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Heavy-flavour production measurements in heavy-ion collisions with ALICE at the LHC

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Summary. — The measurement of heavy-flavour production in ultra-relativistic heavy-ion collisions provides insights into the properties of the Quark-Gluon Plasma (QGP), the state of strongly-interacting matter characterised by high temperature and energy density where quarks and gluons are deconfined. ALICE results on heavy-flavour production in p–Pb and Pb–Pb collisions are presented.

1. – Introduction

Heavy quarks are powerful probes to study the properties of the QGP formed in ultra-relativistic heavy-ion collisions at the Large Hadron Collider (LHC). Charm and beauty are mainly produced in hard scatterings before the QGP formation and they experience all stages of the medium evolution. Heavy quarks lose part of their energy interacting with medium constituents via gluon radiation and collisional processes (see [1, 2] for recent reviews). In the medium, heavy quarks of low momentum can hadronise via recombination with other quarks, in addition to vacuum fragmentation [3, 4]. Recombination, in the strange-quark rich environment, is expected to lead to an increase of the production of D_s^+-meson in comparison to non-strange D mesons [5]. It may also enhance the charm baryon-to-meson production ratio relative to that in proton–proton (pp) collisions at low and intermediate momentum [6-8]. The energy loss and the dynamics of heavy-quark hadronisation are studied using the nuclear modification factor $R_{\mathrm{AA}} = (\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}})/(\langle T_{\mathrm{AA}}\rangle \times \mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}})$, which compares the transverse-momentum (p_{T}) differential production yields in nucleus–nucleus collisions ($\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}$) with the cross section in pp collisions ($\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}$) scaled by the average nuclear overlap function ($\langle T_{\mathrm{AA}}\rangle$). Heavy quarks can participate in the collective expansion of the system [9]. Measurements of anisotropies in the azimuthal distribution of heavy-flavour hadrons are sensitive to these phenomena. The anisotropy is quantified through the second-order Fourier coefficient $v_2 = \langle\cos[2(\varphi - \Psi_2)]\rangle$ of the azimuthal distribution of particle momenta relative to the symmetry-plane angles (Ψ_n), denoted as elliptic flow.

The presence of a nucleus in the colliding system can modify the production of heavy quarks even if the QGP is not formed. Cold Nuclear Matter (CNM) effects are studied via the measurement of heavy-flavour production in p–Pb collisions.

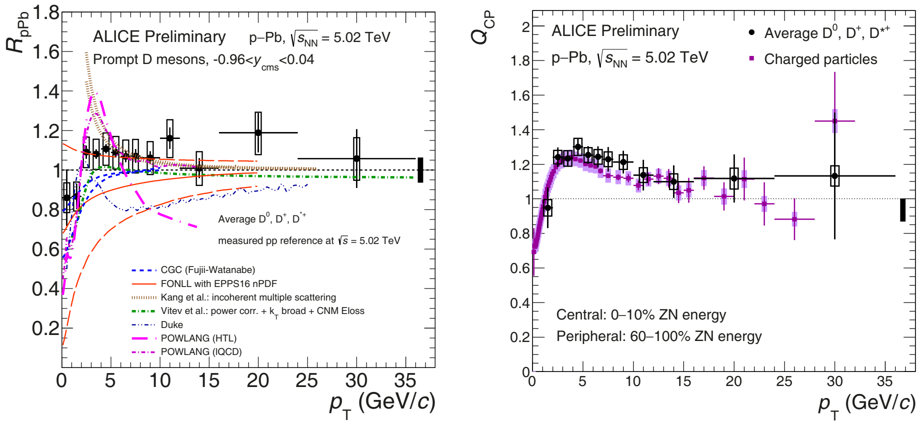

Fig. 1. – Left: prompt D-meson $R_{\rm pPb}$ in p–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV in $-0.96 < y_{\rm cms} < 0.04$ compared to model calculations [11]. Right: prompt D-meson average central-to-peripheral ratio compared to that of charged particles.

Heavy-flavour production was studied with ALICE [10] in p–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV and in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$, 5.02 TeV by measuring electrons and muons from semi-leptonic decays of heavy-flavour hadrons and fully reconstructed D-meson and Λ_c^+ hadronic decays. Electron tracks were reconstructed and identified in the central rapidity region using the information provided by the Time Projection Chamber (TPC), the Time Of Flight (TOF) detector and the electromagnetic calorimeter (EMCAL). Muon tracks were reconstructed in the forward Muon Spectrometer ($-4 < \eta < -2.5$). D mesons and Λ_c^+-baryons displaced decay vertices were reconstructed at mid-rapidity ($|y| < 0.5$) exploiting the high track spatial resolution of the Inner Tracking System (ITS). Charged pions, kaons and protons were identified using TPC and TOF signals.

2. – Results in p–Pb collisions

The average of the nuclear modification factor $R_{\rm pPb}$ of prompt $\rm D^0$, $\rm D^+$ and $\rm D^{*+}$ mesons is shown in the left panel of fig. **2** [11]. The $R_{\rm pPb}$ was computed by dividing the $p_{\rm T}$-differential cross section in p–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV by the cross section measured in pp collisions at the same collision energy, multiplied by the Pb atomic mass number. The D-meson $R_{\rm pPb}$ is compatible with unity over the $p_{\rm T}$ interval covered by the measurement. The experimental results are described by models including CNM effects and they disfavour a suppression larger than 10% in the interval $3 < p_{\rm T} < 12$ GeV/c, in contrast to expectations of Duke and POWLANG HTL models, which assume the formation of a QGP also in p–Pb collisions and predict a moderate suppression at high $p_{\rm T}$. The right panel of fig. **2** shows the central-to-peripheral ratio ($Q_{\rm CP}$), defined as the ratio of the yields in the 0–10% class to that in the 60–80% centrality class, both normalised by the average nuclear overlap function in the corresponding centrality class, of prompt non-strange D mesons compared to that of charged particles. A similar trend is observed for the two measurements and the D-meson $Q_{\rm CP}$ is larger than unity by 1.5 standard deviations of the statistical and systematic uncertainties in the interval $3 < p_{\rm T} < 8$ GeV/c.

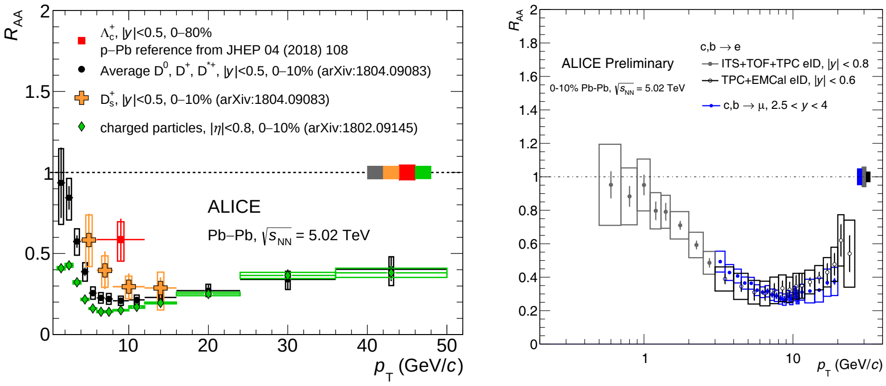

Fig. 2. – Left: R_{AA} of prompt Λ_c^+ in 0–80% Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV [13] compared to that of non-strange D mesons, D_s^+-meson, and charged particle in 0–10% centrality class. Right: R_{AA} of electrons and muons from heavy-flavour hadron decays in 10% most central Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV measured at mid and forward rapidity, respectively.

3. – Results in Pb–Pb collisions

A strong suppression of the D-meson R_{AA} for $p_T > 5$ GeV/c was measured in the 10% most central Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV (fig. **3** left) [12]. A similar suppression was observed for electrons and for muons coming from heavy-flavour hadron decays measured at mid and forward rapidity, respectively (fig. **3** right). The left panel of fig. **3** shows the comparison of prompt Λ_c^+-baryon R_{AA} measured in the 0–80% centrality class [13] to that of non-strange D mesons, D_s^+ and charged particles [14] measured in the 0-10% centrality class. The R_{AA} of charged particles is smaller than that of D mesons by more than 2σ (combined statistical and systematic uncertainties) up to $p_T = 8$ GeV/c, while the results are compatible within 1σ for $p_T > 10$ GeV/c. The observed difference is important to set constraints on the dependence of energy loss on the Casimir factor and on the quark mass [15]. Although compatible within 1σ, the D_s^+ R_{AA} values are larger than those of non-strange D mesons. A hint of larger Λ_c^+ R_{AA} than that of non-strange D mesons is observed.

In the left panel of fig. **3** the Λ_c^+/D^0 ratio measured in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV [13] is compared to the results in pp and p–Pb collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s_{NN}} = 5.02$ TeV [16], respectively. The ratio measured in Pb–Pb collisions is higher than that measured in pp and p–Pb collisions.

The non-strange D-meson v_2 measured in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV in the 30–50% centrality class [17] is larger than zero in $2 < p_T < 10$ GeV/c (right panel of fig. **3**). The result is described by models where the charm azimuthal anisotropy is mainly caused by processes like elastic collisions or hadronisation via coalescence that transfer to charm particles the anisotropy of the hydrodinamically-expanding medium. The calculations that describe the data with $\chi^2/\mathrm{ndf} < 1$ provide a charm quark thermalisation time of $\tau_{\mathrm{charm}} \sim 3-14$ fm/c ($m_{\mathrm{charm}} = 1.5$ GeV/c^2), comparable to the estimated decoupling time of the system [17].

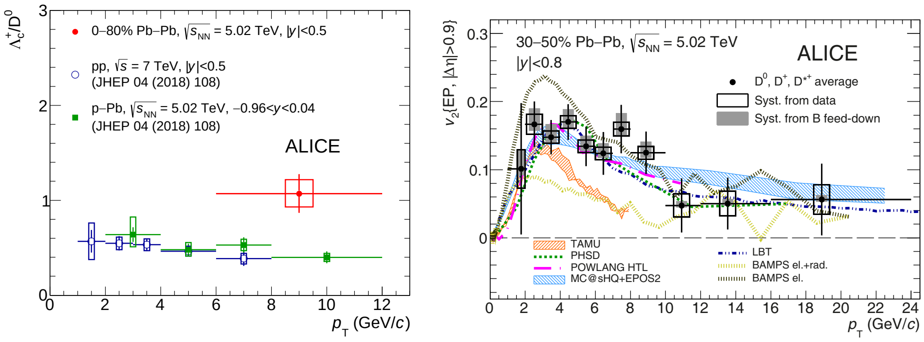

Fig. 3. – Left: Λ_c^+/D^0 ratio in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV [13] compared with the measurements in pp and p–Pb collisions [16]. Right: average D^0, D^+ and D^{*+} elliptic flow v_2 in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV in the 30–50% centrality class compared with model calculations [17].

4. – Conclusions

The suppression of heavy-flavour production measured in central Pb–Pb collisions demonstrates that charm quarks interact strongly with the high-density QCD medium. The results in p–Pb collisions confirm that the effects observed at intermediate/high p_T in Pb–Pb collisions are induced by the presence of the QGP. The first measurement of the Λ_c^+-baryon production in Pb–Pb collisions shows a hint of a larger yield relative to that of the D^0 meson with respect to those measured in pp and p–Pb collisions, in line with what expected in a scenario where charm quarks hadronise, at least partly, via coalescence with light quarks from the medium. The measured non-zero D-meson v_2 indicates that low-momentum charm quarks take part in the collective motion of the QGP and that collisional interaction processes as well as recombination of charm and light quarks contribute to the observed elliptic flow.

REFERENCES

[1] A. Andronic *et al.*, *Eur. Phys. J. C*, **76** (2016) 107
[2] F. Prino and R. Rapp, *J. Phys. G*, **43** (2016) 093002
[3] V. Greco, C. M. Ko and R. Rapp, *Phys. Lett. B*, **595** (2004) 202
[4] A. Andronic *et al.*, *Phys. Lett. B*, **571** (2003) 36-44
[5] I. Kuznetsova and J. Rafelski, *J. Phys. G*, **32** (2006) S499
[6] S. Plumari *et al.*, *Eur. Phys. J. C*, **78** (2018) 348
[7] Y. Oh *et al.*, *Phys. Rev. C*, **79** (2009) 044905
[8] S. H. Lee *et al.*, *Phys. Rev. Lett.* , **100** (2008) 222301
[9] S. Batsouli, S. Kelly, M. Gyulassy and J. L. Nagle, *Phys. Lett. B*, **557** (2003) 26
[10] [ALICE Collaboration], B. B. Abelev *et al.*, *Int. J. Mod. Phys. A*, **29** (2014) 1430044
[11] [ALICE Collaboration], preprint ALICE-PUBLIC-2017-008
[12] [ALICE Collaboration], S. Acharya *et al.*, preprint arXiv:1804.09083 [nucl-ex]
[13] [ALICE Collaboration], S. Acharya *et al.*, preprint arXiv:1809.10922 [nucl-ex]
[14] [ALICE Collaboration], S. Acharya *et al.*, preprint arXiv:1802.09145 [nucl-ex]
[15] M. Djordjevic, *Phys. Rev. Lett.* , **112** (2014) 042302
[16] [ALICE Collaboration], S. Acharya *et al.*, *JHEP*, **1804** (2018) 108
[17] [ALICE Collaboration], S. Acharya *et al.*, *Phys. Rev. Lett.*, **120** (2018) 102301