Escaping Large Fine Tuning and Little Hierarchy Problems

in NMSSM and $h \to aa$ decays

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R.D. and J. F. Gunion, hep-ph/0502105

EWSB in MSSM

Minimum of the Higgs potential:

$$\frac{1}{2}\, m_Z^2 \;=\; -\mu^2 + \frac{m_{H_d}^2 - \tan^2\beta\, m_{H_u}^2}{\tan^2\beta - 1}\,, \qquad \tan\beta = \frac{v_u}{v_d}$$

$\tan\beta = 10$:

$$\begin{aligned} m_Z^2 \;\simeq\; & -2.0\;\mu^2(0) + 5.9\;M_3^2(0) + 0.8\;m_Q^2(0) + 0.6\;m_u^2(0) \\ & -1.2\;m_{H_u}^2(0) - 0.7\;M_3(0)A_t(0) + \ldots \end{aligned}$$

Without specific relations between SSB parameters and/or μ:

$$m_Z \;\sim\; M_3(0),\; m_Q(0),\; m_u(0) \;\sim\; m_{\tilde{g}},\; m_{\tilde{t}}$$

natural EWSB $\rightarrow$ light gluino and stop!

Higgs Mass in MSSM

$$m_h^2 \simeq m_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2} v^2 y_t^4 \sin^4 \beta \log\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}\right) + \ldots$$

$$m_h^2 \simeq (91\mathrm{GeV})^2 + (38\mathrm{GeV})^2 \log\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}\right)$$

LEP limit: $m_h \gtrsim 115$ GeV

$$m_{\tilde{t}_1} m_{\tilde{t}_2} \gtrsim (\ 950\,\mathrm{GeV}\ )^2$$

LEP $\rightarrow$ heavy stop!

Little Hierarchy Problem in MSSM

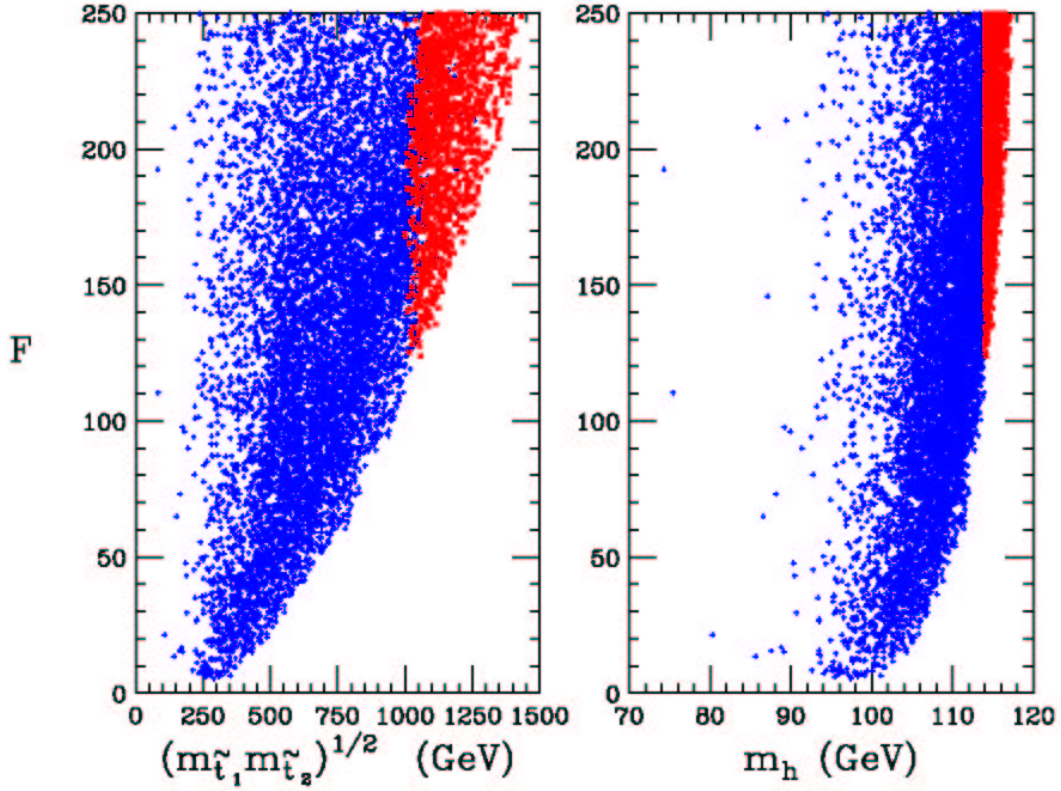
$$m_Z^2 = \frac{1}{2}(g_2^2 + g'^2)(v_u^2 + v_d^2)$$
$$v_u = v_u(a),\ v_d = v_d(a)$$

Fine tuning measure:

$$F = Max_a F_a = Max_a \left| \frac{d \log m_Z}{d \log a} \right|$$

$$a \in \{M_i(0), i = 1, 2, 3; m_s^2(0), s = Q, u, d, L, e, H_u, H_d; A_t(0), \mu(0), B_\mu(0)\}$$

Little Hierarchy Problem in MSSM



$+\ m_h < 115$ GeV

x $m_h > 115$ GeV

$M_1(m_Z) = 100$ GeV

$M_2(m_Z) = 200$ GeV

$M_3(m_Z) = 300$ GeV

$\tan\beta = 10$

other SSB parameters

randomly generated

$m_Z^2 = \frac{1}{2}(g_2^2 + g'^2)(v_u^2 + v_d^2)$

$v_u = v_u(a),\ v_d = v_d(a)$

Fine tuning measure:

$$F = Max_a F_a = Max_a \left| \frac{d \log m_Z}{d \log a} \right|$$

$$a \in \{M_i(0), i = 1,2,3; m_s^2(0), s = Q, u, d, L, e, H_u, H_d; A_t(0), \mu(0), B_\mu(0)\}$$

NMSSM - brief review

MSSM + one additional singlet superfield (results in one CP-even and one CP-odd neutral Higgs bosons, and one additional neutralino):

$$W = W_{MSSM} + \lambda \, \widehat{S}\widehat{H}_u\widehat{H}_d + \frac{\kappa}{3} \, \widehat{S}^3$$

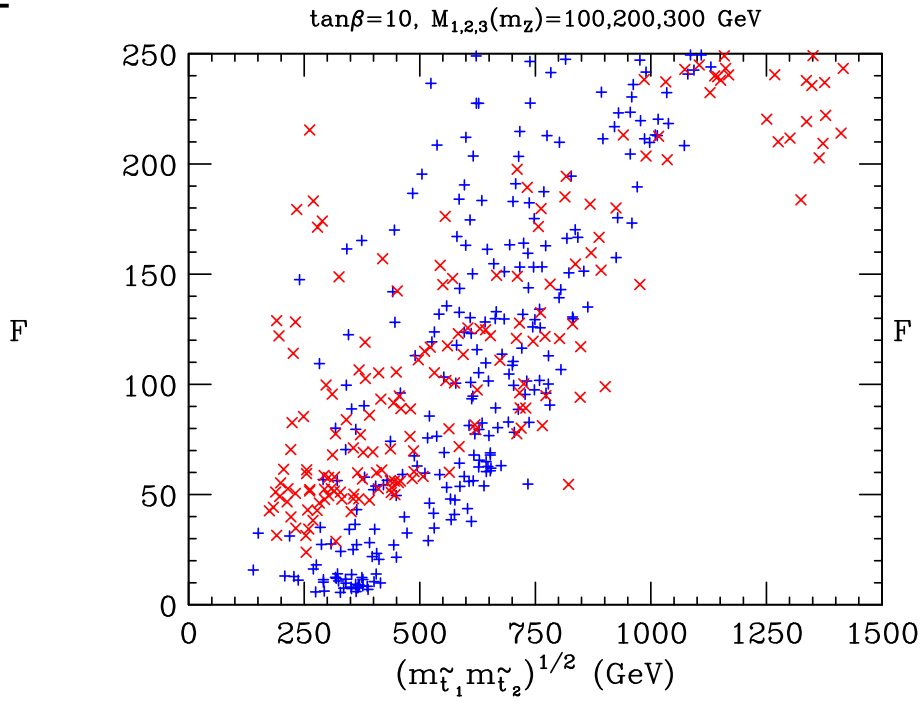
$$\mathcal{L}^{SSB} = \mathcal{L}^{SSB}_{MSSM} + \lambda A_\lambda S H_u H_d + \frac{\kappa}{3} A_\kappa S^3 + m_S^2 S S^*$$

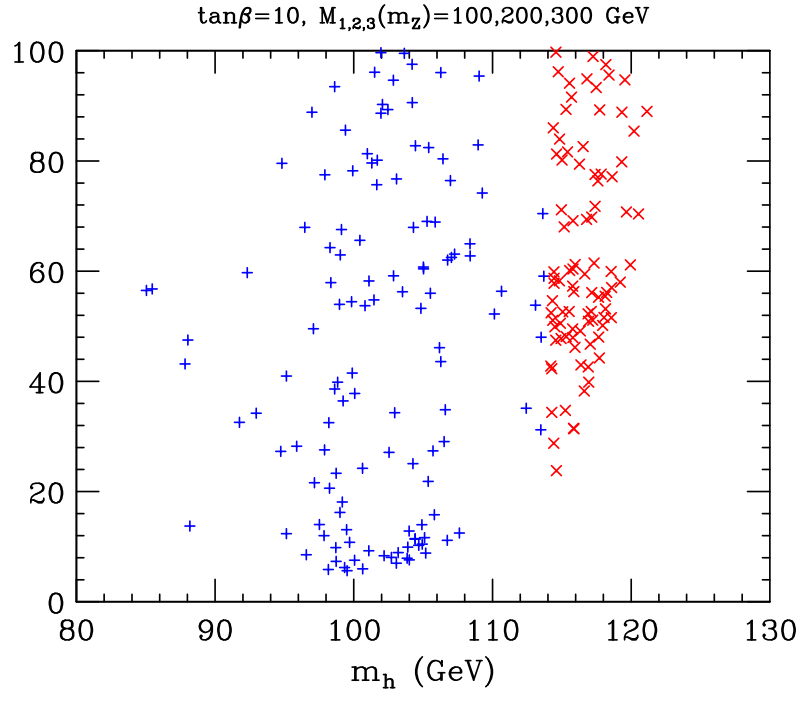
$$\tan\beta = \frac{v_u}{v_d}\,, \quad \mu_{eff} = \lambda s$$

$$m_Z^2 = \tfrac{1}{2}(g_2^2 + g'^2)(v_u^2 + v_d^2)$$

$m^2_{H_u}$, $m^2_{H_d}$, m^2_S determined by 3 minimization eqs. of the scalar potential

Fine Tuning in NMSSM, $\tan\beta = 10$





\+ escapes LEP because $h \longrightarrow aa$

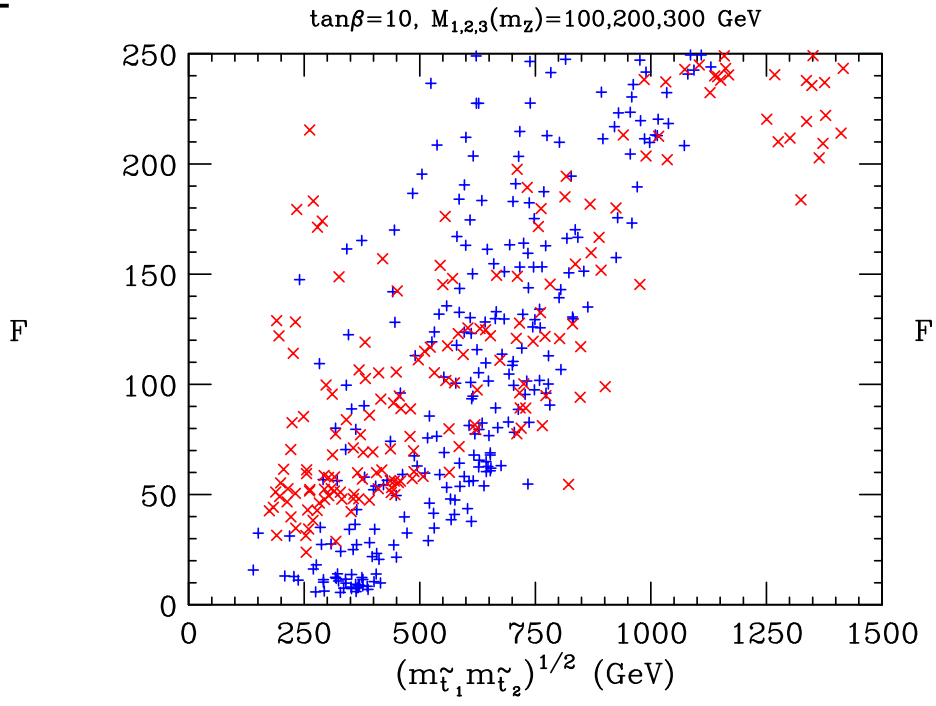
× escapes LEP because $m_h > 115$ GeV

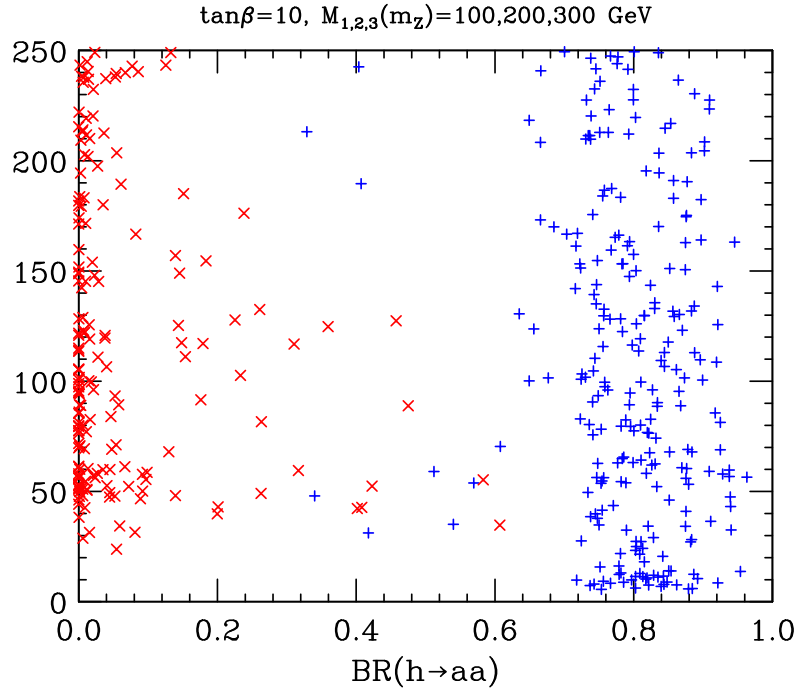
Fine tuning measure:

$$F = Max_a F_a = Max_a \left| \frac{d \log m_Z}{d \log a} \right|$$

$$a \in \{M_i(0), i = 1, 2, 3; m_s^2(0), s = Q, u, d, L, e, H_u, H_d; A_t(0), A_\lambda(0), A_\kappa(0)\}$$

Fine Tuning in NMSSM, $\tan\beta = 10$





$+$ ($m_{h_1} < 115$ GeV) $\quad h_1 \to a_1 a_1$ dominates

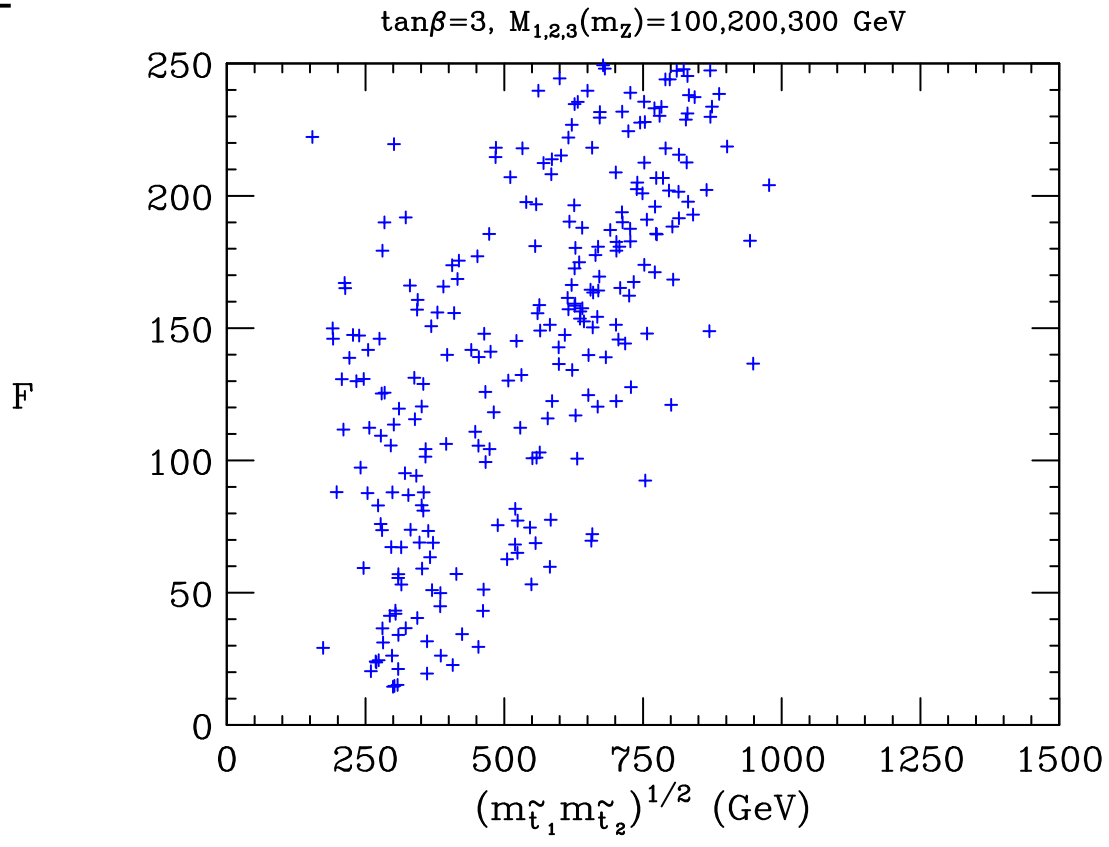
$\times$ ($m_{h_1} > 115$ GeV) $\quad h_1 \to b\bar{b}$ dominates

Fine tuning measure:

$$F = Max_a F_a = Max_a \left| \frac{d \log m_Z}{d \log a} \right|$$

$$a \in \{M_i(0), i = 1,2,3; m_s^2(0), s = Q, u, d, L, e, H_u, H_d; A_t(0), A_\lambda(0), A_\kappa(0)\}$$

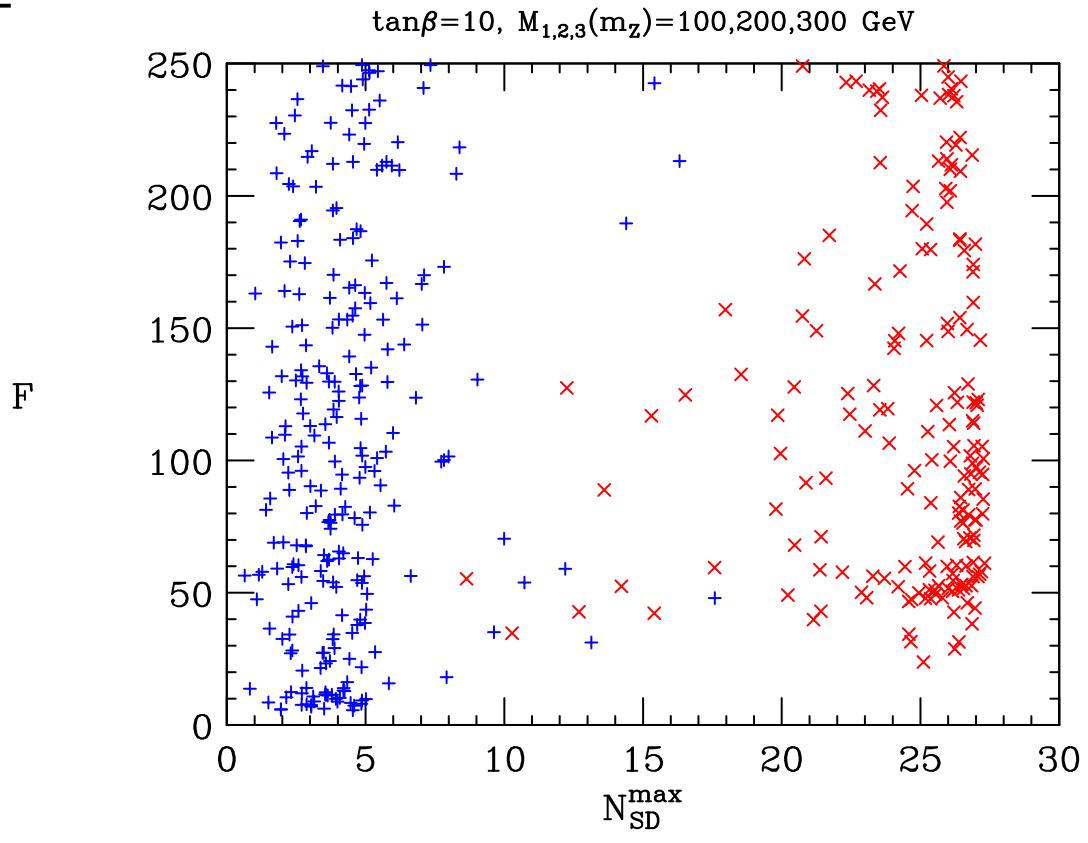
Fine Tuning in NMSSM $\tan\beta = 3$



\+ escapes LEP because $h \to aa$

x escapes LEP because $m_h > 115$ GeV

LHC Discovery Potential



Standard decay modes:

$gg \to h/a \to \gamma\gamma$

associated Wh/a or $t\bar{t}h/a$ prod.

with $\gamma\gamma l^{\pm}$ in the final state

$t\bar{t}h/a$ prod. with $h/a \to b\bar{b}$

$b\bar{b}h/a$ prod. with $h/a \to \tau^+\tau^-$

$gg \to h \to ZZ^{(*)} \to$ 4 leptons

$gg \to h \to WW^{(*)} \to l^+l^-\nu\bar{\nu}$

$WW \to h \to \tau^+\tau^-$

$WW \to h \to WW^{(*)}$

$WW \to h \to invisible$

for an integrated luminosity: $L = 300 fb^{-1}$

see the talk of J. Gunion, at LHC-ILC on Wednesday

Conclusions

- NMSSM provides a simple escape from the large fine tuning and little hierarchy problems present in MSSM
- relevant models imply $h_1 \longrightarrow a_1 a_1$ to be dominant!
  - $WW \longrightarrow h_1 \longrightarrow a_1 a_1 \longrightarrow b\,\bar{b}\,\tau^+\tau^-$ when $m_{a_1} > 2m_b$ marginal LHC signal

    U. Ellwanger, J.F. Gunion, C. Hugonie and S. Moretti

    hep-ph/0401228, hep-ph/0305109
  - $h_1 \longrightarrow a_1 a_1 \longrightarrow \tau^+\tau^-\tau^+\tau^-$ when $2m_\tau < m_{a_1} < 2m_b$ should be carefully studied!

    B. McElrath, at CPNSH on Friday
- similar results to be expected in many SUSY models with more complicated Higgs sector