Heavy-quark energy loss at RHIC and LHC

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Abstract. The attenuation of heavy-flavored particles in nucleus–nucleus collisions tests the microscopic dynamics of medium-induced parton energy loss and, in particular, its expected dependence on the identity (color charge and mass) of the parent parton. We discuss the comparison of theoretical calculations with recent single-electron data from RHIC experiments. Then, we present predictions for the heavy-to-light ratios of D and B mesons at LHC energy.

INTRODUCTION

Believed to be the main origin of the jet quenching phenomena observed [1] in nucleus–nucleus collisions at RHIC energy $\sqrt{s_{\rm NN}} = 62$–200 GeV, parton energy loss via gluon-radiation is expected to depend on the properties (gluon density and volume) of the 'medium' formed in the collision and on the properties (color charge and mass) of the 'probe' parton [2]. Hard gluons would lose more energy than hard quarks due to the stronger color coupling with the medium. In addition, charm and beauty quarks are qualitatively different probes with respect to light partons, since their energy loss is expected to be reduced, as a consequence of a mass-dependent restriction in the phase-space into which gluon radiation can occur [3, 4, 5, 6].

We study quenching effects for heavy quarks by supplementing perturbative QCD calculations of the baseline p_T distributions with in-medium energy loss, included via the BDMPS quenching weights. The quenching weights, computed for light quarks and gluons in [7] and for heavy quarks in [8], depend on the transport coefficient $\hat{q}$, a measure of the medium density, and on the in-medium path length. These inputs are evaluated on a parton-by-parton level, using a Glauber-model based description of the local $\hat{q}$ profile in the transverse direction [9]. The $\hat{q}$ value is chosen in order to reproduce the light-flavor particles nuclear modification factor $R_{\rm AA}(p_T)$ measured in central Au–Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV (Fig. 1, left): the range favored by the data for the parton-averaged transport coefficient is $\hat{q} = 4$–$14~\mathrm{GeV}^2/\mathrm{fm}$.

SINGLE ELECTRONS AT RHIC

Heavy-quark energy loss is presently studied at RHIC using measurements of the nuclear modification factor $R_{\rm AA}$ of 'non-photonic' (γ-conversion- and π^0-Dalitz-subtracted)

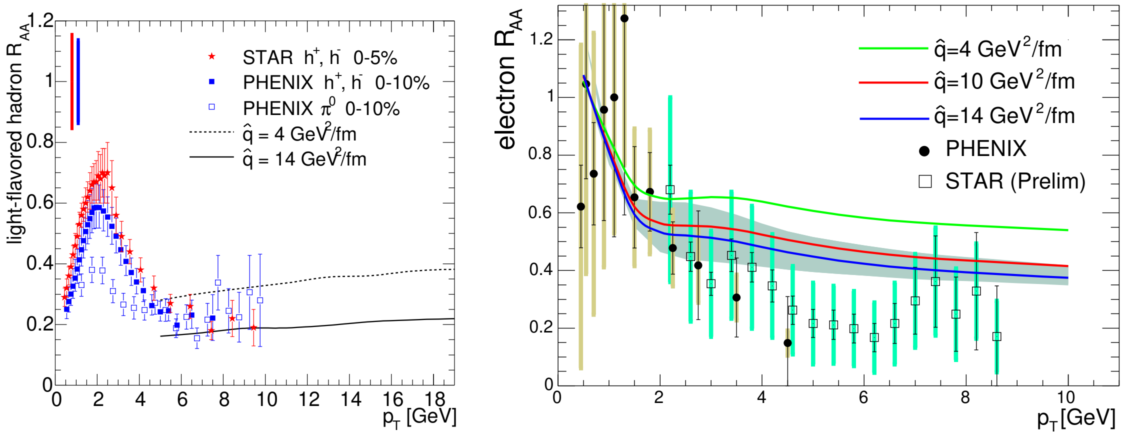

FIGURE 1. Central Au–Au collisions at $\sqrt{s_{NN}} = 200$ GeV: R_{AA} for light-flavored hadrons (left, adapted from [9]) and for heavy-flavor decay electrons (right, from [12])

single electrons. The most recent data by PHENIX [10] and STAR [11], reaching out to 5 and 9 GeV, respectively, are shown in Fig. 1 (right). Since this is an inclusive measurement, with charm decays dominating at low p_T and beauty decays dominating at high p_T, the comparison with mass-dependent energy loss predictions should rely on a solid and data-validated pp baseline. Such baseline is still lacking at the moment, as we explain in the following. The state-of-the-art perturbative predictions (FONLL), that we use as a baseline, indicate that, in pp collisions, charm decays dominate the electron p_T spectrum up to about 5 GeV [12]. However, there is a large perturbative uncertainty on position in p_T of the c-decay/b-decay crossing point: depending on the choice of the factorization and renormalization scales this position can vary from 3 to 9 GeV [12]. In addition, the calculation tends to underpredict the non-photonic electron spectrum measured in pp collisions [12].

For our electron R_{AA} results (Fig. 1, right), in addition to the uncertainty on the medium density (curves for $\hat{q} = 4$, 10, 14 GeV^2/fm), we also account for the perturbative uncertainty by varying the values of the scales and of the c and b quark masses (shaded band associated to the $\hat{q} = 14$ GeV^2/fm curve) [12]. We find that the nuclear modification factor of single electrons is about 0.2 larger than that of light-flavor hadrons. Thus, electrons are in principle sensitive to the mass hierarchy of parton energy loss. The available data neither allow us to support claims of inconsistency between theory and experiment, nor do they support yet the expected mass hierarchy. It is important to note that, in general, the perturbative uncertainty in calculating the partonic baseline spectrum is comparable to the model-intrinsic uncertainty in determining $\hat{q}$. If future experimental studies at RHIC succeeded in disentangling the charm and beauty contributions to single electrons, the sensitivity in the theory-data comparison would be largely improved.

HEAVY-TO-LIGHT RATIOS AT LHC

Heavy quarks will be produced with large cross sections at LHC energy and the experiments will be equipped with detectors optimized for the separation of charm and beauty

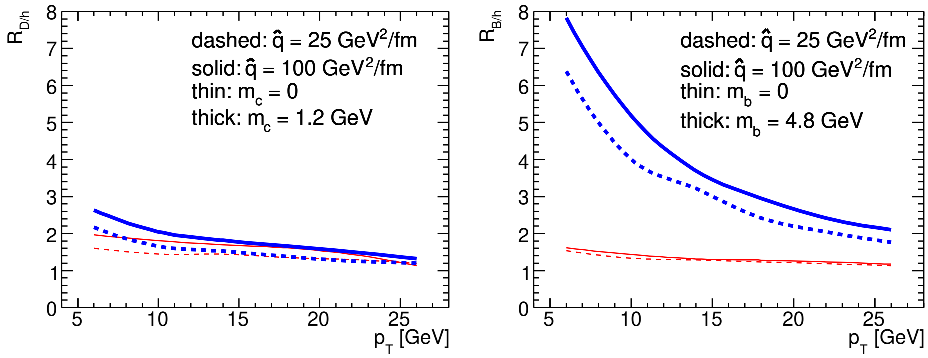

FIGURE 2. Heavy-to-light ratios for D (left) and B (right) mesons for the case of realistic heavy-quark masses and for a case study in which the quark mass dependence of parton energy loss is neglected [8]

decay vertices. Thus, it should be possible to carry out a direct comparison of the attenuation of light-flavor hadrons, D mesons, and B mesons. We calculate the expected nuclear modification factors R_{AA} exploring a conservatively-large range in the medium density for central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.5$ TeV: $25 < \hat{q} < 100\ \mathrm{GeV}^2/\mathrm{fm}$. We use standard NLO perturbative predictions for the c and b p_T-differential cross sections [13].

Figure 2 (thick lines) shows our results for the heavy-to-light ratios of D and B mesons [8], defined as the ratios of the nuclear modification factors of $D(B)$ mesons to that of light-flavor hadrons (h): $R_{D(B)/h} = R_{\mathrm{AA}}^{D(B)}/R_{\mathrm{AA}}^{h}$. We illustrate the effect of the mass by artificially neglecting the mass dependence of parton energy loss (thin curves). The enhancement above unity that persists in the $m_{c(b)} = 0$ cases is mainly due to the color-charge dependence of energy loss, since at LHC energy most of the light-flavor hadrons will originate from a gluon parent. Our results indicate that, for D mesons, the mass effect is small and limited the region $p_T \lesssim 10$ GeV, while for B mesons a large enhancement can be expected up to 20 GeV. Therefore, the comparison of the high-p_T suppression for D mesons and for light-flavor hadrons will test the color-charge dependence (quark parent vs. gluon parent) of parton energy loss, while the comparison for B mesons and for light-flavor hadrons will test its mass dependence [8].

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