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Beauty production in heavy–ion collisions with ALICE at the LHC

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Abstract. In this contribution, the measurement of the centrality dependence of the nuclear modification factor (R_{AA}) of non-prompt D^0 meson in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV is presented. This measurement provides important constraints to the in-medium mass dependence of energy loss and hadronization of the beauty quark. In addition, the first measurements of non-prompt $\mathrm{D_s^+}$ meson production in central and semi-central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV are discussed. The non-prompt $\mathrm{D_s^+}$ meson measurements provide further information on the production and hadronization of $\mathrm{B_s^0}$ mesons. Finally, the first measurement of non-prompt D-meson elliptic flow in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV is shown. This measurement can help to investigate the degree of thermalization of beauty quarks in the hot and dense QCD medium.

1 Introduction

The formation of a colour-deconfined state, called quark-gluon plasma (QGP) in ultra-relativistic collisions of heavy ions is expected from quantum chromodynamics calculations on the lattice [1]. Heavy quarks (i.e. charm and beauty) are produced in hard-scattering processes occurring in the early stage of the collision. As the medium expands in presence of pressure gradients, the heavy quarks interact with its constituents via elastic and inelastic (gluon radiation) scatterings. The measurement of the nuclear modification factor (R_{AA}) of heavy-flavor hadrons allows us to study the mechanisms of energy loss, which provides information on the medium properties and expansion. For heavy-flavour hadrons, in absence of in-medium effects, the R_{AA} is expected to be equal to unity and be independent from transverse momentum (p_{T}). At low momenta, heavy-quark propagation through the medium can be described by transport models as a diffusion process [2]. Heavy-quarks undergo multiple low-energy-transfer interactions that favour the participation of heavy quarks in the collective expansion of the medium, which can alter their azimuthal distribution. This can be probed by measuring their elliptic flow (v_2). The study of the energy loss and the possible thermalization of heavy quarks in the medium provide constraints on the transport coefficient (D_{s}) of the QGP.

2 Beauty in-medium energy loss and thermalization

Prompt and non-prompt D^0-meson R_{AA} were measured by ALICE in central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. Figure 1 shows their ratio as a function of p_{T} [3]. The non-prompt to prompt D^0 R_{AA} ratio is compared with predictions from various models, namely

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MC@sHQ+EPOS2 [4], LGR [5, 6], TAMU [7], and CUJET3.1 [8]. The predictions for $p_{\mathrm{T}} < 5$ GeV/c are similar among the different models: they show a depletion close to unity in $2 < p_{\mathrm{T}} < 3$ GeV/c and an increase at lower and higher p_{T}. The data show a flat trend as a function of p_{T}, about 3.9 σ above unity, for $p_{\mathrm{T}} > 6$ GeV/c. Only the TAMU model predicts a decrease of the R_{AA} ratio in this p_{T} region. This different trend could derive from the absence in the TAMU model of radiative processes, which dominate energy loss in the high p_{T} region in the other models. A differential study of the LGR model predictions is shown in the bottom panel of Fig 1. In particular, the following configurations are implemented to estimate the effect of the different assumptions on the final prediction: the mass of the beauty is set to the one of the charm quark in the energy-loss (I) and in the hadronization (II) processes, the shadowing effect (III) and the hadronization via coalescence (IV) are excluded. In the low-p_{T} region, the absence of the hadronization via coalescence (IV) largely overestimates the data. The main difference observed in the high-p_{T} region is related to the change of the beauty mass in the energy-loss processes supporting the interpretation of the deviation of the measured ratio from unity as a result of the mass-dependence of quark in-medium energy-loss, which is expected to be smaller for more massive quarks.

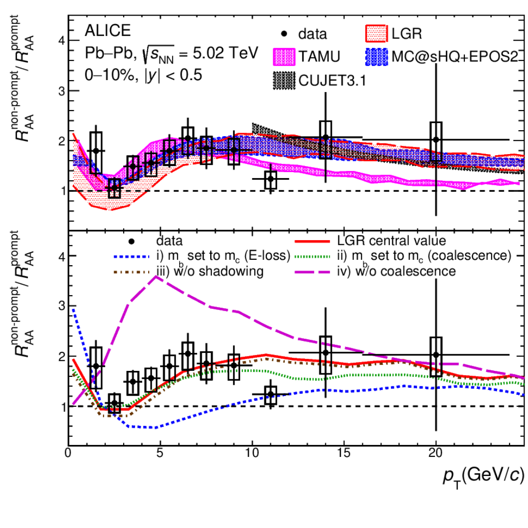

Figure 1. Non-prompt to prompt D^0-meson R_{AA} ratio [3] as a function of p_{T} in central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, compared to model predictions [4–8] (top), and to different modifications of LGR calculations (bottom).

Measurements of strange D mesons provide additional information to investigate the in-medium energy loss and the degree of thermalization of beauty quarks. Figure 2 shows the comparison of the non-prompt to prompt D_s^+-meson R_{AA} ratio (left panel) and non-prompt D_s^+ to D^0-meson R_{AA} ratio (right panel) measured in central and semi-central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. The non-prompt to prompt D_s^+ (non-prompt D_s^+ to D^0) R_{AA} ratio in central collisions shows a hint of enhancement of about 1.6 σ (1.7 σ) with respect to unity in the $p_{\mathrm{T}} < 12$ GeV/c interval. This effect could be caused by a smaller energy-loss for beauty than charm quarks, similarly to the non-prompt-to-prompt D^0-meson R_{AA} ratio. The enhancement observed for non-prompt strange to non-strange D mesons R_{AA} ratio could be due to a substantial contribution of hadronization via recombination of the beauty quark with light quarks in the strangeness-rich QGP environment. The amount of strange quarks relative to that of light quarks is expected to increase from pp to Pb–Pb collisions. Thus, the production of strange to non-strange beauty mesons is expected to increase in Pb–Pb collisions in the low transverse momentum interval. Given the large uncertainties affecting both measurements, a firm conclusion on the size of this effect is not possible. The R_{AA} ratios are also compared with the predictions from the TAMU model. The TAMU model qualitatively describes the trend of the data indicating an enhancement of the R_{AA} ratios in the low-p_T region with respect to unity and a decrease at higher transverse momentum. However, it overestimates the measurements.

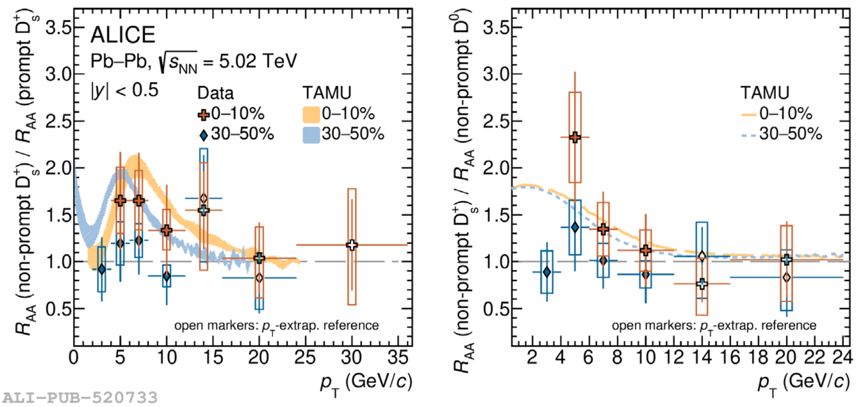

Figure 2. The R_{AA} of non-prompt D_s^+ meson divided by the one of prompt D_s^+ meson (left panel) and non-prompt D^0 meson (right panel) for central and semi-central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV [9]. The measurements are compared with TAMU model predictions [7].

The degree of thermalization of beauty quarks in the QGP can be further studied by measuring the elliptic flow of beauty hadrons. Figure 3 shows the v_2 of prompt and non-prompt D^0 mesons in semi-central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. The non-prompt D^0 mesons show a positive v_2 with a 2.7 σ significance in the $2 < p_T < 12$ GeV/c region. A larger v_2 for prompt D^0 with respect to the one measured for non-prompt D^0 is measured with a significance of 3.2 σ in the low p_T interval. Since the beauty quark is more massive than the charm one, a larger relaxation time is expected. If the relaxation time of beauty quarks is comparable with or larger than the lifetime of the QGP, then the beauty quarks would be able to thermalize only partially.
Finally, the R_{AA} and v_2 of non-prompt D^0 mesons together can set constraints on heavy-quark D_s. Figure 4 shows the R_{AA} and v_2 of non-prompt D^0 compared to theoretical predictions based on Langevin calculations adopting two different values of D_s [10].

3 Conclusion

Heavy quarks are unique probes of the QGP that allow us to characterize its properties. ALICE results show that heavy quarks experience different in-medium energy loss and partially reach thermal equilibrium with the QGP medium. To be able to describe the data, models have to include both the elastic and the radiative energy loss processes. A significant dependence of energy loss on the mass of the quark is observed. The discrepancy observed between prompt and non-prompt D^0 meson v_2 suggests that beauty quarks are less coupled to the medium. More precise measurements, also of fully-reconstructed beauty-hadron decay, will be available in the next data-taking period at the LHC, helping us to further constrain the spatial diffusion coefficient of heavy quarks.

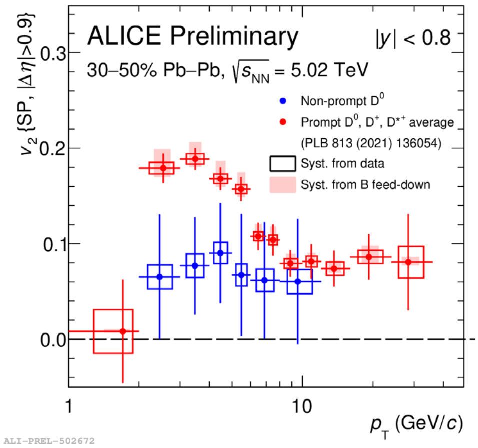

Figure 3. Prompt and non-prompt D^0 meson v_2 in semi-central (30–50%) Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV.

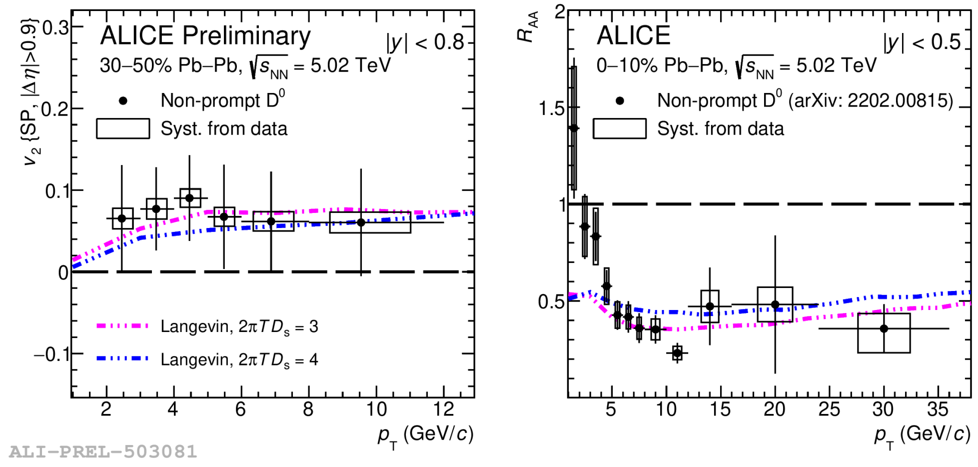

Figure 4. Non-prompt D^0 meson v_2 (left) and R_{AA} (right) in central and semi-central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, respectively. The results are compared with theoretical predictions based on Langevin calculations that adopt different values for the diffusion coefficient [10].

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