Heavy-flavour measurements at LHC-ALICE

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Heavy Flavour (HF) in pp, p-Pb & Pb-Pb

- Heavy-flavour (charm & beauty) production
  - Initial hard scatterings ($M_{HF} >> \Lambda_{QCD}$)
- pp collisions
  - Test for perturbative QCD (pQCD)
  - Reference for heavy ion collisions (both experiment & theory)
- Heavy ion collisions
  - Created in initial parton-parton scatterings
  - Traverse and interact with the hot & dense QCD matter
    - A good probe to study properties of the QCD matter
    - Energy loss (R_{AA}), collectivity (v_2), hadronization
- pA collisions
  - Control measurement for heavy ion collisions to disentangle initial from final state effects
    - Cold nuclear matter effect on heavy-flavour production

Energy Loss of heavy flavours

- In-medium parton energy loss
  - Radiative energy loss (PLB 632, 81)
    - gluon bremsstrahlung
    - smaller energy loss for heavy than for light quarks due to "dead cone" effect (PLB 519 (2001) 199.)
    - energy loss depends on the colour charge and is larger for gluons than for quarks
  - Collisional energy loss (PLB 649, 139)
    - energy loss via elastic scattering
- Theoretical predictions:
  - mass & colour charge dependence of energy loss
  - $E_{loss}(g) > E_{loss}(u,d,s) > E_{loss}(c) > E_{loss}(b)$

$$R_{AA}^{\pi} < R_{AA}^{D} < R_{AA}^{B} \quad ?$$

Nuclear modification factor

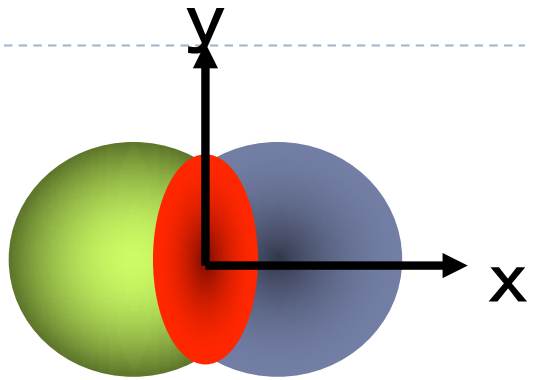
$$R_{AA}(p_T) = \frac{d\,N_{AA}/dp_T}{\langle T_{AA} \rangle \times d\sigma_{pp}/dp_T}$$

Azimuthal anisotropy of Heavy flavours

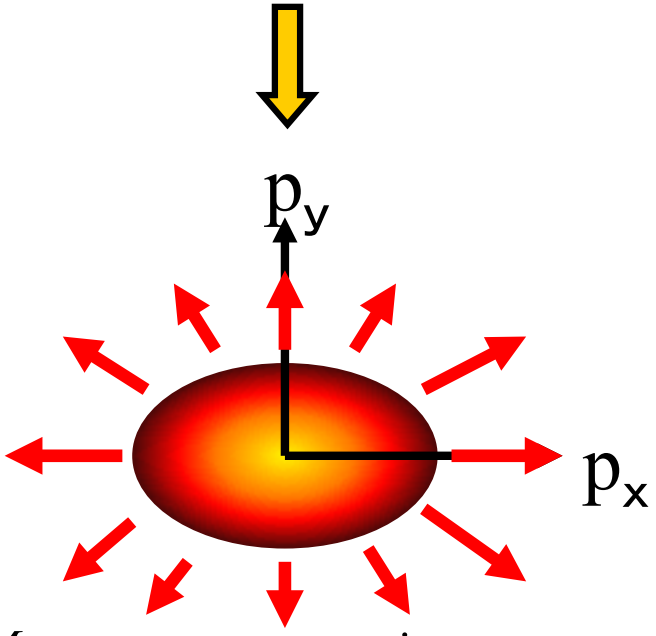
- Elliptic flow

$$dN/d(\phi-\psi_{RP}) = \ldots + N_0(1+2v_2\cos(2(\phi-\psi_{RP}))) + \ldots$$

- Transfer initial spatial anisotropy to momentum anisotropy
  - macroscopic: hydro model
    => pressure gradient
  - microscopic
    => scattering in the medium
- Low p_T
  - coupling of heavy quarks with the medium and their thermalization
- Intermediate p_T
  - Hadronization mechanism (recombination)
- High p_T
  - Path-length dependence of energy loss



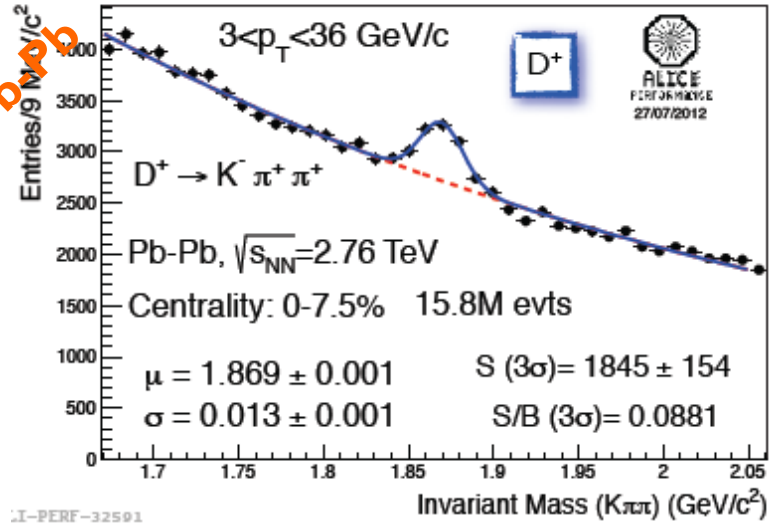
Initial spatial anisotropy



Momentum space anisotropy of particle emission

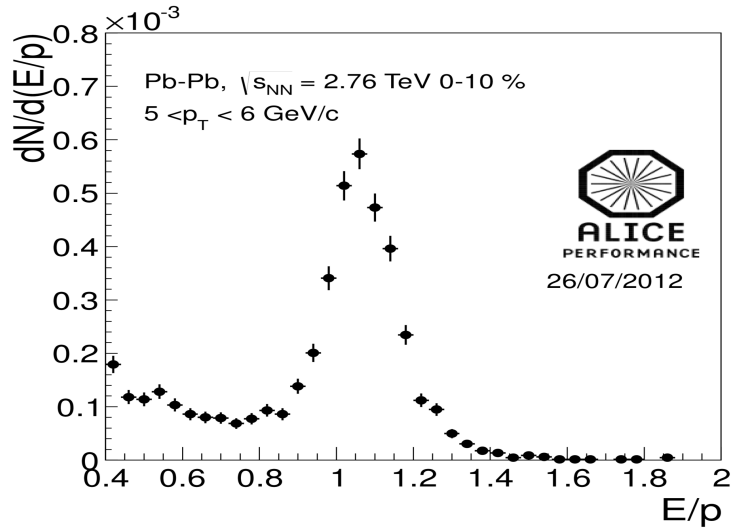
Heavy-flavour measurements in ALICE

Pb-Pb



Pb-Pb

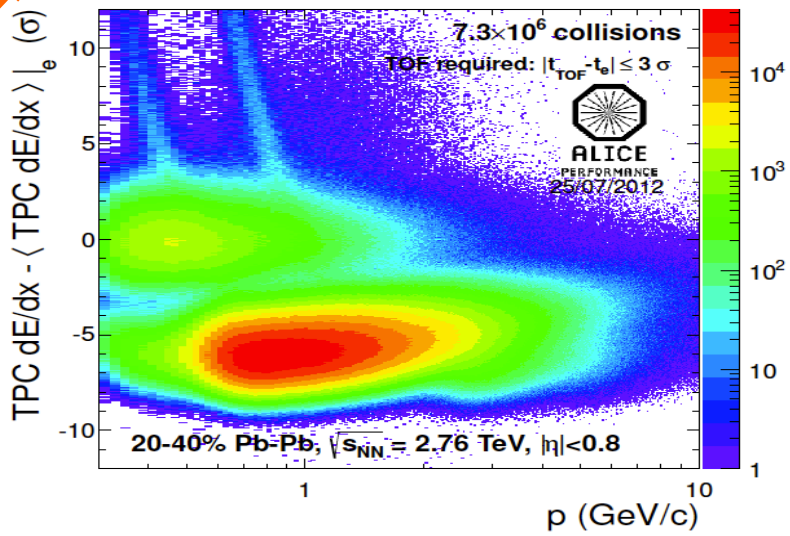
TPC + EMCal (dE/dx+E/p)



- D meson reconstruction (|y|<0.5)
  - displaced-vertex topology
  - π/K ID: TPC+TOF
- HFE (|y|<0.5 or 0.6)
  - background subtraction: cocktail & invariant mass method
- HFM (2.5<y<4)
  - background subtraction: used MC normalized to data at low p_T (pp), inputs from central-barrel & extrapolation with MC (Pb-Pb)

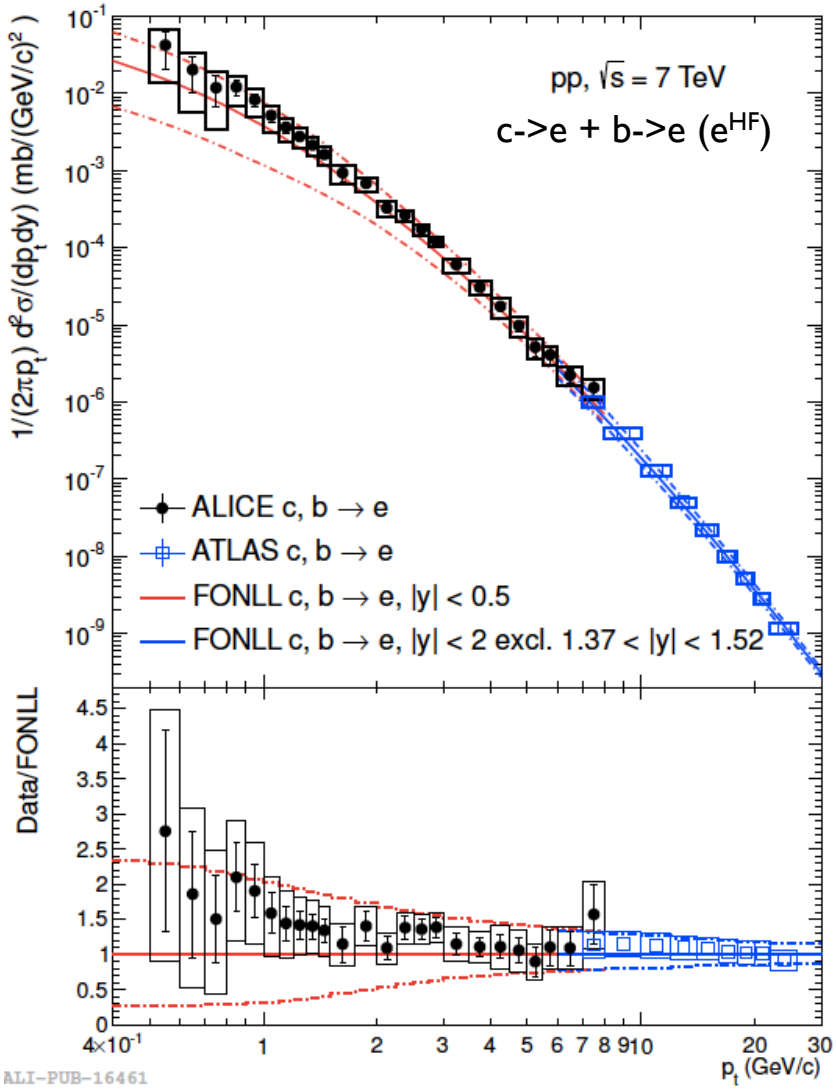
Pb-Pb

TPC +TOF (dE/dx+TOF)

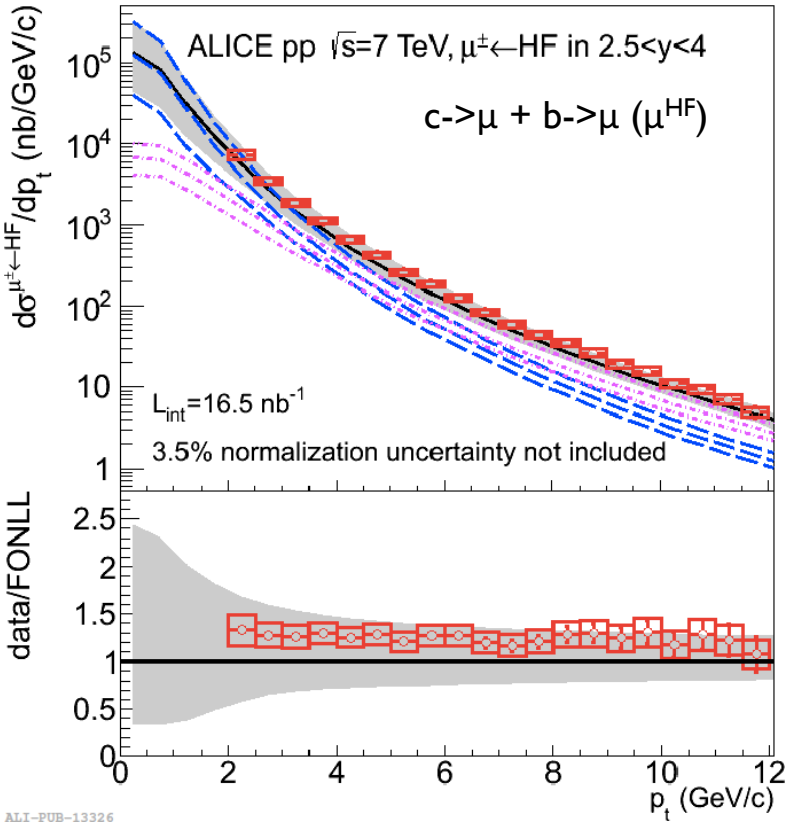


HF production (c,b->l) in pp collisions

Phys. Rev. D 86, 112007

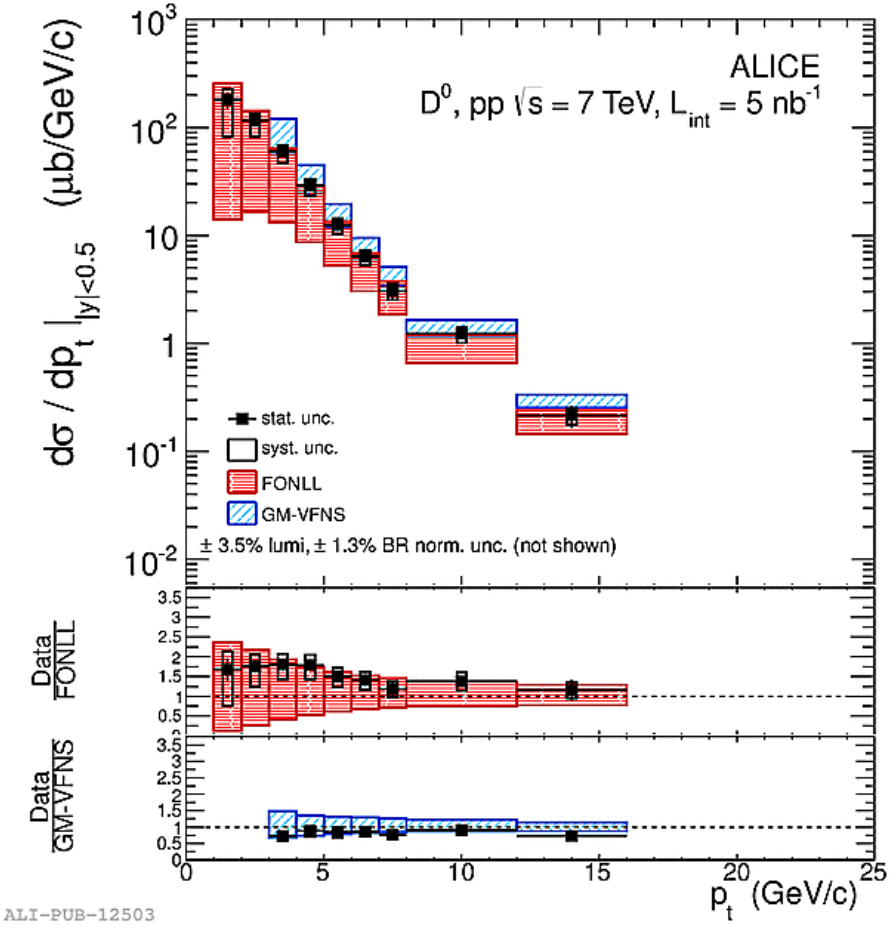


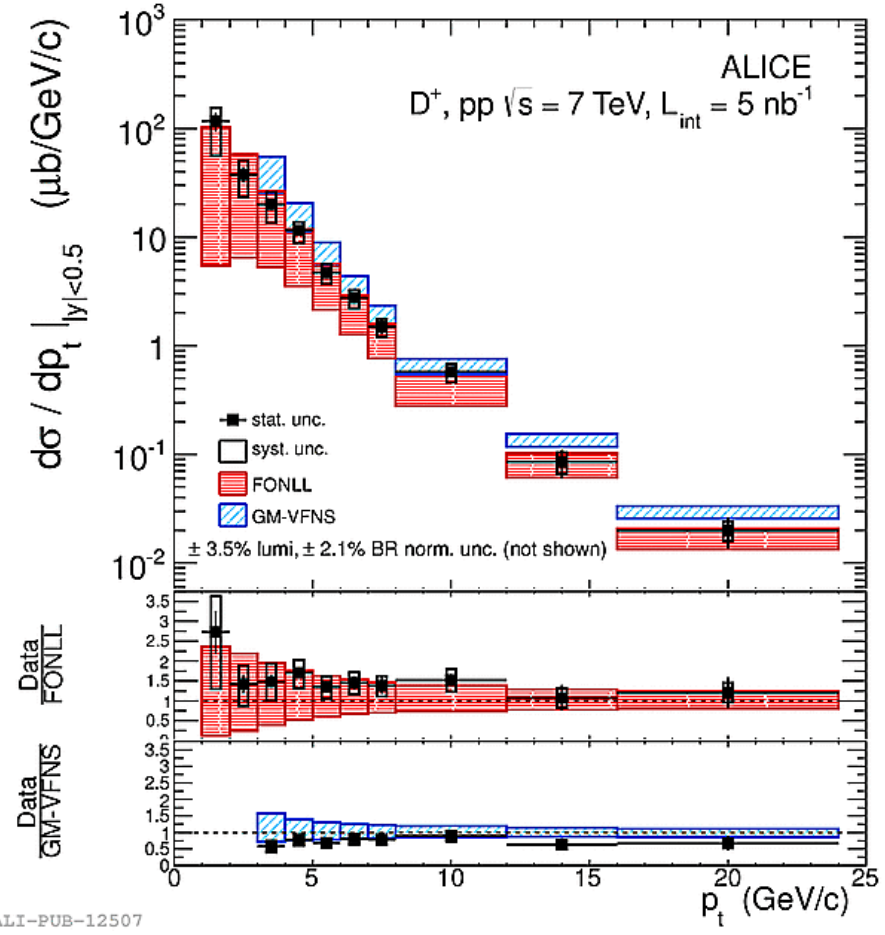
Phys. Lett. B 708(2012) 265



- Productions of leptons (e,μ) from charm + beauty decays in different rapidity ranges are described by pQCD calculations

HF production (D mesons) in pp collisions





- D meson productions in pp collisions at 7 TeV are consistent with pQCD calculations

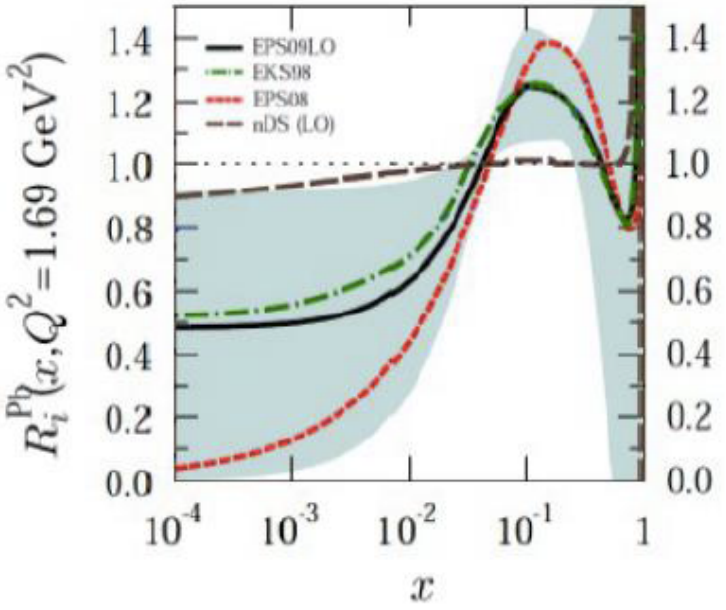
Initial state effects: p-A collisions

- Heavy-flavour in p-A collisions
  - control measurement for heavy-ion collisions to disentangle initial (cold nuclear matter effects) from final state effects
- Cold nuclear matter effects
  - nuclear modification of Parton distribution Functions (PDF): shadowing or gluon saturation

    K.J. Eskola et al., JHEP 0904(2009)65

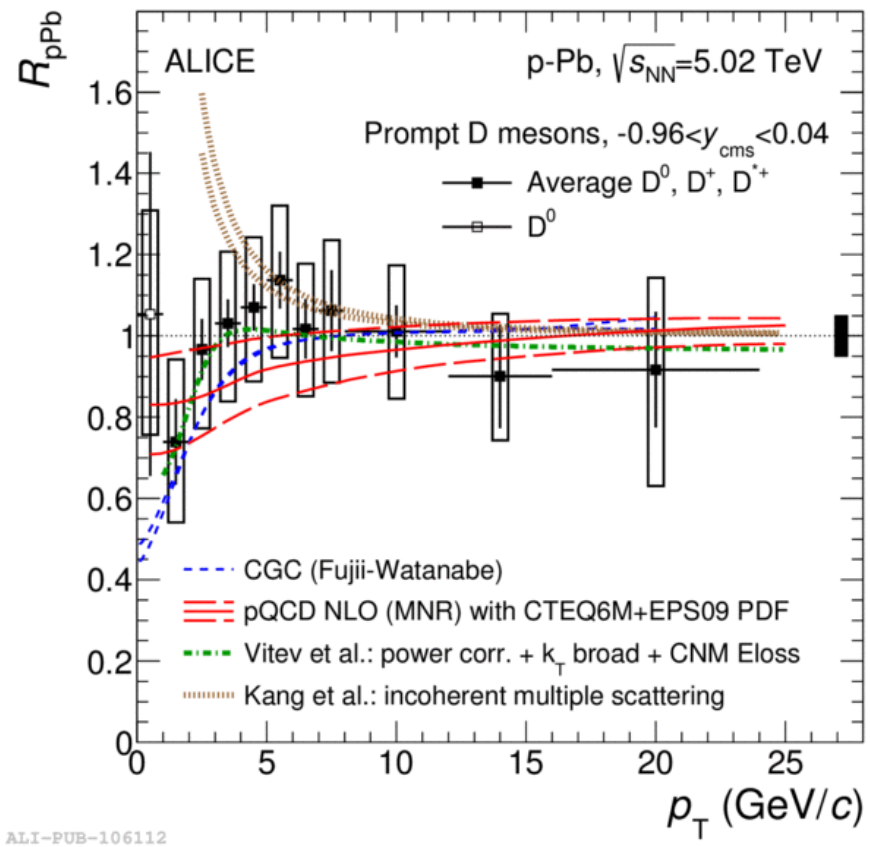
    H. Fuji & K. Watanabe, NPA 915 (2013) 1
  - energy loss I.Vitev et al., PRC 75(2007) 064906
  - k_T broadening (Cronin enhancement)
  - multiple collisions

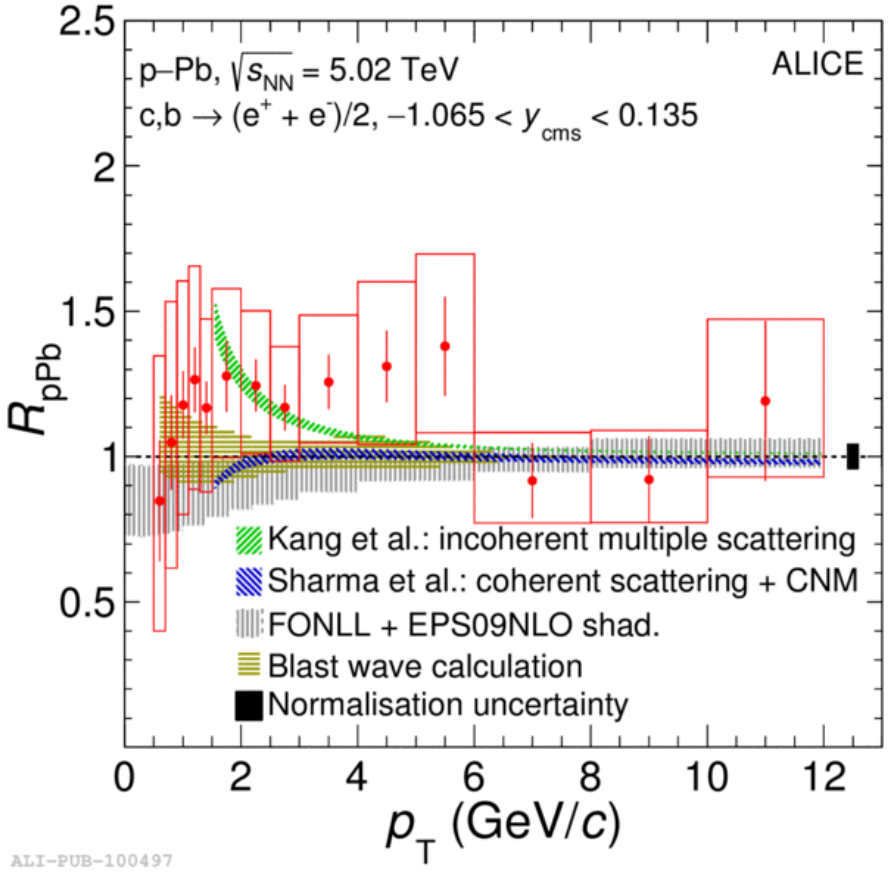
    A.M. Glenn et al., PLB 644(2007)119



$$R_{pPb}(p_T) = \frac{d\,N_{pPb}/dp_T}{\langle T_{AA}\rangle \times d\sigma_{pp}/dp_T}$$

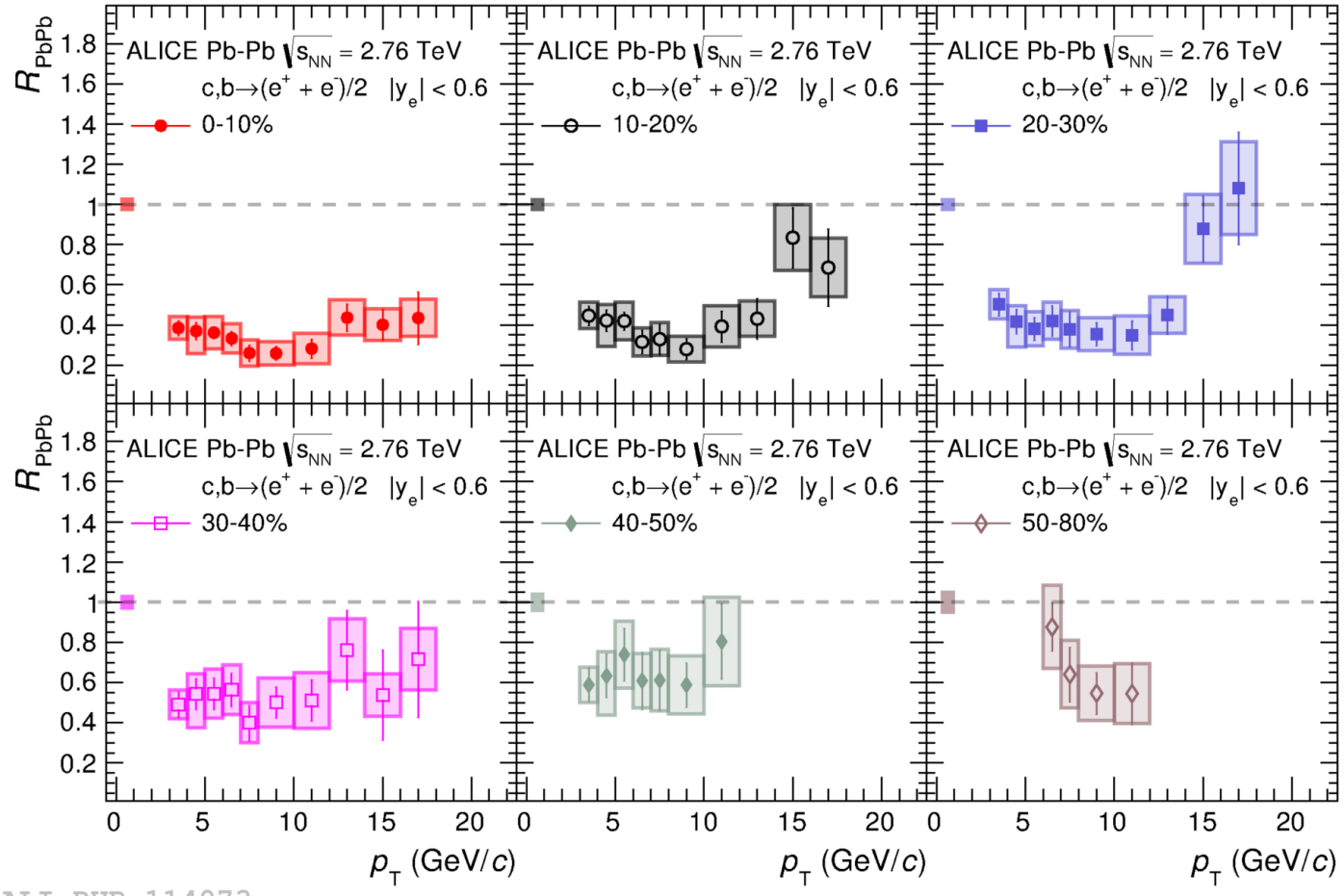
Initial state effects on heavy-flavour productions





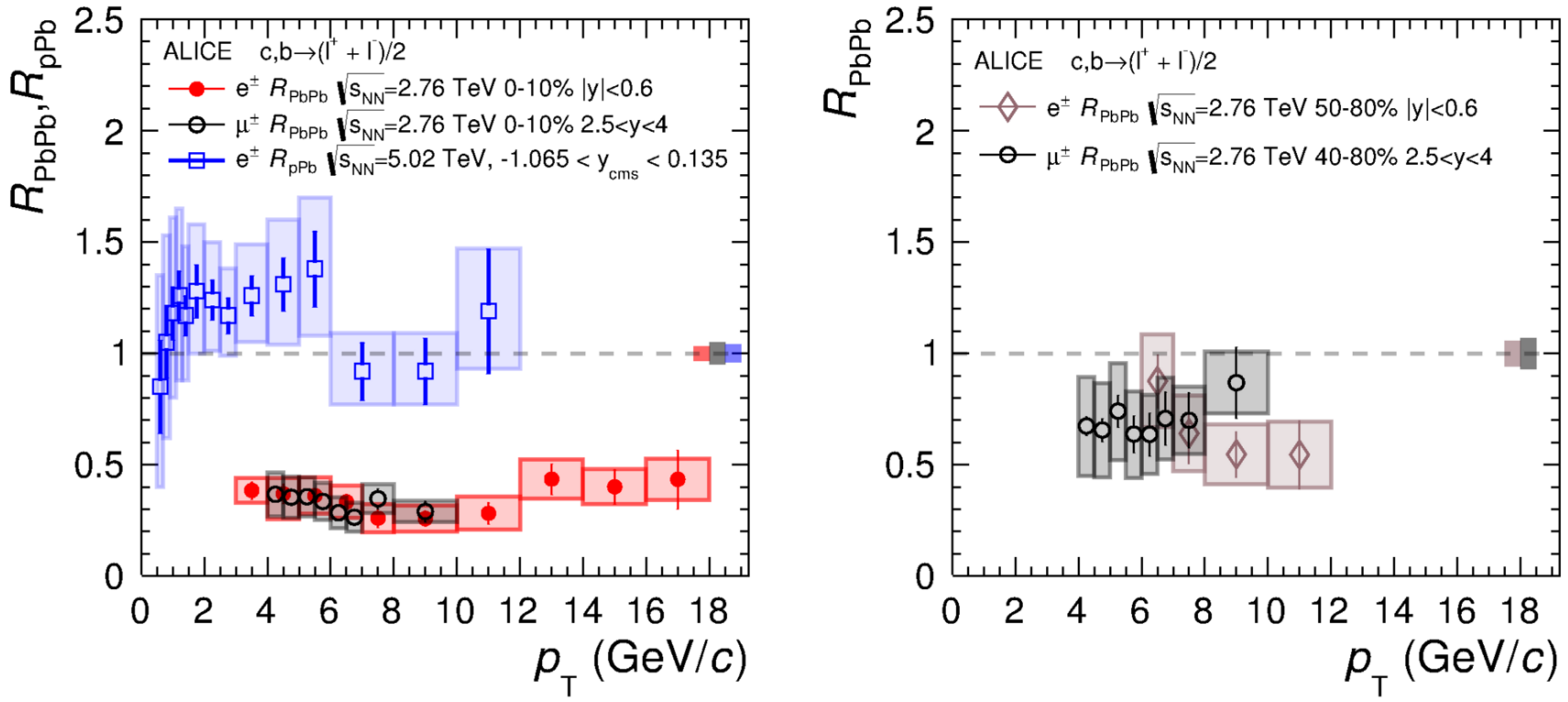
- No Significant cold nuclear matter effects on heavy-flavour production
- A small suppression at low pT is consistent with models included PDF

HF productions (c,b->e) in PbPb collisions at 2.76 TeV



- A strong suppression of heavy-flavour production in most-central collisions
  - Energy loss of heavy quarks in the dense QCD matter
- Less suppression in peripheral collisions

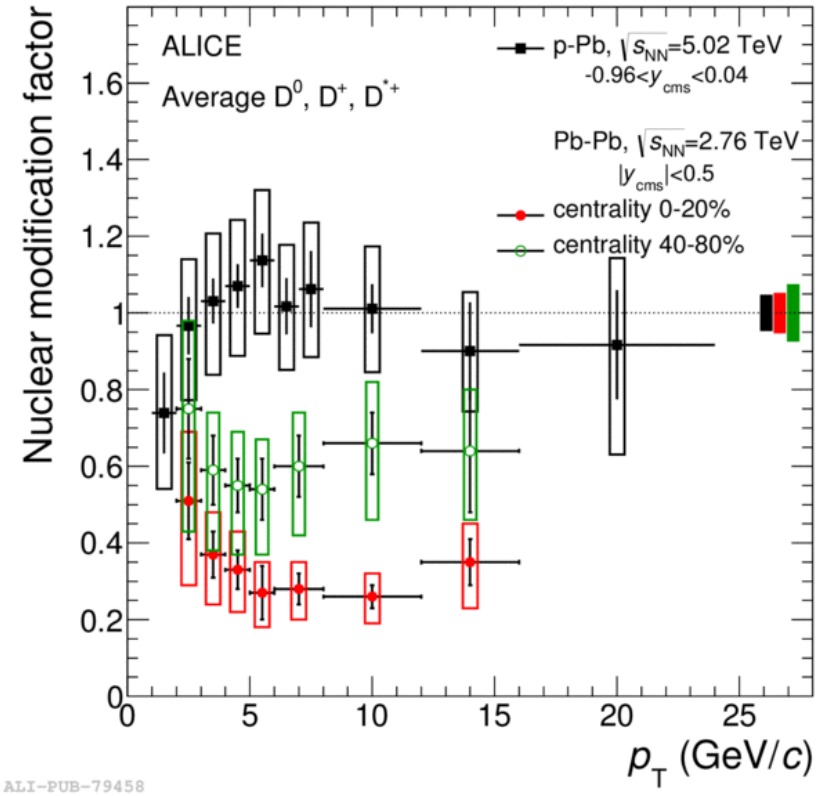
HF productions (c,b->l) in PbPb collisions at 2.76 TeV

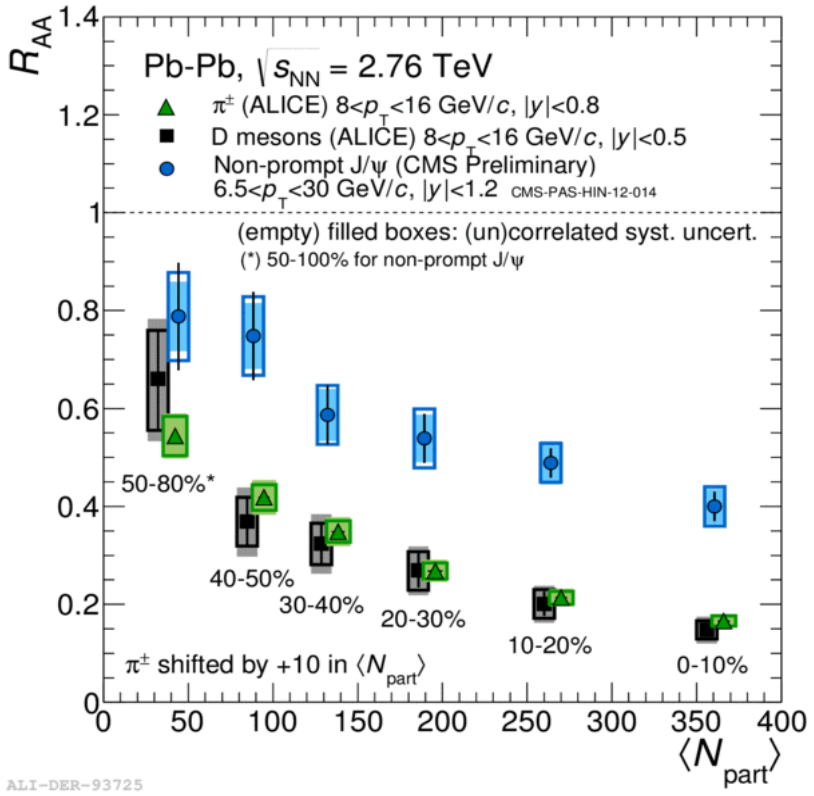


ALI-PUB-114077

- Similar suppression between mid (electrons) and forward (muon) rapidity
  - No significant y dependence of heavy flavour productions

D mesons in central Pb-Pb collisions

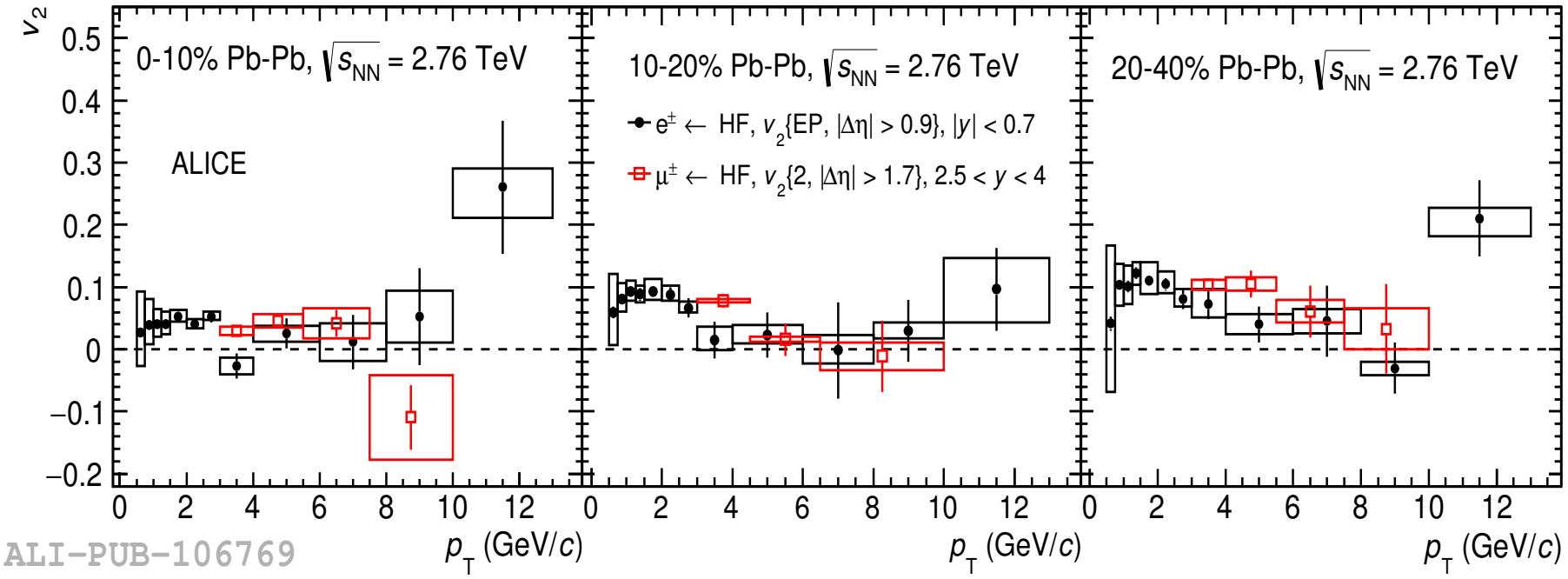




- Strong suppression of D meson production in most central (0-20%) collissions
- Less suppress from central to peripheral
- Similar suppression of light hadrons
- Larger suppression than non-prompt J/ps (B decays)

Azimuthal anisotropy of e^{HF} and μ^{HF}

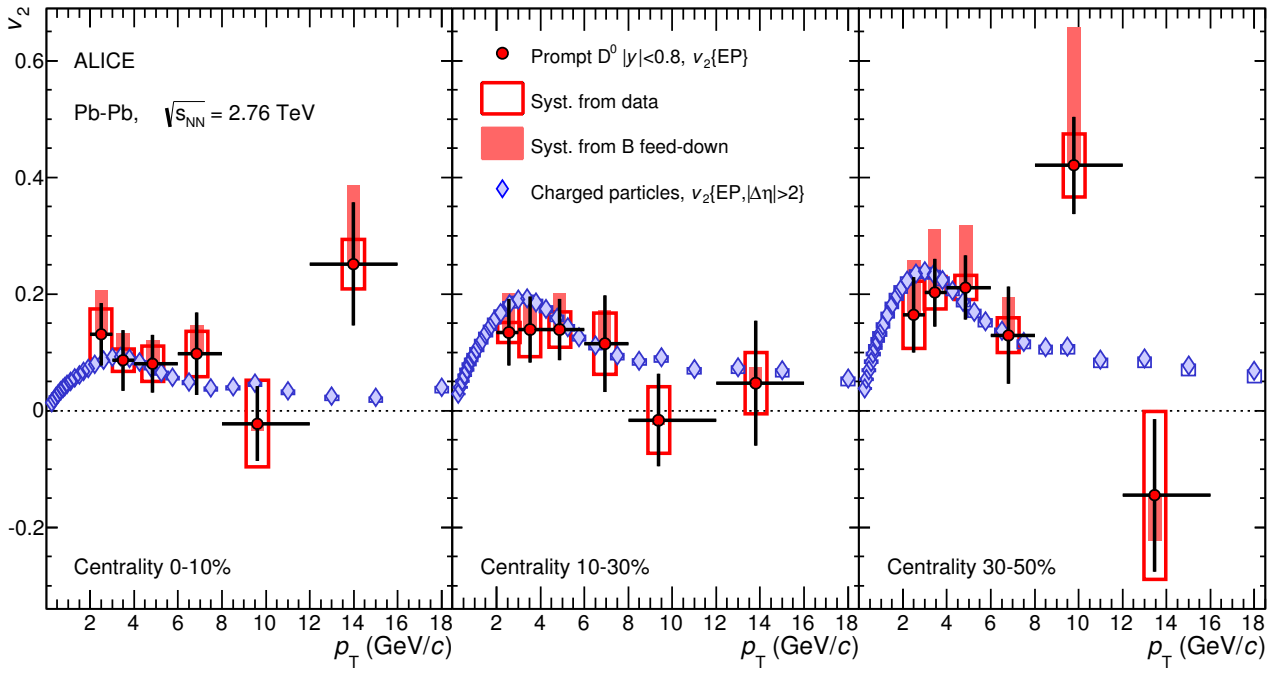
e^{HF} :arXiv: 1606.00321, μHF: PLB 753 (2016) 41-56



- Non-zero v_2 of e^{HF} at |y|<0.7 and μ^{HF} at 2.5<y<4
  - the magnitude is compatible in mid- and forward-rapidities
- v_2 of e^{HF} measured from p_T > 0.5 GeV/*c*
  - similar p_T dependence to other light hadron v_2

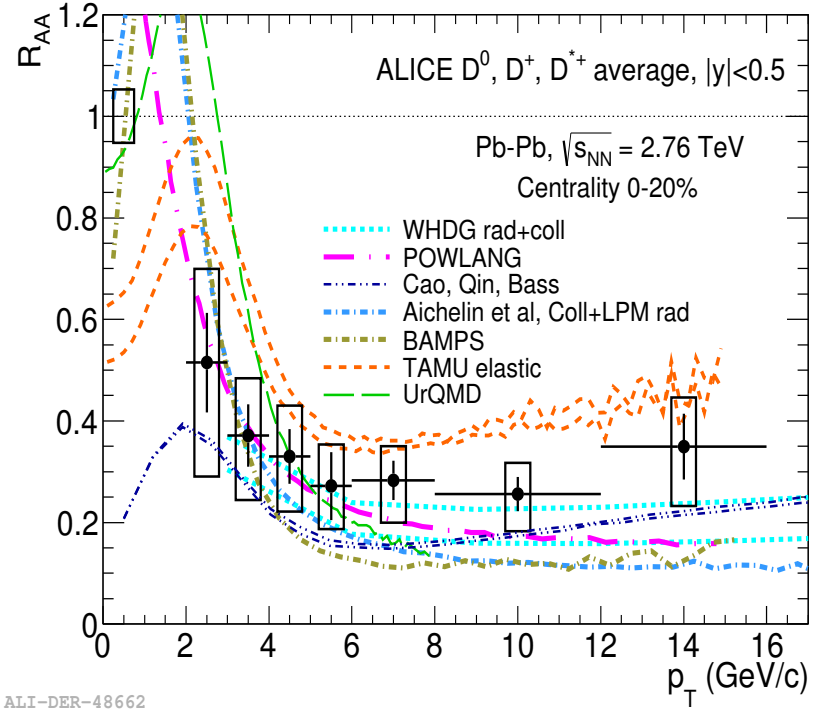
Azimuthal anisotropy of D mesons

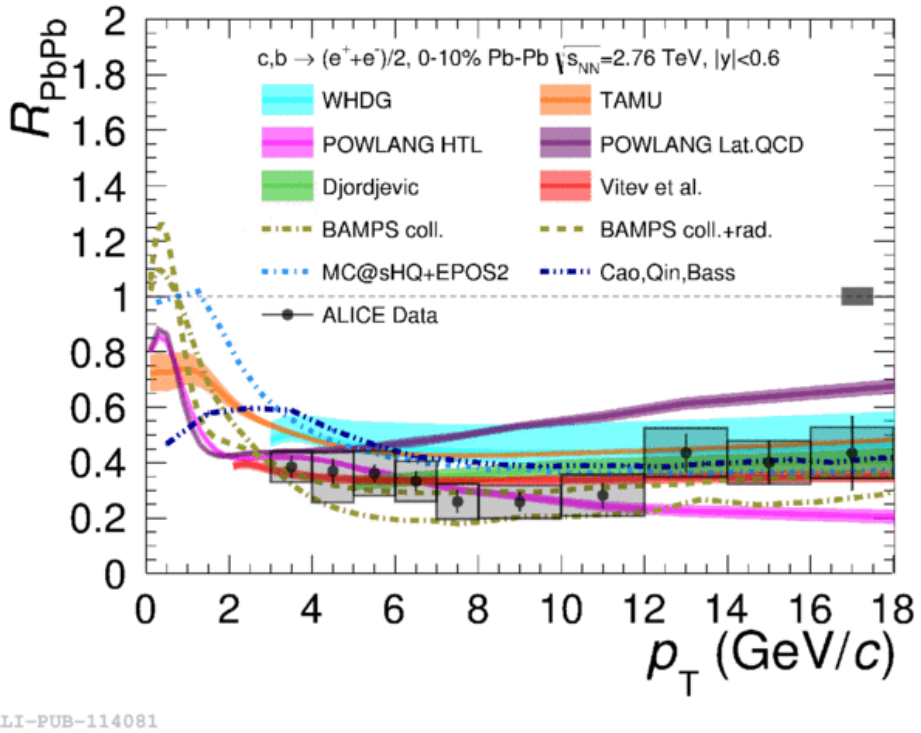
PRC 90 (2014) 034904



- Non zero D v_2 at low p_T
- Tends to get large from central (0-10%) to mid-central (30-50%)
  - Hydrodinamical behavior
- Consistent with charged particle v_2
- Heavy quarks participate collective expansion in the QCD matter

Comparison with models (1)



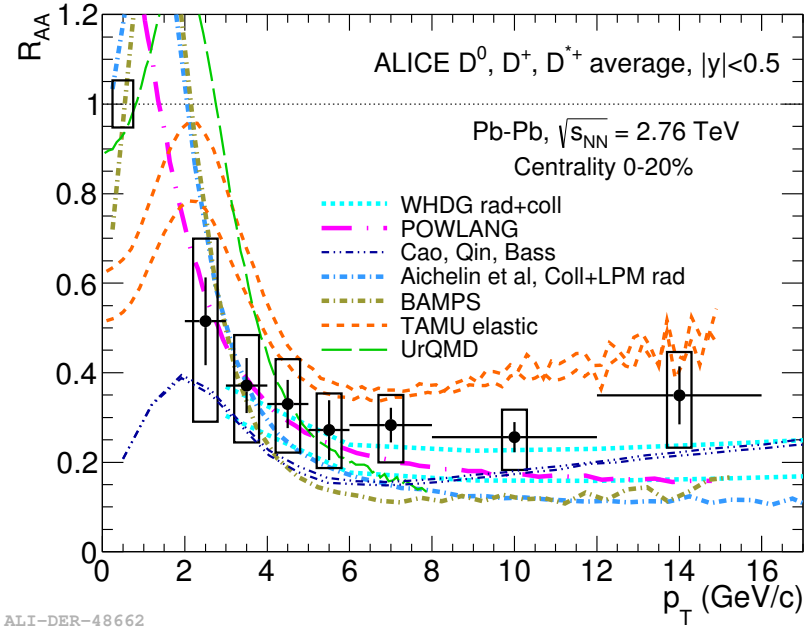


- Theoretical calculations
  - initial: with/without cold nuclear matter from PDF
  - medium modeling: Hydro, Glauber, parton transportation
  - interaction: radiative, collisional, resonant interaction
  - hadronization: fragmentation, coalesenc

BAMPS: J. Phys. G 38 (2011) 124152,
POWLANG: Eur. Phys. J C 71(2011)1666,
UrQMD: arXiv:1211.6912,J. Phys. Conf. Ser. 426,012032(2013),
TAMU: Phys. Rev. C 86 (2012) 014903,
WHDG: J. Phys. G38(2011)124114,
Aichelin: Phys. Rev. C79(2009)044906, J. Phys. G37(2010)094019
Cao,Qin, Bass: arXiv:1308.0617

Comparison with models (2)

JHEP09(2012)112



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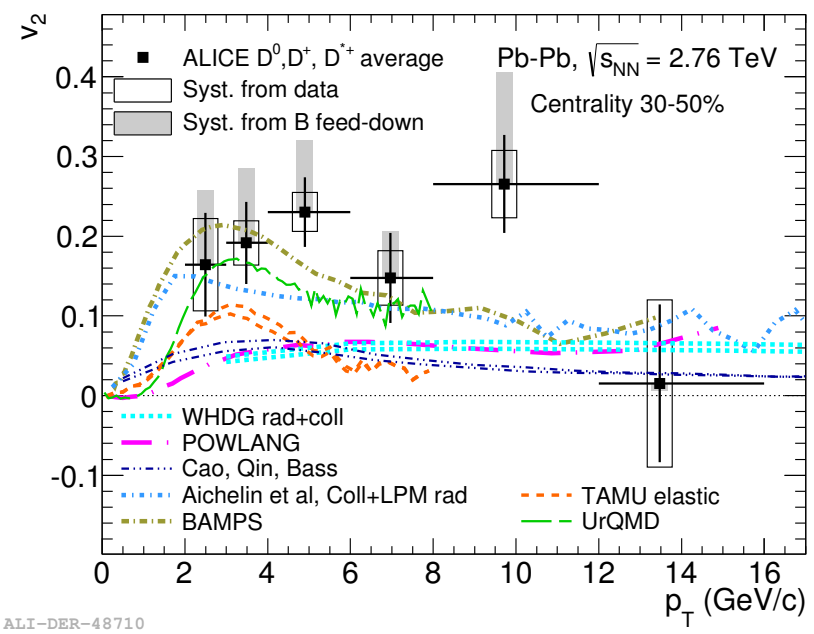

- Theoretical calculations
  - initial: with/without cold nuclear matter from PDF
  - medium modeling: Hydro, Glauber, parton transportation
  - interaction: radiative, collisional, resonant interaction
  - hadronization: fragmentation, coalesence
- Large suppression and non-zero v_2 (at low p_T) are represented by models, but simultaneous reproduction of the R_{AA} and v_2 is challenging

Summary

- Heavy-flavour measurements at LHC-ALICE
  - Studies by measuring leptons from charm and beauty decays and D
- The productions are well described by pQCD calculations in pp collisions
- Cold nuclear matter effects is very small on heavy-flavour productions
- Pb-Pb collisions
  - Strong suppression of heavy-flavour productions
    - Clear indication for substantial energy loss of charm and beauty in the hot
      - No rapidity and energy dependence
  - Non-zero & centrality dependence of v_2
    - Suggest strong re-interaction in the medium
- Heavy flavours observed to be significantly affected by hot and dense QCD medium
- Outlook at Run2: beauty (e, non-prompy J/psi), heavy-flavour jet,
  heavy-flavour correlations