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D-meson nuclear modification factor and elliptic flow measurements in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV with ALICE at the LHC

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Abstract

ALICE measured the nuclear modification factor ($R_{\rm AA}$) and elliptic flow (v_2) of D mesons ($\rm D^0$, $\rm D^+$, $\rm D^{*+}$ and $\rm D_s^+$) in semi-central Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV. The increased amount of data in semi-central Pb–Pb events obtained with the LHC Run 2 provides access to more precise measurements for the $R_{\rm AA}$ and the non-strange D-meson v_2 with respect to Run 1 results, as well as to the first measurement of the $\rm D_s$-meson v_2 at LHC energies. The first application of the Event Shape Engineering technique in the analysis of the v_2 coefficient of $\rm D^0$ and $\rm D^+$ mesons is also illustrated.

Keywords: Quark-gluon plasma, Relativistic heavy-ion collisions, Heavy-quark production, Collective flow

1. Introduction

Charm and beauty quarks constitute a sensitive probe to study the properties of the Quark-Gluon Plasma (QGP) formed in high-energy heavy-ion collisions. Heavy quarks are produced in initial hard parton-scattering processes and at short time scales compared to the QGP formation time [1]. Evidence for heavy-quark energy loss inside the medium is provided by the measurement of the nuclear modification factor $R_{\rm AA} = ({\rm d}N_{\rm AA}/{\rm d}p_{\rm T})/(\langle T_{\rm AA}\rangle {\rm d}\sigma_{\rm pp}/{\rm d}p_{\rm T})$, where ${\rm d}N_{\rm AA}/{\rm d}p_{\rm T}$ and ${\rm d}\sigma_{\rm pp}/{\rm d}p_T$ are the $p_{\rm T}$-differential yield and production cross section in A–A and pp collisions, respectively, and $\langle T_{\rm AA}\rangle$ is the average nuclear overlap function, proportional to the number of nucleon-nucleon collisions per A–A interaction. The measurement of the $R_{\rm AA}$ of charmed hadrons allows us to gain insight into the colour-charge and parton-mass dependence of partonic energy loss as well as into possible modifications of hadronization in presence of the medium [2, 3, 4, 5]. The possibility of coalescence of charm quarks with the medium constituents, together with the observed strangeness enhancement in heavy-ion collisions, should lead to a larger relative abundance of $\rm D_s$ mesons compared to non-strange D mesons, when going from pp to Pb–Pb collisions [4, 5]. Results from Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV [6] indicate that the momentum distributions of charmed mesons are modified in Pb–Pb with respect to pp collisions. The D-meson $R_{\rm AA}$ exhibits a suppression of a factor of 5-6 for $p_{\rm T} \approx 10$ GeV/c in central collisions, owing to quenching effects of heavy quarks in the hot and dense medium. A hint of reduced suppression for $\rm D_s$ mesons as compared to non-strange D mesons was also reported [7], however the large uncertainties prevented from drawing strong conclusions. The measurement of the elliptic flow $v_2 = \langle \cos 2(\varphi - \psi_2)\rangle$ provides further insight into the interactions of charm quarks

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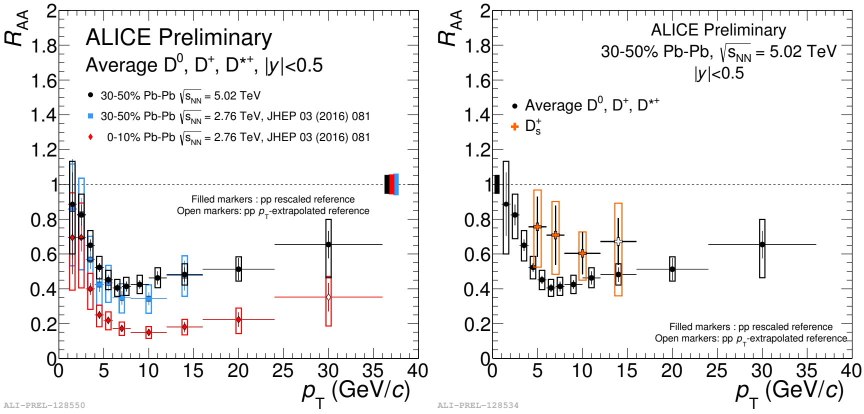

Fig. 1. Left: comparison of the average non-strange D-meson R_{AA} as a function of p_T for 30–50% semi-central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV (black) and $\sqrt{s_{NN}}$ = 2.76 TeV (blue), and the 10% most central events at $\sqrt{s_{NN}}$ = 2.76 TeV (red). Right: comparison of average non-strange D-meson (black) and D_s^+-meson (orange) R_{AA} in 30–50% Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV.

with the medium. In the v_2 definition, φ is the D-meson azimuthal angle and ψ_2 is the symmetry plane of the second-order harmonic in the Fourier decomposition of the azimuthal distribution of the particles produced in the event. At low p_T, D-meson v_2 offers the unique opportunity to test whether also charm quarks participate in the collective expansion dynamics and possibly thermalize in the medium [5, 8]. At low and intermediate p_T, the elliptic flow is also expected to be sensitive to the hadronization mechanism [5], while at high p_T, it can constrain the path-length dependence of parton energy loss [9].

2. Data sample and D-meson reconstruction

The analysed data sample consists of 21×10^6 semi-central (30–50%) Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV collected with the ALICE detector [10] in 2015. The minimum bias trigger was based on the V0 scintillators, covering the pseudorapidity intervals $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$, which also provided the determination of the centrality and of the Event Plane (estimator of the symmetry plane ψ_2) of the collision. D mesons were reconstructed at mid-rapidity via their hadronic decay channels $D^0 \to K^-\pi^+$ (with branching ratio BR = 3.93 ± 0.04%), $D^+ \to K^-\pi^+\pi^+$ (BR = 9.46 ± 0.24%), $D^{*+}(2010) \to D^0\pi^+$ (strong decay with BR = 67.7 ± 0.5%) with $D^0 \to K^-\pi^+$, and $D_s^+ \to \phi\pi^+$ (BR = 2.27 ± 0.08%) with $\phi \to K^-K^+$, together with their charge conjugates [11]. The D-meson decay particles were reconstructed in the pseudorapidity interval $|\eta| < 0.8$ with the Inner Tracking System (ITS), a six-layer silicon detector, and the Time Projection Chamber (TPC). Particle identification was provided by the TPC via specific energy-loss measurements and by the Time-Of-Flight (TOF) detector. Geometrical selections on the D-meson decay topology were applied to reduce the combinatorial background [6]. The raw D-meson yields were extracted via an invariant-mass analysis of the candidates passing the selections and were corrected, for the R_{AA} measurement, for the reconstruction and selection efficiencies provided by simulations. The contribution of D mesons from beauty-hadron decays, estimated using (i) FONLL calculations [12], (ii) a hypothesis on their R_{AA} and (iii) the efficiency from the simulation, was subtracted [6].

3. Results

The nuclear modification factors of prompt D^0, D^+, D^{*+} and D_s^+ mesons at $\sqrt{s_{NN}}$ = 5.02 TeV in the 30-50% centrality class were calculated using a pp reference obtained from the production cross sections measured in pp collisions at $\sqrt{s}$ = 7 TeV (for which a recent re-analysis allowed us to extend the p_T coverage and to reduce the systematic uncertainties by a factor of about two [13]), and scaled to $\sqrt{s}$ = 5.02 TeV with

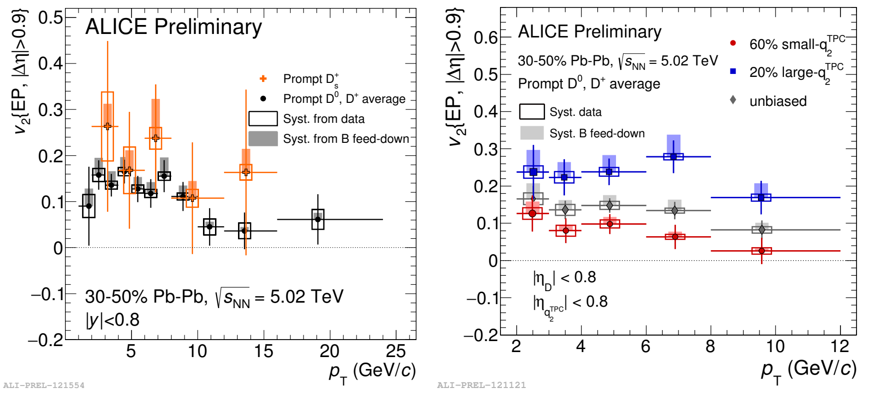

Fig. 2. Left: comparison of prompt D^0 and D^+ average v_2 (black) with D_s-meson v_2 (orange) in 30–50% Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, as a function of p_T. Right: prompt D^0, D^+ average v_2 in 30–50% Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV for events with largest q_2 (blue), smallest q_2 (red) and using the full sample (grey).

FONLL. In Fig. 1 (left) [1] the average of D^0, D^+ and D^{*+} R_{AA} as a function of p_T for 30–50% semi-central collisions in the p_T interval from 1 to 36 GeV/c is presented [14]. The largest suppression is around 6-7 GeV/c. The result is compatible with that observed at $\sqrt{s_{NN}}$ = 2.76 TeV in the same centrality class [6]. The smaller uncertainties of the measurements at $\sqrt{s_{NN}}$ = 5.02 TeV set stronger constraints on the centrality dependence of the suppression, which increases when going to more central collisions, as it can be seen by comparing to the measurements in Fig. 1 (left) for the 0–10% Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV [6]. The right panel of Fig. 1 shows the comparison with the R_{AA} of the D_s^+ meson in the same centrality class. The central values of D_s^+-meson R_{AA} are higher than those of the average of non-strange D mesons in the full p_T interval, though compatible within uncertainties. A similar hint was also observed in the 10% most central collisions at $\sqrt{s_{NN}}$ = 2.76 TeV [7]. The elliptic flow of prompt D^0 and D^+ mesons was also measured in the 30–50% class, with the Event Plane method [15]. Non-flow contributions in the v_2 measurement, i.e. correlations not induced by the collective expansion but rather by decays and jet production, were strongly reduced by the separation of at least 0.9 units in η ($|\Delta\eta| > 0.9$) between the D mesons and the particles used to estimate the event plane. In Fig. 2 (left) the average of the D^0- and D^+-meson v_2 is shown as a function of p_T. The measured v_2 is larger than 0 in the interval $2 < p_T < 8$ GeV/c, as already observed in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV [16], suggesting that charm quarks take part in the collective motion of the medium and that collisional interaction processes as well as quark recombination may contribute to the observed elliptic flow. Furthermore, Fig. 2 (left) presents the first measurement of the D_s-meson v_2 at the LHC, which agrees within uncertainties with the average of non-strange D-meson v_2. The v_2 of D^0 and D^+ mesons was also measured for the first time with an Event Shape Engineering technique [17]. This method relies on calculating v_2 in events with large or small anisotropic flow based on the value of $q_2 = \sqrt{Q_{2,x}^2 + Q_{2,y}^2} / \sqrt{M}$, where, given the azimuthal angle φ of the i-th particle and the multiplicity M of the event, $Q_{2,x} = \sum_{i=1}^{M} \cos 2\varphi_i$ and $Q_{2,y} = \sum_{i=1}^{M} \sin 2\varphi_i$. By calculating the q_2 with tracks reconstructed in the TPC, the D-meson v_2 was measured separately in the 20% of the events with the largest q_2 and in the 60% with the smallest q_2. The result, presented in the right panel of Fig. 2, shows a significant separation between D-meson v_2 in events with large and small q_2, suggesting that charm quarks may be influenced by the bulk collectivity and by the event-by-event initial condition fluctuations. This measurement is potentially affected by non-flow correlations, because the q_2 values and the D mesons are measured in the same pseudo-rapidity

[1] The results for Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV shown in Fig. 1 and in Fig. 3 (left) are updated with respect to those reported at the Quark Matter 2017 conference because of an issue in the normalization. The physics message is unchanged.

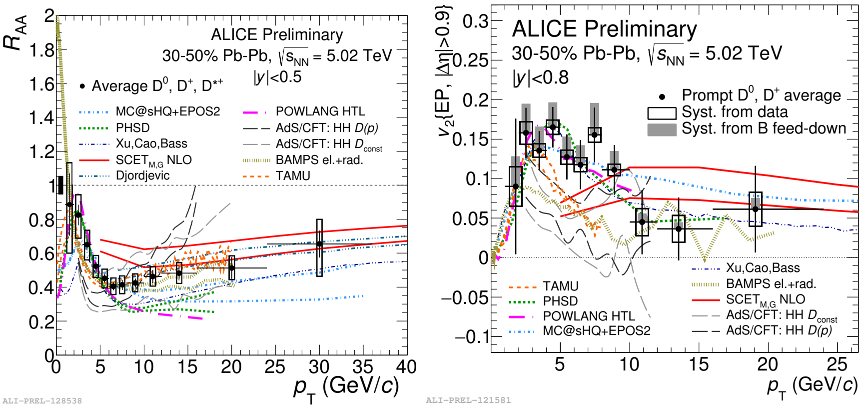

Fig. 3. Prompt D-meson R_{AA} (left) and v_2 (right) in 30–50% Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, compared to theoretical models.

region. It was verified that a different v_2 of D mesons in large-q_2 and small-q_2 events is observed even if the D mesons and the q_2 are measured in separate acceptance regions ($\eta_{q_2} > 0$ and $\eta_D < 0$ and viceversa). In the latter case, the difference of the v_2 values is reduced with respect to those shown in Fig. 2, and the reduction is quantitatively consistent with the weaker selectivity of the q_2 variable, when estimated with one half of the original track sample. Finally, in Fig. 3, the prompt D-meson R_{AA} and v_2 are compared to the available model expectations. The models that include substantial elastic interactions with an expanding medium (all shown in Fig. 3, excluding AdS/CFT [18, 19]) provide a good description of the observed anisotropy and in-medium suppression (see references in [6] for model calculations). This paves the way to constrain the values of the QGP transport coefficients.

4. Conclusions

ALICE measured the nuclear modification factor and elliptic flow of D mesons in 30–50% Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. The R_{AA} of D^0, D^+ and D^{*+} mesons exhibits a similar suppression and their v_2 is similar to that measured at $\sqrt{s_{NN}}$ = 2.76 TeV in the same centrality class. A hint of smaller suppression for D_s^+ meson relative to non-strange D mesons is observed, though the measured R_{AA} are compatible within uncertainties. The first measurement of prompt D_s v_2 was presented, together with the first application of the Event Shape Engineering technique on the elliptic flow of D^0 and D^+ mesons.

References

[1] F.-M. Liu, S.-X. Liu, Phys. Rev. C89 (3) (2014) 034906.
[2] R. Baier, Y. L. Dokshitzer, A. H. Mueller, S. Peigne, D. Schiff, Nucl. Phys. B483 (1997) 291–320.
[3] Y. L. Dokshitzer, D. E. Kharzeev, Phys. Lett. B519 (2001) 199–206.
[4] I. Kuznetsova, J. Rafelski, Eur. Phys. J. C51 (2007) 113–133.
[5] V. Greco, C. M. Ko, R. Rapp, Phys. Lett. B595 (2004) 202–208.
[6] J. Adam, et al., JHEP 03 (2016) 081.
[7] J. Adam, et al., JHEP 03 (2016) 082.
[8] J.-Y. Ollitrault, Phys. Rev. D 46 (1992) 229–245.
[9] M. Gyulassy, I. Vitev, X. N. Wang, Phys. Rev. Lett. 86 (2001) 2537–2540.
[10] K. Aamodt, et al., JINST 3 (2008) S08002.
[11] C. Patrignani, et al., Chin. Phys. C40 (10) (2016) 100001.
[12] M. Cacciari, et al., JHEP 10 (2012) 137.
[13] S. Acharya, et al.arXiv:1702.00766.
[14] ALICE Collaboration, ALICE-PUBLIC-2017-003 (in preparation).
[15] A. M. Poskanzer, S. A. Voloshin, Phys. Rev. C58 (1998) 1671–1678.
[16] B. B. Abelev, et al., Phys. Rev. C90 (3) (2014) 034904.
[17] J. Adam, et al., Phys. Rev. C93 (3) (2016) 034916.
[18] W. A. Horowitz, Phys. Rev. D91 (8) (2015) 085019.
[19] R. W. Moerman, et al.arXiv:1605.09285.