

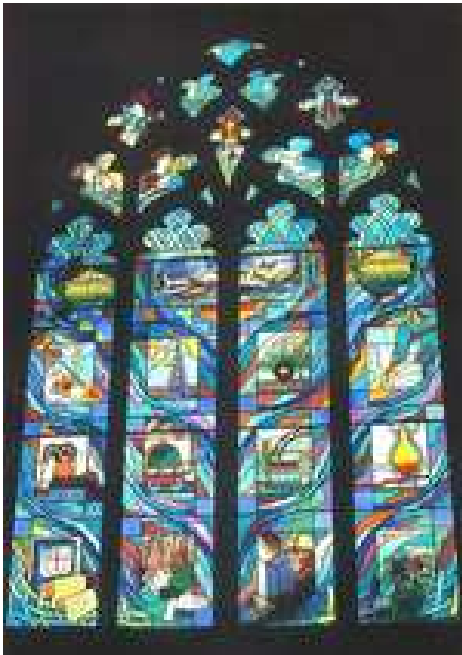
$\tau$

# Current constraints on SUSY parameters from LFV searches in $\tau$ decays



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- Motivation
- Input to the comparison
- Results for mSUGRA with heavy right-handed neutrino
- Results for mSUGRA extended with off-diagonal elements
- Outlook



- Many searches of supersymmetric contributions are being performed at current experiments. Among them are rare  $B$  decays, lepton flavor violation in  $\tau$  decays, precision test of Standard Model
- Large work is being done by SUSY phenomenologists to prepare for LHC/ILC (E.g. SPA, SUSY Les Houches Accord). Low energy observables are being neglected.
- Lepton flavor violation is claimed to be significantly enhanced by SUSY. However, usual SUSY models to be compared to data (mSUGRA, GMSB, AMSB) are flavor blind. The alternatives are mSUGRA with heavy right-handed neutrinos and SU(5).
- Need to consider all data simultaneously - LFV, LEP searches, cold dark matter, neutrino mixing, etc.

Conclude on validity of SUSY with low energy observables



- Calculate SUSY spectrum at  $m_{GUT}$  and RGE to weak scale with SPheno
- Lepton flavor violation in tau, muon and Z decays follows Brignole and Rossi hep-ph/0404211, based on general unconstrained MSSM. Neglect cross-contribution of  $\tau - \mu$ ,  $\tau - e$  and  $\mu - e$  mixing
- Cold dark matter density  $\Omega_{CDM}h^2$  is estimated with Micromegas
- MSSM contribution to muon magnetic anomalous moment  $a_\mu$  is as in hep-ph/0404211, taking into account LFV
- $\Delta\rho$  and  $\mathcal{B}(b \rightarrow s\gamma)$  are taken from SPheno (not yet very precise calculation)
- comparison with data is done for grid of SUSY parameters



90% confidence limits:

$\mathcal{B}(\tau \rightarrow \mu\gamma)$	$< 6.8 \cdot 10^{-8}$	BABAR
$\mathcal{B}(\tau \rightarrow e\gamma)$	$< 1.1 \cdot 10^{-7}$	preliminary BABAR (talk by H.Hadavand)
$\mathcal{B}(\tau \rightarrow \ell\ell\ell)$	$< 0.7 - 2 \cdot 10^{-7}$	combined BABAR and Belle
$\mathcal{B}(\tau \rightarrow \ell\rho, \ell\eta, \ell\eta')$	$1 - 5 \cdot 10^{-7}$	BABAR or Belle
$\mathcal{B}(\mu \rightarrow e\gamma)$	$< 1.2 \cdot 10^{-11}$	PDG2004
$\mathcal{B}(\mu \rightarrow eee)$	$< 1.0 \cdot 10^{-12}$	PDG2004
$\Omega_{CDM}h^2$	$< 0.129$	WMAP
$a_\mu$	$\in [0, 40 \cdot 10^{-9}]$	g-2 with $a_\mu^{hadr}$ from $e^+e^- \rightarrow \pi^+\pi^-$ , not neglecting $\tau$ data
$\Delta\rho$	$\in [-0.0022, 0.0017]$	$3\sigma$ , PDG2004
$\mathcal{B}(b \rightarrow s\gamma)$	$\in [2.2 \cdot 10^{-4}, 4.8 \cdot 10^{-4}]$	add 30% errors for NLO

# mSugra with heavy right handed neutrinos (mSugraNuR)

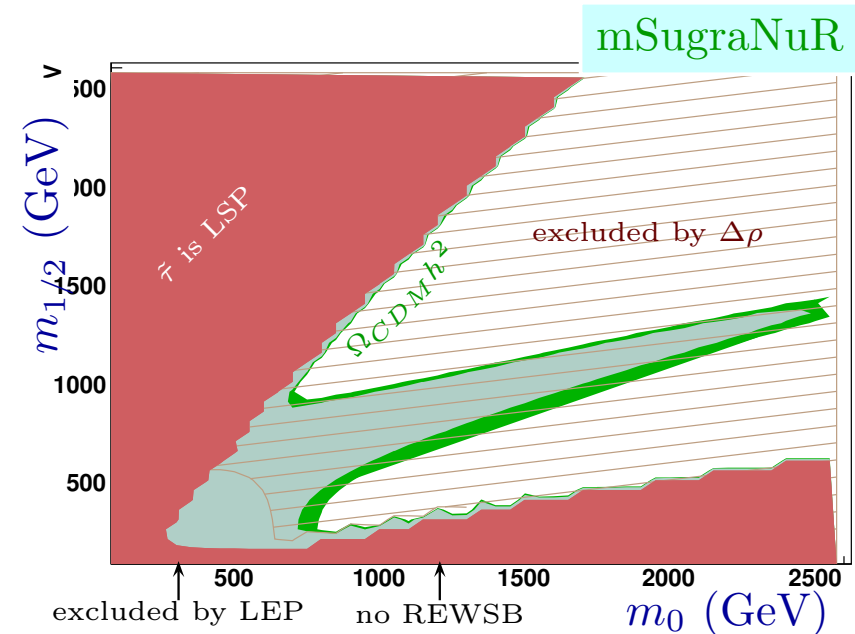
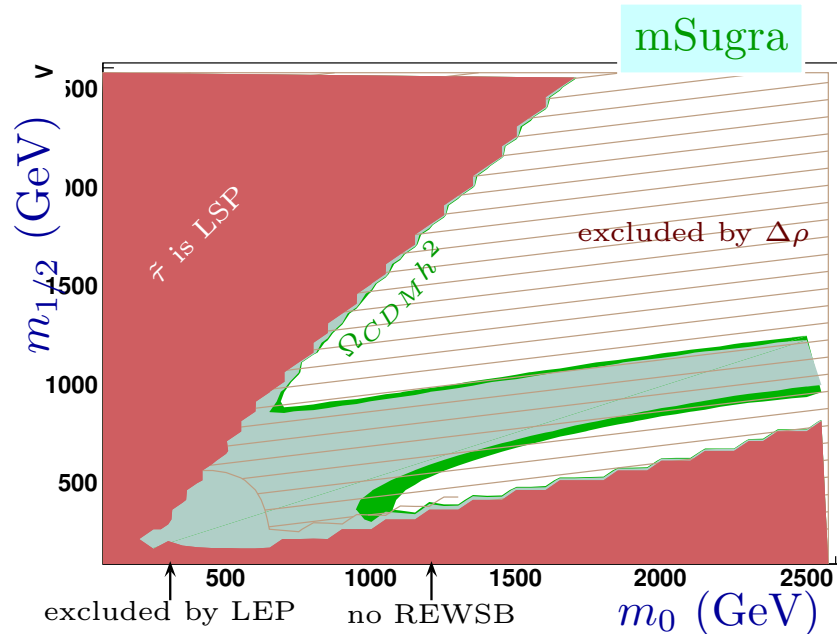
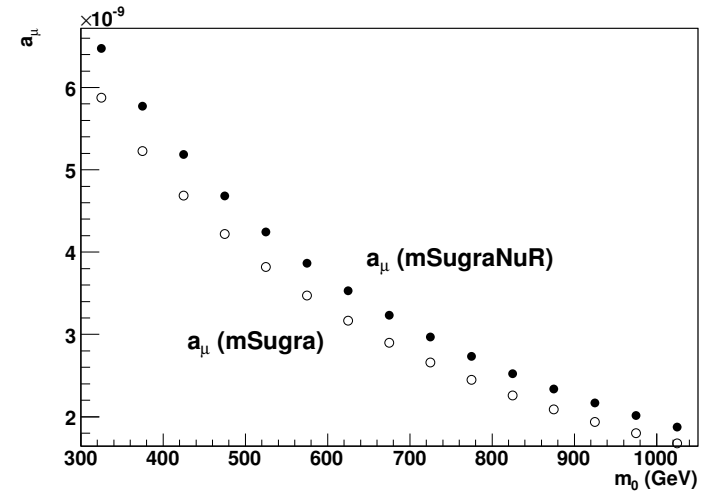
Relevant part of Lagrangian

$$\mathcal{L} = Y_\nu L \tilde{H}_2 N_R + Y_\ell L \tilde{H}_1 E - M_{\tilde{L}}^2 \tilde{L}^* \tilde{L} - M_{\tilde{E}}^2 \tilde{E}^* \tilde{E} - A_\ell \tilde{L} H_1 \tilde{E}^* - \mu \tilde{H}_1 \tilde{H}_2 - B\mu H_1 H_2 + h.c.$$

- gaugino mass parameter:  $M_j(m_{GUT}) = m_{1/2}$
- scalar mass parameter:  $M_i^2(m_{GUT}) = m_0^2$
- trilinear couplings:  $A_i(m_{GUT}) = Y_i(m_{GUT}) \cdot A_0$
- $Y_\nu = V_R V_{MNS}$  where  $V_{R_{ii}}(m_{\nu_R}) = \sqrt{2m_{\nu_i} m_{\nu_R}}/v_2$  (as suggested by Hisano *et al.*),  $V_{MNS}$  is neutrino mixing matrix with normal hierarchy, taken from the best fit to data.  $m_{\nu_R} = 5 \cdot 10^{14}$ .  $\Theta_{13} = 0$ ,  $\delta = 0$
- Sign  $\mu$  : positive  $\mu$  is favored by g-2 data

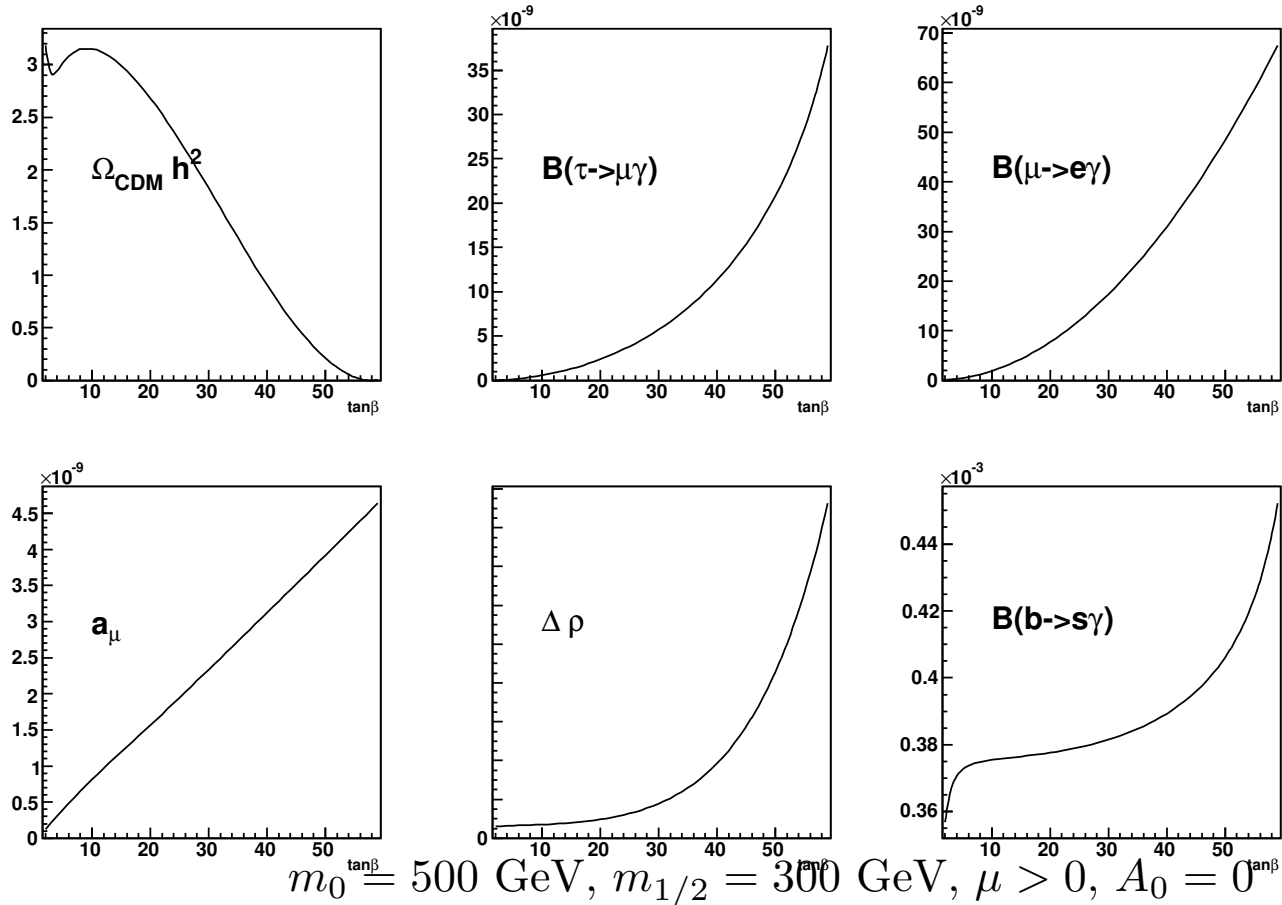


- $a_\mu$  is sensitive to off-diagonal  $M_{\tilde{L}}^2$  and  $M_{\tilde{E}}^2$
- $\Omega_{CDM}h^2$ ,  $\Delta\rho$  slightly depend on  $N$



$$\tan\beta = 55, A_0 = 0, \mu > 0$$

# mSugraNuR: Dependence on $\tan\beta$



the larger  $\tan\beta$  the smaller  $\Omega_{CDM}h^2$  and the larger LFV.

$a_\mu$  is small and does not favor  $g-2 + e^+e^- \rightarrow \pi^+\pi^-$  data  
 $(25.2 \pm 9.2)10^{-9}$ ,  $b \rightarrow s\gamma$  deviation from SM is small

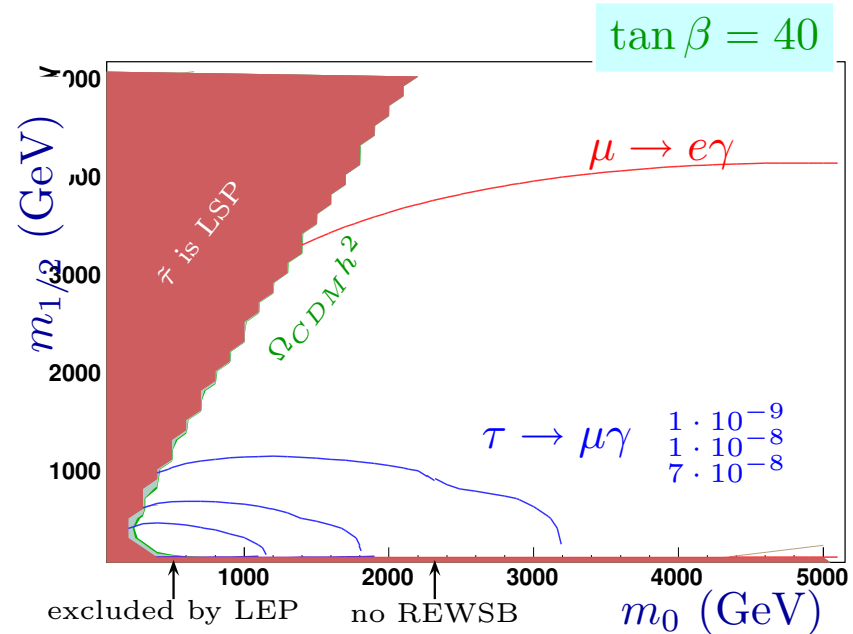
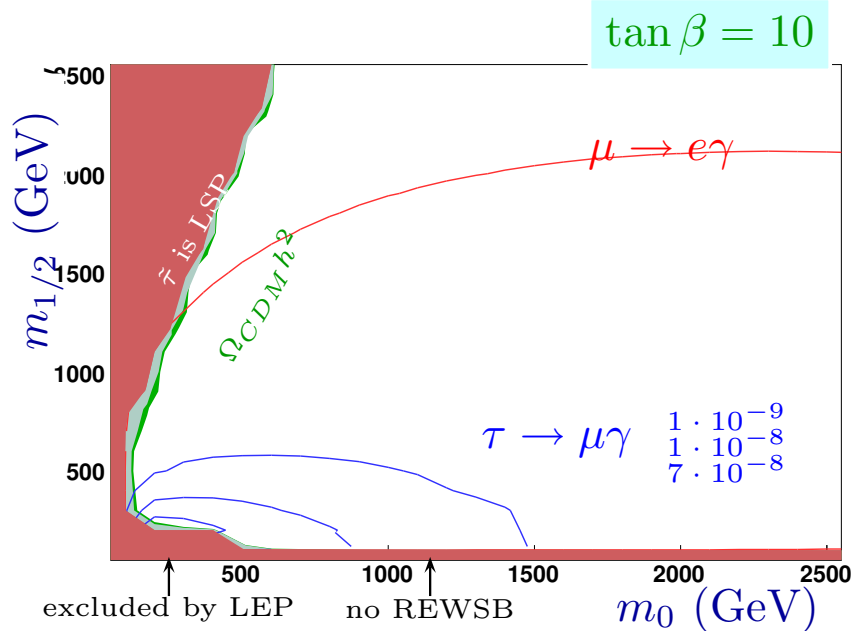
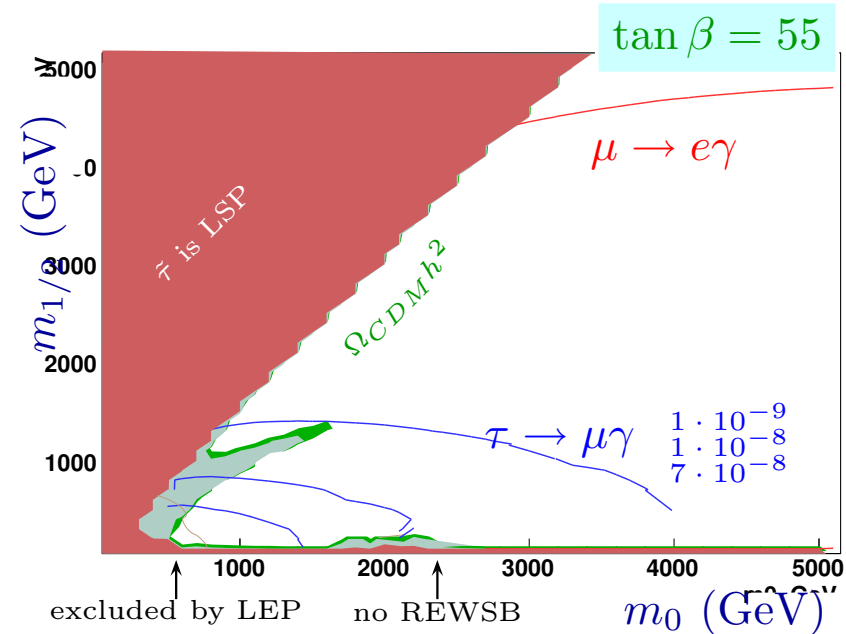
# mSugraNuR: Exclusion plots for $\tan\beta = 55, 40, 10$



90% CL,  $A_0 = 0$ ,  $\mu > 0$

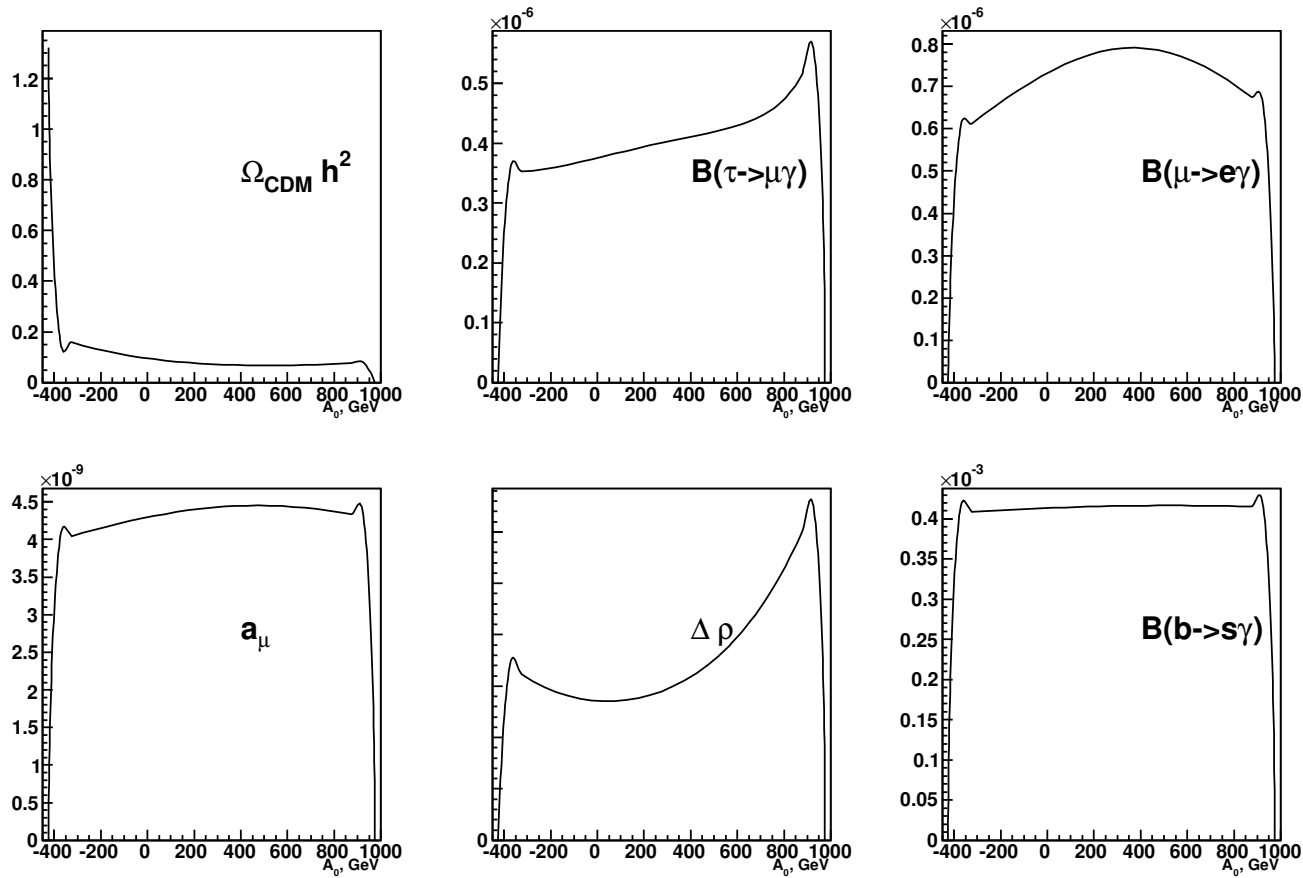
LFV excludes areas of *small*  $m_{1/2}$  and *small*  $m_0$ .

LFV together with  $\Omega_{CDM}h^2$  and  $\Delta\rho$  excludes practically complete range





# mSugraNuR: Dependence on trilinear constant $A_0$

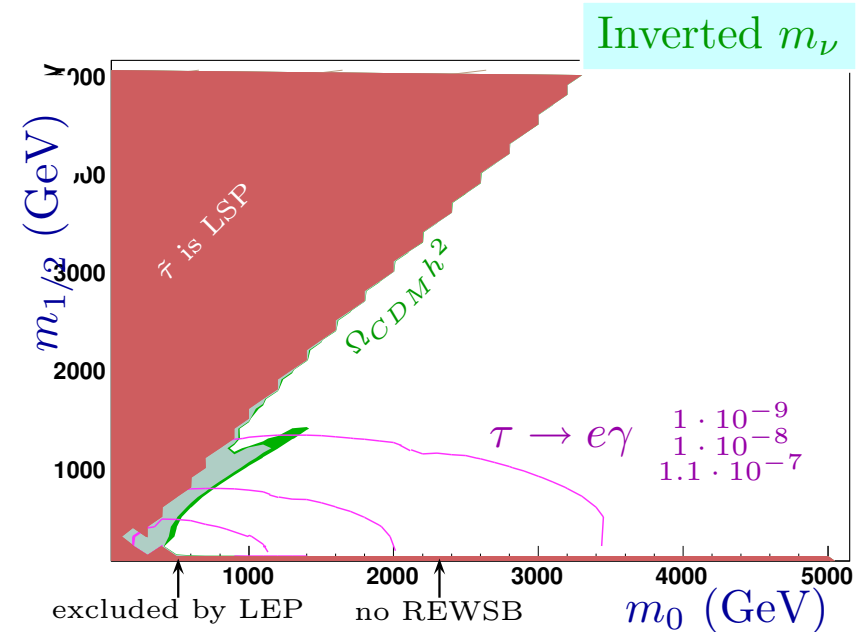
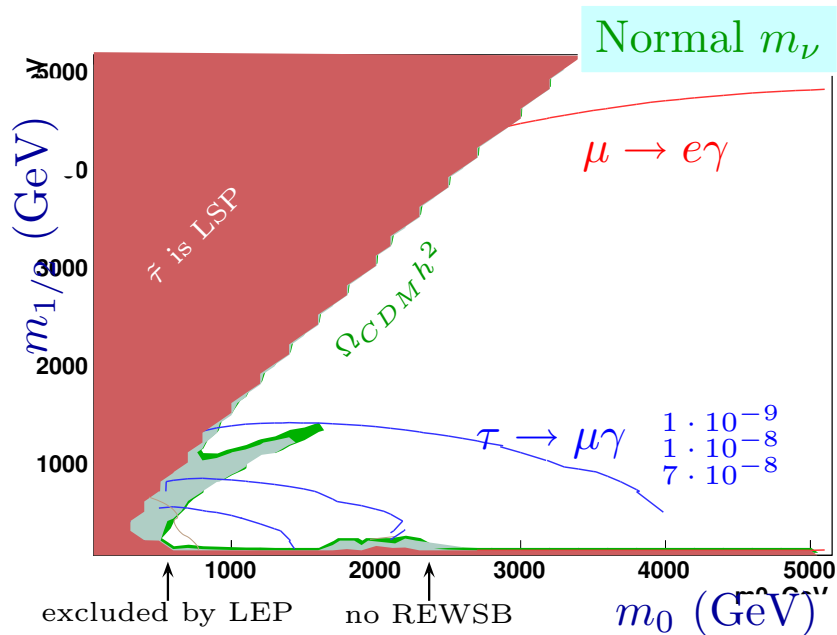


$m_0 = 500$  GeV,  $m_{1/2} = 300$  GeV,  $\mu > 0$ ,  $\tan \beta = 55$

for  $A_0 < -400$  GeV and  $A_0 > 1000$  GeV  $M_{\tilde{L}}^2(2, 3), M_{\tilde{L}}^2(1, 2) > M_{\tilde{L}}^2(i, i)$

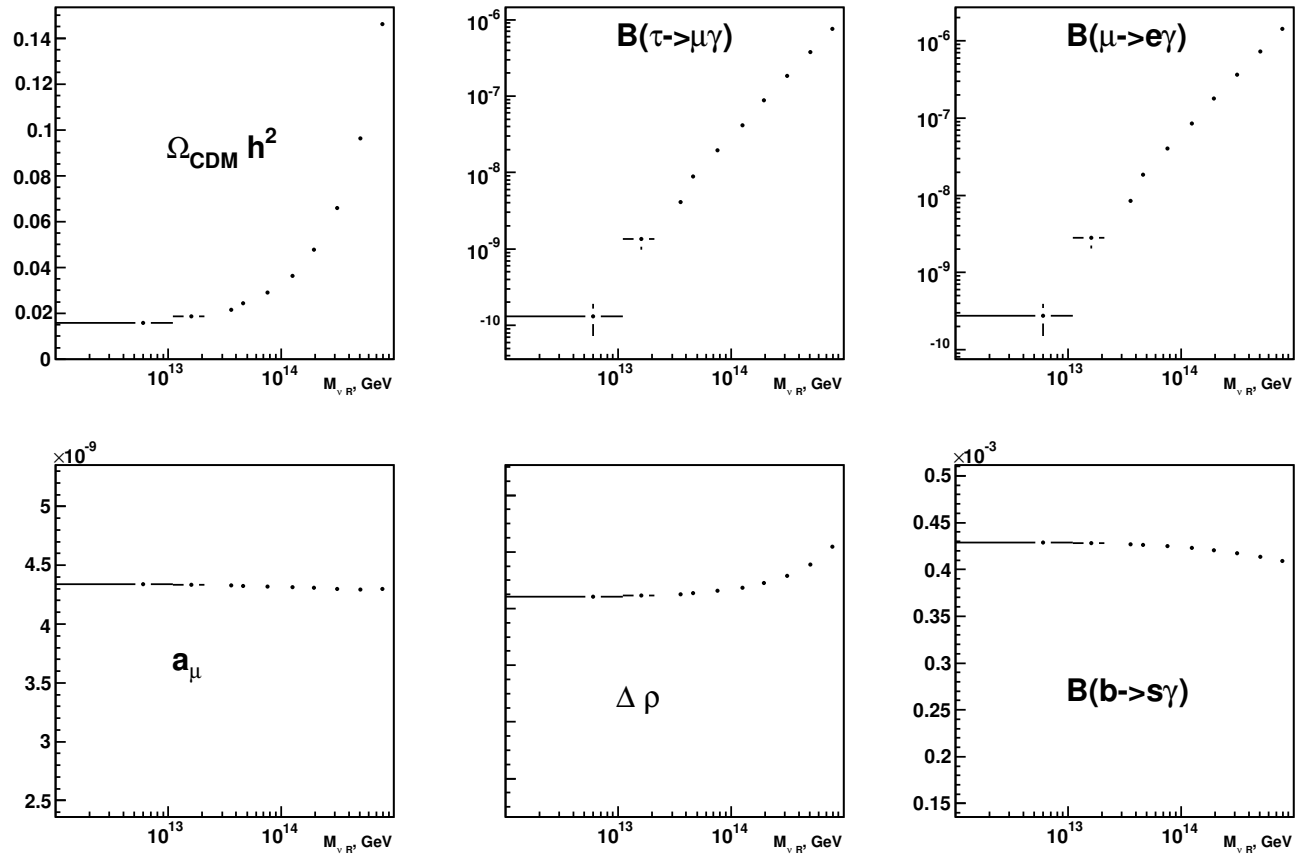
# mSugraNuR: Correlation between different LFV processes

- Given best fit neutrino data and *normal*  $m_\nu$  hierarchy  
 $\mathcal{B}(\tau \rightarrow \mu\gamma) \sim \mathcal{B}(\mu \rightarrow e\gamma) \gg \mathcal{B}(\tau \rightarrow e\gamma)$  for most range of parameters. Therefore current upper limits of  $\mathcal{B}(\mu \rightarrow e\gamma)$  provides stringiest constraints.  
 In case of *inverted*  $m_\nu$  hierarchy  $\mathcal{B}(\tau \rightarrow \mu\gamma)$  can be order of magnitude larger or smaller than  $\mathcal{B}(\mu \rightarrow e\gamma)$ , while  $\mathcal{B}(\tau \rightarrow e\gamma)$  is significantly larger than both. →
- $\mathcal{B}(\tau \rightarrow \mu\gamma)$  can be much larger or much smaller than  $\mathcal{B}(\tau \rightarrow e\gamma)$
- For the set of parameters scanned  
 $\mathcal{B}(\tau \rightarrow \mu\gamma) \gg \mathcal{B}(\tau \rightarrow \mu X, X \neq \gamma)$  and  
 $\mathcal{B}(\tau \rightarrow e\gamma) \gg \mathcal{B}(\tau \rightarrow eX, X \neq \gamma)$
- $\mathcal{B}(Z \rightarrow \ell\tau) \sim 10^{-12}$  not yet reachable by experiment



scale of  $m_0, m_{1/2}$  is different from previous plot

variation of neutrino mixing parameters ( $V_{MNS}, m_\nu$ ) within experimental uncertainties results in  $\sim 30\%$  variation of LFV



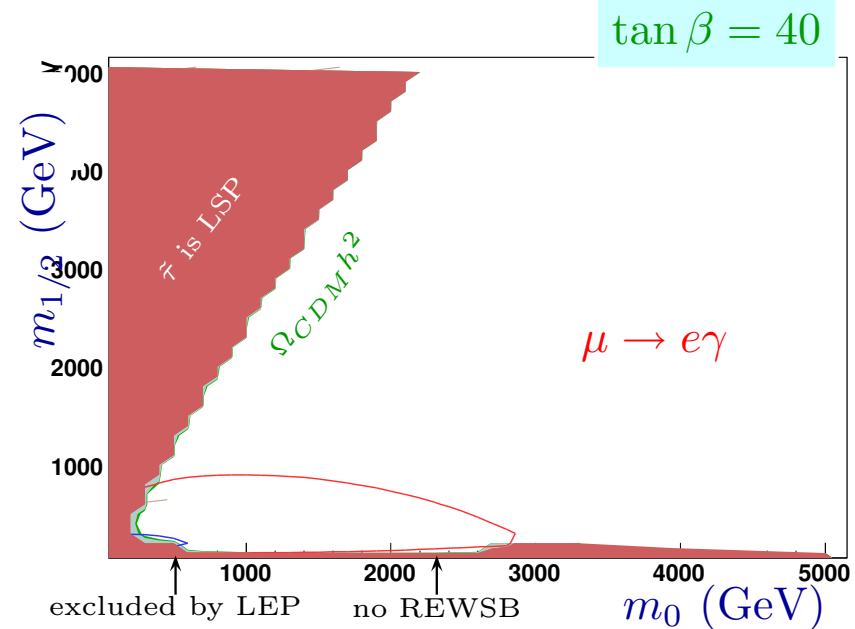
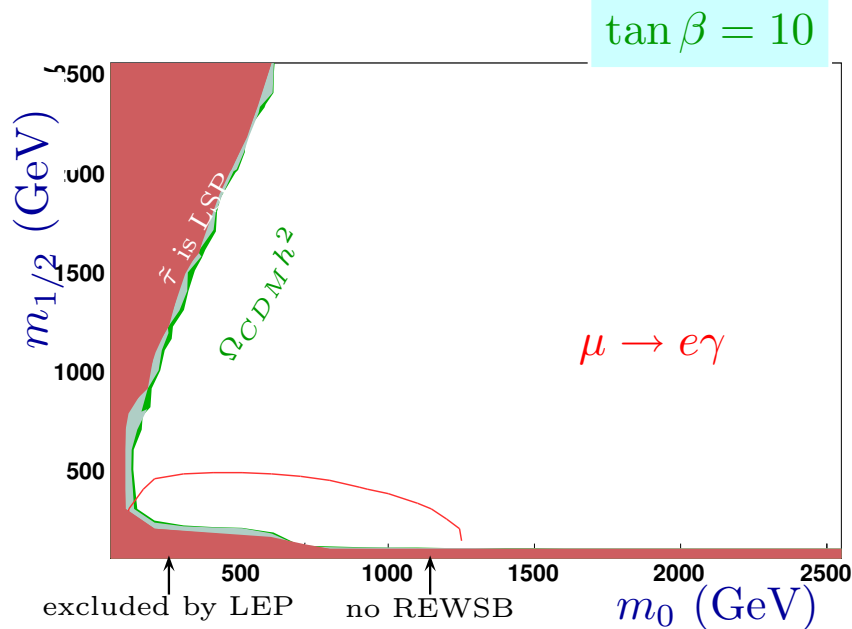
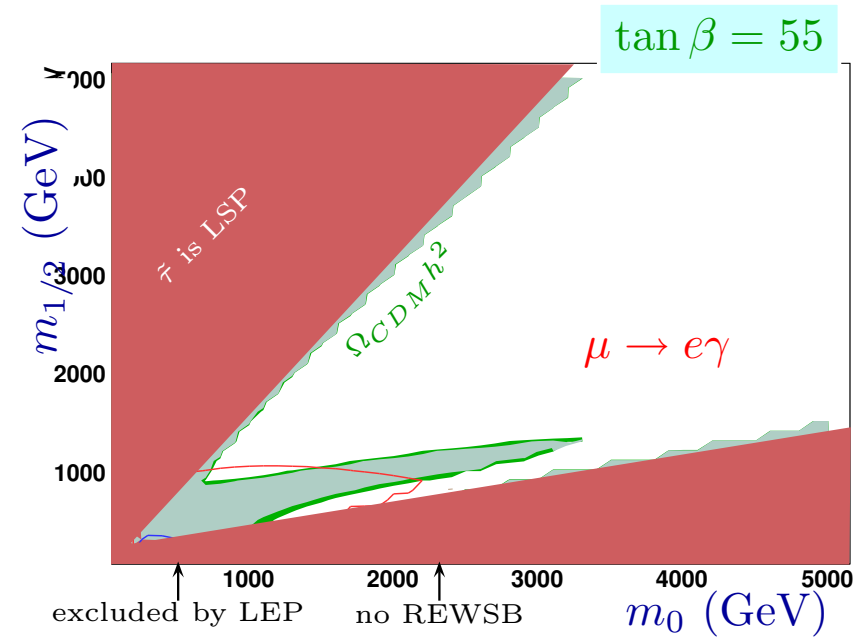
$$m_0 = 500 \text{ GeV}, m_{1/2} = 300 \text{ GeV}, \mu > 0, A_0 = 0, \tan \beta = 55$$

# mSugraNuR: Exclusion plots for $m_{\nu_R} = 10^{13}$



90% CL,  $m_{\nu_R} = 1 \cdot 10^{13}$ ,  $A_0 = 0$

the constraints are weaker for smaller  $m_{\nu_R}$ , but still quite exclusive





- LFV rates can be significant in mSugra with heavy right handed neutrinos
- LFV excludes area of small  $m_0$  and small  $m_{1/2}$ . Together with  $\Omega_{CDM}h^2$  and  $\Delta\rho$  it excludes very large range of parameters.
- LFV is very sensitive to  $m_{\nu_R}$ ,  $m_\nu$  and to neutrino mixing angles.
- $\mathcal{B}(\mu \rightarrow e\gamma)$  provides strongest LFV limits in case of normal neutrino hierarchy, while  $\mathcal{B}(\tau \rightarrow e\gamma)$  is critical for inverted neutrino hierarchy.



Relevant part of Lagrangian:

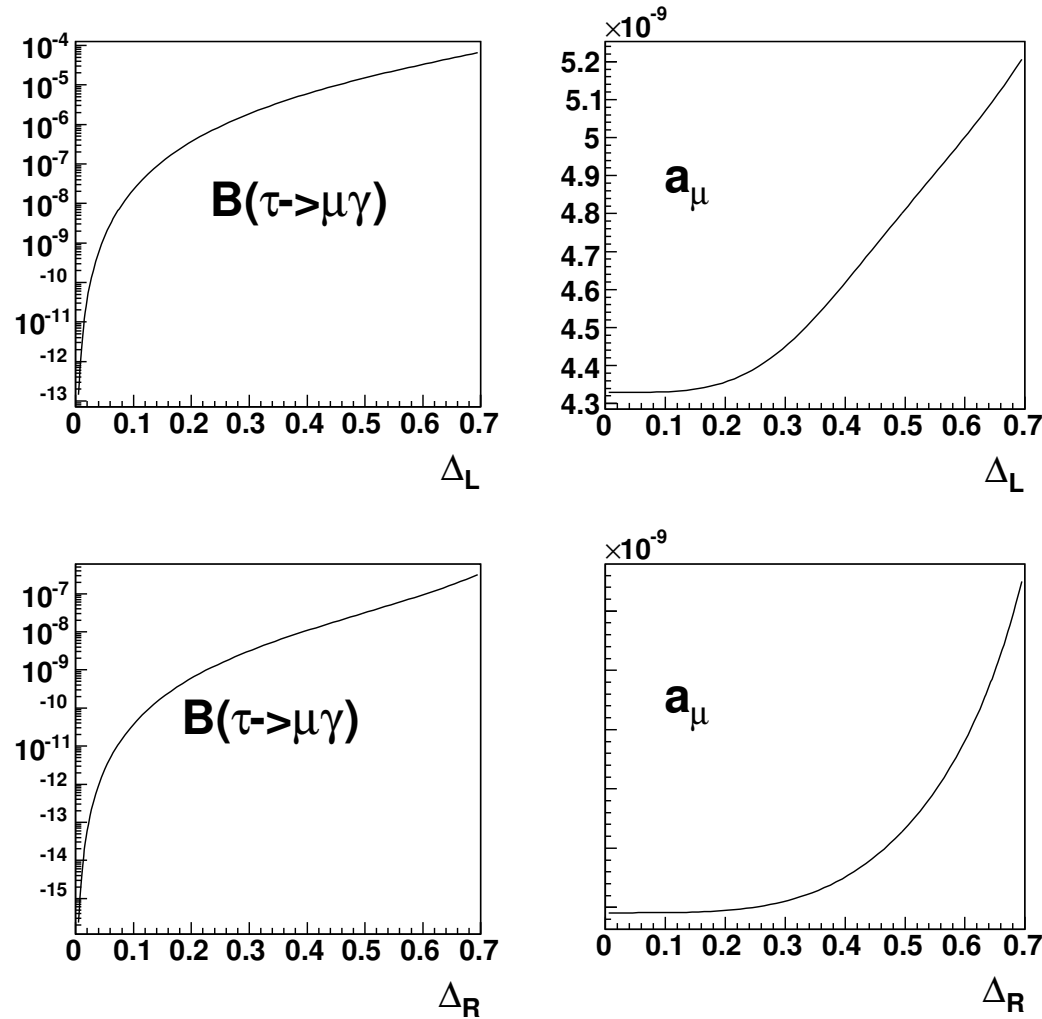
$$\mathcal{L} = Y_\ell L \tilde{H}_1 E - M_{\tilde{L}}^2 \tilde{L}^* \tilde{L} - M_{\tilde{E}}^2 \tilde{E}^* \tilde{E} - A_\ell \tilde{L} H_1 \tilde{E}^* - \mu \tilde{H}_1 \tilde{H}_2 - B\mu H_1 H_2 + h.c.$$

- gaugino mass parameter:  $M_j(m_{GUT}) = m_{1/2}$
- scalar mass parameter:  $M_i^2(m_{GUT}) = m_0^2$
- trilinear couplings:  $A_i(m_{GUT}) = Y_i(m_{GUT}) \cdot A_0$
- Extend flavor blind mSugra with off-diagonal elements
 
$$M_{\tilde{L}}^2(2, 3)(m_{GUT}) = \Delta_L^2 m_0^2,$$

$$M_{\tilde{E}}^2(2, 3)(m_{GUT}) = \Delta_R^2 m_0^2$$
 (mixing angle is maximal) .
- Sign  $\mu$  : positive  $\mu$  is favored by g-2 data

Use MSSM RGE (no right-handed neutrinos) to estimate parameters at weak scale. The plots shown are for  $\tau \rightarrow \mu X$  only, but the conclusions are applicable to  $\mu \rightarrow e X$  and  $\tau \rightarrow e X$  as well.

# mSugraNuR: Dependence on $\Delta_L, \Delta_R$



$$m_0 = 500 \text{ GeV}, m_{1/2} = 300 \text{ GeV}, \mu > 0, A_0 = 0$$

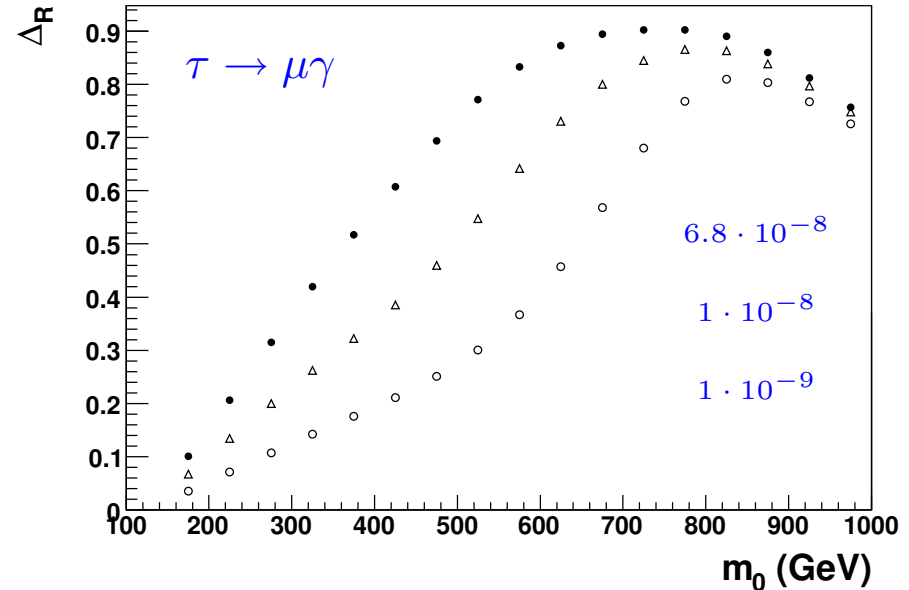
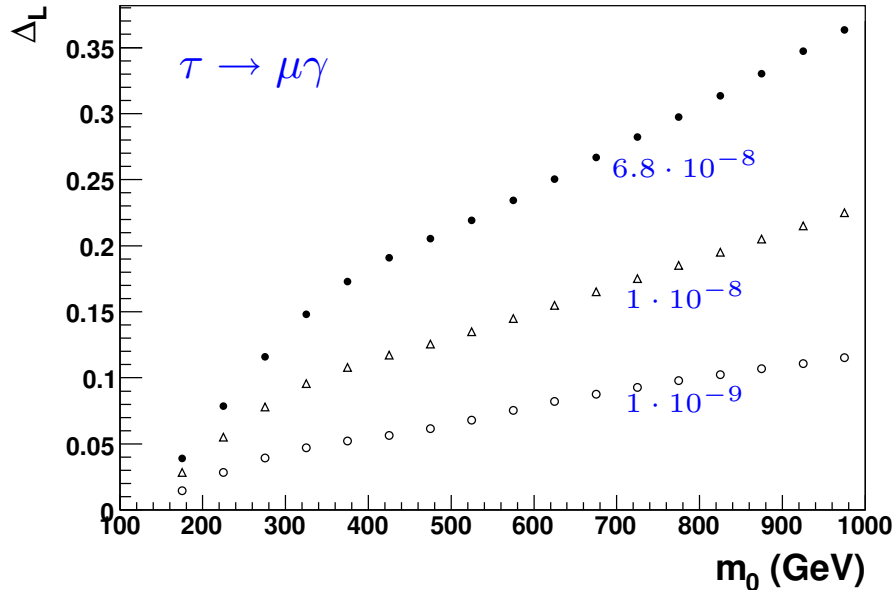


# Constraints on $\Delta_L$ and $\Delta_R$ from $\mathcal{B}(\tau \rightarrow \mu\gamma)$

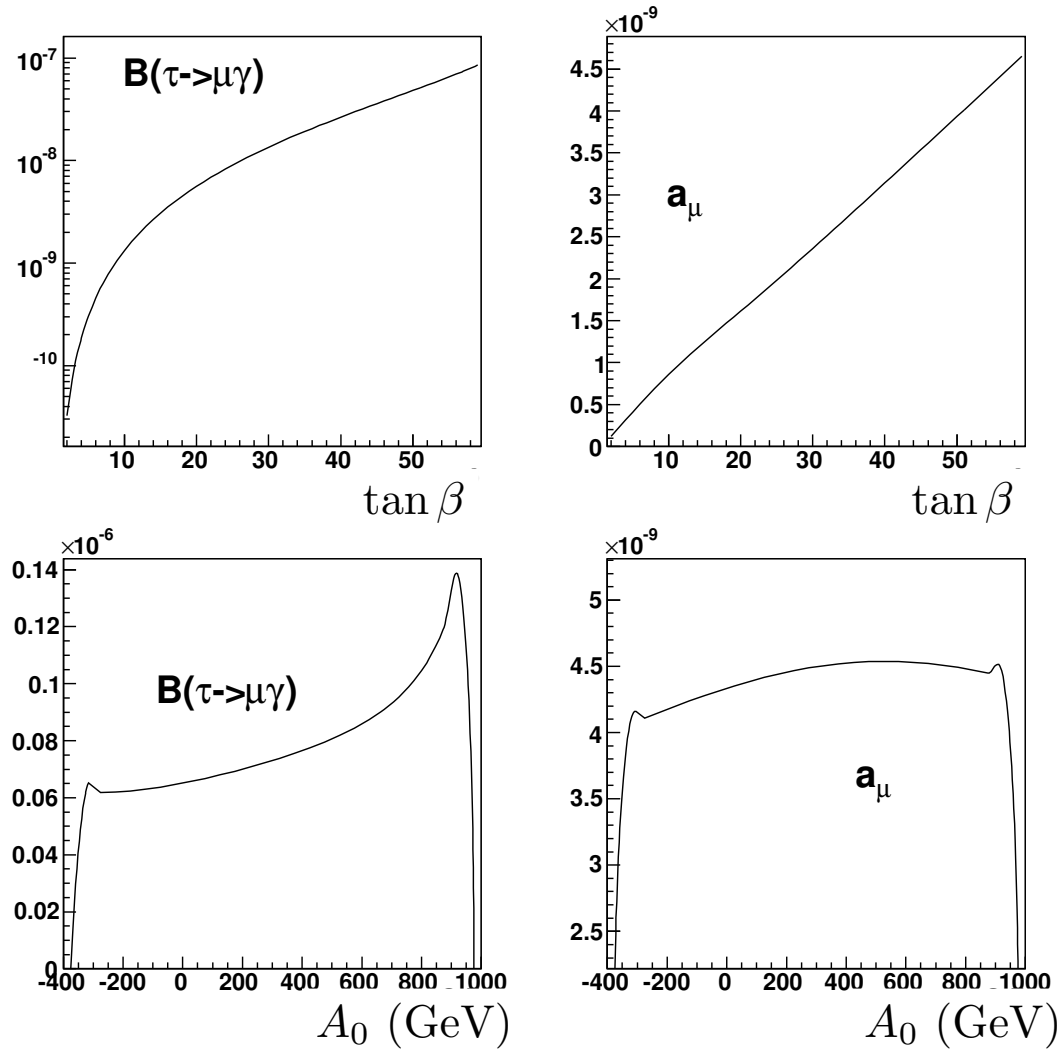


$$m_{1/2} = 100 + 0.8 \cdot m_0 \text{ (within favorable } \Omega_{CDM} h^2 \text{ region)}$$

$$\tan \beta = 55, \mu > 0, A_0 = 0$$



Strong constraints on  $\Delta_L$ , less strong on  $\Delta_R$



$$m_0 = 500 \text{ GeV}, m_{1/2} = 300 \text{ GeV}, \mu > 0, A_0 = 0$$

similar to mSugraNuR, but different amplitude



- It is important to consider LFV process/low energy observables to validate SUSY
- mSugraNuR:
  - $a_\mu$  and  $\Omega_{CDM}h^2$  are sensitive to presence of heavy right-handed neutrinos
  - $a_\mu$  is small ( $\sim 4 \cdot 10^{-9}$ )
  - large  $\tan\beta$  results in small  $\Omega_{CDM}h^2$  and large LFV
  - given normal  $m_\nu$  hierarchy  $\mathcal{B}(\mu \rightarrow e\gamma)$  excludes large range of SUSY parameters. For inverted  $m_\nu$  hierarchy  $\mathcal{B}(\tau \rightarrow e\gamma)$  is very strict.
  - LFV strongly depends on  $m_{\nu_R}$  and less strongly on  $V_{MNS}$

- mSugra with off-diagonal elements:
  - both  $\mathcal{B}(\tau \rightarrow \mu\gamma)$  and  $a_\mu$  are very sensitive to off-diagonal  $\Delta_L(2,3)$  and  $\Delta_R(2,3)$
  - $\mathcal{B}(\ell_i \rightarrow \ell_j\gamma)$  strongly constrains  $\Delta_L$  and less  $\Delta_R$ . E.g. current constraint on  $\mathcal{B}(\tau \rightarrow \mu\gamma)$  suggests that  $\Delta_L < 0.4$  for full range of other parameters.
  - $\mathcal{B}(\tau \rightarrow \mu X, X \neq \gamma)$  is less restrictive than  $\mathcal{B}(\tau \rightarrow \mu\gamma)$
  
- Analysis is in progress -  
interested to test well motivated high scale SUSY models,  
aiming to constrain SUSY parameters in *model independent* way