Polarization aspects in radiative neutralino production

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We study the impact of beam polarization on radiative neutralino production $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma$ at the International Linear Collider. We show that longitudinal polarized beams significantly enhance the signal and simultaneously reduce the Standard Model background from radiative neutrino production $e^+e^- \to \nu\bar{\nu}\gamma$. We point out that the radiative production of neutralinos could be the only accessible SUSY particles, if neutralinos, charginos, sleptons, as well as squarks and gluinos are too heavy to be pair-produced in the first stage of the ILC at $\sqrt{s} = 500$ GeV.

1 Introduction

The Minimal Supersymmetric Standard Model (MSSM) is a promising extension of the Standard Model of particle physics (SM) [2]. At the International Linear Collider (ILC) [3], the masses, decay widths, couplings, and spins of the new SUSY particles can be measured with high precision [4]. In particular, the lightest states like pairs of neutralinos, charginos, and sleptons, can be studied in the initial stage of the ILC, with a center-of-mass energy $\sqrt{s} = 500$ GeV, and a luminosity of $\mathcal{L} = 500$ fb^{-1}. The lightest SUSY state is a pair of radiatively produced neutralinos [5–12]

$$e^+ + e^- \to \tilde{\chi}_1^0 + \tilde{\chi}_1^0 + \gamma. \tag{1}$$

The signal is a single high energetic photon, radiated off the incoming beams or off the exchanged selectrons, and missing energy, carried by the neutralinos [13–15].

2 Signal and background

The main Standard Model background is photons from radiatively produced neutrinos $e^+e^- \to \nu\bar{\nu}\gamma$ [14, 15]. In order to quantify whether an excess of signal photons from radiative neutralino production, $N_{\rm S} = \sigma\mathcal{L}$, can be observed over the SM background photons, $N_{\rm B} = \sigma_{\rm B}\mathcal{L}$, we define the theoretical significance S, and the signal to background ratio r [11]

$$S = \frac{N_{\rm S}}{\sqrt{N_{\rm S} + N_{\rm B}}} = \frac{\sigma}{\sqrt{\sigma + \sigma_{\rm B}}}\sqrt{\mathcal{L}}, \qquad r = \frac{N_{\rm S}}{N_{\rm B}} = \frac{\sigma}{\sigma_{\rm B}}. \tag{2}$$

For example, a theoretical significance of $S = 1$ implies that the signal can be measured at the statistical 68% confidence level. If the experimental error of the background cross section is 1%, the signal to background ratio must be larger than 1%. A detection of the signal requires at least

$$S > 1 \quad \text{and} \quad r > 1\%. \tag{3}$$

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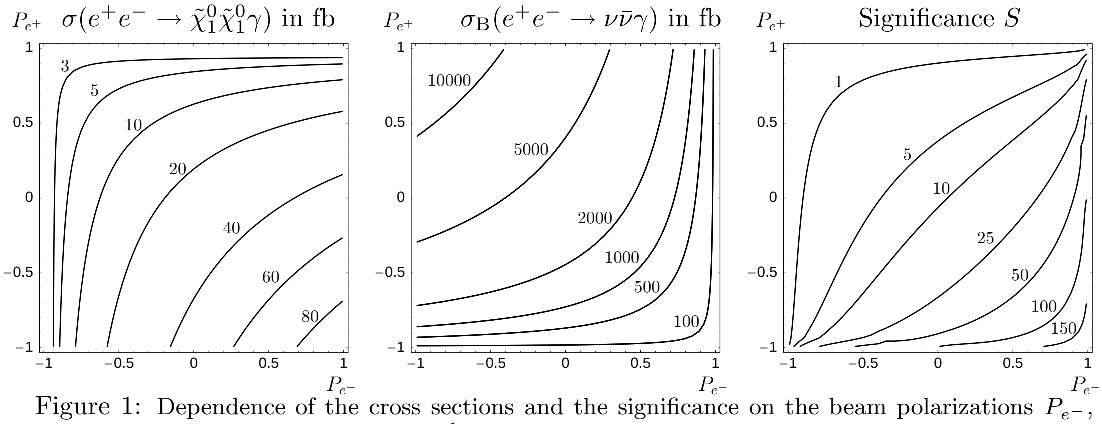

Figure 1: Dependence of the cross sections and the significance on the beam polarizations P_{e^-}, P_{e^+} with $\sqrt{s} = 500$ GeV, $\mathcal{L} = 500$ fb^{-1} for SPS1a with $\mu = 352$ GeV, $M_2 = 193$ GeV, $\tan\beta = 10$, $m_0 = 100$ GeV, $m_{\tilde{\chi}_1^0} = 94$ GeV, and $m_{\tilde{\ell}_{R(L)}} = 143(204)$ GeV [11].

3 Cuts on photon angle and energy

For the tree-level calculation of the cross sections σ for signal and background, we use the formulas for the amplitudes squared as given in Ref. [11]. To regularize the infrared and collinear divergences, we apply cuts on the photon scattering angle θ_γ and energy E_γ [11]

$$|\cos\theta_\gamma| \leq 0.99, \qquad 0.02 \leq x \leq \; 1 - \frac{m^2_{\chi_1^0}}{E^2_{\rm beam}}, \qquad x = \frac{E_\gamma}{E_{\rm beam}}, \tag{4}$$

The upper cut on the photon energy $x^{\rm max} = 1 - m^2_{\chi_1^0}/E^2_{\rm beam}$ is the kinematical limit of radiative neutralino production. This cut also reduces much of the on-shell Z boson contribution to the background from radiative neutrino production [11]. Note that the ratios r and S do not depend very sensitively on the choice of the cuts $|\cos\theta_\gamma| \leq 0.99$ and $0.02 \leq x$, since signal and background have very similar distributions in energy E_γ and angle θ_γ.

4 Numerical Results

We present numerical results of the signal and background cross sections with emphasis on their dependence on the beam polarization [16], and on the higgsino and gaugino mass parameters μ and M_2, respectively. Finally we discuss a mSUGRA scenario, where radiative production of neutralinos is the only accessible SUSY state at $\sqrt{s} = 500$ GeV.

4.1 Beam polarization dependence

In Fig. 1, we show the beam polarization dependence of the signal $\sigma(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma)$ and background cross sections $\sigma_{\rm B}(e^+e^- \to \nu\bar{\nu}\gamma)$. In the SPS 1a scenario [17], the neutralino is mostly bino, such that radiative neutralino production dominantly proceeds via right selectron $\tilde{e}_R$ exchange. The background, radiative neutrino production, mainly proceeds via W boson exchange. Thus positive electron beam polarization P_{e^-} and negative positron beam polarization P_{e^+} enhance the signal cross section and reduce the background at the same time, such that the significance is greatly enhanced, see Fig. 1. For beam polarizations of $(P_{e^-}, P_{e^+}) = (0.8, -0.3)[(0.8, -0.6)]$, the signal cross section is $\sigma(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma) =$ 56[70] fb, the background is $\sigma_{\rm B}(e^+e^- \to \nu\bar{\nu}\gamma) = 540[330]$ fb, such that the significance

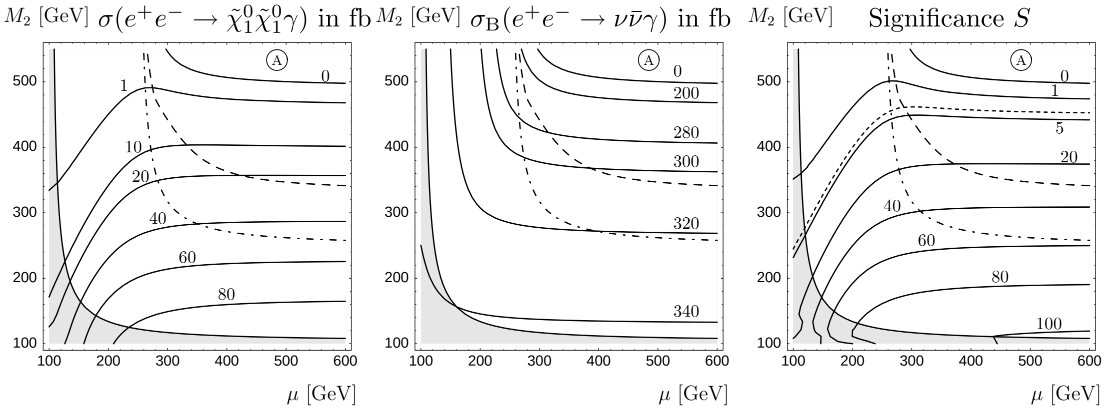

Figure 2: Dependence of the cross sections and the significance on μ, M_2 with $\sqrt{s} = 500$ GeV, $\mathcal{L} = 500$ fb^{-1}, $(P_{e^-}, P_{e^+}) = (0.8, -0.6)$, and $\tan\beta = 10$, $m_0 = 100$ GeV [11]. The dashed line indicates the kinematical limit $m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_2^0} = \sqrt{s}$, and the dot-dashed line the kinematical limit $2m_{\tilde{\chi}_1^\pm} = \sqrt{s}$. Along the dotted line the signal to background ratio is $\sigma/\sigma_{\rm B} = 0.01$. The area A is kinematically forbidden by the cut on the photon energy E_γ, see Eq. (4). In the gray area $m_{\tilde{\chi}_1^\pm} < 104$ GeV.

is $S = 50[80]$, and the signal to background ratio is $r = 10\%[20\%]$. These results should motivate a detailed experimental analysis including Monte Carlo studies [15, 18].

4.2 Dependence on μ and M_2

In Fig. 1, we show contour lines of the signal $\sigma(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma)$ and background cross section $\sigma_{\rm B}(e^+e^- \to \nu\bar{\nu}\gamma)$ in the μ–M_2 plane. The signal is decreasing for increasing M_2, since the neutralino mass $m_{\tilde{\chi}_1^0}$ and the selectron mass $m_{\tilde{e}_R}$ are increasing. For decreasing values of $\mu \lesssim 300$ GeV, the bino component of the neutralino is decreasing, leading to a decreasing signal cross section $\sigma(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma)$. Note that the background cross section also depends on μ and M_2, since the kinematical cuts include the neutralino mass, see Eq. (4). In Fig. 1, we also indicate the kinematical limits of the production of neutralinos $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0$ (dashed line) and charginos $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$ (dot-dashed line). Above these lines, the radiative production of neutralinos is the only kinematically allowed SUSY state, which can however be observed with a significance of up to $S = 20$.

4.3 The only state to be observed?

Consider, as an example, the mSUGRA scenario $M_0 = 200$ GeV, $M_{1/2} = 415$ GeV, $A_0 = -200$ GeV, and $\tan\beta = 10$. In this scenario, we have $M_2 = 349$ GeV, $\mu = 560$ GeV, and the particle masses are $m_{\tilde{\chi}_{1(2)}^0} = 180(344)$ GeV, $m_{\tilde{\chi}_1^\pm} = 344$ GeV, $m_{\tilde{\tau}_1} = 253$ GeV, $m_{\tilde{e}_{R(L)}} = 261(356)$ GeV. The neutralinos, charginos and selectrons are too heavy to be pair produced at $\sqrt{s} = 500$ GeV. However, neutralinos can still be radiatively produced. In Table 1, we show the cross section and the background from radiative neutrino production for different sets of beam polarizations with $P_{e^+} = 0, -0.3, -0.6$ and $P_{e^-} = 0, 0.8, 0.9$. Polarized beams enhance the signal, in particular the background is strongly reduced by a high degree of electron polarization $P_{e^-} = 0.9$. Note that without beam polarization, the signal cannot be observed.

(P_{e^+}, P_{e^-})	$(0\|0)$	$(0\|0.8)$	$(-0.3\|0.8)$	$(0\|0.9)$	$(-0.3\|0.9)$	$(-0.6\|0.8)$
$\sigma(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma)$	4.7 fb	8.2 fb	11 fb	8.6 fb	11.2 fb	13 fb
$\sigma_{\rm B}(e^+e^- \to \nu\bar{\nu}\gamma)$	3354 fb	689 fb	495 fb	356 fb	263 fb	301 fb
S	1.8	7	11	10	15	17
r	0.1%	1.2%	2.2%	2.4%	4.3%	4.4%

Table 1: Cross sections, significance S, and signal to background ratio r, for different sets of beam polarizations, for $\sqrt{s} = 500$ GeV, $\mathcal{L} = 500$ fb^{-1}, and $M_0 = 200$ GeV, $M_{1/2} = 415$ GeV, $A_0 = -200$ GeV, $\tan\beta = 10$ [12].

4.4 Summary and conclusions

A pair of radiatively produced neutralinos $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma$ is the lightest state of SUSY particles to be produced at e^+e^- colliders. The signal is a single high energetic photon and missing energy. The signal could not be observed at LEP due to the large background from radiative neutrino production $e^+e^- \to \nu\bar{\nu}\gamma$. At the ILC, however, polarized beams enhance the signal and simultaneously reduce the background. We have shown that the significance for observing the signal can be as large as $S = 100$, and that the signal to background ratio can be as large as $r = 20\%$. These results should motivate detailed experimental studies, to learn as much as possible about Supersymmetry through the process of radiatively produced neutralinos.

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