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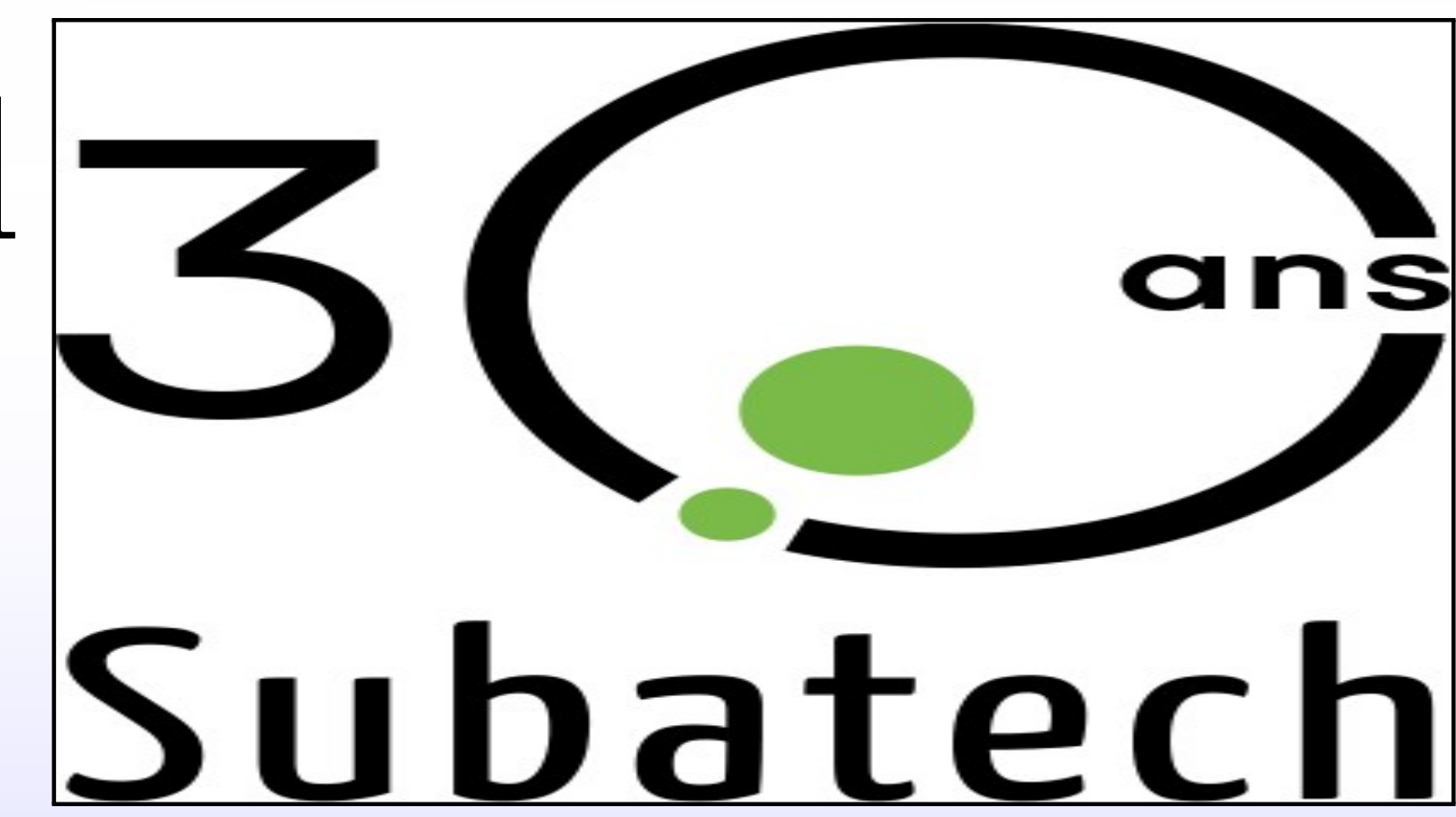


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# The force-force correlator at the hard thermal scale of hot QCD

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with Jacopo Ghiglieri, Philipp Schicho, Niels Schlusser



## Asymptotic mass

Consider hard parton propagating through quark-gluon plasma.

Forward scattering with medium induces shift in parton's dispersion relation  $\Rightarrow m_\infty^2$ , known as **asymptotic mass**.

In heavy-ion collisions, along with transverse scattering rate,  $\mathcal{C}(k_\perp)$ , serves as key input for calculations of:

- jet modification (i.e, medium-induced radiation and transverse momentum broadening)
- thermalisation, transport

In hot QCD, take parton momentum

$p^+ = \frac{p^0 + p^z}{2} \gg T$ , temperature of plasma

$\Rightarrow$  Can integrate out scale  $p^+$  to write  $m_\infty^2$  [1]

$$m_\infty^2 = g^2 C_R \left( Z_g + Z_f \right) + \mathcal{O}\left(\frac{1}{p^+}\right) \quad (1)$$

$$= g^2 C_R \left( \left[ \frac{T^2}{6} + \mathcal{O}(g) \right] + \left[ \frac{T^2}{12} + \mathcal{O}(g^2) \right] \right) + \mathcal{O}\left(\frac{1}{p^+}\right)$$

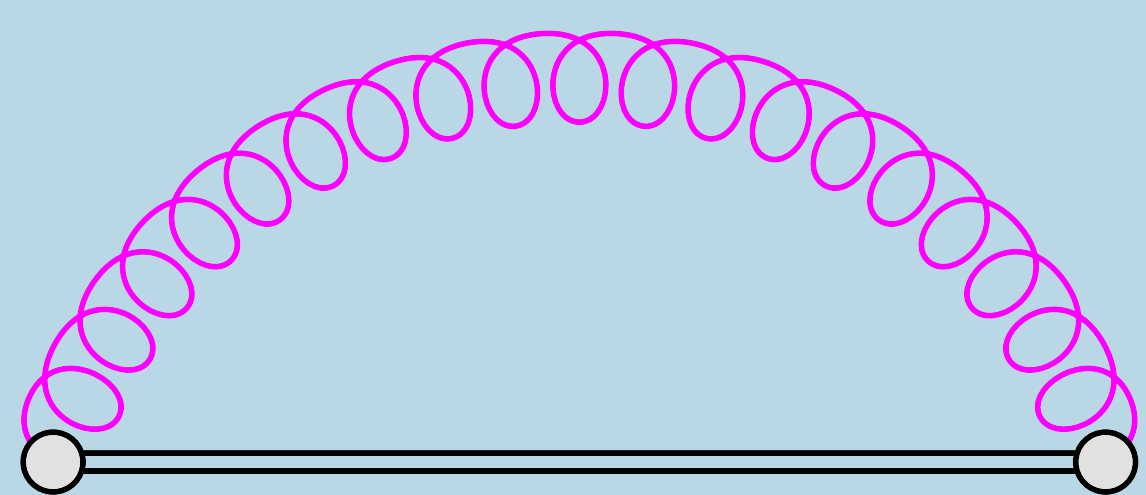
as sum of gluonic and fermionic condensates.

## Classical Corrections

$Z_g$  given in terms of Wilson lines (representing hard parton) and field strength insertions

$$Z_g = \frac{1}{d_R C_R} \int_0^\infty dx^+ x^+ \text{Tr} \langle U_R(-\infty; x^+) \times F^{-\perp}(x^+) U_R(x^+; 0) F^{-\perp}(0) U_R(0; -\infty) \rangle \quad (2)$$

Starting at  $\mathcal{O}(g)$ ,  $Z_g$  receives contribution from



with **gluon** soft  $\sim gT$ .

Associated Bose-Einstein statistical function

$$n_B(\omega) = \frac{1}{e^{\frac{\omega}{T}} - 1} \approx \frac{T}{\omega} \gg 1$$

$\Rightarrow$  Bose enhancement!

These are **classical corrections**:

- Originate from **zero Matsubara mode**
- For soft gluon exchange, corrections can be computed using Hard Thermal Loop Effective Theory (HTL) but analytically difficult in practice
- Can also have **ultrasoft** gluon  $\sim g^2 T$  exchange – these corrections **cannot** be studied perturbatively (Linde problem)

## References

- [1] Simon Caron-Huot, 0808.0155
- [2] Simon Caron-Huot, 0811.1603
- [3] Guy Moore, Niels Schlusser, 2009.06614
- [4] Jacopo Ghiglieri, Guy Moore, Philipp Schicho, Niels Schlusser, 2112.01407
- [5] Jacopo Ghiglieri, Philipp Schicho, Niels Schlusser, Eamonn Weitz, 2312.11731
- [6] Soeren Schlichting, Ismail Soudi, 2111.13731

## Lattice Determination from EQCD

To go from hot QCD to electrostatic QCD (EQCD), integrate out all but zero Matsubara mode. Arrive at **static 3D EFT for Matsubara zero-mode** (dimensional reduction):

- $A^0$  field  $\Rightarrow -i\Phi$ , adjoint scalar picks up Debye mass,  $m_D \sim gT$
- $g_{3d}^2 \sim g^2 T$ ,  $U_R \Rightarrow \tilde{U}_R$

But why is this relevant here? Lightcone analyticity arguments allow us to compute classical corrections to  $Z_g$  with EQCD [2]

$\Rightarrow$  Can bypass horrible HTL computation and more importantly, gain access to non-perturbative evaluation of classical corrections by studying EQCD on the **lattice**!

Arrive at EQCD version of Eq. (2):  $Z_g^{3d} = -\frac{4T}{d_A} \int_0^\infty dL L \langle FF \rangle$  defined through  $\tilde{U}_R$ ,  $D_i \Phi$  and  $F_{ij}$

Short-distance behavior:  $\langle FF \rangle_{m_D L \ll 1} = \frac{c_0}{L^3} + \frac{c_2 g_{3d}^2}{L^2} + \frac{c_4 g_{3d}^4}{L} + \dots$

To obtain **finite lattice determination**, subtract off LO, UV **power law** divergence and separate into pieces

$$Z_g^{3d}|_{\text{merge}} = -\frac{4T}{d_A} \left\{ \int_0^{L_{\min}} dL L \left[ \langle FF \rangle_{\text{NLO}} - \frac{c_0}{L^3} - \frac{g_{3d}^2 c_2}{L^2} \right] + \int_{L_{\min}}^{L_{\max}} dL L \left[ \langle FF \rangle_{\text{lattice}} - \frac{c_0}{L^3} \right] + \int_{L_{\max}}^\infty dL L \left[ \langle FF \rangle_{\text{tail}} - \frac{c_0}{L^3} \right] \right\} \quad (3)$$

**Lattice piece calculated** and **IR tail fitted** in [3, 4]

At short distances, switch to **perturbative NLO EQCD evaluation**, calculated in [4]

$\Rightarrow$  additionally subtract off  $\mathcal{O}(g^2)$  logarithmic divergence  $\sim c_2$

**Motivation for our work [5]**, where we compute  $\mathcal{O}(g^2)$  **thermal scale  $\sim T$  contribution from hot QCD**:

- $\mathcal{O}(g^2)$  EQCD logarithmic divergence still needs to be matched against corresponding one from hot QCD to eliminate spurious  $L_{\min}$ -dependence
- Obtain all  $\mathcal{O}(g^2)$  corrections to  $Z_g$

## Cutoff-independent results

We find that in Feynman gauge, only need to compute one diagram in hot QCD (left below) Compare to its EQCD counterpart (right below)



Isolate K zero-mode contribution

Probe UV limit by taking  $K \gg gT$

Logarithmic divergences cancel  $\Rightarrow$  Finite cutoff-independent result for non-perturbative evaluation!

$T$	$\frac{Z_g^{\text{non-pert class only}}}{T^2}$	$\frac{Z_g^{\text{non-pert class + finite } \mathcal{O}(g^2)}}{T^2}$	$\frac{Z_{g,LO}^{3d}}{T^2} = -\frac{m_D}{2\pi T}$
250 MeV	-0.513(138)(45)(7)	-0.340(138)(45)(7)	-0.376
500 MeV	-0.619(99)(39)(3)	-0.491(99)(39)(3)	-0.324
1 GeV	-0.462(71)(9)(7)	-0.356(71)(9)(7)	-0.305
100 GeV	-0.327(16)(5)(2)	-0.274(16)(5)(2)	-0.223

Errors from statistical errors in lattice EQCD (first bracket), **integration of IR tail** (second bracket) and quadrature of lattice data (third bracket)

First column contains non-perturbative evaluation. Second contains in addition finite part (see outlook) of quantum  $\mathcal{O}(g^2)$  corrections from  $T$  scale  $\Rightarrow$  **Larger in magnitude** than  $Z_g^{LO}$  for all temperatures!

## Outlook

- Find double-logarithmic divergence in region  $k^+ \gtrsim T$ ,  $k^- \lesssim g^2 T$ ,  $k_\perp \sim gT \Rightarrow K^2 \sim g^2 T^2$   
 $\Rightarrow$  Collinear, hard divergence hints at sensitivity to regions where:
  - LPM resummation in necessary
  - Scale hierarchy assumed in Eq. (1) is no longer respected

$\Rightarrow$  Outstanding divergence implies our separation of non-perturbative classical corrections and quantum  $\mathcal{O}(g^2)$  ones is somewhat ambiguous. Complete  $\mathcal{O}(g^2)$  evaluation of collinear and hard contributions needed

- Looking farther forward, want to evaluate impact of non-perturbative corrections on medium-induced radiation, similar to what was done in [6] for  $\mathcal{C}(k_\perp)$