Modification of heavy quark hadronization in high-multiplicity collisions at LHCb

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Abstract. The ratio of heavy flavor hadrons is very sensitive to the hadronization mechanism. This proceeding will present recent LHCb results on the cross-section ratios of D_s^+/D^+, Ξ_c^+/Λ_c^+ and Λ_b^0/B^0 in different collision systems. The significantly enhanced production ratios D_s^+/D^+ and Λ_b^0/B^0 with the increase of multiplicity may imply that hadronization mechanisms are modified in high-multiplicity events.

1 Introduction

In the context of hadron colliders, heavy quarks primarily originate from hard parton-parton interactions in the initial stages of the collisions. These interactions are well described by perturbative QCD calculations, which rely on the factorization theorem. According to this theorem, the cross-sections of heavy-flavour hadrons depend on several key factors: the parton distribution functions within the incoming nucleons, the cross-section of hard parton-parton scattering, and the fragmentation functions. For different types of heavy-flavored hadrons, the contributions from the first two items are similar, and only the hadronization process makes the difference. Traditionally, assuming that hadronization of heavy quarks is a universal process independent of colliding systems, these fragmentation functions are parameterized using data collected from *ee* or *ep* collisions. Some recent measurements from the LHCb experiment on the D_s^+/D^+ and Λ_b^0/B^0 ratios have revealed a significant enhancement from low-multiplicity collisions to high-multiplicity collisions. These results indicate the existence of other hadronization mechanisms that are dependent on the collision size.

2 The cross-sections ratio D_s^+/D^+ versus multiplicity in pPb collisions

In pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, LHCb conducted measurement of prompt D_s^+ and D^+ production, and studied relative production ratios [1]. The D_s^+/D^+ ratio observed in backward rapidity is slightly higher than that in forward rapidity and pp collisions [2]. Previous findings from LHCb [3] suggest that backward rapidity result in a higher yield of charged particles compared to forward rapidity within the symmetric kinematic interval. These results suggest a potential enhancement in the D_s^+/D^+ ratio with increasing multiplicity.

Figure 1 illustrates the cross-section ratio D_s^+/D^+ as a function of normalized event multiplicity in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV [4]. The event multiplicity is denoted by

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$N_{\text{tracks}}^{\text{PV}}$, representing the number of tracks used for reconstructing the primary vertex (PV). The charged particle multiplicity is normalized to the mean value observed in minimum-bias events. All panels exhibit a significant dependence on multiplicity, with a pronounced enhancement observed, particularly in the backward rapidity. This enhancement can be attributed to the combined effects of the coalescence mechanism and strangeness enhancement. However, this enhancement shows no tendency to weaken in the high transverse momentum ($6 < p_{\text{T}} < 12$ GeV/c) ranges.

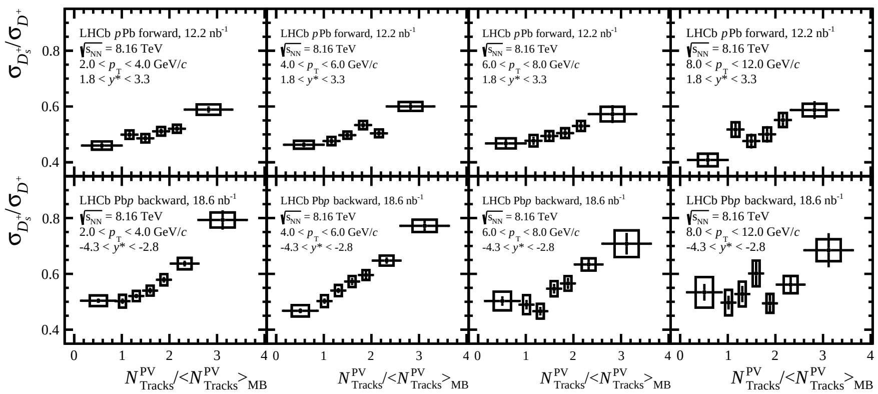

Figure 1. Cross-section ratio $\sigma_{D_s^+}/\sigma_{D^+}$ versus the normalised event multiplicity in different p_{T} ranges for (top) forward and (bottom) backward rapidity [4].

3 Measurement of Ξ_c^+ production in pPb collisions at $\sqrt{s_{\text{NN}}} = 8.16$ TeV

Figure 2 shows production ratio of strange baryons to non-strange baryons, Ξ_c^+/Λ_c^+, and the production ratio of strange baryons to non-strange mesons, Ξ_c^+/D^0, in pPb collisions at $\sqrt{s_{\text{NN}}} = 8.16$ TeV [5]. Both the Ξ_c^+/Λ_c^+ and Ξ_c^+/D^0 ratios show no significant p_{T} dependence. The Ξ_c^+/Λ_c^+ and Ξ_c^+/D^0 ratios are consistent within the error for forward and backward rapidity, but the Ξ_c^+/Λ_c^+ ratio in the backward rapidity is slightly higher than that in the forward rapidity.

The measurements are compared with the EPPS16 calculation [6], but both Ξ_c^+/Λ_c^+ and Ξ_c^+/D^0 are overestimated. The calculations from Pythia 8.3 with color reconnection [7] and EPOS4HQ [8, 9] are also shown in Figure 2, both of which are based on results from pp collisions.

4 Enhanced production of Λ_b^0 in high-multiplicity pp collisions at $\sqrt{s} = 13$ TeV

Figure 3 presents cross-sections ratio Λ_b^0/B^0 as a function of p_{T} in different multiplicity bins in pp collisions at $\sqrt{s} = 13$ TeV [10]. The event multiplicity is characterized by $\text{N}_{\text{tracks}}^{\text{VELO}}$ and $\text{N}_{\text{tracks}}^{\text{back}}$. $\text{N}_{\text{tracks}}^{\text{VELO}}$ denotes the total number of charged tracks reconstructed in the VELO detector, while $\text{N}_{\text{tracks}}^{\text{back}}$ represents the subset of $\text{N}_{\text{tracks}}^{\text{VELO}}$ pointing away from the LHCb detector. Both plots show a significant dependence on multiplicity, with clear enhancements observed,

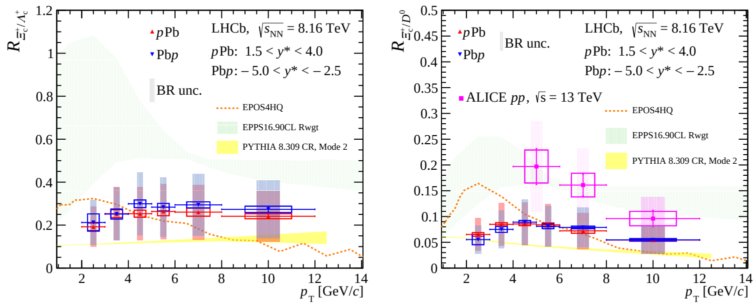

Figure 2. Production ratios, (left) Ξ_c^+/Λ_c^+ and (right) Ξ_c^+/D^0, as a function of p_T in the pPb (red triangles) and Pbp (blue triangles) data samples [5].

particularly evident when utilizing VELO tracks. At low p_T, the Λ_b^0/B^0 ratio is significantly higher than the value observed in e^+e^- collisions. However, as the p_T increases, the Λ_b^0/B^0 ratio tends to align with the results obtained from e^+e^- collisions.

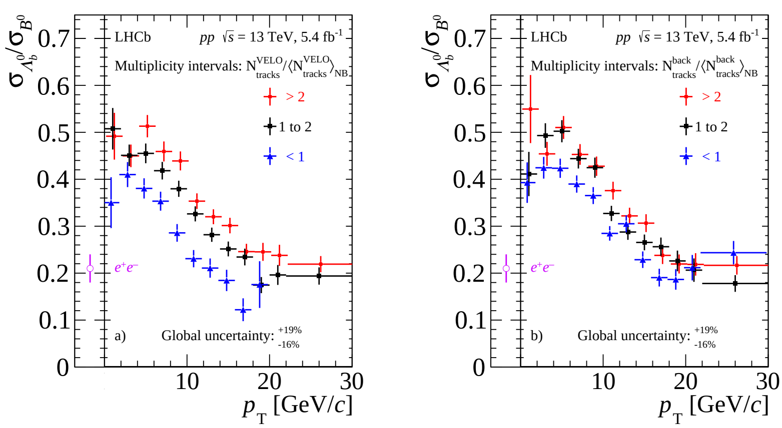

Figure 3. Cross-section ratio $\sigma_{\Lambda_b^0}/\sigma_{B^0}$ as a function of p_T in different multiplicity bins.

Figure 4 shows cross-sections ratio Λ_b^0/B^0 as a function of p_T. The data are compared to previous pp measurement [11] and pPb measurement [12], and generally consistent with them within uncertainties. Additionally, two curves from b quarks statistical hadronization model [13] are also shown in Figure 4. The green solid curve considers feeddown contributions from b baryons which have been collected by Particle Data Group [14]. The black dashed curve takes into account feeddown contributions from an expanded set of b baryons predicted by the Relativistic Quark Model [15].

5 Summary

In recent LHCb studies, cross-section ratios, D_s^+/D^+ and Λ_b^0/B^0, were measured in both low and high multiplicity collisions. Ξ_c^+/Λ_c^+ was measured in both pPb and Pbp collisions. The

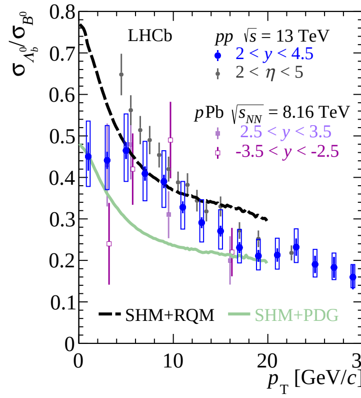

Figure 4. Cross-section ratio $\sigma_{\Lambda_b^0}/\sigma_{B^0}$ as a function of p_T.

Ξ_c^+/Λ_c^+ shows little variation between forward and backward rapidity within uncertainties. The D_s^+/D^+ and Λ_b^0/B^0 show a significant enhancement in high-multiplicity collisions compared to low-multiplicity collisions. The Λ_b^0/B^0 ratio decreases with p_T and converges to the e^+e^- result at high p_T. These suggest the potential presence of other hadronization mechanisms in high-multiplicity collisions. Furthermore, it is also possible that in high-multiplicity collisions, the more contribution from excited state feeddown could lead to the observed enhancement in cross-section ratios. It is worth noting that this enhanced feeddown of SHM+RQM relative to SHM+PDG does not weaken as p_T increases, as predicted in Figure 4.

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