

Identifying the NMSSM by the interplay of LHC and ILC¹

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The interplay between the LHC and the e^+e^- International Linear Collider (ILC) with $\sqrt{s} = 500$ GeV might be crucial for the discrimination between the minimal and next-to-minimal supersymmetric standard model. We present an NMSSM scenario, where the light neutralinos have a significant singlino component, that cannot be distinguished from the MSSM by cross sections and mass measurements. Mass and mixing state predictions for the heavier neutralinos from the ILC analysis at different energy stages and comparison with observation at the LHC, lead to clear identification of the particle character and identify the underlying supersymmetric model.

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The interplay between the LHC and the e^+e^- International Linear Collider (ILC) with $\sqrt{s} = 500$ GeV might be crucial for the discrimination between the minimal and next-to-minimal supersymmetric standard model. We present an NMSSM scenario, where the light neutralinos have a significant singlino component, that cannot be distinguished from the MSSM by cross sections and mass measurements. Mass and mixing state predictions for the heavier neutralinos from the ILC analysis at different energy stages and comparison with observation at the LHC, lead to clear identification of the particle character and identify the underlying supersymmetric model.

1. INTRODUCTION

Supersymmetry (SUSY) is one of the most promising extensions to the Standard Model (SM). Since low-energy SUSY is broken there exist numerous free parameters that make it a highly challenging task to reveal the underlying model at the Large Hadron Collider (LHC) and at the International Linear Collider (ILC). It is planned that the ILC starts with an energy of $\sqrt{s} = 500$ GeV, which will be upgraded to about 1 TeV [1]. However, already at the first energy stage, the ILC could reach higher energy up to about $\sqrt{s} = 650$ GeV at cost of luminosity. In this study we sketch a possible motivation to apply this higher energy option. Particularly interesting are case studies which apply interplay of search strategies at the LHC and the ILC [2]. We extend in this paper the methods for combined LHC/ILC analyses developed in [3].

An interesting possibility for the determination of the supersymmetric model is to study the gaugino/higgsino particles, which are expected to be among the lightest supersymmetric particles. In this paper we consider two basic supersymmetric models: the minimal supersymmetric standard model (MSSM) and the next-to-minimal supersymmetric standard model (NMSSM). The MSSM contains four neutralinos $\tilde{\chi}_i^0$, the mass eigenstates of the photino, zino and neutral higgsinos, and two charginos $\tilde{\chi}_i^\pm$, being mixtures of wino and charged higgsino. The neutralino/chargino sector depends at tree level on four parameters: the U(1) and SU(2) gaugino masses M_1 and M_2 , the higgsino mass parameter μ , and the ratio $\tan\beta$ of the vacuum expectation values of the Higgs fields. For the determination of these parameters, straightforward strategies [4, 5] have been worked out even if only the light neutralinos and charginos $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ are kinematically accessible at the first stage of the ILC [6].

The NMSSM [7] is the simplest extension of the MSSM by an additional Higgs singlet field. New parameters in the neutralino sector are the vacuum expectation value x of the singlet field and the trilinear couplings λ and κ in the superpotential, where the product $\lambda x = \mu_{\text{eff}}$ replaces the μ -parameter of the MSSM [8, 9]. The additional fifth neutralino may significantly change the phenomenology of the neutralino sector. In scenarios where the lightest supersymmetric particle is a nearly pure singlino, the existence of displaced vertices leads to a particularly interesting experimental signature [10, 11]. In case only a part of the particle spectrum is kinematically accessible the distinction between the models may become challenging.

It has already been worked out that there exist MSSM and NMSSM scenarios with the same mass spectra of the light neutralinos but different neutralino mixing. In this case beam polarization is crucial for distinguishing the two models [12]. We present a scenario where all kinematically accessible neutralinos and charginos have similar masses and almost identical cross sections, within experimental errors, in MSSM and NMSSM. Although the second

lightest neutralino in the NMSSM has a significant singlino component, the models cannot be distinguished by the experimental results at the LHC or at the ILC₅₀₀ with $\sqrt{s} = 500$ GeV alone if only measurements of masses, cross sections and gaugino branching ratios are considered. Precision measurements of the neutralino branching ratio into the lightest Higgs particle and of the mass difference between the lightest and next-to-lightest SUSY particle [13] may give first evidence for the SUSY model but are difficult to realize in our case. Therefore the identification of the underlying model requires precision measurements of the heavier neutralinos by combined analyses of LHC and ILC as described in the following section.

2. CASE STUDY

We study an NMSSM scenario with the parameters

$$M_1 = 360 \text{ GeV}, \quad M_2 = 147 \text{ GeV}, \quad \tan\beta = 10, \quad \lambda = 0.5, \quad x = 915 \text{ GeV}, \quad \kappa = 0.2. \quad (1)$$

The hierarchy $M_1 > M_2$ of the U(1) and SU(2) mass parameters leads to very similar masses of the lightest neutralino $\tilde{\chi}_1^0$, which is assumed to be the lightest supersymmetric particle (LSP), and of the light chargino $\tilde{\chi}_1^\pm$. This mass degeneration is also typical for minimal anomaly mediated SUSY breaking (mAMSB) scenarios. Rather small mass differences may be resolved experimentally by applying the ISR method [14] at the linear collider [13] as well as at the LHC [15].

The NMSSM parameters lead to the following gaugino/higgsino masses and eigenstates:

$$m_{\tilde{\chi}_1^0} = 138 \text{ GeV}, \quad \tilde{\chi}_1^0 = (-0.02, +0.97, -0.20, +0.09, -0.07), \quad (2)$$

$$m_{\tilde{\chi}_2^0} = 337 \text{ GeV}, \quad \tilde{\chi}_2^0 = (+0.62, +0.14, +0.25, -0.31, +0.65), \quad (3)$$

$$m_{\tilde{\chi}_3^0} = 367 \text{ GeV}, \quad \tilde{\chi}_3^0 = (-0.75, +0.04, +0.01, -0.12, +0.65), \quad (4)$$

$$m_{\tilde{\chi}_4^0} = 468 \text{ GeV}, \quad \tilde{\chi}_4^0 = (-0.03, +0.08, +0.70, +0.70, +0.08), \quad (5)$$

$$m_{\tilde{\chi}_5^0} = 499 \text{ GeV}, \quad \tilde{\chi}_5^0 = (+0.21, -0.16, -0.64, +0.62, +0.37), \quad (6)$$

where the neutralino eigenstates are given in the basis $(\tilde{B}^0, \tilde{W}^0, \tilde{H}_1^0, \tilde{H}_2^0, \tilde{S})$. As can be seen from eqs. (3) and (4), the particles $\tilde{\chi}_2^0$ and $\tilde{\chi}_3^0$ have a rather strong singlino admixture.

The Higgs sector does not allow the identification of the NMSSM [16] if scalar and pseudoscalar Higgs bosons with dominant singlet character escape detection. A scan with NMHDECAY [17] in our scenario over the remaining parameters in the Higgs sector, A_λ and A_κ , results in parameter points which survive the theoretical and experimental constraints in the region $2740 \text{ GeV} < A_\lambda < 5465 \text{ GeV}$ and $-553 \text{ GeV} < A_\kappa < 0$. For $-443 \text{ GeV} < A_\kappa < -91 \text{ GeV}$ the second lightest scalar (S_2) and the lightest pseudoscalar (P_1) Higgs particle have very pure singlet character and are heavier than the mass difference $m_{\tilde{\chi}_3^0} - m_{\tilde{\chi}_1^0}$, hence the decays of the neutralinos $\tilde{\chi}_2^0$ and $\tilde{\chi}_3^0$, which will be discussed in the following, are not affected by S_2 and P_1 , see figure 1 (left panel). For our specific case study we choose $A_\lambda = 4000 \text{ GeV}$ and $A_\kappa = -200 \text{ GeV}$, which leads to $m_{S_2} = 311 \text{ GeV}$, $m_{P_1} = 335 \text{ GeV}$ and m_{S_3}, m_{P_2} and $m_{H^\pm} > 4 \text{ TeV}$. Furthermore the lightest scalar Higgs S_1 has MSSM-like character in this parameter range with a mass of about 124 GeV. Also the branching ratio of $\tilde{\chi}_1^0$ in the lightest Higgs particle differs only by a factor two in both scenarios. In case that a precise measurement of this BR is possible first hints for the inconsistency of the model could be derived at the ILC.

2.1. Strategy for the gaugino/higgsino sector

In our NMSSM scenario in the gaugino/higgsino sector only the light chargino $\tilde{\chi}_1^\pm$ and the light neutralinos $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$ are accessible at the ILC₅₀₀. We calculate the masses of the charginos and neutralinos and the cross sections for the pair production of the light chargino $e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^-$ and for the associated production of the light neutralinos $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$ with polarized and unpolarized beams.

The masses and cross sections in different beam polarization configurations provide the experimental input for deriving the supersymmetric parameters within the MSSM using standard methods [5, 6]:

- We assume an uncertainty of $\mathcal{O}(1 - 2\%)$ for the masses $m_{\tilde{\chi}_1^\pm}$, $m_{\tilde{\chi}_1^0}$, $m_{\tilde{\chi}_2^0}$, $m_{\tilde{\nu}_e}$, $m_{\tilde{e}_L}$ and $m_{\tilde{e}_R}$. The errors of the cross sections, $e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^-$ and $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$, are composed of the error due to the mass uncertainties, polarization uncertainty and one standard deviation statistical error based on $\int \mathcal{L} = 100 \text{ fb}^{-1}$ for each polarization configuration. Deviations in the cross sections due to the polarization uncertainty of $\Delta P_{e^\pm}/P_{e^\pm} = 0.5\%$ are generally small; it is expected that the error could even be reduced up to $\Delta P_{e^\pm}/P_{e^\pm} = 0.2\% - 0.1\%$, [18]. The assumed uncertainties in total are listed in table I.
- From the chargino mass $m_{\tilde{\chi}_1^\pm}$ and the cross section $e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^-$ measured at two energies, $\sqrt{s} = 400 \text{ GeV}$ and 500 GeV , we determine bounds for the elements U_{11} and V_{11} of the chargino mixing matrices:

$$U_{11}^2 = [0.84, 1.0], \quad V_{11}^2 = [0.83, 1.0]. \quad (7)$$

Polarized beams allow the resolution of ambiguities and the improvement of the accuracy.

- Using the mixing matrix elements U_{11} and V_{11} , the masses $m_{\tilde{\chi}_1^\pm}$, $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\chi}_2^0}$, and the cross sections for $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$, we derive constraints for the parameters M_1 , M_2 , μ and $\tan\beta$:

$$M_1 = 377 \pm 42 \text{ GeV}, \quad (8)$$

$$M_2 = 150 \pm 20 \text{ GeV}, \quad (9)$$

$$\mu = 450 \pm 100 \text{ GeV}, \quad (10)$$

$$\tan\beta = [1, 30]. \quad (11)$$

Note that, in our scenario with $M_1 > M_2$, the crucial observable to determine the parameter M_1 is $m_{\tilde{\chi}_2^0}$ and not $m_{\tilde{\chi}_1^0}$ as often assumed. Such a hierarchy could be naturally embedded in mAMSB scenarios. For even larger $M_1 \gg M_2$ the heavier neutralinos $\tilde{\chi}_{3,4}^0$ become crucial for M_1 determination see [3, 19]. Since the heavier neutralino and chargino states are not produced, some of the parameters—in our case μ and $\tan\beta$ —can only be determined with a considerable uncertainty.

Within these limits an explicit MSSM scenario,

$$M_1 = 375 \text{ GeV}, \quad M_2 = 152 \text{ GeV}, \quad \tan\beta = 8, \quad \mu = 360 \text{ GeV}, \quad (12)$$

leads to the same (lighter) neutralino/chargino masses and cross sections:

$$m_{\tilde{\chi}_1^0} = 138 \text{ GeV}, \quad \tilde{\chi}_1^0 = (+0.03, -0.96, +0.26, -0.13), \quad (13)$$

$$m_{\tilde{\chi}_2^0} = 344 \text{ GeV}, \quad \tilde{\chi}_2^0 = (+0.72, +0.22, +0.48, -0.46), \quad (14)$$

$$m_{\tilde{\chi}_3^0} = 366 \text{ GeV}, \quad \tilde{\chi}_3^0 = (-0.04, +0.10, -0.70, -0.71), \quad (15)$$

$$m_{\tilde{\chi}_4^0} = 410 \text{ GeV}, \quad \tilde{\chi}_4^0 = (-0.70, +0.18, +0.47, -0.52), \quad (16)$$

where the neutralino mixing states are given in the basis $(\tilde{B}^0, \tilde{W}^0, \tilde{H}_1^0, \tilde{H}_2^0)$. Comparing eqs. (13)–(15) with eqs. (2)–(4) shows that the three lightest neutralino masses are the same within the experimental uncertainties. We checked that also the accessible cross sections at the ILC₅₀₀ and the BR's of $\tilde{\chi}_2^0$ are consistent.

- After the determination of the fundamental MSSM parameters we calculate the heavy chargino and neutralino masses and expected mixing characters. For the masses we obtain:

$$m_{\tilde{\chi}_3^0} = 443 \pm 107 \text{ GeV}, \quad m_{\tilde{\chi}_4^0} = 490 \pm 110 \text{ GeV}, \quad m_{\tilde{\chi}_2^\pm} = 475 \pm 125 \text{ GeV}. \quad (17)$$

The predicted gaugino admixture of $\tilde{\chi}_3^0$, $\tilde{\chi}_4^0$ within the allowed parameter ranges, eqs.(8)–(11), are shown in figure 1 (right panel). Obviously, the heavy neutralino $\tilde{\chi}_3^0$ should be almost a pure higgsino within the MSSM prediction. The predicted properties of the heavier particles can now be compared with mass measurements of such SUSY particles via the analysis of cascade decays at the LHC [2].

We emphasize that although we started with an NMSSM scenario where $\tilde{\chi}_2^0$ and $\tilde{\chi}_3^0$ have large singlino admixtures, the MSSM parameter strategy does not fail and the experimental results from the ILC₅₀₀ with $\sqrt{s} = 400$ GeV and 500 GeV lead to a consistent parameter determination in the MSSM. Hence in the considered scenario the analyses at the ILC₅₀₀ or LHC alone do not allow a clear discrimination between MSSM and NMSSM. All predictions for the heavier gaugino/higgsino masses are consistent with both models. However, the ILC₅₀₀ analysis predicts an almost pure higgsino-like state for $\tilde{\chi}_3^0$ and a mixed gaugino-higgsino-like $\tilde{\chi}_4^0$, see figure 1 (right panel). This allows the identification of the underlying supersymmetric model in combined analyses at the LHC and the ILC₆₅₀ ^{$\mathcal{L}=1/3$} .

2.2. Interplay between LHC and ILC

The expected large cross sections for squark and gluino production at the LHC give access to a large spectrum of coloured as well as non-coloured supersymmetric particles via the cascade decays. Heavy gaugino-states appear almost only in cascade decays and there exist some true simulations how to measure the heavier gauginos in such decays at the LHC [20]. Particularly helpful for the identification of the particles involved in the cascades, e.g. for more model-independent analyses, are mass predictions from the ILC analysis which lead to an increase of statistical sensitivity for the LHC analysis and open the possibility of identifying even marginal signals in the squark cascades [2]. However, since higgsino-like charginos and neutralinos do not couple to squarks, their detection via cascade decays is not possible.

In our original NMSSM scenario the neutralinos $\tilde{\chi}_2^0$ and $\tilde{\chi}_3^0$ have a large bino-admixture and therefore appear in the squark decay cascades. The dominant decay mode of $\tilde{\chi}_2^0$ has a branching ratio $BR(\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^\pm W^\mp) \sim 50\%$, while for the $\tilde{\chi}_3^0$ decays $BR(\tilde{\chi}_3^0 \rightarrow \tilde{\ell}_{L,R}^\pm \ell^\mp) \sim 45\%$ is largest. Since the heavier neutralinos, $\tilde{\chi}_4^0$, $\tilde{\chi}_5^0$, are mainly higgsino-like, no visible edges from these particles occur in the cascades. It is expected to see the edges for $\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_R^\pm \ell^\mp$, $\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_L^\pm \ell^\mp$, $\tilde{\chi}_3^0 \rightarrow \tilde{\ell}_R^\pm \ell^\mp$ and for $\tilde{\chi}_3^0 \rightarrow \tilde{\ell}_L^\pm \ell^\mp$ [21].

With a precise mass measurement of $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\ell}_{L,R}$ and $\tilde{\nu}$ from the ILC₅₀₀ analysis, a clear identification and separation of the edges of the two gauginos at the LHC is possible without imposing specific model assumptions. We therefore assume a precision of about 2% for the measurement of $m_{\tilde{\chi}_3^0}$, in analogy to [20]:

$$m_{\tilde{\chi}_3^0} = 367 \pm 7 \text{ GeV.} \quad (18)$$

The precise mass measurement of $\tilde{\chi}_3^0$ is compatible with the mass predictions of the ILC₅₀₀ but not with the prediction of the mixing character, see e.g. eq. (15). However, it is not clear that the measured particle at the LHC is indeed the $\tilde{\chi}_3^0$. Often in the constrained MSSM, as e.g. also in our MSSM comparison scenario, the second heaviest neutralino $\tilde{\chi}_3^0$ is nearly a pure higgsino and does not couple in the cascade decays. In those cases, the heaviest neutralino $\tilde{\chi}_4^0$ has frequently a sufficiently large gaugino component and could be measured in cascades, as shown in [2, 20].

Therefore it is inevitable to discuss the following cases of possible particle *identification* of the measured gaugino mass $m_{\tilde{\chi}_3^0}$ at the LHC:

- interpretation of the measured particle as $\tilde{\chi}_3^0$ and feeding it back in the ILC analysis leads to improved parameter determination and mass prediction for $m_{\tilde{\chi}_4^0}$, $m_{\tilde{\chi}_2^\pm}$. Using eq. (18) for the ILC₅₀₀ analysis leads in our case, after rechecking with the allowed cross sections of $\tilde{\chi}_1^0 \tilde{\chi}_2^0$ and $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ production, to rather precise mass predictions:

$$m_{\tilde{\chi}_4^0} = [384, 393] \text{ GeV} \quad \text{and} \quad m_{\tilde{\chi}_2^\pm} = [360, 380] \text{ GeV.} \quad (19)$$

- interpretation of the measured particle as $\tilde{\chi}_4^0$ and feeding it back in the parameter determination of the ILC analysis leads to inconsistency with the measured cross sections of $\tilde{\chi}_1^0 \tilde{\chi}_2^0$ and $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ production.

$m_{\tilde{\chi}_1^0}/\text{GeV} = 138 \pm 2.8$	$m_{\tilde{\chi}_2^0}/\text{GeV} = 337 \pm 5.1$	$\sigma(e^+e^- \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp)/\text{fb}$		$\sigma(e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0)/\text{fb}$	
		(P_{e^-}, P_{e^+})	$\sqrt{s} = 400 \text{ GeV}$	$\sqrt{s} = 500 \text{ GeV}$	$\sqrt{s} = 500 \text{ GeV}$
$m_{\tilde{\chi}_1^\pm}/\text{GeV} = 139 \pm 2.8$		Unpolarized	323.9 ± 33.5	287.5 ± 16.5	4.0 ± 1.2
$m_{\tilde{e}_L}/\text{GeV} = 240 \pm 3.6$		(-90%, +60%)	984.0 ± 101.6	873.9 ± 50.1	12.1 ± 3.8
$m_{\tilde{e}_R}/\text{GeV} = 220 \pm 3.3$		(+90%, -60%)	13.6 ± 1.6	11.7 ± 1.2	0.2 ± 0.1
$m_{\tilde{\nu}_e}/\text{GeV} = 226 \pm 3.4$					

Table I: Masses with 1.5% ($\tilde{\chi}_{2,3}^0$, $\tilde{e}_{L,R}$, $\tilde{\nu}_e$) and 2% ($\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$) uncertainty and cross sections with an error composed of the error due to the mass uncertainties, polarization uncertainty and one standard deviation statistical error based on $\int \mathcal{L} = 100 \text{ fb}^{-1}$, for both unpolarized beams and polarized beams with $(P_{e^-}, P_{e^+}) = (\mp 90\%, \pm 60\%)$ and $\Delta P(e^\pm)/P(e^\pm) = 0.5\%$, in analogy to the study in [2].

The combined LHC \leftrightarrow ILC₅₀₀ analysis leads therefore to a correct interpretation of the measured particles in the cascades. However, a neutralino $\tilde{\chi}_3^0$ with sufficiently large gaugino admixture to couple to squarks is incompatible with the allowed parameter ranges of eqs. (8)–(11) in the MSSM, cf. figure 1 (right panel).

We point out that a measurement of the neutralino masses $m_{\tilde{\chi}_1^0}$, $m_{\tilde{\chi}_2^0}$, $m_{\tilde{\chi}_3^0}$ which could take place at the LHC alone is not sufficient to distinguish the SUSY models since rather similar mass spectra could exist, cf. eqs. (2)–(4) with eqs. (13)–(15).

Therefore the cross sections in different beam polarization configurations at the ILC have to be included in the analysis. The combined results from the LHC and the ILC₅₀₀ analyses and the rather precise predictions for the missing chargino/neutralino masses, eq. (19), constitute a serious motivation to apply immediately the low-luminosity but higher-energy option ILC₆₅₀ ^{$\mathcal{L}=1/3$} , which finally leads to the right identification of the underlying model. The expected polarized and unpolarized cross sections, including the statistical error on the basis of one third of the luminosity of the ILC₅₀₀, are given in Table II. The neutralino $\tilde{\chi}_3^0$ as well as the higgsino-like heavy neutralino $\tilde{\chi}_4^0$ and the chargino $\tilde{\chi}_2^\pm$ are now accessible at the ILC₆₅₀ ^{$\mathcal{L}=1/3$} . Already the high rates for $\tilde{\chi}_1^0 \tilde{\chi}_3^0$ production give last true evidence for the obvious contradiction with an corresponding MSSM scenario. Together with the mass measurements of $m_{\tilde{\chi}_4^0} = 468 \text{ GeV}$ and $m_{\tilde{\chi}_2^\pm} = 474 \text{ GeV}$, which are also in strong disagreement with the mass prediction, eq. (19), one has sufficient observables which point to the NMSSM. Extensions of existing fit programs for the NMSSM may lead to an exact resolution of the underlying parameters [22].

3. CONCLUSIONS

We have presented a scenario in the next-to-minimal supersymmetric standard model (NMSSM) that could not be distinguished from the MSSM at either the LHC or at the first stage of the International Linear Collider with $\sqrt{s} = 500 \text{ GeV}$. It turns out that the most promising sector for distinction is the gaugino/higgsino sector. Although a light neutralino has a significant singlet component in the NMSSM, the masses of the accessible light neutralinos and charginos, as well as the production cross sections, lead to identical values in the two models within experimental errors. The comparison of the predicted masses and mixing character of the heavier neutralinos and charginos with the measured masses in combined analyses with the LHC followed by a precise measurement of the cross sections at the ILC at $\sqrt{s} = 650 \text{ GeV}$ leads to a clear identification of the supersymmetric model.

The exemplary scenario shows that the interplay between the two experiments could be crucial for the determination of the supersymmetric model. A possible feed-back of ILC₅₀₀/LHC results could motivate the immediate use of the low-luminosity option of the ILC at $\sqrt{s} = 650 \text{ GeV}$ in order to resolve model ambiguities even at an early stage of the experiment and outline future search strategies at the upgraded ILC at 1 TeV.

	$\sigma(e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_j^0)/\text{fb}$ at $\sqrt{s} = 650$ GeV			$\sigma(e^+e^- \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^\mp)/\text{fb}$ at $\sqrt{s} = 650$ GeV
	$j = 3$	$j = 4$	$j = 5$	
Unpolarized beams	12.2 ± 0.6	5.5 ± 0.4	≤ 0.02	2.4 ± 0.3
$P(e^-) = -90\%$, $P(e^+) = +60\%$	36.9 ± 1.1	14.8 ± 0.7	≤ 0.07	5.8 ± 0.4
$P(e^-) = +90\%$, $P(e^+) = -60\%$	0.6 ± 0.1	2.2 ± 0.3	≤ 0.01	1.6 ± 0.2

Table II: Expected cross sections for the associated production of the heavier neutralinos and charginos in the NMSSM scenario for the $\text{ILC}_{650}^{\mathcal{L}=1/3}$ option with one sigma statistical error based on $\int \mathcal{L} = 33 \text{ fb}^{-1}$ for both unpolarized and polarized beams.

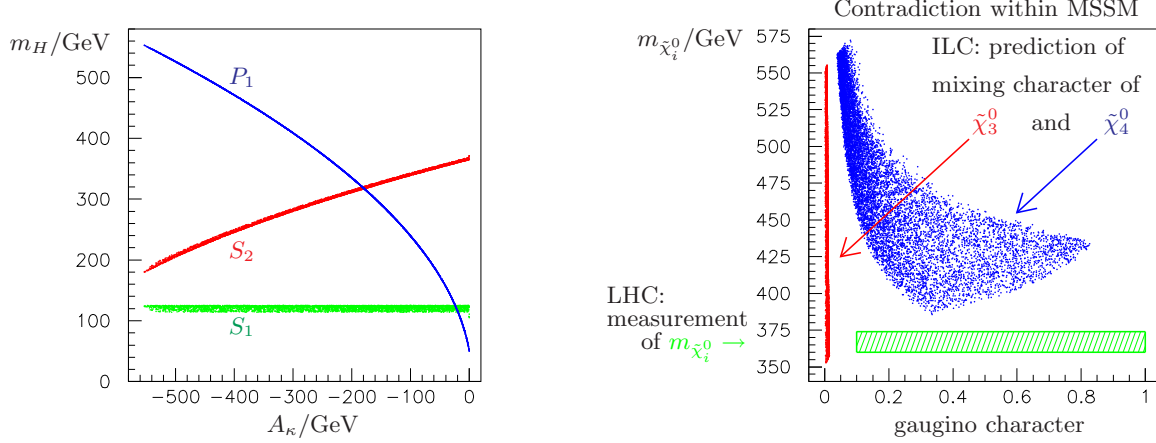


Figure 1: Left: The possible masses of the two light scalar Higgs bosons, m_{S_1} , m_{S_2} , and of the lightest pseudoscalar Higgs boson m_{P_1} as function of the trilinear Higgs parameter A_κ in the NMSSM. In our chosen scenario, S_1 is MSSM-like and S_2 and P_1 are heavy singlet-dominated Higgs particles. Right: Predicted masses and gaugino admixture for the heavier neutralinos $\tilde{\chi}_3^0$ and $\tilde{\chi}_4^0$ within the consistent parameter ranges derived at the ILC_{500} analysis in the MSSM and measured mass $m_{\tilde{\chi}_i^0} = 367 \pm 7$ GeV of a neutralino with sufficiently high gaugino admixture in cascade decays at the LHC. We took a lower bound of sufficient gaugino admixture of about 10% for the heavy neutralinos, cf. [20].

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