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Prompt Λ_c^+ baryons and D^0 meson production cross-section and nuclear modification in pPb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV with the LHCb detector

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Abstract

Λ_c^+ baryons and D^0 mesons are studied in pPb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV. The nuclear modification factor and forward-backward cross-section asymmetry are measured in order to study the cold nuclear matter effects. The prompt Λ_c^+ production cross-section is compared to that of the prompt D^0 mesons, providing insights into the hadronisation mechanism of charmed hadrons.

Keywords:
heavy-ion collisions, open charm, cold nuclear matter effects, LHCb

1. Introduction

Heavy quarks are sensitive probes to study the properties of the Quark-Gluon Plasma (QGP). The QGP is a state of matter consisting of deconfined quarks and gluons produced at high temperature in ultrarelativistic heavy-ion collisions. Heavy quarks are created in pairs in the early stage of heavy-ion collisions, and undergo rescatterings or energy loss in the hot and deconfined medium. Several experimental measurements of D^0 meson production in heavy-ion collisions at RHIC [1] and at the LHC [2] indicate strong interactions between charm quarks and the medium. In order to quantify the effects induced by the hot medium, cold nuclear matter effects, which also affect heavy-quark production in nucleus-nucleus interactions, must be quantitatively disentangled. The results on prompt D^0 meson production in pPb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV in the forward rapidity region [3] will be presented, in comparison with theoretical calculations including nuclear modification of the parton distribution functions, as well as the expectations from Color Glass Condensate models. Furthermore, the measurement of prompt Λ_c^+ production in pPb collisions [4] extends the study of cold nuclear matter effects to charmed baryons. The forward-backward asymmetry of prompt Λ_c^+ production is measured as well as the baryon-to-meson production ratios for charmed hadrons to probe the charm-hadron formation mechanisms [5, 6]. Measurements of the baryon-to-meson ratio for light and strange hadrons have shown a significant baryon enhancement at intermediate transverse momentum ($p_{\rm T}$)

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in central heavy-ion collisions [7, 8]. The STAR experiment has reported a significant enhancement of the Λ_c^+ production in AuAu collisions at $\sqrt{s_{\rm NN}} = 200$ GeV [9]. In addition, the ALICE collaboration has recently measured Λ_c^+ production in pPb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV in the central rapidity region [10]. The measurement of Λ_c^+ production in the forward rapidity region provides complementary information helping the interpretation these results.

2. LHCb detector and data sample

The LHCb detector [11] is a single-arm spectrometer, which covers the forward pseudorapidity range $2 < \eta < 5$. It is designed for precision measurements of heavy flavour hadrons with unique capabilities, which include hadron reconstruction down to very low $p_{\rm T}$, precise decay vertex reconstruction to distinguish prompt and secondary decay particles, and excellent particle identification based on the RICH detectors.

The open charm analyses use a data sample of pPb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV, with $E_p = 4$ TeV and $E_{\rm Pb} = 1.58$ TeV per nucleon, leading to a rapidity shift of $\Delta y = 0.465$ in the nucleon-nucleon centre-of-mass system with respect to the laboratory frame. Since the LHCb detector covers only one direction of the full rapidity acceptance, two distinctive beam configurations were used. In the 'forward' ('backward') configuration, the proton (lead) beam enters the LHCb detector from the interaction point. The acceptance is $1.5 < y^* < 4.0$ for the forward configuration and $2.5 < y^* < 5.0$ for the backward configuration, where y^* denotes the rapidity in the nucleon-nucleon centre-of-mass system. The analysed integrated luminosity is $1.06 \pm 0.02\,{\rm nb}^{-1}$ and $0.52 \pm 0.01\,{\rm nb}^{-1}$ for the forward and backward configurations, respectively.

3. Prompt D^0 and Λ_c^+ production in pPb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV

D^0 candidates are reconstructed via the hadronic decay channel $D^0 \to K^-\pi^+$. The prompt and non-prompt (originating from b-hadron decays) D^0 candidates are distinguished by using the D^0 impact parameter with respect to the primary vertex. The nuclear modification factor $R_{p{\rm Pb}}$ is the ratio of D^0 production cross-section in pPb collisions to that in pp collisions, $R_{p{\rm Pb}} \equiv 1/A \times \sigma_{p{\rm Pb}}(p_{\rm T}, y^*)/\sigma_{pp}(p_{\rm T}, y^*)$, where $A = 208$ is the mass number of the lead nucleus. The LHCb measurement of prompt D^0 production in pp collisions at $\sqrt{s} = 5.02\,{\rm TeV}$ [12] is used to evaluate the $R_{p{\rm Pb}}$ ratio. Fig. 1 shows the prompt D^0 nuclear modification factor in bins of y^* and $p_{\rm T}$ in the forward configuration. The measured $R_{p{\rm Pb}}$ ratio is close to one at backward rapidity, while a significant suppression is observed at low $p_{\rm T}$ in the forward rapidity region. The suppression decreases slowly with increasing $p_{\rm T}$. The measurement is compared with theoretical calculations using the nuclear parton distribution functions (nPDFs), as well as the colour glass condensate framework. The theoretical calculations show reasonable agreement with the data. The experimental uncertainties are significantly smaller than the uncertainties related to the nPDFs in the calculations.

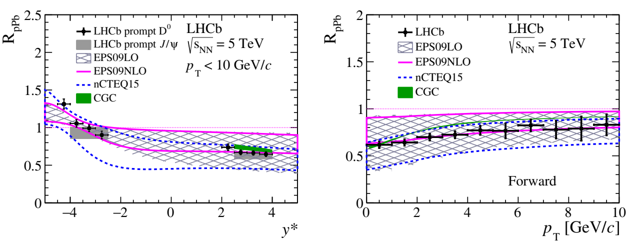

Fig. 1. Nuclear modification factor $R_{p{\rm Pb}}$ of prompt D^0 mesons in pPb collisions in bins of (a) y^* and (b) $p_{\rm T}$ in the forward configuration sample. The error bars represent the quadratic sum of the statistical and the systematic uncertainties.

The Λ_c^+ baryons are reconstructed through the $\Lambda_c^+ \to pK^-\pi^+$ decay channel. Proton, kaon and pion candidates are selected with particle identification requirements based on the RICH detectors signals. The impact parameter of the Λ_c^+ candidates with respect to the primary vertex is used to separate prompt Λ_c^+

candidates from nonprompt Λ_c^+ candidates originating from b-hadron decays. The raw Λ_c^+ signals are determined from fits to the $m(pK^-\pi^+)$ invariant mass distribution and the Λ_c^+ impact parameter distribution. The total efficiency is decomposed into the geometrical acceptance, the reconstruction and selection efficiency, and the PID efficiency. The geometrical acceptance is determined from simulations at the generator level. A full detector simulation based on GEANT4 [13, 14] is used to calculate the reconstruction and selection efficiency, which is corrected to account for detector occupancy effects. The particle identification efficiency is estimated by a data-driving method using high purity samples of D^0 mesons from $D^*(2010)^+$ decays for kaons and pions, and Λ baryons for protons. The prompt Λ_c^+ production results presented in these proceedings and the related publication [4] supersede the preliminary results reported in Ref. [15].

The forward-backward ratio $R_{\rm FB}$ measures the Λ_c^+ production asymmetry in the forward and backward rapidity regions. It is defined as $R_{\rm FB} \equiv \sigma(+|y^*|, p_{\rm T})/\sigma(-|y^*|, p_{\rm T})$, where $\sigma(+|y^*|, p_{\rm T})$ and $\sigma(-|y^*|, p_{\rm T})$ correspond to the cross-sections of the forward and backward rapidity regions, respectively. Fig. 2 shows the prompt Λ_c^+ $R_{\rm FB}$ ratio as a function of $p_{\rm T}$ in the common rapidity region between the two configurations $2.5 < |y^*| < 4.0$, and the $R_{\rm FB}$ ratio as a function of y^* in the region $2 < p_{\rm T} < 10\,{\rm GeV}/c$. The results are compared to calculations [16] using the HELAC-Onia generator [17, 18], where the Λ_c^+ production cross-section is parameterised starting from the Λ_c^+ cross section measured in pp collisions [19]. The calculations incorporate EPS09LO, EPS09NLO [20] and nCTEQ15 [21] nPDFs. Good consistency between the data and the calculations is observed.

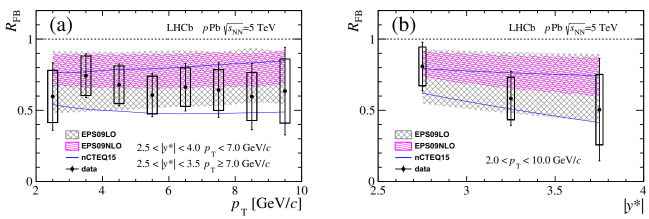

Fig. 2. Forward-backward production ratios $R_{\rm FB}$ as function of (a) $p_{\rm T}$ integrated over $2.5 < y^* < 4.0$ and (b) y^* integrated over $2 < p_{\rm T} < 10\,{\rm GeV}/c$. The error bars represent the sum in quadrature of the statistical and the systematic uncertainties.

The measured D^0 and Λ_c^+ cross-sections in pPb collisions at 5.02 TeV are used to calculate the baryon-to-meson production ratio, $R_{\Lambda_c^+/D^0} \equiv \sigma(\Lambda_c^+)/\sigma(D^0)$. The $R_{\Lambda_c^+/D^0}$ ratio is sensitive to the fraction of c quarks fragmenting into Λ_c^+ and D^0 hadrons. Fig. 3 shows the $p_{\rm T}$ and y^* dependence of the measured $R_{\Lambda_c^+/D^0}$ ratio. The coloured curves illustrate the HELAC-Onia calculations [16, 17, 18]. The effects of the nPDFs tend to cancel in the ratio $R_{\Lambda_c^+/D^0}$, and the calculations with the three nPDFs show comparable values and similar trends. The data points are in general consistent with the calculations. At $p_{\rm T}$ greater than $7\,{\rm GeV}/c$, the calculations overestimate the experimental results. The $R_{\Lambda_c^+/D^0}$ ratio shows a relative flat distribution for the full rapidity range. The ALICE collaboration has recently published a $R_{\Lambda_c^+/D^0}$ ratio equal to $0.602 \pm 0.060\,({\rm stat})\,^{+0.159}_{-0.087}\,({\rm syst})$ in $2 < p_{\rm T} < 12\,{\rm GeV}/c$ and $-0.96 < y < 0.04$ in pPb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV [10]. The result reported in these proceedings is generally lower, but still compatible, than the ALICE measurement.

4. Conclusion and prospects

Prompt D^0 mesons and Λ_c^+ baryons production cross-sections and nuclear modification factors are studied in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The production ratio $R_{\Lambda_c^+/D^0}$ between Λ_c^+ baryons and D^0 mesons is presented. The results show reasonable agreement with theoretical calculations, and demonstrate the LHCb experiment's ability to make a significant contribution to precision measurements of open heavy flavour in heavy-ion collisions. The experiment collected a dataset of $34\,{\rm nb}^{-1}$ pPb collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV in 2016, which is about 20 times larger than the 5.02 TeV dataset. An improvement in the precision of heavy flavour measurements is, thus, expected to be achievable in the near future.

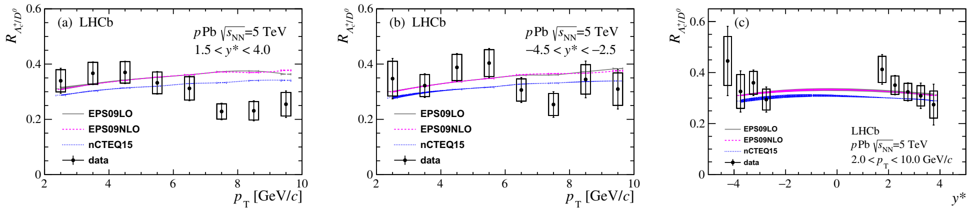

Fig. 3. The cross-section ratio $R_{\Lambda_c^+/D^0}$ between Λ_c^+ baryons and D^0 mesons as a function of p_T in (a) the forward rapidity region, (b) the backward rapidity region, and (c) as a function of y^* integrated over $2 < p_T < 10\,\text{GeV}/c$. The error bars represent the sum in quadrature of the statistical and the systematic uncertainties. The coloured curves represent HELAC-Onia calculations with nPDFs EPS09LO/NLO and nCTEQ15.

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References

[1] L. Adamczyk, et al., Observation of D^0 meson nuclear modifications in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, Phys. Rev. Lett. 113 (2014) 142301. arXiv:1404.6185, doi:10.1103/PhysRevLett.113.142301.

[2] B. Abelev, et al., Azimuthal anisotropy of D meson production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Rev. C90 (2014) 034904. arXiv:1405.2001, doi:10.1103/PhysRevC.90.034904.

[3] R. Aaij, et al., Study of prompt D^0 meson production in pPb collisions at $\sqrt{s_{NN}} = 5$ TeV, JHEP 10 (2017) 090. arXiv:1707.02750, doi:10.1007/JHEP10(2017)090.

[4] R. Aaij, et al., Prompt Λ_c^+ production in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeVarXiv:1809.01404.

[5] Y. Oh, C. M. Ko, S. H. Lee, S. Yasui, Heavy baryon/meson ratios in relativistic heavy ion collisions, Phys. Rev. C79 (2009) 044905. arXiv:0901.1382, doi:10.1103/PhysRevC.79.044905.

[6] S. H. Lee, K. Ohnishi, S. Yasui, I.-K. Yoo, C.-M. Ko, Lambda(c) enhancement from strongly coupled quark-gluon plasma, Phys. Rev. Lett. 100 (2008) 222301. arXiv:0709.3637, doi:10.1103/PhysRevLett.100.222301.

[7] M. A. C. Lamont, the STAR Collaboration, Recent results on strangeness production at rhic, J. Phys. G 32 (12) (2006) S105. arXiv:nucl-ex/0608017, doi:10.1088/0954-3899/32/12/S13.
URL `http://stacks.iop.org/0954-3899/32/i=12/a=S13`

[8] B. B. Abelev, et al., K_S^0 and Λ production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Rev. Lett. 111 (2013) 222301. arXiv:1307.5530, doi:10.1103/PhysRevLett.111.222301.

[9] G. Xie, Λ_c Production in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV measured by the STAR experiment, Nucl. Phys. A967 (2017) 928–931. arXiv:1704.04353, doi:10.1016/j.nuclphysa.2017.06.004.

[10] S. Acharya, et al., Λ_c^+ production in pp collisions at $\sqrt{s} = 7$ TeV and in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, JHEP 04 (2018) 108. arXiv:1712.09581, doi:10.1007/JHEP04(2018)108.

[11] R. Aaij, et al., LHCb detector performance, Int. J. Mod. Phys. A30 (2015) 1530022. arXiv:1412.6352, doi:10.1142/S0217751X15300227.

[12] R. Aaij, et al., Measurements of prompt charm production cross-sections in pp collisions at $\sqrt{s} = 5$ TeV, JHEP 06 (2017) 147. arXiv:1610.02230, doi:10.1007/JHEP06(2017)147.

[13] S. Agostinelli, et al., Geant4: A simulation toolkit, Nucl. Instrum. Meth. A506 (2003) 250. doi:10.1016/S0168-9002(03)01368-8.

[14] J. Allison, K. Amako, J. Apostolakis, H. Araujo, P. Dubois, et al., Geant4 developments and applications, IEEE Trans.Nucl.Sci. 53 (2006) 270. doi:10.1109/TNS.2006.869826.

[15] R. Aaij, et al., Prompt Λ_c^+ production in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV (LHCb-CONF-2017-005).

[16] J.-P. Lansberg, H.-S. Shao, Towards an automated tool to evaluate the impact of the nuclear modification of the gluon density on quarkonium, D and B meson production in proton-nucleus collisions, Eur. Phys. J. C77 (2017) 1. arXiv:1610.05382, doi:10.1140/epjc/s10052-016-4575-x.

[17] H.-S. Shao, HELAC-Onia: An automatic matrix element generator for heavy quarkonium physics, Comput. Phys. Commun. 184 (2013) 2562–2570. arXiv:1212.5293, doi:10.1016/j.cpc.2013.05.023.

[18] H.-S. Shao, HELAC-Onia 2.0: an upgraded matrix-element and event generator for heavy quarkonium physics, Comput. Phys. Commun. 198 (2016) 238–259. arXiv:1507.03435, doi:10.1016/j.cpc.2015.09.011.

[19] R. Aaij, et al., Prompt charm production in pp collisions at $\sqrt{s} = 7$ TeV, Nucl. Phys. B871 (2013) 1. arXiv:1302.2864, doi:10.1016/j.nuclphysb.2013.02.010.

[20] K. J. Eskola, H. Paukkunen, C. A. Salgado, EPS09: A New Generation of NLO and LO Nuclear Parton Distribution Functions, JHEP 04 (2009) 065. arXiv:0902.4154, doi:10.1088/1126-6708/2009/04/065.

[21] K. Kovarik, et al., nCTEQ15 - Global analysis of nuclear parton distributions with uncertainties in the CTEQ framework, Phys. Rev. D93 (8) (2016) 085037. arXiv:1509.00792, doi:10.1103/PhysRevD.93.085037.