The fine tuning guide for SUSY searches

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based on work with Graham Ross[1,2] and Dumitru Ghilencea[2]

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- Motivation for analysis of fine tuning
- A quantitative measure

The “Barbieri-Giudice" measure [Nucl. Phys. B**306** (1988) 63] for an observable, X, with input parameter, p.

$$\Delta_p(X) \equiv \frac{p}{X}\frac{\partial X}{\partial p} \qquad \Delta = \max(|\Delta_p|) \;\; or \;\; \sqrt{\sum_p (\Delta_p)^2}$$

(Ellis, Enquist, Nanopoulos, Zwirner [Mod. Phys. Lett. A1 (1986) 57])

$$v^2 = -\frac{m^2}{\lambda} \qquad \Delta_p\left(v^2\right) \approx -\frac{p}{\lambda v^2}\frac{\partial m^2}{\partial p}$$

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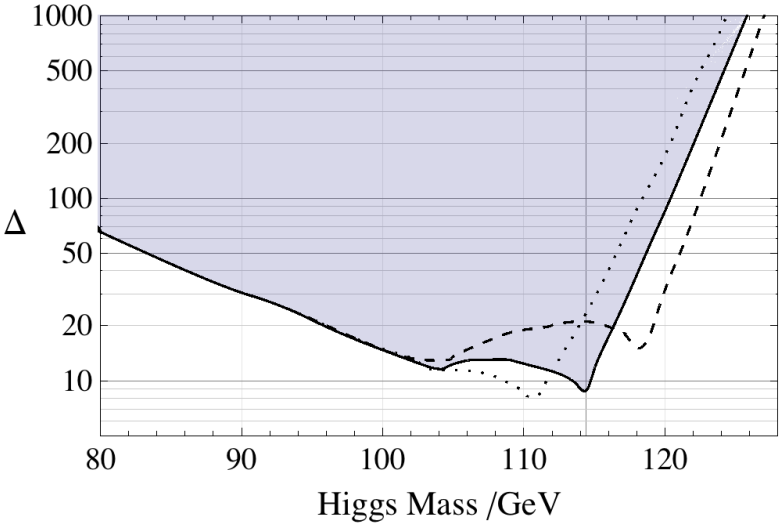

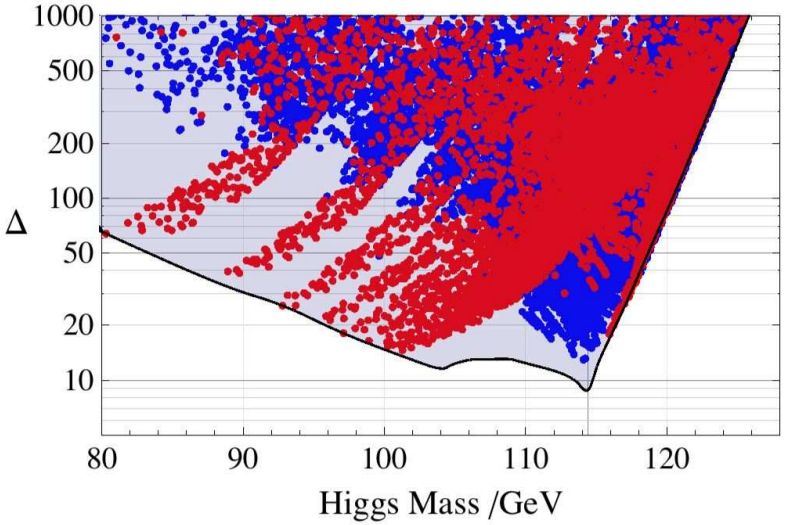

Figure: Minimum fine tuning vs Higgs mass for the scan $2 \leq \tan\beta \leq 55$. The solid, dashed, dotted lines are for $(\alpha_s, M_t) =$ (0.1176, 173.1 GeV), (0.1156, 174.4 GeV) and (0.1196, 171.8 GeV) respectively.
The points have $\Omega h^2 < 0.0913$ and $\Omega h^2 \in 0.1099 \pm 3 \times 0.0062$ [WMAP 3σ bounds]

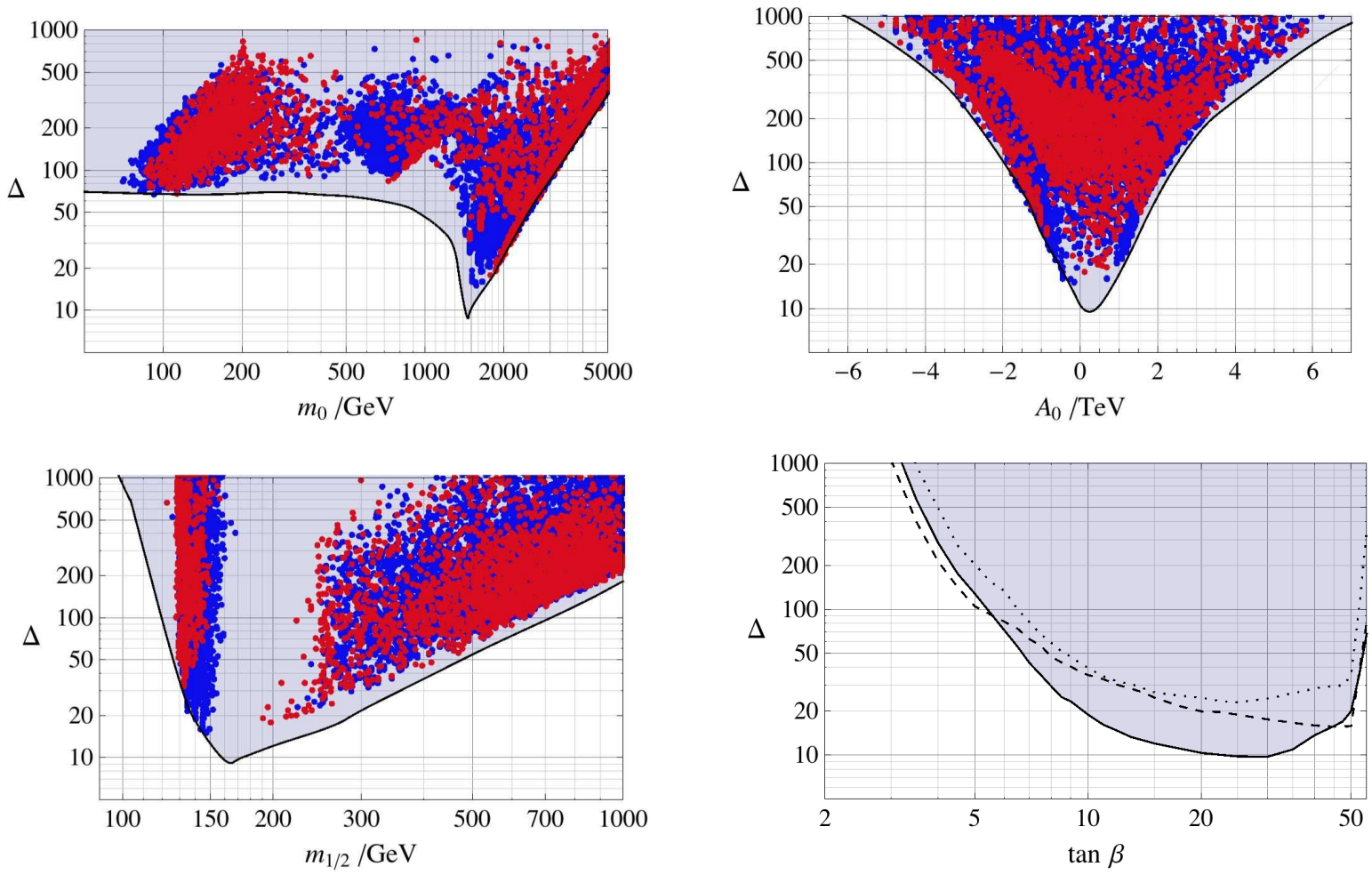

Figure: Fine tuning vs mSUGRA parameters, with $m_h > 114.4$ GeV.

Conclusions

- Having used naturalness as a theoretical motivation for low energy SUSY, we should then expect SUSY to be realised in a region of parameter space that has low fine tuning. An SPS2**-like** spectrum with light gauginos and heavy scalars is preferred.
- Focus points lead to reduced fine tuning. This analysis using 2-loop EWSB and current experimental constraints demonstrates that an O(10%) fine tuning is still possible. Dark matter constraints do not significantly increase fine tuning.
- Testing SUSY with respect to a specific model that posseses scalar and gaugino focus points is powerful in eliminating more general models on naturalness grounds.

$\tilde{g}$	χ_1^0	χ_2^0	χ_3^0	χ_4^0	$\chi_1^\pm$	$\chi_2^\pm$	$\tilde{t}_1$	$\tilde{t}_2$	$\tilde{b}_1$	$\tilde{b}_2$
1720	305	550	660	665	550	670	2080	2660	2660	3140

Table: Upper mass limits on superpartners in GeV (for 1% fine tuning)

h^0	114.5	$\tilde{\chi}_1^0$	79	$\tilde{b}_1$	1147	$\tilde{u}_L$	1444
H^0	1264	$\tilde{\chi}_2^0$	142	$\tilde{b}_2$	1369	$\tilde{u}_R$	1446
$H^\pm$	1267	$\tilde{\chi}_3^0$	255	$\tilde{\tau}_1$	1328	$\tilde{d}_L$	1448
A^0	1264	$\tilde{\chi}_4^0$	280	$\tilde{\tau}_2$	1368	$\tilde{d}_R$	1446
$\tilde{g}$	549	$\tilde{\chi}_1^\pm$	142	$\tilde{\mu}_L$	1406	$\tilde{s}_L$	1448
$\tilde{\nu}_\tau$	1366	$\tilde{\chi}_2^\pm$	280	$\tilde{\mu}_R$	1406	$\tilde{s}_R$	1446
$\tilde{\nu}_\mu$	1404	$\tilde{t}_1$	873	$\tilde{e}_L$	1406	$\tilde{c}_L$	1444
$\tilde{\nu}_e$	1404	$\tilde{t}_2$	1158	$\tilde{e}_R$	1406	$\tilde{c}_R$	1446

Table: A favoured CMSSM spectrum ($\Delta = 14.7$). Masses are given in GeV.

- Allowed parameter space

Constraints on superpartner masses:

$m(\tilde{\chi}_1^0) \gtrsim 46\,\text{GeV}$ $\quad m(\tilde{\chi}_1^\pm) \gtrsim 94\,\text{GeV}$ $\quad m(\tilde{g}) \gtrsim 308\,\text{GeV}$

Constraints from precision tests:

$\text{Br}(b \to s\gamma) = (3.52 \pm 0.32) \times 10^{-4}$
$\text{Br}(b \to \mu\mu) < 1.8 \times 10^{-8}$
$-0.0007 < \delta\rho < 0.0012$
$\delta a_\mu \ < 366 \times 10^{-11}$

WMAP consistent thermal relic density:

$\Omega_{n.b.m.} h^2 = 0.1099 \pm 0.0062$

Non-Universal soft masses

For $\tan\beta = 2.5$, [G. L. Kane and S. F. King, Phys. Lett. B **451**, 113 (1999)]:

$$\begin{aligned}\frac{m_Z^2}{2} &= -0.87\,|\mu_0|^2 + 3.6\,M_3^2 - 0.12\,M_2^2 + 0.007\,M_1^2 \\ &\quad +0.25\,M_2\,M_3 + 0.03\,M_1\,M_3 + 0.007\,M_1\,M_2 \\ &\quad -0.71\,m_{H_2}^2 + 0.19\,m_{H_1}^2 + 0.48\left(m_Q^2 + m_U^2\right) \\ &\quad -0.34\,A_t\,M_3 - 0.07\,A_t\,M_2 - 0.01\,A_t\,M_1 + 0.09\,A_t^2\end{aligned}$$

Constrained MSSM (CMSSM / mSUGRA)

- The notation used is defined below:

$$W = -\mu H_1 H_2 + Y_e L H_1 E + Y_d Q H_1 D + Y_u Q H_2 U$$

$$V_{\text{SOFT}} = m_0^2 \sum_i |\phi_i|^2 + m_{1/2} \sum_j \lambda_j \lambda_j - \left(B_0 \mu_0 H_1 H_2 + h.c.\right)$$
$$+ \left[A_0 \left(Y_e L H_1 E + Y_d Q H_1 D + Y_u Q H_2 U\right) + h.c.\right]$$

$$V_{\text{2HDM}} = m_1^2 |H_1|^2 + m_2^2 |H_2|^2 - \left(m_3^2 H_1 H_2 + h.c.\right)$$
$$+ \tfrac{\lambda_1}{2} |H_1|^4 + \tfrac{\lambda_2}{2} |H_2|^4 + \lambda_3 |H_1|^2 |H_2|^2 + \lambda_4 |H_1 H_2|^2$$
$$+ \left[\tfrac{\lambda_5}{2} (H_1 H_2)^2 + \lambda_6 |H_1|^2 (H_1 H_2) + \lambda_7 |H_2|^2 (H_1 H_2) + h.c.\right]$$

$$\langle H_1 \rangle = \begin{pmatrix} v \cos\beta/\sqrt{2} \\ 0 \end{pmatrix} \qquad \langle H_2 \rangle = \begin{pmatrix} 0 \\ v \sin\beta/\sqrt{2} \end{pmatrix}$$