Single sneutrino production in association with fermion pairs at polarized photon colliders

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Introduction

- The matter superfields of the MSSM

$$Q_i = \begin{pmatrix} U_i \\ D_i \end{pmatrix};\ L_i = \begin{pmatrix} N_i \\ E_i \end{pmatrix}$$

$$H_2 = \begin{pmatrix} \Phi_2^+ \\ \Phi_2^0 \end{pmatrix};\ H_1 = \begin{pmatrix} \Phi_1^0 \\ \Phi_d^- \end{pmatrix}$$

$$\bar{U}_i;\ \bar{D}_i;\ \bar{E}_i$$

- Superpotential of MSSM

$$\begin{aligned} \mathcal{W} &= \mathcal{W}_{MSSM} + \mathcal{W}_{\not{R}} \\ \mathcal{W}_{MSSM} &= h^u_{ij} Q_i H_u \overline{U}_j + h^d_{ij} Q_i H_d \overline{D}_j + h^e_{ij} L_i H_d \overline{E}_j + \mu H_u H_d \\ \mathcal{W}_{\not{R}} &= \lambda_{[ij]k} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \lambda''_{i[jk]} \overline{U}_i \overline{D}_j \overline{D}_k \end{aligned}$$

- $\lambda, \quad \lambda' \Rightarrow \not{L}, \qquad \lambda'' \Rightarrow \not{B}$

- There are 9 λ, 27 λ' and 9 λ'' types of new couplings

- Simultaneous presence of both λ and λ' coupling can lead to rapid proton decay.

- This can be prevented by imposing a discrete parity called R-parity, defined as $R = (-1)^{3B+L+2S}$.

Interesting features of R-parity violating models

- L or B number violation is possible.

- LSP is no longer a stable particle, can decay in the detector.

- It is also no longer a dark matter candidate.

- The lightest neutralino is not necessarily the LSP.

- The single production of SUSY particle is possible.

$$
\begin{array}{rl}
e^+e^- \to \widetilde{\nu}_{Lj}: & \lambda_{1j1} \\
e^+\bar{d}_k \to \overline{\widetilde{u}}_{Lj}: & \lambda'_{1jk} \\
d_j + \bar{d}_k \to \overline{\widetilde{\nu}}_{Li}: & \lambda'_{1jk} \\
d_j + d_k \to \overline{\widetilde{u}}_{Ri}: & \lambda''_{1jk}
\end{array}
$$

• We have studied single sneutrino production in association with fermion pair at $\gamma\gamma$ collider. [M. Chaichian *et al.* Phys. Lett. **B 518**, 261 (2001)]

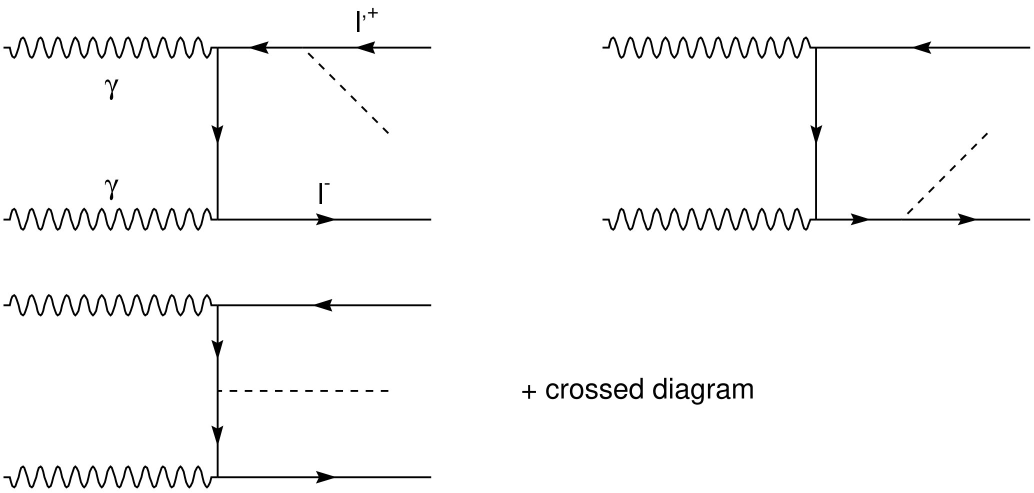
• One can scan a wider range of sneutrino mass as long as $\sqrt{s_{\gamma\gamma}} > M_{\tilde{\nu}}$.

• This mode may also induce flavour changing final state, which are basically SM background free.

$$\gamma\gamma \to \tilde{\nu}\ell^{\pm}\ell'^{\mp} \quad \text{or} \quad \tilde{\nu}q^{\pm}q'^{\mp}$$

with

$$\tilde{\nu} \to \ell''^{\pm}\ell'''^{\mp} \quad \text{or} \quad \tilde{\nu} \to q''^{\pm}q'''^{\mp}$$


l'+
γ
γ
l-
+ crossed diagram

Set	μ (GeV)	M_2 (GeV)	$\tan\beta$	$M_{\tilde{\chi}_1^0}$ (GeV)	$M_{\tilde{\chi}_1^\pm}$ (GeV)
A	-400	150	5	76. 4	150.3
B	200	350	40	150.4	185.6
C	175	500	40	155.6	169.4

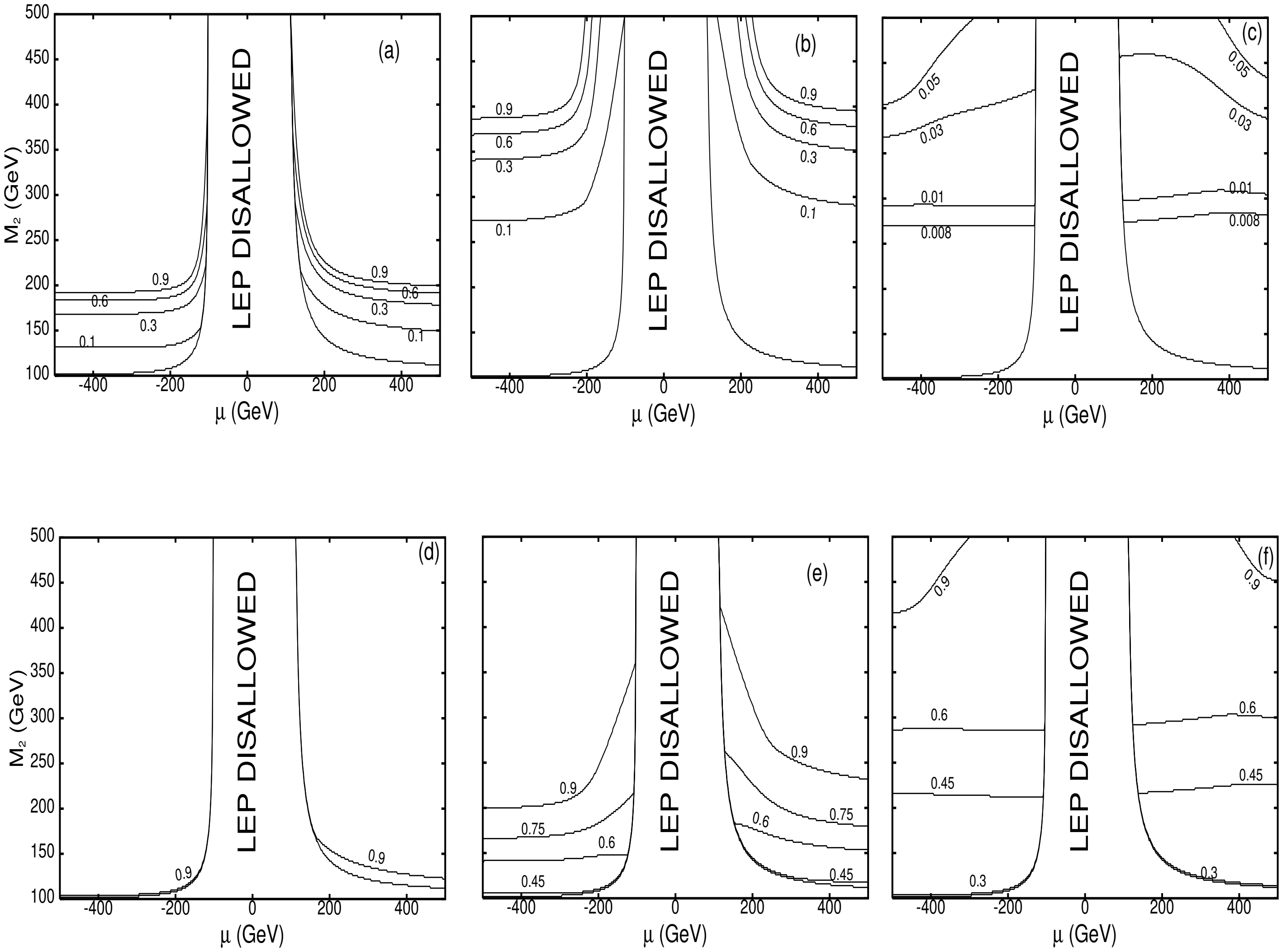
- Set of selected points in the MSSM parameter space with LSP and lighter chargino mass (and nature) given explicitly. gaugino dominated , mixed state, and higgsino dominated.

- Following set of R-parity violating couplings are considered : $\lambda_{311} = 0.062$, $\lambda_{323} = 0.070$, $\lambda'_{323} = 0.52$, $\lambda'_{333} = 0.45$,

- Decay of sneutrino :

$$\begin{aligned}\tilde{\nu} &\rightarrow f\bar{f}' \\ \tilde{\nu} &\rightarrow \tilde{\chi}_i^0 \nu \\ \tilde{\nu} &\rightarrow \tilde{\chi}_i^+ \ell^-\end{aligned}$$

- Sneutrino LSP: $\tilde{\nu} \rightarrow f\bar{f}'$.



• Constant BR contours of the decay $\tilde{\nu}_\tau \to e^+e^-$ for three values of sneutrino masses: 100 GeV (a), 200 GeV (b) and 400 GeV (c). Figures (d)–(f) represents contours of constant BR($\tilde{\nu}_\tau \to b\bar{b}$), for a 100, 200 and 400 GeV sneutrino mass, respectively. The relevant L-violating couplings are here: $\lambda_{311} = 0.062$ for (a)–(c) and $\lambda'_{333} = 0.45$ for (d)–(f). The level curves are function of μ and M_2, whereas the other relevant MSSM parameters are those of set A.

	P_{γ_+}	P_{γ_-}	P_{e^+}	P_{e^-}
$\sigma(+-)$	$+1$	-1	-0.8	$+0.9$
$\sigma(++)$	$+1$	$+1$	-0.8	-0.9
$\sigma(00)$	0	0	0	0

- Values of laser and electron(positron) beam polarizations adopted in our analysis. The $\sigma(+-)$ and $\sigma(++)$ denote the corresponding Polaris ed production cross-sections, with $\sigma(00)$ the unpolarized one. Convention : $P_{-(+)} = -1(+1)$ for purely left-(right) polarizations.

- We impose following set of selection cuts on the final state particles :

$$5^{\circ} < \theta < 175^{\circ} \quad \text{(angular cut on lepton and jets)},$$
$$E_\ell > 5 \text{ GeV} \quad \text{(energy cut on leptons)},$$
$$E_j > 10 \text{ GeV} \quad \text{(energy cut on jets)}.$$

- We will consider $\sqrt{s_{e^+e^-}} = 500$ GeV and 1 TeV NLC.

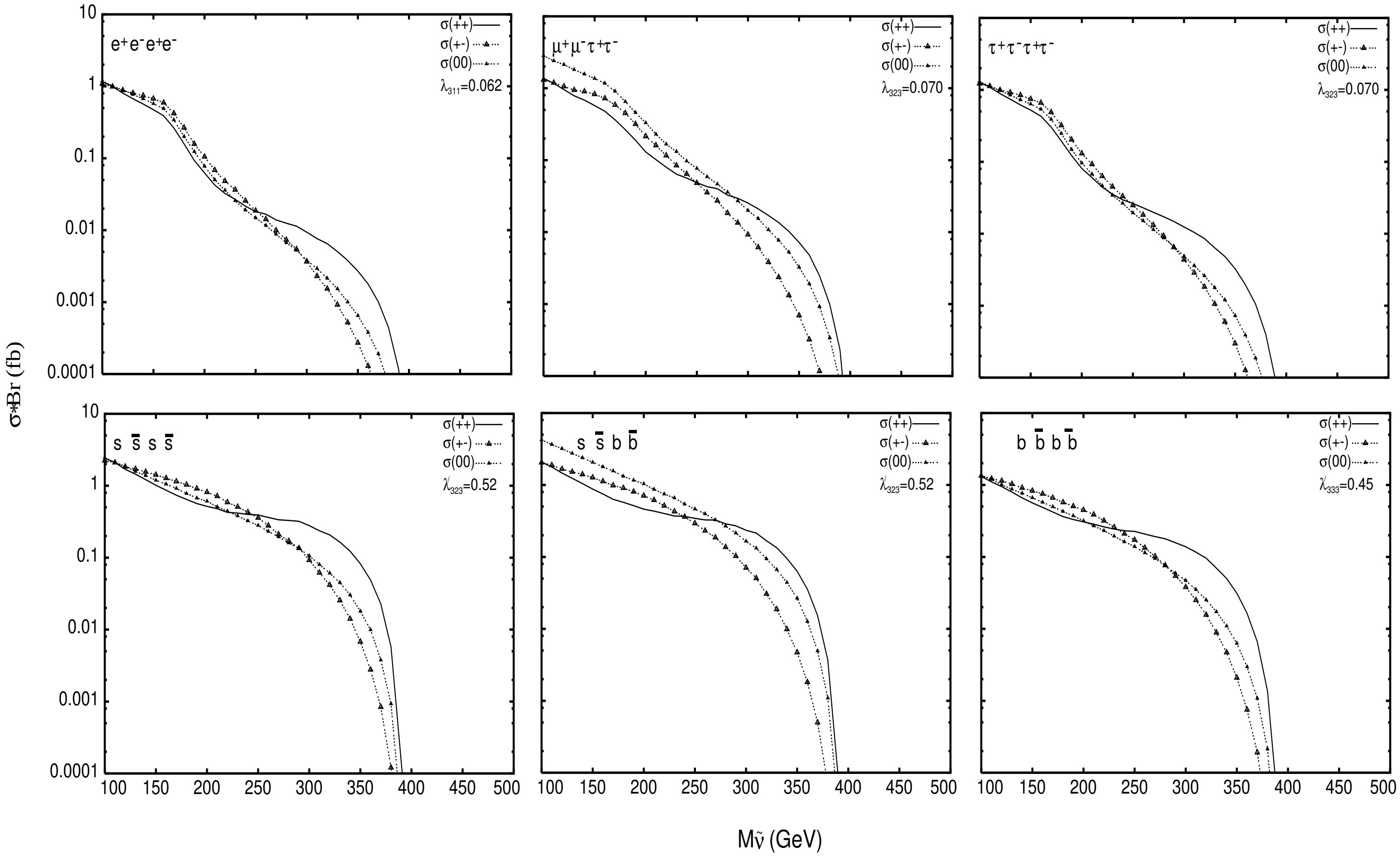
Different final state topologies

• Signal from the λ_{311} coupling : This coupling leads $\tilde{\nu}_\tau$ to decay into e^+e^- pair, with $e^+e^-e^+e^-$ final state.

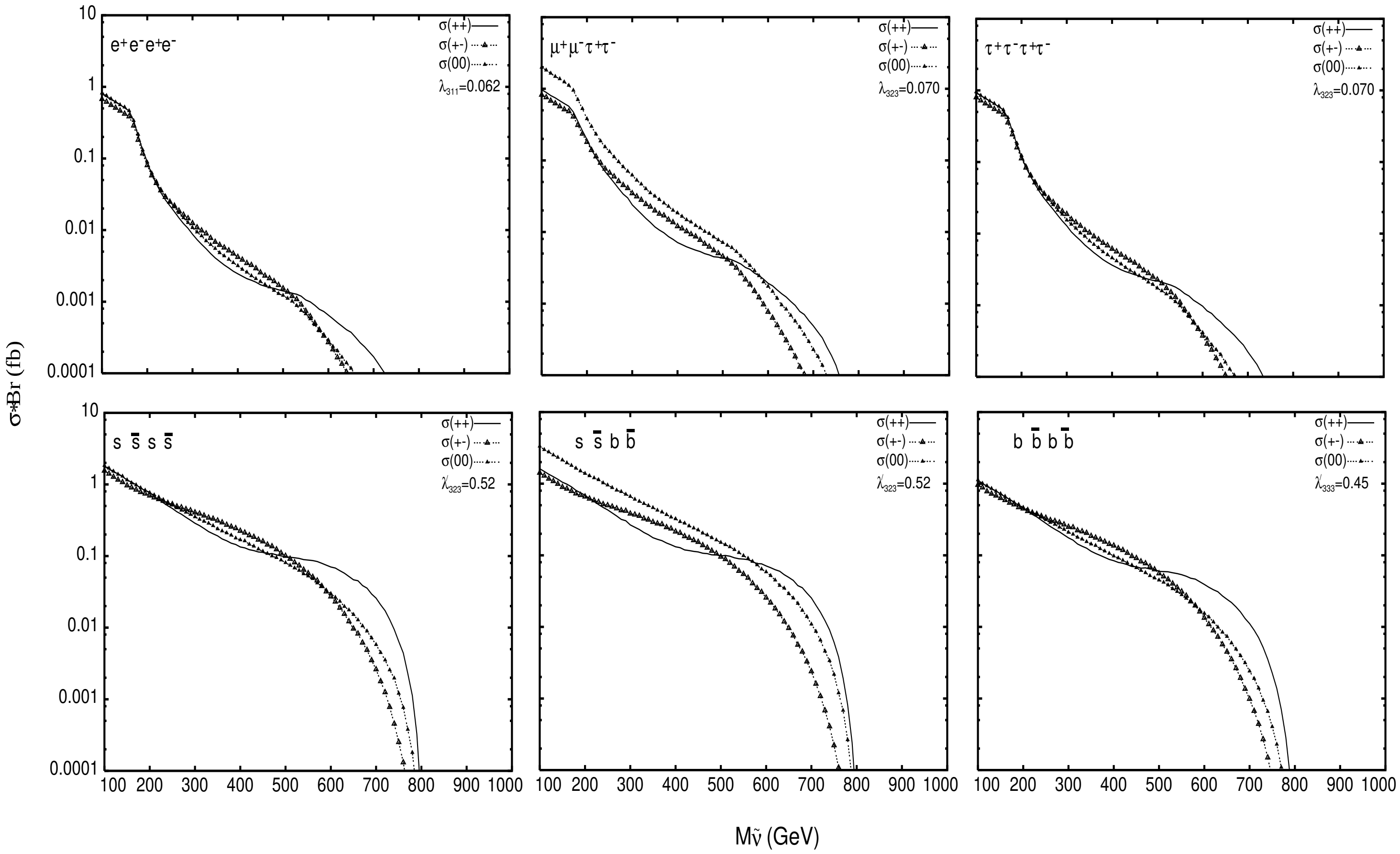
• Signal from the λ_{323} coupling : This coupling gives rise two types of signals : (a) flavour conserving : $\tau^+\tau^-\tau^+\tau^-$ and (b) flavour changing : $\mu^+\mu^-\tau^+\tau^-$ and (c.c's).

• Signal from the λ'_{323} coupling : This coupling gives rise three types of signals : (a) flavour conserving: $s\bar{s}s\bar{s}$ and $b\bar{b}b\bar{b}$, (b) the flavour violating : $s\bar{s}b\bar{b}$ (and c.c.'s).

• Signal from the λ'_{333} coupling : In this case, we have only one type of signal (flavour conserving) : $b\bar{b}b\bar{b}$.



• Variation of $\sigma(\gamma\gamma \to \tilde{\nu}_i f_j \bar{f}_k) * \mathrm{BR}(\tilde{\nu}_i \to f_j \bar{f}_k)$ at $\sqrt{s_{e^+e^-}} =$ 500 GeV with the sneutrino mass, for fixed values of the relevant λ_{ijk} and λ'_{ijk} couplings. The MSSM parameters are $\mu = 175$ GeV, $M_2 = 500$ GeV and $\tan\beta = 40$ (set C). Final state flavours are shown in the each figure. We include the C.C. states for the dissimilar final states.



• Variation of $\sigma(\gamma\gamma \to \tilde{\nu}_i f_j \bar{f}_k) * \mathrm{BR}(\tilde{\nu}_i \to f_j \bar{f}_k)$ at $\sqrt{s_{e^+e^-}} =$ 1 TeV with the sneutrino mass, for fixed values of the relevant λ_{ijk} and λ'_{ijk} couplings. The MSSM parameters are $\mu = 175$ GeV, $M_2 = 500$ GeV and $\tan\beta = 40$ (set C). Final state flavours are shown in the each figure. We include the C.C. states for the dissimilar final states.

The SM background

• If $M_{\tilde{\nu}} \sim 80 - 90$ GeV, the dominant SM background will come from associated production of a Z boson with a fermion pair, with the gauge boson decaying into further fermions :

$$\gamma\gamma \to Z\ell^{\pm}\ell^{\mp}, \quad \text{or} \quad Zq\bar{q}$$

with

$$Z \to \ell'^{\pm}\ell'^{\mp}, \quad \text{or} \quad Z \to q'\bar{q}'$$

• Only in the case of four-quark final states, one has to deal with $W^{\pm}$ mediated production:

$$\gamma\gamma \to W^{\pm}q\bar{q}'$$

with

$$W^{\pm} \to q''\bar{q}'''$$

• When the sneutrino mass starts departing from M_Z (or M_W), then a variety of SM processes could produce sizable irreducible backgrounds.

• At very heavy $M_{\tilde{\nu}}$ values only the tails of the SM distributions can actually play a role.

• Four fermion final states : $e^+e^-e^+e^-, \mu^+\mu^-\tau^+\tau^-, \tau^+\tau^-\tau^+\tau^-$, $s\bar{s}s\bar{s}, s\bar{s}b\bar{b}$, and $b\bar{b}b\bar{b}$.

	$e^+e^-e^+e^-$	$\mu^+\mu^-\tau^+\tau^{-*}$	$\tau^+\tau^-\tau^+\tau^-$	$s\bar{s}s\bar{s}$	$s\bar{s}b\bar{b}^*$	$b\bar{b}b\bar{b}$
$\sigma(+-)$	4.7×10^9	2169	232	532048	3409	313
$\sigma(++)$	4.7×10^9	2288	233	551620	3485	317
$\sigma(00)$	4.7×10^9	2228	232	541824	3447	315
$\sqrt{s_{e^+e^-}}$ = 500 GeV						
$\sigma(+-)$	1.9×10^9	1054	114	241093	1629	161
$\sigma(++)$	1.9×10^9	1042	115	240166	1707	162
$\sigma(00)$	1.9×10^9	1048	114	240612	1668	161
$\sqrt{s_{e^+e^-}}$ = 1 TeV						
*Other c.c.'s are free from SM background						

- Cross-section (fb) for the full four-fermion SM processes discussed in the text, for the three beam polarization configurations, after the cuts.

- Several selection cuts can be applied in order to improve the signal-to-background ratio $(S/\sqrt{B})$.

- Z mediated noise in 4-lepton final states can be reduced by requiring that no $M_{\ell^+\ell^-}$ reproduce M_Z within a few GeV.

- Similarly, in the case of 4-quark final state, reject events with M_{jj} in the vicinity of M_Z and M_W.

- The 4τ signature is more difficult.

- QCD induced 4-jet backgrounds tend to produce at least one jet-jet pair with small invariant mass.

- $\mid M_{f\bar{f}} - M_{\tilde{\nu}} \mid <$ 5 GeV constraint can further improve $S/\sqrt{B}$.

$M_{\tilde{\nu}}$ (GeV)	$e^+e^-e^+e^-$	$\mu^+\mu^-\tau^+\tau^-$	$\tau^+\tau^-\tau^+\tau^-$	$s\bar{s}s\bar{s}$	$s\bar{s}b\bar{b}$	$b\bar{b}b\bar{b}$
100	0.00031	2.0	1.9	0.25	2.7	5.2
	0.0019	6.0	9.5	0.25	2.7	5.4
	0.0019	6.0	9.5	0.25	2.7	5.4
200	7.6×10^{-6}	0.087	0.047	0.082	0.97	1.3
	0.00011	1.0	0.63	0.13	1.2	2.3
	0.0020	1.7	1.14	0.13	1.3	2.3
300	1.2×10^{-6}	0.0082	0.0054	0.023	0.28	0.29
	8.1×10^{-6}	0.053	0.035	0.048	0.44	0.68
	1.9×10^{-5}	0.12	0.083	0.054	0.47	0.79

• Significances ($S/\sqrt{B}$) at $\sqrt{s_{e^+e^-}} = 500$ GeV after 1 ab^{-1} for the four-fermion final states. (first three rows for MSSM set A,B and C respectively) for unpolarized beams, after the basic cuts plus the additional constraint $|M_{ff} - M_{\tilde{\nu}}| < 5$ GeV, for several sneutrino masses. (Here, ff refer to either lepton-lepton or jet-jet pairs and only one $M_{\tilde{\nu}}$ is required to be reconstructed.)

$M_{\tilde{\nu}}$ (GeV)	$e^+e^-e^+e^-$	$\mu^+\mu^-\tau^+\tau^-$	$\tau^+\tau^-\tau^+\tau^-$	$s\bar{s}s\bar{s}$	$s\bar{s}b\bar{b}$	$b\bar{b}b\bar{b}$
100	0.00029	1.5	1.6	0.28	3.1	6.5
	0.0018	4.5	8.0	0.29	3.2	6.7
	0.0018	4.5	8.0	0.29	3.2	6.7
200	$1.1\ \times 10^{-5}$	0.090	0.044	0.12	1.3	2.1
	0.00015	1.1	0.59	0.19	1.7	3.5
	0.00028	1.8	1.1	0.19	1.7	3.6
300	$3.2\ \times 10^{-6}$	0.025	0.021	0.055	0.88	0.86
	$2.1\ \times 10^{-5}$	0.16	0.14	0.11	1.4	2.0
	$4.9\ \times 10^{-5}$	0.37	0.33	0.13	1.5	2.4
400	$1.8\ \times 10^{-6}$	0.012	0.0092	0.039	0.61	0.63
	$9.4\ \times 10^{-6}$	0.063	0.048	0.087	1.04	1.6
	$2.2\ \times 10^{-5}$	0.14	0.11	0.10	1.1	1.9
500	$1.2\ \times 10^{-6}$	0.013	0.0079	0.025	0.42	0.42
	$3.1\ \times 10^{-6}$	0.035	0.022	0.044	0.64	0.80
	$1.3\ \times 10^{-5}$	0.14	0.088	0.067	0.82	1.3

- Significances ($S/\sqrt{B}$) at $\sqrt{s_{e^+e^-}} = 1$ TeV after 1 ab^{-1} for the four-fermion final states. (first three rows for MSSM set A,B and C respectively) for unpolarized beams, after the basic cuts plus the additional constraint $|M_{ff} - M_{\tilde{\nu}}| < 5$ GeV, for several sneutrino masses. (Here, ff refer to either lepton-lepton or jet-jet pairs and only one $M_{\tilde{\nu}}$ is required to be reconstructed.)

Summary

• We have studied single sneutrino production in association with fermion at future polarized $\gamma\gamma$ collider.

• With the present values of RPV couplings of the type $\lambda_{311}, \lambda_{323}, \lambda'_{323}, \lambda'_{333}$, over a sizable regions of the MSSM parameter space, several four-fermion signatures induced by a sneutrino with a mass $M_{\tilde{\nu}} \leq 150$ GeV if $\sqrt{s_{e^+e^-}} = 500$ GeV and ≤ 250 GeV if $\sqrt{s_{e^+e^-}} = 1$ TeV can be accessed.

• The typical annual rate should be several hundreds to a thousand events in each of the three channels $\mu^+\mu^-\tau^+\tau^-$, $\tau^+\tau^-\tau^+\tau^-$ and $b\bar{b}b\bar{b}$, depending on the actual sneutrino mass and assuming a luminosity of 1 ab^{-1}.

• A full Monte Carlo simulation, including all signals and backgrounds that we have discussed here should be performed in the presence of both hadronization and detector effects in order to get more accurate results.

• The flavour changing final states $\mu^+\mu^+\tau^-\tau^-$ and $\mu^-\mu^-\tau^+\tau^+$ will come practically free from SM background, hence promptly detectable at a future LC.

• We have not included the effect of finite experimental efficiency in tagging leptons and jets. Our final significances may be somewhat overestimated.