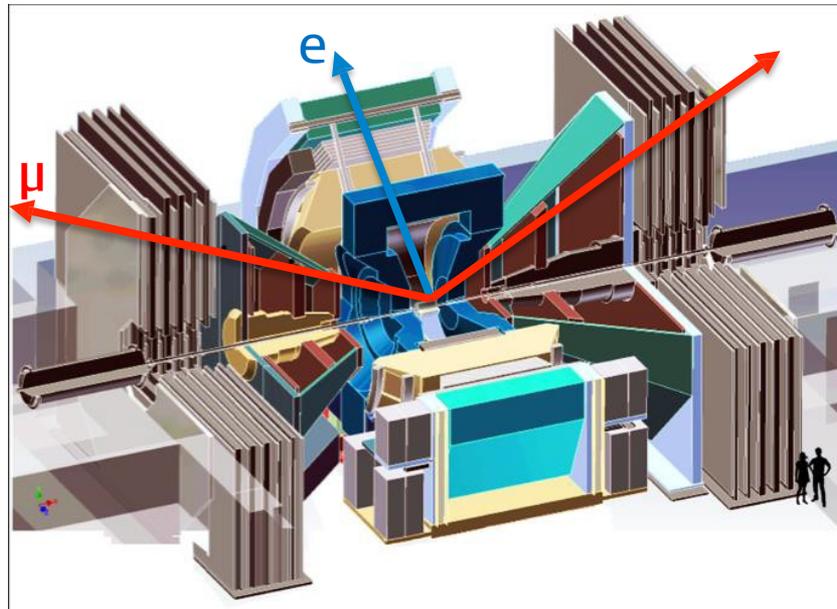
Heavy flavor in PHENIX

- 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

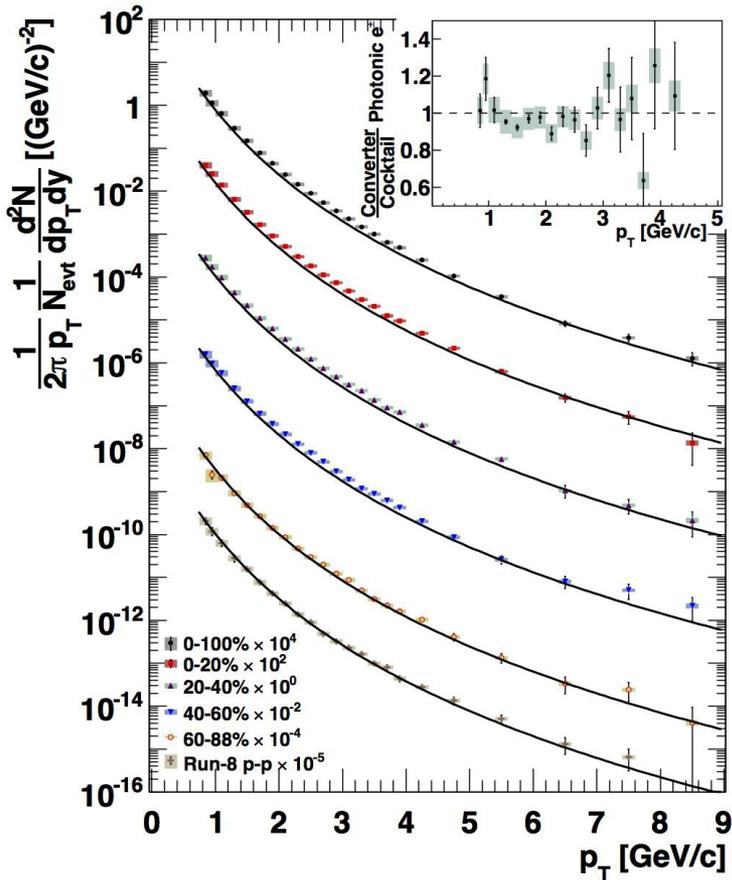


- **Muons** at Muon arm

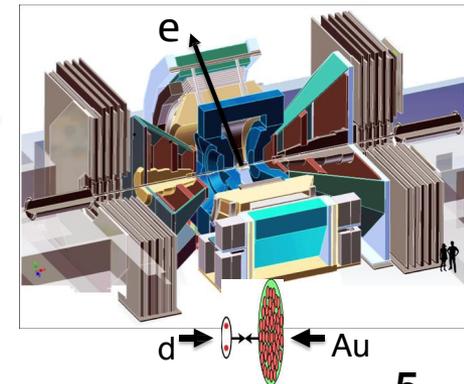
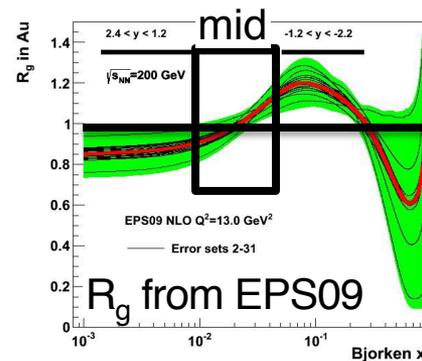
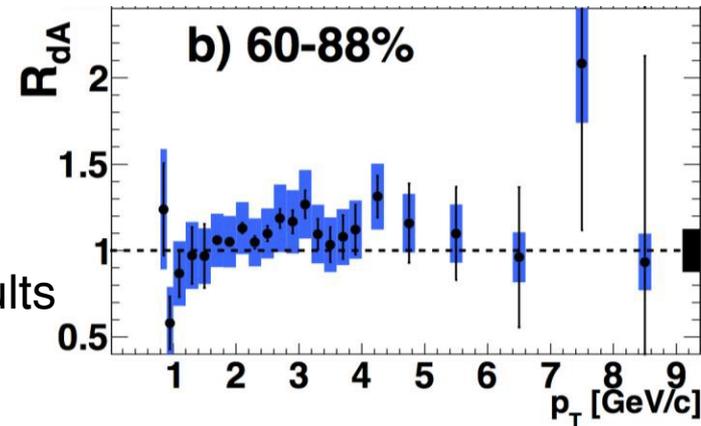
- $1.2 < |\eta| < 2.2$
- $\Delta\phi = 2\pi$
- $\sim 10\lambda$ absorber
- Tracking w/ wire chamber
- muID w/ 5 layers of steel and larocci tube plane

HF electrons @ mid-rapidity

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



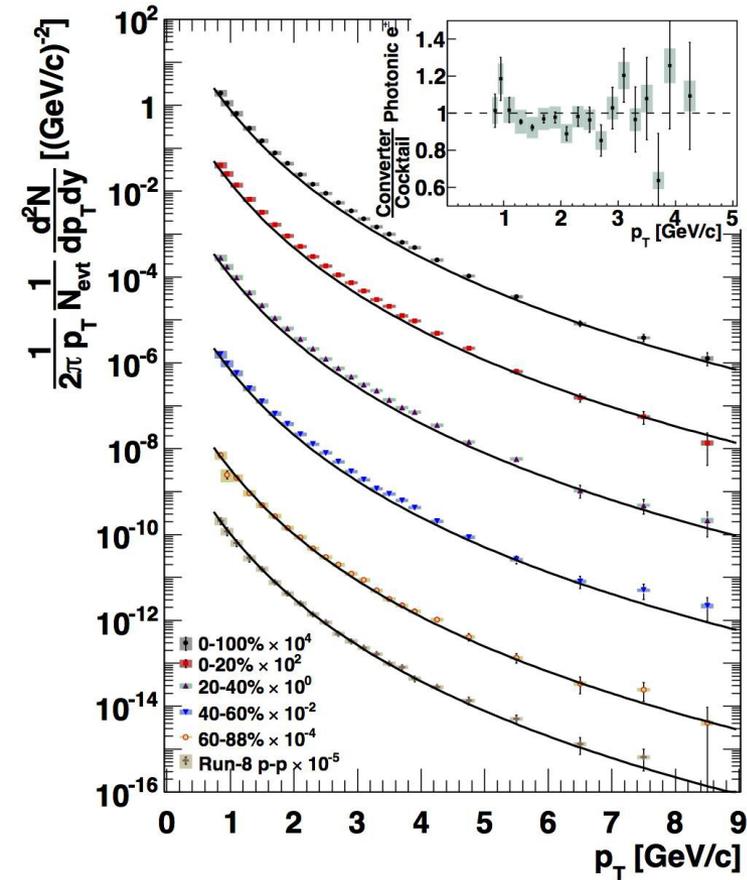
Peripheral:
Consistent with
the scaled p+p results



Heavy flavor in PHENIX

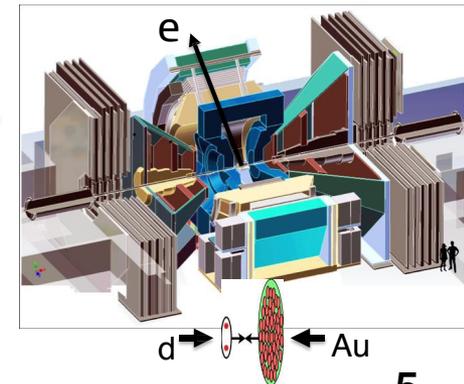
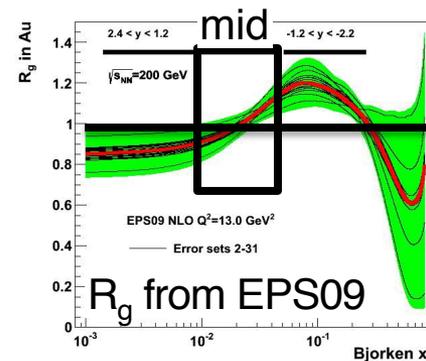
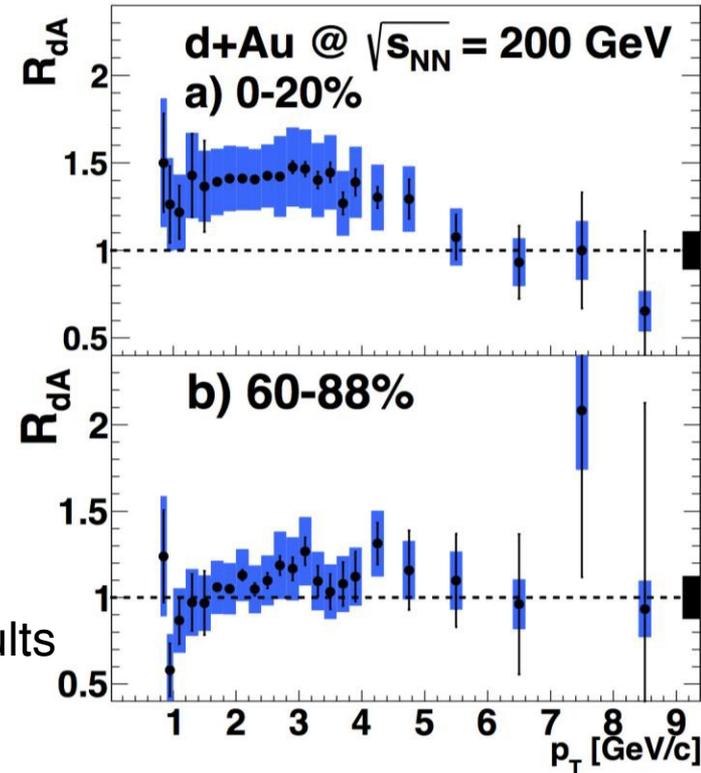
HF electrons @ mid-rapidity

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



Central:
Enhancement
at intermediate p_T

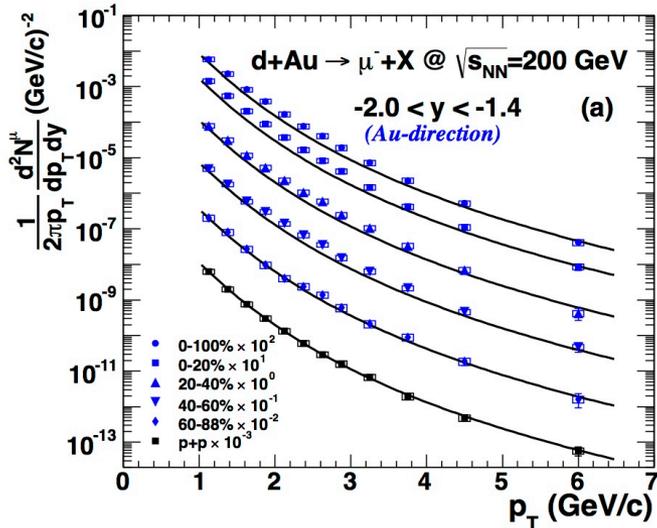
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Consistent with
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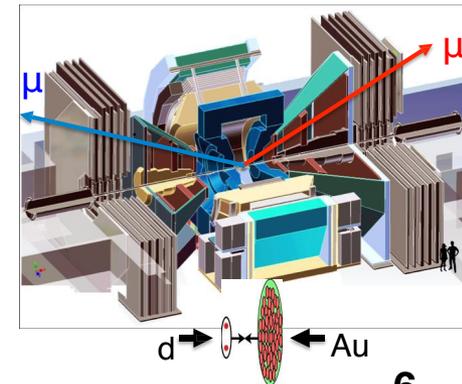
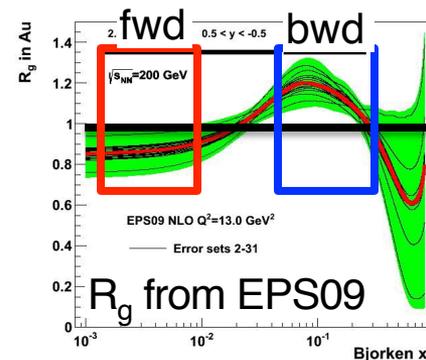
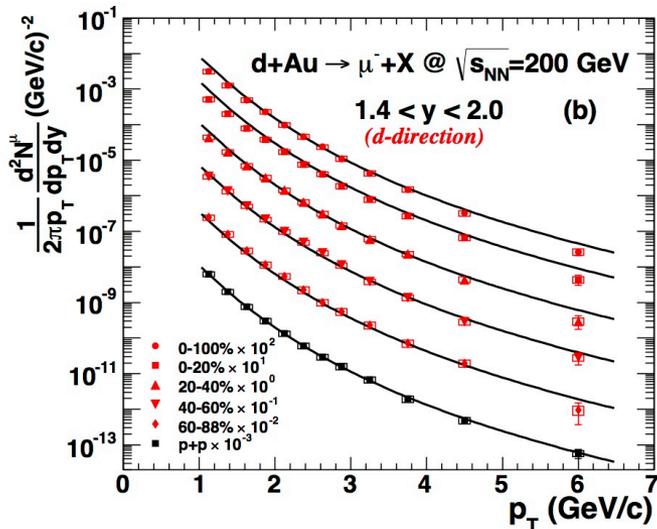
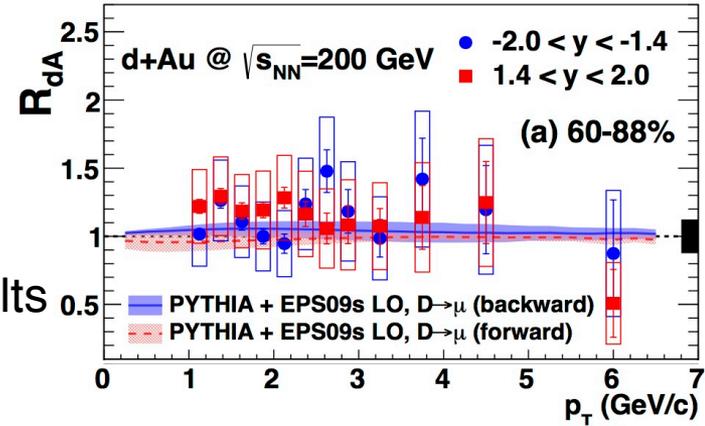
Heavy flavor in PHENIX

HF muons @ forward/backward rapidity

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



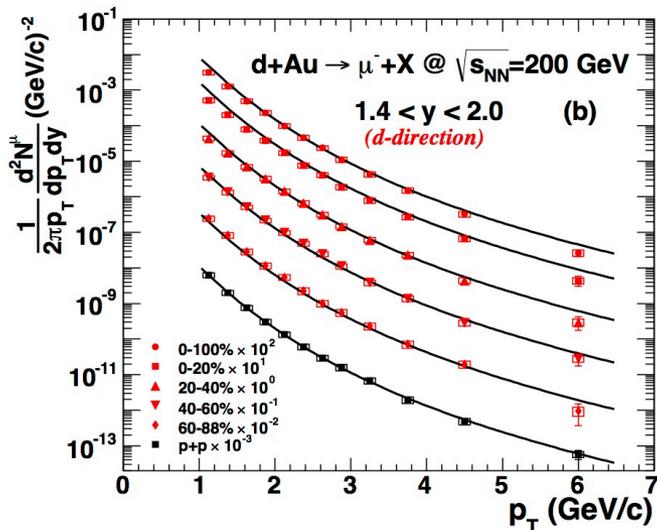
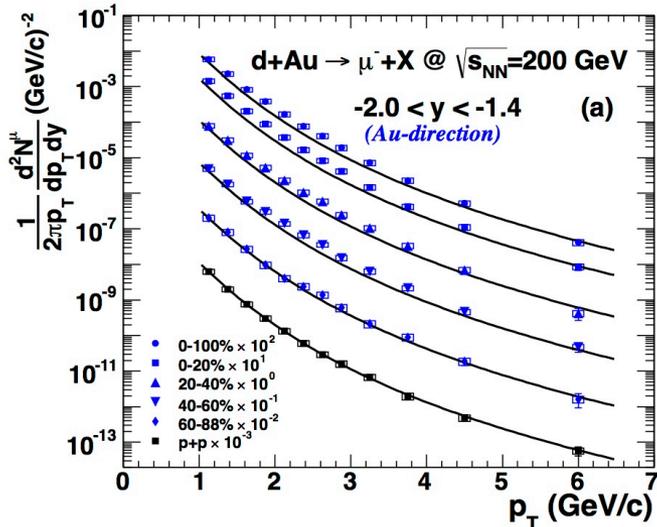
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 Consistent with
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Heavy flavor in PHENIX

HF muons @ forward/backward rapidity

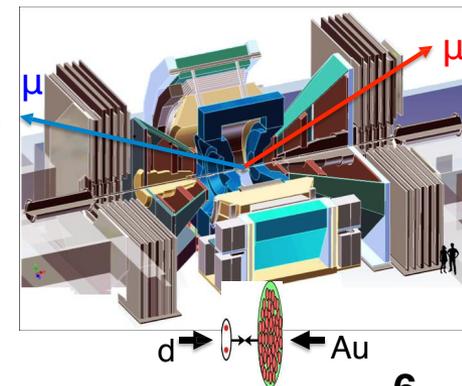
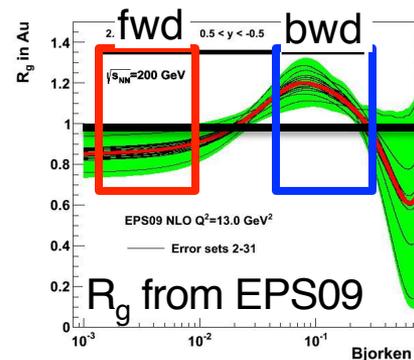
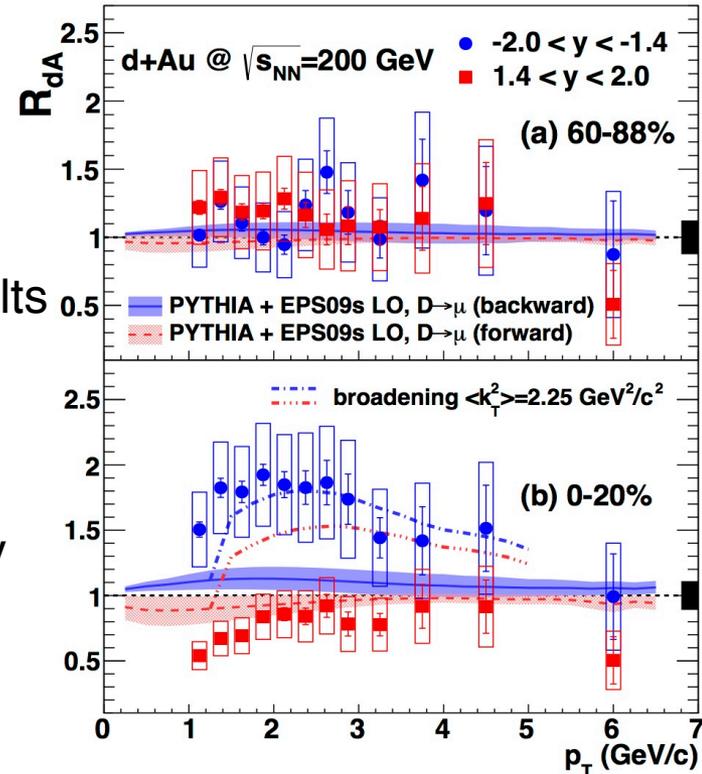
Phys. Rev. Lett. 112, 252301 (2014)



Peripheral:
 Consistent with
 the scaled p+p results

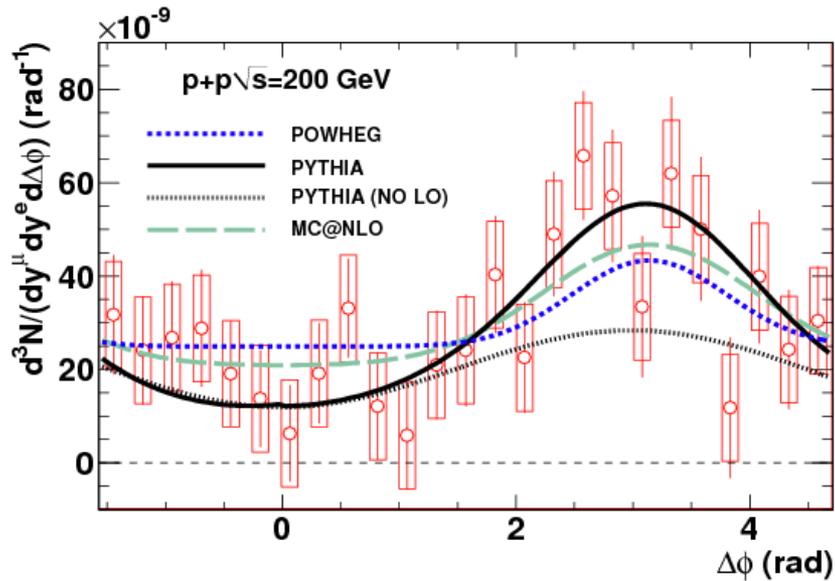
Central:
Enhancement
 at backward rapidity

Suppression
 at forward rapidity

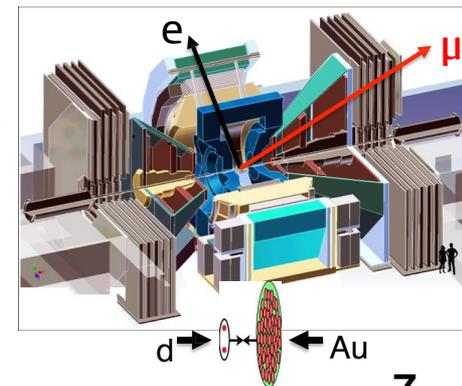
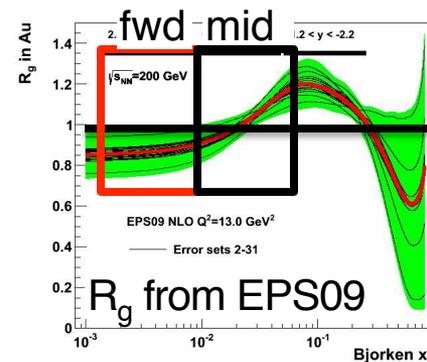


HF e - μ correlation

Phys. Rev. C. 89, 034915 (2014)



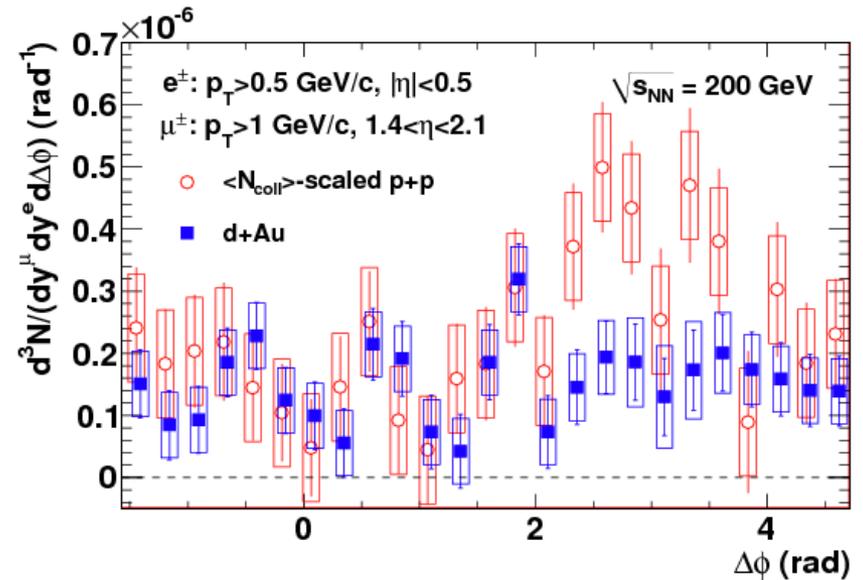
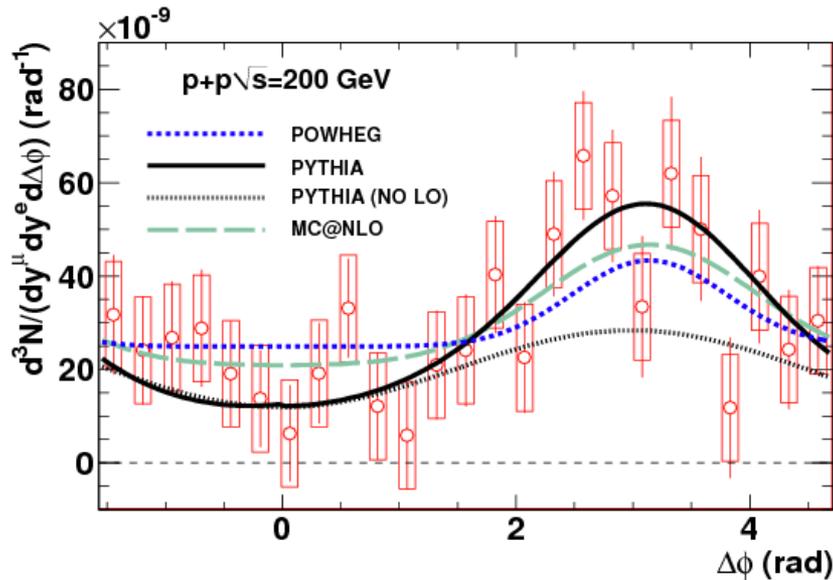
- pQCD-based models agrees with the data in p+p collisions



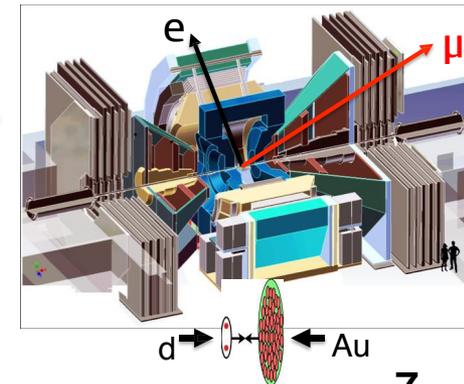
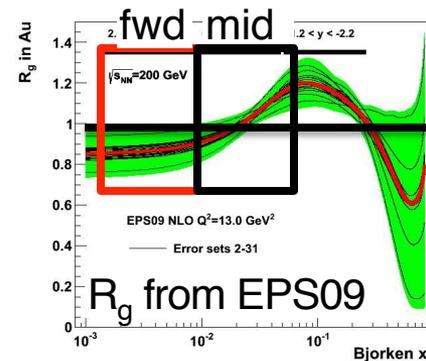
Heavy flavor in PHENIX

HF e - μ correlation

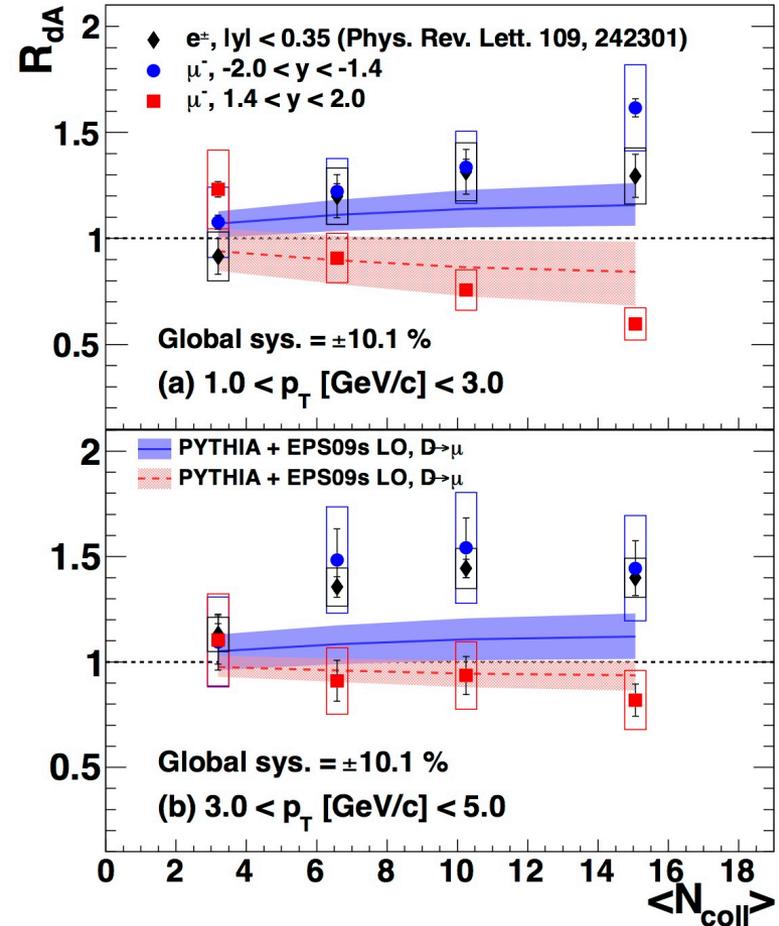
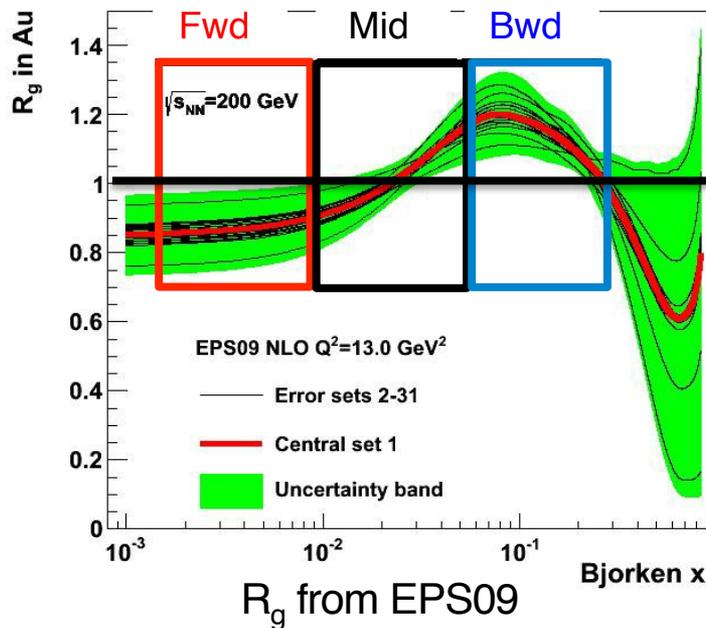
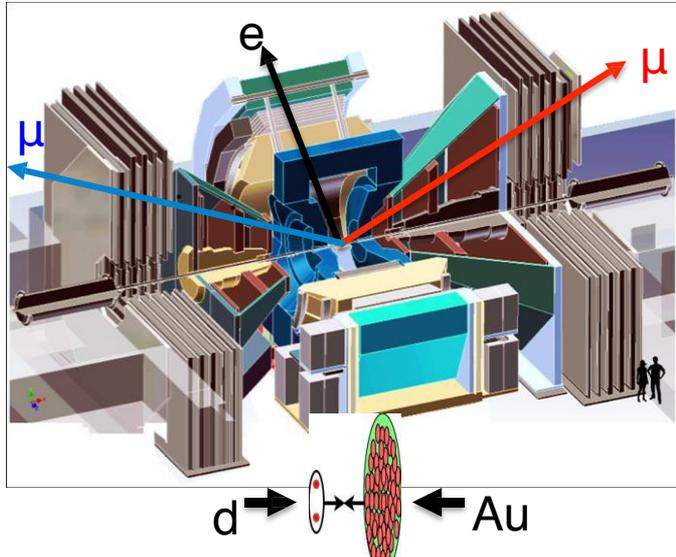
Phys. Rev. C. 89, 034915 (2014)



- pQCD-based models agrees with the data in p+p collisions
- ***Clear suppression*** of e - μ correlation in d+Au collisions
 - shadowing effects at forward rapidity?
 - additional final-state interaction?



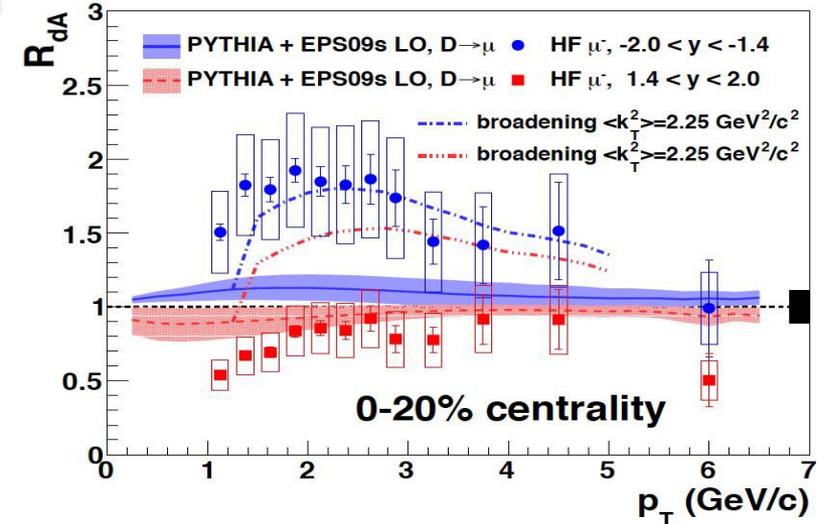
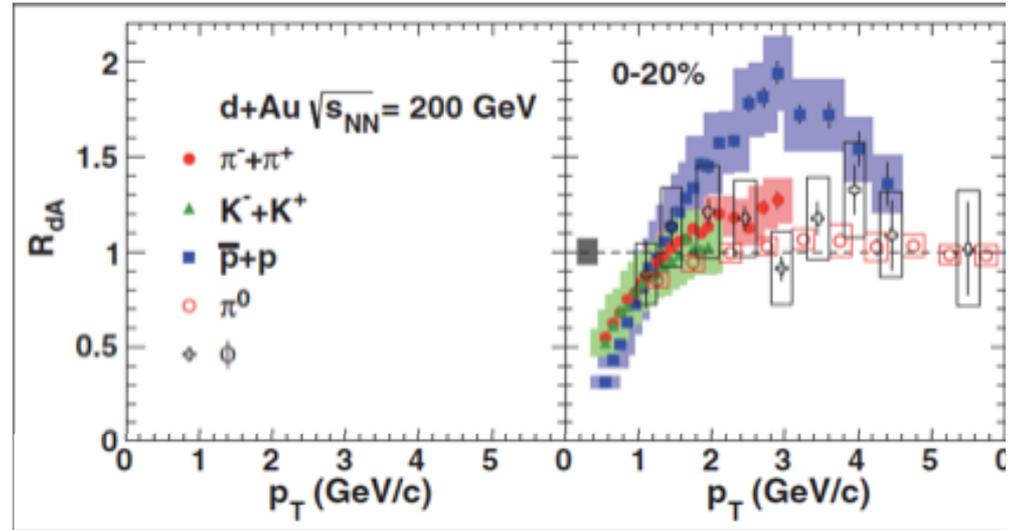
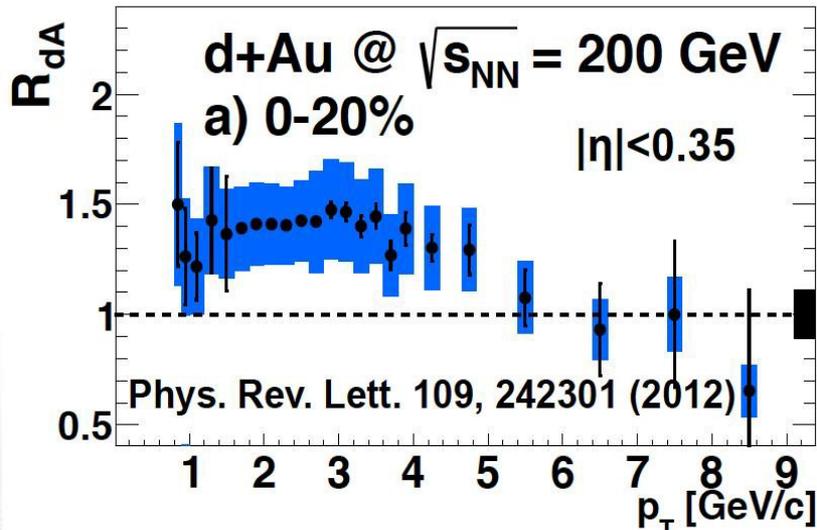
Rapidity expansion



- The difference between forward and backward is larger than the expectation from EPS09s

Enhancement in d+Au collisions

light hadrons: Phys. Rev. C. 88, 024906 (2013)

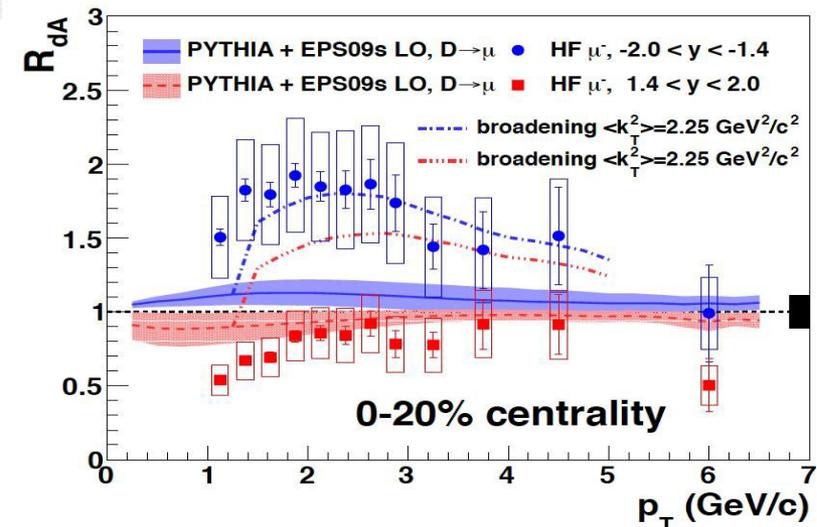
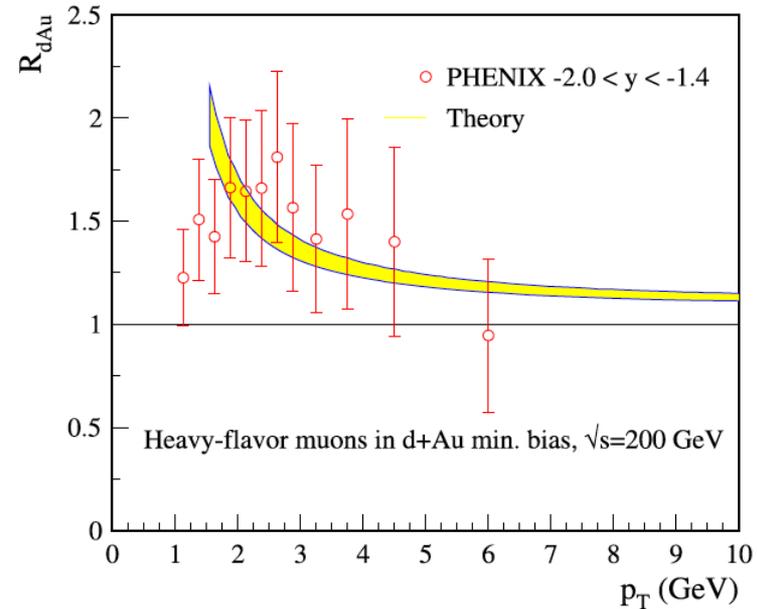
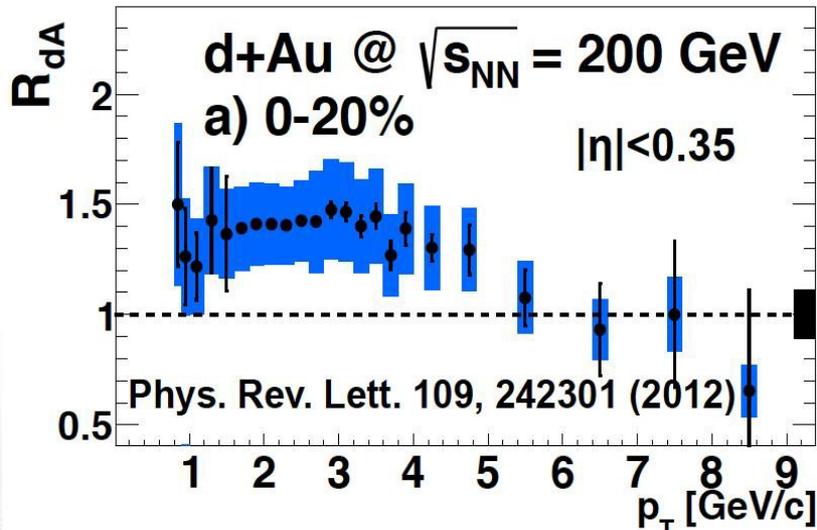


- Cronin enhancement?
 - initial k_T component due to multiple scattering of incoming partons
- Fail to reproduce the data at both rapidity simultaneously w/ combinations of initial-state effects
 - modification of nPDF
 - initial k_T broadening

Clear enhancement at mid and backward!

Enhancement in d+Au collisions

theory: Phys. Lett. B740 (2015) 25

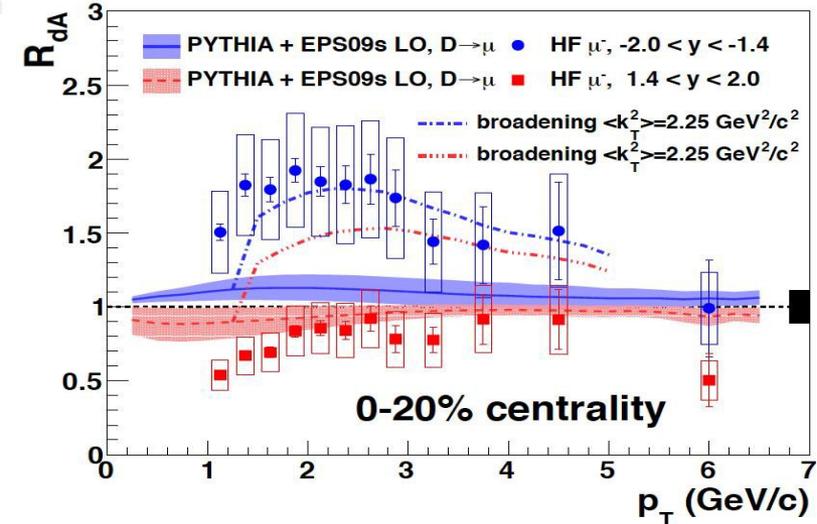
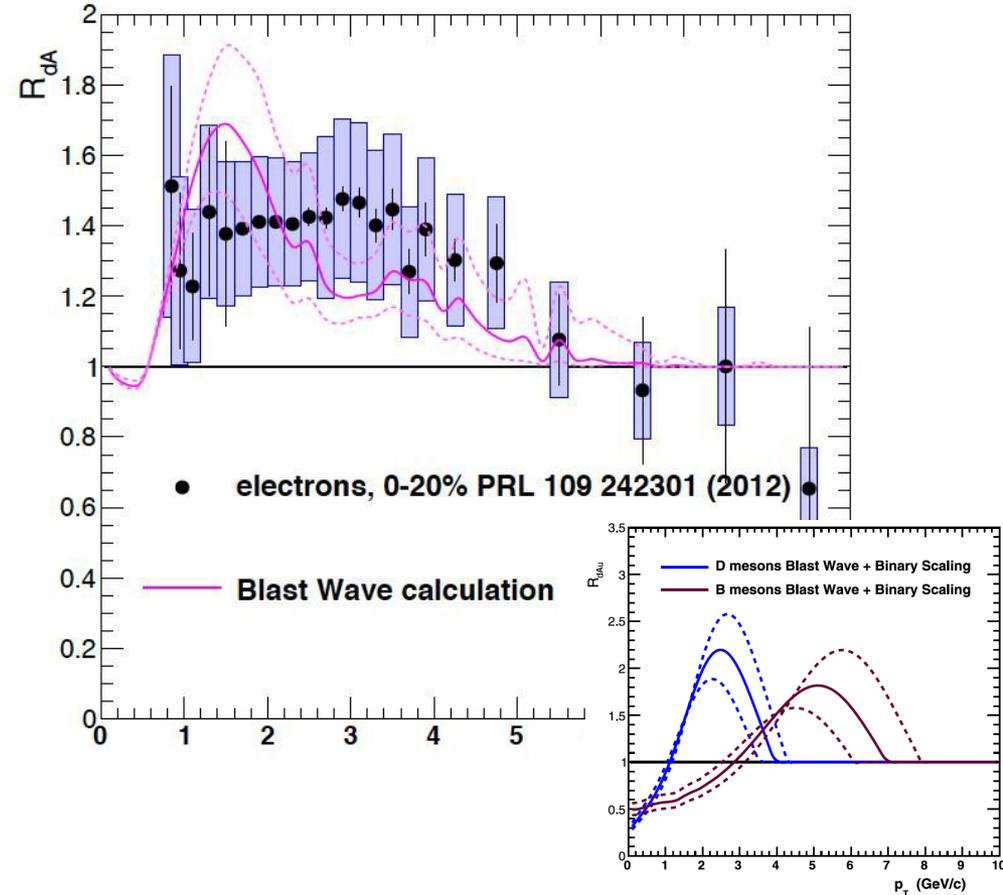
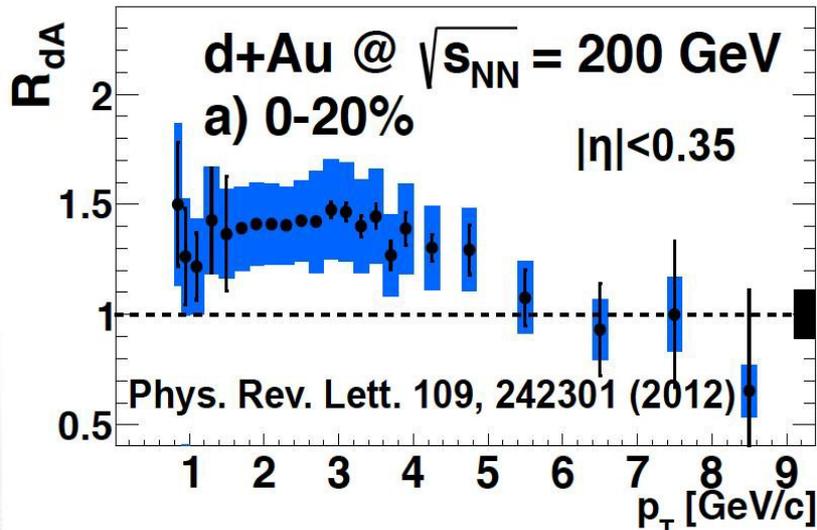


- pQCD calculation considering incoherent multiple scattering reproduce the enhancement at backward rapidity

Clear enhancement at mid and backward!

Enhancement in d+Au collisions

model calculation: Phys. Lett. B731 (2014) 51

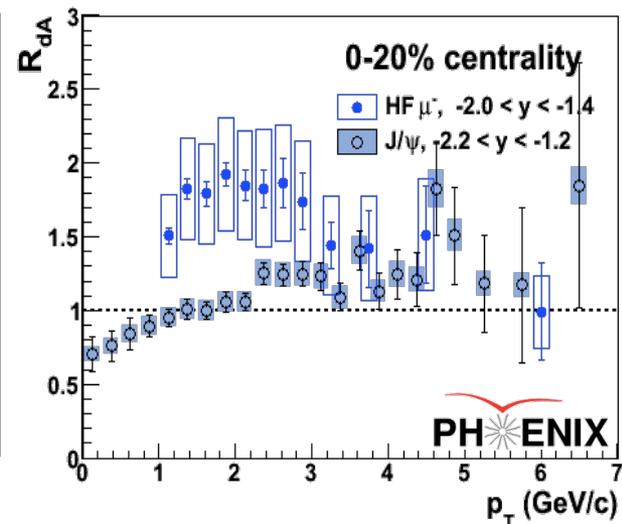
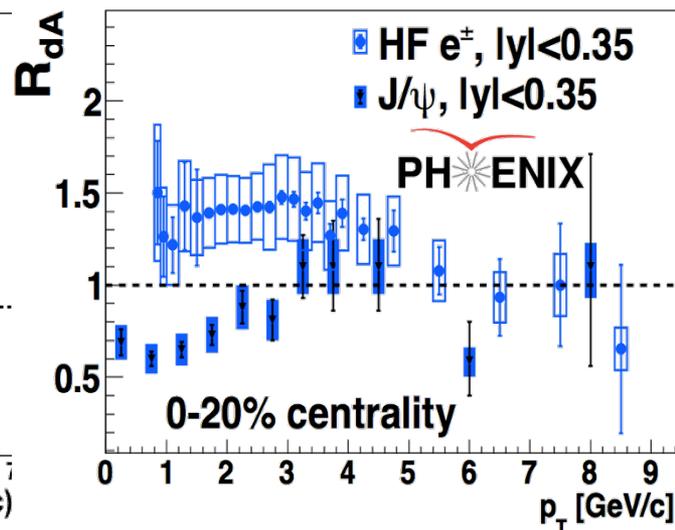
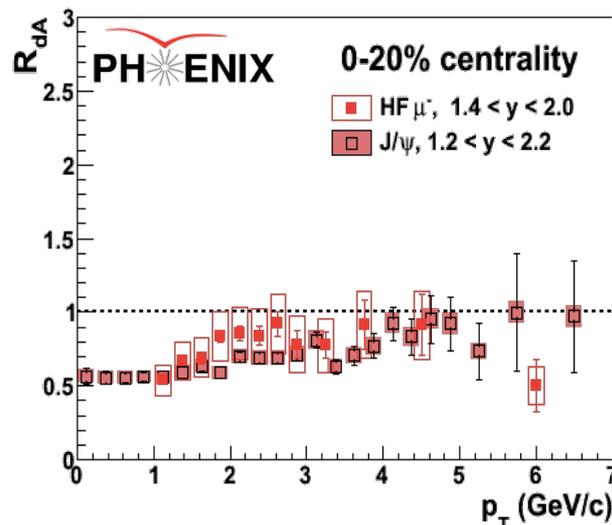


- Radial flow also qualitatively reproduce the enhancement as well

Clear enhancement at mid and backward!

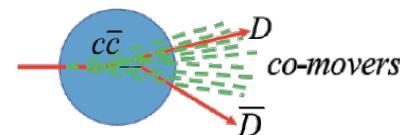
Comparison to J/ψ

J/ψ : Phys. Rev. C. 87, 034904 (2013)



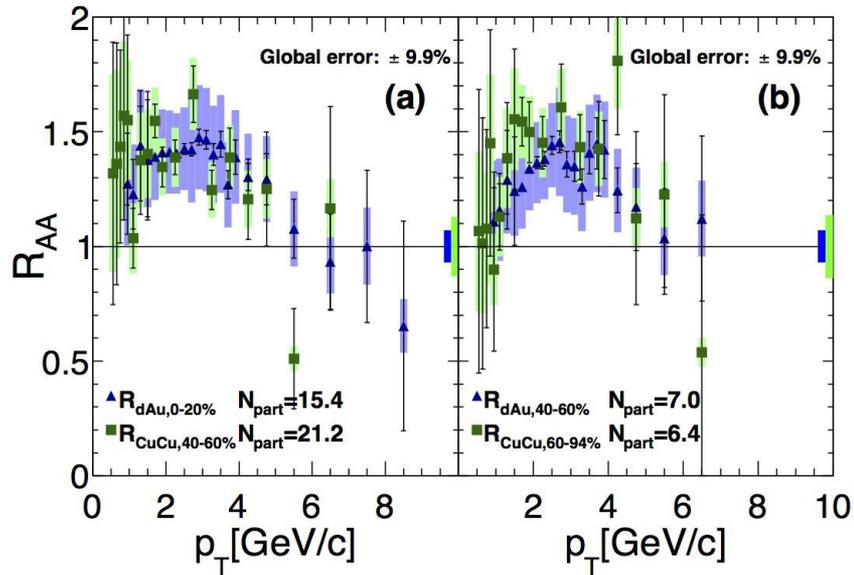
*additional decay kinematics in HF leptons

- Similar suppression at forward rapidity, but different behavior at mid and backward rapidity
 - sensitive to same initial-state effects (e.g. nPDF modification, k_T broadening, partonic energy loss in nucleus)
 - different effect is nuclear break-up of bound states
- Larger nuclear break-up effects at higher-density region



Comparison to heavy-ion collisions

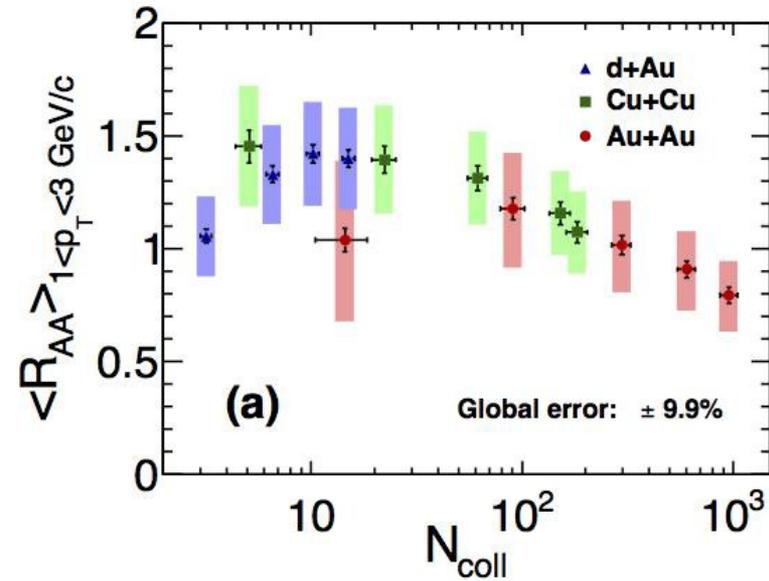
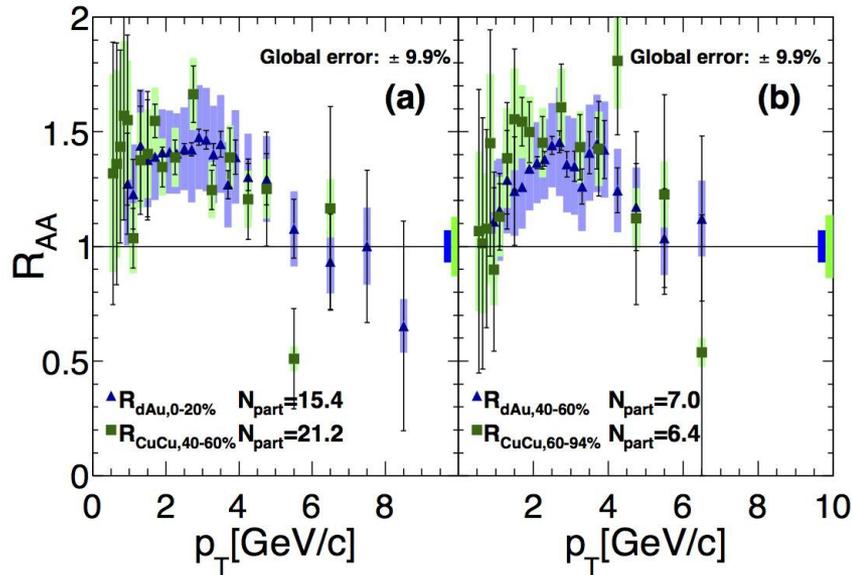
Cu+Cu: Phys. Rev. C. 90, 034903 (2014)



- Consistent nuclear modification factors between d+Au and Cu+Cu collisions of similar system size (N_{part})

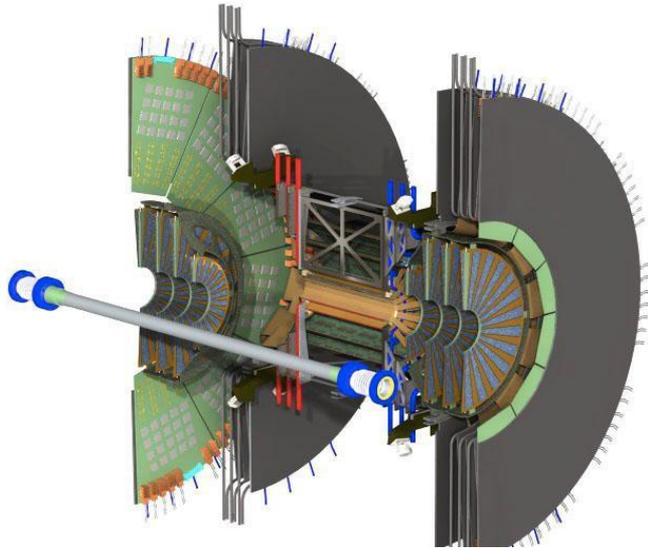
Comparison to heavy-ion collisions

Cu+Cu: Phys. Rev. C. 90, 034903 (2014)

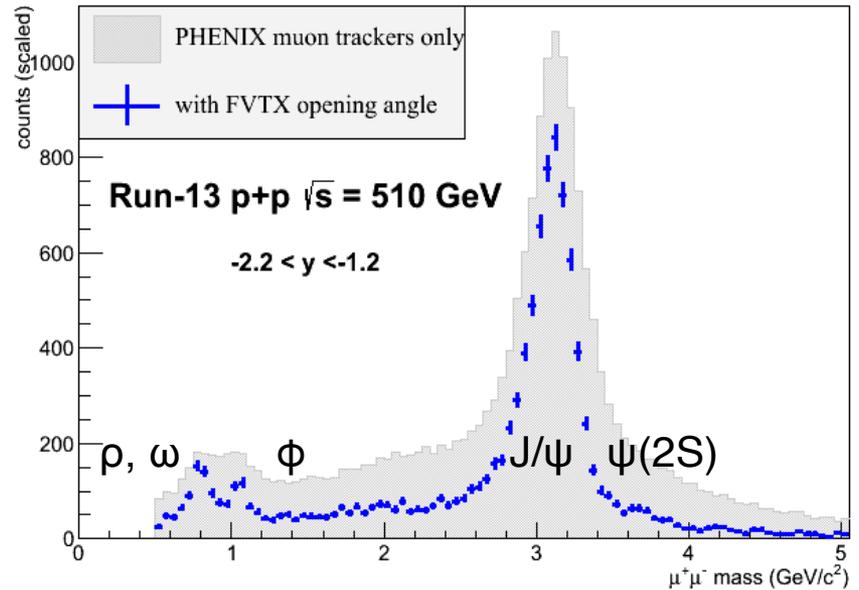


- Consistent nuclear modification factors between d+Au and Cu+Cu collisions of similar system size (N_{part})
- A nice trend from d+Au and peripheral Cu+Cu collisions,
where enhancement effects are dominating
- To central Cu+Cu and Au+Au collisions,
where suppression effects take over

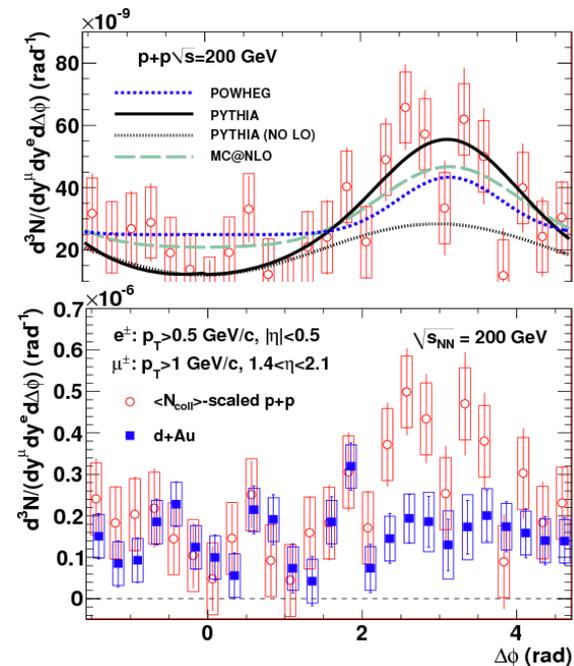
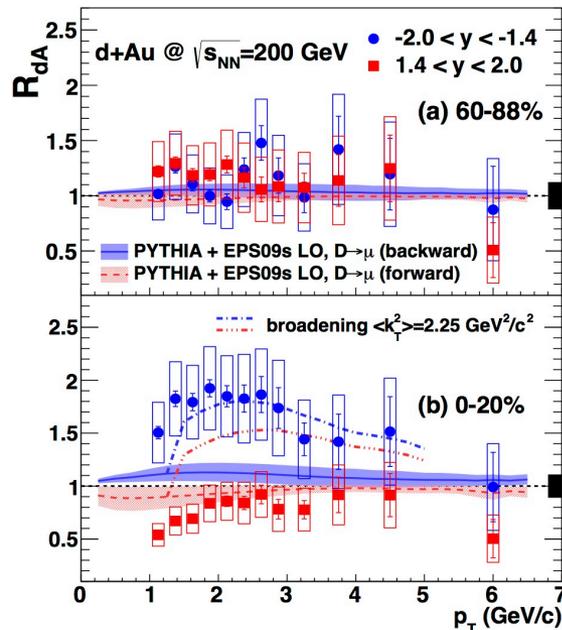
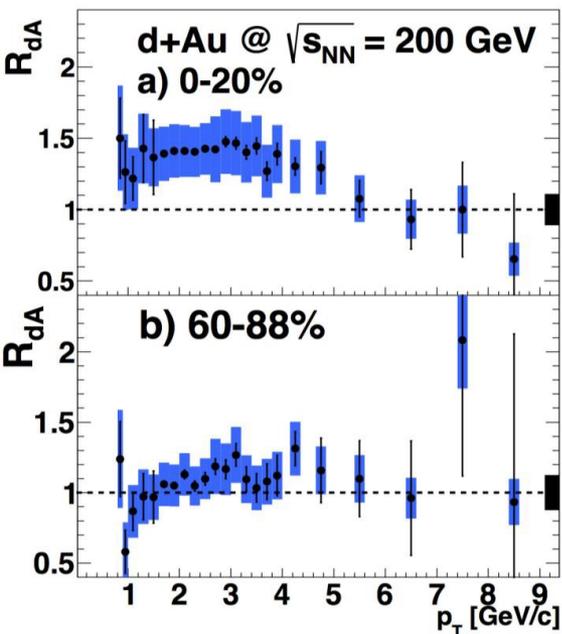
Future measurements!



PHENIX silicon vertex tracking system



- p+p and p+Au collisions are planned in RHIC Run15
 - charm/bottom separated R_{pA} can be obtained
 - FVTX will allow to measure $\psi(2S)$ at forward/backward rapidity
 - good comparison with LHC results from p+Pb collisions

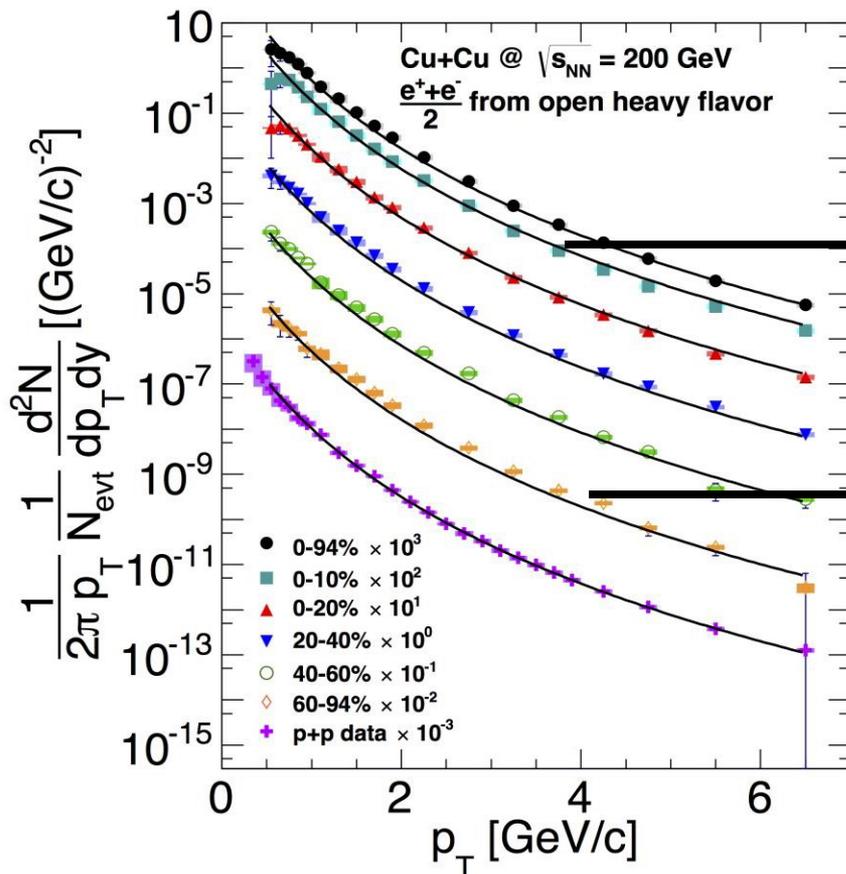


- PHENIX has obtained very nice heavy-flavor measurements in d+Au collisions at wide rapidity range
 - suppression at forward rapidity
 - enhancement at mid and backward rapidity
 - nice system-size dependence from d+Au to heavy-ion collisions
- More precise study will be possible with p+Au collision data in this year!

BACK UP

In Cu+Cu collisions

Phys. Rev. C. 90, 034903 (2014)

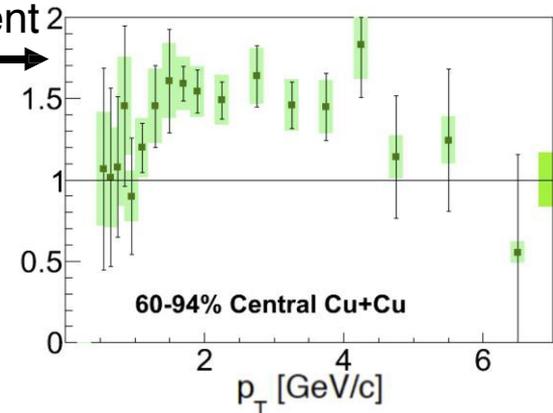
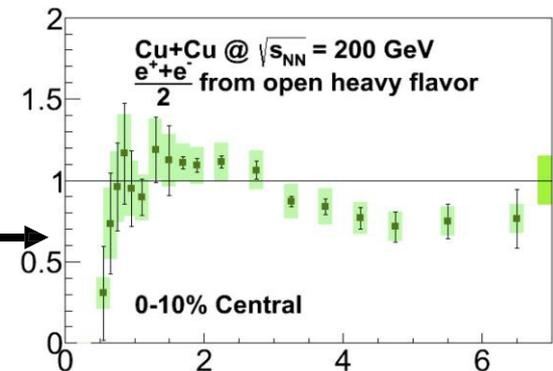


Slight suppression

$\langle N_{coll} \rangle \approx 182.7$

Significant enhancement

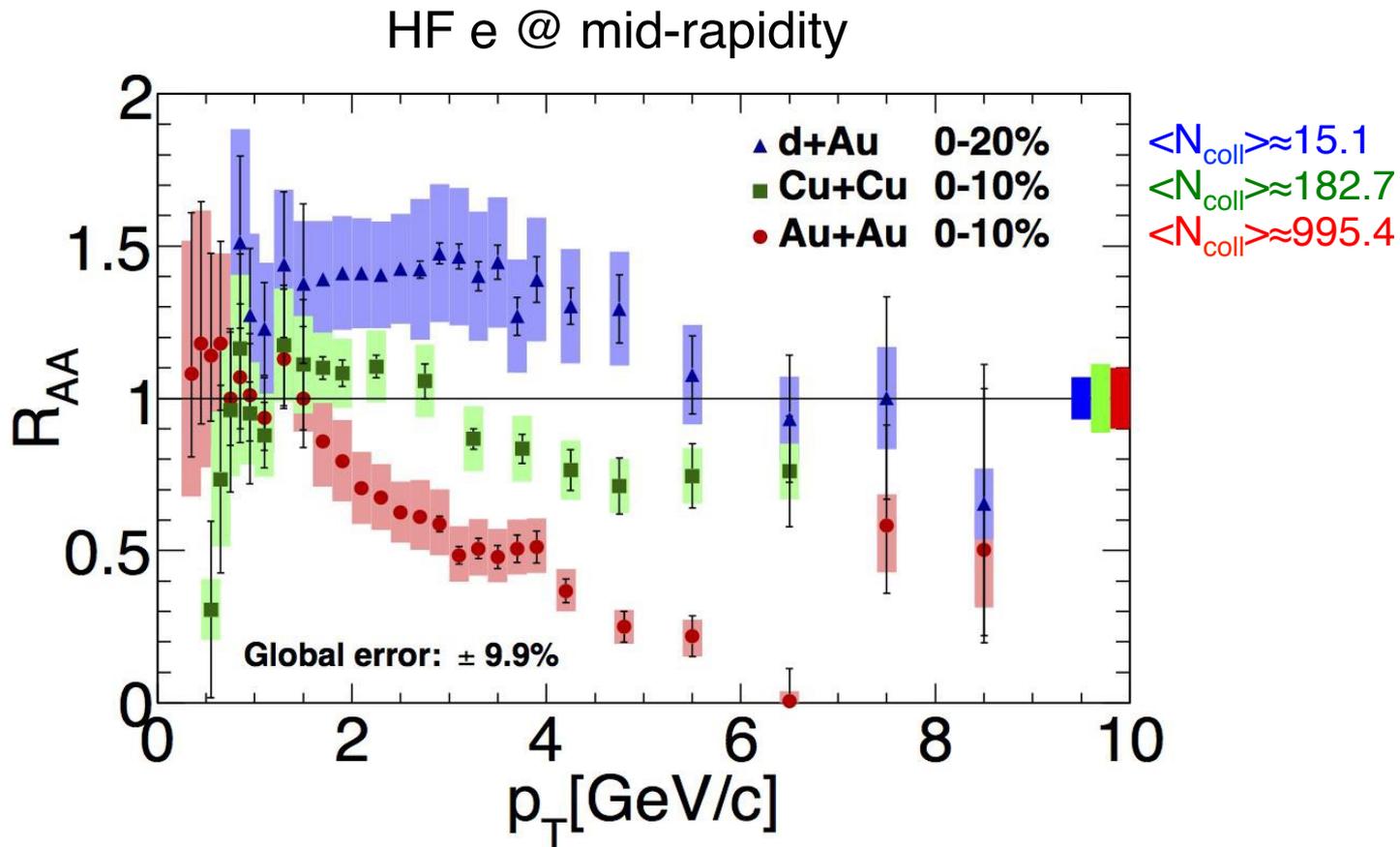
$\langle N_{coll} \rangle \approx 5.1$



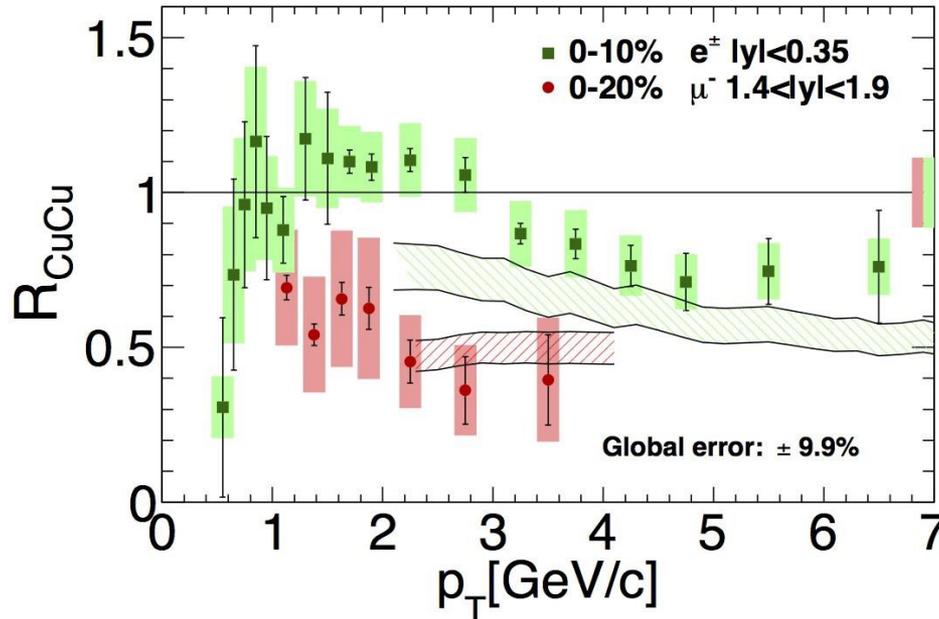
Heavy flavor in PHENIX

Most central collisions

Phys. Rev. C. 90, 034903 (2014)



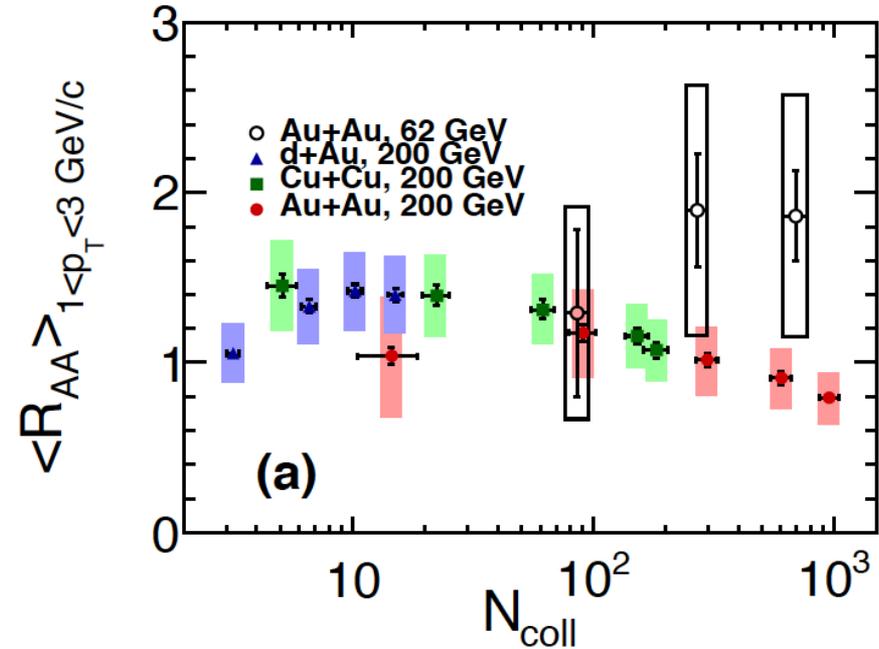
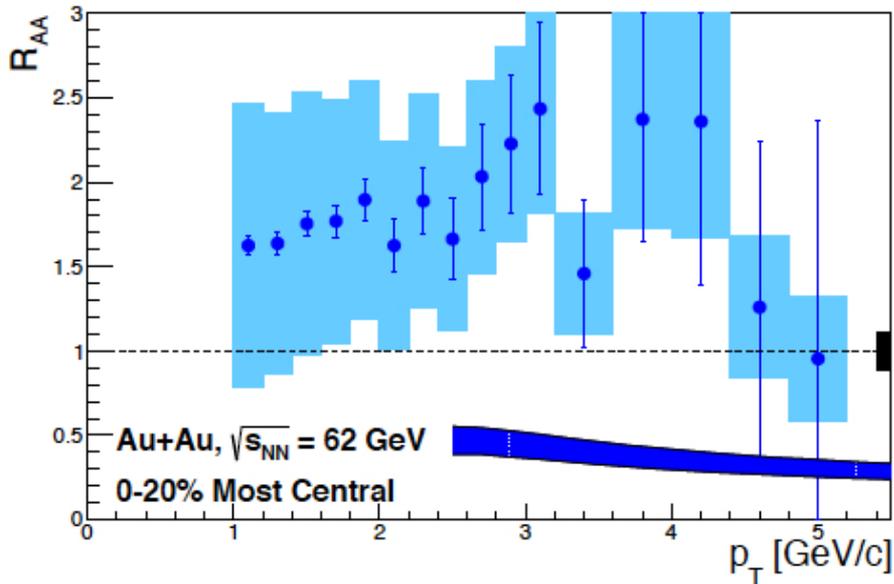
Rapidity expansion in Cu+Cu



- Larger suppression at forward rapidity
 - may need additional CNM effects (shadowing) at forward rapidity
 - theoretical calculations considering both hot and cold nuclear matter effects
 - consistent with the data at forward rapidity
 - slightly overestimate the suppression at $p_T > 3 \text{ GeV}/c$, but does not match at $p_T < 3 \text{ GeV}/c$ at mid-rapidity

HF e in Au+Au collisions @ 62.4 GeV

arXiv:1405.3301



- Enhancement relative to scaled p+p results (ISR data)
 - Cronin-like enhancement is dominating at lower beam energy?
 - sizeable difference from the theory considering energy loss