The Composite Twin Higgs

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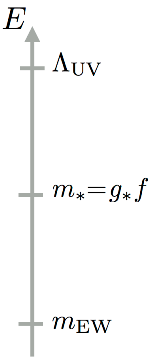
The hierarchy problem

- After LHC run I, the Higgs boson has been discovered, marking an important step in the understanding of EWSB.
- However, in the SM any elementary scalar is unstable under radiative corrections, so the Higgs should be as heavy as the Planck scale.
- We may solve the tension between naturalness and the actual Higgs mass by lowering the SM cut-off to a few TeV.
- A new dynamics should exist at that scale, endowed with a symmetry protection mechanism that keeps the Higgs mass light.

The Composite Higgs



Ingredients:

Composite Sector

Stable $\Lambda_{\rm UV}$—m_* Hierarchy from slow running

CS parameters:

- mass: m_*
- coupling: g_*

CS symmetry:

$$\mathcal{G} \xrightarrow{f} \mathcal{H}$$

$$H \in \mathcal{G}/\mathcal{H}$$

$$\longleftrightarrow \; \mathcal{L}_{\rm int}^{\not{\mathcal{G}}}$$

Elementary Sector

Contains other SM fields:

$$W_\mu^{1,2,3},\; B_\mu$$
$$f_L,\; f_R$$

Weakly Interacting:

$$g_{\rm E} < g_*$$

Coupled by Partial Compositeness

Minimal source of tuning: $\xi = \dfrac{v^2}{f^2} \ll 1$ (from EWPT&Higgs)

The composite Higgs potential

- The Higgs potential is generated at one-loop due to the Composite-Elementary mixing:

$$\mathcal{L}_{mix} = g W^{\alpha}_{\mu} J^{\mu}_{\alpha} + y_L f \bar{q}_L U \Psi + y_R f \bar{t}_R U \Psi$$

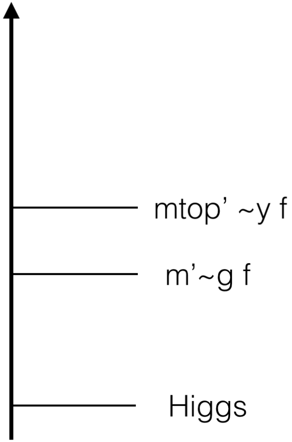
- The biggest contribution comes from the top sector:

$$V(h) \sim \frac{N_C}{16\pi^2} M_\Psi^4 \left[a \left(\frac{y_L}{g_*} \right)^2 F_2 \left(\frac{h}{f} \right) + b \left(\frac{y_L}{g_*} \right)^4 F_4 \left(\frac{h}{f} \right) \right]$$

- The Higgs mass is highly sensitive to the fermionic scale so a light Higgs requires light coloured top partners:

$$m_H^2 \sim \frac{N_C y_L^2}{8\pi^2} M_\Psi^2$$

The Twin Higgs



Ingredients

SU(4)/SU(3) breaking
in the Higgs sector

A mirror copy of the SM

3 GBs are eaten by W/Z,
3 by W'/Z', 1 is the Higgs

The quadratic divergences
can be cancelled without
coloured top partners.

The Twin Higgs potential

- The gauging breaks the global symmetry and generates a potential for the Higgs at 1-loop:

$$\Delta V = \frac{9g^2\Lambda^2}{64\pi^2} H^\dagger H + \frac{9\widetilde{g}^2\Lambda^2}{64\pi^2} \widetilde{H}^\dagger \widetilde{H}.$$

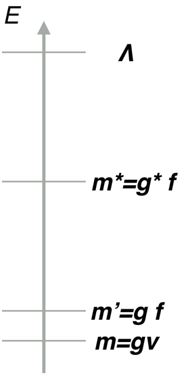
- Imposing the Z_2 symmetry $g = \widetilde{g}$ and the Higgs mass vanishes:

$$\Delta V = \frac{9g^2\Lambda^2}{64\pi^2} \left(H^\dagger H + \widetilde{H}^\dagger \widetilde{H} \right).$$

- At order $O(g^4)$, there are contributions breaking $SU(4)$ and generating a non-vanishing potential:

$$\Delta V = \frac{g^4}{16\pi^2} \log\left(\frac{\Lambda}{gf}\right) (H^4 + \widetilde{H}^4).$$

The Composite Twin Higgs - Gauge sector



Ingredients

Composite Sector		**Elementary Sector**
SO(8)→ SO(7)	G breaking ↔	SM gauge bosons: **W, Z, A**
SO(8) ⊂ SO(4) ×SO(4)'		Twin gauge bosons: **W', Z', A'**
7 NGBs= Higgs+ 6		

Bosonic spectrum

MW ~MZ ~ g v
MA=0

MW'~MZ'~g f
MA' = 0

The resonances at the scale m* can be much heavier.

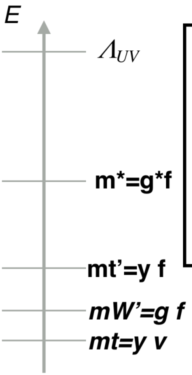
The Composite Twin Higgs potential - Gauge sector

- The gauge contribution to the Higgs potential cancels in the Z_2 symmetric limit:

$$V(h)_{g^2} = \frac{9 g_*^2 f^4}{512\pi^2} \left(g_2^2 \sin^2 \frac{h}{f} + \tilde{g}_2^2 \cos^2 \frac{h}{f} \right) .$$

- The cancellation can be proven by spurion analysis:
  invariant operators = (H invariants) - (G invariants).
- Since for $SO(8)/SO(7)$, $\mathbf{28} = \mathbf{21} \oplus \mathbf{7}$, only one operator can appear.
- For the original $SU(4)/SU(3)$, $\mathbf{15} = \mathbf{8} \oplus \mathbf{3} \oplus \bar{\mathbf{3}} \oplus \mathbf{1}$, there are two invariants and the protection of the Higgs mass is not guaranteed.

The Composite Twin Higgs - Top Sector



The fermionic sector

Composite Sector

SO(8)→ SO(7)

×

$U(1)_X \times U(1)'_X \times SU(3) \times SU(3)'$

×

Twin Parity

G breaking ↔

Elementary Sector

Top and bottom:

$Q_L \quad t_R$

Twin top and bottom:

$Q'_L \quad t'_R$

Embedded in **8** and **1**

$$L_{int} = y_L\, f\, Q_L\, U\, \Psi^8_R + y_R\, t_R\, \Psi^1_L + y_L'\, f\, Q'_L\, U\, (\Psi^8_L)' + y'_R\, f\, t'_R (\Psi^1_L)'$$

$$m_t = \frac{y_L\, y_R}{g_s} \cdot v \qquad\qquad m'_t = \frac{y'_L y'_R}{g_s} f$$

The fermionic resonances at the scale m* need not be light.

The Composite Twin Higgs potential - Top Sector

- The Twin mechanism ensures the cancellation of the Higgs potential at order $O(y_L^2)$, when $y_L = \widetilde{y}_L$.
- The relevant terms in the potential arise at order $O(y_L)^4$:
  - The first is an IR effect corresponding to the running of the Higgs quartic down from the scale m_*

$$V_{IR}(h) = \frac{N_C}{16\pi^2}\left[m_t(h)^4 \log\frac{m_*^2}{m_t(h)^2} + m_{\widetilde{t}}(h)^4 \log\frac{m_*^2}{m_{\widetilde{t}}(h)^2}\right]$$

  - The second is pure y_L^4 contribution not enhanced by IR logs:

$$V_{y^4}(H) \sim \frac{N_C}{16\pi^2}\left(y_L^4 \sin^4\frac{h}{f} + \widetilde{y}_L^4 \cos^4\frac{h}{f}\right).$$

The full potential

- The gauge plus top potential can be rewritten as:

$$V(h) = f^4 \beta \left(s^4 \log \frac{a}{s^2} + c^4 \log \frac{a}{c^2} \right) ,$$

  with $\beta = \frac{3y_t^4}{64\pi^2}$, $\log a = \log \frac{2\mu^2}{y_t^2 f^2} + \frac{y_L^4}{y_t^4} F_1$.
- This potential is not realistic: either it does not have tunable minima or a small fine tuning requires an unacceptably large f.
- We need to turn on Twin Parity breaking sources; one possibility is not to gauge the Twin Hypercharge.

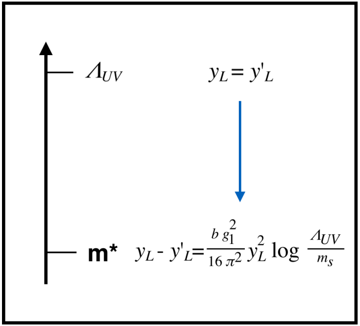
Realistic EWSB

First contribution from hypercharge loops:

$$\Delta V_1(h) = \frac{3\, g_s^2 f^4}{512\, \pi^2} g_1^2 s^2$$

Second from RG running of top sector parameters:

$$\Delta V_2(h) = \frac{N_c f^2\, m_s^2}{32\, \pi^2}\left[y_L^2 s^2 + y'^2_L\, c^2\right]$$



Total potential: $V(h) = \alpha\, f^4 s^2 + \beta\, f^4 \left(s^4 \log \frac{a}{s^2} + c^4 \log \frac{a}{c^2}\right)$

$$\alpha = A\, g_1^2 g_\varrho^2 + B\, \Delta y^2\, g_\Psi^2$$

A light Higgs without colored top partners

- We can obtain a naturally light Higgs for

$$\log a \sim 6 + \log \sqrt{\xi}.$$

- A realistic value of $\xi = 0.1$ requires $a \sim 5$, which can be easily reproduced for $g_* \sim 4\pi$.
- Minimal tuning also implies

$$\log \frac{\Lambda_{UV}}{m_*} \geq \frac{50}{bB},$$

which means a large separation of the two scales.