Unnatural Origin of Fermion Masses for Technicolor

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We explore the scenario in which the breaking of the electroweak symmetry is due to the simultaneous presence and interplay of a dynamical sector and an unnatural elementary Higgs. Here the elementary Higgs represents the sector responsible for fermion masses. Our goal is to investigate the interplay between the technicolor sector and the sector giving masses to the SM fermions, and this simple model works as a well defined framework that permits perturbative calculations.

The idea of bosonic technicolor was originally pioneered in a series of papers by Simmons [1], Kagan and Samuel [2] and Carone and Georgi [3, 4]. More recently this type of model has been investigated also in [5]. It was noted that these models permit to write renormalizable Yukawa interactions with ordinary fermions replacing the extended technicolor dynamics. In comparison to the earlier works we have:

- Included all dimension four operators with at most one mixing between the two scalar sectors.
- Provided an extensive scan of the parameters of the model.
- Updated the comparison with measurements.
- We linked the dynamical sector with models of (Ultra) Minimal Walking technicolor [6, 7, 8, 9].

We start with the following Lagrangian:

$$\mathcal{L}_{UTC} = \mathcal{L}_{SM}\Big|_{\text{Higgs}=0} + \mathcal{L}_{TC} + \mathcal{L}_{\text{Higgs}} + \mathcal{L}_{\text{Yukawa}} \ . \tag{1}$$

The TC-sector has no direct couplings with the SM fermions, but the elementary Higgs has Yukawa couplings with both the SM- and technifermions, encoded in $\mathcal{L}_{\text{Yukawa}}$. We construct

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a low energy effective theory, where both the composite and the elementary scalar sector are described by a linear Lagrangian. The composite field is written as

$$M = \frac{1}{\sqrt{2}}\left(sI_{2\times 2} + 2i\pi_M\right) \propto Q_L\bar{Q}_R, \quad \langle s\rangle \equiv f, \tag{2}$$

where f is the technipion decay constant, and the elementary Higgs field as

$$H = \frac{1}{\sqrt{2}}\left(hI_{2x2} + 2i\pi_H\right), \quad \langle h\rangle \equiv v\ . \tag{3}$$

The Higgs Lagrangian is then given by

$$\mathcal{L}_{\text{Higgs}} = \frac{1}{2}Tr\left[DH^\dagger DH\right] - V_H,\ V_H = \frac{1}{2}m_H^2 Tr\left[H^\dagger H\right] + \frac{\lambda_H}{4!}Tr^2\left[H^\dagger H\right]. \tag{4}$$

The technicolor sector is taken to be the Next to Minimal Walking Technicolor (NMWT) model [7], consisting of two techniflavors in the two-index symmetric representation of $\mathrm{SU}(3)_{\mathrm{TC}}$.

The techniquark Yukawa term

$$-\bar{Q}_L H Y_Q Q_R, \tag{5}$$

breaks the $(\mathrm{SU}(2)_\mathrm{L}\times\mathrm{SU}(2)_\mathrm{R})^2$ global symmetry of the model down to $\mathrm{SU}(2)_\mathrm{R}\times\mathrm{U}(1)_\mathrm{R}$. As the techniquarks form the chiral condensate, this term yields a linear term in the elementary scalar Lagrangian that will generate a vacuum expectation value for the Higgs, regardless of the sign of the original mass term m_H^2. When constructing the effective Lagrangian that mixes the technicolor sector with the elementary scalar, we include all dimension four operators with at most one mixing between the two scalar sectors. Applying Georgi's generalized naive dimensional analysis [10] we arrive at the following Lagrangian for the TC-sector and its coupling with the elemantary Higgs:

$$\begin{aligned}
\mathcal{L}_{TC} - \bar{Q}_L H Y_Q Q_R &\rightarrow \frac{1}{2}\mathrm{Tr}\left[DM^\dagger DM\right] + \frac{1}{2}(c_3/\alpha)\mathrm{Tr}\left[DM^\dagger DHY_Q\right] - V_M \\
V_M &= \frac{1}{2}m_M^2\mathrm{Tr}\left[M^\dagger M\right] + \frac{\lambda_M}{4!}\mathrm{Tr}^2\left[M^\dagger M\right] \\
&\quad -\frac{1}{2}(\alpha c_1)f^2\mathrm{Tr}\left[M^\dagger HY_Q\right] - \frac{1}{24}(\alpha c_2)\mathrm{Tr}\left[M^\dagger M\right]\mathrm{Tr}\left[M^\dagger HY_Q\right] \\
&\quad -\frac{1}{24}(c_4/\alpha)\mathrm{Tr}\left[H^\dagger H\right]\mathrm{Tr}\left[M^\dagger HY_Q\right] + \text{h.c.}
\end{aligned} \tag{6}$$

Here $c_1 \ldots c_4$ are order one dimensionless real coefficients and $\alpha = \Lambda/f$, where Λ is the mass of the lowest lying vector resonance of the theory, is taken to be greater than one.

The above Lagrangian is diagonalized, and the physical propagating fields are given by a non unitary transformation from the original fields, due to the kinetic mixing term. In unitary gauge, the particle spectrum consists of two SM Higgs -like scalars and three massive pions, while three massless pions have been eaten to become the longitudinal degrees of freedom of the weak gauge bosons.

We perform an extensive scan of the parameters of the model, not restricting to any special case for the mass parameter of the fundamental scalar, as opposed to earlier work on models of this type. We constrain the parameters via direct search limits and electroweak and flavor precision tests. The mass patterns for the two scalars, passing all the electroweak and flavor

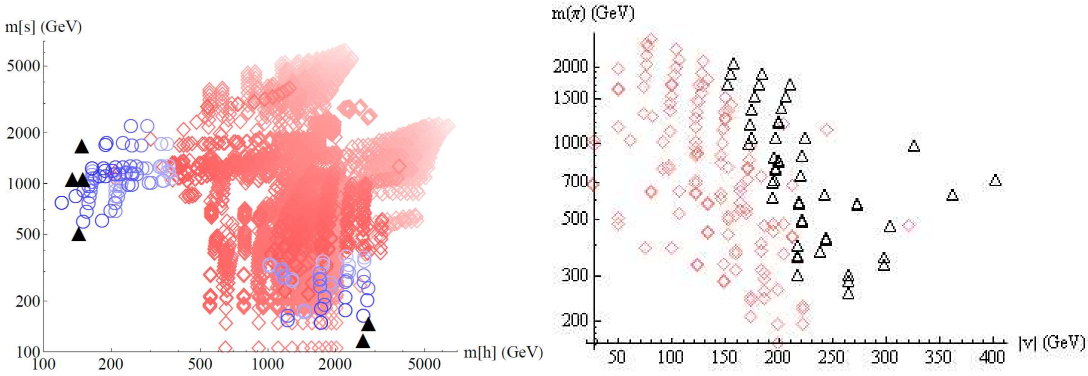

Figure 1: Left: The masses of the scalar particles. The black triangles are allowed by all data, blue circles are less favored by the electroweak precision data and red diamonds are ruled out. Right: The mass of the technipions, as a function of the vacuum expectation value of the elementary scalar. The black triangles are allowed and the read diamonds are ruled out.

tests as well as direct search limits, are shown as black triangles in the left panel of figure 1. Blue circles are less favored by the electroweak precision data and the red diamonds are ruled out. Our model thus predicts the existence of one light and one heavy Higgs-like scalar. The right panel of the figure shows as black triangles the allowed mass of the technipions, as a function of the vacuum expectation value of the elementary scalar. We see that the technipion mass is not very well constrained by the electroweak precision data, ranging from a few hundred GeV to a few TeV.

We find that the model is viable in the light of all existing experimental data and can be seen as a stepping stone towards a well defined extension of the SM featuring a complete solution to both the origin of spontaneous breaking of the electroweak symmetry and the mass of any SM fermion.

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