Rare decays in MFV models: an effective field theory approach

Ringberg, 1 May 2003

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- Introduction [The Flavour Problem]
- Minimal Flavour Violation [an Effective Field Theory approach]
- Present (and future) constraints on MFV models [role of rare decays]
- MFV with two (light) Higgs doublets [tanβ corrections to FCNCs]
- Conclusions

Introduction

Why are we interested in rare decays?

The SM is likely to be an effective theory valid up to a cut–off scale Λ:

$$\mathcal{L} = \mathcal{L}_{\text{gauge}}(A_i, \psi_i) + \mathcal{L}_{\text{Higgs}}(\phi, \psi_i, v) + \sum_i \frac{c_i}{\Lambda^2} O_i^{(6)} + \ldots$$

?

Only 3 couplings
- simple
- tested with high precision

More than 15 coupl.
- complicated
- not very well known yet

2 +...	Higgs Potential
3 +...	Lepton's Yukawa coupl.
10	Quark's Yukawa coupl.

[FLAVOUR PHYSICS]

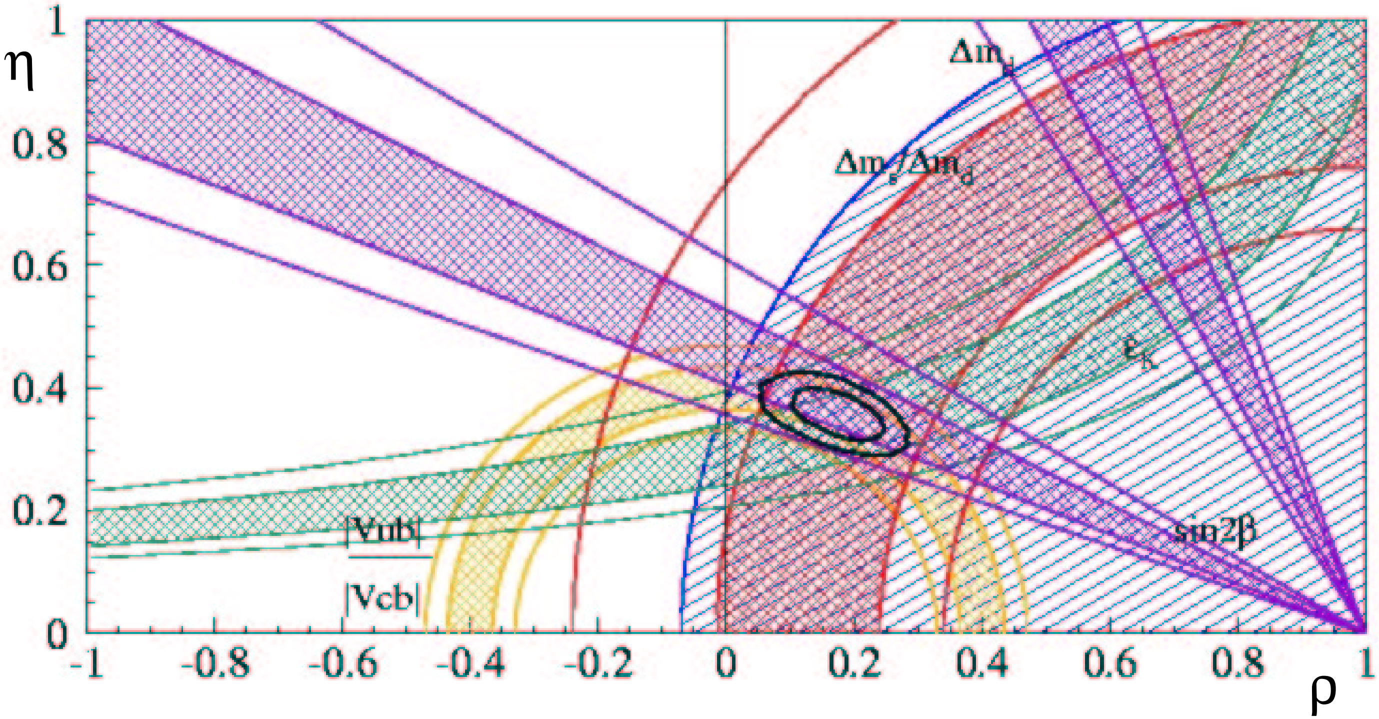
Quark–flavour mixing is a key ingredient to understand the symmetry–breaking sector of the SM and, possibly, to provide an indirect indication about the value of Λ

➡ Most interesting expectations from:

- CP violation
- rare FCNC decays

The Flavour Problem

Available data on ΔF=2 FCNC amplitudes (meson−antimeson mixing) already provides serious constraints on the scale of New Physics...



e.g.:

$K^0-\bar{K}^0$ mixing

$\Downarrow$

$\Lambda \gtrsim 100$ TeV

for $O^{(6)} \sim (\bar{s}d)^2$

much more severe than bounds on the scale of flavour−cons. operators from e.w. precision data

...while a natural stabilization of the Higgs potential $\Rightarrow$ $\Lambda \sim 1$ TeV

After the recent precise data from *B* factories, it is more difficult [although not impossible...] to believe that this is an accident

Two possible solutions:

- *pessimistic* [very unnatural]: $\Lambda > 100$ TeV
  $\Longrightarrow$ almost nothing to learn from other FCNC processes

- *natural*: $\Lambda \sim 1$ TeV + flavour–mixing protected by additional symmetries
  $\Longrightarrow$ still a lot to learn from FCNCs [especially from $\Delta F=1$ processes]

Minimal Flavour Violation (MFV) hypothesis:

The breaking of the flavour symmetry occurs at very high scales and is mediated at low energies only by terms proportional to SM Yukawa coupl.

- natural implementation in many consistent scenarios [SUSY, technicolour, extra dimensions,...] [wide literature]

- possible to build a predictive low−energy EFT including only SM fields $\Longrightarrow$ model−independent approach [D'Ambrosio, Giudice, G.I., Strumia, '02]

Minimal Flavour Violation

The maximal group of unitary field transf. allowed by $\mathcal{L}^{\mathrm{SM}}_{\mathrm{gauge}}$ is:

$$G_F = U(3)^5 = \underbrace{SU(3)^2_l \times SU(3)^3_q \times U(1)_{PQ} \times U(1)_{E_R}}_{\text{subgroup broken by } \mathcal{L}^{\mathrm{SM}}_{\mathrm{Yukawa}}} \times U(1)_B \times U(1)_L \times U(1)_Y$$

$$SU(3)^2_l = SU(3)_{L_L} \times SU(3)_{E_R}$$

$$\boxed{SU(3)^3_q = SU(3)_{Q_L} \times SU(3)_{U_R} \times SU(3)_{D_R}}$$

subgroup responsible for quark mixing
[Yukawa structure, CKM matrix]

$U(1)_{PQ}$: glob. phase of D_R & E_R

$U(1)_{E_R}$: glob. phase of E_R

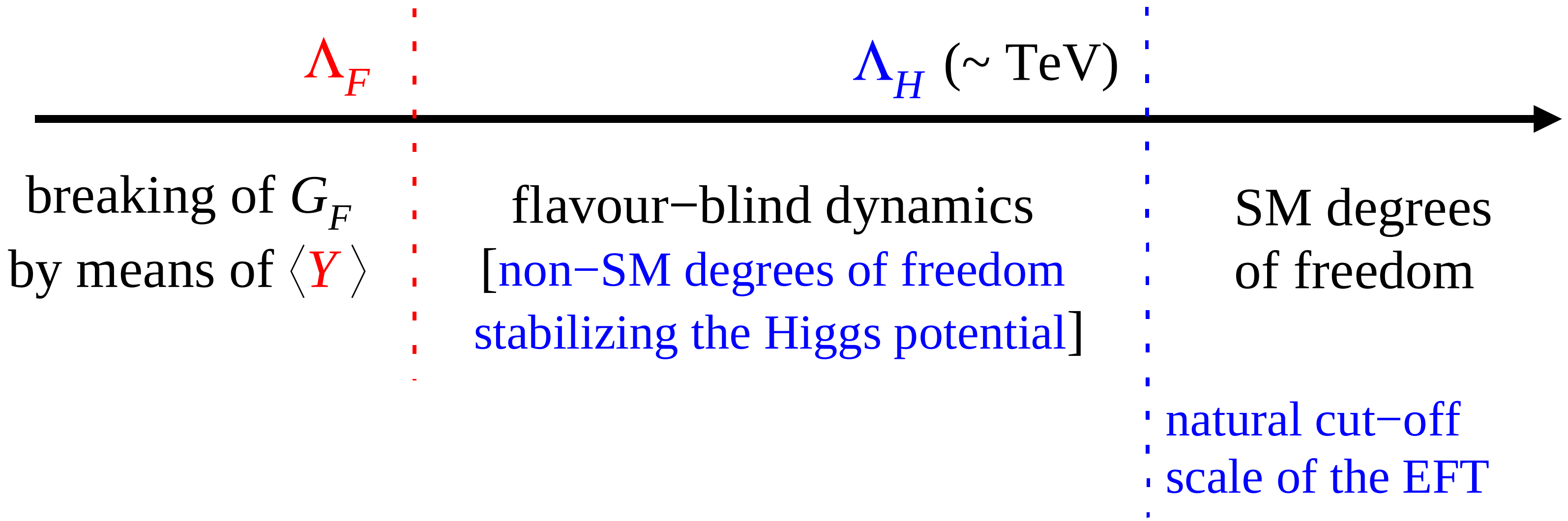
groups relevant in multi−Higgs models [overall Yukawa norm.]

$$\mathcal{L}_{\mathrm{Yukawa}} = \bar{Q}_L Y_D D_R H + \bar{Q}_L Y_U U_R (H)_c + \bar{L}_L Y_L E_R H + \text{h.c.}$$

Since G_F is already broken within the SM, it is not consistent to impose it as an exact symmetry beyond the SM.

However, we can (formally) promote G_F to be an exact symmetry, assuming the Yukawa matrices are the vacuum expectation values of appropriate auxiliary fields:

$$\text{e.g.:}\quad Y_D \sim (3,\bar{3},1) \quad \& \quad Y_U \sim (3,1,\bar{3}) \quad \text{under} \quad SU(3)_{Q_L} \times SU(3)_{U_R} \times SU(3)_{D_R}$$



A low−energy EFT (including only SM fields) satisfies the criterion of MFV if all higher−dimensional operators, constructed from SM and Y fields, are (formally) invariant under G_F

Chivukula & Georgi, ’89
DGIS, ’02

$$Y_D = \mathrm{diag}(y_d, y_s, y_b) \qquad Y_U = V^{+} \times \mathrm{diag}(y_u, y_c, y_t)$$

→ the CKM matrix is the only source of quark mix.

$$(\lambda_{FC})_{ij} = (Y_U Y_U^{+})_{ij} \approx y_t^2 V_{3i}^{*} V_{3j}$$

λ_{FC} is the effective coupl. ruling all FCNCs with external d quarks
(as within the SM for s.d. dominated amplitudes)

- all FCNC amplitudes have the same CKM structure as in the SM
[e.g.: $A(b \to s\gamma) \propto V_{bt} V_{ts}$, $A(s \to d\gamma) \propto V_{st} V_{td}$, ...]

- only the flavour–independent magnitude of FCNC amplitudes can be modified by (non–standard) dimension–six operators

- "*phase measurement*" [e.g.: $a(B \to \psi K_S)$, $\Delta M_{B_d} / \Delta M_{B_s}$] are completely unaffected by (non–standard) dimension–six operators

Construction of the EFT assuming only one light Higgs doublet:

In principle we should consider operators with arbitrary powers of the (adimensional) *Y* fields

Strong simplification with an expansion in off−diagonal CKM elements and small quark masses:

$$\Rightarrow \quad [\, (Y_U\, Y_U^{+})^n\,]_{ij} \approx (\lambda_{FC})_{ij} \approx y_t^2\, V_{3i} V_{3j}$$

Only two basic building blocks [for FCNCs with external down−type quarks]:

$$\boxed{\bar{Q}_L\, \lambda_{FC}\, Q_L \qquad\qquad \bar{D}_R\, \lambda_d\, \lambda_{FC}\, Q_L}$$

$$\Downarrow$$

- 4 $\Delta F=2$ operators [only 1 independ. combination]
- 17 $\Delta F=1$ operators [8 + 5 independ. combinations]

$\hookrightarrow$ $(q_i \to q_j + \gamma,\ l^+ l^-, \nu\nu)$

6 main free param.
[not much more than in flavour−conserving e.w. precision tets]

The operator basis:

- $\Delta F = 1$ Higgs field :

$$\mathcal{O}_{H1} = i\,(\bar{Q}_L \lambda_{\rm FC} \gamma_\mu Q_L)\, H^\dagger D_\mu H\,, \qquad \mathcal{O}_{H2} = i\,(\bar{Q}_L \lambda_{\rm FC} \tau^a \gamma_\mu Q_L)\, H^\dagger \tau^a D_\mu H\,.$$

- $\Delta F = 1$ gauge fields :

$$\mathcal{O}_{G1} = H^\dagger\,(\bar{D}_R \lambda_d \lambda_{\rm FC} \sigma_{\mu\nu} T^a Q_L)\, G^a_{\mu\nu}\,, \qquad \mathcal{O}_{G2} = (\bar{Q}_L \lambda_{\rm FC} \gamma_\mu T^a Q_L)\, D_\mu G^a_{\mu\nu}\,.$$

$$\mathcal{O}_{F1} = H^\dagger\,(\bar{D}_R \lambda_d \lambda_{\rm FC} \sigma_{\mu\nu} Q_L)\, F_{\mu\nu}\,, \qquad \mathcal{O}_{F2} = (\bar{Q}_L \lambda_{\rm FC} \gamma_\mu Q_L)\, D_\mu F_{\mu\nu}\,.$$

- $\Delta F = 1$ four-fermion operators:

$$\mathcal{O}_{\ell 1} = (\bar{Q}_L \lambda_{\rm FC} \gamma_\mu Q_L)\,(\bar{L}_L \gamma_\mu L_L)\,, \qquad \mathcal{O}_{\ell 2} = (\bar{Q}_L \lambda_{\rm FC} \gamma_\mu \tau^a Q_L)\,(\bar{L}_L \gamma_\mu \tau^a L_L)\,,$$
$$\mathcal{O}_{\ell 3} = (\bar{Q}_L \lambda_{\rm FC} \gamma_\mu Q_L)\,(\bar{E}_R \gamma_\mu E_R)\,.$$

$$\mathcal{O}_{q1} = (\bar{Q}_L \lambda_{\rm FC} \gamma_\mu Q_L)\,(\bar{Q}_L \gamma_\mu Q_L)\,, \qquad \mathcal{O}_{q2} = (\bar{Q}_L \lambda_{\rm FC} \gamma_\mu \tau^a Q_L)\,(\bar{Q}_L \gamma_\mu \tau^a Q_L)\,,$$
$$\mathcal{O}_{q3} = (\bar{Q}_L \lambda_{\rm FC} \gamma_\mu T^a Q_L)\,(\bar{Q}_L \gamma_\mu T^a Q_L)\,, \qquad \mathcal{O}_{q4} = \left(\bar{Q}_L \lambda_{\rm FC} \gamma_\mu T^a \tau^b Q_L\right)\,(\bar{Q}_L \gamma_\mu T^a \tau^b Q_L)\,,$$
$$\mathcal{O}_{q5} = (\bar{Q}_L \lambda_{\rm FC} \gamma_\mu Q_L)\,(\bar{D}_R \gamma_\mu D_R)\,, \qquad \mathcal{O}_{q6} = (\bar{Q}_L \lambda_{\rm FC} \gamma_\mu T^a Q_L)\,(\bar{D}_R \gamma_\mu T^a D_R)\,,$$
$$\mathcal{O}_{q7} = (\bar{Q}_L \lambda_{\rm FC} \gamma_\mu Q_L)\,(\bar{U}_R \gamma_\mu U_R)\,, \qquad \mathcal{O}_{q8} = (\bar{Q}_L \lambda_{\rm FC} \gamma_\mu T^a Q_L)\,(\bar{U}_R \gamma_\mu T^a U_R)\,.$$

$$\mathscr{L}_{eff} = \Sigma_i \frac{1}{\Lambda^2} O_i^{(6)}$$

integration of
the heavy
SM fields

$\downarrow$

standard $\cancel{SU(2)}_L$

H_{eff} (ΔF=2, ΔF=1)

with modified $C_i(M_w)$

$\Rightarrow$ all the $C_i(M_w)$ receive independent contributions of order $(\Lambda_0/\Lambda)^2$

$\Lambda_0 = 4\pi g^{-1} M_w \approx 2.4$ TeV = natural scale probed by $O(1)$ constraints
on s.d. dominated FCNCs within MFV models

Possible extensions/generalizations of this approach:

I) Inclusion of extra Higgs doublets $\Leftrightarrow$ breaking of the U(1)'s

The breaking of the SU(3) groups is not necessarily related to the breaking of the U(1)'s

With two Higgs doublets we can assume the Yukawa interaction is invariant under $U(1)_{PQ}$

$$\mathscr{L}_{\text{Yukawa}} = \bar{Q}_L Y_D D_R H_D + \bar{Q}_L Y_U U_R H_U + L_L Y_L E_R H_D + \text{h.c.}$$

$\Rightarrow$ the CKM matrix remains the only source of quark mixing, but we are free to modify the overall normalization of the Y

[$(Y_D Y_D^+)_{ij} \approx y_b^2 \delta_{3i}\delta_{3j}$ new non−negligible source of $\cancel{G_F}$]

II) Inclusion of SUSY degrees of freedoms $\Rightarrow$ EFT valid to higher scales

⋮

Comparison with other definitions/approaches to MFV:

I) *Pragmatic SM–like definition:* No other FCNC operators beyond the SM ones; New Physics modifies only the C_i and not the CKM factors. [Buras et al. '00−'02]

- Not based on a symmetry principle ⇒ not justified in a model−independent way; not clear how to extend this definition to cases with additional degrees of freedom (2HDM, SUSY, etc...)
- Equivalent, in practice, to our approach – under the additional assumption of a single light Higgs doublet.

II) V*arious low–scale mass–matrix assumptions within the MSSM:*

$(M^2)_{LL} \propto I$ [universality]

- compatible with the MFV hypothesis (sufficient condition)
- not RGE invariant

$(M^2)_{LL} \propto \mathrm{diag}[a,b,c]$ in the super−CKM basis [Bobeth et al. '02]

- not compatible with the MFV hypothesis (new source of G_F breaking)
- not RGE invariant

⇒ Our general MFV prescription: $(M^2)_{LL} \propto \sum a_n (Y_U Y_U^+)^n \sim a_0 I + a_1 Y_U Y_U^+$

Present (and future) constraints on MFV models

DGIS, '02

Minimally flavour violating dimension six operator	main observables	Λ [TeV] $-$	Λ [TeV] $+$	
$\mathcal{O}_0 = \frac{1}{2}(\bar{Q}_L \lambda_{\mathrm{FC}} \gamma_\mu Q_L)^2$	ϵ_K, Δm_{B_d}	6.4	5.0	•
$\mathcal{O}_{F1} = e H^\dagger (\bar{D}_R \lambda_d \lambda_{\mathrm{FC}} \sigma_{\mu\nu} Q_L) F_{\mu\nu}$	$B \to X_s \gamma$	4.6	7.3	•
$\mathcal{O}_{G1} = g H^\dagger (\bar{D}_R \lambda_d \lambda_{\mathrm{FC}} \sigma_{\mu\nu} T^a Q_L) G^a_{\mu\nu}$	$B \to X_s \gamma$	2.3	3.8	•
$\mathcal{O}_{\ell 1} = (\bar{Q}_L \lambda_{\mathrm{FC}} \gamma_\mu Q_L)(\bar{L}_L \gamma_\mu L_L)$	$B \to (X)\ell\bar{\ell}$, $K \to \pi\nu\bar{\nu}, (\pi)\ell\bar{\ell}$	3.1	2.7	*
$\mathcal{O}_{\ell 2} = (\bar{Q}_L \lambda_{\mathrm{FC}} \gamma_\mu \tau^a Q_L)(\bar{L}_L \gamma_\mu \tau^a L_L)$	$B \to (X)\ell\bar{\ell}$, $K \to \pi\nu\bar{\nu}, (\pi)\ell\bar{\ell}$	3.4	3.0	*
$\mathcal{O}_{H1} = (\bar{Q}_L \lambda_{\mathrm{FC}} \gamma_\mu Q_L)(H^\dagger i D_\mu H)$	$B \to (X)\ell\bar{\ell}$, $K \to \pi\nu\bar{\nu}, (\pi)\ell\bar{\ell}$	1.6	1.6	*
$\mathcal{O}_{q5} = (\bar{Q}_L \lambda_{\mathrm{FC}} \gamma_\mu Q_L)(\bar{D}_R \gamma_\mu D_R)$	$B \to K\pi$, $\epsilon'/\epsilon, \ldots$	~ 1		•

• = dominated by th. errors [difficult to expect substantial impr. in the near future]

* = dominated by exp. errors [substantial impr. expected the near future]

The bounds are typically weaker (or at most as stringent as) those obtained from flavour −conserving e.w. dynamics [~ 5−10 TeV]

$\Rightarrow$ we are just entering the interesting region...

Predictions derived within the MFV approach [with 1 light Higgs]:

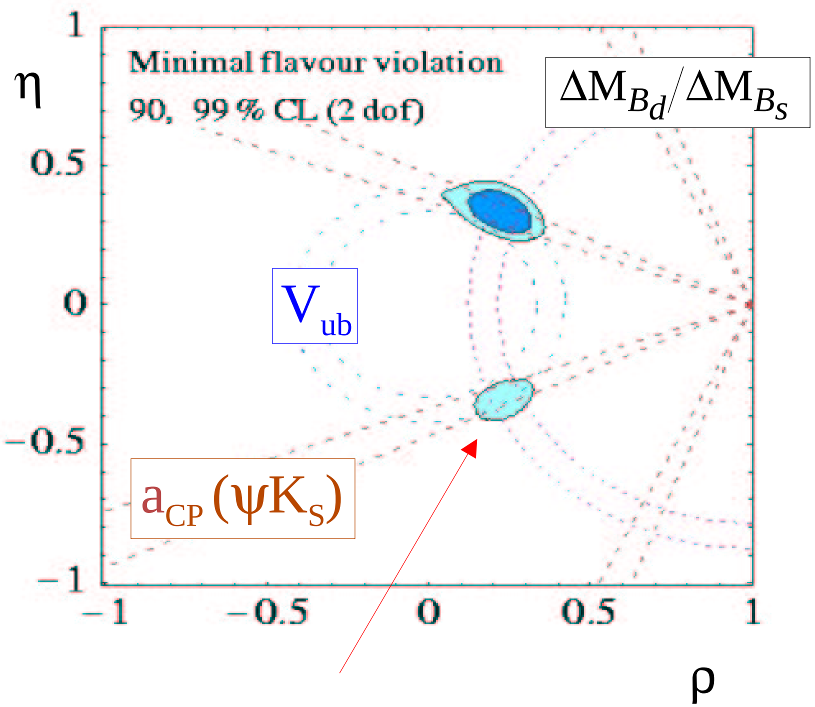
Observable	99(90)% MFV limit	determined by	90% Exp. limit [?]
$\mathcal{B}(B \to X_d \gamma)$	$2(2) \times 10^{-5}$	$\mathcal{B}(B \to X_s \gamma)$	–
$\mathcal{B}(B \to X_s \nu\bar{\nu})$	$8(6) \times 10^{-4}$		6.4×10^{-4}
$\mathcal{B}(B \to X_d \nu\bar{\nu})$	$3(2) \times 10^{-5}$	$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$	–
$\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu})$	$5(4) \times 10^{-10}$		5.9×10^{-7}
$\mathcal{B}(B_s \to \tau^+\tau^-)$	$4(3) \times 10^{-6}$		–
$\mathcal{B}(B_d \to \tau^+\tau^-)$	$1(1) \times 10^{-7}$	$\mathcal{B}(B \to X_s \bar{\ell}\ell)$	–
$\mathcal{B}(B_s \to \mu^+\mu^-)$	$2(1) \times 10^{-8}$	$[\mathcal{B}(K_L \to \mu^+\mu^-)_{\text{short}}]$	2.0×10^{-6}
$\mathcal{B}(B_d \to \mu^+\mu^-)$	$6(5) \times 10^{-10}$		6.1×10^{-7}
$\mathcal{B}(K_L \to \pi^0 e^+ e^-)_{\text{CP-dir}}$	$2(2) \times 10^{-11}$		5.6×10^{-10}

[link between $b \to s$, $b \to d$, $s \to d$]

ΔF=2 and the Unitarity Triangle

The UT can still be determined with high accuracy within MFV models

Ali, London; Buras, Gambino, Gorbahn, Jager, Silvestrini; Fleischer; Laplace, Ligeti, Nir, Perez; Parodi, Stocchi, Bartel et al. ’00−’02

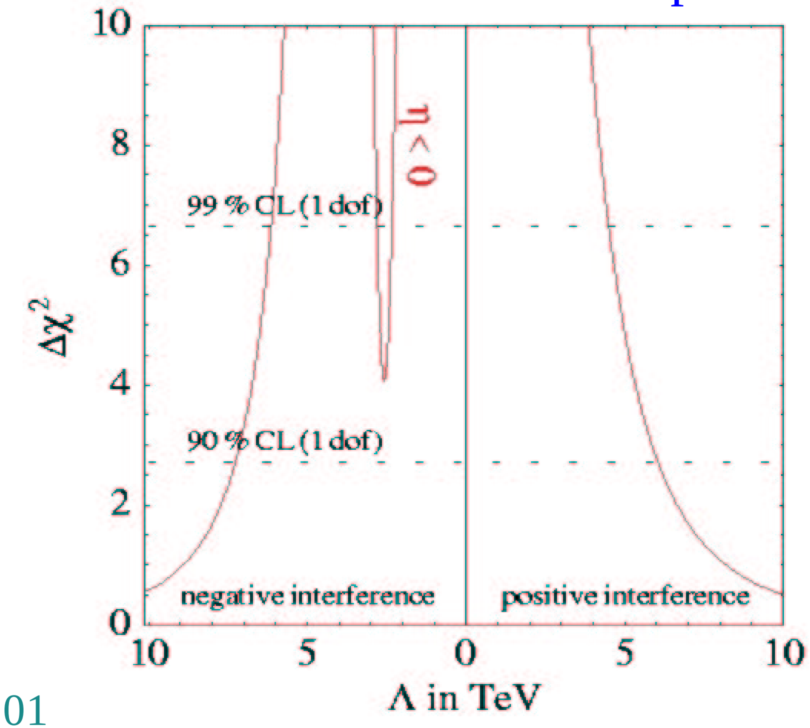


fine−tuned solution arising from a sign change of the s.d. ΔF=2 amplitude

Buras, Fleischer, ’01

unlikely because of light−quark (charm) contributions to ε_K

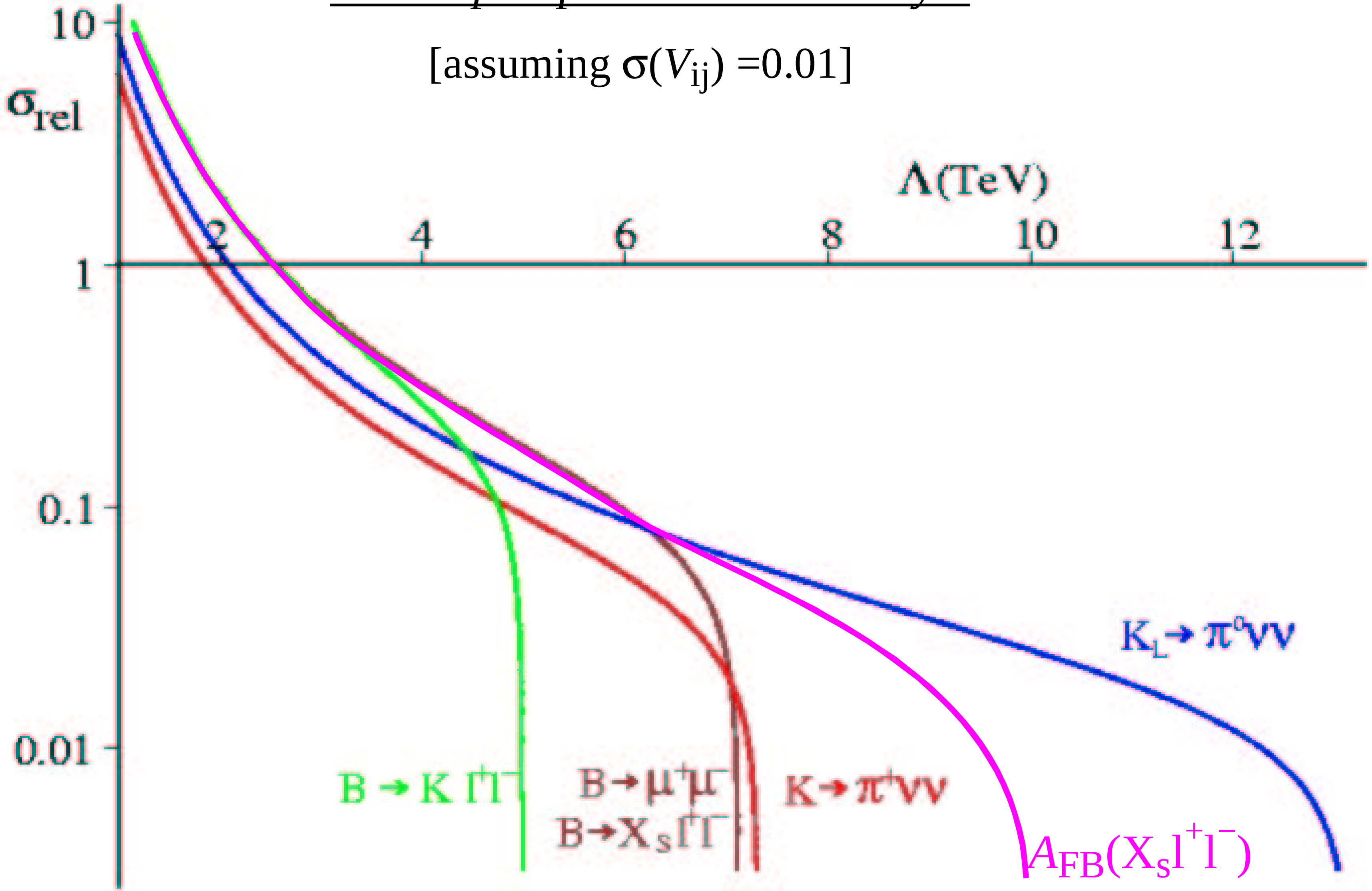
$\Rightarrow$ ε_K & ΔM_{B_d} provides a stringent constraint on the new ΔF=2 operator:



sensitivity to new physics determined by δB_K

Future prospects on rare decays:

[assuming $\sigma(V_{ij}) = 0.01$]



$\Rightarrow$ worth to plan $K_L \to \pi^0 \nu\nu$ dedicated experiments (even in the long term)

MFV with two (light) Higgs doublets

$$\mathscr{L}_{\mathrm{Yukawa}} = \bar{Q}_L Y_D D_R H_D + \bar{Q}_L Y_U U_R H_U + L_L Y_L E_R H_D + \text{h.c.}$$

invariant under $U(1)_{PQ}$

smallness of m_b/m_t naturally attributed to $\tan\beta = \langle H_U\rangle/\langle H_D\rangle \gg 1$

[$(Y_D Y_D^+)_{ij} \approx y_b^2\, \delta_{3i}\delta_{3j}$ new non−negligible source of $\cancel{G}_F$]

breaking of the relation between $b \to s$ & $b \to d$

[contributions from both $(Y_U Y_U^+)$ & $(Y_D Y_D^+)(Y_U Y_U^+)$]

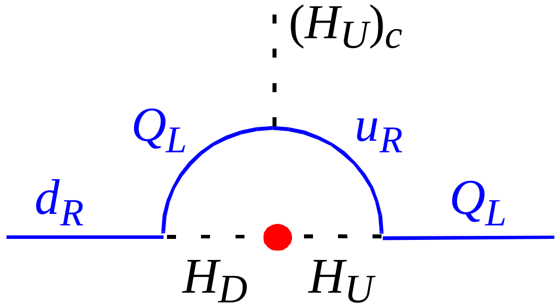
and $s \to d$

[contributions from $(Y_U Y_U^+)$ only]

E.g.: the two solutions of the ρ–η fit become equally probable

Interesting aspects of large $\tan\beta$ corrections to FCNCs related to $\cancel{U(1)}_{PQ}$:

The $U(1)_{PQ}$ symmetry cannot be exact [$\Rightarrow m_A=0$] and it must be broken at least in the Higgs potential [e.g.: $\mu\Phi_U\Phi_D \subset W^{MSSM}$]



$\Rightarrow$ we need to consider also Yukawa–type $U(1)_{PQ}$–breaking terms:

$$\epsilon_i\ \bar{Q}_L(Y_D Y_D^+)^n(Y_U Y_U^+)^m(Y_D Y_D^+)^k Y_D D_R\ (H_U)_c$$

$$\epsilon_j\ \bar{Q}_L(Y_D Y_D^+)^l(Y_U Y_U^+)^p(Y_D Y_D^+)^q Y_U U_R\ (H_D)_c \qquad [\epsilon_i^{MSSM} \sim (16\pi^2)^{-1}]$$

If $\epsilon_{PQ}\tan\beta \sim 1$ these new terms induce O(1) (non−decoupling) corrections to the ordinary ($U(1)_{PQ}$–conserving) Yukawa interaction

[Hall, Rattazzi, Sarid, ’94]

$\Rightarrow$ we need to perform a complete re−diagonalization of all the effective dim−4 Yukawa terms in order to resum the large $\epsilon_{PQ}\tan\beta$ corrections beyond the ordinary perturbative expansion

Assuming the standard hierarchical structure of $Y_{U,D}$ $\Rightarrow$ usual expansion of $(Y_Q Y_Q^+)$
$\Rightarrow$ 8 independent dim−4 $U(1)_{PQ}$−breaking terms $\Rightarrow$ all the interesting effects driven by four terms [all appearing @ 1 loop in the MSSM]:

$$\epsilon_\chi\ \bar{Q}_L Y_U Y_U^+ Y_D D_R (H_U)_c \qquad \epsilon_g\ \bar{Q}_L Y_D D_R (H_U)_c$$

$$\epsilon_\chi'\ \bar{Q}_L Y_D Y_D^+ Y_U U_R (H_D)_c \qquad \epsilon_g'\ \bar{Q}_L Y_U U_R (H_D)_c$$

MSSM literature:

- modification of $M_d = \mathscr{F}(Y_D)$ — [Hall, Rattazzi, Sarid, '94]
- modification of $V_{CKM} = \mathscr{F}(Y_U, Y_D)$ — [Blazek, Rabi, Pokorski, '95]
- appearance of a FCNC $H^0 d_j d_k$ coupling — [Hamazaoui et al. '99, Babu & Kolda, '00]
- modification of the $H^+ u_j d_k$ vertex — [Degrassi et al., Carena et al. '00]

$\Rightarrow$ all four effects play a significant role in rare helicity−suppressed B decays $\Leftarrow$

E.g.: diagonalization of down−type quark masses:

$$\mathscr{L}^{eff}_{down} = \bar{d}_R Y_D [H_D^0 + (\epsilon_g + \epsilon_\chi Y_U^+ Y_U) H_U^{0*}] d_L \; + \; h.c.$$

$$\Downarrow$$

$$\bar{d}^i_R y^i_d [(1+\epsilon_g \tan\beta)\delta_{ij} \; + \; (\epsilon_\chi \tan\beta) y_t^2 V^{0*}_{i3} V^0_{3j}] d^j_L$$

$$\Downarrow$$

$$\mathscr{L}^{eff}_{down} = m_{d_i} \bar{d}^i_R d^i_L + \frac{m_{d_i}}{v} \bar{d}^i_R d^i_L h^0 - \frac{m_{d_i} \tan\beta}{v[1+\epsilon_g \tan\beta + \epsilon_\chi \tan\beta\, y_t^2 \delta_{3i}]} \bar{d}^i_R d^i_L [H^0 - i A^0]$$

$$+ \frac{m_{d_i} \tan\beta \times \epsilon_\chi \tan\beta}{v[1+\epsilon_g \tan\beta + \epsilon_\chi \tan\beta\, y_t^2 \delta_{3i}][1+\epsilon_g \tan\beta]} (y_t^2 V^*_{i3} V_{3j}) \bar{d}^i_R d^{j\neq i}_L [H^0 - i A^0]$$

Effective couplings resumming all the leading (non−decoupling) tanβ corrections

Application to rare decays:

A) $B \to \mu^+\mu^-$ helicity suppression of the standard (axial−vector) contribution
$\Rightarrow$ enhanced sensitivity to Higgs−mediated scalar FCNCs:

$$A_{scalar} \sim \frac{m_b m_\mu}{M_A^2}\, \epsilon \tan^3\beta$$

$$A_{SM} \sim \frac{m_t^2}{16\pi^2 M_W^2}\left(\frac{m_\mu}{m_b}\right)$$

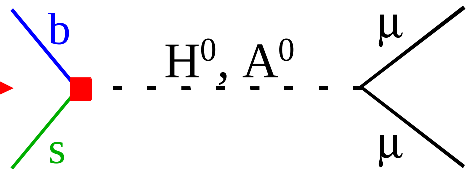
$$\Rightarrow \quad \frac{A_{scalar}}{A_{SM}} \sim 16\pi^2 (\epsilon \tan\beta) \frac{M_W^2}{M_A^2} \frac{m_b^2 \tan^2\beta}{m_t^2}$$

possible huge effetcs for $\tan\beta \sim m_t/m_b$!

Babu & Kolda, ’00
Chankowski et al. ’01
Huang et al. ’01
Bobeth et al. ’01
Dedes et al. ’01
G.I & Retico ’01
⋮

In the effective theory we need to compute only one diagram:

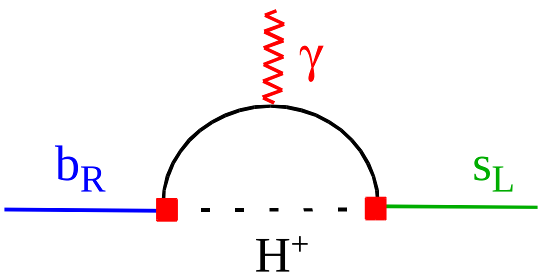
full dependence on the (leading) $\epsilon \tan\beta$ terms

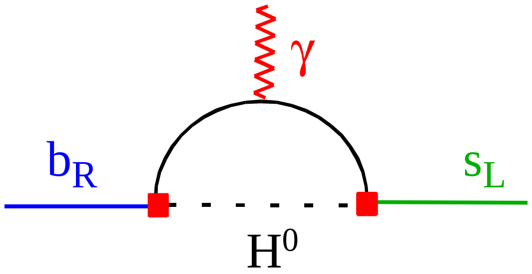


In ordinary pert. theory the calculation is more involved and the result can be wrong even by one order of magnitude for $\tan\beta \sim 50$

B) Neutral & charged Higgs exchange in $b \to s\gamma$

- Interesting example where all the effects plays a non−negligible role:





- Size of the corrections much smaller than in $B \to \mu^+\mu^-$, but relevant given the high exp. precision of $b \to s\gamma$

pure 1−loop:

$$C_{7\gamma}(\mu_W) = F_7^{(2)}(x_{tH})$$

$$x_{tH} = m_t^2 / M_H^2$$
$$t = \tan\beta$$

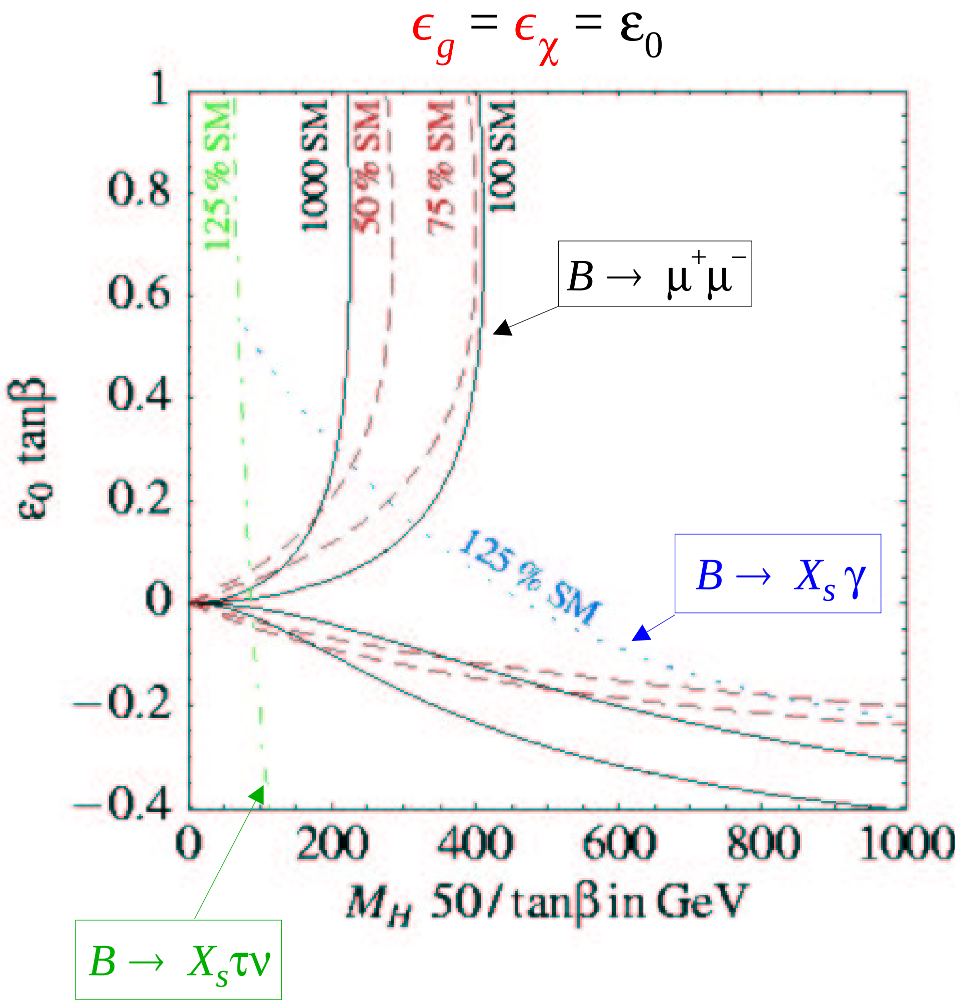
improved
1−loop result:

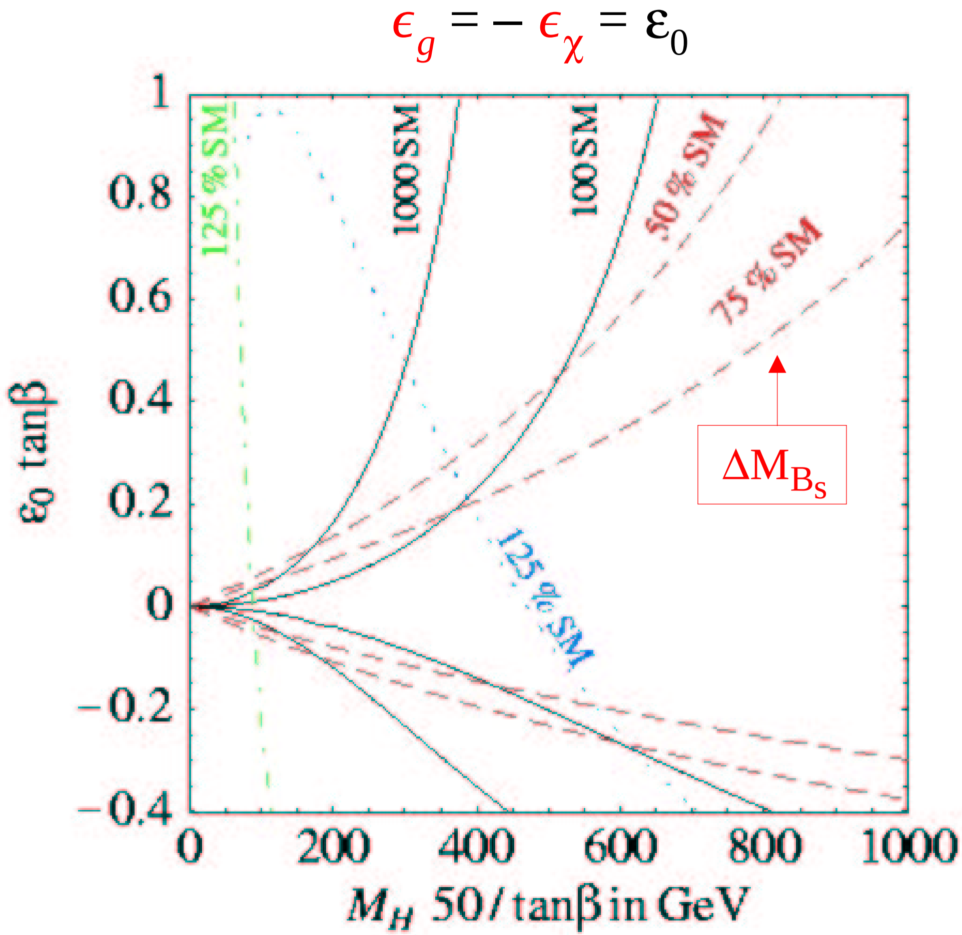
$$C_{7\gamma}(\mu_W) = \frac{1+\epsilon_g' t}{1+(\epsilon_g + y_t^2 \epsilon_\chi) t} F_7^{(2)}(x_{tH})$$
$$- \frac{m_b^2 \epsilon_\chi \epsilon_g' t^4}{m_t [1+(\epsilon_g + y_t^2 \epsilon_\chi) t]^3 [1+\epsilon_g t]} F_7^{(2)}(x_{tH})$$
$$- \frac{m_b^2 \epsilon_\chi t^3}{36 M_H^2 [1+(\epsilon_g + y_t^2 \epsilon_\chi) t]^2 [1+\epsilon_g t]}$$

terms not considered in previous analyses

[DGIS ’02, Buras et al. ’02]

Constraints on [MSSM−like] two−Higgs doublet models:





[DGIS ’02]

Conclusions

A top$\rightarrow$bottom approach to the Flavour Problem would in principle be preferable, but we still lack of a simple and clear theory to describe the breaking of G_F

The general MFV−EFT approach provides a bottom$\rightarrow$top alternative, particularly useful to analyse present & future precise data on FCNCs

$\Rightarrow$ there is still a lot to learn from transitions of the type

$b[s] \to s[d] + l^+ l^- (\nu\nu)$

$\Rightarrow$ it's important to measure clean observables such as $\Gamma(K \to \pi \nu\nu)$, $\Gamma(B \to l^+ l^-)$ and $A_{FB}(B \to X_s l^+ l^-)$ also in the LHC era