Light dilaton and Ultra light scale SYM

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(1107.2932 [hep-ph])

Outline

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Model : ***Perturbative regime***:

Perturbative Fixed Points (FP) structure

The gauge theory we investigate is:

Fields	$[SU(X)]$	$SU(N_f)_L$	$SU(N_f)_R$	$U(1)_V$	$U(1)_{AF}$
λ_m	Adj	1	1	0	1
q	$\square$	$\overline{\square}$	1	$\frac{N_f - X}{X}$	$-\frac{X}{N_f}$
$\widetilde{q}$	$\overline{\square}$	1	$\square$	$-\frac{N_f - X}{X}$	$-\frac{X}{N_f}$
H	1	$\square$	$\overline{\square}$	0	$\frac{2X}{N_f}$
G_μ	Adj	1	1	0	0

Extra Anomaly Free U(1) due to the presence of the gluino

$$\mathcal{L} = \mathcal{L}_K(G_\mu, \lambda_m, q, \widetilde{q}, H) + y_H q H \widetilde{q} + \text{h.c.}$$
$$-u_1 \left(\text{Tr}[HH^\dagger]\right)^2 - u_2 \text{Tr}\left[(HH^\dagger)^2\right],$$

Possible dual scalarless description of the SM: Sannino '11

work in the Veneziano limit $X \to \infty$, $N_f \to \infty$ with $x \equiv N_f/X$ fixed and define the perturbative expansion parameter ϵ through $x \equiv \frac{9}{2}(1-\epsilon)$.

$$a_g = \frac{g^2 X}{(4\pi)^2}, \; a_H = \frac{y_H^2 X}{(4\pi)^2}, \; z_1 = \frac{u_1 N_f^2}{(4\pi)^2}, \; z_2 = \frac{u_2 N_f}{(4\pi)^2}.$$

$$\beta(a_H) = 2a_H\left[(1+x)a_H - 3a_g\right]$$

$$\beta(z_1) = 4(z_1^2 + 4z_1 z_2 + 3z_2^2 + z_1 a_H)$$

$$\beta(z_2) = 4(2z_2^2 + z_2 a_H - \frac{x}{2}a_H^2),$$

$$\beta(a_g) = -2a_g^2\left[\left(3 - \frac{2x}{3}\right) + \left(6 - \frac{13x}{3}\right)a_g + x^2 a_H\right]$$

FP will be perturbative for x such that first coefficient of the gauge beta function vanishes

Model : ***Perturbative regime***:

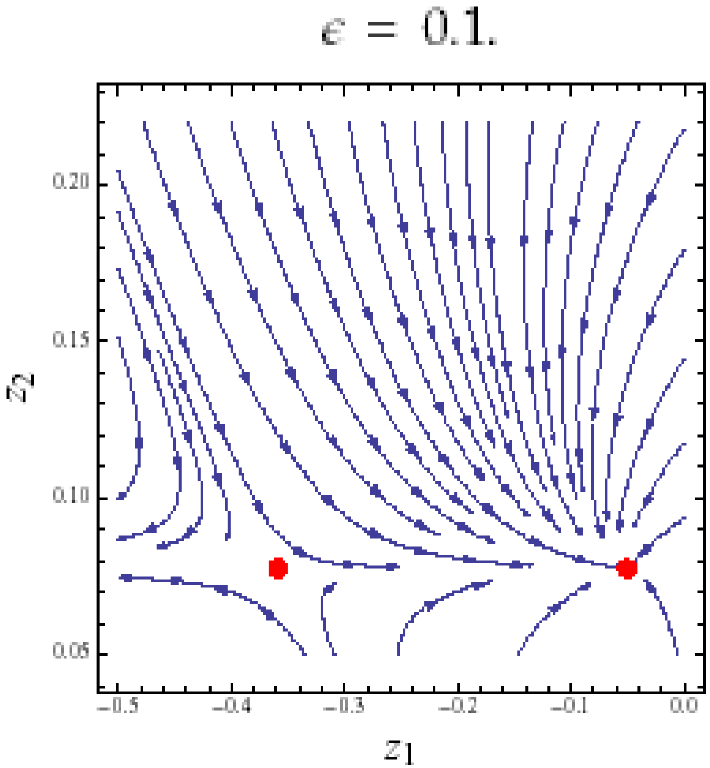
Perturbative Fixed Points (FP) structure

Two real Fixed Points:

$$a_g = \frac{11\epsilon}{9}, \quad a_H = \frac{2\epsilon}{3}$$

$$z_1 = \frac{-2\sqrt{19} \pm \sqrt{2(8+3\sqrt{19})}}{6}\epsilon, \quad z_2 = \frac{-1+\sqrt{19}}{6}\epsilon$$

Interestingly, these interacting FPs will disappear if adjoint fermion is removed from the spectrum. In this case, the model becomes the many-flavor QCD with bifundamental scalar.



Gauge and Yukawa couplings kept at the FP values

Model : ***Perturbative regime***:

Coleman-Weinberg potential, perturbative spectrum and dilaton mass

Gildener and Weinberg '76

1) If the one-loop effective potential $V_{\text{eff}} = V_0 + V_1$ can be calculated at some renormalization scale M_0 for which the tree-level term V_0 vanishes and is a minimum then one-loop perturbation theory can be used to show that V_1 causes V_{eff} to be negative and stationary.

2) The theory possesses, at least, one real light scalar corresponding to the field in the direction in scalar field space along which the potential develops the ground state.

$$m_d^2 = \frac{1}{8\pi^2 \langle H \rangle^2} \sum_i \left[m^4_{scalar} - 4 m^4_{fermion} \right]_i \longrightarrow m_d^2 = 128\pi^2 v^2 \left[4(z_2^0)^2 - x(a_H^0)^2 \right].$$

For our model condition 1) is satisfied if:

$$z_2^0 > 0 \text{ and } z_1^0 + z_2^0 = 0,$$

$$\langle 0|H_{ij}|0\rangle = v\delta_{ij}, \Rightarrow U(N_f) \times U(N_f) \to U(N_f)$$

Perturbative spectrum:

N_f^2 Goldstone bosons

$N_f^2 - 1$ Heavy "Higgses"

1 Pseudo-Goldstone of spontaneously broken scale invariance

Model : ***Perturbative regime***:

Geometric interpretation

Using RG methods, the conditions for the minimum away from the origin are:

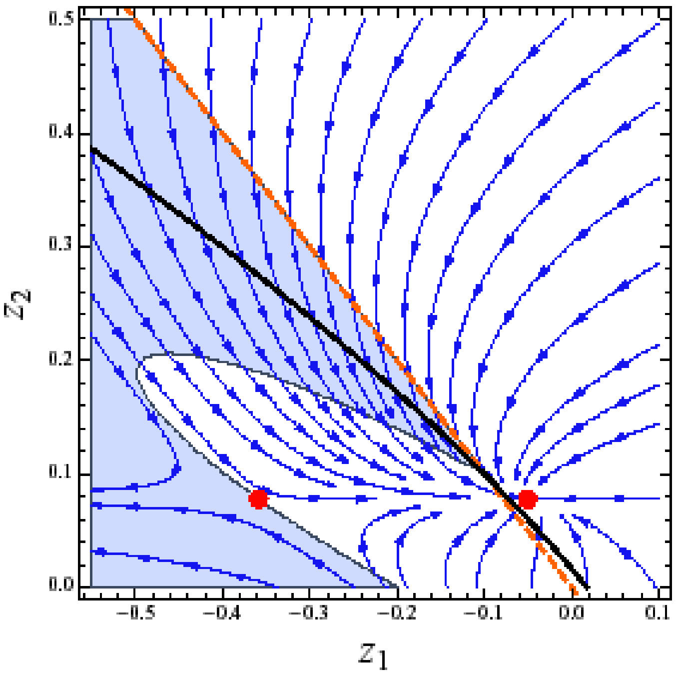
$$z_1 + z_2 < 0, \quad z_2 > 0 \qquad V(\langle H \rangle) < V(0),$$

$$4(z_1 + z_2) + \beta(z_1) + \beta(z_2) = 0 \qquad V'_{\text{eff}}(\langle H \rangle) = 0.$$

$$4[\beta(z_1) + \beta(z_2)] + \underbrace{\sum_j^{1,2} \sum_c^{z_1, z_2, a_H} \beta(c) \frac{\partial \beta(z_j)}{\partial c}}_{} > 0 \qquad V''_{\text{eff}}(\langle H \rangle) > 0.$$

Higher order
In the couplings

$\epsilon = 0.1.$



⇒ allowed region of the stability line lies in the intersection of $z_1 + z_2 < 0$ and $\beta(z_1) + \beta(z_2) > 0$

(shaded region)

<u>For the CW phenomenon RG flow has to cross black line In the shaded region</u>

Model : ***Non-perturbative regime*:**

N=1 SYM

Remaining massless gluino and gluons give rise to the pure N=1 SYM spectrum at low energy. RG-invariant scale of SYM and gluino condensate are given by:

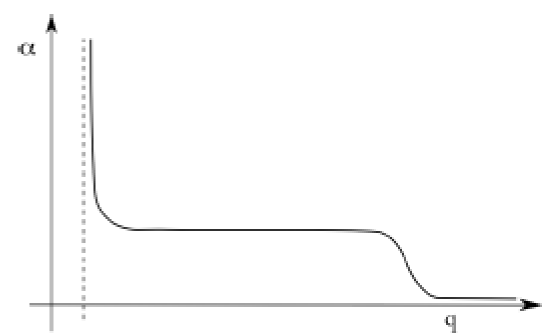
$$\Lambda^3_{SYM} = v^3\left(\frac{16\pi^2}{3X\,g^2(v)}\right)\exp\left(-\frac{8\pi^2}{X\,g^2(v)}\right)$$
$$= v^3\left(\frac{1}{3a_g(v)}\right)\exp\left(-\frac{1}{2a_g(v)}\right)$$
$$= v^3\left(\frac{3}{11\epsilon}\right)\exp\left(-\frac{9}{22\epsilon}\right) \ll v^3 \,.$$

The low energy spectrum of SYM is constituted by a chiral superfield featuring a complex scalar (the gluino ball) and a Majorana fermion (the gluino-glue composite state) which because of supersymmetry are degenerate in mass.

$$\langle\lambda_m\lambda_m\rangle = -\frac{9}{32\pi^2}\Lambda^3_{SYM} \,.$$

<u>This is non-perturbative sector of the theory.</u>

Once heavy quarks and scalars decouple the gauge coupling evolves to the strong coupling regime.



Model : ***Overview***

Energy

Heavy (Nf^2) scalars and (Nf*X) quarks

$$\langle 0|H_{ij}|0\rangle = v\delta_{ij},$$

Parametrically light dilaton

$$m_d^2 = 128\pi^2 v^2 \left[4(z_2^0)^2 - x(a_H^0)^2\right].$$

"tunable" parameter

N=1 SYM

$$\boldsymbol{v}\exp\left(-\frac{9}{22\epsilon}\right).$$

Conclusions

- We introduced calculable model featuring perturbative stable fixed point
- We determined perturbative and non-perturbative spectrum near this fixed point
- We demonstrated that the theory features light scalar degree of freedom (compared to the scalar vev)
- We showed that the lightest states of the theory are associated with N=1 SYM.