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Charmed-baryon production and hadronization studies with ALICE

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Measurements of charmed-baryon production act as a powerful probe of hadronisation. An observed enhancement of the baryon-to-meson ratio could suggest that charm fragmentation is non-universal in pp, p–Pb and e^+e^- collisions. Several mechanisms to explain this enhancement have been suggested. The measurement of higher mass charm states such as the Σ_c and Ξ_c will help to better constrain these theoretical model calculations. New measurements with the ALICE detector at the LHC are presented of charmed baryon (Λ_c^+, $\Sigma_c^{0,++}$, $\Xi_c^{0,+}$) production in pp collisions at 13 TeV.

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1. Introduction

The factorisation approach has been shown to describe the production of charmed mesons within uncertainties [1]. By measuring the ratio of two charmed hadron species, the contributions from parton-parton scattering and parton distribution function terms cancel and allow the fragmentation fractions to be probed. It can be seen that the fragmentation fractions obtained from e^+e^- experiments also give a good description of charmed mesons in pp collisions [2], suggesting that charm fragmentation may be universal for small systems. However, measurements of the Λ_c^+/D^0 ratio are enhanced with respect to predictions based on e^+e^- data. Several mechanisms have been proposed to explain this enhancement. These mechanisms include colour reconnection beyond leading colour approximation [3], coalescence [4], and feed-down from several higher mass charm states as suggested by He and Rapp [5]. In this contribution, we report on measurements made of the charmed baryons Λ_c^+, $\Sigma_c^{0,++}$, $\Xi_c^{0,+}$ in pp collisions at 13 TeV, performed with the ALICE experiment at the LHC.

2. Data Analysis

A description of the ALICE detector can be found in Ref [6]. For the relevant data analyses, three detectors located at midrapidity were used. The Inner Tracking System (ITS) was used for vertexing and track reconstruction. The Time Projection Chamber (TPC), the main tracking detector, also provides $\mathrm{d}E/\mathrm{d}x$ information for the particle identification (PID). The Time Of Flight (TOF) detector provides further complementary PID information. The analyses presented include both hadronic decays and a semileptonic decay. For all decays, selections are made on PID and the decay topology, and implemented with either rectangular cuts or machine learning techniques to remove background events. For hadronic decays, yield extraction was performed directly via invariant mass analyses. For the semileptonic decay, $\Xi_c^0 \to e^+\Xi^-\nu_e$, the Ξ_c^0 invariant mass distribution was obtained by subtracting wrong-sign pairs from right-sign pairs and bayesian unfolding was used to correct for the missing neutrino mass as presented in [7]. For all decays, corrections were made to account for detector efficiency and acceptance. Corrections for the fraction of non-prompt baryons in the signal sample were made for all decays with the exception of the Ξ_c^0 decays which are inclusive.

3. Results

3.1 Λ_c^+ production in pp collisions at $\sqrt{s}$ = 13 TeV

The Λ_c^+/D^0 ratio was measured as a function of p_T in different event multiplicity intervals in pp collisions at 13 TeV. In Fig. 1 (left), the Λ_c^+/D^0 ratio is plotted for four multiplicity classes. In Fig. 1 (right), the highest and lowest multiplicity classes and their corresponding PYTHIA 8 predictions are shown. It can be seen that there is an enhancement of the Λ_c^+/D^0 ratio with increased multiplicity, this enhancement and the trend of the data can be described well by the PYTHIA 8 predictions [8] that include colour reconnection beyond leading colour approximation (Mode 2) [3]. The PYTHIA 8 prediction using the Monash tune however, which lacks colour reconnection beyond leading colour approximation, fails to describe both the multiplicity dependence and p_T dependence shown by the data.

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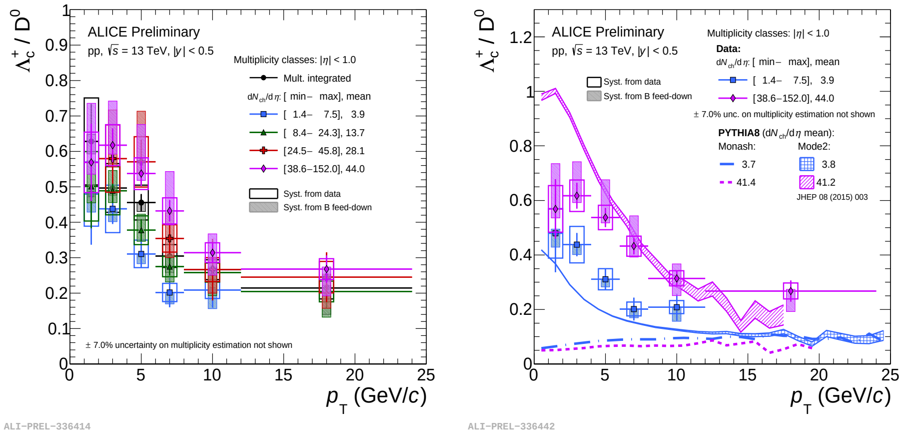

Figure 1: Comparison of Λ_c^+/D^0 ratios measured in different multiplicity classes of pp collisions at $\sqrt{s}$ = 13 TeV. Left: all measured multiplicity classes and the multiplicity integrated Λ_c^+/D^0 ratio are shown. Right: the highest and lowest multiplicity classes and their corresponding PYTHIA predictions are compared.

3.2 $\Sigma_c^{0,++}$ production in pp collisions at $\sqrt{s}$ = 13 TeV

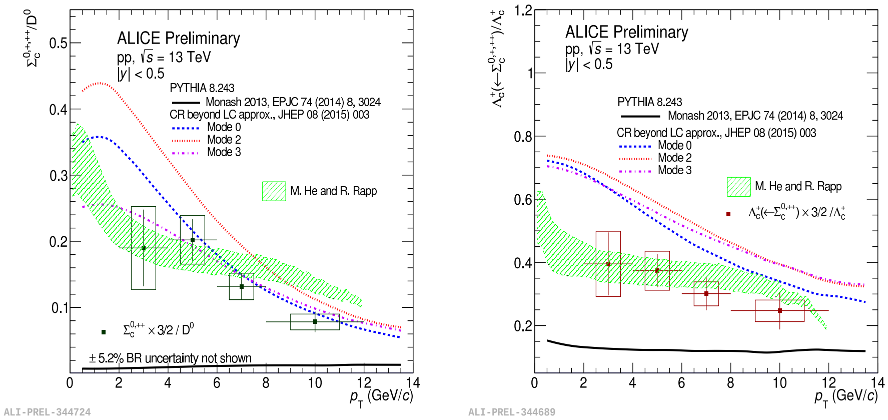

Figure 2: Comparison of $\Sigma_c^{0,++}/D^0$ (left) and $\Lambda_c^+(\leftarrow \Sigma_c^{0,++})/\Lambda_c^+$ (right) ratios measured in pp collisions at $\sqrt{s}$ = 13 TeV with theoretical models.

The measurement of $\Sigma_c^{0,++}$ production is very useful as it helps constrain the production of the Λ_c^+ state. In Fig. 2 (left) the $\Sigma_c^{0,++}/D^0$ ratio is shown as a function of p_T with PYTHIA 8 predictions. The $\Sigma_c^{0,++}$ data shows a similar p_T trend to the previous Λ_c^+ data. The colour reconnection beyond leading colour approximation prediction Mode 3 [3] gives the best description of the data. Modes 2 and 0 overestimate the data at low p_T, converging with the Mode 3 prediction at at 6 and 12 GeV/c respectively. The Monash prediction fails to describe the data at all. The difference between the Monash prediction and data is large (a factor of 20-30 times). The He and Rapp [5] prediction performs similarly to Mode 3 but begins to overestimate at high p_T. Fig. 2 (right) shows the $\Lambda_c^+(\leftarrow \Sigma_c^{0,++})/\Lambda_c^+$ ratio, the fraction of Λ_c^+ produced from $\Sigma_c^{0,++}$ decays. The PYTHIA predictions with colour reconnection beyond leading colour approximation [3] overestimate this ratio and the Monash tune underestimates this ratio, respectively. The He and Rapp [5] model however is in good agreement with the data. Due to the current uncertainties on the measurement, it is difficult to determine the p_T trend of the data.

3.3 $\Xi_c^{0,+}$ production in pp collisions at $\sqrt{s}$ = 13 TeV

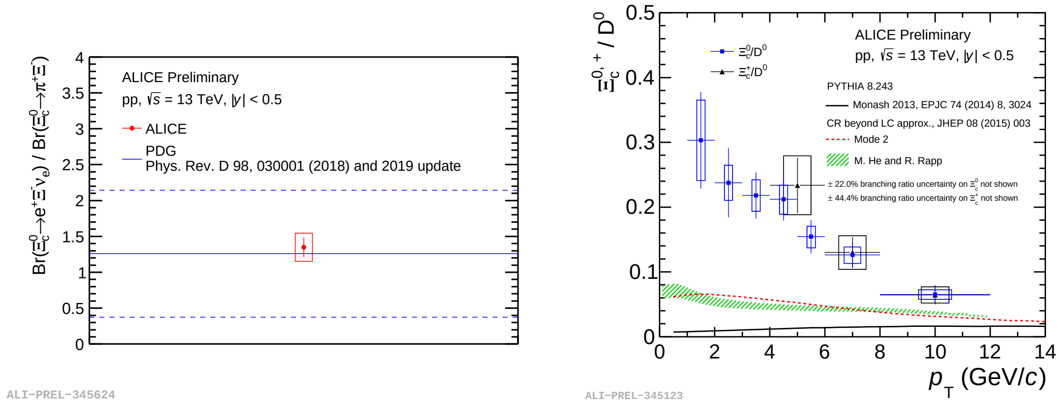

Figure 3: Left: Ratio of semileptonic and hadronic branching ratios measured in pp collisions at $\sqrt{s}$ = 13 TeV compared with the PDG value. Right: $\Xi_c^{0,+}/D^0$ ratio measured in pp collisions at $\sqrt{s}$ = 13 TeV with theoretical models.

One unique measurement performed for the Ξ_c^0 baryon is the the ratio of its semileptonic and hadronic branching ratios, shown in Fig. 3 (left). The measured ratio by ALICE is compared to the PDG value and found to be both consistent and demonstrates a large improvement to the uncertainties. Fig. 3 (right) shows the $\Xi_c^{0,+}/D^0$ ratio compared to theoretical models. It can be seen that the data is underestimated by all models, although the He and Rapp model [5] and the colour reconnection beyond leading colour approximation prediction [3] are still enhanced with respect to the Monash prediction. The Monash prediction underestimates the data by a factor of 20-30 times.

4. Summary and Outlook

Measurements of the baryon-to meson ratios Λ_c^+/D^0, $\Sigma_c^{0,++}/D^0$, and $\Xi_c^{0,+}/D^0$ in pp collisions at $\sqrt{s}$ = 13 TeV with the ALICE have been presented. Models without additional hadronisation mechanisms consistently underestimate the data. Models such as that of He and Rapp or PYTHIA with colour reconnection beyond leading colour approximation give better agreement with the data. Further measurements of higher mass charm baryons will help further constrain possible mechanisms for these enhanced baryon-to-meson ratios and also help provide an accurate measurement of the total charm cross section.

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