Open heavy flavor production at LHCb

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Abstract. The LHCb experiment is a dedicated heavy-flavor experiment at the LHC and is uniquely well-suited to studying heavy-flavor production in heavy-ion collisions. Open heavy-flavor production studies at LHCb provide strong constraints on nuclear parton densities and probe the hadronization process in the hot, dense, nuclear media produced in heavy-ion collisions. Recent measurements of heavy-flavor production in heavy-ion collisions with the LHCb detector are presented, including studies of charm and beauty baryon production.

1 Introduction

Heavy quarks are created at the early stage of ultra-relativistic heavy-ion collisions. Their production can be strongly affected by interactions with deconfined hot nuclear matter, know as quark gluon plasma (QGP). Cold nuclear matter (CNM) effects are also present in the collisions and can be investigated in small systems such as proton-nucleus (pA) collisions, where QGP effects are expected to be negligible. One of the dominant CNM effects is the modification of the initial parton densities, compared to that in free nucleons. These effects can be described by nuclear parton distribution functions (nPDFs) [1, 2] and color glass condensate (CGC) [3] models. Heavy flavor particles also provide unique insights into hadronisation mechanism in heavy-ion collisions. Parton fragmentation is considered as a universal hadronisation process across different collisions [4]. In heavy-ion collisions, quark coalescence can arise as an alternative mechanism [5, 6]. Coalescence will be more important in large systems as the particle density becomes higher. Enhanced baryon-to-meson ratio compared to e^-e^+ is an important signature of quark coalescence. As the enhancement has also been observed in small systems, there have been more discussions on whether hot nuclear matter is created in these collisions.

The LHCb detector is a single-armed detector designed for studying heavy flavor particles. It has become a general-purpose detector for studying pp, pPb, PbPb and fixed-target collisions [7, 8]. These proceedings present the LHCb result of Λ_b^0/D^0 production ratio in high-multiplicity pp collisions at $\sqrt{s} = 13$ TeV [9]. The measurements of charm hadron production in pPb [13–16] and fixed-target pNe and PbNe collisions [17, 18] are also discussed.

2 Λ_b^0/B^0 production ratio in pp collisions at $\sqrt{s} = 13$ TeV

The Λ_b^0/B^0 production ratio is studied as a function of particle multiplicity in pp collisions [9]. The multiplicity is characterised with the total track multiplicity measured in the Vertex Locator (VELO) $N_{\text{VELO}}^{\text{tracks}}$. The result is shown in the left panel of Fig. 1. The points are consistent

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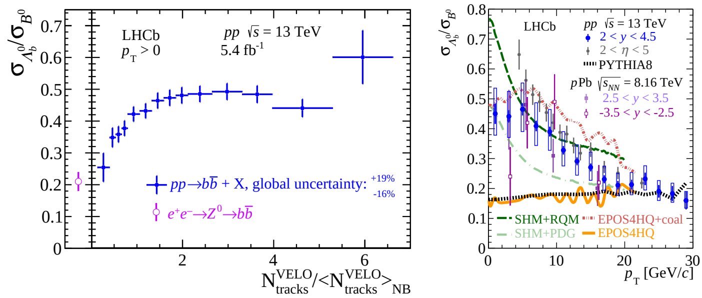

Figure 1. Λ_b^0/B^0 production ratio as a function of (left) number of VELO tracks $N_{\mathrm{VELO}}^{\mathrm{tracks}}$ and (right) p_{T}. $N_{\mathrm{VELO}}^{\mathrm{tracks}}$ is normalised by its averaged value in no-biased data.

with e^+e^- results [10] at very low multiplicity, but increase to about 0.5 as multiplicity increases. These results could indicate that coalescence emerges as an additional production mechanism for baryons at high multiplicity, where multiple quark wave functions overlap. The production ratio is also shown as a function of p_{T} in the right panel of Fig. 2. The ratio is significantly enhanced at low p_{T} and converges to e^+e^- data with increasing p_{T}, which is consistent with the expectation that coalescence is more dominant at low p_{T}. Predictions from statistical hadronisation model (SHM) [11] and EPOS4 [12] also give better descriptions of the ratio by considering coalesence contribution.

3 Open charm production in pPb collisions

LHCb pPb data correspond to center-of-mass energies of $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and 8.16 TeV and include both forward and backward kinematic regions, which cover both shadowing and anti-shadowing regions. Various open-charm hadrons are measured in pPb collisions, including D^+ and D_s^+ production at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV [13], and D^0 [14], Ξ_c^+ [16], D^+ and D_s^+ [15] at $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV. The nuclear modification factor $R_{p\mathrm{Pb}}$ can be derived by comparing the cross-sections in pPb with that in pp collisions. Nuclear modification factors of D^+, D_s^+ and D^0 mesons at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV are shown in Fig. 2. Nuclear modification factors for all

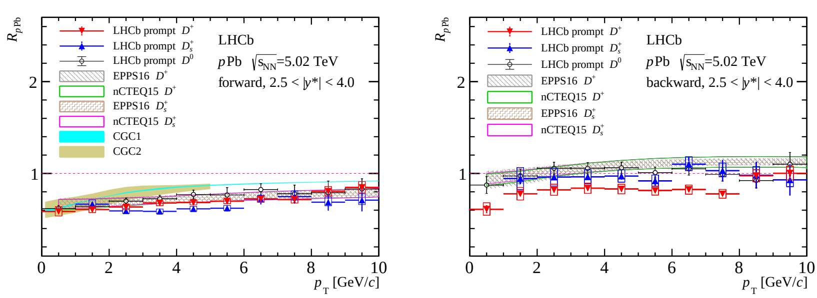

Figure 2. Nuclear modification factor $R_{p\mathrm{Pb}}$ of D mesons in pPb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV at (left) forward and (right) backward rapidities.

mesons show significant suppression at forward rapidity, suggesting the existence of nuclear shadowing. While for backward rapidity $R_{p\mathrm{Pb}}$ is less suppressed, which is consistent with the expectation of anti-shadowing. The nuclear modification factor for D^+ mesons is slightly smaller than that for D_s^+ mesons. It may hint at possible strangeness enhancement.

The forward-backward produciton ratio R_{FB} can be measured when a pp reference is not available. R_{FB} of D^+, D_s^+ and Ξ_c^+ particles are shown in Fig. 3. Nuclear shadowing is also verified from the suppression at low p_{T}. At high p_{T}, R_{FB} of D^+, D_s^+ mesons show a rising trend toward unity, similar to that of D^0 mesons at $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV [14]. However, $R_{\mathrm{FB}}(\Xi_c^+)$ shows no significant dependence on p_{T}.

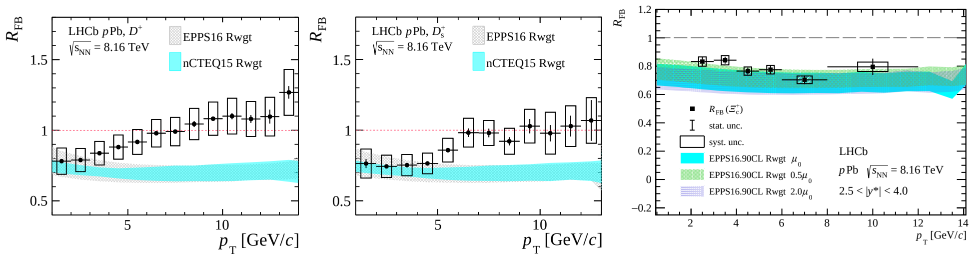

Figure 3. Forward-backward production ratio R_{FB} of (left) D^+, (middle) D_s^+, and (right) Ξ_c^+ particles as a function p_{T} in pPb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV.

4 Open charm production in fixed-target collisions

The LHCb detector provides unique fixed-target mode at the LHC, with various species of noble gas target (He, Ne, Ar). The $D^0 - \overline{D}^0$ production asymmetry is measured to study the intrinsic charm in nucleons [17]. The result is presented in the left panel of Fig. 4. An asymmetry as large as 15% is observed at the most backward rapidity, and MS model with 1% intrisic charm and 10% recombination gives the best description of the data [19]. The J/ψ and D^0 production cross-sections are also measured in PbNe collisions [18]. The $J/\psi/D^0$ ratios as a function of N_{coll} in both pNe and PbNe collisions are shown together in Fig. 4. A power-law dependence of $R_{J/\psi/D^0} \propto (N_{\mathrm{coll}})^{\alpha'-1}$ is observed across different collisions, and no evidence of anomalous suppression or QGP formation is seen.

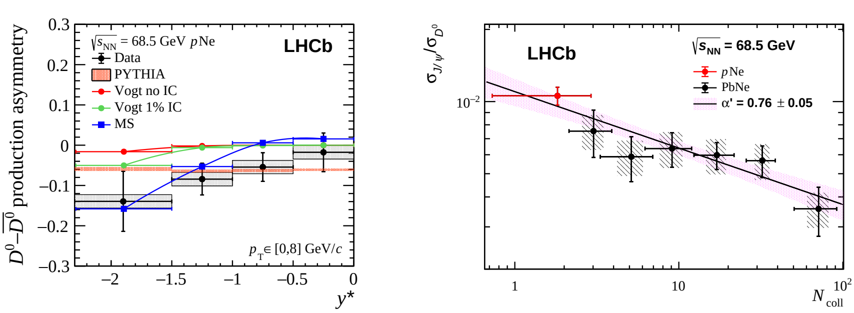

Figure 4. (left) $D^0 - \overline{D}^0$ production asymmetry as a function of y^* in pNe collisions and (right) $J/\psi/D^0$ ratio as a function of N_{coll} at $\sqrt{s_{\mathrm{NN}}}$ = 68.5 GeV.

5 Conclusion

The LHCb experiment has strong capabilities to study heavy flavor particles. The Λ_b^0/B^0 ratio shows an enhancement in high multiplicity pp collisions compared to e^+e^- results, indicating the coalescence contribution in b-quark hadronization. The nuclear modification factor and forward backward production ratios are measured in pPb collisions. The significant suppression at forward rapidity agrees with the expectation from nuclear shadowing. D^0 production and $J/\psi/D^0$ ratio are measured in fixed-target pNe and PbNe collisions. No evidence for anomalous suppression or existence of hot nuclear medium is found in these systems.

References

[1] K. Kovařík and A. Kusina et al. Phys. Rev., D93, (2016) 8, 085037. https://doi.org/10.1103/PhysRevD.93.085037.

[2] K. J. Eskola and P. Paakkinen and H. Paukkunen and C. A. Salgado. Eur. Phys. J. C77, (2017), 3. https://doi.org/10.1140/epjc/s10052-017-4725-9.

[3] F. Gelos and E. Iancu and J. Jalilian-Marian and R. Venugopalan. Ann. Rev. Nucl. Part. Sci. 60 (2010) 463-489. https://doi.org/10.1146/annurev.nucl.010909.083629.

[4] B. Andersson and G. Gustafson and G. Ingelman and T. Sjostrand. Phys. Rept. 97 (1983) 31–145. https://doi.org/10.1016/0370-1573(83)90080-7

[5] R. J. Fries and B. Müller and C. Nonaka and S. A. Bass. Phys. Rev. Lett. 90 (2003) 202303. https://doi.org/10.1103/PhysRevLett.90.202303

[6] V. Greco and C. M. Ko and P. Levai. Phys. Rev. Lett. 90 (2003) 202302. https://doi.org/10.1103/PhysRevLett.90.202302

[7] LHCb Collaboration. JINST 3 (2008) S08005. https://doi.org/10.1088/1748-0221/3/08/S08005

[8] LHCb Collaboration. Int. J. Mod. Phys. A. 30 (2015) 1530022. https://doi.org/10.1142/S0217751X15300227

[9] LHCb Collaboration. Phys. Rev. Lett. 132 (2024) 081901. https://doi.org/10.1103/PhysRevLett.132.081901

[10] HFLAV Collaboration. Eur. Phys. J. C81 (2021) 226 https://doi.org/10.1140/epjc/s10052-020-8156-7

[11] M. He and R. Rapp. Phys. Rev. Lett. 131 (2023) 012301. https://doi.org/10.1103/PhysRevLett.131.012301

[12] J. Zhao and J. Aichelin and P. B. Gossiaux and K. Werner. Phys.Rev.D 109 (2024) 5, 054011. https://doi.org/10.1103/PhysRevD.109.054011

[13] LHCb Collaboration. JHEP 01 (2024) 070 https://doi.org/10.1007/JHEP01(2024)070

[14] LHCb Collaboration. Phys.Rev.Lett. 131 (2023) 102301 https://doi.org/10.1103/PhysRevLett.131.102301

[15] LHCb Collaboration. Phys.Rev.D 110 (2024) L031105 https://doi.org/10.1103/PhysRevLett.131.102301

[16] LHCb Collaboration. Phys. Rev. C 109 (2024) 044901 https://doi.org/10.1103/PhysRevC.109.044901

[17] LHCb Collaboration. Eur. Phys. J. C83 (2023) 541 https://doi.org/10.1140/epjc/s10052-023-11641-5

[18] LHCb Collaboration. Eur. Phys. J. C83 (2023) 658 https://doi.org/10.1140/epjc/s10052-023-11674-w

[19] R. Maciula and A. Szczurek. Phys. Lett. B835 (2022) 137530 https://doi.org/10.1016/j.physletb.2022.137530