JOINT INSTITUTE FOR NUCLEAR RESEARCH
Strangeness in Quark Matter 2015

D-meson production in pp and p-Pb collisions measured with ALICE at the LHC

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Outline

- Heavy flavour in ALICE
  - pp and p-Pb collisions: physics motivations
  - Charm production vs multiplicity

- Open heavy-flavour reconstruction in ALICE

- Measurements in pp collisions
  - D-meson cross sections
  - D mesons vs multiplicity

- Measurements in p-Pb collisions
  - Nuclear modification factor
  - D mesons vs multiplicity

- Conclusions

Heavy-flavour physics in pp and p-Pb collisions

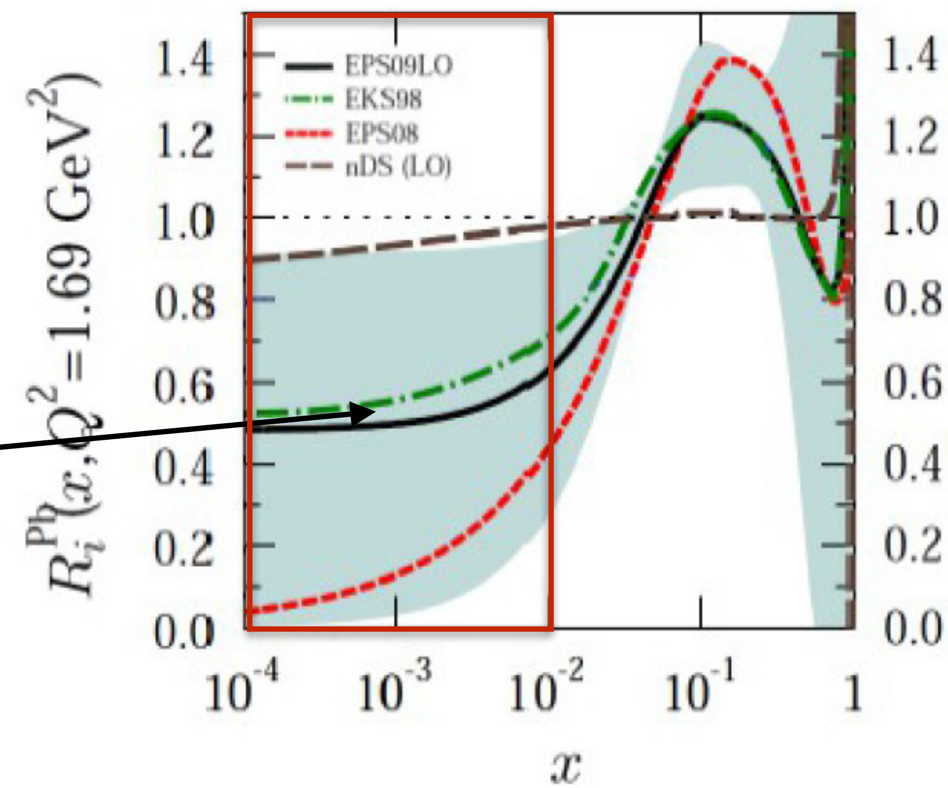
- **pp collisions**
  - Heavy quarks are produced in partonic scatterings with large Q^2 —> of prime interest as a test of perturbative QCD calculations
  - Reference for corresponding measurements in heavy-ion collisions
- **p-Pb collisions**
  - Quantify Cold Nuclear Matter (CNM) effects on charm production
    - modification of parton densities in nuclei via shadowing or saturation

      K.J. Eskola et al JHEP04(2009)065
      M. Hirai et al Phys.Rev. C76 (2007) 065207
    - k_T-broadening: "initial-state multiple scattering"

      M. Lev and B. Petersson, *Z.Phys.* C21 (1983) 155,
      B. Kopeliovich et al Phys.Rev.Lett. 88 (2002) 232303
    - parton energy loss in cold nuclear matter

      I. Vitev, Phys.Rev. C75 (2007) 064906

JHEP 0904 (2009) 65



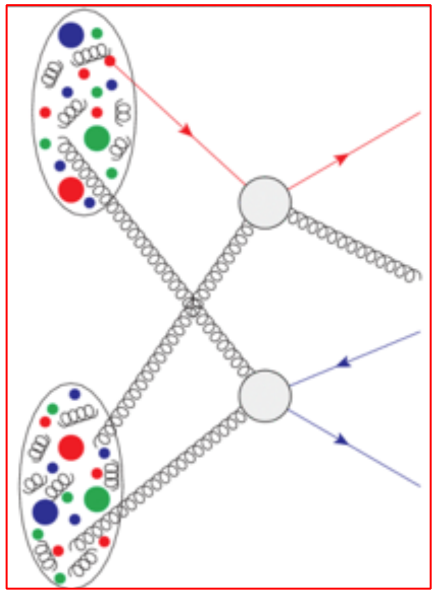
shadowing

gluon PDF: very large uncertainties

(at LHC: x —> 10^{-2} -10^{-4})

Charm production vs multiplicity

Heavy-flavour **production as a function of the multiplicity** of charged particles produced in pp and p-Pb collisions:



- Interplay between **hard and soft contributions** to particle production
- **Multi-Parton Interactions (MPI)**: several hard partonic interactions occurring in a single collision at high centre-of-mass energies
  - number of elementary interactions is connected to the multiplicity of the events
  - yield of particles from hard processes should increase with multiplicity

- **MPI and heavy flavour:**
  - **NA27** measured that events with open charm production have 20% higher average charged-particle multiplicity (pp collisions at SPS $\sqrt{s}$ = 28 GeV) **(NA27 Coll.Z.Phys.C41:191 (1988)**
  - **ALICE measured an approximately linear increase of the J/ψ yield vs multiplicity**
    (Phys.Lett. B712 (2012) 165-175)

Investigate the role of MPI:
Extend to open charm: D mesons

- Compare open/hidden charm production
- Study yield of D mesons vs. multiplicity in p_T intervals

Reconstruction of D mesons with ALICE

D-meson decays reconstructed:

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

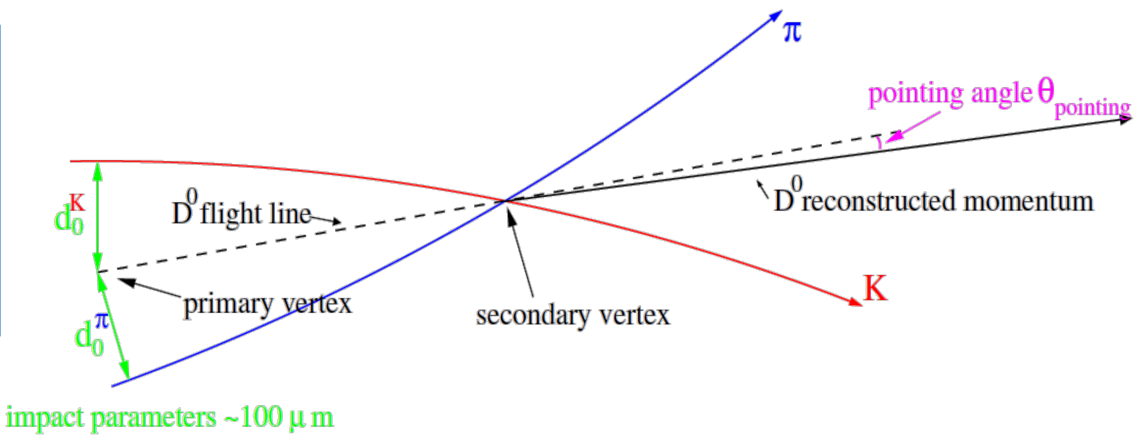
$D^+ \rightarrow K^- \pi^+ \pi^+$

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

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

talk A. Barbano

$c\tau$ 100-300 μm: displaced decay vertex is a signature of D-meson decay



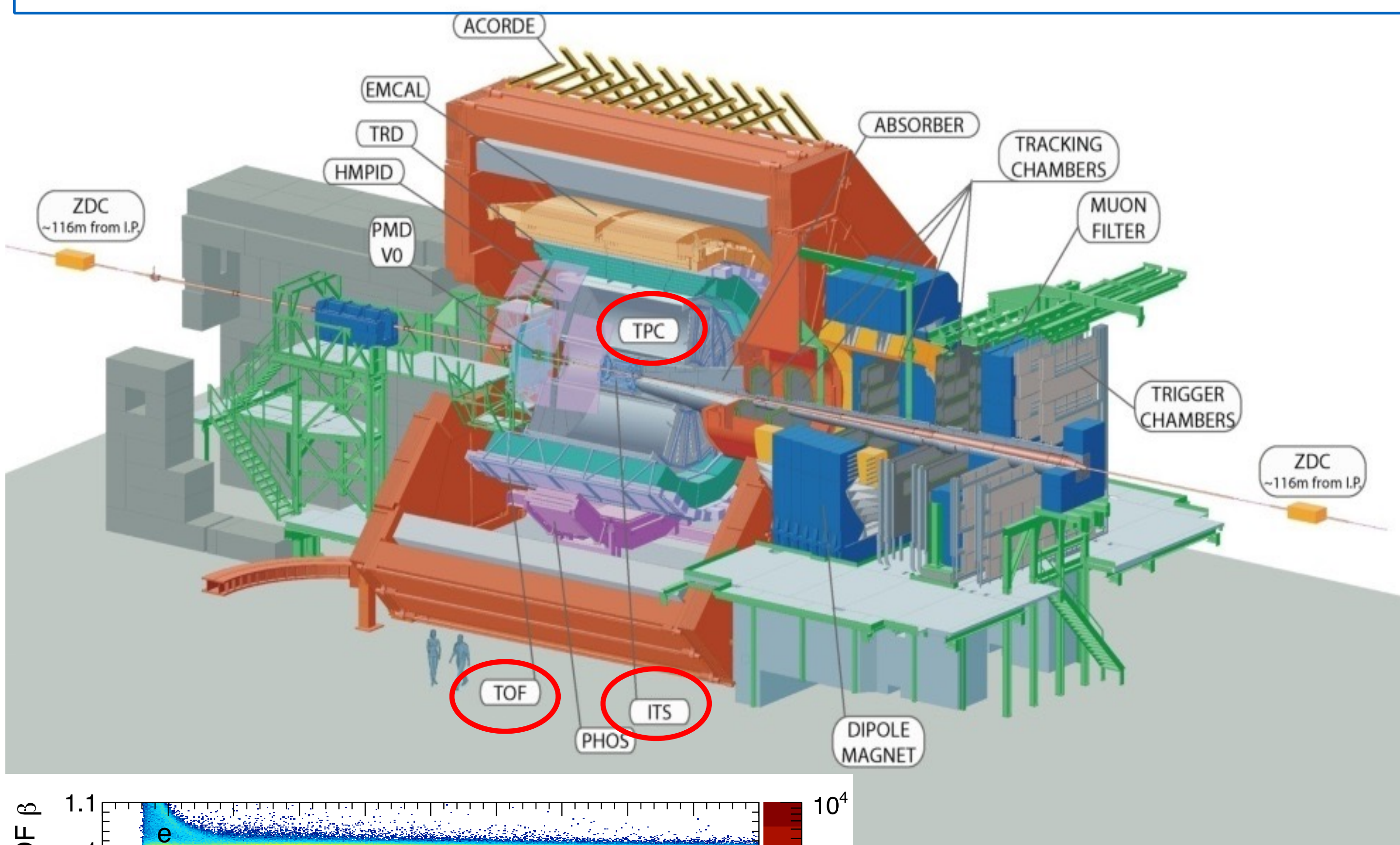
Analysis strategy:

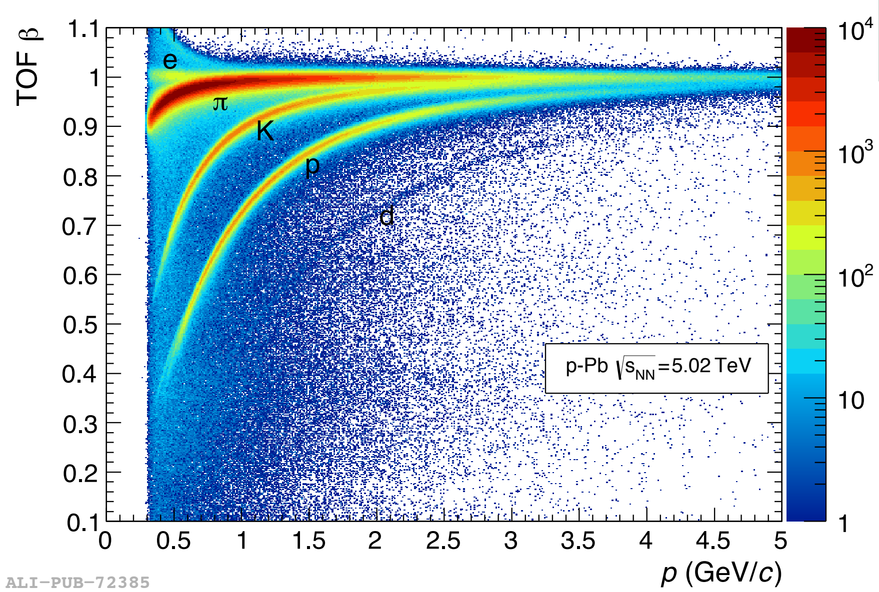
- Secondary-vertex reconstruction
- Invariant mass measurement
- Large combinatorial background
  - Particle identification and topological cuts
  - ➡ improve signal to background ratio

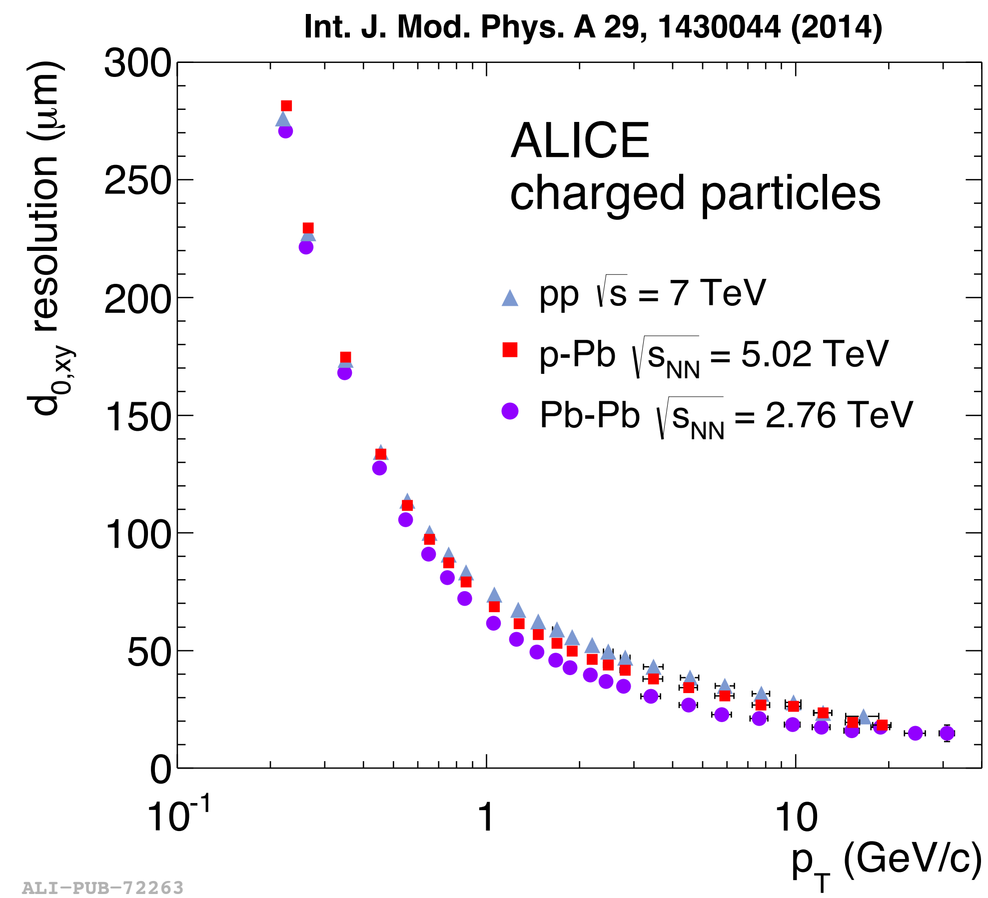
tracking and vertexing precision crucial for heavy-flavour analysis

Reconstruction of D mesons with ALICE

- Inner Tracking System (ITS): precision vertexing, tracking
- Time Projection Chamber (TPC): tracking, particle identification
- Time Of Flight (TOF): particle identification







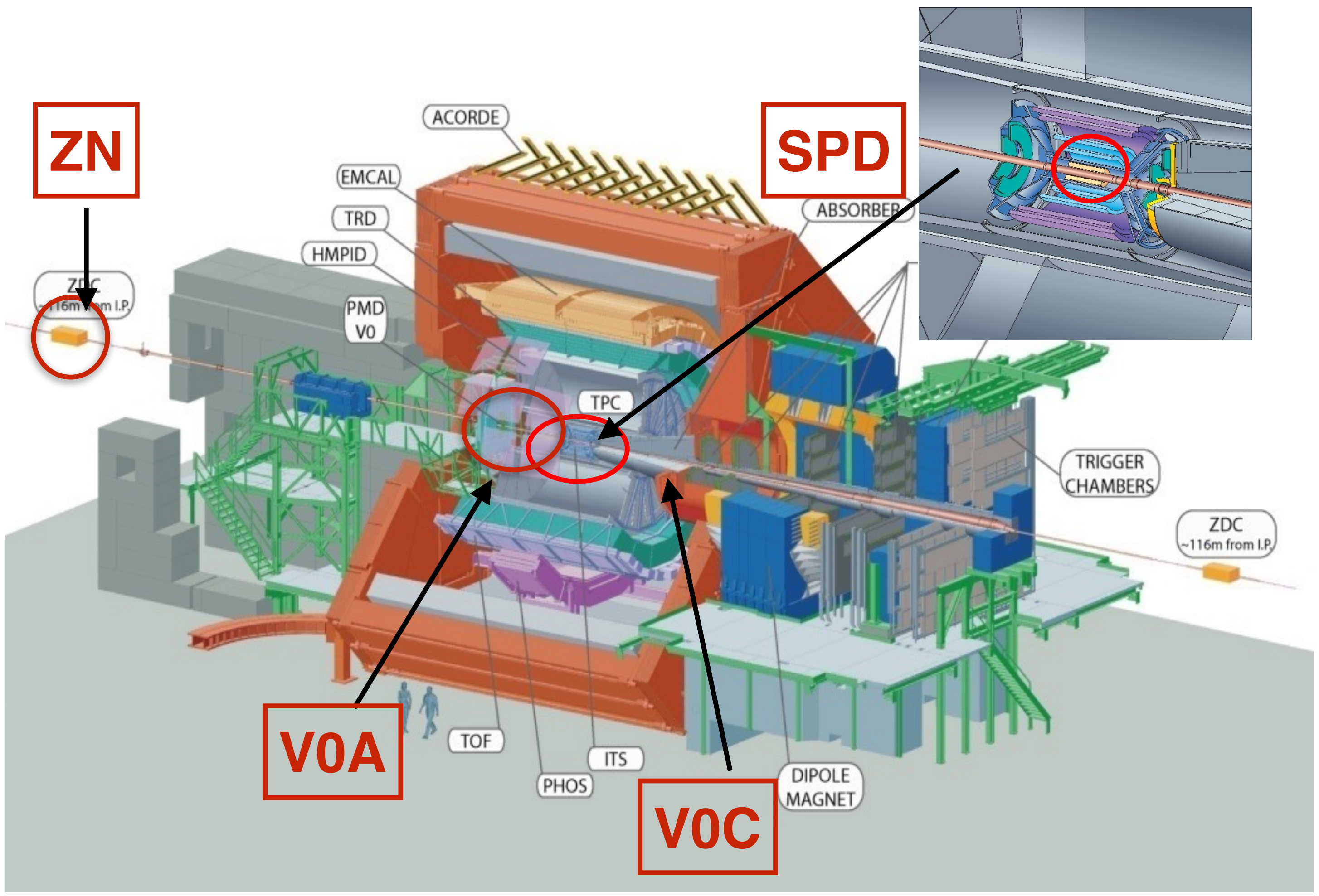
Data samples analyzed:

pp 2010 data $\sqrt{s}$ = 7 TeV ~ 3×10^8 events

p-Pb 2013 data $\sqrt{s_{NN}}$ = 5.02 TeV ~ 10^8 events

Multiplicity measurements with ALICE

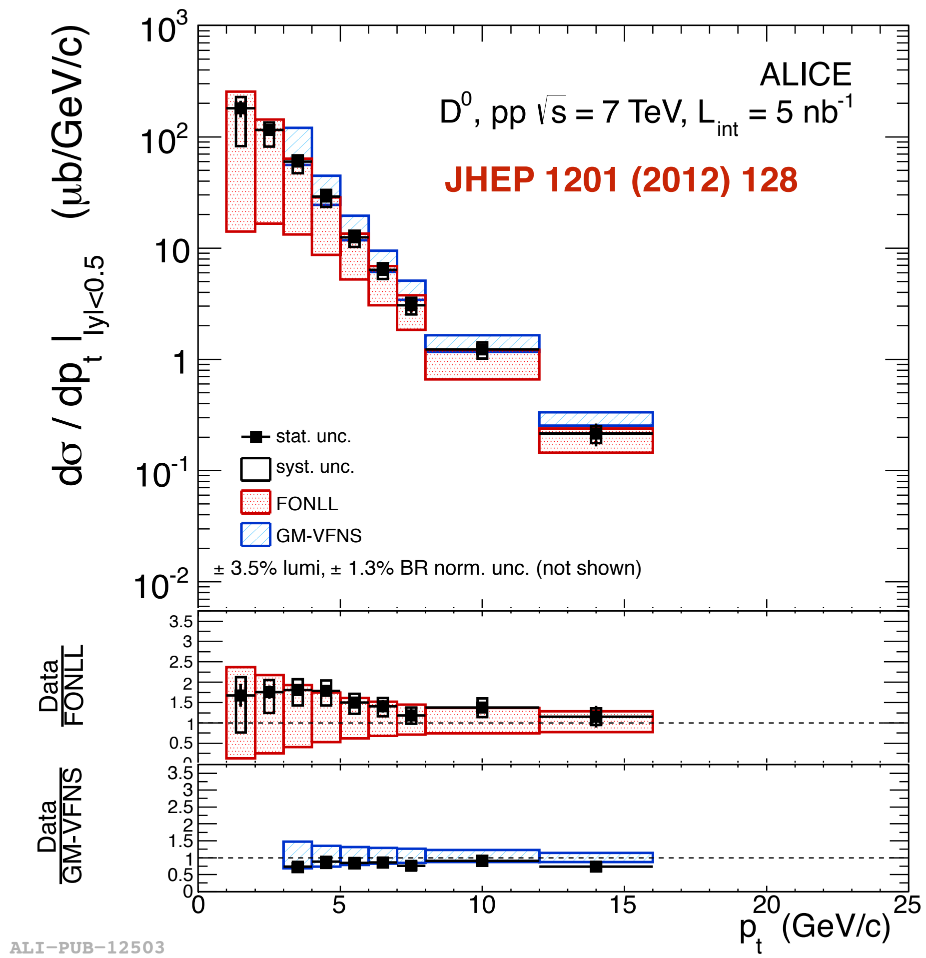
- **Detectors used for multiplicity measurements**

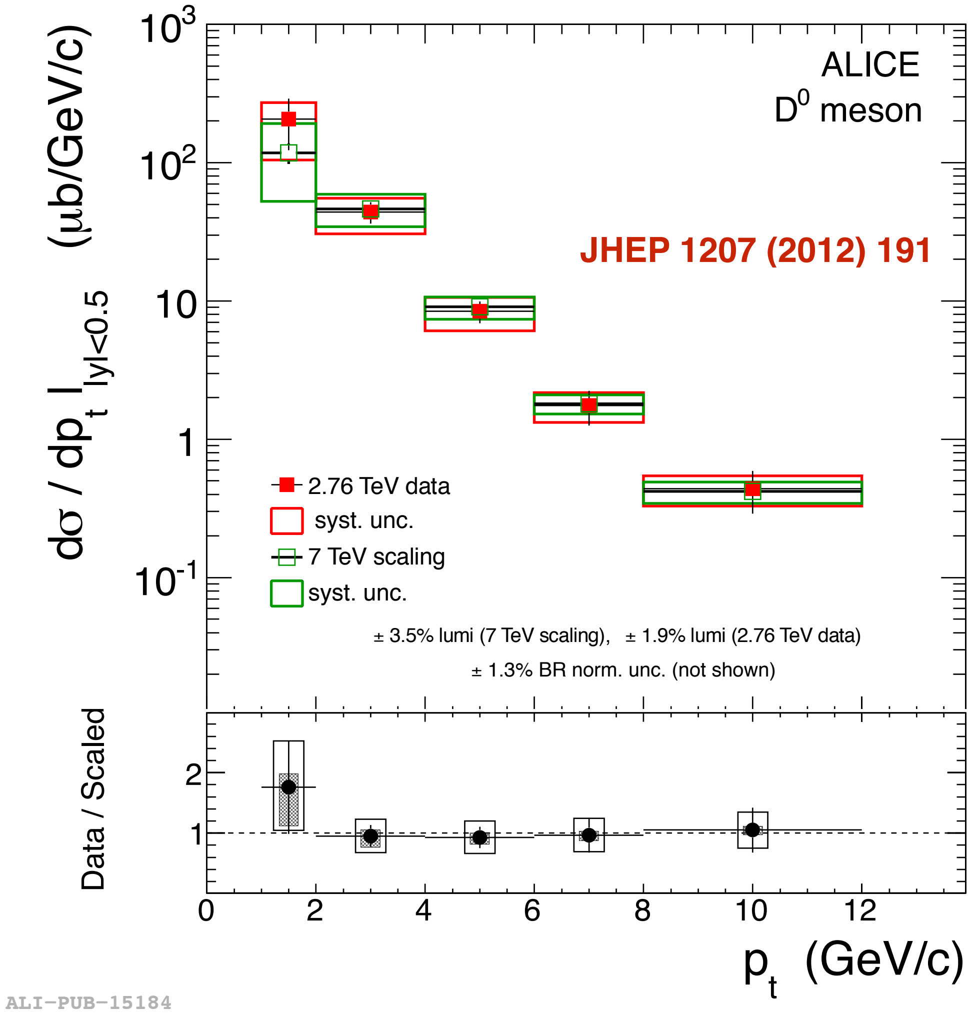


- Silicon Pixel Detector (SPD)
  - $N_{tracklets}$ = # track segments reconstructed in the SPD layers (two innermost layers of the ITS), $|\eta|<1$
  - $N_{tracklets} \propto dN_{ch}/d\eta$
- Zero degree Neutron calorimeter (ZN)
  - energy deposition of neutrons
- Forward Scintillator arrays (V0)
  - $2.8<\eta<5.1$ and $-3.7<\eta<-1.7$
  - signal amplitude N_{V0}

Different pseudo-rapidity intervals
to test possible bias due to the measurement of the charged-particle multiplicity in the same pseudo-rapidity region of the D-meson decay particles

pp collisions: D-meson cross section





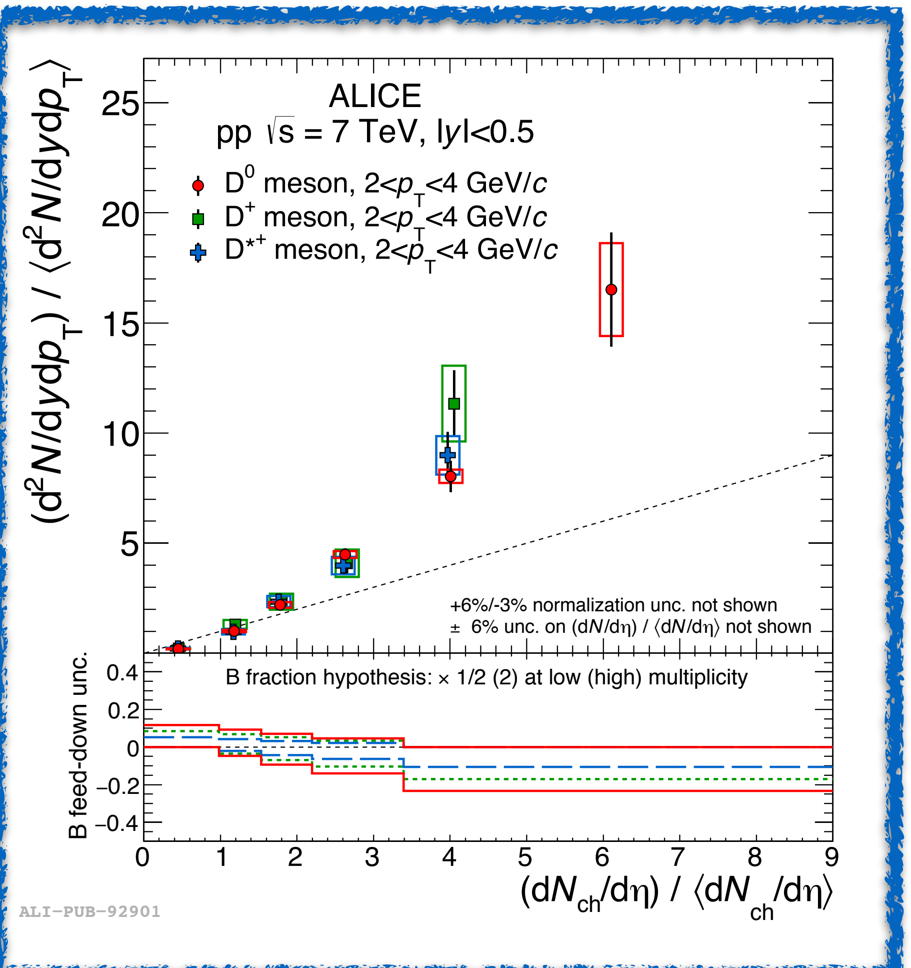
- **D-meson p_T differential cross section measured in pp collisions at $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 2.76 TeV**
- **pQCD-based calculations compatible with data**
  - **FONLL** Cacciari et al., JHEP 1210 (2012) 137
  - **GM-VFNS** Kniehl et al., EPJ C72 (2012) 2082
  - **k_T factorization** Maciula, Szczurek, PRD 87 (2013) 094022

- **pQCD-based energy scaling of the 7 TeV cross section to 2.76 TeV is in good agreement with the measured cross section at the same energy**
  - **$\sqrt{s}$ extrapolation based on FONLL used to define references for Pb-Pb and p-Pb measurements**

pp collisions: D vs multiplicity

$$\frac{(\mathrm{d}^2N^{\mathrm{D}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}})^j}{\langle \mathrm{d}^2N^{\mathrm{D}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}\rangle} = \left(\frac{1}{N^j_{\mathrm{events}}}\frac{N^j_{\mathrm{raw\ D}}}{\varepsilon^j_{\mathrm{prompt\ D}}}\right) \Big/ \left(\frac{1}{N_{\mathrm{MB\ trigger}}/\varepsilon_{\mathrm{MB\ trigger}}}\frac{\langle N_{\mathrm{raw\ D}}\rangle}{\langle \varepsilon_{\mathrm{prompt\ D}}\rangle}\right)$$

ALICE, arXiv:1505.00664



- D^0, D^+,D^* measurements are **in agreement** with each other within uncertainties
- Self-normalized yields increase with multiplicity

pp collisions: D vs multiplicity

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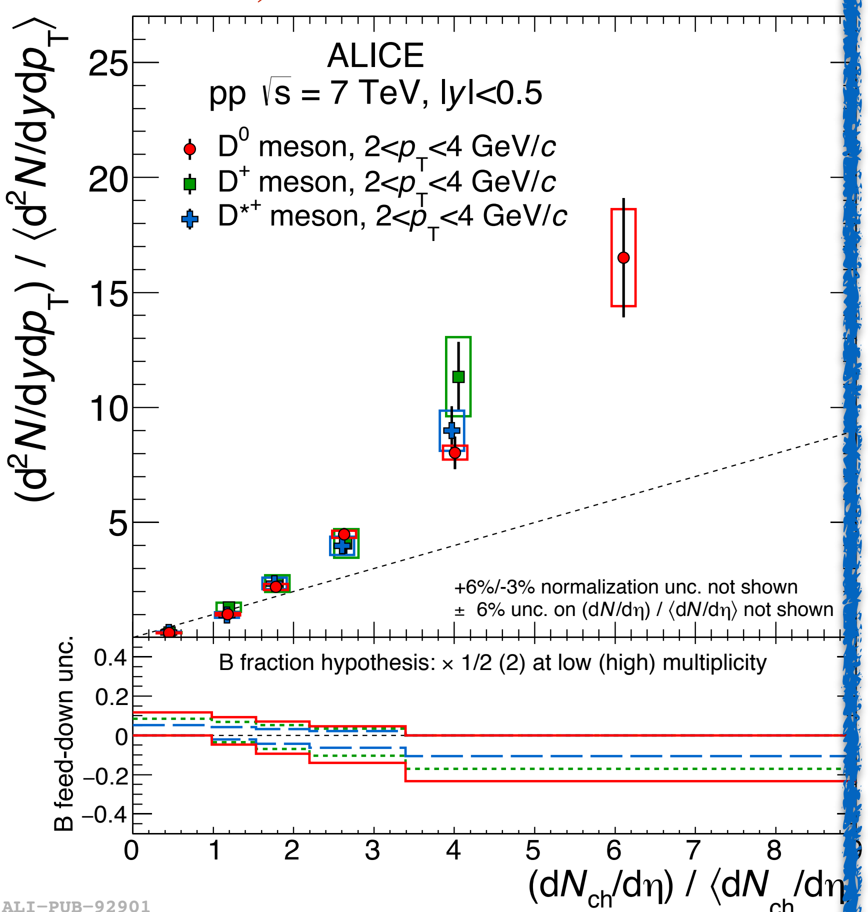

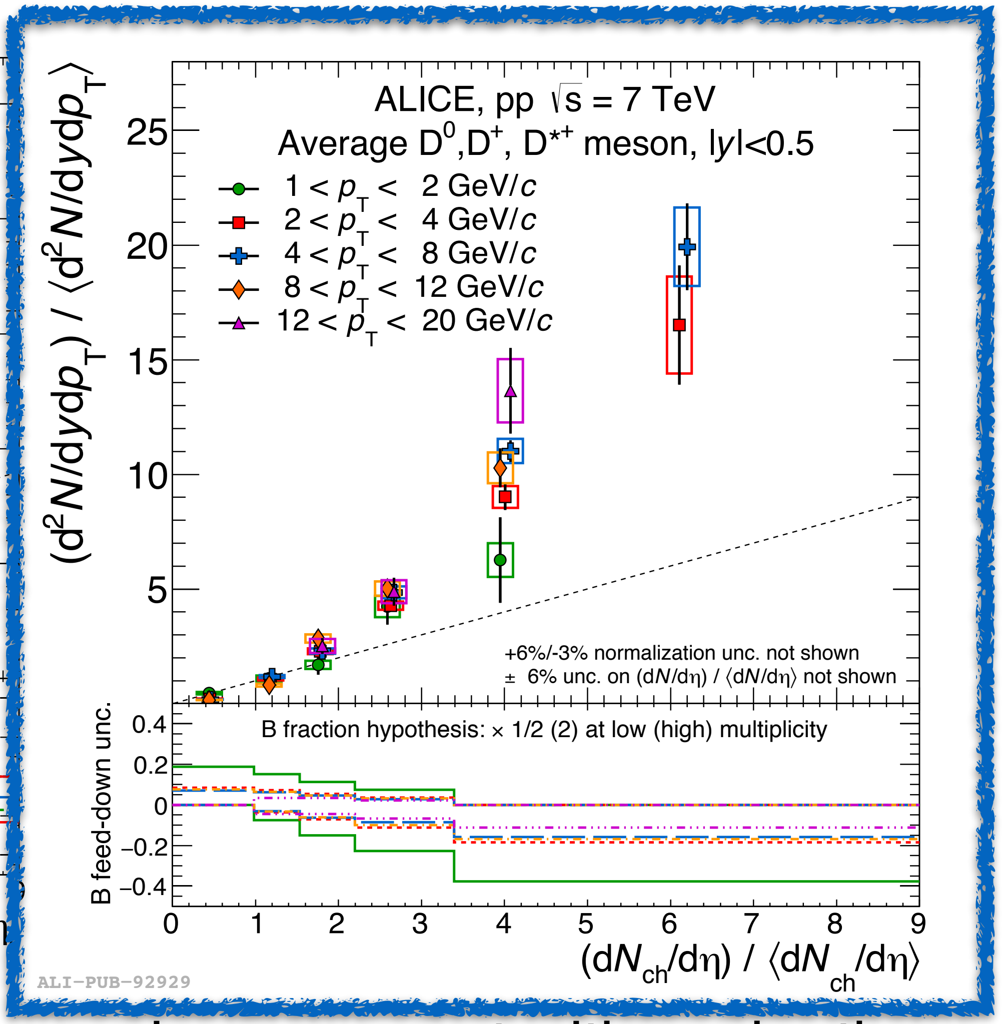

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- Self-normalized yields increase with multiplicity

—> Average D-meson self-normalized yields

- ***p_T* independent** within uncertainties

pp collisions: D vs multiplicity

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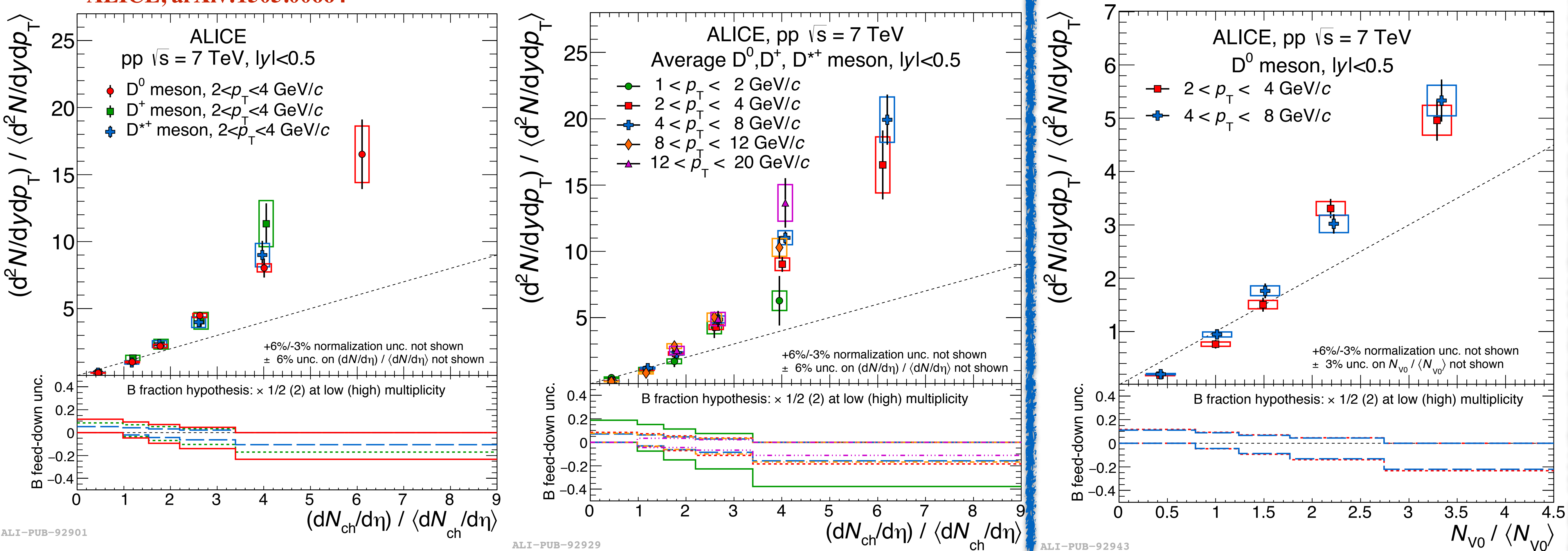


- D^0, D^+,D^* measurements are in agreement with each other within uncertainties
- Self-normalized yields increase with multiplicity

—> Average D-meson self-normalized yields

- p_T independent trend within uncertainties
- Increasing trend vs multiplicity
  - **also** observed estimating the multiplicity **at forward rapidities**

  ➡increase with multiplicity is not due to a possible bias at mid rapidity.

pp collisions: D and J/ψ vs multiplicity

Average **D-meson and inclusive J/ψ** self-normalized yields as a function of the self-normalized charged-particle multiplicity at mid rapidity

- D meson: $2 < p_T < 4$ GeV/c
- inclusive J/ψ: $p_T > 0$.

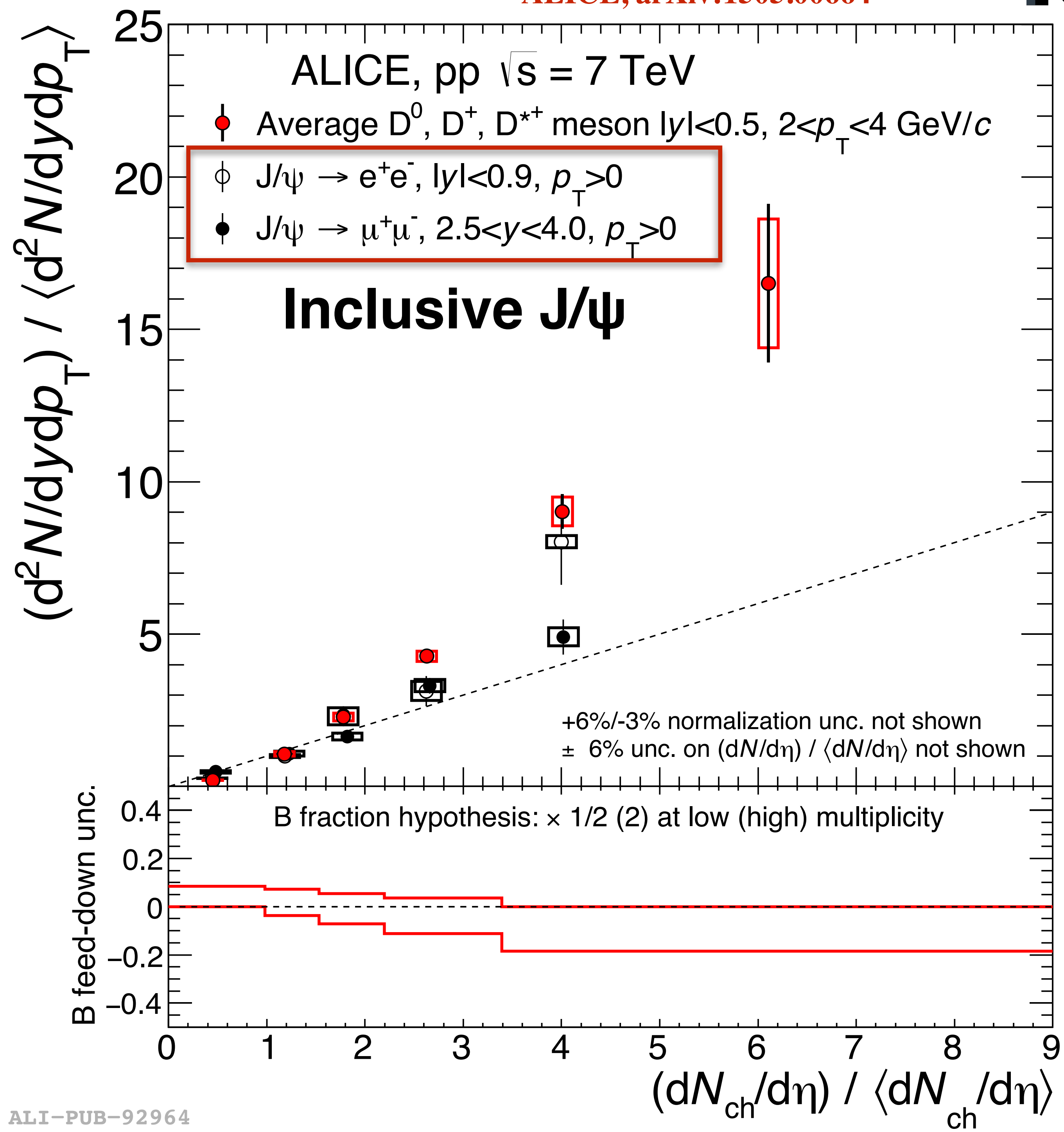
Similar increase with multiplicity of open and hidden charm:

but

- different p_T and η ranges

Similar increase with multiplicity also for D mesons and non-prompt J/ψ , i.e. for charm and beauty

ALICE, arXiv:1505.00664



pp collisions: comparison with models

Percolation model: Ferreiro, Pajares, PRC 86 (2012) 034903

particle production via exchange of colour sources between projectile and target (close to MPI scenario)

only p_T integrated results

- faster than linear increase

EPOS 3.099: Werner et al., PRC 89 (2014) 064903

initial conditions:

Gribov-Regge multiple scattering, saturation scale to model non-linear effects, # of MPI related to multiplicity, hadronization via string fragmentation

- linear increase and p_T dependence

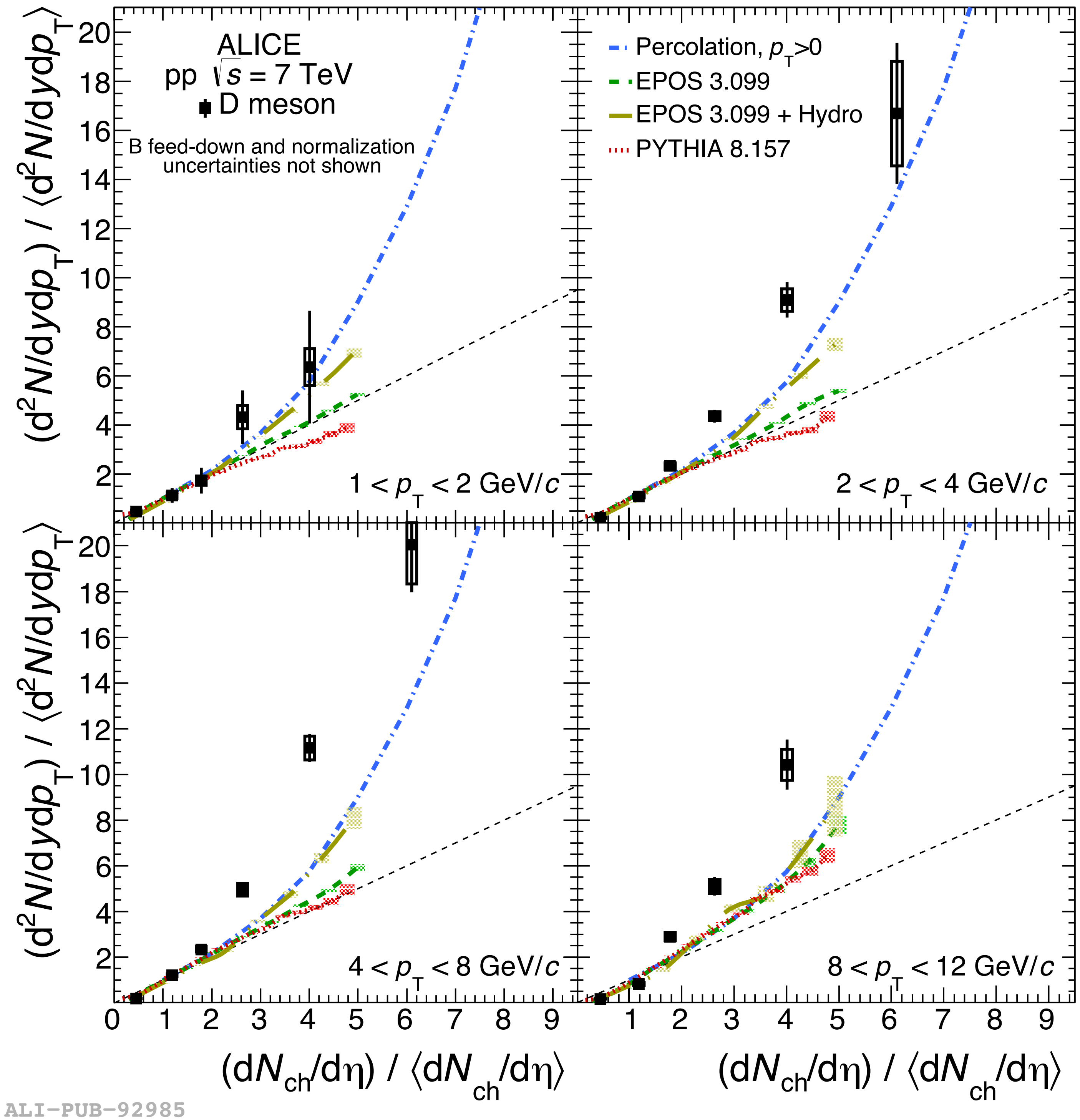
EPOS 3.099 + hydrodynamical evolution

- faster than linear increase

PYTHIA 8: Sjostrand et al., Comp.Phys.C178 (2008) arXiv:0710.3820

Soft QCD tune included, color reconnections, MPI scenario, gluon radiation in initial and final state

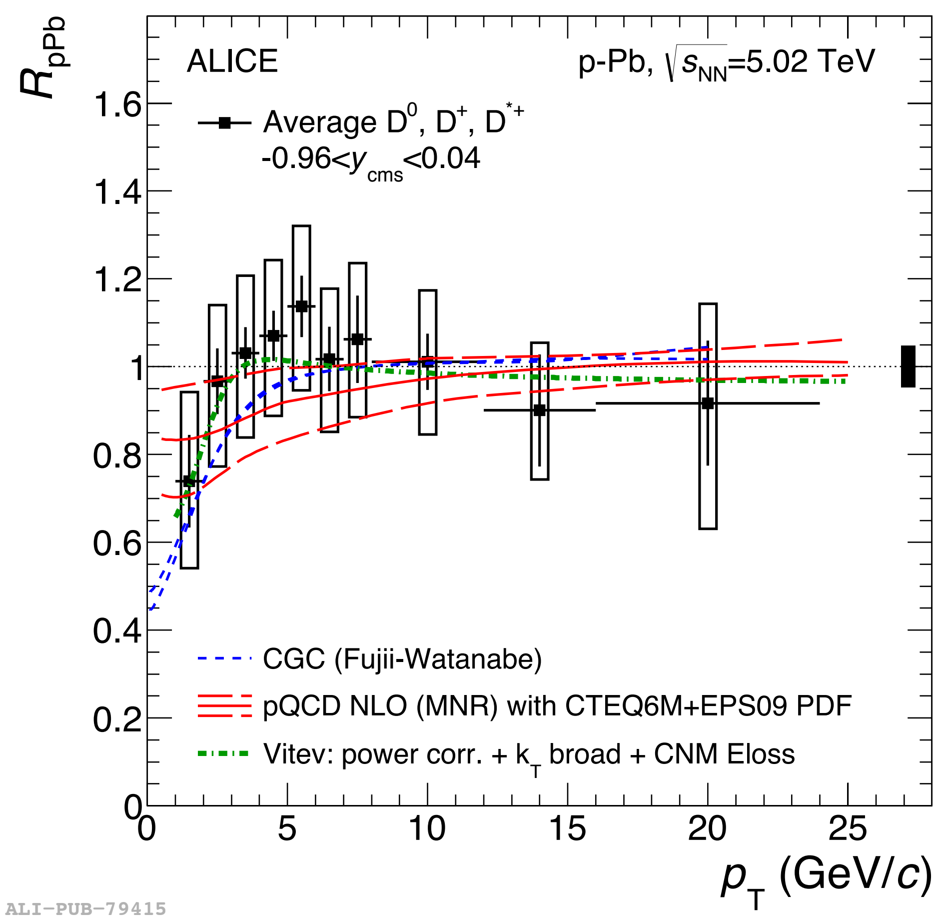
- linear increase and p_T dependence

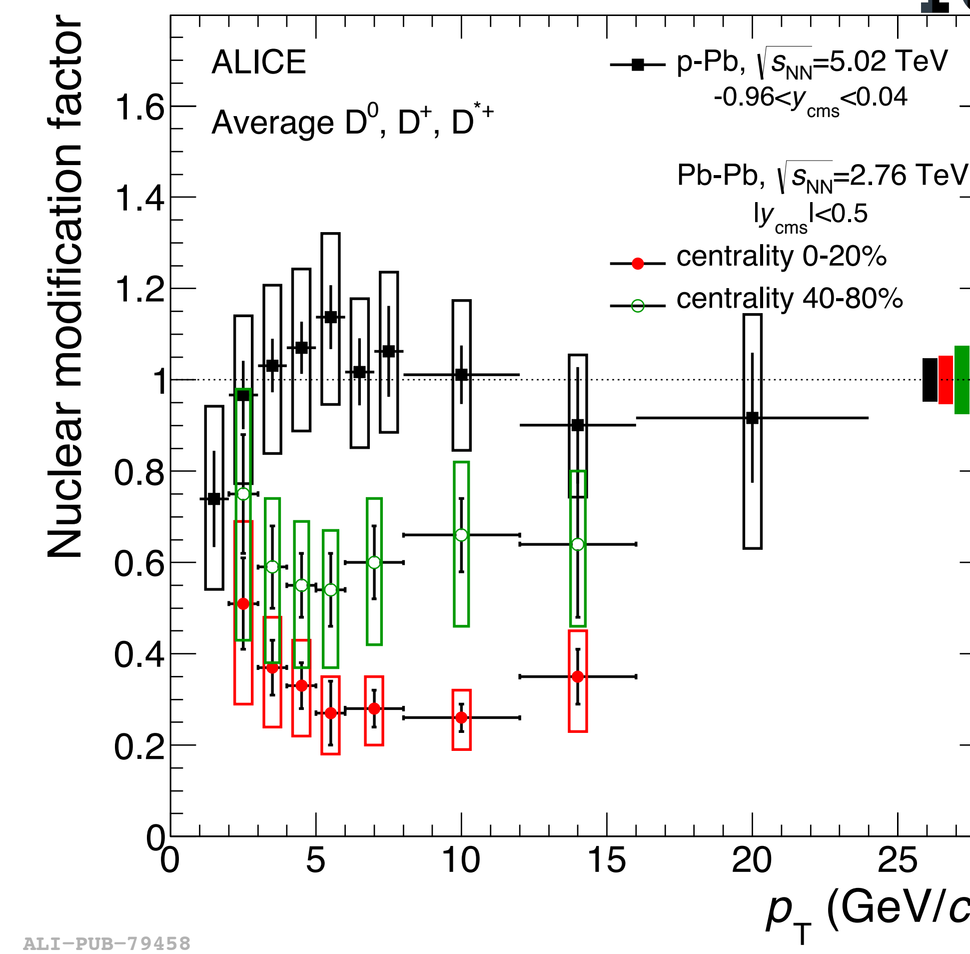


Models including MPI describe the increasing trend

p-Pb collisions: R_{pPb}

$$R_{\mathrm{pPb}} = \frac{\left(\frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}}\right)_{\mathrm{pPb}}}{A \times \left(\frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}}\right)_{\mathrm{pp}}}$$





- D-meson R_{pPb} at high p_{T} **compatible with unity** within uncertainties Phys.Rev.Lett. 113 (2014) 23, 232301
- Models including CNM effects describe the data within uncertainties:
  - pQCD+Shadowing (EPS09) Phys. B 373 (1992) 295
  - k_{T} broadening and CNM energy loss (JHEP 09 (2012) 112 Phys. Rev. C 80 (2009) 054902)
  - Color Glass Condensate Nucl. Phys.A 920 (2013) 78
- Comparison with R_{AA} in **central** and **peripheral** Pb-Pb collisions: strong suppression at high p_{T} is due to final-state effects **JHEP 9 (2012) 112**

talk A. Festanti

p-Pb collisions: event-activity estimator

talk A. Toia

Centrality in p-Pb collisions: arxiv:1412.6828

biases in the determination of <N_{coll}>

- multiplicity fluctuations, jet-veto bias, geometrical bias

➡ Lose correlations between N_{part}, multiplicity and impact parameter *b*

➡ bias depends on estimator used for multiplicity determination

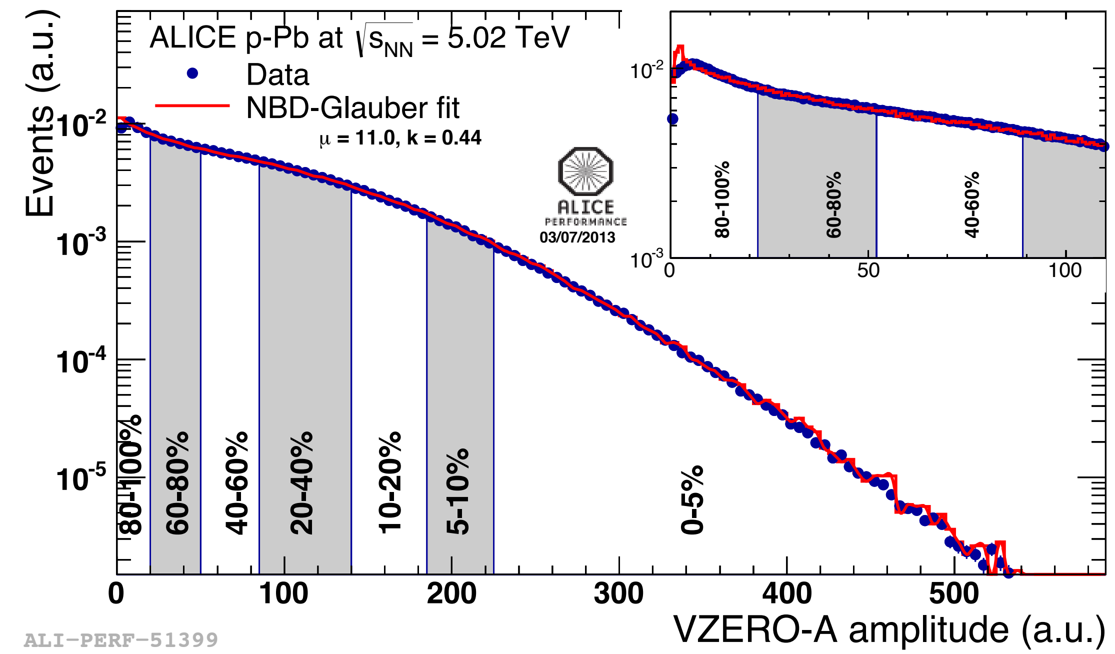
Experimentally:

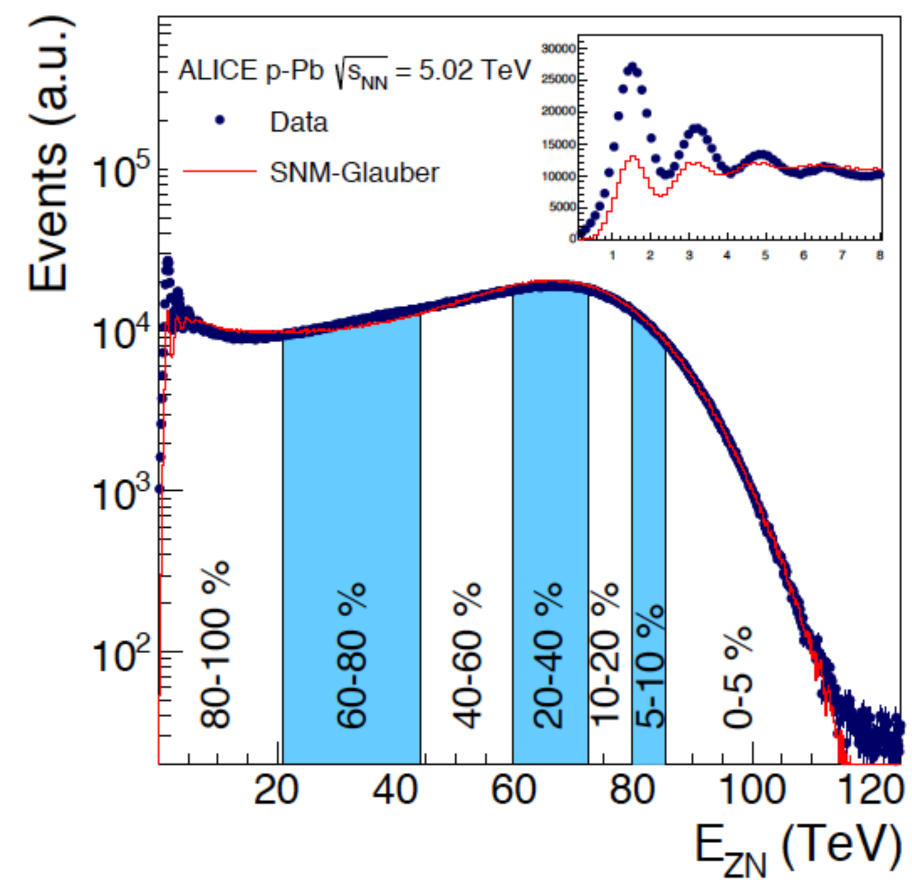
V0A: <N_{coll}> determined by Glauber fit of V0 amplitude

ZNA: <N_{coll}> obtained with a "Hybrid method"

- slice events in ZN energy (Pb going side)
- <N_{coll}> in ZN energy class obtained by scaling the minimum bias value with the ratio between the average charged-particle multiplicity at mid rapidity in the same class and that measured in the minimum bias sample

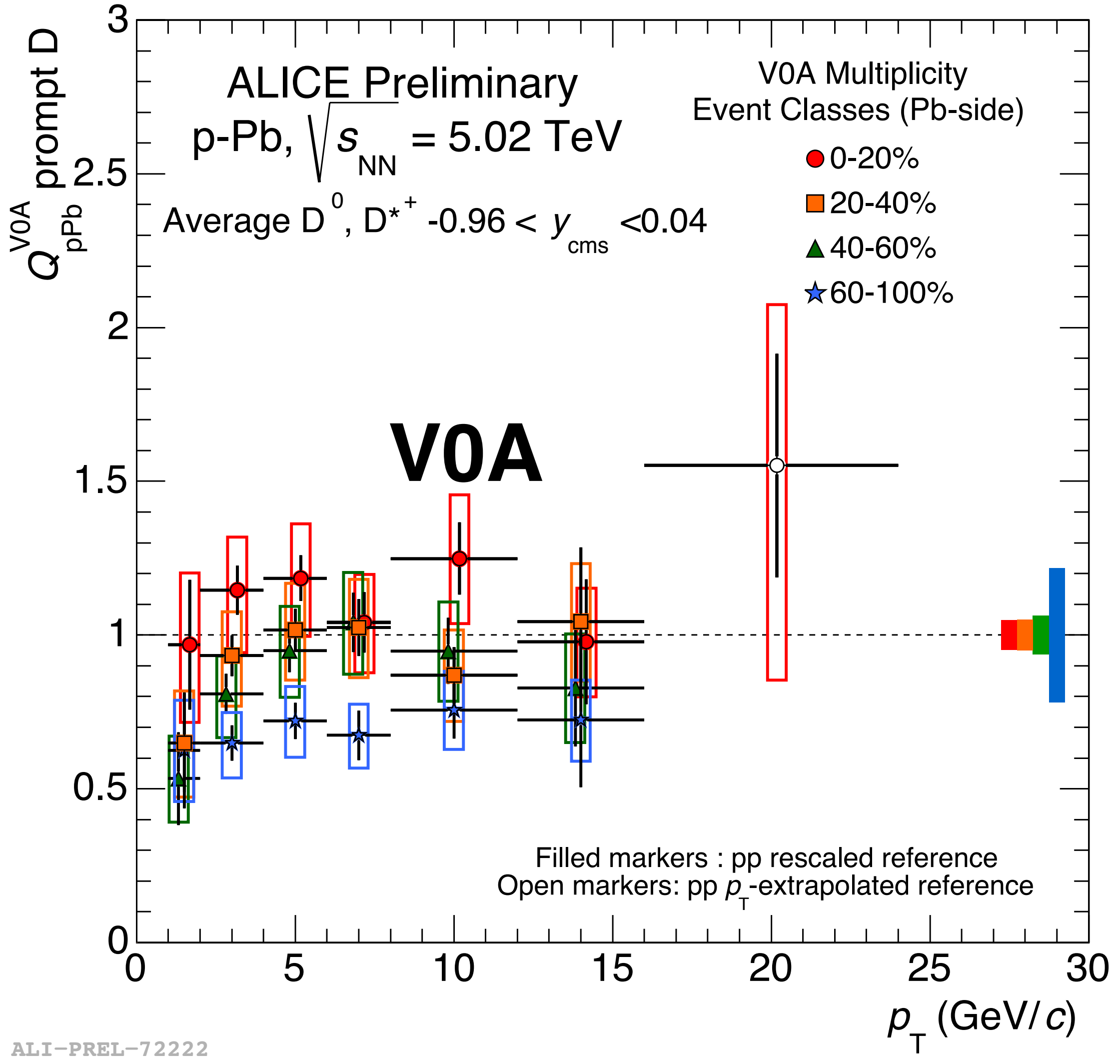
$$Q_{pPb} = \frac{(dN^{D}/dp_{T})_{pPb}}{\langle T_{pPb}\rangle \times (d\sigma^{D}/dp_{T})_{pp}} \qquad \langle T_{pPb}\rangle = \frac{\langle N_{coll}\rangle_i}{\sigma_{NN}}$$

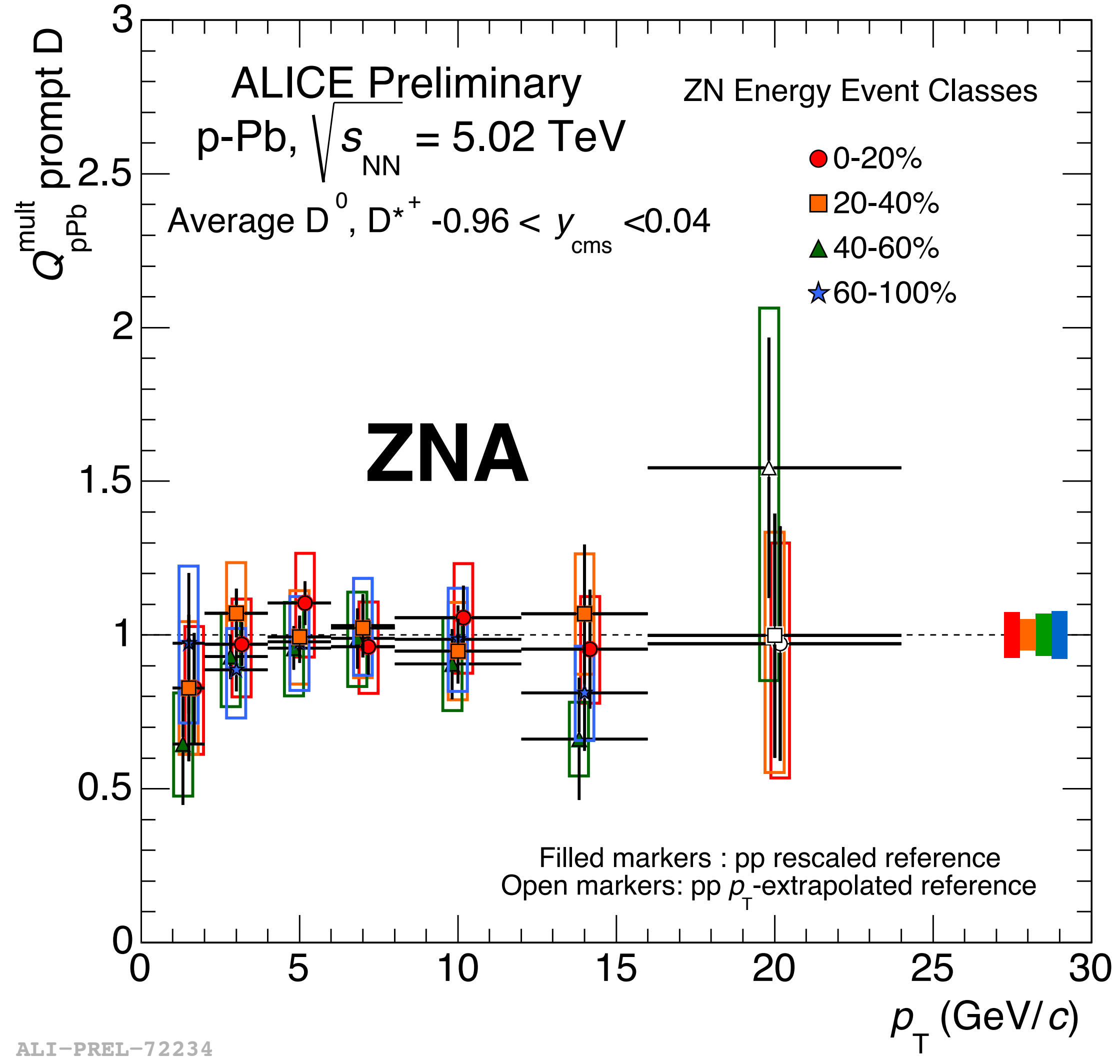




investigate charm production in p-Pb collisions w.r.t. pp collisions: possible multiplicity dependent modification of the p_T spectra in p-Pb?

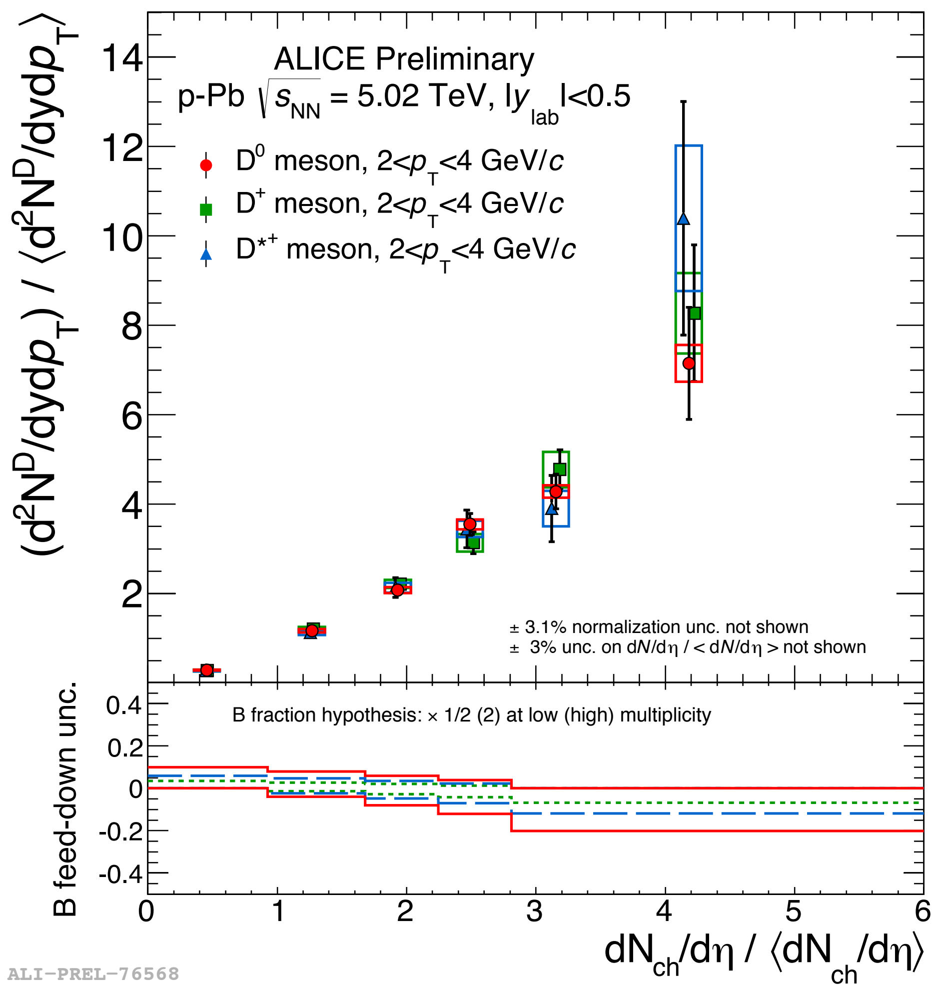
p-Pb collisions: Q_{pPb}

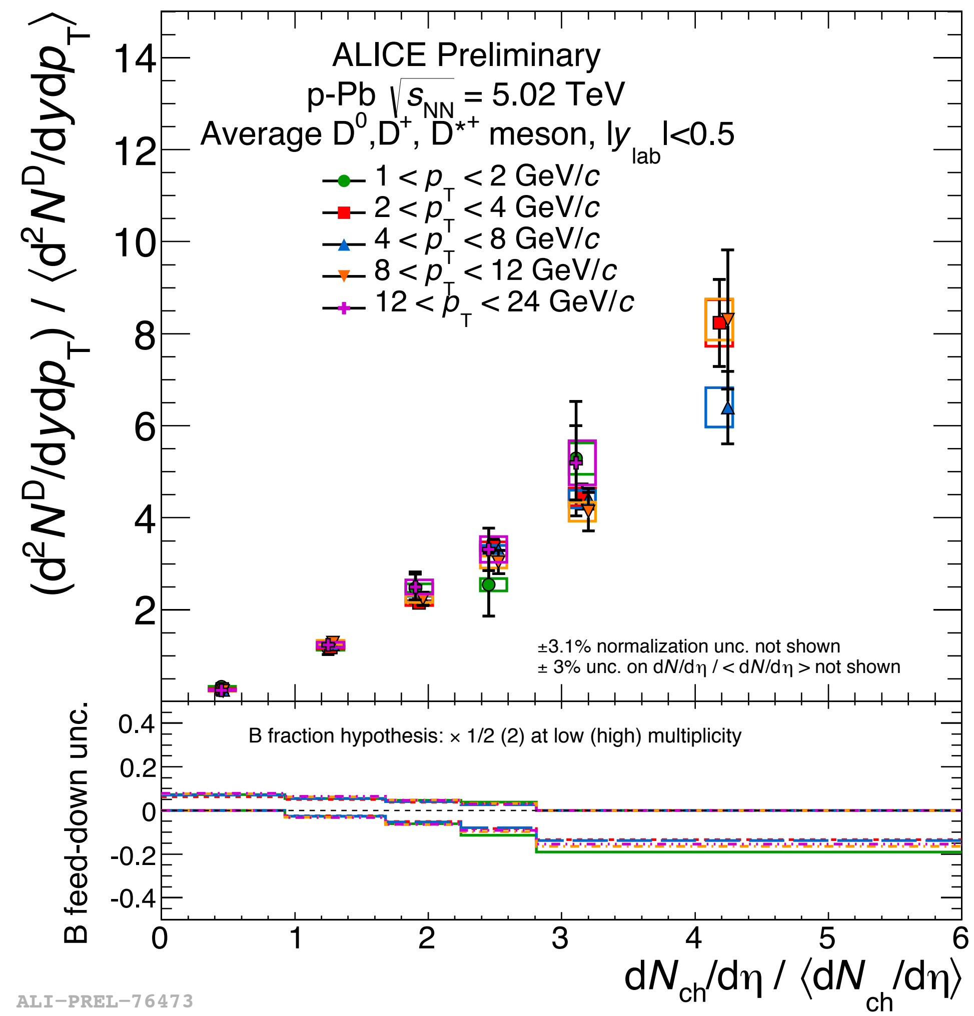




- ***Q_{pPb}* computed with V0A estimator:** hierarchy going from higher multiplicity to lower multiplicity
- ***Q_{pPb}* with ZNA:** no hierarchy is present. Less biased estimator.
  - same trend as the charged-particle nuclear modification factor in the same event activity classes estimated with V0A and ZNA
  - **no dependence of nuclear modification factor on event activity**

p-Pb collisions: D mesons vs multiplicity





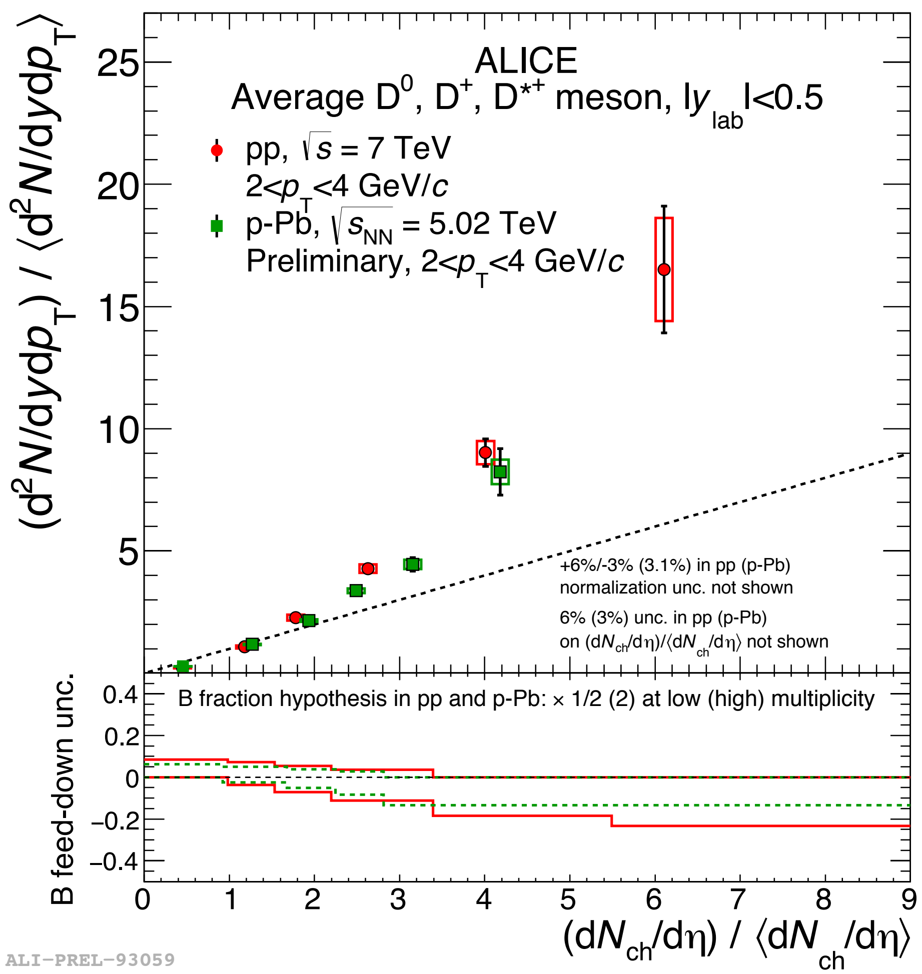
Multiplicity estimator: $N_{tracklets}$

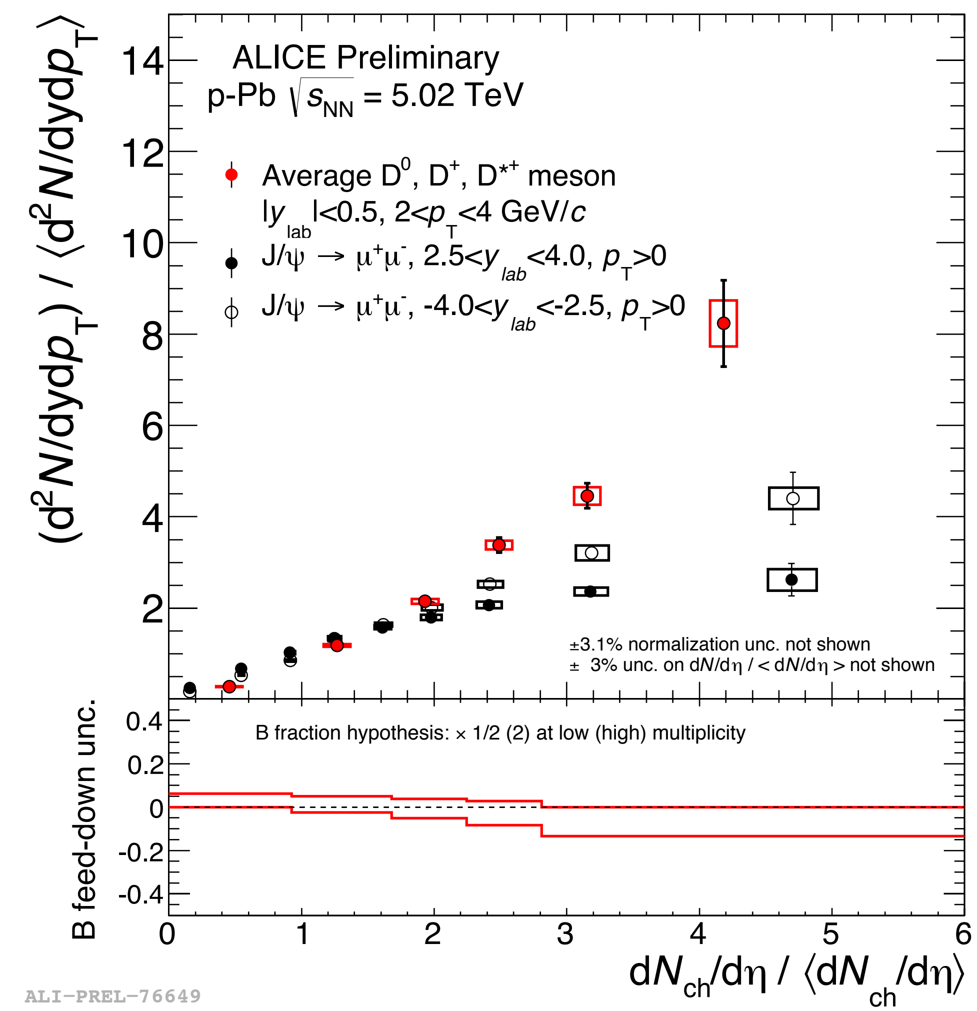
- D^0, D^+,D^* measurements are in agreement within uncertainties
- **Self-normalized yields increase with multiplicity**

—> Average D-meson self-normalized yields

- ***p_T* independent** within uncertainties

p-Pb collisions: comparison with pp and J/ψ in p-Pb





Similar observations in pp and p-Pb:

- **pp** described by MPI models
  - not affected by hadronization mechanism

  ALICE, arXiv:1505.00664
- **p-Pb** also affected by the multiple binary nucleon-nucleon interactions in each p-Pb collision

J/ψ self-normalized yields increase in p-Pb with multiplicity

- different magnitude with respect to D mesons at high multiplicity
- but: different p_T and η of the measurement

  ⇒ different CNM effects expected and different Bjorken-x probed.

Conclusions

D-meson production in pp collisions:

- **test for pQCD:** D-meson production well described by models within uncertainties

D-meson production in p-Pb collisions:

- **constrain CNM effects**
  - R_{pPb} is compatible with models including CNM effects, but large uncertainties → comparison not conclusive
  - R_{pPb} at high p_T compatible with unity within uncertainties confirms that the suppression observed in Pb-Pb collisions is a dense and hot nuclear matter effect

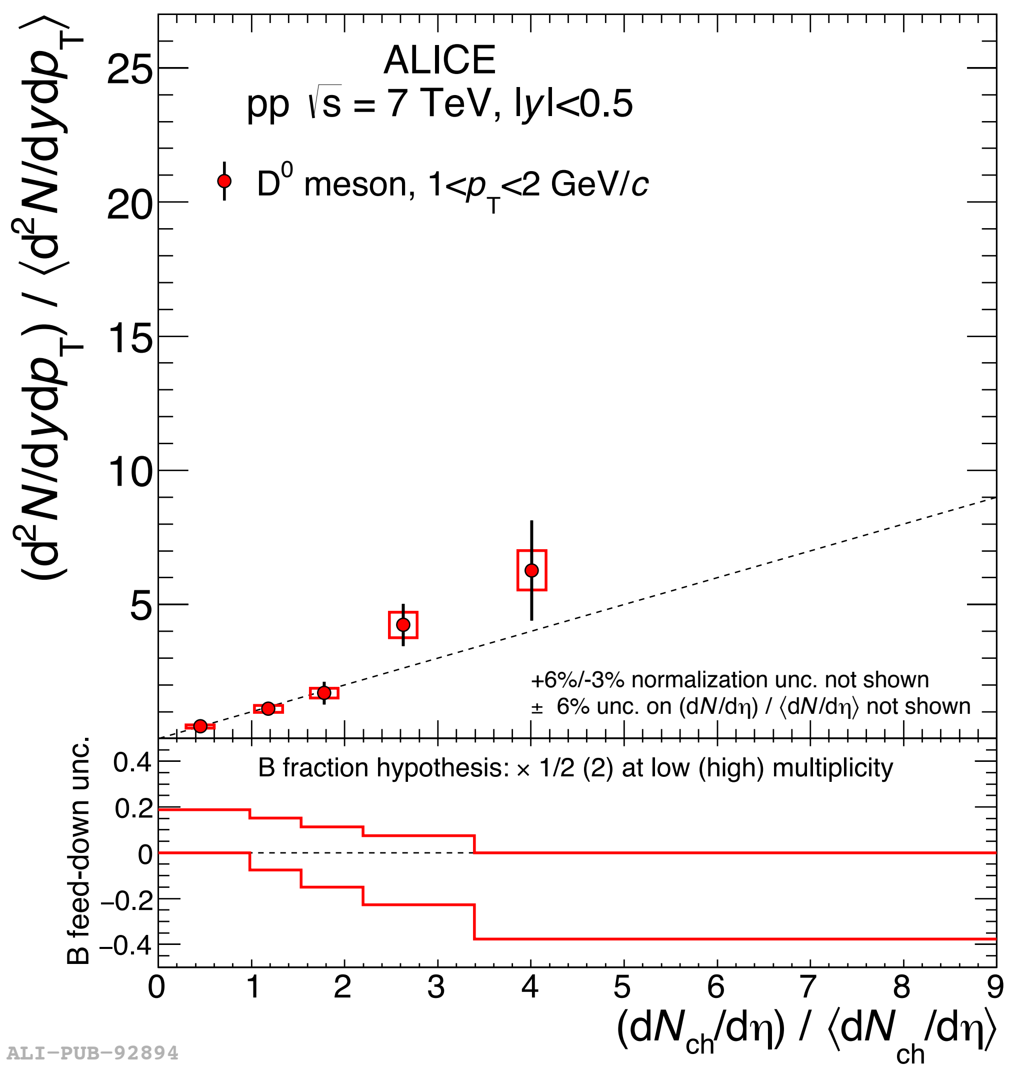
D-meson production vs multiplicity in pp and p-Pb collisions:

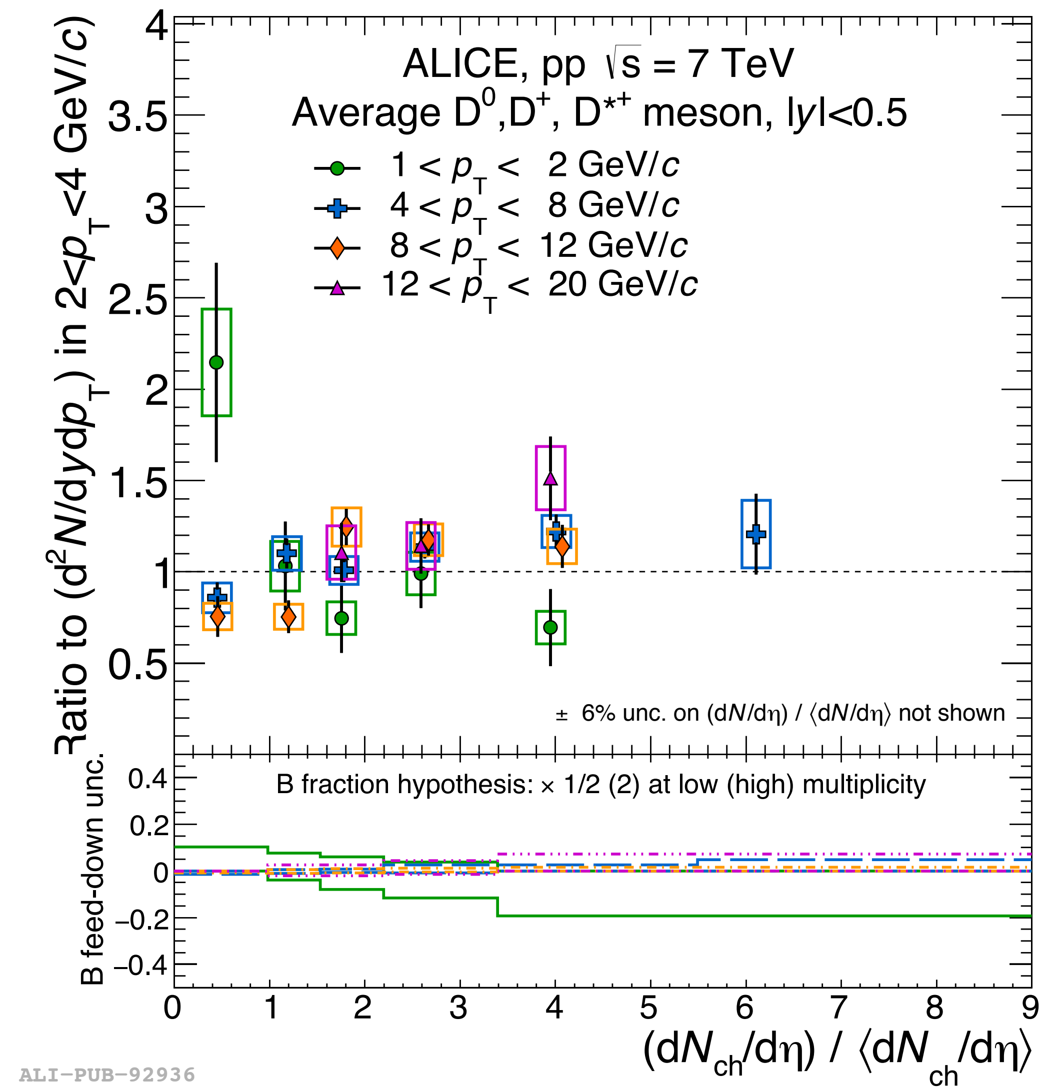
- in p-Pb collisions no evidence for a multiplicity dependence of the D-meson nuclear modification factor has been observed
- D-meson self-normalized yields increase with increasing charged-particle multiplicity in the two systems
  - in pp described by models including MPI
  - in p-Pb collisions also affected by multiple binary nucleon-nucleon collisions

Extend these measurements to higher multiplicity and higher $\sqrt{s}$ to investigate the multiplicity dependence more quantitatively —> Run2

backup

D mesons vs multiplicity in pp





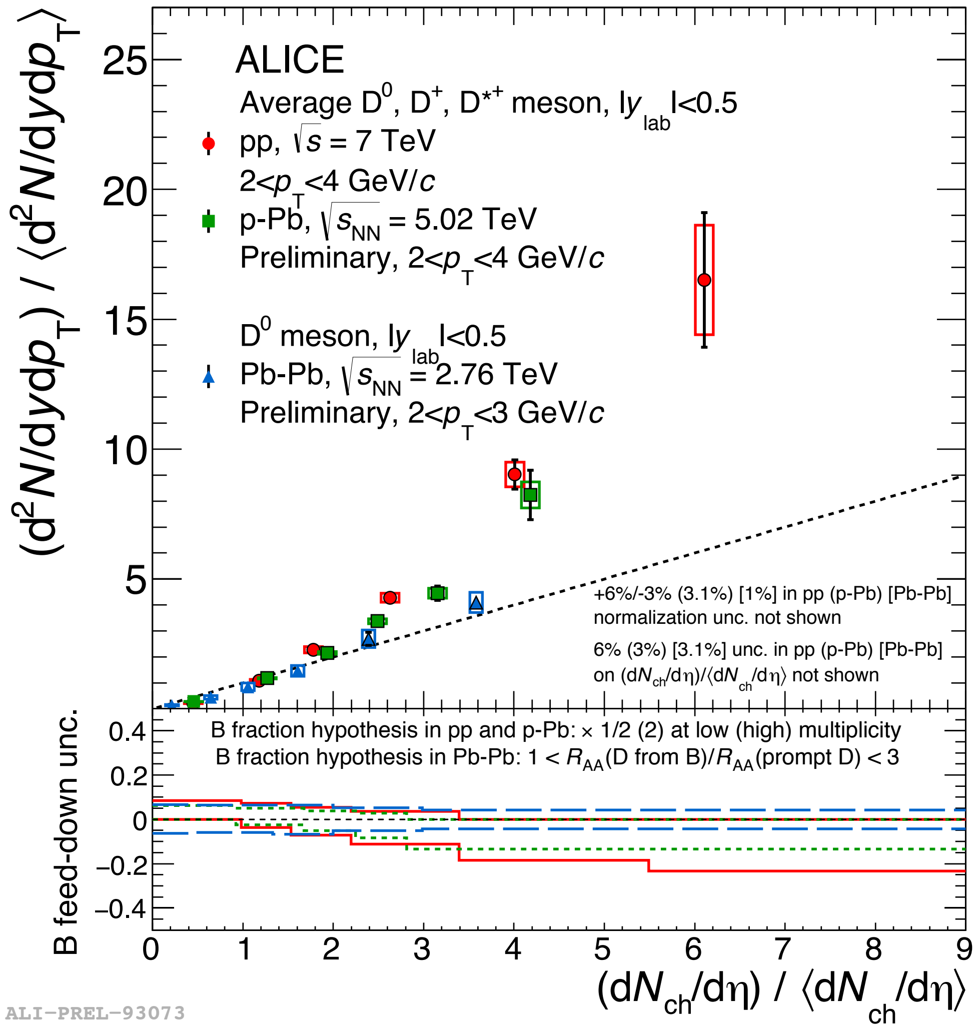
- D^0, D^+,D^* measurements are in agreement within uncertainties

—> Average D-meson relative yields

- p_T independent trend within uncertainties
- Increasing trend vs multiplicity
  - **also** observed estimating the multiplicity **at forward rapidities**

  ➡increasing trend with multiplicity is not due to the possible bias at mid rapidity.

D mesons vs multiplicity in pp, p-Pb, Pb-Pb



- trend reflects evolution of N_{coll} and R_{AA} with centrality
- caveat comparing pp with Pb-Pb collisions: highest multiplicity bin corresponds to 10% of the total cross section in Pb-Pb but only 1% in pp collisions

Centrality estimator in p-Pb: biases

Multiplicity bias: fluctuations sizable

→Bias on Mult/N_{part} at central and peripheral collisions

MC models with multi-parton interaction (MPI) include fluctuations of particle sources (hard scatterings)

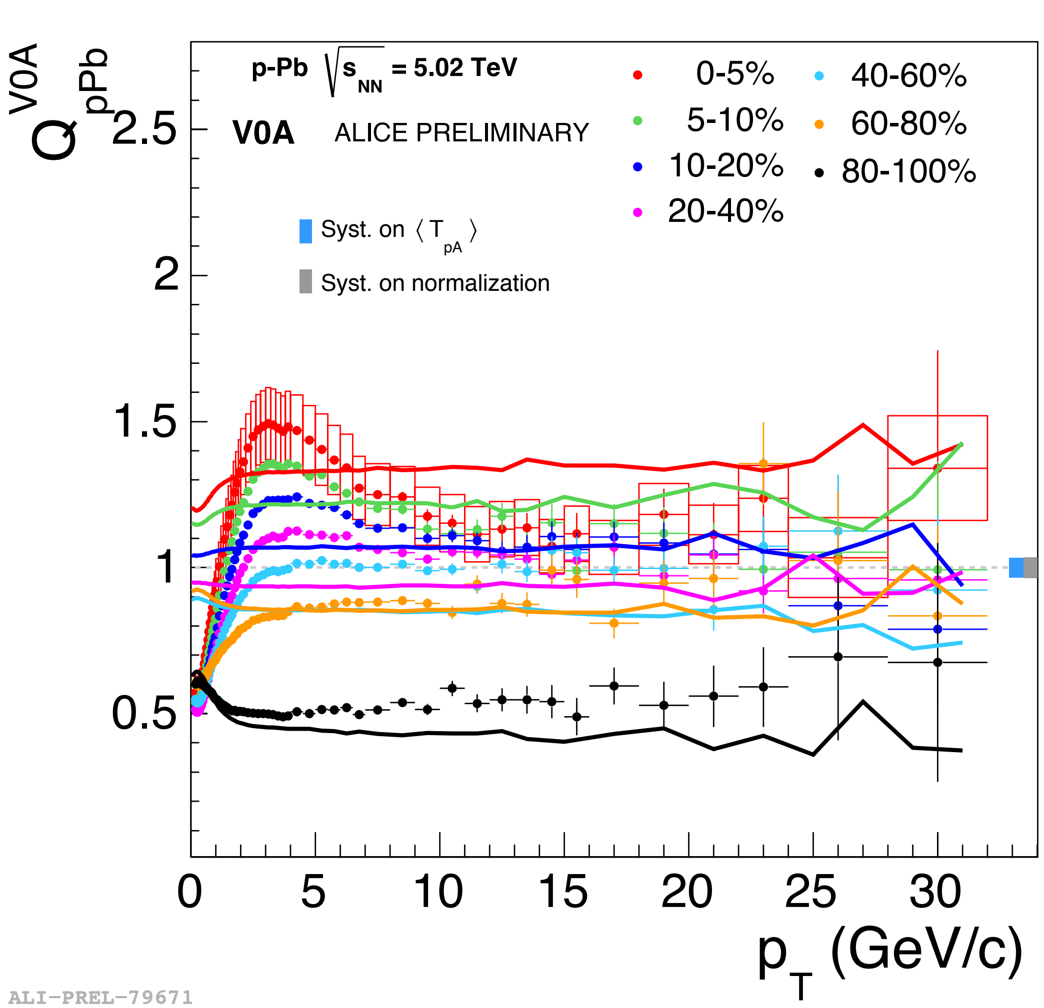
HIJING (X.N. Wang, M. Gyulassy, nucl-th/9502021)

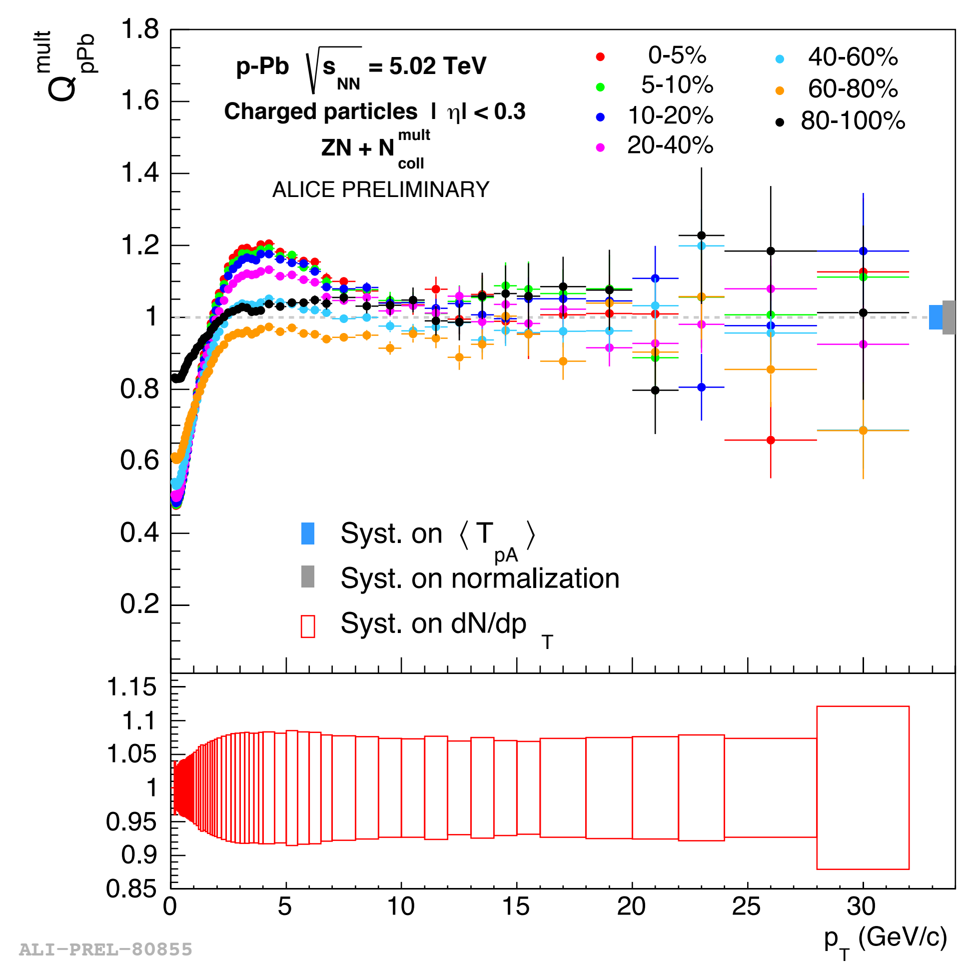
→ bias in mult ~ bias in hard scattering

much smaller in Pb-Pb

- Jet-veto: multiplicity range in peripheral events represent an effective veto on hard processes
- Geometry bias:

Mean nucleon-nucleon impact parameter (b_{NN}) increases in peripheral collisions

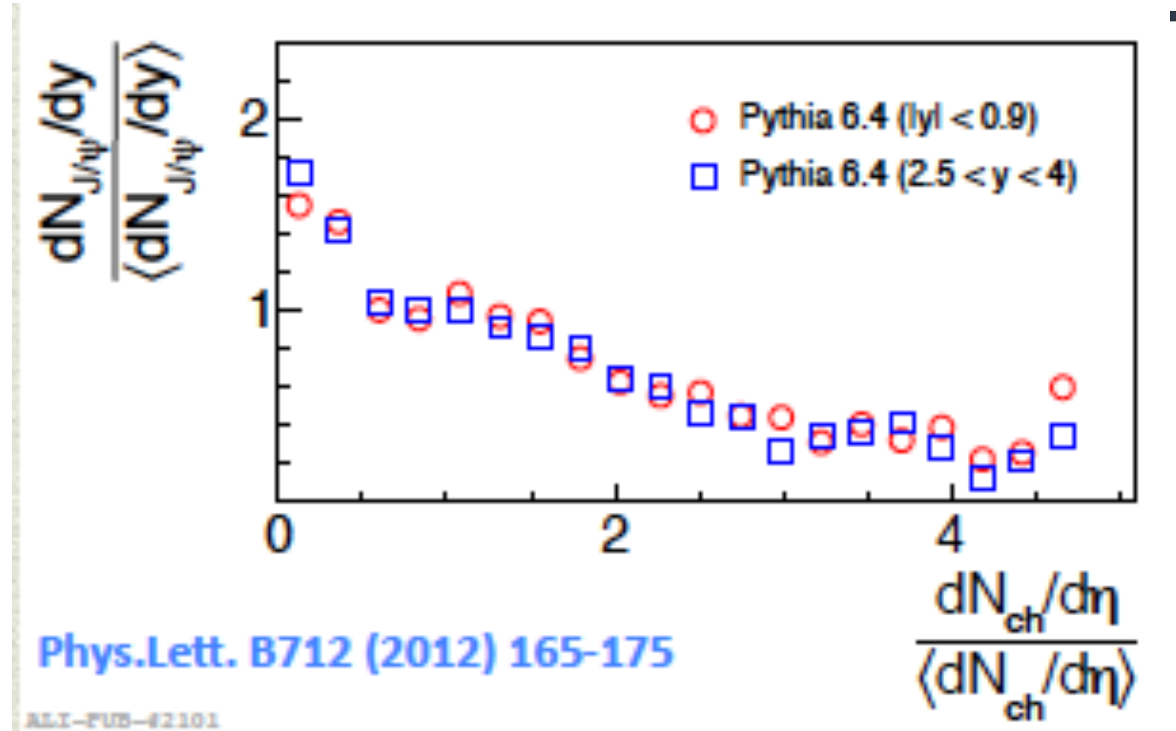




J/ψ in pp

Pythia 6.4 with only first
hard processes as mechanisms
of charm production.
No contributions from
MPI nor clusters formation processes

**Clear different trend w.r.t. data:
models w/o MPIs don't describe the data**



**non-prompt J/ψ fraction in the
inclusive J/ψ yields (f_B)
as a function of
of the relative charged-particle
multiplicity at central rapidity
for p_T>1.3 GeV/*c***

$$\frac{dN^{\mathrm{non-prompt}}_{J/\psi}/dy}{\left\langle dN^{\mathrm{non-prompt}}_{J/\psi}/dy\right\rangle} = \frac{dN_{J/\psi}/dy}{\langle dN_{J/\psi}/dy\rangle}\cdot\frac{f_B}{\langle f_B\rangle}$$