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HIGH ENERGY PHOTON COLLISIONS, NEW PATHS TO LEPTON FLAVOUR VIOLATION*

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The lepton flavour violating (LFV) reactions $\gamma\gamma \to \ell\ell'$ ($\ell, \ell' = e, \mu, \tau$, $\ell \neq \ell'$) which arise at the one loop order of perturbation theory are studied at energies of interest for the $\gamma\gamma$ option of the future ILC. The LFV mechanism is provided by low energy R-conserving SUSY with non diagonal slepton mass matrices. The average slepton masses $\widetilde{m}$ and the off diagonal matrix elements Δm are treated as model independent free phenomenological parameters in order to discover regions in the parameter space, where the signal cross section may be observable, comparing to the existing bounds on these parameters provided by the non-observation of radiative LFV decays and discuss how to reduce the standard model background.

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We report new results obtained in the study of the lepton flavour violating reaction $\gamma\gamma \to \ell\ell'$ with $\ell \neq \ell'$ and $\ell, \ell' = e, \mu, \tau$, which arises at one loop order in supersymmetric scenarios, thus extending to the $\gamma\gamma$ option an analysis done by some of the authors in Ref. [1] for the e^+e^- and e^-e^- mode of the next linear collider. More details and results can be found in [2].

In SUSY extensions (with mSUGRA boundary conditions) of the seesaw mechanism for the explanation of neutrino masses [3], *off-diagonal* matrix

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elements in $(m^2_{\tilde{L}})_{ij}$ are generated. The mixing matrix arising in the diagonalisation of $(m^2_{\tilde{L}})_{ij}$ induces LFV couplings in the lepton-slepton-gaugino vertices. We adopt here a phenomenological approach without referring to a particular neutrino mass texture scenario, and consider the case of two generations for the mass matrix of left-sleptons (and sneutrinos):

$$\widetilde{m}^2_L = \begin{pmatrix} \widetilde{m}^2 & \Delta m^2 \\ \Delta m^2 & \widetilde{m}^2 \end{pmatrix},$$

with eigenvalues: $\widetilde{m}^2_\pm = \widetilde{m}^2 \pm \Delta m^2$ and maximal mixing. Under these assumptions, the lepton flavour violating propagator in momentum space for a scalar line is $\langle \tilde{\ell}_i \tilde{\ell}^\dagger_j \rangle_0 = i\Delta m^2/[(p^2 - \widetilde{m}^2_+)(p^2 - \widetilde{m}^2_-)]$. The quantity $\delta_{LL} = \Delta m^2/\widetilde{m}^2$ is the dimension-less parameter that controls the magnitude of the LFV effect. This approach is similar to the mass insertion approximation (MIA) [4]. Our propagator corresponds to the one in MIA when one assumes the diagonal masses to be equal (which is usually a good approximation due the near degeneracy of the squared slepton masses at the electroweak scale) and $(\Delta m^2)_{ij} \ll \widetilde{m}^2$ which is necessary to make the expansion in δ_{ij}. We further consider the two lightest neutralinos as pure Bino and pure Wino with masses M_1 and M_2 respectively, while charginos are pure charged Winos with mass M_2, M_1 and M_2, In Ref. [2] we show that the calculations with the account of energy and helicity spectra limited to the region of the peak of the luminosity spectrum [5] give results almost identical (within a few %) to the monochromatic calculation with photon energies fixed to their maximum values. Thus, in the following we consider the cases of a photon collider with $2E_0 = 200$ GeV with monochromatic photons in pure helicity states with $E_\gamma = E^{\max}_\gamma$ ($\sqrt{s_{\gamma\gamma}} = 128$ GeV) and use the realistic simulated luminosities of TESLA [5] to estimate event rates: the photon–photon luminosity at the peak is: $L_{\gamma\gamma}$ =0.44 $\times 10^{34}$ cm^{-2}s^{-1}, equivalent to $L_{\gamma\gamma} = 1.3 \times 10^2$ fb^{-1}yr^{-1}.

The helicity of the fermions in the final state are fixed to only one configuration, thus there are only four helicity amplitudes corresponding to the possible combinations of the photon helicities. The amplitudes with opposite helicity photons $\mathcal{M}^{(+,-)}$ and $\mathcal{M}^{(-,+)}$ ($J_z = \pm 2$) dominate the signal, while those with the same helicity photons ($J_z = 0$) give negligible cross sections. Moreover the former are peaked in the forward and backward directions while the latter are suppressed in these regions. The $J_z = \pm 2$ cross sections decrease with increasing energy for they are dominated by diagrams with the exchange of a *light* lepton in the t and u channels. Given luminosities of order $\mathcal{O}(100)$ fb^{-1}yr^{-1}, cross sections greater than 10^{-2} fb are needed. In the case of $2E_0 = 200$ GeV, this happens for $\delta_{LL} \gtrsim 5 \times 10^{-2}$. To see if these large mass splittings are allowed by current experimental constraints we have to take into account the bounds imposed on the model

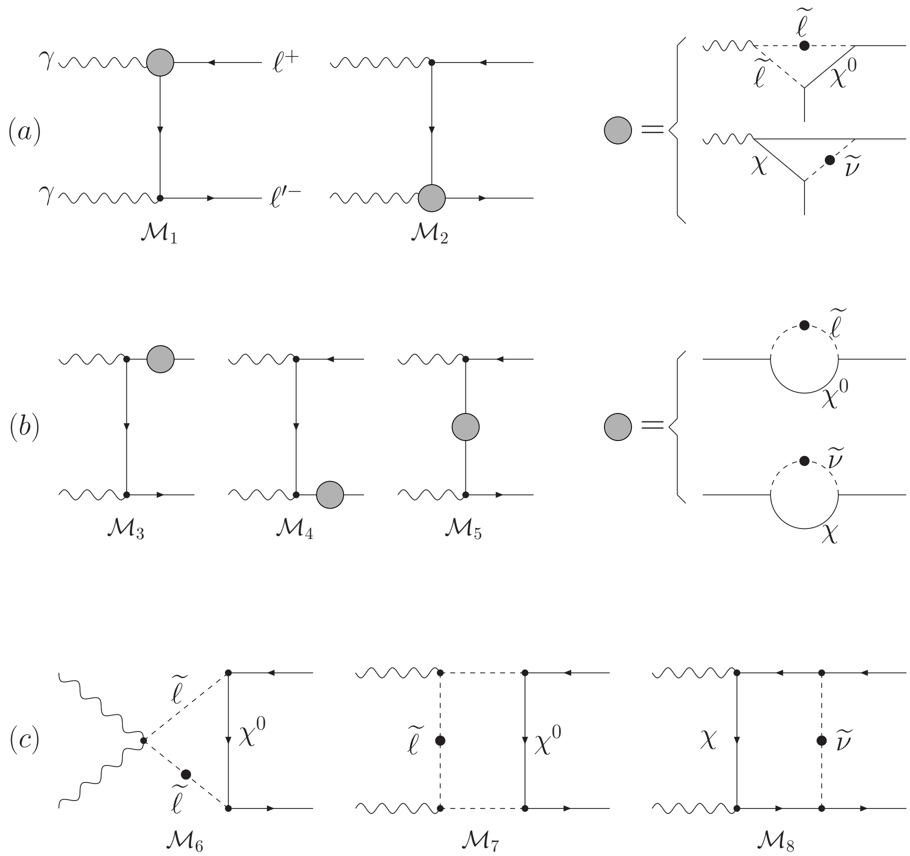

Fig. 1. Diagrams for $\gamma\gamma$ collisions. The full black dot in a scalar line denotes the insertion of the lepton flavour violating propagator.

by the non observation of radiative decays: $B(\mu \to e\gamma) < 1.2 \times 10^{-11}$, $B(\tau \to e\gamma) < 1.1 \times 10^{-7}$, $B(\tau \to \mu\gamma) < 6.8 \times 10^{-8}$ [6]. The computation of the branching ratios is done with the exact formulas given in Ref. [3], using the two family approximation for the left slepton mass matrix. In figure 2, we show scatter plots where the average slepton mass and the relative mass splitting $\delta_{LL} = \Delta m^2/\widetilde{m}^2$ are varied freely, for fixed values of gaugino masses and for $\tan\beta = 10$, 30. In these figures, the values of δ_{LL} that determine a positive signal at the photon collider are compared with the bounds from rare radiative decays. For $\tan\beta = 10$ the parameter space [the $(\widetilde{m}, \delta_{LL})$ plane] is covered by the light grey points (turquoise in colour) that satisfy the bounds $B(\tau \to \gamma\mu, (e)) < 6.8 \times 10^{-8}$ (1.1×10^{-7}) while the dark grey points (red in colour), that satisfy $B(\mu \to e\gamma) < 1.2 \times 10^{-11}$ cover a more

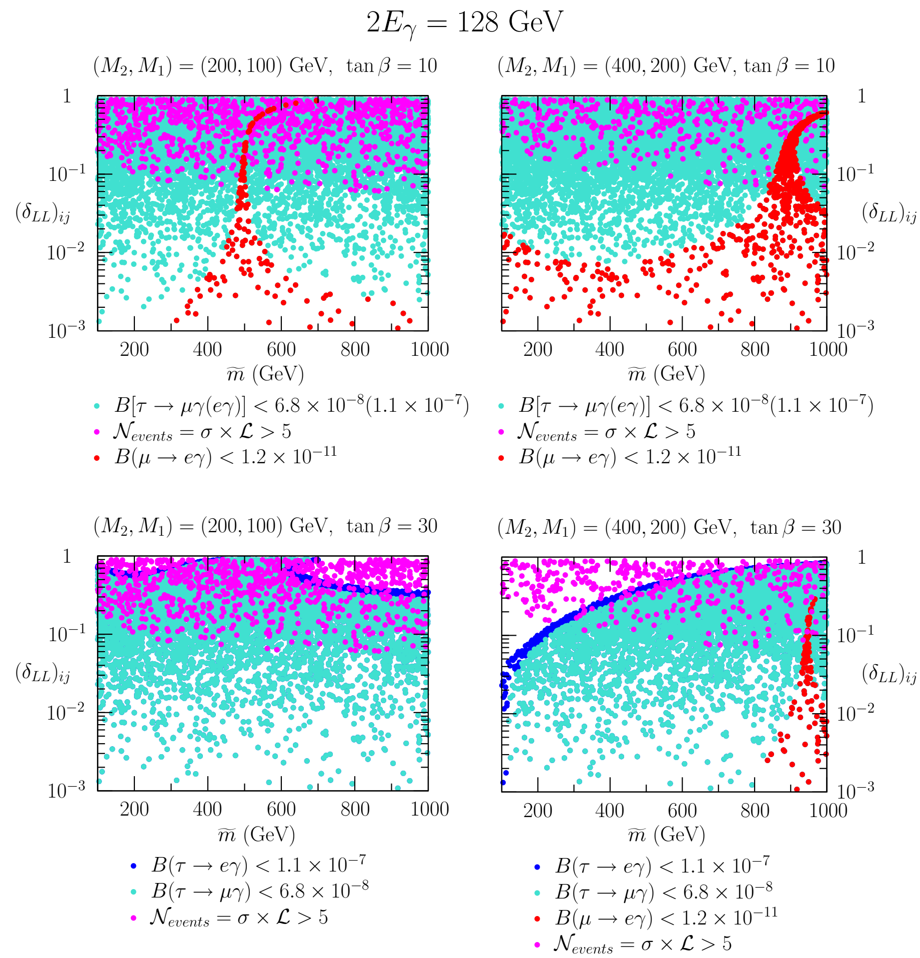

Fig. 2. The case $(M_1, M_2) = (100, 200)$ GeV corresponds to the mSUGRA set of boundary conditions $m_0 = 125$ GeV, $m_{1/2} = 260$ GeV, $\mathrm{sign}(\mu) = +$, $A_0 = 0$, $\tan\beta = 10$, 30, while the case $(M_1, M_2) = (200, 400)$ GeV, corresponds to the mSUGRA set $m_0 = 90$ GeV, $m_{1/2} = 480$ GeV, $\mathrm{sign}(\mu) = +$, $A_0 = 0$, $\tan\beta = 10$, 30. The energy is $\sqrt{s_{\gamma\gamma}} = 128$ GeV and the luminosity $L = 136$ fb^{-1} yr^{-1}.

restricted part. The grey points (magenta in colour) represent those regions of the parameter space with a positive signal at a photon collider and are determined imposing the condition that the number of events be larger than five events per year. The region corresponding to a positive signal overlaps only with the tail of the allowed "μ, e" grey-region (red online) which extends to higher values of δ_{LL}. This tail is due to peculiar cancellations between diagrams, and thus we can conclude that a positive signal for this final state (e, μ) is excluded apart from a small fraction of the parameter space. The μ, τ and the e, τ final state channels can produce a positive signal at a photon collider although they generally require a high-mass splitting, *i.e.* $\delta_{LL} \gtrapprox 10^{-1}$, but the non observation of the corresponding low energy radiative lepton decays does not impose any constraint. With $\tan\beta = 30$ the bounds from radiative decays become more stringent and there are excluded regions also for τ, e and τ, μ final state, in particular for light slepton masses and large δ_{LL}. However, the region of a positive signal at the photon collider still overlaps significantly with the allowed parameter space.

The most important background is given by the reactions:

(a) $\gamma\gamma \to \tau^-\tau^+ \to \tau^-\nu_e\bar{\nu}_\tau e^+$,

(b) $\gamma\gamma \to W^{-*}W^{+*} \to \tau^-\bar{\nu}_\tau\, e^+\nu_e$,

(c) $\gamma\gamma \to e^+e^-\tau^+\tau^-$,

with similar processes for the production of $\mu\tau$ pairs. We used the program COMPHEP [7] for (a) and (b) and a Monte Carlo code developed by some of the authors [7] for (c). We apply: the angular cut $|\cos(\theta)| < 0.9$ ($\theta < 25.8^\circ$) as done for the signal, the back-to-back condition on the background processes, requiring $180^\circ - \theta_{\ell\ell'} < 5^\circ$; one of the event hemisphere should consist of a single muon or electron with energy close to E_γ, final leptons are required to have energy at least 85% of the maximum photon energy $E^\gamma_{\rm max}$. After these cuts are applied, process (a) has a cross section 1.49×10^{-6} fb because tau pairs are almost produced along the collision axis, and process (b) is completely excluded, because the leptons from the decay of W are less energetic and cannot survive the energy cut. The cross section of reaction (c) turns out to be 4.4×10^{-2} fb providing the most dangerous background. The configuration that mimics the signal arises if one $e\tau$ pair is emitted at small angle with respect to the collision axis and *is not* detected (we require $\theta_\ell^{\rm untagged} < 25.8^\circ$), while the other pair is tagged. It is still at the level of 10^{-2} fb, thus remaining competitive with the signal cross section. We consider the statistical significance $SS = \mathcal{L}\sigma^S_{\rm cut}/\sqrt{\mathcal{L}\sigma^{BG}_{\rm cut}}$ and requiring $SS \geq 3$ we obtain $\sigma^S_{\rm cut} > 5.4 \times 10^{-2}$ fb at $\sqrt{s_{ee}} = 200$ GeV. This condition is satisfied if $\delta_{LL} \gtrsim 10^{-1}$ with the values of the other SUSY parameters as specified previously. This region of the parameter space is allowed for the $e\tau$, $\mu\tau$ channels as can be seen in Fig. 2.

REFERENCES

[1] M. Cannoni, S. Kolb, O. Panella, *Phys. Rev.* **D68**, 096002 (2003) [hep-ph/0306170].

[2] M. Cannoni, C. Carimalo, W. Da Silva, O. Panella, hep-ph/0508256, *Phys. Rev.* **D72**, 115004 (2005).

[3] F. Borzumati, A. Masiero, *Phys. Rev. Lett.* **57**, 961 (1986); J. Hisano, T. Moroi, K. Tobe, M. Yamaguchi, *Phys. Rev.* **D53**, 2442 (1996).

[4] F. Gabbiani, E. Gabrielli, A. Masiero, L. Silvestrini, *Nucl. Phys.* **B477**, 321 (1996) [hep-ph/9604387]; P. Paradisi, *J. High Energy Phys.* **0510**, 006 (2005) [hep-ph/0505046].

[5] I.F. Ginzburg, G.L. Kotkin, V.G. Serbo, V.I. Telnov, *Nucl. Instrum. Methods Phys. Res.* **A205**, 47 (1983); I.F. Ginzburg, G.L. Kotkin, S.L. Panfil, V.G. Serbo, V.I. Telnov, *Nucl. Instrum. Methods Phys. Res.* **A219**, 5 (1984); B. Badelek *et al.*, *Int. J. Mod. Phys.* **A19**, 5097 (2004) [hep-ex/0108012].

[6] M. Ahmed *et al.* [MEGA Collaboration], *Phys. Rev.* **D65**, 112002 (2002); B. Aubert [BABAR Collaboration], hep-ex/0508012; *Phys. Rev. Lett.* **95**, 041802 (2005) [hep-ex/0502032].

[7] A. Pukhov *et al.*, hep-ph/9908288; C. Carimalo, W. da Silva, F. Kapusta, *Nucl. Phys. Proc. Suppl.* **82**, 391 (2000) [hep-ph/9909339]; *Nucl. Instrum. Methods Phys. Res.* **A472**, 185 (2001).