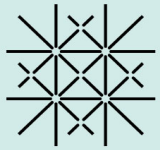

Universität Basel

An imprint of SO(10) on the MSSM spectrum

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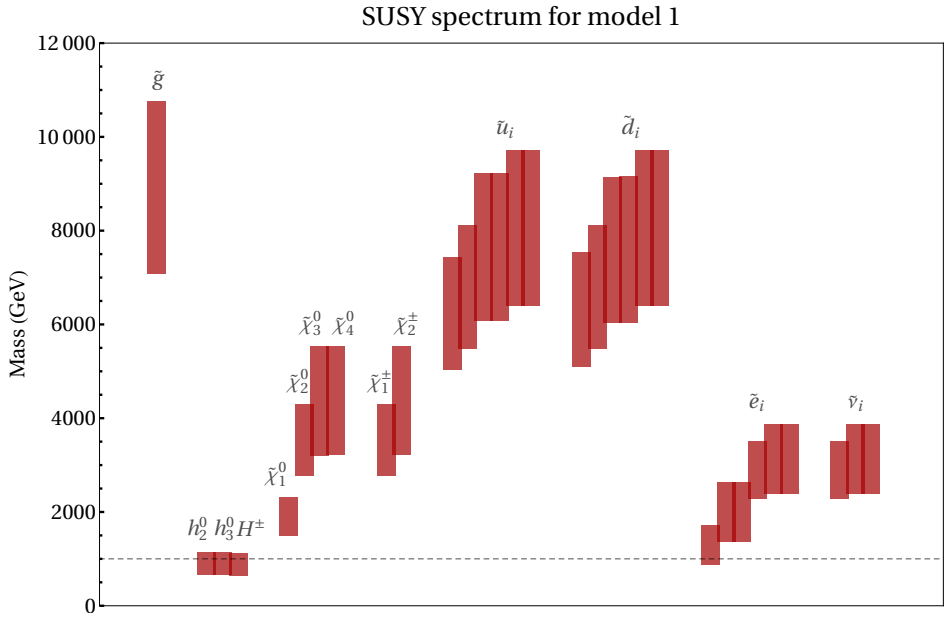
Motivation

- UV model $\Rightarrow$ MSSM sparticle spectrum

  Any imprints/features in the spectrum from UV?

- Previous talk (by Christian Hohl):

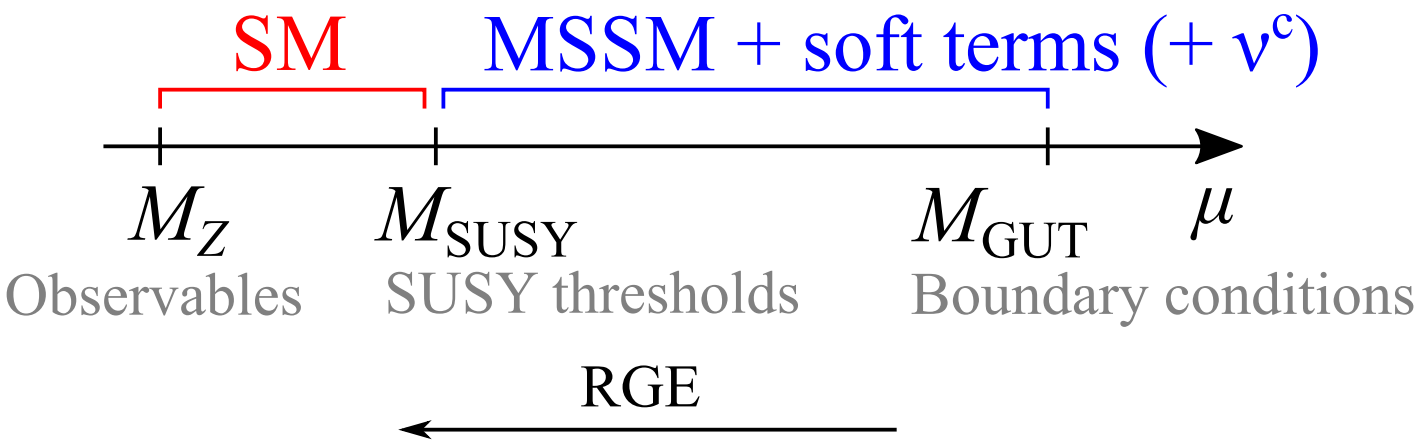


- SO(10) and t-b-τ unification:
  Extra Higgs particles are lightest part of the MSSM spectrum!

SO(10) with t-b-τ unification

- Consider: SO(10) SUSY GUT with t-b-τ unification

$$y_0 := (y_t = y_b = y_\tau)\big|_{M_{\text{GUT}}} \text{ from operator } \mathbf{16_3} \cdot \mathbf{16_3} \cdot \mathbf{10} \quad (1)$$



- MSSM notation: Q, L, u^c, d^c, e^c, ν^c, H_u, H_d
- Soft terms: gaugino masses, soft masses, A trilinear terms
- We will be considering a **simplified scenario**:
  only 3rd Yukawa family, no Majorana terms for ν^c

Boundary conditions, extra Higgses

- **Boundary conditions** at M_{GUT}:

$$M_i = M_{1/2}, \quad \mathbf{A}_x = a_0 \mathbf{Y}_x, \tag{2}$$

$$\text{Constrained MSSM}: \quad \mathbf{m}_f^2 = m_0^2 \mathbf{1}, \quad m_h^2 = m_0^2. \tag{3}$$

$$\mathrm{SO}(10): \quad \mathbf{m}_f^2 = m_{16}^2 \mathbf{1}, \quad m_h^2 = m_{10}^2. \tag{4}$$

$i \in \{1,2,3\}$, $x \in \{u,d,e,\nu\}$, $f \in \{Q, L, u^c, d^c, e^c, \nu^c\}$, $h \in \{H_u, H_d\}$

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- **Extra Higgs boson masses** (tree level) for H^0, A^0, $H^\pm$ (when $m_{H_d}^2 - m_{H_u}^2 \gg m_Z^2$ and $\tan\beta \gg 1$, EW vacuum inserted)

$$m_{A^0}^2 = \frac{\tan^2\beta + 1}{\tan^2\beta - 1}\,(m_{H_d}^2 - m_{H_u}^2) - m_Z^2$$

$$\longrightarrow (m_{H_d}^2 - m_{H_u}^2) \text{ sets the scale}, \tag{5}$$

$$m_{H^0}^2 = \tfrac{1}{2}(m_{A^0}^2 + m_Z^2 + \sqrt{(m_{A^0}^2 - m_Z^2)^2 + 4 m_Z^2\, m_{A^0}^2\, \sin^2(2\beta)}), \tag{6}$$

$$m_{H^\pm}^2 = m_{A^0}^2 + m_W^2. \tag{7}$$

RGE for $m^2_{H_d} - m^2_{H_u}$, generic point

- 1-loop **RGE** for $m^2_{H_d} - m^2_{H_u}$:

$$\begin{aligned} 16\pi^2 \tfrac{d}{dt}(m^2_{H_d} - m^2_{H_u}) = \quad & 6|y_b|^2 \left(|a_d|^2 + m^2_{H_d} + m^2_{Q_3} + m^2_{d_3}\right) \\ & - 6|y_t|^2 \left(|a_u|^2 + m^2_{H_u} + m^2_{Q_3} + m^2_{u_3}\right) \\ & + 2|y_\tau|^2 \left(|a_e|^2 + m^2_{H_d} + m^2_{L_3} + m^2_{e_3}\right) \\ & - 2|y_\nu|^2 \left(|a_\nu|^2 + m^2_{H_u} + m^2_{L_3} + m^2_{\nu_3}\right) - \tfrac{6}{5} g_1^2 S \qquad (8) \\ \approx (\text{`}\tau - \nu\text{'}) & - (\text{`}t - b\text{'}). \qquad (9) \end{aligned}$$

S is a combination of soft masses: cancellations, so numerically negligible

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- Study **generic point** (with good Yukawa fit at M_Z):

$$\tan\beta = 51, \qquad m_0^2 = (2400\,\mathrm{GeV})^2, \quad M_{1/2} = 3700\,\mathrm{GeV},$$
$$y_0 = 0.483, \quad a_0 = -3200\,\mathrm{GeV}. \qquad (10)$$

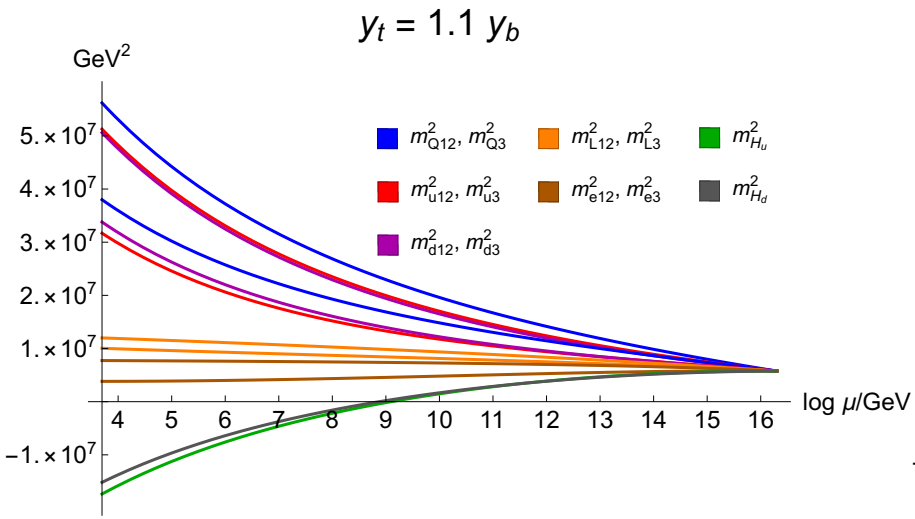
Soft terms at multiple TeV.

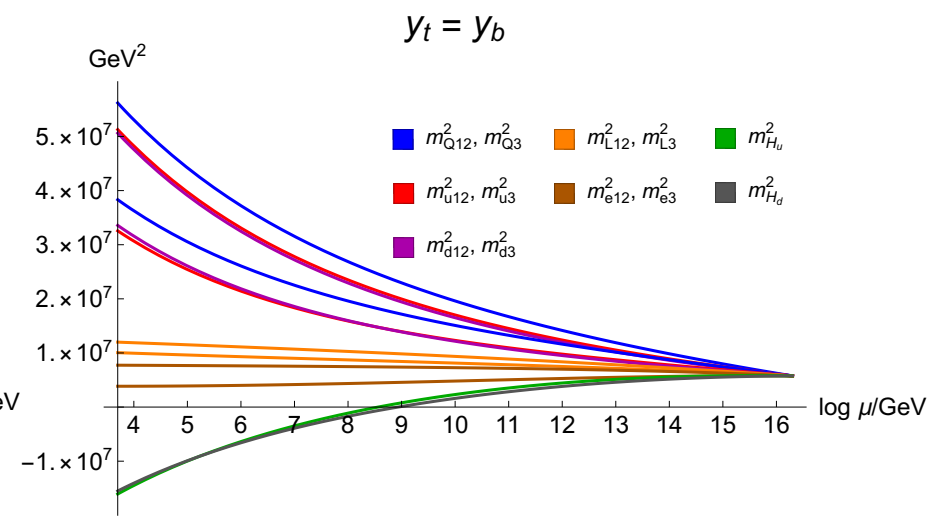
$M_R = M_{\mathrm{GUT}} = 2.0 \cdot 10^{16}\,\mathrm{GeV}$. (ignore ν^c below GUT scale)

1-loop RGE running for generic point

- Effect of t-b unification: deformed (left) vs exact (right).
- Not much (relative) change in the soft parameters themselves.
  But crucial change in $m^2_{H_d} - m^2_{H_u}$!

  Affects mass of extra MSSM Higgs particles.
- Running of soft parameters:





1-loop RGE running for generic point

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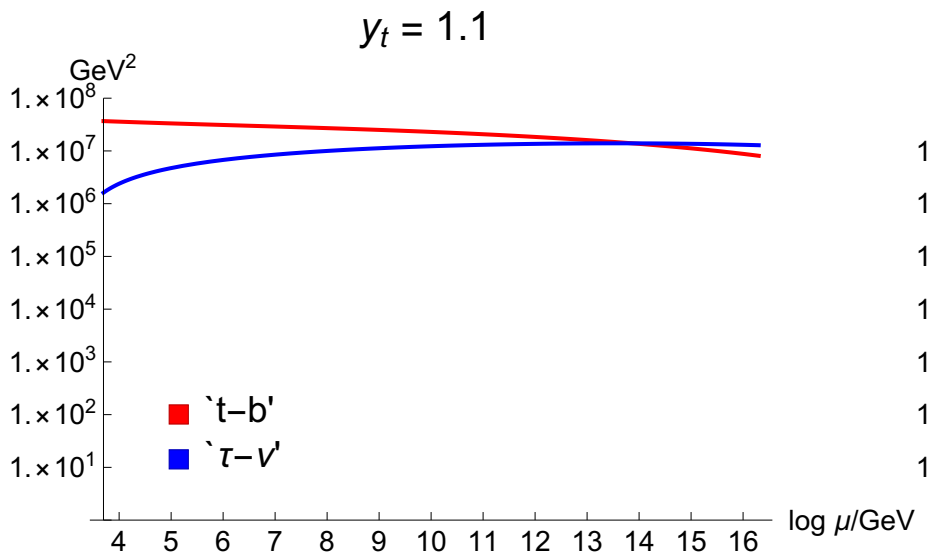
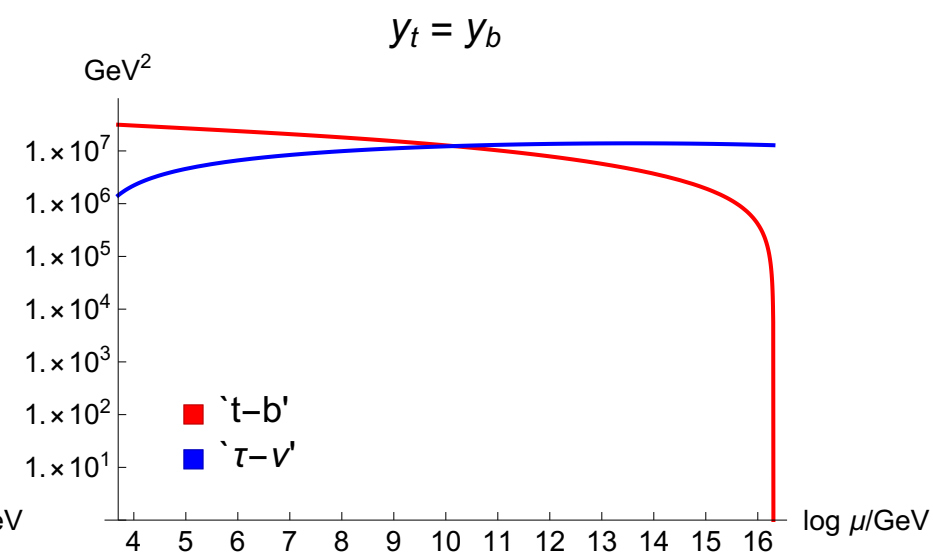
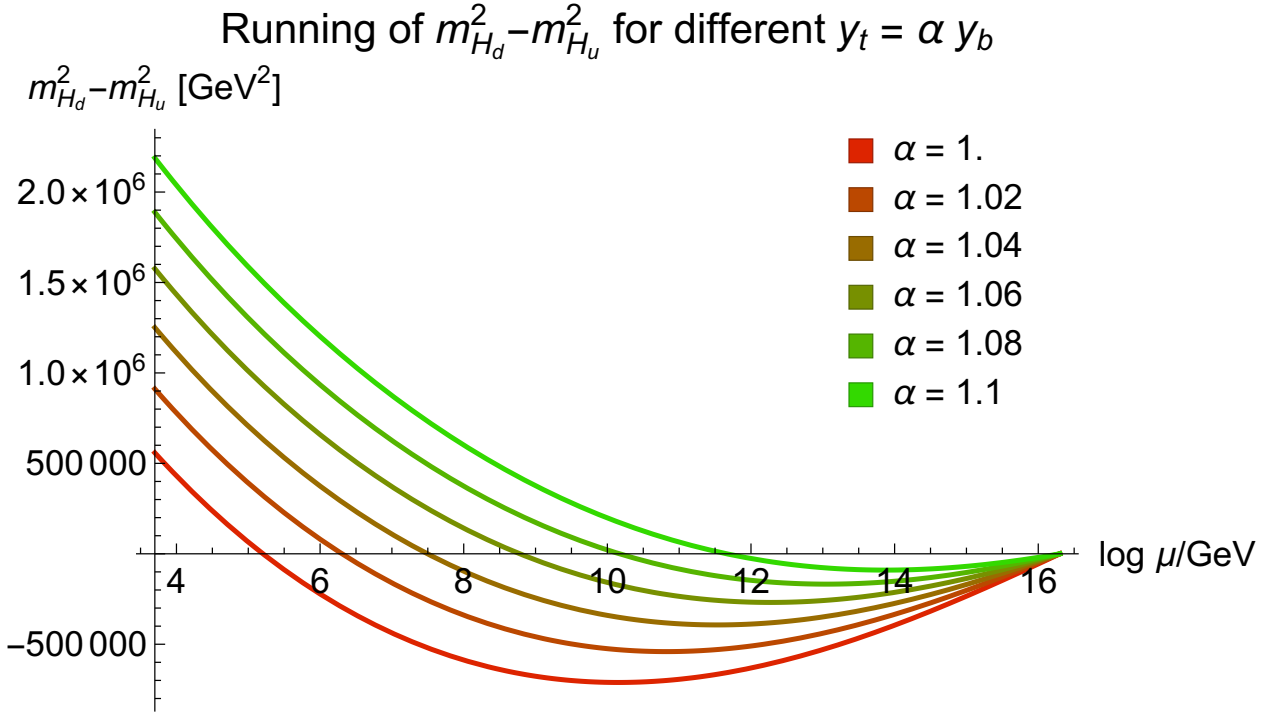
- Contributions to $\beta(m^2_{H_d} - m^2_{H_u})$:





Generic point — sensitivity to t-b unification

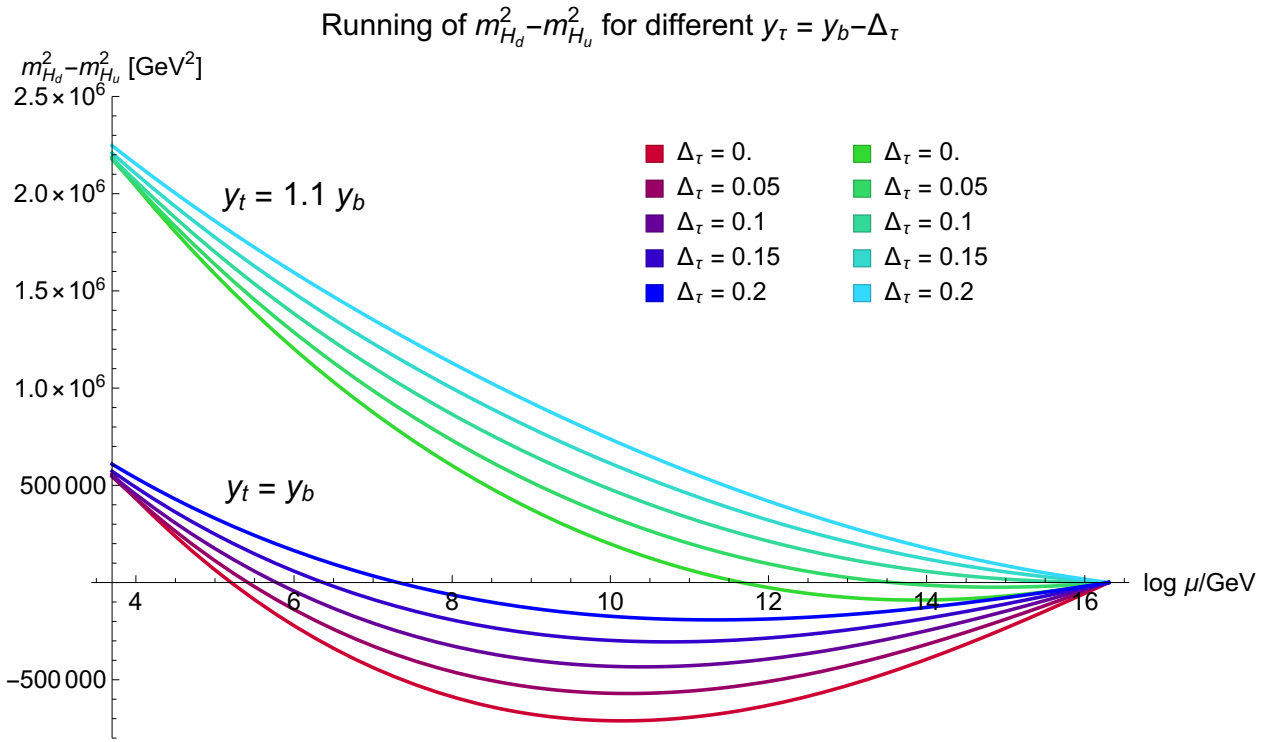
- Positive slope: '$\tau - \nu$' contribution dominates
  Negative slope: '$t - b$' contribution dominates
- t-b unification: delays the dominance of '$t - b$'



Generic point — sensitivity to other parameters

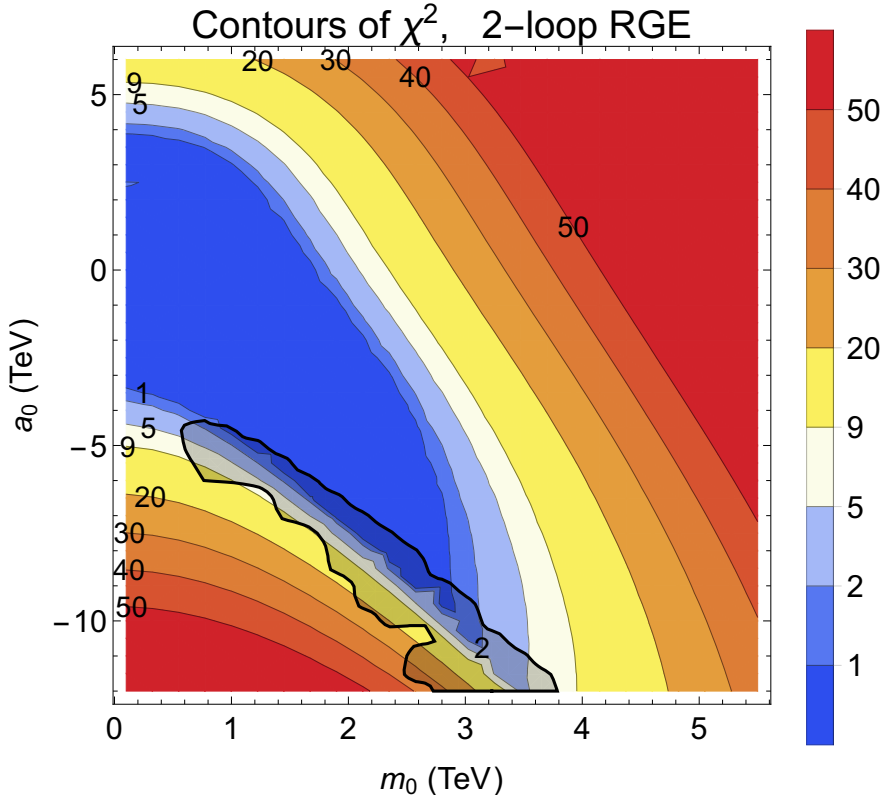
Low $m_{H_d}^2 - m_{H_u}^2$ effect relatively **insensitive** to

1. b-τ unification (see figure)
2. scale M_R of ν^c
3. m_{10} and m_{16}



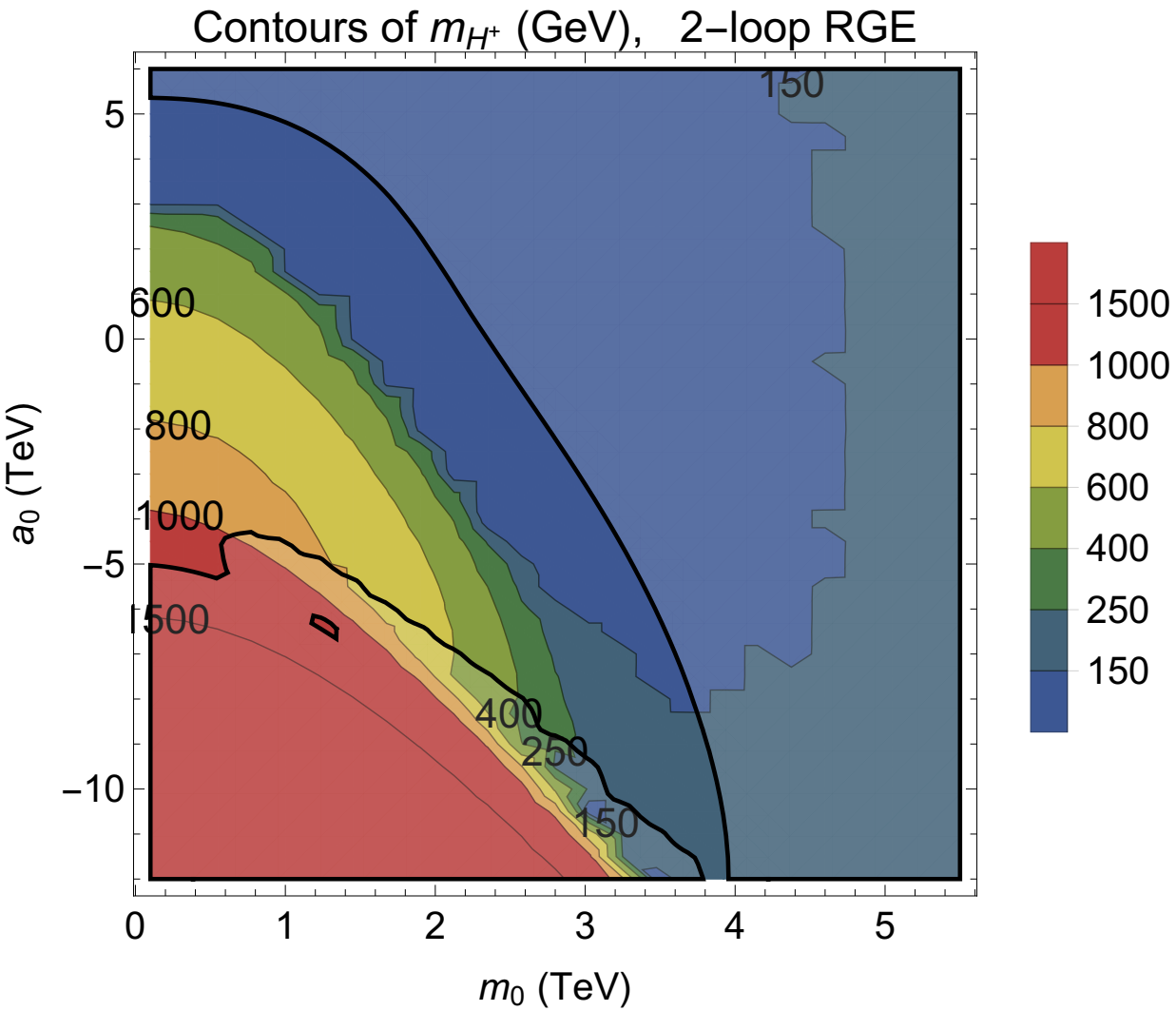
Exploration of CMSSM parameter space

- For a **fixed** m_0, a_0: Minimize χ^2 with **3 free parameters:** $\tan\beta$, $M_{1/2}$, y_0. **4 obervables**: y_t, y_b, y_τ, m_h.
- 2-loop RGE with SusyTC 1.2, 2-loop m_h with FeynHiggs 2.13.0
- Shaded: EW vacuum lifetime $< 10\, t_{\text{universe}}$ (Vevacious)



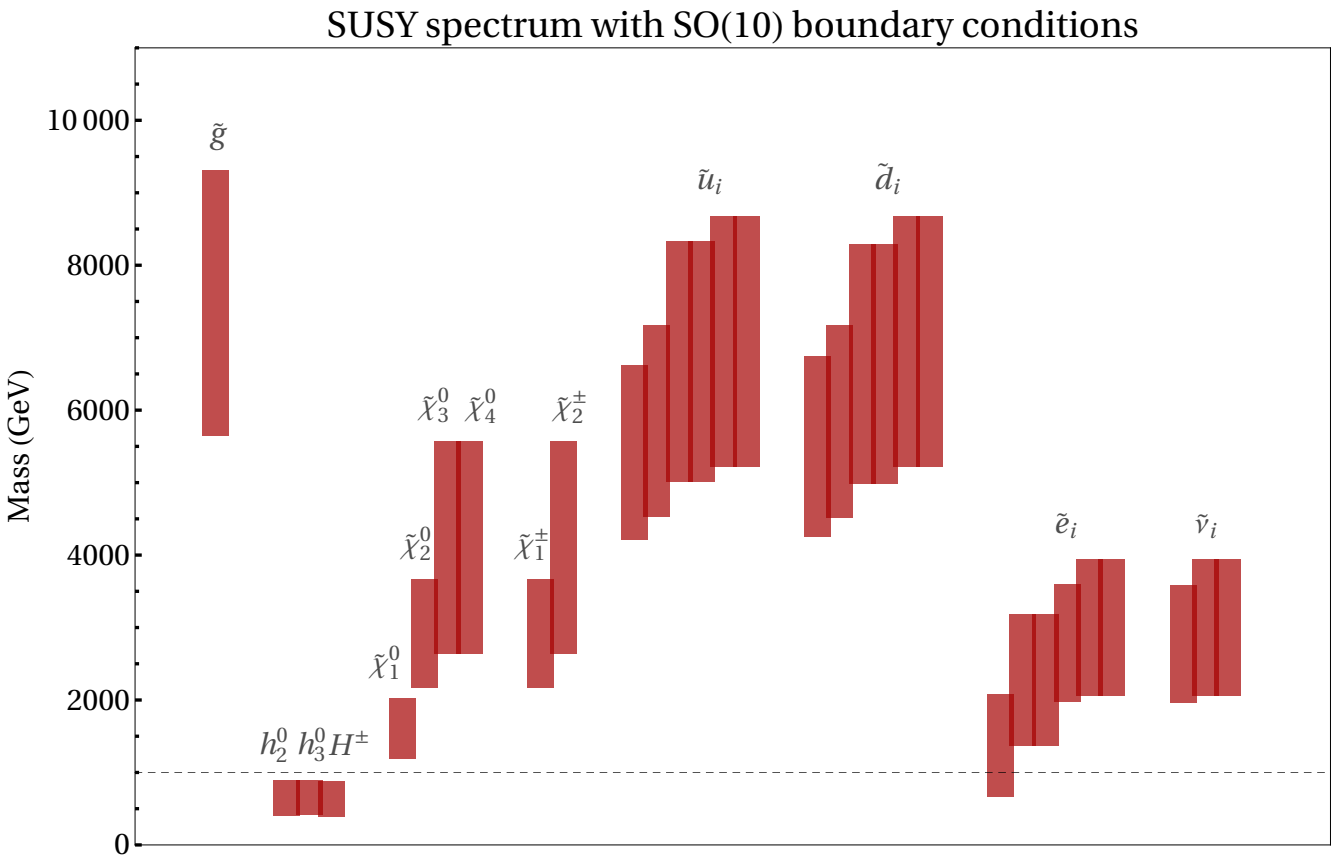
χ^2: $\sigma_y/y \sim 1\,\%, \sigma_h \sim 2\,\mathrm{GeV}$; software arXiv:1512.06727,1706.00346,1307.1477

Contours for m_{H^+}



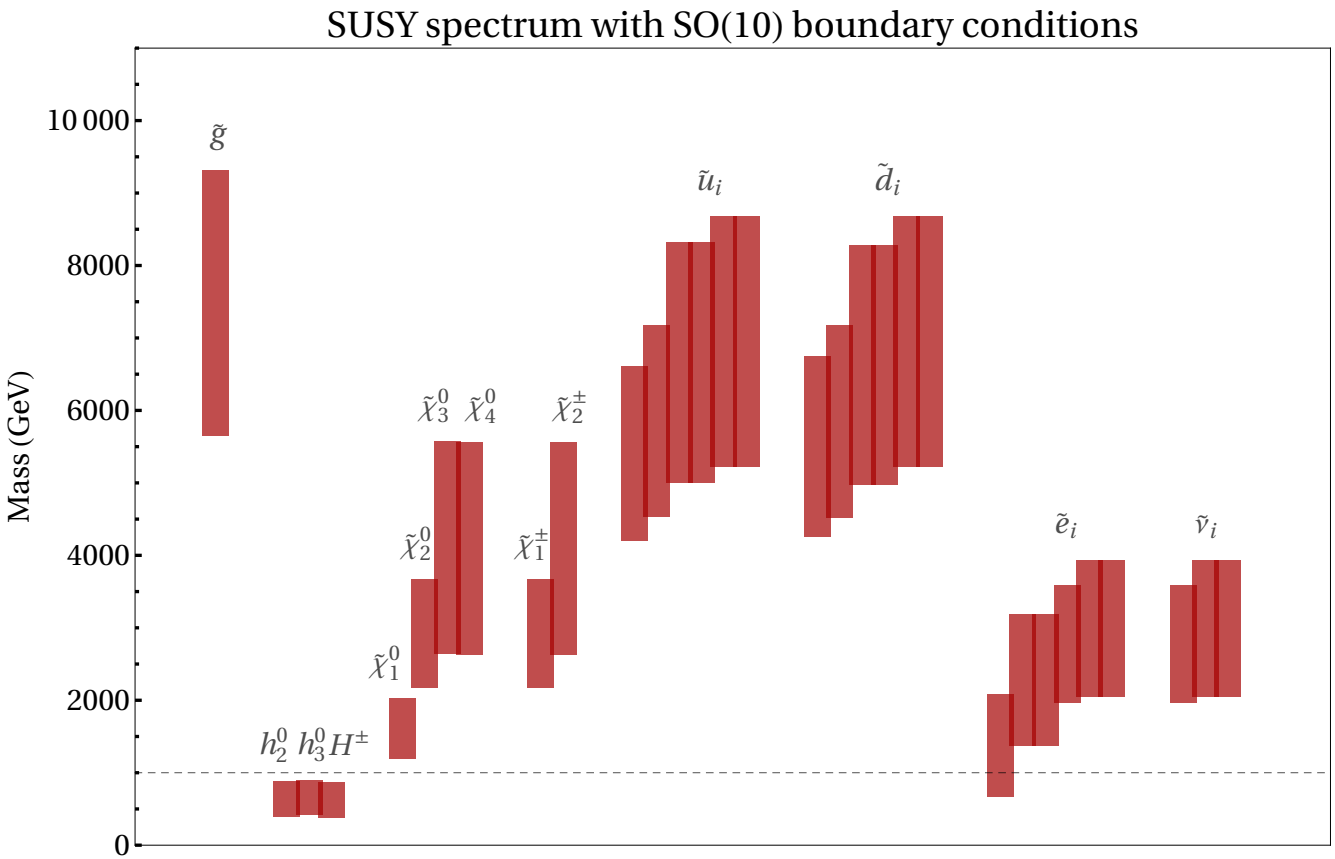
- 2-loop RGE, m_{H^+} computed at 1-loop. Generically: low m_{H^+}! Values only for minimized χ^2, more maneuvering space .

Predictive SUSY spectrum in SO(10)



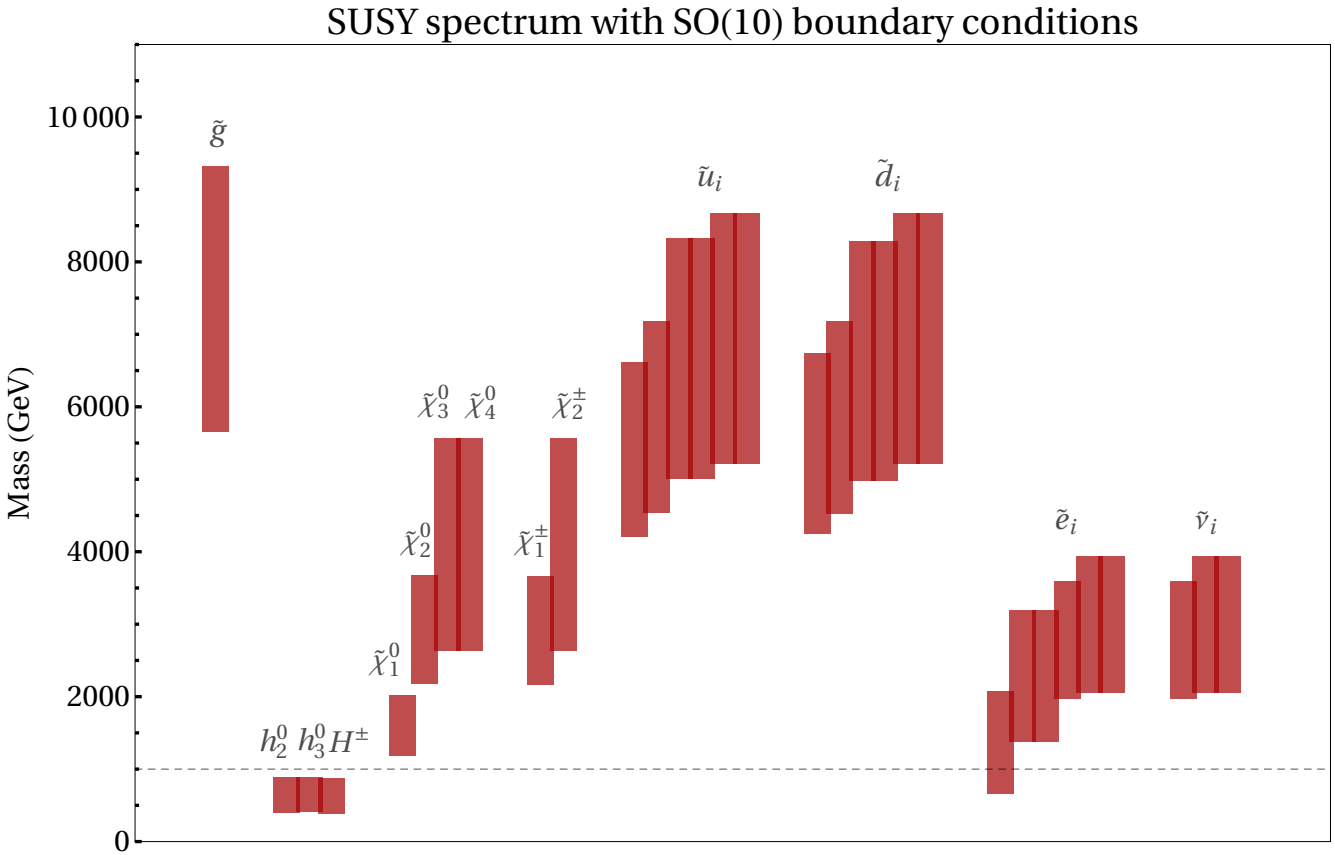
Explore space with SO(10) boundary conditions.
Markov Chain Monte Carlo, $\sim 10^6$ points.
6 parameters: y_0, $\tan\beta$, m_{10}, m_{16}, $M_{1/2}$, a_0. **Fit**: y_t, y_b, y_τ, m_h.
Shown: 1σ *highest posterior density intervals* for the SUSY spectrum.

Broader considerations for SUSY spectrum



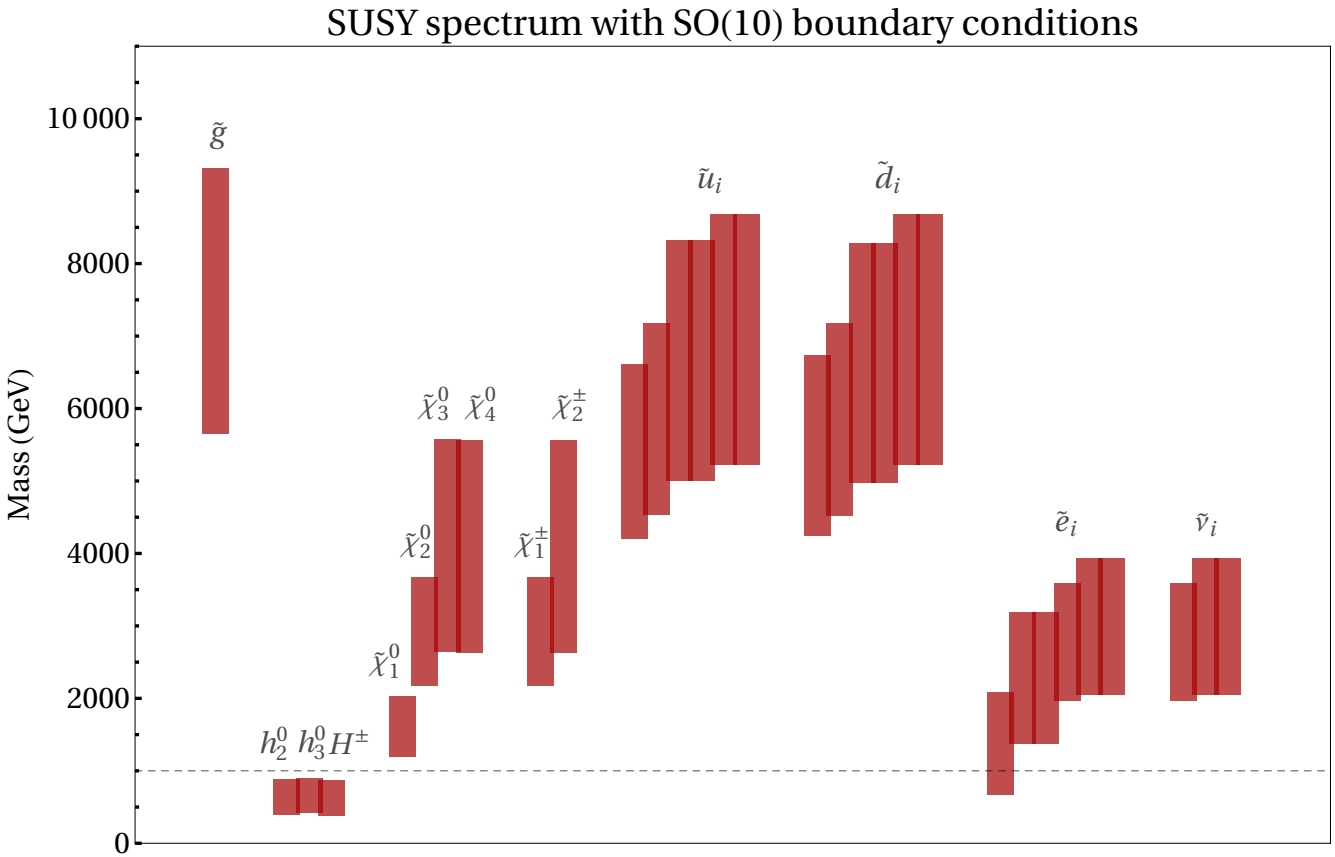
- **Features** of the spectrum:
  1. low extra Higgses (lightest MSSM particles).
  2. sleptons are low (lower than squarks).

Broader considerations for SUSY spectrum



- **Constraints** to consider (these slash parameters space further, but good points exist):
  1. neutral dark matter: neutralino should be lighter than slepton
  2. Tension from bounds on m_A from LHC searches of $H^0/A^0 \to \tau\tau$ decays (arXiv:1608.00890)

Broader considerations for SUSY spectrum



- **Caveats** (what could change in a full model):
  1. Our GUT scale was fixed
  2. GUT threshold corrections: small split t-b increases the masses of extra Higgses

Conclusions

$\mathrm{SO}(10)$ SUSY GUT with t-b-τ unification:

1. General feature in the MSSM spectrum:
   low extra Higgs masses

2. Other considerations for this effect:
   - This is a RGE running effect, seen from top down,
   - predictive: sparticle mass ranges (at a few TeV),
   - Sensitivity to GUT threshold corrections,
     especially t-b unification.