Higgs mediated FCNC in the MSSM

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in collaboration with M. Gorbahn, U. Nierste, S. Trine (0901.2065)

Outline

MSSM at large $\tan\beta$

Symmetry & renormalization issues

Results & Conclusions

MSSM

There are 5 types of fermionic gauge multiplets, in 3 generations, and a Higgs doublet

Q	$\tilde{q}$	q	$(3, 2; 1/6)$
U^c	$\tilde{u}^c$	u^c	$(\bar{3}, 1; -2/3)$
D^c	$\tilde{d}^c$	d^c	$(\bar{3}, 1; 1/3)$
L	$\tilde{l}$	l	$(1, 2; -1/2)$
E^c	$\tilde{e}^c$	e^c	$(1, 1; 1)$
H_d	h_d	$\tilde{h}_d$	$(1, 2; -1/2)$
H_u	h_u	$\tilde{h}_u$	$(1, 2; 1/2)$

Their supersymmetric non-gauge interactions derive from a (holomorphic) superpotential

$$W = \mu H_u \cdot H_d + Y_{ij}^U Q_i \cdot H_u U_j^c \; + Y_{ij}^D H_d \cdot Q_i D_j^c + Y_{ij}^E H_d \cdot L_i E_j^c$$

Holomorphy of W required two Higgs doublets H_u, H_d

One couples to up-type quarks, the other to down-type quarks:

a two-higgs doublet model of “type II”

Soft SUSY breaking

For phenomenological reasons, supersymmetry must be broken.
Soft breaking (i.e. breaking that preserves absence of quadratic cutoff dependence) by explicit scalar masses and self-interactions

$$\begin{aligned}\mathcal{L}_{\rm soft} = & -m^2_{\tilde{q}ij}\tilde{q}_i^\dagger \tilde{q}_j - m^2_{\tilde{u}ij}\tilde{u}^{c\dagger}\tilde{u}^c - m^2_{\tilde{d}ij}\tilde{d}^{c\dagger}\tilde{d}^c \qquad (18 \\ & -m^2_{\tilde{l}ij}\tilde{l}^\dagger\tilde{l} - m^2_{\tilde{e}ij}\tilde{e}^{c\dagger}\tilde{e}^c - m^2_{h_U}h_u^\dagger h_u - m^2_{h_d}h_d^\dagger h_d \\ & -\Big[m_1\tilde{b}\tilde{b} + m_2\tilde{w}^A\tilde{w}^A + m_3\tilde{g}^A\tilde{g}^A + B_\mu h_u\cdot h_d \\ & +T^U_{ij}\tilde{q}_i\cdot h_u\tilde{u}^c_j + T^D_{ij}h_d\cdot\tilde{q}_i\tilde{d}^c_j + T^E_{ij}h_d\cdot\tilde{l}_i\tilde{e}^c_j + \text{h.c.}\Big]\end{aligned}$$

(in the MSSM) arbitrary bilinear and trilinear interactions are soft, but usually one restricts them to the above set (closed under renormalization) which corresponds 1:1 to the superpotential (Yukawa + mu-term)

Sflavour

Masses & trilinear soft terms are 3x3 matrices in flavour space: Many flavour and CP-violating parameters

Minimal flavour violation: Only Yukawas violate flavour

$$m^2_{\tilde{q}ij} = m_0^2 \mathbf{1} + c_1 Y^{U*} Y^{U^T} + c_2 Y^{D*} Y^{D^T} + \dots$$

even simpler form (assumed below, valid at most at one scale)

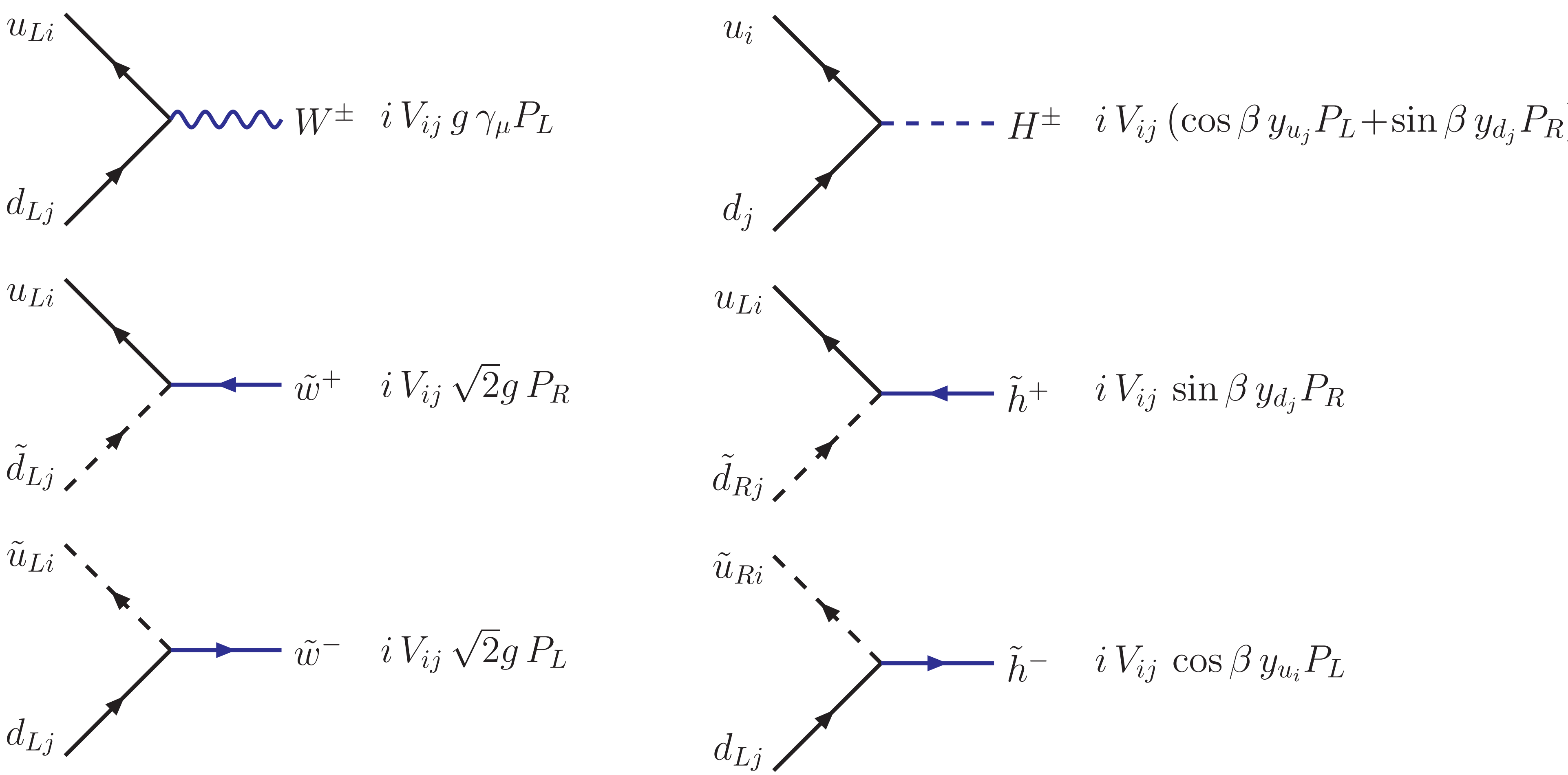
$$m^2_{\tilde{q}ij} = m^2_{\tilde{t}_L} \mathbf{1}, \quad m^2_{\tilde{u}ij} = m^2_{\tilde{t}_R} \mathbf{1}, \quad \dots$$

$$T^U = a_t Y^U, \dots$$

approximately true at M_W in low-scale gauge mediation,
at M_{Pl} in gravity mediation models with dilaton dominance

Scharged current

The brothers and sisters of the $W^{+/-}$ couplings:



in minimal flavour violation, these are the only flavour violating vertices involving quarks

MSSM Higgs potential

Superpotential and soft terms contribute just mass terms to the Higgs self-interactions, rest fixed by SUSY gauge invariance

$$\mathcal{L}_h = |D_\mu h_u|^2 + |D_\mu h_d|^2 - (|\mu|^2 + m_{h_u}^2) h_u^\dagger h_u - (|\mu|^2 + m_{h_d}^2) h_d^\dagger h_d - [B_\mu h_u \cdot h_d + \text{h.c.}]$$
$$- \frac{g^2 + g'^2}{8} (h_u^\dagger h_u - h_d^\dagger h_d^2)^2 - \frac{g^2}{2} (h_u^\dagger h_d)(h_d^\dagger h_u)$$

compare to most general renormalizable case

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$$V = m_{11}^2 H_d^\dagger H_d + m_{22}^2 H_u^\dagger H_u + \left\{ m_{12}^2 H_u \cdot H_d + h.c. \right\}$$
$$+ \frac{\lambda_1}{2} (H_d^\dagger H_d)^2 + \frac{\lambda_2}{2} (H_u^\dagger H_u)^2 + \lambda_3 (H_u^\dagger H_u)(H_d^\dagger H_d) + \lambda_4 (H_u^\dagger H_d)(H_d^\dagger H_u)$$
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n.b. model II (H_d->-H_d invariance) would allow λ_5, forbid $\lambda_{6,7}$

SUSY large tan(β) B physics

In SM, higgs couplings flavour diagonal
(proportional mass matrix)

$$M^d_{ij} = v \ Y^d_{ij}$$

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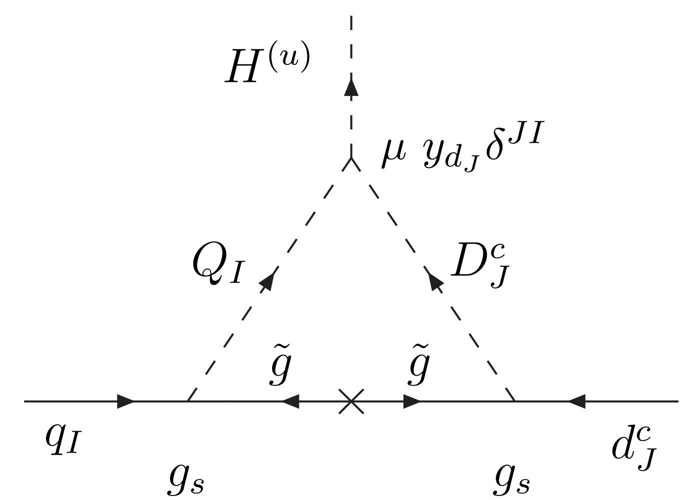

In MSSM, 3 neutral higgses, 2 vevs v_u, v_d

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parametrically large if $v_u \gg v_d$

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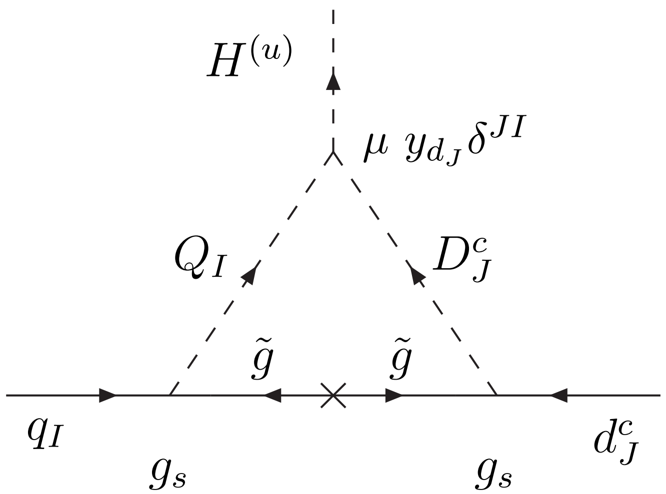

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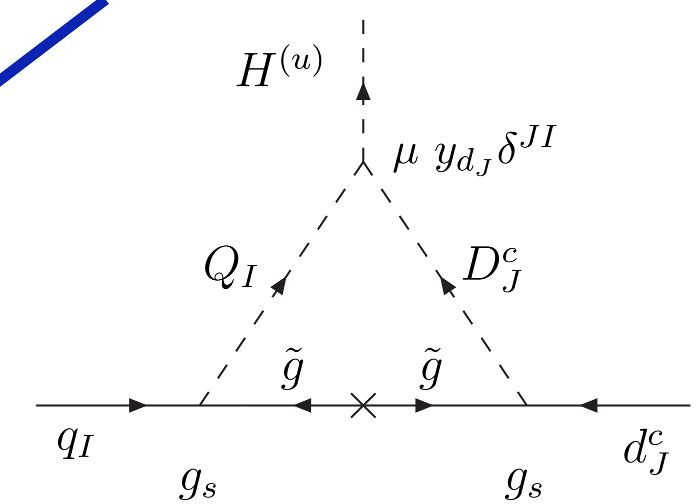

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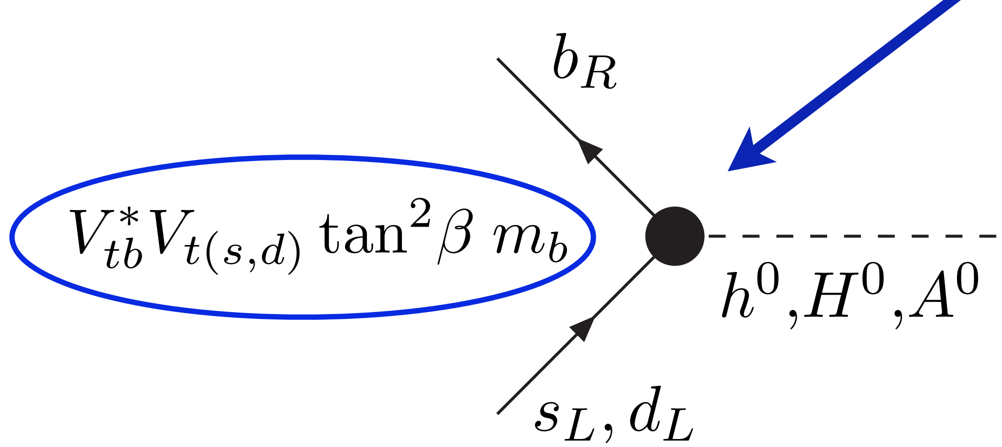
Yukawa becomes flavour-violating



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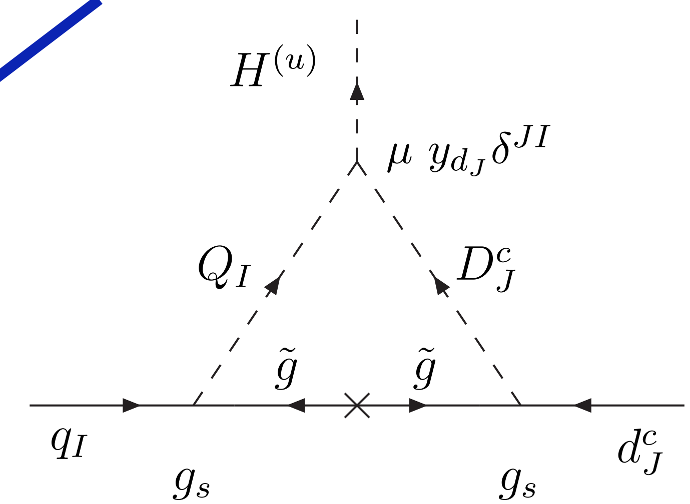

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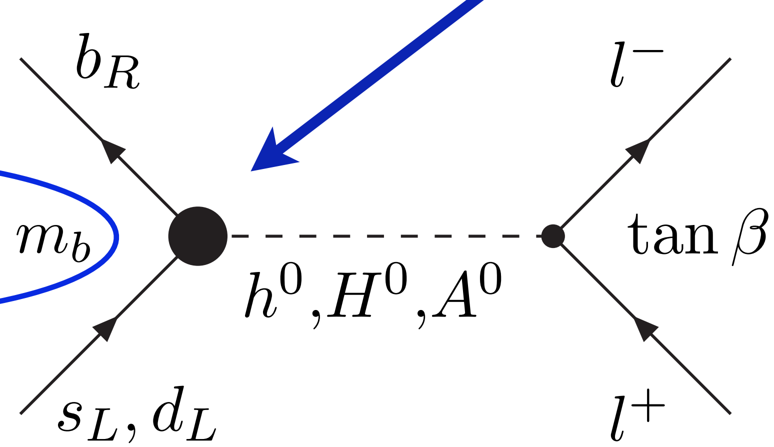
$V^*_{tb} V_{t(s,d)} \tan^2\beta\ m_b$

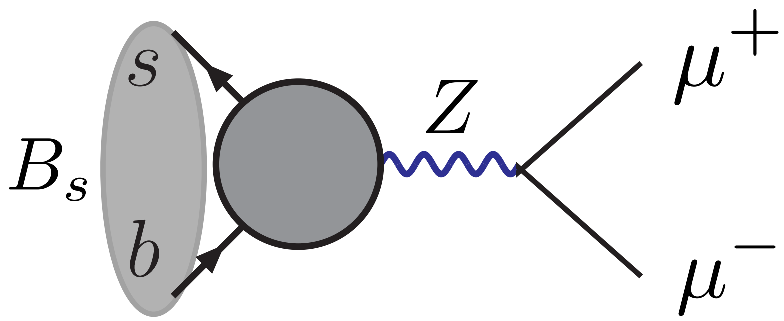


(for minimal flavour violation)

$$BR(B_s \to \mu\mu) \propto \tan^6\beta$$

[Choudhury&Gaur 99; Hamzaoui, Pospelov, Toharia 99; Babu, Kolda 99; Isidori, Retico; Buras et al 02; Foster et al 04-06,...]

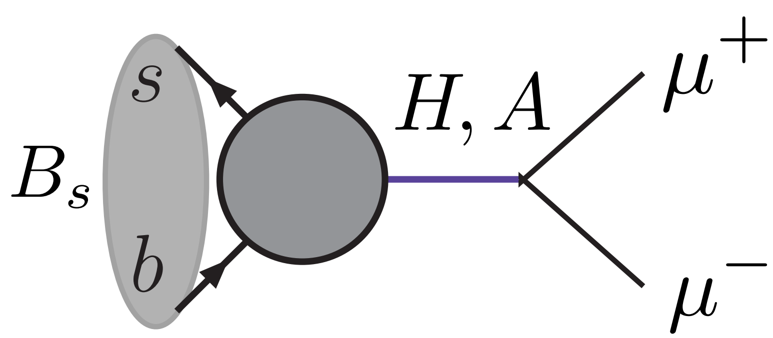
Leptonic decay



$$\propto \frac{m_\mu^2}{M_W^2}$$

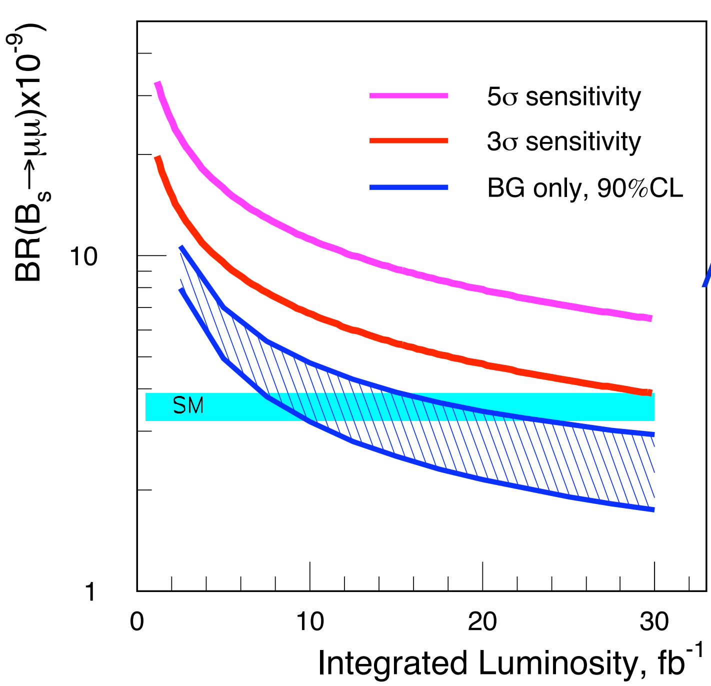
helicity suppressed
theoretically clean in SM
(normalize to ΔM_s) Buras 03

$$BR(B_s \to \mu^+\mu^-)_{\rm SM} = (3.5 \pm 0.5) \times 10^{-9}$$

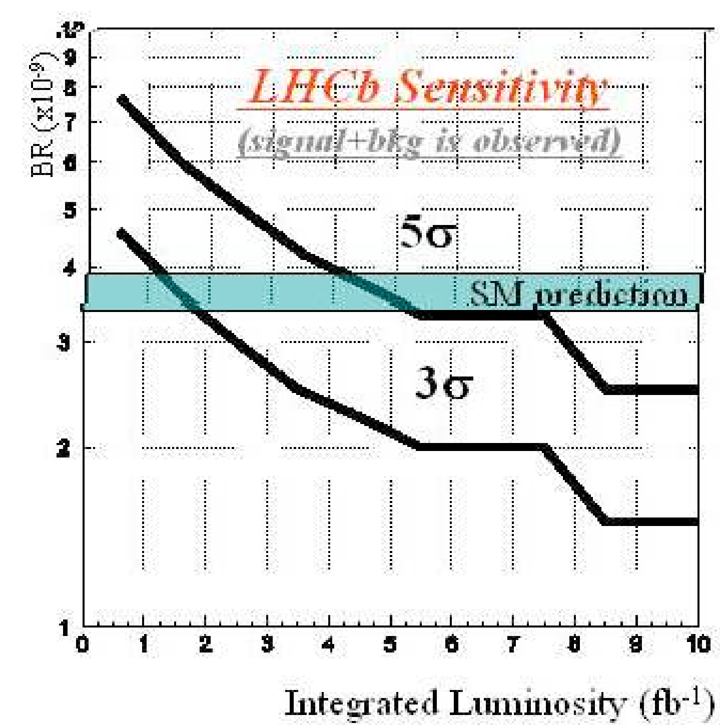


$$\propto \frac{m_b^2 m_\mu^2}{M_W^4} \tan^6\beta$$

Yukawa suppressed in SM
strong enhancement in 2HDM
(or MSSM) possible



ATLAS/CMS



LHCb

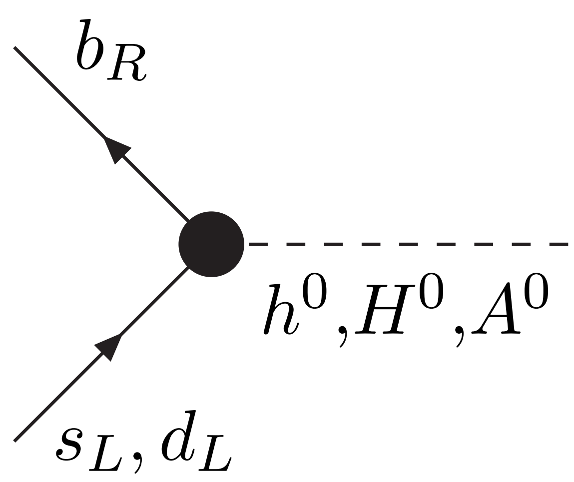
Structure of the coupling

assume $M_{SUSY} \gg M_{H,A,h} \sim v=246$ GeV ; effective 2HDM description

$$M^d_{ij} = v_d Y^d_{ij} + v_u \Delta_{ij}$$

parametrically large if tan β ≫ 1

diagonalization of M^d rotates Y^d out of diagonal form:



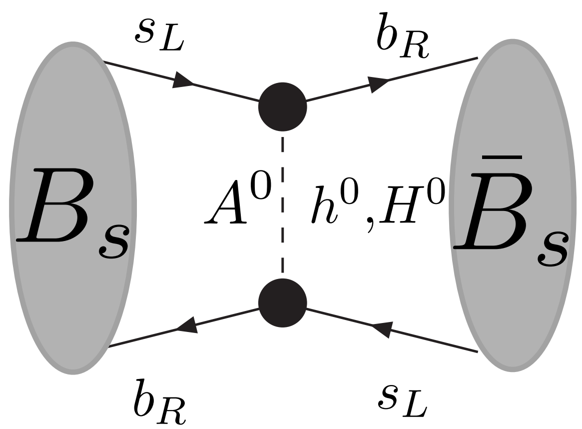
$$\mathcal{L}_{\rm eff} \supset \kappa(\cos\beta h_u^{0*} - \sin\beta h_d^0)[y_b \bar{b}_R s_L + y_s \bar{b}_L s_R]$$

$$\kappa \propto V^*_{tb} V_{ts} \frac{\tan\beta}{16\pi^2}$$

minimal flavour violation

note the hierarchy between the two couplings

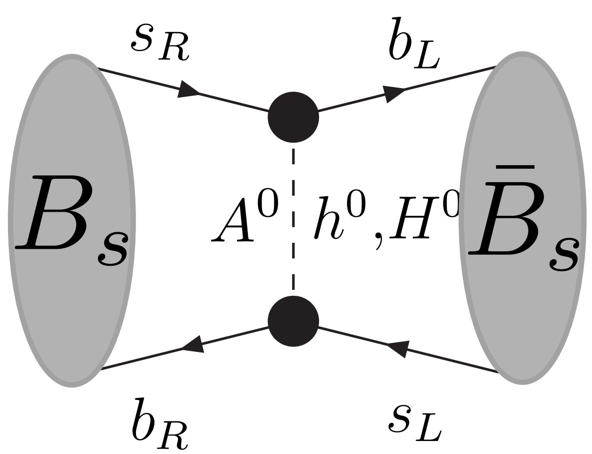
B mixing at large tan (β)



$$\propto \kappa^2 y_b^2 \Big[\frac{\sin^2(\alpha-\beta)}{M_H^2} + \frac{\cos^2(\alpha-\beta)}{M_h^2} - \frac{1}{M_A^2} \Big] = 0$$

[LO higgs masses & mixing angle α]

Flipping the chirality of one b (hence one s) quark,



$$\propto |\kappa^2| y_b y_s \Big[\frac{\sin^2(\alpha-\beta)}{M_H^2} + \frac{\cos^2(\alpha-\beta)}{M_h^2} + \frac{1}{M_A^2} \Big] \neq 0$$

costs a factor m_s/m_b (in $B_d - \bar{B}_d$ mixing: m_d/m_b - negligible)

But this is only one of several small parameters!

$$1/(16\pi^2) \sim m_s/m_b \sim 1/\tan\beta \sim 10^{-2}$$

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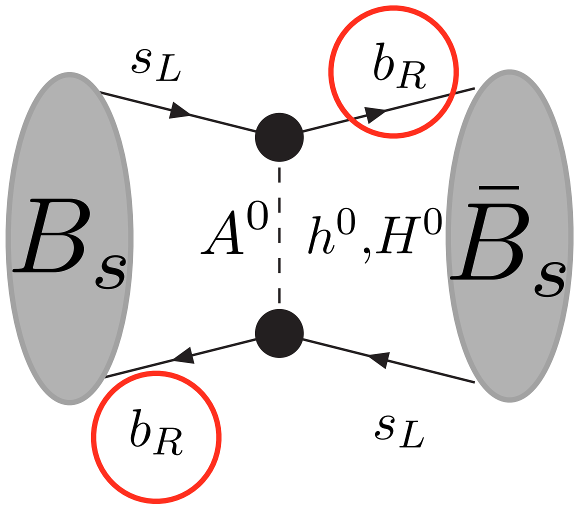

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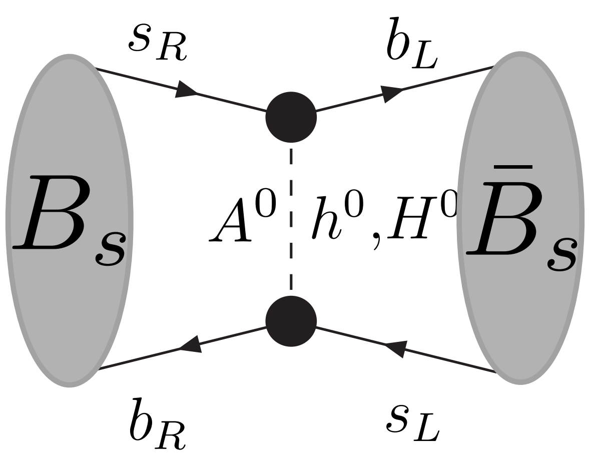

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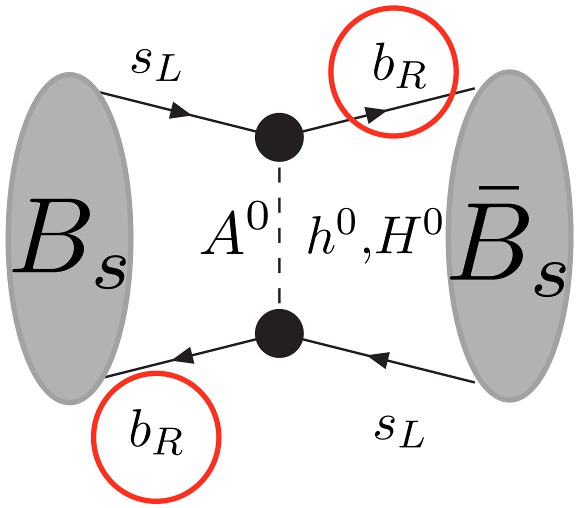

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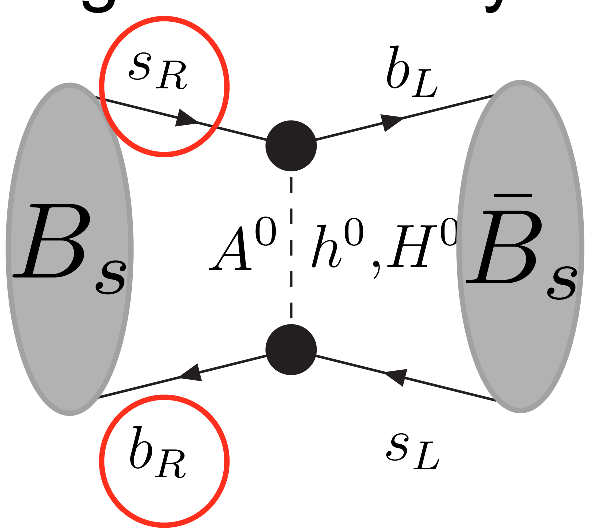

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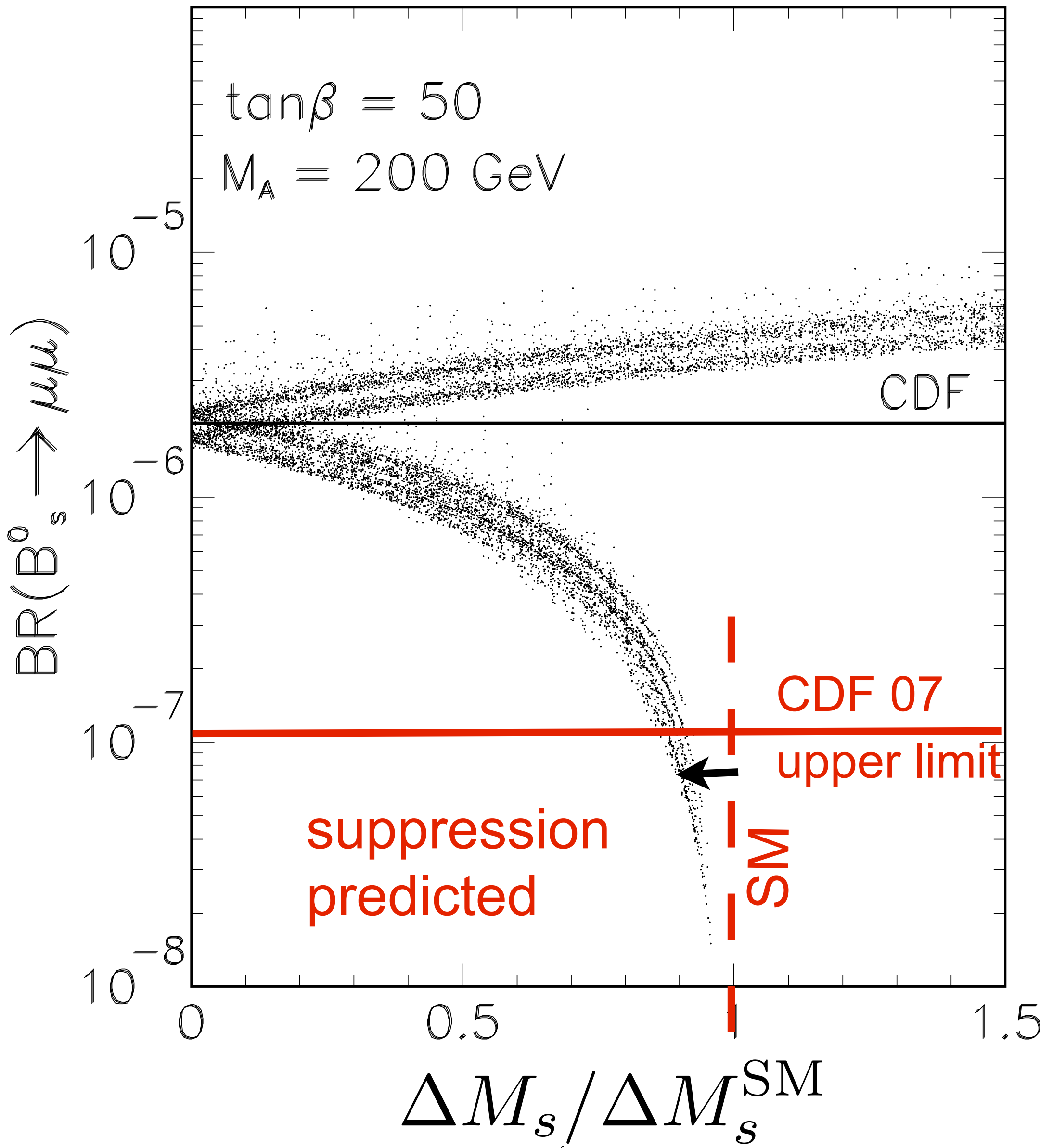


Strong correlation between ΔM_{B_s} and $BR(B_s \to \mu^+\mu^-)$

[Buras et al 02]

$$(\Delta M_s)_{\rm exp} = (17.77 \pm 0.12)\mathrm{ps}^{-1}$$

$$\Delta M_s^{\rm SM} \approx 16\ldots 27\,\mathrm{ps}^{-1}$$

(recent claims of CP violation, ~ zero in SM)

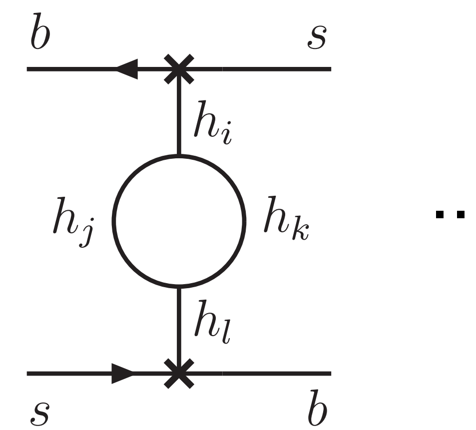
A (naively) subleading effect: arises at first order in m_s/m_b

Can more loops or 1/tan(β) corrections remove m_s/m_b suppression?
claims of large effects from Higgs self-energies
both in ΔM_d and ΔM_s in recent literature [Parry 06; Freitas,Gasser,Haisch 07]

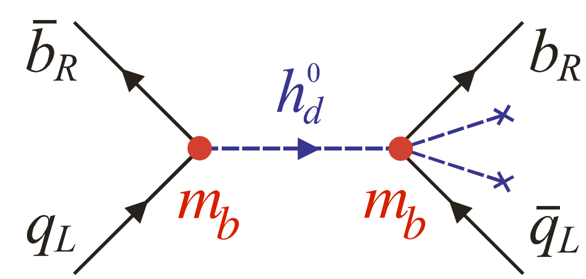
“Subleading” contributions to ΔM_s

The nonvanishing “effective” tree diagram (double penguin from MSSM viewpoint) is m_s/m_b suppressed over the naive expectation.

Do higher loop corrections remove this suppression and give O(1) corrections?



bs{h,H,A} vertex derived in limit v << M_{SUSY}, what about v/M corrections?



Is the cancellation broken at $(1/\tan\beta)^n$ level for some n?

tan β is renormalization scheme dependent, impact on ΔM_s ? More generally, on flavour physics?

Plan of attack

Assume hierarchy $M_{SUSY} \gg M_{H,A,h} \sim v=246$ GeV

Integrate out all superpartners. Since $M \gg v$, this can be done in the "symmetric phase", ie without shifting Higgs fields by v

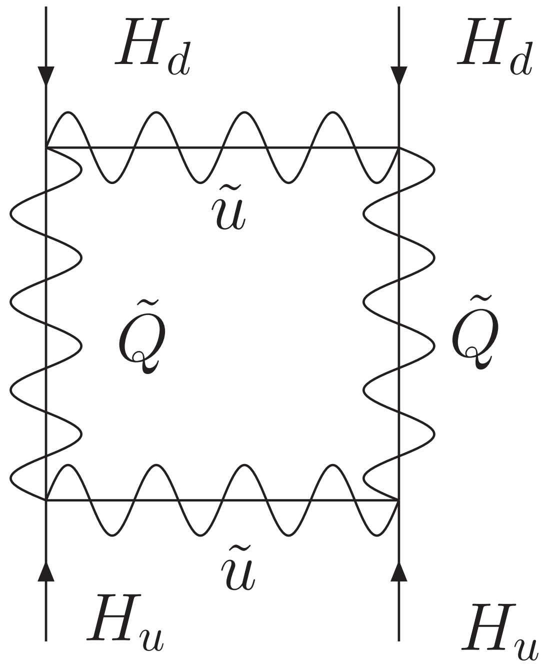
$$\int D[\tilde{g}, \tilde{f}, \tilde{h}] D[A, \psi, h_i] e^{i\int d^4x (\mathcal{L}_{gauge+kin}[\tilde{g}, \tilde{f}, \tilde{h}, A, \psi, h_i] - V(h_i))}$$

$$= \int D[A, \psi, h_i] e^{i\int d^4x (\mathcal{L}_{gauge-kin}[A, \psi, h_i] - V_{\text{eff}}(h_i))}$$

$$V = \frac{g^2 + g'^2}{8}(h_u^\dagger h_u - h_d^\dagger h_d)^2 + \frac{g^2}{2}(h_u^\dagger h_d)(h_d^\dagger h_u) \quad \Rightarrow \quad V_{\text{eff}} = \sum \lambda_i Q_i[h_u, h_d]$$

then shift Higgs fields and compute loops with Higgs particles

Loop-corrected Higgs potential



Sparticle loops generate most general quartics

break tree-level relation giving zero O(1) amplitude

previous calculations [Haber, Hempfling unpublished; Carena et al. ; ...?]
in the context of Higgs masses & mixings
here: complete computation including arbitrary MSSM flavour structure

$$V = m_{11}^2 H_d^\dagger H_d + m_{22}^2 H_u^\dagger H_u + \left\{ m_{12}^2 H_u \cdot H_d + h.c. \right\}$$

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+higher-dim operators

(v/M corrections)

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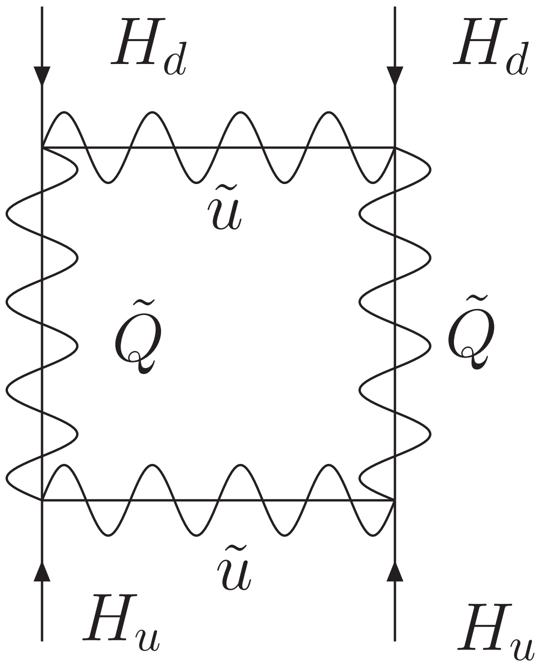

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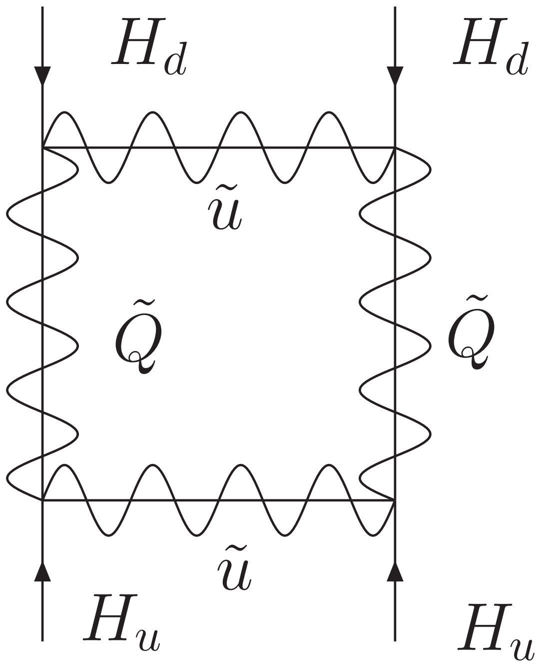
+higher-dim operators

(v/M corrections)

not present in tree-level MSSM

$$\lambda_1^{(0)} = \lambda_2^{(0)} = -\lambda_3^{(0)} = (g^2 + g'^2)/4 \equiv \tilde{g}^2/4, \quad \lambda_4^{(0)} = g^2/2$$

Loop-corrected Higgs potential



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$$V = m_{11}^2 H_d^\dagger H_d + m_{22}^2 H_u^\dagger H_u + \left\{ m_{12}^2 H_u \cdot H_d + h.c. \right\}$$

$$+ \frac{\lambda_1}{2}(H_d^\dagger H_d)^2 + \frac{\lambda_2}{2}(H_u^\dagger H_u)^2 + \lambda_3 (H_u^\dagger H_u)(H_d^\dagger H_d) + \lambda_4 (H_u^\dagger H_d)(H_d^\dagger H_u)$$

$$+ \underbrace{\left\{ \frac{\lambda_5}{2}(H_u \cdot H_d)^2 - \lambda_6 (H_d^\dagger H_d)(H_u \cdot H_d) - \lambda_7 (H_u^\dagger H_u)(H_u \cdot H_d) + \text{h.c.} \right\}}_{\text{not present in tree-level MSSM}}$$

+higher-dim operators

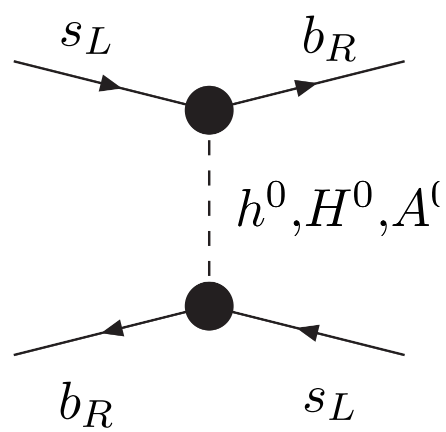
(v/M corrections)

allowed in a model II

not present in tree-level MSSM

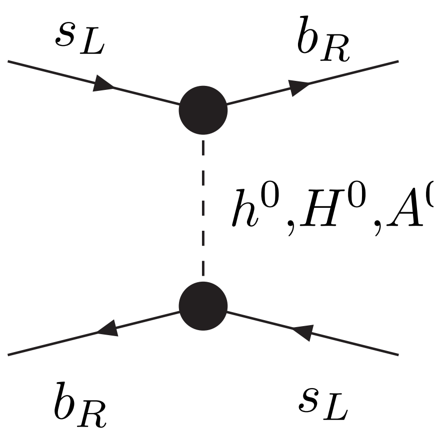
$$\lambda_1^{(0)} = \lambda_2^{(0)} = -\lambda_3^{(0)} = (g^2 + g'^2)/4 \equiv \tilde{g}^2/4, \quad \lambda_4^{(0)} = g^2/2$$

Effective tree diagram (loop-corrected)



$$= (V_{tb}^* V_{ts})^2 \times (\text{fermion coupling}) \times \mathcal{F}^-$$

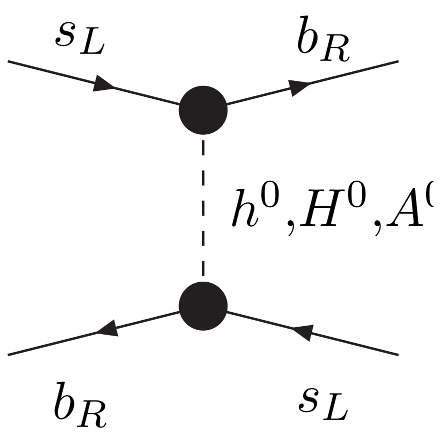
Effective tree diagram (loop-corrected)



$$= (V_{tb}^* V_{ts})^2 \times (\text{fermion coupling}) \times \mathcal{F}^-$$

$$\mathcal{F}^- = -\frac{v^4}{m_h^2 m_H^2 m_A^2} \times \Big[(\lambda_2 \lambda_5^* - \lambda_7^{*2})\, s_\beta^4 + 2\,(\lambda_2 \lambda_6^* - \lambda_3 \lambda_7^* + \lambda_5^* \lambda_7)\, s_\beta^3 c_\beta$$
$$+ (\lambda_1 \lambda_2 - \lambda_3^2 + |\lambda_5|^2 - 2\lambda_6 \lambda_7^* + 4\lambda_6^* \lambda_7)\, s_\beta^2 c_\beta^2$$
$$+ 2(\lambda_5 \lambda_6^* - \lambda_3 \lambda_6 + \lambda_1 \lambda_7) s_\beta c_\beta^3 + (\lambda_1 \lambda_5 - \lambda_6^2) c_\beta^4 \Big]$$

Effective tree diagram (loop-corrected)



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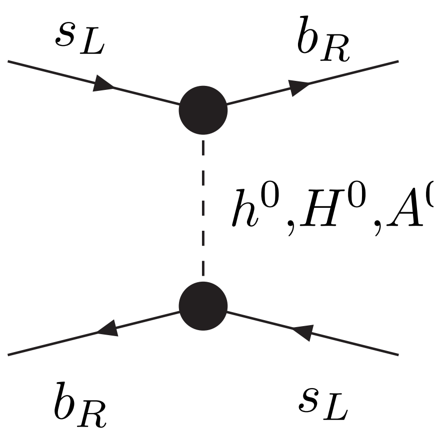
$$+ 2(\lambda_5\lambda_6^* - \lambda_3\lambda_6 + \lambda_1\lambda_7) s_\beta c_\beta^3 + (\lambda_1\lambda_5 - \lambda_6^2) c_\beta^4\Big]$$

only contribution with tree-level matching is down by two powers of 1/tan β
in fact $\lambda_1\ \lambda_2 - \lambda_3^2 = 0$, but cancellation removed by leading logs(v/M)

Effective tree diagram (loop-corrected)



$$= (V_{tb}^* V_{ts})^2 \times (\text{fermion coupling}) \times \mathcal{F}^-$$

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$$+ 2(\lambda_5\lambda_6^* - \lambda_3\lambda_6 + \lambda_1\lambda_7) s_\beta c_\beta^3 + (\lambda_1\lambda_5 - \lambda_6^2) c_\beta^4 \Big]$$

only contribution with tree-level matching is down by two powers of 1/tan β
in fact $\lambda_1 \lambda_2 - \lambda_3^2 = 0$, but cancellation removed by leading logs(v/M)

New contribution at one loop matching
neither m_s/m_b nor tan β suppressed

U(1)$_{PQ}$ symmetry at large tan (β)

What is the reason for the leading-order cancellation?

cannot be model-II restrictions, because λ_5 is allowed by these

The relevant symmetry is continuous and of the Peccei-Quinn type:

$$h_d \to e^{i\alpha} h_d$$

$$h_u \to h_u$$

+ suitable (chiral) transformations of fermion

broken in MSSM only by the μ parameter

This is a symmetry which forbids $\lambda_{5,6,7}$ but allows $\lambda_{1...4}$

The useful aspect is that it is not spontaneously broken in the large tanβ limit $\langle h_d \rangle = 0$

Large tan (β) effective Lagrangian

- leading-order Higgs potential invariant under $h_d \to e^{i\alpha} h_d$
  even if electroweak symmetry broken, at $\tan\beta = \infty$
  loop-corrected potential still approximately invariant, at

$$V_{\rm ltb}^{(2)} = \left[m_A^2 + \frac{\lambda_5^r}{2}v^2\right] H_d^\dagger H_d + \frac{\lambda_4}{2} v^2 |h_d^-|^2 + \frac{\lambda_2}{2} v^2 \phi_u^2$$

preserves U(1)

$$+\left[\frac{\lambda_5}{4}(h_d^{0*})^2 + \frac{\lambda_7}{\sqrt{2}}\phi_u h_d^{0*} + \text{h.c.}\right] v^2,$$

breaks U(1) but loop suppressed

(have shifted $h_u^0 = \frac{1}{\sqrt{2}}(v_u + \phi_u)$)

- For the fermions assign charge only to b_R: $b_R \to e^{i\alpha} b_R$

$$\mathcal{L}_{\rm eff} \supset \kappa(\cos\beta h_u^{0*} - \sin\beta h_d^0)[y_b \bar{b}_R s_L + y_s \bar{s}_R b_L]$$

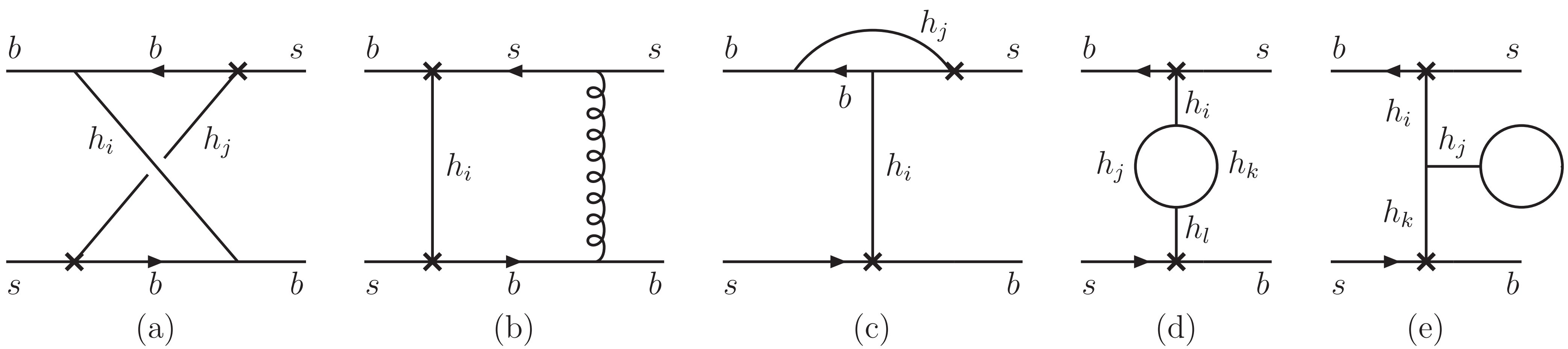
preserves breaks U(1)

All U(1) breaking in EFT proportional to small parameters $\lambda_{5,7}$, y_s, $1/\tan\beta$

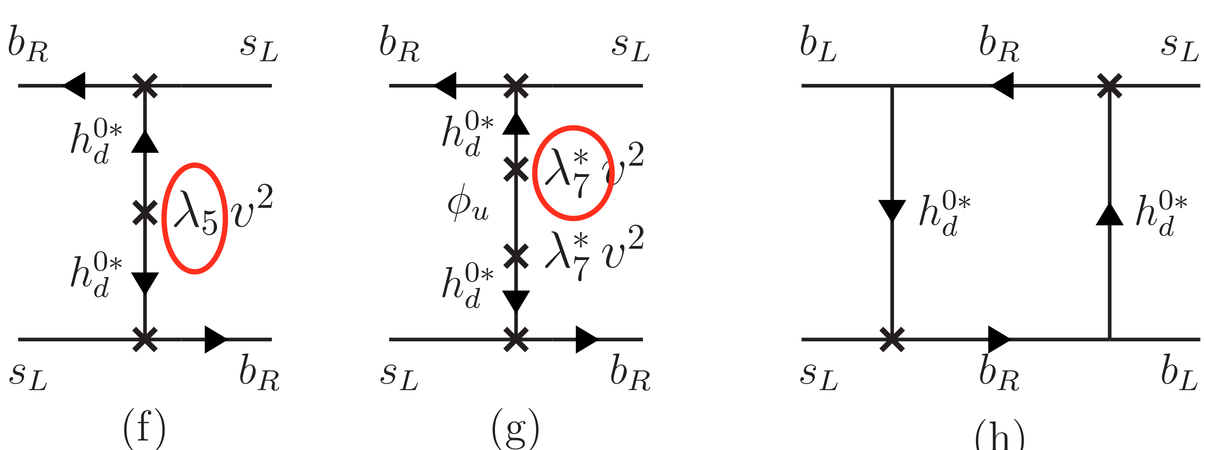
Effective loops

Large tan(beta) effective Lagrangian allows to compute in terms of complex fields and symmetry-breaking insertions

$$h_d = H_0 - iA_0 + \mathcal{O}(\text{loop};\, 1/\tan\beta)$$



small subset of diagrams that cancel due to the symmetry



only one loop diagram remains (3-loop in MSSM)

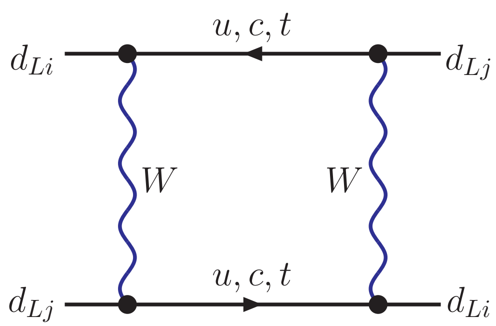
U(1) breaking couplings (sfermion-loop suppressed)

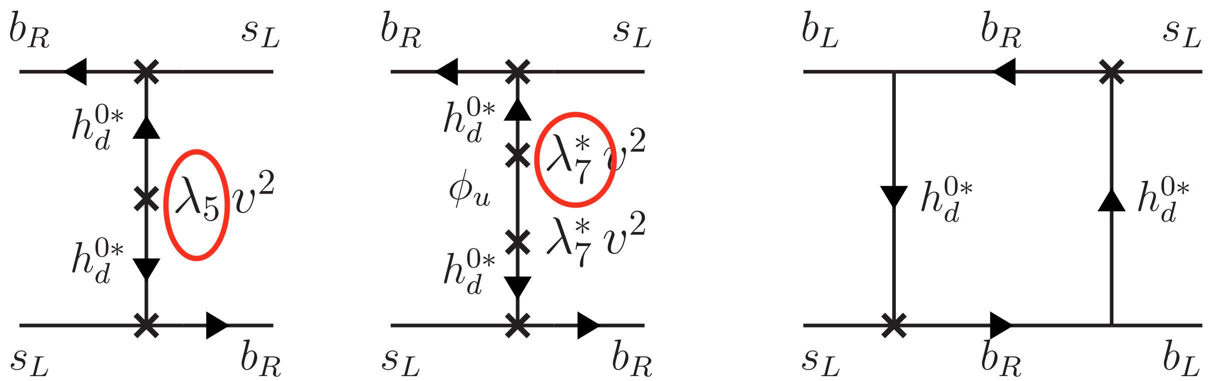
$\longrightarrow \mathcal{O}(\bar{b}_R s_L \bar{b}_R s_L)$

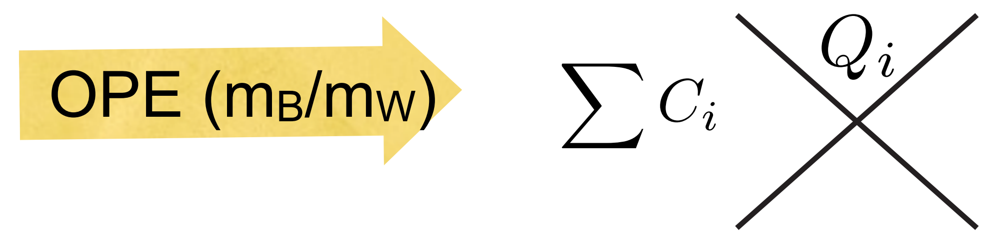
U(1) preserving Higgs loop

$\longrightarrow \mathcal{O}(\bar{b}_L s_L \bar{b}_L s_L)$

Effective hamiltonian





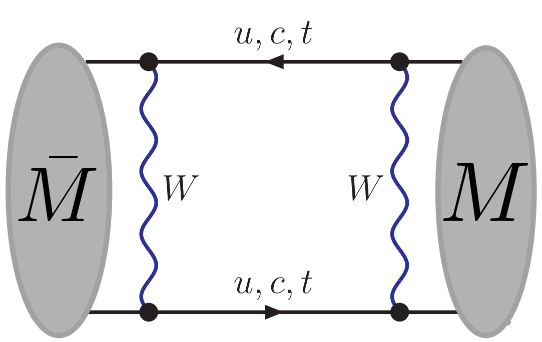


$$Q_1 = (\bar{s}_L^a \gamma_\mu b_L^a)(\bar{s}_L^b \gamma^\mu b_L^b),$$

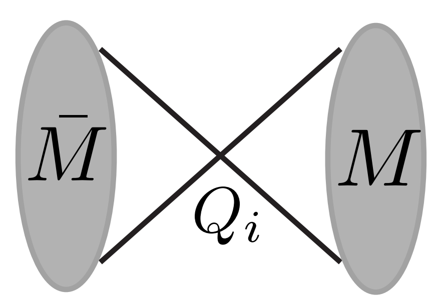
only operator present in SM

$$Q_2 = (\bar{s}_R^a b_L^a)(\bar{s}_R^b b_L^b),$$
$$Q_3 = (\bar{s}_R^a b_L^b)(\bar{s}_R^b b_L^a),$$
$$Q_4 = (\bar{s}_R^a b_L^a)(\bar{s}_L^b b_R^b),$$
$$Q_5 = (\bar{s}_R^a b_L^b)(\bar{s}_L^b b_R^a)$$

+ 3 more



+ NP + QCD $= \sum C_i$



$= \sum C_i \langle \bar{M} | Q_i | M \rangle$

U(1) classification of mixing amplitudes

$$\mathcal{A}(B \to \bar{B}) = \sum_i C_i \langle \bar{B} | \mathcal{O}_i | B \rangle$$ weak hamiltonian (4-quark operators)

operator(s)	U(1) charge	suppression of leading Higgs contribution		
$\mathcal{O}(\bar{b}_R s_L \bar{b}_R s_L)$	$\Delta Q = 2$	λ_5 / sparticle loop	new	formally of same size
$\mathcal{O}(\bar{b}_R s_L \bar{b}_L s_R)$	$\Delta Q = 1$	y_s	known	
$\mathcal{O}(\bar{b}_L s_L \bar{b}_L s_L)$ (SM)	$\Delta Q = 0$	2HDM loop (no scalar tree)	new	
$\mathcal{O}(\bar{b}_R s_R \bar{b}_R s_R)$	$\Delta Q = 2$	$(y_s)^2$ and 2HDM loop		tiny, ignore
$\mathcal{O}(\bar{b}_L s_R \bar{b}_L s_R)$	$\Delta Q = 0$ $[\Delta Q' = -2]$ [modified assignment]	$(y_s)^2$ and λ_5/sparticle loop		

v/M$_{\text{SUSY}}$ corrections

consider a higher-dimensional higgs-fermion coupling

$$Q^{(6)} = \frac{1}{M^2_{\text{SUSY}}} (H_u^\dagger H_u)(\bar{b}_R H_u^\dagger Q_{2L}) \quad \Rightarrow \quad \frac{2\sqrt{2}\, v_u^3}{M^2_{\text{SUSY}}}\, \bar{b}_R s_L + \frac{2\, v_u^2}{M^2_{\text{SUSY}}} (\bar{b}_R s_L h_u^0 + 2\, \bar{b}_R s_L h_u^{0*})$$

U(1)-breaking

contributes, but is loop-suppressed (with no compensating tanβ factor)

do not consider higher-dimensional Higgs self couplings, as all possible amplitudes are already generated at dimension-4 level

tanβ scheme dependence

$\mathcal{F}^-$ first arises at this order, scheme independent up to higher orders.

However, higher orders in relation defining tanβ can in principle be themselves tanβ enhanced! [see also Freitas, Stöckinger 03; Beneke et al 08]

1-loop effective action due to heavy particles, for DRbar fields:

$$S_{gh} = \int d^4x \Big[(1+\Delta Z_W)(-\frac{1}{4}) W^A_{\mu\nu} W^{\mu\nu A} + (1+\Delta Z_B)(-\frac{1}{4}) B_{\mu\nu} B^{\mu\nu}$$
$$+(\delta_{ij}+\Delta Z_{ij})(D_\mu H_i)^\dagger (D^\mu H_j) - \hat{m}^2_{ij} H_i^\dagger H_j - \sum_{k=1}^{7} \hat{\lambda}_k O_k + \ldots \Big]$$

can directly interpreted as effective Lagrangian for non-canonical fields

many ways to make EFT fields MSbar:

$$\begin{pmatrix} -\epsilon H_d^{\overline{\rm DR}} \\ H_u^{\overline{\rm DR}} \end{pmatrix} = \begin{pmatrix} Z_{dd} & Z_{du} \\ Z_{ud} & Z_{uu} \end{pmatrix} \begin{pmatrix} H_1^{\rm eff} \\ H_2^{\rm eff} \end{pmatrix}$$

tanβ scheme dependence

choose $$\begin{pmatrix} v_u^{\text{eff}} \\ v_d^{\text{eff}} \end{pmatrix} = \begin{pmatrix} 1+\delta Z_{uu}/2 & \delta Z_{ud}/2 \\ 0 & 1+\delta Z_{dd}/2 \end{pmatrix} \begin{pmatrix} v_u \\ v_d \end{pmatrix}$$

relation between MSSM and EFT tanβ

$$\bar{v}_2(\mu) \equiv v_2(\mu)^{\text{eff}} = v_u^{\text{DR}} - \delta Z_{ud} v_d - \delta Z_{uu} v_u + \delta v_2^{\text{tad}}$$

$$\bar{v}_1(\mu) \equiv v_1(\mu)^{\overline{\text{eff}}} = v_d^{\overline{\text{DR}}} - \delta Z_{dd} v_d + \delta v_1^{\text{tad}}$$

$$\tan\beta(\mu)^{\overline{\text{eff}}} = \tan\beta^{\overline{\text{DR}}} \left(1 - \frac{\delta v_1^{\text{tad}}}{v_1} + \frac{\delta v_2^{\text{tad}}}{v_2} + \delta Z_{dd} - \delta Z_{uu} - \delta Z_{ud} \cot\beta \right)$$

where δv_i^{tad} renormalizes tadpole ($v + \delta v = \langle \phi \rangle$, any field)

$$\tan\beta = \tan\beta^{\overline{\text{DR}}} + \text{small (i.e. not } \tan\beta \text{ enhanced) shift}$$

had we chosen $\delta Z_{du} \neq 0$, a term proportional tanβ would appear

Phenomenology

nonperturbative
QCD effects

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

known effect

$$+ \left\{ \begin{array}{c} 4.4{\rm ps}^{-1} \\ .13{\rm ps}^{-1} \end{array} \right\} X \left[\frac{M_W^2 \left(-\lambda_5 + \frac{\lambda_7^2}{\lambda_2}\right) 16\pi^2}{M_A^2}\right] \left[\frac{m_b}{3{\rm GeV}}\right]^2 \left[\frac{P_1^{\rm SLL}}{-1.06}\right]$$

new effect

numerically
small

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

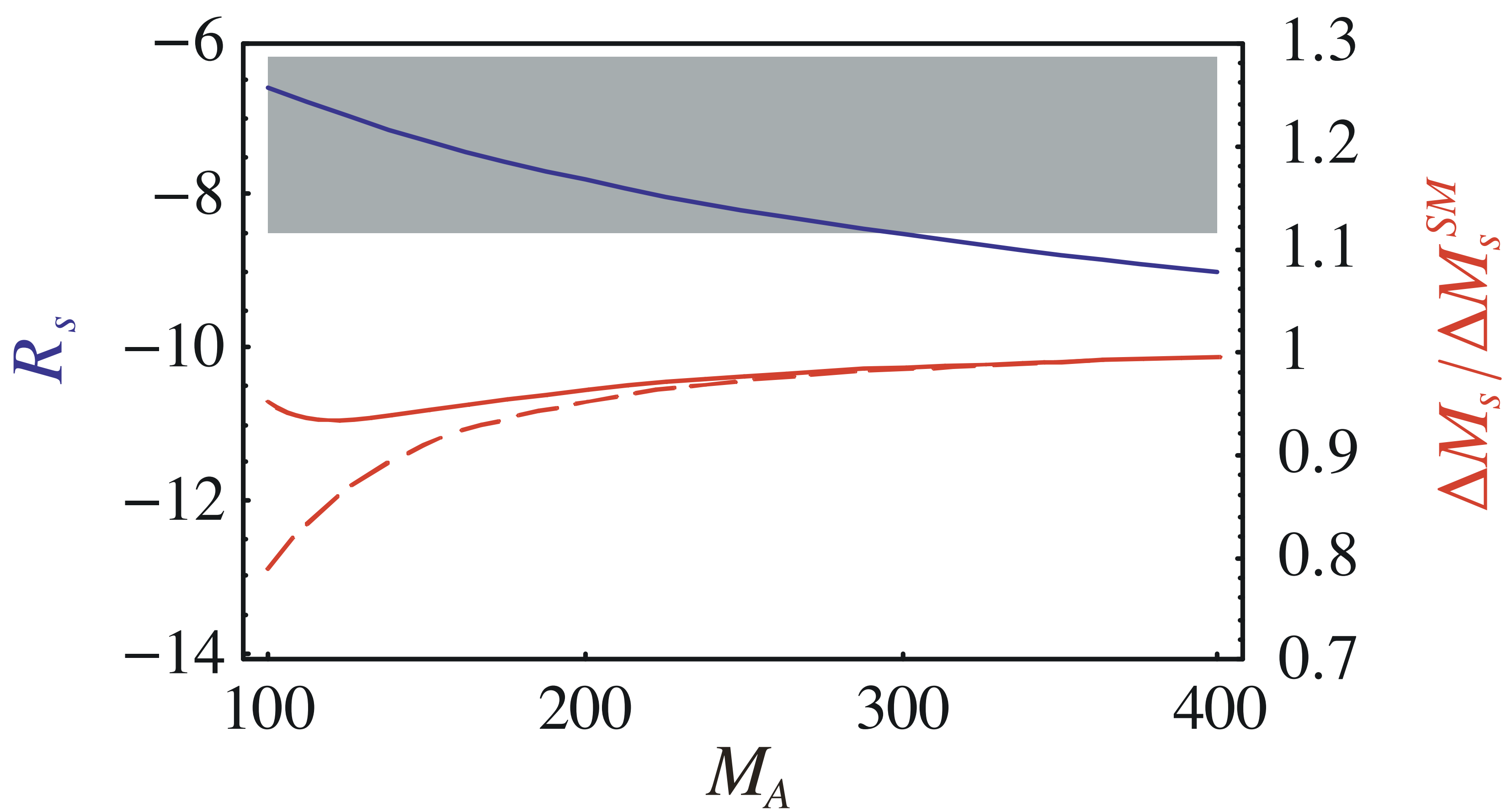
All new effects numerically somewhat (accidentally) suppressed

$$(\Delta M_s)_{\rm exp} = (17.77 \pm 0.12){\rm ps}^{-1}$$

$$\Delta M_s^{\rm SM} \approx 16\ldots 27\,{\rm ps}^{-1}$$

$$(\Delta M_d)_{\rm exp} = (0.507 \pm 0.005){\rm ps}^{-1}$$

Zero! (Almost)



[Gorbahn, SJ, Nierste, Trine, in progress]

excluding
including
new corrections

$\tan\beta = 40$

$a_{t,b} = 2000\,\mathrm{GeV},$

$M_{\tilde{g}} = \mu = 1500\,\mathrm{GeV}$

$M_{\tilde{q}} = M_2 = 1000\,\mathrm{GeV}$

$M_1 = 500\,\mathrm{GeV}$

- $R_s = \log_{10}[BR(B_s \to \mu^+\mu^-)/\Delta M_{B_s}\,\mathrm{ps}]$
- $\Delta M_s/\Delta M_s^{\mathrm{SM}}$

main features - and correlations - of ΔM_{B_s} and $BR(B_s \to \mu^+\mu^-)$ are preserved

tanβ scheme conversion

We have seen that no extra enhanced terms appear in B-physics observables if expressed through $\tan\beta^{\overline{\mathrm{DR}}}$.

Not so for other schemes: We show that different schemes in the literature differ by tanβ-enhanced terms. Start with:

$$\tan\beta^0 \equiv \frac{v_u^0}{v_d^0} \overset{1-\mathrm{loop}}{=} \tan\beta\left(1+\frac{1}{2}\delta Z_u - \frac{1}{2}\delta Z_d - \frac{\delta v_u}{v_u} + \frac{\delta v_d}{v_d}\right) \equiv \tan\beta + \delta\tan\beta$$

$$\langle h_i^0 - \frac{1}{\sqrt{2}} v_i^0 \rangle \overset{!}{=} 0 \qquad\qquad v_i^0 = Z_i^{1/2}(v_i - \delta v_i)$$

$$\tan\beta^R - \tan\beta^{R'} = \delta\tan\beta^{R'} - \delta\tan\beta^R$$

$\overline{\mathrm{DR}}$ $\quad Z_i = \delta v_i = \mathrm{minimal} \quad \Longrightarrow \delta\tan\beta = \text{pure divergence}$

"DCPR" set of on-shell conditions; vanishing A^0-Z^0 mixing and

$$\frac{\delta v_u}{v_u} = \frac{\delta v_d}{v_d}$$

tanβ scheme conversion

Now interpet

$$S_{gh} = \int d^4x \Big[(1+\Delta Z_W)(-\frac{1}{4}) W^A_{\mu\nu} W^{\mu\nu A} + (1+\Delta Z_B)(-\frac{1}{4}) B_{\mu\nu} B^{\mu\nu}$$
$$+ (\delta_{ij} + \Delta Z_{ij})(D_\mu H_i)^\dagger (D^\mu H_j) - \hat{m}^2_{ij} H^\dagger_i H_j - \sum_{k=1}^{7} \hat{\lambda}_k O_k + \ldots \Big]$$

within the MSSM. The Higgs kinetic operator contributes to A^0-Z^0 mixing as:

const $\Delta Z_{21}(1 + \mathcal{O}(\cos\beta)$

However, only "diagonal" wave-function renormalizations $\delta Z_{ii} |D_\mu H_i|^2$ are allowed in the MSSM, contributing:

const $\sin\beta \cos\beta(\delta Z_{uu} - \delta Z_{dd})$

Cancelling A^0Z^0 mixing implies

$$\tan\beta^{\overline{\mathrm{DR}}} - \tan\beta^{\mathrm{DCPR}} = \frac{\tan^2\beta}{2} \mathrm{Re}\Delta_{12}(1 + \mathcal{O}(\cos\beta))$$

Conclusions/outlook

- First systematic study of all "subleading" Higgs-mediated effects in Delta F=2 processes in the large tan(beta) MSSM
- Approximate symmetry allows for transparent & efficient treatment.
- We computed "zero", i.e. no large corrections from Higgs loops. Correlations and phenomenology of e.g. Buras et al remain valid, no relevant corrections at even higher orders expected
- Parametrically large shifts between tanβ schemes in the literature exist