The Higgs Mass Bound in Extensions of the MSSM

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hep-ph/0309149
hep-ph/0404251

The SM

Anagram:

"Tested Damn Hard" (l,o)

The MSSM

Anagram:

"Resilient Scam Amidst Theory-Madmen" (p,l,u,r,m)

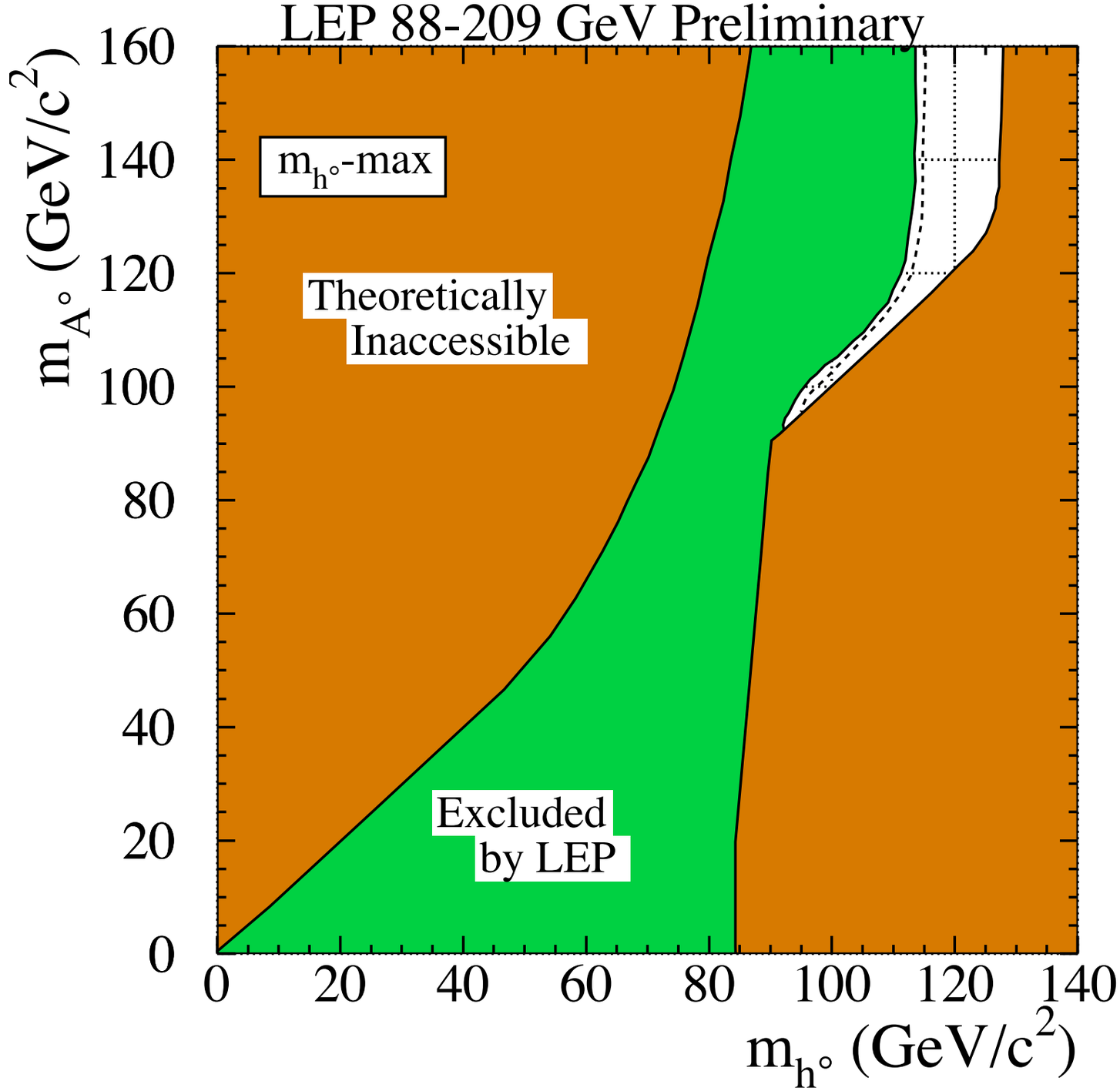
- $m_{h^0} \leq M_Z$
- for large $m_{\tilde{t}}$

  $m_{h^0} \leq 130 \text{ GeV}$

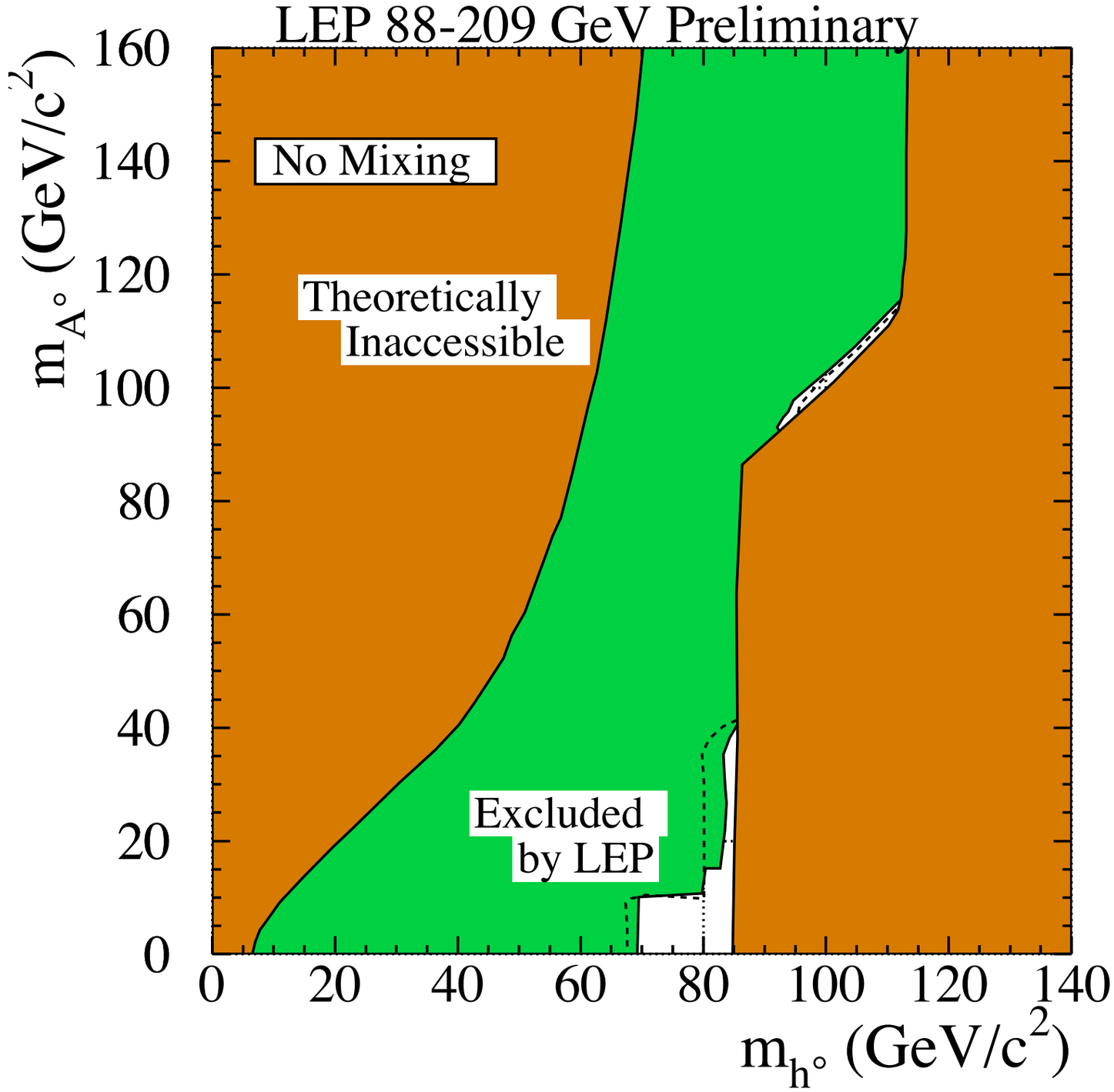
-how much fine tuning?

- maximal mixing?

Maximal Mixing

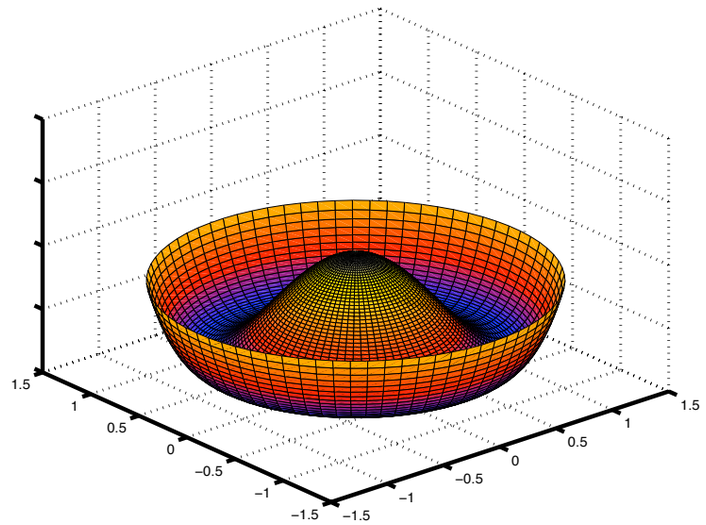


Minimal Mixing



Why is $m_{h^0} < M_Z$?

- the quartic, λ, controls m_{h^0}



$$V_H \supset \lambda H^4$$

$$m_{h^0} \sim \lambda v^2$$

- the SM does not constrain λ
- the MSSM does!

$$\lambda \sim \frac{g^2 + g'^2}{8}$$

which is small, and so then is m_{h^0}

Alphabet Soup?

How to increase λ

1) "MSSM+S"--New Superpotential interactions

- requires new matter and couplings

$$\lambda_S S H \overline{H}$$

$$\lambda \to \lambda + \lambda_S$$

- limited by perturbativity

$$m_{h^0} \leq 200 \text{ GeV}$$

(Espinosa & Quiros,1998)

How to increase λ

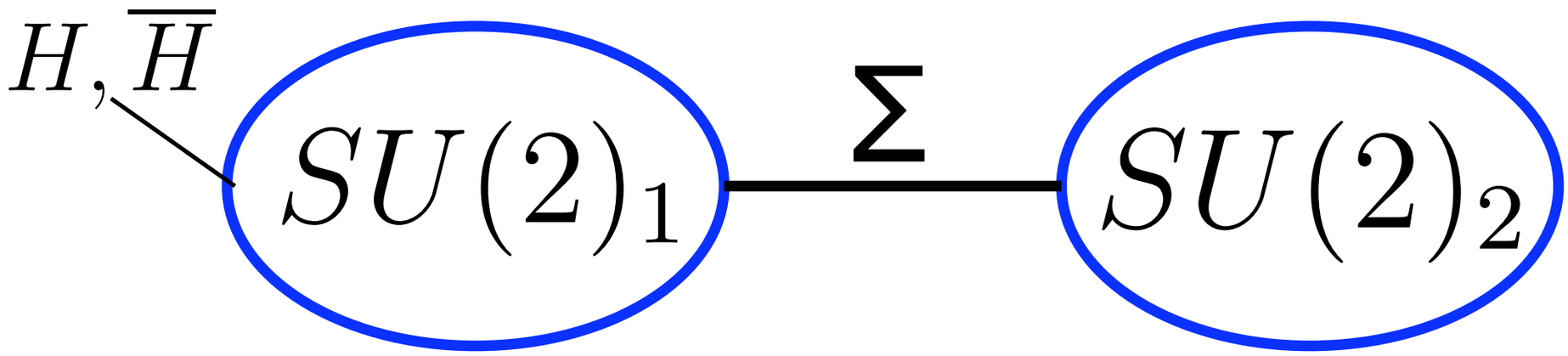
2) new D-terms (gauge interactions)

- substitute

- $\lambda \sim \dfrac{g^2 + g'^2}{8} \rightarrow \dfrac{\Delta g^2 + g'^2}{8}$

- an asymptotically-free contribution
- significantly larger λ, and... m_{h^0}

Decoupling D-terms



- the **Superpotential** gives $\langle \Sigma \rangle = u \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$

- $SU(2)_1 \times SU(2)_2 \to SU(2)_D \equiv SU(2)_L$

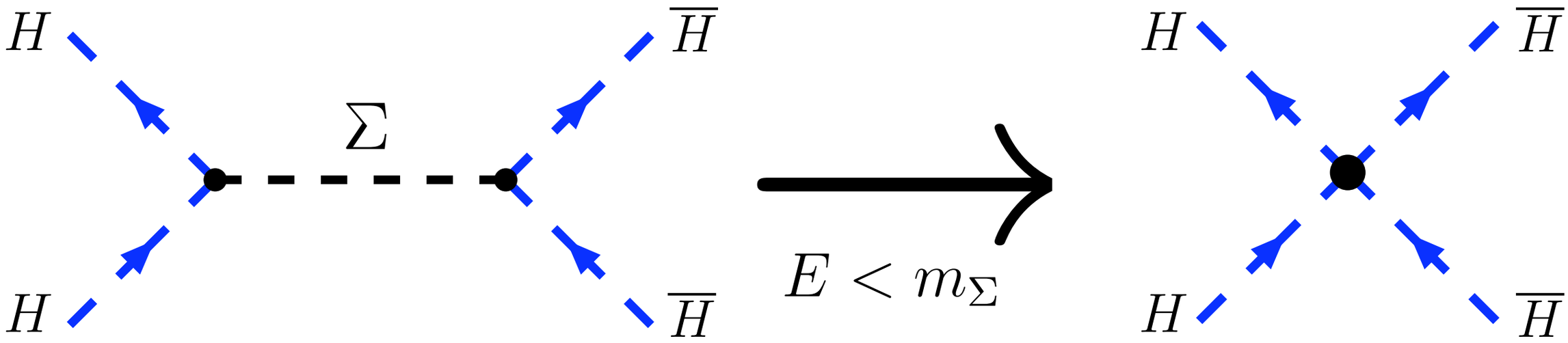
- W', Z' with $m \sim u^2 \left(g_1^2 + g_2^2 \right)$

- no enhancement: $\lambda \sim \dfrac{g^2 + g'^2}{8}$

Non-decoupling D-terms

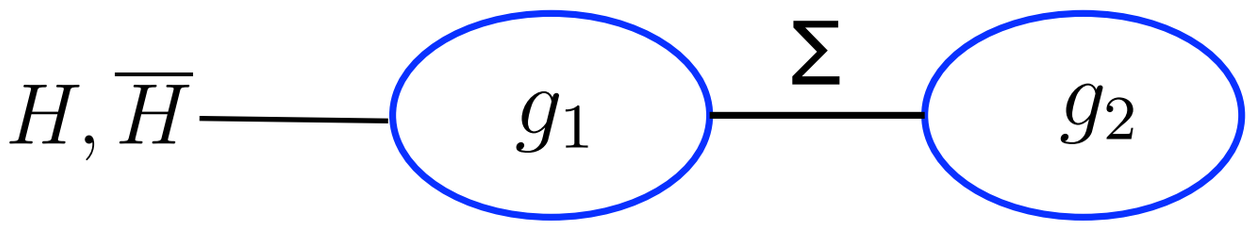
Instead, break SUSY simultaneously with a large soft-mass, $m_\Sigma^2 |\Sigma|^2$

- The low-energy $SU(2)_L$ 'remembers' m_Σ^2



- $\lambda \sim \dfrac{\Delta g^2 + g'^2}{8}$

Non-decoupling D-terms



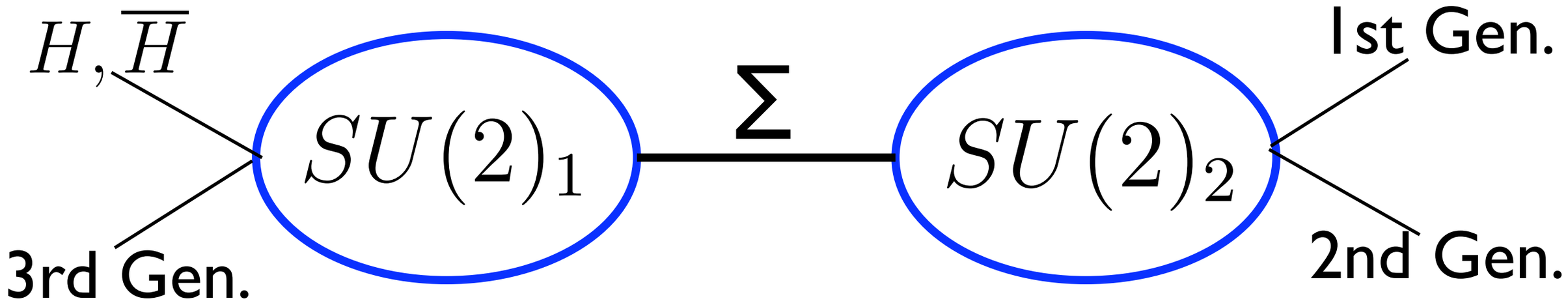
- Δg^2 characterizes the strength of the effect
- Limits

$$m_\Sigma^2 \ll \langle \Sigma \rangle \rightarrow \Delta g^2 \sim g^2 \qquad \text{no effect}$$

$$m_\Sigma^2 \gg \langle \Sigma \rangle \rightarrow \Delta g^2 \sim g_1^2 \qquad \text{big effect!}$$

- if g_1 is large, so then is m_{h^0}

Asymptotic Freedom



"Topflavor"

- Yukawa Couplings?
- Unification?
- Fine-tuning?
- Precision Electroweak Constraints?

Yukawas

- add an extra pair of Higgs-like doublets

- include mixing terms in the Superpotential

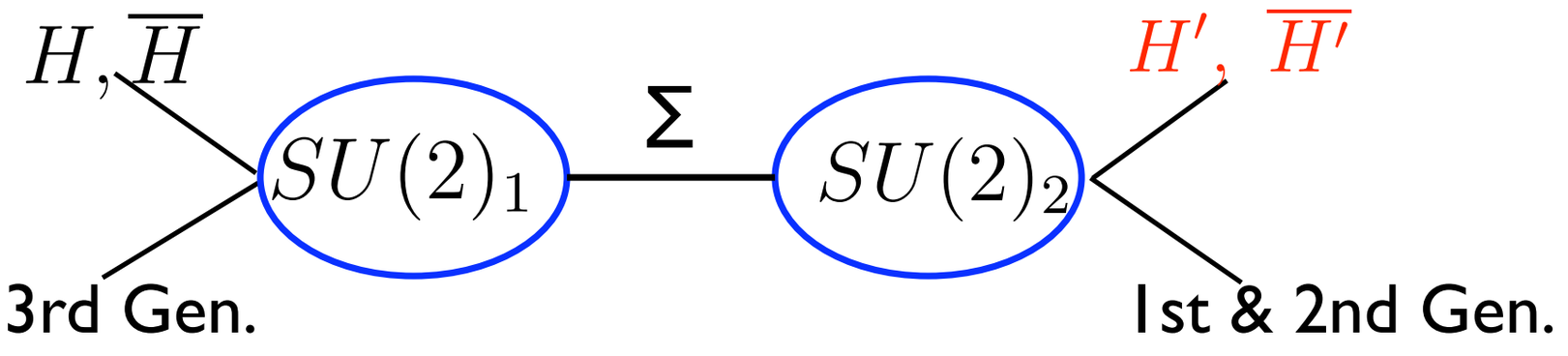
$$W \supset \mu' H' \overline{H'} + \lambda_c Q_c \bar{c} \overline{H'} + \lambda_f H \Sigma \overline{H'} + \lambda_f H' \Sigma \overline{H}$$

Large mass term — $SU(2)_2$ 'Yukawa' — Feeding terms

- at low energies:

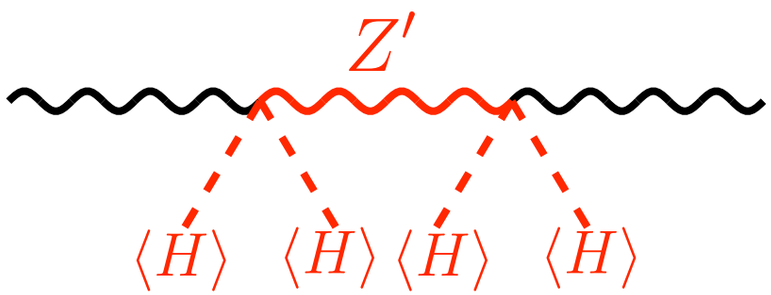
$$W \supset \frac{\lambda_f \lambda_c \langle \Sigma \rangle}{\mu'} Q_c \bar{c} \overline{H}$$

$SU(2)_W$ Yukawa's with natural suppression

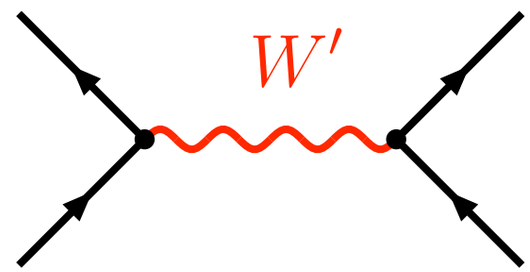


Precision Corrections

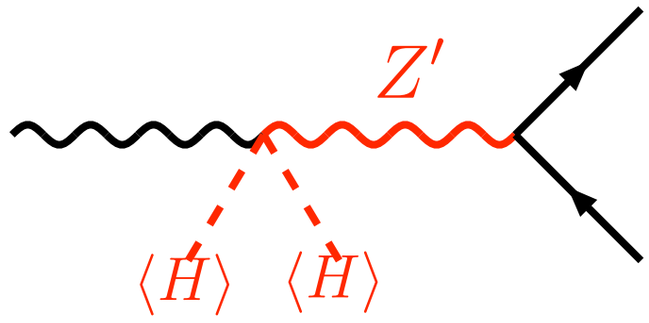
- oblique corrections to M_W, M_Z



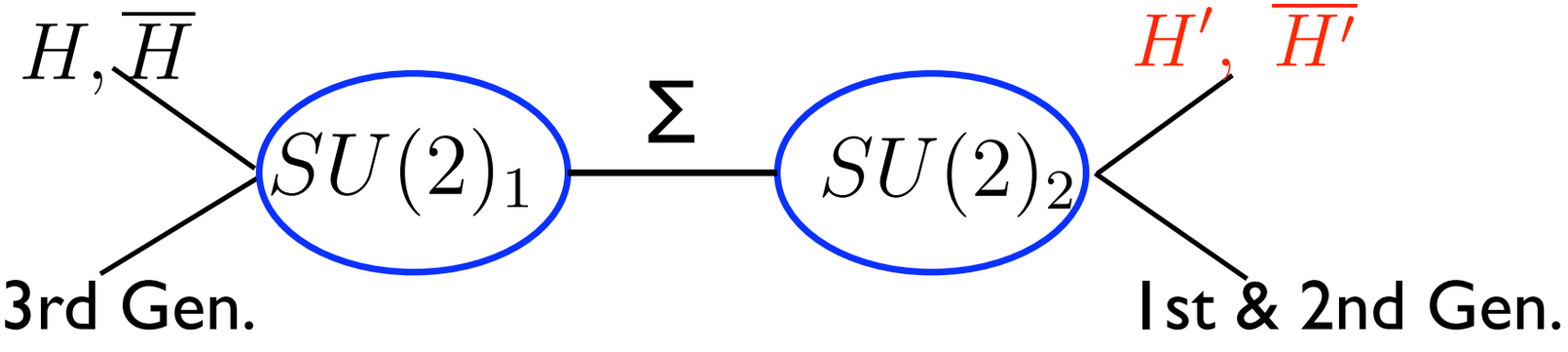
- non-oblique corrections to G_F



- f_L vertex corrections



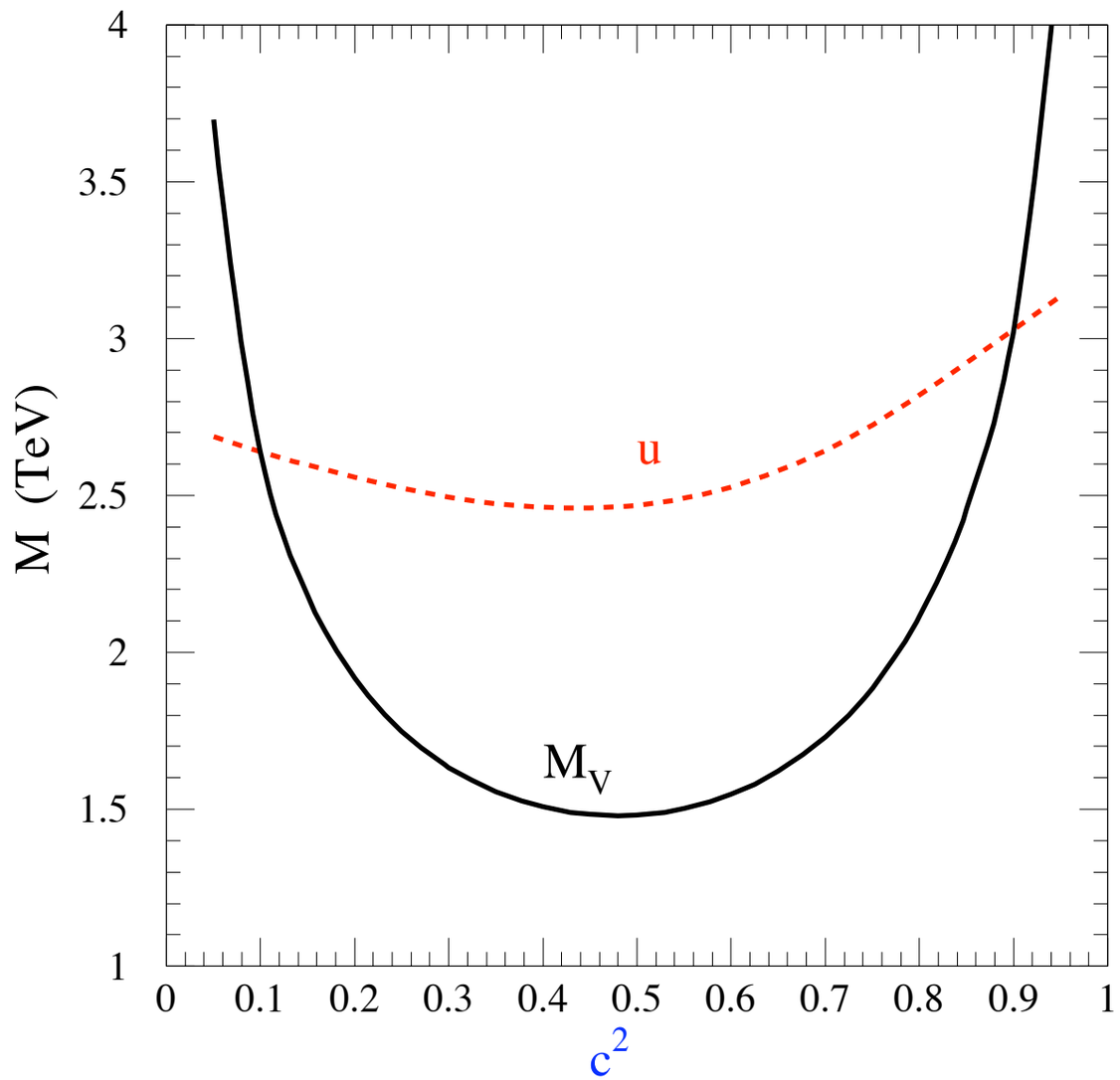
- non-universal 3rd Generation couplings!



Precision Corrections

- $\langle \Sigma \rangle = u \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \quad M_{W',Z'} \sim u^2 \left(g_1^2 + g_2^2 \right) \quad g_1 \equiv \frac{g}{\sin\phi} \quad g_2 \equiv \frac{g}{\cos\phi}$

Lower Bounds as a function of $\cos\phi$



Large g_2
Small g_1

Large g_1
Small g_2

Fine-tuning

Recall, we require $m_\Sigma \gg \langle \Sigma \rangle$

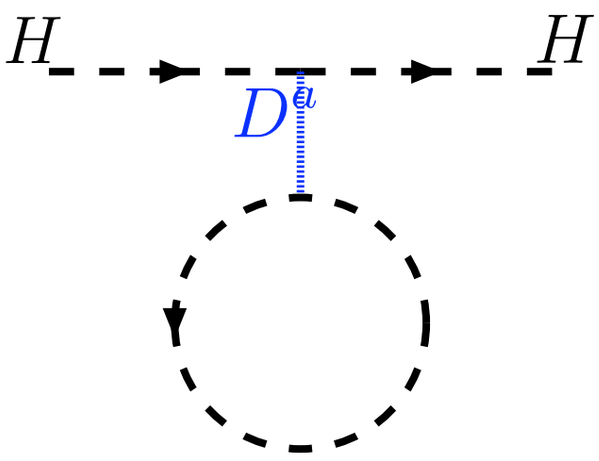
10 TeV 1 TeV

Two sources of fine-tuning:

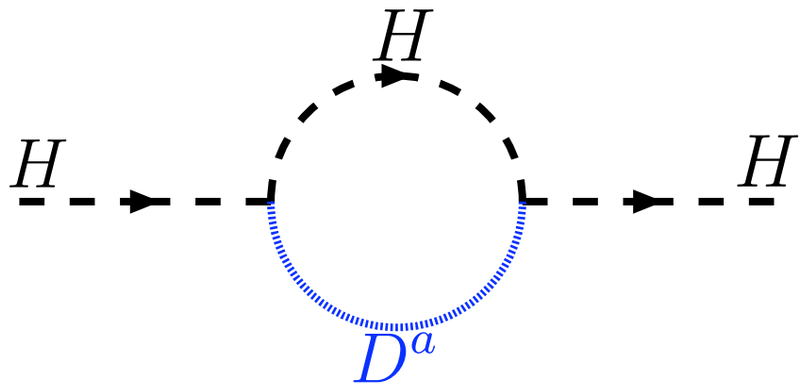
- Below $\langle \Sigma \rangle$, a hard breaking of SUSY in the gauge sector from Δ
- UV sensitive logarithmic contributions of m_Σ^2 into $m_H^2, m_{\overline{H}}^2$

only enters at two-loops!

$$\mathcal{L} \supset D^a \left(\mathrm{Tr} \, \left(\Sigma^\dagger \sigma^a \Sigma \right) + H^\dagger \sigma^a H - \overline{H} \sigma^a \overline{H}^\dagger \right)$$



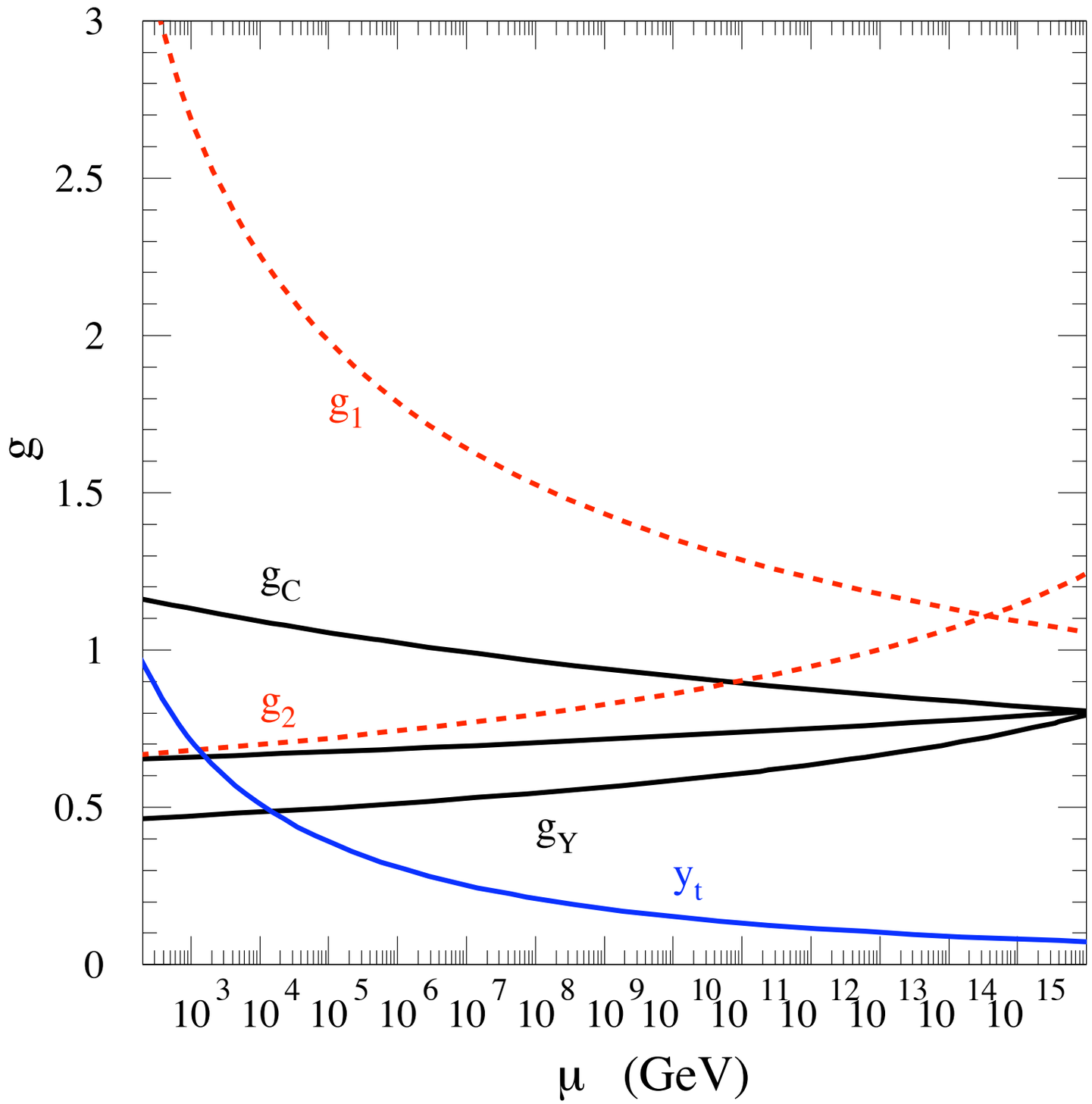
$\propto \mathrm{Tr} \, \sigma^a = 0$



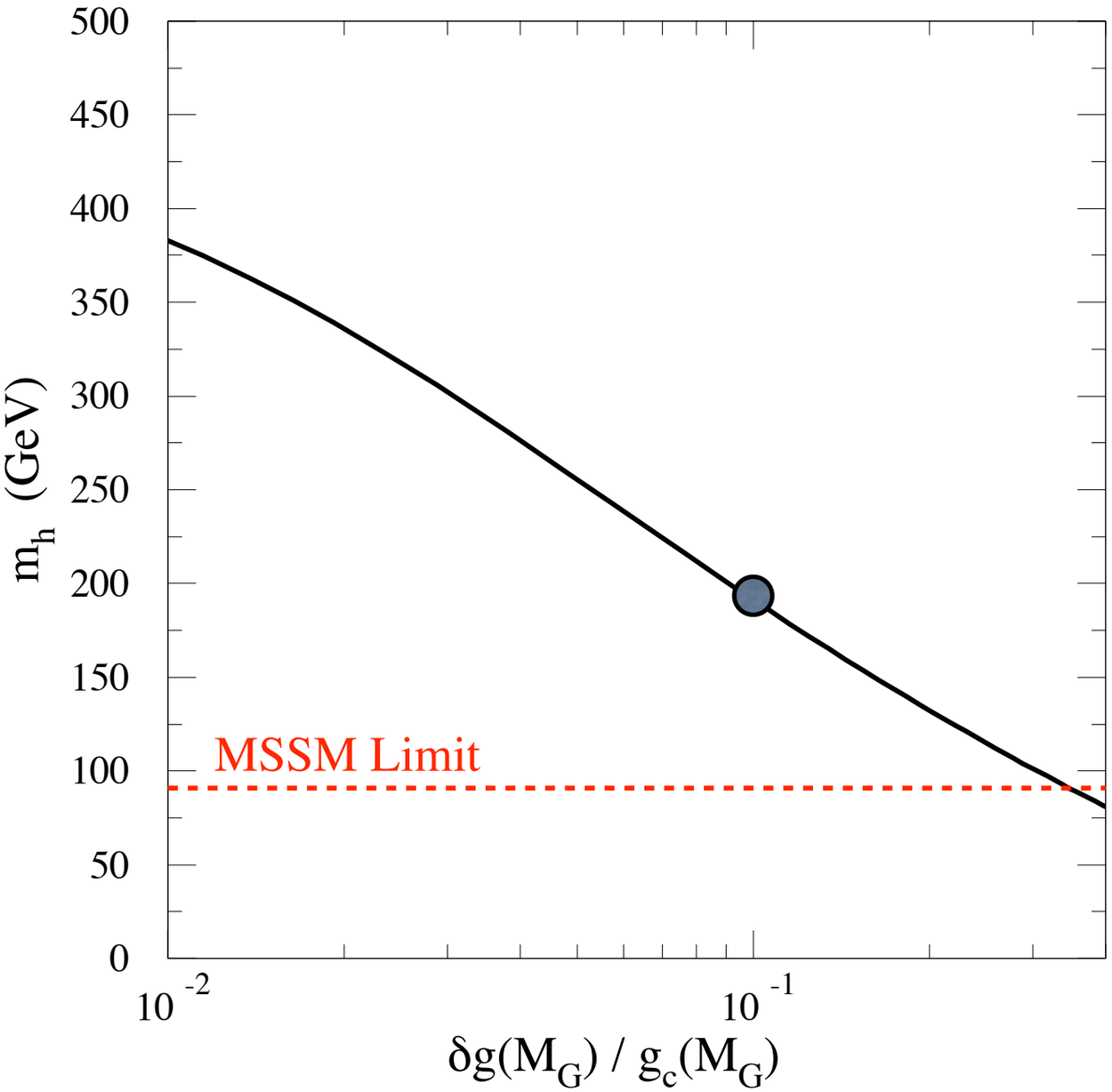
independent of m_Σ

Unification

- Diagonal SU(5) Unification



A New Mass Bound for SUSY



Sample Point:

- $\langle \Sigma \rangle = 2.5 \text{ TeV}, \quad m_\Sigma \sim 10 \text{ TeV}$

$$M_V = 4.5 \text{TeV}$$

$$\Delta \approx 7, \quad m_{h^0} \leq 210 \text{ GeV}$$

$$\boxed{m_{h^0} < \sim 350 \text{ GeV}}$$

Post LHC

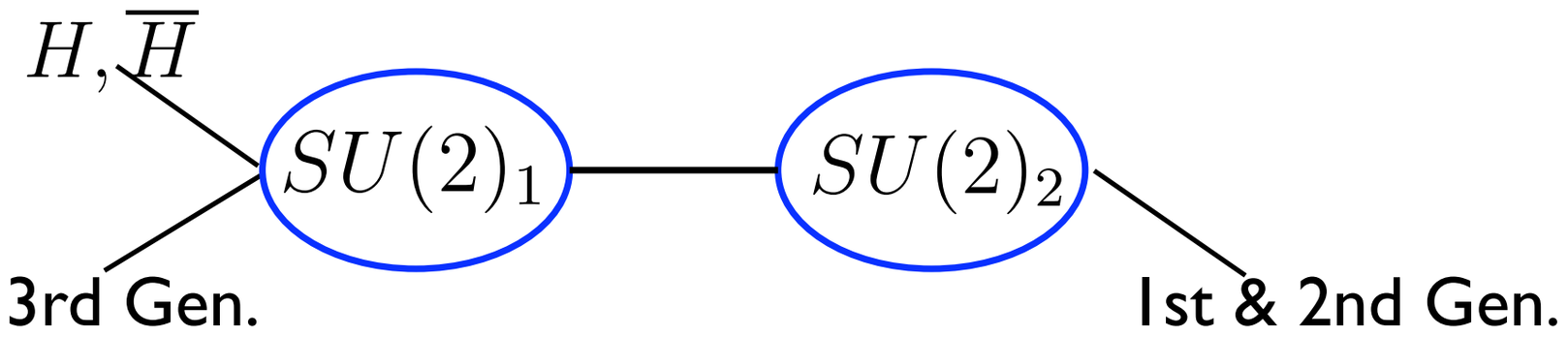
- Confusing SUSY spectra, with heavy W'
- Non-SUSY Higgs potential

$$\lambda \sim \frac{\Delta g^2 + g'^2}{8}$$

- New Higgs mass relation from the top sector

$$m_h = f(M_Z, \cos\beta, m_{\tilde{t}}, \ldots, \Delta)$$

- gauginos which couple differently to the 3rd generation



Recap

- How much parameter space remains for the MSSM?

- D-term quartics:

  Perturbative

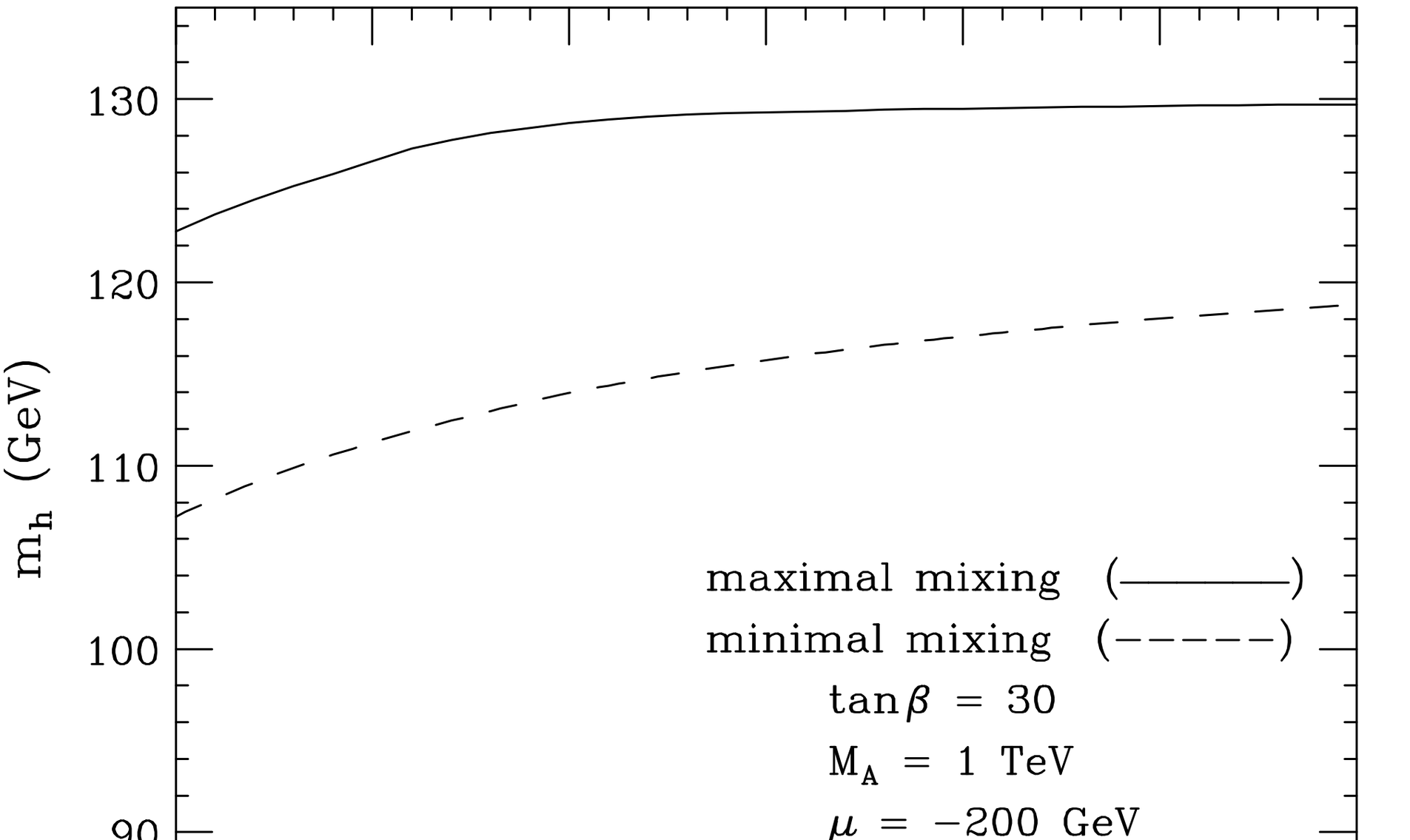
  Not fine-tuned

$$m_{h^0} < \sim 350 \text{ GeV}$$

Not Dicussed--Hybrids:

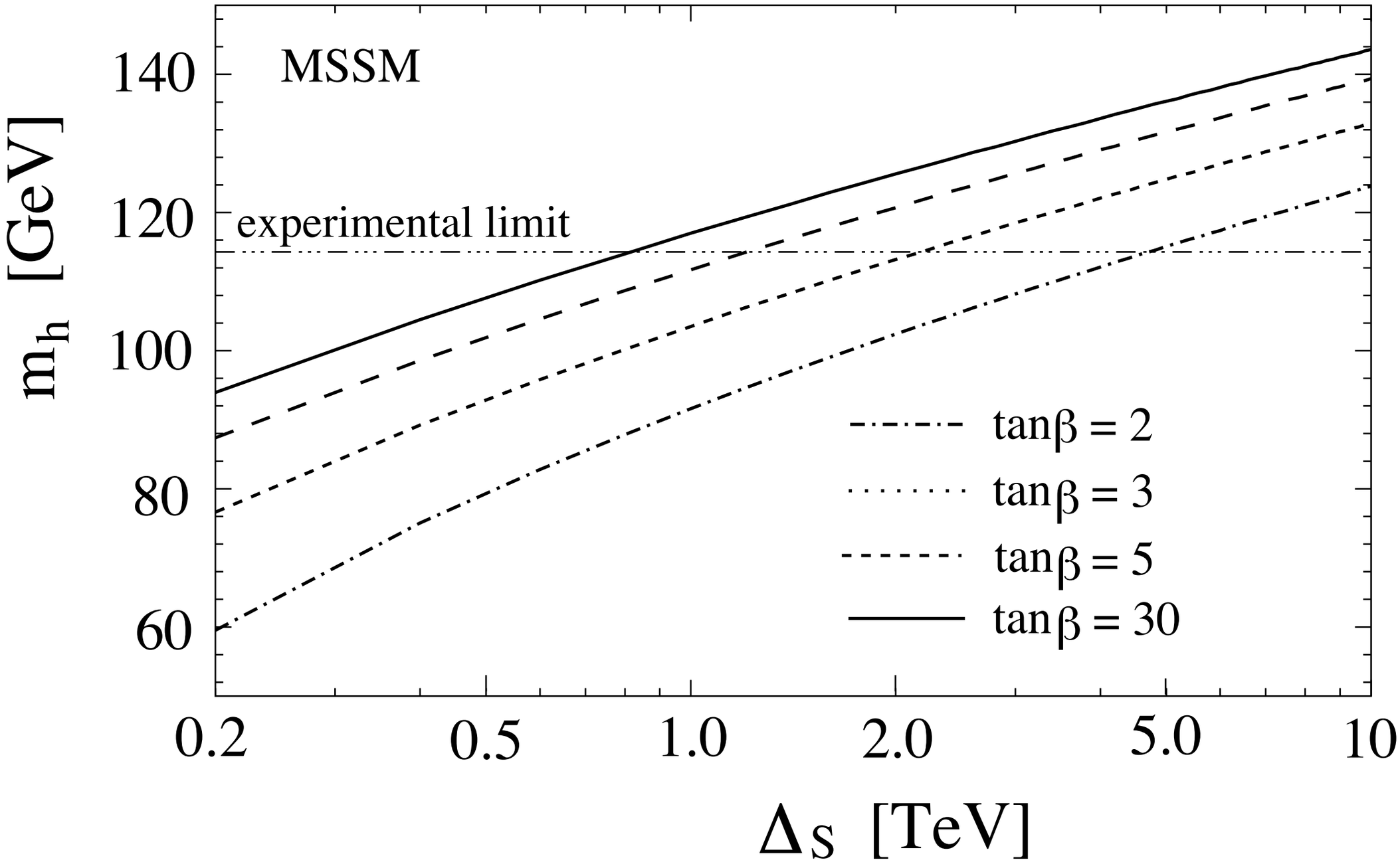
- Asymptotically-free "MSSM+S"; similar mass bounds, novel spectra

SUSY Higgs Bounds



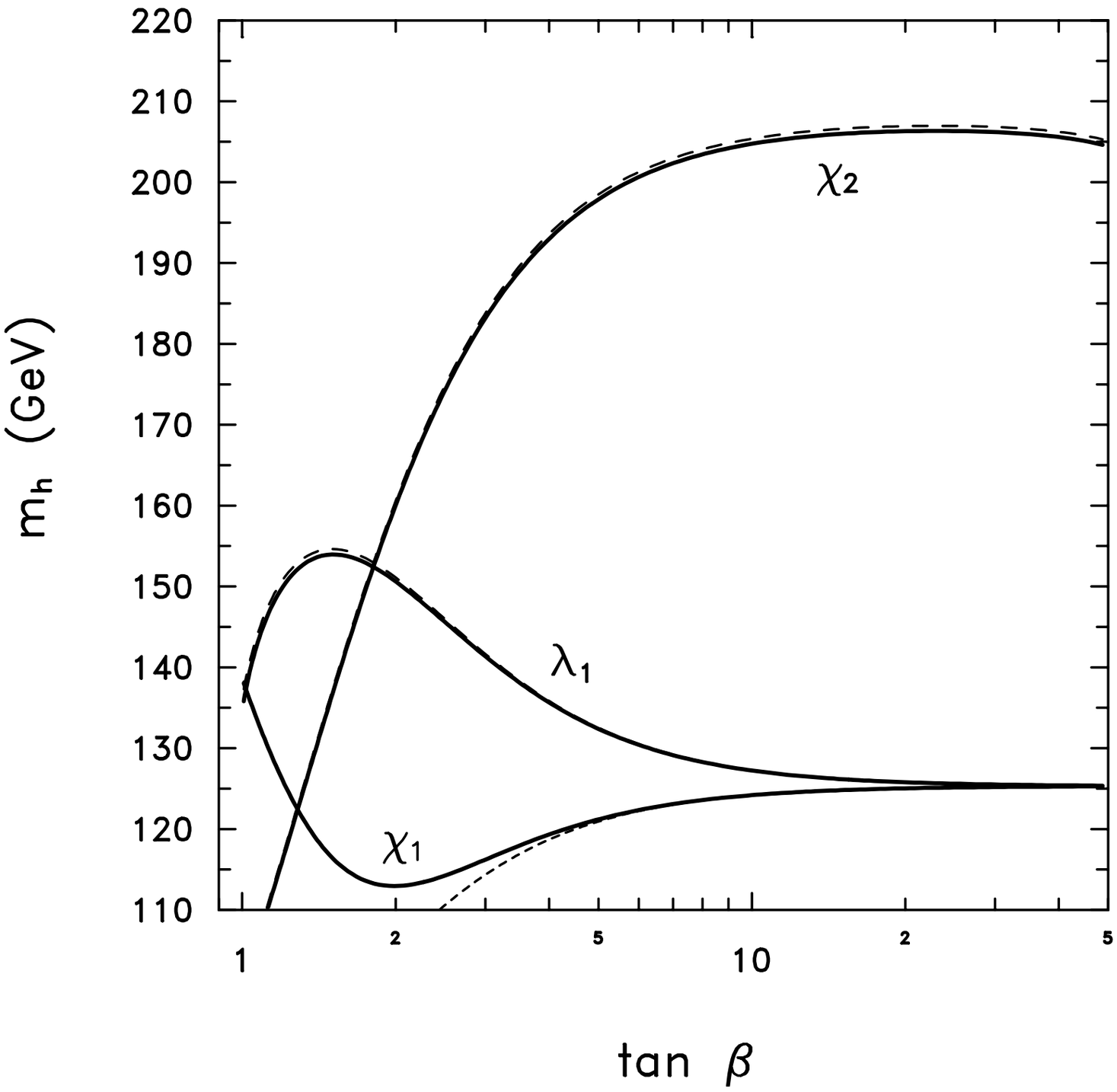
Carena, Haber (2002)

SUSY Higgs Bounds



Tobe, Wells 2002

"MSSM+S" Limits



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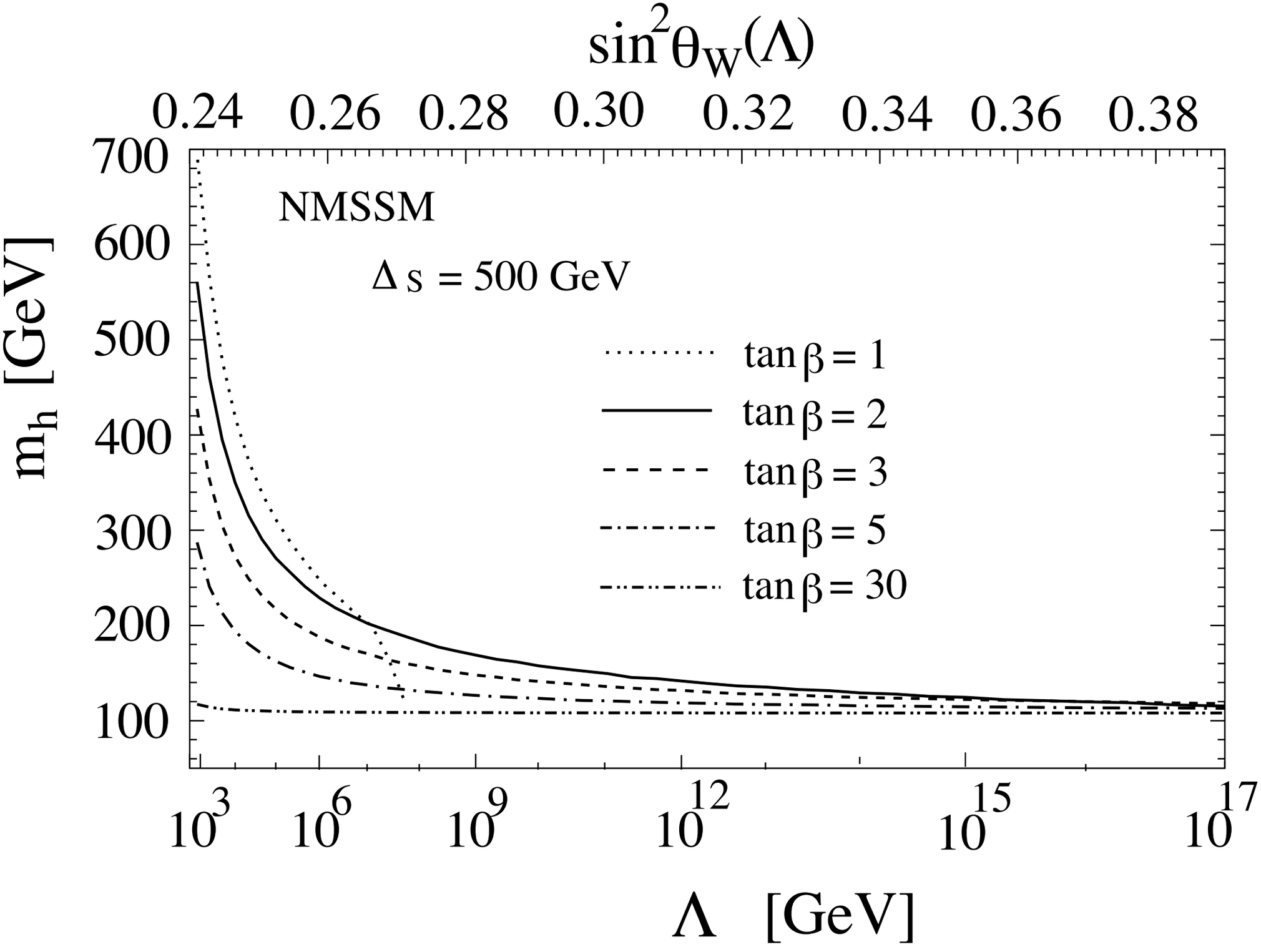

Tobe, Wells 2002

Delta, Delta, Delta

$$\Delta = \frac{1 + \frac{2m_\Sigma^2}{u^2} \frac{1}{g_2^2}}{1 + \frac{2m_\Sigma^2}{u^2} \frac{1}{g_1^2 + g_2^2}}$$