Shedding light on New Phyisics at the (Super)B-factories

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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.

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

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$K \to \pi\nu\bar{\nu}$ and NP

- FCNC processes as $K \to \pi\nu\bar{\nu}$ offers a unique possibility in probing the underlying flavour mixing mechanism of **NP**
  - No SM tree-level contributions (FCNC decays)
  - One-loop SM contributions CKM-suppressed ($V_{ts}^* V_{td} \sim \lambda^5$)
  - Dominance of short distance (e.w.) effects $\to$ SM uncertainties at %
  - Great sensitivity to NP effects of many theories as SUSY, LHT, Z' models.....

$$A(s \to d)_{\rm FCNC} \sim c_{\rm SM} \frac{y_t^2 V_{ts}^* V_{td}}{16\pi^2 M_W^2} + c_{\rm NP} \frac{\delta_{21}}{16\pi^2 \Lambda_{NP}{}^2}$$

- Large NP effects only if $\delta_{21} \not\sim V_{ts}^* V_{td}$ (beyond MFV)

LFV frameworks

- **Neutrino Oscillation** $\Rightarrow m_{\nu_i} \neq m_{\nu_j} \Rightarrow$ **LFV**
- **see-saw**: $m_\nu = \frac{(m_\nu^D)^2}{M_R} \sim eV$, $M_R \sim 10^{14-16} \Rightarrow m_\nu^D \sim m_{top}$
- LFV transitions like $\mu \to e\gamma$ @ 1 loop with exchange of
  - W and ν in the SM framework (GIM)

$$Br(\mu \to e\gamma) \sim |\delta^\ell|^2 \sim \frac{m_\nu^4}{M_W^4} \leq 10^{-50} \qquad m_\nu \sim \mathrm{eV}$$

  - $\tilde{W}$ and $\tilde{\nu}$ in the MSSM framework (SUPER-GIM)

$$Br(\mu \to e\gamma) \sim |\delta^{\tilde{\ell}}|^2 \sim \frac{m_\nu^{D\,4}}{\tilde{m}^4} \leq 10^{-11} \qquad m_\nu^D \sim m_{top}$$

$$\Downarrow$$

- LFV signals are undetectable (detectable) in the SM (MSSM)

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LFV in SUSY

RG induced LFV interactions in SUSY GUTs

- **SUSY SU(5)** [Barbieri & Hall, '95]

$$(\delta^{\tilde{q}}_{LL})_{ij} \sim h^u h^{u\dagger}{}_{ij} \sim h_t^2 V^{ik}_{CKM} V^{kj*}_{CKM} \to (\delta^{\tilde{\ell}}_{RR})_{ij} \simeq (\delta^{\tilde{q}}_{LL})_{ij}$$

- **SUSY SU(5)+RN** [Yanagida et al., '95]

$$(\delta^{\tilde{\ell}}_{LL})_{ij} \sim (h^\nu h^{\nu\dagger})_{ij} \qquad \& \qquad (\delta^{\tilde{\ell}}_{RR})_{ij} \sim (h^u h^{u\dagger})_{ij}$$

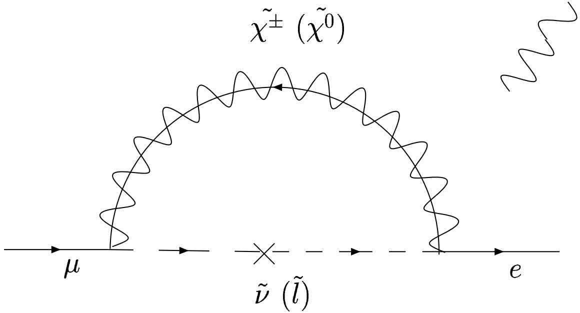
- **SUSY SU(5)+RN** [Moroi, '00] **& SO(10)** [Chang et al., 02]

$$\sin\theta_{\mu\tau} \sim \frac{\sqrt{2}}{2} \Rightarrow (\delta^{\tilde{\nu}}_{LL})_{23} \sim 1 \Rightarrow (\delta^{\tilde{q}}_{RR})_{23} \sim 1$$

LFV in SUSY

LFV interactions – leptons/sleptons/gauginos

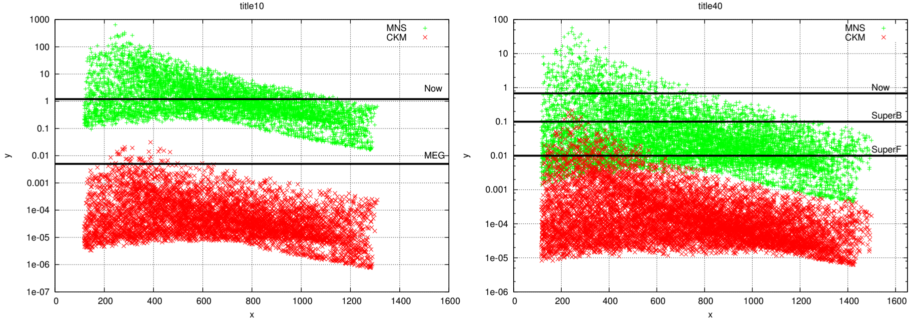
$$\mathcal{L} = \bar{\ell}_i \left(C^R_{ijA} P_R + C^L_{ijA} P_L \right) \tilde{\chi}^-_A \tilde{\nu}_j + \bar{\ell}_i \left(N^R_{ijA} P_R + N^L_{ijA} P_L \right) \tilde{\chi}^0_A \tilde{\ell}_j. \quad (1)$$



$$\left.\frac{BR(\ell_i \to \ell_j \gamma)}{BR(\ell_i \to \ell_j \nu_i \bar{\nu}_j)}\right|_{\text{Gauge}} \simeq \frac{\alpha_{el}}{20\pi} \left(\frac{m_W^4}{m_{SUSY}^4} \right) \left(\delta^{21}_{LL} \right)^2 t_\beta^2$$

$\mu \to e\gamma$ and $\tau \to \mu\gamma$

Br($\mu \to e\gamma$) Br($\tau \to \mu\gamma$)

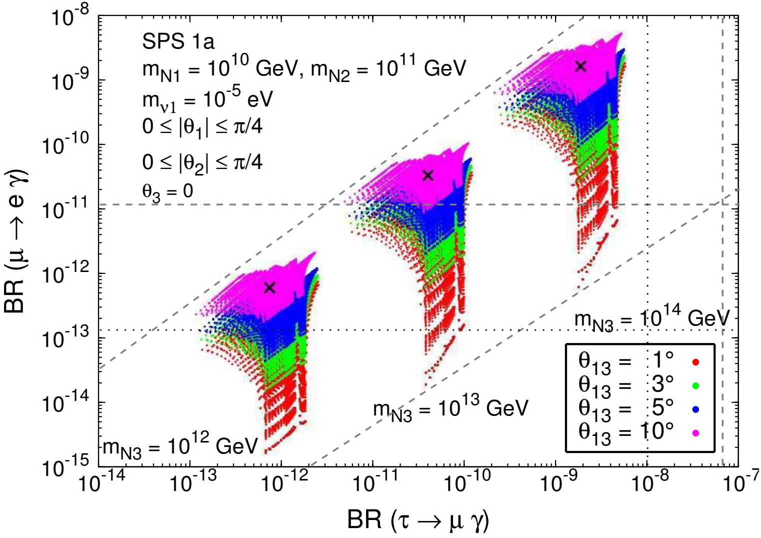


$M_{1/2}$ $M_{1/2}$

$m_0 \leq 1\text{TeV}$, $\tan\beta = 40$

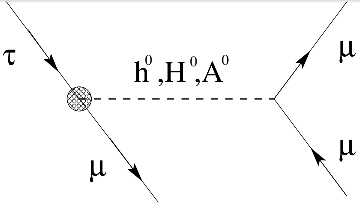
Calibbi, Faccia, Masiero and Vempati, '06

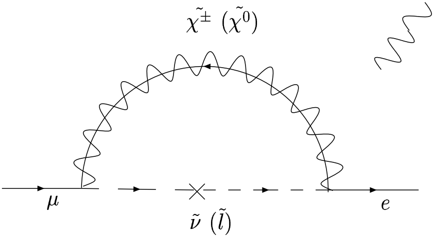
$\mu \to e\gamma$ and $\tau \to \mu\gamma$



Herrero et al., '06

Phenomenology: $\tau \to l_j X$ $(X = \gamma, \eta, l_j l_j (l_k l_k))$





$$\frac{BR(\tau\to 3\mu)}{BR(\tau\to\mu\nu\bar{\nu})} \simeq \left(\frac{\alpha_2}{48\pi}\right)^2 \left(\frac{m_\tau m_\mu}{M_H^2}\right)^2 \delta_{32}^2 t_\beta^6 \qquad \frac{BR(\tau \to \mu\gamma)}{BR(\tau \to \mu\nu\bar{\nu})} \simeq \frac{\alpha_{el}}{20\pi} \frac{m_w^4}{\tilde{m}^4} \delta_{32}^2 t_\beta^2$$

If $t_\beta \sim 50$ and $M_H \ll \tilde{m}$, i.e. $M_H \sim m_w$ and $\tilde{m} \sim TeV$

$$\Downarrow$$

$$\frac{BR(\tau\to 3\mu)}{BR(\tau\to\mu\gamma)} \not\sim \alpha_{el}$$

Lepton Universality @ the B-factories

- τ **Physics**
  - $H^{\pm}$ effects to $R_\tau = \Gamma(\tau \to \mu\nu\bar{\nu})/\Gamma(\mu \to e\nu\bar{\nu})$

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

  - No visible effects in $\Gamma(\tau \to M\nu)/\Gamma(M \to \mu\nu)$, $M = K, \pi$

- B **Physics**
  - Semileptonic B decays, i.e. $B \to X\ell\nu$

$$\frac{\mathcal{B}(B \to X\tau\nu)}{\mathcal{B}(B \to X\tau\nu)|_{SM}} \simeq 1 - 2\frac{m_\tau^2 t_\beta^2}{M_{H^\pm}^2} \simeq 1 - 0.4\left(\frac{t_\beta}{50}\right)^2\left(\frac{200\mathrm{GeV}}{M_{H^\pm}}\right)^2$$

  - Leptonic B decays, i.e. $B \to \ell\nu$

New Generation of Experiments

Experiments

$\pi \to e\nu$

$R^{\exp \pi}_{e/\mu}$ $(\pm 0.4\%)$

$1.2265(34)(44) x 10^{-4}$ TRIUMF (1992)

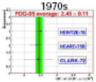
$1.2346(35)(36) x 10^{-4}$ PSI (1993)

$$R^{th}_{e/\mu} - R^{\exp}_{e/\mu} = 43(37) x 10^{-8}$$

$K \to e\nu / K \to \mu\nu$

$R^{\exp K}_{e/\mu}$ $(\pm 2\%)$

$2.45(11) x 10^{-5}$



$2.416(43)(24) x 10^{-5}$ CERN(2006)

$$R^{th}_{e/\mu} - R^{\exp}_{e/\mu} = 56(46) x 10^{-8}$$

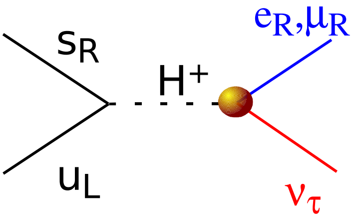
Two new $\pi \to e\nu$ experiments.
Goals: $\pm(5)x10^{-8}$ (0.05%)

KLOE: Stay tuned $\to$ (1-2%?);
New $K \to e\nu$ experiment at CERN.
Goal: $\pm(10)x10^{-8}$ (0.3%)

Bryman at KAON '07

LU in $K \to \ell\nu$

$$R_K^{LFV} = \frac{\sum_i K \to e\nu_i}{\sum_i K \to \mu\nu_i} \simeq \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)} \,, \quad i = e, \mu, \tau$$



$$eH^\pm\nu_\tau \to \frac{g_2}{\sqrt{2}} \frac{m_\tau}{M_W} \Delta_R^{31} \tan^2\beta$$

$$\Delta_R^{31} \sim \frac{\alpha_2}{4\pi} \delta_{RR}^{31}$$

$$\Delta_R^{31} \sim 5 \cdot 10^{-4} \;\; t_\beta = 40 \;\; M_{H^\pm} = 500\mathrm{GeV}$$

$$\Downarrow$$

$$\Delta r_{K\,SUSY}^{e-\mu} \simeq \left(\frac{m_K^4}{M_{H^\pm}^4}\right) \left(\frac{m_\tau^2}{m_e^2}\right) |\Delta_R^{31}|^2 \tan^6\beta \approx 10^{-2}$$

$$\Delta r_{K\,SUSY}^{e-\mu} \approx 10^{-2} \quad \Longrightarrow \quad Br^{th.(exp.)}(\tau \to eX) \leq 10^{-10(-7)}$$

Masiero, P.P, Petronzio '06

LU in $B \to \ell\nu$

- Including LFV channels in $B \to \ell\nu$, with $\ell = e, \mu$

$$R^{\ell/\tau}_{LFV} \simeq R^{\ell/\tau}_{SM}\left[1 + r_H^{-1}\left(\frac{m_B^4}{M^4_{H^\pm}}\right)\left(\frac{m_\tau^2}{m_\ell^2}\right)|\Delta_R^{3\ell}|^2 \tan^6\beta\right]$$

- Imposing the $\tau \to \ell_j X$ $(X = \gamma, \eta, \ell_j\ell_j(\ell_k\ell_k))$ constraints

$$R^{\mu/\tau}_{LFV} \leq 1.5 R^{\mu/\tau}_{SM}\ , \qquad R^{e/\tau}_{LFV} \leq 2 \cdot 10^4 \cdot R^{e/\tau}_{SM}$$

- Imposing the $\mu - e$ universality constraints in R_K

$$\frac{R^{e/\tau}_{LFV}}{R^{e/\tau}_{SM}} \simeq \left[1 + r_H^{-1}\frac{m_B^4}{m_K^4}\Delta r_{K\ Susy}^{e-\mu}\right] \leq 4 \cdot 10^2$$

Isidori, P.P. ’06

The large $\tan\beta$ scenario

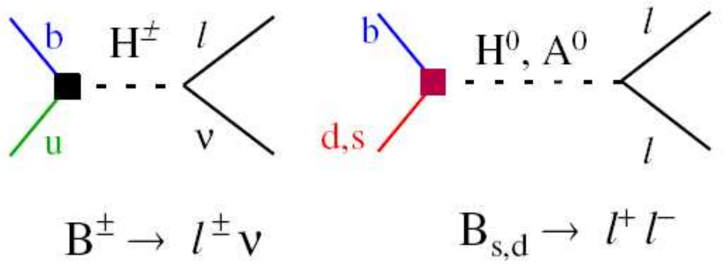
Key ingredients for the LU breaking:

- $M_{\ell 2}$ ($M = \pi,\ K,\ B$) physics:
  - Large $\tan\beta$, $M_H < 1\,TeV$
  - Large LFV slepton minxings, $\delta_{3j} \sim \mathcal{O}(1)$, ($m_{SUSY} \geq 1\text{TeV}$)
- τ physics:
  - Large $\tan\beta$, $M_H < 1\,TeV$
  - No LFV effects
- How natural is the large $\tan\beta$ scenario?
  - Top-Bottom Yukawa unification in GUT ($SO(10)$) $\Rightarrow$ $\tan\beta = (m_t/m_b)$
  - Correlations between $(B \to \tau\nu)$ and $(B \to X_s\gamma)$, ΔM_{B_s}, $(B_{s,d} \to \ell^+\ell^-)$, $(g-2)_\mu$ and m_{h^0}

Isidori, P.P., '06

Phenomenology of MFV at large $\tan\beta$

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

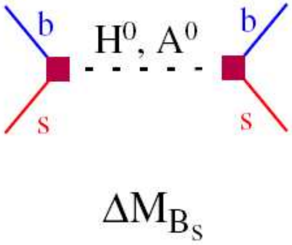


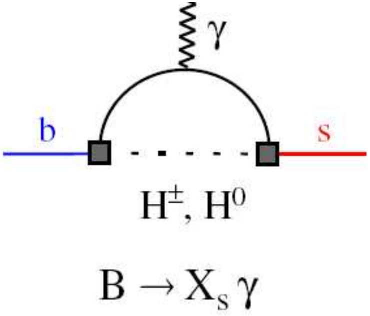
$B^\pm \to l^\pm \nu$ $B_{s,d} \to l^+ l^-$

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

Phenomenology of MFV at large tan β

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





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

Phenomenology of MFV at large $\tan\beta$

- MFV at large $\tan\beta$ predicts a suppression of $B \to \tau\nu$ and ΔM_s with respect to the SM

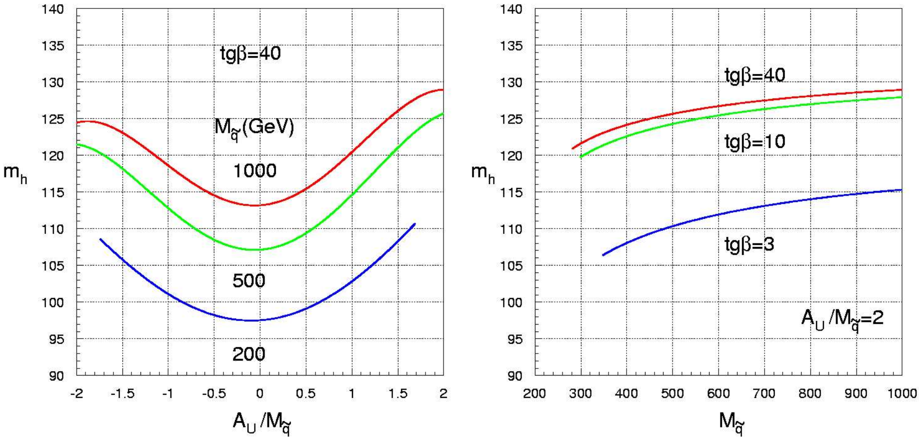
$$\frac{(\Delta M_{B_s})}{(\Delta M_{B_s})^{SM}} \simeq 1 - 3 \times 10^{-2} \left(\frac{\mu A_U}{m_{\tilde{q}}^2}\right)^2 \left(\frac{t_\beta}{50}\right)^4 \left(\frac{400\mathrm{GeV}}{M_H}\right)^2 .$$

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

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

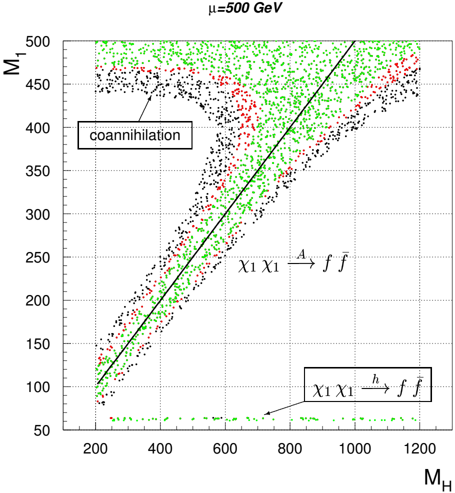
$\frac{Br(B \to \tau\nu)}{(\Delta M_{B_d})} \sim (V_{ub}/V_{td})^2/\hat{B}_d$ much better then $|V_{ub}|^2 f_B^2$!

Lightest Higgs boson mass



G.Isidori, P.P., '06

WMAP constraints @ large tan β



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

- **Dark Matter constraint satisfied for**
- **Coannihilation Processes**: $1 \lesssim \frac{M_{\rm NLSP}}{M_{\rm LSP}} \lesssim 1.1$
- **Resonant Processes**: $M_A \simeq 2M_{\rm LSP}$

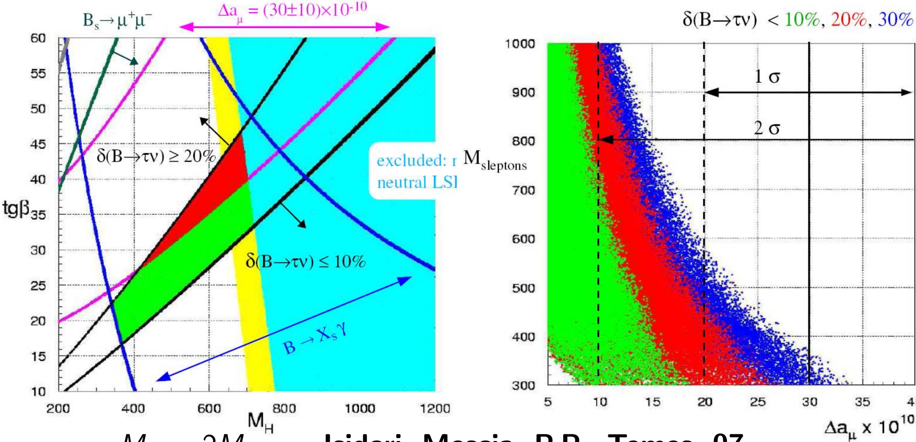
Isidori, Mescia, P.P., Temes, '07

Constraints/Reference-Ranges

Constraints/Reference-Ranges under WMAP constraints

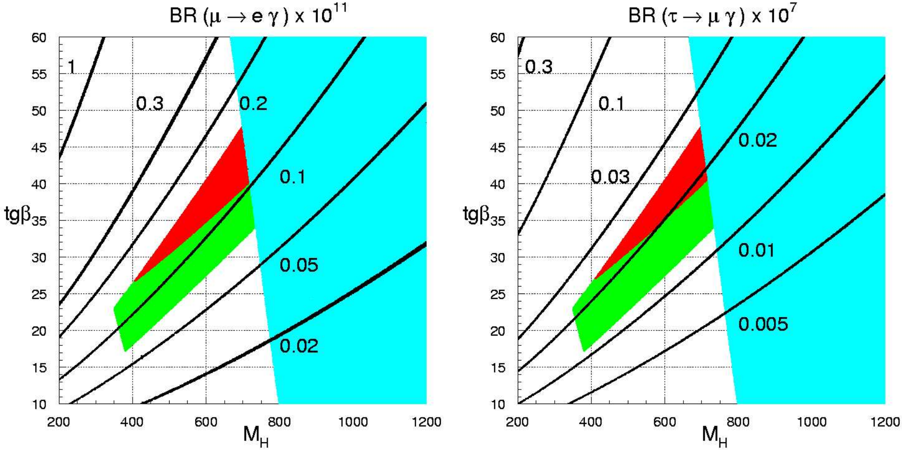
- $\mathbf{B} \to \mathbf{X_s}\gamma$: $[1.01 < \mathbf{R_{Bs\gamma}} < 1.24]$
- $\mathbf{a}_\mu$: $[2 < 10^{-9}(\mathbf{a}_\mu^{\rm exp} - \mathbf{a}_\mu^{\rm SM}) < 4]$
- $\mathbf{B} \to \mu^+\mu^-$: $[\mathcal{B}^{\rm exp} < 8.0 \times 10^{-8}]$
- ΔM_{B_s} : $[\mathbf{\Delta M_{B_s}} = 17.35 \pm 0.25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

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



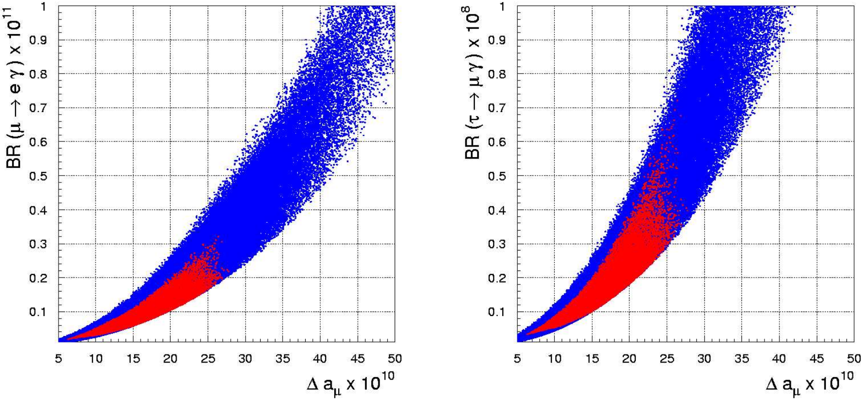
$M_H \sim 2M_1$ **Isidori, Mescia, P.P., Temes, 07**

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



$|\delta^{12}_{LL}| = 10^{-4}$ and $|\delta^{23}_{LL}| = 10^{-2}$, $[\mu, M_{\tilde{\ell}}] = [0.5, 0.4]$ TeV **IMPT, 07**

$(g-2)_\mu$ vs $\ell_i \to \ell_j\gamma$



$|\delta^{12}_{LL}| = 10^{-4}$ and $|\delta^{23}_{LL}| = 10^{-2}$, **IMPT, 07**

$$BR(\ell_i \to \ell_j\gamma) \approx \left[\frac{\Delta a_\mu}{20 \times 10^{-10}}\right]^2 \times \begin{cases} 1 \times 10^{-4} \ |\delta^{12}_{LL}|^2 & [\mu \to e] \\ 2 \times 10^{-5} \ |\delta^{23}_{LL}|^2 & [\tau \to \mu] \end{cases}$$

Conclusions

Where to look for New Physics?

- LFV signals in $\ell_i \to \ell_j\gamma$ would be a clear evidence of NP
- $\ell_i \to \ell_j\gamma$ can probe $\Lambda_{NP} > \mathrm{TeV}$, even beyond the LHC reach
- If we explain the $(g-2)_\mu$ anomaly within SUSY, $\ell_i \to \ell_j\gamma$ is expected to be visible in a vast class of LFV models
- $B^0_{s,d} \to \mu^+\mu^-$ and $B \to \ell\nu$ are still discovery channel and they represent a unique probe for SUSY even in the elegant (but pessimistic) MFV framework
- Visible Lepton Universality breaking effects in $B \to \ell\nu$ and $K \to \ell\nu$ can be generated through LFV effects

$$\Downarrow$$

Flavor Physics, Dark Matter and EWPO tests represents a very powerfull and complementary tool to the LHC to discover or constraint NP.