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Increasing the Higgs mass bound of the MSSM

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Summary. — In the MSSM the Higgs boson mass at tree level cannot exceed the Z boson mass. One could then ask themselves: should we throw away supersymmetry if we do not see the Higgs boson at the LHC? To answer this question it makes sense to consider extensions of the MSSM in which the Higgs boson can be relatively heavier. We consider three possibile models from a bottom-up point of view.

PACS 12.60.Jv – Supersymmetric models.

1. – Introduction

The main virtues of Low-Energy Supersymmetry are: i) naturalness, ii) compatibility with Electroweak Precision Tests (EWPT), iii) perturbativity, and iv) manifest unification. However, after the LEP2 bound $m_h > 114.4\,\text{GeV}$ on the lightest Higgs boson mass, the minimal model (MSSM) has a serious problem in dealing with i) because m_h cannot exceed m_Z at tree level. This motivates adding extra F terms, like in the Next to Minimal Supersymmetric Standard Model (NMSSM) [1], or extra D terms if the Higgs shares new gauge interactions [2, 3], or both. The usual approach is imposing that the new couplings do not become strong before M_{GUT}. For this reason it is typically difficult to go beyond $m_h = 150\,\text{GeV}$. Should we then throw away low-energy (not finetuned) supersymmetry if the lightest Higgs boson is not found below 150 GeV?

To answer this question one should notice that the request of *manifest* unification could be highly too restrictive: there are explicit examples [4] in which some couplings become strong at an intermediate scale without spoiling unification. Thus we stick to a bottom-up point of view, as in [5]. We call Λ the scale of semiperturbativity, at which some expansion parameter becomes equal to 1, and M the scale at which the soft breaking terms are generated, allowing them to be relatively low. We tolerate a finetuning of 10%, according to the usual criterion [6]. In a minimal approach, we make a comparative study (see [7] for details) of the simplest possible extensions of the MSSM which meet the goal: adding a new $U(1)$ or $SU(2)$ gauge interaction [3], or adding a gauge singlet with large coupling to the Higgses [5]. The only constraints come from naturalness and EWPT. In other words, we prefer to retain the virtues i), ii), and iii) at low energies at the price of iv), instead of insisting on iv) paying the price of i).

2. – Comparative study of the three models

Refering to [7] for details, the lightest Higgs boson mass bound is, respectively,

$$\left(m_h^{(tree)}\right)^2 \leq m_Z^2 \cos^2 2\beta \qquad \text{MSSM},$$

$$\left(m_h^{(tree)}\right)^2 \leq \left(m_Z^2 + g_x^2 v^2 \Big/ \left(2 + \frac{M_X^2}{M_\phi^2}\right)\right) \cos^2 2\beta \qquad U(1)_x,$$

$$\left(m_h^{(tree)}\right)^2 \leq m_Z^2 \frac{g'^2 + \eta g^2}{g'^2 + g^2} \cos^2 2\beta, \qquad \eta = \left(1 + \frac{g_I^2 M_\Sigma^2}{g^2 M_X^2}\right) \Big/ \left(1 + \frac{M_\Sigma^2}{M_X^2}\right) \qquad SU(2),$$

$$\left(m_h^{(tree)}\right)^2 \leq m_Z^2 \left(\cos^2 2\beta + \frac{2\lambda^2}{g^2 + g'^2} \sin^2 2\beta\right) \qquad \lambda\text{SUSY},$$

where g_x, g_I and λ are new couplings, M_X is the mass of the new heavy vectors, and M_ϕ, M_Σ are new soft masses. Notice that in the gauge extensions the effect decouples for $M_X \gg M_\phi$, M_Σ, while for λSUSY it is maximized for large λ and low $\tan\beta$.

First of all there must be compatibility with the EWPT. In the $U(1)$ case, from the analysis [8] one can deduce $M_X \gtrsim 5\,\text{TeV}$. For the $SU(2)$ model, in numerical analogy with the previous case, we impose $M_X/(5\,\text{TeV}) \gtrsim g_X/g$, where g_X is the coupling of the triplet of heavy vectors. The case of λSUSY is thoroughly studied in [5] and shown to be compatible with data for low $\tan\beta$ (≤ 3).

On the other hand, there are constraints from the naturalness of the breaking scale of the new gauge groups and of the Fermi scale. For the former we fix some ratios among parameters so that there is a tuning of no more than 10 % at tree level, for the latter the amount of tuning can be shown to be given, in the interesting cases, by

$$\delta m_{H_u}^2 \leq \frac{(m_h^{(tree)})^2}{2} \times \Delta,$$

where $1/\Delta$ is the finetuning as defined by [6], and we accept $\Delta = 10$ at most. From these conditions one obtains, respectively, lower bounds on the ratios $M_X/M_{\phi,\Sigma}$ and upper bounds on the soft masses M_ϕ and M_Σ.

Putting all together one obtains the upper bound on m_h at tree level which is shown in fig. 1.

3. – Conclusions

From a bottom-up point of view, the lightest Higgs boson mass can be significantly raised at tree level. Constraints come from the interplay between naturalness and experimental constraints. The maximum possible m_h that one can obtain is shown in fig. 1 as a function of the scale of semiperturbativity. In the $SU(2)$ case it seems difficult to be consistent with both the EWPT and naturalness if m_h is beyond 270 GeV. The prices that one may have to pay are the following: 1) low semiperturbativity scale Λ; 2) low "messenger" scale M at which the soft terms are generated; 3) the presence of different scales of soft masses; 4) the need for extra positive contributions to T. With low scale we mean $\lesssim 100\,\text{TeV}$, with 3) we mean that, besides the usual soft masses of order of hundreds of GeV, one may need some new soft masses of order 10 TeV. The "performance"

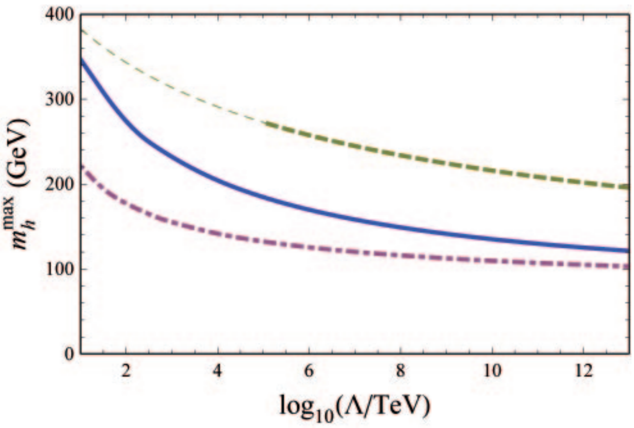

Fig. 1. – Tree level bound on m_h as a function of the scale Λ at which g_I or λ or g_X equals $\sqrt{4\pi}$; for $SU(2)$ (dashed), λSUSY (solid), and $U(1)$ (dot-dashed). For λSUSY one needs $\tan\beta \lesssim 3$, in the other cases $\tan\beta \gg 1$ and 10% finetuning at tree level in the scalar potential which determines the new breaking scale. In the $SU(2)$ case naturalness disfavours $m_h \geq 270\,\mathrm{GeV}$.

TABLE I. – *Summary of the "performance" of the three models, see text.*

Model	m_h^{max}/m_Z	Price to pay
$U(1)$	2	1), 2), 3)
$SU(2)$	2	3)
$SU(2)$	3	2), 3), 4)
λSUSY	2	–
λSUSY	3	1)

of the three models is summarized in table I. A unified viewpoint on the Higgs mass and the flavor problem for this kind of models is presented in [9].

* * *

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