$B_d \to l^+ l^-$ and SuperB

Workshop on New Physics with SuperB
Warwick
14th-17th April 2009

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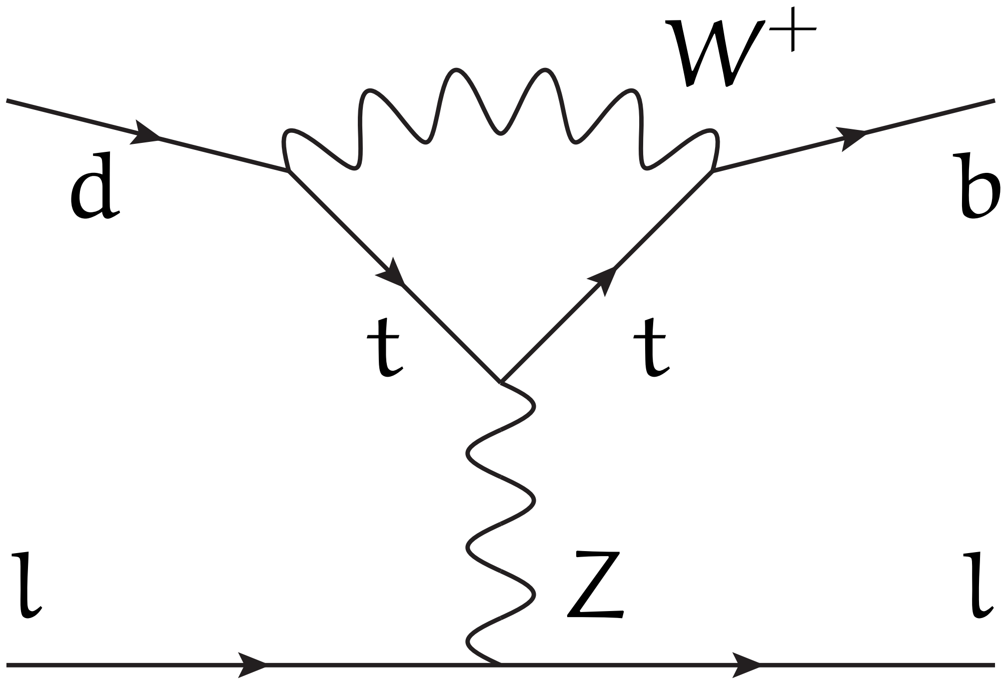
TUM-IAS

Introduction: Standard Model



Lepton pair in C=1: no γ

$$Q_A = (\bar{b}_L \gamma_\mu q_L)(\bar{l}\gamma_\mu \gamma_5 l)$$

Dominant operator (SM)

Wilson Coefficient @ NLO

[Buchalla, Buras; Misiak Urban '93 '99]

helicity suppression $(\propto m_l)$

Effective Hamiltonian in the SM (NP + chirality flipped):

$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \frac{\alpha\, V_{tb}^* V_{td}}{\pi \sin^2\theta_W} \left(C_S Q_S + C_P Q_P + C_A Q_A\right) + \text{h.c.}$$

$$Q_S = m_b(\bar{b}_R q_L)(\bar{l} l) \qquad Q_P = m_b(\bar{b}_R q_L)(\bar{l}\gamma_5 l)$$

SM Predictions

$$\mathcal{B}(B_d \to l^+l^-) = \boxed{X(l^+l^-)} \times \frac{\tau_{B_d}}{1.527\text{ps}} \frac{|V_{td}|^2}{.0082^2} \frac{f_{B_d}^2}{200^2\text{MeV}^2}$$

$X(e^+e^-)$	$X(\mu^+\mu^-)$	$X(\tau^+\tau^-)$
$(2.49 \pm 0.09)10^{-15}$	$(1.06 \pm 0.04)10^{-10}$	$(2.23 \pm 0.08)10^{-8}$

CKMfitter 03'09: $\mathcal{B}(B_d \to \mu^+\mu^-) = 1.078^{+.038}_{-.088} \times 10^{-10}$

Compare with: $\mathcal{B}(B_s \to \mu^+\mu^-) = 3.291^{+.094}_{-.267} \times 10^{-9}$

Reminder: $|V_{ts}/V_{td}|^2 \simeq 22$

Cabibbo suppression: maybe more sensitive to non MFV

Experimental Situation in 201X

CDR[0709.0451]: Super B close to SM (no simulation so far)

LHCb: will measure $\mathcal{B}(B_s \to \mu^+\mu^-)$

LHCb: 3 times as many Bd than Bs

SuperB run on 5s will test $\mathcal{B}(B_s \to \mu^+\mu^-)$

	SuperB $75\mathrm{ab}^{-1}$	LHCb $10\mathrm{fb}^{-1}$
$\mathcal{B}(B_d \to l^+l^-)$, $l \to \mu/e$	$< \mathrm{X} \times 10^{-10}$	$<\sim 1.5/3 \times 10^{-9}$
$\mathcal{B}(B_s \to l^+l^-)$	$< 8 \times 10^{-9}$	$< 1.5 \times 10^{-9}$

$\Upsilon(5S)@30\mathrm{ab}^{-1}$

[Lenzi '07]

$\mathcal{B}(B_d \to \tau^+\mu^-)$ interesting but harder than $\mathcal{B}(B_d \to \mu^+\mu^-)$

New Physics Contributions

SuperB: $\mathcal{B}(B_d \to \mu^+\mu^-)$

Close to SM

LHCb: $\mathcal{B}(B_s \to \mu^+\mu^-)$

Measure SM

Interesting for SuperB

- Need big effects in $\mathcal{B}(B_d \to \mu^+\mu^-)$
- $\mathcal{B}(B_d \to \mu^+\mu^-)$ and $\mathcal{B}(B_s \to \mu^+\mu^-)$ should not always be correlated
- Other constraints have to be fulfilled (e.g. ΔM_d, ϵ_K and EW precision data)

Easiest to have NP in scalar/pseudoscalar operators

MSSM: MFV and large $\tan\beta$

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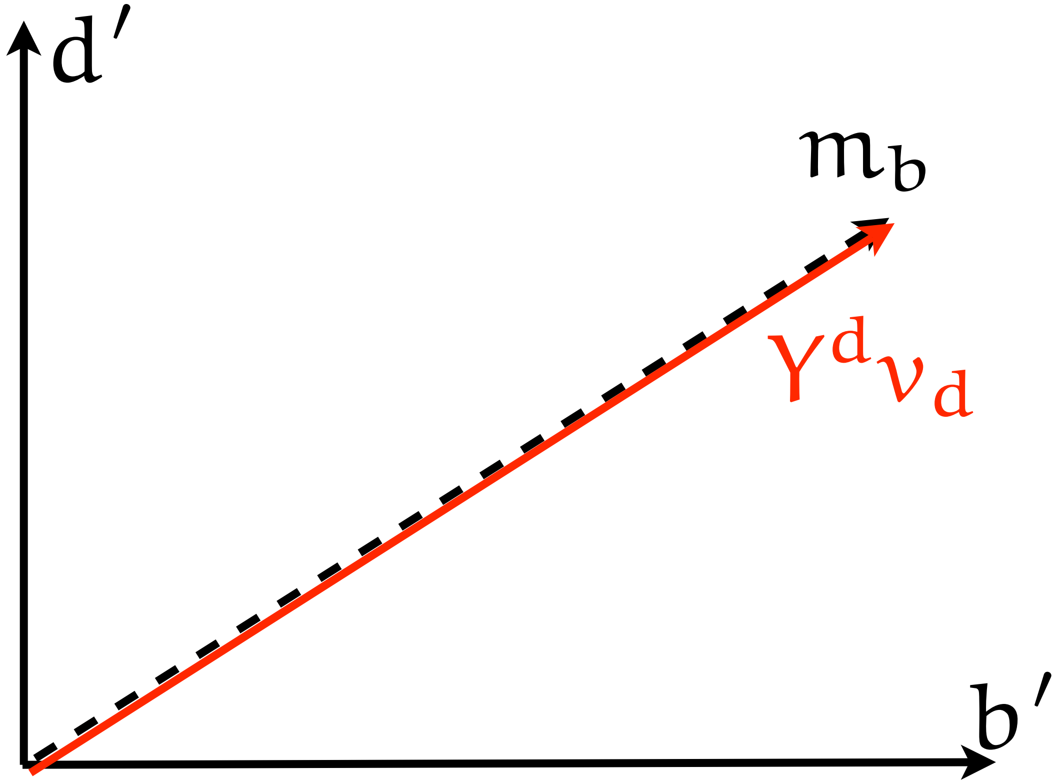
Tree level: Type II 2HDM

$H_d \leftrightarrow d_R \qquad H_u \leftrightarrow u_R$

$$-\mathcal{L} = Y^d_{ij} H_d \bar{d}^i_R q^j + Y^u_{ij} H_u \bar{u}^i_R q^j + \text{h.c.}$$

MSSM: MFV and large $\tan\beta$



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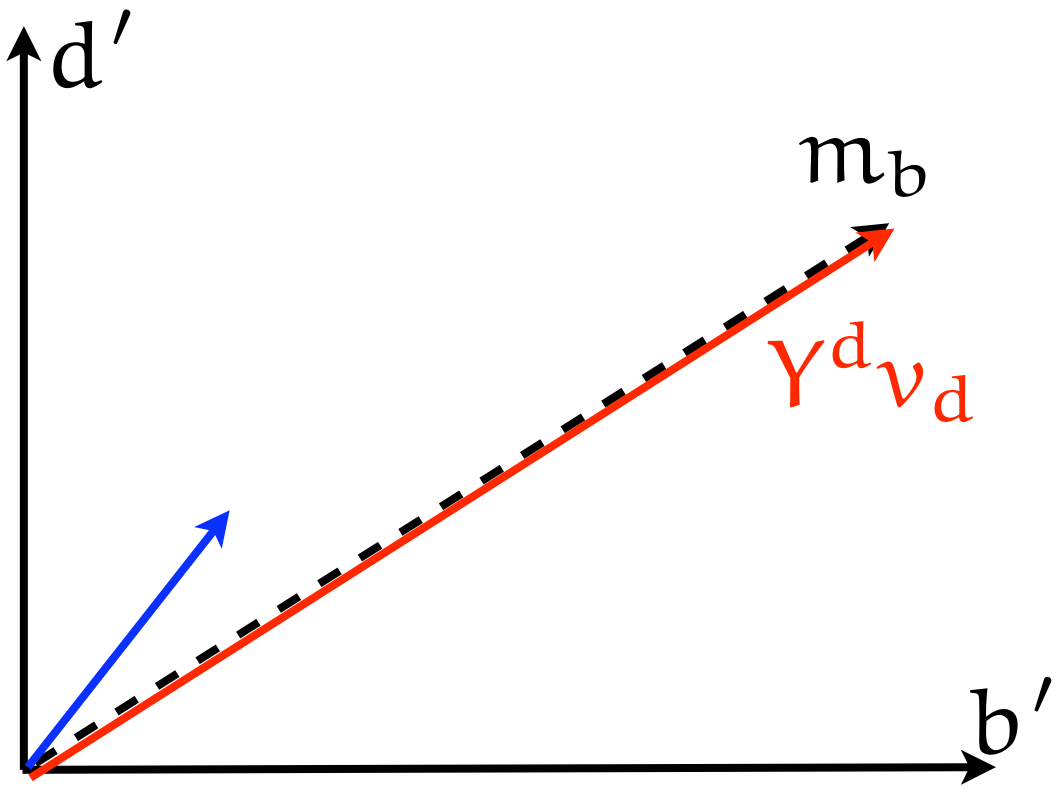

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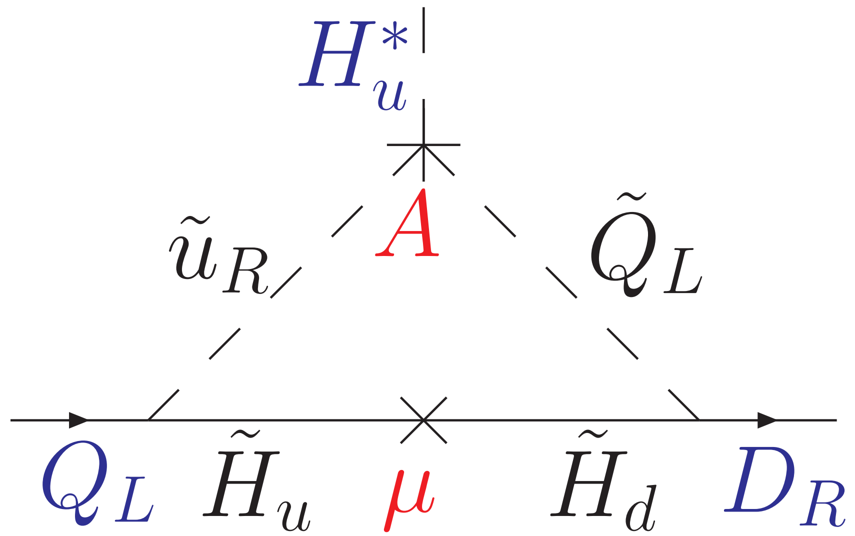
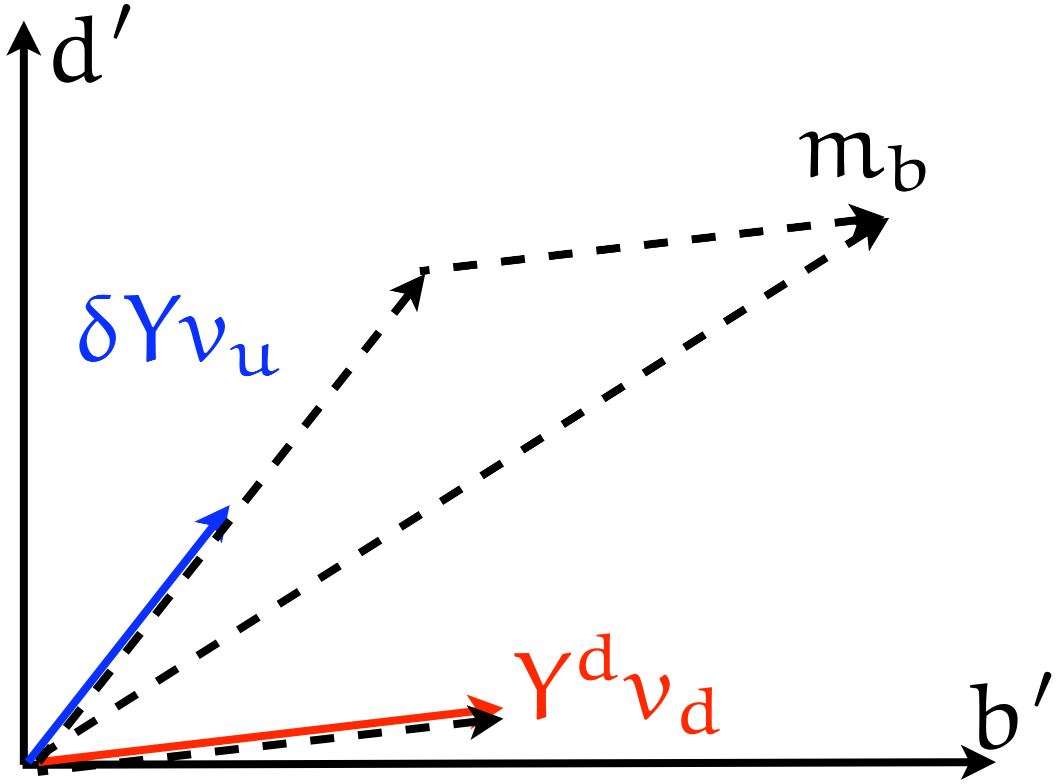


One loop: Type III 2HDM

$$\Delta\mathcal{L}^Y_{\text{eff}} = \epsilon_Y \bar{d}_R Y^d Y^{u\dagger} Y^u H_u^* \cdot Q_L$$

MSSM: MFV and large $\tan\beta$



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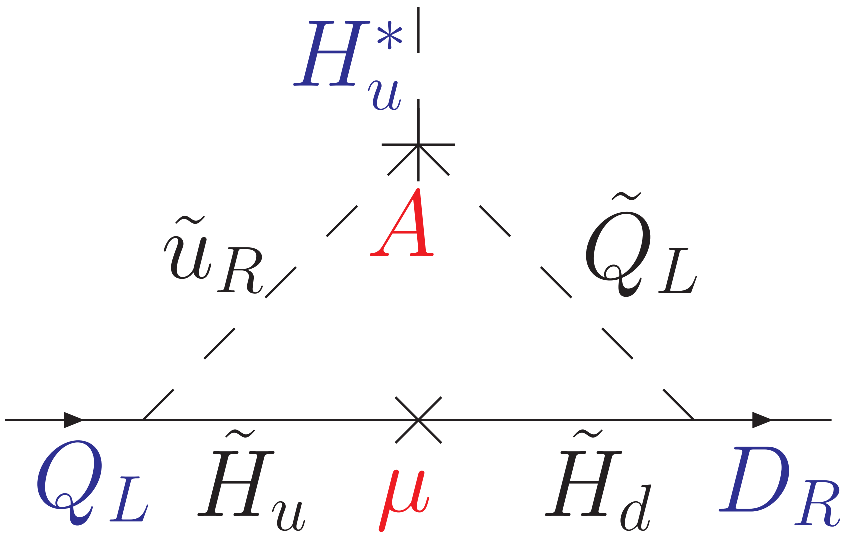

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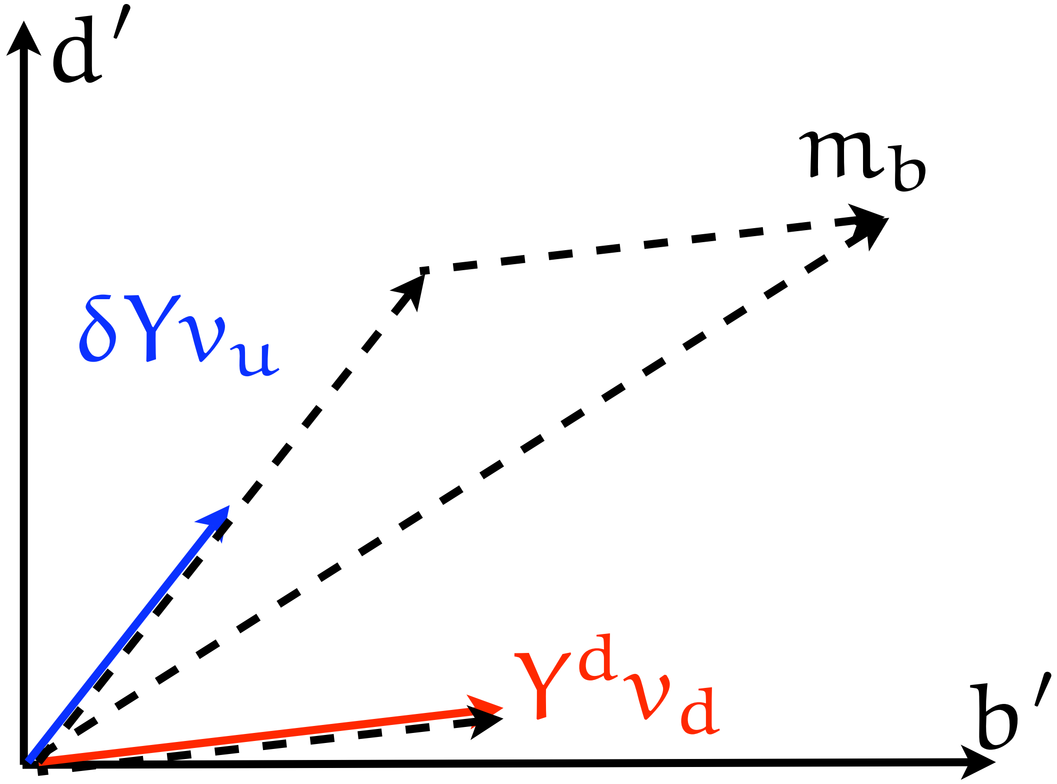

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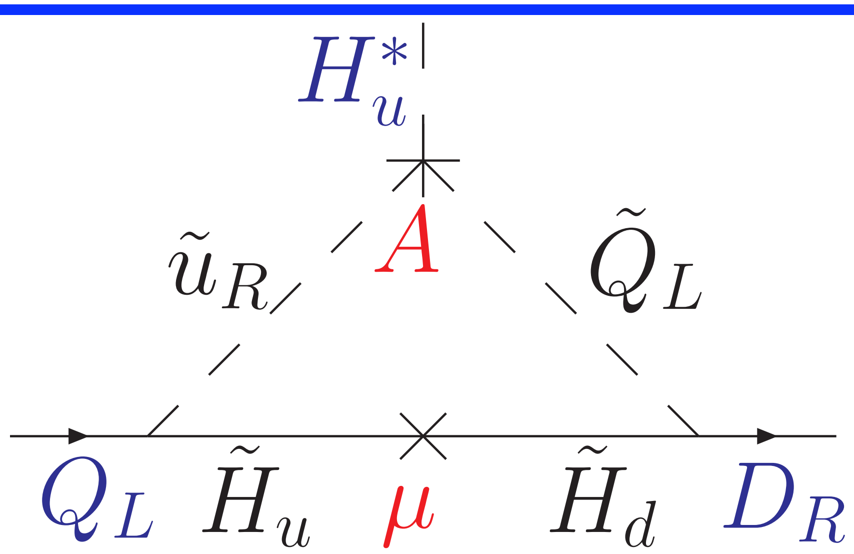
Redefinition of m_b & V_{CKM}

Mass and Yukawa not aligned



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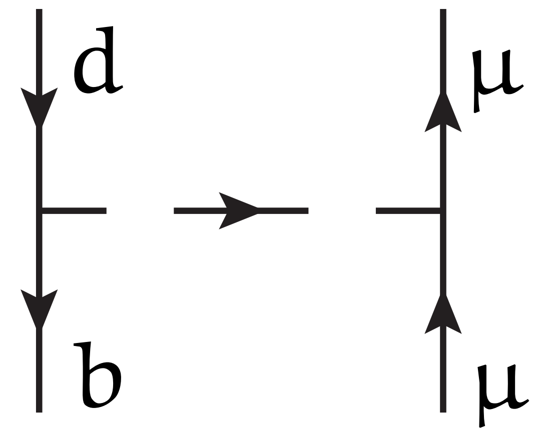
Flavour Violation at large $\tan\beta$

Large FC scalar interactions: $\kappa_b \bar{b}_R s_L h_d^{0*} \propto Y_b$

[Babu, Kolda '00; ...]

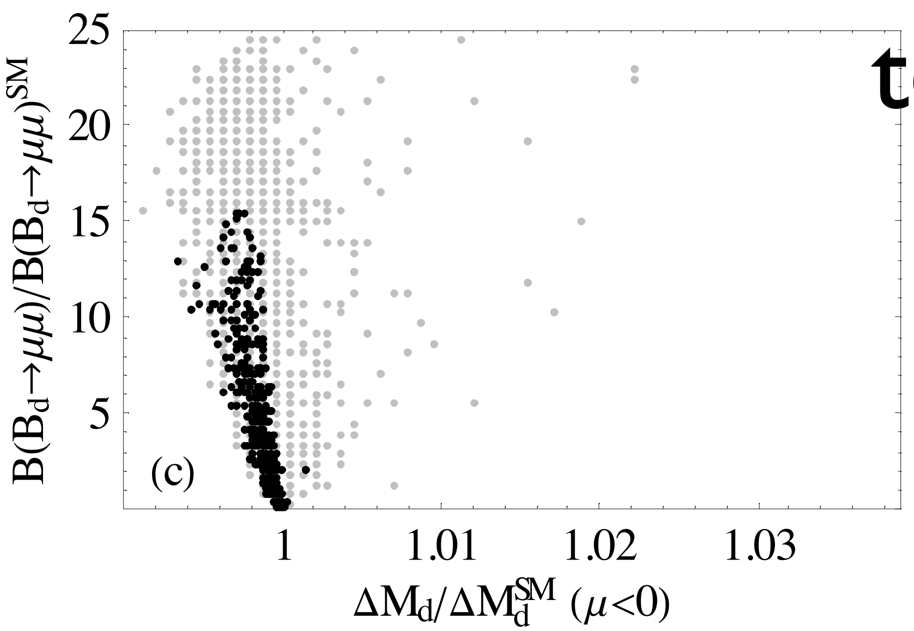


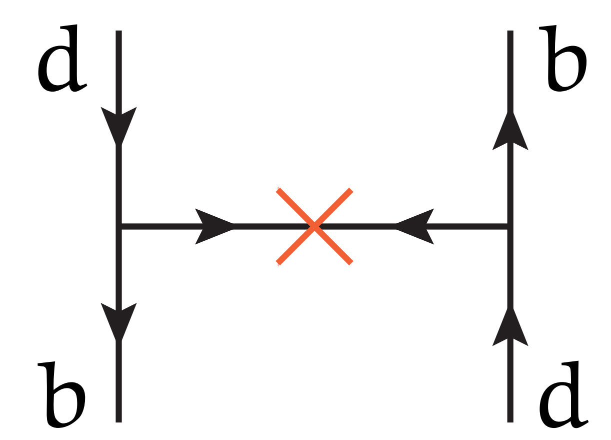
$$\mathcal{B}(B_d \to \mu^+\mu^-) \sim 10^{-8} \left(\frac{\tan\beta}{50}\right)^6 \left(\frac{300\mathrm{GeV}}{M_A}\right)^4$$

MSSM Higgs sector at $v_d = 0$: a symmetry

$Q(H_d) = 1,\ Q(b_R) = 1$ forbids the operator $(\bar{b}_R s_L)(\bar{b}_R s_L)$

This protects ΔM. Contribution of symmetry-breaking terms small [MG, Jäger, Nierste, Trine '09]





Tests of the MSSM Higgs Sector

Conversely: MSSM protects scalar $\Delta B = 2$ interactions and allows for large scalar $\Delta B = 1$ ones.

A large enhancement of $\mathcal{B}(B \to \mu^+\mu^-)$ will be strong hint for a MSSM with large $\tan\beta$

Measurement of $\mathcal{B}(B \to \mu^+\mu^-)$ would test the MSSM Higgs Sector

Are there $\tan\beta$ enhanced corrections to $\mathcal{B}(B \to \mu^+\mu^-)$

Or which $\tan\beta$ is measured in $\mathcal{B}(B \to \mu^+\mu^-)$

$\tan\beta$ used in Flavour Physics

Match the Higgs sector of the MSSM on a 2HDM

$$(\delta_{ij} + \Delta Z_{ij})(D_\mu H_i)^\dagger (D^\mu H_j)$$

Make the kinetic term canonical (+choice of Higgs basis)

$$\begin{pmatrix} -\epsilon H_d^{\overline{DR}} \\ H_u^{\overline{DR}} \end{pmatrix} = \begin{pmatrix} Z_{dd} & 0 \\ Z_{ud} & Z_{uu} \end{pmatrix} \begin{pmatrix} H_1^{\overline{\mathrm{eff}}} \\ H_2^{\overline{\mathrm{eff}}} \end{pmatrix}$$

Define a $\tan\beta^{\overline{MS}}$ in the effective 2HDM

No large corrections to $B \to l^+ l^-$ plus close to $\tan\beta^{\overline{DR}}$

DCPR would be different: $\delta \tan\beta^{\mathrm{DCPR}}_{\mathrm{finite}} \simeq \dfrac{\tan^2\beta}{2} \,\mathrm{Re}\,\Delta Z_{12}$

But in MFV we have $\mathcal{B}(B_s \to \mu^+\mu^-)/\mathcal{B}(B_d \to \mu^+\mu^-) = $ const

MSSM: Beyond MFV

Small $\delta^{13}_{LL,RR,LR}$ mass insertions: enhance $\frac{\mathcal{B}(B_d \to l^+l^-)}{\mathcal{B}(B_s \to l^+l^-)}$

e.g.: δ^{13}_{LL} gluino contribution

$$\bar{d}_{i_R}\, \epsilon_{\tilde{g}_{ij}}\, H_u^* \cdot Q_{j_L} \not\propto Y_d$$

induces a down quark mass term which is not aligned with the down quark Yukawa coupling at $O(\alpha_s)$

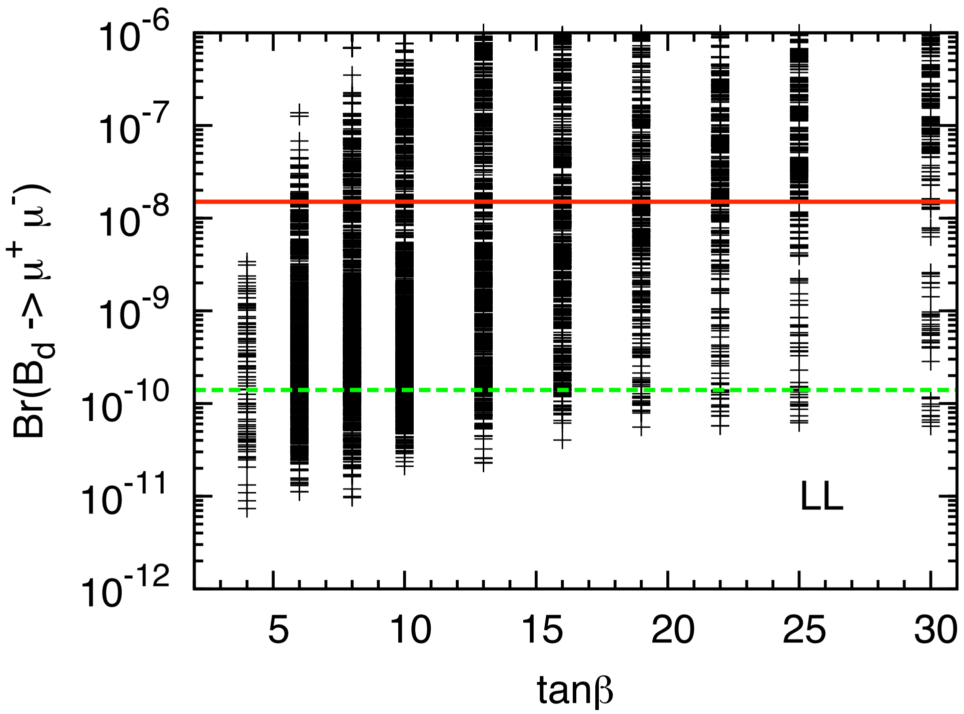
can strongly enhance: $\frac{\mathcal{B}(B_d \to l^+l^-)}{\mathcal{B}(B_s \to l^+l^-)}$

[Bobeth, et. al; Isidori et.al. '02]

If only $\delta^{13}_{LL} \neq 0$ the protection of ΔM still holds.

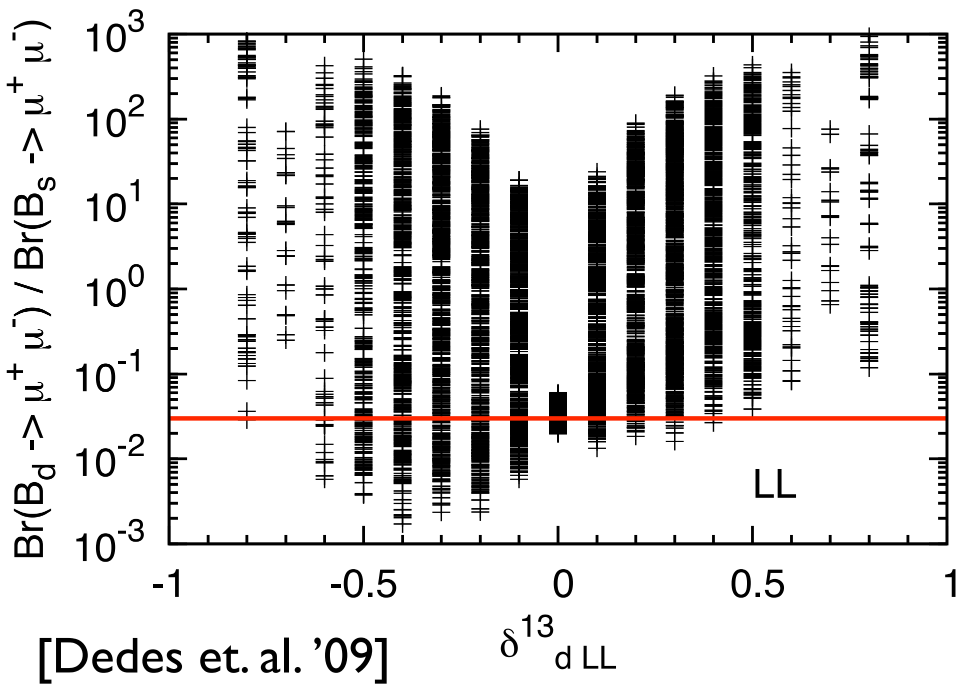
MSSM: Beyond MFV

Small $\delta^{13}_{LL,RR,LR}$ mass insertions: enhance $\dfrac{\mathcal{B}(B_d \to l^+l^-)}{\mathcal{B}(B_s \to l^+l^-)}$



beyond MFV including SU(2)xU(1) breaking effects in the large $\tan\beta$ limit

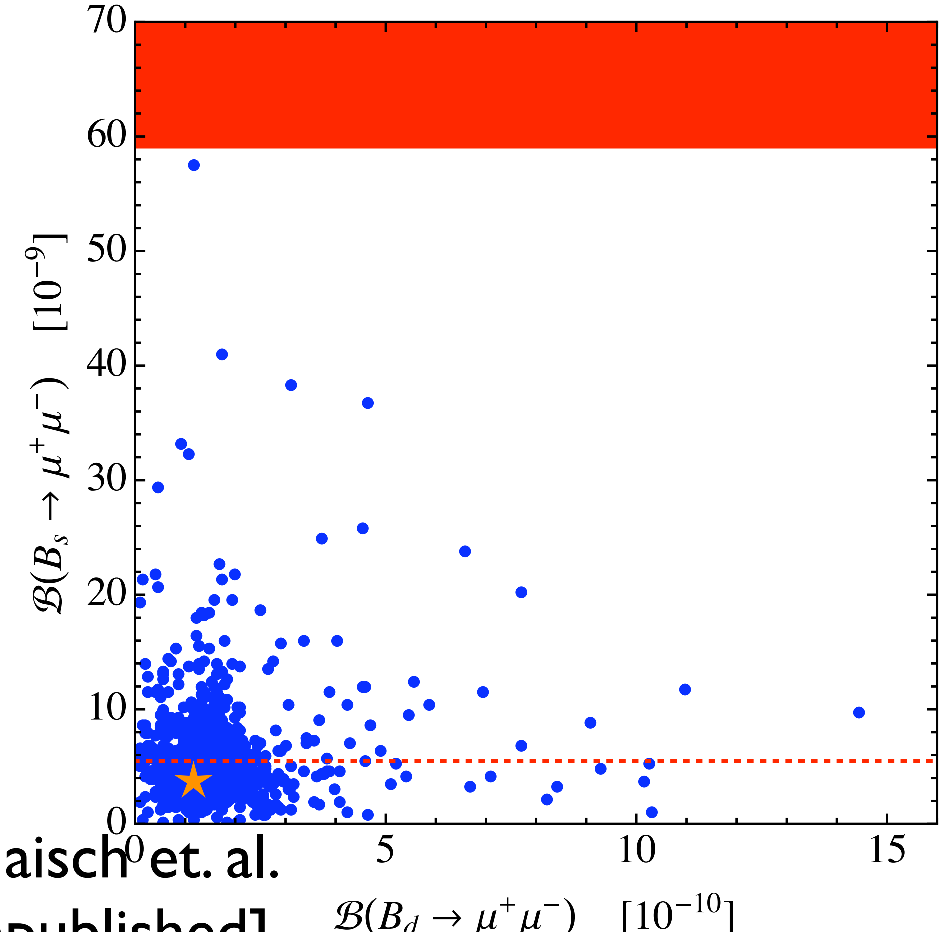
[Buras et. al. '03; Foster et. al. '03]



[Dedes et. al. '09]

Scan + complete small $\tan\beta$ corrections [Dedes et. al. '09]

Warped Extra Dimensions

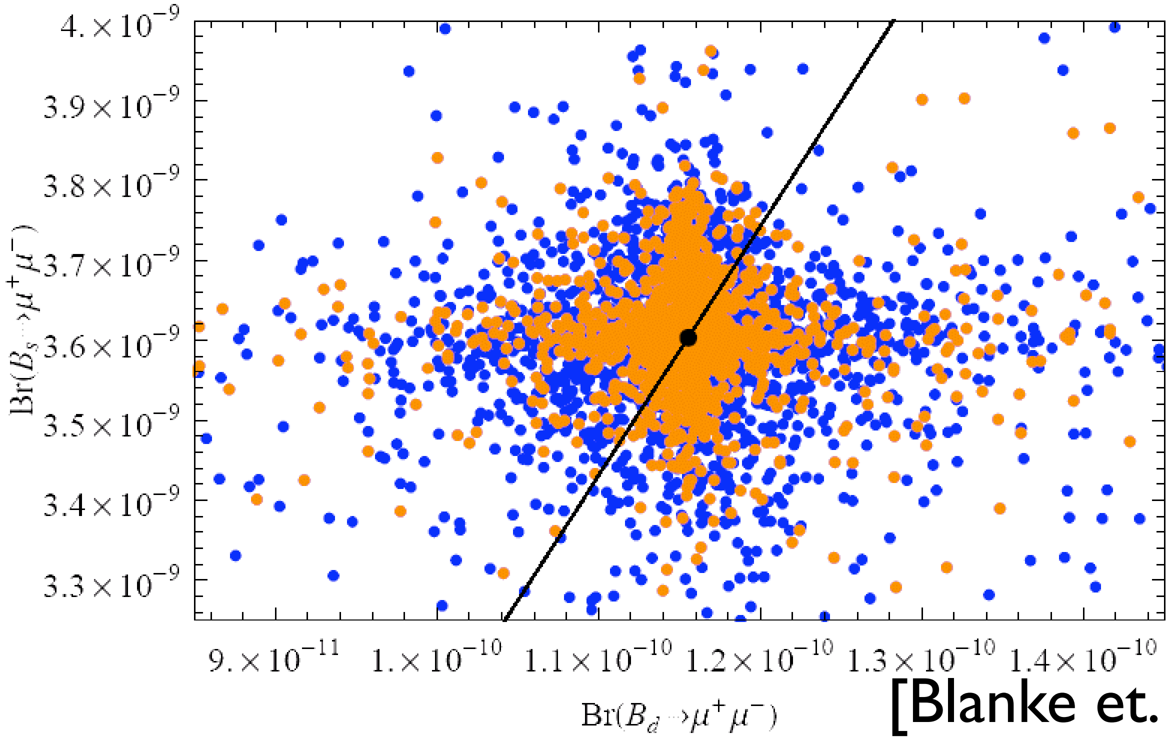


[Haisch et. al. unpublished]

Flavour violation in tree-level vector and KK modes

Strong constraints from EW precsion data ($Z \to b\bar{b}$)

There are points which are OK with EW plus large $B_d \to \mu^+\mu^-$



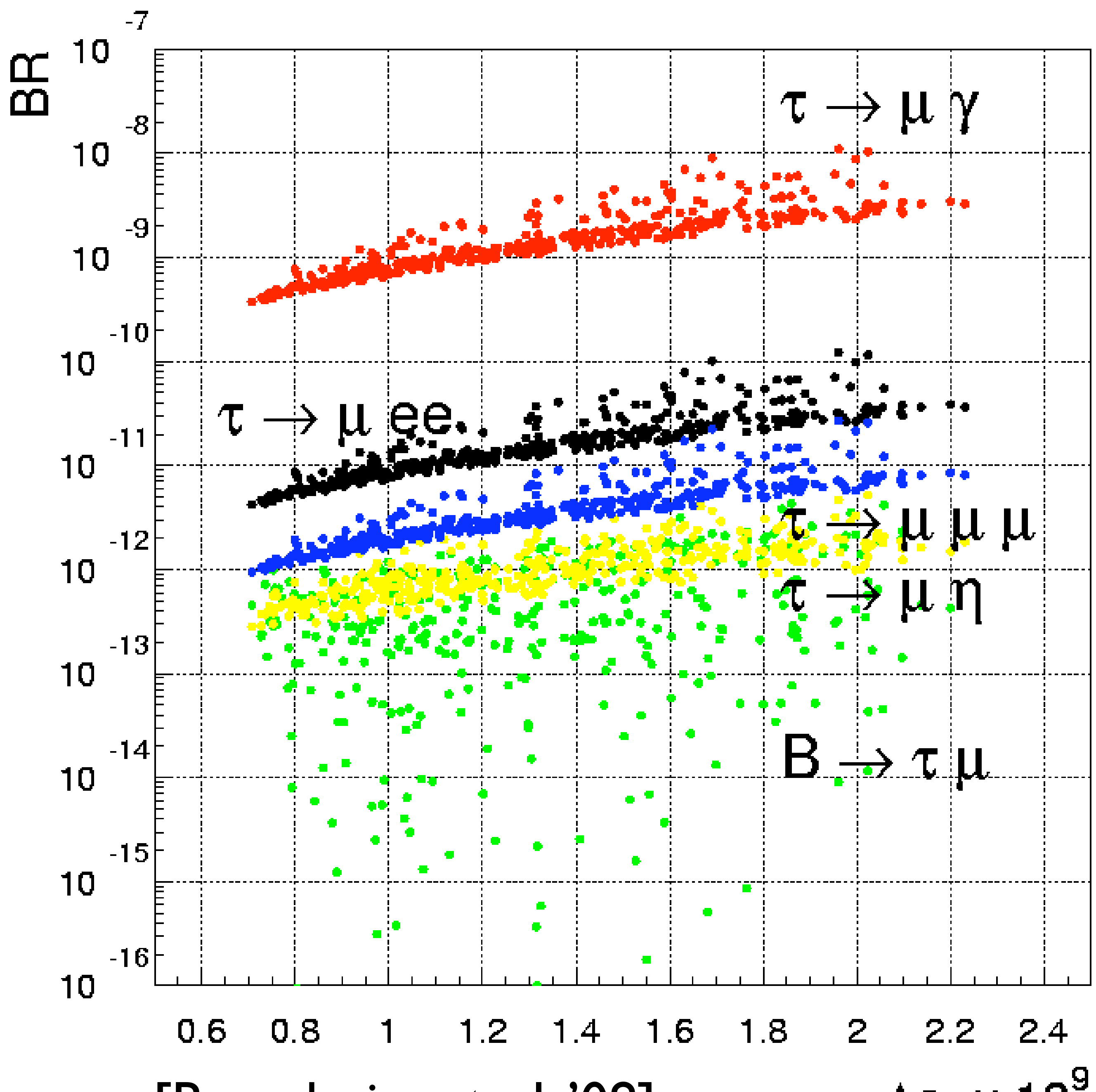
[Blanke et. al. '09]

Warped extra dimensions plus custodial protection:

no large effects in: $B_d \to \mu^+\mu^-$

Lepton Flavour Violation

From experimental side: $\mathcal{B}(B_d \to \tau^+\mu^-)$ is better than $\mathcal{B}(B_d \to \tau^+\tau^-)$ but harder than $\mathcal{B}(B_d \to \mu^+\mu^-)$



[Barenboim et. al. '08]

In SUSY seesaw scenarios $\mathcal{B}(B_d \to \tau^+\mu^-)$ does not exceed $\mathcal{B}(B_d \to \mu^+\mu^-)$
[Dedes, et. al. '02; Barenboim et. al. '08]

Possible large effects in R-parity violation or with lepto-quarks

Conclusions

SuperB close to Standard Model for: $\mathcal{B}(B_d \to \mu^+\mu^-)$

Large effects in Higgs FCNCs: MSSM + large $\tan\beta$

- MFV: $\mathcal{B}(B_d \to \mu^+\mu^-)$ and $\mathcal{B}(B_s \to \mu^+\mu^-)$
  $\to \mathcal{B}(B_s \to \mu^+\mu^-)$ will be seen by LHC
- beyond MFV: $\mathcal{B}(B_d \to \mu^+\mu^-)$ is important
  to disentangle MSSM parameter space

$\mathcal{B}(B_d \to \tau^+\mu^-)$: Interesting, but hard to construct models
where $\mathcal{B}(B_d \to \tau^+\mu^-)$ exceeds $\mathcal{B}(B_d \to \mu^+\mu^-)$