PROCEEDINGS OF SCIENCE

Vacuum stability and scalar masses in the superweak extension of the standard model

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We summarize our analysis for the vacuum stability of the superweak extension of the standard model. The parameter space allowed by the W-boson mass measurements and collider searches for a new scalar particle are also presented. The final result is a well defined non-vanishing portion of the parameter space, where the vacuum is stable, the couplings are perturbative and is not excluded by W mass measurements and collider searches.

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1. Introduction

The superweak extension of the standard model (SWSM) has the potential to explain the origin of (i) neutrino masses and mixing matrix elements [1] and [2] in this conference, (ii) dark matter [3] and [4] in this conference, (iii) cosmic inflation [5], (iv) stabilization of the electroweak vacuum [5] and possibly (v) leptogenesis (under investigation). This model is a beyond the standard model extension adding one layer of interactions below the hierarchic layers of the strong, electromagnetic and weak forces, which is called superweak (SW) force [6], mediated by a new U(1) gauge boson Z'. In order to explain the origin of neutrino masses, the field content is enhanced by three generations of right-handed neutrinos (with Yukawa couplings y_x). The new gauge symmetry is broken spontaneously by the vacuum expectation value w of a new complex scalar singlet.

We focus on (iv), improving significantly on our previous work [5] on constraining the parameters of the scalar sector in the model. Similar analyses have already been performed focusing on vacuum stability [7, 8]. In contrast to those studies, we use higher precision for computing the parameter space with stable vacuum and also investigate the effect of the sterile-neutrino Yukawa couplings.

We used the following high energy physics programs (i) an SWSM model file [1] for `SARAH` [9] to generate the two-loop renormalization group equations (RGE) and model files for `SPheno` [10, 11]. Then (ii) `SPheno` is utilized to compute two-loop Higgs boson masses. Finally, we generated (iii) input files for `HiggsBounds` [12] to obtain exclusion bands by direct Higgs searches.

2. Vacuum stability

The scalar sector of the superweak extension is defined in [6]. The scalar potential is

$$V(H,S) = V_0 - \mu_\phi^2 H^2 - \mu_\chi^2 S^2 + \lambda_\phi H^4 + \lambda_\chi S^4 + \lambda H^2 S^2\,, \tag{1}$$

where the fields H and S mix into the mass eigenstates h and s with the mixing angle θ_s. We check the vacuum stability of the potential (1) and the perturbativity of the couplings from the scale of the top quark mass M_t up to the Planck mass, i.e. $\mu \in (M_\mathrm{t}, M_\mathrm{Pl})$ by solving the two-loop renormalization group equations. We scan the four dimensional parameter space $\lambda_\phi(M_\mathrm{t}), \lambda_\chi(M_\mathrm{t}), \lambda(M_\mathrm{t}), y_x(M_\mathrm{t})$ and extract the corresponding $w(M_\mathrm{t})$ at two-loop accuracy. We only accept parameter points if $w(M_\mathrm{t}) > 0$ in order to obtain non-trivial phenomenology. A three dimensional slice of the allowed parameter space at $y_x(M_\mathrm{t}) = 0.4$ is shown in Fig. 1.

3. Predictions for the W mass in the SWSM

In the $\overline{\mathrm{MS}}$ scheme the scalar SW contribution to the W-boson mass M_W is the sum of the coupling shift effects $\delta g_\mathrm{L}, \delta v$ and the SWSM self-energy correction Π_{WW}^{SW} given by

$$M_W = M_W^{\mathrm{theo.}} + \delta M_W\,, \quad \text{with} \quad \delta M_W = M_W \frac{\delta v}{v} + \frac{1}{2}\delta g_\mathrm{L} v + \frac{1}{2}\frac{\Pi_{WW}^{\mathrm{SW}}(M_W)}{M_W}\,, \tag{2}$$

where we use $M_W^{\mathrm{SM.\ theo.}} = 80.360 \pm 0.012$ GeV as the theoretical prediction for W-boson mass in the SM. The world average of the experiments [13] is $M_W^{\mathrm{exp.}} = (80.379 \pm 0.012)$ GeV, ignoring the recent result from CDFII [14]. The SWSM contribution δM_W is negative for $M_s > M_h$ and positive for $M_s < M_h$.

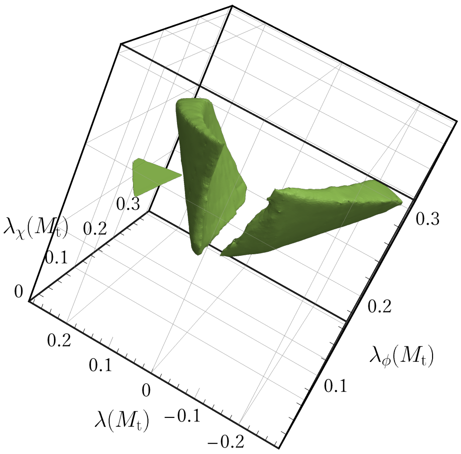

Figure 1: 3d slice of the parameter space allowed by vacuum stability, perturbativity and the existence of the new VEV w computed at $y_x(M_\mathrm{t}) = 0.4$.

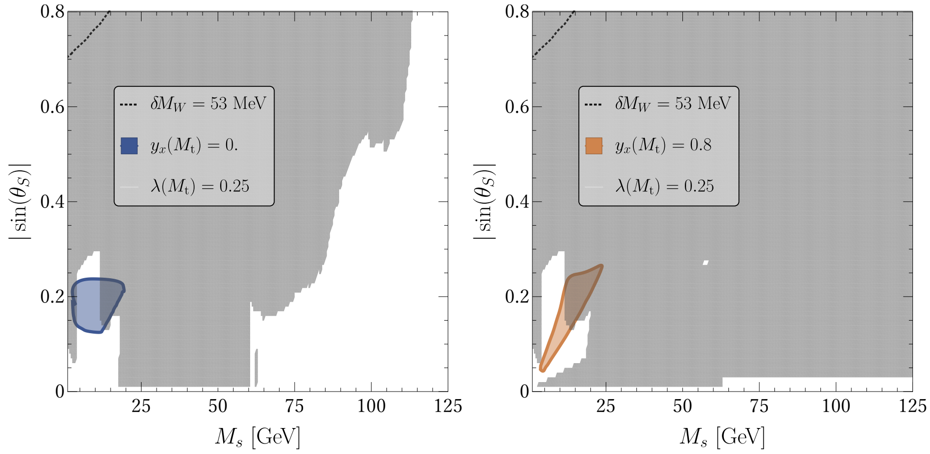

Figure 2: Colored regions: allowed by vacuum stability and perturbativity at different $y_x(M_\mathrm{t})$. Above the dashed line: excluded by W-boson mass measurements. Gray region: excluded by collider searches (`HiggsBounds` 5).

4. Results and outlook

We found a well-defined, allowed parameter space for both $M_s > M_h$ (see [15] in this conference) and $M_s < M_h$ (see Fig. 2). The left figure corresponds to decoupled sterile neutrinos, while the right figure corresponds to a sizeable sterile neutrino Yukawa coupling, where $y_x(M_\mathrm{t}) \gtrsim 0.9$ is excluded by the vacuum stability and perturbativity analysis. The colored region of the parameter space corresponds to the perturbativity of the couplings and stable vacuum, while the gray region is excluded by direct Higgs searches, computed by `HiggsBounds` 5. At this point, our findings suggest, that experimental probes for a scalar particle with higher sensitivity in the mass range 1 GeV − 20 GeV is well motivated. However, these predictions have to be scrutinized severely, i.e. confronted also with coupling measurements of the 125 GeV Higgs boson.

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