Title: Holographic Mesons in a Thermal Bath

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Abstract:

Introduction

A collection of results on the holography of mesons:

At $T = 0$

- Mesons in an $\mathcal{N} = 4$ background
- $m_q \ll \Lambda_{QCD}$ pions
- $m_q \gg \Lambda_{QCD}$ heavy light mesons

Impact of the heat bath

- Phase transitions
- Meson melting

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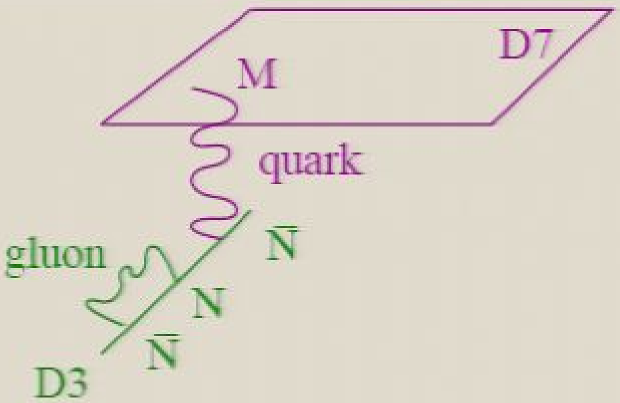
Quarks in AdS_5

Bertolini, DiVecchia...; Polchinski, Grana; Karch, Katz...



Quarks can be introduced via D7 branes in AdS

The brane set up is

	0	1	2	3	4	5	6	7	8	9
D3	—	—	—	—	•	•	•	•	•	•
D7	—	—	—	—	—	—	—	—	•	•

fills radial dim of AdS (4–7); $U(1)_A$ (8–9)

S^3 embedded in S^5

We will treat D7 as a probe - quenching in the gauge theory.

Minimize D7 world volume with DBI action

$$S_{D7} = -T_7 \int d\xi^8 \sqrt{P[G_{ab}]}, \qquad P[G_{ab}] = G_{MN} \frac{dx^M}{d\xi^a} \frac{dx^N}{d\xi^b}$$

Mesons in AdS_5

Kruczenski, Myers, Mateos, Winters

The D7 lie flat in AdS. We can consider fluctuations that describe R-chargeless mesons

$$w_6 + i w_5 = d + \delta(\rho) e^{ik.x}$$

δ satisfies a linearized EoM

$$\partial_\rho^2 \delta + \frac{3}{\rho} \partial_\rho \delta + \frac{M^2}{(\rho^2+1)^2} \delta = 0$$

and the mass spectrum is

$$M = \frac{2d}{R^2} \sqrt{(n+1)(n+2)} \sim \frac{2m}{\lambda_{YM}}$$

Tightly bound - meson masses suppressed relative to quark mass

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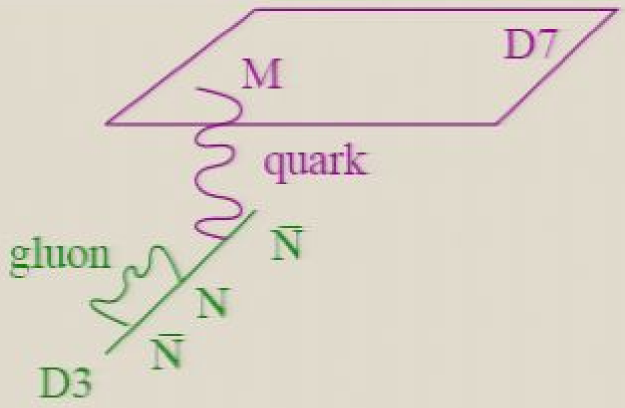

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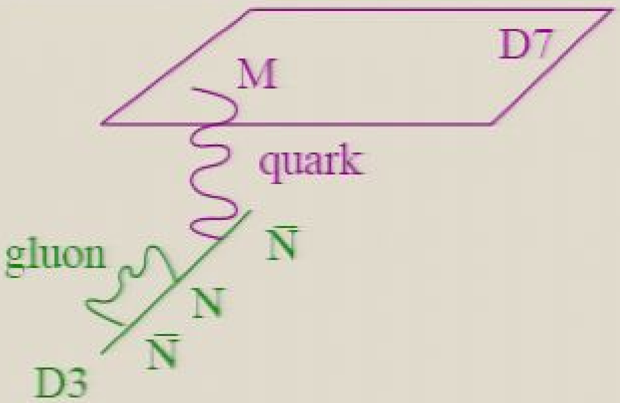

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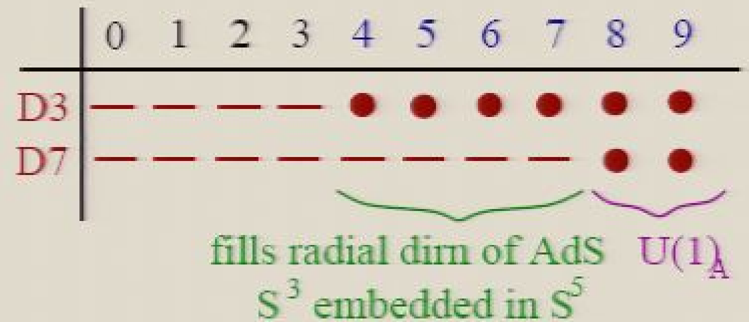

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Mesons in Back Reacted AdS_5

NE, Threfall

The fully back reacted D3 D7 geometry exists in the literature (Polchinski, Kirsch, Vaman)

$$ds^2 = h^{-1/2}dx^2 + h^{1/2}\left[d\rho^2 + \rho^2 d\Omega_3^2 + e^{\psi}(dr^2 + r^2 d\varphi^2)\right]$$

$$h = 1 + \frac{Q_{D3}}{(\rho^2 + e^{\psi} r^2)^2}, \qquad \psi = \frac{1}{g} - \frac{N_f}{4\pi}\ln(r^2 + d^2 - 2dr\cos\varphi)$$

We can again embed a D7 probe (it lies flat) and look at fluctuations. The mass spectrum is

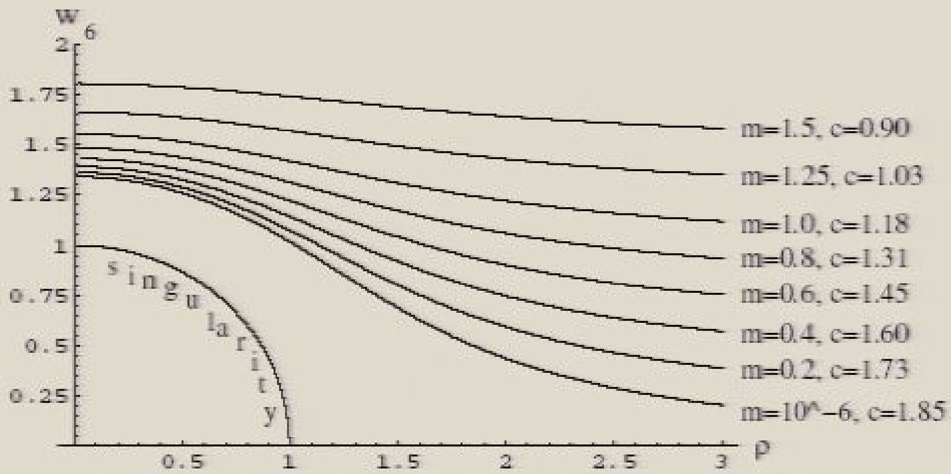
$$M = (1 - \frac{gN_f}{2\pi}\ln d)\frac{2d}{R^2}\sqrt{(n+1)(n+2)}$$

An analytic form for the quenching correction.

Chiral Symmetry Breaking In Deformed D3 D7 System

Babington, Erdmenger, NE, Kirsch, Guralnik

Non-susy D3 geometry is repulsive



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$$= \text{mass + condensate}$$
$$= m + \frac{c}{\rho^2} + \ldots$$

In IR the quarks acquire a dynamical mass.

Determine $\langle \bar{q} q \rangle$ as function of quark mass from asymptotics

Similar stories by - Myers et al, Harvey et al, Johnson et al, Ghoroku et al

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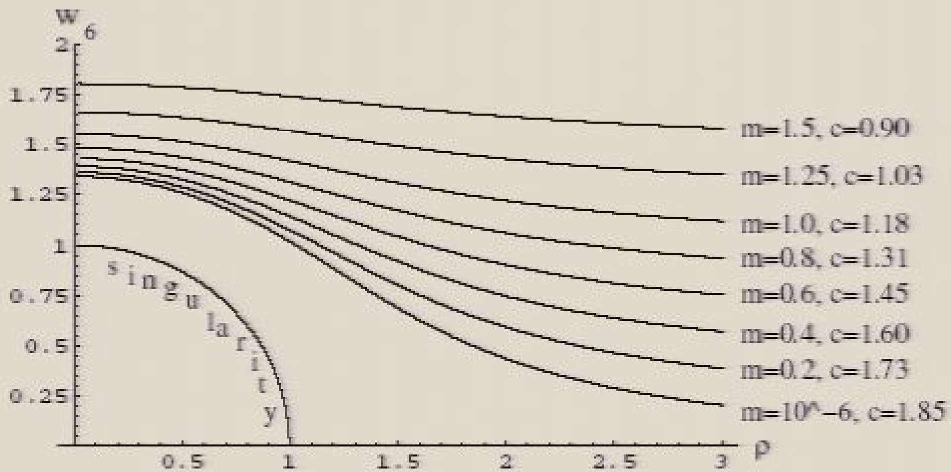

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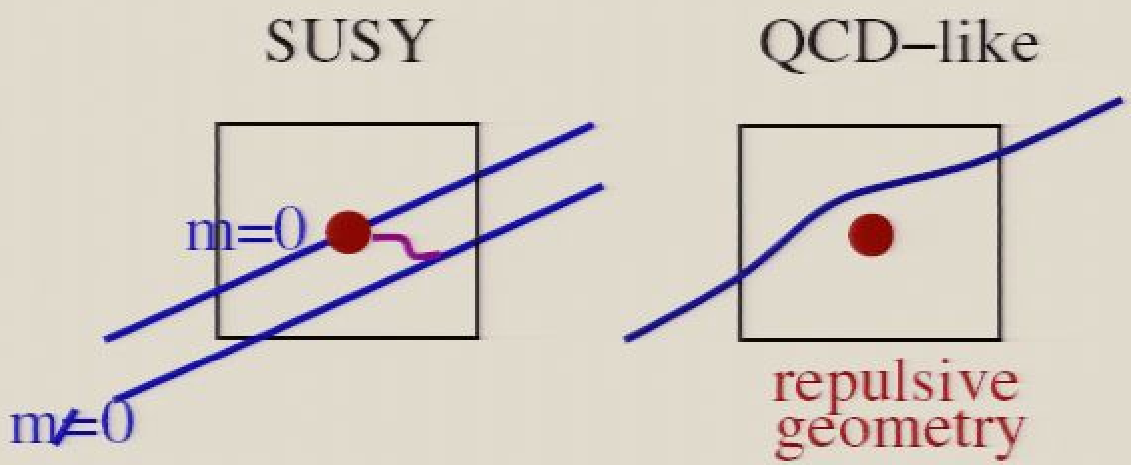
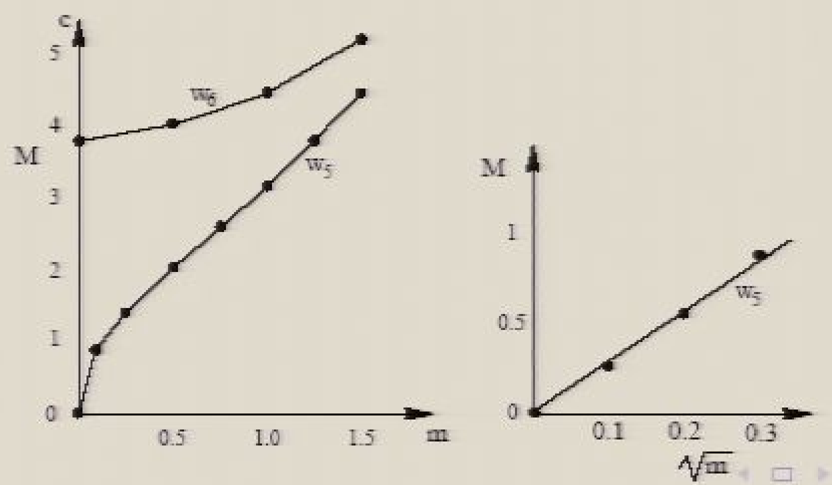
Geometrical Pions

D7s lie in $x_8 - x_9$ plane with explicit $U(1)_A$



Fluctuations about ring = massless pions!



Sakai-Sugimoto Model

NE, Threlfall

One must be careful here about the holographic identification

$$\Phi = \tau e^{iA_z} = \text{condensate} + \text{mass}$$

In massive cases A_z is a phase on both mass and condensate - a correct but spurious symmetry!

Changing the phase of the condensate alone corresponds to

$$\tau = \tau_0 - \frac{\langle \bar{q}q \rangle m}{2\tau_0}\pi^2, \qquad A_z = \frac{\langle \bar{q}q \rangle}{\langle \bar{q}q \rangle + m} \pi$$

Changing the embedding is not a flat direction and we find a massive pion

$$M^2 \sim m_q$$

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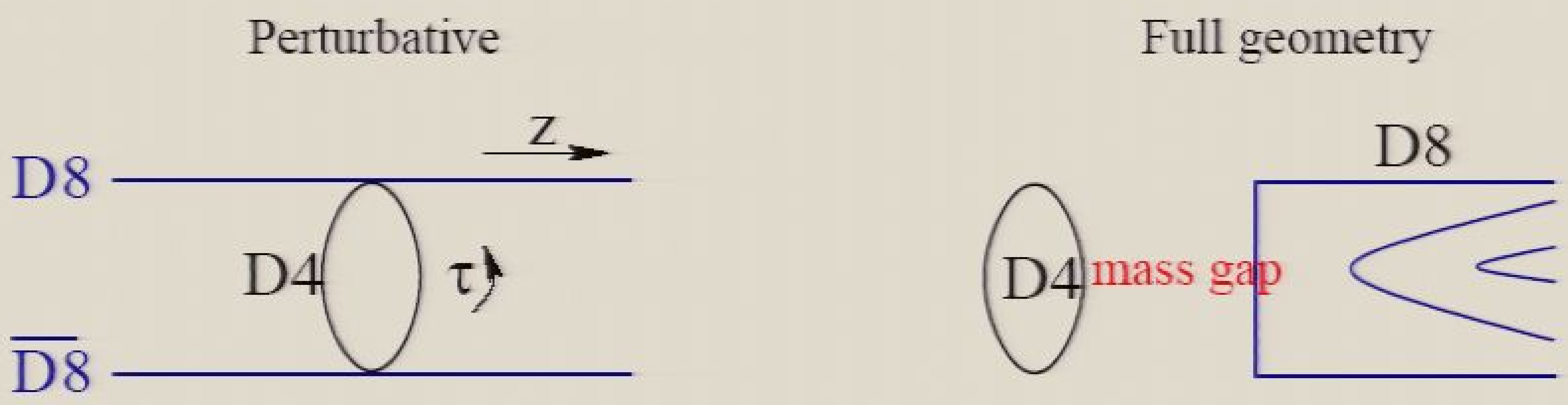
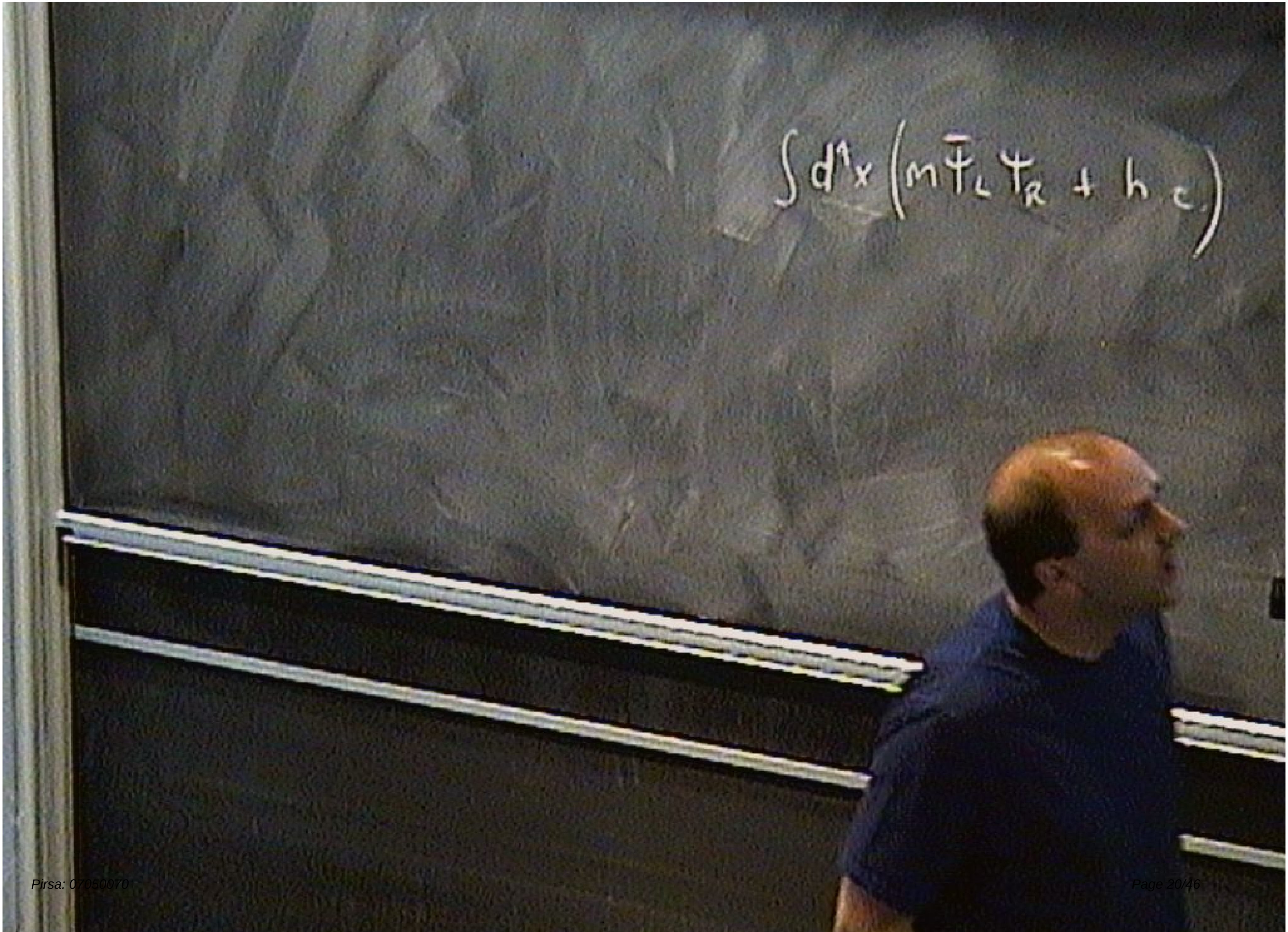


Chiral symmetry is broken by the D8 $\bar{D}8$ combining

$$\tau(z) \sim c + \frac{m}{z^p} + \ldots$$

The closest approach configuration has flat D8 and the pion has been associated with massless mode of the A^z on the D8.

Other configurations appear to decribe quark mass but there is still a massless A_z mode??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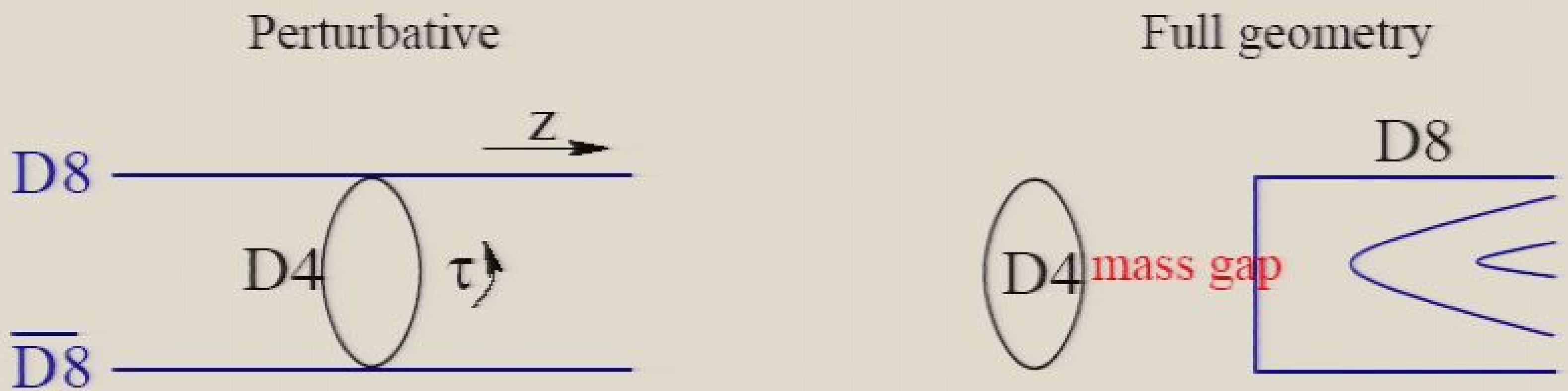

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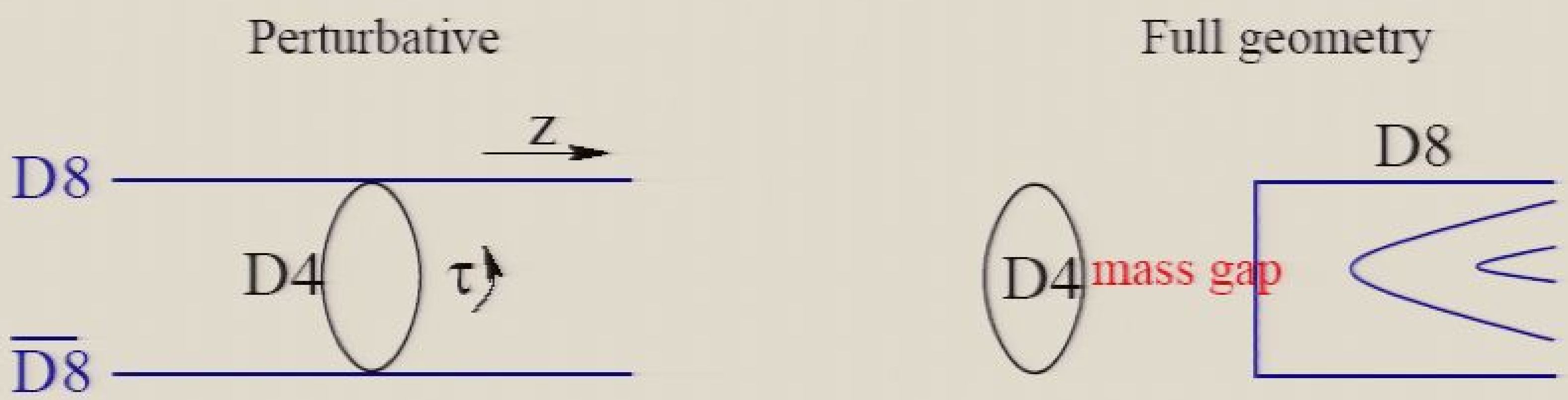

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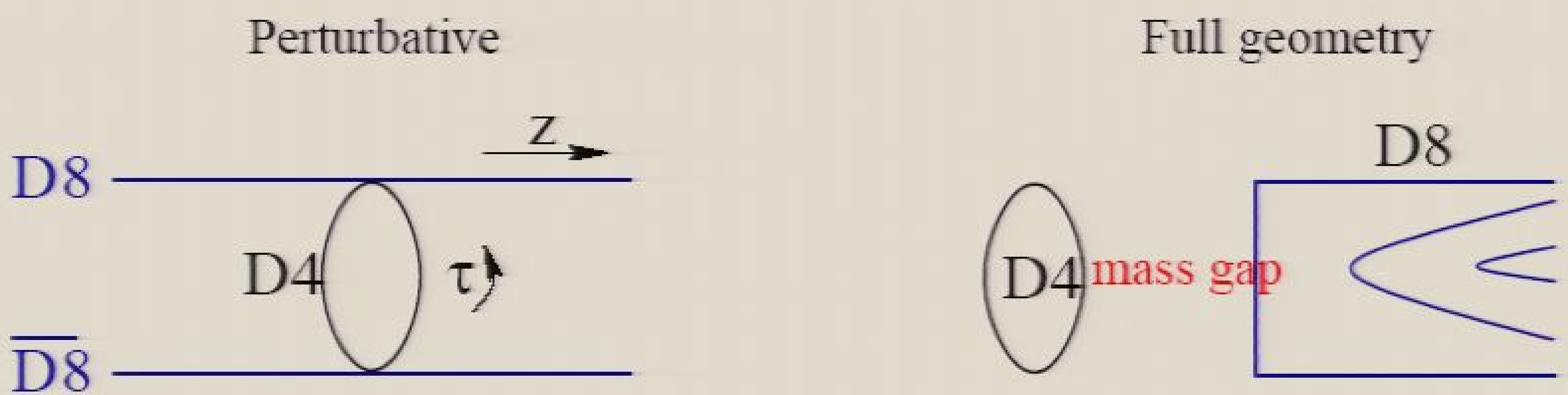

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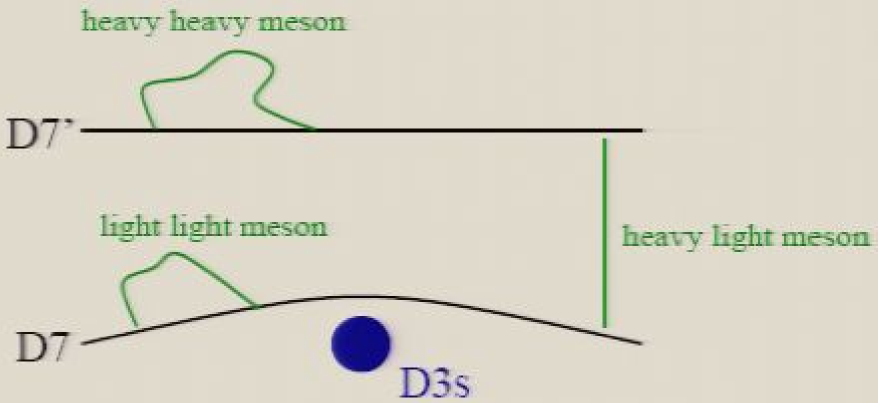
Heavy Light Mesons

NE, Erdmenger, Grosse

Two D7 branes correspond to quarks of different mass



Heavy light systems generate long strings
→ semi-classical description

$M_{\rm meson} = LT$?

Holographically string's mass determines operator dimensions?

Consider the static heavy light string - it lies straight in AdS

$$S \sim \int_0^L d\sigma \sqrt{G_{tt} G_{\sigma\sigma}} \sim \int_0^L d\sigma \sqrt{H^{-1/2}.H^{1/2}}$$

Heavy Light Mesons

Polyakov constraint gives generalized $E^2 - p^2 = m^2$ and hence a wave equation

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Asymptotically this equation is

$$p_x^2 + \rho^4 p_w^2 = L^2 T^2$$

w has energy dimensions in the field theory!!

At large w the string is *massless* $\rightarrow \varphi = m + \frac{c}{\rho^2}$

It is holographic to the mass and operator

$$\mathcal{L} = m_{HL}\bar{H}L + h.c.$$

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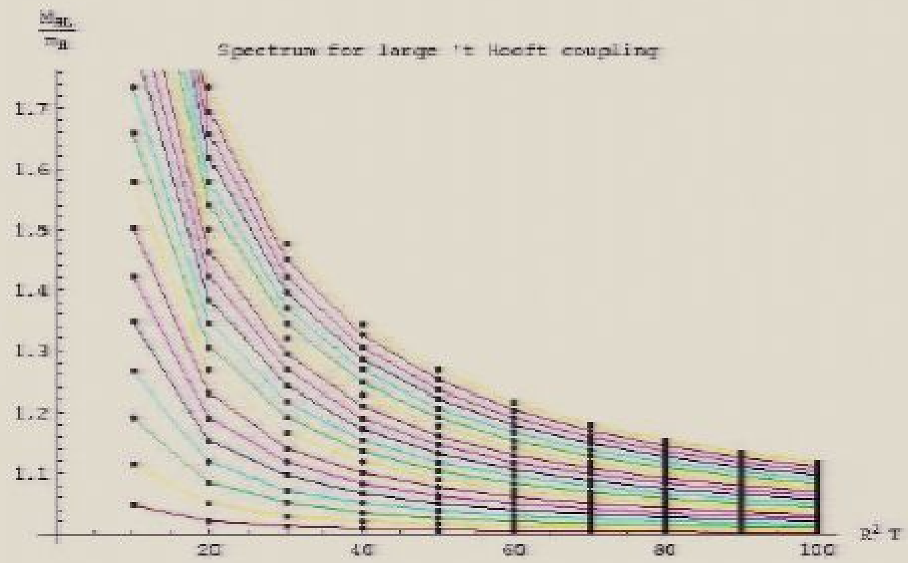
Shooting numerically with b.c. $\varphi \sim e^{ikx}\frac{c}{\rho^2}$ generates the mass spectrum...



Note in the $\lambda_{YM} \to \infty$ limit $M_{\rm meson} = m_H$ - the naive semi-classical answer.

You can compute excited state masses (within straight string approx)

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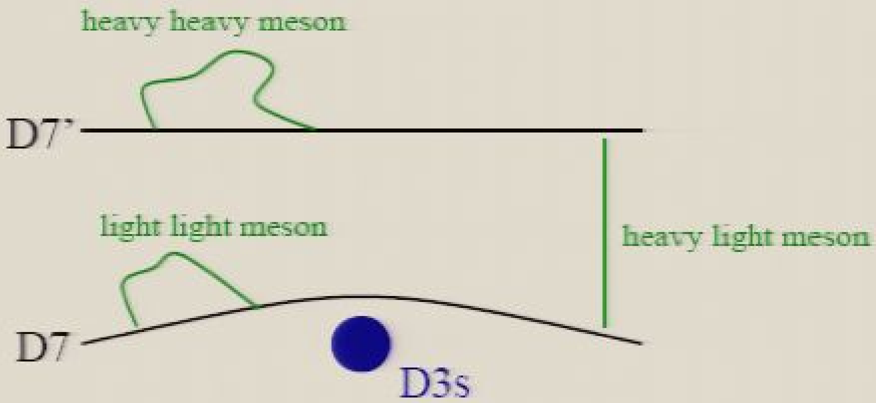

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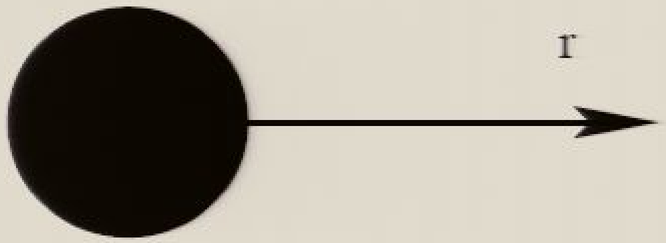
Thermal Transitions

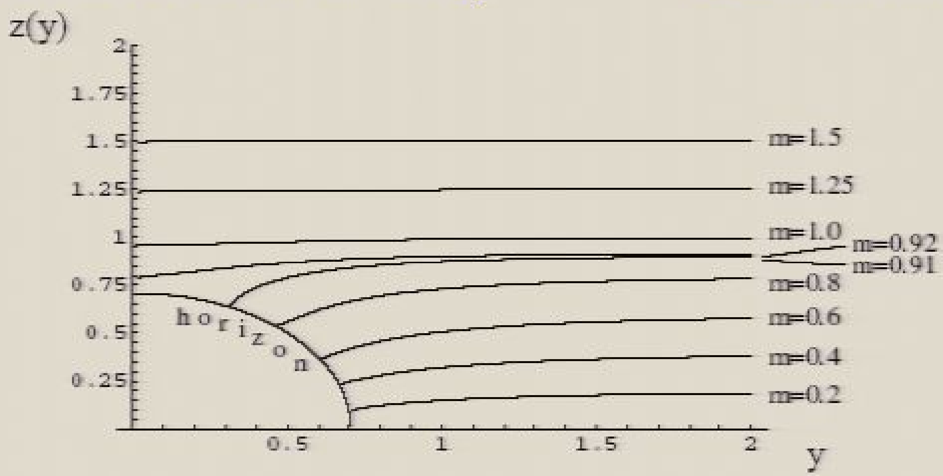
Deconfinement: AdS Black hole forms



The black hole cuts off scales below the temperature scale

Energy $\sim N^0 \quad \rightarrow \quad N^2$

Novel Transition when $T > m_q$ (BEEKG, Kirsch, Myers et al)



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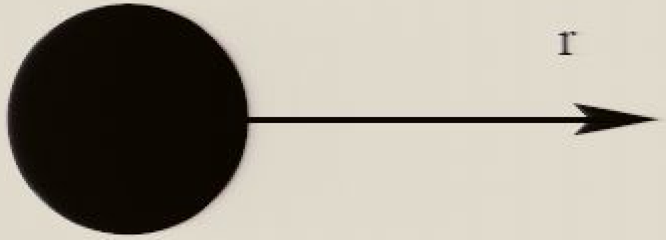

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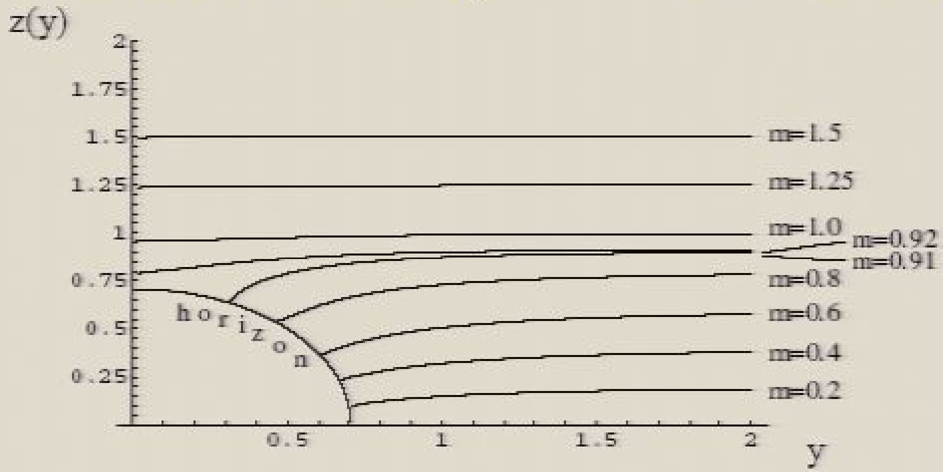

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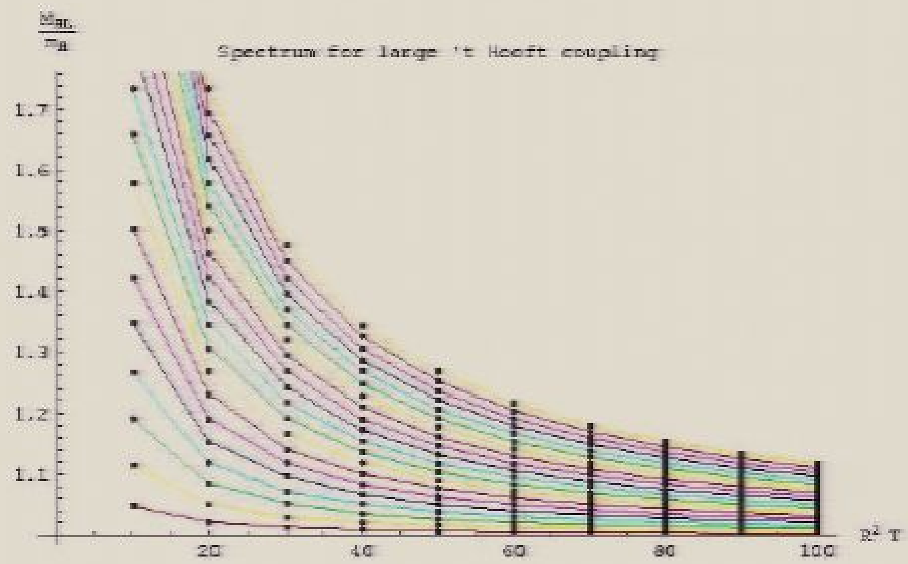

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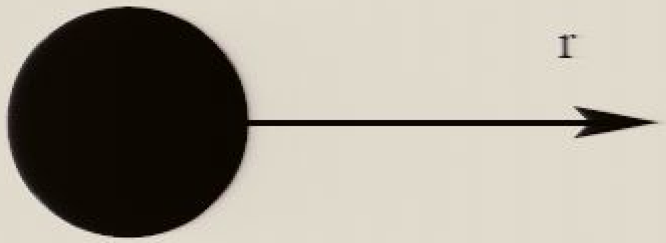

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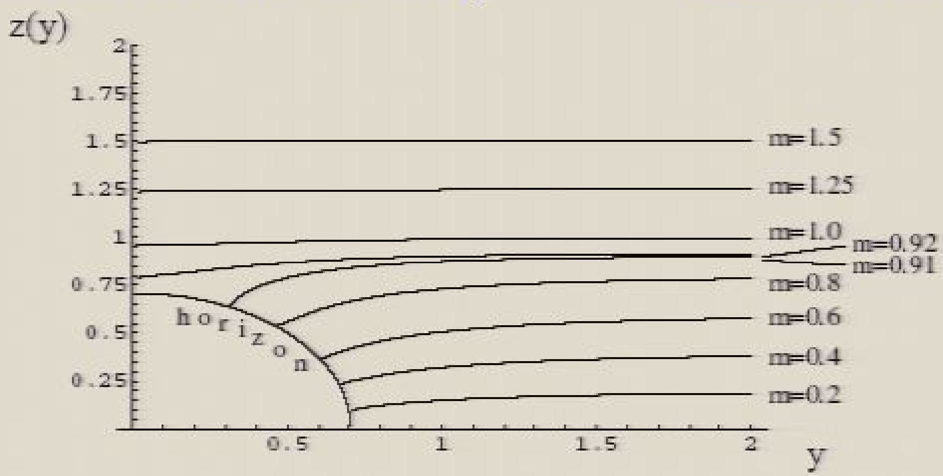
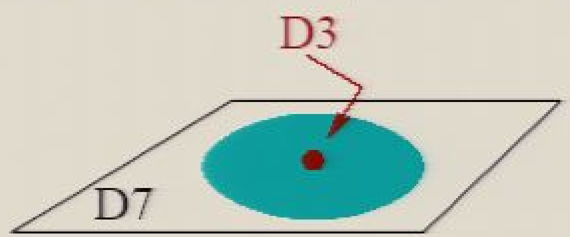


Scalar Potential

Guralnik, Apreda, NE, Erdmenger

In models with susy origin need to check a deformation does not destabilize the scalar moduli space

In D3/D7 system scalar vev corresponds to an instanton



$$S = -\int d^8\xi C^{(4)} \wedge Tr(F \wedge F) + \int d^8\xi e^{-\Phi}\sqrt{-G}TrF^2$$

In AdS terms cancel for any size instanton, $A_m = \frac{2Q^2\bar{\sigma}_{nm}y_n}{y^2(y^2+Q^2)}$

Eg add chemical potential $\langle A^0 \rangle = \mu$

$$V \sim -\mu^2 Q^2$$

A run away....

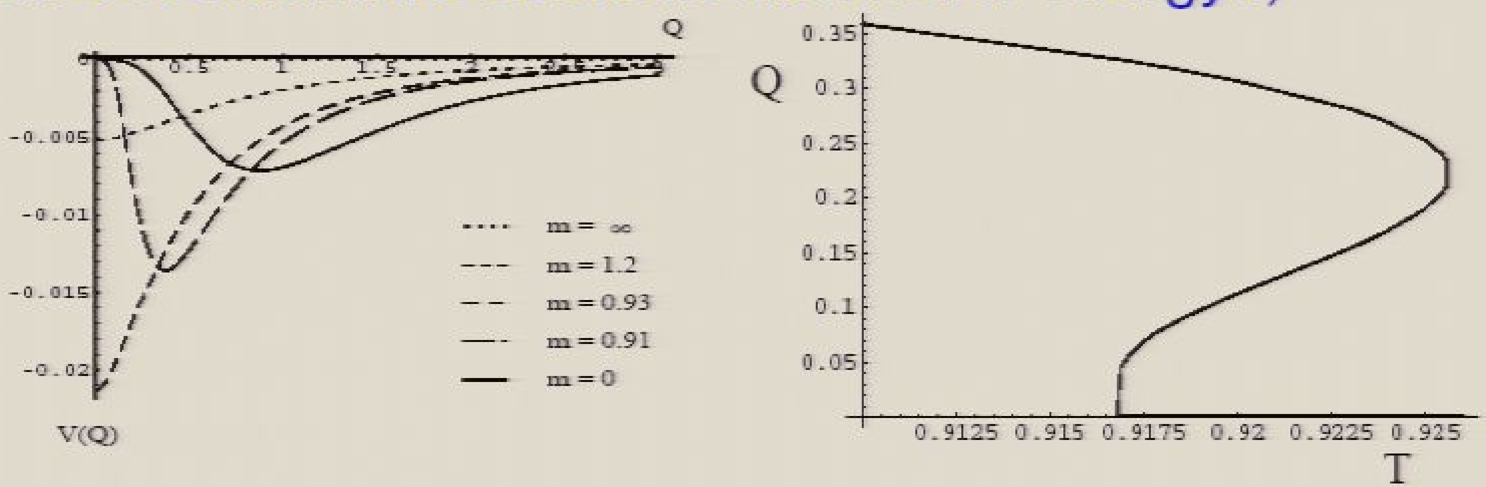
Scalar Potential - Finite T

AdS Schwarzchild deformation governed by parameter T^4 - Asymptotically the leading non-cancelling term is

$$V \sim T^4 - c\frac{T^8}{Q^4} + ...$$

Computing c (+ve) shows bounded potential.

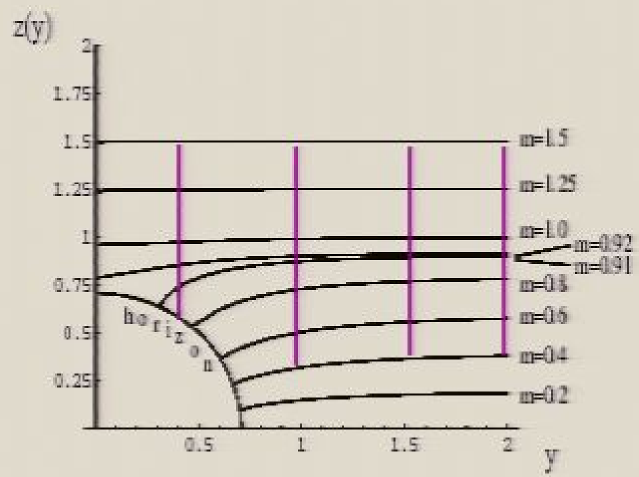
Action of the basic instanton configuration ("lifting" the moduli space... but deformed solutions with lower energy?)



The scalar vev is an order parameter for the transition.

Meson Melting

Hoyos, Lansteiner and Montero have argued that for D7 branes that fall in to the black hole of thermal D3 geometry there is no discrete meson spectrum.



Waves on the D7 fall into the black hole → quasi-normal modes

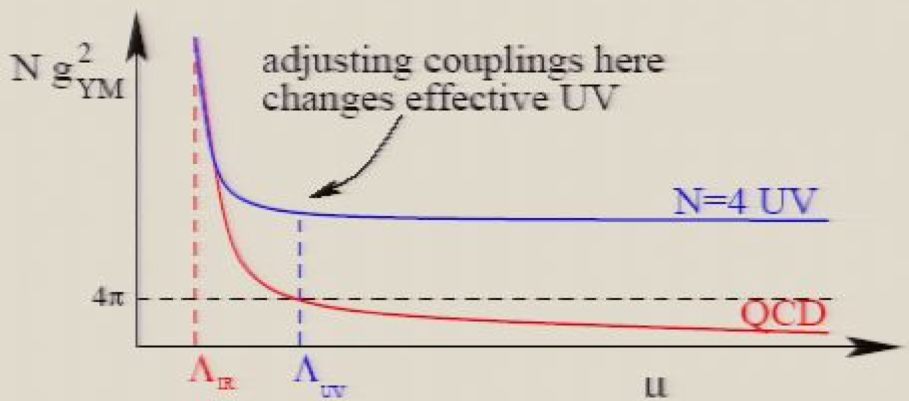
This is light quark mesons melting into the thermal bath

Currently investigating the Heavy Light mesons melting to a heavy quark...

Towards a Perfect Gravity Dual

All our descriptions lack asymptotic freedom - we need a UV cut off - we need higher dimension operators

$$GTrF^4, \qquad G\bar{\psi}\psi\bar{\psi}\psi, \; ....$$



In principle can fix couplings by QCD data.

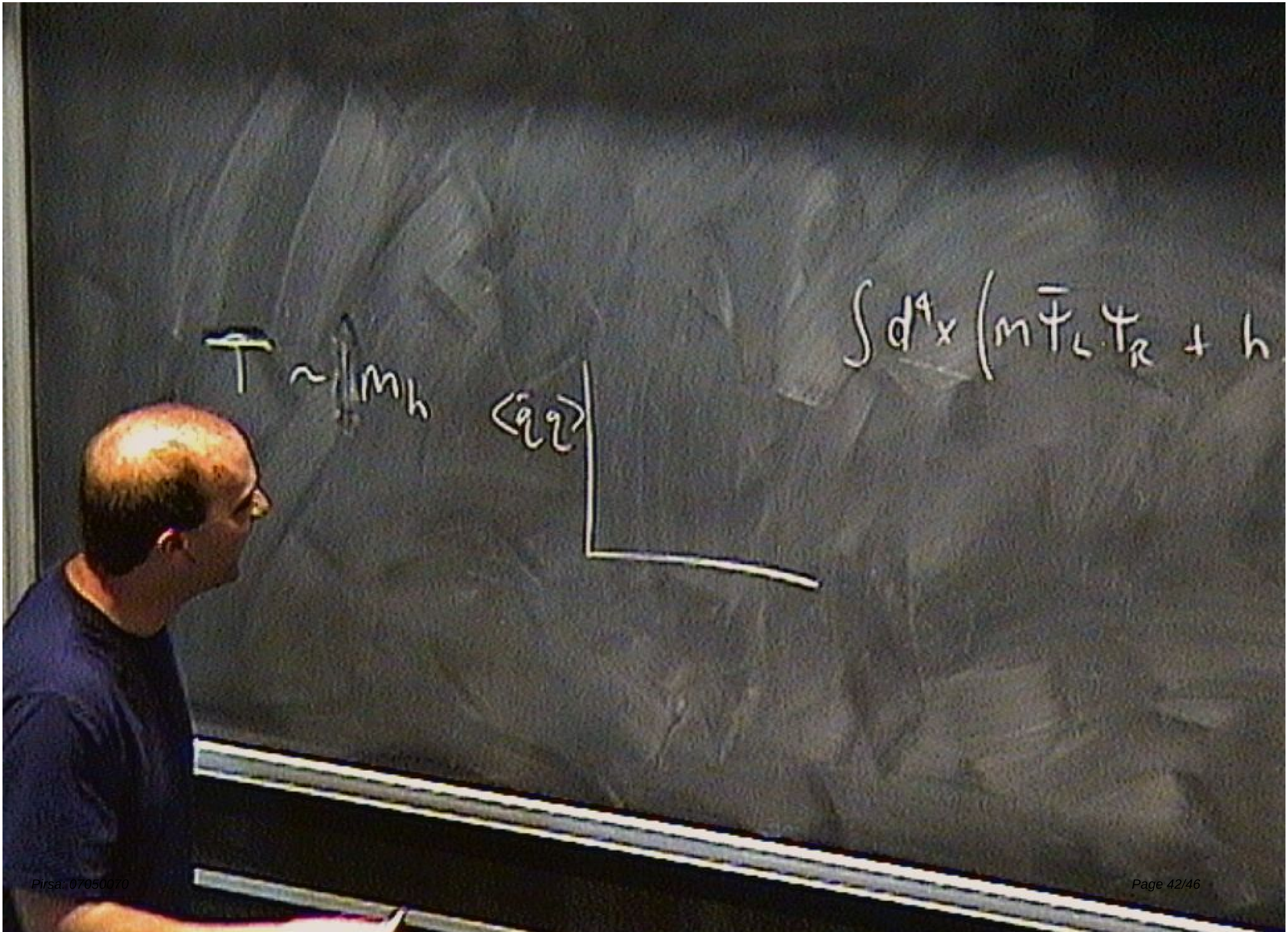
Lessons(!)

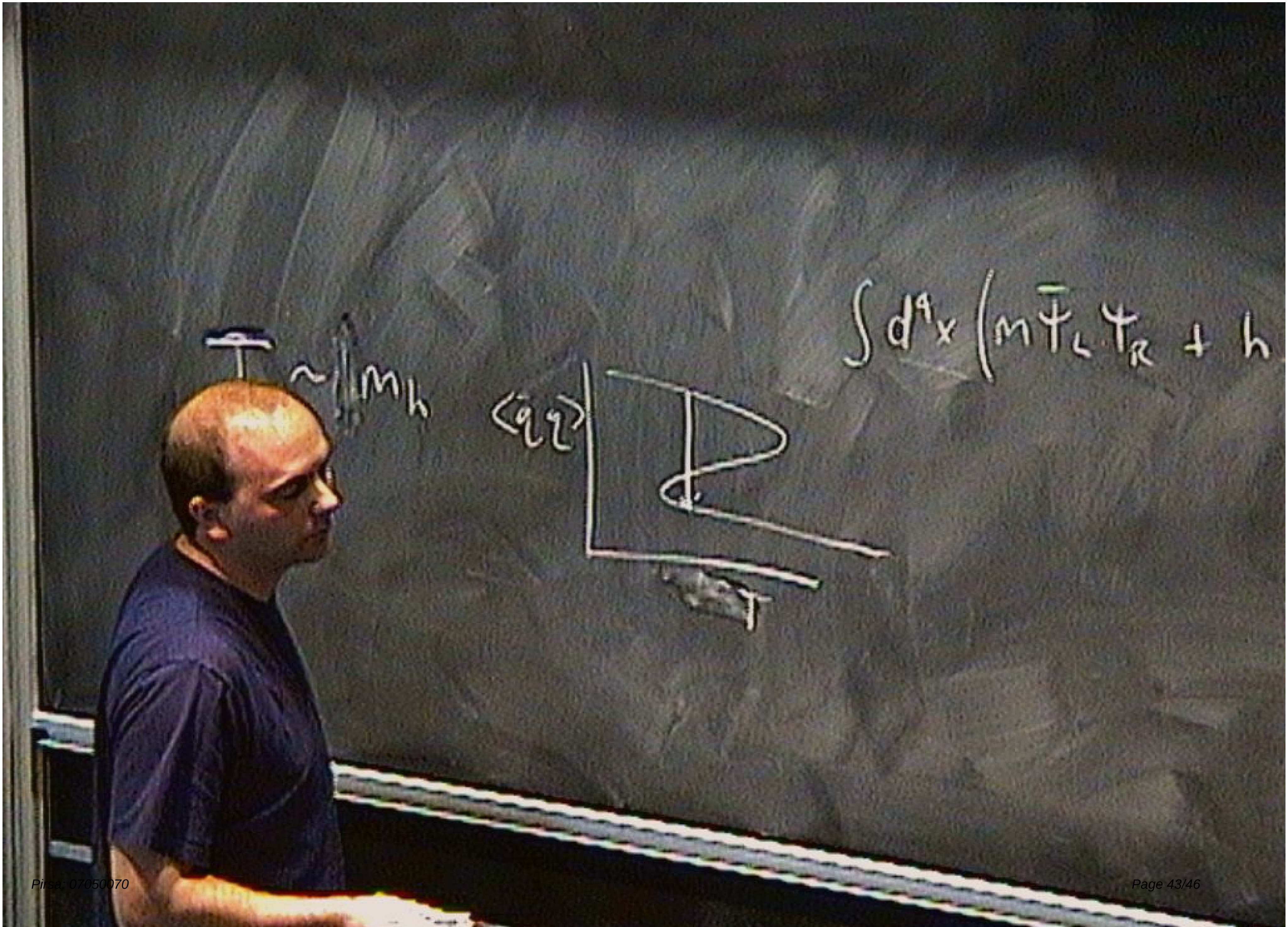
Published:

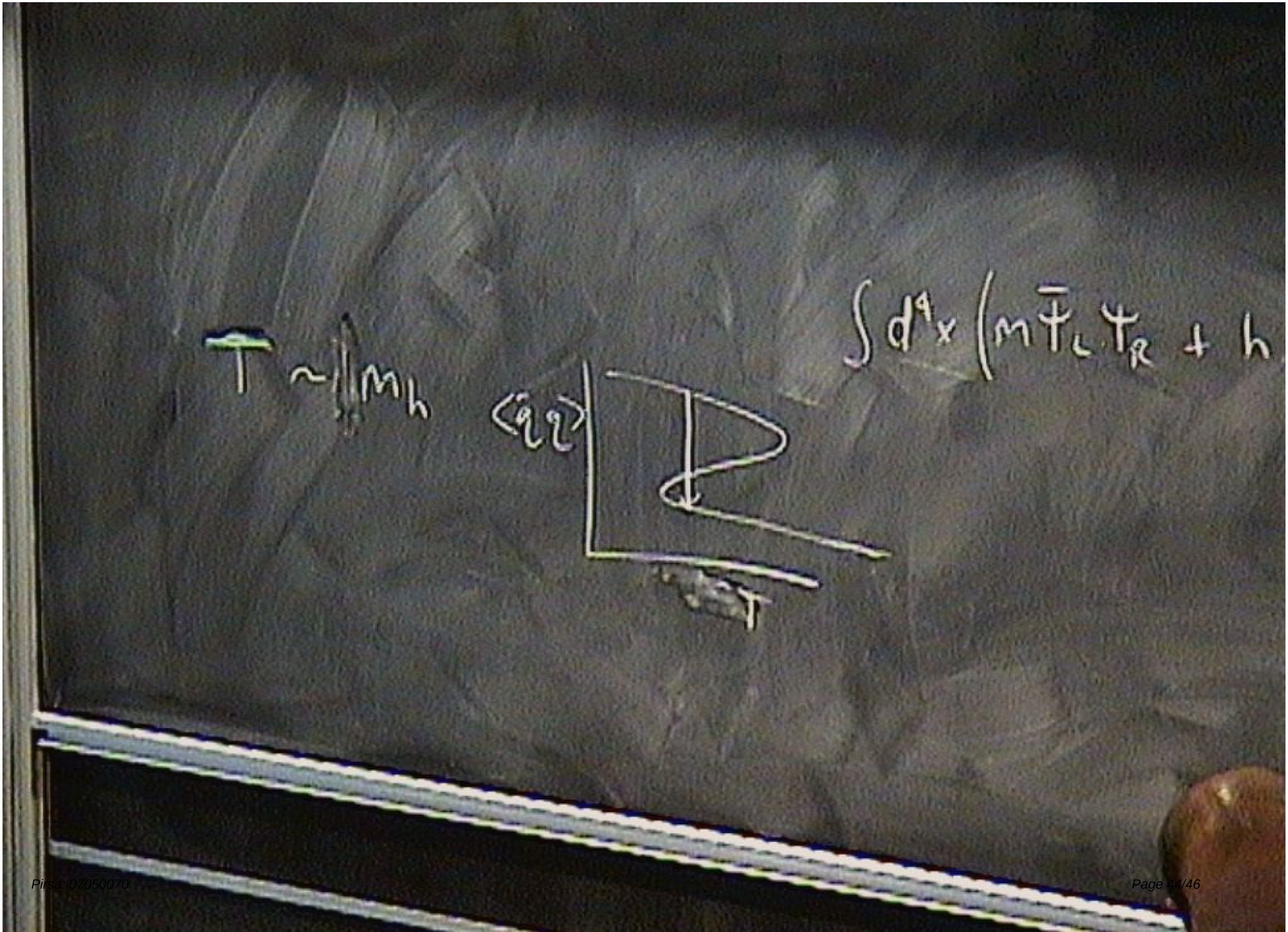
- Quenched mesons are tightly bound
- Susy breaking triggers chiral symmetry breaking
- Heavy Light meson holography
- First order finite T transition & scalar stability

To come:

- Unquenched meson masses
- Quark mass in Sakai Sugimoto
- Heavy Light melting to a heavy quark


T ~ m_h ⟨q̄q⟩
∫d^4x (m Ψ̄_L Ψ_R + h


T ~ m_h
<q̄q>
∫ d⁴x (m Ψ̄_L Ψ_R + h


T ~ m_h
⟨q̄q⟩
∫ d⁴x (m ψ̄_L ψ_R + h

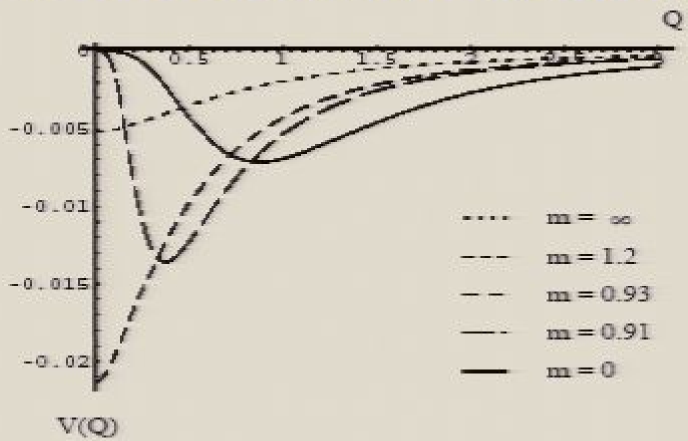
Scalar Potential - Finite T

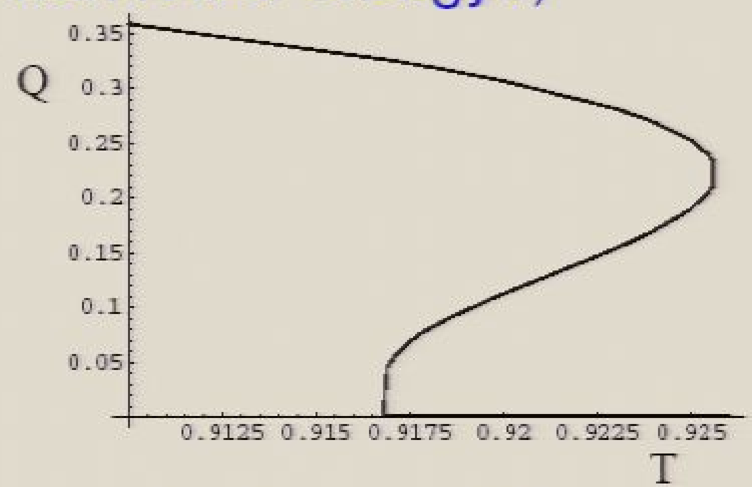
AdS Schwarzchild deformation governed by parameter T^4 - Asymptotically the leading non-cancelling term is

$$V \sim T^4 - c\frac{T^8}{Q^4} + \ldots$$

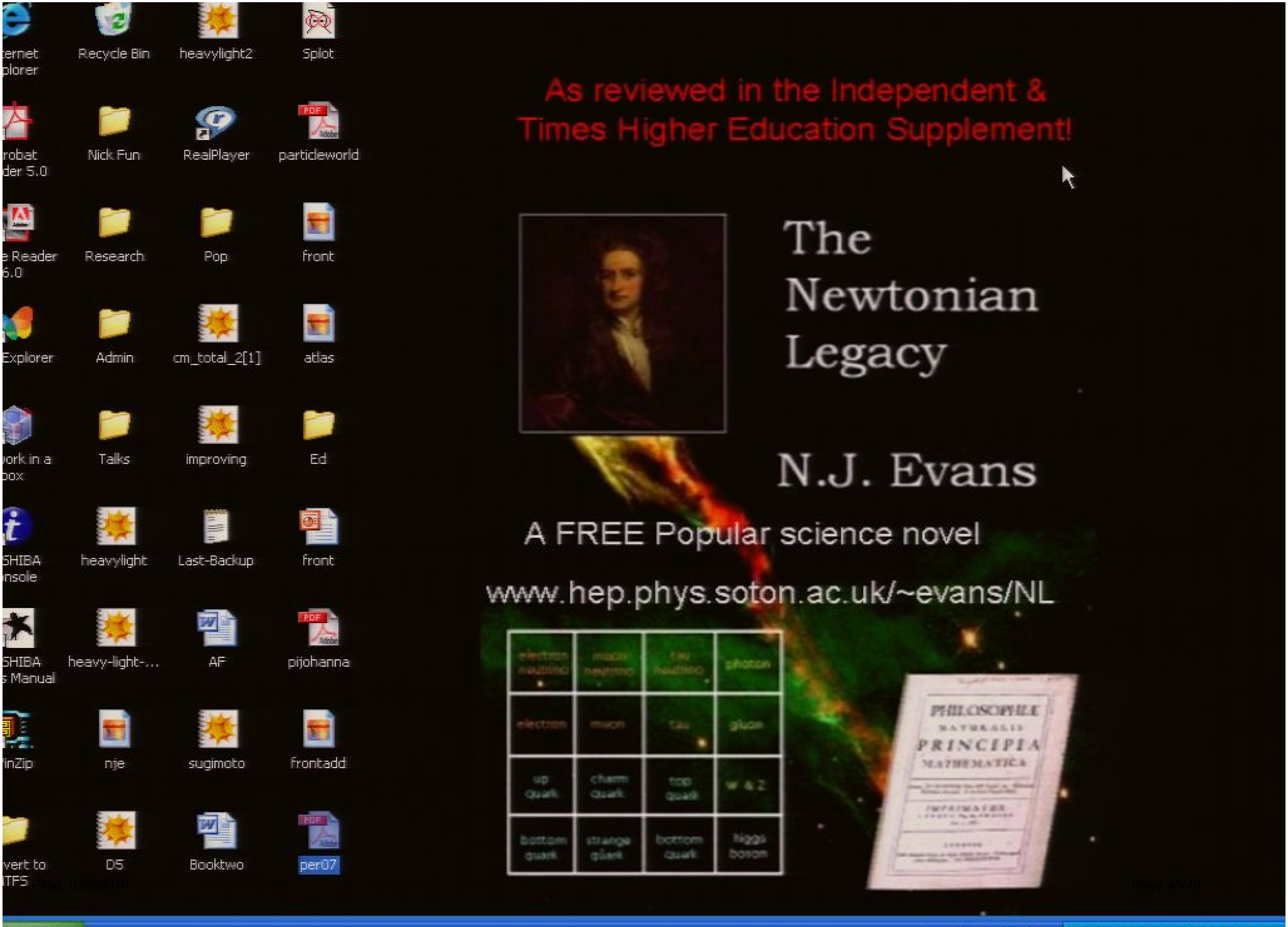
Computing c (+ve) shows bounded potential.

Action of the basic instanton configuration ("lifting" the moduli space... but deformed solutions with lower energy?)





The scalar vev is an order parameter for the transition.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