

# Mass of the Light Higgs in the S-MSSM

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## Can we lift the light Higgs mass at tree-level?

- Extension of the MSSM
  - Popular route: Gauge singlets
- NMSSM:  $\mu$  term  $\rightarrow S$

$$W = W_{Yukawa} + \lambda S H_u H_d + \frac{\kappa}{3} S^3$$
$$\mu_{eff} = \lambda \langle S \rangle$$

A  $\mu$  term is provided when  $S$  acquires a vev, however

- Small  $\langle S \rangle \rightarrow$  Ruled out by experiment
- Large  $\langle S \rangle \rightarrow$  No EW symmetry breaking

## Generalized NMSSM

- Most general extension of MSSM with a gauge singlet imposing gauge symmetry and R-parity:

$$W = W_{Yukawa} + (\mu + \lambda S)H_u H_d + \frac{1}{2}\mu_s S^2 + \frac{1}{3}\kappa S^3 + \xi S$$

We are going to study a version of this model, but first introduce some simplifications

- Require tadpole terms to be small. Large tadpoles  $\Rightarrow$  large  $\langle S \rangle \Rightarrow$  no EWSB
- The cubic term in  $S$  is no longer needed to stabilize the potential in the singlet direction. We assume value is small which is natural

## S-MSSM

- The superpotential we consider is given by:

$$W = W_{Yukawa} + (\mu + \lambda S)H_u H_d + \frac{1}{2}\mu_s S^2$$

- Scalar potential with soft SUSY breaking contributions

$$\begin{aligned} V = & (\mu^2 + m_{H_u}^2)|H_u|^2 + (\mu^2 + m_{H_d}^2)|H_d|^2 + (m_s^2 + \mu_s^2)|S|^2 + (B_s S^2 + h.c.) \\ & + [(\lambda\mu_s S^\dagger + B_\mu + A_\lambda \lambda S)H_u H_d + \lambda\mu S^\dagger (|H_u|^2 + |H_d|^2) + h.c.] \\ & + \lambda^2 (H_u H_d)(H_u H_d)^\dagger + \lambda^2 |S|^2 (|H_u|^2 + |H_d|^2) \\ & + \frac{1}{8}(g^2 + g'^2)(|H_u|^2 - |H_d|^2)^2 + \frac{1}{2}g^2 |H_u^\dagger H_d|^2 \end{aligned}$$

In this model, for  $\mu_s \gg |m_s|$  the potential in the singlet direction is stable

$\langle S \rangle$  generated by  
mixing with  $H_u$  and  $H_d$

• Minimization conditions:

$$\frac{1}{2}m_Z^2 = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2 \beta}{\tan^2 \beta - 1} - \mu_{eff}^2$$

$$\sin 2\beta = \frac{2B_{\mu,eff}}{m_{H_u}^2 + m_{H_d}^2 + 2\mu_{eff}^2 + \lambda^2 v^2}$$

$$v_{u,d} = \langle H_{u,d} \rangle$$

$$\tan \beta = \frac{v_u}{v_d}$$

We define the following parameters  $\Rightarrow$

$$\mu_{eff} = \mu + \lambda v_s$$

$$B_{\mu,eff} = B_\mu + \lambda v_s (\mu_s + A_\lambda)$$

$$v_s = \frac{\lambda v^2 (\mu_s + A_\lambda) \sin 2\beta - 2\mu}{2 \mu_s^2 + \lambda^2 v^2 + m_s^2 + 2B_s}$$

In the limit  $\mu_s \rightarrow \infty$ , the MSSM is recovered as expected

## Higgs Spectrum

Assuming  $\mu_s \gg \mu, m_Z$ , the neutral Higgs masses are given by:

$$m_{A_1^0}^2 \approx \frac{2B_\mu}{\sin 2\beta} + \frac{4A_\lambda \lambda^2 v^2}{\mu_s} - \frac{2\mu \lambda^2 v^2}{\mu_s \sin 2\beta}$$

$$m_{A_2^0, H_2^0}^2 \approx \mu_s^2 + (2\lambda^2 v^2 + m_s^2 \mp 2B_s)$$

$$m_{h^0, H_1^0}^2 \approx m_{h^0, H_{MSSM}^0}^2 + \frac{2\lambda^2 v^2}{\mu_s} (\mu \sin 2\beta - A_\lambda \mp \Delta^2)$$

$$\Delta^2 = \frac{A_\lambda (m_Z^2 - m_{A_1^0}^2) \cos^2 2\beta - \mu (m_{A_1^0}^2 + m_Z^2) \sin 2\beta}{\sqrt{(m_{A_1^0}^2 + m_Z^2)^2 - 4m_{A_1^0}^2 m_Z^2 \cos^2 2\beta}}$$

In the Higgs decoupling limit

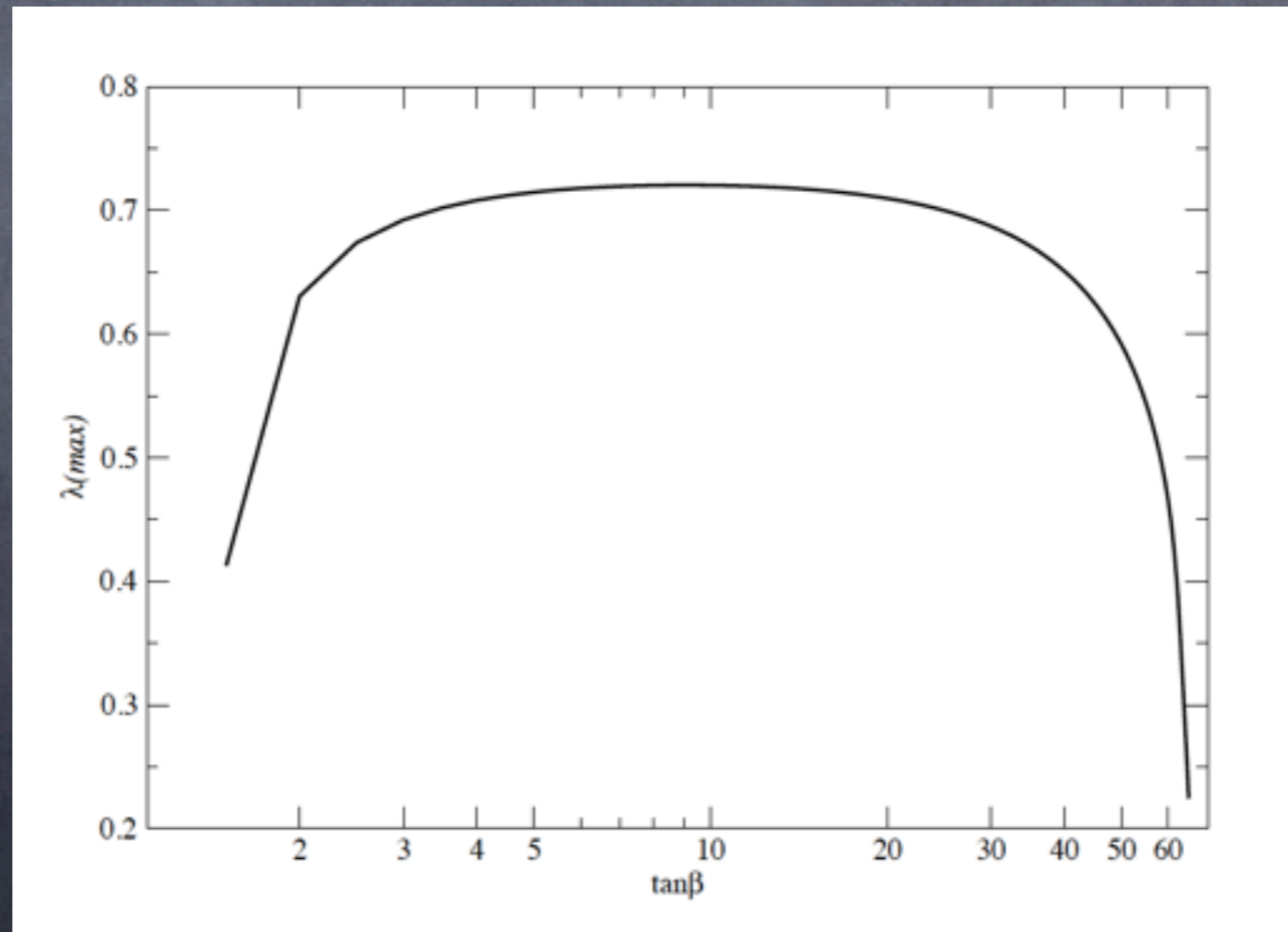
$$m_{h^0}^2 \simeq m_Z^2 \cos^2 2\beta + \frac{2\lambda^2 v^2}{\mu_s} (2\mu \sin 2\beta - A_\lambda \sin^2 2\beta)$$

For  $\mu_s$  finite and greater than  $\mu$  and  $m_Z$

- We have an enhancement on the the Light Higgs mass at tree level which depends on
  - $\frac{\mu}{\mu_s}$  ratio and
  - Size and sign of the ratio  $\frac{A_\lambda}{\mu_s}$

# Analysis

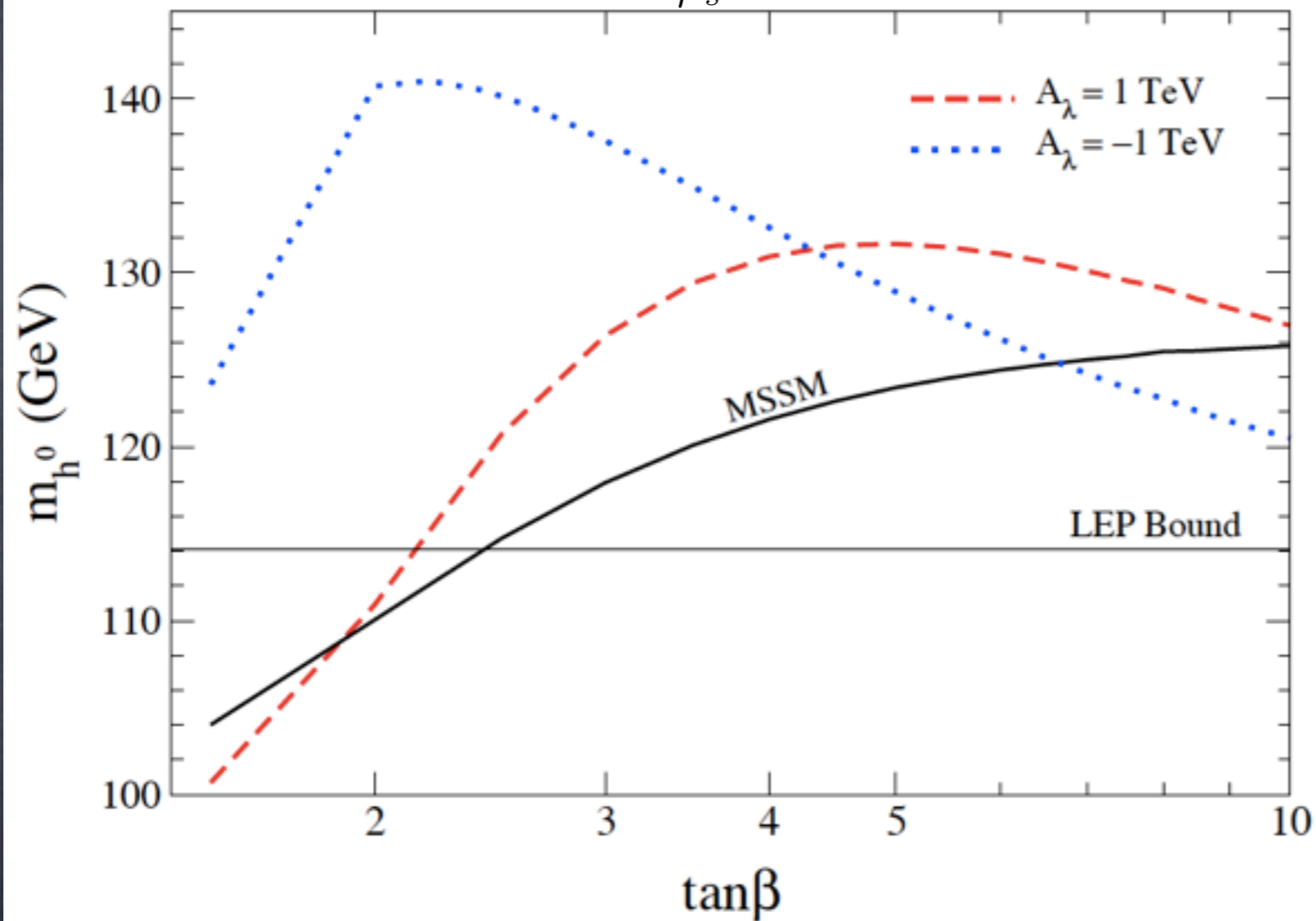
1. Full 1-loop effective potential ↗ top/stop  
↘ Singlet
2. FeynHiggs for two loop contribution
3. Keeping couplings perturbative up to the GUT scale, we maximized  $\lambda$  at  $M_{\text{SUSY}}$





# Light Higgs mass maximized in the S-MSSM

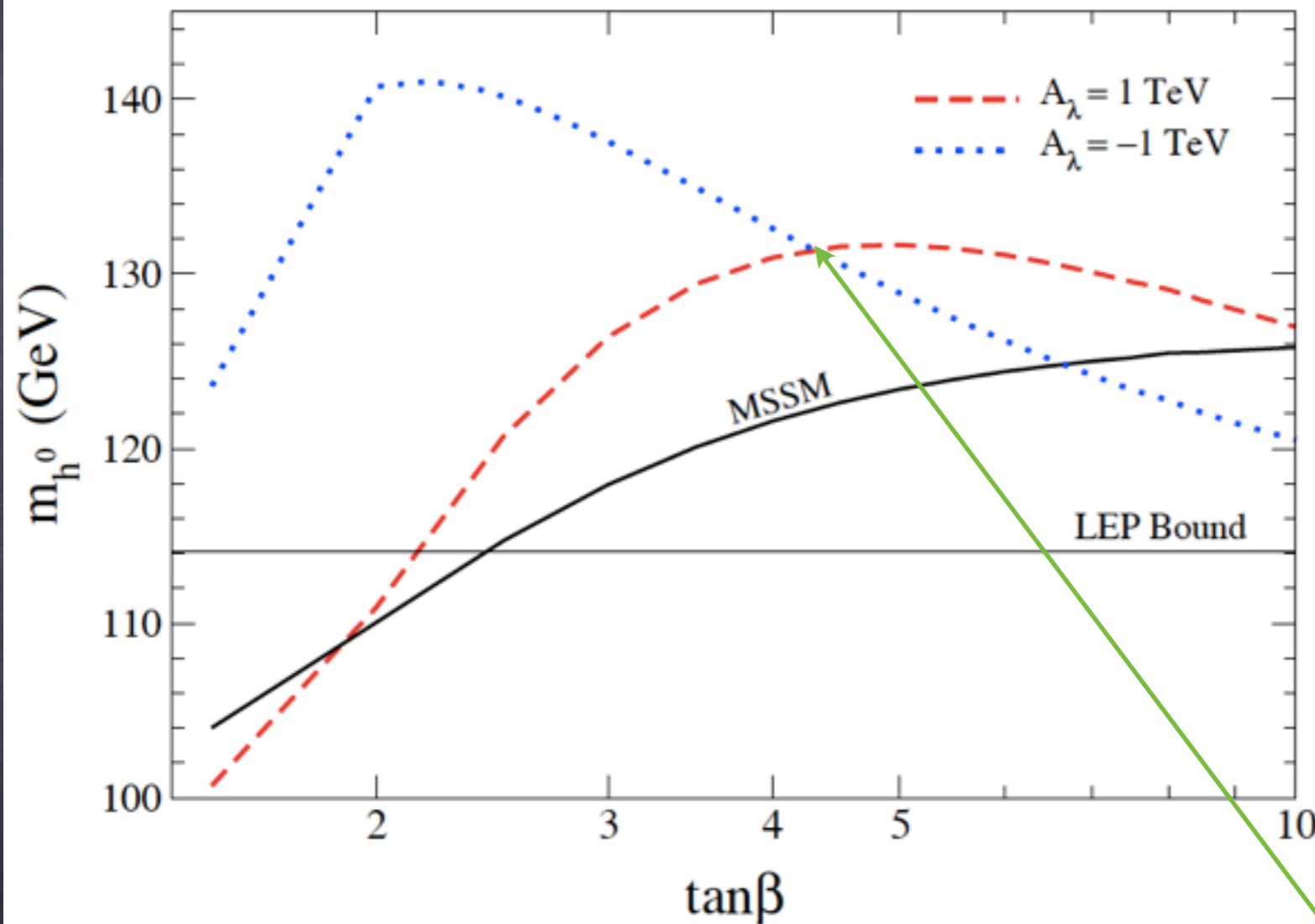
$$m_{h^0}^2 \simeq m_Z^2 \cos^2 2\beta + \frac{2\lambda^2 v^2}{\mu_s} (2\mu \sin 2\beta - A_\lambda \sin^2 \beta)$$



$\mu = 500 \text{ GeV}$   
 $\mu_s = 2 \text{ TeV}$   
 $m_{\tilde{t}} = 1 \text{ TeV}$   
 $A_t = 2.5 \text{ TeV}$

# Light Higgs mass maximized in the S-MSSM

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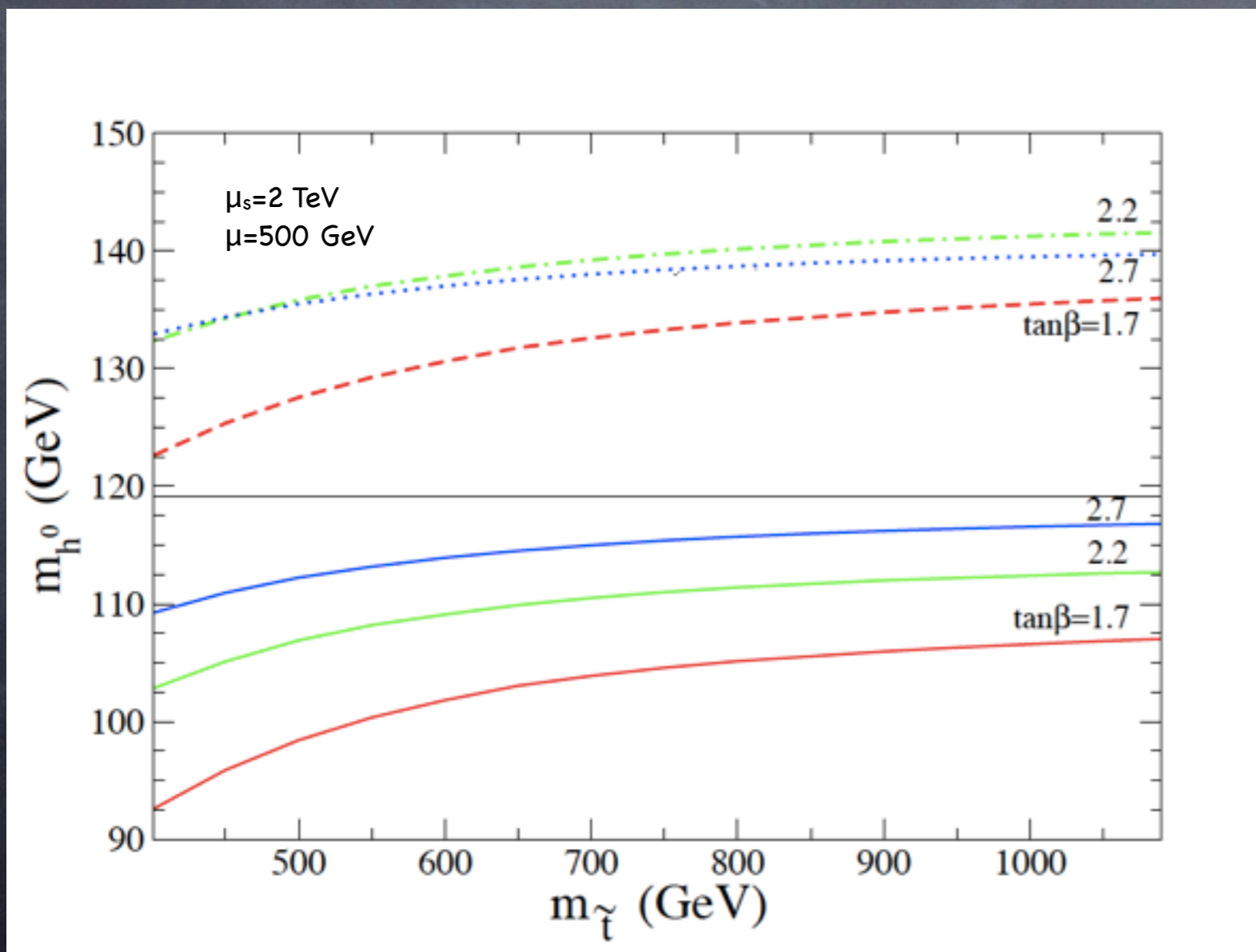


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Crossing due to  $\frac{1}{\mu_s^2}$  contributions

Can we achieve light Higgs masses above the LEP bound using top squarks below 1 TeV?

Largest mass at low  $\tan\beta \sim 2$ .



Parameter scale provided by  $m_{\tilde{t}}$

$$A_t = \sqrt{6} m_{\tilde{t}}$$

$$M_1 = \frac{1}{6} m_{\tilde{t}}$$

$$M_2 = \frac{1}{3} m_{\tilde{t}}$$

$$M_3 = m_{\tilde{t}}$$

$$A_\lambda = -m_{\tilde{t}}$$

## Conclusion

- We extended the NMSSM to include supersymmetric mass terms

Found masses for the light Higgs above the LEP bound  
without the need of a heavy spectrum

⇒ providing a solution to the Little Hierarchy Problem

⇒ and therefore our model is consistent with all  
experimental bounds without being fine tuned

# Back-up Slides

## Higgs sector in the MSSM

The Higgs sector is tightly constrained

In particular, in the Higgs decoupling limit the lightest neutral scalar  $h^0$ :

- Mimics SM Higgs in production and decay
- Its mass is constrained by gauge couplings



$$m_{h^0} \leq m_Z \cos 2\beta$$

It is well known that this bound is lifted through radiative corrections

- In the Higgs decoupling limit, the bound on the MSSM Higgs is the same as that of the SM Higgs from LEP  $\rightarrow$  114 GeV
- Considerable contribution to mass must come from quantum corrections
- Introducing heavy stops above 1 TeV:
  - Creates a fine tuning in the mass parameters since  $m_{\tilde{t}}$  provides the cutoff for the quadratically divergent Higgs mass parameter  $\Rightarrow \frac{dm_{H_u}^2}{dt} \sim y_t^2 m_{\tilde{t}}^2$

This tuning has come to be called Little Hierarchy Problem