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Search for Sfermions, Charginos and Neutralinos in e^+e^-Collisions at $\sqrt{s}$ up to 201.6 GeV and Mass Limit for the Lightest Neutralino

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PRELIMINARY

Abstract

Searches for pair production of sfermions and charginos and associated production of neutralinos have been performed using the data collected by the ALEPH detector at centre-of-mass energies ranging from 188.6 to 201.6 GeV. No evidence for any of such signals is observed in a total of about $410\,\mathrm{pb}^{-1}$ accumulated. The negative results of the searches are translated into exclusion domains in the space of the relevant MSSM parameters, improving significantly on the previous constraints. Under the assumptions of gaugino and sfermion mass unification, these results allow a 95% C.L. lower limit of $37\,\mathrm{GeV}/c^2$ to be set on the mass of the LSP for any $\tan\beta$ and sfermion mass. Additional constraints in the MSSM parameter space have been derived including the negative results of ALEPH searches for Higgs bosons. The results have been finally interpreted in the framework of minimal supergravity.

(ALEPH contribution to the 2000 Summer Conferences)

1 Introduction

This letter describes the results of searches for the supersymmetric partners of fermions (sleptons $\tilde{\ell}$; squarks $\tilde{\mathrm{q}}$) and of Higgs, Z, $\mathrm{W}^{\pm}$ bosons (charginos $\chi^{\pm}$,$\chi_2^{\pm}$; neutralinos χ_i^0), obtained using the data collected by the ALEPH detector during during 1999 (for sfermions) and 1998-1999 (for charginos, neutralinos), at centre-of-mass energies ranging from 188.6 to 201.6 GeV. Details about the analyzed data samples are given in Table 1. Results of slepton and squark searches with the 1998 data sample have been already reported in Ref. [1].

Table 1: Definition of the analyzed data samples.

Sample	*1998*	*1999*			
$\sqrt{s}$ (GeV)	188.6	191.6	195.6	199.6	201.6
$\int \mathcal{L}dt$ (pb^{-1})	173.6	28.9	79.8	86.3	42.0

As in Ref. [2, 3, 4, 1], the theoretical framework is the Minimal Supersymmetric Model (MSSM), with R-parity conservation and the assumption that the lightest neutralino is the Lightest Supersymmetric Particle (LSP). The notations and conventions described in Ref. [2] are used for the MSSM parameters. As a reminder, the unification relation among the gaugino SUSY breaking mass terms calculated at lowest order, $M_1 = \frac{5}{3} M_2 \tan^2\theta_W$, is assumed throughout. The region where $M_2 >> |\mu|$ is referred to as the *higgsino region*, and the region where $|\mu| >> M_2$ as the *gaugino region*. The region of small negative μ and low M_2 is referred to as the *mixed region*.

Masses and couplings of the relevant supersymmetric particles are calculated at tree level. For charginos and neutralinos they are entirely determined by the parameters M_2, μ and $\tan\beta$. When relevant, the sfermion masses are determined using the renormalization group equations with the addition of the parameter m_0 representing a common SUSY breaking mass for all sleptons and squarks at the grand unification scale.

The main features which affect the final state topologies are the difference in mass ΔM between the produced particles and the LSP, and the leptonic decay branching ratios. The final states addressed by the searches are the same as in Ref. [2]. For charginos and neutralinos the leptonic branching ratios are assumed to be lepton-flavour independent, and possible effects due to a large mixing in the third family are not addressed in this paper.

The selection algorithms, needed to optimize the sensitivity to the many possible final state topologies, are also basically the same as in previous publications; however the exact positions of the cuts have been optimized to give the best expected upper limit of the number of produced signal events in the absence of any signal, taking into account the increased centre-of-mass energy and the size of the new data samples. A summary of the topologies studied and of the addressed signal processes is given in Table 2.

The selections used to cope with the various possibilities have been subject to only

Table 2: Topologies studied in the different scenarios; only the main decay chains contributing to the different topologies are indicated in the case of neutralinos.

Production	Decay mode	Topology
$\tilde{\ell}\bar{\tilde{\ell}}$	$\tilde{\ell} \to \ell\chi_1^0$	Acoplanar leptons
$\tilde{e}_{L,(R)}\bar{\tilde{e}}_{R,(L)}$	$\tilde{e} \to e\chi_1^0$	Single electron (small $m_{\tilde{e}_R} - m_{\chi_1^0}$)
$\tilde{q}\bar{\tilde{q}}$	$\tilde{q} \to q\chi_1^0$	Acoplanar jets
$\tilde{t}\bar{\tilde{t}}$	$\tilde{t} \to c\chi_1^0$	Acoplanar jets
$\tilde{b}\bar{\tilde{b}}$	$\tilde{b} \to b\chi_1^0$	Acoplanar b-jets
$\tilde{t}\bar{\tilde{t}}$	$\tilde{t} \to b\ell\tilde{\nu}$	Acoplanar jets plus leptons
$\chi^+\chi^-$	$\chi^\pm \to ud\chi_1^0$	4 jets + $\not{E}$
	$\chi^\pm \to l^\pm\nu\chi_1^0$	Acoplanar leptons
	mixed	2 jets + lepton (τ) + $\not{E}$
$\chi_i^0\chi_j^0$	$\chi_1^0\chi_j^0 \to q\bar{q}\chi_1^0, \chi_i^0\chi_j^0 \to \nu\bar{\nu}\chi_1^0 q\bar{q}\chi_1^0, \ldots$	Acoplanar jets
$j \geq i, j \neq 1$	$\chi_1^0\chi_j^0 \to l^+l^-\chi_1^0, \chi_i^0\chi_j^0 \to \nu\bar{\nu}\chi_1^0 l^+l^-\chi_1^0, \ldots$	Acoplanar leptons

minor modifications with respect to those detailed in Refs. [2, 1]; these modifications and the results of the searches are described in Sections 2.1 and 2.2. In Section 3 the interpretation of these results in several MSSM frameworks is presented. The conclusions of the letter are given in Section 4.

A thorough description of the ALEPH detector can be found in Ref. [5], and an account of its performance as well as a description of the standard analysis algorithms in Ref. [6]. Only a brief summary is given here. Charged particle tracking, down to 16° of the beam axis, is obtained by means of a silicon vertex detector, a cylindrical drift chamber, and a large time projection chamber, all immersed in a 1.5 T magnetic field provided by a superconducting solenoidal coil. Hermetic calorimetric coverage, down to polar angles of 34 mrad, is achieved by means of a highly granular electromagnetic calorimeter, dedicated low angle luminosity monitors, and the iron return yoke instrumented to act as a hadron calorimeter; the latter is complemented with external muon detectors with the main purpose to improve the muon/hadron separation capabilities of the whole system. The information from all these detectors is combined in an energy flow algorithm which provides a list of *particles*, categorized as charged particles (*electron*, *muon*, *charged hadron*), photons, and neutral hadrons [6], used to determine global quantities such as total energy or missing momentum. The resolution achieved on the total energy is $(0.6\sqrt{E} + 0.6)$ GeV (E in GeV).

2 Update of sparticle searches

The searches performed with 1998 and 1999 data samples follow closely those used at the lower centre-of-mass energy, which have been described in detail in Ref.[2]. The selection criteria are optimized according to the $\overline{N}_{95}$ prescription, *i.e.* by minimizing the expected 95% C.L. cross section upper limit in the absence of signal, determined from Monte Carlo simulations [7].

Signal production, including a detailed treatment of cascade decays as well as of initial and final state radiation, have been simulated using SUSYGEN [9]. A fast detector simulation was mainly used for these samples. This fast simulation has been cross-checked with several fully simulated samples.

Standard Model processes have been simulated with UNIBAB [10] for Bhabha production, KORALZ [11] for $\mu^+\mu^-$ and $\tau^+\tau^-$ production, PHOT02 [12] for $\gamma\gamma \to$ leptons events and tagged $\gamma\gamma \to$ hadrons events, PHOJET [13] for untagged $\gamma\gamma \to$ hadrons events, KORALW [14] for $\mathrm{W^+W^-}$ events, GRC4F [15] for $\mathrm{We}\nu$ events, and PYTHIA [16] for all other processes. The simulated samples correspond to at least 25 times the integrated luminosity of the data, except for $\gamma\gamma$ processes where the factor is larger than three. The $\gamma\gamma \to$ hadrons events were generated with hadronic masses in excess of $2.5\,\mathrm{GeV}/c^2$. All standard model background samples were processed through the full detector simulation.

2.1 Update of sfermion searches

The final states studied (see Table 1) are those arising from the following decay channels: $\tilde{\mathrm{t}} \to \mathrm{c}\chi^0_1$, $\tilde{\mathrm{t}} \to \mathrm{b}\ell\tilde{\nu}$, $\tilde{\mathrm{b}} \to \mathrm{b}\chi^0_1$, $\tilde{\mathrm{q}} \to \mathrm{q}\chi^0_1$, $\tilde{\mathrm{e}} \to \mathrm{e}\chi^0_1$, $\tilde{\mu} \to \mu\chi^0_1$ and $\tilde{\tau} \to \tau\chi^0_1$. Events with acoplanar jets and acoplanar jets plus two leptons are signatures for squark production. Events with acoplanar lepton pairs or with single electrons are expected from slepton production. All these channels are characterised by missing energy. The event properties depend significantly on ΔM, the mass difference between the decaying sfermion and the produced χ^0_1 or $\tilde{\nu}$. As explained in Ref. [1], to reach the best sensitivity to the expected signal for a large range of ΔM values, two different selection procedures are employed, specifically addressing the low and the high ΔM cases. In the present analysis the selection cuts have been reoptimized with respect to Ref. [1] to take into account the increased centre-of-mass energy and the larger collected luminosity [7]. Systematics uncertainities on selection efficiencies and background estimations remain at the level quoted in [1].

The number of events selected in the 1999 data by the sfermion searches are reported in Table 3, together with the result obtaibed on the 1998 data sample [1]. In general, agreement is observed between number of candidates and the expectation from standard processes. A slight excess is observed in the acoplanar tau search; the probability for a statistical fluctuation upwards of the expected background is 1.6% for the 1999 sample alone, and 1.2% when the 1998 data are included.

The events selected by the $\tilde{\mathrm{b}}$ acoplanar jet searches are the same as those selected by the $\tilde{\mathrm{t}} \to \mathrm{c}\chi^0_1$ analyses. In total, the acoplanar jet $\tilde{\mathrm{t}}$ and $\tilde{\mathrm{b}}$ analyses observe in the 1999 data sample, ten events, in good agreement with the expectation of 8.4 events from Standard Model processes.

Table 3: Candidates and expected backgrounds in sfermion searches. The results obtained with the 1998 data samples [1] are quoted for comparison.

		1998 data		*1999* data	
		N_{cand}	N_{bkg}	N_{cand}	N_{bkg}
$\tilde{\mathrm{e}}\tilde{\mathrm{e}}$	all	33	32.8	42	48.1
$\tilde{\mu}\tilde{\mu}$	all	28	29.6	39	43.4
$\tilde{\tau}\tilde{\tau}$	all	26	21.5	46	32.7
$\tilde{\mathrm{e}}_{\mathrm{L,(R)}}\tilde{\mathrm{e}}_{\mathrm{R,(L)}}$		8	13.8	22	22.4
$\tilde{\mathrm{t}} \rightarrow \mathrm{c}\chi^0_1$	low ΔM	3	5.5	2	1.9
	high ΔM	5	4.0	8	6.5
$\tilde{\mathrm{b}} \rightarrow \mathrm{b}\chi^0_1$	low ΔM	3	3.3	1	0.9
	high ΔM	0	0.9	1	1.8
$\tilde{\mathrm{t}} \rightarrow \mathrm{b}\ell\tilde{\nu}$	low ΔM	0	1.9	3	1.8
	high ΔM	2	0.4	2	1.3

2.2 Update of gaugino searches

2.2.1 Chargino searches

As described in Ref.[2], searches are performed in all possible different chargino-pair decay topologies as four-jets (4J), hadrons plus electron or muon (2Jℓ), hadrons plus tau (2Jτ) and acoplanar lepton pairs (Aℓ).

The 4J, 2Jℓ and 2Jτ selections are designed to cover different values of the mass difference ΔM between the lightest chargino and the lightest neutralino, so that very low (VL), low (L), and high (H) ΔM regions are addressed by different selections. The Aℓ selections are designed differently for three-body decays (Aℓ-3) or two-body decays to sneutrino (Aℓ-2). Sliding cuts, i.e. cuts depending on the ΔM hypothesis, are introduced. For each ΔM value, the 2Jℓ selections are optimised first. The 4J selections are added and optimised next, while the 2Jτ are optimised in a last step, as additional to the 4J and 2Jℓ selections.

Background subtraction is generally not performed, except for the Aℓ selections, where the level of irreducible contamination due to $\mathrm{W^+W^-} \rightarrow l_1^+\nu_1 l_2^-\bar{\nu}_2$ events is limiting significantly the sensitivity of the search. The procedure discussed in Ref.[2] is used to reject the $\gamma\gamma \rightarrow$ hadrons background, using the same cuts on energy and direction variables as for the 183 GeV searches. The position of the cuts sensitive to the centre-of-mass energy, such as momenta and boosts, have been rescaled according to the increase in $\sqrt{s}$. As a result of the re-optimization all the final cuts are generally tighter than those quoted in Ref. [3] since, when using a larger data sample with partial background subtraction, signal efficiencies and total backgrounds are optimised to lower values.

The optimal combination of the chargino selections is determined as a function of ΔM using samples of chargino events close to the kinematic limit and with $\chi^{\pm} \rightarrow \mathrm{W}^{*}\chi_1^0$ decays. Combinations are defined in five ΔM regions for $0 < \Delta M < 68$ GeV. The lower background and efficiency regime allows the Aℓ selections to contribute in the optimal combinations at low ΔM values ($\Delta M < 15$ GeV). The same ΔM regions are considered to address for enhanced leptonic decays, in the case of light sleptons. In each region the leptonic branching ratio is varied by reweighting the generated chargino events according to their decay, and the optimal combination of the selections is determined as a function of the leptonic branching ratio. As a result, combinations are defined in regions of the (ΔM, BR_{ℓ}) plane, where BR_{ℓ} is the chargino branching ratio into a single lepton flavour. For larger leptonic branching ratios, the 4J selections are eventually dropped from the combinations, while the Aℓ selections contribute over larger ΔM ranges.

The resulting efficiencies and the background level are similar to those of the 183 GeV analyses. The level of the main systematic errors, related to the simulation of the energy flow reconstruction and of lepton identification, is essentially unchanged with respect to the one reported for the analyses at lower energies [2, 3].

2.2.2 Neutralino searches

In the case of heavy sfermion masses (large m_0), the neutralino analyses are used only in the higgsino region where the final state is characterized by acoplanar jets. The sensitivity of the two analyses, dedicated to small and large ΔM (being here defined as the mass difference between the χ_2^0 and the χ_1^0), has been significantly improved by taking into account the 4 fermion expected contamination when reoptimizing the cuts for the increased beam energy and the collected integrated luminosity. For this purpose, the estimation of the main background process, Weν, has been obtained using the GRC4F Monte Carlo generator. With respect to PYTHIA, which was used for the results published in Refs. [2, 3] [1], GRC4F contains a more complete description of the relevant physics processes, including interferences between the contributing diagrams. GRC4F has been shown to describe the data better than PYTHIA [19]. This can also be appreciated from Figs.nn., showing the missing mass and the transverse momentum for the sample of events retained by the acoplanar jets selection prior to the final sliding cuts. In Ref. [19] GRC4F has been found to agree with the data within the statistical errors and estimated detector uncertainities, amounting in total to about 20%. Such an uncertainity has been assigned to the GRC4F prediction in interpreting the result.

For low sfermion masses, the leptonic branching ratios are enhanced through $\chi_2^0 \rightarrow \tilde{\ell}^{*}\ell \rightarrow \ell\ell\chi_1^0$. A new search has been developed addressing final states made of acoplanar electrons or muons, which are expected to be a dominant fraction of neutralino induced events in this case of light sfermions. The selection consists of the preselection of the

[1] PYTHIA was also used to estimate the Weν background in the $\tilde{\mathrm{t}}$ and $\tilde{\mathrm{b}}$ acoplanar jet searches discussed in Sect. 2.1, where no background subtraction is performed.

selectron and smuon searches with a final "sliding" cut on the sum of the two lepton energies whose exact position depends on the mass difference ΔM of the neutralino decay cascade that produces the lepton pair. Selection efficiencies as large as 70% are reached for a large range of ΔM values, with an irreducible background of about 0.37 pb, mainly due to $W^+W^- \to l_1^+\nu_1 l_2^-\bar{\nu}_2$ processes. The systematics uncertainities associated to this new selections are very similar to those quoted for the selectron and smuon searches [1]. For the other searches the values given in [3] apply.

In the case of heavy sleptons, combinations of the analyses are defined in three ΔM regions for $0 < \Delta M < 40$ GeV/c^2. For large leptonic branching ratios the combination of the acoplanar jets and leptonic analyses provides a rather stable signal efficiency in the mixed region despite of the rapid change of the leptonic and hadronic branching ratios as a function of the parameters.

As for charginos, the selection efficiencies and the level of systematics uncertainities remained comparable to those of the analyses applied to the 183 GeV data sample [3].

2.2.3 Results

The number of events observed and expected from SM processes for the chargino and neutralino selections is reported in Table 4. The number of candidates is in good agreement with the expected background for all the selections.

Table 4: Candidates and expected backgrounds in chargino and neutralino searches.

		1998 data		*1999* data	
		N_{cand}	N_{bkg}	N_{cand}	N_{bkg}
Chargino	heavy sfermions	10	8.3	9	12.7
	light sfermions	25	23.0	24	33.9
Neutralino	heavy sfermions	4	3.7	8	5.6
	light sfermions	59	60.0	76	79.8

3 Interpretation of the results in the MSSM

The non-observation of any significant excess of candidates can be interpreted as upper limits on the production cross section for the processes searched for. In the interpretation of the result, due to the sliding cuts and to the transitions between combinations, each candidate contributes to a limited range of ΔM. The systematic uncertainties on the selection efficiencies are included following the method described in [17]. For selections optimized taking into account the expected contamination from 4–fermion production, the result is consistently derived *subtracting* the expected number of events from such background processes according to the prescription of Ref. [18]. The level of the *subtracted* backgrounds is reduced by one standard deviation of their systematic uncertainties in the evaluation of the confidence levels. No *background subtraction* is performed in interpreting the results of the searches for squarks and for non–fully leptonic final states arising from chargino production. Finally, the contraints presented in this section are derived by combining the results presented here with the previous ALEPH ones [3, 4, 1].

3.1 Slepton production

The region excluded at 95% C.L. in the planes $(m_{\tilde{\mathrm{e}}}, m_{\chi_1^0})$ and $(m_{\tilde{\mu}}, m_{\chi_1^0})$ and the expected sensitivity are shown in Figures 1a and 1b assuming a dominant $\tilde{\ell}_R \to \ell\chi_1^0$ decay, $\tan\beta = 2$ and $\mu = -200$ GeV. For large $m_{\tilde{\ell}}$ and small neutralino masses, cascade decays such as $\tilde{\ell}_R \to \ell\chi_j^0$ can play a role. The extent of the excluded region is reduced in the case a vanishing selection efficiency for final states deriving from cascade decays is assumed; this is also shown in the figures. For $\Delta M > 10$ GeV, selectron masses below 92 GeV and smuon masses below 85 GeV are excluded at 95% C.L.

In the case of staus, the regions excluded at 95% C.L. in the plane $(m_{\tilde{\tau}}, m_{\chi_1^0})$ assuming a dominant $\tilde{\tau}_1 \to \tau\chi_1^0$ decay are shown in Fig. 1c for the mixing cases corresponding to minimal cross section and pure right-handed $\tilde{\tau}$. The expected sensitivity in the latter case is also shown. For $\Delta M > 10$ GeV stau masses below 68 GeV are excluded at 95% C.L.; for $\Delta M > 10$ GeV stau masses below 70 GeV are excluded in the case of no mixing.

The results of the searches for acoplanar leptons and of the search for events with single electrons can be combined under the assumption of a common scalar mass at the GUT scale, which allows a relation between the masses of the right- and left-handed sleptons to be derived. The region of the plane $(m_{\tilde{\ell}_R}, m_{\chi_1^0})$ excluded at 95% C.L. for $\tan\beta = 2$ and $\mu = -200$ GeV and the expected sensitivity are shown in Fig. 1d. The loss of sensitivity of the $\tilde{\mathrm{e}}_\mathrm{R}\bar{\tilde{\mathrm{e}}}_\mathrm{R}$ search for very low values of ΔM (< 3 GeV) is recovered for $m_{\tilde{\ell}} < 70$ GeV by the search for $\tilde{\mathrm{e}}_\mathrm{R}^\pm\tilde{\mathrm{e}}_\mathrm{L}^\mp$. It can also be noticed that the effect of cascade decays at low $m_{\chi_1^0}$ is compensated by the search for $\tilde{\ell}_L\tilde{\ell}_L$ production.

3.2 Squark production

In the case of stops, under the assumption of a dominant $\tilde{\mathrm{t}} \to \mathrm{c}\chi_1^0$ decay, the regions excluded at 95% C.L. in the plane $(m_{\tilde{\mathrm{t}}}, m_{\chi_1^0})$ are shown in Fig. 2a, for two values of the $\tilde{\mathrm{t}}$ mixing angle θ_t, 0° and 56°, corresponding to maximal and minimal cross section, respectively. For ΔM in the range from 6 to 40 GeV the lower limit on $m_{\tilde{\mathrm{t}}}$ is 87 GeV, independent of θ_t. In the case of a dominant $\tilde{\mathrm{t}} \to b\ell\tilde{\nu}$ decay, the excluded region in the plane $(m_{\tilde{\mathrm{t}}}, m_{\tilde{\nu}})$ is shown in Fig. 2b, where equal branching ratios for $\ell = \mathrm{e}$, μ and τ have been assumed. Restricting to $\Delta M >$ 10 GeV and using the LEP 1 lower limit on the sneutrino mass of 43 GeV (calculated assuming three mass degenerate $\tilde{\nu}$'s), the θ_t independent lower limit on $m_{\tilde{\mathrm{t}}}$ is, in this case, 88 GeV.

As far as sbottoms are concerned, the excluded region in the plane ($m_{\tilde{\mathrm{b}}}, m_{\chi^0_1}$) is shown in Fig. 2c under the assumption of a dominant $\tilde{\mathrm{b}} \to b\chi^0_1$ decay. A lower limit of 91 GeV is set on $m_{\tilde{\mathrm{b}}}$ in the case of the $\tilde{\mathrm{b}}$ mixing angle $\theta_{\mathrm{b}} = 0°$ (corresponding to the case of maximal cross section) and $\Delta M > 8$ GeV. The region excluded for $\theta_{\mathrm{b}} = 68°$, for which the cross section is minimal, is also shown in Fig. 2c.

The negative results of the searches for acoplanar jets can be interpreted as a lower limit on the mass of degenerate squarks (see, for instabce, Ref. [8]). The following assumptions have been made in order to allow direct comparison of the results with those obtained at the Tevatron: a degenerate mass $m_{\tilde{\mathrm{q}}}$ for left-handed and right-handed $\tilde{\mathrm{u}}, \tilde{\mathrm{d}}, \tilde{\mathrm{c}}, \tilde{\mathrm{s}}, \tilde{\mathrm{b}}$; GUT relation between the soft supersymmetry breaking terms M_i associated with the $SU(2)_L \times U(1)_Y \times SU(3)_C$ gauge group, relating the neutralino and gluino ($m_{\tilde{\mathrm{g}}}$) masses; $\tan\beta = 4$ and $\mu = -400$ GeV. The exclusion region in the plane ($m_{\tilde{\mathrm{g}}}, m_{\tilde{q}}$) derived under these hypotheses is shown in Fig. 2d.

Although addressing a smaller kinematical range, the sensitivity of these squark searches extends to much smaller mass differences than those tested at hadron colliders [20, 21], therefore representing an important complement to the results obtained in such experimental environments.

3.3 Gaugino production

The absence of any significant excess in the chargino and neutralino searches is translated into upper limits for the production cross sections. As an example, Fig. 3a shows the upper limit for the production of chargino pairs for chargino masses close to the kinematic limit at $\sqrt{s} = 201.6$ GeV, assuming W* branching ratios for the decaying chargino. Under the assumption of gaugino mass unification, these results can also be expressed in the (μ, M_2) plane of the MSSM, as shown in Fig. 3b for $\tan\beta = \sqrt{2}$ and large m_0, or as chargino and neutralino lower mass limits, as shown in Figs. 3c and 3d, again for $\tan\beta = \sqrt{2}$ and large m_0. The kinematic limit is closely approached for both chargino and associated neutralino production, except in the deep higgsino region because of the smaller ΔM value, hence lower efficiencies. For $\tan\beta = \sqrt{2}$ and negative μ, the indirect chargino mass limit derived from the neutralino searches extends beyond the kinematic limit by up to $5\,\mathrm{GeV}/c^2$.

3.4 Lower limit on the LSP mass

From these studies, a 95% C.L. lower limit on the mass of the lightest neutralino can be derived as a function of $\tan\beta$, as shown in Fig. 4 for $m_0 = 500\,\mathrm{GeV}/c^2$, where the improvement with respect to the result presented in [4] can also be appreciated. The lowest value of $37.2\,\mathrm{GeV}/c^2$, obtained for $\tan\beta = 1$, $M_2 \simeq 62\,\mathrm{GeV}/c^2$ and $\mu \simeq -72$ GeV, remains valid for larger m_0 values. (Without the neutralino searches, more specifically in the $\chi^0_2\chi^0_4$ channel, the limit obtained by the combination of chargino searches and LEP1 [22] results would only be $35\,\mathrm{GeV}/c^2$.)

For lighter sfermions, the chargino (neutralino) production cross section is reduced (enhanced) by the destructive (constructive) interference between the γ-Z (Z) s-channel and the sneutrino (selectron) t-channel exchanges. Furthermore, the leptonic decay branching ratios are enhanced, and invisible decays such as $\chi_i^0 \to \nu\tilde{\nu}$ become kinematically allowed. In the framework of the MSSM with sfermion mass unification, the resulting loss of sensitivity of the high-ΔM chargino and neutralino searches is compensated by the constraints inferred from slepton and chargino/neutralino leptonic searches, as discussed in Ref. [3].

A scan performed over the whole parameter space, including the deep gaugino region for large $\tan\beta$ and for mass degenerate charginos and sneutrinos, shows that the lower limit on the LSP mass of 37.2 GeV/c^2, obtained at for $\tan\beta$=1 at large m_0, holds for all values of m_0.

It is also worth noticing that the quoted value for the LSP mass limit has been calculated using the lowest order formulas for the gaugino masses and the GUT relation relating M_1 and M_2, the gaugino mass parameters associated with the U(1) and SU(2) symmetry groups. As discussed in Ref. [23], the radiative corrections to chargino and neutralino masses modify the relation between such masses and therefore the interpretation of the interplay between chargino and neutralino searches. A simplified estimation of the effect has shown that, in the region where the limit is found, the corrections lower the LSP mass limit value by about 1 GeV. A further source of theoretical uncertainity is represented by the GUT relation among M_1 and M_2. Higher order corrections to the 1-loop formula used have been estimated using ISAJET [24] to be $\pm 3\%$, affecting by the same amount the LSP mass value.

3.5 Constraints from Higgs Searches

The results of Higgs boson searches can be used to improve the limit on the mass of the LSP presented in the previous sections. At tree level, the lighter CP-even Higgs boson mass m_{h} depends only on the mass m_{A} of the CP-odd Higgs boson and on $\tan\beta$. The value of m_{h} ranges from zero, for $m_{\mathrm{A}} = 0$, to a maximum value of $m_{\mathrm{Z}}|\cos 2\beta|$ for very large values of m_{A}. Therefore, a lower limit on m_{h} can be directly translated into a lower limit on $\tan\beta$. When the radiative corrections due to the large top quark mass are taken into account, m_{h}^2 receives an additional contribution of order

$$\frac{3g^2}{8\pi^2}\frac{M_{\mathrm{t}}^4}{\sin^2\beta m_{\mathrm{W}}^2}\log\left(\frac{m_{\tilde{\mathrm{t}}}^2}{M_{\mathrm{t}}^2}\right),$$

at the one-loop level [26]. Here, the two stops are assumed to be mass-degenerate, with common mass $m_{\tilde{\mathrm{t}}}$. For $m_{\tilde{\mathrm{t}}}$ not much larger than M_{t}, this correction may be sufficiently small to still allow a lower limit on $\tan\beta$ to be obtained. Alternatively, for a given (low) value of $\tan\beta$, a minimum value for $m_{\tilde{\mathrm{t}}}$ can be inferred from the lower limit on m_{h}. Since $m_{\tilde{\mathrm{t}}}$ increases with M_2, this lower limit on $m_{\tilde{\mathrm{t}}}$ can in turn be translated into a lower limit on M_2, once a (low) value of m_0 is chosen. In practice, this simple picture needs to be refined to take stop mixing, which increases the size of the radiative corrections, into account, and also to incorporate radiative corrections beyond the one-loop level.

To derive the results presented below, the most recent calculations of the radiative corrections in the Higgs sector have been used [27], as implemented in the `HZHA` generator [28]. While the stop masses at the weak scale are calculated assuming a universal value for the soft supersymmetry breaking sfermion masses at the GUT scale, the Higgs sector is treated independently, thus leaving m_{A} and μ as free parameters, in contrast to the more commonly used approach of minimal supergravity discussed in the next Section. Furthermore, in the renormalization group equations used to calculate the weak scale stop masses, the effects of the top Yukawa coupling are neglected.[2] In this respect, the results presented in this note can be considered as conservative since, generically, the top Yukawa coupling tends to reduce the stop masses. Unless otherwise specified, a top quark mass of 175 GeV/c^2 is assumed.

For a given set of $\tan\beta$, m_0 and M_2 values, the largest predicted Higgs boson mass is determined. For that purpose, a large value, 2 TeV/c^2, is chosen for m_{A}, and the effect of stop mixing is maximized by varying the combination $\tilde{A}_{\mathrm{t}} = A_{\mathrm{t}} - \mu\cot\beta$.[3] Since the decoupling limit is approached for large m_{A}, the MSSM Higgs boson behaves as in the standard model, and it is sufficient to compare this largest predicted mass to the standard model Higgs boson mass lower limit of 107.7 GeV/c^2, as determined by ALEPH in Ref. [25]. The loophole which might have arisen from possible Higgs boson decays into stop pairs is avoided by the recent ALEPH stop mass lower limit of 63 GeV/c^2, independent of the stop to neutralino mass difference, and of the stop mixing and lifetime [30].

The lower limit on M_2 obtained in this way, $M_2^{\mathrm{h}}(\tan\beta, m_0)$, is displayed in Fig. 5 as a function of $\tan\beta$, for various values of m_0. As expected, the limit is strongest for low values of $\tan\beta$ and low values of m_0. For instance, M_2 has to exceed 110 GeV/c^2 for $\tan\beta = 2.5$ and $m_0 = 200$ GeV/c^2. Although weaker, the constraints on M_2 obtained for large m_0 values are sufficient to improve on the LSP lower mass limit discussed in Sect. 3.4. For $m_0 = 1$ TeV/c^2 the limit is $\sim$47.5 GeV/c^2 found at $\tan\beta \simeq 1.95$, whereas for $m_0 = 2$ TeV/c^2 the limit is $\sim$46 GeV/c^2 (at $\tan\beta \simeq 1.6$).

As discussed in the previous section, in the low m_0 regime the searches for charginos become inefficient if the sneutrino is lighter than but almost mass degenerate with the chargino, a configuration usually dubbed as the *corridor*, whose impact on the final result is reduced by the additional constraints provided by slepton searches. Technically, for given values of $\tan\beta$ and m_0, a $\tilde{\ell}_R$ mass limit can be turned into a lower limit on M_2, hence also on the sneutrino mass. In the corridor, that mass is, approximatively, also the chargino mass, from which μ can be deduced since $\tan\beta$ and M_2 are known, and hence $m_{\chi_1^0}$. Finally, the value of $m_{\chi_1^0}$ thus obtained is minimized with respect to m_0, which provides the χ_1^0 mass lower limit as a function of $\tan\beta$ in the corridor, found for m_0 and M_2 values hereafter referred to as m_0^ℓ and $M_2^\ell(\tan\beta, m_0^\ell)$. The result obtained using the current ALEPH slepton mass limit of 93 GeV/c^2discussed in Sect. 3.1, the value relevant for $m_{\chi_1^0} \sim 40$ GeV/c^2, is displayed in Fig. 6. As expected, the impact of the corridor is maximal at large $\tan\beta$ where, for fixed values of m_0 and M_2, the sneutrino mass is

[2]Otherwise, the structure of the Higgs sector at the GUT scale would have to be specified, in contradiction with the approach taken in this study.

[3]In addition to its contribution to $\tilde{A}_{\mathrm{t}}$, there is a small residual effect of μ which turns out to be maximal for $\mu \sim -100$ GeV/c^2, in the cases relevant for the present study.

smallest while the slepton mass is largest.

The constraints on M_2 coming from slepton searches can be compared to those implied by Higgs searches. For $\tan\beta < 3.5$, the lower limit on M_2 coming from Higgs searches, $M_2^{\mathrm{h}}(\tan\beta, m_0^{\ell})$, is larger than $M_2^{\ell}(\tan\beta, m_0^{\ell})$, in which case an improved lower limit on $m_{\chi_1^0}$ is obtained by adjusting m_0 so that $M_2^{\ell}(\tan\beta, m_0)$ matches $M_2^{\mathrm{h}}(\tan\beta, m_0)$. The result is shown in Fig. 6. For $\tan\beta < 2.85$, the χ_1^0 mass lower limit obtained in this way exceeds the limit from chargino searches for large sfermion masses, and the limit on $m_{\chi_1^0}$ is therefore no longer set in the corridor.

It is worth noticing that, as m_0 is reduced, Higgs boson searches restrict M_2 to larger and larger values, as examplified in Fig. 5. Charginos are therefore more and more confined in the higgsino region ($M_2 \gg |\mu|$), with the result that the deleterious influence of light sleptons and light sneutrinos is less and less important.

In summary, when including the constraints coming from Higgs boson searches, the limit from chargino searches at large m_0 and $\tan\beta < 2.85$

- remains robust for any lower m_0 value, and
- is even superseded by the limit arising from Higgs boson searches for $\tan\beta < 1.95$.

The results obtained using the constraints from Higgs boson searches are however quite sensitive to the top quark mass. If a value of 180 GeV/c^2 is chosen instead of 175 GeV/c^2, the absolute lower limit of 38 GeV/c^2 still holds, but the limit for $\tan\beta < 3$ is reduced to 40 GeV/c^2. If, in addition, m_0 is allowed to take a value as large as 2 TeV/c^2 instead of 1 TeV/c^2, the Higgs boson searches no longer improve at low $\tan\beta$ on the limit of 36.8 GeV/c^2 deduced from the chargino and neutralino searches for large sfermion masses.[4]

3.6 Interpretation in Minimal Supergravity

In the framework of a highly constrained version of the MSSM, referred to as minimal supergravity, the value of μ is determined (up to a sign ambiguity) by the constraint of a correct radiative electroweak symmetry breaking, while all soft SUSY breaking scalar masses are unified at GUT scale, including those pertaining to the Higgs sector; therefore, the latter is now directly related to the gaugino and sfermion sector. The trilinear couplings for all scalars are also assumed to unify to a common value A_0.

The remaining parameters are therefore $m_{1/2}$, m_0, A_0, $\tan\beta$ and the sign of μ. The physically acceptable set of values for these parameters is restricted by the requirements that the top Yukawa coupling should not develop a Landau pole up to the GUT scale, and that none of the scalar particle squared masses should be negative. The ISAJET package [24], with the top quark mass set to 175 GeV/c^2, was used to obtain the results

[4]All these χ_1^0 mass limits are subject to theoretical uncertainties of the order of the GeV/c^2, as discussed in Sect. 3.4.

presented below. Radiative corrections to chargino and neutralino masses have been included as in [23].

The Higgs searches relevant in this case are those for the Standard Model process hZ. The cross section upper limit as a function of m_h given in Ref. [25] has been applied taking into account the reduction factor coming from $\sin^2(\alpha-\beta) < 1$ and the total h decay branching ratio into the modes analyzed in Ref. [25]. The two-loop level calculation for the MSSM Higgs sector [27], implemented in Ref. [28], has been used to get masses and mixing angles. In order to allow for theoretical uncertainities [27], the calculated h mass is conservatively increased by 2 GeV/c^2 when compared to the experimental limit of Ref. [25].

Exclusion domains in the $(m_0, m_{1/2})$ plane are shown in Fig. 7 for $\tan\beta = 5$ and 10, for $\mu < 0$ and $\mu > 0$, and for $A_0 = 0$. In all cases, the theoretical constraints restrict the allowed sets of $\{m_0, m_{1/2}\}$ values. Large regions are excluded by the Higgs boson searches; in particular for negative μ. Slepton searches contribute most effectively for low m_0, while the constraints from the Z width measurement at LEP1 [29] and from chargino searches at LEP2 forbid low $m_{1/2}$ values. However, as already noticed in Ref. [31], by adjusting the A_0 value it is possible to find configurations where the analyses discussed in this paper loose completely their sensitivity; these loopholes open up when the lightest $\tilde{\tau}$ is almost degenerate with the χ_1^0, while the other sleptons being out of the kinematic reach; standard chargino searches are blind in such cases, since the branching ratio for the decay $\chi^\pm \to \tilde{\tau}^\pm\nu_\tau$ is close to 100% and the subsequent $\tilde{\tau}$ decay into a χ_1^0 and a very soft τ is, *de facto*, invisible; the lightest Higgs boson also decays with branching fraction $\sim$100% in $\tilde{\tau}^\pm\tilde{\tau}^\mp$ with subsequent production of a pair of soft taus and two χ_1^0, rendering the standard higgs searches considered here not applicable. Sensitivity to these situations could be recovered with dedicated searches for neutralino processes like $\chi_1^0\chi_2^0 \to \chi_1^0\tilde{\tau}^\pm\tau^\mp \to \chi_1^0\chi_1^0\tau^\pm\tau^\mp$, for which at least one of the τ's can be energetic enough to allow detection, or the Higgs process hZ followed by (quasi) invisible Higgs decays; however, the study of these channels goes beyond the purpose of the present letter. In the rest of this subsection the *stau loopholes* will be removed by restricting the analysis to A_0 values giving $m_{\tilde{\tau}} - m_{\chi_1^0} > 5$ GeV/c^2.

The scans of the $(m_0, m_{1/2})$ planes allow to derive constraints on the mass of the lightest neutralino. The lower limit on $m_{\chi_1^0}$ as a function of $\tan\beta$ is shown in Fig. 8 for $A_0 = 0$ and for both $\mu < 0$ and $\mu > 0$. There is little structure in the limit for both signs of μ. Low $\tan\beta$ values are excluded by the negative result of Higgs boson searches, whereas for larger $\tan\beta$ values the limit is determined mostly by chargino searches. The lowest allowed value for $m_{\chi_1^0}$ is always found at large m_0 and it has been calculated for $m_0 = 1$ TeV/c^2. For negative μ this is a consequence of the large impact of Higgs searches. For μ positive, it is the result of the interplay of Higgs and slepton searches that together reduce the impact of the corridor. Altogether, a χ_1^0 mass lower limit of 49 GeV/c^2 is set for $A_0 = 0$. It is reached for $\tan\beta \sim 4.55$ and $\mu < 0$.

The impact of a non-vanishing A_0 value was studied by scanning the range allowed by theoretical constraints, stop searches and the absence of stau loopholes, with a granularity of 50 GeV/c^2. A point in the $(m_0, m_{1/2})$ plane is considered excluded if it is excluded for all values of A_0 considered. The lower limit on $m_{\chi_1^0}$ as a function of $\tan\beta$ obtained from the A_0 scan is also shown in Fig. 8. Altogether, the χ_1^0 mass lower limit decreases to $48\,\mathrm{GeV}/c^2$, value reached for $\tan\beta \sim 4.5$ and $\mu < 0$.

The lower limit on $m_{\chi_1^0}$ is therefore substantially improved when the additional constraints of minimal supergravity are considered.

4 Conclusions

The previously published ALEPH searches for the supersymmetric partners of fermions and of Higgs, Z, $\mathrm{W}^{\pm}$ bosons have been updated with the data collected during 1999 at centre-of-mass energies up to about 202 GeV, corresponding to an overall integrated luminosity of bout 410 pb^{-1}. In all topologies the number of candidates observed is consistent with the background expected from Standard Model processes.

When interpreted in the framework of the MSSM, such a negative outcome allows improved 95% C.L. lower limits on sfermion masses to be set as summarized below:

- for *selectrons*: 92 GeV, $\Delta M > 10$ GeV, $\tan\beta = 2$ and $\mu = -200$ GeV;
- for *smuons*: 85 GeV, $\Delta M > 10$ GeV, 100% branching ratio $\tilde{\mu} \to \mu\chi_1^0$;
- for *staus*: 68 GeV, $\Delta M > 10$ GeV, 100% branching ratio $\tilde{\tau} \to \tau\chi_1^0$, worst case mixing; 70 GeV, $\Delta M > 10$ GeV, 100% branching ratio $\tilde{\tau} \to \tau\chi_1^0$, right-handed stau;
- for *sleptons*: 93 GeV, $\Delta M > 10$ GeV, 70 GeV, any ΔM, $\tan\beta = 2$, $\mu = -200$ GeV and common scalar mass at GUT scale;
- for *stops*: 87 GeV, dominant $\tilde{\mathrm{t}} \to \mathrm{c}\chi_1^0$, $6 < \Delta M < 40$ GeV; 88 GeV, dominant $\tilde{\mathrm{t}} \to b\ell\tilde{\nu}$, $\Delta M > 10$ GeV;
- for *sbottoms*: 91 GeV, dominant $\tilde{\mathrm{b}} \to \mathrm{b}\chi_1^0$, $\Delta M > 8$ GeV, $\theta_{\mathrm{b}} = 0°$;
- for *degenerate squarks*: 97 GeV, dominant $\tilde{q} \to \mathrm{q}\chi_1^0$, $\Delta M > 6$ GeV.

Chargino and neutralino associated production are excluded up to the kinematic limit over large portions of the MSSM parameter space. The negative results of the searches for the MSSM Higgs bosons presented in Ref. [25] have also been used to further constrain the MSSM parameter space. The link is established by the strong dependence on the stop sector of the radiative corrections to the Higgs bosons masses, under the additional assumption of unification of slepton and squark masses at unification scale. The result depends strongly on the maximum allowed values for m_0 and M_2 and on the top quark mass; severe constraints are set in the low $\tan\beta$ region as shown in Fig. 6 for $m_0^{max}, M_2^{max} = 1$ TeV and M_{t}=175 GeV/c^2.

Finally, as in Ref. [3], a highly constrained model, commonly known as minimal supergravity, has been considered. The model further assumes that all scalar masses (including those pertaining to the Higgs sector) are unified, allowing to incorporate the results of Higgs boson searches. Moreover, electroweak symmetry breaking is induced dynamically, thus allowing the μ parameter to be calculated except for a sign ambiguity. In addition, all trilinear couplings such as A_{t} are assumed to derive from a common value A_0

at GUT scale. The analysis is limited to A_0 values for which $m_{\tilde{\tau}} - m_{\chi_1^0} > 5$ GeV/c^2. Results obtained in this highly constrained model are presented as exclusion domains in the $(m_0, m_{1/2})$ plane for two values of $\tan\beta$. The excluded regions are significantly larger than those reported by the D0 collaboration interpretating the negative results of searches for gluinos and squarks at Tevatron [32].

In the various scenarios considered above, the excluded regions can be turned into lower limits for the mass $m_{\chi_1^0}$ of the lightest neutralino, as summarized below:

- In the MSSM with gaugino mass unification, $m_0 > 500\,\mathrm{GeV}/c^2$, the $\tan\beta$ independent lower limit on $m_{\chi_1^0}$ is $37\,\mathrm{GeV}/c^2$, reached for $\tan\beta = 1$; this limit has been calculated using the lowest order relation between the M_1 and M_2 gaugino mass parameters, using Born level values for the gaugino masses, and assuming negligible mixing in the stau sector. The large m_0 limit has been proven to be valid for all values of m_0 if the results of the slepton searches reported in this paper are included.
- Including the constraints derived from the negative outcome of Higgs bosons and stop searches the limit increases to 47.5 GeV/c^2 for 500 GeV/$c^2 < m_0 < 1$ TeV/c^2, and to about 38 GeV/c^2 if m_0 is left free.
- In minimal supergravity with $A_0 = 0$ and $m_0 < 1$ TeV/c^2 the lower limit on $m_{\chi_1^0}$ is $49\,\mathrm{GeV}/c^2$, calculated including 1-loop radiative correction to chargino and neutralino masses. The limit is decreased to $48\,\mathrm{GeV}/c^2$ when A_0 is varied within the allowed range.

The limits on chargino and neutralino masses and the constraints on the parameter space of the MSSM reported in this paper are significantly better than the results obtained at lower energies by ALEPH [3]. In particular, the χ_1^0 mass lower limit is increased up to about $37\,\mathrm{GeV}/c^2$. The L3 [33] and OPAL [34] collaborations have reported results of their searches for charginos and neutralinos in their 189 GeV data. The most general χ_1^0 mass lower limit set in Ref. [33] to $32.5\,\mathrm{GeV}/c^2$. Analysing data collected up to $\sqrt{s} = 183$ GeV, the DELPHI collaboration has reported a χ_1^0 mass lower limit of $29.1\,\mathrm{GeV}/c^2$ valid for large m_0 [35]. Less general searches for associated production of charginos and neutralinos have also been reported by the CDF [36] and D0 [37] collaborations.

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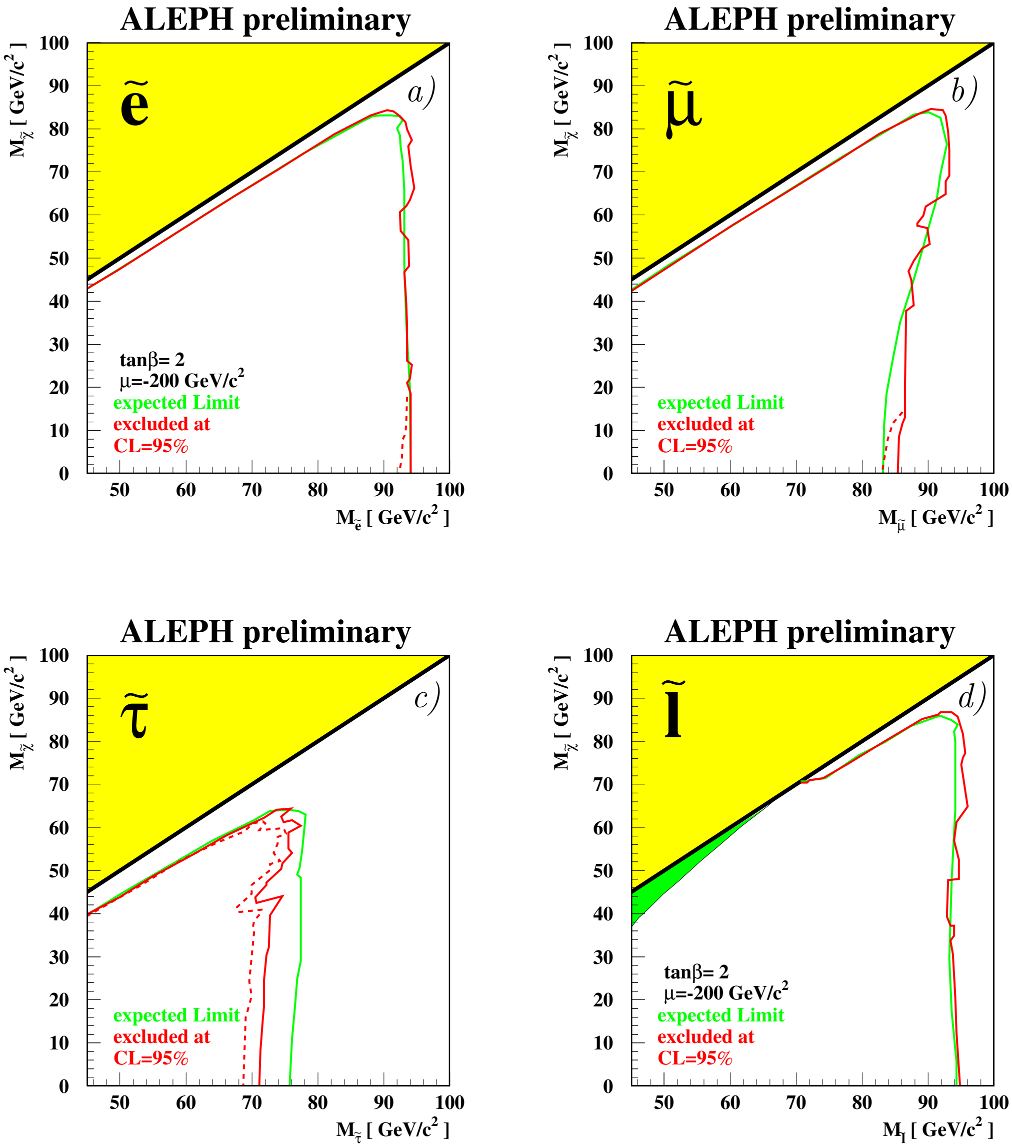

Figure 1: Excluded regions at 95% C.L. in the $m_{\tilde{\ell}_{\rm R}}$ vs $m_{\chi_1^0}$ plane from slepton searches. $\mathrm{BR}(\tilde{\ell} \to \ell\chi_1^0) = 100\%$ is assumed for solid curves in *a)* and *b)* and all curves in it c). The dashed curves in *a)* and *b)* show the effect of cascade decays for $\tan\beta = 2$ and $\mu = -200$GeV, assuming zero efficiency for those decays. The dashed curve in *c)* shows the limit in the $m_{\tilde{\tau}_1}$ vs $m_{\chi_1^0}$ plane in the case of minimal $\tilde{\tau}_1\tilde{\tau}_1$Z coupling. In *d)*, the effect of cascade decays is included. The dark shaded region is not accessible because the common scalar mass at the GUT scale becomes unphysical.

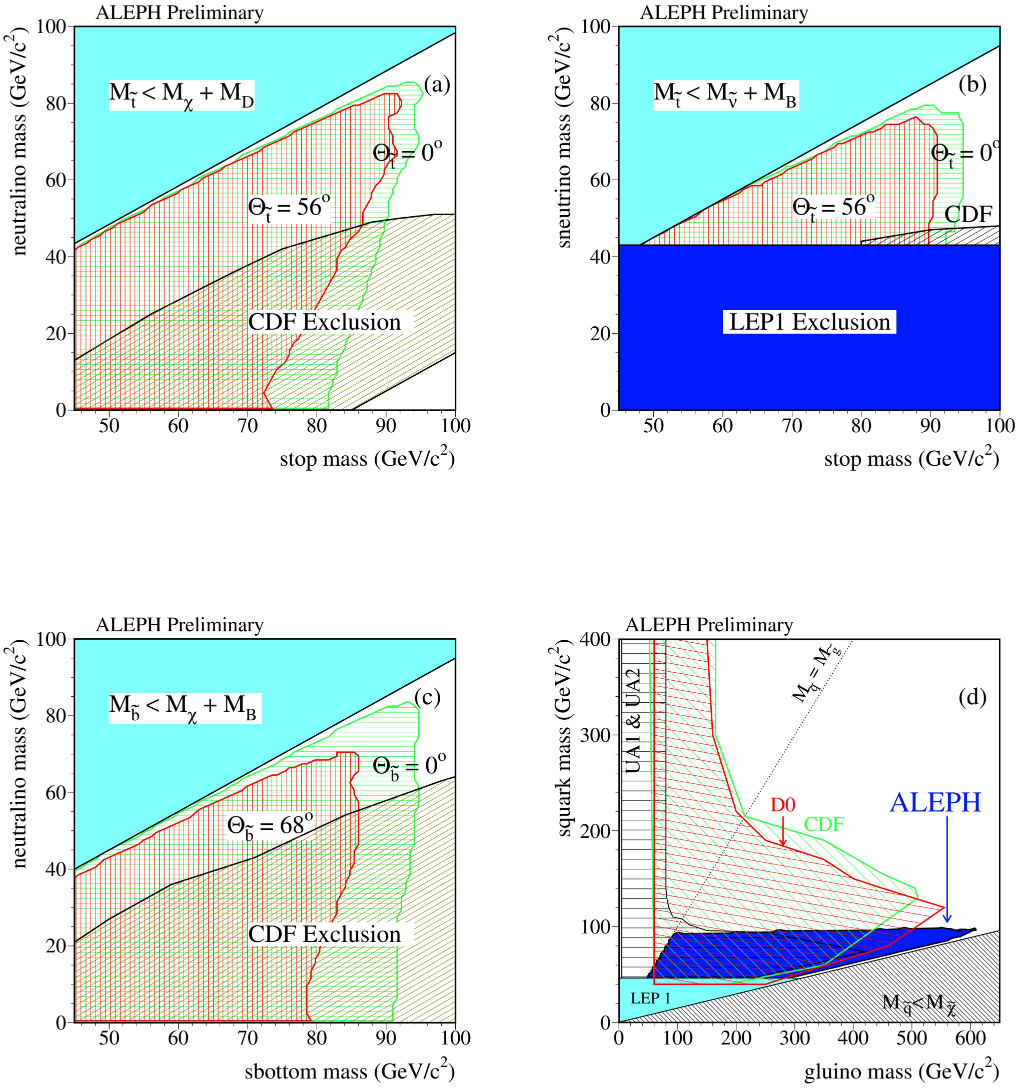

Figure 2: Excluded regions at 95% C.L. from squark searches: *a)* in the ($m_{\chi_1^0}$,$m_{\tilde{t}}$) plane assuming a dominant $\tilde{t} \to c\chi_1^0$ decay; *b)* in the ($m_{\tilde{\nu}}$,$m_{\tilde{t}}$) plane in the case of a dominat $\tilde{t} \to b\ell\tilde{\nu}$ decay and equal branching fractions into e, μ, and τ. *c)* in the ($m_{\chi_1^0}$,$m_{\tilde{b}}$) plane assuming a $\tilde{b} \to b\chi_1^0$ dominant decay; *d)* in the plane ($m_{\rm gluino}$, $m_{\tilde{q}}$) in the case of five degenerate $\tilde{q}$ flavours, tan$\beta = 4$ and $\mu = -400$GeV. The Tevatron results are also shown for comparison.

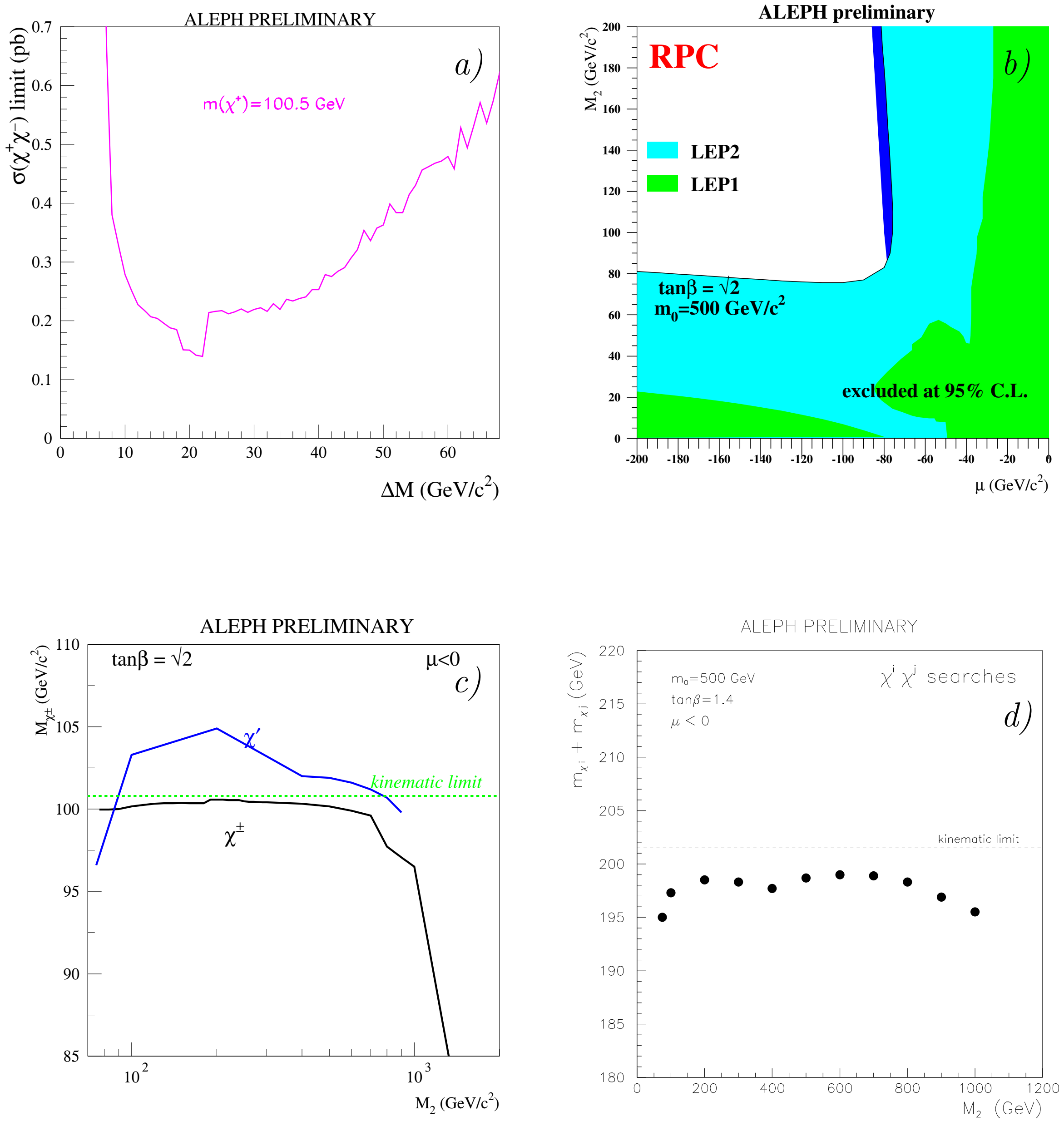

Figure 3: Gaugino searches: *a)* upper limit on chargino pair production cross section for chargino masses close to the kinematic limit at $\sqrt{s} = 202$ GeV, assuming W* branching ratios for the decaying chargino; *b)* excluded domains in the (μ, M_2) plane of the MSSM; *c)* chargino mass lower limit in the higgsino region for $\mu < 0$; *d)* lower limit on the sum of the masses of two neutralinos produced with the largest cross section ($\chi_1^0\chi_2^0$ for large M_2 and mainly $\chi_1^0\chi_3^0$ for small M_2). Where relevant, $m_0 = 500$ GeV$/c^2$ and $\tan\beta = \sqrt{2}$.

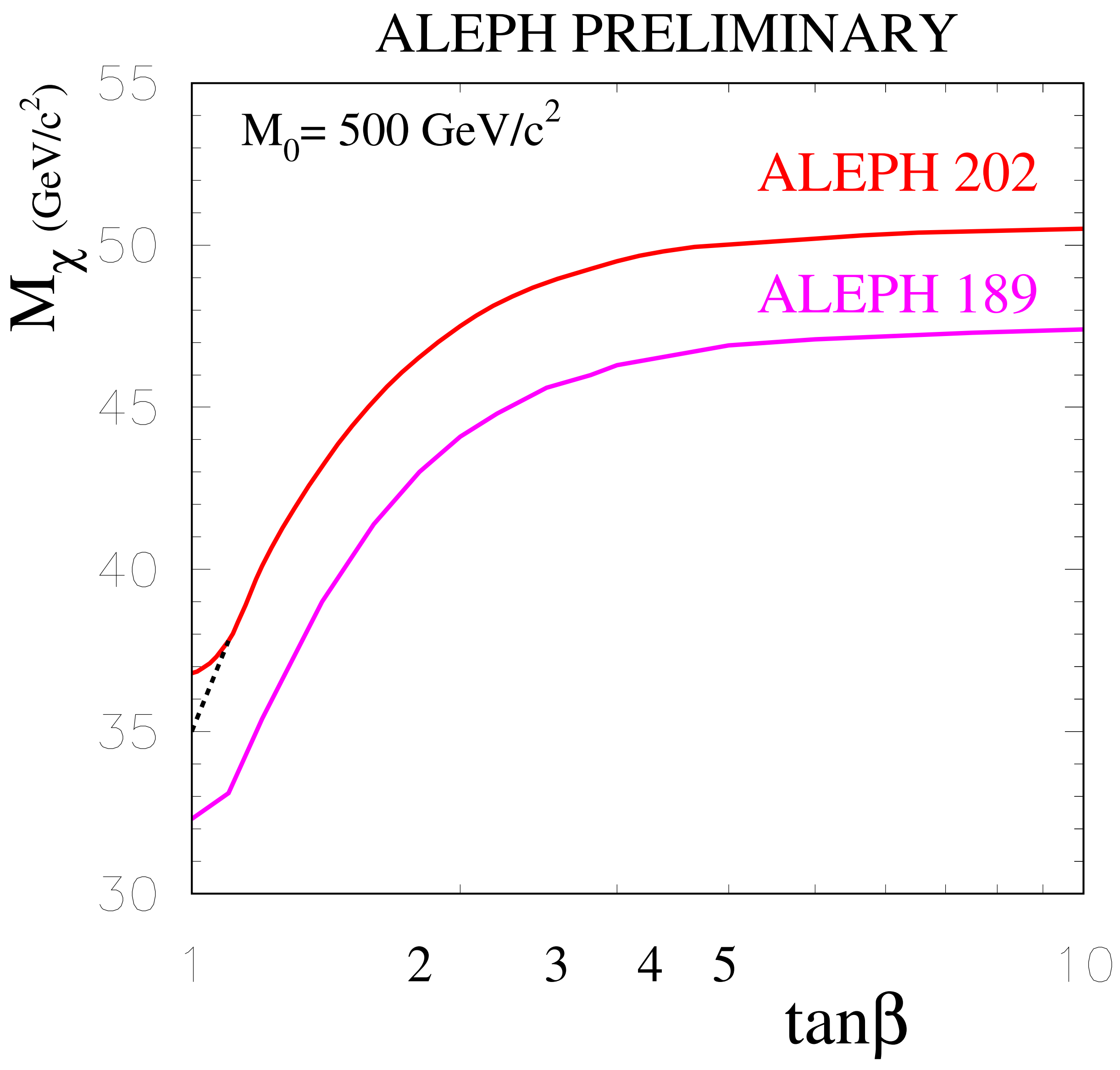

Figure 4: *The 95% C.L. lower limit on the mass of the lightest neutralino as a function of* $\tan\beta$ *for* $m_0 = 500\,\mathrm{GeV}/c^2$. *The dashed line indicates the limit obtained without the constraints from the searches for neutralinos. The result obtained analysing the data collected at* $\sqrt{s}$ *up to 189 GeV is shown for comparison. Higher* m_0 *values give similar limits.*

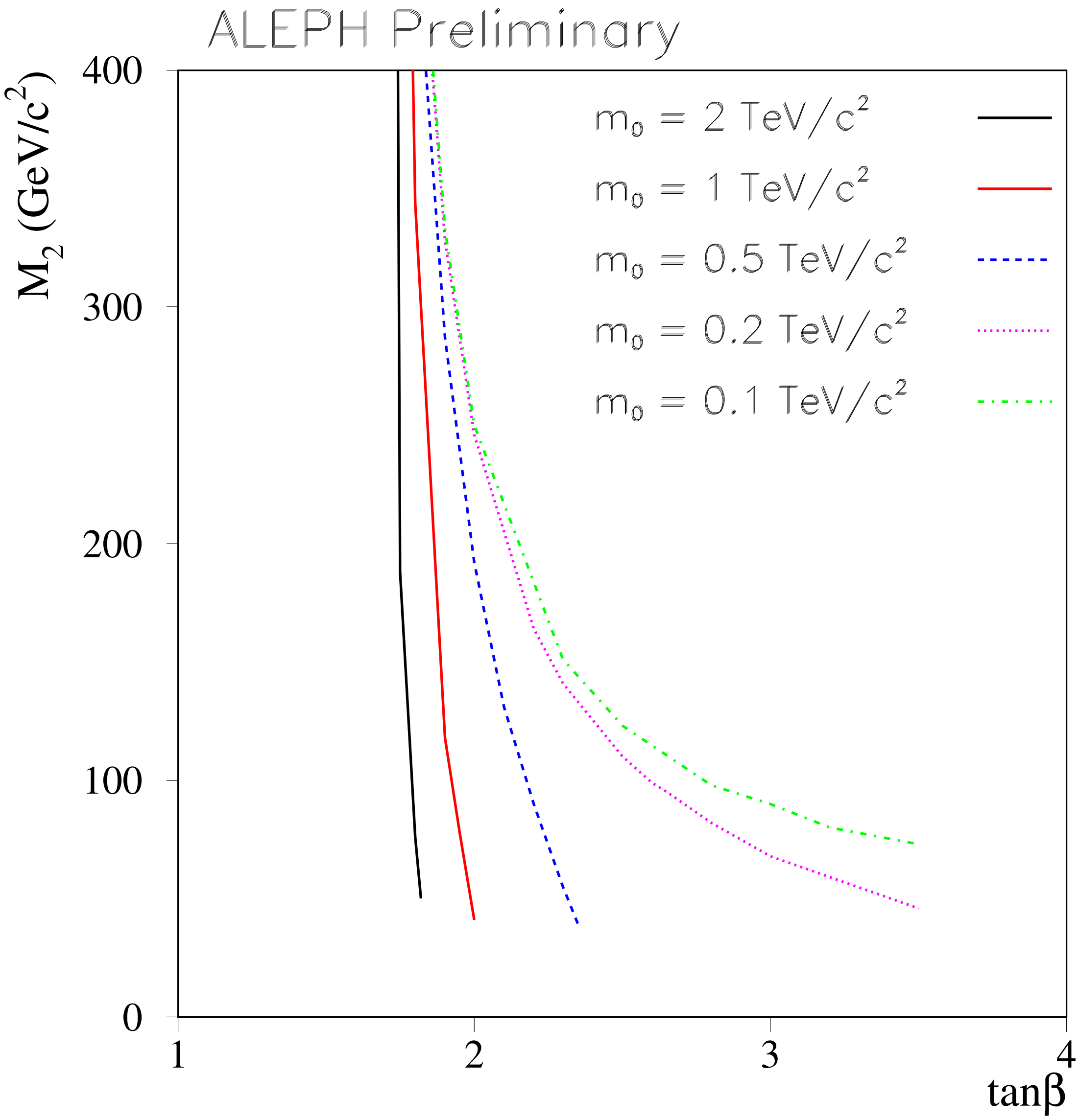

Figure 5: For various values of m_0, lower limit on M_2 as a function of $\tan\beta$, as determined from the result of Higgs boson searches.

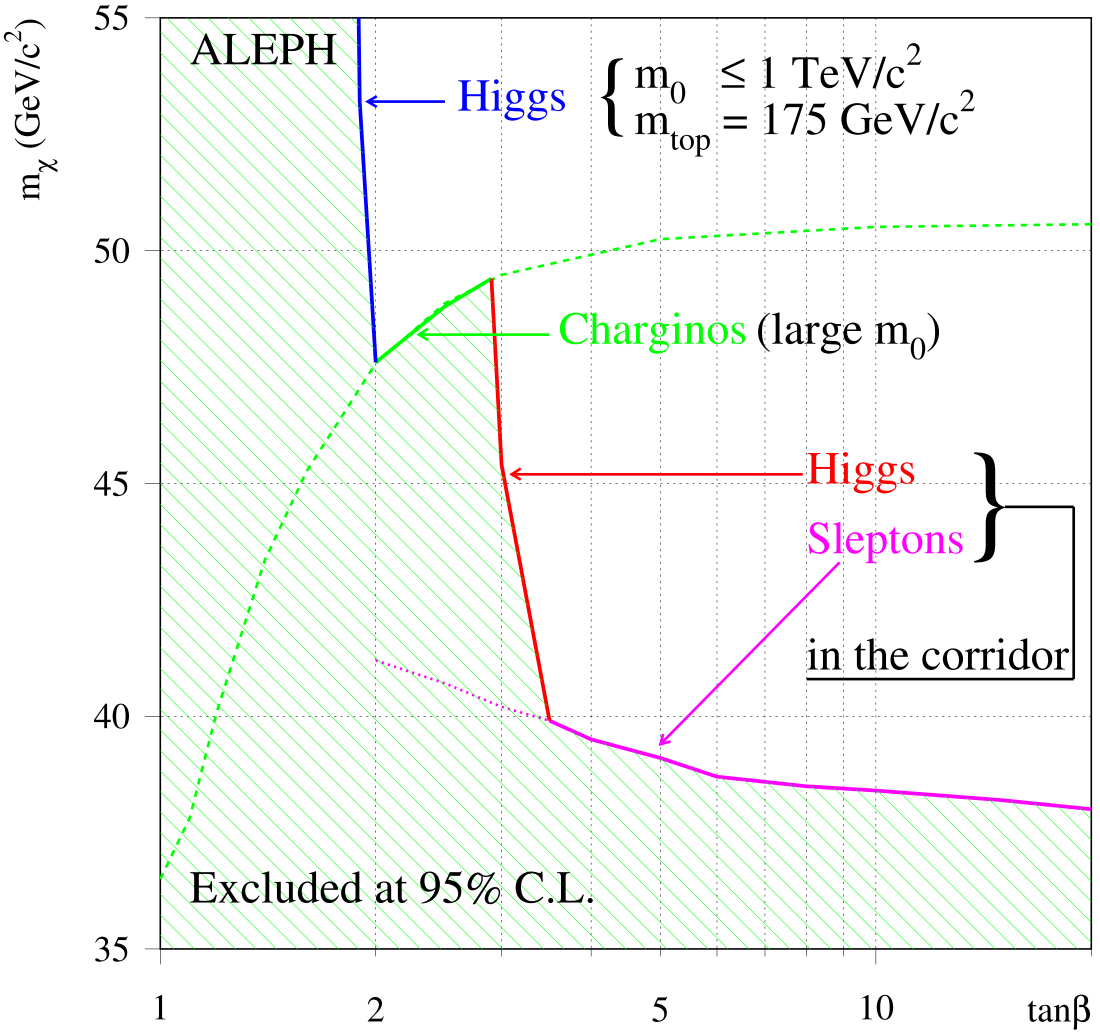

Figure 6: As a function of $\tan\beta$, lower limit on $m_{\chi_1^0}$ from, right to left, slepton searches in the corridor, Higgs boson searches in the corridor, chargino searches for large sfermion masses, and Higgs boson searches. The limits from Higgs boson searches are valid for $M_{\mathrm{t}} = 175\ \mathrm{GeV}/c^2$ and for m_0 not exceeding 1 TeV/c^2. The dashed curve indicates the limit from chargino and neutralino searches for large m_0. The dotted curve shows the limit in the corridor reached without the Higgs boson searches.

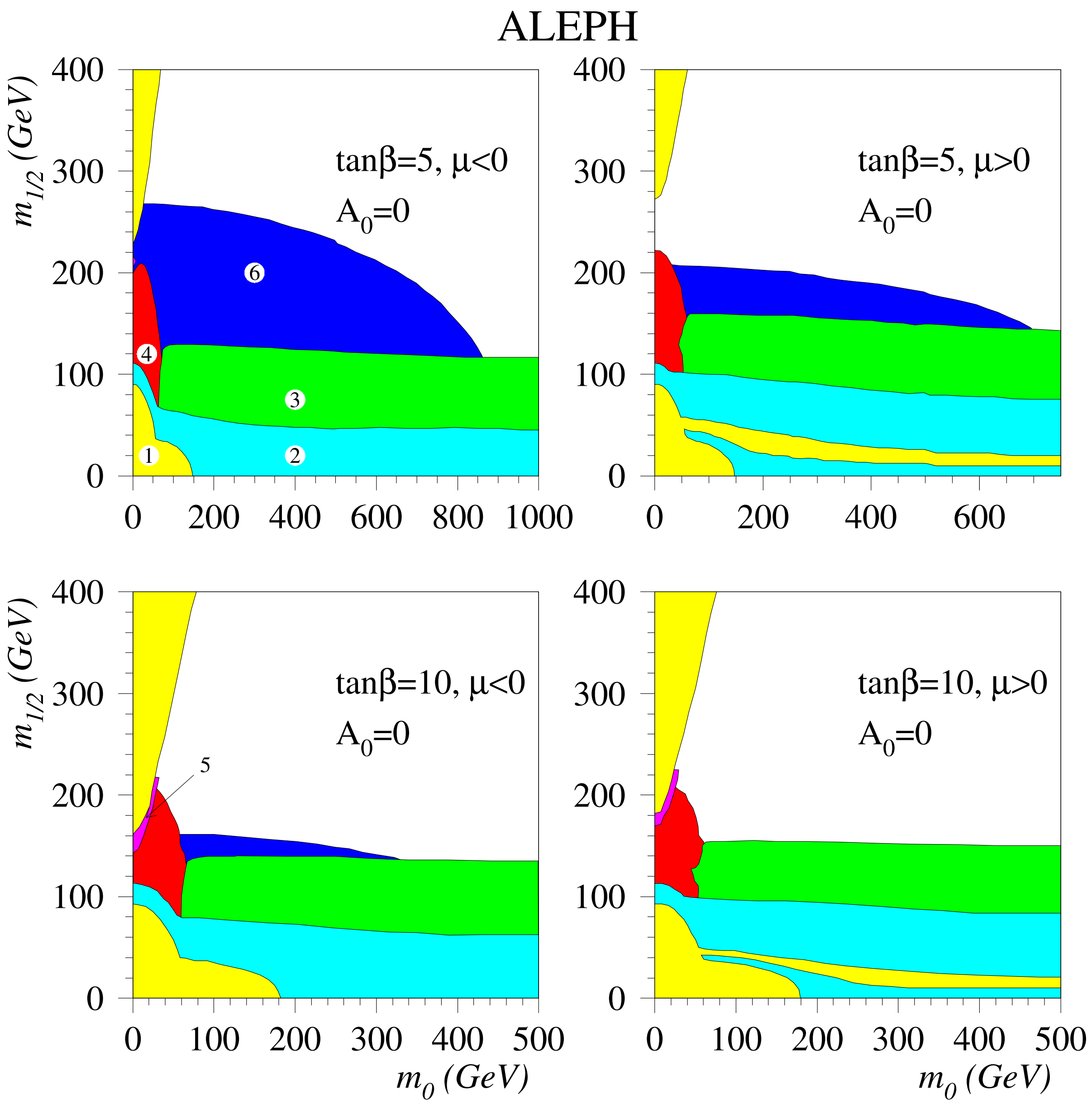

Figure 7: *Minimal supergravity scenario: domains of the* $(m_0, m_{1/2})$ *plane excluded for* $\tan\beta = 5$ *and 10, and for* $A_0 = 0$*. Region 1 is theoretically forbidden. The other regions are excluded by the Z width measurement at LEP1 (2), chargino (3) and slepton (4) searches, stable stau search (5) and Higgs boson searches at* $\sqrt{s} \leq 201.6\,\mathrm{GeV}$ *(6).*

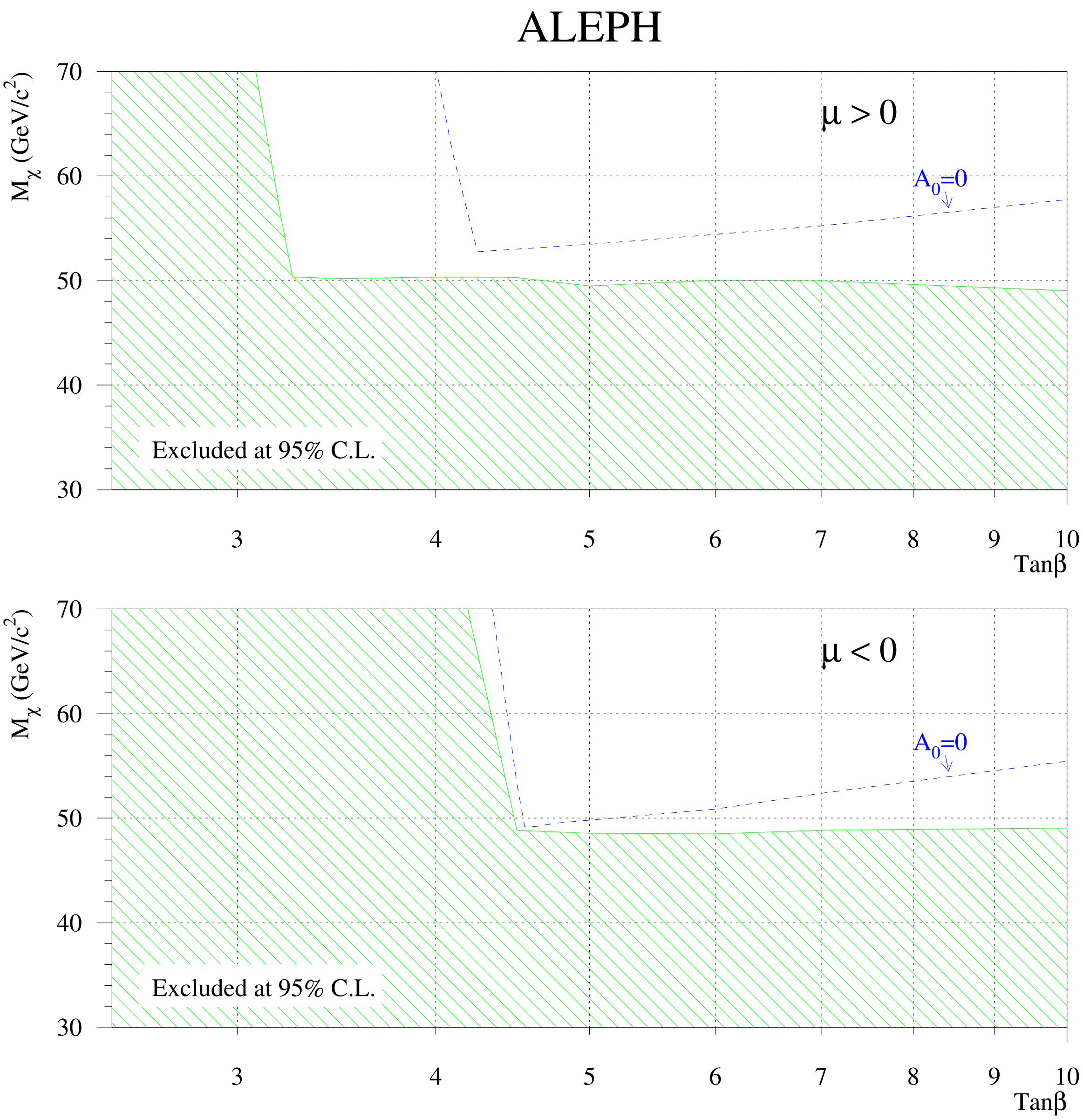

Figure 8: *Minimal supergravity scenario: lower limit on the LSP mass as a function of* $\tan\beta$*. The dashed line shows the result of obtained by assuming* $A_0 = 0$*.*