# Energetic parton in Gribov-Zwanziger plasma†

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High-energy partons, originating from the initial hard scatterings of heavy nuclei at the heavy-ion collision experiments, serve as crucial *hard probes* in understanding the properties of the quark-gluon plasma (QGP) created at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC). These partons traverse through the QGP and their interactions with the medium constituents, via collisional and radiative energy loss, leaving behind imprints of the QCD medium on its measured observables. The energy loss experienced by these moving partons is intricately linked to the properties of the surrounding medium. While traversing the medium, the parton interacts with both hard components and soft modes. The hard components arise from elastic collisions with the constituents of the QCD medium, carrying momenta on the order of the temperature scale denoted as $T$. Meanwhile, the soft modes encode the interactions with gauge fields of momenta around $gT$, where $g$ is the coupling constant. We studied the collisional energy loss exhibited by a fast-moving parton in the Gribov-Zwanziger plasma. Notably, the Gribov-Zwanziger prescription, when applied within the framework of Yang-Mills theory, emerges as an effective method for refining the infrared dynamics of the theory.

Parton energy loss in the Gribov plasma can be described within the Wong equations together with the linearized Yang-Mills equation, as presented in Ref. 1),

$$\frac{dE}{dx} = i\frac{1}{|\mathbf{v}|}g^2 C_F v^i v^j \int \frac{d^3\mathbf{p}}{(2\pi)^3}\omega \Delta^{ij}, \tag{1}$$

where $\omega = \mathbf{p}\cdot\mathbf{v}$ with $\mathbf{v}$ as the velocity of the parton and $C_F$ is the Casimir invariant of $SU(N_c)$. The infrared improved gluon propagator of the Gribov-Zwanziger $\Delta^{ij}$ can be defined as Ref. 2),

$$\begin{aligned}\Delta_{\mu\nu} =& \frac{\xi P_\mu P_\nu}{P^4+\gamma_G^4} + \frac{P^2 A_{\mu\nu}}{P^4+\gamma_G^4 - P^2\Pi_T} \\ &+ \frac{P^2 B_{\mu\nu}}{P^4+\gamma_G^4 - P^2\Pi_L},\end{aligned} \tag{2}$$

with $\xi$ as the gauge parameter, $A^{\mu\nu}$ and $B^{\mu\nu}$ as transverse and longitudinal projection operators, the temperature behavior of the Gribov parameter $\gamma_G$ can be obtained from finite-temperature Yang-Mills theory. We calculated the contributions of gluon, ghost, and quark loops to the gluon self-energy. Notably, the Gribov-Zwanziger approach significantly influences the gluon and ghost loops, affecting the parton energy loss in the Gribov plasma.

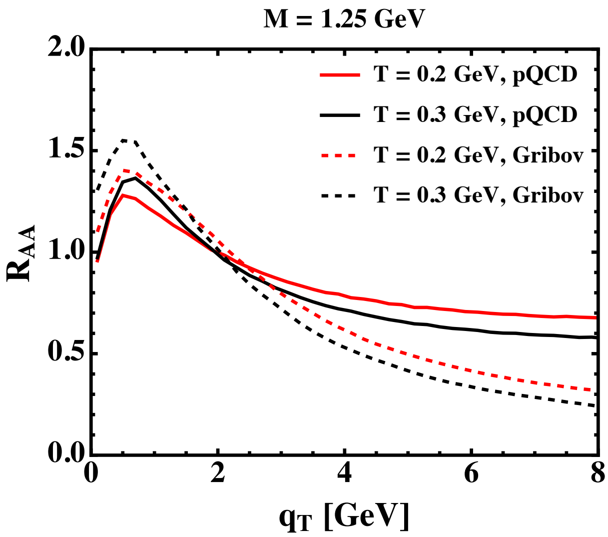


Fig. 1. $R_{AA}$ in the Gribov-Zwanziger plasma as a function of momentum.

The phenomenological significance of the Gribov-modified parton energy loss is studied by analyzing the nuclear suppression factor $R_{AA}(q_T)$ of charm quarks. In our study, we modeled the time evolution of the parton momentum by solving Langevin equations. These equations rely on knowledge of both the stochastic force and the dissipative force experienced by the parton in the QCD medium. The dissipative force is derived from from the Gribov-modified parton energy loss, while the random kicks are modeled by Gaussian noise with a width related to the momentum diffusion. We employed the fluctuation-dissipation theorem to determine the momentum diffusion in our analysis. Our investigation reveals a stronger suppression when non-perturbative effects are included, indicating that the Gribov plasma exerts a greater hindrance on fast-moving partons as they traverse the medium.

In conclusion, by employing the Gribov-Zwanziger prescription for the first time in the analysis of parton energy loss, we demonstrated that its momentum evolution is strongly influenced by non-perturbative effects, playing a significant role in the phenomenological quantities related to energy loss.

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