Induced EWSB and SUSY Naturalness

Markus Luty
UC Davis

A. Azatov, J. Galloway, ML 1106.3346, 1106.4815

J. Galloway, ML, Y. Tsai, Y. Zhao 1306.6354

Introduction

$m_h = 125$ GeV, SM-like couplings (±10%)

Good for SUSY?

MSSM: tree-level: $\lambda_h \sim g \Rightarrow m_h < m_Z$

loops: $\Delta\lambda_h \sim y_t^4 \ln m_{\tilde{t}}$

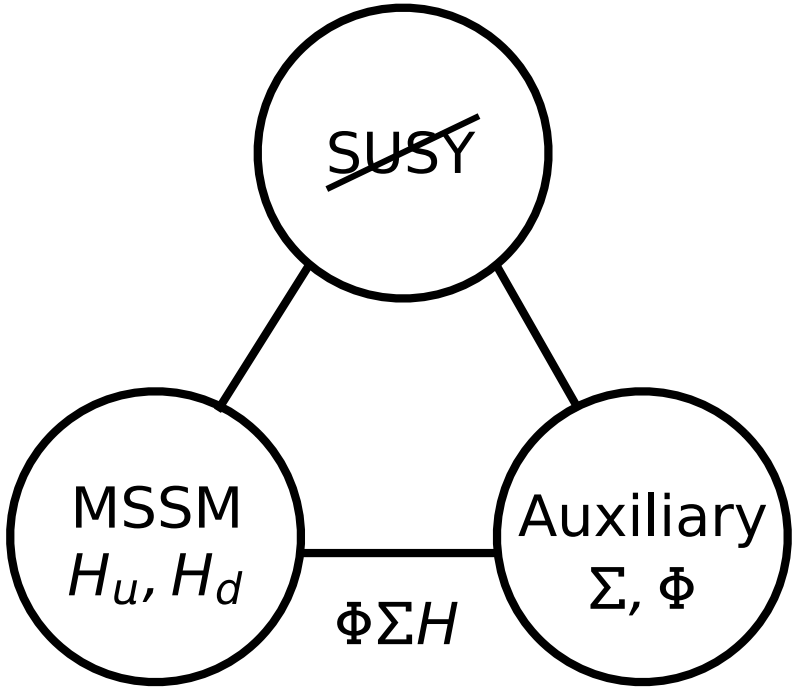
$\Delta m_h^2 \sim y_t^2 m_{\tilde{t}}^2 \Rightarrow$ tuned

NMSSM, non-decoupling D terms, fat Higgs,. . .

- Tension with unification
- ‘Natural’ only for special parameters

Look for robust natural solution

Induced EWSB

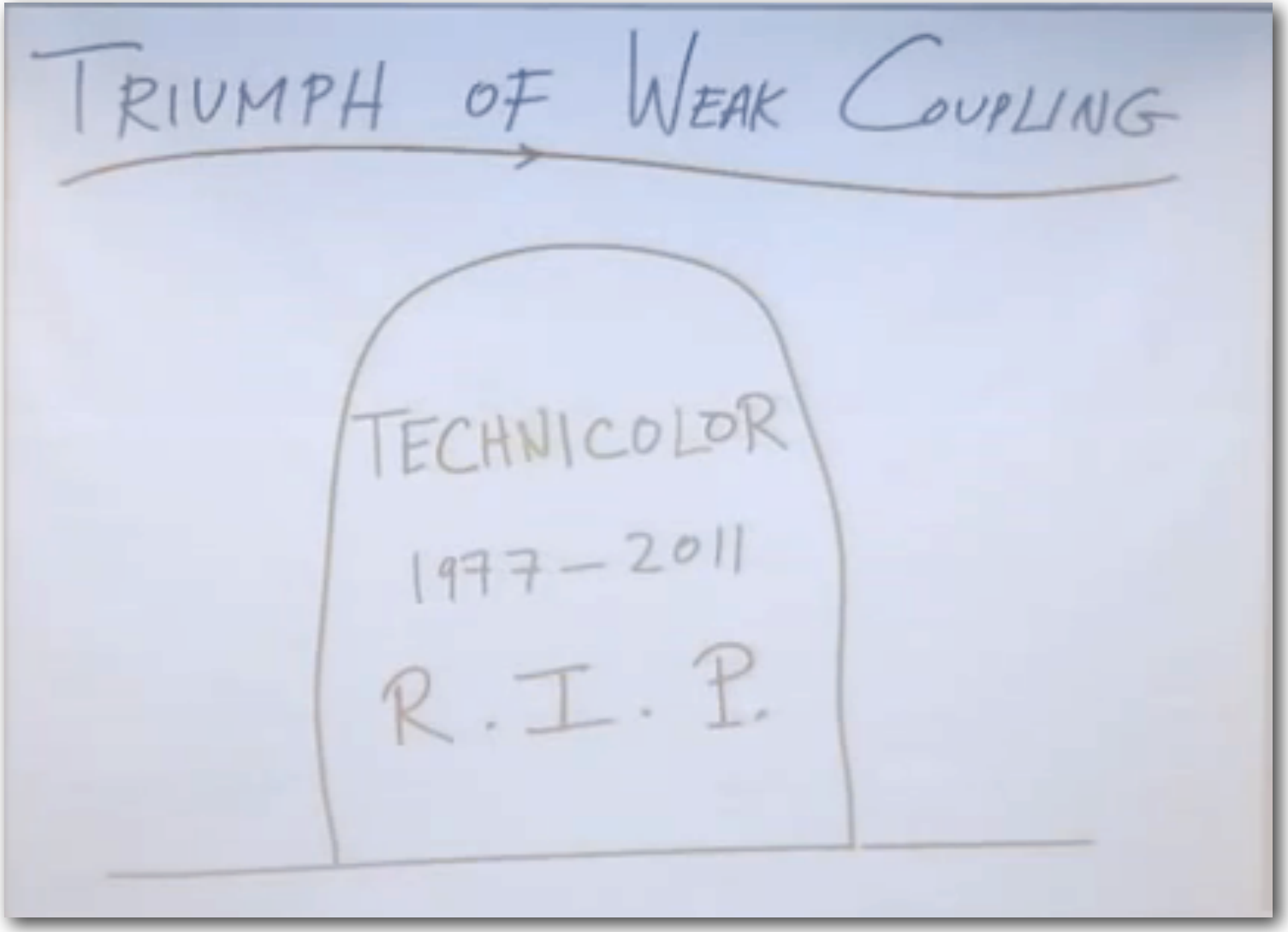


‘Auxiliary’ Higgs sector with large quartic, no Yukawa couplings

$$v^2 = v_u^2 + v_d^2 + f^2 = (246\ \text{GeV})^2$$

$$f \simeq 150\ \text{GeV} \Rightarrow \sqrt{v_u^2 + v_d^2} \simeq 195\ \text{GeV}$$

Superconformal Technicolor



N. Arkani-Hamed

Superconformal Technicolor

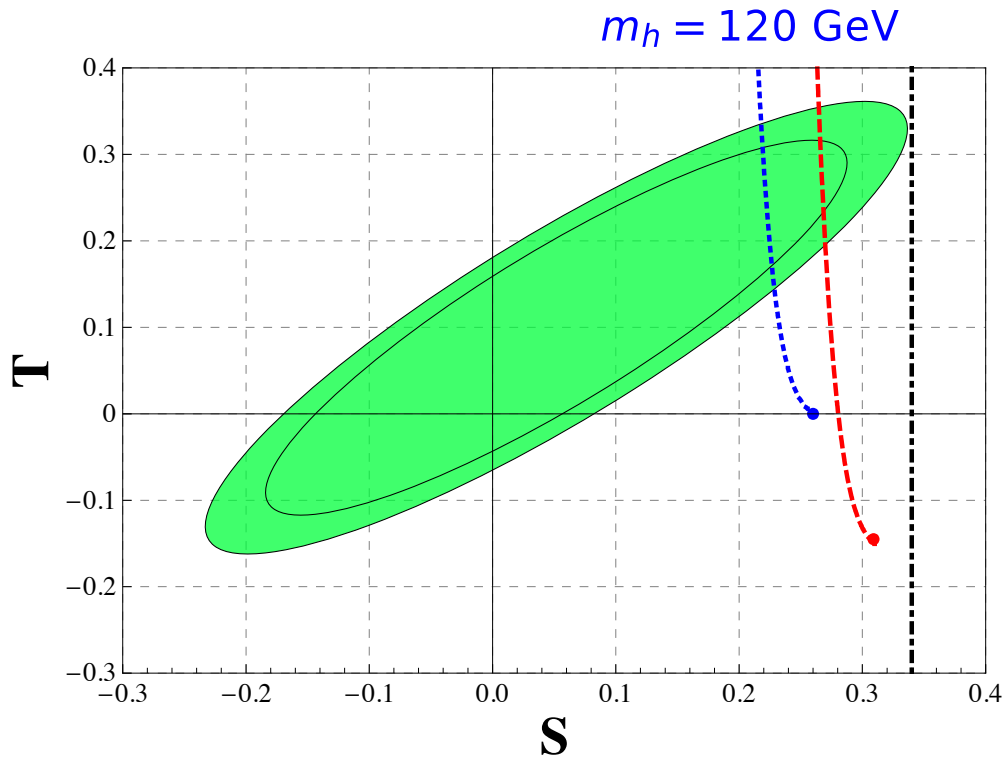
It’s back!

Superconformal Technicolor

SUSY breaking triggers confinement, EWSB in strong superconformal sector

$m_\rho \sim 4\pi f \sim$ TeV

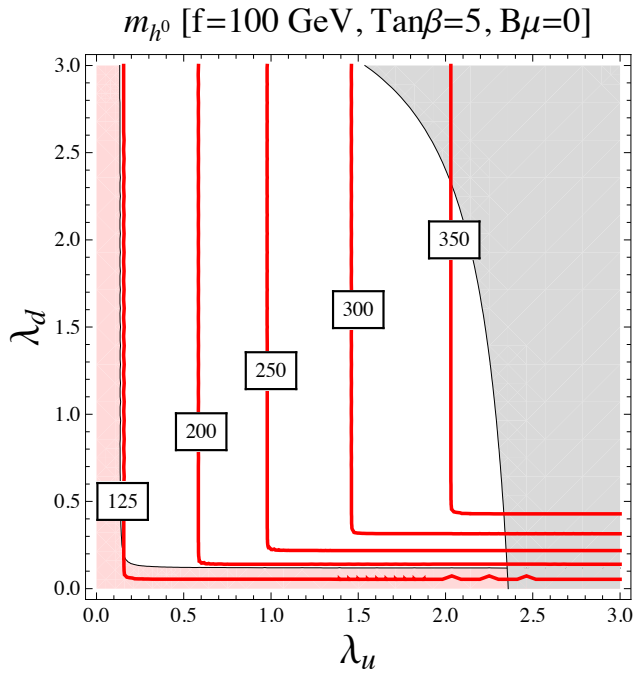
No ETC needed!

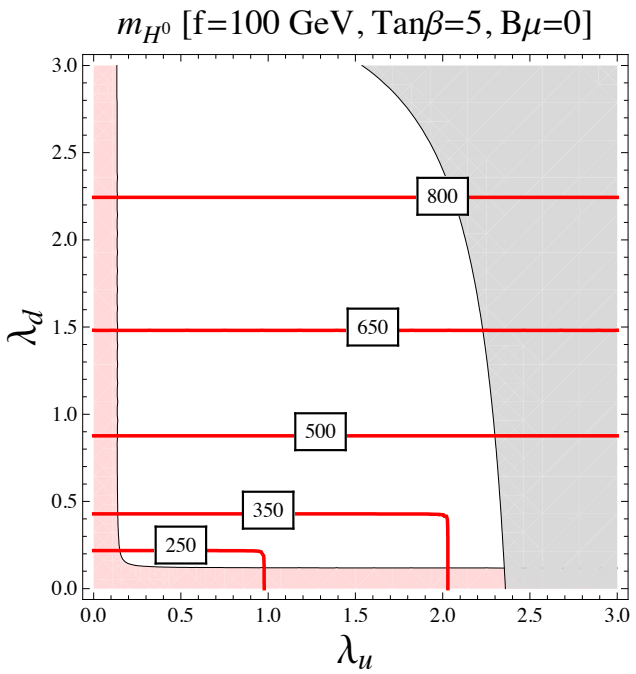


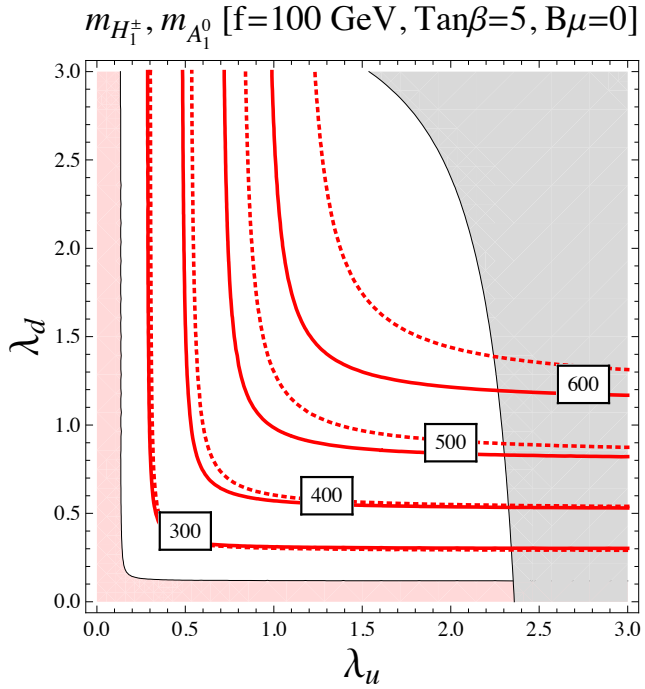
Precision EW:

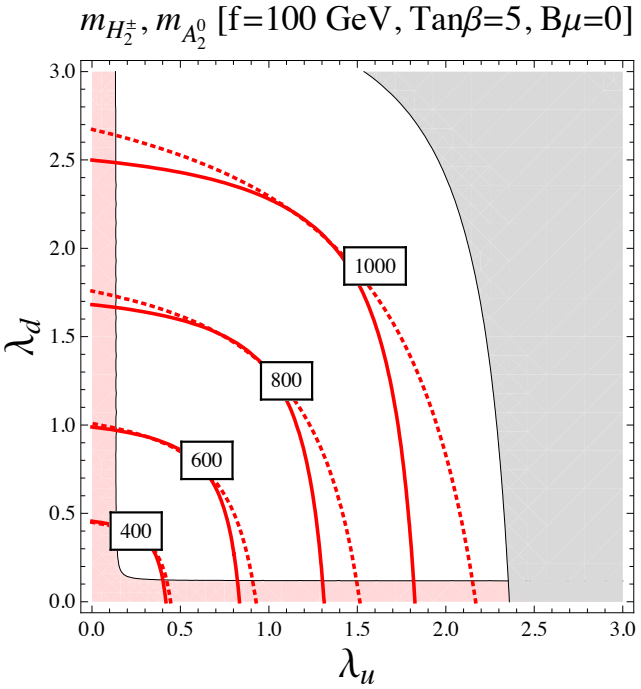
- S reduced because ‘pions’ massive
- $\Delta T > 0$ from $H_u \mathcal{O}_d \neq H_d \mathcal{O}_u$

Superconformal Technicolor









$$\frac{\delta g_{hVV}}{g_{hVV}^{(\mathrm{SM})}} \simeq 8\%$$

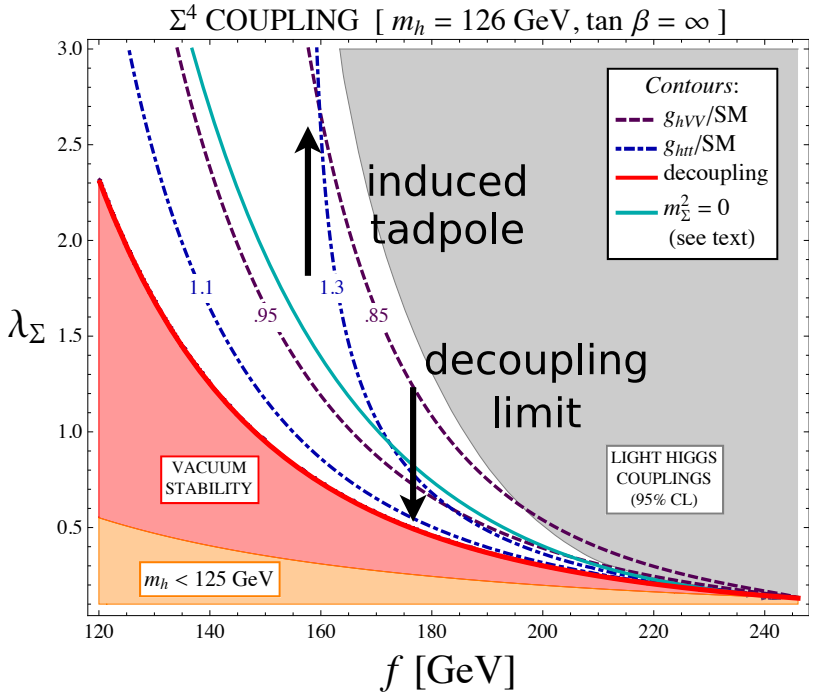
Simplified Perturbative Model

$$V = m_H^2|H|^2 + m_\Sigma^2|\Sigma|^2 - \kappa^2(\Sigma^\dagger H + \text{h.c.}) + \lambda_\Sigma|\Sigma|^4$$

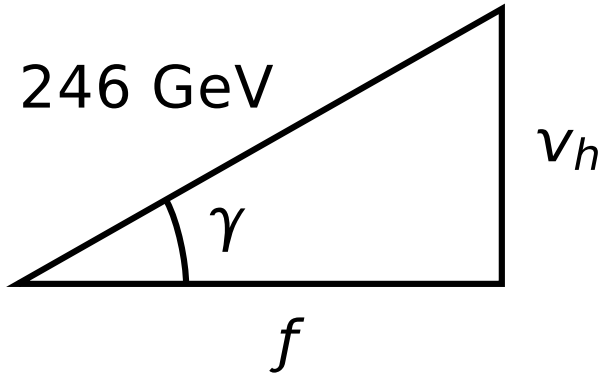
$$\langle H \rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v_h \end{pmatrix} \qquad \langle \Sigma \rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ f \end{pmatrix}$$

Lightest CP-even mass eigenstate = 125 GeV

$\Rightarrow$ 2 parameters (f, λ_Σ)



Decoupling Limit



$\gamma = \text{fixed}$

$$m_2^2 \to +\infty$$

$$\begin{pmatrix} H_1 \\ H_2 \end{pmatrix} = \begin{pmatrix} \sin\gamma & \cos\gamma \\ \cos\gamma & -\sin\gamma \end{pmatrix} \begin{pmatrix} H \\ \Sigma \end{pmatrix}$$

$$V_{\text{eff}} = m_1^2 |H_1|^2 + \underbrace{\lambda_\Sigma \cos^4\gamma |H_1|^4}$$

Induced quartic

Induced Tadpole

$\lambda_\Sigma \to \infty \Rightarrow m_\Sigma^2 \to -\infty$

$\kappa^2 \sim$ constant $\Rightarrow H, \Sigma$ decoupled

$$f^2 = \frac{m_\Sigma^2}{\lambda_\Sigma} = \text{fixed} \qquad m_2^2 = 2\lambda_\Sigma f^2 \to +\infty$$

$$V_{\text{eff}} = \tfrac{1}{2} m_H^2 h_1^2 - \kappa^2 f h_1 + \cdots$$

$$v_h = \frac{\kappa^2 f^2}{m_H} \qquad m_1^2 = m_H^2$$

Higher orders in κ^2 suppressed by $\dfrac{\kappa^2 h}{\lambda_\Sigma f^2} \sim \dfrac{m_1^2}{m_2^2}\dfrac{v_h^2}{f^2}$

Higgs quartic (cubic) can be small!

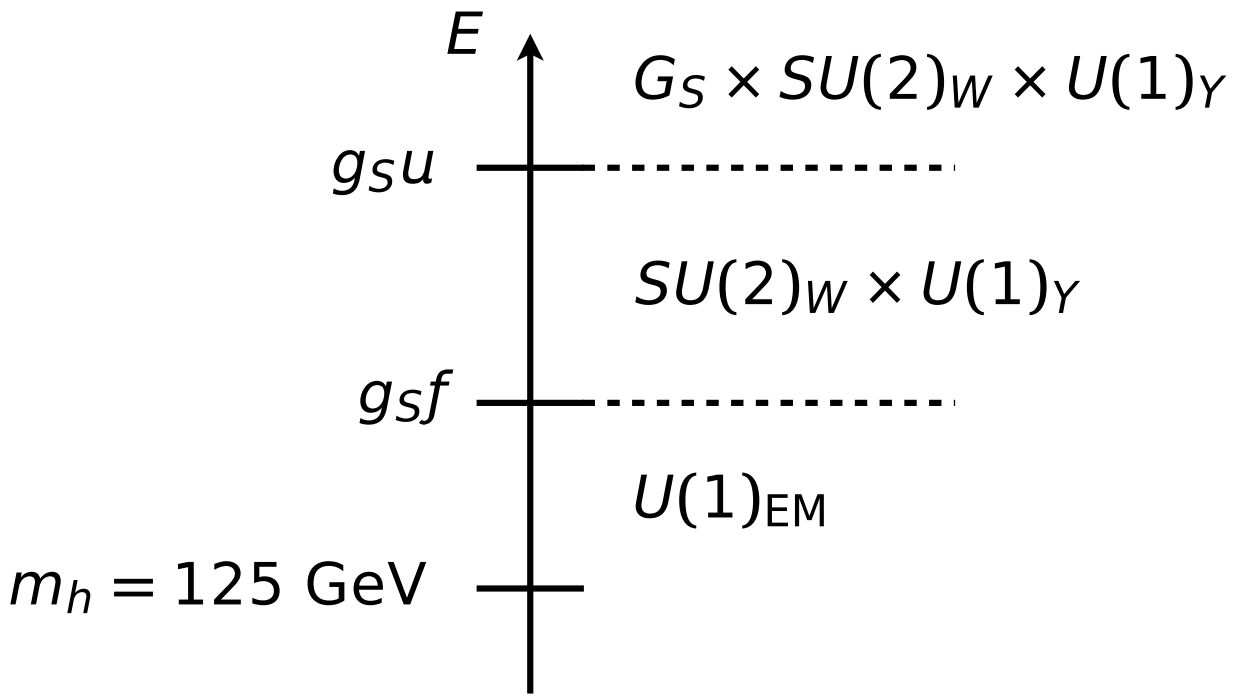
D-Term Models

$\Sigma_{u,d} =$ EW doublets

$\Phi, \tilde{\Phi} =$ EW singlets

Charged under new gauge group $G_S \Rightarrow \lambda_\Sigma \sim g_S^2$

Effective theory (induced tadpole): $\langle \Phi \rangle, \langle \tilde{\Phi} \rangle \sim u$



Unification & Precision EW

Similar to non-decoupling D-term models,
but more ‘modular’

$\Phi, \Sigma \in$ complete $SU(5)$ multiplets $\Rightarrow$ unification

Precision electroweak:

$\langle \Sigma \rangle$ mixes G_S and $SU(2)_W$

$\Rightarrow$ tree-level ΔT

$\Rightarrow u \gtrsim 2$ TeV

Also protects unification. . .

Tuning

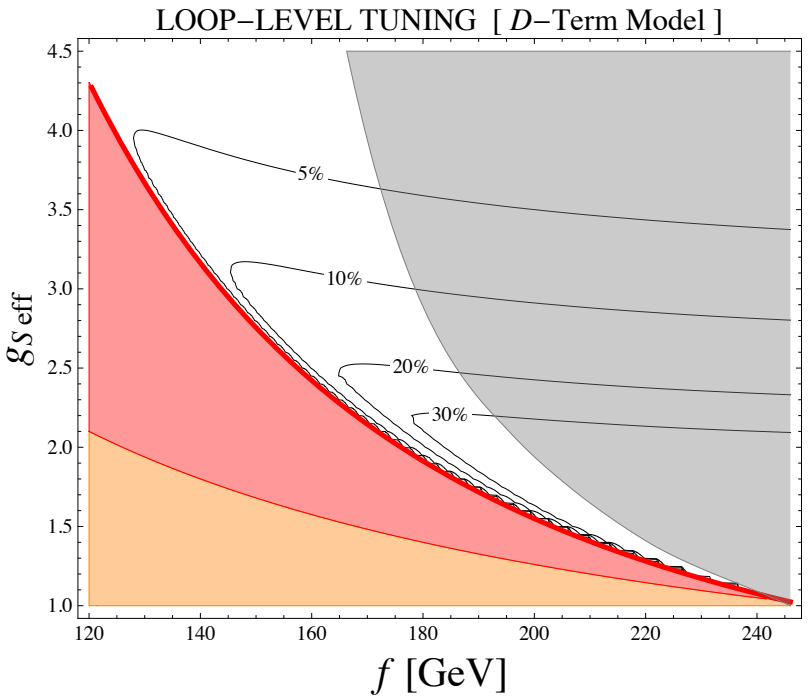
$f, v \sim \frac{u}{10} \Rightarrow$ little hierarchy

Tree level: $\Delta m_\Sigma^2 \sim g_S^2(u^2 - \tilde{u}^2)$

$\Rightarrow u \simeq \tilde{u}$ (D-flat direction)

$u = \langle \Phi \rangle, \ \tilde{u} = \langle \tilde{\Phi} \rangle$

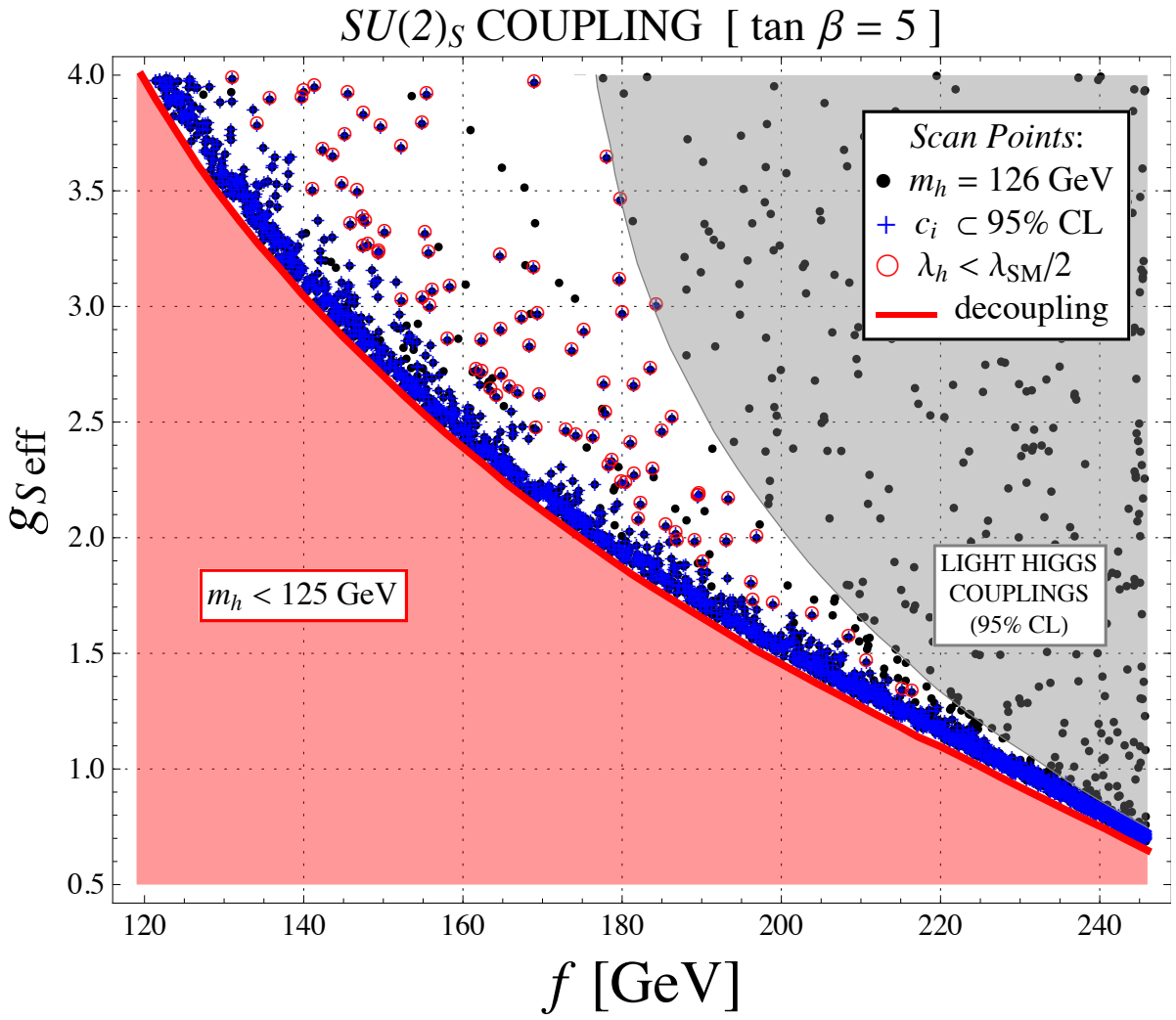
Loop level: $\Delta m_\Sigma^2 \sim \left(\frac{g_S^2}{16\pi^2} \right)^2 m_\Phi^2$



< 10% tuning in <u>all</u> of allowed parameter space

Robust!

Higgs Phenomenology



$\lambda_h < \frac{1}{2}\lambda_{SM}$ in most of parameter space

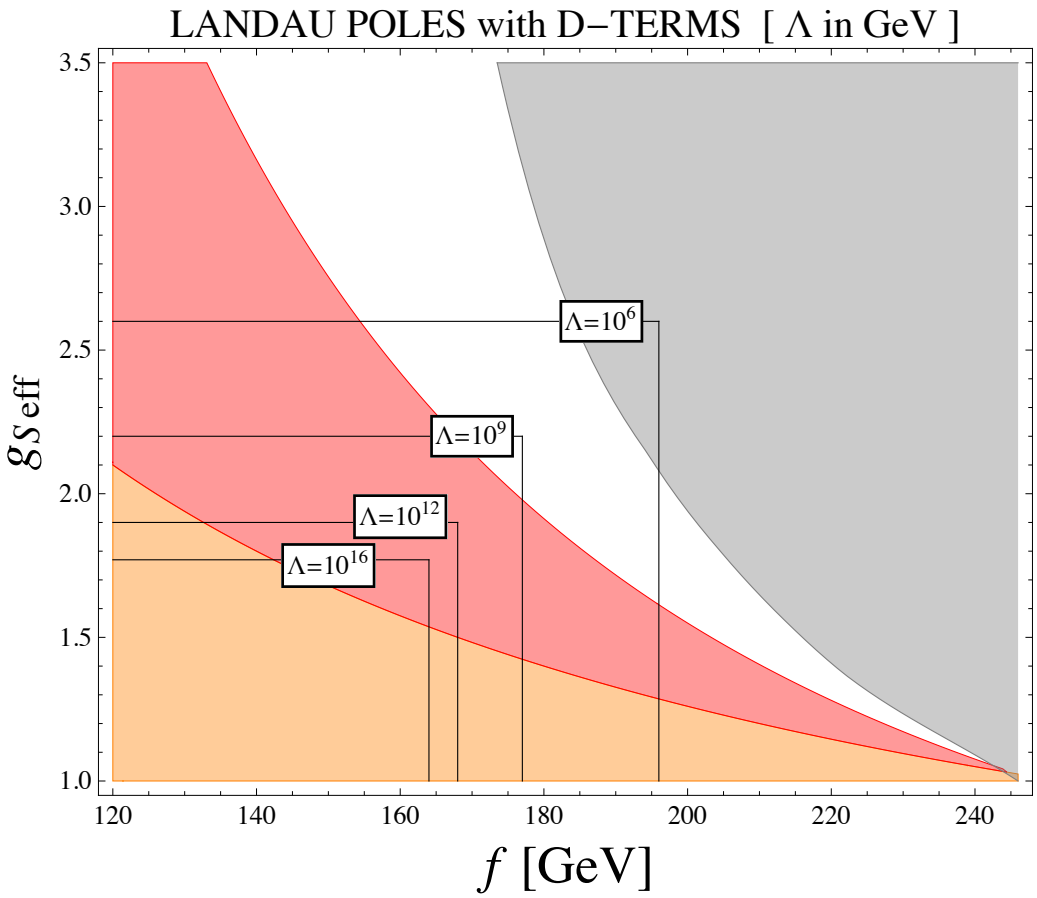
The Model

$SU(2)_S \times SU(5)_{SM}$

$(\Sigma_u, T) \sim (2, 5)$

$(\Sigma_d, \tilde{T}) \sim (2, \bar{5})$

$\Phi, \tilde{\Phi} \sim (2, 1)$



$\beta(g_S) = 2$ loop

$\Rightarrow g_S$ naturally large at weak scale?

UV Completion

All $SU(2)_S$ charged fields in $SU(5)$ multiplets

$\Rightarrow$ simple UV completion of g_S Landau pole

$SU(3)_S$ with 7 flavors

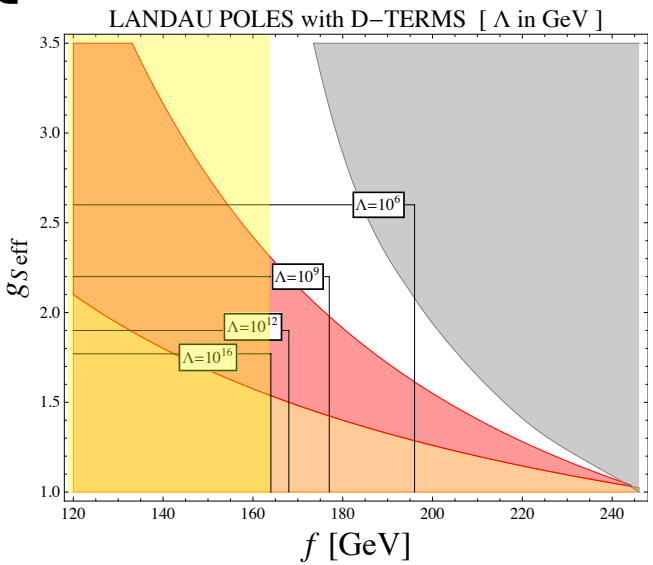
(Extra Higgs field to break $SU(3)_S \to SU(2)_S$)

Has strong IR stable fixed point

Broken at scale $\lesssim 10^3$ TeV

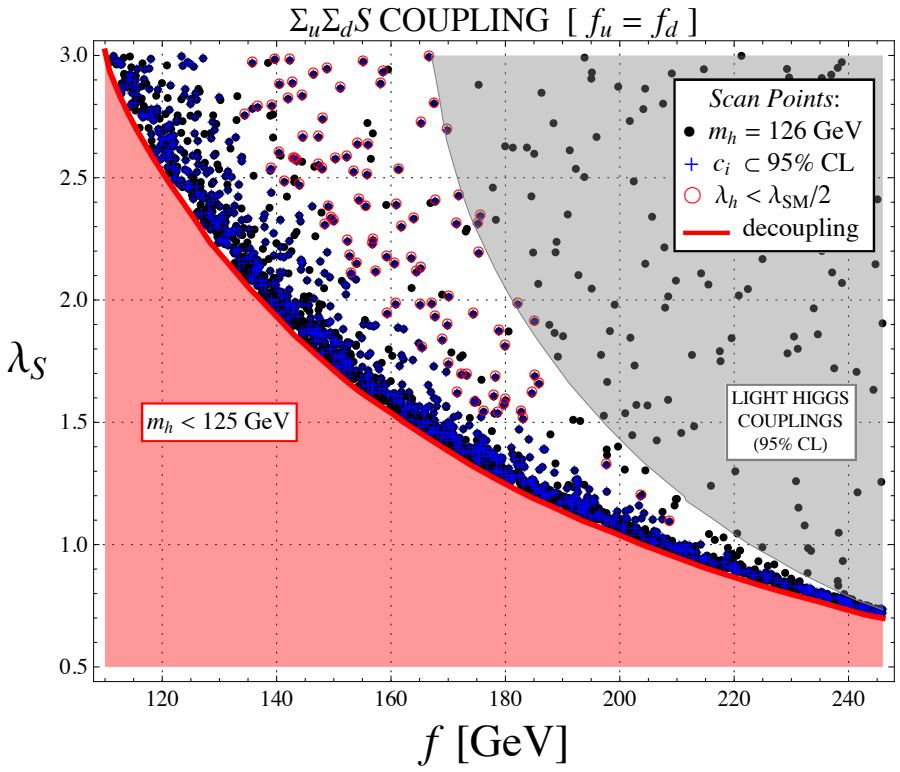
$\Rightarrow g_S \gtrsim 2.3,\ f \lesssim 165$ GeV

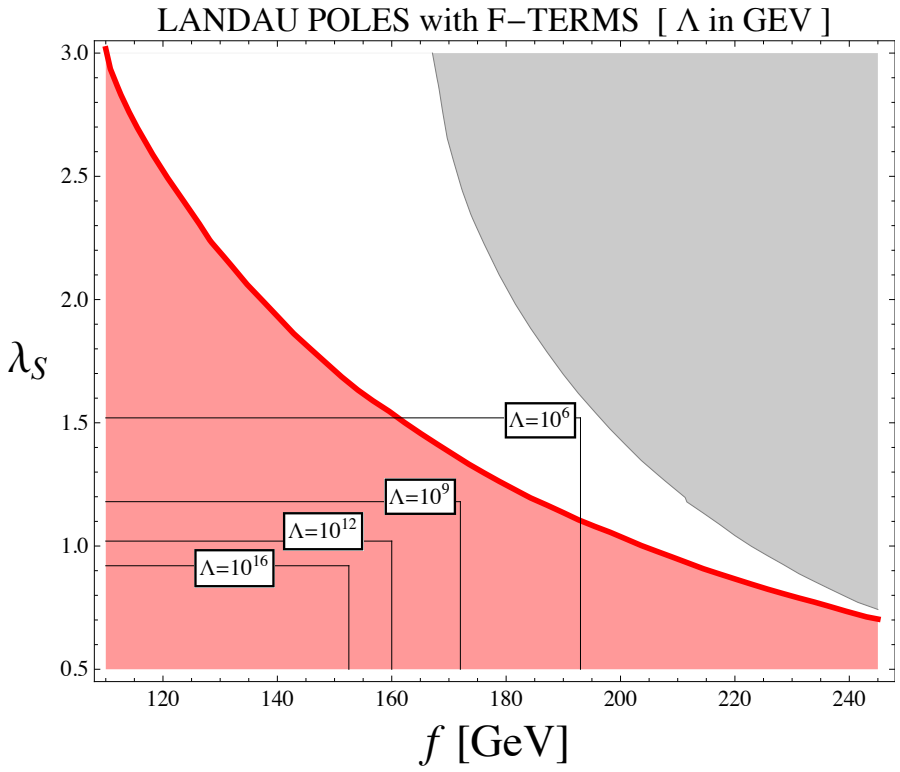
Or top compositeness...



F-Term Models

$$W = \lambda_S S \Sigma_u \Sigma_d$$





Phenomenology

- Auxiliary Higgs must mix with MSSM Higgs

  $\Rightarrow$ can't hide!

- Higgs cubic highly suppressed in most of parameter space

- Naturalness motivates light stop, Higgsino, gluino

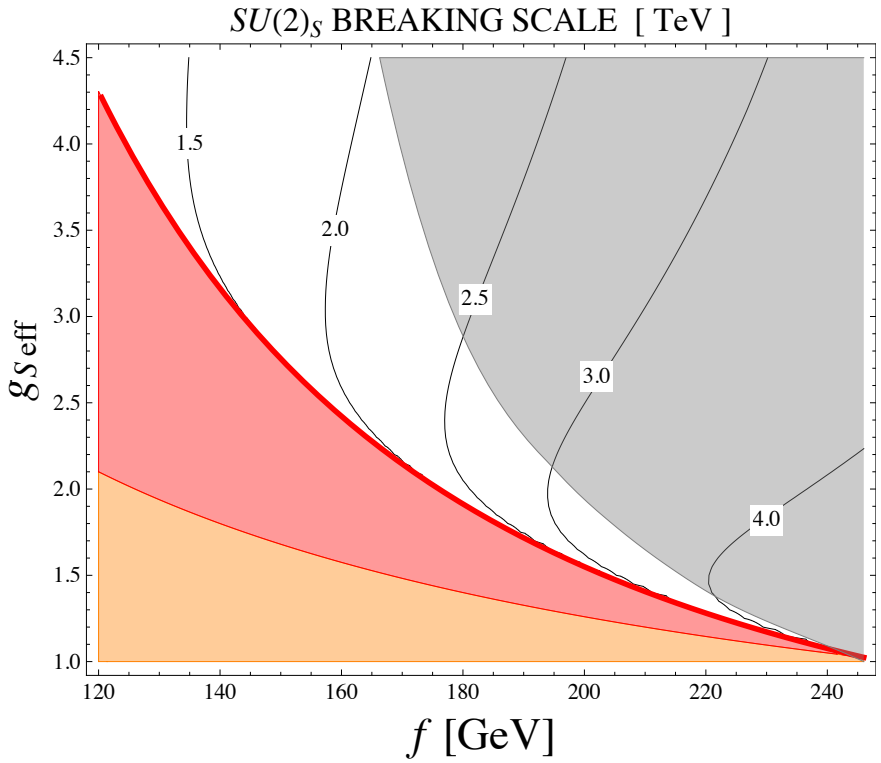
Conclusions

- Induced EWSB gives a robust solution to Higgs naturalness in SUSY

- Will be tested at LHC14

Backup

“Sister Higgs”



$$W = \lambda \Phi \Sigma H$$

$$\Rightarrow \Delta V = |\lambda|^2 \left[\underbrace{|\Sigma H|^2}_{\text{good}} + \underbrace{|\Phi|^2 (|\Sigma|^2 + |H|^2)}_{\text{bad}} \right]$$