Phenomenology of the new strong vector resonance

M. Gintner, gintner@fyzika.uniza.sk, Physics Department, University of Žilina, Žilina, Slovakia and Institute of Experimental and Applied Physics, Czech Technical University in Prague, Prague, Czech Republic, and J. Juráň, josef.juran@utef.cvut.cz, Institute of Physics, Silesian University in Opava, Opava, Czech Republic and Institute of Experimental and Applied Physics, Czech Technical University in Prague, Prague, Czech Republic

INTRODUCTION

The recent analyses of the LHC data strongly suggest that the observed 125-GeV boson is a Higgs-like particle related to the mechanism of electroweak symmetry breaking (ESB). Nevertheless, the question about the nature of ESB remains unsolved. From a theoretical point of view, the alternatives to the SM Higgs get some preference due to the naturalness argument. The extensions of the SM still in the game include theories where electroweak symmetry is broken by new strong interactions, like in Technicolor

On the theoretical front, activities in the modeling, parameterizing, and fitting the 125-GeV Higgs-like boson sector of candidate theories are taking place nowadays. Effectively, the Higgs-like boson can be described as a stand alone singlet added to the non-linear sigma model of the Nambu-Goldstone bosons. Alternatively, the Higgs-like scalar can be made a member of a multiplet of the symmetry of the strong sector [1].

It seems reasonable to expect that beside the composite scalar the new strong interactions would also produce bound states of higher spins. In this paper, we consider the effective Lagrangian where the 125-GeV scalar resonance is complemented with the $SU(2)_{L+R}$ triplet of vector resonances. Theories that can be related to our effective description include 2-site deconstructed models, purely 4-dimensional multi-site models, and composite Higgs models. All these models predict the existence of resonances of higher spins, including the vectorial ones. The idea of partial compositeness that appears in some of these models could justify the exclusivity of the third quark direct couplings to the vector resonances in our effective Lagrangian.

We have introduced the $SU(2)_{L+R}$ triplet vector resonance to the usual $SU(2)_L \times SU(2)_R \to SU(2)_{L+R}$ effective Lagrangian with the non-linearly transforming $SU(2)_{L+R}$ triplet of the would-be Nambu-Goldstone bosons augmented with the $SU(2)_{L+R}$ singlet scalar resonance [2, 3, 4]. The vector triplet is brought in as a gauge field via the hidden local symmetry (HLS) approach [5]. Beside the scalar singlet and the vector triplet, the effective Lagrangian is built out of the SM fields only.

The vector resonance couples directly to the third quark generation only. The interactions of the left and right fields are proportional to b_L and b_R, respectively. In addition, there is a free parameter p which disentangles the right bottom coupling from the right top coupling. The assumption that the vector resonance interaction with the right bottom quark is weaker than the interaction with the right top quark corresponds to the expectation that $0 \leq p \leq 1$. While $p = 1$ leaves the interactions equal, the $p = 0$ turns off the right bottom quark interaction completely and maximally breaks the $SU(2)_R$ part of the Lagrangian symmetry down to $U(1)_{R3}$. In addition the symmetry of the Lagrangian admits non-SM interaction of the fermions with the EW gauge bosons that we include under the assumption that they apply to the third quark generation only. These interactions are proportional to the free parameters λ_L and λ_R. In the unitary (physical) gauge the new physics part of the (t, b) Lagrangian assumes the form

$$\begin{aligned} \mathcal{L}^{\mathrm{NP}}_{(t,b)} &= i b_L \bar{\psi}_L (\not{\mathbf{V}} - \not{\mathbf{W}}) \psi_L \\ &\quad + i b_R \bar{\psi}_R P (\not{\mathbf{V}} - \not{\mathbf{B}}^{R3}) P \psi_R \\ &\quad + i \lambda_L \bar{\psi}_L (\not{\mathbf{W}} - \not{\mathbf{B}}^{R3}) \psi_L \\ &\quad + i \lambda_R \bar{\psi}_R P (\not{\mathbf{W}} - \not{\mathbf{B}}^{R3}) P \psi_R \end{aligned} \qquad (1)$$

where $\not{\mathbf{W}}_\mu = ig \not{W}^a_\mu \tau^a$, $\not{\mathbf{B}}^{R3} = ig' \not{B} \tau^3$, $\not{\mathbf{V}}_\mu = i \frac{g''}{2} \not{V}^a_\mu \tau^a$, and the matrix $P = \mathrm{diag}(1, p)$ disentangles the direct interaction of the vector triplet with the right top quark from the interaction with the right bottom quark.

The direct LHC bottom limits on the vector resonance masses are strongly model dependent. In general, considering the partial compositeness for the third quark generation admits the limits to be as low as 300 GeV, or even less, for certain values of the Higgs-like boson couplings [6]. The most restrictive bottom limit is obtained when no compositeness of the SM fermions is assumed; it is slightly below 1 TeV.

In this paper, we present the best fits of the vector resonance free parameters to the existing data. In setting constraints on the vector resonance couplings the published LHC analyses cannot compete with the low-energy (LE) measurements yet. Therefore we focus on the LE data when calculating the limits.

RESULTS AND CONCLUSIONS

If there is the new vector resonance triplet we can learn about its parameters even before its discovery by measuring deviations of the known particle couplings from their SM values. To confront the resonance free parameters with the LE measurements we have derived the LE Lagrangian by integrating out the vector resonance triplet the assumed mass of which is $\mathcal{O}(10^3)$ GeV. In the process, the number of the free parameters has been reduced. In particular, the low-energy observables depend on the combinations $\Delta L = b_L - 2\lambda_L$ and $\Delta R = b_R + 2\lambda_R$ of b and λ parameters only.

The experimental limits for the LE parameters g'', p, ΔL, and ΔR have been derived by fitting the low-energy (pseudo)observables ϵ_1, ϵ_2, ϵ_3, $\Gamma_b(Z \to b\bar{b})$, and $\mathrm{BR}(B \to X_s \gamma)$. As far as the scalar parameters are concerned the direct LHC measurements restrict them to the vicinity of their SM values. Under the assumptions inspired by the composite Higgs scenario when the Higgs couples equally to all fermions and the NLO couplings are set to zero the parameter a (defined in [3, 4], parameterizing the coupling of the scalar resonance to the electroweak gauge bosons and the vector resonance) is restricted by the combination of the most recent LHC data and the electroweak precision observables from SLC, LEP-1, LEP-2, and the Tevatron to be within 10% of the SM value at 95% CL [7]. Our full-scale analysis resulting in the LE limits for the vector resonance parameters under simplifying assumptions that the scalar resonance couples as the SM Higgs boson can be found in [4].

Here we report the best fits when the parameter a differs from its SM value $a = 1$. In Fig. 1 we show the best-fit values of ΔL and ΔR and the iso-backing contours for the preselected values of g'' and p. The grid of the dot-dashed and dashed lines indicates the best values of ΔL and ΔR, respectively. The numbers attached to the grid lines are 10^3 times the actual values represented by the lines. In the figure, the graphs for three different values of a are shown, $a = 0.9$, 1.0, and 1.1. The cut-off scale $\Lambda = 1$ TeV for all graphs. The vertical solid line in the graphs indicates the naive perturbativity limit for g'': $g''/2 \leq 4\pi$.

We can see that the best values of g'' read 36, 29, and 25, and the best values of p read 0.14, 0.21, and 0.42 when $a = 0.9$, 1.0, and 1.1, respectively. The corresponding best values of $(\Delta L, \Delta R)$ are about $(-0.003, 0.023)$, $(-0.004, 0.016)$, and $(-0.004, 0.008)$. Recall that the direct vector resonance coupling to the left top-bottom quark doublet is proportional to $b_L g''$ and the direct coupling to the right top quark is proportional to $b_R g''$. The couplings of the right bottom quark to the charged and neutral vector resonances are diminished by p and p^2, respectively. The best-fit value of p found in our analysis seems to support the assumption of some models of partial fermion compositeness that the new strong physics resonances couple stronger to the right top quark than to the right bottom quark. Unless the vector resonance is discovered directly further progress in the LHC measurements of the Ztt and Wtb vertices is needed to improve limits on this and other parameters of the studied effective Lagrangian.

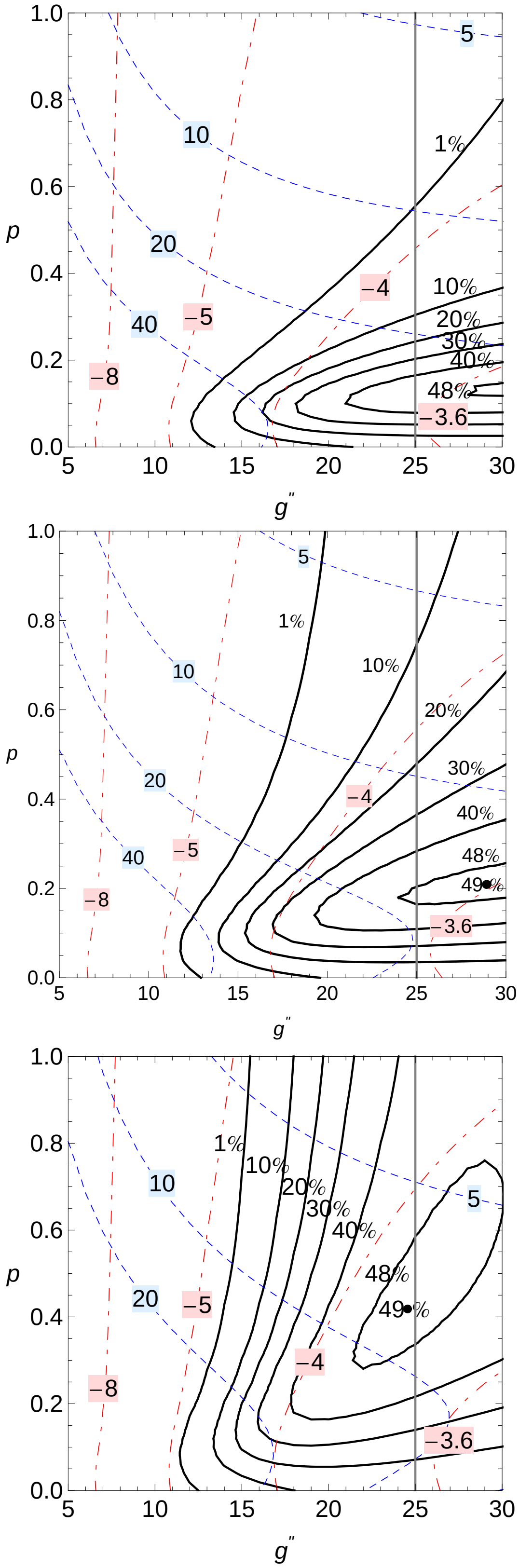

Fig. 1. The best-fit values of ΔL (dot-dashed) and ΔR (dashed) and the iso-backing contours (solid) for the preselected values of g'' and p. (top: $a = 0.9$, middle: $a = 1.0$, bottom: $a = 1.1$.) More information about the graphs can be found in the text.

REFERENCES

1. G. Panico and A. Wulzer, J. High Energy Phys. 09, 135 (2011).
2. M. Gintner, J. Juráň, and I. Melo, Phys. Rev. D **84**, 035013 (2011).
3. M. Gintner, J. Juráň, `arXiv:1301.2124`.
4. M. Gintner, J. Juráň, submitted to the European Physics Journal C.
5. M. Bando, T. Kugo, and K. Yamawaki, Phys. Rep. **164**, 217 (1988).
6. B. Bellazzini, C. Csáki, J. Hubisz, J. Serra, and J. Terning, J. High Energy Phys. 11, 003 (2012).
7. A. Falkowski, F. Riva, and A. Urbano, `arXiv:1303.1812`.