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VLSPs in N=1 SUGRA models

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The lightest supersymmetric particle (LSP)plays a crucial role in the search for supersymmetry (SUSY) since it carries missing transverse energy ($\not{E}_T$) which is traditionally regarded as the most distinctive signature of SUSY particles. In the currently favoured models, the lightest neutralino ($\widetilde{Z}_1$) is assumed to be the LSP [1].

Recently it has been emphasised [2, 3] that there may exist SUSY particles which, though unstable, **decay dominantly into invisible channels**. This occurs if the sneutrinos ($\widetilde{\nu}$) (the super–partners of the neutrinos) , though heavier than the LSP, are lighter than the lighter chargino ($\widetilde{W}_1$) or the second lightest neutralino ($\widetilde{Z}_2$) and are much lighter than all other SUSY particles. As a consequence, the **invisible two-body decay mode $\widetilde{\nu} \longrightarrow \nu\widetilde{Z}_1$ opens up** and completely dominates over others, being the only kinematically allowed two-body decay of the sneutrinos. The other necessary condition for this scheme to work is that the $\widetilde{Z}_1$ has a substantial Zino component. This, however, is almost always the case as long as the gluino (the super–partner of the gluon) has a mass above the lower bound obtained by the SUSY searches at the Tevatron [4]. In such cases the $\widetilde{Z}_2$, which also has a substantial Zino component, decays primarily through the process $\widetilde{Z}_2 \longrightarrow \nu\widetilde{\nu}$. These particles decaying primarily into invisible channels, hereafter called **virtual LSP's** (VLSP's), may act as additional sources of $\not{E}_T$ and can significantly affect the strategy for SUSY searches [2].

Another important consequence is the decay $\widetilde{W}_1 \longrightarrow l\widetilde{\nu}, l = e,\ \mu\ or\ \tau$. Since this is the only kinematically allowed two body decay of $\widetilde{W}_1$ it occurs with a branching ratio(BR) ≈ 1.

In Ref 2. sparticle masses were treated as free phenomenological parameters, although it was commented briefly that it is not unlikely that the VLSP scenario can be accomodated in the N=1 SUGRA models with common squark and gaugino masses at the GUT scale [5]. In this work we show in detail that this indeed is the case for a reasonably large region of the SUSY parameter space.

We assume a minimal N=1 supergravity model [5] with a common scalar mass m_0 and a common gaugino mass $m_{1/2}$ at the GUT scale M_X. We also assume minimal particle content. We follow the standard convention for the neutralino and chargino mass matrices [1].

In the following, M_1 and M_2 are SUSY breaking $U(1)$ and $SU(2)$ gaugino masses, μ is the supersymmetric Higgs(ino) mass and $\tan\beta \equiv \langle H_2^0\rangle/\langle H_1^0\rangle$ is the ratio of the vacuum expectation values (vevs). The assumed unification of gaugino masses leads to the following relation at the weak scale:

$$M_1 = \frac{5}{3}\tan^2\theta_W M_2 \simeq 0.5M_2, \tag{1}$$

where

$$M_2(M_Z) = 0.82m_{1/2} \tag{2}$$

gives the connection to the GUT scale gaugino mass. The above parameters also determine the chargino masses.

The relevant slepton masses [5] at the weak scale are determined by M_2, m_0 and $\tan\beta$:

$$m^2_{\tilde{l}_R} = m_0^2 + 0.223M_2^2 + \sin^2\theta_W D_Z, \tag{3a}$$

$$m^2_{\tilde{l}_L} = m_0^2 + 0.773M_2^2 + (0.5 - \sin^2\theta_W)D_Z, \tag{3b}$$

$$m^2_{\tilde{\nu}} = m_0^2 + 0.773M_2^2 - 0.5D_Z, \tag{3c}$$

where

$$D_Z = M_Z^2\frac{\tan^2\beta - 1}{\tan^2\beta + 1} > 0 \tag{4}$$

for $\tan\beta > 1$. Notice that $m_{\tilde{l}_L} > m_{\tilde{l}_R}$ always.

Our free parameters are thus m_0, M_2 (which we traded for $m_{1/2}$), μ and $\tan\beta$. There are two sets of constraints on the allowed parameter space: direct experimental constraints (primarily from LEP-I [6]) , and requirements for having VLSP's. We took the following experimental constraints into account [6]:

$$m_{\tilde{l}_R} > 45 \text{ GeV}, \quad m_{\tilde{\nu}} > 40 \text{ GeV}, \quad m_{\tilde{W}_1} > 46 \text{ GeV},$$
$$\Gamma(Z \to \tilde{Z}_1\tilde{Z}_1) < 12 \text{ MeV}, \quad \sum_{i,j}\Gamma(Z \to \tilde{Z}_i\tilde{Z}_j) < 0.25 \text{ MeV}, \tag{5}$$

where the sum does not include $(i,j) = (1,1)$.

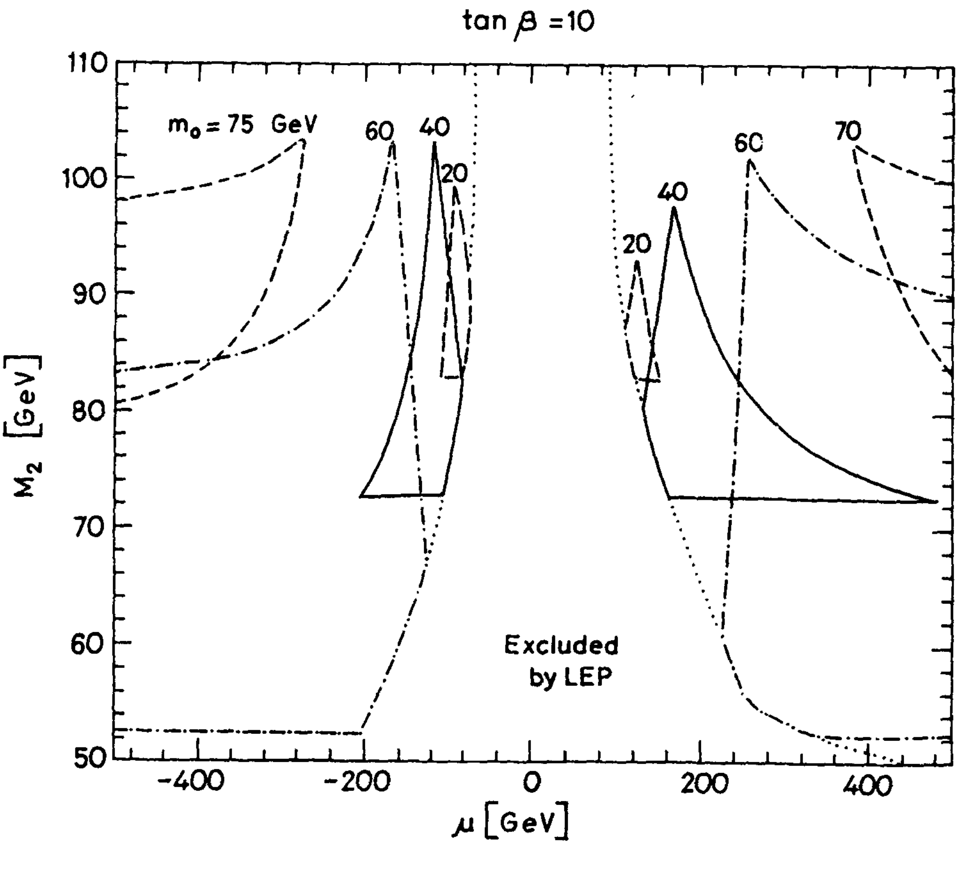
The defining property of the VLSP scenario is that both the sneutrino and $\tilde{Z}_2$ decay invisibly. This implies the following constraints:

$$m_{\tilde{\nu}} < m_{\tilde{Z}_2} < m_{\tilde{l}_L},\ m_{\tilde{l}_R}$$
$$m_{\tilde{\nu}} < m_{\tilde{W}_1} < m_{\tilde{l}_L}. \tag{6}$$

Notice that eq. 6 implies $m_{\tilde{\nu}} < m_{\tilde{l}_R}$; eqs.(3) then give an *upper bound* on M_2:

$$|M_2| \leq 1.15\sqrt{D_Z}. \tag{7}$$

This in turn requires a gluino light enough to be within the striking range of the Tevatron. For example with $\tan\beta = 2$ (10) the upperbound on the gluino mass is 243.45 GeV (284.29 GeV). For each value of the gluino mass there is an upper bound on the lighter chargino mass (see, for example, Datta, Guchait and Raychaudhuri in ref [6]). The above bounds on the gluino mass implies $m_{\tilde{W}_1} < 95$ GeV (approximately). Then eq. 6 implies that m_0 cannot be too large, either, hence



tan β =10
110
100
90
80
70
60
50
-400
-200
0
200
400
m_0 = 75 GeV
60
40
20
70
60
40
20
Excluded
by LEP
M_2 [GeV]
μ [GeV]

Figure 1.

sleptons will also be light. The lightest charged sparticle mass is then expected to be around M_Z. The masses are, therefore, in the region of interest for LEP 200.

Figure 1 shows an example of a allowed region. Here we fixed $\tan\beta = 10$, and plotted the allowed region in the (μ, M_2) plane for various values of m_0. The dotted curve delineates the region excluded by sparticle searches at LEP-I. The allowed region for fixed m_0 is not very large, although the fraction of the plane with a VLSP scenario for *some* value of m_0 is substantial, given only that M_2 satisfies eq 7.

Almost any value of μ can accomodate VLSPs if M_2 and m_0 are chosen properly. In fig.2 we have plotted the allowed region in the (m_0, M_2) plane for $\tan\beta = 2$ (solid

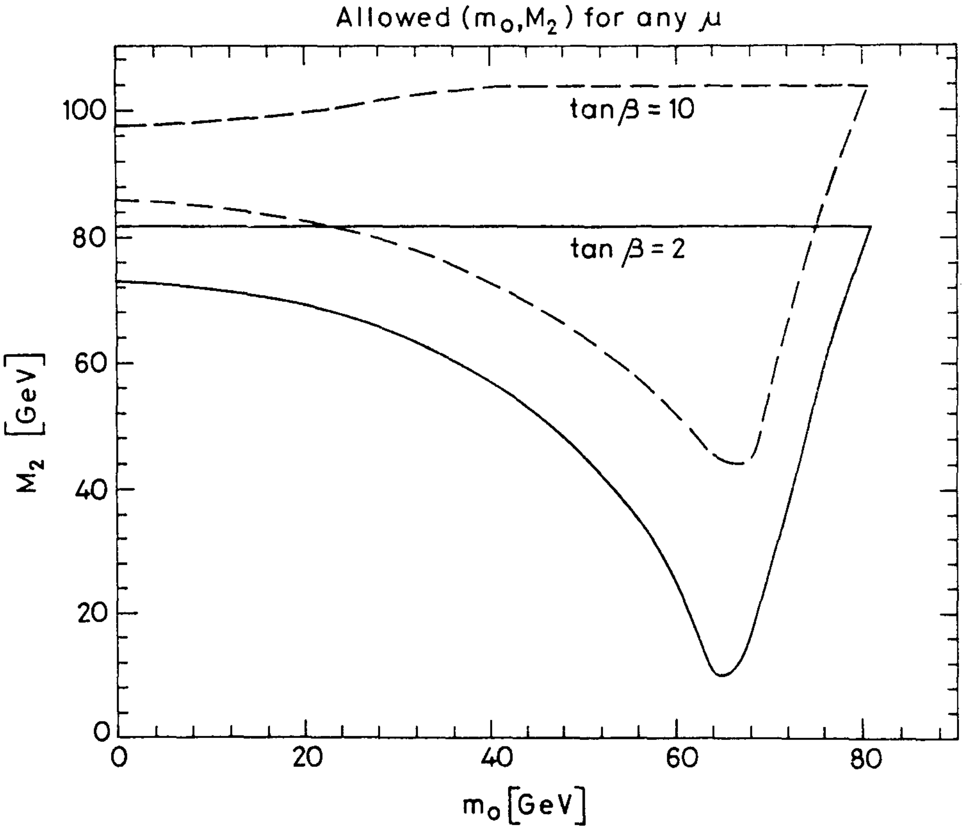


Figure 2.

curve) and 10 (dashed curve), after scanning over all μ; in other words, the curves enclose the region where at least one value of μ can be found so that a valid VLSP scenario emerges.

We now briefly discuss $\tilde{W}_1$ pair production at LEP 200 energies. Our signal is a pair of opposite sign stable dileptons (e or μ) + missing energy, arising from the decay of $\widetilde{W_1}$ s into leptons and VLSPs (sneutrinos).

Since the dilepton final State in this case arises from the decay of spin 1/2 charginos, the distributions of the final state leptons depend on the polarisations of the charginos. These polarisations can be conveniently taken into account by calculating the dilepton cross-section and the related distributions using the helicity projection technique [7].The calculations are tedious but straight forward and the results will be presented elsewhere [8].

In this scenario with a tightly constrained mass spectrum the lighter chargino is the lightest charged sparticle in certain region of the allowed parameter space discussed earlier. These regions can be most conveniently probed by restricting the beam energy below the threshold for the production of other sparticles . The above dilepton signal consisting of any combination of e and μ, after removing the $\gamma-\gamma$, $\tau-\tau$ and WW backgrounds by appropriate kinematical cuts , then provides an unambiguous signal of chargino pair production. For beam energies above the slepton threshold, only e -μ pairs provide a clean signature of chargino production. Such pairs of course cannot arise from slepton pairs whose decays conserve flavour. In the following we shall present some illustrative examples of chargino signals in the VLSP model.

For m_0 =67.5 GeV ,M_2= 53 GeV ,$tan\beta = 2.0$ and μ = -150 GeV, the sparticle spectrum of our interest is given by: $m_{\tilde{\nu}}$ = 65.35 GeV, $m_{\tilde{l}_R}$ = 79.58 GeV, $m_{\tilde{l}_L}$ = 89.98 GeV and $m_{\widetilde{W}_1}$ = 72.74 GeV. In this scenario the dilepton cross-section arising out of direct chargino decays at the c.m. energy $\sqrt{s}$ = 160 GeV is $0.15pb^{-1}$ where the kinematical cuts used are as above (the cut against the W-W background of course is irrelevant in this case). Thus for an integrated luminosity of $500pb^{-1}$ we expect about 75 events. Here since 2 $m_{\tilde{l}_R}$ ¿ $\sqrt{s}$, the dilepton final state consisting of any combination of e and μ provides the signal.

Since the charginos can also decay into τ's, stable leptons from the decays $\tau \longrightarrow e(\ or \ \mu\ )\nu\ \bar{\nu}$ can enhance the signal. The cross-section for this process ,however, turns out to be rather small due to the small leptonic branching ratio of the τ [8].

The end points of the lepton energy spectrum from direct chargino decays are particularly interesting since they determine in principle both $m_{\tilde{\nu}}$ and $m_{\widetilde{W}_1}$. It turns out that the number of stable leptons arising from τ decays is not large enough to obscure completely the characteristics of the above energy spectrum.

We note in passing that in the above example the mass difference between the chargino and the sneutrino is rather small. Yet we get a viable signal. This is to be contrasted with chargino search in this channel at TEVATRON where the signal can be completely washed out if the above mass difference is small [9].

The other case we have considered in some detail consists of the following parameters: m_0 =40 GeV ,M_2= 70 GeV ,$tan\beta$ = 2.0 and μ = -75 GeV. This yields the sparticle spectrum : $m_{\tilde{\nu}}$ = 53.8 GeV, $m_{\tilde{l}_R}$ = 61.9 GeV, $m_{\tilde{l}_L}$ = 82.0 GeV and $m_{\widetilde{W}_1}$ = 79.9 GeV. This case is interesting for two reasons.Firstly, the beam energy has to be above the WW threshold and the cuts against WW background are called for. Secondly , since $m_{\tilde{l}_R} < m_{\widetilde{W}_1}$ only e - μ final states should be considered. A calculation using the standard cuts yields a dilepton cross-section of $0.13pb^{-1}$ from direct decays at c.m. energy $\sqrt{s}$ = 180 GeV .Thus for an integrated luminosity of $500pb^{-1}$ we expect about 65 events.

We have also checked the cross - section for several representative points of the parameter space for tanβ = 10. The number of events for $\sqrt{s} = 150 - 180$ GeV is between 20 - 150 for an integrated luminosity of 500 pb^{-1}.

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