

D-meson nuclear modification factor and v_2 in Pb-Pb collisions at the LHC

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Abstract.

We present the ALICE results on open heavy flavour, focusing on the exclusive reconstruction of charmed mesons via displaced decay topologies. These measurements benefit from the large Pb-Pb statistics collected in 2011. The results on the nuclear modification factor R_{AA} for D mesons indicate a suppression of their yield in central collisions relative to binary-scaled pp collisions in a large momentum range. The comparison to the R_{AA} of non-prompt J/ψ (measured with CMS) indicates a difference in the suppression of charm and beauty, as expected according to the predicted mass hierarchy in energy loss models. The measurement of the azimuthal anisotropy of charmed mesons is also discussed. The observed positive second Fourier harmonic v_2 for transverse momentum $2 < p_T < 6$ GeV/ c in semi-peripheral events is a hint for collective motion of charm quarks. The results discussed above are also compared to theoretical models.

1. Introduction

A quantitative picture of the medium created in high-energy Pb-Pb collisions can be obtained by measuring its properties with observables that give access to the energy-loss mechanism for different parton species and to the transport properties of the medium. Theoretical models of energy loss predict a hierarchical dependence on the colour charge and mass of the parton propagating through the medium. A larger energy loss is expected for gluons, together with a suppression of gluon radiation at small angles for partons with larger mass (“dead-cone” effect [1]). It is therefore interesting to compare medium effects (i.e. the path-length, colour-charge and mass dependence of the energy loss, as well as the collective motion) on heavy quarks versus light quarks and gluons. Such challenging goals require precise heavy-flavour measurements in Pb-Pb collisions and a clear understanding of the reference systems provided by pp and p-Pb collisions. The latter provides the control experiment needed to disentangle effects from the cold matter in absence of a hot and dense medium.

2. Heavy-flavour measurements in ALICE

The ALICE [2] detectors used in these analyses are the Inner Tracking System (ITS), the Time Projection Chamber (TPC) and the Time Of Flight (TOF) detector. They provide tracking, primary and secondary vertex reconstruction and particle identification, like K/π separation up to transverse momentum $p_T \sim 2.5$ GeV/ c . These features are essential ingredients to perform open-heavy flavour analyses over a broad transverse momentum range. In addition,

the VZERO detector is used for triggering on collisions and for centrality measurements. Charmed mesons are reconstructed in ALICE through their hadronic decays: $D^0 \rightarrow K^- \pi^+$, $D^+ \rightarrow K^- \pi^+ \pi^+$, $D^{*+} \rightarrow D^0 \pi^+$ and $D_s^+ \rightarrow \phi(\rightarrow K^- K^+) \pi^+$. The analysis strategy exploits the particle identification and the detector capability to reconstruct secondary vertices displaced by a few hundred μm from the primary vertex. Topological cuts are applied on the reconstructed secondary vertices and the signals are extracted via fits to the invariant mass distributions.

In these proceedings we report on the prompt D -meson nuclear modification factor R_{AA} , defined as the yield in Pb-Pb collisions divided by the cross-section in pp collisions scaled by the average nuclear overlap function in a given Pb-Pb centrality range, as a function of p_T and collision centrality. The prompt D -meson elliptic flow v_2 , defined as the second harmonic coefficient of the Fourier azimuthal expansion, is also reported as a function of p_T in semi-peripheral collisions.

In the R_{AA} analysis, the prompt D -meson yield was obtained after subtracting the contribution of D mesons from beauty hadron decays based on perturbative QCD calculations (FONLL, [3]). The R_{AA} of non-prompt D mesons was assumed to be $R_{AA}^{\text{feed-down}} = 2R_{AA}^{\text{prompt}}$ (on the basis of the CMS results of non-prompt J/ψ , instead of $R_{AA}^{\text{feed-down}} = R_{AA}^{\text{prompt}}$ as done in the previous analysis [4]) and the systematic uncertainty was assessed by varying its value between 1 and 3 times the prompt- D R_{AA} . Due to the lack of statistics of the pp data at $\sqrt{s} = 2.76$ TeV, the pp reference needed for the R_{AA} analysis was determined by scaling the D -meson cross section measured at $\sqrt{s} = 7$ TeV to $\sqrt{s} = 2.76$ TeV using FONLL calculations [5]. The scaling uncertainty varies from $\sim 20\%$ to $\sim 5\%$ from low to high p_T . The contribution of D mesons from beauty decays was also subtracted from the v_2 measurement with an assumption on the R_{AA} (as above) and v_2 of non-prompt D mesons ($0 \leq v_2^{\text{feed-down}} \leq v_2^{\text{prompt}}$ [6]). These analyses were performed on the data from the Pb-Pb runs at $\sqrt{s_{NN}} = 2.76$ TeV collected in 2010 (minimum bias trigger, $\mathcal{L} = 2.12 \mu\text{b}^{-1}$) and 2011 ($\mathcal{L} = 28$ and $6 \mu\text{b}^{-1}$ for 0-7.5% and 10-50% respectively).

3. Results

The R_{AA} of prompt D mesons was measured with ALICE in the 0–7.5% centrality class using the data sample collected in 2011, which extends the measurements to a wider transverse momentum range ($2 < p_T < 36$ GeV/ c) compared to the published results from the 2010 data [4]. As shown in Fig. 1 (left), the R_{AA} values for D^0 , D^+ and D^{*+} agree within the uncertainties and show a strong suppression (factor of 4 – 5 for $5 < p_T < 16$ GeV/ c) of the D -meson yields in Pb-Pb collisions relative to pp collisions. The first measurement of the D_s^+ meson in Pb-Pb collisions is also shown. A suppression of the D_s^+ is observed for $8 < p_T < 12$ GeV/ c , in agreement within the uncertainties with the non-strange charmed mesons R_{AA} in this p_T range. The D_s^+ -meson yield could be less suppressed at lower p_T because of the predicted c -quark recombination with the enhanced strange quarks in the medium [8], however a more precise measurement is needed to draw a conclusion. The R_{AA} as a function of the number of participant nucleons weighted by the number of binary collisions is shown in Fig. 1 (right) for D^0 mesons with $2 < p_T < 3$ GeV/ c and compared to pions measured in the same centrality and p_T intervals. The main correlated systematic uncertainties for the D -meson yields come from the pp cross section and beauty feed down. The uncorrelated systematic uncertainties are mainly due to the D -meson yield extraction and cut variation. The suppression of D mesons with $2 < p_T < 3$ GeV/ c is almost independent of centrality, while the pion R_{AA} decreases with increasing centrality. The magnitude of the suppression is similar for D mesons and pions. A hint of a difference in central collisions is suggested but a larger dataset is needed to draw conclusion on the expected difference between D mesons and pion suppression due to the mass and colour charge dependence of the energy loss. In the higher p_T range the D -meson suppression is no longer flat, rather it increases from peripheral to central collisions (Fig. 2, left).

The R_{AA} of non-prompt J/ψ ($6.5 < p_T < 30$ GeV/ c and $|y| < 1.2$) measured with CMS is

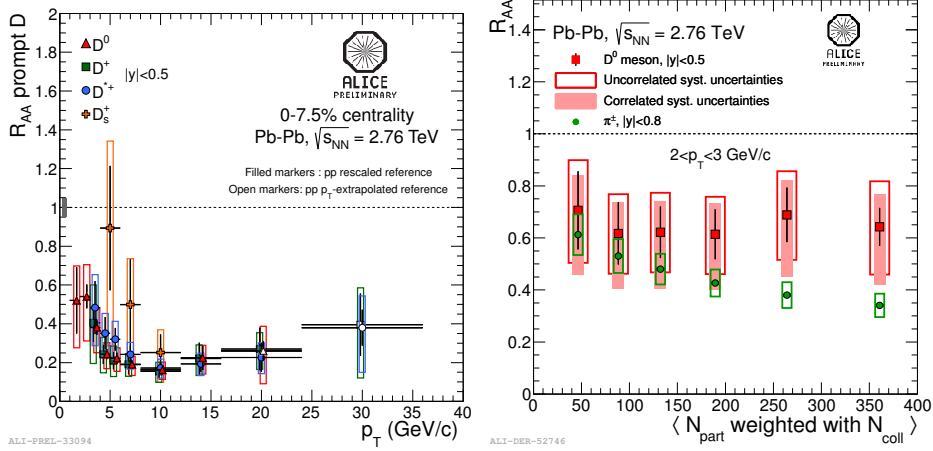


Figure 1. Left: R_{AA} as a function of p_T for prompt D^0 , D^+ , D^{*+} and D_s^+ for the 0 – 7.5% most central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [7]. Right: R_{AA} as a function of centrality for prompt D^0 mesons in the transverse momentum range $2 < p_T < 3$ GeV/c, compared to pions.

reported in Fig. 2 (left) as a function of the number of participants weighted by the number of binary collisions [9]. The results are shown together with the D -meson R_{AA} from ALICE ($8 < p_T < 16$ GeV/c and $|y| < 0.5$). The selected p_T ranges correspond to similar kinematical ranges for the parent b and c quarks, but the measurements are performed in different rapidity ranges. An indication of a difference in the suppression of charm and beauty can be observed in central collisions, consistent with the mass hierarchy expected from various energy-loss models, such as those reported in the figure [10–12]. While the model [11] based on collisional and radiative energy loss in an anisotropic medium agrees with both prompt D mesons and non-prompt J/ψ , the others seem to underestimate both (i.e. [10], based on collisional energy loss in an expanding medium) or to underestimate the suppression of non-prompt J/ψ (i.e. [12], based on radiative energy loss and D -meson in-medium formation and dissociation).

The v_2 for prompt D mesons, reported in Fig. 2 (right), was measured as a function of p_T in the range $2 < p_T < 16$ GeV/c in the 30-50% centrality class [6]. We observe a positive v_2 for prompt D mesons in the transverse momentum range $2 < p_T < 6$ GeV/c, which is comparable to that of charged particles (not shown). This result suggests a collective motion also for heavy quarks at low p_T . At higher momentum a positive v_2 is expected due to the path-length dependence of the in-medium energy loss, given the different paths traveled by a parton propagating through the medium. The measurements of the prompt D -meson v_2 are also compared to various energy-loss models [10, 11, 13, 14, 16, 17]. While several theoretical models based on in-medium parton energy loss reproduce reasonably well the R_{AA} of prompt D mesons as a function of p_T (not shown, see [4]), they are challenged by simultaneously reproducing results from prompt D -meson R_{AA} and v_2 .

4. Conclusions

The suppression of prompt D mesons observed in the momentum range $5 < p_T < 15$ GeV/c in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV is evidence for a strong modification of charm production in Pb-Pb compared to pp collisions due to energy loss. Results for the D_s^+ meson also show a suppression in $8 < p_T < 12$ GeV/c but suffer from statistics limitations that do not allow us to draw conclusions on a possible enhancement at low p_T due to a coalescence of charm quarks with strange quarks. The measurements of prompt D -meson R_{AA} as a function

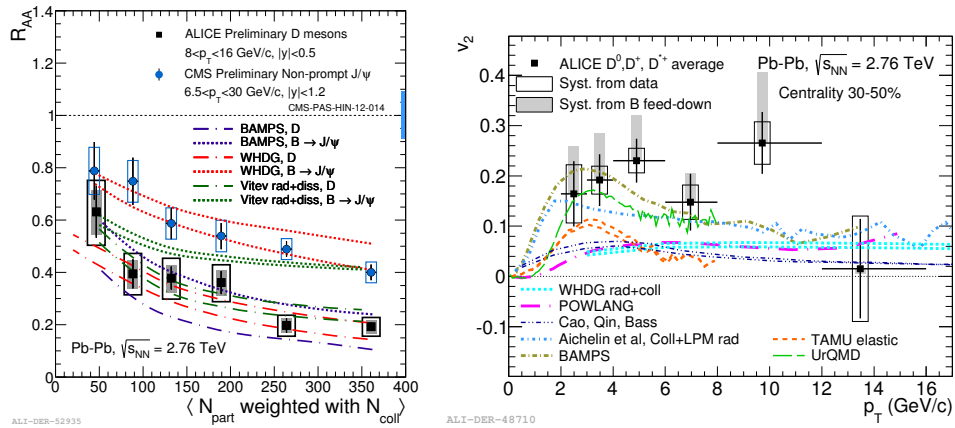


Figure 2. Left: R_{AA} as a function of centrality for prompt D mesons (average of D^0 , D^+ and D^{*+}) in the transverse momentum range $8 < p_T < 16$ GeV/c, compared to non-prompt J/ψ measured with CMS with $6.5 < p_T < 30$ GeV/c. Results from theoretical calculations are superimposed (see text). Right: v_2 for prompt D mesons in the 30-50% centrality class as a function of p_T [6] superimposed to theoretical results.

of centrality indicate that the suppression tends to be constant with centrality in the lowest p_T range, $2 < p_T < 3$ GeV/c, while it increases with centrality at intermediate/high p_T . The observed difference in the suppression of D mesons and non-prompt J/ψ from B-meson decays at high p_T in central collisions suggests a mass dependence in the energy loss of heavy quarks. The positive v_2 for prompt D mesons in the momentum range $2 < p_T < 6$ GeV/c in semi-peripheral Pb-Pb collisions suggests that the interactions with the medium constituents transfer to charm quarks information on the azimuthal anisotropy of the system. Theoretical models of in-medium energy loss reproduce reasonably well the measured prompt D -meson R_{AA} . Nevertheless, a simultaneous description of both R_{AA} and v_2 remains a challenge for models, indicating that the energy-loss mechanisms and the participation of heavy quarks in the collective behavior of the Quark-Gluon Plasma are not yet fully understood today.

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