Momentum Broadening in Weakly Coupled Quark-Gluon Plasma

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Abstract

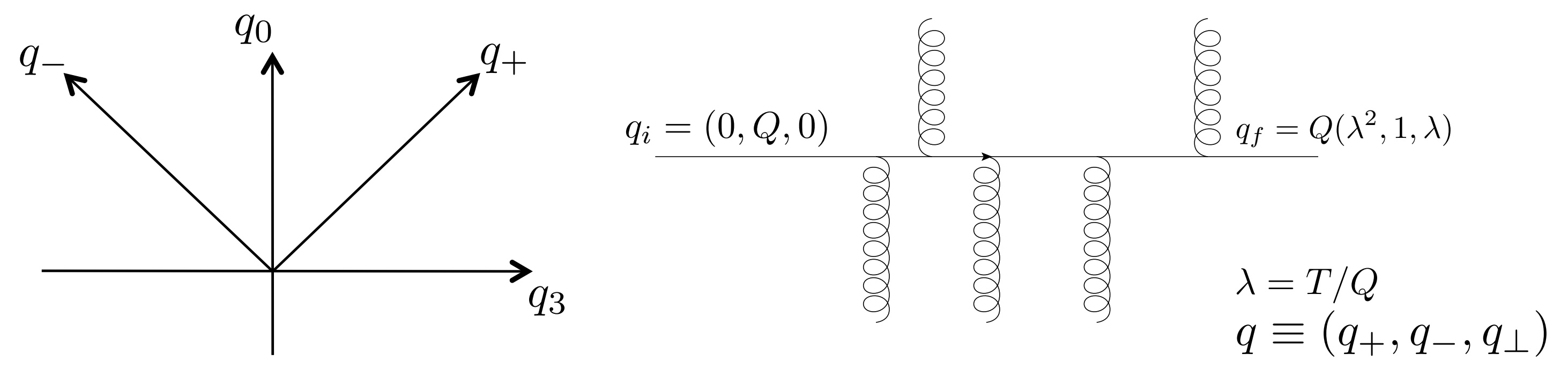
Jet quenching parameter is an important quantity in order to understand energy losses in heavy ion collisions and to get insights into properties of deconfined quark-gluon plasma. Soft Collinear Effective theory (SCET) provides framework to define momentum broadening of probing quark/gluon and thus define jet quenching parameter as the expectation value of two space-like separated light-like Wilson lines which can be evaluated for the desired medium. In this work we evaluate transverse momentum broadening distribution function at weak coupling for quark-gluon plasma in thermal equilibrium using Hard Thermal Loop (HTL) resummed effective thermal field theory and build the framework for going beyond HTL approximation.

Problem set up

- We are interested in evaluating the jet quenching parameter, defined by

$$\hat{q} = \frac{1}{L}\int \frac{d^2q_\perp}{(2\pi)^2} q_\perp^2 P(q_\perp),$$

where L is the longitudinal length of the thermal medium in the direction in which the probing quark(gluon) is propagating.



Definition of light-cone coordinates(left) and depiction of hard (Collinear) probe interacting with medium via thermal (Glauber) gluons which induce transverse momentum broadening.

- Transverse momentum broadening distribution function of quark(gluon) traveling through general medium is given by [1,2,3]:

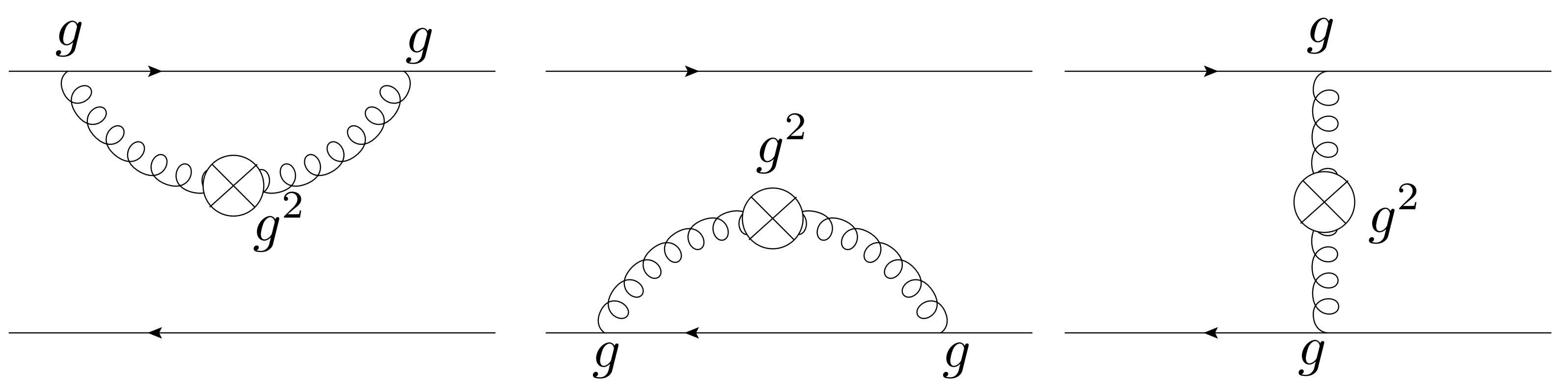
$$P(q_\perp) = \int d^2x_\perp\, e^{-iq_\perp\cdot x_\perp}\, \mathcal{W}_{\mathcal{R}}(x_\perp), \text{ normalized as } \int \frac{d^2q_\perp}{(2\pi)^2} P(q_\perp) = 1$$

$$\text{and} \quad \mathcal{W}_{\mathcal{R}}(x_\perp) = \frac{1}{d\,(\mathcal{R})}\left\langle \mathrm{Tr}\left[W_{\mathcal{R}}^\dagger[x^+ = 0, x_\perp]\, W_{\mathcal{R}}[x^+ = 0, 0]\right]\right\rangle$$

$W_{\mathcal{R}}$ is a Wilson line along x^- direction of length L^-; $\mathcal{R}$ is the $SU(N)$ representation to which the collinear particle belongs. $\langle\rangle$ in this case is an average over thermal medium in equilibrium.

Estimating contributions

- Tree level diagrams involving bare propagators or vertices vanish.
- Leading order contribution to $P(q_\perp)$ is of order g^4.



Leading order diagrams: parton self-energy (left and middle), gluon exchange (right)

- General form $P(q_\perp) = g(q_\perp^0)\delta^2(q_\perp) + P_>(q_\perp)$, where $P_>(q_\perp)$ corresponds to the gluon exchange diagram and term proportional $\delta^2(q_\perp)$ originates from the first two diagrams and does not contribute to $\hat{q}$.

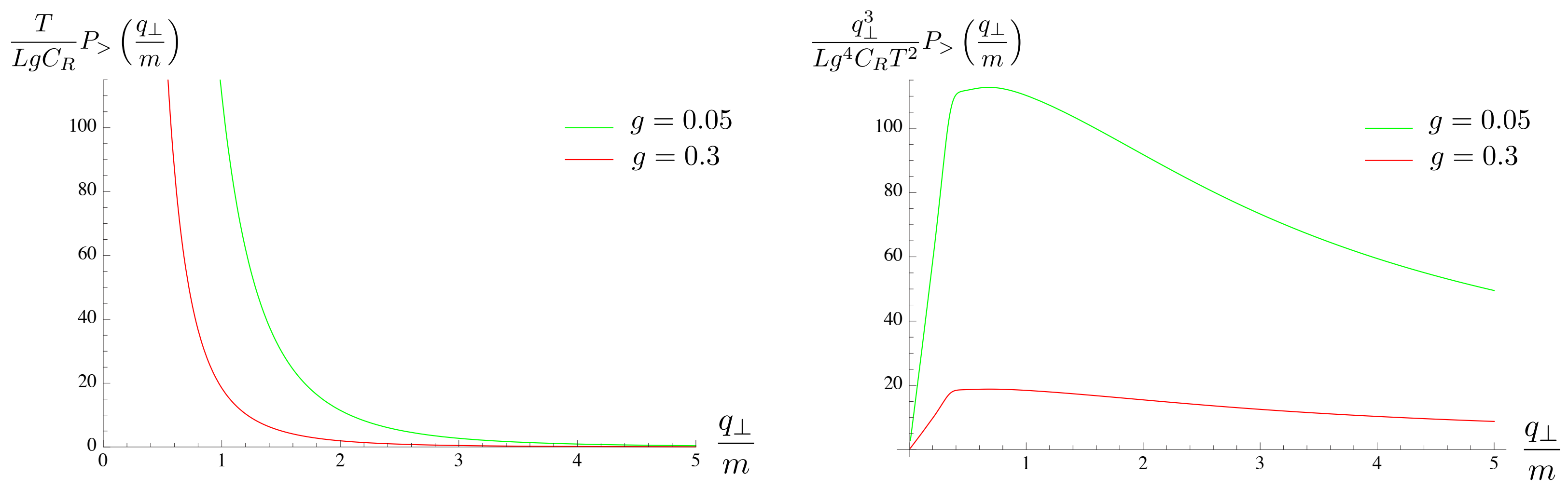
Hard Thermal Loops

- When using (bare) thermal field theory, loop corrections to self-energy are of order $(gT)^2/P^2$.
- When external momentum is "soft" ($P^2 \sim (gT)^2$), loop expansion breaks down ($g \ll 1$).
- Hard Thermal Loops (HTL) is an effective resummed field theory, which enables loop expansion when external momentum is soft.
- Nevertheless, HTL approximation is not valid when external momentum is "hard" ($P^2 \sim T^2$).

Expression for $P(q_\perp)$

- Using HTL approximation transverse momentum broadening distribution function takes the form:

$$P_>(q_\perp) = g^2 C_R \sqrt{2} L \int_{-\infty}^{\infty} \frac{dq_-}{2\pi} q_\perp \coth\left(\frac{q_-}{2\sqrt{2}T}\right) \rho_{HTL}^{++}(0, q_-, q_\perp)$$



Transverse momentum broadening distribution (left) and distribution multiplied by $q_\perp^3$ (right) which is used when evaluating $\hat{q}$; $m = m_{QCD} = \frac{\sqrt{3}}{2}gT$ is thermal mass.

- It is ensured that expression for $\hat{q}$ is IR finite and gauge fixing parameter independent.
- For $q_\perp \lesssim gT$ the contribution of q_- from outside of "soft" region when evaluating $P(q_\perp)$ is estimated to be small. So non-HTL corrections to $P(q_\perp \lesssim gT)$ are assumed to be small.
- For $q_\perp \gtrsim T$, HTL is not valid and appropriate expression for spectral function ρ^{++} needs to be used.

Comments and Outlook

- Wilson line expression for momentum broadening obtained using SCET is taken one step further by evaluating it in equilibrium quark-gluon plasma with the help of HTL.
- We obtained expression for transverse momentum broadening distribution function $P(q_\perp)$ for "soft" momentum.
- The result is general and it is one of the first attempts to calculate the jet quenching parameter using full field theoretical methods.
- The work of including (bare) thermal field theory contributions to $P(q_\perp)$ is under progress.

References

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[3] Z. T. Liang, X. N. Wang and J. Zhou, Phys. Rev. D 77, 125010 (2008) [arXiv:0801.0434 [hep-ph]].