$B - \bar{B}$ mixing and the MSSM Higgs Sector at large $\tan\beta$

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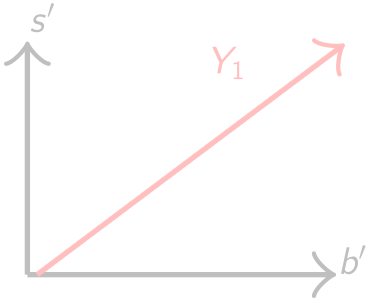
Contents

Introduction: Flavour Changing Higgs Couplings



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- $H_d \leftrightarrow d_R$ and $H_u \leftrightarrow u_R$: $\mathcal{L}_{\text{eff}} = -Y^d_{ij} H_d \bar{d}^i_R q^j - Y^u_{ij} H_u \bar{u}^i_R q^j + \text{h.c.}$

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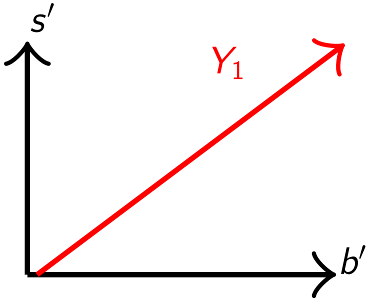

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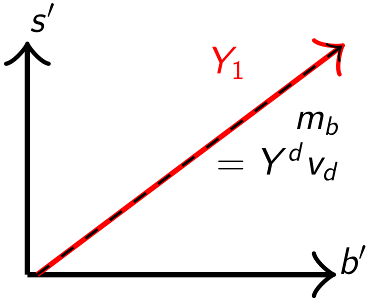

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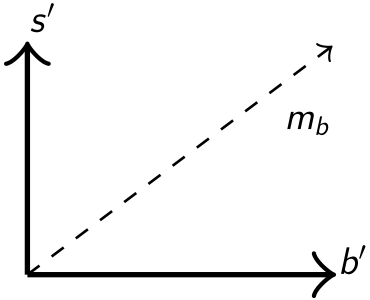

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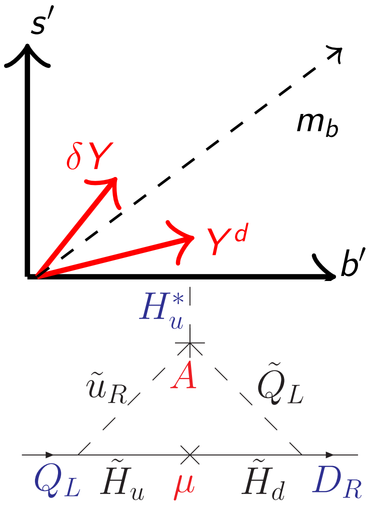

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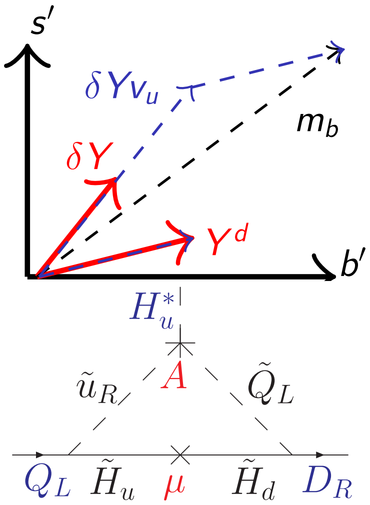

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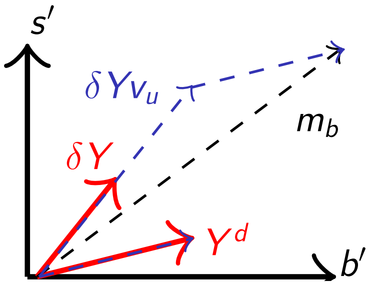

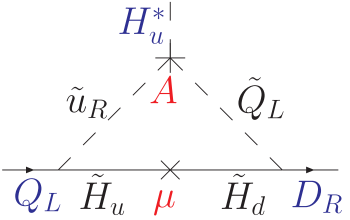

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Flavour Changing Higgs Couplings and $\Delta M_{s/d}$

FC Higgs Couplings

- $\tan\beta \gg 1 \rightarrow v_u \gg v_d$
- Large corrections to the down-type quark masses
- Rediagonalisation

$$\kappa_b \bar{b}_R s_L \left(\cos\beta h_u^{0*} - \sin\beta h_d^{0*}\right) \propto Y_b$$

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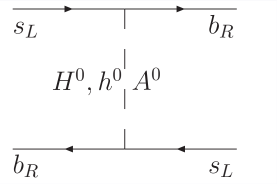
$$\Delta M_q = -\langle \overline{B}_q | \mathcal{L}_{\text{eff}}^{\Delta B=2} | B_q \rangle / m_{B_q}$$

Flavour Changing Higgs Couplings and $\Delta M_{s/d}$

A priori leading contribution



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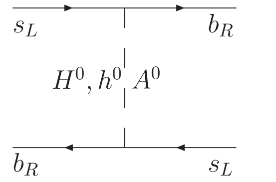

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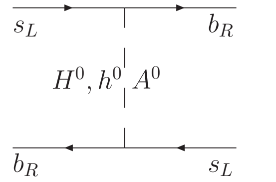

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Claims of large effects in the literature [Freitas et. al. '07]

Peccei-Quinn-Type Symmetry of the Higgs Sector

Higgs-Potential of the MSSM

- Quartic interactions are quite restricted

$$V = m_{11}^2 H_d^\dagger H_d + m_{22}^2 H_u^\dagger H_u + \left\{ m_{12}^2 H_u \cdot H_d + h.c. \right\} + \frac{g^2 + g'^2}{8} \left(H_d^\dagger H_d - H_u^\dagger H_u \right)^2 + \frac{g^2}{8} \left(H_u^\dagger H_d)(H_d^\dagger H_u \right)$$

- Study the Higgs potential in the broken phase for $v_d = 0$

Higgs sector for $\tan\beta \to \infty$

- The quadratic interactions give the Higgs masses ($H_d = (h_d^{0*}, -h_d^-)$):

$$V_{\rm ltb}^{(2)} = m_A^2 h_d^\dagger h_d + \frac{g'^2}{8} v^2 h_d^{-*} h_d^- + \frac{g^2 + g'^2}{8} v^2 h_u^{r\,2}$$

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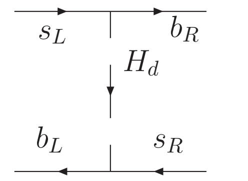

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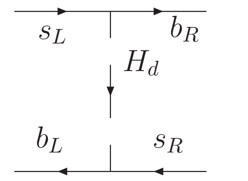

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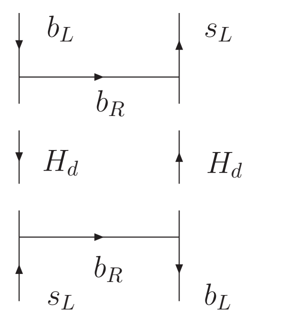

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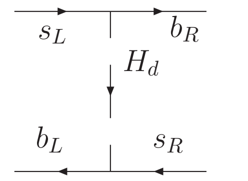

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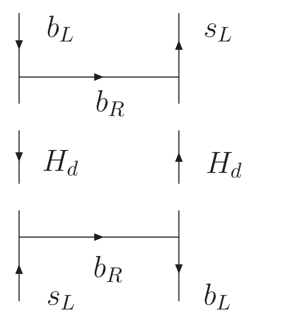

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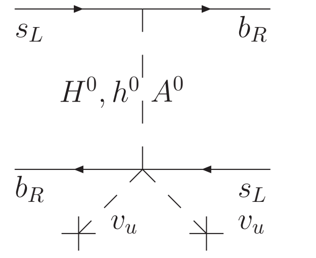
- Non $\tan\beta$ suppressed operators, which give a flavour violating contribution



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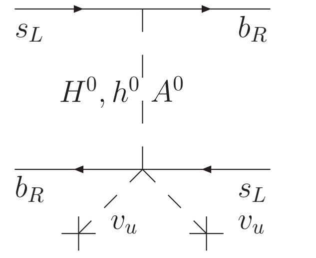

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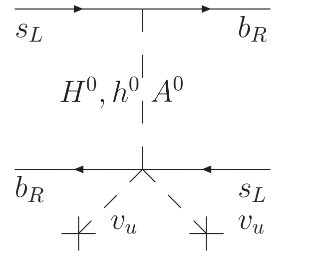

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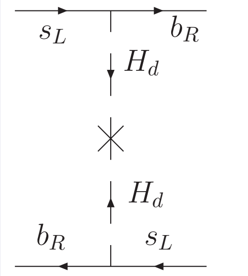

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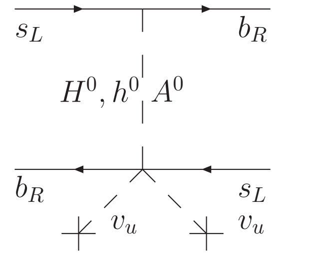

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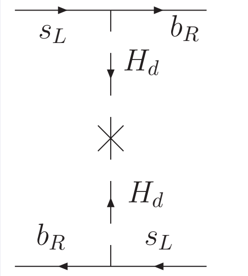

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Effective Theory for the Higgs Sector: Quartic Sector

We need the Higgs potential for small momenta.

- Use effective theory framework for $M_{\mathrm{SUSY}} > M_{\mathrm{2HDM}}$
- The effective Higgs potential is a type-III 2HDM

- Match the 4 point functions:

$$\frac{\lambda_1}{2}(H_d^\dagger H_d)^2 + \frac{\lambda_2}{2}(H_u^\dagger H_u)^2 + \lambda_3(H_u^\dagger H_u)(H_d^\dagger H_d) + \lambda_4(H_u^\dagger H_d)(H_d^\dagger H_u) + \left\{ \frac{\lambda_5}{2}(H_u \cdot H_d)^2 - \lambda_6(H_d^\dagger H_d)(H_u \cdot H_d) - \lambda_7(H_u^\dagger H_u)(H_u \cdot H_d) + \text{h.c.} \right\}$$

[Haber et al., Carena et al. ...]

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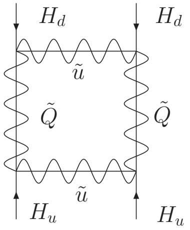

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[Haber et al., Carena et al. ...]

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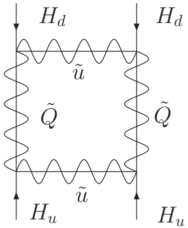

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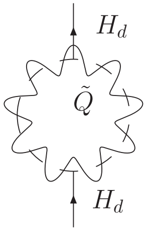

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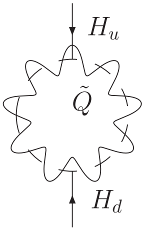

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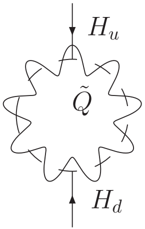

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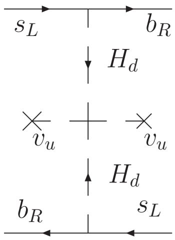

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Results for $\Delta M_{s/d}$

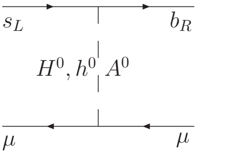
Approximate formula for ΔM

$$(\Delta M - \Delta M_{\rm SM})_{s/d} = \left\{ \begin{array}{c} -14{\rm ps}^{-1} \\ \sim 0{\rm ps}^{-1} \end{array} \right\} X \left[\frac{m_s}{0.06{\rm GeV}}\right] \left[\frac{m_b}{3{\rm GeV}}\right] \left[\frac{P_2^{\rm LR}}{2.56}\right] + \left\{ \begin{array}{c} 4.4{\rm ps}^{-1} \\ .13{\rm ps}^{-1} \end{array} \right\} X \left[\frac{M_W^2 \left(-\lambda_5 + \frac{\lambda_7^2}{\lambda_2}\right) 16\pi^2}{M_A^2}\right] \left[\frac{m_b}{3{\rm GeV}}\right]^2 \left[\frac{P_1^{\rm SLL}}{-1.06}\right]$$

$$X = \frac{m_t^4}{M_W^2 M_A^2} \frac{\left(\epsilon_Y 16\pi^2\right)^2}{(1+\tilde{\epsilon}_3 \tan\beta)^2 (1+\epsilon_0 \tan\beta)^2} \left[\frac{\tan\beta}{50}\right]^4$$

Constraints from $B_{s/d} \to \mu^+\mu^-$ and $B^+ \to \tau^+\nu$

$B_{s/d} \to \mu^+\mu^-$ and $\Delta M_{s/d}$

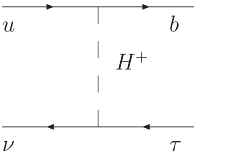


- BR($B_{s/d} \to \mu^+\mu^-$):

$$\propto \left\{ \begin{array}{c} 3.9 \cdot 10^{-5} \\ 1.2 \cdot 10^{-6} \end{array} \right\} \times \frac{M_W^2}{M_A^2} \left[\frac{\tan\beta}{50}\right]^2$$

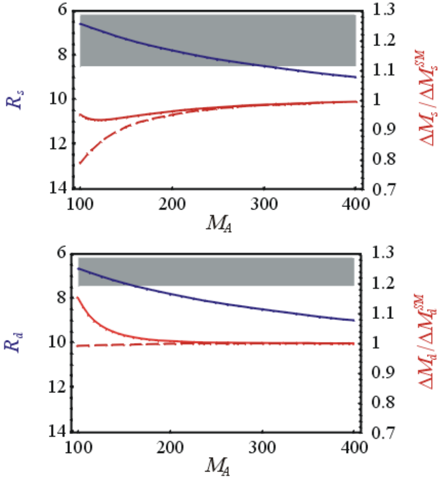
- Is correlated to $\Delta M_{s/d}$
- Severely restricts parameter space

$B^+ \to \tau^+\nu$

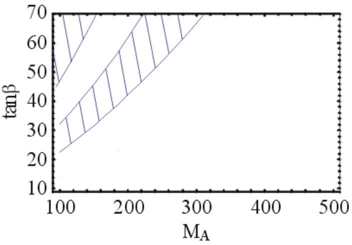


- Is sensitive to M_{H^+}
- Cuts into the light M_A parameter space

Numerics



- $R_{s/d} = \log \mathrm{BR}(B \to \mu\mu)/\Delta M$ constrains possibly large effects for $\Delta M_{s/d}$
- $B \to \tau\nu$ constraints in the $M_A \tan\beta$ plane



Conclusions

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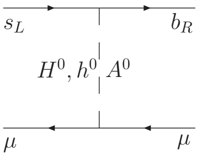

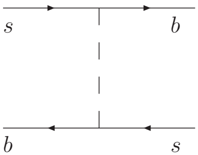

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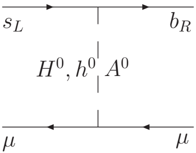

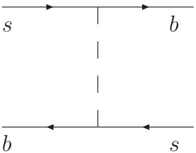

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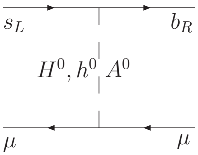

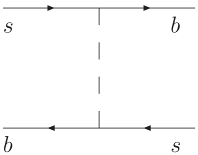

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Wavefunction renormalisation drops out

- $\bar{\lambda}$ wavefunction renormalisation included

M^2_{hHA} mass matrix in the large $\tan\beta$ limit

$$\begin{pmatrix} \bar{\lambda}_5^r v^2 + M_A^2 & v^2\bar{\lambda}_7^r & \frac{1}{2}v^2\bar{\lambda}_5^i \\ v^2\bar{\lambda}_7^r & \frac{1}{4}g^2v^2 + \bar{\lambda}_2 v^2 & v^2\bar{\lambda}_7^i \\ \frac{1}{2}v^2\bar{\lambda}_5^i & v^2\bar{\lambda}_7^i & M_A^2 \end{pmatrix} .$$

- changes: $\frac{\sin^2_{\alpha-\beta}}{M_H^2} + \frac{\cos^2_{\alpha-\beta}}{M_h^2} - \frac{1}{M_A^2}$
- canceled by wavefunction renormalisation in FC Higgs interactions
- only effect from $\overline{\mathrm{DR}}\lambda$