New physics benchmarks in flavour physics

Gino Isidori [*INFN-Frascati*]

- General considerations
- MFV
- MFV with 2 Higgs doublets & large tanβ
  - *recent developments in the MSSM case*
- Beyond MFV
- Conclusions

General considerations

- The effects of new physics in the [*low-energy*] flavour sector can be described in full generality by means of an *effective field theory* [EFT ⇒ *series of local operators written in terms of SM fields, suppressed by the EFT cut-off* Λ *according to their naïve dim..*]

$$\mathscr{L}_{\rm eff} = \mathscr{L}_{\rm gauge}(A_i, \psi_i) + \mathscr{L}_{\rm Higgs}(\phi_i, A_i, \psi_i) + \sum_{d\geq 5} \frac{c_n}{\Lambda^{d-4}} O_n^{\,d}(\phi_i, A_i, \psi_i)$$

- Key role played by the *symmetry breaking structure* of the *flavour group* in the EFT

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- Key role played by the *symmetry breaking structure* of the *flavour group* in the EFT
  - The EFT approach is sufficient to establish correlations among different low-energy flavour-physics observables
  - To analyse the correlations between low-energy observables & high-energy (TeV scale) observables requires an explicit beyond-SM framework [e.g. MSSM]

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► 3 identical fermion families ⇒ huge flavour-degeneracy:

$$U(3)^5 = SU(3)_l^2 \times SU(3)_q^3 \times U(1)^5$$

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

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

subgroup responsible for quark mixing

[CKM matrix, GIM mechanism, ...]

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$$U(3)^5 = SU(3)_l^2 \times SU(3)_q^3 \times U(1)_{PQ} \times U(1)_{e_R} \times U(1)_B \times U(1)_L \times U(1)_Y$$

► partial breaking of the flavour group:

$$\mathcal{L}_{\rm Yukawa} = \bar{Q}_L Y_D D_R \phi + \bar{Q}_L Y_U U_R \phi_c + \bar{L}_L Y_L e_R \phi + \text{h.c.}$$

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[CKM matrix, GIM mechanism, ...]

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

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

groups relevant
in multi-Higgs models
[overall Yukawa normalization]

$$\mathscr{L}_{\rm eff} = \mathscr{L}_{\rm gauge}(A_i, \psi_i) + \mathscr{L}_{\rm Higgs}(\phi_i, A_i, \psi_i; Y) + \sum_{d\geq 5} \frac{c_n}{\Lambda^{d-4}} O_n^{\,d}(\phi_i, A_i, \psi_i)$$

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$(3,1,\bar{3})$

convenient to treat the Y
[& any additional source of flavour sym.breaking]
as spurions of

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- MFV with 1 Higgs [or low tanβ] ⇒ no additional spurions
- MFV with multi Higgs ⇒ additional U(1) spurions
- NMFV ⇒ additional SU(3)-breaking spurions
- ⋮ ⇒ ⋮

▶ *Minimal Flavour Violation* [with 1 light Higgs or small tanβ]

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 the $SU(3)^5$ flavour group

D'Ambrosio,Giudice, G.I., Strumia '02

⬇

$(Y_U Y_U^{+})_{ij} \approx y_t^2 V_{3i} V_{3j}^*$ is the effective coupling ruling all FCNCs with external *d* quarks

⬇

- All FCNC amplitudes have the same CKM structure as in the SM
  [e.g.: $A(b\to s\gamma) \propto V_{bt}V_{ts}$, $A(s\to d\gamma) \propto V_{st}V_{td}$, ...] ⇒ Phase measurements
  [such as $a(B\to\psi K_S)$, $a(B\to\phi K_S)$, $\Delta M_{B_d}/\Delta M_{B_s}$] not sensitive to new physics
- Only the flavour–independent magnitude of FCNC amplitudes can be modified by non–standard effects: typical size 10-30% for electroweak s.d. amplitudes

"pragmatic" definition
[Buras et al. '00-'03]

▶ *Minimal Flavour Violation* [with 1 light Higgs or small tanβ]

The absence of positive signal of new physics in the flavour sector [including the recent ΔM_{B_s} result] ⇒ MFV most plausible scenario

But the MFV hypothesis is still far from being clearly established

A reliable proof of the MFV hypothesis can only come from a positive evidence, which exhibit the [$b \to s$] - [$b \to d$] - [$s \to d$] link predicted by the symmetry

→ Key role of a few clean electroweak FCNC processes

FLAVOUR COUPLING

ELECTROWEAK STRUCTURE

	$b \to s$ [$\sim \lambda^2$ in SM]	$b \to d$ [$\sim \lambda^3$ in SM]	$s \to d$ [$\sim \lambda^5$ in SM]
$\Delta F=2$ box	ΔM_{Bs} $A_{CP}(B_s \to \psi\phi)$, ε_{Bs}	ΔM_{Bd} $A_{CP}(B_d \to \psi K)$, ε_{Bd}	ε_K
$\Delta F=1$ 4-quark ops.	$A_{CP}(B_d \to \phi K)$	$A_{CP}(B_s \to \phi K)$	
gluon penguin	$A_{CP}(B_d \to \phi K)$ $[\Gamma, \Delta\Gamma_{CP}](B \to X_s \gamma)$	$[\Gamma, \Delta\Gamma_{CP}](B \to \rho/\pi\, \gamma)$	$\Gamma(K_L \to \pi^0 l^+ l^-)$
γ penguin	$[\Gamma, \Delta\Gamma_{CP}](B \to X_s \gamma)$ $[\Gamma, \Delta\Gamma_{CP}](B \to X_s\, l^+ l^-)$ $A_{FB}(B \to X_s\, l^+ l^-)$	$[\Gamma, \Delta\Gamma_{CP}](B \to \rho/\pi\, \gamma)$ $[\Gamma, \Delta\Gamma_{CP}](B \to \rho/\pi\, l^+ l^-)$ $A_{FB}(B \to \rho/\pi\, l^+ l^-)$	$\Gamma(K_L \to \pi^0 l^+ l^-)$
Z^0 penguin	$[\Gamma, \Delta\Gamma_{CP}](B \to X_s\, l^+ l^-)$ $A_{FB}(B \to X_s\, l^+ l^-)$ $\Gamma(B \to \mu\mu)$	$[\Gamma, \Delta\Gamma_{CP}](B \to \rho/\pi\, l^+ l^-)$ $A_{FB}(B \to \rho/\pi\, l^+ l^-)$ $\Gamma(B \to \mu\mu)$	$\Gamma(K^+ \to \pi^+ \nu\nu)$ $\Gamma(K_L \to \pi^0 \nu\nu)$ $\Gamma(K_L \to \pi^0 l^+ l^-)$
H^0 penguin	$\Gamma(B_s \to \mu\mu)$	$\Gamma(B_d \to \mu\mu)$	

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→ Key role of a few clean electroweak FCNC processes [especially $B \to l^+l^-$, $B \to X_s\, l^+l^-$ & $K \to \pi\nu\nu$]

- Mandatory to improve th. calculations within the SM and to improve the experimental resolutions [the key *symmetry question* is well formulated already within the EFT framework]

- Worth to study the expectations within explicit models [c.f. wide literature about $B \to X_s \gamma$ in MSSM] $\Rightarrow$ well-defined sensitivity to high-energy parameteres

Minimal Flavour Violation at large tanβ

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

Yukawa interaction invariant under an extra symmetry, $U(1)_{PQ}$,
under which D_R & E_R have the same charge (opposite to H_D)

The Y are still the only source of breaking of $SU(3)_{Q_L} \times SU(3)_{U_R} \times SU(3)_{D_R}$

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

$$y_u = m_u / \langle H_U \rangle$$
$$y_d = m_d / \langle H_D \rangle = \tan\beta \, m_d / \langle H_U \rangle$$

But for $\tan\beta = O(m_t / m_b) \gg 1$ we can have <u>both</u> y_t & y_b of order 1
[scenario particularly welcome in SO(10) GUT frameworks]

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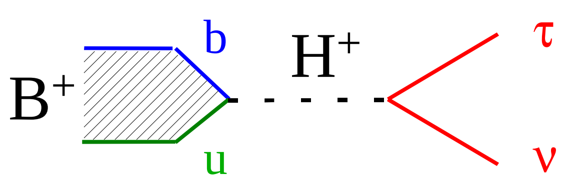
$$y_u = m_u / \langle H_U \rangle$$
$$y_d = m_d / \langle H_D \rangle = \tan\beta\, m_d / \langle H_U \rangle$$

Potentially observable non-standard effects in helicity-suppressed CC interactions:



$$B_{2HDM} = B_{SM} \times [\,1 - (\tan\beta\, m_B/M_H)^2]^2$$

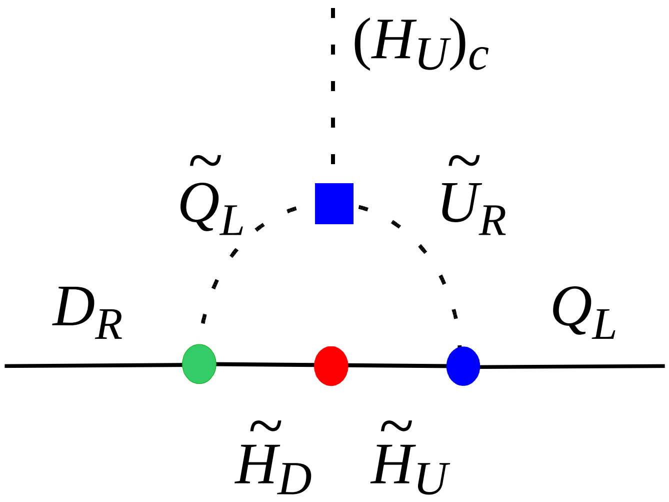
G. Hou, '93

*Minimal Flavour Violation at large tan*β

The $U(1)_{PQ}$ symmetry cannot be exact [$\Rightarrow m_A=0$] and it must be explicitely broken at least in the Higgs potential [e.g.: the $\mu \tilde{H}_U \tilde{H}_D$ coupling in the MSSM]

⇒ At least at the loop level we generate Yukawa–type $U(1)_{PQ}$–breaking terms, such as:

$$\epsilon_{PQ}\, \bar{Q}_L\, Y_U Y_U^+ Y_D\, D_R\, (H_U)_c$$



Even if ϵ_{PQ} is small [$\epsilon_{PQ} \sim (16\pi^2)^{-1}$]
the product $\epsilon_{PQ} \times \tan\beta$ can be $O(1)$ ⇒ large <u>non-decoupling</u> corrections to the ordinary ($U(1)_{PQ}$–conserving) Yukawa interaction

Hall, Rattazzi, Sarid, '94

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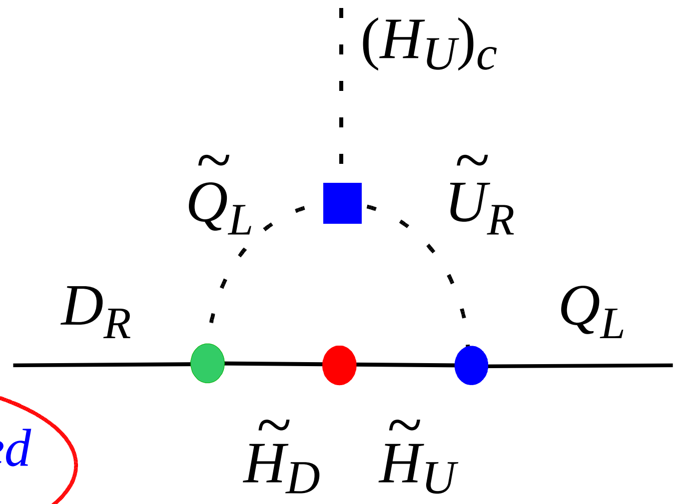
$Y_U Y_U^{+} Y_D \neq Y_D \Rightarrow$ *Higgs-mediated FCNCs !*



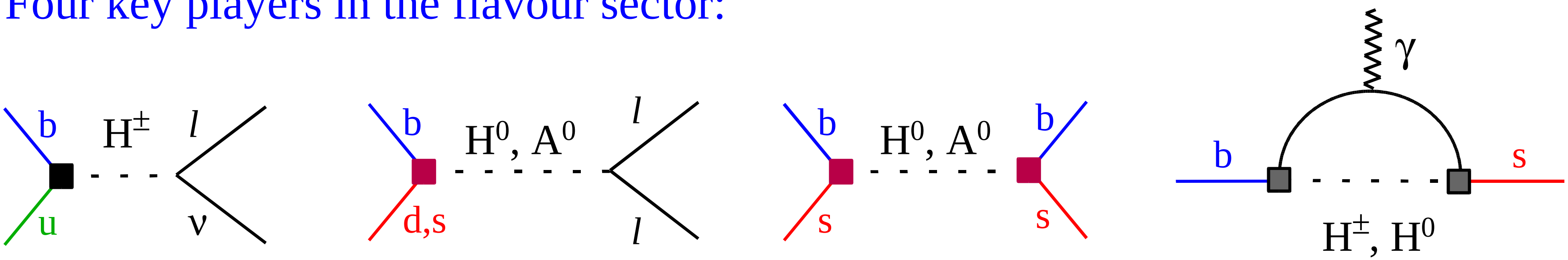
Babu & Kolda, '00
+wide literature

⇒ very interesting consequences for all the helicity-suppressed rare *B* decays

⇒ complete re-diagonalization of all the effective dim-4 Yukawa terms necessay in order to resum the large ϵ_{PQ} tanβ terms beyond the ordinary loop expansion

*Minimal Flavour Violation at large tan*β

Four key players in the flavour sector:



$B^{\pm} \to l^{\pm}\nu$ $B_{s,d} \to l^{+} l^{-}$ ΔM_{B_s} $B \to X_s\gamma$

The recent experimental infos on $B(B^{\pm} \to l^{\pm}\nu)$ [Belle] & ΔM_{B_s} [CDF] allows us to explore this scenario more deeply

G.I. & P.Paradisi '06

Minimal Flavour Violation at large tanβ

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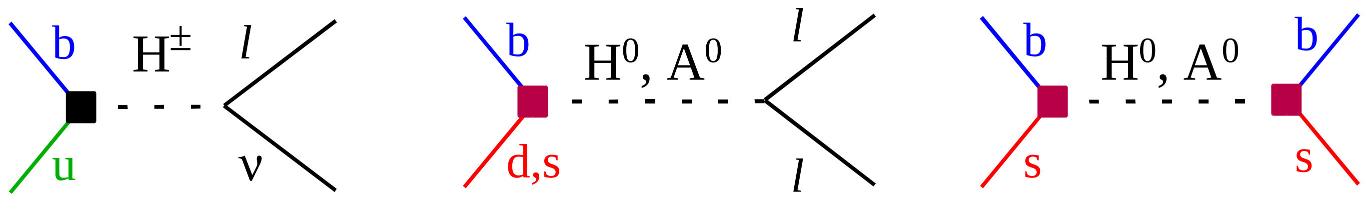

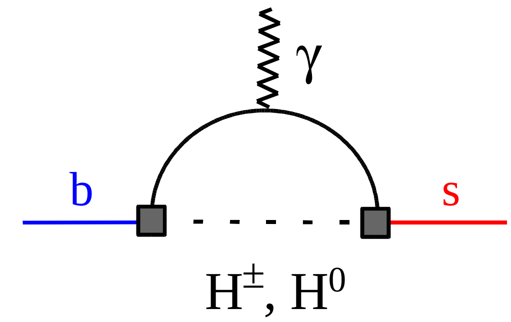

$B^\pm \to l^\pm \nu$	$B_{s,d} \to l^+ l^-$	ΔM_{B_s}	$B \to X_s \gamma$
↓	↓	↓	↓
~(10-50)% suppression	up to 100 × enhancement	~(0-20)% suppression	~(10-50)% enhancement

[qualitative general features for $M_H \sim 500$ GeV & $\tan\beta \sim 50$]

Despite several new free parameters, the framework exhibits a well defined pattern of enhancements & suppressions (consistent with present data)

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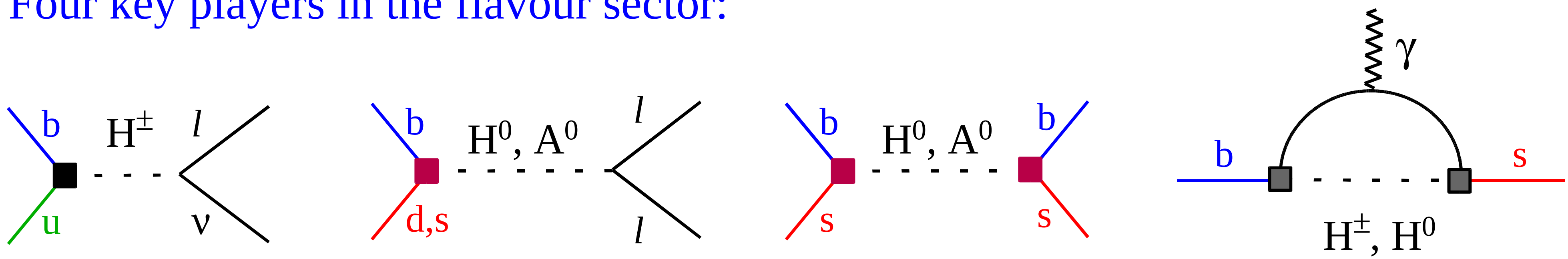

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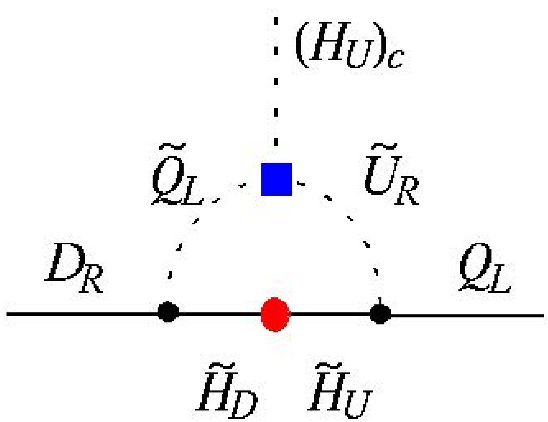
The game becomes more interesing in the explicit realization of this scenario within the MSSM ⇒ connection with flavour-conserving observables



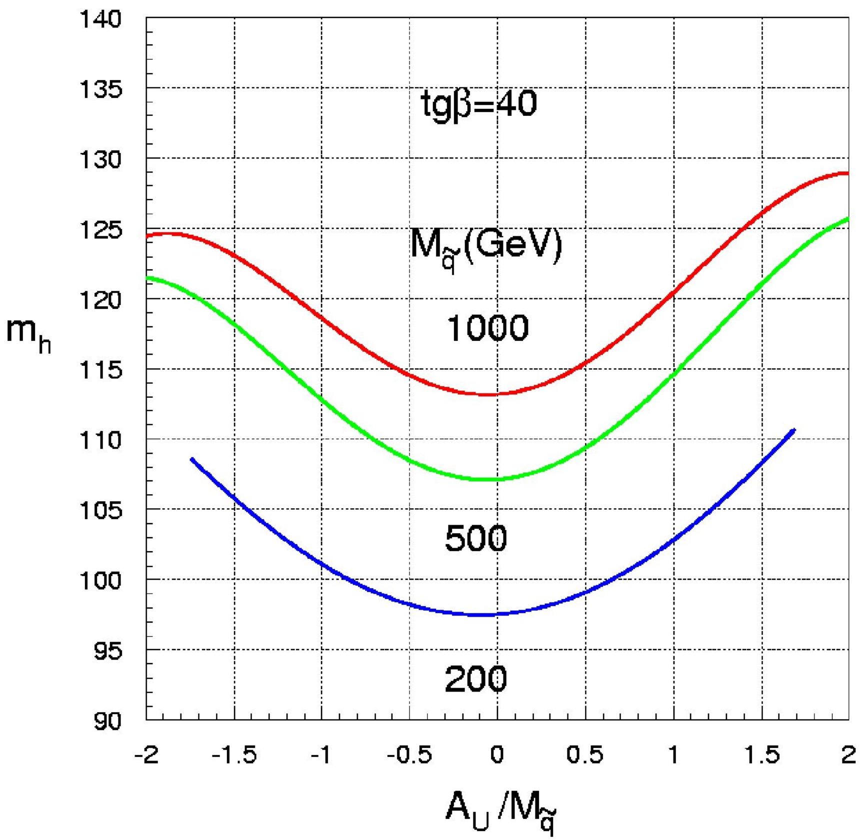
key parameters:

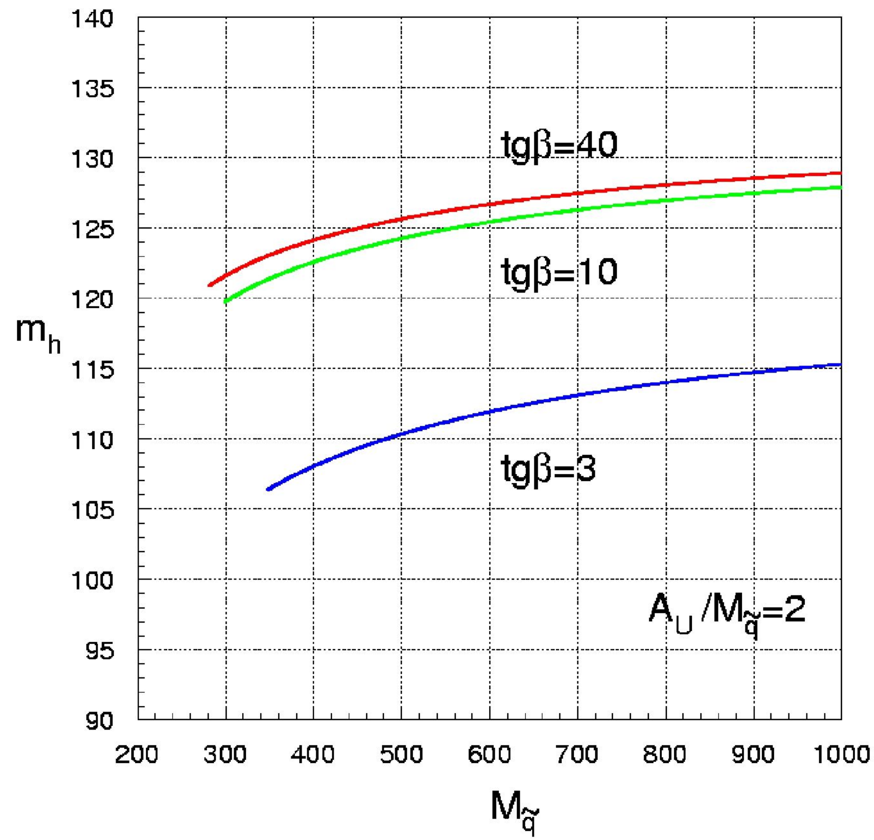
$M_H \oplus \tan\beta \oplus [A_U, \mu, \tilde{m}_q]$

$(m_{h^0})_{min} = f(A_U, \tan\beta, \tilde{m}_q)$

$(g\text{-}2)_\mu = f(\mu, \tan\beta, \tilde{m}_l)$

Minimal Flavour Violation at large tanβ





$(m_{h0})_{min} \geq 115$ GeV →

- large tanβ
- large $\tilde{m}_q$
- large $A_U/\tilde{m}_q$

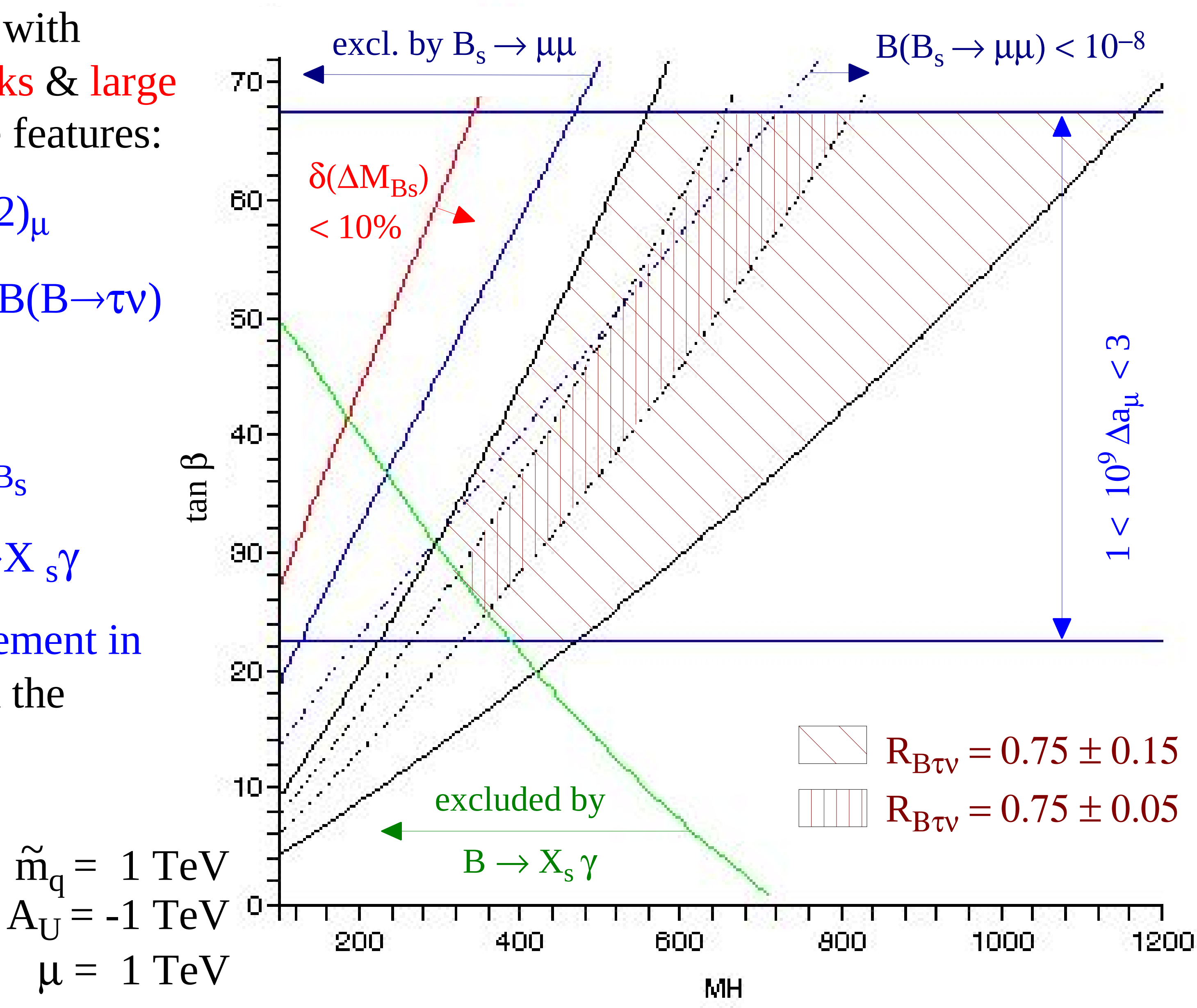
Parameter region with the most interesting large-tanβ effects

Minimal Flavour Violation at large tanβ

G.I. & P.Paradisi '06

The MSSM scenario with large tanβ, heavy squarks & large A terms has a few nice features:

- $O(10^{-9})$ contrib. to $(g-2)_\mu$
- (10-40)% suppress in $B(B\to\tau\nu)$
- Heavy $(m_{h0})_{min}$
- No fine-tuning in ΔM_{B_s}
- No fine-tuning in $B \to X_s\gamma$
- Possible large enhancement in $B \to\mu\mu$ [depending on the precise value of A_U]



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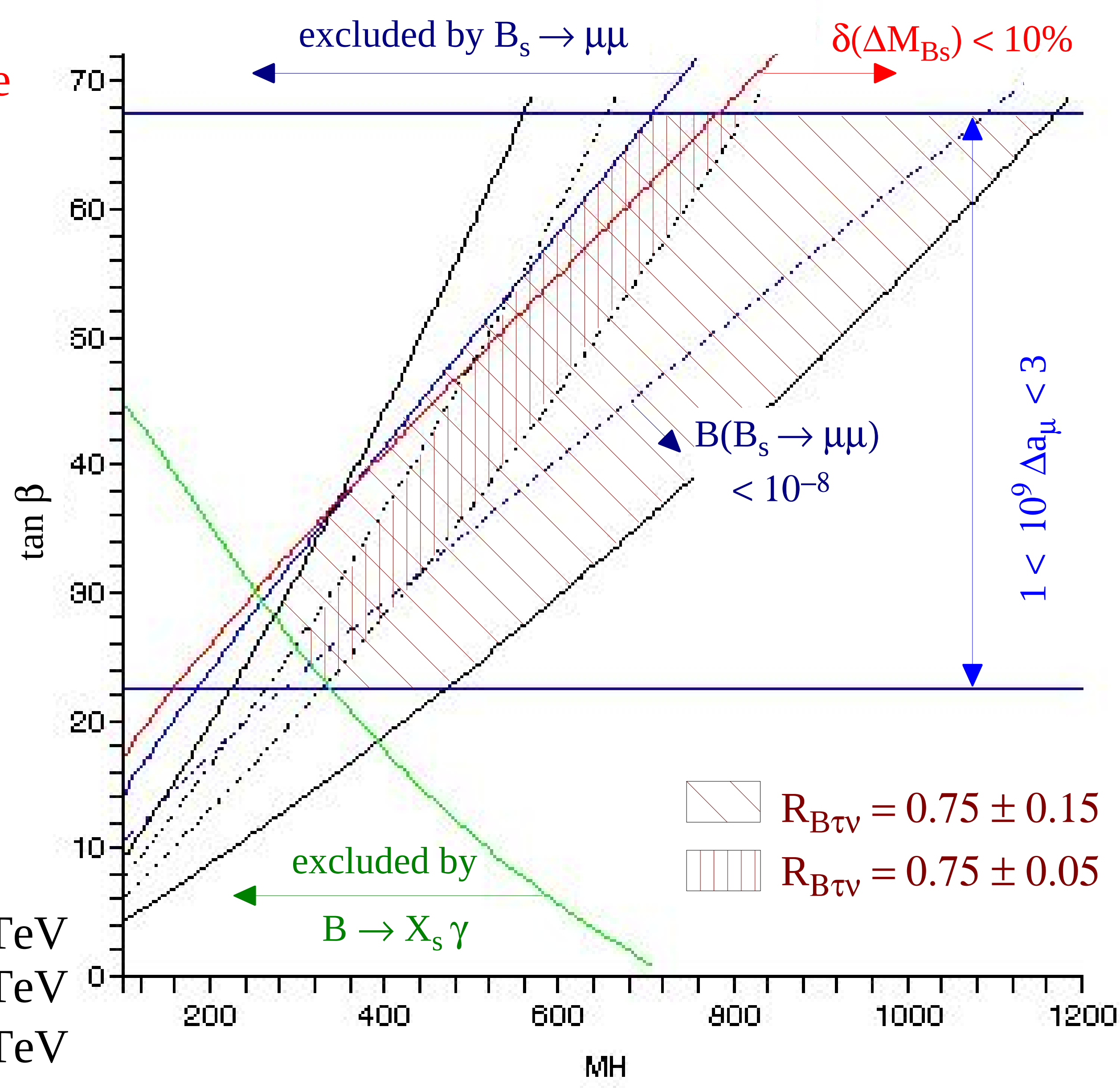
interesting benchmark

$\tilde{m}_q = 1$ TeV
$A_U = -2$ TeV
$\mu = 1$ TeV



Beyond MFV

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super-heavy flavored particles [split-SUSY]

minimal deviations from MFV...

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Worth to analyse specific benchmarks in these cases ?

[hope to receive some inputs form the audience....]

Conclusions

MFV with one Higgs doublet and MFV at large tanβ are two well-defined & phenomenologically motivated frameworks [consistent EFT formulations] which allow us to establish correlations among different falvour-physics observables

↓

Natural implementation within low-energy SUSY ⇒ well-defined connections with specific high-energy benchmark scenarios

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MFV with one Higgs doublet and MFV at large $\tan\beta$ are two well-defined & phenomenologically motivated frameworks [consistent EFT formulations] which allow us to establish correlations among different falvour-physics observables

⇓

Natural implementation within low-energy SUSY ⇒ well-defined connections with specific high-energy benchmark scenarios

Difficult to establish clear connections between low- and high-energy physics without a guiding flavour-symmetry principle...

- worth to explore the NP sensitivity of all accessible low-energy observables

- less interesting to perform dedicated studies of low ↔ high energy correlations in scenarios which are not well defined