MODEL INDEPENDENT UPPER BOUND ON
THE LIGHTEST HIGGS BOSON MASS IN
SUPERSYMMETRIC STANDARD MODELS

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Abstract

One of the main features of the Minimal Supersymmetric Standard Model (MSSM) is the existence of an absolute tree-level upper bound \( m_h \) on the mass of the \( CP = +1 \) lightest Higgs boson, equal to \( m_Z \), that could affect detectability at future colliders. The above bound is spoiled by radiative corrections and by an enlarged Higgs sector, as e.g. a gauge singlet. Radiative corrections in the MSSM can push the upper bound up to 115 GeV for \( m_t \lesssim 150 \) GeV. The presence of an enlarged Higgs sector changes the previous upper bound to one depending on the electroweak scale, \( \tan \beta \) and the gauge and Yukawa couplings of the theory. When radiative corrections are included, the allowed region in the \((m_h, m_t)\) plane depends on the scale \( \Lambda \) below which the theory remains perturbative. In particular, for models with arbitrary Higgs sectors and couplings saturating the scale \( \Lambda = 10^{16} \) GeV we find \( m_h \lesssim 155 \) GeV and \( m_t \lesssim 190 \) GeV.

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1 Minimal Supersymmetric Standard Model

Supersymmetric models have well constrained Higgs sectors which can provide crucial tests of them. In particular, the MSSM contains two Higgs doublets $H_1, H_2$, with hypercharges $Y = \pm 1/2$, coupled to quarks and leptons in the superpotential

$$f_m = h_t Q \cdot H_2 U^c + h_b Q \cdot H_1 D^c + h_L L \cdot H_1 E^c,$$  

(1)

and a physical Higgs sector containing two scalar ($h, H$), one pseudoscalar ($A$) and two charged ($H^\pm$) states. Its most constraining feature is the existence of an absolute upper bound on the tree-level mass of the $CP^= +1$ lightest Higgs boson $h$ given by (with $\tan \beta \equiv v_2/v_1$, $v_i \equiv \langle H^0_i \rangle$),

$$m_h \leq m_Z | \cos 2\beta |.$$  

(2)

The bound (2) would suggest that the light Higgs of the MSSM should be discovered at LEP-200. So, what would happen if the Higgs is not discovered with a mass below $m_Z$? There is still a hope for supersymmetry since the bound (2) is spoiled by radiative corrections and by the presence of an enlarged Higgs sector. The question to be answered in this talk is, how large are those effects?

Radiative corrections in the MSSM have been computed using different methods, with results which are in very good agreement to each other: i) Standard diagrammatic techniques; ii) One-loop effective potential; and, iii) Renormalization group approach (RGA). The latter (RGA) method is reliable for a scale of supersymmetry breaking $\Lambda_s \gg m_W^2$. The technical reason being that in the limit $\Lambda_s^2/m_W^2 \to \infty$ the Higgs $h \to (\cos \beta H_1^\alpha + \sin \beta H_2^\alpha)$ becomes the Standard Model Higgs, with a mass $m_h = m_Z | \cos 2\beta |$, while the other states decouple, since $m_H \sim m_A \sim m_{H^\pm} \sim \Lambda_s$. The RGA method is also universal in the sense that it is valid (can pick the leading radiative contribution from the top-stop sector) for general supersymmetric standard models. We have shown in Fig. 1 the upper bound on $m_h$ in the MSSM for different values of $\Lambda_s$, from 1 to 10 TeV, using the RGA method of Ref. [6], which includes two-loop corrections. From Fig. 1 one can conclude that for $\Lambda_s \lesssim 10$ TeV and $m_t \lesssim 150$ GeV, $m_h \lesssim 115$ GeV.

2 MSSM with singlets

The case of the MSSM with a gauge singlet field $S$ coupled to the rest of the Higgs sector through the cubic superpotential

$$f_h = \lambda S H_1 \cdot H_2 + \frac{1}{3} \chi S^3$$  

(3)

was first studied in where the tree level bound

$$m_h^2 \leq \left( \cos^2 2\beta + \frac{2\lambda^2 \cos^2 \theta_W}{g^2 \sin^2 2\beta} \right) m_Z^2,$$  

(4)
was found. Notice that (4) does not depend either on the supersymmetric masses or on the supersymmetry breaking terms. It depends on \( \lambda \), whose maximum value \( \lambda^{\text{max}} \) is obtained assuming the theory remains perturbative below the high scale \( \Lambda \sim \Lambda_{\text{GUT}} \). We have included \( h_t \) and \( h_b \) in (1) with the boundary condition \( m_b(10 \text{ GeV}) = 5 \text{ GeV} \). For a fixed value of \( \tan \beta \) (i.e. \( h_b \)), \( \lambda \) and \( h_t \) are related to each other through the renormalization group equations (RGE), as shown in Fig. 2a.

Radiative corrections are introduced using different methods (the RGA and the one-loop effective potential with results consistent within less than 5% for all the considered \( m_t \)-range. The final upper bound on \( m_h \) is shown in Fig. 2b from where one can see that the absolute upper bound is \( m_h < \sim 145 \text{ GeV} \), though its precise value depends on \( m_t \) and \( \tan \beta \).

3 General supersymmetric standard models

The previous analysis has been generalized in Refs. to supersymmetric standard models with arbitrary Higgs sectors. We have introduced, on top of the Higgs doublets \( H_1 \) and \( H_2 \), which take vacuum expectation values and are coupled to the quarks and leptons through (1): i) An arbitrary number of extra pairs \( H_j^{(1)}, H_j^{(2)}, j = 1, ..., d \), decoupled from quarks and leptons in order to avoid dangerous flavor changing neutral currents; ii) Gauge singlets \( S^{(\sigma)}, \sigma = 1, ..., n_s \); iii) \( SU(2) \) triplets \( \Sigma^{(a)}, a = 1, ..., t_o \), with \( Y = 0 \); iv) \( SU(2) \) triplets \( \Psi^{(i)}_1, \Psi^{(i)}_2, i = 1, ..., t_1 \), with \( Y = \pm 1 \). Other Higgs representations will only contribute to the gauge \( \beta \)-functions and will not provide renormalizable couplings to \( H_1 \cdot H_2, H_1 \cdot H_1 \) and \( H_2 \cdot H_2 \). They will result in lower values of the upper bounds and need not be considered.

Assuming the most general renormalizable superpotential generalizing (3)

\[
f_h = \tilde{\lambda}_1 \tilde{S} H_1 \cdot H_2 + \tilde{\lambda}_2 H_1 \cdot \Sigma H_2 + \tilde{\chi}_1 \cdot \bar{\Psi}_1 H_1 + \tilde{\chi}_2 \cdot \bar{\Psi}_2 H_2 + \mathcal{O}(\Sigma^3, \Sigma \Psi_1 \Psi_2, S^3) \tag{5}
\]

one can obtain the tree-level bound

\[
m_h^2/\nu^2 \leq \frac{1}{2}(g^2 + g'^2) \cos^2 2\beta + (\tilde{\lambda}_1^2 + \frac{1}{2} \tilde{\lambda}_2^2) \sin^2 2\beta + \tilde{\chi}_1^2 \cos^4 \beta + \tilde{\chi}_2^2 \sin^4 \beta, \tag{6}
\]

where \( \nu^2 \equiv v_1^2 + v_2^2 \) and \( g, g' \) are the \( SU(2) \times U(1)_Y \) gauge couplings. In particular, the bound (4) is recovered when \( \tilde{\lambda}_2 = \tilde{\chi}_2 = 0 \), and the bound (3) in the MSSM when also \( \tilde{\lambda}_1 = 0 \). The bound (5) is independent of the soft-supersymmetry breaking parameters, or any supersymmetric mass terms. It is only controlled by \( \nu \) and dimensionless parameters \( (g, g', \tan \beta, \text{ and Yukawa couplings}) \). Since the former is fixed by the electroweak scale, the latter will determine the bound (5). The upper bound then comes from the requirement that the supersymmetric theory remains perturbative below \( \Lambda \). In particular the bound is maximized when some of the involved couplings (generically \( \lambda \)) saturate the high-scale \( \Lambda \), i.e. when \( \lambda^2(\Lambda)/4\pi \sim 1 \). To guarantee this condition we need to solve the RGE of all gauge and Yukawa couplings of the theory.
Given a model \( m \equiv (n_s, d, t_0, t_1) \), the gauge couplings saturate a particular scale \( \Lambda_m \). Conversely, given a scale \( \Lambda \) there is a set of models whose gauge couplings saturate \( \Lambda \). Out of them we pick the model which provides the maximum value of the upper bound. There is in this way a one-to-one correspondence between models and scales, and we can obtain the upper bound \( m_h(\Lambda) \) for all models which are perturbative below the given scale \( \Lambda \). For instance the scale \( \Lambda = 10^{16} \text{ GeV} \) is saturated by the model \( n_s > 0, d = 5 \) (see also Ref. [18]). For simplicity, we have analyzed the case \( t_0 = t_1 \), where \( \rho_{\text{tree}} = 1 \) by tuning vacuum expectation values.

Radiative corrections are introduced using the RGA [11, 12] with \( \Lambda_s = 1 \text{ TeV} \). The upper bound corresponding to \( \Lambda = 10^{16} \text{ GeV} \) is shown in Fig. 3a. We can see from Fig. 3a that the absolute upper bound is \( m_h \lesssim 155 \text{ GeV} \) for all values of \( m_t \) and \( \tan \beta \), though there is a strong dependence on those parameters. The upper bound \( m_h(\Lambda) \) as a function of \( m_t \), and any value of \( \tan \beta \), is shown in Fig. 3b for different values of the scale \( \Lambda \).

4 Conclusions

We have obtained the most general upper bound for the mass of the lightest Higgs boson in supersymmetric standard models which remain perturbative below a scale \( \Lambda \). Radiative corrections are taken into account using the renormalization group approach. For a given scale the obtained bounds are stronger than those in the Standard Model and satisfy \( m_h(\Lambda) \longrightarrow (m_h)_{\text{SM}} \) for \( \Lambda \rightarrow G_F^{-1/2} \). Our results are not taking into account (and could be affected by): i) The presence of extra colored fermions \( (t', b', \ldots) \) that could introduce new radiative corrections [19]; ii) The presence of an extra gauge group factor \( (g_a, T_a) \) that would result in \( \Delta m_h^2 = O(g_a^2) \).

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Figure captions

Fig.1 Upper bounds on $m_h$ in the MSSM

Fig.2 $\lambda_{\text{max}}$ and $m_h$ in the MSSM with a singlet

Fig.3 $m_h(10^{16} GeV)$ and $m_h(\Lambda)$ for general supersymmetric standard models
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