A brief outline of the top-BESS model

M. Gintner, gintner@fyzika.uniza.sk, Physics Department, University of Žilina, Slovakia and IEAP, Czech Technical University in Prague, Czech Republic, J. Juráň, josef.juran@utef.cvut.cz, IEAP, Czech Technical University in Prague, Czech Republic and I. Melo, melo@fyzika.uniza.sk, Physics Department, University of Žilina, Slovakia

Despite the great success of the Standard Model (SM) one essential component of the theory remains a puzzle: it is the actual mechanism behind the electroweak symmetry breaking (ESB). Spontaneous breaking of electroweak (EW) symmetry accompanied by the Higgs mechanism is the way to reconcile the massive gauge bosons with the principle of gauge invariance. A direct consequence of this hypothesis is the presence of the scalar Higgs boson in the particle spectrum, not observed as of yet, though.

There is a host of candidates for alternative extensions of the SM that offer their own mechanisms of ESB. The formalism of effective Lagrangians can be used to classify and investigate their phenomenology at energies accessible at the LHC and other near future colliders (ILC). We have introduced the *top-BESS model* (tBESS) [1] as an effective description of a high-energy extension of the Higgsless SM where new strong interactions are responsible for ESB. The full formulation of the tBESS model can be found in [1]. In the following we would like to present its basic properties.

The tBESS is the modified version of the BESS (Breaking EW Symmetry Strongly) model [2]. Both models describe a new $SU(2)$ vector boson triplet that can represent the spin-1 bound states of hypothetical new strong interactions. They are based on the $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(2)_{HLS}$ global symmetry of which the $SU(2)_L \times U(1)_Y \times SU(2)_{HLS}$ subgroup is also a local symmetry. "HLS" stands for the *hidden local symmetry* [3] which is an auxiliary gauge symmetry introduced to accommodate the $SU(2)$ triplet of vector resonances. Beside the triplet, the models contain only the observed SM particles.

In the gauge sector new physics is parameterized by the $SU(2)_{HLS}$ gauge coupling g'' and another parameter α. In the limit when g and g' are negligible compared to g'' the masses of the neutral and charged resonances are degenerate, $M_V = \sqrt{\alpha} g'' v/2$. Higher order corrections in g/g'' result in the mass splitting such that $M_{V^0} > M_{V^\pm}$.

In the tBESS model we modify the *direct* interactions of the vector triplet with fermions. While in the BESS model there is a universal direct coupling of the triplet to all fermions of a given chirality, in our modification we admit direct couplings of the new triplet-to-top and bottom quarks only. Our modification is inspired by the speculations about a special role of the top quark in the mechanism of ESB.

In the tBESS model, the triplet-to-top/bottom coupling is proportional to the $SU(2)_{HLS}$ gauge coupling g'' multiplied by the b_L and b_R parameters for the left and right fermion doublets, respectively. In addition, we have disentangled the triplet-to-top-quark right coupling from the triplet-to-bottom-quark right coupling by introducing a free parameter p, $0 \leq p \leq 1$. When $p < 1$, the strength of the triplet-to-bottom right coupling is weakened. The $SU(2)_L$ symmetry does not allow the same splitting for the left quark doublet.

The BESS/tBESS symmetry admits two more invariant terms which were not considered by the authors of the BESS model [2]. The terms introduce additional free parameters, λ_L and λ_R. They do not have a significant impact on the behavior of the model at energies around the mass of the vector triplet, but they do modify the couplings of the EW gauge bosons with fermions.

New vector resonances mix with the EW gauge bosons. It results in the *indirect* — mixing-induced — interactions of the vector triplet with fermions. For the light fermions this is the only way they can interact with the vector triplet in the tBESS model. Of course, the interactions are suppressed.

The vector triplet predominantly decays to the electroweak gauge bosons, $W^\pm$ and Z, and/or to the third generation of quarks (except a special case discussed below). The quark decay channels prevail when the moduli of b parameters assume sufficiently large values. A typical decay width of the 1 TeV triplet is about a few tens of GeV. The total decay widths of the tBESS resonances are shown in Fig. 1.

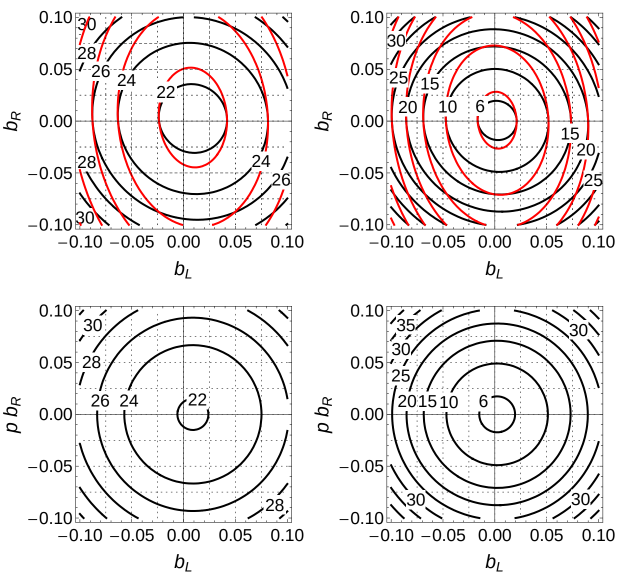

Fig. 1. The total decay width (labels in GeV) contours of the tBESS triplet. The V^0 decay (upper row) for the cases of $p = 1$ (black) and $p = 0$ (red) and the $V^\pm$ decay (bottom row). The left and right columns correspond to $g'' = 10$ and $g'' = 20$, respectively. All graphs have been plotted for $M_{V^0} = 1$ TeV and $\lambda_L = \lambda_R = 0$.

The interplay of the direct and indirect couplings can diminish or even zero a particular top/bottom quark channel decay width of the vector resonance for some nonzero values of the b parameters. Thus, it might happen that even though the direct couplings are nontrivial the resonance will not decay through the given top and/or bottom channel. We call the area of the parameter space where the decay width of the resonance is lower than its indirect coupling generated value, the *Death Valley* (DV). The DV does not virtually depend on the λ values.

The tBESS model is nonrenormalizable and violates unitarity at some energy. The tree-level unitarity constraints have been obtained using the Equivalence theorem (ET) approximation of the $W_L^+W_L^-$, Z_LZ_L, $W_L^\pm Z_L$, and $W_L^\pm W_L^\pm$ scattering, see Fig. 2. The nonrenormalizability implies the upper limit, $\sqrt{s} \approx 3$ TeV, on the applicability of the ET.

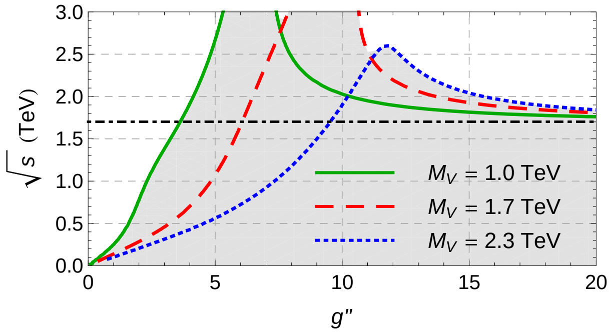

Fig. 2. The tree-level unitarity constraints for various masses of the vector triplet: $M_V = 1$ TeV (solid line), 1.7 TeV (dashed), 2.3 TeV (dotted). The horizontal dashed-dotted line is the Higgsless SM unitarity limit of 1.7 TeV. The shaded area indicates the region where the unitarity holds. No couplings to fermions are assumed.

The existing *electroweak precision data* (EWPD) restrict tBESS induced deviations from the SM at relevant energies. We have used the measured values of the $\epsilon_{1,3,b}$ [4] parameters along with the measurement of the $B \to X_s\gamma$ and $Z \to b\bar{b}$ decays, and the D0 measurement of $p\bar{p} \to WZX$. It resulted in the *low-energy limits* on the parameters of the tBESS model. In particular, the EWPD restrict $b_L - 2\lambda_L$ and $b_R + 2\lambda_R$ rather than b's and λ's individually. The intersection of the allowed regions for $M_{V^0} = 1$ TeV and $g'' = 13$ is shown in Fig. 3. In principle, b's and λ's can assume

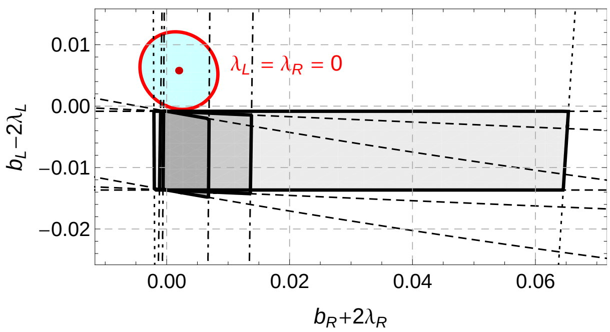

Fig. 3. The intersections (shaded areas) of the 90% C.L. allowed regions for $p = 0$ (the lightest gray), $p = 0.5$ (middle gray), and $p = 1$ (the darkest gray) when $M_{V^0} = 1$ TeV and $g'' = 13$. The red circle bounds the $V^0 \to t\bar{t}$ DV region when $\lambda_{L,R} = 0$. The red dot indicates the zero value of the decay width.

any values if their difference/sum falls within the allowed interval. However, the greater their values, the finer tuning is necessary. Even with this qualification, the low-energy limits on tBESS parameters are significantly less restrictive than in the BESS case.

In Fig. 3, the DV for $V^0 \to t\bar{t}$ decay is also shown. In the $(b_L - 2\lambda_L, b_R + 2\lambda_R)$ space, the position of the DV depends on λ's. The displayed case corresponds to $\lambda_L = \lambda_R = 0$. The size of the DV region shrinks when g'' grows.

The DV effect can hide signals expected in scattering processes. Even if the tBESS resonances existed and coupled to the third quark generation there would be no peak in the scattering experiments for certain final states with top and/or bottom quarks. This would occur if the parameters happened to have their values inside the DV region. To illustrate the DV effect on the scattering amplitudes we have plotted the cross sections for five processes in Fig. 4.

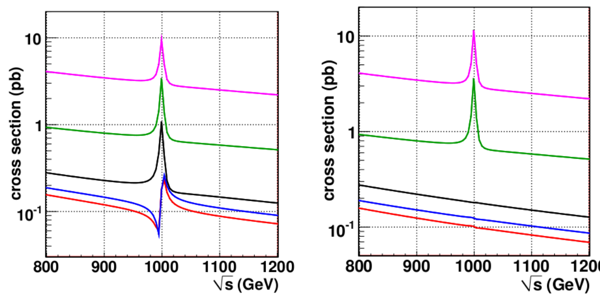

Fig. 4. The cross sections of $e^-e^+ \to W^+W^-$ (magenta), $u\bar{d} \to W^+Z$ (green), $e^-e^+ \to t\bar{t}$ (black), $u\bar{d} \to t\bar{b}$ (blue), $e^-e^+ \to b\bar{b}$ (red); $M_{V^0} = 1$ TeV and $g'' = 20$. Values of the fermion parameters are chosen far away from the DV's (left) and at the bottom of the DV's (right) of all three top/bottom channels.

As a final note, our calculations suggest that there are allowed values of the tBESS parameters which can result in detectable signals at the LHC and/or the ILC. However, this is far from conclusive and a deeper systematic study would be required to settle this question.

ACKNOWLEDGMENT: The work of M.G. and J.J. was supported by the Research Program MSM6840770029 and by the project International Cooperation ATLAS-CERN of the Ministry of Education, Youth and Sports of the Czech Republic. J.J. was also supported by the National Scholarship Program of the Slovak Republic. M.G. and I.M. were supported by the Slovak CERN Fund.

REFERENCES

1. M. Gintner, J. Juráň, I. Melo, Phys. Rev. D **84**, 035013 (2011).
2. R. Casalbuoni, S. De Curtis, D. Dominici, and R. Gatto, Phys. Lett. **155B**, 95 (1985); Nucl. Phys. **B282**, 235 (1987).
3. M. Bando, T. Kugo, and K. Yamawaki, Phys. Rep. **164**, 217 (1988).
4. G. Altarelli, R. Barbieri, and F. Caravaglios, Nucl. Phys. **B405**, 3 (1993).