Soft SUSY-breaking scenarios in the light of Higgs searches at LEP2

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The Higgs boson sector of the Minimal Supersymmetric Standard Model (MSSM) is investigated in a uniform way in the framework of the three most prominent soft SUSY-breaking scenarios, mSUGRA, mGMSB and mAMSB, especially concerning the Higgs searches at LEP2.

1. Introduction

The search for the light neutral Higgs boson is a crucial test of Supersymmetry (SUSY) that can be performed with the present and the next generation of high-energy colliders. The data taken during the final year of LEP running at $\sqrt{s} \gtrsim 206$ GeV, while establishing a 95% C.L. exclusion limit for the Standard Model (SM) Higgs boson of $m_H > 114.1$ GeV, showed at about the 2.1σ level an excess of signal-like events over the background expectation which is in agreement with the expectation for the production of a SM Higgs boson of about 115 GeV [1]. Within the MSSM, the LEP excess can be interpreted as the production of the lightest $\mathcal{CP}$-even Higgs boson, which over a wide parameter range has SM-like couplings, or of the heavier $\mathcal{CP}$-even Higgs boson, in a region of parameter space where the $\mathcal{CP}$-odd Higgs boson A is light and the ratio of the vacuum expectation values of the two Higgs doublets, $\tan\beta$, is relatively large.

In this work we investigate the predictions in the Higgs sector arising from the three SUSY-breaking scenarios: minimal Supergravity (mSUGRA) [2], minimal Gauge Mediated SUSY Breaking (mGMSB) [3] and minimal Anomaly Mediated SUSY Breaking (mAMSB) [4]. We relate the high energy input from these scenarios in a uniform way to the predictions for the low-energy phenomenology in the Higgs sector, allowing thus a direct comparison of the predictions arising from the different scenarios. The MSSM Higgs masses and couplings are calculated using the program *FeynHiggs* [5]. We analyze the consequences of the results obtained from the Higgs search at LEP on the parameter space of the three scenarios. For the case where LEP excess is interpreted as a possible Higgs signal, we furthermore discuss the corresponding spectra of the SUSY particles in each scenario in view of the SUSY searches at the next generation of colliders. For details of the calculations, see [6].

2. Input parameters and phenomenological restrictions

For the numerical analysis we have scanned over about 50000 models each for mSUGRA, mGMSB and mAMSB, where the parameters have been randomly chosen in the intervals as listed in Table I.

We also take into account some further constraints when determining the allowed parameter values. We require the contribution to the ρ-parameter to be smaller than 3×10^{-3} [7]. We impose the lower limits on the SUSY particle masses based on the negative search results of Run I of the Tevatron and at LEP [7]. For the top-quark mass, throughout this paper we use the value $m_t = 175$ GeV. A variation of m_t by ± 1 GeV would results in a change in m_h of about ± 1 GeV [8]. The GUT or high-energy scale parameters are taken to be real and R-parity symmetry is taken to be conserved. We require successful radiative electroweak symmetry breaking (REWSB) and parameter sets that do not fulfill the Charge-Color-Breaking constraints are discarded. We have

Table I Input parameter ranges for mSUGRA, mGMSB and mAMSB, respectively.

mSUGRA			mGMSB			mAMSB		
50 GeV $\leq$	M_0	≤ 1 TeV	10^4 GeV $\leq$	Λ	$\leq 2 \times 10^5$ GeV	20 TeV $\leq$	m_{aux}	≤ 100 TeV
50 GeV $\leq$	$M_{1/2}$	≤ 1 TeV	$1.01\,\Lambda \leq$	M_{mess}	$\leq 10^5\,\Lambda$	$0 \leq$	m_0	≤ 2 TeV
-3 TeV $\leq$	A_0	≤ 3 TeV	$1 \leq$	N_{mess}	≤ 8			
$1.5 \leq$	$\tan\beta$	≤ 60	$1.5 \leq$	$\tan\beta$	≤ 55	$1.5 \leq$	$\tan\beta$	≤ 60
	$\text{sign}\,\mu$	$= \pm 1$		$\text{sign}\,\mu$	$= \pm 1$		$\text{sign}\,\mu$	$= \pm 1$

Table II Upper bound on m_h and exclusion limit on $\tan\beta$ obtained from case (I) for three different scenarios. Corresponding values for the unconstrained MSSM are also shown for the purpose of comparison, where the $\tan\beta$ exclusion limit is obtained in the combination of m_h^{max} and no-mixing scenarios [9, 10].

mSUGRA	mGMSB	mAMSB	unconstrained MSSM
$m_h^{\text{max}} \lesssim 124$ GeV	$m_h^{\text{max}} \lesssim 119$ GeV	$m_h^{\text{max}} \lesssim 122$ GeV	$m_h^{\text{max}} \lesssim 130$ GeV
$\tan\beta \gtrsim 3.3$	$\tan\beta \gtrsim 4.6$	$\tan\beta \gtrsim 3.2$	$\tan\beta \gtrsim 2.4,\ 0.7 \gtrsim \tan\beta$

imposed relatively mild naturalness upper bounds: $m_{\tilde{q}} \lesssim 1.5$ TeV, $m_{\tilde{g}} \lesssim 2$ TeV. We furthermore demand that the lightest SUSY particle is uncolored and uncharged. On the other hand, we do not demand a relic density in the region favored by dark matter constraints. As a conservative approach, we do not apply any further constraints from $g_\mu - 2$ or $b \to s\gamma$ (details can be found in [6]).

For our numerical analysis we will focus on three different cases implying different restrictions on the MSSM parameter space.

(I) We investigate the full parameter space which is allowed in the three scenarios when taking into account the exclusion bounds from the Higgs search [1, 9] and the further constraints discussed above.

(II) The LEP excess is interpreted as production of the lightest $\mathcal{CP}$-even Higgs boson of the MSSM: $m_h = 115 \pm 2$ GeV. In order to allow this interpretation, h has to have SM-like couplings to the Z, i.e. $\sin^2(\beta - \alpha_{\text{eff}}) \gtrsim 0.8$. We also require that the decay of the light $\mathcal{CP}$-even Higgs boson is SM like, i.e. the dominating decay channel is $h \to b\bar{b}$. The $hb\bar{b}$ coupling is mainly altered in two ways compared to the SM: it has an extra factor $\sin\alpha_{\text{eff}} / \cos\beta$ and it receives a correction $\sim 1/(1 + \Delta m_b)$. Therefore we demand $\sin^2\alpha_{\text{eff}} / \cos^2\beta \gtrsim 0.8$ and $|\Delta m_b| < 0.5$.

(III) The LEP excess is interpreted as production of the heavy $\mathcal{CP}$-even Higgs boson of the MSSM: $m_H = 115 \pm 2$ GeV. To have SM-like ZZH and $Hb\bar{b}$ coupling, we require $\cos^2(\beta - \alpha_{\text{eff}}) \gtrsim 0.8$ and $\cos^2\alpha_{\text{eff}} / \cos^2\beta \gtrsim 0.8$. In addition, we apply a bound of $m_h + M_A > 206$ GeV as the associated production $e^+e^- \to Ah$, being $\sim \cos^2(\beta - \alpha_{\text{eff}})$, has to be beyond the kinematic reach of LEP.

3. Numerical analysis

In Fig. 1 we show the variation of the light Higgs boson mass with respect to $\tan\beta$ for the three cases defined in Sect. 2. m_h sharply increases with $\tan\beta$ in the region of low $\tan\beta$, while for $\tan\beta \gtrsim 10$ the m_h values saturate. Values of $\tan\beta \gtrsim 60$ are not allowed due to the REWSB constraint. The LEP2 Higgs boson searches exclude the models with $m_h \lesssim 113$ GeV for $\tan\beta \lesssim 50$. Case (III) can only be realized in the mSUGRA scenario in a small parameter region: $50 \lesssim \tan\beta \lesssim 55$, $103 \text{ GeV} \lesssim m_h, M_A \lesssim 113$ GeV and $m_H = 115 \pm 2$ GeV, where a significant suppression of $\sin^2(\beta - \alpha_{\text{eff}})$ (i.e. the ZZh coupling) occurs. Table II shows the upper bound on m_h and the exclusion limit on $\tan\beta$ for the three different scenarios. The upper bound on m_h is lower than the one in the unconstrained MSSM [9, 10], and the exclusion limit on $\tan\beta$ is also more restrictive. This is caused by the fact that not all parameter combinations of the unconstrained MSSM can be realized in the three SUSY-breaking scenarios that we discussed here.

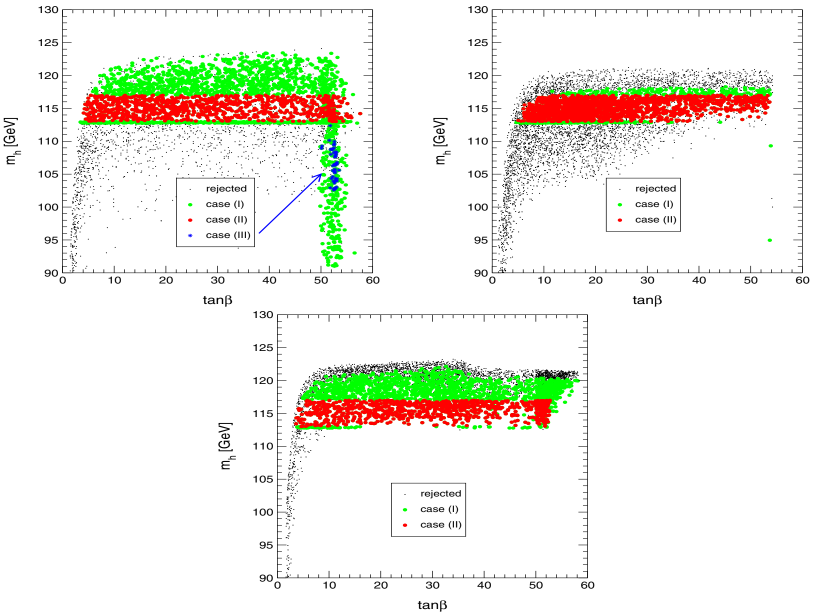

Figure 1: The light $\mathcal{CP}$-even Higgs boson mass m_h as a function of $\tan\beta$ in the mSUGRA (left plot), mGMSB (middle plot) and mAMSB (right plot) scenarios.

In the mSUGRA scenario, cases (II) and (III) result in similar allowed regions of parameter space. While for M_0 the whole range up to 1 TeV is allowed, $M_{1/2}$ is restricted to $M_{1/2} \lesssim 650$ GeV and $|A_0|$ is restricted to $|A_0| \lesssim 2M_0$. A significant enhancement of the $hb\bar{b}$ coupling due to large values of $\sin^2\alpha_{\rm eff}/\cos^2\beta$ is possible over a wide range of the mSUGRA parameter space. Values of $\sin^2(\beta - \alpha_{\rm eff}) \ll 1$ are always correlated in the mSUGRA scenario with negative values of Δm_b in the range of $-0.2 \lesssim \Delta m_b \lesssim -0.4$, giving rise to an enhancement of the $hb\bar{b}$ coupling. Positive values for Δm_b are only possible if the Higgs boson couples with full strength to W and Z (see [6] for details.).

Concerning the underlying mGMSB parameters, $M_{\rm mess}, N_{\rm mess}$ and Λ, no severe restrictions can be deduced for the cases (I) and (II). The region of low $M_{\rm mess}$ and low Λ are excluded by the experimental and theoretical constraints imposed in our analysis. Lower values of $N_{\rm mess}$ correspond to higher values of Λ, and we only find allowed parameter regions for $N_{\rm mess} \leq 7$. In contrast to the mSUGRA case, no values of $\sin^2\alpha_{\rm eff}/\cos^2\beta < 1$ exist. In particular, a significant enhancement of the $hb\bar{b}$ coupling is possible in the region of the highest values of $\tan\beta$. The absolute value of Δm_b is smaller in the mGMSB scenario than in the mSUGRA case and does not exceed $|\Delta m_b| = 0.2$. Values of $|\Delta m_b| > 0.1$ are only realized for $\tan\beta \gtrsim 35$.

In the mAMSB scenario, the experimental and theoretical constraints imposed in our analysis affect in particular the region of large m_0 and $m_{\rm aux}$. We find no allowed models with $m_{\rm aux} \gtrsim 70$ TeV, mostly due to the imposed naturalness bound. Concerning the $hb\bar{b}$ coupling, $\sin^2\alpha_{\rm eff}/\cos^2\beta$ is always larger than 0.9, and values of $\sin^2\alpha_{\rm eff}/\cos^2\beta > 10$ are possible for large $\tan\beta$. Positive values of Δm_b, are bounded from above by $\Delta m_b \lesssim 0.5$. On the other hand, we obtain negative contributions as large as $\Delta m_b \approx -0.8$, giving rise to a strongly enhanced $hb\bar{b}$ Yukawa coupling.

We also studied the mass spectra in the three soft SUSY-breaking scenarios assuming that the LEP excess is due to the production of the h or H boson in the MSSM (cases (II) and (III)), which are shown in Table. III. At Run II of Tevatron, neutralino and chargino searches would be sensitive to part of the parameter space. For the LHC, on the other hand, the third generation squarks and gluinos can always be produced. A LC with $\sqrt{s} \lesssim 1$ TeV will offer a good opportunity to observe part of the gaugino and slepton spectra.

Table III Super particle mass spectra for Case (II) and (III) in the mSUGRA, mGMSB and mAMSB scenarios.

mSUGRA	50 GeV $\lesssim m_{\tilde{\chi}_1^0} \lesssim$ 300 GeV	150 GeV $\lesssim m_{\tilde{t}_1}$	300 GeV $\lesssim m_{\tilde{g}}$	
	100 GeV $\lesssim m_{\tilde{\chi}_2^0,\tilde{\chi}_1^\pm} \lesssim$ 550 GeV	450 GeV $\lesssim m_{\tilde{t}_2}$	100 GeV $\lesssim m_{\tilde{\tau}_1}$	
	250 GeV $\lesssim m_{\tilde{\chi}_2^\pm}$	300 GeV $\lesssim m_{\tilde{b}_1}$	200 GeV $\lesssim m_{\tilde{\tau}_2}$	
mGMSB	100 GeV $\lesssim m_{\tilde{\chi}_1^0} \lesssim$ 350 GeV	600 GeV $\lesssim m_{\tilde{t}_1}$	600 GeV $\lesssim m_{\tilde{g}}$	
	200 GeV $\lesssim m_{\tilde{\chi}_2^0,\tilde{\chi}_1^\pm} \lesssim$ 650 GeV	700 GeV $\lesssim m_{\tilde{t}_2}$	100 GeV $\lesssim m_{\tilde{\tau}_1}$	$\lesssim$ 400 GeV
	350 GeV $\lesssim m_{\tilde{\chi}_2^\pm}$	650 GeV $\lesssim m_{\tilde{b}_1}$	200 GeV $\lesssim m_{\tilde{\tau}_2}$	$\lesssim$ 600 GeV
mAMSB	50 GeV $\lesssim m_{\tilde{\chi}_1^0,\tilde{\chi}_1^\pm} \lesssim$ 200 GeV	400 GeV $\lesssim m_{\tilde{t}_1}$	500 GeV $\lesssim m_{\tilde{g}}$	
	200 GeV $\lesssim m_{\tilde{\chi}_2^0} \lesssim$ 550 GeV	600 GeV $\lesssim m_{\tilde{t}_2}$	100 GeV $\lesssim m_{\tilde{\tau}_1}$	
	250 GeV $\lesssim m_{\tilde{\chi}_2^\pm}$	400 GeV $\lesssim m_{\tilde{b}_1}$	200 GeV $\lesssim m_{\tilde{\tau}_2}$	

4. Conclusion

We have discussed the implication of Higgs searches at LEP2 in the scenarios of mSUGRA, mGMSB and mAMSB. We have found upper bounds on m_h, exclusion limits on $\tan\beta$ and constraints on the parameter space of the three different scenarios. For case (II) and (III), we furthermore investigated the corresponding spectra of the SUSY particles in view of future SUSY searches.

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