Measurement of open heavy-flavour production in p-Pb collisions with ALICE at the LHC

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Outline

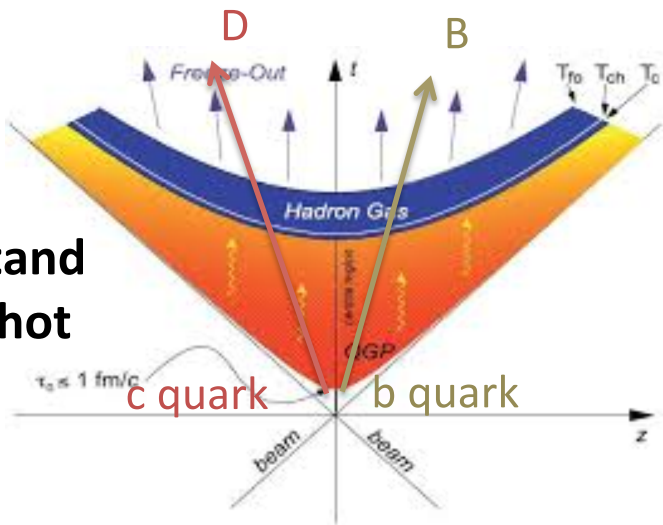
- Physics Motivation
- Observables
- Measurement of open heavy flavours (HF) with ALICE
- Results

  - D-meson and HF-decay electron production as a function of multiplicity
  - Nuclear modification factor of D mesons and HF-decay electrons
  - HF-hadron correlations
  - HF-decay electron flow
- Summary

Physics Motivation

➢ **Heavy quarks, i.e. charm and beauty quarks are excellent probes to study the properties of the strongly-interacting medium created in heavy-ion collisions :**

- ✓ Produced in the early stages of the collisions
- ✓ Witness entire space-time evolution of the system
- ✓ Interact with the hot and dense QCD matter
- ✓ Parton energy loss by radiative and elastic processes



➢ **Comparison of p-Pb and Pb-Pb collisions to understand and disentangle the cold nuclear matter effects from hot nuclear effects**

➢ **Cold nuclear matter effects include:**

- ✓ modifications of the parton distribution functions in nuclei (nPDF)
- ✓ Gluon saturation at low x (color glass condensate)
- ✓ k_T-broadening
- ✓ Energy loss

➢ **Possibility of final-state effects** *: Phys.Rev. D83 (2011) 114036, PLB 718 (2013) 795*

Observables : Nuclear modification factor

- Defined as :

$$R_{\mathrm{pPb}}(p_{\mathrm{T}}) = \frac{dN_{\mathrm{pPb}} / dp_{\mathrm{T}}}{\langle T_{\mathrm{pPb}} \rangle d\sigma_{\mathrm{pp}} / dp_{\mathrm{T}}}$$

$\langle T_{pPb} \rangle$ -> average nuclear overlap function

Centrality dependent nuclear modification factor:

$$Q_{\mathrm{pPb}}(p_{\mathrm{T}}) = \frac{dN^{\mathrm{cent}}_{\mathrm{pPb}} / dp_{\mathrm{T}}}{\langle T^{\mathrm{cent}}_{\mathrm{pPb}} \rangle d\sigma_{\mathrm{pp}} / dp_{\mathrm{T}}}$$

Central to peripheral ratio:

$$Q_{\mathrm{cp}}(p_{\mathrm{T}}) = \frac{(dN^{0-10\%}_{\mathrm{pPb}} / dp_{\mathrm{T}}) / \langle T^{0-10\%}_{\mathrm{pPb}} \rangle}{(dN^{60-100\%}_{\mathrm{pPb}} / dp_{\mathrm{T}}) / \langle T^{60-100\%}_{\mathrm{pPb}} \rangle}$$

- R_{pPb} (Q_{pPb}) = 1 at high transverse momentum (p_T) indicates no medium effects, no CNM effects

- R_{pPb} (Q_{pPb}) < 1 at high p_T indicates a modification/softening of the spectra at high p_T which can be related to parton energy loss.

Observables : Two-particle correlations

- Two-particle correlations of open heavy flavours
- Heavy-flavour electrons or D mesons (trigger particles) with charged particles (associated particles)

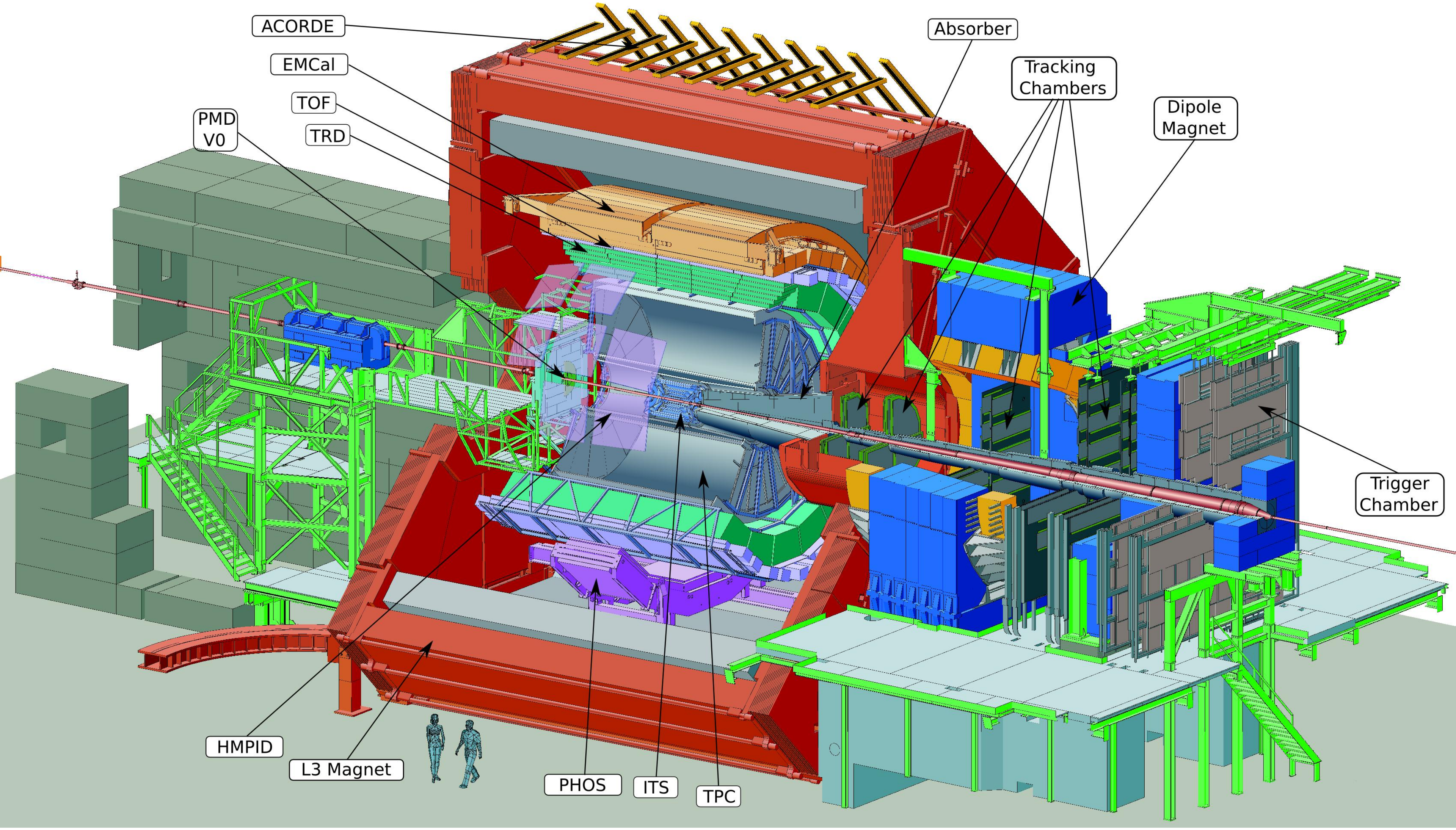
- Two-particle correlation function is defined as:

$$h(\Delta\varphi,\Delta\eta)=\frac{s(\Delta\varphi,\Delta\eta)}{b(\Delta\varphi,\Delta\eta)}$$

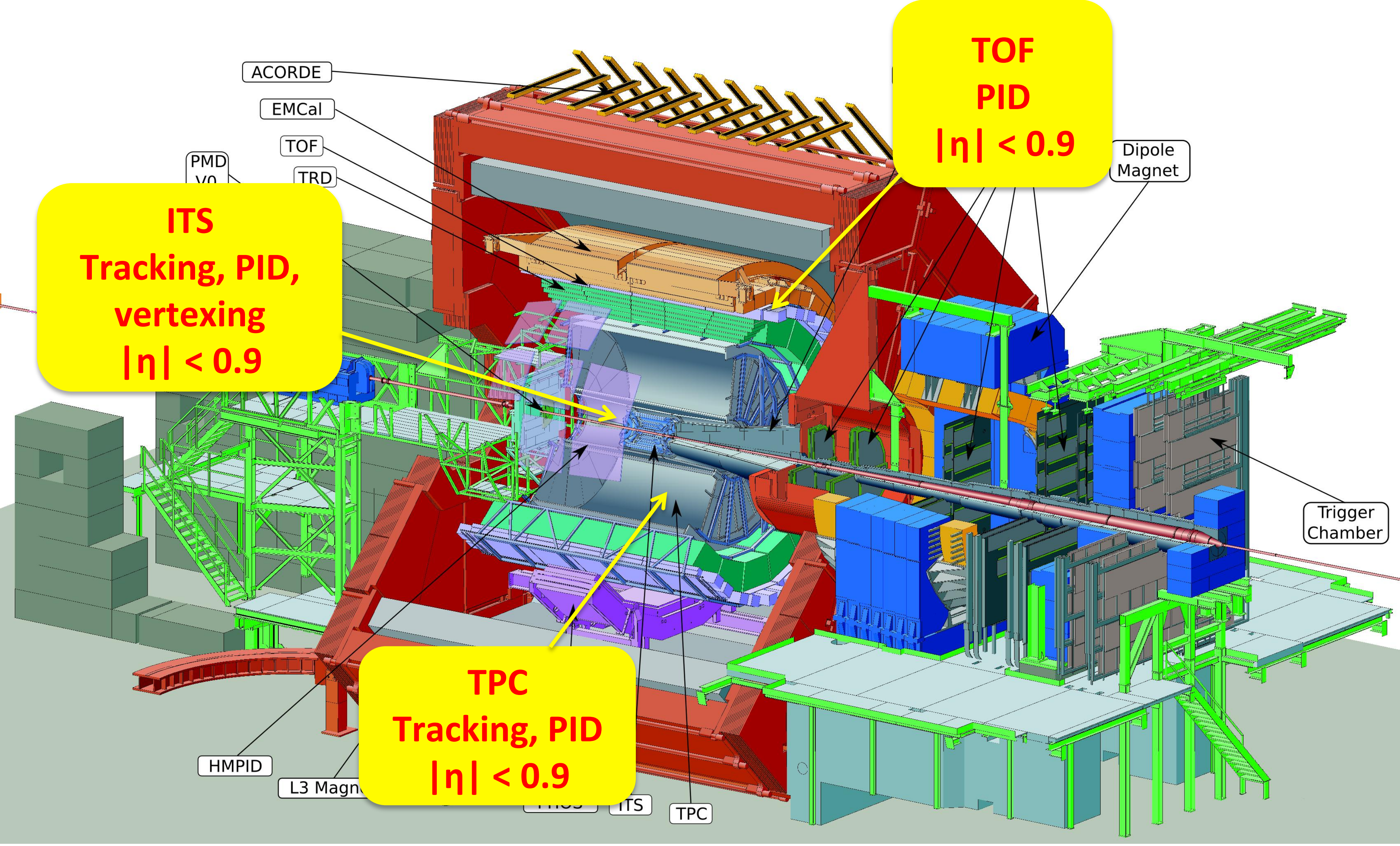
Where,

$$s(\Delta\varphi,\Delta\eta)=\frac{1}{N_{triggers}}\frac{d^2N^{same}_{hf-h}(\Delta\varphi,\Delta\eta)}{d\Delta\varphi d\Delta\eta} \qquad b(\Delta\varphi,\Delta\eta)=N_{norm}\frac{d^2N^{mixed}_{hf-h}(\Delta\varphi,\Delta\eta)}{d\Delta\varphi d\Delta\eta}$$

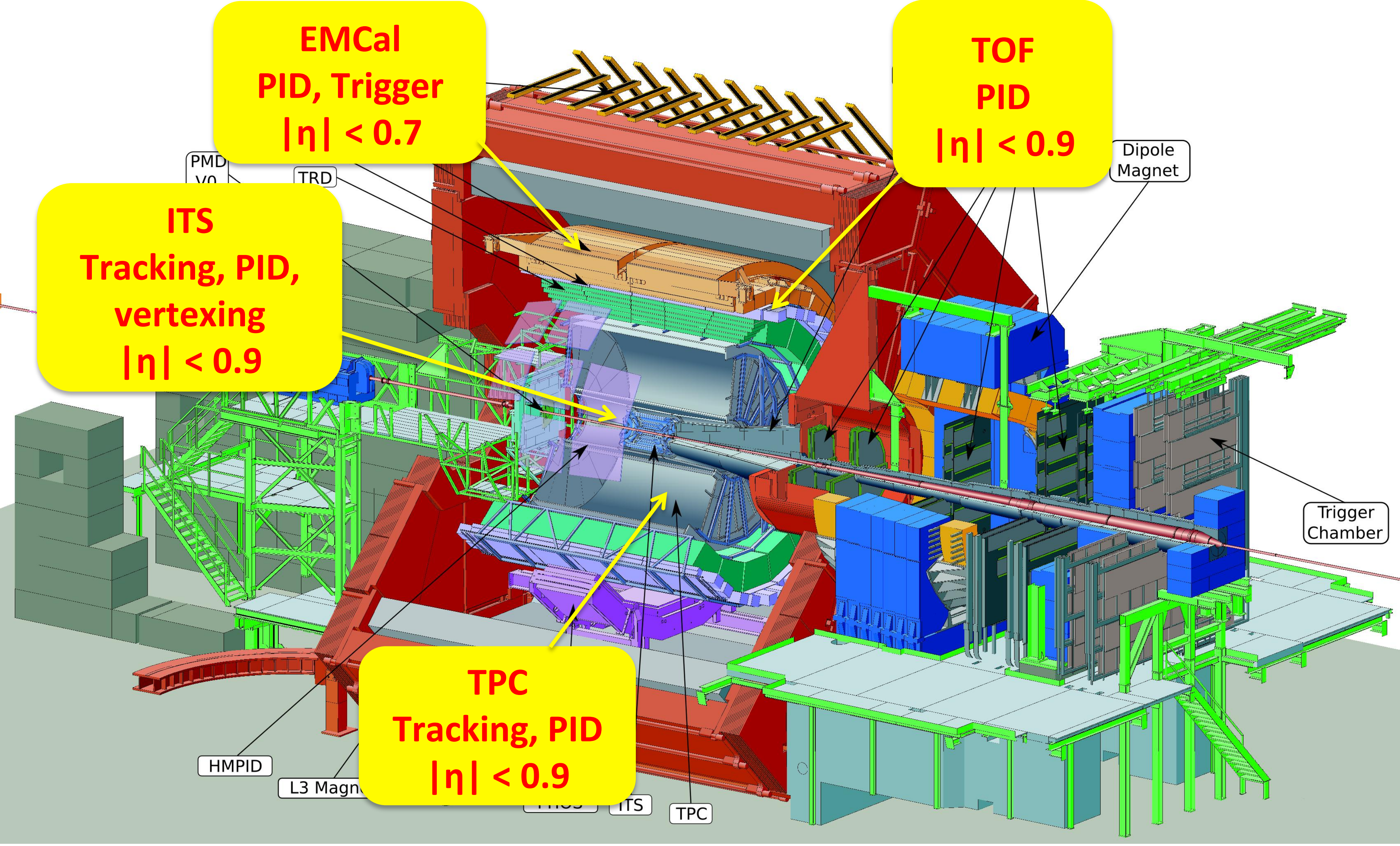
A Large Ion Collider Experiment (ALICE)



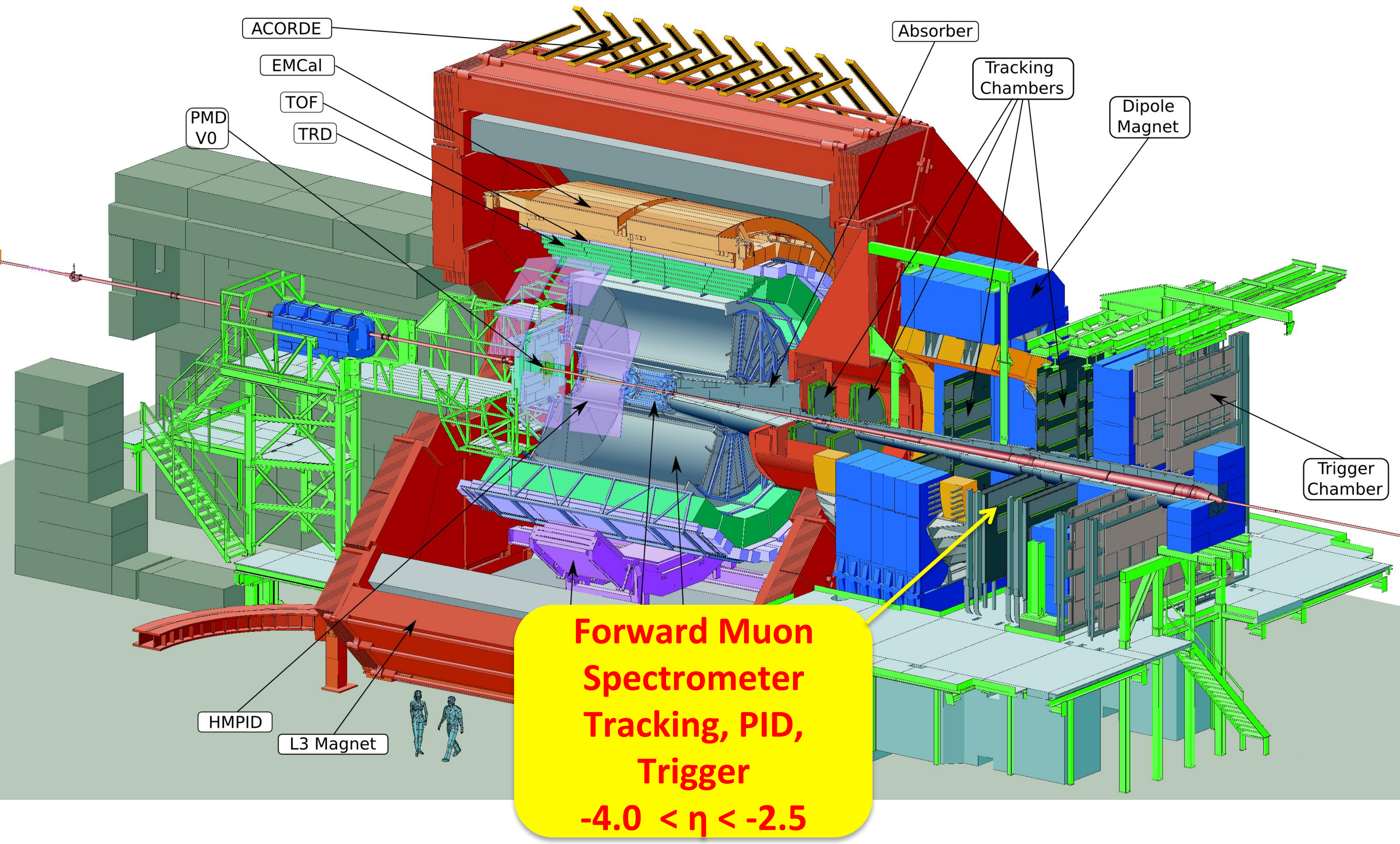
ALICE : D-meson reconstruction



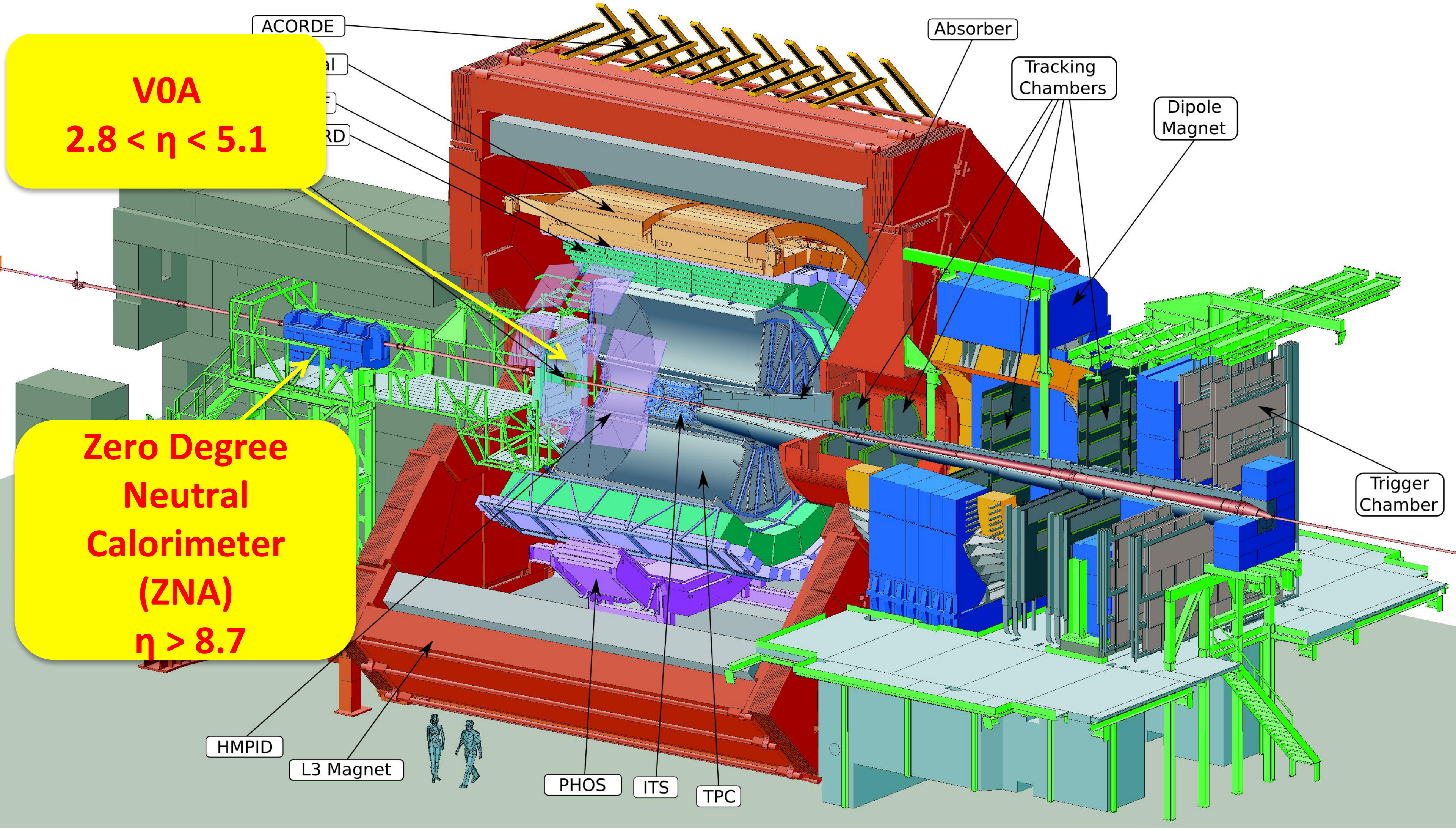
ALICE : heavy-flavour hadron decay electrons



ALICE : heavy-flavour hadron decay muons

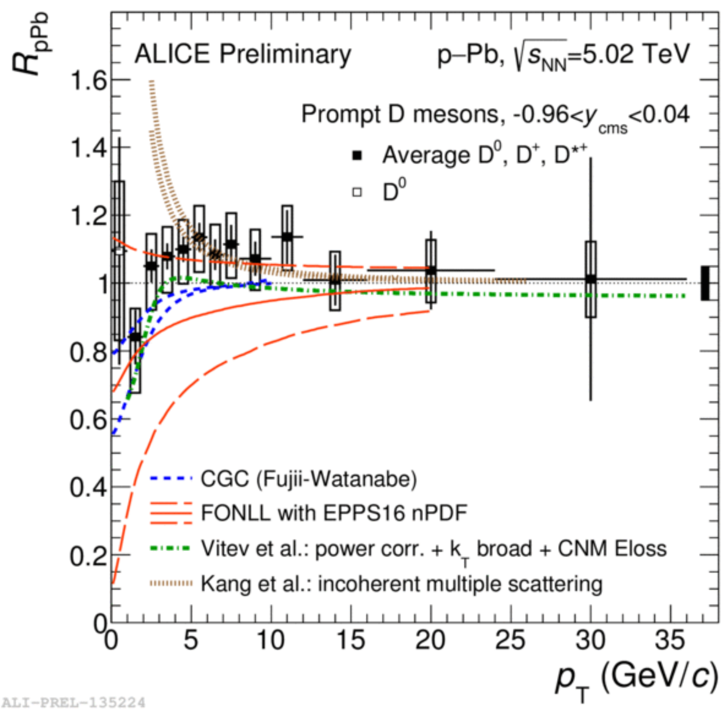


ALICE : centrality estimation



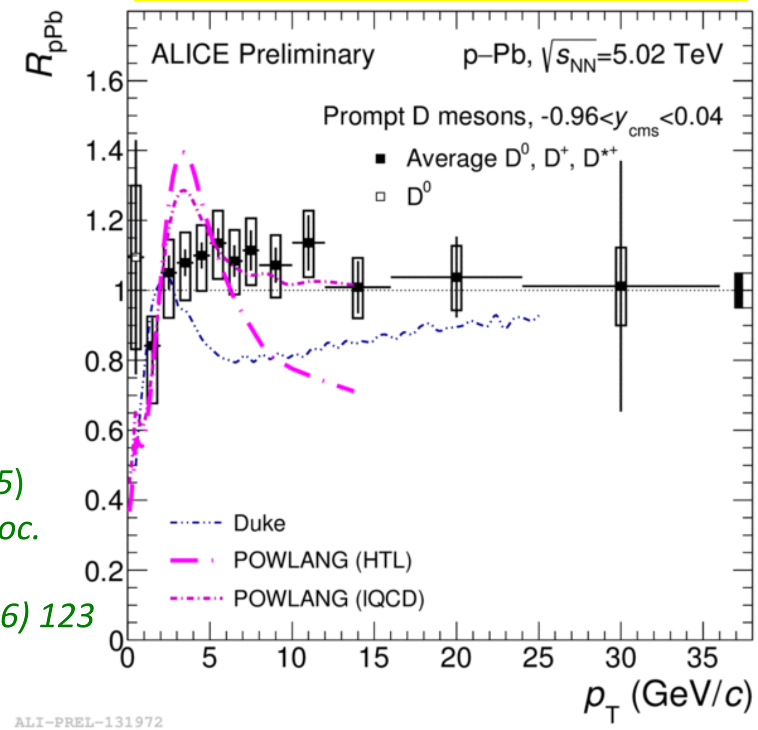
D-meson R_{pPb}

Comparison with CNM based models



CGC:
Nucl. Phys. A 920, 78 (2013)
FONLL with EPS16:
Eur.Phys.J. C77 (2017)
Vitev et al:
Phys. Rev. C 80, 054902 (2009)
Kang et al.:
Phys. Lett. B 740, 23 (2015)
Duke: *Nucl. Part. Phys. Proc. 276278, 225 (2016)*
POWLANG*: JHEP. 03 (2016) 123*

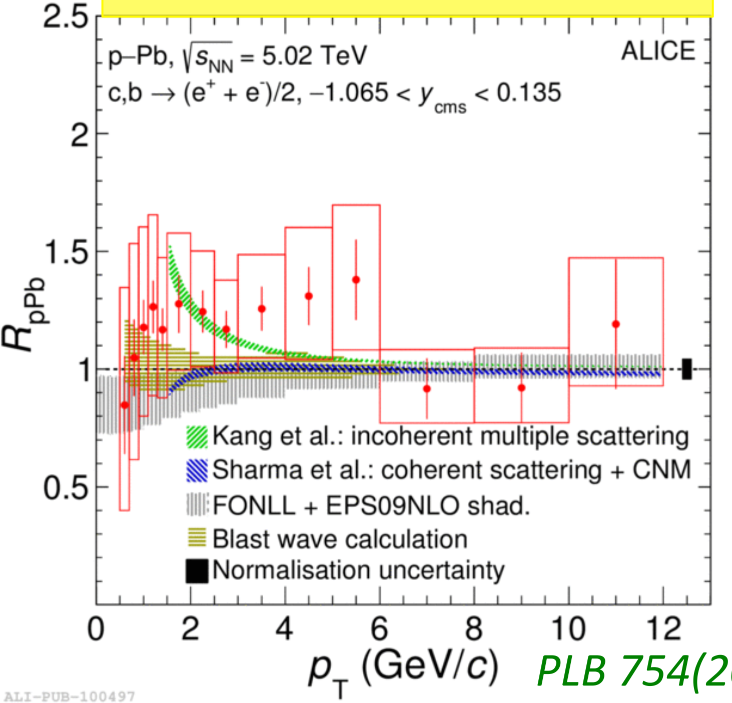
Comparison with final-state effect models



- R_{pPb} of charmed meson compatible with unity at high p_T -> Cold nuclear matter effects are negligible
- Models with CNM effects (left plot) reproduce data
- Models with final-state effects (transport models) also describe the data (right plot) however, data disfavour a suppression larger than 10-15% at high-p_T

Heavy-flavour hadron decay electron R_{pPb}

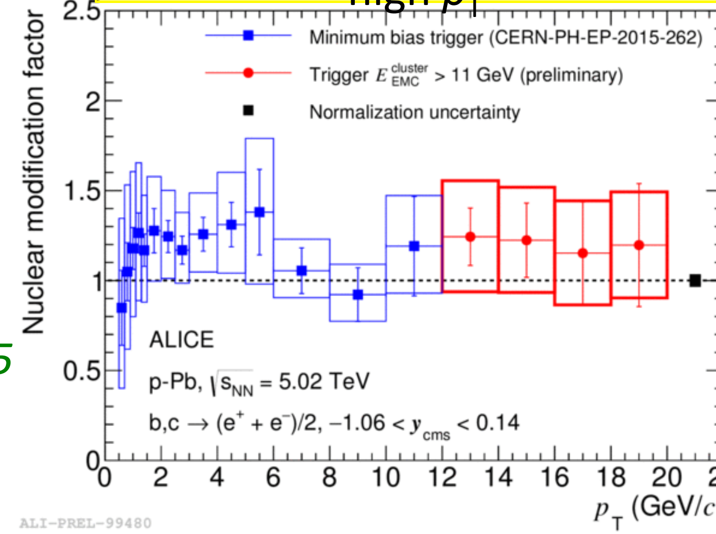
HF hadron decay electrons



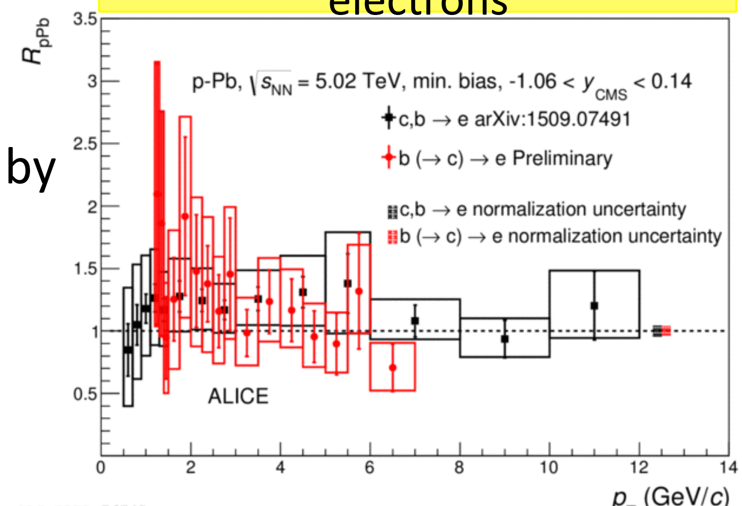
PLB 754(2016)81-93

Kang et al: *PLB 740(2015)23*
Sharma et al: *PRC 80(2009) 054902*
FONLL: *JHEP 9805 (1998)007*
EPOS09: *JHEP 04 (2009)065*

HF hadron decay electrons at high p_T

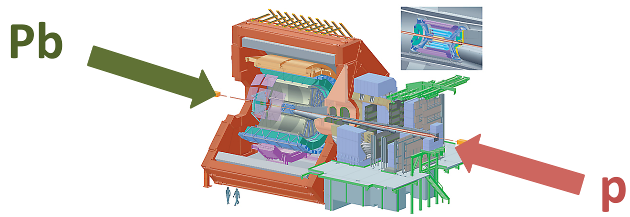


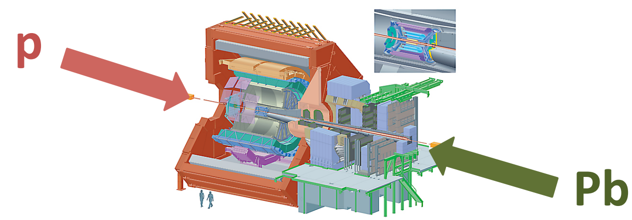
Beauty-hadron decay electrons



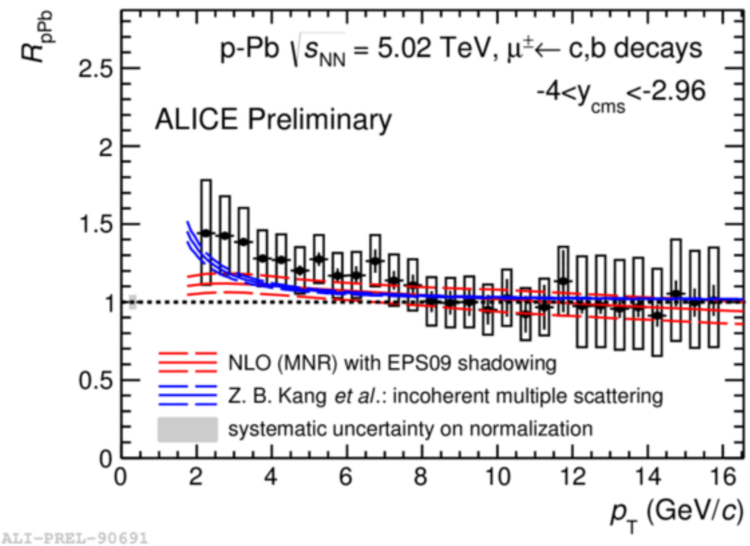
- R_{pPb} of heavy-flavour decay electrons is consistent with unity at high p_T and described by models including initial-state effects
- EMCal detector is used to obtain high-p_T data points
- R_{pPb} of beauty-decay electrons is consistent with HF-decay electrons and with unity

Heavy-flavour hadron decay muons



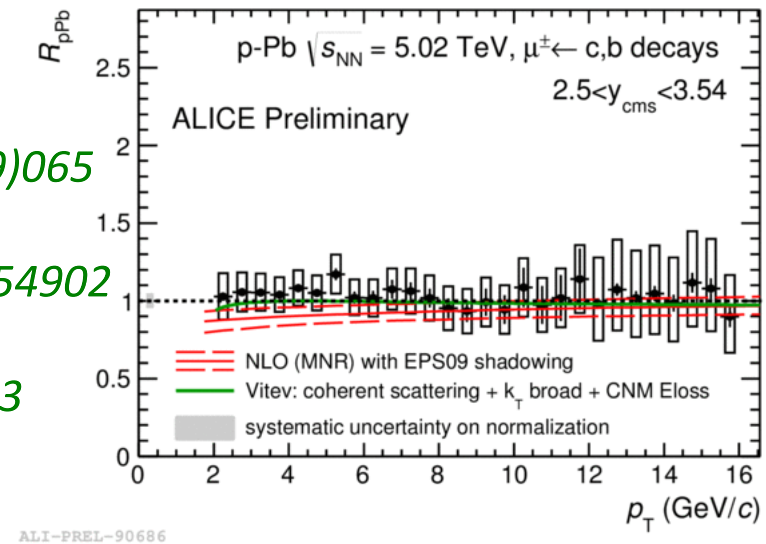


Pb-going (backward)



EPOS09:
JHEP 0904(2009)065
Vitev et al.:
PRC 80(2009)054902
Z.B.Kang et al.:
PLB 740(2015)23

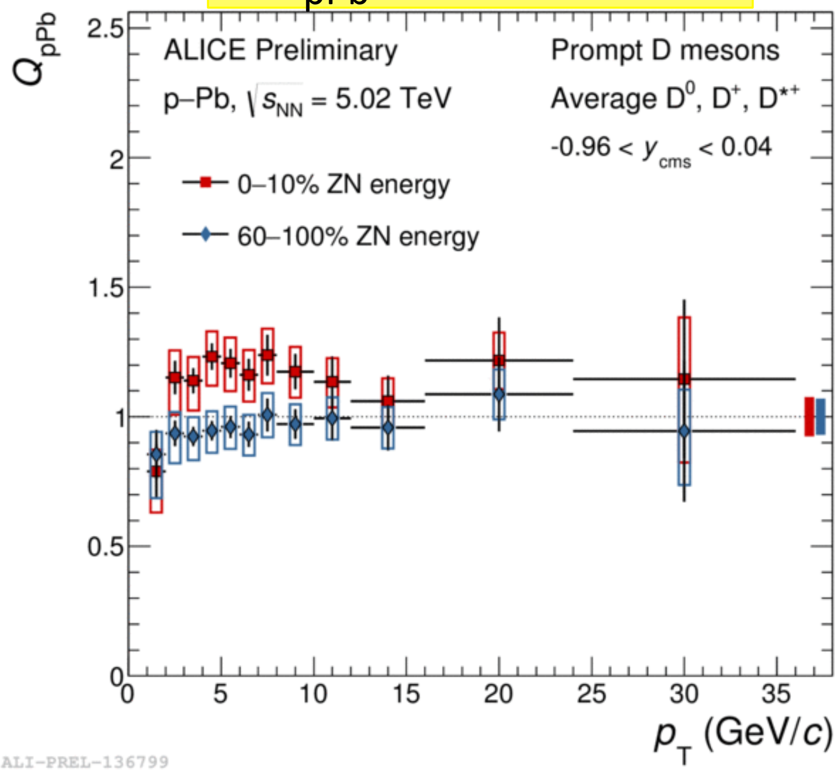
p-going (forward)



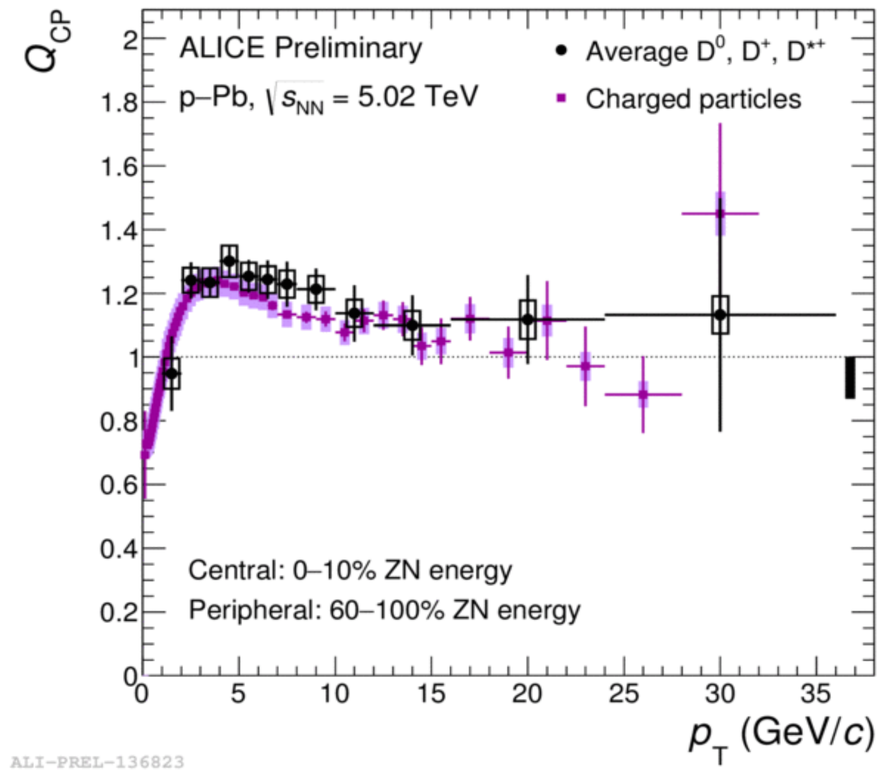
- Study in different rapidity ranges allows us to explore large (backward) and small (forward) Bjorken-x regimes
- R_{pPb} of heavy-flavour decay muons is consistent with unity at forward rapidity and slightly above the unity at backward rapidity in $2 < p_T < 4$ GeV/c
- Models including cold nuclear matter effects describe the data within uncertainties

Q_{pPb} and Q_{cp} of D mesons

Q_{pPb} of D mesons



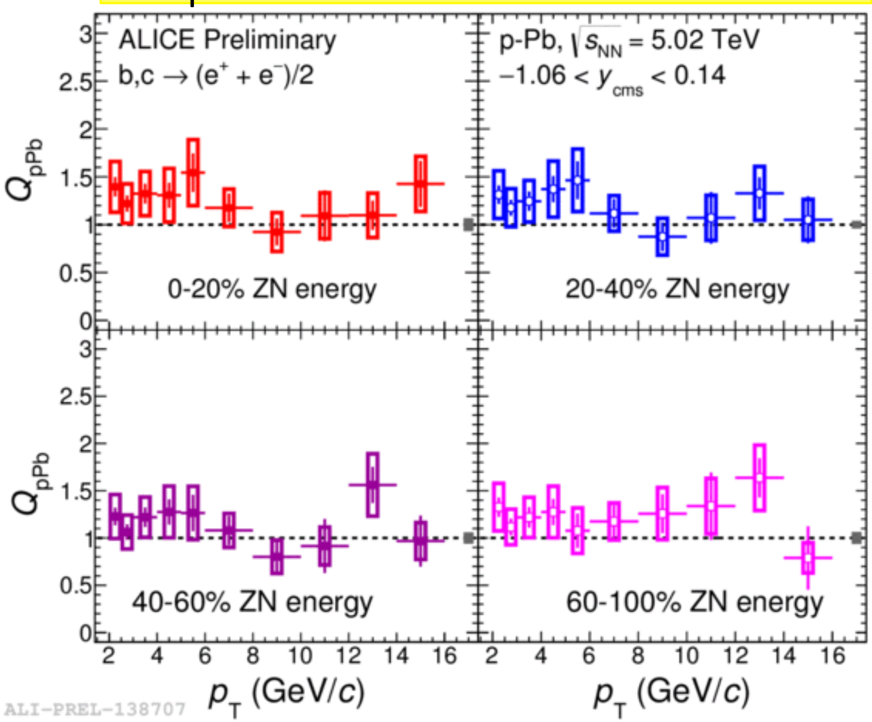
Q_{cp} of D mesons



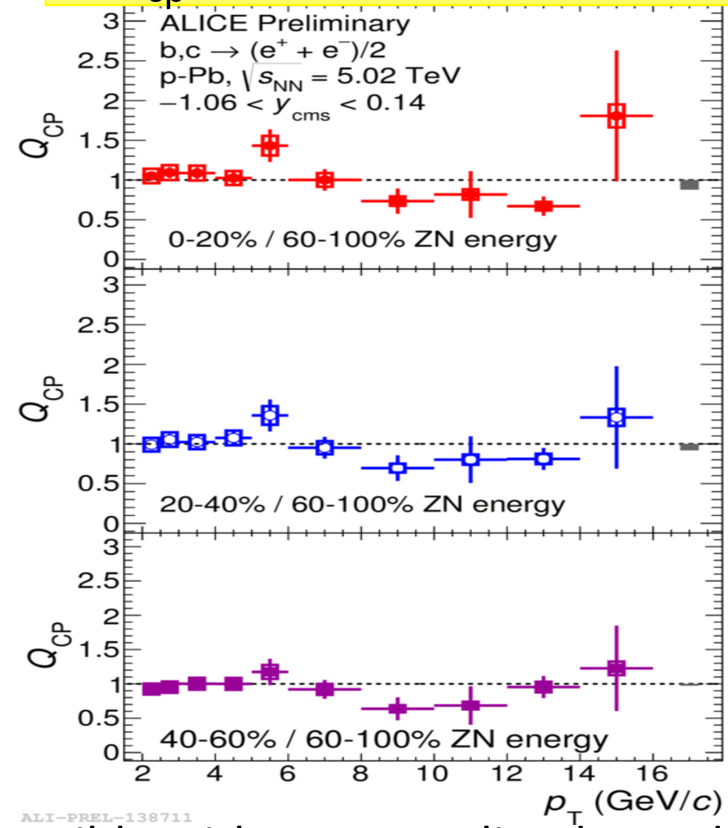
- Q_{pPb} values of D mesons (left plot) are centrality independent and consistent with unity within uncertainties
- Q_{cp} of D mesons (right plot) > 1 by 1.5σ in p_T range 3-8 GeV/c and compatible with charged-particle measurements

Q_{pPb} and Q_{cp} of HF-decay electrons

Q_{pPb} of HF-decay electrons



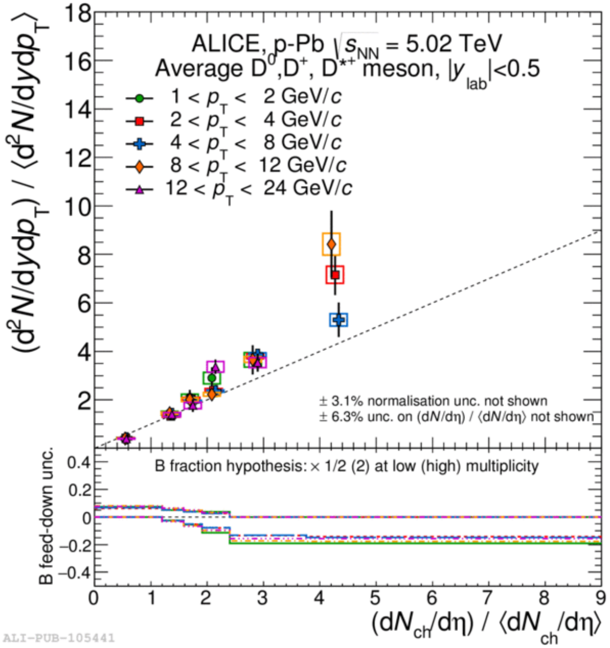
Q_{cp} of HF-decay electrons

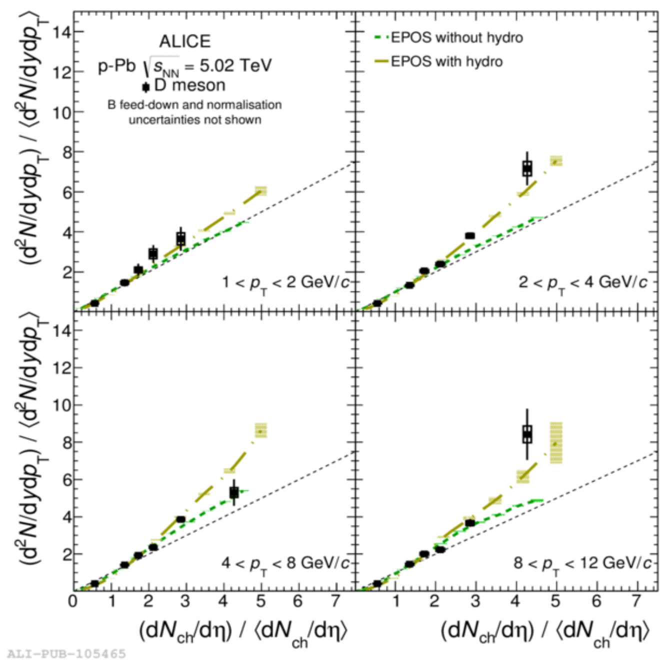


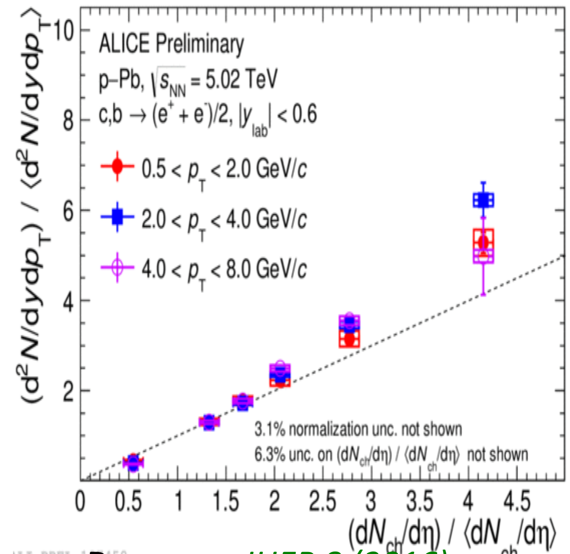
- Q_{pPb} of HF-decay electrons (left plot) are compatible with no centrality dependent and consistent with unity within uncertainties
- Q_{cp} of HF-decay electrons (right plot) are compatible with unity and there is no centrality dependence within uncertainties

Yields vs multiplicity

D-meson	D-meson	HF-decay electrons



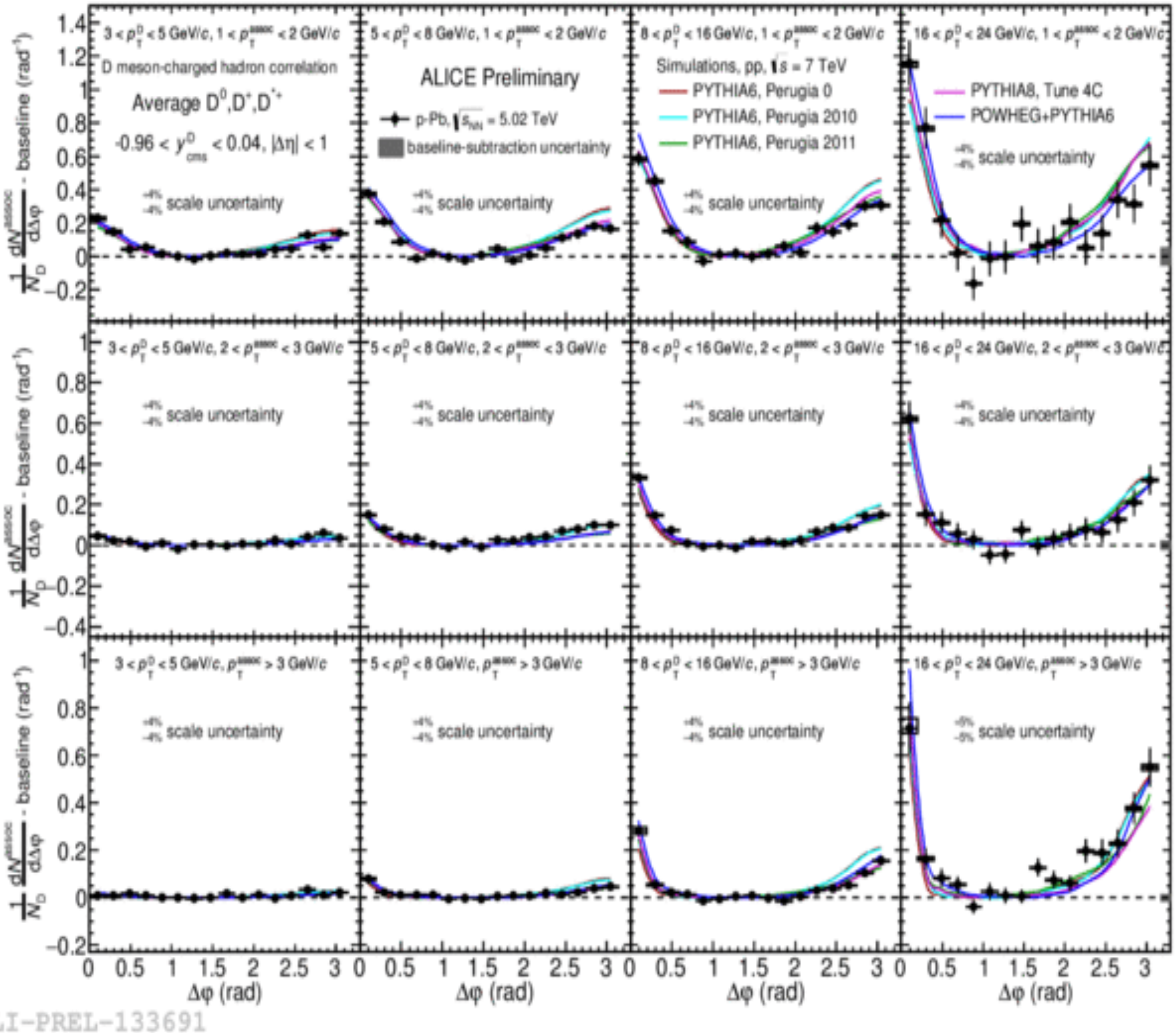




D-meson: *JHEP 8 (2016) 1-44*
EPOS: *PRC 89(2014) 064903*

- ➢ D-meson and HF-decay electron yields exhibit a faster-than-linear increase as a function of charged-particle multiplicity ($dN_{ch}/d\eta$)
- ➢ Similar behaviour was found in pp collisions (*JHEP 09(2015)148*)
- ➢ The EPOS model without hydrodynamic flow explains the data at low multiplicity
- ➢ Data are reproduced by the EPOS model including hydrodynamic flow within uncertainties

Correlations between D mesons and charged particles



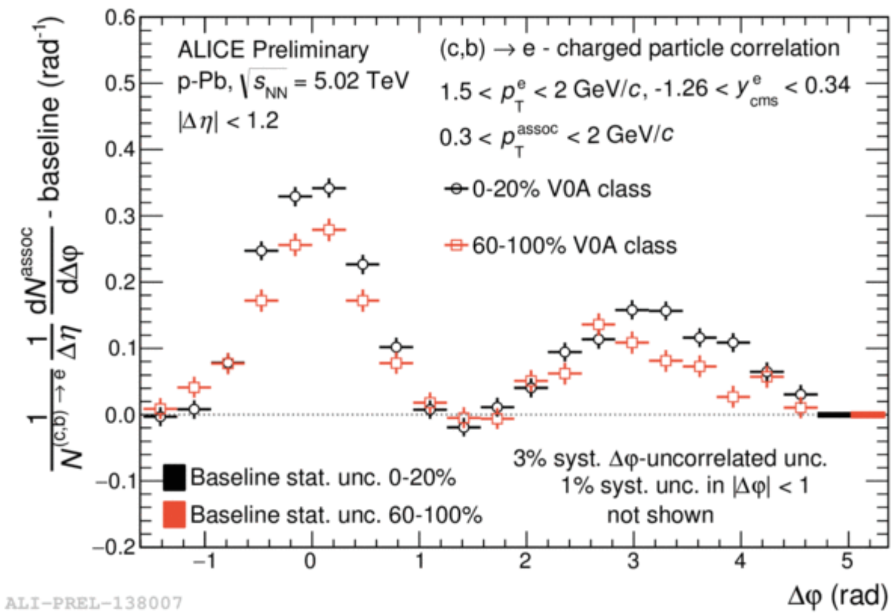
Trigger particle: D mesons
Associated particle: charged particles

- ➢ Run-II data sample offers better precision when compared to Run-I (*Eur. Phys. J. C 77 (2017) 245*)
  ~ 6x more statistics
- ✓ Higher p_T^D and p_T^{assoc} accessible
- ✓ First quantitative access to away side

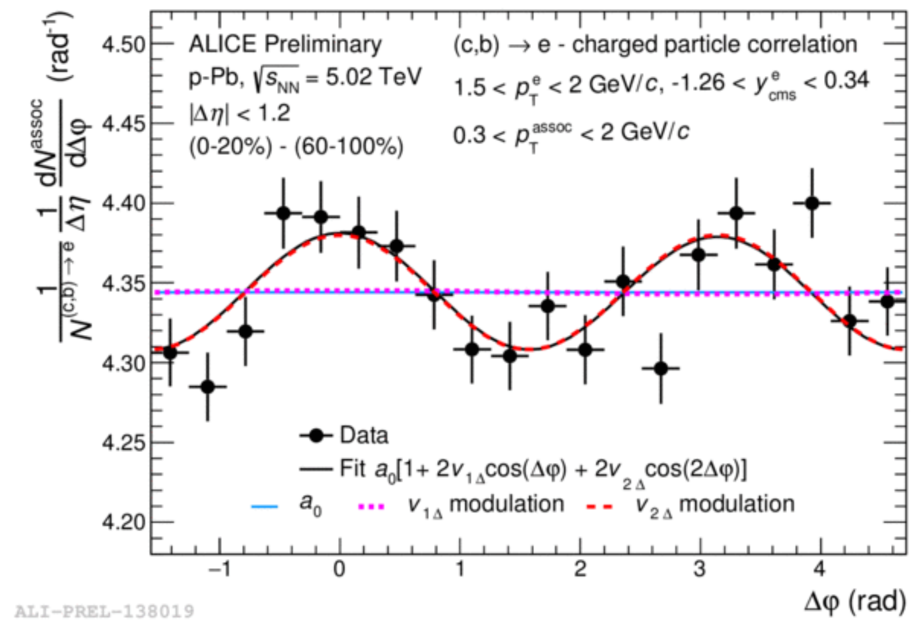
- ➢ Results are described by the different tunes of PYTHIA and POWHEG event generator

Angular correlations between HF-decay electrons and hadrons

$1.5 < p_T^e < 2$ GeV/c



$C_{0-20} - C_{60-100}$

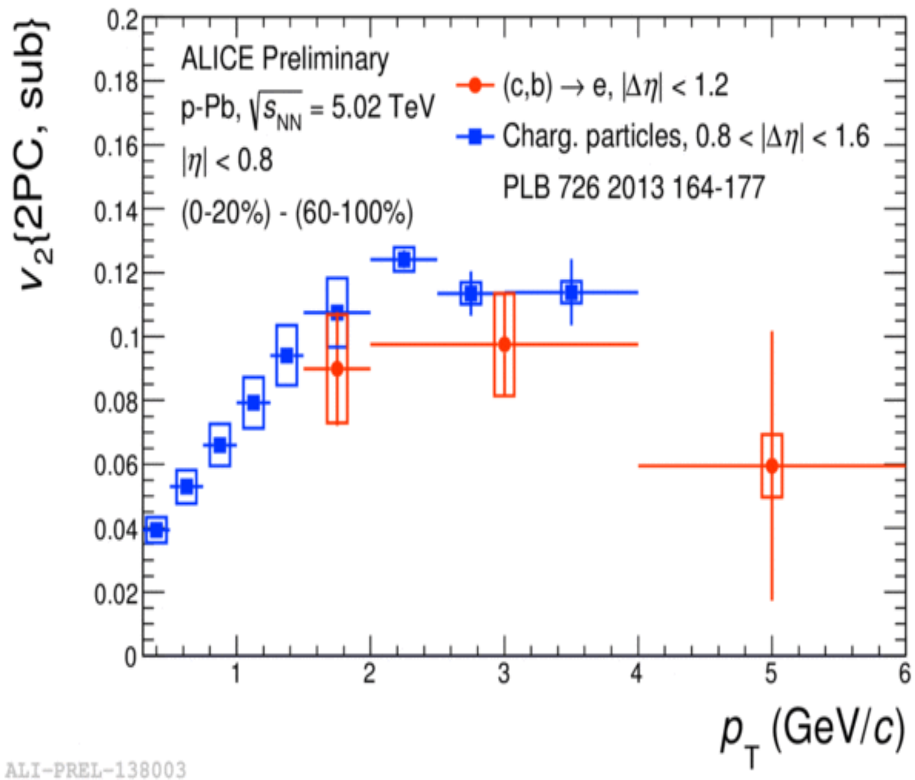


Trigger particle: HF-decay electrons
Associated particle: charged particles

- Difference observed between high multiplicity (0-20%) and low multiplicity (60-100%) (left plot)
- Subtract low-multiplicity correlation function from high-multiplicity correlation function -> observation of v_2-like modulation (right plot)

HF-decay electron v_2

v_2^{HFE} (2PC, sub)



- First time measurement of HF-decay electron v_2^{HFE} (2PC, sub) in p-Pb collisions
- Positive v_2^{HFE} (2PC, sub) observed
- v_2^{HFE} (2PC, sub) similar to charged particles
- Initial-state / collectivity / final-state effects?

Summary

- D-meson and HF-decay electron R_{pPb} are compatible with unity and described by models including initial- and final-state effects
- D-meson and HF-decay electron Q_{pPb} are centrality independent and compatible with unity within uncertainties
- Both measurements indicate that the initial-state effects are negligible at high p_T
- D-meson self-normalized yield as a function of multiplicity is consistent with model calculations including hydrodynamic flow
- centrality-dependent Q_{cp} indicates a D-meson enhancement in more central collisions
- New and precise measurements of correlation between D mesons and charged particles
- Positive v_2^{HFE} (2PC, sub) of HF-decay electrons has been measured. Initial- or final-state effects?

Back up slides

Reconstruction of D mesons

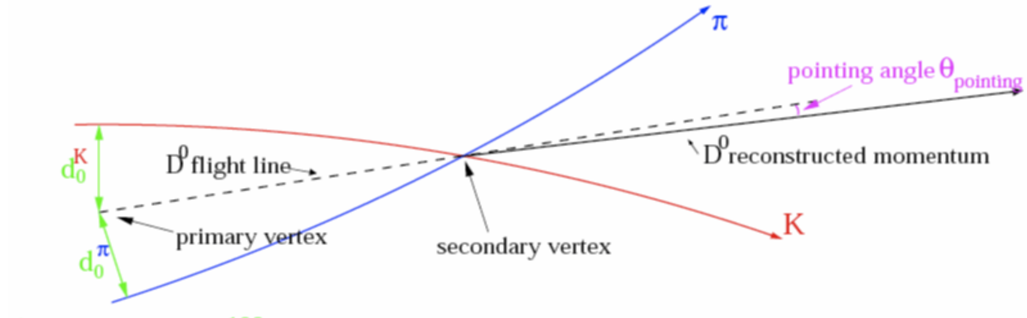
- D-meson reconstruction via their hadronic channels with invariant mass method chanel :

$D^0 \rightarrow K^-\pi^+$ BR -> 3.88%

$D^+ \rightarrow K^-\pi^+\pi^+$ BR -> 9.13%

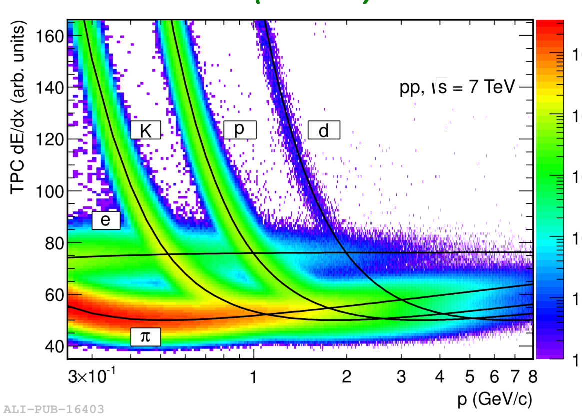
$D^{*+} \rightarrow D^0 \pi^+$ BR -> 67.7%

$D_s^+ \rightarrow \phi\pi^+ \rightarrow K^-K^+\pi^+$ BR -> 2.28%

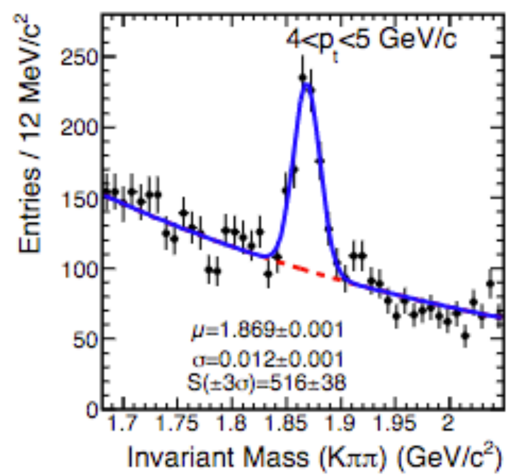


- PID using TPC and TOF
- Analysis performed via reconstruction of decay vertex topologies displaced from the primary vertex
- Feed-down subtracted using pQCD prediction

PRD 86 (2012) 112007



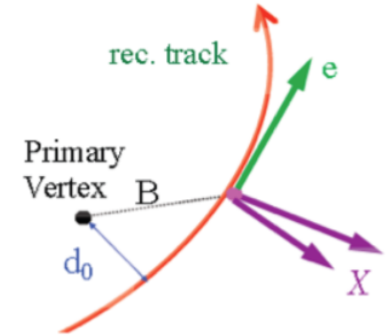
JHEP 01 (2012) 128



Invariant mass distributions of D^+

Reconstruction of heavy-flavour hadron decay electrons

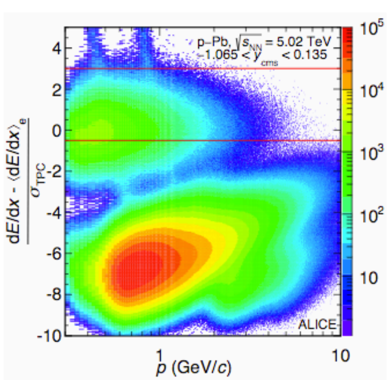
- Heavy flavour hadron decay electrons are identified using TPC and TOF for low p_T and TPC and EMCal For high p_T
- Non heavy-flavour background (Dalitz decay from neutral mesons and photon conversion) removed using invariant mass method i.e. reconstruction of e^+e^- pairs or cocktail method

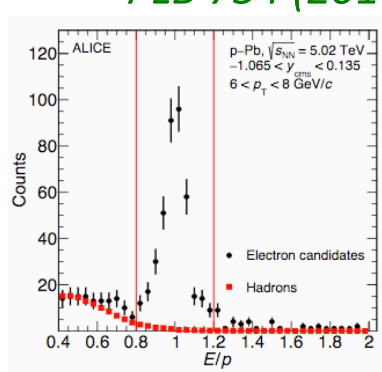


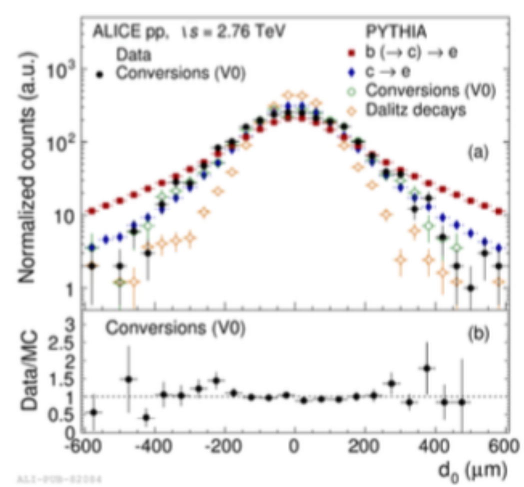
- Beauty-hadron decay electrons are separated using the impact parameter distribution

✓ Beauty-hadron decay electrons have broader track impact parameter distribution due to the longer life time of the beauty hadrons

PLB 754 (2016) 81-93







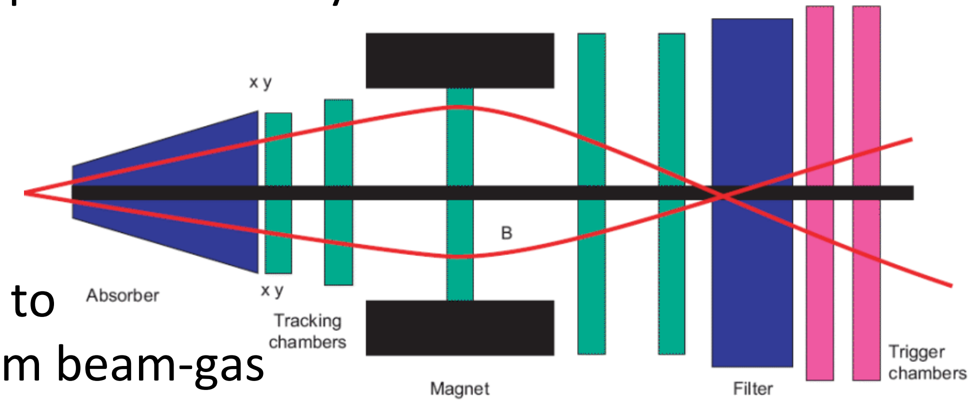
PLB 738 (2014) 97

Reconstruction of heavy-flavour hadron decay muon

- Heavy-flavour hadron decay muons are reconstructed using forward muon spectrometer

- Acceptance and geometrical cuts are applied to identify the muons

- Track matching with trigger chambers is applied to reject hadrons



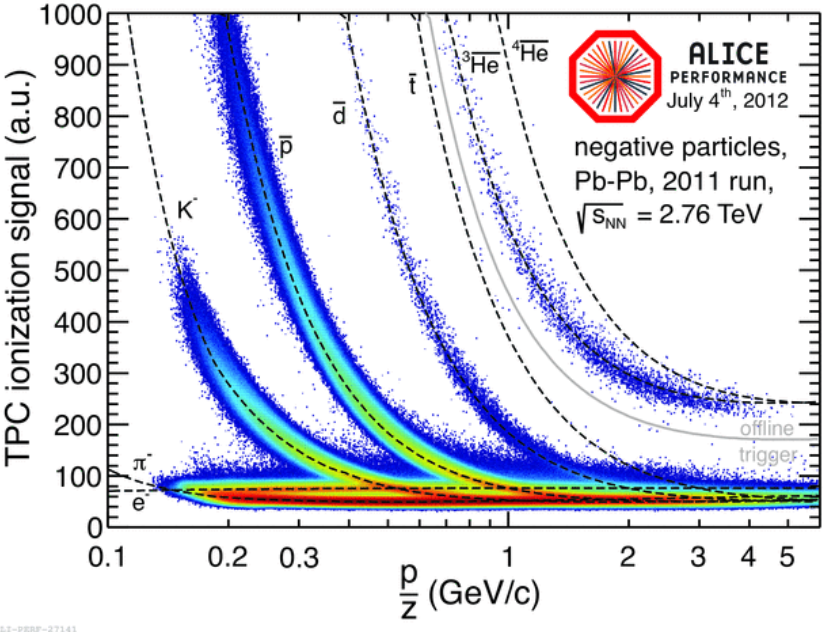
- Cut on the distance of closest approach to the primary vertex to remove tracks from beam-gas interactions

- Background (mainly coming from primary k and π decays) is estimated via Monte Carlo (MC) simulations in pp collisions or via data-tuned MC cocktail in p-Pb and Pb-Pb collisions

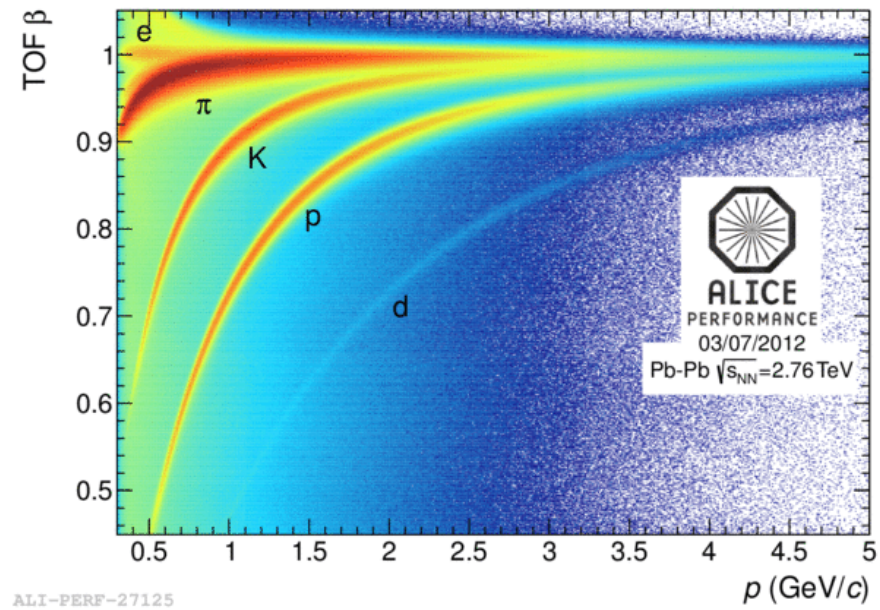
- High p_T background from W decays are estimated using MC simulation

Excellent particle identification in ALICE

TPC PID

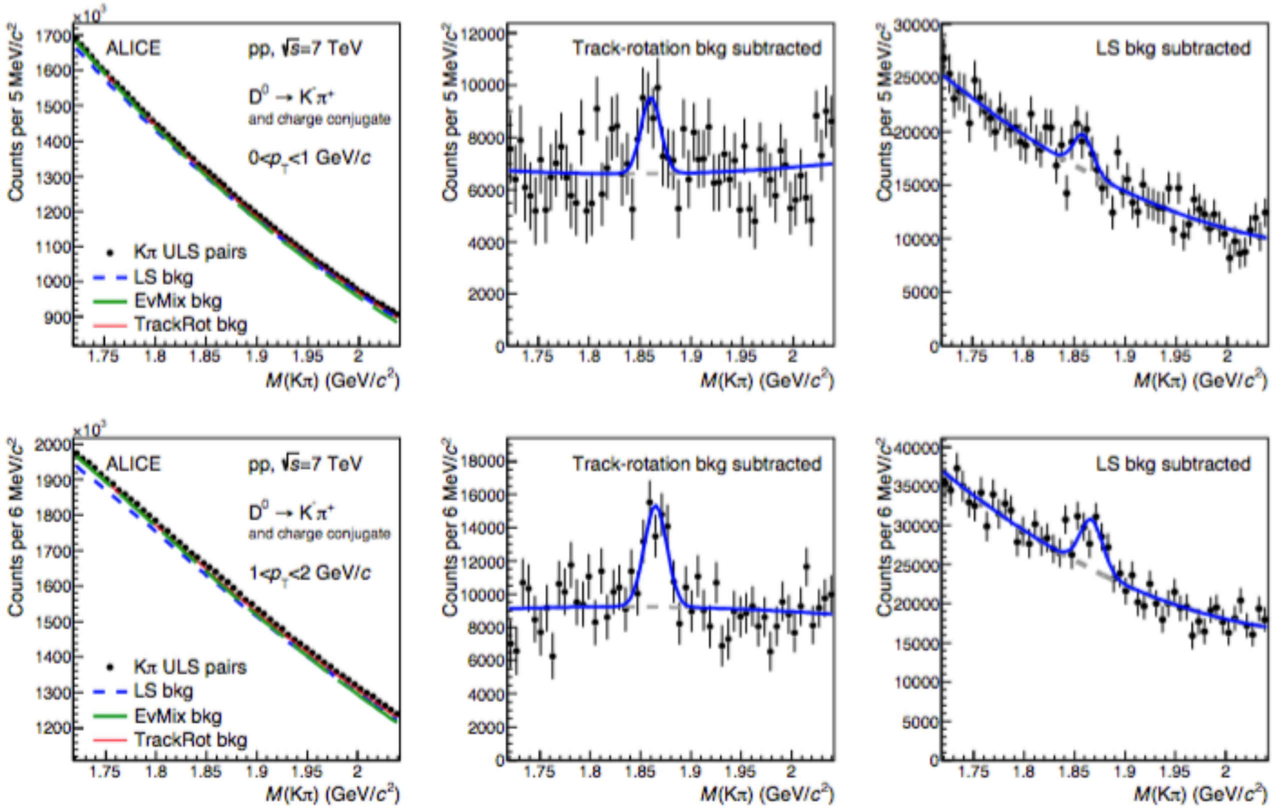


TOF PID



D mesons measurements at $p_T = 0$

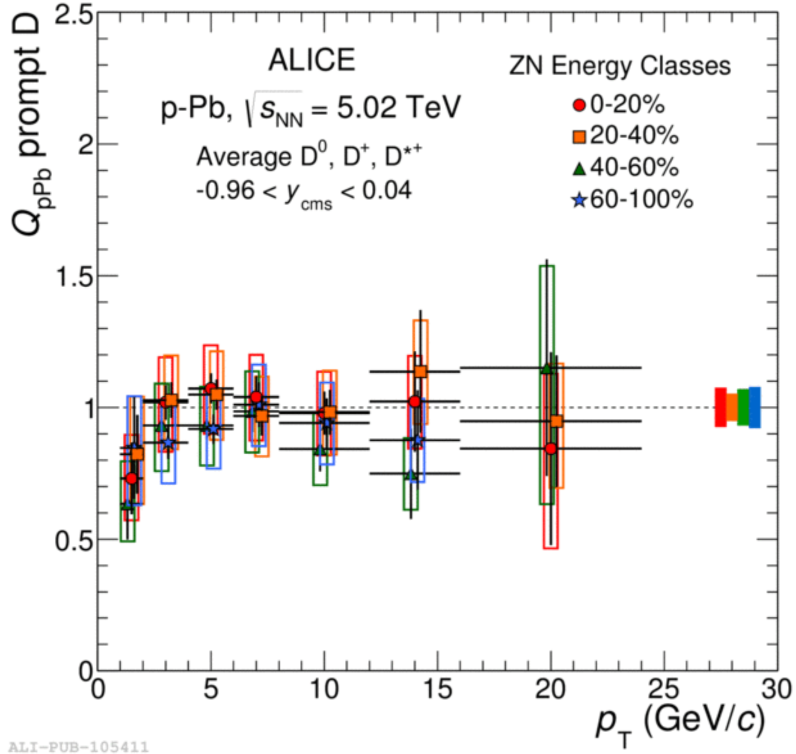
arXiv: 1605.07569v1



- combinatorial background subtraction method is used to extract the signal

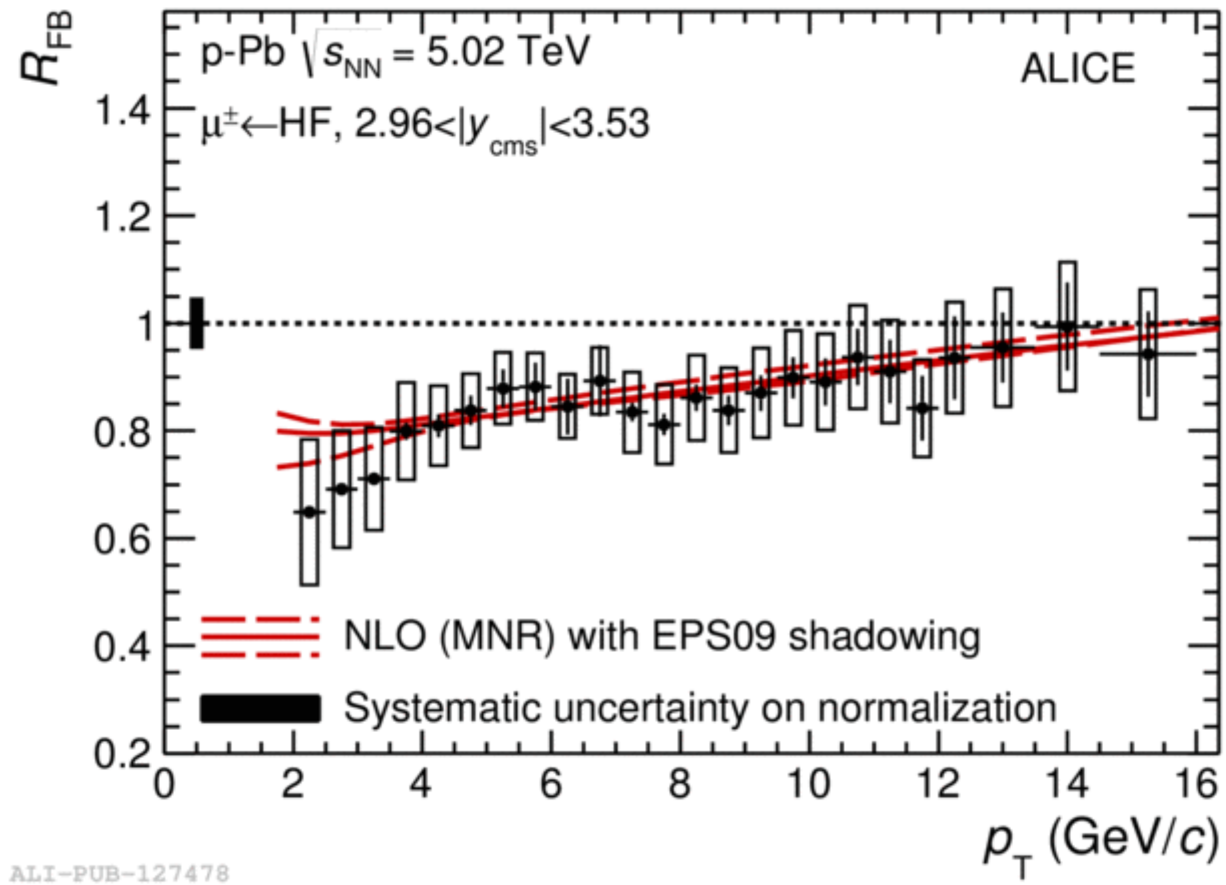
Q_{pPb} pf D mesons

arXive:1602.07240v1



- Models including initial state effects describe the data within uncertainties

Forward-to-backward ratio of muons from heavy-flavour hadron decays



D mesons-hadron correlations: near side