Holographic baryon and its stability analysis

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CPHT - Ecole Polytechnique

Recent Developments in High Energy Physics and Cosmology
Ioannina HEP 2012

- Based on:
  - with K. Sfetsos: JHEP 0808:071,2008, arXiv: 0807.0236 [hep-th].
  - with D. Giataganas, Y. Lozano and M. Picos, arXiv: 1203.6817 [hep-th].

Motivation

- The AdS/CFT correspondence is a tool to extract information for gauge theories at strong coupling from gravity. Prototype was the $AdS_5 \times S^5$ dual to $\mathcal{N}$=4 SYM [Maldacena 99].

- Extensions of this duality include cases with temperature, velocity, Coulomb branch, marginally deformed backgrounds... Recently in the ABJM model [Aharony, Bergman, Jafferis and Maldadena 08].

- Bound states of quarks like as mesons and baryons are dual to classical string (brane) probe solutions of Nambu–Goto, Dirac-Born–Infeld and Chern–Simons actions.

- Discrepancies between field theory/experimental expectations and their gravitational description;
  Baryons: non-colorless bound states.

- Not all probe solutions are suitable for such a description. Besides from identifying a correct asymptotic behavior, a stability analysis of the solution proves to be essential.

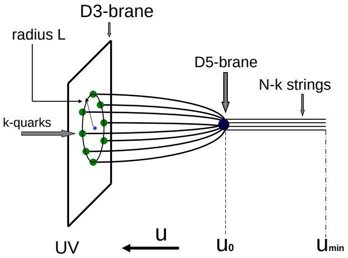
- These discrepancies are (partly) resolved as the probe solutions prove to be unstable. The findings from the gravitational dual side coincide with gauge theory expectations and in some cases they exceed the expectations.

Plan of the talk:

- Construction of baryons within the gravity/gauge theory duality.
- Classical solutions: energy and charges (baryons).
- Stability analysis:
  - Based on general statements concerning the perturbative stability of such string solutions (transcendental equation), rather than (heavy) numerics.
  - Applications and resolutions of the discrepancies, non-singlet solutions.
- Extensions to recent work:
  Klebanov–Witten and Maldacena–Nuñez backgrounds.
  Myers effect and 't Hooft coupling corrections.
- Conclusions and future directions.

Baryons within AdS/CFT

- Baryon alike construction within AdS/CFT is related to a D5 brane wrapped on a S^5 sphere in the interior of AdS(baryon vertex), so to balance the charge of N strings [Witten 98].



- The CS action of the localised $D5$-brane introduces a tadpole, which can be cancelled by N-strings (probes) attached on the vertex; $k, N \gg 1$.

- The strings are uniformly distributed on the internal S^5 and this configuration breaks supersymmetry, each string preserves half of the supersymmetry. [Imamura 98, Callan-Guijosa-Savvidy 98].

- Conformal case $AdS_5 \times S^5$: There is a bound state; the holographic baryon [Brandhuber-Itzaki-Sonnenschein-Yankielowicz 98], when

$$\frac{5}{8} < a \leqslant 1 \ ,$$

$E = E(L)$ Coulomb potential with $dE/dL > 0$ (bound state).

- Stability analysis: The existence of the zero mode is related to the transcendental equation

$${}_2F_1\left(\frac{3}{4}, \frac{3}{2}, \frac{7}{4}; 1-\lambda^2\right) = \frac{3}{2\lambda(1+\lambda^2)} \ , \qquad \lambda \equiv \frac{5}{4a} - 1 \ ,$$

with solution $a \simeq 0.813$. Classical solution is unstable if $a < 0.813$.

Klebanov–Witten Macroscopical

Next we consider baryon in Klebanov–Witten backgrounds $AdS_5 \times T^{1,1}$

$$ds^2 = R^2(ds^2_{AdS} + ds^2_{T^{1,1}}) \; , R^4 = \frac{27\pi N g_s}{4} \; , Vol(T^{1,1}) = \frac{16\pi^3}{27}$$
$$F_5 = 4R^4(1 + \star_{10}) vol(T^{1,1})$$

- $T^{1,1}$ is a abelian fibre of an $S^2 \times S^2$ and the fibre connection is a Kähler two form J.
- The charge of the $D5$ is N; $\exists$ tadpole.
- There is a baryon configuration with the typical behaviour Coulombic behaviour $a > 5/8$.
- Classical solution is unstable if $a < 0.813$.

Klebanov–Witten Microscopical

- The $D5$ brane will be constructed in terms of n-coinsiding D1-branes. We need a fuzzy version of the $T^{1,1}$ [Myers 98].
- Advantage of the microscopical construction is the exploration of the finite 't Hooft coupling; Validity of the approximation $Vol/n \ll \ell_s$.
- We consider the simplest fuzzy $T^{1,1}$ by winding the D1-strings along the $U(1)$ fibre direction ψ over a fuzzy $S^2 \times S^2$.
- A fuzzy 2-sphere can be obtained by imposing the definition of the sphere at the level of matrices. This can be done in the symmetric representation of $SU(2)$, $dim(m,0) = m+1$.
- Computing the DBI-CS actions in the large (m_1, m_2) limit we retrieve the commutative limit and for $m_1 = m_2 = \frac{\mathcal{N}}{3}$ we find the macroscopical result.

Maldacena–Nuñez Macroscopical

Next we consider baryon in Maldacena–Nuñez background (confining)

$$ds^2_{10} = e^{\phi}\left[dx^2_{1,3} + g_s N(\, e^{2h}\left(d\theta_1^2 + \sin^2\theta_1 d\phi_1^2\right) + dr^2 + \frac{1}{4}(wA^a)^2\right],$$

$$A^1 = -a(r)d\theta_1\,, \qquad A^2 = a(r)\sin\theta_1 d\phi_1\,, \qquad A^3 = -\cos\theta_1 d\phi_1\,,$$

$$e^{2\phi} = e^{-2\phi_0}\Lambda(r)\,, \quad e^{2\phi_0} = g_s N\,, \quad wA^a \equiv w^a - A^a\,,$$

$$F_{(3)} = \frac{g_s N}{4}\left\{-wA^1\wedge wA^2 \wedge wA^3 + \sum_a F^a \wedge wA^a\right\}.$$

- We wrap a $D3$-brane (probe) on the S^3-sphere, located at $r = r_0$ and the DBI-CS actions read

$$E^{DBI}_{D3} = \frac{N}{4\pi}\sqrt{\Lambda(\rho_0)}\,, \qquad S^{CS}_{D3} = -N\int_{\mathbb{R}} A\,.$$

- CS action introduces a tadpole, which can be cancelled by N-strings (probes) attached on the vertex.
- No-force condition (and stability analysis) gives a lower bound for the number of quarks at the UV, $a > 3/4$; non-colorless.

Maldacena–Nuñez Microscopical

- The $D3$ brane will be constructed in terms of n-coinsiding D1-branes. We need a fuzzy version of the S^3 sphere [Myers 98].
- We consider a fuzzy S^3-sphere by winding the D1-strings along the $U(1)$ fibre direction ψ over a fuzzy S^2-sphere.
- Computing the DBI-CS actions in the large m limit we retrieve the commutative limit and for $m = 2\mathcal{N}$ we retrieve the macroscopical result with a Kähler form on the S^2-sphere.
- Advantage of microscopical computation, it enables us to study the finite 't Hooft coupling limit.

Summary-future directions

- Built up: Within AdS/CFT we constructed configurations dual to bound states; baryons.
- Gravity side predictions may contradict with gauge theory/experimental expectations.
- A stability analysis of the classical solution is essential.
- Resolved puzzles: Baryons non-colorless states; $a < 1$. Stability analysis icreased this lower bound.
- We studied the construction of our D5 (D3) brane by n-coinciding D1-branes with the use of the Myers effect.
- This is the first step towards the gravitational description of finite 't Hooft corrections of dual baryon configurations...