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SEARCH FOR CHARGINOS AND NEUTRALINOS AT LEP

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We report on the result of a search for charginos and neutralinos in e^+e^- collisions at centre-of-mass energies between 203 GeV and 208 GeV at LEP. No evidence for such particles is found in a data sample of 220 pb^{-1} per experiment. Improved upper limits for these particles are set on the production cross sections. New exclusion contours in the parameter space of the Minimal Supersymmetric Standard Model are derived, as well as new lower limits on the masses of these supersymmetric particles. Chargino masses below 103 GeV are excluded over large regions of the parameter space of the Minimal Supersymmetric Standard Model.

1 Introduction

One of the main goals of the LEP experiments is to search for new particles predicted by theories beyond the Standard Model. We report on the searches for charginos and neutralinos at LEP. These particles are predicted by the Minimal Supersymmetric extension of the Standard Model (MSSM) [1], in addition to the ordinary particles, there is a supersymmetric spectrum of particles with spins differing by one half with respect to their Standard Model partners. For fermions, each helicity has a scalar superpartner and for gauge bosons and Higgs particles their superpartners are called gauginos. There are two mass eigenstates formed by a mixing of the superparteners of the charged gauge bosons and charged Higgs bosons called charginos, $\tilde{\chi}_i^{\pm}$ (i=1,2), and four mass eigenstates associated to the neutral gauge bosons and neutral Higgs bosons called neutralinos $\tilde{\chi}_i^0$ (i=1,...,4). where the indices are ordered in increasing mass. We have an additional multiplicative quantum number called R-parity, which insures the conservation of the lepton and baryon numbers.

In this article we only treat the case where R-parity is conserved, which implies that supersymmetric particles are pair-produced and the lightest supersymmetric particle, assumed to be the lightest neutralino, $\tilde{\chi}_1^0$, is stable.

The mass spectrums and couplings are completely defined by the following parameters : gaugino masses $M_{1,2,3}$ at the electroweak scale, obtained by evolving the GUT scale parameter $m_{1/2}$ (the gauginos common mass) using renormalization group equations, the common sfermion mass at the GUT scale m_0, the Higgsino mass term μ, the ratio of vaccum expectation values of the two Higgs fields tanβ and A_0, the common trilinear coupling parameter. Under this assumption, this model is commonly referred as (CMSSM) a constrained MSSM with R-parity conservation.

2 Phenomenology and search strategies

In CMSSM model with R-parity conservation, the decay chain of supersymmetric particles always contains, beside standard particles, at least two invisible neutralinos causing the missing energy signature.

Charginos are pair produced via s-channel γ/Z or t-channel $\tilde{\nu}$ exchange [2], this two diagrams interfer destructively and the production cross section can be reduced by an order of magnitude when the t-channel exchange is important. Neutralino pairs $e^+e^- \rightarrow \tilde{\chi}^0_i\tilde{\chi}^0_j$ $(i,j = 1,\ldots,4)$ are produced via s-channel Z or t-channel $\tilde{e}_{L,R}$ exchange [3], the diagrams interfer constructively when the t-channel exchange is allowed.

When the masses of the scalar leptons and the charged Higgs bosons $(H^{\pm})$ are very large, the charginos $\tilde{\chi}^{\pm}_{1,2}$ decay through a W^* : $\tilde{\chi}^{\pm}_1 \rightarrow \tilde{\chi}^0_1\mathrm{W}^* \rightarrow \tilde{\chi}^0_1 f\bar{f}'$. The dominant topologies are then hadronic events with missing energy or events with hadrons, an isolated lepton and missing energy or two leptons and missing energy.

If the $\tilde{\ell}^{\pm}$ and $\tilde{\nu}$ masses are comparable to M_W, the chargino also decays via virtual scalar lepton or scalar neutrino and the leptonic branching fraction is enhanced. Finally for $\tilde{\ell}^{\pm}$ and $\tilde{\nu}$ lighter than the chargino, the decay modes $\tilde{\chi}^{\pm}_1 \rightarrow \tilde{\ell}^{\pm}\nu$ or $\tilde{\chi}^{\pm}_1 \rightarrow \tilde{\nu}\ell^{\pm}$ become dominant.

We have also two scenarios for the neutralino decays: when the masses of the neutral SUSY Higgs bosons and of the scalar leptons are very large (high m_0), the heavier neutralinos ($\tilde{\chi}^0_j$, $j \geq 2$) decays via Z*: $\tilde{\chi}^0_j \rightarrow \tilde{\chi}^0_k\mathrm{Z}^* \rightarrow \tilde{\chi}^0_k f\bar{f}$ with $k < j$. The dominant topologies are then hadronic events with missing energy or two leptons (with same flavors) and missing energy. For a chargino lighter than heavier neutralinos, the latter decays via W* such as $\tilde{\chi}^0_j \rightarrow \tilde{\chi}^{\pm}_1 f\bar{f}'$.

If the scalar lepton masses are comparables to the Z mass, the neutralino decays also via a virtual scalar lepton, enhancing the leptonic branching fraction. Finally, for $\tilde{\nu}$ and $\tilde{\ell}^{\pm}$ lighter than neutralinos the two-body decays $\tilde{\chi}^0_j \rightarrow \tilde{\ell}^{\pm}\ell^{\mp}$ or $\tilde{\chi}^0_j \rightarrow \tilde{\nu}\nu$ (j $\geq$ 2) become dominant. The radiative decays $\tilde{\chi}^0_j \rightarrow \tilde{\chi}^0_k\gamma$ are also possible via higher-order diagrams.

The missing energy is carried out by the LSPs or by the presence of neutrinos in the final state of SUSY signals, which implies that the kinematic configuration of the signal events and the detection efficiencies depends strongly on the mass difference between the heavier SUSY particle produced and the LSP: ΔM= M_{SUSY} - M_{LSP}. This quantity is closely connected to the visible energy collected in the detector. The dominant Standard Model background vary significantly with the ΔM range considered. When $\Delta \mathrm{M} \leq 10$ GeV the $\gamma\gamma$ processes are dominant. When ΔM is large the dominant backgrounds are W^+W^-, $W^\pm e^\mp \nu$ and ZZ.

The selections are optimized for various ΔM ranges and for different topologies in order to reach the best signal to background ratio. Searches for charginos and neutralinos in the various topologies have been carried out by all four LEP experiments [4,5,6,7]

3 Results

The results presented here were preliminarily performed with the data collected by the four LEP experiments during 2000 at a center-of-mass energies ranging form 203 GeV to 208 GeV. The collected integrated luminosities are given in table 1

Experiment	A	D	L	O
Luminosity (pb^{-1})	217.0	224.0	217.0	221.0

Table 1. Integrated luminosities (pb^{-1}) for the four LEP experiments (**A:** ALEPH, **D:**DEPHI, **L:**L3, **O:** OPAL)

The numbers of selected candidates and expected events from Standard Model processes in the different channels are reported in table 2. No significant excess of events is observed. This results is then used to set upper limits on chargino and neutralino production cross sections in the framework of the CMSSM. Exclusion limits at 95 % C.L. are derived taking into account background contributions.

Experiment	$\tilde{\chi}_1^+ \tilde{\chi}_1^-$		$\tilde{\chi}_2^0 \tilde{\chi}_1^0$	
	Expected	Observed	Expected	Observed
ALEPH	11.1	11	1.9	1
DEPHI	169.3	160	163.2	183
L3	109.7	112	26.3	24
OPAL	257.7	266	207.0	197
ADLO	547.8	549	398.4	405

Table 2. Results for charginos and neutralinos : Number of data candidates observed and background expected events from Standard Model processes for the four LEP experiments

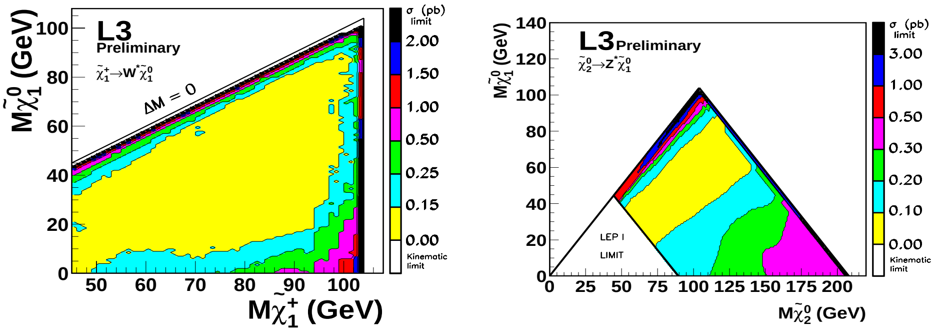

Figure 1. Upper limits on the $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$ production cross section up to 208 GeV in the ($M_{\tilde{\chi}_1^\pm}$,$M_{\tilde{\chi}_1^0}$) mass plan (the left plot) and the Upper limits on the $e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_1^0$ production cross section up to 208 GeV in the ($M_{\tilde{\chi}_2^0}$,$M_{\tilde{\chi}_1^0}$) mass plan (the right plot) .

The L3 upper limits contours on the charginos production cross section assuming $\tilde{\chi}_1^\pm \to W^*\ \tilde{\chi}_1^0$ for the chargino decay with standard W branching fractions are shown in left plot of fig 1. Similarly, the upper limits on the neutralinos $e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_1^0$ production cross section assuming $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z$,with standard Z decays are shown in right plot of Fig 1. The comparison of upper limit on the production cross section to the theoretical calculations allows to exclude the CMSSM parameter regions and to set limits on the chargino and neutralino masses. In order to derive the absolute limits on the masses, the following MSSM typical parameter space is investigated : $0 \le M_2 \le 2000$ GeV, $-2000 \le \mu \le 2000$ GeV, $0 \le m_0 \le 500$GeV, $0.7 \le tan\beta \le 40$. The standard gaugino sector of CMSSM is insensitive to the parameter A. For each point the upper limits on production cross sections are calculated by taking into account the expected backgrounds, the number of observed events and the branching ratios for each topologie.

In Fig 2.a, the region excluded by ALEPH in (μ,M_2) plane is shown for $\tan\beta=\sqrt{2}$ and $m_0 = 500$ GeV. The dark grey region corresponds to LEP1 exclusion, the light grey region is the exclusion from chargino search and the black region is excluded from the neutralino pair production search. This results can also be interpreted to set a lower limit on the chargino mass. In Fig 2.b, the lower mass limits as a function of M_2 are shown for $\tan\beta = \sqrt{2}$ and $\mu < 0$. Charginos $\tilde{\chi}_1^\pm$ are excluded up to the kinematic limit in large space of parameter by using the direct search ($e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$) and the neutralino search extends the domain of the exclusion to kinematically

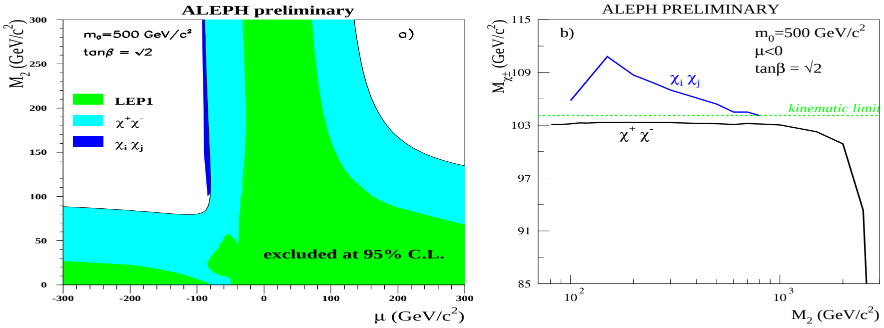

Figure 2. Excluded region of the CMSSM parameter space in the (M_2,μ) (the left plot) and the lower limits on chargino mass as function of M_2 (the right plot)for m_0 = 500 GeV and tan$\beta = \sqrt{2}$

inaccessible chargino masses for $\mu < 0$. All LEP experiments usually present the excluded region in the mass plan (M_{SUSY},M_{LSP}). In Fig 3, the region excluded by L3 is shown in the ($M_{\tilde{\chi}_1^\pm}$,$M_{\tilde{\chi}_1^0}$) plane for m_0 =500 GeV and for tanβ =1 and for tanβ =40. Similarly, the exclusion in term of MSSM parameters can be interpreted to derive a lower limits on the neutralinos masses as shown in Fig 4 obtained by OPAL.

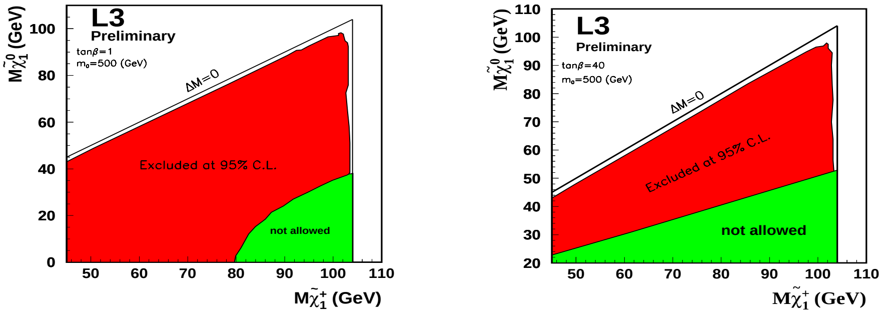

Figure 3. Chargino exclusions expressed in ($M_{\tilde{\chi}_1^\pm}$,$M_{\tilde{\chi}_1^0}$) plane for tanβ = 1 (the left plot) and tanβ = 40 (the right plot). The darker regions are excluded for any value of m_0, and the lighter regions are excluded additionally in the case of $m_0 \geq 500$ GeV

Mainly, one distinguishes the following cases for the determination of lower limits on the neutralino and chargino masses.

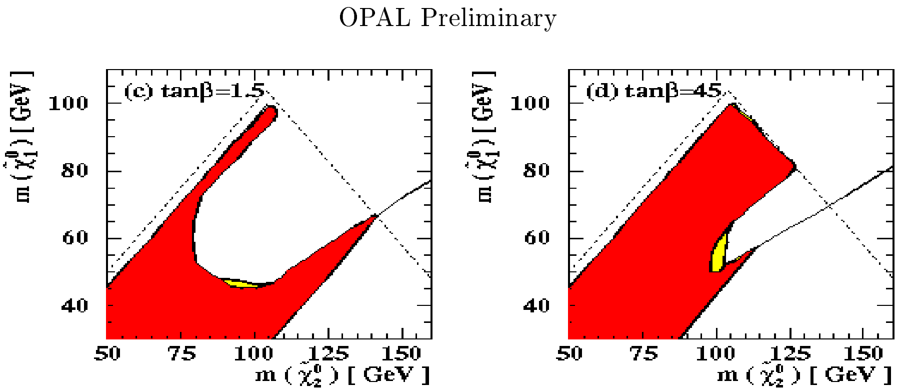

Figure 4. Neutralino exclusions expressed in $(M_{\tilde{\chi}^0_2},M_{\tilde{\chi}^0_1})$ plane for tanβ = 1.5 and m_0 = 500 GeV (the left plot) and tanβ = 45 and m_0 = 500 GeV (the right plot). The exclusions are obtained by OPAL at 208 GeV

For Higgsino-like $\tilde{\chi}^0_2$ and $\tilde{\chi}^{\pm}_1$ ($M_2 >> |\mu|$) the production cross sections do not depend on the sfermion masses, the mass difference between the heavier SUSY particle and the LSP decreases with increasing M_2 as shown in Fig 2.b.

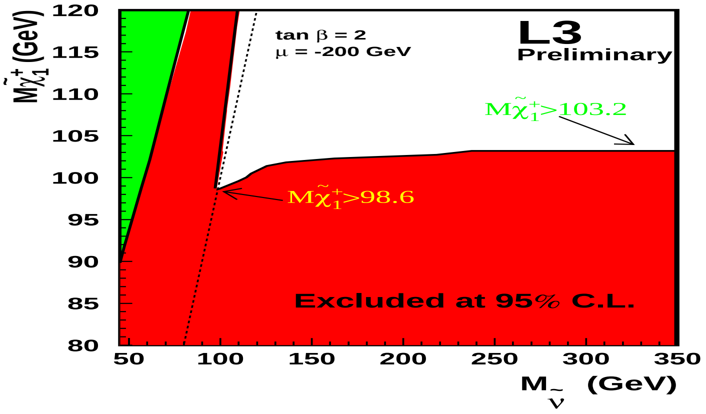

Figure 5. Excluded region in $(M_{\tilde{\chi}^{\pm}_1},M_{\tilde{\nu}})$ plane for tanβ = 2 and μ = -200 GeV. The lowest mass limit is set from charginos and slepton searches

For the chargino search, when the mass difference (ΔM=$M_{\tilde{\chi}_1^\pm}$-$M_{\tilde{\chi}_1^0}$) is smaller than 3 GeV, the signal and the $\gamma\gamma$ interaction background are indistinguishable. In this case one requires in the event an Initial State Radiation photon with high transverse momentum in order to improve the trigger efficiency and the signal to background ratio.

For Gaugino-like $\tilde{\chi}_1^\pm$ ($M_2 << |\mu|$) the chargino cross section depends strongly on the sneutrino ($\tilde{\nu}$) mass, if the sneutrino is light, the cross section decreases with $M_{\tilde{\nu}}$ due to the destructive interference of the t-channel with s-channel. When the $\tilde{\nu}$ is mass degenerate with the chargino $\tilde{\chi}_1^\pm$, one uses the slepton searches to improve the limits. Fig 5 shows the evolution of lower limit of chargino mass as a function of $M_{\tilde{\nu}}$ for tanβ = 2 and $\mu = -200$ GeV, the slepton search can exclude chargino pair production beyond its kinematical limit for lightest values of $M_{\tilde{\nu}}$ (low values of m_0), at large m_0 the mass limit is set from charginos search, and the lightest chargino are excluded up to kinematic limit. The limit independent of m_0 is obtained when the mass difference between the chargino and the sneutrino is small, in this case the lower limit on chargino mass is 98.6 GeV for any m_0.

The limit on the lightest neutralino $\tilde{\chi}_1^0$ obtained by L3 as a function of tanβ and large values of m_0 is shown in the left plot of Fig 6. The limit is constrained to be above 39.4 GeV, obtained at tanβ =1. set from chargino ($\tilde{\chi}_1^+\tilde{\chi}_1^-$) and neutralino searches ($\tilde{\chi}_2^0\tilde{\chi}_1^0$,$\tilde{\chi}_4^0\tilde{\chi}_1^0$,$\tilde{\chi}_2^0\tilde{\chi}_3^0$). One can improve neutralino mass limit including the results from the Higgs searches. In the right plot of Fig 6, the lower limits on $\tilde{\chi}_1^0$ obtained by DELPHI are shown for several scenarios. At maximal M_{h_0} scenario and M_t =174.3 GeV, the tan β region 0.5

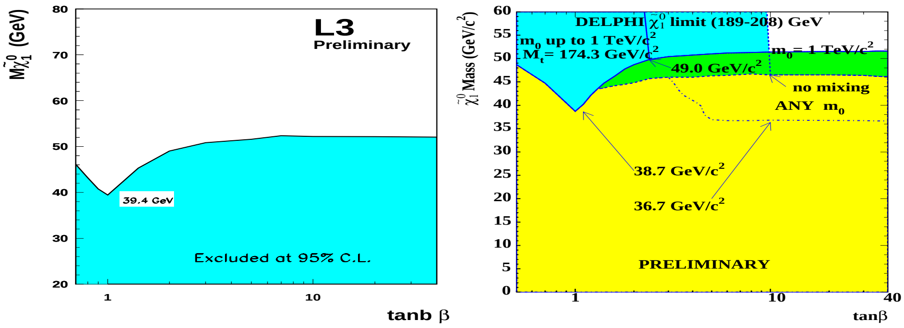

Figure 6. Lower limit on the lightest neutralino mass as function of tanβ for m_0 = 500 GeV obtened by L3 (the left plot) and the results on lightest neutralino search obtained by Delphi (the right plot)

$<$ tanβ $<$ 2.36 is excluded by the Higgs searches ^{5}. The standard lower limit on lightest neutralino is 38.7 GeV obtained for tanβ =1. When we combine with the Higgs searches, the limit is obtained at tanβ = 2.36 and $M_{\tilde{\chi}^0_1} > 49$ GeV.

At low m_0, the limit is obtained from the slepton and chargino searches, the minimum is obtained for A=0 and high tanβ.

3.1 Conclusions

Searches for charginos and neutralinos in e^+e^- collisions at center-of-mass energies up to 208 GeV were performed at LEP. No evidence for signal was found in any of the channels and lower limits at 95 % C.L on charginos and neutralinos masses have been derived. A summary of the limits obtained for the four LEP experiments is presented in table 3.

Charginos

DELPHI	95.0 GeV	$\Delta M \geq 3$ GeV,any m_0, no mixing and $M_{\tilde{\tau}} - M_{\tilde{\chi}^0_1} > 6$
L3	85.9 GeV	any m_0, any ΔM and tanβ <40
OPAL	93.9 GeV	$\Delta M > 5$ GeV and $m_0 < 1$ TeV and tanβ <40

Neutralinos

ALEPH	39.6 GeV	for $m_0 > 0.5$ TeV and tanβ <40
DELPHI	36.7 GeV	any m_0 and tanβ <40
L3	39.4 GeV	for $m_0 > 0.5$ TeV and tanβ <40
OPAL	36.3 GeV	any m_0 and tanβ <40

Table 3. Summary of lower limit at 95 % C.L on chargino and neutralino masses and their validity conditions for the four LEP experiments

References

1. H. P. Nills, Phys. Rep. **110** 1 (1984);
   H. E. Haber and G. L. Kane, Phys. Rep. **117** 75 (1985).
2. A. Bartl, H. Fraas and W. Majerotto, Z. Phys. **C30** 441 (1986);
   A. Bartl, H. Fraas and W. Majerotto, Z. Phys. **C41** 475 (1988).
3. A. Bartl, H. Fraas and W. Majerotto, Nucl. Phys. **B278** 1 (1986).
4. The ALEPH Collaboration ,ALEPH 2001-009 CONF.
5. The DELPHI collaboration, DELPHI 2001-085 CONF 513.
6. The L3 collaboration, L3 note 2707. Submitted to summer Conferences.
7. The OPAL collaboration, OPAL Physics Note PN470.