Romanian Reports in Physics, Vol. 65, No. 2, P. 363–373, 2013

POSSIBLE HIGGS BOSON DECAYS IN A 3-3-1 GAUGE MODEL

ADRIAN PALCU

Faculty of Exact Sciences, “Aurel Vlaicu” University of Arad,
2 Elena Drăgoi str., 310330, Arad, Romania

Received May 22, 2012

Abstract. We explore in this paper certain phenomenological consequences regarding the neutral Higgs boson in a $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ gauge model with right-handed neutrinos. Our analysis is performed in a particular theoretical method of treating gauge models with spontaneous symmetry breaking, in which a single free parameter (a) remains to be tuned, once all the Standard Model phenomenology is recovered.

Key words: Higgs boson, extensions of the SM, 3-3-1 models.

PACS: 14.80.Cp; 12.60.Cn; 12.60.Fr; 14.80.Bn

1. INTRODUCTION

The Standard Model (SM) [1] - [3] for the fundamental interactions among elementary particles - based on the gauge group $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ undergoing a spontaneous symmetry breakdown (SSB) in its electro-weak sector - has established itself as a successful theory in unifying the strong, weak and electromagnetic forces. Nevertheless, some recent evidences - regarding mainly the massive neutrinos oscillation (see [4] and references therein for an excellent review) - definitely call for certain extensions of the SM. In order to explain this new and richer phenomenology, any realistic theoretical model must conceive a consistent device responsible for generating masses of both fermion and boson sectors. In the SM this role is accomplished by the so called Higgs Mechanism [5] - [9] which - up to date - seems to be the paradigmatic procedure to give particles their appropriate masses, while the renormalizability of the model is kept valid. The Higgs mechanism enforces a suitable SSB up to the electromagnetic $U(1)_{em}$ group which remains as the residual symmetry of the model. However, the procedure of mass generation implies not only a great number of Yukawa coupling coefficients (undetermined on theoretical ground) acting in the fermion sector, but also the existence of a still elusive neutral scalar particle - namely, the Higgs boson.

Among the possible extensions of the SM, the so called ”3-3-1” class of models [10] - [14] emerged two decades ago and has meanwhile earned a wide reputation through a systematic study of its rich phenomenology. It is based on the $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$gauge group that undergoes a SSB up to the universal electromagnetic $U(1)_{em}$ symmetry, as in the SM. The discrimination among various models in this class [15] - [17] can be done on the particle content criterion, each model supplying in its own right some new and spectacular phenomenological consequences. We deal here with a particular model [13, 14] that includes both left-handed and right-handed neutrinos along with the well-known left-handed charged lepton in triplet representations of the fermion sector. Besides recovering all the other particles coming from the SM (six quarks and four gauge bosons), it predicts the occurrence of three new exotic quarks and five new gauge bosons. Apart from other versions [10, 11] that claim the existence of exotic electric charges (quarks with $\pm 5e/3$, $\pm 4e/3$ or bosons with $\pm 2e$), the version under consideration here implies only ordinary electric charges (even for the exotic particles).

A few words about the method we have employed to "solve" this class of models. Proposed more than a decade ago by Cotăescu [18], it essentially consists of a general procedure in which electro-weak gauge models with high symmetries ($SU(N)_L \otimes U(1)_X$) achieve their SSB in only one step up to $U(1)_{em}$ by means of a special minimal Higgs mechanism (MHM). At the end, a single physical scalar remains in the spectrum, namely the neutral Higgs boson. Consequently, one gets the exact algebraical general expressions for the mass spectra and currents (charges) of all particles involved in the model. This particular MHM) based on a proper parametrization of the scalar sector (involving also an orthogonal restriction among scalar multiplets) warrants for only one Higgs scalar surviving the SSB, while all other degrees of freedom (Goldstone bosons) are eaten by the gauge bosons to become massive. The advantage of this MHM resides in the fact that a realistic boson mass spectrum appears to be simply a matter of tuning a single remaining free parameter (a, in our approach). However, the procedure is flexible enough, so that a canonical Higgs mechanism (with more than one scalar field surviving) can be implemented as well.

The purpose of this paper is to give an estimate of the properties of the surviving Higgs boson from a 3-3-1 model with right-handed neutrinos (331RHN) solved within the particular approach of finally tuning a single free parameter [19, 20]. We focus especially on the Higgs boson couplings such as HW^+W^-, HZZ, $HZ'Z'$, HXX^*, HY^+Y^-or $H\bar{f}f$ (where capital letters denote bosons of the model, and f fermions), in view of obtaining possible signatures of it at the LHC and finally narrowing its mass estimate around the most plausible values.

The paper is organized as follows. In Sec.2 we offer a brief review of the gauge model under consideration here. Possible Higgs boson decays and other phenomenological consequences are sketched in Sec.3, while in Sec.4 certain numerical estimates in different scenarios are given. Sec.5 is reserved for sketching our conclusions and suggestions for experimental search in the Higgs sector at LHC.

2. BRIEF REVIEW OF THE MODEL

The study of the 331RHN models has revealed a rich phenomenology [21] - [33] including some suitable solutions for the neutrino mass issue [34] - [42]. In the recent years a particular sub-class of the 331RHN models that need only two Higgs triplets in order to spontaneously break the symmetry - called "the economical 3-3-1 model" - has been championed by Long and his collaborators [42] - [48]. However, we begin here with three scalar triplets in order to achieve the SSB.

Therefore, we consider it worthwhile presenting the main features of constructing such a model. It is based on the gauge group $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ and the main pieces are the irreducible representations which correspond to fermion left-handed multiplets. The fermion content is the following:

Lepton families.

$$f_{\alpha L} = \begin{pmatrix} \nu_\alpha^c \\ \nu_\alpha \\ e_\alpha \end{pmatrix}_L \sim (\mathbf{1},\mathbf{3},-1/3) \qquad e_{\alpha R} \sim (\mathbf{1},\mathbf{1},-1) \tag{1}$$

Quark families.

$$Q_{iL} = \begin{pmatrix} D_i \\ -d_i \\ u_i \end{pmatrix}_L \sim (\mathbf{3},\mathbf{3}^*,0) \qquad Q_{3L} = \begin{pmatrix} U_3 \\ u_3 \\ d_3 \end{pmatrix}_L \sim (\mathbf{3},\mathbf{3},+1/3) \tag{2}$$

$$d_{iR}, d_{3R} \sim (\mathbf{3},\mathbf{1},-1/3) \qquad `u_{iR}, u_{3R} \sim (\mathbf{3},\mathbf{1},+2/3) \tag{3}$$

$$U_{3R} \sim (\mathbf{3},\mathbf{1},+2/3) \qquad D_{iR} \sim (\mathbf{3},\mathbf{1},-1/3), \tag{4}$$

with $i = 1,2$.

In the representations presented above one has to assume that two generations of quarks transform differently from the third one in order to cancel all the axial anomalies (by an interplay between families, although each one remains anomalous by itself). In this way one prevents the model from compromising its renormalizability by triangle diagrams. The capital letters denote the exotic quarks included in each family. Many authors consider that $U_{3R} = T$ and $D_{iR} = D, S$ as a possible explanation of the unusual heavy masses of the third generation of quarks, but we restrict ourselves here to make up no particular choice. Moreover, the anomaly cancellation requires the generation number of fermion triplets be a multiple of number of colors (3) which combined with another restriction from QCD - namely, the asymptotic freedom triggering the generation number < 5 - can offer an explanation for the experimentally observed number of generations.

Gauge bosons. The gauge bosons of the model are connected to the generators of the $su(3)$ Lie algebra expressed by the usual Gell-Mann matrices $T_a = \lambda_a/2$. So, the Hermitian diagonal generators of the Cartan sub-algebra are

$$D_1 = T_3 = \frac{1}{2}\mathrm{Diag}(1,-1,0)\,, \quad D_2 = T_8 = \frac{1}{2\sqrt{3}}\mathrm{Diag}(1,1,-2)\,. \tag{5}$$

In this basis the gauge fields are A^0_μ (corresponding to the Lie algebra of the group $U(1)_X$) and $A_\mu \in su(3)$ that is

$$A_\mu = \frac{1}{2}\begin{pmatrix} A^3_\mu + A^8_\mu/\sqrt{3} & \sqrt{2}X_\mu & \sqrt{2}Y_\mu \\ \sqrt{2}X^*_\mu & -A^3_\mu + A^8_\mu/\sqrt{3} & \sqrt{2}W_\mu \\ \sqrt{2}Y^*_\mu & \sqrt{2}W^*_\mu & -2A^8_\mu/\sqrt{3} \end{pmatrix}, \tag{6}$$

where $\sqrt{2}W^{\pm}_\mu = A^6_\mu \mp iA^7_\mu$, $\sqrt{2}Y^{\pm}_\mu = A^4_\mu \pm iA^5_\mu$, and $\sqrt{2}X_\mu = A^1_\mu - iA^2_\mu$, respectively. One notices that apart from the charged Weinberg bosons ($W^{\pm}$) from SM, there are two new complex boson fields, X (neutral) and Y (charged).

The diagonal Hermitian generators are associated to the neutral gauge bosons A^{em}_μ, $Z_\mu$and Z'_μ. On the diagonal terms in Eq.(6) a generalized Weinberg transformation (gWt) must be performed in order to consequently separate the massless electromagnetic field from the other two neutral massive fields. The details of this procedure can be found in Ref. [18] and its concrete realization in the model of interest here in Refs. [19,20].

Scalar sector. In the general method [18], the scalar sector of any gauge model must consists of n Higgs multiplets $\phi^{(1)}$, $\phi^{(2)}$, ... , $\phi^{(n)}$ satisfying the orthogonal condition $\phi^{(i)+}\phi^{(j)} = \phi^2\delta_{ij}$ in order to eliminate unwanted Goldstone bosons that could survive the SSB, ϕ being a gauge-invariant real field variable (acting as a norm in the scalar space) and n is the dimension of the fundamental irreducible representation of the gauge group. The parameter matrix $\eta = \left(\eta_0, \eta^{(1)}, \eta^{(2)}, ..., \eta^{(n)}\right)$ with the property $Tr\eta^2 = 1 - \eta_0^2$ is a key ingredient of the method introduced in order to obtain a non-degenerate boson mass spectrum. Obviously, $\eta_0, \eta^{(i)} \in [0,1)$. Then, the Higgs Lagrangian density (Ld) reads:

$$\mathcal{L}_H = \frac{1}{2}\eta_0^2\partial_\mu\phi\partial^\mu\phi + \frac{1}{2}\sum_{i=1}^{n}\left(\eta^{(i)}\right)^2\left(D_\mu\phi^{(i)}\right)^+\left(D^\mu\phi^{(i)}\right) - V(\phi) \tag{7}$$

where $D_\mu\phi^{(i)} = \partial_\mu\phi^{(i)} - i(gA_\mu + g'y^{(i)}A^0_\mu)\phi^{(i)}$ act as covariant derivatives of the model, and $g$and g' the coupling constants of the groups $SU(N)_L$ and $U(1)_X$ respectively. Real characters $y^{(i)}$ stand as a would-be hypercharge of the new theory. In order to keep valid the renormalizability, the potential V must take the form:

$$V = -\mu^2 \sum_{i=1}^{n} \phi^{(i)+}\phi^{(i)} + \lambda \sum_{i=1}^{n} \left(\phi^{(i)+}\phi^{(i)}\right)^2 \tag{8}$$

Boson Mass Spectrum. After a few manipulations, in the specific case of the 331RHN model one gets the following mass spectrum [20]: $m_W^2 = m^2 a$, $m_Y^2 = m^2\left(1 - a/2\cos^2\theta_W\right)$ and $m_X^2 = m^2\left[1 - a(1-\tan^2\theta_W)/2\right]$ for the charged ones, while $m_Z^2 = m^2 a/\cos^2\theta_W$ is the mass of the Weinberg boson from SM and $m_{Z'}^2 = m^2\left[4\cos^2\theta_W - a\left(3 - 4\sin^2\theta_W + \tan^2\theta_W\right)\right]/\left(3 - 4\sin^2\theta_W\right)$ stands for the mass of the new neutral boson, specific to this 3-3-1 model. We have made the notation: $m^2 = g^2\langle\phi\rangle^2(1-\eta_0^2)/4$. The mass scale is now just a matter of tuning the parameter a in accordance with the possible values for $\langle\phi\rangle$.

One can note for the neutral bosons sector that the diagonalization of the resulting mass matrix [19] has been performed by imposing the specific relation between m_W and m_Z, namely $m_Z^2 = m_W^2/\cos^2\theta_W$. That is why one finally remains with a single free parameter to be tuned a. Moreover, the rotation matrix doing the diagonalising job has established the mixing angle $\sin\phi = 1/2\sqrt{1-\sin^2\theta_W}$. The traditional approach in the literature assumes ϕ as a free parameter restricted on experimental ground. Here it is fixed, the role of ensuring the experimentally observed gap between $m(Z')$ and $m(Z)$ being realized by the free parameter a. In addition, we mention that the correct coupling match is recovered through our method, namely $g' = g\sqrt{3}\sin\theta_W/\sqrt{3-4\sin^2\theta_W}$ and all the couplings in the neutral currents of the model (or, in other words, the neutral charges of the fermions) are given in the Table in Ref. [20]. They are exactly obtained and need no approximation, since the operation of getting the basis of physical states for the neutral bosons has already been achieved.

3. POSSIBLE HIGGS SIGNATURES

In order to analyse the possible phenomenological consequences regarding the Higgs boson decays, one has to observe the terms coupling the Higgs boson to the gauge bosons of the model (HBB). They can be read from the Ld:

$$\frac{g^2}{2}\left(\langle\phi\rangle + H\right)^2 Tr\left[\left(A_\mu + YA_\mu^0\right)\eta^2\left(A^\mu + YA^{\mu 0}\right)\right] \tag{9}$$

In our particular case of the 331RHN model, one gets the HBB couplings by assuming the resulting parametrization that led to the specific mass spectrum in the

Table 1.

Couplings of the Higgs boson to gauge bosons in 331RHN model

Coupling(HBB)	$\times m^2(W)/\langle\phi\rangle$	$\times 6464.14 GeV^2/\langle\phi\rangle$
$g(HZZ)$	$1/\cos^2\theta_W$	$=1.287$
$g(HZ'Z')$	$\frac{1}{a}\left(1+\frac{1}{3-4\sin^2\theta_W}\right)-\left(1+\frac{\tan^2\theta_W}{3-4\sin^2\theta_W}\right)$	$=\frac{1}{a}1.483-1.594$
$g((HW^+W^-)$	2	$=2$
$g((HY^+Y^-)$	$\frac{2}{a}-\frac{1}{\cos^2\theta_W}$	$=\frac{2}{a}-1.287$
$g((HX^*X)$	$\frac{2}{a}-\frac{1-2\sin^2\theta_W}{\cos^2\theta_W}$	$=\frac{2}{a}-0.713$

boson sector, namely $\eta^2=\left(1-\eta_0^2\right)\left[1-a,\frac{a}{2}(1-\tan^2\theta_W),a/2\cos^2\theta_W\right]$. They read

$$\mathcal{L}=\frac{H}{\langle\phi\rangle}(2M_W^2W_\mu^+W^\mu+M_Z^2Z_\mu Z^\mu \\ +2M_X^2X_\mu^+X^\mu+2M_Y^2Y_\mu^+Y^\mu+M_{Z'}^2Z_\mu'^+Z'^\mu), \tag{10}$$

which explicitly leads to the following particular couplings:

$$\frac{m^2a}{\langle\phi\rangle\cos^2\theta_W}HZZ, \tag{11}$$

$$\left[\left(1+\frac{1}{3-4\sin^2\theta_W}\right)-a\left(1+\frac{\tan^2\theta_W}{3-4\sin^2\theta_W}\right)\right]\frac{m^2}{\langle\phi\rangle}HZ'Z', \tag{12}$$

$$2\frac{m^2a}{\langle\phi\rangle}HW^+W^-, \tag{13}$$

$$\left(2-\frac{a}{\cos^2\theta_W}\right)\frac{m^2}{\langle\phi\rangle}HY^+Y^-, \tag{14}$$

$$\left(2-a\frac{1-2\sin^2\theta_W}{\cos^2\theta_W}\right)\frac{m^2}{\langle\phi\rangle}HX^*X. \tag{15}$$

In expressions above (Eqs. 11 - 15) one can enforce a unique factor $m^2a/\langle\phi\rangle=m^2(W)/\langle\phi\rangle$ and get finally couplings depending on the parameter a for the new bosons (Z', X and Y respectively), while those corresponding to the SM bosons (W and Z) remain fixed, once the Weinberg angle θ_W is known.

In the Table 1 are given the numerical values of these couplings depending on the ratio $m^2(W)/\langle\phi\rangle$ which can be plotted.

The most general decay scenario can be considered the one in which the Higgs boson is heavier than double mass of the heaviest boson, so all channels are kinematically allowed. Then, the partial width of the Higgs decay into two any gauge bosons is given in the Born approximation (at tree level) by the well-known formula:

$$\Gamma(H \to BB) = \frac{M_H^2 \alpha}{32\pi\sqrt{2}\langle\phi\rangle^2}\sqrt{1-\frac{4M_B^2}{M_H^2}}\left(4-\frac{16M_B^2}{M_H^2}+\frac{48M_B^4}{M_H^4}\right), \tag{16}$$

with $\alpha = 1$for neutral bosons and $\alpha = 2$ for charged ones and B denoting any gauge boson. Noting the ratio $x = 4M_W^2/M_H^2$, the concrete functions behave as

$$\Gamma(H \to W^+W^-) \sim 2\sqrt{1-x}\left(4-4x+3x^2\right)$$

$$\Gamma(H \to ZZ) \sim \sqrt{1-\frac{x}{\cos^2\theta_W}}\left(4-4\frac{x}{\cos^2\theta_W}+3\frac{x^2}{M_H^4\cos^4\theta_W}\right)$$

$$\Gamma(H \to Y^+Y^-) \sim 2\sqrt{1-x\left(\frac{1}{a}-\frac{1}{2\cos^2\theta_W}\right)} \times\left[4-4x\left(\frac{1}{a}-\frac{1}{2\cos^2\theta_W}\right)+3x^2\left(\frac{1}{a}-\frac{1}{2\cos^2\theta_W}\right)^2\right]$$

$$\Gamma(H \to X^*X) \sim 2\sqrt{1-x\left(\frac{1}{a}-\frac{1-2\sin^2\theta_W}{2\cos^2\theta_W}\right)} \times\left[4-4x\left(\frac{1}{a}-\frac{1-2\sin^2\theta_W}{2\cos^2\theta_W}\right)+3x^2\left(\frac{1}{a}-\frac{1-2\sin^2\theta_W}{2\cos^2\theta_W}\right)^2\right]$$

$$\Gamma(H \to Z'Z') \sim \sqrt{1-x\left[\frac{1}{a}\left(1+\frac{1}{3-4\sin^2\theta_W}\right)-\left(1+\frac{\tan^2\theta_W}{3-4\sin^2\theta_W}\right)\right]} \times\left\{4-4x\left[\frac{1}{a}\left(1+\frac{1}{3-4\sin^2\theta_W}\right)-\left(1+\frac{\tan^2\theta_W}{3-4\sin^2\theta_W}\right)\right] +3x^2\left[\frac{1}{a}\left(1+\frac{1}{3-4\sin^2\theta_W}\right)-\left(1+\frac{\tan^2\theta_W}{3-4\sin^2\theta_W}\right)\right]\right\}$$

Their numerical expressions become:

$$\Gamma(H \to W^+W^-) \sim 2\sqrt{1-x}\left(4-4x+3x^2\right) \tag{17}$$

$$\Gamma(H \to ZZ) \sim \sqrt{1-1.29x}\left(4-5.16x+5x^2\right) \tag{18}$$

$$\Gamma(H \to Y^+Y^-) \sim 2\sqrt{1+0.64x-\frac{x}{a}}\left(4+2.56x-4\frac{x}{a}+3\frac{x^2}{a^2}\right) \tag{19}$$

$$\Gamma(H \to X^*X) \sim 2\sqrt{1+0.35x-\frac{x}{a}}\left(4-1.4x-4\frac{x}{a}+3\frac{x^2}{a^2}\right) \tag{20}$$

$$\Gamma(H \to Z'Z') \sim \sqrt{1+1.15x-\frac{1.48x}{a}}\left(4-4.6x-4\frac{x}{a}+3\frac{x^2}{a^2}\right) \tag{21}$$

Table 2.

Masses of the gauge bosons in 331RHN model

Mass	Scenario A	Scenario B
$m(Y)$	246 GeV – 702 GeV	246 GeV – 2.2289 TeV
$m(X)$	248 GeV – 703 GeV	248 GeV – 2.2293 TeV
$m(Z')$	297.4 GeV – 854.4 GeV	297.4 GeV – 2.7141 TeV

Furthermore, one can plot the different partial widths for Higgs decays and observe the dominant processes at any $a \in [0,1)$.

4. RESULTS AND NUMERICAL ESTIMATES

At this moment one can test some plausible scenarios and obtain some rough estimates. We propose two such versions, namely Scenario (A) in which vev $\langle\phi\rangle \simeq$ 1TeV implying $m^2(W)/\langle\phi\rangle \simeq 0.0065$ and Scenario (B) vev $\langle\phi\rangle \simeq 10$TeV that implies $m^2(W)/\langle\phi\rangle \simeq 0.00065$. Before entering the discussion of the Higgs phenomenology and its restrictions, let's estimate the implications of some verified phenomenological aspects [49]. For instance, the "wrong muon decay" gives at a 98% CL the result

$$R = \frac{\Gamma(\mu^- \to e^- \bar{\nu_\mu}\nu_e)}{\Gamma(\mu^- \to e^- \bar{\nu_e}\nu_\mu)} = \left(\frac{m_W}{m_Y}\right)^4 \leq 1.2\% \tag{22}$$

Hence $m_Y \geq 240$GeV or equivalently - in our approach - to $a \leq 0.123$.

Now, in order to keep the Higgs phenomenology in the perturbative regime, the couplings in Table 1 must lie below 1 at the considered scale. That is, in scenario (A) $a \in (0.013 - 0.123)$ at $\langle\phi\rangle \simeq 1$TeV and in scenario (B) $a \in (0.0013 - 0.123)$ at $\langle\phi\rangle \simeq 10$TeV. Consequently, the ranges for the new gauge bosons are obtained since they depend on the sole free parameter a, while the masses of the old gauge boson remain $m(W) = 80.4$GeV and $m(Z) = 91.1$GeV, as in the SM:

Taking into account Eqs. 19 - 21 and imposing for the amount under square root to be positive one gets successively that $m(H) \geq 1.404$ TeV, $m(H) \geq 1.407$ TeV and $m(H) \geq 1.708$ TeV for scenario (A) and $m(H) \geq 4.457$ TeV, $m(H) \geq 4.458$ TeV and $m(H) \geq 5.423$ TeV in scenario (B). These estimate were inferred by taking into account the minimal allowed value for parameter a: 0.013 in scenario (A) and 0.0013 in scenario (B) respectively.

Inspecting the self couplings of the Higgs boson - $g(\mathbf{HHH}) = m^2(H)/2\langle\phi\rangle$ and $g(\mathbf{HHHH}) = m^2(H)/8\langle\phi\rangle^2$ - one can derive an upper bound on its mass if they are set up to keep perturbativity. That is, the coupling must remain below 1 at the considered breaking scale. In scenario (A) this yields $m(H) \leq 1.4142$ TeV, while scenario (B) provides $m(H) \leq 4.47$ TeV.

In addition, the perturbative unitarity at high energies $\sqrt{s} \sim 10$ TeV (or even greater ones so that $s \gg m^2(H)$) claims certain restrictions on the amplitudes of charged bosons scattering (see Refs. [50, 51] and references therein), namely

$$\left| \frac{m^2(H)}{8\pi \langle \phi \rangle^2} \right| < \frac{1}{2}$$

which leads to upper bounds such as $m(H) \leq 3.544$ TeV in scenario (A) and $m(H) \leq 35.44$ TeV in scenario (B). Let's note that these requirements are already fulfilled by previous estimates in our approach.

5. CONCLUSIONS

We have discussed in this paper some plausible scenarios (given by two reasonable breaking scales 1TeV and 10 TeV respectively) with a special focus on the possible decays of the Higgs boson. Some rough estimates were obtained within a particular 331RHN model, by simply resorting to a general algebraic approach of treating gauge models with SSB in which finally one has to tune a single free parameter a in order to obtain the full boson mass spectrum and the decay rates of the Higgs boson. In any scenario the dominant process is $H \to W^+W^-$ for the most likely range of the free parameter. We summarize below the main predictions of our analysis:

Scenario (A) - $\langle \phi \rangle \simeq 1$ TeV

$m(Y) \in$ (246 GeV – 702 GeV), $m(X) \in$ (248 GeV – 703 GeV), and $m(Z') \in$ (297.4 GeV – 854.4 GeV).

$m(H) \simeq 1.4$ TeV.

Scenario (B) - $\langle \phi \rangle \simeq 10$ TeV

$m(Y) \in$ (246 GeV – 2.2289 TeV), $m(X) \in$ (248 GeV – 2.2293 TeV), and $m(Z') \in$ (297.4 GeV – 2.7141 TeV)

$m(H) \in (4.45 - 4.47)$ TeV.

Of course, there could be also a third scenario in which one keeps the mass range of the Higgs field at its order of magnitude suggested by the SM, namely $m(H) \simeq 140$ GeV. In this case, all its couplings to heavier bosons become irrelevant, since there are no kinematically allowed decays and one recovers the well studied Higgs phenomenology of the SM.

These rough estimates can be improved by more advanced theoretical analysis (in our approach or in a more traditional one) while taking into account more accurate processes and calculus (such as the heavy quarks effects or heavy bosons decays) one could get new results to confirm or discard the actual ones. Notwithstanding, we think our results can be considered as a good and testable hint for searching Higgs signatures at the LHC, since energies around a few TeV are reachable. One could rise the question of using a non-orthodox method in achieving the SSB, but this is not a real issue as long as the scalar sector of any theory remains to date something of a mystery. There is no one who can firmly state the number of scalars surviving the SSB or possess the unique way of implementing a Higgs mechanism (whatsoever it would be). Therefore, our approach can simply be considered to serve as a theoretical tool in giving some hints to be tested at the LHC with regard to the possible mass of the still elusive Higgs boson.

NOTE: After submitting our work some recent data supplied by LHC indicated a possible occurrence of the Higgs boson at around 126 GeV. If this experimental result will be further confirmed by a vast amount of data that undoubtedly establish its mass, the decays of the Higgs boson into other gauge bosons are kinematically ruled out, since the lightest gauge boson weighs $m(W) = 80.4$ GeV, namely more than a half of the Higgs mass. However, even if these preliminary estimates will be confirmed, our approach is flexible enough to be extended as to include more than a single neutral Higgs boson and our results here could stand as a springboard for a larger content of the scalar sector in the 3-3-1 model, but this task exceeds the scope of this work and will be treated in detail elsewhere.

REFERENCES

1. S. Weinberg, Phys. Rev. Lett. **19**, 1264 (1967).
2. S.L. Glashow, Nucl. Phys. **20**, 579 (1961).
3. A. Salam, in "*Elementary Particle Theory*": Relativistic Groups in Analyticity (Nobel Symposium No.8), N. Svartholm (ed.), Almqvist and Wiknell – Stockholm 1968, p.367.
4. A. Strumia and F. Vissani, arXiv: hep-ph/0606054 v3.
5. P.W. Higgs, Phys. Rev. Lett. **13**, 508 (1964).
6. F. Englert and R. Brout, Phys. Rev. Lett. **13**, 321 (1964).
7. G.S. Guralnik, C.R. Hagen and T. Kibble, Phys. Rev. Lett. **13**, 585 (1965).
8. P.W. Higgs, Phys. Rev. **145**, 145 (1966).
9. T. Kibble, Phys. Rev. **155**, 1554 (1967).
10. P.H. Frampton, Phys. Rev. Lett. **69**, 2889 (1992).
11. F. Pisano and V. Pleitez, Phys. Rev. D **46**, 410 (1992).
12. R. Foot, H.N. Long and T.A. Tran, Phys. Rev. D **50**, R34 (1994).
13. H.N. Long, Phys. Rev. D **53**, 437 (1996).
14. H.N. Long, Phys. Rev. D **54**, 4691 (1996).
15. W.A. Ponce, J.B. Florez and L.A. Sanchez, Int. J. Mod. Phys. A **17**, 643 (2002).
16. L.A. Sanchez, W.A. Ponce and R. Martinez, Phys. Rev. D **64**, 075013 (2001).
17. R.A. Diaz, R. Martinez and F. Ochoa, Phys. Rev. D **72**, 035018 (2005).
18. I.I. Cotaescu, Int. J. Mod. Phys. Rev. A **12**, 1483 (1997).
19. A. Palcu, Mod. Phys. Lett. A **21**, 1203 (2006).

20. A. Palcu, Mod. Phys. Lett. A **23**, 387 (2008).
21. H.N. Long and T. Inami, Phys. Rev. D **61**, 075002 (2000).
22. G. Tavares-Velasco and J.J. Toscano, Phys. Rev. D **70**, 053006 (2004).
23. L.D. Ninh and H.N. Long, Phys. Rev. D **72**, 075004 (2005).
24. A.G. Dias, J.C. Montero and V. Pleitez, Phys. Rev. D **73**, 113004 (2006).
25. A. Doff, C.A. de S. Pires and P.S. Rodrigues da Silva, Phys. Rev. D **74**, 015014 (2006).
26. A. Carcamo, R. Martinez and F. Ochoa, Phys. Rev. D **73**, 035007 (2006).
27. E. Ramirez-Barreto, Y.A. Coutinho and J. Sa Borges, Eur. Phys. J. C **50**, 909 (2007).
28. F. Ramirez-Zavaleta, G. Tavares-Velasco and J.J. Toscano, Phys. Rev. D **75**, 075008 (2007).
29. A.G. Dias, C.A. de S. Pires and P.S. Rodrigues da Silva, Phys. Rev. D **77**, 055001 (2008).
30. D. Cogollo, H. Diniz, C.A. de S. Pires and P.S. Rodrigues da Silva, Mod. Phys. Lett. A **23**, 3405 (2008).
31. J.M. Cabarcas, D. Gomez Dumm and R. Martinez, Phys. Rev. D **77**, 036002 (2008).
32. J.M. Cabarcas, D. Gomez Dumm and R. Martinez, Eur. Phys. J. C **58**, 569 (2008).
33. R.H. Benavides, T. Giraldo and W.A. Ponce, Phys. Rev. D **80**, 113009 (2009).
34. A.G. Dias, C.A. de S. Pires and P.S. Roridgues da Silva, Phys. Lett. B **628**, 85 (2005).
35. D. Chang and H.N. Long, Phys. Rev. D **73**, 053006 (2006).
36. A. Palcu, Mod. Phys. Lett. A **21**, 2027 (2006).
37. A. Palcu, Mod. Phys. Lett. A **21**, 2591 (2006).
38. A. Palcu, Mod. Phys. Lett. A **22**, 939 (2007).
39. D. Cogollo, H. Diniz, C.A. de S. Pires and P.S. Rodrigues da Silva, Eur. Phys. J. C **58**, 455 (2008).
40. P.V. Dong and H.N. Long, Phys. Rev. D **77**, 057302 (2008).
41. D. Cogollo, H. Diniz and C.A. de S. Pires, Phys. Lett B **677**, 338 (2009).
42. P.V. Dong, H.N. Long and D.V. Soa, Phys. Rev. D **75**, 073006 (2007).
43. W.A. Ponce, Y. Giraldo and L.A. Sanchez, Phys. Rev. D **67**, 0750-1 (2003).
44. D.A. Gutierrez, W.A. Ponce and L.A. Sanchez, Int. J. Mod. Phys. A **21**, 2217 (2006).
45. P.V. Dong, H.N. Long, D.T. Nhung and D.V. Soa, Phys. Rev. D **73**, 035004 (2006).
46. P.V. Dong, H.N. Long and D.T. Nhung, Phys. Lett. B **639**, 527 (2006).
47. P.V. Dong, H.N. Long and D.V. Soa, Phys. Rev. D **73**, 075005 (2006).
48. P.V. Dong, Tr.T. Huong, D.T. Huong and H.N. Long, Phys. Rev. D **74**, 053003 (2006).
49. K. Nakamura *et al.* (PDG), J. Phys. G **37**, 075021 (2010).
50. A. Djouadi, Phys. Rept. **457**, 1-216 (2008).
51. A. Djouadi, Phys. Rept. **459**, 1-241 (2008).