

Charged Higgs in view of the LHC constraints in phenomenological MSSM

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We discuss the consequences of the observation of a light Higgs boson with the mass and rates reported by the ATLAS and CMS collaborations on the parameter space of the phenomenological MSSM, including also the LHC searches for heavier Higgs bosons and supersymmetric particles, as well as the constraints from B physics and dark matter for the charged Higgs boson.

Prospects for Charged Higgs Discovery at Colliders

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1. Introduction

Charged Higgs bosons are important ingredients in theories with more than one Higgs doublet such as supersymmetry (SUSY), since the observation of a fundamental charged scalar would provide unambiguous evidence for an extended Higgs sector. Before the start of the LHC experiment, the expectation for direct discovery of SUSY particles was very high. After two years of LHC running, we now have evidence for a neutral boson compatible with the Standard Model (SM) Higgs boson, but no signal of SUSY particles has been detected and therefore strong limits on the masses of strongly interacting particles have been obtained. However, most of the analyses have been performed in highly constrained MSSM scenarios, such as CMSSM. Here we will instead discuss the phenomenology of the charged Higgs boson in view of the LHC constraints in the more general and unconstrained set-up of the phenomenological MSSM. We will also show that while direct searches are pushing the masses to larger values, which is not enough to confirm or exclude SUSY, the information from the Higgs sector constitute an alternative and powerful path to constrain SUSY efficiently.

2. Phenomenological MSSM

To study the implication of the LHC Higgs and SUSY searches we consider the unconstrained phenomenological MSSM (pMSSM) with 19 parameters [1]. Most of the previous studies considered the highly constrained models with a small number of free parameters. However, these models are not representative of a generic MSSM scenario where the particle mass parameters are independent. As we will see below, the results can be very different in such generic scenarios.

To explore the pMSSM, we perform a flat scan over the parameters in the ranges given in Table 1. The particle spectra are generated for more than 100M points using `SOFTSUSY` [2] and `SUSPECT` [3]. We impose the SUSY and Higgs mass limits from LEP and Tevatron as described in [4]. The flavour observables, muon anomalous magnetic moment and relic density are computed with `SuperIso Relic` [5], and we apply the constraints given in Table 2. We do not address here the consequences of the dark matter direct detection results which are discussed thoroughly in [6]. To evaluate the consequences of the SUSY searches, we compute the supersymmetric particle decay rates with `SDECAY` [7] and we use `PYTHIA 6` [8] for event generation of inclusive SUSY production in pp interactions. The generated events are then passed through fast detector simulation using `Delphes` [9]. The Higgs decay rates are computed with `HDECAY` [10] and the gluon fusion and VBF cross sections of the lightest CP-even Higgs with `HIGLU` [11] and `FeynHiggs` [12]. More details can be found in [4, 13].

3. Constraints from the lightest Higgs boson mass and decay rates

Another way to efficiently constrain SUSY is using the information from the Higgs sector. In the following, we consider that the new boson discovered at the LHC corresponds to the lightest CP-even Higgs boson. The signal strength, μ , is defined as:

$$\mu_{XX} = \frac{\sigma(pp \rightarrow h) \text{BR}(h \rightarrow XX)}{\sigma(pp \rightarrow h)_{\text{SM}} \text{BR}(h \rightarrow XX)_{\text{SM}}}, \quad (3.1)$$

Parameter	Range	Parameter	Range
$\tan\beta$	[1, 60]	$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[50, 2500]
M_A	[50, 2000]	$M_{\tilde{e}_R} = M_{\tilde{\mu}_R}$	[50, 2500]
M_1	[-2500, 2500]	$M_{\tilde{\tau}_L}$	[50, 2500]
M_2	[-2500, 2500]	$M_{\tilde{\tau}_R}$	[50, 2500]
M_3	[50, 2500]	$M_{\tilde{q}_{1L}} = M_{\tilde{q}_{2L}}$	[50, 2500]
$A_d = A_s = A_b$	[-10000, 10000]	$M_{\tilde{q}_{3L}}$	[50, 2500]
$A_u = A_c = A_t$	[-10000, 10000]	$M_{\tilde{u}_R} = M_{\tilde{c}_R}$	[50, 2500]
$A_e = A_\mu = A_\tau$	[-10000, 10000]	$M_{\tilde{t}_R}$	[50, 2500]
μ	[-1000, 2000]	$M_{\tilde{d}_R} = M_{\tilde{s}_R}$	[50, 2500]
		$M_{\tilde{b}_R}$	[50, 2500]

Table 1: SUSY parameter ranges (in GeV when applicable).

$2.16 \times 10^{-4} < \text{BR}(B \rightarrow X_s \gamma) < 4.93 \times 10^{-4}$
$\text{BR}(B_s \rightarrow \mu^+ \mu^-) < 5.0 \times 10^{-9}$
$0.56 < R(B \rightarrow \tau \nu) < 2.70$
$4.7 \times 10^{-2} < \text{BR}(D_s \rightarrow \tau \nu) < 6.1 \times 10^{-2}$
$2.9 \times 10^{-3} < \text{BR}(B \rightarrow D^0 \tau \nu) < 14.2 \times 10^{-3}$
$0.985 < R_{\mu 23}(K \rightarrow \mu \nu) < 1.013$
$-2.4 \times 10^{-9} < \delta a_\mu < 4.5 \times 10^{-9}$

Table 2: Low energy constraints applied in our analysis.

Parameter	Value	Experiment
M_h	126 ± 2 GeV	ATLAS + CMS
$\mu_{\gamma\gamma}$	1.71 ± 0.26	ATLAS + CMS
μ_{ZZ}	0.97 ± 0.26	ATLAS + CMS
μ_{WW}	0.85 ± 0.23	ATLAS + CMS
$\mu_{b\bar{b}}$	1.28 ± 0.45	ATLAS + CMS + (CDF + D0)
$\mu_{\tau\tau}$	0.71 ± 0.42	ATLAS + CMS

Table 3: Higgs signal strengths [14].

and the combination of the Higgs search results presented by ATLAS and CMS are given in Table 3. All the decay rates at present are compatible with those of the SM Higgs boson, with a possible enhancement in the diphoton channel compared to the SM value.

The leading order couplings of the MSSM Higgs bosons can be written in terms of β and the Higgs mixing angle:

$$\alpha = \frac{1}{2} \arctan \left(\tan(2\beta) \frac{M_A^2 + M_Z^2}{M_A^2 - M_Z^2} \right). \quad (3.2)$$

The tree level couplings are given in Table 4. It should be mentioned that higher order corrections

ϕ	$g_{\phi u\bar{u}}$	$g_{\phi d\bar{d}} = g_{\phi \ell\bar{\ell}}$	$g_{\phi VV}$
h	$\cos \alpha / \sin \beta \rightarrow 1$	$-\sin \alpha / \cos \beta \rightarrow 1$	$\sin(\beta - \alpha) \rightarrow 1$
H	$\sin \alpha / \sin \beta \rightarrow \cot \beta$	$\cos \alpha / \cos \beta \rightarrow \tan \beta$	$\cos(\beta - \alpha) \rightarrow 0$
A	$\cot \beta$	$\tan \beta$	0

Table 4: Higgs couplings relative to the SM ones. The arrow indicates the values in the decoupling limit ($M_A \gg M_Z$).

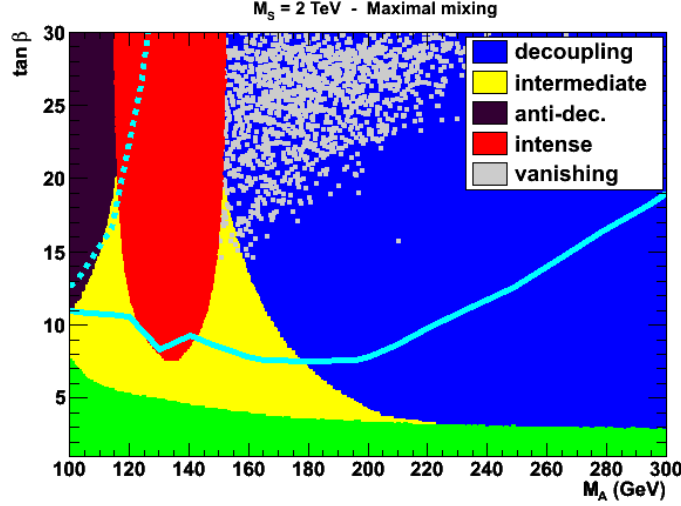


Figure 1: The parameter space for the various regimes of the MSSM Higgs sector in the $(M_A, \tan\beta)$ plane, in the maximal mixing scenario with $M_S = 2$ TeV. The upper limit constraints from $A/H \rightarrow \tau^+\tau^-$ [15] (continuous light blue line) and $t \rightarrow H^+b$ [16] (dashed blue line) searches at the LHC are shown together with the LEP2 excluded region (green area).

to the tree level couplings can be large for light SUSY particles. For the lightest CP-even h , the g_{hbb} is in general the most important coupling. As a result, in the specific SUSY scenarios where this coupling is decreased, the branching fractions to other particles, such as WW/ZZ or $\gamma\gamma$ are in turn enhanced, while $\text{BR}(h \rightarrow b\bar{b})$ is depleted. At tree level the charged Higgs mass is related to the A mass by $M_{H^\pm}^2 = M_A^2 + M_W^2$.

In Fig. 1 we present the various regimes of the pMSSM Higgs sector [17]. We start with the decoupling regime, where the light Higgs has SM-like couplings (*i.e.* $\cos^2(\beta - \alpha)$ is small, corresponding to a vanishing coupling of the H to vector bosons), which occurs at large $M_A \approx M_{H^\pm}$ ($\gtrsim 300$ GeV) and h reaches its maximal value. In contrary, in the anti-decoupling regime, the heavy CP-even Higgs has SM like couplings, it occurs for small M_A , and we have $M_A \approx M_h < M_H, M_{H^\pm}$. The couplings of the h are suppressed in this case, and it can escape the LEP limits. The intermediate regime is between both previous regimes, with intermediate values for M_A and M_{H^\pm} . In the intense coupling regime on the other hand, the couplings of the h to bb and $\tau\tau$ are enhanced. It occurs at small M_A when $M_h \approx M_A \approx M_H$. Finally in the vanishing regime, the couplings of the h to bb or WW/ZZ are very small. This regime occurs generally at large $\tan\beta$ when α is very small

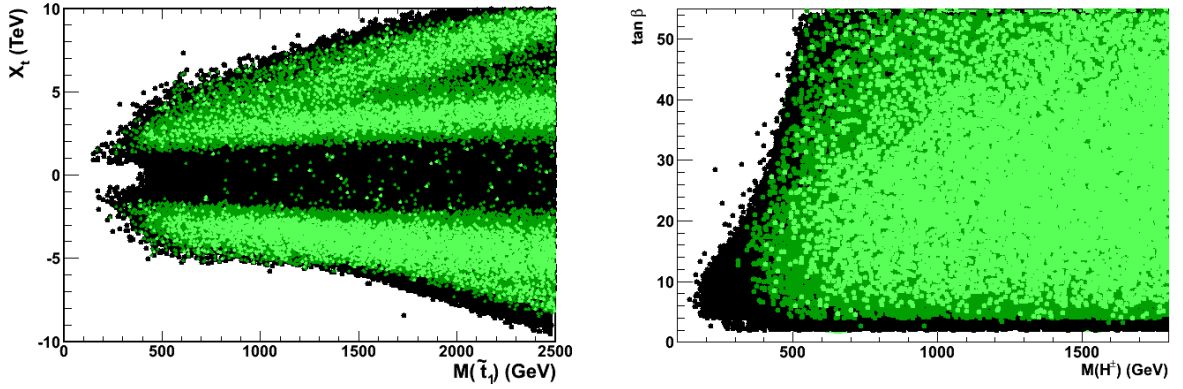


Figure 2: Distributions of the pMSSM points in the $(M_{\tilde{t}_1}, X_t)$ and $(M_{H^\pm}, \tan\beta)$ parameter planes. The black dots show the accepted pMSSM points, those in light (dark) grey the same points compatible at 68% (90%) C.L. with the Higgs constraints of Table 3.

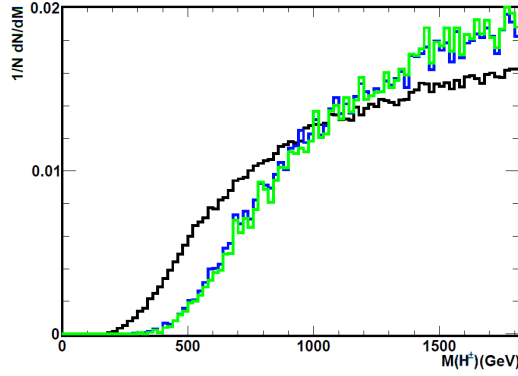


Figure 3: The normalised distribution of the values of M_{H^\pm} for the selected pMSSM points (black line) compared to the probability density function obtained from the χ^2 probability using M_h , $\mu_{\gamma\gamma}$ and μ_{ZZ} (blue line), as well as $\mu_{\tau\tau}$ and μ_{bb} (green line).

(at tree level) or when there is a cancellation between tree level terms and radiative corrections due to SUSY loops. As can be seen from the figure, the $A/H \rightarrow \tau^+ \tau^-$ limit disfavors the vanishing, intense, and anti-decoupling regimes, and favors the decoupling regime.

In Fig. 2 we present the distribution of pMSSM points compatible with the h boson mass and the observed yields, in the $(M_{\tilde{t}_1}, X_t)$ and $(M_{H^\pm}, \tan\beta)$ parameter planes [14]. To achieve this, we combined all the constraints in Table 3 with a χ^2 combination. We notice first that small values of $|X_t|$ are clearly disfavored, and that stop masses as low as 400 GeV are still compatible with the data. This is mainly the result of the Higgs mass measurement which calls for non minimal mixing in the stop sector. Second, $M_{H^\pm} \lesssim 350$ GeV values are strongly disfavored by the Higgs mass and rate measurements for any value of $\tan\beta$, and therefore the decoupling regime seems again to be favored by the data.

The distribution of M_{H^\pm} is presented in Fig. 3, where each pMSSM point enters with a weight

equal to its χ^2 probability. The probability weighted distribution obtained from this analysis are compared to the normalised frequency distribution for the same observables obtained for accepted points within the allowed mass region $122.5 < M_h < 127.5$ GeV. We observe a significant suppression of pMSSM points with the charged Higgs boson mass below 450 GeV. This is due to the combined effect of the $A/H \rightarrow \tau^+ \tau^-$ direct searches and $B_s \rightarrow \mu^+ \mu^-$ rate, which constrain the light M_A and M_{H^\pm} and by the suppression of the non-decoupling regime.

4. Conclusions

The implications of the Higgs boson discovery by the ATLAS and CMS collaborations for the MSSM have been outlined. The study has been based on broad scans over the pMSSM parameter space where points have been preselected based on constraints from electroweak and flavour physics, dark matter and searches at LEP2, Tevatron and the LHC. We showed that the Higgs searches have impressive impacts on the SUSY parameters. The present data tend to disfavour the possibility of a light charged Higgs boson. However, more data will be needed to draw decisive conclusions.

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