

# Heavy-flavour multiplicity dependence in p-Pb collisions with ALICE at the LHC

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**Abstract.** The nuclear modification factor  $Q_{\text{pPb}}$  of  $D^0$ ,  $D^+$  and  $D^{*+}$  mesons is shown in the transverse-momentum ( $p_T$ ) range  $1 < p_T < 24 \text{ GeV}/c$  as a function of centrality in p-Pb collisions at  $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$  as measured with ALICE at the LHC. The  $Q_{\text{pPb}}$  measured in different centrality intervals agree with each other for all D-meson species. Also presented are the self-normalized yields of D mesons in the same  $p_T$  range and of electrons from semi-leptonic heavy-flavour hadron decays in the  $p_T$  range  $0.5 < p_T < 8 \text{ GeV}/c$  as a function of the charged-particle multiplicity. Both measurements agree with each other within their uncertainties. The self-normalized yields increase with the charged-particle multiplicity independent of the  $p_T$  interval.

## 1. Introduction

Heavy-flavour production is studied in p-Pb collisions to gain insight into potential Cold Nuclear Matter (CNM) effects present in Pb-Pb and p-Pb collisions. The  $p_T$ -differential heavy-flavour production cross section is compared to a baseline measurement obtained in pp collisions, where the heavy-flavour cross sections are in good agreement with perturbative QCD calculations. ALICE has measured the nuclear modification factor ( $R_{\text{pPb}}$ ) for D mesons [1] and electrons from heavy-flavour hadron decays [2], indicating insignificant CNM effects for  $p_T > 2 \text{ GeV}/c$  in agreement with various theoretical models. The dependence of these effects on the centrality is an important aspect to understand and constrain these model calculations further. The centrality-dependent nuclear modification factor ( $Q_{\text{pPb}}$ ) is defined as:

$$Q_{\text{pPb}} = \frac{(dN^{\text{D}}/dp_T)_{\text{pPb}}^{\text{cent}}}{\langle T_{\text{pPb}} \rangle \times (d\sigma^{\text{D}}/dp_T)_{\text{pp}}} \quad (1)$$

where  $(dN^{\text{D}}/dp_T)_{\text{pPb}}^{\text{cent}}$  is the yield of prompt D mesons in p-Pb collisions in a given centrality class,  $(d\sigma^{\text{D}}/dp_T)_{\text{pp}}$  is the cross section of prompt D mesons in pp collisions at the same collision energy and  $\langle T_{\text{pPb}} \rangle$  is the average nuclear overlap function in a given centrality class calculated in a Glauber Monte Carlo approach [3].

Another interesting aspect is the interplay between hard processes such as heavy-quark production and the underlying event charged-particle distribution driven by soft processes. This can be studied using self-normalized yields which are yields obtained in a multiplicity interval and normalized to the multiplicity integrated yield. Due to the cancellation of correlated systematic

uncertainties self-normalized yields are a good tool to study high multiplicity events. Unlike for  $Q_{\text{pPb}}$ , in which particle production in samples of 20% of the analyzed events is examined, the self-normalized yields explore events to extremely high multiplicities corresponding to only 5% of the analyzed events in p-Pb collisions [4]. In p-Pb collisions multiple binary collisions take place, for which a linear scaling of the self-normalized heavy-flavour yields as a function of the charged-particle multiplicity is expected. However, at very high multiplicities other effects might play a role such as Multiple Parton Interactions (MPIs). MPIs can be an explanation for a faster-than-linear scaling which is observed in measurements of self-normalized D-meson yields in pp collisions [5].

## 2. Analysis

The centrality and charged-particle multiplicity are estimated in ALICE using various approaches. For the centrality estimation, the zero degree calorimeter (ZNA) and the VZERO scintillator hodoscope (V0A) are used at backward rapidity i.e. in direction of the Pb beam [3]. For the estimation of the charged-particle multiplicity two approaches in different rapidity regions are used. At backward rapidity the V0A is used. At mid-rapidity tracklets, which are connected hits in both Silicon Pixel Detector (SPD) layers pointing to the vertex, are used.

Charm quark production is measured via the reconstruction of D mesons from their decay kaons and pions in an invariant-mass analysis [1]. The combinatorial background is reduced with  $p_{\text{T}}$ -dependent topological cuts. The feed-down contribution from B-meson decays is subtracted to obtain the prompt D-meson yield.

Another approach to measure heavy-flavour production is to determine inclusively the yield of electrons from semi-leptonic heavy-flavour hadron decays [2]. The main contribution to the background is from electrons from Dalitz decays and photon conversion. Since these processes produce low-mass electron-positron pairs the corresponding electron-background yield can be measured via an invariant-mass analysis. The combinatorial background is estimated using the invariant-mass distribution of uncorrelated same-signed electron or positron pairs. The remaining electron background from weak kaon decays ( $K_{e3}$ ) and  $J/\psi$  decays is estimated by Monte Carlo simulations using measured cross sections as input. The inclusive measurement of electrons gives access to beauty physics since the contribution of electrons from semi-leptonic beauty-hadron decays is more than 50% for  $p_{\text{T}} > 4 \text{ GeV}/c$  [6].

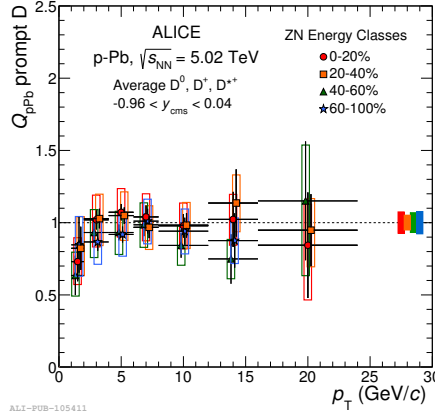
The D-meson cross sections are measured as a function of centrality and multiplicity and are published in [4]. The measurement of self-normalized electron yields is performed as a function of the charged-particle multiplicity.

## 3. Results

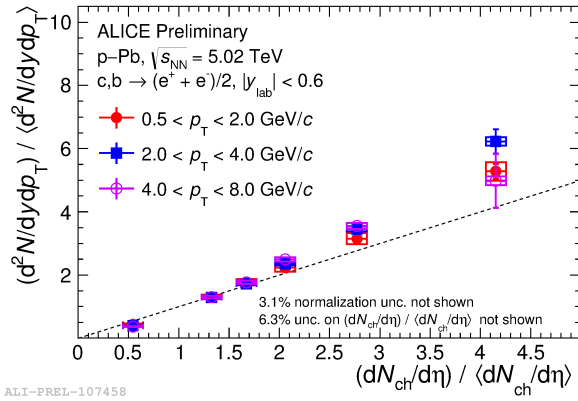
The measurement of the  $Q_{\text{pPb}}$  for different centrality classes is biased due to the method of centrality estimation. The least bias is reached with a hybrid approach using the ZNA as described in [3]. No significant centrality-dependent modification of D-meson production is observed in p-Pb collisions with respect to pp collisions as shown in Figure 1. These results are consistent with those obtained for charged hadrons at high  $p_{\text{T}}$  [3].

ALICE has measured a linear dependence of the self-normalized yields of D mesons in p-Pb collisions at  $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$  as a function of charged-particle multiplicity estimated at backward rapidity and a faster-than-linear increase as a function of the charged-particle multiplicity estimated at mid-rapidity [4].

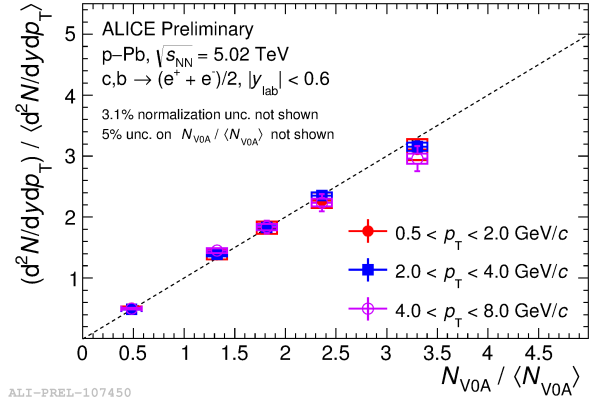
A new measurement of the self-normalized yields of electrons from heavy-flavour hadron decays as a function of the charged particle multiplicity is presented here. The charged-particle multiplicity is estimated in two different rapidity regions (at mid-rapidity and backward rapidity), similar to the analysis of the multiplicity dependence of the self-normalized D-meson



**Figure 1.** Average  $Q_{pPb}$  of  $D^0$ ,  $D^+$  and  $D^{*+}$  mesons as a function of  $p_T$  and event centrality [3].



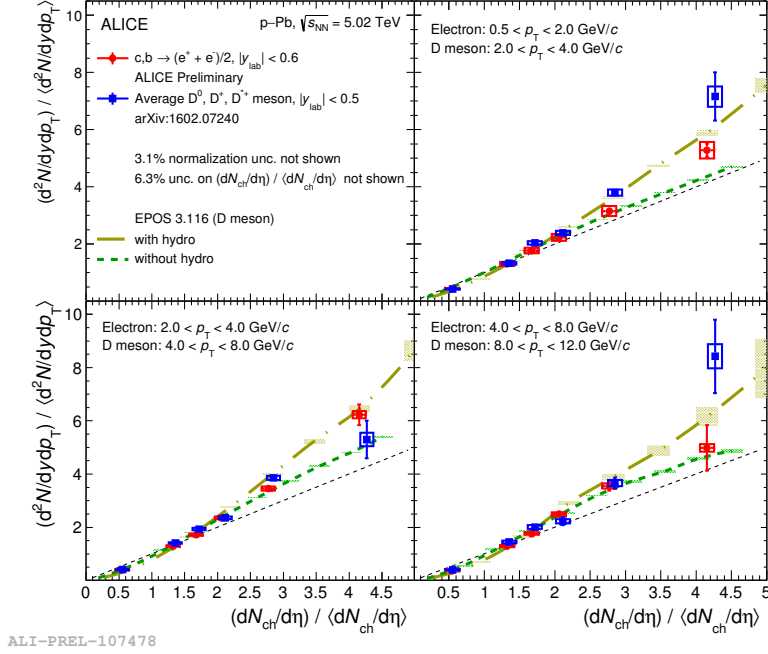
**Figure 2.** Self-normalized yields of electrons from heavy-flavour hadron decays for different electron  $p_T$  as a function of the charged-particle multiplicity estimated at mid-rapidity.



**Figure 3.** Self-normalized yields of electrons from heavy-flavour hadron decays for different electron  $p_T$  as a function of the charged-particle multiplicity estimated at backward rapidity.

yields. In Figures 2 and 3 the self-normalized yields of electrons from semi-leptonic heavy-flavour hadron decays are shown as a function of the charged-particle multiplicities estimated at mid-rapidity and backward rapidity, respectively. The self-normalized yields of electrons and D mesons as a function of the charged-particle multiplicity estimated at mid-rapidity are plotted in Figure 4 in different kinematic ranges in each panel to account for the decay kinematics. The self-normalized yields of electrons and D mesons are compatible with each other within their uncertainties and they do not depend on the transverse momentum. Also shown are results from model calculations using EPOS 3 [7] for D mesons considering two approaches, where the simulated initial conditions are evolved using hydrodynamics in one of the cases. The calculations using a hydrodynamic evolution are in good agreement with the faster-than-linear increase of the D-meson measurement, suggesting that collective effects could play a role in particle production in high-multiplicity p-Pb collisions.

The self-normalized yields of electrons include a significant contribution from electrons from beauty-hadron decays for  $p_T > 4$  GeV/c [6]. No  $p_T$  dependence is observed for the self-normalized yields of electrons as shown in Figures 2 and 3. The measurements give a hint that the production mechanisms of charm and beauty as a function of the multiplicity are similar.



**Figure 4.** Comparison of self-normalized yields of D mesons averaged over all species and electrons from heavy-flavour hadron decays as a function of the charged-particle multiplicity estimated at mid-rapidity. Also shown are the results of EPOS 3 model calculations [7] without hydrodynamic evolution as a dashed line and including a hydrodynamic evolution shown as a dot-dashed line.

#### 4. Summary

No centrality dependence is observed for the  $Q_{pPb}$  of D mesons in p-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV within the uncertainties of the measurement. ALICE has measured the self-normalized yields of D mesons and electrons from semi-leptonic heavy-flavour hadron decays as a function of the charged-particle multiplicity estimated at mid-rapidity and backward rapidity. A linear increase of the self-normalized yields is observed for D mesons and electrons from semi-leptonic heavy-flavour hadron decays as a function of the charged-particle multiplicity at backward rapidity, compatible with each other in all  $p_T$  intervals within uncertainties. A trend for a faster-than-linear increase of the self-normalized yields of electrons as a function of the charged-particle multiplicity estimated at mid-rapidity is observed in agreement with the measurement of D mesons [4]. The faster-than-linear increase gives a hint that other effects besides binary scaling, such as MPIs, might play a role in heavy-flavour production in p-Pb collisions. Model calculations with MPIs can explain a faster-than-linear increase of self-normalized D mesons in pp collisions [5]. No significant difference between various  $p_T$  intervals of the self-normalized yields of electrons has been observed, suggesting similar production mechanisms for charm and beauty quarks as a function of the multiplicity in p-Pb collisions.

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#### References

- [1] Abelev B B *et al.* (ALICE Collaboration) 2014 *Phys. Rev. Lett.* **113** 232301
- [2] Adam J *et al.* (ALICE Collaboration) 2016 *Phys. Lett.* **B754** 81–93
- [3] Adam J *et al.* (ALICE Collaboration) 2015 *Phys. Rev.* **C91** 064905
- [4] Adam J *et al.* (ALICE Collaboration) 2016 *JHEP* **08** 078
- [5] Adam J *et al.* (ALICE Collaboration) 2015 *JHEP* **09** 148
- [6] Abelev B *et al.* (ALICE Collaboration) 2013 *Phys. Lett.* **B721** 13–23
- [7] Werner K *et al.* 2014 *Phys. Rev.* **C89** 064903