Lepton flavor violating decays $l_j \to l_i\gamma\gamma$

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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 study the lepton flavor violation of the $l_j \to l_i\gamma\gamma$ by $U(1)_X SSM$. At the analytical level, we can find many parameters that have direct influence on LFV.

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

$$Br(\mu \to e\gamma\gamma) < 7.2 \times 10^{-11},$$

$$Br(\tau \to \mu\gamma\gamma) < 5.8 \times 10^{-4},$$

$$Br(\tau \to e\gamma\gamma) < 2.5 \times 10^{-4}.$$

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

U(1)xSSM is the U(1) extension of MSSM. To obtain this model, three singlet Higgs superfields and right-handed neutrinos are added to MSSM.

Its local gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_X$.

The particle content and charge assignments for U(1)xSSM:

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

The superpotential

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

The Higgs superfields

$$
H_u = \begin{pmatrix} H_u^+ \\ \frac{1}{\sqrt{2}}\left(v_u + H_u^0 + iP_u^0\right) \end{pmatrix}, \qquad H_d = \begin{pmatrix} \frac{1}{\sqrt{2}}\left(v_d + H_d^0 + iP_d^0\right) \\ H_d^- \end{pmatrix},
$$

$$
\eta = \frac{1}{\sqrt{2}}\left(v_\eta + \phi_\eta^0 + iP_\eta^0\right), \qquad \bar{\eta} = \frac{1}{\sqrt{2}}\left(v_{\bar{\eta}} + \phi_{\bar{\eta}}^0 + iP_{\bar{\eta}}^0\right),
$$

$$
S = \frac{1}{\sqrt{2}}\left(v_S + \phi_S^0 + iP_S^0\right).
$$

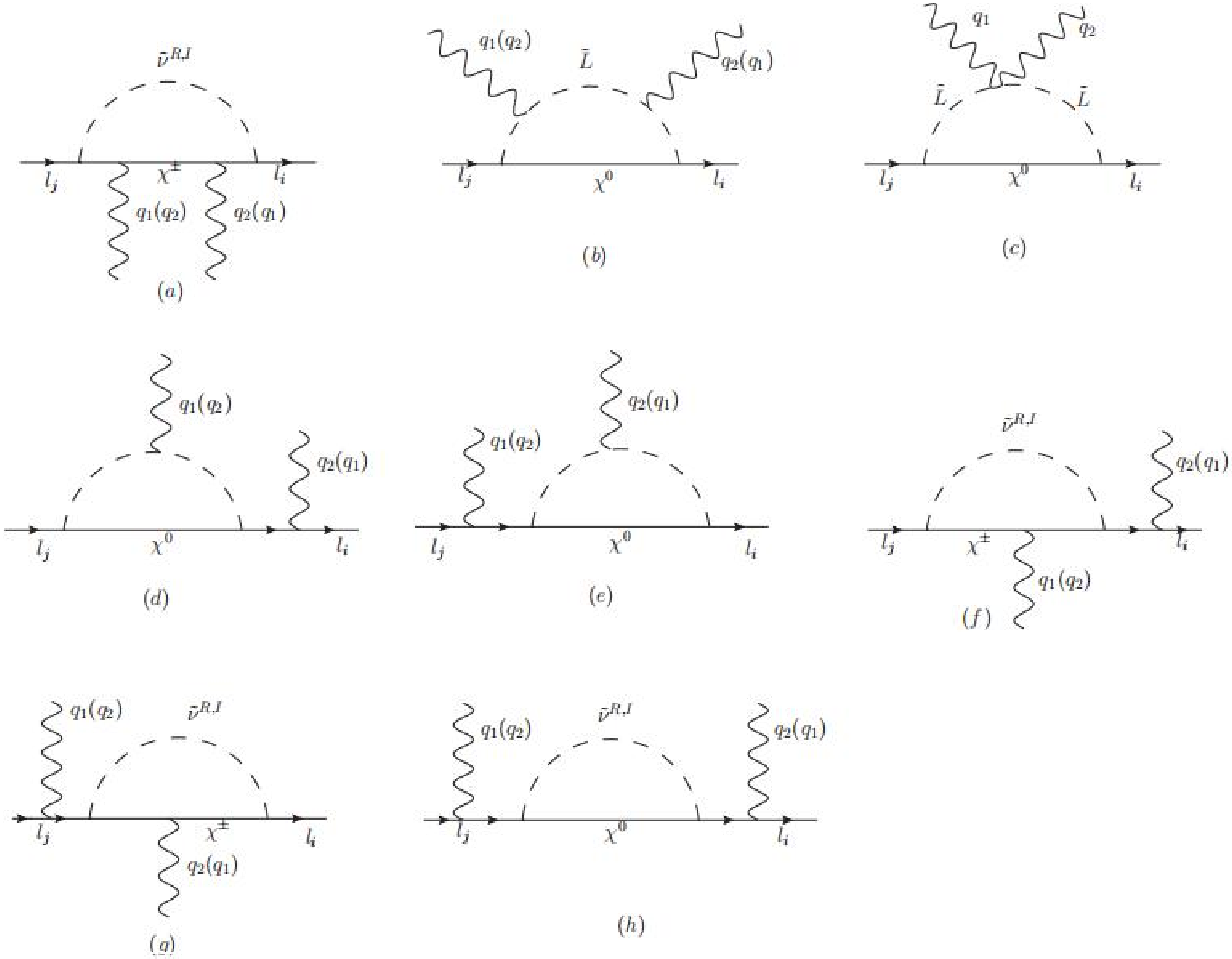
The soft SUSY breaking terms

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

The covariant derivatives of U(1)xSSM

$$D_\mu = \partial_\mu - i\left(Y, X\right) \begin{pmatrix} g_Y, & g'_{YX} \\ g'_{XY}, & g'_X \end{pmatrix} \begin{pmatrix} A_\mu^{\prime Y} \\ A_\mu^{\prime X} \end{pmatrix}$$

3、One loop diagram



decay width

Let the Euler angles are (α, β, γ) to determine the final system with respect to the initial orientation of the particles

$$d\Gamma = \frac{1}{(2\pi)^5}\frac{1}{16M}|\mathcal{M}|^2 dE_1 dE_3 d\alpha d(\cos\beta) d\gamma.$$

$$\Downarrow$$

$$d\Gamma = \frac{1}{(2\pi)^3}\frac{1}{8M}|\mathcal{M}|^2 dE_1 dE_3.$$

the decay width and branching ratio

$$\Gamma(l_j \to l_i\gamma\gamma) = \frac{1}{(2\pi)^3}\frac{1}{8M}\int |\mathcal{M}|^2 dE_1 dE_2,$$

$$Br(l_j \to l_i\gamma\gamma) = \frac{\Gamma(l_j \to l_i\gamma\gamma)}{\Gamma_{l_j}}.$$

4、Numerical results

Experimental limitations considered

1. the lightest CP-even Higgs mass m_{h^0} = 125.25 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

we adopt the following parameters in the numerical calculation

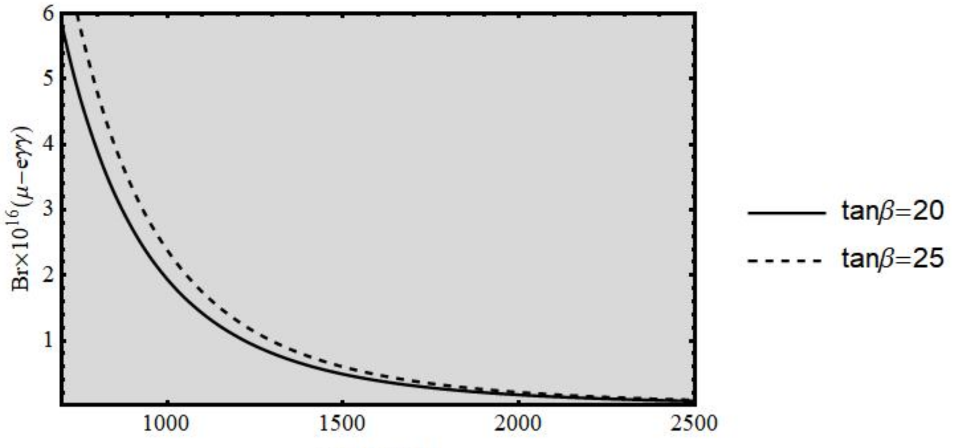
$$\mu = M_{BL} = T_{\lambda_C} = T_{\lambda_H} = T_{\kappa} = 1\ \text{TeV}, \quad M_{BB'} = M_S = 0.4\ \text{TeV},$$

$$\lambda_H = 0.1,\ l_W = B_\mu = B_S = 0.1\ \text{TeV}^2, \quad T_{Xii} = -1\ \text{TeV},$$

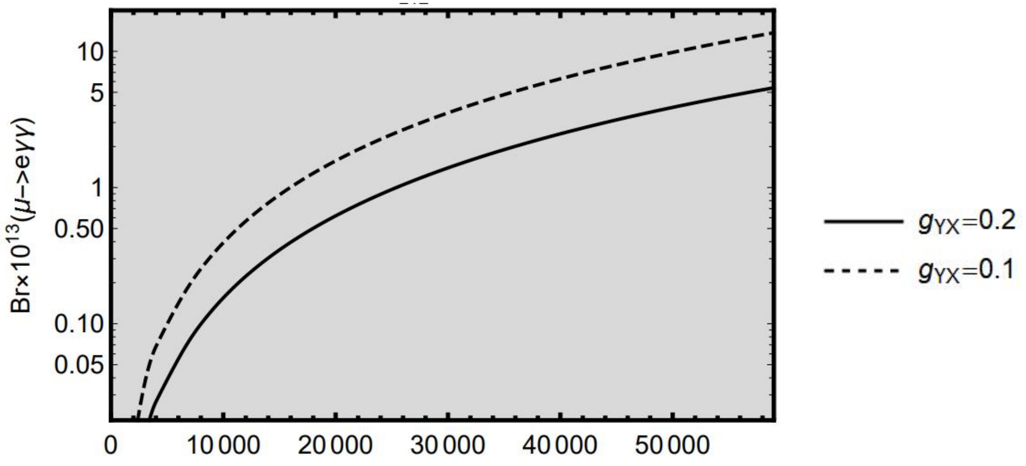
$$\kappa = 0.1, \quad Y_{Xii} = 1\ \text{TeV}(i = 1, 2, 3),\ M^2_{\tilde{E}ii} = 0.8\ \text{TeV}^2,$$

$$M^2_{\tilde{\nu}ii} = 0.3\ \text{TeV}^2, \quad T_{\tilde{e}ii} = 0.5\ \text{TeV},\ \lambda_C = -0.25.$$

μ → eγγ

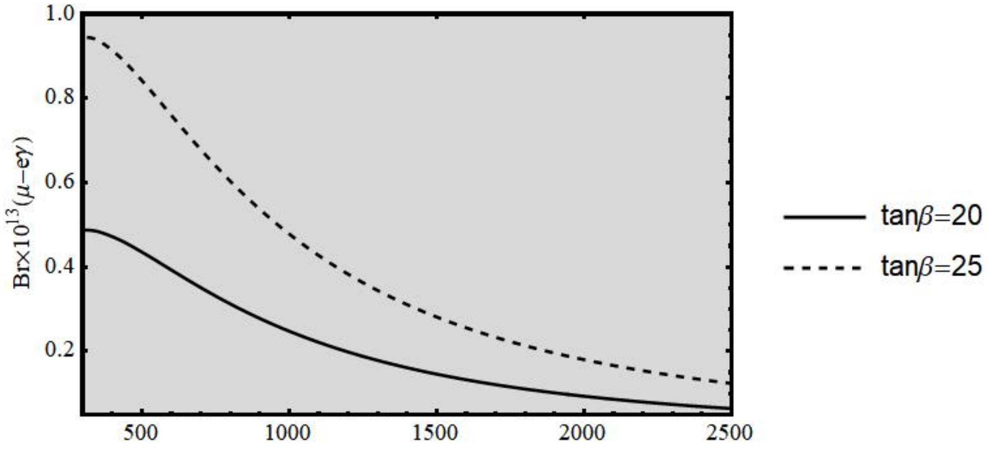


(a)M_2/GeV

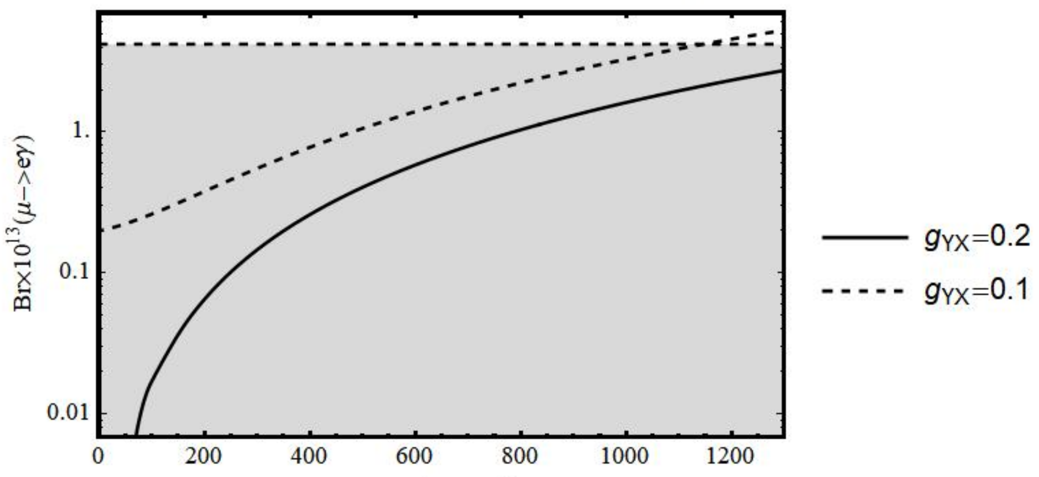


(d)M^2_{E12}/GeV^2

μ → eγ



(e)M_2/GeV



(f)M^2_{E12}/GeV^2

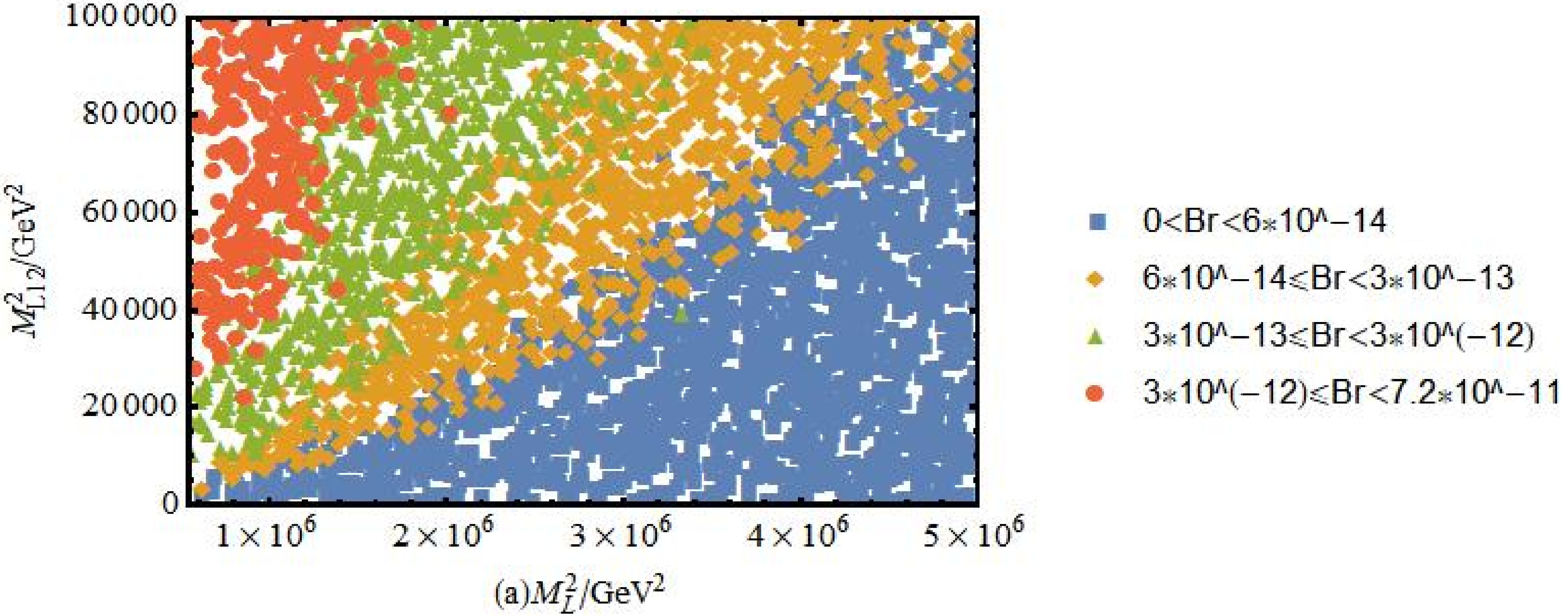
Scanning parameters

ALL processes

Parameters	$\tan\beta$	g_X	g_{YX}	λ_H	λ_C	μ/GeV	M_2/ GeV	$M_{\tilde{L}}^2$/ GeV^2	$M_{\tilde{\nu}}^2$/ GeV^2
Min	5	0.3	0.01	0.1	-0.3	1000	700	4×10^5	3×10^5
Max	50	0.6	0.2	0.3	-0.1	1300	2500	5×10^6	5×10^6

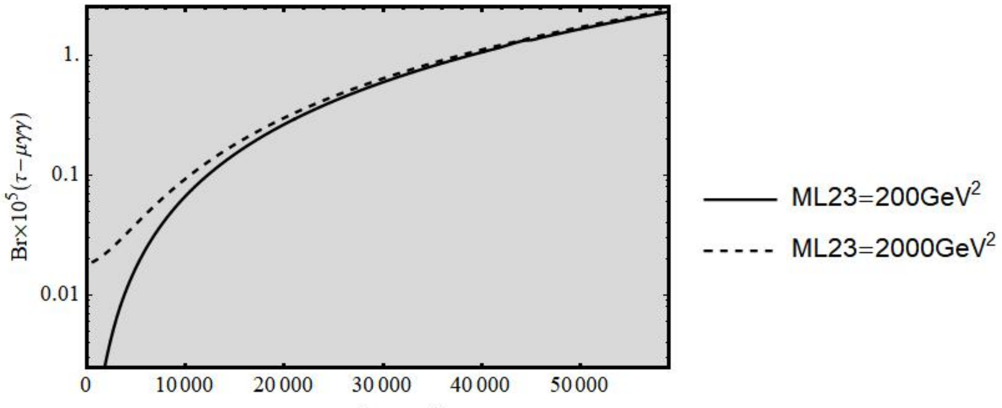
$\mu \to e\gamma\gamma$

Parameters	$M_{\tilde{L}12}^2$/ GeV^2	T_{e12}/ GeV	$T_{\tilde{\nu}12}$/ GeV
Min	0	- 400	- 400
Max	10^5	400	400



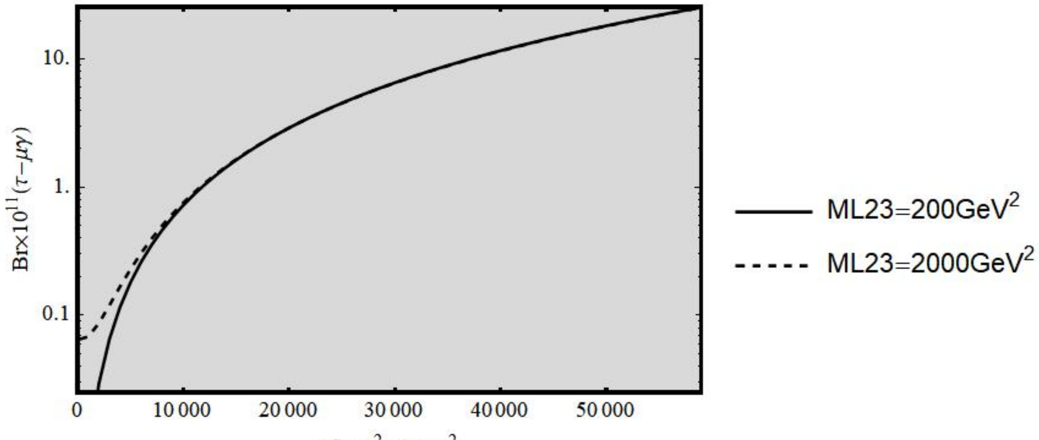
100 000
80 000
60 000
40 000
20 000
0
M^2_{L12}/GeV^2
1×10^6
2×10^6
3×10^6
4×10^6
5×10^6
(a)M^2_L/GeV^2
0<Br<6*10^−14
6*10^−14≤Br<3*10^−13
3*10^−13≤Br<3*10^(−12)
3*10^(−12)≤Br<7.2*10^−11

τ → μγγ



(b) $M^2_{\mathrm{E}23}/\mathrm{GeV}^2$

τ → μγ



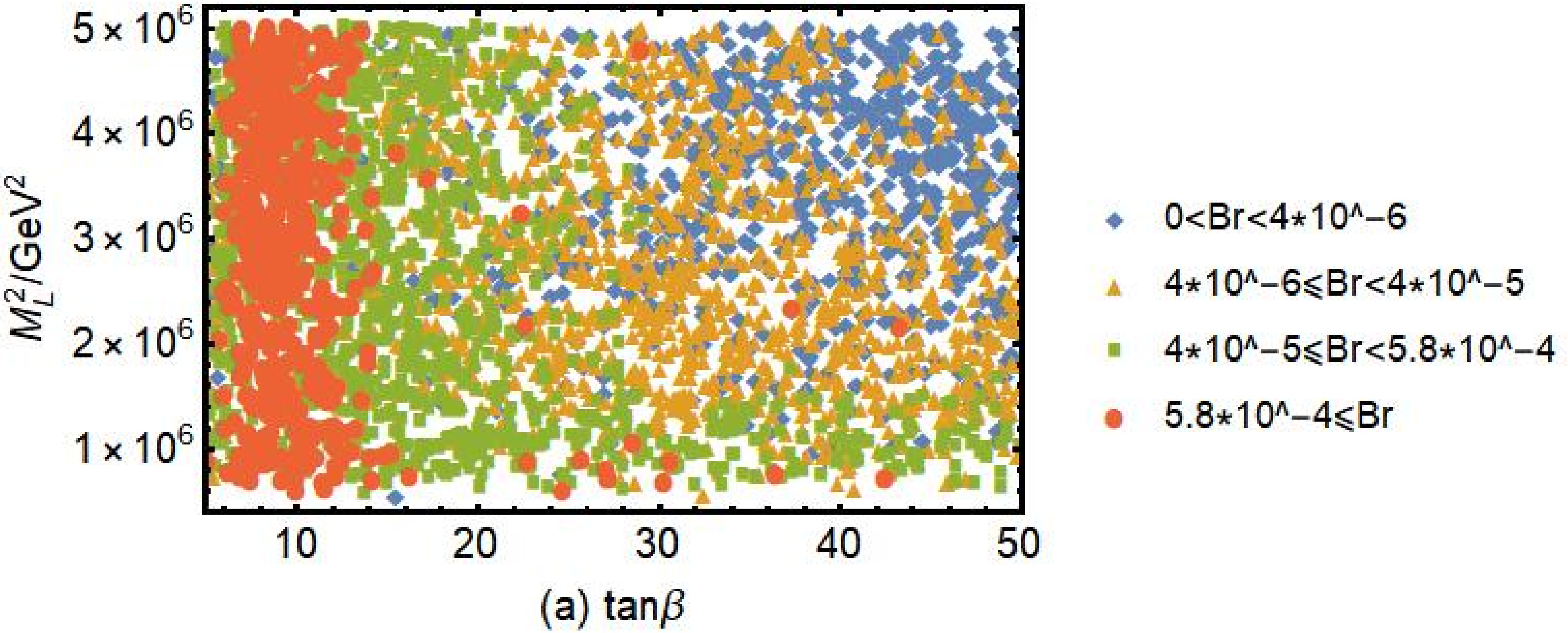
(d) $M^2_{\mathrm{E}23}/\mathrm{GeV}^2$

ALL processes

Parameters	$\tan\beta$	g_X	g_{YX}	λ_H	λ_C	μ/GeV	M_2/ GeV	$M_{\tilde{L}}^2$/ GeV^2	$M_{\tilde{\nu}}^2$/ GeV^2
Min	5	0.3	0.01	0.1	-0.3	1000	700	4×10^5	3×10^5
Max	50	0.6	0.2	0.3	-0.1	1300	2500	5×10^6	5×10^6

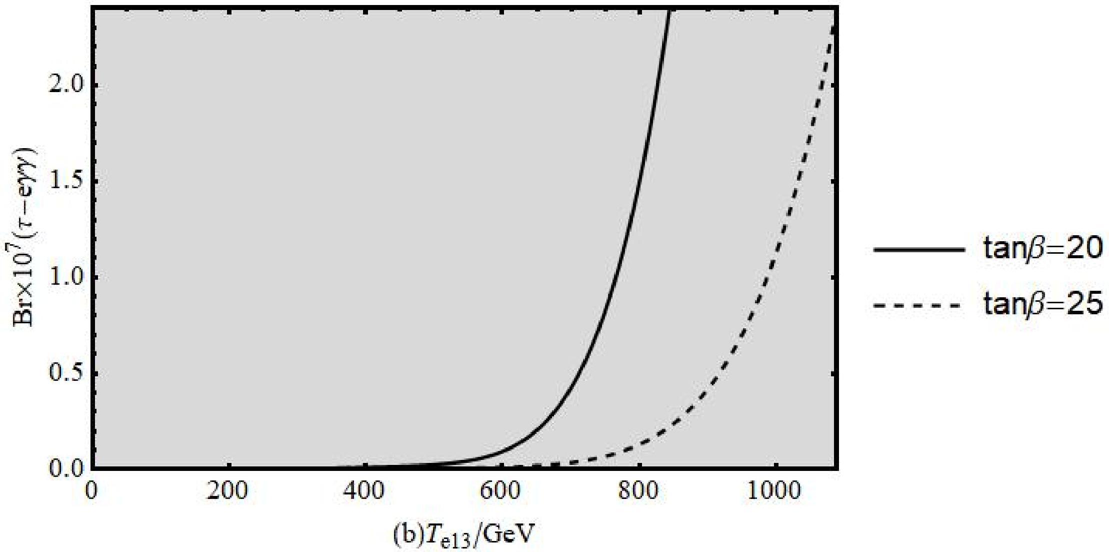
$\tau \to \mu\gamma\gamma$

Parameters	$M_{\tilde{L}23}^2$/ GeV^2	T_{e23}/ GeV	$T_{\tilde{\nu}23}$/ GeV
Min	0	- 400	- 400
Max	10^5	400	400



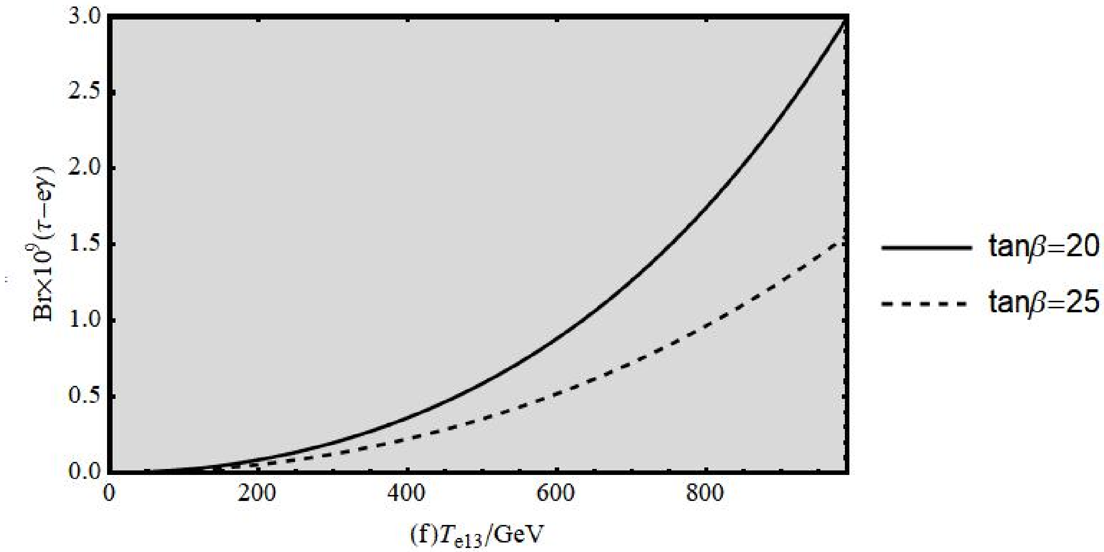
5×10^6
4×10^6
3×10^6
2×10^6
1×10^6
M_L^2/GeV^2
10
20
30
40
50
(a) $\tan\beta$
0<Br<4*10^-6
4*10^-6⩽Br<4*10^-5
4*10^-5⩽Br<5.8*10^-4
5.8*10^-4⩽Br

τ → eγγ



Br×10^7(τ−eγγ)
2.0
1.5
1.0
0.5
0.0
0
200
400
600
800
1000
(b)Te13/GeV
tanβ=20
tanβ=25

τ → eγ



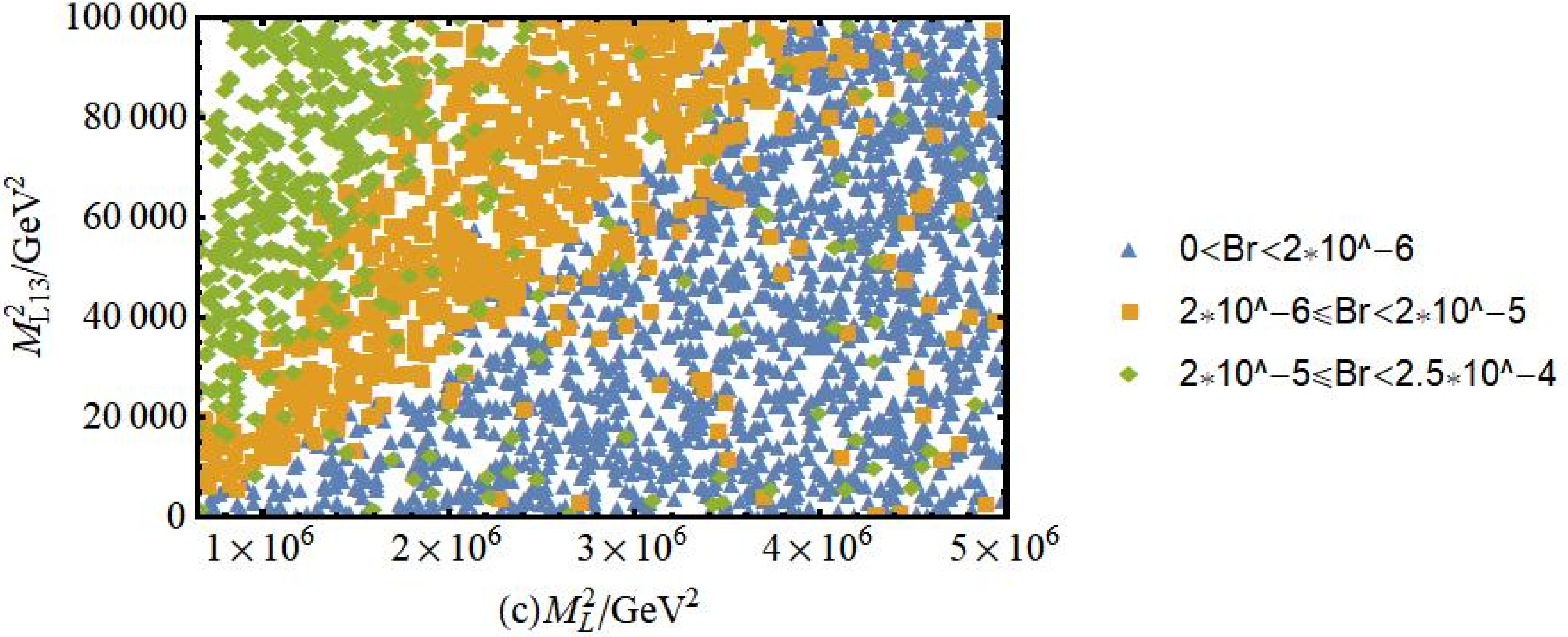
Br×10^9(τ−eγ)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
200
400
600
800
(f)Te13/GeV
tanβ=20
tanβ=25

ALL processes

Parameters	$\tan\beta$	g_X	g_{YX}	λ_H	λ_C	μ/GeV	M_2/ GeV	$M^2_{\tilde{L}}$/ GeV^2	$M^2_{\tilde{\nu}}$/ GeV^2
Min	5	0.3	0.01	0.1	-0.3	1000	700	4×10^5	3×10^5
Max	50	0.6	0.2	0.3	-0.1	1300	2500	5×10^6	5×10^6

τ → eγγ

Parameters	$M^2_{\tilde{L}13}$/ GeV^2	T_{e13}/ GeV	$T_{\tilde{\nu}13}$/ GeV
Min	0	- 400	- 400
Max	10^5	400	400



100 000
80 000
60 000
40 000
20 000
0
M^2_{L13}/GeV^2
1×10^6
2×10^6
3×10^6
4×10^6
5×10^6
(c)M^2_L/GeV^2
0<Br<2*10^-6
2*10^-6⩽Br<2*10^-5
2*10^-5⩽Br<2.5*10^-4

5、Summary

- In the numerical calculation, we take many parameters as variables including：

$$\tan\beta,\ g_X,\ g_{YX},\ \lambda_H,\ \mu,\ M_2,\ M_{\tilde{L}}^2,\ M_{\tilde{\nu}}^2,\ M_{\tilde{L}ij}^2,\ T_{eij},\ T_{\nu ij}.$$

- Fully satisfying the experimental constraints, we analyse the values to obtain branching ratios up to 10^{-12} for $\mu \to e\gamma\gamma$, 10^{-4} for $\tau \to \mu\gamma\gamma$, and 10^{-5} for $\tau \to e\gamma\gamma$， this work can benefit the detection of new physics.

- The non-diagonal elements which correspond to the generations of the initial lepton and final lepton are main sensitive parameters and LFV sources.

Thank you