Fine-tuning in the scale invariant NMSSM

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Outline

SUperSYmmetry (SUSY)

- The MSSM contains the minimal supersymmetric particle content compatible with the Standard Model (SM), $\mathcal{N} = 1$ SUSY (one SUSY charge generator).
- Gauge couplings unify in the MSSM $\Longrightarrow$ strong hint towards GUT theories.
- If R-parity is conserved: avoid proton decay constraints, SUSY particles are produced in even numbers at colliders and the LSP is stable $\Longrightarrow$ Dark Matter (DM) candidate.

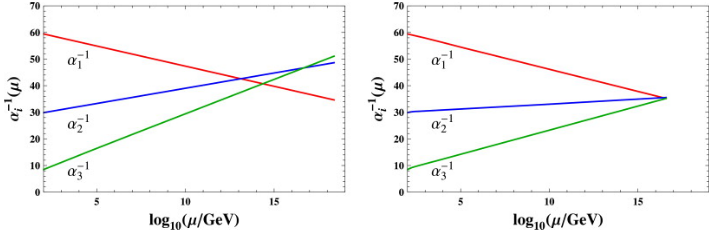


Figure: SM (left) vs MSSM (right).

SUperSYmmetry (SUSY)

- SUSY avoids quadratically divergent quantum corrections to the Higgs mass involving a UV-cutoff Λ.

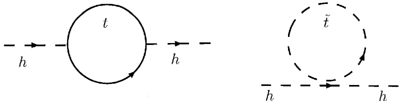


Figure: Top-stop contributions to Higgs mass.

- Quantum corrections still generate large logarithms $\sim \log(\Lambda/m_{\mathrm{soft}}) \Rightarrow$ Summed up via Renormalization Group Equations (β-functions).
- Finite quantum corrections can be taken into account by effective action methods,

$$\mathcal{S}_{eff} = \int d^4x \left\{ \sum_{n=0}^{\infty} Z_i^n \partial_\mu \phi_i^\dagger \partial^\mu \phi_i - \sum_{n=0}^{\infty} V_n \right\}$$

- At one-loop we recover the Coleman-Weinberg formula which in the $\bar{DR}$ scheme is

$$V_1 = \frac{1}{64\pi^2} \mathrm{STr}\, M^4 \left[\ln\left(\frac{M^2}{\mu_r^2} \right) - \frac{3}{2} \right]$$

- Energy scales involved:

Λ	______	Scale at which SUSY breaking is transmitted from hidden sector to visible sector
m_{soft}	______	Scale at which EWSB happens
$m_h \sim v_{EW}$	______	Pole Higgs mass

Fine tuning in the MSSM

- In the MSSM Higgs quartic coupling at tree-level $\lambda_h \propto g^2$ with $g \in SU(2)_W$, (D-terms).
- However, finite loop corrections provide additional contributions to λ_h, the biggest coming from top/stop loops.
- MSSM Higgs mass in the decoupling limit ($m_A^2 \gg m_h^2$) Carena et al.,

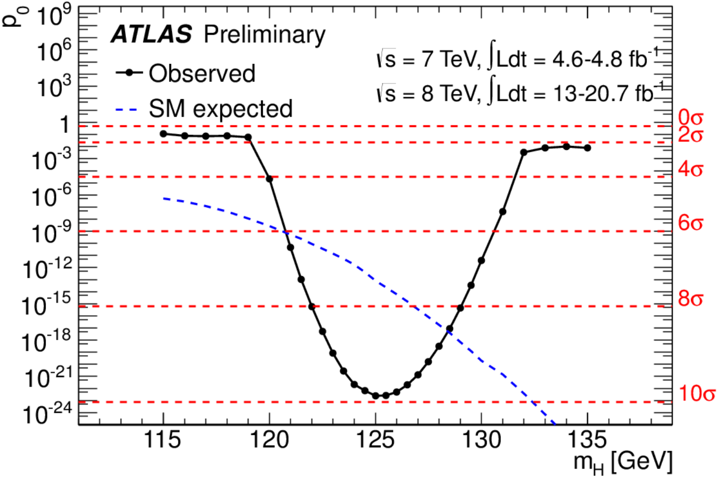
$$
\begin{aligned}
m_h^2 &= m_Z^2 \cos^2 2\beta \left(1 - \frac{3}{8\pi^2} y_t^2 t\right) \\
&+ \frac{3}{4\pi^2} y_t^2 \left[\frac{1}{2} X_t + t + \frac{1}{16\pi^2}\left(\frac{3}{2}\frac{m_t^2}{v^2} - 32\pi\alpha_3\right)(X_t t + t^2)\right]
\end{aligned}
$$

with $t = \ln \frac{m_{\rm soft}^2}{m_t^2}$, $X_t = \frac{2(A_t - \mu \cot\beta)^2}{m_{soft}^2}\left(1 - \frac{(A_t - \mu\cot\beta)^2}{12 m_{soft}^2}\right)$, $m_{soft} = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}} = \mu_r$.

- If $m_h \approx 126$ GeV $\Rightarrow$ large $m_{Q_3}^2$, $m_{u_3}^2$ (enter logarithmically) or large A_t (enters as a power) $\Rightarrow$ lead to large (UV-logarithmically) sensitivity on the Higgs potential at quadratic order.

Higgs resonance at 126 GeV

Impressive ATLAS combined result for local probability p_0 of background-only to be more signal-like than the observation



Fine tuning in the MSSM

- In the MSSM the minimization conditions (including finite loop-corrections) take the form,

$$m_Z^2 = \frac{\hat{m}_{H_u}^2 - m_{H_d}^2}{\cos 2\beta} - \hat{m}_{H_u}^2 - \hat{m}_{H_d}^2 - 2\mu^2, \qquad \frac{2b}{\sin 2\beta} = \hat{m}_{H_u}^2 + \hat{m}_{H_d}^2 + 2\mu^2$$

where $\hat{m}_{H_u}^2 \equiv m_{H_u}^2 + \partial V_{eff}/\partial v_u^2$ and $\hat{m}_{H_d}^2 \equiv m_{H_d}^2 + \partial V_{eff}/\partial v_d^2$.

- From RG evolution in the SUSY theory (in the leading-log approximation)

$$m_{H_u}^2(m_{\rm soft}) = m_{H_u}^2(\Lambda) - \frac{3y_t^2}{8\pi^2}\left[m_{Q_3}^2(\Lambda) + m_{u_3}^2(\Lambda) + A_t^2(\Lambda)\right] \ln\left[\frac{\Lambda}{m_{\rm soft}}\right]$$

$\therefore$ We must tune $m_{H_u}^2(\Lambda)$ in order to compensate large stop corrections $\Rightarrow$ known as the "little hierarchy problem".

Fine tuning in the MSSM

One way to quantify the tuning is with the measure Barbieri, Giudice

$$\Sigma^v \equiv \max_{\xi_i} \left| \frac{\partial \ln v^2}{\partial \ln \xi(\Lambda)} \right|$$

- How much does v change when infinitesimally moving the independent parameters at the high scale Λ.
- In the MSSM the relevant parameters are $\xi_i = (m^2_{H_u}, m^2_{H_d}, \mu, b, m^2_{Q_3}, m^2_{u_3}, m^2_{d_3}, A_t, A_b, M_1, M_2, M_3)$.
- Using the chain rule,

$$\Sigma^v = \max_i \left| \sum_j \frac{\xi_i(\Lambda)}{v^2} \frac{dv^2}{d\xi_j(m_{\rm soft})} \frac{d\xi_j(m_{\rm soft})}{d\xi_i(\Lambda)} \right|$$

$\Rightarrow$

$$\left| \frac{d \log v^2}{d \log m^2_{H_u}(\Lambda)} \right| \simeq \left| \frac{3 y_t^2}{8\pi^2 v^2} (m^2_{Q_3}(\Lambda) + m^2_{u_3}(\Lambda) + A_t^2(\Lambda)) \log\left[\frac{\Lambda}{m_{\rm soft}}\right] \times \frac{dv^2}{dm^2_{H_u}(m_{\rm soft})} \right|$$

Fine tuning in the MSSM

- Neglecting the Coleman-Weinberg corrections in the MSSM and in the regime $\tan\beta \gg 1$

$$\frac{dv^2}{dm_{H_u}^2(m_{\text{soft}})} \simeq -\frac{2v^2}{m_Z^2} + \mathcal{O}\left(\frac{1}{\tan\beta}\right)$$

$\therefore$ NO FREEDOM TO SUPPRESS DERIVATIVE AND REDUCE TUNING!

- In the MSSM with current experimental constraints and $m_h \approx 126$ GeV, $\Sigma^v \gtrsim 500$.

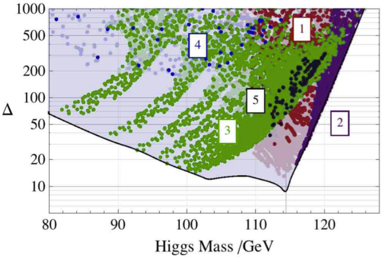


Figure: Cassel et al. 1101.4664 [hep-ph].

Saving low energy SUSY

1. Give up on small tuning: landscape, anthropic principle, split SUSY, . . .
2. Keep naturalness as guiding principle and add additional non-decoupling D-term contributions to the Higgs potential to raise Higgs mass at tree-level (enlarge weak gauge group)
3. Add additional F-term contributions: e.g. NMSSM; introduce a gauge singlet chiral superfield S.

Outline

Scale Invariant NMSSM

- Introduce a gauge singlet chiral superfield S in addition to the MSSM superfield content.
- No mass scale in the new superpotential piece ($\mathbb{Z}_3$ symmetry):

$$W_{NMSSM} = \lambda S H_d H_u + \frac{\kappa}{3} S^3$$

- Soft breaking terms:

$$V_{soft} = m^2_{H_u}|H_u|^2 + m^2_{H_d}|H_d|^2 + m^2_S|S|^2 + \left(a_\lambda S H_d H_u + \frac{a_\kappa}{3} S^3 + h.c\right)$$

Notice from W_{NMSSM} that:

1. If $\langle s \rangle \sim v$ for $\lambda \sim 1 \Rightarrow$ solve the μ-problem found in the MSSM.
2. Contributions to the Higgs potential of the form $F_S F_S^*$ generate a quartic coupling at tree-level proportional to λ^2.

Scale Invariant NMSSM

- Assume CP conservation on the Higgs-singlet sector $\Rightarrow$ scalar Higgs-singlet sector decomposes in 3 CP-even states, 2 CP-odd states and 1 charged Higgs.
- Neutral components: $H_u^0 = v_u + (h_u + ih_{u,I})/\sqrt{2}$, $H_d^0 = v_d + (h_d + ih_{d,I})/\sqrt{2}$ and $S = v_s + (s + is_I)/\sqrt{2}$.
- For neutral CP-even sector is useful to rotate to the basis

$$\begin{pmatrix} h \\ H \\ s \end{pmatrix} = \begin{pmatrix} \sin\beta & \cos\beta & 0 \\ -\cos\beta & \sin\beta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} h_u \\ h_d \\ s \end{pmatrix}$$

  where only $\langle h \rangle = v \neq 0$ (besides $\langle s \rangle = v_s \neq 0$) and $m_{hh}^2 = m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta$.
- We want $\tan\beta \approx 1$ to increase the tree-level Higgs mass (upper bound on the tree-level Higgs mass).
- If lightest eigenstate is mostly h, mixing with either H or s pulls mass down (level repulsion).

Scale Invariant NMSSM

- We take the best case scenario for tuning:
  1. Keep only 3^{rd} generation squarks and gauginos light. All other sparticles have masses $\tilde{m} \sim \Lambda$.
  2. Take a low "messenger" scale (effective cutoff) $\Lambda = 20$ TeV, 100 TeV, 1000 TeV.
- In this way we obtain the largest regions of parameter space consistent with low fine tuning and whose collider and flavor constraints are ameliorated due to family splitting.
- Furthermore, low cutoff allows for a possible large value of $\lambda(m_{\rm soft}) \gtrsim 1$ (if $\Lambda = M_{GUT} \Rightarrow \lambda(m_{\rm soft}) \lesssim 0.65$).
- Models of λ-SUSY Barbieri, Hall, Nomura, Ruderman, . . .
  $\therefore$ Loop corrections not only from the top/stop sector but also from the Higgs-singlet sector become very important and should be included.

Large λ helps

- Minimization conditions for the scale invariant NMSSM

$$
\begin{aligned}
m_Z^2 &= \frac{m_{H_u}^2 - m_{H_d}^2}{\cos 2\beta} - m_{H_u}^2 - m_{H_d}^2 - 2\lambda^2 v_s^2. \\
\lambda^2 v^2 &= \frac{2(a_\lambda v_s + \lambda\kappa v_s^2)}{\sin 2\beta} - m_{H_u}^2 - m_{H_d}^2 - 2\lambda^2 v_s^2 \\
m_s^2 &= \lambda\kappa v^2 \sin 2\beta - 2\kappa^2 v_s^2 - \lambda^2 v^2 - \frac{a_\lambda v^2}{2 v_s} \sin 2\beta - a_\kappa v_s
\end{aligned}
$$

- Parameters $\xi_i = (m_{H_u}^2, m_{H_d}^2, m_s^2, \lambda, \kappa, a_\lambda, a_\kappa, m_{Q_3}^2, m_{u_3}^2, m_{d_3}^2, A_t, A_b, M_1, M_2, M_3)$.
- In this case we find

$$
\frac{dv^2}{dm_{H_u}^2(m_{\text{soft}})} = \frac{\kappa}{\lambda^3} \cot 2\beta + \mathcal{O}\left(\frac{1}{\lambda^4}\right)
$$

Suppressed for large values of λ.
$\therefore$ Large λ seems to help allowing for smaller tuning and/or larger stop masses.

Large λ helps

- All plots have 5 % vev tuning or better.

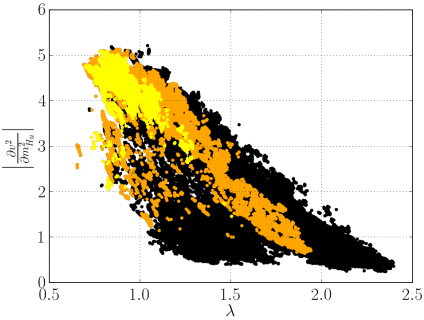


Figure: $|dv^2/dm^2_{H_u}|$ vs λ.

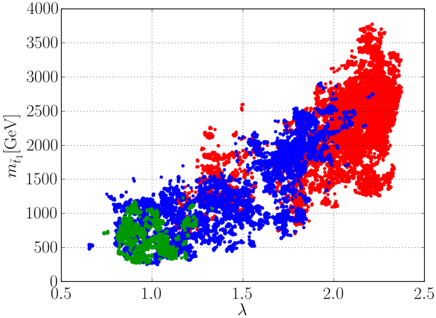


Figure: $m_{\tilde{t}_1}$ [GeV] vs λ.

Large λ hurts

We can write the Higgs mass as,

$$m_h^2 = m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta + \delta m^2_{h\,mix} + \delta m^2_{h,stop} + \delta m^2_{h,S}$$

- For $\tan\beta \approx 1$ and $\lambda \gtrsim 1$ we "overshoot" the Higgs mass at tree-level, $m_{h,tree} \gg 126$ GeV (for $\lambda \simeq 2.4$, $m^2_{h,tree} \approx 10(126\,\mathrm{GeV})^2$).
- For most of our points admixture modifies mass as most by 40 % . Thus pull-down effect is typically not large.
- $\delta m^2_{h,stop}$ generically provides a positive contribution to m_h^2.
- The finite loop corrections from the Higgs-singlet sector can provide large negative contributions to m_h^2.

This leads us to define a new tuning measure in analogy with the EW vev tuning:

$$\Sigma^h \equiv \max_{\xi_i} \left| \frac{d \log m_h^2}{d \log \xi_i} \right|$$

Think of it as a tuning in the quartic Higgs coupling (contrary to the quadratic tuning associated with the v). ξ_i are the same as before except $m^2_{H_u}$, $m^2_{H_d}$ and m_s^2 have been replaced by v_u, v_d and v_s which are kept fixed.

Large λ hurts

- $\Sigma^h \propto \lambda^2$
- At $\tan\beta \gtrsim 3$, m_h^2 decreases two-folded from $\sin 2\beta$ small and because larger $\tan\beta$ $\Rightarrow$ larger higgsino contributions to the T-parameter $\Rightarrow$ λ must be smaller.

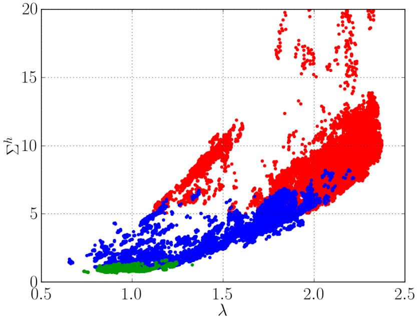


Figure: Σ^h vs λ.

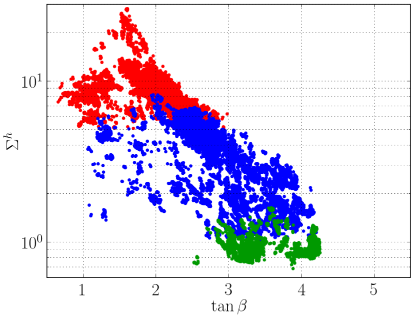


Figure: Σ^h vs $\tan\beta$.

Combined tuning

Define a combined tuning measure $\Sigma^h \times \Sigma^v$ (if two quantities are not correlated, the probablity involving both is $P(A \bigcap B) = P(A).P(B)$).

- Total tuning dominated at small λ by vev tuning and at large λ by Higgs mas tuning. Minimum at $\lambda \approx 1$.
- Brown band corresponds to a characteristic point in the MSSM with $\mu = 200$ GeV, $\tan\beta = 20$, $\Lambda = 20$ TeV, $m_a = 1$ TeV and A_t such that $m_h \in [124, 127]$ GeV. Always better than the MSSM.

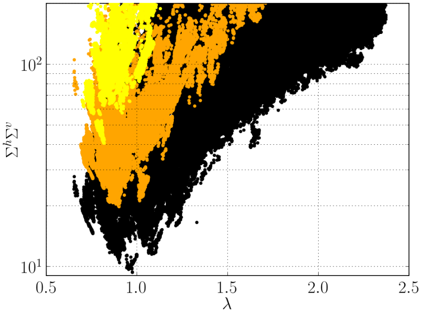


Figure: $\Sigma^v \times \Sigma^h$ vs λ

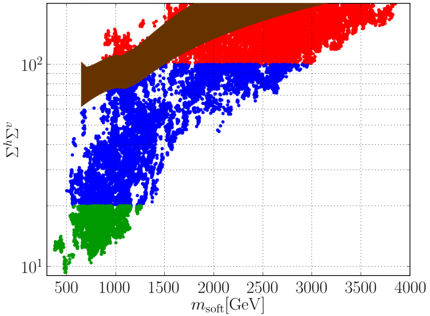


Figure: $\Sigma^v \times \Sigma^h$ vs m_{soft} [GeV]

Numerical Scan

- Markov Chain Monte Carlo
- We used a modified version of NMHDECAY, which is part of NMSSMTools 3.2.1, as well as MicrOMEGAs 2.4.5 for DM
- We scanned linearly in 14-dimensional parameter space

$\tan\beta$	$\tan\beta > 0.08$	m_{Q_3}	$\Delta_{\tilde{g}} m_{Q_3} < m_{Q_3} < 5$	M_1	$0 < M_1 < 8$
μ	$\lvert\mu\rvert < 1$	m_{u_3}	$\Delta_{\tilde{g}} m_{u_3} < m_{u_3} < 5$	M_2	$0 < M_2 < 8$
λ	$0 < \lambda < 3$	m_{d_3}	$0 < m_{d_3} < 8$	M_3	$0.5 < M_3 < 8$
κ	$\lvert\kappa\rvert < 2.75$	A_t	$\lvert\Delta_{\tilde{g}} A_t\rvert < \lvert A_t\rvert < 5$	v	174
A_λ	$\lvert A_\lambda\rvert < 2$	A_b	$\lvert A_b\rvert < 8$	Λ	$20, 100, 1000$
A_κ	$\lvert A_\kappa\rvert < 1$				

$\Rightarrow$ We did not sample the full parameter space. Therefore, there is no statistical interpretation of the scatter plots.

- Likelihood function: product of Gaussians for the Higgs mass centered at 126 and for the VEV finetuning centered at 0.
- We impose the hard cuts summarised in the table as well as

$$|\xi(\Lambda) - \xi(m_{\text{soft}})| < |\xi(\Lambda)| \quad \text{for } \xi = m_{Q_3}^2, m_{u_3}^2, m_{d_3}^2, A_t, A_b$$

similar to "gluino sucks the stop mass up" Arvanitaki, Craig, Dimopoulos, Villadoro(2012)

Electroweak Precision Tests (EWPT)

- impose EWPT at 2σ with $m_{h,ref} = 117$ GeV PDG(2012).

$$S_0 = -0.04 \pm 0.09 \ , \ T_0 = 0.07 \pm 0.08 \text{ and correlation of } 88\% \text{ at } 95\% \text{ C.L.}$$

- Consistent with previous analyses Barbieri et. al.(2006); Franceschini, Gori (2010), we find and singlet scalars do not contribute much to S,T
- (3rd gen) squarks: $\tan\beta$ can not be too large unless cancellation $\tan\beta \neq 1$ breaks custodial SU(2) $\rightarrow$ contribution to T
- Neutralino/chargino sector imposes strong constraint on λ as well as $\tan\beta$

$$M_{\psi^0} = \begin{pmatrix} M_1 & 0 & -\cos\beta\sin\theta_W m_Z & \sin\beta\sin\theta_W m_Z & 0 \\ . & M_2 & \cos\beta\cos\theta_W m_Z & -\sin\beta\cos\theta_W m_Z & 0 \\ . & . & 0 & -\mu & -\lambda v\sin\beta \\ . & . & -\mu & 0 & -\lambda v\cos\beta \\ . & . & . & . & -2\frac{\kappa}{\lambda}\mu \end{pmatrix}$$

$$M_{\psi^\pm} = \begin{pmatrix} 0 & X^T \\ X & 0 \end{pmatrix} \quad \text{with} \quad X = \begin{pmatrix} M_2 & \sqrt{2}m_W\sin\beta \\ \sqrt{2}m_W\cos\beta & 2\mu \end{pmatrix}$$

in gauge-basis $\psi^0 = (\tilde{B}, \tilde{W}^3, 1\tilde{H}_d^0, 1\tilde{H}_u^0, 1\tilde{S})$ and $\psi^\pm = (\tilde{W}^+, 1\tilde{H}_u^+, \tilde{W}^-, 1\tilde{H}_d^-)$

- We find $\tan\beta \lesssim 5$ depending on λ

SUSY searches

Assuming a neutralino LSP, we conservatively exclude the following regions:

- gluino search: $\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$ ATLAS-CONF-2012-151

$$m_{\tilde{g}} < 1310 \qquad \text{if} \;\; m_{\tilde{\chi}_1^0} < 650$$

- sbottom search PDG (2012); CMS-PAS-SUS-12-028; ATLAS-CONF-2012-106

$$m_{\tilde{b}} < 89$$
$$150 < m_{\tilde{b}} < 650 \qquad \text{if} \; m_{\tilde{\chi}_1^0} < 230$$

- stop search PDG(2012); ATLAS (1208.1447, 1208.2590)

$$m_{\tilde{t}} < 95.7$$
$$220 < m_{\tilde{t}} < 500 \qquad \text{if} \;\; m_{\tilde{\chi}_1^0} < 160$$

- chargino search $m_{\tilde{\chi}^\pm} < 94$ PDG (2012) The neutralino/chargino searches by ATLAS/CMS did not lead to further constraints.

Higgs searches

$$R_X \equiv \frac{\sigma(h) \times BR(h \to X)}{\sigma(h_{\rm SM}) \times BR(h_{\rm SM} \to X)}$$

- Higgs resonance at 126

  ATLAS (1207.7214), ATLAS-CONF-2012-162; ATLAS-CONF-2012-170; CMS (1207.7235), CMS-HIG-12-045

$$0.81 < R_{ZZ} < 1.32, \qquad 0.74 < R_{WW} < 1.40,$$
$$0 < R_{b\bar{b}} < 1.10, \qquad 0.27 < R_{\tau\tau} < 1.15,$$

- Heavy Higgs searches CMS-PAS-Higgs-11-024,CMS-PAS-Higgs-11-041

$$\frac{\sigma(s_i) \times BR(s_i \to ZZ)}{\sigma(h_{\rm SM}) \times BR(h_{\rm SM} \to ZZ)} < 0.09$$
$$\frac{\sigma(s_i) \times BR(s_i \to WW)}{\sigma(h_{\rm SM}) \times BR(h_{\rm SM} \to WW)} < 0.2$$

- Charged Higgs PDG(2012)

$$m_{H^\pm} \gtrsim 79.3$$

Flavour Constraints

We use the following flavour physics constraints

- *B*-meson mixing HFAG (1207.1158)

$$\Delta M_s = (17.719 \pm 0.086)\,\mathrm{ps}^{-1}$$
$$\Delta M_d = (0.507 \pm 0.008)\,\mathrm{ps}^{-1}$$

- rare *B*-decays HFAG (1207.1158)

$$\mathrm{Br}(B^+ \to \tau^+ \nu_\tau) = (1.67 \pm 0.60) \times 10^{-4}$$
$$\mathrm{Br}(B \to X_s \gamma) = (3.55 \pm 0.48 \pm 0.18) \times 10^{-4}$$

- recently measured rare decay $B_s^0 \to \mu^+\mu^-$ LHCb (1211.2674)

$$\mathrm{Br}(B_s^0 \to \mu^+\mu^-) = 3.2^{+3.0+1.0}_{-2.4-0.6} \times 10^{-9}$$

Particle Spectrum

- $\mu \in [105, 850]$ GeV.
- EW sector is light (possible light charginos) while coloured sector can be heavy.

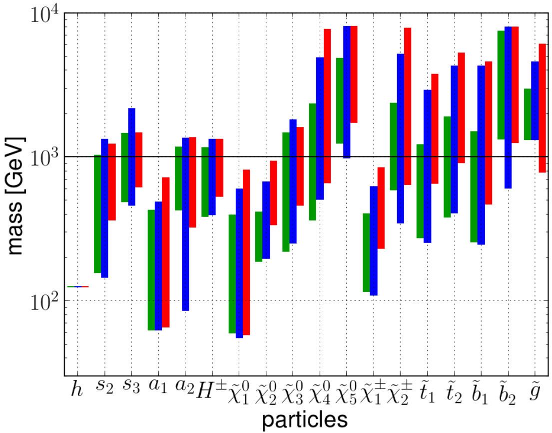


Figure: Particle spectrum

Higgs signal strengths

- Signal strengths always deviate from complete SM-likeness.
- Decrease in $R_{b\bar{b}} \Rightarrow$ increase in $R_{\gamma\gamma} \approx R_{ZZ}$.
- Red points enhancement in $R_{\gamma\gamma}$ due to large λ but also somewhat heavy $\tilde{\chi}_1^+$ ($g_{h\tilde{\chi}_1^+\tilde{\chi}_1^-} \approx \sqrt{2}\lambda V_{s,h}$ and $V_{s,h} < 0$).
- Interesting points with small tuning and enhanced $R_{\gamma\gamma}$ due to light charginos and $\lambda \sim 1.1$ and $\tan\beta \gtrsim 3$, $m_{\tilde{\chi}_1^+} \approx 110$ GeV.

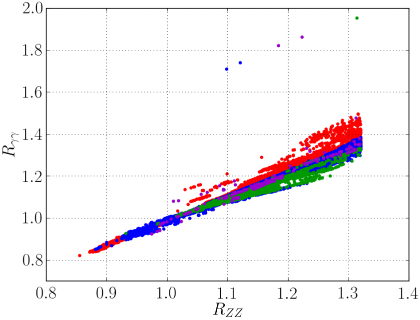


Figure: $R_{\gamma\gamma}$ vs R_{ZZ}

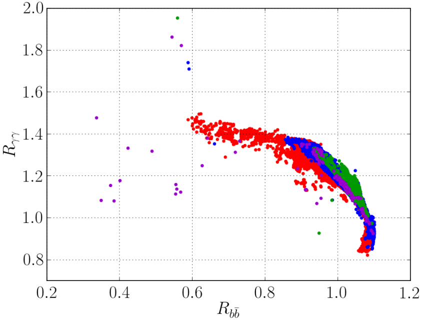


Figure: $R_{\gamma\gamma}$ vs $R_{b\bar{b}}$

SUSY searches

- For total tuning better than 5 %, $m_{\tilde{t}_1} \lesssim 1.3$ TeV, $m_{\tilde{g}} \lesssim 2.5$ TeV, $m_{\tilde{\chi}_1^0} \lesssim 400$ GeV.

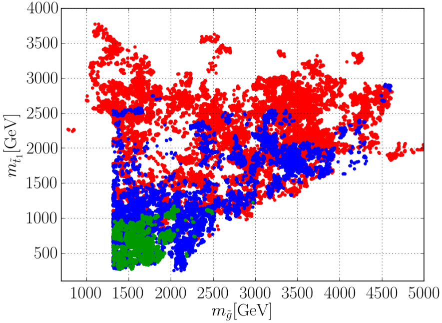


Figure: $m_{\tilde{t}_1}$ [GeV] vs $m_{\tilde{g}}$ [GeV].

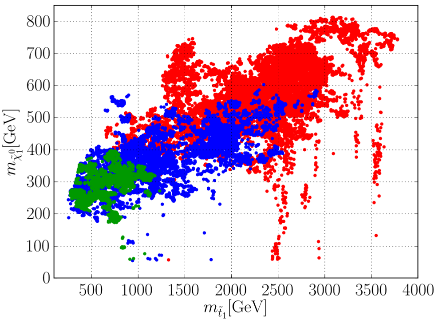


Figure: $m_{\tilde{\chi}_1^0}$ [GeV] vs $m_{\tilde{t}_1}$ [GeV].

Cosmological Constraints and Dark Matter

- Most of the time $\tilde{\chi}_1^0$ is mostly singlino or higgsino $\Rightarrow$ underproduced.
- Colors: green (singlino), blue (higgsino), orange (wino), red (bino), purple (gravitino, $m_{3/2} \simeq 0.01$ eV $\Rightarrow \Omega_{3/2}h^2 \ll \Omega_{WMAP-9}h^2$).
- For points with $\Omega_{DM}h^2 \approx 0.1$, dark matter is mostly Bino with small singlino component (compensates with large λ and κ).

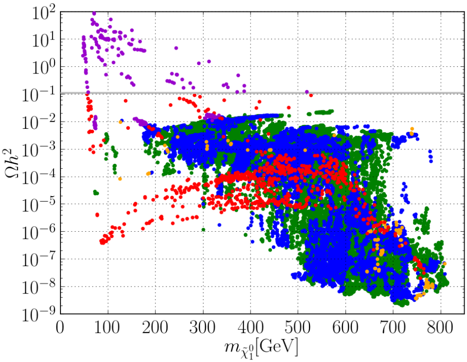


Figure: $\Omega_{\tilde{\chi}_1^0} h^2$ vs $m_{\tilde{\chi}_1^0}$ [GeV].

Dominant annihilation channels to get correct dark matter relic density,

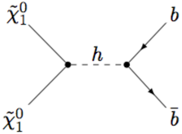


Figure: Resonant p-wave annihilation via h to bottom quarks

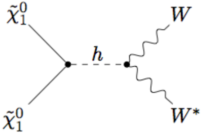


Figure: Resonant p-wave annihilation via h to W bosons

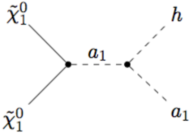


Figure: s-wave annihilation via lightest CP-odd a_1

Outline

Conclusions

- A natural Higgs with a mass $m_h \approx 126$ GeV in accordance with the latest LHC measurements can still be accomplished in SUSY by considering the second simplest extension of the SM, the NMSSM.
- Though large values of the parameter λ seem to help with the usual EW scale tuning, an additional tuning is induced in the effective Higgs quartic coupling which grows as λ^2.
- The total tuning measure defined as the product $\Sigma^v \times \Sigma^h$ is minimized at $\lambda \approx 1$ and can always be better than the tuning in the MSSM.
- For total tuning better than 5 %,$m_{\tilde{t}_1} \lesssim 1.3$ TeV, $m_{\tilde{g}} \lesssim 2.5$ TeV, $m_{\tilde{\chi}_1^0} \lesssim 400$ GeV.
- Enhancement in the two photon Higgs discovery channel can be accomplished in regions of parameter space that have a and $\tan\beta \gtrsim 3$ with moderate tuning.
- A dark matter candidate can be obtained with a dominant Bino component and a small but non-vanishing singlino component.