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Nuclear Physics A 931 (2014) 552–557

NUCLEAR PHYSICS A

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Measurement of heavy-flavour production as a function of multiplicity in pp and p–Pb collisions with ALICE

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Received 30 July 2014; accepted 31 July 2014

Abstract

In these proceedings results are presented from the measurement of open heavy-flavour production as a function of charged-particle multiplicity in pp collisions at $\sqrt{s} = 7$ TeV and p–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV recorded with the ALICE detector in 2010 and 2013, respectively. $\rm D^0$, $\rm D^+$ and $\rm D^{*+}$ mesons are reconstructed from their hadronic decay channels in the central rapidity region, and their production yields are measured in various multiplicity and $p_{\rm T}$ intervals.

The per-event yields of D mesons in the various multiplicity intervals, normalized to their multiplicity-integrated value, and their evolution with $p_{\rm T}$ are measured for pp and p–Pb collisions to study the contribution of Multi-Parton Interactions (MPIs) to open charm production in the two systems. The nuclear modification factor of D mesons in p–Pb collisions, defined as the ratio of the D-meson yields in p–Pb and pp collisions scaled by the average number of binary collisions $\langle N_{\rm coll} \rangle$, is discussed in terms of its dependence on the event activity. Several experimental estimators of the event activity are used in order to assess the role of kinematic biases.

Keywords: QGP; Heavy-flavour; Multi-parton interaction

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1. Introduction

The measurement of heavy-flavour production as a function of the multiplicity of charged particles produced in hadronic collisions is sensitive to the interplay between hard and soft contributions to particle production and could give insight into the role of Multi-Parton Interactions

http://dx.doi.org/10.1016/j.nuclphysa.2014.07.047

(MPIs, i.e. several hard partonic interactions occurring in a single collision between two nucleons).

Particle production at the LHC is expected to have a substantial contribution from MPIs in pp (p–Pb) collisions, where the highest multiplicity values observed are similar to the ones of peripheral Cu–Cu (Pb–Pb) collisions at RHIC (LHC). Measurements by the CMS Collaboration of jet and underlying event properties have shown better agreement with models including MPIs [1]. Measurements by the ALICE Collaboration of minijets point to an increase of MPIs with increasing charged-particle multiplicity [2]. In the heavy-flavour sector several measurements have been performed [3,4]. In particular ALICE found an approximately linear increase of J/ψ yield as a function of multiplicity in pp collisions at $\sqrt{s} = 7$ TeV [5].

Moreover, it is interesting to compare heavy-flavour production in p–Pb collisions with pp results to test whether the yield and the transverse momentum distributions follow a scaling with the number of binary nucleon–nucleon collisions in the p–Pb collision. This scaling is expected for particles produced in hard (high virtuality) partonic scattering processes in the absence of nuclear effects in the initial or in the final state of the p–Pb collision. This is studied by measuring the nuclear modification factor R_{pPb}, defined as the ratio of the p_{T}-differential cross section measured in p–Pb collisions to that measured in pp collisions scaled by the mass number A of the Pb nucleus. The D-meson R_{pPb} in minimum bias p–Pb collisions was found consistent with unity for $p_{\mathrm{T}} > 1$ GeV$/c$ within uncertainties of about 20% [6], showing that Cold Nuclear Matter (CNM) effects (nuclear modifications of the parton distribution functions (PDF), k_{T} broadening, energy loss in cold nuclear matter) do not strongly affect charm-quark production in p–Pb collisions [7]. It is interesting to measure the nuclear modification factor in p–Pb collisions in classes of the event activity, because the latter is related to the collision centrality (i.e. impact parameter as well as the number of participating nucleons and binary collisions) of the p–Pb collisions. The measurement of the R_{pPb} requires to estimate the average number of binary collisions $\langle N_{\mathrm{coll}}\rangle$ for the event activity intervals used in the analysis. ALICE has identified in p–Pb collisions several sources that can induce a bias in the centrality determination based on particle multiplicity measurement [8,9]. This bias have been observed in the measurement of the nuclear modification factor of charged particles in p–Pb collisions in multiplicity classes [9]. This work investigates whether such a bias is also present for D mesons.

The results are presented in form of the D-meson self-normalized yield in pp and p–Pb collisions, defined as

$$\frac{\mathrm{d}^2N^{\mathrm{D}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}{\langle \mathrm{d}^2N^{\mathrm{D}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}\rangle} = \frac{Y^{\mathrm{mult}}/(\epsilon^{\mathrm{mult}})}{Y^{\mathrm{tot}}/(\epsilon^{\mathrm{tot}} \times \epsilon^{\mathrm{trigger}})} \tag{1}$$

where Y^{mult} is the D-meson per-event yield in multiplicity intervals, Y^{tot} the multiplicity integrated per-event yield, ϵ are the corresponding reconstruction and selection efficiencies and $\epsilon^{\mathrm{trigger}}$ is the trigger efficiency (only relevant in pp). Furthermore, the binary scaling is studied in several event activity classes via the Q_{pPb} ratio, defiled as:

$$Q_{\mathrm{pPb}}^{\mathrm{V0A}}(p_{\mathrm{T}}) = \frac{\mathrm{d}N_{\mathrm{mult}}^{\mathrm{pPb}}/\mathrm{d}p_{\mathrm{T}}}{\langle N_{\mathrm{coll}}^{\mathrm{Glauber}}\rangle \mathrm{d}N^{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}} \qquad Q_{\mathrm{pPb}}^{\mathrm{mult}}(p_{\mathrm{T}}) = \frac{\mathrm{d}N_{\mathrm{mult}}^{\mathrm{pPb}}/\mathrm{d}p_{\mathrm{T}}}{\langle N_{\mathrm{coll}}^{\mathrm{mult}}\rangle \mathrm{d}N^{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}} \tag{2}$$

for the V0A and ZNA event activity estimators respectively, defined in the next section. These two observables represent different ways to study the multiplicity dependence of D-meson production in p–Pb collisions: the self-normalized yields are more focused on the study of MPIs, while Q_{pPb} reflects the scaling of charm production in p–Pb collisions relative to pp collisions.

2. Data sample and analysis strategy

The ALICE detector is described in [10]. The data samples analyzed are from the 2010 pp run ($300 \cdot 10^6$ events at $\sqrt{s} = 7$ TeV) and the 2013 p–Pb run ($100 \cdot 10^6$ events at $\sqrt{s_{\rm NN}} = 5.02$ TeV). Details on the trigger and event selections can be found in [6,11]. Events are divided in event activity classes. Three event activity estimators have been used:

- $N_{\rm tracklets}$: number of track segments reconstructed in the Silicon Pixel Detector (SPD – two innermost layers of the Inner Tracking System – $|\eta| < 0.9$);
- V0A: signal amplitude of the A-side VZERO scintillator ($2.8 < \eta < 5.1$ – Pb going direction for p–Pb collisions);
- ZNA: energy from nuclear fragments in the A-side Zero Degree Neutron Calorimeter (112.5 m from interaction point – Pb going direction for p–Pb collisions).

The self-normalized yields are obtained in $N_{\rm tracklets}$ intervals, while the $Q_{\rm pPb}$ analysis adopts V0A and ZNA multiplicity classes (0–20%, 20–40%, 40–60%, 60–100%). The analysis is based on the reconstruction of D mesons in their hadronic decay channels ($\rm D^0 \to K^-\pi^+$, $\rm D^+ \to K^-\pi^+\pi^+$, $\rm D^{*+} \to D^0\pi^+$) in the ALICE central barrel ($|\eta| < 0.9$), exploiting the excellent vertex resolution and particle identification capabilities of the ALICE detector as described in [12]. D-meson efficiency corrections in pp and p–Pb collisions are determined with Monte Carlo simulations based on PYTHIA 6.4.21 and HIJING event generators. A fraction of the total D-meson yield comes from the decay of B mesons. For the $Q_{\rm pPb}$ analysis this contribution was estimated based on FONLL pQCD calculations as described in [12], while for the self-normalized yield analysis no subtraction has been performed, assuming that the fraction of feed-down D mesons does not depend on multiplicity and cancels in the ratio of Eq. (1). A deviation from this assumption has been considered to estimate the corresponding systematic uncertainty. The pp and p–Pb corrected yields have been used to compute the $Q_{\rm pPb}$ as in Eq. (2). The average values of $N_{\rm coll}$ in the four V0A and ZNA event activity classes have been evaluated as follows:

- V0A: the $\langle N_{\rm coll}^{\rm Glauber} \rangle$ values have been obtained for each V0A multiplicity interval with the approach used for Pb–Pb collisions, i.e. via a fit to the V0A multiplicity distribution based on the Glauber model for the collision geometry and a two-component model for particle production [13].
- ZNA: the $\langle N_{\rm part}^{\rm mult} \rangle$ values have been calculated by scaling the $\langle N_{\rm part} \rangle$ in minimum-bias p–Pb collisions by the ratio between the average multiplicity density measured at mid-rapidity for a given ZN energy event class and the one measured in minimum bias collisions. $\langle N_{\rm coll}^{\rm mult} \rangle$ is obtained as $\langle N_{\rm coll}^{\rm mult} \rangle = \langle N_{\rm part}^{\rm mult} \rangle - 1$.

3. Results

The self-normalized yields have been measured for prompt $\rm D^0$, $\rm D^+$ and $\rm D^{*+}$ mesons. They are shown in charged-particle multiplicity ($\mathrm{dN_{ch}/d}\eta$) intervals (Fig. 1), since a simulation study has shown that $N_{\rm tracklets}/\langle N_{\rm tracklets} \rangle$ equals $\mathrm{d}N_{\rm ch}/\mathrm{d}\eta / \langle \mathrm{d}N_{\rm ch}/\mathrm{d}\eta \rangle$. For all the D-meson species, the yield increases with charged-particle multiplicity. No $p_{\rm T}$ dependence of this trend has been observed.

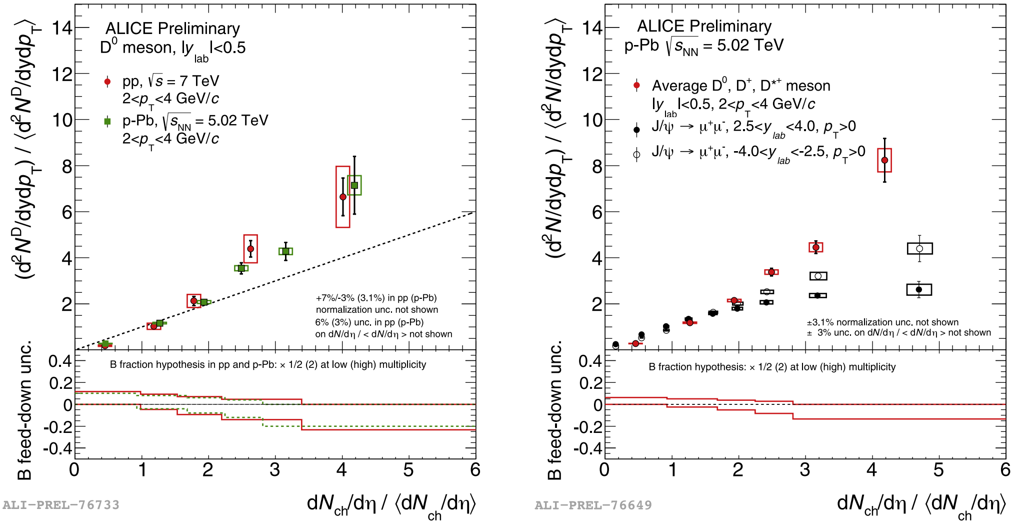

Fig. 1. Left: self-normalized D^0 yields for $2 < p_T < 4$ GeV/c as a function of multiplicity for pp and p–Pb collisions. Right: average D^0, D^+ and D^{*+} self-normalized yields compared to J/ψ in the rapidity intervals $2.5 < y_{lab} < 4.0$ and $-4.0 < y_{lab} < -2.5$ for p–Pb collisions.

The left panel of Fig. 1 shows D^0 self-normalized yields for pp and p–Pb collisions. Both systems show an increase of the yield with charged-particle multiplicity. The trend for pp collisions can be interpreted as being due to strong hadronic activity connected with charm production and to the presence of MPIs affecting the hard momentum scale relevant for heavy-quark production. In the p–Pb case, it should be considered that high-multiplicity events can also originate from a higher number of nucleon–nucleon collisions in the nuclear interaction. The right panel of Fig. 1 shows the average values of self-normalized yields for D^0, D^+ and D^{*+} and J/ψ in p–Pb collisions. J/ψ yields have been measured in $2.5 < y_{lab} < 4.0$ (p-going direction) and $-4.0 < y_{lab} < -2.5$ (Pb-going direction) and they show an increase with charged-particle multiplicity. However, a quantitative comparison of J/ψ and D-meson yields has to take into account the rapidity dependence of cold nuclear matter effects such as gluon shadowing, that depends on the Bjorken x value of the parton involved in the process producing charm, and energy loss in cold nuclear matter [14].

The average value of Q_{pPb} for prompt D^0 and D^{*+} mesons is shown in the left panels of Figs. 2 and 3 for the V0A and ZNA estimators, respectively. A bias can be observed in the V0A measurement, where the low-multiplicity Q_{pPb} is below unity in all six p_T bins, while the ZNA measurement is compatible with unity within systematic and statistical uncertainties at both low and high event activity. These Q_{pPb} results are compared with the ones obtained for charged particles, shown in the right panels of Figs. 2 and 3. These comparisons demonstrate that the Q_{pPb} of high p_T (> 8 GeV/c) charged particles feature a similar pattern as the one of D mesons, confirming the presence of a bias in the V0A-based determination of $\langle N_{coll}^{Glauber}\rangle$ that is reduced using the ZNA estimator. This indicates that the determination of $\langle N_{coll}\rangle$ depends on the rapidity region in which the event activity measurement is performed. With the least biased estimator (ZNA) we observe Q_{pPb} being compatible with unity for all multiplicities and p_T. Details on the N_{coll} bias have been presented at this conference and they are described in [9].

In conclusion, the D-meson self-normalized yields show an increasing trend with increasing charged-particle multiplicity. The trends observed for pp and p–Pb collisions are compatible

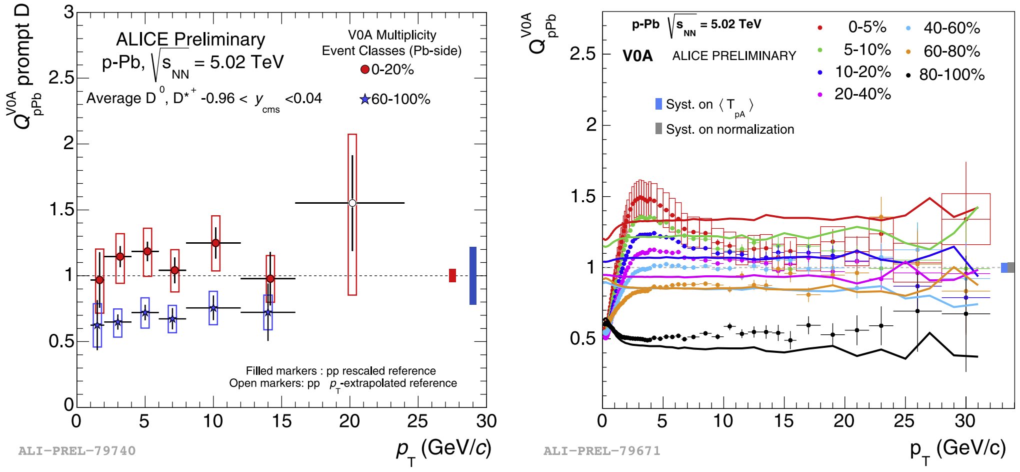

Fig. 2. Left: average p_T differential Q_{pPb} of D^0 and D^{*+} mesons in the 0–20% and 60–100% V0A event activity classes. Right: p_T differential Q_{pPb} of charged hadrons in seven V0A event activity classes.

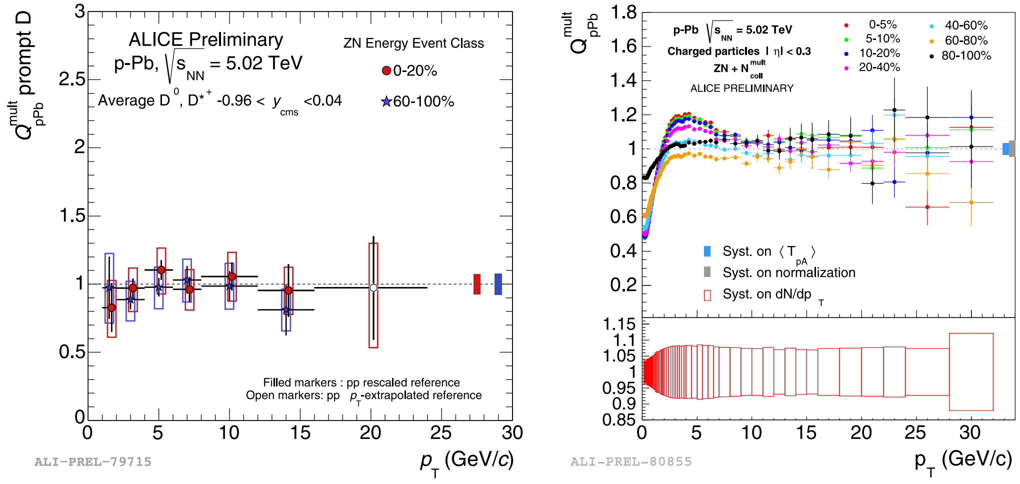

Fig. 3. Left: average p_T differential Q_{pPb} of D^0 and D^{*+}mesons in the 0–20% and 60–100% ZNA event activity classes. Right: p_T differential Q_{pPb} of charged hadrons in seven ZNA event activity classes.

within uncertainties. The Q_{pPb} results for D mesons are qualitatively similar to the ones obtained for high p_T charged particles. In particular the ZNA measurement shows no multiplicity dependence of the D-meson production in p–Pb collisions relative to binary scaling of pp production cross sections while V0A results show a similar bias as observed for high-p_T charged particles.

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