Implications on new physics from present (and future) limits

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General Considerations

Flavor Physics in the LHC era

- **High energy experiments** are the key tool to determine the **energy scale Λ** by direct production of NP particles.
- **Low energy experiments** are a fundamental ingredient to determine the **symmetry properties** of the new d.o.f. via their virtual effects in precision observables.

General Considerations

G. Isidori – *Flavour Physics now and in the LHC era* LP 2007

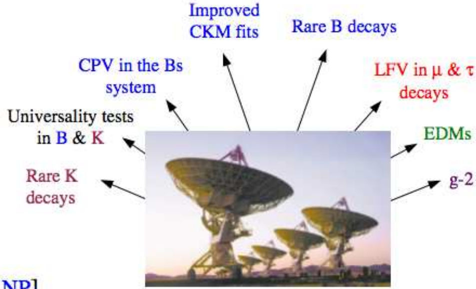
Flavour physics in the LHC era

LHC [high p_T]

A *unique* effort toward the high-energy frontier

[to determine the energy scale of NP]

Flavour physics



A *collective* effort toward the high-intensity frontier

[to determine the flavour structure of NP]

NP search strategies

Where to look for New Physics?

- **Processes very suppressed or even forbidden in the SM**
  - FCNC processes ($\mu \to e\gamma$, $\tau \to \mu\gamma$, $B^0_{s,d} \to \mu^+\mu^-$, $K \to \pi\nu\bar{\nu}$)
  - CPV effects (electron/neutron EDMs, $d_{e,n}$....)
  - CPV in $B_{s,d}$ decay/mixing amplitudes

See talks by Ciuchini, Masiero & Soni

- **Processes predicted with high precision in the SM**
  - EWPO as $\Delta\rho$, $(g-2)_\mu$....
  - LU in $R_M^{e/\mu} = \Gamma(K(\pi) \to e\nu)/\Gamma(K(\pi) \to \mu\nu)$

See talks by Marciano and Spadaro

$B^0_{s,d} \to \mu^+\mu^-$ and NP

FCNC processes as $B^0_{s,d} \to \mu^+\mu^-$ offers a unique possibility in probing the underlying flavour mixing mechanism of **NP**

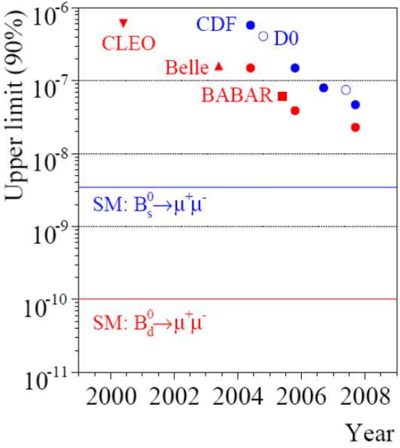
- No SM tree-level contributions (FCNC decays)
- CKM suppression $\to BR(B^0_{s,d} \to \mu^+\mu^-) \sim |V_{ts(td)}|^2$
- Elicity suppression $\to BR(B^0_{s,d} \to \mu^+\mu^-) \sim m_\mu^2$
- Dominance of short distance (e.w.) effects $\to$ SM uncertainties well under control

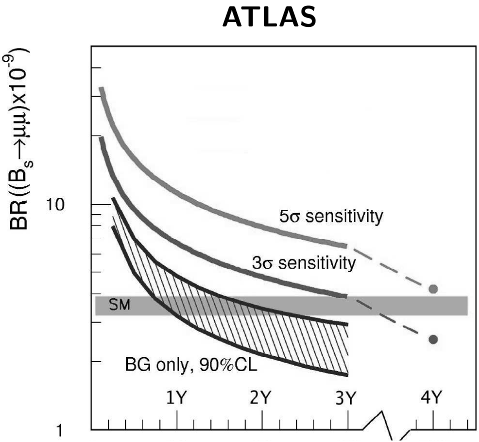
$$\mathcal{B}(B_s \to \mu^+\mu^-)_{\rm SM} = 4.1(8)\times 10^{-9} \quad \mathcal{B}(B_d \to \mu^+\mu^-)_{\rm SM} = 1.3(3)\times 10^{-10}$$

- High sensitivity to NP effects of many theories as SUSY, 2HDM, LHT, Z', RS models.....

$$A(b \to d)_{\rm FCNC} \sim c_{\rm SM}\frac{y_t^2 V_{td}^* V_{tb}}{16\pi^2 M_W^2} + c_{\rm NP}\frac{\delta_{3d}}{16\pi^2 \Lambda_{NP}^2}$$

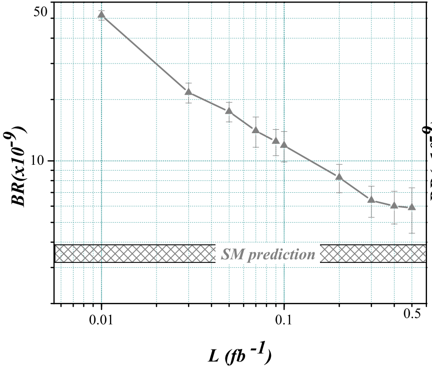
$B_s \to \mu^+\mu^-$ @ LHCb



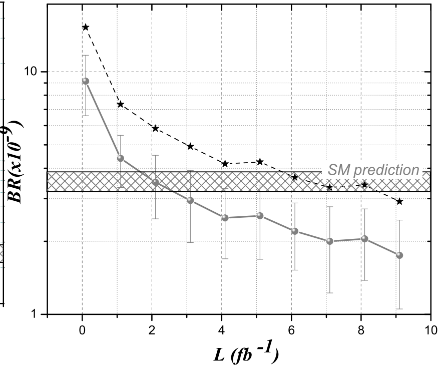


$B_s \to \mu^+\mu^-$ @ LHCb

Exclusion @ 90% CL



Observation @ (3-5)σ



Theory of $B_{s,d} \to \mu^+\mu^-$

- **Effective Hamiltonian for $B_{s,d} \to \mu^+\mu^-$**

$$\mathcal{H}^{\rm eff}_{\Delta F=1} = \mathcal{H}^{\rm eff}_{\rm SM} + C_S O_S + C_P O_P + C'_S O'_S + C'_P O'_P + {\rm h.c.},$$

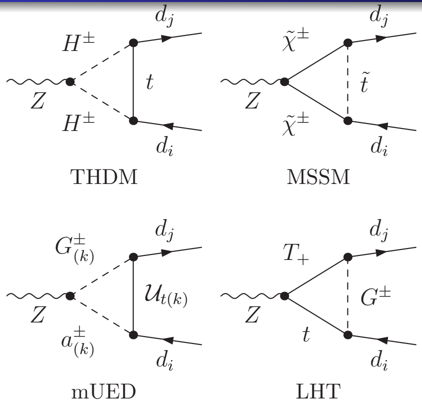
- **SM and CMFV current**

$$\mathcal{H}^{\rm eff}_{\rm SM} = C_{10} Q_{10} \qquad\qquad Q_{10} = \bar{b}_L \gamma^\mu q_L \bar{\ell} \gamma_\mu \gamma_5 \ell,$$

- **Scalar currents (2HDM, SUSY)**

$$O_S = \overline{d}^i_R d^j_L \overline{\ell}\ell\ , \qquad O_P = \overline{d}^i_R d^j_L \overline{\ell}\gamma_5 \ell\ ,$$
$$O'_S = \overline{d}^i_L d^j_R \overline{\ell}\ell\ , \qquad O'_P = \overline{d}^i_L d^j_R \overline{\ell}\gamma_5 \ell\ .$$

$B_s \to \mu^+\mu^-$ & CMFV



- **$Zb\bar{b}$** $\to R_b^0,\ \mathcal{A}_b,\ A_{\rm FB}^{0,b}$
- **$Zd_j\bar{d}_i$** $\to K^+ \to \pi^+\nu\bar{\nu}$, $K_L \to \pi^0\nu\bar{\nu}$, $K_L \to \mu^+\mu^-$, $\bar{B} \to X_{d,s}\nu\bar{\nu}$, $B_{d,s} \to \mu^+\mu^-$
- **$Zd_j\bar{d}_i$** vs **$Zb\bar{b}$**

Observable	CMFV (95%CL)	SM (95%CL)	Exp.
$\mathcal{B}(B_d \to \mu^+\mu^-) \times 10^{10}$	$[0.36, 2.03]$	$[0.87, 1.27]$	$< 1.8 \times 10^2$
$\mathcal{B}(B_s \to \mu^+\mu^-) \times 10^{9}$	$[1.17, 6.67]$	$[2.92, 4.13]$	$< 5.8 \times 10^1$

Haisch & Weiler '07

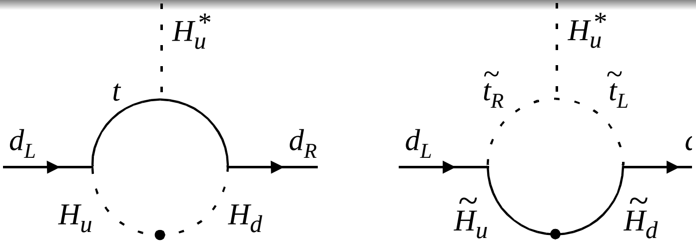
MFV @ large $\tan\beta$

The CKM is the only source of flavor and CP violation also beyond the SM

$$\mathcal{L}_{\text{eff.}} = \mathcal{L}_{\text{Gauge}}(A_i, \Psi_i) + \mathcal{L}_{\text{Higgs}}(A_i, \Psi_i, \phi_i) + \sum_{d \geq 5} \frac{c_n}{\Lambda^{d-4}} O_n^d(A_i, \Psi_i, \phi_i)$$

- $\mathcal{L}_{\text{SM}} = \mathcal{L}_{\text{Gauge}} + \mathcal{L}_{\text{Higgs}} =$ all possible operators with $d \leq 4$ (renormalizable) compatible with the Gauge symmetry.
- $\sum_{d \geq 5} \frac{c_n}{\Lambda^{d-4}} O_n^d$ =most general parameterization of the new (heavy) d.o.f as long as we perform low-energy experiments.
- $\mathcal{L}_{\text{Yukawa}} = \bar{Q}_L \mathbf{Y_D} D_R H_D + \bar{Q}_L \mathbf{Y_U} U_R H_U + \bar{L}_L \mathbf{Y_L} E_R H_D + h.c$
  - $\mathbf{Y_U} = \frac{m_U}{<H_U>}$, $\mathbf{Y_{D,L}} = \frac{m_{D,L}}{<H_D>} = \frac{m_{D,L}}{<H_U>} \tan\beta$.
  - For $\tan\beta = O(m_t/m_b) >> 1 \to \mathbf{Y_t} \sim \mathbf{Y_b} \sim 1$.

MFV @ large $\tan\beta$



a) **2HDM** b) **SUSY**

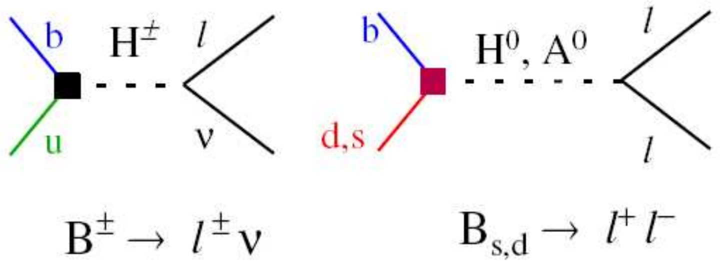
$$\mathcal{L}_d^{\rm eff} = \overline{d}_R Y_d \left[H_d + \left(\epsilon_0 + \epsilon_Y Y_u Y_u^\dagger \right) H_u^* \right] Q_L + \text{h.c.} \; ,$$

$$\mathcal{L}_{\rm FCNC}^{\rm eff} \sim \frac{m_{d_k}}{M_W} y_t^2 V_{k3} V_{3j}^* \, \boldsymbol{\epsilon_Y t_\beta^2} \, \left[c_{\alpha-\beta} h^0 + s_{\alpha-\beta} H^0 - i A^0 \right] \overline{d}_R^k d_L^j + \text{h.c.}$$

$$\epsilon_{\mathbf{Y}}^{\mathbf{2HDM}} \simeq \frac{1}{t_\beta} \frac{\log(m_t^2/m_{H^+}^2)}{16\pi^2} \qquad \epsilon_{\mathbf{Y}}^{\mathbf{SUSY}} \simeq \frac{\mu A_{\tilde{t}}/m_{\tilde{t}}^2}{16\pi^2}$$

B-physics Phenomenology in MFV

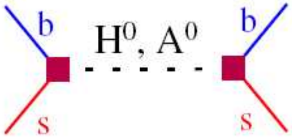
$\tan\beta \sim (30-50)$, $\mathbf{M_H \sim (300-500)GeV}$, $\mathbf{M_{\tilde{q}} \sim (1-2)TeV}$

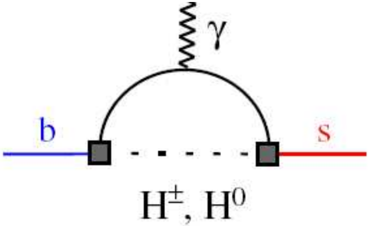


$\sim (10-30)\%$ **suppression** **up to** $10\times$ **enhancement**

B-physics Phenomenology in MFV

$t_\beta \sim (30-50)$, $\mathbf{M_H \sim (300-500)GeV}$, $\mathbf{M_{\tilde{q}} \sim (1-2)TeV}$





ΔM_{B_s} $\quad$ $B \to X_s \gamma$

$\sim (0-10)\%$ **suppression** $\quad$ **up** $\sim (0-20)\%$ **enhancement**

B-physics Phenomenology in MFV

- **Loop induced processes**

$$Br(B_s \to \mu^+\mu^-) \simeq 6 \times 10^{-8} \left(\frac{400\mathrm{GeV}}{M_H}\right)^4 \left(\frac{\mu A_U}{m^2_{\tilde{q}}}\right)^2 \left(\frac{t_\beta}{50}\right)^6$$

$$\frac{(\Delta M_{B_s})}{(\Delta M_{B_s})^{SM}} \simeq 1 - 3 \times 10^{-2} \left(\frac{\mu A_U}{m^2_{\tilde{q}}}\right)^2 \left(\frac{t_\beta}{50}\right)^4 \left(\frac{400\mathrm{GeV}}{M_H}\right)^2 .$$

- **Tree level process**

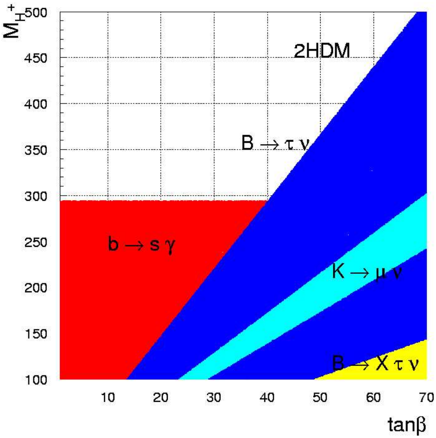
$$\frac{Br(B \to \ell\nu)}{Br(B \to \ell\nu)^{SM}} \simeq \left(1 - 0.3 \left(\frac{t_\beta}{50}\right)^2 \left(\frac{400\mathrm{GeV}}{m_{H^\pm}}\right)^2\right)^2$$

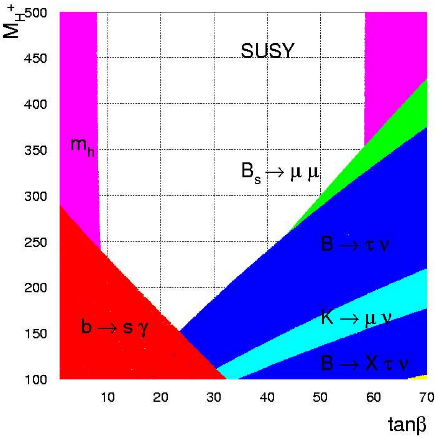
$$Br(B \to \tau\nu)/(\Delta M_{B_d}) \sim (V_{ub}/V_{td})^2/\hat{B}_d = (\sin\beta/\sin\gamma)^2/\hat{B}_d$$

$$Br(B \to \tau\nu) \sim |V_{ub}|^2 f_B^2$$

[Isidori & P.P., '06]

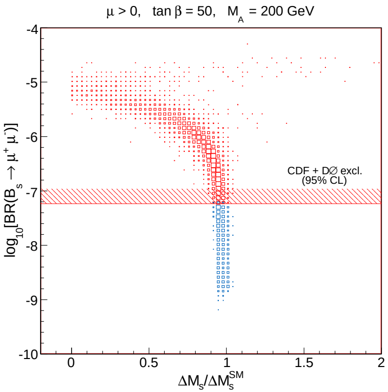
The M_H-$\tan\beta$ plane

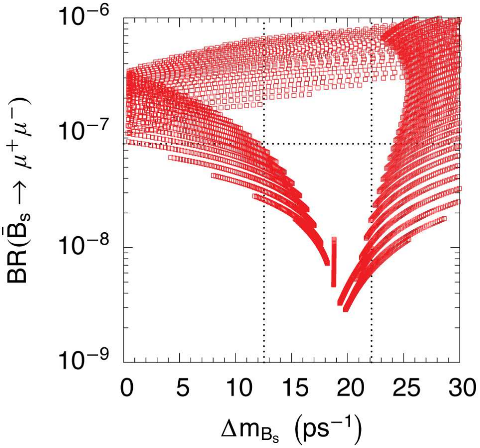




$$m_{SUSY} = -2A_{\tilde{t}} = 1\mathrm{TeV}$$

$B_s \to \mu^+\mu^-$ vs ΔM_s





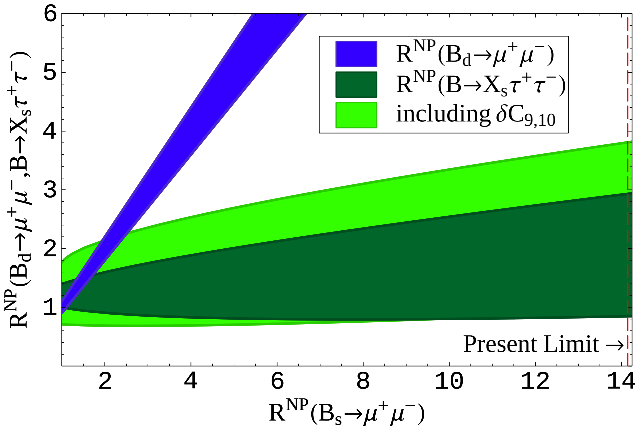
MFV MSSM

Buras et al.'02,'07

GENERAL MSSM

Foster et al. '06

$B_s \to \mu^+\mu^-$ vs $B_d \to \mu^+\mu^-$ in MFV



$$\frac{\Gamma(B_s \to \ell^+\ell^-)}{\Gamma(B_d \to \ell^+\ell^-)} \approx \frac{f_{B_s} m_{B_s}}{f_{B_d} m_{B_d}} \left|\frac{V_{ts}}{V_{td}}\right|^2 .$$

Powerful probe of MFV (Hurt et al. '08)

LU at a (Super)B factories

- $R_\tau^{\mu/e} = \Gamma(\tau \to \mu\nu\bar{\nu})/\Gamma(\tau \to e\nu\bar{\nu})$

$$R_\tau^{\mu/e} \simeq 1 - 10^{-3} \left(\frac{t_\beta}{50}\right)^2 \left(\frac{200\mathrm{GeV}}{M_{H^\pm}}\right)^2$$

Mursula et al. '83

- $R_{B\to D}^{\tau/\ell} = \Gamma(B \to D\tau\nu)/\Gamma(B \to D\ell\nu)$

Hou '92, Tanaka '95, Kiers & Soni '97

$$\frac{R_{B\to D}^{\tau/\mu}}{R_{B\to D}^{\tau/\mu}|_{SM}} \simeq 1 - 0.3 \left(\frac{t_\beta}{50}\right)^2 \left(\frac{200\mathrm{GeV}}{M_{H^\pm}}\right)^2$$

Nierste et al.'08, Kamenik & Mescia '08

see talk by Westhoff

SUSY MFV scenario @ large $\tan\beta$

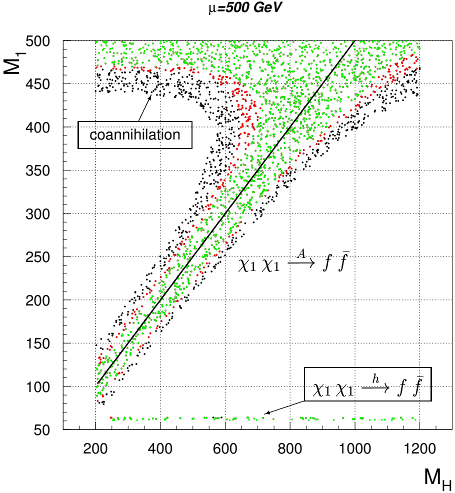
How natural is the MFV SUSY scenario @ large $\tan\beta$?

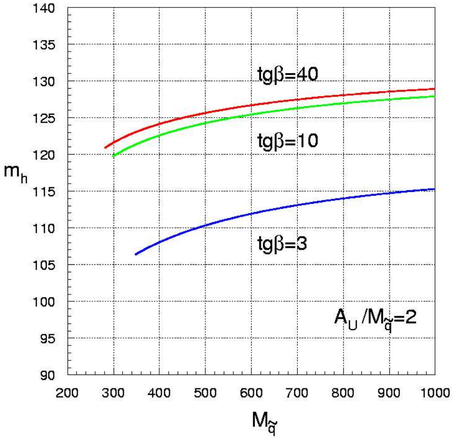
- Top-Bottom Yukawa unification in GUT $\Rightarrow \tan\beta = (m_t/m_b)$
- $m_h > 114\mathrm{GeV}$ constraint better satisfied
- $\Delta a_\mu = (g-2)_\mu/2 = (3 \pm 1) \times 10^{-9}$ naturally explained
- WMAP constraints **"naturally"** satisfied **Ellis et al.**
- Correlations between $\mathcal{B}(B \to \tau\nu)$ and $\mathcal{B}(B \to X_s\gamma)$, ΔM_{B_s}, $\mathcal{B}(B_{s,d} \to \ell^+\ell^-)$, $(g-2)_\mu$ and m_{h^0}

Isidori, P.P., '06

Lightest Higgs boson mass WMAP & $(g-2)_\mu$

$$\Delta a_\mu \simeq 3 \times 10^{-9} \left(\frac{400\text{GeV}}{\tilde{m}}\right)^2 \left(\frac{t_\beta}{50}\right) \; sign\, \mu$$





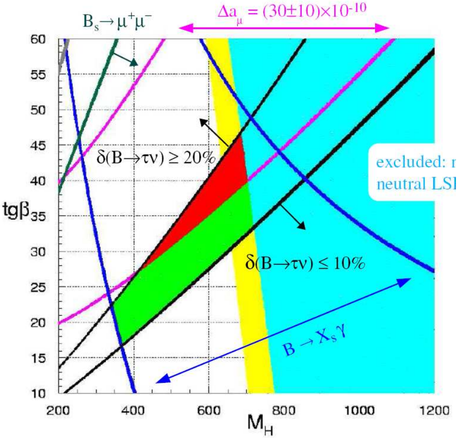
$t_\beta = 20\,(green), 30\,(red), 50\,(black)$

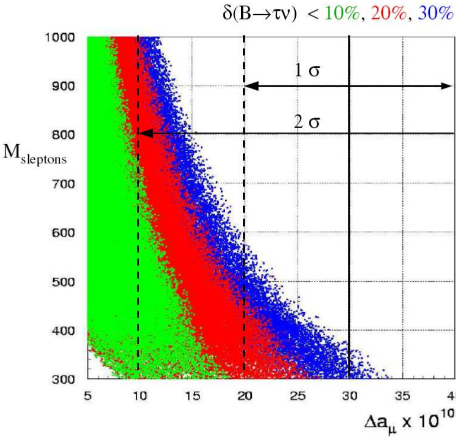
Isidori et al., 06',’07

Constraints

- $\mathbf{B \to X_s}\gamma$: $[1.01 < \mathbf{R_{Bs\gamma}} < 1.24]$
- $\mathbf{a}_\mu$: $[2 < 10^{-9}(\mathbf{a}_\mu^{\rm exp} - \mathbf{a}_\mu^{\rm SM}) < 4]$
- $\mathbf{B} \to \mu^+\mu^-$: $[\mathcal{B}^{\rm exp} < 8.0 \times 10^{-8}]$
- ΔM_{B_s} : $[\mathbf{\Delta M_{B_s}} = 17.35 \pm 0.25 \ {\rm ps}^{-1}]$
- $B \to \tau\nu$: $[0.8 < \mathbf{R_{B\tau\nu}} < 0.9]$

B-physics & $(g-2)_\mu$ under WMAP constraints





$M_H \sim 2M_1$

Isidori, Mescia, P.P., Temes, 07

Conclusions

Where to look for New Physics?

- $B^0_{s,d} \to \mu^+\mu^-$ and $B \to \ell\nu$ are still discovery channels and they represent a unique probe for SUSY even in the elegant (but pessimistic) MFV framework
- A careful study of **correlations**, i.e. $BR(B \to \ell\nu)/\Delta M_{s,d}$, $BR(B^0_{s,d}\to\mu^+\mu^-)/\Delta M_{s,d}$, $BR(B^0_s\to\mu^+\mu^-)/BR(B^0_d\to\mu^+\mu^-)$ etc. is a powerful tool to probe/disentangle NP scenarios.

$$\Downarrow$$

The synergy of Flavor Physics, Dark Matter, EWPO tests and the LHC will represents the best way to shed light on NP.