MSSM SUSY SEARCHES AT LEP2

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The status of SUSY searches at LEP2 up to centre-of-mass energy of $\sqrt{s}$=202 GeV is presented. Search strategies for sleptons, squarks, charginos and neutralinos are discussed in the framework of Minimal Supersymmetric Standard Model with R-parity conservation. With no indication for the production of these particles new limits are set on their masses.

1 Introduction

Increased energies and luminosities at LEP2 have substantially extended its potential for the discovery of new particles. In 1999 LEP operated at $\sqrt{s} = 192-202$ GeV and has delivered integrated luminosity of 230 pb^{-1} per experiment. This data, together with those recorded during previous years at $\sqrt{s} > M_Z$, have been used to search for evidence for new physics beyond the Standard Model (SM).

Extensive searches have been performed for the particles predicted by Supersymmetric (SUSY) theories. Among SUSY models Minimal Supersymmetric Standard Model (MSSM) [1] with the unification of gaugino masses and scalar masses at GUT, often referred to as Constrained MSSM (CMSSM) [2], is widely accepted as a main framework at LEP. CMSSM introduces 6 new parameters: M_2, the $SU(2)_L$ gaugino mass; m_0 and A_0, a universal scalar mass and universal trilinear coupling at GUT scale; $\tan\beta$, the ratio of VEV's of the two Higgs fields; μ, the higgsino mass parameter and M_A, the mass of CP-odd Higgs boson. Masses and couplings of SUSY particles (sparticles) as well as their production cross-sections are entirely determined once the first five parameters are specified.

At LEP2 production of sleptons, $\tilde{\ell}$, squarks, $\tilde{q}$, charginos, $\tilde{\chi}^{\pm}_i$ $(i = 1, 2)$ and neutralinos, $\tilde{\chi}^0_i$ $(i = 1, 2, 3, 4)$, all can take place with sizable cross-sections if kinematically allowed. R-parity conservation implies that sparticles are produced in pairs and ultimately decay to a stable Lightest Supersymmetric Particle (LSP). In CMSSM the best candidate for LSP is the lightest neutralino $\tilde{\chi}^0_1$. Since $\tilde{\chi}^0_1$ is weakly interacting it escapes detection and produces energy imbalance in the event. At LEP2 energies sparticles would mainly decay directly to LSP. For sfermions the dominant decay pattern is $\tilde{\mathrm{f}} \to \mathrm{f}\tilde{\chi}^0_1$, except for stop, for which the relevant decay modes are $\tilde{\mathrm{t}} \to \mathrm{c}\tilde{\chi}^0_1$ and $\tilde{\mathrm{t}} \to \mathrm{b}\ell\tilde{\nu}$ since flavour conserving decay to top is kinematically unaccessible. Charginos and neutralinos decay trough $\tilde{\chi}^+_1 \to \mathrm{f}\bar{\mathrm{f}}'\tilde{\chi}^0_1$ and $\tilde{\chi}^0_\mathrm{i} \to \mathrm{f}\bar{\mathrm{f}}\tilde{\chi}^0_1$. On the other hand, cascade decays such as $\tilde{\mathrm{f}} \to \mathrm{f}\tilde{\chi}^0_2 \to \mathrm{f}\mathrm{f}\bar{\mathrm{f}}\tilde{\chi}^0_1$, $\tilde{\chi}^+_1 \to \tilde{\ell}\nu(\ell\tilde{\nu}) \to \ell\nu\tilde{\chi}^0_1$, $\tilde{\chi}^0_3 \to \mathrm{f}\bar{\mathrm{f}}\tilde{\chi}^0_2 \to \mathrm{f}\bar{\mathrm{f}}\mathrm{f}\bar{\mathrm{f}}\tilde{\chi}^0_1$, $\tilde{\chi}^0_\mathrm{i} \to \tilde{\ell}\ell \to \ell\ell\tilde{\chi}^0_1$, are also important in some regions of the model parameter space. Depending on the identity of the fermion(s) produced in these decays one expects lepton(s), or lepton(s) plus jets, or jets in the final states, all accompanied by missing energy as a fingerprint of the escaping LSP's. Since at least two LSP's are present no explicit reconstruction of sparticle masses is possible. Thus the search strategy is to look for the event excess over the SM expectations in the above listed final states. The signal kinematics depends strongly on the mass difference between produced sparticle and its invisible decay product, $\Delta M = M_{spart} - M_{LSP}$, the quantity which essentially defines the amount of detectable energy.

There are number of SM processes taking place at LEP which may mimic a signal. They can be classified as two-fermion production $\mathrm{f}\bar{\mathrm{f}}(\gamma)$, processes with four-fermions in the final states, $\mathrm{W}^+\mathrm{W}^-$, $\mathrm{We}\nu$, ZZ, $\mathrm{Ze}^+\mathrm{e}^-$ and two-photon interactions, $\mathrm{e}^+\mathrm{e}^-\gamma\gamma \to \mathrm{e}^+\mathrm{e}^-\mathrm{q}\bar{\mathrm{q}}$, $\mathrm{e}^+\mathrm{e}^-\ell^-\ell^+$. When ΔM is low, in the range of 5 GeV to 15–20 GeV, the visible energy in SUSY signal events is low. Here the main and essentially irreducible background is two-photon interactions with final $\mathrm{e}^+/\mathrm{e}^-$ usually escaping undetected in the beam pipe and thus producing missing energy. Furthermore, the cross-section of two-photon interactions ($\sim$16 nb at $\sqrt{s}$=192–202 GeV with $M_{\gamma\gamma} > 3$ GeV) is significantly higher than that of any other processes at LEP2. Hence SUSY signal with low ΔM is the most difficult to probe. At high ΔM values, $\gtrsim$40–50 GeV, the dominant backgrounds are $\mathrm{W}^+\mathrm{W}^-$ and $\mathrm{We}\nu$ productions. In the intermediate ΔM range of 20 GeV to 40 GeV, the two-fermion, four-fermion and two-photon processes all can contribute to the background with comparable proportion. Apparently, dedicated selections are necessary to cover all possible ranges of ΔM. The key kinematical selection variables are visible energy and mass, missing mass, acollinearity, fraction of energy deposition in the forward regions of the detector, event thrust, etc. The selection techniques are conventional, or multivariate, which take into account correlation between kinematical variables in the multidimensional space.

Special situation arises when produced sparticle and its invisible decay product are almost mass degenerate, e. g. $\Delta M \lesssim 3$ GeV. The amount of detectable energy carried by decay products becomes too small and “standard” search strategies are not applicable any more. On the other hand, produced SUSY sparticles can become long-lived due to decay phase-space suppression and can be searched via displaced vertices (quasi-stable sparticle case) or anomalous ionisation measurement (stable sparticle case). Another technique is to tag events with Initial State Radiation (ISR) photon(s).

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width=7.3cm,height=6.3cm,clip=true,draft=false]slep350epsidth=9.0cm,height=6.2cm,clip=true,draft=false]fig2c.e

Figure 1: 95% C.L. lower mass limits for: selectron (L3, top, left), smuon (DELPHI, top, right) and stau (ALEPH, bottom). In case of $\tilde{\mu}_R$ limits are derived for $\tan\beta = 1.5$ and $\mu = -200$ GeV taking into account cascade decays; the shaded region shows obtained exclusion limit and the solid line shows expected limit. In case of stau 100% branching ratio is assumed for $\tilde{\tau} \to \tau\, \tilde{\chi}^0_1$ decay; dark and light solid lines show obtained and expected limits assuming no mixing; dashed line shows obtained limits for minimal cross-section when left–right mixing is taken into account.

Table 1: 95% C.L. lower mass limits for sleptons obtained by LEP experiments with high energy data up to $\sqrt{s} = 192 - 202$ GeV.

Experiment	selectron	smuon	stau
ALEPH	$M_{\tilde{e}_R}$ >92 GeV for ΔM >10 GeV $\mu = -200$ GeV, $\tan\beta$=2	$M_{\tilde{\mu}_R}$ >85 GeV for ΔM >10 GeV BR($\tilde{\mu}_R \to \mu\tilde{\chi}^0_1$)=100%	$M_{\tilde{\tau}_R}$ >70 GeV for ΔM >10 GeV BR($\tilde{\tau}_R \to \tau\tilde{\chi}^0_1$)=100%
DELPHI	$M_{\tilde{e}_R}$ >91 GeV for ΔM >15 GeV $\mu = -200$ GeV, $\tan\beta$=1.5	$M_{\tilde{\mu}_R}$ > 86 GeV for ΔM >10 GeV $\mu = -200$ GeV, $\tan\beta$=1.5	$M_{\tilde{\tau}_R}$ >75.5 GeV for ΔM >15 GeV BR($\tilde{\tau}_R \to \tau\tilde{\chi}^0_1$)=100%
L3	$M_{\tilde{e}_R}$ >91 GeV for ΔM >15 GeV μ=-200 GeV, $\tan\beta = \sqrt{2}$	$M_{\tilde{\mu}_R}$ >78 GeV for ΔM >10 GeV BR($\tilde{\mu}_R \to \mu\tilde{\chi}^0_1$)=100%	$M_{\tilde{\tau}_R}$ >68 GeV for ΔM >15 GeV BR($\tilde{\tau}_R \to \tau\tilde{\chi}^0_1$)=100%

2 Searches for SUSY Partners of Fermions

SUSY introduces scalar partners for each SM fermions, $\tilde{f}_L$ and $\tilde{f}_R$ which mix and form mass eigenstates, $\tilde{f}_1$ and $\tilde{f}_2$. The size of the mixing is proportional to the corresponding SM fermion mass and can be neglected for the first two generations. However, the stop left – right mixing is expected to be large due to heavy top quark. Resulting eigenstates have sizeable mass splitting with the lighter stop, $\tilde{t}_1$, being the lightest of all squarks. In case of sbottom and stau large mixing can occur for $\tan\beta \gtrsim 10$.

Pair production of sfermions in e^+e^- collisions takes place through s-channel γ/Z exchange. For selectrons the production cross-section is enhanced by t-channel exchange of neutralino. Since right handed sleptons are expected to be lighter than the left-handed states, it is assumed that only $\tilde{\ell}^+_R\tilde{\ell}^-_R$ production is kinematically possible. The decay pattern $\tilde{\ell} \to \ell\, \tilde{\chi}^0_1$ gives rise to two acoplanar leptons and missing energy in the final states. In this category of events no excess has been found over the SM background expectations [3,4,5,6]. As an example, L3 has observed 76 events with two acoplanar electrons and missing energy in $\sqrt{s}$ =192-202 GeV data sample. This is consistent with 68.9 events expected from the SM processes. Corresponding exclusion contour for the selectron mass is shown in Fig. 1 assuming $\mu = -200$ GeV and $\tan\beta = \sqrt{2}$. The exclusion holds also for higher values of $|\mu|$ and $\tan\beta$. For smaller values of $|\mu|$ the t-channel contribution to the selectron pair production is suppressed yielding a few GeV decrease in the limit. The values of μ and $\tan\beta$ are also relevant for calculation of branching ratio for cascade decays $\tilde{e} \to e\, \tilde{\chi}^0_2 \to e\, f\, \bar{f}\, \tilde{\chi}^0_1$. The plot gives exclusion contour assuming BR($\tilde{e} \to e\, \tilde{\chi}^0_1$)=100%; it also shows the change in the exclusion contour due to opening up the cascade decays for which vanishing efficiencies are (pessimistically) assumed.

Smuon pair production gives rise to two acoplanar muons and missing energy. In this category of events 13 candidates have been observed by DELPHI. This is consistent with 19.2 events expected from the SM processes. The corresponding exclusion plot is shown in Fig. 1 for $\tan\beta = 1.5$ and $\mu = -200$ GeV taking into account efficiency loss due to cascade decays.

In the search for stau pair production which leads to two taus and missing energy, 46 events have

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width=7.59cm,height=5.88cm,clip=true,draft=false]fig1d.eps

Figure 2: 95% C.L. lower mass limits for: stop decaying via $\tilde{t}_1 \to c\ \tilde{\chi}^0_1$ (L3, top, left); stop decaying via $\tilde{t}_1 \to b\ \ell\tilde{\chi}^0_1$ (OPAL, top, right); sbottom $\tilde{b}_1 \to b\ \tilde{\chi}^0_1$ (DELPHI, bottom, left) and mass-degenerate squarks $\tilde{q} \to q\ \tilde{\chi}^0_1$, $\tilde{q} = \tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{b}$ (ALEPH, bottom, right). The latter is shown in ($M_{\tilde{g}}$, $M_{\tilde{g}}$) plane along with the regions excluded by UA1 [9], UA2 [10] and Tevatron [11,12] experiments. The $\tilde{t}_1$ and $\tilde{b}_1$ mass limits are given for maximal and minimal cross-sections. The stop and sbottom mass limits obtained by CDF [13] are also shown.

been observed by ALEPH, whereas 34.2 is expected from the SM processes. The excluded regions with the assumption of BR($\tilde{\tau} \to \tau\ \tilde{\chi}^0_1$)=100% is shown in Fig. 1. Exclusion contours are derived assuming no mixing and sizable mixing between the left and right eigenstates. In case of mixing the production cross-section can be parametrised as a function of the sfermion mass and the left-right mixing angle, $\cos\theta_{LR}$. The cross-section is maximal for $\cos\theta_{LR}$=1 and is minimal for $\cos\theta_{LR} \simeq 0.61$ when stau decouples from the Z. The contour shown for the mixing case corresponds to the minimal $\sigma(\tilde{\tau}^+\tilde{\tau}^-)$.

Table 1 summarises exclusion limits on slepton masses obtained by ALEPH, DELPHI and L3 Collaborations. Individual limits on selectron mass are set at 91–92 GeV for the mass differences of ΔM >10–15 GeV. Smuon mass exclusion ranges from 78 GeV to 85 GeV for $\Delta M > 10$ GeV, whereas stau limits are relatively modest, in the range of 68–75.5 GeV for ΔM >10–15 GeV.

Among squarks special emphasises are put on the stop and sbottom searches [3,5,6,7] as they are expected to be lighter than others. The stop two-body decay $\tilde{t}_1 \to c\tilde{\chi}^0_1$ gives rise to final states with two jets and missing energy, whereas three-body decay mode $\tilde{t}_1 \to b\ell\tilde{\nu}$ leads to two b-jets plus two leptons plus missing energy signature. For sbottom, the $\tilde{b}_1 \to b\tilde{\chi}^0_1$ decay results in two b-jets and missing energy final states. No indication for the $\tilde{t}_1$ or $\tilde{b}_1$ production has been observed in the above final states and new limits have been derived on their masses, shown in Fig. 2. Exclusions are given for maximal and minimal cross-section assumptions. Table 2 summarises mass limits for the pessimistic case of minimal cross-sections. The stop mass limits range from 82 GeV to 91.5 GeV for the mass differences of ΔM >10–15 GeV, while the sbottom is excluded up to the masses of 76–81.5 GeV for the same ΔM range.

Negative results of the search for the stop two-body decay can be reinterpreted as a lower limit on the mass of $\tilde{q} = \tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}$ ($\tilde{b}$) squarks, as these lead to a similar experimental signature. The obtained results are presented in ($M_{\tilde{q}}, M_{\tilde{g}}$) plane, Fig. 2, in order to directly compare with the Tevatron results. Interpretation of the results in ($M_{\tilde{q}}, M_{\tilde{g}}$) plane is possible thanks to gaugino masses unification assumption at GUT which relates $M_{\tilde{g}}$ and $M_{\tilde{\chi}^0_1}$ at EW scale. The presented limit is valid assuming mass degeneration between $\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}$ and $\tilde{b}$, as well as between their left and right eigenstates.

Dedicated searches have been performed for a stop almost mass degenerate with LSP by ALEPH [8]. When ΔM is less than the c-quark mass the stop decays through $\tilde{t}_1 \to u\tilde{\chi}^0_1$. The decay width for this mode is much smaller than for $\tilde{t}_1 \to c\ \tilde{\chi}^0_1$ which itself has width larger than typical hadronization scale. So for $\Delta M \lesssim 3$ GeV the decay length ranges from few microns to hundreds of meters depending on SUSY model parameters. When stop decays outside detector it can be searched as a heavy stable particle trough anomalous ionisation measurements. When decay occurs inside detector the signal events can contain tracks with large impact parameter. Figure 3 shows complementarity of "stable", "quasi-stable" and "standard" analysis in different ΔM regions. Assuming CMSSM relations between SUSY parameters and $\Gamma(\tilde{t}_1)$ the lower limit of $M_{\tilde{t}_1} > 63$ GeV is set independent of ΔM.

3 Searches for Charginos and Neutralinos

In e^+e^- collisions chargino pairs $\tilde{\chi}^+_i\tilde{\chi}^-_j$ can be produced through s-channel Z/γ or t-channel sneutrino exchange. Neutralino pairs $\tilde{\chi}^0_i\tilde{\chi}^0_j$ are produced via s-channel Z or t-channel selectron exchange. The cross-sections depend, apart from masses, on the Higgsino-gaugino contents of the produced sparticles. When $M_2 \gg |\mu|$ the $\tilde{\chi}^\pm_1$ and $\tilde{\chi}^0_{1,2}$ are mostly Higgsinos and the t-channel contributions are negligible. For $M_2 \ll |\mu|$ the $\tilde{\chi}^\pm_1$ and $\tilde{\chi}^0_{1,2}$ are gaugino-like and, if sfermions are light, the t-channel contributions

Table 2: 95% C.L. lower limits on stop and sbottom masses for minimal cross-section assumptions obtained by LEP experiments with high energy data up to $\sqrt{s} = 192 - 202$ GeV.

Experiment	stop	stop	sbottom
ALEPH	$M_{\tilde{t}_1}$ >87 GeV for 6< ΔM <40 GeV	$M_{\tilde{t}_1}$ >88 GeV for ΔM >10 GeV	$M_{\tilde{b}_1}$ >76 GeV for ΔM >10 GeV
DELPHI	$M_{\tilde{t}_1}$ >91 GeV for ΔM >15 GeV	$M_{\tilde{t}_1}$ >82 GeV for ΔM >15 GeV	$M_{\tilde{b}_1}$ >81 GeV for ΔM >15 GeV
L3	$M_{\tilde{t}_1}$ >87 GeV for ΔM >15 GeV	$M_{\tilde{t}_1}$ >91.5 GeV for ΔM >15 GeV	$M_{\tilde{b}_1}$ >80 GeV for ΔM >15 GeV
OPAL	$M_{\tilde{t}_1}$ >91.5 GeV for ΔM >10 GeV	$M_{\tilde{t}_1}$ >89.5 GeV for ΔM >10 GeV	$M_{\tilde{b}_1}$ >81.5 GeV for ΔM >10 GeV

become important. In case of $\tilde{\chi}_1^+\tilde{\chi}_1^-$ production the t-channel interferes destructively with the s-channel leading to a significant decrease of the $\sigma(\tilde{\chi}_1^+\tilde{\chi}_1^-)$. On the contrary, the t-channel contribution enhances the $\sigma(\tilde{\chi}_1^0\tilde{\chi}_2^0)$. At $\sqrt{s} = 192 - 202$ GeV in most of the CMSSM parameter space the $\sigma(\tilde{\chi}_1^+\tilde{\chi}_1^-)$ amounts to a few pb for the chargino masses up to almost the kinematic limit. For some sets of CMSSM parameters $\sigma(\tilde{\chi}_1^0\tilde{\chi}_2^0)$ can also reach a few pb.

[bb=10 10 550 550, width=9.2cm,height=7.2cm,clip=true,draft=false]stopdegener$_a$*leph.eps*

Figure 3: 95% C.L. lower limits on the stop mass for $\mu = -100$ GeV, $\tan\beta$=1.5 and $\theta_{LR} = 56°$ as a function of ΔM in the region of small mass differences. Regions of different applicable analysis are indicated.

The expected event topologies from chargino and neutralino productions are jets plus missing energy, leptons plus missing energy or jets plus lepton(s) plus missing energy. Searches through these topologies have been carried out by LEP experiments[3,6,14,15] at high energies up to $\sqrt{s} = 192{-}202$ GeV. No evidence has been found for the chargino or neutralino production and limits are derived on their masses. For example, assuming $\tan\beta = 1.5\,(35)$, m_0 >500 GeV and $\Delta M \geq 10$ GeV, the mass limits of $M_{\tilde{\chi}_1^\pm}$ >100.0 GeV (100.1 GeV), $M_{\tilde{\chi}_2^0}$ >75.4 GeV (100.1 GeV), and $M_{\tilde{\chi}_3^0}$ >110.9 GeV (129.4 GeV) have been set by OPAL employing searches for $\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^0\tilde{\chi}_2^0$, $\tilde{\chi}_2^0\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0\tilde{\chi}_3^0$ productions.

Dedicated search strategy has been devised for the chargino mass degenerate with its invisible decay product, $\Delta M \lesssim 4$ GeV [15,16]. In CMSSM this scenario may occur is $\tilde{\chi}_1^\pm$ if higgsino-like. Here, chargino events can be tagged, e.g. with ISR photon(s), so the corresponding final state contains photon(s), missing energy and soft tracks. While in signal events the missing energy is due to weakly interacting particles, in the dominant two-photon background it is due to final state e^+/e^- escaping in the beam pipe. In the latter case, if a photon is present satisfying $E_T^\gamma \geq \sqrt{s}\frac{\sin\theta_d}{1+\sin\theta_d}$ requirement, the e^+ and/or e^- must be deflected into detector and the event can be identified as a background. Here θ_d is the minimum detection angle for the deflected e^+/e^-. For the L3 detector $\theta_d = 1.5°$ leads to $E_T^\gamma \geq 5.5$ GeV — an energy large enough for efficient triggering. The obtained mass limit is shown in Fig. 4 together with the exclusion contours obtained by the "standard" searches and by stable charged particle searches. These different search strategies allow to close up the low ΔM "window". The absolute mass limit for the $\tilde{\chi}_1^\pm$ derived by L3 is shown in Fig. 5 as a function of $\tan\beta$. The limit is valid for any chargino field content and for any value of m_0. The model parameters are scanned in the entire range relevant for the EW scale SUSY: $0.7 \leq \tan\beta \leq 70$, $M_2 \leq 2000$ GeV, $|\mu| \leq 2000$ GeV, $m_0 \leq 2000$ GeV. At low $\tan\beta$ values the limit on the chargino mass is obtained when $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ are mass degenerate (higgsino region). At large $\tan\beta$ values, on the other hand, the limit is obtained when the $\tilde{\chi}_1^\pm$ and $\tilde{\nu}$ are mass degenerate (gaugino region). The absolute limit is set at $M_{\tilde{\chi}_1^\pm} > 80.5$ GeV.

The mass limit on $\tilde{\chi}_1^0$–LSP can be derived only indirectly through searches of other SUSY particles. The $M_{\tilde{\chi}_1^0}$ limits from LEP experiments are summarised in Tab. 3. For large values of m_0, which implies heavy sfermions, the limit is derived using results of chargino and neutralino searches. The LSP mass limits obtained by DELPHI and OPAL assuming high values of m_0 are 35.2 GeV and 35.7 GeV, respectively. For low values of m_0 sfermion searches become important, whereas contributions from chargino pair production diminishes if $\tilde{\chi}_1^{\pm}$ is gaugino-like. General (independent of m_0) $\tilde{\chi}_1^0$ mass limits [15,17] are derived by L3 and ALEPH and are shown in Fig. 6 as a function of $\tan\beta$. In case of L3 the lowest mass limit of 37.5 GeV is observed at $\tan\beta = 1$ and high $m_0 = 500$ GeV and comes from searches of chargino and neutralino pairs. For large $\tan\beta$ values the minimum is found in the gaugino region and for low values of m_0. Here the limit is derived from the slepton searches.

The LSP mass limit derived by ALEPH exploits, along with sparticle searches, lower limit on the light Higgs boson mass set at $M_h >$107.7 GeV for low values of $\tan\beta$ [17]. As indicated in Fig. 6 the Higgs search constraints are important for the regions of $\tan\beta \lesssim 2$ and $3 \lesssim \tan\beta \lesssim 3.5$. Slepton searches allow to set limit at high values of $\tan\beta$ and chargino searches contribute in the region of $2 \lesssim \tan\beta \lesssim 3$. An absolute limit is set at $M_{\tilde{\chi}_1^0} > 38$ GeV. The results obtained using Higgs searches are however quite sensitive to the top quark mass which is assumed to be M_t=175 GeV [17].

Table 3: 95% C.L. lower limits on LSP masses obtained by LEP experiments with high energy data up to $\sqrt{s} = 192 - 202$ GeV.

ALEPH	$M_{\tilde{\chi}_1^0} >$38 GeV	for $M_0 \leq$1 TeV, M_t=175 GeV
DELPHI	$M_{\tilde{\chi}_1^0} >$35.2 GeV	for $M_{\tilde{\nu}} >$300 GeV
L3	$M_{\tilde{\chi}_1^0} >$37.5 GeV	
OPAL	$M_{\tilde{\chi}_1^0} >$35.7 GeV	for $m_0 \geq$ 500 GeV

4 Conclusions

Productions of sleptons, squarks, charginos and neutralinos have been searched for at LEP2 up to $\sqrt{s} = 192 - 202$ GeV in various scenarios of CMSSM. These searches cover large variety of final states such as leptons, lepton(s) plus jets and jets final states all accompanied by missing energy, ISR photon(s) accompanied by soft tracks and missing energy, events with stable heavy charged particles or tracks with large impact parameter. No evidence for SUSY particle productions has been observed and new limits have been set on their masses under specific assumptions on the model parameters. Model parameter independent limits have also been derived for the light stop, lightest chargino and lightest neutralino: $M_{\tilde{t}_1} > 63$ GeV, $M_{\tilde{\chi}_1^{\pm}} > 80.5$ GeV, $M_{\tilde{\chi}_1^0} > 37.5$ GeV.

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References

1. H.P. Nilles, *Phys. Rev.* **110**, 1 (1984).
2. L. Ibáñez *Phys. Lett.* B **118**, 73 (1982).
3. ALEPH Coll., *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*, ALEPH 2000-012 CONF 2000-009.
4. DELPHI Coll., *Search for Sleptons at $\sqrt{s}$ up to 202 GeV*, DELPHI 2000-012 CONF 333.
5. L3 Coll., *Search for Scalar Leptons and Quarks in e^+e^- collisions at $\sqrt{s} = 192 - 202$ GeV* , L3 Note 2524.
6. OPAL Coll., *New Particle Searches in e^+e^- Collisions at $\sqrt{s} = 192 - 202$ GeV*, PN418.

7. DELPHI Coll., *Search for Supersymmetric Partners of Top and Bottom Quarks at* $\sqrt{s} = 192{-}202$ *GeV*, DELPHI 2000-018 CONF 339.
8. ALEPH Coll., *Search for a Scalar Top Almost Degenerate with the Lightest Neutralino*, ALEPH 2000-021 CONF 2000-018.
9. UA1 Coll., C. Albajar *et al., Phys. Lett.* B **198**, 261 (1987).
10. UA2 Coll., J. Alitti *et al., Phys. Lett.* B **235**, 363 (1990).
11. CDF Coll., F. Abe *et al., Phys. Rev.* D **56**, 1357 (1997).
12. D0 Coll., S. Abachi *et al., Phys. Rev. Lett.* **75**, 618 (1995).
13. The CDF Collaboration, T. Affolder *et al., Phys. Rev. Lett.* **84**, 5704 (2000).
14. DELPHI Coll., *Search for Charginos and Neutralinos in* e^+e^- *Interactions at* $\sqrt{s} = 192 - 196 - 200 - 202$ *GeV*, DELPHI 2000-010 CONF 331.
15. L3 Coll., *Searches for Charginos and Neutralinos in* e^+e^- *Collisions at* $\sqrt{s} = 192 - 202$ *GeV*, L3 Note 2522.
16. DELPHI Coll., *Search for Charginos Nearly Mass-degenerate with the Lightest Neutralino at* $\sqrt{s} = 192 - 196 - 200 - 202$ *GeV*, DELPHI 2000-017 CONF 338.
17. ALEPH Coll., *LSP Mass Limit in the MSSM with Higgs Search Constraints*, ALEPH 2000-019 CONF 2000-016.