PROCEEDINGS OF SCIENCE

Open heavy-flavour production and elliptic flow in p–Pb collisions at the LHC with ALICE

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Measurements of open heavy-flavour production in p–Pb collisions allow assessing the Cold Nuclear Matter effects due to the presence of a nucleus in the colliding system. Moreover, the study of a modification of the heavy-flavour hadrons transverse momentum in high-multiplicity p–Pb collisions can give insight into the possible presence of collective effects also in small systems. In this report, the ALICE measurements on open heavy-flavour production in p–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ and 8.16 TeV are presented. Emphasis is given to measurements in high-multiplicity p–Pb collisions and to the recent elliptic flow measurements of leptons from heavy-flavour decay hadrons.

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1. Introduction

Measurements of open heavy-flavour production in p–Pb collisions provide a tool to investigate the role of the Cold Nuclear Matter (CNM) effects [1], which include gluon shadowing, saturation, k_{T} broadening, and energy loss in CNM. The CNM can affect the production rate and the kinematic properties of heavy-flavour hadrons in nuclear collisions. Furthermore, in recent years, some typical effects of nucleus-nucleus collisions have been also observed in pp and p–Pb systems, as the long-range flow-like angular correlations in high-multiplicity events [2] and the strangeness enhancement with multiplicity in small systems [3], usually ascribed to the collective expansion of the Quark–Gluon Plasma (QGP). The CNM effects can be investigated through the measurement of the nuclear modification factor R_{pPb}, that compares the production cross sections in p–Pb collisions with those measured in pp collisions. The study of the nuclear modification factor in high multiplicity events can give insight into a possible modification of the transverse momentum (p_{T}) spectrum, that can originate from initial- or final-state effects, as for example collectivity in the system. In fact, an expanding medium could impart a flow to heavy-flavour quarks, or modify their hadronisation dynamics. The latter can be investigated by studying the ratio of heavy-flavour mesons with different quark content. The measurement of angular correlations of heavy-flavour decay electrons with charged particles provides an important extension of studies performed with light-flavour hadrons to further characterise the flow-like behaviour.

In this contribution, the production measurement of D^0, D^+, D^{*+}, and D_s^+ mesons is presented. The D mesons are reconstructed with the ALICE detector via their hadronic decays at mid-rapidity in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV, consisting of 6×10^8 minimum bias events collected by ALICE in 2016. In particular, the D-meson cross sections down to $p_{\mathrm{T}} = 0$, the nuclear-modification factor, as well as multiplicity- and centrality-dependent studies are reported. The measurements of the production of heavy-flavour hadron decay leptons at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 and 8.16 TeV is also reported, focusing on the measurement of the elliptic flow of heavy-flavour hadron decay electrons and muons in high-multiplicity p–Pb collisions, at mid- and forward-rapidity, respectively. The data are compared to light-flavour results and to theoretical calculations.

2. D-meson production in p–Pb collisions

The nuclear modification factor is defined as $R_{\mathrm{pPb}} = \frac{1}{A}\frac{\mathrm{d}^2\sigma_{\mathrm{pPb}}^{\mathrm{prompt\,D}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}{\mathrm{d}^2\sigma_{\mathrm{pp}}^{\mathrm{prompt\,D}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}$, where $A = 208$ is the Pb mass number and the pp cross section ($\sigma_{\mathrm{pp}}^{\mathrm{prompt\,D}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y$) is obtained by the recent measurements performed at $\sqrt{s}$ = 5.02 TeV [4]. The average R_{pPb} of the non-strange prompt D^0, D^+, and D^{*+}, as a function of p_{T}, is shown in the left panel of Fig. 1, in comparison to that of D_s^+. The two measurements are compatible within each other, and they are compatible with unity over the whole p_{T} coverage. Data are compared with the theoretical calculations including only CNM effects, and also with models that assume a QGP formation in p–Pb collisions [5] (right panel). The measurement is also performed in centrality intervals, 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 ${Q_{\mathrm{pPb}}}^{\mathrm{cent}} = \frac{(\mathrm{d}^2N^{\mathrm{prompt\,D}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y)_{\mathrm{pPb}}^{\mathrm{cent}}}{\langle T_{\mathrm{pPb}}\rangle^{\mathrm{cent}} \times (\mathrm{d}^2\sigma_{\mathrm{pp}}^{\mathrm{prompt\,D}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y)}$ where $(\mathrm{d}^2N^{\mathrm{prompt\,D}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y)_{\mathrm{pPb}}^{\mathrm{cent}}$ is the yield of prompt D mesons in p–Pb collisions in a given centrality class, and $\langle T_{\mathrm{pPb}}\rangle^{\mathrm{cent}}$ is the average nuclear overlap function in the same centrality class [5]. The Q_{pPb} is evaluated in the most central (0–10%) and most peripheral (60–100%) centrality class. The results in the two centralities are consistent within uncertainties. In 0–10% (60–100%) the Q_{pPb} is slightly larger (lower) than unity at intermediate p_{T}, and both the measurements are compatible with those of charged particles, in similar centrality regions, as shown in the left and middle panel of Fig. 2. The Q_{cp}, defined as the ratio of the corrected yield in 0–10% to the 60–100% centrality class, is shown in the right panel of the same figure. The Q_{cp} provides a more precise comparison of the yields, since it is independent of the pp cross section and most of the systematic uncertainties cancel in the ratio. There is an evident trend in the shape of the Q_{cp}, similar to the one of charged particles, with a bump in the intermediate p_{T} region, where it is larger than unity by only 1.5 standard deviations, due to the large normalisation uncertainty. This can be interpreted as a p_{T}-spectra modification in the most central events with respect to the most peripheral ones. It could arise from initial- or final-state effects, or could be explained as radial flow in p–Pb collisions.

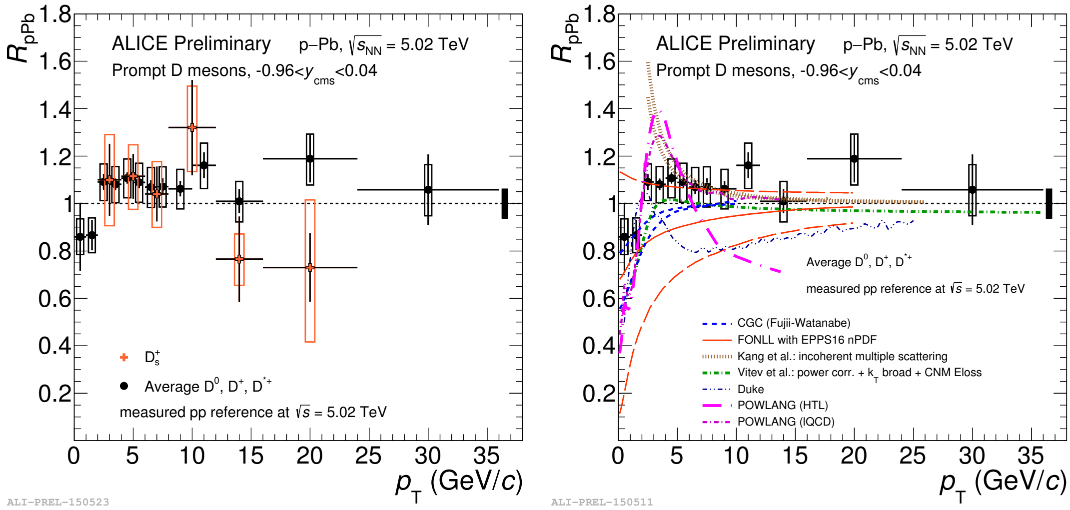

Figure 1: Nuclear modification factor R_{pPb} of prompt D mesons in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. Left: average R_{pPb} of non-strange D mesons and $\mathrm{D_s}$. Right: Comparison with theoretical calculations [5].

The ratio of the $\mathrm{D_s^+}$ and $\mathrm{D^+}$ yields is shown in Fig. 3 as a function of charged-particle multiplicity, $\mathrm{dN_{ch}}/\mathrm{d}\eta$, in different p_{T} ranges. The multiplicity was estimated at mid-rapidity, as described in [6]. The ratios measured in p–Pb collisions are shown with the corresponding results performed in pp collisions at $\sqrt{s}$ = 7 TeV [7]. There is no evidence of a modification of $\mathrm{D_s^+}/\mathrm{D^+}$ yield ratios in p–Pb with respect to the results in pp collisions, indicating that the increasing production of strangeness versus multiplicity observed in the light-flavour sector is not present in the charm-flavour sector.

3. Elliptic flow of heavy-flavour decay leptons in p–Pb collisions

The angular correlations between heavy-flavour decay electrons and charged particles at mid-rapidity has been studied in p–Pb collisions for the 0–20% (high) and 60–100% (low) multiplicity

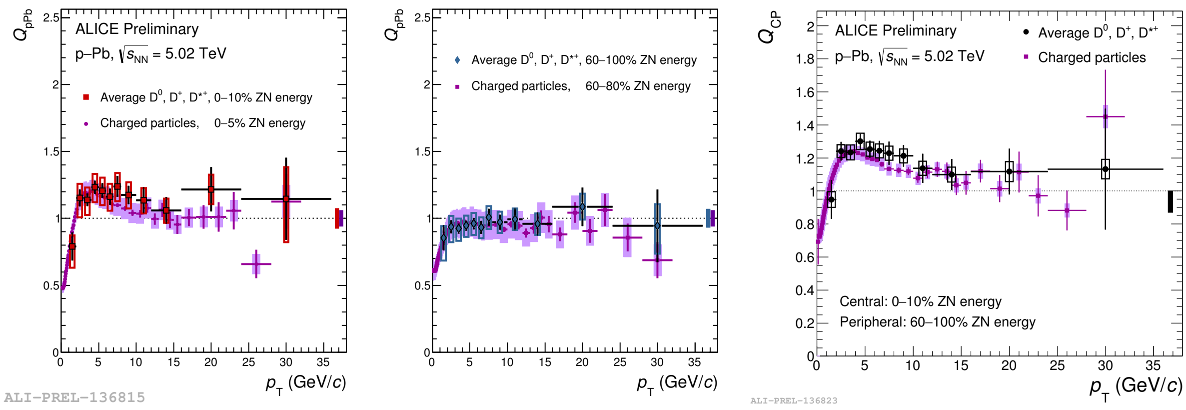

Figure 2: Average non-strange D-meson $Q_{\rm pPb}$ for most central (left panel) and peripheral (middle panel) collisions, and $Q_{\rm cp}$ (right panel) in comparison with charge particle measurement [5].

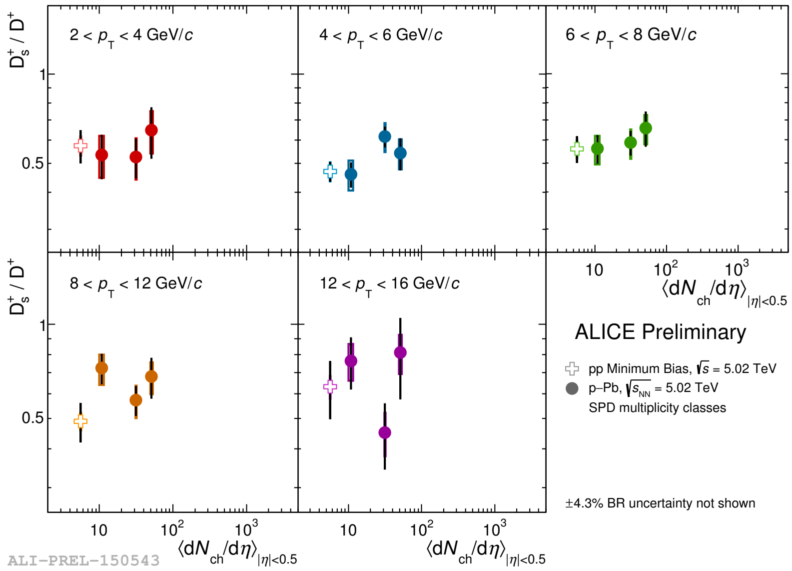

Figure 3: D_s^+/D^+ yield ratios as a function of charged particles per unity of pseudorapidity in pp and p–Pb collisions at $\sqrt{s}$ = 7 TeV and 5.02 TeV, respectively, in different p_T intervals.

ranges. Events are divided in multiplicity classes using the V0A detector, an array of scintillators in the backward (Pb-going) direction ($2.8 < \eta < 5.1$). The jet contribution in the correlation distribution from high-multiplicity events is removed by subtracting the distribution from low-multiplicity events. An azimuthal modulation remains after removing the jet contribution. A Fourier decomposition of the modulation results in a positive second-order coefficient (v_2) for heavy-flavour decay electrons in the transverse momentum interval $1.5 < p_T < 4$ GeV/c in high-multiplicity events, as shown in Fig. 4 (left panel), with a significance larger than 5σ [8]. The results are compared with those of charged particles at mid-rapidity and of inclusive muons at forward rapidity. A similar analysis was performed at forward rapidity for muons in an extended p_T range, where the

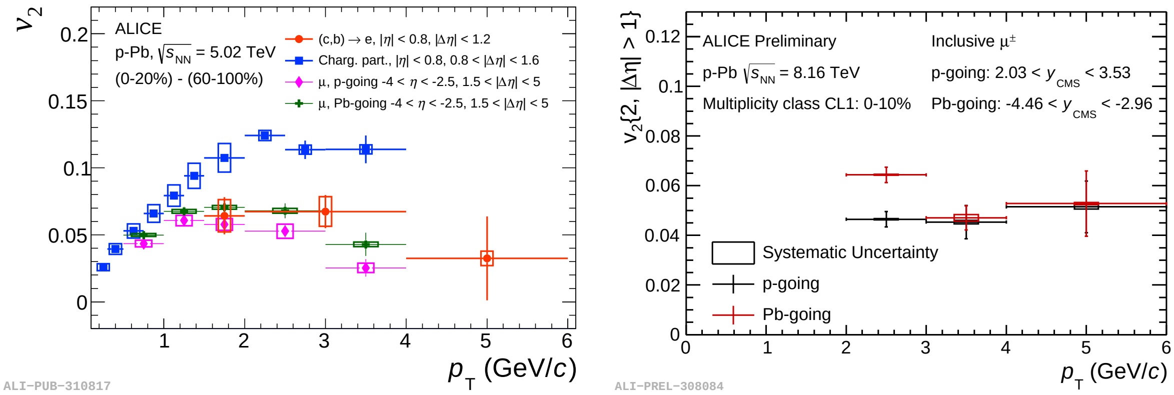

Figure 4: Heavy-flavour decay electron v_2 as a function of p_T measured in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, compared to the v_2 of unidentified charged particles and inclusive muons (left panel). Muon v_2 in an extended p_T range, measured in p–Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV (right panel).

heavy-flavour component dominates the muon spectra, and in a different collisions energy $\sqrt{s_{NN}}$ = 8.16 TeV, in the p- and Pb-going direction, thus probing different rapidity ranges at forward and backward rapidity. The analysis was done for the most central (0-10%) collisions, using the cumulant method with two-particle correlations. A positive muon v_2 is observed with a significance larger than 3σ, and its strength is compatible to the one of electrons at mid-rapidity.

4. Conclusions

The ALICE results on open heavy-flavour production in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV and 8.16 TeV have been reported. The charm meson production in p–Pb collisions is compatible with models that include CNM effects but also with models that assume the formation of a QGP in p–Pb. A hint of modified D-meson 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. The elliptic flow of heavy-flavour hadron decay electrons and muons in high-multiplicity p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV and 8.16 TeV, respectively, is found to be positive with a significance larger than 5σ and 3σ.

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