Holographic three-dimensional YM with compressible matter

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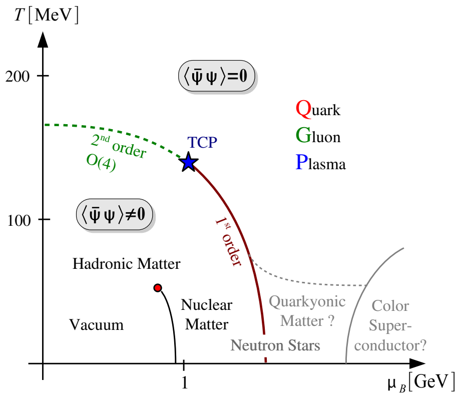
1. Introduction.
2. Uncharged solutions.
3. Charged solutions.
4. Summary and conclusions.

Holography at finite μ

- Strongly interacting systems at finite density. Quark/baryonic matter at high density (neutron stars, QGP). Interesting QCD phase diagram in the T-μ_B plane (from [de Forcrand, Philipsen, Unger '15]).



- We have (perturbative) information in the asymptotic regions

$$\mu \sim 0\,, \quad T \to \infty \qquad\qquad \text{and} \qquad\qquad T \sim 0\,, \quad \mu \to \infty$$

- Intermediate region difficult to access. Lattice computations limited to $\mu/T \leq 1$: sign problem. Effective models also used.

- What can gauge/gravity dualities teach us? Applications beyond particle physics: quantum critical points in CMT...

- Including quarks (fundamental matter) entails new open sectors: additional sets of branes [Karch, Katz '02].

Holography in the Veneziano limit.

- Intersecting (localized) brane solutions are complicated to find. Often probe approximation is considered. Corresponds to 't Hooft limit:

$$N_f = \text{fixed} \qquad\qquad \frac{N_f}{N_c} \to 0$$

- In some situations and for some effects this is not enough: backreaction needed. Veneziano limit:

$$N_f \to \infty \qquad\qquad \frac{N_f}{N_c} = \text{fixed}$$

- Smear the flavour branes in the internal directions [Bigazzi et al. '05]. Preserve some of the (super)symmetries.
- Dual to three-dimensional SYM with (smeared) backreacting flavour in [AF, Mateos, Tarrío '15?]. The internal geometry is beyond six-sphere.

- RG flow from YM to CS driven by (massless) quarks. Transition at the scale

$$U_{\mathrm{flavour}} \sim \lambda \frac{N_{\mathrm{f}}}{N_{\mathrm{c}}}$$

At IR it reaches a fixed point.

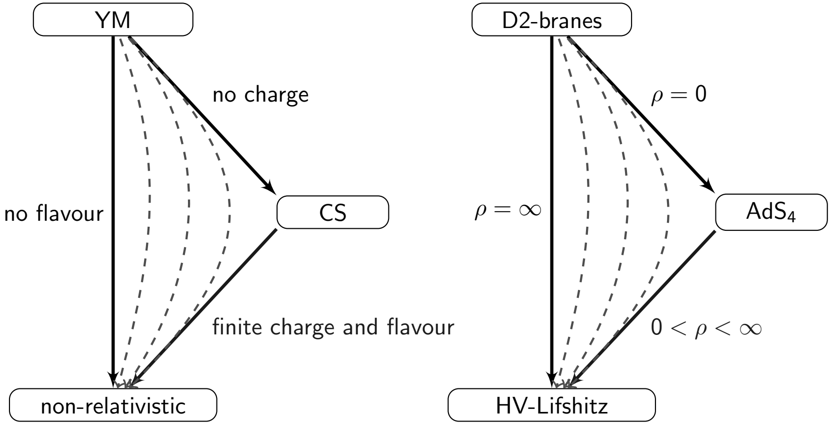
- Introduce a charge density ν_{q}. New scale in the system

$$U_{\mathrm{charge}} \sim \lambda^{\frac{1}{2}} \left(\frac{\nu_{\mathrm{q}}}{N_{\mathrm{c}}^2} \right)^{\frac{1}{4}}$$

breaking conformal invariance in the IR but still scaling properties [Gouteraux, Kiritsis '11].

- Family of RG flows parametrized by ratio

$$\rho \sim \left(\frac{U_{\mathrm{charge}}}{U_{\mathrm{flavour}}} \right)^4 \sim \lambda^{-2} \left(\frac{N_{\mathrm{c}}}{N_{\mathrm{f}}} \right)^4 \frac{\nu_{\mathrm{q}}}{N_{\mathrm{c}}^2}$$


YM
no charge
no flavour
CS
finite charge and flavour
non-relativistic
D2-branes
$\rho = 0$
$\rho = \infty$
AdS_4
$0 < \rho < \infty$
HV-Lifshitz

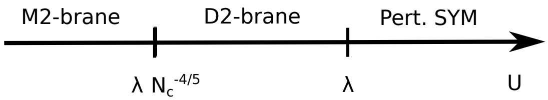
Flavourless solution.

- Stack of N_c D2-branes in flat space. Considered in [Itzhaki et al. '98].

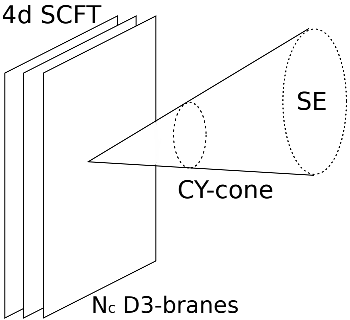
$$\begin{aligned} \mathrm{d}s_s^2 &= h^{-\frac{1}{2}}\,\mathrm{d}x_{1,2}^2 + h^{\frac{1}{2}}\,\left(\mathrm{d}r^2 + r^2\,\mathrm{d}\Omega_6^2\right) \\ e^{\phi} &= h^{\frac{1}{4}} \qquad\qquad h \sim \frac{N_c}{r^5} \end{aligned}$$

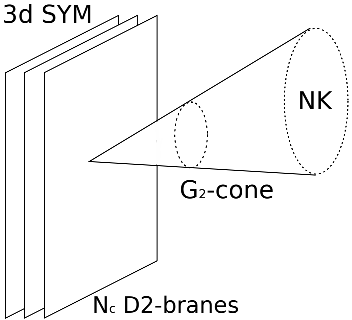
with N_c units of flux along S^6.

- Dual to maximally supersymmetric Yang–Mills in three dimensions. The coupling constant is dimensionful and there is an RG flow.



- To partially break susy, place the stack at the tip of a Ricci flat cone with reduced holonomy [Acharya et al. '98].
- For $\mathcal{N} = 1$, the cone is G_2 with nearly Kähler base. Compare with D3-branes at CY cone with Sasaki–Einstein base.



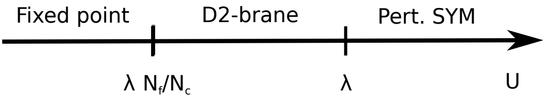


Flavourful solutions.

- To add N_f quarks, consider the intersection:

	x^1	x^2	r			NK			
N_c D2	$\times$	$\times$	$\cdot$	$\cdot$	$\cdot$	$\cdot$	$\cdot$	$\cdot$	$\cdot$
N_f D6	$\times$	$\times$	$\times$	$\times$	$\times$	$\times$	$\cdot$	$\cdot$	$\cdot$

- Analytic, regular solution to sugra + sources [AF, Mateos, Tarrío '15?]. RG flow triggered by flavour. The IR is AdS.



Including charge

- Chemical potential: temporal component of a global U(1). In the dual is a gauge field on the flavour branes [Kobayashi et al. '06].

$$S_{\mathrm{DBI}} = \int e^{-\phi}\sqrt{-\det\left(g + \mathrm{d}A\right)}$$

- Also non-trivial WZ couplings, so new fluxes

$$\begin{aligned} F_2 &= F_2^{\mathrm{flavour}} + Q_{\mathrm{B}}\,\mathrm{d}x^1 \wedge \mathrm{d}x^2 \\ F_4 &= F_4^{\mathrm{colour}} + F_4^{\mathrm{charge}} \end{aligned}$$

with the parameter $Q_{\mathrm{B}} \propto \lambda\,\frac{\nu_{\mathrm{q}}}{N_{\mathrm{c}}^2}$ related to baryon vertex.

- Equations only depend on the dimensionless ratio

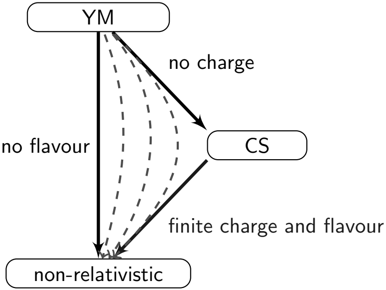
$$\rho \sim \left(\frac{U_{\mathrm{charge}}}{U_{\mathrm{flavour}}}\right)^4 \sim \lambda^{-2}\left(\frac{N_{\mathrm{c}}}{N_{\mathrm{f}}}\right)^4 \frac{\nu_{\mathrm{q}}}{N_{\mathrm{c}}^2}$$

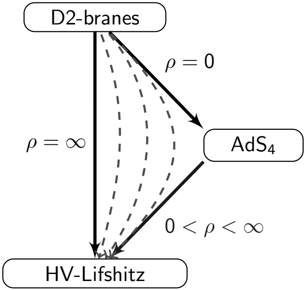
- Charge is relevant deformation in the UV: does not spoil YM asymptotics. Flavour corrections are leading.

- For non-dynamical quarks flows to IR with scaling [AF, Kundu, Mateos, Tarrío '14].

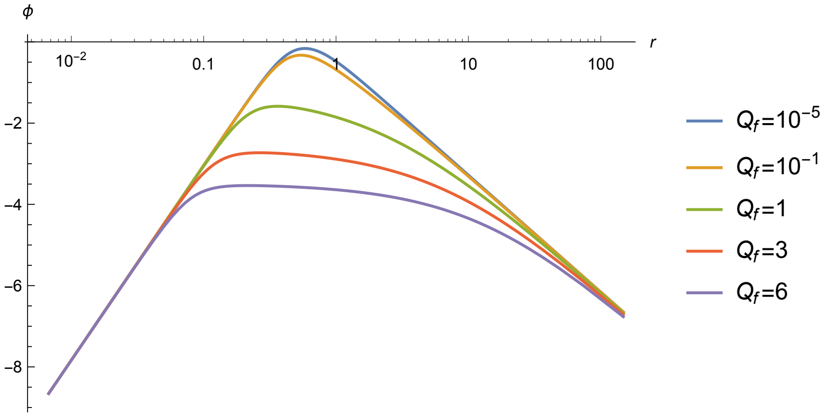
$$t \mapsto a^5\, t \qquad x \mapsto a\, x \qquad \mathrm{d}s \mapsto a^{\frac{1}{2}}\, \mathrm{d}s$$

Metric is Lifshitz with $z = 5$ and hyperscaling with $\theta = 1$.

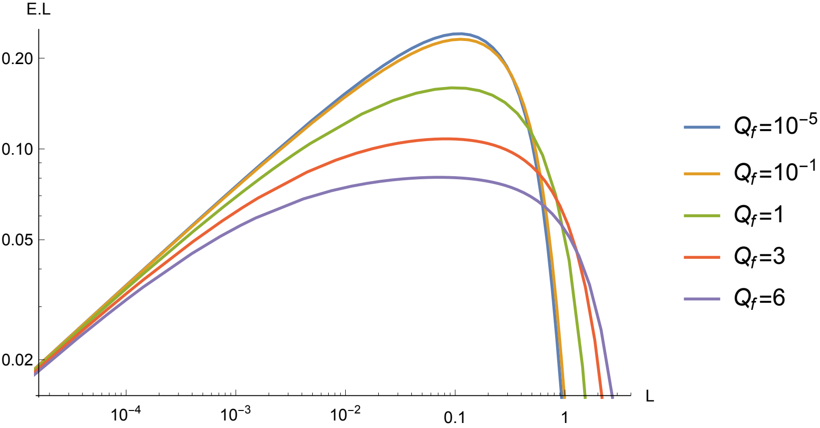




Dilaton



Wilson loop



Summary and conclusions.

- Holographic model $d = 3$, $\mathcal{N} = 1$ SYM with dynamical quarks at finite density. Toy model for QCD or CMT.
- Interesting RG flow depending just on ρ. Possible intermediate conformal region.
- Flow from the fixed point: CS-matter at finite density.
- Guidance for the physically relevant $d = 4$ case.
- Further extensions to resolve IR: temperature and instantons.