Plasmino and Thermal mass in hQCD:

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Based on

arXiv:1205.3377 + To appear. Y.seo+Y.Zhou+SS
For Detail, Y.Zhou's talk

Fermion In hot Medium: T>>m,

$$S(\omega,\mathbf{p}) = \frac{1}{\omega\gamma_0 - \mathbf{p}\cdot\boldsymbol{\gamma} - \Sigma(\omega,\mathbf{p})}$$

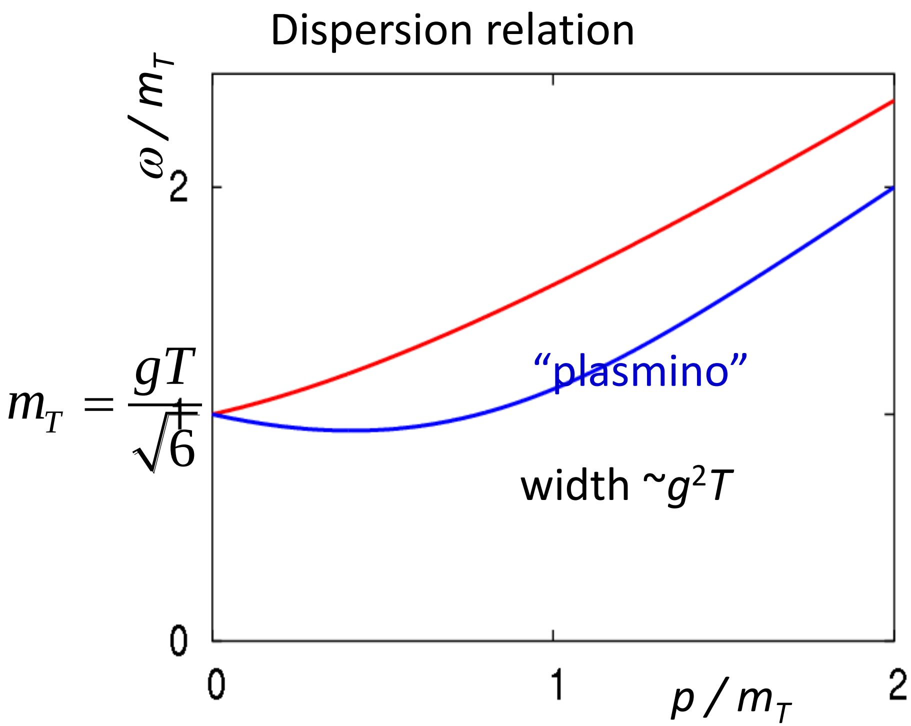
In Hard Thermal loop approximation

1. Thermal mass(Klimov ’82, Weldon ’83)

$$m_T = \frac{gT}{\sqrt{6}}$$

2. Plasmino : New collective mode (Braaten, Pisarski ’89)

Plasmino



- The plasmino mode has a minimum at finite ***p***.

$$p << m_f : \quad \omega_\pm(p) \simeq \pm \frac{1}{3} p \ ,$$
$$p >> m_f : \quad \omega_\pm(p) \simeq p \ .$$

Importance

- Van Hove singularity.
  Density of state is enhenced in low dim.

$$\rho(\omega) = \sum_n \int \frac{d^3k}{(2\pi)^3}\delta(\omega - \omega_n(k))$$

$$= \sum_n \int \frac{dS}{(2\pi)^3}\frac{1}{\nabla_k \omega_n(k))}$$

New mechanism of SC…..
Enhenced dilepton production …..(Thoma ph/0008218)

However

- Resummation needs ladder approximation,
  not justified for strong coupling.

It is not clear whether plasmino continues to exit in the strong coupling limit.

& .....

RHIC exp. says sQGP!

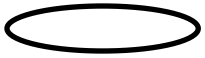
- Need new ideas
  for thermal mass and plasmino

- Duality (strong—weak: g—1/g)

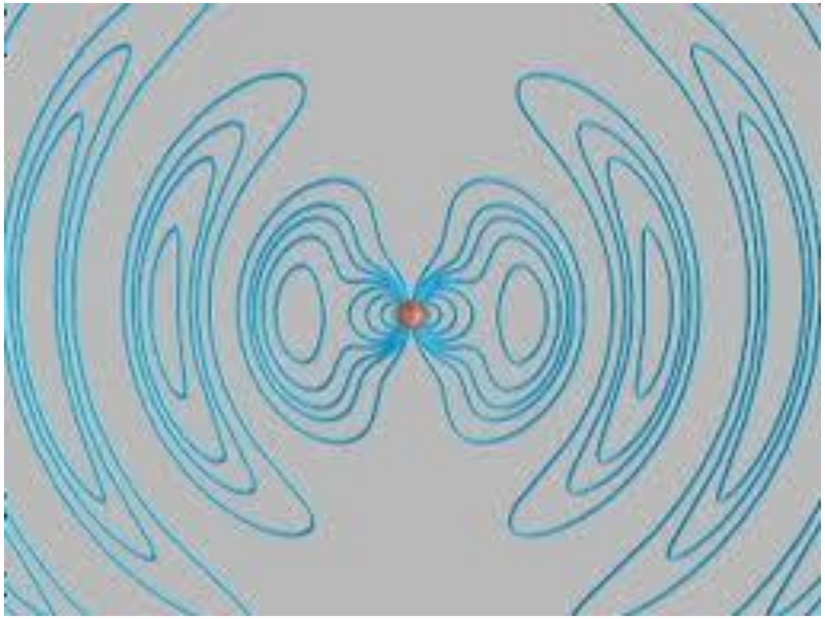
Open – closed duality

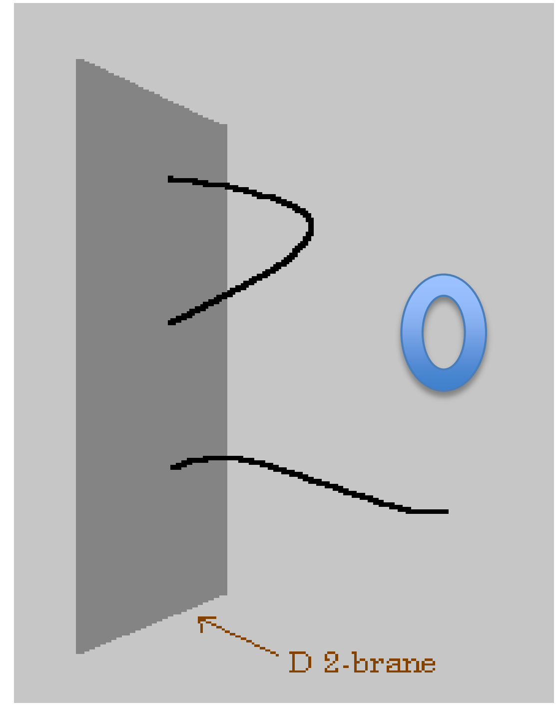
- Open String : gauge theory
  Theory of Matter

- Closed string: gravity
  Theory of space-time



Analogy





D-brane = electron.

Open string: dipole motion of electron.

AdS=Coulomb field.

Closed string: radiation field.

AdS/CFT=electron motion ~ its radiation field.

Consequence of duality

1. Gluon dynamics is replaced by ads gravity.

2. For large N, gravity is weakly coupled.

3. Correlation function in 4d can be calculated by the classical dynamics at the 5 dim AdS. → holographic.

Meaning of extra dimension

Einstein eq. encodes RG flow.

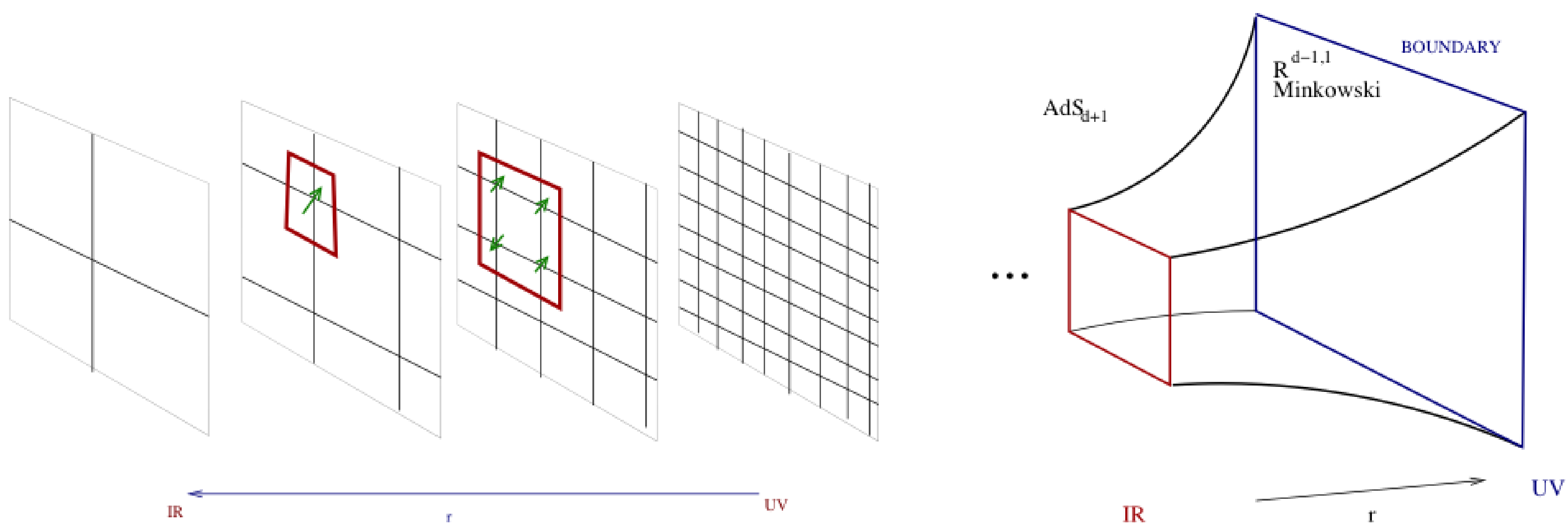


Figure 1. The left figure indicates a series of block spin transformations labelled by a parameter r. The right figure is a cartoon of AdS space, which organizes the field theory information in the same way. In this sense, the bulk picture is a hologram: excitations with different wavelengths get put in different places in the bulk image.

Figure from 1101.0597 by Faulkner et.al

So far applied to

- Viscosity
- Jet quenching
- Thermalization
- Elliptic flow
- Symmetry Energy ….

- Super conductivity
- Quantum Hall
- Non-fermi Liquid …….

Back to the thermal mass

Set up

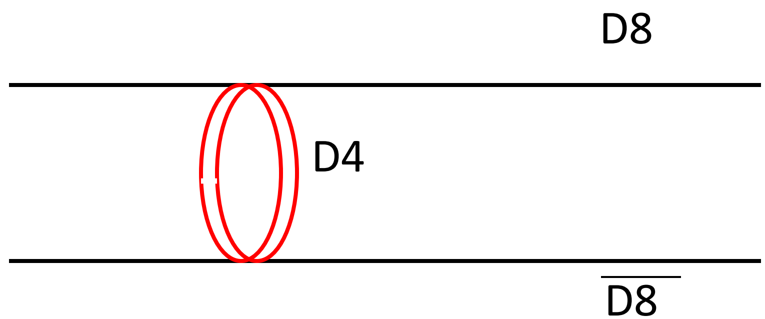
- Use D4/D8/D8bar : SS model :
  Confinement(cf): by solitonic bg.
  Deconfinement (dcf): Black hole bg.

- Chiral Symmetry breaking: Joined D8/D8bar

- Density/chemical potential: U(1) gauge field (sourced by the strings emanating from horizon of the BH or compact D4 (baryon vertex).)

The D4-D8-$\overline{D8}$ System

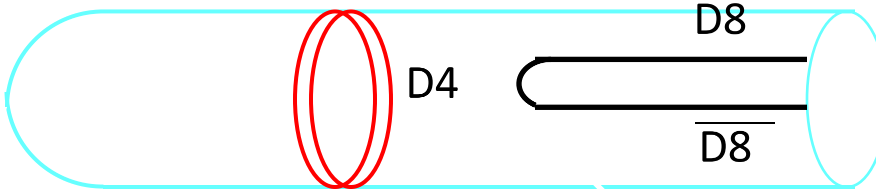
Sakai,Sugimoto



	0	1	2	3	4	5	6	7	8	9
D4	x	x	x	x	x					
D8	x	x	x	x		x	x	x	x	x

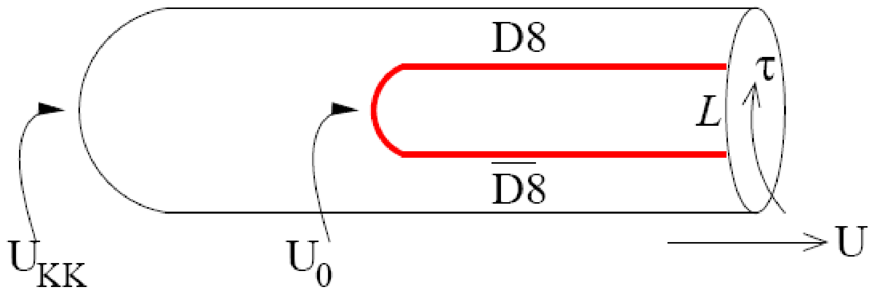
The D4-D8-$\overline{\text{D8}}$ System

Sakai,Sugimoto;
Aharony,Sonnenschein,Yankielowicz



	0	1	2	3	4	5	6	7	8	9
D4	x	x	x	x	x					
D8	x	x	x	x		x	x	x	x	x

D4 brane geometry



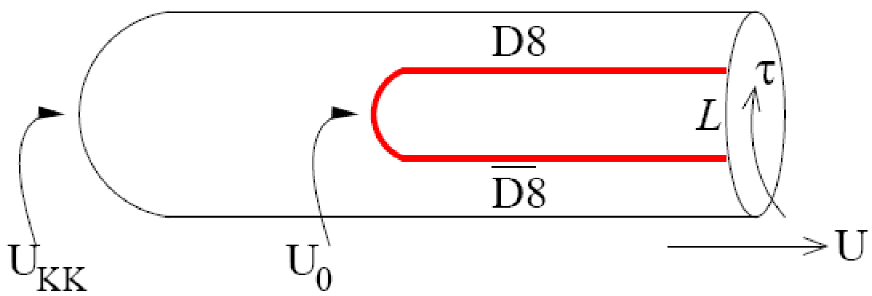
$$ds^2 = \left(\frac{U}{R}\right)^{3/2} \left(\eta_{\mu\nu} dx^\mu dx^\nu - f(U) d\tau^2\right) - \left(\frac{R}{U}\right)^{3/2} \left(\frac{dU^2}{f(U)} + U^2 \, d\Omega_4^2\right)$$

$$f(U) = 1 - \frac{U_{KK}^3}{U^3} \qquad R^3 = \pi g_s N l_s^3$$

τ period: $4\pi R^{3/2}/(3U_{KK}^{1/2})$

Probe brane limit $N_f \ll N_c$

Karch,Katz



D8-brane action

$$S_{DBI} = -T \int d^9x \, e^{-\phi} \sqrt{\det g_{MN}} \qquad e^{\phi} = g_s \left(\frac{U}{R}\right)^{3/4}$$

Stationary Solution:

$$f(U) + \left(\frac{R}{U}\right)^3 \frac{U'(\tau)^2}{f(U)} = \frac{U^8 f(U)^2}{U_0^8 f(U_0)}$$

$$ds^2 = \left(\frac{U}{R}\right)^{3/2} \eta_{\mu\nu} dx^\mu dx^\nu - \left(\frac{R}{U}\right)^{3/2} U^2 \, d\Omega_4^2 - \left(\frac{R}{U}\right)^{3/2} \left[\frac{1}{f(U)} + \left(\frac{U}{R}\right)^3 \frac{f(U)}{U'(\tau)^2}\right] dU^2$$

Vector mesons on the D8-branes

SU(N_f) gauge fields live on the D8-branes

$$S_{D8} = -T \int_{\mathrm{D8}+\overline{\mathrm{D8}}} d^4x\, dU\, d\Omega_4\, e^{-\phi} \sqrt{\det\left(g_{MN} + (2\pi\alpha')F_{MN}\right)}$$

$$S_{D8} \approx -\frac{3}{2}\widetilde{T}(2\pi\alpha')^2 R^3 U_{KK}^{-1/2} \cdot$$
$$\int d^4x\, dU\, \mathrm{Tr}\left[\frac{1}{2}F_{\mu\nu}F^{\mu\nu}\, U^{-1/2}\gamma(U)^{1/2} + F_{\mu U}F^{\mu U}\, U^{5/2}R^{-3}\gamma(U)^{-1/2}\right]$$

$$\gamma(U) = \frac{U^8}{U^8 f(U) - U_0^8 f(U_0)}.$$

Chemical potential, μ

$$S_{D8} = -T_8 \int d^9 x e^{-\phi} \sqrt{-\det(g_{MN} + 2\pi\alpha' F_{MN})}$$

$$\frac{r a_0'(r)}{\sqrt{r^{-3}\left(1/f(r) - a_0'(r)^2\right)}} = D$$

D=baryon density

μ value of $a_0(r)$ at the infinity,

For this, Need IR boundary cond.

$$\mu = m_*/q + \int_{r_0}^{\infty} a_0' dr.$$

If $a_0(r_0) = m_*/q$ For confining case

$a_0 = 0$ at the horizon For dcf case

Fermion on D8

- Fermion =mode of D4-D8 string
  = bi-fundamental field ψ_i^a
- When D4 is replaced by a gravity, color index is interpreted as “averaged over”
  so that D8 fermions are color averaged quarks.
- Here only 1 flavor.
- Remark: NOT a “bulk” fermion, No ads/cft.

Fermion action and eq. of M

- Ignore S4: D8 becomes effectively 5d with one dimension compactified. → 3+1 d theory.

$$S = \int d^5x\sqrt{-g}\; i\left(\bar{\psi}\Gamma^M D_M\psi - m_5\bar{\psi}\psi\right) \;,$$

$$D_M = \partial_M + \tfrac{1}{4}\omega_{abM}\Gamma^{ab} - \; iqA_M .$$

$$\psi = (-gg^{rr})^{-1/4}e^{-i\omega t + ik_i x^i}\Psi$$

$$\sqrt{g_{ii}/g_{rr}}(\Gamma^r\partial_r - m_5\sqrt{g_{rr}})\Psi + iK_\mu\Gamma^\mu\Psi = 0 \;,$$

$$K_\mu = (-v(r), k_i) \text{ and } v(r) = \sqrt{-g_{ii}/g_{tt}}(\omega + qa_0).$$

Def. of Green function

$$\Psi = (\Phi_1, \Phi_2) = (y_1, z_1, y_2, z_2)^T$$

$$G_1(r) := y_1(r)/z_1(r) \text{ and } G_2(r) := y_2(r)/z_2(r)$$

Then,

$$\sqrt{\frac{g_{ii}}{g_{rr}}}\partial_r G_\alpha + 2m_5\sqrt{g_{ii}}G_\alpha = (-1)^\alpha k + v(r) + \left((-1)^{\alpha-1}k + v(r)\right) G_\alpha^2 \ .$$

Finally,

$$G^R_{1,2} = \lim_{\epsilon \to 0} e^{-\frac{1}{2}m_5 R r^{1/4}} G_{1,2}(r)|_{r=1/\epsilon}$$

For retarded green fct, we need Boundary condition:

IR Boundary condition:
1. deconfinging case

- BC← horizon regularity
- Retarded Green function:

$$G_{1,2}(r_0) = i \ ,$$

$$v(r) = (\omega + q a_0(r)) / \sqrt{f}$$
$$a_0(r) = \mu + \int_\infty^r d\hat{r} \left(\frac{D'^2}{\hat{r}^5 + D'^2} \right)^{1/2}$$

IR Boundary condition: 2. confinging case

- For retarded(advanced) green fct

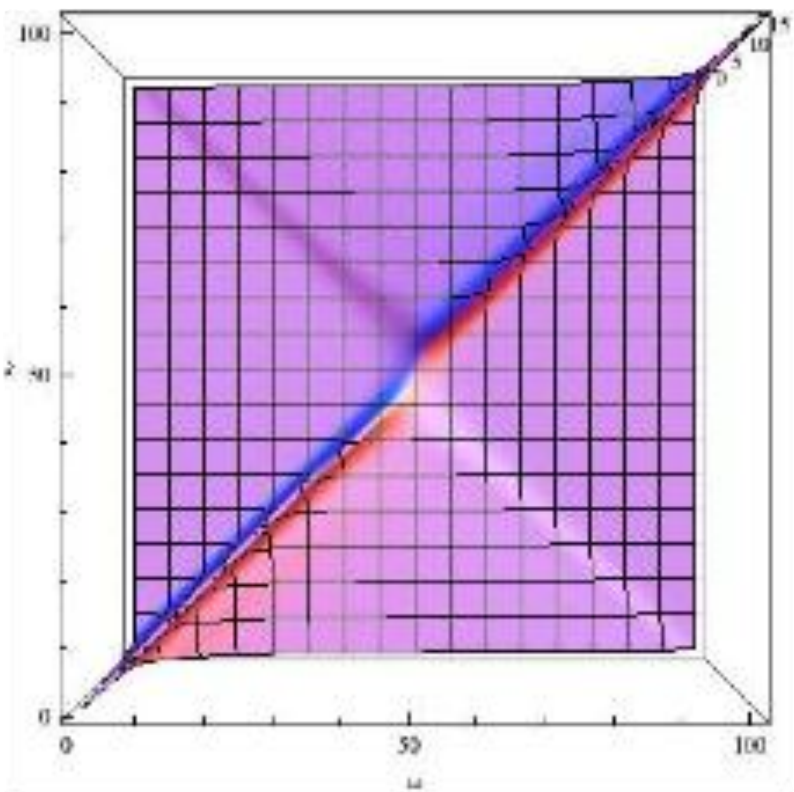
$$G_\alpha(r_0) = \frac{-mR + \sqrt{m^2R^2 + k^2 - \hat{\omega}^2}}{(-1)^\alpha k - \hat{\omega}} ,$$

where $\hat{\omega} = \omega + m_*$ and $m := m_5 r_0^{3/4}$

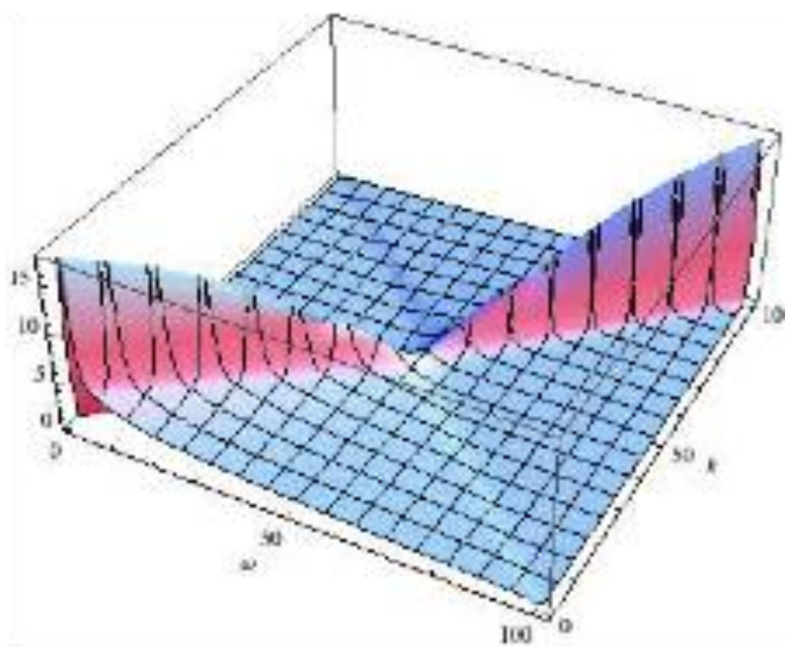
$$\omega \rightarrow \omega + i\epsilon \;\; (\omega \rightarrow \omega - i\epsilon).$$

Result for deconfing case

1. Vanishing thermal mass for zero density
2. No plasmino for zero density



(a)



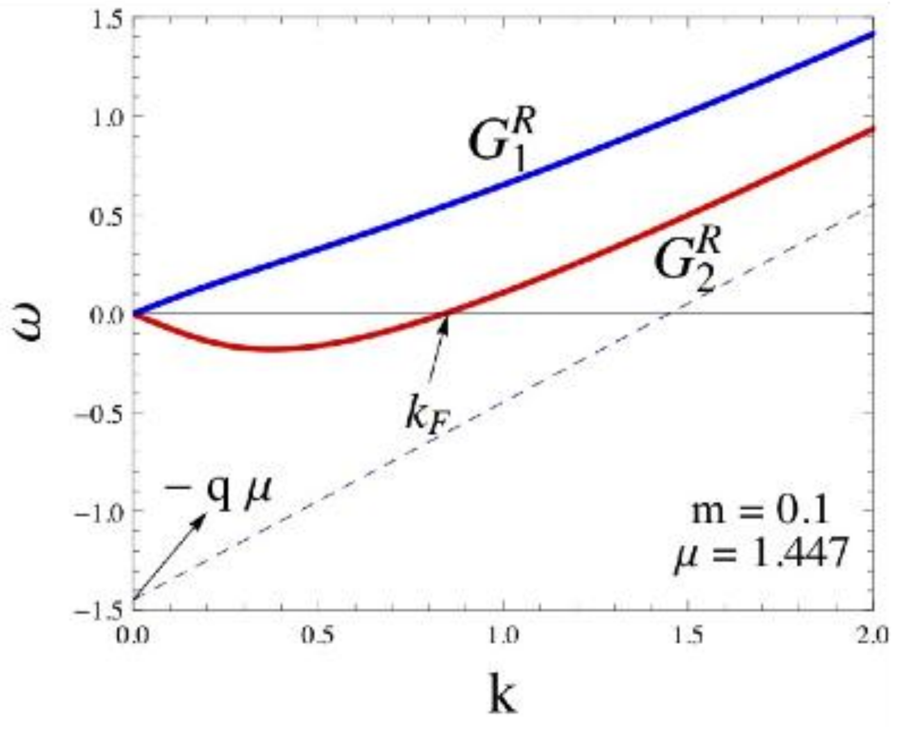
(b)

Confining case

There is Plasmino only for large but not too large chemical potential.

$$\mu_1 \leq \mu \leq \mu_2 .$$

. Extreme high density behavior is very complex and rich and will not be presented here.



Density dependence of plasmino slope at k=0.

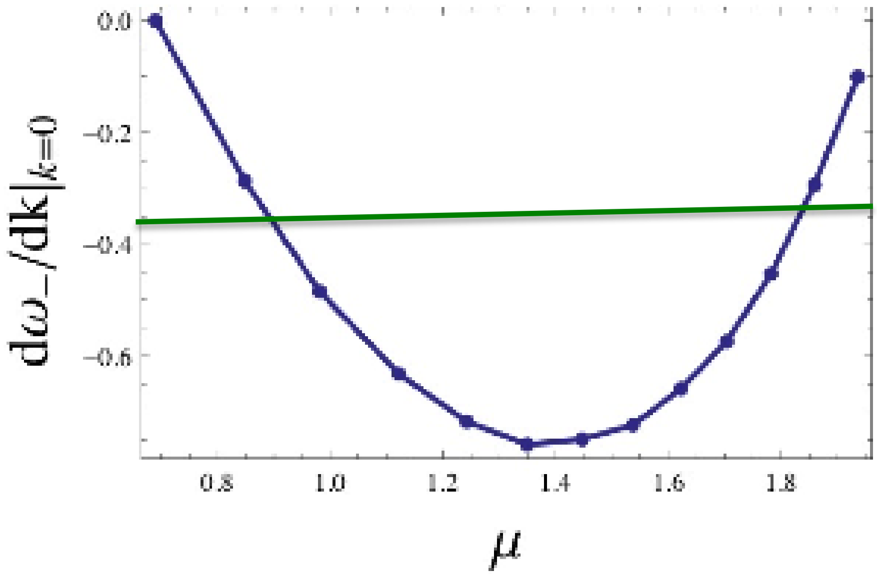


FIG. 3. μ dependence of α. The curve is plotted only in the density window where there is plasmino, namely $\mu_1 \leq \mu \leq \mu_2$.

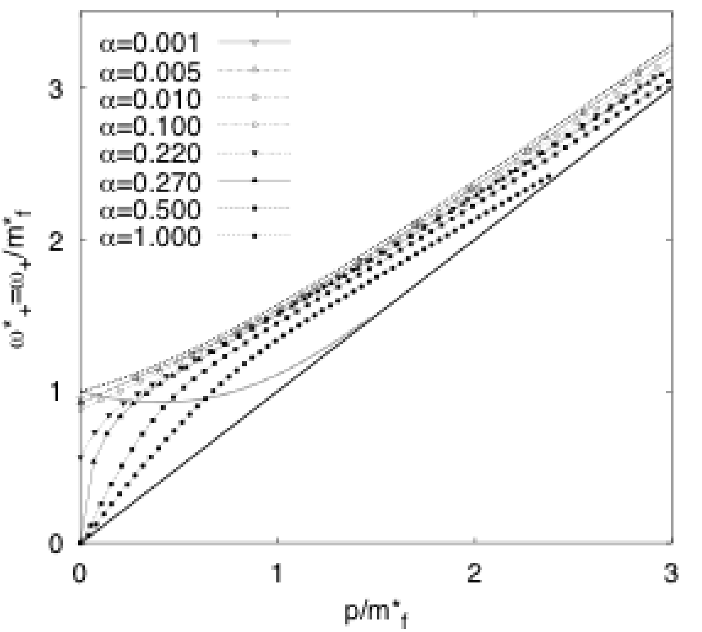
Cf: HTL

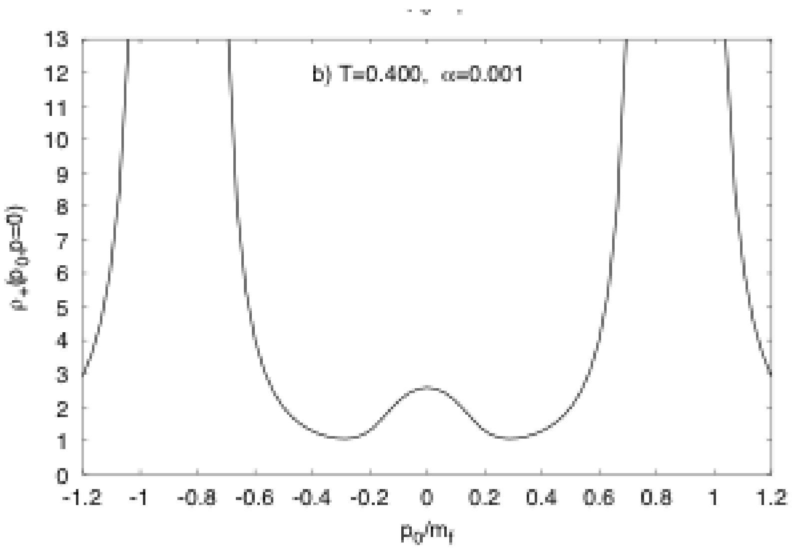
$$p << m_f : \quad \omega_\pm(p) \simeq \pm\frac{1}{3}p ,$$
$$p >> m_f : \quad \omega_\pm(p) \simeq p .$$

Related work

An interesting Numerical study suggested m_T=0.

ArXiv: 1111.0117 , Nakkagawa et.al.





However, this work is also based on SD idea.

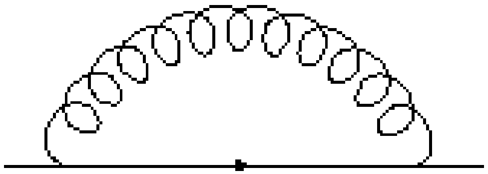
Result for deconfing case:

- If we add brane/bulk mass (curiosity), still no plasmino.
- If we add density also, then plasmino mode appears.

Meaning of no plasmino

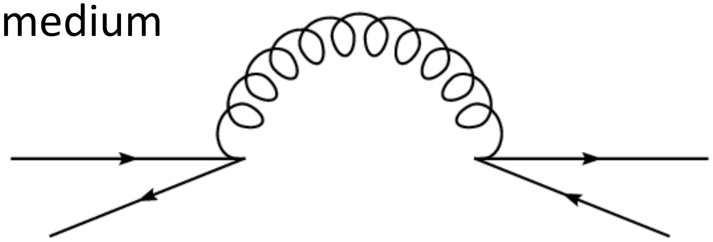
- Preliminary Q: what is the plasmino?

In vacuum



A quark is scattered by a gluon.

In medium



A quark and a thermal/density- excited anti-quark annihilate and produce a gluon.

⇒ The quark turns into the "**anti-quark hole**".

Plasmino is generic for light particle in hot thermal system as Baym et.al showed!

Meaning of no plasmino .

- Hard to avoid not creating plasmino
  as far as the quasi particle picture is valid.

- No plasmino in at 0 quark mass means
  quasi particle picture is lost.
  The system is non-fermi liquid.

- As we add chemical potential, the system
  becomes fermi liquid.

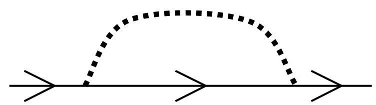
Conclusion

- Plasmino is present only in the presence of density and mass. Plasmino exist only for a window of density in CF case.
- Thermal mass is 0, in deconfined case even at zero mass limit→ non-fermi liquid.
- High Density seems to restore the fermi liquid character. Not very clear. A Future project

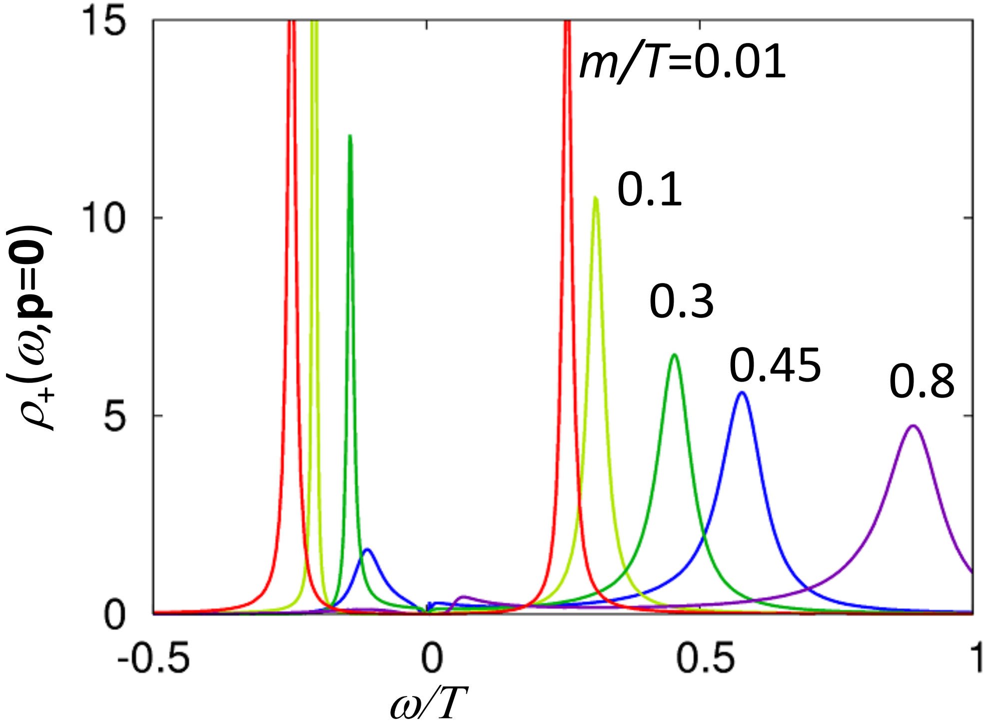
Fermion Spectrum in QED & Yukawa Model

Baym, Blaizot, Svetisky, '92

- Yukawa model: $L = i\bar{\psi}(i\not{\partial} - m_0 - g\sigma)\psi + \frac{1}{2}\partial_\mu \sigma \partial^\mu \sigma$
- 1-loop approx.:



Spectral Function for g =1 , T =1



- $m_0/T \ll 1$
  thermal mass $m_T = gT/4$
- $m_0/T \gg 1$
  single peak at m_0

Plasmino peak disappears as m_0/T larger.

From Kitazawa's 2007 talk file.