Charm-baryon production in proton-proton collisions

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Recent measurements of charm-hadron production in proton-proton collisions [1] at the LHC have found a surprisingly large ratio of Λ_c baryons relative to D mesons, well above expectations from event generators or the statistical hadronization model (SHM) based on known charm-hadron states as listed by the particle data group (PDG). In the present work [2] we revisit the predictions of the SHM by employing a largely augmented set of charm-baryon states beyond the PDG listings, as predicted by the relativistic quark model (RQM) [3] and lattice QCD [4]. The problem of missing baryon resonances is well known from the light- and strange-quark sectors, and even more prominent in the heavy-quark sector where only 6 Λ_c and 3 Σ_c states are firmly established to date. Here, we implement an extra 18 excited states of Λ_c, 42 Σ_c (and further charm-strange baryons), as predicted by the RQM. These states contribute through their strong-decay feeddown to the "prompt" Λ_c production as observed in experiment. We evaluate their abundances using the standard thermal density of states, $n_i = d_i/(2\pi^2)\, m_i^2\, T_H\, K_2(m_i/T_H)$, where m_i is the hadron's mass, d_i its spin-isospin degeneracy and K_2 a modified Bessel function. The only parameter is the hadronization temperature, which we choose in the usual range of T_H=160-170 MeV as extracted from light-hadron production in both *pp* and heavy-ion collisions. For the branching ratios of the excited baryons into final states including a Λ_c, we assume 100% for states below the DN threshold, and a range of 50-100% for states above that threshold. The absolute number of charm hadrons is then fixed by introducing a charm-quark fugacity factor to match the experimentally observed total charm cross section. Several charm-hadron ratios are summarized in Table 1 for the two cases of the input charm-hadron spectrum, i.e., the one listed by the PDG and the one from the RQM, and for two hadronization temperatures. While the various D-meson ratios vary little between the two cases (and agree with experiment), the decisive difference lies in the Λ_c/D^0 ratio which increases by about a factor of 2 upon including the extra RQM states, resulting in fair agreement with the experimental value of 0.543±0.061(stat)±0.160 (sys) measured in 7 TeV *pp* collisions a midrapidity by ALICE [1].

Table I. Ratios of D^+, D^{*+},D_s^+, and Λ_c^+ to D^0 at T_H=170 and 160 MeV (including strong feeddowns) in the PDG and RQM spectrum scenarios.

r_i	D^+/D^0	D^{*+}/D^0	D_s^+/D^0	Λ_c^+/D^0
PDG(170)	0.4391	0.4315	0.2736	0.2851
PDG(160)	0.4450	0.4229	0.2624	0.2404
RQM(170)	0.4391	0.4315	0.2726	0.5696
RQM(160)	0.4450	0.4229	0.2624	0.4409

We have also evaluated the transverse-momentum (p_T) dependence of charm-hadron production, by employing a universal underlying charm-quark spectrum taken from the FONLL framework [5] with pertinent mass-dependent fragmentation functions and associated feeddown kinematics, but with production weights from the SHM as constructed above. It turns out that the ALICE midrapidity data for the D^0, Λ_c, D^+ and D_s^+ spectra, as well as the Λ_c/D^0 ratio, can all be fairly well described, see Fig. 1 for the former two and the latter. Some discrepancy is found in comparison to the LHCb data [6] at forward rapidity, possibly due to a lower phase space density of light quarks where the applicability of the SHM might be limited.

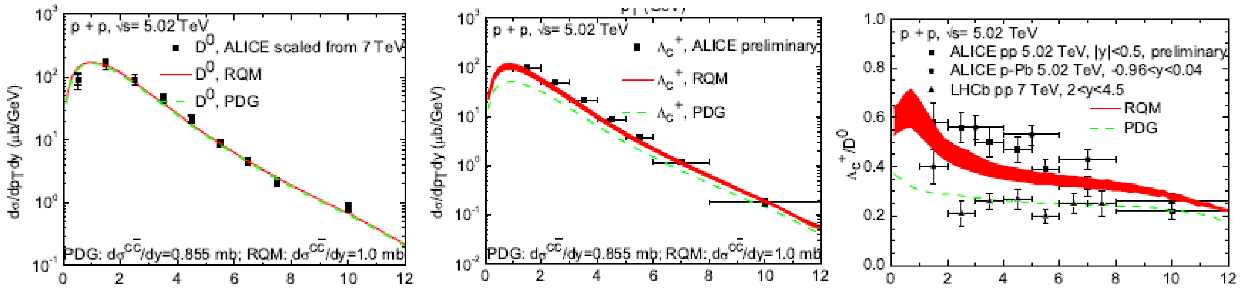

FIG. 1. Transverse-momentum dependence of the prompt D^0(left) and Λ_c (middle) spectra (including strong decay feeddown) and their ratio, compared to ALICE[1] and LHCb data. The bands illustrate the uncertainty in the branching ratios of the charm-baryon resonances.

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