Collective modes of gluon in an anisotropic thermo-magnetic medium

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Bithika Karmakar

Institute of Physics Belgrade

58. Karpacz Winter School of Theoretical Physics

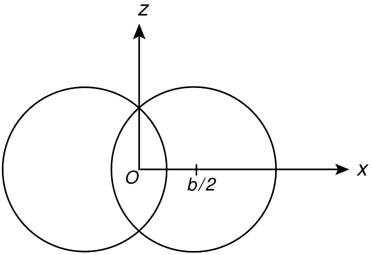
Collaborators: Ritesh Ghosh, Arghya Mukherjee

Outline

1. Magnetic field in non-central HICs
2. Momentum space anisotropy in HICs
3. General structure of gluon self-energy
4. Gluon dispersive modes
5. Are the modes stable?

Magnetic field in non-central HICs

- Magnetic field of strength upto $\sim 20m_\pi^2$ can be created in non-central heavy ion collision.



- In a direction perpendicular to the reaction plane.
- Magnetic field strength decreases with time .

Momentum space anisotropy in HICs

- QGP created in ultra relativistic heavy-ion collisions (URHIC) possess substantial deviation from perfect local isotropic equilibrium.

- QGP has different longitudinal and transverse pressures.
- Leads to large momentum space anisotropy.

- Generally parametized by 'Romatschke-Strickland (RS)' form

$$f_{\text{aniso}}(\boldsymbol{k}) \equiv f_{\text{iso}}\left(\frac{1}{\Lambda_T}\sqrt{\boldsymbol{k}^2 + \xi(\boldsymbol{k}\cdot\boldsymbol{a})^2}\right)$$

- It can be generalized for ellipsoidal mometum space anisotropy

$$f_{\text{aniso}}(\boldsymbol{k}) \equiv f_{\text{iso}}\left(\frac{1}{\Lambda_T}\sqrt{\boldsymbol{k}^2 + \xi_1(\boldsymbol{k}\cdot\boldsymbol{a}_1)^2 + \xi_2(\boldsymbol{k}\cdot\boldsymbol{a}_2)^2}\right)$$

Partons in strong magnetic field

- Only fermions are directly affected by magnetic field.
- Gluons are affected via quark loop.
- Energy of fermion in presence of magnetic field
  $E_n = \sqrt{k_z^2 + m_f^2 + 2n|q_f B|}$.
- Only lowest Landau level in strong field approximation.
- Dimensional reduction $(3+1 \rightarrow 1+1)$ in LLL.

Formalism

1. We consider magnetic field along z direction $\hat{z} = (0, 0, 1) = \mathbf{a_2}$.
2. Beam direction $\hat{x} = (1, 0, 0) = \mathbf{a_1}$.
3. The fermion energy eigenvalue only depends on the longitudinal momentum and the Landau level index.
4. Thus in LLL limit, the nonequilibrium fermion distribution function is constructed as

$$f^{\rm F}_{\rm aniso}(k_z) \quad \equiv f^{\rm F}_{\rm iso}\left(\frac{1}{\Lambda_T}\sqrt{k_z^2 + \xi_2 k_z^2}\right) = f^{\rm F}_{\rm iso}\Big(|k_z|/\lambda_T\Big).$$

General structure of gluon self-energy

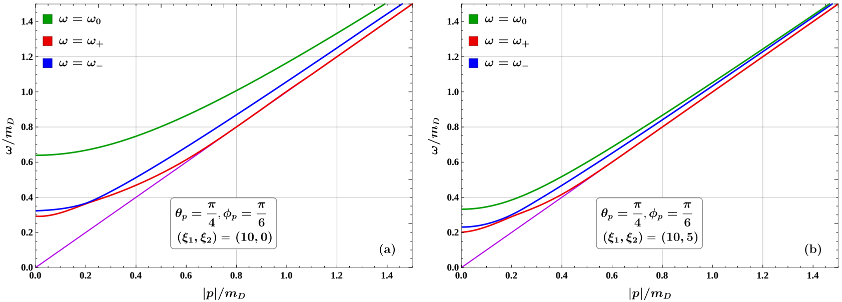
- Six basis tensors needed to represent gluon self-energy in presence of ellipsoidal anisotropy and a magnetic field.
- Gluon self energy
  $\Pi^{\mu\nu} = \alpha A^{\mu\nu} + \beta B^{\mu\nu} + \gamma C^{\mu\nu} + \delta D^{\mu\nu} + \sigma E^{\mu\nu} + \lambda F^{\mu\nu}.$
- The form factors are calculated from one-loop gluon self-energy diagram using HTL approximations.

Quark loop contribution of gluon self-energy

$$\bar{\Pi}^{\mu\nu}_{ab}(p) = \delta_{ab} \sum_f g_s^2 \frac{|e_f B|}{8\pi^2} \exp\Big(-\frac{p_\perp^2}{2|e_f B|}\Big) \sum_{\mathrm{sgn}(k_z)=\pm 1} \frac{v_{\shortparallel}^{\mu} v_{\shortparallel}^{l}}{1+\xi_2} \left[\eta_{\shortparallel}^{\nu l} - \frac{v_{\shortparallel}^{\nu} p^l}{(v_{\shortparallel} \cdot p_{\shortparallel} + i\epsilon)}\right]\Bigg|_{l=3} .$$

Gluon dispersive modes

$$eB = 30m_\pi^2$$



- Three dispersive modes of gluon ω_0 and $\omega_\pm$ which can be found from the pole of the effective gluon propagator.

Are the modes stable?

- The gluon dispersive modes are stable in isotropic thermal medium.
- These modes are also stable in isotropic thermomagnetic medium.
- To analyze the stability three mass scales can be defined for the three dispersive modes of gluon.
- A negative value of the squared mass indicates unstable mode.

Mass scales

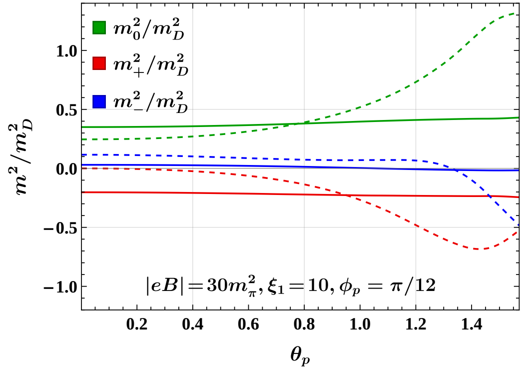
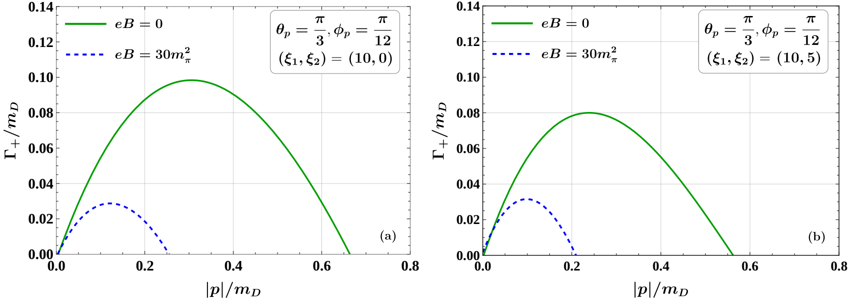


Figure: The continuous and the dashed curves represent $\xi_2 = 5$ and $\xi_2 = 0$ respectively.

Growth rate of unstable modes

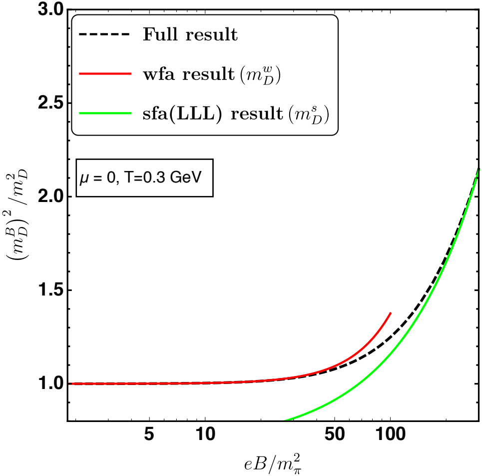
- Growth rate of the unstable modes is defined as the imaginary part of the mode frequency ($\omega \to i\Gamma$).
- This can be found from the pole of effective gluon propagator.



Summary

1. Ellipsoidal momentum distribution in presence of a background magnetic field is considered.
2. Polar and azimuthal symmetry of the system breaks.
3. The magnetic field and the anisotropy along this direction act very differently.
4. Modes become unstable in presence of anisotropic thermomagnetic medium.
5. Growth rate of the instability decreases in presence of magnetic field.
6. Although, any critical magnetic field strength above which the modes become stable, is unlikely to be present.

Thank you for your attention!



Full result
wfa result (m_D^w)
sfa(LLL) result (m_D^s)
μ = 0, T=0.3 GeV
3.0
2.5
2.0
1.5
1.0
$\left(m_D^B\right)^2/m_D^2$
5
10
50
100
eB/m_π^2