Fermionic Spectrum at Ultrasoft Region in a Hot QED/QCD Plasma

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Introduction

motivation: **quark spectrum** in the quark-gluon plasma (QGP)

(collective excitation, quasi-particle picture)

F. Karsch and M. Kitazawa, Phys. Lett. B **658**, 45 (2007).

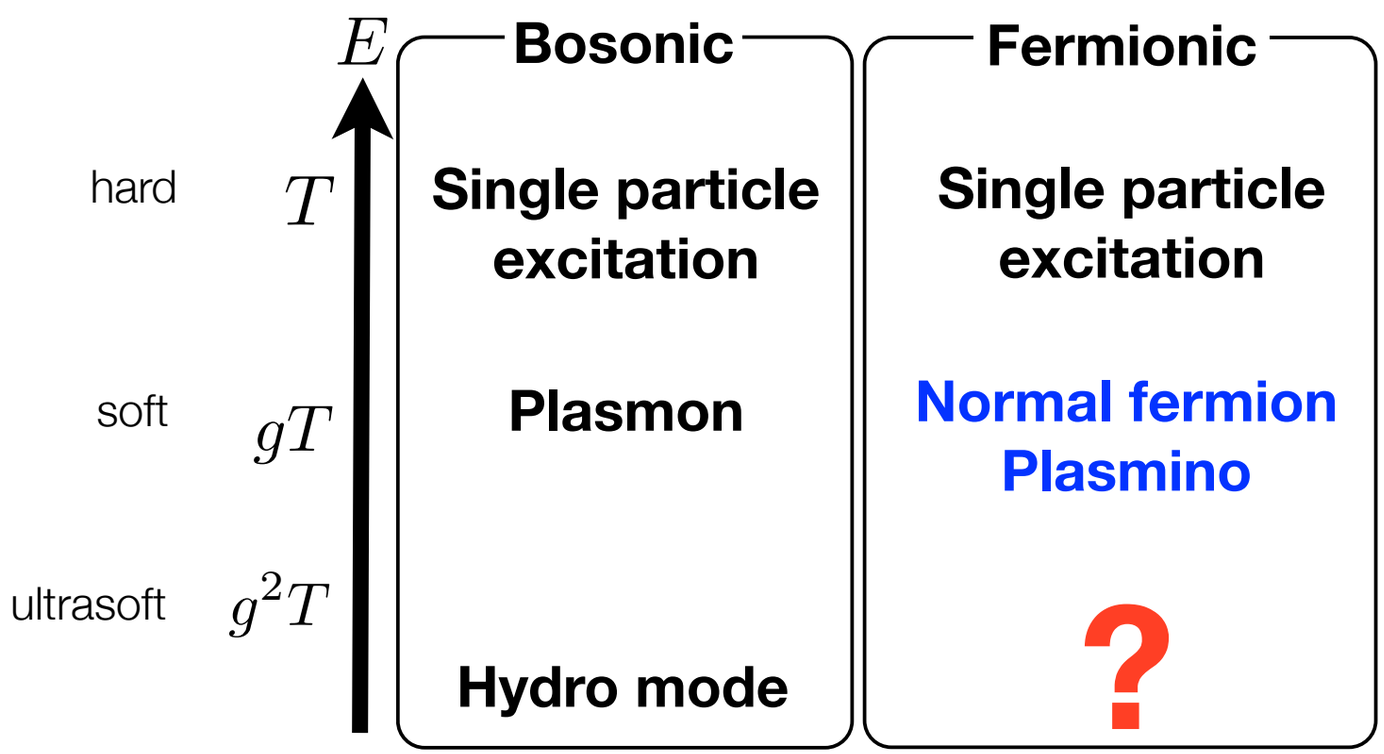
- how many excitation modes?
- how are dispersion relation, decay width, strength?

very fundamental problems, but **not well investigated** even in the weak coupling region ($g<<1$).

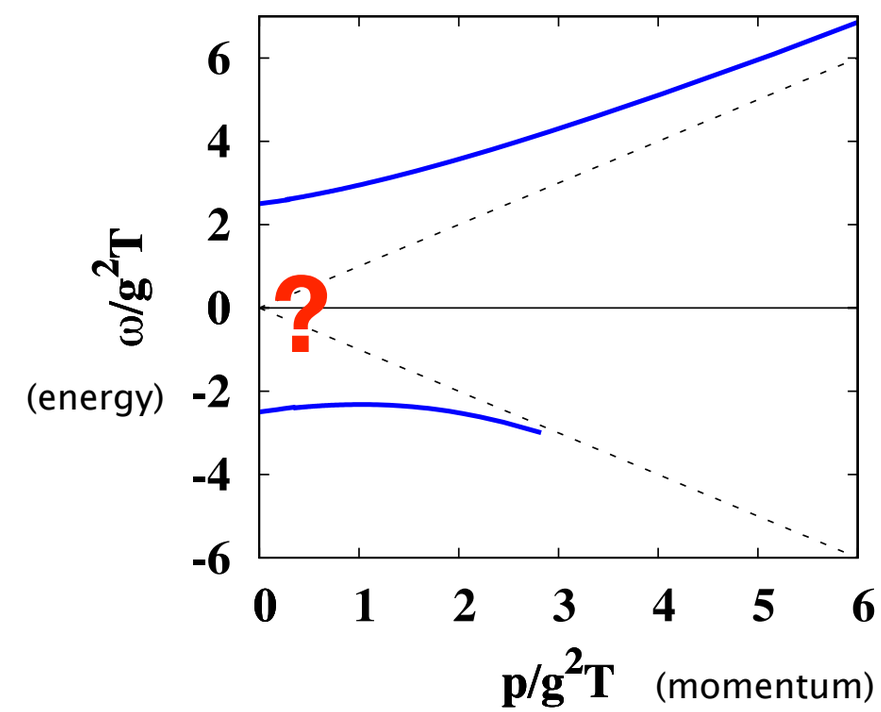
Introduction

spectrum of boson-fermion system **at high temperature**

(Yukawa model, QED/QCD) $(T >> \text{any mass})$



H. Weldon, PRD **26**, 2789 (1982)



dispersion relation in the fermionic sector

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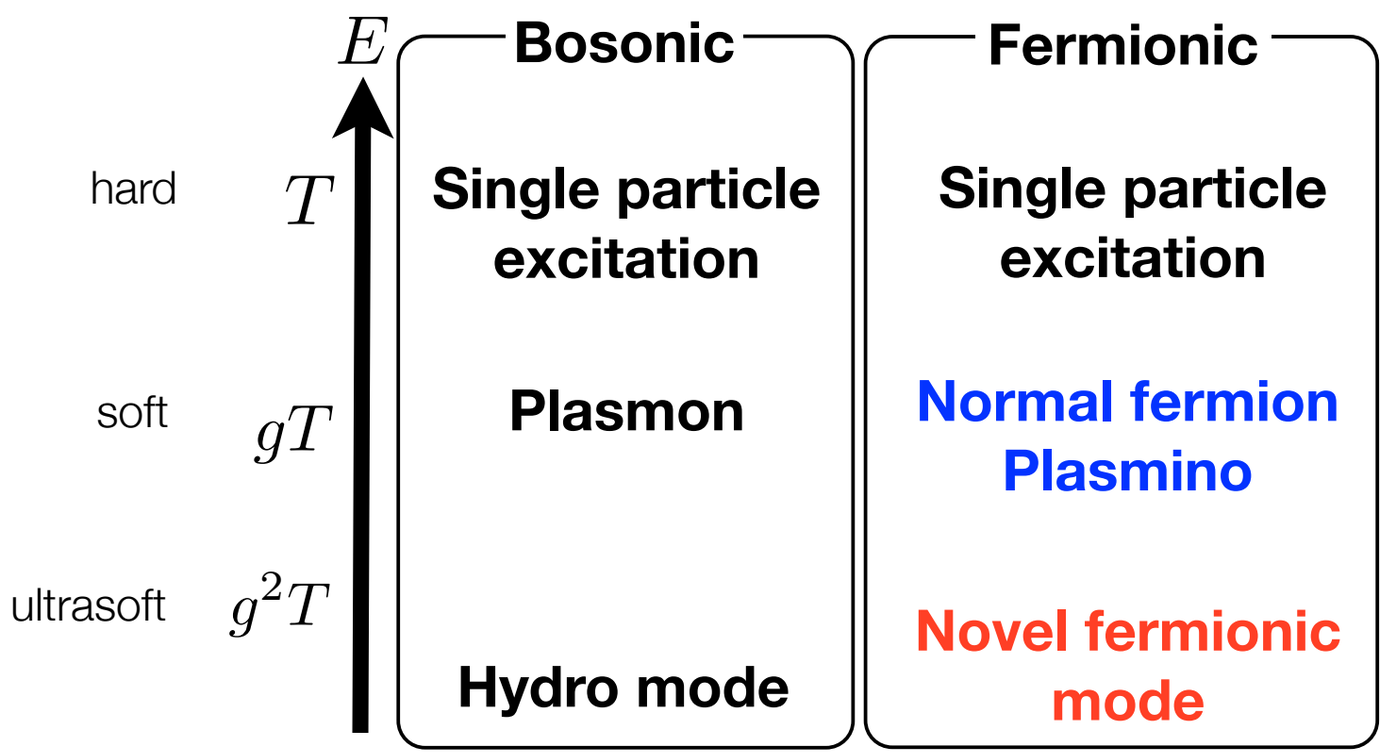

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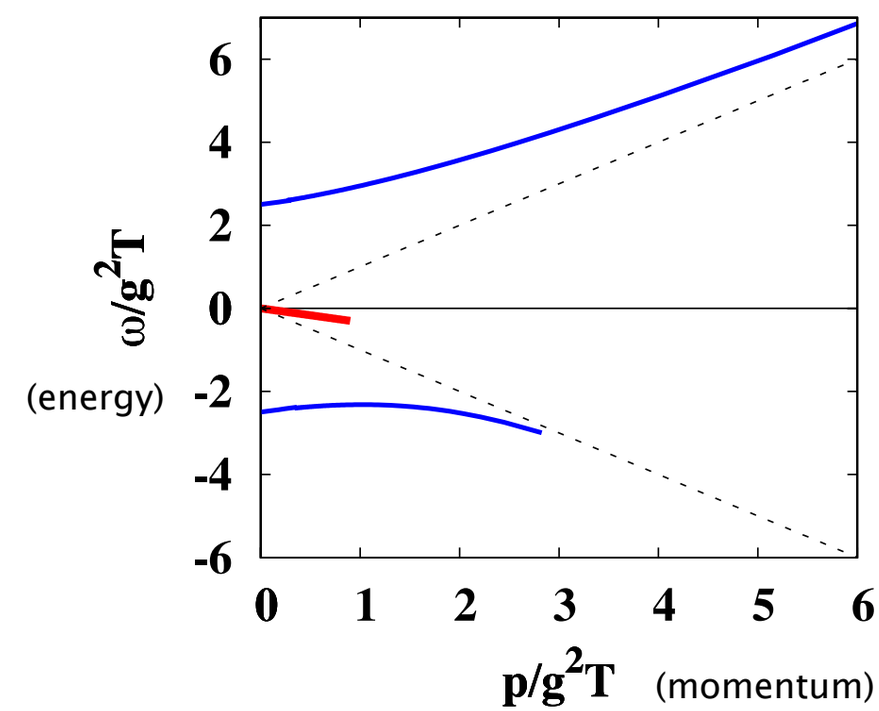
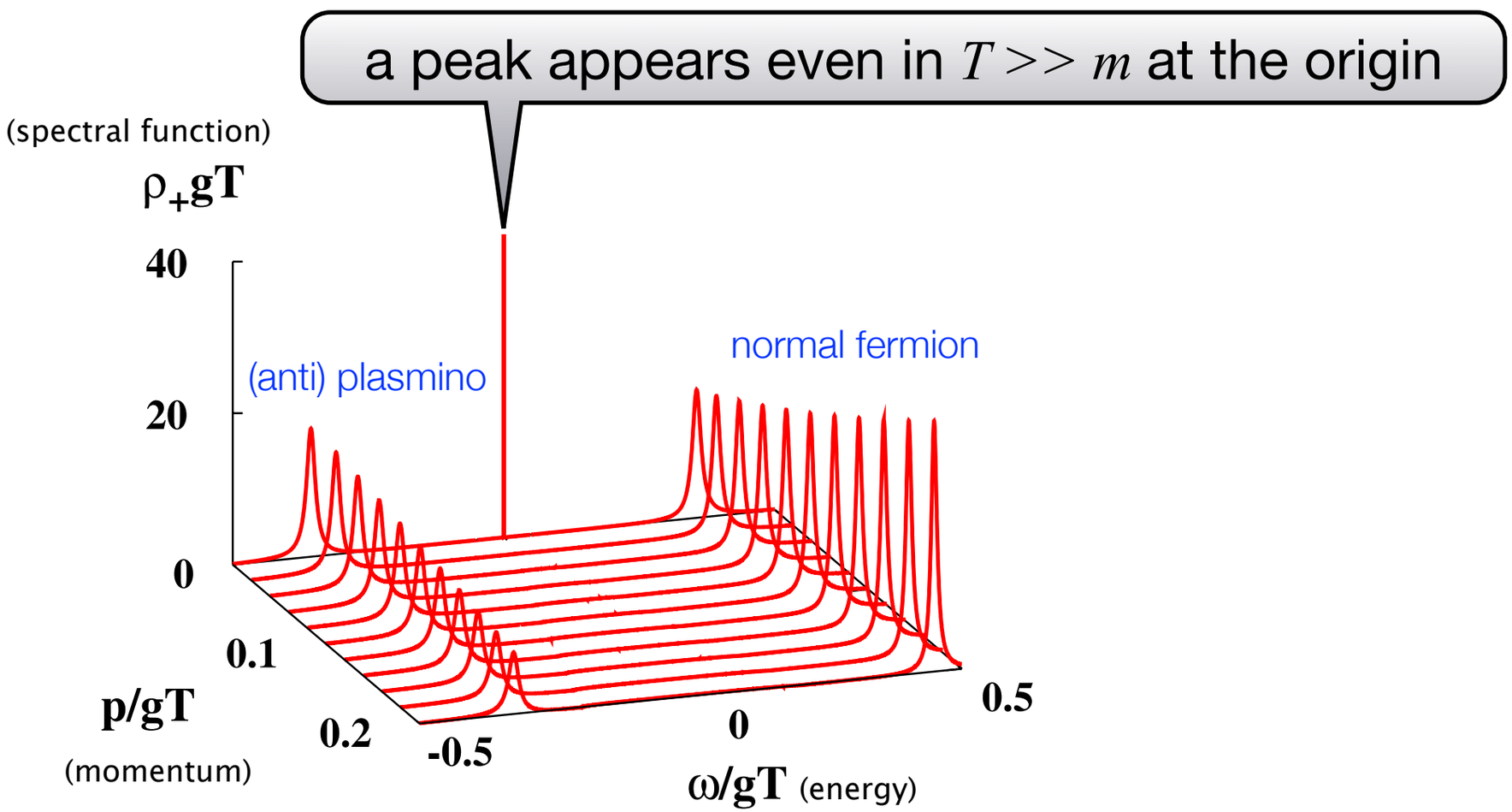


dispersion relation in the fermionic sector

Ultrasoft fermionic mode

one-loop analysis (m: boson mass)

D. S., Y. Hidaka and T. Kunihiro, PRD **83** 045017 (2011).
see also M. Kitazawa, T. Kunihiro and Y. Nemoto, PTP **117**, 103 (2007).



spectral function in the fermion sector

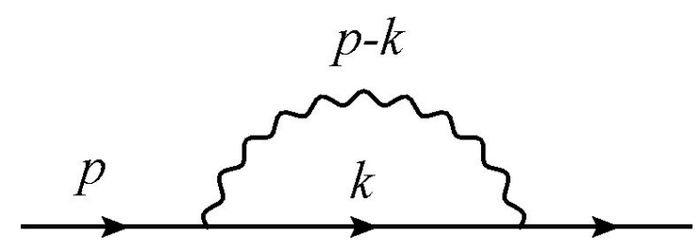
Pinch singularity

in ultrasoft ($p << g^2T$) region, the ordinary perturbation (Hard Thermal Loop (HTL) approximation) is not applicable.

1. $p \to 0$ limit can not be taken (pinch singularity)

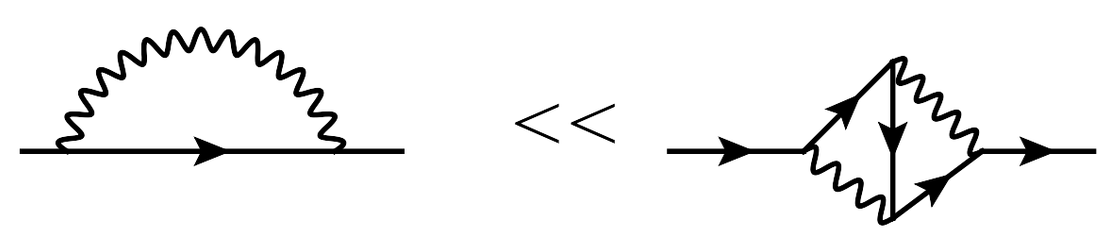
pinch singularity in computing transport coefficient:
S. Jeon, PRD **52**, 3591 (1995),
Y. Hidaka and T. Kunihiro, PRD **83**, 076004 (2011).

$$g^2 \int \frac{d^4k}{(2\pi)^4} 2\pi\theta(k^0)\delta(k^2)(N(k^0)+n(k^0)) \frac{\not{k}}{2p\cdot k - p^2} \xrightarrow{p\to 0} \infty$$



2. (one loop) << (multi loop)

$$\frac{g^2}{p\cdot k} \qquad \left(\frac{g^2}{p\cdot k}\right)^2$$



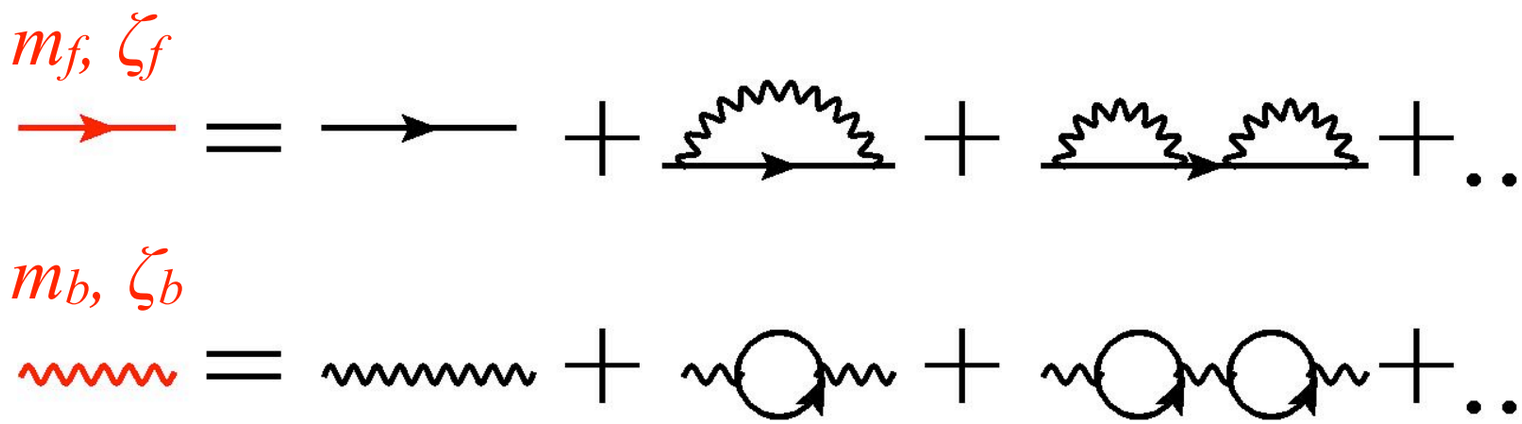
reorganizing perturbation expansion is necessary

Resummed Perturbation (V. V. Lebedev and A. V. Smilga, Annals Phys. **202,** 229 (1990))

(1) resum thermal mass (m_f, m_b=$O(gT)$) A. Peshier, K. Schertler and M. H. Thoma, Annals Phys. **266**, 162 (1998).

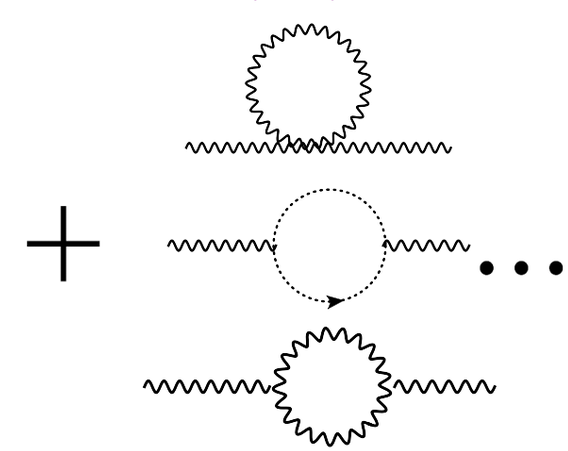
and decay width (ζ_f, ζ_b=$O(g^2T)$ or $O(g^4T)$) J. P. Blaizot and E. Iancu, PRL, **76**, 3080 (1996)

photon

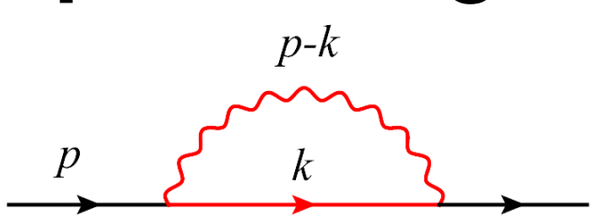


- Landau gauge
- residue is unity (same as bare one)
- no longitudinal mode

(QCD)



→pinch singularity is regularized.



$$g^2 \frac{\not{k}}{2p\cdot k + \delta m^2 + 2i\zeta k^0} \xrightarrow{p\to 0} O(g^0)$$

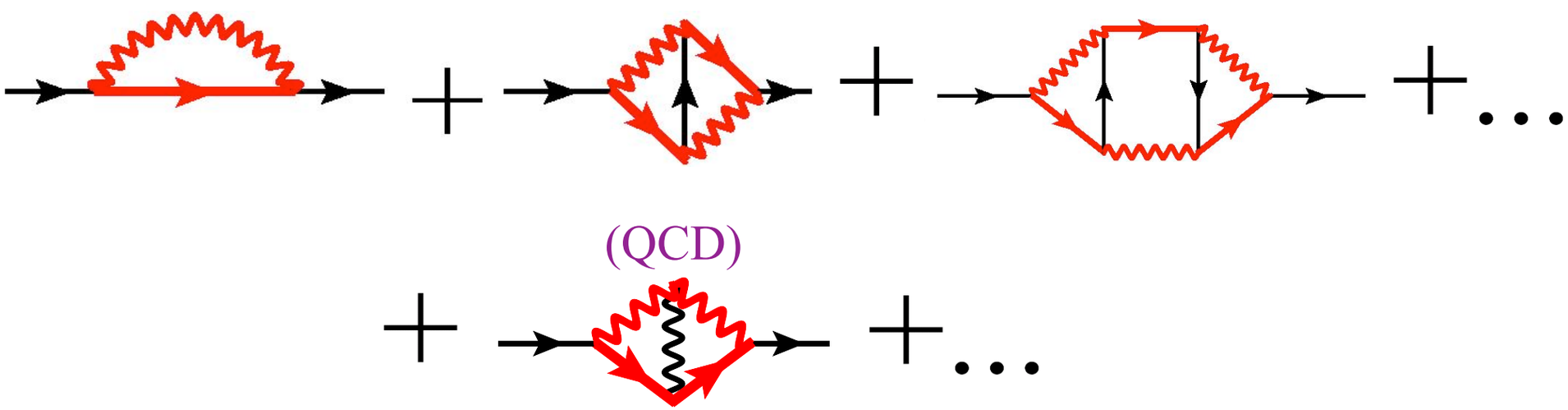
$\delta m^2 = m^2_b - m^2_f$, $\zeta = \zeta_f + \zeta_b$

Resummed Perturbation (V. V. Lebedev and A. V. Smilga, Annals Phys. **202,** 229 (1990))

the singularity is regularized, but all of the ladder diagrams contribute at the same order.

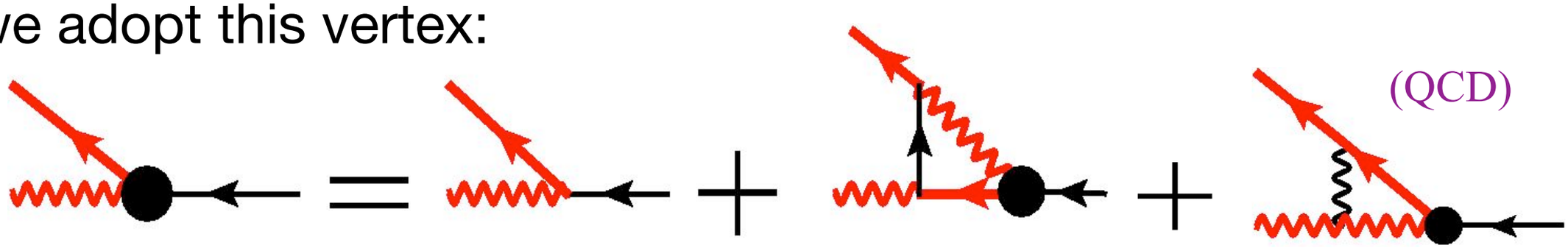
$$\frac{g^2}{2p\cdot k+\delta m^2+2i\zeta k^0}=O(g^0) \qquad \left(\frac{g^2}{2p\cdot k+\delta m^2+2i\zeta k^0}\right)^2=O(g^0)$$

(#vertex)/(#resummed propagator)=1



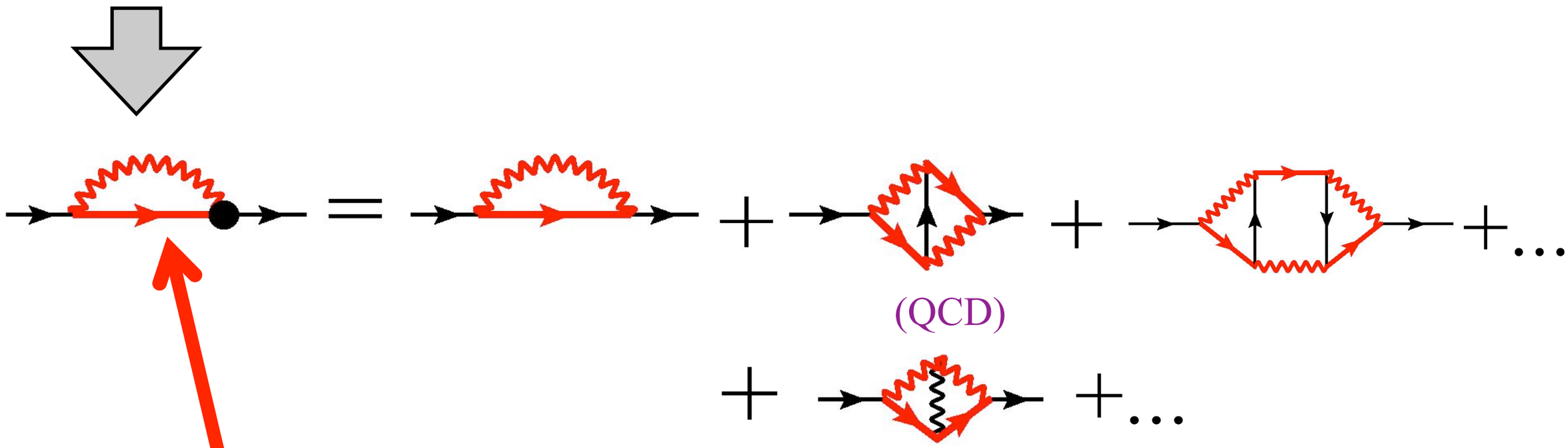
(2) sum up all the ladder diagrams.

we adopt this vertex:



Resummed Perturbation (V. V. Lebedev and A. V. Smilga, Annals Phys. **202,** 229 (1990))

(1) and (2)



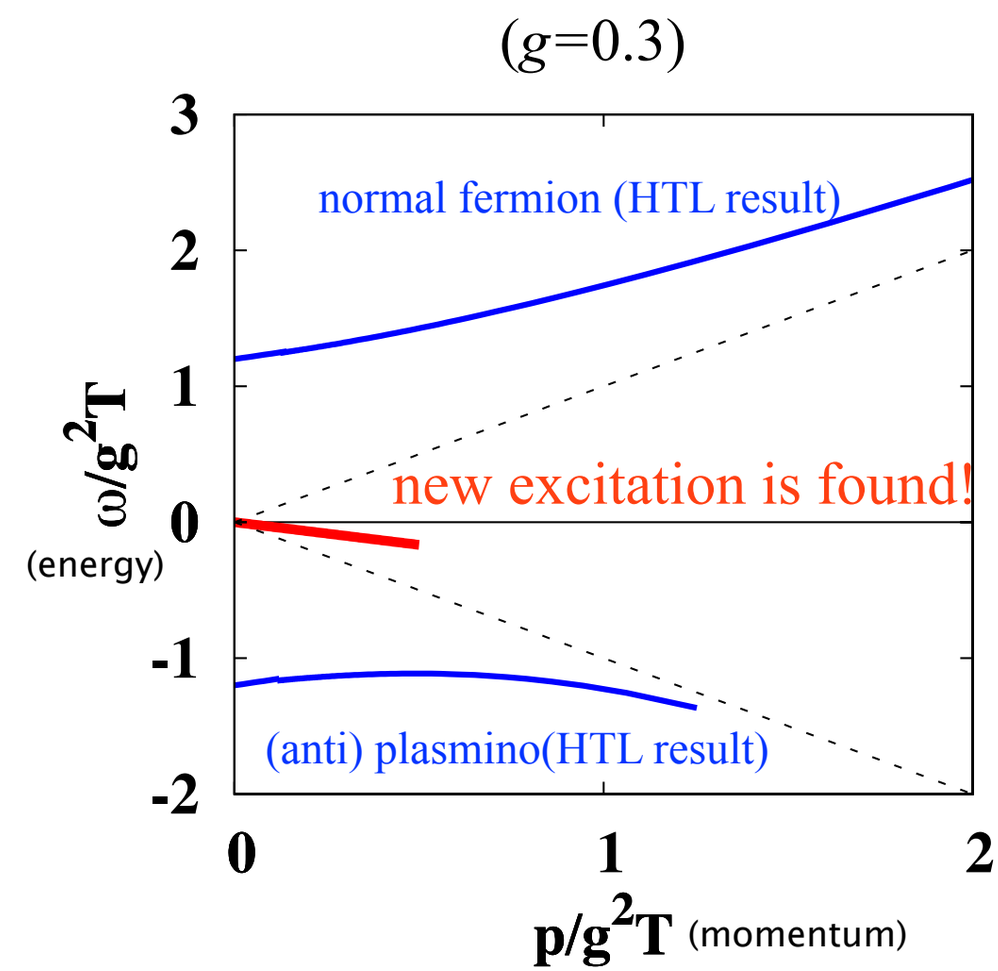
this diagram contains
all of the leading order contribution. $(O(p/g^2))$

Result

(Yukawa model: Y. Hidaka, D. S., and T. Kunihiro, arXiv: 1105.0423 [hep-ph])

novel excitation is found in ultrasoft ($p,\omega << g^2T$) region.

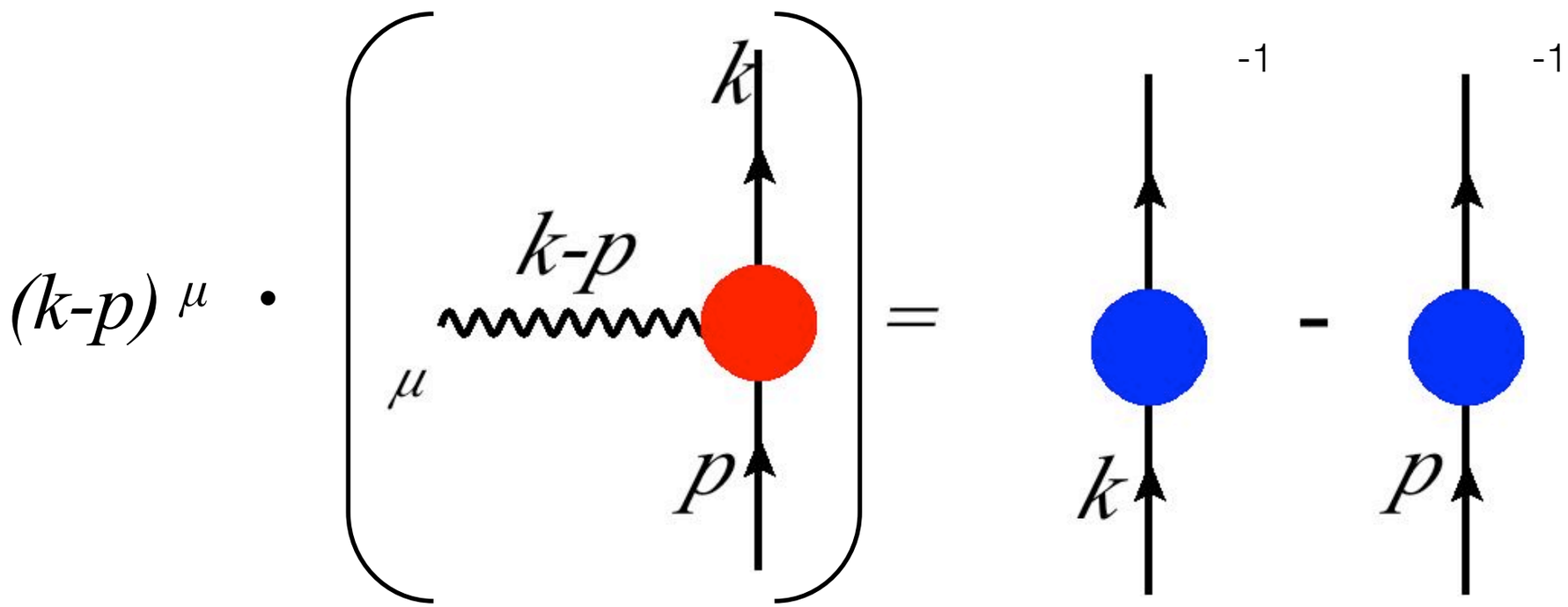
dispersion relation	$\mathrm{Re}\omega = -p/3$ (cf: anti-plasmino)
decay width	$\mathrm{Im}\omega = \zeta = O(g^2T)$
residue	$Z = \frac{g^2}{16\pi^2}\left(C_f + 8\frac{\delta m^2}{g^2T^2}\right)^2 = O(g^2)$ $= \begin{cases} \frac{g^2}{144\pi^2} & \text{(QED)} \\ \frac{g^2}{16\pi^2}\left(\frac{4N_f}{3} + \frac{13N}{6} + \frac{1}{2N}\right)^2 & \text{(QCD)} \end{cases}$



dispersion relation in the fermionic sector

Check of gauge symmetry

Ward-Takahashi identity is derived from the gauge symmetry.

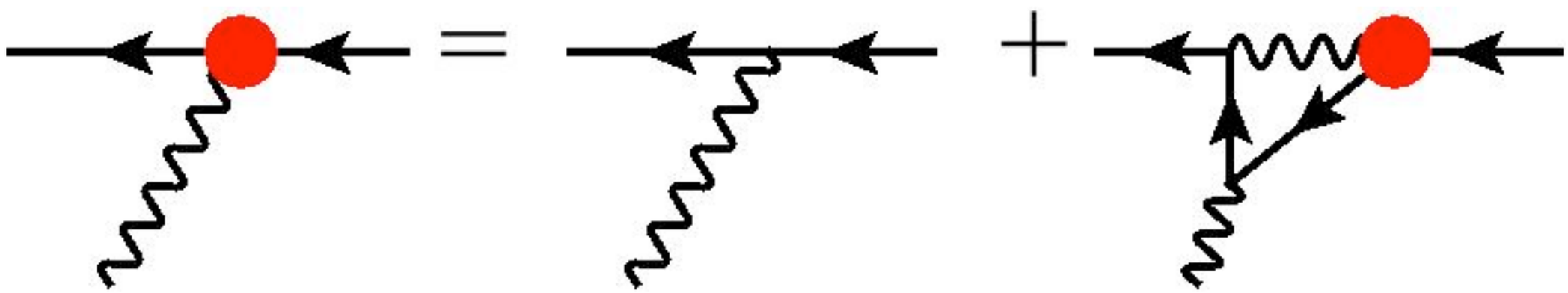


$$S^{-1}(k) \simeq \not{k} \qquad -S^{-1}(p) \simeq \Sigma(p)$$

This identity relates vertex to self-energy.

Check of gauge symmetry

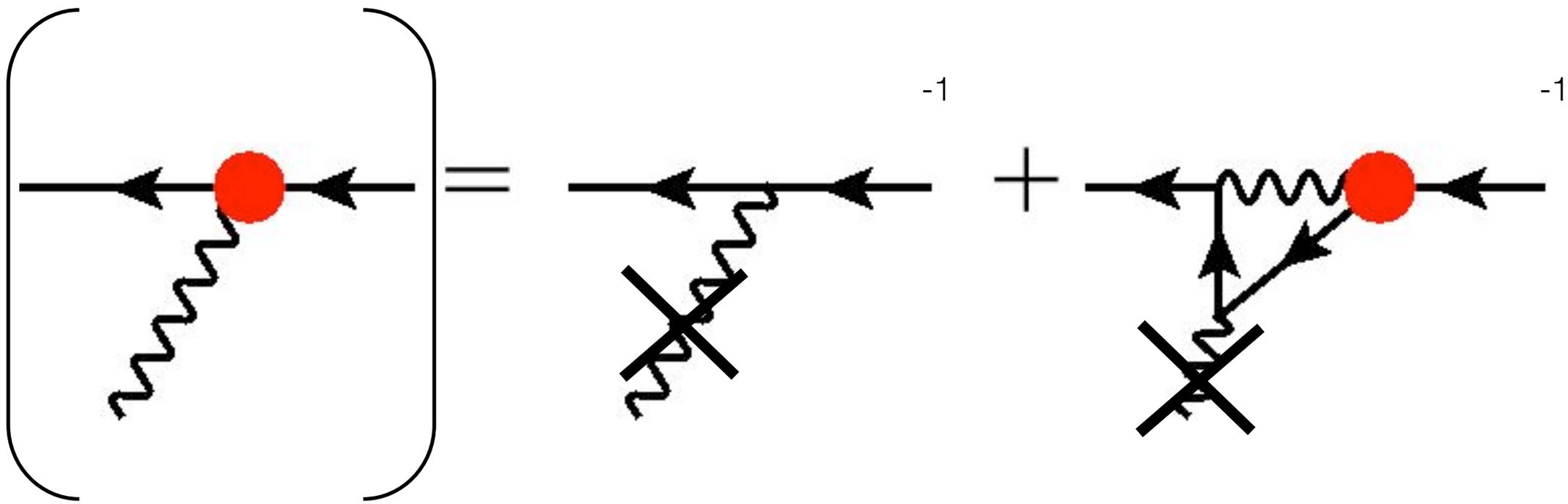
self-consistent eq. :



Check of gauge symmetry

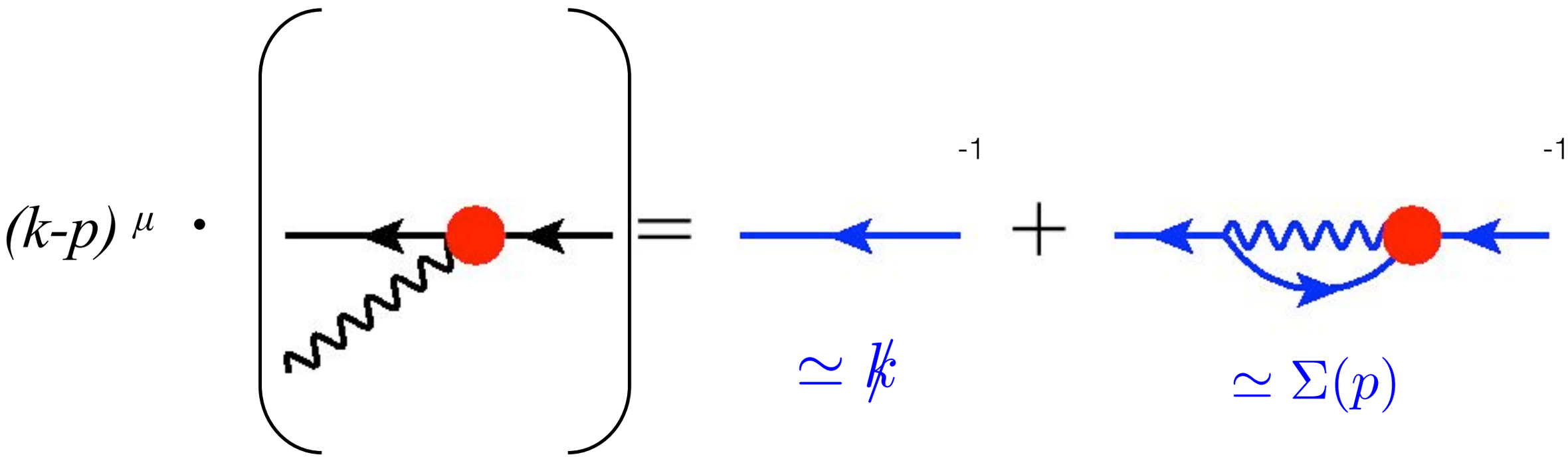
self-consistent eq. :

$(k\text{-}p)^{\mu}$ ·



Check of gauge symmetry

self-consistent eq. ⇒ W-T identity



Our vertex and self-energy satisfy this identity; We passed the consistency-check!

Summary

- we found the **novel fermionic mode** in ultrasoft ($<<g^2T$) region with a resummed perturbation in QED/QCD.

- we obtained the expression of the **dispersion relation, decay width** and **residue**.

- the obtained vertex and the fermion self-energy satisfy the **Ward-Takahashi identity**.

Future plan

- Systematic derivation of the resummed perturbation theory from the Kadanoff-Baym equation

- Effect to observables