Interplay for B Physics and Dark matter search limit in the MSSM

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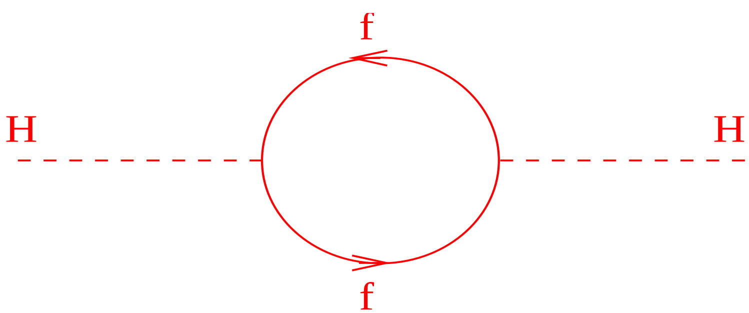
Based on:

M. Carena, A. Menon and C. Wagner, arXiv:xxxx.;

The Minimal Supersymmetric Standard Model: a solution

Motivation: Hierarchy Problem



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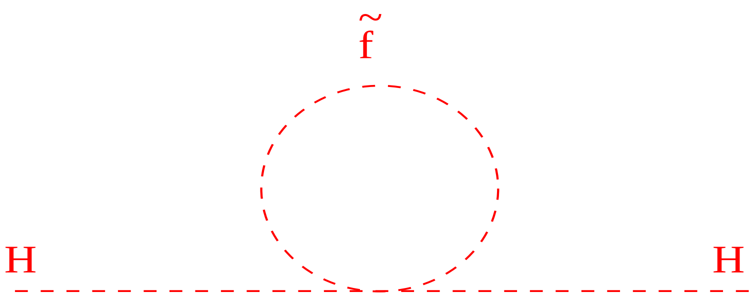
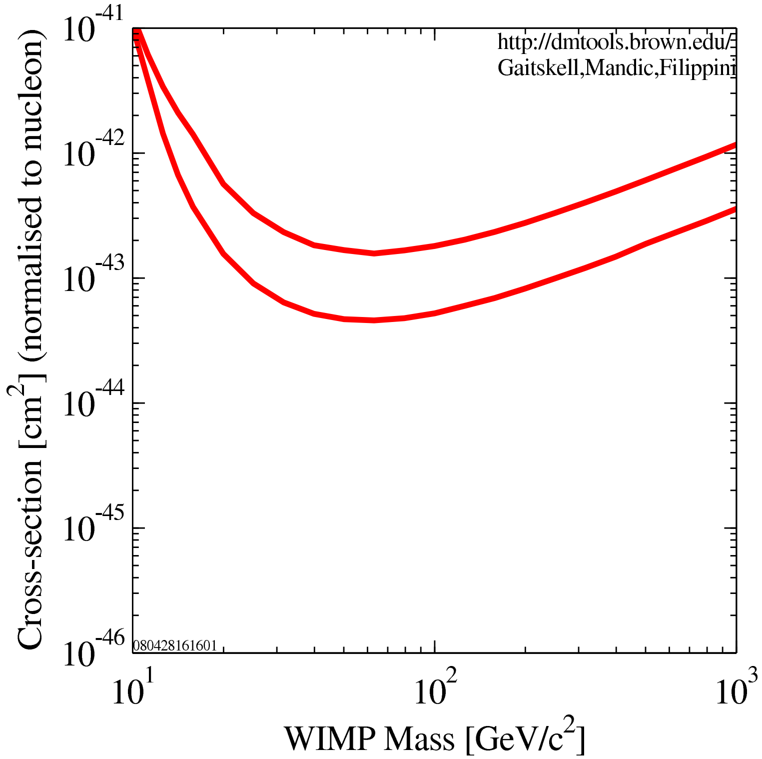


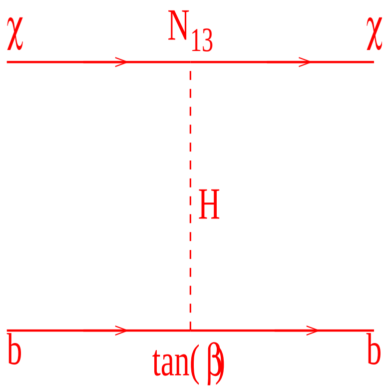
MSSM: Parameters

- Up and down quark Yukawas: Y_u and Y_u
- Up and down trilinears: $\bar{u} A_u Q H_u$ and $\bar{d} A_d Q H_d$
- Soft squark mass parameters:
  $-\tilde{Q}^\dagger m_Q^2 \tilde{Q} - \tilde{\bar{u}} m_{\bar{u}}^2 \tilde{\bar{u}}^\dagger - \tilde{\bar{d}} m_{\bar{d}}^2 \tilde{\bar{d}}^\dagger$
- Soft gaugino mass parameters:
  $-\frac{1}{2}(M_3 \tilde{g}\tilde{g} + M_2 \tilde{W}\tilde{W} + M_1 \tilde{B}\tilde{B})$

- h, H are CP-even and M_A CP-odd
- Ratio of Higgs boson VEV's $\frac{v_u}{v_d} = \tan\beta$.
- Stop mixing parameter $X_t = A_t - \frac{\mu}{\tan\beta}$.

Dark matter in the MSSM





$$\Rightarrow \frac{\sigma_{SI}}{A^4} \approx \frac{0.1 g_1^2 g_2^2 N_{11}^2 N_{13}^2 m_p^4 \tan^2\beta}{4\pi m_W^2 M_A^4}$$

RGE evolution on the soft squarks masses

- Running of the soft squark masses induces:

$$\Delta M^2_{\tilde{Q}} \simeq -\frac{1}{8\pi^2}\left[\left(2m_0^2 + M^2_{H_u}(0) + A_0^2\right) Y_u^\dagger Y_u + \left(2m_0^2 + M^2_{H_d}(0) + A_0^2\right) Y_d^\dagger Y_d\right] \log\left(\frac{M}{M_{SUSY}}\right),$$

$$\Delta M^2_{\tilde{u}_R} \simeq -\frac{2}{8\pi^2}\left(2m_0^2 + M^2_{H_u}(0) + A_0^2\right) Y_u Y_u^\dagger \log\left(\frac{M}{M_{\mathrm{SUSY}}}\right)$$

$$\Delta M^2_{\tilde{d}_R} \simeq -\frac{2}{8\pi^2}\left(2m_0^2 + M^2_{H_d}(0) + A_0^2\right) Y_d Y_d^\dagger \log\left(\frac{M}{M_{\mathrm{SUSY}}}\right)$$

M. Dugan, B. Grinstein and L. J. Hall, Nucl. Phys. B **255**, 413 (1985).

- $M \sim M_{SUSY}$ corrections are small and the squark masses remain diagonal.

- $M \sim M_{GUT}$ corrections are significant and $\Delta M^2_{\tilde{Q}}$ picks up off-diagonal terms.

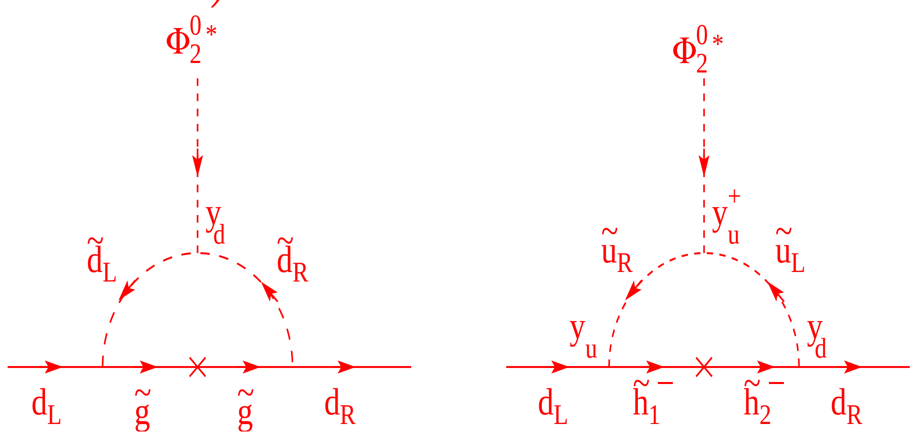
The Flavor Problem in MFV

• No tree-level flavor changing neutral currents as: $\mathcal{L} = \bar{Q}_L(\widehat{Y}_d \Phi_d d_R + \widehat{Y}_u \Phi_u u_R) + h.c.$, but loop suppression effects offset by large $\tan\beta$ effects.

• Including 1-loop effects both quarks couple to both the Higgses so that:

$$-\mathcal{L}_{eff} = \bar{d}_R^0 \hat{\mathbf{Y}}_\mathbf{d}[\Phi_d^{0*} + \Phi_u^{*0}\left(\hat{\epsilon}_\mathbf{0} + \hat{\epsilon}_\mathbf{Y} \hat{\mathbf{Y}}_\mathbf{u}^\dagger \hat{\mathbf{Y}}_\mathbf{u}\right)] d_L^0 + h.c.$$

where the ϵ loop factors are:



and have the structure:

$$\epsilon_0^I \approx \frac{2\alpha_s}{3\pi} M_3 \mu C_0(m^2_{\tilde{d}_1^I}, m^2_{\tilde{d}_2^I}, M_3^2)$$

$$\epsilon_Y \approx \frac{1}{16\pi^2} A_t \mu C_0(m^2_{\tilde{t}_1}, m^2_{\tilde{t}_2}, \mu^2)$$

Kolda, Babu, Buras, Roszkowski...

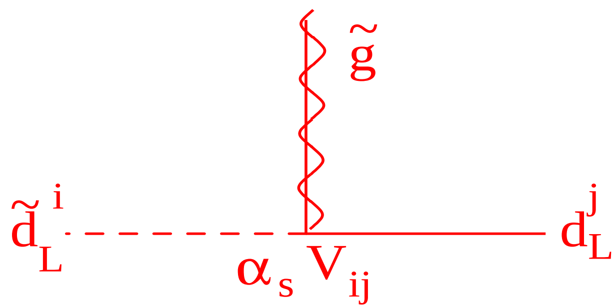
• Low scale structure of the squark masses determines the flavor violating terms induced.

Soft masses in $M \sim M_{GUT}$ scenario and their implications

- $M \sim M_{GUT}$ down squarks are diagonalized by the U_L rotation matrix rather than D_L upto corrections of $Y_d^\dagger Y_d$ to the diagonal mass matrix.

- Flavor violating gluino vertex:

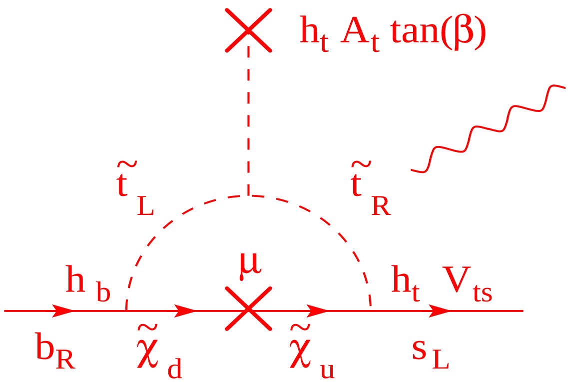
$$\mathcal{L}_g \supset \sqrt{2} g_3 \tilde{g}^a \left((V_{CKM})^{JI} (\tilde{d}_L^*)^J T^a d_L^I - (\tilde{d}_R^*)^I T^a d_R^I \right)$$



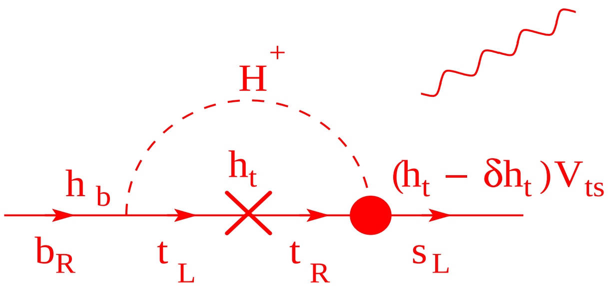
- Off-diagonal mass terms in the $L - R$ mixing:

$$\mathcal{L}_{mass} \supset (\tilde{d}_L^*)^I (m_Q^2)^I (\tilde{d}_L)^J + (\tilde{d}_R^*)^I (m_R^2)^I (\tilde{d}_R)^J + \tilde{\mu}^* (\tilde{d}_L^*)^I V_{CKM}^{IJ} m_{d_J} (\tilde{d}_R)^I + h.c.$$

$b \to s\gamma$ for in MFV

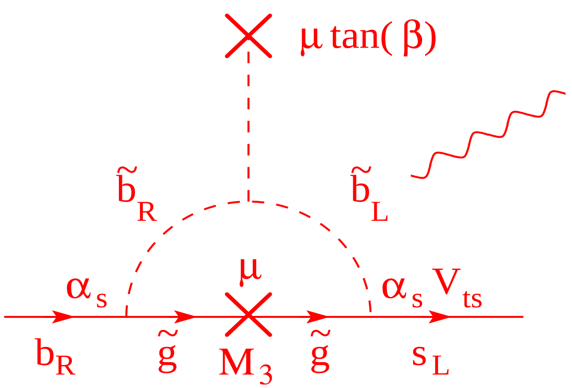


$\propto \mu A_t \tan\beta$



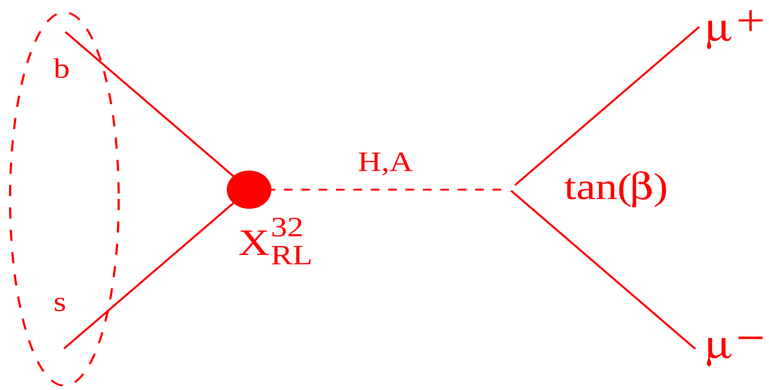
$\propto h_t - \delta h_t \tan\beta$ where $\frac{\delta h_t}{h_t} \propto \frac{\alpha_s}{3\pi}\mu M_3 \epsilon'_0$

M. Carena et. al. Phys. Lett. B **499**, 141 (2001)



$\propto \mu M_3(m_0^2 - m_{Q_3}^2)\tan\beta$ only for the $M \simeq M_{GUT}$ scenario.

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



- For $M \simeq M_{SUSY}$ we find $(X^S_{RL})^{32} \propto \epsilon_Y \tan\beta \sim \mu A_t \tan\beta$

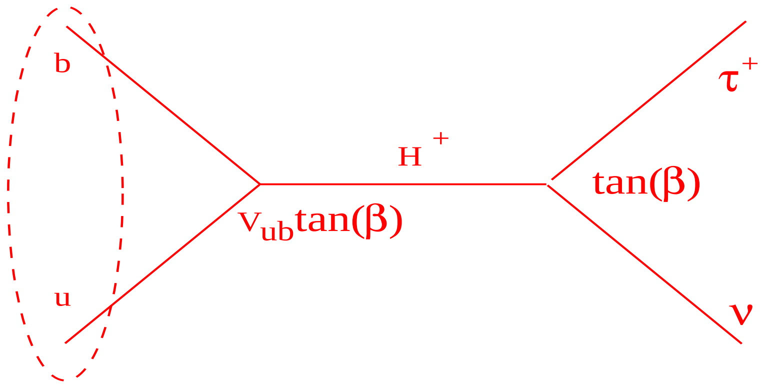
  A. J. Buras et.al., Nucl. Phys. B **659**, 3 (2003) [arXiv:hep-ph/0210145].

- For $M \simeq M_{GUT}$ we find $(X^S_{RL})^{32} \propto (\epsilon_0^3 + \epsilon_Y - \epsilon_0) \tan\beta$

  A. Dedes et. al. Phys. Rev. D **67**, 015012 (2003) [arXiv:hep-ph/0209306].

The dominant SUSY contribution is $\mathcal{BR}(B_s \to \mu^+\mu^-) = \tan^2\beta |(X^A_{RL})^{32}|^2 M_A^{-4}$

$B_u \to \tau\nu$ for both senarios



$$\Rightarrow R_{B\tau\nu} = \frac{\mathcal{BR}(B_u \to \tau\nu)^{\mathsf{MSSM}}}{\mathcal{BR}(B_u \to \tau\nu)^{\mathsf{SM}}} = \left[1 - \left(\frac{m_B^2}{m_{H^\pm}^2}\right) \frac{\tan^2\beta}{1+\epsilon_0 \tan\beta}\right]^2$$

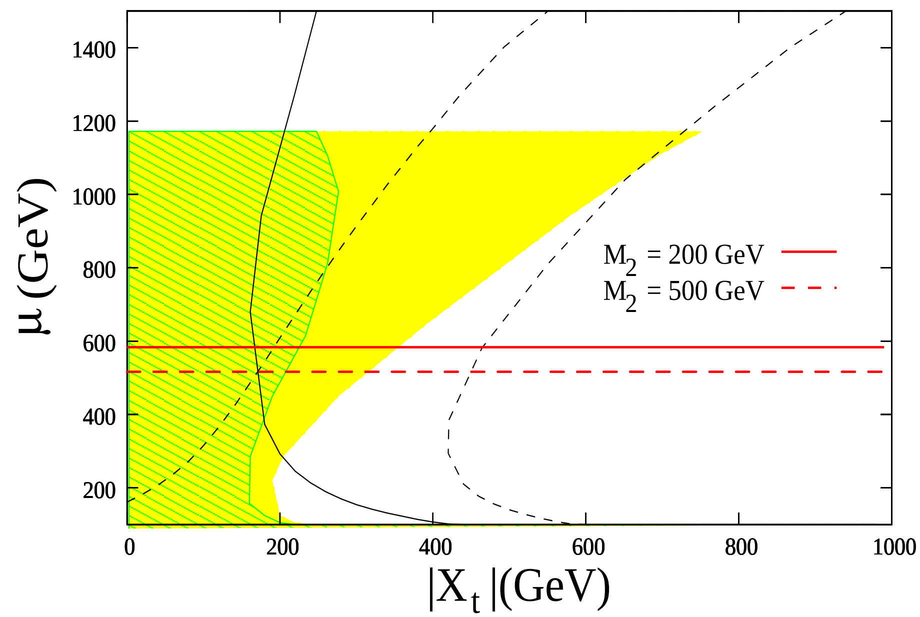
W. S. Hou, Phys. Rev. D **48**, 2342 (1993).

A. G. Akeroyd and S. Recksiegel, J. Phys. G **29**, 2311 (2003)

B physics experimental limits and the SM predictions

Quantity	SM prediction	Exp. meas./limit
$\mathcal{BR}(b \to s\gamma)$	$(3.15 \pm 0.23) \times 10^{-4}$ M. Misiak *et al.*, Phys. Rev. Lett. **98**, 022002 (2007)	$(3.55 \pm 0.24^{+0.09}_{-0.10} \pm 0.03) \times 10^{-4}$ HFAG
$\mathcal{BR}(B_s \to \mu^+\mu^-)$	$(3.8 \pm 0.1) \times 10^{-9}$ H.E.Logan et.al. Nucl. Phys. B **586**, 39 (2000)	$< 5.8 \times 10^{-8}$ at 95% C.L R. Bernhard *et al.*,. arXiv:hep-ex/0508058
$\mathcal{BR}(B_u \to \tau\nu)$	$(1.09 \pm 0.40) \times 10^{-4}$ Using LQCD f_b and V_{ub} from HFAG	$(1.41 \pm 0.43) \times 10^{-4}$ UTfit combination of Belle and Babar

X_t vs μ plane constraints



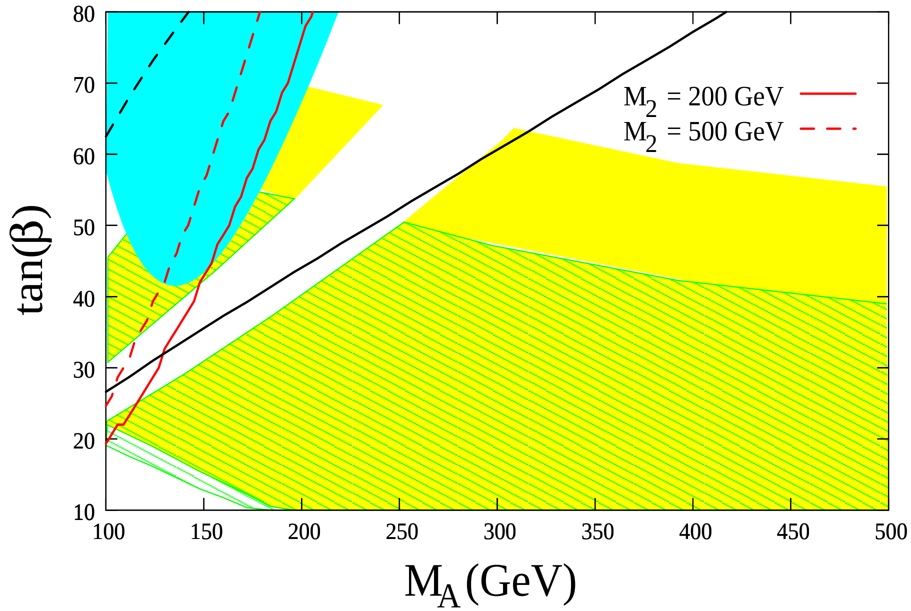
$M_A = 200$ GeV $\tan\beta = 60.0$

Below red lines are excluded by CDMS direct dark matter detection experiment for neutralino dark matter.

Left of the black line is allowed, at present, by the $B_s \to \mu^+\mu^-$ in $M \sim M_{SUSY}$, while the region between dashed lines allowed by the same process for $M \simeq M_{GUT}$.

Green region hatched region allowed by $b \to s\gamma$ and $B_u \to \tau\nu$ for $M \sim M_{SUSY}$, while yellow region is allowed by same processes for M_{GUT} including the extra gluino contribution.

M_A vs tan plane constraints



$X_t = -400$ GeV $\mu = 800.0$ GeV

- Blue region excluded by $H/A \to \tau\tau$ at the Tevatron
- Above red lines are excluded by CDMS direct dark matter detection experiment for neutralino dark matter.
- Right of the black line is allowed, at present, by the $B_s \to \mu^+\mu^-$ in $M \sim M_{SUSY}$, while left of the dashed lines is allowed by the same process for $M \simeq M_{GUT}$.
- Green region hatched region allowed by $b \to s\gamma$ and $B_u \to \tau\nu$ for $M \sim M_{SUSY}$, while yellow region is allowed by same processes for M_{GUT} including the extra gluino contribution.

Conclusions

• We have showed that there is an extra gluino contribution to the $b \to s\gamma$ rare decay in SUSY that can be important for large $\tan\beta$, μ and M_3 and is proportional to the splitting in soft masses between the first two generations and the third generation.

• Dark matter detection experiments generally suggest either large μ or large M_A.

• We find that in large to moderate μ, a small non-zero X_t for $M \simeq M_{GUT}$ and close to zero X_t for $M \sim M_{SUSY}$.

• Small values of X_t, which controls the size of stop corrections to the SM-like Higgs mass, implies an $m_h \leq 120$ GeV. This value is within the reach of the Tevatron and eventually the LHC.