Are light sneutrinos buried in LEP data?

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Abstract
Supersymmetry may resolve the disagreement between the precision electroweak data and the direct limit on the higgs mass, if there are light sneutrinos in the mass range $55 \text{ GeV} < m_{\tilde{\nu}} < 80 \text{ GeV}$. Such sneutrinos should decay invisibly with 100\% branching ratio and contribute to the $\gamma + \text{missing energy}$ signal, investigated by all the LEP groups. It is shown that while the data accumulated by a single group may not be adequate to reveal such sneutrinos, a combined analysis of the data collected by all four groups will be sensitive to $m_{\tilde{\nu}}$ in the above range. If no signal is found a lower bound on $m_{\tilde{\nu}}$ stronger than that obtained from the $Z$-pole data may emerge.

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1 Introduction

It is generally believed that the precision electroweak (EW) data are in good agreement with the standard model (SM) of particle physics [1]. Yet one has to admit that during the last couple of years a subset of the data has made the situation somewhat uncomfortable for the SM [2, 3, 4]. If only a small subset of a large volume of data is in strong disagreement with theory, such that its removal improves the quality of the fit, then one would normally believe that either statistical fluctuations or some hitherto unknown systematic errors might have affected this subset. A conservative approach would then be to keep the subset in the cold storage awaiting improved statistics or a better understanding of the systematics, rather than invoking a new physics model.

The situation, unfortunately, is not that simple in the present case. It is now well known that the effective leptonic weak mixing angle (given by \(\sin^2 \theta_W = x_W^l\)) determined from the leptonic asymmetries measured by the LEP groups and SLD are in severe disagreement with the same parameter as determined by the hadronic asymmetries [1]. The discrepancy in the global analysis becomes more prominent if the effective on-shell weak mixing angle extracted from recent neutrino scattering data [5] is taken into account [4]. In Ref. [1] several standard model fits were performed (see Table 13.2) and it was noted that the \(\chi^2/\text{d.o.f}\) was large in each case. The large dispersion in the fitted value of \(x_W^l\) from various asymmetries, responsible for the poor fit, was interpreted as the result of fluctuations in one or more of the experimental inputs and the issue was not pursued any further. Unfortunately no improvement in statistics is expected in the near future. Most of the analyses based on the measurements at the \(Z\)-pole are now more or less final [1]. With more than 700 pb\(^{-1}\) of data per experiment at energies higher than the \(Z\)-pole an improved accuracy in \(m_W\) measurement is expected which in turn may lead to a better understanding of the SM vis-à-vis LEP data.

If the hadronic asymmetries are discarded the quality of the fit improves dramatically, as expected, but the mass of the Higgs boson obtained from the fit turns out to be much smaller [2, 3, 4] than the lower limit obtained from the direct searches at LEP [6]. Given the theoretical uncertainties (unknown higher order corrections, the precise value of an important input - the fine structure constant evaluated at \(m_Z\) etc.) nicely reviewed in Ref. [1], the possibility of statistical fluctuations and poorly understood systematics, it is not impossible that the data can still be in agreement with the SM. However, as analyzed in great details in Ref. [4], something totally unexpected has to happen. For example, if statistical fluctuation is the possible explanation then it is imperative that not only the measurements in disagreement (some of the hadronic asymmetries, say) with the SM but also the ones which have been thought to be the evidence for the SM for so many years must involve large fluctuations. It was, therefore, argued in Ref. [4] that new physics seems to be the favoured solution, although the evidence is not fully conclusive.

Several new physics models have already been proposed as possible solutions of the alleged
conflict between the SM and the data (see Ref.[4] for a list of further references). In this paper the focus will be on the supersymmetric solution[3]. This solution seems to be attractive because one does not need supersymmetry only to ameliorate the malady in the precision electroweak data. It is needed to answer deeper issues. It solves the hierarchy puzzle that haunts non-supersymmetric grand unified theories and facilitates the coupling constant unification. The supersymmetric extension of the minimal standard model (MSSM), therefore, seems to be a well motivated step beyond the SM. It was shown in Ref.[3] that the quality of the fit to the precision electroweak data as well as the agreement with the lower bound on the Higgs mass improve in the MSSM with light slepton-sneutrinos. In particular, the MSSM with sneutrino ($\tilde{\nu}$)s having mass in the range 55 – 80 GeV seems to be preferred by the data[3]. The left slepton masses ($m_{\tilde{\ell}_L}$) are related to $m_{\tilde{\nu}}$ by the SU(2) breaking D-term in a model independent way. In order to make them heavier than the LEP bound moderate or large tan $\beta$ was needed The fit favoured much heavier squarks (mass $\sim$ 1 TeV), was practically independent of $m_A$ (the mass of the pseudoscalar Higgs boson) and $m_{\tilde{\ell}_R}$ (the mass of the right slepton). Gaugino mass unification was assumed although the U(1) gaugino mass parameter had little impact. Mass of the lighter chargino ($m_{\tilde{\chi}^\pm}$) $< 150$ GeV improved the fit although higher masses also had reasonable agreement with the data. Left sleptons and sneutrinos belonging to different generations were assumed to be degenerate.

The emphasis of this paper would be on the possibility of testing the light sneutrino hypothesis via direct searches using existing data. This is especially important since any immediate improvement in the indirect test of this scenario using electroweak data is not feasible. It is gratifying to note that the existing LEP data on single $\gamma$ + missing energy events [7] can indeed shed light on this issue.

However, before taking up the main issue, we want to review briefly a related topic. Is there a theoretically well motivated supersymmetry breaking mechanism which leads naturally to the light slepton scenario? It was noted in Ref.[3] that this scenario cannot be accommodated in the popular minimal supergravity (mSUGRA) model where supersymmetry breaking is driven by gravity mediated interactions leading to a common scalar mass ($m_0$) at a scale which is often assumed, somewhat arbitrarily, to be the GUT scale ($M_G$). In such models the masses of the sleptons and the sneutrinos are correlated. As a result $m_{\tilde{\nu}}$ in the above mass range would inevitably lead to a somewhat lighter right slepton with mass ($m_{\tilde{\ell}_R}$) in conflict with the existing LEP lower bound.

This observation has recently been quantified by the ALEPH collaboration. Their work is based on a model, similar to mSUGRA, with a common $m_0$ and a common gaugino mass at the GUT scale[8]. The limit is based on the data for various sfermion-gaugino searches. No direct sneutrino signal was searched for. Yet from the absence of any slepton signal they obtained a model dependent lower bound on the sneutrino mass ($m_{\tilde{\nu}} > 84$ GeV) by exploiting the correlation between slepton and sneutrino masses.

Possible alternative scenarios with light sleptons were qualitatively discussed in Ref.[3]. It was noted that if $m_0$ is generated at the Planck scale ($M_P$) instead of $M_G$ then the running
between $M_P$ and $M_G$ may indeed lead to a somewhat larger $m_{\tilde{\ell}_R}$ at the weak scale. This avoids the conflict with the LEP bound. In fact an inspection of this running within the framework of an SU(5) SUSY GUT, as given in Ref.[9], would encourage this scenario. The other viable model proposed was the anomaly mediated supersymmetry breaking (AMSB) model[10]. In the latter model, without any additional assumption, the slepton-sneutrino masses turn out to be tachyonic. In the simplest version of this model one adds a common soft breaking term making the mass squared terms positive. The slepton mass can, therefore, be arbitrarily small and apparently the light slepton-sneutrino scenario can be accommodated.

Both the above solutions, however, lead to an unstable electroweak symmetry breaking vacuum[11, 12] as the potential becomes unbounded from below[13]. In fact in the case of the AMSB model the requirement of vacuum stability leads to a lower bound on the slepton mass which after allowing for all theoretical uncertainties is approximately 300 GeV[12]. Of course one can argue that we are living in a false vacuum with a life time larger than the age of the universe[14] which makes the requirement of vacuum stability redundant. However, it is difficult to accept this solution uncritically. First of all the calculation of the probability of tunnelling from the false vacuum to the true one, which is rather straightforward in a model with a single scalar, becomes far too complicated in the MSSM with multiple scalars. In fact the earlier calculations of this probability have been criticized by more recent ones (see the second paper of Ref.[14]). Yet there is no way of testing the reliability of the recent calculations as they cannot be verified experimentally. Furthermore tunnelling being a probabilistic phenomenon, the unpleasant possibility that charge and colour symmetry will be broken at the very next moment always remains open. In our opinion, therefore, the false vacuum scenario should remain as a theoretical curiosity unless the complete determination of the sparticle spectrum in future experiments points unmistakably to a set of SUSY parameters leading to an unstable electroweak symmetry breaking vacuum.

In view of the above discussions it is prudent to look for a model with light sleptons without jeopardizing the stability of the vacuum. Such a scenario arises when an SO(10) SUSY GUT directly breaks down to the SM gauge group[11]. Certain U(1) symmetry breaking $D$-terms at $M_G$[15] can then lead to a sparticle spectrum with right sleptons naturally heavier than the left slepton/sneutrinos. In fact it was shown in Ref.[11] that in this model one may have sneutrinos in the mass range preferred by the precision electroweak data while the right selectron mass is beyond the kinematic reach of LEP.

This is not to suggest that the above model is the only or even the most appealing model with light sneutrinos. It simply demonstrates that the physics at $M_G$ or $M_P$ involves too many uncertainties to determine precisely from the boundary conditions at $M_G$, what the sparticle spectrum at low energies should look like. Any mass spectrum apparently preferred by the data should, therefore, be taken seriously irrespective of being favoured or disfavoured by the currently prevailing theoretical prejudices. However, further direct experimental tests to confirm the spectrum is urgently needed. We shall now turn our attention to this task.

If the sneutrino and other sparticle masses are indeed in the range preferred by the
precision electroweak data then the $\tilde{\nu}$ would be the next lightest supersymmetric particle (NLSP), the lightest neutralino ($\tilde{\chi}^0_1$) being the lightest supersymmetric particle (LSP). Such a sneutrino will decay into the invisible mode $\tilde{\nu} \rightarrow \nu \tilde{\chi}^0_1$ with 100% branching ratio (BR). As such sneutrinos will act as carriers of missing energy just like the $\tilde{\chi}^0_1$ in a $R$-parity conserving model, they have been called virtual lightest supersymmetric particle (VLSP) or the effective lightest supersymmetric particle (ELSP)\cite{16}. Such sneutrino pairs produced in association with an energetic photon will lead to the signal $e^+e^- \rightarrow \gamma + \text{missing energy}$\cite{17} This signal if seen over the SM background may indicate the existence of light sneutrinos. In the MSSM there are, however, other processes leading to the same final state. Of course the processes $e^+e^- \rightarrow \gamma \tilde{\chi}^0_1\tilde{\chi}^0_1$ is present in all versions of the $R$-parity conserving model. If the second lightest neutralino ($\tilde{\chi}^0_2$) decays into the channel $\tilde{\chi}^0_2 \rightarrow \tilde{\nu}\nu$ with a large BR, then all processes belonging to the class $e^+e^- \rightarrow \gamma \tilde{\chi}^0_i\tilde{\chi}^0_j$ ($i = 1,2$), will also contribute to the signal. The actual value of this BR, however, is more model dependent as it depends also on $m_{\tilde{\ell}_R}$.

The cross sections of all supersymmetric contributions to $e^+e^- \rightarrow \gamma + \text{missing energy}$ were exactly computed in Ref.\cite{17}. It was shown that with special kinematic cuts (see below) the signal can be seen over the SM background. However, the results of\cite{17} were computed on the basis of 500 pb$^{-1}$ of integrated luminosity collected at $\sqrt{s} = 190$ GeV. More recently LEP has run over a more varied range of $\sqrt{s}$ including energies considerably higher than $\sqrt{s} = 190$ GeV. The total accumulated luminosity\cite{18} also happens to be much larger than that considered in Ref.\cite{17}. Since the sneutrino VLSP signal assumes new significance in the light of the precision electroweak data, a re-examination of the analysis of Ref.\cite{17} is called for.

It may be recalled that all the LEP groups have extensively studied the single $\gamma + \text{missing energy}$ signal\cite{7}. In most of the analyses the cross section of the SM process $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ was measured and the result was then used for neutrino counting. The kinematical cuts were optimized to suppress the backgrounds to this process (radiative Bhabha scattering etc.). This process receives a large contribution when the photon energy is such that an on shell $Z$ is produced which subsequently decays to a $\nu\bar{\nu}$ pair. An appropriate upper cut on the photon energy excludes this radiative return to the $Z$-pole and drastically reduces this cross section\cite{17}. However, in the presence of initial state radiations the photon energy appropriate for radiative return is somewhat smeared and the efficiency of the cut is reduced to some extent (see below). Nevertheless this cut is very useful to improve the signal to background ratio. In a limited number of new physics searches such cuts were also employed by some of the LEP collaborations. For example DELPHI\cite{19} looked for the production of a pair of superlight gravitinos in association with a photon, where $E_\gamma$ was restricted to $E_\gamma < 50$ GeV. The dynamics and kinematics of this process is, however, quite different from the production of a pair of heavy sneutrinos and their conclusions cannot be extended to the case under study in a straightforward way.

In the following we shall repeat the analyses of Ref.\cite{17} for realistic energies and luminosities. We, however, find that the data collected at a particular energy or by a particular
group is not enough to produce a signal to background ratio which is statistically significant. On the other hand, if the data from all the groups at different energies are combined more significant results may be obtained. Admittedly this is a difficult task and should be carried out by the experts. In particular combining the systematics of different experiments requires special care. Moreover, the integrated luminosities accumulated by each group at a given energy are not always available. For example, in the energy range \( \sqrt{s} = 191.6 - 201.6 \text{ GeV} \) the total luminosity collected by OPAL is said to be 212 pb\(^{-1}\). We could not find out further break-ups. On the other hand the break-ups of the total luminosity collected by the other groups at different energies in this range were available in most cases (see Table 1)[18].

The purpose of our simple minded analysis is, therefore, not to obtain rigorous bounds. We are rather interested in illustrating the sensitivity of the existing data to sneutrino masses in the range preferred by the precision electroweak data. We, therefore, often take recourse to various approximations. For example, we roughly estimate the OPAL luminosity at a particular \( \sqrt{s} \), by scaling the corresponding quantity given by another group, by the ratio of the total luminosity collected by OPAL and the other group in the entire energy range. Whenever the detailed break-ups were not available, we employed this approximation. The information that we could gather from the literature[18] is summarized in Table 1:

| \( \sqrt{s} \) (GeV) | ALEPH | DELPHI | L3 | OPAL | Total \( \int \mathcal{L} \) (pb\(^{-1}\)) |
|----------------------|--------|--------|----|------|-----------------|
| 188.6                | 173.6  | 154.7  | 176.4 | 177.3 | 682.0           |
| 191.6                | 28.9   | 25.9   | 29.5 | \( \sim 25.7 \) | \( \sim 110.0 \) |
| 195.5                | 79.9   | 76.4   | 83.0 | \( \sim 73.0 \) | \( \sim 312.3 \) |
| 199.5                | 87.0   | 83.4   | 82.1 | \( \sim 76.8 \) | \( \sim 329.3 \) |
| 201.6                | 44.4   | 40.6   | 36.9 | \( \sim 36.4 \) | \( \sim 158.3 \) |
| 203.7                | \( \sim 6.9 \) | 8.4    | \( \sim 8.5 \) | \( \sim 6.3 \) | \( \sim 30.1 \) |
| 205.2                | 75.3   | 76.2   | \( \sim 77.9 \) | \( \sim 57.8 \) | \( \sim 287.2 \) |
| 206.7                | 122.6  | 121.6  | \( \sim 125.6 \) | \( \sim 93.2 \) | \( \sim 463.0 \) |
| 208.2                | 9.4    | 8.3    | \( \sim 9.1 \) | \( \sim 6.8 \) | \( \sim 33.6 \) |
| Total                | 628.0  | 595.5  | \( \sim 629.0 \) | \( \sim 553.3 \) | 2405.8          |

Table 1. The breakups for luminosities accumulated by the LEP groups in different \( \sqrt{s} \)-bins in the range 188.6 < \( \sqrt{s} \) < 208.2 GeV. The approximated luminosities are indicated explicitly and follow from the treatment explained in the text.

In Table 2 we present a sample analysis. For this analysis we assume gaugino mass unification and the slepton masses to be flavour independent. The SUSY parameters are chosen to be \( m_{\tilde{e}} = 56 \text{ GeV} \), \( M_2 \) (the SU(2) gaugino mass) = 110 GeV, \( \mu \) (the higgsino mass parameter) = \( -300 \text{ GeV} \) and \( \tan \beta \) (the ratio of the vacuum expectation values of the
two Higgs bosons) = 10. These immediately lead to the following mass pattern: $m_{\tilde{\ell}_L}$ (the mass of the left slepton) = 96.96 GeV, $m_{\tilde{\chi}^\pm}$ (the mass of the lighter chargino) = 106.5 GeV, $m_{\tilde{\chi}_1^0}$ (mass of the lightest neutralino) = 55.1 GeV and $m_{\tilde{\chi}_2^0}$ (the mass of the second lightest neutralino) = 106.3 GeV. The mass of the right slepton ($m_{\tilde{\ell}_R}$) cannot be fixed without further assumption. We assume it to be 100 GeV. As discussed above $\tilde{\chi}_2^0$ can decay into charged leptons and sleptons and, hence, may not decay into the invisible channel $\nu \bar{\nu}$ with 100% BR. In order to obtain a conservative estimate we, therefore, ignore the $\tilde{\chi}_1^0 + \tilde{\chi}_2^0 + \gamma$ events, although a significant fraction of such events may also lead to the signal under study. Thus in practice the signal in Table 2 can be somewhat larger than what has been shown.

The kinematic cuts imposed are as follows. Only hard photons emitted into the angular interval $15^\circ < \theta_\gamma < 165^\circ$ are considered, where $\theta_\gamma$ is the polar angle of the photon with respect to the beam direction. Roughly speaking this covers the barrel and the end cap regions of a typical LEP detector. Of course, the detailed geometries are different for different experiments. The detection efficiency of photons, which is detector dependent, is taken to be unity for simplicity. There is a lower cut on the photon energy $E_\gamma$ (or $p_T\gamma$) which along with the above angular cuts reduces the background from radiative Bhabha scattering and other processes. This lower cut on photon energy is parametrized by a variable $x_\gamma$ defined to be $x_\gamma = E_\gamma / E_{\text{beam}}$. Typically the LEP experiments require $x_\gamma > 0.06$ in the barrel regions and $x_\gamma > 0.1$ in the end cap regions. As we are trying to include the end cap region in our analysis we conservatively set $x_\gamma > 0.09$ for all $\theta_\gamma$ which is likely to compensate for the gaps actually present between the end cap and the barrel regions that we neglect in our analysis. In addition there should be an upper cut on the photon energy to exclude events with radiative return to the $Z$-pole. Again, in principle, this cut should be a function of $\sqrt{s}$ and $m_\nu$ to be probed. But in our simple minded analysis the photon energy is restricted to the range $E_{\text{min}} < E_\gamma < 60$ GeV at all c.m. energies. The signal to background ratio can be further improved by optimizing the upper cut with beam energy and $m_\nu$. 
Table 2. The signal and the background rates for different values of \( \sqrt{s} \). The kinematic cuts employed are \( 15^\circ < \theta_\gamma < 165^\circ \), \( E_\gamma^{\text{min}} < E_\gamma < 60 \text{ GeV} \) where \( E_\gamma^{\text{min}} = x_\gamma E_b \). The SUSY parameters are \( \mu = -300 \text{ GeV} \), \( \tan \beta = 10 \) and \( M_2 = 2M_1 = 110 \text{ GeV} \), \( m_{\tilde{\nu}} = 56 \text{ GeV} \), \( m_{\tilde{\nu}_L} = 96.96 \text{ GeV} \) and \( m_{\tilde{\nu}_R} = 100 \text{ GeV} \).

A few remarks on the method of calculation are now in order. It was noted in Ref.[17] that the cross section for \( e^+e^- \rightarrow \bar{\nu}\nu\gamma \) calculated by us was smaller than the cross sections reported by other groups. Subsequently we found a sign error in one of the interfering amplitudes and our results are now in exact agreement with the other groups. The cross section corrected for initial state radiation as discussed in Ref.[17], agrees nicely with the result obtained by using the package CompHEP[20]. There was also a sign error in one of the interfering amplitudes for the process \( e^+e^- \rightarrow \tilde{\nu}\tilde{\nu}^*\gamma \) which underestimated the signal cross section. Since both the signal and the background were underestimated in Ref.[17], the conclusions were roughly correct albeit somewhat fortuitously. After corrections our result for \( e^+e^- \rightarrow \tilde{\nu}\tilde{\nu}^*\gamma \) agrees with that from CompHEP. Also, the cross sections of \( \chi_1^0 \) pair + \( \gamma \) production is in agreement with results from CompHEP. All the results in Table 2 have been obtained by CompHEP and cross checked against our corrected codes.

In Table 2 the cross sections are given for SUSY parameters and kinematic cuts as discussed above. In column 2 we present the cross section for \( e^+e^- \rightarrow \bar{\nu}\nu\gamma \). The first number corresponds to cross section of the bare process and the number in parenthesis to that corrected for initial state radiations. The latter is somewhat larger than the former for reasons discussed above. The SUSY signal cross sections are presented in columns 3 and 4, while the total integrated luminosity at each energy as given by Table 1, is presented.
in column 5. It was already noted in Ref.[17] that the signal cross sections are by and large unaffected by correcting for initial state radiation. The number of background events without (with) initial state radiation is given in column 6, while the total number of signal events (obtained from the information in column 3, 4 and 5) is given in column 7. It is quite clear that the signal(S) to $\sqrt{\text{background}}(B)$ ratio at any particular energy is not statistically very significant. However, adding the numbers in the last two columns of Table 2 as shown in the last row, we find that $S/\sqrt{B}$ is 4.4 if initial state radiation is taken into account.

It may be recalled that the range of the sneutrino mass preferred by the precision electroweak data is $55 \text{ GeV} < m_{\tilde{\nu}} < 80 \text{ GeV}$. On the face of it, therefore, it appears as though only the lower edge of this mass range can be probed. However, there are some opportunities for improvement. First of all LEP data above the Z-pole may be considered (the present analysis is restricted to $\sqrt{s} > 189 \text{ GeV}$). In view of the approximate nature of the present analysis we made no attempt to optimize the cuts. For example, a fixed upper cut on $E_{\gamma}$ has been employed in the present analysis at all energies. Alternatively cuts suitably tailored for probing a particular $m_{\tilde{\nu}}$ at a specific C.M. energy may be employed. Finally the contribution of $e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_2^0\gamma$, where $\tilde{\chi}_2^0$ also decay invisibly, may further enhance the signal.

There are reasons to be optimistic about this analysis. It is encouraging to note that there is already an attempt[21] to combine the single photon + missing energy data, at all energies above the Z-pole, of the four LEP groups to constrain some new physics scenarios. From the combined recoil mass (M) distribution it even appears that there is a modest excess of events over the SM background for M $\geq 160 \text{ GeV}$. It should be relatively straightforward to extend this analysis to the case of a pair of heavy invisible sneutrinos produced in association with the photon. If no signal is found, some sneutrino masses in the range preferred by the precision data will be excluded. Even this is an improvement over the current weak lower bound on $m_{\tilde{\nu}}$ ($\approx 0.5m_Z$) obtained from the Z-pole data. Of course the latter bound is model independent, while one under consideration depends on gaugino mass unification and on assumptions about $m_{\tilde{\nu}_R}$. Yet for the first time one will probe $m_{\tilde{\nu}}$ through direct production of invisible sneutrino pairs even if sleptons are beyond the kinematic reach of LEP. In that sense the model dependent assumptions employed are quite different from the assumptions implicit in mSUGRA. The bounds obtained by this method will therefore be complimentary to that obtained, e.g., in Ref.[8]. How a completely model independent bound can be obtained by this method will be discussed below.

Since $m_{\tilde{\nu}_R}$ was somewhat arbitrarily chosen in our analysis, some discussion of the sensitivity of the signal to this parameter is in order. This parameter does not affect the cross section of $e^+e^- \rightarrow \tilde{\nu}\tilde{\nu}^*\gamma$ which is by far the dominant contribution to the signal for low and moderate $m_{\tilde{\nu}}$. However, if $m_{\tilde{\nu}}$ is close to the upper end of the range preferred by the electroweak precision data, the observability of the signal can indeed be affected by $m_{\tilde{\nu}_R}$ as can be seen from Figure 1 drawn for $\sqrt{s} = 205 \text{ GeV}$. The upper (lower) curve corresponds to $m_{\tilde{\nu}_R} = m_{\tilde{\nu}_L}$ ($m_{\tilde{\nu}_R} = 1.5m_{\tilde{\nu}_L}$). The other SUSY parameters are as in Table 2. The background cross section at this energy is given in Table 2.
One can use the absence of signal to put a lower bound on the mass of any invisible sneutrino in a model independent way. If we do not make any additional assumption like gaugino mass unification then the neutralino contributions to the $\gamma + \text{missing energy}$ signal is uncorrelated to the sneutrino contribution. The most conservative lower bound on the sneutrino mass can, therefore, be obtained by comparing the data with the sneutrino contribution alone, which is independent of $m_{\tilde{\nu}_R}$.

For $\tilde{\nu}_\mu$ and $\tilde{\nu}_\tau$ only the $Z$-mediated $s$-channel diagrams contribute. Hence, the cross sections are model independent and depend on $m_{\tilde{\nu}}$ alone. The $\tilde{\nu}_e$ contribution depends on $m_{\tilde{\nu}}, M_2, \mu$ and $\tan \beta$. The last three parameters determine the chargino mass and its coupling with the sneutrino. The amplitude has two pieces: the $s$-channel $Z$-exchange terms and the $t$-channel chargino exchange terms. The key observation is that the interference among the $s$-channel and $t$-channel diagrams are always constructive for all choices of $M_2, \mu$ and $\tan \beta$. Thus the smallest possible signal cross section can be obtained by neglecting the contribution of the $t$-channel diagrams. This corresponds to infinite chargino mass or Higgsino dominated charginos, completely decoupled from the sneutrinos. Now one obtains the minimum signal as a function of $m_{\tilde{\nu}}$ only by assuming three generations of degenerate sneutrinos.

Considering only the $s$-channel contribution to the signal we find 96(64) events for $m_{\tilde{\nu}} = 50(55)$ GeV for the entire energy range shown in Table 2. Such a small signal will be swamped by the background. Obviously the current data alone is not adequate to significantly strengthen the existing model independent lower bound on $m_{\tilde{\nu}}$. However, the size of the signal at the Next Linear Collider as given in [17] suggests that if no signal is found a model independent bound may emerge. The inclusion of other SUSY contributions in specific models, can only strengthen this bound.

Light sneutrinos in the mass range indicated by the precision electroweak data may dramatically influence the SUSY search strategies at the upgraded Tevatron. It has been
already been noted since long back, that the hadronically quiet trilepton $+ \not{E}_T$ event resulting from $\tilde{\chi}_1^0\tilde{\chi}_2^0$ pairs is the best channel for SUSY search at this machine[22]. In the presence of light sneutrinos, however, many of the $\tilde{\chi}_2^0$s will decay into the invisible channel $\nu - \tilde{\nu}^*$. Thus the trilepton channel may be considerably weakened or wiped out depending on the BR of the invisible channel, which is model dependent. On the other hand $\tilde{\chi}^\pm$ pair also has a healthy production cross section at the upgraded Tevatron [22]. Since these charginos will decay into the two body channel $l + \tilde{\nu}$ with a large BR, the opposite sign dilepton $+ \not{E}_T$ signal will be enhanced [23]. Suitable kinematical cuts can show this signal over WW and other relevant backgrounds. From the results of [23] it appears that the entire range of $m_\tilde{\nu}$ preferred by the electroweak data can be probed.

**Acknowledgements** : AD thanks Professor H. Dreiner and other members of the Theoretical Physics Group, University of Bonn where part of the work was done. He thanks Professor M. Kobel for discussions. Aseshkrishna Datta is supported by French MNERT fellowship and subsequently by CNRS France. He also likes to thank the Theoretical Physics Group of Abdus Salam ICTP, Trieste for a visit during summer 2001 where this project was started.

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