Mass of the Light Higgs in the S-MSSM

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Outline

- The Higgs sector in the MSSM and the Little Hierarchy Problem
- Attempts at lifting the light Higgs mass
- S-MSSM

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

$$\Downarrow$$

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

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->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 $\Rightarrow \frac{dm^2_{H_u}}{dt} \sim y_t^2 m^2_{\tilde{t}}$

This tuning has come to be called Little Hierarchy Problem

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

- Extension of the MSSM
  - Popular route: Gauge singlets
- NMSSM: μ term -> S

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

A μ term is provided when S acquires a vev, however

- Small <S> -> Ruled out by experiment
- Large <S> -> No EW symmetry breaking

Generalized NMSSM

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

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

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

- Require tadpole terms to be small. Large tadpoles⇒large <S>⇒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

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

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

<S> 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 $\Rightarrow$

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

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

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

Higgs Spectrum

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

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

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

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

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

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 μ_s finite and greater than μ and m_Z

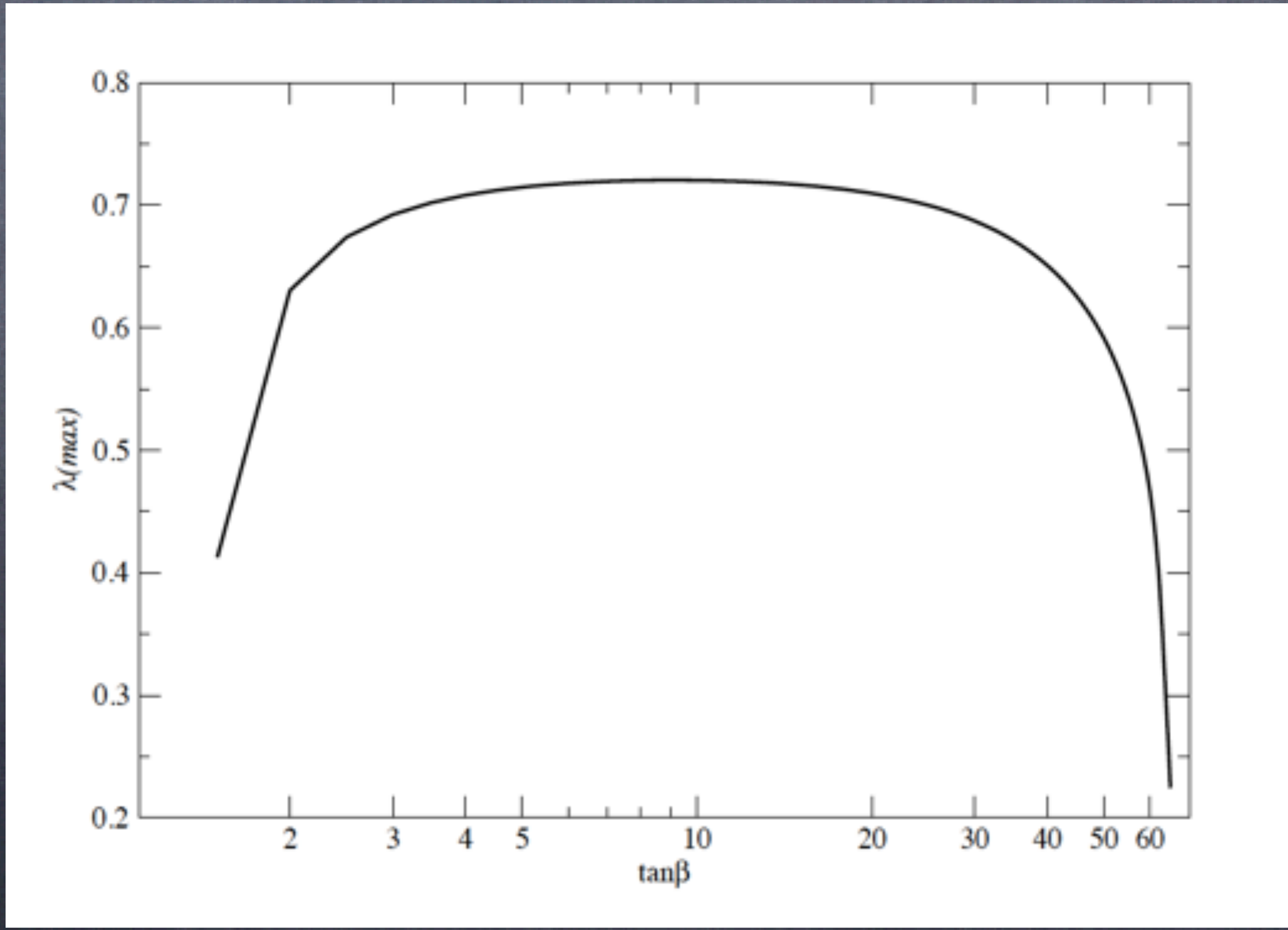
- We have an enhancement on the the Light Higgs mass at tree level which depends on
  - $\frac{\mu}{\mu_s}$ ratio and
  - Size and sign of the ratio $\frac{A_\lambda}{\mu_s}$

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 λ at M_{SUSY}



Light Higgs mass maximized in the S-MSSM

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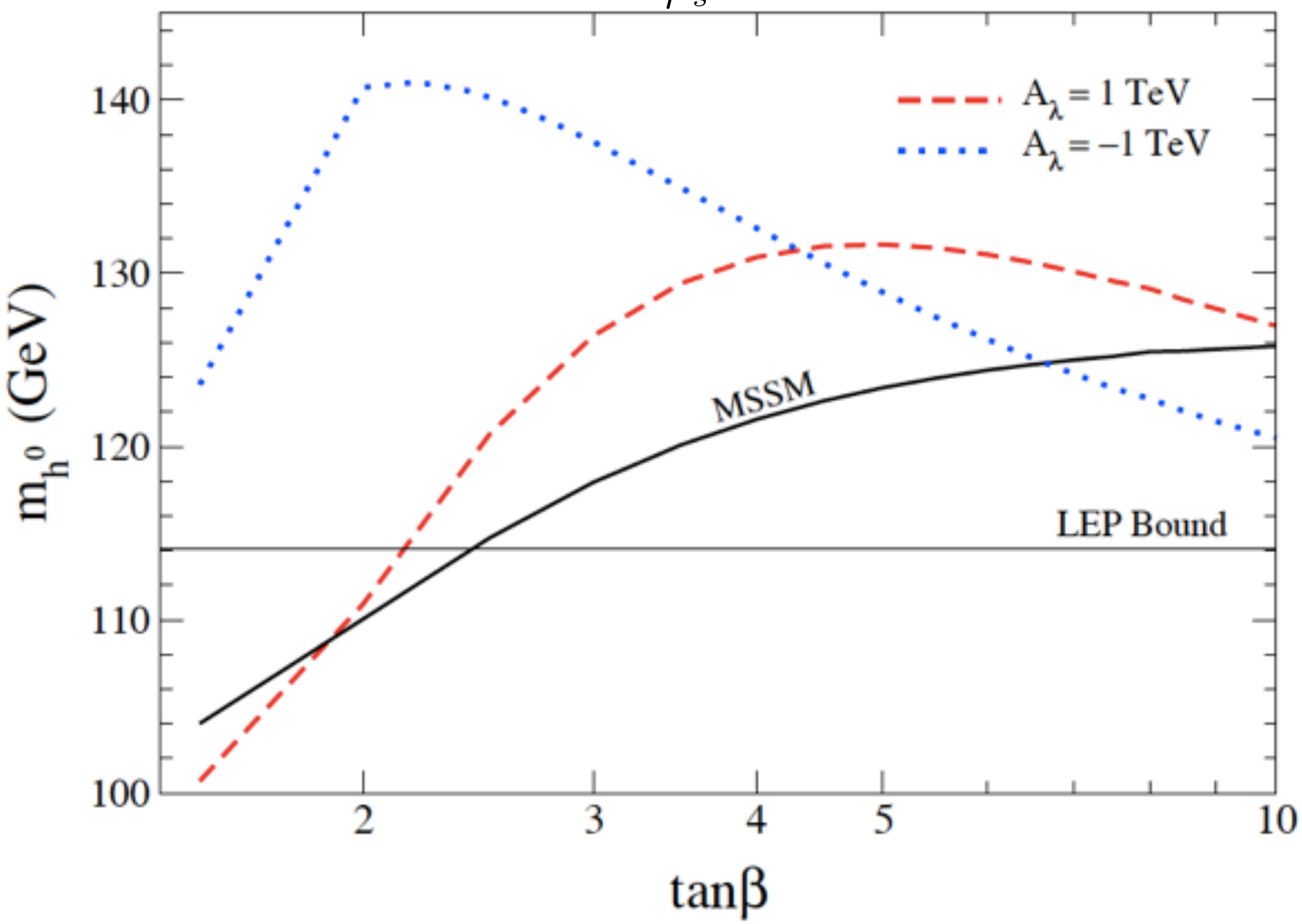

$$\mu = 500\text{GeV}$$
$$\mu_s = 2\text{TeV}$$
$$m_{\tilde{t}} = 1\text{TeV}$$
$$A_t = 2.5\text{TeV}$$

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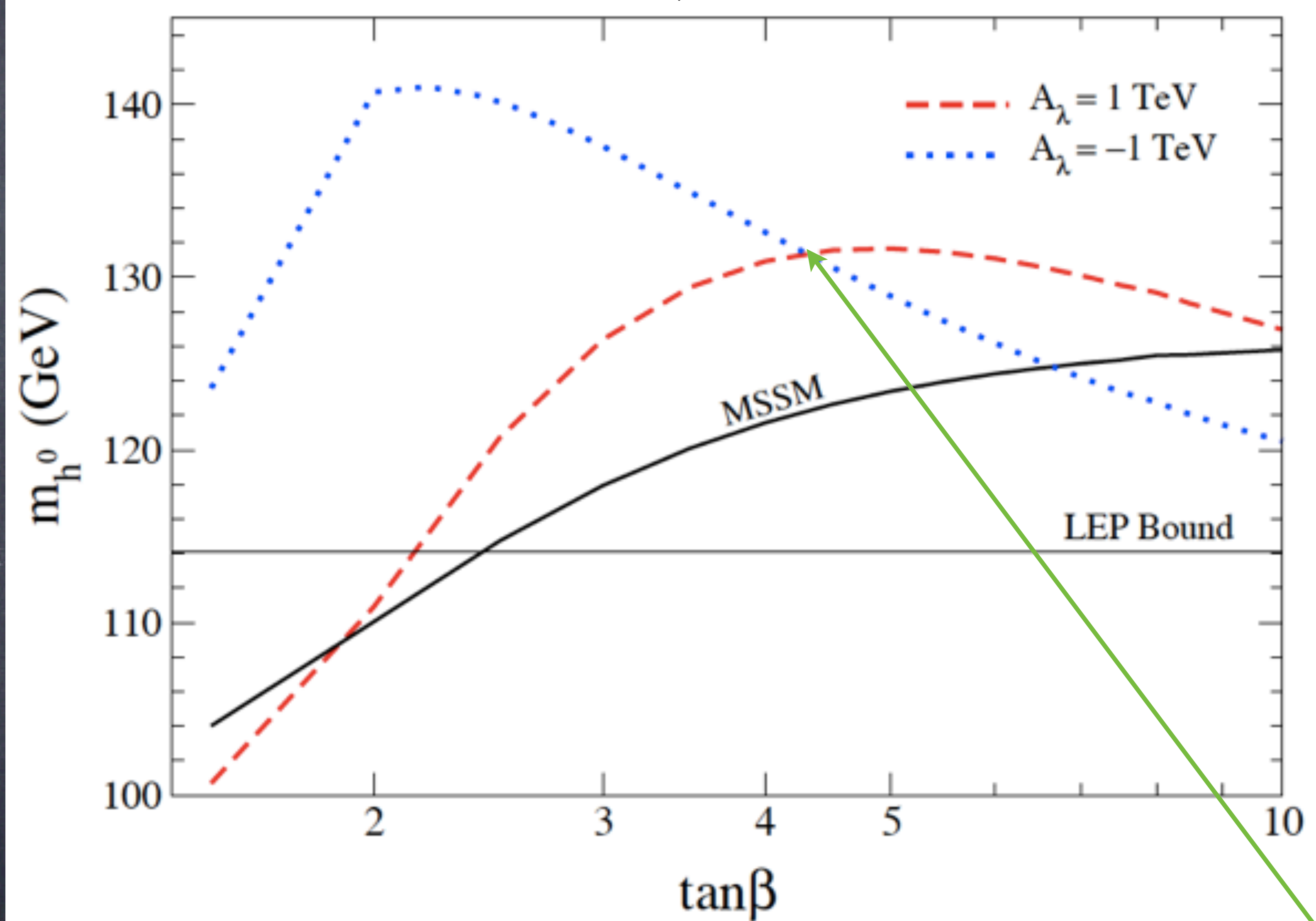

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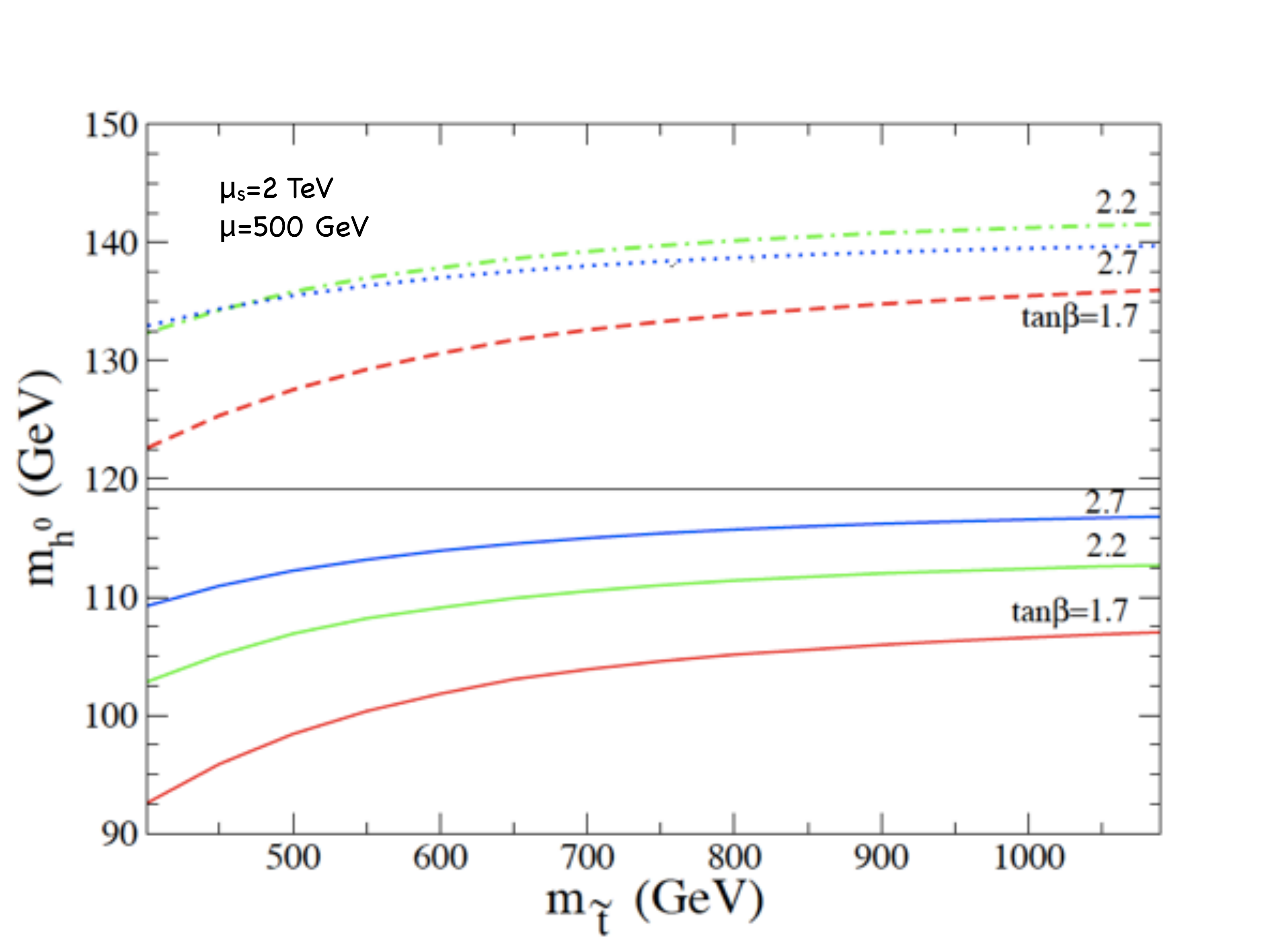
Crossing due to $\frac{1}{\mu_s^2}$ contributions

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

Largest mass at low tanβ~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