

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 ($M_{\text{HF}} \gg \Lambda_{\text{QCD}}$)
- ▶ **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
 - $E_{\text{loss}}(g) > E_{\text{loss}}(u,d,s) > E_{\text{loss}}(c) > E_{\text{loss}}(b)$

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

Nuclear modification factor

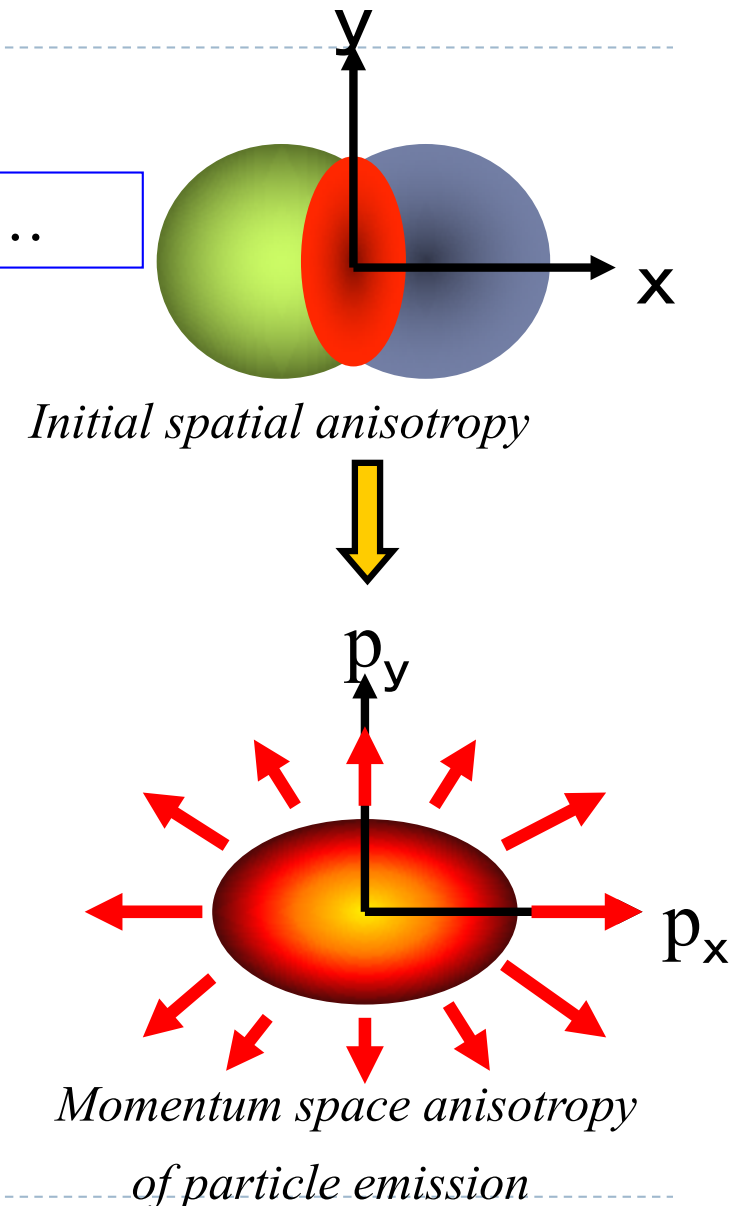
$$R_{AA}(p_T) = \frac{d N_{AA}/dp_T}{\langle T_{AA} \rangle \times d\sigma_{pp}/dp_T}$$

Azimuthal anisotropy of Heavy flavours

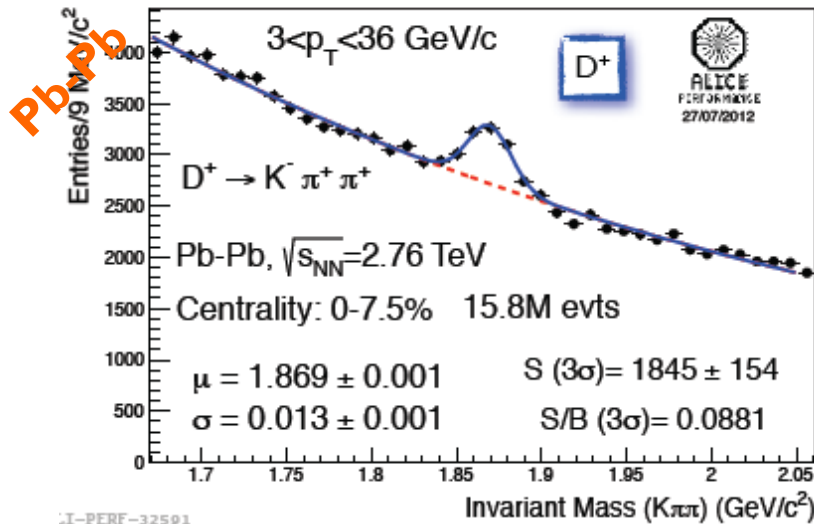
■ Elliptic flow

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

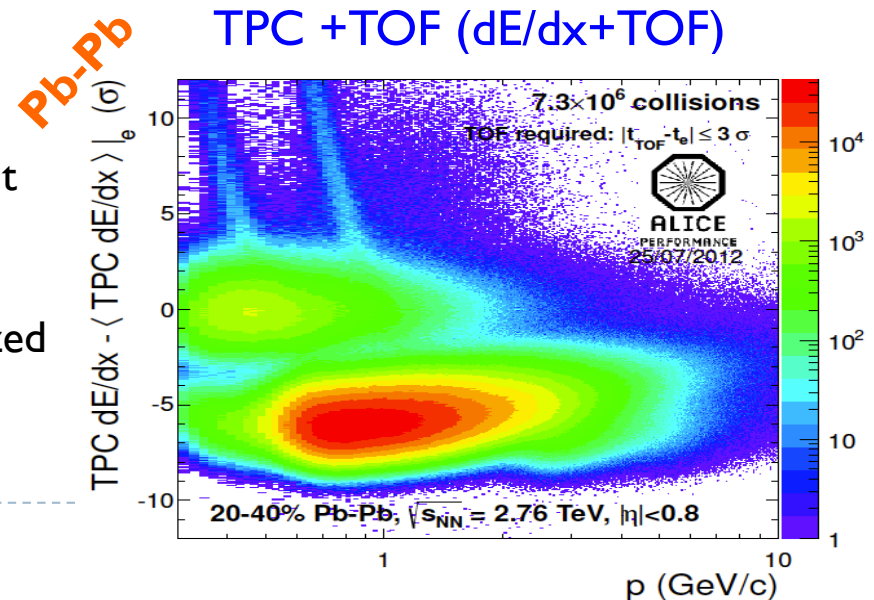
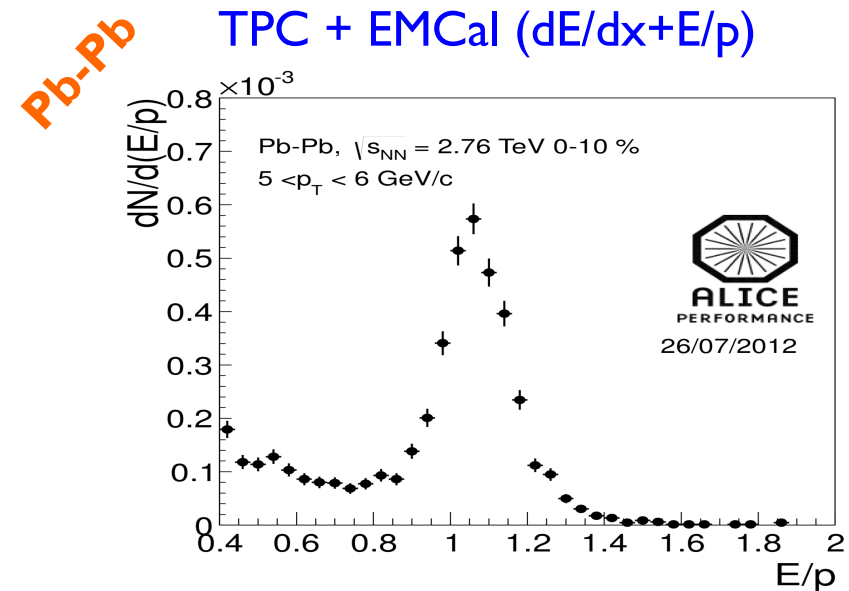
- Transfer initial spatial anisotropy to momentum anisotropy
 - macroscopic: hydro model
 - => pressure gradient
 - microscopic
 - => scattering in the medium
- Low p_T
 - coupling of heavy quarks with the medium and their thermalization
- Intermediate p_T
 - Hadronization mechanism (recombination)
-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



Heavy-flavour measurements in ALICE

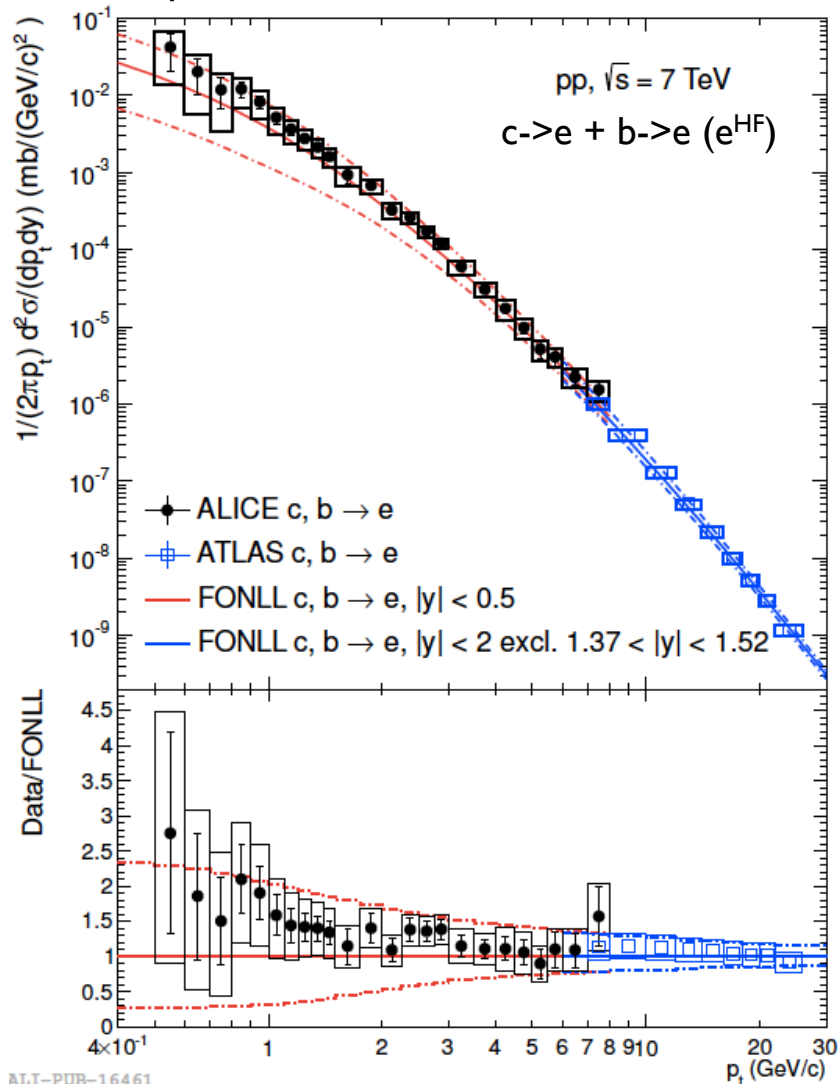


- D meson reconstruction ($|y| < 0.5$)
 - displaced-vertex topology
 - π/K ID: TPC+TOF
- HFE ($|y| < 0.5$ or 0.6)
 - background subtraction: cocktail & invariant mass method
- HFM ($2.5 < y < 4$)
 - background subtraction: used MC normalized to data at low p_T (pp), inputs from central-barrel & extrapolation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



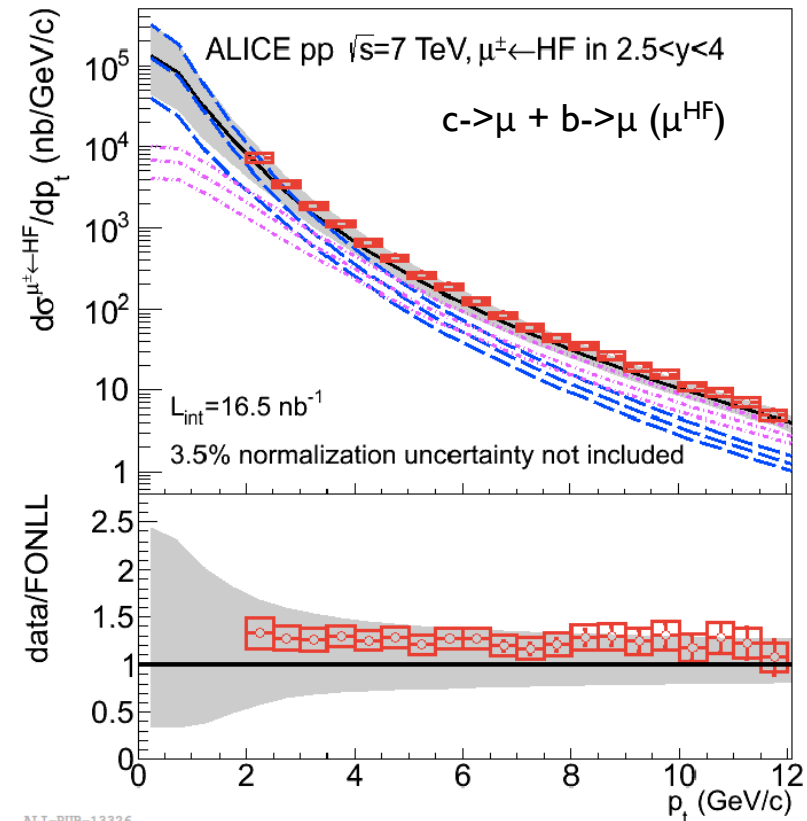
HF production (c,b→l) in pp collisions

Phys. Rev. D 86, 112007



ALI-PUB-16461

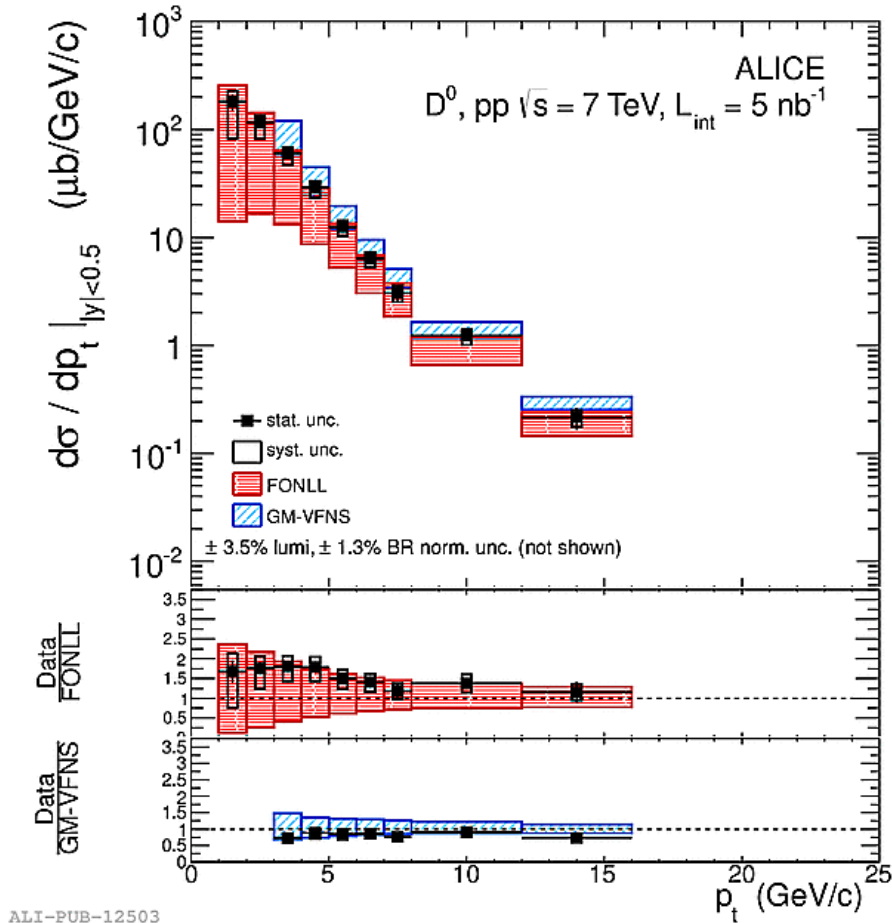
Phys. Lett. B 708(2012) 265



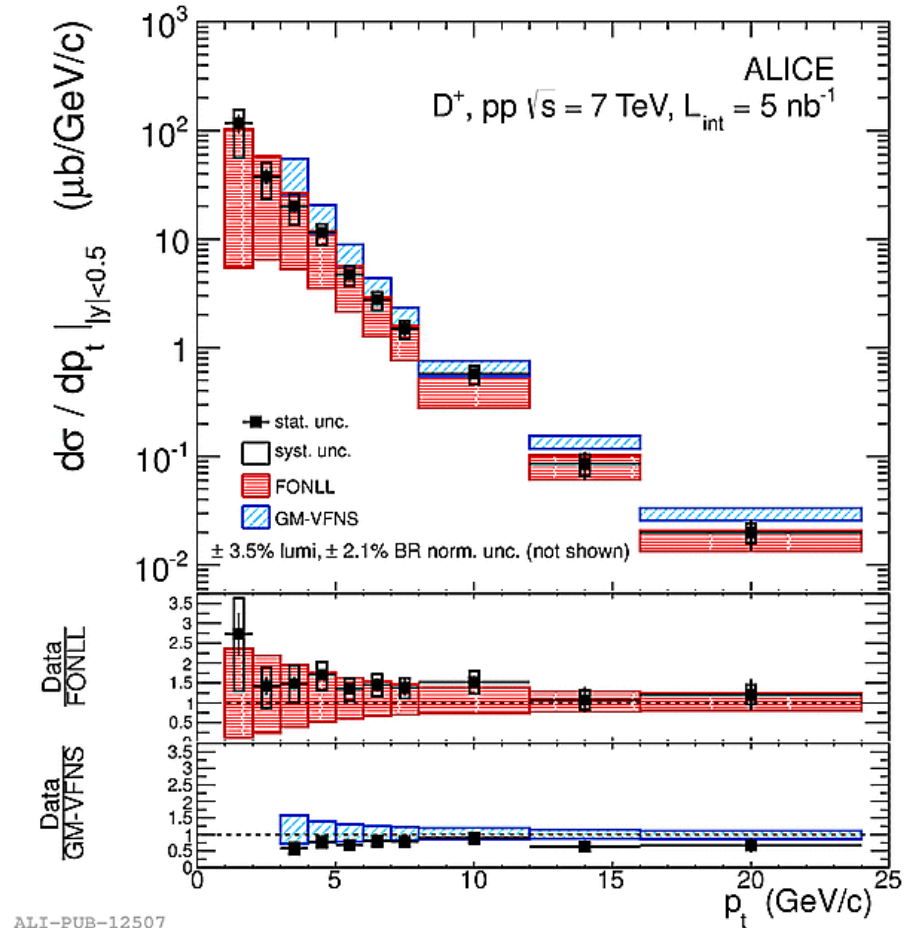
ALI-PUB-13326

- 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



ALI-PUB-12503



ALI-PUB-12507

- 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

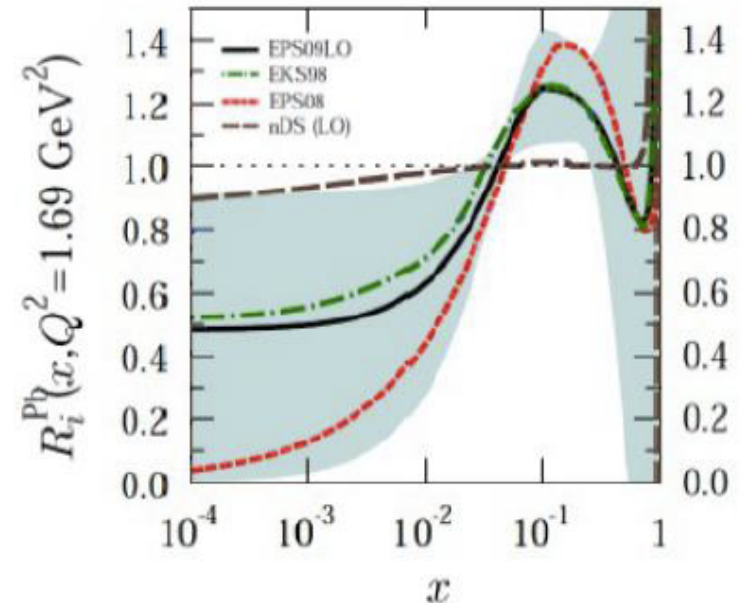
- nuclear modification of Parton distribution Functions (PDF): shadowing or gluon saturation

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

H. Fuji & K. Watanabe, NPA 915 (2013) 1

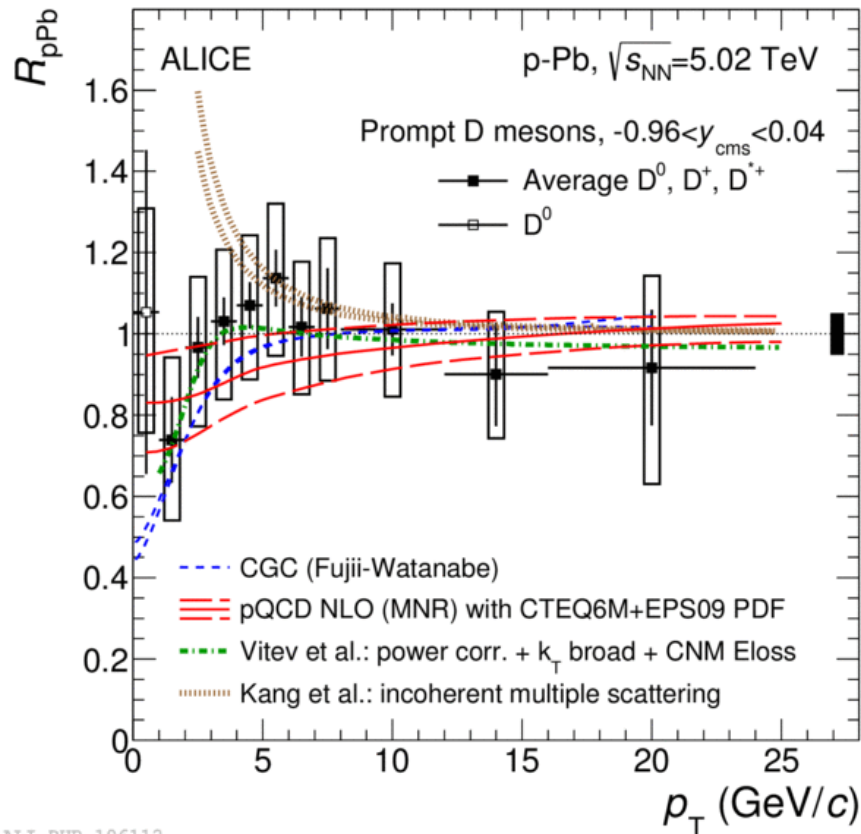
- energy loss I. Vitev et al., PRC 75(2007) 064906
- k_T broadening (Cronin enhancement)
- multiple collisions

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

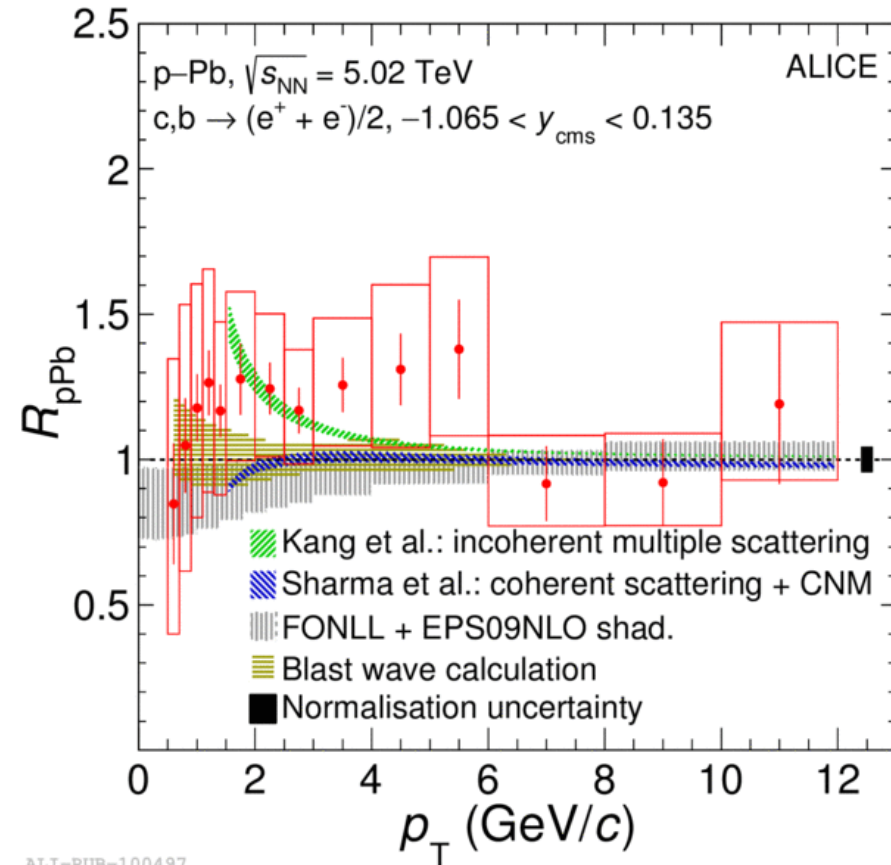


$$R_{pPb}(p_T) = \frac{d N_{pPb}/dp_T}{\langle T_{AA} \rangle \times d\sigma_{pp}/dp_T}$$

Initial state effects on heavy-flavour productions



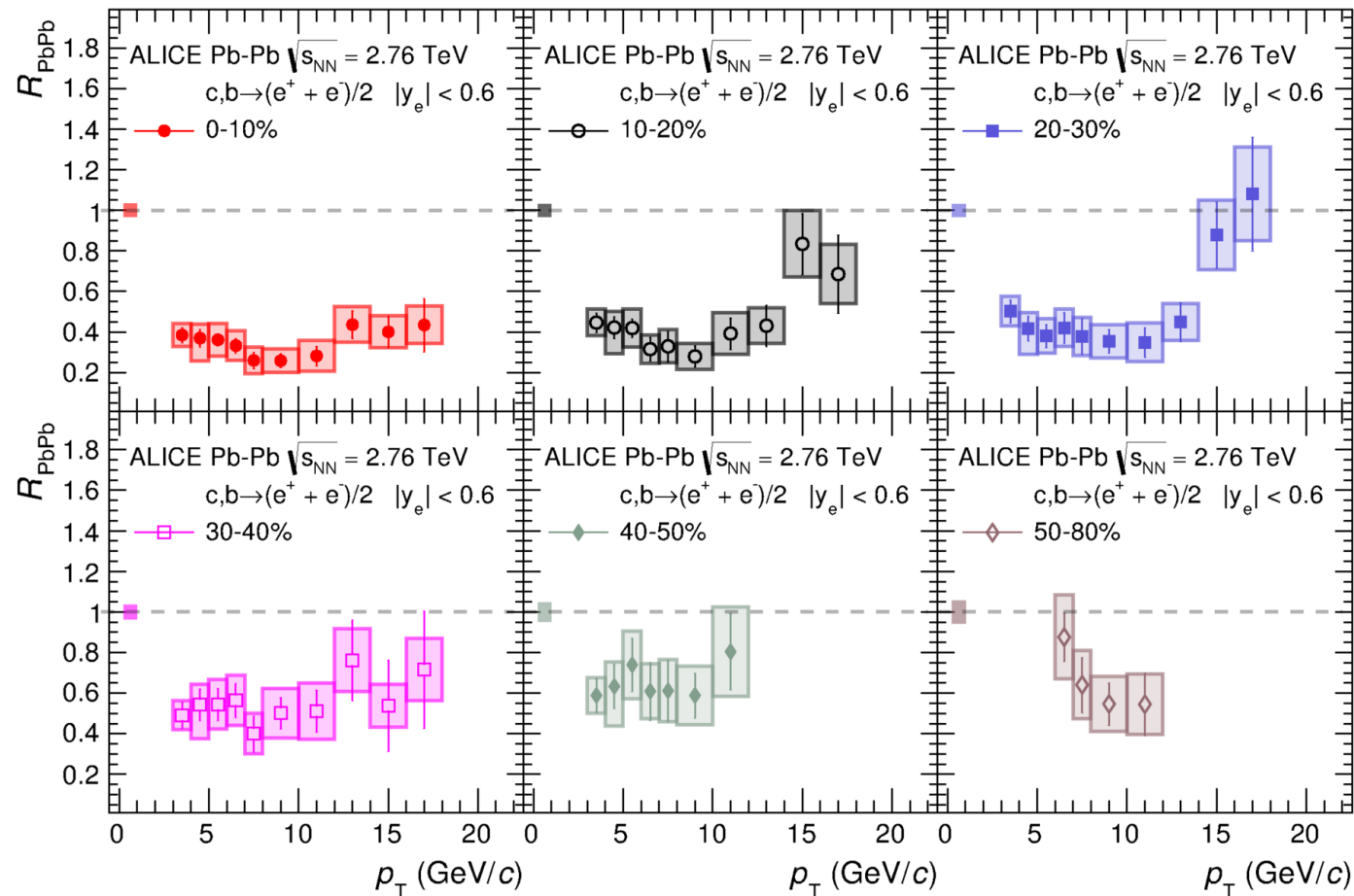
ALI-PUB-106112



ALI-PUB-100497

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

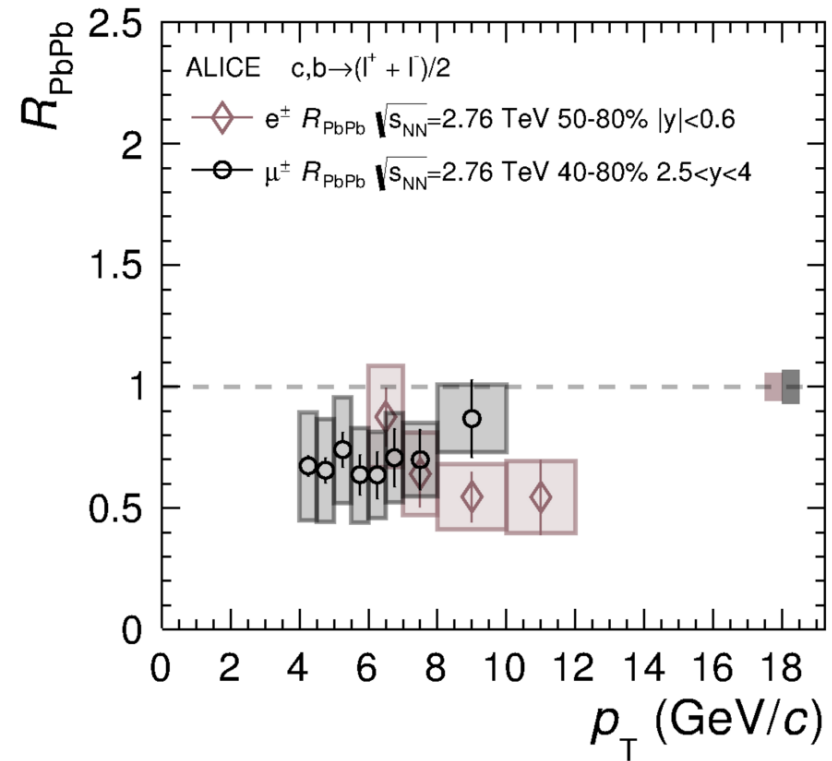
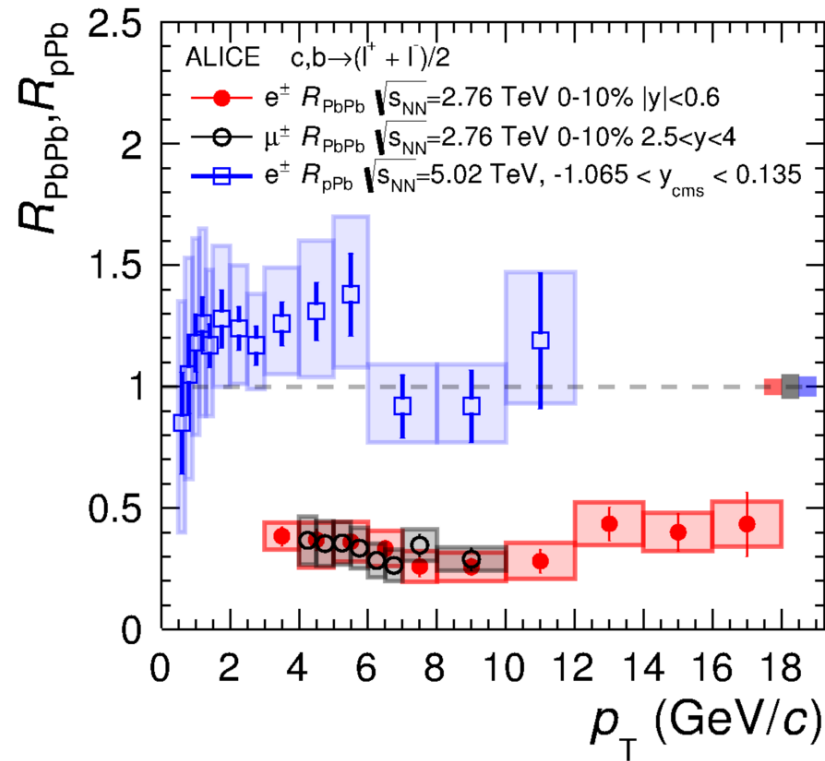
HF productions (c,b $\rightarrow$ e) in PbPb collisions at 2.76 TeV



ALICE-PUB-114073

- 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

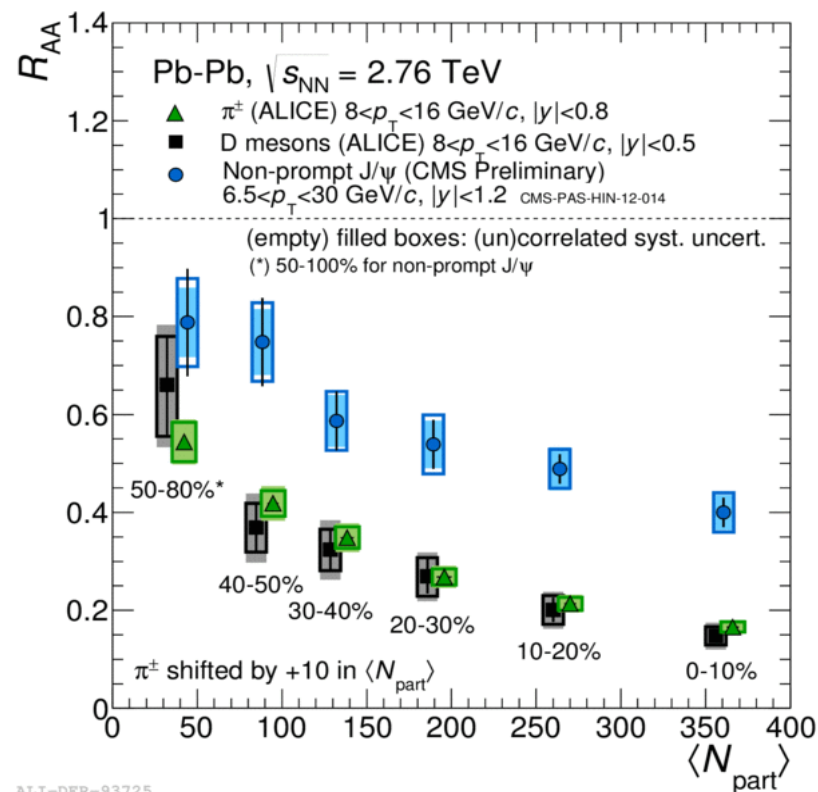
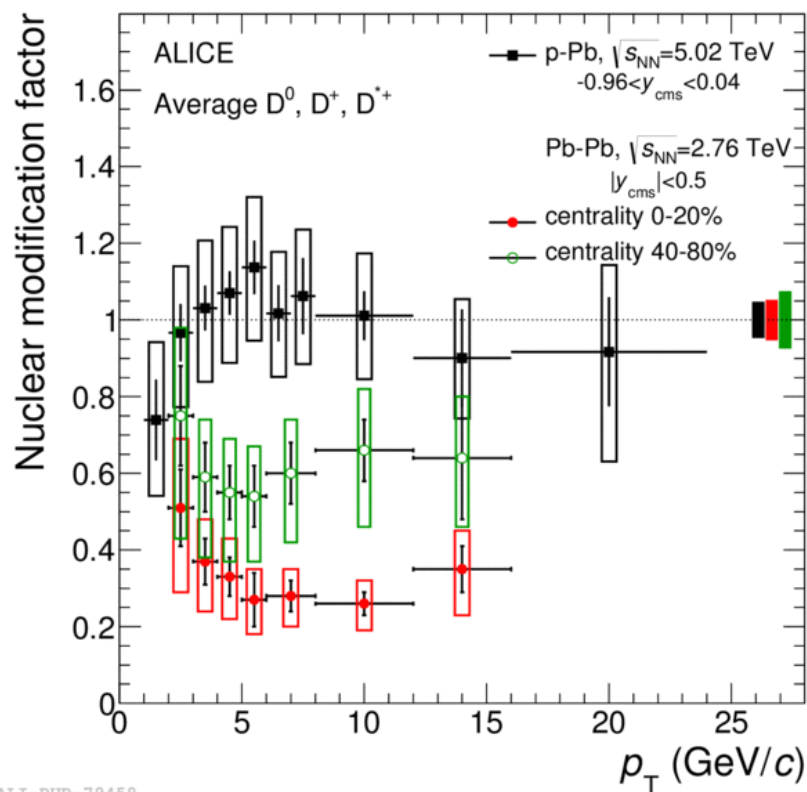
HF productions (c,b $\rightarrow$ l) in PbPb collisions at 2.76 TeV



ALI-PUB-114077

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

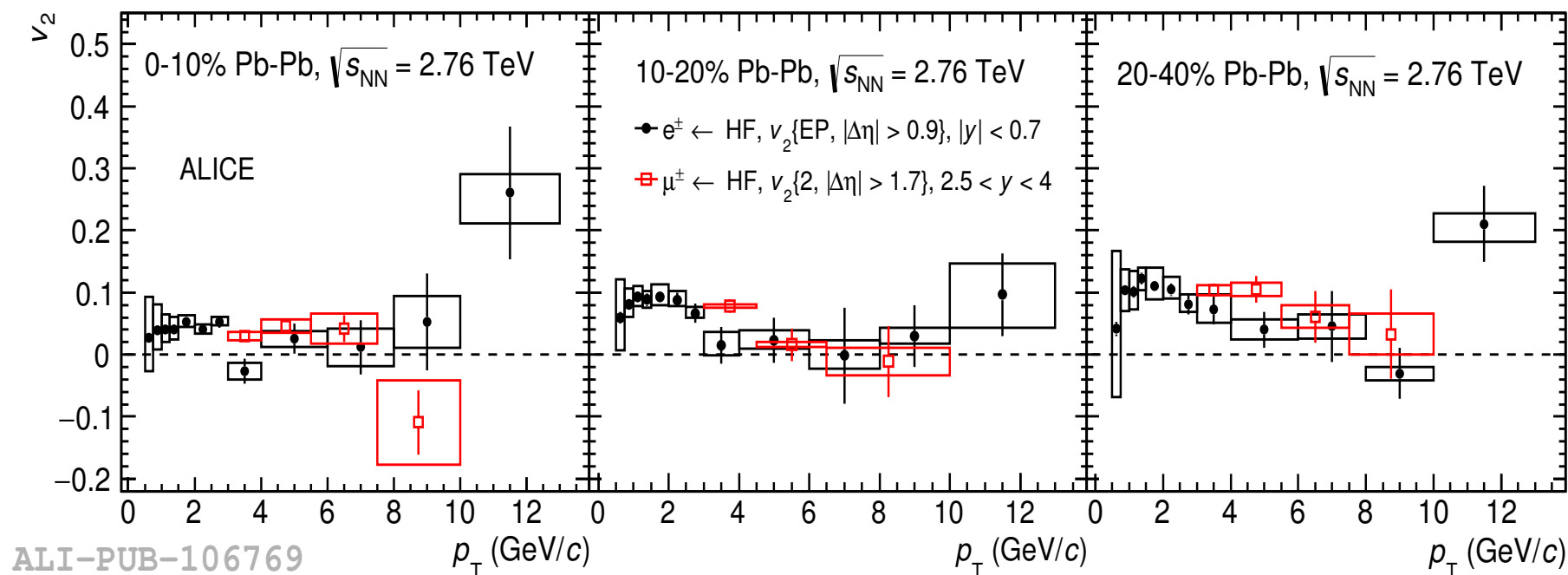
D mesons in central Pb-Pb collisions



- Strong suppression of D meson production in most central (0-20%) collisions
- 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}

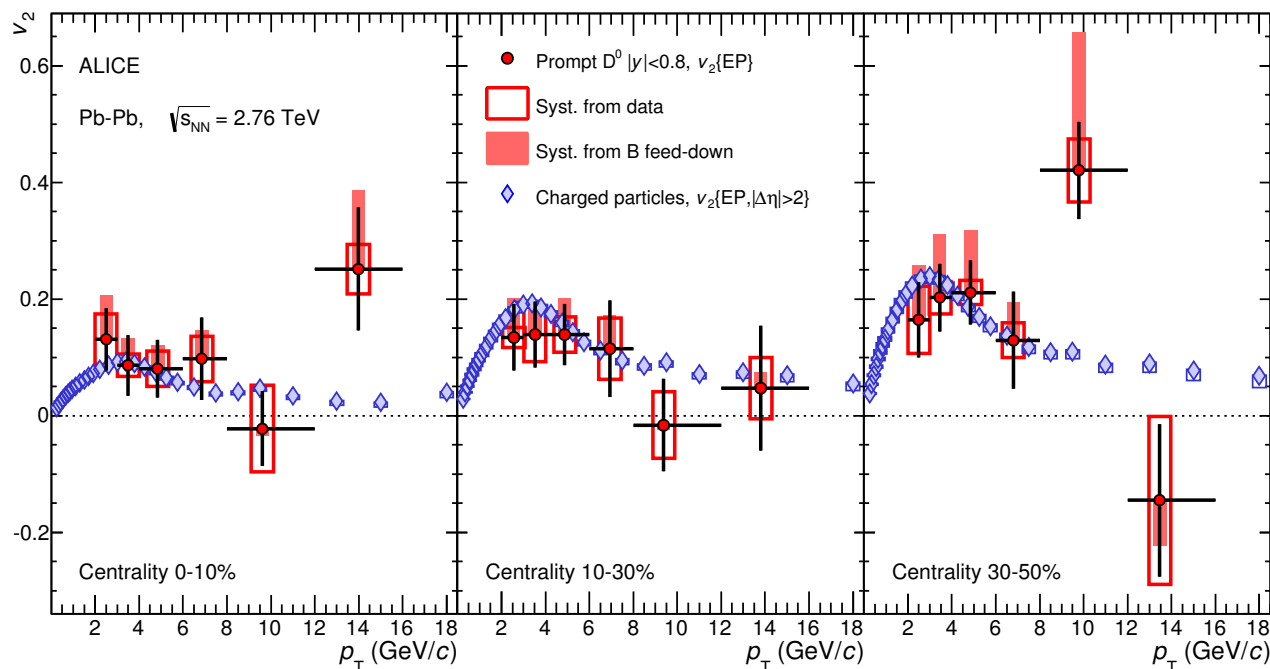
e^{HF} : arXiv: 1606.00321, μ^{HF} : PLB 753 (2016) 41-56



- 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 $p_{\text{T}} > 0.5$ GeV/c
 - similar p_{T} dependence to other light hadron v_2

Azimuthal anisotropy of D mesons

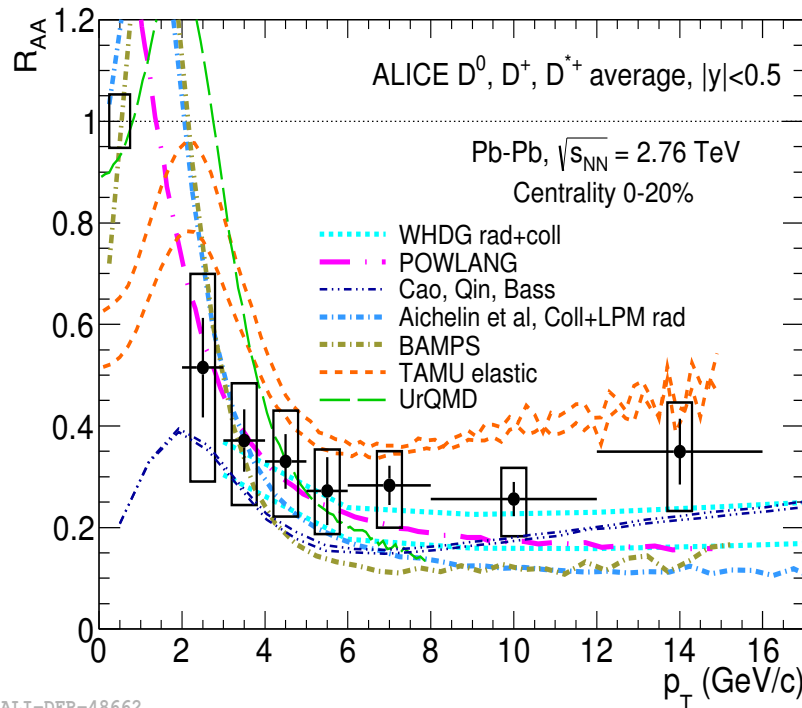
PRC 90 (2014) 034904



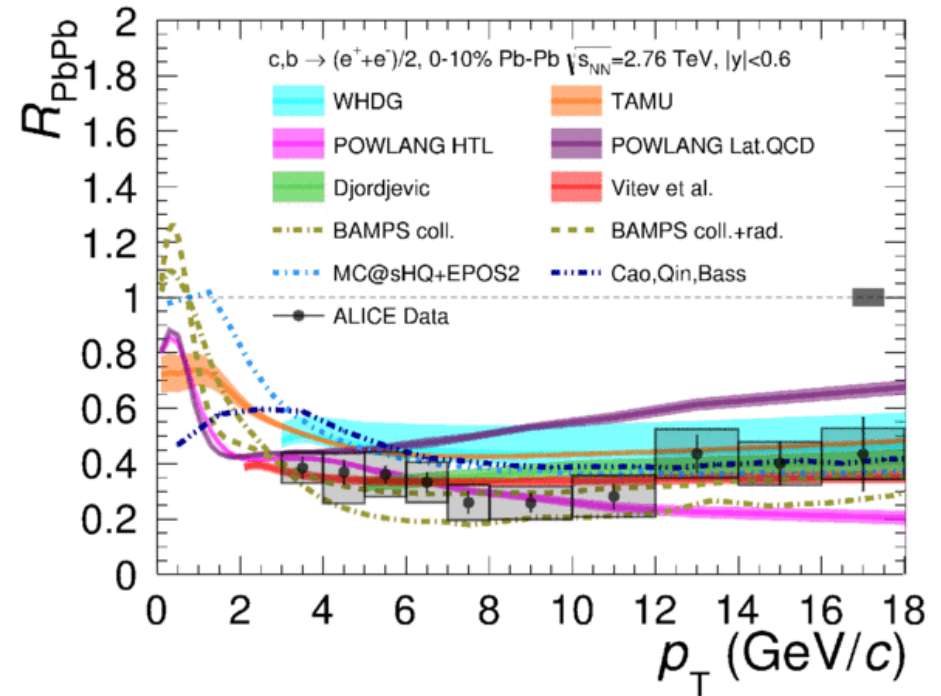
ALI-PUB-70100

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

Comparison with models (1)



ALI-DER-48662



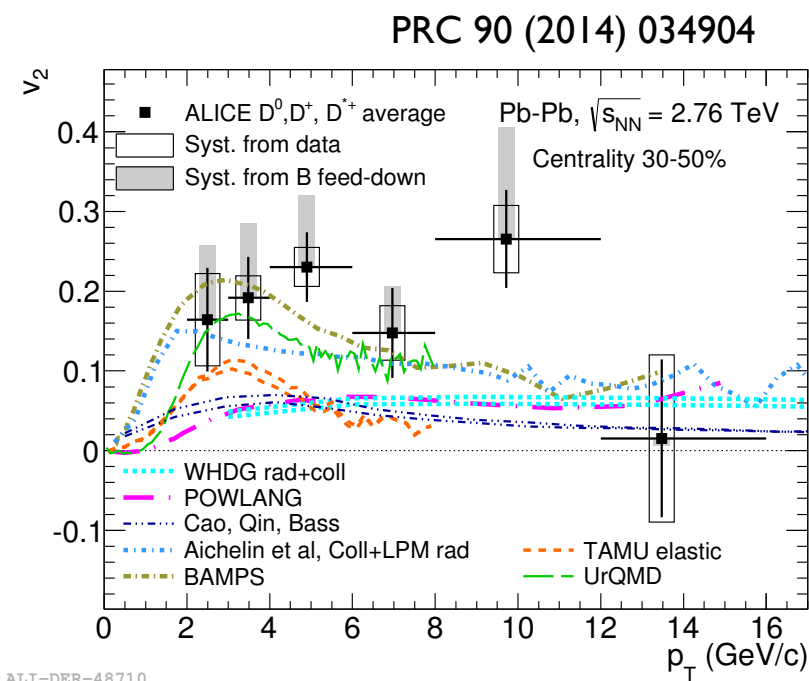
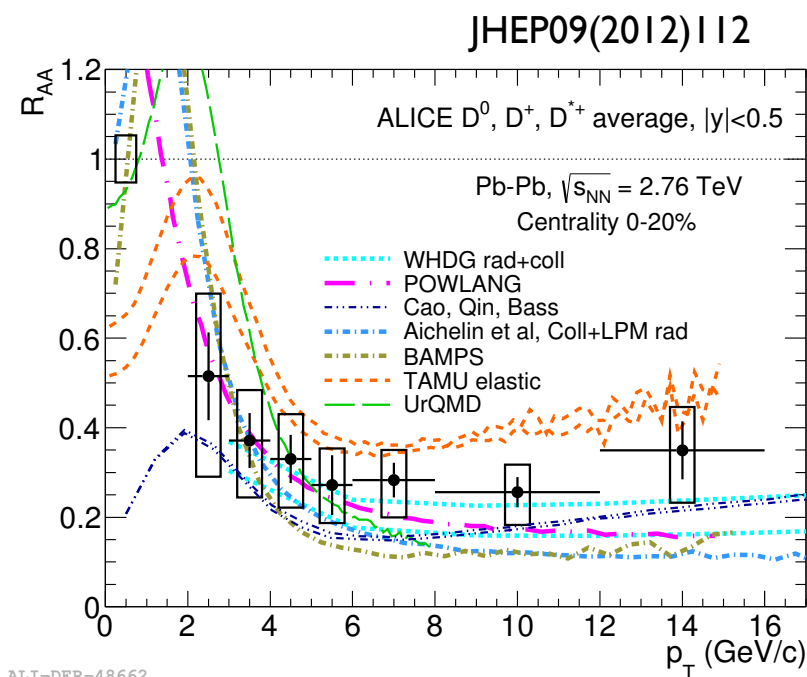
ALI-PUB-114081

Theoretical calculations

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

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)



- Theoretical calculations
 - initial: with/without cold nuclear matter from PDF
 - medium modeling: Hydro, Glauber, parton transportation
 - interaction: radiative, collisional, resonant interaction
 - hadronization: fragmentation, coalescence
- 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-prompt J/psi), heavy-flavour jet, heavy-flavour correlations

