Supersymmetry breaking deformations and phase transitions in five dimensions

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1. Introduction

In $d = 5$ gauge theories are non-renormalizable , with dimensionful gauge coupling $[h] = [1/g^2] = 1$.
However, **in presence of $\mathcal{N} = 1$ SUSY**, it was shown [1] that many of these theories admit UV fixed points which are interacting SCFTs.
Moreover, many string theory constructions [2, 3] are known for these theories and a large zoo of SCFTs was discovered.
In absence of SUSY, however, it is difficult to understand CFTs in 5d. This gives rise to an important question:

Are there non-SUSY CFTs in $d = 5$?

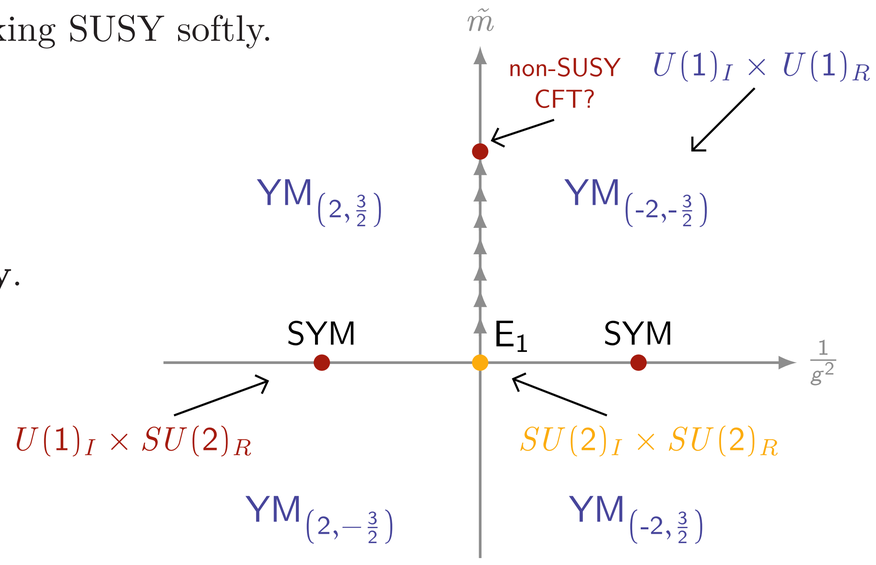
2. Soft SUSY breaking

Start from known SCFTs and deform it breaking SUSY softly.
***SU*(2) SYM theory**:

- Topological global symmetry $U(1)_I$;
- $SU(2)_R$ symmetry;
- UV fixed point at $1/g^2 \to 0$: ***E*$_1$ theory**.

***E*$_1$ theory**:

- $U(1)_I$ is enhanced to $SU(2)_I$;
- Higgs branch $\mathbb{C}^2/\mathbb{Z}_2$ opens up.



Soft SUSY breaking of *E*$_1$ theory [4]: source lowest component of flavor current multiplet $\mu^{(ab)}_{(ij)}$:

- (ab) and (ij) fundamental indices of $SU(2)_I \times SU(2)_R$: source breaks $SU(2)_I \times SU(2)_R \to U(1)_I \times U(1)_R$;
- Breaks SUSY and conformality $\delta\mathcal{L} = \tilde{m}\mu^{(12)}_{(12)}$ with $[\tilde{m}] = 2$.

Deformation of *SU*(2) SYM: flow to $SU(2)$ pure YM with CS levels for $U(1)_I \times U(1)_R$.
Different CS levels between $h > 0$ and $h < 0$: phase transition on the $\tilde{m}$ axis.

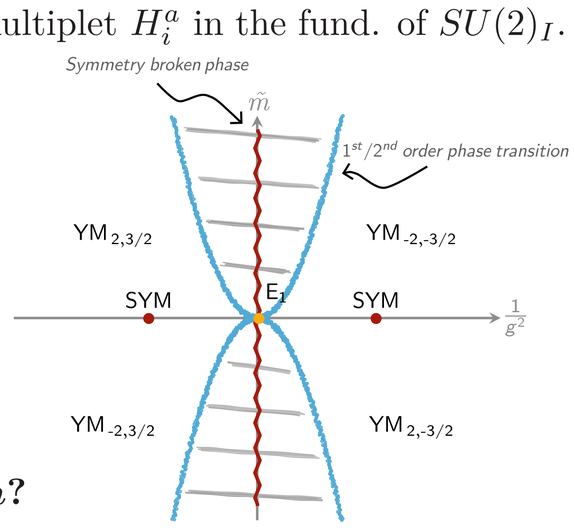
Non-SUSY CFT on the $\tilde{m}$ axis?

3. Higgs branch instability

***E*$_1$ Higgs branch**: parametrized (locally) by a free half-hypermultiplet H^a_i in the fund. of $SU(2)_I$.
EFT on the Higgs branch: deformation is $\mu^{(ab)}_{(ij)} \sim H^{(a}_{(i} H^{b)}_{j)}$:

- Tachyonic mass for H^1_2;
- NLSM phase: $U(1)_I \times U(1)_R \to U(1)_D$.

Robust under quantum corrections [5].
Finite coupling $h \neq 0$: mass for $H^1_2 \sim h^2$, resolution of the instability and symmetry restoration for $h^2 \sim \tilde{m}$



Non-SUSY CFT at $h^2 \sim \tilde{m}$?

6. Conclusions

The SUSY breaking deformation acting on the Higgs branch EFT introduces a tachyon mass for one scalar, leading to an instability. Its condensation breaks the $U(1)_I \times U(1)_R$ symmetry down to its diagonal, leading to a NLSM phase at strong coupling.

At leading order, a finite gauge coupling stabilizes the scalar, leading to a second order phase transition at $h^2 \sim \tilde{m}$ between the NLSM and the YM phases.

Also a string theory construction confirms this expectation.

Still second order taking into account corrections?

7. References

[1] N. Seiberg, Phys. Lett. B **388** (1996), 753-760.
[2] O. Aharony, A. Hanany and B. Kol, JHEP **01** (1998), 002.
[3] D. R. Morrison and N. Seiberg, Nucl. Phys. B **483** (1997), 229-247.
[4] P. Benetti Genolini, M. Honda, H. C. Kim, D. Tong and C. Vafa, JHEP **05** (2020), 058.
[5] M. Bertolini and F. Mignosa, JHEP **10** (2021), 244.

4. pq-web constructions

Type IIB string theory: (p, q) bound states of p D5 and q NS5 branes along 01234 and (p_i, q_i) in (x, y).

***SU*(2)$_R$ symmetry**: $SO(3)_{789}$ isometry of D-directions.

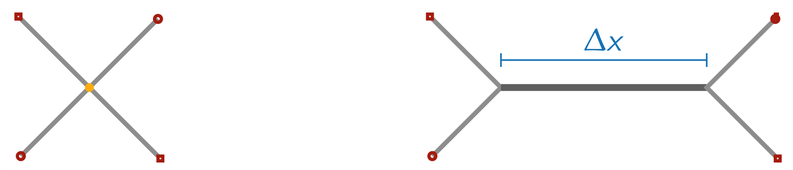
$\mathcal{N} = 1$ junction: (p_i, q_i) branes meet at a point with

$$\sum_i p_i = \sum_i q_i = 0, \quad \tan\theta_i = p_i/q_i$$

5d $\mathcal{N} = 1$ field theories: D5 branes suspended among (p, q) branes.

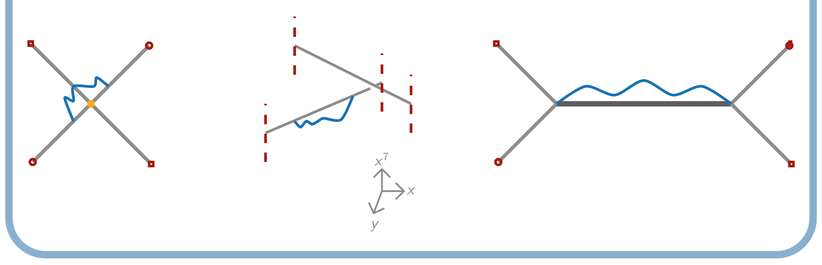
7-branes: at the end of (p, q) prongs (red), transverse to (x, y), host flavor symmetry.

***SU*(2) SYM**: two D5 branes between $(1, 1)/(1, -1)$ junctions with $\Delta x \sim h$



Higgs branch: $(1, 1)$ string connecting $(1, 1)$ prongs (blue).

VEV of hyper = position of $(1, 1)$ brane segment in $\mathbb{R}^{789}$.



5. pq-web deformation

$\tilde{m}$ deformation: rotate by α two right prongs of the pq-web (outside the plane).

***E*$_1$ theory**:

- $SU(2)_I \times SU(2)_R \to U(1)_I \times U(1)_R$;
- Web is no more SUSY;
- Higgs branch: $(1, 1)$ string is tachyonic $\sim -\alpha/l_s^2$.

***SU*(2) SYM**:

- Fermions and scalars on D5 gapped by rotation;
- Positive mass $\sim h^2$ for $(1, 1)$ string due to stretching.

Massless tachyon at $h^2 \sim \tilde{m}$!

Corrections from string theory?