Lepton Flavour Violating Z Decays in the MSSM

José I. Illana

in collaboration with: **Manuel Masip**

Universidad de Granada

- **Present status of LFV**
- **SUSY: parametrization of slepton mass matrices**
- $\boxed{Z \to \ell_I \ell_J}$ **at DESY's TESLA GigaZ**
- **Bounds from** $\boxed{\ell_J \to \ell_I \gamma}$
- **LFV and** $\boxed{(g_\mu - 2)}$
- **Summary and conclusions**

[hep-ph/0207328, Phys. Rev. D (Feb 2003)]

Status of LFV

$\mathrm{BR}(\mu \to e\gamma) < 1.2 \times 10^{-11}$	[MEGA '99]	$\mathrm{BR}(\mu \to 3e) < 1.0 \times 10^{-12}$	[SINDRUM '88]
$\mathrm{BR}(\tau \to e\gamma) < 2.7 \times 10^{-6}$	[CLEO '99]	$\mathrm{BR}(\tau \to 3e) < 2.9 \times 10^{-6}$	[CLEO '98]
new: 6×10^{-7} $\mathrm{BR}(\tau \to \mu\gamma) < 1.1 \times 10^{-6}$	[Belle '02] [CLEO '00]	$\mathrm{BR}(\tau \to 3\mu) < 1.9 \times 10^{-6}$	[CLEO '98]

$\mathrm{R}(\mu\mathrm{Ti} \to e\mathrm{Ti}) < 6.1 \times 10^{-13}$ [SINDRUM '98]

$\mathrm{BR}(Z \to \mu e) < 1.7 \times 10^{-6}$	[OPAL '95]		$< 2.0 \times 10^{-9}$	**[GigaZ]**
$\mathrm{BR}(Z \to \tau e) < 9.8 \times 10^{-6}$	[OPAL '95]	$\Longrightarrow$	$< \kappa \times 6.5 \times 10^{-8}$	$(\kappa = 0.2 - 1.0)$
$\mathrm{BR}(Z \to \tau\mu) < 1.2 \times 10^{-5}$	[DELPHI '97]		$< \kappa \times 2.2 \times 10^{-8}$	

- Neutrino oscillations (neutral LFV) $\Rightarrow$ νSM predicts tiny charged LFV [LFC in SM]
- SUSY models (unbroken R–parity) $\Rightarrow$ slepton mass matrix natural source of LFV

Aim: $Z \to \ell_I \ell_J$	**GigaZ potential, independently of origin of SUSY breaking**

with constraints dominantly from $\ell_J \to \ell_I\gamma$ since:

$$\mathrm{BR}(\ell_J \to 3\ell_I) \approx \alpha_{em}\mathrm{BR}(\ell_J \to \ell_I\gamma), \quad \mathrm{R}(\mu\mathrm{Ti} \to e\mathrm{Ti}) \approx 5 \times 10^{-3} \times \mathrm{BR}(\mu \to e\gamma)$$

General Lorentz Structure $V\bar{\ell}_I\ell_J$

- **Amplitudes** for **on–shell** external legs: one–loop parametrization $[\alpha_W = g^2/(4\pi)]$

$$\mathcal{M}_Z = -ig\,\frac{\alpha_W}{4\pi}\,\varepsilon_Z^\mu \bar{u}_{\ell_I}(p_2)\left[\gamma_\mu(f_V^Z - f_A^Z\gamma_5) + \frac{\sigma_{\mu\nu}q^\nu}{M_W}(if_M^Z + f_E^Z\gamma_5)\right]u_{\ell_J}(p_1)$$

$$\mathcal{M}_\gamma = -ie\,\frac{\alpha_W}{4\pi}\,\varepsilon_\gamma^\mu \bar{u}_{\ell_I}(p_2)\left[\gamma_\mu\underbrace{f_V^\gamma}_{=0\ \text{for}\ I\neq J} + \frac{\sigma_{\mu\nu}q^\nu}{m_{\ell_J}}(if_M^\gamma + f_E^\gamma\gamma_5)\right]u_{\ell_J}(p_1)$$

Dipole form factors (f_M, f_E) are chirality flipping (proportional to a fermion mass)

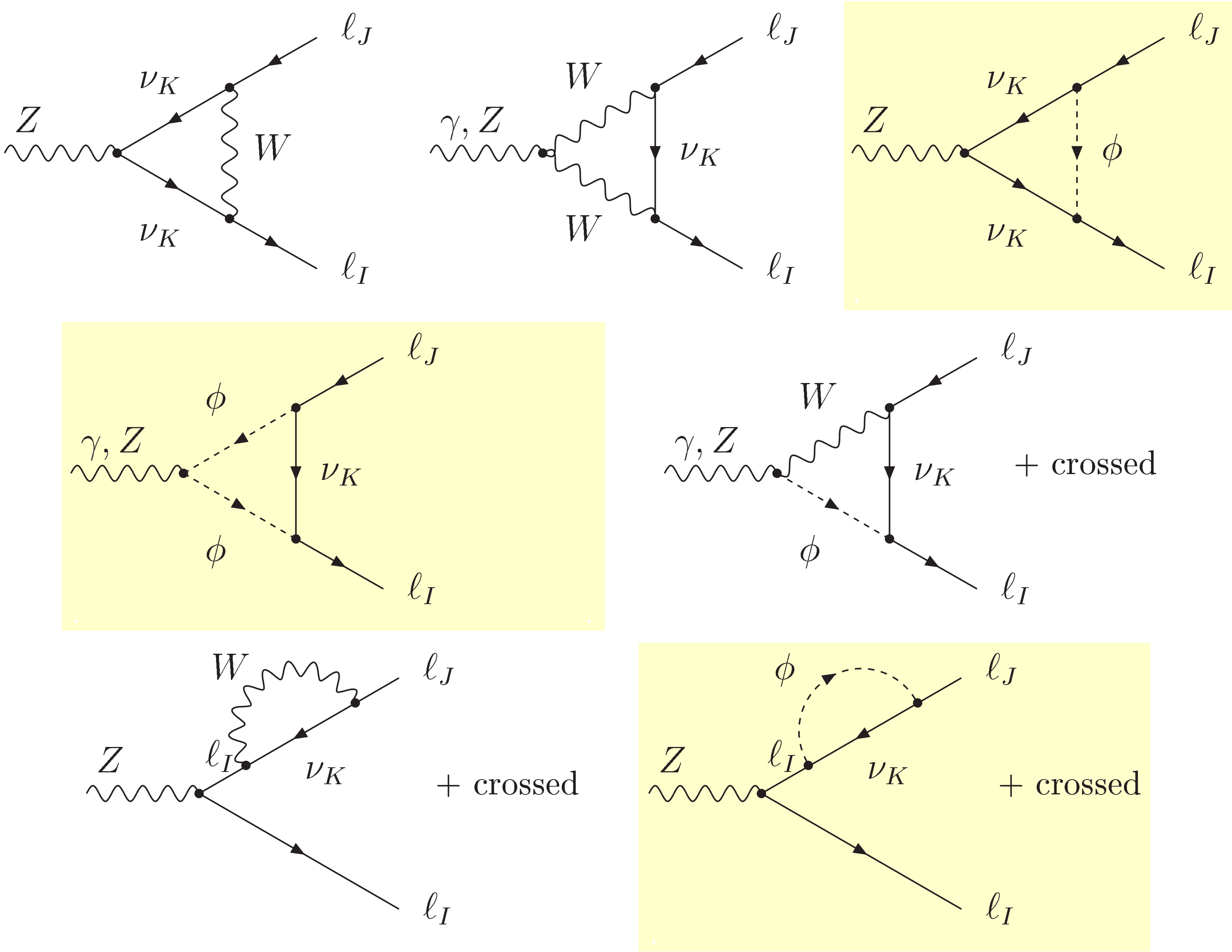
- **Branching ratios** $[f_{L,R} = f_V \pm f_A]$

$$\mathrm{BR}(Z\to\bar{\ell}_I\ell_J + \ell_I\bar{\ell}_J) = \underbrace{\frac{\alpha_W^3 M_Z}{48\pi^2\Gamma_Z}}_{\mathcal{O}(10^{-6})}\left[|f_L^Z|^2 + |f_R^Z|^2 + \frac{1}{c_W^2}(|f_M^Z|^2 + |f_E^Z|^2)\right]$$

$$\mathrm{BR}(\ell_J\to\ell_I\gamma) = \frac{12\alpha}{\pi}\frac{M_W^4}{m_{\ell_J}^4}\left(|f_M^\gamma|^2 + |f_E^\gamma|^2\right)\times\underbrace{\mathrm{BR}(\ell_J\to\ell_I\nu_J\bar{\nu}_I)}_{=1/0.17/0.17\ \text{for}\ \mu e/\tau e/\tau\mu}$$

- For $\ell\equiv\ell_I=\ell_J$, **anomalous magnetic dipole moment** $a_\ell = (g_\ell-2)/2 = \dfrac{\alpha_W}{4\pi}f_M^\gamma$

Standard Model + massive neutrinos



$$\mathcal{M} \propto \sin^2 2\theta \, \frac{\Delta m_{IJ}^2}{M_W^2}$$

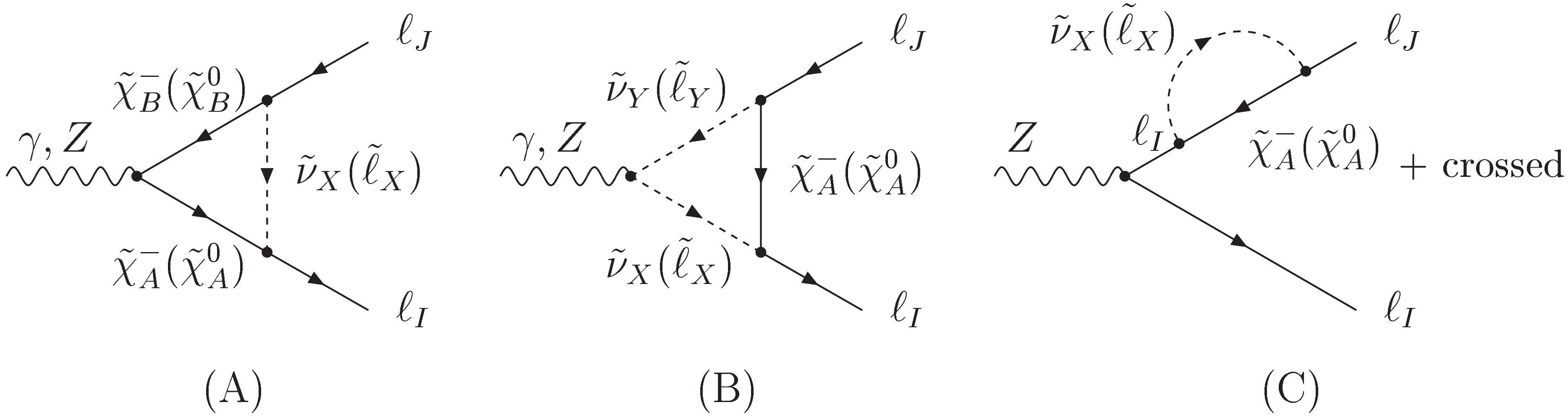
Oscillation data $\Rightarrow$

$$\text{BR}(\ell_J \to \ell_I \gamma) \lesssim 10^{-48}$$

$$\text{BR}(Z \to \ell_I \ell_J) \lesssim 10^{-54}$$

hopeless!

MSSM



- Charginos–sneutrinos $(\tilde{\chi}^{\pm}_{A=1,2}$; $\tilde{\nu}_{X=1,2,3}$ 'L')
  Neutralinos–charged sleptons $(\tilde{\chi}^{0}_{A=1,2,3,4}$; $\tilde{\ell}_{X=1,\ldots,6}$ 'L' and 'R')
- (A)+(B)+(C): ultraviolet finite and decoupling of heavy SUSY particles
- (C) no contribution to $\ell_J \to \ell_I \gamma$ (no dipole structure)
- FCNC/LFV $(\ell_I \neq \ell_J) \Leftrightarrow \begin{cases} \text{slepton family mixing} \\ \text{slepton mass splitting (non–degeneracy)} \end{cases}$ (LL, RR, LR)

Slepton mass matrices

Sneutrinos	Charged sleptons
$\mathbf{M}^2_{\tilde\nu} = (\mathbf{m}^2_{\tilde\nu_L})_{3\times 3}$	$\mathbf{M}^2_{\tilde\ell} = \begin{pmatrix} \mathbf{m}^2_{LL} & \mathbf{m}^{2T}_{LR} \\ \mathbf{m}^2_{LR} & \mathbf{m}^2_{RR} \end{pmatrix}_{6\times 6}$
$(\mathbf{m}^2_{\tilde\nu_L})_{IJ} = (\mathbf{m}^2_{\tilde L})_{IJ} + \frac{1}{2} M_Z^2 c2\beta\ \delta_{IJ}$	$(\mathbf{m}^2_{LL})_{IJ} = (\mathbf{m}^2_{\tilde L})_{IJ} + \left[m^2_{\ell_I} + \left(-\frac{1}{2} + s^2_W\right) M_Z^2 c2\beta\right] \delta_{IJ}$ $(\mathbf{m}^2_{RR})_{IJ} = (\mathbf{m}^2_{\tilde R})_{IJ} + \left[m^2_{\ell_I} - M_Z^2 c2\beta s^2_W\right] \delta_{IJ}$ $(\mathbf{m}^2_{LR})_{IJ} = (\mathbf{A}_\ell)_{IJ}\ v\cos\beta/\sqrt{2} - m_{\ell_I}\mu\tan\beta\ \delta_{IJ}$

(symmetric, with generation indices $I, J = 1, 2, 3$)

Off–diagonal contributions (LL, RR, LR) from soft SUSY breaking terms responsible for LFV

We analyze two scenarios:

1. Two–family mixing (particular case of three–family mixing)

2. Three–family mixing (with maximal mixing angles)

Two-family mixing

- Assume two–generation mixing (IJ) and no alignment between fermion and scalar fields. Let $\mathbf{m}^2$ be the relevant 2×2 submatrix of $\mathbf{M}^2_{\tilde\nu}$ or $\mathbf{M}^2_{\tilde\ell}$:

$$\mathbf{m}^2 \equiv \tilde m^2 \begin{pmatrix} \sqrt{1+\delta^2} & \delta \\ \delta & \sqrt{1+\delta^2} \end{pmatrix} \qquad \delta = \delta^{\tilde\nu\, IJ}_{LL},\ \delta^{\tilde\ell\, IJ}_{LL},\ \delta^{\tilde\ell\, IJ}_{RR},\ \delta^{\tilde\ell\, IJ}_{LR}$$

(only one type of $\delta \neq 0$ and the others vanishing) diagonalized by (maximal mixing)

$$\mathbf{U} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & -1 \\ 1 & 1 \end{pmatrix} \qquad (\theta = \pi/4)$$

$\Rightarrow$ Two parameters: $\tilde m^2 = \tilde m_1 \tilde m_2\ ; \quad \delta = \dfrac{\tilde m_2^2 - \tilde m_1^2}{2\tilde m^2}$

$\tilde m =$ SUSY scale and $\delta =$ mass splitting $=$ off–diagonal mass insertion $\Rightarrow$ LFV

[possible to decouple second family: $\delta \to \infty$]

[for arbitrary mixing θ and small δ : $\mathcal{M}_{\text{LFV}} \propto \sin 2\theta\ \delta$]

Three-family mixing

Relevant 3×3 submatrix (for off–diagonal mass entries $\tilde{\delta} = \tilde{\delta}^{\tilde{\nu}}_{LL}, \ \tilde{\delta}^{\tilde{\ell}}_{LL}, \ \tilde{\delta}^{\tilde{\ell}}_{RR}, \ \tilde{\delta}^{\tilde{\ell}}_{LR}$):

$$\mathbf{m}^2 \equiv \tilde{m}_1{}^2 \begin{pmatrix} \tilde{\delta}^{11} & \cdot & \cdot \\ \tilde{\delta}^{12} & \tilde{\delta}^{22} & \cdot \\ \tilde{\delta}^{13} & \tilde{\delta}^{23} & \tilde{\delta}^{33} \end{pmatrix} ; \quad \mathbf{U} = \text{standard parametrization } (\theta_{12}, \ \theta_{13}, \ \theta_{23}; \ \phi_{\mathrm{CP}} = 0)$$

mass splitting $\delta^{IJ} = \dfrac{\tilde{m}_J^2 - \tilde{m}_I^2}{2\tilde{m}_1^2} \neq$ off–diagonal mass insertion $\tilde{\delta}^{IJ}$

[mass splittings are correlated: $\delta^{23} = \delta^{13} - \delta^{12}$] $[\mathcal{M}_{\mathrm{LFV}} \propto \tilde{\delta}^{IJ}]$

A. If ℓ_K does not mix much with ℓ_I and ℓ_J ($\theta_{IK} \approx \theta_{JK} \approx 0$) $\Rightarrow$ **two–family case**

B. If maximal mixing ($\theta_{12} \approx \theta_{13} \approx \theta_{23} \approx \pi/4$) $\Rightarrow$ Three parameters: $\tilde{m}_1^2$, δ^{12}, δ^{13}

Case	$\lvert\tilde{\delta}^{12}\rvert$ $[\mu e]$	$\lvert\tilde{\delta}^{13}\rvert$ $[\tau e]$	$\lvert\tilde{\delta}^{23}\rvert$ $[\tau\mu]$
B1. $\delta^{12} = 0$, $\delta^{13} = \delta$	$\delta/4$	$(2+\sqrt{2})\delta/4$	$(2-\sqrt{2})\delta/4$
B2. $\delta^{12} = \delta$, $\delta^{13} = 0$	$\delta/2$	$(2-\sqrt{2})\delta/4$	$(2+\sqrt{2})\delta/4$
B3. $\delta^{12} = \delta^{13} = \delta$	$\delta/2$	$\delta/\sqrt{2}$	$\delta/\sqrt{2}$

$\Rightarrow$ Limits from different channels correlated

Calculation

- **Analytical expressions** in terms of generic couplings and one–loop tensor integrals, implemented with complete MSSM Feynman rules (full chargino and neutralino mixings)

- **Constraints on SUSY masses** [PDB]:

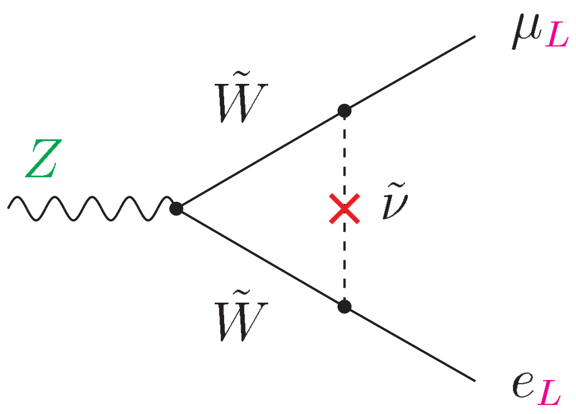
lightest slepton ($\tilde{m}_1$)	$m_{\tilde{\nu}} > 45$ GeV $m_{\tilde{\ell}_{L,R}} > 90$ GeV *
lightest chargino	$m_{\tilde{\chi}_1^+} > 75$ GeV, if $m_{\tilde{\nu}} > m_{\chi_1^+}$ > 45 GeV, otherwise
lightest neutralino	$m_{\tilde{\chi}_1^0} > 35$ GeV

* $m_{\tilde{\nu}}^2 = m_{\tilde{\ell}_L}^2 + M_Z^2 c_W^2 \cos 2\beta \Rightarrow m_{\tilde{\nu}} > 65\ (40)$ GeV for $\tan\beta = 2\ (50)$

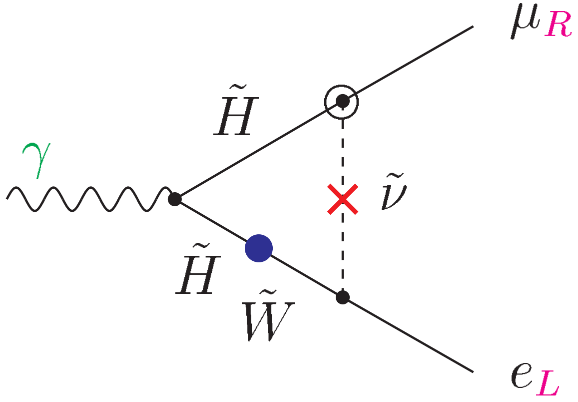
- **Inputs**: M_2, μ, $\tan\beta$ (spectra and couplings of charginos/neutralinos),
  $\tilde{m}_1$ (relevant lightest scalar mass), δ (LFV parameter)

- **Dominating diagrams** (mass insertion method): proportional to δ (if small)
  `diag`

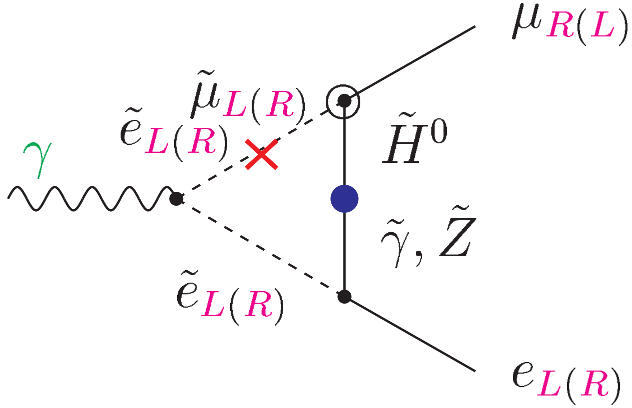
Dominating diagrams



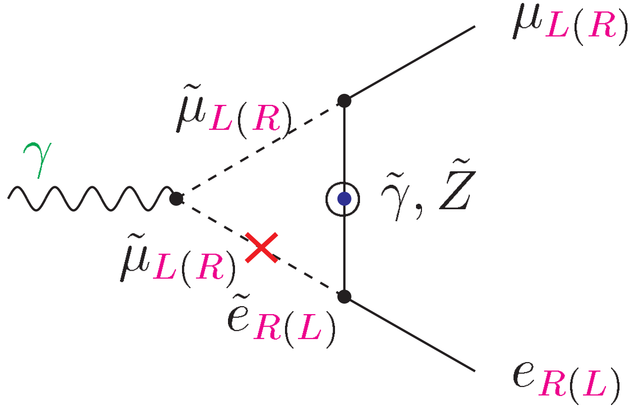
(a) $\delta^{\tilde{\nu}\,12}_{LL}$



(b1) $\delta^{\tilde{\nu}\,12}_{LL}$ $m_\mu \tan\beta$



(b2) $\delta^{\tilde{\ell}\,12}_{LL(RR)}$ $m_\mu \tan\beta$



(b3) $\delta^{\tilde{\ell}\,12}_{LR}$ $m_{\tilde{\gamma},\tilde{Z}}$

SUSY predictions for $Z \to \ell_I \ell_J$

- **Ignoring other LFV processes**:
  - Maximal effects for a decoupled second family ($\delta^{IJ} \to \infty$)
  - Chargino–sneutrino diagrams dominate by $\mathcal{O}(10)$

    Results almost independent of lepton masses

    Mild dependence on $\tan\beta$

  √ BR($Z \to \ell_I \ell_J$) up to 2.5×10^{-8} (7.5×10^{-8}) for $\tan\beta = 2$ (50)

  √ BR($Z \to \ell_I \ell_J$) $> 2 \times 10^{-9}$ (2×10^{-8}) for $m_{\tilde{\nu}} < 305$ (85) GeV, $m_{\tilde{\chi}_1^+} < 270$ (105) GeV

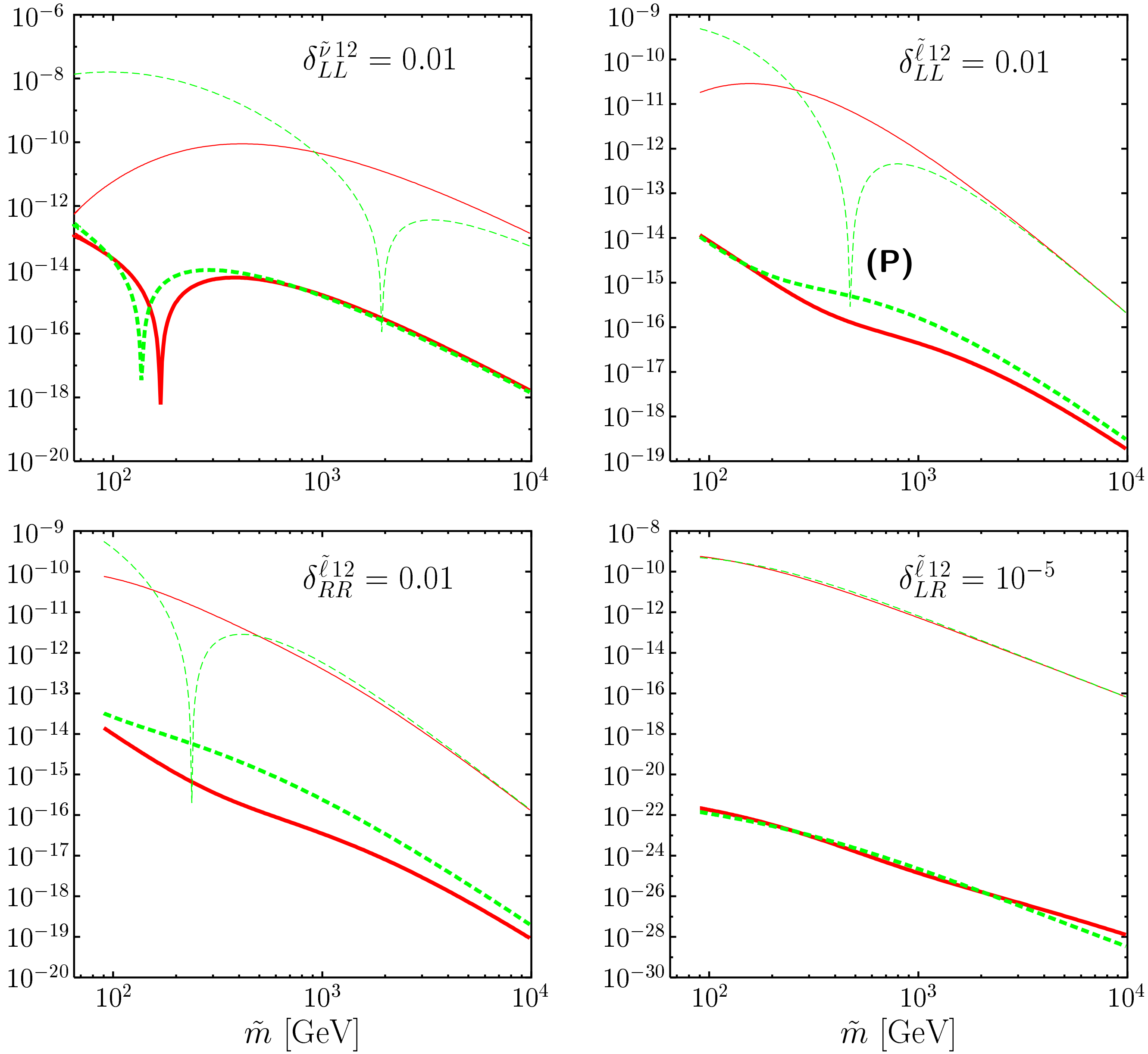
  - **Cancellations**: contributions from different particles have opposite signs `plot`

- **Correlation with $\ell_J \to \ell_I \gamma$**:

  BR($\mu \to e\gamma$) $< 1.2 \times 10^{-11} \Rightarrow$ BR($Z \to \mu e$) $< 1.5 \times 10^{-10}$

  BR($Z \to \tau e;\ \tau\mu$) **at reach** of best projection of GigaZ ($\kappa < 1$)
  with BR($\tau \to e\gamma;\ \mu\gamma$) $\ll$ present limits `plot`

$\mathbf{BR}(Z \to \mu e)$ & $\mathbf{BR}(\mu \to e\gamma)$

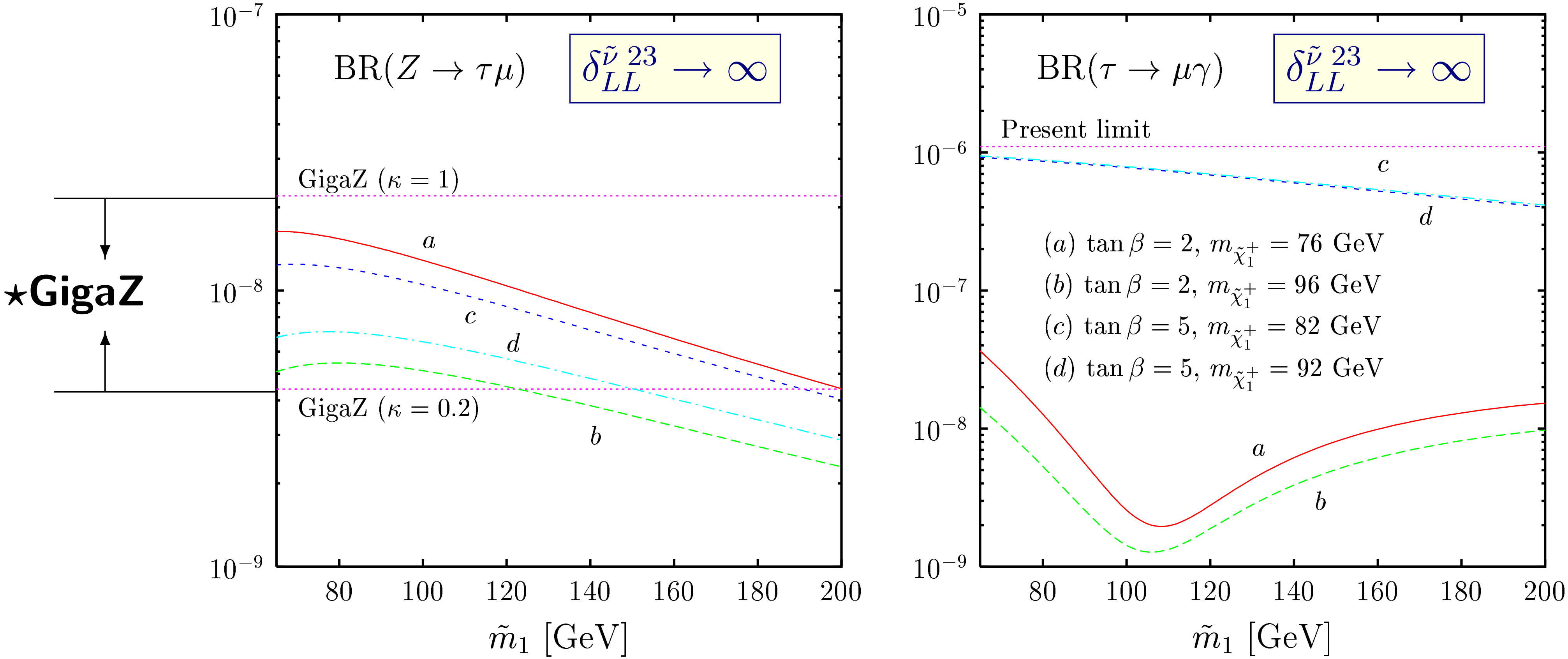


	$\tan\beta = 2$
solid	$M_2 = 150$ GeV
	$\mu = -500$ GeV
dashed	$M_2 = \mu = 150$ GeV

asymptotically $\propto \dfrac{\delta^2}{\tilde{m}^4}$

(small δ)

$\mathbf{BR}(Z \to \tau\mu)$ & $\mathbf{BR}(\tau \to \mu\gamma)$



(Best) **GigaZ reach**: $55 < m_{\tilde{\nu}} < 215$ GeV

$75 < m_{\tilde{\chi}_1^+} < 100$ GeV

$\tan\beta < 7$

Bounds from $\ell_J \to \ell_I \gamma$

- Provide most stringent constraints on slepton LFV mass terms (today)
- Establish how severe is the **flavour problem** in the lepton sector of the MSSM
- **Aim**: update works by [Masiero *et alter* '86–'96] (only photino–mediated diagrams) with complete MSSM $\Rightarrow$ frequent cancellations `e.g. plot`
- Bounds involving the **first two families** are very restrictive `table`

$\delta^{\tilde\nu\,12}_{LL}$, $\delta^{\tilde\ell\,12}_{LL}$, $\delta^{\tilde\ell\,12}_{RR}$	:	$\mathcal{O}(10^{-3}\ldots 10^{-5})$	stronger for high $\tan\beta$
$\delta^{\tilde\ell\,12}_{LR}$	:	$\mathcal{O}(10^{-6})$	independent of $\tan\beta$

- Bounds involving the **third family** are much weaker (or unexistent!)

		low $\tan\beta$	high $\tan\beta$
$\delta^{\tilde\nu\,I3}_{LL}$	:	∞	0.03 to 1.3
$\delta^{\tilde\ell\,I3}_{LL}$	:	∞	0.14 to ∞
$\delta^{\tilde\ell\,I3}_{RR}$	:	∞	0.11 to ∞
$\delta^{\tilde\ell\,I3}_{LR}$	:	0.05 to ∞	

Bounds from $\mu \to e\gamma < 1.2 \times 10^{-11}$

$\tilde{m}_1$	M_2	$\delta_{LL}^{\tilde{\nu}\,12}$ $\mu = -500$	$\mu = -150$	$\mu = 150$	$\mu = 500$	$\delta_{LL}^{\tilde{\ell}\,12}$ $\mu = -500$	$\mu = -150$	$\mu = 150$	$\mu = 500$
		$\tan\beta = 2$				$\tan\beta = 2$			
100	150	14×10^{-3}	1.0×10^{-3}	0.3×10^{-3}	1.0×10^{-3}	7.5×10^{-3}	2.6×10^{-3}	1.7×10^{-3}	5.0×10^{-3}
	500	33×10^{-3}	3.0×10^{-3}	1.7×10^{-3}	13×10^{-3}	84×10^{-3}	11×10^{-3}	7.0×10^{-3}	41×10^{-3}
500	150	3.7×10^{-3}	1.1×10^{-3}	1.2×10^{-3}	1.7×10^{-3}	14×10^{-3}	8.5×10^{-3}	**0.12 (P)**	32×10^{-3}
	500	7.3×10^{-3}	2.6×10^{-3}	2.3×10^{-3}	4.1×10^{-3}	24×10^{-3}	20×10^{-3}	32×10^{-3}	26×10^{-3}
		$\tan\beta = 50$				$\tan\beta = 50$			
100	150	9.3×10^{-5}	2.1×10^{-5}	2.0×10^{-5}	8.6×10^{-5}	2.4×10^{-4}	0.8×10^{-4}	0.8×10^{-4}	2.4×10^{-4}
	500	80×10^{-5}	9.0×10^{-5}	8.8×10^{-5}	77×10^{-5}	24×10^{-4}	3.5×10^{-4}	3.4×10^{-4}	23×10^{-4}
500	150	9.7×10^{-5}	4.5×10^{-5}	4.5×10^{-5}	9.4×10^{-5}	7.4×10^{-4}	6.4×10^{-4}	6.9×10^{-4}	7.6×10^{-4}
	500	22×10^{-5}	9.6×10^{-5}	9.5×10^{-5}	21×10^{-5}	9.7×10^{-4}	9.6×10^{-4}	9.8×10^{-4}	9.7×10^{-4}

$\tilde{m}_1$	M_2	$\delta_{RR}^{\tilde{\ell}\,12}$ $\mu = -500$	$\mu = -150$	$\mu = 150$	$\mu = 500$	$\delta_{LR}^{\tilde{\ell}\,12}$ $\mu = -500$	$\mu = -150$	$\mu = 150$	$\mu = 500$
		$\tan\beta = 2$				$\tan\beta = 2$			
100	150	4.2×10^{-3}	1.5×10^{-3}	1.8×10^{-3}	3.7×10^{-3}	1.6×10^{-6}	1.5×10^{-6}	1.6×10^{-6}	1.7×10^{-6}
	500	11×10^{-3}	3.2×10^{-3}	2.5×10^{-3}	8.3×10^{-3}	4.5×10^{-6}	4.4×10^{-6}	4.7×10^{-6}	4.6×10^{-6}
500	150	22×10^{-3}	10×10^{-3}	22×10^{-3}	**0.33**	1.3×10^{-6}	1.2×10^{-6}	1.2×10^{-6}	1.2×10^{-6}
	500	19×10^{-3}	12×10^{-3}	**0.33**	35×10^{-3}	7.6×10^{-6}	7.5×10^{-6}	7.6×10^{-6}	7.7×10^{-6}
		$\tan\beta = 50$				$\tan\beta = 50$			
100	150	1.6×10^{-4}	0.6×10^{-4}	0.6×10^{-4}	1.5×10^{-4}	1.6×10^{-6}	1.5×10^{-6}	1.6×10^{-6}	1.6×10^{-6}
	500	3.8×10^{-4}	1.1×10^{-4}	1.1×10^{-4}	3.8×10^{-4}	4.5×10^{-6}	4.5×10^{-6}	4.6×10^{-6}	4.5×10^{-6}
100	150	16×10^{-4}	13×10^{-4}	15×10^{-4}	17×10^{-4}	1.3×10^{-6}	1.2×10^{-6}	1.2×10^{-6}	1.3×10^{-6}
	500	9.4×10^{-4}	8.1×10^{-4}	8.7×10^{-4}	9.6×10^{-4}	7.7×10^{-6}	7.6×10^{-6}	7.6×10^{-6}	7.7×10^{-6}

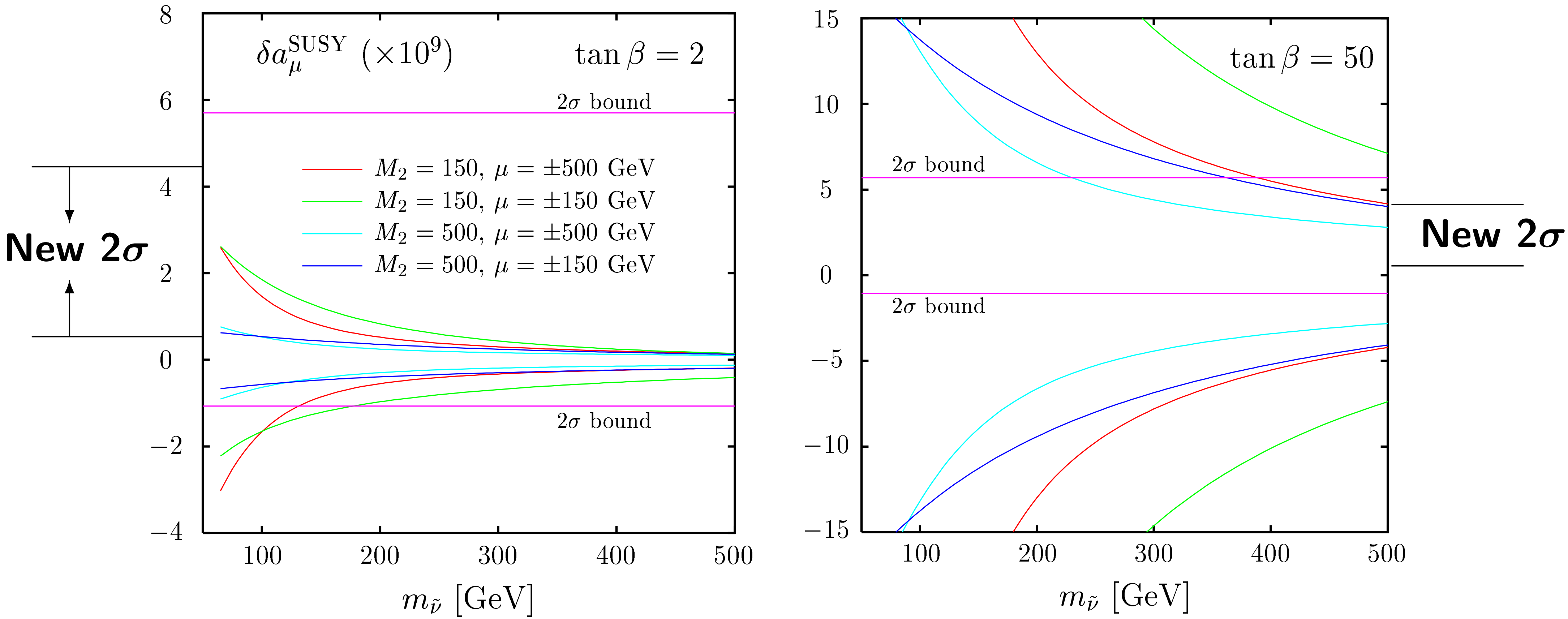
LFV and $(g_\mu - 2)$

$$\left.\begin{array}{lcl}
\text{World average:} \quad a_\mu^{\rm exp} & = & \underbrace{11\,659\,202.3\ (15.1) \times 10^{-10}}_{11\,659\,203\ (8)\times 10^{-10}} \\
\text{including new BNL:} & & \\
\text{SM prediction:} \quad a_\mu^{\rm SM} & = & 11\,659\,179.2\ \ (9.4) \times 10^{-10}
\end{array}\right\} \Rightarrow \delta a_\mu = (\underbrace{23.1}_{24} \pm \underbrace{16.9}_{10}) \times 10^{-10}$$

new:

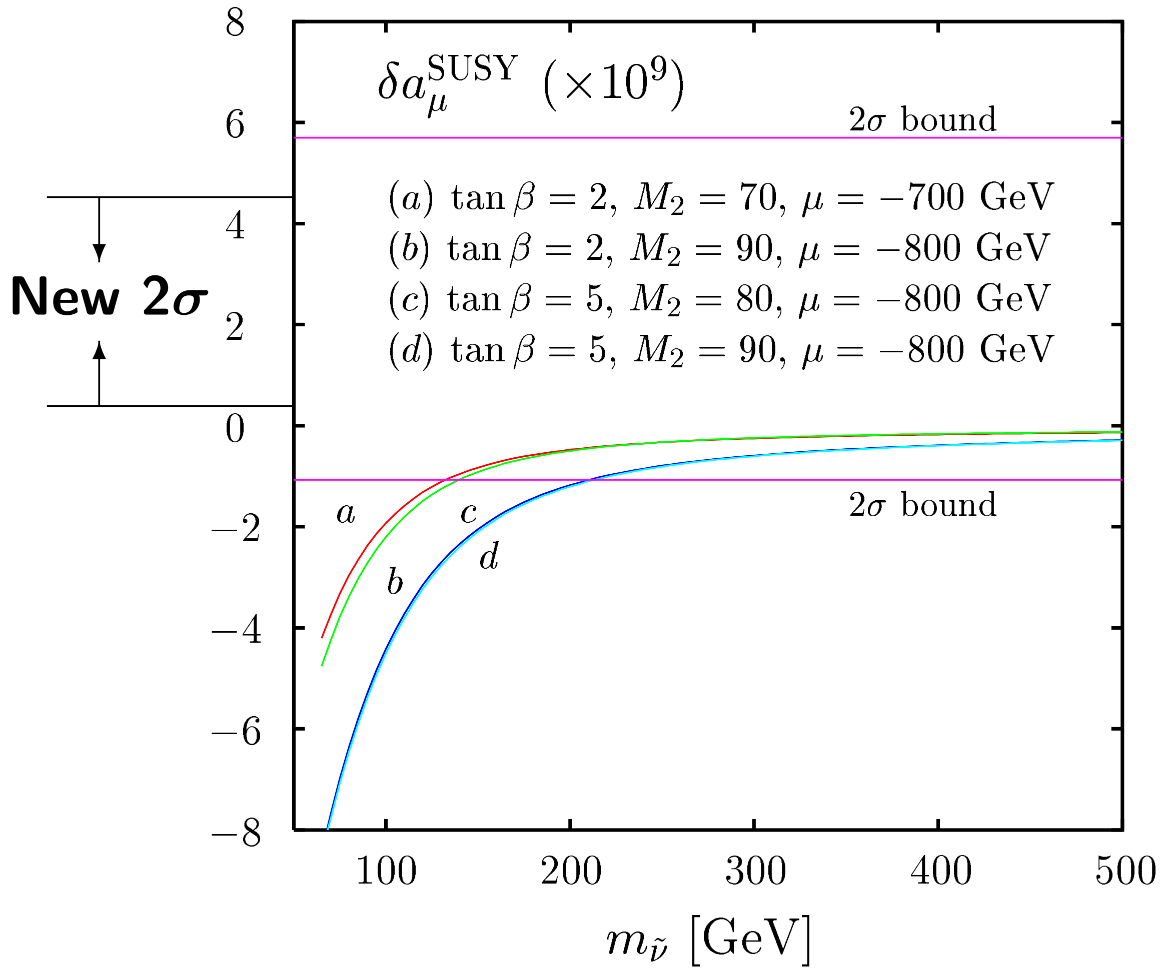
- $(g_\mu - 2) \approx$ 'normalization' of LFV lepton decays (small deltas):
  (similar diagrams $\Rightarrow$ replace $\delta_{LR}^{\tilde{\ell}\,IJ}$ by $\delta_{LR}^{\tilde{\ell}\,22}$ and remove all other delta insertions)
- $\boxed{\delta a_\mu^{\rm SUSY} = \delta a_\mu}$ $\Rightarrow$ **large uncertainties**
  - SM prediction
  - Extra assumptions:
    - $*$ take same mass scales $\tilde{m}$ involved in $(g_\mu - 2)$ as in $\mu \to e\gamma$ or $\tau \to \mu\gamma$
    - $*$ soft–breaking terms m_L and m_R involved at the same time in $(g_\mu - 2)$
- **But taking present results seriously ...**

$(g_\mu - 2)$ and SUSY



- Positive Higgsino mass parameter μ preferred (now even more with new BNL data)

$\mathrm{BR}(Z \to \tau\mu)$ & $(g_\mu - 2)$: very speculative!



- Assuming $m_L = m_R$: the favourite scenario for $Z \to \tau\mu$ in GigaZ restricted to higher slepton masses (or practically ruled out by new BNL data)

Summary and conclusions

- **Slepton sector of SUSY** (soft–breaking terms) provides a **natural source of LFV**:

  effects $\approx$ proportional to slepton mass squared differences (degeneracy δ)

- **Our calculation**:
  - $\boxed{Z \to \ell_I \ell_J}$ realistically correlated with $\boxed{\ell_J \to \ell_I \gamma}$ in SUSY models (no SUSY–breaking mechanism assumed and exact beyond mass insertion approx.)
  - update to include complete MSSM (several δ types) and more recent experiments

- **GigaZ reach** [most optimistic scenario: two–family mixing]:
  - $\boxed{Z \to \mu e \text{ excluded by } \mu \to e\gamma}$ not by limits on SUSY masses
  - $\boxed{Z \to \tau e; \tau\mu \text{ possible}}$ $(\kappa < 1)$ thanks to chargino–sneutrino contributions

- **Best bounds from $\ell_J \to \ell_I \gamma$ $\Rightarrow$ SUSY lepton flavour problem?**
  - Non–observation of $\mu \to e\gamma \Rightarrow$ $\boxed{\delta^{\tilde{\nu}|\tilde{\ell}\ 12}_{LL,RR,LR} \approx 10^{-3} \ldots 10^{-6}}$ (large degeneracy!)

    . . . maybe justifiable by weakness of Yukawas of light lepton sector
  - Non–observation of $\tau \to e\gamma; \mu\gamma \Rightarrow$ $\boxed{\text{very weak (even unexistent) constraints on } \delta^{I3}\text{s}}$