2024-4

Spring School on Superstring Theory and Related Topics

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Holography and strongly coupled model building
Lecture 4

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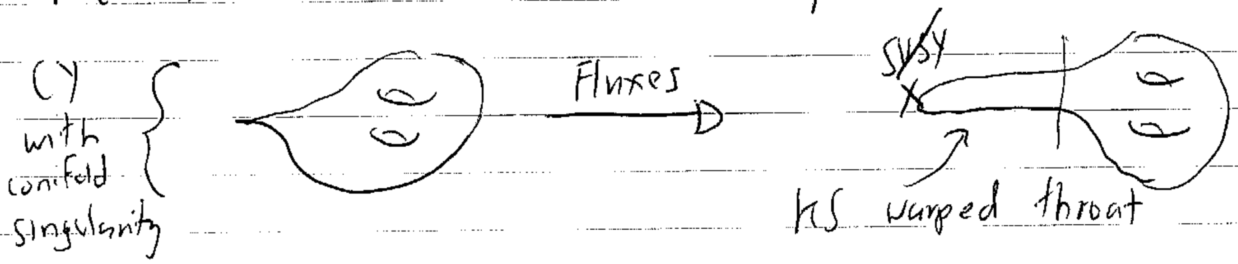
Trieste '09, Lecture IV

Kachru

IV a) continued

We have arrived at a picture

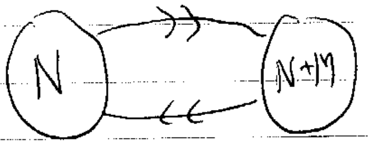


To add SM gauge fields & matter, we consider adding k D7s wrapping

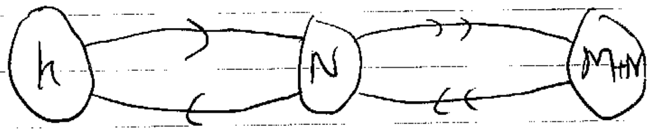
$$Z_4 = \mu \quad \subset \quad \sum_{i=1}^{4} z_i^2$$

What is the holographic field theory dual?

To KS



we should add the "3-7" strings



$$W = \epsilon^{ij}\epsilon^{kl} A_i B_k A_j B_l + \tilde{q}\,(A_1 B_1 + A_2 B_2)\,q$$
$$+ \mu\, \tilde{q}\, q$$

where:	$SU(k)$	$SU(N)$	$SU(N+M)$
$A_{1,2}$	1	N	$\overline{N+M}$
$B_{1,2}$	1	$\bar{N}$	$N+M$
q	k	$\bar{N}$	1
$\tilde{q}$	$\bar{k}$	N	1

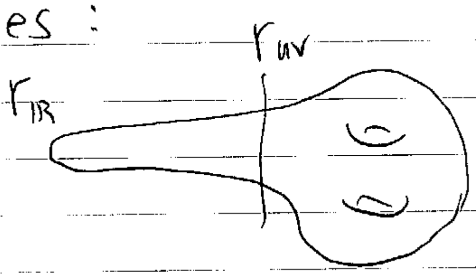
Important fact: $U(1)_R$ symmetry of $M=0$ conifold (FT was rotation $z_i \to e^{i\theta} z_i$.

KS breaks this to $\mathbb{Z}_{2M}$ (by anomaly) & $\mathbb{Z}_2$ (spontaneously in IR).

The k D7s break $U(1)_R$ completely if $M \neq 0$.

b) Matter?

Two possibilities:



i) $r_1 = r_2 = r_3 = r_{UV}$ All 3 generations arise out of throat in CY; we don't care how.

ii) One or more of $r_{1,2,3} << r_{uv}$

In case $\left\{\begin{array}{l} \text{i)} \\ \text{ii)} \end{array}\right.$, matter is $\left\{\begin{array}{l} \text{elementary} \\ \text{composite} \end{array}\right.$

in terms of dual CFT dynamics.

Here, we'll sketch results for i), then motivate ii) (but not get to stringy picture).

c) $\cancel{SUSY}$ & its transmission (+ in case i))

~~(cf Benini, Dymarsky, Franco, SK, Simic, Verlinde)~~

- Now, we consider K Kuperstein-embedded D7 branes in the $\cancel{SUSY}$ solution of lecture III. Our Question: What does the $\cancel{SUSY}$ in the "MSSM" look like?

- Only the gauge bosons & gaugino "live in" the throat as 5D fields -- others are in UV (eg in CY part of D7).

So our question boils down to -- what SU$\cancel{S}$Y gaugino mass is induced on the D7 by the SU$\cancel{S}$Y sugra solution?

We'll find the answer in 4 (short) steps.

Step 1: Direct mass from DKM sol'n?

The D7 in KS solution preserves $\mathcal{N}=1$ SUSY & has massless (non-normalizable) A_μ, λ^α in 4D. Do the metric, (1,2) flux & dilaton gradient at $\mathcal{O}(S)$ directly result in a mass $\lambda_\alpha \lambda^\alpha$ from DBI probe action for D7?

Grana '03
Camara, Ibanez, Uranga, '03

Answer: NO. Cf papers on soft terms from fluxes -- no (0,3) flux.

Step 2: The quarks q, $\tilde{q}$ probably get split & then (being charged under

SU(k)) split the gaugino.

What are the "meson masses" of the mesons made out of $q, \tilde{q}$?

Meson masses in KT background:

For simplicity, consider fluctuations of "$Z_4 = \mu$" (adjoint mode).

- Massless adjoint projected out by BC

$$S = -\frac{\mu_7}{g_s} \int d^8\sigma \sqrt{|\gamma|} \Big(g_{4\bar{4}} \gamma^{ab} \partial_a X^4 \partial_b X^{\bar{4}} \qquad (\star)$$
$$+ \gamma^{ac} \gamma^{bd} F_{cb} F_{da} \Big)$$

Notice: No g_{44}, $g_{\bar{4}\bar{4}}$ terms -- these vanish in KT but not in DKM.

Say $\mathbb{R}^4 \times \Sigma_4$ coords are $(\vec{x}, \vec{y})$. Expand

$$X^4 = \sum_n \phi_n(x) \xi_n(y) \qquad \text{KK reduction}$$

Then the ξ_n satisfy the diff eqn:

$$\partial_b\left(\sqrt{|\gamma|}\; g_{4\bar{4}}\; g^{ab}\; \partial_a \xi_n(y)\right) = -\lambda_n^2\, \xi_n(y)$$

- Projected out 0-mode ⇒ $\lambda_n^2 > 0$

We would like to package the n^{th} meson supermult. $\Phi_n(x)$ is an

$$\mathcal{L}_{4D} \supset \int d^4\theta\; \Phi_n \bar{\Phi}_n + \int d^2\theta\; X_n \Phi_n \Phi_n$$

spurion → $X_n = \underset{\uparrow\,\text{SUSY mass}}{M_n} + \theta\theta\, \underset{\uparrow\,\cancel{\text{SUSY}}\text{ mass}}{F_n}$

- It follows directly from (☆) that

$$M_n^2 = \frac{\int d^4y\; \sqrt{|\gamma|}\; g_{4\bar{4}}\; \gamma^{ab}\, \partial_a \xi_n\, \partial_b \bar{\xi}_n}{\int d^4y\; \sqrt{|\gamma|}\; h(r)\; \tilde{g}_{4\bar{4}}\; \xi_n \bar{\xi}_n}$$

$h(r)$ = KT warp factor $\left(\sim \dfrac{L^4_{eff}(r)}{r^4}\right)$

$\tilde{g}$ = un-warped metric $\left(\tilde{g}_{4\bar{4}} \sim \dfrac{1}{r}\right)$

where recall $L^4_{eff}(r) \sim 4\pi g_s N \alpha'^2 \ln(r/r_{IR})$

$= 4\pi \alpha'^2\, \lambda_{eff}(r)$

Now, replacing

$$\int d^4y\,\sqrt{|\gamma|} \to \int_{r=|\mu|^{2/3}}^{r_{uv}} dr\, r^3$$

and assuming ξ_n are well-localized around $r = |\mu|^{2/3}$, switching integration variable to $x = \frac{r}{|\mu|^{2/3}}$ $\to$

$$\boxed{M_n \propto \frac{|\mu|^{2/3}}{\sqrt{4\pi\lambda_{eff}(\mu)}}} \Bigg\}$$

Deeply bound mesons

$\left(\sim 1/\sqrt{4\pi g N}\right)$

Meson masses including $\cancel{\text{SUSY}}$

In KT, $M_n \neq 0$ but $F_n = 0$.

The leading DKM correction to our D7 action will be terms

$$(\Delta)\ \delta S_{DKM} = \frac{-M_7}{g_s}\int d^8\sigma\,\sqrt{|\gamma|}\,\Big(g_{44}\gamma^{ab}\partial_a X^4 \partial_b X^4 + g_{\bar4\bar4}\gamma^{ab}\partial_a X^4 \partial_b X^{\bar4}\Big)$$

As we discussed in lecture III,

the DKM sol'n perturbs KT metric - so ∃ also g_{44}, $g_{\bar{4}\bar{4}}$ components. We find

$$\tilde{g}_{44} = h^{-1/2} g_{44} \sim \frac{\bar{\mu}^2 S}{r^8}$$

where S was SU$\cancel{\text{S}}$Y order parameter.

Then reducing (Δ) to 4D →

$$F_n \simeq \frac{\int d^4y \sqrt{|\gamma|}\, g_{44}\, \gamma^{ab} \partial_a \xi_n \partial_b \xi_n}{\int d^4y \sqrt{|\gamma|}\, h\, \tilde{g}_{4\bar{4}}\, \xi \bar{\xi}}$$

Using same technique we used to get M_n →

$$F_n \sim \frac{\bar{\mu}^2 S}{|\mu|^{10/3}\, 4\pi\, \lambda_{eff}(\mu)}$$

Step 3 : Gaugino Mass

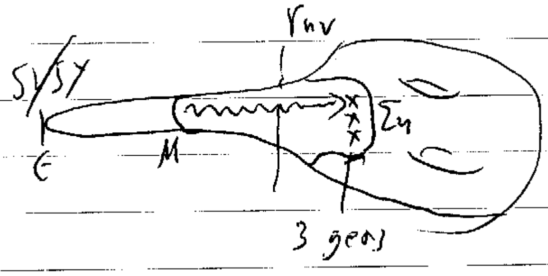
The gaugino now gets a mass from loop diagrams where it sees split meson multiplets.

Using standard gauge mediation formulae, + summing over tower of mesons to $n_{max} \sim (g_s N_{eff})^{1/2}$ [above this n they de-confine!] →

$$m_\lambda = \frac{g_{sm} k}{16\pi^2} \frac{S}{\mu^2 \sqrt{4\pi \lambda_{eff}}} \sum n \longrightarrow$$

$$\boxed{m_\lambda \simeq \frac{g_{sm} k}{16\pi^2} \frac{S}{\mu^2} (4\pi g_s N_{eff})^{1/2}}$$

Step 4: The gaugino/gauge multiplet live on whole D7, & can "gaugino mediate" $\cancel{SUSY}$ to MSSM matter:

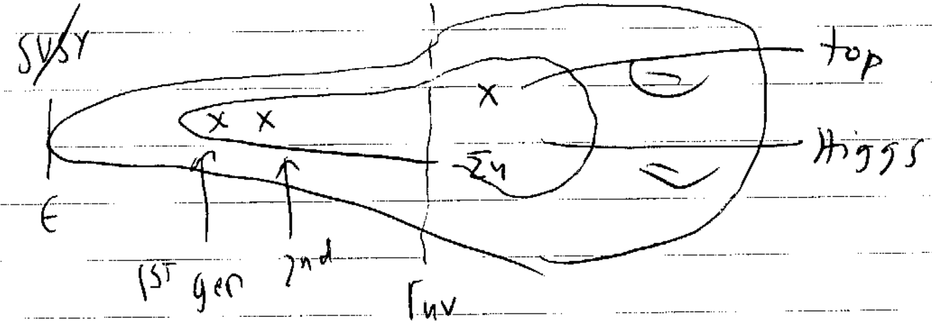


Gaugino mediation (see '99 pheno papers) → flavor blind spectrum of soft masses:

$$\boxed{m^2 \sim \alpha_{sm} m_\lambda^2 \log\left(\frac{M_{z}}{M_*}\right)}$$

← cutoff on 4d thy.

d) Very interesting class of generalizations:



Make 1st, 2nd gens **composite** (move them into throat; by intersecting Σ_4 w/ Σ_{Flavor}, $\int_{\Sigma_4 \cap \Sigma_{\text{Flavor}}} (F_1 - \underset{\uparrow \text{ field str on D7s}}{F_2}) \neq 0$).

- Then, distance from H → tiny Yukawas ✓
- stop mass from gaugino med ~ 500 GeV

⇒ **much heavier** 1st, 2nd gen sparticles (they are much closer to $\cancel{\text{SUSY}}$ & get direct contribution to soft mass). This is **good** for flavor physics, and predicts

Smaller Yukawas ⟺ Heavier Spartners.

Much more generally, hopefully you're convinced that AdS/CFT may be a useful tool in geometrizing strongly coupled models of DSB + mediation.

Even more interesting: Non-SUSY throats w/ stable (radiatively), composite Higgs? 1st step is to design such stable non-SUSY throats.