

Production of open charm and beauty states in pPb collisions with LHCb

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These proceedings summarize the LHCb measurements of charm- and beauty-hadron production in pPb collisions. The studies are made down to very low- p_T of the observed heavy-flavor hadrons using fully reconstructed decays. Nuclear matter effects are quantified via nuclear modification factors and forward-backward production ratios. A strong suppression is observed at positive rapidity (proton beam direction), while a modest or no suppression is seen for the backward rapidity (lead beam direction). The nuclear parton distributions of the lead nucleus is constrained down to Bjorken- $x \sim 10^{-5}$, assuming it is the only nuclear effect for open heavy-flavor production. These data provide important inputs to understand the Quark-Gluon Plasma formed in heavy-nucleus collisions.

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1. Introduction

Heavy-flavor quarks (charm and beauty) are unique probes of nuclear matter. Thanks to their heavy masses, they are produced at the early times of the collisions, and experience the whole evolution of the nuclear medium before hadronisation. As a result, their kinematics and hadronisation contain information on the properties of the medium. The heavy-quark masses provide also a hard scale that allows theoretical predictions of their production based on perturbative QCD approach. Studies of heavy-quark production in pPb collisions help to quantify cold nuclear matter effects (CNM), referring to those affecting particle production that are not related to the presence of a deconfined medium, i.e. the Quark-Gluon Plasma. The most extensively discussed CNM effects include the modification of collinear parton distribution functions described in the framework of nuclear PDF (nPDF) [1] or color-glass condensate (CGC) [2]. One way to quantify the CNM effects is to measure the nuclear modification factor, R_{pA} , defined as the ratio of the cross-sections in p-nucleus to pp collisions, scaled by the nucleus atomic number, A . A deviation from unity of this factor for heavy-flavor production would indicate the presence of nuclear matter effect.

These proceedings present the measurements of D^0 [3], Λ_c^+ [4], B^+ , B^0 and Λ_b^0 production [5] in pPb collisions at $\sqrt{s_{NN}} = 5$ and 8.16 TeV by the LHCb collaboration.¹ The pPb data correspond to an integrated luminosity of about 2 nb^{-1} and about 30 nb^{-1} for the charm and beauty measurements. The data were collected with final state particles in either proton (forward, positive y) or lead beam (backward, negative y) direction pointing into the LHCb acceptance from the interaction region. The LHCb experiment was designed for precision measurements of beauty and charm hadrons in pp collisions, with optimized vertexing, tracking and particle identification systems, and flexible trigger strategy, and now becomes a general-purpose detector. The detailed description of LHCb detector and operation performances can be found in Refs. [6, 7].

2. Prompt D^0 production in pPb data at $\sqrt{s_{NN}} = 5 \text{ TeV}$

The D^0 candidates are reconstructed through $D^0 \rightarrow K^\pm \pi^\mp$ decays. Prompt D^0 and those feed-down from beauty decays are separated by studying the D^0 impact parameter distribution. The forward-to-backward cross-section ratio, R_{FB} , quantifies the relative nuclear modification in the p- and the Pb-beam direction. Displayed at the top of Fig. 1, the $R_{FB}(D^0)$ indicates significant production asymmetry between p- and Pb-beam direction. The asymmetry increases at large absolute rapidity and reduces at high p_T . If the effect is dominated by nPDF, it suggests a larger asymmetry of modifications of gluon PDF at small and large- x . The measurements display reasonable agreements with calculations using different nPDF sets in the HELAC-Onia framework [8]. The measurement of R_{pA} for prompt D^0 as a function of p_T and y is shown at the bottom of Fig. 1. The $D^0 R_{pA}$ as a function of rapidity shows a strong suppression ($\sim 30\%$) at positive rapidity, while it is compatible with no suppression at negative rapidity with a hint of enhancement at extreme backward rapidity. The result suggests strong shadowing effect in the small- x region and hint of anti-shadowing in the appropriate large- x area. Considering R_{pA} as a function of p_T (Fig. 1 bottom right), the pattern is very similar for different rapidity bins, increasing from low- p_T to high- p_T . The slope and magnitude of R_{pA} as a function of p_T vary only marginally across the rapidity bins

¹Charge conjugated states are included throughout this manuscript.

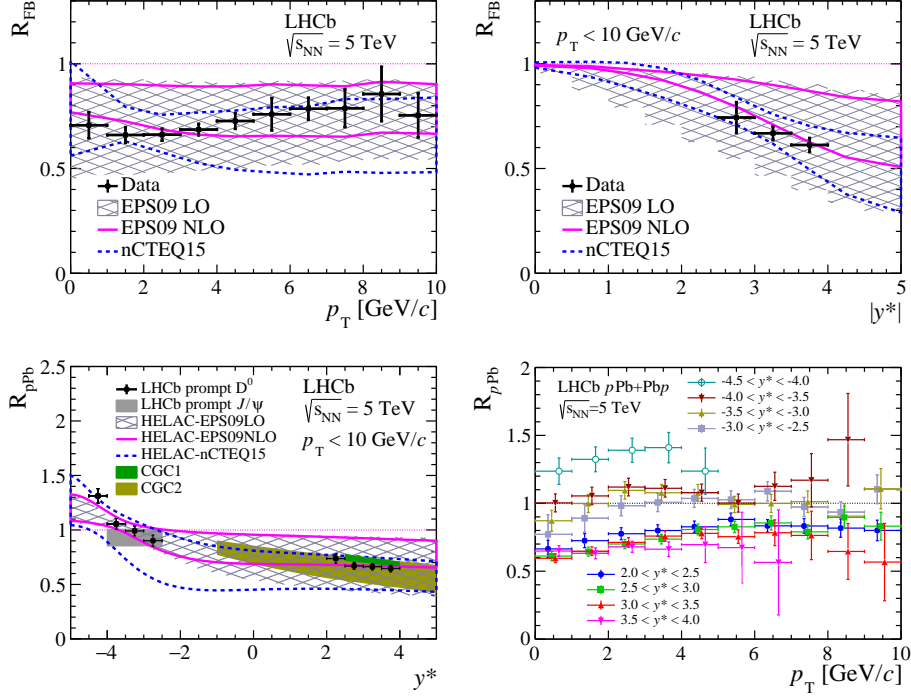


Figure 1: The D^0 meson R_{FB} as a function of (top left) p_T and (top right) y of the hadron and R_{pA} (bottom left) as a function of rapidity and (bottom right) p_T for different rapidity bins.

for both pPb and PbP data. The R_{pA} for prompt D^0 mesons is also consistent with that of J/ψ hadrons within current experimental precision, and both agree with HELAC-Onia calculations using nPDF sets. At forward rapidity, the D^0 R_{pA} is also described by CGC calculations [9, 10] with chosen saturation scales that model J/ψ data. The precision of the D^0 R_{pA} data has contributed to constraint significantly recent nPDF predictions [11].

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

The Λ_c^+ baryon is reconstructed with $\Lambda_c^+ \rightarrow pK^- \pi^+$ decays, resulting in thousands of signals with little background contamination. The forward-backward ratio (left of Fig. 2), being smaller than unity, indicates a stronger suppression of Λ_c^+ production in the forward region compared with the negative rapidity, consistent with predictions using nPDF sets. The charm baryon-to-meson ratio, $R_{\Lambda_c^+/D^0}$, which is sensitive to charm quark fragmentation, is also studied. Shown on the right of Fig. 2, the magnitude of $R_{\Lambda_c^+/D^0}$ is consistent with nPDF predictions, which implies that cold nuclear matter effect is almost identical for different charm-hadron species. There might be a hint of discrepancy at high- p_T , which will be followed up by studies using the larger sample of LHCb Run II pPb data. The ratio $R_{\Lambda_c^+/D^0}$ measured by LHCb, however, has tensions with the ALICE result that gives a value around 0.5 at low- p_T and mid rapidity [12], more than $2\text{-}\sigma$ deviations from LHCb. More detailed studies are required to understand this puzzle using the larger pPb sample collected at $\sqrt{s_{NN}} = 8.16$ TeV.

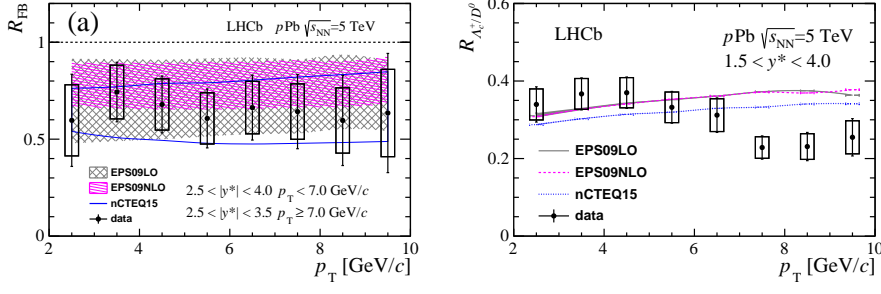


Figure 2: (Left) R_{FB} for prompt Λ_c^+ production and (right) Λ_c^+ over D^0 production ratio in pPb data.

4. Beauty hadron production in pPb data at $\sqrt{s_{NN}} = 8.16$ TeV

The B^+ , B^0 and Λ_b^0 production is studied using exclusive decays $B^+ \rightarrow J/\psi K^+$, $\bar{D}^0 \pi^+$, $B^0 \rightarrow D^- \pi^+$ and $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$. The B^0/B^+ cross-section ratio is found to be consistent with unity within one standard deviation, independent of p_T or y , confirming the isospin symmetry in pPb collisions. The Λ_b^0/B^0 cross-section ratio is about 40% averaging over the range $2 < p_T < 20$ GeV/ c and $2.5 < |y| < 3.5$. With a decreasing trend for increasing p_T , the Λ_b^0/B^0 cross-section ratio reaches a value similar to LEP data [13] at $p_T \sim 20$ GeV/ c . The Λ_b^0/B^0 production ratio in pPb data over that in pp collisions, shown on the top left of Fig. 3, is compatible with unity in all p_T bins, which suggests a similar nuclear effect between the beauty baryon and mesons. Displayed on the top right of Fig. 3 is the measurement of R_{FB} for B^+ , B^0 and Λ_b^0 . Results are similar for the three beauty-hadron species. The R_{FB} for B^+ , which has a better experimental precision, is smaller than unity and is in good agreement with nPDF calculations. The R_{pPb} is also calculated for the B^+ hadron, depicted at the bottom of Fig. 3 as a function of p_T . The pattern is similar to that of D^0 . The result shows significant suppression of B^+ production at low- p_T at positive rapidity, which almost vanishes going to high- p_T . At backward rapidity, the R_{pPb} for the B^+ hadron is consistent with unity and demonstrates no obvious p_T dependence. The measurement agrees with predictions involving nPDF sets, and specifically the nPDF set that is constrained by LHCb data of prompt D^0 production in pPb collisions. The result also confirms previous LHCb measurement using J/ψ from b -hadron decays. If the modification of PDF in nucleus is the dominant nuclear effects, R_{pA} for different beauty-hadron species is predicted to be almost identical, as is the case for charm hadrons. With the experimental uncertainty being smaller than those for theoretical calculations at forward rapidity, LHCb beauty-hadron measurement provides further constraints to nPDF.

5. Summary

With the precise and diverse measurements of charm and beauty hadrons in pPb collisions, LHCb made important contributions to the studies of heavy-ion physics. Prompt D^0 cross-section is measured down to zero- p_T , showing strong suppression for production in proton beam direction. The cross-section ratio of Λ_b^0 over B^0 is consistent with expectation from pp collisions with current precision, indicating similar nuclear effects for beauty baryon and meson production in pPb colli-

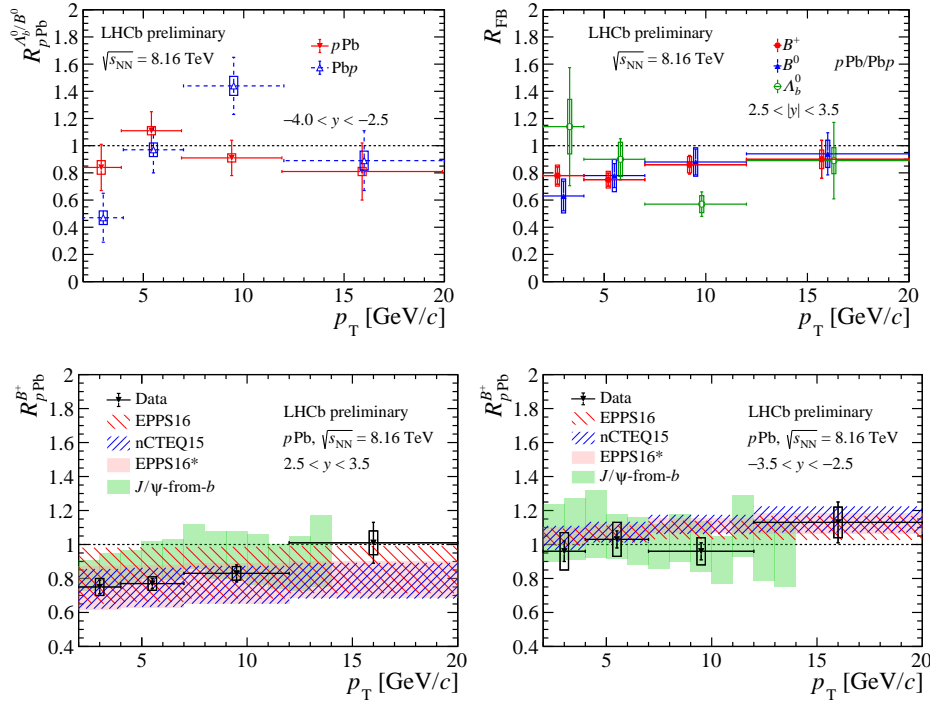


Figure 3: (Top left) Beauty hadron R_{pPb} and (top right) Λ_b^0 over B^0 production ratio. Nuclear modification of B^+ at (bottom left) negative and (bottom right) positive rapidity.

sions. More measurements involving charm and beauty hadron are under study using the new pPb data samples collected at $\sqrt{s_{NN}} = 8.16$ TeV.

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