Higgs couplings in composite models

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May 31, 2013

based on work in progress with

M. Montull, F. Riva and R. Torre
14 + 14, two-site model

\[ \mathcal{L} = (\text{kin terms}) - M_1 \overline{\psi}_1 \psi_1 - M_4 \overline{\psi}_4 \psi_4 - M_9 \text{Tr} [\overline{\psi}_9 \psi_9] \\
- F_q \text{Tr} [\overline{Q}_L U^T \psi_R U] - F_u \text{Tr} [U^T \overline{\psi}_L U \mathcal{T}_R] + \text{h.c.} \]

where \( \psi \) is a complete 14 of \( SO(5) \). Recall that 14 \( \sim 9 + 4 + 1 \) under \( SO(4) \). \( U \) is the Goldstone matrix. \( q_L = (t_L, b_L)^T \in Q_L \) and \( t_R \in T_R \)

Higgs potential is

\[ V \sim \alpha \sin^2(h/f) + \beta \sin^4(h/f) \]

where \( \alpha, \beta \) are \( \mathcal{O}(\epsilon^2) \) and logarithmically divergent, for example

\[ \beta = 2N_c \int \frac{d^4p}{(2\pi)^4} \left( F_q^2 - 5F_u^2/4 \right) \left( \frac{5/4}{p^2 + M_1^2} - \frac{2}{p^2 + M_4^2} + \frac{3/4}{p^2 + M_9^2} \right) \]

\( \epsilon \sim F_{q,u}/M_i \)
Estimate of tuning and Higgs mass

\[ V \sim \frac{N_c}{16\pi^2} \epsilon^2 m_\psi^4 \left[ \alpha s_h^2 + \beta s_h^4 \right] \]

\[ \xi \equiv \frac{v^2}{f^2} = -a/2b \quad \text{tuning needed is 'minimal',} \quad \sim \xi \lesssim 0.2 \]

However, the potential is generically large (arises at quadratic order in the breaking), giving a large Higgs mass

\[ m_h^2 \gtrsim \frac{N_c}{2\pi^2} y_t^2 g_\psi^2 v^2 \quad \rightarrow \quad m_h \gtrsim 400 \text{ GeV} \left( \frac{g_\psi}{5} \right) \]

therefore need small \( g_\psi \sim 1 \): all resonances should be light, around 1 ÷ 1.5 TeV for \( \xi \sim 0.1 \) (\( f \sim 800 \text{ GeV} \)).

Panico, Redi, Tesi and Wulzer, 1210.7114
Higgs couplings

\[
\frac{\lambda_{hgg}}{\lambda_{hgg}^{SM}} \approx 1 + \frac{3M_1 M_4 - 11M_1 M_9 + 8M_4 M_9}{2M_9(M_1 - M_4)} \xi
\]

BSM correction depends strongly on resonance spectrum

\[
\frac{\lambda_{hWW}}{\lambda_{hWW}^{SM}} = \sqrt{1 - \xi} \approx 1 - \frac{\xi}{2}
\]

dictated by \(SO(5)/SO(4)\)

\[
\frac{\lambda_{h\gamma\gamma}}{\lambda_{h\gamma\gamma}^{SM}} \approx 1.27 \frac{\lambda_{hWW}^{SM}}{\lambda_{hWW}^{SM}} - 0.27 \frac{\lambda_{hgg}^{SM}}{\lambda_{hgg}^{SM}}
\]

fermionic contribution is same as for \(hgg\) : no colorless el. charged states (no partners for leptons)

\[
\frac{\lambda_{hbb}}{\lambda_{hbb}^{SM}} = \frac{1 - 2\xi}{\sqrt{1 - \xi}} \approx 1 - \frac{3}{2} \xi
\]

assume \(q_L, b_R \sim 5 - 1/3\) and neglect effects of bottom partners (link with Higgs potential is much weaker than for top)

Bottom line: the most relevant couplings are fixed by 3 parameters

\[
\xi, \quad r_{41} = \frac{M_4}{M_1}, \quad r_{91} = \frac{M_9}{M_1}
\]
Spectrum

• In the two-site model, all the Higgs potential is logarithmically divergent. To make it finite, need to go to 3 sites.
• But to study Higgs couplings, all we need is the distribution of $M_4/M_1$ and $M_9/M_1$ for realistic points.
• So go for very simplified treatment: regularize divergences with a UV cutoff $\Lambda$ (roughly representing the mass of the next layer of resonances). Overall scale of resonances is sensitive to the choice of $\Lambda$, but it cancels out in the mass ratios.
• Typical mass hierarchy is $M_1^p < M_9^p < M_4^p$
• Fit to current Higgs data, assuming the value quoted before for $h\bar{b}b$, $hWW$ couplings and leaving $hgg$, $h\gamma\gamma$ as free parameters:
Relation between $hgg$ and $htt$

- In partial compositeness, the $hgg$ coupling does not receive corrections of $\mathcal{O}(\epsilon)$.
- The $htt$ coupling is equal to $hgg$ at leading order, but does receive corrections:

$$\frac{\lambda_{htt}}{\lambda_{hgg}^{\text{SM}}} \simeq \frac{\lambda_{hgg}^{\text{SM}}}{\lambda_{hgg}} + \left[ \frac{5F_q^2}{4} \left( \frac{2}{M_4^2} - \frac{1}{M_1^2} - \frac{1}{M_9^2} \right) + \frac{5F_u^2}{2} \left( \frac{1}{M_1^2} - \frac{1}{M_4^2} \right) \right] \xi$$

\[ \xi = 0.1 \]

$m_h < 200$ GeV