Disentangling fundamental MSSM Parameters:
Light Gaugino/Higgsino System

Gudrid Moortgat-Pick[**]

DESY, Deutsches Elektronen-Synchrotron, D-22603 Hamburg, Germany,
II. Institut für Theoret. Physik, Universität Hamburg, D-22761 Hamburg, Germany

Abstract

In order to reveal the underlying structure of Supersymmetry one has to determine the low–energy parameters without assuming a specific SUSY breaking scheme. In this paper we show a procedure how to determine M_1, Φ_{M_1}, M_2, μ, Φ_μ and $\tan\beta$ even in the case when only light charginos $\tilde{\chi}_1^\pm$ and neutralinos $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ would be accessible at the first stage of a future Linear Collider with polarized beams.

1 Introduction

Supersymmetry is one of the best motivated extensions of the Standard Model (SM). Since, however, SUSY has to be broken the unconstrained version of the Minimal Supersymmetric extension of the Standard Model (MSSM) leads to about 105 new parameters to express all possible soft breaking terms. In order to reveal the breaking mechanism one has to determine these fundamental parameters in future experiments without assuming a specific structure of the breaking mechanism.

We concentrate in this paper on the gaugino/higgsino system, charginos and neutralinos, which are the SUSY partners of the neutral and charged vector and Higgs bosons. The mixing between these particles depends on the fundamental U(1), SU(2) and higgsino mass parameters including CP–violating phases – M_1, Φ_{M_1}, M_2, μ, Φ_μ – and the ratio of the two Higgs vacuum expectation values $\tan\beta = v_2/v_1$. Several strategies have already been worked out for determining these parameters at a future Linear Collider in the energy range of $\sqrt{s}$ = 500–1000 GeV, as e.g. TESLA [1]. We demonstrate in this paper a procedure for determining the parameters in the case that only the light states $\tilde{\chi}_1^\pm$, $\tilde{\chi}_{1,2}^0$ would be accessible at the first stage of a LC (see [2]).

2 MSSM Parameter Determination

2.1 Chargino Sector

The 2×2 chargino mixing depends on the parameters M_2, μ, Φ_μ and $\tan\beta$. It can be described by two mixing angles. The mixing angles can be determined e.g. when studying cross sections with longitudinally polarized beams [3]. Inversion of the equations leads to the determination of the parameters with a sign ambiguity in Φ_μ, even if both $m_{\tilde{\chi}_{1,2}^\pm}$ are known.
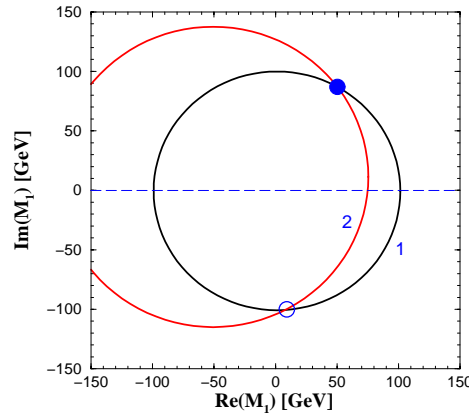

[**]gudrid@mail.desy.de

Figure 1: Contours in the $Re(M_1) - Im(M_1)$ plane for two measured masses $m_{\tilde{\chi}^0_{1,2}}$. The other MSSM parameters are $M_2 = 190.8$ GeV, $|\mu| = 365.1$ GeV, $\Phi_\mu = \pi/8$, $\tan\beta = 10$ [2, 4].

2.2 Neutralino Sector

The neutralino mixing depends – in addition to the parameters of the chargino system – on the parameters M_1, Φ_{M_1}. The characteristic equation of the mass matrix squared, $MM^\dagger$, can be written as a second order polynomial in M_1. Therefore we are left with a two–fold ambiguity for M_1, Φ_{M_1}, when only exploring the two lightest masses $\tilde{\chi}^0_1$, $\tilde{\chi}^0_2$, Fig. 1 [2].

For an unambiguous determination (up to a simple sign ambiguity in the phase) one therefore needs either three neutralino masses or two masses and one cross section to resolve the ambiguity. We investigate which of these possibilities would lead to a higher accuracy for the determination of M_1. We compare the two cases, taking into account the expected errors for neutralino mass measurements at TESLA done for a given SUSY scenario [1] and the statistical error of the measured cross sections [5], see Figs. 2a, b. The experimental constraints for Φ_{M_1} are weaker than those for Φ_μ, so that a relatively large phase for M_1 can not be excluded a priori. This is different for Φ_μ, where the experimental constraints for the dipole moments of the electron, neutron and mercury atom are rather strict (see [6] and references therein).

We see from Figs. 2a, b that one can determine the phase Φ_{M_1} about one order of magnitude more accurate when studying the two light masses and the corresponding polarized cross section, $\Phi_{M_1} = 30^0 \pm 3^0$, as compared to the case when three masses are studied, $\Phi_{M_1} = 30^0 \pm 10^0$.

2.3 Parameters from only light Charginos/Neutralinos

In the case where one could only measure $\tilde{\chi}^\pm_1$ and the polarized cross sections $\sigma_{L,R}(e^+e^- \to \tilde{\chi}^+_1\tilde{\chi}^-_1)$ it is not possible to determine the parameters M_2, μ, Φ_μ and $\tan\beta$ uniquely. Instead of the two crossing points, Fig. 1, one gets two parameter samples as function of the heavier unknown mass $m_{\tilde{\chi}^\pm_2}$. Since charginos are a 2×2 system one can set bounds
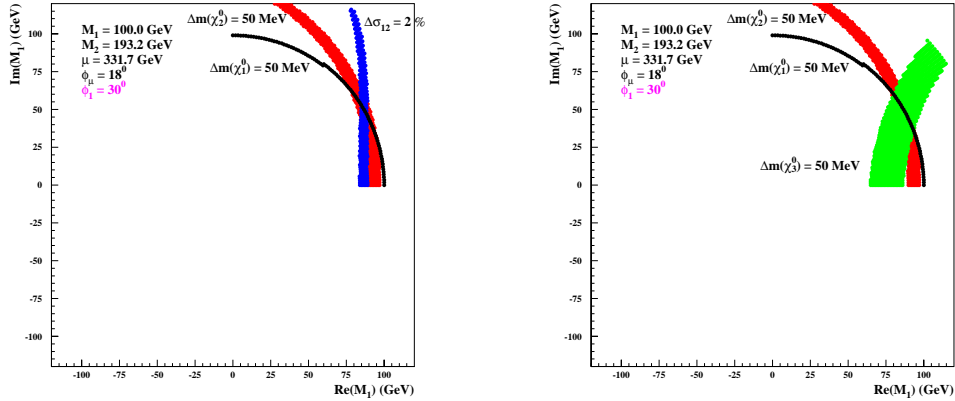
Figure 2: Contour lines in the $Re(M_1) - Im(M_1)$ plane for the case where a) the two lightest masses $m_{\tilde{\chi}^0_{1,2}}$ and the cross section $\sigma(e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2)$ are measured (left) and b) the three lightest masses $m_{\tilde{\chi}^0_{1,2,3}}$ are measured (right). It has been assumed $\delta(m_{\tilde{\chi}^0_i}) \sim 50$ MeV and the statistical uncertainty for σ [5].

for $m_{\tilde{\chi}^\pm_2}$:

$$\frac{1}{2}\sqrt{s} - m_{\tilde{\chi}^\pm_1} \leq m_{\tilde{\chi}^\pm_2} \leq \sqrt{m^2_{\tilde{\chi}^\pm_1} + 4m^2_W |\cos 2\Phi_L - \cos 2\Phi_R|}. \tag{1}$$

We show in Fig. 3a, b the parameters $Re(M_1)$ and $Im(M_1)$ as function of $m_{\tilde{\chi}^\pm_2}$. In order to fix the parameters one has to explore in addition polarized cross sections for neutralino production $\sigma_{L,R}(e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2)$, Fig. 3c, d. With this procedure one gets in addition to the determination of the parameters M_1, Φ_{M_1} also a prediction for the heavier mass $m_{\tilde{\chi}^\pm_2}$. This is done by comparing the theoretical prediction for the cross sections with the measured rates for $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2$. The procedure for the parameter determination from only the light system is illustrated in Fig. 4 where the trajectories of the two crossing points of $m_{\tilde{\chi}^0_1}$, $m_{\tilde{\chi}^0_2}$ are given in the $Re(M_1)$, $Im(M_1)$ plane as function of $m_{\tilde{\chi}^\pm_2}$. The thick dotted point denotes the correct solution where the theoretical prediction for the cross section coincides with its measured value [2].

3   Conclusions and Outlook

A future Linear Collider will be well suited to discover and reveal precisely the underlying structure of the MSSM. We have shown how to determine the fundamental parameters of the chargino and neutralino mixing matrices: the parameters M_2, μ, Φ_μ and moderate $\tan\beta$ can be determined via the chargino sector. The parameters M_1, Φ_{M_1} can be determined by measuring two neutralino masses and one cross section with high precision at a LC. The proposed procedure works also in the case where only the lightest chargino and the two lightest neutralino are accessible and leads in addition to a prediction for $m_{\tilde{\chi}^\pm_2}$.

If $\tan\beta > 10$, however, the chargino/neutralino sector is rather insensitive to this parameter. The shown procedure could then be explored in combination with the $\tau/\tilde{\tau}$ system leading also in this case to an accurate parameter determination (see also [7]).
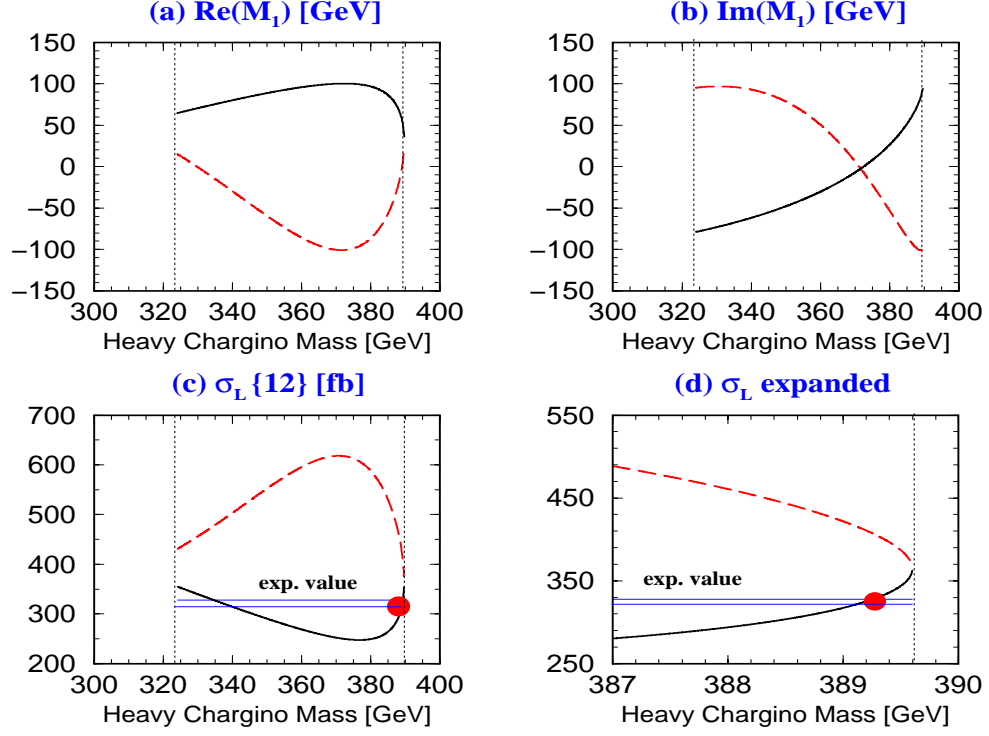
Figure 3: The parameter set $(Re(M_1), Im(M_1))$ and the prediction for the cross sections of neutralino production $\sigma_L(e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0)$ as function of $m_{\tilde{\chi}_2^\pm}$ for the crossing points of the two circles in Fig. 1.
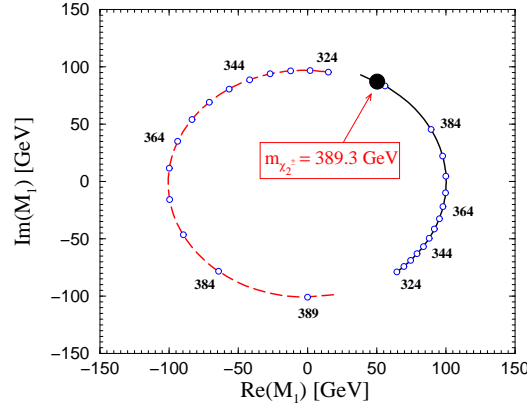

Figure 4: The trajectories of the two crossing points of $m_{\tilde{\chi}_1^0}$, $m_{\tilde{\chi}_2^0}$ as function of $m_{\tilde{\chi}_2^\pm}$. The thick dotted point denotes the correct solution where the theoretical prediction for the cross section coincides with its measured value.

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