Ultrasoft Fermionic Mode in Hot Gauge Theories

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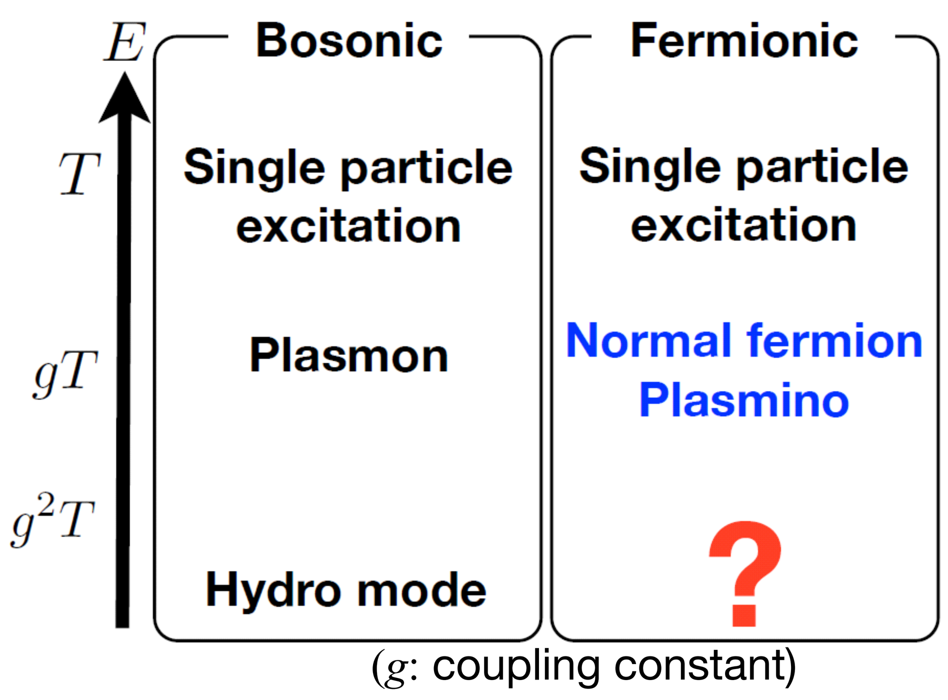
Collective modes at high T

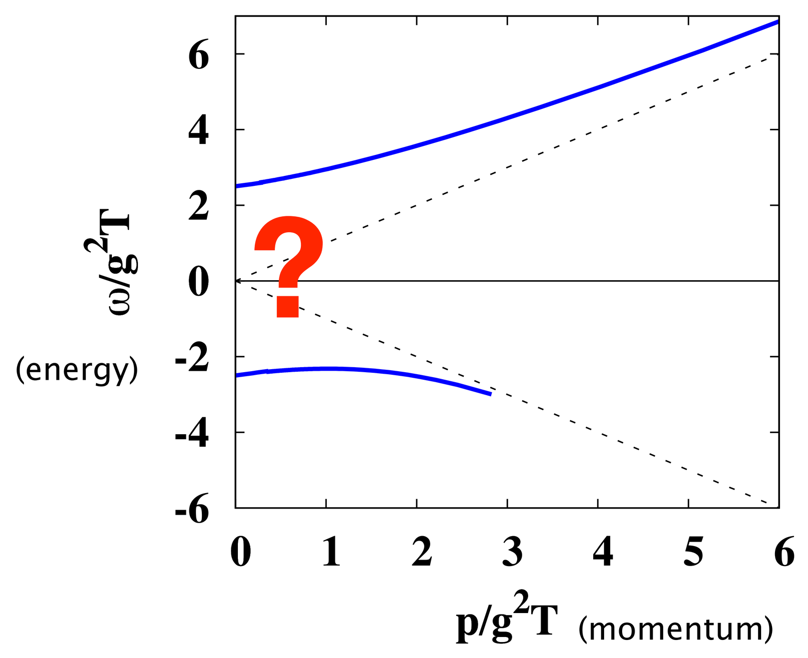
Massless fermion-boson system (Yukawa, QED, QCD)



(g: coupling constant)

Low energy excitations are collective.
In bosonic sector, hydro mode exists as zero modes.

H. Weldon, PRD 26, 2789 (1982)



Dispersion relation in fermionic sector

Is there fermionic ultrasoft mode at high T?

cf: fermionic ultrasoft mode was suggested:
massive boson case: M. Kitazawa, T. Kunihiro and Y. Nemoto, PTP 117, 103 (2007).
massless case: V. V. Lebedev and A. V. Smilga, Annals Phys. 202, 229 (1990).
neutrino in the EW theory: M. Kohtaroh, Y. Hidaka, **D. S.**, T. Kunihiro, in preparation.

Perturbation theory at high T

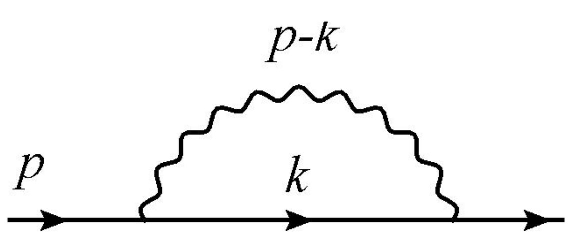
Naive perturbation does not work at ultrasoft momentum region

Bare propagators

Fermion: $D_R(k)=\dfrac{\not k}{k^2+i\epsilon k^0}$ Boson: $G_A(k)=\dfrac{1}{k^2-i\epsilon}$ (scalar, photon, gluon,..)

One-loop analysis

$n_F(k)$, $n_B(k)$: Fermi, Bose distribution function



$$\simeq g^2\int\frac{d^4k}{(2\pi)^4}\not k(n_F(k)+n_B(k))G_A(k)D_R(k+p)$$

$$\simeq g^2\int\frac{d^4k}{(2\pi)^4}\not k(n_F(k)+n_B(k))\frac{1}{2p\cdot k}(2\pi)\delta(k^2)$$

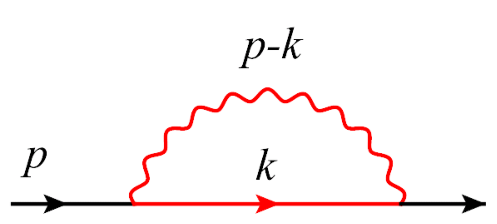
diverges as $p\to 0$. **Need improvement.**

Resummed perturbation theory

1. Dressed propagators

$$D_R(k)=\frac{\not k}{k^2-m_f^2+2ik^0\gamma_f}\qquad G_A(k)=\frac{1}{k^2-m_b^2-2ik^0\gamma_b}$$

m_f^2, m_b^2 : thermal masses ($\sim g^2T$) γ_f,γ_b : damping rates ($\sim g^2T$)



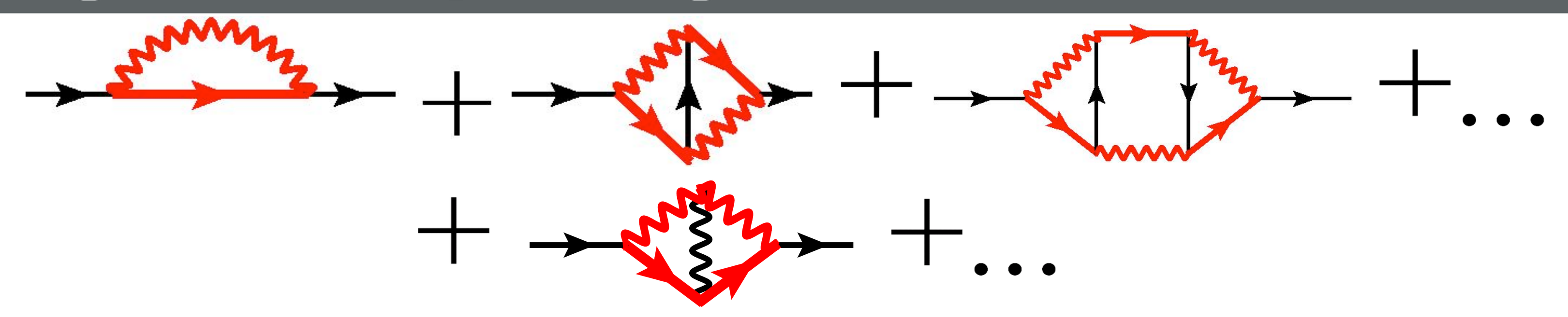
$$\simeq g^2\int\frac{d^4k}{(2\pi)^4}\not k(n_F(k)+n_B(k))\frac{1}{\delta m^2+2(p\cdot k+ik^0\gamma)}$$

$$\xrightarrow[p\to 0]{} g^2\int\frac{d^4k}{(2\pi)^4}\not k(n_F(k)+n_B(k))\frac{1}{\delta m^2+2(ik^0\gamma)}$$

Finite, improved!

where $\delta m^2=m_b^2-m_f^2\quad \gamma=\gamma_b+\gamma_f$

Higher loop diagrams

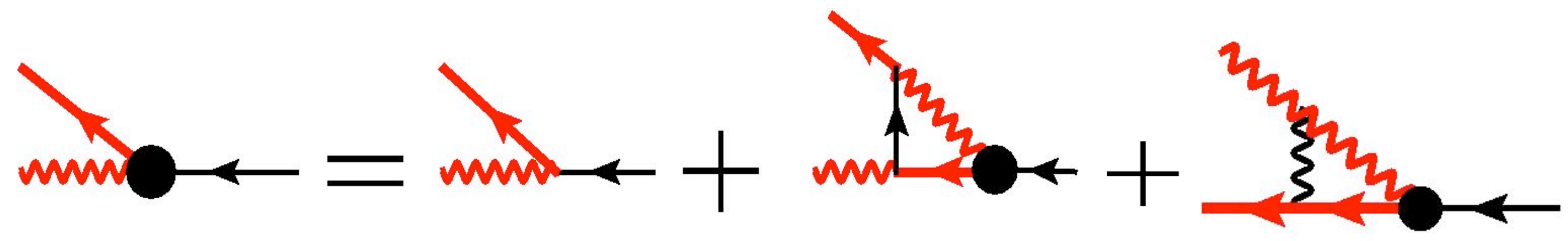


$$\sim\frac{1}{g^2}\qquad \sim\left(\frac{1}{g^2}\right)^2\times g^2\sim\frac{1}{g^2}\qquad \sim\left(\frac{1}{g^2}\right)^3\times g^4\sim\frac{1}{g^2}$$

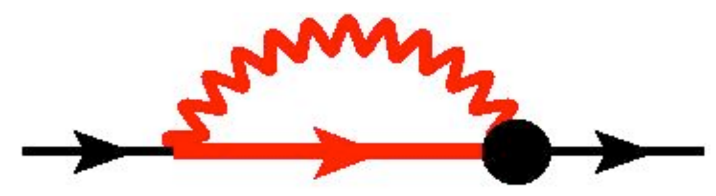
All ladder diagram contributes to the leading order.

Summation of ladder diagrams

2. Self-consistent equation



1. & 2. ➡ Self-energy in the leading order



cf: Systematic derivation and kinetic interpretation of the resummed perturbation theory:
D. S. and Y. Hidaka, PRD, 85, 116009 (2012).

This vertex and self-energy satisfies the Ward-Takahashi identity.

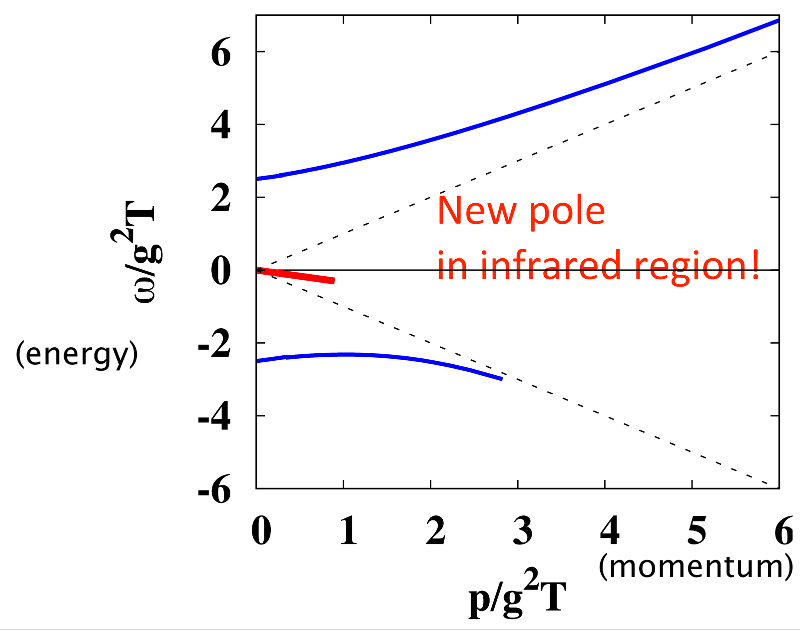
Results

Pole	Residue
$\omega=\pm\frac{1}{3}p+i\gamma$	$Z=\frac{g^2}{16\pi^2}c$

The velocity is 1/3, the residue is of order g^2.

cf: Extension to the finite chemical potential: **D. S.** and J. P. Blaizot, in preparation.

	γ	c
Yukawa model	$\sim g^4T$	$2/9$
QED	$\gamma_f\sim g^2T$	$1/9$
QCD	$\sim g^2T$	$(N_f+4)^2/3$



Summary

- We established novel fermionic mode in ultrasoft ($\lesssim g^2T$) region, and obtained the expressions for **dispersion relation, decay width, and residue**. using the **resummed perturbation**.
- We also show that the vertex function and the fermion propagator satisfy the Ward-Takahashi identity.