hep-ph/0210196
CERN-TH/2002-268

Exotic SUSY scenarios [1]

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Abstract

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[1] Talk presented at the International Conference of High Energy Physics, July 24-31,2002, Amsterdam, The Netherlands.
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Exotic SUSY scenarios

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In this talk I discuss some scenarios which involve small extensions of the ideas usually considered in the Minimal Supersymmetric Standard Model (MSSM). I present results of a study of the implication of non-universal gaugino masses (NGM) for the invisible decays of the lightest scalar and the correlation of the same with the relic density of the lightest supersymmetric particle (LSP) in the Universe. Further I discuss SUSY with $\not{R}_p$. Decay of $\tilde{\chi}_1^0$ in the case of dominant $\not{R}_p$ and $\not{L}$, trilinear λ and λ' couplings, and also that of $\tilde{\chi}_1^0, \tilde{\chi}_1^+$ caused by the bilinear $\not{R}_p$, $\not{L}$ couplings are discussed. The effect of the latter for the trilepton signal at the Tevatron is presented. I end with a discussion of signals of Heavy Majorana Neutrinos (HMN) at the LHC.

1. Introduction

In this talk I summarize salient features of the results of four different investigations. Small departures from the standard assumptions of the SM and the MSSM are the common feature unifying all of them. The results presented are based on four abstracts [1,2,3,4] submitted to this meeting. Supersymmetry and models for non-zero ν masses indeed form a very big part of all the current Beyond the Standard Model (BSM) discussions. In this talk I refer to the effects of relaxing two of the assumptions normally made: that of universal gaugino masses [1] and R_p conservation [2,3]. $\not{R}_p$ SUSY provides one of the most economical ways of generating non-zero ν masses. In the last abstract [4] a new aspect of the collider signatures of the heavy Majorana neutrino, an important ingredient of all the models of ν masses not involving $\not{R}_p$ SUSY, is presented.

2. Non-Universal Gaugino Masses

MSSM assumes universal masses for the $SU(3), SU(2)$ and $U(1)$ gauginos at the high scale. This implies $M_1 \simeq 0.5 M_2$ at the electroweak scale, where M_1, M_2 are the $U(1), SU(2)$ gaugino masses. However, this assumption need not be true even in the very restrictive mSUGRA model wherein the non-universality is possible for a non-minimal kinetic term for the gauge superfields. Non-universal gaugino masses are expected also in models with anomaly-mediated SUSY breaking (AMSB) or moduli-dominated SUSY breaking. In general, therefore, we can expect $M_1 = rM_2$ with $r \neq 0.5$ at the EW scale. We studied the effect of such a scenario on the 'invisible' decays of the h. A ratio r between the two gaugino masses at the EW scale needs

$$M_1 = 2rM_2 \tag{1}$$

at the GUT scale. Most of the above-mentioned models normally imply values of $r > 1$. Taking a phenomenological approach, however, we consider two values of $r < 1$, viz. $0.1, 0.2$. As a result of such a non-universality, for a given $\tilde{\chi}_1^\pm$ mass, the mass of the $\tilde{\chi}_1^0$ is smaller than that in the universal case. Hence it is possible to have $h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$ while respecting all the LEP constraints, in spite of the theoretical upper limit of ~ 130 GeV on the mass of the lightest h among the SUSY higgses. Of course it is necessary to rework [5] all the LEP constraints for the non-universal case. B.R. $(h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0)$ is maximized for moderate $\tan\beta$, small μ and M_2. Unlike the case of universal gaugino masses, we found large regions of the M_2–μ plane where B.R. for the 'invisible', $\tilde{\chi}_1^0 \tilde{\chi}_1^0$ decay mode can be as large as 0.65 *even* after all the LEP constraints are imposed, as shown in Figure 1. Such a large 'invisible' branching ratio for

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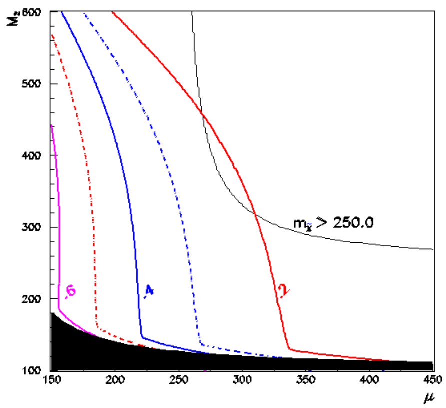

Figure 1. Contours of B.R.$(h \to \tilde{\chi}_1^0\tilde{\chi}_1^0)$ for $r = 0.1$ along with the LEP constraints on the $\tilde{\chi}_1^+$ mass indicated by the black region. $\tan\beta = 5$ and $m_h = 125$ GeV.

the h decreases that into the $\gamma\gamma$ and $b\bar{b}$ channels. The latter indeed provide the best possible signature for the h produced 'inclusively' and in association with a $W/Z/t\bar{t}$. If we define,

$$R_{\gamma\gamma} = \frac{\text{B.R.}(h \to \gamma\gamma)_{SUSY}}{\text{B.R.}(h \to \gamma\gamma)_{SM}}$$

and $R_{b\bar{b}}$ similarly, we find that

$$R_{\gamma\gamma} = R_{b\bar{b}} = 1.0 - \text{B.R.}(h \to \tilde{\chi}_1^0\tilde{\chi}_1^0).$$

Thus B.R.$(h \to \tilde{\chi}_1^0\tilde{\chi}_1^0) \sim 0.3$–$0.4$ can mean loss of the signal for the lightest Higgs at the LHC.

A light $\tilde{\chi}_1^0$ also has implications for the relic density of the neutralinos in the Universe, as the latter is decided by $\sigma(\tilde{\chi}_1^0\tilde{\chi}_1^0 \to f^+f^-)$. For a light $\tilde{\chi}_1^0$, the Z/h-mediated s channel process contributes to the annihilation. If the $\tilde{l}_R$ is light the cross-section also receives a contribution from the t-channel $\tilde{l}_R$ exchange. There is a clear correlation between the expected 'invisible' branching ratio for the h and the relic density of the $\tilde{\chi}_1^0$ as the same couplings are involved. Figure 2 shows results obtained for $r = 0.1$ with $\tan\beta = 5$ and $m_{\tilde{l}_R} \sim 100$ GeV [1] using the micrOMEGAs [6] program to calculate the relic density. These show that the requirement of an acceptable relic density does constrain the M_2–μ plane quite substantially. However, there exist large regions of

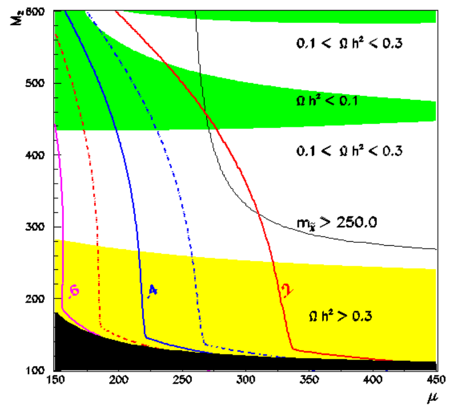

Figure 2. Contours of $B.R.(h \to \tilde{\chi}_1^0\tilde{\chi}_1^0)$ for $r = 0.1$ along with the DM and LEP constraints. The white region corresponds to $0.1 < \Omega h^2 < 0.3$, for $m_0 = 94$ GeV, $\tan\beta = 5$ and $m_h = 125$ GeV. The black region is the LEP-excluded region. The lightly (heavily) shaded region corresponds to $\Omega h^2 > 0.3$ (< 0.1).

this plane where the 'invisible' branching ratio of h is as large as 0.5–0.6, even for 'large' (~ 200 GeV) $\tilde{l}_R$, consistent with the LEP constraints and with an acceptable relic density. The small mass of the $\tilde{\chi}_1^0$ in this case means that the trilepton signal at the Tevatron will be qualitatively different from the universal case. Thus this scenario can be tested at the Tevatron via the trilepton events. As a matter of fact, one can also obtain a model-independent limit on M_1 and hence on the $\tilde{\chi}_1^0$ mass, by considerations of relic density.

3. Decaying $\tilde{\chi}_1^0$ in R_p-violating theories:

B, L are symmetries of the SM but not of the MSSM; i.e. it is possible to write terms in the Lagrangian which are $\not{L}$, $\not{B}$ but respect gauge invariance as well as supersymmetry. Non-zero ν masses can be generated in $\not{R}_p$ supersymmetric theories, without introducing any new fields; at the tree level via the bilinear $\not{R}_p$ terms in the superpotential and quantum one or two loop level via the trilinear λ, λ' couplings [7]. A large number of these couplings are constrained by low energy processes, cosmological arguments as well as explicit collider searches [8]. Some of the strongest constraints on the $\Delta L = 1$ processes come from ν masses. As said earlier, since the heavy scale involved in the mass-generation mechanism is decided by the sparticle masses, this leads to constraints on the size of the $\not{R}_p$ couplings and hence to clear predictions of the $\not{L}$, $\not{B}$ signals in collider processes involving these sparticles. Since some of the constraints do depend on the details of the specific SUSY model, it is important to study the direct effect of the *very same* couplings that are so indirectly constrained, at the colliders. Such studies can help clarify the picture for model building.

The main constraints on $\not{L}$ couplings λ, λ' with more than one third-generation index come from models for ν masses and not from collider experiments. Probes of these $\not{L}$ couplings at the colliders involve studying the physics of third-generation fermions. The third generation sfermions are also likely to give rise to larger virtual effects, as they are expected to be lighter than those of the first two generations. For $\tilde{\chi}_1^0, \tilde{\chi}_1^+$ with masses of interest at the LHC and NLC, final states with third-generation fermions including t are possible. One thus needs a study of the $\not{R}_p$ decays of $\tilde{\chi}_1^0, \tilde{\chi}_1^\pm$ retaining effects of the mass of the third generation fermions, for L-violating coupling. An interesting example is the resonant or non-resonant production of the $\tilde{\tau}$ via the $\not{L}$ λ'_{333} coupling in $pp \to t\bar{b}\tilde{\tau}$, similar to the case of $t\bar{b}H^+$ production via the Yukawa coupling. Even for λ'_{333} as small as 0.01 and $m_{\tilde{t}} > m_t$, the rates are appreciable. The $\tilde{\tau}$ thus produced will have both R_p-conserving decay $\tilde{\tau} \to \tau\tilde{\chi}_1^0, \tilde{\tau} \to \nu_\tau\tilde{\chi}_1^-$ for $m_t > m_{\tilde{\tau}}$ and the R_p-violating one $\tilde{\tau} \to b\bar{t}$ for $m_t < m_{\tilde{\tau}}$. The final state composition will depend on the $\not{R}_p$ decays of the $\tilde{\chi}_1^0$ as well. Production of $\tilde{\tau}$ through $\not{R}_p$ couplings and its decay via the *same* will give rise to $pp \to t\bar{b}\tilde{\tau}X \to t\bar{b}t\bar{b}X$, which is the same as the expected final state for the $H^\pm$ production. Thus the $\tilde{\tau}$ in this case can fake the $H^\pm$ signal. R_p conserving decays of the $\tilde{\tau}$ and $\not{R}_p$ decays of the $\tilde{\chi}_1^0$ can also produce

$$pp \to t\bar{b}\tilde{\tau}X \to (2t)(2b)(2\tau)X \to tb\ (2\bar{b})\ \tau\nu_\tau X. \tag{2}$$

In the latter case the final state has the tell-tale signature of $\not{L}$, the like-sign fermion pairs.

We calculated [2] the three-body decays of the LSP for dominant $\not{L}$ trilinear couplings and obtained explicit expressions for the most general case of complex mass matrices, including the effect of the mass of the third-generation fermions. Of course the results depend on the L–R mixing in the sfermion sector, gaugino–higgsino mixing and $\tan\beta$, as well as on the generation structure of the particular $\not{L}$ couplings that is large. One can have the 'massive' and 'massless' modes with/without a t in the final state. Figure 3 shows the results for the case with λ'_{333} dominant, for two different choices of L–R mixing in the squark sector and different composition of the $\tilde{\chi}_1^0$. The massive decay mode has a large width for low $\tan\beta$ and large higgsino–gaugino mixing. Otherwise the massless mode is larger, although the massive mode is non-negligible. Even for smaller but dominant $\not{R}_p$, λ and λ' couplings, with more than one third-generation index, the three-body $\not{R}_p$ decays of $\tilde{\chi}_1^0, \tilde{\chi}_1^+$ can have important phenomenological consequences for new particle searches at the future colliders.

In the above discussion the bilinear $\not{R}_p$ terms were assumed to be zero. In the analysis of Ref. [3], a particular case of non-zero κ_3 is considered. The $\not{R}_p$ and R_p-conserving decays of the $\tilde{\chi}_1^0, \tilde{\chi}_1^\pm$ in this case are given by Eqs. (3) and (4) respectively.

$$\begin{aligned} \tilde{\chi}_1^0 &\to \nu_\tau Z^* \to \nu_\tau f\bar{f}, \quad \tilde{\chi}_1^0 \to \tau W^\pm \to \tau f\bar{f}' \\ \tilde{\chi}_1^\pm &\to \tau Z^* \to \tau f\bar{f}, \quad \tilde{\chi}_1^\pm \to \nu_\tau W^\pm \to \nu_\tau f\bar{f}', \end{aligned} \tag{3}$$

and

$$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\ell^+\ell^-, \tilde{\chi}_1^\pm \to \tilde{\chi}_1^0\ell\nu_\ell. \tag{4}$$

It is clear the $\not{R}_p$ decays will enhance the number of leptons in the final state and give very clear signals. These authors analysed, in an mSUGRA picture, the multilepton signals at the Tevatron. The multilepton signal is one of the promising channel for discovery of SUSY at the Tevatron. Hence such an analysis is important. This one shows that the reach in the multilepton channel for the $\not{R}_p$ case is much better than for the R_p-conserving case at large values of m_0. For small m_0 the situation is reversed, owing to slepton-mediated $\tilde{\chi}_2^0$ decay.

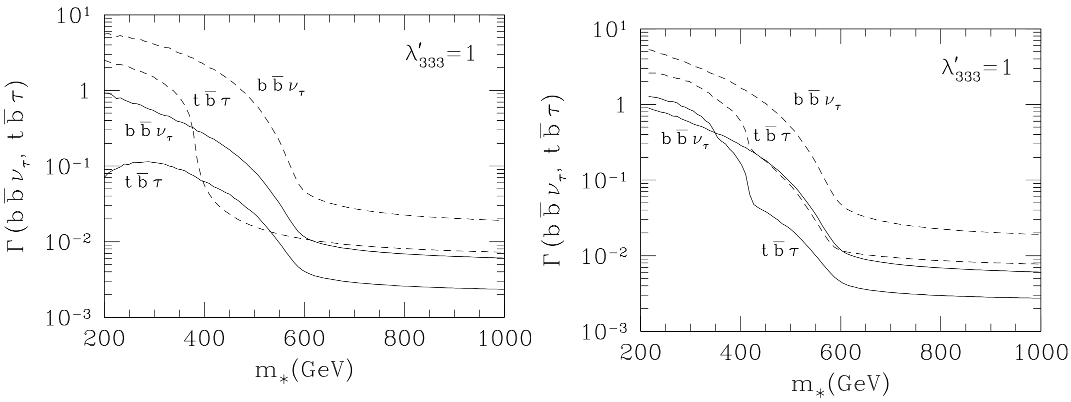

Figure 3. $\tilde{\chi}_1^0$ widths for no (moderate) L–R squark mixing in left (right) panel. Dashed (solid) lines for a wino (bino) like $\tilde{\chi}_1^0$. $A_t - \mu\cot\beta = 150$ GeV, $A_b - \mu\tan\beta = 2000$ GeV for non-zero mixing.

4. Signals for Heavy Majorana Neutrino

The authors [4] consider models of ν masses which have an isosinglet neutrino N that mixes with the ordinary light one but wherein the mass and the mixing of the N are not linked together, unlike in the usual models based on he see-saw mechanism. This mixing is then treated as a phenomenological parameter constrained by the LEP data. It is possible in these models to have N mass 'naturally' in the range: $100 < M_N < 1000$ GeV [9]. The issue of characteristic $\not{L}$ signals for the HMN via like sign dilepton (LSD) events. was revisited in this investigation. They considered both the fusion contribution from

$$q_i+\bar{q}_j \to q_k+\bar{q}_l+W^{+*}+W^{+*} \to q_k+\bar{q}_l+l^++l^+ \quad (5)$$

where the N is exchanged in the t channel and also from the resonant production of N via

$$q_i + \bar{q}_j \to W^{+*} \to l^+N \quad \to l^+ + l^+ + W^- \\ \to l^+l^+q_k\bar{q}_l. \quad (6)$$

Explicit formulae were obtained in helicity formalism and errors in the earlier calculations [10], traced to dropping of the ghost diagrams, were corrected. The predicted LSD cross-section increases by about 20% as a result of this. The reach of the LHC, just from rates, is $M_N = 200$–250 GeV. Detailed simulations will be needed to make these conclusions firmer, as the cuts can then be optimized.

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