THE MSSM WITH DECOUPLED SCALARS AT THE LHC

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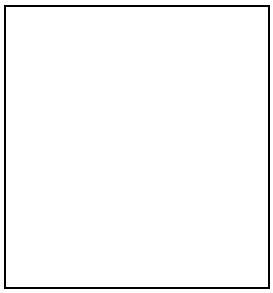

The discovery potential for the MSSM with heavy scalars at the LHC in the case of light inos is examined. We discuss the phenomenology of the model and the observables to determine the parameters. We show that for light gauginos, the model parameters can be constrained with a precision of the order of 15%.

1 Introduction

Assuming a large soft–breaking scale for the MSSM scalars [1,2,3,4,5] pushes squarks, sfermions and heavy Higgses out of the kinematic reach of the LHC without affecting the gaugino sector. The hierarchy problem will not be solved without an additional logarithmic fine tuning of the Higgs sector. Nevertheless, a model can be constructed to provide a good candidate for dark matter and realize grand unification while minimizing proton decay and FCNCs. We investigate the LHC phenomenology of the model, where all scalars are decoupled from the low energy spectrum. We focus on gaugino–related signatures to estimate the accuracy with which its underlying parameters can be determined.

2 Phenomenology

The spectrum at the LHC is reduced to the gauginos, Higgsinos and the light Higgs. At the intermediate scale M_S the effective theory is matched to the full theory and the usual MSSM renormalization group equations apply. The Higgsino mass parameter μ and the ratio $\tan\beta$ in the Higgs sector correspond to their MSSM counterparts. The gauginos masses $M_{1,2,3}$ and the Higgs-sfermion-sfermion couplings unify, and M_S replaces the sfermion and the heavy Higgs'

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$\tilde{g}\tilde{g}$	68 pb	$\tilde{} \tilde{g}$	311 fb
$\tilde{} \tilde{}^0$	12 pb	$\tilde{}^0\tilde{g}$	223 fb
$\tilde{} \tilde{}$	6 pb	$\tilde{}^0\tilde{}^0$	98 fb
Total		87 pb	

Table 1: NLO cross sections for SUSY pair production at the LHC.

mass parameters. This set resembles the mSUGRA parameter set except for tan now playing the role of a matching parameter (with the heavy Higgses being decoupled) rather than that of an actual vev ratio [6].

We select our parameter point according to three constraints: first, we minimize the amount of fine tuning necessary to bring the light Higgs mass into the 100 to 200 GeV range and reduce M_S to 10 TeV, still well outside the LHC mass range. The main reason for this low breaking scale is that we want the gluino to decay inside the detector (preferably at the interaction point) instead of being long{lived [8,4].

Secondly, we obtain the correct relic dark{matter density $h^2 = 0{:}111^{+0{:}006}_{0{:}008}$ [10] by setting = 290 GeV and $M_2(M_{GUT}) = 132{:}4$ GeV or $M_2(M_{weak}) = 129$ GeV. This corresponds to the light{Higgs funnel $m_{LSP} \quad M_2/2 \quad M_h/2$, where the s-channel Higgs exchange enhances the LSP annihilation rate. And finally, m_h needs to be well above the LEP limit, which we achieve by choosing tan = 30. We obtain $m_h = 129$ GeV, $m_{\tilde{g}} = 438$ GeV, chargino masses of 117 and 313 GeV, and neutralino masses of 60, 117, 296, and 310 GeV with a modified version of SuSpect [5,11], decoupling the heavy scalars from the MSSM RGEs. $\tilde{}^0_2$ and $\tilde{}_1$ as well as $\tilde{}^0_4$ and $\tilde{}_2$ are degenerate in mass. All supersymmetric particles and most notably the gluino are much lighter than in the SPS1a parameter point It is important to note that this feature is specific to our choice of parameters and not generic in heavy{scalar models. As a consequence, all LHC production cross sections are greatly enhanced with respect to SPS1a.

Table 1 shows the main (NLO) cross sections at the LHC from Prospino2 [12,13,14]. The SUSY production is dominated by gluino pairs whose rate is eight times that of the SPS1a point: the lower gluino mass enlarges the available phase space, while in addition the destructive interference between s and t{channel diagrams is absent. The second largest process is the $\tilde{}_1 \tilde{}^0_2$ production, which gives rise to a 145 fb of hard-jet free, e and trilepton signal, more than a hundred times that of the SPS1a point.

3 OBSERVABLES

The first obvious observable is the light Higgs mass m_h. Although slightly higher than in most MSSM points, m_h can still be measured in the Higgs to two photons decay [15] ($m_h < 150$ GeV). The systematic error on this measurement is mainly due to the incertainty on the knowledge of the electromagnetic energy scale.

A measurement of the gluino pair production cross section appears feasible and could be very helpful to determine M_3. The branching ratio of gluinos decaying through a virtual squark into a chargino or a neutralino along with two jets is 85% . The chargino will in turn decay mostly into the LSP plus two leptons or jets. Such events would feature at least 4 high-p_T jets, a large amount of missing energy due to the two $\tilde{}^0_1$ in the final state and possibly leptons. The main backgrounds for such signatures are $t\bar{t}$ pairs, W + jets and Z + jets with respective production rates of 830 pb, 4640 pb and 220 pb [16]. Despite these large cross sections, most of the background can be eliminated by applying standard cuts on $\not{E}_T$, the number of high-p_T jets as well as the effective mass[b] which we checked using a fast LHC-like simulation. The main

[b] $M_e = \not{E}_T + \sum p_T(\text{jets})$.

source of systematic errors for this observable is the 5% error on the knowledge of the luminosity. We take the theoretical error on the calculation of the cross section to be roughly 20%.

The next observable is the trilepton signal. After gluino pairs, the next dominant channel is the direct production of $\tilde{}_1\ \tilde{}^0_2$. 22% of $\tilde{}_1$s decay through a virtual W into an electron or muon and a neutrino and the LSP. Similarly, 7% of $\tilde{}^0_2$s decay through a virtual Z into an Opposite-Sign-Same-Flavour lepton pair (OSSF) and the LSP. The resulting signal features three leptons among which two are OSSF, a large amount of missing transverse energy due to the two LSPs plus the neutrino and no jet in the hard process. The background for this signature is mainly WZ and ZZ in which one of the leptons was non-identified or outside acceptance. According to PYTHIA the lepton production (e and) rates are 386 fb for WZ and 73 fb for ZZ. The trilepton signal has a rate of 145 fb, using SDECAY[17] for the calculation of the branching ratios. Including identification efficiencies of 65% for electrons and of 80% for muons[18] gives rates of 110 to 211 fb for the background and 40 to 74 fb for the signal before any cut. A study with full detector simulation and reconstruction would provide a better understanding of signal and background. As in the previous case, the main source of systematic errors is the uncertainty on the luminosity. We also take the theoretical error on the value of the trilepton cross section to be roughly 20%.

Within this trilepton signal lies another observable. 10% of $\tilde{}^0_2$s decay into an OSSF lepton pair and the LSP. The distribution of the invariant mass of the pair features a kinematic upper edge whose value is $m_{\tilde{}^0_2} - m_{\tilde{}^0_1}$. Such an observable gives precious information on the neutralino sector and hence on M_1. The systematic error is dominated by the lepton energy scale. The statistical error was extracted from a ROOT fit of the $M_{\ell\ell}$ distribution and we estimate the theoretical accuracy to be of the order of 1%.

The last observable we use in this study is the ratio of gluino decays including a b quark to those not including a b. A systematic error of 5% due to the tagging of b-jets and a theoretical uncertainties of 20% are assumed.

Observables		Exp. systematic errors		Statistical errors	Theoretical
	Value	Error	Source	100 fb^{-1}	
m_h	128.8 GeV	0.1%	energy scale	0.1%	4%
$m_{\tilde{}^0_2} - m_{\tilde{}^0_1}$	57 GeV	0.1%	energy scale	0.3%	1%
(3′)	145.2 fb	5%	luminosity	3%	20%
R(g̃ → b/b̄)	0.11	5%	b-tagging	0.3%	20%
(gg̃g)	68.2 pb	5%	luminosity	0.1%	20%

Table 2: Summary of the observables and the corresponding errors.

Table 2 summarises the value and error of the observables assumed in this study. The third and fourth columns give the experimental systematic errors and there source. The fifth column gives the statistical errors for an integrated luminosity of 100 fb^{-1} corresponding to one year of data-taking at the LHC nominal luminosity. The last column gives an estimation of the theoretical uncertainties.

4 PARAMETER DETERMINATION

We use different sets of errors for the fits. First we determine the parameters in the low statistic scenario ignoring theoretical uncertainties. Second we assume an infinite statistic and therefore assume negligeable statistical errors to estimate the ultimate precision barrier imposed by experimental systematic errors. Finally the effect of theoretical uncertainties is estimated by including them into the previous set. We expect these to dominate.

With no information on the squark and sfermion sector at all, except for non-observation, we are forced to fix M_S and A_t and set M_2 to be equal to M_1. We fit the parameters to the observables using the Minuit fitter. The minimum of the χ^2 is found by MIGRAD. We start from a point far from the nominal values ($\{M_1; M_3; \tan\beta; \mu\} = \{100; 200; 10; 320\}$) and reach the values reported in table 3. Errors are determined with MINOS. Theoretical errors are treated as Gaussian.

Parameter	Nom. values	Fit values	Low stat.		1 fb^{-1} stat.		1 fb^{-1} stat.+th	
M_S	10 TeV		fixed					
A_t	0		fixed					
M_1	132.4 GeV	132.8 GeV	$= M_2$					
M_2	132.4 GeV	132.8 GeV	6	5%	0.24	0.2%	21.2	16%
M_3	132.4 GeV	132.7 GeV	0.8	0.6%	0.16	0.1%	5.1	4%
$\tan\beta$	30	28.3	60	undet.	1.24	4%	177	undet.
μ	290 GeV	288 GeV	3.8	1.3%	1.1	0.4%	48	17%

Table 3: Result of the fits. Errors on the determination of the parameter are given for the three error sets. Both absolute and relative values are given.

Table 3 shows the result of the fits in both absolute and relative values. It is interesting to note that $\tan\beta$ in undetermined except in the case of infinite statistical and theoretical accuracy. The quality of the trilepton and gluino signals gives very good precision on the determination of M_1 and M_3 even with low statisic. The inclusion of theoretical uncertainties indeed decreases the accuracy but still allows for a determination. M_3 only depends on the large gluino signal and its decays, explaining its relative stability. M_1 and M_2 see the largest impact of theoretical errors. This is because they depend on first order on the trilepton cross-section and on second order on the b to non b gluino decays ratio both of which bear a large theoretical error.

5 CONCLUSION

The MSSM with heavy scalars can very well satisfy current experimental and theoretical limits on physics beyond the standard model and also solve a good number of issues present in the traditionnal MSSM. We described its phenomenology at the LHC in the case of light inos and showed that such a simple and light spectrum could lead to very high production rates making the model discoverable. The main observable channels are gluino pairs and the trilepton channel whose hard-jet free channel makes it well distinct from SM and SUSY backgrounds. Other observables such as the light Higgs mass, the $|m_{\tilde{\chi}^0_2} - m_{\tilde{\chi}^0_1}|$ kinematic edge and the b to non b producing gluino decays could lead to a determination of most parameters to the level of a few percent with 100 fb^{-1} ignoring theoretical errors. In a more realistic picture where we assumed non-zero theoretical errors, we saw that most parameters can be determined with a precision of 15%. We also saw that the scalar section including $\tan\beta$ could only be poorly determined if at all.
New complementary observables could help determine better the scalar sector. Equally, a look at other parameter points will provide a more complete view of the discovery potential of a MSSM with decoupled scalars at the LHC.

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