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Longitudinal dependence of B and D meson nuclear modifications in heavy-ion collisions at RHIC and the LHC

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Abstract

It is widely acknowledged that heavy flavor probes are sensitive to the properties of the quark-gluon plasma and are often considered an important tool for the plasma tomography studies. Forward rapidity observables can provide further insight on the dynamics of the medium due to the interplay between the medium size and the differences in the production spectra of heavy quark probes. In this proceedings we present the nuclear modification factor R_{AA} 's for B and D mesons, as well as heavy flavor leptons, in the rapidity range $-4.0 < y < 4.0$ obtained from relativistic Langevin equation with gluon radiation coupled with a (3+1)-dimensional viscous hydrodynamics medium background. We present comparison with experimental data at mid-rapidity as well as predictions for different rapidity ranges.

Keywords: heavy ion collisions, quark-gluon plasma, open heavy flavor, parton suppression

1. Introduction

Heavy quarks are extremely valuable probes for the tomographic study of the hot and dense nuclear matter known as the quark-gluon plasma (QGP) produced in relativistic heavy-ion collisions [1–5]. Final observables from heavy quarks, such as the nuclear modification factor, contain cumulative information of the evolution dynamics of the QGP.

One of the most common observables pertaining heavy flavor studies is the nuclear modification factor R_{AA} , which is usually associated with parton energy loss through the medium. It is defined as the ratio between the particle spectrum in nuclei collisions dN_{AA}/dp_T , and the spectrum in pp collisions, dN_{pp}/dp_T [6]:

$$R_{AA}(p_T, y) = \frac{1}{N} \frac{dN_{AA}/dp_T dy}{dN_{pp}/dp_T dy}, \quad (1)$$

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where N is the average number of binary nucleon-nucleon collisions for a given centrality class of AA collisions.

Many studies attempted to use R_{AA} to investigate mechanisms of parton transport and energy loss or to constraint phenomenological models together with other observables. However, it was not until recently that longitudinal dependence of heavy flavor observables started to be explored [7–11]. In this direction we recently calculated the nuclear modification factor R_{AA} of open heavy flavor in a wide range of rapidity [12].

In this talk we present the longitudinal dependence of the R_{AA} of heavy flavor mesons (B and D) as well as electrons and muons decayed from these particles [12]. We use the three dimensional medium profiles generated from CLVisc hydrodynamics code [13–15] to construct averaged QGP backgrounds in which heavy quarks are sampled and allowed to propagate using relativistic Langevin equations with gluon radiation and a hybrid fragmentation plus coalescence model for hadronization [16, 17]. The initial position of the sampled heavy quarks is obtained from Monte Carlo Glauber model while their initial momentum distribution is calculated using leading order perturbative QCD [18] that includes flavor excitation, pair production, and nuclear shadowing and anti-shadowing effects [17, 19, 20]. The initial production cross section is also used to calculate the relative fraction between bottom and charm quarks in order to obtain heavy quark decayed leptons spectra. Predictions are made for different rapidity bins in the range of $-4.0 < y < 4.0$ on the nuclear modification factor of open heavy flavor mesons.

2. Numerical Results

Using the setup as described in reference [12], we present the numerical results from our simulations. Calculations for D meson R_{AA} are shown in Fig. 1 for collisions of Au+Au at $\sqrt{s_{NN}} = 200$ GeV, Pb+Pb at $\sqrt{s_{NN}} = 2.76$ TeV, and Pb+Pb at $\sqrt{s_{NN}} = 5.02$ TeV. The solid red curves in the plots correspond to mid-rapidity calculations and are compared with experimental data. Good agreement with CMS data for both Pb+Pb collisions throughout the whole p_T range is observed. For the lowest energy collision of Au+Au at $\sqrt{s_{NN}} = 200$ GeV our results show consistency with data from the STAR experiment for $p_T \geq 4$ GeV. At the lower p_T regime a complex interplay of different physical processes, is expected to occur. One such physical process that is very important is the recombination mechanism which dominates the heavy quark hadronization at this regime and has been shown to decrease the R_{AA} at low p_T while also increasing it at high p_T . We also present predictions for forward rapidity R_{AA} .

The calculations for B meson R_{AA} are shown in Fig. 2. The same trend as the case for D mesons is observed at high p_T , where a larger parton suppression is observed in larger rapidity bins.

In Fig. 3 we show heavy flavor electron results. In these plots the solid black curves with a different rapidity range than that of the previous plots is used to compare our calculations results with experimental data from ALICE at $|y| < 0.6$. For Au+Au collisions we observe a good agreement with the PHENIX data, despite the difference in the rapidity range, as it would be expected in this regime. We also observe a good agreement for the Pb+Pb collisions although our results slightly overestimate the data at $\sqrt{s_{NN}} = 2.76$ TeV.

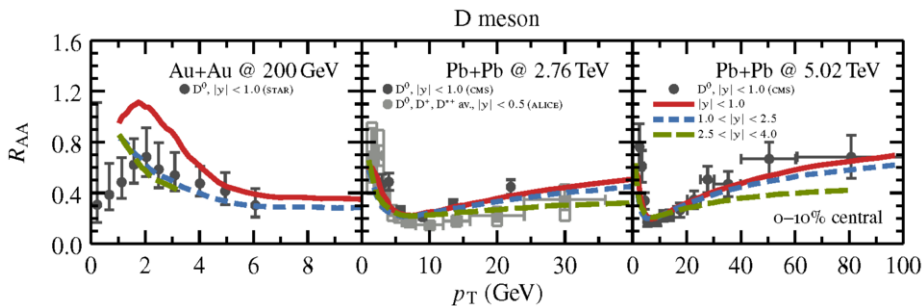


Fig. 1. (Color online) Nuclear modification factor of D mesons for central collisions in different ranges of rapidity. Mid-rapidity experimental data from STAR [21] (left), ALICE [22] and CMS [23] (middle), and CMS [24] (right) are also shown.

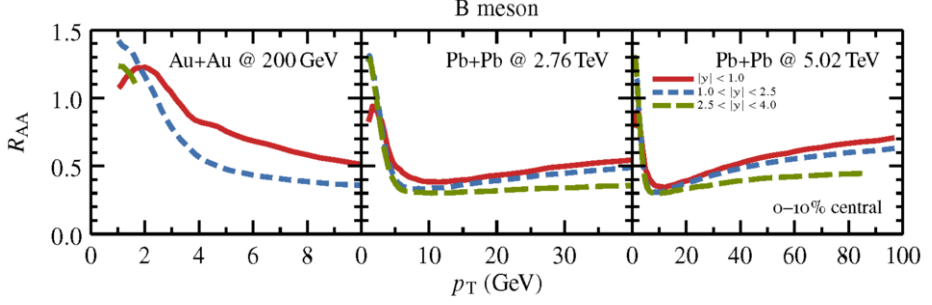


Fig. 2. (Color online) Nuclear modification factor of B mesons for central collisions in different ranges of rapidity for Au+Au at $\sqrt{s_{NN}} = 200$ GeV (left), Pb+Pb at $\sqrt{s_{NN}} = 2.76$ TeV (middle) and Pb+Pb at $\sqrt{s_{NN}} = 5.02$ TeV (right).

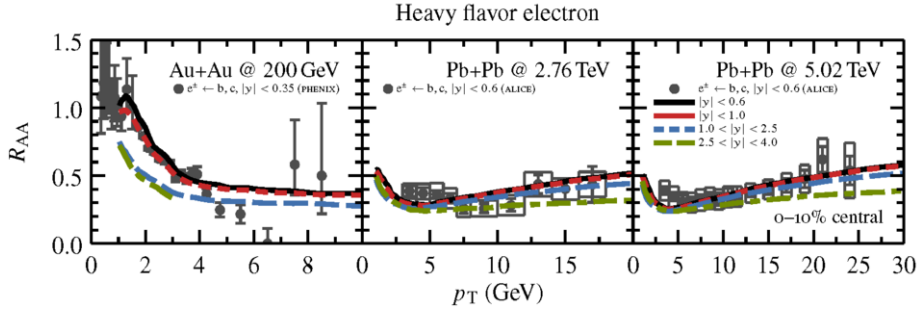


Fig. 3. (Color online) Nuclear modification factor of heavy flavor electrons for central collisions in different ranges of rapidity. Mid-rapidity experimental data from PHENIX [25] (left), ALICE [26] (middle), and ALICE [27] (right) are also shown.

The results for the heavy flavor decayed muons are shown in Fig. 4. The comparison with experimental data shows good agreement especially for the larger beam energy at high p_T . In these plots, however, since experimental data only spreads over a very limited range of p_T , it is harder to use data to discriminate between the different curves due to the proximity of the latter in this p_T range.

Overall the above results show that when increasing the rapidity, we observe a larger suppression at the high p_T regime, even though the expected medium size in these conditions is smaller. Since R_{AA} not only

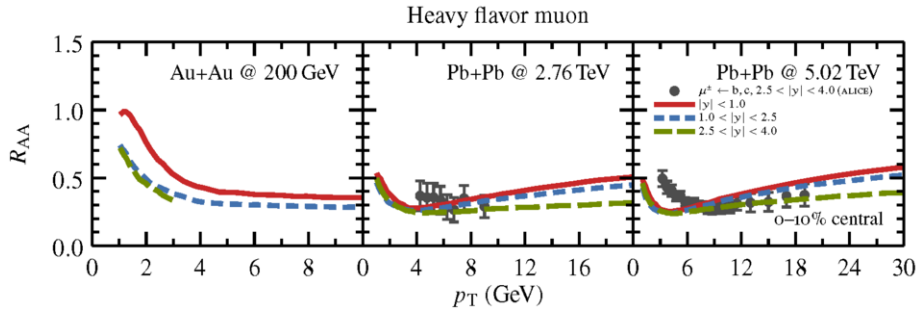


Fig. 4. (Color online) Nuclear modification factor of heavy flavor muons for central collisions in different ranges of rapidity for Au+Au at $\sqrt{s_{NN}} = 200$ GeV (left), Pb+Pb at $\sqrt{s_{NN}} = 2.76$ TeV (middle) and Pb+Pb at $\sqrt{s_{NN}} = 5.02$ TeV (right). Experimental data from ALICE [28, 29] at forward rapidity is also shown.

depends on the path length experienced by the parton inside the medium, but also on the initial production spectra, these two effects compete with each other in the final result. Here, a stronger effect from the initial heavy quark spectra, which is steeper for large rapidities in comparison with mid-rapidity, is observed to dominate in this region of p_T leading to a larger suppression of the R_{AA} .

3. Conclusions

We present the longitudinal dependence of heavy flavor nuclear modification factor obtained by coupling the (3+1)-dimensional viscous hydrodynamic medium background modeled by CLVisc with a relativistic Langevin equation based transport model incorporating both collisional and radiative energy loss. The observed results are consistent with currently available experimental data and predictions for forward rapidity R_{AA} of heavy flavor mesons and leptons are presented for three different collision energies. Our calculations have shown to indicate that at large rapidity, the smaller size of the medium and the steeper initial spectra of heavy quarks compete with each other in the resulting R_{AA} .

Further studies on the longitudinal dependence of heavy flavor observables are needed to provide more sensitive constraints on the phenomenological models of the QGP dynamics.

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