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Suppression and Two-Particle Correlations of Heavy Mesons in Heavy-Ion Collisions

Shanshan Cao[a], Guang-You Qin[b], Steffen A Bass[c]

[a]Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
[b]Institute of Particle Physics and Key Laboratory of Quark and Lepton Physics (MOE), Central China Normal University, Wuhan, 430079, China
[c]Department of Physics, Duke University, Durham, NC 27708, USA

Abstract

We study the medium modification of heavy quarks produced in heavy-ion collisions. The evolution of heavy quarks inside the QGP is described using a modified Langevin framework that simultaneously incorporates their collisional and radiative energy loss. Within this framework, we provide good descriptions of the heavy meson suppression and predictions for the two-particle correlation functions of heavy meson pairs.

Keywords: heavy flavor, nuclear modification, correlation function

1. Introduction

Heavy quarks serve as excellent probes of the quark-gluon plasma (QGP) matter created in ultrarelativistic heavy-ion collisions. Experimental observations at both RHIC and LHC have revealed many interesting data on heavy flavor mesons and their decay electrons, among which the most surprising ones are their small values of R_{AA} and large values of v_2 that are comparable to those of light hadrons [1, 2, 3]. This seems inconsistent with earlier expectation of the mass hierarchy of parton energy loss and thus requires a thorough understanding of heavy flavor dynamics. We establish a comprehensive numerical framework to describe the temporal evolution of heavy flavor in heavy-ion collisions [4, 5, 6, 7], including their initial production, energy loss inside QGP and hadronization into heavy hadrons. Within this framework, we provide good descriptions of the heavy meson suppression observed at RHIC and LHC, predictions for two-particle correlations of D meson pairs are also presented [8, 9] and shown to be potential new observables that reveal more detailed information of heavy quark dynamics inside a deconfined QCD medium.

2. Heavy Meson Suppression

Since heavy quarks are primarily produced in the early stage of heavy-ion collisions through hard scatterings, we use a Monte-Carlo Glauber model to initialize their positions and pQCD calculations for their momenta. The CTEQ parametrization is adopted for the parton distribution functions and the nuclear shadowing effect is taken into account by using the EPS09 parametrization. In the QGP stage, the space-time

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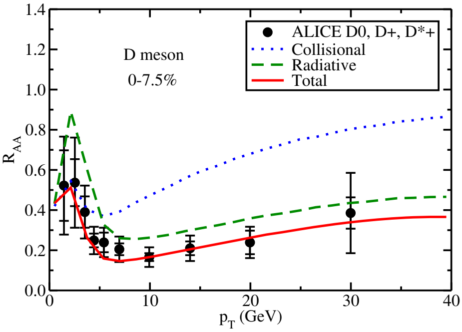

Fig. 1. (Color online) The D meson $R_{\rm AA}$ in 0-7.5% 2.76 TeV Pb-Pb collisions, compared between different energy loss mechanisms.

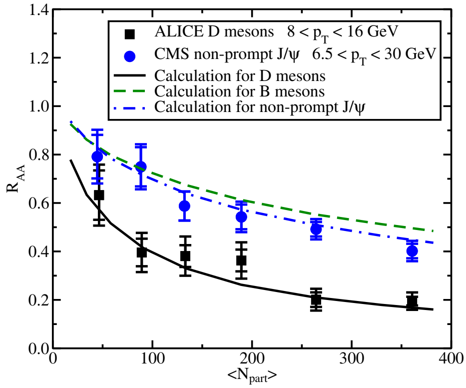

Fig. 2. (Color online) The mass hierarchy of heavy meson suppression.

evolution of the bulk matter is simulated by a (2+1)-D viscous hydrodynamic model [10] and the in-medium evolution of heavy quarks is described using an improved Langevin equation [6, 7]:

$$\frac{d\vec{p}}{dt} = -\eta_D(p)\vec{p} + \vec{\xi} + \vec{f}_g. \tag{1}$$

The first two terms on the right are taken from the classical Langevin equation describing the drag and the thermal forces heavy quarks experience while they are scattered inside a thermal medium, and are related by the fluctuation-dissipation theorem $\eta_D(p) = \kappa/(2TE)$, in which the momentum space diffusion coefficient κ is defined as $\langle \xi^i(t)\xi^j(t')\rangle = \kappa\delta^{ij}\delta(t-t')$. The third term $\vec{f}_g = -d\vec{p}_g/dt$ is introduced to describe the recoil force exerted on heavy quarks while they radiate gluons. We adopt the following higher-twist calculation of the medium-induced gluon distribution function to determine the rate of gluon radiation and its energy-momentum distribution [11]:

$$\frac{dN_g}{dx dk_\perp^2 dt} = \frac{2\alpha_s(k_\perp)}{\pi} P(x) \frac{\hat{q}}{k_\perp^4} \sin^2\left(\frac{t-t_i}{2\tau_f}\right)\left(\frac{k_\perp^2}{k_\perp^2 + x^2 M^2}\right)^4, \tag{2}$$

where $\hat{q}$ is the gluon transport coefficient, x is the fractional energy carried by radiated gluon, and $k_\perp$ is its transverse momentum. In our work, the spatial diffusion coefficient of heavy quarks D is related to κ and $\hat{q}$ via $D = 2T^2/\kappa$ and $\hat{q} = 2\kappa C_A/C_F$. After heavy quarks travel outside the QGP regime, their conversion into the hadron states are calculated based on our hybrid model of fragmentation plus coalescence [6, 7].

In Fig. 1 we show our calculations of the D meson $R_{\rm AA}$ in central Pb-Pb collisions at the LHC energy. The diffusion coefficient of heavy quarks is set as $D = 5/(2\pi T)$ as tuned in [7]. We observe that collisional energy loss dominates the D meson spectrum at low $p_{\rm T}$, however, radiative energy loss is important at high $p_{\rm T}$. In Fig. 2, we present the participant number dependence of $R_{\rm AA}$ for D meson, B meson and non-prompt J/ψ decayed from B meson. Due to the larger mass of b quarks than c quarks, the former lose less energy inside the QGP and therefore a larger $R_{\rm AA}$ is observed for non-prompt J/ψ's than D mesons. Calculations for heavy meson flow coefficient and for the RHIC experiment as well can be found in our earlier work [7].

3. Transverse Momentum Imbalance and Angular Correlation Functions of *D* Meson Pairs

In addition to the single heavy meson spectrum, the two-particle correlation functions of heavy meson pairs have also been discussed in [12, 13, 14, 8, 9] and shown able to reveal additional information on heavy flavor dynamics. In Fig. 3 we study the transverse momentum imbalance of D meson pairs in heavy-ion collisions. For each event, we select the D or $\overline{D}$ meson possessing the highest transverse momentum