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Dynamical Origin for the 125 GeV Higgs; a Hybrid setup

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We describe a hybrid framework for electroweak symmetry breaking (EWSB), in which the Higgs mechanism is combined with a Nambu-Jona-Lasinio mechanism. The model introduces an unconstrained scalar (i.e., acts as "fundamental" but not the SM field) and a strongly coupled doublet of heavy quarks with a mass around 500 GeV, which forms a condensate at a compositeness scale $\Lambda \sim \mathcal{O}(1)$ TeV. This setup is matched at that scale to a tightly constrained hybrid two Higgs doublet model, where both the composite and unconstrained scalars participate in EWSB. This allows us to get a good candidate for the recently observed 125 GeV scalar which has properties very similar to the Standard Model Higgs. The heavier (mostly composite) CP-even scalar has a mass around 500 GeV, while the pseudoscalar and the charged Higgs particles have masses in the range 200 -300 GeV.

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PoS(EPS-HEP 2013)258

1. Introduction

With the recent LHC discovery of the 125 GeV scalar particle [1], we are one step closer to understanding the mechanism of EWSB. Is it a Standard Model (SM) Higgs? or may be it is the SUSY light Higgs? so far it certainly seems to resemble the SM Higgs, but in the grand picture it makes no sense; where is the new physics to account for the hierarchy problem, dark matter, flavor etc...? there is still no hint for that and/or for SUSY yet.

Another attractive alternative for new TeV-scale physics is strong dynamics. Albeit, the strong dynamics setup is difficult to realize with a light (125 GeV) composite Higgs, unless this light scalar state is a pseudo-Goldstone boson of a global symmetry breaking at the strong interactions scale. Indeed, in this talk we will toy with this idea, proposing a specific hybrid framework for Dynamical EWSB (DEWSB), where an unconstrained scalar field (which behaves as a “fundamental" field) is added at the compositeness scale where additional super-critical attractive 4-Fermi operators of heavy fermions form a composite scalar sector [2]. The “fundamental" scalar is unconstrained at the compositeness scale and may result from the underlying strong dynamics, e.g., it can be the pseudo-Goldstone boson mentioned above. This strongly coupled composite-plus-fundamental sectors are then matched at the compositeness scale to a hybrid 2HDM with a 4th generation of heavy fermions (named here after h4G2HDM), where the fundamental-like field (Φ_ℓ) couples to the SM's lighter fermions and the auxiliary (composite) field (Φ_h) couples to the heavy 4th generation fermions.[1]

Let us recall an old idea: that a heavy fermion, ψ, may be the agent for DEWSB [3, 4, 5, 6, 7, 8]. In this case, the Higgs is viewed as a fermion-antifermion bound state $<\bar{\psi}\psi>\neq 0$, and there is no need to introduce an elementary Higgs field. One of the early attempts in this direction investigated the possibility of using the top-quark as the agent for DEWSB via top-condensation [10], in a generalization of the Nambu-Jona-Lassinio (NJL) model [9]. However, the resulting dynamical top mass turns out to be appreciably heavier than $m_t \approx 175$ GeV, thus making it difficult for top condensation to provide a viable picture. Moreover, top-condensate models require the cut-off/threshold for the new strong interactions to be of $\mathscr{O}(10^{17})$ GeV, i.e., many orders of magnitudes larger than m_t, thus resulting in a severely fine-tuned picture of DEWSB. Nonetheless, several interesting generalizations of the top-condensate model which potentially avoid these obstacles, have been suggested. For example, the condensation of new heavier quarks and/or leptons may drive EWSB [3, 4, 5, 6, 7, 8].

2. DEWSB with the NJL mechanism

We adopt here a simple and ”modest" logic for parameterizing our ignorance with regard to the details of the would be TeV-scale strong dynamics. In particular, without any explicit model building, we follow two guiding principles which underly the NJL model [9]:

1. Assume the existence of a strongly interacting fermionic sector above the compositeness scale Λ.

[1] We do not consider here explicitly the choice by which the 4th generation leptons couple to the Higgs sector; they can either couple to the fundamental Higgs or to the auxiliary field. In either case, we assume that their couplings are sub-critical and, therefore, do not play any role in DEWSB (see also discussion in [2]).

2. Trade our ignorance for effective couplings + appropriate boundary conditions at the scale Λ.

In particular, at Λ, physics is described by an effective (attractive) 4-Fermi interaction of the strongly coupled fermions:

$$\mathscr{L}_{NJL} = G_\psi \left(\bar{\psi}_L \psi_R\right)\left(\bar{\psi}_R \psi_L\right) \ . \tag{2.1}$$

One then solves the Gap equation (i.e., keeping only fermions loops - bubble diagrams), and if G_ψ is greater than some critical value $G_\psi > G_c$, then (see e.g., [10]):

- EW symmetry can be broken
- The field ψ acquires a dynamical mass
- The low-energy theory contains a scalar bound state: $S \sim <\bar{\psi}\psi>$

To get a realistic framework, one can introduce an auxiliary field H, which reproduces the 4-Fermi interaction when it is integrated out:

$$\mathscr{L} = g_0^\psi \left(\bar{\psi}_L \psi_R H + h.c.\right) - m_0^2 H^\dagger H \overset{integrate\ H}{\longrightarrow} \mathscr{L}_{NJL} = \frac{g_0^\psi}{m_0^2}\left(\bar{\psi}_L \psi_R\right)\left(\bar{\psi}_R \psi_L\right) \ . \tag{2.2}$$

Then, below the cutoff Λ, H develops kinetic terms and quartic interactions (from the fermion loops) in the effective action, becoming a dynamical field, and the theory containing H is exactly equivalent to the theory written in terms of the fermions with $G_\psi = \frac{g_0^\psi}{m_0^2}$, i.e., in terms of $\mathscr{L}_{NJL}$. Thus, H is interpreted as the bound $H \sim <\bar{\psi}\psi>$.

In a more general and natural setup one should expect multiple bound states, $<\bar{t}'t'>$, $<\bar{b}'b'>$ ..., and, therefore, multiple scalar states below the compositeness scale [4, 5, 6, 7, 8, 11]. Moreover, new heavy fermions embedded within multi-Higgs models are more favorable when confronted with the data [12, 13, 14].

Indeed, a wide "spectrum" of DEWSB/NJL models were suggested in the past two decades: models of top-condensation and models of new heavy quarks or new heavy leptons condensation, producing either a single Higgs composite or multi-Higgs composites. These models can be divided into two categories:

- Models where the condensing fermions have a mass of order the EW-scale (e.g., top-condensation models), for which the cutoff is $\Lambda \sim \mathscr{O}(10^{17})$ GeV.
- Models with new heavy fermions of mass $\mathscr{O}(500)$ GeV (e.g., 4th generation models), having a compositeness scale as low as $\Lambda \sim \mathscr{O}(1)$ TeV.

However, there is one major caveat in all fermion-condensation models of the "conventional" NJL type: the typical mass of the composite $<\bar{\psi}\psi>$ tends to lie in the range $m_\psi < m_{<\bar{\psi}\psi>} < 2m_\psi$, thus being too heavy to account for the recently discovered ~ 125 GeV Higgs-like particle.

To bypass this difficulty, we have proposed in [2] an alternative solution for the TeV-scale DEWSB scenario, which leads to a light SM-like Higgs with a mass of $\mathscr{O}(m_W)$. In particular, as mentioned earlier, we suggest a hybrid DEWSB setup with new heavy quarks and a cutoff/threshold of $\Lambda \sim \mathscr{O}(\text{few})$ TeV, by adding an unconstrained (i.e., fundamental) scalar field (Φ_ℓ) at the compositeness scale, where the super-critical 4-Fermi operators form an additional heavy composite (Φ_h).

3. The low-energy hybrid 2HDM (h4G2HDM)

As a toy framework, we consider a new chiral 4th generation doublet, assumed to be charged under some new strong interaction that dynamically break EW symmetry.[2] The theory at the compositeness scale, Λ, can then be parameterized by adding to the light SM degrees of freedom the following set of strongly coupled 4-Fermi terms:

$$\mathscr{L} = \mathscr{L}_{SM}(\Lambda) + G_{t'}\bar{Q}'_L t'_R \bar{t}'_R Q'_L + G_{b'}\bar{Q}'_L b'_R \bar{b}'_R Q'_L + G_{t'b'}\left(\bar{Q}'_L b'_R \bar{t}'^c_R i\tau_2 Q'^c_L + h.c.\right) , \quad (3.1)$$

where $Q'_L = (t'_L \; b'_L)^T$ and $\mathscr{L}_{SM}(\Lambda)$ stands for the bare SM Lagrangian with a single fundamental Higgs field, Φ_ℓ, which is essentially responsible for the origin of mass of the lighter fermions. As described in the previous section, the above Lagrangian/theory can be reproduced by introducing an auxiliary Higgs doublet Φ_h, which couples ONLY to the 4th generation quarks as follows:

$$\mathscr{L}_{q'}(\Lambda) = g^0_{b'}\left(\bar{Q}'_L \Phi_h b'_R + h.c.\right) + g^0_{t'}\left(\bar{Q}'_L \tilde{\Phi}_h t'_R + h.c.\right) - (\mu^0_h)^2 \Phi^\dagger_h \Phi_h , \quad (3.2)$$

so that the full theory at Λ is then described by:[3]

$$\mathscr{L}(\Lambda) = \mathscr{L}_{SM}(\Lambda) + \mathscr{L}_{q'}(\Lambda) + (\mu^0_{h\ell})^2\left(\Phi^\dagger_h \Phi_\ell + h.c.\right) . \quad (3.3)$$

Thus, integrating out Φ_h, we recover the 4-Fermi Lagrangian with:

$$G_{t'} = \frac{(g^0_{t'})^2}{(\mu^0_h)^2} , \; G_{b'} = \frac{(g^0_{b'})^2}{(\mu^0_h)^2} , \; G_{t'b'} = -\frac{g^0_{t'} g^0_{b'}}{(\mu^0_h)^2} , \quad (3.4)$$

plus additional subleading interaction terms between the light Higgs and the new heavy quarks with Yukawa couplings of $\mathscr{O}\left(\frac{(\mu^0_{h\ell})^2}{(\mu^0_h)^2}\cdot g^0_{t'/b'}\right)$ (see [2]). In particular, Φ_h is now viewed as a composite of the form $\Phi_h \sim g_{t'} < \bar{Q}'_L t'_R > + g_{b'} < \bar{Q}'_L b'_R >$.

We thus end up with a specific 2HDM, where one (composite) doublet, Φ_h, couples to the new 4th generation fermions (which acquire their mass dynamically) and one fundamental-like doublet (at Λ), Φ_ℓ, which may be viewed as a pseudo-Goldstone of the underlying theory (see below) and which is responsible for the mass generation of the SM fermions and for the CKM flavor structure.

At energies below Λ, Φ_h acquires a kinetic term as well as large self interactions from the heavy fermion loops (as we will see below, the Φ_ℓ quartic term does not receive such large corrections), and the theory behaves like the 4G2HDM of [12], with the scalar potential:

$$\begin{aligned} V_{h4G2HDM}(\Phi_h,\Phi_\ell) \;=\; & \mu^2_\ell \Phi^\dagger_\ell \Phi_\ell + \mu^2_h \Phi^\dagger_h \Phi_h - \mu^2_{h\ell}\left(\Phi^\dagger_h \Phi_\ell + h.c.\right) + \frac{1}{2}\lambda_\ell\left(\Phi^\dagger_\ell \Phi_\ell\right)^2 \\ & + \frac{1}{2}\lambda_h\left(\Phi^\dagger_h \Phi_h\right)^2 \lambda_3\left(\Phi^\dagger_h \Phi_h\right)\left(\Phi^\dagger_\ell \Phi_\ell\right) + \lambda_4\left(\Phi^\dagger_h \Phi_\ell\right)\left(\Phi^\dagger_\ell \Phi_h\right) , \end{aligned} \quad (3.5)$$

[2]The DEWSB mechanism proposed here can be generalized to the case of non-sequential TeV-scale vector-like quarks.

[3]We have added a $\Phi_h - \Phi_\ell$ mixing term $\propto (\mu^0_{h\ell})^2$, which may arise e.g., from QCD-like instanton effects associated with the underlying strong dynamics (see e.g., [15, 16]) or from sub-critical couplings of the fundamental Higgs to the 4th generation quarks. This term explicitly breaks the $U(1)$ Peccei-Quinn (PQ) symmetry [17], which is otherwise possessed by the model, thus avoiding the presence of a massless pseudoscalar in the spectrum. Note that, in any realistic scenario we expect $\mu_{h\ell}(\mu \sim m_W) \sim \mathscr{O}(m_W)$ and, since this is the only term which breaks the PQ symmetry, it evolves only logarithmically under the RGE so that, at the compositeness scale, we remain with $\mu^0_{h\ell} \equiv \mu_{h\ell}(\mu \sim \Lambda) \sim \mathscr{O}(m_W)$. Therefore, since $\mu^0_{h/\ell} \equiv \mu_{h/\ell}(\mu \sim \Lambda) \sim \mathscr{O}(\Lambda)$, we expect $(\mu^0_{h\ell})^2/(\mu^0_h)^2 \sim \mathscr{O}(m^2_W/\Lambda^2) \ll 1$.

where all the above mass terms and quartic couplings run as a function of the energy scale μ, as dictated by the RGE for this model.[4] Note that the stability condition for the above potential reads $\lambda_\ell, \lambda_h > 0$ and $\sqrt{\lambda_\ell \lambda_h} > -\lambda_3 - \lambda_4$.

The 4-Fermi theory is now matched at Λ to our h4G2HDM, by solving the RGE of the model with the compositeness boundary conditions:

$$g_{q'}(\Lambda) \to \infty \ , \ \lambda_{h,3,4}(\Lambda) \to \infty \ , \ \lambda_h(\Lambda)/g_{q'}^4(\Lambda) \to 0 \ , \ \lambda_{3,4}(\Lambda)/g_{q'}^2(\Lambda) \to 0 \ , \tag{3.6}$$

where $q' = t', b'$. That is, the composite theory is effectively a strongly coupled Higgs-Yukawa and Higgs-quartic systems, while $\lambda_\ell(\mu \to \Lambda) \to \lambda_\ell^{(0)}$, where $\lambda_\ell^{(0)}$ is a free parameter of the model. The Higgs mass parameters (obtained after minimizing the above potential, see [2]) are given by:

$$\mu_\ell^2 \simeq \frac{\mu_{h\ell}^2}{t_\beta} - \frac{v^2}{2} c_\beta^2 \lambda_\ell \ , \ \mu_h^2 \simeq t_\beta \mu_{h\ell}^2 - \frac{v^2}{2} s_\beta^2 \lambda_h \ , \tag{3.7}$$

where $t_\beta = v_h/v_\ell$, $s_\beta, c_\beta = \sin\beta, \cos\beta$ and it is understood that the quartic couplings are evaluated at $\mu \sim v$, i.e., $\lambda_h = \lambda_h(\mu \sim v)$ and $\lambda_\ell = \lambda_\ell(\mu \sim v)$, and we also have $\mu_{h\ell}(m_W) \sim m_W$.

4. The h4G2HDM and the 125 GeV Higgs

The dominant RGE in our model are given approximately by (taking for simplicity $g_{t'} = g_{b'} \equiv g_{q'}$):

$$\mathscr{D} g_{q'} \approx 6 g_{q'}^3 \ , \ \mathscr{D} \lambda_h \approx 4 \lambda_h \left(3\lambda_h + 6 g_{q'}^2 \right) - 24 g_{q'}^4 \ , \tag{4.1}$$

where $\mathscr{D} \equiv 16\pi^2 \mu \frac{d}{d\mu}$. With the compositeness boundary conditions in Eq. 3.6, the above RGE's have a simple analytic solution:

$$g_{q'}(\mu) = \sqrt{\frac{4\pi^2}{3 ln\frac{\Lambda}{\mu}}} \ , \ \lambda_h(\mu) = \frac{4\pi^2}{3 ln\frac{\Lambda}{\mu}} \ . \tag{4.2}$$

Thus, using $m_{q'} = \frac{v_h \cdot g_{q'}(\mu = m_{q'})}{\sqrt{2}}$, we can obtain the compositeness scale Λ as a function of $m_{q'}$ and t_β:

$$\Lambda \approx m_{q'} \cdot exp\left(\frac{2\pi^2 \left(s_\beta v\right)^2}{3 m_{q'}^2} \right) \ , \tag{4.3}$$

so that for $m_{q'} \sim \mathscr{O}(500)$ GeV and $\tan\beta \sim \mathscr{O}(1)$ we obtain $\Lambda \sim 1 - 1.5$ TeV. This is many orders of magnitudes smaller than the cutoff in the top-condensation scenario: $\Lambda \sim m_t \cdot exp\left(\frac{16\pi^2 v^2}{9 m_t^2}\right) \sim 10^{17}$ GeV (obtained by solving the SM-like RGE for g_t: $\mathscr{D} g_t \approx \frac{9}{2} g_t^3$), which, therefore, introduces a severe fine-tuning problem.

The physical scalar masses are given by: $m_A^2 = m_{H^+}^2 = \frac{\mu_{h\ell}^2}{s_\beta c_\beta}$ and

$$m_{h,H}^2 = \left(m_1^2 + m_2^2 \mp \sqrt{(m_1^2 - m_2^2)^2 + 4\mu_{h\ell}^4} \right) / 2 \ , \tag{4.4}$$

[4] The most general 2HDM potential also includes the quartic couplings $\lambda_{5,6,7}$, which, in our model, are absent at any scale.

PoS(EPS-HEP 2013)258

where (see also Eq. 3.7):

$$m_1^2 \simeq \mu_h^2 + 3s_\beta^2 v^2 \lambda_h/2 \simeq t_\beta \mu_{h\ell}^2 + s_\beta^2 v^2 \lambda_h \,, \tag{4.5}$$

$$m_2^2 \simeq \mu_\ell^2 + 3c_\beta^2 v^2/2\lambda_\ell \simeq \mu_{h\ell}^2/t_\beta + c_\beta^2 v^2 \lambda_\ell \,. \tag{4.6}$$

The Higgs mixing angle, which is defined by: $h = \cos\alpha \cdot \mathrm{Re}(\Phi_\ell^0) - \sin\alpha \cdot \mathrm{Re}(\Phi_h^0)$ and $H = \cos\alpha \cdot \mathrm{Re}(\Phi_h^0) + \sin\alpha \cdot \mathrm{Re}(\Phi_\ell^0)$, is given by:

$$\tan 2\alpha \simeq \left(\cot 2\beta - \frac{v^2 \left(s_\beta^2 \lambda_h - c_\beta^2 \lambda_\ell \right)}{2\mu_{h\ell}^2} \right)^{-1} \,. \tag{4.7}$$

Solving the RGE and evaluating the Higgs masses, we find that a light Higgs requires $\lambda_\ell(\mu = \Lambda) \to 0$, as demonstrated in Fig. 1, in which case the fundamental-like doublet has a vanishing quartic term at Λ and is, therefore, not the SM doublet, but should rather be viewed as a pseudo-Goldstone boson of the underlying strong dynamics. In particular, for $\lambda_\ell(\Lambda) \to 0$ and $\tan\beta \sim \mathscr{O}(1)$, we obtain $m_h \sim m_A/\sqrt{2}$. Thus, for $m_A \sim 200-300$ GeV, we get $m_h \sim 125$ GeV ($\pm 10\%$), see Fig. 1. Furthermore, the above solution corresponds to a small Higgs mixing angle of $\alpha \sim \mathscr{O}(10^0)$, so that the light 125 GeV Higgs, h, is mostly the fundamental state.

The mass of the heavy CP-even Higgs, which is mostly the composite state, is given by $m_H \sim v\sqrt{\lambda_h/2}$, which for $m_{q'} \sim \mathscr{O}(500)$ GeV is: $m_H \sim 500 \pm 100$ GeV.

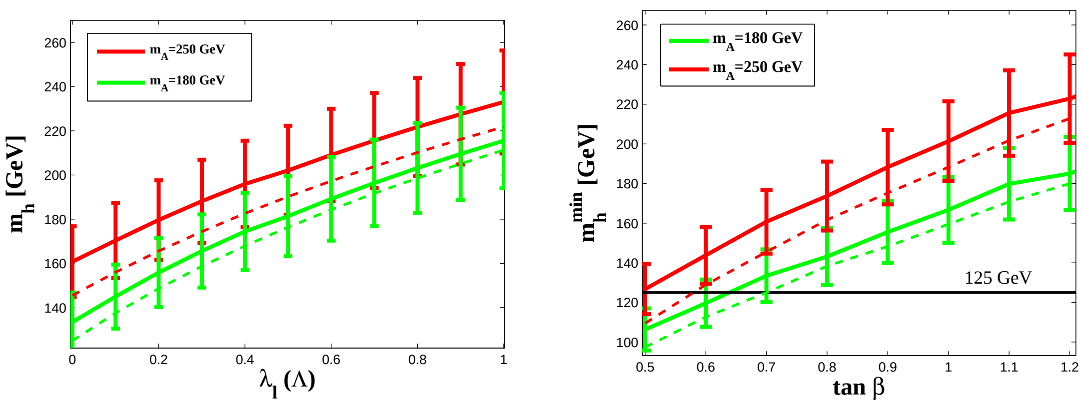

Figure 1: *Left:* m_h *as a function of* $\lambda_\ell(\Lambda)$, *for* $\tan\beta = 0.7$. *Right: The minimal value of* m_h, *obtained by choosing* $\lambda_\ell(\Lambda) = 0$ *(see text), as a function of* $\tan\beta$. *Both plots are for* $m_{q'} = 400$ *GeV and for* $m_A = 180$ *and* 250 *GeV. The approximate analytic solutions are shown by solid lines and exact results (obtained from a full RGE analysis) without errors by the dashed lines.*

Finally, the range of values for the free parameters $\tan\beta$ and m_A, which gives a viable light Higgs candidate in our model, i.e., $\tan\beta \sim \mathscr{O}(1)$ and $m_A \sim 200-300$ GeV, also reproduce all the measured 125 GeV Higgs signals, as shown in [2].

To summarize, we have introduced a hybrid mechanism for DEWSB, where the compositeness scale is of order of a few TeV. The model has new heavy quarks which acquire dynamical masses and which form a heavy composite scalar. A fundamental-like scalar is added at the compositeness scale and is responsible for the SM's flavor structure and for the mass generation of the lighter fermions. The EW symmetry is broken by combining the Higgs mechanism with the NJL mechanism. This allows us to get a viable 125 GeV Higgs candidate, which is mostly fundamental and, therefore, protected from large q' loops. Our model is consistent with all currently measured 125 GeV Higgs signals as well as with EW precision data. The other low-energy Higgs states are a charged scalar H^+ and a pseudo-scalar m_A - both with a mass in the range $m_A, m_{H^+} \sim 200-300$ GeV, and a heavy CP-even Higgs with a mass around 500 GeV.

References

[1] S. Chatrchyan *et al.*, [CMS Collaboration], Phys. Lett. **B716**, 30 (2012); G. Aad *et al.*, [ATLAS Collaboration], Phys. Lett. **B716**, 1 (2012).

[2] M. Geller, S. Bar-Shalom and A. Soni, arXiv:1302.2915 [hep-ph].

[3] B. Holdom, Phys. Rev. Lett. **57**, 2496 (1986), Erratum-ibid. **58**, 177 (1987); S.F. King, Phys. Lett. **B234**, 108 (1990); P.Q. Hung and G. Isidori Phys. Lett. **B402**, 122 (1997); B. Holdom, JHEP **0608**, 76 (2006); Y. Mimura, W.S. Hou and H Kohyama, arXiv:1206.6063 [hep-ph].

[4] M.A. Luty, Phys. Rev. **D41**, 2893 (1990).

[5] M. Hashimoto and V.A. Miransky, Phys. Rev. **D81**, 055014 (2010).

[6] C. Hill, M. Luty and E.A. Paschos, Phys. Rev. **D43**, 3011 (1991).

[7] G. Burdman and L. Da Rold, JHEP **0712**, 86 (2007).

[8] P.Q. Hung, C. Xiong, Nucl. Phys. **B848**, 288 (2011); *ibid.*, Phys. Lett. **B694**, 430 (2011); for an earlier discussion see also, "Dynamical symmetry breaking due to strong coupling Yukawa interaction" by M. Tanabashi, K. Yamawaki and K. Kondo, in *Nagoya 1989, Proceedings, Dynamical symmetry breaking* 28-36.

[9] Y. Nambu and G. Jona-Lasinio Phys. Rev. **122**, 345 (1961).

[10] V.A. Miransky, M. Tanabashi and K. Yamawaki, Phys. Lett. **B221**, 177 (1989); *ibid.*, Mod. Phys. Lett. **A4**, 1043 (1989); W.A. Bardeen, C.T. Hill and M. Lindner, Phys. Rev. **D41**, 1647 (1990); see also Y. Nambu in e.g., EFI report #89-08, 1989 (unpublished).

[11] C.M. Ho, P.Q. Hung and T.W. Kephart, **JHEP 1206**, 045 (2012); G. Burdman, L. de Lima and R.D. Matheus, Phys. Rev. **D83**, 035012 (2011); G. Burdman and C.E.F. Haluch, **JHEP 1112**, 038 (2011); B. Holdom, Phys. Lett. **B721**, 290 (2013); A. Smetana, arXiv:1301.1554 [hep-ph]; G. Burdman, L. Da Rold, O. Eboli and R. D'Elia Matheus, Phys. Rev. **D79**, 075026 (2009); A.E.C. Hernandez, C.O. Dib, N. Neill H and A.R. Zerwekh, **JHEP 1202**, 132 (2012).

[12] S. Bar-Shalom, S. Nandi and A. Soni, Phys. Rev. **D84**, 053009 (2011).

[13] S. Bar-Shalom, M. Geller, S. Nandi and A. Soni, arXiv:1208.3195 [hep-ph], Published in: Advances in High Energy Physics (AHEP), 2013, 672972 (2013).

[14] M. Geller, S. Bar-Shalom, G. Eilam and A. Soni, Phys. Rev. **D86**, 115008 (2012).

[15] C.T. Hill, Phys. Lett. **B345**, 483 (1995).

[16] "Top mode standard model" by K. Yamawaki, in *Strong Coupling Gauge Theories and beyond* (SCGT 90), Proceedings 28-31, Jul 1990, Nagoya, Japan.

[17] R.D. Peccei and H.R. Quinn, Phys. Rev. **D16**, 1791 (1977).

PoS(EPS-HEP 2013)258