Gluon Condensates and Energetic Lepton Pairs from Quark Gluon Plasma

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Outline

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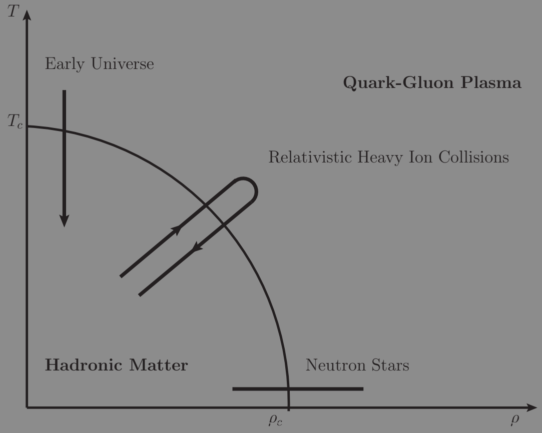
Motivations



Phase diagram of Nuclear Matter

Dilepton Rate: Introduction

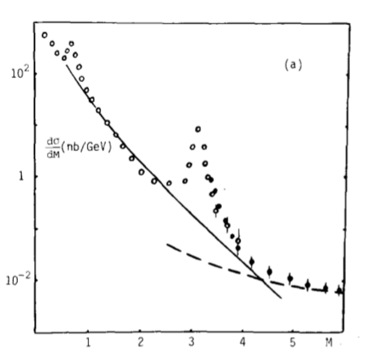
- A locally equilibrated plasma is formed only transiently in the collision.
- Production of dileptons $\Longrightarrow$ Signal of plasma formation.
- Without further interaction real photon escapes unperturbed and virtual photon decays into a lepton pair in the process.

$$\frac{dR}{d^4p} = -\frac{\alpha_{\mathsf{em}}}{12\pi^3 M^2} n_B(\omega)\,\rho(\omega,p)$$

$$\rho(\omega,p) = \frac{1}{\pi}\mathrm{Im}\,\Pi^{\mu}_{\mu}(p_0+i\eta,p)$$

Intermediate mass Dileptons

[E.V.Shuryak, Phys. Lett. B 78, 150(1978)]



Intermediate mass Dileptons $\longrightarrow m_\phi \approx 1$ GeV $< M < m_\psi \approx 3$ GeV
Below 1 GeV, the hadronic process dominates, whereas, above 3 GeV the Drell-Yan process and the charmonium decays are the major processes.

Goal

Study the $D = 4$ gluon and quark operators in medium

$\Downarrow$

Evaluate the two point correlation function

$\Downarrow$

Spectral functions

$\Downarrow$

Intermediate mass Dilepton Rate

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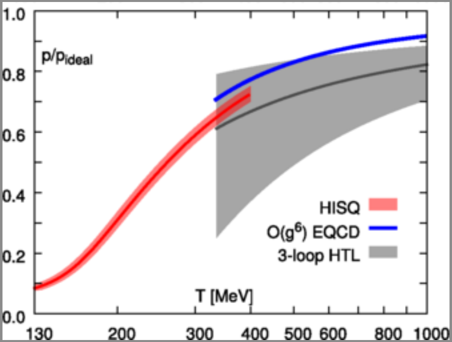
QCD Equation Of State

[A.Bazavov et al, Phys.Rev. D90 (2014) 9, 094503]



- Phenomenologically interesting domain $\longrightarrow g \approx 2$
- Thermal scales are not well separated. $(g^2T < gT < T \; (?))$

Alternative methods

- Perturbation Theory (PT)- is it sufficient?
- Lattice techniques (Euclidean) $\Longrightarrow$ Spectral function (Minkowski)

  Analytic continuation in LQCD is very error prone.
- Alternative method is required where we can exploit both perturbative and non-perturbative domain separately.

Operator Product Expansion

- Correlator in QCD ::

  In a background of quark and gluon fields (i.e the QCD vacuum) it can be expressed in terms of vacuum condensates and coefficient functions.

$$\langle J_\mu(x) J_\nu(0)\rangle \approx \sum_i c_i \, O_i$$

- **Operator product expansion(OPE)**

  short distance effects $\longrightarrow c_i \longrightarrow$ wilson co-efficients (PT)

  large distance effects $\longrightarrow O_i \longrightarrow$ vacuum condensates (Phenomenology)

In medium corrections

- Zero temperature D=4 operators

$$\text{gluonic} \longrightarrow \langle G^2 \rangle, \ \text{quark} \longrightarrow \langle \bar{\psi}\psi \rangle$$

- Additional in medium operators,

$$\begin{aligned} \text{gluonic} \quad &\longrightarrow \quad \langle u\Theta^g u\rangle \\ \text{quark} \quad &\longrightarrow \quad \langle u\Theta^f u\rangle \end{aligned}$$

where $u^\mu \longrightarrow$ four velocity of the heat bath.

- $\Theta^g_{\mu\nu} + \Theta^f_{\mu\nu} \Longrightarrow$ Traceless part of stress tensor $\Longrightarrow$ determines the shape of the spectral function.

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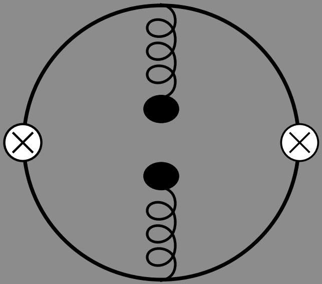
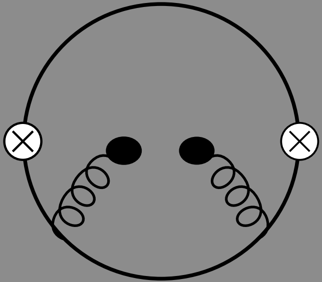
Topology I



In medium, for the case of light quarks,

$$[\Pi_G(p)]_{I,m=0} = \langle G^2\rangle \frac{g^2 N_f}{16\pi^2 p^2} - \langle u\Theta^g u\rangle \frac{g^2 N_f}{3\pi^2 p^2}\left[\frac{\omega^2}{p^2} - \frac{1}{4}\right]$$

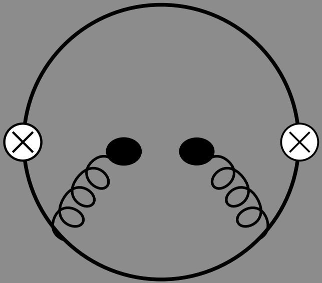
Topology II



For light quarks, no contribution in Vacuum. In medium,

$$[\Pi_G(p)]_{II,m=0} = \frac{g^2 N_f}{9\pi^2 p^2}\langle u\Theta^g u\rangle \left[\log\left(\frac{-p^2}{\Lambda^2}\right)\left(1-\frac{4\omega^2}{p^2}\right) - 2 + 6\frac{\omega^2}{p^2}\right]$$

Topology II : Ambiguities



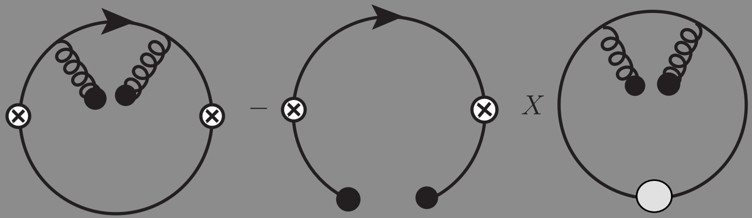
There are two possibilities.

The Gluon line can be soft.

The quark line in between can also be soft $\longrightarrow$ quark condensate $\longrightarrow$ mixed via gluonic effects.

Mixing must be subtracted out.

Topology II : Remedy



Gluon operators - Quark operators × contributions of the gluonic operators to those quark operators.

S.C.Generalis and D.J.Broadhurst, Phys. Lett. 139B (1984) 85

A.G.Grozin, Int.J.Mod.Phys. A10 (1995) 3497-3529

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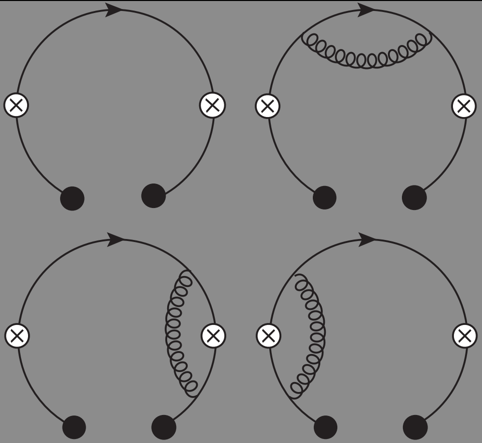
D=4 Quark condensate contribution



D=4 quark condensate (lowest order diagram and gluonic corrections)

(top left) quark vacuum condensate, (top right) self energy correction
(bottom left and bottom right) vertex correction

Correlation Function for light quarks

Leading Order

$$[\Pi_Q(p)]_{m=0} = \langle u\Theta^f u\rangle \frac{8}{3p^2}\left(1-4\frac{\omega^2}{p^2}\right)$$

Next to Leading Order (Gluonic corrections)

$$[\Pi_Q(p)]_{m=0} = \langle u\Theta^f u\rangle \frac{16g^2}{27\pi^2p^2}\left(1-4\frac{\omega^2}{p^2}\right)\left(1-\log\left(\frac{-p^2}{\Lambda^2}\right)\right)$$

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Final expressions

- So, putting it altogether,

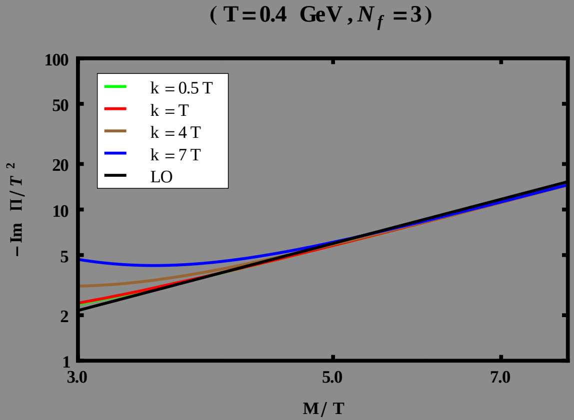
$$\Pi_G(p)|_{m=0} = \langle u\Theta^g u\rangle \frac{g^2 N_f}{9\pi^2 p^2}\left[\log\left(\frac{-p^2}{\Lambda^2}\right)\left(1-\frac{4\omega^2}{p^2}\right)\right]$$

$$\Pi_Q(p)|_{m=0} = -\langle u\Theta^f u\rangle \frac{16 g^2}{27\pi^2 p^2}\left[\log\left(\frac{-p^2}{\Lambda^2}\right)\left(1-\frac{4\omega^2}{p^2}\right)\right]$$

- The leading spectral function correction is given by,

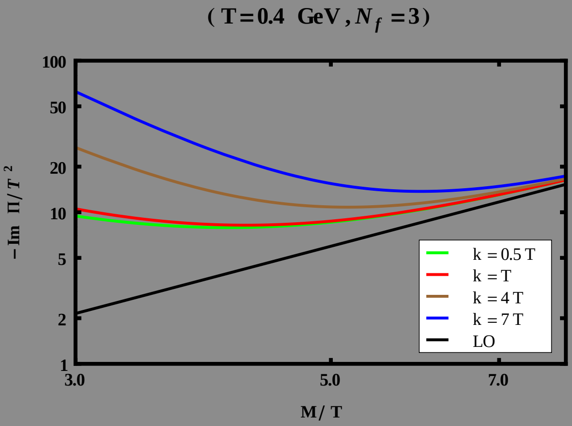
$$\delta\rho(\omega,p) = -\frac{4g^2}{9\pi p^2}\left(1-4\frac{\omega^2}{p^2}\right)\left[\frac{8}{3}\Theta_f^{00} - \frac{N_f}{2}\Theta_g^{00}\right]$$

NLO perturbative spectral function



NLO spectral function obtained via PT and comparison with Born Rate

NLO OPE spectral function (Free Limit)



NLO spectral function obtained via OPE in the stefan boltzman limit and comparison with Born Rate

Outline

Conclusions and Outlook

- The in medium spectral function is obtained nonperturbatively using Operator Product Expansion.
- Taking the Stephan Boltzmann limit of the NLO spectral function obtained by OPE shows enhancement over the perturbative case.
- The final result needs condensates close to T_c from LQCD as inputs.

Thank you for your kind attention.