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

Grazia Luparello for the ALICE Collaboration
University of Trieste & INFN-Trieste

Outline

✓ Physics motivations for open heavy-flavour measurements in pp collisions

✓ The ALICE detector and open heavy-flavour reconstruction

✓ Main results

- Open heavy-flavour cross sections
- D-meson production as a function of the charged-particle multiplicity
- Angular correlations of D mesons and charged particles

✓ Conclusions and outlook

Outline

✓ **Physics motivations for open heavy-flavour measurements in pp collisions**

✓ The ALICE detector and open heavy-flavour reconstruction

✓ Main results

- Open heavy-flavour cross sections
- D-meson production as a function of the charged-particle multiplicity
- Angular correlations of D mesons and charged particles

✓ Conclusions and outlook

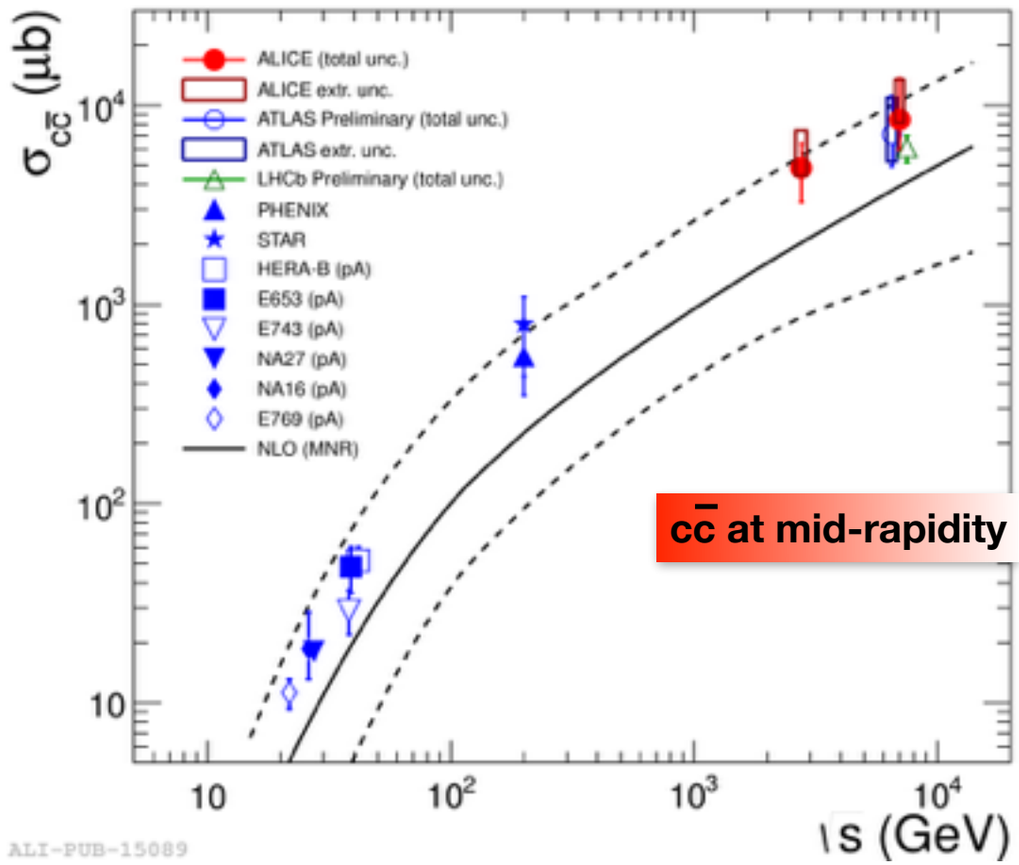
Physics motivations

- Charm and beauty quarks are produced in partonic scattering processes with large Q^2 transfer
  - Production cross sections can be calculated with perturbative QCD calculations based on the factorisation approach

- Open heavy-flavour measurements are a test for pQCD calculations

- Fundamental reference for p-Pb and Pb-Pb measurements

JHEP 1207 (2012) 191



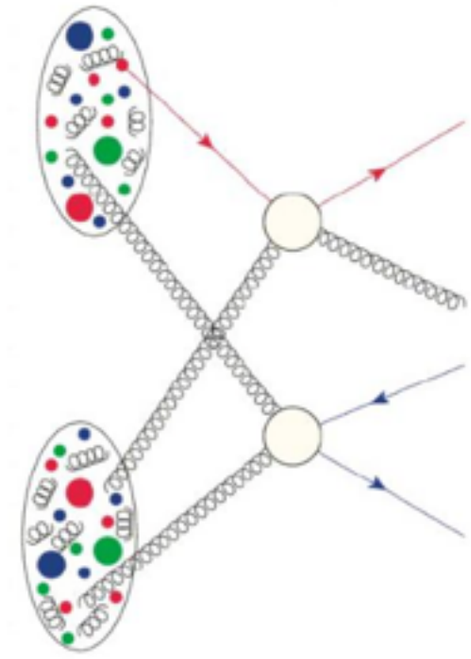
- **More differential measurements**

-> deeper insight into heavy-flavour production in pp collisions

  - **Charm production as a function of the charged-particle multiplicity in pp collisions**
  - **Angular correlations between D mesons and charged hadrons**

Open heavy-flavour production vs multiplicity

- **Interplay between hard and soft processes in particle production**
- **Study the role of multi-parton interactions (MPI)**

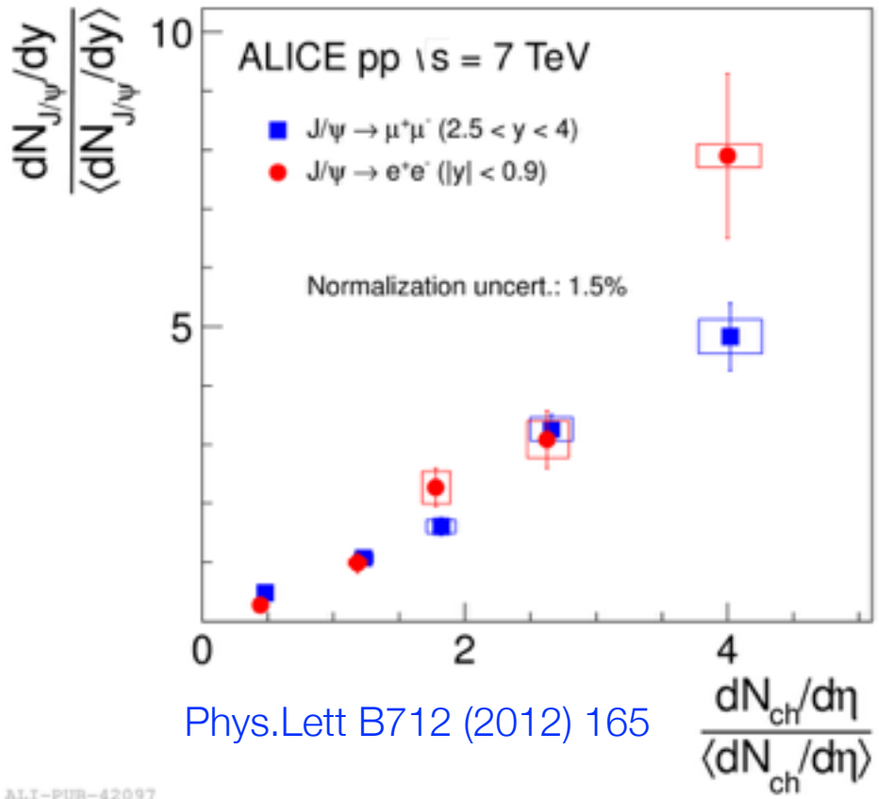


MPI at the LHC

- Particle production in high-energy pp collisions at the LHC expected to have a substantial contribution from MPI
- CMS measurement of jets and underlying events Eur. Phys. J. C73(2013) 2674
  - better agreement with models including MPI
- ALICE minijet analysis in pp collisions JHEP 09 (2013) 049
  - increase of MPI with charged-particle-multiplicity

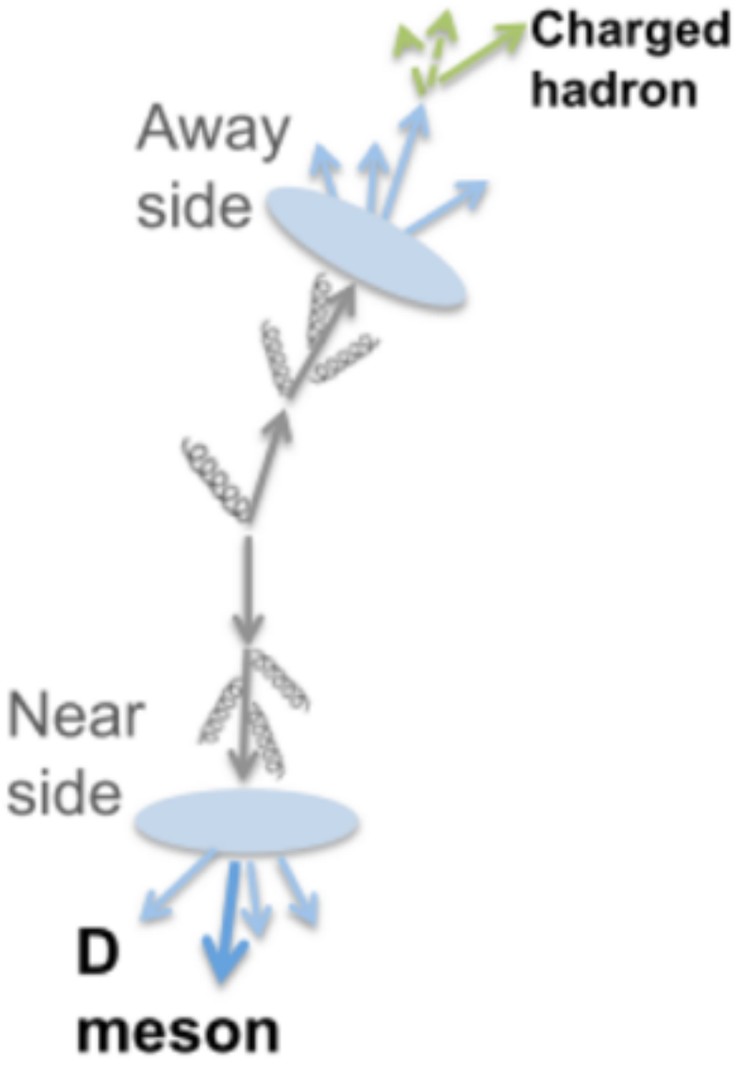
What has been observed in the charm sector?

- NA27 (pp collisions at $\sqrt{s}$=28 GeV) NA27 Coll. Z.Phys.C41 (1988)191
  - Events with charm have larger charged-particle multiplicity
- LHCb measurement of double-charm production JHEP 06 (2012) 141
  - better agreement with models including double-parton scattering
- ALICE measurement of increase of J/ψ yields with increasing charged-particle multiplicity. Phys.Lett B712 (2012) 165



Phys.Lett B712 (2012) 165

Open HF - charged-particle angular correlations



- Angular correlation between **open heavy-flavour particles (i.e. D mesons or heavy-flavour decay electrons) and charged hadrons**
- Investigate heavy-flavour production processes, complementing the information obtained with the measurements of p_T-differential cross sections
- Sensitive to jet-parton showers and fragmentation
- Extract relative contribution of electrons from charm and beauty decays using correlations between heavy-flavour decay electrons and charged particles PLB 738 (2014) 97-108
- Reference for p-Pb and Pb-Pb measurements
  - Correlations in A-A collisions provide important information on in-medium modifications of jet properties and energy loss: need knowledge of correlations in pp collisions as reference

Outline

✓ Physics motivations for open heavy-flavour measurements in pp collisions

✓ **The ALICE detector and open heavy-flavour reconstruction**

✓ Main results

- Open heavy-flavour cross sections
- D-meson production as a function of the charged-particle multiplicity
- Angular correlations of D mesons and charged particles

✓ Conclusions and outlook

ALICE detector

EMCAL
electron identification

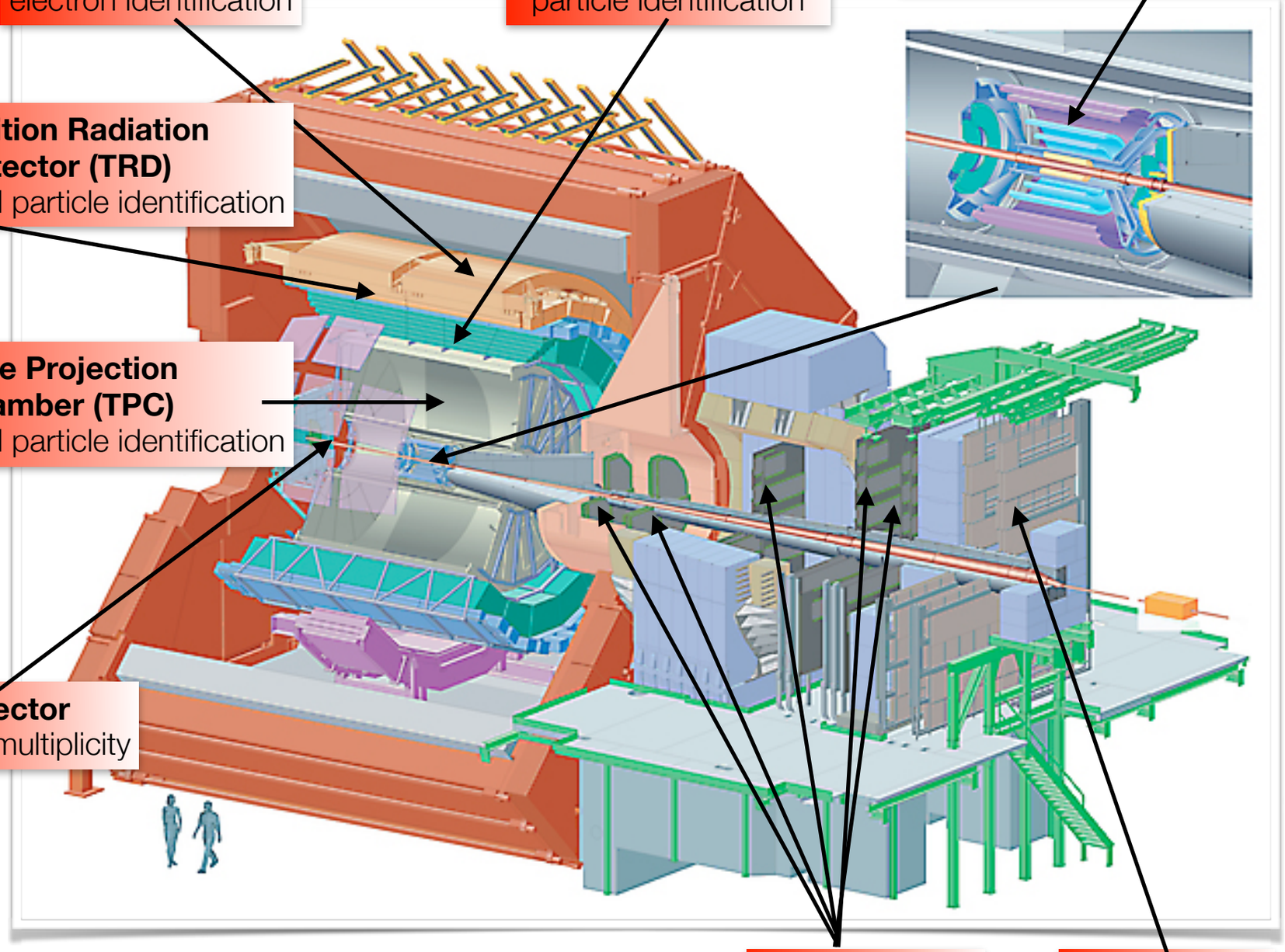
Time Of Flight (TOF)
particle identification

Inner Tracking System (ITS)
tracking and vertexing

Transition Radiation Detector (TRD)
tracking and particle identification

Time Projection Chamber (TPC)
tracking and particle identification

V0 detector
trigger and multiplicity



Muon Tracking

Muon Trigger

Open HF measurements in ALICE

- D mesons

$D^0 \rightarrow K^-\pi^+$

$D^+ \rightarrow K^-\pi^+\pi^+$

$D^{*+} \rightarrow D^0\pi^+$

$D_s \rightarrow \phi\ \pi^+ \rightarrow K^-K^+\pi^+$

- Open HF electrons

B-> e + X

C-> e + X

- Open HF muons

B-> μ + X

C-> μ + X

Results on open HF decay leptons in the heavy-ion session in **L. Valencia Palomo**'s talk

Data collected in pp collisions at both $\sqrt{s}$ = 2.76 TeV and $\sqrt{s}$ = 7 TeV

Outline

✓ Physics motivations for open heavy-flavour measurements in pp collisions

✓ The ALICE detector and open heavy-flavour reconstruction

✓ **Main results**

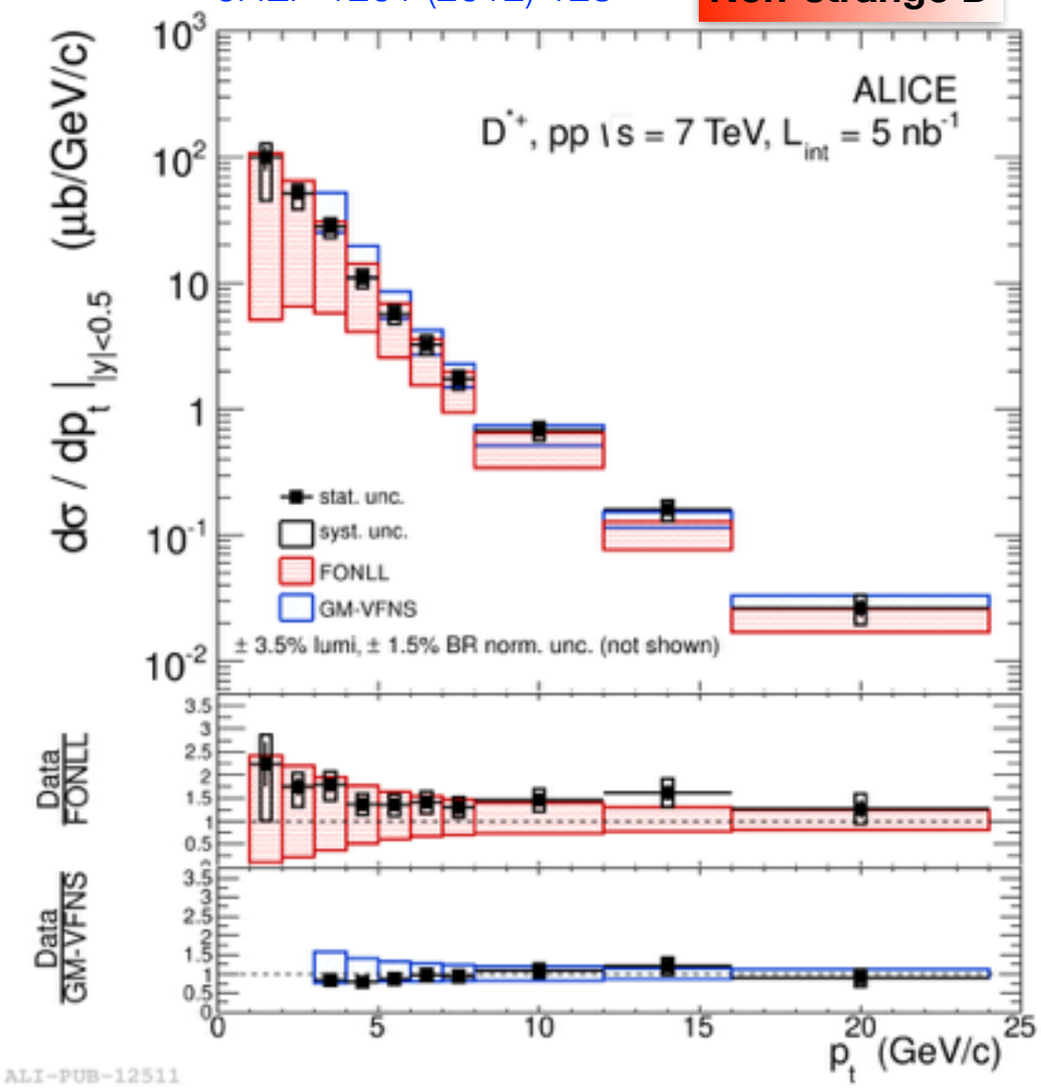
- **Open heavy-flavour cross sections**
- **D-meson production as a function of the charged-particle multiplicity**
- **Angular correlations of D mesons and charged particles**

✓ Conclusions and outlook

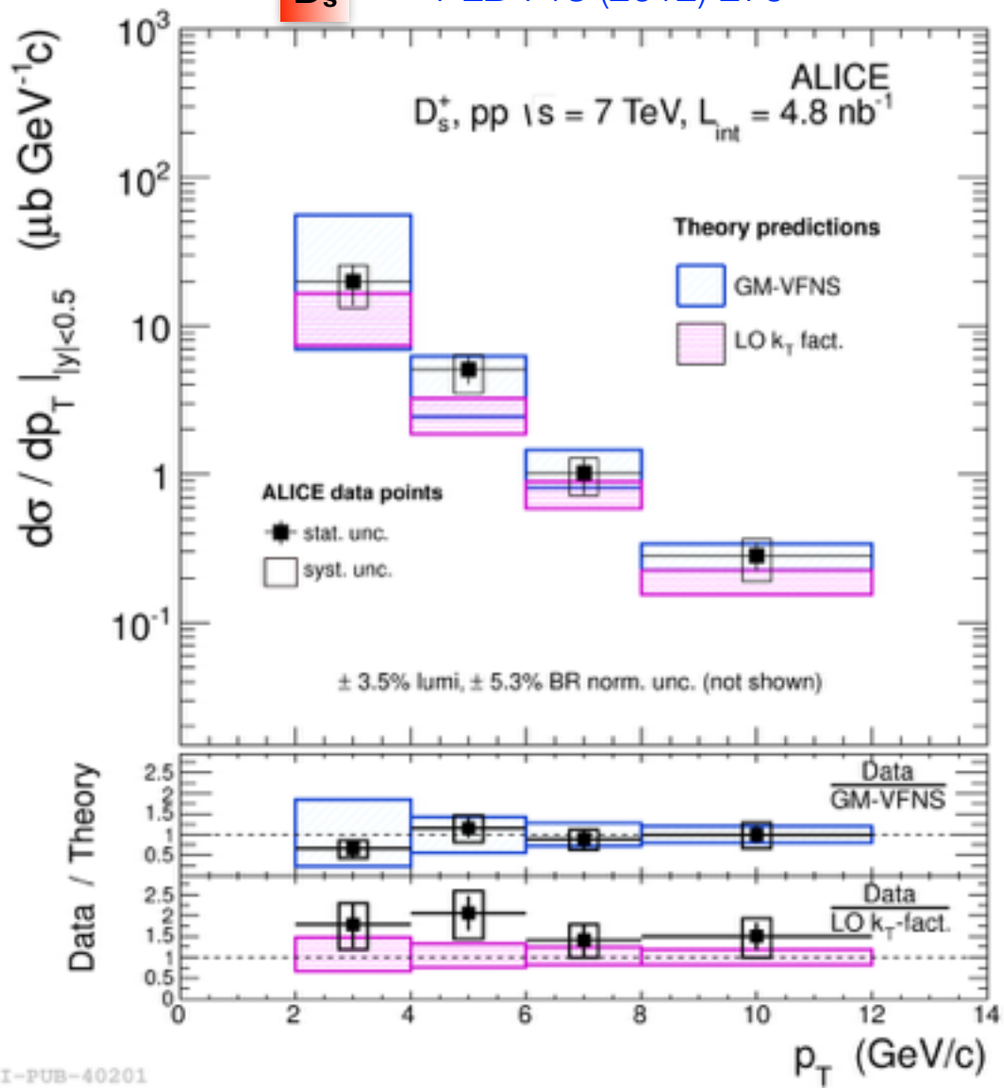
Prompt D meson p_T-differential cross sections

pp

JHEP 1201 (2012) 128 **Non-strange D**



D_s PLB 718 (2012) 279



FONLL: JHEP1210(2012)137;
GM-VFNS: Eur.Phys.JC72(2012) 2082;
LO k_T-factorization: Phys. Rev. D(2013)094022

D mesons at √s= 2.76 TeV
JHEP 1207 (2012) 191

- **pQCD calculations are compatible with data at both $\sqrt{s}$ = 2.76 TeV and 7 TeV**

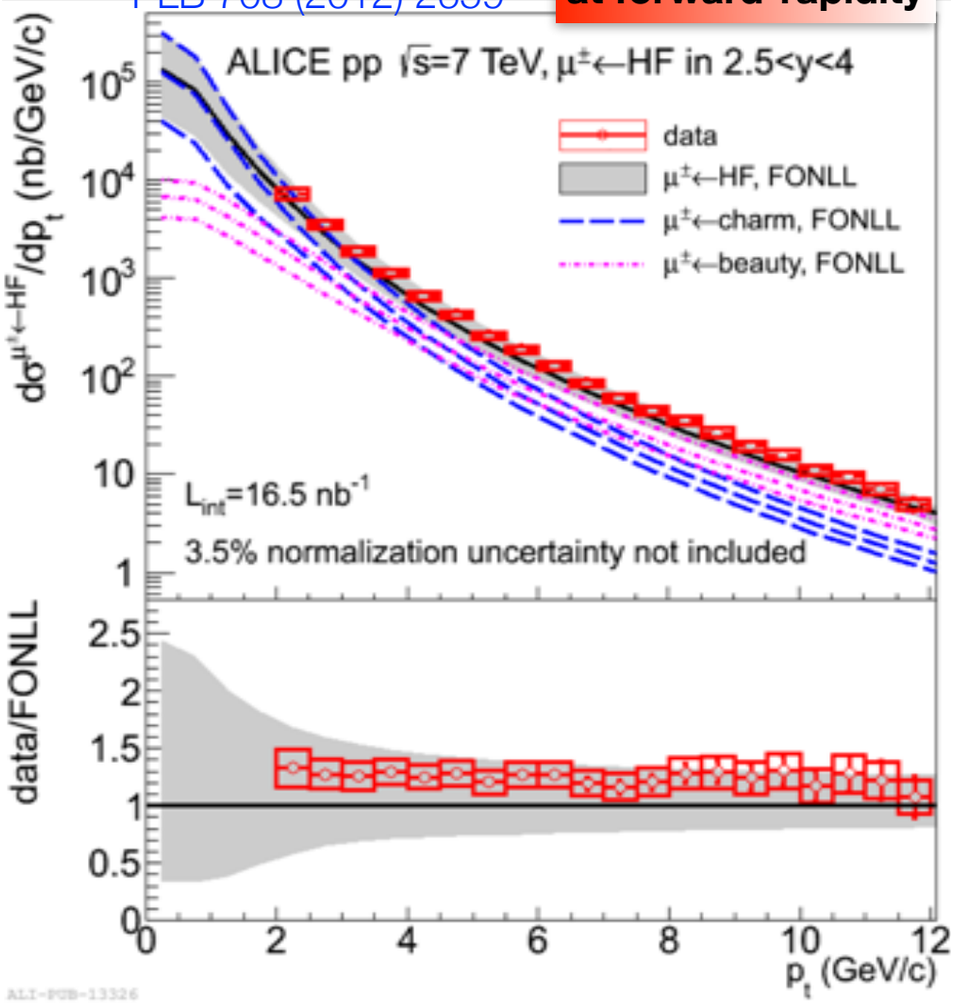
HF-decay lepton p_T-differential cross sections

pp

Includes contributions from charm and beauty

HF-decay muons at forward-rapidity

PLB 708 (2012) 2659

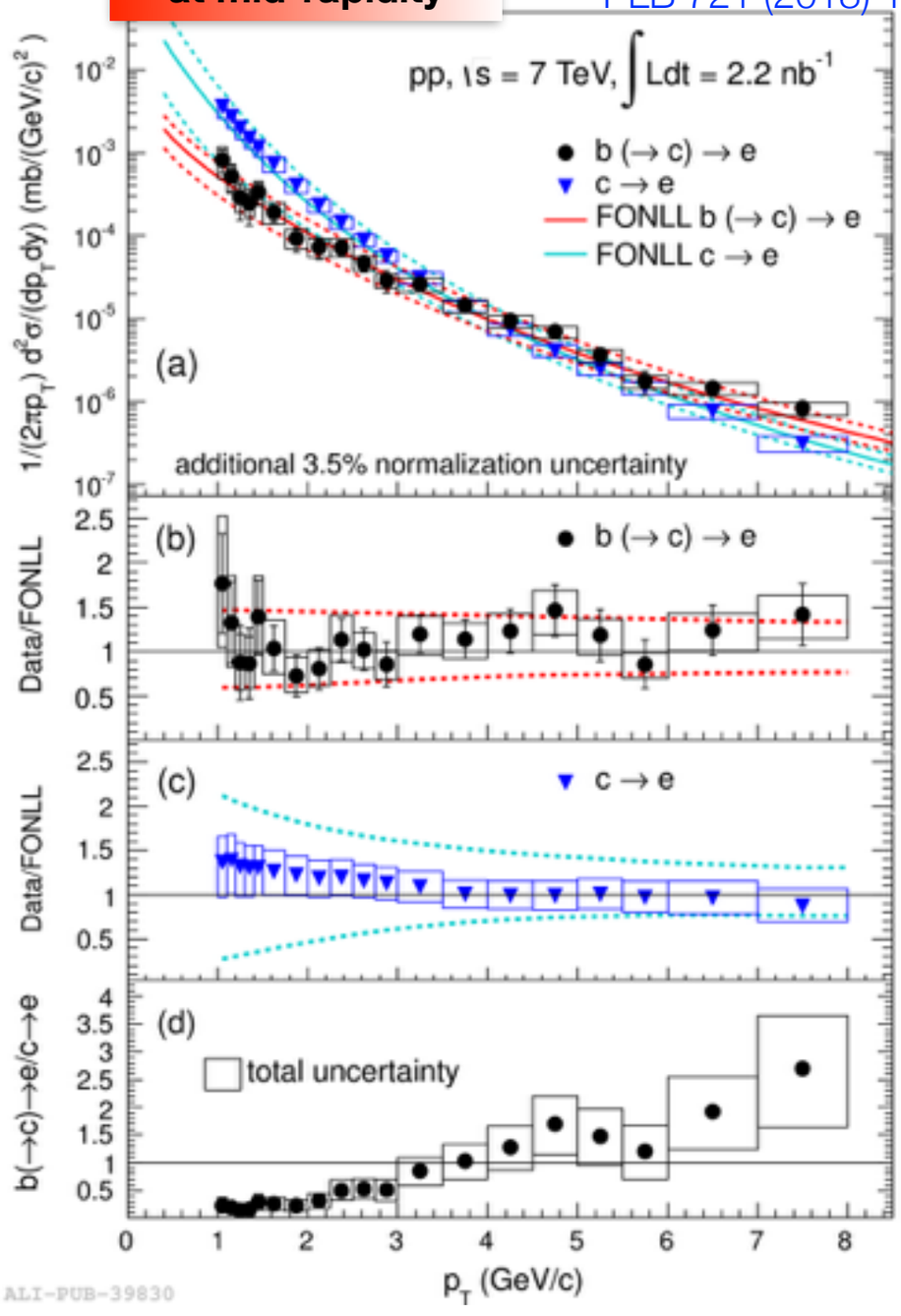


FONLL: JHEP1210(2012)137;
GM-VFNS: Eur.Phys.JC72(2012) 2082;
LO k_T-factorization: Phys. Rev. D(2013)094022

HF-decay e at √s= 2.76 TeV: PLB 738 (2014) 97-108
HF-decay μ at √s= 2.76 TeV: PRL 109(2012)112301

HF-decay electrons at mid-rapidity

PLB 721 (2013) 13



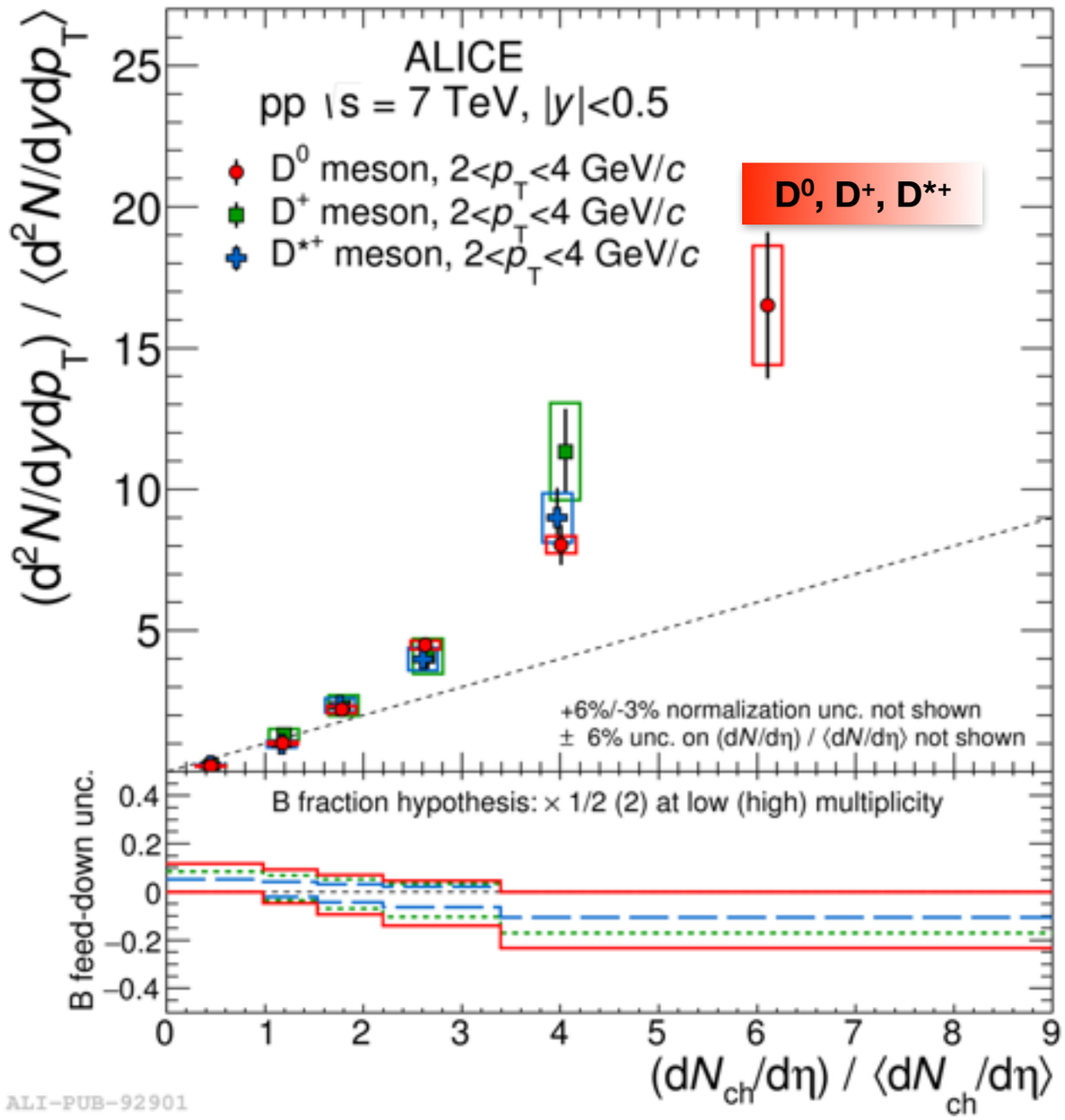
Charm and beauty contributions are separated

- **pQCD calculations are compatible with data at both $\sqrt{s}$ = 2.76 TeV and 7 TeV**

Multiplicity dependence of open HF production

pp

arXiv:1505:00664



Self-normalised yields

$$\frac{d^2N/dydp_T}{\langle d^2N/dydp_T\rangle} = \frac{Y^{mult}/(\epsilon^{mult}\times N^{mult}_{event})}{Y^{tot}/(\epsilon^{tot}\times N^{tot}_{event}/\epsilon^{trigger})}$$

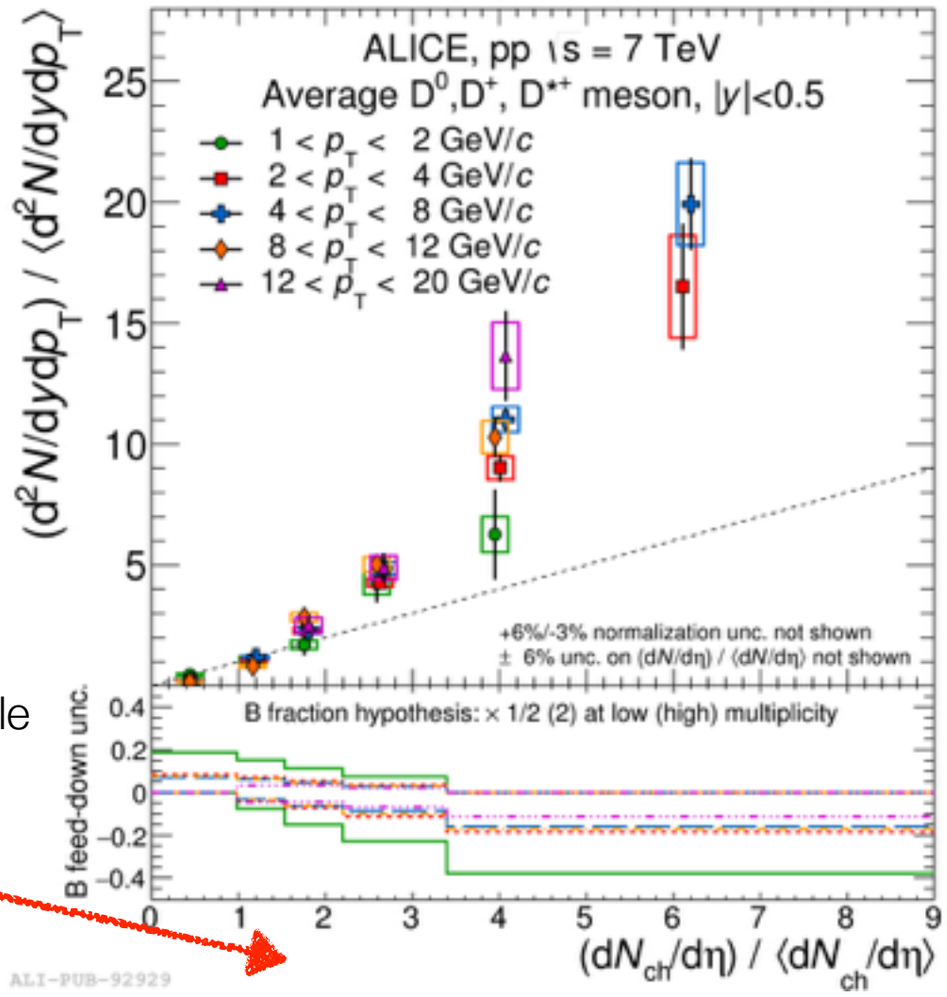
- **Self-normalised D-meson yields increase as a function of the charged-particle multiplicity**
  - Compatible for the different D-meson species
  - Faster-than-linear increase
- **Suggest that MPI affect hard momentum scale relevant for heavy-flavour production**

Charged-particle multiplicity at mid-rapidity

Multiplicity dependence of open HF production

pp

arXiv:1505:00664



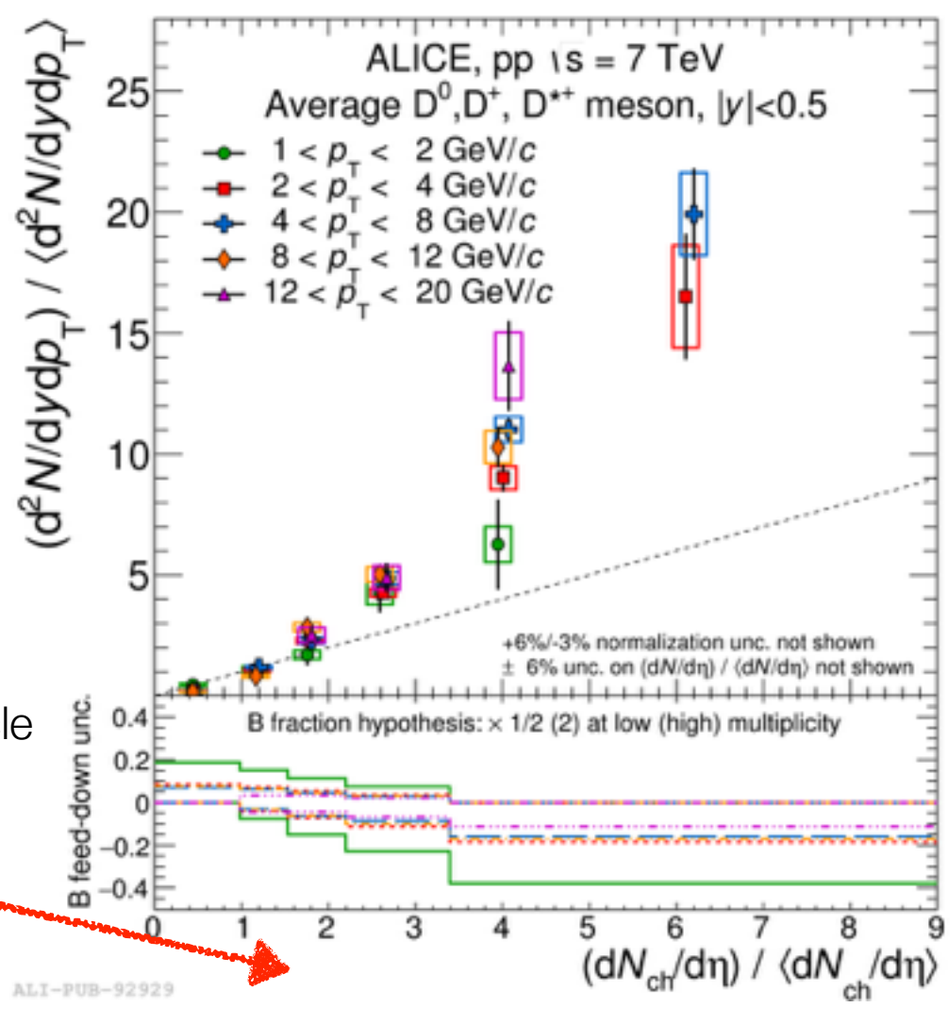
Charged-particle multiplicity at mid-rapidity

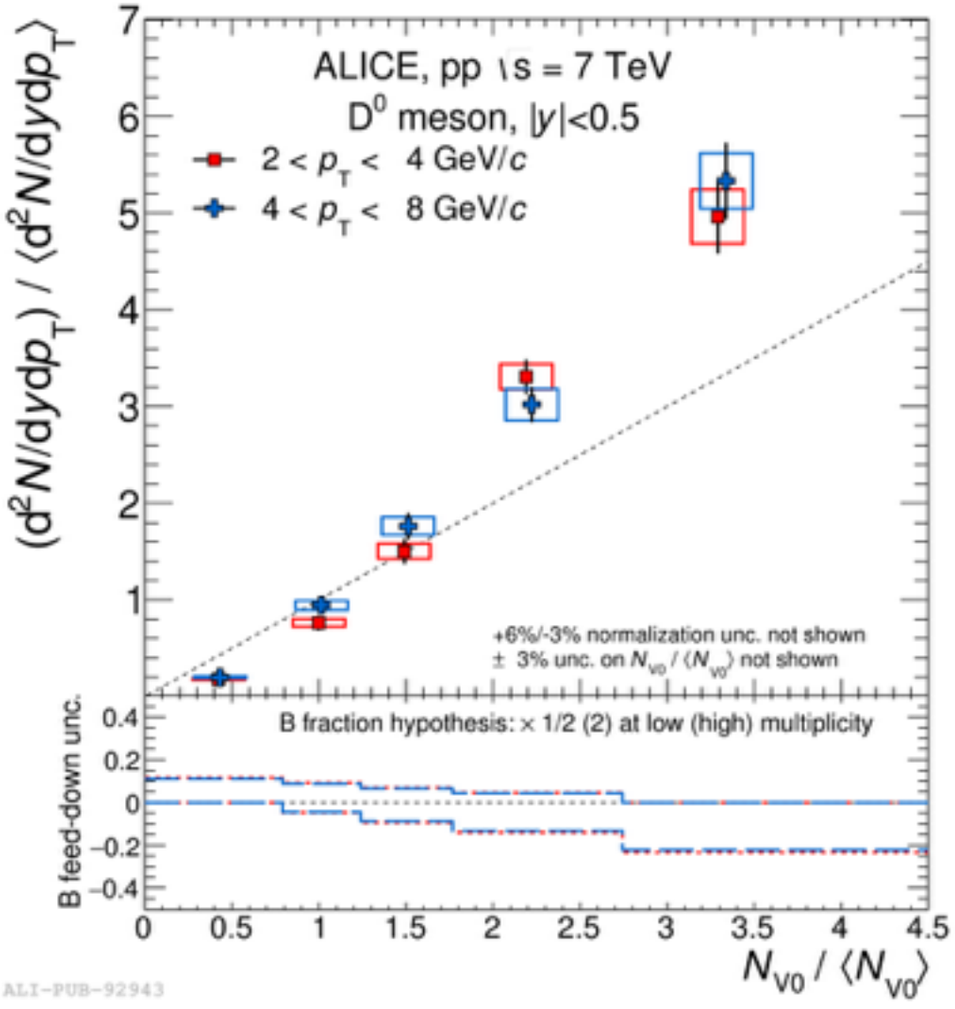
- **Self-normalized D-meson yields increase as a function of the charged-particle multiplicity**
  - No evidence of p_T-dependence within uncertainties
  - Faster-than-linear increase

Multiplicity dependence of open HF production

pp arXiv:1505:00664

Charged-particle multiplicity at mid-rapidity





Charged-particle multiplicity at forward-rapidity

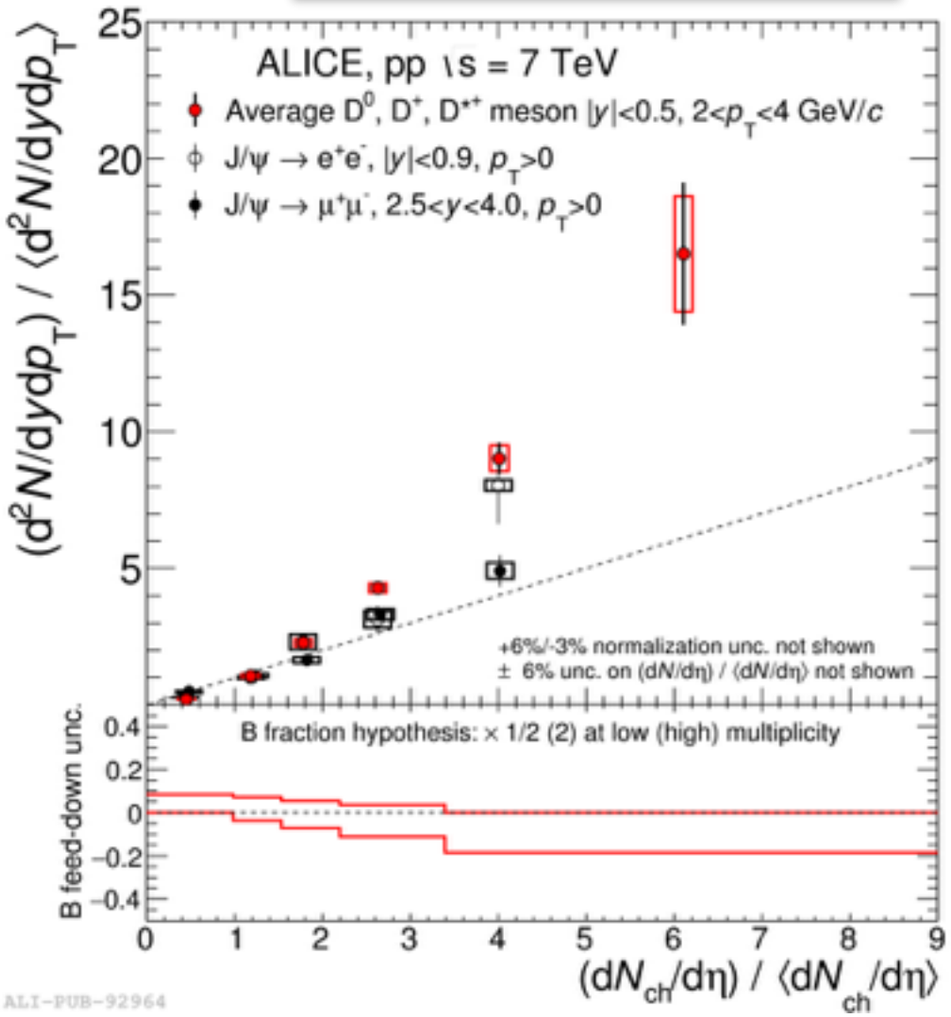
- **Self-normalized D-meson yields increase as a function of the charged-particle multiplicity**
  - No evidence of p_T-dependence within uncertainties
  - Faster-than-linear increase
- **Introducing an η-gap between the region of D-meson reconstruction (mid-rapidity) and multiplicity estimation (forward-rapidity) one can conclude that the increase is not due to possible bias**

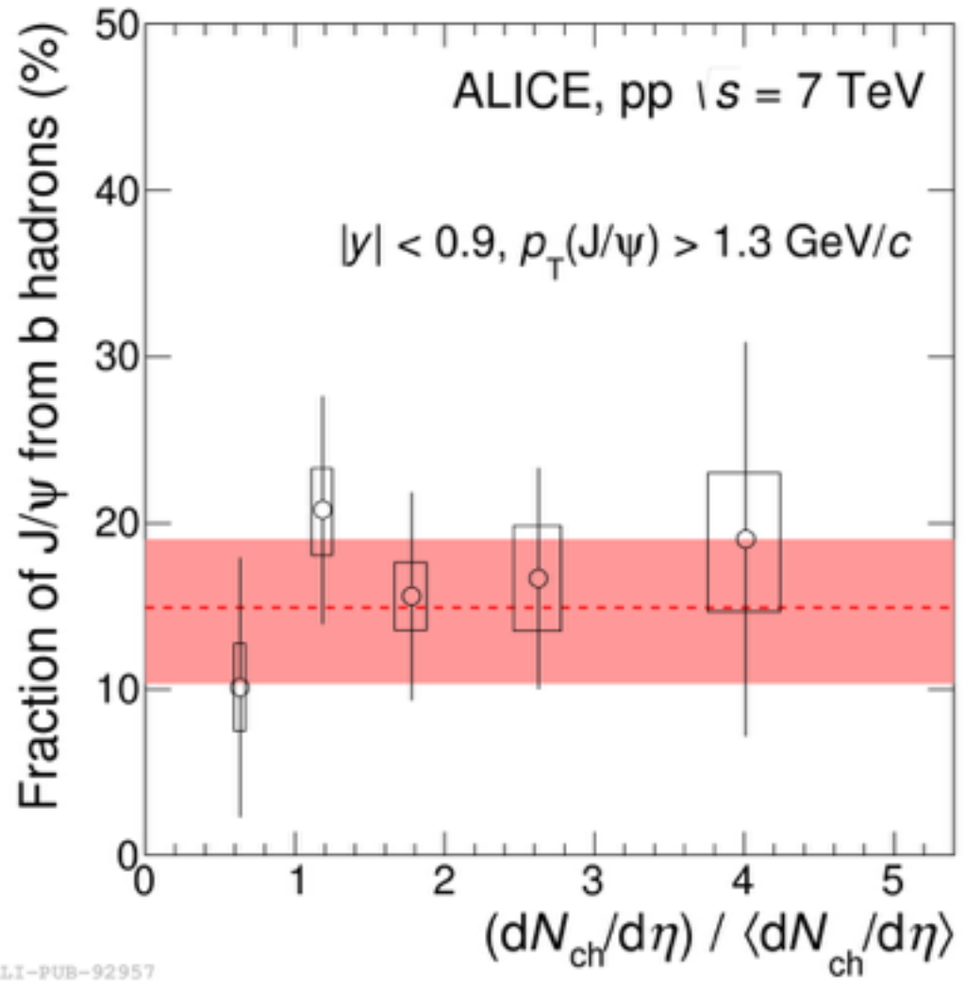
Open charm vs hidden charm (prompt and feed-down)

pp

arXiv:1505:00664

D mesons: 2< p_T < 4 GeV/c
Inclusive J/Ψ: p_T>0



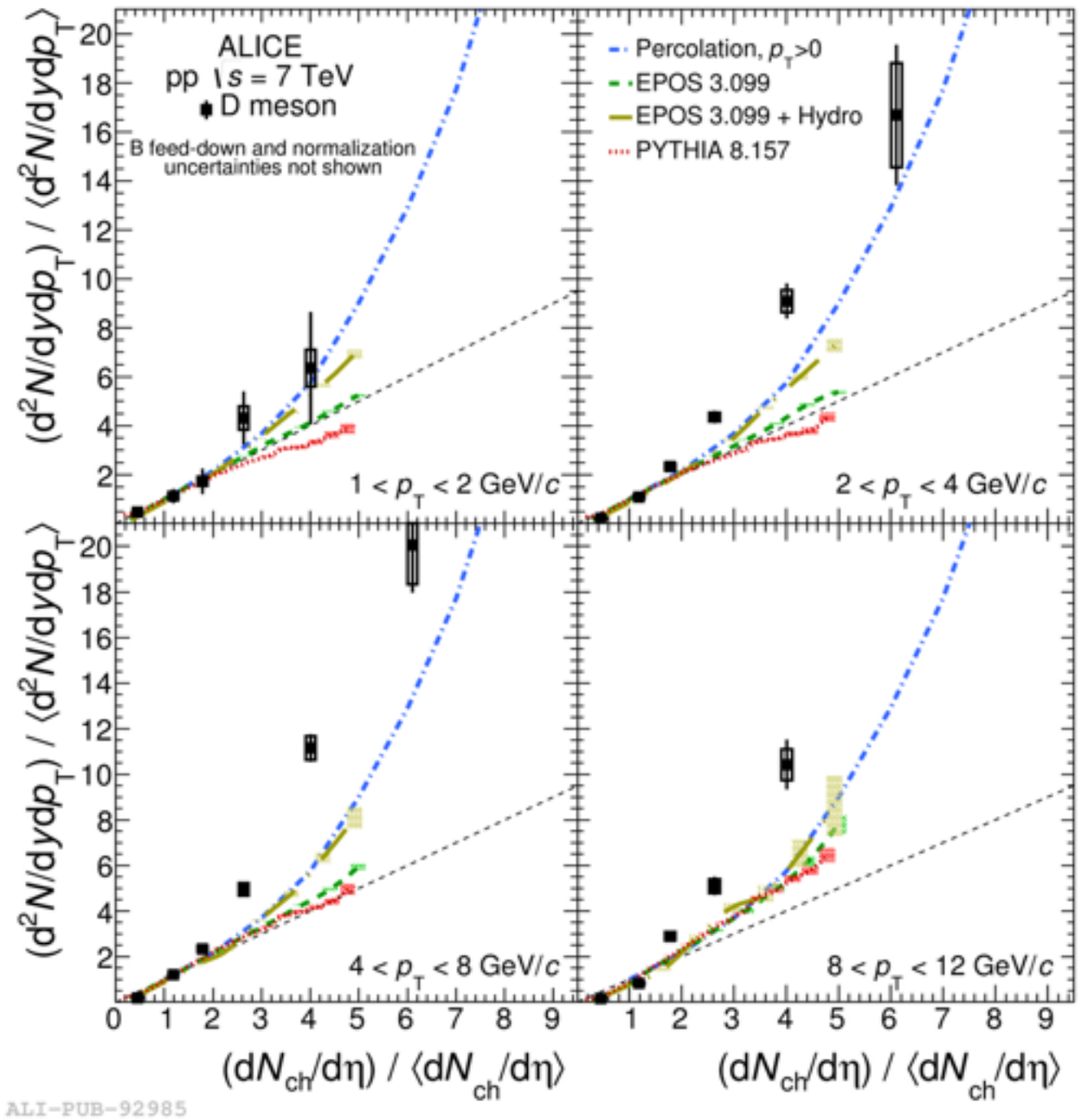


- Similar increase with multiplicity for open and hidden charm
  - different p_T and η range
- Similar increase with multiplicity for D mesons and non-prompt J/Ψ (i.e. for charm and beauty)
  - different p_T
- Suggest that the effect is not due to the hadronisation mechanism

D meson vs multiplicity: comparison with models

pp

arXiv:1505:00664



- **Models qualitatively describe the enhancement**

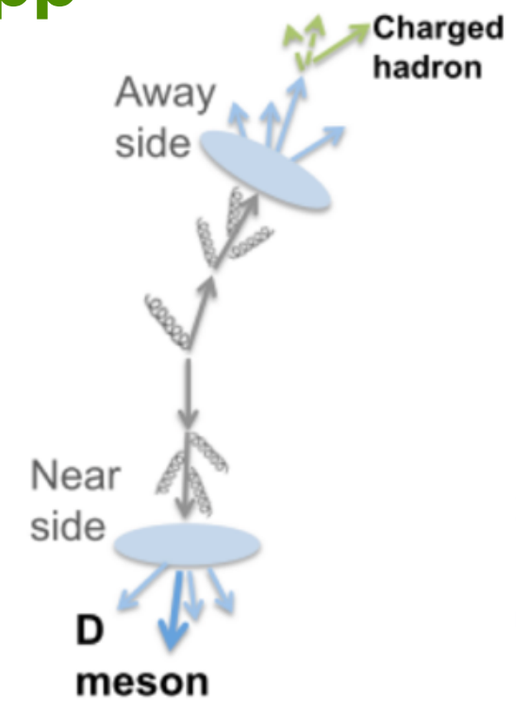
- **Percolation** Ferreiro, Pajares, PRC 86 (2012) 034903
  - Particle production via exchange of colour sources between projectile and target (close to MPI scenario)
    - faster-than-linear increase

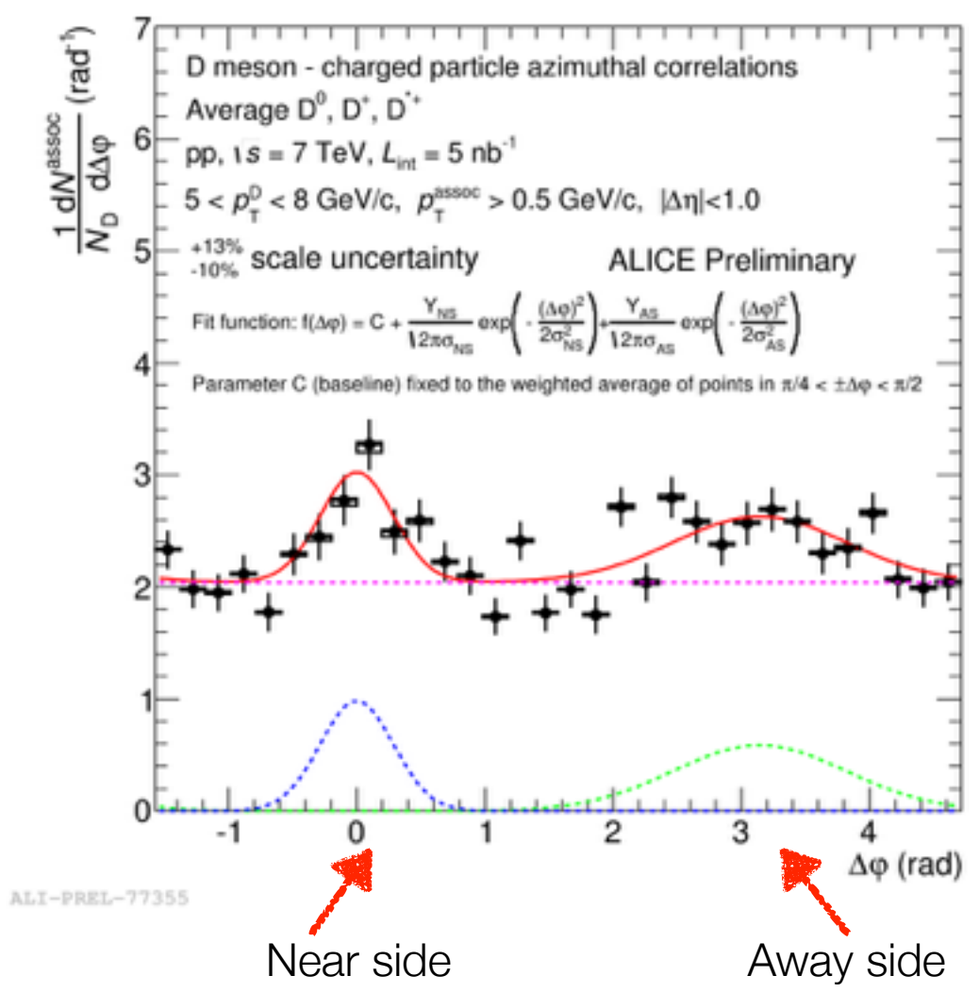
- **EPOS 3.099** Werner et al., PRC 89 (2014) 064903
  - Gribov-Regge multiple-scattering formalism
  - Saturation scale to model non-linear effects
  - Hadronization via string fragmentation
  - Number of MPI directly related to multiplicity
    - linear increase
  - With hydrodynamical evolution applied to the core of the collision
    - faster-than-linear increase

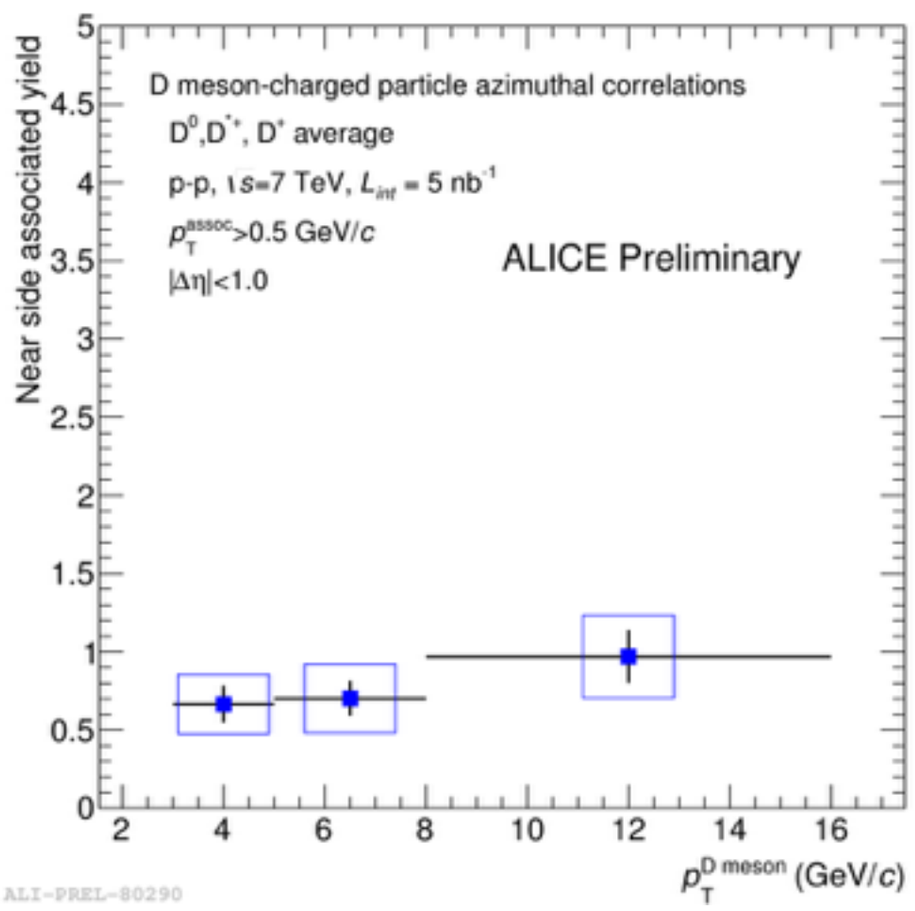
- **PYTHIA 8**
  - Soft-QCD tune
  - Colour reconnections
  - MPI
  - Initial and final state gluon radiation
    - linear increase

D meson - charged particle angular correlations

pp







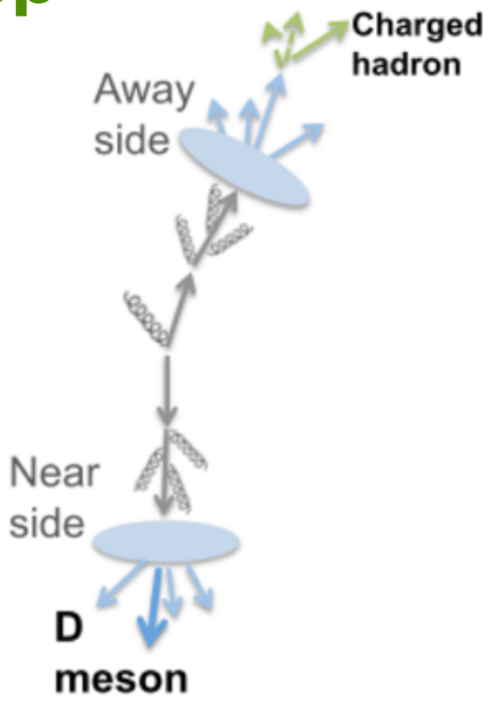
- Angular correlations in three intervals of D-meson p_T (3-5, 5-8, 8-16 GeV/c) and three thresholds for associated-particle p_T (0.3, 0.5, 1.0 GeV/c)
- The distributions show the typical near and away-side correlation structure
- Fit function

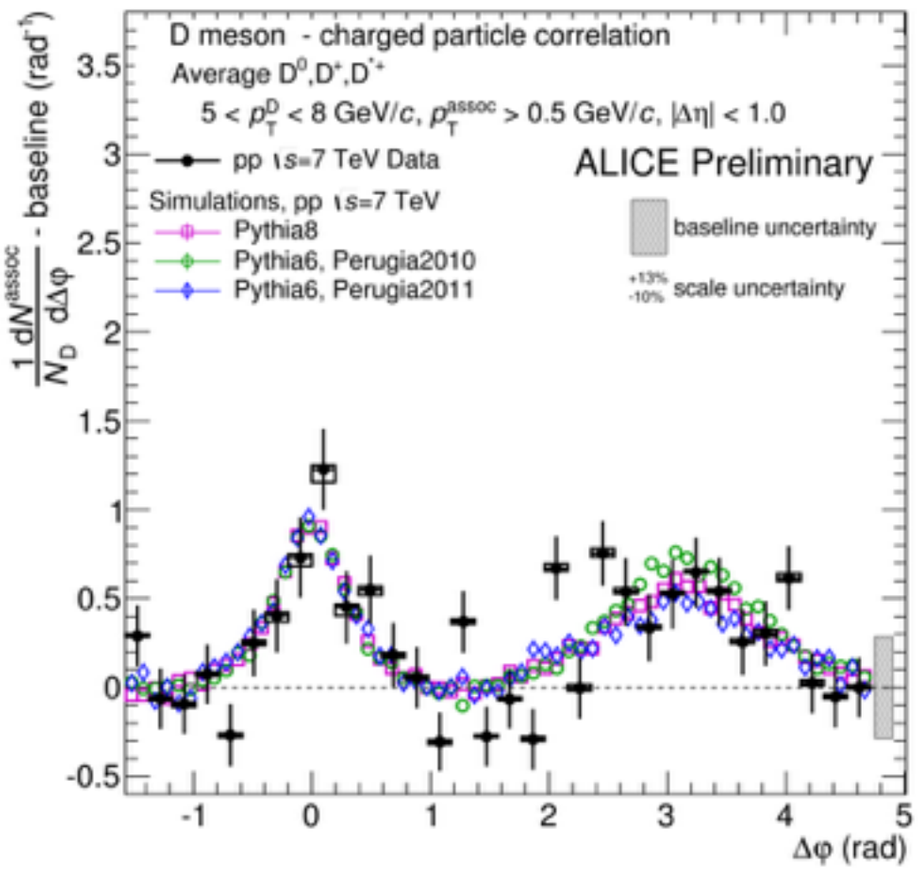
$$f(\Delta\varphi) = C + \frac{Y_{NS}}{\sqrt{2\pi\sigma_{NS}}} \exp\left(-\frac{(\Delta\varphi)^2}{2\sigma_{NS}^2}\right) + \frac{Y_{AS}}{\sqrt{2\pi\sigma_{AS}}} \exp\left(-\frac{(\Delta\varphi)^2}{2\sigma_{AS}^2}\right)$$

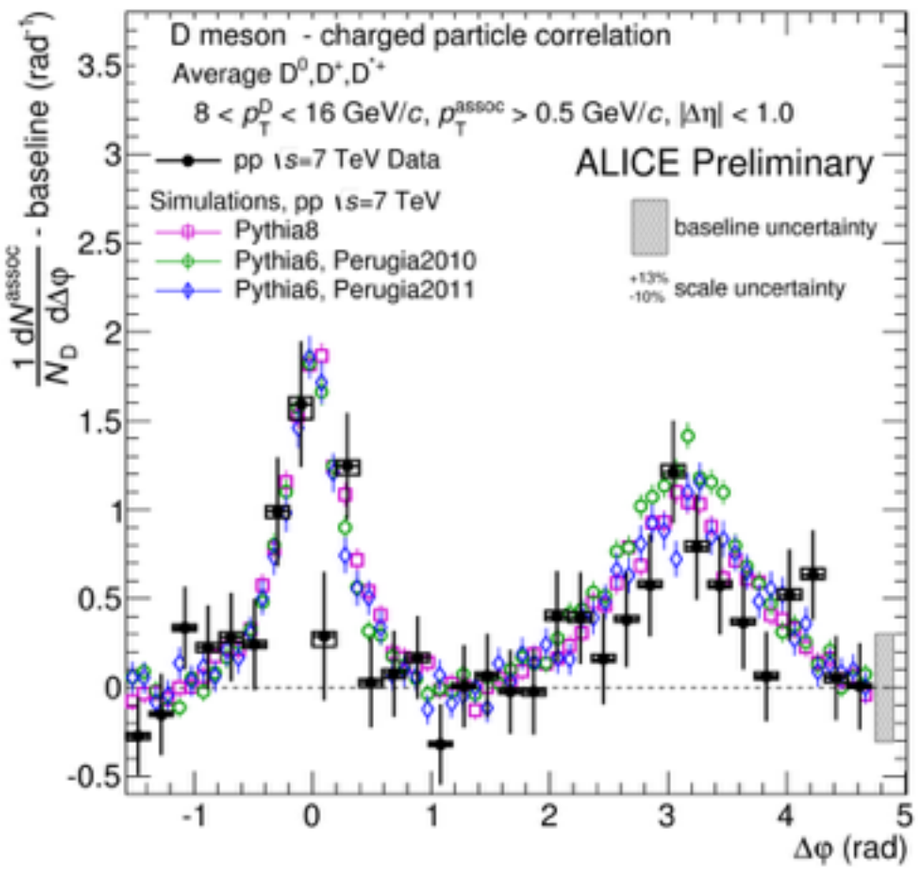
Y_{NS} = near-side yield
Y_{AS} = away-side yield
C= baseline

D meson - charged particle angular correlations: comparison with models

pp







- **Near-side and away-side correlations are compatible with different PYTHIA tunes** in two different intervals of D-meson p_T (baseline subtracted)

Outline

✓ Physics motivations for open heavy-flavour measurements in pp collisions

✓ The ALICE detector and open heavy-flavour reconstruction

✓ Main results

- Open heavy-flavour cross sections
- D-meson production as a function of the charged-particle multiplicity
- Angular correlations of D mesons and charged particles

✓ **Conclusions and outlook**

Conclusions

- **Open heavy-flavour production in pp collisions at LHC is well described by pQCD calculations**

- **Open heavy-flavour (charm and beauty) hadron yields increase with the multiplicity of charged particles produced in the collision**
  - Suggest that, in pp collisions, MPI affect hard momentum scale relevant for heavy-flavour production

- **D meson - charged particle angular correlations measured**
  - Results in pp collisions are compatible with PYTHIA expectations

- **LHC Run 2**
  - Higher statistics, higher multiplicities and higher energy
  - More precise measurements and p_{T}-range extension

Back-up slides

Open HF measurements in ALICE

D mesons in the hadronic decay channels

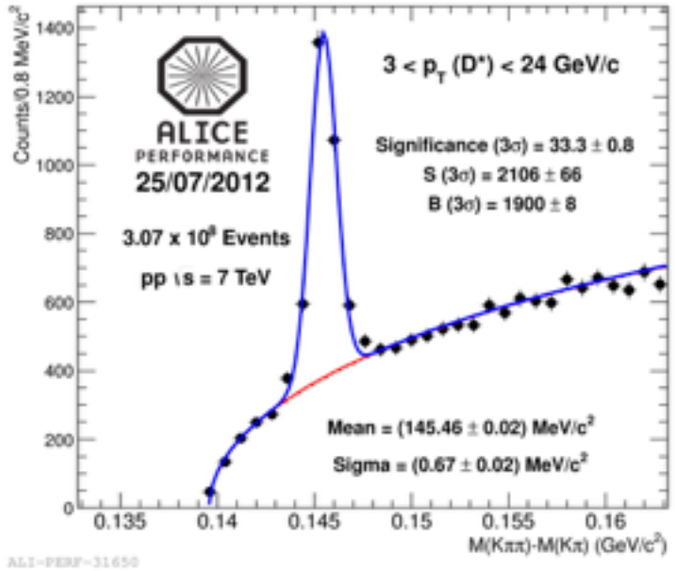
$D^0 \rightarrow K^-\pi^+$ BR=(3.88±0.05)%, cτ ≈ 120μm

$D^+ \rightarrow K^-\pi^+\pi^+$ BR=(9.13±0.19)%, cτ ≈ 310μm

$D^{*+} \rightarrow D^0\pi^+$ BR=(67.7±0.5)% [strong decay]

$D_s \rightarrow \phi\,\pi^+ \rightarrow K^-K^+\pi^+$ BR=(2.28± 0.12)%, cτ ≈ 150μm

- Reconstruction of secondary vertices displaced from the primary vertex and invariant mass analysis

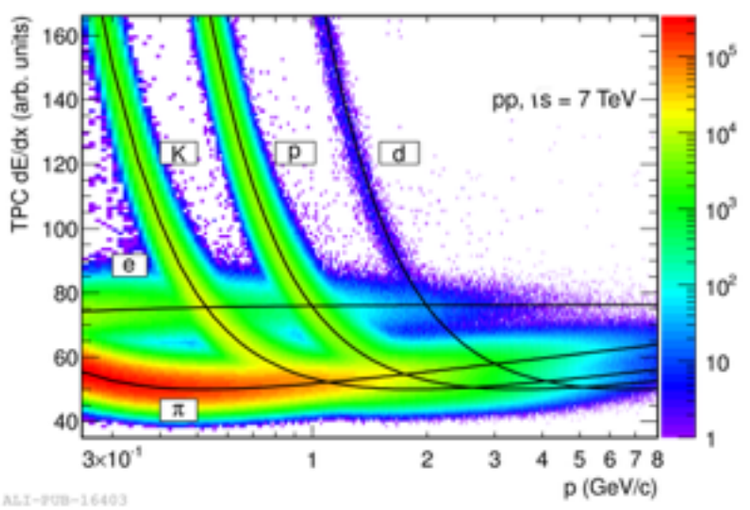


Open heavy-flavour decay electrons

B-> e + X (BR ~ 11%)

C-> e + X (BR ~ 10%)

- Identified at mid-rapidity with TPC, TOF, TRD, EMCAL
- Background subtraction based on a MC cocktail of the relevant background sources (photon conversions, Dalitz decay of π^0, η and light mesons)



Open heavy-flavour decay muons

B-> μ + X (BR ~ 11%)

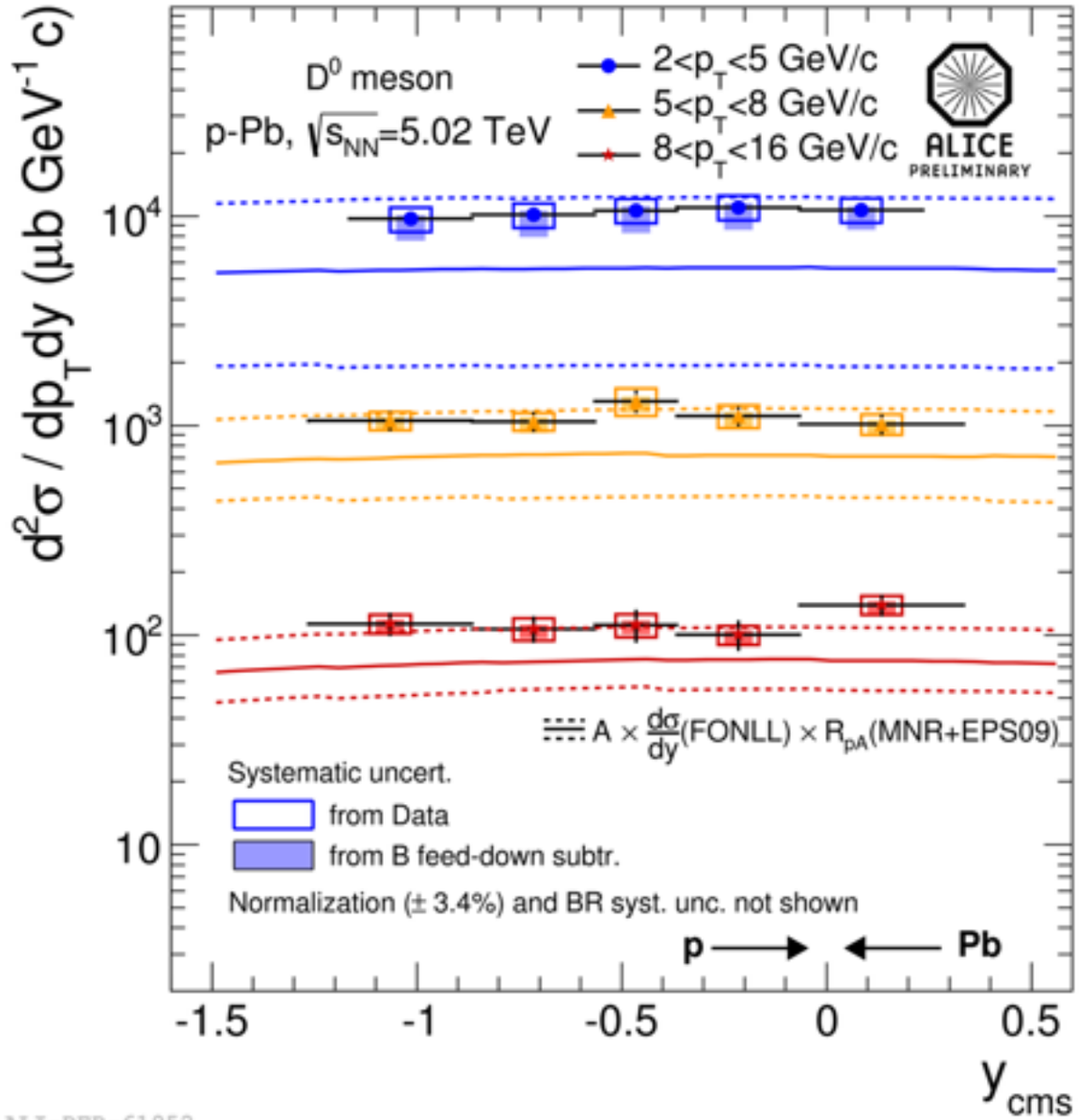
C-> μ + X (BR ~ 10%)

- Identified with the Muon Spectrometer at -4 < η <-2.5
- Background from $\pi^{\pm}$ and $K^{\pm}$ estimated with event generators and subtracted

Results on open HF decay leptons in the heavy-ion session in **L. Valencia Palomo**'s talk

Prompt D meson *y*-differential cross sections

p-Pb

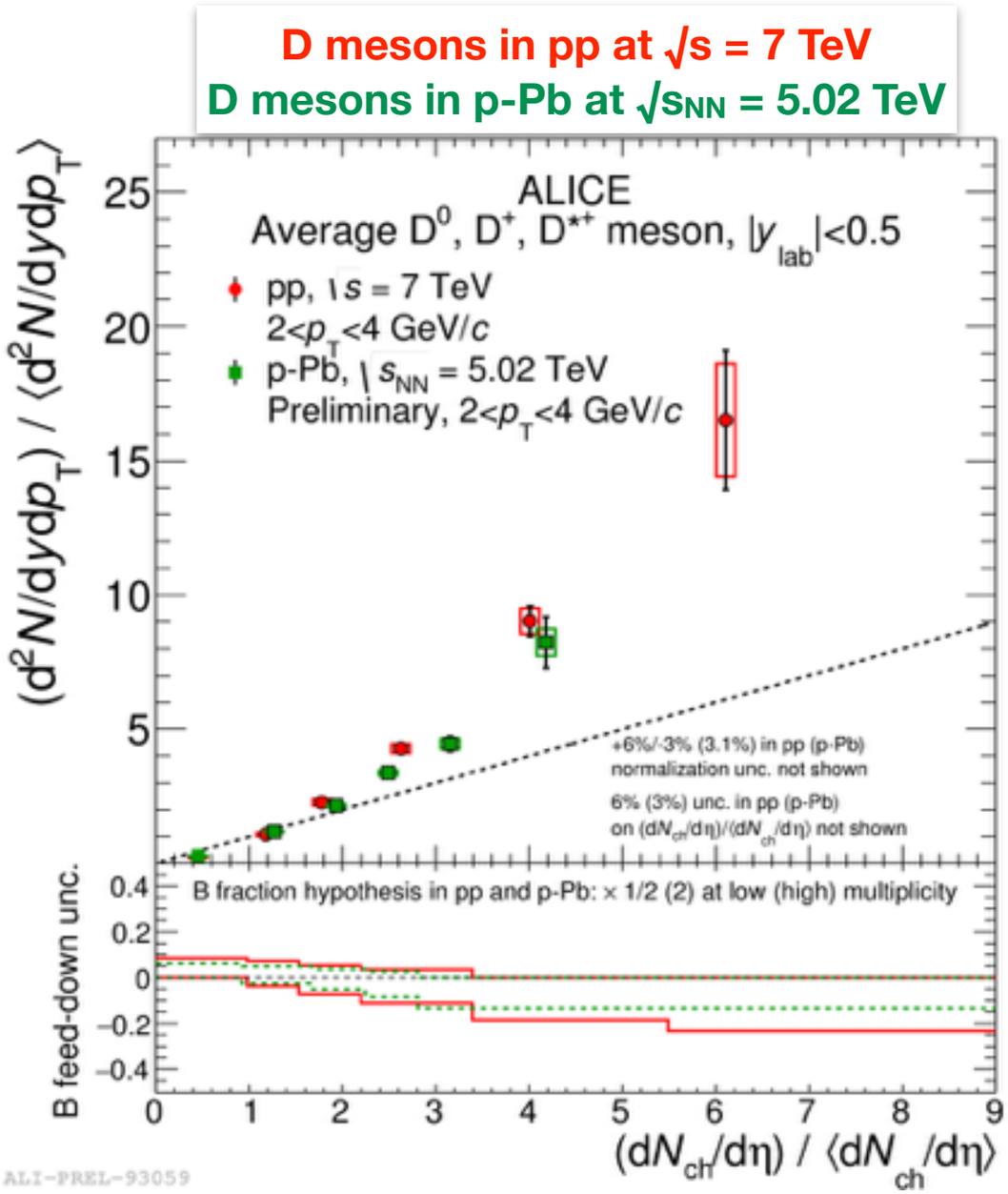


- Measurement done in p-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV
- *y*-differential cross section does not vary in the considered *y* interval
- Good agreement with the cross section calculated from FONLL multiplied by an R_{pA} based on MNR+EPS09 predictions and by the atomic mass number *A*

FONLL: JHEP1210(2012)137;
MNR: Nucl. Phys. B373 (1992) 295
EPS09: JHEP 04 (2009) 065

D meson yields vs multiplicity in p-Pb collisions

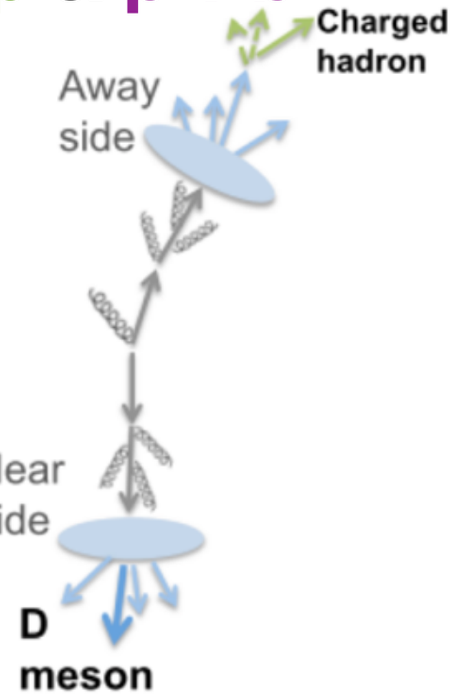
pp & p-Pb



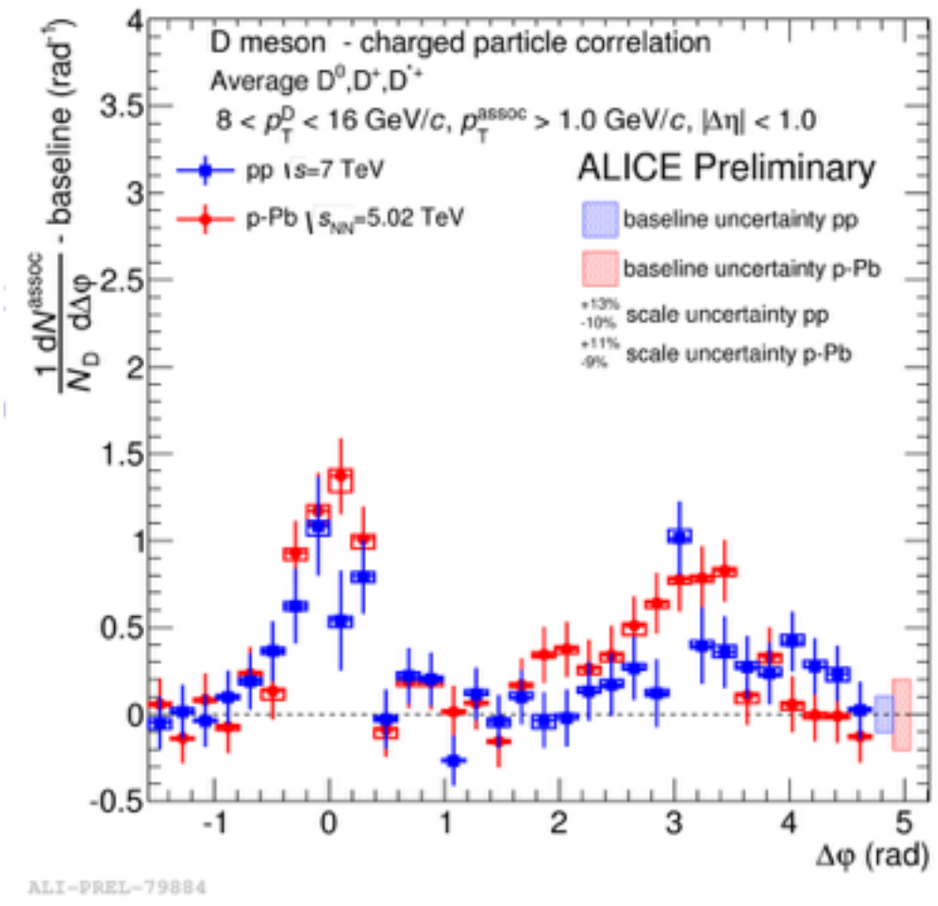
- **Similar faster-than-linear increase observed in pp and p-Pb collisions**
- Some caveats:
  - pp: high-multiplicity events are mainly from MPI
  - p-Pb: high-multiplicity events are also affected by multiple binary nucleon-nucleon interactions

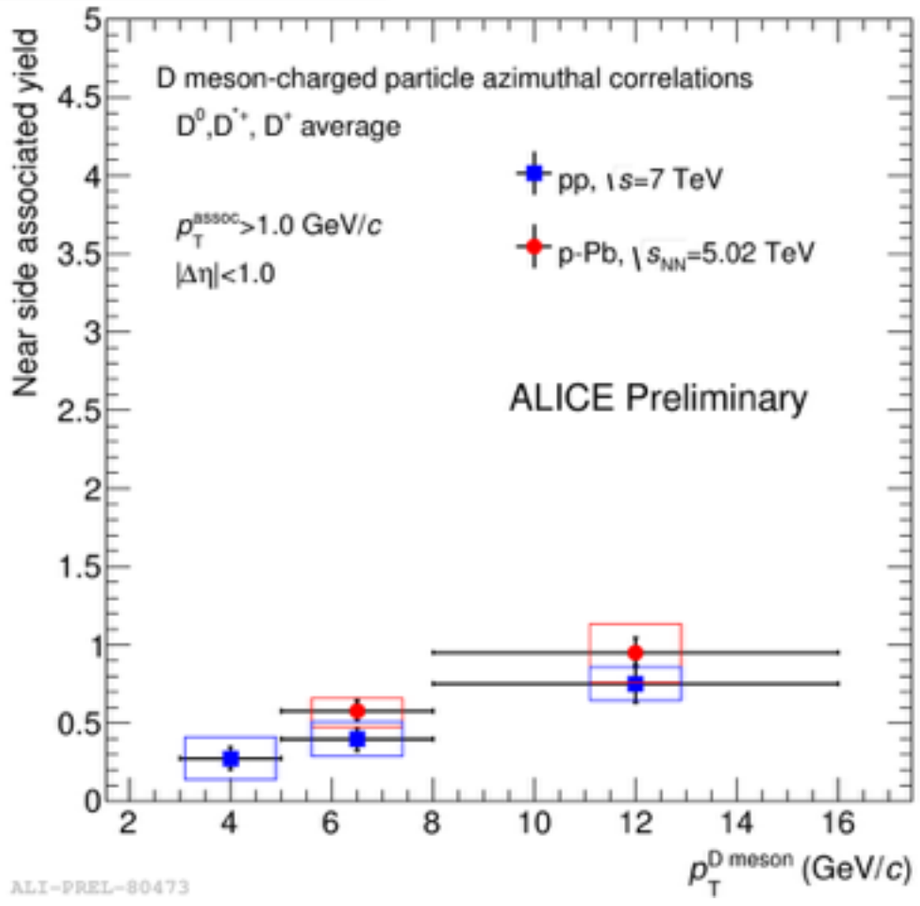
D meson - charged particle angular correlations: comparison with p-Pb

pp & p-Pb



D mesons in pp at √s = 7 TeV
D mesons in p-Pb at √s_{NN} = 5.02 TeV





- Compatibility within uncertainties between the correlation distributions in pp collisions at √s = 7 TeV and p-Pb collisions at √s_{NN} = 5.02 TeV