The constrained NMSSM and Higgs near 125 GeV

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Abstract

We assess the extent to which various constrained versions of the NMSSM are able to describe the recent hints of a Higgs signal at the LHC corresponding to a Higgs mass in the range 123 – 128 GeV.

The Large Hadron Collider (LHC) data from the ATLAS \cite{1} and CMS \cite{2} collaborations suggests the possibility of a fairly Standard Model (SM) like Higgs boson with mass of order 123 – 128 GeV. In particular, promising hints appear of a narrow excess over background in the $\gamma\gamma$ and $ZZ \to 4\ell$ final states with strong supporting evidence from the $WW \to \ell\nu\ell\nu$ mode. While the ATLAS and CMS results suggest that the $\gamma\gamma$ rate may be somewhat enhanced with respect to the SM expectation, this is by at most one standard-deviation (1$\sigma$).

In this Letter, we explore the ability or lack thereof of three constrained versions of the next-to-minimal supersymmetric standard model (NMSSM) to describe these observations while remaining consistent with all relevant constraints, including those from LEP and TEVATRON searches, $B$-physics, the muon anomalous magnetic moment, $a_\mu \equiv (g-2)/2$, and the relic density of dark matter, $\Omega h^2$.

The possibility of describing the LHC observations in the context of the MSSM has been explored in numerous papers, including \cite{3}\cite{4}\cite{5}\cite{6}\cite{7}\cite{8}\cite{9}\cite{10}\cite{11}. A general conclusion seems to be that if all the constraints noted above, including $a_\mu$ and $\Omega h^2$, are imposed rigorously, then the MSSM—especially a constrained version such as the CMSSM—is hard pressed to yield a fairly SM-like light Higgs boson at 125 GeV. This is somewhat alleviated when the $a_\mu$ constraint is dropped \cite{3}\cite{7}. Overall, however, large mixing and large SUSY masses are needed to achieve $m_h \sim 125$ GeV. There has also been some exploration in the context of the NMSSM \cite{12}\cite{13}\cite{11}, showing that for completely general parameters there is less tension between a light Higgs with mass $\sim 125$ GeV and a lighter SUSY mass spectrum. The study presented here will be done in the context of several constrained versions of the NMSSM with universal or semi-universal GUT scale boundary conditions. Results for a very constrained version of the NMSSM, termed the cNMSSM, appear in \cite{11}\cite{15}\cite{14} — we discuss comparisons later in the paper.

The three models which we discuss here are defined in terms of grand-unification (GUT) scale parameters as follows: I) a version of the constrained
NMSSM (CNMSSM) in which we adopt universal $m_0$, $m_{1/2}$, $A_0 = A_{t,b,	au}$ values but require $A_\lambda = A_t = 0$, as motivated by the $U(1)_R$ symmetry limit of the NMSSM; II) the non-universal Higgs mass (NUHM) relaxation of model I in which $m_{H_u}$ and $m_{H_d}$ are chosen independently of $m_0$, but still with $A_\lambda = A_t = 0$; and III) universal $m_0$, $m_{1/2}$, $A_0$ with NUHM relaxation and general $A_\lambda$ and $A_t$.

We use NMSSMTools-3.0.2 [10][17][18] for the numerical analysis, performing extensive scans over the parameter spaces of the models considered. The precise constraints imposed are the following. Our ‘basic constraints’ will be to require that an NMSSM parameter choice be such as to give a proper RGE solution, have no Landau pole, have a neutralino LSP and obey Higgs and SUSY mass limits as implemented in NMSSMTools-3.0.2 (Higgs mass limits are from LEP, TEVATRON, and early LHC data; SUSY mass limits are essentially from LEP).

Regarding $B$ physics, the constraints considered are those on $\text{BR}(B_s \rightarrow X_s\gamma)$, $\Delta M_s$, $\Delta M_d$, $\text{BR}(B_s \rightarrow \mu^+\mu^-)$, $\text{BR}(B^+ \rightarrow \tau^+\nu_\tau)$ and $\text{BR}(B \rightarrow X_s\mu^+\mu^-)$ at $2\sigma$ as encoded in NMSSMTools-3.0.2, except that we updated the bound on the radiative $B_s$ decay to $3.04 < \text{BR}(B_s \rightarrow X_s\gamma) \times 10^4 < 4.06$; theoretical uncertainties in $B$-physics observables are taken into account as implemented in NMSSMTools-3.0.2. These combined constraints we term the ‘$B$-physics contraints’. Regarding $a_\mu$, we require that the extra NMSSM contribution, $\delta a_\mu$, falls into the window defined in NMSSMTools of $8.77 \times 10^{-10} < \delta a_\mu < 4.61 \times 10^{-9}$ expanded to $5.77 \times 10^{-10} < \delta a_\mu < 4.91 \times 10^{-9}$ after allowing for a $1\sigma$ theoretical error in the NMSSM calculation of $\pm 3 \times 10^{-10}$. In fact, points that fail to fall into the above $\delta a_\mu$ window always do so by virtue of $\delta a_\mu$ being too small. For $\Omega h^2$, we declare that the relic density is consistent with WMAP data provided $0.094 < \Omega h^2 < 0.136$, which is the ‘WMAP window’ defined in NMSSMTools-3.0.2 after including theoretical and experimental systematic uncertainties. We will also consider the implications of relaxing this constraint to simply $\Omega h^2 < 0.136$ so as to allow for scenarios in which the relic density arises at least in part from some other source. A “perfect” point will be one for which all constraints are satisfied including requiring that $\delta a_\mu$ is in the above defined window and $\Omega h^2$ is in the WMAP window.

We find that only in models II and III is it possible for a “perfect” point to have a light scalar Higgs in the mass range $123 – 128$ GeV as consistent with the hints from the recent LHC Higgs searches. The largest $m_{h_1}$ achieved for perfect points is about 125 GeV. However, relaxing the $a_\mu$ constraint vastly increases the number of accepted points and it is possible to have $m_{h_1} \gtrsim 126$ GeV in both models II and III even if $\delta a_\mu$ is just slightly outside (below) the allowed window. Comparing with [3], the tension between obtaining an ideal or nearly ideal $\delta a_\mu$ while predicting a SM-like light Higgs near 125 GeV appears to be somewhat less in NUHM variants of the NMSSM than in those of the MSSM.

In the plots shown in the following, the coding for the plotted points is as follows:

- grey squares pass the ‘basic’ constraints but fail $B$-physics constraints (such points are rare);
- green squares pass the basic constraints and $B$-physics constraints;
- blue plusses (+) observe $B$-physics constraints as above and in addition have
\( \Omega h^2 < 0.136 \), thereby allowing for other contributions to the dark matter density (a fraction of order 20\% of these points have 0.094 < \Omega h^2 < 0.136) but they do not necessarily have acceptable \( \delta a_\mu \):

- magenta crosses (\( \times \)) have satisfactory \( \delta a_\mu \) as well as satisfying B-physics constraints, but arbitrary \( \Omega h^2 \);
- golden triangle points pass all the same constraints as the magenta points and in addition have \( \Omega h^2 < 0.136 \);
- open black/grey triangles are perfect, completely allowed points in the sense that they pass all the constraints listed earlier, including \( 5.77 \times 10^{-10} < \delta a_\mu < 4.91 \times 10^{-9} \) and 0.094 < \( \Omega h^2 \) < 0.136;
- open white diamonds are points with \( m_{h_1} \geq 123 \text{ GeV} \) that pass basic constraints, B-physics constraints and predict 0.094 < \( \Omega h^2 \) < 0.136 but have \( 4.27 \times 10^{-10} < \delta a_\mu < 5.77 \times 10^{-10} \), that is we allow an excursion of half the 1\( \sigma \) theoretical systematic uncertainty below the earlier defined window. We will call these "almost perfect" points.

The only Higgs production mechanism relevant for current LHC data is gluon-gluon to Higgs. For our plots it will thus be useful to employ the ratio of the employed.

Proceed as follows. To compute the SM denominator, we

\[
R^{\text{SM}}(Y) = \frac{\Gamma(Y \rightarrow i)}{\Gamma(Y \rightarrow \text{tot})}.
\]

where \( Y \) is the \( i \)th NMSM scalar Higgs, and \( h_{\text{SM}} \) is the SM Higgs boson. The ratio is computed in a self-consistent manner (that is, treating radiative corrections for the SM Higgs boson in the same manner as for the NMSM Higgs bosons) using an appropriate additional routine for the SM Higgs added to the NMHDECAY component of the NMSMTools package. To compute the SM denominator, we proceed as follows\[2\]. NMHDECAY computes couplings for each \( h_i \) defined by \( C_Y \) \( i \equiv g_{h_i Y}/g_{h_{\text{SM}} Y} \), where \( Y = gg, VV, bb, \tau^+ \tau^-, \gamma \gamma, \ldots \), as well as \( \Gamma_{\text{tot}}^{h_i} \) and \( \text{BR}(h_i \rightarrow Y) \) for all \( Y \). We then have all the information needed to compute \( R^{h_1} \) for some given final state \( X \).

We begin by presenting the crucial plots of Fig. 1 in which we show \( R^{h_1}(\gamma \gamma) \) as a function of \( m_{h_1} \) for cases I, II and III. Only in cases II and III do we find points that pass all constraints (the open black triangles) with \( m_{h_1} \sim 124 - 125 \text{ GeV} \).

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1For perfect points, we will use black triangles if \( m_{h_1} \geq 123 \text{ GeV} \) and grey triangles if \( m_{h_1} < 123 \text{ GeV} \) in plots where \( m_{h_1} \) does not label the x axis.

2Ideally, the same radiative corrections would be present in NMHDECAY as are present in HDECAY \[19\] and we could then employ HDECAY results for the SM Higgs denominator. But, this is not the case at present, with HDECAY yielding, e.g., larger \( gg \) production rates. However, we note that since we compute the ratios of NMSM rates to SM rates using the \( C_Y \) couplings, as discussed below, the computed ratios will be quite insensitive to the precise radiative corrections employed.
Figure 1: Scatter plots of $R^{h_i}(\gamma\gamma)$ versus $m_{h_i}$ for boundary condition cases I, II and III. See text for symbol/color notations.
These typically have $R^{h_1}(\gamma\gamma)$ of order 0.98. Somewhat surprisingly, such points were more easily found by our scanning procedure in case II than in case III. Many additional points with $m_{h_1} \sim 125$ GeV emerge if we relax only slightly the $\delta a_\mu$ constraint. The white diamonds show points for cases for which $4.27 \times 10^{-10} < \delta a_\mu < 5.77 \times 10^{-10}$ having $m_{h_1} \gtrsim 123$ GeV. As can be seen in more detail from the sample point tables presented later, the parameter choices that give the largest $m_{h_1}$ values are ones for which the $h_1$ is really very SM-like in terms of its couplings and branching ratios. Our scans did not find parameter choices for which $R^{h_1}(\gamma\gamma)$ was significantly larger than 1 for $m_{h_1} = 123 - 128$ GeV, as hinted at by the ATLAS data.

As regards $h_2$, if we require $m_{h_2} \in [110 - 150]$ GeV then we find points that pass the basic constraints and the $B$-physics constraints, but none that pass the further constraints. So, it appears that within these models it is the $h_1$ that must be identified with the Higgs observed at the LHC. In contrast, if parameters are chosen at the SUSY scale without regard to GUT-scale unification, it is possible to find scenarios in which $m_{h_2} \approx 125$ GeV and, moreover, $R^{h_2}(\gamma\gamma) > 1$ [13].

In passing, we note that should the Higgs hints disappear and a low-mass SM-like Higgs be excluded then it is of interest to know if BR($h_1 \rightarrow a_1 a_1$) can be large for $m_{h_1}$ in the $\lesssim 130$ GeV range. It turns out that, although large BR($h_1 \rightarrow a_1 a_1$) is possible while satisfying basic and $B$-physics constraints, once additional constraints are imposed, BR($h_1 \rightarrow a_1 a_1$) $\lesssim 0.2$ for all three model cases being considered. Small BR($h_1 \rightarrow a_1 a_1$) is expected [20] (see also [21]) when the $a_1$ is very singlet, as is the case in our scenarios once all constraints are imposed. So, in these models a light Higgs has nowhere to hide.

The points in the scatter plots were primarily obtained through random scans over the parameter spaces of the three models considered. In addition, we performed Markov Chain Monte Carlo (MCMC) scans to zero in better on points with $m_{h_1} \sim 125$ GeV that observe all constraints. For this purpose, we defined a $\chi^2(m_{h_1}) = (m_{h_1} - 125)^2/(1.5)^2$. The $B$-physics constraints were also implemented using a $\chi^2$ approach with the 1$\sigma$ errors from theory and experiment (as implemented in NMSSMTools) combined in quadrature. The global likelihood was then computed as $L_{tot} = \prod_i L_i$ with $L_i = e^{-x_i^2/2}$ for two-sided constraints and $L_i = 1/(1 + e^{(x-x_i^\text{exp})}/(0.01x_i^\text{exp}))$ when $x_i^\text{exp}$ is a 95% CL upper limit. The $a_\mu$ and $\Omega h^2$ constraints were either implemented a-posteriori using the $2\sigma$ window approach of NMSSMTools, or also included in the global likelihood. Since CMSSM-like boundary conditions with $A_\lambda = A_\kappa = 0$ did not generate points anywhere near the interesting region, we have only performed this kind of scan for cases II and III. This allowed us to find additional “perfect” and “almost perfect” points for models II and III with $m_{h_1} \gtrsim 123$ GeV.

We next illustrate in Fig. 2 $R^{h_1}(VV)$ (the ratio being the same for $VV = WW$ and $VV = ZZ$) for boundary condition cases II and III. As for the $\gamma\gamma$ final state, for $m_{h_1} \gtrsim 123$ GeV the predicted rates in the $VV$ channels are very nearly SM-like. Overall, it is clear that, for the GUT scale boundary conditions considered here, one finds that for parameter choices yielding consistency with all constraints and yielding $m_{h_1}$ close to 125 GeV, the $h_1$ will be very SM-like. If future data confirms a $\gamma\gamma$ rate in excess of the SM prediction, then it will be necessary to go
Figure 2: Scatter plots of $R^{h_1}(VV = ZZ, WW)$ versus $m_{h_1}$ for models II and III. See text for symbol/color notations.
beyond the constrained versions of the NMSSM considered here (cf. [13]). And, certainly it is very difficult within the constrained models considered here to obtain a SM-like Higgs with mass much above 126 GeV for parameter choices such that all constraints, including δaμ and Ωh^2, are satisfied.

Should a later LHC data set prove consistent with a rather SM-like Higgs in the vicinity of m_h \sim 125 GeV (rather than one with an enhanced γγ rate), it will be of interest to know the nature of the parameter choices that yield the perfect, black triangle and almost perfect white diamond points with m_h \sim 125 GeV and what the other experimental signatures of these points are. We therefore present a brief summary of the most interesting features. First, one must ask if such points are consistent with current LHC limits on SUSY particles, in particular squarks and gluinos. To this end, Fig. 3 shows the distribution of squark and gluino masses for the various kinds of points for models II and III. Interestingly, all the perfect, black triangle and almost perfect, white diamond points with m_h \gtrsim 123 GeV have squark and gluino masses above 1 TeV and thus have not yet been probed by current LHC results. (Note that since we are considering models with universal m_0 and m_{1/2} for squarks and gauginos, analyses in the context of the CMSSM apply.) It is quite intriguing that the regions of parameter space that are consistent with a Higgs of mass close to 125 GeV automatically evade the current limits from LHC SUSY searches.

In order to further detail the parameters and some relevant features of perfect and almost perfect points we present in Tables 1–4 seven exemplary points with m_h \gtrsim 124 GeV from models II and III. Some useful observations include the following:

- Because of the way we initiated our model III MCMC scans, restricting |A_λ,κ| \leq 1 TeV, most of the tabulated model III points have quite modest A_λ and A_κ. However, a completely random scan finds almost perfect points with quite large A_λ and A_κ values as exemplified by tabulated point #7. The fact that the general scan over A_λ and A_κ did not find any perfect points with m_h \gtrsim 124 GeV, whereas such points were fairly quickly found using the MCMC technique, suggests that such points are quite fine-tuned in the general scan sense. See Table 1 for specifics.

- In Table 2 we display various details regarding the Higgs bosons for each of our exemplary points. As already noted, for the perfect and almost perfect points the h_1 is very SM-like when m_{h_1} \gtrsim 123 GeV. To quantify how well the LHC Higgs data is described for each of our exemplary points, we use a chi-squared approach. In practice, only the ATLAS collaboration has presented the best fit values for R^h(γγ,ZZ → 4ℓ,WW → ℓνℓν) along with 1σ upper and lower errors as a function of m_h. Identifying h with the NMSSM h_1, we have employed Fig. 8 of [1] to compute a χ^2(ATLAS) for each point in the NMSSM parameter space (but this was not included in the global likelihood used for our MCMC scans). From Table 2 we see that the smallest χ^2(ATLAS) values (of order 0.6 to 0.7) are obtained for m_{h_1} \sim 124 GeV. This is simply because at this mass the ATLAS fits to R^h(γγ) and R^h(4ℓ) are very close to one, the natural prediction in the NMSSM context. For
Figure 3: Scatter plots of squark versus gluino masses for models II and III. Here we use black (grey) open triangles for perfect points with $m_{h_1} \geq 123$ GeV ($m_{h_1} < 123$ GeV). See text for remaining symbol/color notations.
$m_h \sim 125$ GeV, the $R^h$'s for the ATLAS data are somewhat larger than 1 leading to a discrepancy with the NMSSM SM-like prediction and a roughly doubling of $\chi^2$ (ATLAS) to values of order 1.3 to 1.6 for our exemplary points. In this context, we should note that at a Higgs mass of 125 GeV the CMS data is best fit if the Higgs signals are not enhanced and, indeed, are very close to SM values.

- The mass of the neutralino LSP, $\tilde{\chi}_1^0$, is rather similar, $m_{\tilde{\chi}_1^0} \approx 300 - 450$ GeV, for the different perfect and almost perfect points with $m_{h_1} \gtrsim 124$ GeV. For all but pt. #5, the $\tilde{\chi}_1^0$ is approximately an equal mixture of higgsino and bino. There is some variation in the primary annihilation mechanism, with $\tilde{\tau}_1 \tilde{\tau}_1$ and $\tilde{\chi}_1^0 \tilde{\chi}_1^0$ annihilation being the dominant channels except for pt. #2 for which $\tilde{\nu}_\tau \tilde{\nu}_\tau$ and $\tilde{\nu}_\tau \tilde{\nu}_\tau$ annihilations are dominant. In the case of dominant $\tilde{\tau}_1 \tilde{\tau}_1$ annihilation, the bulk of the $\tilde{\chi}_1^0$'s come from those $\tilde{\tau}_1$'s that have not annihilated against one another or co-annihilated with a $\tilde{\chi}_1^0$.

- All the tabulated points yield a spin-independent direct detection cross section of order $(3.5 - 6) \times 10^{-8}$ pb. For the above $m_{\tilde{\chi}_1^0}$ values, current limits on $\sigma_{SI}$ are not that far above this mark and upcoming probes of $\sigma_{SI}$ will definitely reach this level.

- The 7 points all have $m_{\tilde{g}}$ and $m_{\tilde{q}}$ above 1.5 TeV and in some cases above 2 TeV. Detection of the superparticles may have to await the LHC upgrade to 14 TeV.

- Only the $\tilde{t}_1$ is seen to have a mass distinctly below 1 TeV for the tabulated points. Still, for all the points $m_{\tilde{t}_1}$ is substantial, ranging from $\sim 500$ GeV to above 1 TeV. For such masses, detection of the $\tilde{t}_1$ as an entity separate from the other squarks and the gluino will be quite difficult and again may require the 14 TeV LHC upgrade.

- The effective superpotential $\mu$-term, $\mu_{\text{eff}}$, is small for all the exemplary points. This is interesting regarding the question of electroweak fine-tuning.

For completeness, we have run separate scans for the case of the cNMSSM of [14][15] with completely universal $m_0 = 0$ and $A_0 \equiv A_t = A_b = A_\tau = A_\lambda = A_\kappa$ (which is in fact a limit case of our model III). Here, one can have a singlino LSP. This requires small $\lambda < 10^{-2}$. Correct relic density is achieved via co-annihilation with $\tilde{\tau}_R$ for the rather definite choice of $A_0 \sim -\frac{1}{4} M_1/2$. For small enough $m_{1/2}$, the $h_1$ is dominantly singlet, while the $h_2$ is SM-like. For larger $m_{1/2}$, the $h_1$ is SM-like, and the $h_2$ is mostly singlet. The cross-over where $h_1$ and $h_2$ are highly mixed occurs roughly in the range of $m_{1/2} = 500 - 600$ GeV, depending on $\lambda$. Overall, we find that the $h_1$ can attain a mass of at most $\sim 121$ GeV in this scenario in the limit of large $m_{1/2}$.

3A similar conclusion was reached in [4] based on a mSUGRA scenario with $m_0 \approx 0$ and $A_0 \approx -\frac{1}{4} M_1/2$, which approximately corresponds to the cNMSSM case with the singlet Higgs superfield decoupling from the rest of the spectrum; a maximum $h^0$ mass of 123.5 GeV was found in this case.
Table 1: Input parameters for the exemplary points. We give $\tan \beta (m_Z)$ and GUT scale parameters, with masses in GeV and masses-squared in GeV$^2$. Starred points are the perfect points satisfying all constraints, including $\delta a_\mu > 5.77 \times 10^{-10}$ and $0.094 < \Omega h^2 < 0.136$. Unstarred points are the almost perfect points that have $4.27 \times 10^{-10} < \delta a_\mu < 5.77 \times 10^{-10}$ and $0.094 < \Omega h^2 < 0.136$.

| Pt. # | 1* | 2* | 3 | 4* | 5 | 6 | 7 |
|-------|----|----|---|----|---|---|---|
| $\tan \beta (m_Z)$ | 17.9 | 17.8 | 21.4 | 15.1 | 26.2 | 17.9 | 24.2 |
| $\lambda$ | 0.078 | 0.0096 | 0.023 | 0.084 | 0.028 | 0.027 | 0.064 |
| $\kappa$ | 0.079 | 0.011 | 0.037 | 0.158 | -0.045 | 0.020 | 0.343 |
| $m_{1/2}$ | 923 | 1026 | 1087 | 842 | 738 | 1104 | 1143 |
| $m_0$ | 447 | 297 | 809 | 244 | 1038 | 252 | 582 |
| $A_0$ | -1948 | -2236 | -2399 | -1755 | -2447 | -2403 | -2306 |
| $A_\lambda$ | 0 | 0 | 0 | -251 | -385 | -86.8 | -2910 |
| $A_\kappa$ | 0 | 0 | 0 | -920 | 883 | -199 | -5292 |
| $m^2_{H_d}$ | (2942)$^2$ | (3365)$^2$ | (4361)$^2$ | (2481)$^2$ | (935)$^2$ | (3202)$^2$ | (3253)$^2$ |
| $m^2_{H_u}$ | (1774)$^2$ | (1922)$^2$ | (2089)$^2$ | (1612)$^2$ | (1998)$^2$ | (2073)$^2$ | (2127)$^2$ |

In summary, we find that the fully constrained version of the NMSSM is not able to yield a Higgs boson consistent with the current hints from LHC data for a fairly SM-like Higgs with mass $\sim 125$ GeV, once all experimental constraints are imposed including acceptable $a_\mu$ and $\Omega h^2$ in the WMAP window. However, by relaxing the CNMSSM to allow for non-universal Higgs soft-masses-squared (NUHM scenarios), it is possible to obtain quite perfect points in parameter space satisfying all constraints with $m_{h_1} \sim 125$ GeV even if the attractive $U(1)_R$ symmetry limit of $A_\lambda = A_\kappa = 0$ is imposed at the GUT scale and certainly if general $A_\lambda$ and $A_\kappa$ values are allowed. We observe a mild tension between the $a_\mu$ constraint and obtaining $m_{h_1} \sim 125$ GeV; just slightly relaxing the $a_\mu$ requirement makes it much easier to find viable points with $m_{h_1} \sim 125$ GeV, thus opening up interesting regions of parameter space. We also note that our scanning suggests that relatively small $A_\lambda, A_\kappa$ values are preferred for (almost) perfect points. Masses of SUSY particles for perfect/almost perfect points are such that direct detection of SUSY may have to await the 14 TeV upgrade of the LHC. However, the predicted $\tilde{\chi}^0_1$ masses and associated spin-independent cross sections suggest that direct detection of the $\tilde{\chi}^0_1$ will be possible with the next round of upgrades to the direct detection experiments.
Table 2: Upper section: Higgs masses. Middle section: reduced $h_1$ couplings to up- and down-type quarks, $V = W, Z$ bosons, photons, and gluons. Bottom section: total width in GeV, decay branching ratios, $R_{h_1}$($\gamma\gamma$), $R_{h_1}$($VV$) and $\chi^2_{\text{ATLAS}}$ of the lightest CP-even Higgs for the seven exemplary points.

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**References**

[1] ATLAS Collaboration, Combination of Higgs Boson Searches with up to 4.9 fb$^{-1}$ of pp Collisions Data Taken at a center-of-mass energy of 7 TeV with the ATLAS Experiment at the LHC, [ATLAS-CONF-2011-163](http://atlas.web.cern.ch/Atlas/GROUPS/DISP/CONF/CONF-011-163.pdf).

[2] CMS Collaboration, Combination of SM Higgs Searches, [CMS-PAS-HIG-11-032](http://cds.cern.ch/record/1459807).

[3] H. Baer, V. Barger and A. Mustafayev, Implications of a 125 GeV Higgs scalar for LHC SUSY and neutralino dark matter searches, [arXiv:1112.3017](http://arxiv.org/abs/1112.3017).

[4] A. Arbey, M. Battaglia, A. Djouadi, F. Mahmoudi, J. Quevillon, Implications of a 125 GeV Higgs for supersymmetric models, [arXiv:1112.3028](http://arxiv.org/abs/1112.3028).
### Table 3: Top section: $\mu_{\text{eff}}$ and sparticle masses at the SUSY scale in GeV. Bottom section: LSP decomposition.

| Pt. # | $\mu_{\text{eff}}$ | $m_{\tilde{q}}$ | $m_{\tilde{t}_1}$ | $m_{\tilde{b}_1}$ | $m_{\tilde{q}_L}$ | $m_{\tilde{q}_R}$ | $m_{\tilde{t}}$ | $m_{\tilde{b}}$ | $m_{\tilde{q}}$ | $m_{\tilde{b}}$ |
|------|----------------|----------------|-----------------|-----------------|----------------|----------------|--------------|--------------|--------------|--------------|
| 1*   | 400            | 2048           | 535             | 363             | 648            | 771            | 727           | 727           | 398          | 363          |
| 2*   | 447            | 2253           | 416             | 410             | 581            | 785            | 691           | 691           | 446          | 410          |
| 3    | 472            | 2397           | 642             | 438             | 878            | 1244           | 775           | 775           | 472          | 438          |
| 4*   | 368            | 1876           | 581             | 433             | 520            | 581            | 658           | 658           | 364          | 328          |
| 5    | 421            | 1699           | 1716            | 784             | 997            | 997            | 498           | 498           | 408          | 307          |
| 6    | 472            | 2410           | 1217            | 1664            | 727            | 727            | 1796          | 1796          | 408          | 307          |
| 7    | 477            | 2497           | 1644            | 1754            | 2410           | 2410           | 748           | 748           | 471          | 440          |

### Table 4: $\delta a_\mu$ in units of $10^{-10}$, LSP relic abundance, primary annihilation channels and spin-independent LSP scattering cross section off protons.

| Pt. # | $\delta a_\mu$ | $\Omega h^2$ | Prim. Ann. Channels | $\sigma_{\text{SI}}$ [pb] |
|------|----------------|--------------|---------------------|---------------------------|
| 1*   | 6.01           | 0.094        | $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to W^+W^-(31.5\%), ZZ(21.1\%)$ | $4.3 \times 10^{-8}$ |
| 2*   | 5.85           | 0.099        | $\tilde{\nu}_\tau\tilde{\nu}_\tau \to \nu_\tau\nu_\tau(11.4\%), \tilde{\nu}_\tau\tilde{\nu}_\tau \to W^+W^- (8.8\%)$ | $3.8 \times 10^{-8}$ |
| 3    | 4.48           | 0.114        | $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to W^+W^- (23.9\%), ZZ(17.1\%)$ | $3.7 \times 10^{-8}$ |
| 4*   | 6.87           | 0.097        | $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to W^+W^- (36.9\%), ZZ(23.5\%)$ | $4.5 \times 10^{-8}$ |
| 5    | 5.31           | 0.135        | $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to b\bar{b}(39.5\%), h_1a_1(20.3\%)$ | $5.8 \times 10^{-8}$ |
| 6    | 4.89           | 0.128        | $\tilde{\tau}_1\tilde{\tau}_1 \to \tau\tau(17.4\%), \tilde{\chi}_1^0\tilde{\chi}_1^0 \to W^+W^- (14.8\%)$ | $4.0 \times 10^{-8}$ |
| 7    | 4.96           | 0.101        | $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to W^+W^- (17.7\%), ZZ(12.9\%)$ | $4.0 \times 10^{-8}$ |
[5] A. Arbey, M. Battaglia, F. Mahmoudi, Constraints on the MSSM from the
Higgs Sector - A pMSSM Study of Higgs Searches, B_s \rightarrow \mu^+\mu^- and Dark
Matter Direct Detection, arXiv:1112.3032

[6] M. Carena, S. Gori, N. R. Shah, C. E. Wagner, A 125 GeV SM-like Higgs in
the MSSM and the γγ rate, arXiv:1112.3336

[7] O. Buchmueller, R. Cavanaugh, A. De Roeck, et al., Higgs and Supersymmetry,
arXiv:1112.3564 [hep-ph].

[8] S. Akula, B. Altunkaynak, D. Feldman, P. Nath, G. Peim, Higgs Boson Mass
Predictions in SUGRA Unification, Recent LHC-7 Results, and Dark Matter,
arXiv:1112.3645.

[9] M. Kadastik, K. Kannike, A. Racioppi, M. Raidal, Implications of 125 GeV
Higgs boson on scalar dark matter and on the CMSSM phenomenology,
arXiv:1112.3647.

[10] J. Cao, Z. Heng, D. Li, J. M. Yang, Current experimental constraints on the
lightest Higgs boson mass in the constrained MSSM, arXiv:1112.4391.

[11] A. Arvanitaki, G. Villadoro, A Non Standard Model Higgs at the LHC as a
Sign of Naturalness, arXiv:1112.4835.

[12] L. J. Hall, D. Pinner, J. T. Ruderman, A Natural SUSY Higgs Near 126 GeV,
arXiv:1112.2703.

[13] U. Ellwanger, A Higgs boson near 125 GeV with enhanced di-photon signal
in the NMSSM, arXiv:1112.3548.

[14] A. Djouadi, U. Ellwanger and A. M. Teixeira, The Constrained next-to-
minimal supersymmetric standard model, Phys. Rev. Lett. 101 (2008) 101802,
arXiv:0803.0253.

[15] A. Djouadi, U. Ellwanger and A. M. Teixeira, Phenomenology of the con-
strained NMSSM, JHEP 0904 (2009) 031 arXiv:0811.2699.

[16] U. Ellwanger, J. F. Gunion, C. Hugonie, NMHDECAY: A Fortran code for
the Higgs masses, couplings and decay widths in the NMSSM, JHEP 0502
(2005) 066, arXiv:hep-ph/0406215.

[17] U. Ellwanger, C. Hugonie, NMHDECAY 2.0: An Updated program for spar-
ticle masses, Higgs masses, couplings and decay widths in the NMSSM, Comput.
Phys. Commun. 175 (2006) 290–303, arXiv:hep-ph/0508022.

[18] http://www.th.u-psud.fr/NMHDECAY/nmssmtools.html.

[19] A. Djouadi, J. Kalinowski, M. Spira, HDECAY: A Program for Higgs bo-
son decays in the standard model and its supersymmetric extension, Comput.
Phys. Commun. 108 (1998) 56–74, arXiv:hep-ph/9704448.
[20] R. Dermisek, J. F. Gunion, The NMSSM Close to the R-symmetry Limit and Naturalness in $h \to aa$ Decays for $m_a < 2m_b$, Phys. Rev. D75 (2007) 075019, arXiv:hep-ph/0611142

[21] B. A. Dobrescu, K. T. Matchev, Light axion within the next-to-minimal supersymmetric standard model, JHEP 0009 (2000) 031, arXiv:hep-ph/0008192.