Heavy quark transport coefficients in a non-trivial Polyakov loop background

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Outline

Introduction

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- Interactions of heavy quarks in the QGP reflect in the transverse momentum (p_T) spectra of open mesons, most notably their elliptic flow, v_2.
- Heavy quarks do not thermalise with bulk and make multiple collisions with the light quarks and gluons.
- Charm and bottom quarks are heavy.

- $m_Q \gg \mathrm{T}$

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Fokker-Plank equation

- Small momentum transfer leads to Brownian motion which can be described by Fokker Plank equation.

Heavy quark in the plasma of light quarks

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Boltzman Equation

$$\left[\frac{\partial}{\partial t} + \frac{\vec{p}}{E} \cdot \frac{\partial}{\partial \vec{x}} + \vec{F} \cdot \frac{\partial}{\partial \vec{p}}\right] f(\vec{x}, \vec{p}, t) = \left[\frac{\partial f}{\partial t}\right]_{col} \tag{1}$$

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$$\left[\frac{\partial f}{\partial t}\right]_{col} = \int d^3k \left[\omega(p+k, k) f(p+k) - \omega(p, k) f(p)\right] \quad (2)$$

collision rate $\omega(p, k)$

$$\omega(p, k) = g \int \frac{d^3q}{(2\pi)^3} f(q) v_{rel} \sigma_{p,q \to p-k,q+k} \quad (3)$$

- Assuming the scattering process to be dominated by small momentum transfer

$$\omega(p+k,k)f(p+k) \approx \omega(p,k)f(p) + k\frac{\partial}{\partial p}(\omega p) + \frac{1}{2}k_i k_j \frac{\partial^2}{\partial p_i \partial_j}(\omega p). \tag{4}$$

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- Boltzmann equation reduces to Fokker-Plank equation i.e,

$$\left[\frac{\partial f}{\partial t}\right]_{col} = \frac{\partial}{\partial p_i}\left[A_i(p)f + \frac{\partial}{\partial p_i}[B_{ij}(p)f]\right] \tag{5}$$

where the kernels A_i and B_{ij} stands for drag and diffusion coefficients respectiely.

Drag

- If p and p' are initial and final momenta of heavy quark then $A_i(p)$ is written as

$$A_i(p) = \frac{1}{2E_p}\int\frac{d^3q}{(2\pi)^3E_q}\int\frac{d^3p'}{(2\pi)^3E_{p'}}\int\frac{d^3q'}{(2\pi)^3E_{q'}} \times\frac{1}{g_{HQ}}\sum\overline{|M|^2}(2\pi)^4\delta^4(p+q-p'-q')f(q) (1+f(q'))[(p-p')_i] \equiv \langle\langle(p-p')\rangle\rangle \quad (6)$$

where $\overline{|M|^2}$ is scattering amplitude squared for the processes $l/g(q),\ HQ(p) \to l/g(q'),\ HQ(p')$.

Diffusion

- $B_{ij}(p)$ is given as

$$B_{ij}(p) = \frac{1}{2E_p}\int\frac{d^3q}{(2\pi)^3E_q}\int\frac{d^3p'}{(2\pi)^3E_{p'}}\int\frac{d^3q'}{(2\pi)^3E_{q'}} \times\frac{1}{g_{HQ}}\sum\overline{|M|^2}(2\pi)^4\delta^4(p+q-p'-q')f(q) (1+f(q'))[\frac{1}{2}(p-p')_i(p-p')_j] \equiv \langle\langle(p-p')_i(p-p')_j\rangle\rangle \tag{7}$$

Non-perturbative effects

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- $\overline{|M|^2}$ is evaluated in a quasi-particle approach where thermal quark and gluon masses are required.
- Effect of Polyakov loop in drag and diffusion coefficients is manifested through thermal masses of quark and gluon.
- The value of Polyakov loop ($T_c \approx 170$ MeV, $l(T_c) \approx 0.5$) and constituent quark masses ($m(T_c) = 134$) is taken taken from PQM model.

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- Quark and gluon distribution functions

$\tilde{f}_a(E) = \frac{1}{e^{\beta(E - iQ^a)} + 1}$

$f_{ab}(E) = \frac{1}{e^{\beta(E - i(Q^a - Q^b))} - 1}$

- Diagrams for debye and thermal mass

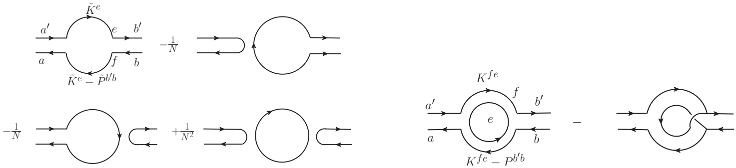

Figure: Gluon self energy in double line notation

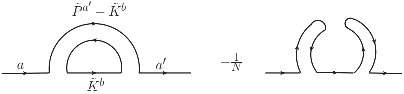

Figure: Fermion self energy in double line notation

- Debye mass and quark thermal mass

Masses

$$M_D^2 = \sum_{a=1}^{3} \frac{M_a^2}{3}$$

$$M_a^2 = \frac{g^2}{3}\left[\sum_{e=1}^{N} \mathcal{A}(Q_{ae}) - N_f \tilde{\mathcal{A}}(Q^a)\right]$$

$$m_a^2 = \frac{g^2}{24}\sum_{c=1}^{3}\left(\mathcal{A}(Q_{ac}) - \tilde{\mathcal{A}}(Q_c) - \frac{1}{3}(\mathcal{A}(0) - \tilde{\mathcal{A}}(Q_a))\right)$$

$$\mathcal{A}(Q) = \frac{3}{\pi^2}\int_0^\infty kdk\left(\frac{1}{e^{\beta(E-iQ)}-1} + \frac{1}{e^{\beta(E+iQ)}-1}\right)$$

$$\tilde{\mathcal{A}}(Q) = \mathcal{A}(Q + \pi T)$$

Thermal masses:

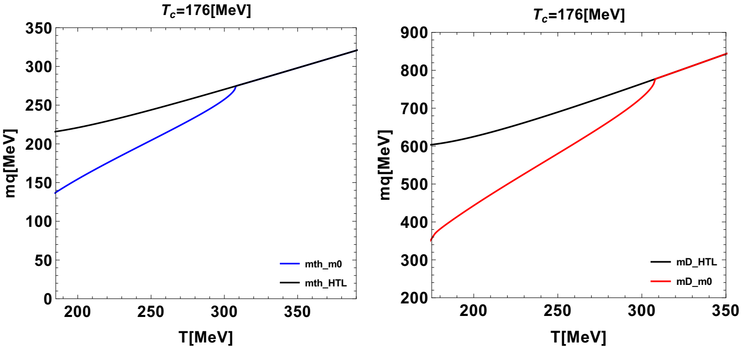

Figure: Left panel: Quark thermal mass. Right panel: Debye screening mass

Drag coefficient:

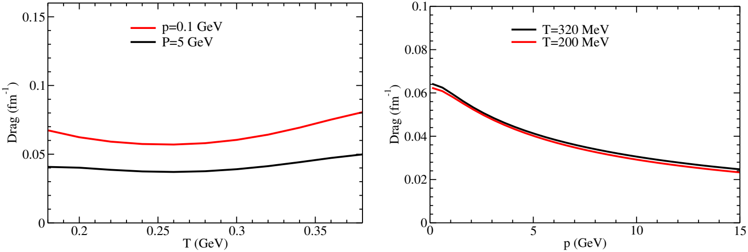

Figure: Left panel: Drag coefficient for different value of p. Right panel: Drag coefficient for different value of T

Diffusion coefficient:

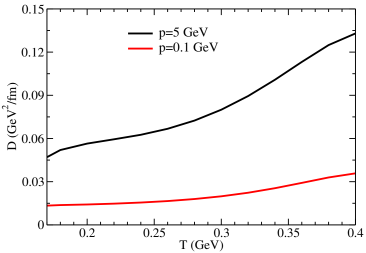

Figure: Left panel: Diffusion coefficient for different value of p. Right panel: Diffusion coefficient for different value of T

Summary and Conclusion

1. Non-perturbative effects are important at low T.
2. In the quark thermal mass and gluon Debye mass the non-perturbative effects are important below temperature 300 MeV for transition temperature $T_c = 174$ MeV.
3. Heavy quark drag coefficient has almost constant dependence of temperature.
4. Heavy quark Diffusion coefficient increase with increase in temperature.

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THANK YOU

- A comparison [1]

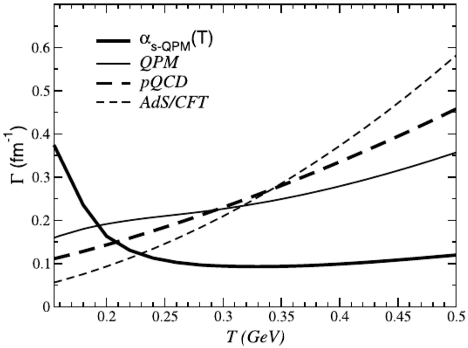

Figure: Drag in different models

[1] S. K. Das, F. Scardina, S. Plumari and V. Greco, Phys. Lett. B 747, 260 (2015)