Compositeness and supersymmetry with ALEPH detector

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Abstract

In the framework of its various search program, ALEPH collaboration performed an exhaustive study in two main sectors : Supersymmetry and Compositeness. After completing a full analysis of the data recorded at the Z^0 peak and at 130-136 GeV, new limits on SUSY particle masses have been set, essentially on the neutralino mass considered as the Lightest Supersymmetric Particle (LSP). In the Compositeness domain, a complete search for excited leptons and quarks have been made, both in single and double production. A new lower limit on the compositeness energy scale Λ has been deduced.

1 Introduction

Until now, the data collected by the four LEPI experiments probe with a high degree of accuracy the predictions of the Standard Model of strong and electroweak interactions between fundamental particles. However, the S.M. introduces a lot of parameters and does not yet give any answer concerning the masses of the particles (which range from some eV for the ν_e to 176GeV for the top quark), their electric charge, the number of generations and many other parameters.

These questions could be elucidated by performing theoretical models which purpose is to go beyond the standard model. These models can be classified mainly into two groups : **Supersymmetry** and **Compositeness**. The first one which includes supersymmetric Grand Unified Theories supposes that quarks and leptons are *elementary* and that all the patterns of known particles can be explained by a deeper symmetry linking fermions and bosons, Supersymmetry. Compositeness models departe from another point of view : quarks and leptons are not elementary; they are *bound states* of more fundamental fields, *Preons*, which arrangements can reproduce the known generations of particles and their fundamental properties like lepton number, quark colour and other physical parameters.

In the present note, update of ALEPH results concerning the Minimum Supersymmetric Standard Model (MSSM) are presented by stressing on the mass lower limits of SUSY particles and especially the Neutralino mass. As far as Composite models are concerned, emphasis will be put on the search for both radiative and weak decays of excited fermions (excited charged leptons, excited neutrinos and excited quarks) and limits on the compositeness energy scale will be inferred.

As it will be shown below, final states coming from the decays of supersymmetric particles and excited ones present many common features which can be gathered into three classes :

- purely leptonic final states.
- hadronic final states.
- semi-leptonic final states which include both leptons and hadrons.

These three different classes can be accompanied by missing energy-momentum characterized by the emission of one or several neutrinos or the emission of a stable neutralino. In both cases, emphasis will be put on the analysis methods consisting of the kinematic features and the topology of the events without going too much into technical details. Full and complete analysis of these searches have been already described in many ALEPH publications [1]. Forthcoming papers are in preparation and will be published soon.

2 Search for Excited Fermions

A direct way to probe an eventual substructure common to all fermions is to search for excited leptons and excited quarks with very specific decays.

In the case of lepton production, Hagiwara's model [2] has been successfully used for all signal simulations. It introduces two main parameters : the coupling constants C_{Vl^*l} (V $= \gamma, W^{\pm}, Z^0$) and the energy scale Λ which physical significance is the energy at which compositeness effects can arise. For q^* production, the Renard-Boudjema model [3], [4] is used and it introduces one parameter, λ/m_*, where λ and m_* are respectively the coupling constant at the Zq^*q vertex and the q^* mass.

In the case of double production, $e^+e^- \to f^*\bar{f}^*$ where $f = l^{\pm}, \nu, q$; the Standard Model couplings are used in addition to form-factors at the $Zf^*\bar{f}^*$ vertex.

Once an excited fermion is produced, it can decay either *radiatively* or *weakly* via off-shell W and Z vector bosons. In the case of an excited quark, the dominant decay channel is $q^* \to q + g$ ($g =$ gluon) which represents 90% of the decay modes and its weak decays are completely neglected.

A great number of final states arise from all the possible f^* weak and radiative decays. In order to found signal events, the investigation tools performed in the data analysis consist essentially of : i) kinematical characteristics of the reaction which is looked for, ii) its specific topology and iii) lepton ($e^{\pm}$ or $\mu^{\pm}$) identification or photon identification in some special channels.

The aim of these searches is the difficult task of rejecting all the backgrounds and keeping a good signal efficiency in order to set limits on the compositeness parameters, especially the energy scale Λ. Each class of f^* decays will provide their own set of limits and in the case of the multiple channels coming from l^* and ν^* weak decays (charged current and neutral one) combination of the different limits is done, which direct consequence is the improvement of the value of Λ.

2.1 Radiative decays of excited leptons

In the charged sector, there are two main reactions :

$$\begin{aligned} e^+e^- &\longrightarrow \ell^*\ell \\ &\longrightarrow \ell^*\overline{\ell^*} \\ \ell^* &\longrightarrow \ell+\gamma \end{aligned}$$

Final states are characterized by two charged leptons and by one or two energetic photons. In the case of $e^-e^+ \rightarrow \tau^*\tau$, search has been limited to one-prong τ decays. The main backgrounds are : $e^-e^+ \rightarrow e^-e^+(\gamma), \mu^-\mu^+(\gamma), \tau^-\tau^+(\gamma)$.

Event selection requires two acollinear tracks (the two track angle being in the angular range 10° and 170°), lepton identification and energetic photon identification. Then, the invariant masses of the lepton and the photon of the remaining events are reconstructed in order to find l^* candidates. The whole analysis indicates that the observed data and the expected backgrounds are in complete agreement both in number of events and invariant mass shape.

In the case of single l^* production, upper limits are inferred on the ratio C_{Zl^*l}/Λ assuming that the branching ratio $Br(l^* \rightarrow l+\gamma)$ is 100% (Fig.2). The values are respectively:

$$\frac{C_{Z\ell^*\ell}}{\Lambda} \leq 0.05 \text{ TeV}^{-1} \text{ for } e^*,\ \mu^*$$

$$\text{and } \frac{C_{Z\tau^*\tau}}{\Lambda} \leq 0.1 \text{ TeV}^{-1}$$

in a l^* mass range varying from 10 GeV/c^2 to 80 GeV/c^2.

In the case of double production, no data events survive after the selection and upper limits at 95% confidence level on the Zl^*l^* form-factors are set.

Assuming the valididty of the universality of electroweak interaction in the excited lepton sector, excited neutrinos are expected to decay radiatively like their charged partners l^*. Search for excited neutrinos have been done both in single and double production :

$$\begin{aligned} e^+e^- &\longrightarrow \nu^*\overline{\nu} \\ &\longrightarrow \nu^*\overline{\nu^*} \\ \nu^* &\longrightarrow \nu+\gamma \end{aligned}$$

Topology of the corresponding final states is very simple: i) one energetic photon wich energy varies from 17 GeV to the beam energy E_b in the single production and ii) two acollinear energetic photons which angle is smaller than 176° in the double production.

Applying the criteria above, no events survive among the data and limits at 95% confidence level are set on the unknown parameters which appear like

$$(C_{Zl^*l}/\Lambda)\sqrt{Br(\nu^* \to \nu + \gamma)}.$$

Its value is almost constant and equal to 0.1 TeV^{-1} in the ν^* mass interval ranging from 10 GeV/c^2 to 85 GeV/c^2.

2.2 Weak decays of excited leptons

This chapter is devoted to describe a new way to search for excited leptons. Weak decays of ℓ^* or ν^* is a three-body problem involving the emission of a virtual W or virtual Z which in turn decays into leptons or hadrons (Fig.1). The dynamics of this decay is fully described in [5] which has been used to generate all the signal Monte-Carlo events.

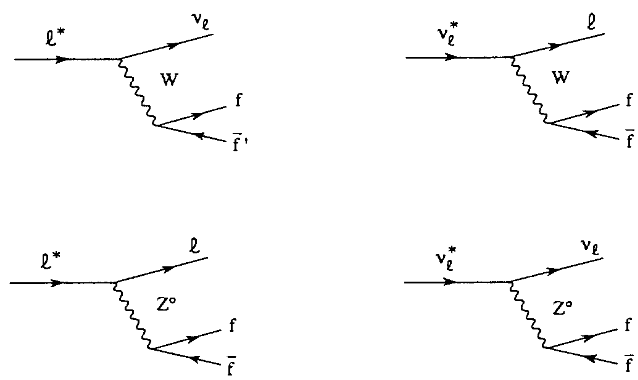

Figure 1: Feynman diagrams of l^* and ν^* three-body weak decays (f, f' being leptons or quarks)

Two categories of final states arise :

- purely leptonic final states
- semi-leptonic and hadronic final states.

Each category includes several classes of signal topologies depending usually i) on the ℓ^* or ν^* mass, ii) on its flavour iii) and on the nature of its weak decay (charged current or neutral one).

Backgrounds are the leptonic channels coming from the Z^0 decays and the four-fermion final states which include virtual photon collisions.

2.2.1 Purely leptonic final states

These channels are illustrated by reactions like :

$$
\begin{array}{lll}
 & e^+e^- \longrightarrow \ell^*\ell & \\
 & \quad\quad \stackrel{W}{\longrightarrow} \nu(\ell'\nu_{\ell'}) & \\
\text{or} & e^+e^- \longrightarrow \ell^*\ell & \\
 & \quad\quad \stackrel{Z}{\longrightarrow} \ell(\nu\overline{\nu}) & \\
 & \quad\quad\quad\quad \ell(e^+e^-) &
\end{array}
$$

Different final states come from these decays both in the single production or double production of ℓ^* or ν^*. They can be gathered essentially into four topologies :

- 2 prongs with missing energy and missing transverse momentum (E, P_t)
- 4 prongs with missing (E, P_t)
- 4 prongs without missing (E, P_t)
- 6 prongs without missing (E, P_t)

with a vanishing total electric charge.

In the 2 prong topology, event selection is based mainly on the acollinearity and acoplanarity of the tracks and the missing P_t of the event.

In the four track topologies, lepton identification is required for at least two prongs and the maximum angle among three tracks localised in one hemisphere must be greater than 11° in order to reject the remaining $\tau^+\tau^-$ background.

In the 6 track topology, events are searched for by requiring the conservation of energy momentum and a thrust value smaller than 0.95.

In all the leptonic channels, the numbers of observed events are in good agreement with the expected backgrounds with an analysis efficiency varying from 20% to 70%. Limits are deduced on the free compositeness parameters which appear in the following form :

$$\frac{C_{Z\ell^*\ell}}{\Lambda}\sqrt{Br(L^* \to LV)} \quad (L = l, \nu)$$

as function of the excited lepton mass which varies from 10 GeV/c^2 to 90 GeV/c^2.

In the special case of double production, limits are set on the product $F * BR(f^* \to fV)$ where F is the f^* form-factor at the $Zf^*\bar{f}^*$ vertex (see figure 3 in the case of $\nu^*\bar{\nu}^*$)

2.2.2 Semileptonic and hadronic final states

For an excited lepton mass greater than 10 GeV/c^2, the hadronic branching ratios of the virtual W and Z emitted by a ℓ^* or a ν^* are equal to the ones predicted by the Standard Model for on-shell W and $Z(\#70\%)$. It seems natural to look for hadronic weak decays of ℓ^* and ν^*.

Three main final states arise :

- hadronic final states without charged lepton and with missing (E, P_t) coming from the following reaction :

$$\nu^* \bar{\nu} \quad \llcorner\!\xrightarrow{Z} \nu(q\bar{q})$$

- One identified charged lepton, hadrons and one neutrino defined from missing $(E, \vec{P})$ illustrated by the following reactions:

$$\begin{aligned} e^+e^- &\longrightarrow \ell\ell^* \xrightarrow{W} \nu_e(q\bar{q}) \\ &\longrightarrow \nu\,\bar{\nu}^* \\ &\qquad\quad \llcorner\!\xrightarrow{W} \ell(q\bar{q}') \end{aligned}$$

- Two charged leptons of same flavour and opposite charge, hadrons and no missing $(E, \vec{P})$. These correspond to the reactions :

$$\begin{aligned} e^+e^- &\longrightarrow \ell^*\ell \\ &\qquad \llcorner\!\xrightarrow{Z} \ell(q\bar{q}) \end{aligned}$$

Backgrounds for hadronic weak decays of L^* $(L = l, \nu)$ are essentially the hadronic decays of the Z^0, the four-fermion final states and the $\tau^+\tau^-$ channel which is important in the low multiplicity L^* channel.

Whatever is the final state, two kind of configurations occur. They depend on the ℓ^* or ν^* mass :

a) For ℓ^* (ν^*) mass smaller than 30 GeV/c^2, all the tracks except the energetic lepton or neutrino $(E_\ell, E_\nu > 5$ GeV) are localised in one hemisphere. This interesting geometrical property allows to reject the main background $\tau^+\tau^-$.

b) For $\ell^*(\nu^*)$ mass greater than 30 GeV/c^2, search for signal events is based mainly on the jet topology. Two or three jets are required with specific angular distributions and the particular topology of the energetic lepton $(E_{l,\nu} > 5$ GeV)according to the jets allows to remove the remaining $(q\bar{q})$ background.

Signal efficiency in the semi-leptonic searches is almost stable in a wide range of L^* mass. It varies from 35% to 60% and the best efficiency is obtained in the ν^* neutral current decay channel where its average is 60%.

As in the purely leptonic final states, the number of observed events is in good agreement with the expected background and limits are set on the parameters :

$$\frac{C_{ZL^*L}}{\Lambda}\sqrt{Br(L^* \to LV)}$$

in the different studied channels according to the L^* mass.

2.2.3 Combined limits

Several final states come from the same kind of weak decay (charged current or neutral one) like :

$$\ell^* \xrightarrow{Z} \begin{array}{l} \ell(\nu\bar{\nu}) \to 20\% \\ \ell(e^+e^-) \to 10\% \\ \ell(q\bar{q}) \to 70\% \end{array}$$

Combining all the results is an essential task in order to deduce final limits independently on the branching ratios above.

Assuming the most conservative hypothesis, $Br(\ell^* \to \ell Z) = Br(\ell^* \to \nu_\ell W) = 50\%$, an upper limit on the ratio of the free parameters $\left(\frac{C_{Z\ell^*\ell}}{\Lambda}, \frac{C_{Z\nu^*\nu}}{\Lambda}\right)$ can be inferred.

In the framework of the Hagiwara's model and taking the simplest hypothesis ($f = f' = 1$), the coupling constants have typical values : $C_{Z\nu^*\nu} = 0.593$; $C_{Z\ell^*\ell} = 0.320$.

Constrained limits on C_{ZL^*L}/Λ allow a lower limit on the compositeness energy scale Λ. In the mass range [10 GeV/c^2 , 80 GeV/c^2], this lower limit is greater than 1 TeV in the (e^*, μ^*) channels while it is better than 2 TeV in the (ν_e^* , ν_μ^*) channels where a value close to 8 TeV is reached (Fig.4).

2.3 Searches for excited quarks and a scalar partner of the Z^0

The extension of the S.M. towards compositeness models implies also the existence of excited quarks which undergo the two following decays :

$$q^* \longrightarrow q + g \longrightarrow \sim 90\%$$
$$q^* \longrightarrow q + j \longrightarrow \sim 10\%$$

the excited quarks being produced singly or in pairs :

$$e^+e^- \longrightarrow q^*\,q$$
$$\hookrightarrow q + g \longrightarrow \simeq 90\%$$

$$e^+e^- \longrightarrow q^*\,\bar{q}^*$$
$$\hookrightarrow \bar{q} + g$$
$$\hookrightarrow q + g$$

In the single production, three jets are required and invariant masses of two jets among the three are reconstructed. In the double production, four jets are required; then invariant masses are reconstructed by taking the jets 2 by 2 and demanding that among all possible combinations the one which is chosen corresponds to the minimum of $|\mathcal{M}_{ij} - \mathcal{M}_{k\ell}|$, where i, j, k, ℓ are respectively the indices of the four jets.

• In the case of a q^* electromagnetic radiative decay, gluon jet is replaced by an energetic photon which must be isolated from the hadronic jets; the main background being : $e^+e^- \longrightarrow q\bar{q}\gamma$

• The signal efficiency is around 60% at 40 GeV/c^2.

• Limits on compositeness form-factors are set in the $(q^*\bar{q}^*)$; while in the $(q^*\bar{q})$ channels limits are set on the coupling $\left(\frac{\lambda}{m_{q^*}}\right)\sqrt{B}$ where B is one of the two branching ratios mentionned above (Fig.5).

If the Z^0 resonance is composite and made from preons, those subconstituents can combine and give rise to a bound-state of spin $j = 0$ (scalar resonance) which can be looked for in the Z^0 radiative decay :

$$\begin{aligned} Z \longrightarrow \gamma\, S & \\ & \hookrightarrow \ell^+\ell^- \\ & \hookrightarrow q\bar{q} \\ & \hookrightarrow gg \end{aligned}$$

So final states are the same ones than ℓ^* and q^* radiative decays and coupling are derived from composite models although S is similar to the Higgs boson. Experimental searches are similar to the ℓ^* and q^* ones, the photon energy being extended to 3 GeV.

There is no evidence for a peak in both $(\ell\ell)$ and (jet–jet) invariant masses and limits are set on the branching ratio $Br(Z \rightarrow \gamma + S)$ as function of the S mass in the range 10 GeV/c^2 to 90 GeV/c^2

The most conservative upper limit comes from :

$$\begin{aligned} Z \longrightarrow \gamma S & \\ & \hookrightarrow gg \end{aligned}$$

and it is around 2.8×10^{-5} ; the S.M. prediction being $\simeq 7 \times 10^{-7}$, while some composite models (Renard et al) predict values ranging from 10^{-5} to 10^{-2}.

3 Search for Supersymmetric Particles

The minimum extension of the Standard Model towards Supersymmetry (Minimum Supersymmetric Model) assumes that a supersymmetric (susy) partner is associated to each fundamental particle (lepton, quark, vector bosons and Higgs boson) ; the spin of the susy particle being $\left(j \pm \frac{1}{2}\right)$ where j is the spin of the ordinary one. [6]

However, in order to avoid standard anomalies, two scalar Higgs doublets to which correspond two spin 1/2 higgsino doublets must be introduced. So, in the gauginos and higgsinos sectors two categories of particles appear : the *weak* eigenstates and the *mass* eigenstates, the latter being linear combination of the first ones and representing the physical particles.

Mixing among charged gauginos $\widetilde{W}^{\pm}$ and charged higgsinos $\widetilde{H}^{\pm}$ leads to Charginos $\chi^{\pm}_{1,2}$; while mixing among neutral ones, $\widetilde{\gamma}$, $\widetilde{Z}^0$, $\widetilde{H}^0_1$, $\widetilde{H}^0_2$, provides Neutralinos which are usually ordered by increasing mass : χ, χ', χ'', χ'''.

The MSSM introduces new parameters ; the most important ones being :

i) the two energy scales $\mathcal{M}_1$ and $\mathcal{M}_2$ related respectively to the gauge groups $U(1)$ and $SU(2)$;

ii) a mass parameter, μ, in the Higgs superpotential ;

iii) the rate of the vacuum expectation values of the Higgs fields given by $tan\beta = \frac{v_2}{v_1}$.

In addition to the Z^0 mass, $\mathcal{M}_Z$, and to $\sin^2\theta_W$, the Neutralino mass matrix depends on the four parameters mentionned above.

Independently of the mass parameters, a new quantum number is introduced in order to distinguish between ordinary particles and susy ones ; it is the R-parity ([7]) which algebraic expression is :

$$R = (-1)^{3(B-L)+2S}$$

where B,L and S are respectively the baryonic number, the leptonic number and the spin of the particle. R is equal to 1 for ordinary particles and to -1 for susy ones. If R is supposed to be conserved, supersymmetric particles can be produced only by pairs; like : $e^+e^- \longrightarrow Z^0 \longrightarrow \widetilde{e}\overline{\widetilde{e}}$

In the hypothesis of R-conservation, the lightest susy particle must be neutral and colourless because of cosmological and astrophysical constraints. Indirect searches coming from the Z^0 width indicate that the lowest limit on the sneutrino mass is 42 GeV/c^2 ; which leaves the Neutralino as the only lightest supersymmetric particle (LSP) candidate.

In the following, results concerning the searches for squarks, sleptons, charginos and neutralinos will be summarized by emphasizing two aspects: R-parity conservation and R-parity violation. Once limits are set on the masses and production cross-sections of $\widetilde{e}$, $\widetilde{\nu}$, $\chi^{\pm}$, χ and χ' ; other limits on the SUSY free parameters will be inferred in both the two hypothesis mentionned above.

3.1 Search for SUSY particles with R-parity conservation

R-parity being a multiplicative quantum number, SUSY particles are produced by pairs. To each lepton two partners are associated ; each one related to the chiral nature of the lepton (left-handed or right-handed).

Because of Supersymmetry breaking, the cross-section of the process: $e^+e^- \longrightarrow \widetilde{e}_R\overline{\widetilde{e}_R}$ is smaller than $e^+e^- \longrightarrow \widetilde{e}_L\overline{\widetilde{e}_L}$ cross-section and limits will be set on the right slepton production at both energies $\sqrt{s} = M_Z$ and $\sqrt{s} = 130 - 136$ GeV.

The main reactions which were looked for are:

$$\begin{aligned} e^+e^- &\longrightarrow \tilde{\ell}\bar{\tilde{\ell}} \text{ (sleptons)} \\ &\longrightarrow \chi^+\chi^- \text{ (charginos)} \\ &\longrightarrow \chi\chi' \text{ (neutralinos)} \\ &\longrightarrow \tilde{t}\bar{\tilde{t}} \text{ (stop quarks)} \end{aligned}$$

In addition to R-parity conservation, conservation of leptonic and baryonic number is required.

3.1.1 Sleptons

$$e^+e^- \longrightarrow \tilde{\ell}\bar{\tilde{\ell}}$$
$$\hookrightarrow \bar{\ell} + \chi$$
$$\hookrightarrow \ell + \chi$$

Each slepton emitting a neutralino, final states require two charged leptons of same flavour and opposite charge with important missing energy and missing transverse momentum P_t.

3.1.2 Charginos

$$e^+e^- \longrightarrow \chi^+\chi^-$$

According to SUSY hypothesis inspired from the MSSM, the charged current decay of $\chi^\pm$ is the dominant one.

$$\chi^\pm \longrightarrow \chi + W^\pm$$
$$\hookrightarrow \ell^\pm \nu_e$$
$$\longrightarrow q\bar{q}'$$

So, three kinds of final states arise :

- Purely leptonic final state accompanied by missing (E, P_t)
- Isolated lepton, jets and missing (E, P_t)
- Acoplanar jets and missing (E, P_t).

A special decay can occur if the $\tilde{\nu}$ mass is close to the $\chi^\pm$ mass. It is a two-body decay: $\chi^\pm \longrightarrow \ell^\pm + \tilde{\nu}$, which final state consists in two acoplanar tracks and missing (E, P_t).

3.1.3 Neutralinos

Neutralinos can be produced in three different reactions:

$$\begin{aligned} e^+e^- &\longrightarrow \chi\chi \quad (1) \\ &\longrightarrow \chi\chi' \quad (2) \\ &\longrightarrow \chi'\chi'' \quad (3) \end{aligned}$$

where χ is the lightest neutralino and χ' is one of the three heavy ones.

Heavy neutralino χ' decays mainly by neutral current:

$$\chi' \longrightarrow \chi + Z^0$$
$$\hookrightarrow \ell^+\ell^-$$
$$\longrightarrow q\bar{q}$$

Charged current decay, $\chi' \longrightarrow \chi^{\pm}W^{\mp}$, is disfavoured because of the lowest limit of 45 GeV/c^2 set on the $\chi^{\pm}$ mass already obtained from the Z^0 width.

In the case of two heavy neutralino search, the branching ratio $Br(\chi' \longrightarrow \chi Z)$ is assumed to be dominant (100%) and three possible final states can arise :

i) One pair of charged leptons (e^+e^-), jets and missing (E, P_t)

ii) Two lepton pairs and missing (E, P_t)

iii) Four jets and missing (E, P_t).

3.1.4 Stops: $e^+e^- \longrightarrow \tilde{t}\bar{\tilde{t}}$

Because of the top quark mass and the lowest limit on the $\chi^{\pm}$ mass, the two following decays are forbidden:

$$\tilde{t} \not\rightarrow t + \chi \quad , \quad \tilde{t} \not\rightarrow \chi^+ + b$$

Only the decay: $\tilde{t} \longrightarrow \chi + c$ is allowed.

Search for $\tilde{t}\bar{\tilde{t}}$ is performed by looking for two acoplanar jets characterized by important missing E and P_t.

3.1.5 Results and limits

No events have been observed after performing cuts on the main kinematical parameters in each signal topology at both the two energies $\sqrt{s} = M_Z$ and $\sqrt{s} = 130 - 136$ GeV. Limits are inferred on both the cross-sections and the masses of the susy particles (see Fig.6 for some limits).

In the case of sleptons, following limits are set :

$$\begin{aligned} m(\tilde{e}_R) &\geq 53 \text{ GeV/c}^2, \quad \text{if } m(\chi) < 35 \text{ GeV/c}^2 \\ m(\tilde{e}_R) &\geq 59 \text{ GeV/c}^2, \quad \text{if } m(\chi) = 0 \end{aligned}$$

For charginos, the cross-section $\sigma(e^+e^- \to \chi^+\chi^-)$ depends on the mass difference

$$\Delta m = m(\chi^\pm) - m(\chi)$$

So different limits can be deduced:

$$\sigma < 3\ pb \text{ with } \begin{cases} m(\chi^+) < 64 \text{ GeV/c}^2 \\ \text{and } \Delta m > 5 \text{ GeV/c}^2 \end{cases}$$

$$\text{or with } \begin{cases} 64 \leq m(\chi^+) < 67.8 \text{ GeV/c}^2 \\ \text{and } \Delta m > 10 \text{ GeV/c}^2 \end{cases}$$

$$\text{Or} \quad \sigma < 5\ pb \ \text{ for } \ \Delta m > 5 \text{ GeV/c}^2$$

which leads to a lower limit on the $\chi^\pm$ mass:

$$m(\chi^\pm) > 67.8 \text{ GeV/c}^2, \text{ if } m(\tilde{\nu}) > 200 \text{ GeV/c}^2$$
$$m(\chi^\pm) > 65 \quad \text{GeV/c}^2, \text{ if } \Delta m > 10 \text{ GeV/c}^2$$

For heavy neutralinos, lowest limit on χ' mass is 69 GeV/c^2 if $\Delta m \geq 10$ GeV/c^2. Interesting result has been obtained concerning the lightest neutralino mass [8]. By fixing the $\tilde{\nu}$ mass to 200 GeV/c^2 and combining both LEP1 and LEP1.5 results, a lower limit on χ mass can be inferred for low values of $tan\beta$:

$$M(\chi) > 12.8 \text{ GeV/c}^2 \ (95\% \ C.L.)$$

For large values of $tan\beta$, $M(\chi)$ scales at 34 GeV/c^2 (Fig.7).

The limits obtained on the masses of the susy particles can be transposed into other limits related to the MSSM parameters. By using some specific hypothesis inspired from Supergravity models and by fixing the value of $tan\beta = \frac{v_2}{v_1}$, new domain in the $(M_2,\ m_0)$ plane can be excluded (Fig.8); m_0 being the common mass for scalar particles in SUGRA theories.

3.2 Search for SUSY particles with R-parity violation

R-parity violation hypothesis assumes that the neutralino χ is no longer stable. In this framework the particle χ decays essentially into leptons which implies the non-conservation of the leptonic number.

$$\chi \longrightarrow \begin{array}{l} \overline{\nu}_i\ \ell_j^+\ \ell_k^- \\ \overline{\nu}_j\ \ell_i^+\ \ell_k^- \\ \nu_i\ \ell_j^-\ \ell_k^+ \\ \nu_j\ \ell_i^-\ \ell_k^+ \end{array}$$

i, j, k representing the three family indices [9].

In the following the χ lifetime is neglected. At center of mass energies $\sqrt{s}$ = 130 − 136 GeV, new backgrounds arise ; these are

$$\begin{aligned} e^+e^- &\longrightarrow ZZ^* \\ &\longrightarrow Z\gamma^* \\ &\longrightarrow \gamma^*\gamma^* \\ &\longrightarrow WW^* \end{aligned}$$

Topology of the signal final states coming from $\chi^{\pm}$ decays depends on:

i) the chargino decay modes

ii) the chargino mass

From the reaction :

$$\begin{aligned} e^+e^- &\longrightarrow \chi^+\chi^- \\ \chi^{\pm} &\longrightarrow \chi(\ell\nu_\ell) \\ & \chi(q\bar{q}') \end{aligned}$$

the neutralino χ in turn decaying into leptons; three classes of decay modes appear : purely leptonic, hadronic and mixed ones.

Selection criteria are similar to those mentionned before, they consist in : the number of charged tracks, the visible energy E_{vis}, the leptonic energy E_ℓ, the non-leptonic energy $E_{n\ell}$, the missing transverse momentum $\not{P}_t$ and the thrust.

Cuts on these variables vary according to the $\chi^{\pm}$ mass from one class to another one. *No events remain* after analysing all the data.

Another way of search has been performed by looking for neutralino production and their leptonic decays:

$$\begin{aligned} e^+e^- &\longrightarrow \chi\chi\,,\,\chi\chi'\,,\,\chi'\chi'' \\ \chi(\chi') &\longrightarrow \nu_i\,\ell_j\,\ell_k \end{aligned}$$

The selection criteria are very simple: the total number of prongs must be comprised between 4 and 8, an important missing transverse momentum is required, $\not{P}_t \geq 7$ GeV/c, and at least one lepton ($e^{\pm}$, $\mu^{\pm}$) must be identified.

No events remain after applying these cuts.

Results of these searches improve some limits deduced from R-parity conservation searches : charginos are excluded up to the kinematical limit of 68 GeV/c^2. Consequently, if these limits are transposed in the domain of the SUSY parameter plane :

$$\frac{\mu}{M_Z} \text{ and } \frac{m_{\tilde{\gamma}}}{M_Z}$$

where $m_{\tilde{\gamma}}$ is the photino mass, new regions are excluded for different values of $tan\beta$. It is worth noticing that the ratio $\left|\frac{\mu}{M_Z}\right|$ is at least greater than 2 at 95% confidence level (Fig.8).

4 Conclusion

All possible ways of search for Compositeness and Supersymmetry have been intensively explored by ALEPH collaboration by using standard tools (jet reconstruction, lepton identification, photon detection in a wide energy range) which are very powerful, due to the hermiticity and the granularity of the apparatus. Despite the detailed analysis performed in the different phenomenological aspects of these two extensions of the Standard Model (leptonic, hadronic, semileptonic and photonic final states), no signal of excited or supersymmetric particles have been found.

However, stringent limits have been set on the main physical parameters of both Compositeness and SUSY models :

• In the simplest form of Hagiwara's model, lower limits on the compositeness energy scale Λ are set. They can reach 6.4 TeV in the l^* radiative decay channel and 8 TeV in the weak hadronic decay channel of a ν^*. The physical significance of those limits is very clear : leptons and quarks are *point-like particles* at the current accelerator energies and still do not reveal any substructure.

• In the framework of the MSSM, previous limits from LEPI data on supersymmetric particles have been extended thanks to LEP1.5 data. The lowest limit on the Chargino mass is 68 GeV/c^2. If the MSSM is supplied by some inspired-SUGRA hypothesis and assuming R-parity conservation, a lower limit of 12.8 GeV/c^2 on the Neutralino mass has been derived; this result could have interesting cosmological implications essentially for the search for dark matter in the Universe.

A common feature for all these searches is the fact that the energy scale for New Physics is pushed further than 1 TeV.

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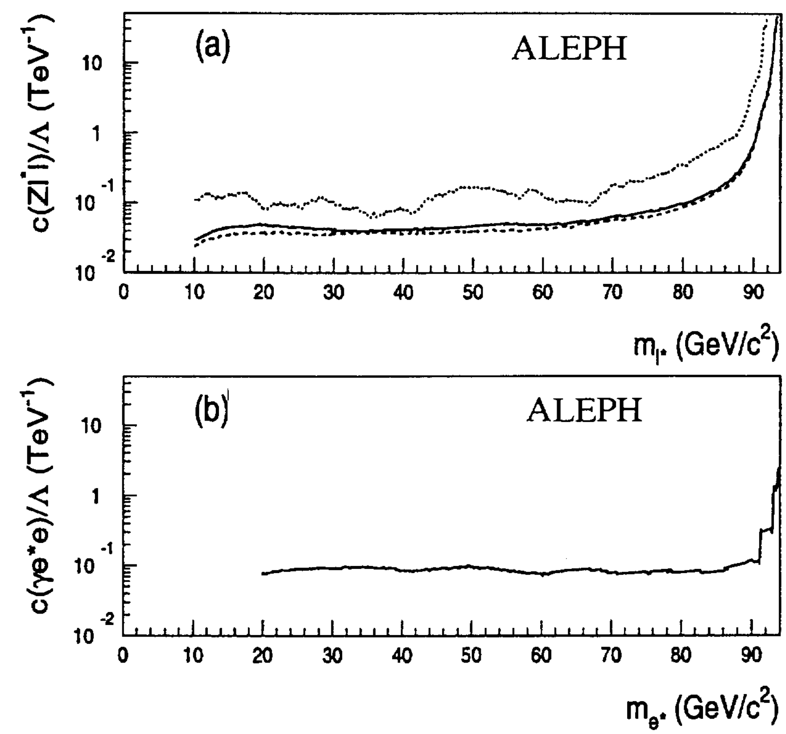

Figure 2: Limits on the free compositeness parameters from l^* radiative decays. s-channel production(upper figure). e^* production in t-channel(lower figure)

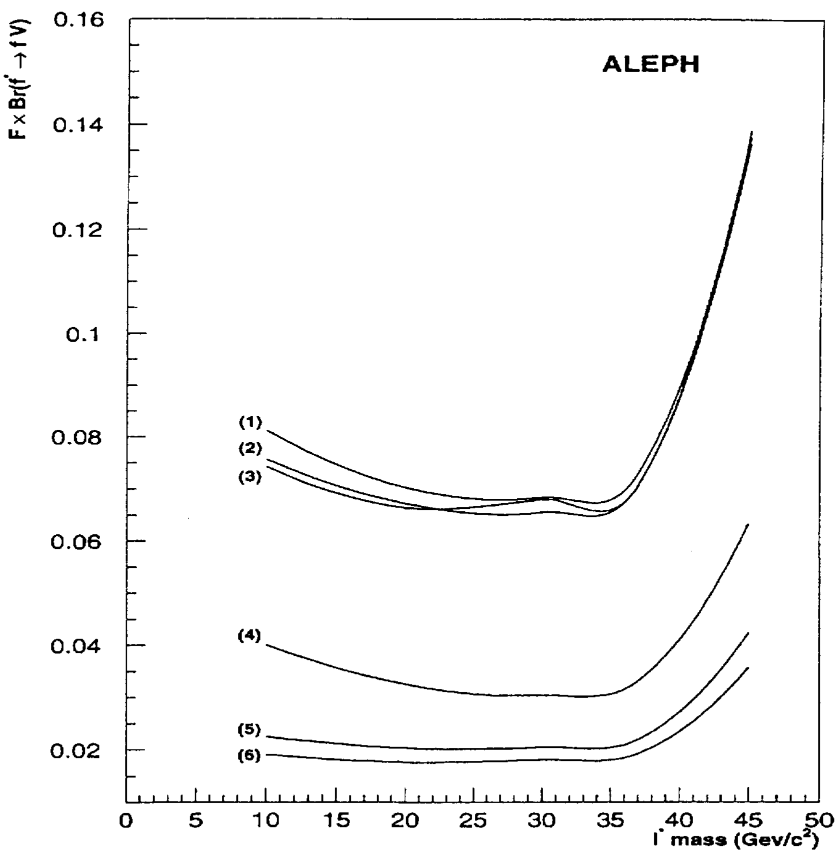

Figure 3: Limits on the Compositeness free parameters in the double production of ν^* with four track final states. Curves (1), (2), (3) correspond to neutral current decay : $\nu_j^* \bar{\nu}_j^* \to \nu_j(l^+l^-)\bar{\nu}_j(l^+l^-)$. Curves (4), (5), (6) correspond to charged current decay : $\nu_j^* \bar{\nu}_j^* \to l_j(l\nu_l)\bar{l}_j(l\nu_l)$, with $j = \tau, e, \mu$

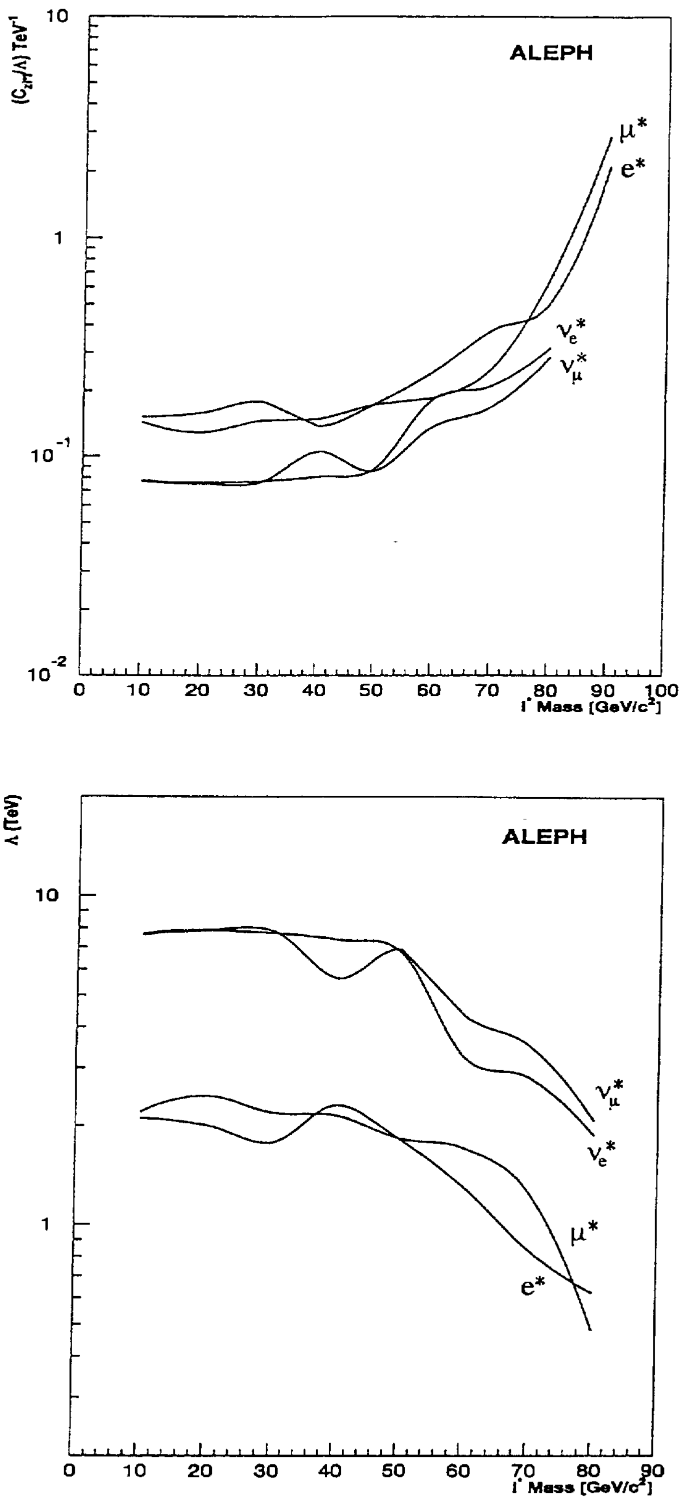

Figure 4: Limits on the free compositeness parameters from L^* weak decays (upper figure). Limits on the compositeness energy scale Λ (lower figure)

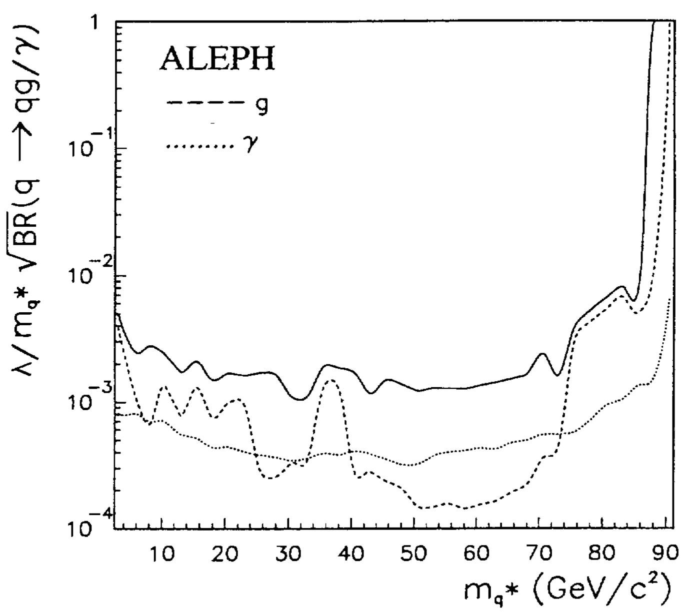

Figure 5: Limits on the free compositeness parameters from radiative and gluonic decays of excited quark (Solid curve is the combination of the dot and dashed curve)

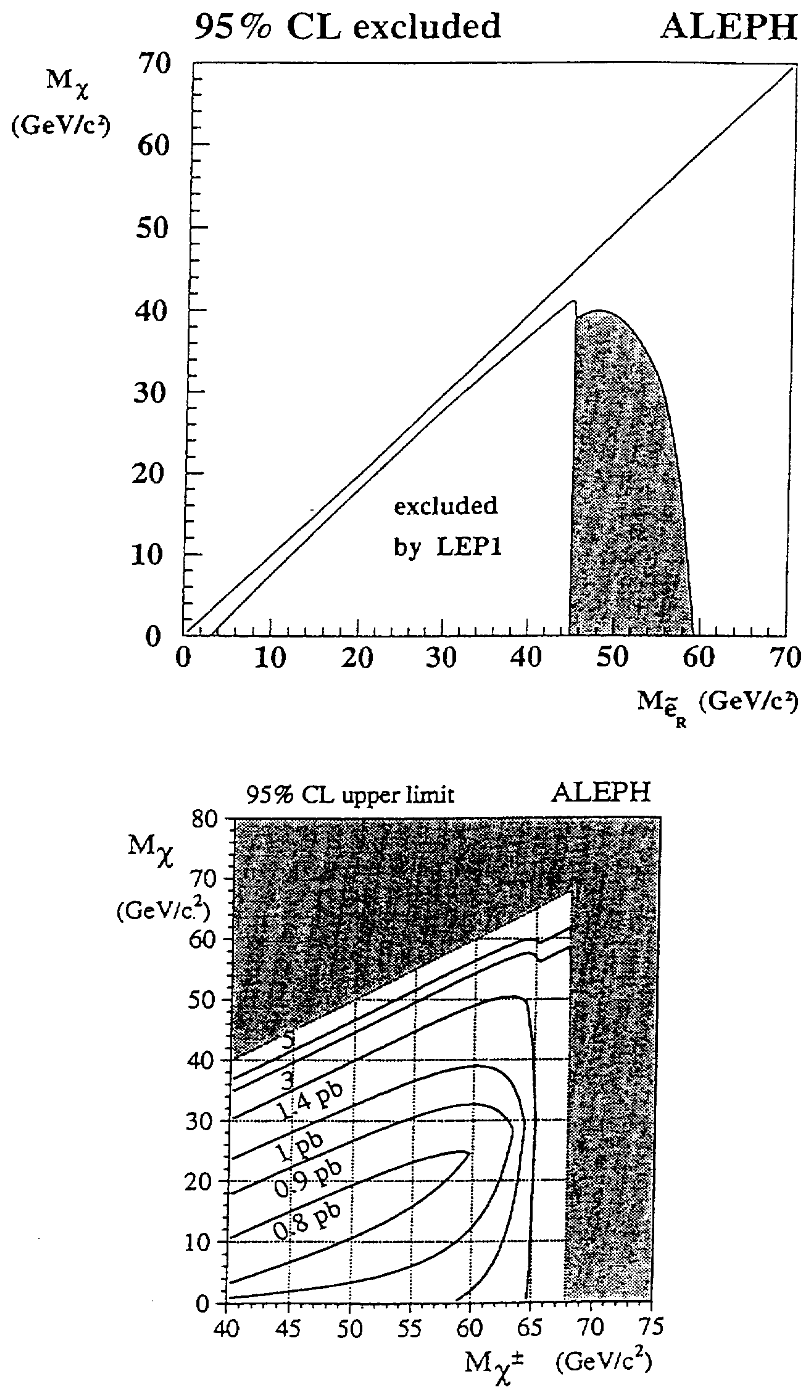

Figure 6: Limits on SUSY particle masses at 95% confidence level

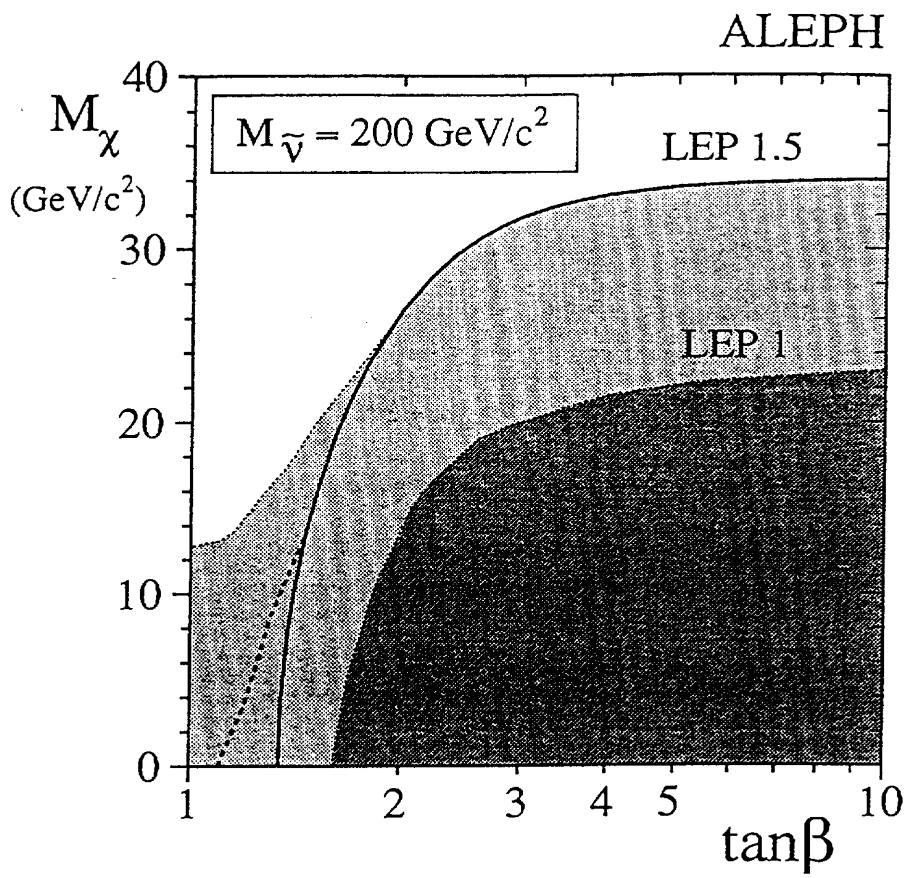

Figure 7: Limits on Neutralino mass according to $\tan\beta$ (Combined results of both LEP1 and LEP1.5 are given by the light shaded area)

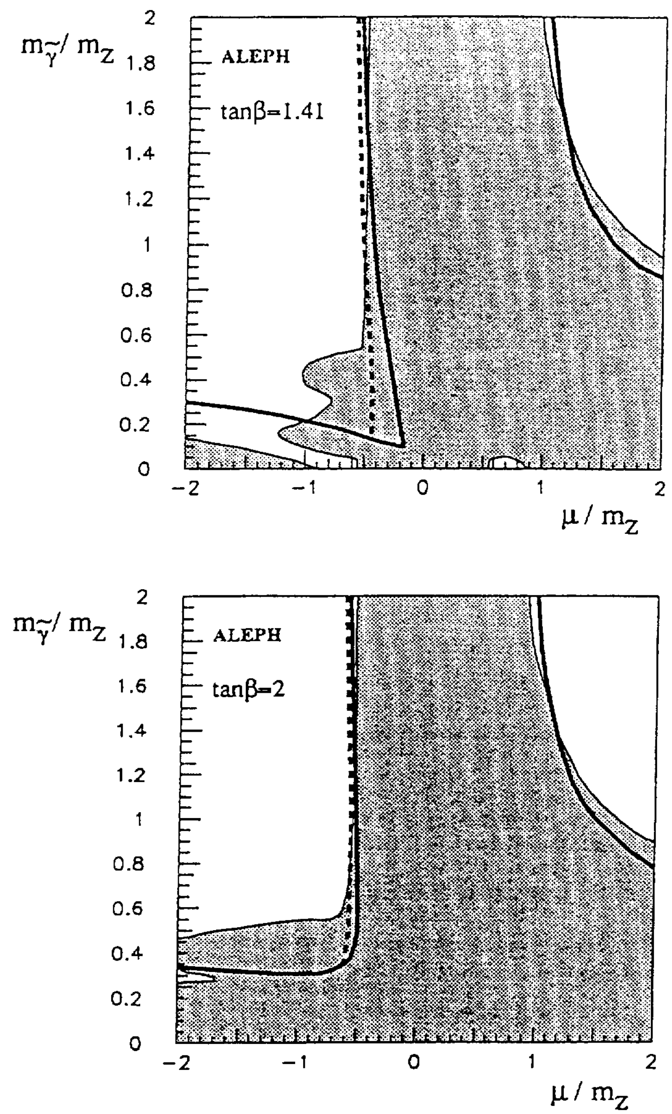

Figure 8: Domains in the MSSM plane excluded at 95% C.L. at LEP1 (shaded), by the chargino search at 130-136 GeV(heavy solid line) and by the neutralino search at 130-136 GeV (dashed line)