Heavy-to-light ratios as a test of medium-induced energy loss at RHIC and the LHC

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The ratio of nuclear modification factors of high-p_T heavy-flavored mesons to light-flavored hadrons (heavy-to-light ratio) is shown to be a sensitive tool to test medium-induced energy loss at RHIC and LHC energies. Heavy-to-light ratios of D mesons at RHIC in the region $7 < p_T < 12$ GeV, and of D and B mesons at the LHC in the region $10 < p_T < 20$ GeV, are proposed for such a test. Finally, the different contributions to the nuclear modification factor for electrons at RHIC are analyzed. Preliminary PHENIX and STAR data are compatible with radiative energy loss provided the contribution of electrons from beauty decays is small compared to that from charm.

1. INTRODUCTION

Energy loss by medium-induced gluon radiation is the standard explanation for the suppression of high transverse momentum hadron spectra in nucleus-nucleus collisions compared to p-p collisions. The description of this effect (see [1] and references therein) considers the rescattering of the emitted gluon with a medium characterized by its length L, and by the so-called BDMPS transport coefficient $\hat{q}$. This transport coefficient measures the color field strength in the medium by characterizing the amount of squared transverse momentum transferred from the medium to the hard parton per unit path length. It is one general expectation of parton energy loss that due to their larger color charge, gluons will radiate more than light quarks which, due to their vanishing mass, will radiate more than heavy quarks [2,3].

Heavy-to-light ratios $R_{D(B)/h} = R_{AA}^{D(B)}/R_{AA}^h$ are mainly sensitive to two effects. First, in hadronic collisions at sufficiently high center of mass energy, light hadrons are predominantly produced by gluons, while heavy mesons have quark parents. $R_{D(B)/h}$ increases due to this color charge effect. Second, heavy quarks radiate less energy than light ones - this mass effect increases $R_{D(B)/h}$ further. There are additional smaller effects which affect $R_{D(B)/h}$ and which are discussed in [4].

Our model [4] is based on a LO pQCD formalism, as implemented in the PYTHIA event generator [5], supplemented by radiative energy loss via quenching weights [2], which give the probability that a parton traversing a medium characterized by $\hat{q}$ and L loses a given fraction of its energy. The geometry of the medium is modeled realistically [6]. After their quenching, partons are fragmented according to standard procedures, see [4].

2. HEAVY-TO-LIGHT RATIOS

2.1. RHIC

In order to get predictions at RHIC energies, the value of the only medium-dependent model parameter, $\hat{q}$, is fixed from the high-p_T suppression of light hadrons in central Au–Au at $\sqrt{s_{NN}} = 200$ GeV. Values of $\hat{q}$ lie [6] within the range $4 \div 14$ GeV^2/fm. In [4], the description of experimental data in d–Au collisions and the predictions for the nuclear ratios of D-mesons and electrons from charm at RHIC, are presented.
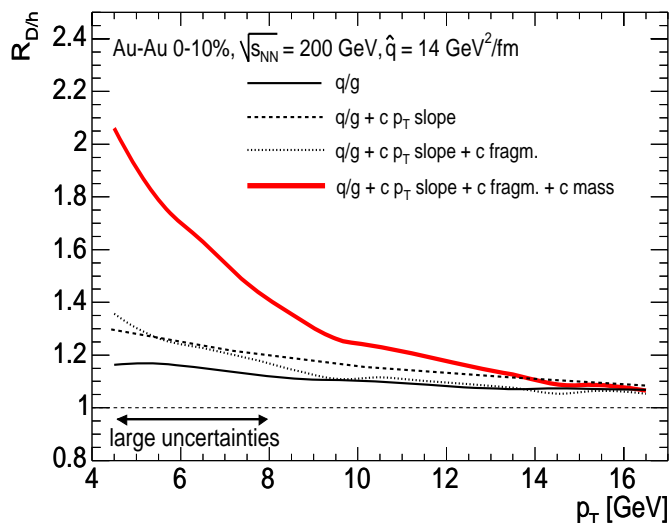

Figure 1. Different contributions to the heavy-to-light ratio of D mesons in central (0–10%) Au–Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Different curves correspond to the case in which the charm distribution is described i) with the same p_T spectrum, fragmentation function and parton energy loss as a light quark, ii) with a realistic charm p_T spectrum only, iii) with the charm p_T spectrum and fragmentation function of a realistic charm quark and iv) for the realistic case including the mass dependence of parton energy loss.

Here we show in Fig. 1 the heavy-to-light ratio of D mesons, with the different ingredients discussed in the previous Section selectively switched on. The mass effect turns out to be the largest in the region $p_T < 7 \div 8$ GeV, a region subject to large uncertainties due to the possibility of fragmentation in medium. For light hadrons this is indicated by the baryon-to-meson anomaly, and heavy quarks could be more affected due to their slower movement through the medium. On the other hand, in the region $7 < p_T < 12$ GeV both the color charge and the mass effects play a similar quantitative role.

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[2]Publicly available FORTRAN routines to compute quenching weights in the massive case can be found in www.pd.infn.it/~dainesea/qwmassive.html.

2.2. LHC

To extrapolate the value of $\hat{q}$ for different energies, a proportionality of the density with the multiplicity is assumed. Extrapolations from RHIC to LHC lie in the range $2.5 \div 7$ [6,7]. Conservatively, a wide range $\hat{q} = 4$, 25 and 100 GeV^2/fm is explored [4].
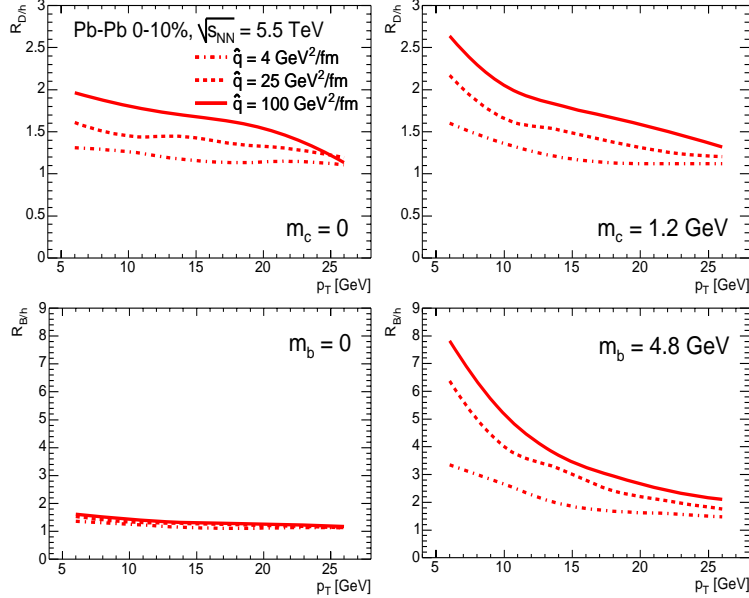

Figure 2. Heavy-to-light ratios in central Pb–Pb at the LHC for D (upper plots) and B mesons (lower plots) for a realistic heavy quark mass (plots on the right) and for a case in which the quark mass dependence of parton energy loss is neglected (plots on the left).

Results for nuclear ratios of B and D mesons and decay electrons can be found in [4]. Here in Fig. 2 the heavy-to-light ratios of B and D mesons are shown, with explicit indication of the effect of the mass on the quenching. $R_{D/h}$ is sensitive mainly to the color charge effect, which is more pronounced than at RHIC due to the smaller Bjorken x. $R_{B/h}$ is very sensitive to the mass effect. Both can be seen in the window $10 < p_T < 20$ GeV, which should be safe from the influence of a medium on fragmentation.

3. NUCLEAR MODIFICATION FACTOR FOR ELECTRONS AT RHIC

With heavy-flavor mesons not directly reconstructed in nucleus-nucleus collisions at RHIC, the present discussion is focused on nuclear ratios for non-photonic electrons R_{AA}^e [8]. Preliminary measurements by PHENIX and STAR [9] show a large suppression by a factor $3 \div 5$, $R_{AuAu}^e \sim 0.2 \div 0.4$, in the region $4 < p_T^e < 10$ GeV, which has been considered as incompatible with radiative energy loss [10] and/or indicative of heavy quark thermalization [11]. As discussed in [10], bottom quarks should be less suppressed than charm quarks due to their higher mass, and their contribution to the electron spectra should tend to increase the corresponding nuclear ratio. In order to analyze this point, we have supplemented state-of-the-art pQCD computations of heavy flavor production [12] (FONLL: fixed order NLO plus NLL resummation) with energy loss via quenching weights [4]. Full details and a discussion of uncertainties will be presented elsewhere [13]. Here we show in Fig. 3 the different heavy flavor contributions to R_{AA}^e, with the uncertainty in FONLL given by a variation in heavy quark masses. These results are

compatible with preliminary data [9] provided the contribution of electrons from beauty decays with respect to charm is smaller than predicted by FONLL. Thus an estimation of the uncertainties [13] in charm [14] and beauty spectra at RHIC energies becomes crucial.
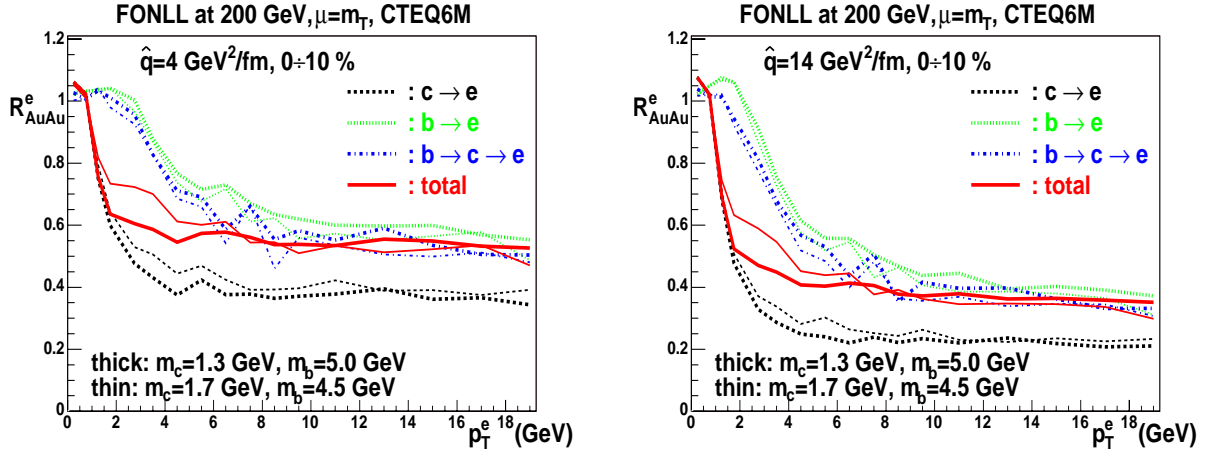

Figure 3. Contributions at RHIC to R_{AA}^e for electrons coming from heavy meson decay for $\hat{q} = 4$ (plot on the left) and 14 (plot on the right) GeV^2/fm, for different quark masses.

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