UWThPh-2002-32
WUE-ITP-2002-028
LC-TH-2003-006
hep-ph/0210363

Singlino-dominated Neutralinos in Extended Supersymmetric Models*

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Abstract

We adopt the SUSY benchmark scenario SPS 1a in supersymmetric models where the Higgs sector is extended by singlet superfields. We consider light neutralinos with dominant singlino character whose couplings are generally suppressed. The cross sections for direct production of the singlino-dominated neutralinos can be of the order of several fb for singlet vevs of some TeV. Hence even exotic neutralinos which are not the LSP and are omitted in the decay chains of the other supersymmetric particles may be visible at a high luminosity linear e^+e^- collider. If, however, the LSP is singlino-dominated the decay width of the NLSP can be very small and displaced vertices exist for large singlet vacuum expectation values.

1 Introduction

In the Next-to-Minimal Supersymmetric Standard Model (NMSSM) [1] or an E_6 inspired model with one extra neutral gauge boson Z' and one additional singlet superfield [2] neutralinos with a dominant singlet higgsino (singlino) component exist for large values of the singlet vacuum expectation value (vev) $x \gtrsim 1$ TeV. We study scenarios where the MSSM-like neutralinos have similar masses and mixing character as in the 'typical mSUGRA' SPS 1a scenario for the MSSM [3].

Since the singlino component does not couple to gauge bosons, gauginos, (scalar) leptons and (scalar) quarks, cross sections for the production of the exotic neutralinos

*Contribution to the Proceedings of the *10th International Conference on Supersymmetry and Unification of Fundamental Interactions* (SUSY 02), DESY, Hamburg, Germany, 17 – 23 June 2002.

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are generally small. We analyze the regions of x where the associated production of the singlino-dominated neutralino yields detectable cross sections at a linear e^+e^-collider.

Since also the decay of an MSSM-like neutralino into a singlino-dominated neutralino is strongly suppressed the decay vertex can be significantly displaced from the production vertex in the detector. Within the SPS 1a scenario we discuss the singlet vacuum expectation values which lead to displaced decay vertices of an MSSM-like next-to-lightest supersymmetric particle (NLSP) decaying into an exotic LSP. The production of singlino-dominated neutralinos is extensively discussed in [4, 5, 6]. More details of displaced vertices can be found in [7].

2 Scenarios

2.1 NMSSM

The NMSSM parameters (for details see [1]) $M_1 = 99$ GeV, $M_2 = 193$ GeV, $\tan\beta = 10$ and the effective μ parameter $\mu_{\text{eff}} = \lambda x = 352$ GeV are chosen according to the scenario SPS 1a. For large $x \gg |M_2|$ a singlino-dominated neutralino $\tilde{\chi}^0_S$ with mass $\approx 2\kappa x$ in zeroth approximation decouples in the neutralino mixing matrix while the other four neutralinos $\tilde{\chi}^0_{1,\dots,4}$ have MSSM character as in SPS 1a with masses 96 GeV, 177 GeV, 359 GeV and 378 GeV.

Fig. 1 shows the mixing character of $\tilde{\chi}^0_S$ as a function of the singlet vacuum expectation value x while $m_{\tilde{\chi}^0_S} = 70$ GeV and 120 GeV and μ_{eff} are fixed by the parameters κ and λ, respectively. In order to obtain a singlino content of 90% (99%), x must be larger than about 1200 GeV (4000 GeV) for $m_{\tilde{\chi}^0_S} = 70$ GeV and 1500 GeV (5000 GeV) for $m_{\tilde{\chi}^0_S} = 120$ GeV. Generally the singlino content increases with increasing value of x. The couplings of the singlino-dominated neutralino and therefore the production cross sections and decay widths are determined by the remaining MSSM content, which decreases as $1/x^2$ in good approximation. In the SPS 1a inspired scenario the gaugino content dominates the MSSM content of $\tilde{\chi}^0_S$, which increases the couplings to the gaugino-like $\tilde{\chi}^0_1$ and $\tilde{\chi}^0_2$ [4].

2.2 $\mathbf{E_6}$ model

We consider an E_6 inspired model with one extra neutral gauge boson Z' and one additional singlet superfield which contains six neutralinos [2]. Again the MSSM parameters and masses of the MSSM-like neutralinos are fixed according to the scenario SPS 1a, while a nearly pure light singlino-like neutralino $\tilde{\chi}^0_S$ with mass $\approx 0.18\, x^2/|M'|$ in zeroth approximation exists for very large values $|M'| \gg x$ [8]. The sign of M' is fixed by requiring relative sign $+1$ between the mass eigenvalues of $\tilde{\chi}^0_S$ and $\tilde{\chi}^0_1$ [4].

In scenario SPS 1a with $m_{\tilde{\chi}^0_S} = 70$ GeV the $\tilde{Z}'$ content is very small (Fig. 1). Hence the MSSM components of the singlino-dominated neutralino are of comparable size as in the corresponding NMSSM scenario. A singlino purity of 90 % is reached at $x = 1260$ GeV and 99 % at $x = 4200$ GeV. In the scenario with $m_{\tilde{\chi}^0_S} = 120$ GeV the $\tilde{Z}'$ content is larger resulting in a smaller gaugino content of $\tilde{\chi}^0_S$ than in the NMSSM. Here x must be larger than 1600 GeV and 5200 GeV to obtain a singlino content of 90 % and 99 %, respectively.

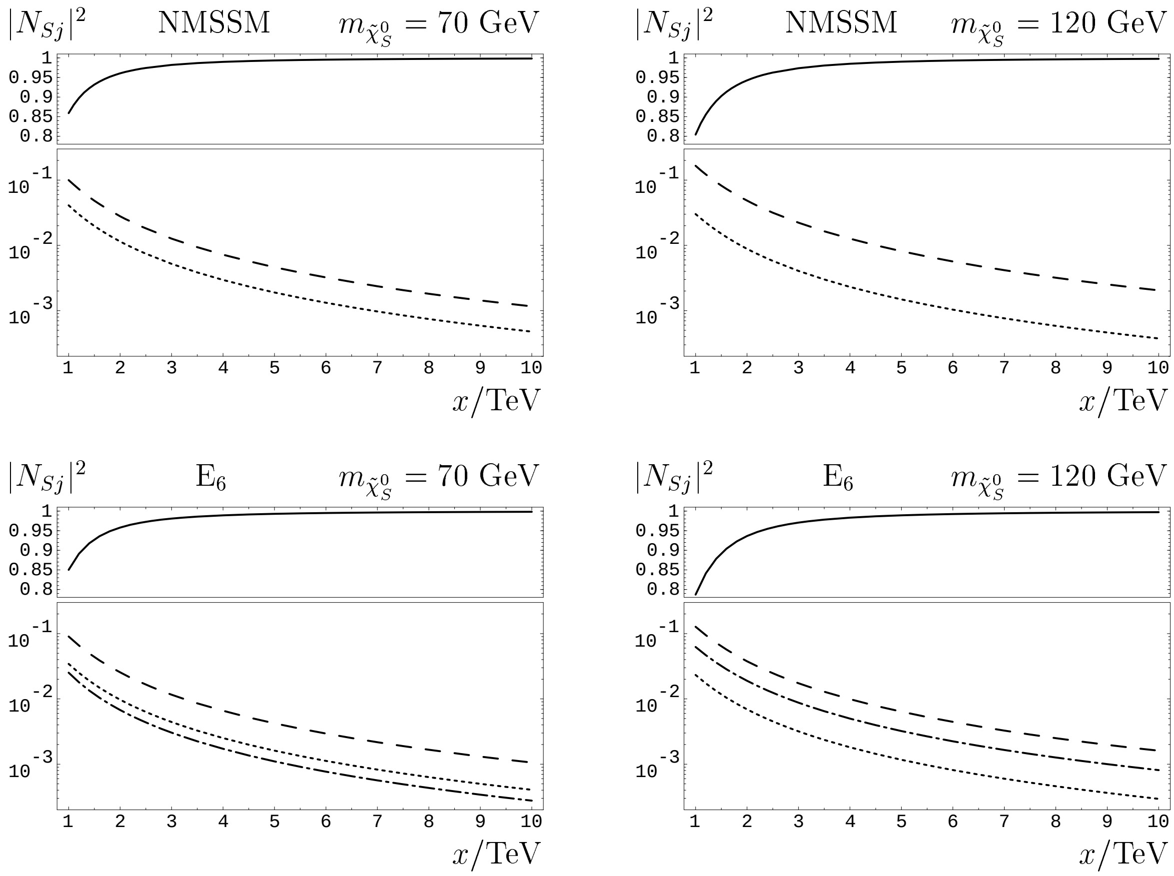

Figure 1: Mixing of the singlino-dominated neutralino $\tilde{\chi}_S^0$ in the SPS 1a inspired scenarios in the NMSSM and E_6 model with $M_1 = 99$ GeV, $M_2 = 193$ GeV, $\tan\beta = 10$ and $\mu_{\rm eff} = \lambda x = 352$ GeV: singlino content $|N_{S5}|^2$ (solid line), MSSM gaugino content $|N_{S1}|^2 + |N_{S2}|^2$ (dashed), MSSM doublet higgsino content $|N_{S3}|^2 + |N_{S4}|^2$ (dotted) and $\tilde{Z}'$ content $|N_{S6}|^2$ (dashed-dotted). The mass of $\tilde{\chi}_S^0$ is fixed at 70 GeV and 120 GeV by the parameters κ (NMSSM) and M' (E_6 model).

3 Production of singlino-dominated neutralinos

Direct experimental evidence of a fifth neutralino would be an explicit proof for an extended SUSY model. An exotic neutralino which is not the LSP is omitted in the decay cascades and must be directly produced with sufficient cross section to be detected. The visibility of the cross sections for neutralinos with major exotic components is also crucial to apply sum rules in order to test the closure of the neutralino system [9].

We discuss the associated production of the singlino-dominated $\tilde{\chi}_S^0$ together with the lightest MSSM-like neutralino $\tilde{\chi}_1^0$ in e^+e^- annihilation. Since in the SPS 1a inspired scenario $\tilde{\chi}_1^0$ is gaugino-like the production proceeds mainly via t- and u-channel exchange of selectrons and the gaugino content of $\tilde{\chi}_S^0$ is crucial for the size of the cross section (Fig. 1). Analytical formulae are given in [10] for the NMSSM and [2] for the E_6 model. The selectron masses are fixed according to the SPS 1a scenario in both models: $m_{\tilde{e}_R} =$

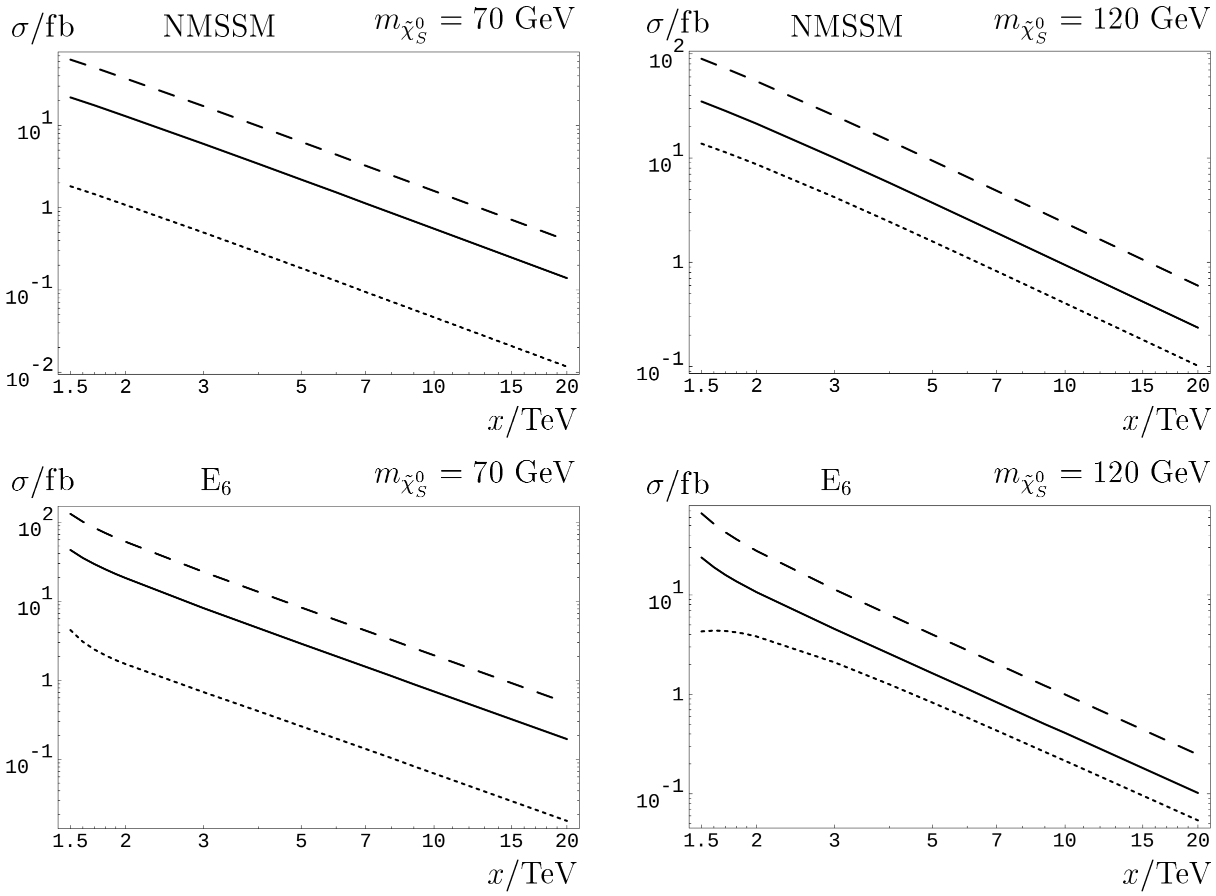

Figure 2: Cross sections for the production of a singlino-dominated neutralino $\tilde{\chi}^0_S$ via $e^+e^- \to \tilde{\chi}^0_S \tilde{\chi}^0_1$ for $\sqrt{s} = 500$ GeV in the SPS 1a inspired scenarios in the NMSSM and E_6 model with $M_1 = 99$ GeV, $M_2 = 193$ GeV, $\tan\beta = 10$ and $\mu_{\rm eff} = \lambda x = 352$ GeV with unpolarized beams (solid) and beam polarizations $P_- = +0.8$, $P_+ = -0.6$ (dashed) and $P_- = -0.8$, $P_+ = +0.6$ (dotted). The mass of $\tilde{\chi}^0_S$ is fixed at 70 GeV and 120 GeV by the parameters κ (NMSSM) and M' (E_6 model).

143 GeV and $m_{\tilde{e}_L} = 202$ GeV. We will assume a cross section of 1 fb to be sufficient of the production process. Of course the discovery limit depends on the neutralino decay properties that are discussed in detail in [7, 10, 11].

In Fig. 2 the cross sections are shown for two masses 70 and 120 GeV of $\tilde{\chi}^0_S$, where the singlino-dominated neutralino is the LSP and NLSP, respectively. In all scenarios the cross sections are decreasing in good approximation as $1/x^2$ according to the gaugino content of $\tilde{\chi}^0_S$. In the NMSSM with $m_{\tilde{\chi}^0_S} = 70$ GeV (120 GeV) the unpolarized cross section is larger than 1 fb for $x < 7.4$ TeV (9.7 TeV) which corresponds to a singlino content of 99.7 %. While the cross sections in the E_6 model with $m_{\tilde{\chi}^0_S} = 70$ GeV are enhanced because of a positive $\tilde{Z}'$ contribution to the electron-selectron-neutralino coupling, the smaller gaugino content of $\tilde{\chi}^0_S$ and a negative $\tilde{Z}'$ contribution reduces the cross section for $m_{\tilde{\chi}^0_S} = 120$ GeV.

We also show the cross sections for polarized beams with 80 % electron and 60 % positron polarizations expected at a future linear collider [12]. In the extended SPS 1a

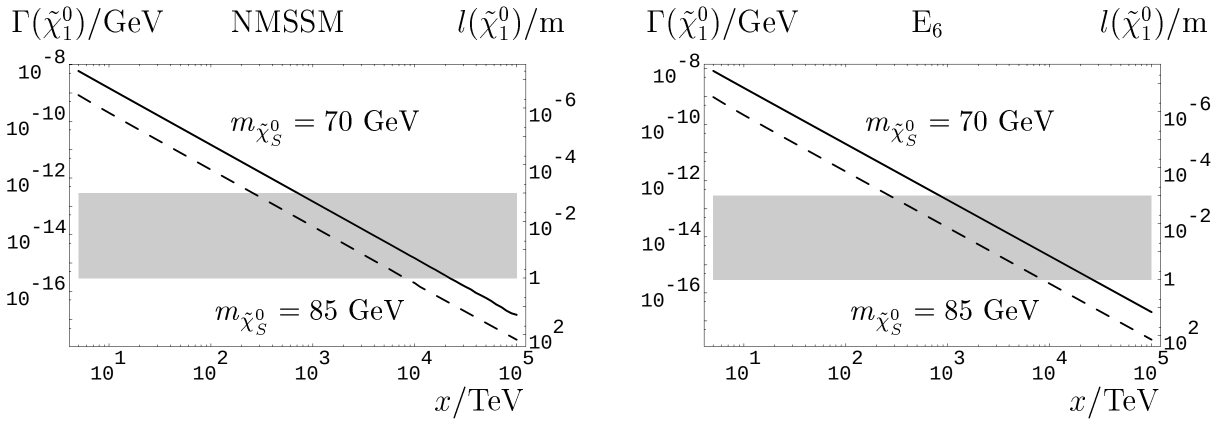

Figure 3: Total decay widths of the lightest MSSM-like neutralino $\tilde{\chi}_1^0$ decaying into a singlino-dominated neutralino $\tilde{\chi}_S^0$ in the SPS 1a inspired scenarios in the NMSSM and E_6 model with $M_1 = 99$ GeV, $M_2 = 193$ GeV, $\tan\beta = 10$ and $\mu_{\rm eff} = \lambda x = 352$ GeV. The mass of $\tilde{\chi}_S^0$ is fixed at 70 GeV and 85 GeV by the parameters κ (NMSSM) and M' (E_6 model). The shaded area marks the decay widths where displaced vertices exist. Below this area the decaying particle escapes detection.

scenarios always the configuration $P_- = +0.8$, $P_+ = -0.6$ enhances the cross sections by a factor 2 – 3 [6, 13].

4 Displaced vertices

Displaced vertices of an MSSM-like NLSP appear if the couplings of a singlino-dominated LSP to the NLSP are strongly suppressed at large values of x [7, 11]. Then assuming conserved R-parity all SUSY particles first decay into the NLSP which finally decays into the LSP with a decay vertex displaced from the production vertex.

In Fig. 3 we show the total decay width and decay length of the MSSM-like NLSP $\tilde{\chi}_1^0$ for two masses of the singlino-like LSP $\tilde{\chi}_S^0$ of 70 GeV and 85 GeV. For the larger mass difference between $\tilde{\chi}_S^0$ and $\tilde{\chi}_1^0$ displaced vertices appear for $x > 7 \cdot 10^2$ TeV and $x > 8 \cdot 10^2$ TeV in the NMSSM and E_6 model, respectively. For the smaller mass difference phase space effects outweigh the larger mixing and the area of displaced vertices is reached for $x > 3 \cdot 10^2$ TeV [7].

Since the direct production of singlino-like neutralinos is visible up to $\mathcal{O}(10$ TeV$)$, displaced vertices would be helpful to study exotic LSPs for large $x = 10^2 - 10^4$ TeV. If, however, the $\tilde{\chi}_S^0$ is not the LSP it remains invisible in this parameter region.

5 Conclusion

We have discussed the production of singlino-dominated neutralinos and the neutralino decay with displaced vertices in extended versions of the SPS 1a scenario within the NMSSM and an E_6 inspired model with one new gauge boson. Since the singlet vacuum expectation value x determines the singlino content it is the crucial parameter which triggers the production and decay properties of the exotic neutralino.

An exotic neutralino that is not the LSP is only visible in direct production since it is omitted in the decay cascades of the other SUSY particles. At a high luminosity linear e^+e^- collider the associated production of a singlino-dominated neutralino is detectable up to x values of order 10 TeV, which corresponds to a singlino content of more than 99 %. Displaced vertices of an MSSM-like NLSP into a singlino-dominated LSP exist for very large x of order 100 – 1000 TeV, significantly above the region where direct production occurs.

Acknowledgment

We thank A. Bartl and H. Fraas for many helpful discussions and the careful reading of the manuscript. This work is supported by the 'Fonds zur Förderung der wissenschaftlichen Forschung' of Austria, FWF Project No. P13139-PHY, by the EU TMR Project No. HPRN-CT-2000-00149 and by the Deutsche Forschungsgemeinschaft (DFG) under contract No. FR 1064/5-1.

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