Non-perturbative effect in charm diffusion from the Gribov-Zwanziger approach

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Introduction

By employing the Gribov-Zwanziger prescription to model the infrared behavior of QCD, we analyze the momentum diffusion coefficient κ of the charm quark, focusing on its dependence on both the medium temperature and the its incident momentum. The momentum diffusion coefficient is found to increase with momentum and temperature. Under the same conditions, the longitudinal coefficient κ_L exhibits a more rapid ascent compared to the transverse coefficient κ_T.

Gribov-Zwanziger prescription

One of the efficient ways to incorporate the effects of the npQCD within the framework of the standard pQCD calculations is the application of the Gribov-Zwanziger prescription for the gluon propagator[1].

- the GZ gluon propagator.

$$iD_{\mu\nu}(Q) = \frac{-iQ^2}{Q^4+\gamma_G^4}[g_{\mu\nu} - (1-\frac{1}{\lambda})\frac{Q_\mu Q_\nu}{Q^2}]$$

- the gluon propagator depends on the temperature-dependent Gribov mass parameter $\gamma_G(T)$, which has been obtained self-consistently from the one-loop gap equation.

$$\frac{d-1}{d}N_c g^2 \int \frac{d^d q}{(2\pi)^d}\frac{1}{q^4+\gamma_G^4} = 1$$

- the one-loop running coupling with $N_f = 3$.

$$\alpha_s^{\rm per} = \frac{6\pi}{(11N_c - 2N_f)\ln[2\pi T/\Lambda_{\overline{\rm MS}}]}$$

Langevin Equation

The Langevin equation corresponding to the momentum evolu tion of the non-relativistic heavy quarks in a background medium.

$$\frac{dp_i}{dt} = -\eta p_i + \xi_i, \langle \xi_i(t)\xi_j(t')\rangle = \kappa\delta_{ij}\delta(t-t')$$

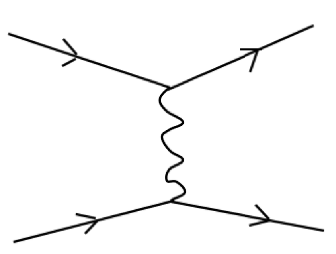
- the longitudinal coefficient κ_L.

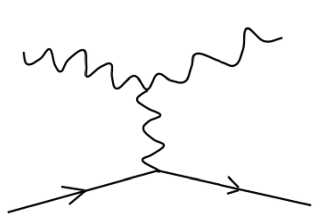
$$2\kappa_T = \langle q_T^2\rangle = \langle q^2\rangle - \langle (q\cos\theta_{pq})^2\rangle = \langle q^2\rangle - \langle q_L^2\rangle$$

- the transverse coefficient κ_T.

$$\kappa_L = \langle q_L^2\rangle - \frac{\langle q_L^2\rangle}{\langle 1\rangle}$$

- The two body elastic scattering amplitude $|\mathcal{M}|^2$ in t-channel. The only $2 \leftrightarrow 2$ scattering process are $qH \to qH$ (H the heavy quark, q the light quark) and $gH \to gH$(g the gluon) in the lowest order tree diagram.

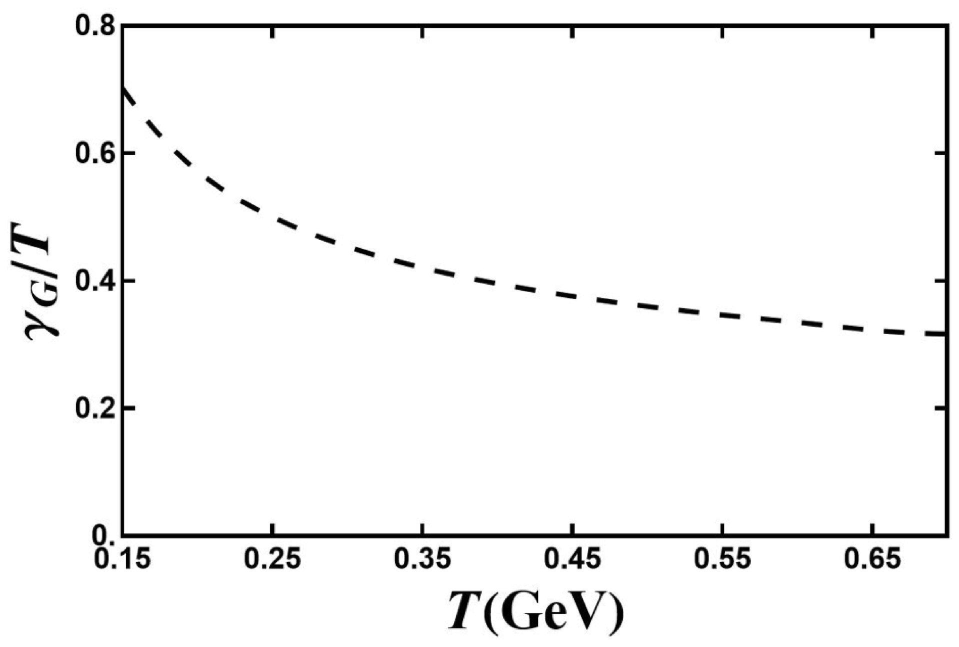




Results

The value of Gribov parameter γ_G is extracted by solving the Gap equation:

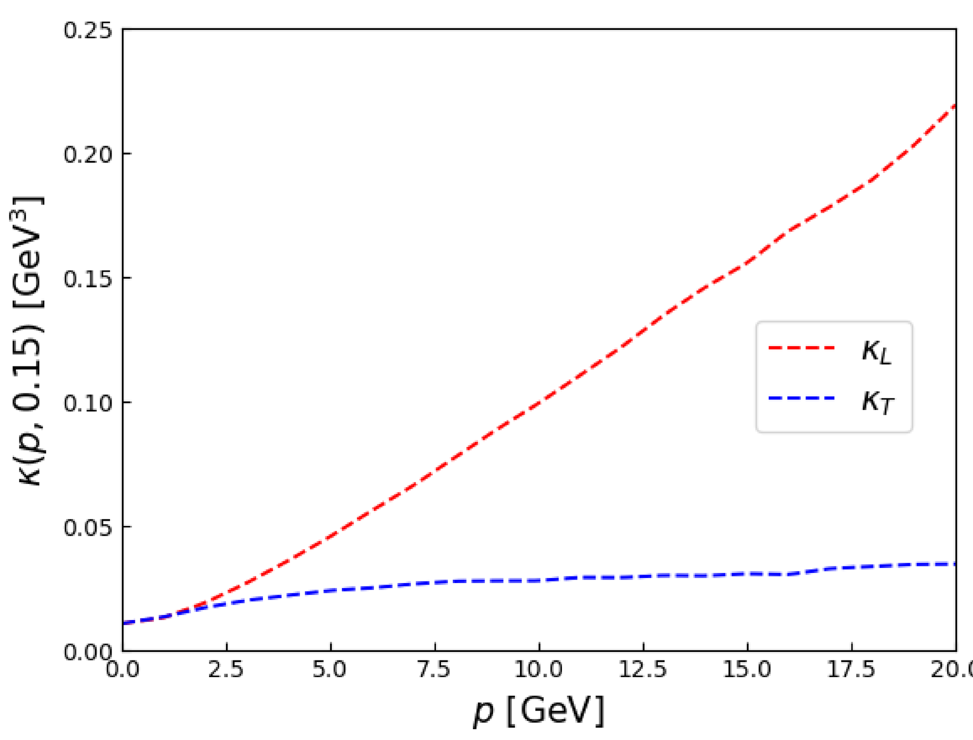
$$\frac{3N_c g^2}{64\pi^2}[\frac{5}{6} - \ln\frac{\gamma_G^2}{\mu_0^2} + \frac{4}{i\gamma_G^2}\int_0^\infty dpp^2(\frac{f_B(\omega_-)}{\omega_-} - \frac{f_B(\omega_+)}{\omega_+})] = 1$$

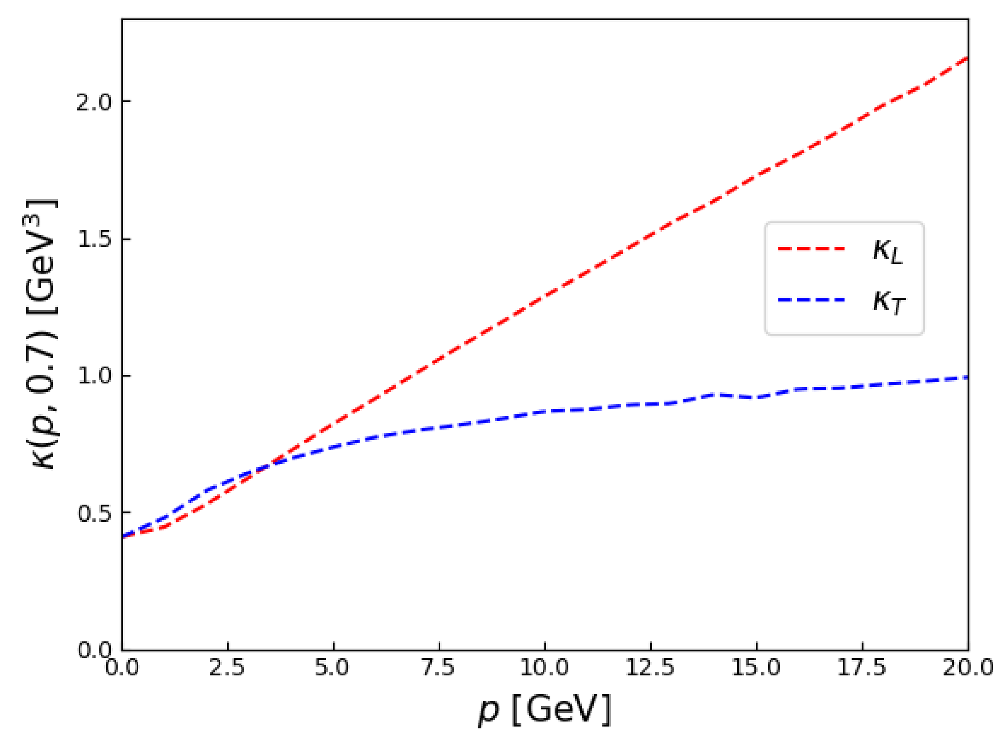


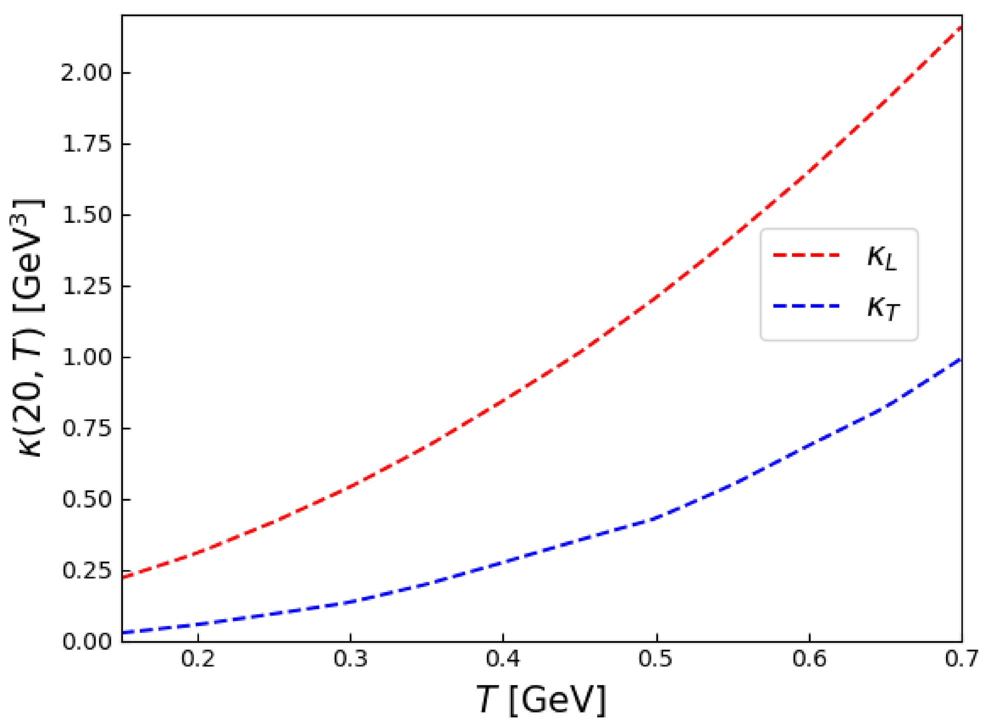
The momentum diffusion coefficient κ can be obtained from the mean squared momentum transfer per unit time. We employ a straightforward method for this representation:

$$\langle q^2\rangle = \int\frac{d^3\boldsymbol{k}}{(2\pi)^3}\int\frac{d^3\boldsymbol{p}'}{(2\pi)^3}\int\frac{d^3\boldsymbol{k}'}{(2\pi)^3} \quad q^2\omega(P,K|P',K')f(\boldsymbol{k})[1\pm f(\boldsymbol{k}')]$$

- When the medium temperature is fixed at $T = 0.15$ GeV, the dependence of the momentum diffusion coefficient on the incident momentum
- Same as above, but the medium temperature $T = 0.7$ GeV.







When the incident momentum is fixed at $p = 20$GeV , the dependence of the momentum diffusion coefficients on the medium temperature.

Summary

In this study, we investigated the momentum diffusion coefficient κ for the charm quark by employing the Gribov-Zwanziger framework and calculated the mean squared momentum transfer per unit time through the lowest order two-body elastic scattering process.

Due to the strongly interacting medium, non-perturbative effects reduce the magnitudes of the transport coefficients more significantly than next-to-leading order (NLO) perturbative results[1].

Under the same fixed conditions, the longitudinal coefficient κ_L increases more rapidly than transverse coefficient κ_T.

References

[1] Madni, Sadaf and Mukherjee, Arghya and Bandyopadhyay, Aritra and Haque, Najmul. Phys.Lett.B 838 (2023) 137714.