Measurements of heavy-flavour production in pp and p-Pb collisions with ALICE at the LHC

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Heavy quarks in heavy-ion collisions

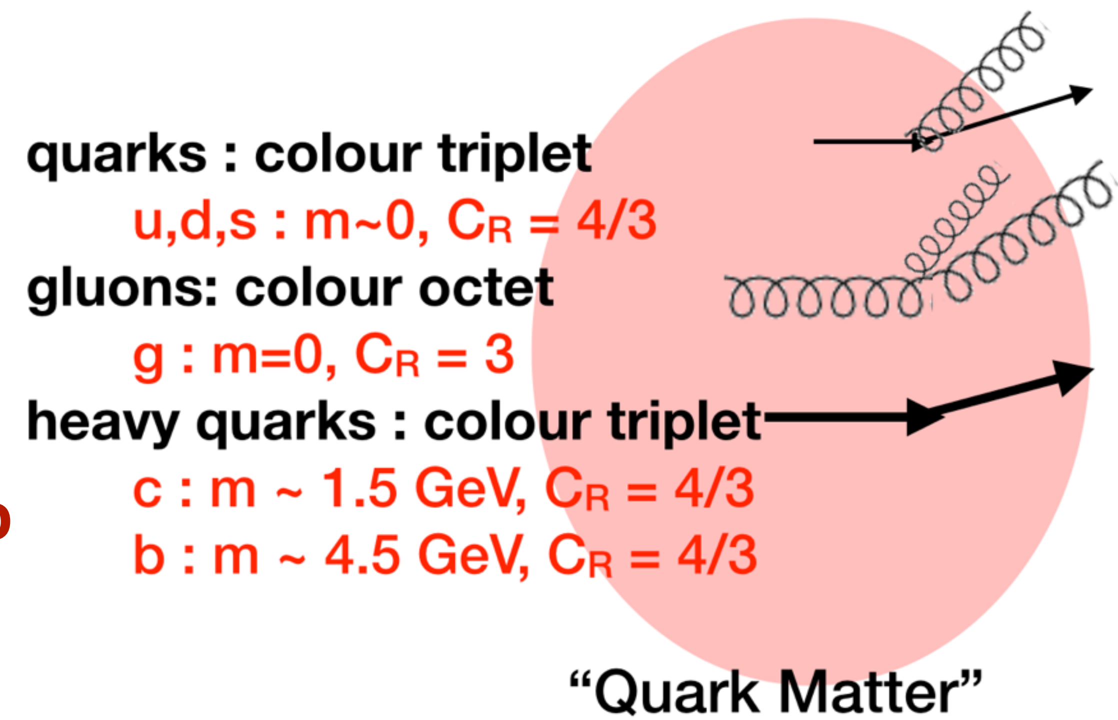
- **Heavy-ion (HI) collisions at the LHC energies**
  - QGP phase expected (lifetime ~ O(10 fm/c))

- **Heavy quarks**
  - Large mass ($m_q \gg \Lambda_{QCD}$) → produced in the early stages of the HI collision with short formation time (t_{charm} ~ 1/m_c ~ 0.1 fm/c << τ_{QGP} ~ O(10 fm/c)), traverse the medium interacting with its constituents, without changing flavour identity

    ➡ natural probe of the hot and dense medium created in HI collisions, transported through the full system evolution

Heavy-flavour physics program in pp, p-A, A-A collisions

- **Pb-Pb collisions**
  - **Study the interaction of heavy quarks with the medium :**
    parton energy loss via radiative and collisional processes depends on :
    - color charge
    - quark mass
    - path length in the medium
    - medium density and temperature
    - ➡**expect: $\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$**
    - ➡**$R_{AA}^{\pi} < R_{AA}^{D} < R_{AA}^{B}$?**



  - **Collectivity in the medium**
    - initial spatial asymmetry in non-central collisions
    - thermalization via sufficient re-scattering due to large mass at low/intermediate p_T
    - path-length dependence of energy loss at high p_T

Heavy-flavour physics program in pp, p-A, A-A collisions

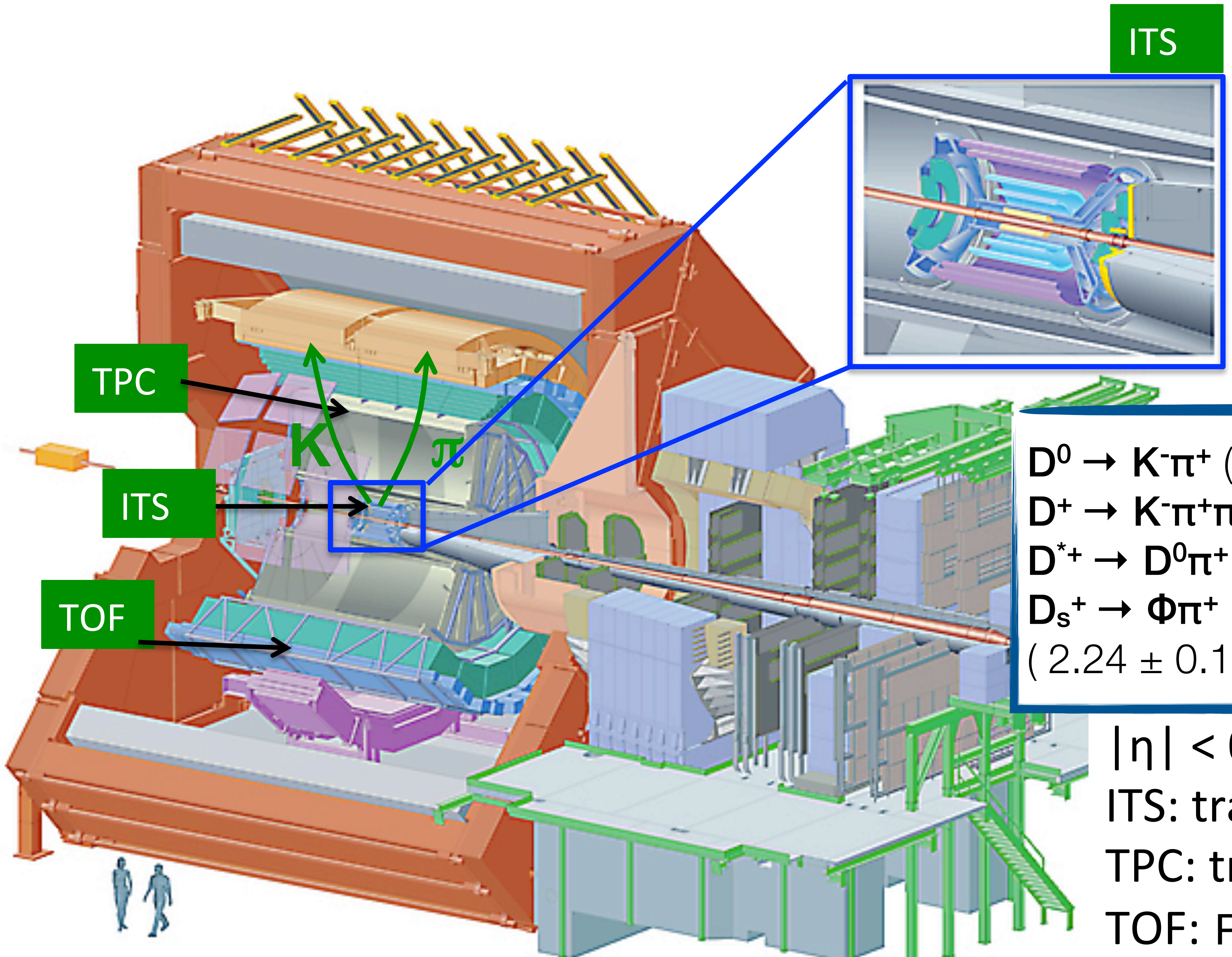
- **pp collisions**
  - **- Reference for p-Pb and Pb-Pb collisions**
  - **- Test understanding of heavy-quark production**
    - testing ground for perturbative QCD calculations : theoretical uncertainties are driven by renormalization and factorization scales and quark masses
    - more QCD aspects to be investigated with differential measurements:
      - effect of Multi Parton Interactions (MPIs) on the hard scale relevant for HF production, via multiplicity dependence studies of heavy-flavour production cross sections
      - production mechanisms of LO (gluon fusion, quark-antiquark annihilation), NLO (gluon splitting, flavour excitation) contributions, via heavy-flavour azimuthal correlations

Heavy-flavour physics program in pp, p-A, A-A collisions

- **p-Pb collisions**
  - **Control experiment for the Pb-Pb measurements: indication for final-state effects?**
  - **Address cold nuclear matter effects**
    - nuclear modification of parton distribution functions
      shadowing: K.J. Eskola et al., JHEP 0904 (2009) 65
      gluon saturation, Color Glass Condensate: H. Fuji & K. Watanabe, NPA 915(2013) 1
    - k_T broadening
    - energy loss in cold nuclear matter
      I. Vitev at al., PRC 75 (2007) 064906
    - multiple binary nucleon collisions
      A.M. Glenn et al., PLB 644 (2007) 119

I'll focus on the results in pp and p-A collisions today

D mesons in ALICE

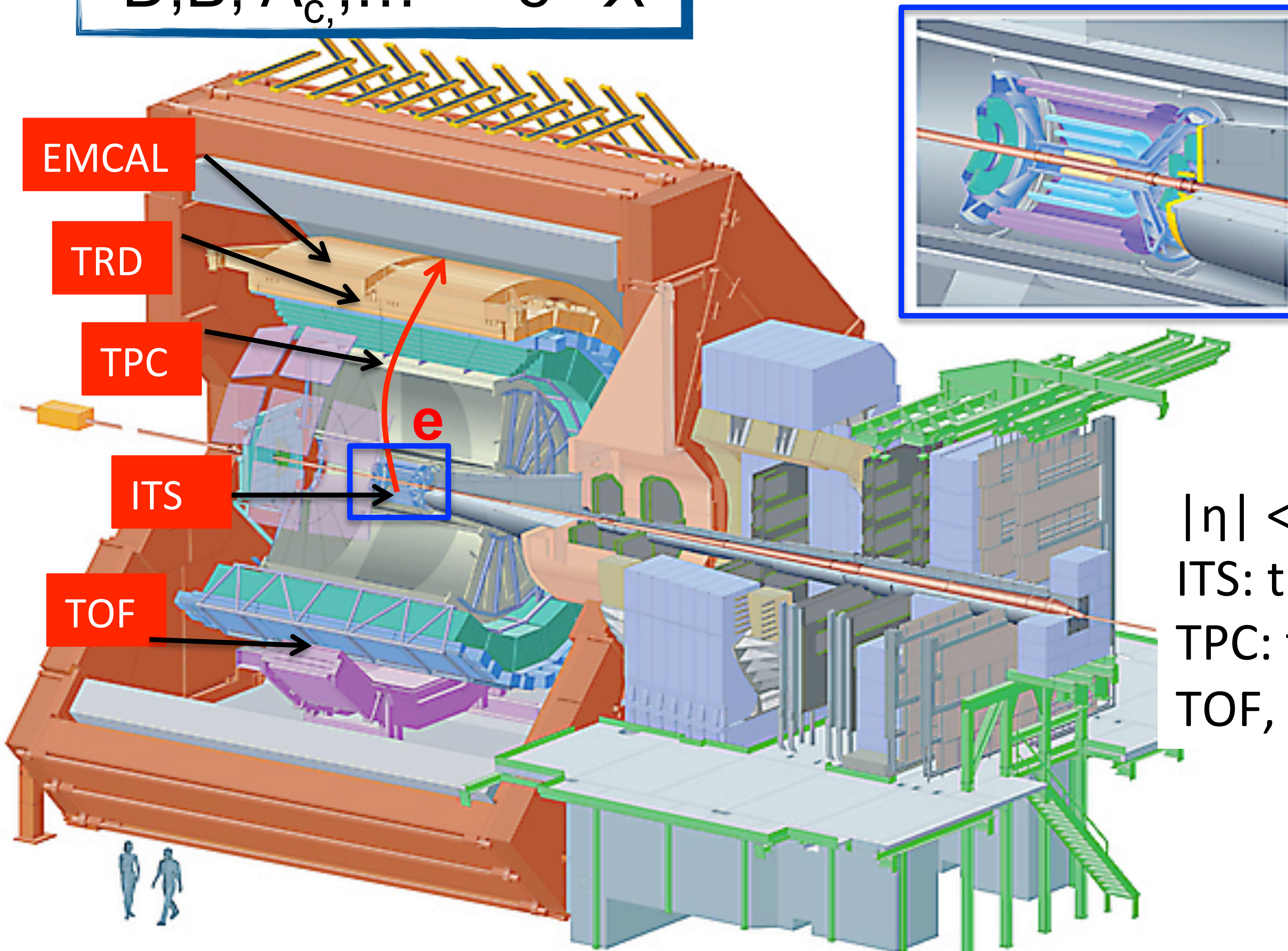


$D^0 \rightarrow K^-\pi^+$ (3.88 ± 0.05) %
$D^+ \rightarrow K^-\pi^+\pi^+$ (9.13 ± 0.19) %
$D^{*+} \rightarrow D^0\pi^+$ (67.7 ± 0.5) %
$D_s^+ \rightarrow \Phi\pi^+ \rightarrow K^+K^-\pi^+$
(2.24 ± 0.10) %

$|\eta| < 0.9$
ITS: tracking, vertexing
TPC: tracking, PID
TOF: PID

Heavy-flavour decay electrons in ALICE

$D, B, \Lambda_{c}, \ldots \rightarrow e + X$



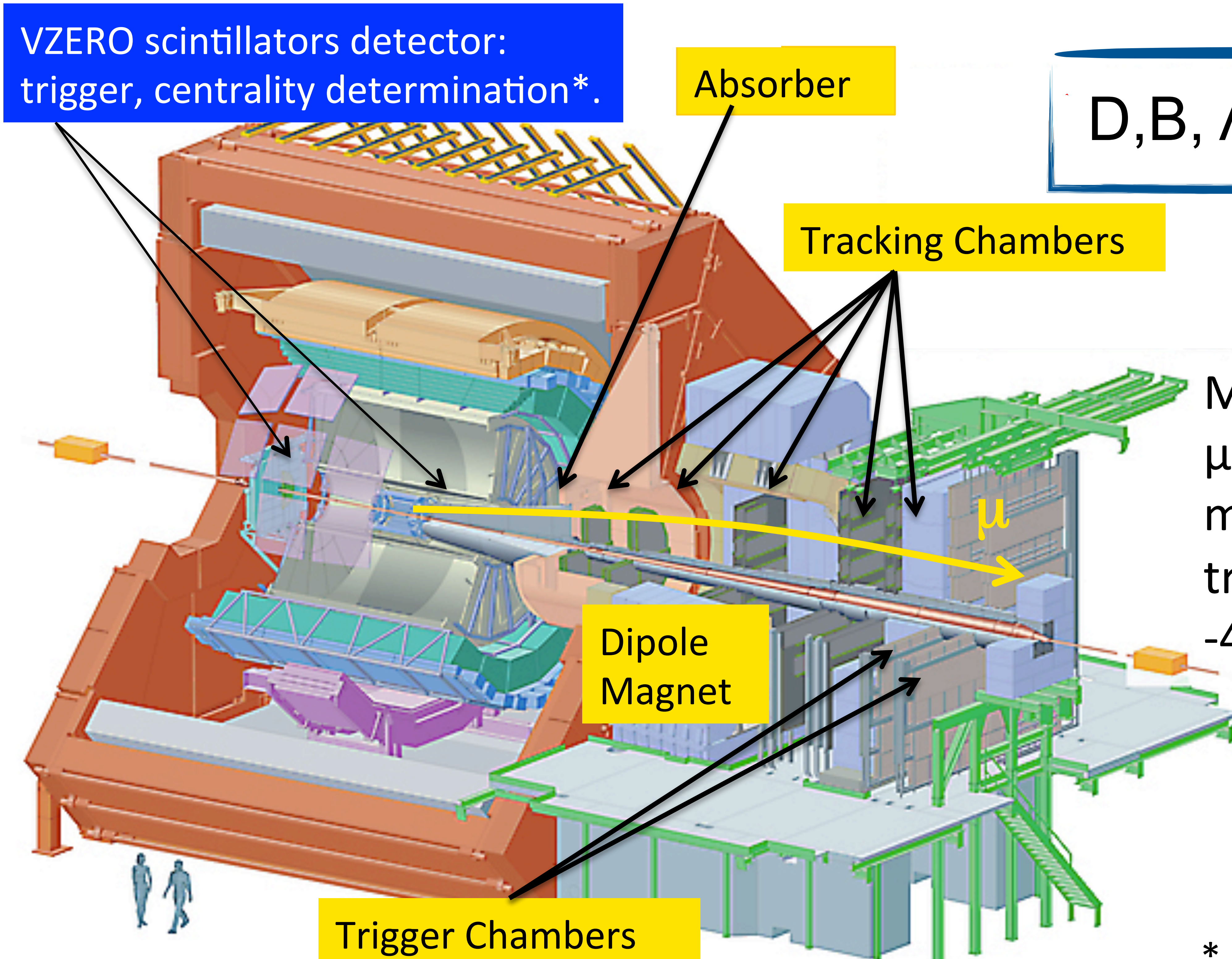
|η| < 0.9

ITS: tracking, vertexing

TPC: tracking, PID

TOF, EMCAL, TRD: e-ID

Heavy-flavour decay muons in ALICE



$D, B, \Lambda_{c}, \ldots \rightarrow \mu + X$

Muon spectrometer:
μ-ID via tracks
matched with
trigger system
$-4 < \eta < -2.5$

* common for all analyses

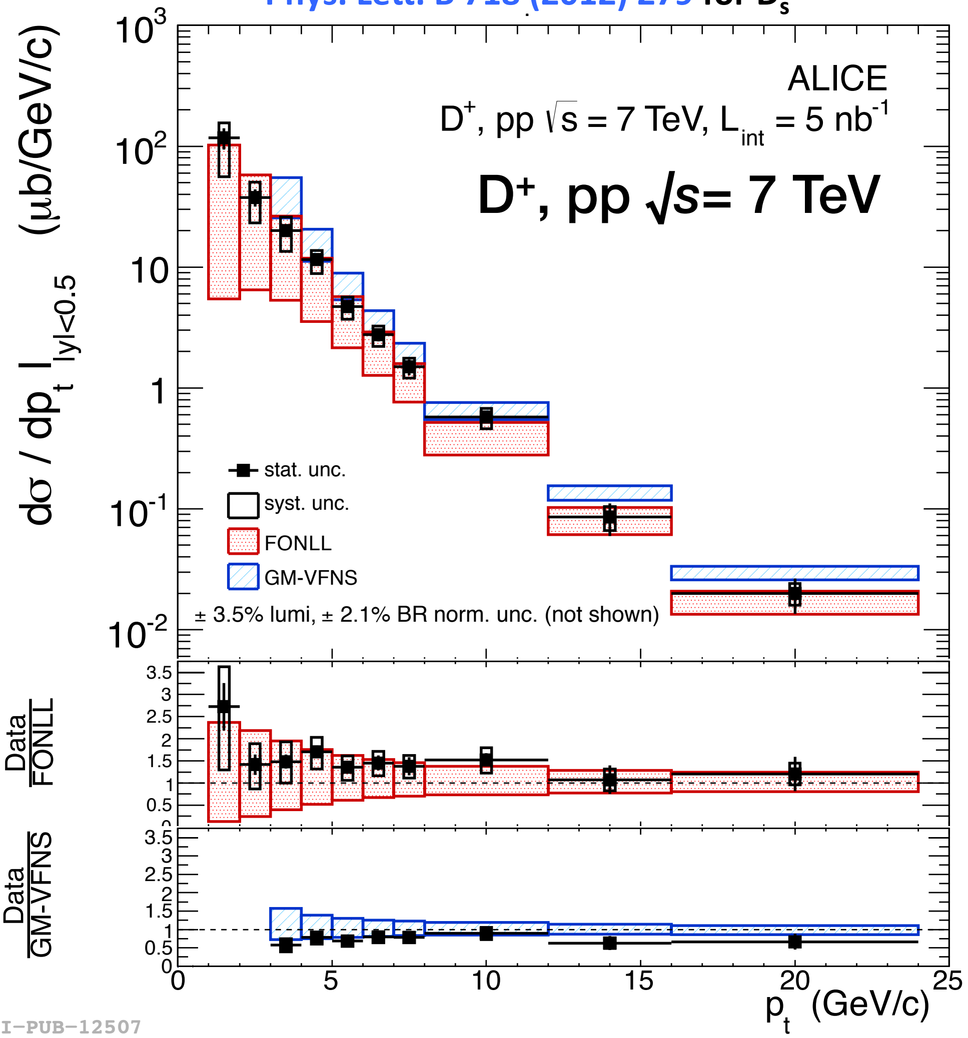
Results in pp collisions at $\sqrt{s}$= 7 TeV and $\sqrt{s}$= 2.76 TeV

Heavy-flavour p_T-differential cross section

Prompt D meson

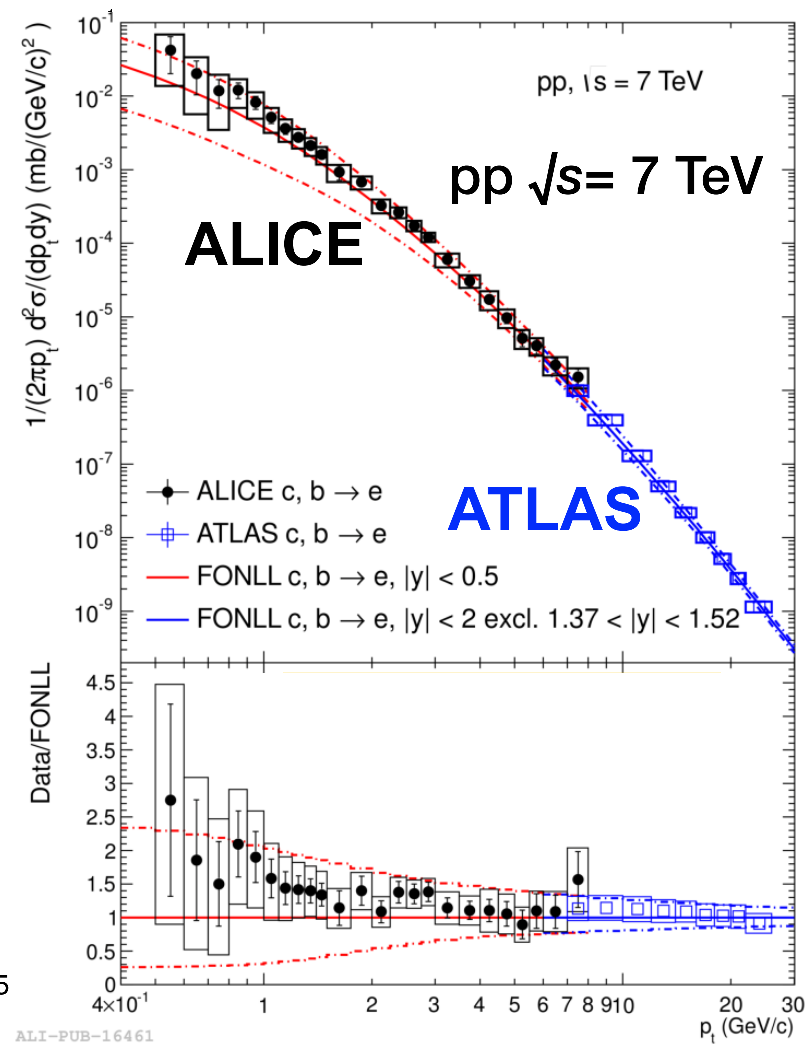
JHEP 1201 (2012) 128

Phys. Lett. B 718 (2012) 279 for D_s



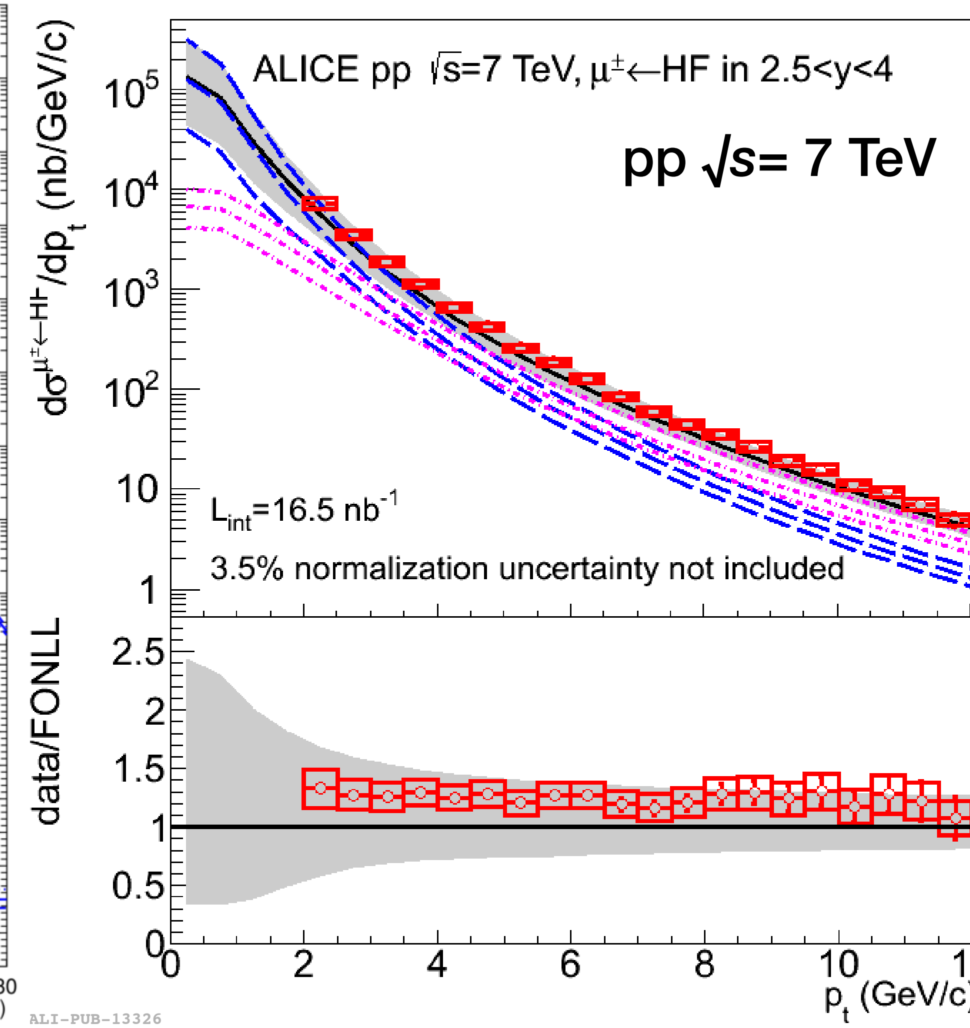
HF-decay electrons

Phys. Rev. D 86, 112007 (2012)



HF-decay muons

Phys. Lett. B 708 (2012) 265



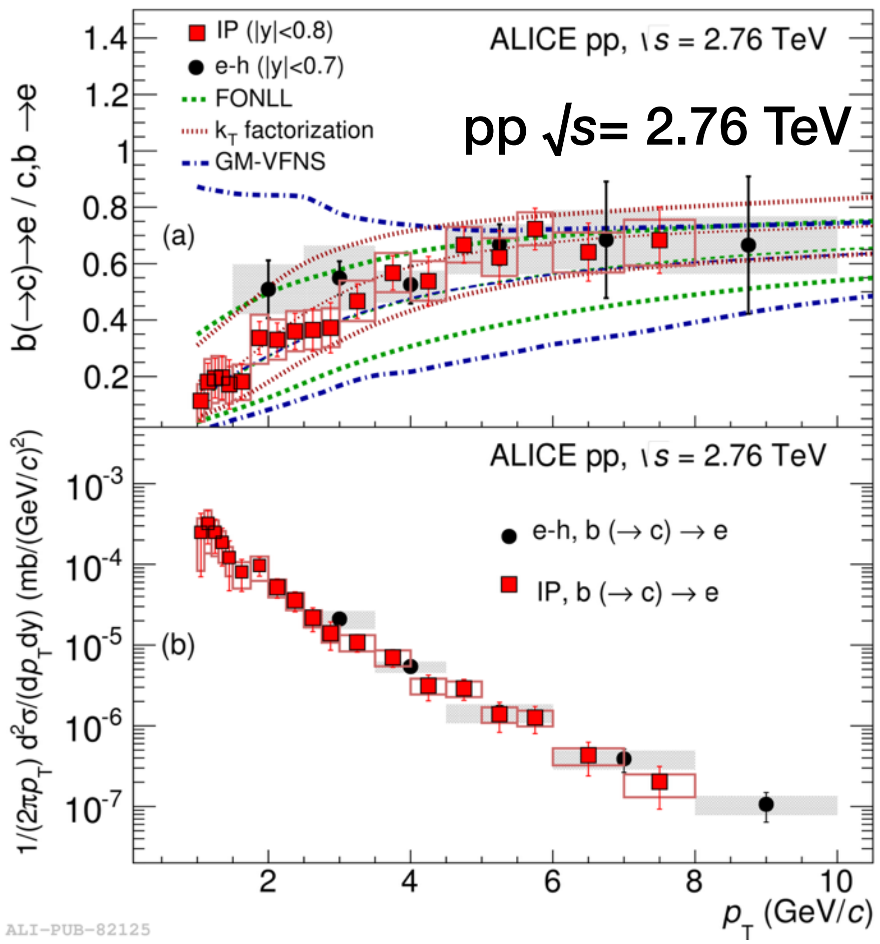
- Heavy-flavour cross section measured in various channels
- pQCD-based calculations (FONLL, GM-VFNS, k_T factorization) compatible with data FONLL: JHEP 1210 (2012) 137, GM-VFNS: Eur. Phys. J. C 72 (2012) 2082, k_T factorisation: arXiv:1301.3033
- Similar situation at $\sqrt{s}$ = 2.76 TeV

HFE : Phys. Rev. D 91, 012001(2015) D mesons : JHEP07(2012)191 HFM : Phys. Rev. Lett. 109, 112301(2012)

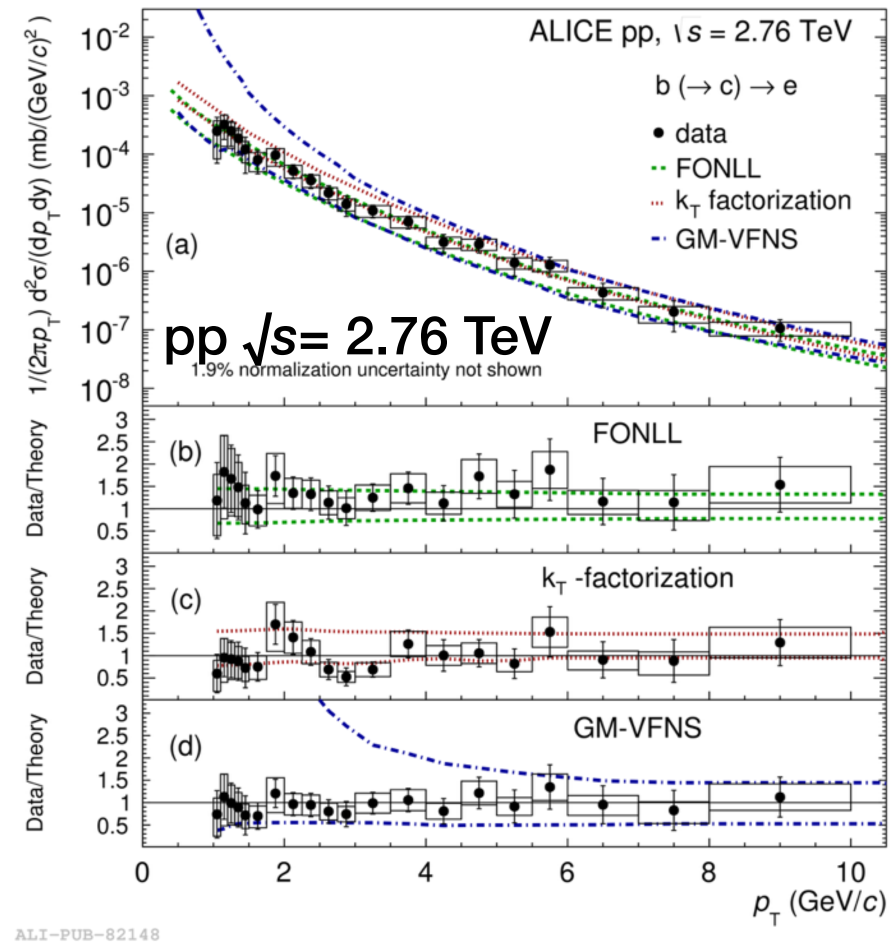
Heavy-flavour p_T-differential cross section

Beauty-decay electrons

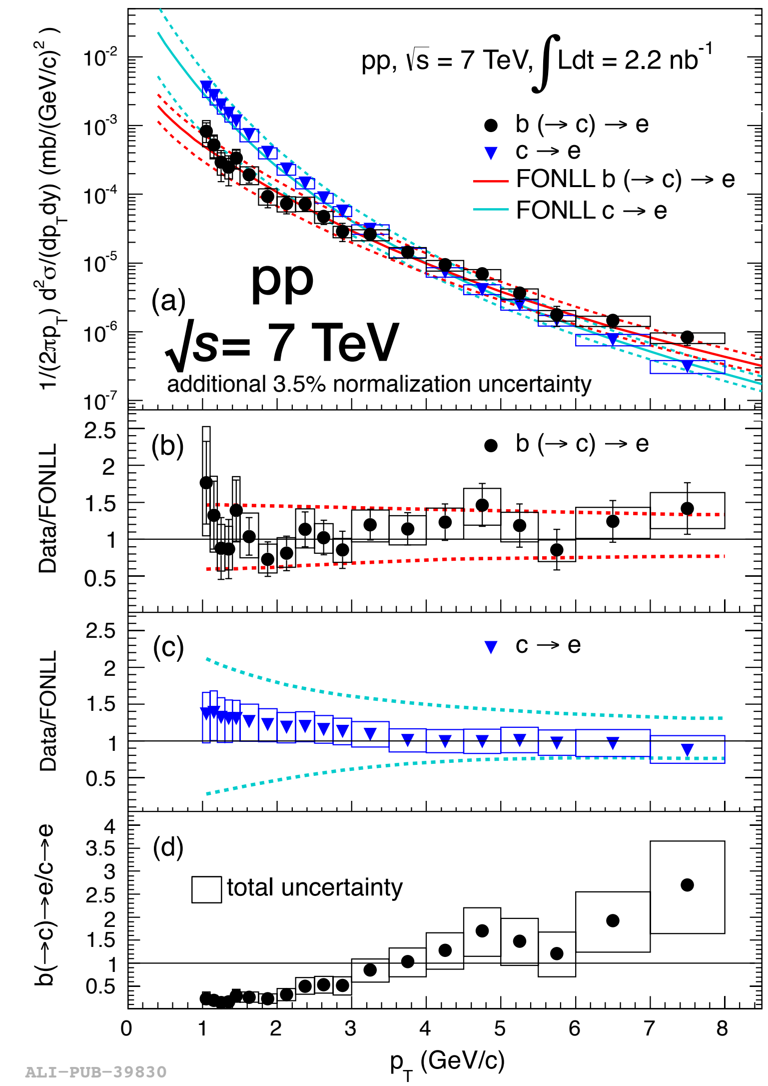
Phys. Lett. B 738, (2014)97



Phys. Lett. B 738, (2014)97



Phys. Lett. B 721 (2013) 13–23



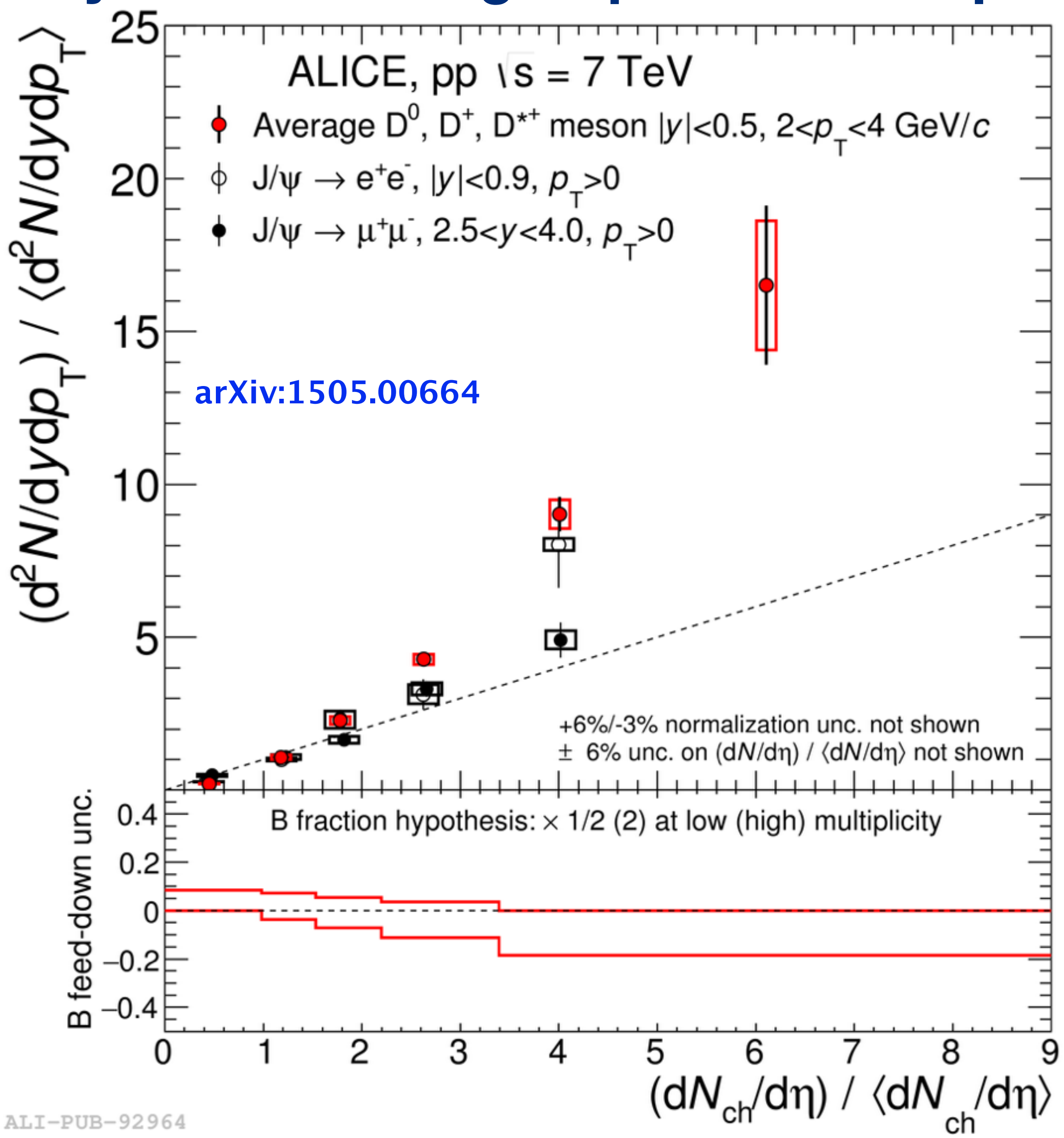
- Statistical separation of e± from charm and beauty decays using :
  - displaced secondary vertex (B meson cτ ~ 500μm)
  - electron-hadron angular correlation
- Relative contributions of charm and beauty decays as well as beauty decay electron cross section reproduced by pQCD-based calculations

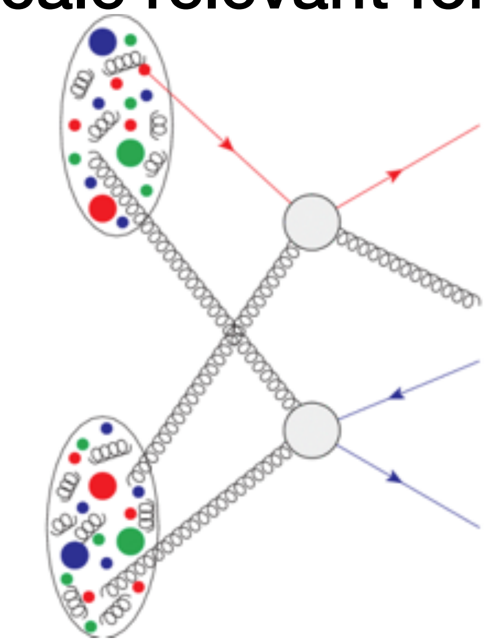
FONLL: JHEP 1210 (2012) 137, GM-VFNS: Eur. Phys. J. C 72 (2012) 2082, k_T factorisation: arXiv:1301.3033

Multiplicity dependent charm production

- LHCb results of double charm and J/ψ suggest that MPIs (Multi-Parton Interactions) play a role at the hard momentum scale relevant for $c\bar{c}$ production

Self-normalized D-meson and J/ψ yields vs. charged-particle multiplicity



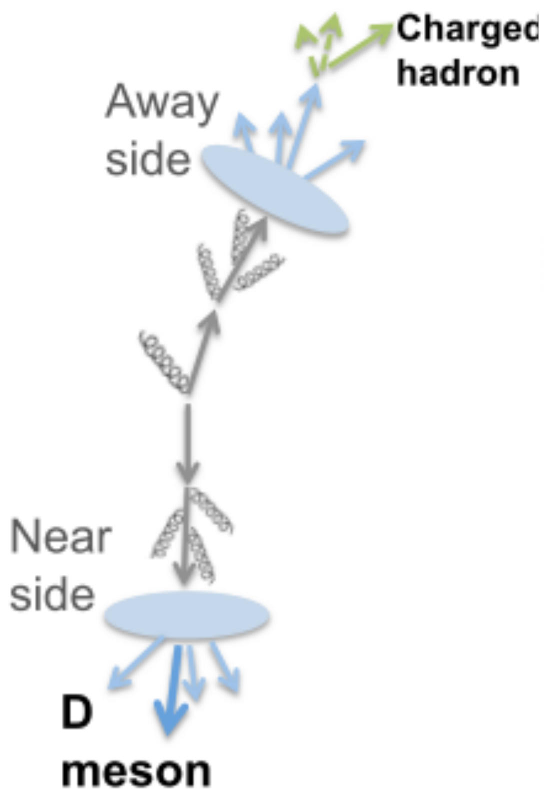


Phys.Lett. B707 (2012) 52–59

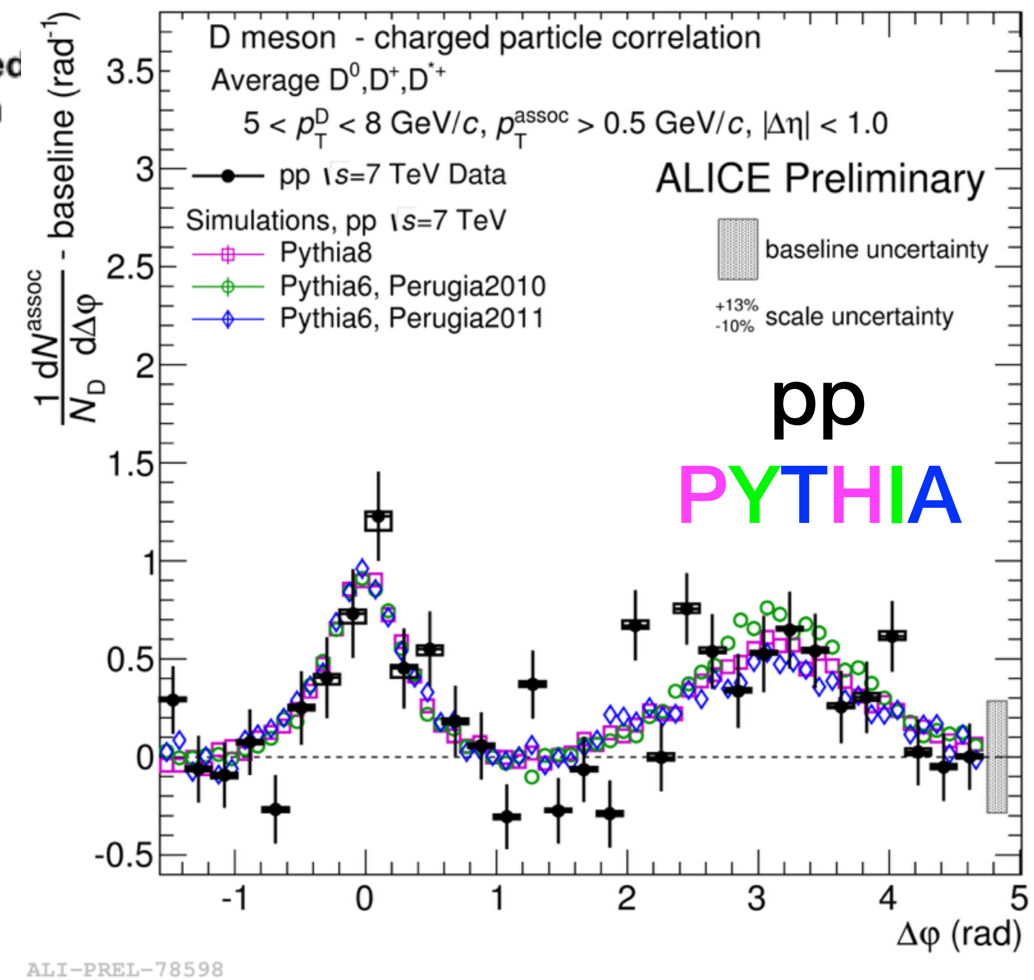
JHEP 1206 (2012) 141

- Self-normalised yields in multiplicity intervals show an increasing trend vs. multiplicity
- Similar behaviour for open (D meson) and hidden(J/Ψ) charm
  - more related to production mechanism (MPIs) rather than hadronization process

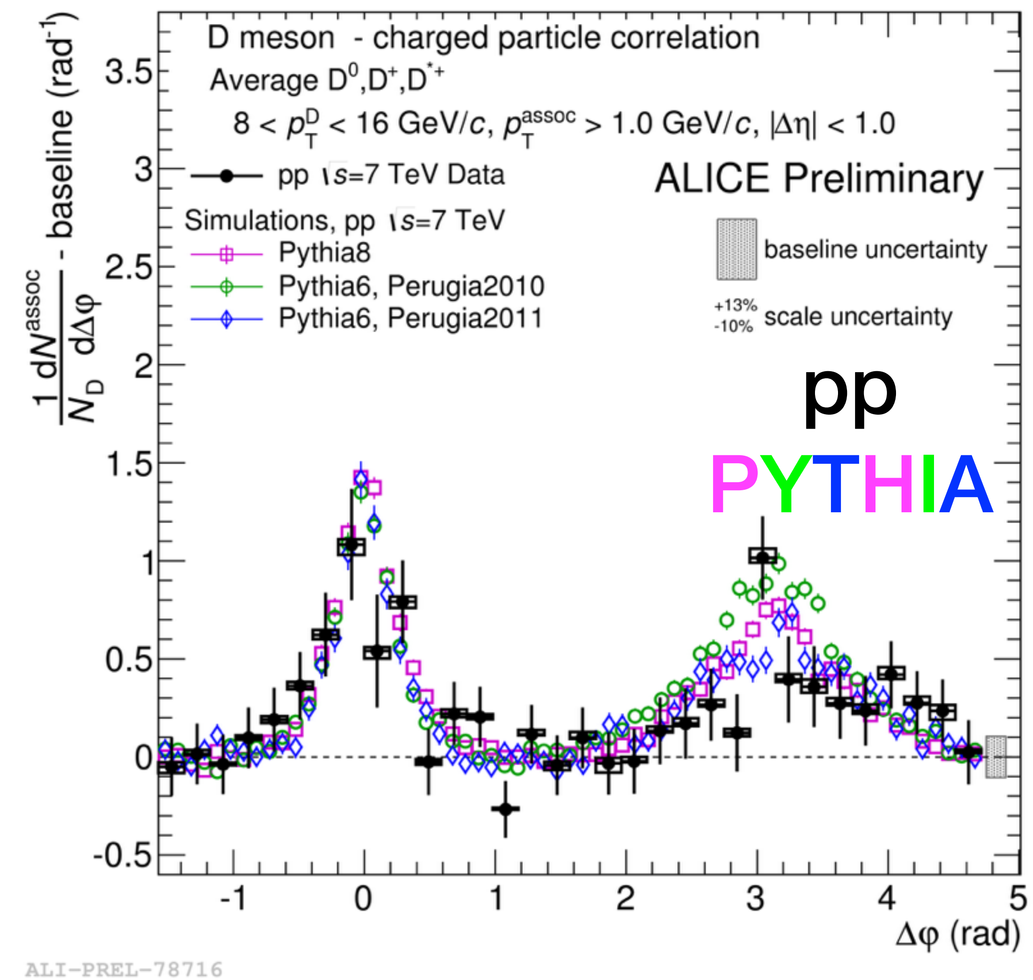
D meson - hadron angular correlation



5 < p_T^D < 8 GeV/c, p_T^{assoc}>0.5 GeV/c



8<p_T^D< 16 GeV/c, p_T^{assoc}>1 GeV/c



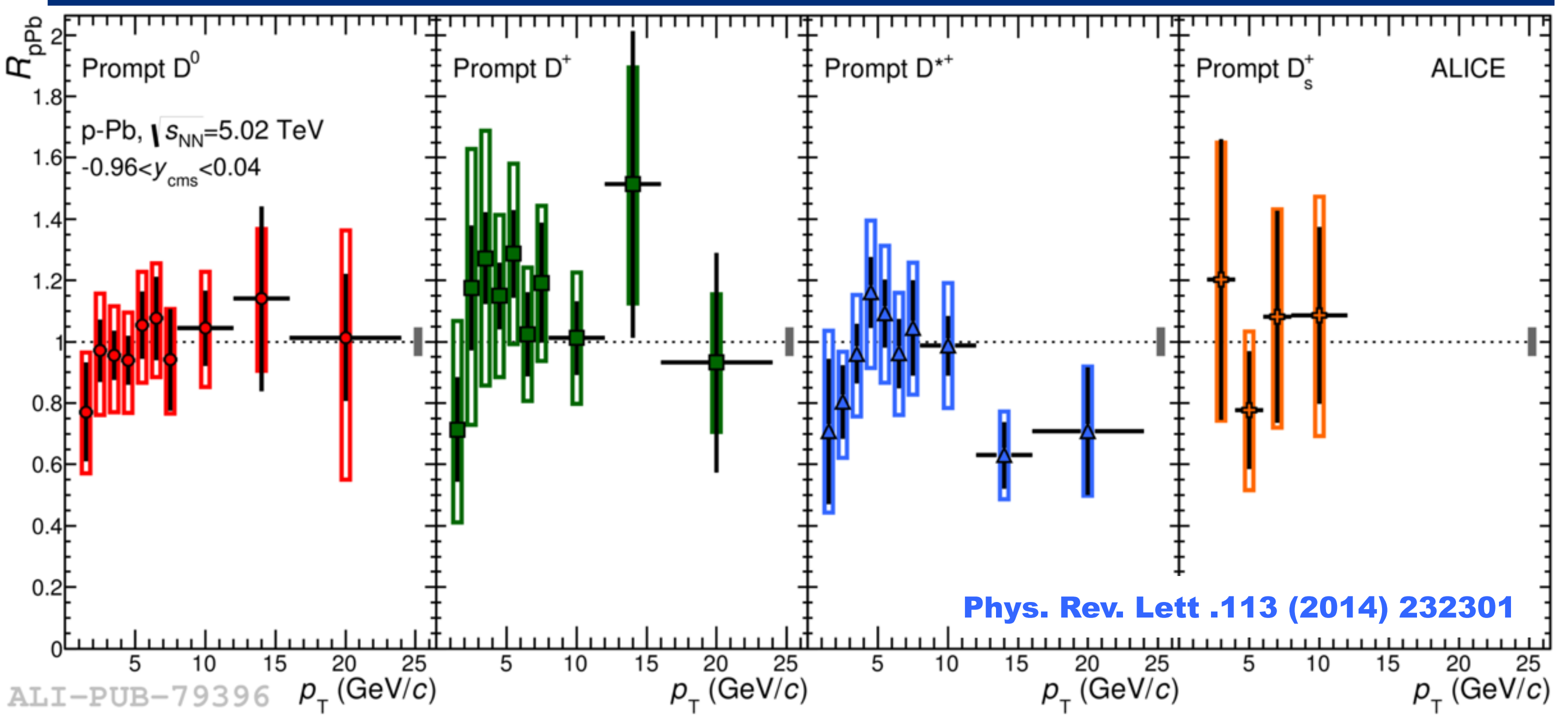
- Sensitive to charm production mechanism and fragmentation
- The data are compatible with different PYTHIA tunes after baseline subtraction
- High precision measurement is needed

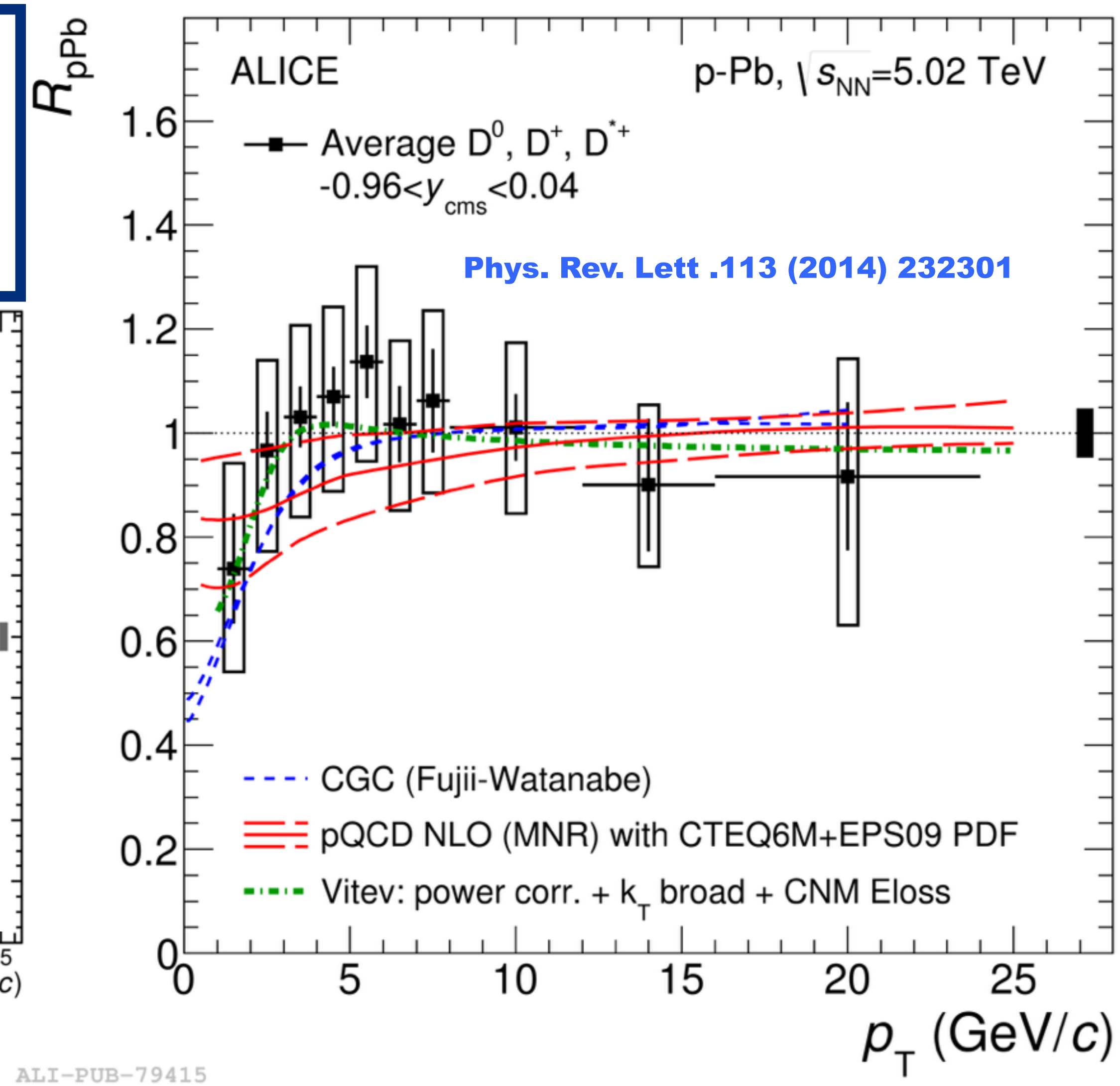
Results in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

Heavy-flavour nuclear modification factor R_{pPb}

Nuclear modification factor in p-Pb : $R_{pPb} = \frac{(d\sigma/dp_T)_{pPb}}{A \times (d\sigma/dp_T)_{pp}}$

$R_{pPb} \neq 1$: address possible cold-nuclear matter effects





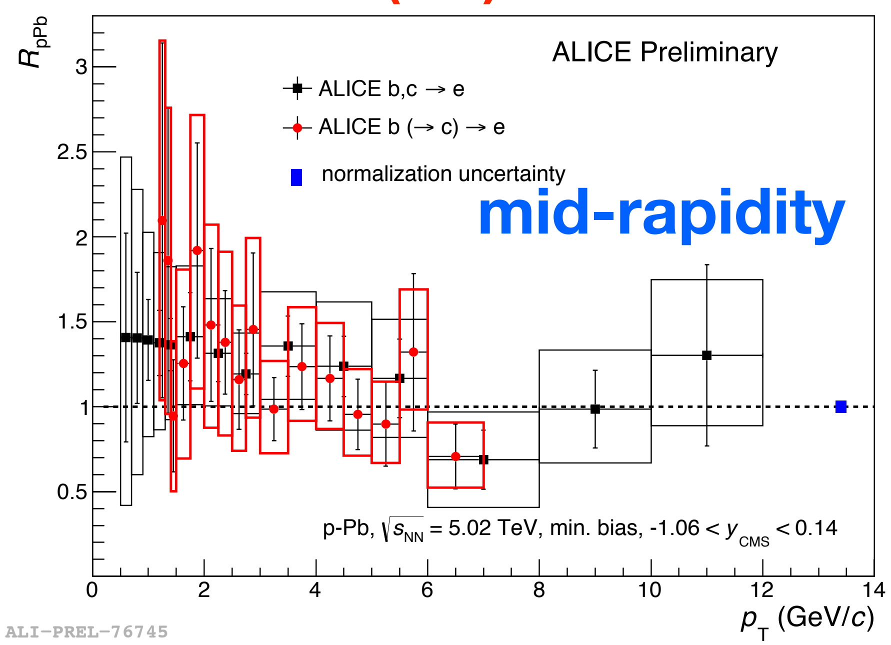
- R_{pPb} consistent with unity for all D-meson species
- D-meson R_{pPb} can be described by :
  - Color Glass Condensate (CGC) calculations arXiv:1308.1258
  - MNR pQCD calculations NPB 373(1992)295 with EPS09 nuclear PDF JHEP 04(2009)065
  - model including energy loss in cold nuclear matter, nuclear shadowing, and k_T broadening PRC 75(2007)064906

Heavy-flavour nuclear modification factor R_{pPb}

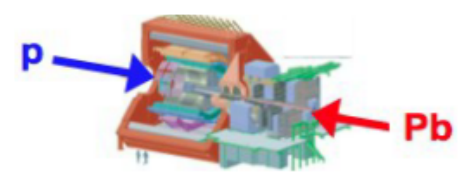
HF-decay electrons

b,c→e

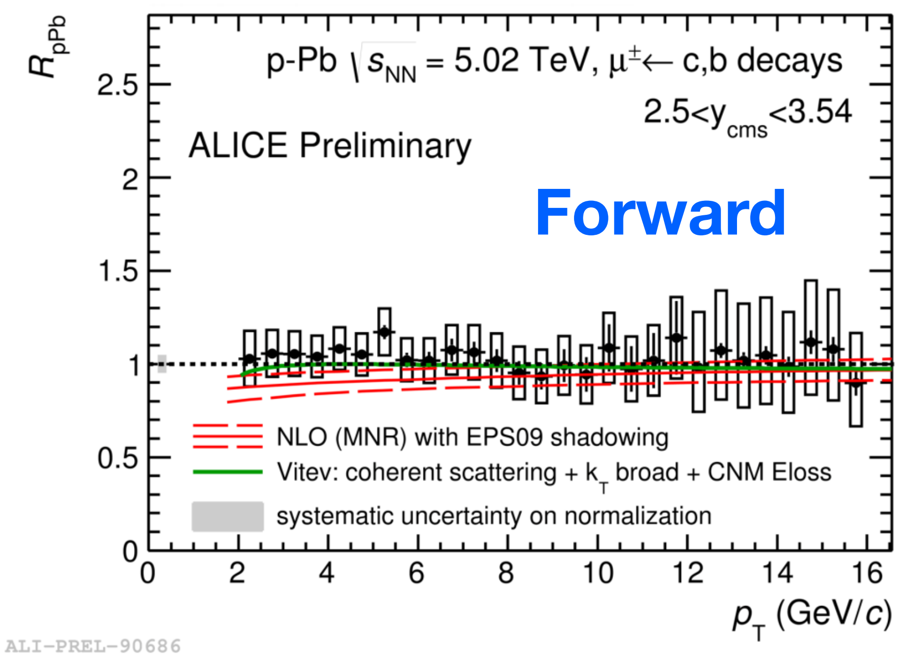
b(→c)→e

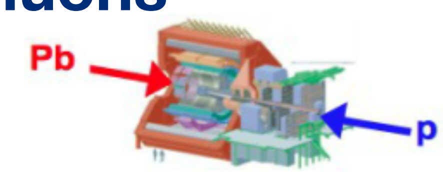


HF-decay muons

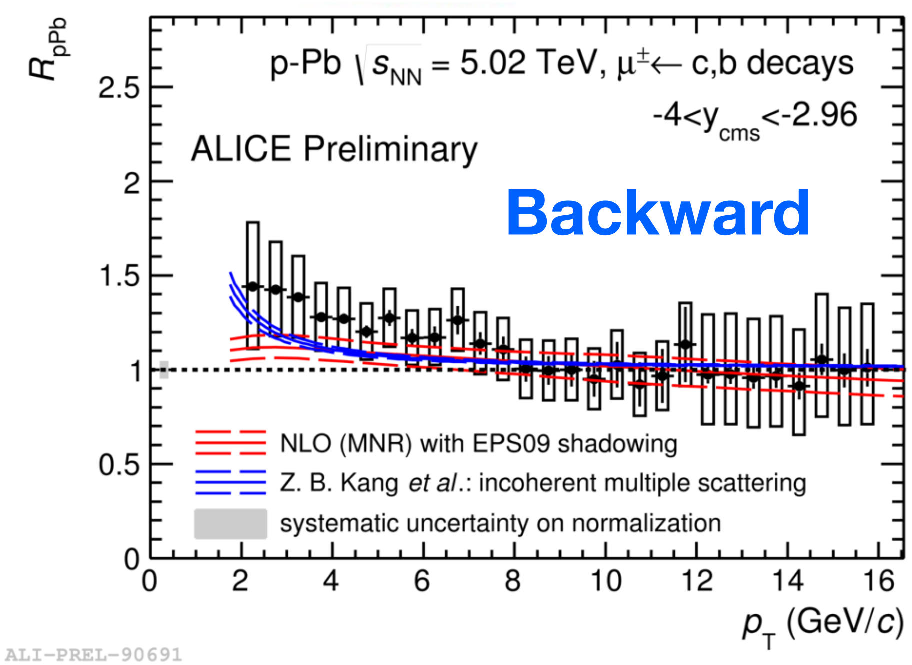


Forward: p-going



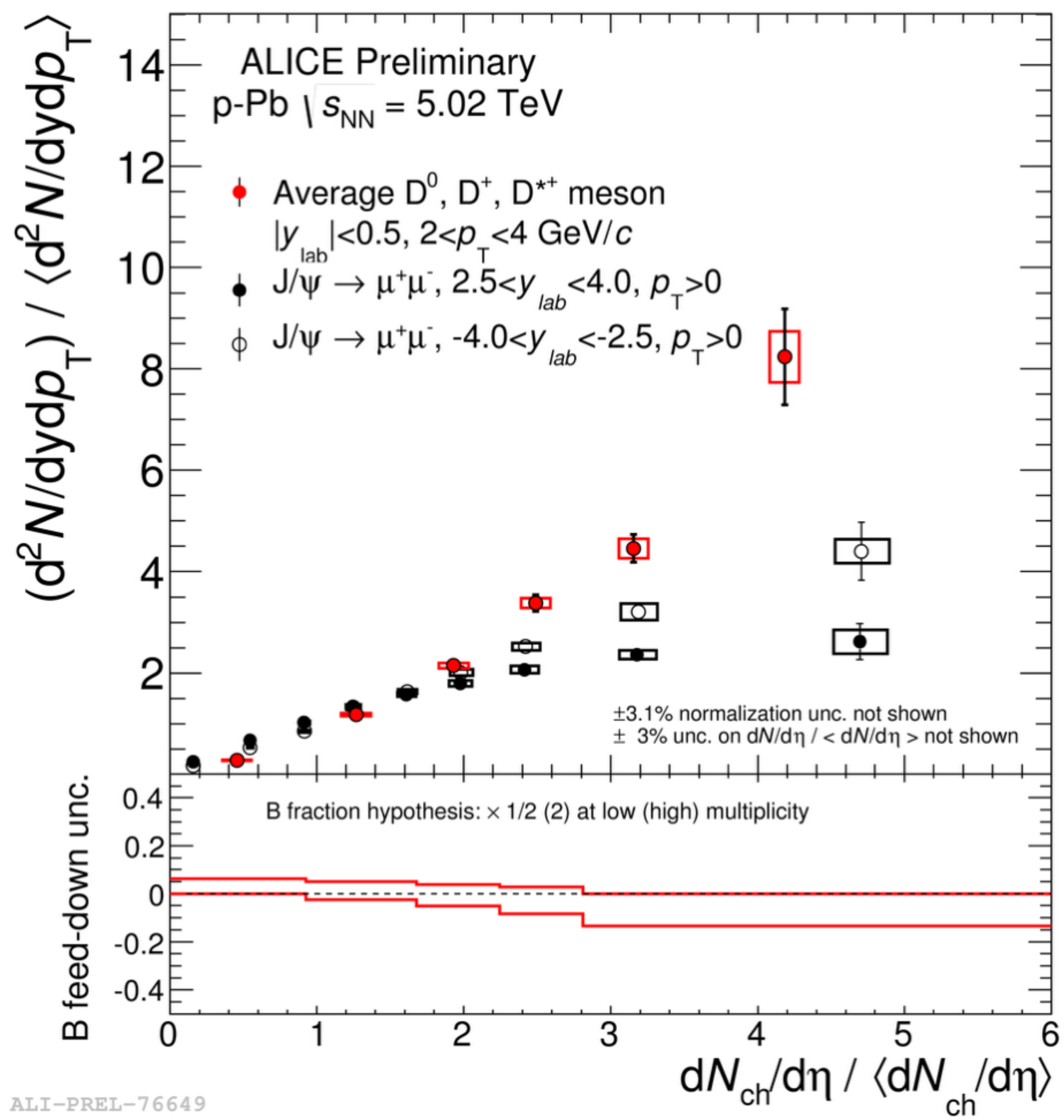


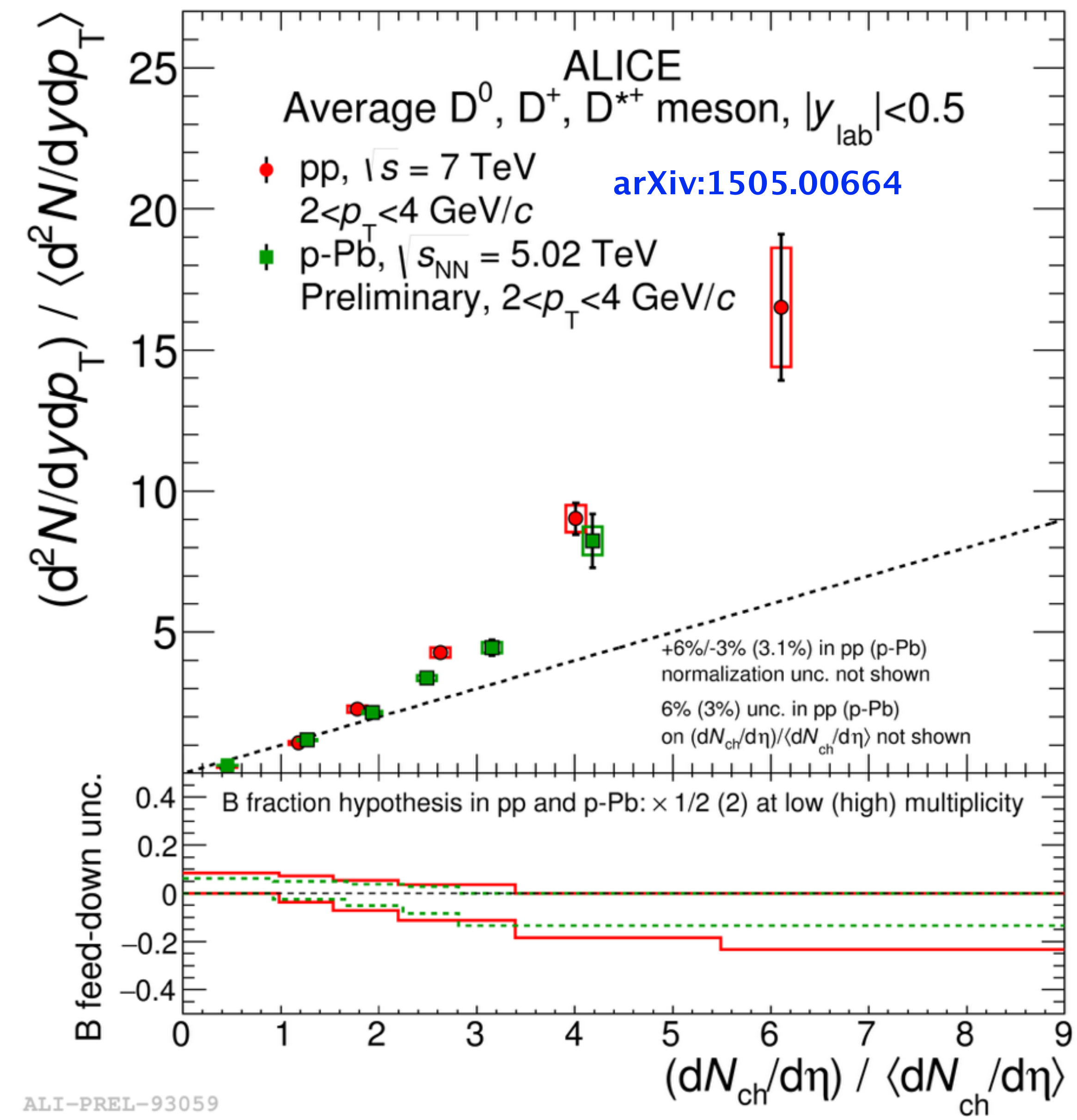
Backward: Pb-going



- Different *x* regions can be explored in different rapidity ranges
- Heavy-flavour decay lepton R_{pPb} close to unity for forward/backward and mid rapidity
- Slight enhancement at backward rapidity for $2 < p_T < 4$ GeV/c
- Within uncertainties, data can be described by pQCD calculations with EPS09 parameterization of shadowing

Multiplicity dependent D meson production

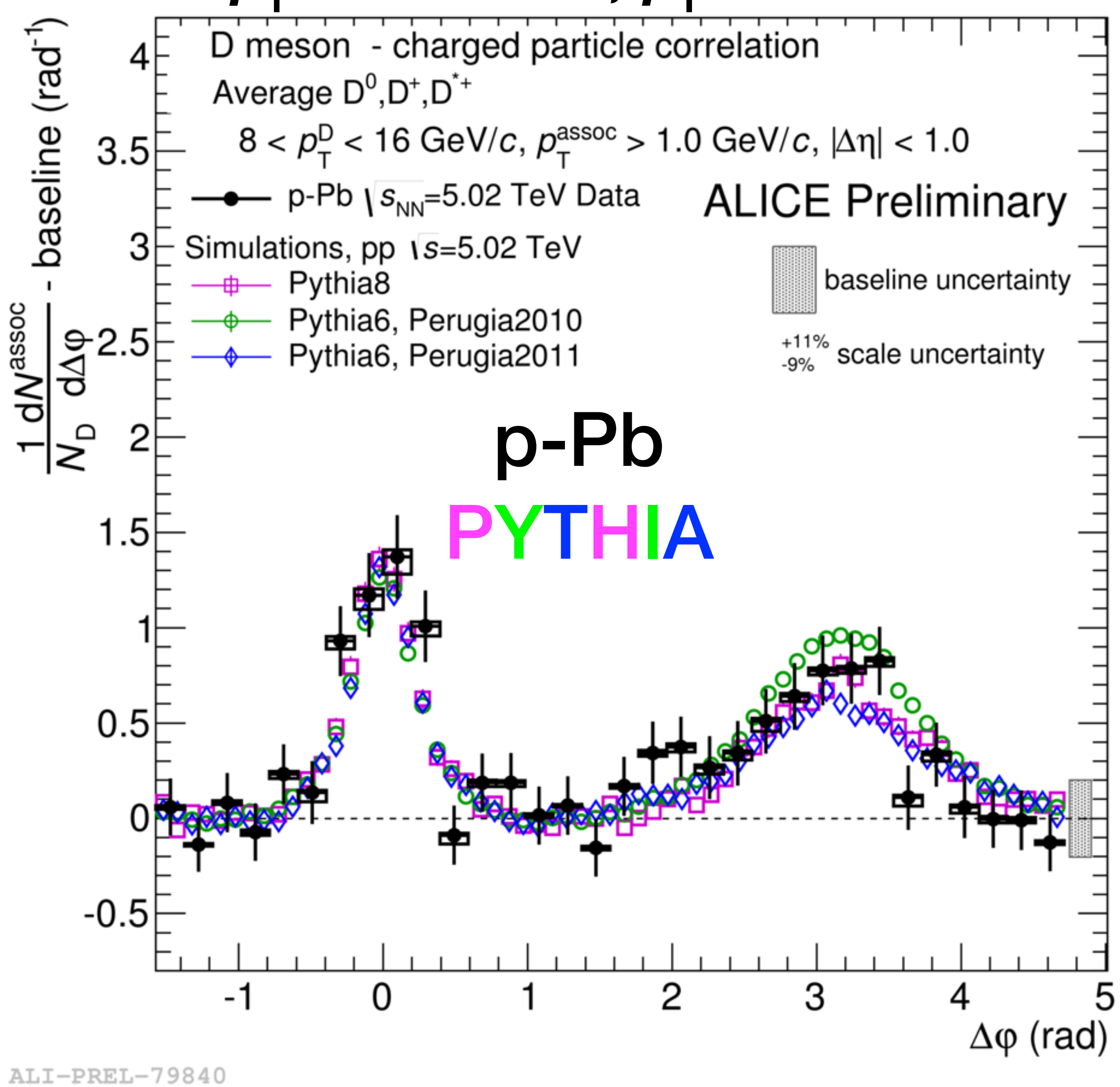




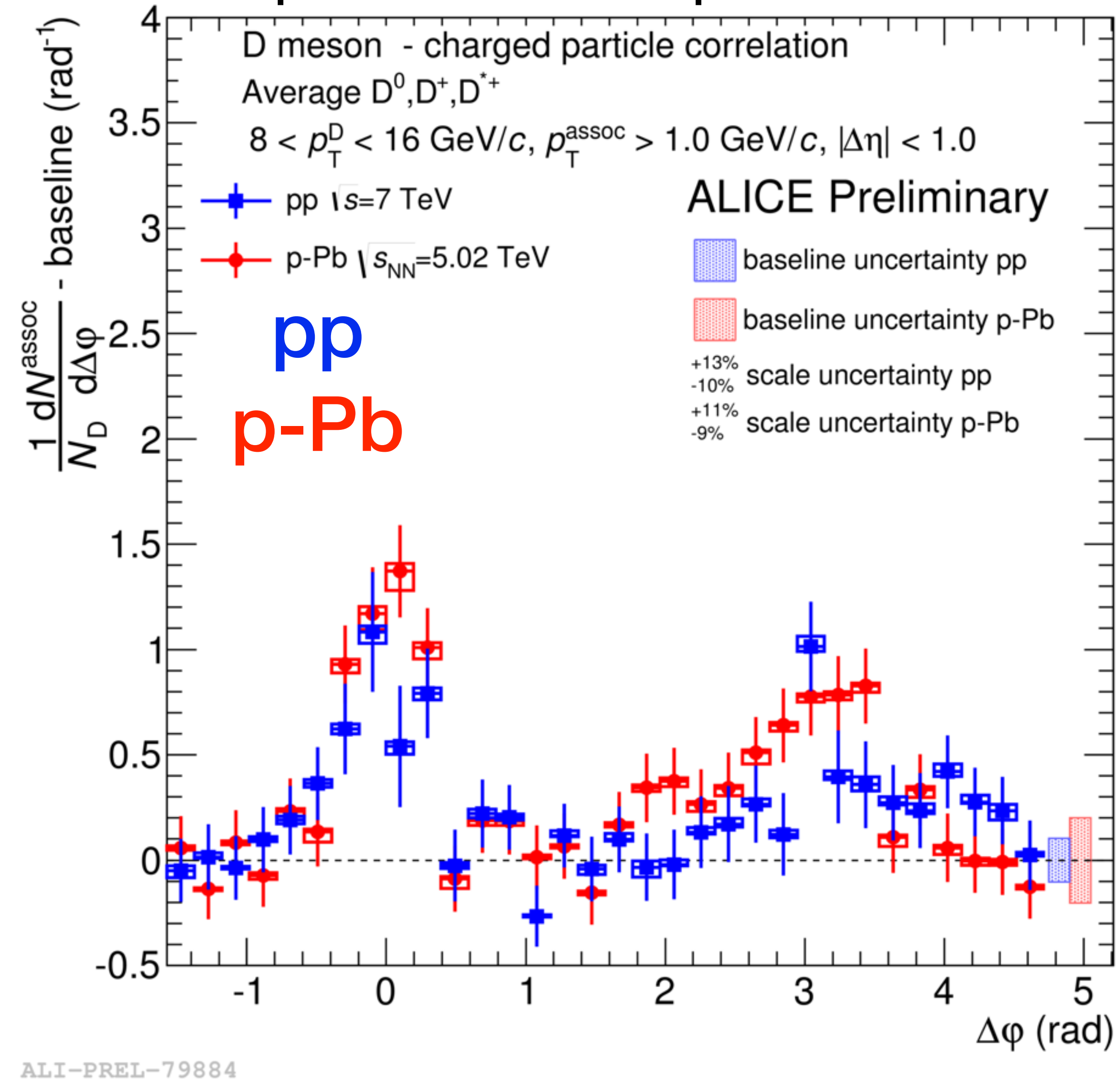
- Similar trend of D-meson production vs. multiplicity in pp and p-Pb collisions
  - pp collisions: high-multiplicity events are mainly from MPI
  - p-Pb collisions: high-multiplicity events are also due to large number of binary collisions

D meson - hadron angular correlation

8< p_T^D < 16 GeV/*c*, p_T^{assoc} >1 GeV/*c*



8< p_T^D < 16 GeV/*c*, p_T^{assoc} >1 GeV/*c*

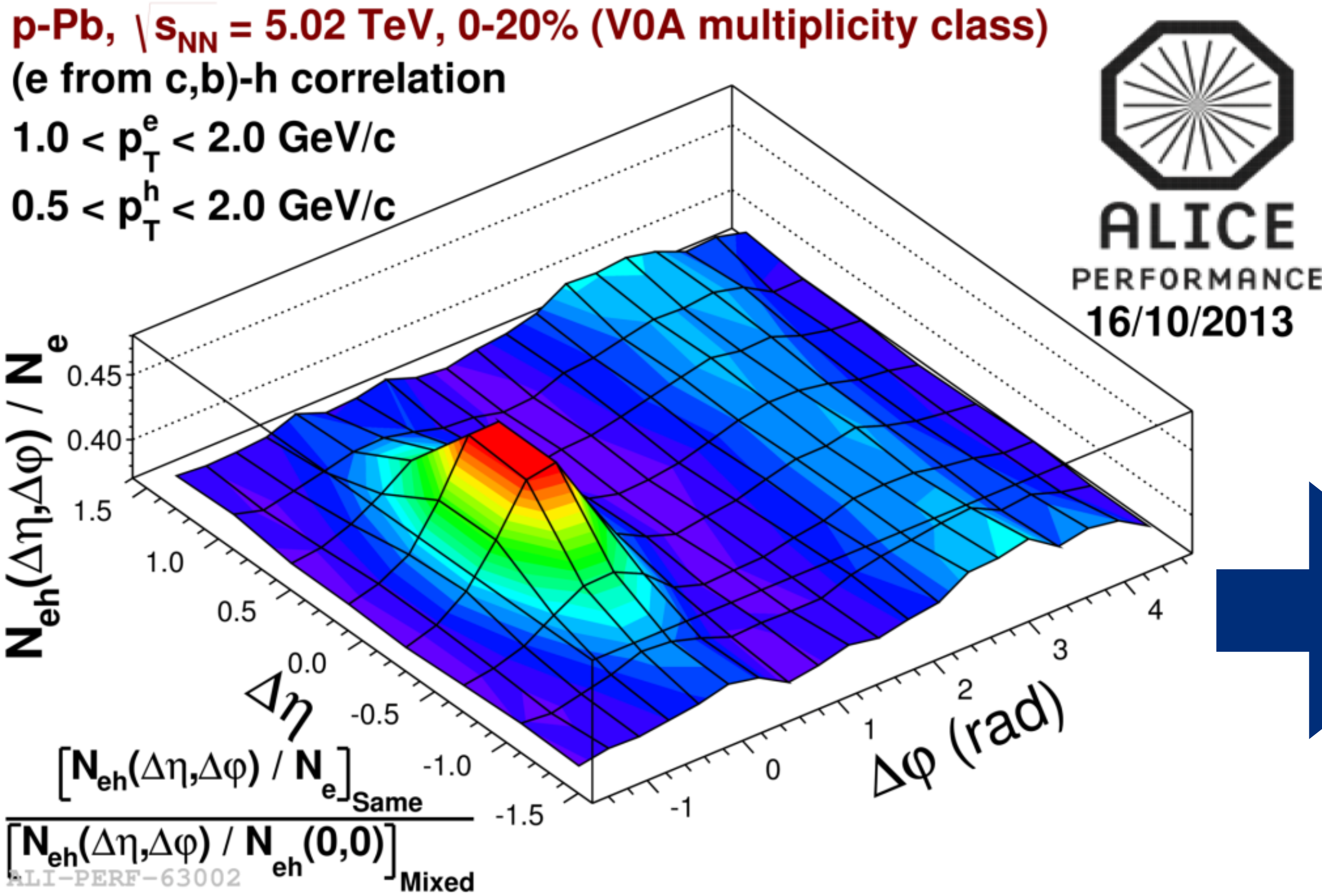


- Angular correlations in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV after baseline subtraction, well described by different PYTHIA tunes
- Compatible with angular correlations in pp collisions at $\sqrt{s}$ = 7 TeV
- Better precision requires more data from Run-II at the LHC

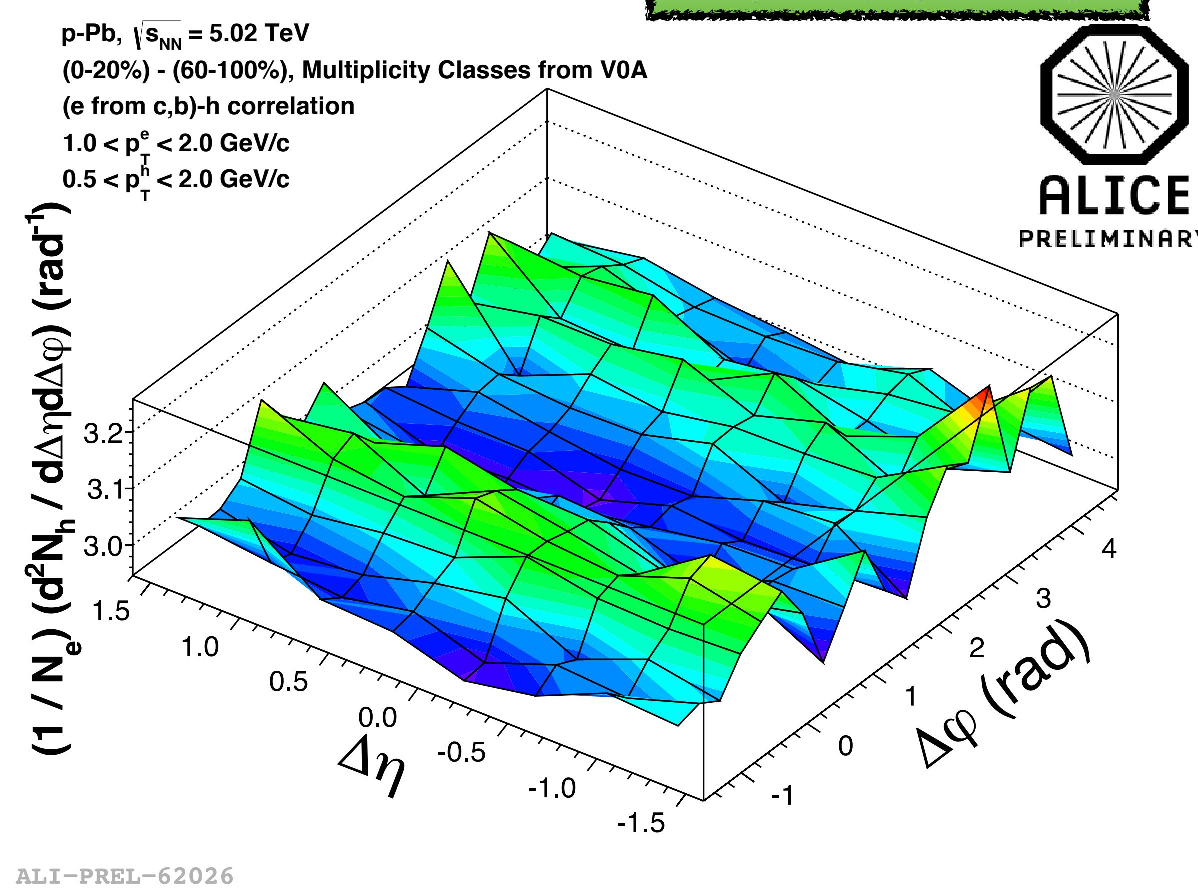
Heavy-flavour decay electron - hadron angular correlation

PLB 719(2013)29

- Long-range angular correlation (“double ridge“) was observed in the light-flavor sector
  - ➡ Same correlation in the heavy-flavour sector?



Multiplicity class:
(0-20%) - (60-100%)



remove jet components by subtracting the lowest multiplicity (60-100 %) class from the highest one (0-20 %)

Heavy-flavour decay electron - hadron angular correlation

PLB 719(2013)29

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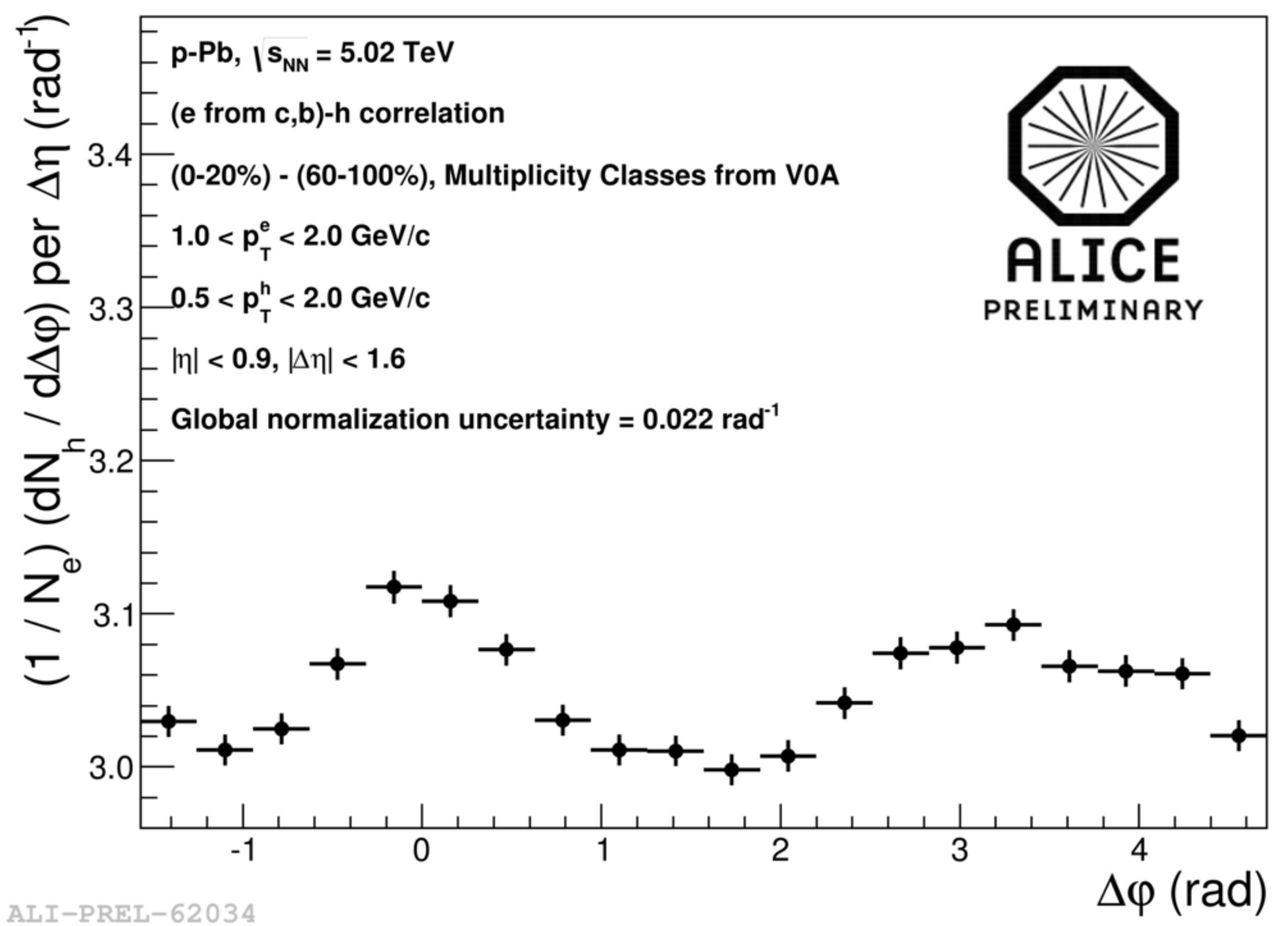

- Double-ridge structure for HF decay e-h angular correlations is observed at low p_T^e
- Possible explanation of double ridge :
  - CGC in initial state (Dusling & Venugopolan, PRD 87(2013)094034)
  - Hydrodynamics in final state (Bozek & Broniowski, PLB 718(2013)1557)

Summary & Outlook

- Thanks to excellent tracking, vertexing and particle-identification capabilities provided by ALICE, heavy-flavour production is studied in detail
- Heavy-flavour results in pp collisions are compatible with pQCD-based calculations
- Heavy-flavour results in p-Pb collisions are consistent with pQCD-based calculations + cold nuclear matter effects
- From the differential measurements :
  - can access the interplay of soft and hard processes in the charm sector in pp collisions and p-Pb collisions
  - can investigate possible collective effects on charm production at high multiplicities in small collision systems like p-Pb collisions
- Better precision, more statistics, extended p_T coverage measurements will be possible with Run-II and Run-III data.

Thanks for your attention!

Back Up