Measurement of Open Heavy-Flavour Production in pp and p-Pb Collisions with ALICE at the LHC

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The Large Hadron Collider at CERN allows us to study heavy-ion collisions at an unprecedented energy. ALICE, A Large Ion Collider Experiment, is the experiment dedicated to the investigation of heavy-ion collisions. In this contribution, recent open heavy-flavour results from pp collisions at $\sqrt{s}=5.02, 7, 8$ and 13 TeV and p-Pb collisions at $\sqrt{s_{NN}}=5.02$ TeV, collected with the ALICE detector during the LHC Run-1 and Run-2 are presented. The results include the production cross section, nuclear modification factor and multiplicity dependence studies of production of D mesons and electrons from heavy-flavour hadron decays at mid-rapidity and of muons from heavy-flavour hadron decays at forward rapidity. Charm production was measured down to $p_T = 0$ GeV/c in pp and p-Pb collisions. Recent measurements of the production cross section of heavy charmed baryons such as Λ_c (in pp and p-Pb) and Ξ_c (in pp) are discussed. The results are compared with theoretical model predictions.

Keywords: Open heavy flavour; pQCD; cross section; nuclear modification factor; CNM effect.

1. Introduction

The measurements of heavy-flavour production in pp collisions are important to test predictions from perturbative QCD and provide an essential baseline for the studies in heavy-ion collisions. Differential studies of their production as a function of the multiplicity of charged particles produced in the collisions can give insight into multi-parton interaction phenomena, and into the interplay between hard and soft processes. The study of heavy-flavour production in p-Pb collisions is also required to disentangle the influence on particle production of cold nuclear matter effects from those related to the formation of a QGP in Pb-Pb collisions.

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2. Open heavy-flavour reconstruction with ALICE

The ALICE apparatus has excellent capabilities for heavy-flavour measurements. It is composed of a central barrel and a forward muon arm. A detailed description of the experimental setup can be found in¹. At mid rapidity ($|\eta| < 0.9$), open heavy-flavour production is measured via the hadronic decays of D mesons (D^0, D^+, D^{*+} and D_s^+) and Λ_c^+ baryon, the partial reconstruction of prompt $\Lambda_c^+ \rightarrow e^+ \nu_e \Lambda$ and ($\Xi_b \rightarrow \Xi_c^0 \rightarrow e^+ \Xi^- \nu_e$) decays, and via the identification of electrons from semileptonic decays of charm and beauty hadrons. At forward rapidity ($-4 < \eta < -2.5$), muons from heavy-flavour hadron decays are reconstructed in the muon spectrometer.

3. Results in pp collisions

The differential production cross sections of prompt D mesons (D^0, D^+, D^{*+} and D_s^+), heavy-flavour decay electrons, electrons from beauty-hadron decays and heavy-flavour decay muons were measured in pp collisions at $\sqrt{s}=7^{2,3}, 2.76^4, 8$ and 13 TeV. They are well described by pQCD calculations^{5,6,7}. The first measurement

Fig. 1. Left: p_T -differential cross section of Λ_c^+ baryons in pp collisions⁸ compared with model predictions^{9,10,11}. Right: Ratio of Λ_c^+ baryon and D^0 -meson yields in pp collisions at $\sqrt{s}=7$ TeV and p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV compared with the model predictions.

of the production cross section of Λ_c^+ at mid-rapidity at LHC is shown in fig.1 (left) which is also compared with model predictions. In the whole p_T range considered, the models underestimate the data by a factor 2-10 which can be seen at the bottom of the figure 1. Figure 1 (right) shows the baryon-to-meson ratio Λ_c^+/D^0 which is also compared with theoretical predictions. While all models underpredict the data, PYTHIA8 with enhanced colour reconnection manages to reproduce the observed p_T -trend. Also, The Λ_c^+/D^0 ratio in pp collisions is compatible with the same ratio in p-Pb collisions within uncertainties. Further, The open heavy flavour production is also studied as a function of multiplicity of charged particles

Fig. 2. Left: Average D^0 , D^+ and D^{*+} and inclusive J/ψ relative yields as a function of charged-particle multiplicity (see text). Right: comparison of the results of D-meson production and inclusive J/ψ at $\sqrt{s}=7$ TeV to inclusive J/ψ at $\sqrt{s}=13$ TeV

produced in the collision. In figure 2 (left) average D^0 , D^+ and D^{*+} and inclusive J/ψ yield per multiplicity intervals normalized to the yield obtained in the multiplicity-integrated sample is shown as a function of charged-particle multiplicity normalized by its average measured in multiplicity-integrated events¹². An increasing trend as a function of charged particle multiplicity is observed for both J/ψ and D mesons, suggesting that multi-parton interactions (MPI), which substantially contribute to high-multiplicity events, are important to understand heavy-flavour production rate as a function of the event multiplicity. Also the current measurement of J/ψ in pp at $\sqrt{s}=13$ TeV are compared to the measurements of J/ψ and D-meson production at $\sqrt{s}=7$ TeV. The results are in agreement, indicating that no significant energy dependence of the relative increase of the production with event multiplicity could be observed.

4. Results in p-Pb collisions

In p-Pb collisions, cold nuclear matter (CNM) effects such as the modification of the PDFs due to the presence of the nucleus are expected to affect the heavy-quark yield and p_T distributions relative to the pp collisions. The p-Pb spectra are quantitatively compared to the pp reference by computing the nuclear modification factor R_{pPb} which is defined as: $R_{pPb} = \frac{1}{A} \frac{d\sigma_{pPb}/dp_T}{d\sigma_{pp}/dp_T}$, where A is the Pb atomic mass number, σ_{pp} and σ_{pPb} are the production cross section in pp and p-Pb collisions, respectively. Figure 3 shows the average of the non-strange D mesons (D^0 , D^+ and D^{*+}) R_{pPb} compared to the D_s^+ in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV using data from Run-2 at the LHC. The R_{pPb} is consistent with unity for strange as well as non-strange D mesons. The results are compatible with those obtained in Run-1 results¹³. The data are described by models including CNM effects, as well as by models assuming the formation of QGP in p-Pb collisions, though at high p_T a suppression larger than 15% is disfavoured. The nuclear modification factor of

Fig. 3. Left: Average of D-meson (D^0, D^+, D^+) R_{pPb} and D_s^+ R_{pPb} as a function of p_T . Right: averaged D-mesons (D^0, D^+, D^+) R_{pPb} in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV compared to model calculations.

prompt D-mesons was also computed as a function of centrality, where centrality is determined using the energy deposited in the zero-degree neutron calorimeter in the Pb-going side (ZNA) i.e Q_{pPb}

$$Q_{pPb} = \frac{(d^2 N^{\text{prompt D}}/dp_T dy)_{pPb}^{\text{cent}}}{\langle T_{pPb} \rangle^{\text{mult}} \times (d^2 \sigma_{pp}^{\text{prompt D}}/dp_T dy)}$$

where $(d^2 N/dp_T dy)_{pPb}^{\text{cent}}$ and $\langle T_{pPb} \rangle^{\text{mult}}$ are the yield of prompt D mesons in p-Pb collisions and the average nuclear overlap function in a given centrality class, respectively. The Q_{pPb} was evaluated in the most central collisions in the 0–10% class and in the most peripheral collisions in the 60–100% centrality class, offering the possibility to compute the central-to-peripheral ratio Q_{CP} .

$$Q_{CP} = \frac{(d^2 N^{\text{prompt D}}/dp_T dy)_{pPb}^{0-10} / \langle T_{pPb} \rangle^{0-10}}{(d^2 N^{\text{prompt D}}/dp_T dy)_{pPb}^{60-100} / \langle T_{pPb} \rangle^{60-100}}$$

Figure 4 (left panel) presents the Q_{pPb} results for average of prompt D-mesons as a function of p_T for the 0–10% and 60–100% centrality classes. The results in the two centrality classes are consistent with unity within the uncertainties, although the central values of the Q_{pPb} are generally larger than unity in the 0–10% class and slightly lower than unity in the 60–100% class. The right panel of figure 4 shows the average D-mesons Q_{CP} superimposed to the one obtained from charged particles. A similar trend is observed for both the particles: the Q_{CP} increases in the interval 1–5 GeV/c, reaching values of about 1.3 and then tends to decrease in the interval 7–16 GeV/c. The average value of the D-meson Q_{CP} in the interval $3 < p_T < 8$ GeV/c is larger than unity by 1.5 standard deviations of the statistical and systematic uncertainty. In figure 5, 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 including POWHEG+PYTHIA with EPS09 nuclear PDF¹¹ and a prediction

Fig. 4. Left: Averaged nuclear modification factor of D-mesons as a function of p_T in 0–10 % and 60–100 % centrality classes. Right: D-meson central to peripheral nuclear modification factor.

Fig. 5. Left: 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 ^{?,14} (right panel).

for charmed hadrons which assumes a small size QGP formed¹⁴, are presented in the right panel of the figure. The precision achieved with the current measurement does not allow us to distinguish between calculations with and without hot medium effects. Figure 6 shows the p_T -differential cross section times branching ratio of the Ξ_c^0 baryon (including prompt and non-prompt contributions), and the baryon-to-meson ratio Ξ_c^0/D^0 in comparison to predictions from PYTHIA. The shaded band for the models spans the range of theoretical predictions for the Ξ_c^0 branching ratio^{16,17,18}. As for the Λ_c^+/D^0 ratio, all predictions significantly underestimate the data.

5. Summary

Recent results on open charm and baryon production in pp and p-Pb collisions has been reported. The p_T -differential cross sections for open-charm mesons in pp collisions are reproduced within uncertainties by theoretical predictions based on

Fig. 6. Left: The p_T -differential cross section times branching ratio of the Ξ_c^0 baryon in pp collisions at $\sqrt{s} = 7$ TeV. Right: The Ξ_c^0/D^0 ratio compared to theoretical predictions.¹⁵

pQCD calculations, where as for the baryon production, all models underestimates the data. R_{pPb} of charm and baryon in p-Pb collisions is consistent with unity within uncertainties, providing evidence that CNM effects are small in the measured p_T range. The average value of the D-meson Q_{CP} in the interval $3 < p_T < 8$ GeV/c is larger than unity by 1.5 standard deviations of the statistical and systematic uncertainty, that could derive from the initial- or final-state effects, including the possible presence of radial flow in p-Pb collisions.

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