PROCEEDINGS OF SCIENCE

D-meson measurements in Pb-Pb collisions with the ALICE detector at the LHC

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Heavy quarks (charm and beauty) are effective probes to investigate the properties of the hot and dense strongly-interacting medium created in heavy-ion collisions as they are produced in partonic scattering processes occurring in the early stages of the collision. Due to their long life time, they probe all the stages of the medium evolution and they interact with its constituents, losing energy via gluon radiation and elastic collisions. The measurement of the D-meson nuclear modification factor provides a key test of parton energy-loss models. These models predict that beauty quarks lose less energy than charm quarks and the latter experience less in-medium energy loss than light quarks and gluons.

D-meson production was measured with ALICE in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV. D mesons were reconstructed via their hadronic decays at central rapidity. We will discuss the latest results of the measurement of the D-meson nuclear modification factor as a function of transverse momentum (p_{T}) and collision centrality. In addition, the measurement of the azimuthal anisotropy (v_2) of charmed-meson production as a function of p_{T} in different centrality intervals will be presented.

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1. Introduction

Heavy quarks are unique probes to study the Quark-Gluon Plasma produced in heavy-ion collisions at the LHC. Due to their large masses, they are produced predominantly in hard scatterings, during the initial phase of the collision. Therefore, they experience the entire evolution of the medium created in the collision and can act as probes of its properties. One of the key methods used to characterise the medium (i.e its medium density, temperature and heavy-quark transport coefficient) is the study of energy loss of the partons traversing it. In a QCD picture, radiative in-medium energy loss is one of the main mechanisms expected to contribute, with dependence on the mass and the color charge of the particle. The radiation is suppressed at small angles for massive partons because of the dead-cone effect [1] and is larger for gluons, which have stronger color charge with respect to quarks (Casimir coupling factor). Therefore, a hierarchy in the $R_{\rm AA}$ is expected to be observed when comparing the mostly gluon-originated light-flavor hadrons (e.g. pions) to D and to B mesons. The measurement and comparison of these different probes of the medium provides a unique test of the colour charge and mass dependence of parton energy loss [2].

Further insight into the medium properties is provided by the measurement of the anisotropy in the azimuthal distribution of particle momenta. In non-central heavy-ion collisions, the anisotropy in the spatial distribution of the nucleons participating in the collision is converted into a momentum anisotropy, if sufficient rescatterings with the medium constituents occur. Hence the azimuthal distribution of the particles in the final state reflects the initial anisotropy and the medium characteristics. The azimuthal anisotropy of produced particles is characterized by the second Fourier coefficient $\mathrm{v}_2 = \langle \cos[2(\varphi - \Psi_2)] \rangle$, where φ is the azimuthal angle of the particle momentum, and Ψ_2 is the azimuthal angle of the initial-state symmetry plane for the second harmonic [3]. At low $p_{\rm T}$, the v_2 of heavy-flavour hadrons is sensitive to the degree of thermalization of charm and beauty quarks in the deconfined medium. At higher $p_{\rm T}$, the measurement of v_2 carries information on the path length dependence of in-medium parton energy loss. The measurement of heavy-flavour v_2 offers a unique opportunity to test whether also quarks with large mass participate in the collective expansion dynamics and possibly thermalize in the QGP.

2. D-meson measurement with ALICE

ALICE (A Large Ion Collider Experiment) is the LHC experiment dedicated to heavy-ion studies. ALICE [4] consists of: a barrel at central rapidity, a muon spectrometer at forward rapidity and a set of detectors for global properties determination. For the present analysis, we use the information from a subset of the central barrel detectors, namely the Inner Tracking System (ITS), the Time Projection Chamber (TPC) and the Time Of Flight detector (TOF) for charged particle tracking and identification, the T0 for collision time measurement and the VZERO scintillator for triggering and centrality measurement. The two tracking detectors, ITS and TPC, allow the reconstruction of charged-particle tracks in the pseudorapidity range $-0.9 < \eta < 0.9$ with a momentum resolution better than 2% for $p_{\rm T} < 20$ GeV/c. The TPC provides the particle identification via a dE/dx measurement. The ITS, in particular, is a key detector for open heavy-flavour studies because it allows us to measure the track impact parameter (i.e. the distance of closest approach of the track to the primary vertex) with a resolution better than 65 μm for $p_{\rm T} > 1$ GeV/c, thus providing

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the capability to reconstruct secondary vertices originating from heavy-flavour hadron decays. The TOF detector provides particle identification by time of flight measurement.

D^0, D^+, D^{*+} and D_s^+ mesons are reconstructed in the central rapidity region from their hadronic decay channels $D^0 \to K^-\pi^+, D^+ \to K^-\pi^+\pi^+, D^{*+} \to D^0\pi^+ \to K^-\pi^+\pi^+$ and $D_s^+ \to \phi\pi^+ \to K^+K^-\pi^+$ (and charge conjugates). The D-meson yield is measured with an invariant mass analysis of fully reconstructed decay topologies displaced from the interaction vertex selected by requiring a large decay length and a good alignment between the reconstructed D-meson momentum vector and its flight line. The identification of charged kaons in the TPC and TOF detectors helps to further reduce the background at low p_T.

In this proceeding, we will discuss the ALICE measurements of D-meson production in Pb–Pb collisions at $\sqrt{s_{NN}}$= 2.76 TeV.

2.1 Nuclear Modification Factor (R_{AA})

The nuclear modification factor is defined as the ratio of the transverse momentum spectrum measured in nucleus-nucleus (AA) collisions to the one measured in pp collisions at the same centre of mass energy, rescaled by the average number of binary nucleon-nucleon collisions (N_{coll}) expected in heavy-ion collisions. The ratio can be expressed also in terms of average nuclear overlap function (T_{AA}) estimated within the Glauber model [5].

$$R_{AA}(p_T) = \frac{1}{<T_{AA}>}\frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

The pp reference is scaled from 7 to 2.76 TeV using pQCD calculations (FONLL) [6]. The scaling was validated comparing the scaled results with the available measurement in pp collisions at $\sqrt{s}$ = 2.76 TeV [7] (this sample was not used in the R_{AA} measurement due to the limited statistics).

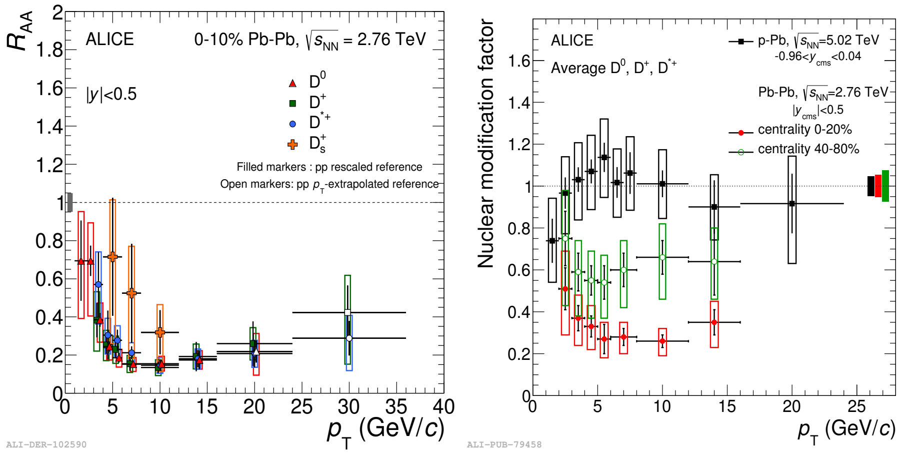

Figure 1: Left: R_{AA} of D^0, D^+, D^{*+} and D_s^+ mesons as a function of p_T in central collision [9, 10]. Right: Average R_{pPb} of D mesons as a function of p_T compared to D-meson R_{AA} in 20% most central and 40-80% Pb-Pb collisions.

Figure 1 (left) represents the nuclear modification factor of D^0, D^+ and D^{*+} mesons as a function of p_T in most central collisions [9] . The R_{AA} of the three D-meson species are compatible

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within uncertainties. A suppression up to a factor five is seen at $p_{\rm T} \sim 10$ GeV/c. The first measurement of $\rm D_s^+$ $R_{\rm AA}$ [10] in heavy-ion collisions is also shown. In the highest measured $p_{\rm T}$ bin (8-12 GeV/c), the $R_{\rm AA}$ of $\rm D_s^+$ mesons is compatible with that of non-strange charmed mesons. At lower $p_{\rm T}$, the $R_{\rm AA}$ of $\rm D_s^+$ seems to increase, but with the current statistical and systematic uncertainties no conclusion can be drawn on the expected enhancement of $\rm D_s^+$-meson production with respect to that of non-strange D mesons at low $p_{\rm T}$, due to c-quark coalescence with the abundant strange quarks [8].

Figure 1 (right) shows the average D-meson nuclear modification factor measured in minimum-bias p-Pb collisions at $\sqrt{s_{\rm NN}}$= 5.02 TeV [11]. Since no significant modification of the D-meson yield is observed in p-Pb collisions for $p_{\rm T} > 2$ GeV/c, it can be concluded that the strong suppression observed in central Pb-Pb collisions is due to the interaction of heavy quarks with the hot and dense medium.

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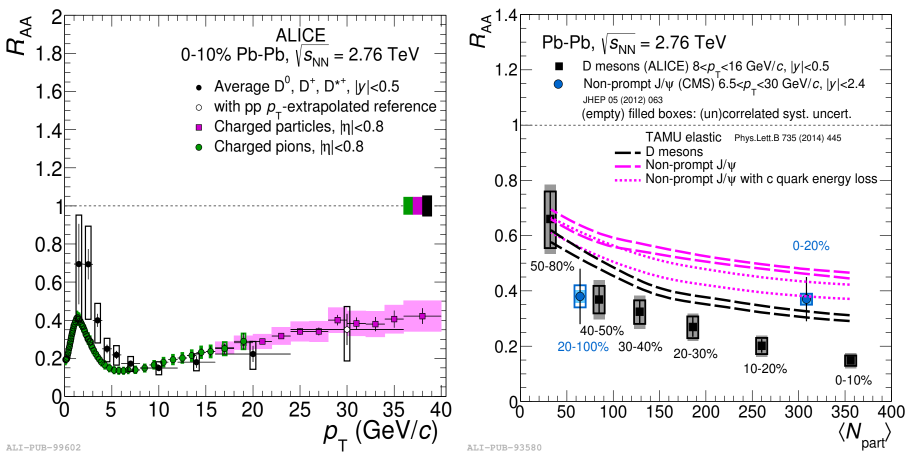

Figure 2: D-meson nuclear modification factor, $R_{\rm AA}$, in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. Left: $R_{\rm AA}$ as a function of $p_{\rm T}$ compared to charged hadrons and pions. Right: $R_{\rm AA}$ as a function of $N_{\rm part}$ [13] compared to non-prompt J/ψ measured by the CMS collaboration [14].

D-meson nuclear modification factor is similar to that of charged pions and charged particles in the measured $p_{\rm T}$ interval within uncertainties as shown in Fig. 2 (left). It should be noted that the $R_{\rm AA}$ of D mesons and pions is also sensitive to the shape of the parton momentum distribution and their fragmentation functions. Model calculations including those effects and a colour-charge hierarchy in parton energy loss are able to describe the measurements, see [12] as example.

In Fig. 2 (right), $R_{\rm AA}^{\rm D}$ as a function of collision centrality (quantified by the average number of participant nucleons) [13] is shown. This measurement is compared with results from the CMS collaboration of non-prompt J/ψ [14] and theoretical predictions from [15, 16, 21]. For D mesons, a smaller suppression in peripheral than in central collisions is observed. A larger suppression in central collisions is seen for D mesons than for non-prompt J/ψ, indicating a different energy loss for charm and beauty quarks. This observation is supported by predictions from energy-loss models, where the difference between the $R_{\rm AA}$ of D and B mesons arises from the different masses of c and b quarks.

2.2 Elliptic Flow (v_2)

The v_2 of prompt D^0, D^+ and D^{*+} mesons at mid-rapidity was measured in the three centrality classes 0-10%, 10-30% and 30-50% [17, 18]. The D^0 meson v_2 as a function of p_T in the three centrality classes is shown in the Fig.3, compared with the measured v_2 of charged particles.

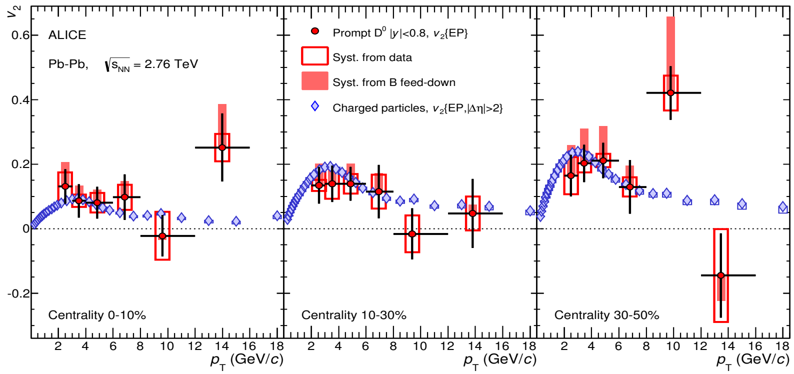

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Figure 3: v_2 of D^0 as a function of p_T in three centrality ranges, compared with the v_2 of charged particles [17, 18].

The average of the v_2 of D^0, D^+ and D^{*+} in the centrality class 30-50% is larger than zero with 5σ significance in the range $2 < p_T < 6$ GeV/c. A positive v_2 is also observed for $p_T > 6$ GeV/c, which most likely originates from the path length dependence of the in-medium partonic energy loss, although the present statistics does not allow to give a firm conclusion on this. The measured D-meson v_2 is comparable in magnitude with that of the charged particles, which are mostly light-flavour hadrons. This result indicates that low-p_T charm quarks take part in the collective motion of the system. The v_2 of D mesons decreases from peripheral to central collisions as expected due to the decreasing initial geometrical anisotropy.

R_{AA} and v_2 are two complementary measurements to gain insight into the heavy-quark transport coefficient of the medium. Several theoretical model calculations are available for the R_{AA} and v_2 of heavy flavour hadrons. Fig. 4 shows the D-meson R_{AA} (left) and v_2 (right) compared to predictions from various models [19, 20, 21, 22, 23, 24, 25, 26]. A simultaneous description of the R_{AA} and v_2 starts to provide constraints to the models themselves.

3. Conclusions

The ALICE detector provides excellent tracking, vertexing and particle identification to allow measurements of charmed mesons via their hadronic decays, over a wide range of transverse momentum. The nuclear modification factor and the elliptic azimuthal anisotropy of prompt D mesons were measured in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. The first measurement of the D_s^+-meson production has also been presented. The D-meson nuclear modification factor is similar to that of charged particles and pions in central collisions. An ordering is observed for nuclear modification factor of prompt D and non-prompt J/ψ in central collisions, in agreement with the expectation of a

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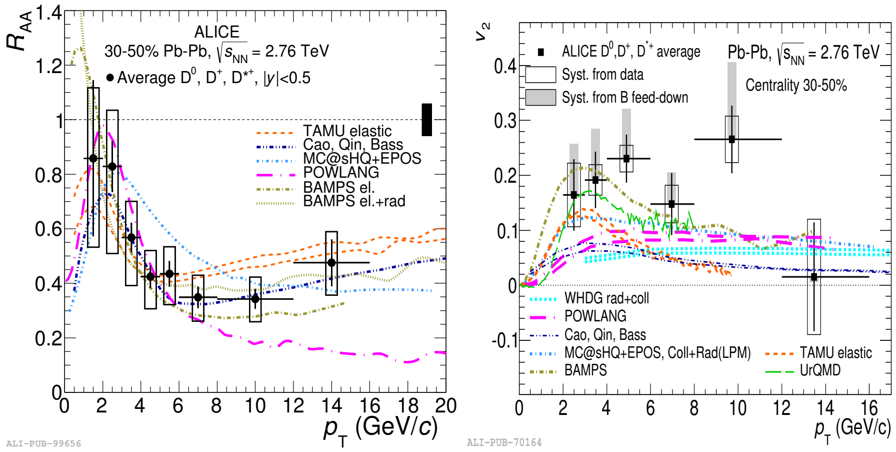

Figure 4: D-meson R_{AA} and v_2 compared to model predictions. Only models with predictions for both R_{AA} and v_2 are shown. Left: D-meson R_{AA} as a function of p_T. Right: D-meson v_2 as a function of p_T.

larger in-medium energy loss of charm compared to beauty quarks. A positive v_2 is measured, suggesting that charm quarks take part in the collective expansion of the medium. The models based on parton energy loss in the medium describe the data within the uncertainties, but the simultaneous description of R_{AA} and v_2 remains challenging. The improvement of statistical and systematic uncertainties expected in Run 2 will help to provide further constraints to models.

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