



ALICE



# **Heavy-flavour production in small systems with ALICE**

Elena Bruna (INFN-GSI/EMMI)  
for the ALICE Collaboration

3rd International Conference on the Initial Stages in High-Energy Nuclear Collisions (InitialStages2016)

# Outline

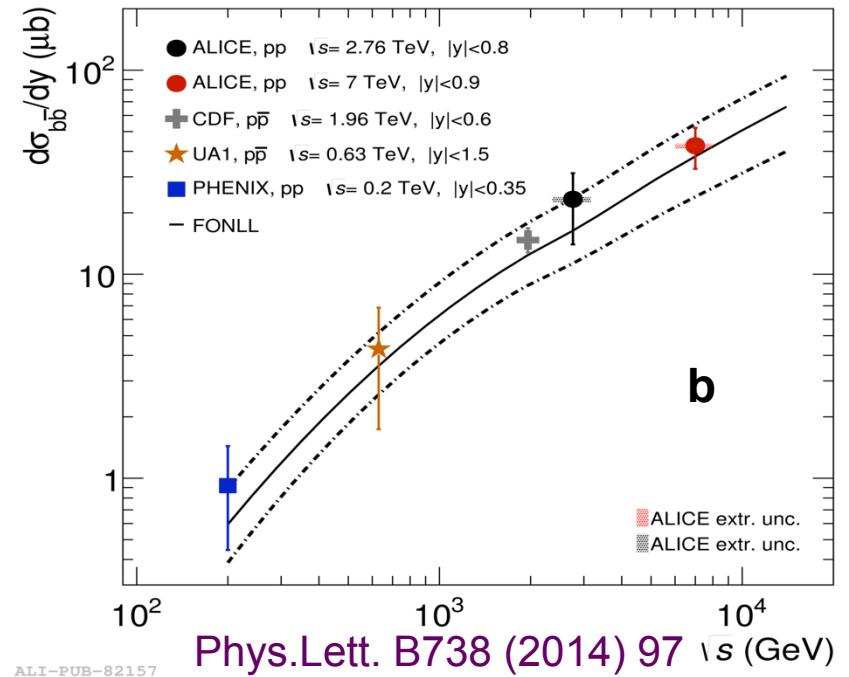
- Physics motivations
- The ALICE experiment
- Results
  - Heavy-flavour cross section in pp and p-Pb collisions
    - Down to  $p_T=0$  **New on arXiv:1605.07569**
  - Multiplicity dependence of heavy-flavour production in pp and p-Pb collisions **New on arXiv:1602.07240**
  - Azimuthal correlations of D mesons with charged particles in pp and p-Pb collisions **New on arXiv:1605.06963**
- Conclusions

# Why Heavy Flavours (charm and beauty)?

Heavy quarks are produced in initial high- $Q^2$  scattering processes

Production calculable with pQCD

Heavy-flavour (HF) results described by pQCD at LHC energies



pp system is the reference for p-Pb and Pb-Pb collisions

p-Pb collisions provide the control experiment to study Cold Nuclear Matter (CNM) effects

More differential measurements provide more insight into heavy-flavour (HF) production mechanisms in small systems

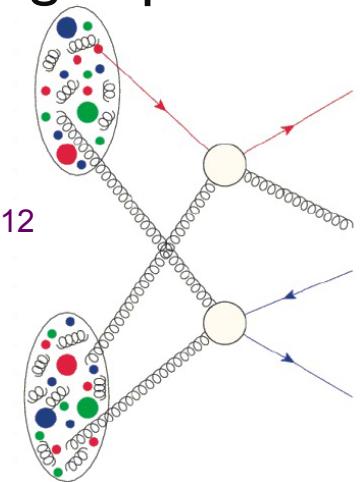
# HF production in pp collisions at LHC

- Several hard partonic interactions can occur
- In events with multi-parton interactions (MPIs) higher charged-particle multiplicity expected

Bartalini, Fano, arXiv:1003.4220

In addition:

- Role of the collision geometry Frankfurt, Strikman, Weiss, PRD 83 (2011) 054012  
Azarkin, Dremin, Strikman, PLB 735 (2014) 244
- Final-state effects Ferreiro, Pajares, PRC 86 (2012) 034903  
Werner et al., PRC 83 (2011) 044915
- Collectivity at high multiplicities?



→ **Effects of MPIs and geometry/final-state/collectivity on the heavy-flavour sector in pp collisions?**

→ **Can we assess charm fragmentation and jet properties?**

## More differential HF observables:

Multiplicity dependence of HF production in pp collisions

Angular correlations of D mesons with charged particles in pp collisions

# Additional effects in p-Pb collisions

In presence of a nucleus (p-Pb collisions):

- Multiple nucleon-nucleon collisions
- Nuclear PDFs, saturation effects
- Initial-state  $k_T$  broadening
- Initial/final-state energy loss

→ Collective-like effects observed for light quarks. Same mechanisms (CGC/hydro) for light and heavy flavours?

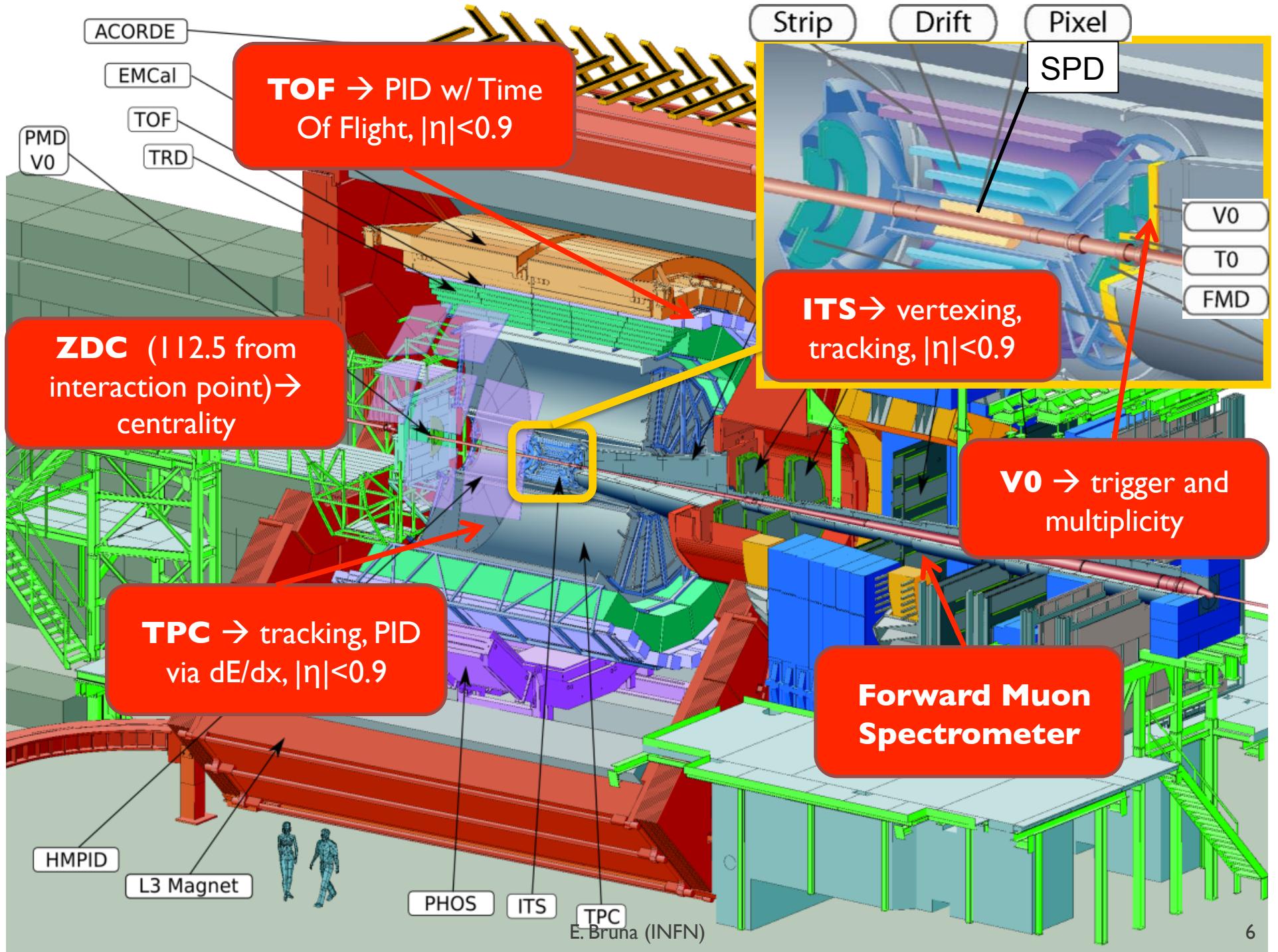
→ Do CNM effects influence HF production depending on collision geometry and/or multiplicity density?

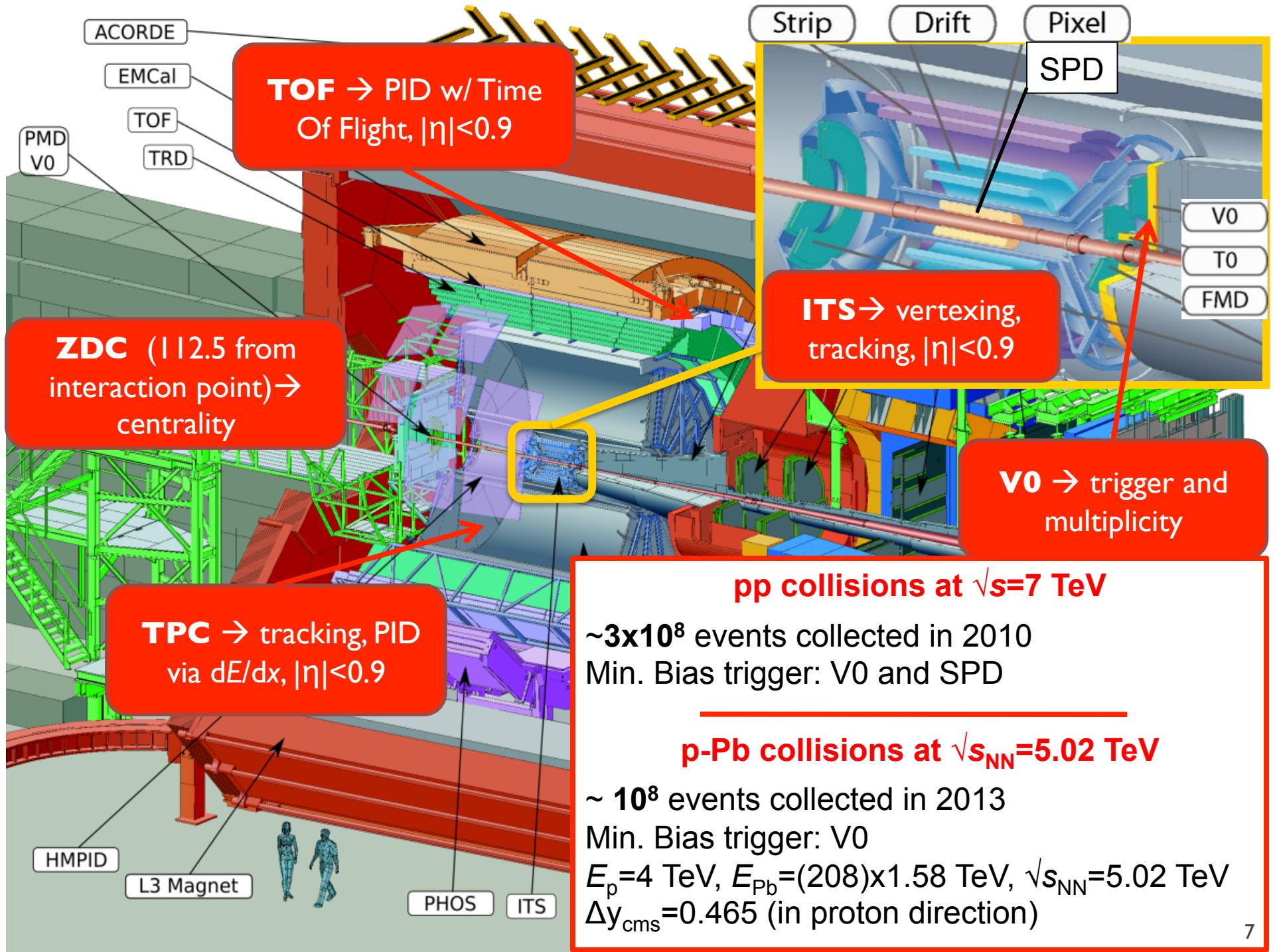
→ Can we assess possible effects of charm fragmentation/jet properties in the presence of the nucleus?

## More differential HF observables also in p-Pb collisions

Multiplicity dependence

Angular correlations

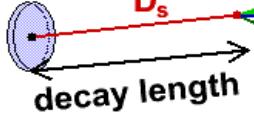




# Heavy flavours with ALICE

## Full reconstruction of D-meson hadronic decays (prompt D mesons)

$$\begin{aligned} D^0 &\rightarrow K^- \pi^+ \\ D^+ &\rightarrow K^- \pi^+ \pi^+ \\ D^{*+} &\rightarrow D^0 \pi^+ \\ D_s^+ &\rightarrow \phi \pi^+ \rightarrow K^- K^+ \pi^+ \end{aligned}$$



decay length

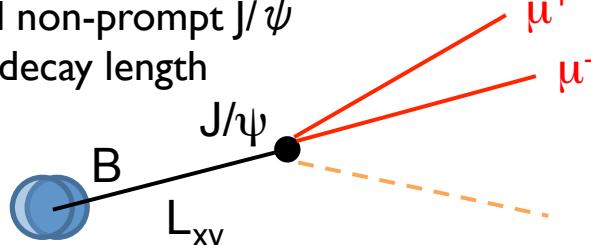
Invariant mass analysis based on displaced **secondary vertices**, selected with **topological cuts and PID**

Correction for beauty feed-down (based on FONLL) to extract results for **prompt D mesons**

## Displaced electrons, J/ $\psi$ (from B decays)

Separation of prompt and non-prompt J/ $\psi$  using the pseudo-proper decay length

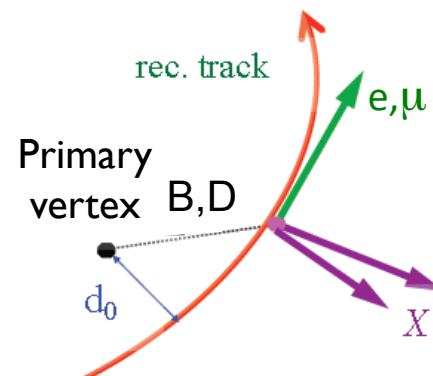
Beauty-decay electrons:  
Exploit displaced track impact parameter



$L_{xy}$

## Semi-leptonic decays (charm, beauty)

Electrons: mid-rapidity  
Muons: forward rapidity



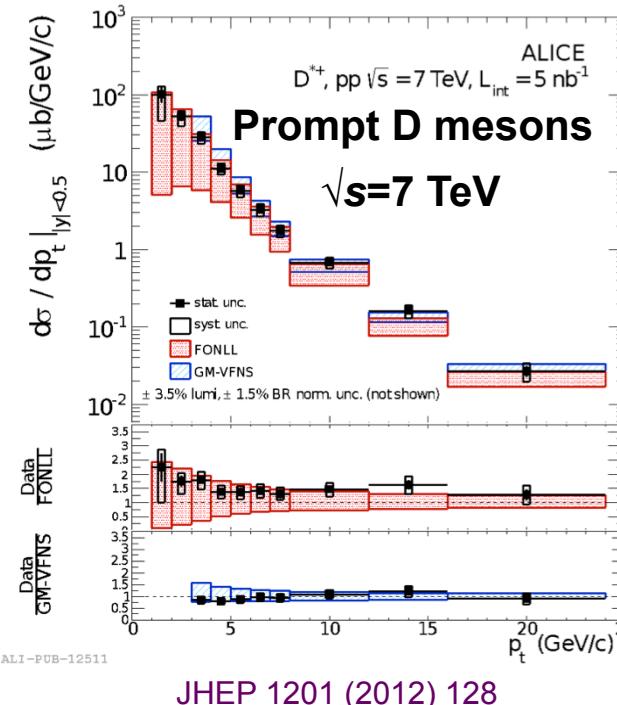
Electrons: background ( $\pi^0$  and  $\eta$  Dalitz decays, photon conversions)  
subtracted with **Invariant mass method (e+e-)** and cocktail

Muons: background ( $\pi, K \rightarrow \mu$ )  
subtracted with **MC (pp)** and **data-tuned MC cocktail (p-Pb, Pb-Pb)**

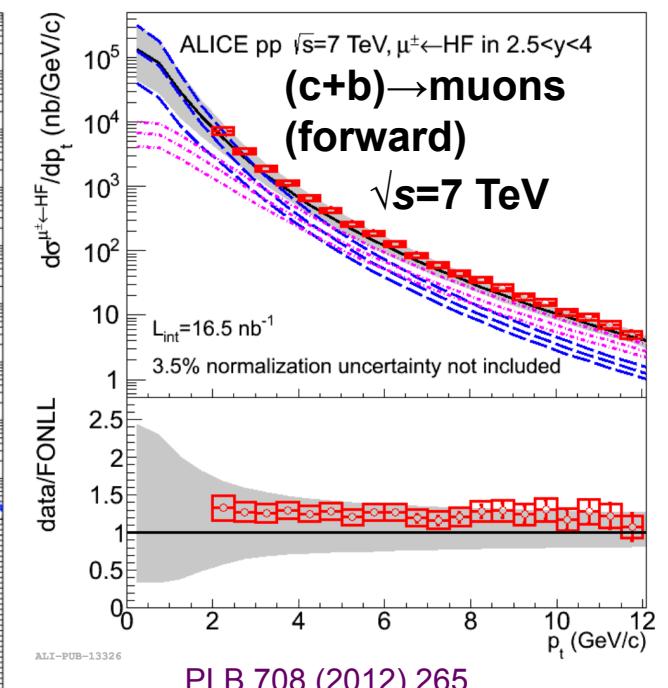
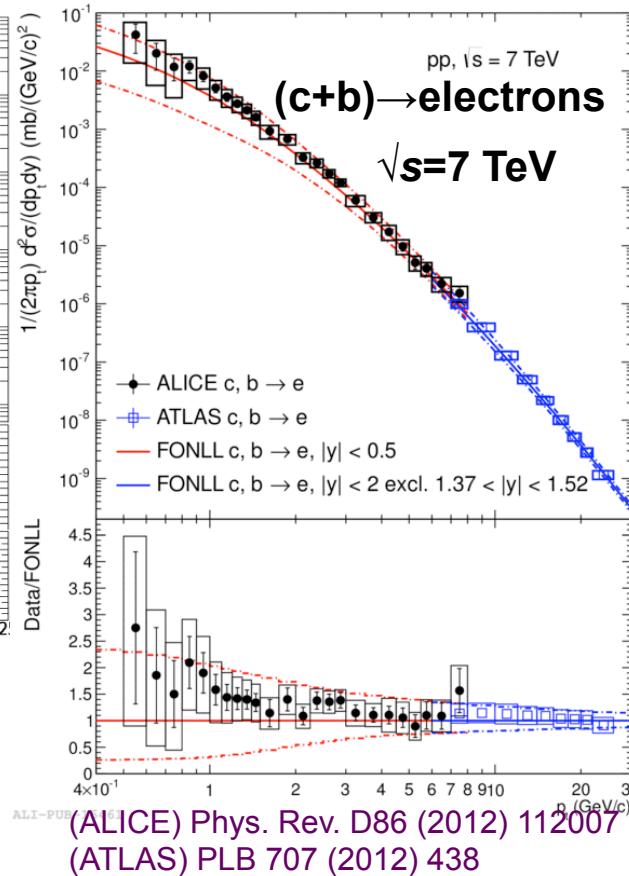


# **Cross sections in pp and p-Pb collisions**

# Heavy-flavour cross sections in pp collisions



JHEP 1201 (2012) 128



PLB 708 (2012) 265

FONLL: JHEP0407 (2004) 033,  
 JHEP, 1210 (2012) 137.

GM-VFNS: Eur.Phys.J., C72 (2012) 2082.

LO  $k_T$  fact: Phys.Rev., D87 (2013) 094022.

Cross sections described by FONLL, GM-VFNS,  $k_T$  factorization pQCD calculations

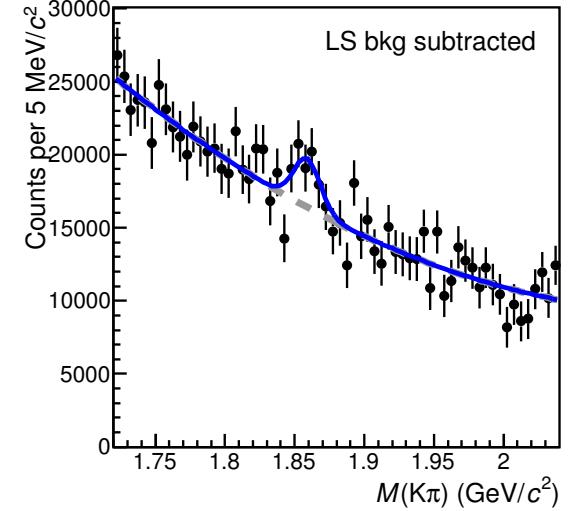
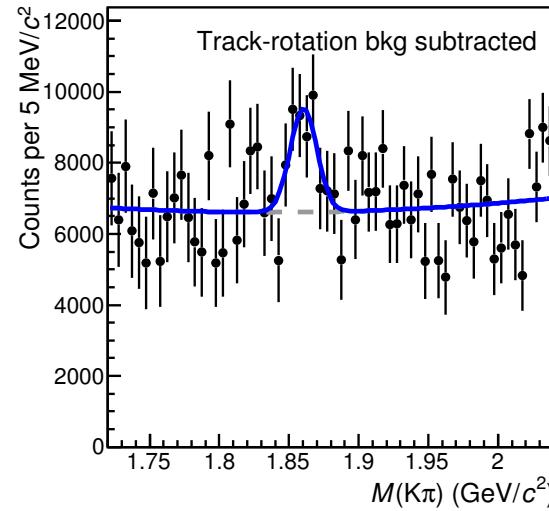
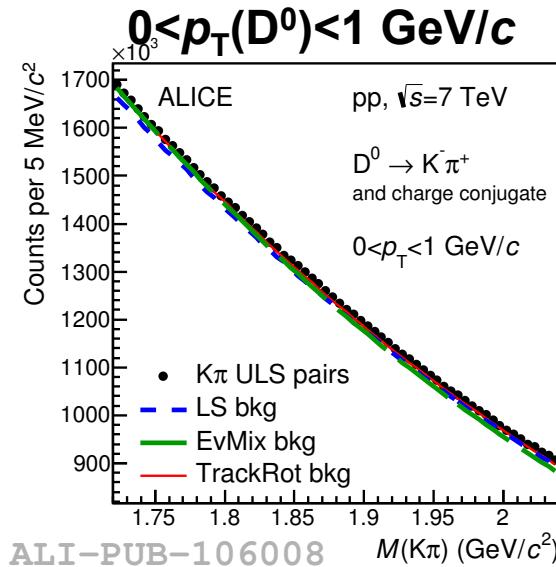
Low  $p_T$  semi-leptonic cross section in good agreement with ATLAS at high  $p_T$



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# D<sup>0</sup> cross section in pp collisions - down to $p_T=0$

arXiv:1605.07569



No secondary vertex reconstruction

Combinatorial background subtraction via:  
event mixing, like sign, track rotation, side-band fit



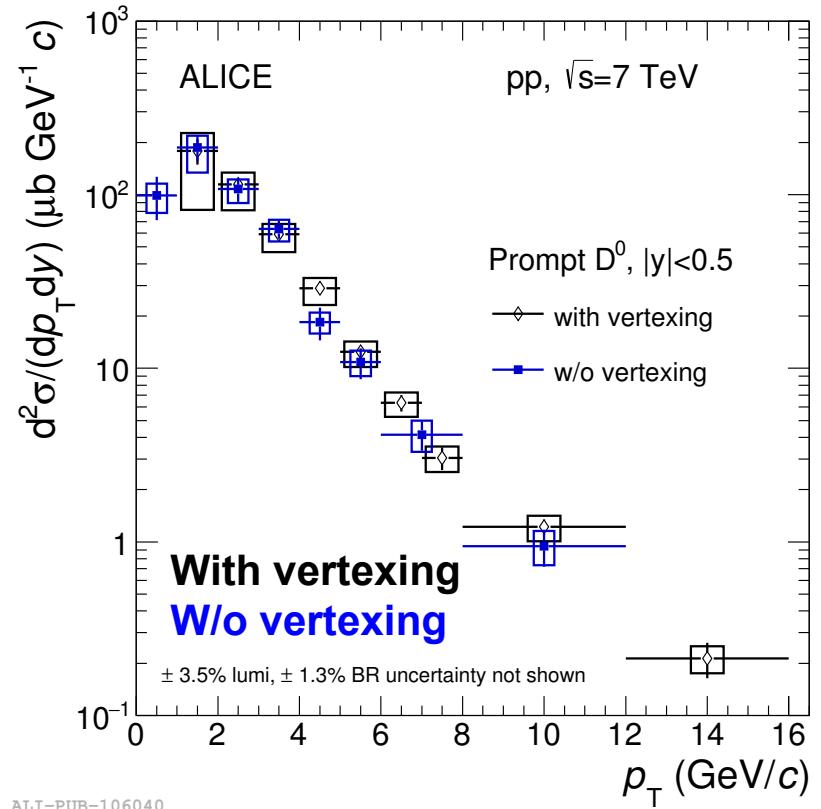
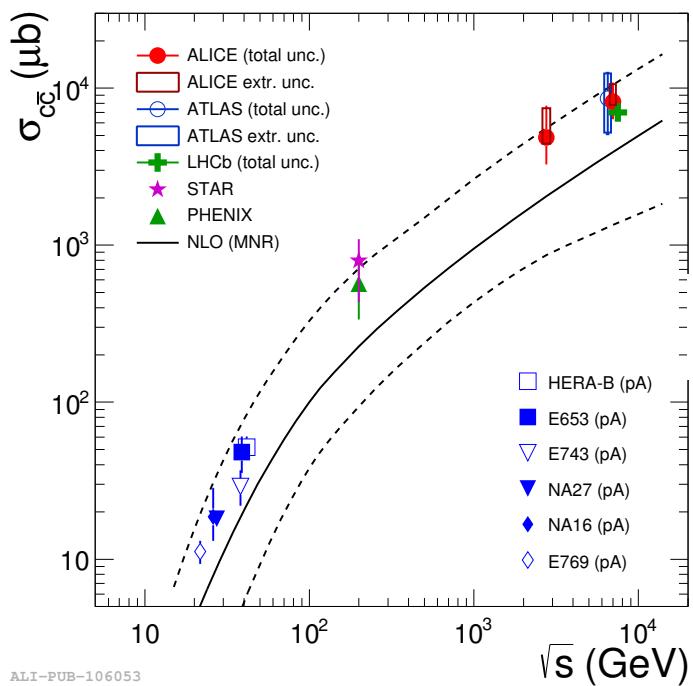
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# D<sup>0</sup> cross section in pp collisions

## - down to $p_T=0$

arXiv:1605.07569

Good agreement with the measurement at higher  $p_T$  based on secondary vertex topology



**pp collisions at  $\sqrt{s} = 7$  TeV:**

$$d\sigma_{pp, 7\text{TeV}}^{\text{prompt } D^0} / dy = 518 \pm 43 \text{ (stat.)}^{+ 57}_{- 102} \text{ (syst.)} \pm 18 \text{ (lumi.)} \pm 7 \text{ (BR)} \mu\text{b}$$

→ updated total charm cross section with reduced uncertainty

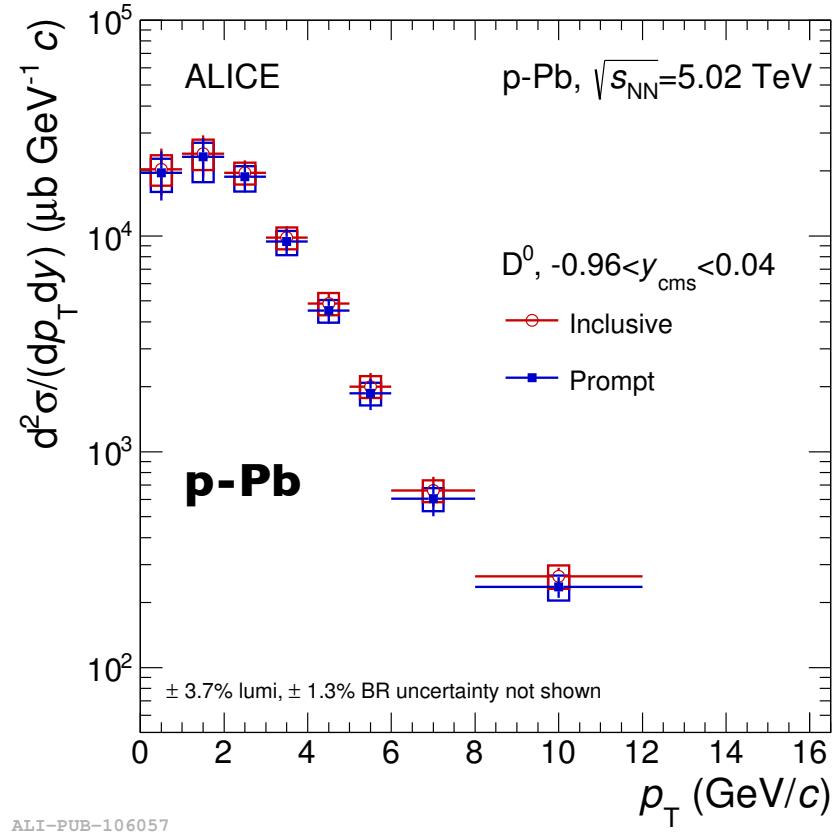


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# D<sup>0</sup> cross section in p-Pb collisions - down to $p_T=0$

arXiv:1605.07569

Measurement of **inclusive** (no B feed-down subtraction) and **prompt** D<sup>0</sup> meson cross section



**p-Pb collisions at  $\sqrt{s_{NN}}=5.02 \text{ TeV}$ :**

$$d\sigma_{\text{p-Pb}, 5.02 \text{ TeV}}^{\text{promptD}^0}/dy = 79.0 \pm 7.3 \text{ (stat.)}^{+ 7.1}_{- 13.4} \text{ (syst.)} \pm 2.9 \text{ (lumi.)} \pm 1.0 \text{ (BR)} \text{ mb}$$

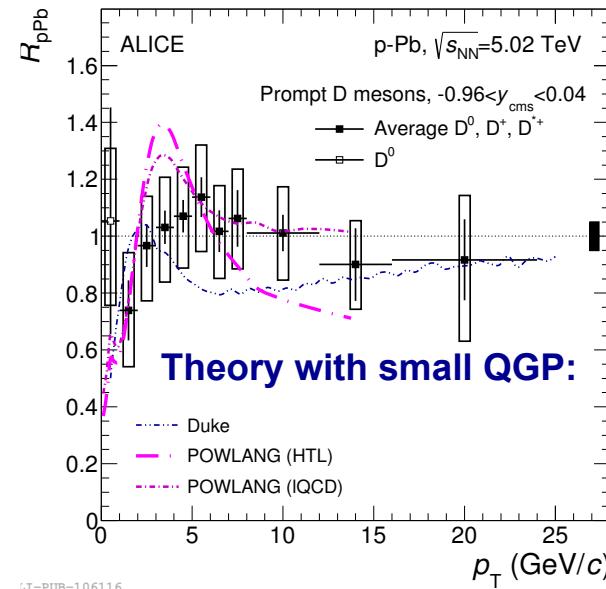
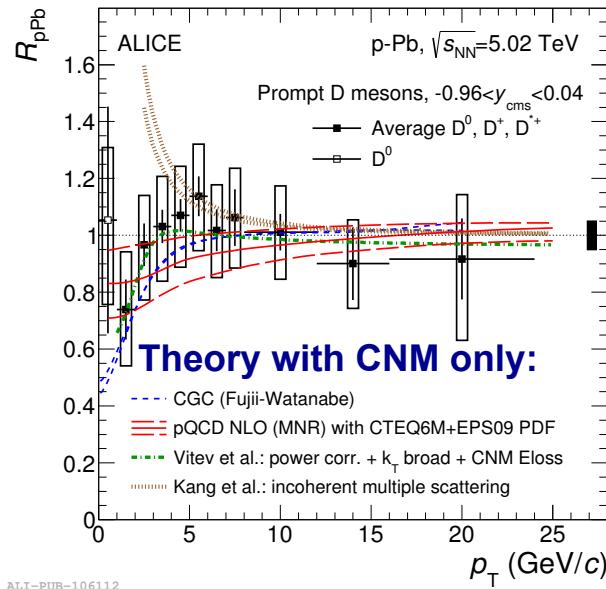
# Nuclear modification factor in p-Pb collisions

$$R_{pPb} = \frac{(d\sigma/dp_T)_{pPb}}{A \times (d\sigma/dp_T)_{pp}}$$

Results shown as a function of  $p_T$  and  $y$

# D-meson $R_{\text{pPb}}$ down to $p_T=0$

arXiv:1605.07569



PRL 113 (2014) 232301

Data described within uncertainties by models with:

- initial-state effects
- final-state effects due to the presence of hot nuclear medium (high- $p_T$  suppression, radial flow bump at intermediate  $p_T$ )

Data disfavour suppression larger than 15% at high  $p_T$

**$D^0$   $p_T$ -integrated  $R_{\text{pPb}}$ :**

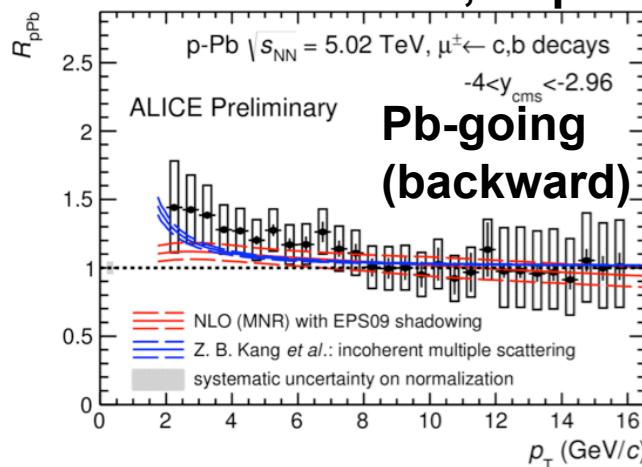
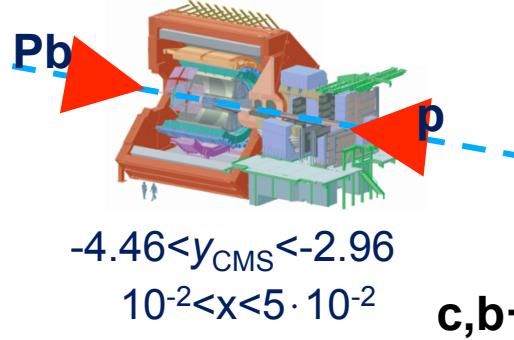
$$R_{\text{pPb}}^{\text{prompt } D^0}(p_T > 0, -0.96 < y_{\text{cms}} < 0.04) = 0.89 \pm 0.11 \text{ (stat.)} {}^{+0.13}_{-0.18} \text{ (syst.)}$$

H. Fuji et al., Nucl Phys A920 (2013) 78  
 M. Mangano et al., Nucl. Phys. B373 (1992) 295  
 K. J. Eskola et al., JHEP 0904 (2009) 065  
 Vitev et al., Phys. Rev. C 80 (2009) 05490  
 Z.-B. Kang et al., Phys. Lett.B740 (2015) 23

Y. Xu et al., arXiv:1510.07520  
 A. Beraudo et al., JHEP 03 (2016) 123

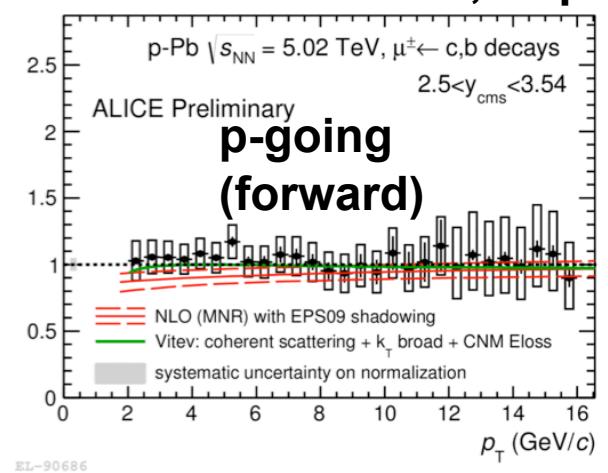
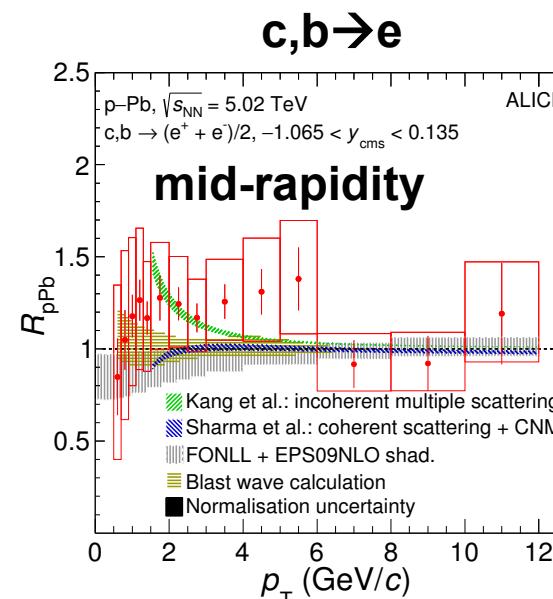
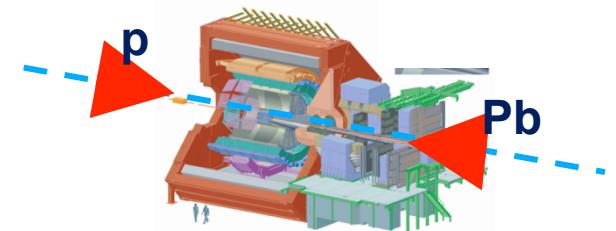


# HF $R_{pPb}$ at different rapidities



ALI-PREL-90691

$$R_{pPb} = \frac{(d\sigma/dp_T)_{pPb}}{A \times (d\sigma/dp_T)_{pp}}$$



- M. Mangano, P. Nason and G. Ridolfi, Nucl. Phys. B373 (1992) 295  
 K. J. Eskola, H. Paukkunen and C. A. Salgado, JHEP 0904 (2009) 065  
 R. Sharma, I. Vitev et al., PRC 80 (2009) 054902  
 Z.B. Kang et al., PLB 740 (2015) 23

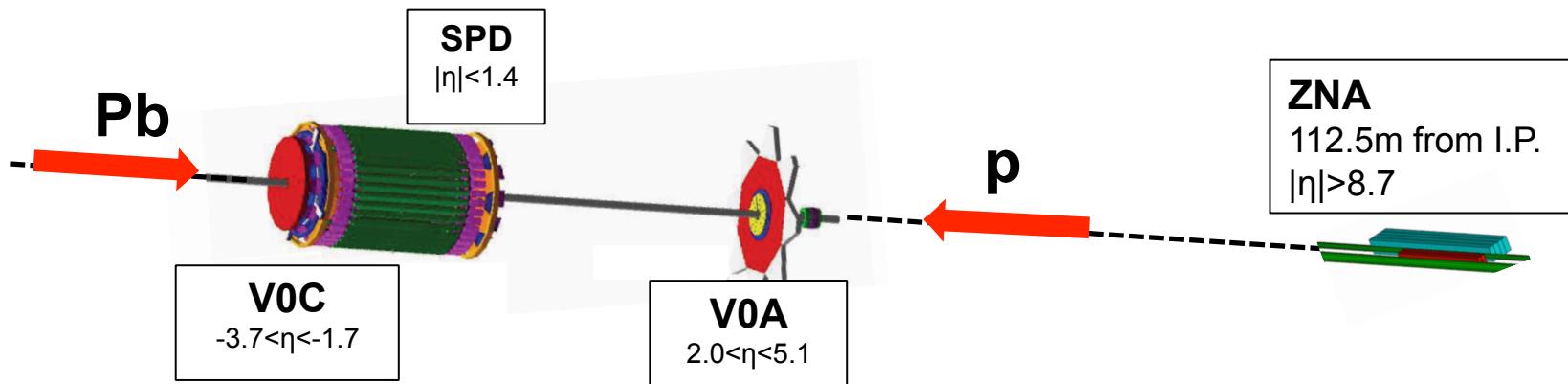
Phys. Lett. B 754 (2016) 81

Different  $x$  regimes explored in different rapidity ranges with HF probes  
 → shadowing/saturation relevant at low  $p_T$  at the LHC

Data described within uncertainties by the models with CNM effects

# **Multiplicity dependence** of HF production in pp and p-Pb collisions

# Centrality/multiplicity estimators in pp and p-Pb collisions



**Centrality estimators in p-Pb collisions** Phys. Rev. C91 (2015) 064905

**CLI** (clusters in outer SPD layer)

**V0A (Pb-going)** amplitude

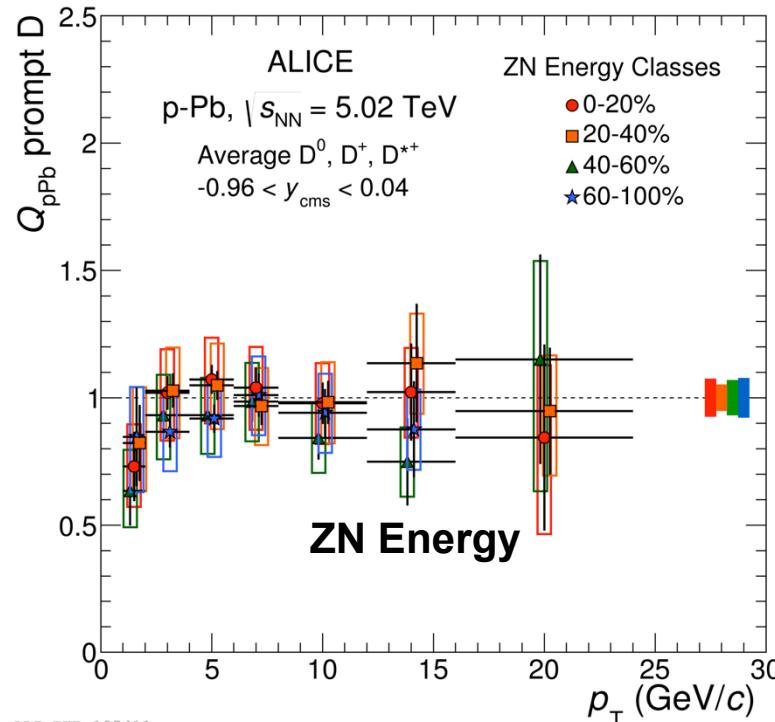
**ZNA (Pb-going)**:  $\langle N_{\text{part}} \rangle$  in ZN energy class from scaling the min. bias value assuming scaling with multiplicity at mid-rapidity.

**Multiplicity estimators in pp and p-Pb collisions**

**Number of track segments (or tracklets) of the SPD**

**Sum of amplitudes** in the **V0** scintillator arrays (**V0A only for p-Pb**)

# D-meson production in different p-Pb centrality classes



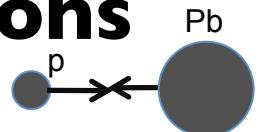
arXiv:1602.07240

$$Q_{\text{pPb}}^{\text{mult}}(p_T) = \frac{dN_{\text{mult}}^{\text{pPb}}/dp_T}{N_{\text{coll}}^{\text{mult}} dN^{\text{pp}}/dp_T}$$

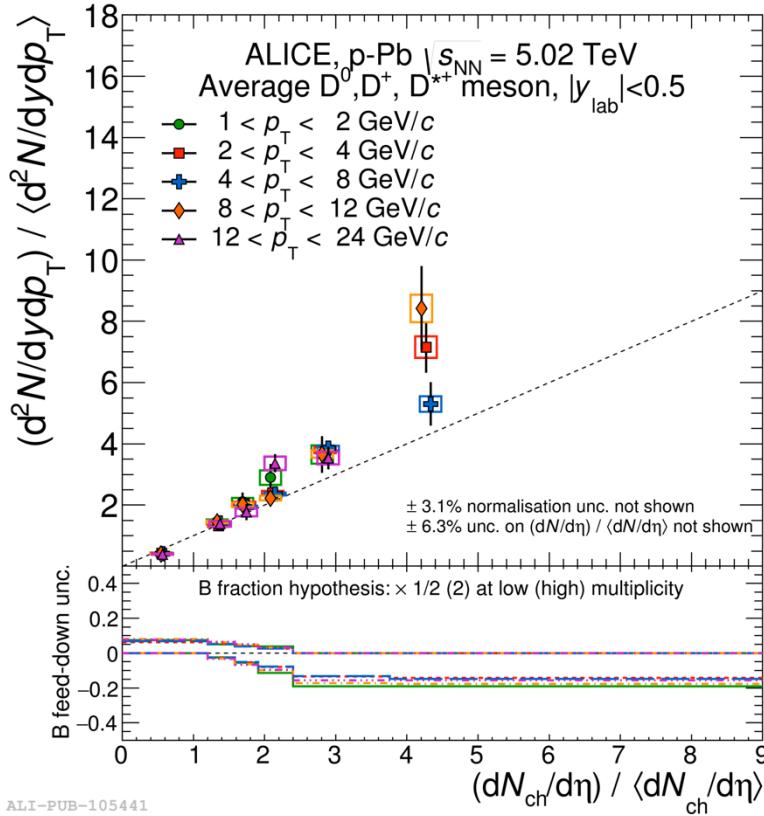
With ZN estimator: free from biases due to event selection (multiplicity fluctuations/jet-veto).  
 Phys. Rev. C91 (2015) 064905

**No multiplicity dependent modification** of D-meson production relative to pp collisions within uncertainties.  
**Consistent with binary collision scaling of the yield in pp collisions.**

# Per-event yields vs. $N_{\text{ch}}$ in p-Pb collisions



arXiv:1602.07240



y axis:

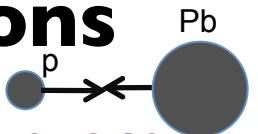
$$\frac{d^2N^D/dydp_T}{\langle d^2N^D/dydp_T \rangle} = \frac{Y^{\text{mult}} / (\epsilon^{\text{mult}} \times N_{\text{event}}^{\text{mult}})}{Y^{\text{tot}} / (\epsilon^{\text{tot}} \times N_{\text{event}}^{\text{tot}} / \epsilon^{\text{trigger}})}$$

## Increase of D-meson yields with charged-particle multiplicity at mid rapidity:

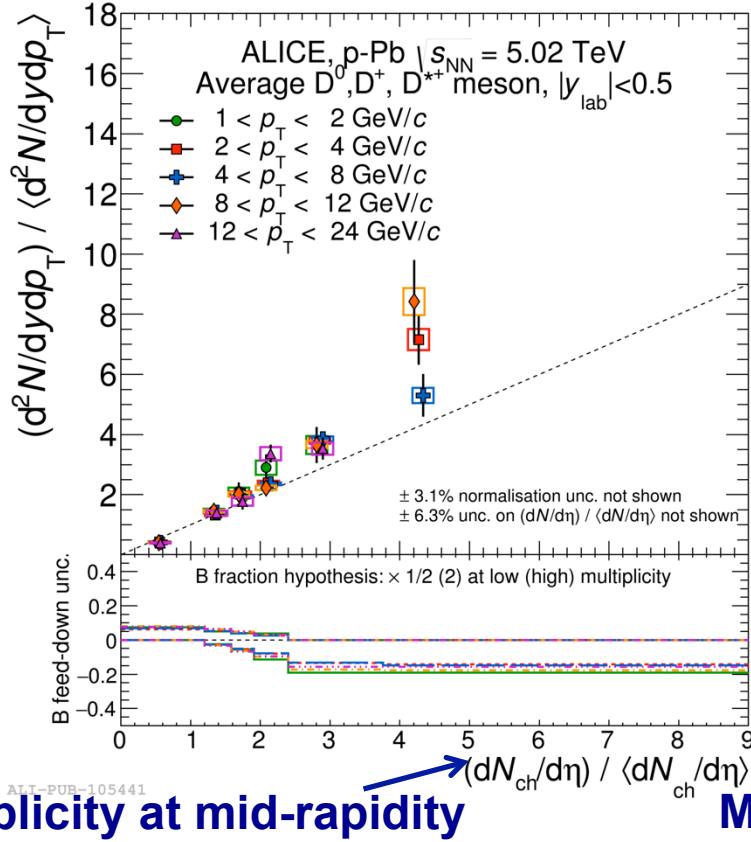
- slightly faster-than-linear increase at large multiplicities,
- independent of  $p_T$  within uncertainties.

# Per-event yields vs. $N_{\text{ch}}$ in p-Pb collisions

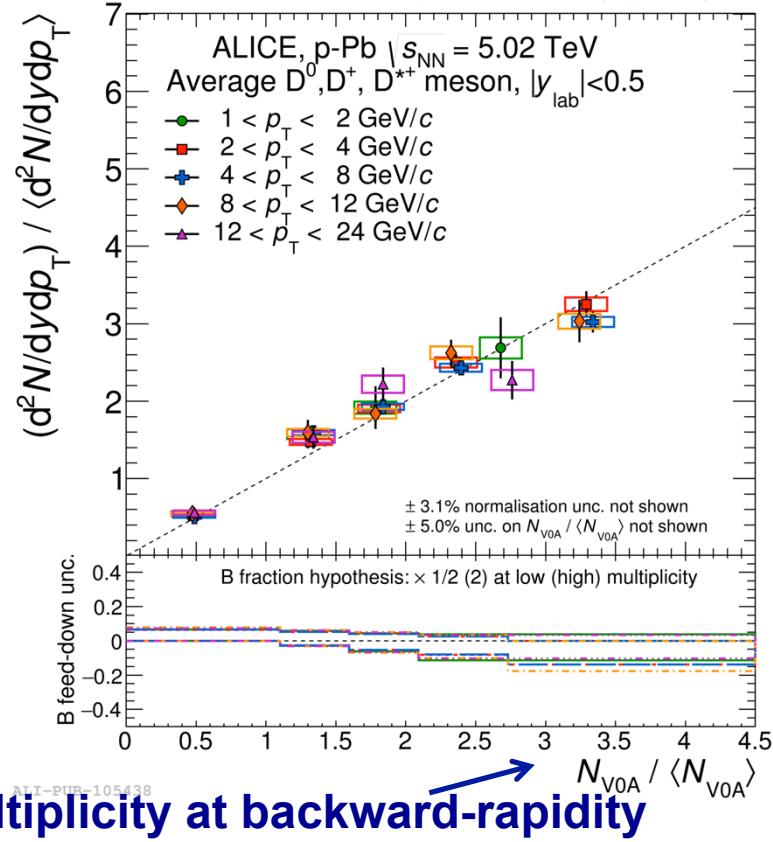
- Introducing an  $\eta$  gap -



arXiv:1602.07240



Multiplicity at mid-rapidity



Multiplicity at backward-rapidity

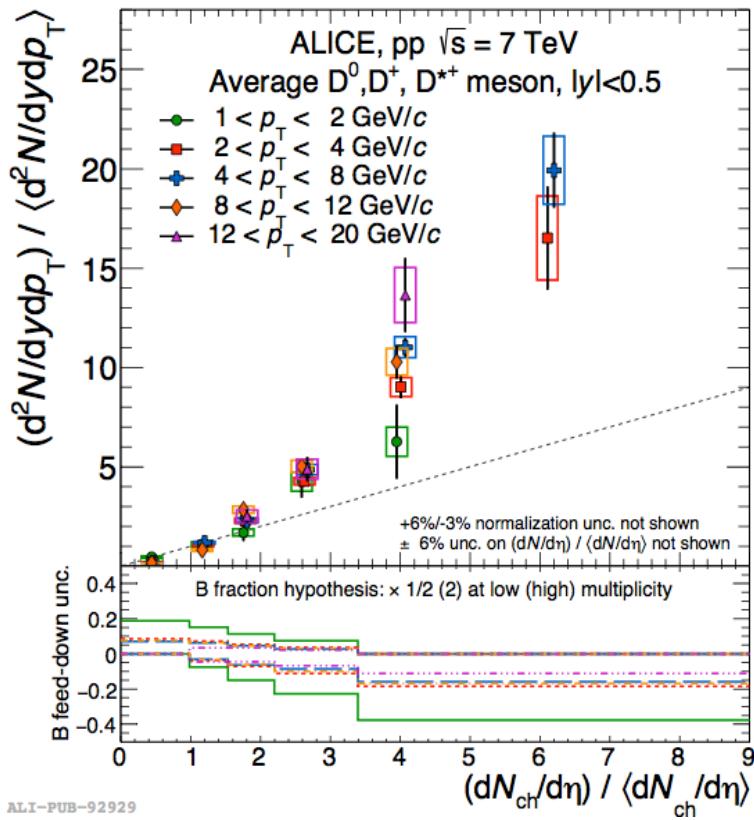
**Nearly linear increase with multiplicity at backward rapidity (Pb-going direction).**

Results consistent within uncertainties when an  $\eta$  gap is introduced between the regions where the D mesons and the multiplicity are measured

# Per-event yields vs. $N_{\text{ch}}$ in pp collisions



ALICE, JHEP 09 (2015) 148



y axis:

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

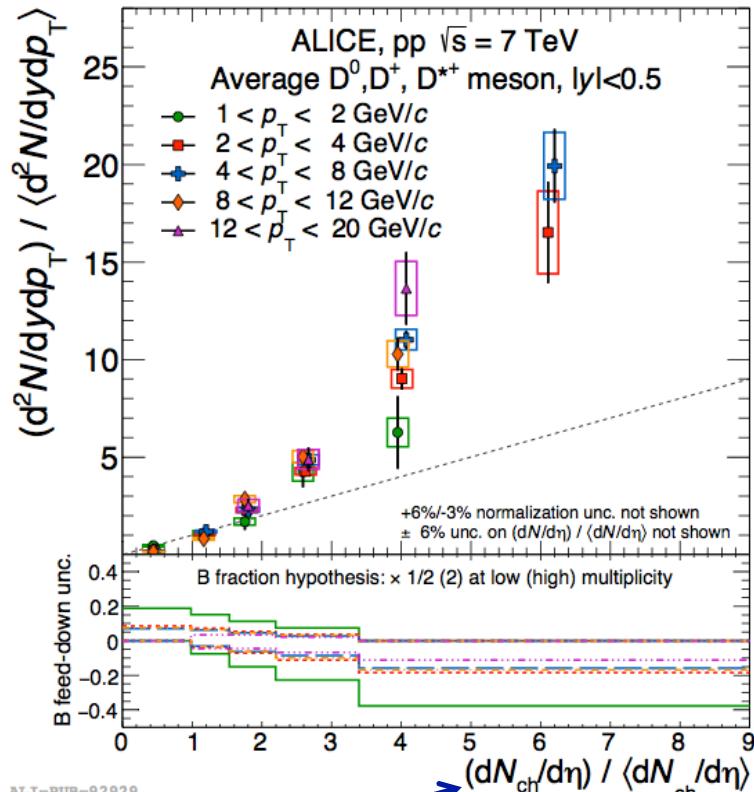
**Increase of D-meson yields with charged-particle multiplicity** at mid rapidity:

- faster-than-linear increase at large multiplicities
- independent of  $p_T$  within uncertainties

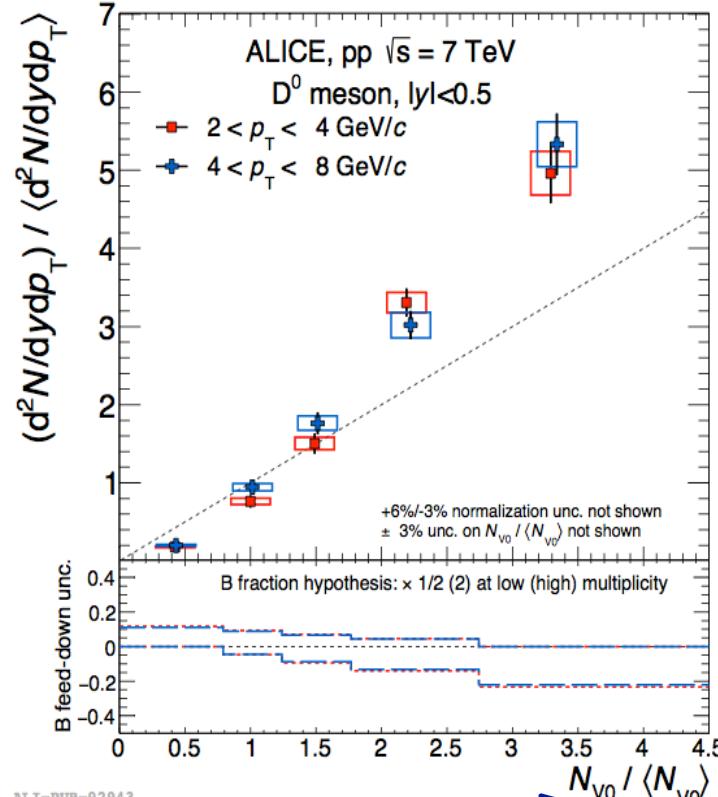
# Per-event yields vs. $N_{\text{ch}}$ in pp collisions

- Introducing an  $\eta$  gap -

ALICE, JHEP 09 (2015) 148



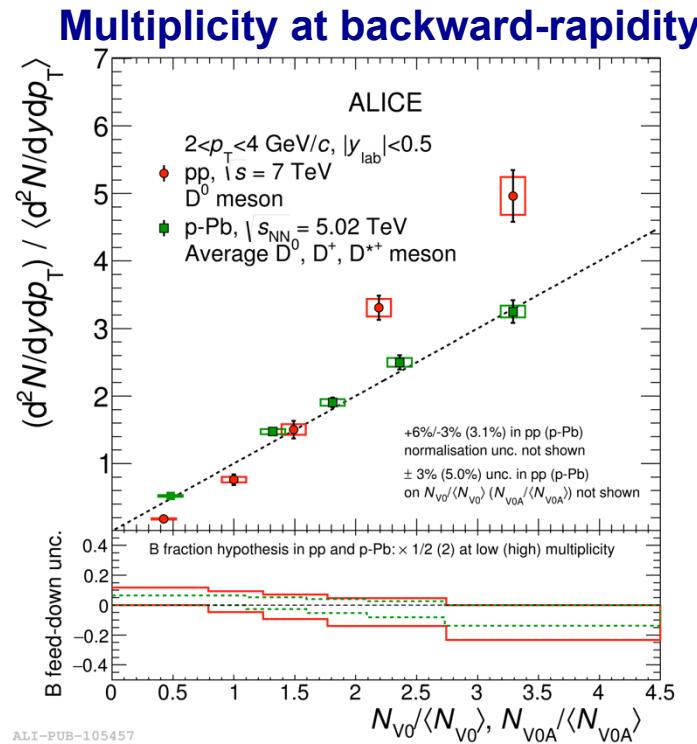
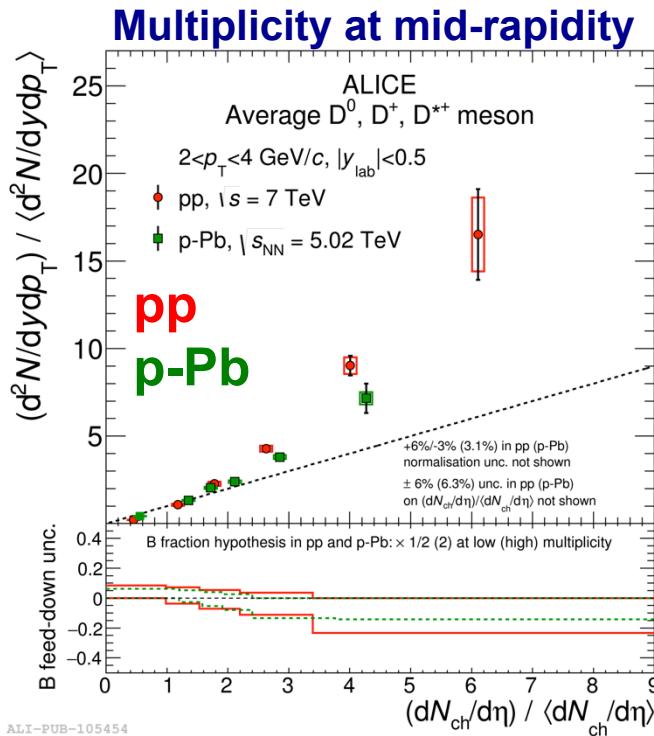
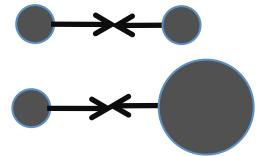
Multiplicity at mid-rapidity



Multiplicity at forward-rapidity

**Qualitatively similar increasing trend of D-meson yields when an  $\eta$  gap is introduced** between the regions where the D mesons and the multiplicity are measured

# Comparison of pp and p-Pb results



Multiplicity at **mid rapidity**: similar trend for in pp and p-Pb collisions

Multiplicity at **large (backward) rapidities**:

- measured in different  $\eta$  ranges in pp and p-Pb collisions
- faster increase of D-meson yields in pp than in p-Pb collisions

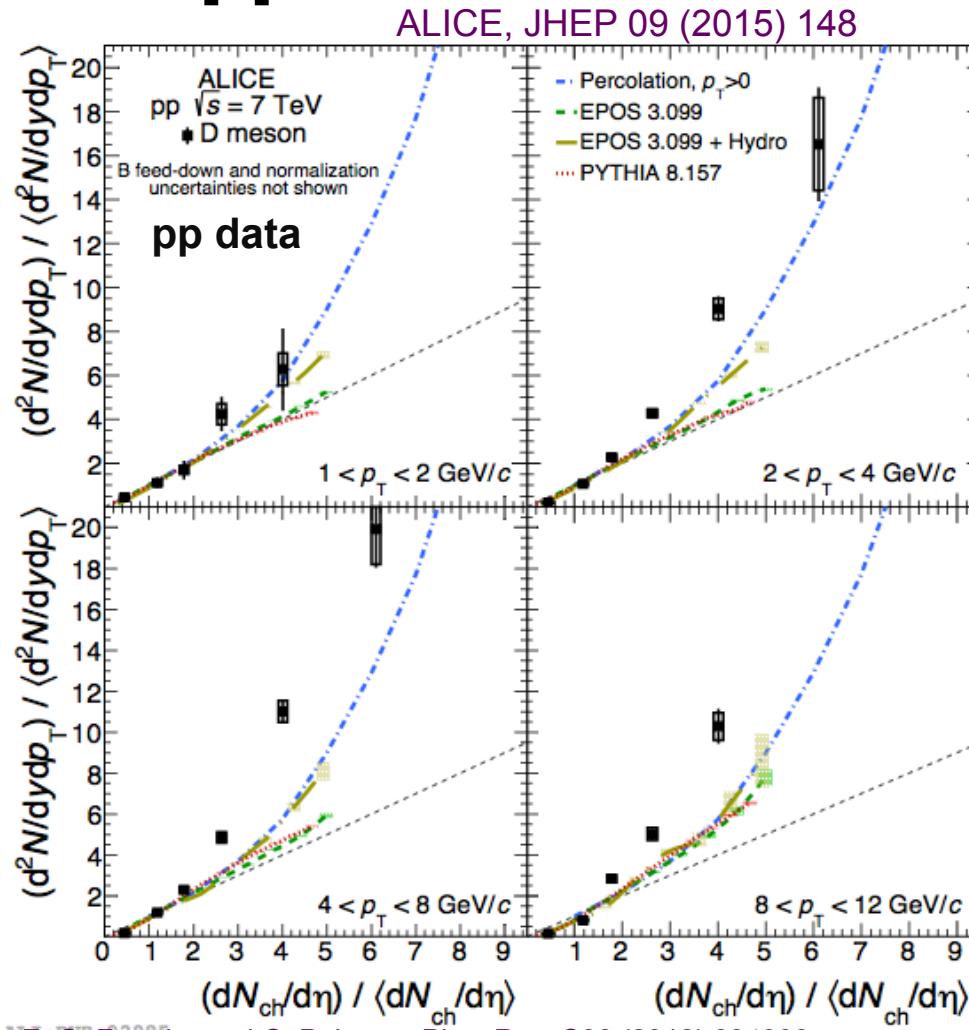
arXiv:1602.07240

Possible effects due to MPI in high-multiplicity pp collisions

**p-Pb: multiple (and softer) nucleon-nucleon collisions also contribute**



# Per-event yields: comparison with models in pp collisions



E. G. Ferreiro and C. Pajares, Phys.Rev. C86 (2012) 034903.

E. G. Ferreiro and C. Pajares, arXiv:1501.03381 (2015).

H. Drescher, M. Hladik, S. Ostapchenko, T. Pierog, and K. Werner, Phys.Rept. 350 (2001) 93

K. Werner, B. Guiot, I. Karpenko, and T. Pierog, Phys.Rev. C89 (2014) 064903

T. Sjostrand, S. Mrenna, and P. Z. Skands, Comput.Phys.Commun. 178 (2008) 852



## Percolation:

- interactions driven by the exchange of colour sources (strings  $\sim$  MPI scenario)

## EPOS 3 (event generator)

- Flux-tube initial conditions
- Hydrodynamical evolution

## PYTHIA 8:

- SoftQCD process selection
- including colour reconnection
- MPI

Results qualitative described by models including MPIs

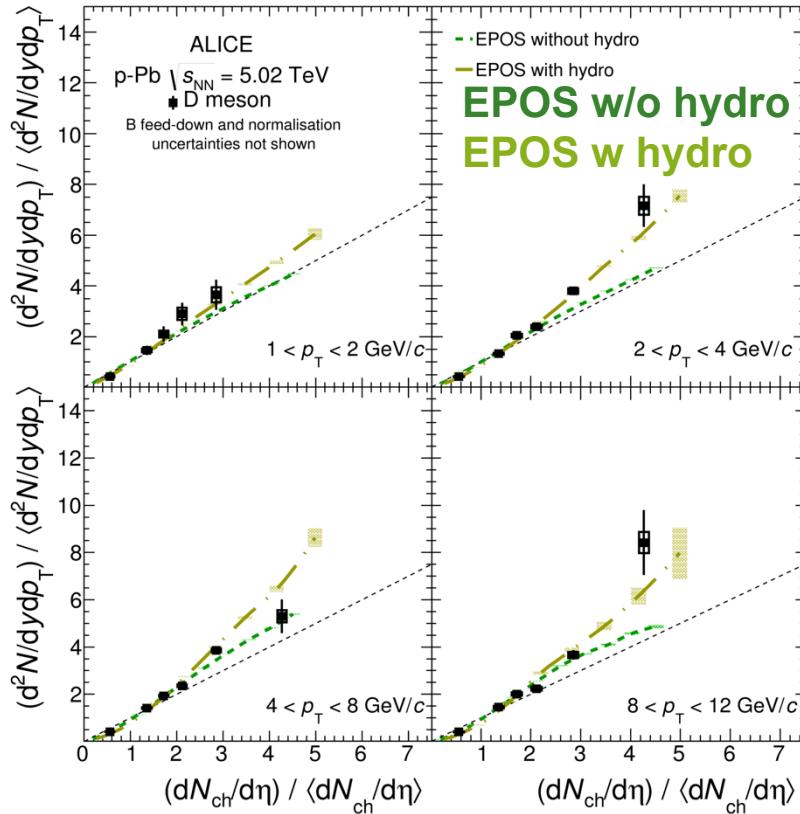


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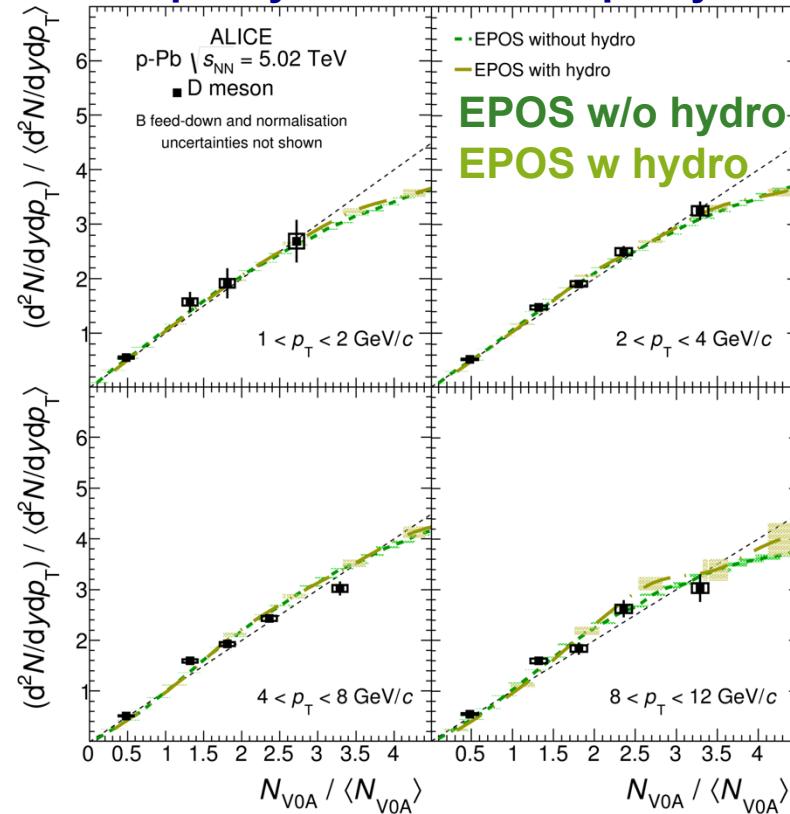
# Comparison with models in p-Pb collisions



## Multiplicity at mid-rapidity



## Multiplicity at backward-rapidity



## EPOS 3 with initial conditions and hydrodynamic evolution

- faster-than-linear increase of D-meson yields with multiplicity at mid rapidity
- approximately linear trend with multiplicity at backward rapidity (reduced influence of hydro on charged-particle production at backward rapidity)

H. Drescher, M. Hladik, S. Ostapchenko, T. Pierog, and K. Werner, Phys.Rept. 350 (2001) 93

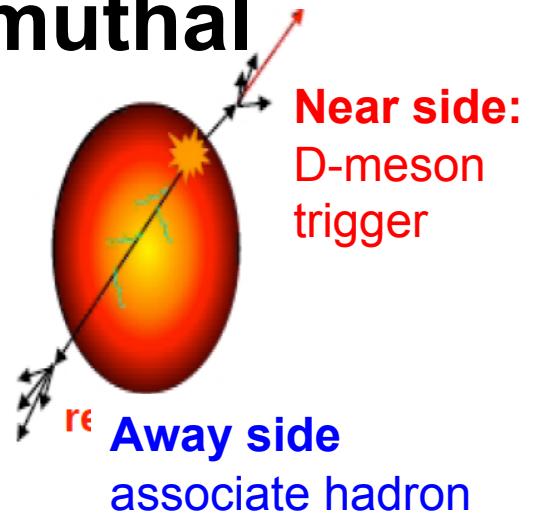
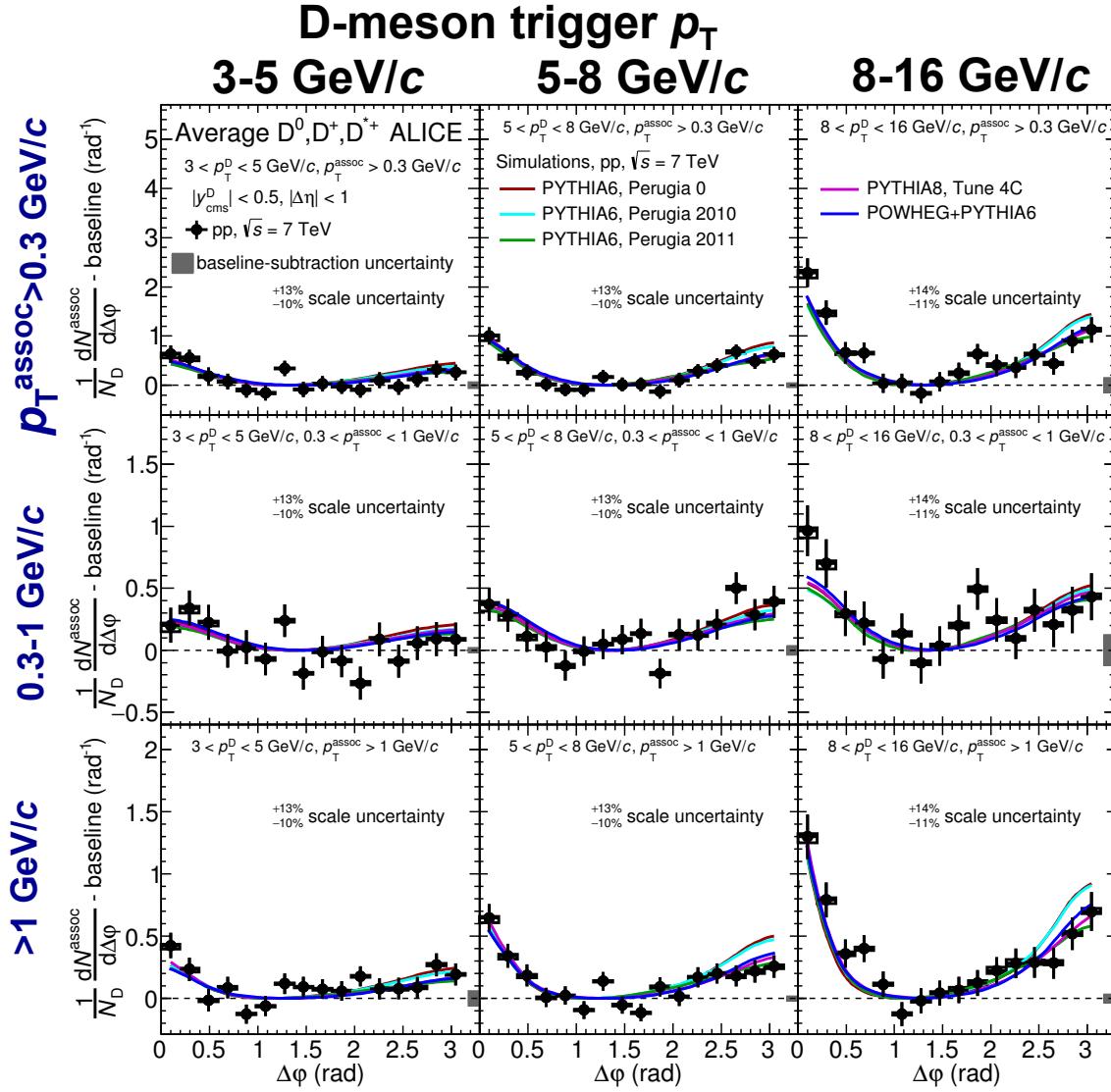
K. Werner, B. Guiot, I. Karpenko, and T. Pierog, Phys.Rev. C89 (2014) 064903

arXiv:1602.07240

# **Azimuthal correlations** of D mesons with charged particles in pp and p-Pb collisions

# D meson- charged particle azimuthal correlations

arXiv:1605.06963



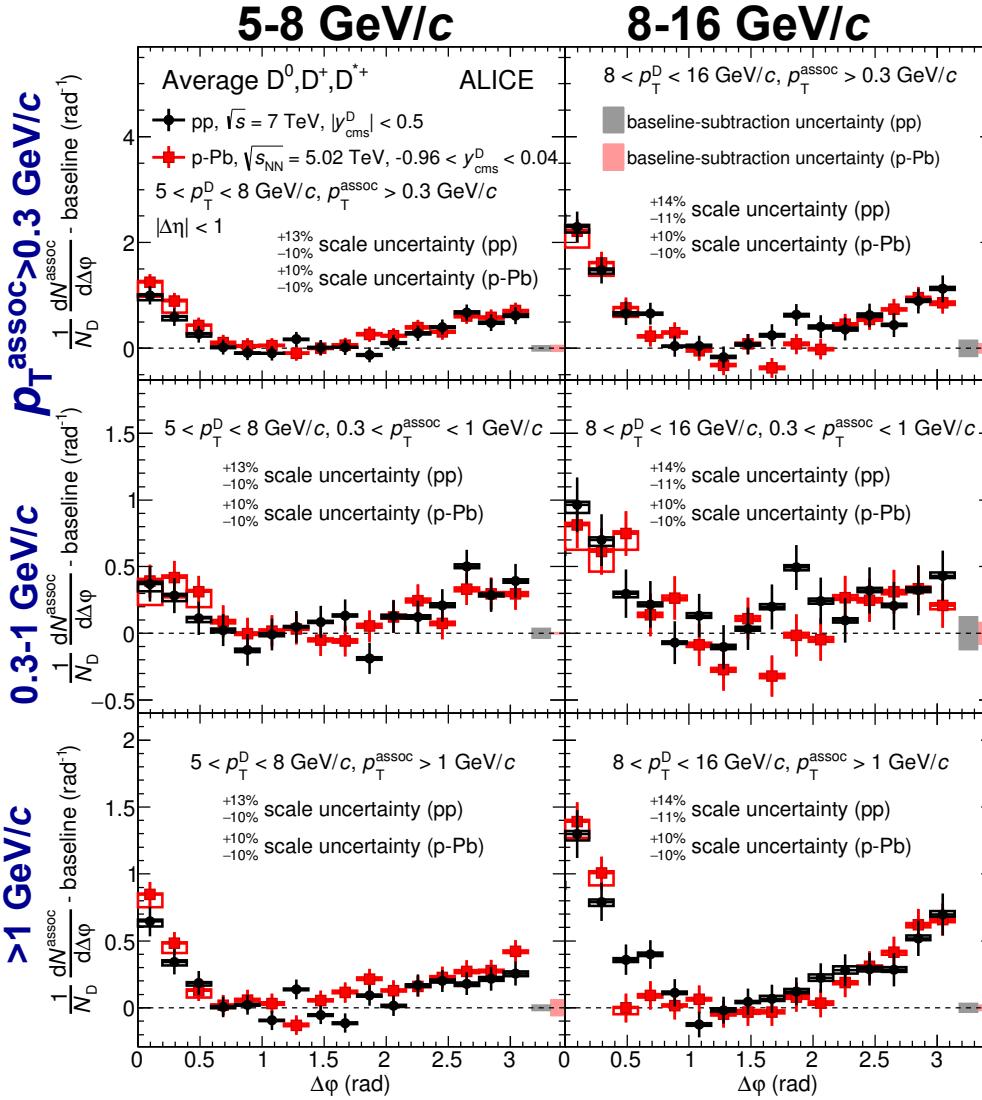
In pp collisions:

- Address charm fragmentation
- Reference for comparison with Pb-Pb and p-Pb collisions

Compatible within uncertainties with expectations from different MC generators and tunes (PYTHIA6, PYTHIA8, POWHEG+PYTHIA) after baseline subtraction

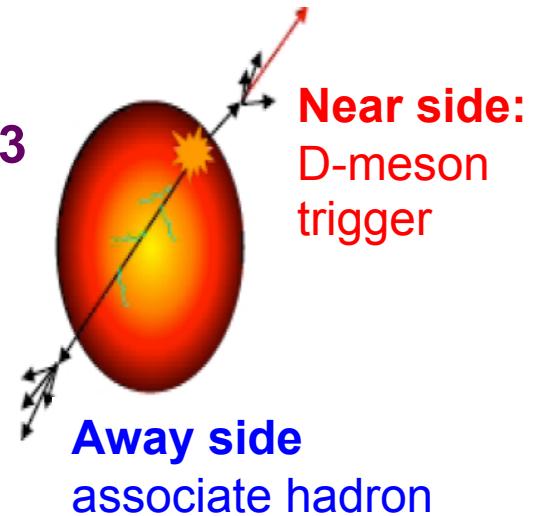
# Comparison to p-Pb collisions

D-meson trigger  $p_T$ :



arXiv:1605.06963

**pp**  
**p-Pb**



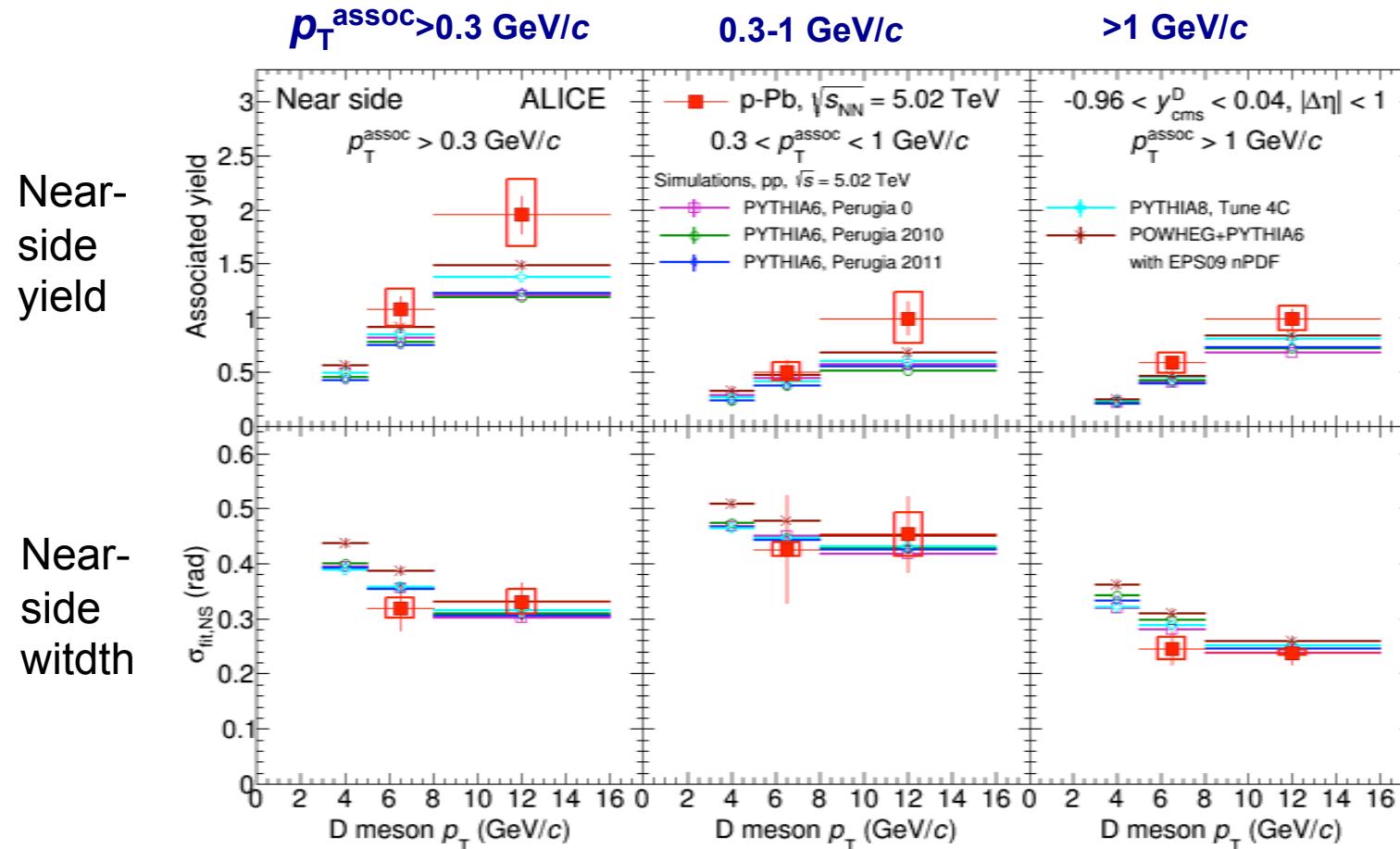
In p-Pb collisions:

- Are heavy-flavour jet properties affected by nuclear effects due to the Pb nucleus?

Compatibility within uncertainties between pp collisions at  $\sqrt{s} = 7 \text{ TeV}$  and p-Pb collisions at  $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$  after baseline subtraction

# Near-side yields and widths in p-Pb collisions

arXiv:1605.06963



Near-side yields and widths compatible in data and simulations within uncertainties

# Conclusions

**Cross sections** in pp collisions for D mesons and leptons from heavy-flavour decays described by pQCD, **down to  $p_T=0$  ( $D^0$ )**

→ heavy flavours as test for pQCD at LHC energies

**$R_{pPb}$**  compatible with unity within uncertainties, **down to  $p_T=0$  ( $D^0$ )**

→ described by different models of initial-/final- state effects,

→ no centrality dependence

Relative **D-meson yields increase with charged-particle multiplicity** in pp and p-Pb collisions

→ Models including multiple-parton interactions reproduce pp results.

→ In p-Pb collisions, also contributions from multiple nucleon-nucleon collisions

**D-charged particle correlations** in pp and p-Pb collisions:

→ Near-side structure in good agreement with Monte Carlo generators

**Outlook:** larger data samples in Run 2, higher  $\sqrt{s}$ , higher multiplicities: access to physics-rich program down to  $p_T=0$ , angular correlations in high-multiplicity events

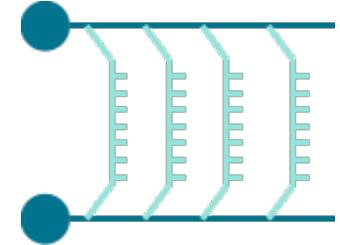


# Extra slides

# (Some) measured effects on the hard scale

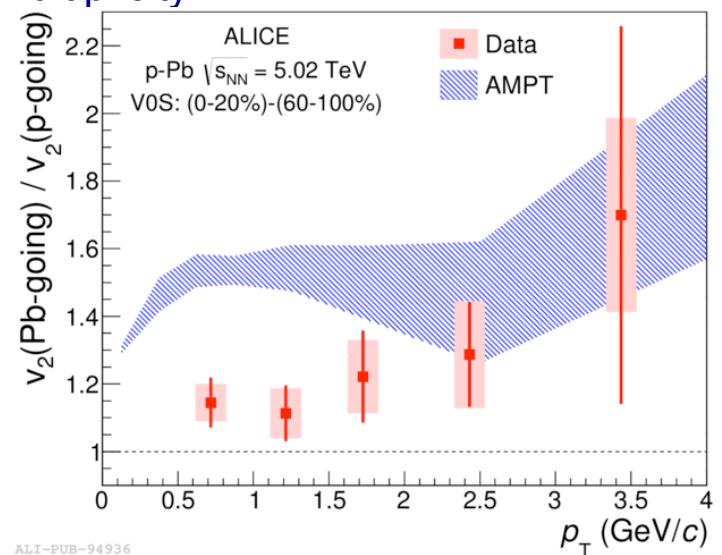
## In pp collisions:

- NA27 (pp collisions at  $\sqrt{s} = 28$  GeV): NA27 Coll. Z.Phys.C41:191  
Events with charm have larger charged particle multiplicity
- CMS (pp collisions at  $\sqrt{s} = 7$  TeV): Eur. Phys. J. C 73 (2013) 2674  
Studies on jets and underlying event are better agreement with models including MPI
- LHCb (pp collisions at  $\sqrt{s} = 7$  TeV): J. High Energy Phys., 06 (2012) 141  
Double charm production agrees better with models including double parton scattering
- ALICE (pp collisions at  $\sqrt{s} = 7$  TeV): Phys.Lett. B712 (2012) 165  
Approximately linear increase of  $J/\psi$  yield as a function of multiplicity



## And in pA collisions:

- PHENIX (d+Au at 200 GeV)  
CNM effects observed from  $e-\mu$  correlations
- ALICE (p-Pb collisions at 5 TeV)  
Collective effects for high- $p_T$  muons in high-multiplicity events via  $\mu-h$  correlations  
Phys. Lett. B 753 (2016) 126a

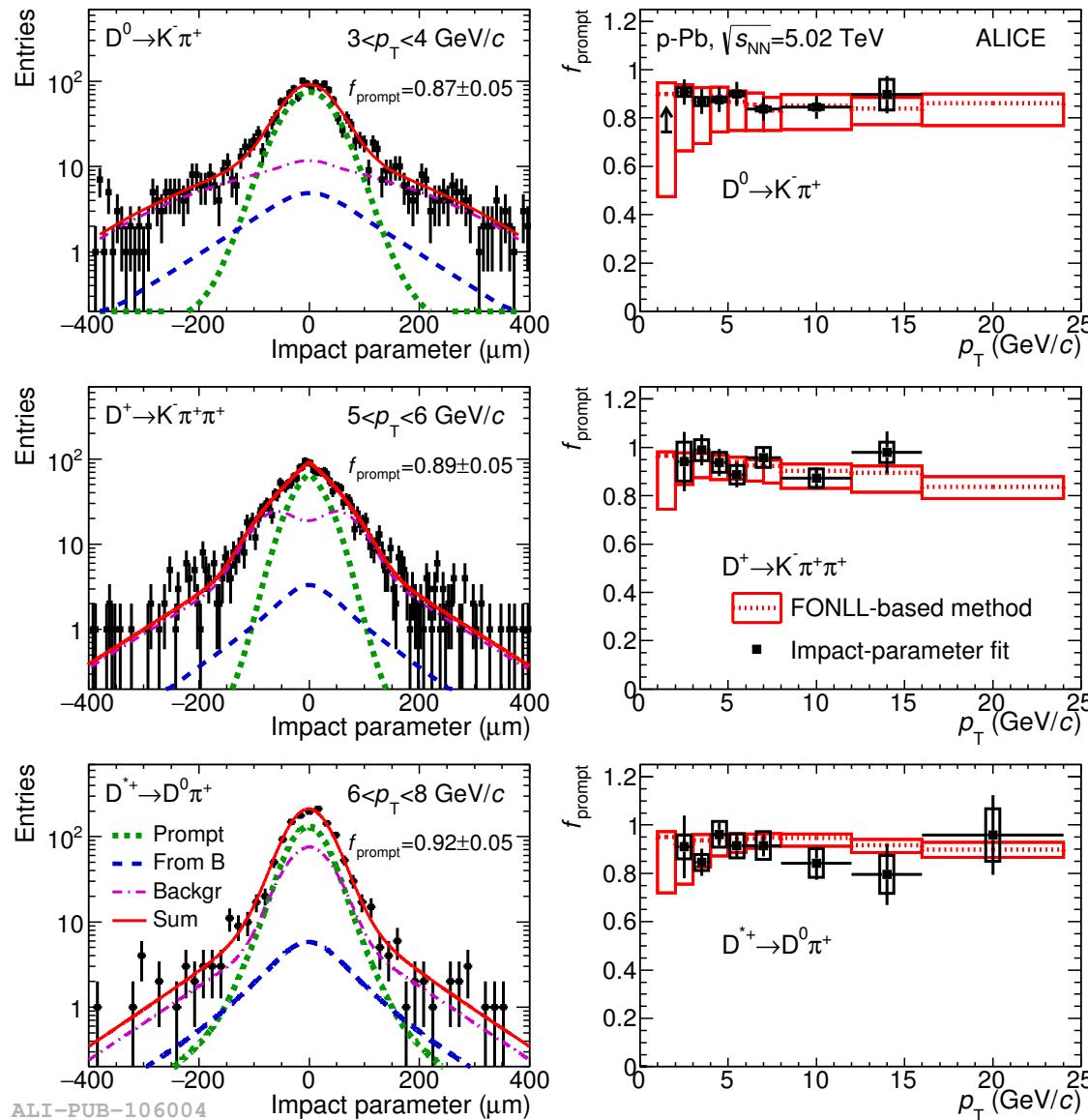




ALICE

# Data-driven feed-down subtraction

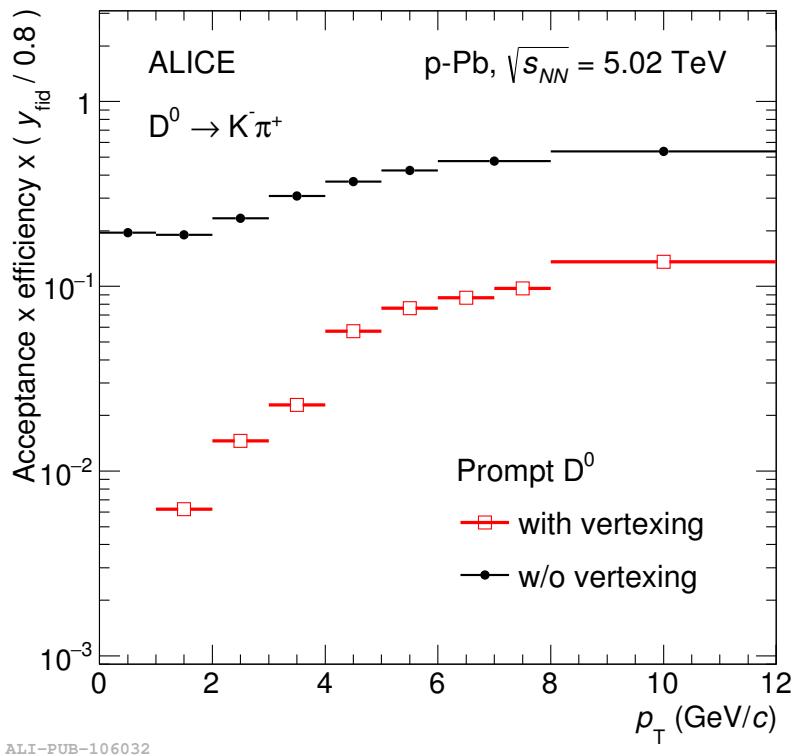
arXiv:1605.07569



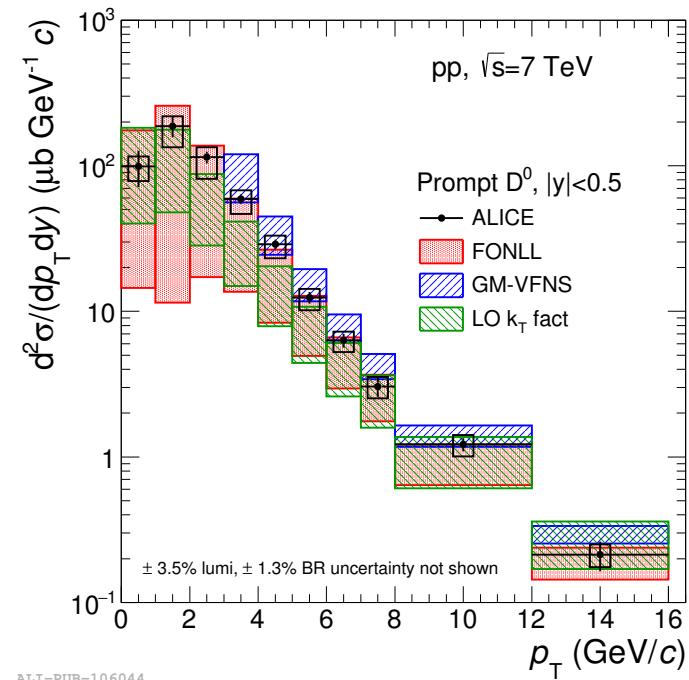


# Low- $p_T$ D<sup>0</sup>

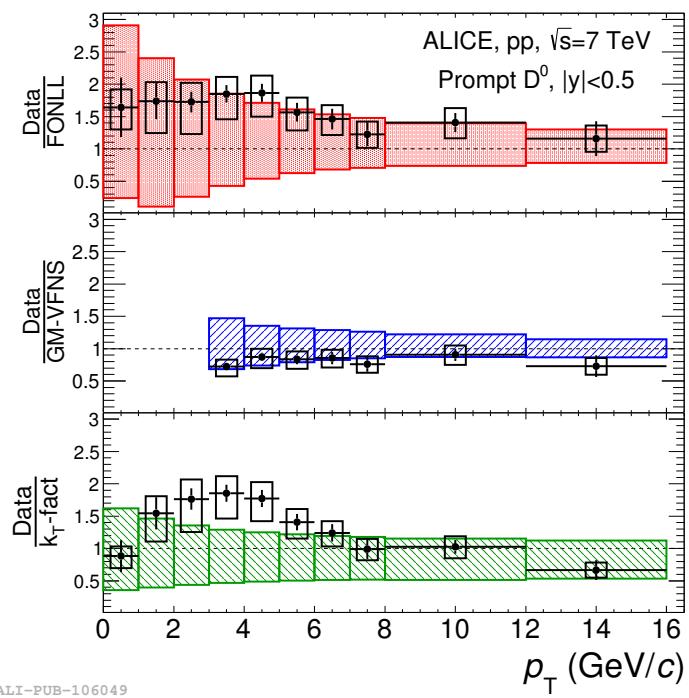
arXiv:1605.07569



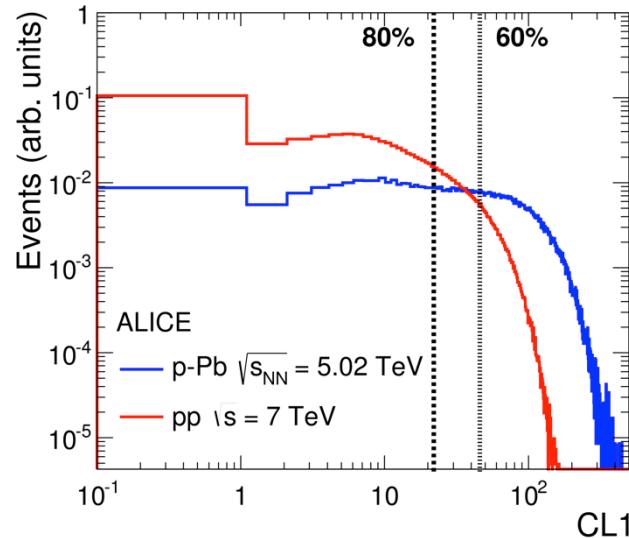
ALI-PUB-106032



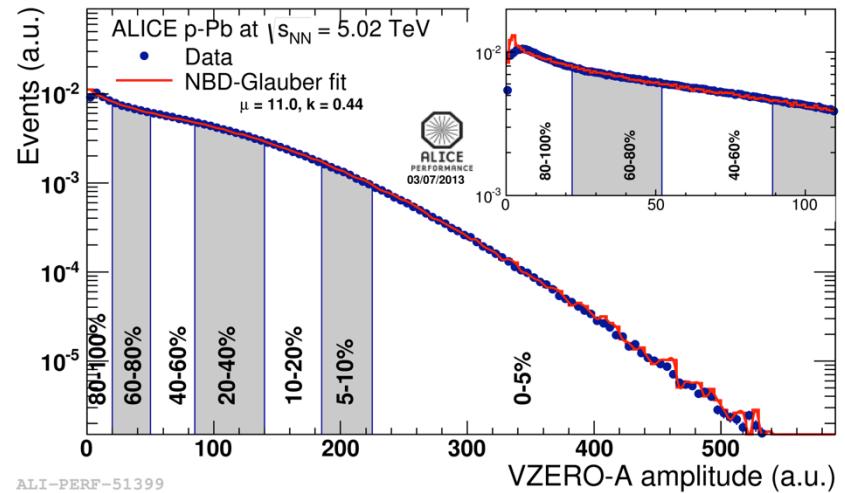
ALI-PUB-106044



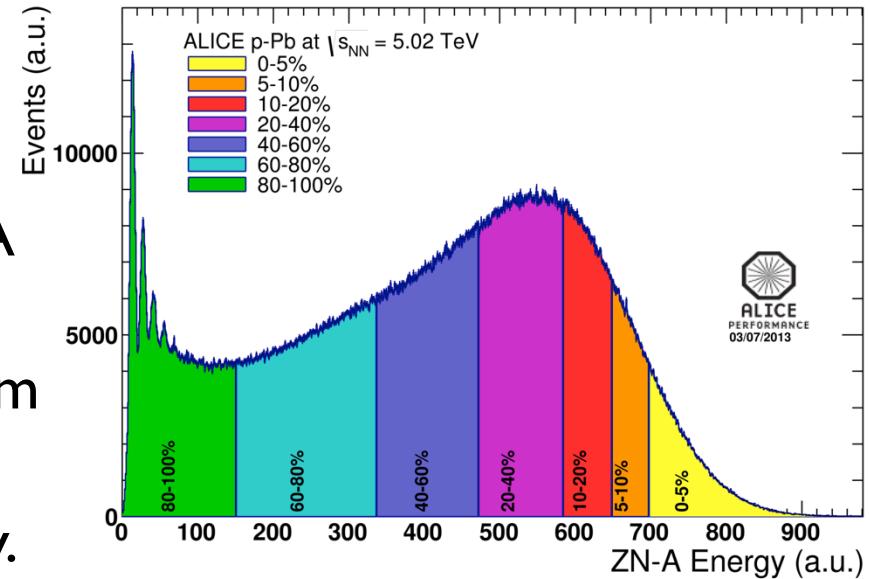
# Centrality estimation in p-Pb collisions



ALI-PUB-100585



ALI-PERF-51399



ALI-PERF-51392

**CL1** (clusters in outer SPD layer):  
 $\langle N_{\text{coll}} \rangle$  from Glauber fit to cluster distribution

**V0A:**  $\langle N_{\text{coll}} \rangle$  from Glauber fit to V0A amplitude

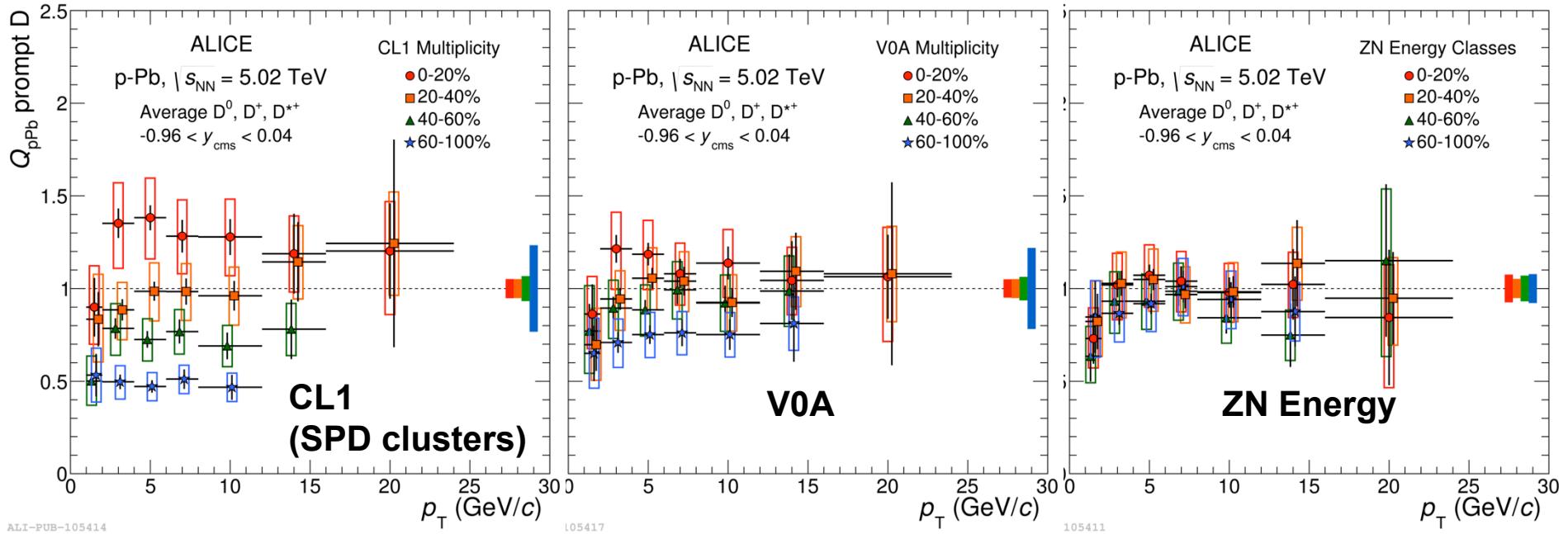
**ZNA:**  $\langle N_{\text{part}} \rangle$  in ZN energy class from scaling the min. bias value assuming scaling with multiplicity at mid-rapidity.

Phys.Rev. C91 (2015) 064905



# **Q<sub>pPb</sub> in p-Pb collisions**

$$Q_{p\text{Pb}}^{\text{mult}}(p_T) = \frac{dN_{\text{mult}}^{\text{pPb}}/dp_T}{N_{\text{coll}}^{\text{mult}} dN^{\text{pp}}/dp_T}$$



**Average  $D^0$ ,  $D^+$  and  $D^{*+}$   $Q_{p\text{Pb}}$  shows:**

[arXiv:1602.07240](https://arxiv.org/abs/1602.07240)

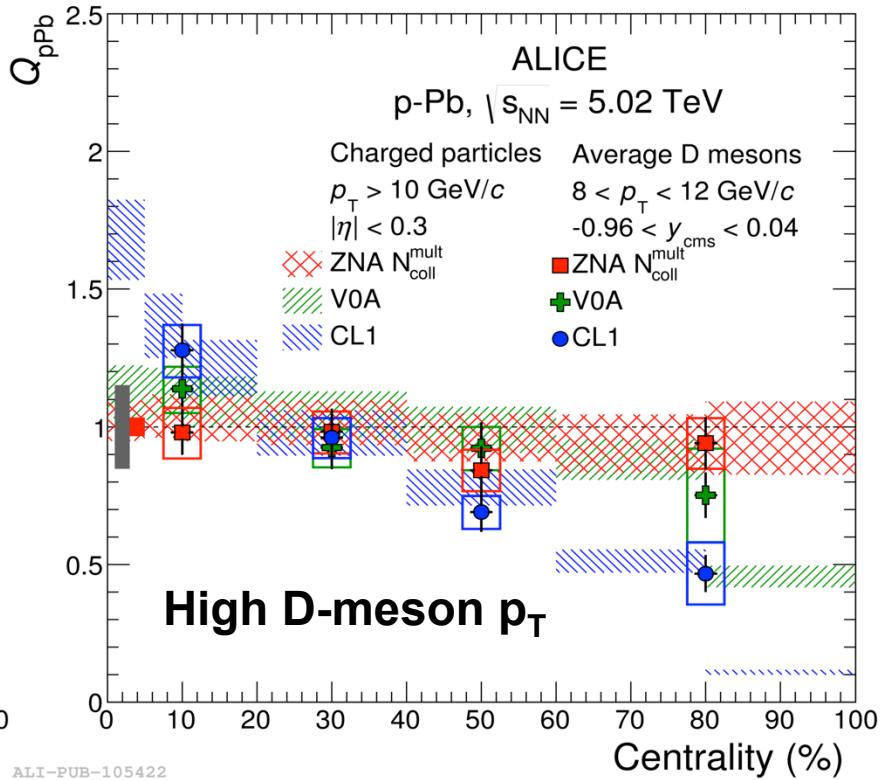
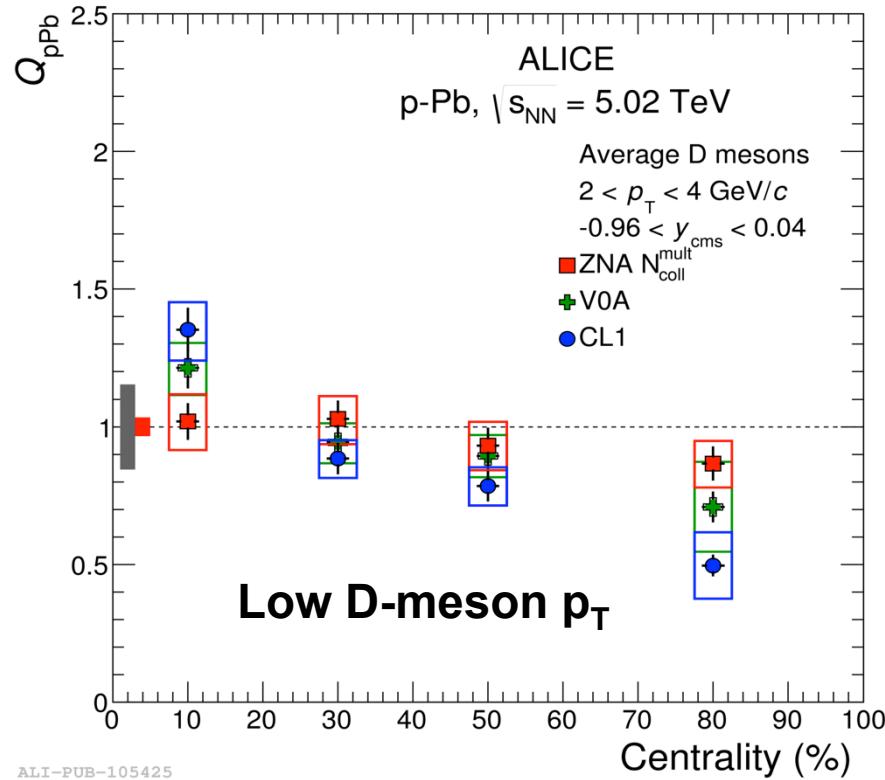
- ordering from low to high multiplicity when evaluated with **CL1** (bias on multiplicity fluctuation/jets)
- a residual bias when computed using the **V0A** estimator (a rapidity gap)
- that is reduced when using **ZN** one.

With ZN estimator: **no multiplicity dependent modification** of D meson production relative to pp collisions within uncertainties.

**Consistent with binary collision scaling of the yield in pp collisions.**

# $Q_{\text{pPb}}$ in p-Pb collisions vs centrality

arXiv:1602.07240



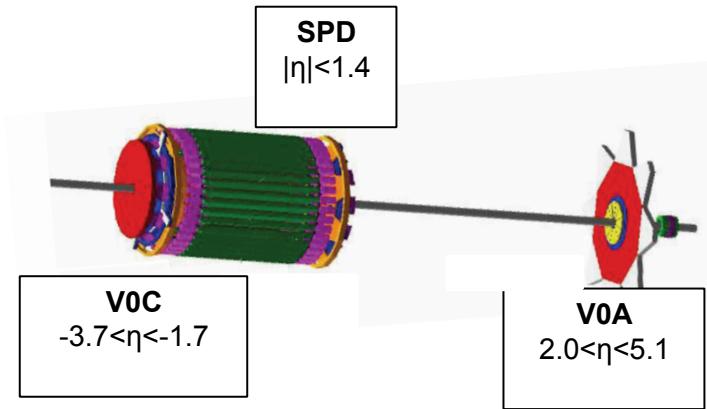
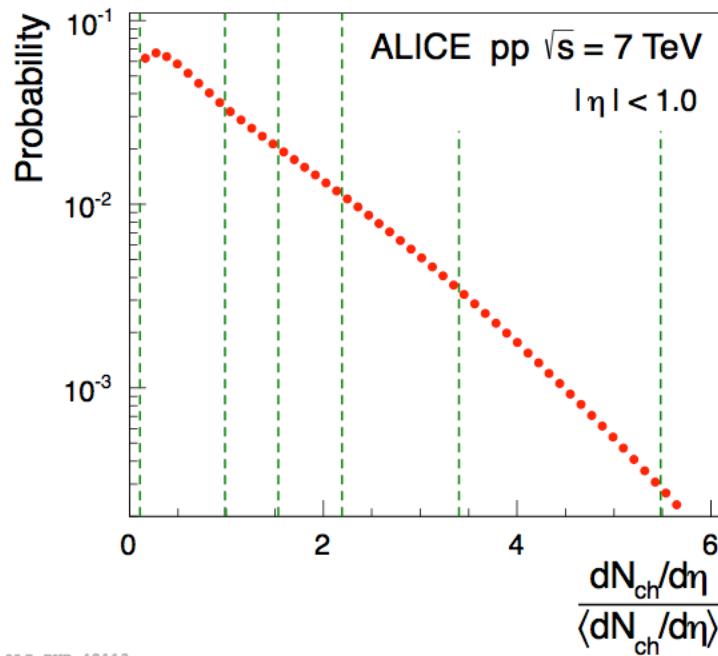
Average D meson  $Q_{\text{pPb}}$  shows a **similar trend as a function of centrality** with the three estimators at low and high  $p_{\text{T}}$ .

**At high  $p_{\text{T}}$ , the trend is similar to that of charged hadrons** (expected to scale with  $N_{\text{coll}}$  only at high  $p_{\text{T}}$ ).

# Multiplicity estimation

Multiplicity estimators:

- number of track segments (or *tracklets*) of the **Silicon Pixel Detector** (2 innermost layers of the *Inner Tracking System*).
- sum of amplitudes in the **V0 scintillator arrays**



SPD layers of radii of 3.9 cm (1cm from beam vacuum tube) and 7.6 cm. Formed by  $9.8 \times 10^6$  pixels of size  $50(r\phi) \times 425(z)$   $\mu\text{m}^2$ , with intrinsic spatial resolution of  $12(r\phi) \times 100(z)$   $\mu\text{m}^2$ .

V0 scintillator arrays at  $-3.7 < \eta < -1.7$  and  $2.8 < \eta < 5.1$

- $N_{\text{tracklets}} \propto dN_{\text{ch}} / d\eta$
- $\langle dN_{\text{ch}} / d\eta \rangle = 6.01 \pm 0.01 (\text{stat.})^{+0.20}_{-0.12} (\text{syst.})$  for  $|\eta| < 1.0$  in pp

collisions at 7 TeV

ALICE Coll., Eur. Phys. J. C 68 (2010) 345.

ALICE Coll., Phys. Lett. B 712 (2012) 3, 165–175

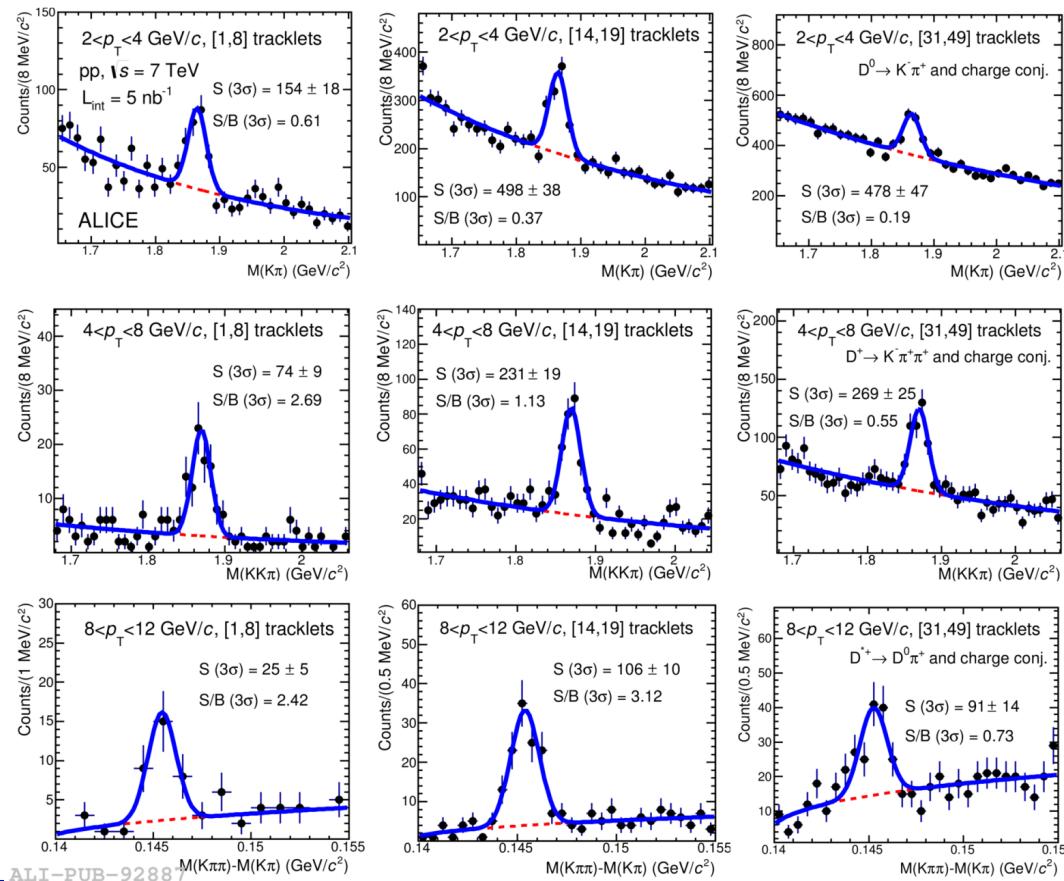
# Open-charm production vs multiplicity

D-meson yield in multiplicity intervals (pp and p-Pb)

**Multiplicity estimator:** N tracklets=n. track segments reconstructed in SPD ( $|\eta|<1$ )

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

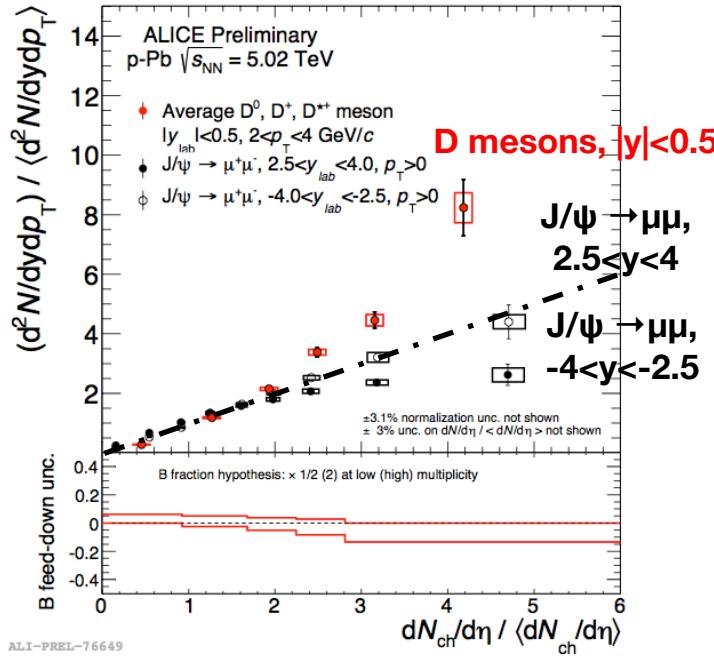
D yield/event integrated in multiplicity,  
corrected for reconstruction and trigger efficiencies



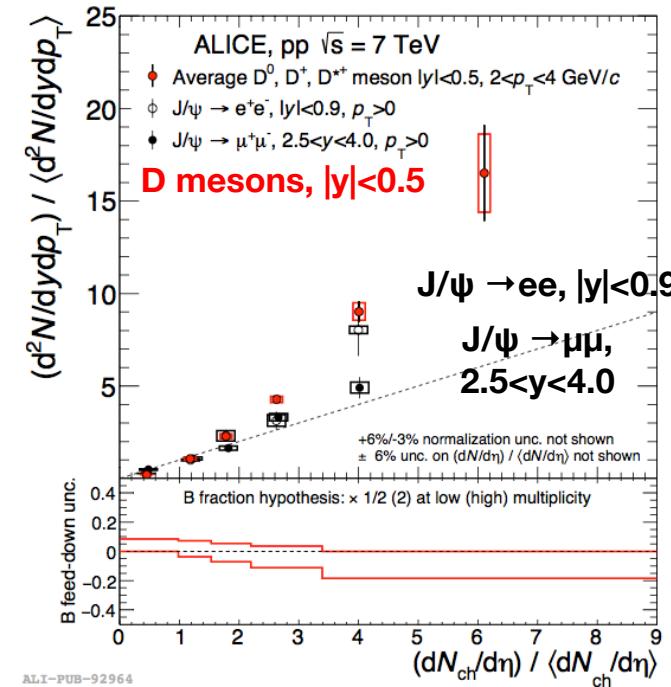
Example:  $D^+$  meson  
 $pp \sqrt{s}=7 \text{ TeV}$

# Comparison of open vs hidden heavy flavours

p-Pb  
data



pp data



- Heavy-flavour yields increase with charged-particle multiplicity at mid rapidity;
  - similar trend in pp collisions,
  - in p-Pb collisions, D mesons increase faster than  $J/\psi$ .  
**In particular for  $J/\psi$  yields measured at forward rapidity (p-going direction).**

Note:  $J/\psi$  yields measured in  
the p-going direction probe  
low-x gluons

Error bars: statistical uncertainty.

Vertical size of boxes : systematic uncertainties but feed-down.

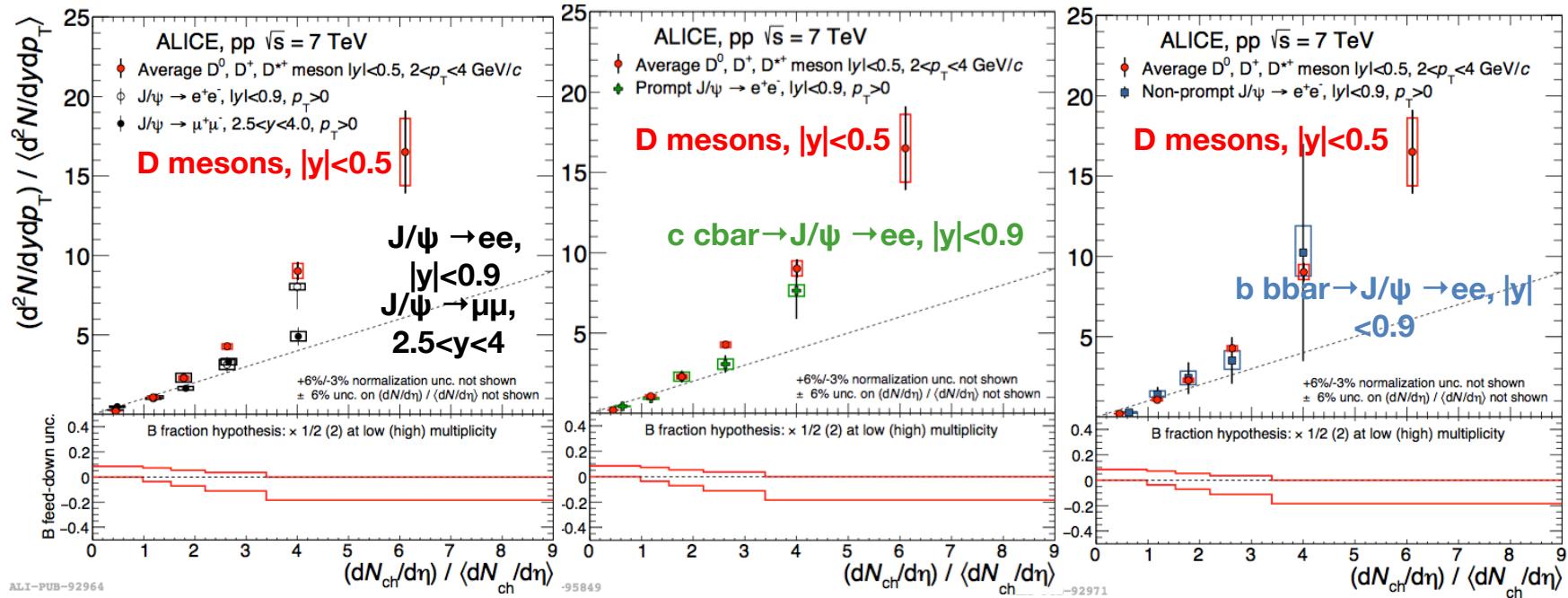
Bottom panels lines: relative feed-down systematic uncertainties.

Not shown : systematic uncertainty on  $(dN/d\eta)/\langle dN/d\eta \rangle$ . and normalisation.

ALICE, JHEP 09 (2015) 148.

ALICE, Phys.Lett. B712 (2012) 165–175

# Comparison of open and hidden heavy flavours in pp collisions



- Similar increase of open charm, open beauty and charmonia yields as a function of charged-particle multiplicity at mid rapidity.
  - Caveats: different rapidity and  $p_T$  interval of the measurements.
  - Likely related to heavy-flavour production processes, and not significantly influenced by hadronisation.

ALICE, Phys.Lett. B712 (2012) 165–175

ALICE, JHEP 09 (2015) 148.

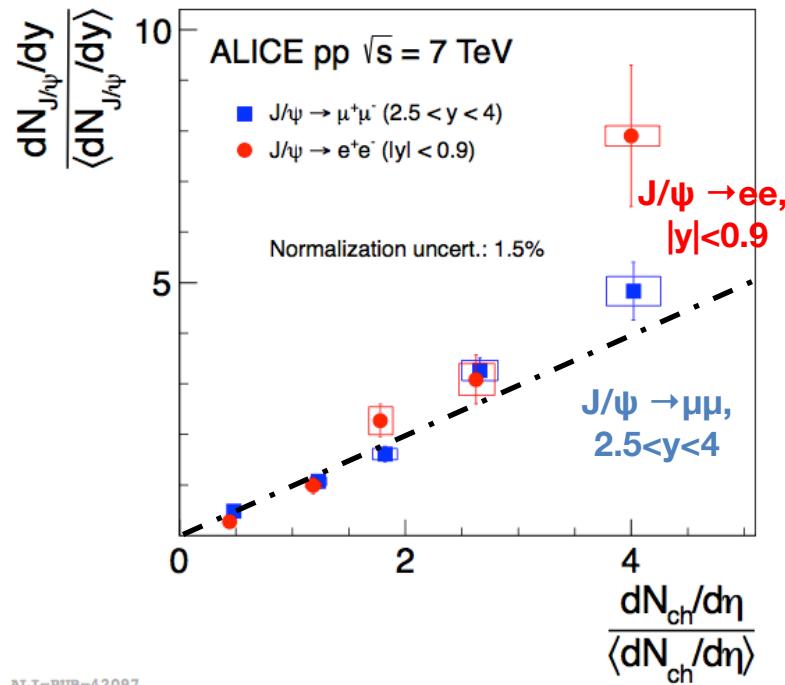
Error bars: statistical uncertainty.

Vertical size of boxes : systematic uncertainties but feed-down.

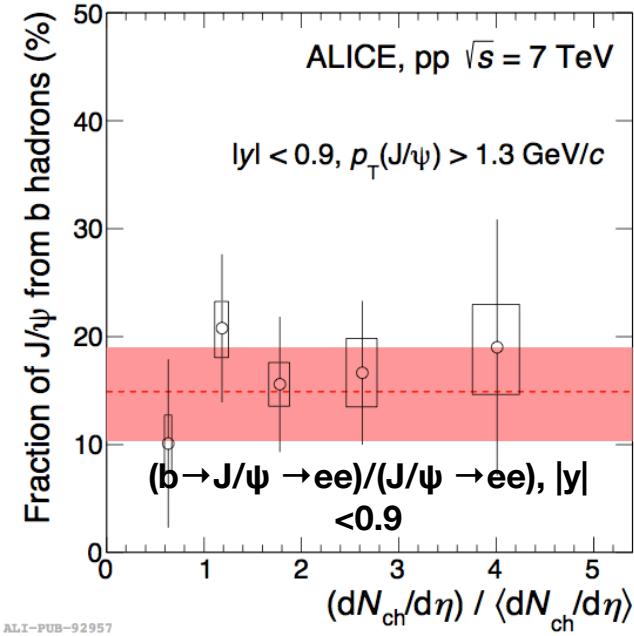
Bottom panels lines: relative feed-down systematic uncertainties.

Not shown : systematic uncertainty on  $(dN/d\eta)/\langle dN/d\eta \rangle$ . and normalisation.

# Quarkonia vs. multiplicity



ALI-PUB-42097



ALI-PUB-92957

- Increase of  $J/\psi$  yields as a function of multiplicity at mid rapidity.
  - Similar increase of  $J/\psi$  yields measured at central and forward rapidity.
- The fraction of non-prompt  $J/\psi$  in the inclusive yields shows no multiplicity dependence with multiplicity within uncertainties.

ALICE, Phys.Lett. B712 (2012) 165–175

ALICE, JHEP 09 (2015) 148.

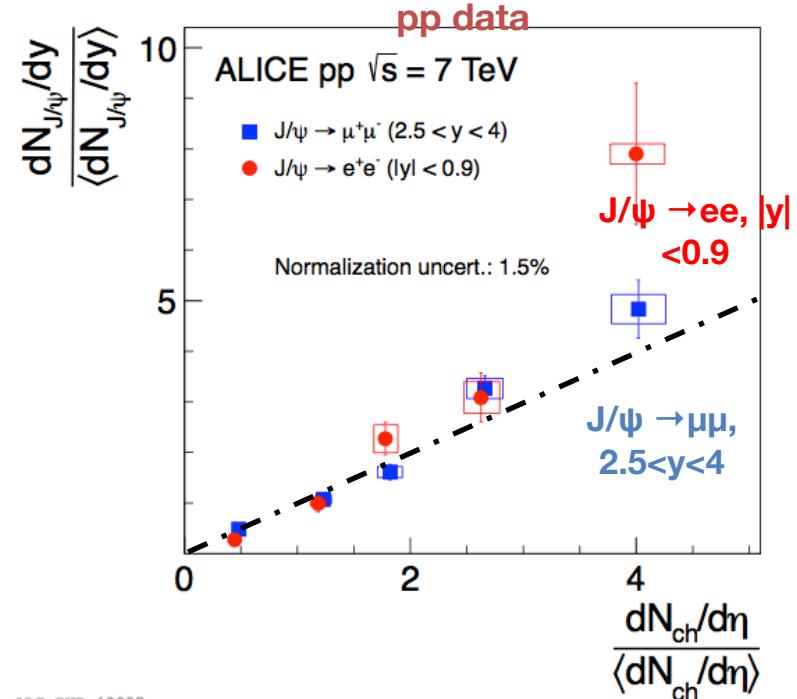
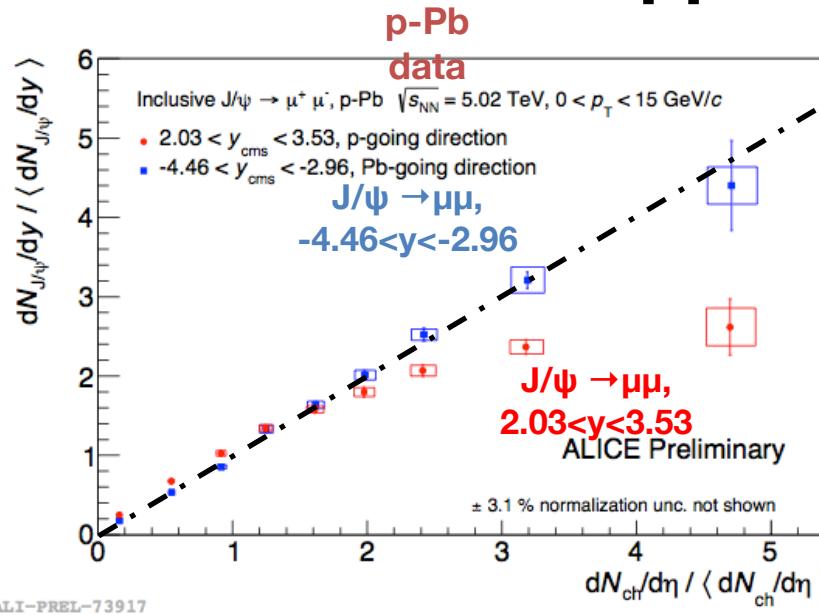
Error bars: statistical uncertainty.

Horizontal size of boxes : systematic uncertainty on  $(dN/d\eta)/\langle dN/d\eta \rangle$ .

Vertical size of boxes : systematic uncertainties but feed-down.

Not shown : normalisation systematic uncertainty.

# Quarkonia in pp and p-Pb collisions



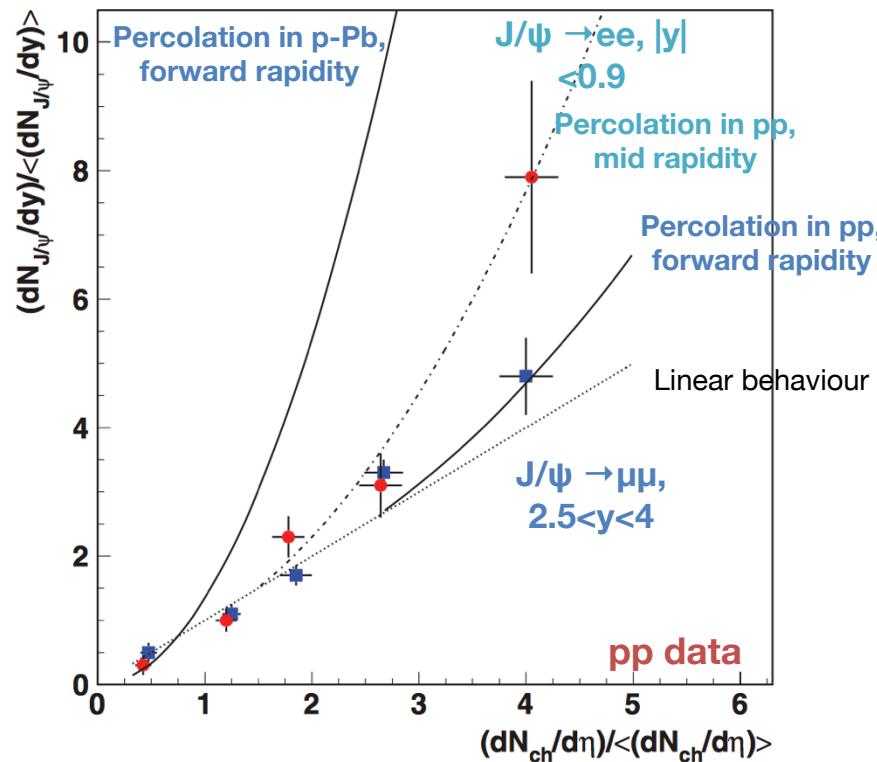
- **Multiplicity at mid rapidity:**
  - similar trend for  $J/\psi$  yields measured in pp and p-Pb collisions at backward rapidity (Pb-going direction),
  - deviation of  $J/\psi$  yields measured at forward rapidity (p-going direction).

ALICE, Phys.Lett. B712 (2012) 165–175

Note:  $J/\psi$  yields measured in the p-going direction probe low-x gluons

Error bars: statistical uncertainty.  
Horizontal size of boxes : systematic uncertainty on  $(dN/d\eta)/\langle dN/d\eta \rangle$ .  
Vertical size of boxes : systematic uncertainties but feed-down.  
Not shown : normalisation systematic uncertainty.

# J/ $\psi$ in pp collisions vs. percolation model

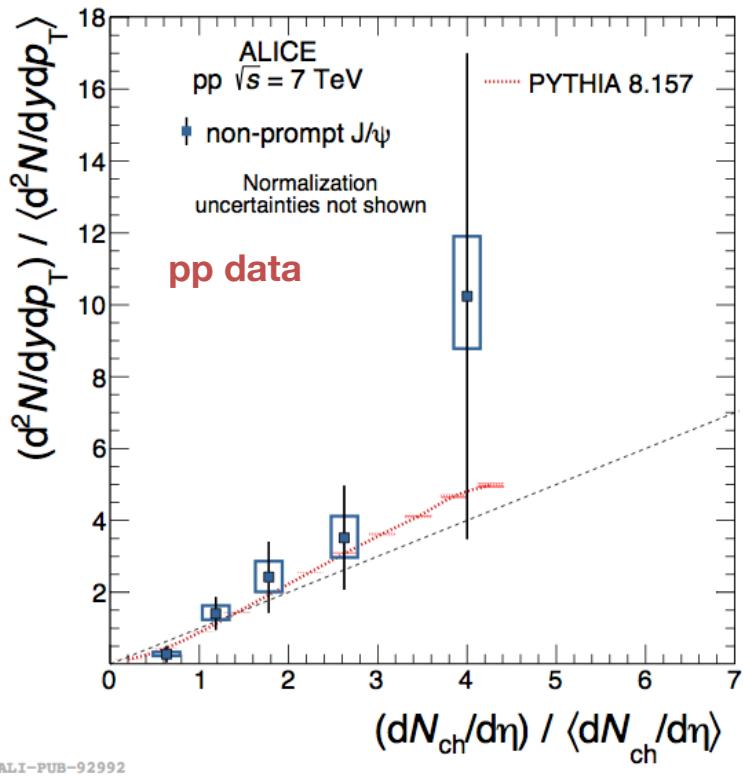


- **Percolation:**

- interactions driven by the **exchange of colour sources** (strings ~ MPI scenario);
- the strings **have a finite spatial extension and can interact**,
  - at high density the coherence leads to a reduction of their number, i.e. a reduction of charged-particle multiplicity,
  - heavy-flavours are less affected due to the smaller transverse size of hard sources;

❖ **faster-than-linear increase of J/ $\psi$  yield with multiplicity**

# Non-prompt J/ $\psi$ in pp collisions vs. models



ALICE-PUB-92992

- **PYTHIA 8:**
  - SoftQCD process selection,
  - including colour reconnection,
  - as well as MPI,
  - and diffractive processes
- **nearly linear trend of B-hadron yield with multiplicity.**

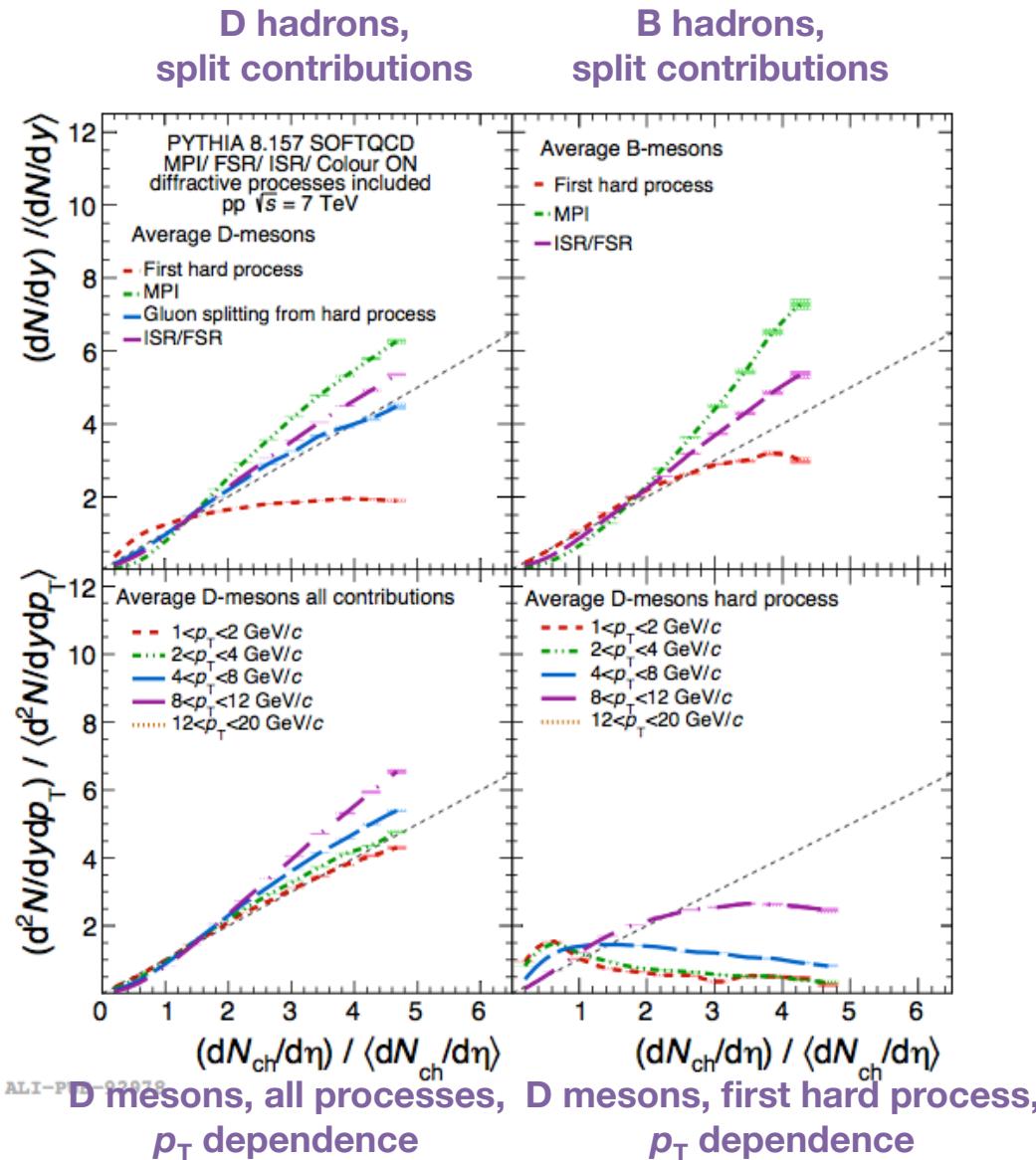
ALICE, JHEP 09 (2015) 148.

T. Sjostrand, S. Mrenna, and P. Z. Skands, Comput.Phys.Commun. 178 (2008) 852–867



ALICE

# More details on PYTHIA 8

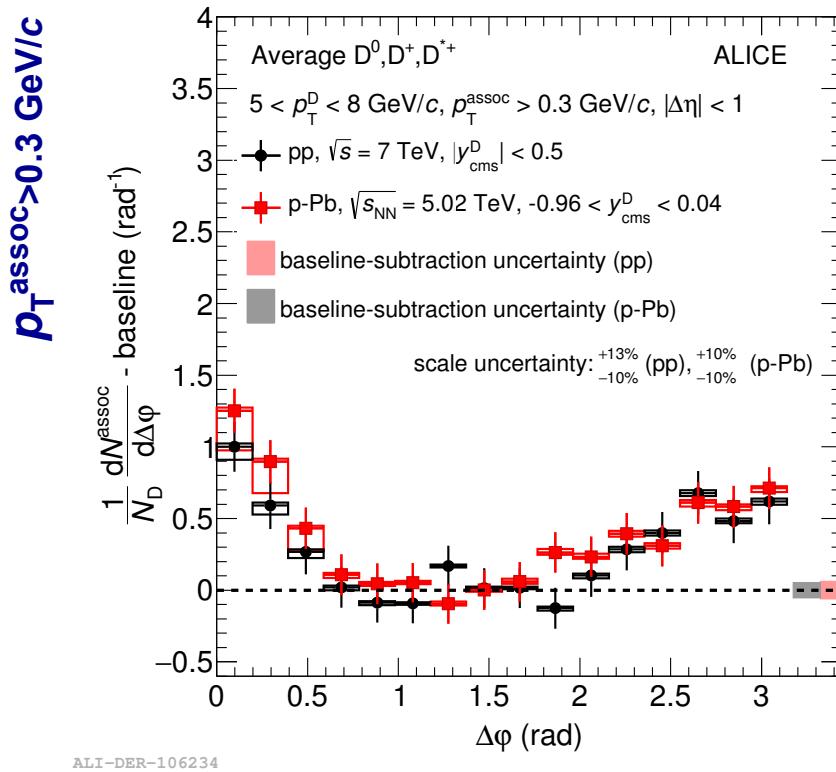


- Calculation: SoftQCD process selection, including colour reconnection and diffractive processes.
- Contributions of:
  - **first hard process**  $\approx$  hardest process
    - **weak dependence on multiplicity** (slight increase at low multiplicities followed by a saturation)
  - **MPI**  $\approx$  subsequent hard process
    - **increasing trend vs. multiplicity**
  - **gluon splitting from hard process**
    - **increasing trend vs. multiplicity**
  - **initial and final-state radiation**
    - **increasing trend vs. multiplicity**

T. Sjostrand, S. Mrenna, and P. Z. Skands,  
Comput.Phys.Commun. 178 (2008) 852–867

# Comparison to p-Pb collisions

D-meson trigger  $p_T$ :  
5-8 GeV/c



arXiv:1605.06963

**pp**  
**p-Pb**



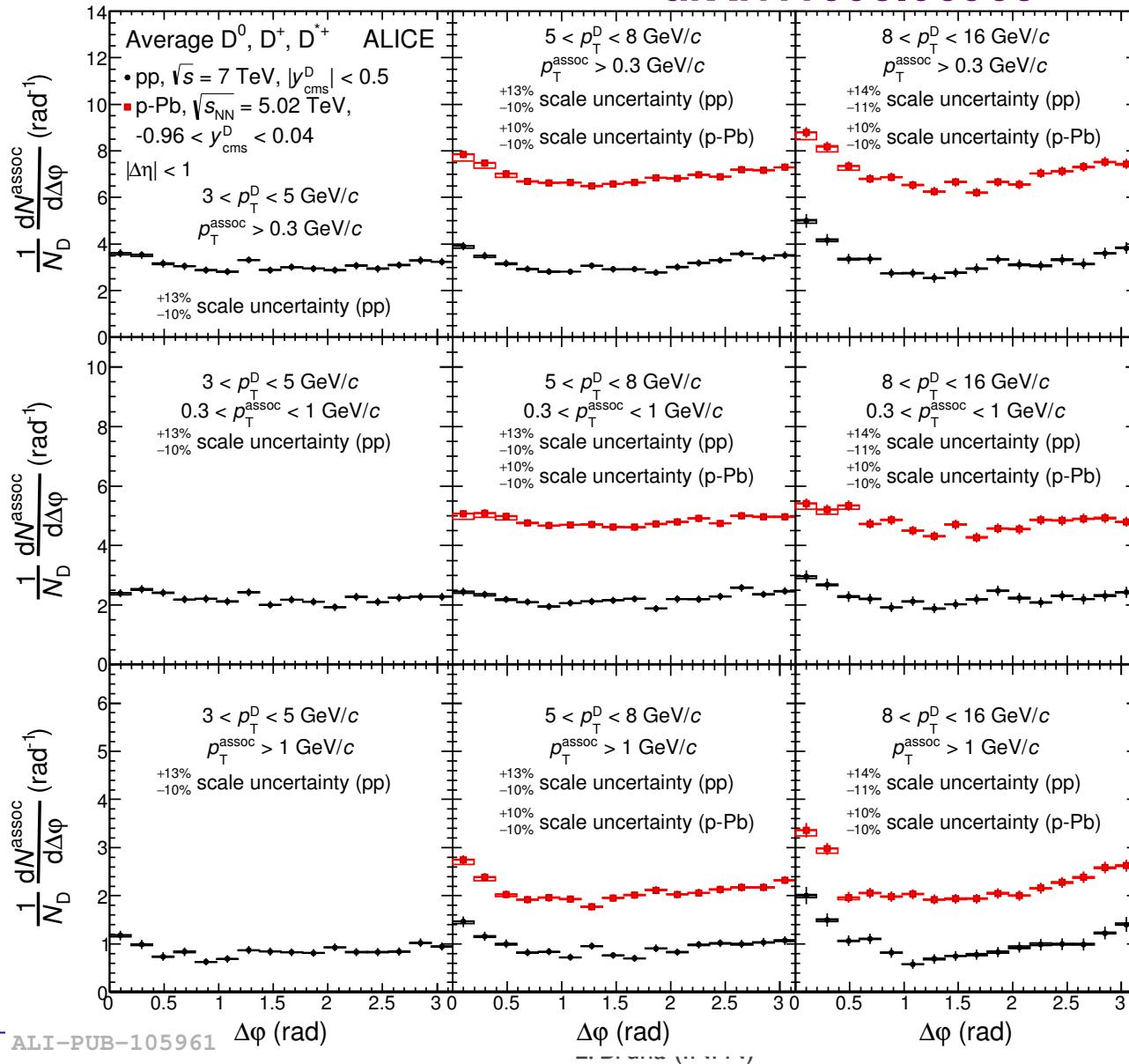
In p-Pb collisions:

- Are heavy-flavour jet properties affected by nuclear effects due to the Pb nucleus?

Compatibility within uncertainties between pp collisions at  $\sqrt{s} = 7$  TeV and p-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV after baseline subtraction

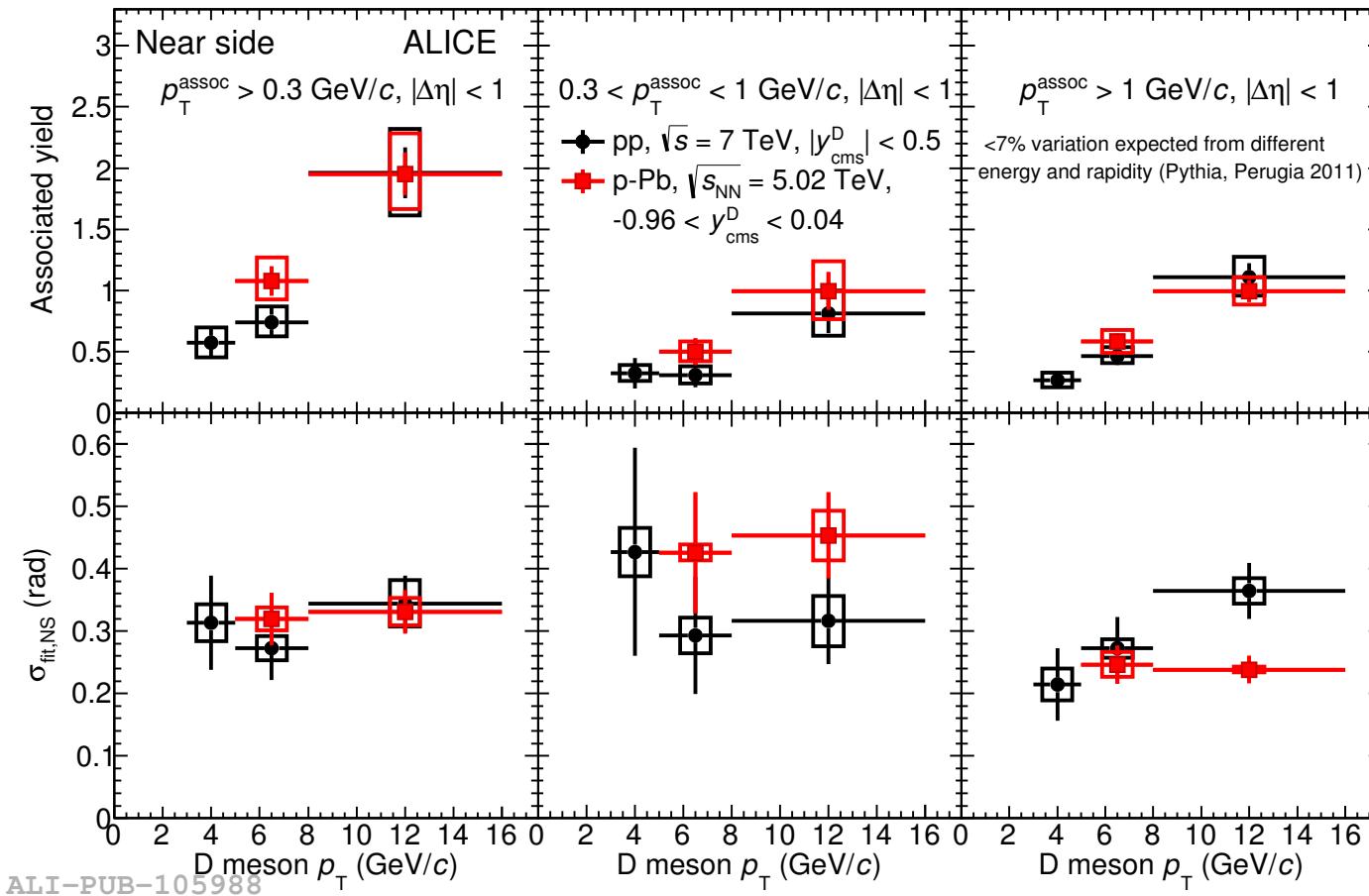
# Correlations in pp and p-Pb collisions

arXiv:1605.06963



# Near-side yields and widths in pp and p-Pb collisions

arXiv:1605.06963



# Near-side yields and widths in pp collisions

arXiv:1605.06963

