Λ_c^+ production cross section in pp and p–Pb collisions down to $p_T = 0$ at $\sqrt{s_{NN}}$ = 5.02 TeV measured with ALICE

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The open heavy-flavour hadron measurements in proton–proton and proton–lead collisions give insight into the charm production and hadronization mechanisms. In this contribution, the latest measurements of the production cross section of prompt Λ_c^+ and its charge conjugate performed with the ALICE detector at midrapidity in pp, and the new measurement of $\Lambda_c^+ \to pK_S^0$ performed down to $p_T = 0$ in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV are presented. We also present the first ALICE measurement of the baryon-to-meson ratio Λ_c^+/D^0 and the Λ_c^+ nuclear modification factor R_{pPb} down to $p_T = 0$ in p–Pb collisions. The Λ_c^+/D^0 ratio at midrapidity at the LHC is significantly higher than the one in e^+e^- collisions, suggesting that the fragmentation of charm is not universal across different collision systems. The results are compared with theoretical calculations.

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1. Introduction

The production cross sections of open heavy-flavour hadrons are typically described within the factorisation approach as the convolution of the parton distribution functions of the incoming protons, the perturbative QCD partonic cross section, and the fragmentation functions. The fragmentation functions are parametrised from measurements in e^+e^- collisions, assuming a universality across different collision systems. Thus, measurements of charm-baryon production are crucial to study the charm quark hadronization in pp and p–Pb collisions and its difference with respect to e^+e^- collisions. Especially the baryon-to-meson ratio Λ_c^+/D^0 is sensitive to the charm hadronization mechanism. In the recent ALICE measurements an enhanced Λ_c^+ baryon production was observed with respect to e^+e^- collisions [1]. This could hint to further colour reconnection string topologies due to a larger number of multi-parton interactions or to the formation of a hot deconfined medium in small collision systems which would allow hadronization via coalescence. Furthermore, measurements of charm-baryon production in p–Pb collisions provide important information about Cold Nuclear Matter (CNM) effects quantified in the nuclear modification factor R_{pPb}:

$$R_{pPb} = \frac{d\sigma_{pPb}/dp_T}{A \cdot d\sigma_{pp}/dp_T}, \tag{1}$$

where $d\sigma_{pPb(pp)}/dp_T$ are the p_T-differential cross sections in p–Pb and pp collisions at a given centre-of-mass energy, and $A = 208$ is the lead mass number. The charm hadron production measurement could also help us to understand how the possible presence of collective effects could modify the production of heavy-flavour hadrons in different colliding systems.

In this contribution recent ALICE results on the Λ_c^+ baryon production in pp and p–Pb collisions will be shown [1], as well as a new measurement of the $\Lambda_c^+ \to pK_S^0$ production cross section down to $p_T = 0$ in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The extension of the measured p_T range in p–Pb collisions is possible, since for the first time in ALICE the Λ_c^+ candidates are reconstructed employing the KFParticle package [2], together with machine learning techniques. The package is based on the Kalman filter method, and it is especially suitable for short-lived particles like the Λ_c^+, which decay before reaching the innermost detectors of the ALICE apparatus. Furthermore, particle identification and topological selections are optimized using the machine learning algorithm XGBoost [3]. The extracted signal is corrected for the detector acceptance and reconstruction efficiency, and contributions from the decay of beauty hadrons are subtracted. Due to the extended p_T range for Λ_c^+ baryons in p–Pb collisions a measurement of Λ_c^+/D^0 and R_{pPb} down to $p_T = 0$ is presented.

2. Production cross section and baryon-to-meson ratio

The measurement of the Λ_c^+ production cross section is performed with the ALICE detector at a nucleon-nucleon centre-of-mass energy of $\sqrt{s_{NN}} = 5.02$ TeV. The published p_T-differential cross section in p–Pb collisions in the range $1 < p_T < 24$ GeV/c [1] is extended with the new measurement down to $p_T = 0$. In Fig. 1 the result is compared to a model calculation with the POWHEG event generator [5] and PYTHIA 6 [6] for the parton shower generation using the parton distribution functions CT14NLO [7]. The nuclear modifications of the PDFs in p–Pb collisions are modelled
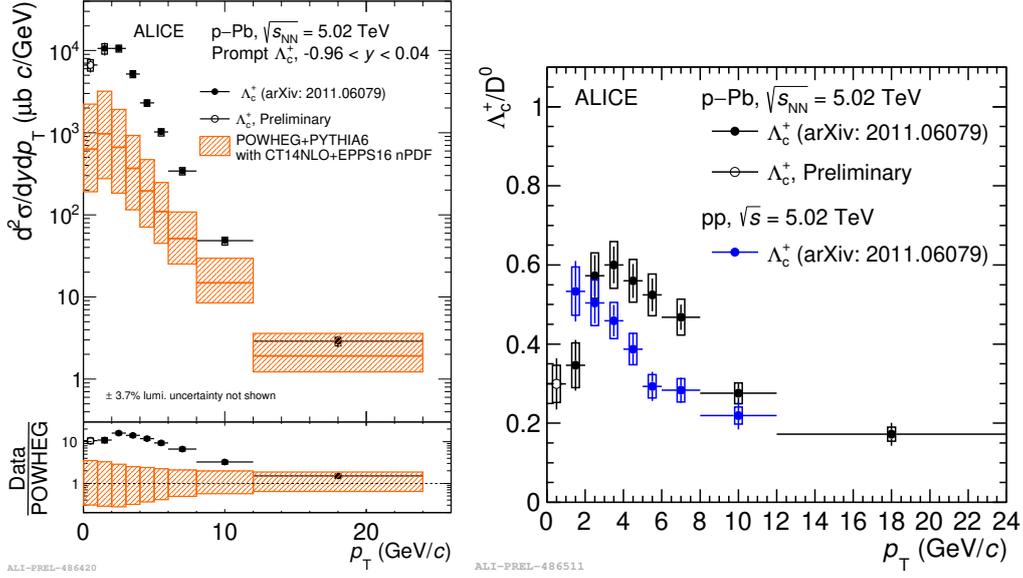
Figure 1: Left: Prompt Λ_c^+ cross section in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV [1] in comparison with POWHEG event generator [5] plus PYTHIA 6 model calculation [6]. Right: Λ_c^+/D^0 ratio in pp and p–Pb collisions.

with the EPPS 16 nPDF parametrisation [8]. This model is based on the factorisation approach, using fragmentation functions tuned on data from e^+e^- collisions. As shown in the left panel of Fig. 1 the central prediction of the model significantly underestimates the data for $p_T < 8$ GeV/c. The relative abundances of the charm meson species are sensitive to the fragmentation functions, and thus to the hadronization process. The baryon-to-meson Λ_c^+/D^0 ratios are shown in the right panel of Fig. 1, where the measurements in pp and p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV are compared. An enhancement is observed in both collision systems compared to e^+e^- collisions ($\Lambda_c^+/D^0 = 0.113 \pm 0.013 \pm 0.006$ [4]), suggesting that the charm fragmentation is not a universal process across different collision systems. Furthermore, a shift of the p_T distribution in p–Pb collisions with respect to pp collisions is observed. This could be an indication of radial flow in p–Pb collisions or of a multiplicity dependence of the charm quark hadronization. A hardening of the p_T spectra is predicted by models in the presence of a deconfined medium and also observed in the strange sector [9]. Thus, this behaviour for heavy-flavour hadrons could also be interpreted as a hint of collective behaviour in p–Pb collisions.

3. Nuclear modification factor

The nuclear modification factor R_{pPb} provides a comparison of the production cross section in pp and p–Pb collisions scaled by the lead mass number. The Λ_c^+ cross section in pp collisions was obtained by the ALICE Collaboration in the range $1 < p_T < 12$ GeV/c [1] and extrapolated to lower and higher transverse momenta using a PYTHIA 8 model calculation [11]. In the left panel of Fig. 2 the nuclear modification factor for prompt Λ_c^+ in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV is compared to non-strange D-mesons [10]. While the R_{pPb} is consistent with unity for the mesons, a
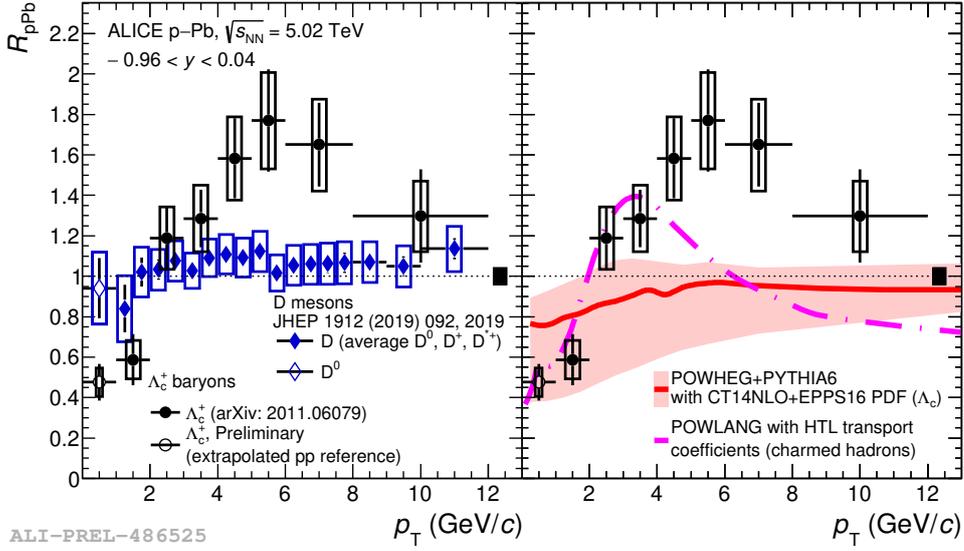
Figure 2: Nuclear modification factor R_{pPb} for prompt Λ_c^+ in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV in the transverse momentum range $0 < p_T < 12$ GeV/c [1]. Left: Comparison to non-strange D mesons [10]. Right: Comparison of the measurement to POWHEG + PYTHIA 6 [5], [6], POWLANG model calculations [12].

suppression is observed at low p_T for Λ_c^+ and an enhancement at intermediate p_T. The right panel of Fig. 2 shows a comparison of the nuclear modification factor with different models. The above mentioned model, using the POWHEG event generator and PYTHIA 6, assumes hadronization via fragmentation and takes into account initial-state effects for the $c\bar{c}$ production, that occur in the collision of a proton with a heavy nucleus. While the model agrees with the measurement within the uncertainties at low p_T, a tension can be seen at intermediate and high p_T. Additionally, the shape of the distribution is not captured. The POWLANG transport model [12] takes into account initial-state effects as well, but it assumes the formation of a hot deconfined medium in p–Pb collisions implementing hadronization via fragmentation and recombination of a charm quark with light quarks in the medium. Since the model assumes the formation of a medium the heavy quark will loose energy in the medium, which leads to a suppression of the nuclear modification factor at low p_T. Although the model describes the measured R_{pPb} at $p_T < 3$ GeV/c, a deviation can be seen at intermediate and high p_T.

4. Summary

In this contribution the new ALICE measurements of the Λ_c^+ cross section, Λ_c^+/D^0 and Λ_c^+ R_{pPb} down to $p_T = 0$ in p–Pb collisions were shown. The baryon-to-meson ratio is enhanced with respect to e^+e^- collisions, indicating that the charm fragmentation is not a universal process across different collision systems. In the future the measurement precision of heavy-flavour hadrons will improve in Run 3 and beyond due to increased data taking rates and upgraded tracking detectors. An improved tracking resolution of the new Inner Tracking System will also allow a better separation of the reconstructed signal from the large combinatorial background [13].

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