Persistent Fine-Tuning in Supersymmetry and the NMSSM

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$\rightarrow$ Tuning is persistent!

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- Naively, $m_S \gtrsim 500$ GeV $\rightarrow$ the weak scale already looks unnatural at the 1% level!

A Little Hiearchy Problem in SUSY?

- $m_Z^2 = \frac{1-\cos(2\beta)}{\cos(2\beta)} m_{H_u}^2 - \frac{1+\cos(2\beta)}{\cos(2\beta)} m_{H_d}^2 - 2\mu^2.$

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- The entire SUSY spectrum seems heavier than M_Z!

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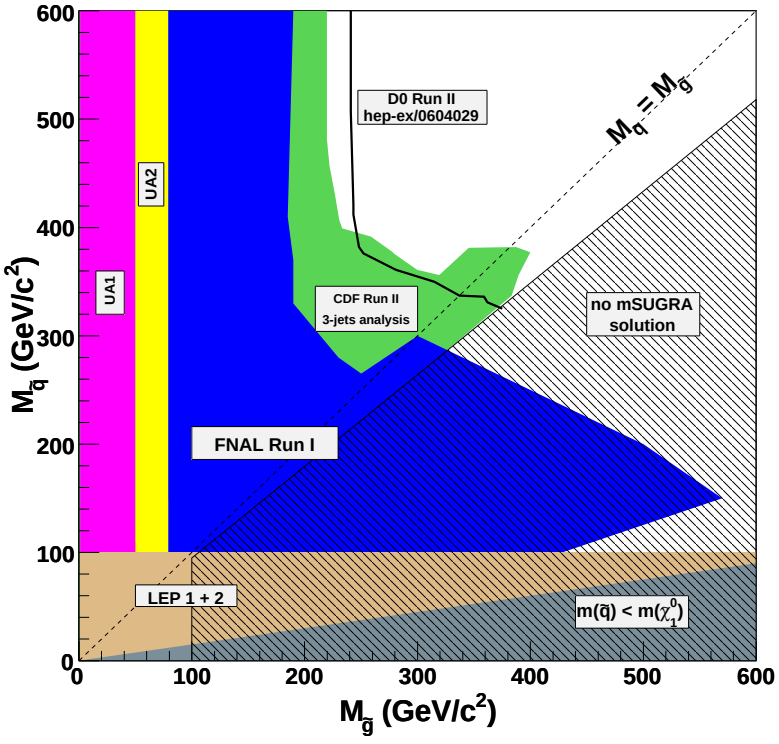
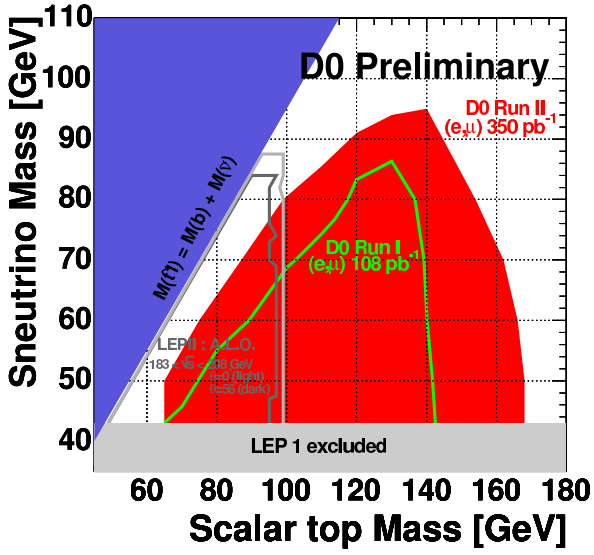
- Do non-standard Higgs scenarios relieve fine-tuning?
- What should we expect the SUSY spectrum to look like?

Gluino and Squark Searches

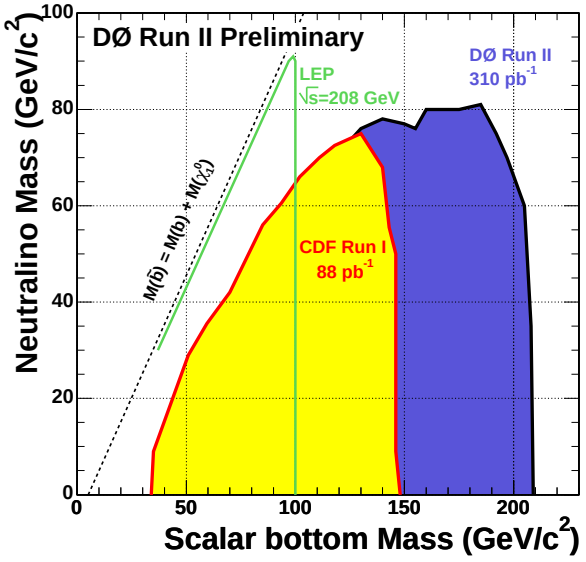


CDF Run II Prelim.

Stop and Sbottom Searches



D0 note 5050-CONF



D0 note 4832-CONF

Third generation squarks should be light while first two generations are $\gtrsim 400$ GeV.

Tuning from Heavy Higgs

- $m_h^2 < M_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2} v^2 y_t^4 \sin^4 \beta \ln\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}\right).$

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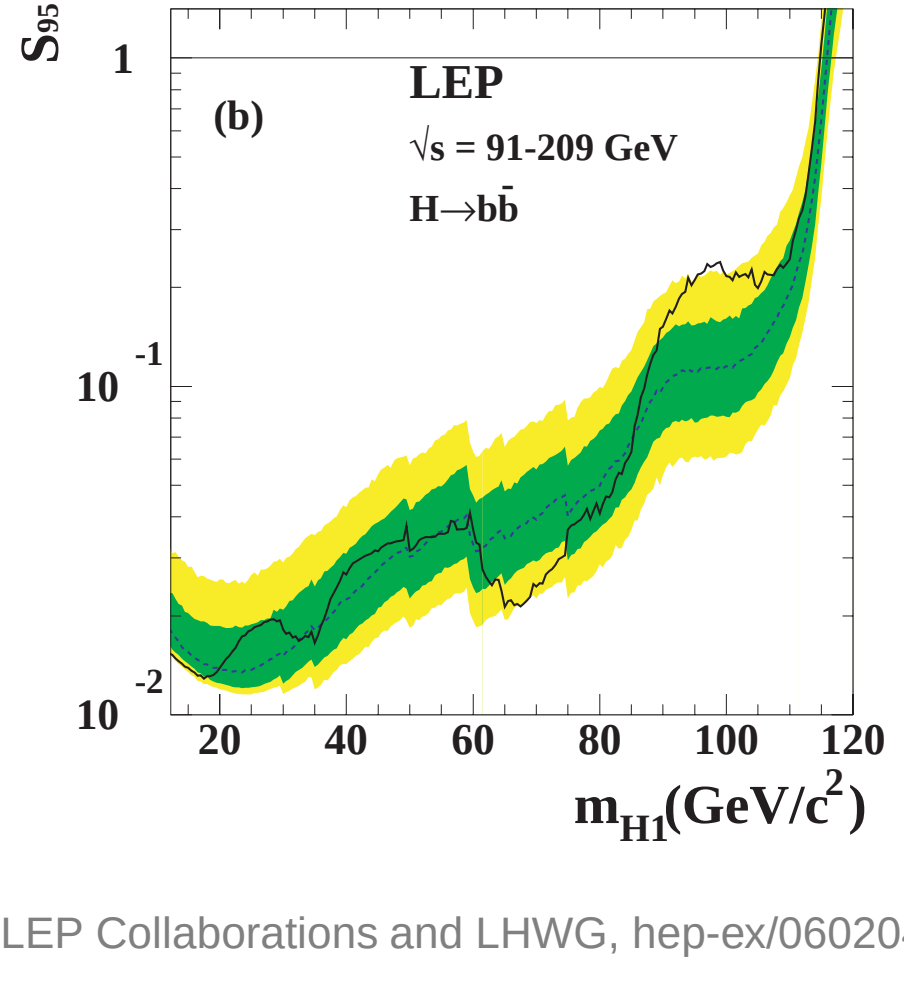
- Possible solutions invalidate tree level relation (new contributions to Higgs quartic coupling, lower the SUSY mediation scale, non-standard Higgs...etc).

Tension with Heavy Higgs



LEP Collaborations and LHWG, hep-ex/0602042

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  $\lambda^2(h_u^2 s^2 + h_d^2 s^2 + h_u^2 h_d^2) + \kappa^2 s^4 - 2\lambda\kappa h_u h_d s^2 + \frac{1}{4} g^2 (h_u^2 - h_d^2)^2$
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- Extra singlet scalar and pseudo-scalar that mix with Higgs states. Extra fermion singlino.

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- Two approximate symmetry limits generate a naturally light a, $U(1)_{PQ}$ and $U(1)_R$.

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- To keep $m_{a_1} \lesssim 10$ GeV, need $\kappa \lesssim 0.01\lambda$.

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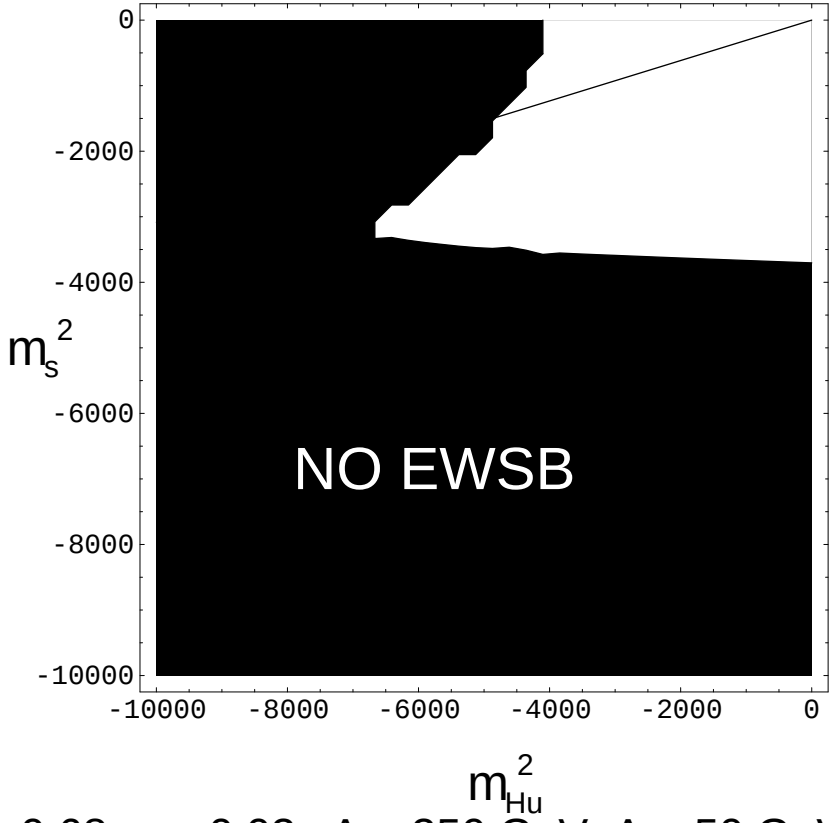
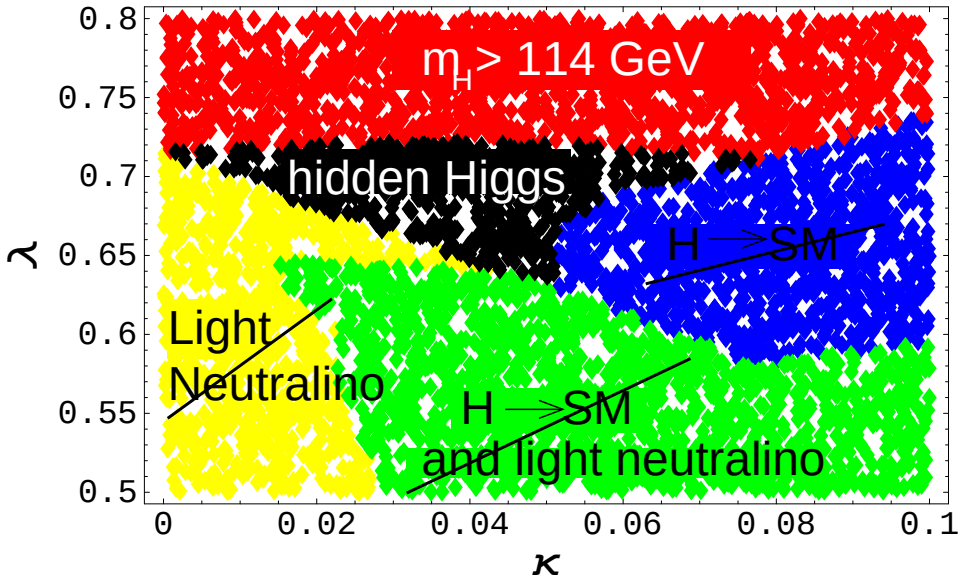
- Large μ requires large $A_\lambda \gtrsim (250-350)$ GeV $\rightarrow$ EW tuning

Tuning for Electroweak Symmetry Breaking



λ=0.68 κ=0.03 A_λ=350 GeV A_κ=50 GeV

Phenomenology Tuning



$A_\lambda = 350$ GeV $A_\kappa = 50$ GeV $m_{Hu}^2 = -(40\text{ GeV})^2$ $m_s^2 = 0$

Analyzed using NMHDECAY I (Ellwanger, Hugonie, hep-ph/0406215).
Thanks to A. Sopczak for LEP $H \to 4b$ exclusion contours

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- $m_{a_1}^2 \approx \frac{9\lambda^2 v^2 A_\lambda \sin(2\beta)}{4\mu} - \frac{3\mu A_\kappa}{2}$.

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- SM A-terms and gaugino masses break $U(1)_R$, generating $\delta A_\lambda \sim 100$ GeV.
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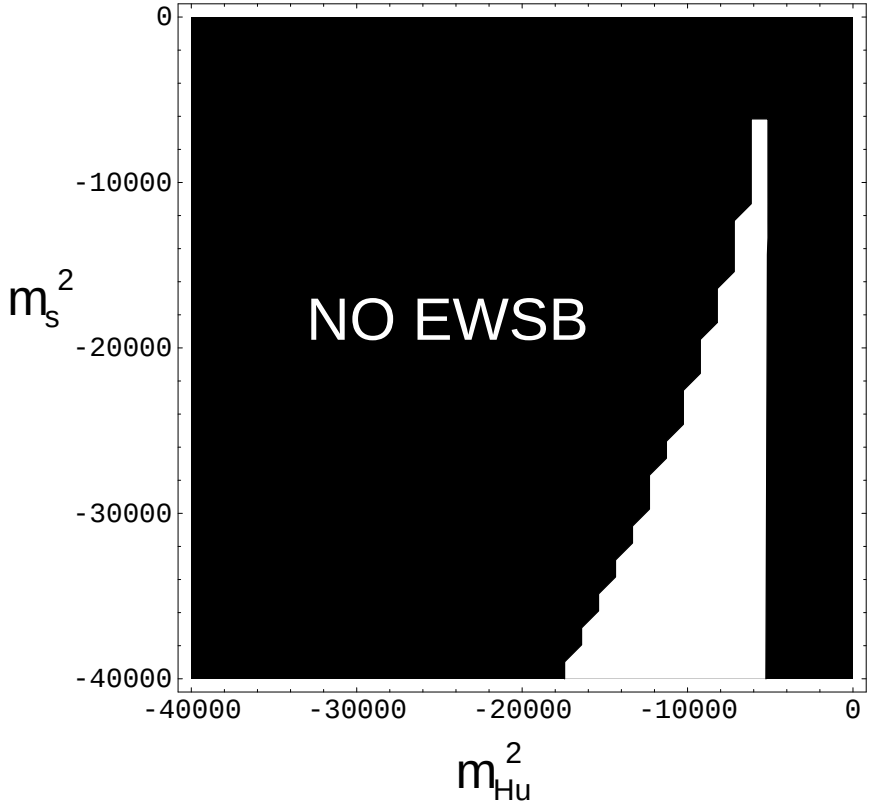
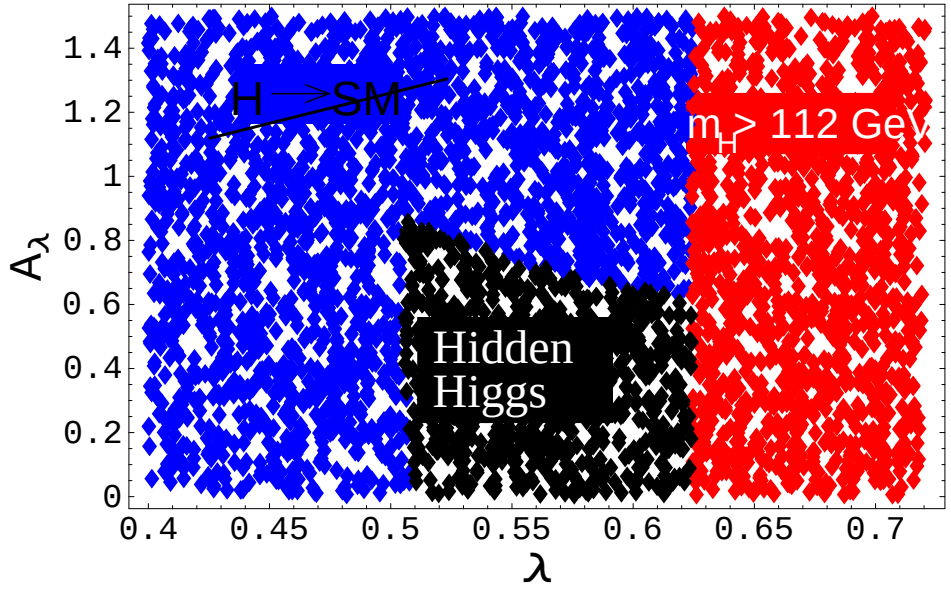
- Radiative EWSB works, but requires negative m_S^2 at high scales.

Electroweak Symmetry Breaking in the R-Limit



$\kappa = \lambda = 0.63$ $A_\lambda = 0.5$ GeV $A_\kappa = 0$

$U(1)_R$ Higgs Constraints



$\kappa = 0.65 \quad A_\kappa = 0 \qquad m_s^2 = 4\, m_{Hu}^2 = -(200\ \mathrm{GeV})^2$

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- NMSSM (or extensions) can accommodate non-standard Higgs scenarios.

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