

# A Non Standard Supersymmetric Spectrum

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# Outlook

1. The Spectrum (motivations)
2. Some particular models ( $U(1)$ ,  $SU(2)$ ,  $\lambda$ SUSY)
3. LHC phenomenology
4. Dark Matter and the Well Tempered Neutralino
5. Conclusions

# Higgs and Flavour Problem

Higgs Problem: MSSM:  $m_h \lesssim m_Z |\cos 2\beta| + \text{rad. corr}$

But  $m_h \geq 114.5 \text{ GeV} \rightarrow$  fine tuning measured by

$$\frac{m_{\tilde{t}}^2}{m_h^2} \frac{\delta m_h^2}{\delta m_{\tilde{t}}^2} < \Delta \quad \frac{m_{\tilde{f}_{1,2}}^2}{m_h^2} \frac{\delta m_h^2}{\delta m_{\tilde{f}_{1,2}}^2} < \Delta$$

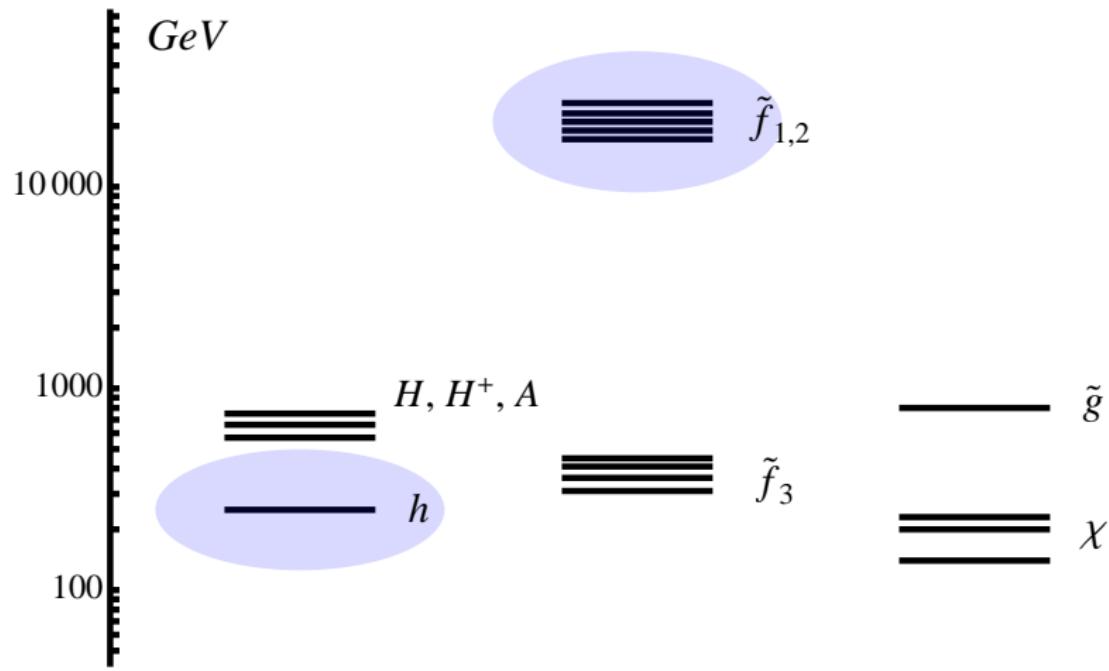
Flavour Problem: Lack of signals in flavour experiments  $\rightarrow$

- ▶  $m_{\tilde{q}_{1,2}} \gtrsim 800 \text{ TeV}$  (no degeneracy nor alignment);
- ▶  $m_{\tilde{q}_{1,2}} \gtrsim 12 \text{ TeV}$  (degeneracy + alignment  $\mathcal{O}(\lambda_c)$ )

$\Rightarrow$  Spectrum:

- ▶  $m_{\tilde{q}_{1,2}}$  high (to solve flavour problem)
- ▶  $m_h$  high (to solve Higgs problem and to control fine tuning)

# The Spectrum



# How to raise the Higgs boson mass?

$$V(H) = -\mu^2|H|^2 + \lambda|H|^4 \Rightarrow m_H^2 \propto \lambda v^2$$

In SUSY theories:

$$V = \sum_i \underbrace{\left| \frac{\partial W}{\partial \varphi_i} \right|^2}_{\sim \varphi^4 \text{ if } \begin{array}{l} \\ \\ \end{array}} + \underbrace{\frac{1}{2} \sum_a g_a^2 (\varphi_i^* T^a \varphi_i)^2}_{\sim \varphi^4}$$

$\sim \varphi^4$   
 $W \sim \varphi^3$   
 $W \sim S\varphi^2$

$\Rightarrow$  one can raise the Higgs boson mass already at tree level both via F-terms and D-terms

# Extensions of the MSSM

- ▶ U(1) gauge extension :  $SU(3) \times SU(2)_L \times U(1)_Y \times U(1)_X$   
(Batra, Delgado, Kaplan, Tait, 2004)

$$m_h^2 \leq (m_Z^2 + \frac{g_x^2 v^2}{2(1 + M_X^2/2M_\phi^2)}) \cos^2 2\beta$$

- ▶ SU(2) gauge extension :  
 $SU(3) \times SU(2)_I \times SU(2)_{II} \times U(1)_Y$

(Batra, Delgado, Kaplan, Tait, 2004)

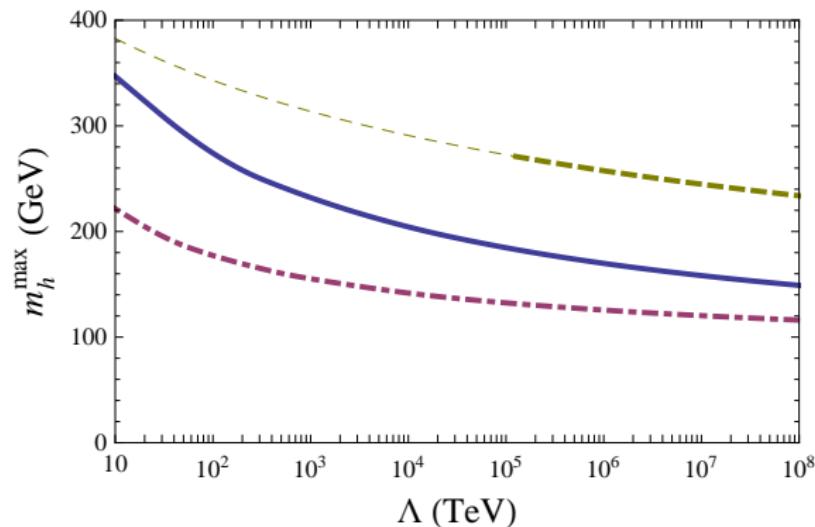
$$m_h^2 \leq m_Z^2 \frac{g'^2 + \eta g^2}{g'^2 + g^2} \cos^2 2\beta, \quad \eta = \left(1 + \frac{g_I^2 M_\Sigma^2}{g^2 M_X^2}\right) / \left(1 + \frac{M_\Sigma^2}{M_X^2}\right)$$

- ▶ λSUSY :  $W = \lambda S H_1 H_2 + f(S)$

(Barbieri, Hall, Nomura, Rychkov, 2006)

$$m_h^2 \leq m_Z^2 (\cos^2 2\beta + \frac{2\lambda^2}{g^2 + g'^2} \sin^2 2\beta)$$

# Mass of the Higgs boson



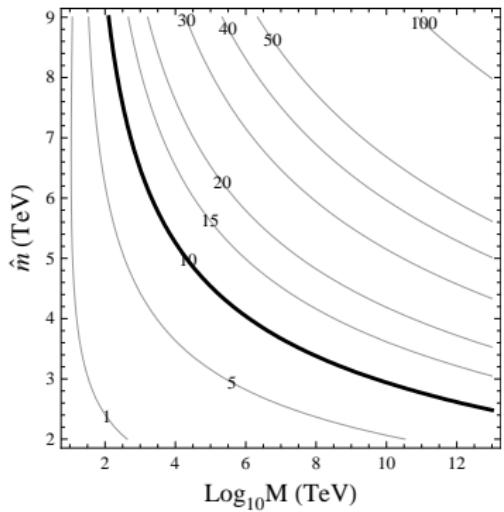
dotdashed = U(1)

solid =  $\lambda$ SUSY

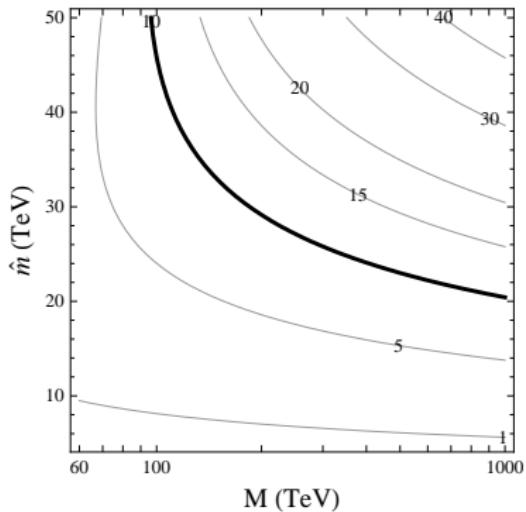
dashed = SU(2)

$\Lambda$  = scale at which some coupling becomes semiperturbative

Naturalness bounds from  $\frac{m_{\tilde{f}_{1,2}}^2}{m_h^2} \frac{\delta m_h^2}{\delta m_{\tilde{f}_{1,2}}^2} < \Delta$

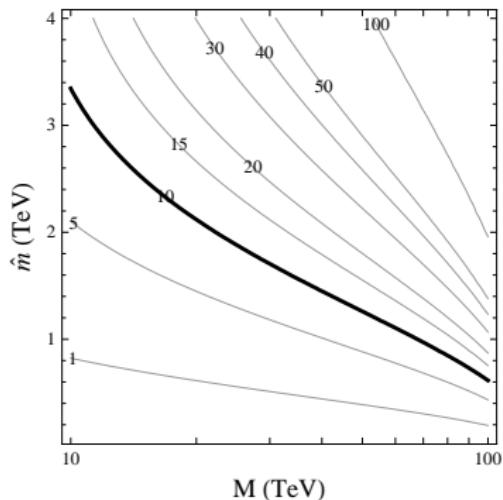


MSSM

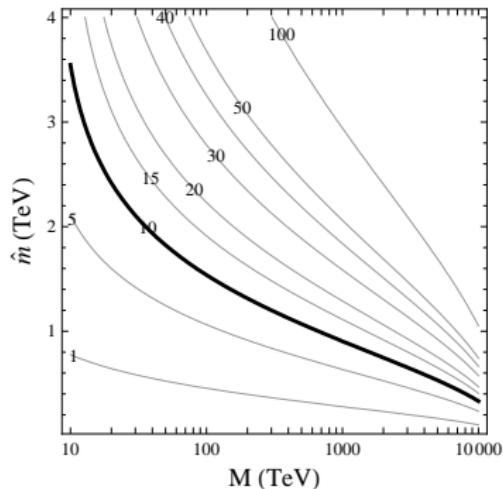


$\lambda$ SUSY ( $m_h = 250$  GeV)

Naturalness bounds from  $\frac{m_{\tilde{f}_{1,2}}^2}{m_h^2} \frac{\delta m_h^2}{\delta m_{\tilde{f}_{1,2}}^2} < \Delta$

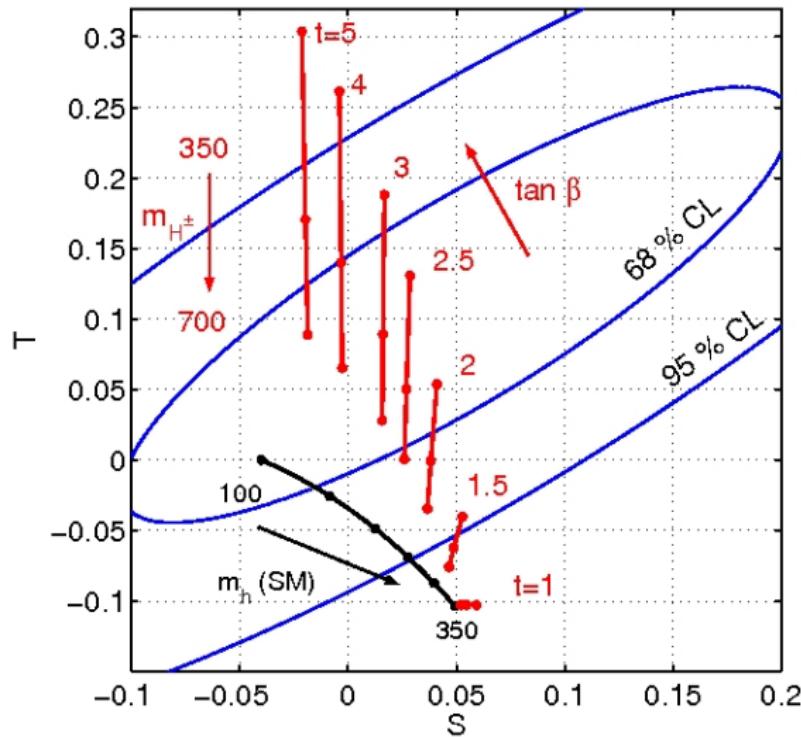


$U(1)$  ( $m_h = 180$  GeV)



$SU(2)$  ( $m_h = 250$  GeV)

# $\lambda$ SUSY - EWPT



# LHC phenomenology

Relevant processes:

Gluino pair production       $pp \rightarrow \tilde{g}\tilde{g}$

Gluino decays:     $\tilde{g} \rightarrow \tilde{t}_{1,2}\bar{t}, \tilde{b}_{1,2}\bar{b}$        $\left\{ \begin{array}{l} \tilde{q} \rightarrow q'\chi^{0,\pm}, q'V, q'S \\ \tilde{b} \rightarrow b\chi \sim (m_b/m_t) t_\beta \end{array} \right.$

So we end up with a multitop rich final state:

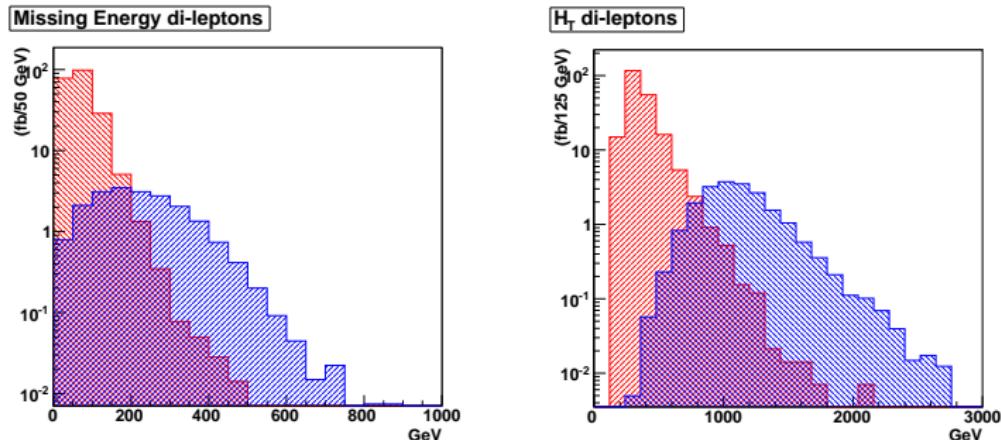
$$\tilde{g} \rightarrow \left\{ \begin{array}{l} t\bar{t}X \\ t\bar{b}X \\ b\bar{b}X \end{array} \right. + \tilde{g} \rightarrow \left\{ \begin{array}{l} t\bar{t}X \\ t\bar{b}X \\ b\bar{b}X \end{array} \right.$$

$\Rightarrow$  Same sign dileptons with  $BR \simeq (2 \div 4)\%$

# LHC phenomenology: discovery potential at 14 TeV

$$m_{\tilde{g}} = 800 \text{ GeV}, m_{\tilde{t}_1} = 400 \text{ GeV}, m_{\tilde{t}_2} = 680 \text{ GeV}, \theta_t = \pi/8,$$

$$\mu = 150 \text{ GeV}, M_1 = 600 \text{ GeV}, M_2 = 500 \text{ GeV}$$

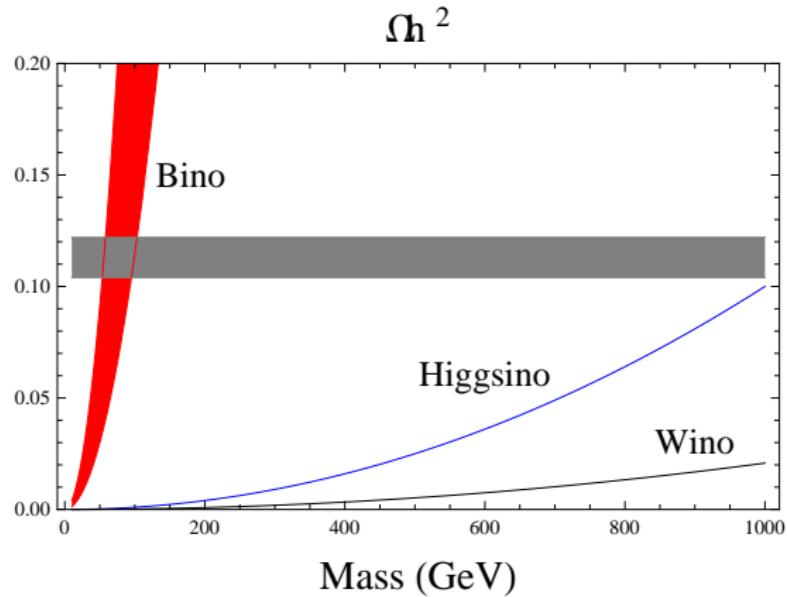


Barbieri, Pappadopulo 2009

Main bkg:  $t\bar{t}$  with 1% probability of misidentify the lepton charge

$$\left. \begin{array}{l} \text{Integrated luminosity} = 1 \text{ fb}^{-1} \\ \text{Cut at } H_t = 1 \text{ TeV} \end{array} \right\} \begin{array}{l} 14 \text{ events} \\ 1 \text{ background} \end{array}$$

# Dark Matter: the Well Tempered Neutralino



Arkani-Hamed, Delgado, Giudice, 2006

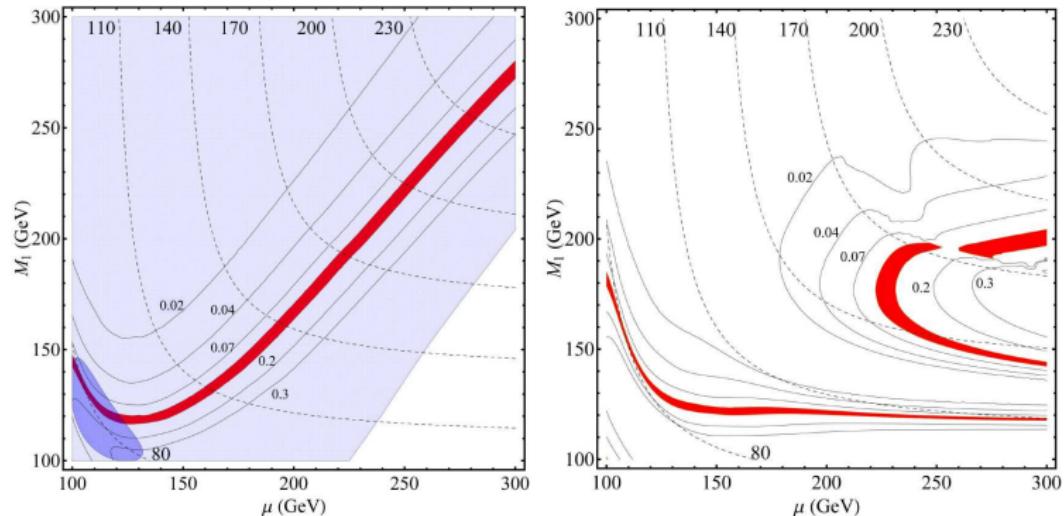
# The Well Tempered Neutralino

$\mu \simeq M_1 \ll M_2 \rightarrow$  Bino-Higgsino LSP

$M_1 \simeq M_2 \ll \mu \rightarrow$  Bino-Wino LSP

Favored by naturalness

# Bino-Higgsino Dark Matter



MSSM

$$m_h = 120 \text{ GeV}$$
$$\tan \beta = 10$$

$\lambda$ SUSY

$$m_h = 250 \text{ GeV}$$
$$\tan \beta = 2$$

Dark blue: CDMS exclusion (now)

Light blue: Xenon100 exclusion (projection)

# Conclusions

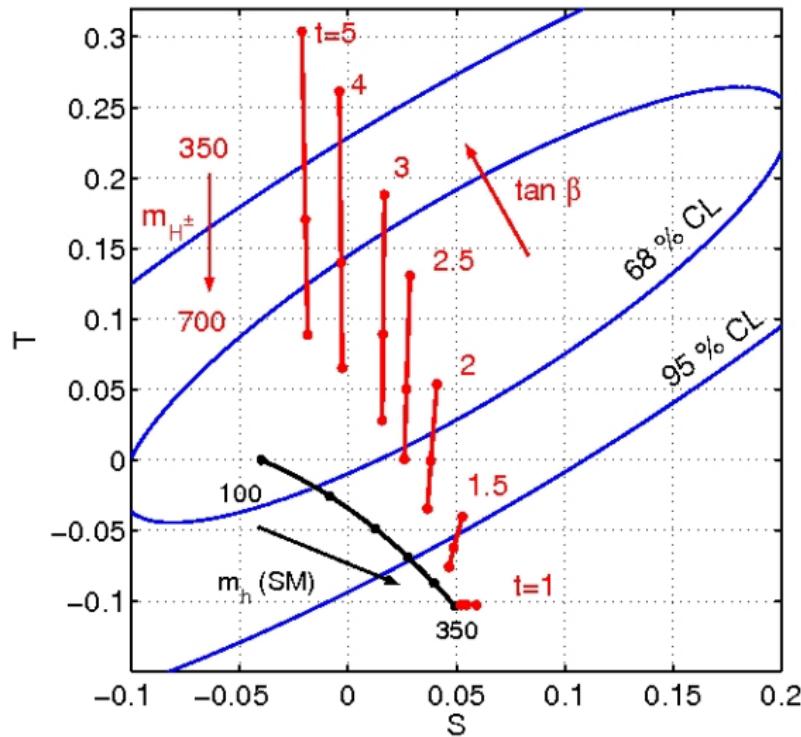
- ▶ The Higgs boson mass and the flavour problem may be related and suggest a *Non Standard Supersymmetric Spectrum* in which

$$\begin{aligned} m_h &= (200 \div 300) \text{ GeV} \\ m_{\tilde{f}_{1,2}} &\gtrsim (20 \div 30) \text{ TeV} \gg m_{\tilde{f}_3} \end{aligned}$$

- ▶ This can be achieved at least in  $\lambda$ SUSY
- ▶ Phenomenology:
  - ▶ Same sign dileptons from gluino pair production
  - ▶ "Golden Higgs boson decay"  $h \rightarrow ZZ$
  - ▶ DM: no well-temperament

# Backup slides

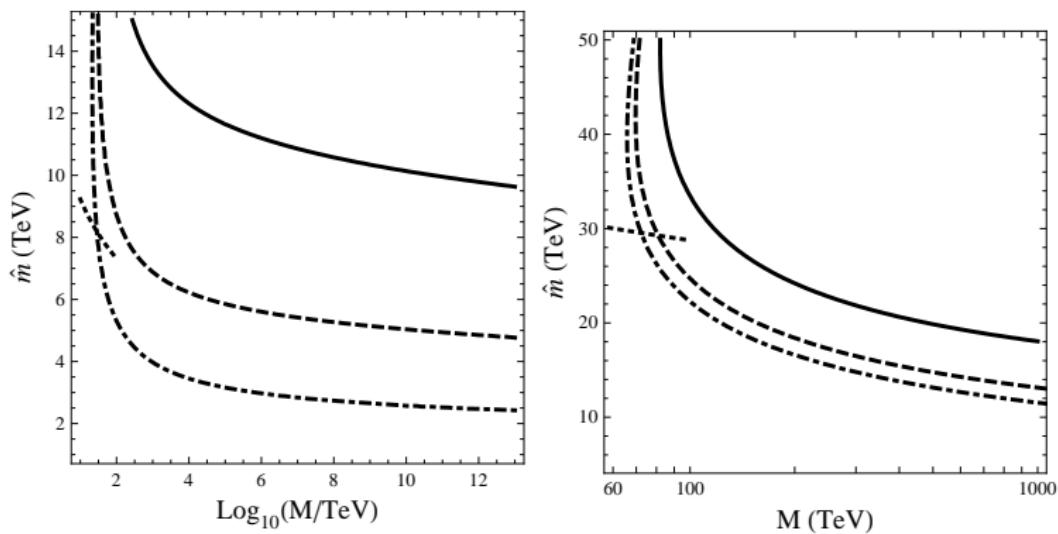
# $\lambda$ SUSY - EWPT



# Colour conservation

1<sup>st</sup>, 2<sup>nd</sup> generation of squarks  $\rightarrow$  affects evolution of  $m_{\tilde{u}_3}^2$ ,  $m_{\tilde{Q}_3}^2$

Colour conservation  $\rightarrow$   $m_{\tilde{u}_3}^2, m_{\tilde{Q}_3}^2 \geq 0$



$$m_h = m_Z$$

(Solid =  $m_{\tilde{g}} = 2$  TeV, dashed =  $m_{\tilde{g}} = 1$  TeV, dotdashed =  $m_{\tilde{g}} = 500$  GeV)