# Composite Higgs Models in Holography

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# Composite Higgs Models

**The Basic Idea:**

- We consider the existence of an additional **strongly interacting sector** at high energies.
- At low energies, a global symmetry of this sector is **broken**.
- The Higgs particle emerges as a **pseudo-Nambu-Goldstone boson** composed of a quark-anti-quark pair (similar to the meson in QCD).

**Aspects of Composite Higgs Models Relevant for us:**

- The Higgs is a **meson-like** state.
- Composite Higgs models include light fermionic bound states, **top partners**. (important for strong coupling between top-quark and composite Higgs, Higgs mass and potential)

D. Kaplan, H. Georgi, Phys. Lett. B 136 (1984); G. Ferretti, D. Karateev, JHEP (2014);
J. Barnard, T. Gherghetta, T. Ray, JHEP (2014) and many others

We aim at constructing a **holographic model** with these properties.

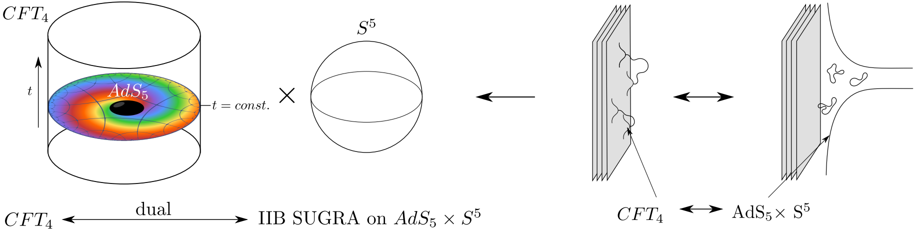
**Subtlety:**

The AdS/CFT correspondence does **not contain** quarks.

# Outline

# AdS/CFT Correspondence

AdS/CFT is a postulate for a **duality** between a $1+3$ dimensional **conformal field theory** ($CFT_4$) and a **theory of gravity** on asymptotic Anti-deSitter spaces ($AdS_5$). J. Maldacena, Adv.Theor.Math.Phys.2, (1998)
It is motivated by the **open** and **closed string picture** of a stack of $N$ D3 branes in ten-dimensional **superstring theory**.

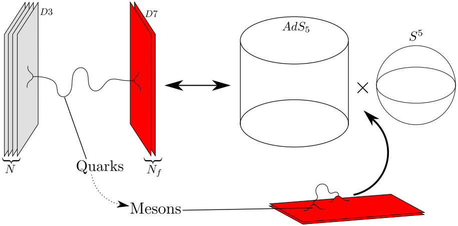





- All open strings have **both endpoints** on the stack of $D3$ branes.
- Therefore, they are in the **adjoint representation** of $SU(N)$.

# $D7$ probe branes in AdS/CFT

We add $N_f \ll N$ (**probe limit**) $D7$ branes to have strings with only one end attached to the stack of $D3$ branes.




- On the gravity side, $D7$ branes are hypersurfaces that lie in $AdS_5 \times S^5$
- The branes are embedded in the following way:

| | $x^0$ | $x^1$ | $x^2$ | $x^3$ | $x^4$ | $x^5$ | $x^6$ | $x^7$ | $x^8$ | $x^9$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $D3$ | X | X | X | X | | | | | | |
| $D7$ | X | X | X | X | X | X | X | X | | |

On the gravity side we can model mesons as excitations of $D7$ branes that lie in $AdS_5 \times S^5$.

A. Karch, E. Katz, N. Weiner, Phys. Rev. Lett. 90 (2003)

# D7 Brane Embedding and Mass Spectra of Mesons

We consider the metric of $AdS_5 \times S^5$ in the form

$$ds^2 = \frac{\rho^2 + Y^2 + Z^2}{R^2} \eta_{\mu\nu} dx^\mu dx^\nu + \frac{R^2}{\rho^2 + Y^2 + Z^2} \left( d\rho^2 + \rho^2 d\Omega_3^2 + dY^2 + dZ^2 \right),$$

where $R$ is the AdS-radius. The D7 branes are embedded along the the $x^\mu$, $\rho$ and $S^3$ directions at constant

$$Y^2 + Z^2 = L^2 .$$

The mass spectrum for the **scalar mesons** (fluctuations in $Y$ and $Z$ directions) in this setup is given by M. Kruczenski, D. Mateos, R.Myers, D. Winters, JHEP (2003)

$$M_s = \frac{2L}{R^2} \sqrt{(n + \ell + 1)(n + \ell + 2)} \quad n, \ell = 0, 1, \ldots .$$

(There are also vector mesons)

The mass spectrum of the superpartners (**mesinos**) is given by I. Kirsch, JHEP (2006); J. Erdmenger, N. Evans, I. Kirsch, E. Threlfall, Eur. Phys. J. A 35 (2008)

$$M_{\mathcal{G}} = \frac{2L}{R^2} \sqrt{(n + \ell + 2)(n + \ell + 3)}, \quad M_{\mathcal{F}} = \frac{2L}{R^2} \sqrt{(n + \ell + 1)(n + \ell + 2)}.$$

# Applying the Model to Composite Higgs

We are aiming at modeling the **Higgs** as a **meson** and the **top partners** as **mesinos**. In order to do so we need to

**(1) Make the Mesinos lighter.** We do this by introducing an higher dimension operator in the field theory

$$\Delta\mathcal{L}_{UV} = \frac{g^2}{\Lambda_{UV}^p}\bar{\mathcal{O}}_B\mathcal{O}_B$$

leading to a mass shift in the IR via Witten's multi-trace prescription.
E. Witten, arXiv: hep-th/0112258

**(2) Break supersymmetry.** We need to consider embeddings of the D7 brane that are **not** plane,

$$Y^2 + Z^2 = L(\rho)^2 \,.$$

Therefore, we consider geometries different from pure $AdS_5 \times S^5$

$$ds^2 = e^{2\chi}\left(\frac{r^2}{R^2}B^2(r)\eta_{\mu\nu}dx^\mu dx^\nu + \frac{R^2}{r^2}\left(d\rho^2 + \rho^2 d\Omega_3^2 + dY^2 + dZ^2\right)\right),$$

where $r^2 = \rho^2 + Y^2 + Z^2$.

# Equations of Motion for the Fermionic D7 Excitations

The resulting equations of motion for the fermionic D7 excitations are

$$\left(\Gamma^A D_A - \frac{ie^{\Phi}}{1920}\Gamma^A F_{NPQRS}\Gamma^{NPQRS}\Gamma_A - \frac{1}{2}\Gamma^M \partial_M \Phi\right)\Psi = 0\,,$$

where $\Phi$ is the dilaton, $F_{NPQRS}$ is the Ramond-Ramond five-form and $\Gamma^M$ are the Dirac matrices in ten dimensions.

$$\begin{aligned}\Gamma^A D_A =& \frac{R}{Bre^{\chi}}\gamma_\mu \eta^{\mu\nu}\partial_\nu + \frac{r}{Re^{\chi}(1+(\partial_\rho L)^2)}(\gamma_\rho + \partial_\rho L \gamma_L)\partial_\rho + \frac{r}{R\rho e^{\chi}}\not\nabla_{S^3} \\ &+ \frac{1}{2Re^{\chi}}\Bigg(4(1 + r\partial_r\chi + r\frac{\partial_r B}{B})\rho + \frac{(1-r\partial_r\chi)(L-\rho\partial_\rho L)}{1+(\partial_\rho L)^2}\partial_\rho L \\ &\quad + \frac{3}{\rho}(r^2 + \rho^2(r\partial_r\chi - 1))\Bigg)\gamma_\rho \\ &+ \frac{1}{2Re^{\chi}}\Bigg(4(1 + r\partial_r\chi + r\frac{\partial_r B}{B})L + \frac{(1-r\partial_r\chi)(\rho\partial_\rho L - L)}{1+(\partial_\rho L)^2} + 3(r\partial_r\chi - 1)L\Bigg)\gamma_L\,.\end{aligned}$$

Based on formulas provided in L. Martucci, J. Rosseel, D. Van den Bleeken, A. Van Proeyen Class. Quant. Grav. 22 (2005)

# Conclusion

- Aspects of composite Higgs we focus on:
  - Higgs modeled as a **meson-like state**.
  - Presence of **light fermionic bound states**.
- Introducing quarks by **adding probe branes**.
- Making contact with composite Higgs:
  - **Lightening the fermionic bound states** by introducing additional interaction terms to the Lagrangian.
  - **Breaking supersymmetry** by considering geometries different from pure $AdS_5 \times S^5$.