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Effects of memory on the dynamics of heavy quarks in the quark-gluon plasma

Pooja[1,*], Jai Prakash[1,$], Santosh K. Das[1,#], Marco Ruggieri[2,¶]

[1]School of Physical Sciences, Indian Institute of Technology Goa, Ponda-403401, Goa, India

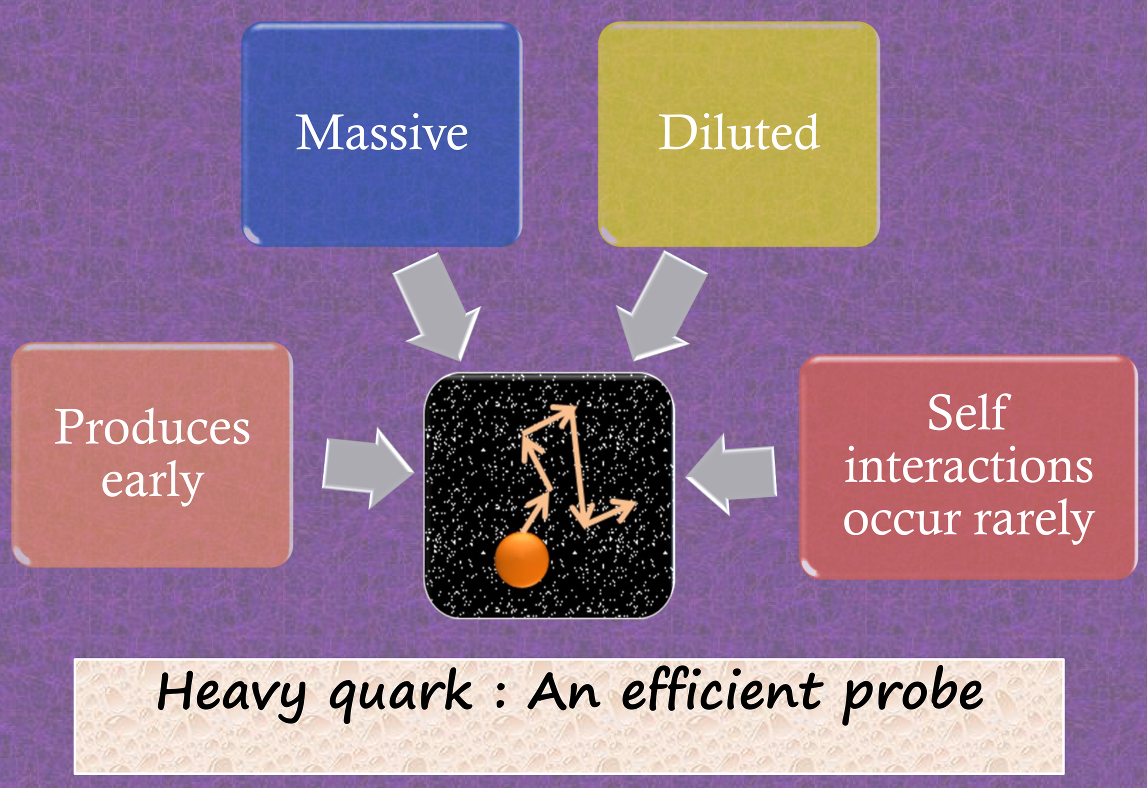
[2]Department of Physics and Astronomy "Ettore Majorana", University of Catania, Via S. Sofia 64, I-95123 Catania, Italy

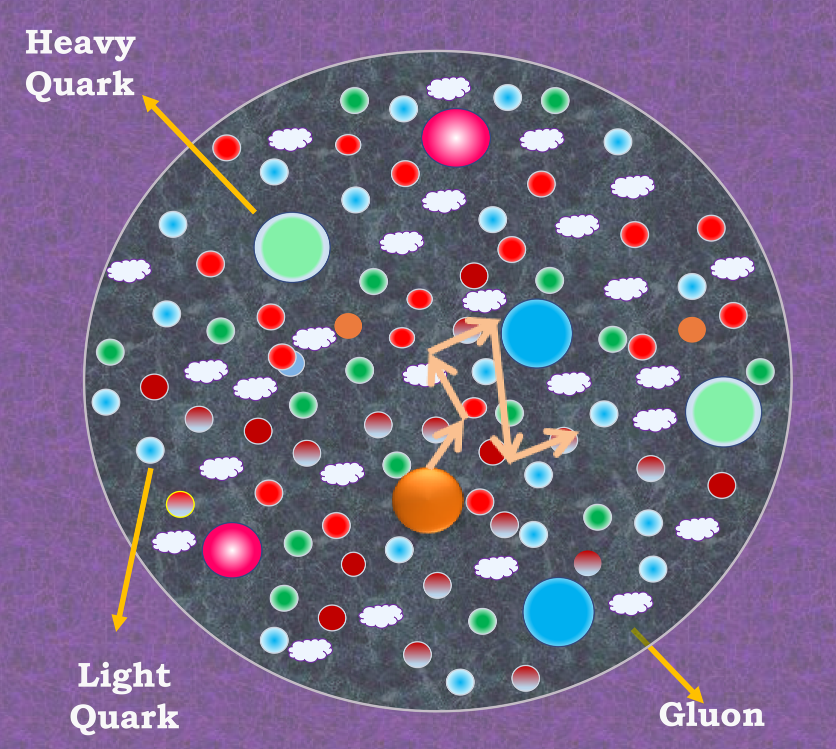
Abstract

We study the dynamics of heavy quarks in a thermalized quark-gluon plasma with a time-correlated thermal noise, η. We call η as memory time. We use an integro-differential Langevin equation in which the memory enters via the thermal noise and the dissipative force. We assume that the time correlations of the noise decay exponentially on a timescale, τ, which we treat as a free parameter. We compute the effects of $\tau \neq 0$ on the momentum broadening, and on the nuclear modification factor of heavy quarks. We find that overall memory slows down the momentum evolution of heavy quarks.

Introduction

A hot and dense phase of nuclear matter, the quark-gluon plasma (QGP), is expected to form in the ultrarelativistic heavy-ion collisions at the Relativistic Heavy-Ion Collider (RHIC) and the Large Hadron Collider (LHC) energies. Probing and characterizing the bulk properties of QGP is a field of high contemporary interest. Heavy quarks (HQs) such as charm and beauty are considered as good probes of the system produced in high-energy nuclear collisions. We study the dynamics of HQs in a hot QCD medium with a time-correlated noise, η. The effect of memory introduced through η and the dissipative force in the Generalized Langevin equation. We supposed that the time correlations of the colored noise decay exponentially with time, called the memory time, τ .





FORMALISM

Ancillary Process

$$\frac{dh}{dt} = -\alpha h + \alpha\xi$$

- $\langle h(t)\rangle = 0$
- $\langle h(t)h(t')\rangle \approx \frac{e^{-\alpha|t-t'|}}{2}$

If $\tau \to 0,\ \alpha\langle h(t)h(t')\rangle \approx \delta(t-t')$

- $\delta(t-t') \to \frac{\delta_{t,t'}}{\Delta t}$
- $\xi(t) = \rho(t)\sqrt{\frac{1}{\alpha\Delta t}}$

$$\Delta h = -\alpha h\Delta t + \rho(t)\sqrt{\alpha\Delta t}$$

Generalised Langevin equation

- $\frac{dp(t)}{dt} = -\int_0^t \gamma(t,t')p(t')dt' + \eta(t)$

Correlations of noise

- $\langle\eta(t)\rangle \approx \sqrt{\frac{2D}{\tau}}\,h(t)$
- $\langle\eta(t)\eta(t')\rangle = 2D\,\frac{e^{-|t-t'|/\tau}}{2\tau}$, with $\langle\eta(t)\eta(t')\rangle \approx 2D\delta(t-t')$

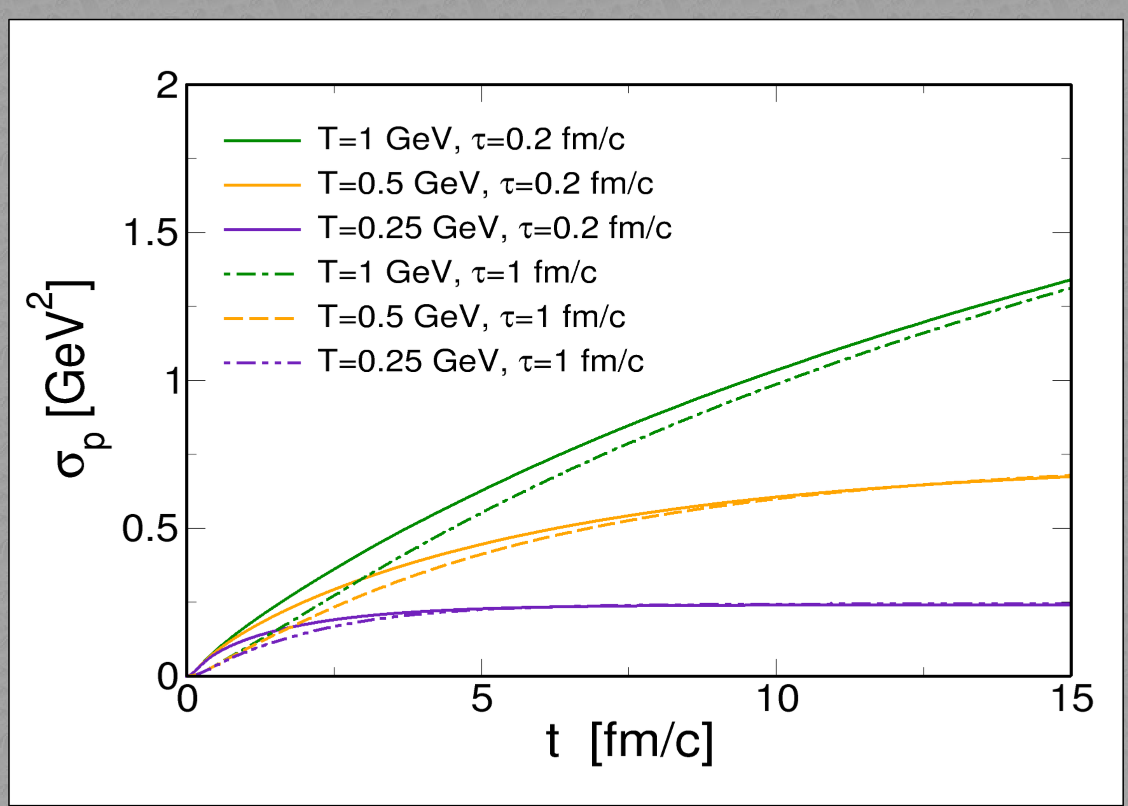
Generalised Langevin equation with memory

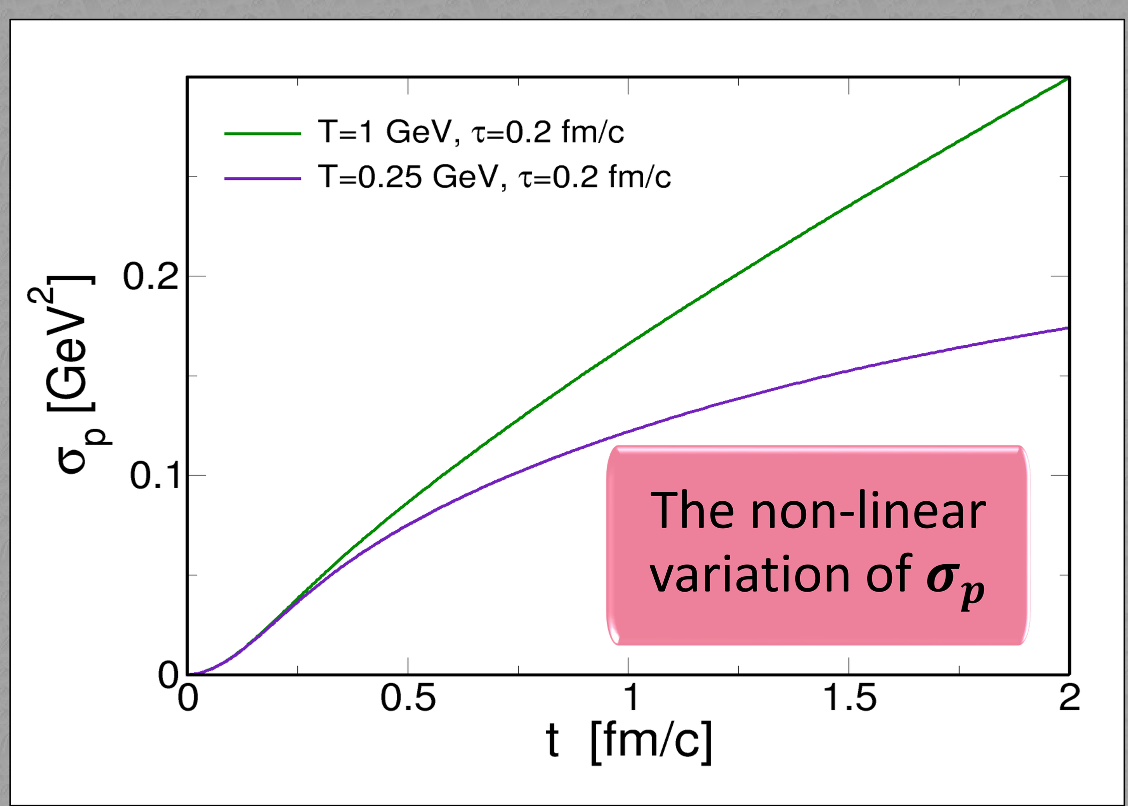
- $\frac{dp(t)}{dt} = -\int_0^t \gamma(t,t')p(t')dt' + \sqrt{\frac{2D}{\tau}}\,h(t)$
- $\gamma(t,t') = \frac{2D}{E(t')T}\,\frac{e^{-|t-t'|/\tau}}{2\tau}$

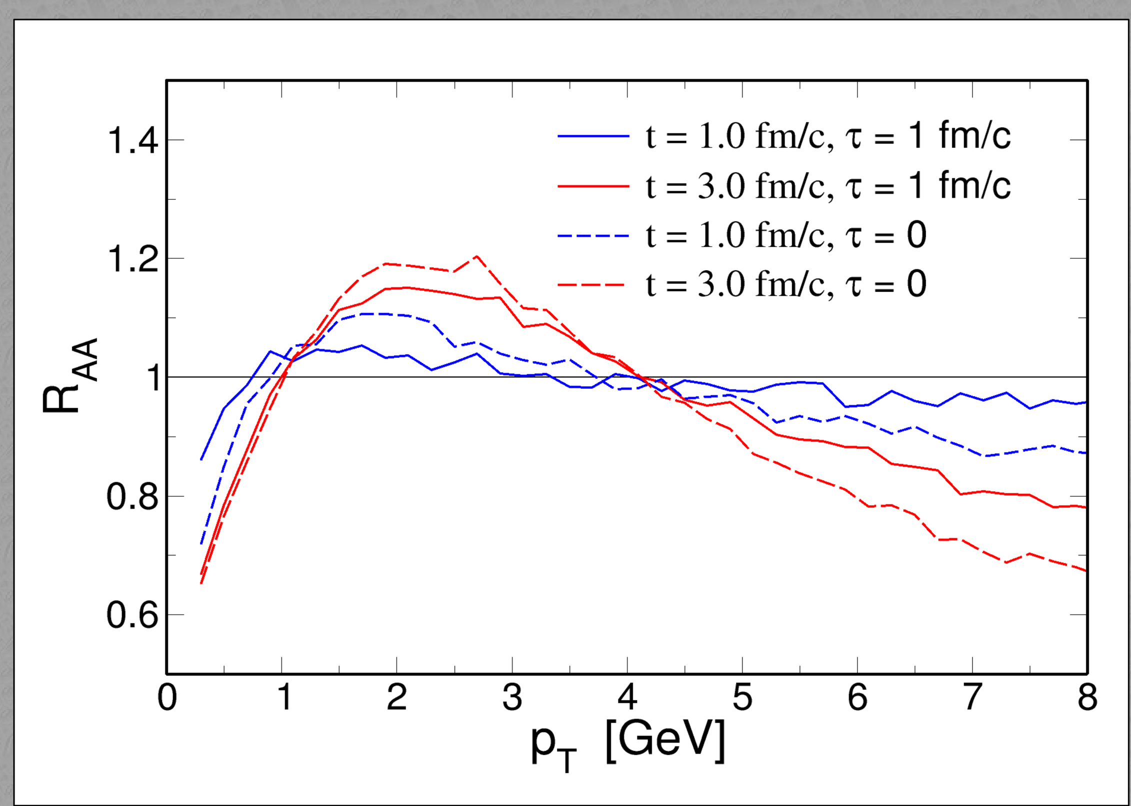
RESULTS

Transverse Momentum Broadening : $\sigma_p = <(p_T - \langle p_T\rangle)^2>$

Nuclear Modification Factor : $R_{AA} = \frac{f_{\tau_f}}{f_{\tau_i}}$







Memory slows down the $\boldsymbol{\sigma_p}$.

Memory slows down the formation of $\boldsymbol{R_{AA}}$.

Conclusions

We study the processes with time-correlated noise. We have seen that the memory slows down the momentum broadening as well as the formation of R_{AA}.

References

Marco Ruggieri, **Pooja**, Jai Prakash, and Santosh K. Das, Phys. Rev. D 106, 034032 (2022).

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Contact

*pooja19221102@iitgoa.ac.in