SUSY07

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The MSSM Higgs sector & ΔM_{B_q} for large tanβ

Karlsruhe Institute of Technology

Stéphanie Trine

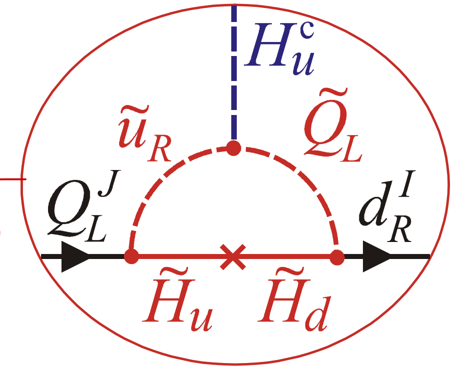
In collaboration with M. Gorbahn, S. Jäger and U. Nierste

Motivation

- Soft SUSY-breaking $\rightarrow$ 2HDM-III structure at loop level :

$$\mathcal{L}_{eff} \supset \bar{d}_R^I \left[\mathbf{Y}_d H_d + \varepsilon_Y \mathbf{Y}_d \mathbf{Y}_u^\dagger \mathbf{Y}_u H_u^c \right]^{IJ} \cdot Q_L^J$$

(MFV)



$\Rightarrow$ Higgs-mediated FCNC for large tanβ $\equiv t_\beta = v_u / v_d$:

$$\kappa^{IJ} \bar{d}_R^I d_L^J \left[c_\beta h_u^{0*} - s_\beta h_d^{0*} \right] + \kappa^{JI*} \bar{d}_L^I d_R^J \left[c_\beta h_u^{0} - s_\beta h_d^{0} \right] \qquad \kappa^{IJ} \sim \varepsilon_Y t_\beta^2 m_I / v$$

- Rich phenomenology!

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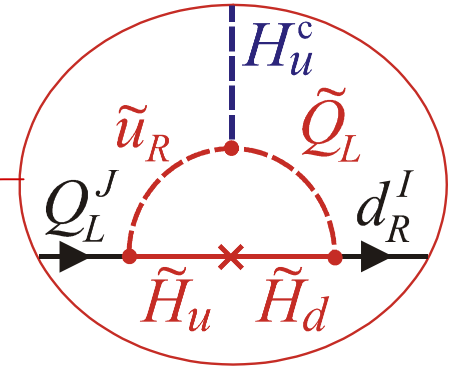

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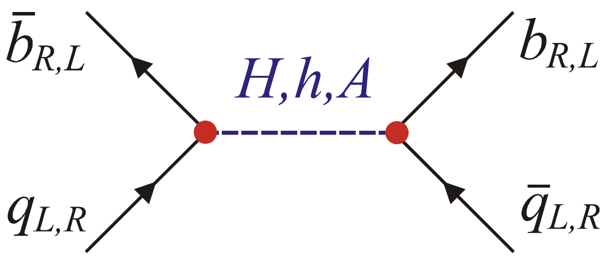
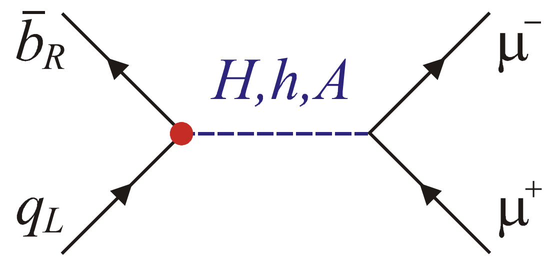
- Rich phenomenology! Interesting signature within MFV : $(q = d, s)$



correlated

[Buras et al '02]



$\Delta M_q^{(m_b^2)} = 0$ $\quad \Delta M_{s(d)}$ decreased (unaffected) $\qquad \mathcal{B}(B_q \to \mu^+ \mu^-)$ increased

Look at __all__ (sub-)leading contributions before concluding!

Outline

I. ΔM_{B_q} anatomy

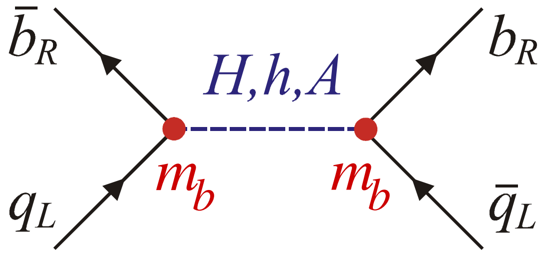
II. Matching MSSM $\rightarrow$ 2HDM

III. Higgs effects in ΔM_{B_q} versus $B_q \rightarrow \mu^+\mu^-$

I. ΔM_{B_q} anatomy

Why the cancellation?

$$\Delta M_q^{(m_b^2)} \propto$$



$$= 0$$

[Babu, Kolda '00]

Sparticle masses $\gg$ Higgs masses $\Rightarrow$ effective 2HDM :

- $$V = m_{11}^2 H_d^\dagger H_d + m_{22}^2 H_u^\dagger H_u + \left\{ m_{12}^2 H_u \cdot H_d + h.c. \right\}$$
  $$+ \frac{\tilde{g}^2}{8}\left[\left(H_d^\dagger H_d\right) - \left(H_u^\dagger H_u\right)\right]^2 + \frac{g^2}{8}\left(H_u^\dagger H_d\right)\left(H_d^\dagger H_u\right)$$
- $$\mathcal{L}_{FCNC}^{Higgs} = \kappa^{IJ}\, \bar{d}_R^I d_L^J \left[c_\beta h_u^{0*} - s_\beta h_d^{0*}\right] + \kappa^{JI*}\, \bar{d}_L^I d_R^J \left[c_\beta h_u^0 - s_\beta h_d^0\right]$$

  - Dim-4 operators, V at tree-level
  - After SSB, for $\tan\beta \to \infty$, the theory is inv. under the PQ-type symmetry :

$$U(1)_{PQ}: \;\; \mathcal{Q}(H_d) = \mathcal{Q}(d_R^I) = 1, \;\; \mathcal{Q}(other) = 0$$

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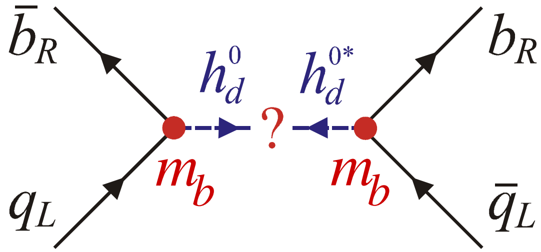

$\Delta Q = 2$ $\Rightarrow$ $=0$ (LO in 1/tanβ)

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$m_{12}^2 = s_\beta c_\beta M_A^2$, tanβ-suppressed for fixed M_A

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What are the leading contributions?

Look at <u>all</u> contributions with $\boxed{\textit{1 suppression factor}}$

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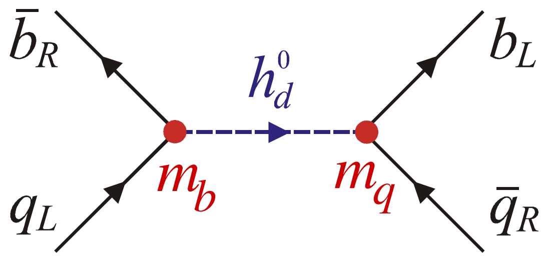
A/ *Chirality flipped contribution* ("LR")



$$\Delta Q = 0 \quad \Rightarrow \quad \Delta M_q^{LR} \propto \frac{m_b \boxed{m_q}}{v^2} \quad \text{decreases } \Delta M_q$$

[Buras, Chankowski, Rosiek, Sławianowska '02]

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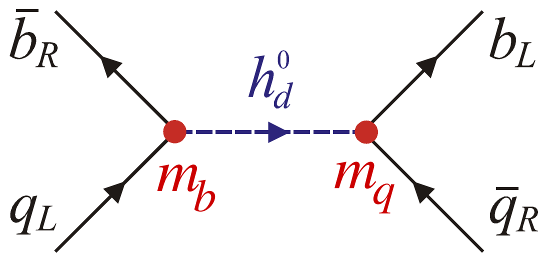

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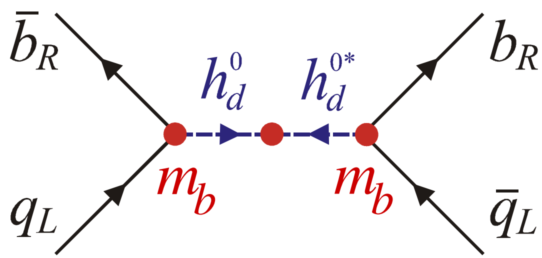
[Buras, Chankowski, Rosiek, Sławianowska '02]

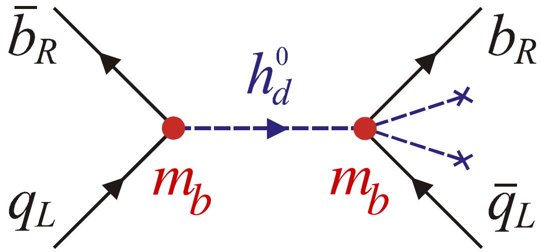
B/ *Corrections to Higgs masses/mixings* ("RR")



$$\Delta Q = 2 \quad \Rightarrow \quad \Delta M_q^{RR} \propto \frac{m_b^2}{v^2} \times \boxed{\begin{array}{c}\textit{SUSY loop in}\\ \textit{Higgs potential}\end{array}}$$

Corrections to the Higgs sector have already been extensively studied. However, contradictory statements about their effects on $B-\bar{B}$ mixing are found in the literature. We thus go through them again in part II.

C/ Higher dimension operator contribution



$$\Delta Q = 2 \quad \Rightarrow \quad \Delta M_q^{\mathrm{d6}} \propto \frac{m_b^2}{v^2} \times \boxed{\frac{v^2}{M_{SUSY}^2}}$$

Higgs-FCNC are always of the type $\bar{d}_R^I d_L^J h_d^{0*} / \bar{d}_L^I d_R^J h_d^0$ for large tanβ, no matter the number of Higgs field insertions

→ The required breaking of the PQ symmetry cannot be produced and $\Delta M_q^{\mathrm{d6}} = 0$ at LO in tan β

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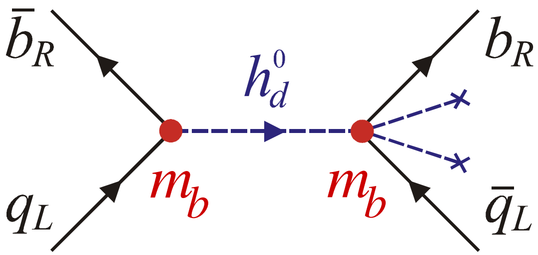

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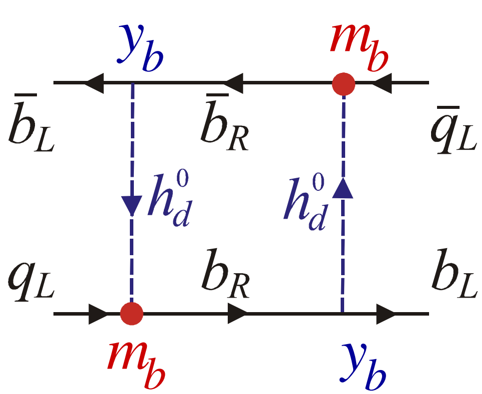
D/ *Weak scale loop contribution*



$$\Delta Q = 0 \quad \Rightarrow \quad \Delta M_q^{WS} \propto \frac{m_b^2}{v^2} \times \boxed{\frac{y_b^2}{16\pi^2}}$$

increases ΔM_q, but numerically small

II. Matching
MSSM $\rightarrow$ 2HDM

($\rightarrow$ *Corrections to Higgs masses/mixings*)

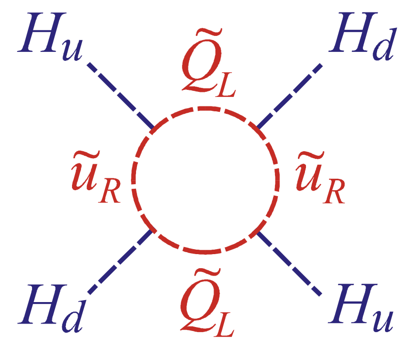
Higgs potential at 1-loop level

V has the most general structure compatible with gauge symmetry :

- $$V = m_{11}^2 H_d^\dagger H_d + m_{22}^2 H_u^\dagger H_u + \left\{ m_{12}^2 H_u \cdot H_d + h.c. \right\}$$
$$+ \frac{\lambda_1}{2}\left(H_d^\dagger H_d\right)^2 + \frac{\lambda_2}{2}\left(H_u^\dagger H_u\right)^2 + \lambda_3 \left(H_u^\dagger H_u\right)\left(H_d^\dagger H_d\right) + \lambda_4 \left(H_u^\dagger H_d\right)\left(H_d^\dagger H_u\right)$$
$$+ \left\{ \frac{\lambda_5}{2}\left(H_u \cdot H_d\right)^2 - \lambda_6 \left(H_d^\dagger H_d\right)\left(H_u \cdot H_d\right) - \lambda_7 \left(H_u^\dagger H_u\right)\left(H_u \cdot H_d\right) + h.c. \right\}$$

Ex: $$\lambda_5 = -\frac{3 y_t^4}{8\pi^2} \frac{a_t^2 \mu^2}{M_{\tilde{t}_R}^4} L_1\left(M_{\tilde{Q}_L}^2 / M_{\tilde{t}_R}^2\right) + \ldots$$

$$L_1(x) = \frac{-1}{(1-x)^2} - \frac{(1+x)\ln x}{2(1-x)^3}$$



$+\ldots$

Note: many refs! However, due to the large cancellations at play in ΔM_q, a fully analytical treatment is desirable, and the explicit expressions for the λ's we found in the literature are given for $M_{\tilde{Q}_L}^2 = M_{\tilde{t}_R}^2 = M_{\tilde{b}_R}^2$

[Haber, Hempfling '93][Carena, Espinosa, Quirós, Wagner '95][Higgs physics at LEP-2 WG '96]

WF renormalization and definition of tanβ

$$\mathcal{L}_{Kin} = Z^r_{uu} \partial_\mu H_u^\dagger \partial^\mu H_u + Z^r_{dd} \partial_\mu H_d^\dagger \partial^\mu H_d + \left\{ Z_{ud} \partial_\mu H_u \cdot \partial^\mu H_d + h.c. \right\}$$

$$\begin{pmatrix} H_u' \\ -H_d^{c'} \end{pmatrix} = \begin{pmatrix} 1 + (\delta Z^r_{uu} + i\delta H^r_{uu})/2 & (\delta Z^*_{ud} + i\delta H^*_{ud})/2 \\ (\delta Z_{ud} + i\delta H_{ud})/2 & 1 + (\delta Z^r_{dd} + i\delta H^r_{dd})/2 \end{pmatrix} \begin{pmatrix} H_u \\ -H_d^c \end{pmatrix}$$

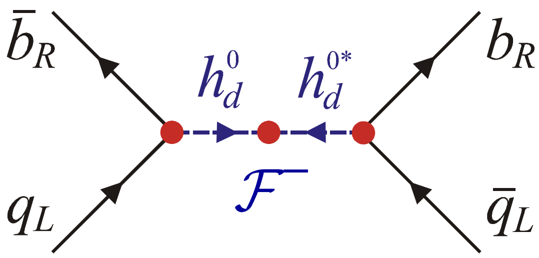
arbitrary

$m_{11}^2, m_{22}^2, \operatorname{Im} m_{12}^2$ are renormalized such that the bare fields in the eff. 2HDM stay at the minimum of the potential $\Rightarrow v_{i,eff} = Z_{WF,ij} \cdot v_{j,tree}$

We exploit the freedom to change the Higgs basis to
- keep the vevs real and positive
- prevent tanβ from getting tanβ-enhanced corrections !

$$\begin{pmatrix} v_{u,eff} \\ v_{d,eff} \end{pmatrix} = \begin{pmatrix} 1 + \delta Z^r_{uu}/2 + i\, t_\beta^{-1}\, \delta Z^i_{ud} & \delta Z^*_{ud} \\ 0 & 1 + \delta Z^r_{dd}/2 \end{pmatrix} \begin{pmatrix} v_{u,tree} \\ v_{d,tree} \end{pmatrix}$$

Corrections to Higgs masses and mixings



$$\mathcal{F}^- = \frac{\sin^2(\alpha-\beta)}{M_H^2} + \frac{\cos^2(\alpha-\beta)}{M_h^2} - \frac{1}{M_A^2} \neq 0$$

Corrected masses and mixing angles obtained from the diagonalization of $\mathbf{M}_{ij}^2 = \partial^2 V \big/ \partial h_i^0 \partial h_j^0$

+ Higgs WF renormalization in the effective FCNC vertex

Earlier approaches

[Parry '06] : Corrections to $\alpha, \beta, M_{h,H,A}$ using the FeynHiggs package

[Freitas, Gasser, Haisch '07] : $\delta\mathcal{F}^- \propto \dfrac{M_h^2}{M_H^2 - M_h^2}\varepsilon_{GP}$ This pole singularity is not present in our result

There are many cancellations at play.
These are built in in the effective Lagrangian approach.

III. Higgs effects in ΔM_{B_q} vs $B_q \to \mu^+\mu^-$

Final formulae

$$\mathcal{B}(B_{\{s,d\}} \to \mu^+\mu^-) = \begin{Bmatrix} 3.9\cdot 10^{-5} \\ 1.2\cdot 10^{-6} \end{Bmatrix} X \frac{M_W^2}{M_A^2}\left[\frac{\tan\beta}{50}\right]^2$$

[Babu, Kolda '00]
[Chankowski, Sławianowska '01]
[Bobeth et al '01]
[Huang et al '01][Buras et al '02]
[Isidori, Retico '01]…

$$(\Delta M - \Delta M^{SM})_{\{s,d\}} = \begin{Bmatrix} -14\, ps^{-1} \\ \sim 0\, ps^{-1} \end{Bmatrix} X \left[\frac{m_s}{0.06\, GeV}\right]\left[\frac{m_b}{3\, GeV}\right]\left[\frac{P_2^{LR}}{2.56}\right]$$

$$+ \begin{Bmatrix} +4.4\, ps^{-1} \\ +0.13\, ps^{-1} \end{Bmatrix} X \frac{M_W^2(-\lambda_5 + \lambda_7^2/\lambda_2)(16\pi^2)}{M_A^2}\left[\frac{m_b}{3\, GeV}\right]^2\left[\frac{P_1^{SLL}}{-1.06}\right]$$

$$+ \begin{Bmatrix} 0.16\, ps^{-1} \\ 0.005\, ps^{-1} \end{Bmatrix} X\, y_b^2\left[\frac{m_b}{3\, GeV}\right]^2\left[\frac{\eta_B \hat{B}}{0.715}\right]) \quad \leftarrow \text{small !}$$

$$X = \frac{(\varepsilon_Y 16\pi^2)^2}{(1+\tilde{\varepsilon}_3 \tan\beta)^2 (1+\varepsilon_0 \tan\beta)^2}\frac{m_t^4}{M_W^2 M_A^2}\left[\frac{\tan\beta}{50}\right]^4$$

$$\begin{cases} |V_{ts}| = 0.041; \; F_{B_s} = 0.24\, GeV \\ |V_{td}| = 0.0086; \; F_{B_d} = 0.20\, GeV \end{cases}$$

Sensitivity to Higgs self-couplings

$$(\Delta M - \Delta M^{SM})_{\{s,d\}} = \left\{ \begin{matrix} -14\,ps^{-1} \\ \sim 0\,ps^{-1} \end{matrix} \right\} X \left[\frac{m_s}{0.06\,GeV}\right]\left[\frac{m_b}{3\,GeV}\right]\left[\frac{P_2^{LR}}{2.56}\right]$$

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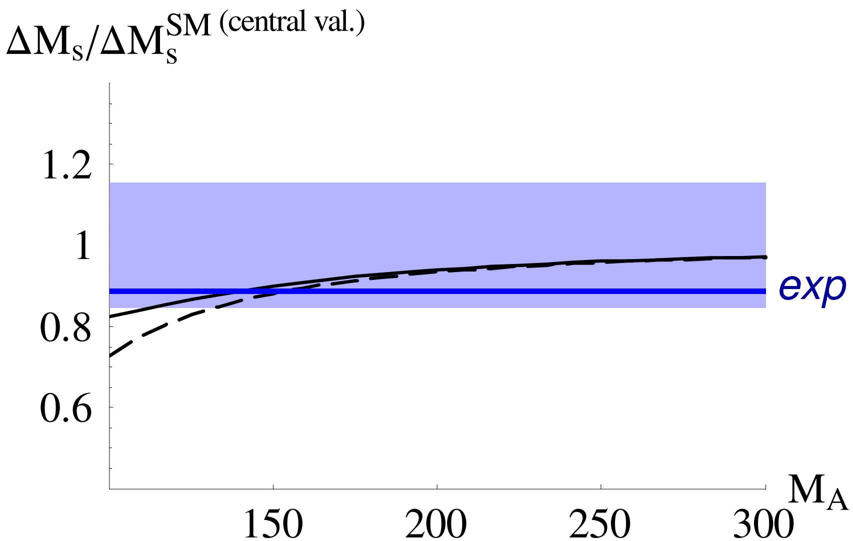
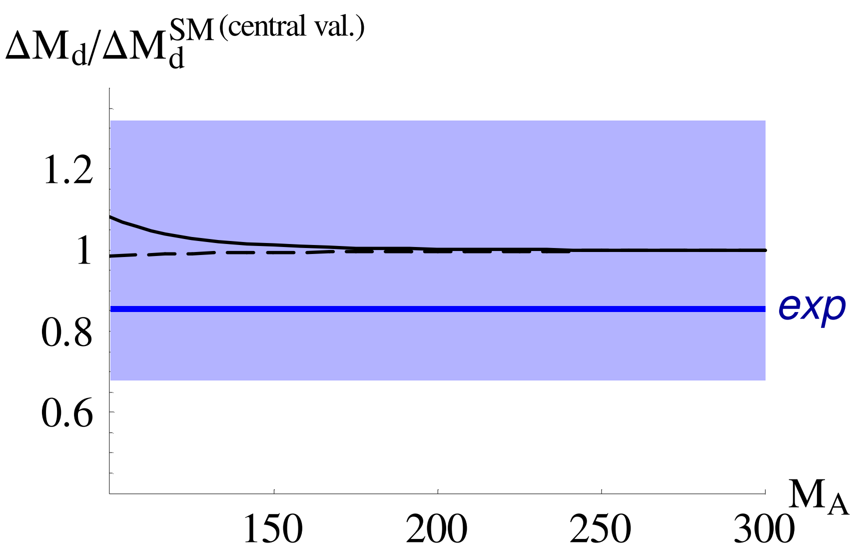
Typically: $M_{\tilde{q}} = \mu = a_{t,b} \Rightarrow \frac{(y_t^2 + y_b^2)}{2}\frac{M_W^2}{M_A^2}$

- Sensitivity to PQ-violating Higgs self-couplings rather limited… (☹)
- In a large part of the parameter space, the correlation to $\mathcal{B}(B_s \to \mu^+\mu^-)$ remains function of $(M_A, \tan\beta)$ only (☺)

New effect : for small M_A only



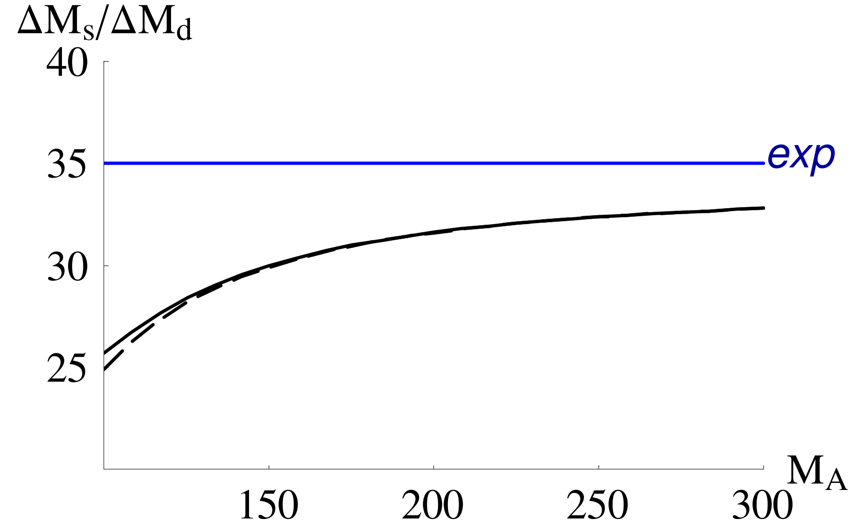


(stop, sbottom only)

Plain: $\Delta M_q^{SM+LR+RR}$

Dashed: ΔM_q^{SM+LR}

Shaded: size of th. error



$\tan\beta = 50;\ M_{\tilde{q}} = M_{\tilde{g}} = 0.8 TeV$

$a_{t,b} = 1 TeV;\ \mu = 1.2 TeV$

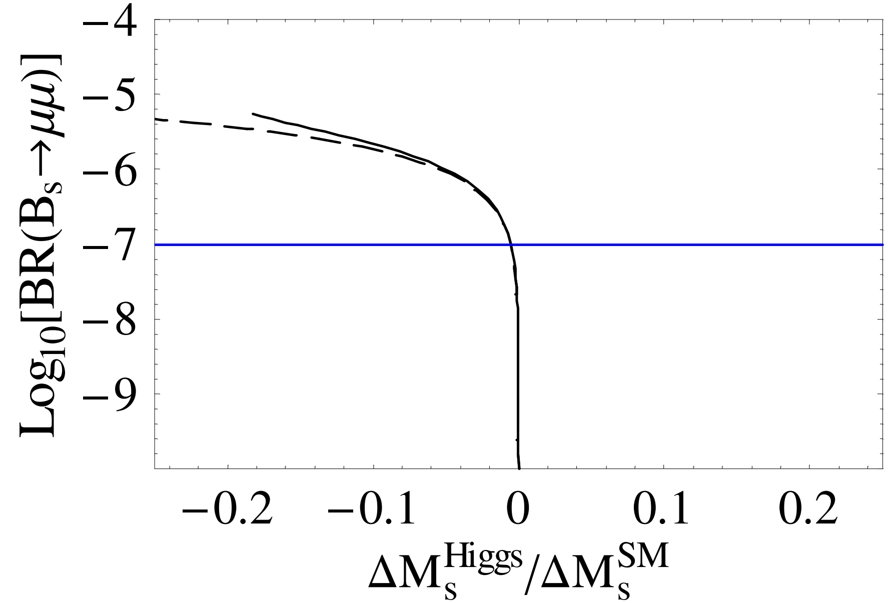
$$\mathbf{M}^2_{\tilde{t}_L \tilde{t}_R} = -m_t (a_t + \mu^* \cot\beta)$$

ΔM_{B_q} versus $B_q \to \mu^+\mu^-$

$M_A = 0.14 TeV$; $\tan\beta = 50$

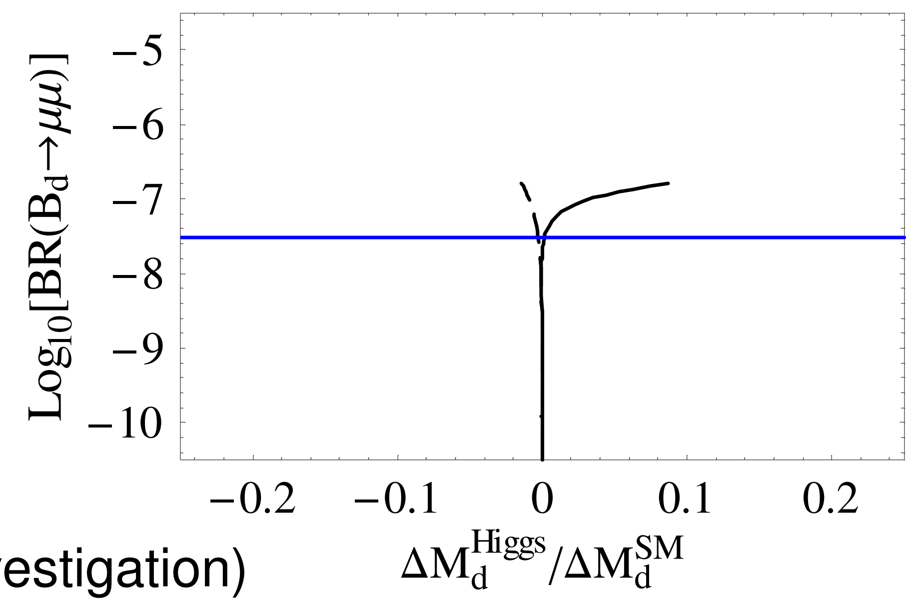
$M_{\tilde{q}} = M_{\tilde{g}} = 0.8 TeV$

$a_t = a_b \in [0, 1.5 TeV]$; $\mu = 1.2 TeV$



The exp. bound on $\mathcal{B}(B_s \to \mu^+\mu^-)$ excludes a decrease of ΔM_s if the only relevant NP effect is ΔM_s^{LR}

[Altmannshofer, Buras, Guadagnoli '07]



This is even more so in the presence of ΔM_s^{RR}. Besides, the expected increase in the B_d system is correlated, and thus constrained to be quite small.

Large effects could survive in some corners of parameter space ? (under investigation)

Conclusion

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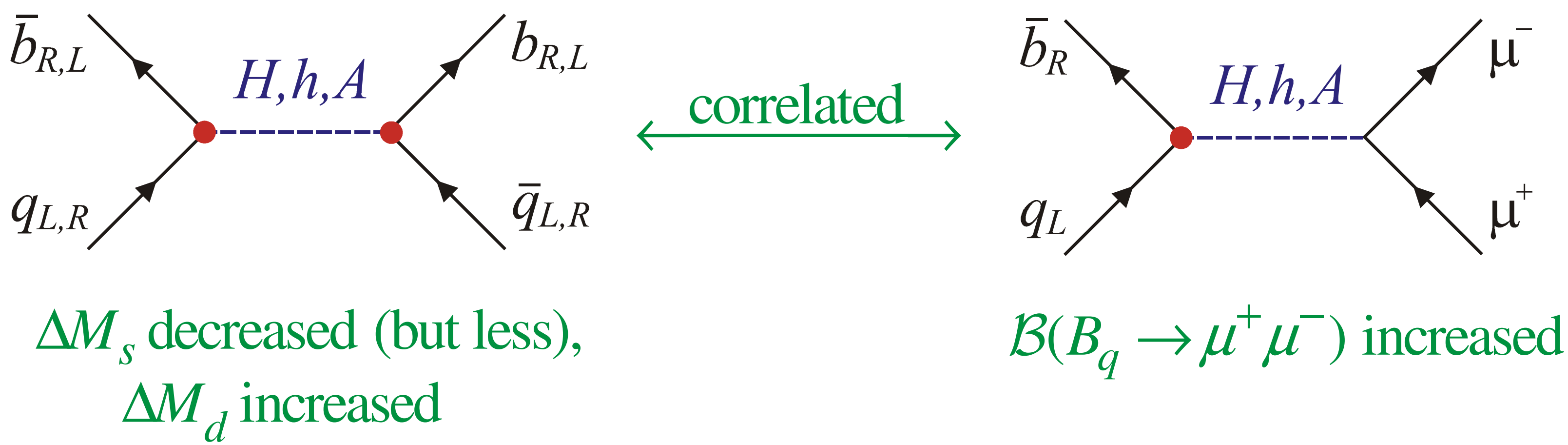
- Systematic investigation of *all leading contributions* to ΔM_q in the MFV-MSSM with large tanβ and heavy sparticles

- No new large effects are found. Still, *corrections to Higgs masses/mixings* can be relevant for *small* M_A (< 200 GeV). They *add* to the SM contribution.

- Correlation to $\mathcal{B}(B_q \to \mu^+\mu^-)$:



- With all contributions under control: the present experimental bounds on $\mathcal{B}(B_q \to \mu^+\mu^-)$ *impede a significant decrease* (*increase*) of $\Delta M_s (\Delta M_d)$