PROCEEDINGS OF SCIENCE

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

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The baryon-to-meson and meson-to-meson production ratios of heavy quarks are well suited to study the hadronization mechanism. Here we will present LHCb results on the production ratios of B_s^0/B^0, D_s^+/D^+ and Λ_c^+/D^0 in differents collision systems. These measurements show cross-sections ratios B_s^0/B^0, D_s^+/D^+ increase with multiplicity and imply that there may be hadronization mechanisms other than fragmentation mechanisms in high-multiplicity collisions.

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1. Introduction

At hadron colliders, the heavy quarks are mainly produced by hard parton-parton interactions in the initial stages of the collisions, and are well described by perturbative QCD calculations. These calculations are based on the factorisation theorem, according to which the heavy-flavour hadrons cross-sections are dependence on the parton distribution functions of the incoming nucleons, the hard parton-parton scattering cross-section, and the fragmentation functions. The baryon-to-meson and meson-to-meson production ratios of heavy quarks are very sensitive to the fragmentation functions since the contributions from parton distribution function and parton-parton scattering terms cancel in the ratio. The fragmentation functions are typically parameterised from measurements performed in ee or ep collisions, assuming that the hadronization of heavy quarks is a universal process independent of the colliding systems [1]. However, some recent measurements from the LHCb experiment have shown that heavy quark hadronization differs between low-multiplicity and high-multiplicity collisions. These results suggest the existence of other hadronization mechanisms than fragmentation.

2. The cross-sections ratio B_s^0/B^0 versus multiplicity in pp collisions at $\sqrt{s}$ = 13 TeV

This LHCb measurement [2] shows cross-sections ratio B_s^0/B^0 as a function of charged particle multiplicity and p_T in pp collisions at $\sqrt{s}$ = 13 TeV. Both B_s^0 and B^0 are reconstructed by same final state ($J/\psi\pi^+\pi^-$). The charged particle multiplicity is represented by $\mathrm{N}_\mathrm{tracks}^\mathrm{VELO}$ and $\mathrm{N}_\mathrm{tracks}^\mathrm{back}$. $\mathrm{N}_\mathrm{tracks}^\mathrm{VELO}$ is the total number of charged tracks reconstructed in the VELO detector. $\mathrm{N}_\mathrm{tracks}^\mathrm{back}$ is the subset of $\mathrm{N}_\mathrm{tracks}^\mathrm{VELO}$ which points away from LHCb detector.

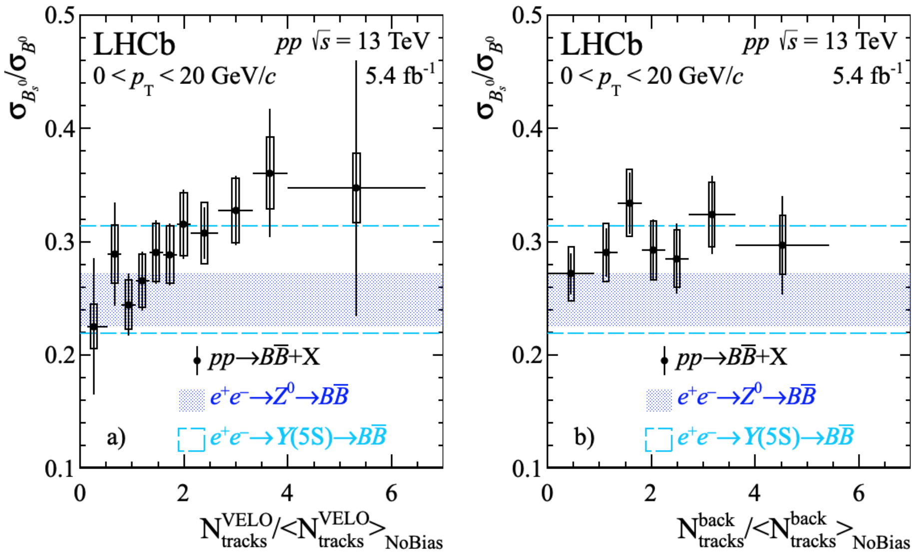

Figure 1: The cross-sections ratio B_s^0/B^0 as a function of normalized $\mathrm{N}_\mathrm{tracks}^\mathrm{VELO}$ and $\mathrm{N}_\mathrm{tracks}^\mathrm{back}$

The Figure 1 shows cross-sections ratio B_s^0/B^0 as a function of these two multiplicity matrices. The charged particle multiplicity is normalized to the mean value found in NoBias events which are only selected based on the LHC beam clock. The left panel shows an increasing trend with the normalized $\mathrm{N}_{\text{tracks}}^{\text{VELO}}$. The right panel shows no significant dependence on the normalized $\mathrm{N}_{\text{tracks}}^{\text{back}}$ and the values consistent with the values measured in ee collisions [3]. This implies that the ratio increase is related to the local particle density.

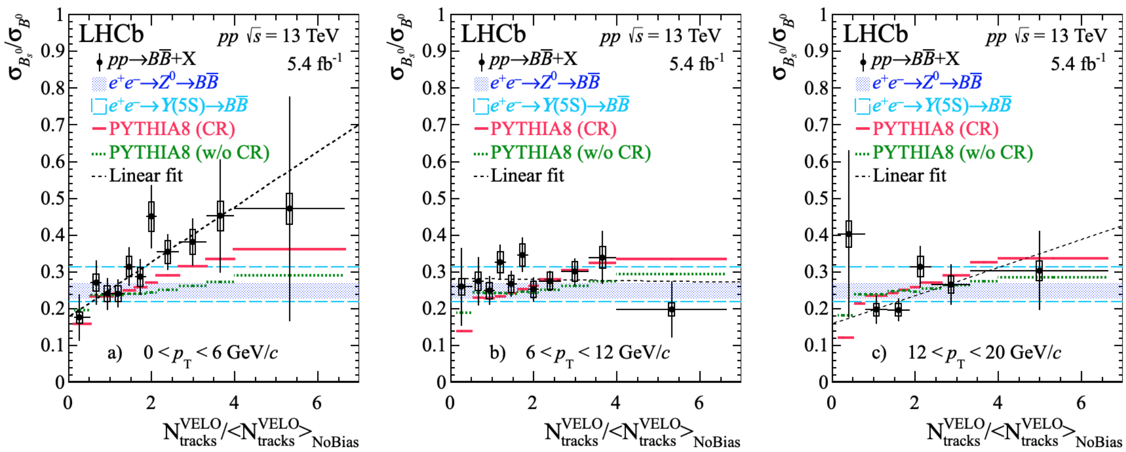

Figure 2: The cross-sections ratio B_s^0/B^0 as a function of normalized $\mathrm{N}_{\text{tracks}}^{\text{VELO}}$ in different p_{T} intervals

The Figure 2 shows cross-sections ratio B_s^0/B^0 as a function of normalized $\mathrm{N}_{\text{tracks}}^{\text{VELO}}$ in different p_{T} intervals. In the $0 < p_{\mathrm{T}} < 6$ GeV/c interval, the ratio increases with normalized $\mathrm{N}_{\text{tracks}}^{\text{VELO}}$ and has a closer trend to the PYTHIA8 predictions including color reconnection (CR) [4] compare to without color reconnection. The slope of a line fit to these data deviates from zero by 3.4σ. In the $6 < p_{\mathrm{T}} < 12$ GeV/c and $12 < p_{\mathrm{T}} < 20$ GeV/c interval, these ratios show no significant dependence on the normalized $\mathrm{N}_{\text{tracks}}^{\text{VELO}}$ and are consistent with the measurement from ee collisions [3]. This is qualitatively consistent with the expectation of coalescence mechanism.

3. The cross-sections ratio D_s^+/D^+ in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

This LHCb measurement (preliminary) shows cross-sections ratio D_s^+/D^+ in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. There are two different collision configurations due to the asymmetry of the colliding beam energies. The forward collisions where the proton beam points towards the LHCb arm cover the range of $1.5 < y^* < 4.0$, and the backward collisions where the lead beam points towards the LHCb arm cover the range of $-5.0 < y^* < -2.5$. The y^* is the rapidity in the nucleon-nucleon center-of-mass system. The average charged particle multiplicity in the backward collisions is higher than that in the forward collisions.

The Figure 3 shows cross-sections ratio D_s^+/D^+ as a function of p_{T} and y^* in different data sample. The cross-sections ratio D_s^+/D^+ from backward pPb collisions is slightly higher than that in forward pPb collisions and pp collisions [5]. The cross-sections ratios D_s^+/D^+ results from LHCb collaboration are consistent with the results from ALICE collaboration in pPb [6] collisions and in pp [7] collisions within error.

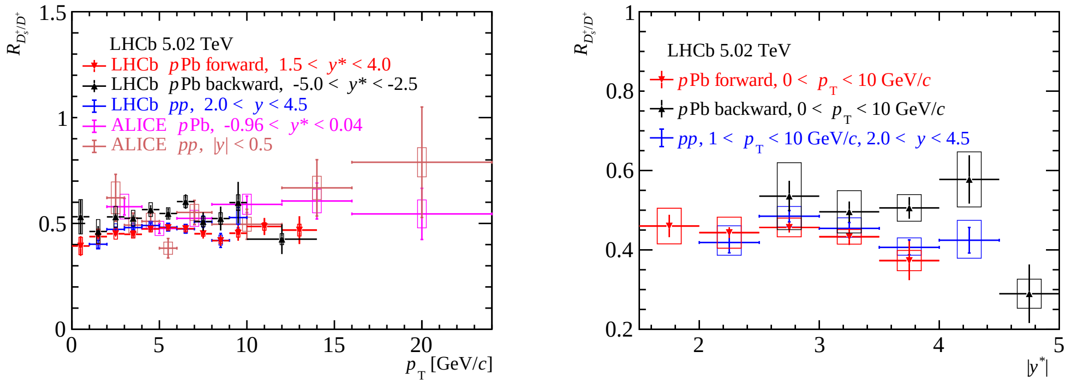

Figure 3: The cross-sections ratio D_s^+/D^+ as a function of p_{T} (left panel) and y^* (right panel)

4. The cross-sections ratio Λ_c^+/D^0 in peripheral PbPb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV

This LHCb measurement [8] shows the cross-sections ratio Λ_c^+/D^0 in peripheral PbPb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. The data sample used to calculate Λ_c^+/D^0 is selected by $1000 < N_c < 10000$ which N_c is the number of clusters in VELO detector. The Glauber Monte Carlo (GMC) [9] is used to estimate the centrality (corresponds to 65–90%) and the mean number of nucleons participating in the collision ($<$ N$_{\mathrm{part}}$ $>$) from recorded data [10].

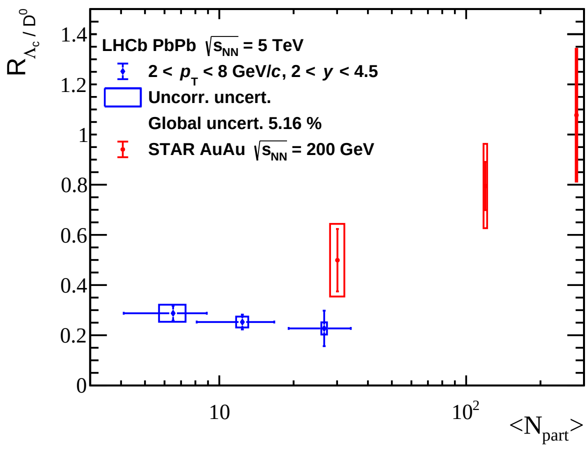

Figure 4: The cross-sections ratio Λ_c^+/D^0 as a function of $<$ N$_{\mathrm{part}}$ $>$

The Figure 4 shows the cross-sections ratio Λ_c^+/D^0 has no dependence on $<$ N$_{\mathrm{part}}$ $>$ and is lower than the results from STAR collaboration in AuAu collisions [11] in different $<$ N$_{\mathrm{part}}$ $>$ intervals. The Figure 5 shows cross-sections ratio Λ_c^+/D^0 as a function of p_{T} and y^* in different data sample. In the left panel, Λ_c^+/D^0 decreases with p_{T}, a trend similar to the results from ALICE collaboration in PbPb collisions [12], but is systematically lower than their within error. In the right panel, Λ_c^+/D^0 shows no significant dependence on rapidity and is systematically lower than the results from ALICE collaboration in pp and pPb collisions [13, 14]. The Λ_c^+/D^0 from LHCb is systematically lower than that from STAR and ALICE, which may come from the fact that these

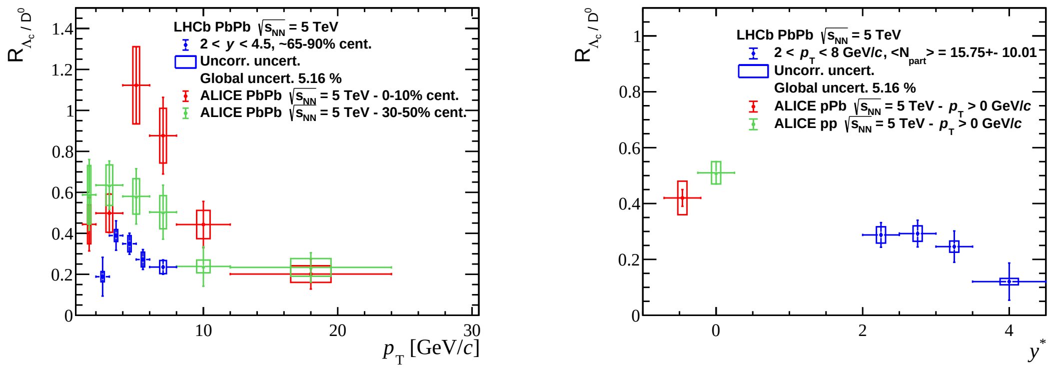

Figure 5: The cross-sections ratio Λ_c^+/D^0 as a function of p_T (left panel) and y^* (right panel)

detectors cover different rapidity regions, resulting in different particle densities and thus different recombination mechanism contributions.

5. Summary and outlook

The latest baryon-to-meson and meson-to-meson production ratios of heavy quarks from LHCb in high-multiplicity collisions have been discussed, including B_s^0/B^0 in pp collisions at $\sqrt{s} = 13$ TeV, D_s^+/D^+ in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and Λ_c^+/D^0 in peripheral PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. All results imply potential modification of the hadronization mechanism in high-multiplicity collisions and this potential mechanism is related to the local particle density. Many other measurements are ongoing or planned to further shed light on hadronization mechanisms. In past Run 2, looking forward to the LHCb collaboration releasing open charm results in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV. For the upcoming Run 3, the upgraded LHCb detector will reduce hardware limitations and allow to access higher centrality PbPb collisions.

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