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Heavy-flavour and quarkonium measurements in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV with ALICE

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Abstract. We report on the latest results on heavy-flavour and J/ψ production at both mid-rapidity and forward rapidity, in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV, measured with the ALICE experiment at the LHC. We present measurements of the nuclear modification factor for open heavy-flavours and J/ψ and compare these results to model predictions. Preliminary results on the elliptic flow of D mesons and J/ψ are discussed.

1. Introduction

ALICE [1] is the dedicated heavy-ion experiment at the LHC, optimized to study the properties of strongly interacting matter in the extreme conditions of high temperature and energy density expected to be reached. Heavy quarks (charm and beauty), abundantly produced at the LHC, are regarded as effective probes of this medium. Due to their large masses, they are created mainly in hard scattering processes in the early stage of the collision and subsequently interact with this medium. In particular, open heavy-flavour hadrons are expected to be sensitive to the energy density of the system through the mechanism of in-medium energy loss of heavy quarks, while quarkonia should provide an estimate of the medium temperature through their dissociation due to color screening [2]. The in-medium effects are usually quantified by means of the nuclear modification factor R_{AA} defined as:

$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{1}{\langle T_{\mathrm{AA}} \rangle} \times \frac{\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}, \quad (1)$$

where $\langle T_{\mathrm{AA}} \rangle$ is the average nuclear overlap function in a given centrality class. $\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}$ is the p_{T}-differential yield in nucleus-nucleus (AA) collisions, while $\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}$ is the p_{T}-differential cross section in pp collisions. According to QCD, quarks should lose less energy than gluons. In addition, heavy quarks are expected to lose less energy than light quarks due to the dead-cone effect [3]. Furthermore, the J/ψ suppression could be counteracted by regeneration processes which may become important at the LHC. The measurement of the elliptic flow v_2 of heavy-flavour particles and J/ψ should carry additional information on the medium transport properties. It is expected to provide insights on the possible degree of thermalization of heavy quarks in the medium at low p_{T} and on the path length dependence of energy loss at high p_{T}.

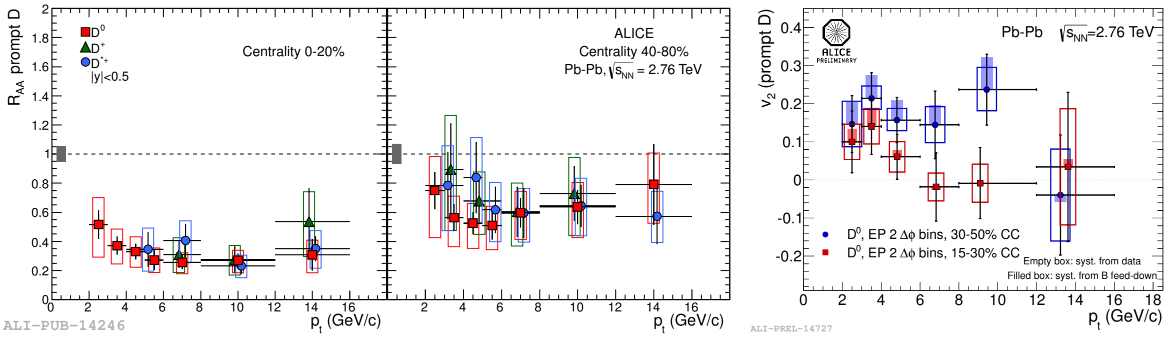

Figure 1. R_{AA} for prompt D^0, D^+ and D^{*+} in the 0-20% (left) and 40%-80% (middle) centrality classes [5]. The statistical (bars), systematic (empty boxes) and normalization (filled boxes) uncertainties are displayed. Right: v_2 of D^0 mesons in the 15%–30% and 30%–50% centrality classes. The statistical (bars), systematic (empty boxes) and B feed-down contribution (filled boxes) uncertainties are drawn. Horizontal error bars represent the bin widths.

2. Heavy-flavour and J/ψ detection in the ALICE experiment

The ALICE experiment, described in detail in [1], is composed of a central barrel (pseudo-rapidity coverage $|\eta| < 0.9$), a muon spectrometer ($-4 < \eta < -2.5$) and a set of detectors for global collision characterization and triggering located in the forward and backward pseudo-rapidity regions. Among those, the VZERO detector, made of two scintillator arrays, and the two Zero Degree Calorimeters (ZDC) are used for the analyses presented here. The Silicon Pixel Detector (SPD), the innermost part of the Inner Tracking System (ITS) is included in the trigger logic and is also needed for the interaction vertex reconstruction.

Open heavy flavours are measured in the charm hadronic decay channels (including $\mathrm{D}^0 \to \mathrm{K}^-\pi^+$, $\mathrm{D}^+ \to \mathrm{K}^-\pi^+\pi^+$, $\mathrm{D}^{*+} \to \mathrm{D}^0\pi^+$, $\mathrm{D}_s^+ \to \mathrm{K}^+\mathrm{K}^-\pi^+$ and charge conjugates in $|y| < 0.5$), in the semi-electronic decay channel (inclusive $\mathrm{D}, \mathrm{B} \to \mathrm{e}^\pm + \mathrm{X}$ in $|y| < 0.8$) and in the semi-muonic decay channel ($\mathrm{D}, \mathrm{B} \to \mu^\pm + \mathrm{X}$ in $2.5 < y < 4$). J/ψ are reconstructed down to $p_{\mathrm{T}} = 0$ via unlike-sign dielectrons and unlike-sign dimuons at mid-rapidity ($|y| < 0.9$) and forward rapidity ($2.5 < y < 4$), respectively. The detectors used for particle tracking and identification are the ITS, the Time Projection Chamber (TPC), the Transition Radiation Detector (TRD), the Time of Flight (ToF) and the ElectroMagnetic Calorimeter (EMCal) in the central barrel, and the muon spectrometer at forward rapidity. Details on the reconstruction of D mesons and J/ψ, and on the identification of electrons and muons from heavy-flavour decays can be found in [4–10].

The results are based on the analysis of data samples collected in 2010 and 2011 with minimum bias (MB) and (di)muon triggers. Events are classified according to their centrality by means of the sum of the amplitudes of the signals in the VZERO detectors [11].

3. Heavy-flavour nuclear modification factor and elliptic flow measurements

The study of in-medium effects via the heavy-flavour R_{AA} requires the measurement of the production cross sections in pp collisions (Eq. (1)). The latter are obtained from the pp data sample at $\sqrt{s} = 2.76$ TeV (semi-leptonic channels [10]) or/and the pp data at $\sqrt{s} = 7$ TeV by scaling down to $\sqrt{s} = 2.76$ TeV according to pQCD calculations [12] (hadronic and semi-electronic channels [4, 8]).

Figure 1 shows the p_{T}-differential R_{AA} for prompt D^0, D^+ and D^{*+} in the 0–20% (left) and 40%–80% (middle) centrality classes. The results for the three meson species agree within uncertainties. They show a suppression reaching a factor 3–4 in central collisions, for $p_{\mathrm{T}} > 5$ GeV/c. For $p_{\mathrm{T}} < 5$ GeV/c, the D^0 meson R_{AA} shows a weak rise with decreasing p_{T}. The

40%-80% centrality class exhibits less suppression by roughly a factor of two. A complementary analysis to the parton energy loss study by means of the $R_{\rm AA}$ is provided by the elliptic flow measurement. The $p_{\rm T}$-differential v_2 of $\rm D^0$ mesons in the centrality classes 15%–30% and 30%–50% is presented in Fig. 1 (right), v_2 being extracted from the relative difference between the number of candidates in-plane and out-of-plane [13]. The results for semi-central collisions (30%–50%) show a non-zero v_2 (with a 3 σ significance) in $2 < p_{\rm T} < 6$ GeV/c. The magnitude of v_2 decreases as the collision centrality increases.

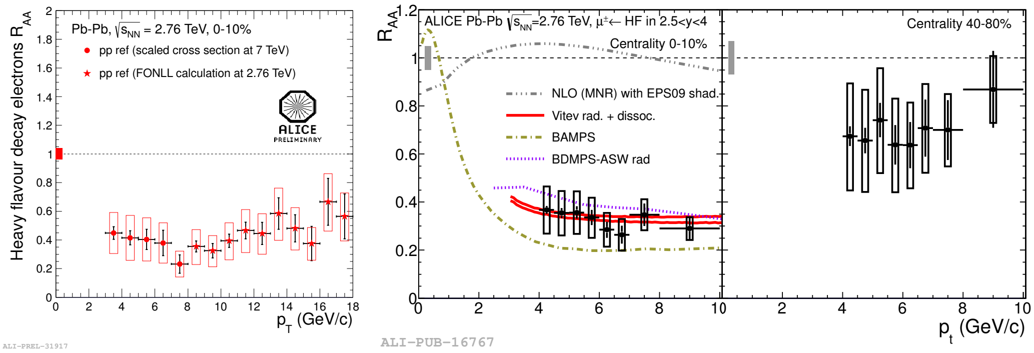

Figure 2. $R_{\rm AA}$ of electrons (left) and muons (middle and right) from heavy-flavour decays for different centrality classes. The statistical (bars), systematic (empty boxes) and normalization (filled boxes) uncertainties are shown. $R_{\rm AA}$ of muons from heavy-flavour decays [10] is compared to models including only shadowing and to models implementing in-medium energy loss.

The $p_{\rm T}$-differential $R_{\rm AA}$ is also measured for electrons from heavy-flavour decays in the 0–10% centrality class, as displayed in Fig. 2 (left). A suppression of a factor 2–4 is evidenced in $3 < p_{\rm T} < 18$ GeV/c. The $R_{\rm AA}$ of muons from heavy-flavour decays in the two centrality classes 0–10% and 40%–80% is shown in Fig. 2 (middle and right). A larger suppression is measured in central collisions than in peripheral collisions with no significant $p_{\rm T}$ dependence. The suppression reaches a factor 3–4 in the 10% most central collisions. The comparison with model predictions (Fig. 2, middle) indicates that nuclear shadowing alone cannot explain the observed suppression at forward rapidity [14]. Moreover, models implementing in-medium partonic energy loss [15] describe reasonably well the data within uncertainties. A similar agreement between the average nuclear modification factor of D mesons and transport model predictions was also reported [5].

4. J/ψ nuclear modification factor and elliptic flow measurements

The inclusive J/ψ $R_{\rm AA}$ has been measured at mid-rapidity and forward rapidity, down to $p_{\rm T} = 0$, in the dielectron channel and in the dimuon channel, respectively. The pp reference (Eq. (1)) is obtained from the analysis of the pp run at $\sqrt{s}$ = 2.76 TeV [6]. The inclusive J/ψ $R_{\rm AA}$ as a function of $\langle N_{\rm part}\rangle$ (mean number of participating nucleons), $p_{\rm T}$ and y is displayed in the left, middle and right panel of Fig. 3, respectively. A clear suppression of about a factor two is measured at forward rapidity for $\langle N_{\rm part}\rangle > 70$, with almost no centrality dependence. A similar pattern could be evidenced at mid-rapidity within uncertainties. In the forward rapidity region, the J/ψ suppression increases significantly with increasing $p_{\rm T}$ ($R_{\rm AA}$ varies from about 0.6 to 0.35 from $p_{\rm T} = 0$ up to $p_{\rm T} = 8$ GeV/c). The suppression measured at high $p_{\rm T}$ in ALICE is similar to that reported by the CMS Collaboration [16], although in a different rapidity region ($1.6 < |y| < 2.4$). On the other hand, in the range $p_{\rm T} < 4$ GeV/c, a stronger suppression is measured in $1.2 < |y| < 2.2$ for the 20% most central Au–Au collisions at $\sqrt{s_{\rm NN}} = 0.2$ TeV [17] compared to the ALICE measurement in $2.5 < y < 4$. These observations hint at regeneration as one of the mechanisms responsible for J/ψ production at the LHC. It is worth noticing that

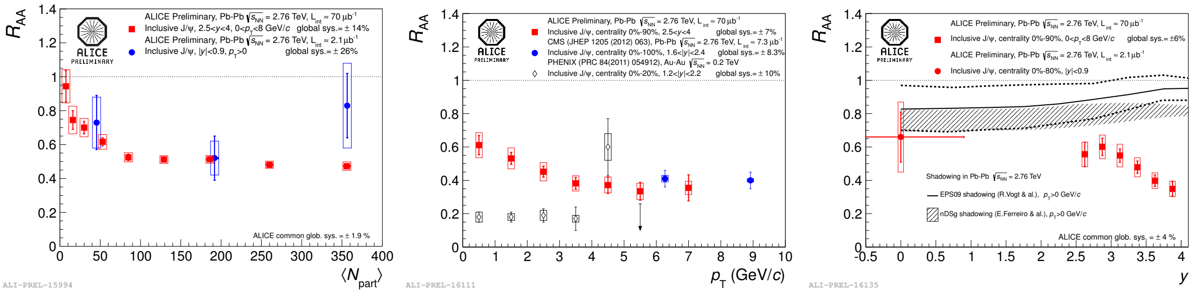

Figure 3. R_{AA} of inclusive J/ψ as function of $\langle N_{\mathrm{part}}\rangle$ (left), p_{T} (middle) and y (right). The p_{T}-differential R_{AA} from ALICE is compared to the one measured in PHENIX and CMS Collaborations and the y-differential R_{AA} is compared to model calculations including only shadowing effects (EPS09 and nDSg parameterizations [18]).

transport models including a J/ψ regeneration component from deconfined charm quarks in the medium and the statistical hadronization model reproduce the data within uncertainties (see [7] and references therein). The inclusive J/ψ R_{AA} increases by about 40% from $y = 4$ to $y = 2.5$ and tends to saturate to $y = 0$ (Fig. 3). The comparison of the data with model predictions [18] indicates that shadowing effects are expected to be similar over the whole rapidity range and could be responsible for a large part of the measured suppression in $0 < y < 3$. Finally, a non-zero J/ψ v_2 [19] (2.2 σ significance) was recently measured at intermediate p_{T} in semi-central collisions, supporting that a fraction of J/ψ could be produced by recombination processes

5. Conclusion

The production of open heavy-flavour particles and inclusive J/ψ has been measured at mid-rapidity and forward rapidity in pp and Pb–Pb collisions with the ALICE detector. The open heavy-flavour results give evidence for strong in-medium energy loss of heavy quarks. The inclusive J/ψ results indicate that a significant fraction of J/ψ may be produced from charm quarks in the deconfined medium. The p–Pb run scheduled for the beginning of 2013 should allow us to assess initial state effects and to quantify the amount of nuclear shadowing.

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