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Search for Scalar Leptons in e^+e^- collisions at $\sqrt{s} = 192 - 202$ GeV

The L3 collaboration

Abstract

We report the result of a search for scalar leptons in e^+e^- collisions at centre-of-mass energies between 192 GeV and 202 GeV at LEP. No evidence for such particles is found in a data sample of 233 pb^{-1}. Improved upper limits are set on the production cross sections for most of these new particles. 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.

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1 Introduction

One of the main goals of the LEP experiments is to search for new particles predicted by theories beyond the Standard Model. In this note we report on searches for unstable scalar leptons. These particles are predicted by supersymmetric theories (SUSY) [1]. In SUSY theories with minimal particle content (MSSM) [2], in addition to the ordinary particles, there is a supersymmetric spectrum of particles with spins which differ by one half with respect to their Standard Model partners.

Scalar leptons ($\tilde{\ell}^{\pm}_R$ and $\tilde{\ell}^{\pm}_L$) are the supersymmetric partners of the right- and left-handed leptons. Pair production takes place through s-channel γ/Z exchange. For scalar electrons the production cross section is enhanced by t-channel exchange of a neutralino. Scalar electrons can also be singly produced in association with $\tilde{\chi}^0_1(\mathrm{e})$ via t-channel diagrams.

Short-lived supersymmetric particles are expected in R-parity conserving SUSY models. The R-parity is a quantum number which distinguishes ordinary particles from supersymmetric particles. If R-parity is conserved supersymmetric particles are pair-produced and the lightest supersymmetric particle, the lightest neutralino $\tilde{\chi}^0_1$, is stable. The neutralino is weakly-interacting and escapes detection. In this note we assume R-parity conservation, which implies that the decay chain of supersymmetric particles always contains, besides standard particles, two invisible neutralinos causing the missing energy signature.

The scalar lepton decays into its partner lepton mainly via $\tilde{\ell}^{\pm} \rightarrow \tilde{\chi}^0_1 \ell^{\pm}$, but also via the cascade decay, such as $\tilde{\ell}^{\pm} \rightarrow \tilde{\chi}^0_2 \ell^{\pm} \rightarrow \tilde{\chi}^0_1 \mathrm{Z}^* \ell^{\pm}$, which may dominate in some regions of the parameter space of the MSSM.

In general, scalar lepton signals appear as acoplanar lepton in the detector. This might not be the case for the process $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\mathrm{e}}_R \tilde{\mathrm{e}}_L$ which can lead to single-electron or electron plus soft-track final states for very small mass differences between $\tilde{\mathrm{e}}_R$ and $\tilde{\chi}^0_1$. The visible electron comes from the decay of $\tilde{\mathrm{e}}_L$, being the latter substantially heavier than $\tilde{\mathrm{e}}_R$. Similarly, the t-channel process $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\mathrm{e}}_R \tilde{\chi}^0_1(\mathrm{e})$ leads to single-electron final states since one of the two final state electrons escapes along the beam axis.

Results presented in this note for the acoplanar lepton searches are obtained following similar analysis procedures as those reported in Ref. [3], while a new single-electron analysis is presented.

2 Data Sample and Simulation

We present the analysis of data collected with the L3 detector [4] in 1999, corresponding to an integrated luminosity of 233 pb^{-1} at an average centre-of-mass energy, $\sqrt{s}$, of 197.4 GeV, denoted hereafter as $\sqrt{s} = 197$ GeV.

Standard Model reactions are simulated with the following Monte Carlo generators: `PYTHIA` [5] for $\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{q}\bar{\mathrm{q}}$, $\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{Z}\,\mathrm{e}^+\mathrm{e}^-$ and $\mathrm{e}^+\mathrm{e}^- \rightarrow \gamma/\mathrm{Z}\,\gamma/\mathrm{Z}$; `EXCALIBUR` [6] for $\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{f}\ \mathrm{f}'\mathrm{f}''\mathrm{f}'''$; `KORALZ` [7] for $\mathrm{e}^+\mathrm{e}^- \rightarrow \mu^+\mu^-$ and $\mathrm{e}^+\mathrm{e}^- \rightarrow \tau^+\tau^-$; `BHWIDE` [8] for $\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{e}^+\mathrm{e}^-$; `KORALW` [9] for $\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{W}^+\mathrm{W}^-$; two-photon interaction processes have been simulated using `DIAG36` [10] ($\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{e}^+\mathrm{e}^-\ell^+\ell^-$) and `PHOJET` [11] ($\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{e}^+\mathrm{e}^-$ hadrons), requiring at least 3 GeV for the invariant mass of the two-photon system. The number of simulated events for each background process is equivalent to more than 100 times the statistics of the collected data sample except for two-photon interactions for which it is more than two times the data statistics.

Scalar lepton events are generated with the Monte Carlo program `SUSYGEN` [12], for masses of SUSY particles (M_{SUSY}) ranging from 45 GeV up to the kinematic limit, and for ΔM values

($\Delta M = M_{\rm SUSY} - M_{\tilde{\chi}_1^0}$) between 0 and $M_{\rm SUSY} - 1$ GeV. For efficiency studies of $e^+e^- \rightarrow \tilde{e}_R \tilde{\chi}_1^0(e)$ events are generated using the SUSY23 [13] Monte Carlo generator.

The detector response is simulated using the GEANT package [14]. It takes into account effects of energy loss, multiple scattering and showering in the detector materials and in the beam pipe. Hadronic interactions are simulated with the GHEISHA program [15]. Time dependent inefficiencies of the different subdetectors are also taken into account in the simulation procedure.

3 Single-electron analysis

For this channel a new analysis has been devised and our previous preliminary results [16] are superseded.

The number of charged tracks must be 1 or 2 and one of them must be associated to an electron identified in the BGO. The quality criteria required for the electron track restrict the fiducial region to $|\cos\theta_e| < 0.73$. If a second track is present its transverse momentum must not exceed 1 GeV. In order to reduce the background contribution from four-fermion processes we require low energy in the hadronic calorimeter ($E_{HCAL} \leq 5$ GeV), in the EGAP (< 5 GeV), and in the forward calorimeters ($E_{ALR} \leq 0.5$ GeV and $E_{LUMI} \leq 2$ GeV). To reduce the contamination from $\nu\bar{\nu}\gamma$ background when the photon converts in the material of the detector we require no track in a 20° cone around the direction of the electron. If the two tracks from the γ-conversion are not resolved we require $M_{recoil} - M_{Z^\circ} \geq 10$ GeV, where M_{recoil} is the electron recoil mass. Finally the event transverse momentum is required to exceed 20 GeV if the event contains only one track (single-electron) or 18 GeV if it contains 2 tracks (hard electron plus soft system).

4 Results

Results for the single electron analysis are summarised in Table 1. A slight excess of data is observed with respect to the Standard Model. The transverse momentum distributions for the selected data and background Monte Carlo events at $\sqrt{s} = 197$ GeV are shown in Figure 1 for the entire sample and for the subset of single-electron final state. Signal efficiencies vary from 4% at $m_{\tilde{e}_L} - m_{\tilde{\chi}_1^0} = 5$ GeV to 60% at $m_{\tilde{e}_L} - m_{\tilde{\chi}_1^0} = 50$ GeV, and they do not change for any values of $m_{\tilde{e}_R} - m_{\tilde{\chi}_1^0}$ smaller than 4 GeV. Similar efficiencies are obtained for single scalar electron production in association with $\tilde{\chi}_1^0(e)$, where the electron escapes in the beam pipe.

All the acoplanar lepton selections are parametrised as a function of a single parameter, $\Delta M/M_{\tilde{\ell}} \cdot \sqrt{s}/2$. Thus, optimal cuts are obtained for any given $\tilde{\ell}-\tilde{\chi}_1^0$ mass point by adjusting the above parameter. As illustrated in Figure 2 for scalar electrons, muons, and taus the data and Monte Carlo simulations are in general in good agreement for any parameter value. The results obtained at $\sqrt{s} = 197$ GeV for the acoplanar lepton searches are shown in Table 2 in total, and for the low ΔM ($\Delta M/M_{\tilde{\ell}} \cdot \sqrt{s}/2 < 10$ GeV), medium ΔM (10 GeV $< \Delta M/M_{\tilde{\ell}} \cdot \sqrt{s}/2 <$ 30 GeV), and high ΔM regions ($\Delta M/M_{\tilde{\ell}} \cdot \sqrt{s}/2 > 30$ GeV) separately. In general, a good agreement between the expected background from Standard Model processes and the selected data is observed. The slight excess observed at $\sqrt{s} = 189$ GeV in the scalar tau channel for medium and high ΔM is confirmed by new data.

Selection efficiencies for scalar lepton pair production, as well as systematic errors are very similar to those reported in Ref. [3]. We set 95% C.L. upper limits on scalar lepton production cross sections taking into account background contributions. To derive the new upper limits on the production cross sections, and for interpretations in the MSSM we combine the 1999 data sample with those collected at lower centre-of-mass energies.

Assuming a branching fraction for $\tilde{\ell}^{\pm} \rightarrow \tilde{\chi}^0_1 \ell^{\pm}$ of 100%, upper limits are set on pair production cross sections of scalar electrons, muons and taus in the plane $M_{\tilde{\chi}^0_1}$ versus $M_{\tilde{\ell}^{\pm}}$ as depicted in Figure 3.

5 Limits on scalar lepton masses in the MSSM

All the limits are obtained by combining these results with those obtained at lower centre-of-mass energies. To derive limits in the MSSM, we optimise the global selection for any different point in the parameter space. This is obtained, choosing every time the combination of selections providing the highest sensitivity, given the production cross sections and the decay branching fractions which are calculated with the generator `SUSYGEN`.

In general, the SUSY partners of the right-handed leptons ($\tilde{\ell}^{\pm}_R$) are expected to be lighter than their counterparts for left-handed leptons. Hence, we show in Figures 4a, 4b and 4c the exclusion contours in the $M_{\tilde{\chi}^0_1} - M_{\tilde{\ell}^{\pm}_R}$ plane considering only the reaction $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\ell}^{\pm}_R \tilde{\ell}^{\mp}_R$ and setting $\mu = -200$ GeV and $\tan\beta = \sqrt{2}$. These exclusions hold also for higher $\tan\beta$ and $|\mu|$ values. For smaller $|\mu|$ values, the t-channel contribution to the scalar electron cross section is reduced, thus reducing by a few GeV the limit on its mass shown in Figure 4a. The values of μ and $\tan\beta$ are also relevant for the calculation of the branching ratio for the decay $\tilde{\ell}^{\pm} \rightarrow \tilde{\chi}^0_2 \ell^{\pm} \rightarrow \tilde{\chi}^0_1 \mathrm{Z}^* \ell^{\pm}$ in Figures 4a–c. To derive these exclusions, only the purely leptonic decay $\tilde{\ell}^{\pm}_R \rightarrow \ell^{\pm} \tilde{\chi}^0_1$ is considered, neglecting any additional efficiency from cascade decays.

The observed limit on the scalar tau mass (Figure 4c) is considerably lower than the one expected by performing Monte Carlo experiments with background only. This is due to the slight excess observed in this channel from $\sqrt{s} = 189$ GeV to $\sqrt{s} = 202$ GeV.

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	Single-electron + X		Pure Single-electron	
$\sqrt{s}$ (GeV)	N_{Data}	N_{MCExp}	N_{Data}	N_{MCExp}
192	3	2.2	2	1.8
196	8	7.0	7	6.0
200	10	7.3	9	6.4
202	8	3.4	5	2.8
192–202	29	19.9	23	17.0

Table 1: Results of the $\tilde{e}_R\tilde{e}_L$ searches at various centre-of-mass energies.

	Low ΔM		Medium ΔM		High ΔM		Total	
	N_{data}	N_{exp}	N_{data}	N_{exp}	N_{data}	N_{exp}	N_{data}	N_{exp}
$\tilde{e}$	31	28.3	10	12.7	24	24.5	60	56.2
$\tilde{\mu}$	48	42.2	20	16.7	48	40.1	99	85.6
$\tilde{\tau}$	191	199.3	72	59.1	41	33.8	226	226.6

Table 2: Results of the acoplanar lepton searches at $\sqrt{s} = 197$ GeV.

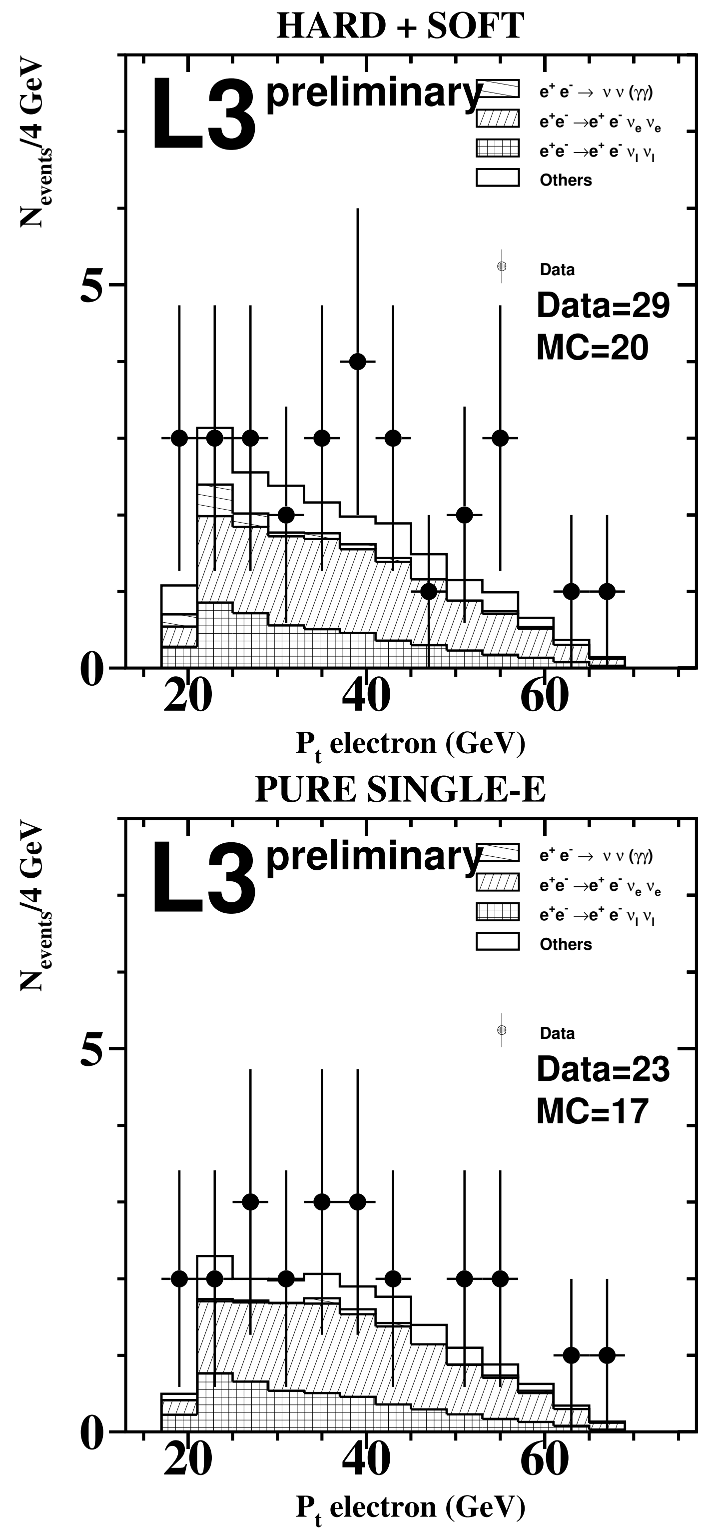

Figure 1: Transverse momentum distribution for the selected events in the single-electron analysis, a) for the entire sample and b) for the subset of single-electron final state. Data events observed at $\sqrt{s} = 197$ GeV are compared to Standard Model background processes.

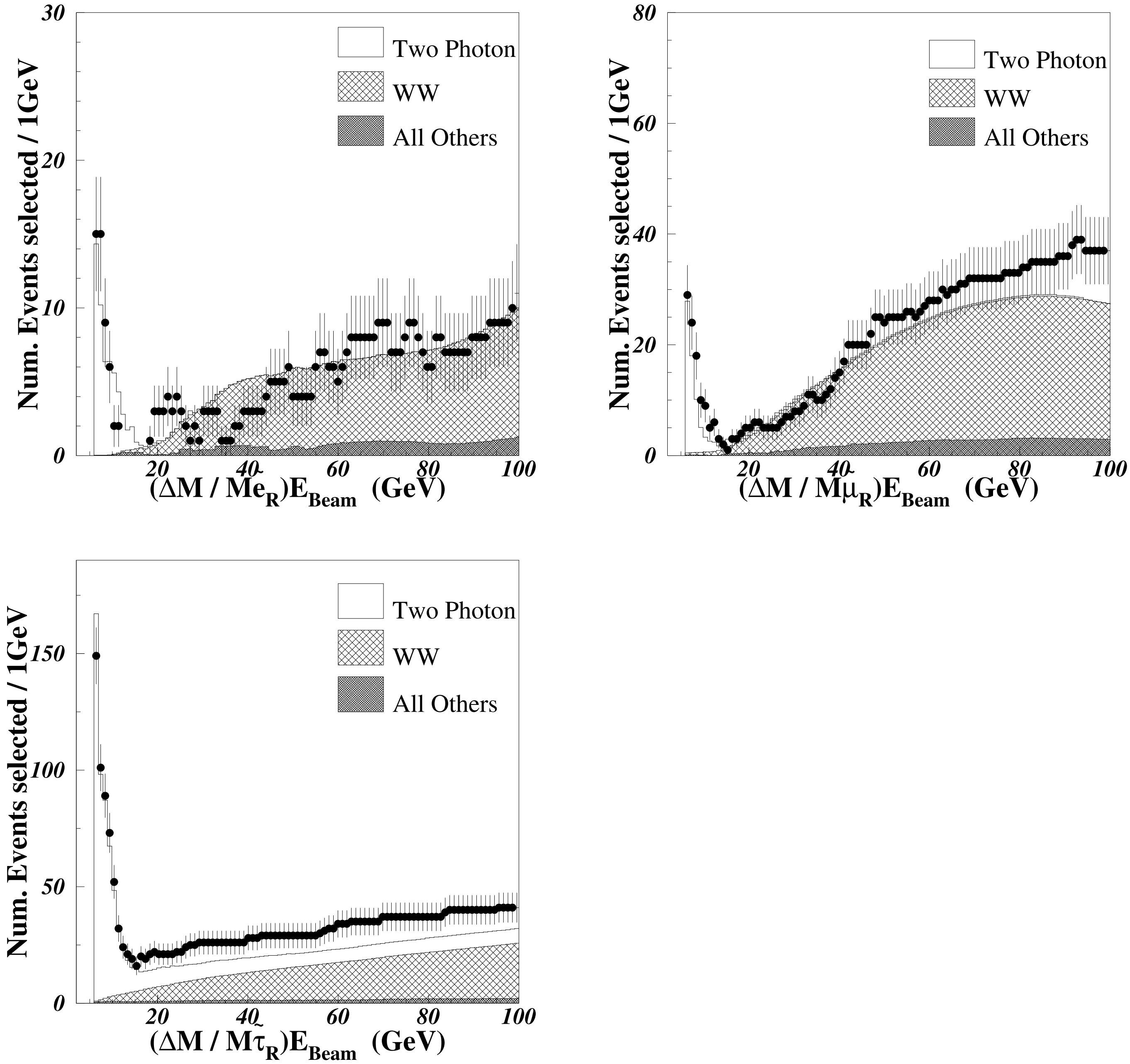

Figure 2: Number of events selected in data (dots) and expected from Standard Model background (solid line) as a function of the ratio $\Delta M/M_{\tilde{\ell}} \cdot \sqrt{s}/2$. Distributions for the a) scalar electron, b) scalar muon, and c) scalar tau are shown.

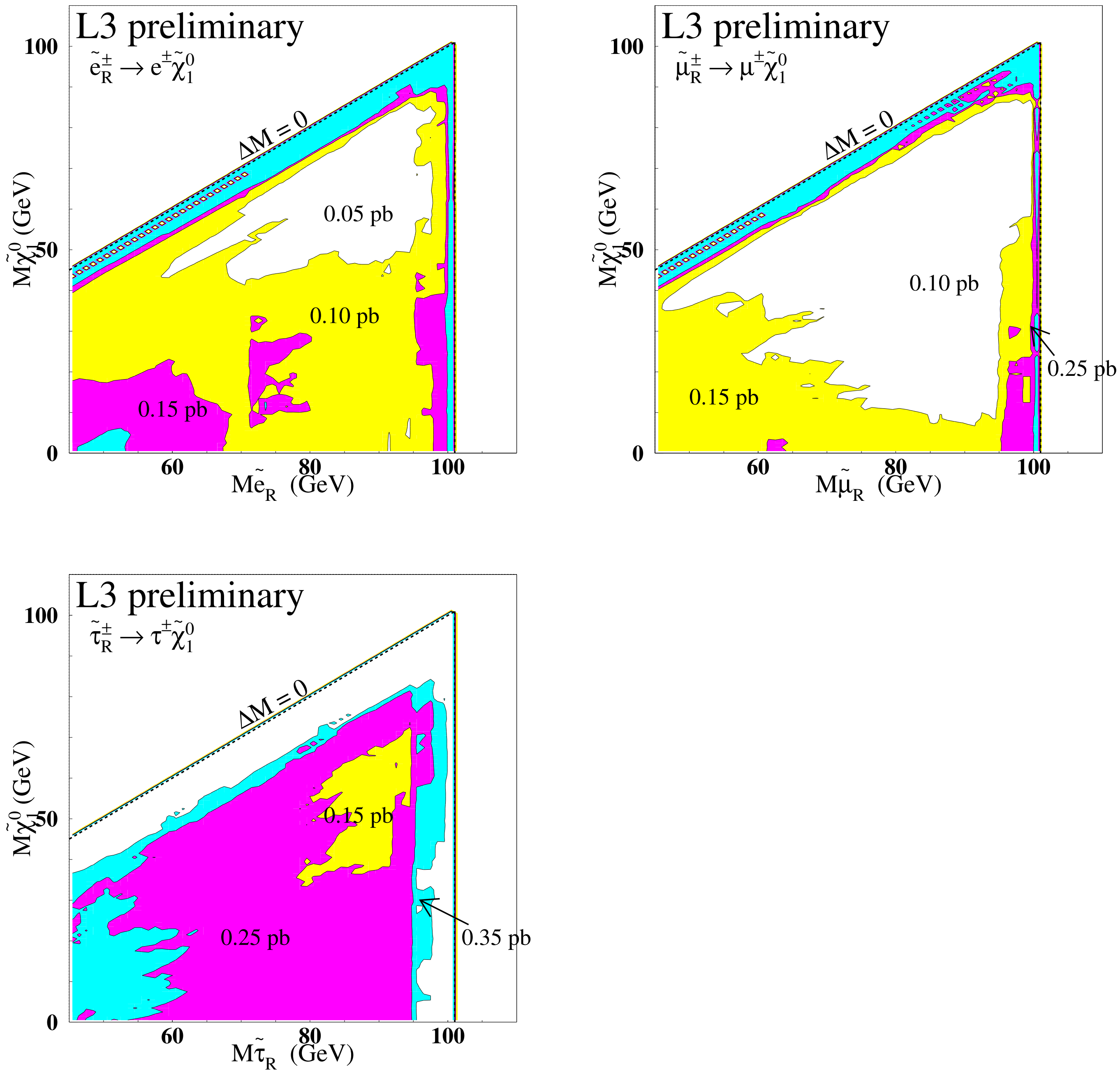

Figure 3: Upper limits on the production cross sections up to $\sqrt{s} = 202$ GeV shown in the mass plane $M_{\tilde{\ell}} - M_{\tilde{\chi}^0_1}$ for scalar leptons. Figures a), b) and c) show the limits for scalar electrons, muons and taus, respectively.

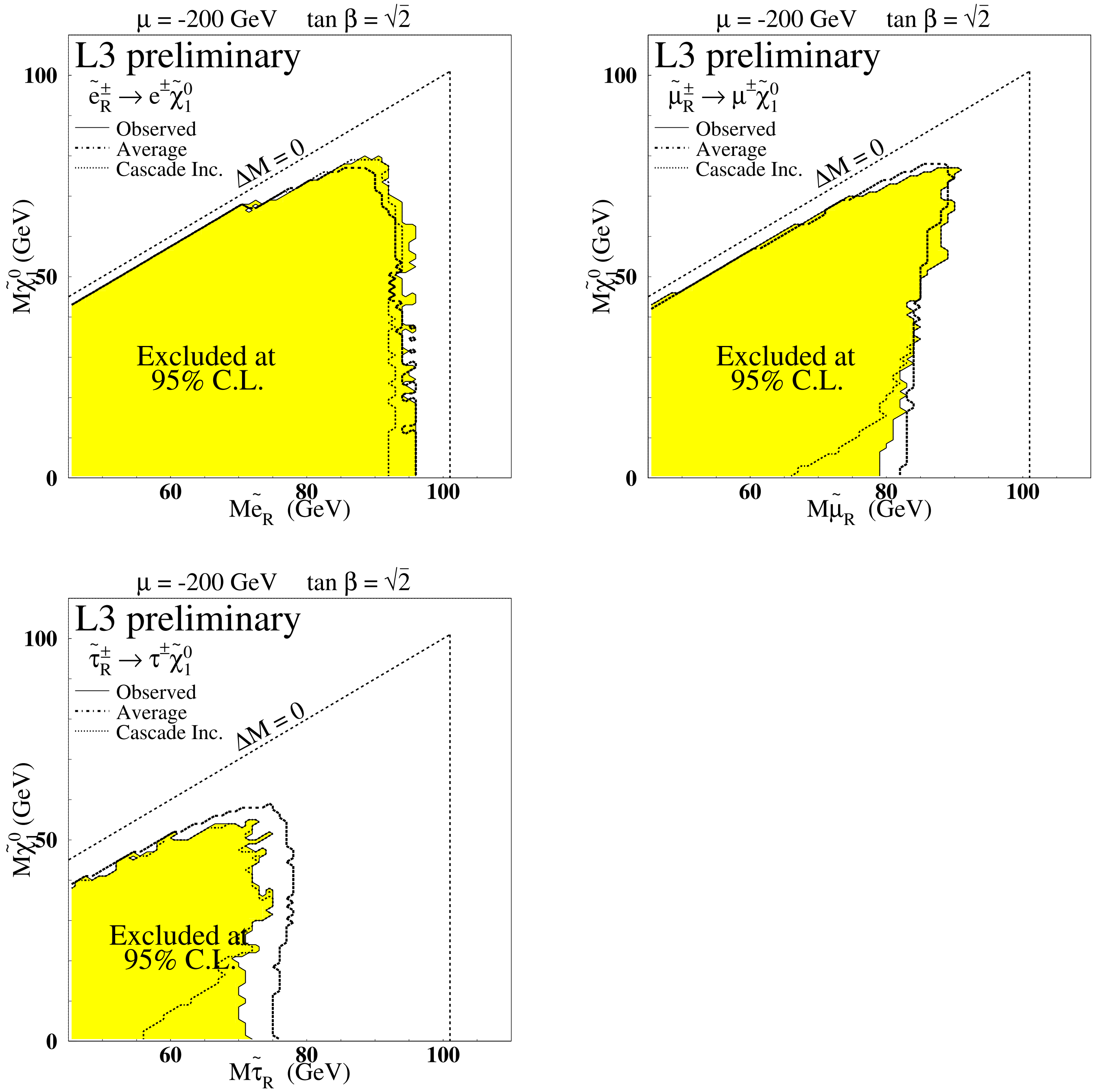

Figure 4: Mass limits on the scalar partners of right-handed electrons a), muons b) and taus c) as a function of the neutralino mass $M_{\tilde{\chi}_1^0}$. These three figures are obtained using only the upper limits on the cross section from direct searches at centre-of-mass energies between 189 GeV and 202 GeV. The dashed lines show the average limits obtained with Monte Carlo trials with background only.