

Determining MSSM parameters via chargino production at the LC: a one-loop analysis

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Very precise measurements of masses and cross sections are expected to be achievable with a future linear collider. With such an accuracy one must incorporate loop corrections in order to make meaningful predictions for the underlying new physics parameters. For the electroweakino sector, this involves fitting one-loop predictions to expected measurements of the cross section and forward-backward asymmetry for chargino pair production and of the accessible chargino and neutralino masses. We consider two scenarios with characteristic features, chosen taking recent LHC SUSY and Higgs searches into account. Our analysis allows the accurate determination of the desired parameters and, additionally, access to stop sector parameters that enter via loop corrections.

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1. Introduction

A linear collider (LC) is ideally suited to high precision studies of physics beyond the standard model (BSM). Light electroweakinos, motivated by naturalness arguments (see e.g. ref. [1]) and GUT motivated SUSY models [2], could well be within reach of a first stage LC. This would allow the nature of the underlying SUSY model to be probed via the determination of the fundamental parameters. LO studies (see ref. [3] and references therein) have shown that the U(1) parameter M_1 , the SU(2) parameter M_2 , the higgsino parameter μ and $\tan\beta$, the ratio of the vacuum expectation values of the two neutral Higgs doublet fields, can be determined at the percent level via chargino and neutralino pair-production. However, as one-loop effects in the MSSM can be large, higher order calculations are crucial in order to perform an accurate assessment. These corrections mean that additional MSSM parameters become relevant, such as the masses of the stops which are so far only weakly constrained by the LHC. Fitting experimental results to loop corrected predictions, calculated in the on-shell scheme, it should therefore be possible to extract the parameters of the chargino–neutralino sector of the MSSM Lagrangian, as well as to indirectly gain insight into other sectors. In sec. 2 we discuss the strategy used to fit the MSSM parameters and briefly describe the calculation of NLO corrections. Then in sec. 3 we present our numerical results and finally in sec. 4 we discuss the implications of these results.

2. Fit strategy and the calculation of NLO corrections

In the chargino and neutralino sectors there are four real parameters which we fit to: M_1 , M_2 , μ and $\tan\beta$. If beyond the direct reach of the LC, the sneutrino mass is also included in the fit. Depending on the scenario, only limited knowledge about the remaining MSSM parameters, e.g. for the stop sector, which will all contribute at the loop level, may be available. Our analysis also offers unique indirect sensitivity to such parameters at the LC. In the fit we use the polarised cross-sections and forward backward asymmetry for chargino production as well as the $\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$ and $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0$ masses, calculated at NLO in an on-shell scheme as described below. We assume the masses to have been measured at the LC using the threshold scan method, however we also investigate how the fit precision changes if the masses were obtained from the continuum [4]. Further details of the fit method and errors are given in ref. [5]. We carry out the fit for two scenarios, S1 and S2, shown in tab. 1.¹ Due to the current status of direct LHC searches [6], in both scenarios we require first and second generation squarks and gluinos to be heavy, but on the other hand assume the stop sector to be light. Further, indirect limits, checked using `micrOmegas 2.4.1` [7], lead us to choosing mixed gaugino higgsino scenarios, favoured by the relic density measurements [8] and relatively high pseudoscalar Higgs masses, preferred by flavour physics constraints i.e. the branching ratio $\mathcal{B}(b \rightarrow s\gamma)$ and $\Delta(g_\mu - 2)/2$. Our scenarios are chosen in order to assess the fit sensitivity for different possible choices of parameters e.g. the pseudoscalar Higgs mass M_{A^0} . Note that for S2, $m_h (=125 \text{ GeV})$ is compatible with the recent Higgs results from the LHC [9].

The one-loop corrections to the polarised cross-section and forward backward asymmetry for $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-$ are calculated in full within the MSSM, following [10], using the program

¹Note that S2 corresponds to S3 in ref. [5].

S1				S2			
Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
M_1	125	M_2	250	M_1	106	M_2	212
μ	180	M_{A^0}	1000	μ	180	M_{A^0}	500
M_3	700	$\tan\beta$	10	M_3	1500	$\tan\beta$	12
$M_{e_{1,2}}$	1500	M_{e_3}	1500	$M_{e_{1,2}}$	125	M_{e_3}	106
M_{l_i}	1500	$M_{q_{1,2}}$	1500	M_{l_i}	180	M_{q_i}	1500
M_{q/u_3}	400	A_f	650	M_{u_3}	450	A_f	-1850

Table 1: Table of parameters (with the exception of $\tan\beta$ in GeV), for scenarios 1 (S1) and 2 (S2). Here $M_{(l/q)_i}$ and $M_{(e/u)_i}$ represent the left and right handed mass parameters for of a slepton/squark of generation i respectively, and A_f is the trilinear coupling for a sfermion \tilde{f} .

FeynArts [11], which allowed an automated generation of the Feynman diagrams and amplitudes. Together with the packages FormCalc [12] and LoopTools [13] we derived the final matrix elements and loop integrals. The regularisation method we use is dimensional reduction (see e.g. [14]), which ensures that SUSY is preserved, as in e.g. ref. [15]. The results at NLO depend on many MSSM parameters beyond the small subset at tree level. Finite results at one-loop order are obtained by adding counterterm diagrams, also generated by FeynArts, however expressions for the counterterms which renormalise the tree-level couplings are required as input, as given in detail in ref. [5]. Using this prescription to renormalise the vertices we obtain UV-finite results. Soft and collinear radiation must be included to obtain a result free of infra-red and collinear singularities. In the regions $E < \Delta E$ and $\theta < \Delta\theta$ where ΔE and $\Delta\theta$ denote the cut-offs, the radiative cross-section can be factorised into analytically integrable expressions proportional to the tree-level cross-section $\sigma^{\text{tree}}(e^+e^- \rightarrow \tilde{\chi}_i^+ \tilde{\chi}_j^-)$. The soft contribution can easily be incorporated using FormCalc, however the collinear contribution must be added explicitly, this is done as described in ref. [5].

3. Numerical results

In S1, only the charginos and three neutralinos will be accessible at the LC. It should be possible to probe the supersymmetric QCD sector, with masses of ~ 1.5 TeV, at the LHC. As input for the fit we therefore use: the masses of the charginos ($\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$) and three lightest neutralinos ($\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0$); the production cross section $\sigma(\tilde{\chi}_1^+ \tilde{\chi}_1^-)$ with polarised beams at $\sqrt{s} = 350$ and 500 GeV; the forward-backward asymmetry A_{FB} at $\sqrt{s} = 350$ and 500 GeV; the branching ratio $\mathcal{B}(b \rightarrow s\gamma)$ calculated using micrOmegas 2.4.1 [7], see tab. 2. Note that $\mathcal{B}(b \rightarrow s\gamma)$ increases sensitivity to the third generation squark sector, and the estimated experimental precision is $0.3 \cdot 10^{-4}$ [16]. As the impact of the muon anomalous magnetic moment is negligible it is not included in the fit.

Observable	S1				S2			
	Tree	Loop	δ_{exp}	δ_{th}	Tree	Loop	δ_{exp}	δ_{th}
$m_{\tilde{\chi}_1^\pm}$	149.6	–	0.1 (0.2)	–	139.3	–	0.1	–
$m_{\tilde{\chi}_2^\pm}$	292.3	–	0.5 (2)	–	266.2	–	0.5	–
$m_{\tilde{\chi}_1^0}$	106.9	–	0.2	–	92.8	–	0.2	–
$m_{\tilde{\chi}_2^0}$	164.0	2.0	0.5 (1)	0.5	148.5	2.4	0.5	0.5
$m_{\tilde{\chi}_3^0}$	188.6	–1.5	0.5 (1)	0.5	189.7	–7.3	0.5	0.5
$\sigma(\tilde{\chi}_1^+ \tilde{\chi}_1^-)_{(-0.8,0.6)}^{350/400}$	2347.5	–291.3	8.7	2.0	709.7	–85.1	0.7	–
$\sigma(\tilde{\chi}_1^+ \tilde{\chi}_1^-)_{(0.8,-0.6)}^{350/400}$	224.4	7.6	2.7	0.5	129.8	20.0	0.3	–
$\sigma(\tilde{\chi}_1^+ \tilde{\chi}_1^-)_{(-0.8,0.6)}^{500}$	1450.6	–24.4	6.7	2.0	560.0	–70.1	0.7	–
$\sigma(\tilde{\chi}_1^+ \tilde{\chi}_1^-)_{(0.8,-0.6)}^{500}$	154.8	12.7	2.0	0.5	97.1	16.4	0.3	–
$A_{FB}^{350/400}(\%)$	–2.2	6.8	0.8	0.1	24.7	–2.8	1.4	0.1
$A_{FB}^{500}(\%)$	–2.6	5.3	1.0	0.1	39.2	–5.8	1.5	0.1

Table 2: Observables (masses in GeV, cross sections in fb) used as input for the fit in S1 (left) and S2 (right), tree-level values and loop corrections are specified along with the expected experimental and theoretical errors (δ_{exp} and δ_{th}). Here the superscript on σ and A_{FB} , i.e. 350/400 (for S1/S2) and 500, denotes \sqrt{s} in GeV, and the subscript on σ denotes the beam polarisation ($\mathcal{P}(e^-)$, $\mathcal{P}(e^+)$). The central value of the theoretical prediction, $\mathcal{B}(b \rightarrow s\gamma) = 3.3 \cdot 10^{-4}$ GeV for S1, and $\mathcal{B}(b \rightarrow s\gamma) = 2.7 \cdot 10^{-4}$, $\Delta(g_\mu - 2)/2 = 2.4 \cdot 10^{-9}$ and $m_h = 125$ GeV for S2 are also included in the fit. Errors in brackets are for masses obtained from the continuum. See text for details of error estimation.

For S2, the input for the fit, as summarised in tab. 2, is the same as in S1, however we consider a centre of mass energy $\sqrt{s} = 400$ GeV instead of 350 GeV, and this is supplemented by the Higgs boson mass, m_h , with a theoretical uncertainty of ~ 1 GeV, calculated using `FeynHiggs 2.9.1` [17]. The estimated experimental precision at the LC for m_h , taken from ref. [4], is adopted. The anomalous muon magnetic moment $\Delta(g_\mu - 2)/2$, calculated using `micrOmegas 2.4.1` [7], plays a role and is therefore included in the fit, with a projected experimental error of $3.4 \cdot 10^{-10}$ [18], which we assume would dominate over the theoretical uncertainty. We assume that the sneutrino mass has been measured. The results for S1, given in tab. 3, show the fit to the 8 MSSM parameters: M_1 , M_2 , μ , $\tan\beta$, $m_{\tilde{\nu}}$, $\cos\theta_{\tilde{t}}$, $m_{\tilde{t}_1}$, and $m_{\tilde{t}_2}$. We find that the gaugino and higgsino mass parameters are determined with an accuracy better than 1%, while $\tan\beta$ is determined with an accuracy of 5%, and 2-3% for the sneutrino mass. The limited access to the stop sector (tab. 3) could nevertheless lead to hints allowing a well-targeted search at the LHC. In tab. 3 we also compare the fit results obtained using masses of the charginos and neutralinos from threshold scans to those obtained using masses from the continuum. For the latter, the fit quality deteriorates, clearly indicating the need to measure these masses via threshold scans. For S2, the heavy Higgs boson mass is added to and the sneutrino mass is removed from the set of fit parameters. The results

Parameter	S1		S2
	Threshold fit	Continuum fit	Threshold fit
M_1	125 ± 0.3 (± 0.7)	125 ± 0.6 (± 1.2)	106 ± 0.3 (± 0.5)
M_2	250 ± 0.6 (± 1.3)	250 ± 1.6 (± 3)	212 ± 0.5 (± 1.0)
μ	180 ± 0.4 (± 0.8)	180 ± 0.7 (± 1.3)	180 ± 0.4 (± 0.9)
$\tan \beta$	10 ± 0.5 (± 1)	10 ± 1.3 (± 2.6)	12 ± 0.3 (± 0.7)
$m_{\tilde{\nu}}$	1500 ± 24 ($^{+60}_{-40}$)	1500 ± 20 (± 40)	—
$\cos \theta_{\tilde{t}}$	$0.15^{+0.08}_{-0.06}$ ($^{+0.16}_{-0.09}$)	0 ± 0.15 ($^{+0.4}_{-0.3}$)	—
$m_{\tilde{t}_1}$	400^{+180}_{-120} (at limit at limit)	—	430^{+200}_{-130} ($^{+300}_{-400}$)
$m_{\tilde{t}_2}$	800^{+300}_{-170} ($^{+1000}_{-290}$)	800^{+350}_{-220} (at limit at limit)	1520^{+200}_{-300} ($^{+300}_{-400}$)
m_{A^0}	—	—	< 650 (< 1000)

Table 3: Fit results (masses in GeV) for S1 (left) and S2 (right), for masses obtained from threshold scans (threshold fit) and from the continuum (continuum fit). Numbers in brackets denote 2σ errors.

seen in tab. 3 show that the electroweakino parameters are precisely determined, and that the fit is sensitive to $m_{\tilde{t}_2}$, with an accuracy better than 20%. In addition, an upper limit on the mass of the heavy Higgs boson can be placed at 1000 GeV, at the 2σ level.

4. Conclusion

We have extended previous analyses to extract fundamental MSSM parameters via chargino production at the LC, by incorporating loop corrections. The polarised cross-sections and forward backward asymmetry for chargino production as well as the $\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$ and $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0$ masses, are calculated at NLO in an on-shell scheme. When M_1, M_2 and μ are light, we determine them at $\mathcal{O}(\%)$, and $\tan \beta$ to $< 5\%$. Masses obtained from the continuum as opposed to threshold scans result in doubled uncertainties on the fundamental parameters. For our 125 GeV Higgs mass compatible scenario we obtain an accuracy of better than 20% on the mass of the heavy, left-handed stop. In summary, incorporating NLO corrections is shown to be required for the precise determination of the fundamental electroweakino parameters at the LC, and to provide sensitivity to the parameters describing particles contributing via loops.

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