EPJ Web of Conferences **276**, 02005 (2023) https://doi.org/10.1051/epjconf/202327602005
SQM 2022

Constraining hadronization processes with charmed baryons in pp and p–Pb collisions with ALICE

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Abstract. The latest measurements of D^0, D^+ and $D_s{}^+$ mesons with the final measurements of Λ_c^+, $\Xi_c^{0,+}$, $\Sigma_c^{0,++}$, and the first measurement of Ω_c^0 baryons performed with the ALICE detector at midrapidity in pp collisions at $\sqrt{s} = 5.02$ TeV and $\sqrt{s} = 13$ TeV are presented. Furthermore, the recent Λ_c^+/D^0 yield ratio, measured down to $p_T = 0$ in p–Pb collisions are discussed. Finally, the first measurements of charm fragmentation fractions and charm production cross section at midrapidity per unit of rapidity are shown for both pp and p–Pb collisions using all measured charm ground state hadrons.

1 Introduction

The production cross sections of heavy flavor mesons are well described by theoretical models based on perturbative QCD calculations that assume fragmentation functions of charm to be universal among different collision systems. Recent measurements of charm-baryon production at midrapidity in pp and p–Pb collisions systems show a baryon-to-meson ratio significantly higher than that in e^+e^- collisions [1, 2], suggesting that the fragmentation of charm is not universal. Therefore, measurements of charm-baryon production are crucial to study the charm quark hadronization in a partonic-rich environment like the one produced in pp collisions at LHC energies. Thanks to the excellent particle identification capabilities, and optimal vertex resolution, ALICE is well suited to measure various charmed hadrons. These measurements provide information about the hadronization process of heavy quarks.

2 Charmed baryon measurements

2.1 Λ_c^+ and $\Sigma_c^{0,++}$measurements

ALICE measured the Λ_c^+/D^0 ratio in pp collisions at $\sqrt{s} = 5.02$ TeV [3, 4] and 13 TeV [5] down to $p_T = 0$, showing that they are compatible within uncertainties. The Λ_c^+/D^0 ratio, shown in Fig. 1 (left), presents for $p_T < 10$ GeV/c an enhancement with respect to the values $\Lambda_c^+/D^0 \sim 0.11$ [1, 2] measured in e^+e^- and ep collisions, as well as strong p_T dependence not expected by models, which by assuming the fragmentation functions in pp collisions to be the same as those extracted from e^+e^- and ep collisions values. The p_T dependence of charmed baryon-to-meson ratio may suggest that the assumption of universality of charm fragmentation among collision systems is not valid.

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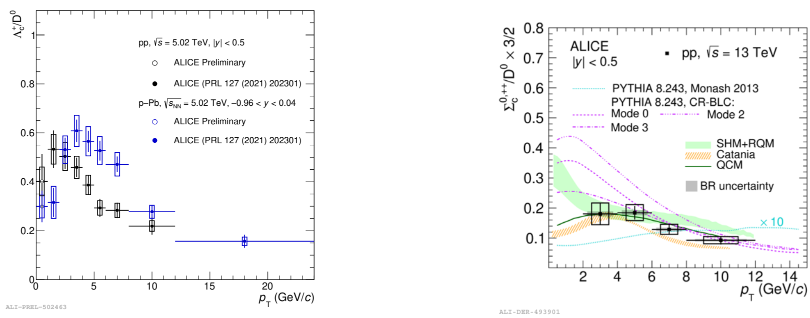

Figure 1. Left panel: Λ_c^+/D^0 as a function of p_T in pp and p–Pb collisions at $\sqrt{s} = 5.02$ TeV . Right panel: $\Sigma_c^{0,++}/D^0$ ratio as a function of p_T at $\sqrt{s} = 13$ TeV.

The production of Λ_c^+ in p–Pb collisions is also measured down to $p_T = 0$. The Λ_c^+/D^0 ratio measured in p–Pb collisions is higher than the one measured in pp collisions for $p_T > 3$ GeV/c, and lower for $p_T < 2$ GeV/c. This could be interpreted as a consequence of radial flow [6] or different hadronization processes between pp and p–Pb collisions [7]. The p_T integrated yields of Λ_c^+/D^0 ratio in both collision systems are compatible within uncertainties [4].

ALICE measured $\Sigma_c^{0,++}$to investigate further the charmed baryon production in pp collisions at $\sqrt{s} = 13$ TeV. The ratio shown in Fig. 1 (right) presents an enhancement in the measured p_T region with respect to the e^+e^- predictions of models based on e^+e^- data and assuming hadronization to be unaltered in pp collisions. The PYTHIA8 Monash [8] uses the Lund string model and the fragmentation functions tuned to reproduce e^+e^- data. The PYTHIA8 Mode 0,2,3 tunes implement the new Color Reconnection topologies beyond leading color approximation (CR-BLC) [9], including junctions. The junctions (three-leg topology) increase the chance to connect partons from different multi-parton interactions, enhancing the formation of baryons. Therefore, the PYTHIA 8 with CR-BLC can describe the enhancement of Λ_c^+ and $\Sigma_c^{0,++}$. The Catania model [10] assumes that the hadronization occurs via vacuum fragmentation and coalescence of charm quarks with light quarks in a hot QCD matter in pp collisions. A blast wave parametrization is used for the light quark spectra, and the FONLL calculation [11, 12] is used for the heavy quark spectra. The Statistical Hadrobnization Model (SHM) [13], which assumes that the yields of the various hadron species are determined by thermal weights depending mainly on the system temperature and hadron masses, can reproduce the Λ_c^+/D^0 and $\Sigma_c^{0,++}/D^0$ ratios by assuming the existence of exciting charm baryon states which are not yet observed. All three CR modes and the SHM describe the observed p_T dependence, while the PYTHIA8 Monash tune significantly underestimates the measurement by a factor of 15-20 at low p_T and a factor of 5 at high p_T [5].

2.2 Ξ_c^0 and Ω_c^0 measurements

The charm-strange baryons, $\Xi_c^{0,+}$ and Ω_c^0, were measured by ALICE in pp collisions at $\sqrt{s} = 13$ TeV. The $\Xi_c^{0,+}/D^0$ ratios [14] are shown in the left panel of Fig. 2, and the Ω_c^0/D^0 [15] ratio is shown in the right panel. The branching ratio (BR) of this Ω_c^0 decay is not yet measured, and a theoretical calculation [16] is used to scale the model predictions. Most models significantly underestimate the measurements, except for Catania model, which is close to the data in the measured p_T interval, both for the $\Xi_c^{0,+}/D^0$ and the Ω_c^0/D^0 ratios.

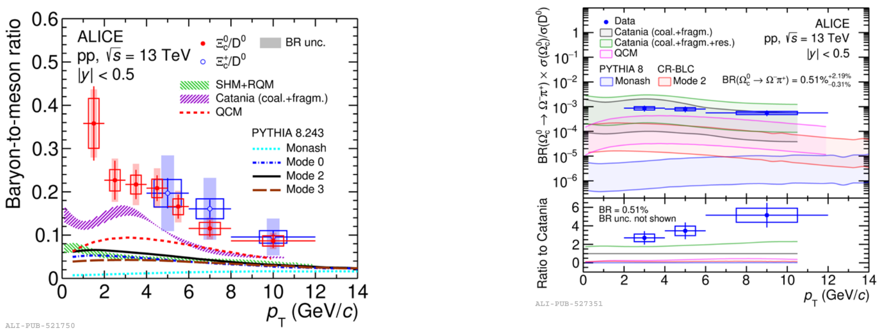

Figure 2. Left panel: $\Xi_c^{0,+}/D^0$ as a function of p_T in pp collisions at $\sqrt{s}$ = 13 TeV. Right panel: BR × Ω_c^0/D^0 ratio as a function of p_T in pp collisions at $\sqrt{s}$ = 13 TeV.

ALICE also measured $\Xi_c^{0,+}/\Sigma_c^{0,++}$ ratio yield. Most models underestimate the $\Xi_c^{0,+}/\Sigma_c^{0,++}$ ratio measurement, as observed for the charmed baryon-to-meson ratio measurements. However, the PYTHIA8 Monash describes the measurement of $\Xi_c^{0,+}/\Sigma_c^{0,++}$, and the value shows a similar enhancement with respect to e^+e^- results. A possible explanation for this behavior may be the similar masses of the light diquarks in the two baryons ($m(uu, ud, dd)_1 \approx m(ds)_0$), which implies a similar suppression with respect to Λ_c^+ yield due to the lower probability of forming the needed diquark-pair in a string breaking with respect to the lighter diquark ($m(ud)_0$) necessary to form a Λ_c^+ .

2.3 Charm fragmentation fractions and production cross section

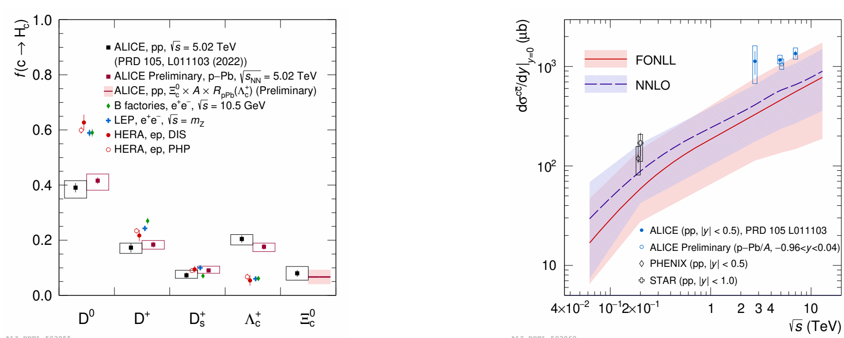

Figure 3. Left panel: Charm-quark fragmentation fractions into charm hadrons in pp and p–Pb collisions at $\sqrt{s}$ = 5.02 TeV . Right panel: charm production cross section at midrapidity as a function of the collision energy.

The charm fragmentation fractions in pp [17] and p–Pb collisions at $\sqrt{s}$ = 5.02 TeV are calculated summing the production cross section of all all single charm hadron ground states measured by ALICE. Thanks to measurements of D^0 [18, 19], D^+, and Λ_c^+ [3] performed down to $p_T = 0$ in pp and p–Pb collisions, and the measurement of D_s^+ and Ξ_c^0 down to very low p_T (extrapolated to $p_T = 0$ with theoretical predictions), ALICE was could determine the charm fragmentation fractions in pp and p–Pb collisions for the first time.

The Ω_c^0 was not measured in pp and p–Pb collisions at $\sqrt{s} = 5.02\,\text{TeV}$. Its contribution is treated as a systematic uncertainty, taking into consideration the measurement performed in pp collisions at $\sqrt{s} = 13\,\text{TeV}$. Charm fragmentation fractions in pp and p–Pb collisions are presented in the left panel of Fig. 3, showing significant baryon enhancement with respect to the fragmentation fractions measured in e^+e^- and ep collisions.

The total charm production cross section per unit of rapidity at midrapidity measured in pp [17] and p–Pb collisions at $\sqrt{s} = 5.02\,\text{TeV}$ are shown in Fig. 3 (right). They are compatible within uncertainties. Using the new charm fragmentation fractions [17], the charm production cross section in pp collisions at $\sqrt{s} = 2.76$ TeV [20] and 7 TeV [21] are about 40% higher than the previously published results. The updated charm production cross section lies on the upper edge of the pQCD calculation uncertainty bands [11].

3 Conclusions

ALICE measured the production cross section of all charm hadron ground states in pp collisions. The productions of Λ_c^+ was measured down to $p_T = 0$ in pp and p–Pb collisions. A large enhancement of all charm baryon-to-meson ratios is observed in pp collisions with respect to e^+e^- collisions. None of the models describes the enhancement for all charm-baryons. Reproducing the measurements of charm baryons with a strange quark is particularly challenging. The charm fragmentation fractions measured in pp and p–Pb collisions at $\sqrt{s} = 5.02\,\text{TeV}$ show that the assumption of the universality of charm fragmentation fractions across colliding systems is not valid already from e^+e^- to pp collisions.

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