THE CHALLENGE OF DETERMINING SUSY PARAMETERS IN FOCUS-POINT-INSPIRED CASES

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We discuss the potential of combined LHC and ILC experiments for SUSY searches in a difficult region of the parameter space, in which all sfermion masses are above the TeV scale. Precision analyses of cross sections of light chargino production and forward–backward asymmetries of decay leptons and hadrons at the ILC, together with mass information on $\tilde{\chi}_2^0$ and squarks from the LHC, allow us to fit rather precisely the underlying fundamental gaugino/higgsino MSSM parameters and to constrain the masses of the heavy virtual sparticles. For such analyses the complete spin correlations between the production and decay processes have to be taken into account. We also took into account expected experimental uncertainties.

1 Introduction

Supersymmetry (SUSY) is one of the most promising extensions of the Standard Model (SM) since, among other things, it solves the hierarchy problem, provides a cold dark matter candidate, and enables gauge couplings unification. Because of the unknown mechanism of SUSY breaking, supersymmetric extensions of the Standard Model contain a large number of new parameters: 105 appear in the Minimal Supersymmetric Standard Model (MSSM) and have to be specified. Experiments at future accelerators, the LHC and the ILC, will have not only to discover SUSY but also to determine precisely the underlying scenario without theoretical prejudices on the SUSY breaking mechanism. Particularly challenging are those scenarios where the scalar SUSY particle sector is heavy, as required e.g. in focus-point scenarios (FP) as well as in split SUSY (sS).

Since it is not easy to determine experimentally cross sections for production processes, studies have been made to exploit the whole production-and-decay process. Angular and energy

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distributions of the decay products in production processes with subsequent three-body decays have been studied for chargino as well as for neutralino processes [1]. Since such observables depend strongly on the polarization of the decaying particle, the complete spin correlations between production and decay can have a lot of influence and must be taken into account. Exploiting such spin effects, it has been shown[2] that, once the chargino parameters are known, useful indirect bounds for the mass of the heavy virtual particles could be derived from forward–backward asymmetries of the final lepton $A_{\rm FB}(\ell)$.

2 Chosen Scenario: Focus-Point-Inspired Case

In this section we take a FP-inspired mSUGRA scenario defined at the GUT scale[3]. However, in order to assess the possibility of unravelling such a challenging new physics scenario, our analysis is entirely performed at the EW scale without any reference to the underlying SUSY-breaking mechanism. The parameters at the EW scale are obtained with the help of the code SPheno[4]. The low-scale gaugino/higgsino/gluino masses, as well as the derived masses of SUSY particles, are listed in Table 1. As can be seen, the chargino/neutralino sector, as well as the gluino, are rather light, whereas the scalar particles have masses of about 2 TeV (with the only exception of h, which is a SM-like light Higgs boson).

M_1	M_2	M_3	μ	$\tan\beta$	$m_{\tilde\chi_1^\pm}$	$m_{\tilde\chi_2^\pm}$	$m_{\tilde\chi_1^0}$	$m_{\tilde\chi_2^0}$	$m_{\tilde\chi_3^0}$	$m_{\tilde\chi_4^0}$	$m_{\tilde g}$
60	121	322	540	20	117	552	59	117	545	550	416
m_h	$m_{H,A}$	$m_{H^\pm}$	$m_{\tilde\nu}$	$m_{\tilde e_{\rm R}}$	$m_{\tilde e_{\rm L}}$	$m_{\tilde\tau_1}$	$m_{\tilde\tau_2}$	$m_{\tilde q_{\rm R}}$	$m_{\tilde q_{\rm L}}$	$m_{\tilde t_1}$	$m_{\tilde t_2}$
119	1934	1935	1994	1996	1998	1930	1963	2002	2008	1093	1584

Table 1: Low-scale MSSM parameters and the particle masses in our scenario in GeV.

2.1 Expectations at the LHC

As can be seen from Table 1, all squarks are kinematically accessible at the LHC. The largest squark production cross section is for $\tilde t_{1,2}$. However, with stops decaying mainly to $\tilde g t$ [with $BR(\tilde t_{1,2} \to \tilde g t) \sim 66\%$], where the background from top production will be large, the reconstruction of the stops will be very challenging. The other squarks decay mainly via $\tilde g q$, but since they are very heavy, $m_{\tilde q_{\rm L,R}} \sim 2$ TeV, precise mass reconstruction will be difficult. Nevertheless, the indication that the scalar quarks are very heavy will be very important in narrowing experimental uncertainty on the slepton sector from the ILC measurements.

The gluino production is expected to have very high rates. Therefore several gluino decay channels can be exploited. The largest branching ratio for the gluino decay in our scenario is into neutralinos $BR(\tilde g \to \tilde\chi_2^0 b\bar b) \sim 14\%$ with a subsequent leptonic neutralino decay $BR(\tilde\chi_2^0 \to \tilde\chi_1^0 \ell^+\ell^-) \sim 6\%$, $\ell = e, \mu$. In this channel the dilepton edge will be clearly visible, since this process is practically background-free. The mass difference between the two light neutralino masses could be measured from the dilepton edge with an uncertainty of about [3]

$$\delta(m_{\tilde\chi_2^0} - m_{\tilde\chi_1^0}) \sim 0.5 \text{ GeV}. \tag{1}$$

2.2 Expectations at the ILC

At the ILC with $\sqrt{s} = 500$ GeV, only light charginos and neutralinos are kinematically accessible. However, in this scenario the neutralino sector is characterized by very low production cross sections, below 1 fb, so that it might not be fully exploitable. Only the chargino pair production

$\sqrt{s}$/GeV	(P_{e^-}, P_{e^+})	$\sigma(\tilde{\chi}^+_1\tilde{\chi}^-_1) \times BR \times \varepsilon$/fb	$A_{FB}(\ell^-)$/%
350	$(-90\%, +60\%)$	1062.5±4.0	4.42±0.29
	$(+90\%, -60\%)$	14.6±0.7	4.6±2.5
500	$(-90\%, +60\%)$	521.6±2.3	4.62±0.41
	$(+90\%, -60\%)$	6.9±0.4	4.9±3.6

Table 2: Cross sections for the process $e^+e^- \to \tilde{\chi}^+_1\tilde{\chi}^-_1$ and forward–backward asymmetries for this process followed by $\tilde{\chi}^-_1 \to \tilde{\chi}^0_1\ell^-\bar{\nu}_\ell$, with $\ell = e, \mu$, for different beam polarization P_{e^-}, P_{e^+} configurations at the center of mass energies $\sqrt{s} = 350$ GeV and 500 GeV at the ILC. Errors include 1σ statistical uncertainty assuming luminosity $\mathcal{L} = 200$ fb^{-1} for each polarization configuration, efficiency $\varepsilon = 50\%$ and the beam polarization uncertainty of 0.5%. $BR \simeq 0.34$, see Section 2.2.

process has high rates at the ILC, see Table 2, and all information obtainable from this sector has to be used. In the following we study the production process

$$e^+e^- \to \tilde{\chi}^+_1\tilde{\chi}^-_1 \tag{2}$$

followed by leptonic and hadronic decays of the charginos, for which the analytical formulae including the complete spin correlations are given in a compact form [1]. The production process occurs via γ and Z exchange in the s-channel and $\tilde{\nu}_e$ exchange in the t-channel, and the decay processes get contributions from $W^\pm$ and $\tilde{\nu}_\ell$, $\tilde{\ell}_L$ (leptonic decays) or $\tilde{q}_{d_L}$, $\tilde{q}_{u_L}$ exchange (hadronic decays). The light chargino has a leptonic branching ratio of about $BR(\tilde{\chi}^-_1 \to \tilde{\chi}^0_1\ell^-\bar{\nu}_\ell) \sim 11\%$ for each family and a hadronic branching ratio of about $BR(\tilde{\chi}^-_1 \to \tilde{\chi}^0_1 q_d\bar{q}_u) \sim 33\%$.

In our analysis we use cross sections multiplied by the branching ratios of semileptonic chargino decays: $\sigma(e^+e^- \to \tilde{\chi}^+_1\tilde{\chi}^-_1) \times BR$, with $BR = 2 \times BR(\tilde{\chi}^+_1 \to \tilde{\chi}^0_1\bar{q}_d q_u) \times BR(\tilde{\chi}^-_1 \to \tilde{\chi}^0_1\ell^-\bar{\nu}_\ell) + [BR(\tilde{\chi}^-_1 \to \tilde{\chi}^0_1\ell^-\bar{\nu}_\ell)]^2 \sim 0.34$, $\ell = e, \mu$, $q_u = u, c$, $q_d = d, s$.

From the ILC scan at the threshold [5], because of the steep s-wave excitation curve in $\tilde{\chi}^+_1\tilde{\chi}^-_1$ production, the determination of the light chargino mass will be possible with an accuracy of about [6]

$$m_{\tilde{\chi}^\pm_1} = 117.1 \pm 0.1 \text{ GeV}. \tag{3}$$

The mass of the lightest neutralino $m_{\tilde{\chi}^0_1}$ can be derived either from the energy distribution of the lepton ℓ^- or, in hadronic decays, from the invariant mass distribution of the two jets from $\tilde{\chi}^\pm_1$ decays. We therefore assume [3] that

$$m_{\tilde{\chi}^0_1} = 59.2 \pm 0.2 \text{ GeV}. \tag{4}$$

Together with the information from the LHC, Eq. (1), a mass uncertainty for the second lightest neutralino of about

$$m_{\tilde{\chi}^0_2} = 117.1 \pm 0.5 \text{ GeV} \tag{5}$$

can be assumed.

3 Determination of Parameters

Following the method proposed in [2] we include in the fit the forward–backward asymmetries of the final leptons. As explained before, this observable is very sensitive to the mass of the exchanged scalar particles, even for rather heavy masses. Since in the decay process also the left selectron exchange contributes, the $SU(2)$ relation between the left selectron and sneutrino masses: $m^2_{\tilde{e}_L} = m^2_{\tilde{\nu}_e} + m^2_Z \cos(2\beta)(-1 + \sin^2\theta_W)$ has been assumed. In principle this assumption could also be relaxed [3].

Applying the 5-parameter χ^2 fit procedure with the leptonic forward–backward asymmetries included leads to [3]:

$$M_1 = 60.00 \pm 0.35 \text{ GeV}, \quad M_2 = 121.0 \pm 1.1 \text{ GeV}, \quad 500 \leq \mu \leq 610 \text{ GeV},$$
$$m_{\tilde{\nu}_e} = 1995 \pm 100 \text{ GeV}, \quad 14 \leq \tan\beta \leq 31. \qquad (6)$$

Including forward–backward asymmetries in the multiparameter fit provides strong constraints for the mass of the heavy virtual particle, $m_{\tilde{\nu}_e}$, and decreases its error by a factor of about 2 with respect to the fit without FB asymmetry [3]. The constraints for the gaugino mass parameters M_1 and M_2 are improved by a factor of about 5, thanks to the constraint on the value of $\tan\beta$. It is clear that in order to improve considerably the bounds for the parameters μ and $\tan\beta$, the measurement of the heavy higgsino-like chargino and/or neutralino masses will be necessary at the second phase of the ILC with $\sqrt{s} \sim 1000$ GeV.

4 Conclusions

We have demonstrated a method for constraining heavy virtual particles and for determining the SUSY parameters in focus-point-inspired scenarios. These appear very challenging since only little experimental information on the SUSY sector is accessible at both the LHC and the ILC at its first energy stage of $\sqrt{s} = 500$ GeV. However, we show that a careful exploitation of the data leads to significant constraints on the unknown parameters. The most powerful tool in this kind of analysis turns out to be the forward–backward asymmetry. A proper treatment of spin correlations between the production and the decay is indispensable in that context. This asymmetry is strongly dependent on the mass of the exchanged heavy particle. We want to stress the important role of the LHC/ILC interplay since none of these colliders alone can provide us with the data needed to perform the determination of the SUSY parameters in focus-like scenarios.

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