Study of nuclear effects in small collision systems connecting proton-proton and heavy-ion collisions

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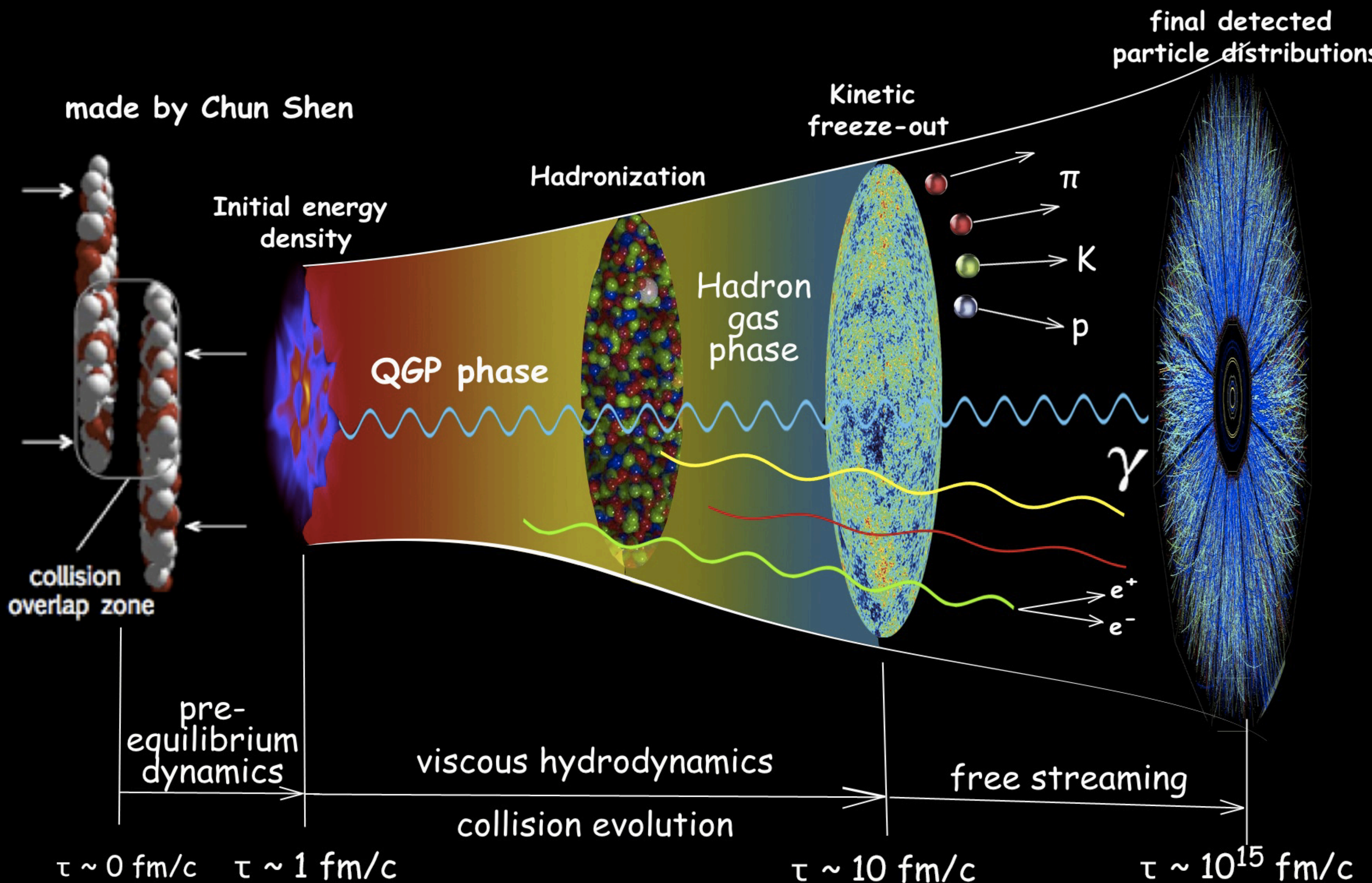
Pusan National University

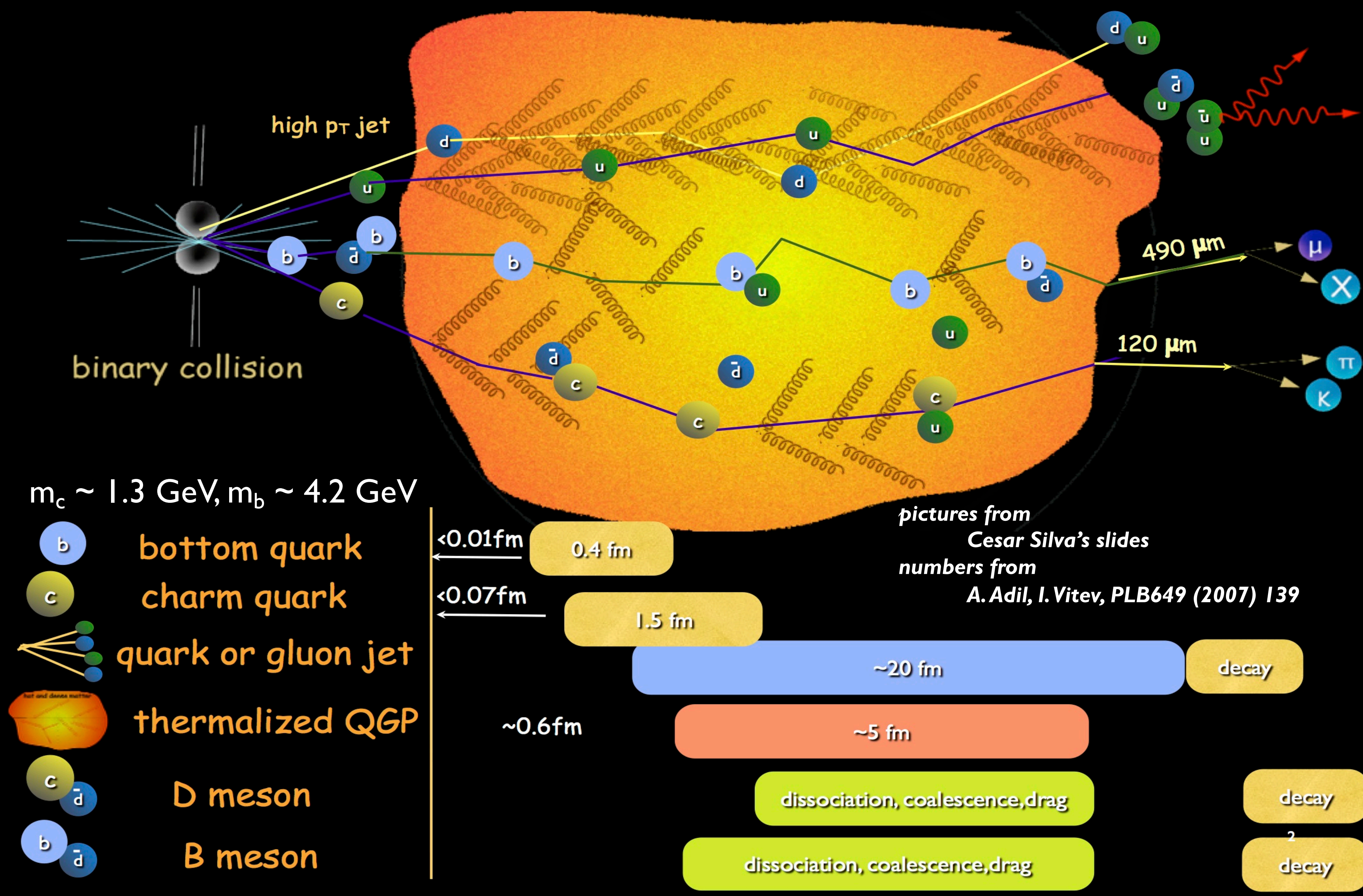
Nuclear Physics Seminar @ BNL

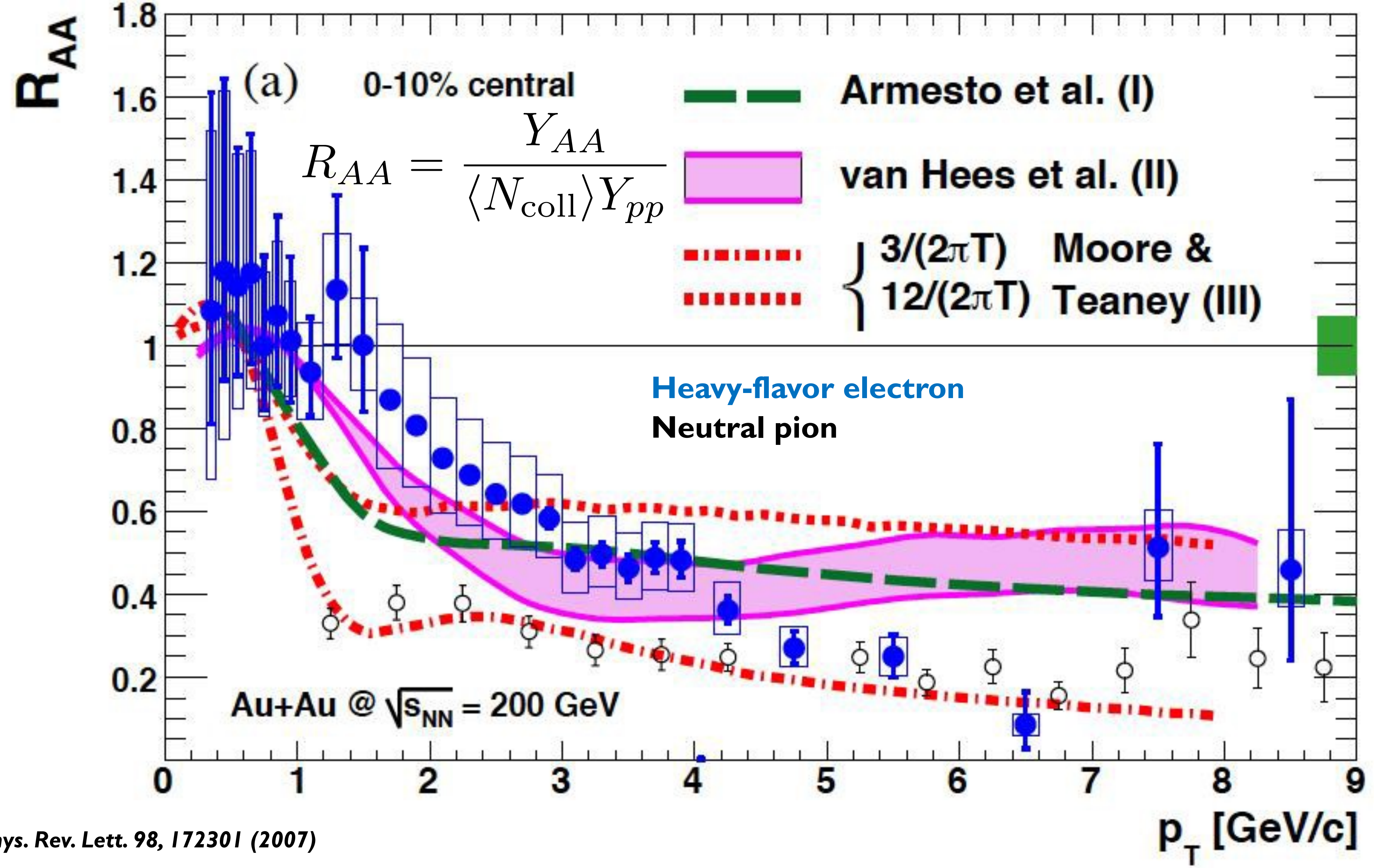
Jan-14-2020

Relativistic heavy-ion collisions



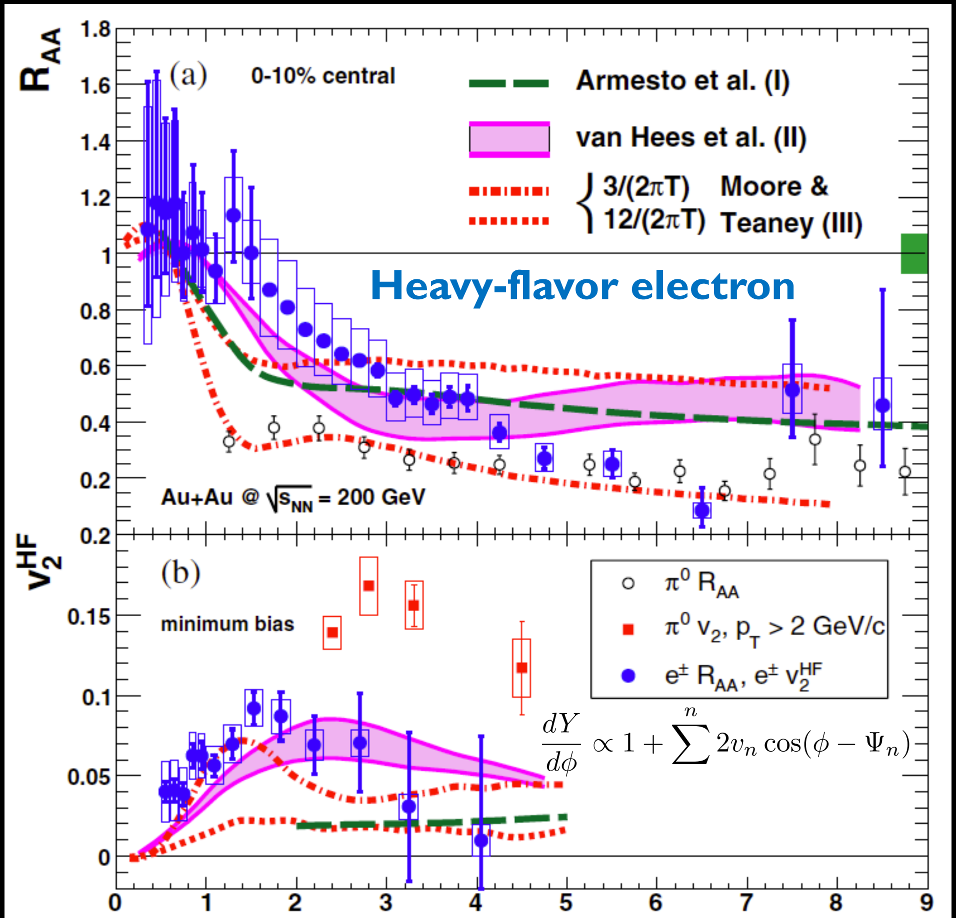
Inside the QGP





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

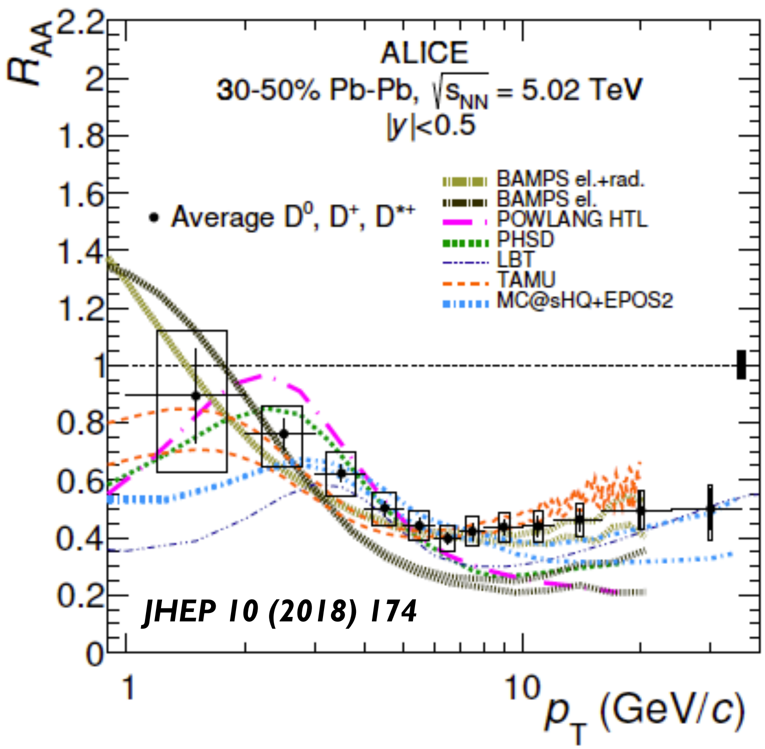
Heavy quark production in heavy-ion collisions

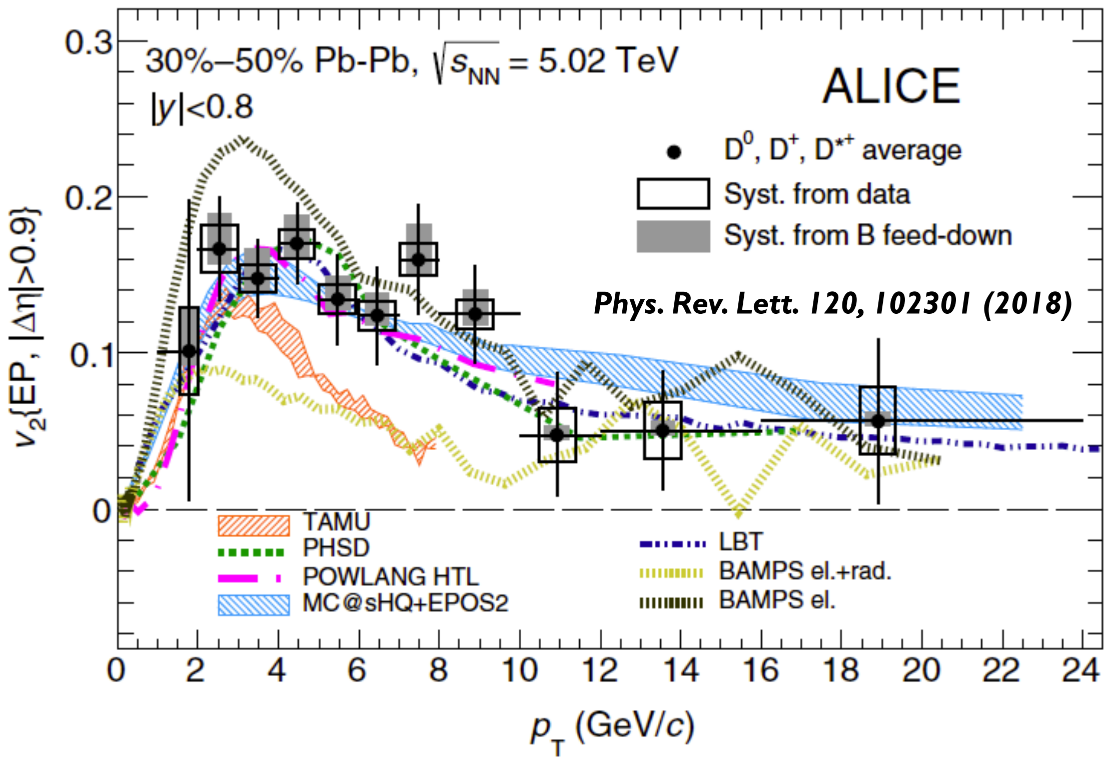


Phys. Rev. Lett. 98, 172301 (2007)

- Electrons from heavy-flavor decays in Au+Au collisions at 200 GeV
  - Strong suppression in high p_T
  - Significant v_2

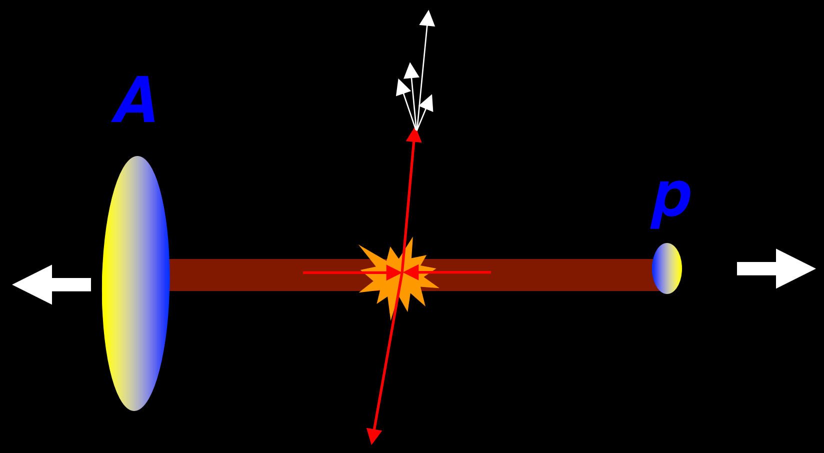
Heavy quark production in heavy-ion collisions



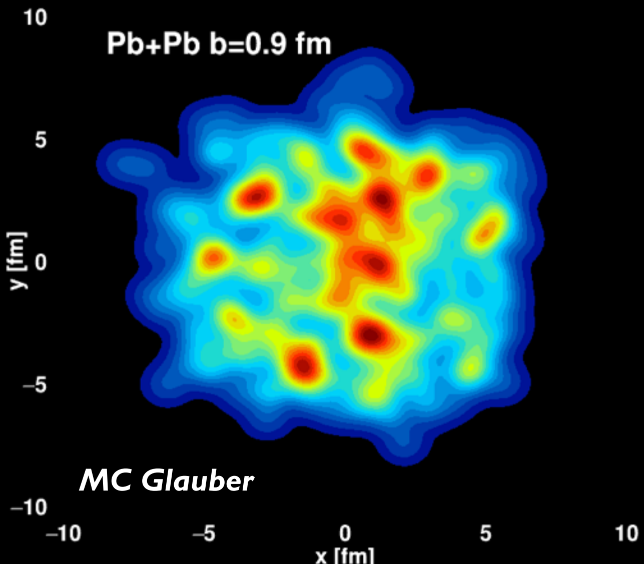


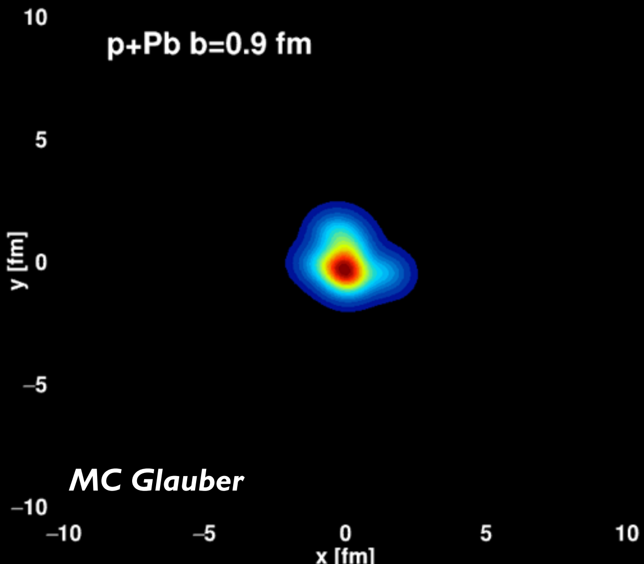
- Similar results at the LHC
- Several models can reproduce both R_{AA} and v_2 simultaneously

What's happened in p+A collisions ?

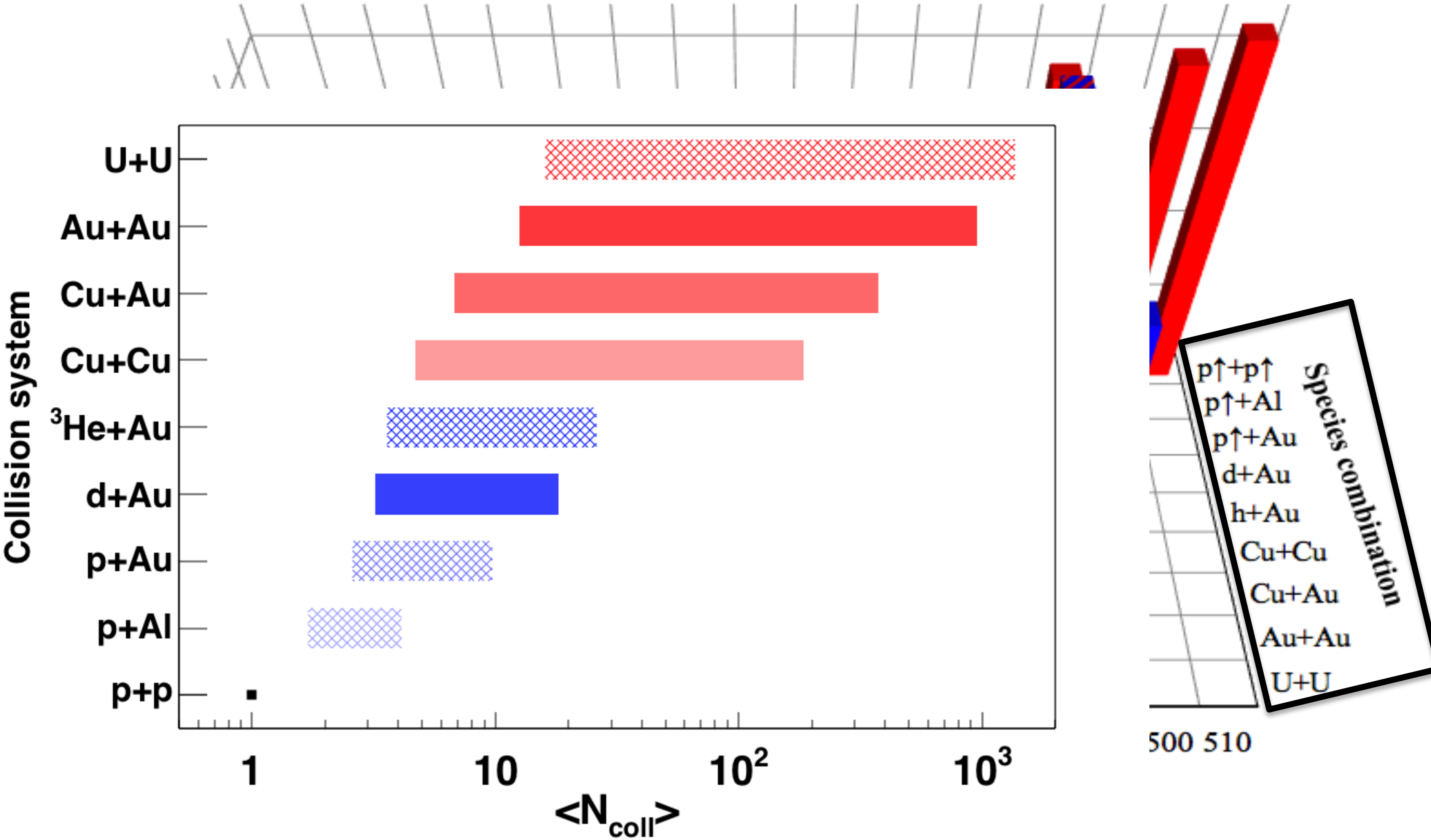


Initial geometry



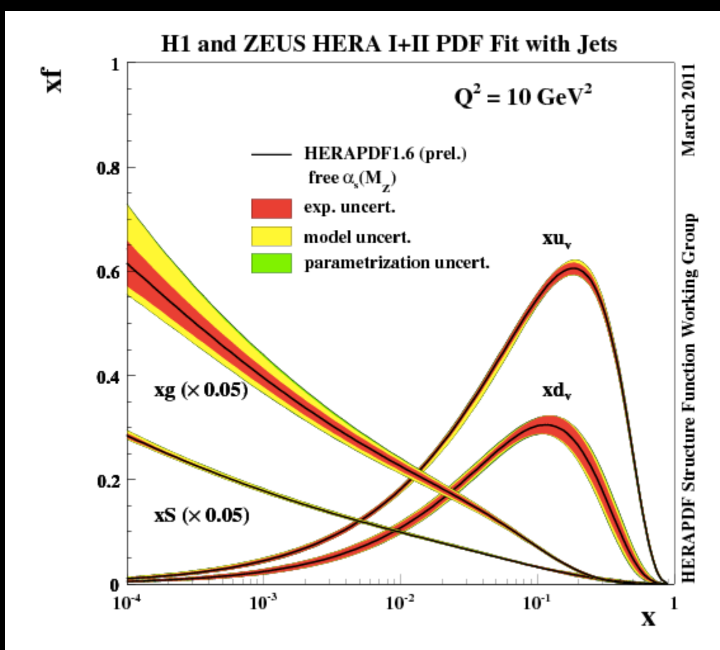


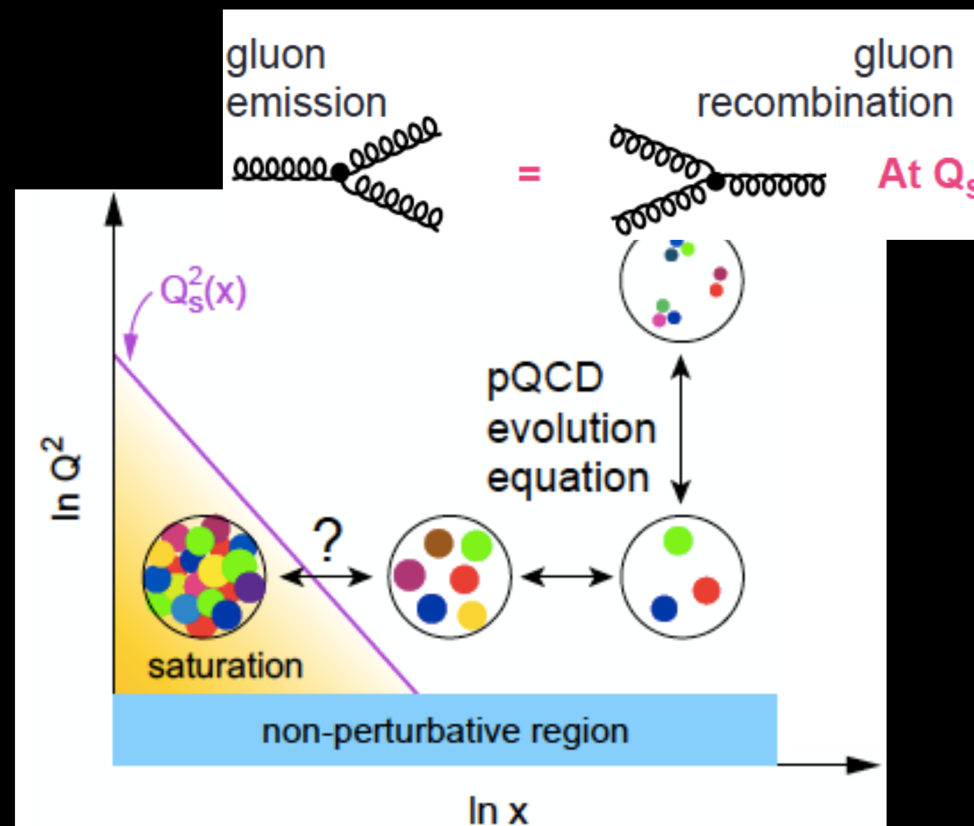
RHIC energies, species combinations and luminosities (Run-1 to 17)



Cold Nuclear Matter effects
Gluon saturation

- Gluons density increases with decreasing x
  - Gluon density should be finite
  - Gluons can interact with each other
- At a certain scale called saturation scale, $Q_s(x)$, gluon density may not increase any more

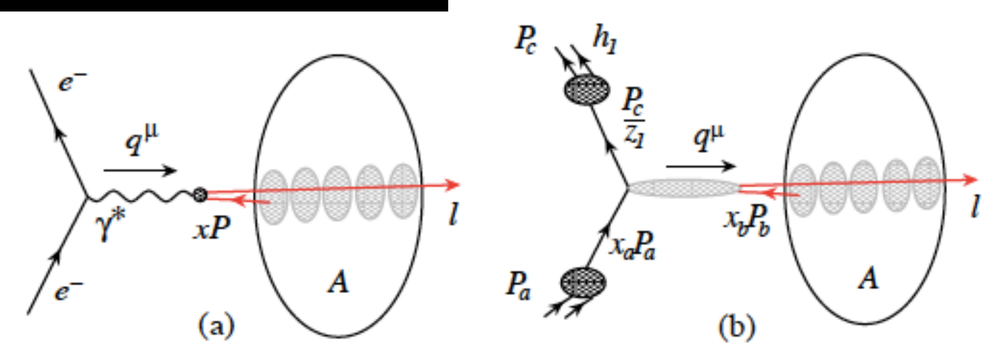


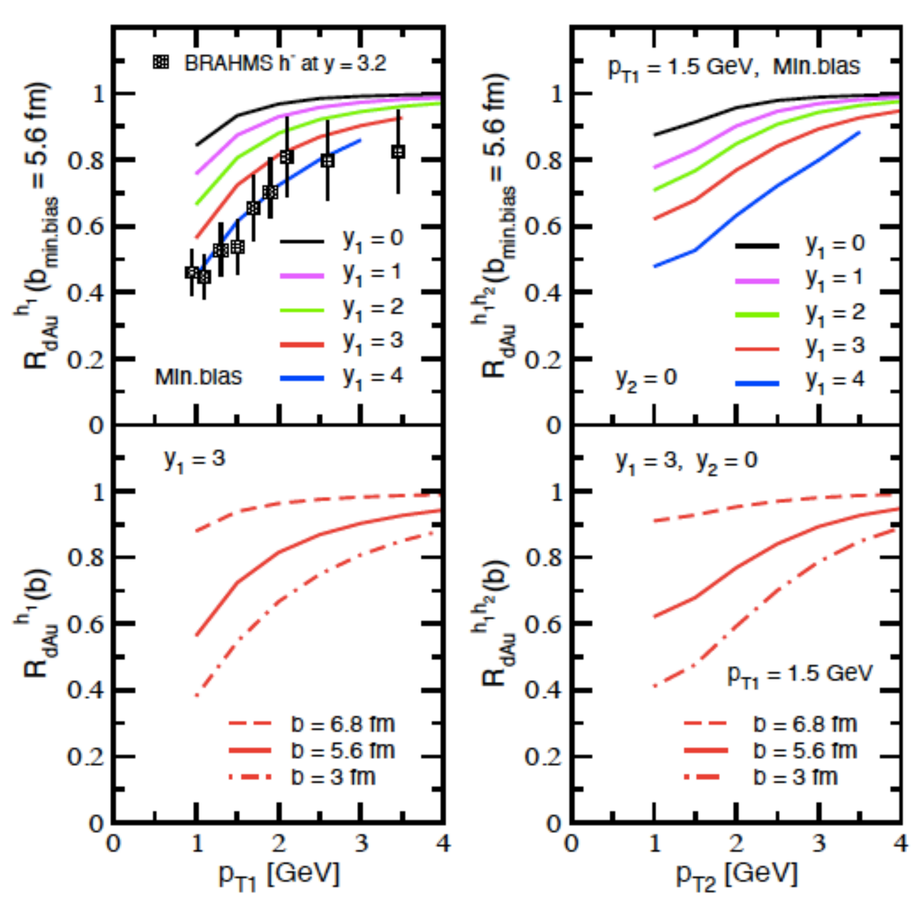


Cold Nuclear Matter effects
Shadowing w/ pQCD

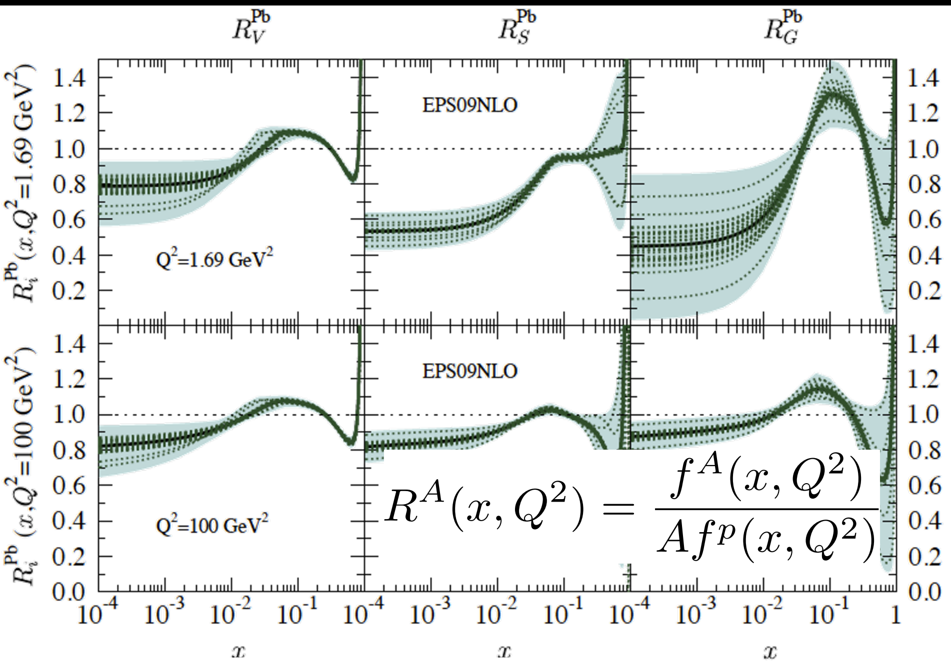
- In case of particle production at forward rapidity where parton's x inside the nucles is small, interactions with the partons inside the nucleus happen coherently.
  - Resumming the coherent multiple scattering is equivalent to a shift of the momentum fraction of the active parton from the nucleus
    ➔Lead to a net suppression of the cross section

Phys. Lett. B 632 (2006) 507

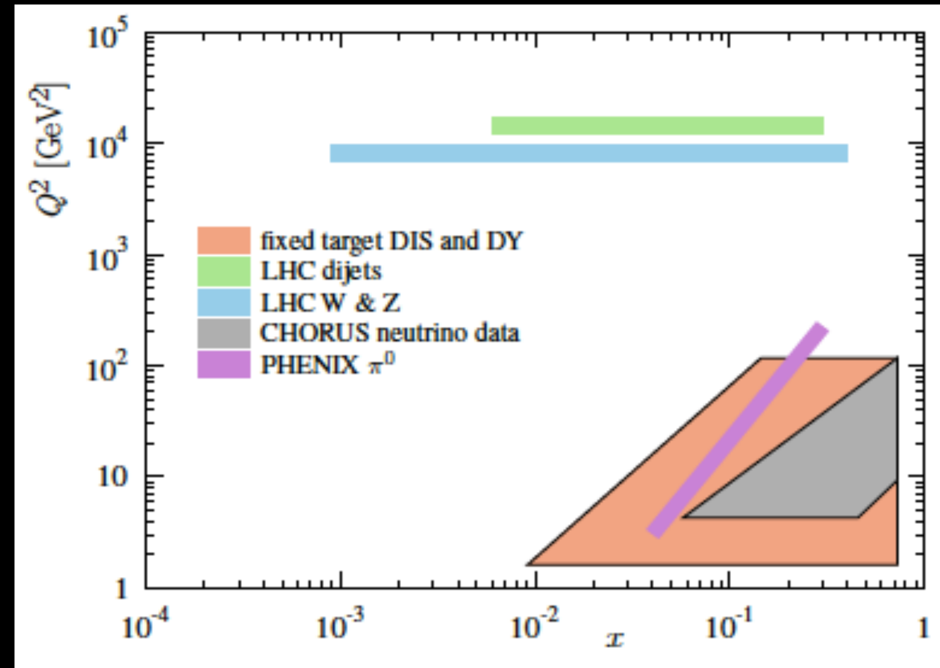




Cold Nuclear Matter effects
Modification of nPDFs (Parameterization)



EPS09 parameterization
arXiv:0902.4154



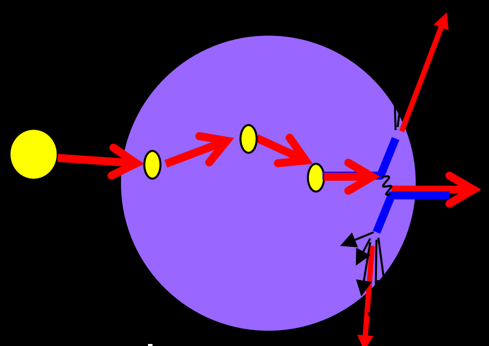
Data used EPPS16 parameterization
arXiv:1612.05741

- Parameterization of nPDFs
  - Modification depends on x and Q^2
  - The most recent nPDF set (EPPS16) starts to include LHC results
    ➔Still large uncertainty particularly on gluon distribution
  - Can be used to pQCD calculation for pA collisions
  - Possible to be affected by some other CNM effects

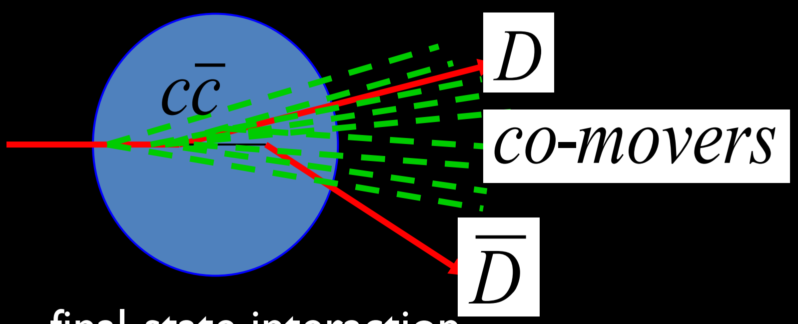
Cold Nuclear Matter effects
Initial-state energy loss & Breakup of Quarkonia

- Initial-state energy loss
  - Partons can loose their energy before hard scattering

- Breakup of Quarkonia states
  - Quarkonia can be broken by interacting with co-moving particles
  - Breakup cross section can be varied with binding energy



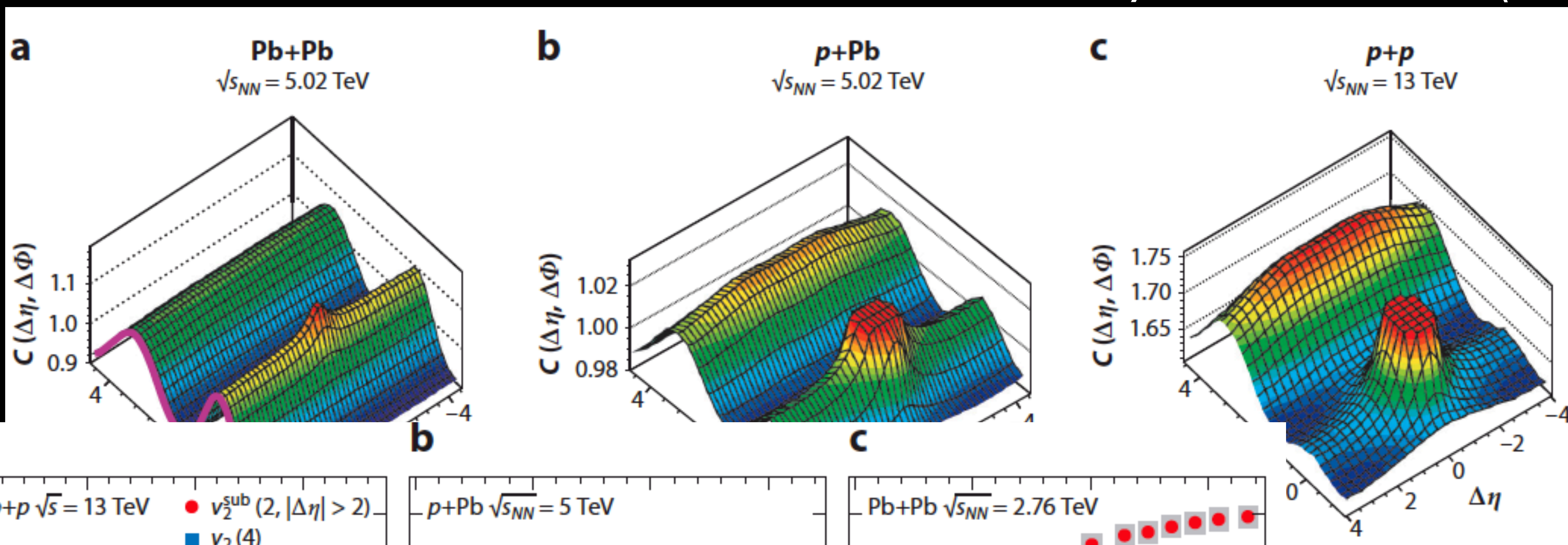
initial-state interaction

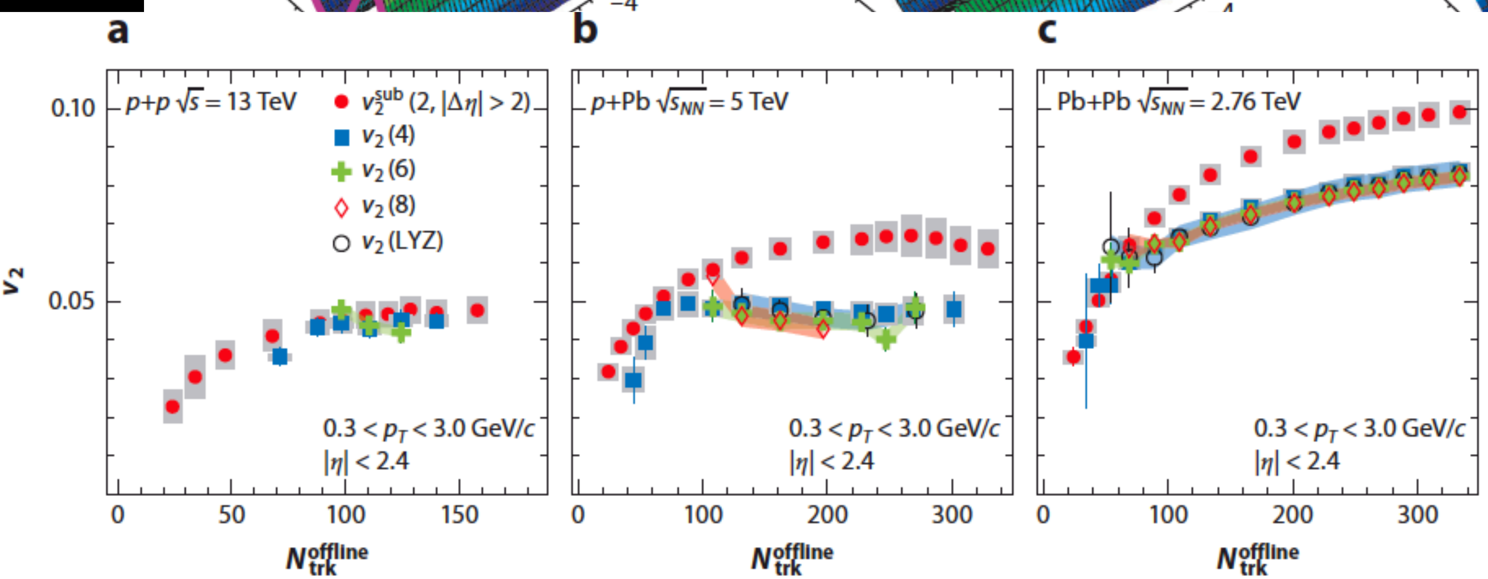


final-state interaction

- Observed significant amount of v_2 in various small collision systems
  - QGP in small systems?
  - Other origins of the anisotropy?

Phys. Rev. Lett. 116 172301 (2016)

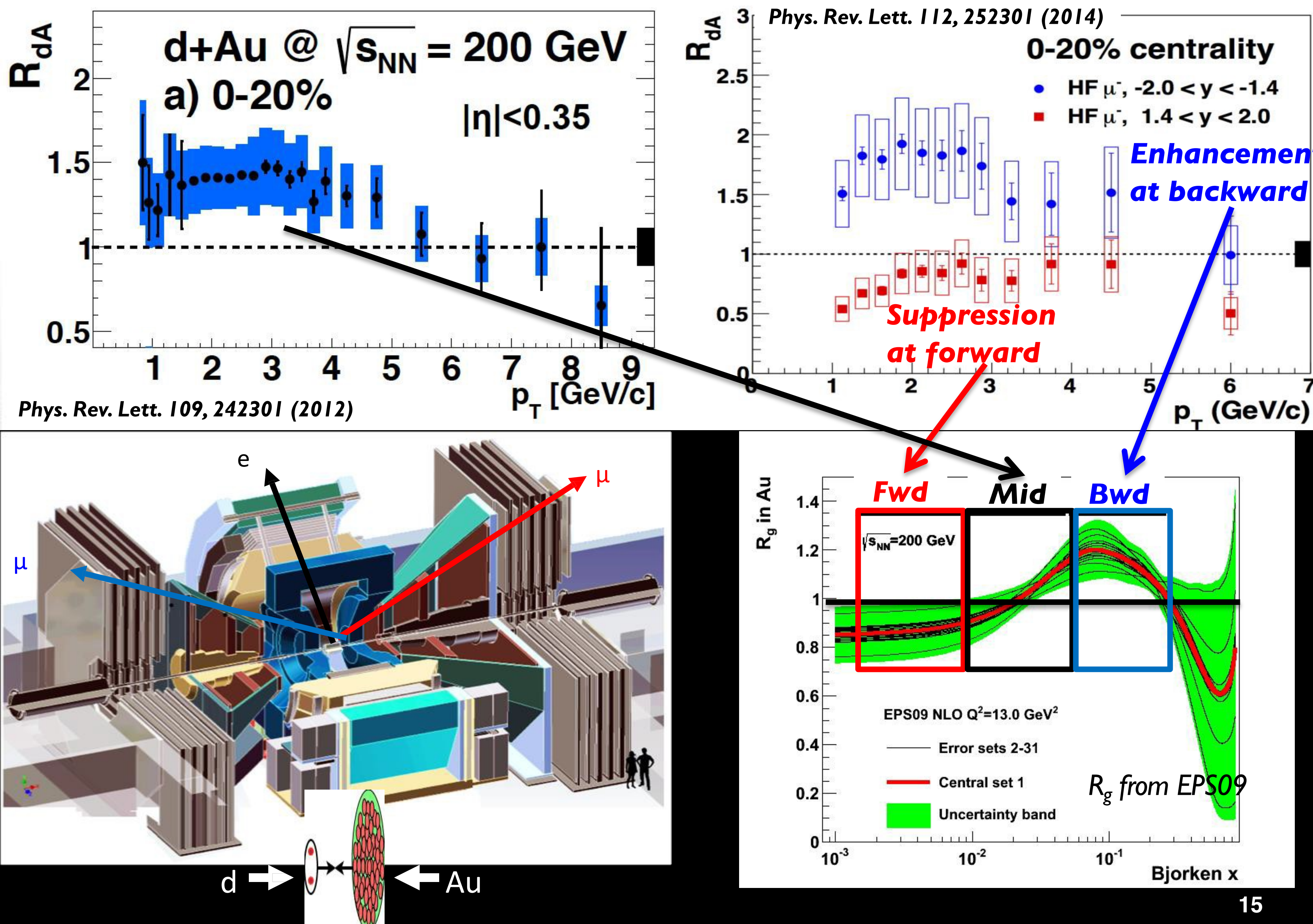




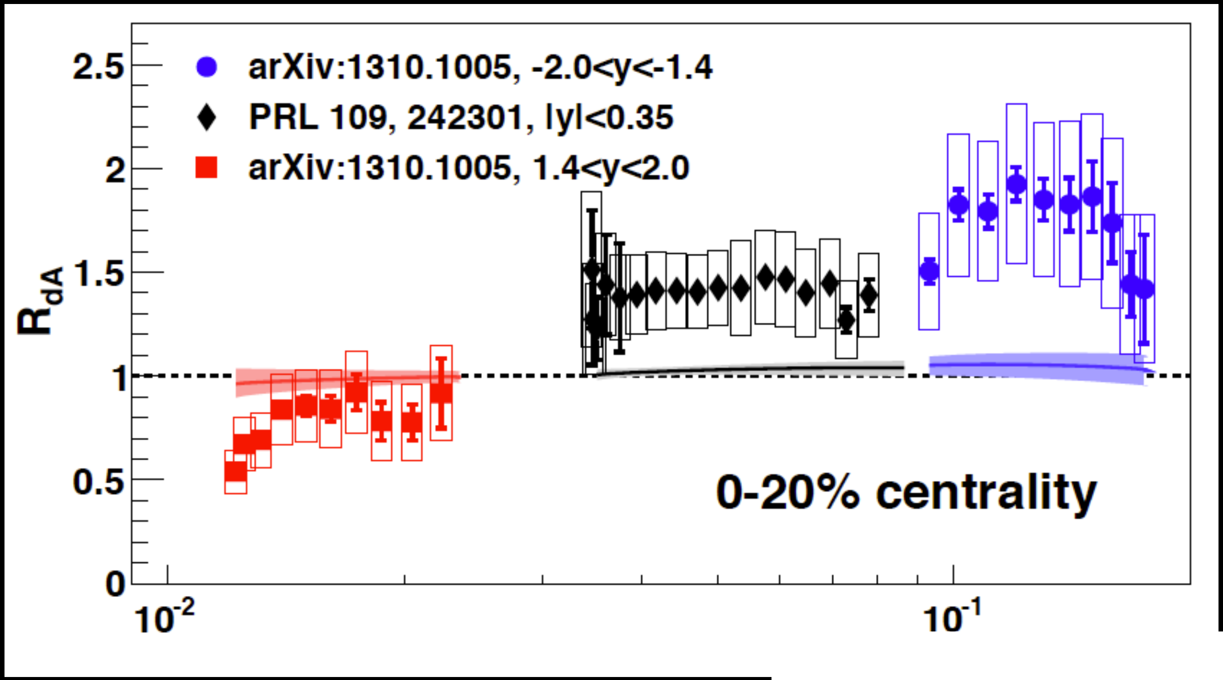
Phys. Lett. B 765 193 (2017)

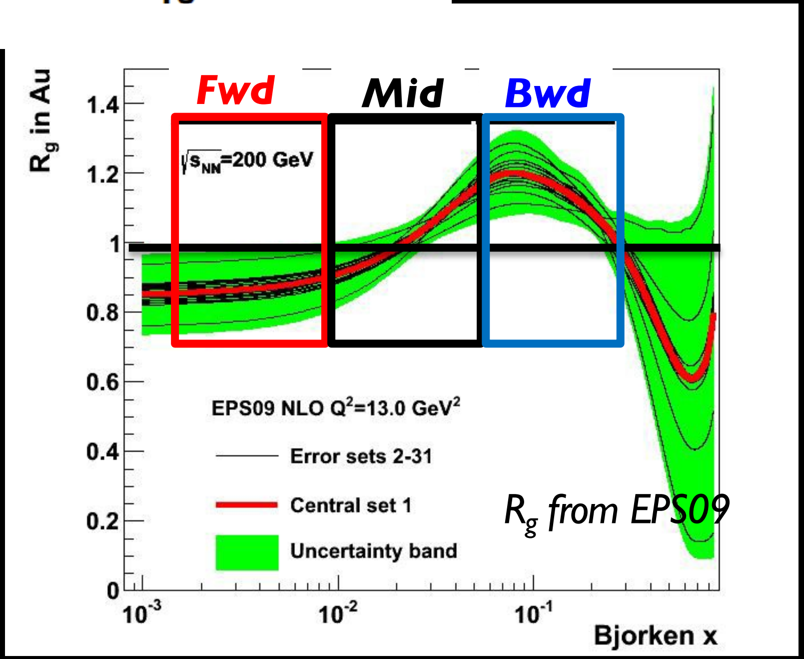
Experimental results in small systems

Heavy quark production in d+Au collisions



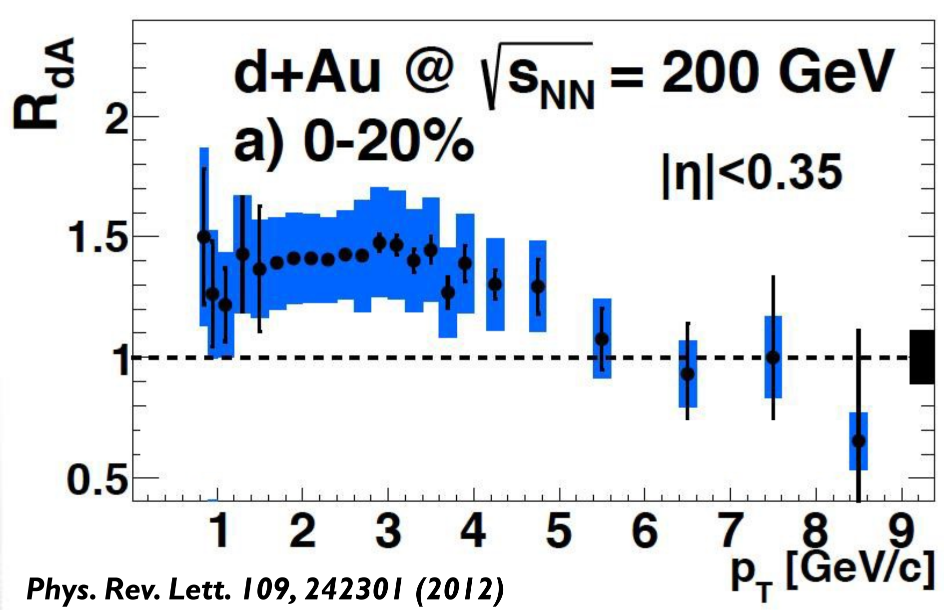
Heavy quark production in d+Au collisions



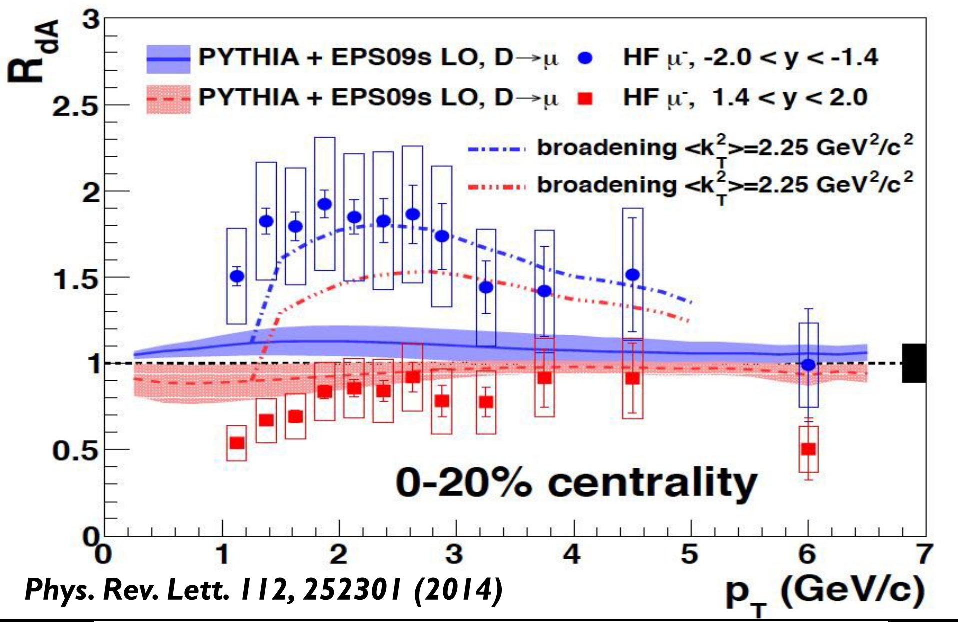


- nPDF only can not describe the rapidity-dependent modification

Heavy quark production in d+Au collisions

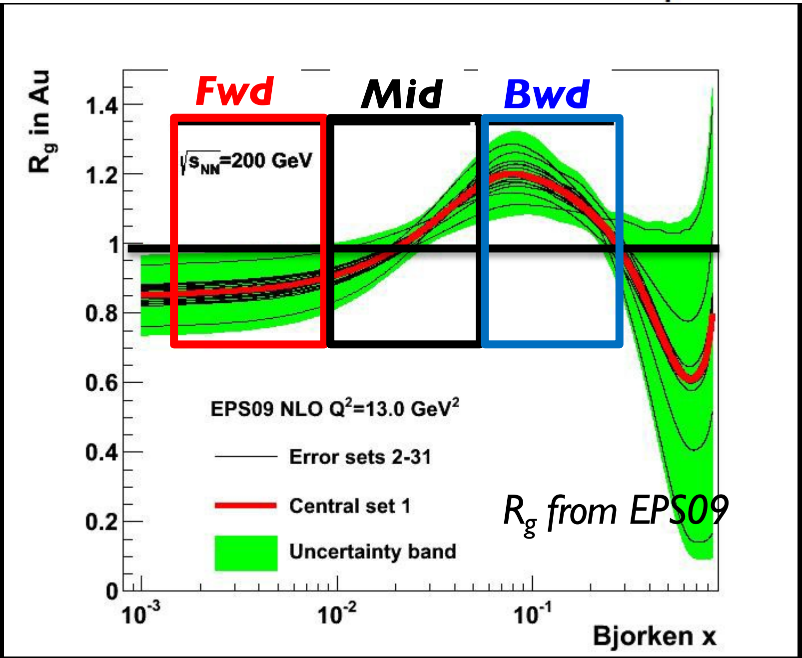


Phys. Rev. Lett. 109, 242301 (2012)

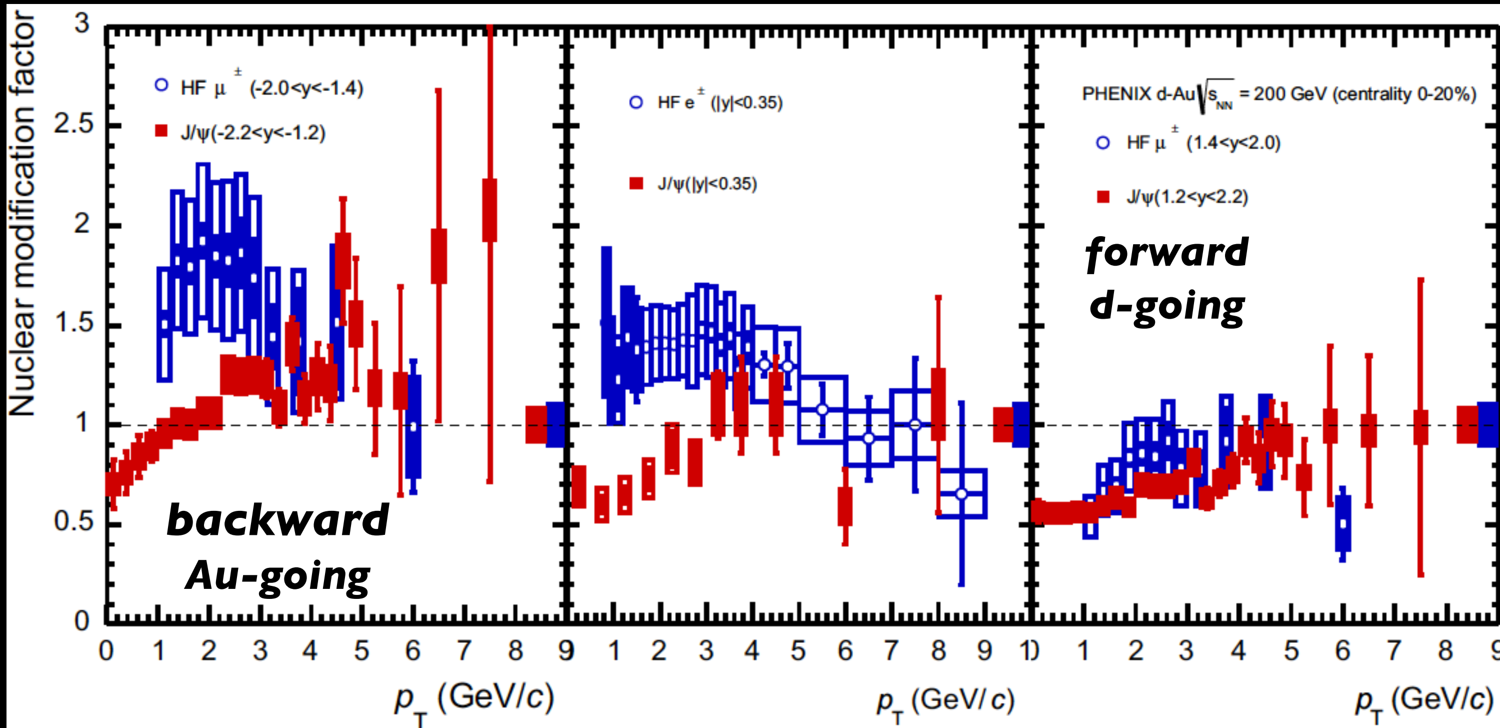


Phys. Rev. Lett. 112, 252301 (2014)

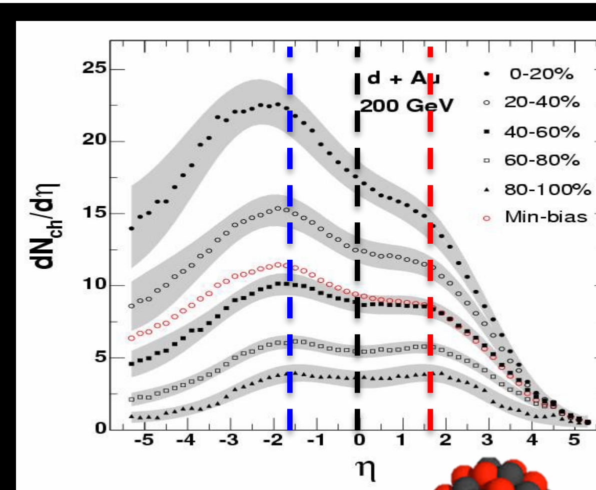
- Fail to reproduce the data at both rapidity simultaneously w/ combinations of initial-state effects
  - modification of nPDF
  - initial k_T broadening

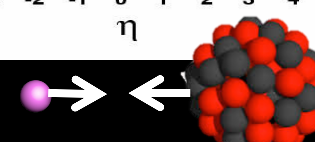


Comparison with J/ψ

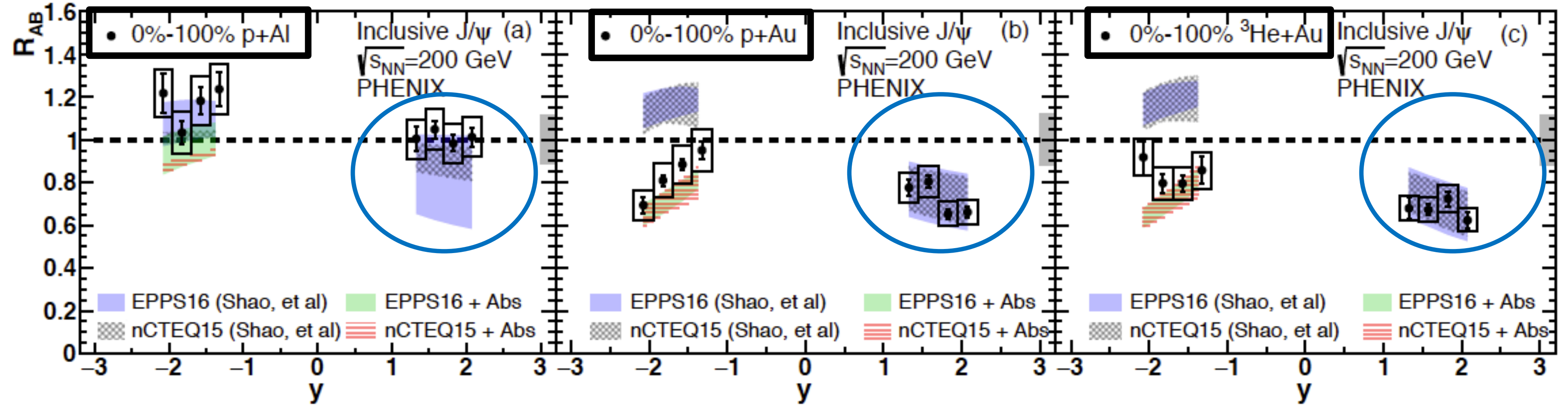


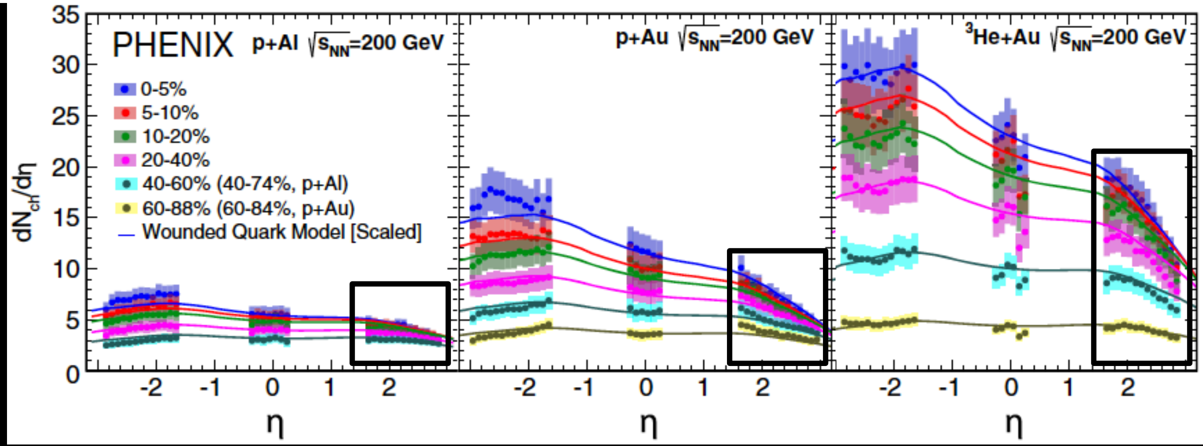
- In **0-20% central** d+Au collisions
  - R_{dA} of HF muon and J/ψ are similar at forward rapidity
  - **charm production is enhanced but J/ψ production is significantly suppressed** at mid- and backward rapidity
  - Larger break-up in range of higher multiplicity (A-going)





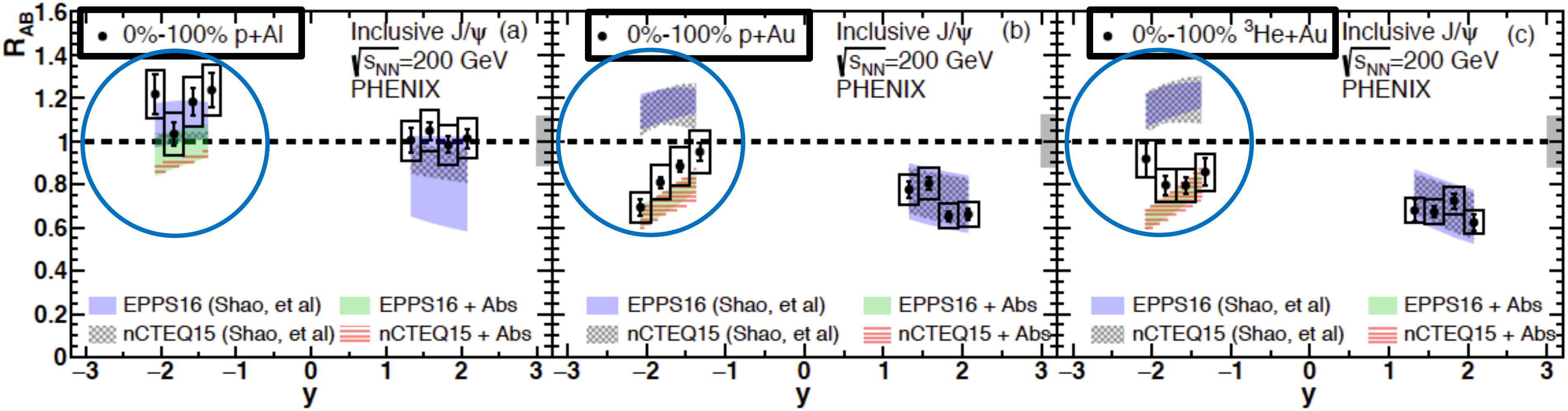
System size dependence?

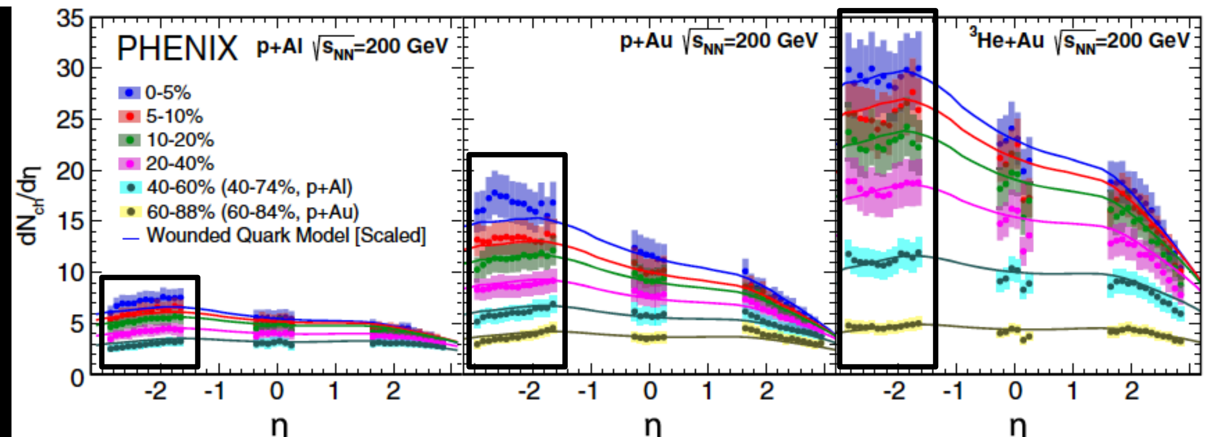




- Clear A-dependence at forward rapidity
  ➔Different shadowing/energy loss

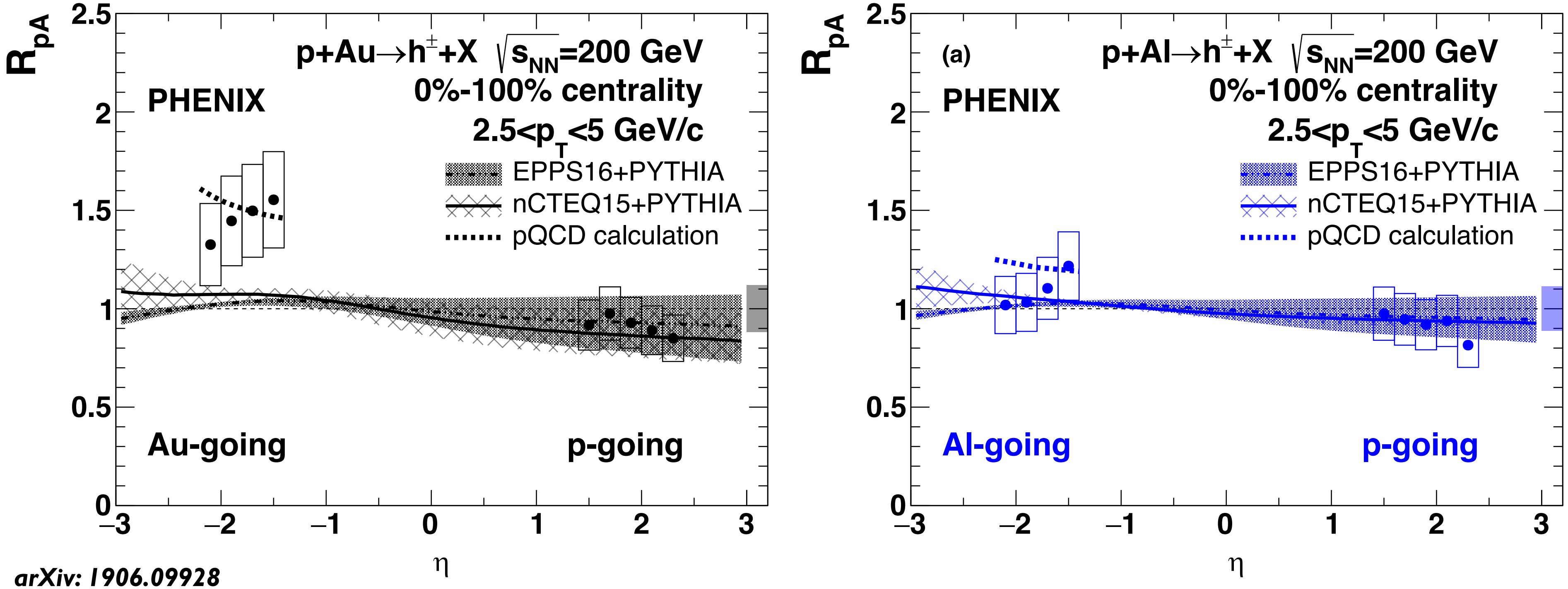
System size dependence?





- Clear A-dependence at forward rapidity
  ➔Different shadowing/energy loss
- A-dependence at backward rapidity as well
  ➔Larger nuclear absorption effect in Au than Al (relevant at RHIC energy)

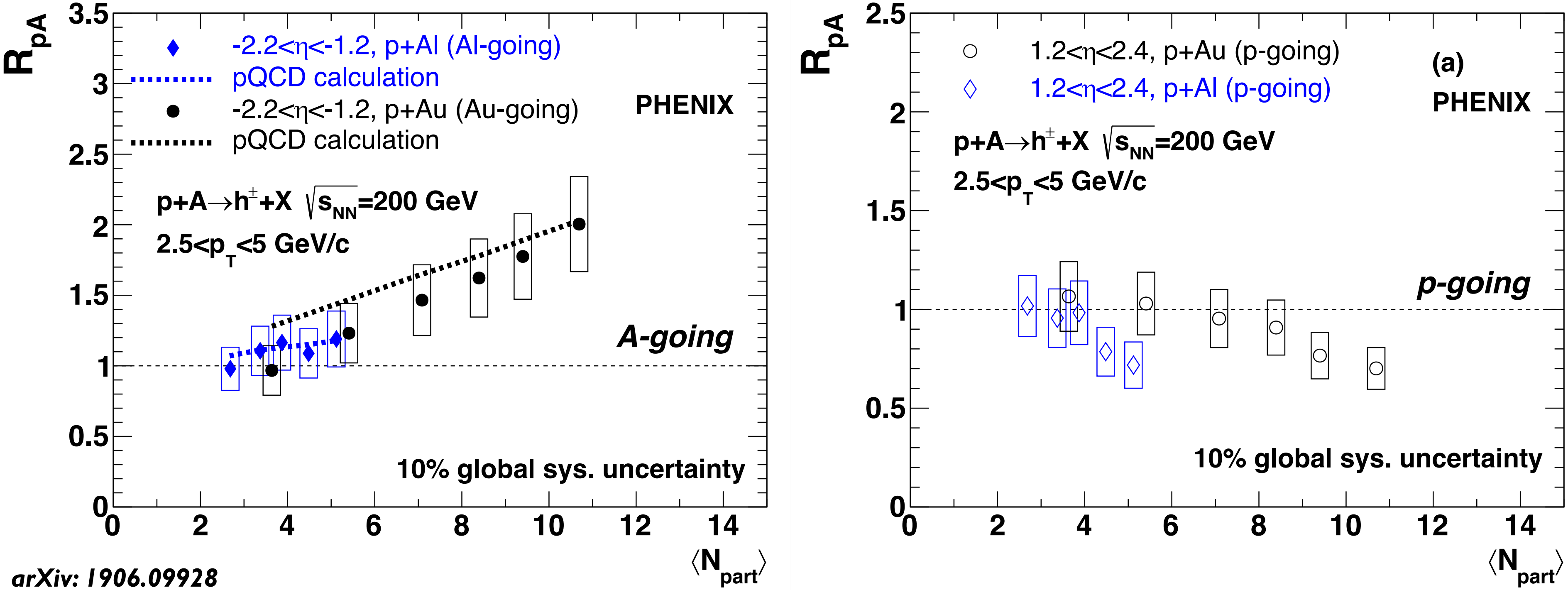
Charged hadrons in p+A



arXiv: 1906.09928

pQCD calculation: Phys. Lett. B 740, 23 (2015)

- In charged hadron production, very similar modification as the ϕ results
  - Modification based on nPDF sets can describe the forward results but underestimate the enhancement at backward
- In p+Al collisions, a clear A-dependence only at backward (A-going direction)
  - pQCD calculation considering incoherent multiple scattering can describe the difference between p+Au and p+Al collsions

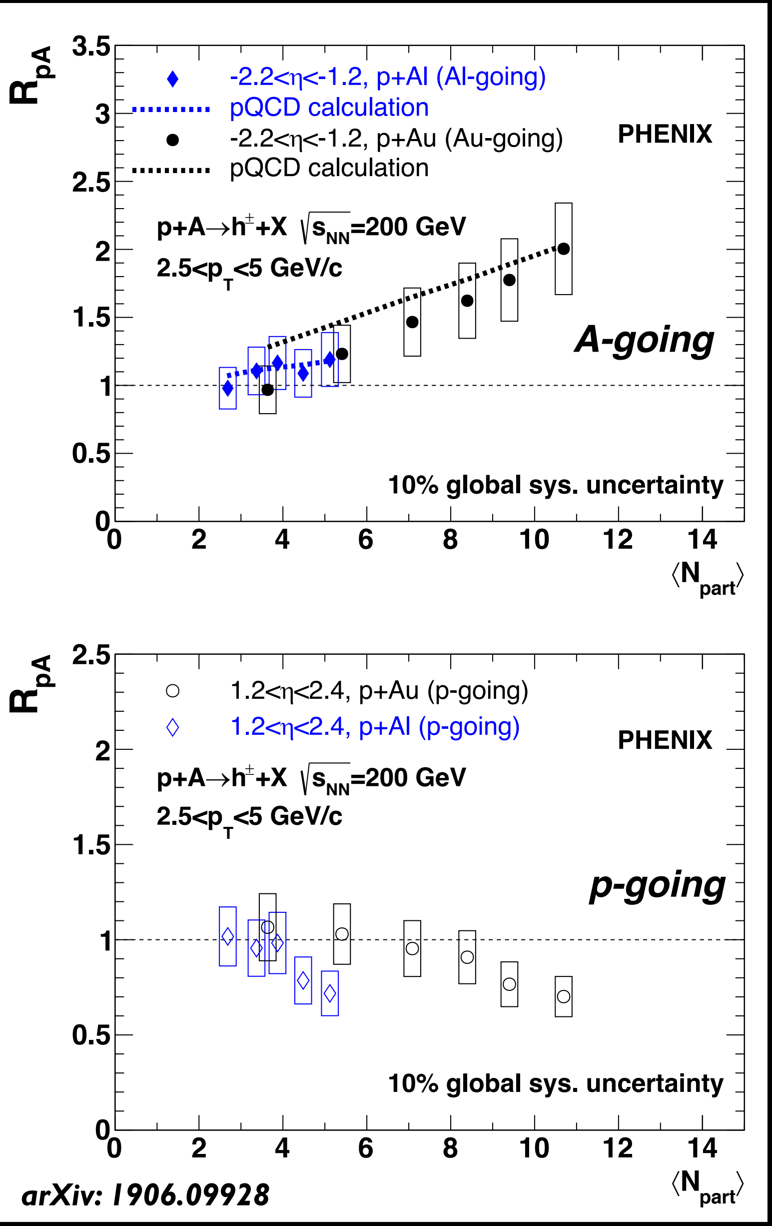


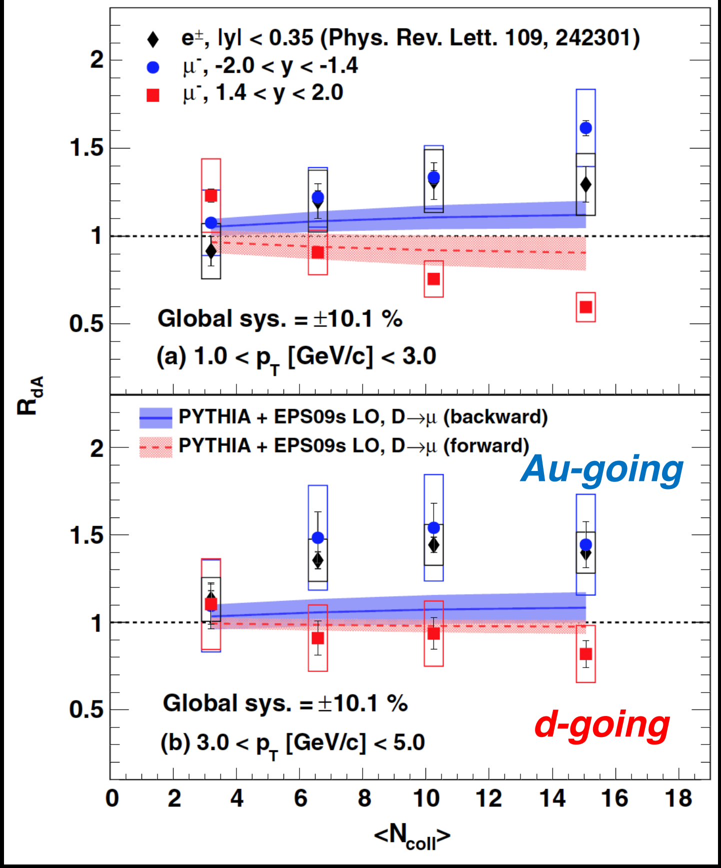
arXiv: 1906.09928

pQCD calculation: Phys. Lett. B 740, 23 (2015)

- At backward rapidity (A-going direction)
  - R_{pA} in p+Au and p+Al follows the same trend of increasing with $<N_{part}>$
  - Dominated by final-state effects (multiplicity)?
- At forward rapidity (p-going direction)
  - R_{pA} in p+Au and p+Al show their own trend of decreasing with $<N_{part}>$
  - Dominated by initial-state effects (impact parameter)?

Comparison with heavy-flavor



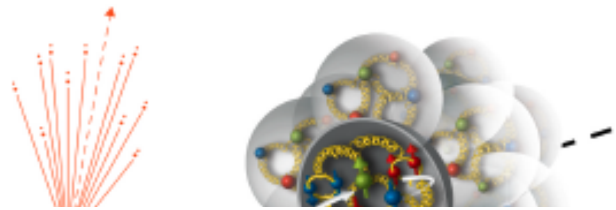


Phys. Rev. Lett. 112, 252301 (2014)

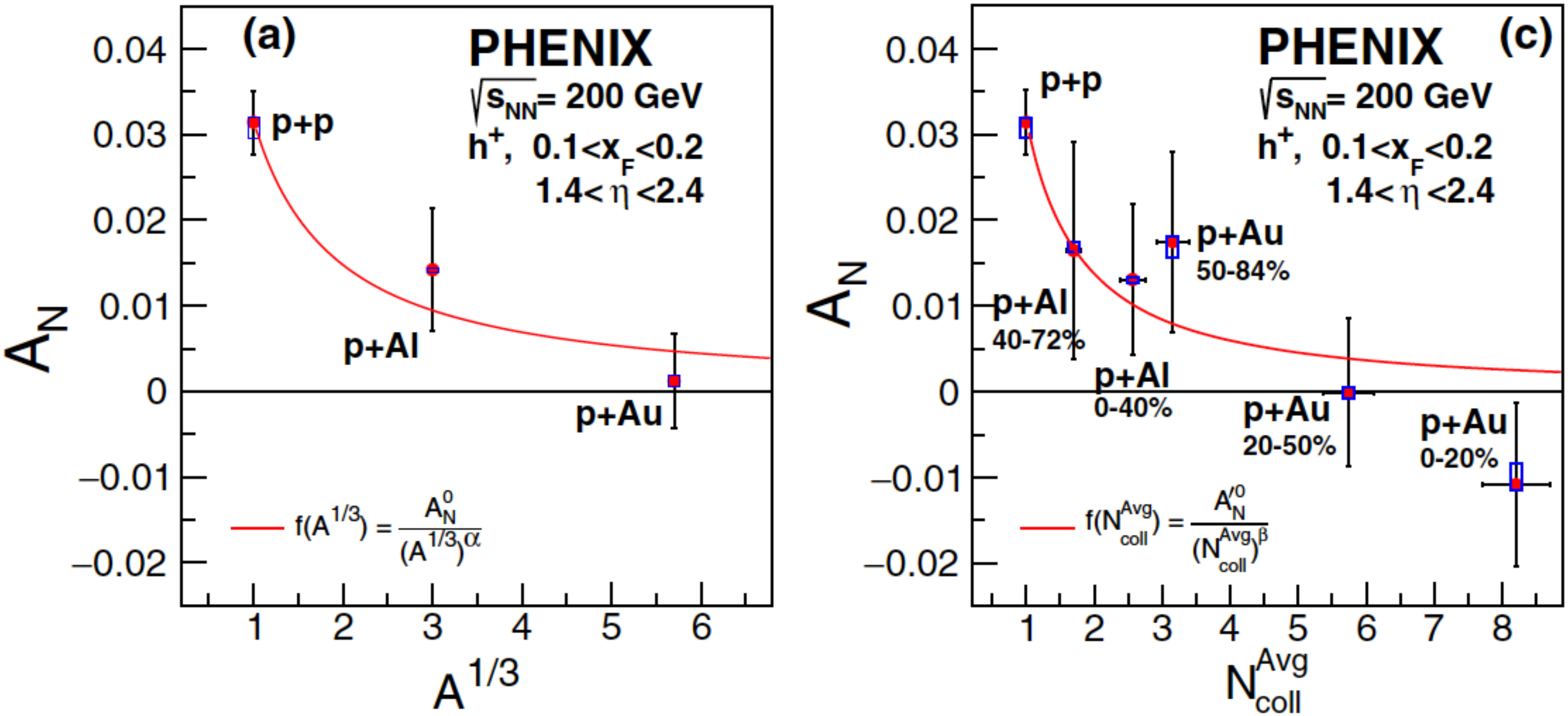
- Similar modification in charged hadrons and heavy-flavor muons (dominated by charm)
- Common nuclear effects for light and charm in small collision systems?

CNM effects in A_N?

$$A_N = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}}$$



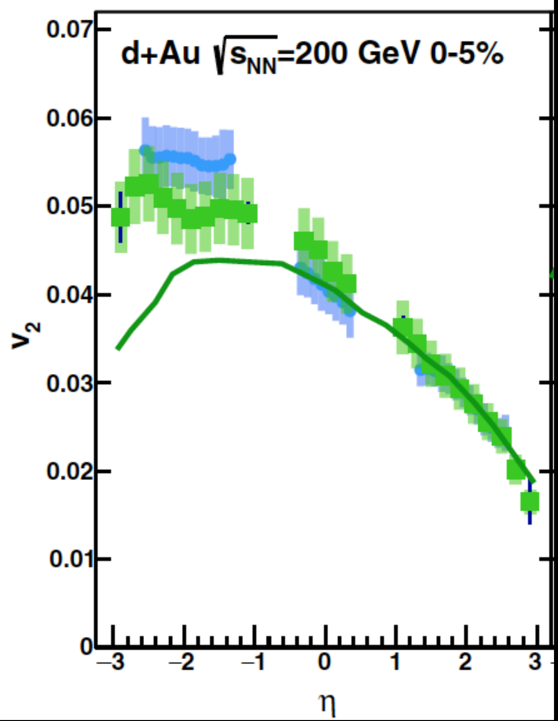
- Charged hadron production at forward (p-going)



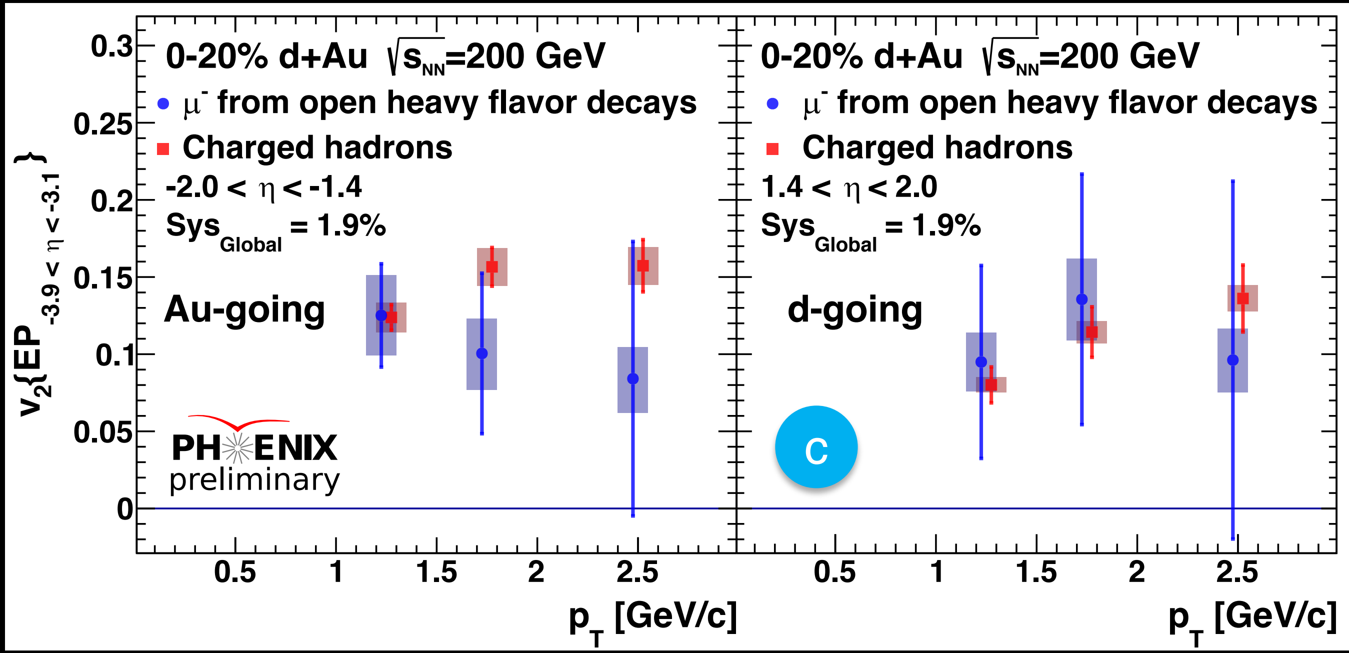
Phys. Rev. Lett. 123, 122001 (2019)

- Clear A-dependence of A_N
  → Related to A-dependent p_T broadening?

Heavy-flavor v_2 in small systems

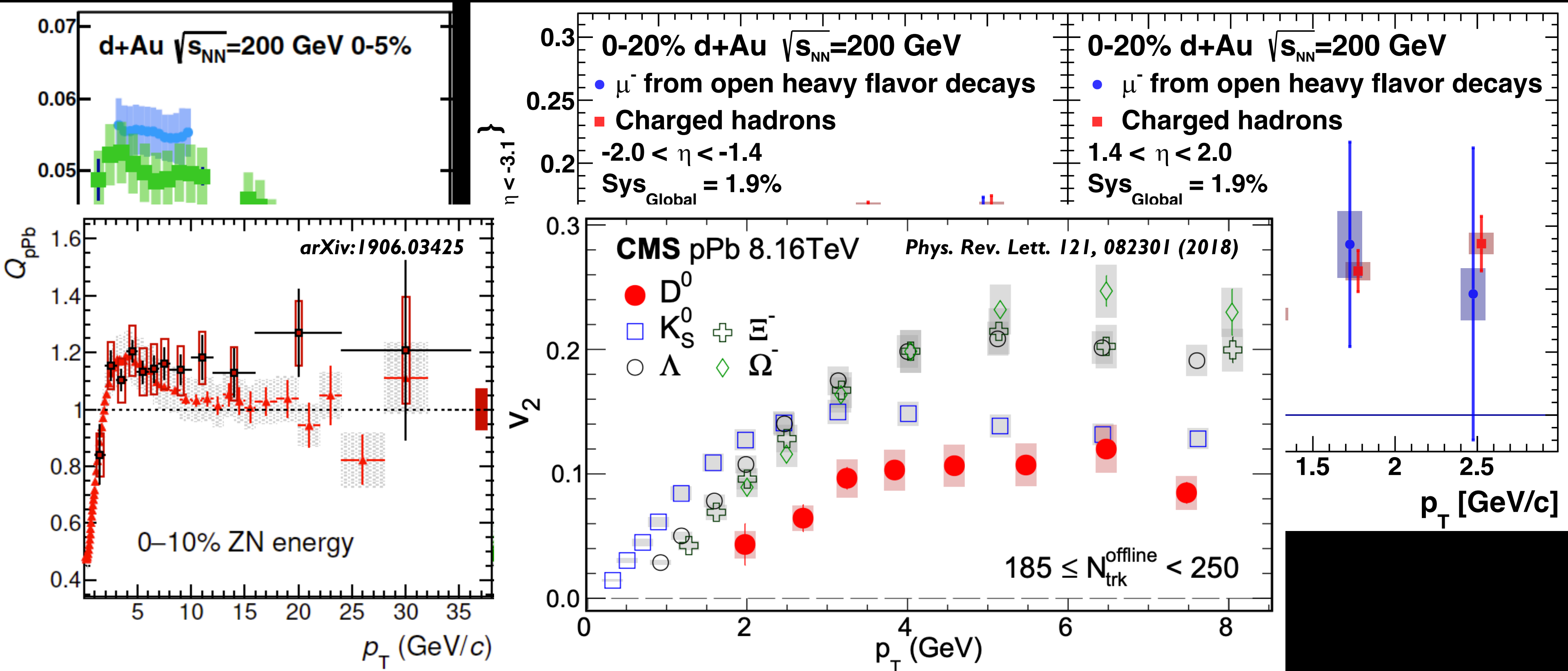


Phys. Rev. Lett. 121, 222301 (2018)



- Non-zero v_2 of muons from heavy-flavor decays (mostly charm) at forward and backward in d+Au collisions

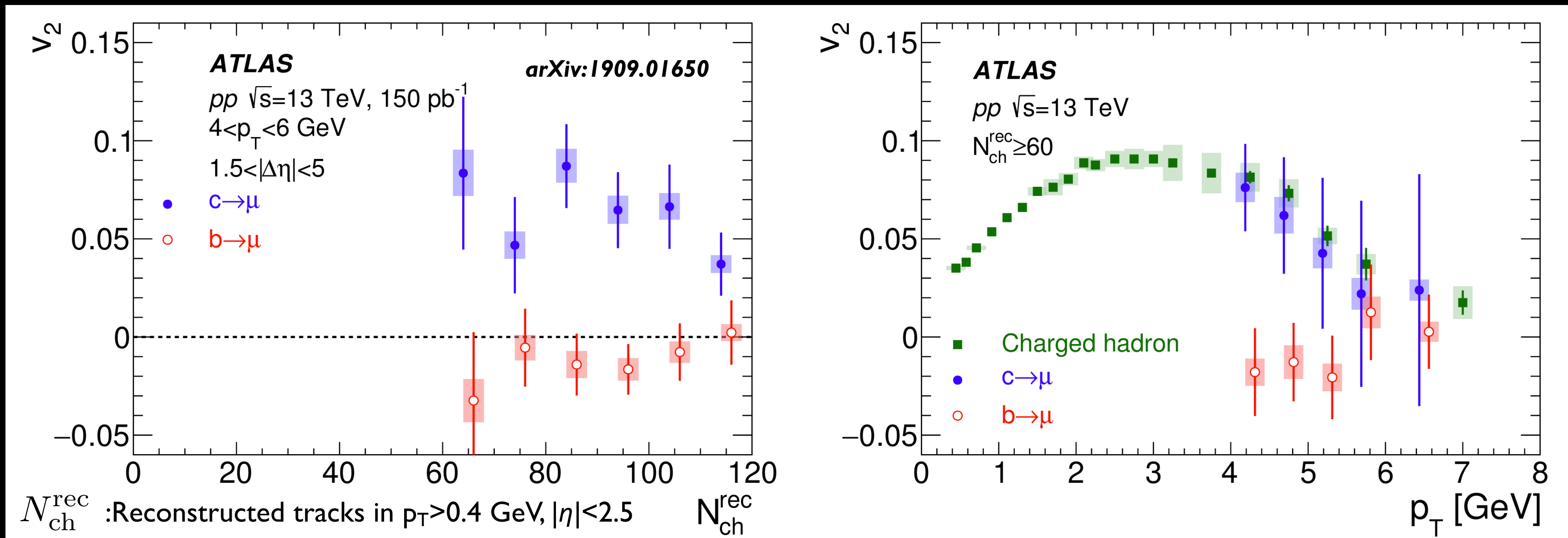
Heavy-flavor v_2 in small systems

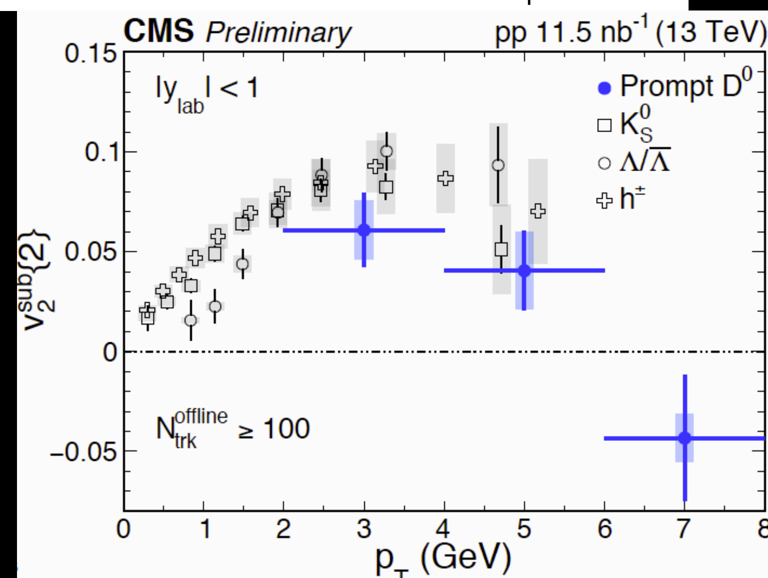


- Non-zero v2 of muons from heavy-flavor decays (mostly charm) at forward and backward in d+Au collisions
- Similar results at the LHC
- These results can not be reproduced by models used for heavy-ion collisions

Can we turn off the flow?

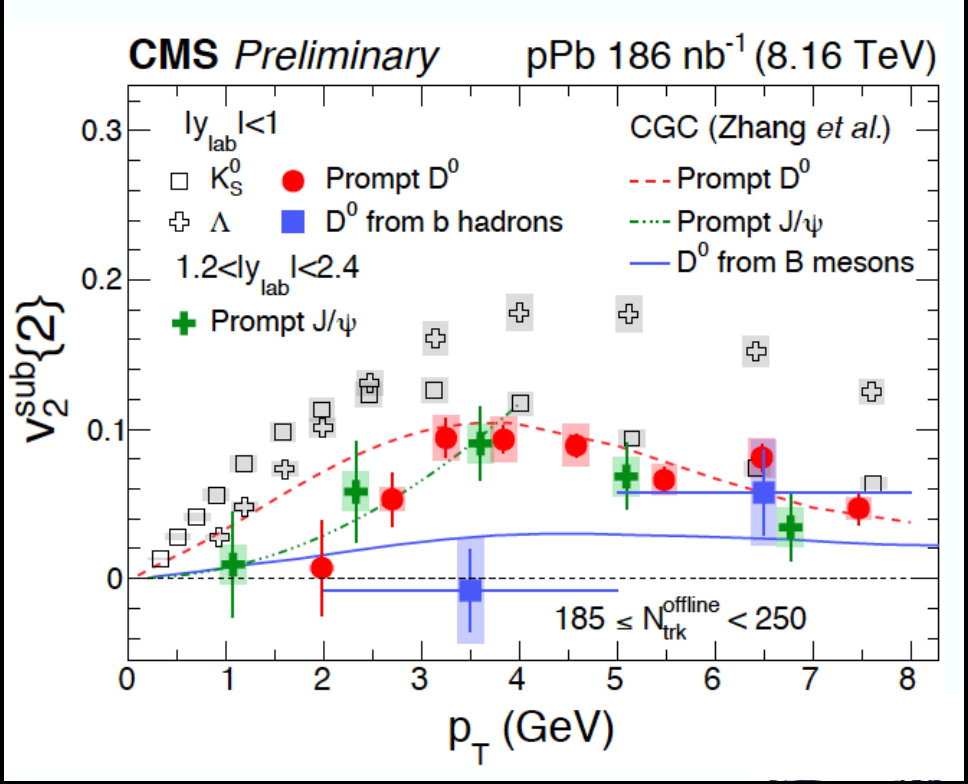
Charm and bottom v_2 in *p+p*





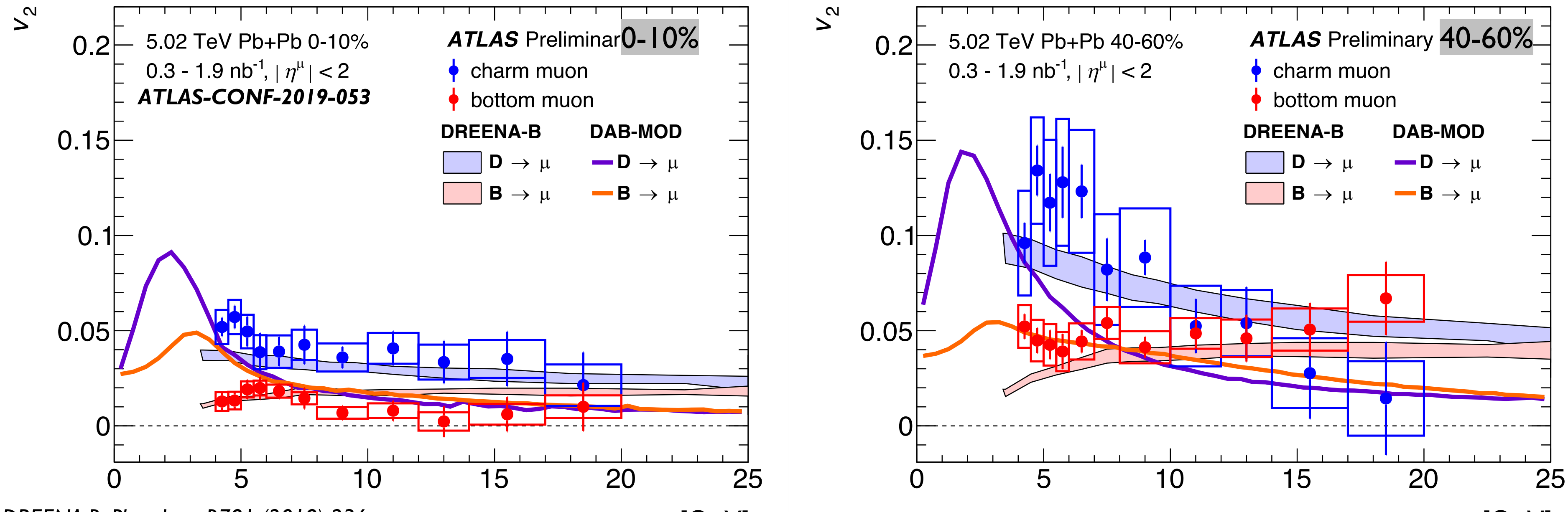
- Significant non-zero v_2 for charm muons Consistent with independent of multiplicity and decreasing with p_T
- Bottom muon v_2 is consistent with zero in multiplicity and p_T
- Clear difference between charm and bottom in *p+p* collisions
  ➔No theory/model for comparison yet

Charm and *bottom* v_2 in *p+Pb*



- Non prompt D0 v_2 in high multiplicity in p+Pb collisions
  Consistent with zero within uncertainties
- Clear difference between charm and bottom
  ➔Similar with the results in *p+p* collisions

Charm and *bottom* v_2 in Pb+Pb

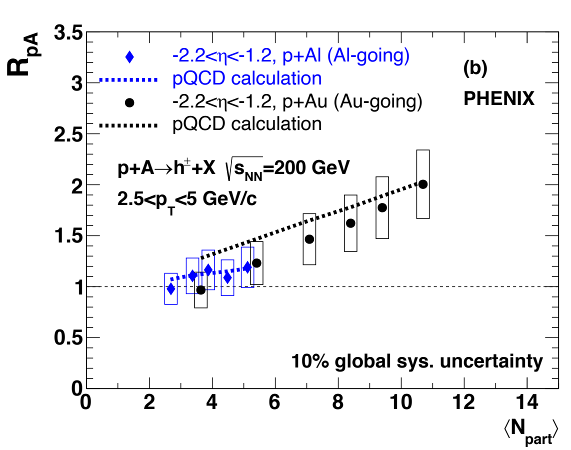


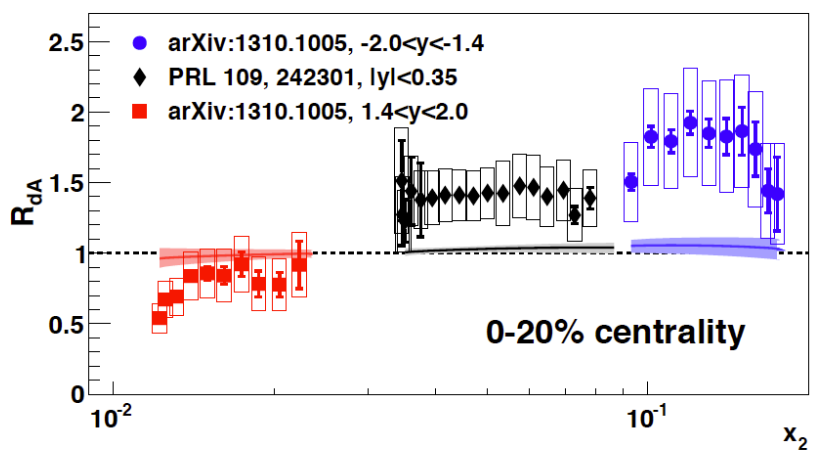
DREENA-B: Phys. Lett. B791 (2019) 236
DAB-MOD: arXiv:1906.10768

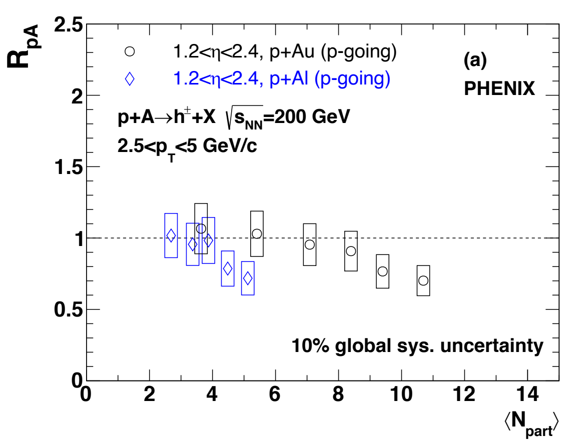
- Non-zero bottom muon v_2
- Charm muon v_2 is higher than bottom muon v_2 in lower p_T region and becomes similar in higher p_T of 40-60% centrality interval

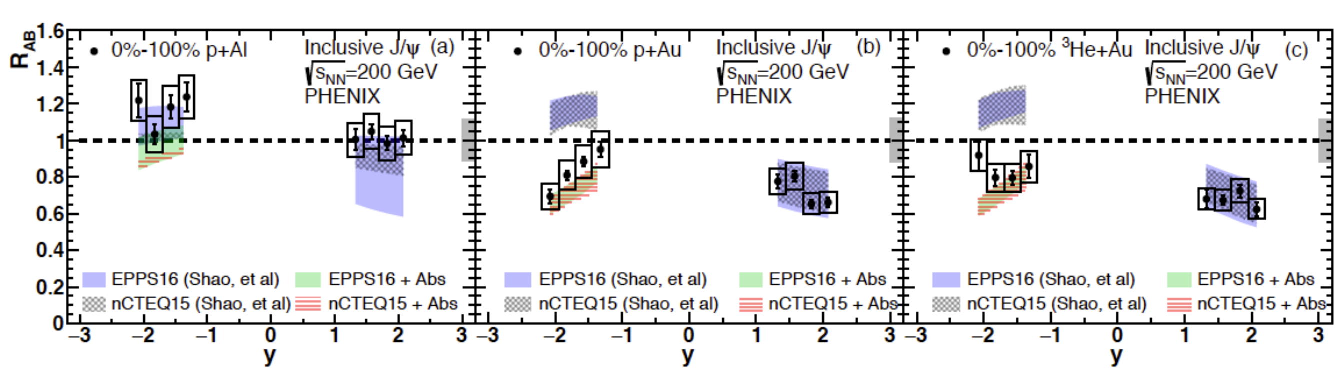
- DREENA-B considering energy loss inside medium can reproduce the magnitude of v_2 both for charm and bottom muon
- DAB-MOD model including Langevin drag and diffusion underestimates charm muon v_2

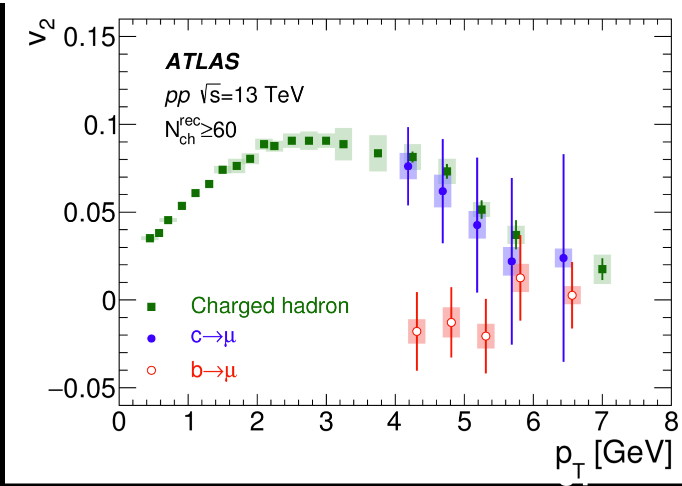
Summary











- Extensive studies have been done in small systems to learn interesting physics!
- More things to do!
  Flow in small systems, nPDF, saturation…

BACKUP