カイラル相転移臨界点におけるクォークスペクトル

Quark spectrum near the critical point of chiral transition

根本幸雄（聖マリアンナ医大）

共同研究者：北沢正清（阪大），国広悌二（京大）

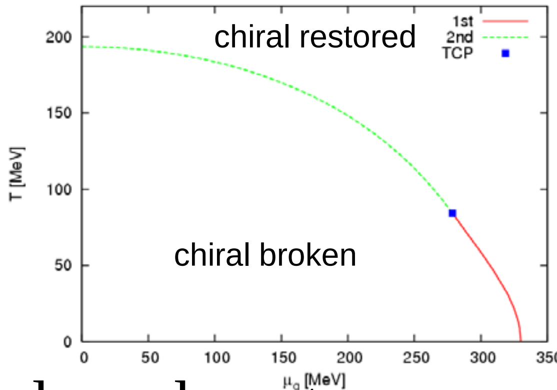
熱場の量子論とその応用　2013.8.26.

Our previous study on the quark spectrum

How do the fluctuations of the chiral condensate affect the quark spectrum near Tc?

- model: Nambu-Jona-Lasinio model (2-flavor, **chiral limit**)
- phase diagram of the chiral transition

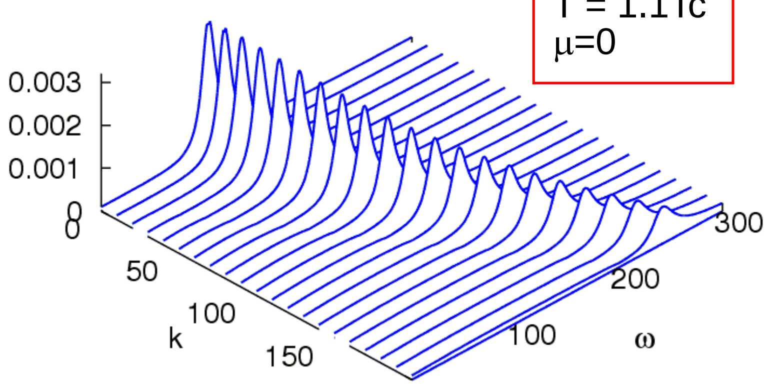
2nd order in the low density region
1st order in the high density region

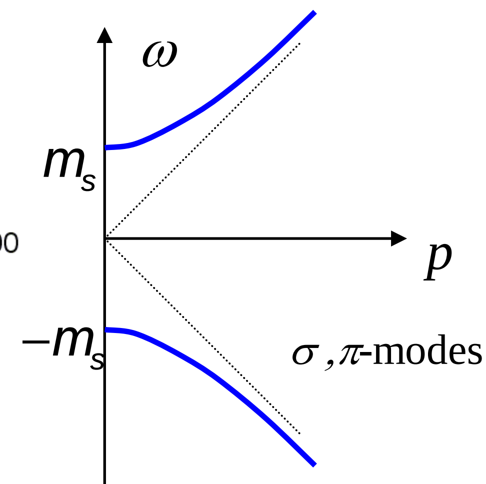


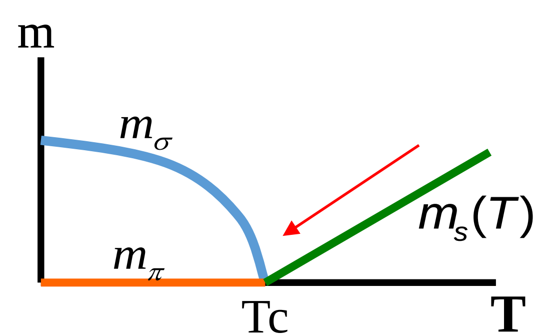
- spectrum of the fluctuations of the chiral condensate

(Hatsuda-Kunihiro 85)

T = 1.1Tc
μ=0



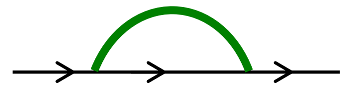




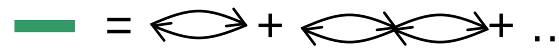
quark spectrum

(Kitazawa-Kunihiro-YN 07)

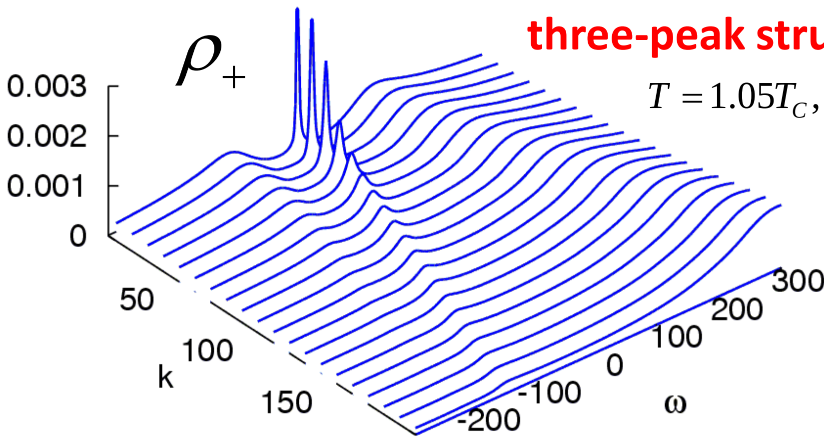
quark self-energy: $\Sigma(p_0, p)$:



fluctuations



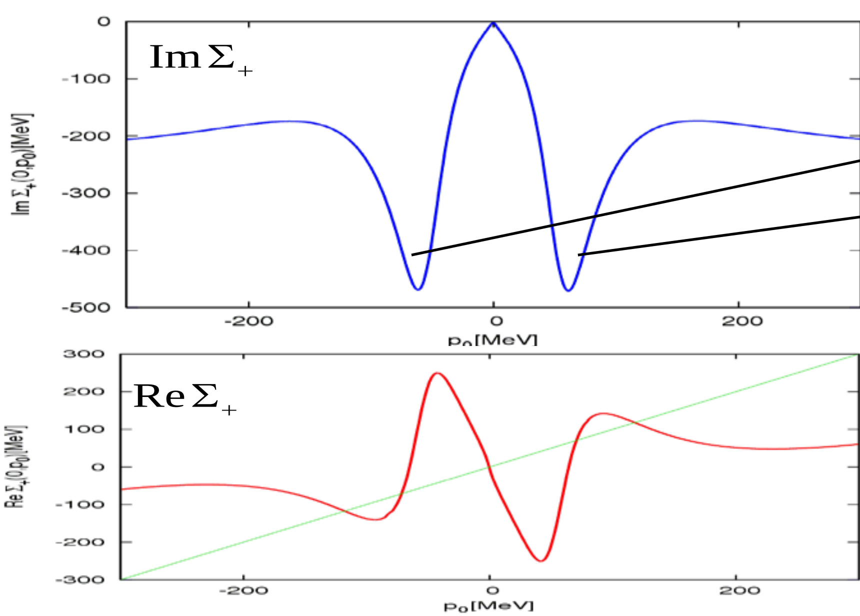
quark spectral function:

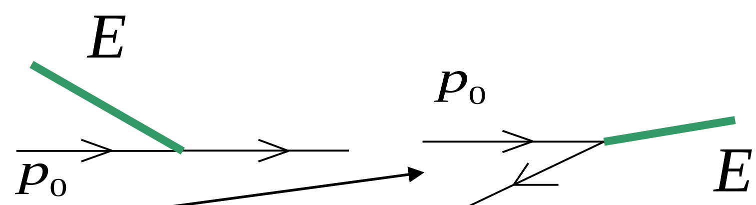


three-peak structure

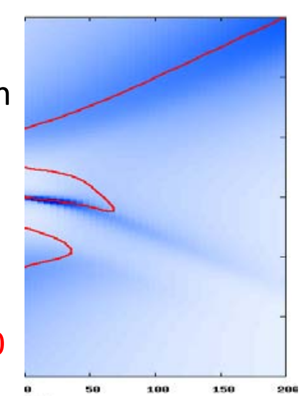
$T = 1.05T_C, \mu = 0$

The scattering off the fluctuations forms the three-peak structure.





Contour of
the spectral funcion

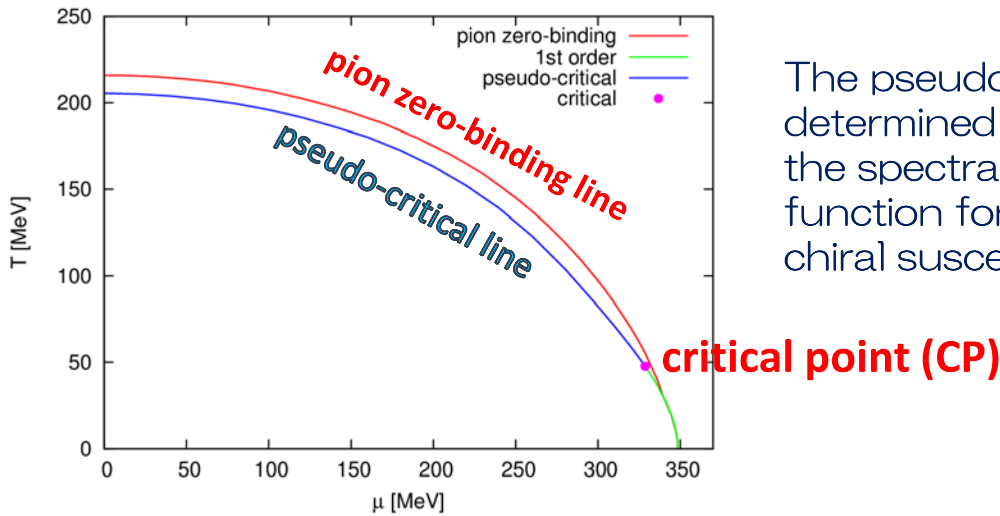


red lines:
$\omega - |\mathbf{p}| - \mathrm{Re}\Sigma_+ = 0$

This study: FINITE current quark mass

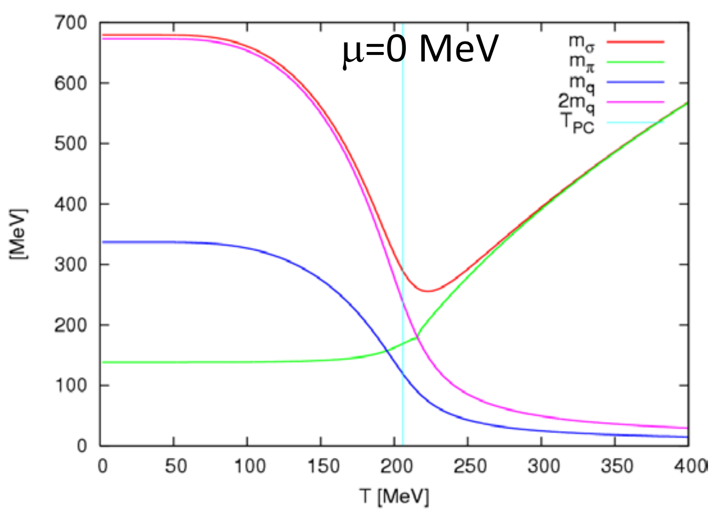
- **phase diagram of the chiral phase transition**

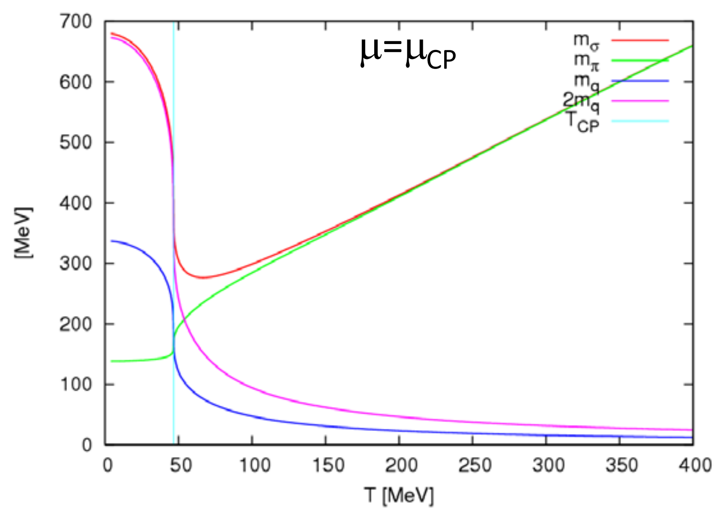
current quark mass: 5.5 MeV



The pseudo-critical line is determined from a maximum of the spectral function for p=10 MeV (dynamic chiral susceptibility).

- **masses of the sigma, pion, and dynamical quark**





Soft mode near CP

The sigma meson has still a non-zero mass at CP,
because the chiral symmetry is explicitly broken.

What is the soft mode at CP?

The soft mode is **not** the sigma mode, but appears in the **space-like** region.

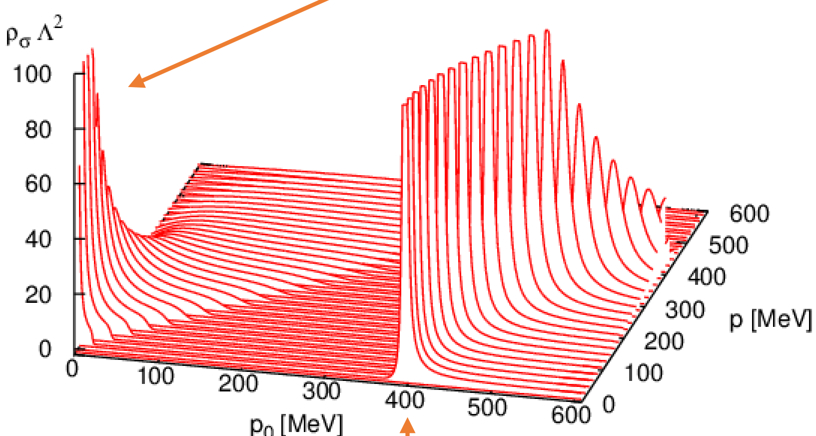
(Fujii 03, Fujii-Ohtani 04)

scalar density fluc.
$\langle \bar{q}q(p,p_0)\bar{q}q(0,0)\rangle$

pseudo-scalar density fluc.
$\langle \bar{q}i\gamma_5\tau q(p,p_0)\bar{q}i\gamma_5\tau q(0,0)\rangle$

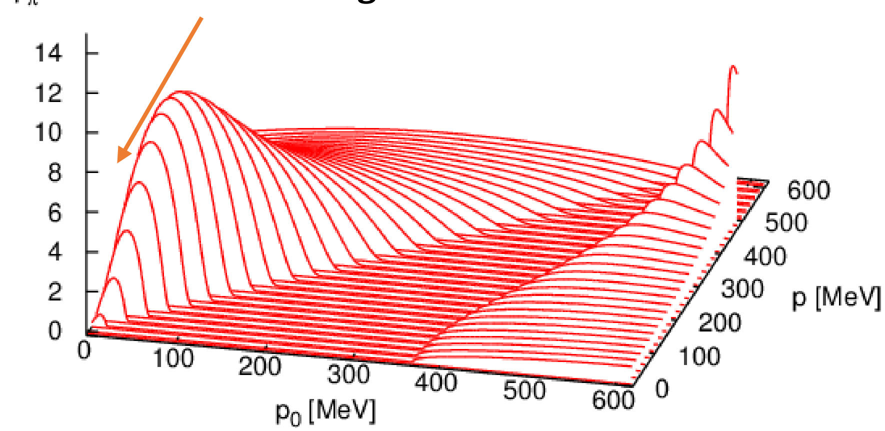
$\mu = \mu_{CP}, T \sim T_{CP}$

softneing



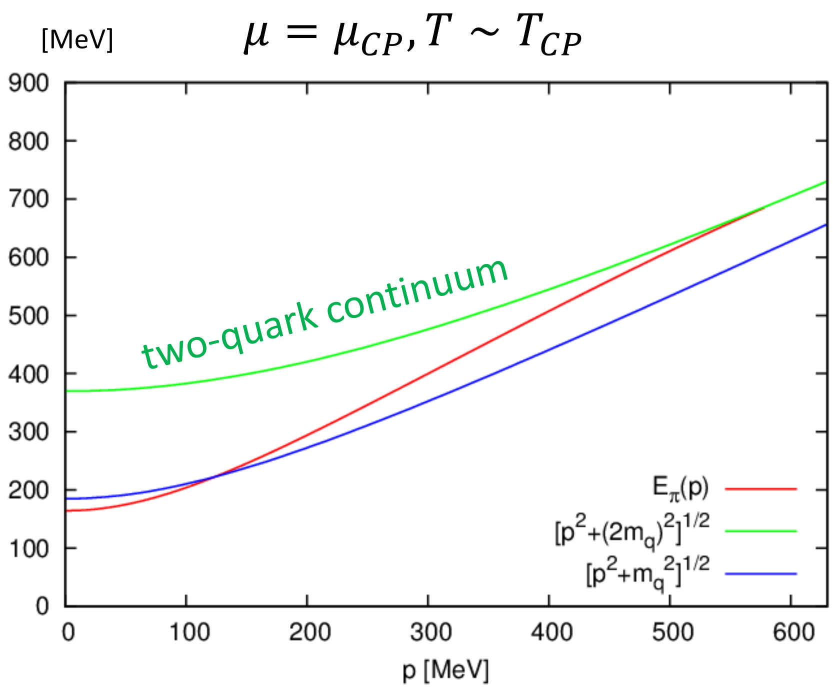
sigma meson, $m_\sigma \sim 2m_q$

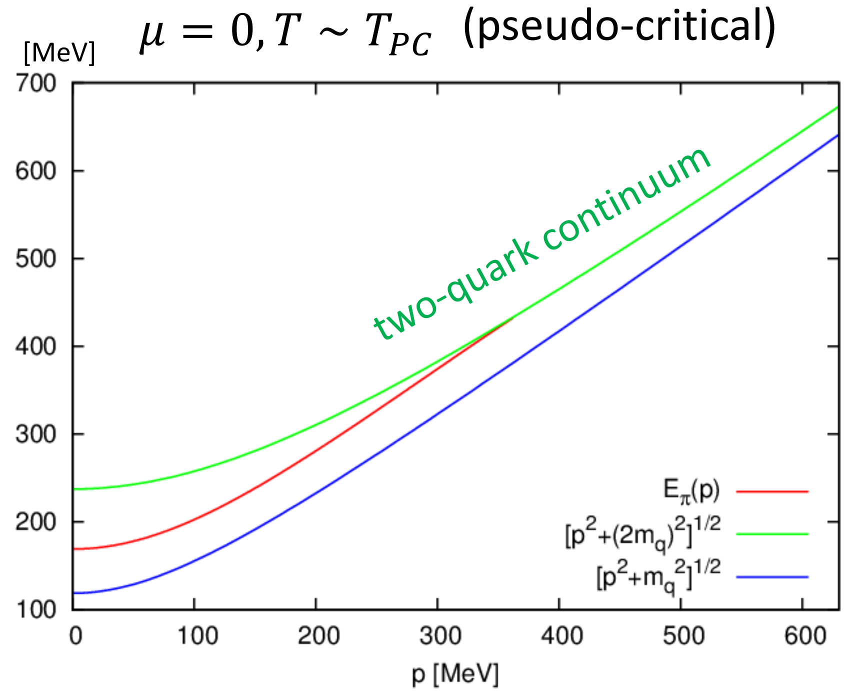
NOT softneing



pion pole: not shown

pion dispersion relations in medium





m_q: dynamically generated (constituent) quark mass (mean field)

pion dispersion relation:

$$E_\pi(p) \neq \sqrt{p^2 + E_\pi(0)^2}$$

c.f: fermion and gauge boson in HTL

Quark spectrum near CP

•Quark spectral function $\rho_{\pm}$ for p=0

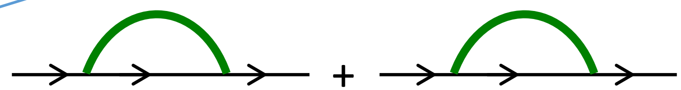
$$\rho_{\pm}(p_0,0) = -\frac{1}{\pi}\mathrm{Im}\frac{1}{p_0+\mu\mp m_q-\Sigma_{\pm}(p_0,0)}$$

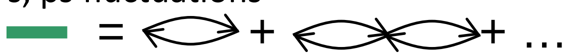
self-energy

scalar fluc.

pseudo-scalar fluc.

s, ps fluctuations

$\Sigma =$ 



soft mode
space-like
sigma mode
time-like (cont.)

pi mode
time-like
(pole or cont.)

ex. pion pole contribution

pion pole residue

BE dist. Func.

FD dist. Func.

$$\mathrm{Im}\,\Sigma_+(0,p_0) \sim \int^{\Lambda} dq\left(1-\frac{m}{E_q}\right)Z(E_\pi(q))\delta(p_0-E_q+\mu-E_\pi(q))\left(1+n(E_\pi(q))-f(E_q-\mu)\right)$$

$$+\left(1-\frac{m}{E_q}\right)Z(E_\pi(q))\delta(p_0-E_q+\mu+E_\pi(q))\left(n(E_\pi(q))+f(E_q-\mu)\right)$$

$$+\left(1+\frac{m}{E_q}\right)Z(E_\pi(q))\delta(p_0+E_q+\mu-E_\pi(q))\left(n(E_\pi(q))+f(E_q+\mu)\right)$$

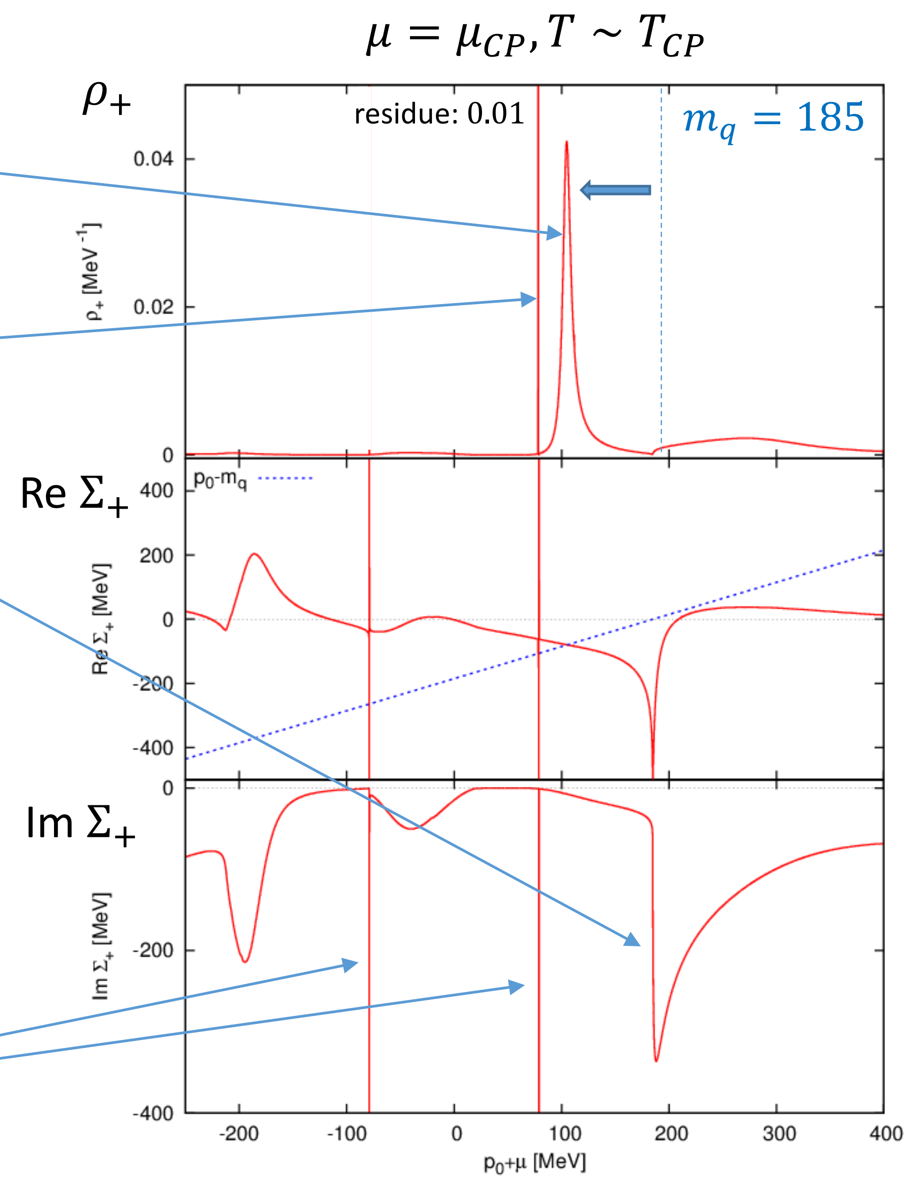
$$+\left(1+\frac{m}{E_q}\right)Z(E_\pi(q))\delta(p_0+E_q+\mu+E_\pi(q))\left(1+n(E_\pi(q))-f(E_q+\mu)\right)$$

Quark spectrum near the critical point

- quark spectrum:
  - one peak at 120 MeV

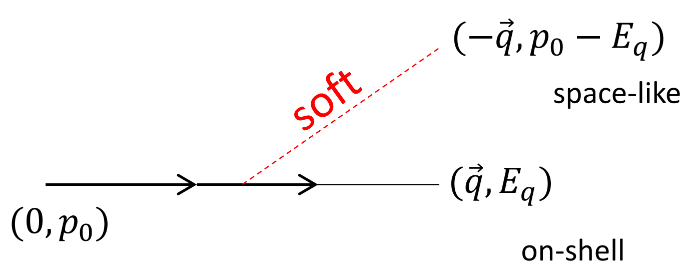
    shift by coupling with
    the soft mode
  - the other peak at 80 MeV

    but small residue ∼0.01



- self-energy
  - large imaginary around 200 MeV

    through the below process



  - divergence at ± 80 MeV

    van Hove singularities

van Hove singularity

- **van Hove singularity = divergence of density of states**
  - density of states $D(E)$

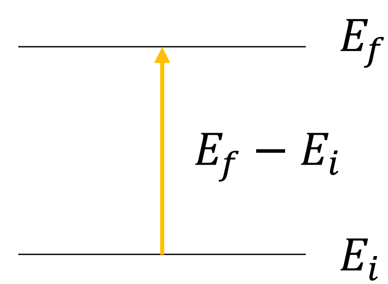
$$D(E)dE = \int_{E<E(p)<E+dE} d^3p \sim \frac{1}{|\nabla_p E(p)|} dE$$

$D(E)$ diverges when $E(p)$ has a maximum.

ex: plasmino in HTL

  - joint density of states

$$D(E)dE = \int_{E<E_f-E_i<E+dE} d^3p \sim \frac{1}{|\nabla_p (E_f - E_i)|} dE$$



$D(E)$ diverges when $E_f(p) - E_i(p)$ has a maximum.

present case