A SEARCH FOR PAIR PRODUCTION OF THE LSP $\tilde{\nu_\tau}$ AT THE CLIC VIA RPV DECAYS

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The pair production of tau sneutrinos at the Compact Linear Collider (CLIC) has been investigated. We assume that tau sneutrino is the lightest supersymmetric particle and decays into $e\mu$ pair via R-parity violating interactions. Backgroundless subprocess $e^-e^+ \to \tilde{\nu_\tau}\bar{\tilde{\nu_\tau}} \to \mu^+\mu^+e^-e^-$ $(\mu^-\mu^-e^+e^+)$ is analyzed in details. Achievable limits on $\mathrm{Br}\,(\tilde{\nu}_\tau \to \mu e)$ are obtained depending on $\tilde{\nu}_\tau$ mass. It is shown that CLIC with $\sqrt{S} = 0.5\,\mathrm{TeV}$ and $L_{\mathrm{int}} = 2.3\,\mathrm{fb}^{-1}$ will give opportunity to discover $\tilde{\nu}_\tau$ if its mass is below 234 GeV. The CLIC with, $\sqrt{S} = 3\,\mathrm{TeV}$ and $L_{\mathrm{int}} = 5.9\,\mathrm{fb}^{-1}$ will enlarge the discovery region up to $M_{\tilde{\nu}_\tau} = 1030\,\mathrm{GeV}$.

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Standard Model (SM) has, so far, been in agreement with results of numerous experimental High Energy Physics (HEP) data. But SM has not yet answered a number of fundamental questions. There are different theoretical approaches beyond the SM that have been developed to answer these questions. Supersymmetry (SUSY) is one of the favorite candidates for the Beyond the Standard Model (BSM) physics [1]. A search for supersymmetric particle is the substantial part of the Large Hadron Collider (LHC), as well as future colliders, experimental programs. The searching strategy for SUSY strongly depends on the lightest supersymmetric particle (LSP). As it was

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shown in [2], the LEP data allows "right" sneutrino to be the LSP. R-parity violation allowing decays of LSP sneutrino to ordinary SM particles leads to potentially rich phenomenology at high energy colliders [3–9]. R-parity is represented by $R = (-1)^{2S+3B+L}$, where B and L are the baryon and lepton numbers and S is the spin [10, 11]. If the lightest supersymmetric particles is the tau-sneutrino, its decay may be realized only via R-parity violation (RPV): $\tilde{\nu} \to l^+ l^{'-}$, $\tilde{\nu} \to q^+ q^{'-}$.

If R-parity is violated, $e^- e^+ \to \tilde{\nu_\tau} \bar{\tilde{\nu_\tau}} \to \mu^+ \mu^+ e^- e^-$ process becomes very important. In this work, we consider the process $e^- e^+ \to \tilde{\nu_\tau} \bar{\tilde{\nu_\tau}} \to \mu^+ \mu^+ e^- e^- (\mu^- \mu^- e^+ e^+)$ at the Compact Linear Collider (CLIC) energies $\sqrt{S} = 0.5\,\mathrm{TeV}$ and $\sqrt{S} = 3\,\mathrm{TeV}$. The Feynman diagram for tau-sneutrino production process is shown in figure 1.

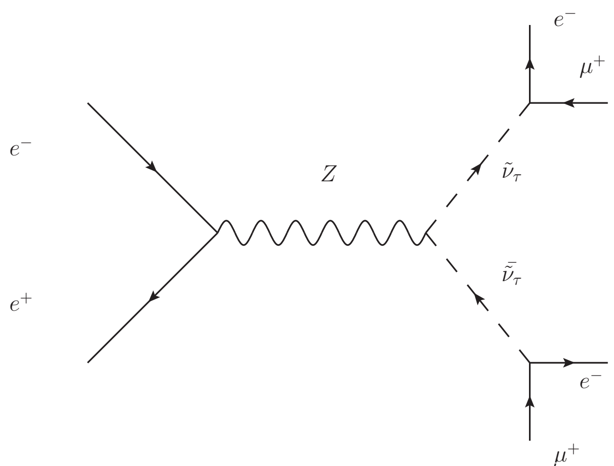

Fig. 1. Feynman diagram for $e^+ e^- \to \tilde{\nu_\tau} \overline{\tilde{\nu_\tau}} \to \mu^+ e^- \mu^+ e^-$process.

The R-parity violation part of the Minimal Supersymmetric Standard Model (MSSM) superpotential [3] is given by Eq. (1)

$$W_{\mathrm{RPV}} = \tfrac{1}{2}\lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \tfrac{1}{2}\lambda''_{ijk} U_i^c D_j^c D_k^c\,, \tag{1}$$

where $L\,(E)$ is an SU(2) doublet (singlet) lepton superfield and $Q(U, D)$ is (are) an SU(2) doublet (singlet) quark superfield(s), and indices i, j, k = 1, 2, 3 denote flavor. The coefficients λ_{ijk} and λ''_{ijk} correspond to the lepton number violating and baryon number violating couplings, respectively.

R-parity violation (RPV) interaction Lagrangian responsible for $\tilde{\nu_\tau} \to \mu^+ e^-$ and $\mu^- e^+$ decays is given below

$$L = -\tfrac{1}{2}\lambda_{312} \widetilde{\nu}_{\tau\mathrm{L}} \bar{e}_{\mathrm{R}} \mu_{\mathrm{L}} - \tfrac{1}{2}\lambda_{321} \widetilde{\nu}_{\tau\mathrm{L}} \bar{\mu}_{\mathrm{R}} e_{\mathrm{L}} + \mathrm{h.c.} \tag{2}$$

For the numerical calculations, we implement the Lagrangian (2) into the CALCHEP MSSM package [12]. The cross section for pair production of tau-sneutrinos at CLIC with $\sqrt{s} = 0.5$ TeV is shown in figure 2. Initial State Radiation (ISR) and Beamstrahlung effects at CLIC are calculated with CALCHEP program using beam parameters given in Table I [13, 14].

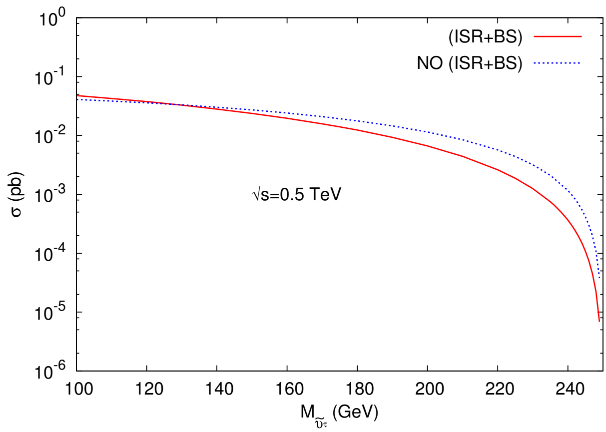

Fig. 2. Cross sections for $e^-e^+ \to \tilde{\nu_\tau}\overline{\tilde{\nu_\tau}}$ process at CLIC with $\sqrt{s} = 0.5$ TeV.

TABLE I

Main parameters of CLIC. Here N is the number of particles in bunch. σ_x and σ_y are RMS beam sizes at Interaction Point (IP), σ_z is the RMS bunch length.

Collider parameters	$\sqrt{s} = 0.5$ TeV	$\sqrt{s} = 3$ TeV
$E\,(\sqrt{s})$ TeV	0.5	3
$L\,(10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1})$	2.3	5.9
$N\,(10^{10})$	0.68	0.372
$\sigma_x\,(nm)$	202	45
$\sigma_y\,(nm)$	2.3	1
$\sigma_z\,(\mu m)$	44	44

It is seen from figure 2 that ISR and BS effects lead to increasing (decreasing) of the cross section for $M_{\tilde{\nu}_\tau}$ below (above) 130 GeV. In figure 3, we present similar calculations for the CLIC with $\sqrt{s} = 3$ TeV. It is seen that ISR and BS effects are more effective at higher center of mass energy. ISR+BS effects leads to increasing of the cross sections for $M_{\tilde{\nu}_\tau} < 450$ GeV. After $M_{\tilde{\nu}_\tau} = 450$ GeV, ISR+BS effects decrease the cross sections.

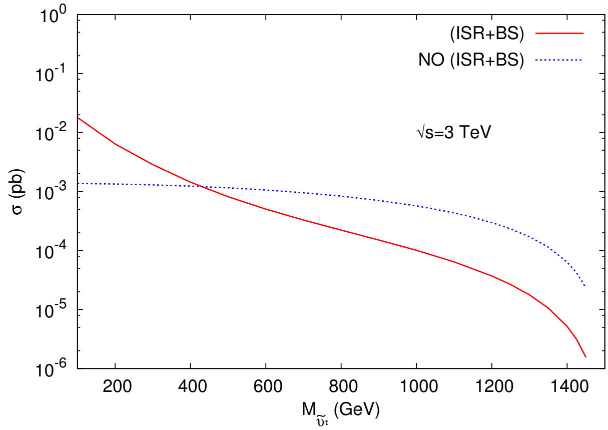

Fig. 3. Cross sections for $e^-e^+ \to \widetilde{\nu}_\tau\overline{\widetilde{\nu}_\tau}$ process at CLIC with $\sqrt{s} = 3$ TeV.

We propose $e^-e^+ \to \widetilde{\nu}_\tau\overline{\widetilde{\nu}_\tau} \to (\mu^+e^-)(\mu^+e^-)$ backgroundless process to analysis at CLIC. In order to analyze the signal, following basic cuts are applied: $P_{\rm T} > 20$ GeV and $|\eta| < 2.5$ for the final state electrons and muons. Assuming $\lambda_{321} = \lambda_{312}$ and taking other possible RPV interaction constants to be 0, which means $\mathrm{Br}\,(\widetilde{\nu}_\tau \to \mu^+e^-) = \mathrm{Br}\,(\overline{\widetilde{\nu}_\tau} \to \mu^+e^-) = 1/2$, we obtain cross section values given in Table II (III) for CLIC with $\sqrt{s} = 0.5$ TeV (3 TeV). Event number given in the last columns include both $\mu^+\mu^+e^-e^-$ and $\mu^-\mu^-e^+e^+$ final states.

TABLE II

Cross sections and event number depending on mass of tau-sneutrinos at $\sqrt{s} = 0.5$ TeV with $P_{\rm T} > 20$ GeV and $|\eta| < 2.5$ cuts.

$M_{\widetilde{\nu}_\tau}$ [GeV]	Cross section [pb]	Event number (N)
100	8.00×10^{-3}	3686
120	7.02×10^{-3}	3230
140	5.80×10^{-3}	2676
160	4.25×10^{-3}	1957
180	2.70×10^{-3}	1269
200	1.51×10^{-3}	696
220	6.10×10^{-4}	279
240	9.60×10^{-5}	44
250	1.10×10^{-5}	5

TABLE III

The same as for Table II but for $\sqrt{s} = 3\,\text{TeV}$.

$M_{\widetilde{\nu}_\tau}$ [GeV]	Cross section [pb]	Event number (N)
100	3.08×10^{-3}	3629
200	1.32×10^{-3}	1562
400	3.35×10^{-4}	395
600	1.21×10^{-4}	142
800	5.35×10^{-5}	63
1000	2.42×10^{-5}	28
1200	8.82×10^{-6}	10
1300	4.21×10^{-6}	5
1400	1.27×10^{-6}	2

In order to estimate statistical significance, we have used the following formula

$$S = \frac{\sigma_{\mathrm{s}}}{\sqrt{\sigma_{\mathrm{s}} + \sigma_{\mathrm{B}}}} \sqrt{L_{\mathrm{int}}}\,. \tag{3}$$

Here, S is statistical significance, σ_{s} is signal cross sections values, σ_{B} is background cross sections and L_{int} is integrated luminosity. We have backgroundless processes, therefore, σ_{B} is taken zero. From Eq. (3), discovery (5σ), observation (3σ) and exclusion (2σ) limits for tau-sneutrino at CLIC with $\sqrt{s} = 0.5\,\text{TeV}$ are obtained as follows: achievable tau-sneutrino mass values are 243 GeV for discovery, 248 GeV for observation and 251 GeV for exclusion. Corresponding values for CLIC with $\sqrt{s} = 3\,\text{TeV}$ are: 1030 GeV for discovery, 1225 GeV for observation and 1325 for exclusion.

So far, the ideal case, namely, maximal possible Branching Ratio (Br) for the channel under consideration had been analyzed. In more general case, Branching Ratio is less than 1/2, because of other possible decay channels. In figure 4, we present 5σ, 3σ and 2σ plots for Br $(\widetilde{\nu}_\tau \to \mu^+ e^-) \times$ Br $(\overline{\widetilde{\nu}_\tau} \to \mu^+ e^-)$ depending on the $\widetilde{\nu}_\tau$ mass for CLIC with $\sqrt{s} = 0.5\,\text{TeV}$. One can see from figure 4 that for Br $(\widetilde{\nu}_\tau \to \mu^+ e^-) \times$ Br $(\overline{\widetilde{\nu}_\tau} \to \mu^+ e^-) = 2.5 \times 10^{-3}$ (hundred times smaller than in the ideal case) 5σ, 3σ and 2σ limits become 150 GeV, 190 GeV and 215 GeV, respectively. Corresponding plots for $\sqrt{s} = 3\,\text{TeV}$ are presented in figure 5.

In Table IV (V) discovery, observation and exclusion limits for Br $(\widetilde{\nu}_\tau \to \mu^+ e^-) \times$ Br $(\overline{\widetilde{\nu}_\tau} \to \mu^+ e^-)$ at the CLIC with $\sqrt{s} = 0.5\,\text{TeV}$ (3 TeV) are given for several values of the $\widetilde{\nu}_\tau$ mass.

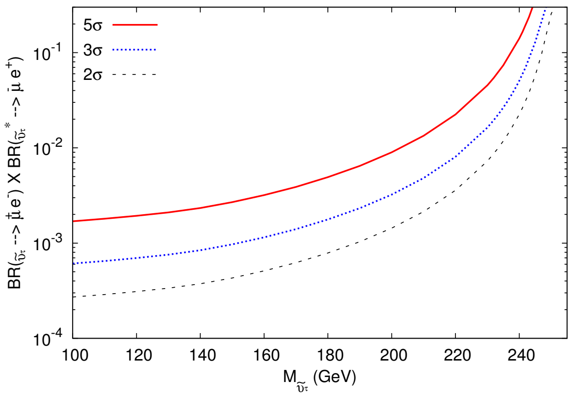

Fig. 4. Achievable limits for Br $(\widetilde{\nu}_\tau \to \mu^+e^-) \times$ Br $(\overline{\widetilde{\nu}_\tau} \to \mu^+e^-)$ *versus* tau-sneutrino mass values at CLIC with $\sqrt{s} = 0.5$ TeV.

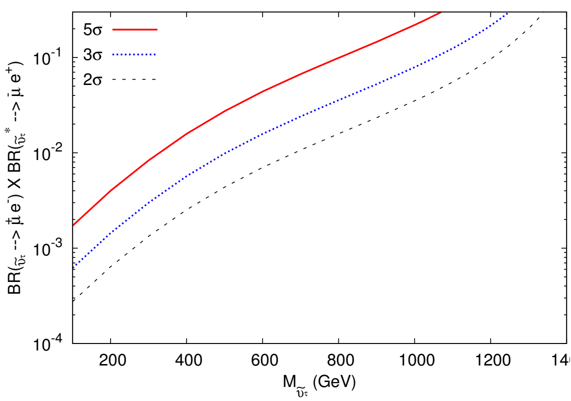

Fig. 5. Achievable limits for Br $(\widetilde{\nu}_\tau \to \mu^+e^-) \times$ Br $(\overline{\widetilde{\nu}_\tau} \to \mu^+e^-)$ *versus* tau-sneutrino mass values at CLIC with $\sqrt{s} = 3$ TeV.

TABLE IV

Achievable limits of Br $(\widetilde{\nu}_\tau \to \mu^+e^-) \times$ Br $(\overline{\widetilde{\nu}_\nu} \to \mu^+e^-)$ at the CLIC with $\sqrt{s} =$ 0.5 TeV.

$M_{\widetilde{\nu}_\tau}$ [GeV]	5σ	3σ	2σ
120	0.00193	0.00069	0.00031
160	0.00319	0.00115	0.00051
200	0.00898	0.00323	0.00144
240	0.14066	0.05064	0.02251

TABLE V

Achievable limits of $\mathrm{Br}\,(\widetilde{\nu}_\tau \to \mu^+ e^-) \times \mathrm{Br}\,(\overline{\widetilde{\nu}_\tau} \to \mu^+ e^-)$ at the CLIC with $\sqrt{s} = 3\,\mathrm{TeV}$.

$M_{\widetilde{\nu}_\tau}$ [GeV]	5σ	3σ	2σ
100	0.00172	0.00062	0.00027
400	0.01582	0.00569	0.00253
800	0.09899	0.03564	0.01584
1100	0.34578	0.12448	0.05532

In conclusion, the process $e^+e^- \to \widetilde{\nu}_\tau \overline{\widetilde{\nu}_\tau} \to \mu^+\mu^+e^-e^-(\mu^-\mu^-e^+e^+)$ will provide powerful signature for LSP $\widetilde{\nu}_\tau$, if $\mathrm{Br}\,(\widetilde{\nu}_\tau \to \mu^+ e^-)$ and $\mathrm{Br}\,(\overline{\widetilde{\nu}_\tau} \to \mu^+ e^-)$ are sufficiently large.

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