Higher-order quark and gluon propagators in thermal medium

NAJMUL HAQUE

National Institute of Science Education and Research (NISER), India

ICPAQGP2023

Hard thermal loop Lagrangian (LO)

- The HTLpt Lagrangian density (LO) can be written as

$$\mathcal{L} = (\mathcal{L}_{\rm QCD} + \mathcal{L}_{\rm HTL})\big|_{g\to\sqrt{\delta}g} + \Delta\mathcal{L}_{\rm HTL}\,,$$

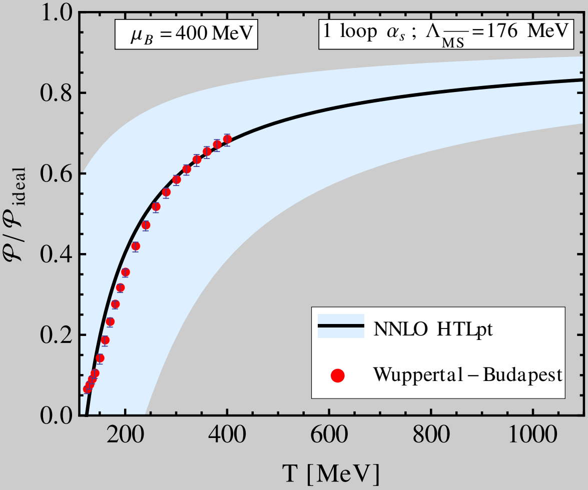
where the HTL improvement term is

$$\mathcal{L}_{\rm HTL} = (1-\delta)im_q^2\bar{\psi}\gamma^\mu\left\langle\frac{y_\mu}{y\cdot D}\right\rangle_{\hat{\mathbf{y}}}\psi - \frac{1}{2}(1-\delta)m_D^2{\rm Tr}\left(F_{\mu\alpha}\left\langle\frac{y^\alpha y_\beta}{(y\cdot D)^2}\right\rangle_{\hat{\mathbf{y}}}F^{\mu\beta}\right)\,,$$

- HTL (LO) quarks and gluon propagatore are used study dilepton/photon production rate, quark/gluon damping rate, NNLO QCD thermodynamics and many more.

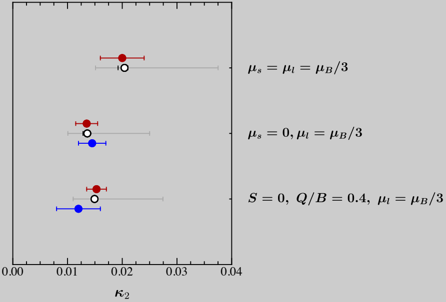
QCD thermodynamics

NH et. al., JHEP 2014



Curvature of QCD phase transition line

NH et. al., PRC-L(2021)



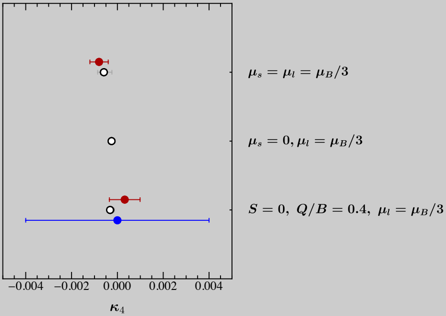


Figure: Filled circles are lattice calculations and black open circles are the NNLO HTLpt predictions

NLO gluon debye mass

- The NLO gluon debye screening mass has been obtained by Rebhan [PRD 48] and Brateen [PRL73] independently using the standard HTL resummation techniques and by calculating the Polyakov loop correlators respectively. The result obtained is

$$\delta m^2 = gm^2 N\sqrt{\frac{6}{2N+N_f}}\frac{1}{2\pi}\left(\ln\frac{2m}{m_{\text{magn}}}-\frac{1}{2}\right)+O\left(g^2\right)$$

where $m_{magn} \sim g^2 T$

Quark NLO

- The quark NLO thermal mass is obtained in ref. [Carrington et. el. PRD 78 (2008)] at zero momentum (for $N_f = 2, N_c = 3$) which is given by

$$M_{\rm QCD} = \frac{gT}{\sqrt{6}}\left[1 + (1.867 \pm 0.02)\frac{g}{4\pi}\right] + \mathcal{O}\left(g^3 T\right),$$

- Since there is no quark damping in the leading order. Damping rate for quarks at NLO results are obtained by E Brateen in ref. [PRD 46]

$$\begin{aligned}\gamma_{\pm}(0) &\approx 0.151 g^2 T \quad (\text{For } N_f = 3)\\ &\approx 0.149 g^2 T \quad (\text{For } N_f = 2)\end{aligned}$$

- Motivation: To study the quark thermal mass and damping rate at finite quark momentum.

NLO HTL Lagrangian (QED)

Carrington et. al., PLB (2019)

- HTL QED Lagrangian density in NLO

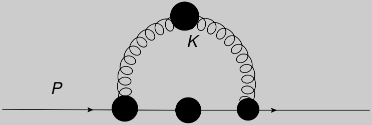
$$\mathscr{L}_{HTL}^{\text{NLO}} = \frac{e^2 v^{3-d}}{2} \int \frac{d^d\mathbf{p}}{(2\pi)^d} \left\{ \frac{N_f(p)}{2p^3} F_{\rho\alpha} \frac{v^\alpha v^\beta}{(v\cdot\partial)^4} \partial^4 F_\beta{}^\rho + \right.$$

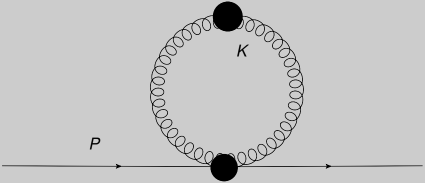
$$e^2(d-1)\Lambda_{(d)}^2 \left(\frac{N_f(p)}{p^3} F_{\rho\alpha} \left[\frac{v^\alpha v^\beta}{(v\cdot\partial)^2} \left(\frac{1}{2} + \frac{\partial_0}{v\cdot\partial} \right) - \frac{n^\alpha v^\beta + v^\alpha n^\beta}{2(v\cdot\partial)^2} \right] F_\beta{}^\rho \right.$$

$$\left.\left. - \frac{1}{2p^2} \frac{dN_f(p)}{dp} F_{\rho\alpha} \frac{v^\alpha v^\beta}{(v\cdot\partial)^2} F_\beta{}^\rho \right) \right\},$$

- Full HTL QCD lagrangian in NLO will be an interesting result.

Quark NLO at finite momentum   arXiv:2201.07173





Quark quasi-particle energy

$$\Omega(p) = \Omega^{(0)}(p) + \Omega^{(1)}(p) + \cdots$$

Quark self-energy Σ

$$\Sigma(P) = \Sigma_{\rm HTL}(P) + \Sigma^{(1)}(P) + \cdots ,$$

where $\Sigma_{\rm HTL}$ is the lowest-order quark self-energy having gT order, whereas $\Sigma^{(1)}$ the NLO contribution of quark self-energy, with order g^2T.

For a slow-moving quark slow-moving quarks, we can take $p \sim gT$, and we get

$$\Omega_{\pm}^{(1)}(p) = \frac{{\Omega_{\pm}^{(0)}}^2(p) - p^2}{2m_q^2}\Sigma_{\pm}^{(1)}\left(\Omega_{\pm}^{(0)}(p), p\right).$$

We need to determine the NLO quark self-energy to evaluate the above equation.

Quark dispersion relation

- Comparison of quark mass in leading order with NLO in terms of couping constant g.

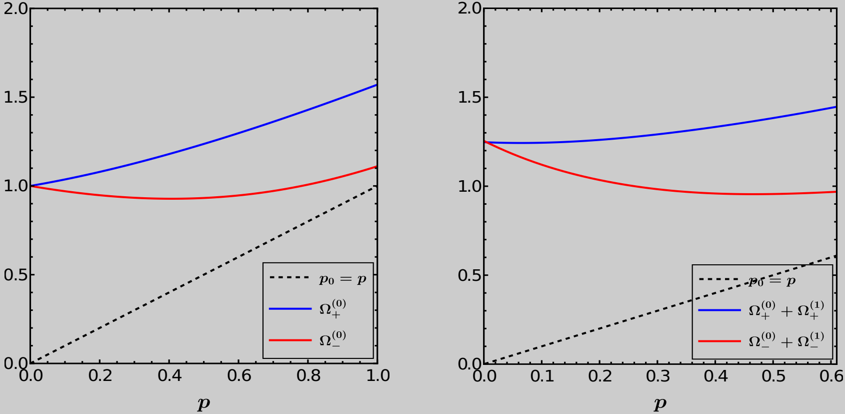


Figure: NLO quark dispersion relation

Quark damping rate

- Damping rate can be obtained from

$$\det\left(\Phi - \mathbf{\Sigma}_{\text{total}}\left(Q\right)\right)\Big|_{q_0=M-i\gamma} = 0$$

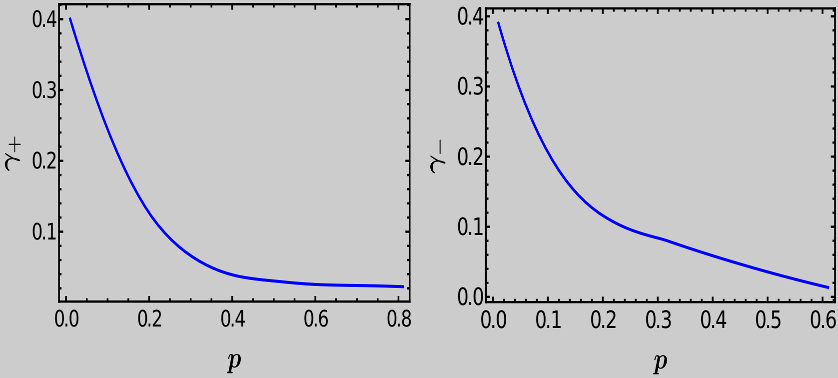


Figure: Quark damping rate

- Velocity variation of quasi-quarks with soft momentum p.

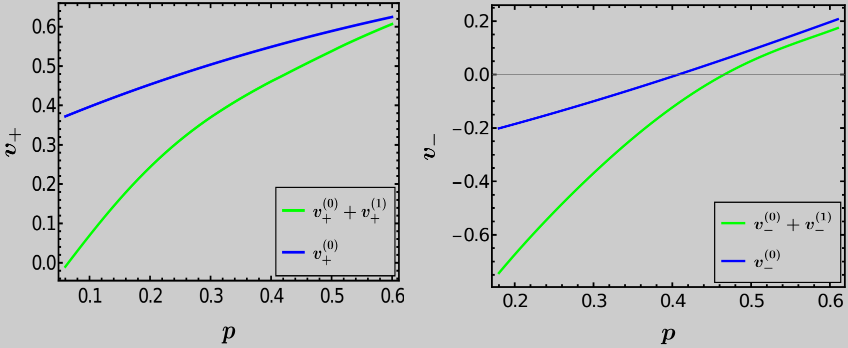


Figure: Velocity variation with respect to soft momentum p for quark mode and plasmino mode.

Thank you for your attention