Search for New Heavy Leptons at LEP

S. Shevchenko

Lauritsen Laboratory of Physics, California Institute of Technology,
Pasadena, CA 91125 USA

The energy upgrade at LEP allows new regimes to be explored in the search for New Physics. In this paper the preliminary results on searches for new 4th generation sequential leptons and excited leptons at $\sqrt{s}$ = 161 and 172 GeV are presented.

1. Introduction

The standard model (SM) of elecroweak and strong interaction has been very successful in describing the experimental data. Nevertheless it seems to be not the ultimate theory because too many facts are unexplained, e.g. the family structure of quarks and leptons and their masses. A search for heavy states in a new mass domain provides an opportunity to glimpse various types of physics beyond the SM and would significantly influence the development of a new theory if evidence for new states would be found.

Here we report on direct searches for fourth generation sequential leptons and excited leptons using the ALEPH, DELPHI, L3 and OPAL data ($\sim$ 20 pb^{-1} per experiment) obtained at $\sqrt{s}$ = 161 and 172 GeV at LEP.

2. New Heavy Sequential Leptons

Electron-positron colliders are well suited for the search for new heavy leptons, with masses up to the kinematic limit $m_{\rm L} \leq E_{\rm beam}$ [1]. The predicted production cross sections are large ($\sim$ 1 pb) and final state particles can be identified cleanly. Heavy neutral and charged leptons that have not so far been observed are predicted by various models [2]. The sequential fourth generation neutral and charged leptons are the most natural extension. Here we report on a direct search for 4th generation sequential neutral heavy leptons (heavy neutrinos), L^0, of the Dirac or Majorana type, and charged heavy leptons, $L^{\pm}$.

Sequential heavy leptons are pair-produced through the s-channel: $\rm e^+e^- \rightarrow \gamma/Z \rightarrow L^+L^-$, $\rm L^0\overline{L}^0$. The following decay modes were considered:

(1) $\rm L^0 \rightarrow \ell^{\pm}$+$\rm W^{\mp *}$ via lepton flavour mixing, where ℓ is e, μ or τ, and W* is a virtual or real W boson.

(2) $\rm L^{\pm} \rightarrow L^0$+$\rm W^{\pm *}$, where L^0 is associated stable heavy neutrino and assumed to be heav-

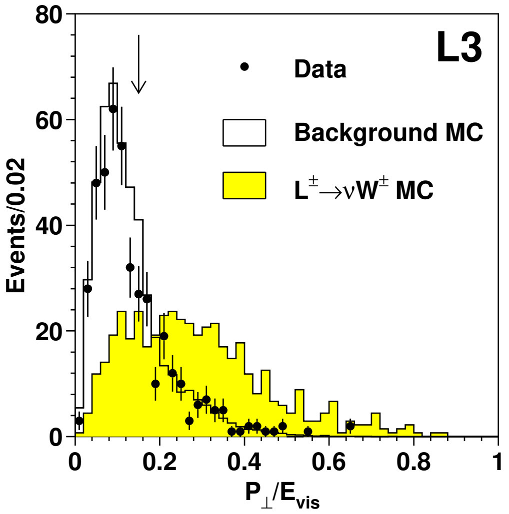

Figure 1. The ratio of the transverse momentum imbalance and the total visible energy. The dots are the data selected by L3, the solid histogram is the background Monte Carlo. The dashed histogram is a predicted signal $\rm e^+e^- \rightarrow L^+L^-$ with $\rm m_{L^{\pm}}$ = 75 GeV and arbitrary normalization.

ier than the lower mass limit from LEP1 data ($\sim$ 40 GeV/c^2).

(3) $L^{\pm} \rightarrow \nu_\ell + W^{\pm *}$, where ν_ℓ is ν_e, ν_μ or ν_τ, and the decay occurs via lepton flavour mixing.

Table 1
95% C.L. lower mass limit in GeV/c^2 for unstable neutral heavy lepton L^0.

	Decay mode	Dirac	Majorana
L3	$L^0 \rightarrow eW$	78.0	66.7
	$L^0 \rightarrow \mu W$	78.0	66.7
	$L^0 \rightarrow \tau W$	72.2	58.2
OPAL	$L^0 \rightarrow eW$	79.1	69.8
	$L^0 \rightarrow \mu W$	78.5	68.5
	$L^0 \rightarrow \tau W$	69.0	55.7

The expected experimental signature in the search for heavy neutrino $L^0\overline{L}^0$ is at least two isolated leptons with the same flavour. The signature for L^+L^- events in both cases, (2) and (3), is that of large, unbalanced transverse momentum (see Figure 1, obtained by L3), missing energy, and/or isolated leptons. The events in case (2) are expected to have a larger missing energy than in case (3), because the two heavy neutrinos carry away more energy. No signal was found after selection cuts. The number of candidates found in data are consistent with expected number of background events from known processes. The 95% C.L. lower limits are shown in Table 1 and Table 2. Figure 2 shows the 95% C.L. exclusion contour in the $m_{L^\pm}$ - m_{L^0} mass plane, obtained by OPAL. A similar exclusion contour was obtained by L3.

Table 2
95% C.L. lower mass limit in GeV/c^2 for unstable charged heavy lepton $L^{\pm}$.

	Decay mode	
L3	$L^- \rightarrow L^0 W^-$	81.0
	$L^- \rightarrow \nu_\ell W^-$	78.7
OPAL	$L^- \rightarrow L^0 W^-$	80.2
	$L^- \rightarrow \nu_\ell W^-$	81.4

If the associated neutral heavy lepton L^0 is heavier than its charged partner $L^{\pm}$ and there is no or very small mixing into light neutrinos, then the charged heavy lepton should be stable in the detector. The experimental signature of the production of stable charged heavy lepton is two back to back highly ionizing charged tracks, and the search for this particle is based on the inonization loss measurement in the tracking device. Figure 3 shows the track ionization distributions for the 172 GeV data and expected signal, obtained by L3. There were no signal events observed in the data. This corresponds to a mass limit of $m_{L^\pm} > 84.2$ GeV and to an upper limit on the cross section for pair-production of heavy stable charged particles of mass 60-84 GeV and charge $\pm 1e$ of between 0.3-0.5 pb at 95% C.L. Similar limits on the cross section for pair-production of heavy stable charged particles were obtained by ALEPH [3] and DELPHI [4].

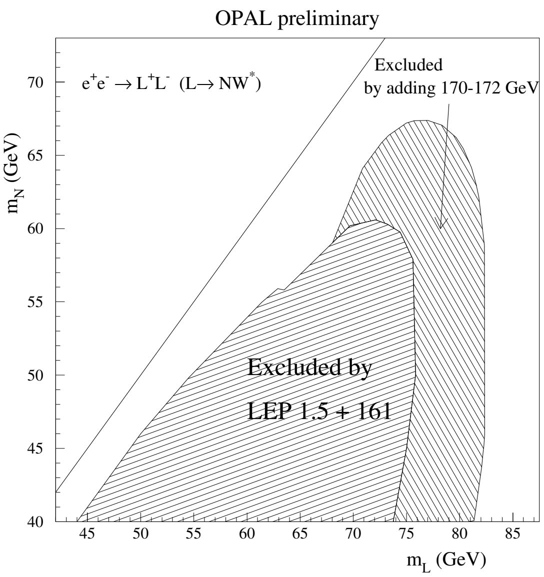

Figure 2. The 95% confidence level limits on the charged heavy lepton mass $m_{L^\pm}$ (horizontal scale) and the associated neutral heavy lepton mass m_{L^0} (vertical scale) assuming L^0 is stable at $\sqrt{s} = 172$ GeV. Also shown is the limit from the previous OPAL results at $\sqrt{s} = 133$ GeV and 161 GeV.

3. Excited Leptons

Excited leptons are natural consequence of models where the standard leptons are composite rather then elementary particles [5]. These models of quarks and leptons have attracted physicists because they could potentially explain the family (or generation) problem, and could make the fermion masses and weak mixing angles into calculable parameters.

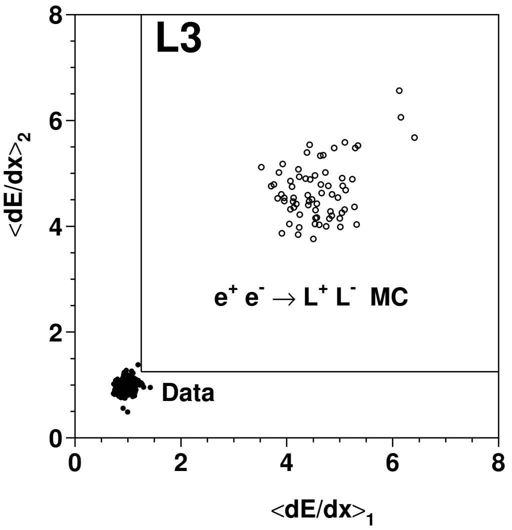

Figure 3. The normalized measured track energy loss of track 2 vs track 1 for the data (solid circles) obtained by L3 at $\sqrt{s} = 172$ GeV and the expected signal (arbitrary normalization) for a mass 84 GeV stable heavy charged lepton (open circles). The lines represent the cuts.

At e^+e^- colliders, excited leptons would be produced in pairs ($e^+e^- \to \ell^*\ell^*$, through s-channel) or singly ($e^+e^- \to \ell\ell^*$, through s-channel, and additionally through t-channel, but only for first generation excited leptons). For pair production, the maximum mass of excited lepton is limited to the beam energy, whereas in the case of single production, it can reach mass region close to the center-of-mass energy. Over the new mass range covered by LEP2 at $\sqrt{s} = 172$ GeV, the cross section for pair production can be as large as several pb. For the single production the cross section is suppressed by a factor $1/\Lambda$, where the parameter Λ can be regarded as the 'compositeness scale'. The effective coupling is frequently parametrised as $\lambda/\mathrm{m}_{\ell^*} = f/\sqrt{2}\Lambda$, although in general it could be more complicated.

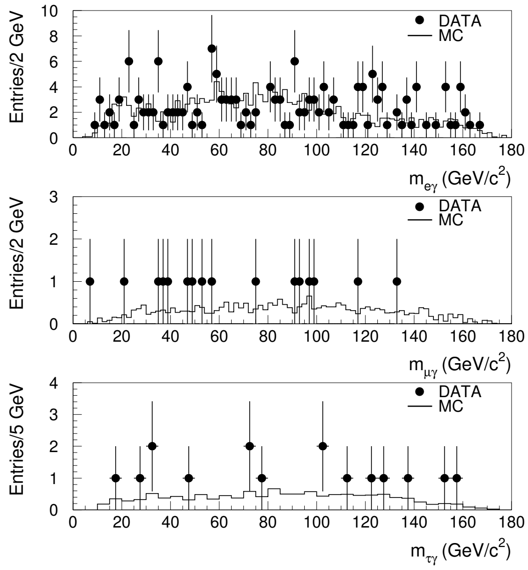

Figure 4. Invariant mass distributions for all possible lepton-photon combinations in single production searches, obtained by ALEPH: electron (upper plot), muon (middle plot) and tau (bottom plot) channels. The dots are the data and the solid histogram is the background simulation.

Table 3
95% C.L. lower mass limits in GeV/c^2 for pair produced excited leptons

	e^*	μ^*	τ^*	ν^*
ALEPH	84.6	84.7	84.5	
DELPHI	84.6	84.6	84.6	67.6
L3	85.1	85.0	84.1	78.9
OPAL	85.1	85.1	84.1	84.0

Searches for excited leptons ℓ^* were performed using three potential decay modes: $\ell^{\pm *} \to \ell^{\pm}\gamma$, $\ell^{\pm *} \to \nu\mathrm{W}^{\pm}$, $\ell^{\pm *} \to \ell^{\pm}\mathrm{Z}$ for charged excited leptons, and $\nu^* \to \nu\gamma$, $\nu^* \to \ell^{\pm}\mathrm{W}^{\mp}$, $\nu^* \to \nu\mathrm{Z}$ for excited neutrinos. The signatures for excited leptons are energetic photons plus missing energy, energetic photons plus acoplanar pair of leptons, isolated leptons plus hadronic jets and acoplanar hadronic jets plus missing energy. In addition one can look for the peaks in $\ell^{\pm}\gamma$ invariant mass distribution if excited charged lepton decays radiatively. Figure 4 shows $\ell^{\pm}\gamma$ invariant mass distributions obtained by ALEPH for e^*, μ^* and τ^*, respectively.

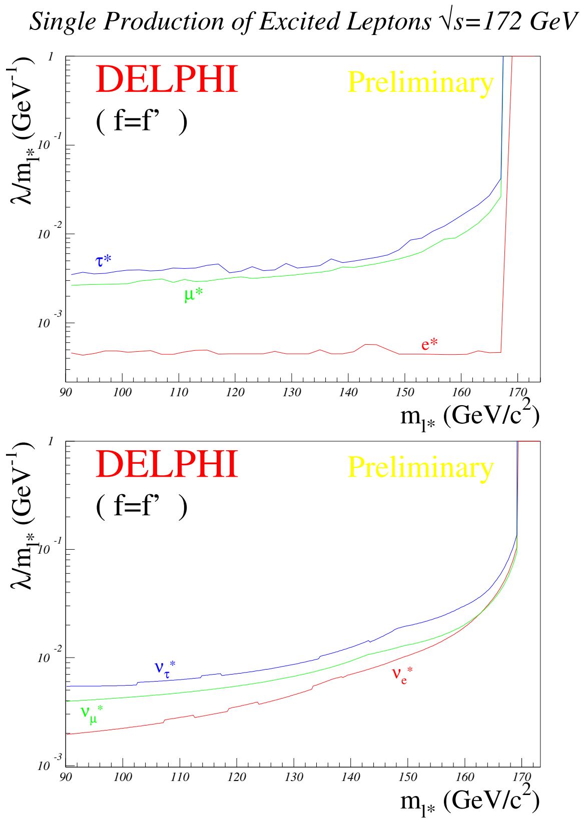

Figure 5. Single production of excited leptons: the lines show the compositeness limits at 95% C.L. of the ratio of the coupling of the excited lepton to the mass ($\lambda/\mathrm{m}_{\ell^{\pm *}}$) as a function of the mass for electron, muon and tau generations.

No signal was observed and new 95% C.L. limits were set on pair produced excited lepton masses to nearly kinematical limit, as shown in Table 3. Coupling limits for single excited lepton production obtained by DELPHI are shown in Figure 5 and Figure 6. Similar limits were obtained by ALEPH, L3 and OPAL.

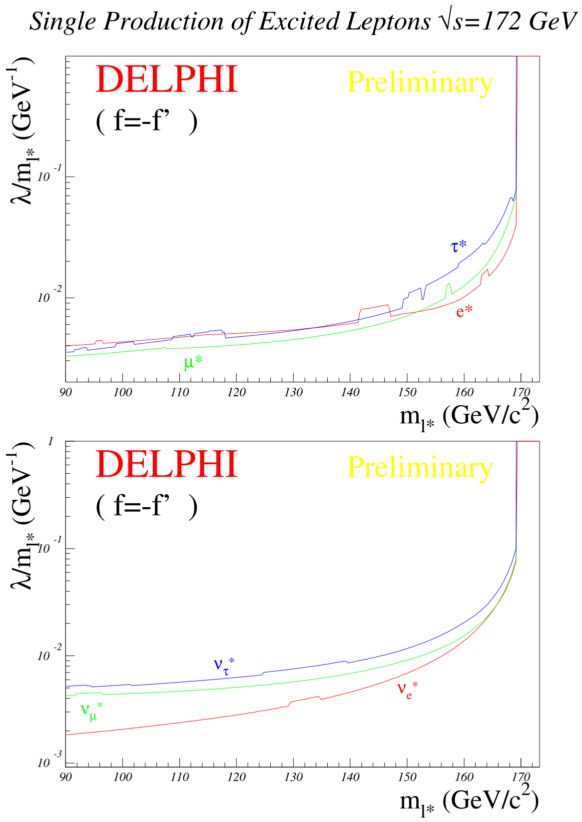

Figure 6. Single production of excited leptons: the lines show the compositeness limits at 95% C.L. of the ratio of the coupling of the excited lepton to the mass ($\lambda/\mathrm{m}_{\ell^{\pm *}}$) as a function of the mass for electron, muon and tau generations.

4. Conclusion

No evidence for new heavy leptons has been found at LEP at $\sqrt{s}$ = 161 and 172 GeV. New lower limits on their masses have been set, which significantly (by $\sim$ 20 GeV) improve the mass limits obtained at $\sqrt{s}$ = 133 GeV.

5. Acknowledgments

The author would like to thank W. De Boer, P. Giacomelli, R. McNeil, W.D. Schlatter, C. Yang and Z. Zhang for their help during the preparation of the talk.

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