Anomaly Mediation and Flavour Physics

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The MSSM and MSUGRA

The MSSM has a large set of soft supersymmetry breaking terms. Most analyses use MSUGRA which features at the gauge unification scale:

- Unification of the soft supersymmetry-breaking $\phi^*\phi$ scalar masses
- Unification of the gaugino masses
- Cubic scalar ϕ^3 interactions of the same form as the Yukawa couplings and related to them by a common constant of proportionality, the A parameter.

AMSB is an attractive alternative to this orthodoxy.

AMSB

Anomaly mediated supersymmetry breaking takes an elegant form.

In AMSB, the running $\phi^*\phi$ masses, m^2, ϕ^3 couplings, h, and gaugino masses, M are all determined by the appropriate power of the gravitino mass multiplied by perturbatively calculable functions of the dimensionless couplings of the underlying supersymmetric theory. These results are RENORMALISATION GROUP INVARIANT.

The AMSB forms for M, h and m^2 are obtained if the only source of breaking is a vev in the supergravity multiplet itself.

AMSB

$$
\begin{aligned}
M &= m_{3/2}\beta_g/g \\
h &= -m_{3/2}\beta_Y \\
m^2 &= \tfrac{1}{2}m_{3/2}^2\mu\frac{d}{d\mu}\gamma \\
b &= \kappa m_{3/2}\mu - m_{3/2}\beta_\mu
\end{aligned}
$$

The form of the b-term is more model dependent than the other soft breaking terms. Hence we can determine the Higgs B parameter (along with the μ term) as usual by the minimisation of the scalar potential. Note that the arbitrary parameter κ will be determined to be rather small.

Gaugino, Quark and Slepton Masses

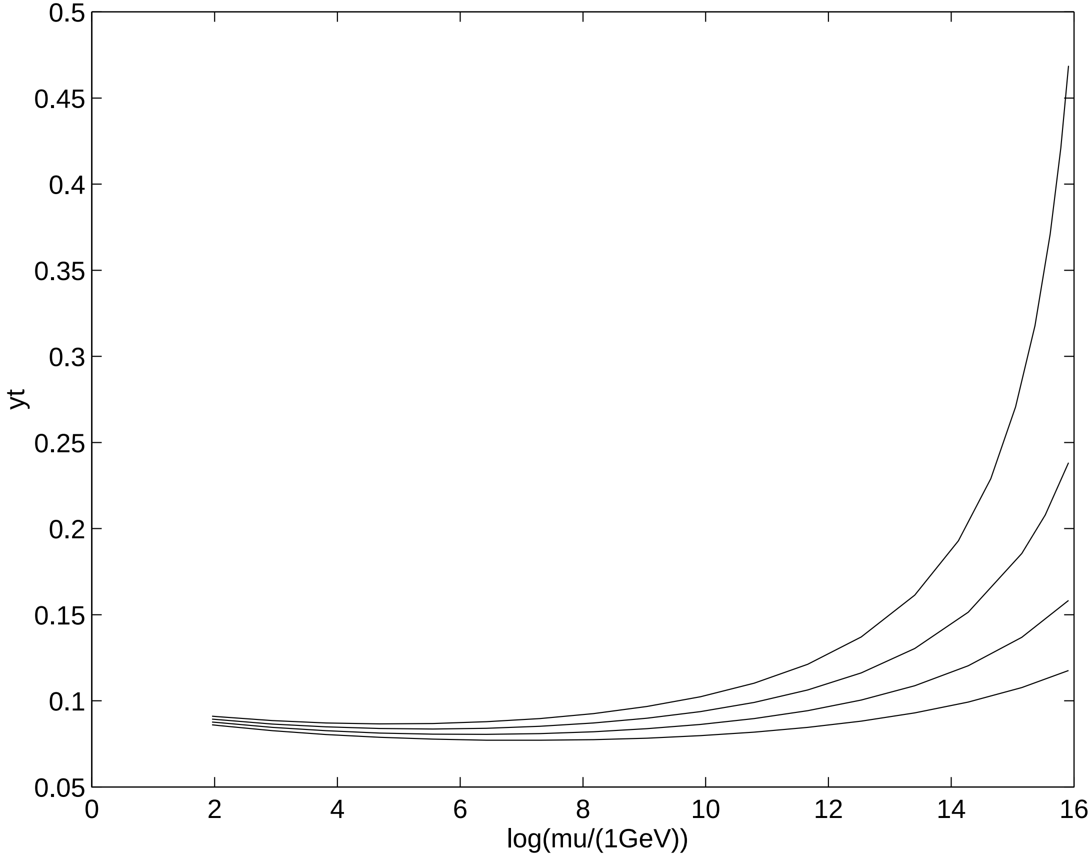
$$
\begin{aligned}
M_i &\sim \beta_{g_i} \\
m^2 &\sim \left[\beta_Y \cdot \frac{\partial}{\partial Y} + \beta_g \cdot \frac{\partial}{\partial g}\right] \left(Y^2 - g^2 + \cdots\right)
\end{aligned}
$$

where

$$
\beta_Y \sim Y(Y^2 - g^2), \qquad \beta_g \sim g^3
$$

- $M_2 < M_1$ and $M_3 < 0$.
- m^2 is a power series in the Yukawa matrices (MFV)
- flavour violation is suppressed if $\beta_Y \to 0$.
- there are tachyonic sleptons

The Infrared Quasi-Fixed Point



Plot of y_t against $\log_{10} \frac{\mu}{1\mathrm{GeV}}$ for various values of $y_t(M_X)$

Slepton Mass Fixes

A common scalar mass:

(1) $$(\overline{m}^2)^i{}_j = \frac{1}{2} m_{3/2}^2 \mu \frac{d}{d\mu} \gamma^i{}_j + m_0^2 \delta^i{}_j$$

or Fayet-Iliopoulos terms:

(2) $$(\overline{m}^2)^i{}_j = \frac{1}{2} m_{3/2}^2 \mu \frac{d}{d\mu} \gamma^i{}_j + \xi \mathcal{Y}_i \delta^i{}_j$$

or R-parity violating terms:

(3) $$W \to W + \lambda L \overline{E E}$$

Anomaly-free $U(1)$ symmetries

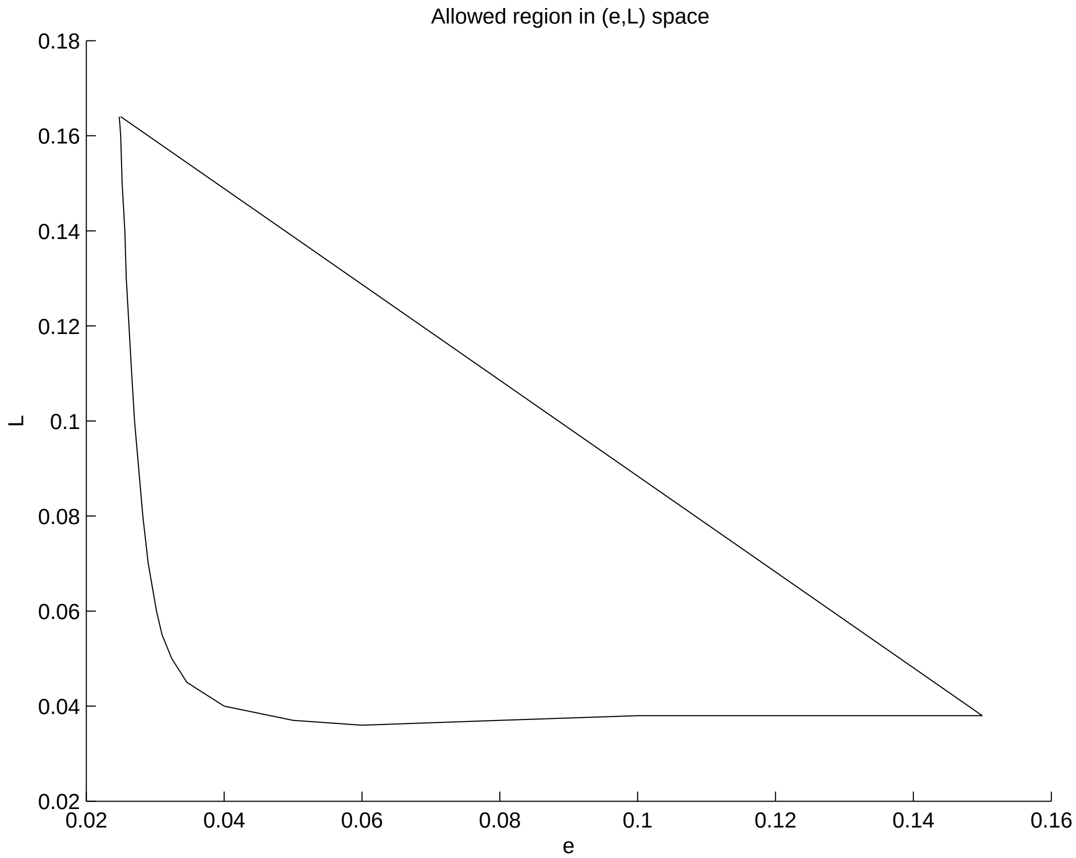
The MSSM (including right-handed neutrinos) admits two independent generation-blind anomaly-free U_1 symmetries:

Q	u^c	d^c	H_1	H_2	ν^c
$-\frac{1}{3}L$	$-e-\frac{2}{3}L$	$e+\frac{4}{3}L$	$-e-L$	$e+L$	$-2L-e$

Anomaly free $U(1)$ symmetry for arbitrary lepton doublet and singlet charges.

Choose both $L > 0$ and $e > 0$ to solve the slepton problem. Range of allowed e, L turns out to be restricted.

Allowed Range of e, L



Allowed region of (e, L) space for $m_0 = 40$TeV and $\tan\beta = 10$.

The Sparticle Spectrum

The mass spectrum (in GeV) for

- $m_0 = 40$TeV, $\tan\beta = 10$, $L = 0.3$, $e = 0.3$

$\tilde{g}$	$\tilde{t}_1$	$\tilde{t}_2$	$\tilde{u}_L$	$\tilde{u}_R$	$\tilde{b}_1$	$\tilde{b}_2$	$\tilde{d}_L$	$\tilde{d}_R$
890	763	576	818	785	727	900	822	909
$\tilde{\tau}_1$	$\tilde{\tau}_2$	$\tilde{e}_L$	$\tilde{e}_R$	$\tilde{\nu}_e$	$\tilde{\nu}_\tau$	h	H	A
131	191	158	177	137	133	117	455	454

$H^\pm$	χ_1	χ_2	χ_3	χ_4	$\chi_1^\pm$	$\chi_2^\pm$
462	130	362	599	609	130	606

$\chi_1^\pm - \chi_1$ (MeV)	194

Flavour-Violating Mass Insertions

We begin by choosing a basis such that the Yukawa matrices are

$$Y_U = V^T \text{diag}(\lambda_u, \lambda_c, \lambda_t), \qquad Y_D = \text{diag}(\lambda_d, \lambda_s, \lambda_b)$$

where V is the CKM matrix,

Then we rotate both quarks and squarks to the quark-mass diagonal (super-CKM) basis.

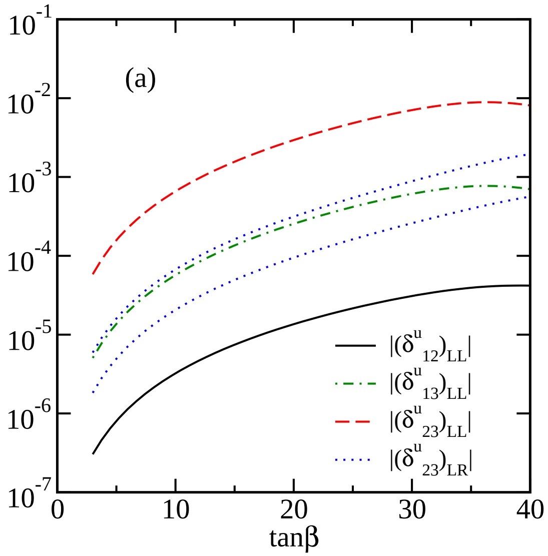
It is then useful to look at the approximation where we retain only λ_t, λ_b.

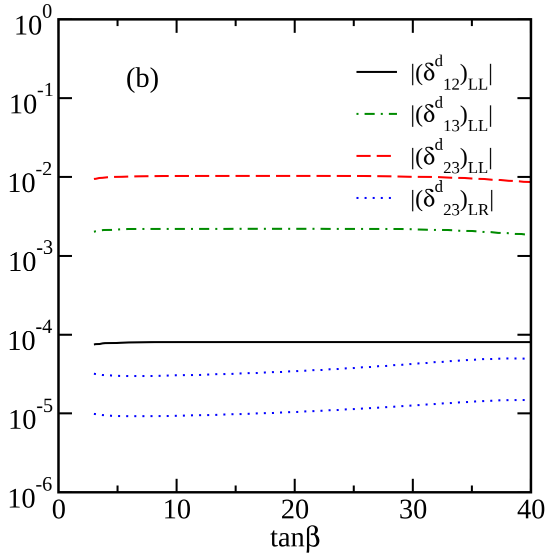
Flavour-Violating Mass Insertions

At one loop we find, (showing here only terms that contribute when $i \neq j$)

$$\begin{aligned}
\left(m^2_{\tilde{U}_L}\right)_{ij} &= \frac{m^2_{3/2}}{(16\pi^2)^2}\left[V_{ib}V^*_{jb}\lambda_b^2(\hat{\beta}_{\lambda_b} - \lambda_t^2)\right. \\
&+ \left.\lambda_t^2\lambda_b^2(\delta_{i3}V^*_{jb}V_{tb} + \delta_{j3}V_{ib}V^*_{tb})\right] \\
\left(\widehat{h}_U\right)_{ij} &= -\delta_{i3}\frac{m_{3/2}}{16\pi^2}\lambda_t\left[\lambda_b^2 V^*_{jb}V_{tb}\right] \\
\left(m^2_{\tilde{D}_L}\right)_{ij} &= \frac{m^2_{3/2}}{(16\pi^2)^2}\left[V^*_{ti}V_{tj}\lambda_t^2(\hat{\beta}_{\lambda_t} - \lambda_b^2)\right. \\
&+ \left.\lambda_t^2\lambda_b^2(\delta_{j3}V^*_{ti}V_{tb} + \delta_{i3}V_{tj}V^*_{tb})\right] \\
(h_D)_{ij} &= -\delta_{j3}\frac{m_{3/2}}{16\pi^2}\lambda_b\left[\lambda_t^2 V_{ti}V^*_{tb}\right]
\end{aligned}$$

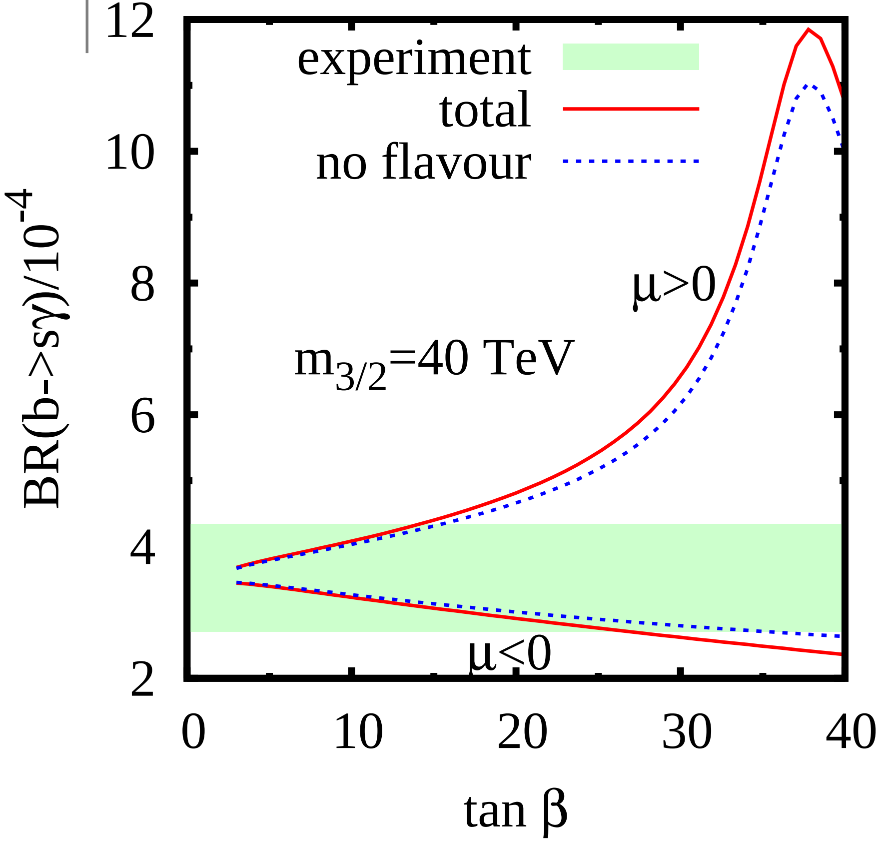
Flavour-Violating Mass Insertions

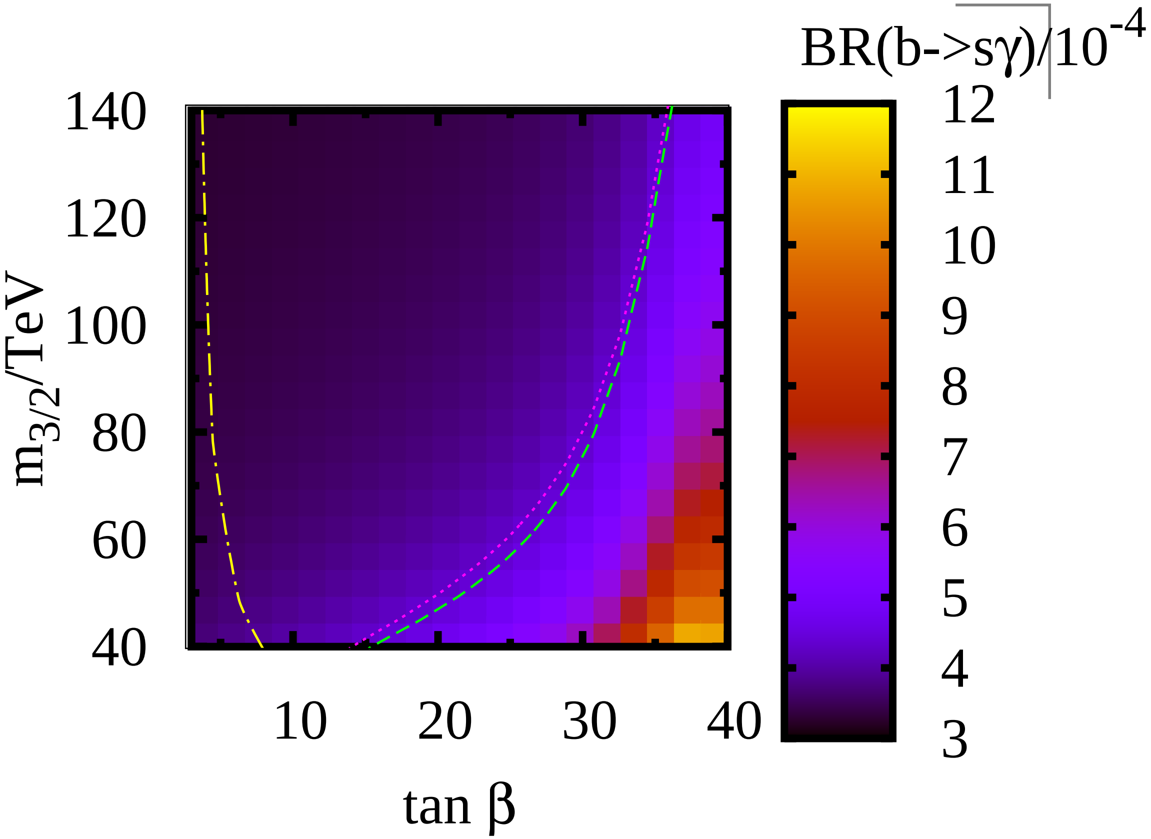




Magnitudes of mass insertions $\delta^q_{ij} = (m^2_{\tilde{q}})_{ij}/\sqrt{(m^2_{\tilde{q}})_{ii}(m^2_{\tilde{q}})_{jj}}$ as functions of $\tan\beta$, for $m_{3/2} = 40, 140$ TeV. Closest GGMS bound is $(\delta^d_{13})_{LL} < 0.16$.

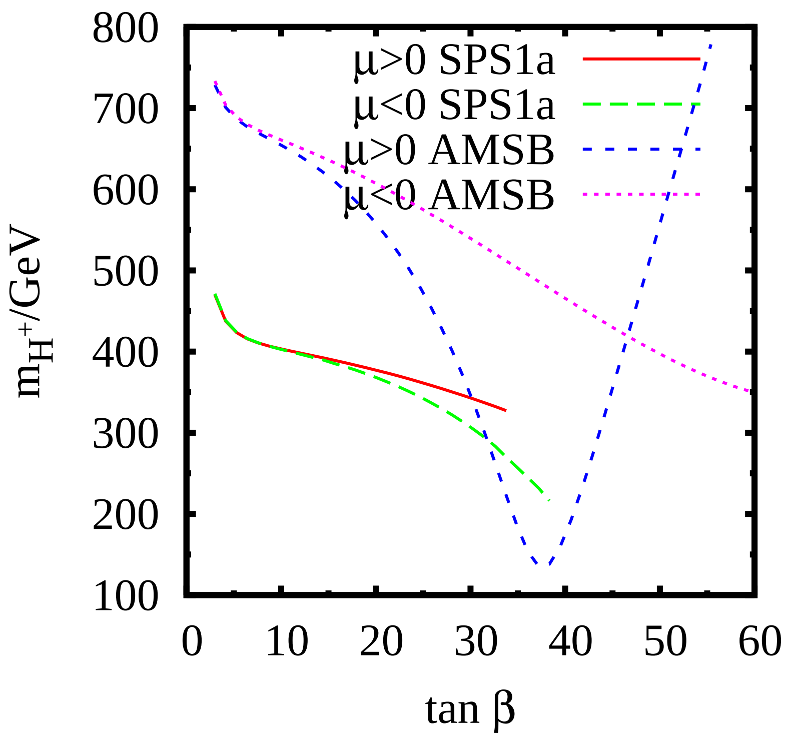
$B \to X_s\gamma$ Decay





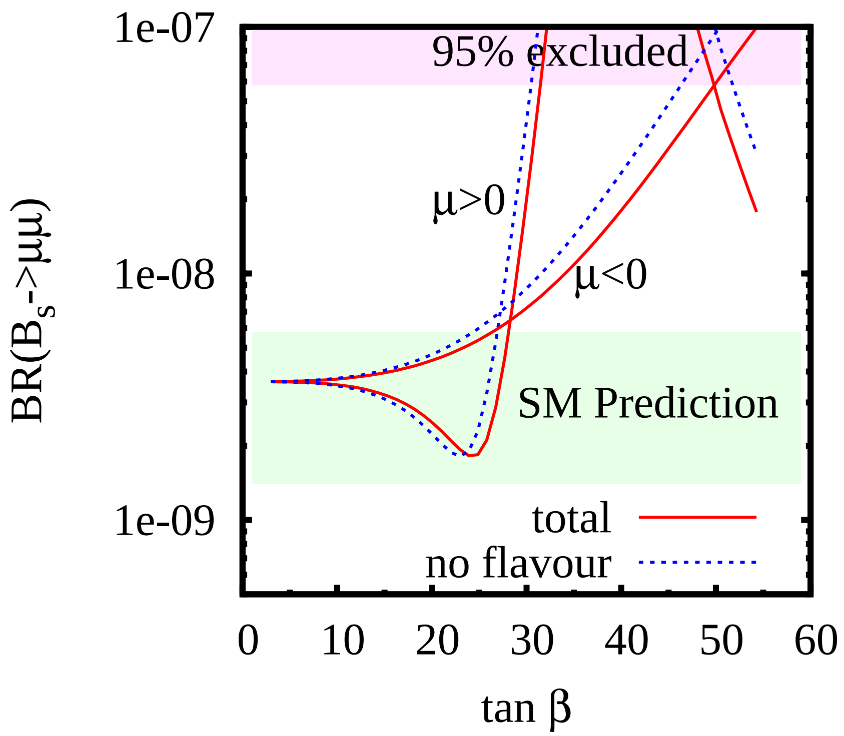
Constraints on the AMSB parameter space from the rare decay $B \to X_s\gamma$ as a function of $\tan\beta$ for $m_{3/2} = 40$ TeV.

The Charged Higgs Mass



The charged Higgs boson mass as a function of $\tan\beta$ in mSUGRA model SPS1a and pure AMSB with $m_{3/2} = 40$ TeV.

$B_s \to \mu\mu$ decay



BR($B_s \to \mu\mu$) in pure AMSB. Also shown is the standard model prediction and the current experimental upper bound. For $\mu > 0$, we predict the $B_s \to \mu\mu$ branching ratio does not exceed its standard model value

$B \to \tau\nu$ decay

The susy contribution is dominated by the charged higgs:

$$R_{\tau\nu} \equiv \frac{\mathrm{BR}(B \to \tau\nu)}{\mathrm{BR}(B \to \tau\nu)_{\mathrm{SM}}} = \left(1 - \frac{m_B^2}{m_{H^\pm}^2} \frac{\tan^2\beta}{1 + \epsilon_g \tan\beta}\right)^2 .$$

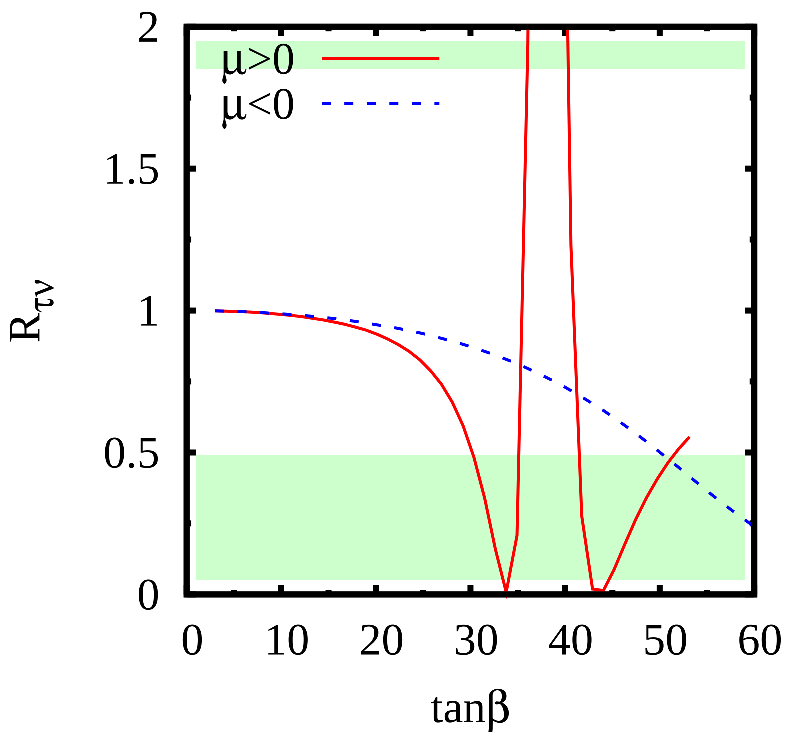
where

$$\mathrm{BR}(B \to \tau\nu)_{\mathrm{SM}} = 1.29 \times 10^{-4} \left(\frac{|V_{ub}|}{3.95 \cdot 10^{-3}}\right)^2 \left(\frac{f_B}{0.216\,\mathrm{GeV}}\right)^2 ,$$

and

$$R_{\tau\nu}^{\mathrm{exp}} = 1.17 \pm 0.34.$$

$B \to \tau\nu$ decay



The ratio $R_{\tau\nu}$ in pure AMSB for $m_{3/2} = 40$ TeV and either sign of μ. The green regions are disfavoured at the 2σ level.

Muon anomalous magnetic moment

Relying on e^+e^- data, one finds

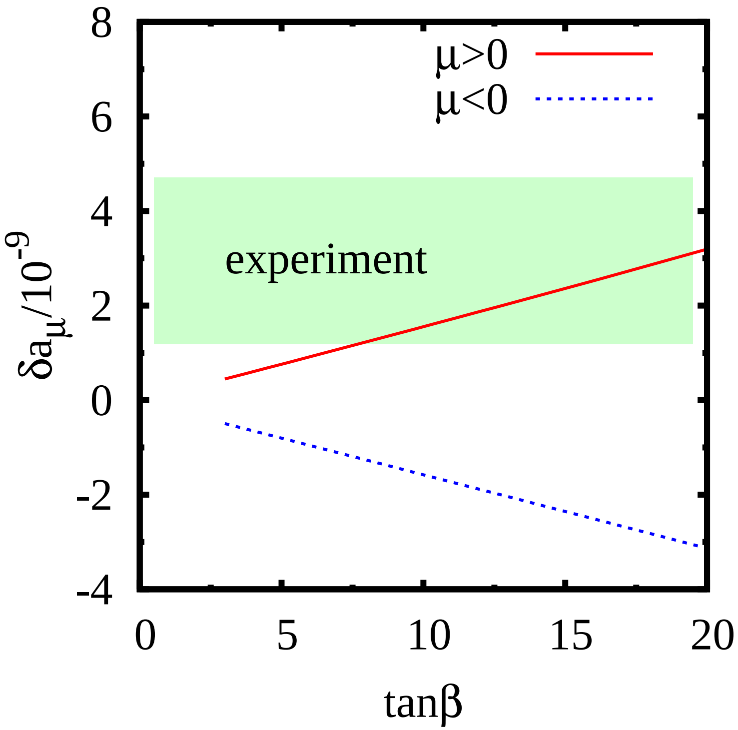
$$\delta a_\mu \equiv \delta \frac{(g-2)_\mu}{2} = (29.5 \pm 8.8) \times 10^{-10}$$

as the discrepancy between the empirical value and the Standard Model (standard model) prediction.
The one-loop gaugino contribution to this is given at large $\tan\beta$ by

$$a_\mu^{SUSY} \approx \frac{m_\mu^2 \mu \tan\beta}{16\pi^2} \left(g_1^2 M_1 F_1 + g_2^2 M_2 F_2\right),$$

where $F_{1,2}$ are positive definite functions. So a supersymmetric explanation of δa_μ favours $\mu > 0$.

Supersymmetric Contributions to $(g-2)_\mu$



Supersymmetric contribution to the anomalous magnetic moment of the muon in $U(1)'$ AMSB, for $m_{3/2} = 40$ TeV. Compatible with both δa_μ and $B \to X_s \gamma$ if $\mu > 0$ and $8 < \tan\beta < 14$.

Conclusions

AMSB leads to a distinctive and constrained particle spectrum, easily distinguishable from mSUGRA, with a light wino and distinctive sum rules for the sparticle masses.

The flavour changing signals of AMSB are MFV in character: they feature CKM-induced CP asymmetries and CKM relations between $b \to s$ and $b \to d$ processes.

Flavour violation is naturally suppressed for small $\tan\beta$, because with small $\tan\beta$ we are near the top quark Yukawa IRQFP, where $\beta_{\lambda_t} \approx 0$.

We have shown explicitly that there are regions of AMSB parameter space that can accommodate the measurements of the $B \to X_s \gamma$ branching ratio as well as the anomalous magnetic moment of the muon.