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Exploring heavy flavor $R_{AA} - v_2$ puzzle with anomalous diffusion via Fractional Langevin Equation

The study of heavy quark (HQ) dynamics in the quark-gluon plasma (QGP) produced in heavy-ion collisions at facilities like RHIC and LHC has provided crucial insights into QGP properties. Due to their large masses, HQs evolve over the QGP's short lifetime while retaining information about their interaction with the medium. Typically, HQ evolution is studied using the Langevin equation under the assumption of normal diffusion, where mean-square displacement (MSD) increases linearly with time [1]. However, this approach fails to fully capture the nuclear modification factor (R_{AA}) and elliptic flow (v_2) simultaneously—a challenge known as the R_{AA} - v_2 puzzle [2].

In this work, we address heavy flavor R_{AA} - v_2 puzzle employing the anomalous (super-) diffusion of HQs in the QGP through a fractional Langevin equation (FLE) approach [3], considering a hydrodynamically expanding medium. Unlike the standard Langevin equation, the FLE replaces integer-order derivatives with Caputo fractional derivatives [4], allowing for a broader range of diffusion behaviours, including super-diffusion, where the MSD of HQs increases faster than linearly with time. This model is highly relevant for heavy particles moving through a complex medium like the QGP, where strong correlations and long-range interactions lead to memory effects in particle motion. Our results demonstrate that due to super-diffusion, the HQ energy loss is significantly enhanced in the QGP medium, captures the R_{AA} correctly and contributes to higher values of elliptic flow as the strong interactions with the medium induce greater momentum anisotropy.

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2: S. K. Das, et al., Phys. Lett. B 747, 260-264 (2015).
3: Eugenio Meg´ıas, et al., Phys. Let. B 848 (2024).
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Category

Theory

Collaboration (if applicable)

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