Heavy flavour production in low p_{T} at RHIC and LHC

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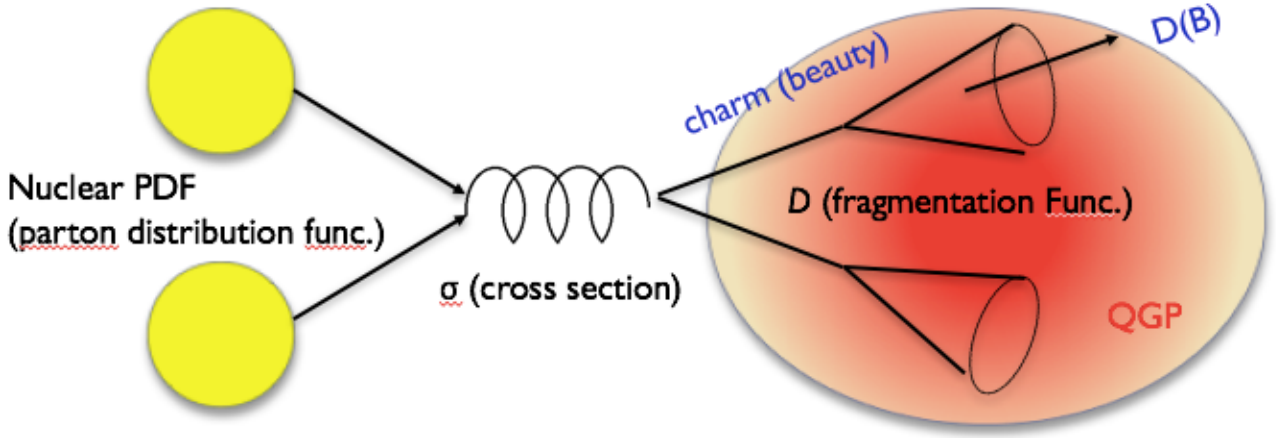
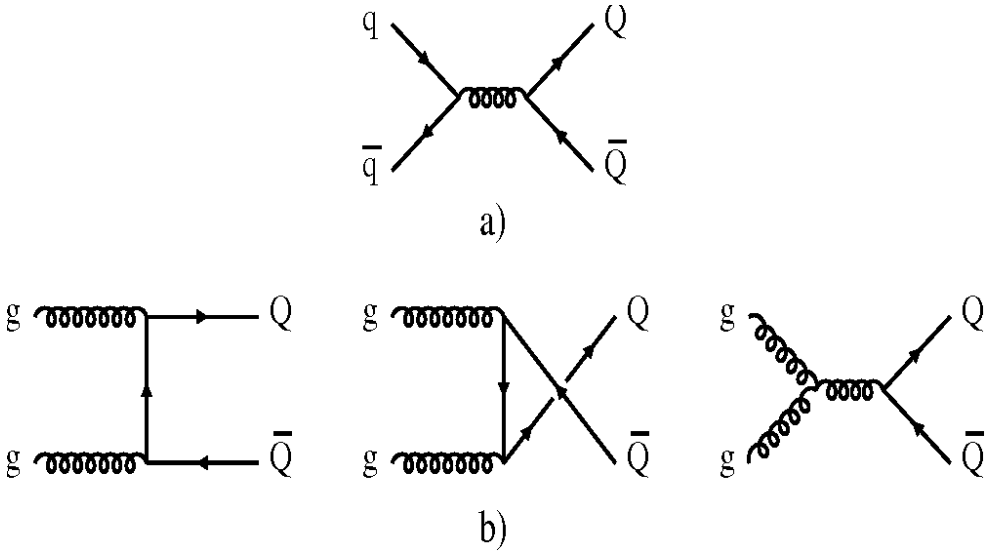
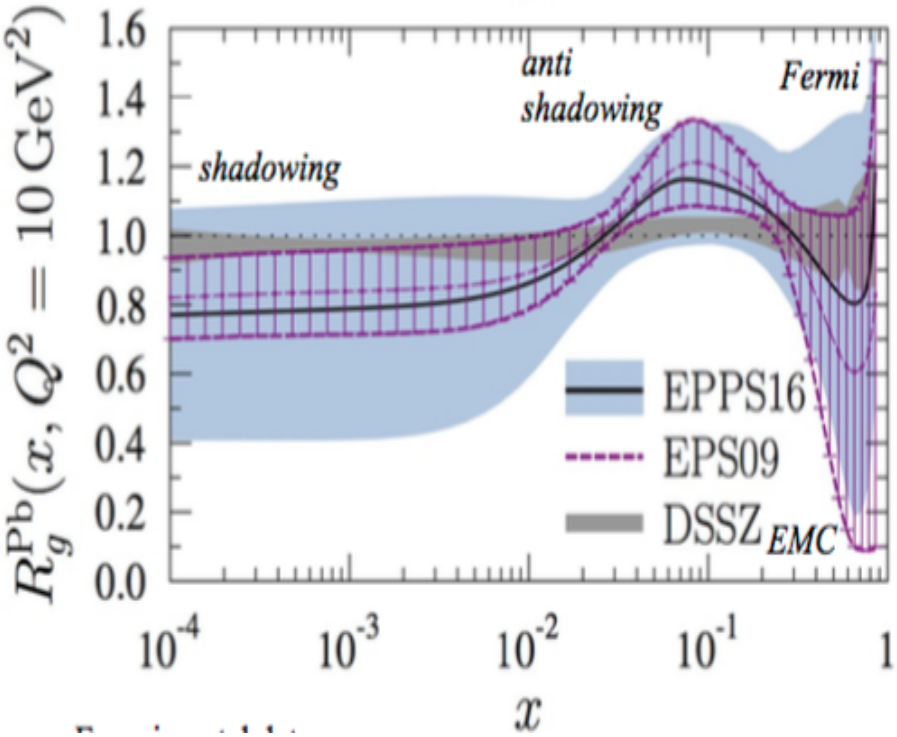
Heavy flavour production in heavy-ion collisions



- Heavy flavour (charm & beauty)
  - Large mass : m_c (~1.5 GeV/c), m_b (~4.5 GeV/c) >> Λ_{QCD} (0.2 GeV/c)
    - Produced initial hard partonic scattering processes
      - Cross section calculate by perturbative QCD (pQCD)
  - Formation time $\tau \sim 1/2\ m_q \sim 0.07$ fm < QGP (~0.1-1 fm)
    - Produce before QGP and go through the medium
- low p_T heavy-flavour production is sensitive to
  - gluon nuclear PDF
  - hadronization (fragmentation vs. recombination)
  - energy loss (collisional vs. radiative energy loss) & collective motion => transport coefficient

Heavy-flavour production

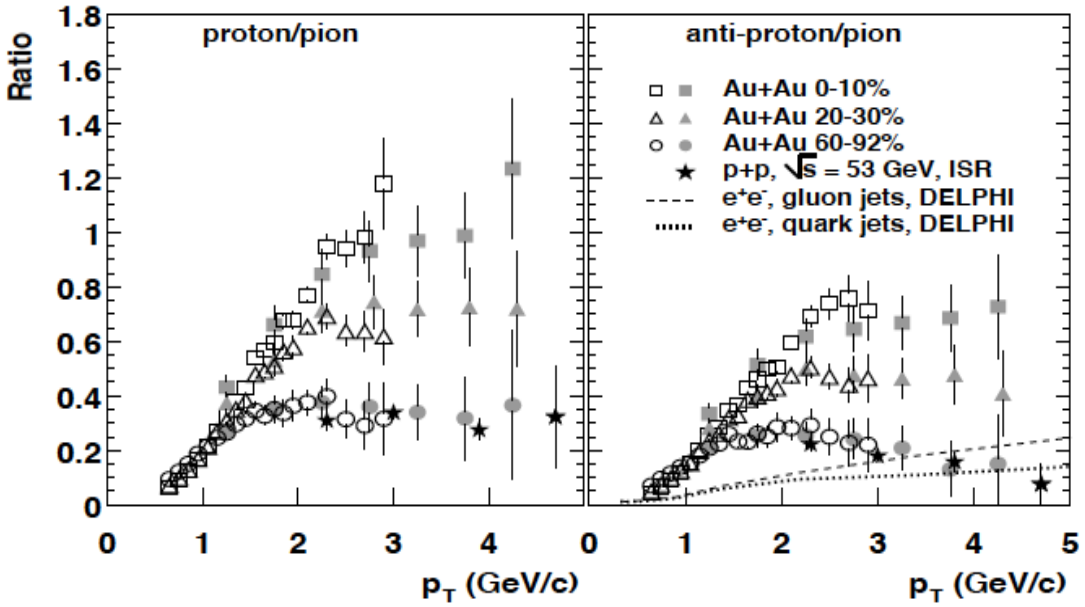


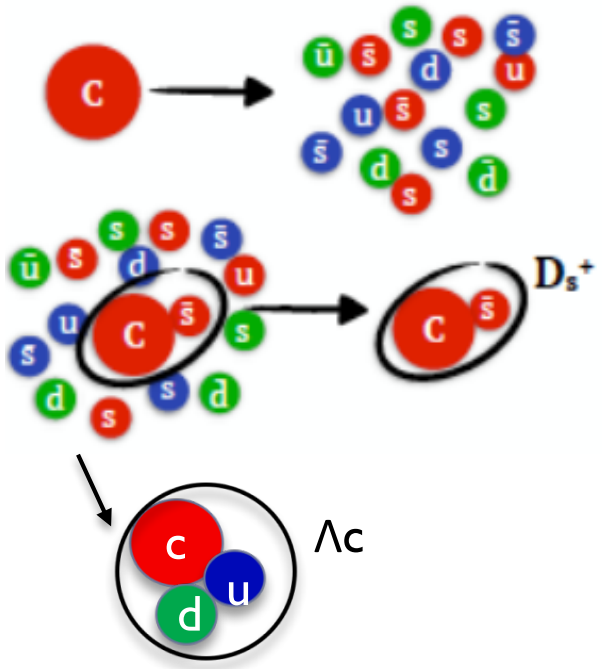


- Heavy flavour production process in LO + NLO
  - Gluon scattering is dominant in high energy

    -> sensitive to gluon nPDF in pA and AA collisions

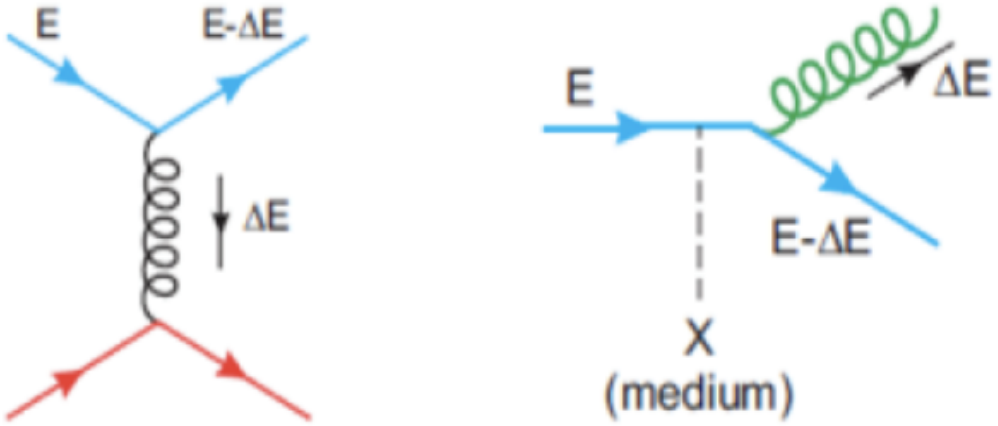
Heavy flavours hadronization in QGP





- Hadronization in pp collisions
  - Fragmentation
- Hadronization in QGP
  - Fragmentation + recombination (qq->Meson, qqq->Baryons)
    - Observed π, p production
    - Possibly enhance charm (bottom) baryon and D_s (B_s)*
      * QGP rich in strange quarks
    - Regeneration of J/Ψ

Heavy flavours energy loss in QGP



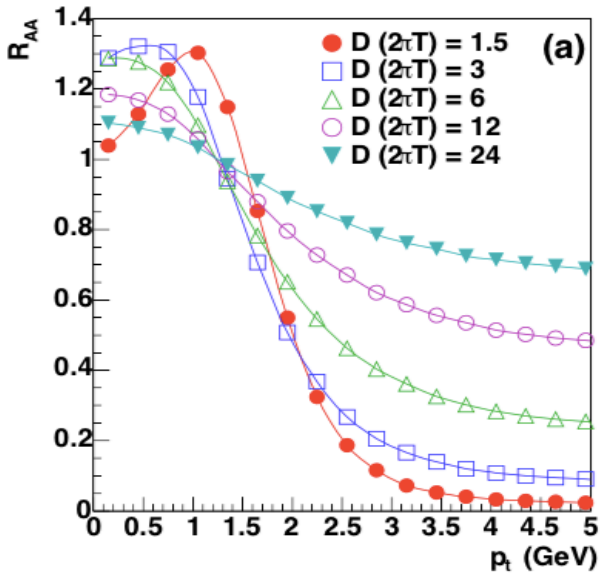
- Interaction between heavy flavour and QGP
  - Low p_T : Elastic scattering -> "collisional energy loss"
  - High p_T : Gluon bremsstrahlung -> "radiative energy loss"

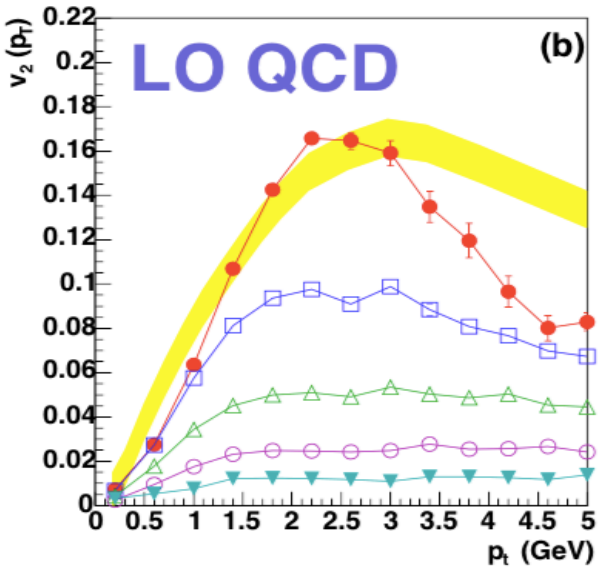
- Radiative energy loss
  - Smaller energy loss for heavy quark than for light quarks due to "dead cone" effect
  - Bremsstrahlung probability $\propto 1/(\theta^2 + (m/E)^2)^2$
  - $E_{loss}(g) > E_{loss}(u,d,s) > E_{loss}(c) > E_{loss}(b)$

Heavy flavours propagation in QGP

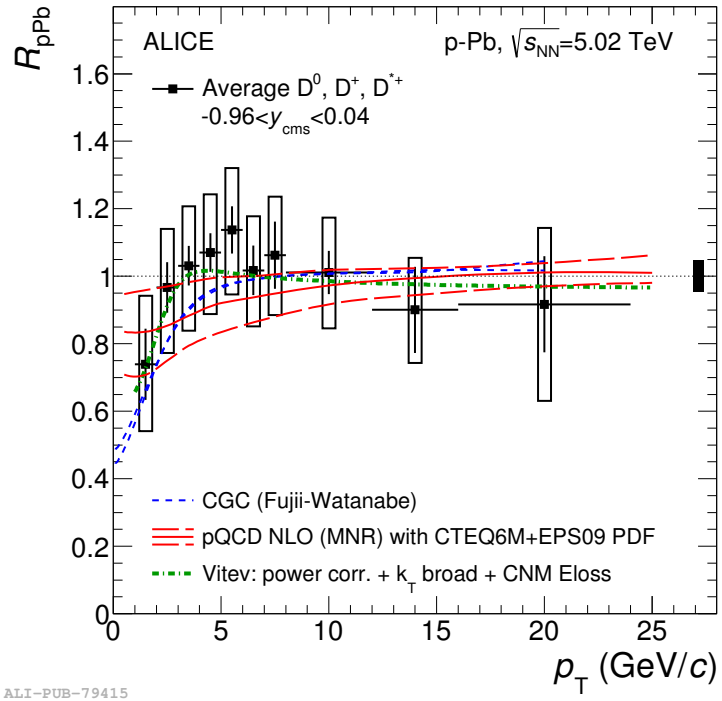
- "Brownian motion" in QGP
  - Follow Langevin equation
  - D_s (diffusion coefficient) $\propto 1/\eta_D$ (drag coefficient)
    - Sensitive to QGP transport coefficient
    - A small value of D_s -> strong coupling
    - Large R_{AA} & v_2 of heavy flavours indicate strong coupling with medium

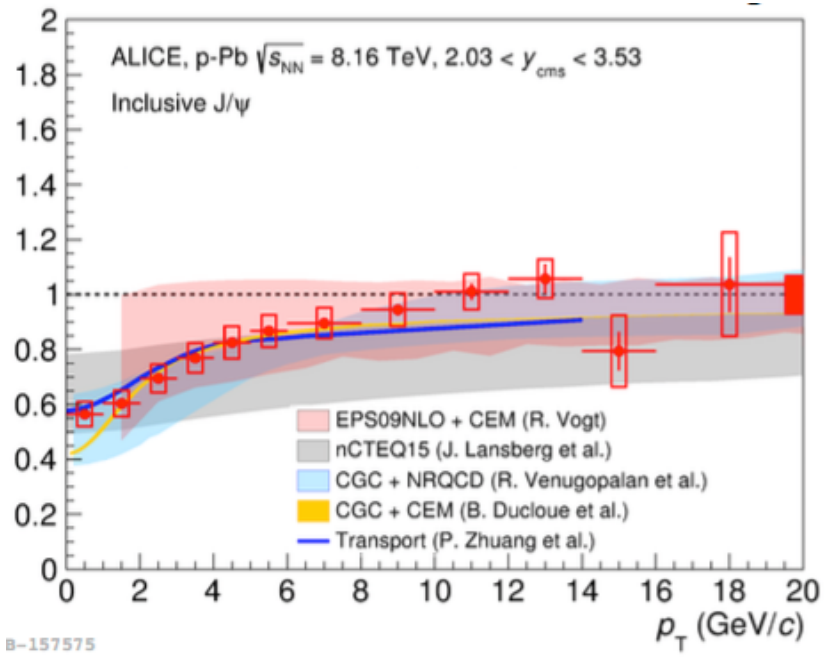
$$\frac{d\vec{p}}{dt} = -\eta_D(p)\,\vec{p} + \vec{\xi}$$





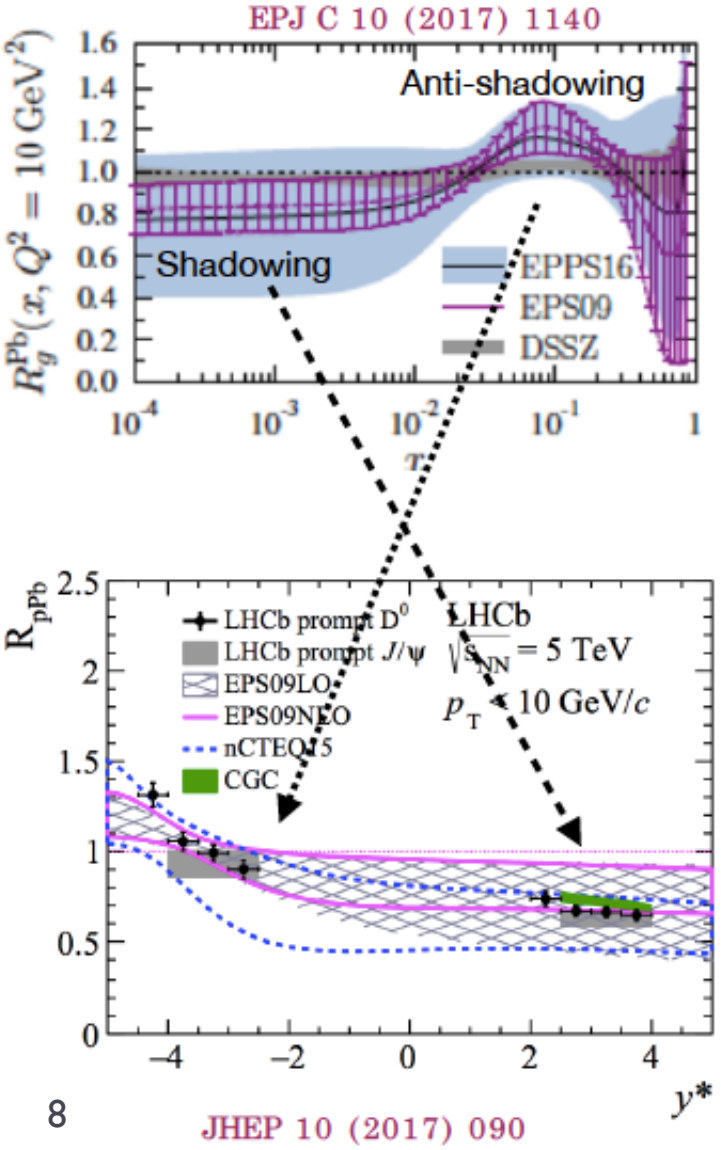
nPDF: Heavy flavour production in pA (1)

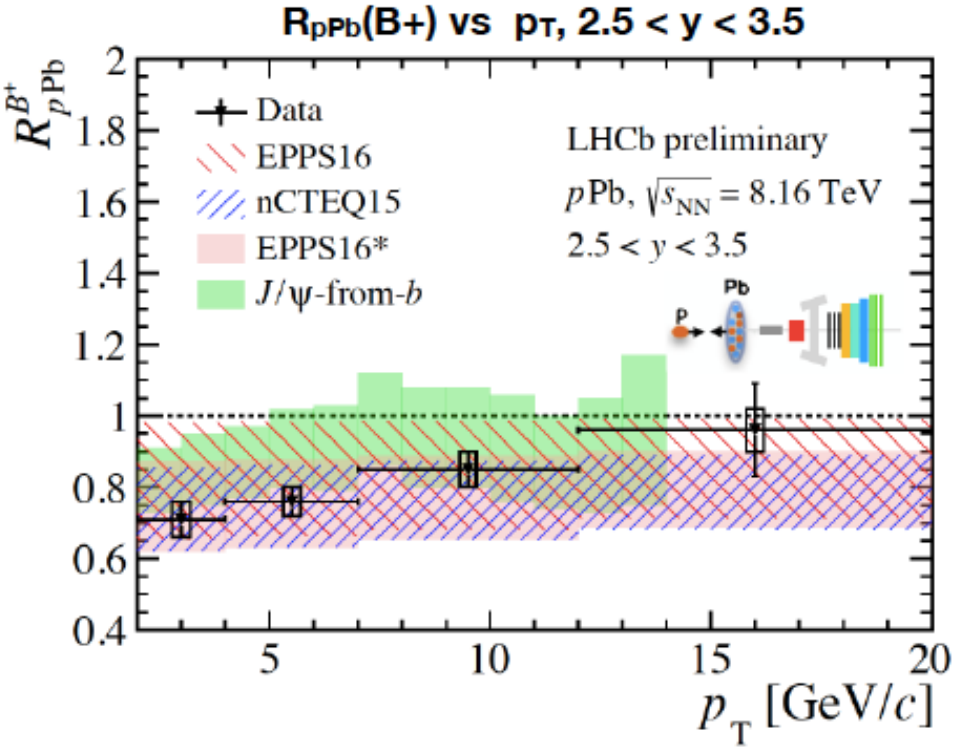




- Low p_T : Possibly modify of charm production due to shadowing in nPDF or CGC
  - More clear in J/Ψ production in 2<y<3.5
- High p_T : no modification of the productions

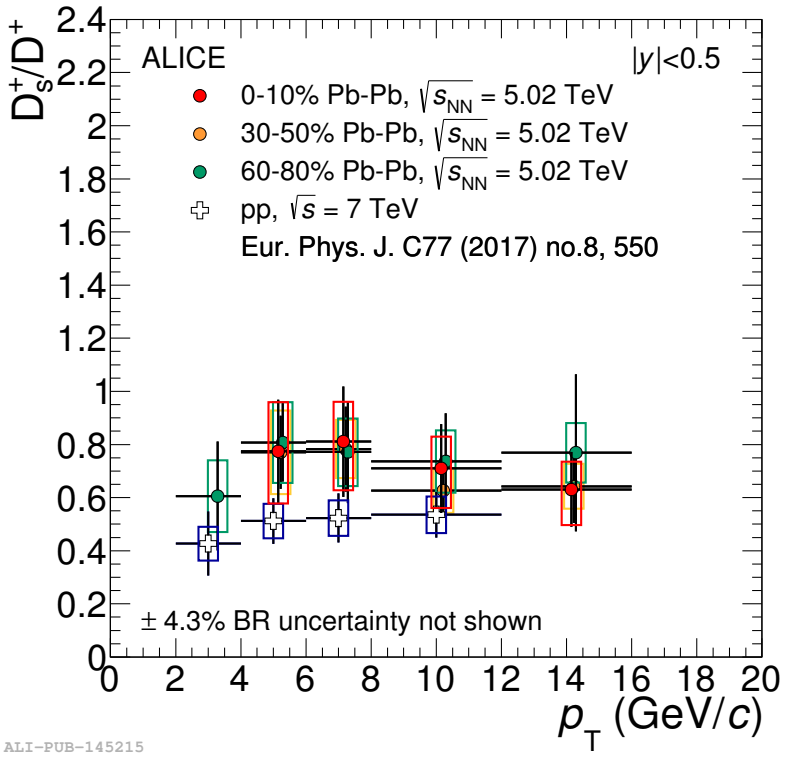
nPDF: Heavy flavour production in pA (2)

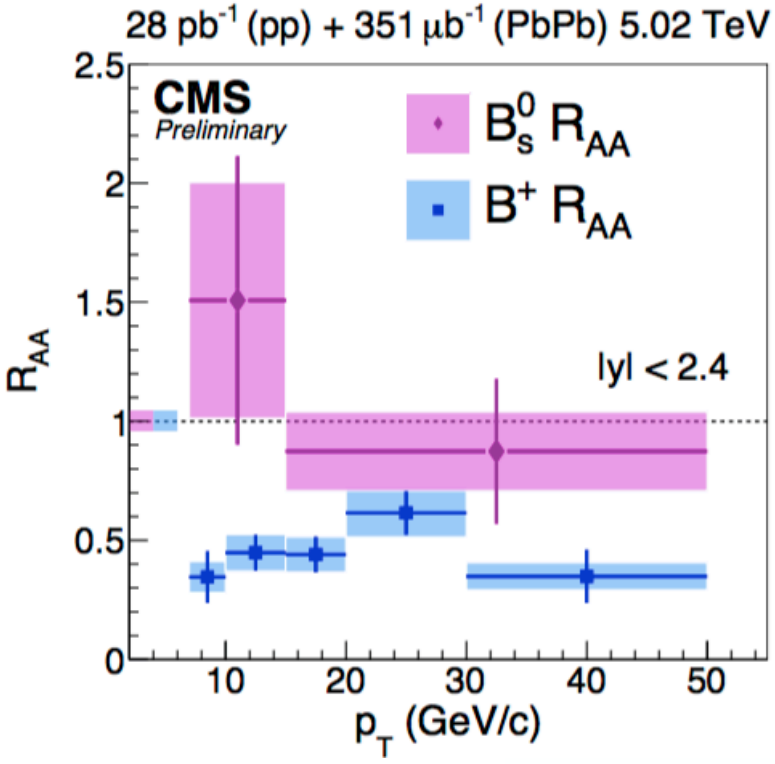


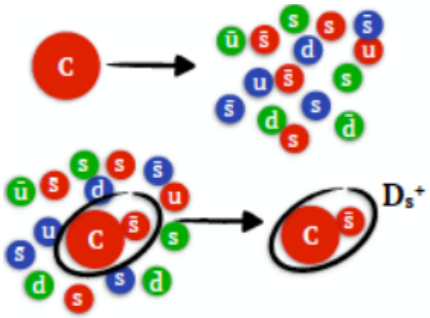


- Indicate the effect from shadowing in 2<y<4, and Anti-shadowing in -2<y<-4 on D^0 production
- Suppression of B production is also observed

Hadronization: D_s and B_s productions in AA

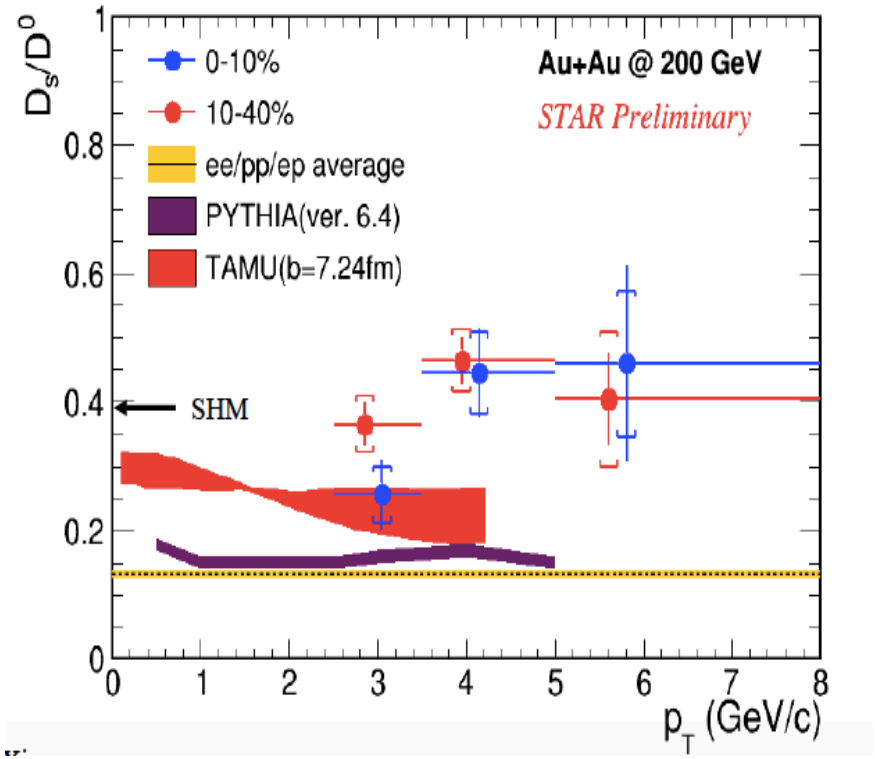


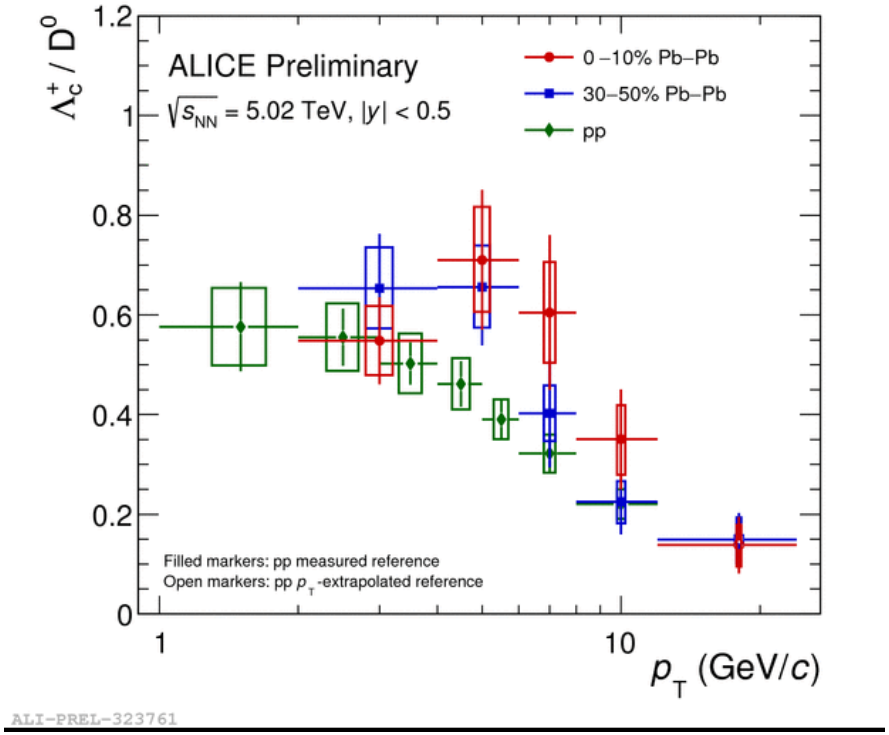




- D_S and B_s productions in Pb-Pb are enhanced w.r.t. their productions in pp
  - Indicate a contribution of coalesce mechanisms to charm hadron formation in the medium

Hadronization: Λ_c production in AA

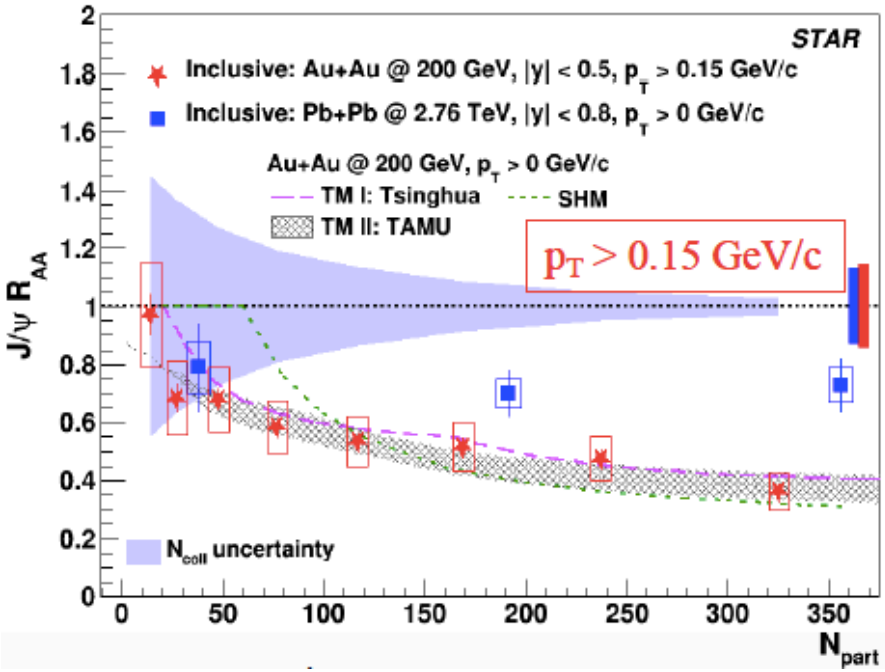




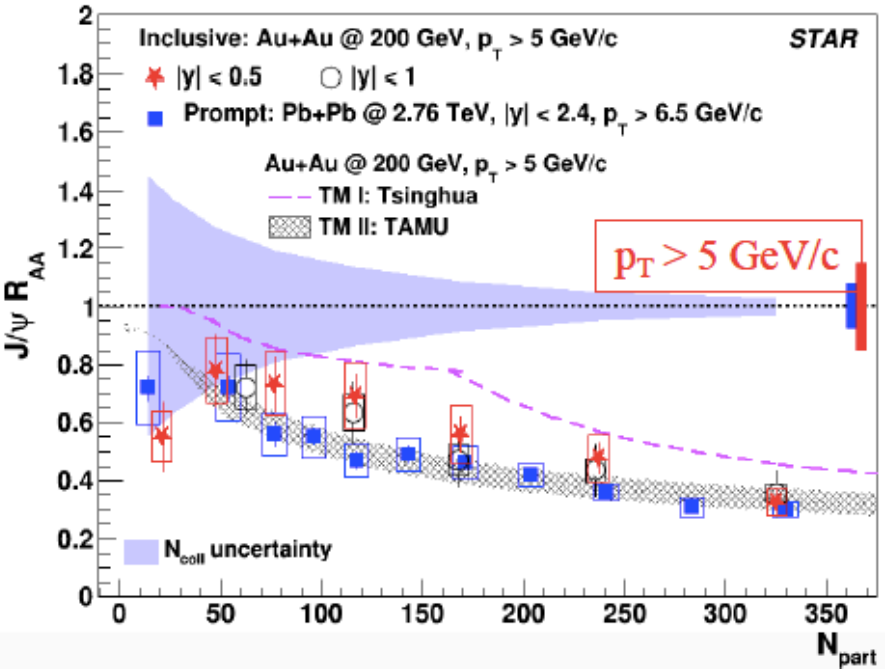
- Λ_c production in Au+Au and Pb-Pb is enhanced w.r.t. in pp collisions
- Indicate coalesce mechanisms play a role in charm hadronization

Hadronization: J/Ψ production in AA

arXiv:1905.13669 , submitted to P.L.B

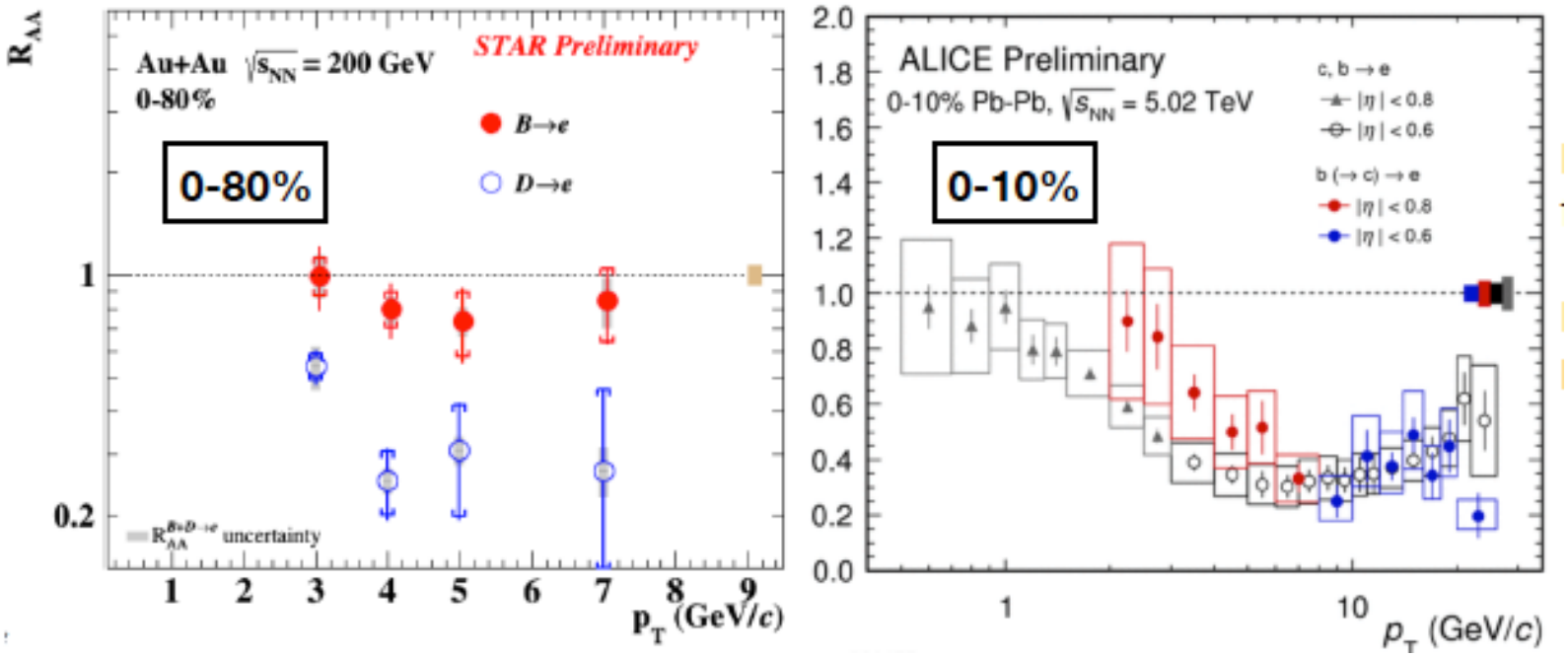


Inclusive J/ψ from STAR



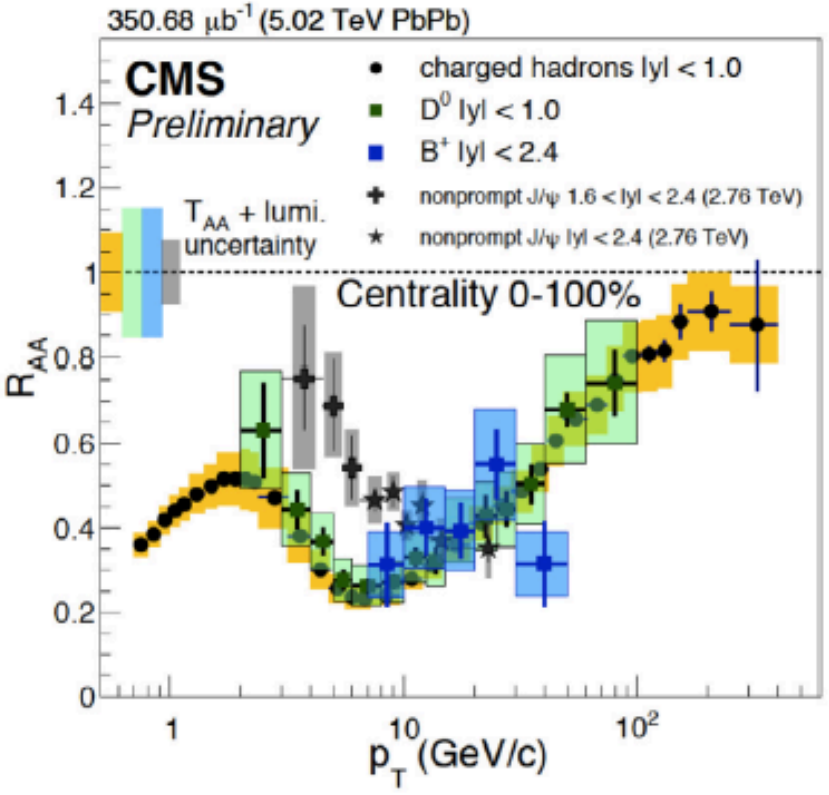
- J/Ψ production in RHIC (Au+Au 200 GeV) and LHC (Pb-Pb 2.76 TeV)
  - LHC result higher than RHIC result in low p_T
  - Indicate regeneration is important process of J/Ψ production in LHC

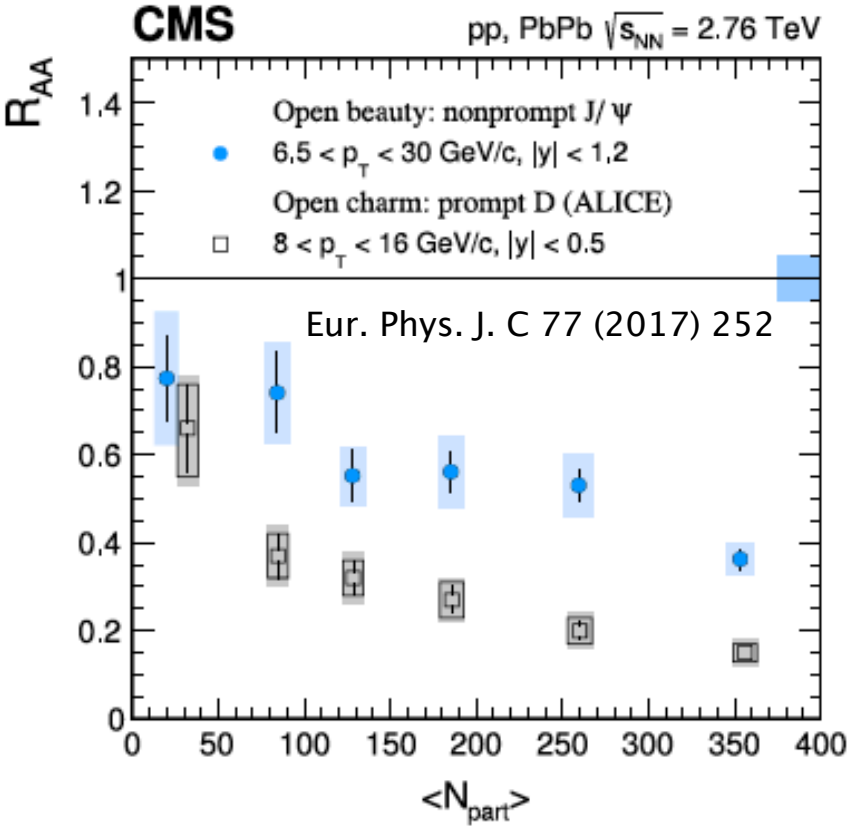
Energy loss: charm vs. beauty (1)



- R_{AA} of b->e is larger than c->e in low p_T
  - Indicate smaller energy loss of beauty than charm in low p_T
- Similar suppression of beauty and charm in p_T > 10 GeV/c

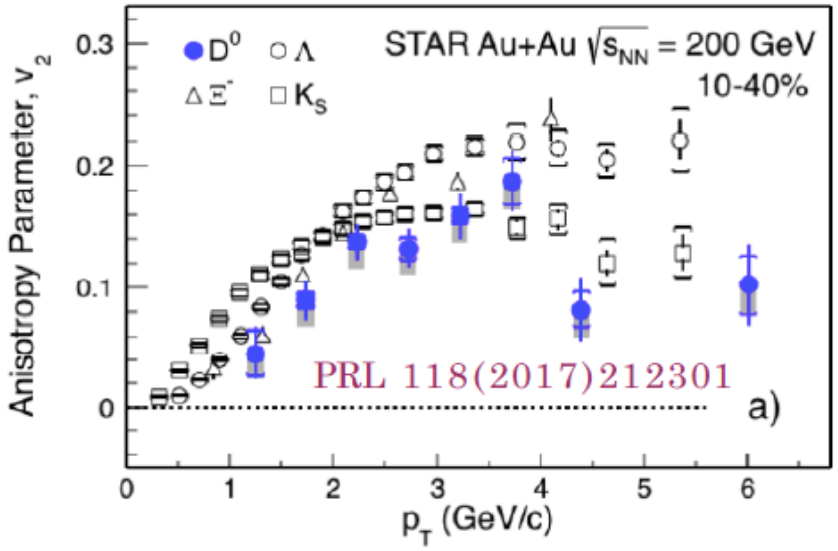
Energy loss: charm vs. beauty (2)

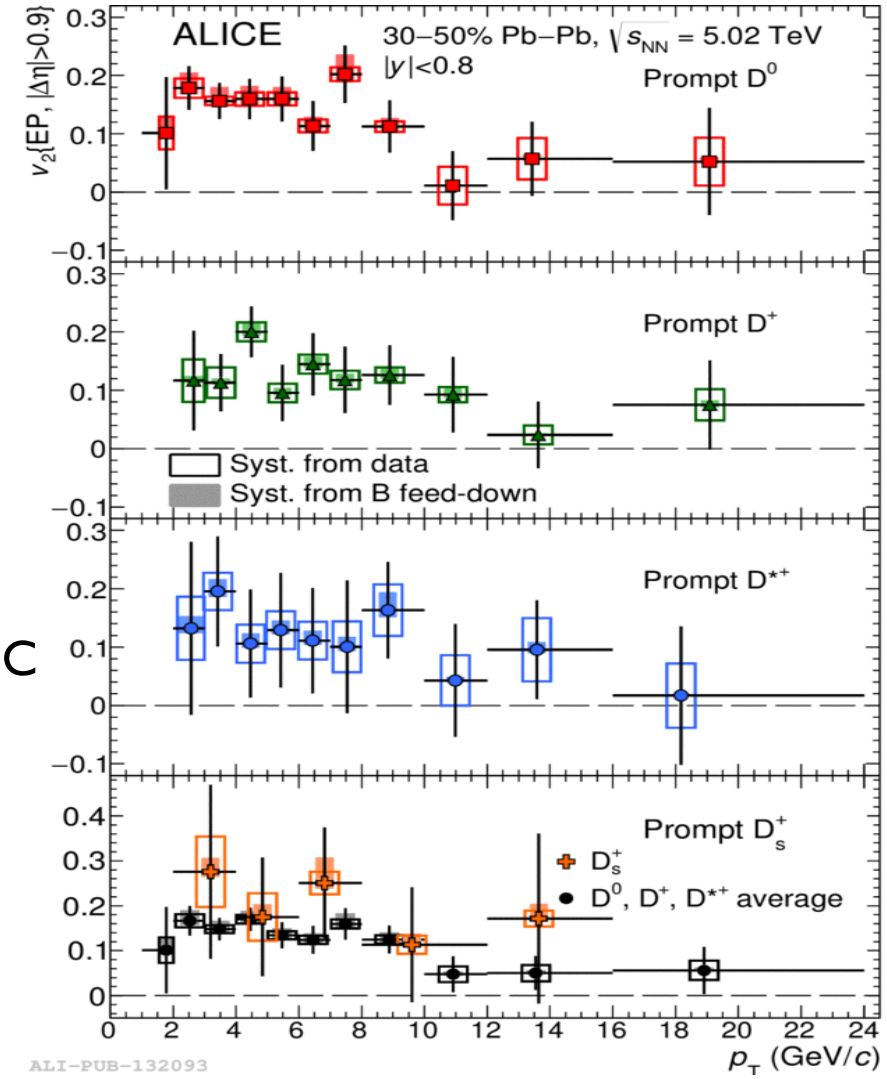




- R_{AA} : mass ordering up to 10 GeV/c
  - Above 10 GeV/c, R_{AA} for charged particles, D (J/Ψ) and B are similart

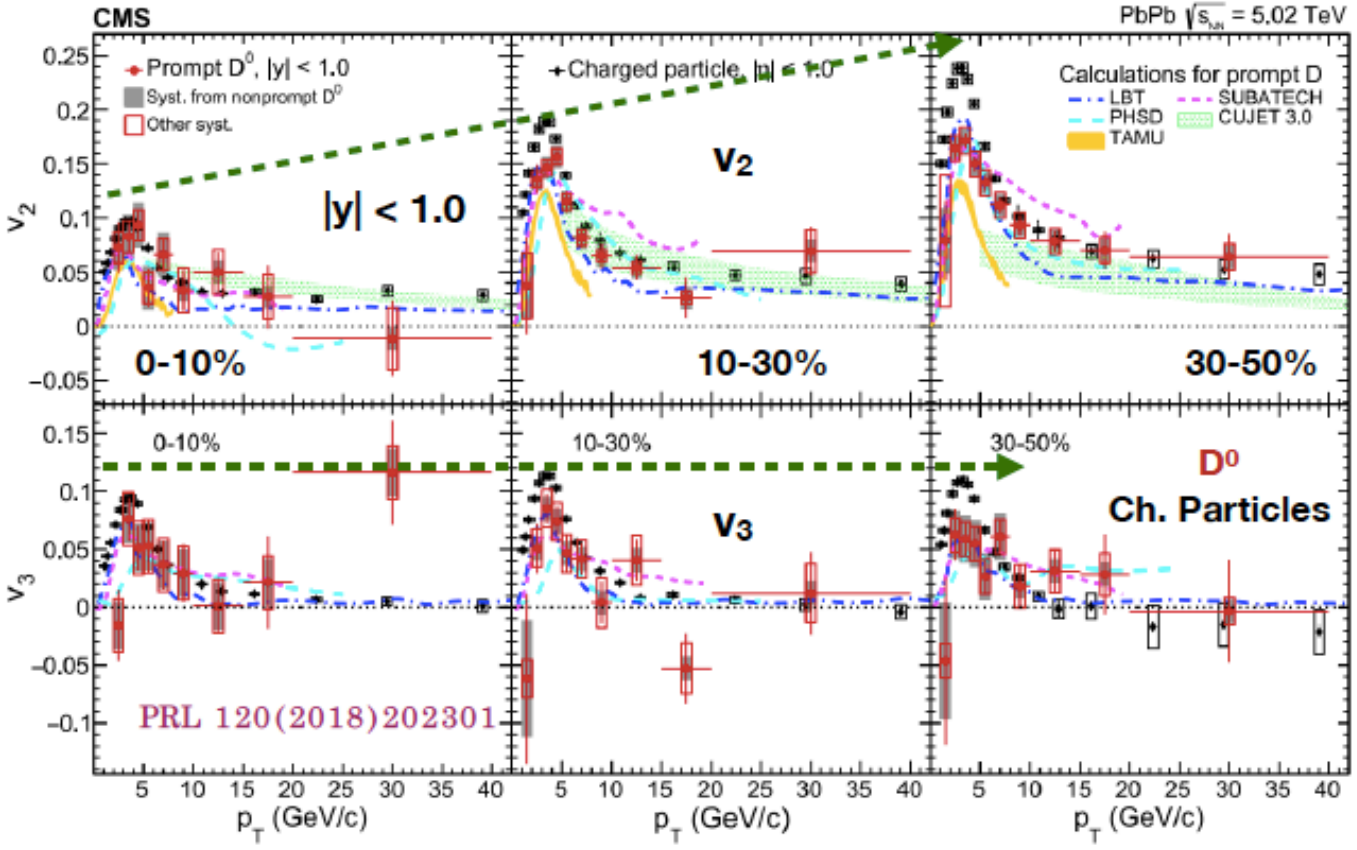
Collective motion: D meson v_2 (1)





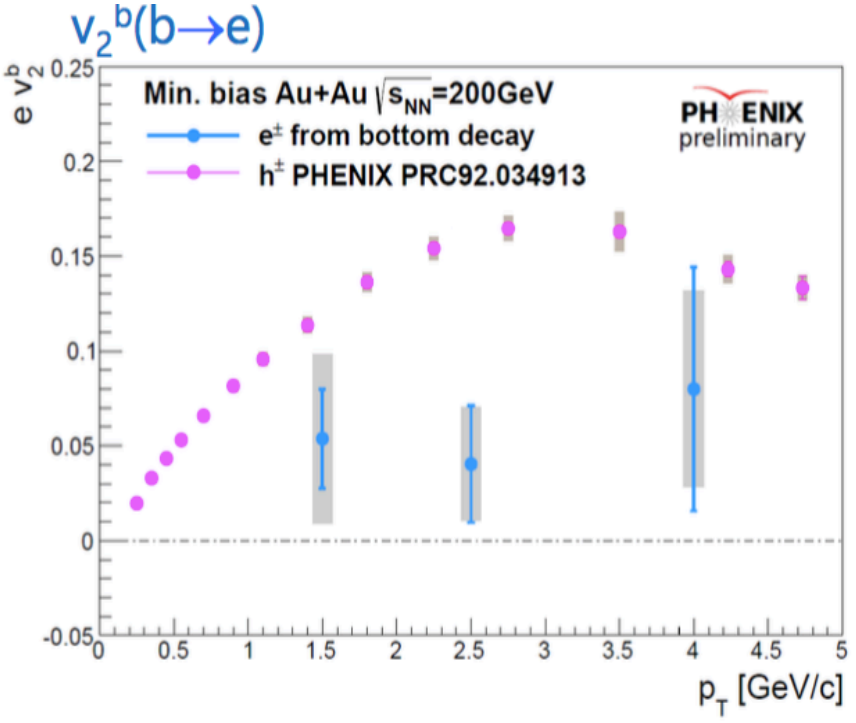
- Non-zero v_2 observed both RHIC and LHC
  - Charm quark participate collective motion
- Smaller v_2 of D mesons w.r.t. v_2 for Λ, Ks
  - Mass ordering

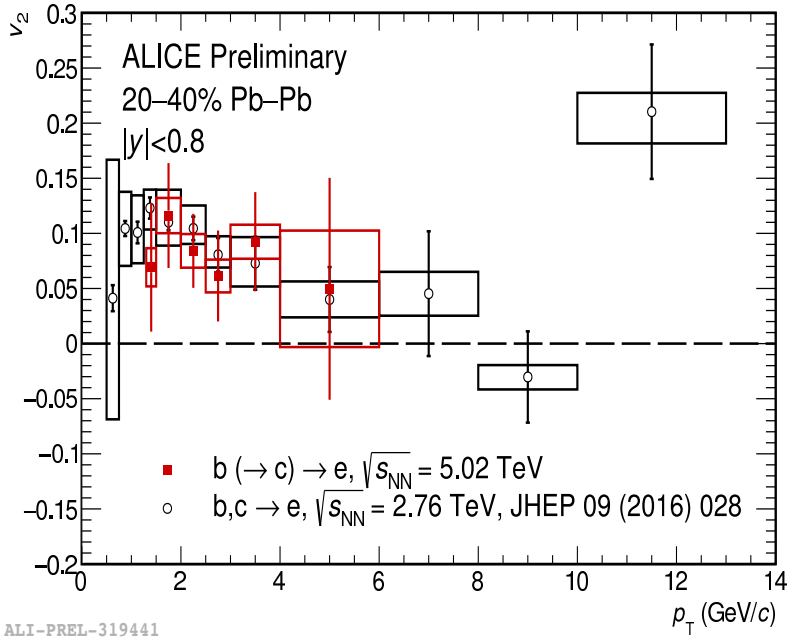
Collective motion: D meson v_2 (2)



- v_2 increase with centrality (central to semi-central)
  - Hydro dynamical behavior
- v3 : centrality independent
- Models : include initial-state fluctuation (LBT, PHSD & SUBATECH)

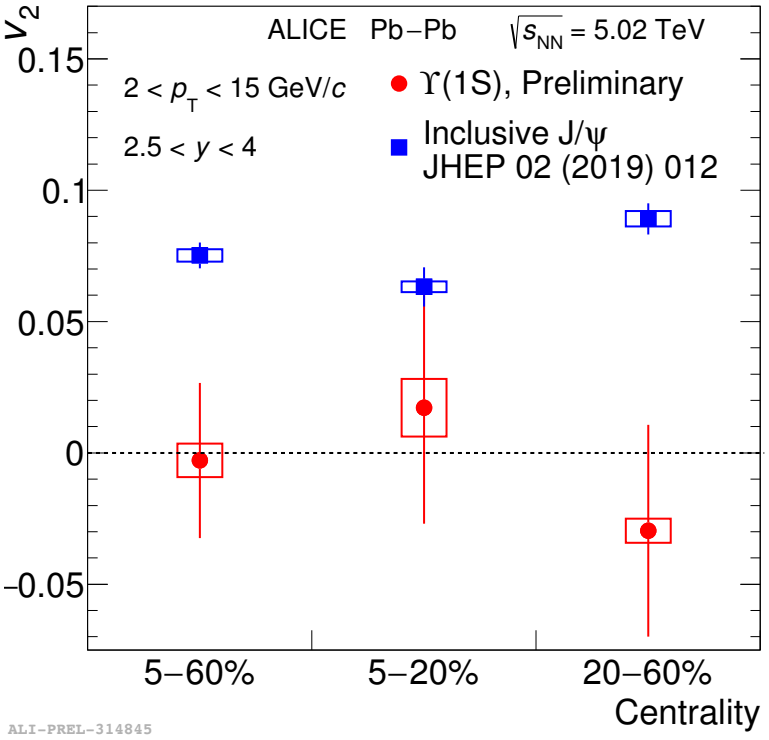
Collective motion: beauty (open)

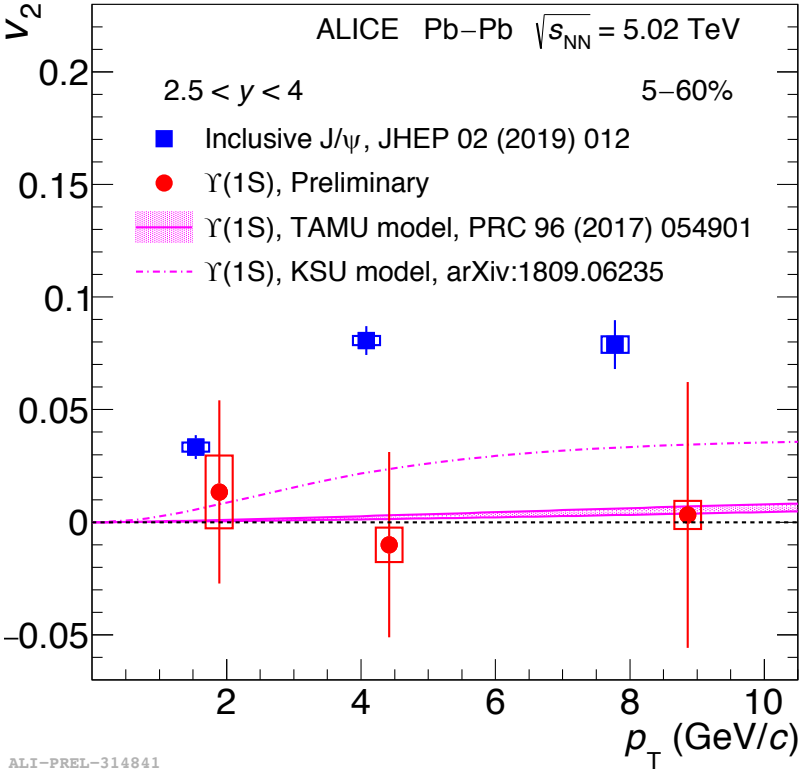




- Smaller v_2 of b->e w.r.t. inclusive hadron v_2
- Similar v_2 of b->e and c->e ?
  - Need more precise measurement with large data sample (2018)

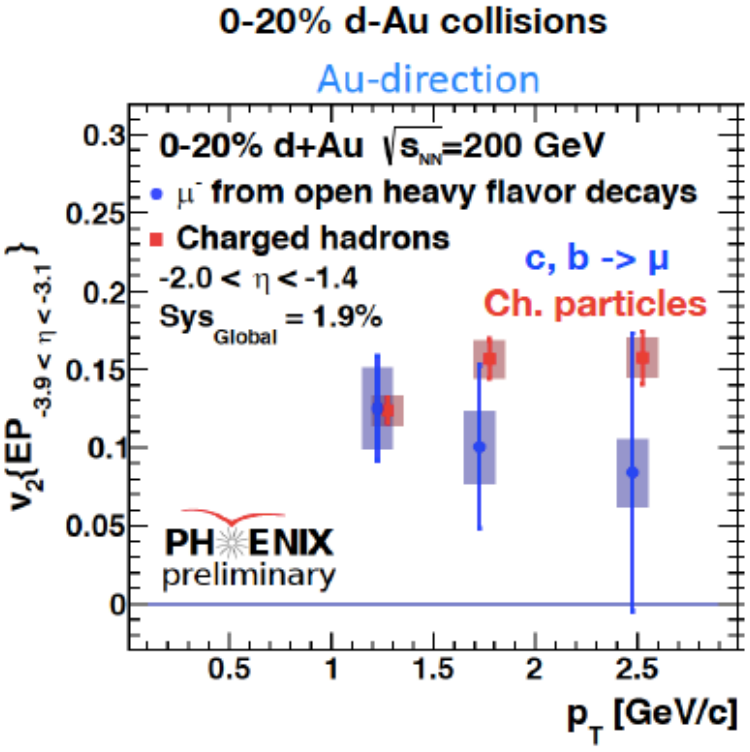
Collective motion: charm & beauty (close)

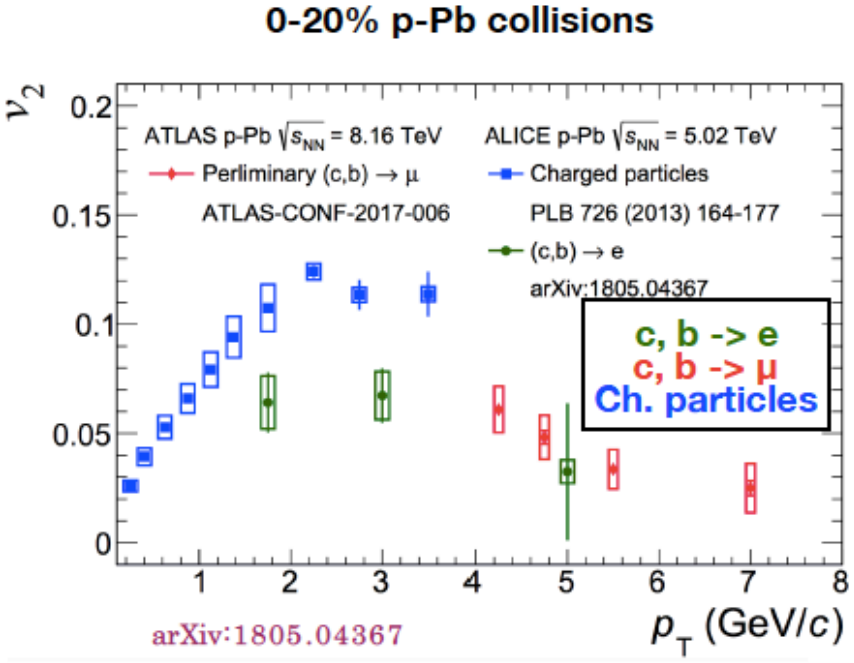




- Comparison of J/Ψ v_2 (charm) and Υ v_2 (beuaty)
  - Smaller Υ v_2 than J/Ψ v_2
  - Υ v_2 is consistent with zero

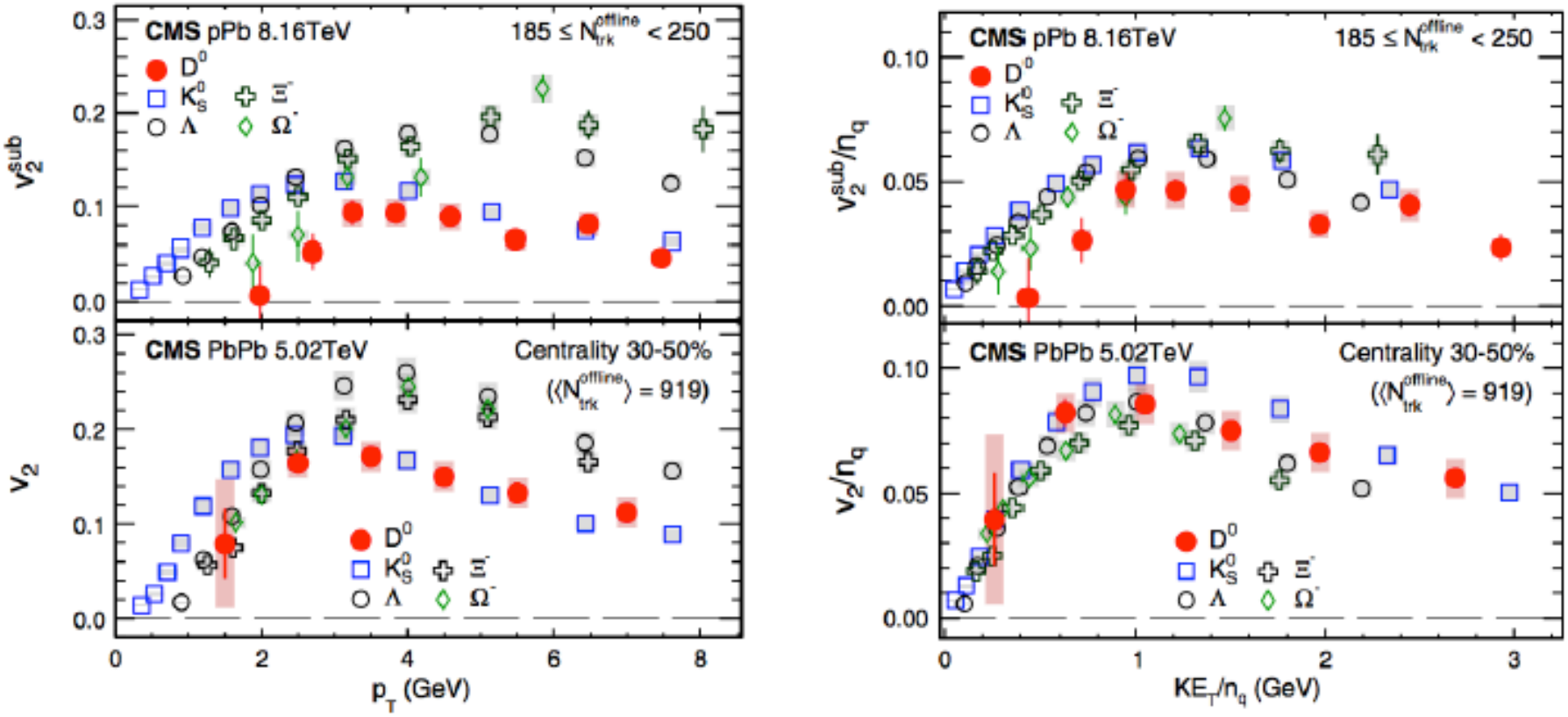
Collective motion: in pA collisions (1)





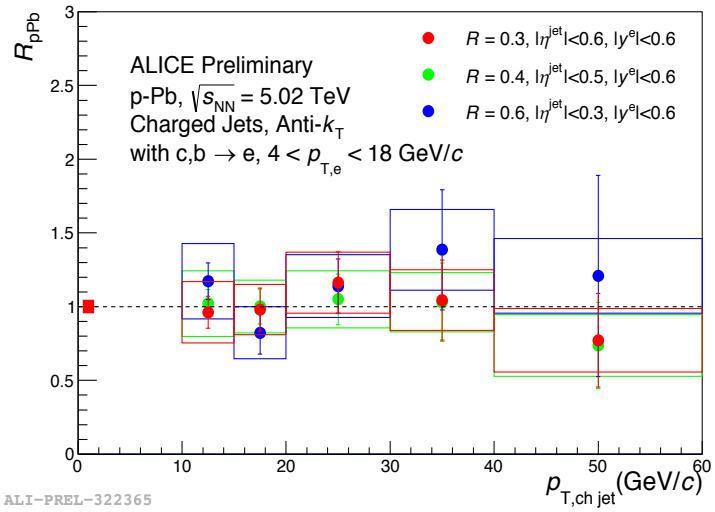
- Observed positive v_2 of heavy flavours (leptonic channel) both RHIC and LHC
  - Smaller v_2 than chared hadron v_2
    - same as AA collisions

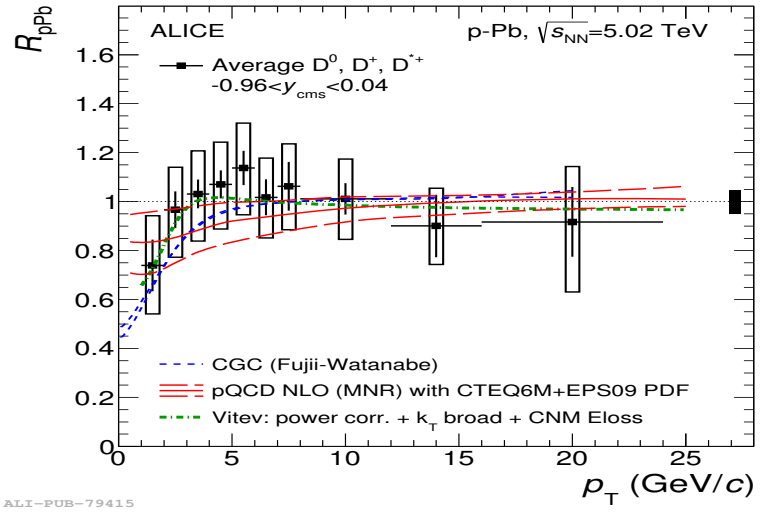
Collective motion: in pA collisions (2)

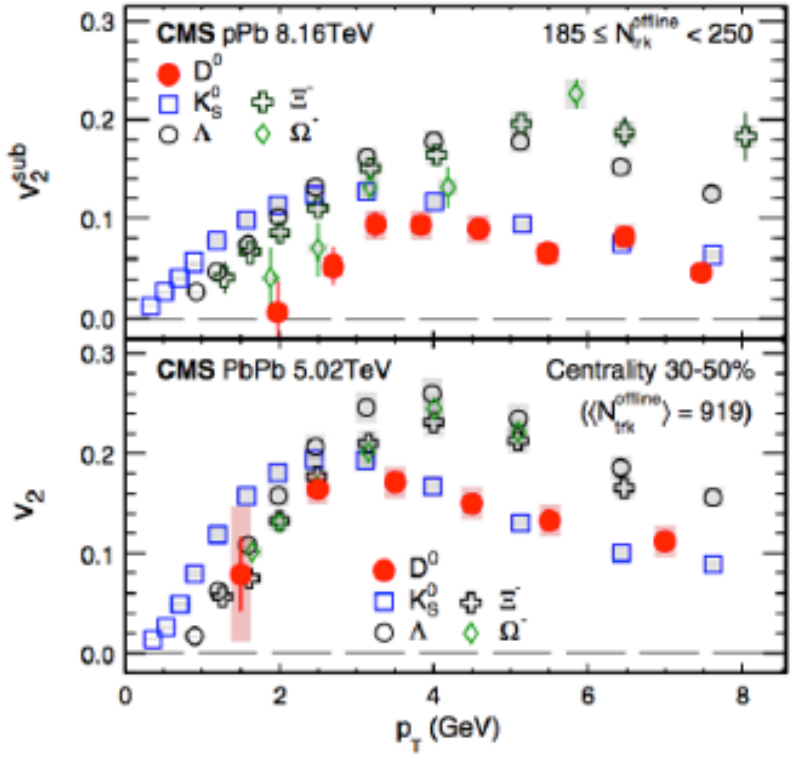


- Observed positive v_2 of D meson in p-Pb collisions
- The number of quark scaling doesn't work in D meson v_2 in p-Pb
  - Indicate smaller v_2 of charm quark in p-Pb

QGP in small system ?

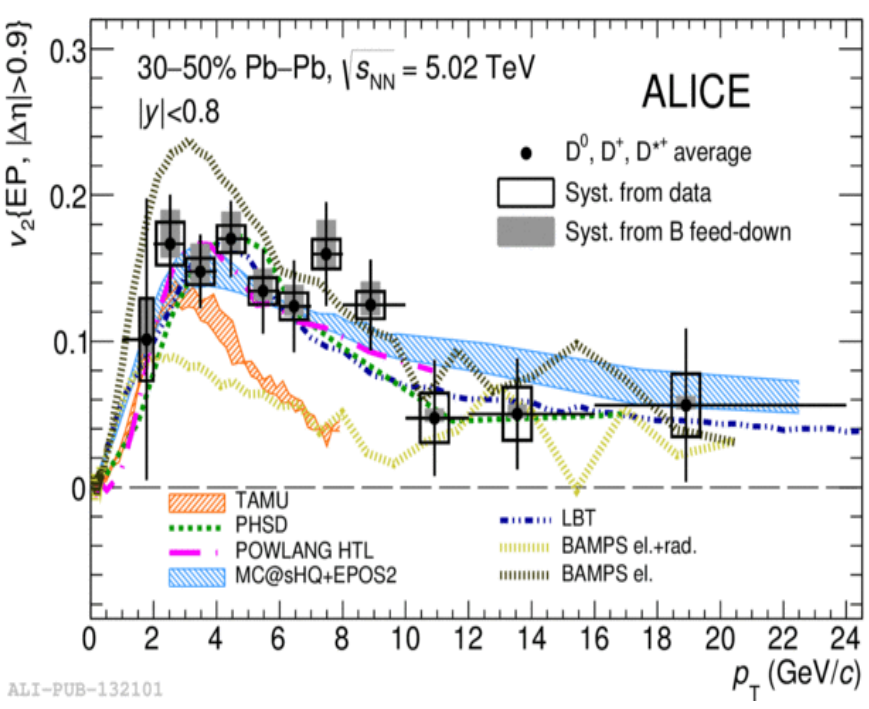


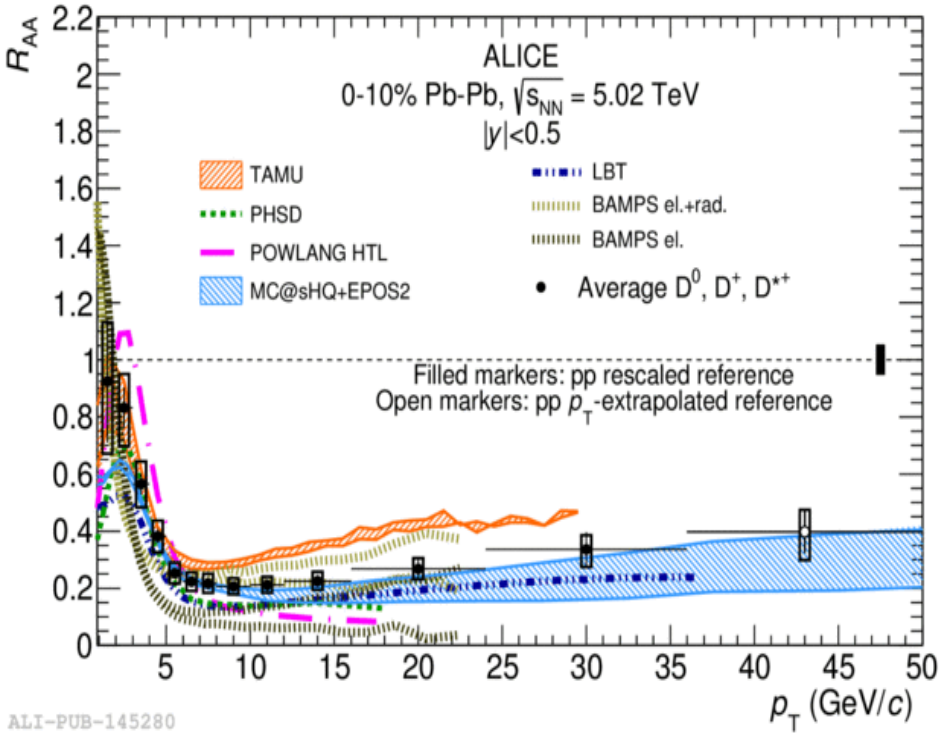




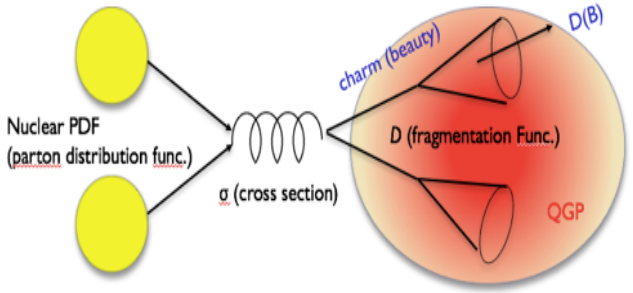
- v_2 has been thought be a signal of QGP
- Not observed suppression of HF production and modification of HF jet in pA collisions so far.

Comparison with models (1)





- Model calculations for heavy-flavour R_{AA} & v_2
  - Nuclear PDF : with/without PDF
  - Cross section : PYTHIA, FONLL, MC@NLO …
  - Medium modeling : Hydro, Glauber, Bolzmann ...
  - Interaction : collisional and/or radiative
  - Hadronization : fragmentation and/or recombination



Comparison with models (2)

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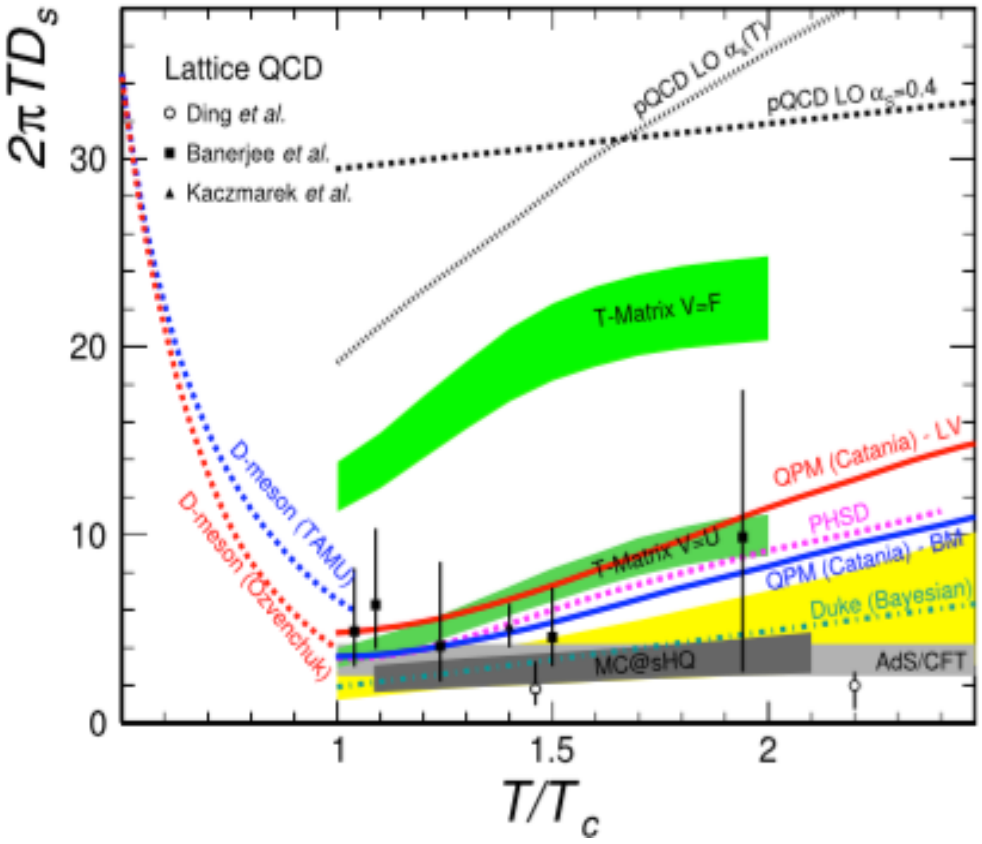

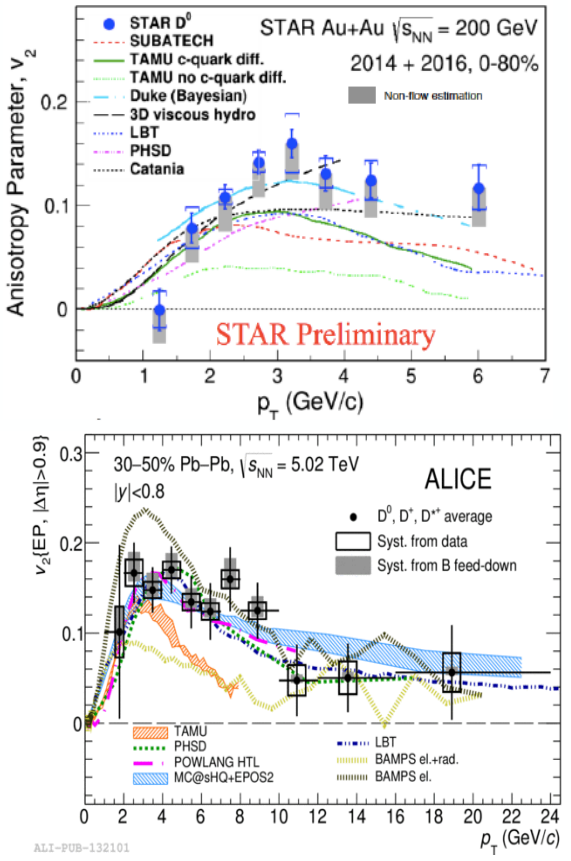

- Sensitivity to charm diffusion coefficient 2πTDs as a function of T/Tc

Summary

- Heavy flavour production in low p_T is sensitive to
  - Gluon nPDF
    - Suppression of low p_T HF production in pA
    - Effect from shadowing in 2<y<4 and Anti-shadowing in -2<y<-4
  - hadronization (fragmentation vs. recombination)
    - Enhancement of Ds, Bs, Λc and J/Ψ
      - Indicate recombination process for heavy flavour hadronization
  - Energy loss (collisional energy loss) & collective motion
    - Strong suppression of particles from charm and beauty
    - Positive v_2 of particles from charm and beaty
      - Indicate mass ordering energy loss & v_2 in low p_T
      - Models with small Ds (diffusion coefficient) reproduce R_{AA} and v_2