Viability of MSSM scenarios at very large tan β

based on arXiv:1004.1993 [hep-ph]

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SUSY10
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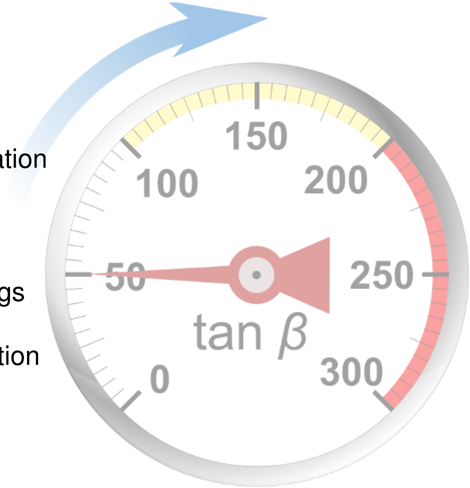
Outline

1. Why not very large tan β?
   - Yukawa perturbativity
   - FCNCs
2. Why very large tan β?
   - The $B\mu$ problem of gauge mediation
   - Uplifted SUSY
3. Numerical analysis
   - Perturbativity of Yukawa couplings
   - Low energy scan
   - Very large tan β in gauge mediation
4. Conclusions



Demotivation 1: perturbativity of Yukawa couplings

3rd generation fermion masses at tree level:

$$m_t = v_u y_t, \qquad m_b = v_d y_b, \qquad m_\tau = v_d y_\tau \tag{1}$$

$$\tan\beta = \frac{v_u}{v_d}, \qquad v_u^2 + v_d^2 = (174\text{ GeV})^2$$

Large $\tan\beta \Rightarrow$ small $v_d \Rightarrow$ large down-type Yukawas

Using these tree-level relations,

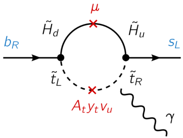
- y_b and y_τ would be non-perturbative for $\tan\beta \gtrsim 250$
- y_b and y_τ would have a Landau pole below M_{GUT} for $\tan\beta \gtrsim 75$

Ways out:

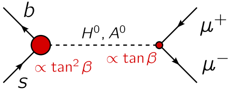
- $\tan\beta$ enhanced threshold corrections to (1)
- Perturbativity up to M_{GUT} not strictly necessary

Demotivation 2: flavour violation

Large tan $\beta \Rightarrow$ enhanced contributions to B decays even for flavour-blind soft terms:



$$\frac{\mathrm{BR}(B \to X_s \gamma)}{\mathrm{BR}(B \to X_s \gamma)_{\mathrm{SM}}} - 1 \propto -\frac{\mu A_t}{\tilde{m}_{\tilde{t}}^2} \tan\beta$$



$$\frac{\mathrm{BR}(B_s \to \mu^+ \mu^-)}{\mathrm{BR}(B_s \to \mu^+ \mu^-)_{\mathrm{SM}}} - 1 \propto \frac{|\mu A_t|^2}{M_A^4} (\tan\beta)^6$$

Under control if trilinear terms are small (as in gauge mediation)

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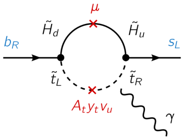

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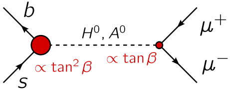

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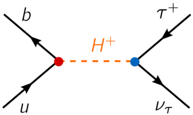

$$\frac{\mathrm{BR}(B^+ \to \tau^+\nu)}{\mathrm{BR}(B^+ \to \tau^+\nu)_{\mathrm{SM}}} \simeq \left(1 - \frac{m_{B^+}^2}{M_{H^+}^2} \frac{\tan^2\beta}{(1+\epsilon_0 t_\beta)(1+\epsilon_\ell t_\beta)}\right)^2$$

Under control if M_{H^+} is large

Outline

Motivation 1: the $\mu/B\mu$ problem of gauge mediation

$$\mathcal{W} \supset \mu\, H_u H_d\ , \qquad \mathcal{L}_{\text{soft}} \supset -B\mu\, H_u H_d + \text{h.c.}$$

- Difficult to generate $B\mu$ of the right size in GMSB
  $\Rightarrow B\mu(M) = 0$ natural possibility
- $\tan\beta = \dfrac{m_A^2}{B\mu}$ at tree level
- Non-zero $B\mu$ generated by RG effects $\Rightarrow$ large $\tan\beta$
  [Dine, Nir, Shirman (1993)]

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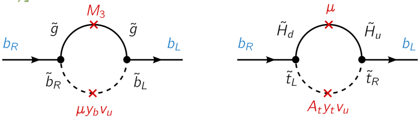
Additional nice features:

- Soft terms are flavour blind
- Trilinear couplings are small
- Mediation scale can be quite low (perturbativity!)

Motivation 2: Uplifted SUSY

Tree-level relations between masses and Yukawas are modified by $\tan\beta$ enhanced threshold corrections:

[Hall, Rattazzi, Sarid (1993)]



$$m_{b,\tau} = y_{b,\tau} v_d + \Delta m_{b,\tau} = y_{b,\tau}(v_d + \epsilon_{b,\tau} v_u) = y_{b,\tau} v_d (1 + \epsilon_{b,\tau} \tan\beta)$$

$$\epsilon_b = \epsilon_b^{\widetilde{B}} + \epsilon_b^{\widetilde{W}} + \epsilon_b^{\widetilde{g}} + \epsilon_b^{\widetilde{H}}$$

$$\epsilon_\tau = \epsilon_b^{\widetilde{B}} + \epsilon_b^{\widetilde{W}}$$

"Uplifted SUSY" [Dobrescu, Fox (2010)]

For $\tan\beta \gg 50$, one could have $\Delta m_{b,\tau} \gtrsim y_{b,\tau} v_d$

- Loop contribution to b/τ mass comparable to tree-level contribution
- Yukawas remain perturbative even for very large $\tan\beta$
- Can be a consequence of $B\mu = 0$ at some scale

Outline

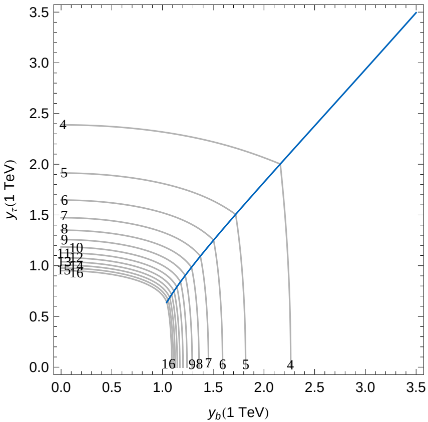
RG evolution of Yukawa couplings

Yukawa RGE:

$$\frac{dy_i}{dt} = \frac{y_i}{16\pi^2} \sum_{j,k} (a_j\, y_j^2 - b_k\, g_k^2)$$

Gray contours:

The scale (10^X GeV) where y_b or y_τ reach $y^{max} = \sqrt{4\pi}$, depending on their value at the TeV scale.



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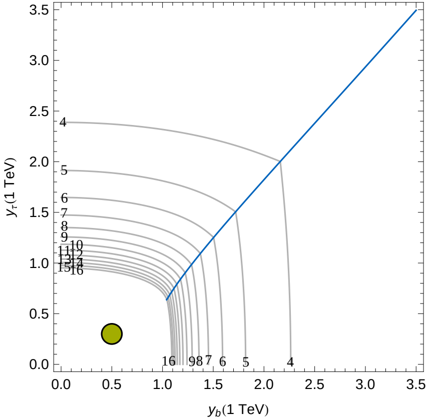

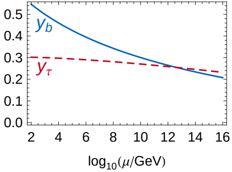

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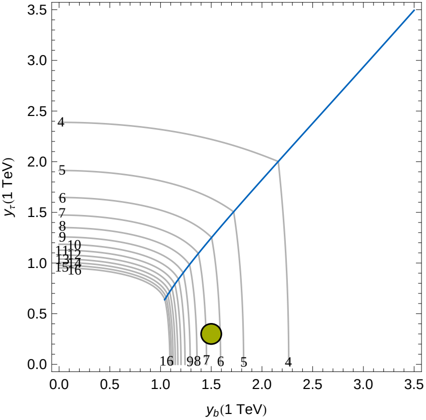

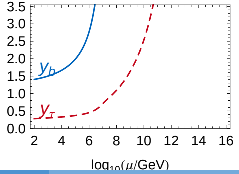

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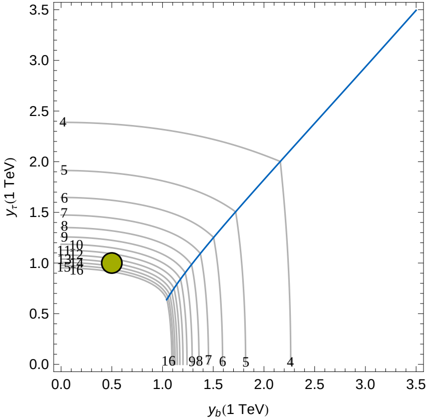

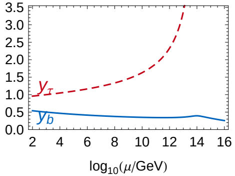

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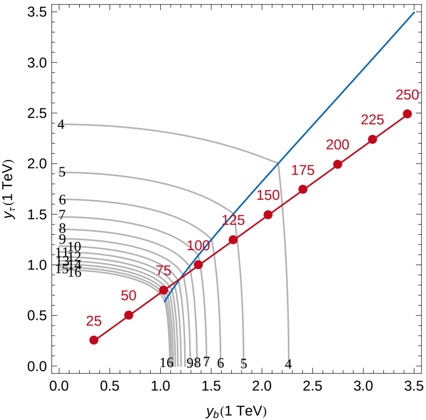
Red line:

Value of $y_{b,\tau}$ at 1 TeV without threshold corrections



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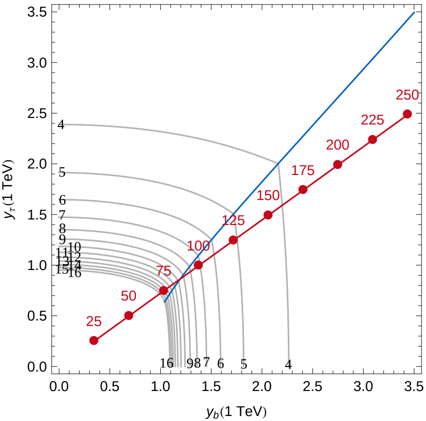


At what scale do the Yukawas become non-perturbative

$\Leftrightarrow$ how far can the actual Yukawas deviate from the red line?

Viability of very large tan β

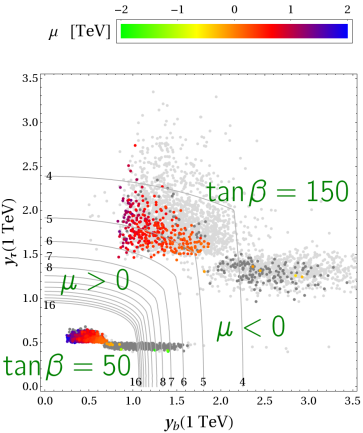
Low-energy parameter scan

Vary the low-energy MSSM parameters for fixed values of tan β, assuming

- no new sources of CP violation
- flavour-blind soft terms

Scan ranges:

$$m_{Q,U,D,L,E} \in [0.1, 2] \text{ TeV}, \quad A_{u,d,l} \in [-0.5, 0.5] \text{ TeV},$$
$$\mu \in [-2, 2] \text{ TeV}, \quad M_{A^0} \in [0.1, 2] \text{ TeV},$$
$$M_1 \in [-1, 1] \text{ TeV}, \quad M_2 \in [-2, 2] \text{ TeV}, \quad M_3 \in [0, 6] \text{ TeV},$$



$M_2 > 0$

Threshold correction to y_τ

$$-\Delta y_\tau^{\widetilde{W}} \propto \tan\beta \times \text{sgn}(\mu M_2)$$

Threshold correction to y_b

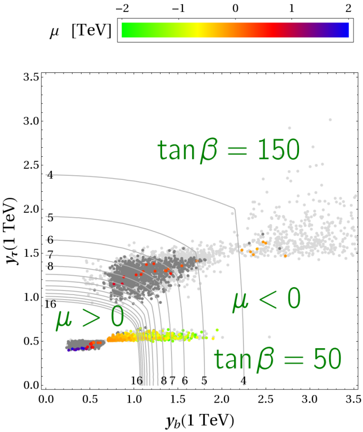
$$\Delta y_\tau^{\widetilde{g}} \propto \tan\beta \times \text{sgn}(\mu M_3)$$

The muon $g-2$

$$\Delta a_\mu^{\text{exp}} = (25.5 \pm 8.0) \times 10^{-10}$$

$$\Delta a_\mu^{\text{SUSY}} \propto \tan\beta \times \text{sgn}(\mu M_2)$$

Numerical results: Yukawas



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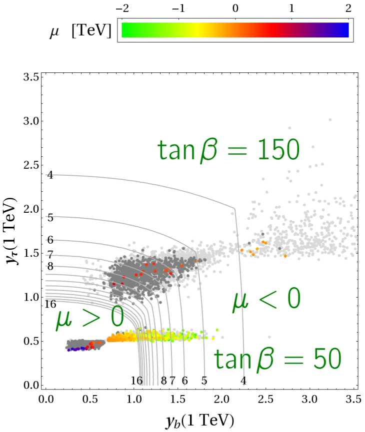

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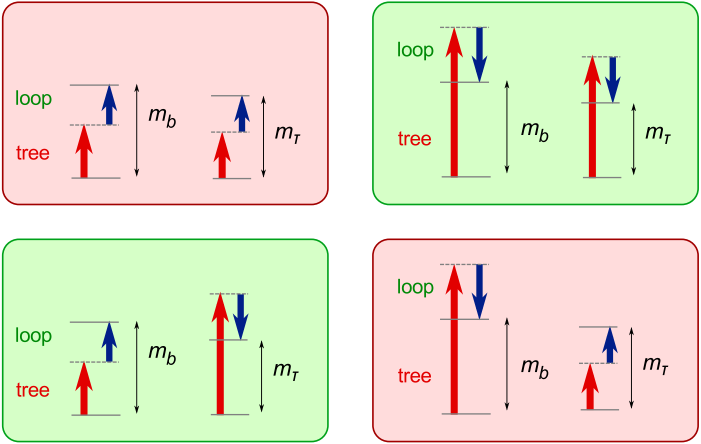
Simultaneous $\Delta y_\tau > 0$ and $\Delta y_b > 0$ strongly disfavoured by $(g-2)_\mu$

Threshold corrections vs. $g - 2$

ruled out by *g*-2



ruled out by *g*-2

Large $\tan\beta$ in gauge mediation

Gauge mediation

- Can naturally lead to $B\mu(M) = 0$ ($\Rightarrow$ large $\tan\beta$)
- Small A terms suppress $\tan\beta$ enhanced FCNCs
- Low mediation scale welcome due to Yukawa Landau poles

Setup: General gauge mediation (GGM) [Meade, Seiberg, Shih (2008)]

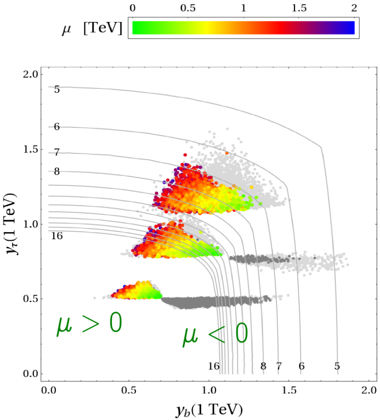
Large class of GM models described while the soft terms are parametrized in terms of a small number of parameters

$$M_k = g_k^2 M B_k \,, \qquad m_f^2 = g_1^2 Y_f \zeta + \sum_k g_k^4 C_2(f,k) A_k \,, \qquad A^{IJ}_{u,d,l} = 0 \,,$$

GGM parameter scan

- Mediation scale fixed to 100 TeV
- Gaugino masses assumed to be positive

GGM: Numerical results – Yukawa couplings



$M = 10^5$ GeV, $M_2 > 0$

$\tan\beta =$

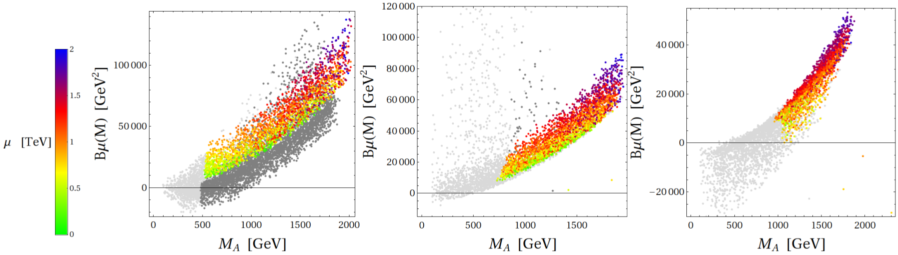
100

75

50

No convergence for $\tan\beta \gg 100$: Yukawas non-perturbative at mediation scale M

GGM: Numerical results – $B\mu$ term



$\tan\beta =$ 50 75 100

Points with $B\mu(M) = 0$ ruled out by BR($B \to \tau\nu$) and/or $(g-2)_\mu$

Conclusion

- $B\mu = 0$ at $M = 100$ TeV not compatible with $\tan\beta \gg 50$
- $B\mu(M) = 0$ possible for $M > 100$ TeV, but then $\tan\beta < 100$

Conclusions

Low-energy analysis of the MSSM with very large $\tan\beta$

- At $\tan\beta = 100$ (150), Yukawas are at most perturbative up to 10^{12} (10^6) GeV.
- $(g-2)_\mu$ rules out $\Delta y_b > 0$ and $\Delta y_\tau > 0$ at $\tan\beta \gg 50$

General gauge mediation with very large $\tan\beta$

With $M = 100$ TeV,

- $\tan\beta \sim 100$ allowed for $\mu > 0$
- $\tan\beta \sim 150$ ruled out by perturbativity
- $B\mu(M) = 0$ ruled out by $(g-2)_\mu$ and $\mathrm{BR}(B \to \tau\nu)$