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Measurements of heavy-flavour decay lepton productions in Pb–Pb and Xe–Xe collisions with ALICE at the LHC

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Charm and beauty quarks are expected to form on a shorter time scale with respect to the strongly interacting medium, Quark-Gluon Plasma (QGP), produced in high-energy heavy-ion collisions. Therefore, expecting the full evolution of the collision, they are effective probes to study the mechanisms of parton energy loss and hadronisation in the hot and dense medium, giving insight on the QGP evolution and its transport coefficients. The heavy-flavour nuclear modification factor (R_{AA}) is one of the key observables which allows investigate the interaction strength of heavy quarks with the medium constituents.

We report on the latest measurements of the R_{AA} of open heavy-flavour hadrons via semi-leptonic decays to electrons at mid-rapidity and muons at forward rapidity in Pb–Pb collisions and Xe–Xe collisions with ALICE at LHC. Comparisons with model calculations including the interaction of heavy quarks with the hot, dense, and deconfined medium will be also shown.

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1. Introduction

ALICE [1] is the dedicated heavy-ion experiment at the LHC, optimized to investigate the properties of strongly-interacting matter under extreme conditions of temperature and energy density where the formation of the Quark-Gluon Plasma (QGP) is expected. Heavy quarks (charm and beauty) are regarded as efficient probes of the properties of the QGP as they are created on a very short time scale in initial hard parton scattering processes and subsequently interact with the medium. Open heavy flavours are expected to be sensitive to the energy density of the system through the in-medium energy loss of heavy quarks. In the high p_{T} region, the suppression of the heavy-favour yields is quantified by means of the nuclear modification factor, R_{AA}:

$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{\mathrm{d}^2 N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}{< T_{\mathrm{AA}} > \mathrm{d}^2\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} \tag{1.1}$$

It is defined as the ratio of the p_{T}-differential particle yield measured in A–A collisions to the corresponding p_{T}-differential cross section measured in pp collisions scaled by the average nuclear overlap function. Due to the color-charge effect, the radiative energy loss of gluons should be larger than that of quarks. Moreover, heavy-quark energy loss may be reduced with respect to that of light quarks due to the dead-cone effect [3].

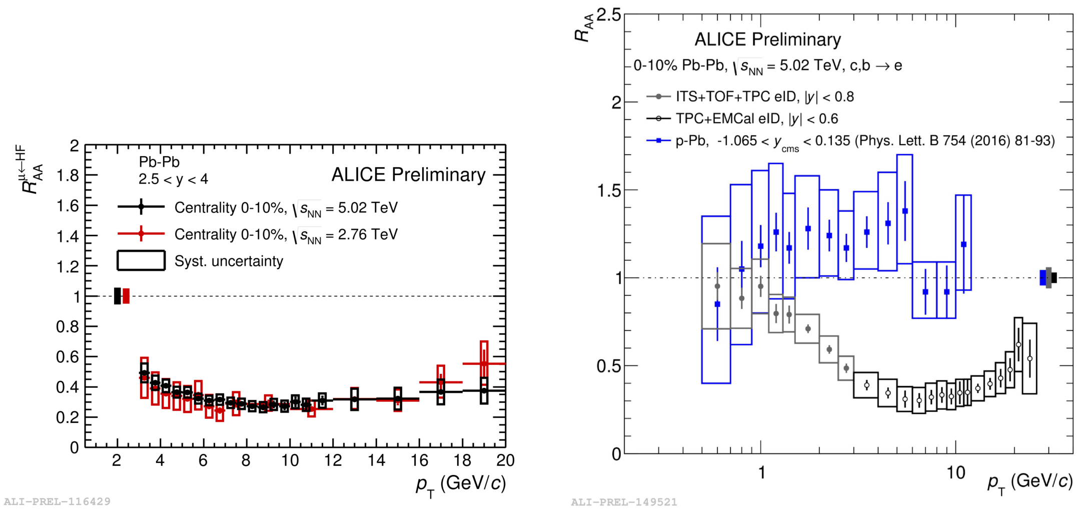

Figure 1: Left: p_{T}-differential R_{AA} of heavy-flavour hadron decay muons at forward rapidity (2.5 < y < 4) in central (0-10%) Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 (black markers) compared with the measurement at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV (red markers). Right: R_{AA} of electrons from heavy-flavour hadron decays at mid-rapidity as a function of p_{T} in central (0-10%) Pb–Pb (black markers) and in p–Pb (blue markers) collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV.

2. Heavy-flavour hadron decay leptons in Pb–Pb and Xe–Xe collisions

The ALICE collaboration measured the production of muons and electrons from heavy-flavour hadron decays in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV and 5.02 TeV at forward rapidity and mid-rapidity, respectively. The left panel of Fig. 1 presents a comparison of the p_{T}-differential R_{AA} of heavy-flavour hadron decay muons at forward rapidity in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and 2.76 TeV. The open boxes include the systematic uncertainty sources except the systematic uncertainty on normalization which is shown as a filled box at $R_{\mathrm{AA}} = 1$. A strong suppression is observed in central collisions, with no significant p_{T} dependence within uncertainties. A similar suppression is observed at both $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and 2.76 TeV within uncertainties. The suppression reaches a factor of about three in the 10% most central collisions. The right panel of Fig. 1 shows the R_{AA} of electrons from heavy-flavour hadron decays as a function of p_{T} in central (0-10%) Pb–Pb and in p–Pb collisions [4] at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. A strong suppression is observed in central Pb–Pb collisions for $p_{\mathrm{T}} > 1$ GeV/c, while an R_{pPb} consistent with unity is measured in p–Pb collisions, confirming that the suppression observed in central Pb–Pb collisions is predominantly induced by final-state effects related to the heavy-quark energy loss in the medium [2].

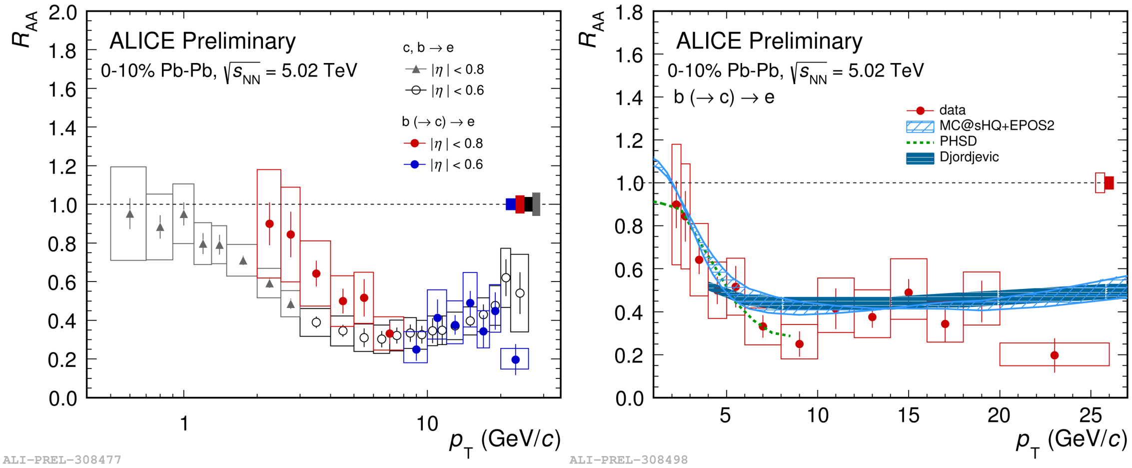

Figure 2: Left: Comparison of the R_{AA} of electrons from beauty-hadron decays (red markers) with the one from charm- plus beauty hadron decays (black markers) in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. Right: of electrons from beauty hadron decay in comparison with models implementing mass-dependent energy loss [5, 6, 7, 8, 9] in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV.

A comparison of the R_{AA} of electrons from beauty-hadron decays with the one of electrons from heavy-flavour decays is shown in the left panel of Fig. 2 for the 10% most central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV. The contribution to the heavy-flavour decay electron yield due to beauty- hadron decays was extracted by means of a fit to the electron impact parameter distribution. The two R_{AA} are fully compatible for $p_{\mathrm{T}} > 6$ GeV/c. At lower p_{T}, where the charm contribution dominates, the data indicates a smaller suppression for electrons coming from beauty-hadron decays with respect to electrons from inclusive heavy-flavour hadron decays. The right panel of Fig. 2 shows that the measured R_{AA} is in agreement within uncertainties with models implementing mass-dependent energy loss [5, 6, 7, 8, 9].

The measured R_{AA} of muons from beauty-hadron decays in central (0-10%), semi-central (20-40%) and peripheral(60-80%) collisions is compared with MC@sHQ + EPOS2 prediction [7, 8], for $\mu \leftarrow$c, $\mu \leftarrow$b, $\mu \leftarrow$c+b. The data are described with uncertainties by the model predictions. Moreover, one can see that the model predictions for $\mu \leftarrow$b reproduce well the data at high p_{T} for all centralities within uncertainties.

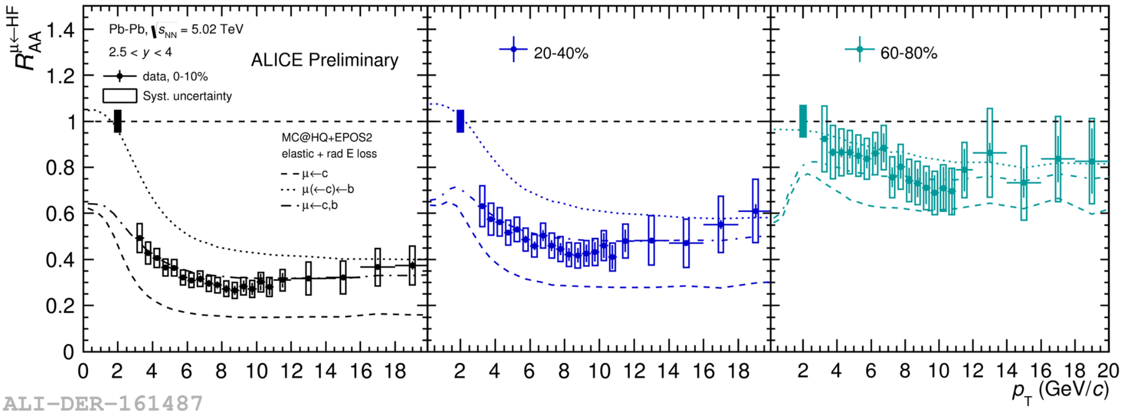

Figure 3: p_T-differential R_{AA} of heavy-flavour hadron decay muons at forward rapidity in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV compared with the MC@sHQ + EPOS2 predictions in the centrality classes 0–10%, 20–40% and 60–80%.

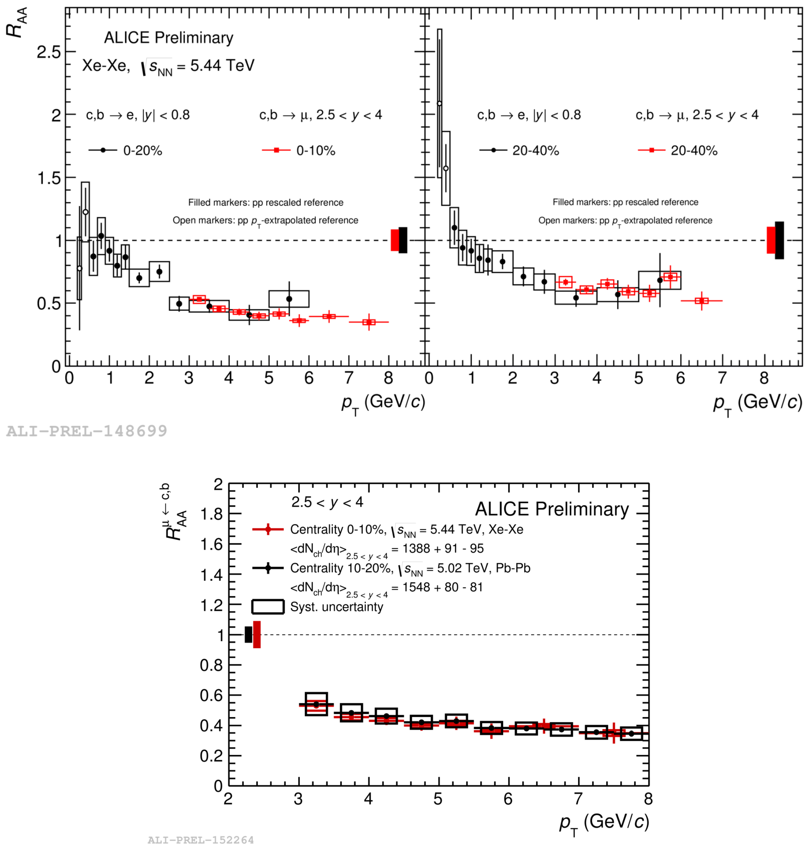

Figure 4: Upper: p_T-differential R_{AA} of electrons (black markers) and muons (red markers) from heavy-flavour hadron decay in central (left panel) and semi-central (right panel) Xe–Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV. Bottom: p_T-differential R_{AA} of muons from heavy-flavour hadron decays in Xe-Xe (centrality:0-10%) collisions at 5.44 TeV in comparison with that in Pb–Pb (centrality:10-20%) collisons at 5.02 TeV.

Upper panel of Fig. 4 shows a comparison with the R_{AA} measured at mid-rapidity for electrons from heavy-flavour hadron decays in central and semi-central Xe–Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV. A similar suppression is observed at both forward and mid-rapidity within uncertainty. This is an indication that heavy quarks suffer a strong interaction in a wide rapidity internal. When comparing the nuclear modification factors of heavy-flavour decay muons in Pb-Pb and Xe-Xe collisions at a similar range of averaged charged particle multiplicity densities, a remarkable similarity between two systems at a similar center-of-mass energy is observed in bottom panel of Fig. 4 shows. The comparison of the measured R_{AA} values in the two colliding systems could enable a test of the path length dependence of medium-induced parton energy loss [10].

3. Conclusion

We presented measurements of the nuclear modification factor of open heavy flavours with ALICE via semi-leptonic decays to electrons at mid-rapidity ($|y| < 0.8$) and muons at forward rapidity ($2.5 < y < 4$) in a wide p_T interval in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and Xe–Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV collected in the LHC Run2. A strong suppression in the 10% most central collisions reaching a factor of about three in $7 < p_T < 12$ GeV/c is observed. Results are compatible within uncertainties with those obtained at $\sqrt{s_{NN}} = 2.76$ TeV. The measured suppression is due to final-state effects. The results of R_{AA} in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV in various centrality classes may provide important constraints to the models. Moreover, a similar suppression is observed at both forward and mid-rapidity within uncertainty in Xe–Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV. This is an indication that heavy quarks suffer a strong interaction in a wide rapidity internal. Moreover, the comparison of the measured R_{AA} values in the two colliding systems could enable a test of the path length dependence of medium-induced parton energy loss.

Acknowledgement

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