$H \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$ in the NMSSM

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Overview

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2. Methods
3. Preliminary results
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The NMSSM

The NMSSM is specified by the Superpotential:

$$\mathcal{W} = \mathcal{W}^{\not\mu}_{\text{MSSM}} + \lambda \hat{S} \hat{H}_u \cdot \hat{H}_d + \frac{1}{3} \kappa \hat{S}^3, \tag{1}$$

where $\mathcal{W}^{\not\mu}_{\text{MSSM}}$ contain the Yukawa couplings as in the MSSM. The second is $\mu_{\mathit{eff}} = \lambda s$, which is generated as the singlet superfield $\hat{S}$ acquires a vacuum expectation value (VEV). λ is the coupling of $\hat{S}$ to the up and down Higgs fields $\hat{H}_u, \hat{H}_d$. The third term is the self-coupling of $\hat{S}$.

Higgs potential

The Higgs and the SM singlet superfields acquire VEVs as,

$$\langle H_1 \rangle = \begin{pmatrix} v_1 \\ 0 \end{pmatrix}, \quad \langle H_2 \rangle = \begin{pmatrix} 0 \\ v_2 \end{pmatrix}, \langle S \rangle = v_3, \tag{2}$$

The Higgs potential is,

$$\begin{aligned} V_{\text{NMSSM}} =& m_1^2 v_1^2 + m_2^2 v_2^2 + \lambda^2 v_1^2 v_2^2 + 2\mu_{\text{eff}} B_{\text{eff}} v_1 v_2 \\ &+ \frac{\bar{g}^2}{8}(v_1^2 - v_2^2)^2 + v_3^2 (m_S^2 + \frac{2}{3} k v_3 A_\kappa + \kappa^2 v_3^2). \end{aligned} \tag{3}$$

where, $m_j^2 = m_{H_j}^2 + \mu_{\text{eff}}^2$, for $j = 1, 2$. $\mu_{\text{eff}} = \lambda v_3$ and $B_{\text{eff}} = \kappa v_3 + A_\lambda$ are effective terms produced as the SM singlet acquires its VEV. A_λ and A_κ are trilinear soft terms associated with the couplings λ and κ. m_S is the soft mass of the singlet. And $\bar{g}^2 = g_1^2 + g_2^2$, where g_1 and g_2 are the gauge couplings associated with $U(1)_Y$ and $SU(2)_L$, respectively.

EWSB conditions

In the NMSSM, there are three conditions for Electroweak Symmetry Breaking, which can be written in terms of the mass of the Z boson, M_Z, and $\sin 2\beta$, where $\tan\beta = \frac{v_2}{v_1}$, and the soft mass of the SM singlet, m_S:

$$\frac{M_Z^2}{2} = \frac{m_1^2 - \tan^2\beta m_2^2}{\tan^2\beta - 1}, \tag{4}$$

$$\sin 2\beta = \frac{2\mu_{\text{eff}} B_{\text{eff}}}{m_1^2 + m_2^2 + \lambda^2 v^2}, \tag{5}$$

$$m_S^2 + \kappa A_\kappa v_3 + \kappa^2 v_3^2 \simeq 0 \tag{6}$$

where, $v^2 = v_1^2 + v_2^2 = (174 \text{ GeV})^2$.
Equations 4- 5 are similar to those of the MSSM, while Equation 6 is absent in the MSSM. In contrast to the MSSM, the μ_{eff} in the NMSSM depends on soft parameters as it includes v_3, which, in turn, can be written in terms of m_S and A_κ by using Equation 6.

Soft parameters and the SM-like Higgs

Using NMSSM RGEs, we can expand the soft terms, $\{m_{H_j}, m_S, A_\kappa$, and $A_\lambda\}$, at the low scale, e.g. $M_{\rm SUSY} \sim \mathcal{O}(1\text{TeV})$, in terms of the fundamental parameters of the NMSSM at the GUT scale. In the framework of mSUGRA/CNMSSM, all scalar masses share a common mass: m_0, all gaugions share a common mass: $m_{1/2}$, and all trilinear couplings share a common value: A_0.
The tree-level physical Higgs mass in the NMSSM receives an additional F-term contribution (which is a welcome feature):

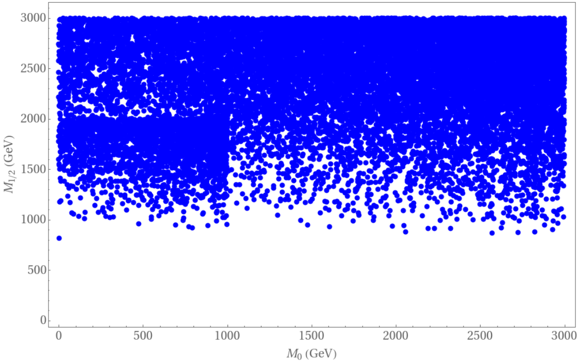
$$m_h^2 \leq M_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta, \tag{7}$$

Frame Title

Using NMSSMTools5.5.3, we apply all constraints except for (g-2) of the muon, and we only require DM relic density to satisfy the upper limit, while maintaining the limits from direct detection. Moreover, I work in the Z3-invariant semi-constrained NMSSM, where the Up- and Down-Higgs mass parameters can differ from m_0 at the GUT scale. The scanned range of parameters is,

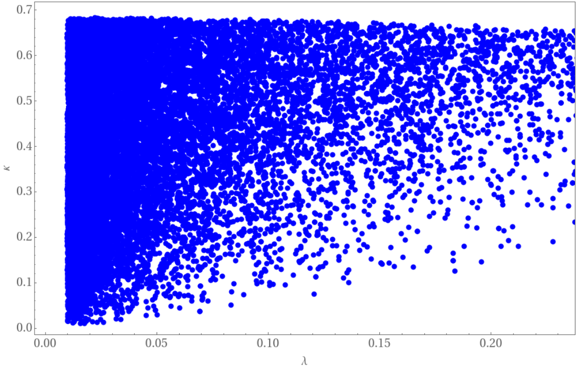
$$0 < m_0 < 3 \text{ TeV}$$
$$0 < m_{1/2} < 3 \text{ TeV}$$
$$-10 < A < 10 \text{ TeV}$$
$$-10 < A_\lambda < 10 \text{ TeV}$$
$$-10 < A_\kappa < 10 \text{ TeV}$$
$$100 < \mu_{\text{eff}} < 1000 \text{ GeV}$$
$$1 < \tan\beta < 60$$
$$0.01 < \lambda < 0.7$$
$$0.01 < \kappa < 0.7$$

m_0-$m_{1/2}$

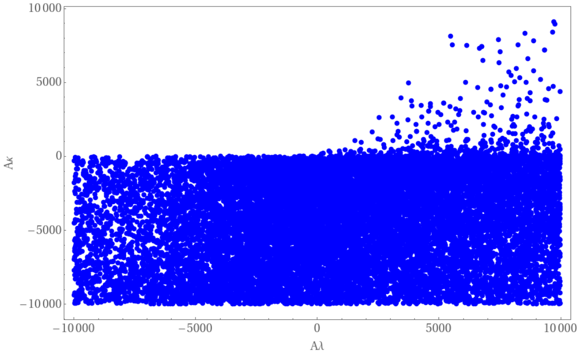


3000
2500
2000
1500
1000
500
0
$M_{1/2}$ (GeV)
0
500
1000
1500
2000
2500
3000
M_0 (GeV)

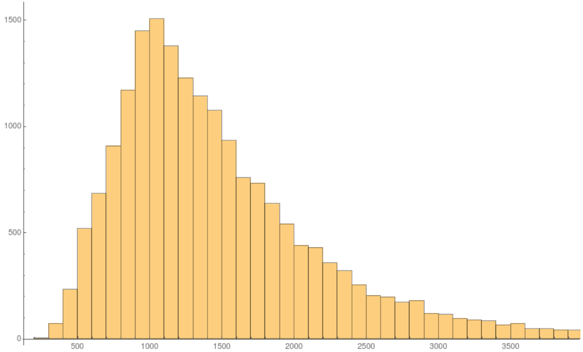
λ-κ



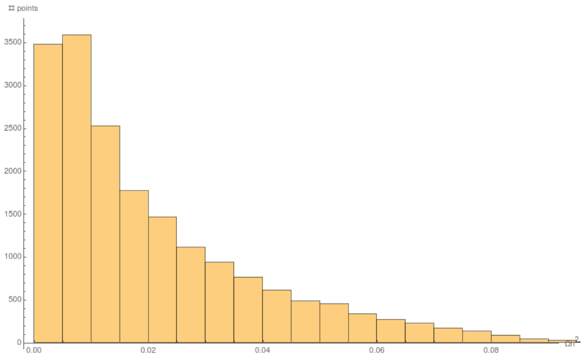
A_λ-A_κ



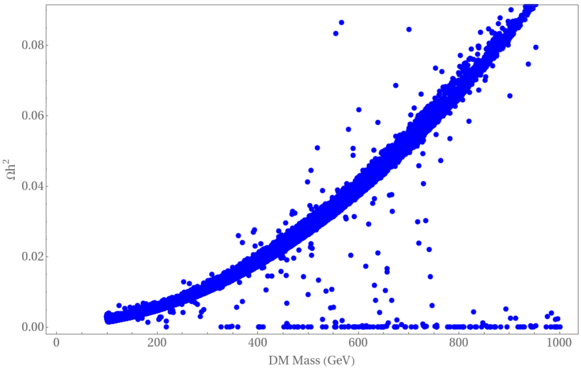
Fine tuning Data



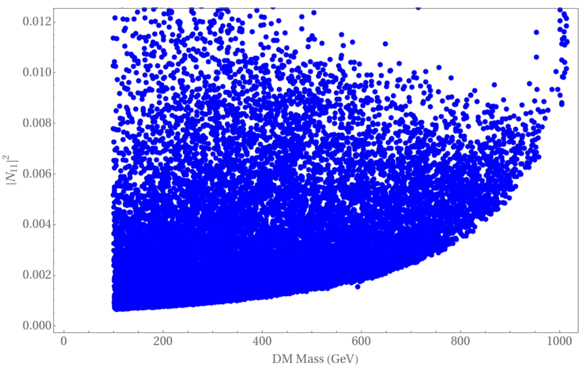
$\Omega h^2 data$



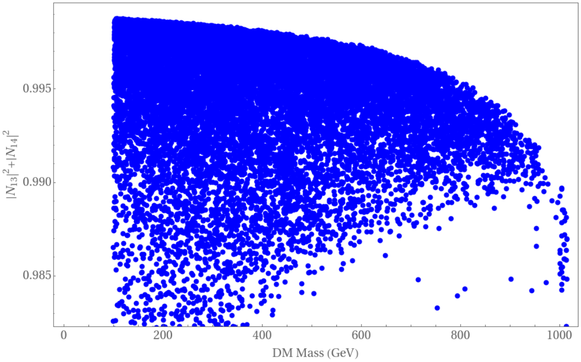
$m_{\tilde{\chi}_1^0} - \Omega h^2$



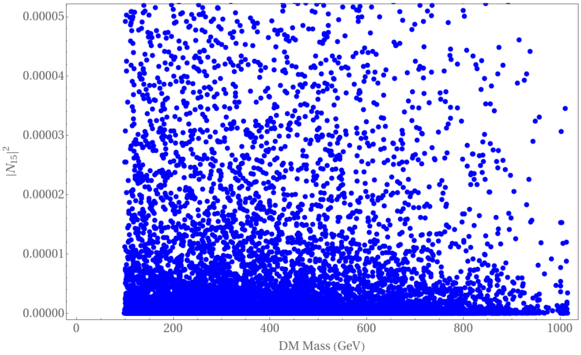
Bino component of DM particle



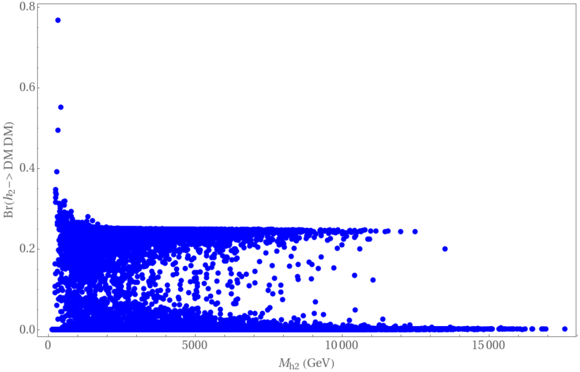
Higgsino component of DM particle



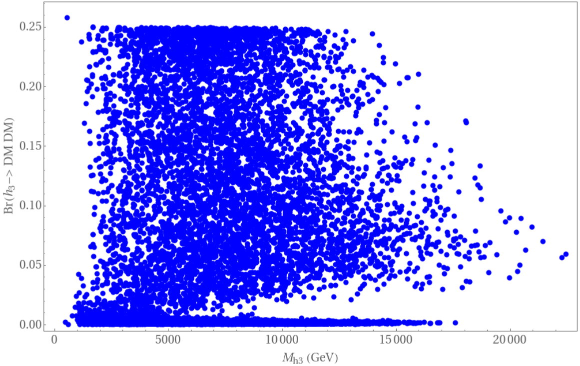
Singlet component of DM particle



$h_2 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$



$h_3 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$



Conclusions

- Ωh^2 reaches up to 0.126, but in most of the scanned parameter space it is below the lower limit on DM relic density.
- h_1 is the SM-like Higgs, and its singlet component is mostly negligible or very small (maximum 6%)
- Fine tuning can be as low as 280, and mostly around 1000.
- The smallest mass of neutralino DM is about 100 GeV, hence $h_1 \to DMDM$ is kinematically forbidden. But other Higgs bosons (CP-even or -odd) can decay into DMs.
- The maximum value of $Br(h_2 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0)$ is about 0.76 for $m_{h_2} = 300$ GeV.
- The maximum value of $Br(h_3 \to \tilde{\chi}_1^0 \tilde{\chi}_1^0)$ is about 0.26 for $m_{h_3} = 523$ GeV.
- Next step is to explore DM mass below 100 GeV.
- Compute $\sigma \times Br$ for Higgs sector Higgs bosons decaying into Chargino-Neutralino Sector in the NMSSM (work in progress).

The End