Heavy quark production in small collision systems

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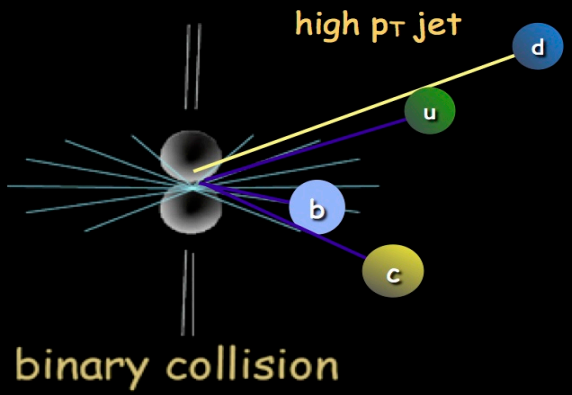
Pusan National University

HIM, 2019.10.17.

Heavy quarks in heavy-ion collisions



$m_c \sim 1.3$ GeV, $m_b \sim 4.2$ GeV

b bottom quark

c charm quark

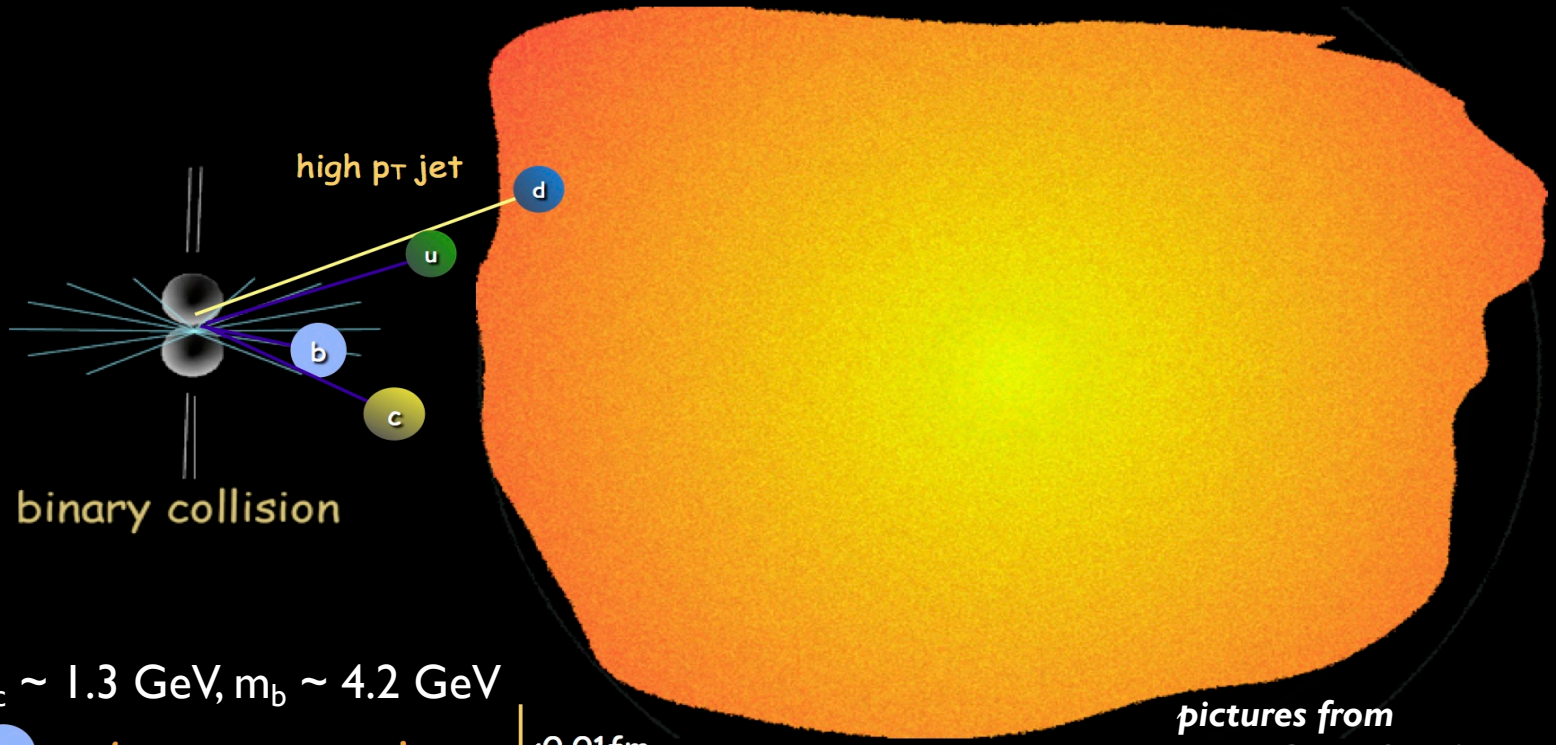
quark or gluon jet

<0.01fm

<0.07fm

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

Heavy quarks in heavy-ion collisions



$m_c \sim 1.3$ GeV, $m_b \sim 4.2$ GeV

b bottom quark

c charm quark

quark or gluon jet

thermalized QGP

<0.01fm

<0.07fm

~0.6fm

~5 fm

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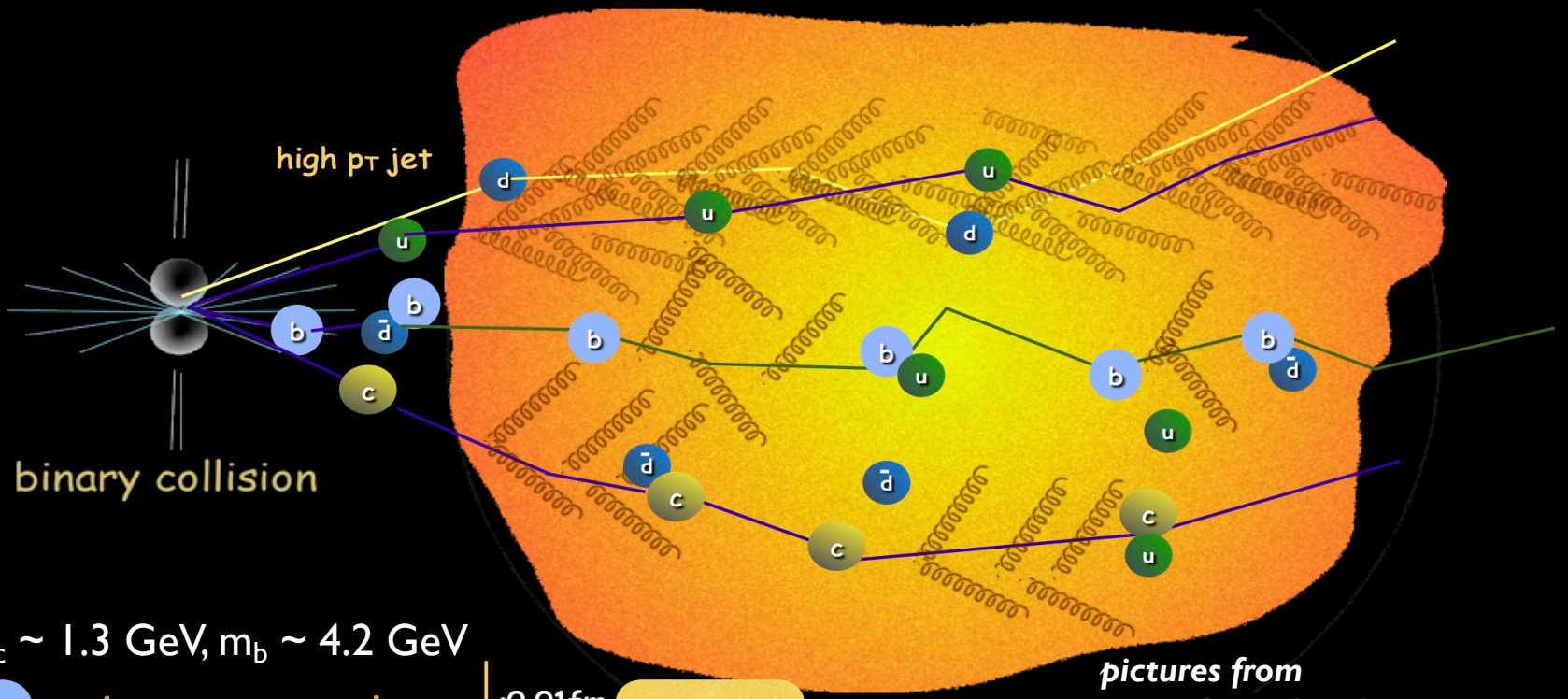

$m_c \sim 1.3$ GeV, $m_b \sim 4.2$ GeV

b bottom quark

c charm quark

quark or gluon jet

thermalized QGP

D meson

B meson

<0.01fm

0.4 fm

<0.07fm

1.5 fm

~20 fm

~0.6fm

~5 fm

dissociation, coalescence,drag

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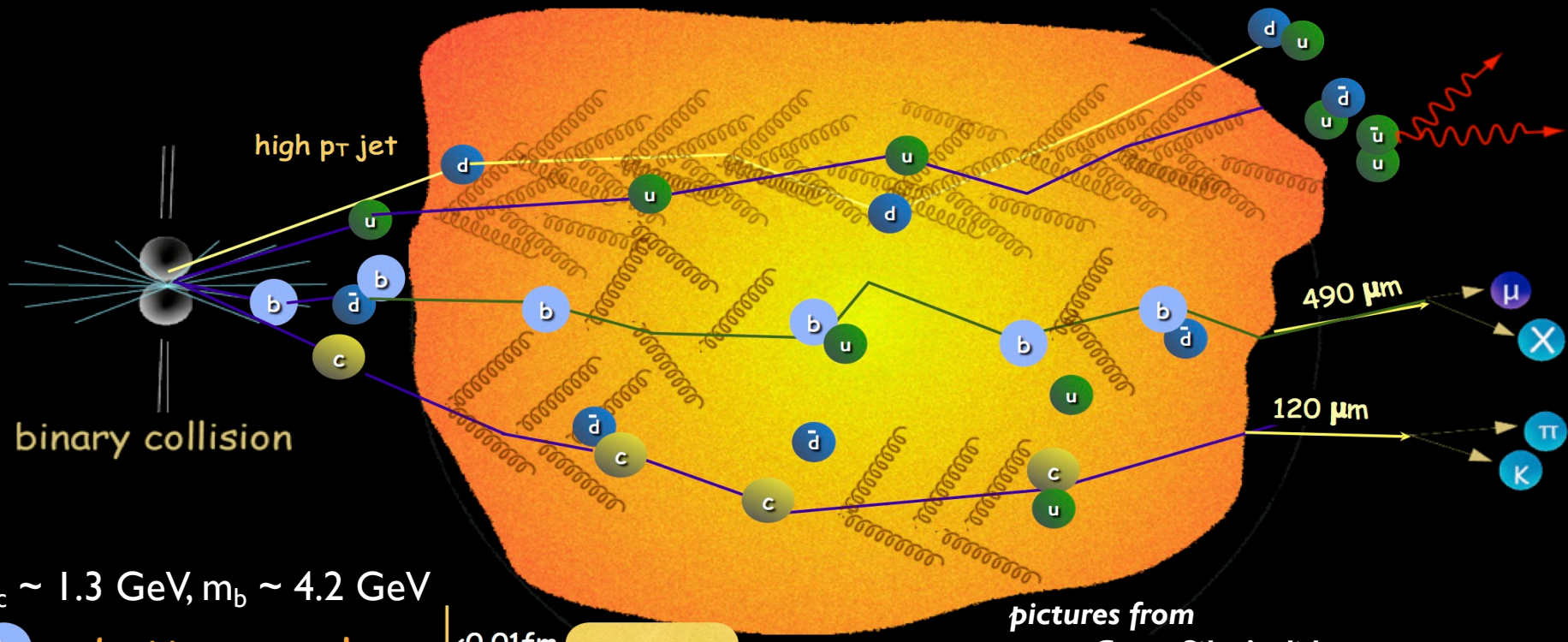

m_c ~ 1.3 GeV, m_b ~ 4.2 GeV

b bottom quark

c charm quark

quark or gluon jet

thermalized QGP

c $\bar{d}$ D meson

b $\bar{d}$ B meson

<0.01fm 0.4 fm

<0.07fm 1.5 fm

~20 fm decay

~0.6fm ~5 fm

dissociation, coalescence,drag decay

dissociation, coalescence,drag decay

pictures from
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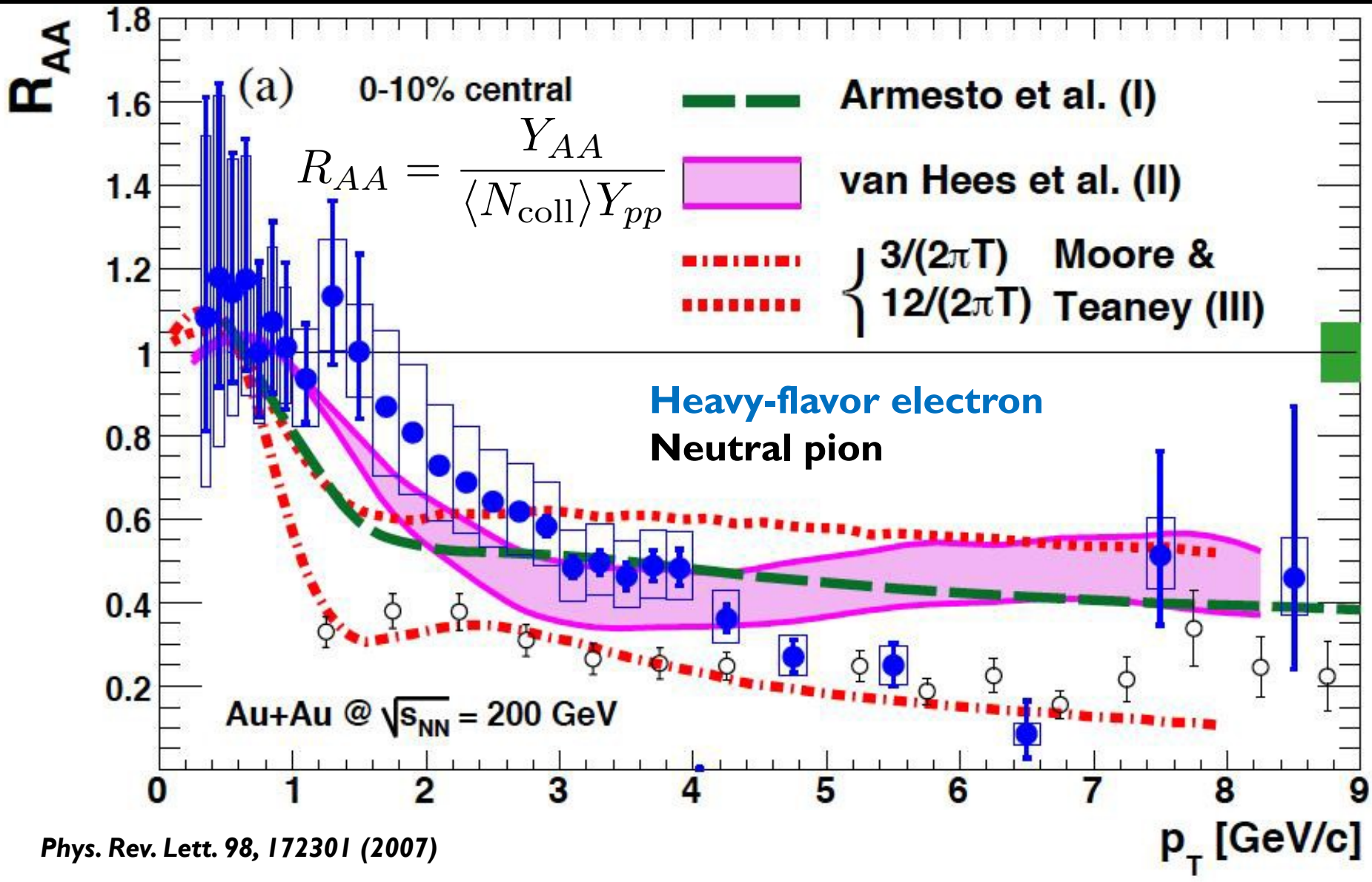
A. Adil, I. Vitev, PLB649 (2007) 139

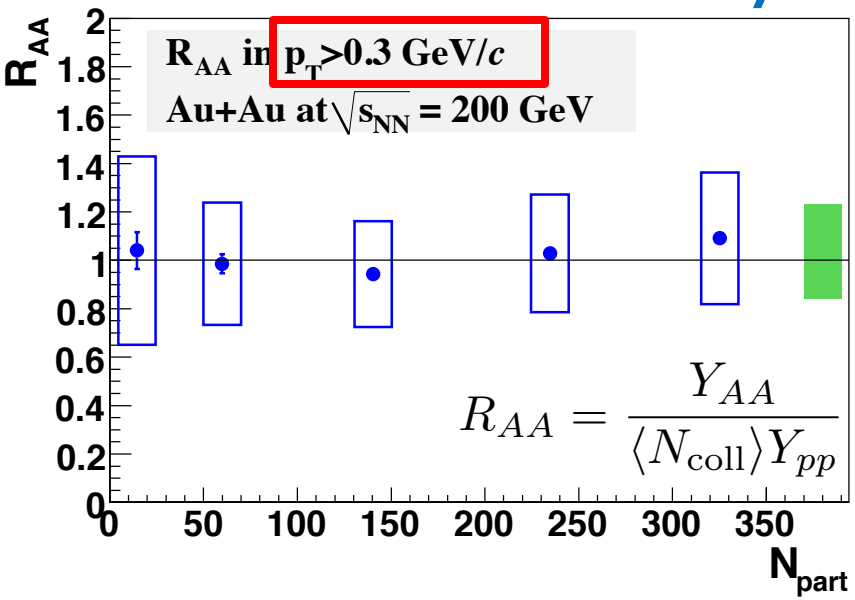
Heavy quark production in central Au+Au collisions

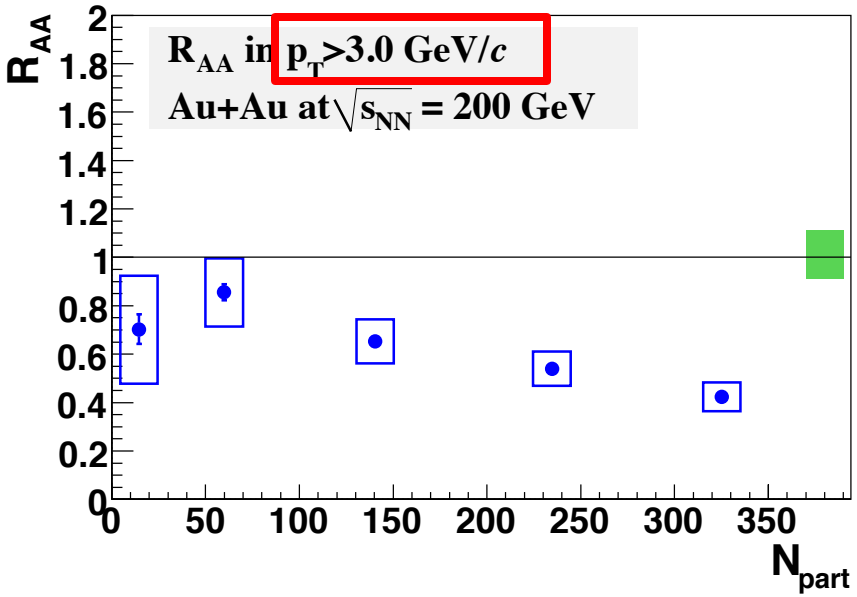


Phys. Rev. Lett. 98, 172301 (2007)

Heavy quark production in central Au+Au collisions

Heavy-flavor electron

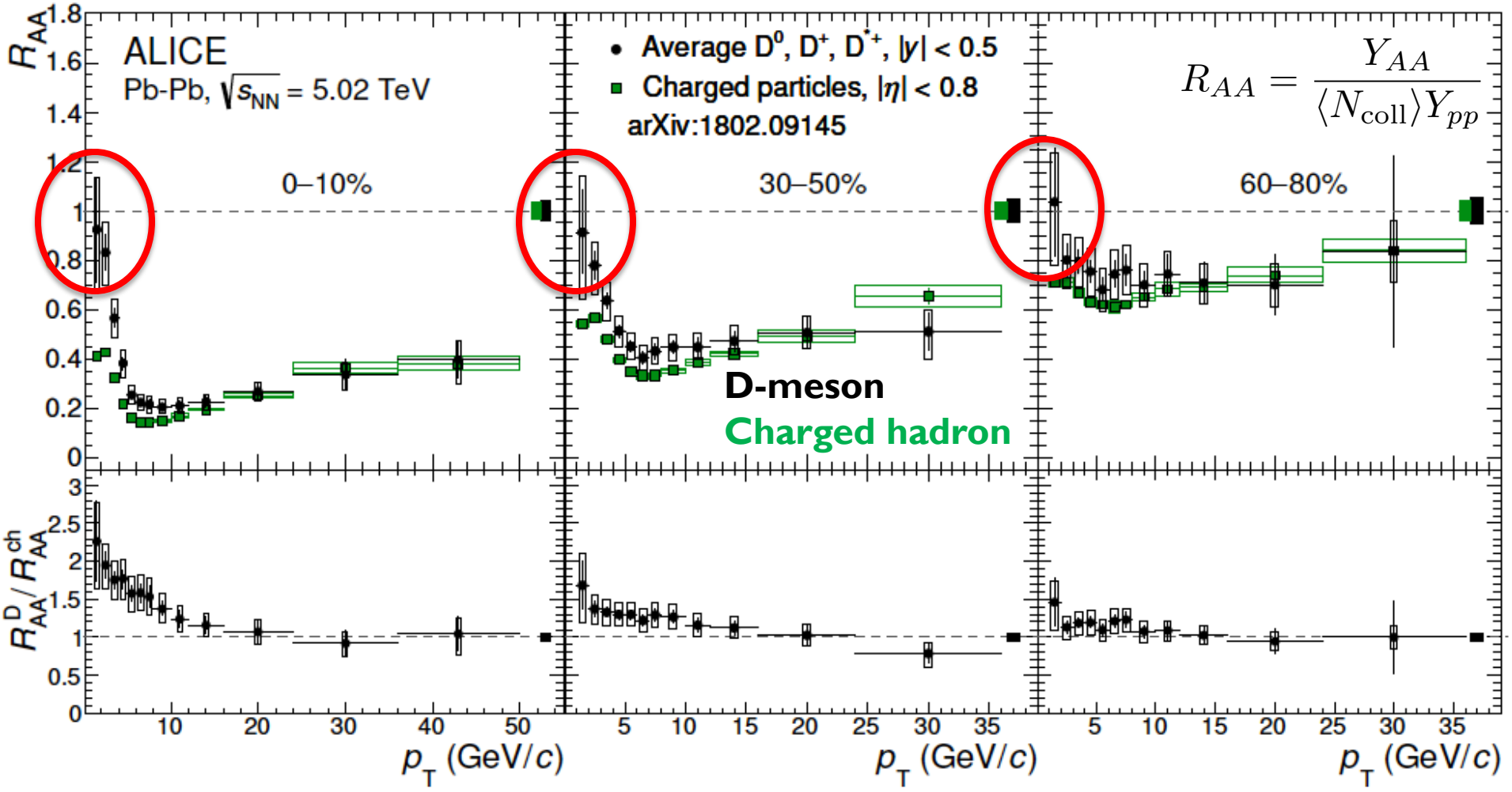




Phys. Rev. C 84 044905 (2011)

- Centrality dependent modification is only seen at p_T>3 GeV/c
- Binary scaling looks working for heavy quarks production at RHIC

Heavy quark production in Pb+Pb collisions



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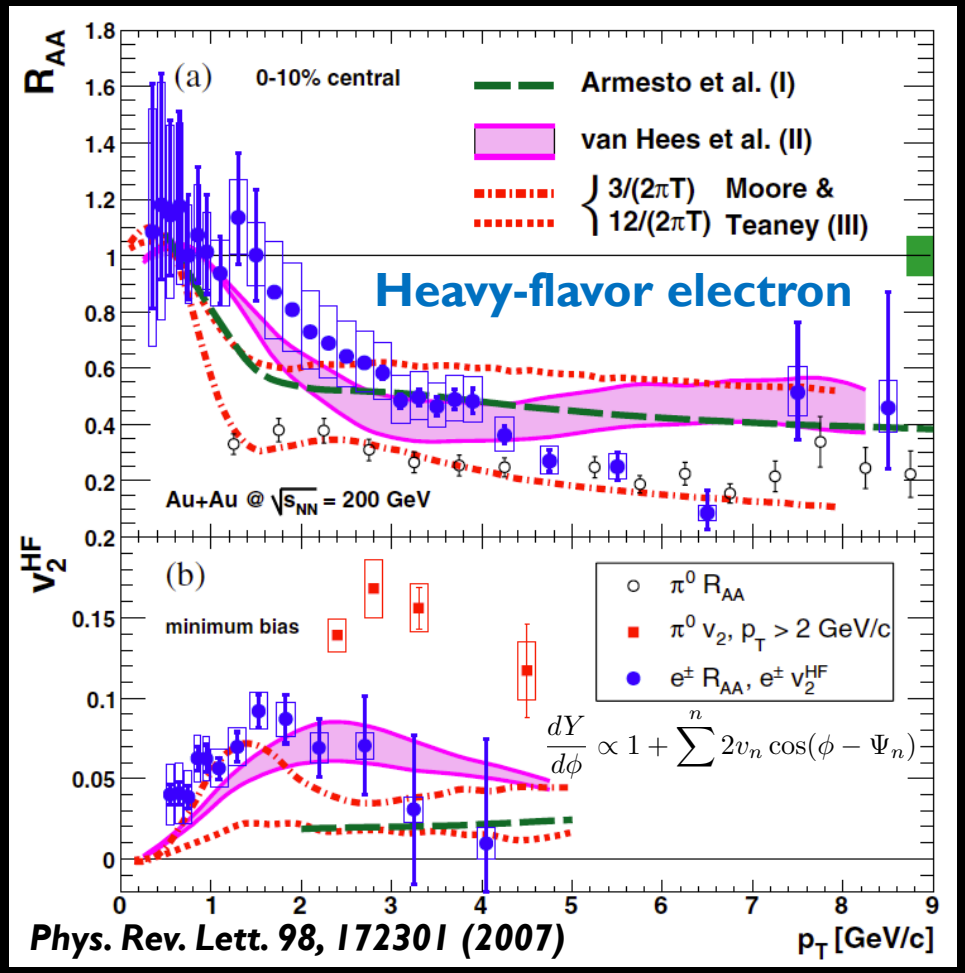
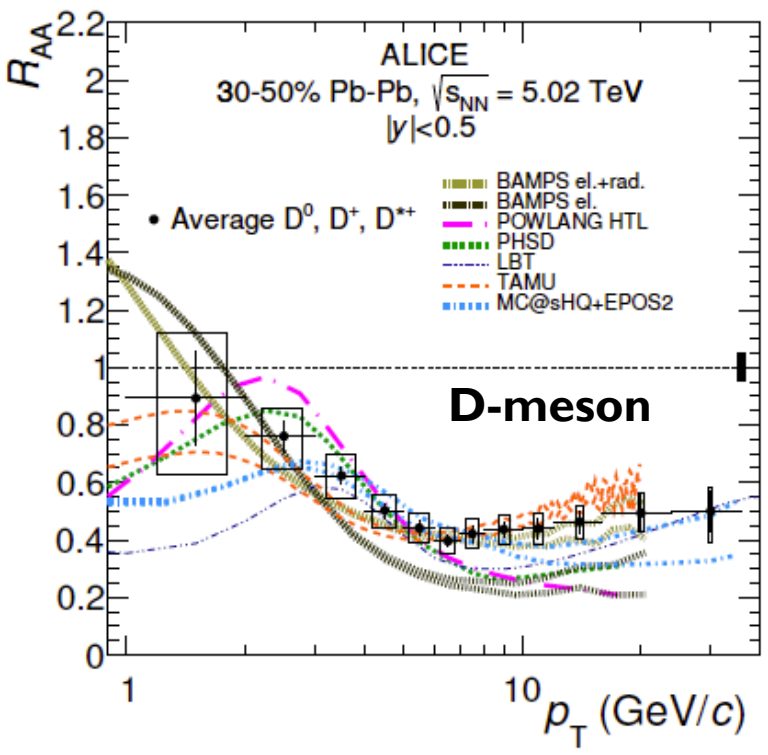
- Similar at the LHC
  - Suppression at high p_T
  - RAA ~ 1 at very low p_T

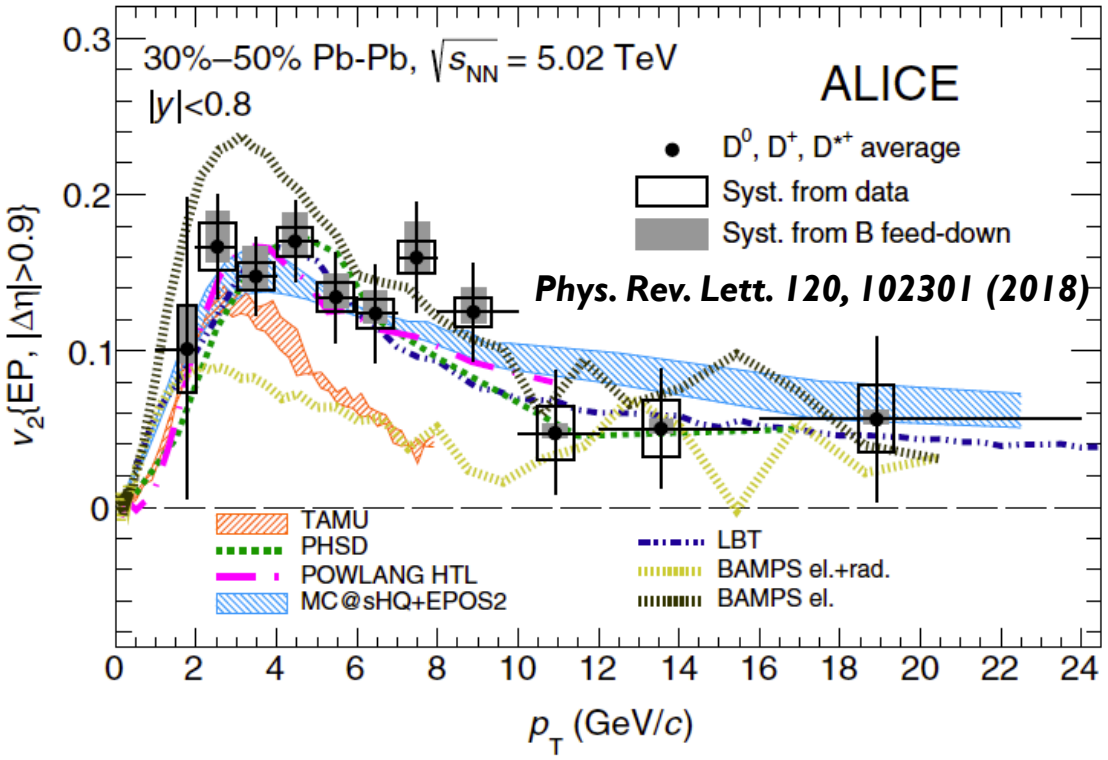
R_{AA} and flow in large systems



- Electrons from heavy-flavor decays in central Au+Au collisions at 200 GeV
  - Strong suppression in high p_T
  - Significant v_2
  - A number of models can reproduce both R_{AA} and v_2 simultaneously

R_{AA} and flow in large systems





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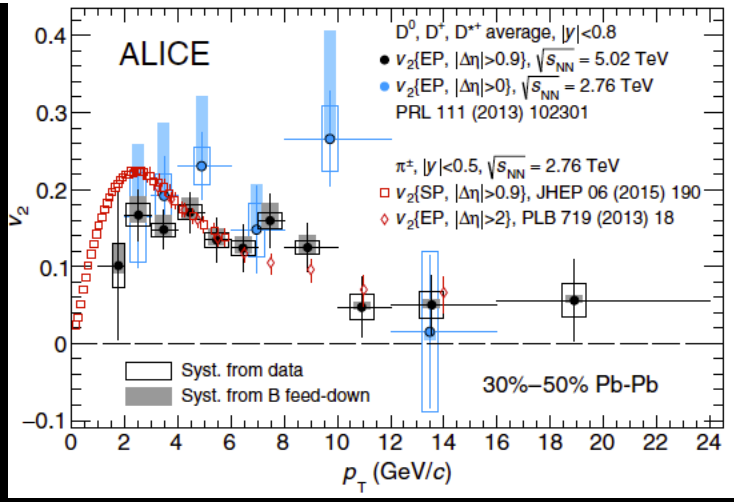
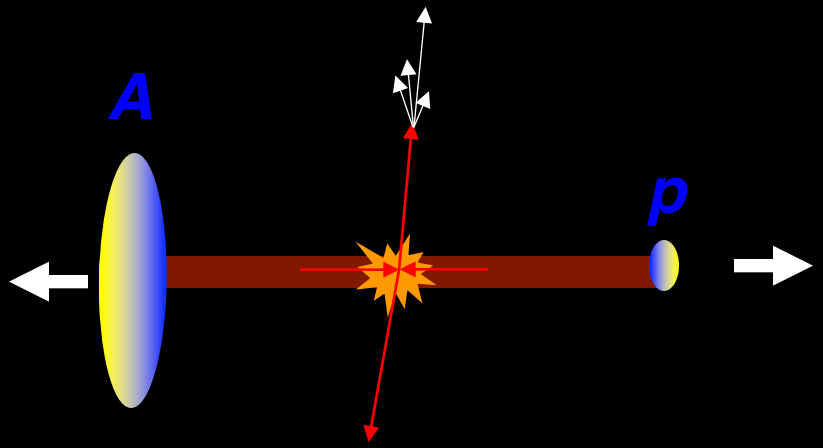
- Similar results at the LHC

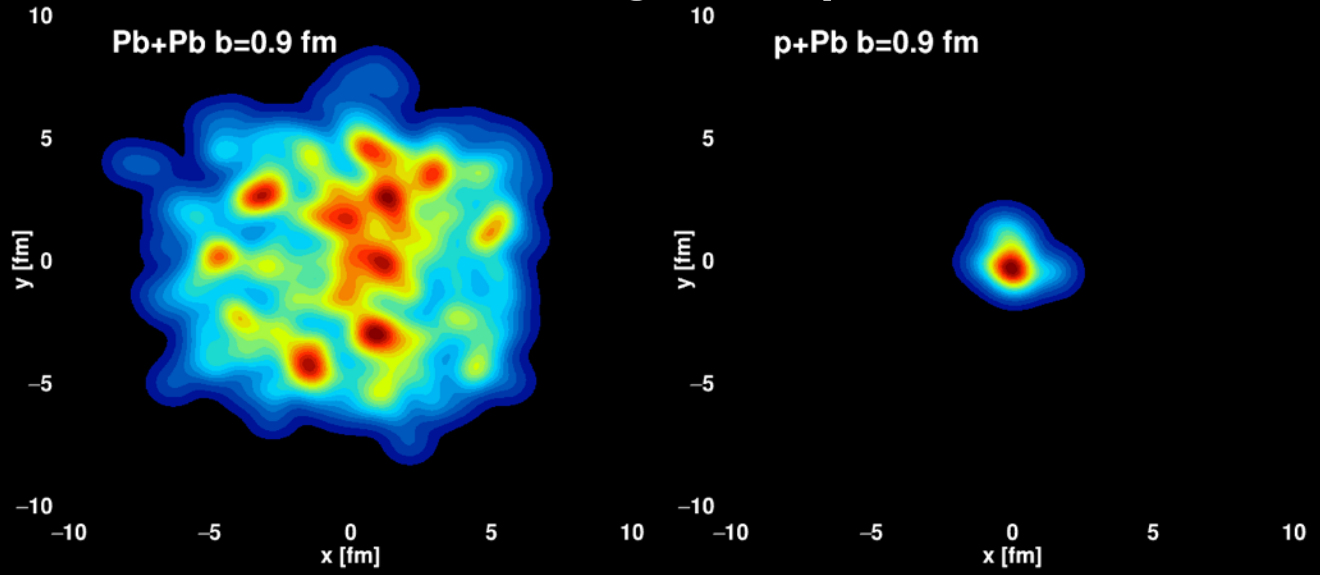


Control experiment

What's happened in p+A collisions ?

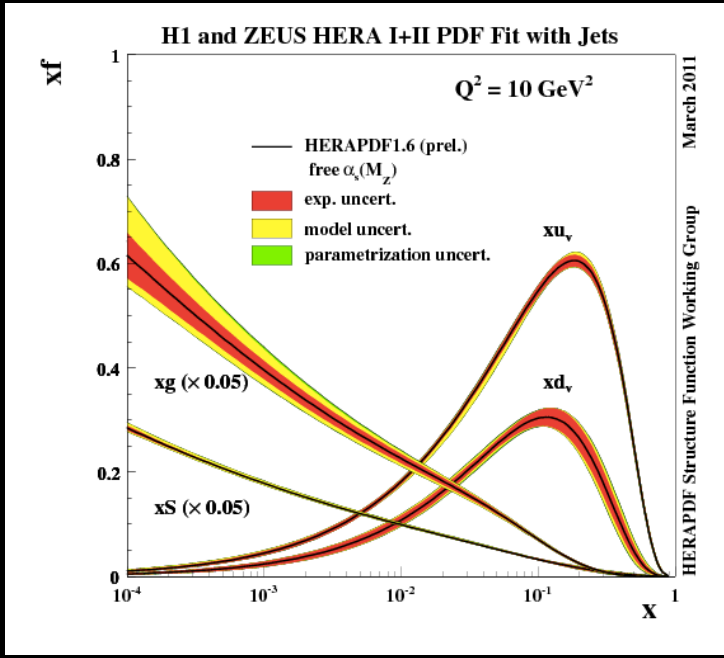


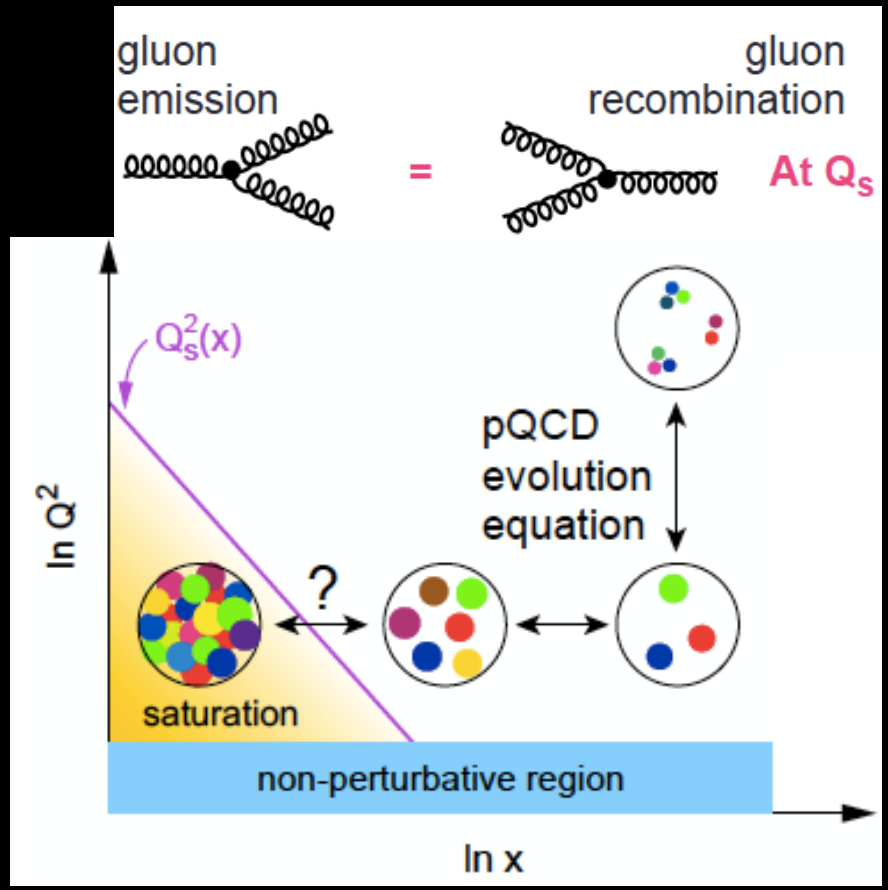
Initial geometry



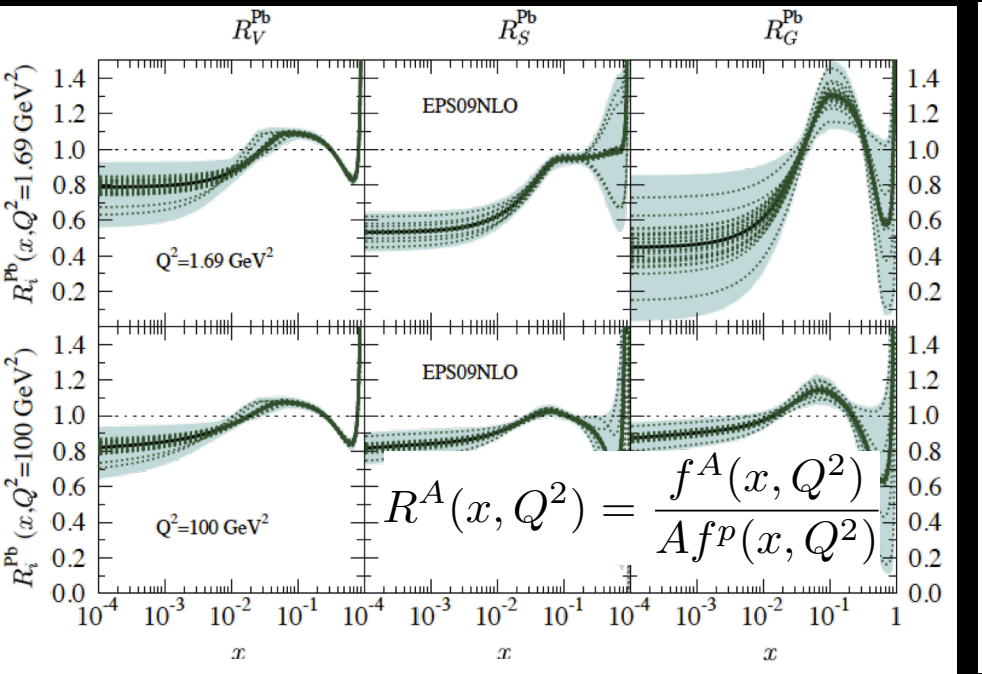
Cold Nuclear Matter effects
Gluon saturation

- 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

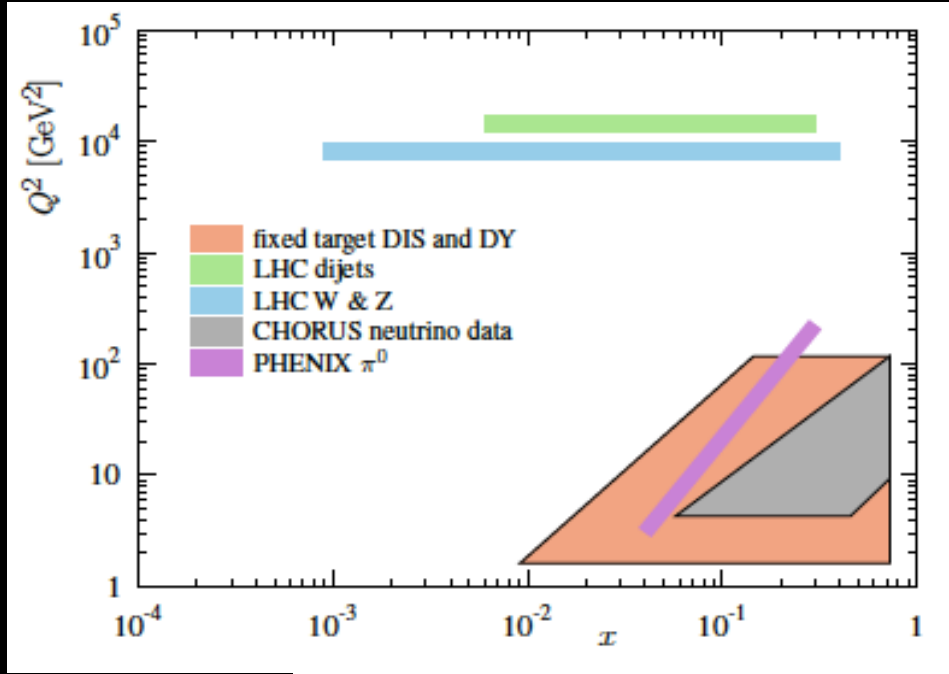




Cold Nuclear Matter effects
Modification of nPDFs (Parameterization)



EPS09 parameterization
arXiv:0902.4154



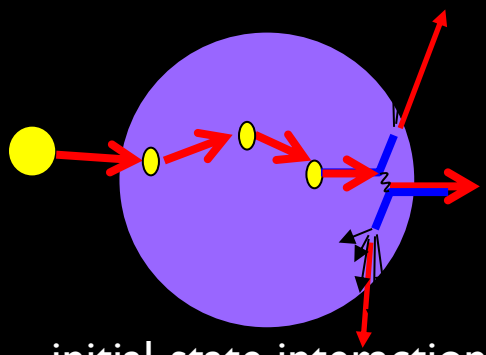
Data used EPPS16 parameterization
arXiv:1612.05741

- 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

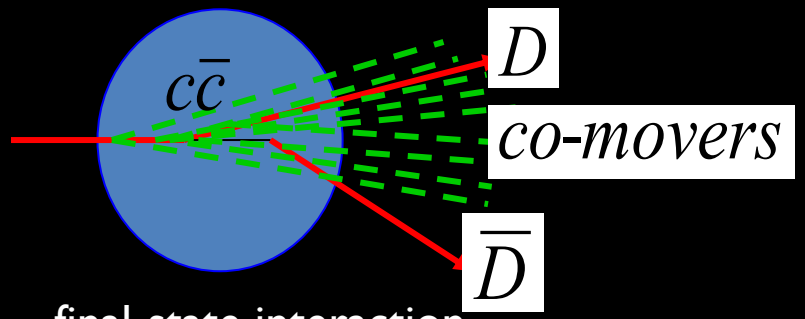
Cold Nuclear Matter effects
Initial-state *energy loss & Breakup of Quarkonia*

- Initial-state energy loss and k_T
  - Partons can loose their energy before hard scattering
  - Partons can have small transverse momentum

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



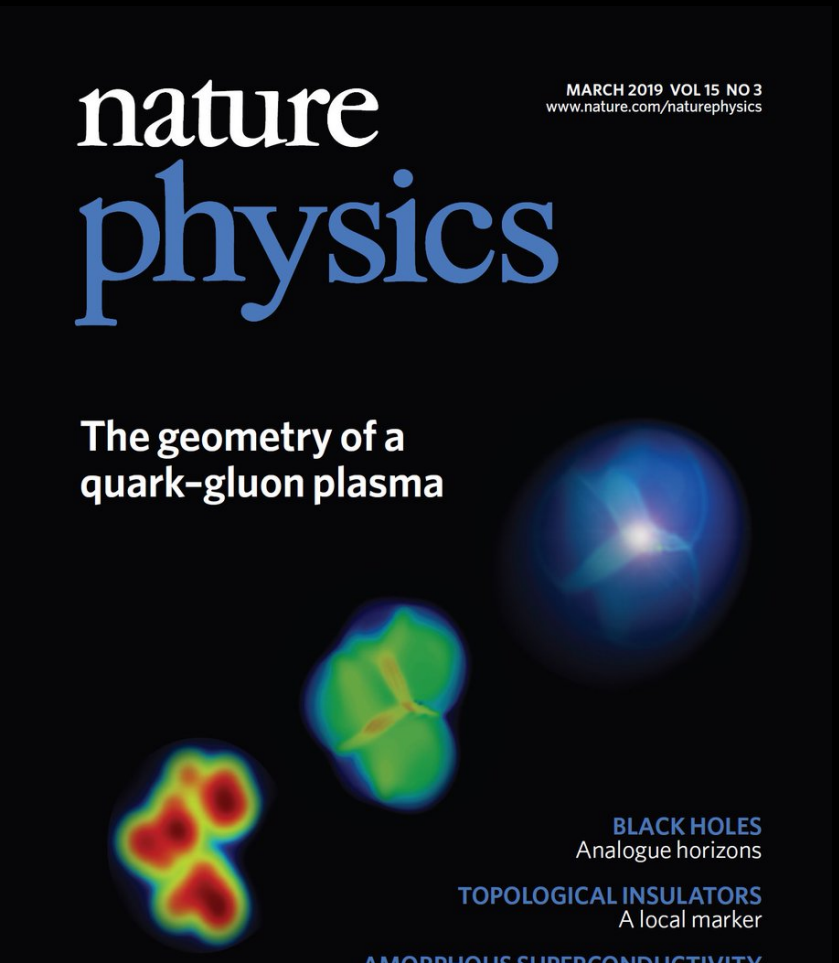
initial-state interaction

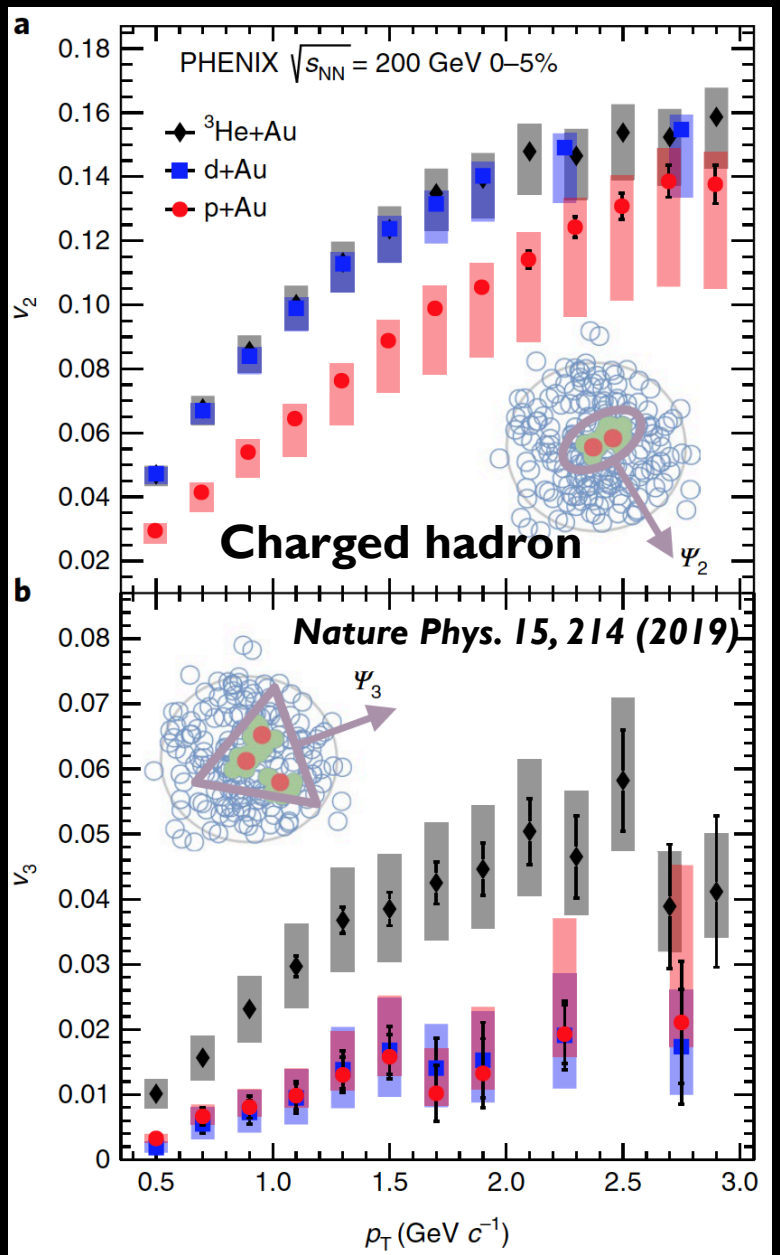


final-state interaction

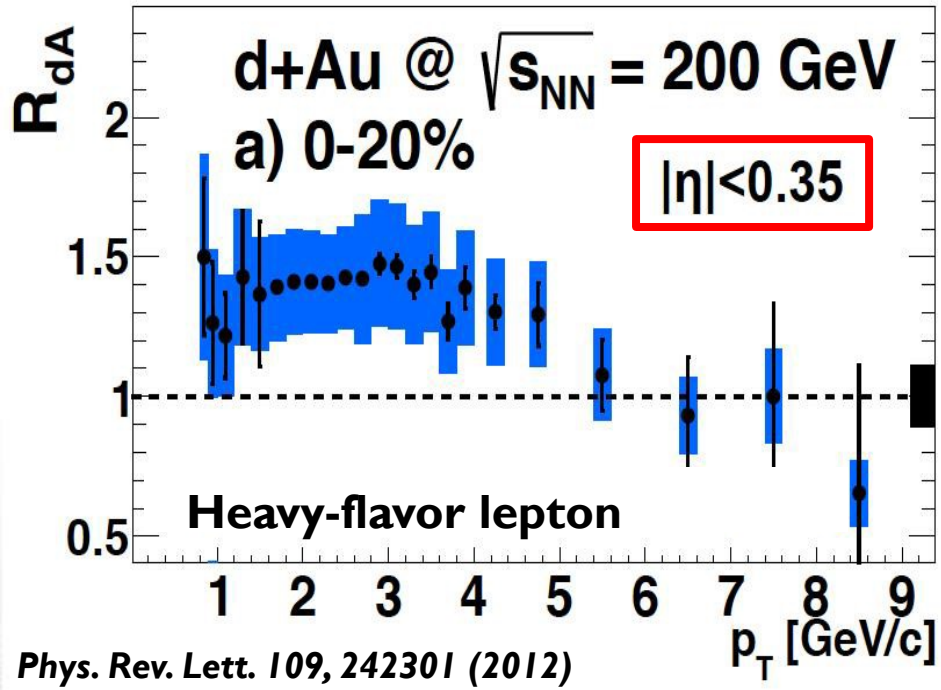
A hint of Quark-Gluon-Plasma

- Observed significant amount of v2 in various small collision systems
  - QGP in small systems?
  - Any other origin of the anisotropy?

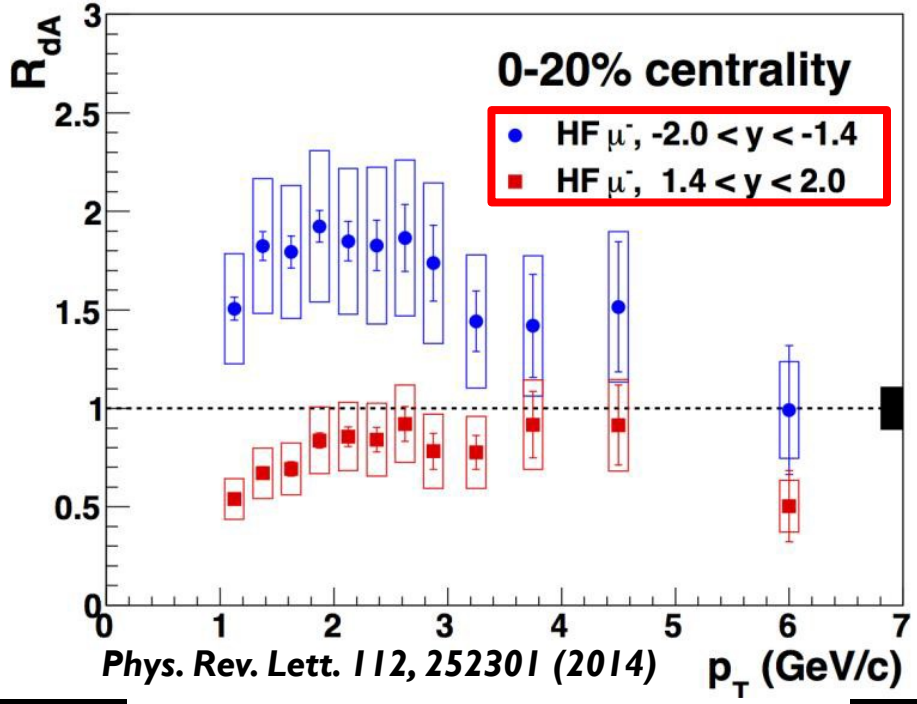




Heavy quark production in small system at RHIC

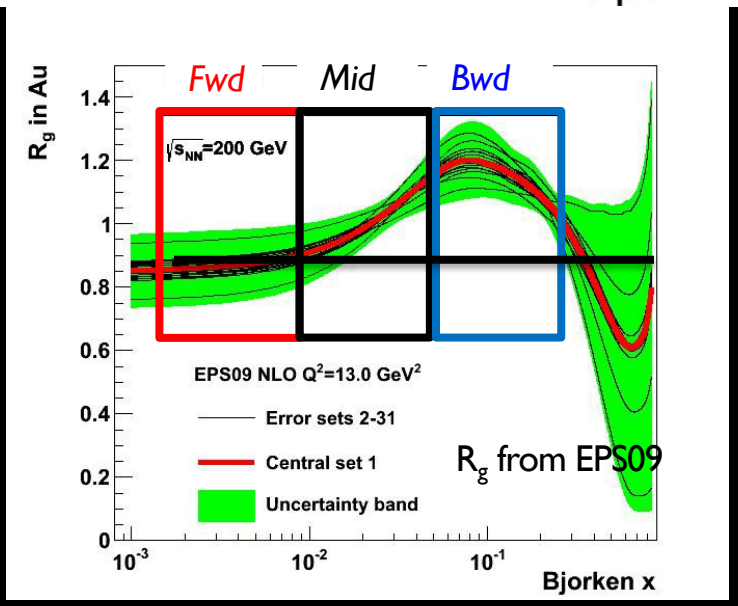


Phys. Rev. Lett. 109, 242301 (2012)



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

- A clear rapidity-dependent modification was observed in d+Au collisions at RHIC



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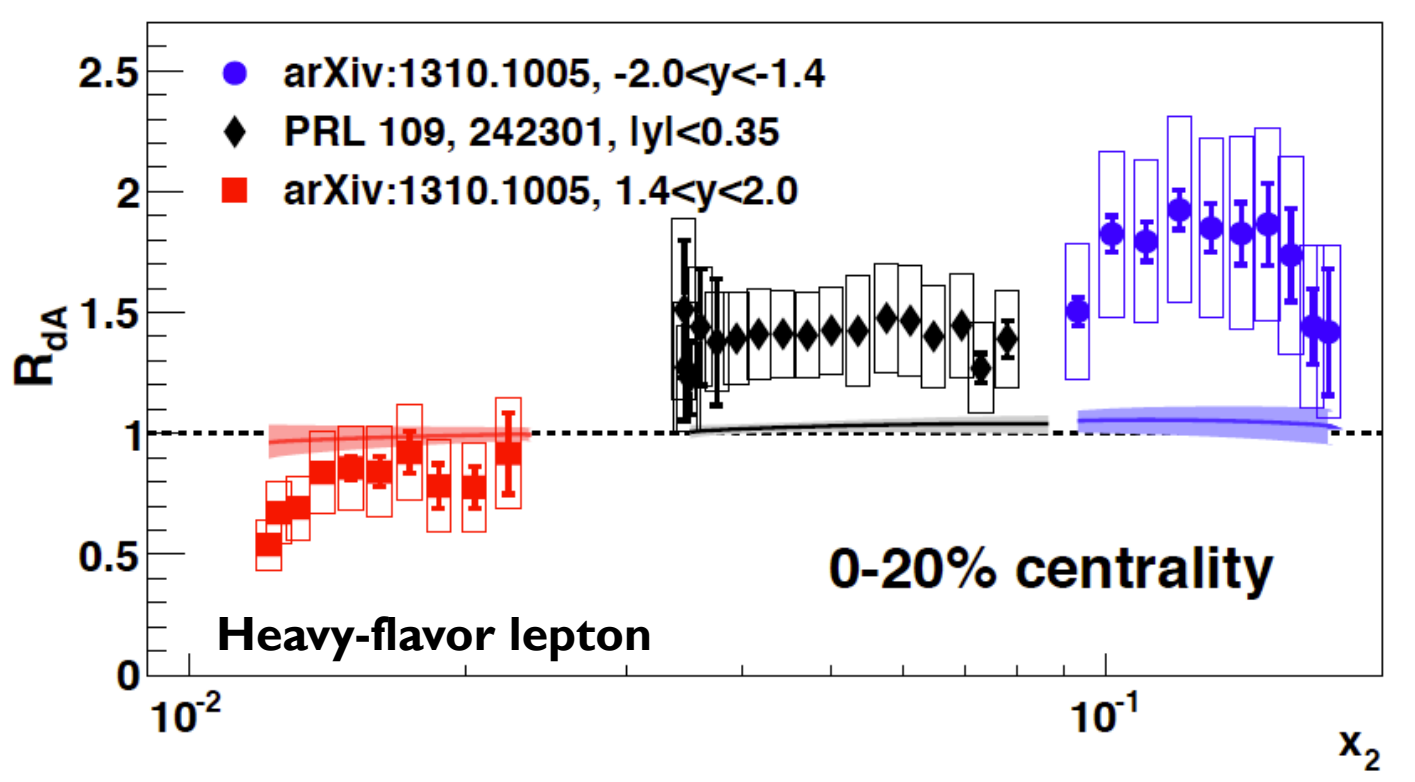
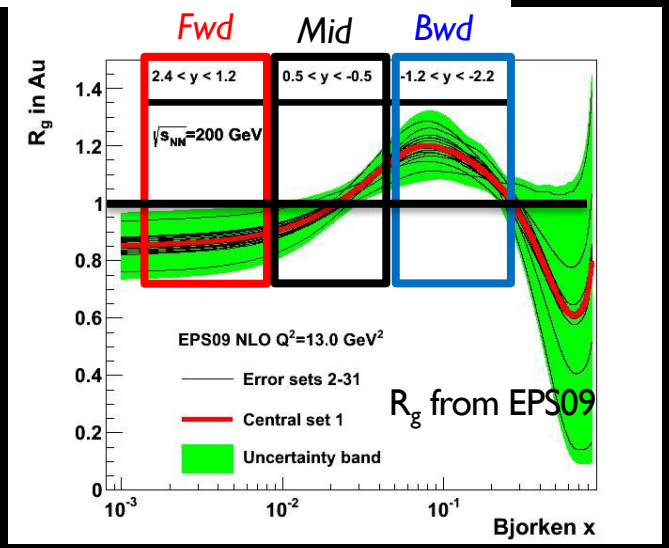


- nPDF only can not describe the rapidity-dependent modification



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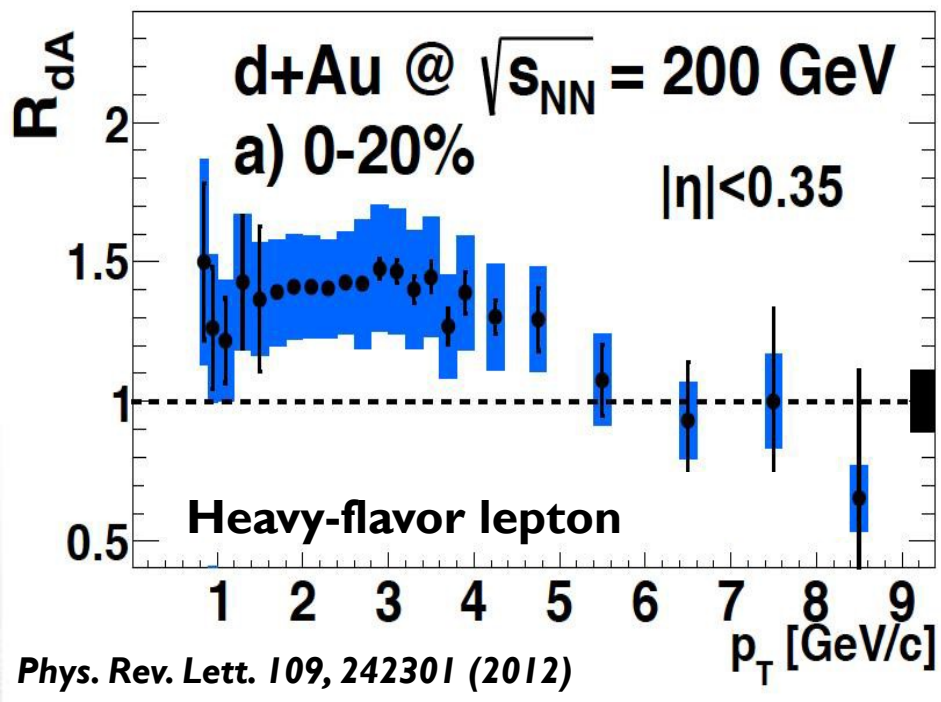
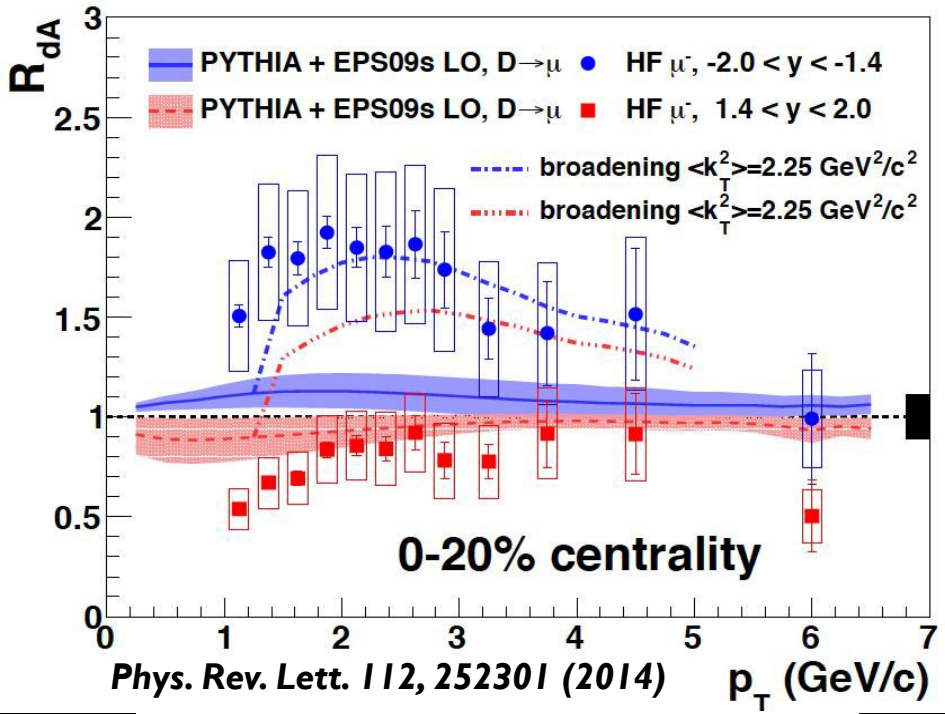
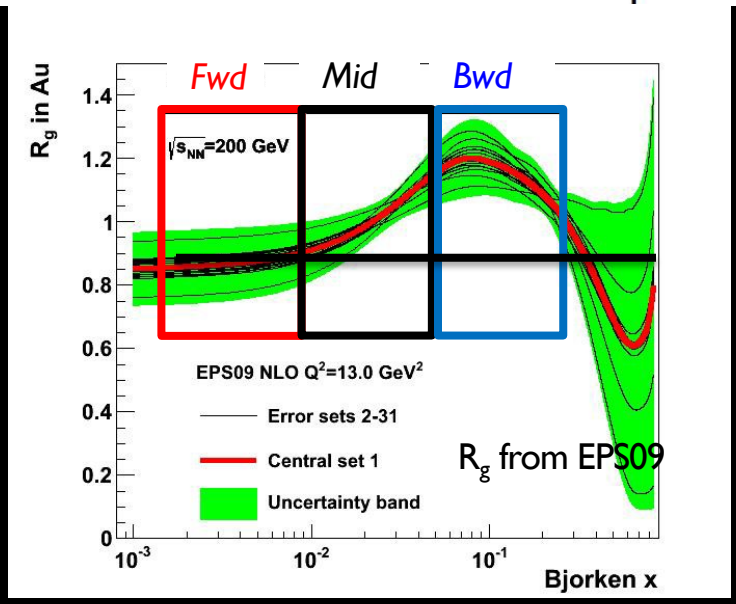
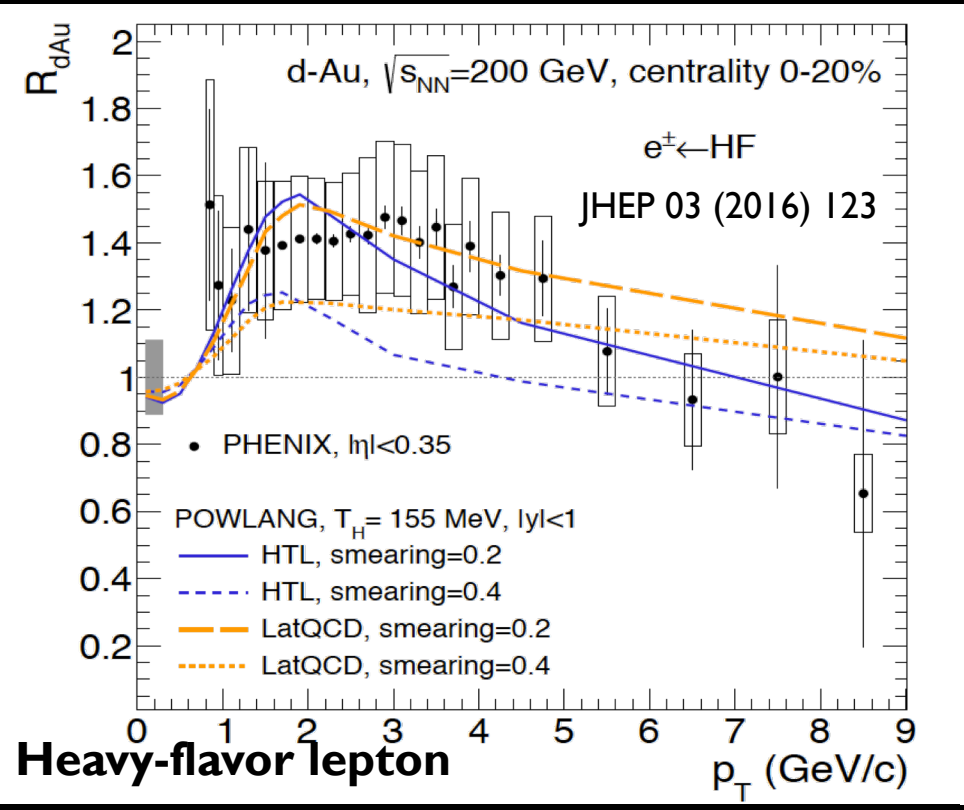


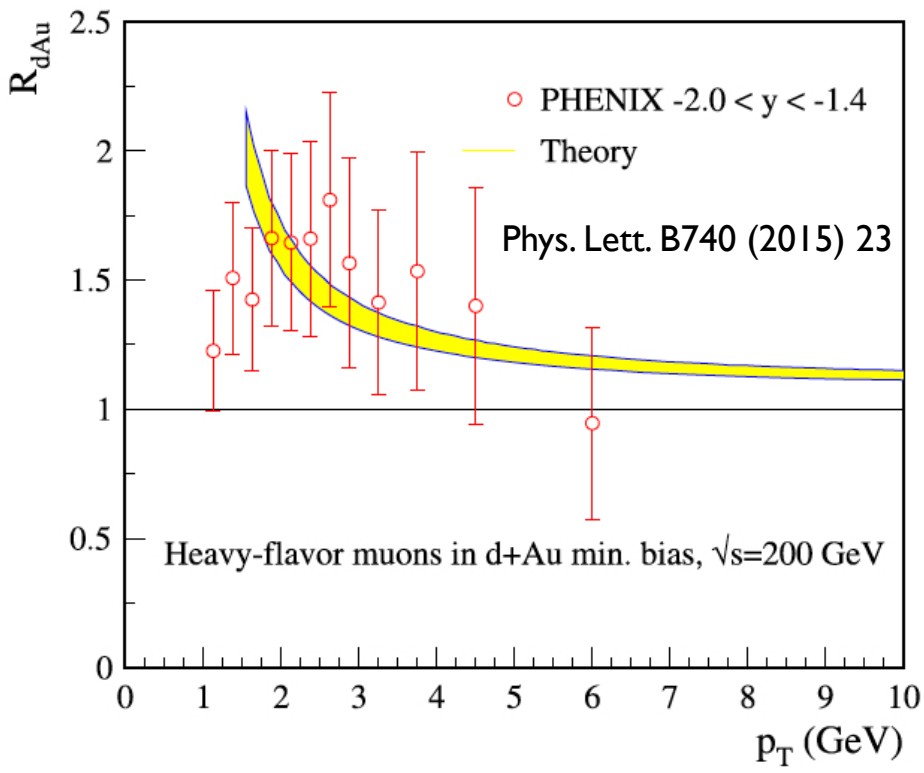


- Initial k_T broadening + nPDF modification still can not describe the data



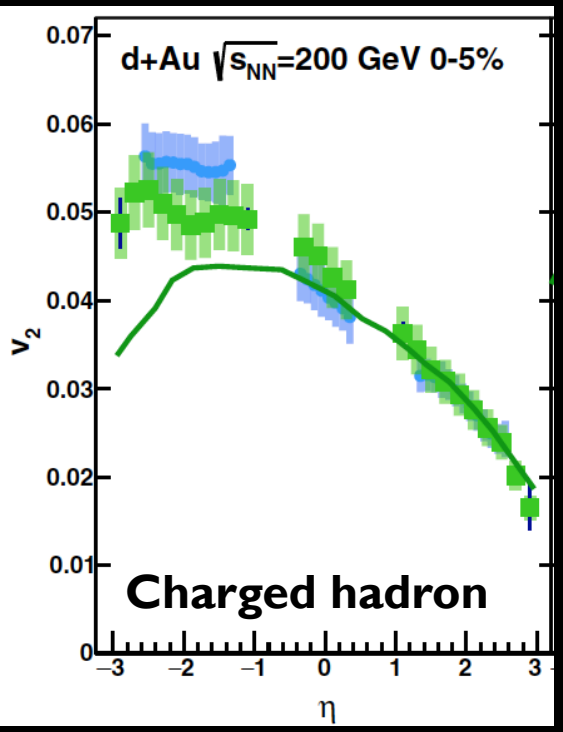
Heavy quark production in small system at RHIC

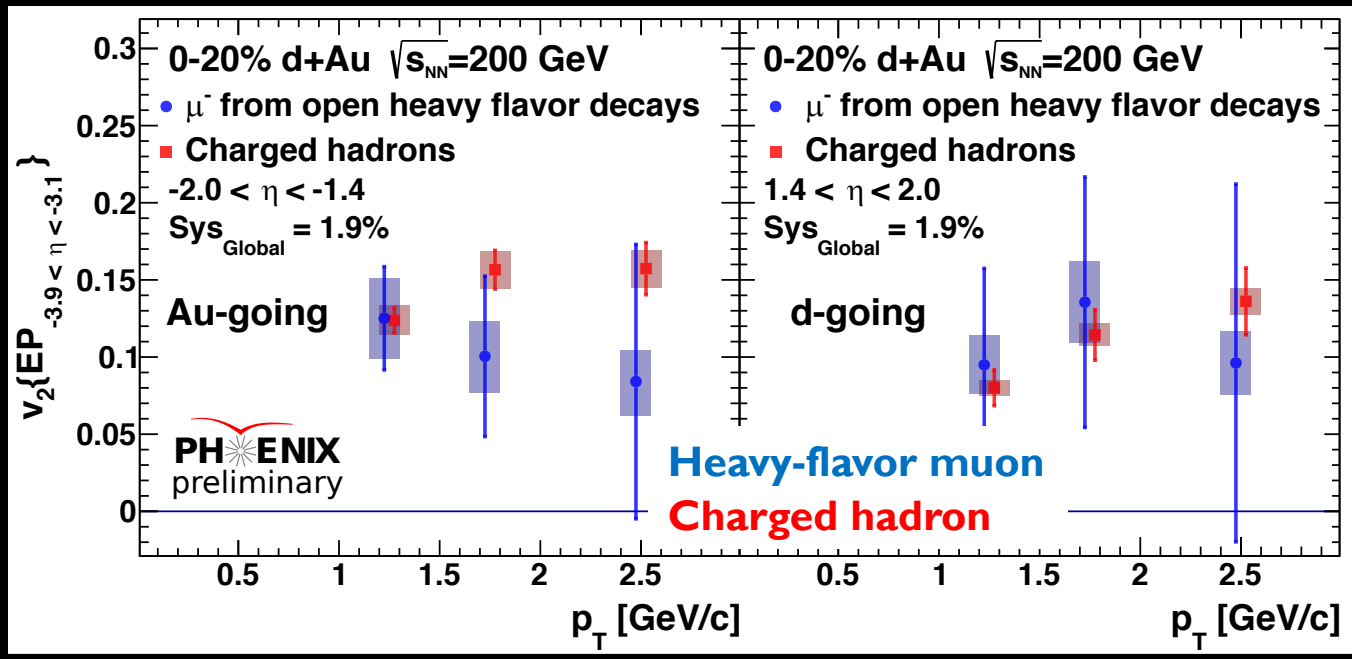




- nPDF model + initial k_T + **short time-scale thermalized medium effects**
- pQCD calculation considering **incoherent multiple scattering effects at final-state**

Heavy quark production in small system at RHIC

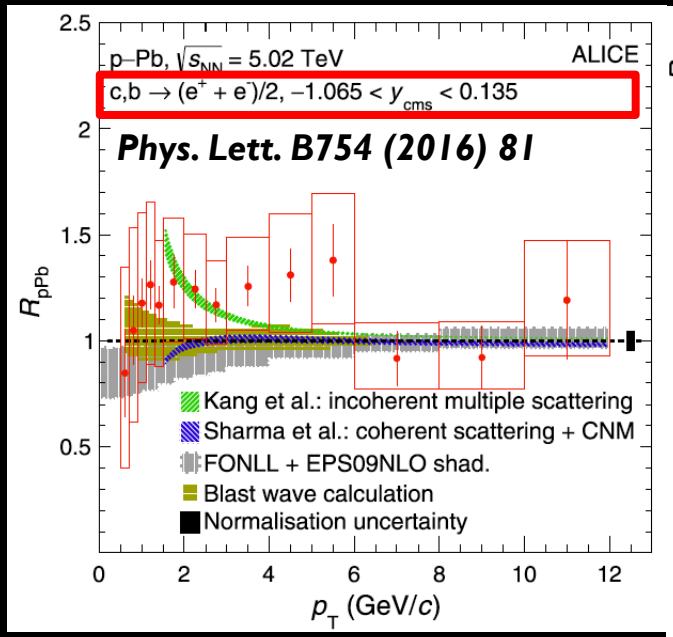


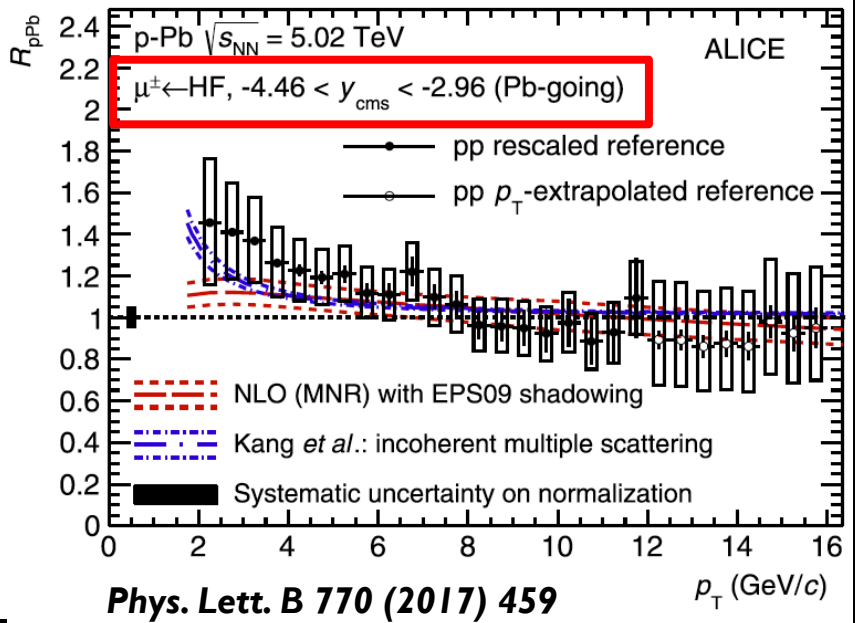


Phys. Rev. Lett. 121, 222301 (2018)

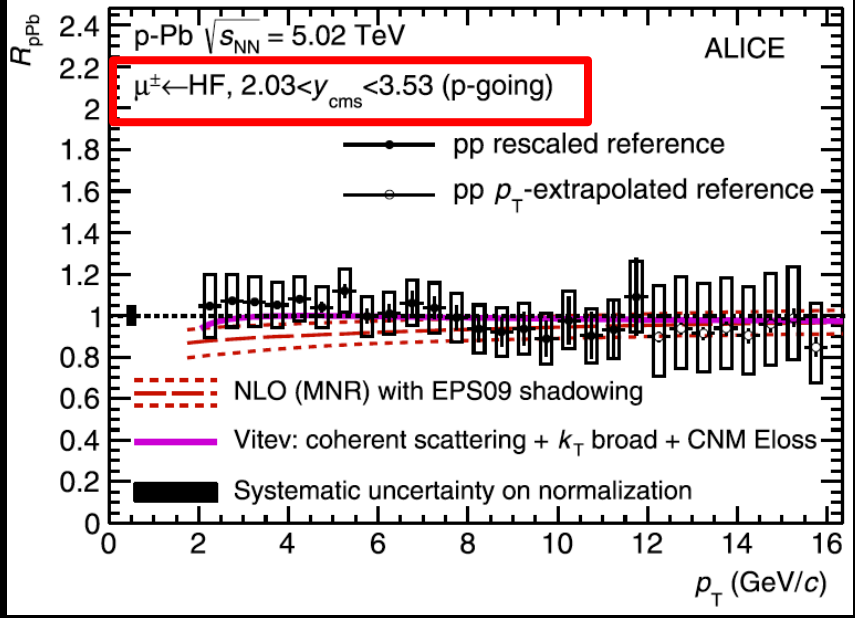
- Non-zero v_2 of muons from heavy-flavor decays (mostly charm) at forward and backward rapidity in d+Au collisions
- No model describing the non-zero v_2 and rapidity-dependent R_{pA} simultaneously

Heavy quark production in small system at the LHC



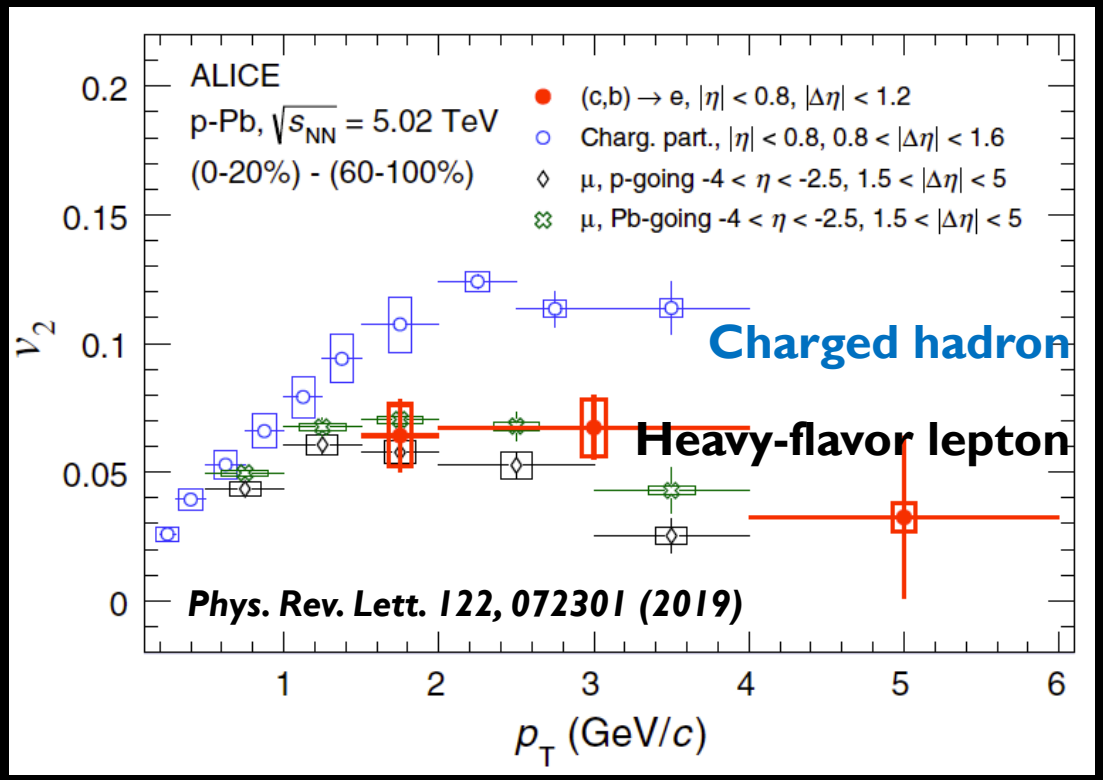


Heavy-flavor lepton



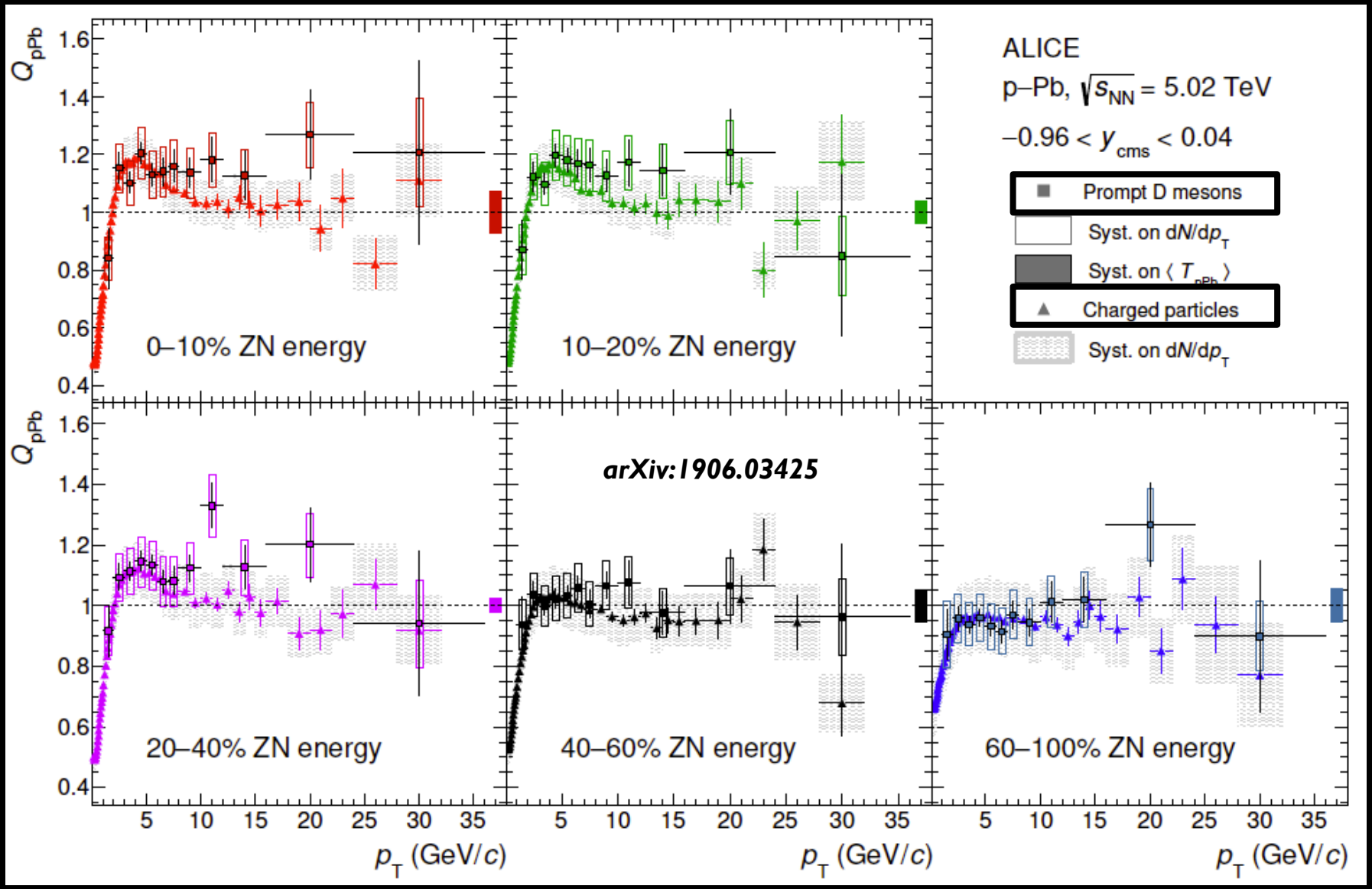
- Similar trend of modification of heavy-flavor lepton production in p+Pb collisions at the LHC

Heavy quark production in small system at the LHC



- Clear non-zero v_2 of heavy-flavor leptons in p+Pb collisions
- Quite different R_{AA} and v_2 trend observed in heavy-ion collisions

More precise recent measurements



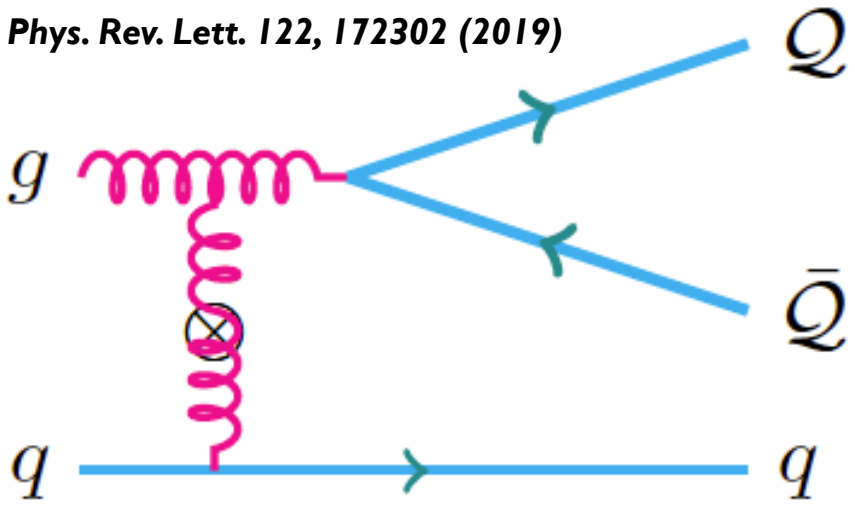
- ~10% modification of D-meson in 0-10% central p+Pb collisions

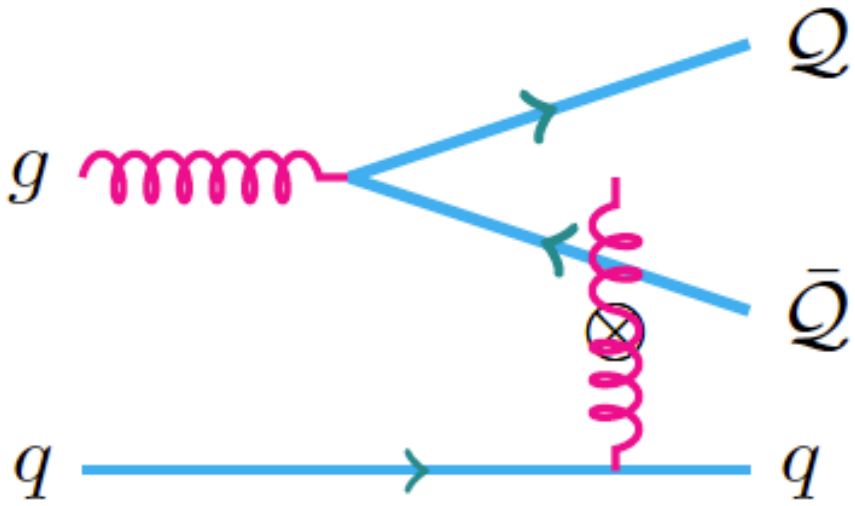
No clear indication of energy loss in p+A collisions

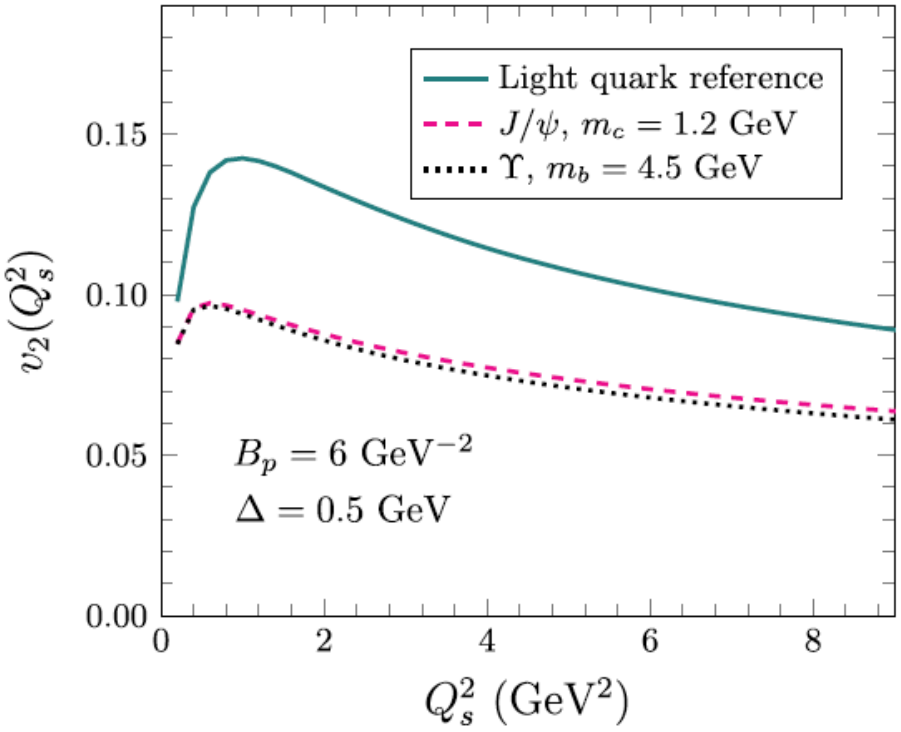
What's the origin of collective behavior in p+A collisions ?

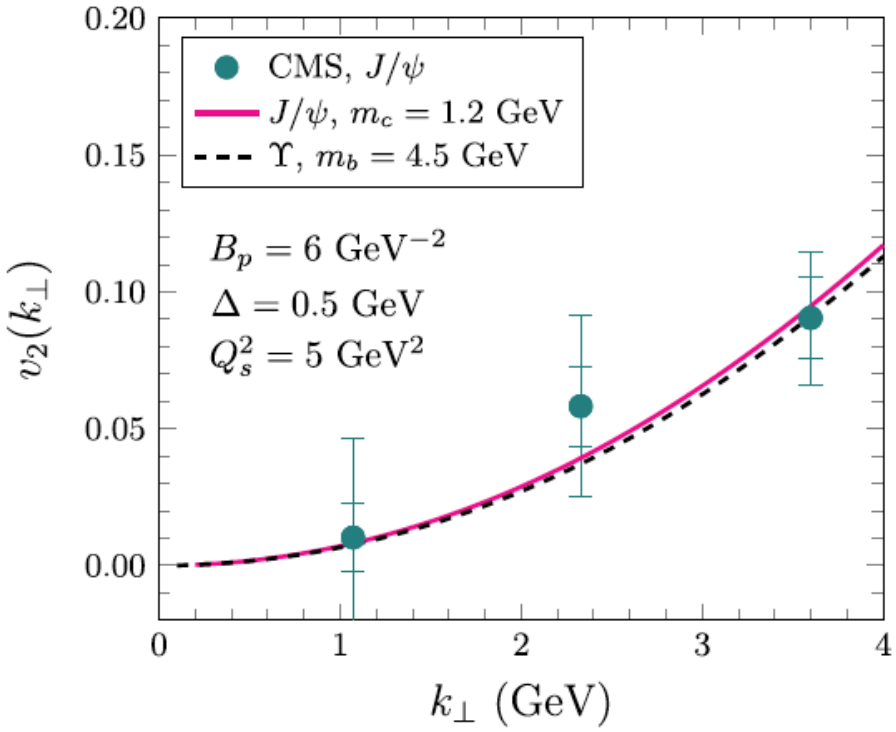
Initial-state correlation in CGC ?

Phys. Rev. Lett. 122, 172302 (2019)

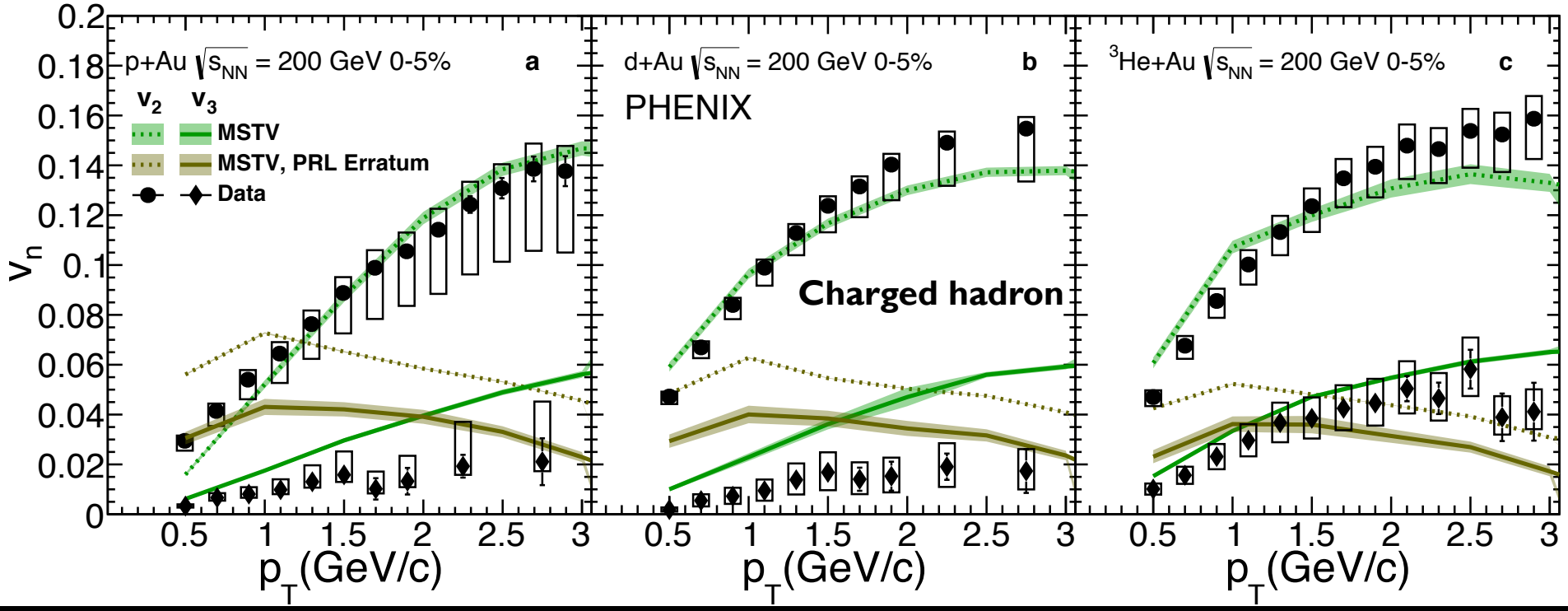








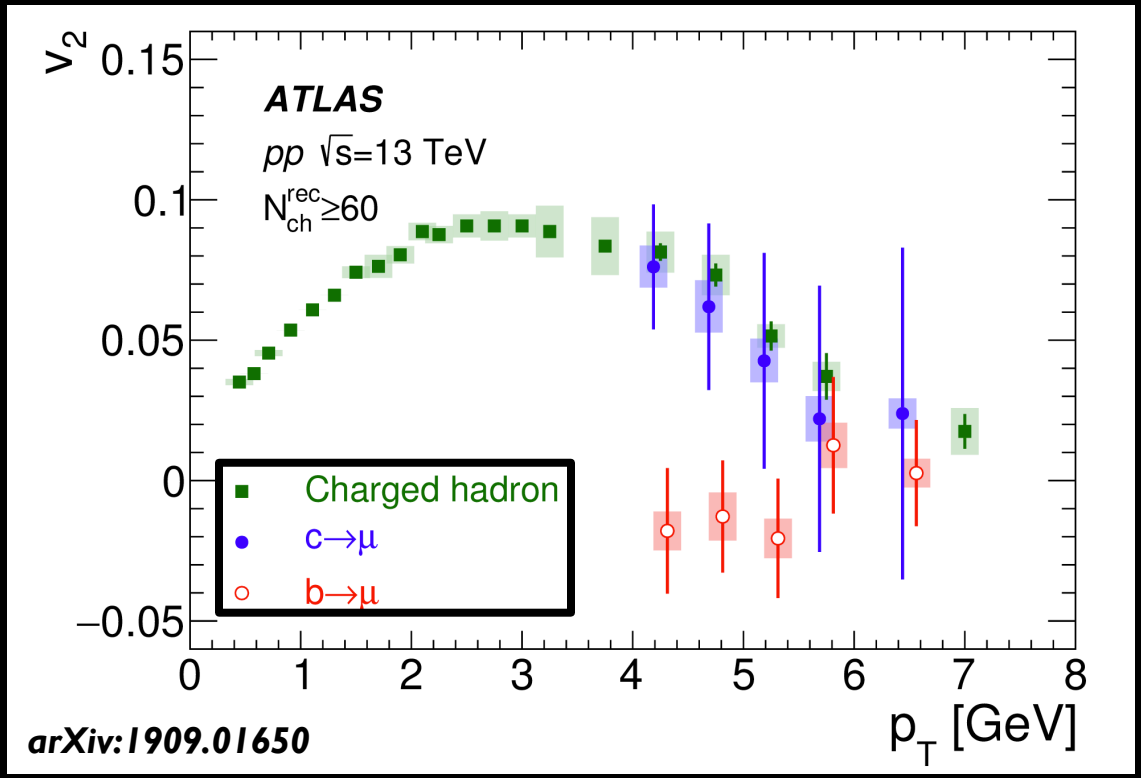
Initial-state correlation in CGC ?



- Failed to describe the data in p/d/^{3}He+Au collisions
- Further developments are on going

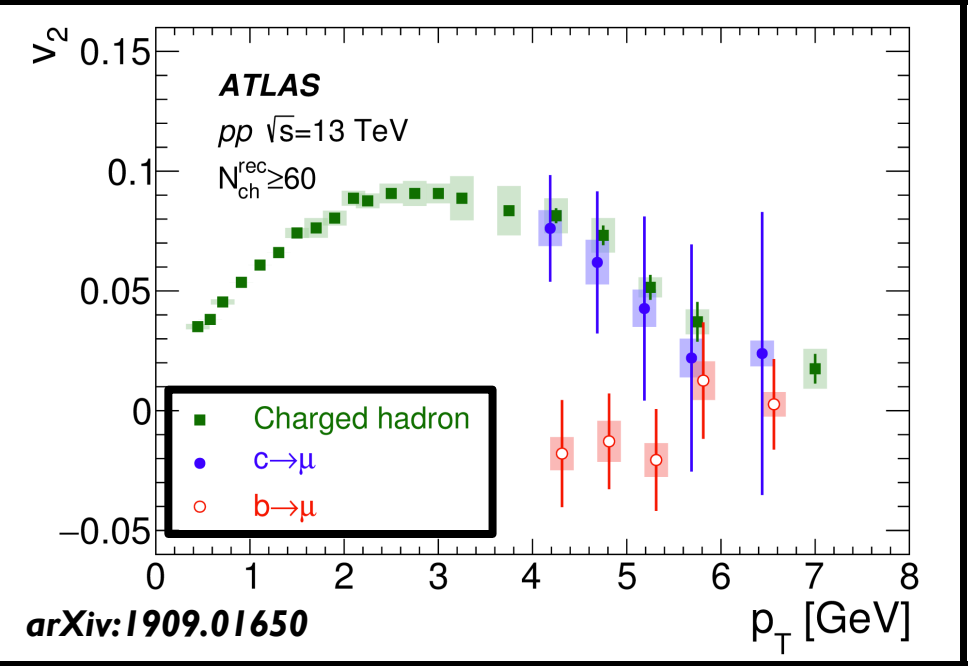
Can we turn off the flow signal ?

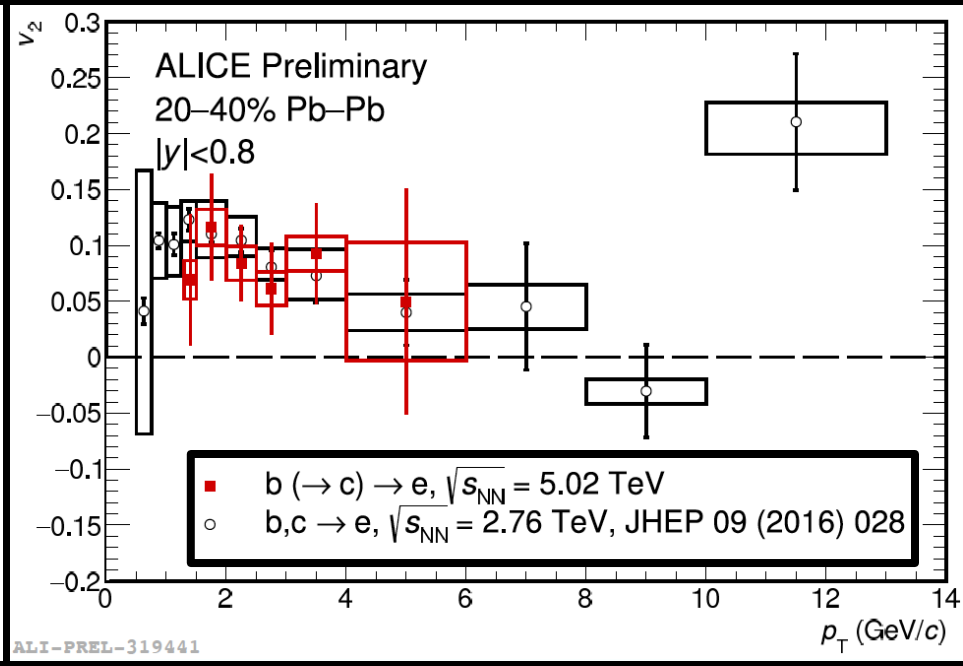
b-flow in p+p collisions



- Consistent with zero for muons from bottom decay in p_T>4 GeV/c

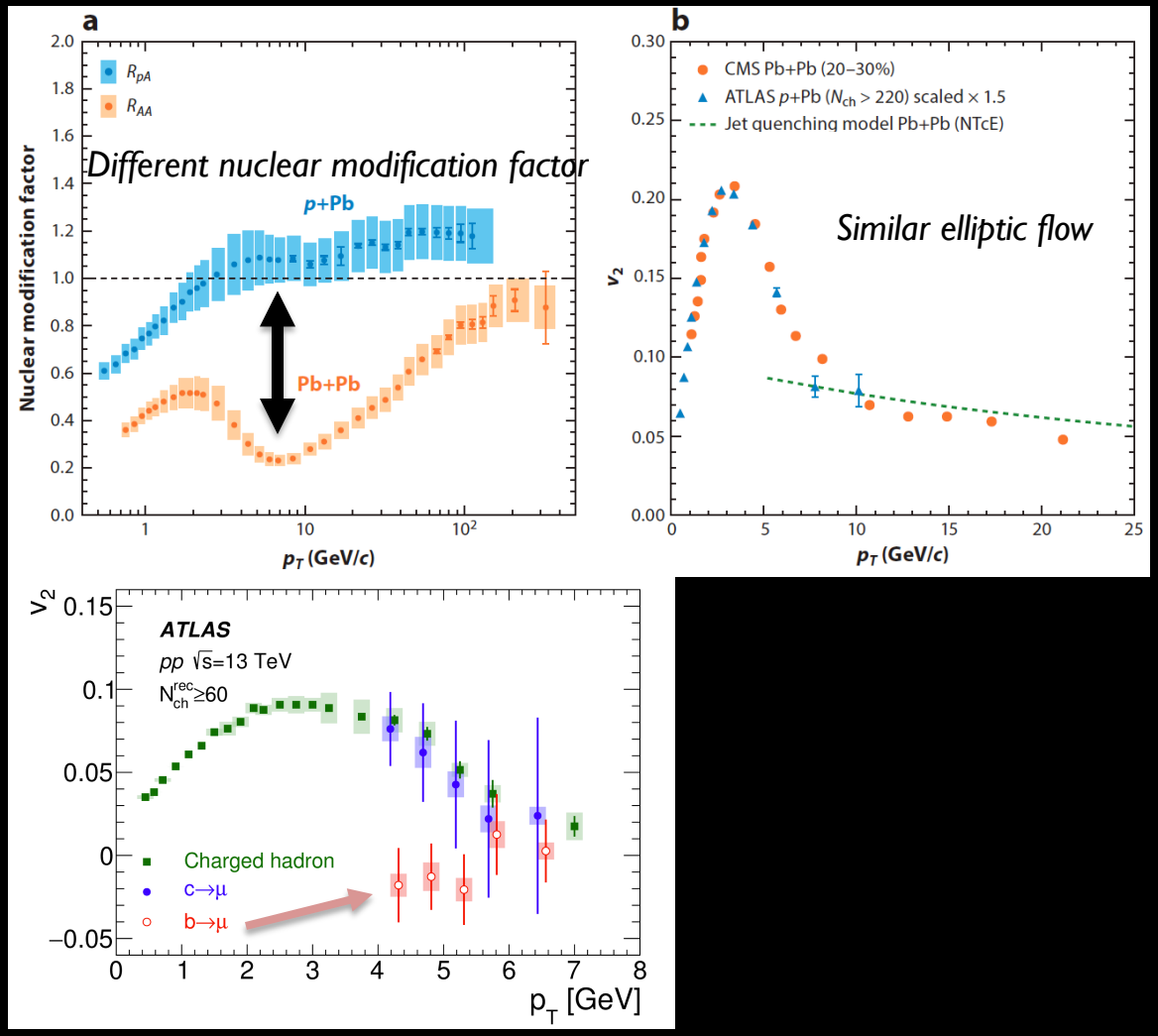
Further study in the near future





- Consistent with zero for muons from bottom decay in p_T>4 GeV/c
- Interesting measurements in the future
  - In p+Pb and Pb+Pb (Pb+Pb results will be presented in QM19)
  - At lower p_T (ALICE can do)

Summary

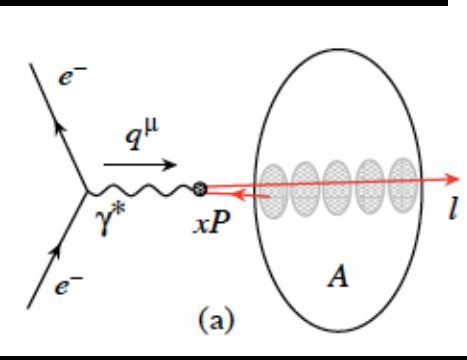


- Charm/bottom measurements in different system size (pp/pA/AA) can provide important information for a comprehensive understanding of nuclear effects

BACKUP

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



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