Production cross-sections of prompt Λ_c^+ in pPb collisions at $\sqrt{s_{NN}} = 5$ TeV with the LHCb detector

Jiayin Sun on behalf of the LHCb collaboration[1,⋆]

[1] *Center for High Energy Physics, Tsinghua University, Beijing, China*

Abstract. The study of the nuclear modification factor and the forward/backward asymmetry in pPb collisions at $\sqrt{s_{NN}} = 5$ TeV is extended to the Λ_c^+ baryon, providing the first measurement of charmed baryon production in pA collisions. The result is compared to the analogous measurement on charmed mesons, providing an insight on the production mechanism of charmed hadrons.

1 Introduction

Heavy quarks are sensitive probes to explore the properties of the Quark-Gluon-Plasma (QGP), a state of matter consisting of deconfined quarks and gluons. They are created in pairs in the early stage of the space-time evolution of heavy-ion collisions. Multiple experimental measurements of D^0 meson production in heavy-ion collisions at RHIC [1] and the LHC [2] indicate strong interactions between the c quark and the medium. To fully intepret these results, one needs to first disentangle quantitatively the cold nuclear matter (CNM) effects, which can be studied in proton-nucleus collisions, from hot medium effects. Measurement of prompt Λ_c^+ production in pPb collisions extends the study of CNM effects to charmed baryons. Furthermore, the baryon-to-meson production ratio for charmed hadrons can be obtained, with possible relevance to the hadronisation mechanism at the charm sector [3, 4]. Measurements of baryon-to-meson ratio for light and strange hadrons have shown a significant baryon enhancement at intermediate transverse momentum (p_T) in central heavy-ion collisions [5, 6]. Recently, the STAR experiment has reported a significant Λ_c^+ enhancement above theoretical expectations in semi-central AuAu collisions at 200 GeV [7]. The measurement of Λ_c^+ in pPb will provide an important baseline to fully understand the implication of this observation.

2 LHCb detector and heavy-ion data taking

The LHCb detector[8, 9] is a single-arm spectrometer covering 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_T, precise decay vertex reconstruction to distinguish prompt and secondary decay particles, and excellent particle identification based on the RICH detectors.

⋆e-mail: jiayin.sun@cern.ch

The experiment took its first dataset of heavy-ion collisions in 2013, with pPb collisions at $\sqrt{s_{\rm NN}} = 5$ TeV. It successfully collected data of $3-5\mu$b^{-1} PbPb collisions at $\sqrt{s_{\rm NN}} = 5$ TeV in 2015, and 34 nb^{-1} pPb collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV in 2016. This analysis uses the first data sample of pPb collisions at $\sqrt{s_{\rm NN}} = 5$ TeV, with $E_p = 4$ TeV and $E_{\rm Pb} = 1.58$ TeV per nucleon, leading to a rapidity shift of $\Delta y = 0.4645$ 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 integrated luminosity is 1.06 ± 0.02 nb^{-1} and 0.52 ± 0.01 nb^{-1} for the forward and backward collisions, respectively.

3 Prompt Λ_c^+ production in pPb collisions at $\sqrt{s_{\rm NN}} = 5$ TeV

The Λ_c^+ baryons are reconstructed through the $\Lambda_c^+ \to pK^-\pi^+$ decay channel. Tight particle identification requirements based on the RICH detectors are applied to suppress the combinatorial background. The impact parameter with respect to the collision vertex is used to separate the prompt Λ_c^+ and non-prompt Λ_c^+ originating from b-hadron decays. The number of prompt Λ_c^+ signals are determined from fits to the $m(pK^-\pi^+)$ invariant mass distribution and the Λ_c^+ impact parameter distribution. A full detector simulation based on Geant4 [10, 11] is used to calculate the reconstruction and selection efficiency, which is corrected to account for the effects of detector occupancy. The particle identification efficiency is estimated from a calibration data sample. The differential production cross-sections of Λ_c^+ baryons are measured as a function of the Λ_c^+ transverse momentum and rapidity in the kinematic range $2 < p_{\rm T} < 10$ GeV/c and $1.5 < y^* < 4.0$ for the forward sample and $-4.5 < y^* < -2.5$ for the backward sample. Fig. 1 shows the corresponding one-dimensional differential Λ_c^+ cross-section as a function of $p_{\rm T}$ and y^*.

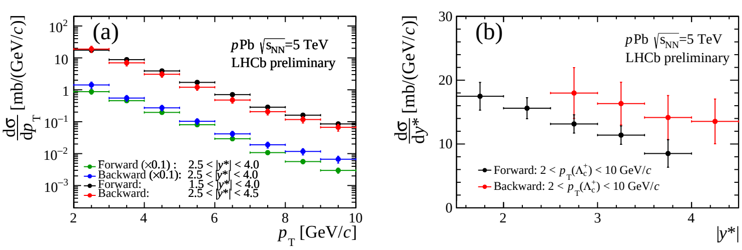

Figure 1. Differential cross-section of prompt Λ_c^+ baryons in pPb collisions as a function of (a) $p_{\rm T}$ and (b) y^* in the forward and backward samples. The error bars represent the quadratic sum of the statistical and the systematic uncertainties.

The forward-backward ratio $R_{\rm FB}$ measures the Λ_c^+ production asymmetry in the forward and backward rapidity regions. It is defined as the ratio of the cross-sections in the two rapidity regions, $R_{\rm FB} \equiv \sigma(+|y^*|, p_{\rm T})/\sigma(-|y^*|, p_{\rm T})$, 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. The left and right panels of Fig. 2 display the prompt Λ_c^+ $R_{\rm FB}$ ratio as a function of $p_{\rm T}$ in the common rapidity region $2.5 < |y^*| < 4.0$, and the $R_{\rm FB}$ ratio as a function of y^* in the region $2 < p_{\rm T} < 10$ GeV/c, respectively. The points are compared to calculations [12] by HELAC-Onia [13, 14]. Constrained by measured prompt Λ_c^+ cross section in pp collisions, the calculations incorporate the parton distribution functions of EPS09LO, EPS09NLO [15] and nCTEQ15 [16]. Good consistency between the data and the calculations is observed.

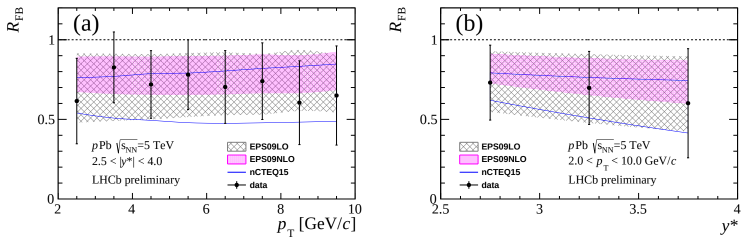

Figure 2. Forward-backward production ratios R_{FB} as function of (a) p_{T} integrated over $2.5 < y^* < 4.0$ and (b) y^* integrated over $2 < p_{\mathrm{T}} < 10\,\mathrm{GeV}/c$.

The LHCb measurement of D^0 cross-sections in pPb collisions at 5 TeV [17] allows the calculation of the baryon-to-meson production ratio, $R_{\Lambda_c^+/D^0} \equiv \sigma(\Lambda_c^+)/\sigma(D^0)$. Fig. 3 and Fig. 4 show the p_{T} and y^* dependence of the measured $R_{\Lambda_c^+/D^0}$ ratio. The coloured curves illustrate the HELAC-Onia calculations [12–14]. The data points are in general consistent with the calculations within uncertainty. At higher p_{T} the data fall below the calculations at forward rapidity. Compared to the relatively flat theoretical curves, the $R_{\Lambda_c^+/D^0}$ ratios tend to increase with increasing $|y^*|$. The trend difference is more pronounced in the backward data. The result is generally below the ALICE measurement of $R_{\Lambda_c^+/D^0}$ ratio in midrapidity in pPb collisions at 5 TeV [18].

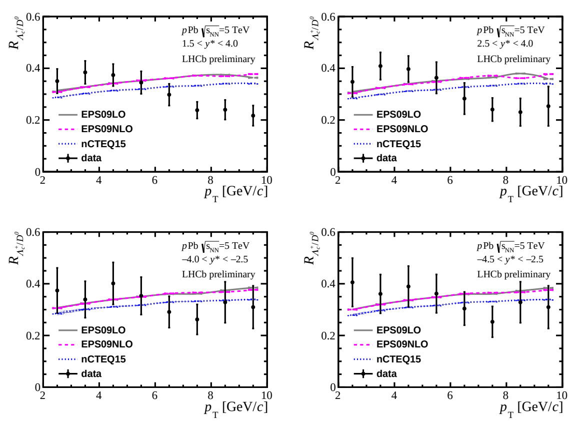

Figure 3. The baryon-to-meson production ratio $R_{\Lambda_c^+/D^0}$ as a function of p_{T} integrated over four different rapidity regions.

4 Conclusion and prospects

In this proceeding, preliminary results of prompt Λ_c^+ production cross-sections are obtained with pPb collision data at $\sqrt{s_{NN}} = 5$ TeV collected by the LHCb experiment. The prompt Λ_c^+ forward-

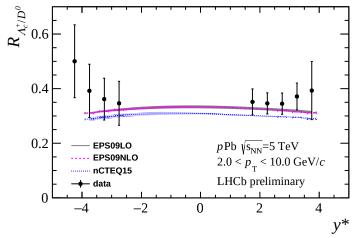

Figure 4. The baryon-to-meson production ratio $R_{\Lambda_c^+/D^0}$ as a function of y^* integrated over $2 < p_{\mathrm{T}} < 10\,\mathrm{GeV}/c$.

backward production ratio R_{FB} and the production ratio $R_{\Lambda_c^+/D^0}$ between Λ_c^+ baryons and D^0 mesons are presented. The results show reasonable agreement with theoretical calculations incorporating nuclear parton distribution functions within uncertainties. The results demonstrate the LHCb experiment's ability to make a significant contribution to precision measurements of open heavy flavour in heavy-ion collisions. With the significantly larger pPb dataset at $\sqrt{s_{NN}} = 8.16$ TeV, more heavy flavour measurements with improved precision in the forward rapidity are expected in the near future to provide information on the cold nuclear matter effects.

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