PROCEEDINGS OF SCIENCE

Open heavy-flavour production in p–Pb collisions measured with ALICE at the LHC

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Heavy flavours are sensitive probes of the hot and dense quark–gluon plasma formed in high-energy nucleus–nucleus collisions. Measurements of their production in p–Pb collisions are crucial for the interpretation of heavy-ion results, because they allow the cold nuclear matter effects to be investigated. In addition, the study of heavy-flavour $p_{\rm T}$ modification in high-multiplicity p–Pb collisions could give insight into the possible presence of collective effects. The measurements of open heavy-flavour production performed with ALICE at the LHC in p–Pb collisions at $\sqrt{s_{\rm NN}}$= 5.02 TeV are presented. Emphasis is given to the recent measurements of $\rm D^0$ production in high multiplicity p–Pb collisions and to the first measurement of Λ_c production at central rapidity.

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1. Introduction

Heavy quarks (charm and beauty) are produced in hard partonic scattering processes with large momentum transfer, occurring in the initial stage of the collision. In proton–nucleus collisions heavy-flavour production can be affected by the presence of a nucleus in the colliding system. The possible effects, called Cold Nuclear Matter (CNM) (for a recent review, see [1]), can be explored through the measurement of the nuclear modification factor $R_{\rm pPb}$, that compares the production cross section in p–Pb collisions with the expectation from pp collisions. The study of the nuclear modification factor in different event multiplicity classes is interesting to assess the possible modification of the $p_{\rm T}$ spectrum in high multiplicity events, also due to final-state effects, including those arising from the system collectivity. For instance, an expanding medium could impart a flow to heavy-flavour quarks, or modify the hadronisation dynamics of heavy-quarks. The study of azimuthal correlations of D mesons and heavy-flavour decay electrons with charged particles can give insight into the fragmentation of charm and on the properties of jets with charm content. We report measurements of the production cross sections and nuclear modification factors of D mesons and Λ_c baryons and of azimuthal correlations of D mesons and heavy-flavour decay electrons with charged particles in p–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV, recorded in 2016 and 2013, with the ALICE detector.

2. D-meson production in p–Pb collisions

The modification of the D-meson yield in p–Pb collisions with respect to pp collisions is quantified by the nuclear modification factor $R_{\rm pPb} = \frac{1}{A}\frac{{\rm d}^2\sigma^{\rm prompt\,D}_{\rm pPb}/{\rm d}p_{\rm T}{\rm d}y}{{\rm d}^2\sigma^{\rm prompt\,D}_{\rm pp}/{\rm d}p_{\rm T}{\rm d}y}$ where $A = 208$ is the Pb mass number and the pp cross section is obtained by scaling the measurement at $\sqrt{s}$= 7 TeV [2] to $\sqrt{s}$= 5 TeV. The data sample consists of $6 \cdot 10^8$ minimum bias p–Pb events collected by ALICE in 2016. In Fig. 1, on the left, the $R_{\rm pPb}$ of non-strange D mesons, resulting from the average of the $\rm D^0$, $\rm D^+$, $\rm D^{*+}$ $R_{\rm pPb}$, is shown [3]. The data are compatible with unity, within uncertainties. The figure shows the comparison with models including CNM effects and models that include the formation of a Quark Gluon Plasma (QGP) in p–Pb collisions. Models can describe the results in the intermediate $p_{\rm T}$ region, however the data disfavor a suppression at high $p_{\rm T}$. At low $p_{\rm T}$, where the models tend to disagree, the uncertainties of the data are larger and they prevent from discriminating between models. The measurement was also performed in centrality intervals, where the centrality is determined using the energy deposited in the zero-degree neutron calorimeter in the Pb-going side (ZNA). For each centrality class the nuclear modification factor is defined as ${Q_{\rm pPb}}^{\rm cent} = \frac{({\rm d}^2N^{\rm prompt\,D}/{\rm d}p_{\rm T}{\rm d}y)^{\rm cent}_{\rm pPb}}{\langle T_{\rm pPb}\rangle^{\rm cent} \times ({\rm d}^2\sigma^{\rm prompt\,D}_{\rm pp}/{\rm d}p_{\rm T}{\rm d}y)}$ where $({\rm d}^2N^{\rm prompt\,D}/{\rm d}p_{\rm T}{\rm d}y)^{\rm cent}_{\rm pPb}$ is the yield of prompt D mesons in p–Pb collisions in a given centrality class, and $\langle T_{\rm pPb}\rangle^{\rm cent}$ is the average nuclear overlap function in the same centrality class [4].

The middle panel of Fig. 1 presents the $Q_{\rm pPb}$ results for $\rm D^0$ as a function of $p_{\rm T}$ for the 0–10% and 60–100% centrality classes. The results in the two centrality classes are compatible with unity within the uncertainties, although the central values of the $Q_{\rm pPb}$ are generally larger than unity in the 0–10% class and closer to unity in the 60–100% class. The $Q_{\rm CP}$ observable was used to compare with better precision the $p_{\rm T}$-differential yields in central and peripheral p–Pb collisions, since it is independent of the pp cross section. Therefore, it has reduced systematic uncertainties with respect to Q_{pPb}, also because most of the systematic uncertainty cancels in the ratio. The resulting Q_{CP} increases in the interval 1–4 GeV/c, reaching values of about 1.25 and then tends to decrease in the interval 7–24 GeV/c. The average value of the $\mathrm{D^0}$-meson Q_{CP} in the interval $3 < p_{\mathrm{T}} < 8$ GeV/c is larger than unity by 1.7 standard deviations. The observed trend could be caused by initial- as well as final- state effects, including the possible presence of radial flow in p–Pb collisions.

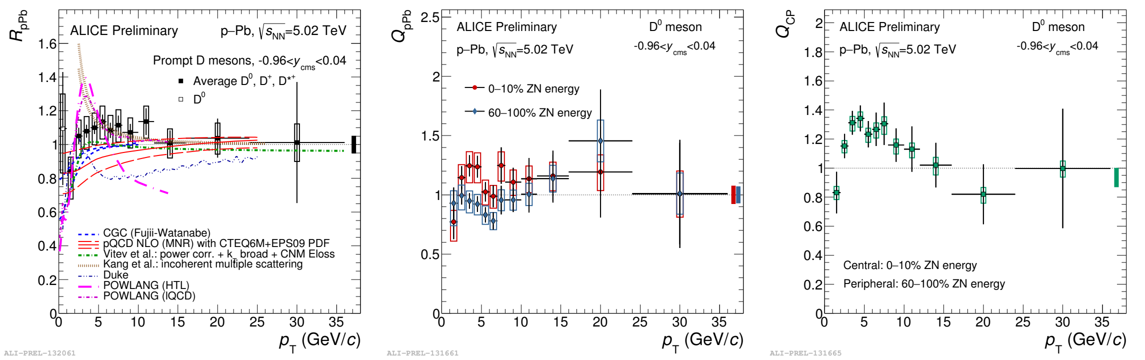

Figure 1: Left: Average nuclear modification factor R_{pPb} of the three non-strange D-meson species in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ =5.02 TeV. Middle: $\mathrm{D^0}$ meson nuclear modification factors as a function of p_{T} in the 0–10% and 60–100% centrality classes. Right: $\mathrm{D^0}$ central-to-peripheral nuclear modification factor. The colour-filled boxes at 1 represent the normalisation uncertainties [3]

3. Λ_c-baryon production in p–Pb collisions

The first measurement of the Λ_{c} baryon in p–Pb collisions at the LHC was carried out in two different decay channels, $\Lambda_{\mathrm{c}}^+ \to \mathrm{pK}^-\pi^+$ and $\Lambda_{\mathrm{c}}^+ \to \mathrm{pK}^0_{\mathrm{s}}$, and with two different analysis techniques. The Λ_{c} was extracted in four p_{T} intervals, from 2 to 12 GeV/c. In Fig. 2, on the left, the average cross section of all the four measurements is shown, in comparison with a calculation based on POWHEG [5], that underpredicts the measured values. The ratio Λ_{c}/D is sensitive to the c-quark hadronisation mechanism. The measurement is shown in Fig. 2, on the right: the results in pp and p–Pb collisions are compatible within uncertainties. The results are compared with predictions from Monte Carlo event generators, PYTHIA8 with Monash tune and with a tune that includes a model of string formation beyond the leading-colour approximation [6], DIPSY with ropes parameters taken from [7], and with the HERWIG7 [8] event generator that uses a cluster hadronisation mechanism. The enhanced colour reconnection mechanisms in PYTHIA8 increases the baryon-to-meson ratio also in the charm sector, qualitatively describing the data better, even if significantly underestimating the measured values. In Fig. 3 the first measurement at the LHC of the Λ_{c} R_{pPb}, is shown. It is consistent with unity and with that of D mesons within uncertainties. Predictions from theoretical models are presented in the right panel of the figure [5, 9]. The precision achieved with the current measurement does not allow us to distinguish between calculations with and without hot medium effects.

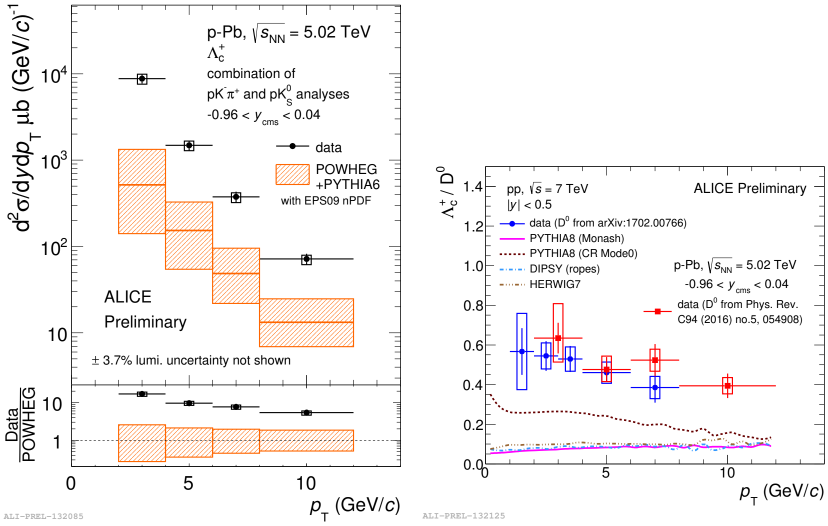

Figure 2: Left: prompt Λ_c-baryon p_T-differential cross section in p–Pb collisions, in comparisons with expectation from POWHEG event generator [5]. Right: Λ_c/D^0 ratio measured in pp (blue markers) and p–Pb (red markers). The measurements from pp collisions are compared with an expectation from the different event generators [6, 7, 8]

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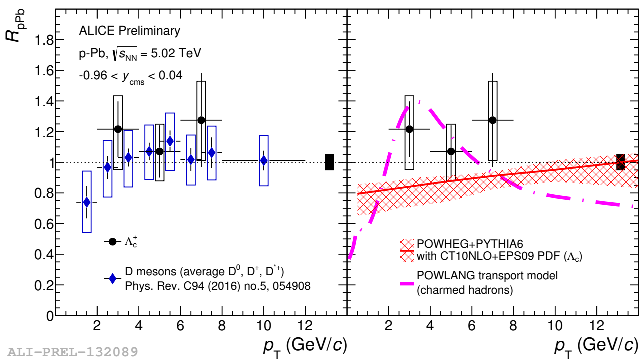

Figure 3: R_{pPb} of prompt Λ_c baryon in p–Pb collisions as a function of p_T compared with that of D mesons (left panel) and with model calculations [5, 9] (right panel).

4. Azimuthal correlations of D mesons and heavy-flavour decay electrons with charged particles

The angular correlation of D mesons [10] and electrons with charged particles (D-h and HFe-h in the following, respectively) has been measured by ALICE in p–Pb collisions. Fig. 4 (left) shows the averaged D^0, D^+, D^{*+} azimuthal correlation with charged particles in two different D-meson p_T ranges after subtraction of a constant term (baseline) that represents an estimate of the physical minimum of the distribution. The data are compared with expectations from event generators that can describe the results, and, on the right, HFe-h correlation in different centrality ranges are shown. The distributions show a nearside peak at $\Delta\varphi = 0$ and a broader away side peak at $\Delta\varphi = \pi$. No dependence on centrality is observed, within uncertainties, for the HFe-h correlations. Possibile collective mechanisms in high-multiplicity p–Pb collisions could modify the associated yield and width of the near-side peak, if charm participates to the expansion of the medium, introducing an "elliptic-flow" like modulation.

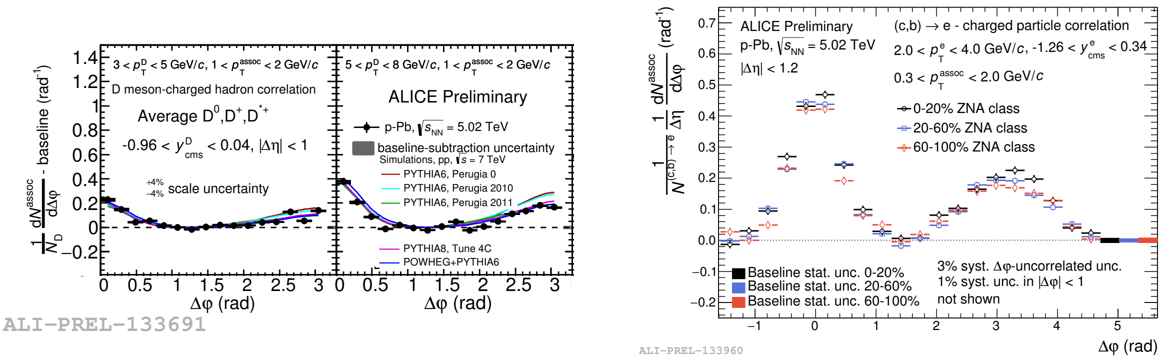

Figure 4: Left: Comparison of the azimuthal correlation distributions of D mesons with charged particles in p–Pb collisions in two different D-meson p_{T} intervals with the expectations from different Monte Carlo event generators. Right: azimuthal correlation distributions of heavy-flavour hadron decay electrons with charged particles in different centrality ranges.

5. Conclusion

The ALICE results on open heavy-flavour production in p–Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV have been reported. The charm meson and baryon production in p–Pb collisions is compatible with models that include CNM effects. A hint of modified D^0 production in high-multiplicity p–Pb collisions is observed, that could derive from initial- or final-state effects, including the possible presence of radial flow in p–Pb collisions. Azimuthal correlation of D mesons and electrons from heavy-flavour hadron decays with charged particles are in agreement with model calculations. The shown studies as a function of centrality can give further insight into the possible presence of collective mechanisms in high-multiplicity p–Pb collisions.

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