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RADIATIVE PRODUCTION OF THE LIGHTEST NEUTRALINO

A. I. Ahmadov[1]

Baku State University, Baku, Azerbaijan

We study the production of the lightest, stable neutralino in the process $e^+e^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0\gamma$ including general mixing of gauginos and Higgsinos. General formulae for the differential cross section are presented. The dependence of the differential cross section on the photon energy spectrum and selectron mass and also the dependence of the total cross section on the beam energies for three different mixing scenarios are illustrated.

Мы изучаем рождение легких стабильных нейтралино в процессе $e^+e^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0\gamma$ с включением общего смешивания хиггсино и калибрино. Приведены общие формулы для дифференциальных сечений. Проиллюстрирована зависимость дифференциального эффективного сечения от спектра энергии фотона, массы сэлектрона, а также зависимость полного эффективного сечения от энергии пучка для трех различных сценариев.

INTRODUCTION

In the Minimal Supersymmetric Standard Model (MSSM) with conserved R parity [1], the lightest supersymmetric (SUSY) partner of the known particles is predicted to be stable, neutral and weakly interacting. The usual candidate for this role is the lightest of the four neutralinos. When produced in a normal collider experiment, the lightest neutralino ($\widetilde{\chi}_1^0$) is expected to generate missing energy and momentum in the final state. Furthermore, SUSY partners must be produced in pairs. In e^+e^- collisions, from the point of view of the available phase space, the $\widetilde{\chi}_1^0$-pair production would be the easiest SUSY channel. Actually, the occurrence of this invisible channel could only be detected by the measurement of the Z invisible width (if $m_{\widetilde{\chi}_1^0} < M_Z/2$). However, the coupling $Z\widetilde{\chi}_1^0\widetilde{\chi}_1^0$ generally turns out to be small and the presence of a sizeable neutralino contribution to $\Gamma_Z^{\rm inv}$ can only rarely exclude regions of the parameter space not already ruled out by searches for visibile channels. Hence, in e^+e^- collisions, the best way to produce, at tree level, observable final states from neutralinos is through the channel $e^+e^- \to \widetilde{\chi}_1^0\widetilde{\chi}_2^0$, where $\widetilde{\chi}_2^0$ is the next-to-lightest neutralino [2]. This process can be competitive with the production of light-chargino pairs for particular regions of the SUSY parameter space [3]. In this work, we study instead the production of $\widetilde{\chi}_1^0$ pairs accompanied by a hard large-angle photon $e^+e^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0\gamma$ for TESLA linear collider [4], assuming as c.m. energy $\sqrt{s} = 500$ GeV. Its experimental signature consists of single-photon events with missing energy and momentum. For moderate cuts on the photon energy, the available phase space for this process is larger than that for the $\widetilde{\chi}_1^0\widetilde{\chi}_2^0$ final state. On the

[1]E-mail: ahmadovazar@yahoo.com

other hand, the radiative $e^+e^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0\gamma$ cross sections are penalized by a further power of $\alpha_{\rm em}$ in the coupling. The neutralinos are, however, in general, mixtures of the photino $\widetilde{\gamma}$ with the zino $\widetilde{Z}^0$ and the Higgsinos $\widetilde{H}_{a,b}^0$. Since the Higgsino components couple to the Z^0, the radiative pair production of the lightest neutralino proceeds also via Z^0 exchange. The relative importance of the two production mechanisms ($\widetilde{e}$ exchange and Z^0 exchange) depends on the strengths of the $\widetilde{\gamma}$, $\widetilde{Z}_0$ and $\widetilde{H}_{a,b}^0$ components of the $\widetilde{\chi}_1^0$, thus significant differences in the cross sections are to be expected for the case of a photino-like and of a Higgsino-like neutralino, respectively. Especially the dependence of the cross sections on the selectron mass will be strongly suppressed by the dominating Z^0 exchange if the neutralino has a strong Higgsino component.

In the MSSM, all neutralino masses and couplings can be expressed at tree level in terms of three parameters [5]: μ (the SUSY Higgs-mixing mass), M_2 (the $SU(2)$ gaugino mass, which also fixes all the other gaugino masses if unification conditions are imposed at the GUT scale, through, e.g., $M_1 = M_2((5/3)\tan^2\theta_W)$), and $\tan\beta$ (the ratio of vacuum expectation values for the two Higgs doublets). In order to study $e^+e^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0\gamma$ cross sections, two further parameters are needed, i.e., the masses of the left and right selectrons, $m_{\widetilde{e}_{L,R}}$. Since the corresponding contributions do not interfere, we assume them to be degenerate without loss of generality. Although the LEP experiments in the Z^0 region [6, 7] have given no evidence for the existence of supersymmetric partners of the standard particles, the idea of supersymmetry has not lost attraction. Thus the search for supersymmetric particles will be an essential part of the experimental program of TESLA in the energy range up to 500 GeV centre-of-mass energy and also of the next-generation accelerators. In [8–11] the neutralino mass spectra and production cross sections at e^+e^- linear collider in superstring-inspired E_6 models were studied. For different E_6 models, the authors develop scenarios with new light exotic neutralinos which may offer important possibilities to distinguish between the models. Also, the neutralino sector in E_6 inspired extended supersymmetric models with additional neutral gauge bosons, and singlet Higgs fields was analyzed. To obey the experimental lower mass bounds of the new gauge bosons, the vacuum expectation values of the singlet fields must be of the order of several TeV. It was shown that in a rank-5 model with two singlets the lightest neutralino is always a very light nearly pure singlino. Light neutralinos with singlino character also appear in a rank-5 model with one singlet and in the rank-6 model if the $U(1)'\ U(1)''$ gaugino mass parameter M' (M'') takes large values 0(10 TeV) because of a seesaw-like mechanism in the submatrix of the exotic neutralinos. Two light singlino-like neutralinos may exist in the rank-5 model with two singlets for large M' and in the rank-6 model for large M' and M''. However, light neutralinos in the discussed E_6 models never have dominant $Z'(Z'')$ gaugino character. In the phenomenology of the minimal supersymmetric extension of the standard model the neutralinos which are the neutral mass eigenstates of the gauge and Higgs fermion system play an outstanding role: Usually the lightest neutralino state $\widetilde{\chi}_1^0$ is supposed to be the lightest supersymmetric particle which is stable. Since it weakly interacts, it escapes detection and there is no experimental signature for the pair-production process $e^+e^- \to \widetilde{\chi}_1^0\chi_1^0$. Thus the higher order radiative production $e^+e^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0\gamma$ gains considerable importance.

Although this process has already extensively been discussed [12–15], all authors confine themselves to the special case of the lightest neutralino being a photino. Since in this case this process proceeds solely through selectron exchange, it has been used to derive upper limits for the selectron mass [16]. It is worth mentioning that an additional single-photon signature in the neutralino sector can arise at TESLA from the $\tilde{\chi}_1^0\tilde{\chi}_2^0$ production followed by the one-loop radiative decay $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\gamma$ [17, 18]. In particular parameter regions where the main $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\ f\overline{f}$ decays are depleted, the branching ratio for the radiative $\tilde{\chi}_2^0$ decay can be of order 1 [19]. A single-photon signal can also be associated to the $\tilde{\chi}_1^0\tilde{\chi}_2^0/\tilde{\chi}_2^0\tilde{\chi}_2^0$ production whenever the $\tilde{\chi}_2^0$ decay into invisible production ($\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\nu\bar{\nu}$), through graphs analogous to these in Fig. 1 with one or both $\tilde{\chi}_1^0$ replaced by $\tilde{\chi}_2^0$.

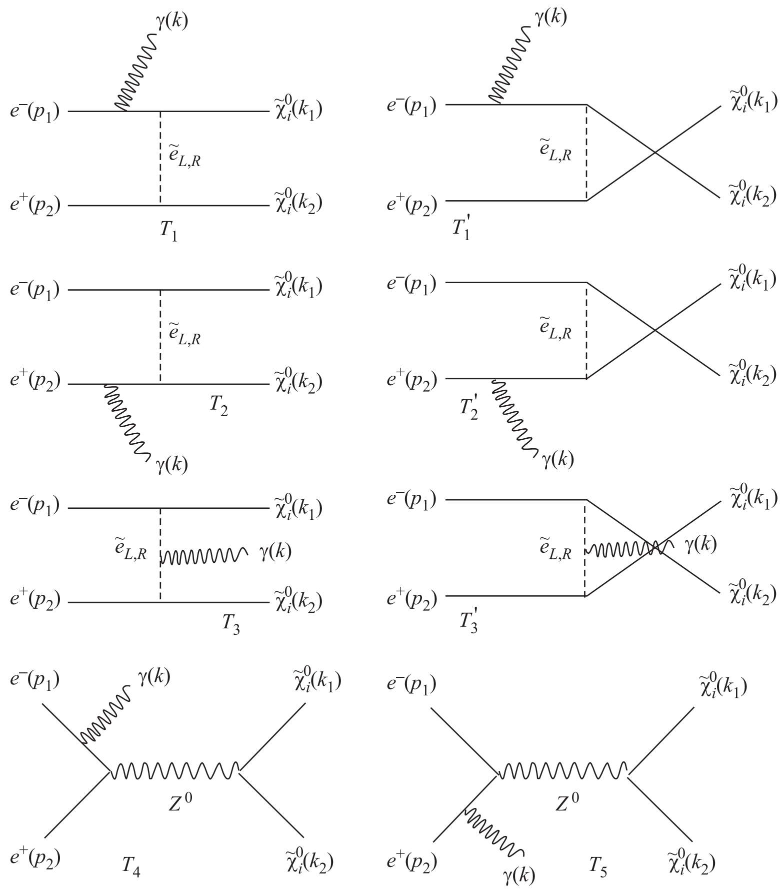

Fig. 1. Feynman graphs for $e^+ + e^- \to \tilde{\chi}_i^0 + \tilde{\chi}_i^0 + \gamma$

In Sec. 1 we shall give some formulae for the amplitudes and the differential cross section. To illustrate the influence of neutralino mixing on the photon energy spectrum and on the total cross section, we shall present in Sec. 2 some numerical results for three scenarios of gaugino mixing, differing significantly by the nature (photino-like, Higgsino-like, general mixture) of the lightest neutralino. In the final section, we draw our conclusions.

In the analytic calculations particular attention has been paid to gauge invariance and to the relative sign of the amplitudes due to the fermionic nature of the neutralinos.

1. CROSS SECTION

The Feynman diagrams contributing to the radiative production of a pair of identical neutralinos

$$e^+ + e^- \to \gamma + \widetilde{\chi}_i^0 + \widetilde{\chi}_i^0 \quad (i = 1, \dots, 4) \tag{1}$$

are shown in Fig. 1. The four-momenta of e^-, e^+, γ and the two neutralinos are denoted by p_1, p_2, k and k_1, k_2, respectively. The relevant couplings of the supersymmetric particles are deduced from the following interaction Lagrangians of the supersymmetric Standard Model [1]:

$$L_{e\widetilde{e}\widetilde{\chi}_i^0} = g f_i^L e P_R \widetilde{\chi}_i^0 \widetilde{e}_L + g f_i^R e P_L \widetilde{\chi}_i^0 \widetilde{e}_R + \text{h.c.}, \tag{2}$$

$$L_{Z^0 \widetilde{\chi}_i^0 \widetilde{\chi}_j^0} = \frac{1}{2} \frac{g}{\cos\theta_W} Z_\mu \overline{\widetilde{\chi}}_i^0 \gamma^\mu (O''^L_{ij} P_L + O''^R_{ij} P_R) \widetilde{\chi}_j^0. \tag{3}$$

In Eqs. (2) and (3), $\widetilde{\chi}_i^0$ and e are four-component spinor fields and $\widetilde{e}_L\,(\widetilde{e}_R)$ is the field of the left-handed (right-handed) selectron. Furthermore, $g = e/\sin\theta_W$ $(e > 0)$ is the weak coupling constant, $P_{R,L} = \frac{1}{2}(1 \pm \gamma^5)$, while the coupling constants $f_i^{L,R}$ and $O''^{\,L,R}_{ij}$ are given by

$$\begin{aligned} f_i^L &= \sqrt{2}\left\{\frac{1}{\cos\theta_W}\left(\frac{1}{2} - \sin^2\theta_W\right) N_{i2} + \sin\theta_W N_{i1}\right\}, \\ f_i^R &= \sqrt{2}\sin\theta_W \{\tan\theta_W \cdot N_{i2}^* - N_{i1}^*\} \end{aligned} \tag{4}$$

and

$$\begin{aligned} O''^{\,L}_{ij} &= \frac{1}{2}(N_{i3}N_{j3}^* - N_{i4}N_{j4}^*)\cos 2\beta - \frac{1}{2}(N_{i3}N_{j4}^* + N_{i4}N_{j3}^*)\sin 2\beta, \\ O''^R_{ij} &= -O''^{L*}_{ij}. \end{aligned} \tag{5}$$

In Eqs. (4) and (5), N_{ij} are elements of the 4×4 unitary matrix which diagonalizes the neutral gaugino-Higgsino mass matrix and $\tan\beta = \vartheta_2/\vartheta_1$ with $\vartheta_{2,1}$ the vacuum expectation values of the two neutral Higgs fields. (For details about neutralino mixing see, e.g., [1, 2].)

For completeness we add the Lagrangian for the Z^0 $e^+ e^-$ and photon with lepton and slepton coupling:

$$\begin{gathered} L_{Z^0\, e^+ e^-} = -\frac{g}{\cos\theta_W} Z_\mu \overline{e} \gamma^\mu (L P_L + R P_R) e, \\ L = -\frac{1}{2} + \sin^2\theta_W \quad \text{and} \quad R = \sin^2\theta_W, \end{gathered} \tag{6}$$

$$L = -ie\left(\overline{f}\gamma_\mu f + \widetilde{f}_L^+ \overleftrightarrow{\partial_\mu} \widetilde{f}_L + \widetilde{f}_R^+ \overleftrightarrow{\partial_\mu} \widetilde{f}_R\right) A^\mu. \tag{7}$$

The process proceeds via both $\widetilde{e}_L$ and $\widetilde{e}_R$ exchange. Because of the chiral nature of the couplings there is, however, no interference between both contributions in the limit of vanishing electron mass that we assume. We therefore give the amplitudes for $\widetilde{e}_L$ exchange only, those for $\widetilde{e}_R$ exchange are obtained by substituting the coupling constant f_i^L by f_i^R and the mass $m_{\widetilde{e}_L}$ by $m_{\widetilde{e}_R}$. The contributions of the first three Feynman graphs in Fig. 1 are

$$T_1 = -\frac{ieg^2|f_i^L|^2}{2p_1k(\triangle - 2k_2p_2)}[\overline{\vartheta}(p_2)P_L\vartheta(k_2)][\overline{u}(k_1)P_R(\hat{p}_1 - \hat{k})\hat{\epsilon}u(p_1)],$$
$$T_2 = \frac{ieg^2|f_i^L|^2}{2p_2k(\triangle - 2k_1p_1)}[\overline{\vartheta}(p_2)\hat{\epsilon}(\hat{p}_2 - \hat{k})P_L\vartheta(k_2)][\overline{u}(k_1)P_Ru(p_1)], \tag{8}$$
$$T_3 = -\frac{ieg^2|f_i^L|^2(k_1 - k_2 - p_1 + p_2)}{(\triangle - 2k_1p_1)(\triangle - 2k_2p_2)}\epsilon[\overline{\vartheta}(p_2)P_L\vartheta(k_2)][\overline{u}(k_1)P_R\,u(p_1)].$$

Here $\epsilon^\mu(k)$ is the polarization four-vector of the photon and $\triangle = m^2 - m^2_{\widetilde{e}_L}$, m being the neutralino mass. The amplitudes T_1', T_2', T_3' are obtained from T_1, T_2, T_3 by interchanging k_1 and k_2 and changing the overall sign due to Fermi statistics. For the contribution of Z_0 exchange we obtain the two amplitudes

$$T_4 = \frac{ieg^2}{2p_1k\cos^2\theta_W((p_1+p_2-k)^2 - m_Z^2 + i\Gamma_Z m_Z)}[\overline{\vartheta}(p_2)\gamma^\mu(LP_L + RP_R)\times \\ \times (\hat{p}_1 - \hat{k})\hat{\epsilon}u(p_1)][\overline{u}(k_1)\gamma_\mu(O''^L_{ii}P_L + O''^R_{ii}P_R)\vartheta(k_2)],$$
$$T_5 = \frac{-ieg^2}{2p_2k\cos^2\theta_W((p_1+p_2-k)^2 - m_Z^2 + i\Gamma_Z m_Z)}[\overline{\vartheta}(p_2)\hat{\epsilon}(\hat{p}_2 - \hat{k})(LP_L + RP_R)\times \\ \times u(p_1)][\overline{u}(k_1)\gamma_\mu(O''^L_{ii}P_L + O''^R_{ii}P_R)\vartheta(k_2)]. \tag{9}$$

Since in the total Z^0 exchange amplitude T_4+T_5 the respective contributions of the $q^\mu q^\nu$ term of the Z^0 propagator $D_Z^{\mu\nu}(q) = i(-g^{\mu\nu} + q^\mu q^\nu/m_Z^2)/(q^2 - m_Z^2 + im_Z\Gamma_Z)$ compensate, we have suppressed these contributions in the expression for the partial amplitudes (see Eq. (8)).

The relative signs of the amplitudes for Z^0 exchange and for $\widetilde{e}$ exchange are different from those we would expect by «naive» application of the standard Feynman rule. They are obtained by ordering the fermionic operators of the external particles in the Wick expansion of the S matrix. The spin averaged products of the respective Feynman amplitudes corresponding to the graphs of Fig. 1 shall be denoted as

$$M(i,j) = \frac{1}{2}(2 - \delta_{ij})\sum{}'(T_iT_j^* + T_i^*T_j),$$
$$M(i,j') = \sum{}'(T_i{T_j}'^* + T_i^*{T_j}'),$$
$$M(i',j') = \frac{1}{2}(2 - \delta_{ij})\sum{}'({T_i}'{T_j}'^* + {T_i}'^*{T_j}')$$

with $i, j = 1, \ldots, 5$ and $i', j' = 1, 2, 3$. Then the spin average of the total amplitude squared is obtained as

$$\sum{}'|T|^2 = \sum_{i\leqslant j} M(i,j) + \sum M(i,j') + \sum_{i'\leqslant j'} M(i',j').$$

Further we use the abbreviation

$$\triangle_{ij} = \triangle - 2k_ip_j \quad \text{with} \quad \triangle = m^2 - m^2_{\widetilde{e}}.$$

(When selectron mixing is neglected, $\widetilde{e}_R$ and $\widetilde{e}_L$ have the same mass: $m_{\widetilde{e}_L} = m_{\widetilde{e}_R} = m_{\widetilde{e}}$.)

From the total (gauge-invariant) amplitude T, which is the sum of the partial amplitudes (Eqs. (7) and (8)), and the crossed amplitudes $T_i{}'$ $(i = 1, 2, 3)$, we obtain the differential cross section

$$\frac{d\sigma}{dx} = \frac{1}{64(2\pi)^4} \int_{-1}^{+1} d(\cos\theta') \int_0^{2\pi} d\varphi \int_{z_m}^{z_p} dz \sum{}' |T|^2. \tag{10}$$

Here all quantities are in the e^+e^- centre-of-mass system. We use the variables $x = E_\gamma/E$ and $z = E_1/E$, where E_γ and E_1 are the energies of the photon and the neutralino with four-momentum k_1, respectively, and E is the beam energy. Furthermore, θ' is the angle between the electron beam and the neutralino k_1, and φ is the angle between the planes $(\mathbf{p_1}, \mathbf{k_1})$ and $(\mathbf{k_1}, \mathbf{k_2}, \mathbf{k})$, describing rotations of the plane $(\mathbf{k_2}, \mathbf{k})$ around $\mathbf{k_1}$ (Fig. 2).

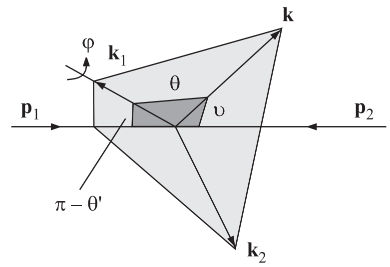

Fig. 2. Definition of the angular variables in the $e^+ + e^-$ centre-of-mass system

The boundary values of the variable z are

$$\begin{aligned} z_m &= 1 - \frac{x}{2}\left(1 + \sqrt{1 - \frac{m^2}{E^2(1-x)}}\right), \\ z_p &= 1 - \frac{x}{2}\left(1 - \sqrt{1 - \frac{m^2}{E^2(1-x)}}\right). \end{aligned} \tag{11}$$

From Eq. (10) total cross sections will be calculated for cuts of the photon energy $x \geqslant 0.25$ and of the photon scattering angle $|\cos\theta'| \leqslant 0.95$ (corresponding to about $\theta' > 18°$), which corresponds to transverse photon momenta $k_T \geqslant 0.08E$, where E is the beam energy.

2. NUMERICAL RESULTS AND DISCUSSION

Both the magnitude and the energy dependence of the cross sections depend strongly on the nature of the lightest neutralino which is determined by the way gauginos and Higgsinos are mixed. We shall illustrate this for three extremely different scenarios given in table. There the lightest neutralino mass eigenstate $\widetilde{\chi}^0$ is expressed as a linear combination of $\widetilde{\gamma}$, $\widetilde{Z}^0$ and the Higgsinos $\widetilde{H}_a^0, \widetilde{H}_b^0$ (see [1, 2] for details of neutralino mixing). As one can see in scenario (A), $\widetilde{\chi}_1^0$ is nearly a pure photino state, whereas in case (B) it is almost a Higgsino and in case (C) it is a mixture with a large zino component. We have adjusted the parameters of the neutralino mass matrix such that the three scenarios are compatible with the existing experimental lower bounds for the chargino mass obtained by the DELPHI collaboration [6] and by the ALEPH collaboration [7], respectively. In order to illustrate the influence of the selectron mass, cross sections have been calculated for three values $m_{\widetilde{e}} = 250$, 400 and 500 GeV. In the numerical examples we have neglected selectron mixing, i.e., $m_{\widetilde{e}_L} = m_{\widetilde{e}_R} = m_{\widetilde{e}}$.

Figure 3 (scenario A) and Fig. 4 (scenarios B and C) show a dependence of differential cross section on the photon energy spectrum for beam energies $\sqrt{s} = 500$ GeV, differential cross sections with a cut $x \geqslant 0.25$ for the photon energy and $|\cos\theta'| \leqslant 0.95$ for the photon scattering angle. We analyzed scenarios A, B and C for different selectron masses. Since in scenario A the neutralino is nearly a pure photino, the cross section is dominated by selectron

Scenarios of neutralino mixing

Scenario	A	B	C
M_2, GeV	M_Z	200	200
μ, GeV	$-2M_Z$	–150	300
$\tan\beta$	1.72	1.72	1.72
m, GeV	35	44	49
$m_{\widetilde{\chi}_1^\pm}$, GeV	175.6	175.6	127.7
M_1	$M_2((5/3)\tan^2\theta_W)$		
N_{11}	–1	–0.05	–0.52
N_{12}	0.06	0.09	0.76
N_{13}	0.05	–0.05	–0.35
N_{14}	0.03	0.99	–0.18

Note. Mass eigenvalues m and mixing parameters N_{1i} of the lightest neutralino $\widetilde{\chi}_1^0 = N_{11}\widetilde{\gamma} + N_{12}\widetilde{Z}^0 + N_{13}\widetilde{H}_a^0 + N_{14}\widetilde{H}_b^0$ in three different mixing scenarios. M_2, μ and $\tan\beta$ are the parameters of the neutral gaugino-Higgsino mass matrix. For completeness the mass values $m_{\widetilde{\chi}_1^\pm}$ of the light charginos are also shown.

exchange, whereas for the light Higgsino case of scenario B the Z^0 exchange dominates by far. This changes drastically for the Higgsino-like neutralino of scenario B. As seen from Figs. 3 and 4, all the three scenarios have maximum approximately at one point $x = E_\gamma/E$. This means that at high energies the dependence of the cross section on the photon's energy spectrum demonstrates the same behavior. Differential cross section is monotonuosly decreasing with increasing selectron mass. Therefore, experimental search for the neutralino pair at lower values of the selectron mass is preferable.

As a consequence of the photon energy cut ($x \geqslant 0.25$) this characteristic signature of a Higgsino-like neutralino is cut off for the lowest energy ($E = 200$ GeV). By increase in the beam energy from 400 to 500 GeV the enhancement decreases by a factor of approximately 0.4. Since in scenario C the neutralino has both a rather large zino and a rather large photino components, the cross section is more than one order of magnitude smaller than in scenario B.

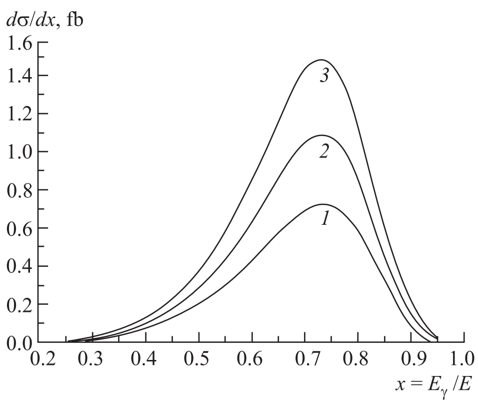

Fig. 3. Differential cross section $d\sigma(e^+ + e^- \to \widetilde{\chi}_1^0\widetilde{\chi}_1^0\gamma)/dx$ as a function of $x = E_\gamma/E$ at beam energies $\sqrt{s} = 500$ GeV for scenario A. The curves correspond: *1* — $m_{\widetilde{e}} = 500$ GeV; *2* — $m_{\widetilde{e}} = 400$ GeV; *3* — $m_{\widetilde{e}} = 250$ GeV

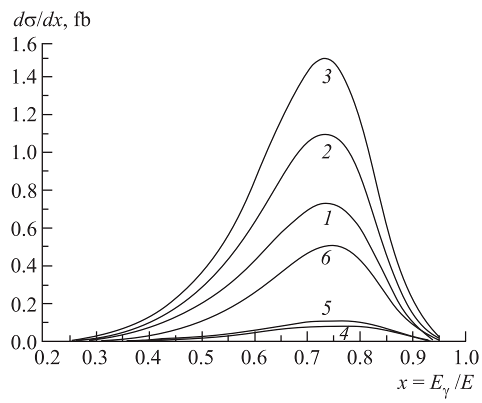

Fig. 4. The same as in Fig. 3, but for scenarios B and C. The curves correspond: for scenario B: *1* — $m_{\widetilde{e}} = 500$ GeV; *2* — $m_{\widetilde{e}} = 400$ GeV; *3* — $m_{\widetilde{e}} = 250$ GeV; for scenario C: *4* — $m_{\widetilde{e}} = 500$ GeV; *5* — $m_{\widetilde{e}} = 400$ GeV; *6* — $m_{\widetilde{e}} = 250$ GeV

Figure 5 (scenario A) and Fig. 6 (scenarios B and C) show a dependence of the total cross section on the beam energies. The total cross section is monotonously decreasing beginning from 400 GeV with increase in selectron, neutralino masses and beam energy. Again Z^0

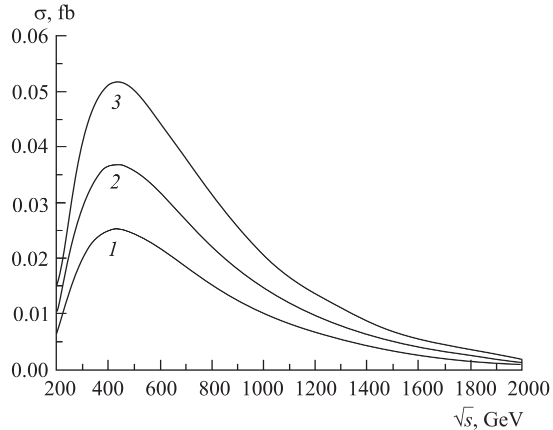

Fig. 5. Total cross section $\sigma(e^+ + e^- \to \widetilde{\chi}_1^0 \widetilde{\chi}_1^0 \gamma)$ as a function of the beam energy for scenario A. The curves correspond: *1* — $m_{\widetilde{e}} = 500$ GeV; *2* — $m_{\widetilde{e}} = 400$ GeV; *3* — $m_{\widetilde{e}} = 250$ GeV

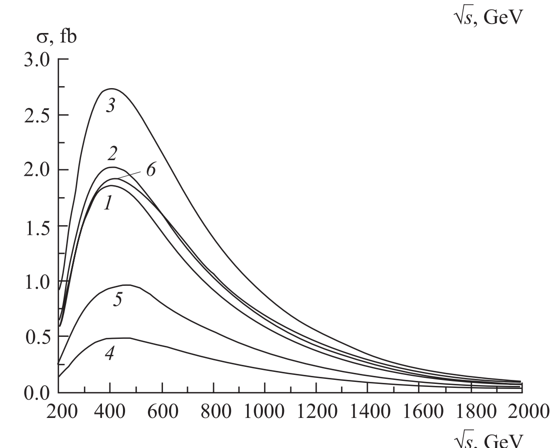

Fig. 6. The same as in Fig. 5, but for scenarios B and C. The curves correspond: for scenario B: *1* — $m_{\widetilde{e}} = 500$ GeV; *2* — $m_{\widetilde{e}} = 400$ GeV; *3* — $m_{\widetilde{e}} = 250$ GeV; for scenario C: *4* — $m_{\widetilde{e}} = 500$ GeV; *5* — $m_{\widetilde{e}} = 400$ GeV; *6* — $m_{\widetilde{e}} = 250$ GeV

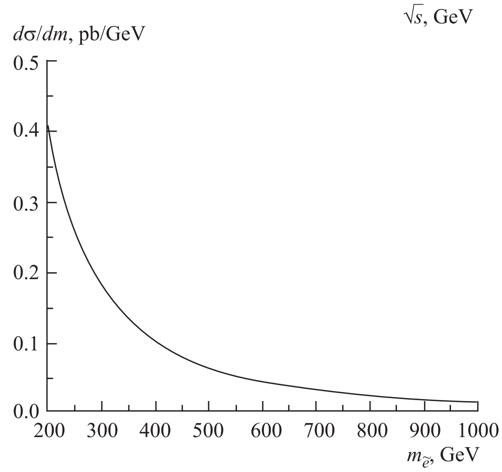

Fig. 7. Differential cross section $d\sigma(e^+ + e^- \to \widetilde{\chi}_1^0 \widetilde{\chi}_1^0 \gamma)/dm$ as a function of the selectron mass at beam energy $\sqrt{s} = 500$ GeV. SUSY parameters were taken as follows: $\mu = 300$ GeV, $M_1 = M_2 = 200$ GeV, $\tan\beta = 3$

exchange creates strong variation with energy both for a Higgsino-like neutralino and for the more general mixture of scenario C, whereas in the light photino case of scenario A the variation of the cross sections is of the order of 10–12% only. Finally, Fig. 7 shows differential cross section as a function of the selectron mass at beam energy $\sqrt{s}$ = 500 GeV. In this case, differential cross section decreases with increase in selectron masses.

CONCLUSIONS

The production of invisible pairs of lightest neutralinos in association with a large-angle hard photon at TESLA energies has been analyzed in the MSSM. Instead of relying upon an explicit diagrammatic calculation, we have calculated the differential cross sections as functions of the photon energy spectrum and selectron mass, as well as the total cross section as a function of beam energies for three different mixing scenarios. Since in scenario A the neutralino is nearly a pure photino, the cross section is dominated by selectron exchange, whereas for the light Higgsino case of scenario B the Z^0 exchange dominates by far. As seen from Figs. 3 and 4, all the three scenarios have maximum approximately at one point $x = E_\gamma/E$. Also, the differential cross section is monotonously decreasing with increasing selectron mass. Such a distribution of the curves in dependence of differential cross section on the photon energy spectrum and of total cross section on the beam energy is confirmed by Fig. 7. Therefore, experimental search for the neutralino pair at lower values of the selectron mass is preferable. As seen from Figs. 5–7, dependence of the total cross section on the beam energies is monotonously decreasing beginning from 400 GeV with increasing selectron, neutralino masses and beam energy. The differential cross section decreases with increase in selectron masses. The main irreducible background for this reaction is the Standard Model (SM) process of neutrino pair plus photon production $e^+e^- \to \nu\nu\gamma$, which is produced by W, Z exchange. It should be noted that in our case the background cross section is about 3 orders of magnitude larger than the signal.

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