Lepton flavor violating decays $l_j \to l_i \gamma$ in the U(1)xSSM model within the Mass Insertion Approximation

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目　录

1、The lepton flavor violation

The breaking theory of electric weak symmetry and neutrino oscillation experiment show that lepton flavor violation exists both theoretically and experimentally. However, the lepton number is conserved in the SM. It is necessary to expand the SM. Any sign of LFV can be regarded as evidence of the existence of new physics.

We use mass insertion approximation with the electroweak interaction eigenstate and treats perturbatively the mass insertions changing slepton flavor. At the analytical level, we can find many parameters that have direct impact on LFV.

The latest upper limits on the LFV branching ratio of $\mu \to e\gamma$, $\tau \to \mu\gamma$ and $\tau \to e\gamma$ at 90% confidence level (CL) are

$$Br(\mu \to e\gamma) < 4.2 \times 10^{-13},$$

$$Br(\tau \to \mu\gamma) < 4.4 \times 10^{-8},$$

$$Br(\tau \to e\gamma) < 3.3 \times 10^{-8}.$$

2、The U(1)xSSM

The local gauge group

$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_X$

$U(1)_X$SSM is the U(1) extension of MSSM.

Comparing with MSSM, $U(1)_X$SSM has more superfields including: right- handed neutrinos and three Higgs singlets.

Superfields	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$
$\hat{Q}_i$	3	2	1/6	0
$\hat{u}_i^c$	$\bar{3}$	1	-2/3	-1/2
$\hat{d}_i^c$	$\bar{3}$	1	1/3	1/2
$\hat{L}_i$	1	2	-1/2	0
$\hat{e}_i^c$	1	1	1	1/2
$\hat{\nu}_i$	1	1	0	-1/2
$\hat{H}_u$	1	2	1/2	1/2
$\hat{H}_d$	1	2	-1/2	-1/2
$\hat{\eta}$	1	1	0	-1
$\hat{\bar{\eta}}$	1	1	0	1
$\hat{S}$	1	1	0	0

The superpotential

$$W = l_W \hat{S} + \mu \hat{H}_u \hat{H}_d + M_S \hat{S}\hat{S} - Y_d \hat{d}\hat{q}\hat{H}_d - Y_e \hat{e}\hat{l}\hat{H}_d + \lambda_H \hat{S}\hat{H}_u\hat{H}_d$$
$$+\lambda_C \hat{S}\hat{\eta}\hat{\bar{\eta}} + \frac{\kappa}{3}\hat{S}\hat{S}\hat{S} + Y_u \hat{u}\hat{q}\hat{H}_u + Y_X \hat{\nu}\hat{\bar{\eta}}\hat{\nu} + Y_\nu \hat{\nu}\hat{l}\hat{H}_u.$$

The Higgs superfields

$$H_u = \begin{pmatrix} H_u^+ \\ \frac{1}{\sqrt{2}}\left(v_u + H_u^0 + iP_u^0\right) \end{pmatrix}, \qquad H_d = \begin{pmatrix} \frac{1}{\sqrt{2}}\left(v_d + H_d^0 + iP_d^0\right) \\ H_d^- \end{pmatrix},$$
$$\eta = \frac{1}{\sqrt{2}}\left(v_\eta + \phi_\eta^0 + iP_\eta^0\right), \qquad \bar{\eta} = \frac{1}{\sqrt{2}}\left(v_{\bar{\eta}} + \phi_{\bar{\eta}}^0 + iP_{\bar{\eta}}^0\right),$$
$$S = \frac{1}{\sqrt{2}}\left(v_S + \phi_S^0 + iP_S^0\right).$$

The soft breaking terms are

$$\mathcal{L}_{soft} = \mathcal{L}_{soft}^{MSSM} - B_S S^2 - L_S S - \frac{T_\kappa}{3} S^3 - T_{\lambda_C} S\eta\bar{\eta} + \epsilon_{ij} T_{\lambda_H} S H_d^i H_u^j$$
$$-T_X^{IJ}\bar{\eta}\tilde{\nu}_R^{*I}\tilde{\nu}_R^{*J} + \epsilon_{ij}T_\nu^{IJ}H_u^i\tilde{\nu}_R^{I*}\tilde{l}_j^J - m_\eta^2|\eta|^2 - m_{\bar{\eta}}^2|\bar{\eta}|^2 -$$
$$-m_S^2 S^2 - (m_{\tilde{\nu}_R}^2)^{IJ}\tilde{\nu}_R^{I*}\tilde{\nu}_R^J - \frac{1}{2}\Big(M_X\lambda_{\tilde{X}}^2 + 2M_{BB'}\lambda_{\tilde{B}}\lambda_{\tilde{X}}\Big) + h.c \ .$$

The covariant derivatives of this model is shown in the general form

$$D_\mu = \partial_\mu - i\begin{pmatrix} Y, & X \end{pmatrix}\begin{pmatrix} g_Y, & g'_{YX} \\ g'_{XY}, & g'_X \end{pmatrix}\begin{pmatrix} A'^Y_\mu \\ A'^X_\mu \end{pmatrix},$$

With the two Abelian gauge groups unbroken condition,
we use the matrix R to obtain

$$\begin{pmatrix} g_Y, & g'_{YX} \\ g'_{XY}, & g'_X \end{pmatrix} R^T = \begin{pmatrix} g_1, & g_{YX} \\ 0, & g_X \end{pmatrix}.$$

The gauge fields of $\mathrm{U}(1)_Y$ and $\mathrm{U}(1)_X$ are denoted by A'^Y_μ and A'^X_μ.

In this model, the gauge bosons A^X_μ, A^Y_μ and V^3_μ mix together at the tree level.

$$\begin{pmatrix} \frac{1}{8}g_1^2v^2 & -\frac{1}{8}g_1g_2v^2 & \frac{1}{8}g_1(g_{YX}+g_X)v^2 \\ -\frac{1}{8}g_1g_2v^2 & \frac{1}{8}g_2^2v^2 & -\frac{1}{8}g_2(g_{YX}+g_X)v^2 \\ \frac{1}{8}g_1(g_{YX}+g_X)v^2 & -\frac{1}{8}g_2(g_{YX}+g_X)v^2 & \frac{1}{8}(g_{YX}+g_X)^2v^2+\frac{1}{8}g_X^2\xi^2 \end{pmatrix},$$

$$\begin{pmatrix} \gamma \\ Z \\ Z' \end{pmatrix} = \begin{pmatrix} \cos\theta_W & \sin\theta_W & 0 \\ -\sin\theta_W\cos\theta'_W & \cos\theta_W\cos\theta'_W & \sin\theta'_W \\ \sin\theta_W\sin\theta'_W & -\cos\theta'_W\sin\theta'_W & \cos\theta'_W \end{pmatrix} \begin{pmatrix} A^Y \\ V^3 \\ A^X \end{pmatrix}.$$

得到的质量本征值

$$m_\gamma^2 = 0,$$

$$m^2_{Z,Z'} = \frac{1}{8}\Big((g_1^2+g_2^2+(g_{YX}+g_X)^2)v^2+4g_X^2\xi^2$$

$$\mp\sqrt{(g_1^2+g_2^2+(g_{YX}+g_X)^2)^2v^4+8((g_{YX}+g_X)^2-g_1^2-g_2^2)g_X^2v^2\xi^2+16g_X^4\xi^4}\Big).$$

$$\sin^2\theta'_W = \frac{1}{2} - \frac{(g_{YX}^2 - g_1^2 - g_2^2)v^2 + 4g_X^2\xi^2}{2\sqrt{(g_{YX}^2 + g_1^2 + g_2^2)^2 v^4 + 8g_X^2(g_{YX}^2 - g_1^2 - g_2^2)v^2\xi^2 + 16g_X^4\xi^4}},$$

with $v^2 = v_u^2 + v_d^2$ and $\xi^2 = v_\eta^2 + v_{\bar{\eta}}^2$.

The neutrino mass matrix is deduced in the base $(\nu_L, \bar{\nu}_R)$

$$M_\nu = \begin{pmatrix} 0 & \frac{v_u}{\sqrt{2}}(Y_\nu^T)^{IJ} \\ \frac{v_u}{\sqrt{2}}(Y_\nu)^{IJ} & \sqrt{2}v_{\bar{\eta}}(Y_X)^{IJ} \end{pmatrix},$$

Here, we show some needed couplings in this model. We deduce the vertexes of $\bar{l}_i - \chi_j^- - \tilde{\nu}_k^R(\tilde{\nu}_k^I)$

$$\mathcal{L}_{\bar{l}\chi^-\tilde{\nu}^R} = \frac{1}{\sqrt{2}}\bar{l}_i\Big\{\tilde{\nu}_L^R Y_l^i P_L \tilde{H}_1^- - g_2\tilde{\nu}_L^R P_R \tilde{W}^-\Big\},$$

$$\mathcal{L}_{\bar{l}\chi^-\tilde{\nu}^I} = \frac{i}{\sqrt{2}}\bar{l}_i\Big\{\tilde{\nu}_L^I Y_l^i P_L \tilde{H}_1^- - g_2\tilde{\nu}_L^I P_R \tilde{W}^-\Big\}.$$

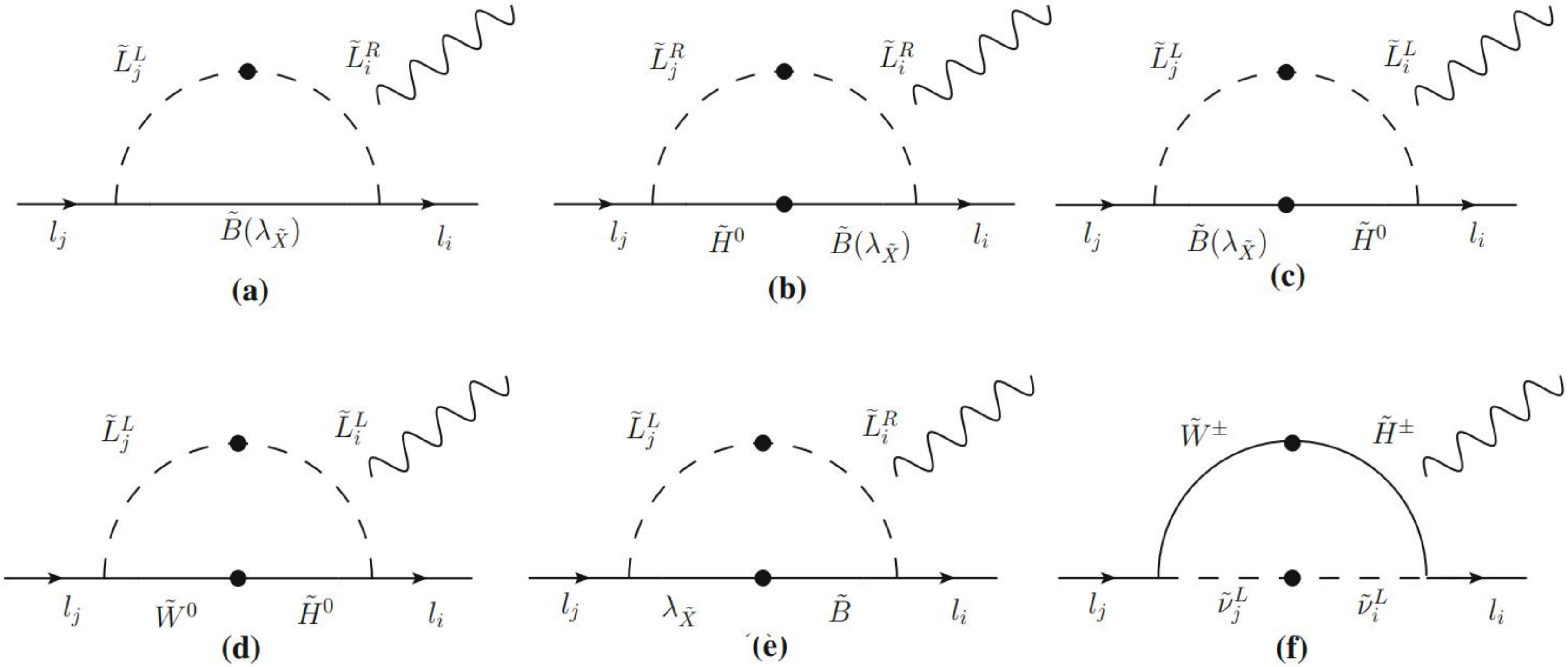
We deduce the vertex couplings of neutralino-lepton-slepton

$$\mathcal{L}_{\bar{\chi}^0 l\tilde{L}} = \Big\{\Big(\frac{1}{\sqrt{2}}(g_1\lambda_{\tilde{B}} + g_2\tilde{W}^0 + g_{YX}\lambda_{\tilde{X}})\tilde{L}^L - \tilde{H}_d^0 Y_l^j \tilde{L}^R\Big)P_L$$
$$-\Big[\frac{1}{\sqrt{2}}\Big(2g_1\lambda_{\tilde{B}} + (2g_{YX} + g_X)\lambda_{\tilde{X}}\Big)\tilde{L}^R + \tilde{H}_d^0 Y_l^j \tilde{L}^L\Big]P_R\Big\}l_j.$$

3、One loop diagram

If the external lepton is on shell, the amplitude of $l_j \to l_i \gamma$ is

$$\mathcal{M} = e\varepsilon^{\mu}\bar{u}_i(p+q)[q^2\gamma_\mu(C_1^L P_L + C_1^R P_R) + m_{l_j} i\sigma_{\mu\nu}q^{\nu}(C_2^L P_L + C_2^R P_R)]u_j(p),$$



Feynman diagrams for $l_j \to l_i \gamma$ in the MIA

1. The one-loop contributions from $\tilde{B}(\lambda_{\tilde{X}})$-$\tilde{L}_j^L$-$\tilde{L}_i^R$.

$$C_2^1(\tilde{L}_j^L, \tilde{L}_i^R, \tilde{B}) = \frac{-1}{2m_{l_i}\Lambda^3}\Delta_{ij}^{LR} g_1^2 \sqrt{x_1}[I_1(x_{\tilde{L}_j^L}, x_1) + I_1(x_{\tilde{L}_i^R}, x_1) - 2I_2(x_{\tilde{L}_j^L}, x_1) - I_2(x_{\tilde{L}_i^R}, x_1)],$$

$$C_2^1(\tilde{L}_j^L, \tilde{L}_i^R, \lambda_{\tilde{X}}) = \frac{-1}{2m_{l_j}\Lambda^3}\Delta_{ij}^{LR}(g_{YX}^2 + \frac{1}{2} g_{YX} g_X)\sqrt{x_{\lambda_{\tilde{X}}}}[I_1(x_{\tilde{L}_j^L}, x_{\lambda_{\tilde{X}}}) + I_1(x_{\tilde{L}_i^R}, x_{\lambda_{\tilde{X}}}) - 2I_2(x_{\tilde{L}_j^L}, x_{\lambda_{\tilde{X}}}) - I_2(x_{\tilde{L}_i^R}, x_{\lambda_{\tilde{X}}})],$$

here, m is the particle mass, with $x = \frac{m^2}{\Lambda^2}$. The functions $I_1(x, y)$ and $I_2(x, y)$ are

$$I_1(x, y) = \frac{1}{32\pi^2}\left\{\frac{1}{x(x-y)} - \frac{2 + 2\log x}{(x-y)^2} + \frac{2x\log x - 2y\log y}{(x-y)^3}\right\},$$

$$I_2(x, y) = \frac{1}{96\pi^2}\left\{\frac{2}{x(x-y)} - \frac{9 + 6\log x}{(x-y)^2} + \frac{6x + 12x\log x}{(x-y)^3} - \frac{6x^2\log x - 6y^2\log y}{(x-y)^4}\right\}.$$

2. The one-loop contributions from $\tilde{B}(\lambda_{\tilde{X}})$-$\tilde{H}^0$-$\tilde{L}_j^R$-$\tilde{L}_i^R$.

$$C_2^2(\tilde{L}_j^R, \tilde{L}_i^R, \tilde{B}, \tilde{H}^0) = \frac{1}{2\Lambda^4} g_1^2 \tan\beta \sqrt{x_1 x_{\mu'_H}} \Delta_{ij}^{RR} [2I_4(x_{\tilde{L}_i^R}, x_1, x_{\mu'_H}) + 3I_3(x_{\tilde{L}_j^R}, x_1, x_{\mu'_H})],$$

$$C_2^2(\tilde{L}_j^R, \tilde{L}_i^R, \lambda_{\tilde{X}}, \tilde{H}^0) = \frac{1}{2\Lambda^4}\frac{1}{2}(2g_{YX} + g_X)(g_{YX} + g_X) \tan\beta \sqrt{x_{\lambda_{\tilde{X}}} x_{\mu'_H}} \Delta_{ij}^{RR} \times [2I_4(x_{\tilde{L}_i^R}, x_{\lambda_{\tilde{X}}}, x_{\mu'_H}) + 3I_3(x_{\tilde{L}_j^R}, x_{\lambda_{\tilde{X}}}, x_{\mu'_H})],$$

here $\mu'_H = \frac{\lambda_H v_S}{\sqrt{2}} + \mu$ and $x_{\mu'_H} = \frac{\mu'^2_H}{\Lambda^2}$.

3. The one-loop contributions from $\tilde{B}(\lambda_{\tilde{X}})$-$\tilde{H}^0$-$\tilde{L}_j^L$-$\tilde{L}_i^L$.

$$C_2^3(\tilde{L}_j^L, \tilde{L}_i^L, \tilde{H}^0, \tilde{B}) = \frac{-m_{l_i}}{4m_{l_j}\Lambda^4} g_1^2 \tan\beta \sqrt{x_1 x_{\mu'_H}} \Delta_{ij}^{LL} [2I_4(x_{\tilde{L}_i^L}, x_1, x_{\mu'_H}) + 3I_3(x_{\tilde{L}_j^L}, x_1, x_{\mu'_H})],$$

$$C_2^3(\tilde{L}_j^L, \tilde{L}_i^L, \tilde{H}^0, \lambda_{\tilde{X}}) = \frac{-m_{l_i}}{4m_{l_j}\Lambda^4} g_{YX}(g_{YX} + g_X) \tan\beta \sqrt{x_{\lambda_{\tilde{X}}} x_{\mu'_H}} \Delta_{ij}^{LL} \times [2I_4(x_{\tilde{L}_i^L}, x_{\lambda_{\tilde{X}}}, x_{\mu'_H}) + 3I_3(x_{\tilde{L}_j^L}, x_{\lambda_{\tilde{X}}}, x_{\mu'_H})].$$

4. The one-loop contributions from $\tilde{W}^0$-$\tilde{H}^0$-$\tilde{L}_j^L$-$\tilde{L}_i^L$.

$$C_2^4(\tilde{L}_j^L, \tilde{L}_i^L, \tilde{H}^0, \tilde{W}^0) = \frac{m_{l_i}}{4m_{l_j}\Lambda^4} g_2^2 \tan\beta \sqrt{x_2 x_{\mu'_H}} \Delta_{ij}^{LL} \times [2I_4(x_{\tilde{L}_i^L}, x_2, x_{\mu'_H}) + 3I_3(x_{\tilde{L}_j^L}, x_2, x_{\mu'_H})].$$

5. The one-loop contributions from $\tilde{B} - \lambda_{\tilde{X}} - \tilde{L}_j^L - \tilde{L}_i^R$.

$$C_2^5(\tilde{L}_j^L, \tilde{L}_i^R, \tilde{B}, \lambda_{\tilde{X}}) = \frac{-1}{2m_{l_j}\Lambda^3} \Delta_{ij}^{LR} g_1 g_{YX} \sqrt{x_{BB'} x_1 x_{\lambda_{\tilde{X}}}} [I_4(x_{\tilde{L}_j^L}, x_1, x_{\lambda_{\tilde{X}}}) + I_4(x_{\tilde{L}_i^R}, x_1, x_{\lambda_{\tilde{X}}}) + I_5(x_{\tilde{L}_j^L}, x_1, x_{\lambda_{\tilde{X}}}) + 2I_5(x_{\tilde{L}_i^R}, x_1, x_{\lambda_{\tilde{X}}})] + \frac{1}{2m_{l_j}\Lambda^3} \Delta_{ij}^{LR} g_1 g_{YX} \sqrt{x_{BB'}} [I_6(x_{\tilde{L}_j^L}, x_1, x_{\lambda_{\tilde{X}}}) + I_6(x_{\tilde{L}_i^R}, x_1, x_{\lambda_{\tilde{X}}}) + I_7(x_{\tilde{L}_j^L}, x_1, x_{\lambda_{\tilde{X}}}) + 2I_7(x_{\tilde{L}_i^R}, x_1, x_{\lambda_{\tilde{X}}})].$$

6. The one-loop contributions from chargino and left- handed CP-even(odd) sneutrino.

$$C_2^6(\tilde{\nu}_{Lj}^I, \tilde{\nu}_{Li}^I, \tilde{H}^\pm, \tilde{W}^\pm) = \frac{1}{2\Lambda^4} g_2^2 \Delta_{ij}^{LL} \tan\beta\{(\sqrt{x_2 x_{\mu'_H}} + x_{\mu'_H}) I_8(x_{\mu'_H}, x_2, x_{\tilde{\nu}_{Li}^I})$$

$$+(\sqrt{x_2 x_{\mu'_H}} + x_2) I_8(x_2, x_{\mu'_H}, x_{\tilde{\nu}_{Lj}^I}) + \sqrt{x_2 x_{\mu'_H}} I_9(x_2, x_{\mu'_H}, x_{\tilde{\nu}_{Li}^I}) - I_{10}(x_2, x_{\mu'_H}, x_{\tilde{\nu}_{Lj}^I})\},$$

$$C_2^6(\tilde{\nu}_{Lj}^R, \tilde{\nu}_{Li}^R, \tilde{H}^\pm, \tilde{W}^\pm) = \frac{1}{2\Lambda^4} g_2^2 \Delta_{ij}^{LL} \tan\beta\{(\sqrt{x_2 x_{\mu'_H}} + x_{\mu'_H}) I_8(x_{\mu'_H}, x_2, x_{\tilde{\nu}_{Li}^R})$$

$$+(\sqrt{x_2 x_{\mu'_H}} + x_2) I_8(x_2, x_{\mu'_H}, x_{\tilde{\nu}_{Lj}^R}) + \sqrt{x_2 x_{\mu'_H}} I_9(x_2, x_{\mu'_H}, x_{\tilde{\nu}_{Li}^R}) - I_{10}(x_2, x_{\mu'_H}, x_{\tilde{\nu}_{Lj}^R})\}.$$

Finally, we get the final Wilson coefficient and decay width of $l_j \to l_i \gamma$,

$$C_2 = \sum_i^{i=1\cdots 6} C_2^i, \qquad \Gamma(l_j \to l_i \gamma) = \frac{e^2}{8\pi} m_{l_j}^5 |C_2|^2.$$

The branching ratio of $l_j \to l_i \gamma$ is $Br(l_j \to l_i \gamma) = \Gamma(l_j \to l_i \gamma)/\Gamma_{l_j}$.

Degenerate result

We suppose that all the masses of the superparticles are almost degenerate, where the masses for superparticles are equal to M_{susy}

$$M_1 = |M_2| = \mu'_H = m_{\tilde{L}_L} = m_{\tilde{L}_R} = M_{\lambda_{\tilde{X}}} = |M_{BB'}| = M_{SUSY}.$$

The functions $I_i(i = 1 \cdots 9)$ and $\Delta_{ij}^{AB}(A, B = L, R)$ are much simplified as

$$I_1(1,1) = \frac{-1}{96\pi^2}, \quad I_2(1,1) = \frac{-1}{192\pi^2}, \quad I_3(1,1,1) = \frac{-1}{480\pi^2},$$

$$I_4(1,1,1) = \frac{1}{192\pi^2}, \quad I_5(1,1,1) = \frac{1}{192\pi^2}, \quad I_6(1,1,1) = \frac{-1}{320\pi^2},$$

$$I_7(1,1,1) = \frac{-1}{480\pi^2}, \quad I_8(1,1,1) = \frac{-1}{480\pi^2}, \quad I_9(1,1,1) = \frac{1}{384\pi^2},$$

$$\Delta_{ij}^{LR} = m_{l_j} m_{\tilde{L}_L} \delta_{ij}^{LR}, \quad \Delta_{ij}^{LL} = m_{\tilde{L}_L}^2 \delta_{ij}^{LL}, \quad \Delta_{ij}^{RR} = m_{\tilde{L}_R}^2 \delta_{ij}^{RR}.$$

Then, we obtain the much simplified one-loop results of C_2

$$C_2 = \frac{(2g_1^2\mathtt{sign}[M_1\mu'_H] + (2g_{YX}^2 + 3g_{YX}g_X + g_X^2)\mathtt{sign}[M_{\lambda_{\tilde{X}}}\mu'_H])\tan\beta\delta_{ij}^{RR}}{960\pi^2 M_{SUSY}^2}$$
$$+\frac{(-g_1^2\mathtt{sign}[M_1\mu'_H] - (g_{YX}^2 + g_{YX}g_X)\mathtt{sign}[M_{\lambda_{\tilde{X}}}\mu'_H] + g_2^2\mathtt{sign}[M_2\mu'_H])m_{l_i}\tan\beta\delta_{ij}^{LL}}{960\pi^2 M_{SUSY}^2 m_{l_j}}$$
$$+\frac{(-4g_2^2\mathtt{sign}[M_2^2] - 4g_2^2\mathtt{sign}[\mu'^2_H] - 12g_2^2\mathtt{sign}[\mu'_H M_2] + 5g_2^2)\tan\beta\delta_{ij}^{LL}}{3840\pi^2 M_{SUSY}^2}$$
$$+\frac{1}{1920\pi^2 M_{SUSY}^2} \times \{(5g_1^2\mathtt{sign}[M_1] + 5(g_{YX}^2 + \frac{1}{2}g_{YX}g_X)\mathtt{sign}[M_{\lambda_{\tilde{X}}}]$$
$$-4g_1 g_{YX}\mathtt{sign}[M_{BB'}M_1 M_{\lambda_{\tilde{X}}}] + g_1 g_{YX}\mathtt{sign}[M_{BB'}])\delta_{ij}^{LR}\}.$$

The result with $\frac{m_{l_i}}{m_{l_j}}$ is 2–3 orders of magnitude smaller than other terms. Therefore, we will not consider the term with $\frac{m_{l_i}}{m_{l_j}}$ here.

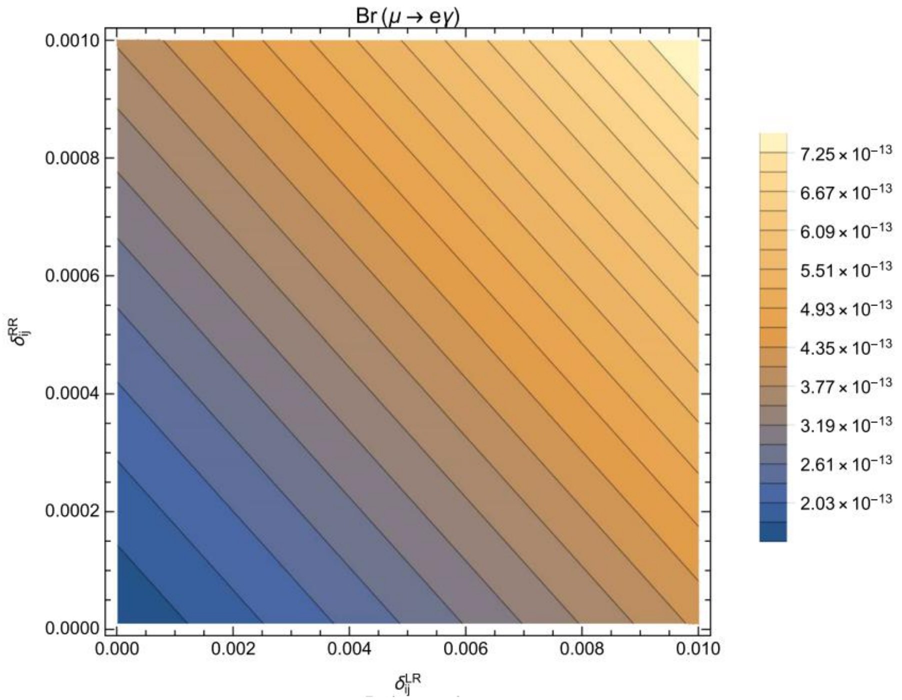
According to $1 > g_X > g_{YX} > 0$, we assume $\texttt{sign}[M_1] = \texttt{sign}[M_{\lambda_{\tilde{X}}}] = \texttt{sign}[\mu'_H] = 1$ and $\texttt{sign}[M_2] = \texttt{sign}[M_{BB'}] = -1$, and get the larger value

$$C_2 = \frac{(5g_1^2 + 5(g_{YX}^2 + \frac{1}{2}g_{YX}g_X) + 3g_1 g_{YX})\delta_{ij}^{LR}}{1920\pi^2 M_{SUSY}^2} + \frac{3g_2^2 \tan\beta\delta_{ij}^{LL}}{1280\pi^2 M_{SUSY}^2}$$

$$+ \frac{(2g_1^2 + (2g_{YX}^2 + 3g_{YX}g_X + g_X^2))\tan\beta\delta_{ij}^{RR}}{960\pi^2 M_{SUSY}^2}.$$

4、Numerical results

$g_{YX} = 0.2$, $g_X = 0.3$ and $\delta_{ij}^{LL} = 1 \times 10^{-3}$, the effect of δ_{ij}^{LR} and δ_{ij}^{RR} on $Br(\mu \to e\gamma)$.

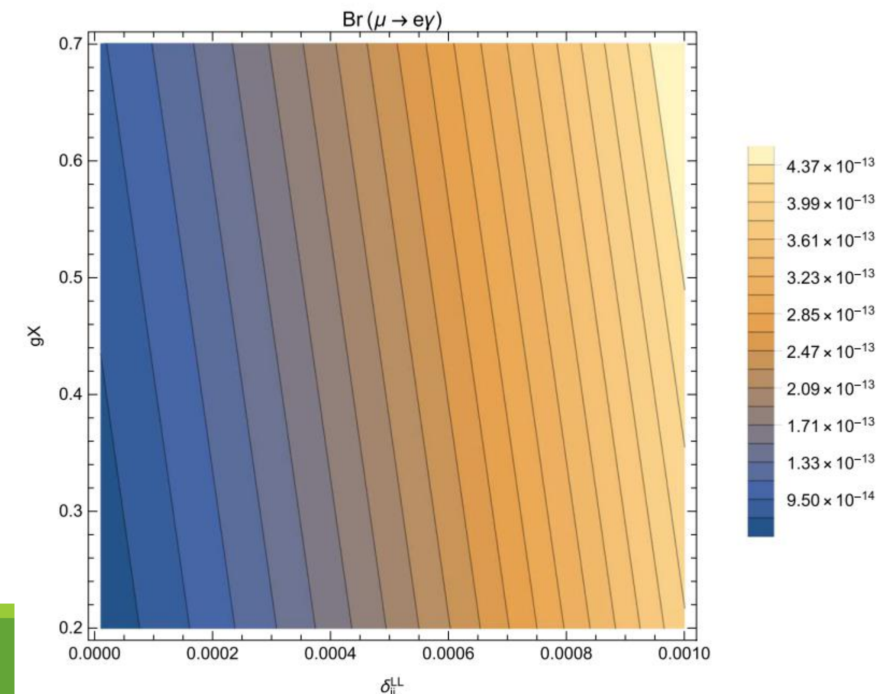


The x-axis represents δ_{ij}^{LR} from 1×10^{-5} to 1×10^{-2}, and the y-axis represents $1 \times 10^{-5} < \delta_{ij}^{RR} < 1 \times 10^{-3}$.

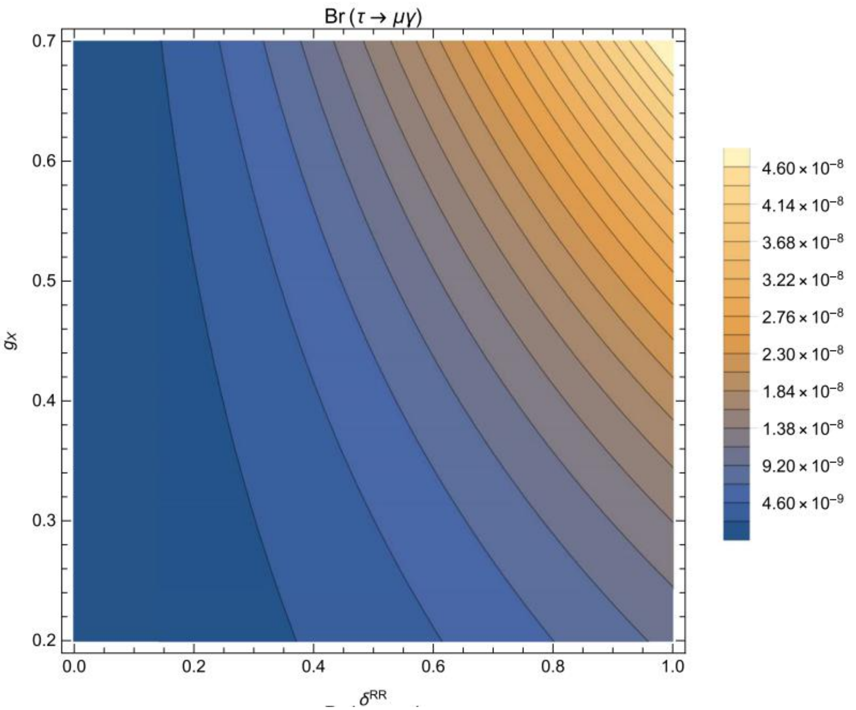
$g_{YX} = 0.2$, $\delta_{ij}^{RR} = 1 \times 10^{-6}$ and $\delta_{ij}^{LR} = 1 \times 10^{-2}$, δ_{ij}^{LL} versus g_X about $Br(\mu \to e\gamma)$.

$1 \times 10^{-5} < \delta_{ij}^{LL} < 1 \times 10^{-3}$

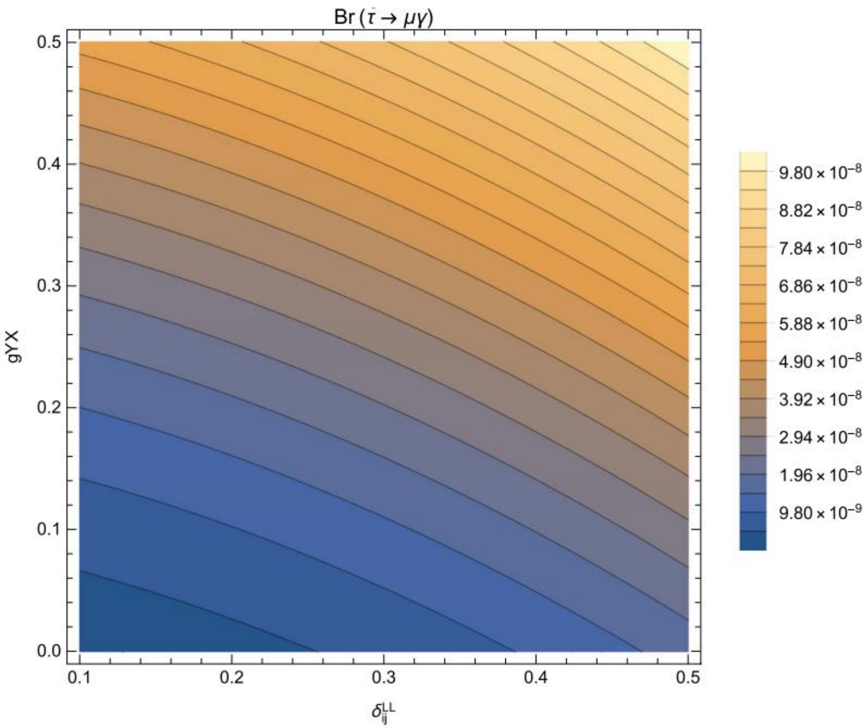
$0.2 < g_X < 0.7$.



$\delta_{ij}^{LR} = 0.1$, $g_{YX} = 0.2$ and $\delta_{ij}^{LL} = 0.1$, the effect of δ_{ij}^{RR} and g_X on $Br(\tau \to \mu\gamma)$. The x-axis representing the range of δ_{ij}^{RR} is from 10^{-5} to 1, and the y-axis represents $0.2 < g_X < 0.7$.



$\delta_{ij}^{RR} = 0.2$, $g_X = 0.3$ and $\delta_{ij}^{LR} = 0.5$, δ_{ij}^{LL} versus g_{YX} about $Br(\tau \to \mu\gamma)$. The abscissa is $1 \times 10^{-5} < \delta_{ij}^{LL} < 0.5$ and the ordinate represents $0.1 < g_{YX} < 0.5$.



考虑的实验限制

1. the lightest CP-even Higgs mass $m_{h^0} = 125.1$ GeV
2. The latest experimental results of the mass of the heavy vector boson Z' is $M_{Z'} > 5.1$ TeV
3. The limits for the masses of other particles beyond SM.
4. The bound on the ratio between $M_{Z'}$ and its gauge coupling g_X is $M_{Z'}/g_X \geq 6$ TeV at 99% CL
5. The constraint from LHC data, $\tan\beta_\eta < 1.5$
6. The scalar lepton masses larger than 700 GeV and chargino masses larger than 1100 GeV

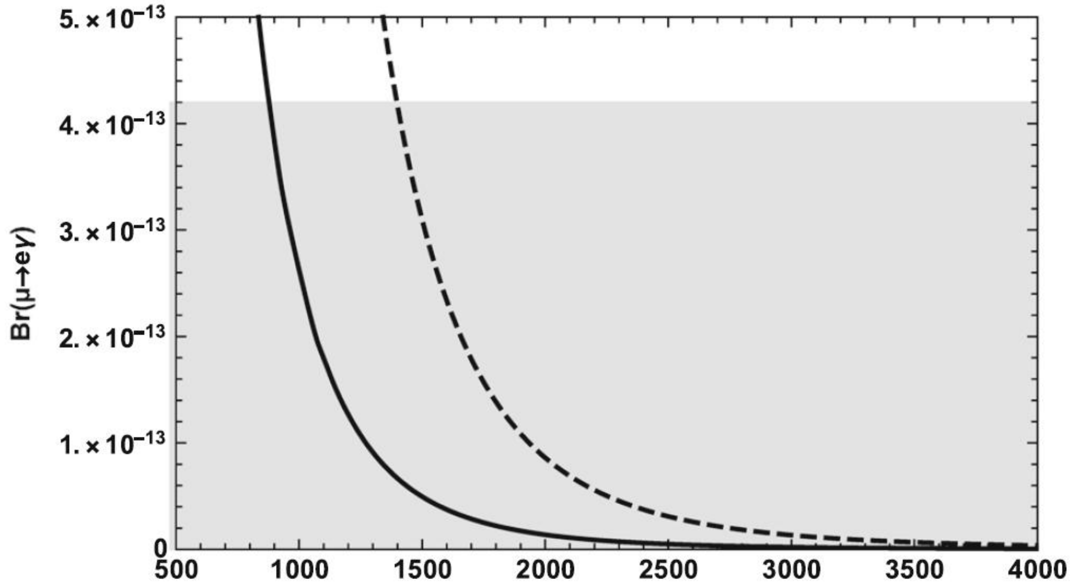
$$M_S = 2.7\text{ TeV},\ T_\kappa = 1.6\text{ TeV},\ M_1 = 1.2\text{ TeV},\ M_2 = M_{BL} = 1\text{ TeV},\ g_{YX} = 0.2,$$

$$\xi = 17\text{ TeV},\ Y_{X11} = Y_{X22} = Y_{X33} = \kappa = 1,\ \lambda_C = -0.08,\ v_S = 4.3\text{ TeV},\ \lambda_H = 0.1,$$

$$M_{BB'} = 0.4\text{ TeV},\ T_{\lambda_H} = 0.3\text{ TeV},\ M^2_{\tilde{L}11} = M^2_{\tilde{L}22} = M^2_{\tilde{L}33} = M^2_{\tilde{L}} = 0.5\text{ TeV}^2,$$

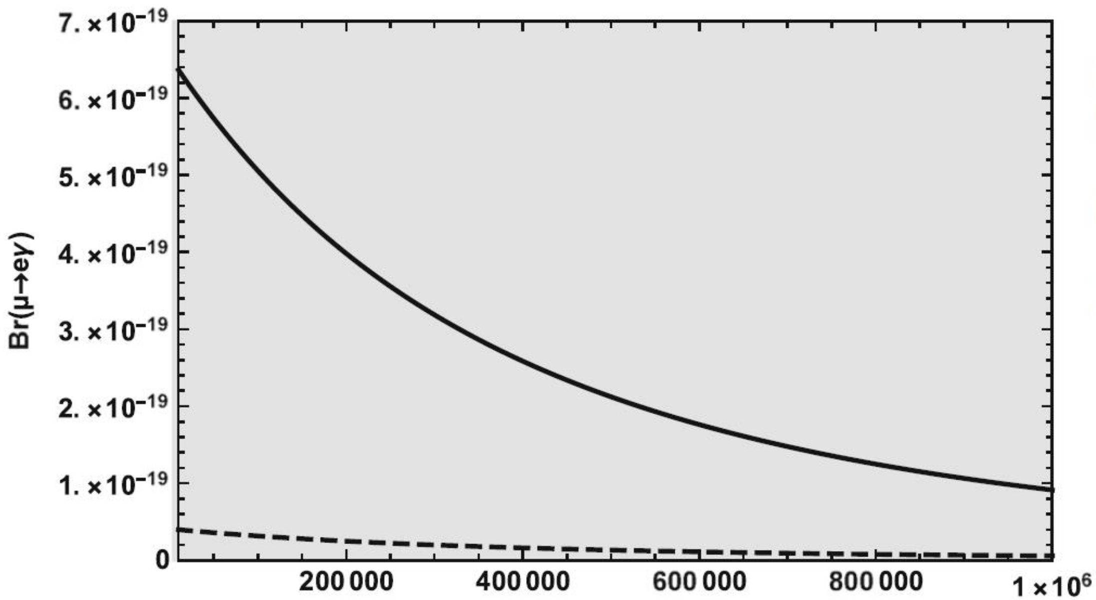
$$l_W = 4\text{ TeV}^2,\ T_{e11} = T_{e22} = T_{e33} = 5\text{ TeV},\ \tan\beta_\eta = 0.8,\ g_X = 0.3,\ \mu = 0.5\text{ TeV},$$

$$B_\mu = B_S = 1\text{ TeV}^2,\ T_{\lambda_C} = -0.1\text{ TeV},\ M^2_{\tilde{E}11} = M^2_{\tilde{E}22} = M^2_{\tilde{E}33} = M^2_{\tilde{E}} = 3.6\text{ TeV}^2.$$



(a) $m_{\tilde{\nu}_L}$/GeV

As $T_{e12} = 0$, the dashed and solid lines in **a** correspond to $M^2_{\tilde{L}12} = 500\ \text{GeV}^2$ and $M^2_{\tilde{L}12} = 200\ \text{GeV}^2$.

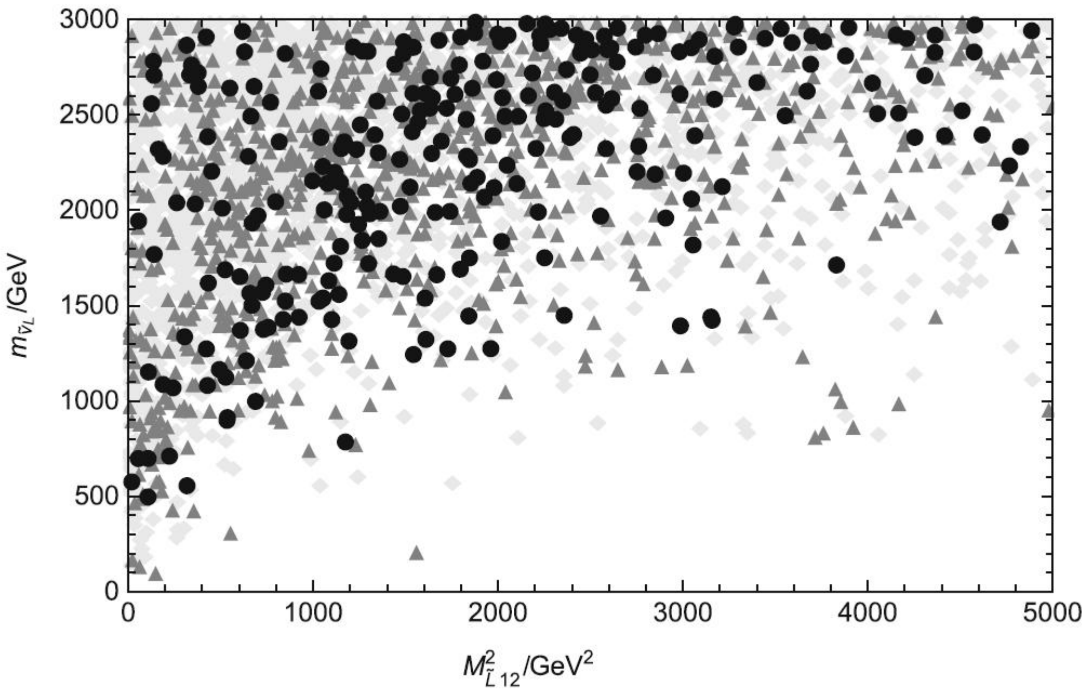


(b) $M^2_{\tilde{L}}/\text{GeV}^2$

The dashed line and solid line respectively represent $T_{e12} = 50$ GeV and 100 GeV in **b**.

Table 1 Scanning parameters. Without special statement, the non-zero values of non-diagonal elements $m^2_{\tilde{L}ij}, m^2_{\tilde{E}ij}, T_{eij}$ corresponding to $l_j \to l_i\gamma$ are shown in the column

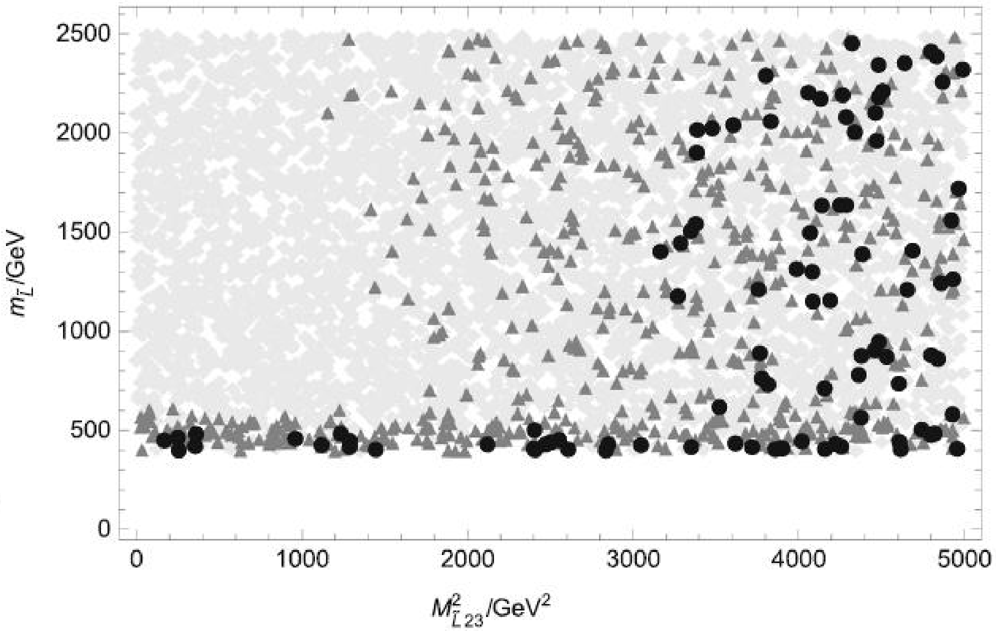
Parameters/range/processes	$\mu \to e\gamma(j=2, i=1)$	$\tau \to \mu\gamma\ (j=3, i=2)$	$\tau \to e\gamma\ (j=3, i=1)$
$\tan\beta$	$0.5 \sim 50$	$0.5 \sim 50$	$0.5 \sim 50$
$M^2_{\tilde{L}ij}/\mathrm{GeV}^2$	$0 \sim 5000$	$0 \sim 5000$	$0 \sim 5000$
$M^2_{\tilde{E}ij}/\mathrm{GeV}^2$	$0 \sim 10^4$	$0 \sim 10^4$	$0 \sim 10^4$
T_{eij}/GeV	$-1 \sim 1$	$-50 \sim 50$	$-50 \sim 50$
$m_{\tilde{\nu}_L}/\mathrm{GeV}$	$100 \sim 3000$	$100 \sim 3000$	$100 \sim 3000$
$m_{\tilde{L}}/\mathrm{GeV}$	$400 \sim 2500$	$400 \sim 2500$	$400 \sim 2500$



◆ mean the value of $Br(\mu \to e\gamma)$ less than 1.5×10^{-13},

▲ mean $Br(\mu \to e\gamma)$ in the range of 1.5×10^{-13} to 3.5×10^{-13},

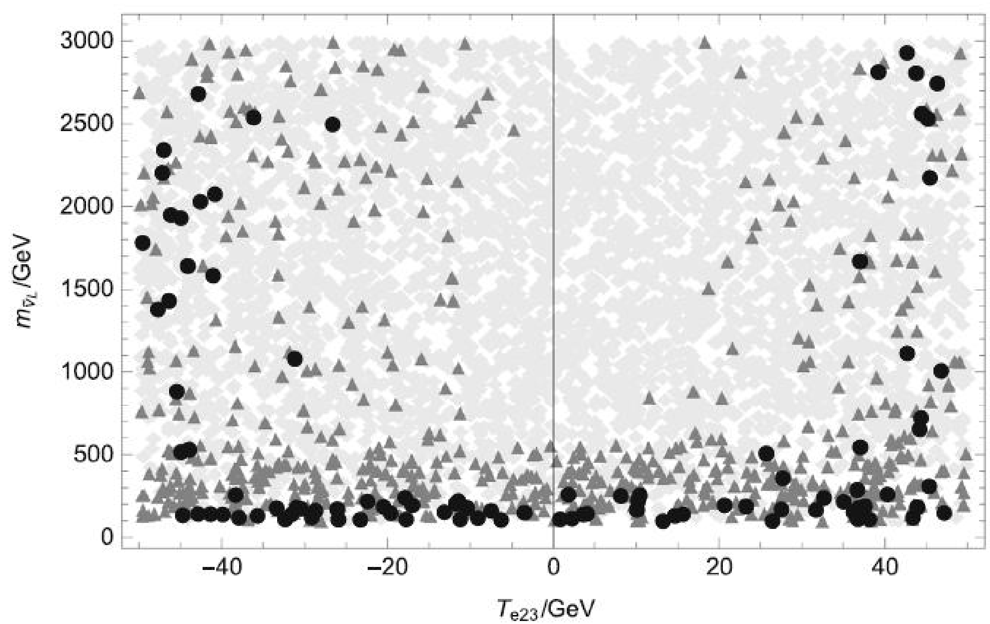
● show 3.5×10^{-13} to 4.2×10^{-13}

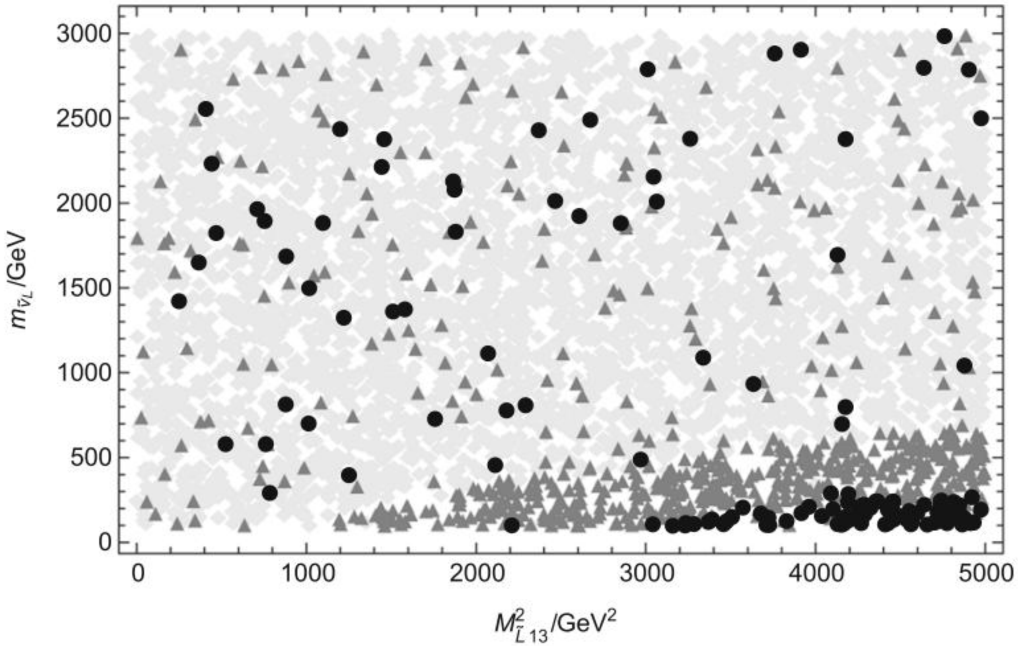


$\blacklozenge$ $0 < Br(\tau \to \mu\gamma) < 1 \times 10^{-10}$,

$\blacktriangle$ $10^{-10} \leq Br(\tau \to \mu\gamma) < 9 \times 10^{-10}$

$\bullet$ $9 \times 10^{-10} \leq Br(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$



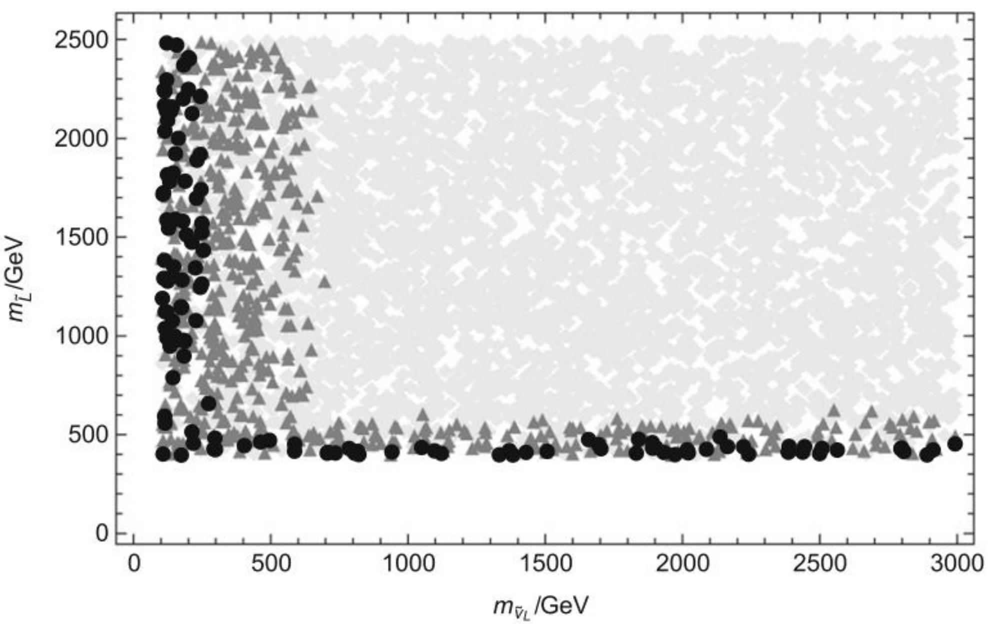


$$Br(\tau \to e\gamma)$$

♦ represent less than 1.0×10^{-10}.

▲ represent the range of 1.0×10^{-10} to 8.0×10^{-10},

• represent the range of 8.0×10^{-10} to 3.3×10^{-8}



5. Summary

- In the numerical calculation, we take many parameters as variables including $\tan\beta$, g_X, g_{YX}, $M^2_{\tilde{L}}$, $M^2_{\tilde{L}ij}$, $M^2_{\tilde{E}}$, $M^2_{\tilde{E}ij}$, δ^{AB}_{ij}, $m_{\tilde{L}}$, $m_{\tilde{\nu}_L}$ and T_{eij}.
- $M^2_{\tilde{L}ij}$, $M^2_{\tilde{E}ij}$, g_{YX}, δ^{AB}_{ij}, $m_{\tilde{L}}$, $m_{\tilde{\nu}_L}$ and T_{eij} are sensitive parameters.
- $Br(l_j \to l_i\gamma)$ is an increasing function of $M^2_{\tilde{L}ij}$, $M^2_{\tilde{E}ij}$, T_{eij}, g_{YX}, δ^{AB}_{ij}, and decreasing function of $m_{\tilde{L}}$ and $m_{\tilde{\nu}_L}$.
- g_X can also give influence on the numerical results but not very large.
- The non-diagonal elements which correspond to the generations of the initial lepton and final lepton are main sensitive parameters and LFV sources.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