The Effects of Memory on Heavy Quarks Dynamics in the Quark-Gluon Plasma

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Introduction

The relativistic heavy-ion collision experiments at Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC) proposed the existence of a hot and dense phase of nuclear matter, quark-gluon plasma (QGP). The heavy quarks (HQs) are consider as a novel probes to study the evolution of the QGP [2, 3]. They do not thermalize quickly in hot QCD matter; thus, the HQs are expected to carry information about the entire evolution of the fireball.
We study the momentum evolution of HQs within the framework of the Langevin equation, where correlated thermal noise follows the Wiener process, thus the delta correlation. In this article, we have studied the time-correlated thermal noise η, which describes the processes with memory. We assumed that the time correlation of thermal noise is exponentially decaying over a particular time scale, τ, called the memory time. The memory enters through the η and dissipative force in the Langevin equation. We have observed the significant impact of memory on the HQs dynamics in the thermalized QGP medium. The momentum broadening σ_p and the formation of nuclear suppression factor, R_{AA} are slowed down in the presence of memory in the system.

Formalism

The Langevin equations for momentum evolution of the HQs in the hot QCD matter can be written as follow,

$$\frac{dp_i}{dt} = -\int_0^t \gamma(t-s)p(s)ds + \eta(t), \qquad (1)$$

where p is the momentum of the HQs, the integral term in Eq. (1) is a dissipative force, and $\eta(t)$ is a stochastic term that models the noise, the time-correlation of thermal noise is non-zero at different time, written as follows,

$$\langle \eta(t)\eta(t')\rangle = 2\mathcal{D}g(|t-t'|). \qquad (2)$$

The fluctuation-dissipation theorem relates the drag term with the thermal noise as follows,

$$\gamma(t,t') = \frac{1}{ET}\langle \eta(t)\eta(t')\rangle. \qquad (3)$$

The exponential correlator in Eq. (2) and Eq. (3), describe as follow,

$$g(|t-t'|) = \frac{1}{2\tau}e^{-|t-t'|/\tau}, \qquad (4)$$

the momentum evolution of HQs is explored for $t \geq t'$.
To generate the time-correlated thermal noise for the Langevin equation, we introduce an ancillary process,

$$\frac{dh}{dt} = -\alpha h + \alpha\xi, \qquad (5)$$

where h denotes the ancillary process, ξ is the uncorrelated noise, with the properties, $\langle\xi\rangle = 0$, $\langle \xi(t)\xi(t')\rangle = \frac{1}{\alpha}\delta(t-t')$, where α is inverse of memory time. The approximate solution of Eq. (5), can be written as,

$$\langle h(t)h(t')\rangle \approx \frac{e^{-\alpha|t-t'|}}{2}. \qquad (6)$$

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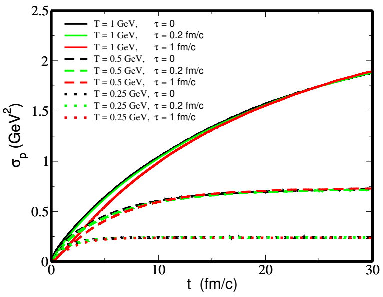

FIG. 1: σ_p versus time for three different temperature (T= 0.25 GeV, 0.5 GeV and 1 GeV) and for three value of memory time (τ=1 fm, 0.2 fm and 0).

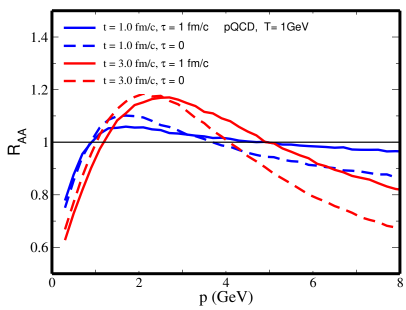

FIG. 2: R_{AA} versus transverse momentum at temperature 1 GeV for pQCD, for evolution time (t = 1 fm and 3 fm).

The rescale of $\eta(t)$ in Eq. (1) ca be written as follow,

$$\eta(t) = \sqrt{\frac{2\mathcal{D}}{\tau}} h(t). \qquad (7)$$

Results

We have calculated the transverse momentum broadening, σ_p, for the HQs in the presence of memory in the system; we write σ_p as follows,

$$\sigma_p = \langle (p_T - \langle p_T \rangle)^2 \rangle. \qquad (8)$$

In Fig. 1, the σ_p is plotted for three different temperatures and for three different τ value at a constant diffusion coefficient, $\mathcal{D}$=0.2 GeV^2/fm. It is clear that the memory slows down the evolution of σ_p of HQs in the QGP medium[1].
The effect of memory has been calculated on the nuclear modification factor, R_{AA}, for HQs in the thermalized QGP medium within perturbative QCD (pQCD) at temperature 1 GeV, as shown in Fig. 2. In the presence of memory, the formation of R_{AA} delays. The memory slows down the energy loss of HQs in the thermalized QGP [1].

Summary

We have studied the effect of memory on the dynamics of heavy quarks (HQs) in the QCD medium within the ambit of an integro-differential Langevin equation. We have explored the effect of non-zero values of τ on the transverse momentum broadening, σ_p and nuclear modification factor, R_{AA} of the HQs. In the presence of memory, the evolution of σ_p and the formation of R_{AA} are slowed down. The energy loss of HQs delays and, thus, thermalization time, increases in the hot QCD matter.

Acknowledgments

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