Departure from Yukawa coupling unification in SUSY GUTs

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Based on collaboration with:
Wolfgang Altmannshofer and Diego Guadagnoli

Outline

Simultaneous fit to FCNC observables presents a serious problem for certain SUSY GUTs.

[Albrecht, Altmannshofer, Buras, Guadagnoli, DS (2007); see talk by Diego Guadagnoli]

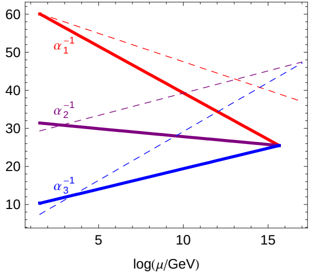
Questions:

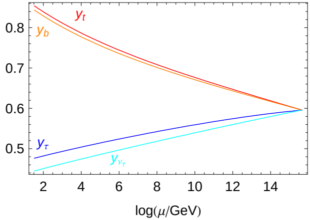
- How model-dependent are these issues?
  - A problem of *all* SUSY GUTs featuring t-b-τ Yukawa unification
- How can those problems be solved?
  - By breaking t-b unification but maintaining b-τ unification

Outline

1. Yukawa unification in SUSY GUTs
2. Impact on SUSY parameter space
3. Consequences for FCNC observables $B_s \to \mu^+\mu^-$ and $B \to X_s\gamma$
4. Numerical results

Yukawa unification in SO(10)





Minimal SO(10):

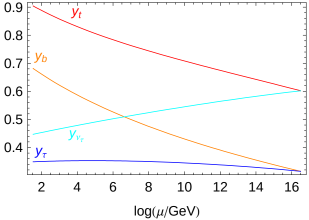
- Matter superfields of one generation contained in $\mathbf{16} = (Q, \bar{U}, \bar{D}, L, \bar{E}, \bar{\nu})$
- MSSM Higgs doublets $(H_u, H_d) \subset \mathbf{10_H}$
- 3rd generation Yukawa coupling $\mathbf{16_3}.\mathbf{10_H}.\mathbf{16_3}$
  $\Rightarrow y_t = y_b = y_\tau = y_{\nu_\tau}$

$m_t = v_u\, y_t,\ m_b = v_d\, y_b,$

$$\Rightarrow \tan\beta = \frac{v_u}{v_d} \approx 50$$

Bottom-tau unification

- SU(5): $\bar{\mathbf{5}} = (\bar{D}, L)$, $\mathbf{10} = (Q, \bar{U}, \bar{E})$
- Complete SO(10) models require additional representations (e.g. $\mathbf{16_H}$) which contain doublets
- Doublets can mix with $(H_u^{\mathbf{10_H}}, H_d^{\mathbf{10_H}})$



Example:

$H_d = H_d^{\mathbf{10_H}} \cos\gamma + H_d^{\mathbf{16_H}} \sin\gamma$

$\Rightarrow y_b = y_t \cos\gamma$

$\Rightarrow \tan\beta < 50$

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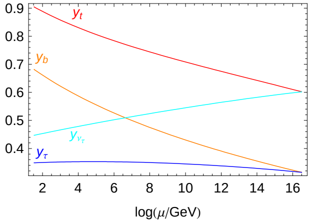

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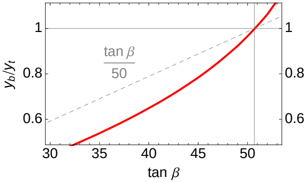

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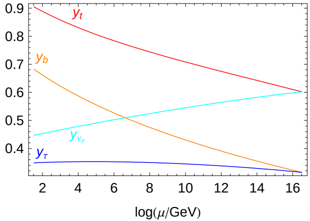

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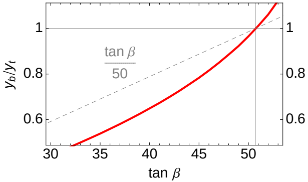
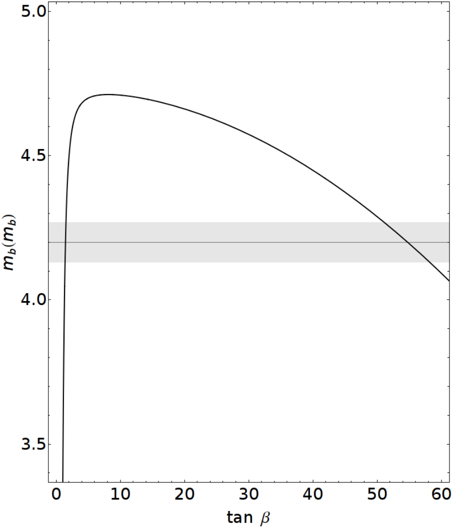


- t-b unification can be broken by Higgs mixing
- This can occur even in models of minimal SO(10) breaking [Barr & Raby (1997), Albright & Barr (1998)]
- Higgs mixing preserves b-τ unification

Yukawa unification in the MSSM

Fix m_t, m_τ, require b-τ unification $\Rightarrow$ predict m_b

[Arason et al. (1991), Carena et al. (1993), Ananthanarayan et al. (1994), . . .]



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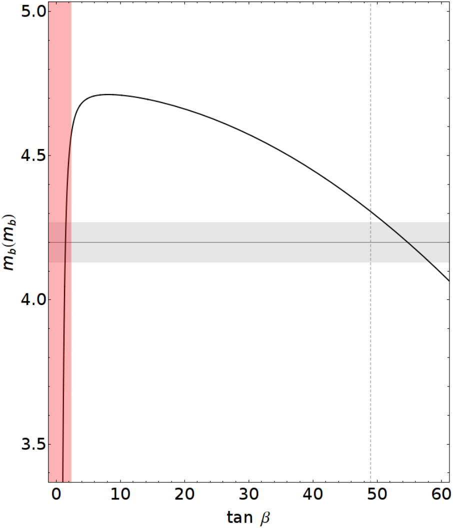

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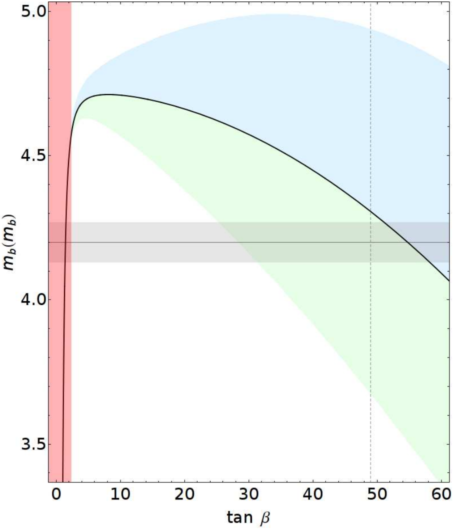
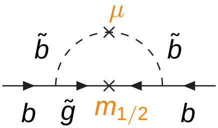
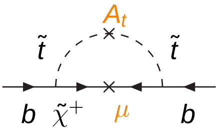


Finite threshold corrections to m_b: [Hall, Rattazzi, Sarid 1994]



$\propto \mu m_{\tilde{g}} \tan\beta \frac{1}{m_{\tilde{b}}^2}$



$\propto \mu A_t \tan\beta \frac{1}{m_{\tilde{t}}^2}$

Yukawa unification & inverted mass hierarchy

- $(t\text{-})b\text{-}\tau$ unification requires $A_t \ll 0$, $m_{\tilde{t}} \ll m_{\tilde{b}}$, and small $m_{\tilde{g}}$
- EWSB requires $m_{H_u}(M_G) \neq m_{H_d}(M_G)$ (a.k.a. NUHM scenario)

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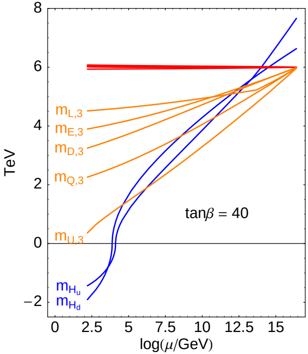
- Leads to an inverted scalar mass hierarchy [Blažek, Dermíšek, Raby 2001]



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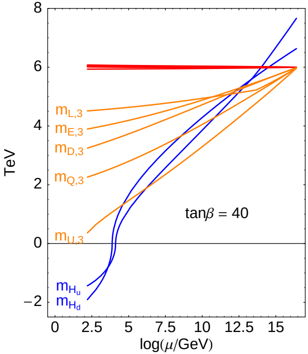

Predictions of $(t\text{-})b\text{-}\tau$ unification

- 1 stop, 1 neutralino, 1 chargino are light
- 1st and 2nd generation sfermions very heavy

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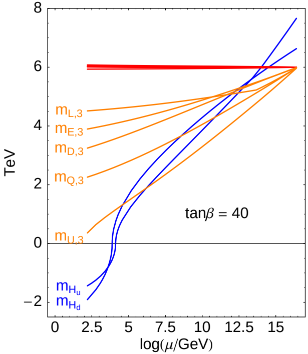

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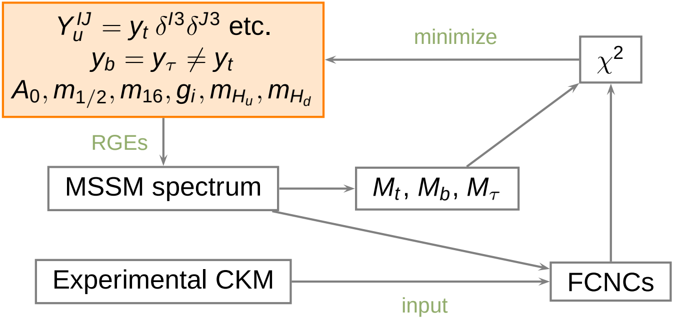
Sufficient to consider 3rd generation effects in FCNCs

Procedure



1. Only 3rd generation Yukawa couplings at the GUT scale
2. RG running to the EW scale
3. Use experimentally measured CKM matrix
4. calculate FCNCs and t, b, τ masses
5. minimize χ^2 function

$M_W, M_Z, G_\mu, \alpha_{em}, \alpha_s, M_t, M_b, M_\tau, B \to X_s\gamma, B \to X_s\ell^+\ell^-, \Delta M_s/\Delta M_d$

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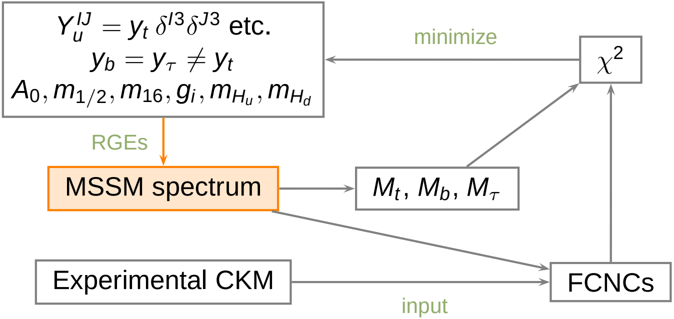

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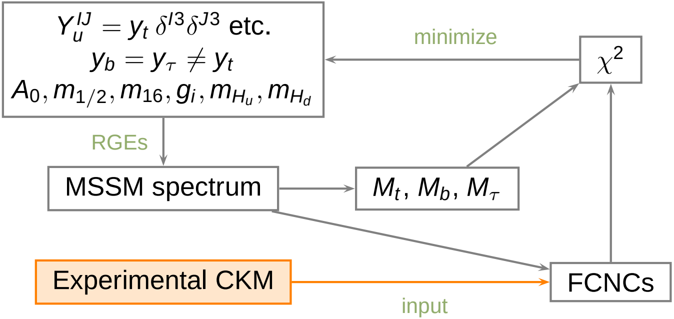

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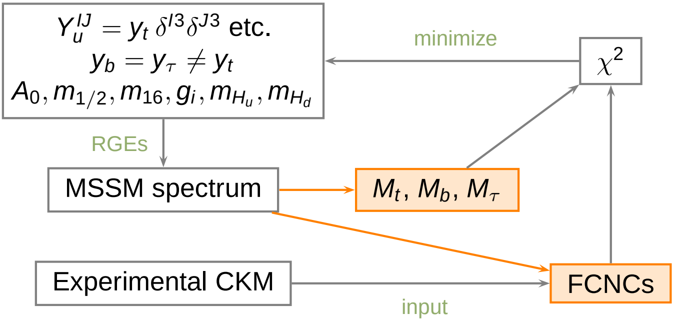

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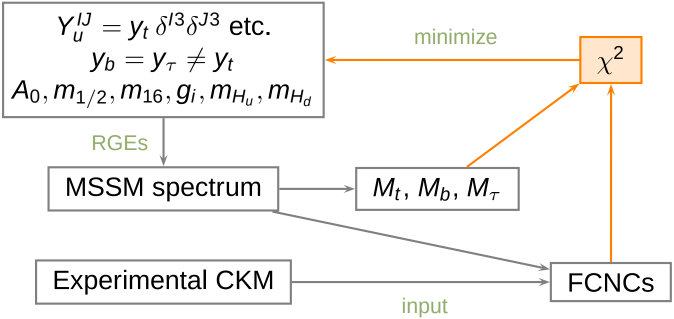

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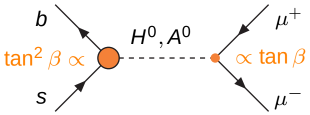
$B_s \to \mu^+\mu^-$

$\mathrm{BR}(B_s \to \mu^+\mu^-)$

SM	$(3.35 \pm 0.32) \times 10^{-9}$
exp.	$< 5.8 \times 10^{-8}$ [CDF]



- Decay is helicity suppressed in the SM
- SUSY contribution potentially large, dominated by Higgs penguin

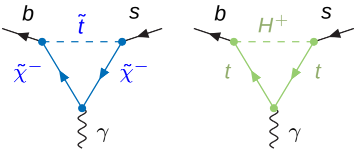
$$\mathrm{BR}(B_s \to \mu^+\mu^-)^{\mathrm{HP}} \propto A_t^2 \frac{\tan^6\beta}{M_A^4}$$

[Buras, Chankowksi, Rosiek, Sławianoska (2002)]

- With $\tan\beta = 50$ (t-b-τ unification!), very heavy A^0, H^0, H^+ required
- Smaller $\tan\beta$ allows lighter Higgs spectrum

$B \to X_s \gamma$

- BR $\sim |C_7^{\text{SM}}|^2 + 2\text{Re}(C_7^{\text{SM}} C_7^{\text{SUSY}})$
- $C_7^{H^+} \propto +1/M_{H^+}^2$, $C_7^{\tilde{\chi}^+} \propto A_t \mu \tan\beta$
- $\tilde{\chi}^+$ and H^+ contributions tend to cancel each other for $\mu > 0$



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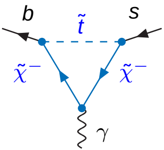
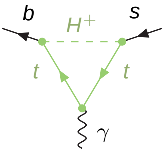
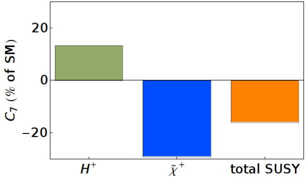




$\tan\beta = 50$

- large $\tan\beta \Rightarrow$ large $C_7^{\tilde{\chi}^+}$
- heavy Higgses $\Rightarrow$ small $C_7^{H^+}$



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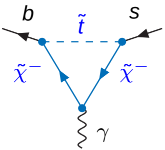

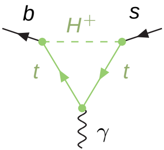

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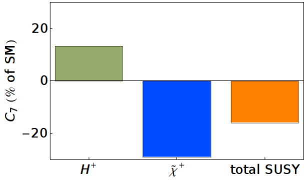
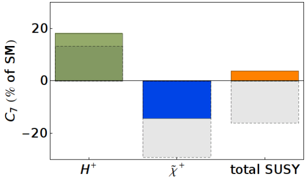


$\tan\beta \approx 40$

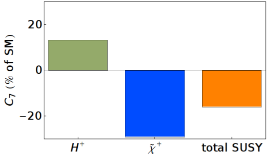
- $\tan\beta \searrow \Rightarrow |C_7^{\tilde{\chi}^+}| \searrow$
- $M_{H^+} \searrow \Rightarrow |C_7^{H^+}| \nearrow$



Overview

$\tan\beta \gtrsim 45$

- t-b-τ unification possible, but:
- Combined $B_s \to \mu^+\mu^-$ and $B \to X_s\gamma$ constraints impossible to fulfill



Overview

$\tan\beta \approx 40$

- b-τ unification possible
- $B_s \to \mu^+\mu^-$ and $B \to X_s\gamma$ compatible with experiment

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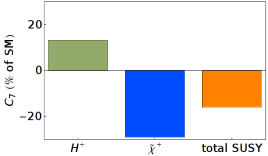
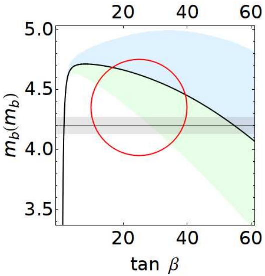


Overview

$\tan\beta \lesssim 35$

- b-τ unification impossible to achieve



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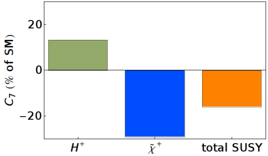
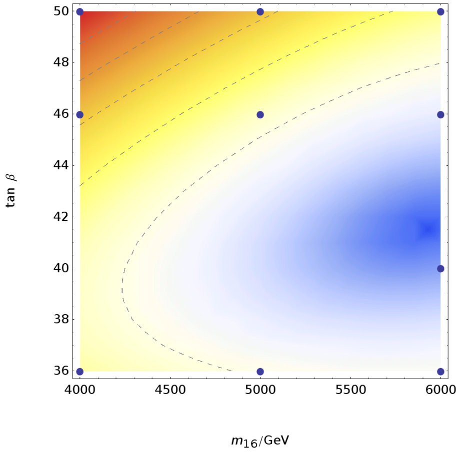


Results of global χ^2 analysis

χ^2 distribution from preliminary fit results:



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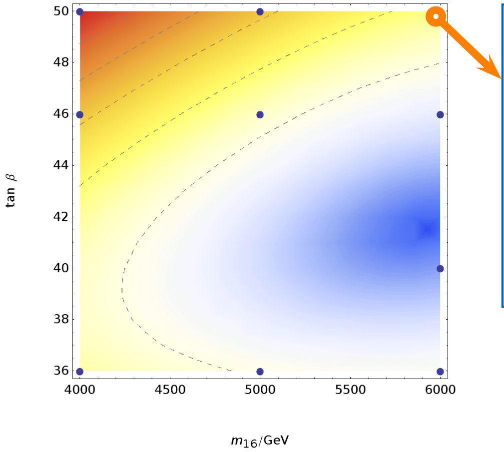

$\text{BR}(B \to X_s\gamma)$	2.2σ too low
m_b	2.5σ too big
$M_{\tilde{t}_1}$	$= 1370\,\text{GeV}$
M_A	$= 560\,\text{GeV}$
χ^2	$= 21$

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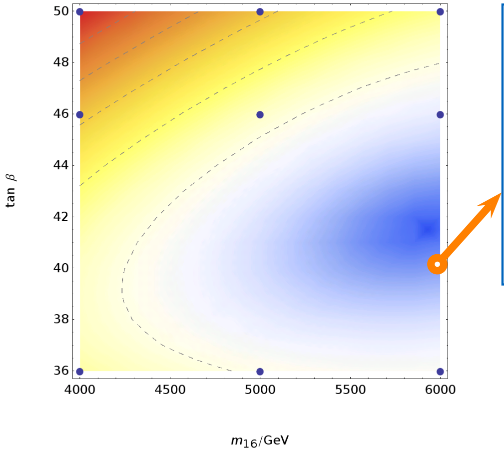

$\mathrm{BR}(B \to X_s\gamma)$ 1.5σ too low

m_b 0.4σ too big

$M_{\tilde{t}_1} = 830\,\mathrm{GeV}$

$M_A = 503\,\mathrm{GeV}$

$\chi^2 = 12$

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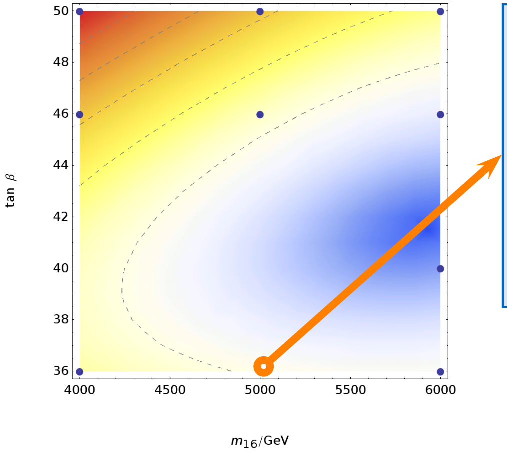

$$\mathrm{BR}(B \to X_s\gamma) \quad 0.9\sigma \text{ too low}$$

$$m_b \quad 2.4\sigma \text{ too big}$$

$$M_{\tilde{t}_1} = 730\,\mathrm{GeV}$$

$$M_A = 400\,\mathrm{GeV}$$

$$\chi^2 = 17$$

Conclusions

Main Messages

- The tension between $B \to X_s\gamma$ and $B_s \to \mu^+\mu^-$ is a universal problem of SUSY GUTs with t-b-τ Yukawa unification (assuming universal sfermion and gaugino masses)
- b-τ Yukawa unification is possible with moderate sfermion masses for $35 \lesssim \tan\beta \lesssim 45$
- LHC predictions: light stop, light neutralino, light chargino