DELPHI Collaboration DELPHI 2001-069 CONF 497
3 July, 2001

Search for AMSB with the DELPHI data

T. Alderweireld[1], **P. Johansson**[2], **A. Lipniacka**[2], **S. Paiano**[3], **A. Perrotta**[3]
[1] Faculté des Sciences, Université de l'Etat Mons, Mons, Belgium
[2] Fysikum, Stockholm University, Box 6730, S-113 85 Stockholm, Sweden
[3] Dipartimento di Fisica, Università di Bologna and INFN, Bologna, Italy

Abstract

The data collected by the DELPHI experiment up to the highest LEP2 energies were used to put constraints on the Anomaly Mediated SUSY Breaking model with a flavour independent m_0 parameter. The experimental searches covered many possible signatures experimentally accessible at LEP, with either the neutralino, the sneutrino or the stau being the LSP. They included the search for nearly mass degenerate chargino and neutralino (always present in AMSB), the search for stable staus, and the search for cascade decays resulting in the LSP (neutralino or sneutrino) and a low multiplicity final state containing neutrinos.

Contributed Paper for EPS HEP 2001 (Budapest) and LP01 (Rome)

1 Introduction

After many years of searches in the collider experiments, there is still no evidence of the existence of supersymmetric particles. There are indeed several theoretical motivations to believe that nature must be supersymmetric and that the so far negative results of the searches can only set constraints on the spectrum of the SUSY particles and on the parameters of the model. The mechanism of SUSY breaking itself is still unclear. In the gravity mediated scenario (SUGRA), SUSY gets broken in a hidden sector and the breaking is transmitted gravitationally to the observable sector. This mechanism is elegant, since it only requires already existing fields and interactions (like gravity). It suffers however from the so called SUSY flavour problem, that is the minimal version of SUGRA (mSUGRA) requires a large amount of fine tuning to avoid unobserved large Flavour Changing Neutral Current effects.

To cope with the SUSY flavour problem, different breaking mechanisms have been inspected. In the Gauge Mediated SUSY Breaking scenario (GMSB) the breaking is transmitted via gauge forces. It gives a very characteristic mass spectrum, with a light gravitino as the Lightest Supersymmetric Particle (LSP) and typically long lived NLSP's.

Anomaly Mediated Supersymmetry Breaking (AMSB) [1, 2] is another interesting solution to the flavour problem of mSUGRA. Rescaling anomalies in the supergravity lagrangian always gives rise to soft mass parameters in the observable sector. It follows that anomalies contribute to the SUSY breaking in any case, whatever is the symmetry breaking mechanism. We'll refer to AMSB as the model in which all other components that mediate the SUSY breaking are suppressed, and the anomaly mediation is the dominant mechanism.

AMSB is very predictive: all the low energy phenomenology can be derived by adding to the Standard Model (SM) just two extra parameters and one sign. Unfortunately, the minimal AMSB model results in tachyonic masses for sleptons at the electroweak scale. One way of getting rid of tachyons is to suppose additional, non anomaly, contributions to the SUSY breaking which can generate a positive contribution to the soft masses squared. There are few string motivated solutions that generate such positive contribution without spoiling the RG invariance of the soft terms. In most cases, such contribution is universal for all sfermion masses and it is practically enough to add just one extra parameter to the model. This arises, for instance, if the visible and the hidden sectors lie in separate 3-branes that communicate only through gravitation [1]. There are other solutions [3] that lead to flavour dependent mass terms; such possibilities are less predictive (since the sfermion spectrum depends on more parameters) and will not be investigated further in this note. However, the characteristic gaugino spectrum of AMSB is the same also for those models, and many of the considerations that follows can be applied also to them.

2 Phenomenology of AMSB

If there is only one common squared mass term for all scalars, all masses and couplings can be derived in terms of just three parameters and one sign:

- the mass of the gravitino, $m_{3/2}$;
- the ratio of the vacuum expectation values, $\tan\beta$;

- the common scalar mass parameter m_0.
- the sign of the Higgs term, $sign(\mu)$.

In this context, m_0 can even be considered as a phenomenological term that parameterizes the lack of knowledge of the method with which the sleptons acquire physical masses.

Low energy gaugino masses, scalar masses and trilinear couplings in AMSB are given by:

$$M_i = \frac{\beta_g}{g} m_{3/2} \quad (1)$$

$$M_{\tilde{Q}}^2 = -\frac{1}{4}\left(\frac{\partial\gamma}{\partial g}\beta_g + \frac{\partial\gamma}{\partial y}\beta_y\right) {m_{3/2}}^2 + {m_0}^2 \quad (2)$$

$$A_y = -\frac{\beta_y}{y} m_{3/2} \quad (3)$$

where g are the gauge couplings, y the Yukawa couplings and γ and β are renormalization group functions. This soft mass spectrum has distinctive features [2] which differ from the usual SUGRA or GMSB scenarios.

- The gravitino is heavy (and this has several advantages for the cosmology).
- The ratios of gaugino masses at the electroweak scale are determined by the ratios of the corresponding β functions. Therefore, they assume in a natural way different values with respect to the theories with gaugino mass unification at GUT:

  $$M_1 : M_2 : M_3 \simeq 2.8 : 1 : -8.3 \quad (4)$$

  These ratios have been computed by including the largest next to leading corrections [2]. Typical values of μ allowed by the model imply $M_2 < M_1 < |\mu|$. The chargino and neutralino mass eigenstates are therefore well approximated by either pure gaugino and pure higgsino states, with $M_{\tilde{\chi}_1^0} \sim M_{\tilde{\chi}_1^\pm} \sim M_2$, $M_{\tilde{\chi}_2^0} \sim M_1$, $M_{\tilde{\chi}_{3,4}^0} \sim M_{\tilde{\chi}_2^\pm} \sim |\mu|$, and the lightest chargino and neutralino are always a nearly mass degenerate triplet of gauginos.
- Squark masses are rather insensitive to m_0. AMSB implies squarks and gluinos much heavier than the LSP's, completely out of reach at LEP and also at many of the proposed future colliders.
- In the slepton sector, if both the R and the L states receive the same ${m_0}^2$ contribution, the diagonal entries of the mass matrix are accidentally highly degenerate. Nearly mass degenerate and highly mixed same flavour sleptons are a distinctive feature of the minimal AMSB with a flavour independent m_0. The lightest stau is always the lightest charged slepton. The sneutrino can be lighter than all charged sleptons, and typically the stau sneutrino is the lightest sneutrino.
- The CP-odd neutral Higgs A is usually much heavier than the Z, and the lightest CP-even neutral Higgs h^0 is analogous to the SM one [6]. Also the mass of h^0 is still more tightly bounded than in the usual SUSY scenarios, and it should lie in the range 80-120 GeV/c^2. Therefore, the lower limit obtained at LEP for the SM

Higgs mass already strongly constrains the AMSB parameter space. Moreover, if such a light Higgs will not be found in the first runs at the Tevatron or, further on, at the LHC, the AMSB itself will be completely ruled out.

In the model considered here, only the slepton mass spectrum and, to some extent, the Higgs depend on the assumptions of a common scalar term m_0. All other features are characteristics of any AMSB scenario, whatever is the procedure used to cope with the tachyonic masses of the sleptons.

Since m_0 is a free parameter, according to its value there are three possible candidates for the LSP: either the nearly mass degenerate $\tilde{\chi}_1^0/\tilde{\chi}_1^{\pm}$, the $\tilde{\nu}$ or the $\tilde{\tau}$. Scenarios with any of the above as LSP will be explored in the following by using the data collected by the DELPHI experiment during the period at high (LEP2) and low (LEP1) energy of the LEP operation.

3 Data and simulation samples

The results listed in this paper reinterpret in terms of AMSB the results of searches performed in the DELPHI experiment [7] at LEP. Those searches are described in more details in the relevant papers cited in the following sections. Some of them were used unmodified. In other cases, that are described in the following, it was necessary to adapt the original techniques to the requirements specific of the AMSB scenarios. If not otherwise specified in the text, refer to the papers cited for the description of the samples of the data and of the Standard Model background simulation used in the different analyses.

SUSYGEN [4] was used for signal simulation. As it does not allow for the calculation of the particle spectrum of the AMSB models, the input parameters were set in a way to obtain a spectrum close to the one resulting from the precise calculations in the AMSB framework of [2].

ISAJET [5], since version 7.47, allows the calculation of the particle masses and decay branching modes of the AMSB model of [1, 2] as a function of the four parameters m_0, $m_{3/2}$, $\tan\beta$ and $sign(\mu)$. At the moment only the Leading Order (LO) corrections to masses are included in ISAJET. For a meaningful quantitative comparison with experimental results it would be advisable to use a level of precision comparable with the exact calculations [2], which can be achieved upgrading ISAJET with Next-to-Leading Order (NLO) calculations.

In this paper, ISAJET will be used to gain some qualitative idea on the AMSB spectra. The updated code containing the NLO calculations will permit a direct test of the predictions of the model. In section 5, as an exercise, a preliminary comparison of the experimental results with the predictions of ISAJET 7.51 (LO) is attempted.

4 Searches used to investigate the AMSB scenario

4.1 LEP1 limits

The precise measurement of the Z width at LEP1 put severe constraints on all possible non standard contributions. In particular, charginos with mass below 45 GeV/c^2 and sneutrinos with mass below 43 GeV/c^2 were ruled out, independently of their field composition and decay modes [8].

4.2 Search for nearly mass degenerate chargino-neutralino

One of the key features of AMSB is the very small difference between the masses of the lightest chargino and neutralino. Therefore, the results of the search for nearly mass degenerate chargino and neutralino [9] can be used to investigate AMSB. To maximize the sensitivity to AMSB scenarios, the analysis of [9] was redone under the following assumptions:

- only the gaugino case is of interest for AMSB;
- in the scan over the SUSY parameters, the ratio M_1/M_2 was fixed at 2.8;
- two additional scenarios were explored, both of them involving a possible light sneutrino. In one scenario, the sneutrino was considered to be close in mass with the chargino (and the neutralino). In this case the chargino production cross-section is to be suppressed by the t-channel sneutrino exchange, and the chargino decays promptly. Minimal chargino production cross-section was considered. The second scenario is applicable for $M_{\tilde{\chi}_1^\pm} + 1\mathrm{GeV}/c^2 < M_{\tilde{\nu}} < 500\ \mathrm{GeV}/c^2$. The minimal cross-section allowed for $M_{\tilde{\chi}_1^\pm} < M_{\tilde{\nu}}$ was considered, and the possibility that the chargino is long-lived was examined.

The results of the search are practically the same as in [9]. The only difference is in the hypothesis of a light sneutrino (either lighter than the chargino or not more than a couple of GeV/c^2 heavier), where the leptonic width gets largely enhanced and the lifetime shortens: in that case, the efficiencies at the smallest $\Delta M = M_{\tilde{\chi}_1^\pm} - M_{\tilde{\chi}_1^0}$ are larger than the ones computed in [9] for the same ΔM.

The lack of evidence of excesses above the expectations, as discussed in [9], allows the exclusion at the 95% CL of points in the plane ($M_{\tilde{\chi}_1^\pm}$,ΔM). Figure 1 shows the regions excluded by the different techniques used in the search for degenerate charginos (the search for long-lived charginos with the veto in the Cherenkov counters and/or an anomalous specific ionization in the TPC, or the search for displaced decay vertices; the search for few soft particles accompanied by a high p_{t} photon). Figure 1 (a) is a repetition of the plot with the gaugino exclusion in [9], and includes AMSB scenarios when $M_{\tilde{\nu}} > 500\ \mathrm{GeV}/c^2$. Figure 1 (b) was obtained with the minimal chargino cross-section (with respect to $M_{\tilde{\nu}}$) and with the lifetime corresponding to $M_{\tilde{\nu}} = M_{\tilde{\chi}_1^\pm} + 1\ \mathrm{GeV}/c^2$. This exclusion can be considered as conservative for all AMSB scenarios with $M_{\tilde{\chi}_1^\pm} + 1\mathrm{GeV}/c^2 < M_{\tilde{\nu}} < 500\mathrm{GeV}/c^2$, since as $M_{\tilde{\nu}}$ increases the s-t channels interference weakens and the cross-sections gets larger; moreover, also the lifetime increases, thus adding sensitivity to all searches for long-lived charginos. Figure 1 (c) is applicable for the minimal chargino cross-section (again with respect to $M_{\tilde{\nu}}$) and for short lived charginos. It can be used to constrain AMSB scenarios with $M_{\tilde{\nu}} < M_{\tilde{\chi}_1^\pm} + 1\mathrm{GeV}/c^2$ (see also section 4.3).

4.3 Search for $\tilde{\chi}_1^\pm \to \tilde{\nu} l^\pm$ decays

If the sneutrino is lighter than the chargino, the chargino decays with practically 100% branching ratio into a sneutrino and a charged lepton. The 'fully leptonic' search for charginos described in [9] can be used to explore this scenario for all $\Delta M_{\tilde{\nu}} = M_{\tilde{\chi}_1^\pm} - M_{\tilde{\nu}}$ larger than 3 GeV/c^2. The upper limits on the chargino cross-section were obtained in [9]

$< E_{cm} >$ (GeV):	191.6	195.6	199.6	201.7	204.9	206.7	208.2
$\int \mathcal{L}$ (pb^{-1}):	25.8	76.8	84.3	40.5	78.3	78.8	7.2
	$3 \leq \Delta M_{\tilde{\nu}} < 5$ GeV/c^2						
Obs. events:	3	21	23	11	25	28	1
Expect. events:	$8.5\,^{+0.8}_{-0.5}$	$25.4\,^{+2.2}_{-1.6}$	$25.5\,^{+2.0}_{-1.4}$	$12.3\,^{+1.0}_{-0.7}$	$26.0\,^{+2.2}_{-1.6}$	$26.3\,^{+2.2}_{-1.6}$	$2.4\,^{+0.2}_{-0.1}$
	$5 \leq \Delta M_{\tilde{\nu}} < 10$ GeV/c^2						
Obs. events:	2	2	4	5	8	8	2
Expect. events:	$1.3\,^{+0.4}_{-0.2}$	$3.8\,^{+1.1}_{-0.5}$	$4.2\,^{+1.0}_{-0.4}$	$2.1\,^{+0.5}_{-0.2}$	$5.0\,^{+1.2}_{-0.5}$	$5.1\,^{+1.2}_{-0.5}$	$2.8\,^{+0.2}_{-0.2}$
	$10 \leq \Delta M_{\tilde{\nu}} < 25$ GeV/c^2						
Obs. events:	1	5	11	5	9	13	1
Expect. events:	$1.6\,^{+0.4}_{-0.1}$	$5.0\,^{+1.0}_{-0.3}$	$8.3\,^{+1.1}_{-0.5}$	$4.1\,^{+0.6}_{-0.3}$	$9.0\,^{+1.3}_{-0.6}$	$9.0\,^{+1.3}_{-0.6}$	$0.8\,^{+0.1}_{-0.1}$
	$25 \leq \Delta M_{\tilde{\nu}} < 35$ GeV/c^2						
Obs. events:	2	11	8	3	11	14	1
Expect. events:	$2.8\,^{+0.4}_{-0.2}$	$9.0\,^{+1.1}_{-0.4}$	$10.6\,^{+1.0}_{-0.4}$	$5.1\,^{+0.5}_{-0.2}$	$10.1\,^{+1.1}_{-0.5}$	$10.2\,^{+1.1}_{-0.5}$	$0.9\,^{+0.1}_{-0.1}$
	$35 \leq \Delta M_{\tilde{\nu}} < 50$ GeV/c^2						
Obs. events:	6	20	13	5	13	15	2
Expect. events:	$5.5\,^{+0.4}_{-0.2}$	$16.0\,^{+1.1}_{-0.5}$	$18.0\,^{+1.1}_{-0.5}$	$8.5\,^{+0.5}_{-0.3}$	$17.3\,^{+1.2}_{-0.6}$	$17.5\,^{+1.2}_{-0.6}$	$1.6\,^{+0.1}_{-0.1}$
	50 GeV/$c^2 \leq \Delta M_{\tilde{\nu}}$						
Obs. events:	9	32	18	8	25	17	2
Expect. events:	$8.4\,^{+0.5}_{-0.2}$	$23.8\,^{+1.2}_{-0.6}$	$26.5\,^{+1.2}_{-0.6}$	$12.8\,^{+0.6}_{-0.3}$	$22.7\,^{+1.2}_{-0.6}$	$22.9\,^{+1.2}_{-0.6}$	$2.3\,^{+0.1}_{-0.1}$
	TOTAL (logical .OR. between different $\Delta M_{\tilde{\nu}}$ windows)						
Obs. events:	11	59	40	17	49	49	3
Expect. events:	$18.1\,^{+0.9}_{-0.6}$	$53.6\,^{+2.4}_{-1.8}$	$51.4\,^{+2.1}_{-1.6}$	$24.8\,^{+1.1}_{-0.8}$	$50.2\,^{+2.4}_{-1.7}$	$50.7\,^{+2.4}_{-1.8}$	$4.6\,^{+0.2}_{-0.1}$

Table 1: The number of events observed in data and the expected number of background events in the search for chargino decaying into a sneutrino and a charged lepton, at the centre-of-mass energies collected by DELPHI in 1999 and 2000.

assuming W decays for the chargino, and they cannot be translated directly into limits in the supposed decay mode. To explore the AMSB scenario, new limits were computed assuming only leptonic decays. For $\Delta M_{\tilde{\nu}} < 3$ GeV/c^2 the results of the search for nearly mass degenerate charginos can be used, the ones obtained in the light sneutrino hypothesis and once substituting ΔM with $\Delta M_{\tilde{\nu}}$.

For the large $\Delta M_{\tilde{\nu}}$ analysys, table 1 summarizes the number of events observed and expected, and the luminosities collected and used at the different centre-of-mass energies. No excess is observed above the SM expectations. The efficiencies at the centre-of-mass energy of 208 GeV (as example) of the fully leptonic selection are plotted in figure 2 (a) as function of the chargino and sneutrino masses. Since up to five visible charged particles were allowed [9], those efficiencies had only very little dependence on the flavour of the charged lepton in the final state.

There was no evidence of excess above the SM expectations: figure 2 (b) displays the 95% CL upper limit of the chargino cross-section at the reference centre-of-mass energy of 208 GeV, as function of the masses of the chargino and of the sneutrino. If that exclusion is compared with the theoretical expectation of the same cross-section (in figure 2 (c) is shown the minimal expected $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-$ cross-section, as function of $M_{\tilde{\nu}}$), one can exclude a region in the plane ($M_{\tilde{\chi}_1^\pm}$,$M_{\tilde{\nu}}$) at the same confidence level: the excluded region is shown in figure 2 (d). The exclusion when $0 < \Delta M_{\tilde{\nu}} < 3$ GeV/c^2, as obtained with the results of the search for mass degenerate charginos, can be derived from figure 1 (c), by simply substituting ΔM with $\Delta M_{\tilde{\nu}}$ in the y axis. For $M_{\tilde{\chi}_1^\pm} < 54$ GeV/c^2, only a narrow band that corresponds to $0 < \Delta M_{\tilde{\nu}} < 200$ MeV/c^2 cannot be excluded, at present, by the DELPHI results.

If also the stau, or some other charged slepton, has a mass which is intermediate between the mass of the chargino and that of the sneutrino the considerations above may change drastically. Figure 2 (b) should be intended in that case as the 95% CL upper limit of the chargino cross-section times its branching ratio into $l^\pm\tilde{\nu}$.

4.4 Search for $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0$

Searches for $\tilde{\chi}_1^0\tilde{\chi}_2^0$ production with $\tilde{\chi}_2^0 \to q\bar{q}\tilde{\chi}_1^0$, $\tilde{\chi}_2^0 \to \mu^+\mu^-\tilde{\chi}_1^0$, $\tilde{\chi}_2^0 \to \mathrm{e^+e^-}\tilde{\chi}_1^0$, $\tilde{\chi}_2^0 \to \mathrm{Z}\tilde{\chi}_1^0$, and $\tilde{\chi}_2^0 \to \tilde{\tau}\tau$ decays have been presented in [9]. Limits for production cross-section times branching ratio to the corresponding final state have been set and they range typically from 0.05 pb to 0.2 pb, depending primarily on $M_{\tilde{\chi}_2^0} - M_{\tilde{\chi}_1^0}$.

Since in AMSB $M_1/M_2 \sim 2.8$, and $M_{\tilde{\chi}_1^0} \sim M_{\tilde{\chi}_1^\pm} \sim M_2$ and $M_{\tilde{\chi}_2^0} \sim M_1$, there is relatively little room for the production of $\tilde{\chi}_1^0\tilde{\chi}_2^0$ at the LEP energies. Indeed, only if $\tilde{\chi}_1^0$ is sufficiently light a $\tilde{\chi}_2^0$ almost three times as heavy can be produced in association, as $M_{\tilde{\chi}_1^0} + M_{\tilde{\chi}_2^0}$ must be below $\sqrt{s}$. In that case, the $\tilde{\chi}_2^0$ decays mainly to $\tilde{\chi}_1^0\mathrm{Z}$ and $\tilde{\chi}_1^\pm W^\mp$ [5]. For the $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\mathrm{Z}$ decay, the results of the neutralino searches presented in [9] can be directly used. As in AMSB scenarios the chargino is nearly mass degenerate with the neutralino, the decay $\tilde{\chi}_2^0 \to \tilde{\chi}_1^\pm W^\mp$, with $\tilde{\chi}_1^\pm \to \pi^\mp\tilde{\chi}_1^0$ and $W \to q\bar{q}'$, results in the same final state as $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 q\bar{q}$. Also in this case, limits on $\tilde{\chi}_1^0\tilde{\chi}_2^0$ production with the above final state presented in [9] can be used. However, if the W decays leptonically, a dedicated search is needed, not yet ready for this report.

If there are sleptons with a mass between $M_{\tilde{\chi}_1^0}$ and $M_{\tilde{\chi}_2^0}$, cascade decays of $\tilde{\chi}_2^0$ ($\tilde{\chi}_2^0 \to \tilde{\ell}l$, $\tilde{\ell} \to \tilde{\chi}_1^0 l$) can take place. In this case there are two mass differences ($\Delta M_{\tilde{\ell}}$) characterizing the process: $M_{\tilde{\chi}_2^0} - M_{\tilde{\ell}}$ and $M_{\tilde{\ell}} - M_{\tilde{\chi}_1^0}$. It was verified that if $\tilde{\ell} = (\tilde{\mu}, \tilde{\mathrm{e}})$ the results of the searches for the $\tilde{\chi}_2^0 \to \mu^+\mu^-\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \to \mathrm{e^+e^-}\tilde{\chi}_1^0$ can be used, provided that from the $\Delta M_{\tilde{\ell}}$ definitions above the one giving the more conservative result is used in place of $M_{\tilde{\chi}_2^0} - M_{\tilde{\chi}_1^0}$. For $\tilde{\tau}_1$ as the intermediate slepton, the search presented in [9] was studied in a wider range of $M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0}$. The resulting cross-section limits are shown in figure 3.

Light sneutrinos lead to an undetectable $\tilde{\chi}_2^0 \to \tilde{\nu}\bar{\nu}$ and $\tilde{\nu} \to \tilde{\chi}_1^0\nu$ decay chain.

4.5 Search for a charged slepton as the LSP

It is somehow rather unlikely that a stau (or another charged slepton) is the LSP in the AMSB. In a scan of the parameter space performed with ISAJET [5] no points were obtained with $M_{\tilde{\chi}_1^0} > M_{\tilde{\tau}}$. However, the calculations in [2] allow some corner in the space of the AMSB parameters with the $\tilde{\tau}_1$ being the LSP. In that case, if R-parity is conserved, the stau must be stable. The DELPHI results of the search for heavy stable charged particles were already presented in [10], together with the description of the method used in the analysis.

Staus are expected to be almost maximally mixed in AMSB [2]. Reference [10] showed that, even at the level of mixing that gives the lowest $\tilde{\tau}_1^+\tilde{\tau}_1^-$ production cross-section, the results of the search for heavy stable charged particles in DELPHI can exclude a stable $\tilde{\tau}_1$ with mass below 96 GeV/c^2 at the 95% CL.

4.6 Search for cascades from sleptons

Considering that the decay $\tilde{l}^{\pm} \to \tilde{\chi}_1^{\pm}\nu_l$ is practically invisible, due to the softness of the visible decay products of the chargino, the only cascades originating from a charged slepton (namely, a stau) in AMSB that can be taken into account are:

- $\tilde{\tau}_1 \to \tilde{\chi}_1^0\tau$, the same channel searched for in MSSM;
- $\tilde{\tau}_1 \to \tilde{\nu}_\tau f f'$, with final states that can be similar to the previous ones, but with some additional missing energy.

In the case of the sneutrino production, the decay $\tilde{\nu} \to \tilde{\chi}_1^0\nu$ is clearly invisible. On the other hand, $\tilde{\nu} \to \tilde{\chi}_1^+ l^-$ can be observed, probably with similar techniques as those used in the usual searches for sleptons.

Results on the cascades from sleptons were not yet ready for this report.

4.7 Search for the (SM) Higgs boson

Since in AMSB $m_{\mathrm{A}} \gg m_{\mathrm{Z}}$, the lightest suspersymmetric neutral Higgs h^0 behaves like the SM Higgs boson, and the limits obtained on the mass of the Higgs in the SM can be translated into the same lower limits on the mass of the h^0 in AMSB, provided that the decay branching fractions of the Higgs into supersymmetric particles are small.

If $m_{\mathrm{A}} \gg m_{\mathrm{Z}}$, h^0 can be produced at LEP only in association with the Z (higgsstrahlung), and with the same cross-section as in the SM. When there are SUSY particles lighter than $m_{\mathrm{h}^0}/2$, also decays of the Higgs into those particles are allowed. This is the case of AMSB, when there are light winos, sneutrinos or charged sleptons. Possible SUSY decays of the h^0 are:

- $\mathrm{h}^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0$, $\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\nu}\tilde{\nu}$, all invisible or practically invisible in AMSB, apart from some possible cascades;
- $\mathrm{h}^0 \to \tilde{l}^+\tilde{l}^-$, the visibility of which depends on the mass difference between the slepton and the LSP.

The most recent DELPHI bound on the SM Higgs mass is $M_H > 114.3$ GeV/c^2 at the 95% CL [11]. DELPHI measured also the limit on the production cross-section of an invisibily decaying Higgs boson [12]. Assuming a 100% BR into invisible particles, DELPHI can exclude Higgs masses below 113.0 GeV/c^2. Figure 8 of reference [12] shows how the limit on the mass of the lightest supersymmetric Higgs boson depends on the branching fraction into invisible states, assuming that all other decay modes are the SM ones: that limit starts from 114.3 GeV/c^2 when BR($\mathrm{h}^0 \to$ inv.) $= 0$ (that is, the h^0 decays according the SM) and 113.0 GeV/c^2 when BR($\mathrm{h}^0 \to$ inv.) $= 1$. The same limits on m_{h^0} apply in AMSB, provided there are no visible SUSY decays with sizeable branching fractions.

5 Constraints to the AMSB spectrum

Just as an exercise, the negative results of the searches described in this note were used to constrain the AMSB parameter space. To do that, the experimental exclusions measured were compared with the mass spectra produced by ISAJET [5]. A scan over the AMSB parameters was done by varying them in the following ranges: $2 < m_{3/2} < 50$ TeV/c^2 at steps of 2 TeV/c^2; $40 < m_0 < 1000$ GeV/c^2 at steps of 10 GeV/c^2 if m_0 was below 200 GeV/c^2, 50 GeV/c^2 otherwise; $1.5 < \tan\beta < 30.5$ at steps of 1 if $\tan\beta < 5$, steps of 5 otherwise; both positive and negative μ.

Figure 4 (a) shows the points in the plane (m_0,$m_{3/2}$) generated with ISAJET. The region of the space without points were considered as not allowed by the program, because some of the sparticle masses would have become tachyonic. One can notice that this imply a certain degree of correlation between m_0 and $m_{3/2}$, that is by cutting away slices at low $m_{3/2}$ also the value of the lowest admissible m_0 gets increased. Figure 4 (b) shows the points in the same plane that remains after the application of the model independent bounds on the chargino and sneutrino masses of LEP1. In figure 4 (c) are plotted instead the points remaining after the application of all searches described in this paper.

Since in AMSB the Higgs is preferably light, the most of the exclusion in the space of the AMSB parameters was given exactly by the results of the SM and of the invisible Higgs search. The negative results of the other searches could improve further the rejection especially at low $m_{3/2}$ (chargino searches) and low m_0 (searches with sleptons).

It is interesting to observe the impact of the searches for AMSB on some particle masses. Figure 5 shows the number of points generated by ISAJET, and passing the three steps of selection as in the previous figure, as a function of the mass of the lightest neutralino. The full and dashed lines represents respectively the points with positive and negative μ. The shape of the obtained spectrum has no particular meaning, but it turns out that neutralinos lighter than approximately 70 GeV/c^2 should not be allowed in AMSB. The same considerations can be done on figure 6, where the allowed sneutrino masses are shown. As before, should one trust this exercize, it would imply that sneutrinos lighter than 100 GeV/c^2 cannot exist in AMSB.

In ISAJET the AMSB spectra are computed at the LO only, and the outcomes of this exercize must be considered at the moment just as qualitative results. Moreover, it should be checked more carefully whether the small blind spots that exists in some of the analyses used were not missed by chance only because of the rough granularity of the scan.

Having all those caveats in mind, one can just continue with the exercice, and notice that, whenever those findings would be confirmed even using NLO calculation to compare with the data, the possible AMSB explanation for a light sneutrino ($M_{\tilde{\nu}}$ less than about 80 GeV/c^2), suggested to cure some of the discrepancies in the fit of the precision electroweak data [13], could be ruled out by the present DELPHI data.

6 Conclusions

A compilation of preliminary results of the searches performed with the data collected with the DELPHI detector at LEP, and relevant to explore AMSB scenarios, was presented. A reinterpretation of the limits obtained in searches motivated by other SUSY breaking scenarions was presented, whenever appropriate. Some of the searches were developed to improve the sensitivity to AMSB, and most of them were ready to be used in this report. There was no evidence for a signal beyond the Standard Model, and limits were set on the sparticle production in the AMSB framework.

Such collection of results can be relevant in itself and can provide phenomenologists with the experimental input needed to carefully test the model. As an illustration of the possible tests of AMSB that can be performed once accurate calculations of sparticle spectra will be available, the limits on sparticle production were translated using the LO calculations, to constrains on the AMSB parameters parameter space.

Acknowledgements

We thank Gian Giudice for the valuable comments and suggestions that helped us in interpreting the experimental results within the AMSB phenomenology.

References

[1] L. Randall, R. Sundrum, Nucl. Phys. **B557** (1999) 79.

[2] G.F. Giudice, M. Luty, H.Murayama, R.Rattazzi, JHEP 98 (1998) 12;
T. Gherghetta, G.F. Giudice, J.D. Wells,Nucl. Phys. **B559** (1999) 27;
J. L. Feng, T. Moroi, Phys. Rev. **D61** (2000) 095004.

[3] A. Pomarol, R. Rattazzi, JHEP 99 (1999) 5.

[4] S.Katsanevas and P.Morawitz, Comp. Phys. Comm. **112** (98) 227.

[5] H. Baer, F.E. Paige, S.D. Protopopescu, X. Tata, "Simulating Supersymmetry with ISAJET 7.0/ISASUSY 1.0", Published in Argonne Accel.Phys.1993:0703-720.

[6] S. Su, Nucl. Phys. **B573** (2000) 87.

[7] DELPHI Coll., P. Aarnio *et al.*, Nucl. Instr. and Meth. **303** (91) 233;
DELPHI Coll., P. Abreu *et al.*, Nucl. Instr. and Meth. **378** (96) 57.

[8] Particle Data Group, D. Groom, *et al.*, E. Phys. J. **C15** (2000) 1

[9] J. Abdallah, *et al.*, DELPHI 2001-085 CONF 513, EPS 333 - LP01 145.

[10] R. Alemany, E. Anashkin, F. Cavallo, P. Checchia, C. Garcia, F. Navarria, F. Mazzucato, E. Piotto, U. Schwickerath, DELPHI 2001-075 CONF 503.

[11] DELPHI 2001-077 CONF 505.

[12] M. Stanitzki, A. Sopczak, G. Gomez-Ceballos, F. Matorras, DELPHI 2001-079 CONF 507, EPS 327 - LP01 140.

[13] G. Altarelli, F. Caravaglios, G.F. Giudice, P. Gambino, G. Ridolfi, CERN-TH/2001-145.

DELPHI PRELIMINARY

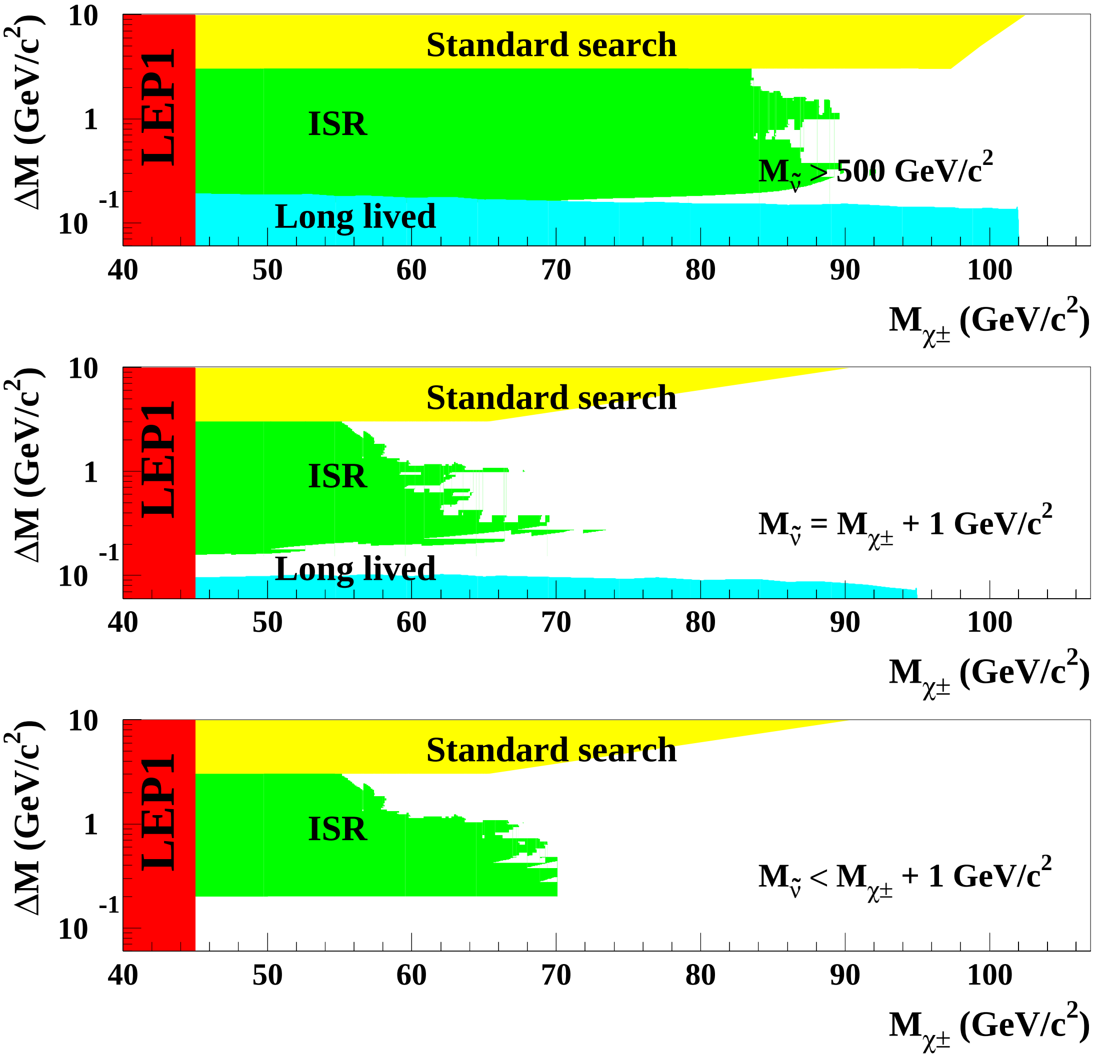

Figure 1: Regions in the plane $(M_{\tilde{\chi}_1^\pm}, \Delta M = M_{\tilde{\chi}_1^\pm} - M_{\tilde{\chi}_1^0})$ excluded by DELPHI at the 95% CL when the chargino is gaugino-like, as in AMSB. The standard search for high ΔM charginos, the search for soft particles accompanied by ISR, and the search for long-lived charginos were used. The scenarios in the three plots are: (a) $M_{\tilde{\nu}} > 500$ GeV$/c^2$; (b) $M_{\tilde{\nu}} = M_{\tilde{\chi}_1^\pm} + 1$ GeV$/c^2$ and flying charginos; (c) $M_{\tilde{\nu}} = M_{\tilde{\chi}_1^\pm} + 1$ GeV$/c^2$ and short lived charginos.

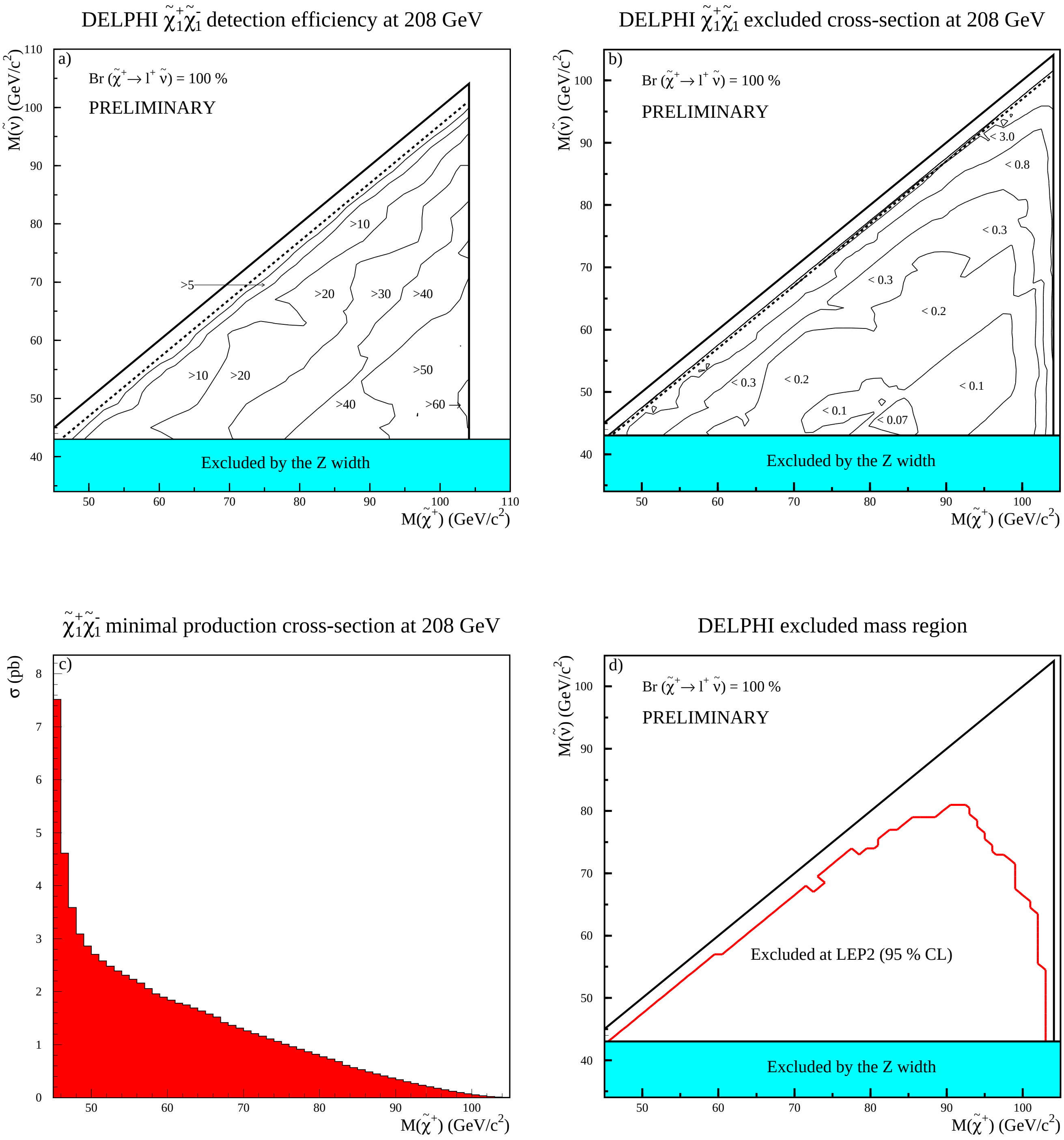

Figure 2: a) Chargino pair production detection efficiencies (%) for the fully leptonic decay channel at $\sqrt{s}$=208 GeV in the $(M_{\tilde{\chi}_1^\pm}, M_{\tilde{\nu}})$ plane; a 100% BR of $\tilde{\chi}_1^\pm \to \tilde{\nu} l^\pm$ is assumed. b) Excluded cross-section at 208 GeV. c) Minimal, with respect to $M_{\tilde{\nu}}$, $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$ cross-section in AMSB, as function of the mass of the chargino. d) Region excluded in the plane $(M_{\tilde{\chi}_1^\pm}, M_{\tilde{\nu}})$ by the search described in the text. Sneutrinos lighter than 43 GeV/c^2 were already excluded at LEP1.

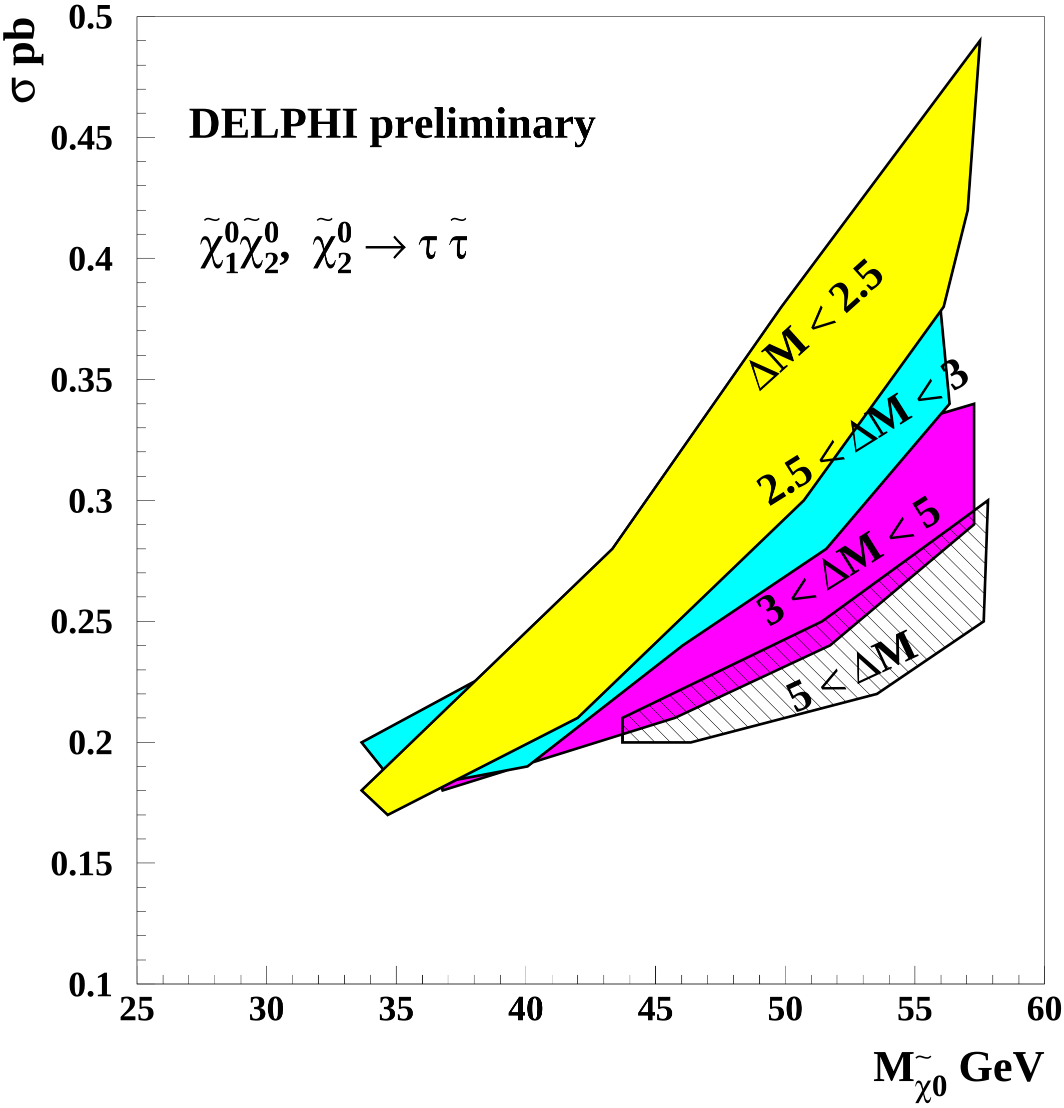

Figure 3: Cross-section limits for the $\tilde{\chi}^0_1\tilde{\chi}^0_2$ production when $\tilde{\chi}^0_2$ decays entirely to $\tilde{\tau}_1\tau$. The limits are shown for several ranges of ΔM=$M_{\tilde{\tau}_1}$-$M_{\tilde{\chi}^0_1}$. The widths of the bands are due to dependence of the limit on ΔM and to statistical fluctuations of the efficiency due to limited Monte Carlo statistics.

DELPHI PRELIMINARY

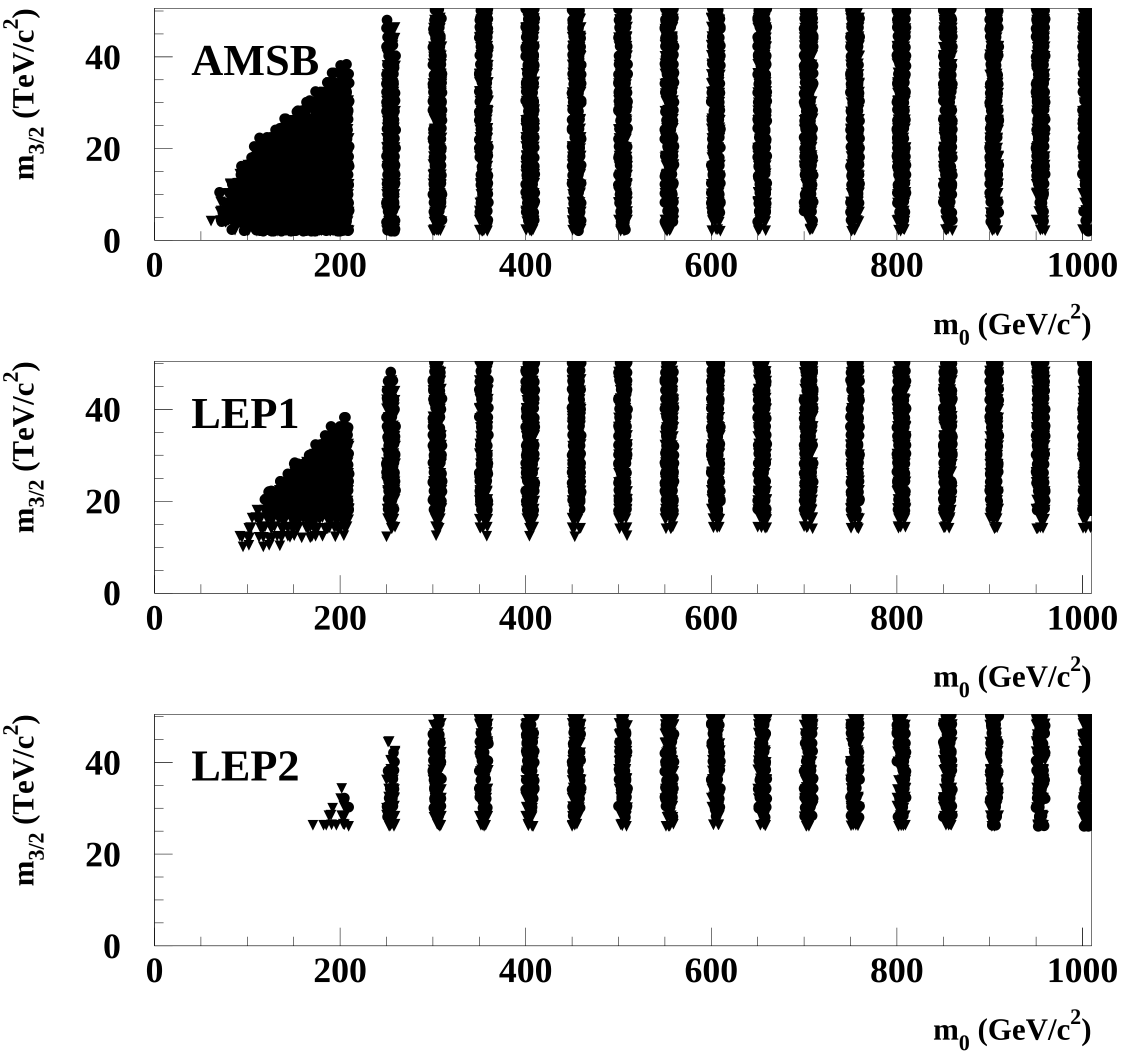

Figure 4: (a) Physically allowed m_0 and $m_{3/2}$ parameters in AMSB, as obtained in a scan of the AMSB parameter space with ISAJET, as described in the text. (b) The points that remains after applying the chargino and sneutrino mass bound of LEP1. (c) The set of points from the scan remaining after applying the results of the searches described in this work.

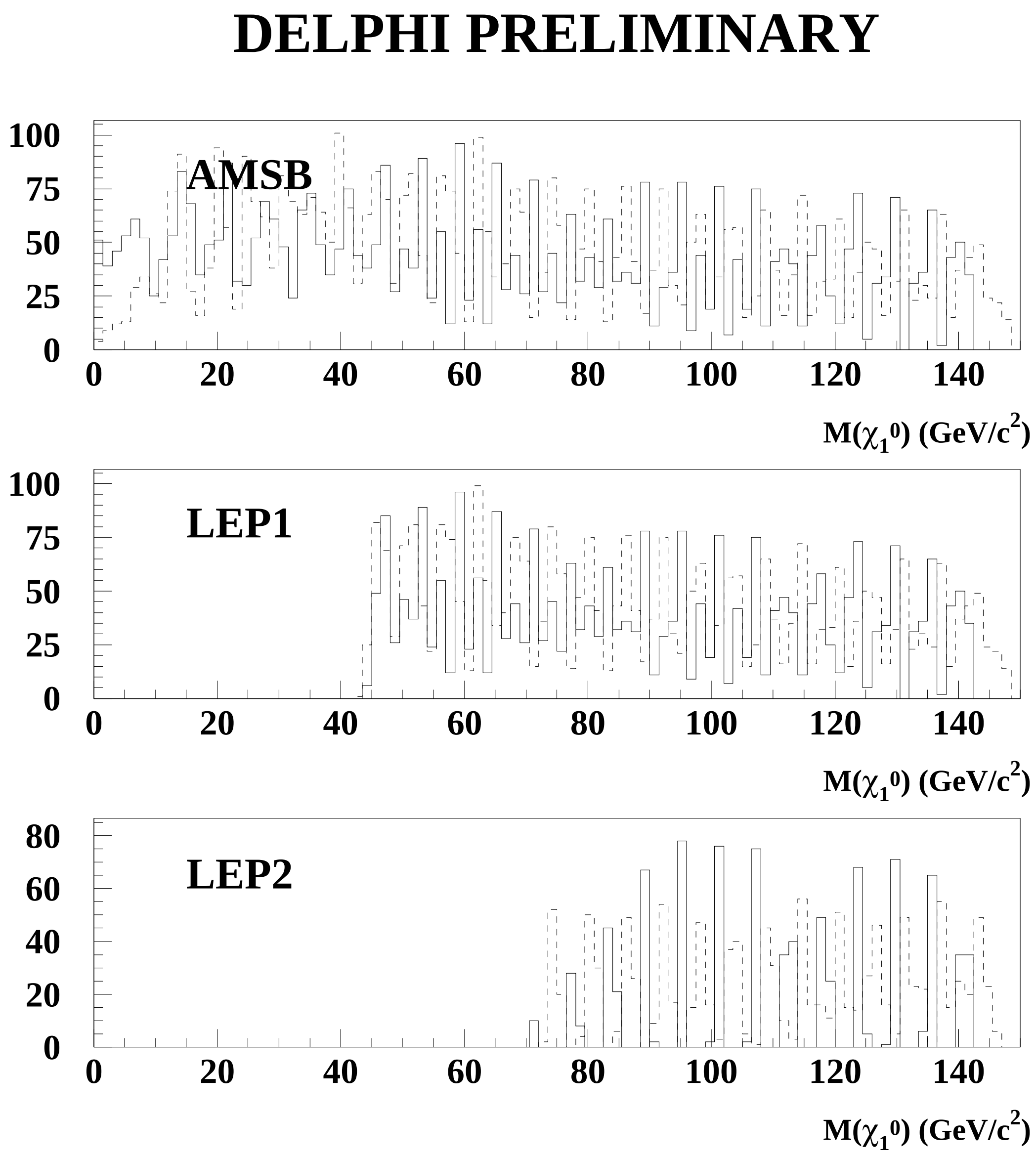

Figure 5: (a) Physically allowed $M_{\tilde{\chi}_1^0}$ in AMSB, as obtained in a scan of the AMSB parameter space with ISAJET, as described in the text. (b) The points that remains after applying the chargino and sneutrino mass bound of LEP1. (c) The set of points from the scan remaining after applying the results of the searches described in this work.

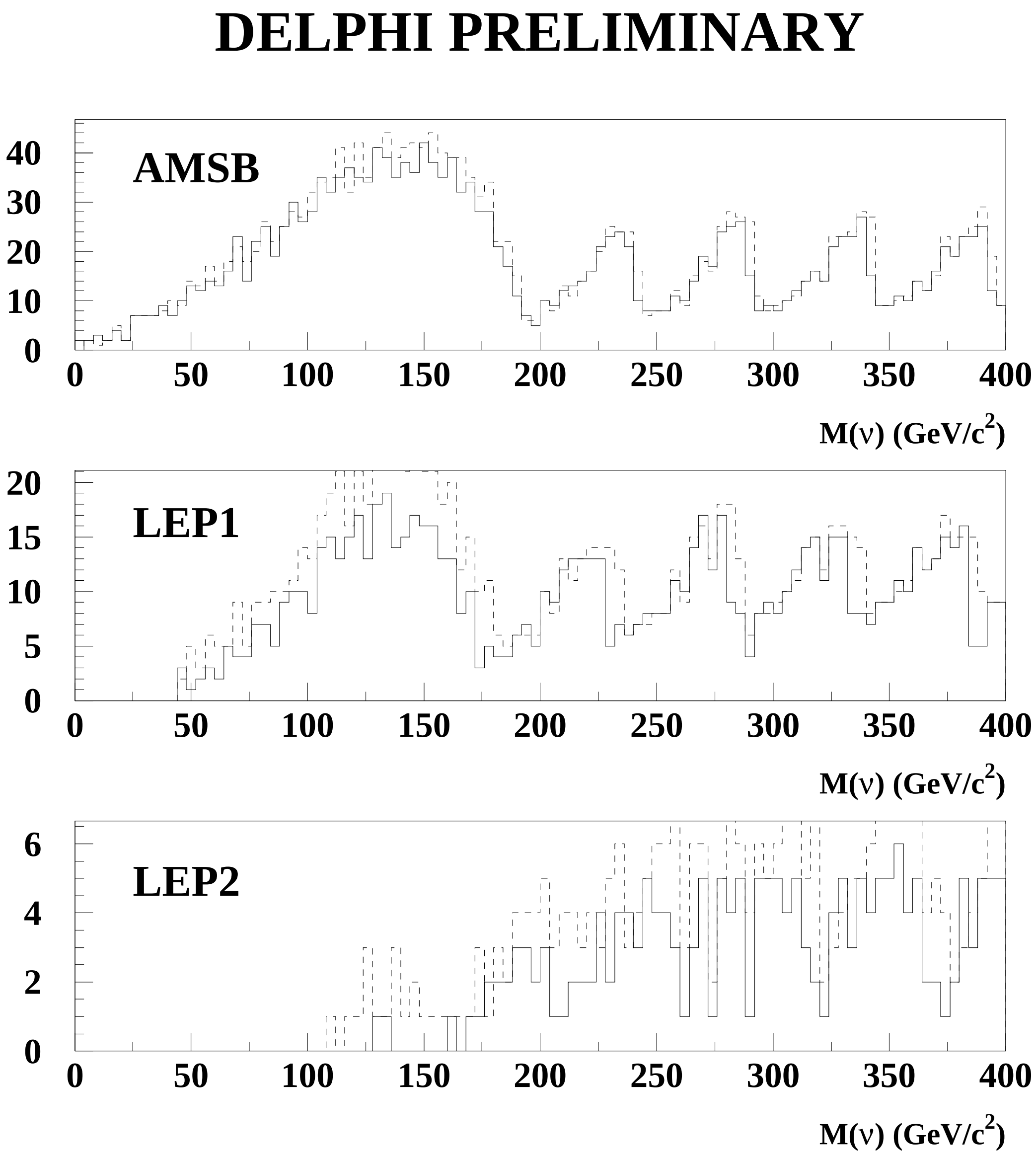

Figure 6: (a) Physically allowed sneutrino masses in AMSB, as obtained in a scan of the AMSB parameter space with ISAJET, as described in the text. (b) The points that remains after applying the chargino and sneutrino mass bound of LEP1. (c) The set of points from the scan remaining after applying the results of the searches described in this work.