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Heavy flavour and exotic production at LHCb

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These proceedings summarise recent LHCb results on heavy-flavour and exotic production in high-multiplicity pp and heavy-ion collisions, covering the measurement of B_s^0/B^0 production ratio, the study of the prompt D^0 nuclear modification factor, the first measurement of Λ_c^+/D^0 production ratio in peripheral PbPb collisions in the forward rapidity region, and the first measurement of prompt $\chi_{c1}(3872)$ production in pPb collisions. These results indicate that other possible initial- or final-state effects beyond current theoretical models may exist in heavy-ion collisions, which is important for the investigation of cold nuclear matter effects. More works are in progress to further investigate these effects.

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1. Introduction

Heavy quarks are produced in the early-stage hard processes of ultra-relativistic heavy-ion collisions and are strongly affected by the presence of quark-gluon plasma (QGP), as well as by cold nuclear matter effects. Measurements on heavy flavour provide unique opportunities to study these nuclear matter effects in heavy-ion collisions and may help to better understand high-multiplicity pp collisions. In initial stages of heavy-ion collisions, the modified parton distribution function in the nuclear environment (nPDF) [1, 2], or the possible existence of a colour glass condensate (CGC) [3, 4], as well as initial and final-state energy loss [5–7], will lead to modification of heavy-quark production cross-sections with respect to extrapolation from pp collisions. Though the fragmentation mechanism [8, 9] dominates the hadron quark hadronisation in e^+e^- collisions, recent measurements have shown that charm quark hadronisation differs between e^+e^- and pp collisions [10]. The quark coalescence mechanism [11] can become important for heavy quarks when the number of quarks increases in the system. It will lead to enhanced production of baryons, exotic states and hadrons with strangeness, especially in heavy-ion collisions.

The LHCb experiment is designed for precision measurements of beauty and charm hadrons.A detailed description of the LHCb detector and operation performances can be found in Refs. [12, 13]. It has become a generally proposed detector for analysing pp, pPb and PbPb data. The asymmetric pPb data include two different beam configurations with final state particles in either proton (forward, positive rapidity) or lead beam (backward, negative rapidity) direction pointing into the LHCb acceptance from the interaction region. These proceedings present the measurements of $B_s^0/\ B^0$ production ratio in pp at $\sqrt{s} = 13\,\text{TeV}$[14], prompt D^0 production [15] and $\chi_{c1}(3872)/\psi(2S)$ production ratio [16] in pPb at $\sqrt{s_{\text{NN}}} = 8.16\,\text{TeV}$ and the prompt Λ_c^+/D^0 ratio in peripheral PbPb collisions [17]. These measurements help to investigate the initial- and final-state effects in heavy flavour production in heavy-ion collisions.

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

The production ratio of B_s^0 mesons relative to B^0 mesons is measured as a function of event multiplicity [14], using a sample of pp collisions collected at a centre-of-mass energy of $\sqrt{s} = 13\,\text{TeV}$, corresponding to an integrated luminosity of $5.4\,\text{fb}^{-1}$. Both particles are reconstructed via the common final states $J/\psi\pi^+\pi^-$. The multiplicity dependence $\sigma_{B_s^0}/\sigma_{B^0}$ is shown in three different intervals of the B meson p_{T} in Fig. 1. In the lowest p_{T} interval, $0 < p_{\text{T}} < 6\,\text{GeV}/c$, the $\sigma_{B_s^0}/\sigma_{B^0}$ ratio is consistent with results from e^-e^+ collisionswhile increases with multiplicity. The significance of the slope from linear fit differs from zero by 3.4 standard deviations. The measurements in higher p_{T} intervals are consistent with data from e^-e^+ and display no multiplicity dependence. These measurements are qualitatively consistent with expectations based on the emergence, in such high-multiplicity environment, of quark coalescence as an additional hadronisation mechanism, rather than fragmentation [8, 9] alone.

3. Prompt D^0 production in pPb at $\sqrt{s_{\text{NN}}} = 8.16$ TeV

The D^0 production cross-section is measured in pPb collisions at a center-of-mass energy per nucleon pair of $\sqrt{s_{\text{NN}}} = 8.16\,\text{TeV}$ [15]. The prompt D^0 candidates are distinguished from those from

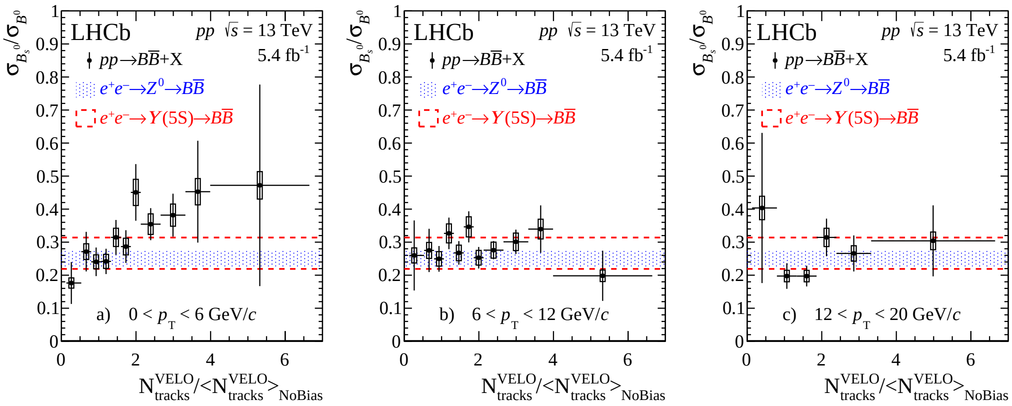

Figure 1: $\sigma_{B_s^0}/\sigma_{B^0}$ ratio versus normalised multiplicity in the transverse momentum region of (left) $0 < p_{\mathrm{T}} < 12\,\mathrm{GeV}/c$, (middle) $6 < p_{\mathrm{T}} < 12\,\mathrm{GeV}/c$ and (right) $12 < p_{\mathrm{T}} < 20\,\mathrm{GeV}/c$.

beauty decays by the distribution of the charm-hadron impact parameter. The nuclear modification factor $R_{p\mathrm{Pb}}$ is calculated by comparing the cross-section with that in pp collisions. The data points, as well as LHCb results at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$ [18] and theoretical calculations [1–4] are displayed in Fig. 2. A significant suppression compared to unity is observed in the forward rapidity, which is consistent with the LHCb 5 TeV result and theoretical calculations. The D^0 $R_{p\mathrm{Pb}}$ shows a slight suppression compared to nPDF calculations at high-p_{T} in the backward rapidity region, indicating possible initial- or final-state effects other than anti-shadowing.

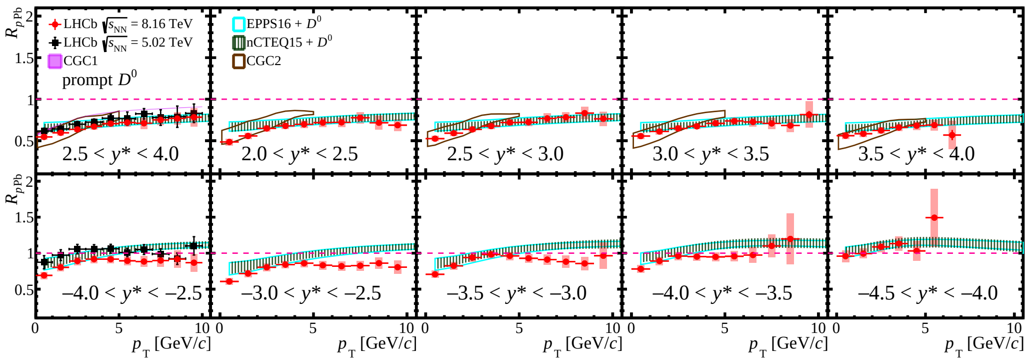

Figure 2: Nuclear modification factor as a function of p_{T} in different y^* intervals for prompt D^0 mesons in the (top) forward and (bottom) backward regions.

4. Prompt Λ_c^+/D^0 ratio in peripheral PbPb collisions

The baryon-to-meson production ratios are excellent probes to study hadronisation in heavy-ion physics. This measurement gives the first result on Λ_c^+/D^0 production ratio $R_{\Lambda_c^+/D^0}$ in peripheral PbPb collisions in the forward rapidity region [17]. The mean value of the ratio $\langle R_{\Lambda_c^+/D^0} \rangle$ is about 0.27 and the results are given as a function of p_{T} and rapidity in Fig. 3, in a centrality region of 65 – 90%. The data are compatible with Pythia 8 [19] calculation incorporating colour reconnection mechanism for $p_{\mathrm{T}} > 5\,\mathrm{GeV}/c$. However, discrepancies are observed with predictions from the statistical hadronisation model [20]. The new result also indicates a dependence of $R_{\Lambda_c^+/D^0}$ on rapidity, where the suppression with respect to Pythia 8 originates from the difference in $p_{\mathrm{T}} < 3\,\mathrm{GeV}/c$.

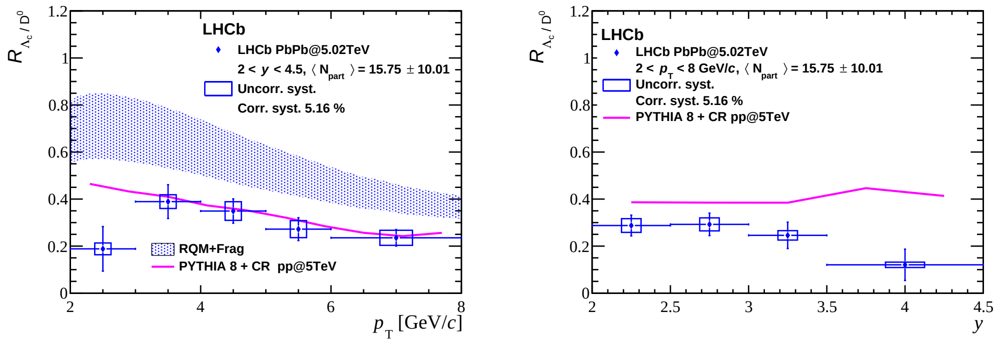

Figure 3: Prompt $R_{\Lambda_c^+/D^0}$ production ratio as a function of (left)p_{T} and (right) rapidity.

5. Prompt $\chi_{c1}(3872)/\psi(2S)$ ratio in pPb

There is still no consensus on the structure of the exotic hadron $\chi_{c1}(3872)$ states. The behaviour of these exotic states in heavy-ion collisions provides new ways to probe their properties. This is the first measurement of $\chi_{c1}(3872)$ states in pPb collisions [16]. The production of $\chi_{c1}(3872)$ states is compared to that of $\psi(2S)$ mesons to study the final-state effects, while initial-state effects largely cancel in the $\chi_{c1}(3872)/\psi(2S)$ ratio. The ratio in both forward and backward rapidity regions are compared to that in pp collisions [21] and PbPb collision [22], as shown in Fig. 4. A rising trend as a function of the collision system size is found, which is different from the observed decreasing trend versus multiplicity in pp collisions [21]. This may indicate that the hadronic densities achieved in the forward and backward pPb collisions allow the quark coalescence to become the dominant mechanism affecting χ_{c1} production. Future measurements of the nuclear modification factor of $\chi_{c1}(3872)$ and $\psi(2S)$, which are in progress at LHCb, can clarify these effects.

6. Summary

The LHCb detector has strong capabilities to study heavy flavour particles and exotic states in pp, pPb and PbPb collisions. Evidence of enhancement of the B_s^0/B^0 production ratio with respect to event multiplicity is found at low-p_{T} in pp collisions, qualitatively consistent with expectations from the quark coalescence model. The D^0 nuclear modification factor is measured in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16\,\mathrm{TeV}$. The result is consistent with theoretical calculations in forward rapidity regions, while a stronger suppression compared to nPDF calculations is seen at high-p_{T} in backward rapidity regions. The measurement of $R_{\Lambda_c^+/D^0}$ is first performed in forward regions. The points show general agreement with Pythia 8 calculation incorporating colour reconnection mechanism for $p_{\mathrm{T}} > 5\,\mathrm{GeV}/c$, while the statistical hadronisation model does not reproduce the data. The $\chi_{c1}(3872)/\psi(2S)$ production ratio is measured in both pPb and Pbp collisions for the first time.

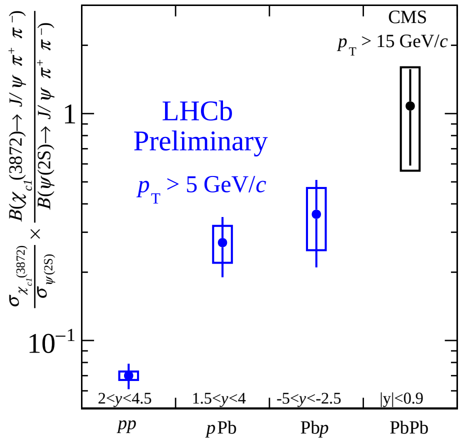

Figure 4: The ratio of $\chi_{c1}(3872)$ to $\psi(2S)$ cross-sections in pp, pPb and PbPb collisions.

The ratio is compared across different collision systems and an increasing trend versus system size is observed, which indicates that quark coalescence may dominate the $\chi_{c1}(3872)$ production in pPb collisions. More measurements are in progress with LHCb data to further investigate the nuclear matter effects and hadronisation mechanisms of heavy quark productions in heavy-ion collisions.

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