Can the Higgs be supersymmetric and composite?

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Introduction: Models for EWSB

- Although the SM has been tested to an impressive accuracy it gives no explanation for the EWSB mechanism, it just introduces an ad-hoc scalar field with a potential.
- The nature of this scalar field and its potential has been the guiding principle for physics beyond SM.
- There has been essentially to different approaches to explain the nature of EWSB: SUSY or strong dynamics (Technicolour or PGB)

- Both type of approaches has its owns problems

- Most models of Technicolour or Higgs as PGB predict too large corrections to the EW observables, and they have really big issues with flavour or the Higgs potential.

- The MSSM on the other hand, has very little impact on EW observables, but there are problems related to supersymmetry breaking. Although the worst problem is the fine-tuning related to the Higgs mass.

Composite Higgs?

- Since SUSY have the benefit of not affecting the EW parameters and strong dynamics can increase the Higgs mass.
- I am going to present a model where the Higgs and the top quark are composites.
- With this set-up the large yukawa of the top can be explain due to the compositeness of those particle and thus related to the strong dynamics.
- EWSB is aided by a singlet and is generated at tree-level.

- The model is based on the gauge structure:

$$SU(3)_s \times SU(3)_c \times SU(2)_W \times U(1)_Y$$

- Where the $SU(3)_s$ will eventually condense and produce some of the SM particles as composites

- The preons of that groups are sumarized in the following table:

	$SU(3)_s$	$SU(3)_c$	$SU(2)_W$	$U(1)_Y$	Z_2
P_3	$\Box$	$\Box$	$\mathbf{1}$	0	$+$
P_1	$\Box$	$\mathbf{1}$	$\mathbf{1}$	$-2/3$	$-$
$\overline{P}_2$	$\overline{\Box}$	$\mathbf{1}$	$\Box$	$+1/6$	$-$
$\overline{P}_1$	$\overline{\Box}$	$\mathbf{1}$	$\mathbf{1}$	$+2/3$	$+$
$\overline{P}_{\tilde{1}}$	$\overline{\Box}$	$\mathbf{1}$	$\mathbf{1}$	$-1/3$	$-$
P'	$\Box$	$\mathbf{1}$	$\mathbf{1}$	$+1/3$	$-$
$\overline{P}'$	$\overline{\Box}$	$\mathbf{1}$	$\mathbf{1}$	$-1/3$	$-$

- This model has anomalies with respect to the SM gauge group which simply show that NOT ALL of the SM fields are composite.

- We have the following fundamental fields:

	$SU(3)_s$	$SU(3)_c$	$SU(2)_W$	$U(1)_Y$	Z_2
L_i	$\mathbf{1}$	$\mathbf{1}$	$\square$	$-1/2$	$-$
e_i	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$+1$	$-$
$Q_{1,2}$	$\mathbf{1}$	$\square$	$\square$	$+1/6$	$-$
d_i	$\mathbf{1}$	$\overline{\square}$	$\mathbf{1}$	$+1/3$	$-$
$u_{1,2}$	$\mathbf{1}$	$\overline{\square}$	$\mathbf{1}$	$-2/3$	$-$
$\overline{q}_1$	$\mathbf{1}$	$\overline{\square}$	$\mathbf{1}$	$-2/3$	$+$
$\overline{q}_2$	$\mathbf{1}$	$\overline{\square}$	$\mathbf{1}$	$+1/3$	$-$
H'	$\mathbf{1}$	$\mathbf{1}$	$\square$	$+1/2$	$+$
$\overline{H}'$	$\mathbf{1}$	$\mathbf{1}$	$\square$	$-1/2$	$+$

- The strong group has 3 colours and 5 flavours so is in the conformal window, but if we include the following superpotential:

$$W = M\overline{P}'P'$$

- Below the scale M the theory will condense and can be described with the following fields:

		$SU(3)_c$	$SU(2)_W$	$U(1)_Y$	Z_2
$B_1 \leftrightarrow t_R$	$P_3P_3P_1$	$\overline{\square}$	$\mathbf{1}$	$-2/3$	$-$
$B_2 \leftrightarrow S$	$P_3P_3P_3$	$\mathbf{1}$	$\mathbf{1}$	0	$+$
$\overline{B}_1 \leftrightarrow H$	$\overline{P}_2\overline{P}_1\overline{P}_{\tilde{1}}$	$\mathbf{1}$	$\square$	$+1/2$	$+$
$\overline{B}_2 \leftrightarrow \psi$	$\overline{P}_2\overline{P}_2\overline{P}_1$	$\mathbf{1}$	$\mathbf{1}$	$+1$	$+$
$\overline{B}_3 \leftrightarrow \chi$	$\overline{P}_2\overline{P}_2\overline{P}_{\tilde{1}}$	$\mathbf{1}$	$\mathbf{1}$	0	$-$
$M_1 \leftrightarrow Q_3$	$P_3\overline{P}_2$	$\square$	$\square$	$+1/6$	$-$
$M_2 \leftrightarrow q_1$	$P_3\overline{P}_1$	$\square$	$\mathbf{1}$	$+2/3$	$+$
$M_3 \leftrightarrow q_2$	$P_3\overline{P}_{\tilde{1}}$	$\square$	$\mathbf{1}$	$-1/3$	$-$
$M_4 \leftrightarrow \overline{H}$	$P_1\overline{P}_2$	$\mathbf{1}$	$\square$	$-1/2$	$+$
$M_5 \leftrightarrow \overline{\chi}$	$P_1\overline{P}_1$	$\mathbf{1}$	$\mathbf{1}$	0	$-$
$M_6 \leftrightarrow \overline{\psi}$	$P_1\overline{P}_{\tilde{1}}$	$\mathbf{1}$	$\mathbf{1}$	-1	$+$

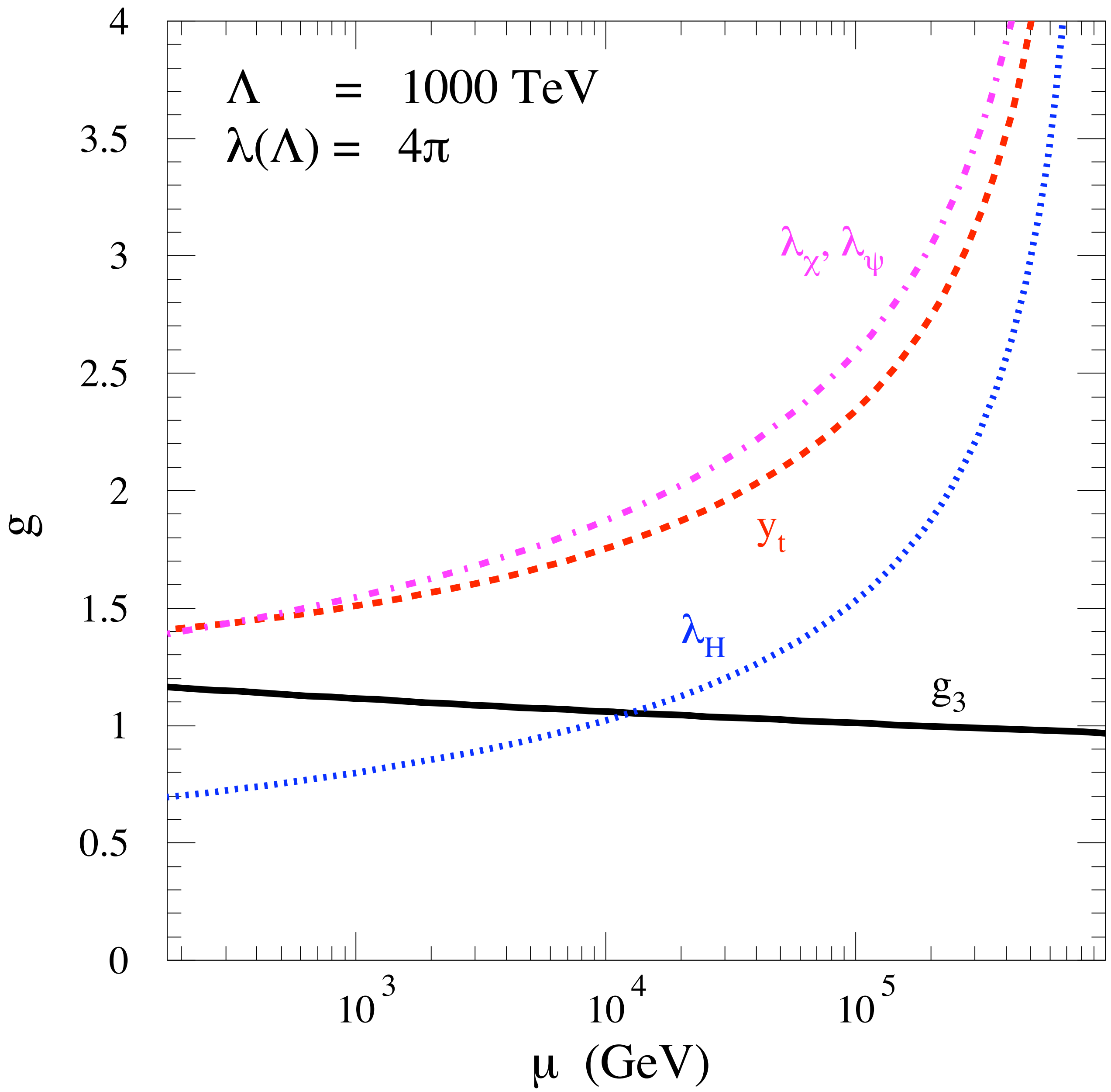
- Upon condensation the following superpotential is dynamically generated:

$$W = \frac{1}{\Lambda^3}(\overline{B}MB - detM)$$

$$\rightarrow \lambda(HQ_3 t_R + H\overline{H}S + \ldots)$$

- So among some other terms we generate both the yukawa for the top and a quartic coupling for the Higgs.

- We are left to calculate the value of the condensation scale.



- For $\Lambda = 1000\ TeV$ we manage to reproduce the observed top mass.

- EWSB is not radiative but tree-level adding the following superpotential coupling:

$$W_s = -y_s \epsilon_{\alpha\beta\gamma} P_3^\alpha P_3^\beta P_3^\gamma$$

$$\rightarrow -\left(\frac{y_s}{4\pi}\Lambda^2\right) S$$

- This will add up to the following Higgs potential:

$$V = \lambda_H S(H\overline{H} - v_0^2)$$

- Where $v_0^2 = \frac{y_s}{16\pi^2}\Lambda^2$

- The rest of yukawa couplings for the fundamental fermions are generated through superpotential couplings between preons, they are naturally smaller than the yukawa coupling of the top.

- Phenomenology of the model include an extra stable particle apart from the LSP, and a long lived one.

- The Higg mass is naturally greater than the LEP bound.

- Unification can be accomodated but not in a GUT.

Conclusions

- We have shown how the Higgs could be at the same time composite and supersymmetric.
- The model predicts why the top mass is much larger than the rest of the fermions of the SM.
- Since light fermions still couple weakly with the Higgs sector the impact on EW observables is small.
- Unification is still preserved and the Higgs mass is naturally large.