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Open heavy-flavor production in pPb collisions at 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, suggesting a strong suppression for the forward rapidity and no suppression for the backward rapidity. The results help to constrain nuclear parton distribution distribution down to Bjorken-$x \sim 10^{-5}$. The charm pair production is first measured in pPb data, which comfirms the enhancement of double parton scattering in pPb collisons. These data provide important inputs to understand the Quark-Gluon Plasma formed in heavy-nucleus collisions.

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1. Introduction

Heavy quarks are produced in the hard processes in the early stage of ultra-relativistic heavy ion collisions. These quarks interact with the hot and dense medium created in such collisions and undergo significant energy loss when traversing the medium. Measurements of heavy-flavor production can reveal important information about the properties of the hot medium, which is generally believed to consist of deconfined quarks and gluons, and is known as the Quark-Gluon Plasma (QGP). In addition to the effects due to the hot and dense nuclear matter, cold nuclear matter (CNM) effects are also present in nucleus-nucleus interactions and can modify the heavy-flavor production rate. The CNM effects can be studied with pA collisions, where any potential effects from QGP formation are not expected to be dominant. One of the CNM effects is the modification of the initial Parton density compared to that in free nucleons, which can be accounted by calculations based on nPDFs [1] or color-glass condensate effective theory (CGC) [2]. One variable that quantities the CNM effects is the nuclear modification factor $R_{p\mathrm{A}}$, defined as the ratio of the cross-sections in pA to pp collisions, scaled by the nucleus mass 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 measurement of D^0 [3] and Λ_c^+ [4] production at $\sqrt{s_{\mathrm{NN}}}$= 5.02 TeV and D^0 [5],B^+, B^0, Λ_b^0 [6] and charm pair production [7] at $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV with pPb collision data by the LHCb collaboration. [1] The pPb data at 5.02 TeV and 8.16 TeV correspond to an integrated luminosity of about 2 nb^{-1} and 30 nb^{-1} respectively. These data include two different beam configurations 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, with optimized vertexing, tracking and particle identification systems, and flexible trigger strategy. The detailed description of LHCb detector and operation performances can be found in Refs. [8, 9].

2. Prompt D^0 and Λ_c^+ production in pPb data

For both 5.02 TeV and 8.16 TeV data, D^0 candidates are reconstructed through $D^0 \to K^\mp\pi^\pm$ decays, while for Λ_c^+ baryons the decay channel is $\Lambda_c^+ \to pK^-\pi^+$. Prompt D^0 and Λ_c^+ candidates and those from beauty decays are separated by the distribution of the charm-hadron impact parameter. The left panel of the Fig.1 shows the prompt D^0 $R_{p\mathrm{Pb}}$ as a function of rapidity for the 5.02 TeV data, hinting at an enhancement at extreme backward rapidity. The result suggests strong shadowing effects in the small-x region and hints of anti-shadowing in the appropriate large-x area. The result is consistent with J/ψ $R_{p\mathrm{Pb}}$ data and calculations with different nPDF sets in the HELAC-Onia framework [10]. The D^0 $R_{p\mathrm{Pb}}$ is also described by CGC calculations at forward rapidity [11]. The precise D^0 measurement provides significant constraints to nPDFs at very small x region in recent theoretical works [12]. The charm baryon-to-meson ratio, $R_{\Lambda_c^+/D^0}$, displayed on the right panel of Fig.1, is sensitive to the charm quark hadronization. The $R_{\Lambda_c^+/D^0}$ data are consistent with nPDF calculations based on pp cross-sections. However, $R_{\Lambda_c^+/D^0}$ by LHCb is lower than the ALICE result obtained in mid-rapidity region. The difference will be further investigated in future measurements.

[1]Charge conjugated states are included throughout this manuscript.

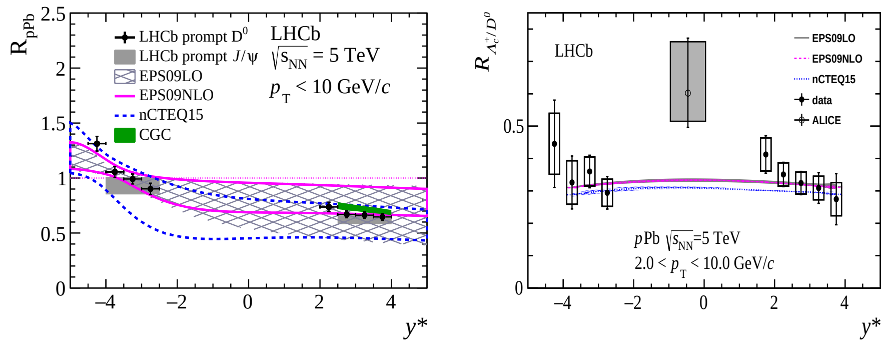

Figure 1: (Left) D^0 $R_{p\mathrm{Pb}}$ and (right) Λ_c^+/D^0 production ratio as a function of y in pPb data at $\sqrt{s_{\mathrm{NN}}}$ = 5 TeV.

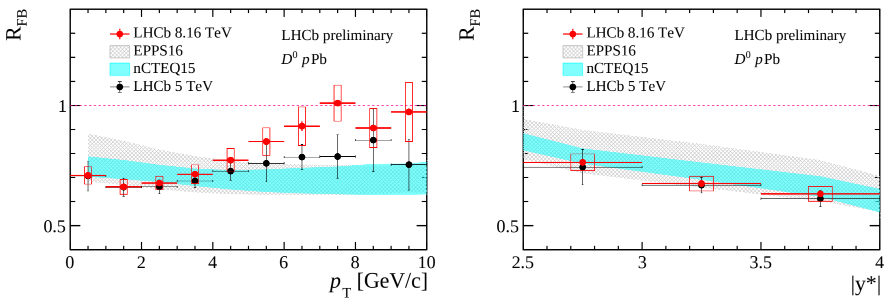

Figure 2: D^0 R_{FB} as a function of (left) p_{T} and (right) y in pPb data at $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV compared with measurements at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV.

Fig.2 shows the preliminary result of forward-backward production ratio R_{FB} for prompt D^0 meson at $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV, which is consistent with the 5.02 TeV measurements. It decreases as a function of y, consistent with the nPDF calculations. The ratio increases with increasing p_{T} , and is consistent with the nPDF calculations at low p_{T} but clearly larger than theory at p_{T} >6 GeV/c.

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

The B^+ , B^0 and Λ_b^0 hadrons are reconstructed using exclusive hadronic decays $B^+ \to J/\psi K^+, B^+ \to \overline{D}^0\pi^+, B^0 \to D^-\pi^+$ and $\Lambda_b^0 \to \Lambda_c^+\pi^-$. The Λ_b^0/B^0 ratio is about 0.39 averaging over the range $2 < p_{\mathrm{T}} < 20$ GeV/c and $2.5 < |y| < 3.5$, similar to results in LHCb pp data. The ratio shows a decreasing trend as a function of p_{T} at $p_{\mathrm{T}} > 5$ GeV/c, as displayed in the left panel of Fig.3. The right panel of Fig.3 presents the result of $R_{p\mathrm{Pb}}$ for B^+ meson as a function of y. It shows significant suppression in low-p_{T} regions for forward data, while for backward data the result is consistent with unity. The measurement agrees with calculations using different nPDF sets and confirms previous LHCb results with J/ψ from beauty decay. With the experimental uncertainty being smaller than those for theoretical calculations at forward rapidity, LHCb beauty-hadron measurement provides further constraints to nPDFs.

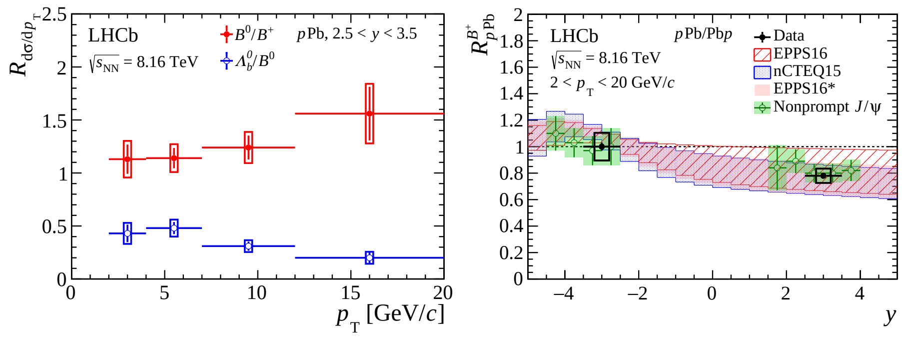

Figure 3: B^0/B^+ and Λ_b^0/B^0 ratio as a function of $p_{\rm T}$ and (right) B^+ $R_{p\rm Pb}$ as a function of y.

4. Prompt charm pair production in pPb data at $\sqrt{s_{\rm NN}}$ = 8.16 TeV

At high energy hadron colliders, particles can be generated from a single primary parton scattering (SPS) or multiple parton scattering. For a production of two final states particle A and B, the DPS process can be parametrized as

$$\sigma^{AB}_{\rm DPS} = \frac{1}{1+\delta_{AB}} \frac{\sigma^A \sigma^B}{\sigma_{\rm eff}} , \tag{1}$$

where $\delta_{AB} = 1$ if A and B are identical and is zero otherwise, $\sigma^{A(B)}$ is the inclusive cross-section for $A(B)$, and $\sigma_{\rm eff}$ is the effective cross-section, expected to be independent of the final state. The measurement of double charm pair production in pPb collisions is the first study of Double Parton Scattering (DPS) in heavy ion collisions. It reconstructs charm hadrons via decays of $D^0 \rightarrow K^-\pi^+, D^+ \rightarrow K^-\pi^+\pi^+, D_s^+ \rightarrow K^-K^+\pi^+$ and $J/\psi \rightarrow \mu^+\mu^-$. Fig.4 displays the invariant-mass and $\Delta\phi$ distribution for D^0D^0 pair, The invariant-mass of the D^0D^0 pairs hints at a different distribution between the like-sign D^0D^0 and opposite-sign $D^0\overline{D}^0$ pairs. The like-sign pairs, where a large contribution from DPS is expected, suggests a harder spectrum than the opposite-sign pairs, which are produced dominantly by a single $c\bar{c}$ pair via SPS. The $\Delta\phi$ distribution of the like-sign pairs is consistent with a flat distribution, whereas the opposite sign pairs show a peak at $\Delta\phi \sim 0$ at higher charm $p_{\rm T}$. The $\sigma_{\rm eff}$ is calculated using the D^0 D^0 and J/ψ D^0 cross-sections, with a typical value of order 1 b. The result confirms the expectation that DPS production is enhanced by a factor of three compared to SPS from pp to pPb collisions. The $\sigma_{\rm eff}$ value from $J/\psi D^0$ cross-section is smaller compared to that from D^0 D^0 cross-sections. The difference, which may be of physical origin, can be investigated with future measurements. The $\sigma_{\rm eff}$ in forward region is higher than that in the backward region, suggesting a different level of DPS enhancement when comparing forward and backward data.

5. Summary

LHCb has strong capabilities to study heavy flavor in heavy-ion collisions, and has performed precise and diverse measurements of charm and beauty hadrons in pPb collisions. The prompt D^0 results help to constrain nPDFs. The prompt Λ_c^+/D^0 production ratio is consistent with calculations using nPDFs. The preliminary result on promp D^0 $R_{\rm FB}$ at 8.16 TeV hints at an increasing

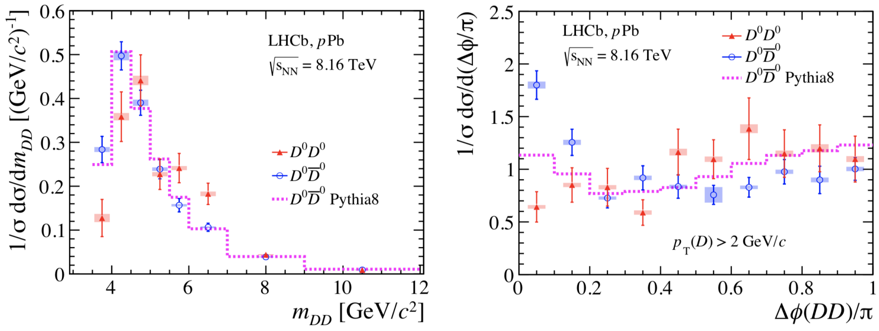

Figure 4: (Left) the invariant-mass distribution of $D^0 D^0$ and $D^0 \overline{D}^0$ pair for forward data, and (right) the $\Delta\phi$ distribution for $D^0 D^0$ and $D^0 \overline{D}^0$ pair for forward data with $p_T > 2$GeV/c.

trend towards high p_T. The measurements of b-hadron $R_{p\text{Pb}}$ show a significant suppression in pPb data compared to pp in forward rapidity region. The charm pair production is first measured in pPb data, confirming the DPS is enhanced by a factor of three compared to SPS. More precision measurements with heavy flavors from the LHCb can be anticipated in the near future.

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