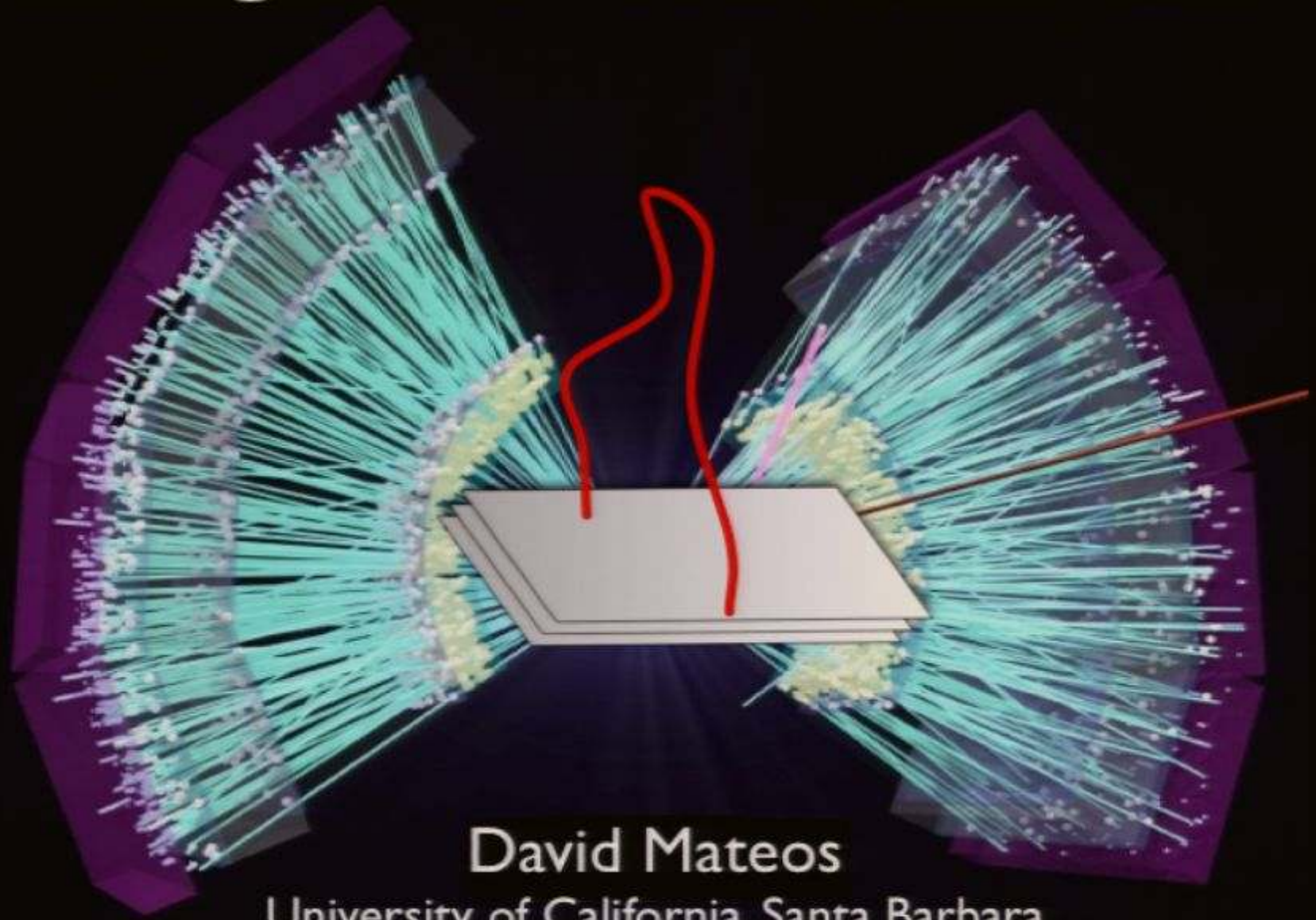
Title: Bright Branes for RHIC

Date: May 24, 2007 02:40 PM

URL: http://pirsa.org/07050069

Abstract:

Bright Branes for RHIC



David Mateos
University of California, Santa Barbara

Plan

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i) Motivational remarks.

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ii) Photon production.

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iii) Viscosity of fundamental matter.

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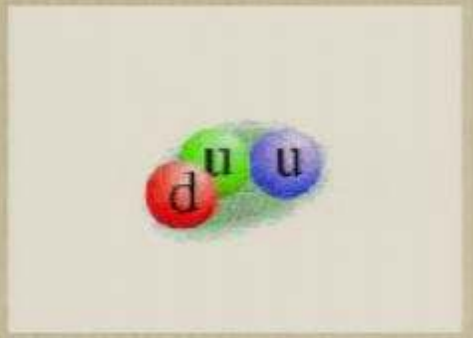
The QCD challenge



- QCD remains a challenge after 34 years!

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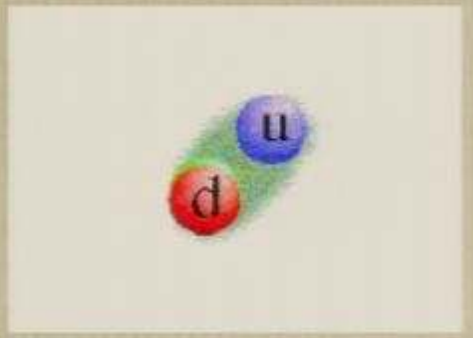

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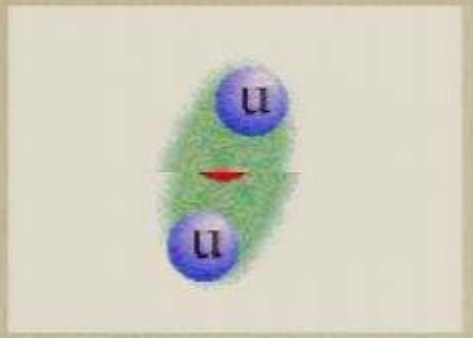

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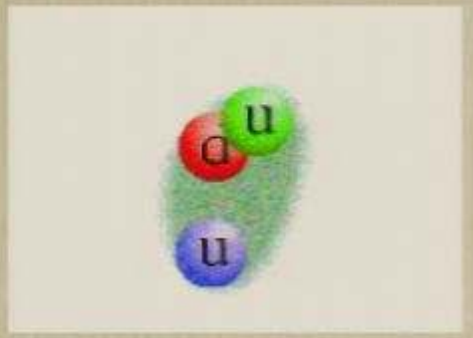

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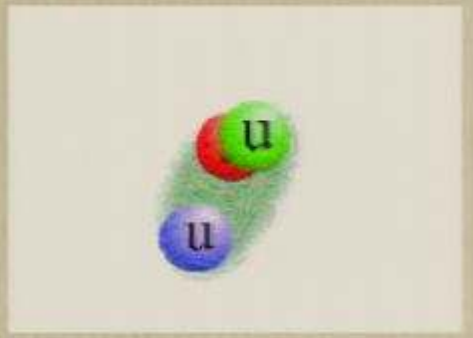

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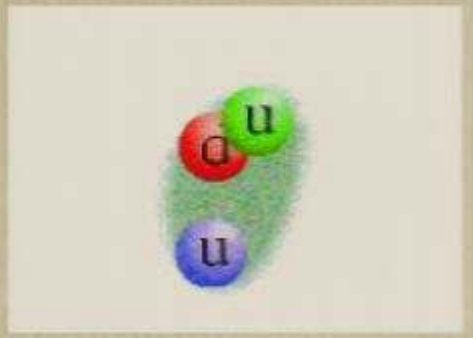

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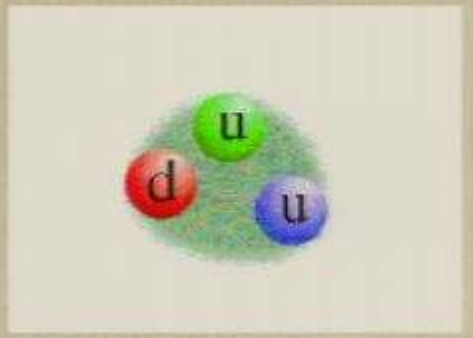

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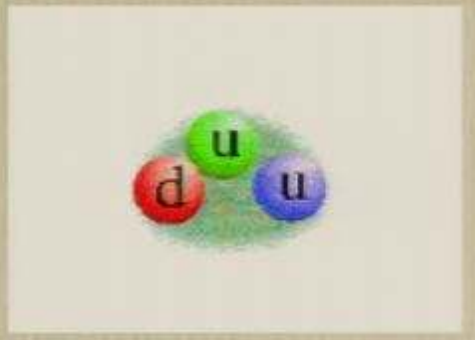

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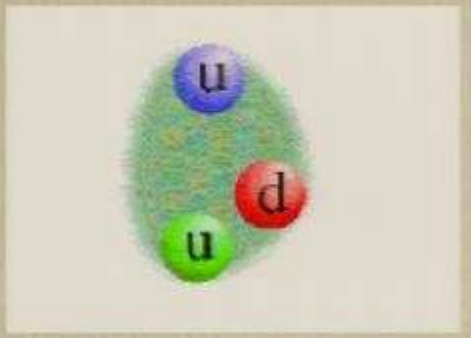

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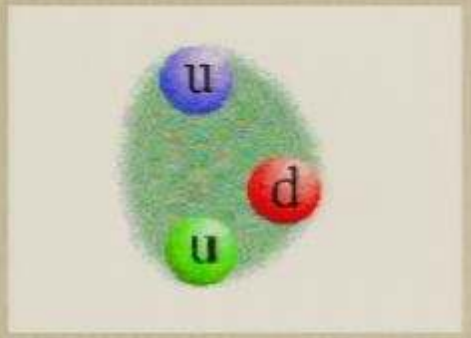

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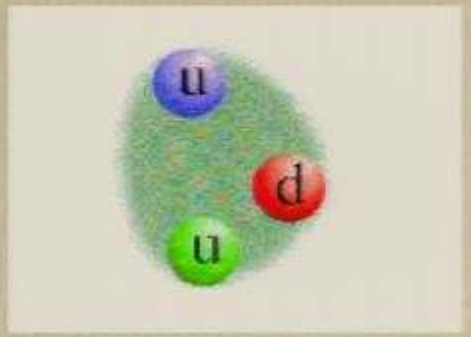

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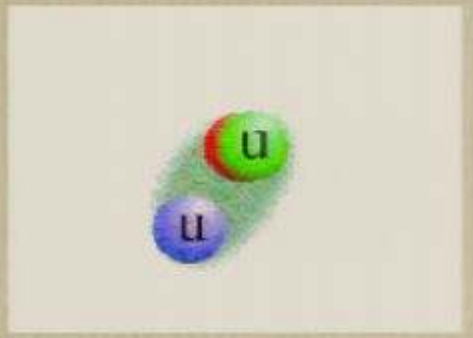

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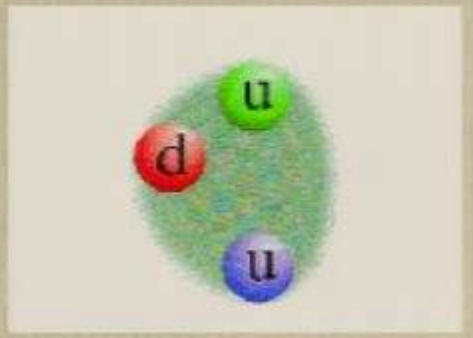

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- Same for all gauge theories with gravity dual: Different dimensions, with or without fundamental matter, with or without chemical potential, etc.

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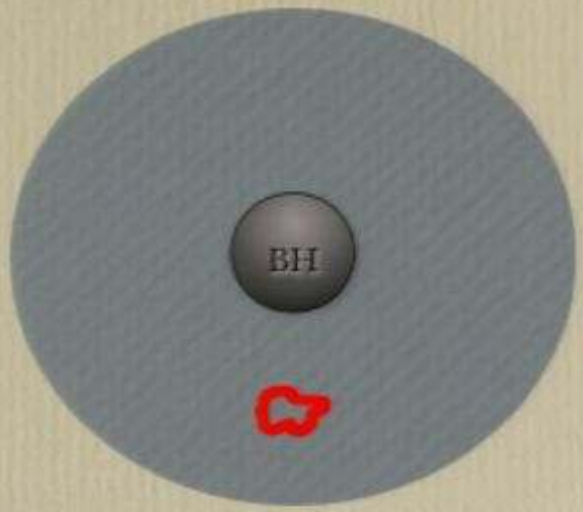
  Gravity dual of a deconfined plasma contains a black hole



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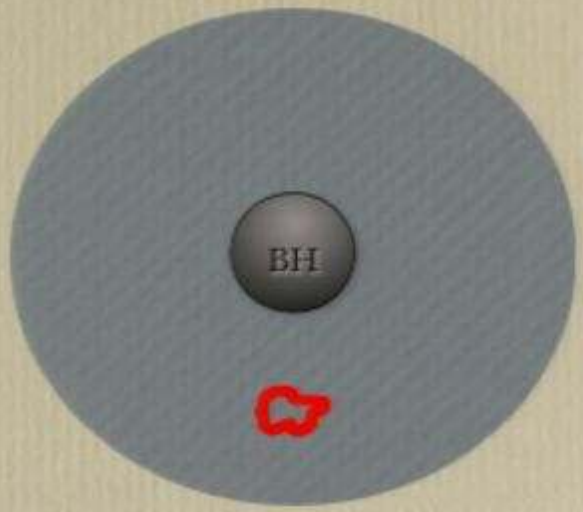
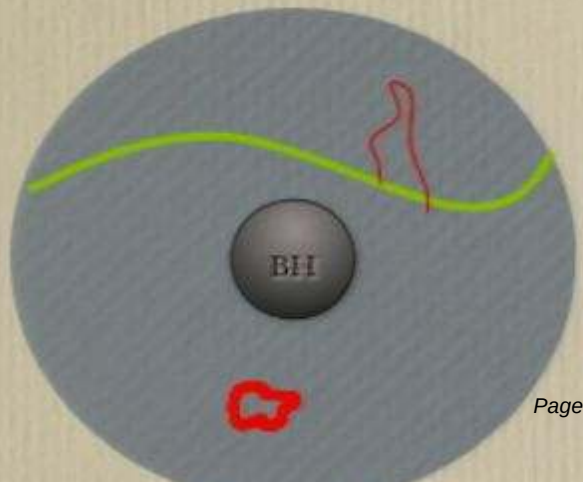


- Combine with another one:

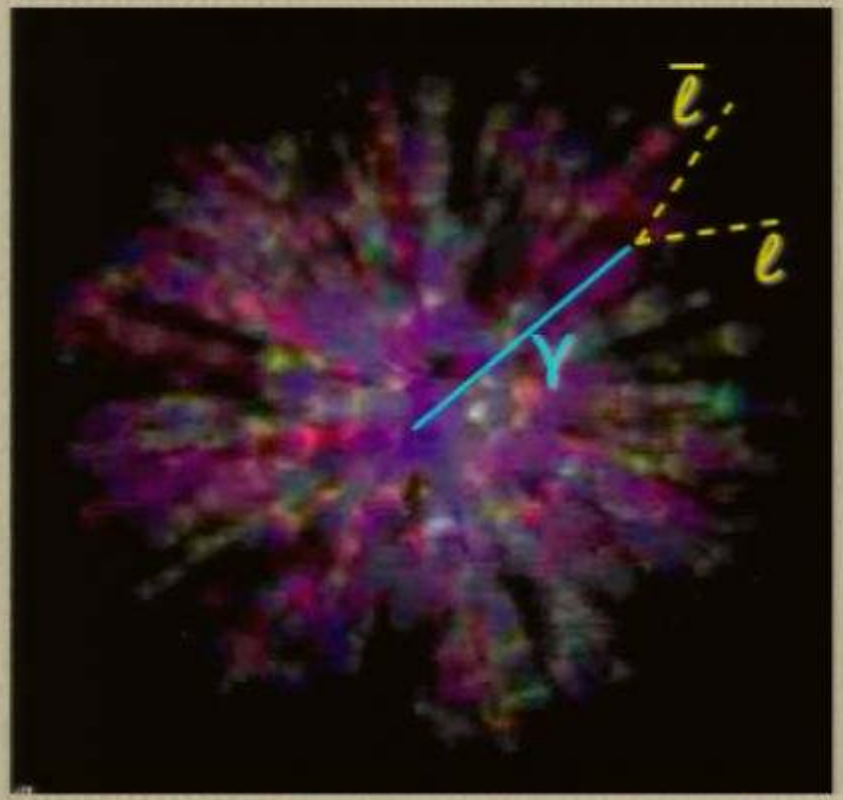
$N_f << N_c$ quark flavours correspond to N_f probe branes

Karch & Katz



ii) Photon production.

D.M., Patiño-Jaidar



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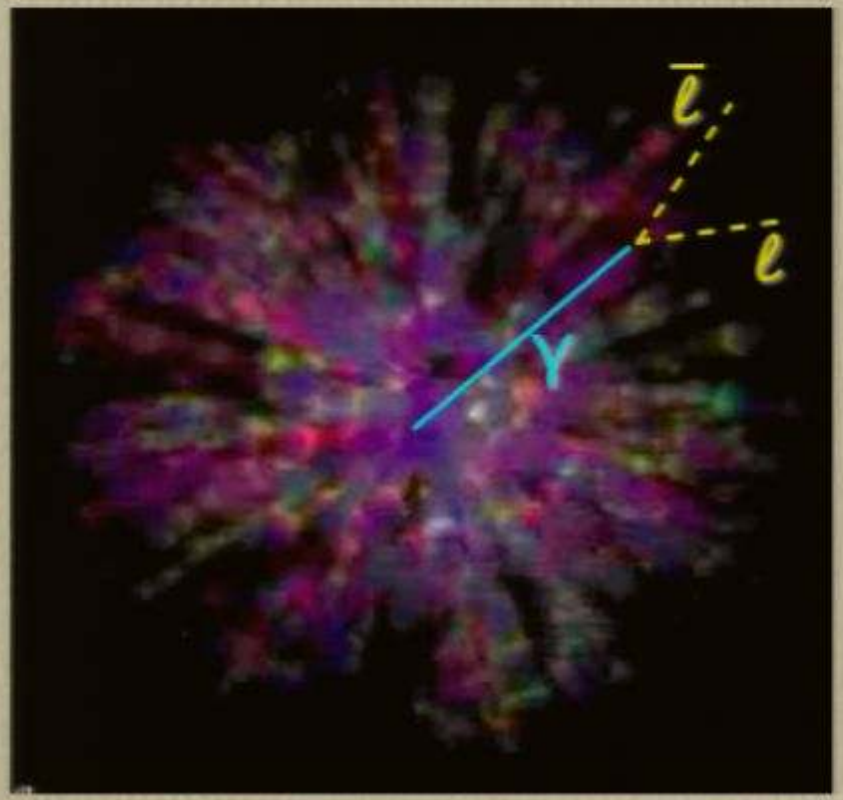

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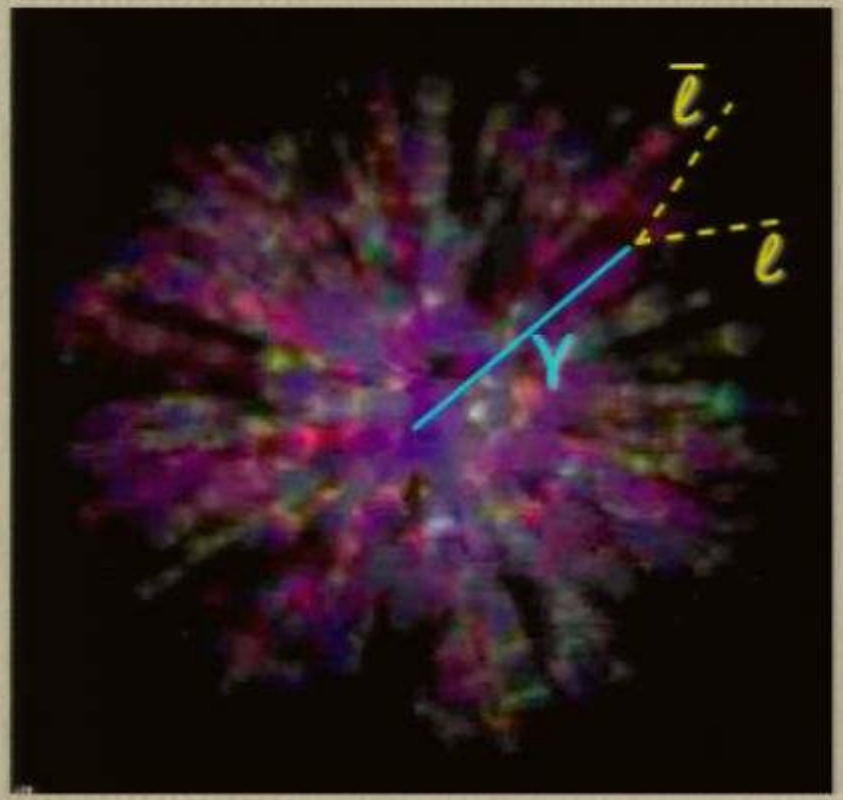

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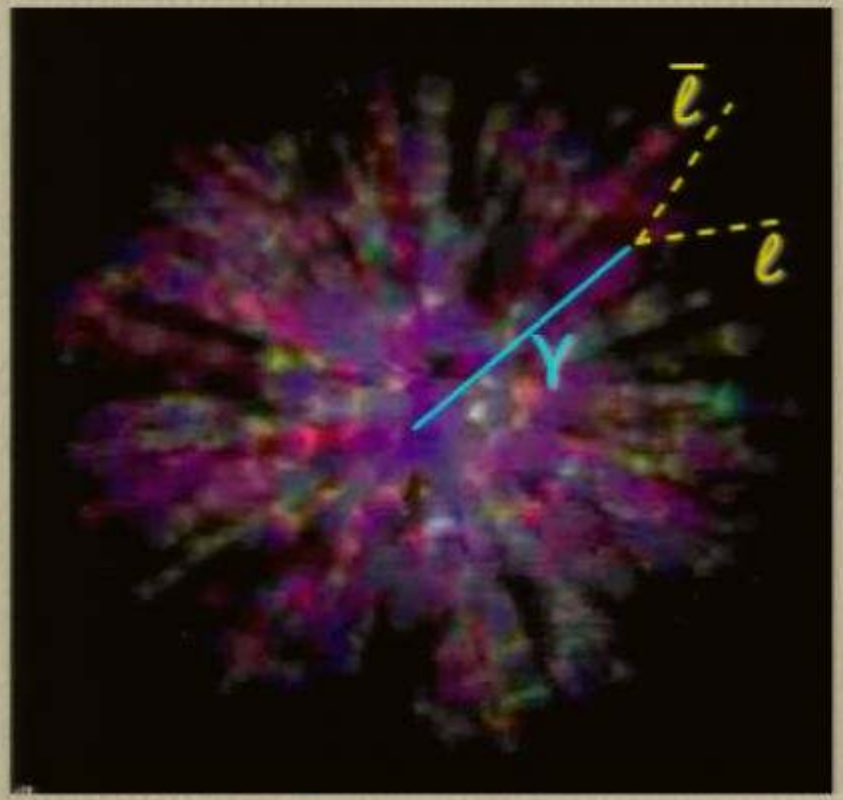

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$$\mathcal{L} = \mathcal{L}_{SU(N_c)} - \frac{1}{4}\mathcal{F}_{\mu\nu}^2 + e\mathcal{A}^\mu J_\mu^{\rm EM}$$

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- Note: We assign zero electric charge to adjoint matter.

- In this way we obtain an $SU(N_c) \times U(1)_{\rm EM}$ theory in which, to leading order in "e":

$$\frac{d\Gamma}{d^d\mathbf{k}} = \frac{e^2}{(2\pi)^d\, 2|\mathbf{k}|}\, \frac{1}{e^{k^0/T}-1}\, \eta^{\mu\nu}\chi_{\mu\nu}(k)$$

$k = (k^0, \mathbf{k})$, with $k^0 = |\mathbf{k}|$, is the photon null momentum

$\chi_{\mu\nu}(k) = -2\,\mathrm{Im}\, G^{\rm R}_{\mu\nu}(k)$ is the spectral density

$$G^{\rm R}_{\mu\nu}(k) = -i \int d^{d+1}x\, e^{-ik\cdot x}\, \Theta(x^0) \langle [J^{\rm EM}_\mu(x), J^{\rm EM}_\nu(0)] \rangle$$

- Thus we need correlator in $SU(N_c) \times U(1)_{\rm EM}$ theory:

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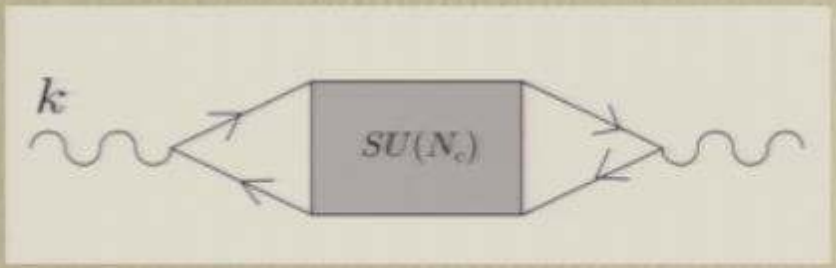
- However, to leading order in "e" we can:

  (I) Drop $\mathcal{A}_\mu$ in the current.

  (I) Compute correlator in SU(N_c) theory:



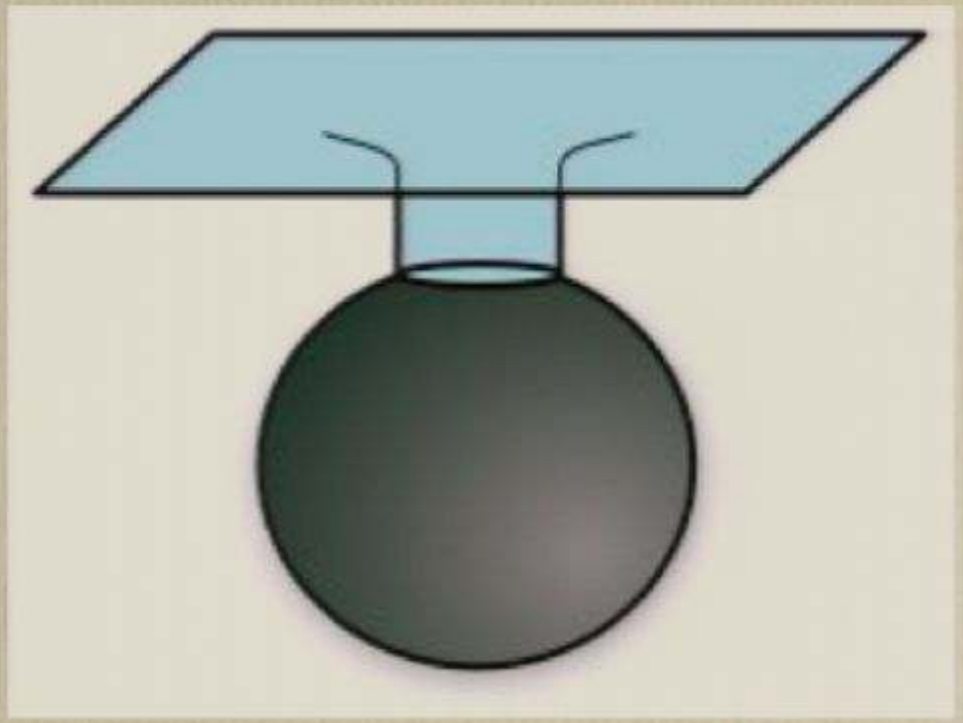
Holographic calculation

Gauge theory

N_f flavours of equal mass

String theory

N_f overlapping Dq-branes



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Conserved J_μ^{EM}

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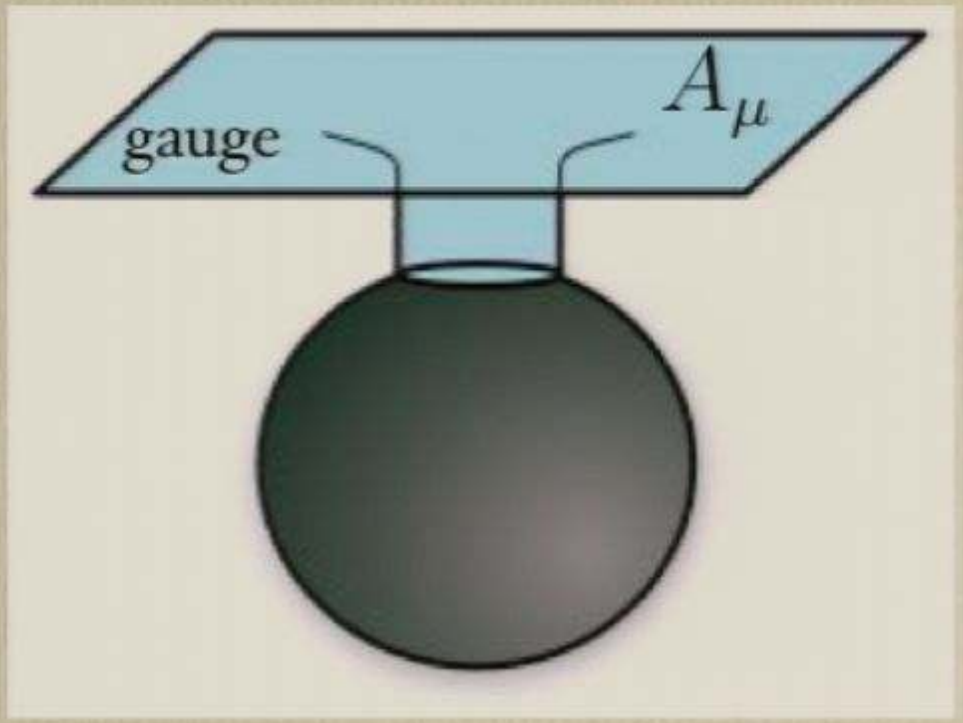

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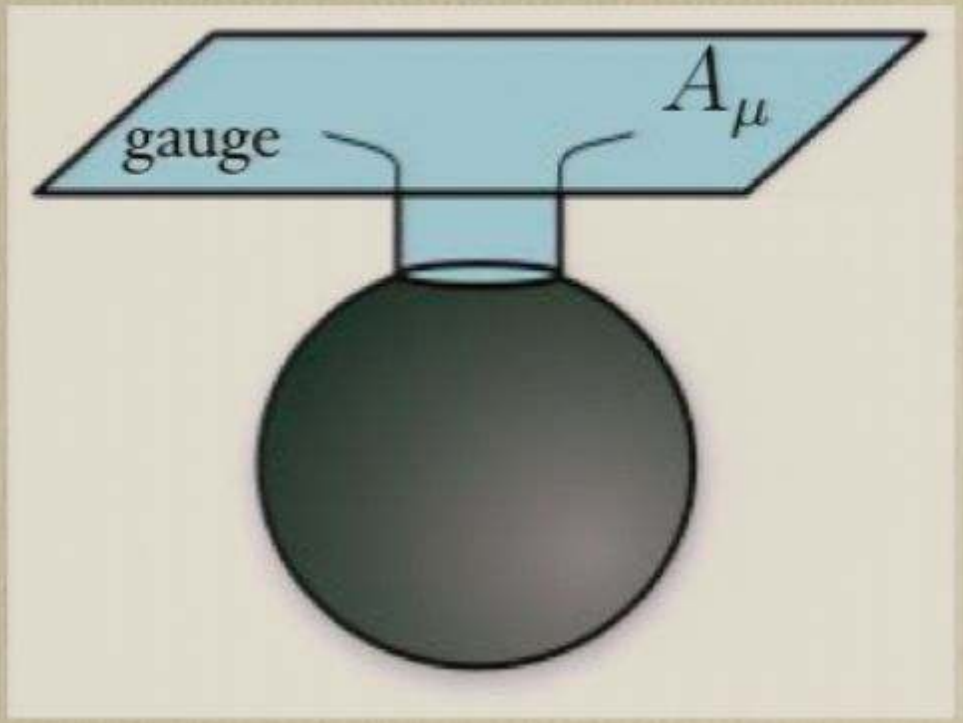

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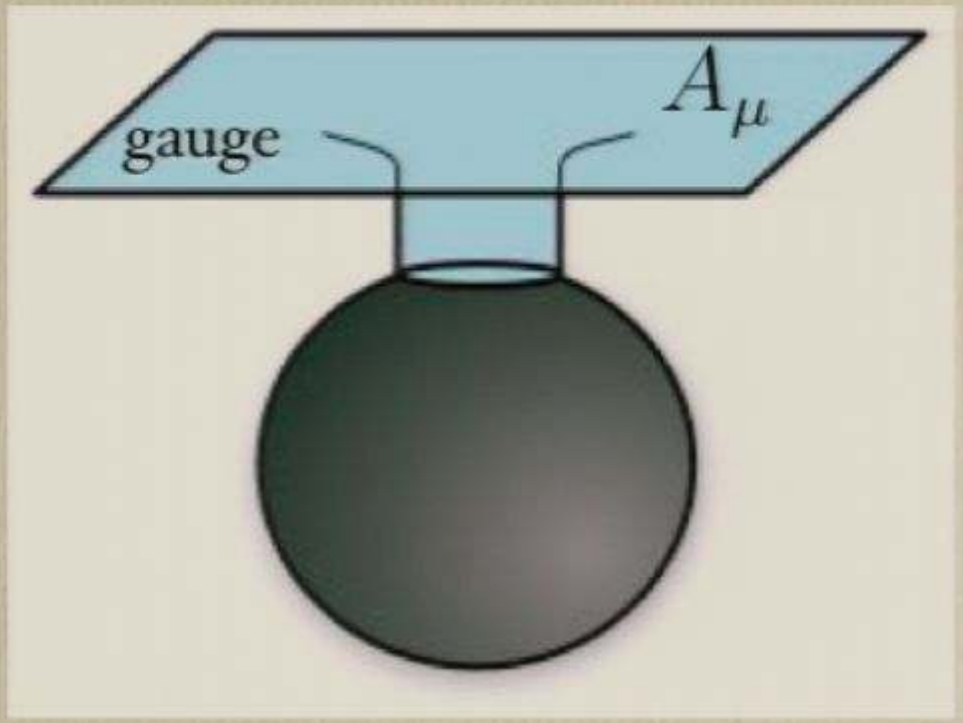
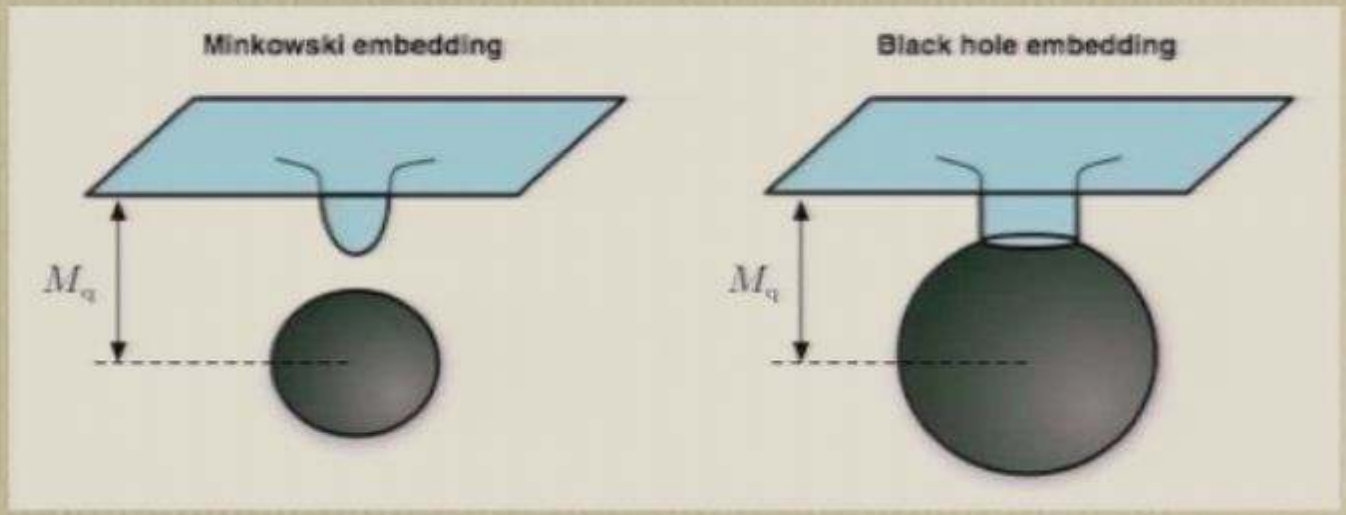


Poetically: Dynamical photon lives on the dual, `bright branes'.

Comments:

- Concentrate on BH embeddings:



$$\chi \sim \sum_n c_n \delta(p^2 + m_n^2), \qquad m_n^2 > 0$$

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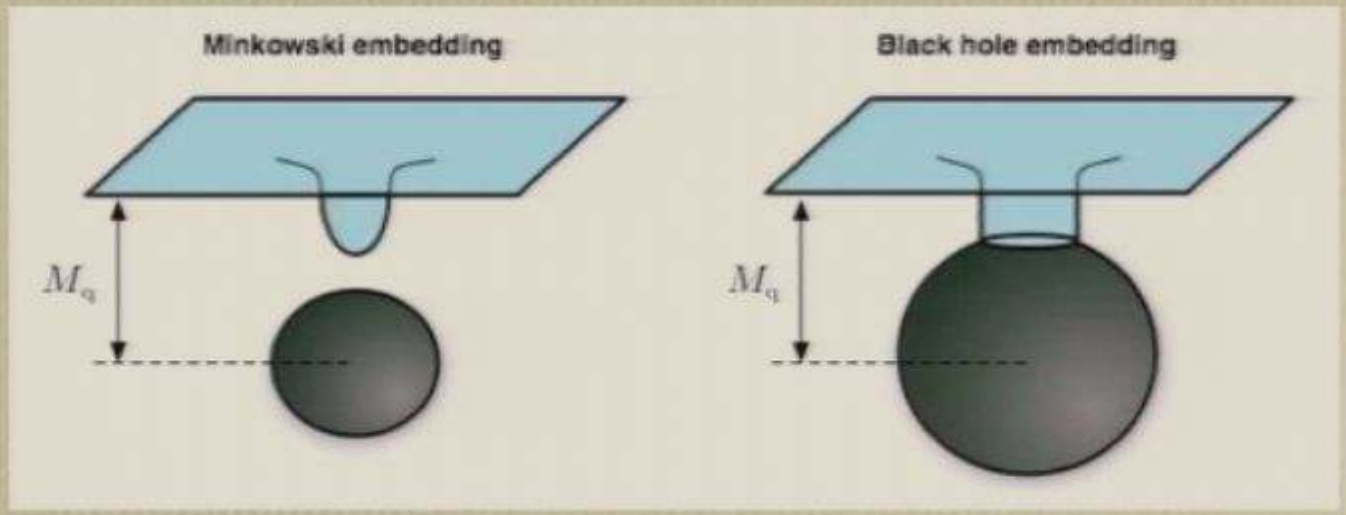

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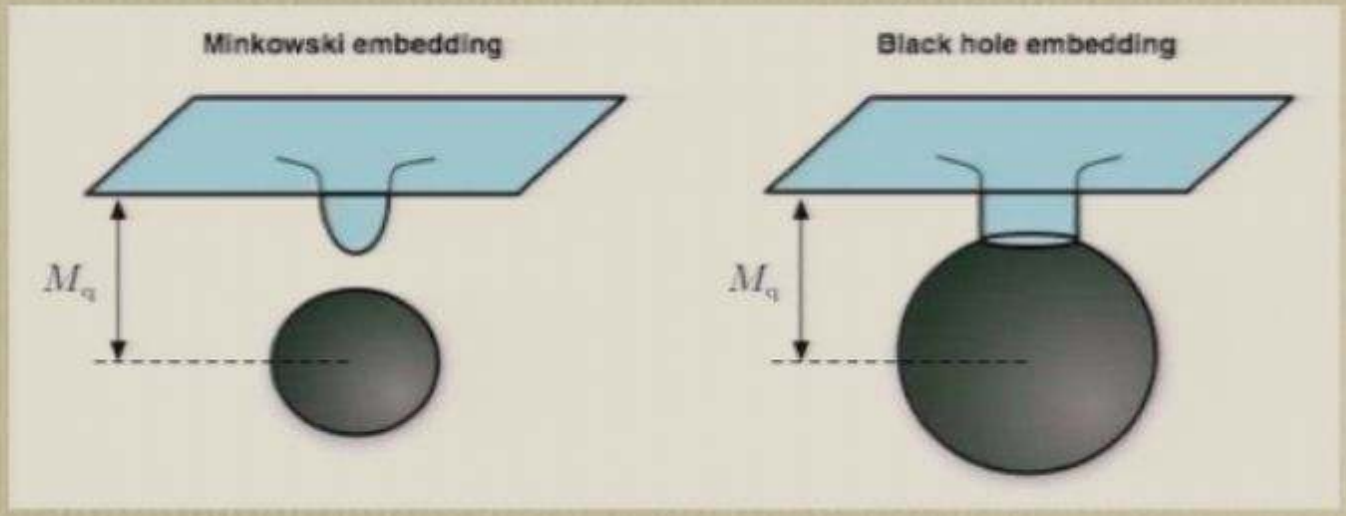

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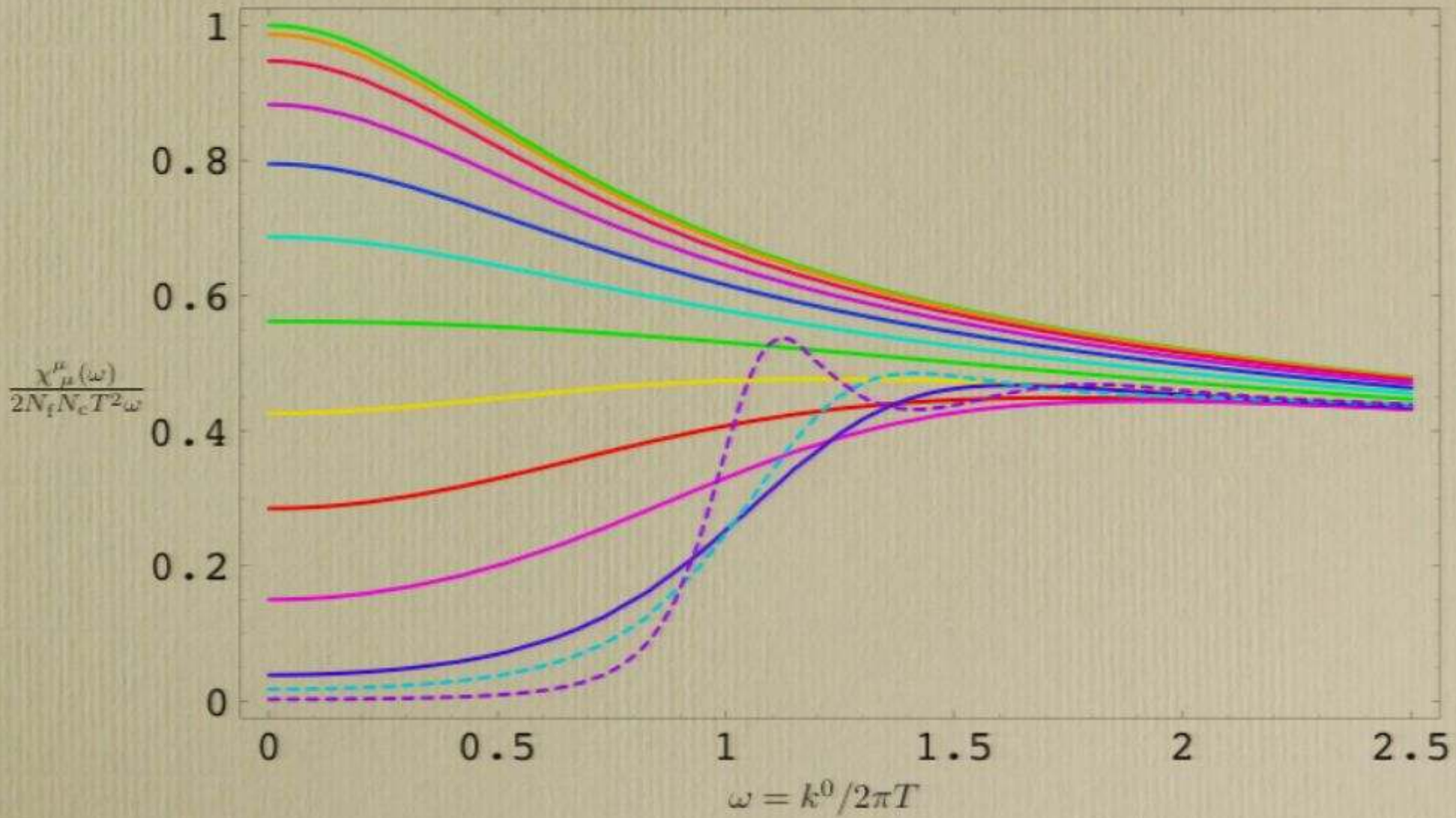
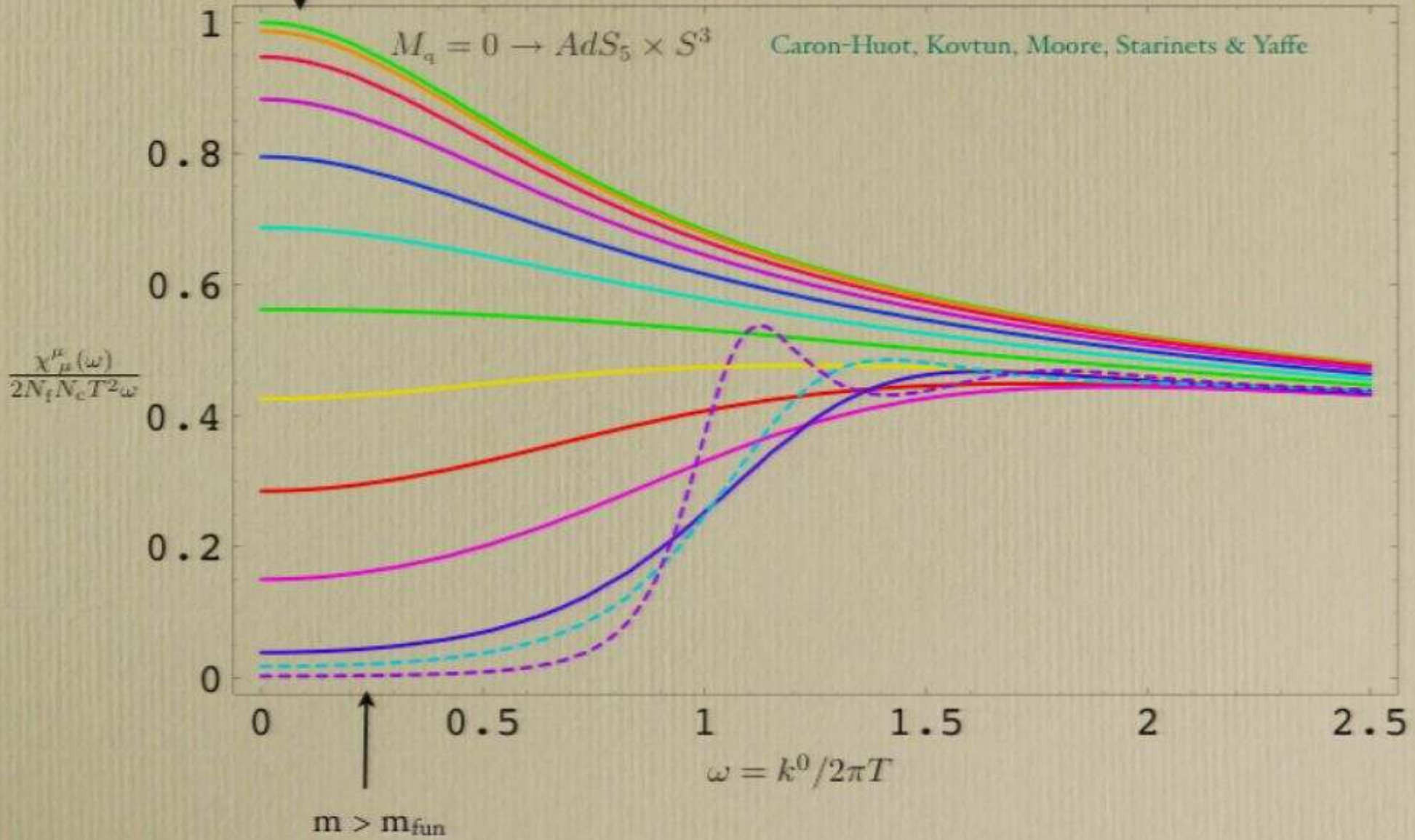
But this assumes existence of quasi-particles!

D_3/D_7


1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
$\frac{\chi^{\mu}_{\mu}(\omega)}{2N_f N_c T^2 \omega}$
$\omega = k^0/2\pi T$

D_3/D_7

$$m = \frac{2M_q}{\sqrt{\lambda}T}$$



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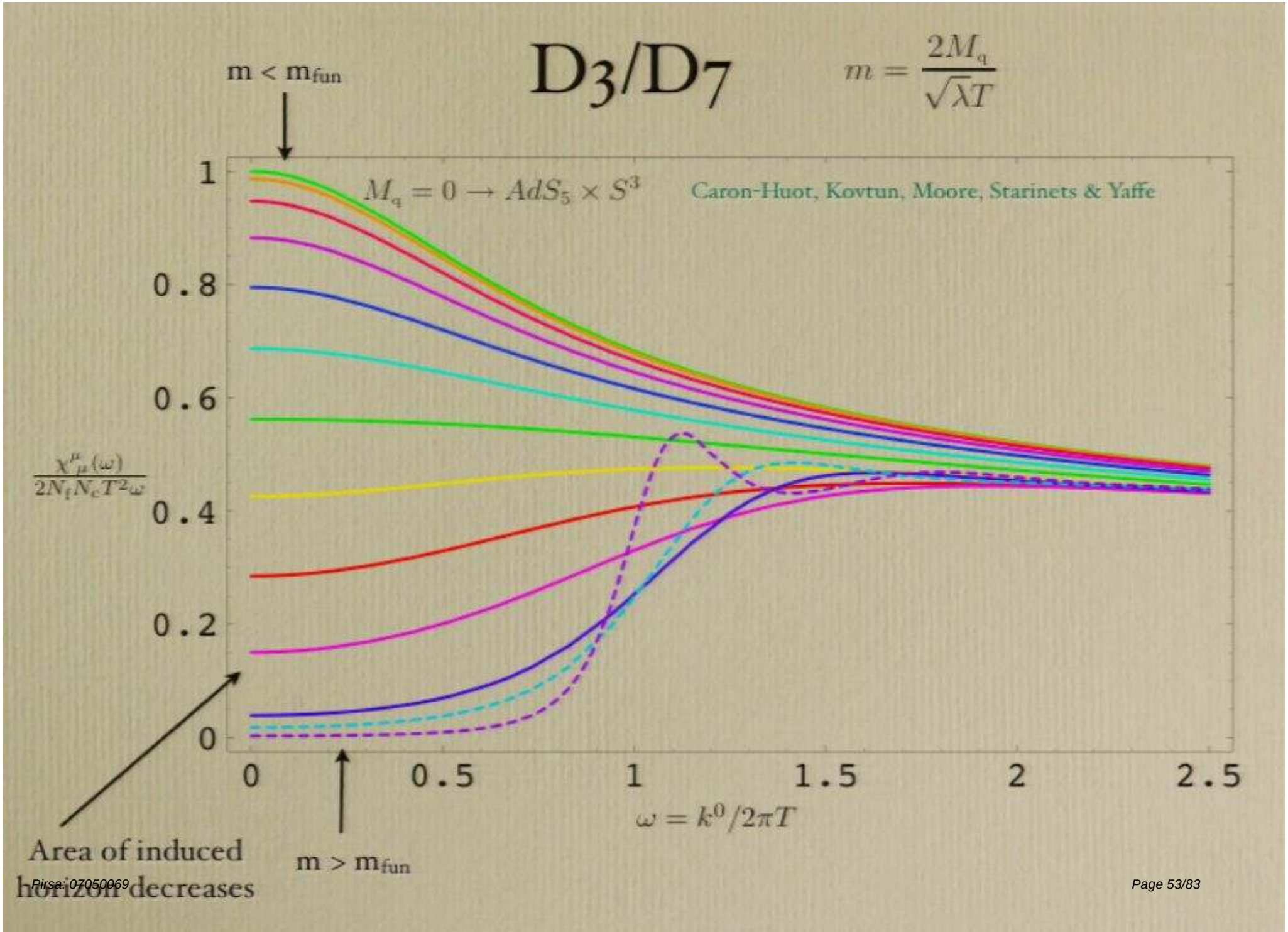

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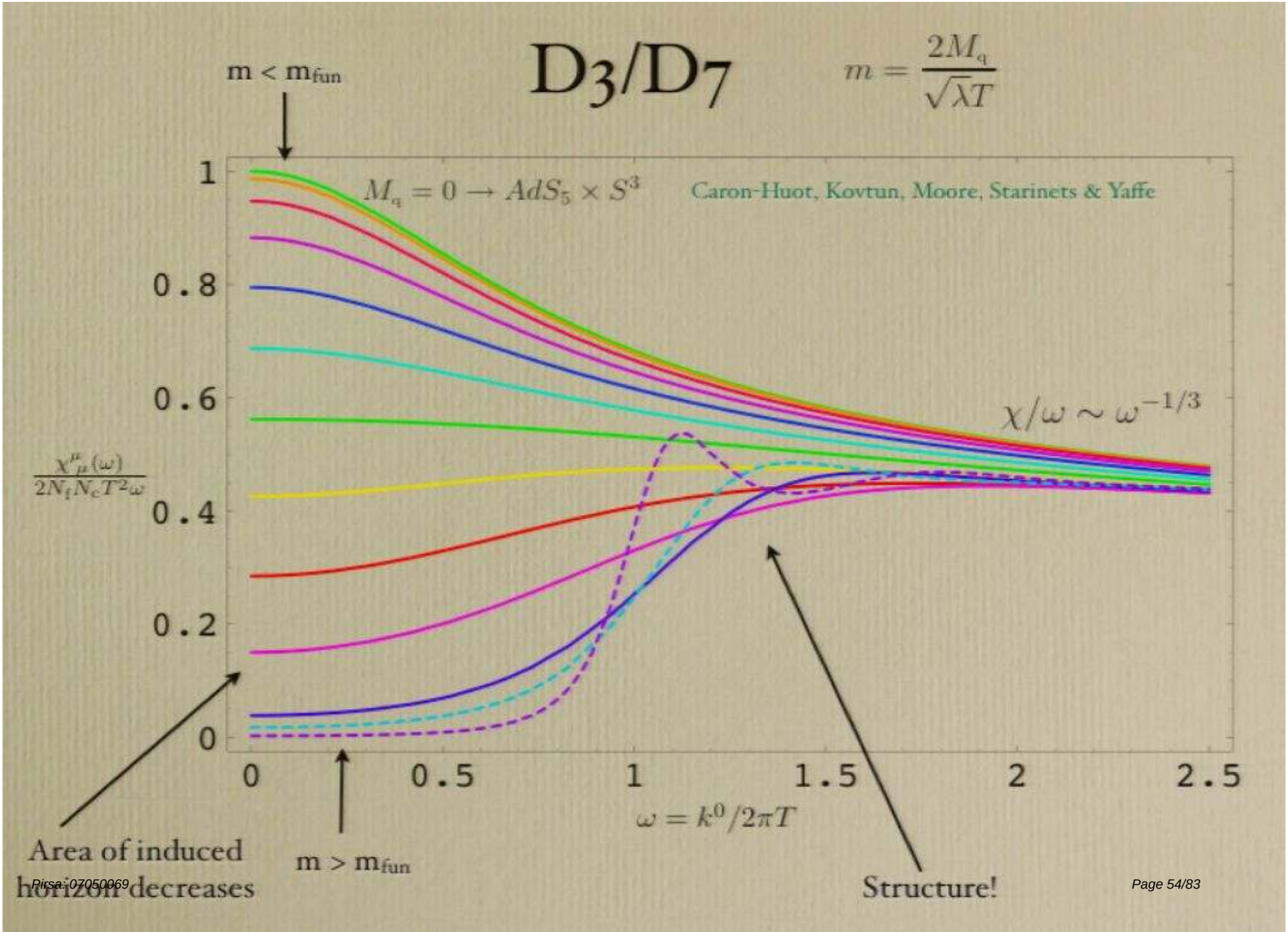

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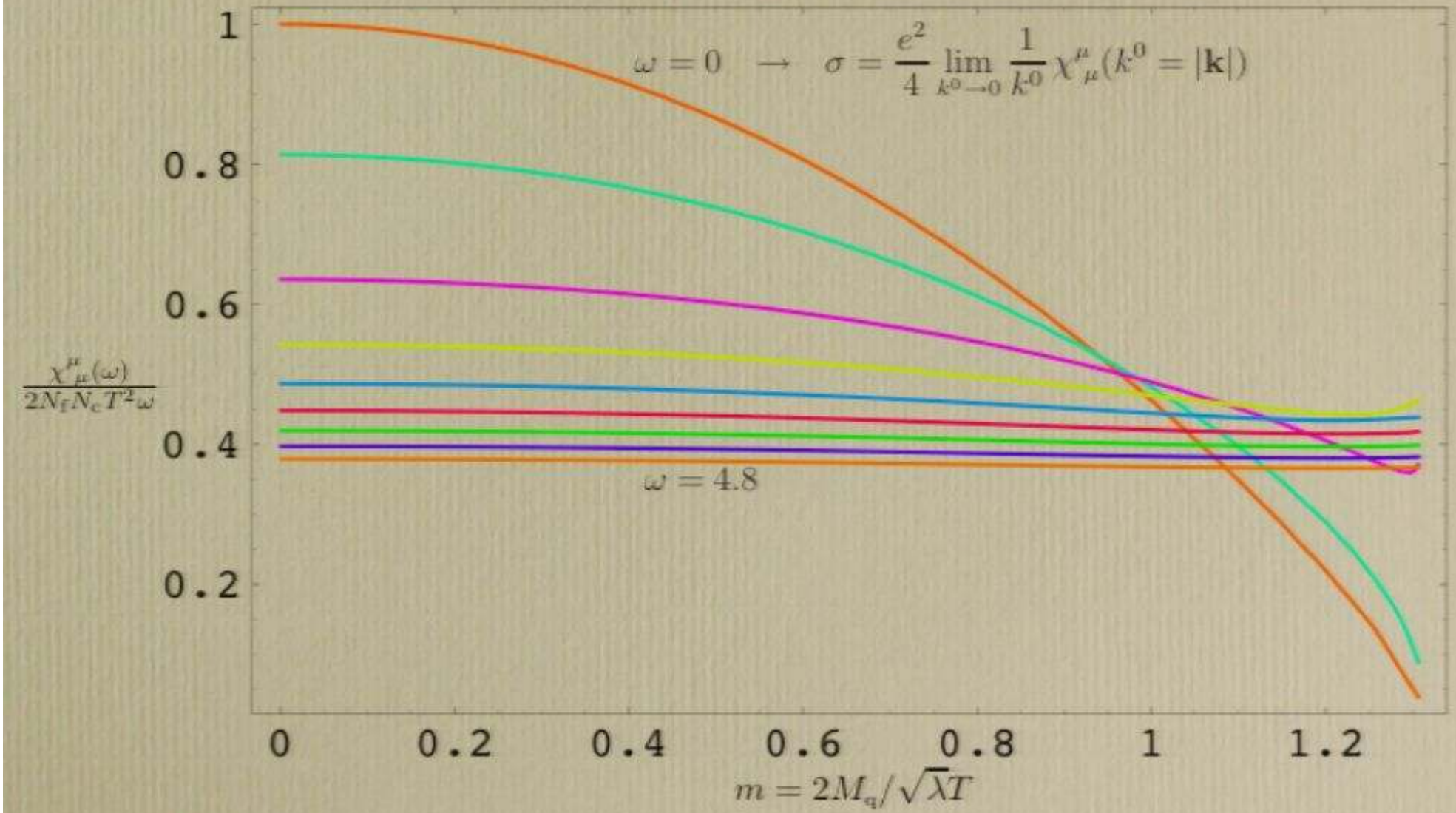
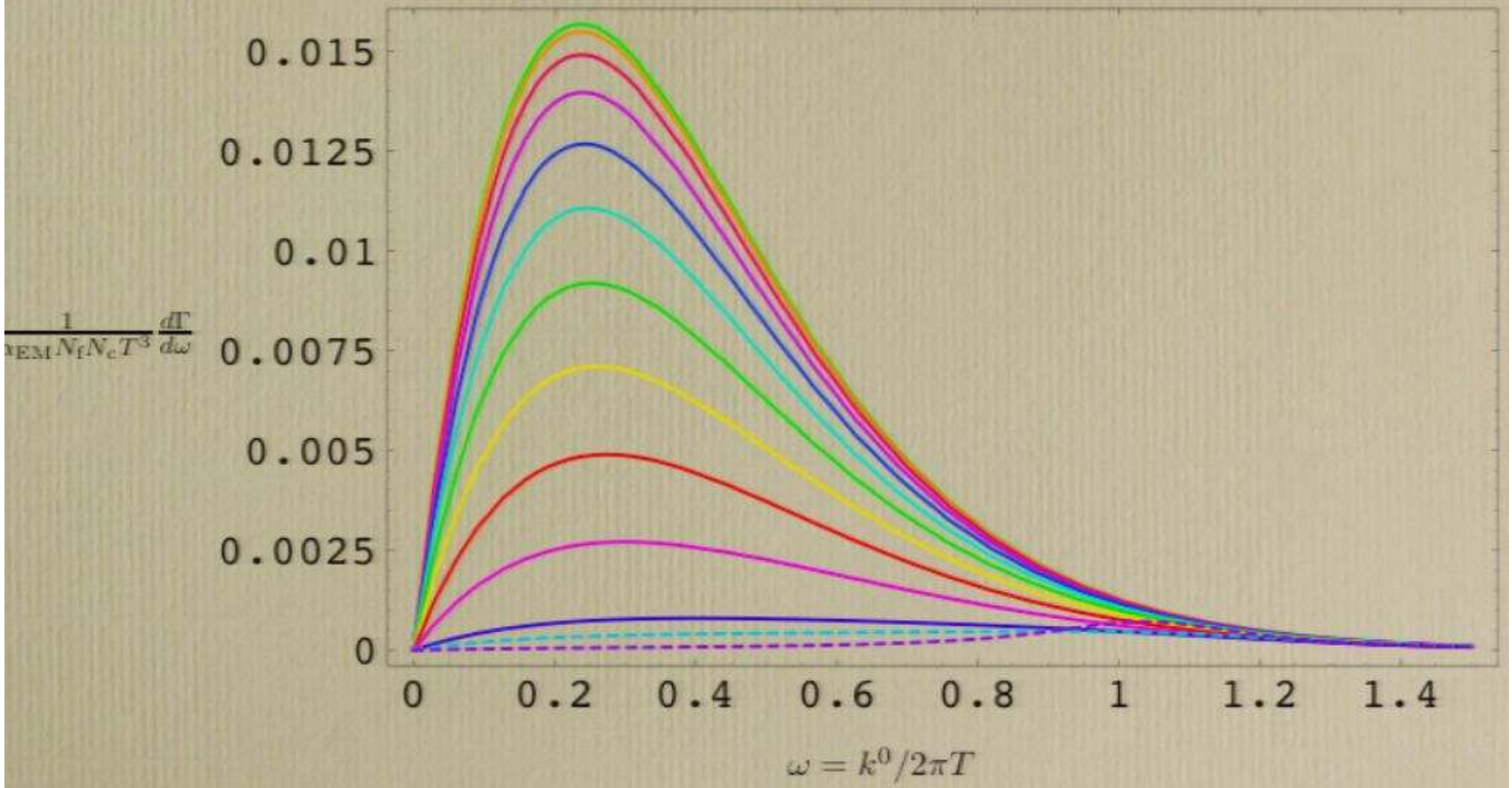
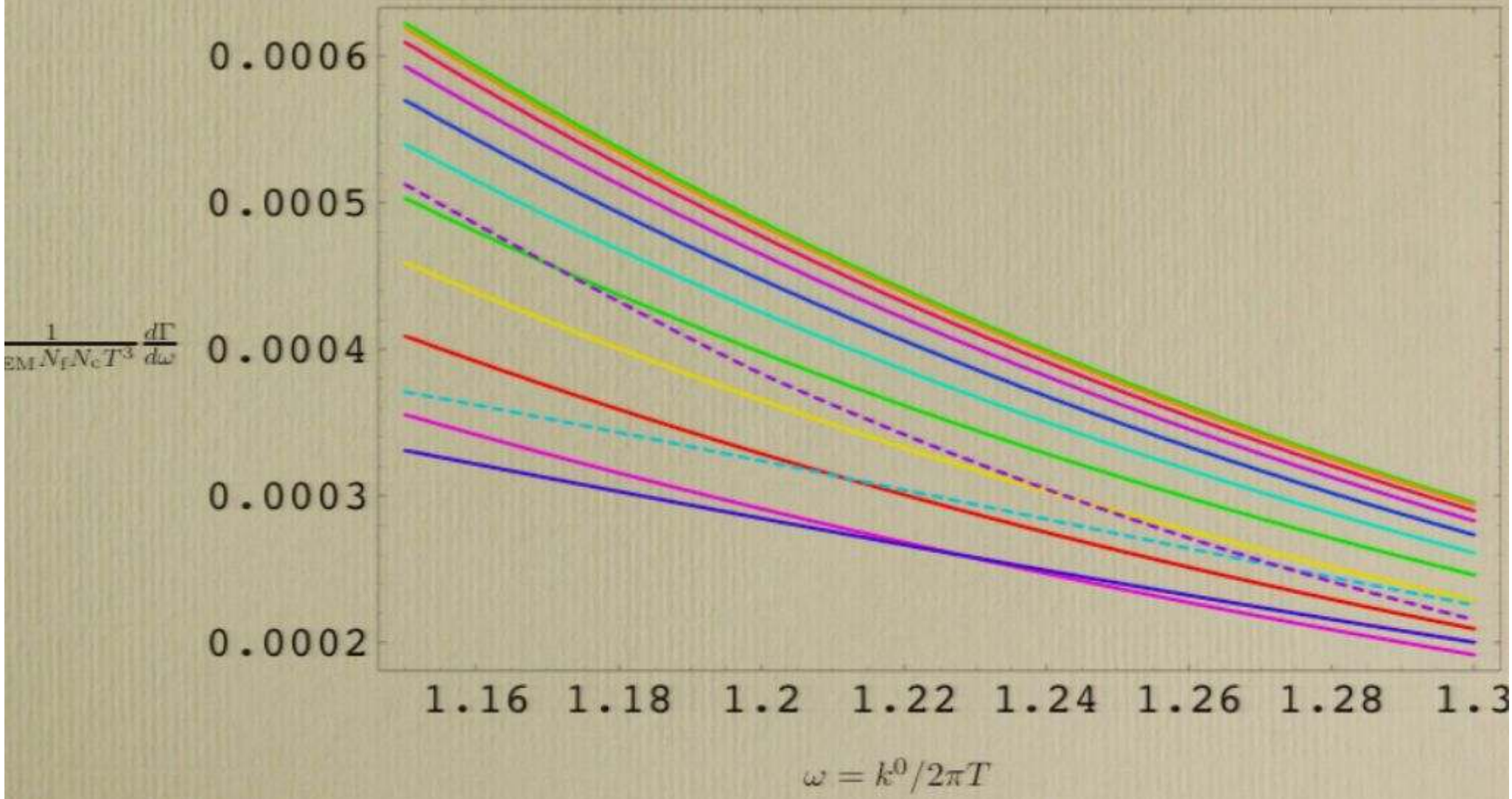

$\omega = 0 \quad \rightarrow \quad \sigma = \frac{e^2}{4} \lim_{k^0 \to 0} \frac{1}{k^0} \chi^{\mu}_{\mu}(k^0 = |\mathbf{k}|)$
$\omega = 4.8$
$\frac{\chi^{\mu}_{\mu}(\omega)}{2N_f N_c T^2 \omega}$
1
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1
1.2
$m = 2M_q/\sqrt{\lambda}T$

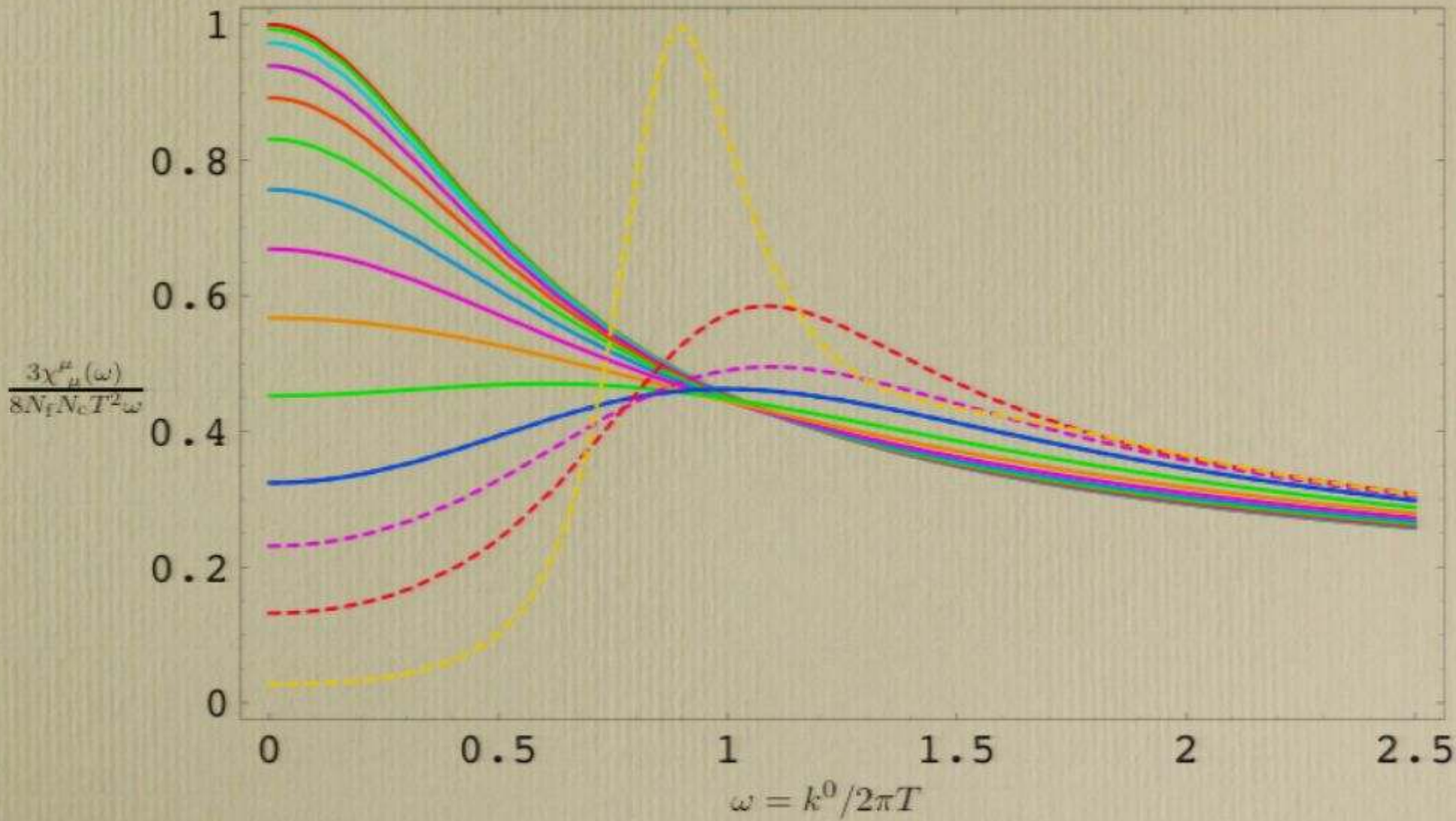
D_3/D_7


$\frac{1}{\alpha_{EM} N_f N_c T^3} \frac{dI}{d\omega}$
0.015
0.0125
0.01
0.0075
0.005
0.0025
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
$\omega = k^0/2\pi T$

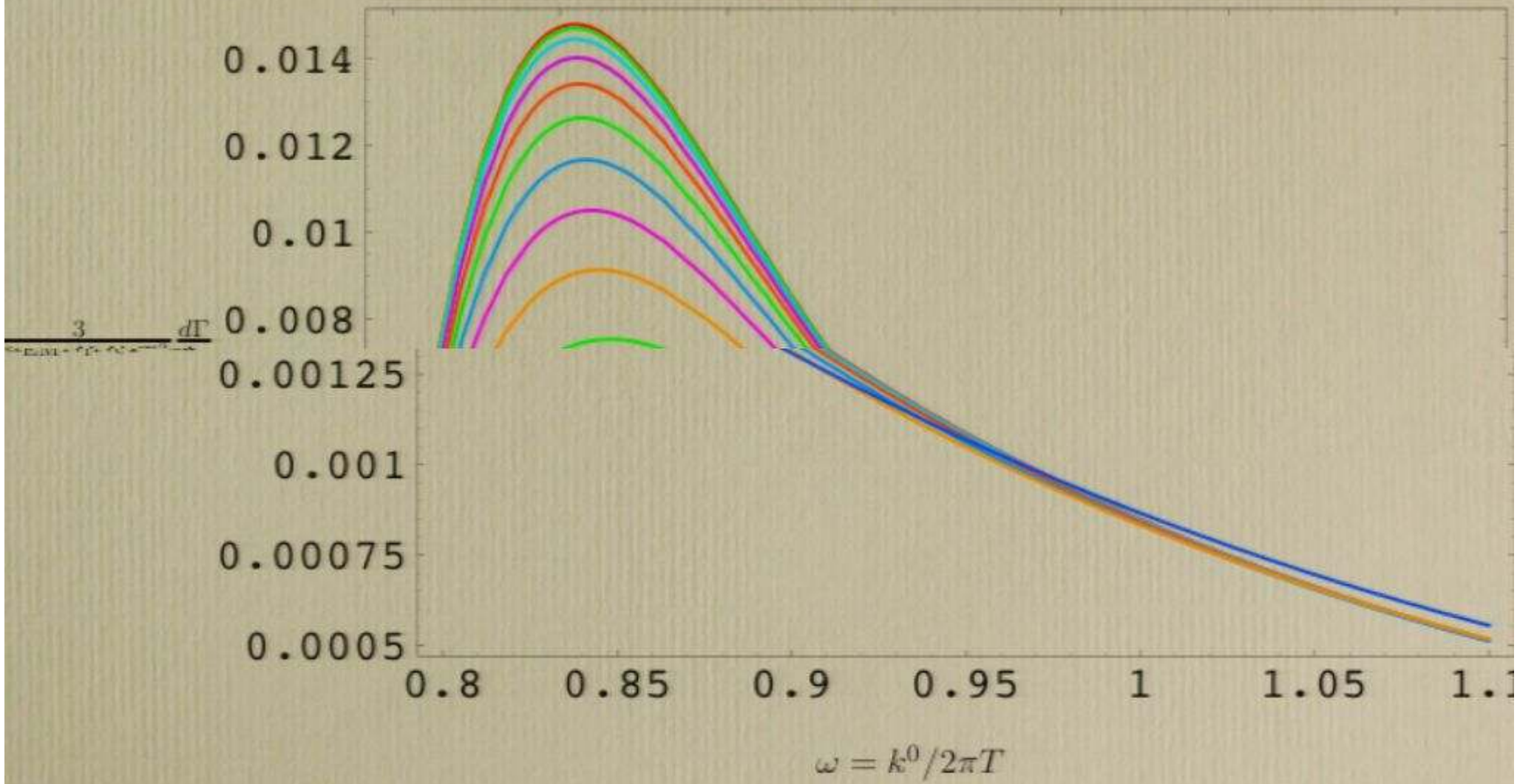
D_3/D_7


0.0006
0.0005
0.0004
0.0003
0.0002
$\frac{1}{\varepsilon_M N_f N_c T^3}\frac{d\Gamma}{d\omega}$
1.16
1.18
1.2
1.22
1.24
1.26
1.28
1.3
$\omega = k^0/2\pi T$

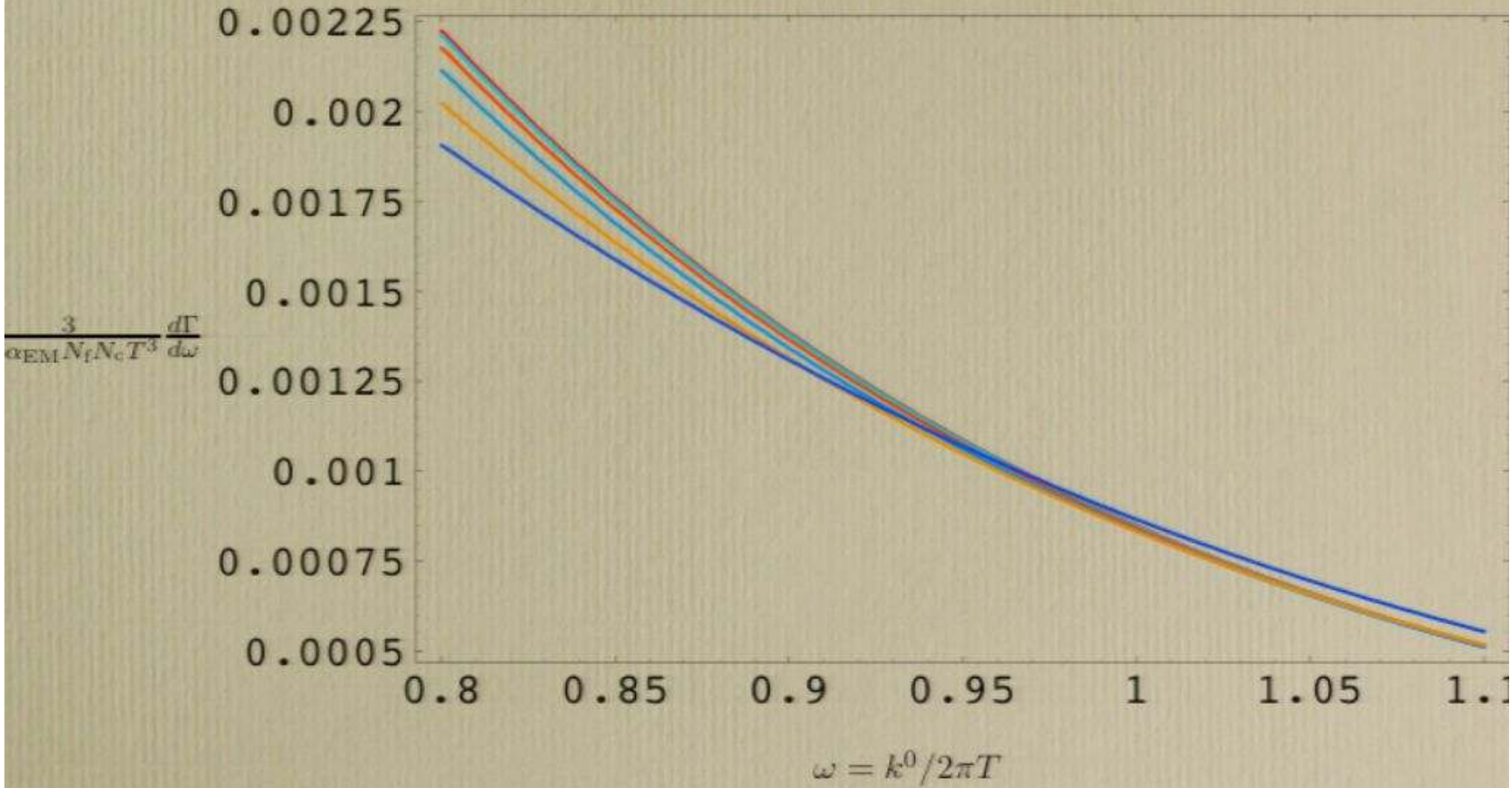
D4/D6


1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
$\frac{3\chi^{\mu}_{\mu}(\omega)}{8N_f N_c T^2 \omega}$
$\omega = k^0/2\pi T$

D4/D6


0.014
0.012
0.01
0.008
0.00125
0.001
0.00075
0.0005
0.8
0.85
0.9
0.95
1
1.05
$\omega = k^0/2\pi T$

D4/D6


0.00225
0.002
0.00175
0.0015
0.00125
0.001
0.00075
0.0005
0.8
0.85
0.9
0.95
1
1.05
$\frac{3}{\alpha_{EM} N_f N_c T^3} \frac{d\Gamma}{d\omega}$
$\omega = k^0/2\pi T$

iii) Viscosity of fundamental matter.

D.M., Myers & Thomson

Universal viscosity bound

- Kovtun, Son & Starinets have conjectured a universal bound:

$$\frac{\eta}{s} \geq \frac{1}{4\pi}$$

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- What about when quarks are included?
- Not only QCD has them, but they provide the leading N_f/N_c correction.

Idea

Kubo: $$\eta = \lim_{\omega \to 0} \frac{1}{2\omega} \int dt\, d^3x\, e^{i\omega t} \langle [T_{ij}(x), T_{ij}(0)] \rangle$$

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Couples to g_{ij}

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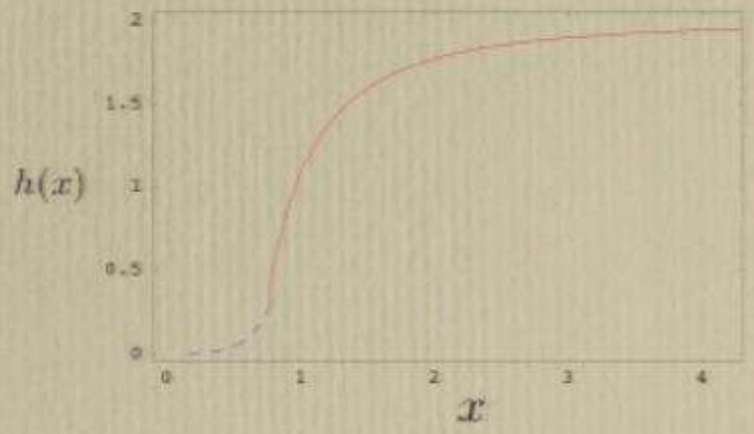
Couples to g_{ij} → $$\eta_{\rm fun} \sim \frac{\delta^2 S_{\rm Dq}}{\delta g_{ij}^2}$$

The ratio is not corrected at order N_f/N_c. Therefore:

$$\eta = \frac{\pi}{8} N_c^2 T^3 \left[1 + \frac{\lambda}{8\pi^2} \frac{N_f}{N_c} h\left(\frac{\lambda T}{M_q} \right) + \cdots \right]$$



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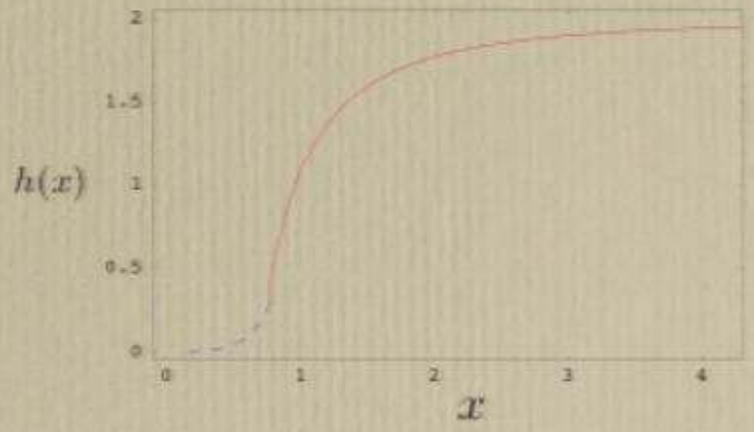
Enhancement



Potential consequence for the "jet quenching" thermometer:

$$\hat{q} = c\sqrt{\lambda} T^3$$

iv) Finite baryon density.

Kobayashi, D.M., Matsuura, Myers & Thomson

Gauge theory

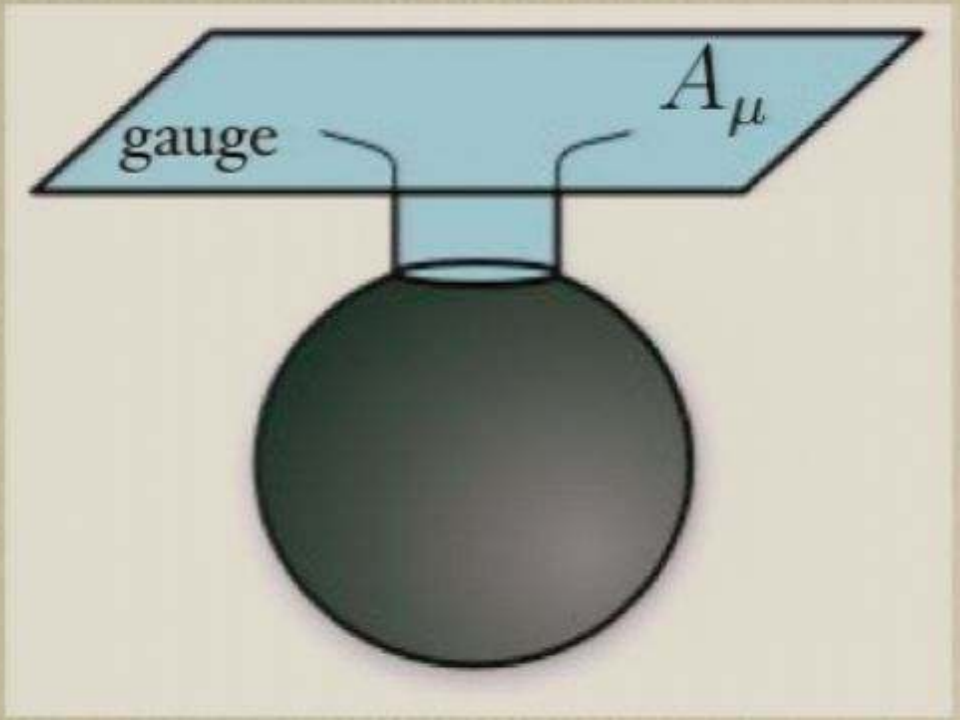
N_f flavours of equal mass

$$U(N_f) \simeq SU(N_f) \times U(1)_B$$

Conserved J_μ

String theory

N_f overlapping Dq-branes



Gauge theory

N_f flavours of equal mass

$$U(N_f) \simeq SU(N_f) \times U(1)_B$$

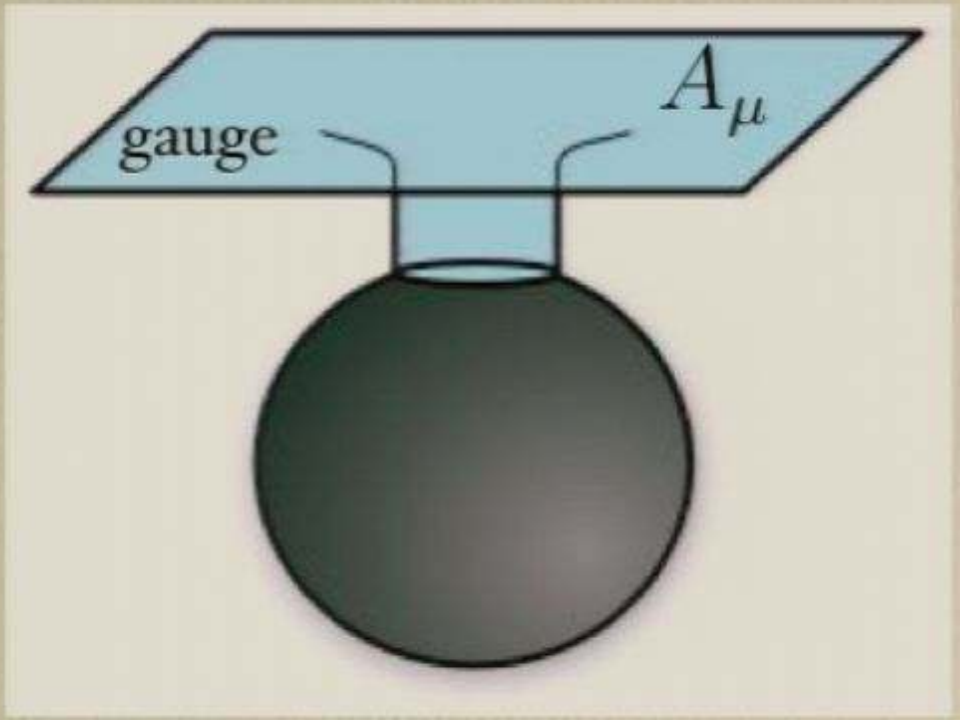
Conserved J_μ

$$H \to H + \mu_B J^0$$

$$\langle J^0 \rangle = n_B$$

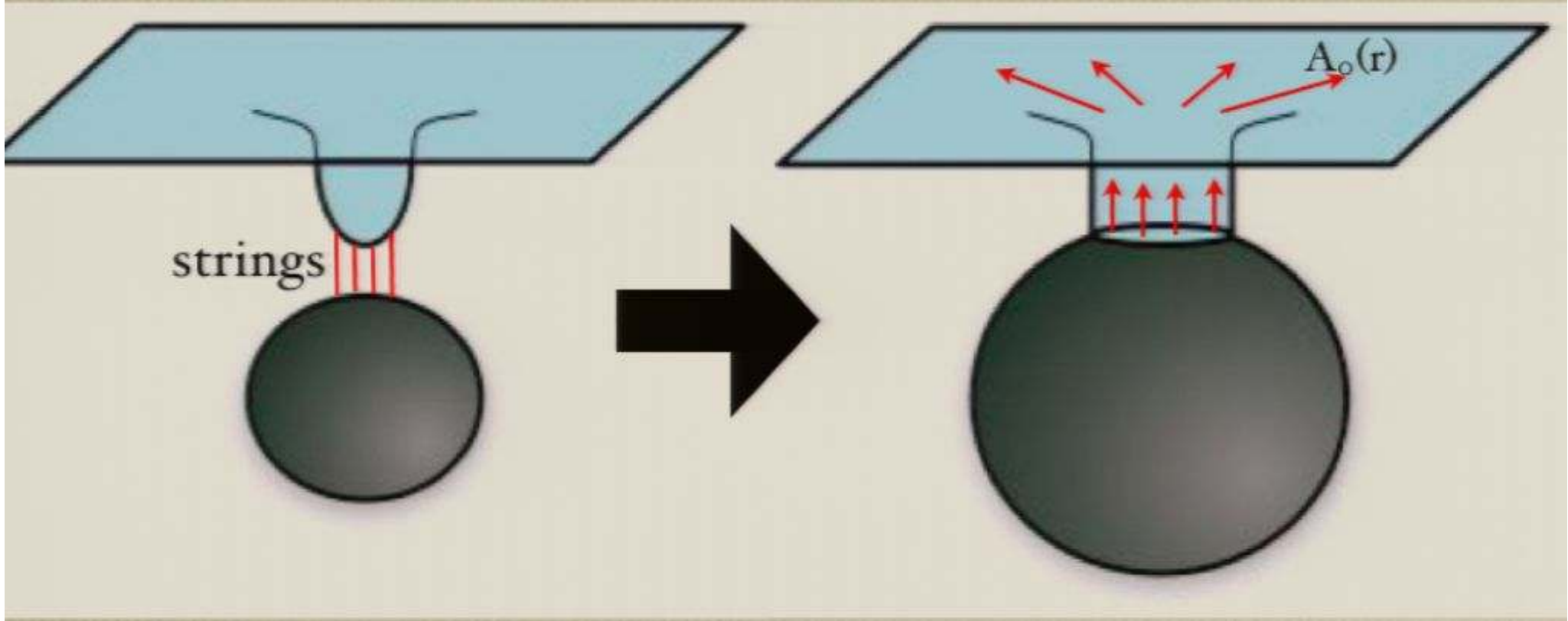
String theory

N_f overlapping Dq-branes

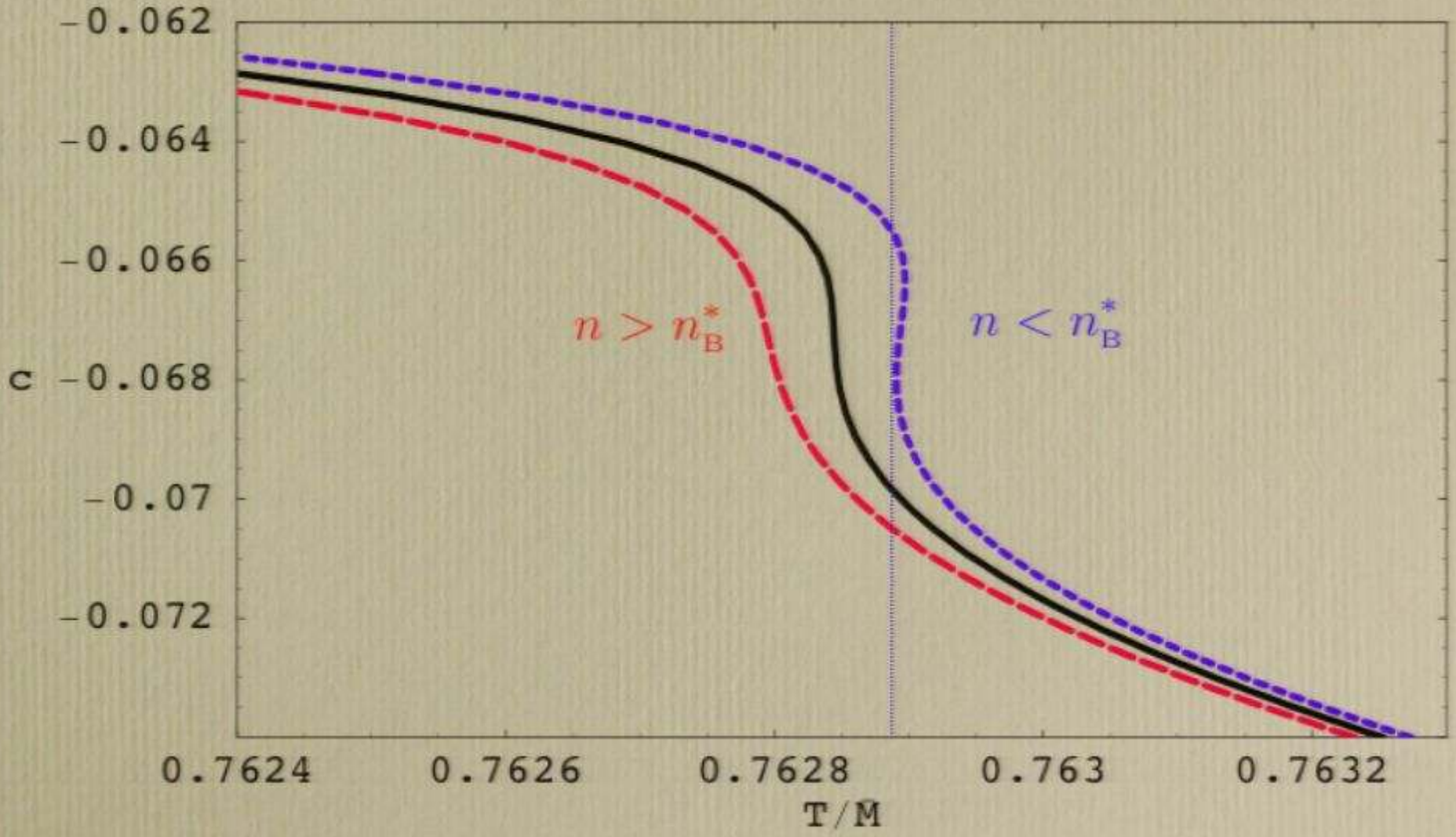


$$A_0 = \mu_B + \frac{n_B}{r^2} + \cdots$$

With finite density, all embeddings are of BH type:

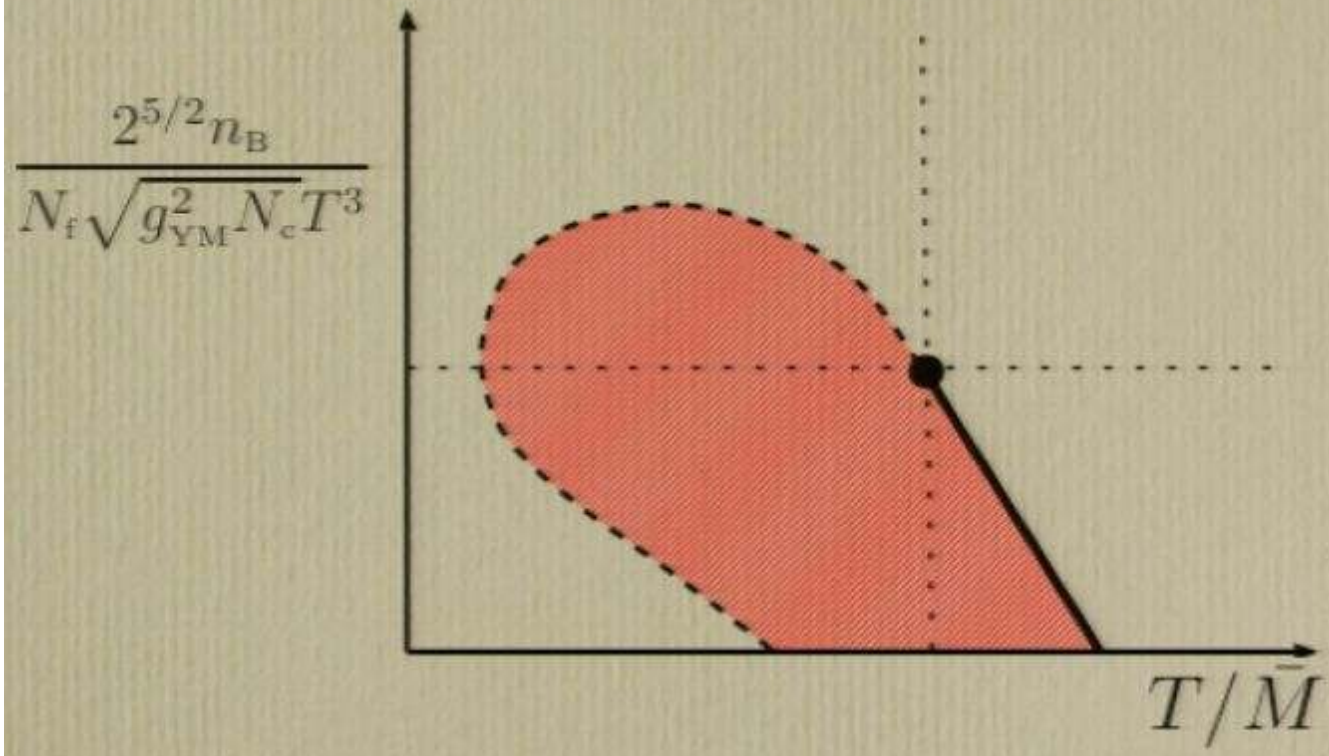


Transition persists up to $n_{\rm B}^*$

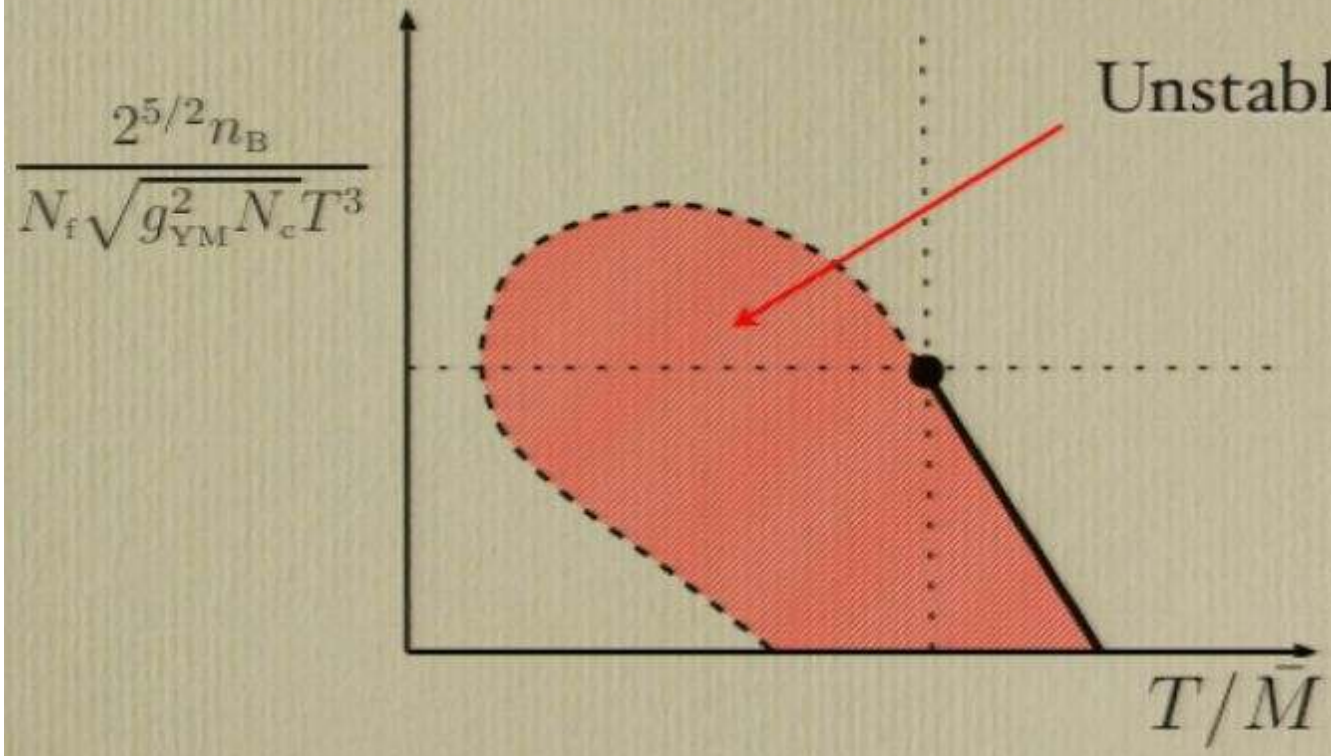


$c \sim \langle \bar{\psi}\psi \rangle$ $\qquad \bar{M} \sim M_{\rm meson} \sim \dfrac{M_q}{\sqrt{g_{\rm YM}^2 N_c}}$

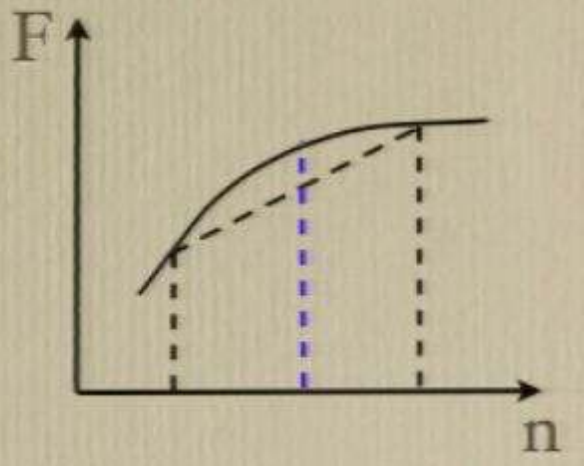
Phase Diagram



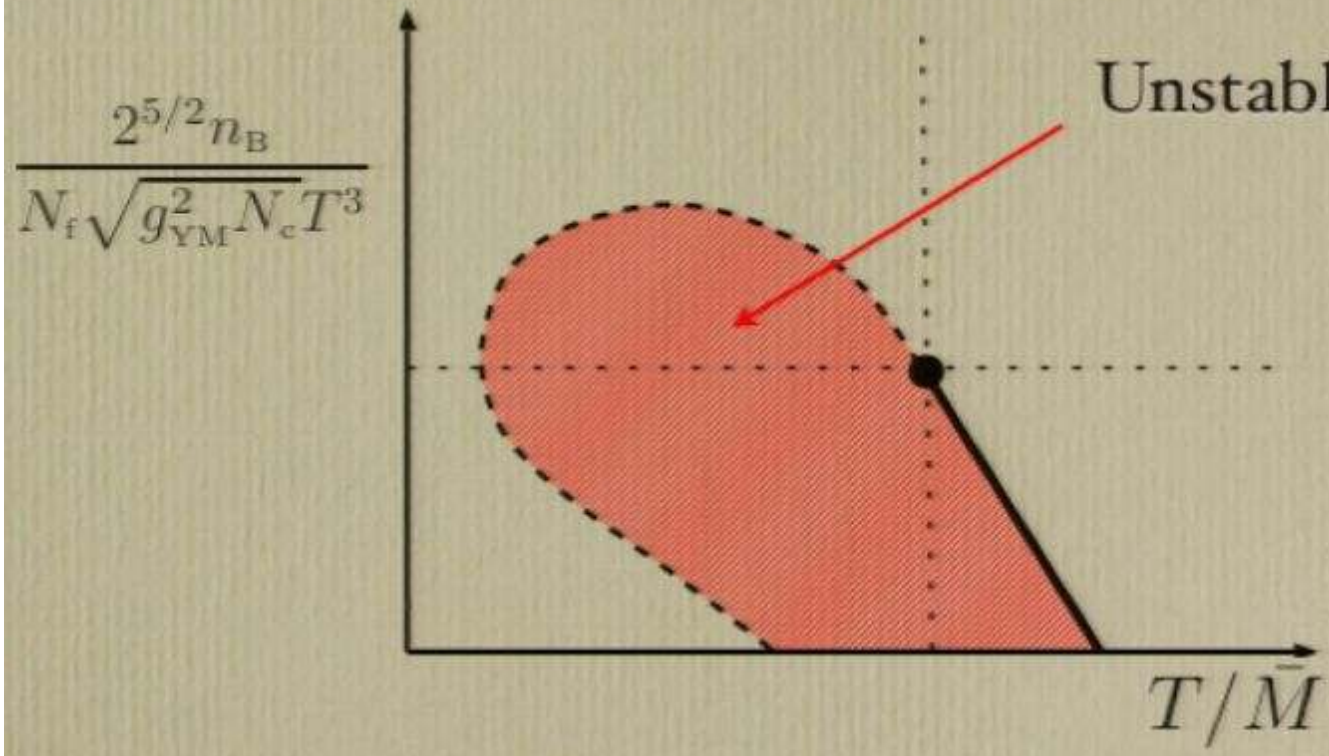
Phase Diagram



Unstable: $\left(\frac{\partial \mu}{\partial n_{\rm b}}\right)_T = \left(\frac{\partial^2 F}{\partial n_{\rm b}^2}\right)_T < 0$



Phase Diagram



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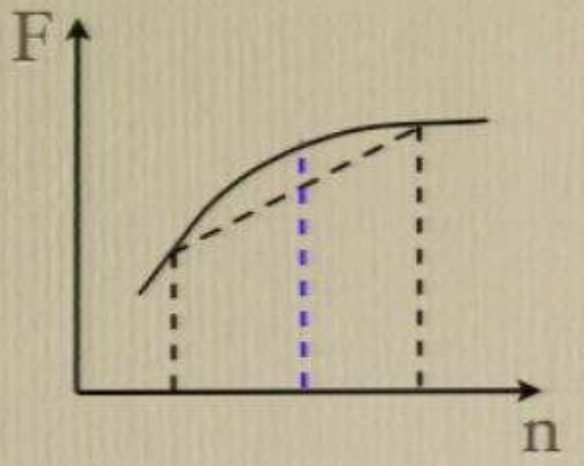


True ground state?

Inhomogeneous charge distribution
(in different D-branes or in space),
baryon vertex, ...

v) Future directions.

Lots to do at finite density

- With charged scalars → Bose-Einstein condensation (eg. spontaneous breaking of rotational symmetry)

  Cf. Miransky's talk

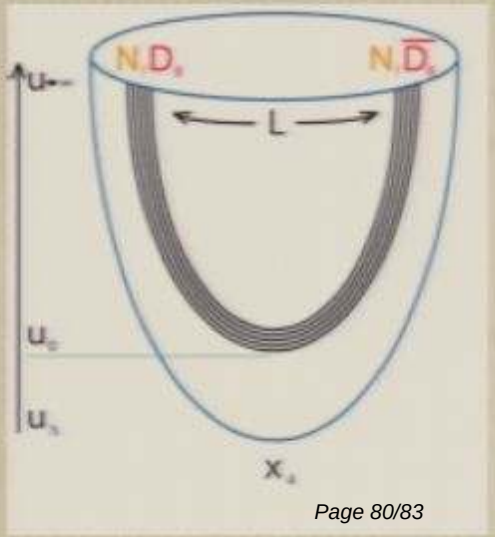
- Physics of the Fermi surface.

- Colour superconductivity vs. chiral waves:

$$\langle \bar{\psi}\psi(x) \rangle \sim e^{ik\cdot x}$$

- Need model with only fundamental fermions:

  Sakai & Sugimoto



Towards far from equilibrium

Horizons encode properties of QGPs:

- Static, eg S=A/4G. Gubser, Klebanov & Peet
- Near equilibrium, eg viscosity. Policastro, Son & Starinets; Kovtun, Son & Starinets
- Far from equilibrium, eg. inhomogeneities, collective instabilities, dynamical evolution of the QGP fireball, etc.
- One strong motivation:
  Understand fast thermalisation of the QGP.

One conclusion:

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Work hard and be universal.