Search for Heavy and Excited Fermions at LEP2

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The energy upgrade at LEP2 allows new regimes to be explored in the search for New Physics. In this paper the preliminary results on searches for new heavy sequential leptons, isosinglet neutrinos, and excited leptons and quarks at $\sqrt{s}$ = 183 and 189 GeV are presented.

1 Introduction

Despite its tremendous success in describing all experimental data available today, the Standard Model is widely believed not to be the ultimate truth. Besides the fact that it has too many parameters which are merely incorporated by hand, the Standard Model does not unify the electroweak and strong forces in a satisfactory way since the coupling constants of these interactions are different and seem to be independent. Extensions (such as string and GUT models) or radically new descriptions (such as composite models) have been proposed. These theories beyond the Standard Model predict the existence of new matter particles: sequential fermions, singlet fermions, excited fermions.

Here we report on direct searches for new heavy sequential leptons, isosinglet neutrinos, and excited leptons and quarks using the DELPHI, L3 and OPAL data ($\sim$ 230 pb^{-1} per experiment) obtained at $\sqrt{s}$ = 183 and 189 GeV at LEP2.

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: $e^+e^- \to \gamma/Z \to L^+L^-$, $L^0\overline{L}^0$. The following decay modes were considered:

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

(2) $L^{\pm} \to \nu_\ell + W^{\pm *}$, 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	$L^0 \to eW$	92.4	81.8
$\sqrt{s}$=161-189 GeV	$L^0 \to \mu W$	93.3	84.1
	$L^0 \to \tau W$	83.3	73.5
OPAL	$L^0 \to eW$	93.4	84.9
$\sqrt{s}$=183-189 GeV	$L^0 \to \mu W$	92.9	83.4
	$L^0 \to \tau W$	80.1	62.6
DELPHI	$L^0 \to eW$	76.5	
$\sqrt{s}$=183 GeV	$L^0 \to \mu W$	79.5	
	$L^0 \to \tau W$	60.5	

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 is that of unbalanced transverse momentum, missing energy, and/or isolated leptons. 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.

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

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

	Decay mode	
L3	$\mathbf{L}^- \to nu_\ell W^-$	92.4
$\sqrt{s}$=189 GeV	Stable $\mathbf{L}^-$	93.5
OPAL	$L^- \to \nu_\ell W^-$	91.3
$\sqrt{s}$=189 GeV	Stable L^-	92.6
DELPHI	$L^- \to \nu_\ell W^-$	78.3
$\sqrt{s}$=183 GeV		

in the tracking device. There were no signal events observed in the data. The 95% C.L. lower limits are shown in Table 2.

3 New Heavy Isosinglet Neutrinos

Isosinglet heavy neutrinos arise in many models that attempt to unify the presently observed interactions into a single gauge scheme such as Grand Unified Theories or Superstring models [3], left-right symmetric and see-saw models [4]. The dominant production cross section is single production ($e^+e^- \to \nu N$) as the result of the mixing with the standard neutrino. The single production process proceeds through s-channel Z exchange in the case of second and third generations, N_μ and N_τ. For the first generation, N_e, when heavy neutrinos have a direct coupling with electron, there is the additional contribution from t-channel W exchange. Due to this additional contribution the production cross section for "first generation" heavy neutrinos is significantly higher. Since the mixing amplitude is expected to be smaller than $\mathcal{O}(10^{-1})$ [5], the production cross section for N_μ and N_τ are too small to be explored at LEP2. Therefore, in this analysis we concentrate on the search for "first generation" heavy singlet neutrino, N_e.

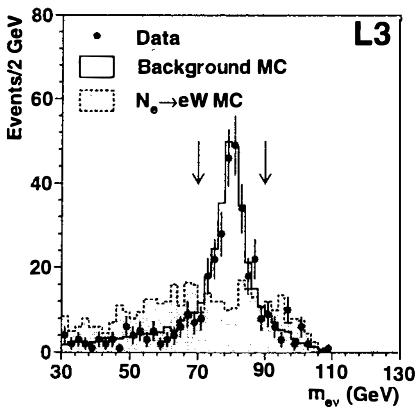

Figure 1: The invariant mass, $m_{e\nu}$, of the isolated lepton and missing momentum. The dots are the data taken at $\sqrt{s}$ = 189 GeV, the solid histogram is the background Monte Carlo. The dashed histogram is a predicted signal $e^+e^- \to \nu N$ for the mass of heavy neutrino m_N = 140 GeV. The normalization for the signal Monte Carlo is arbitrary. The arrows indicate the corresponding value of the applied cut.

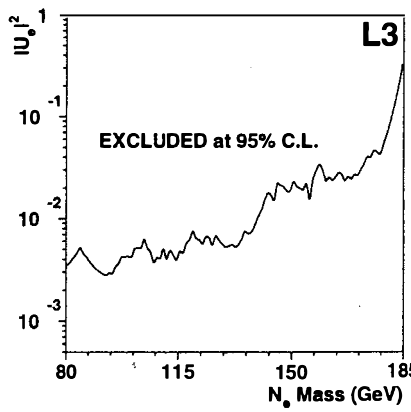

Figure 2: Upper limit at the 95% C.L. on the mixing matrix element as a function of heavy neutrino mass.

The most clean decay channel is $N_e \to eW \to e + 2\ jets$. Events are selected by requiring an isolated electron plus missing momentum and hadronic activity. Then hadronic activity (jets) is required to be consistent with on-shell W, while the invariant mass of the electron and missing momentum is inconsistent with on-shell W to reject the main WW background. Figure 1 shows the distribution of the invariant mass of the electron and missing momentum, $m_{e\nu}$, for events after the kinematic fit has been applied. One can see a clear peak at 80 GeV from WW background. After applying the cut, $m_{e\nu} < 70$ GeV or $m_{e\nu} > 90$ GeV, the 82% of the background are rejected. The heavy neutrino mass is found from the invariant mass of visible particles with resolution ≈ 2 GeV. The excellent L3 electromagnetic resolution is essential to reject WW background and to reconstruct the heavy neutrino mass with high resolution.

No signal was found. We calculate the 95% confidence level upper limit on the coupling constant $|U_e|^2$ as a finction of the mass (see Figure 2). These are the only results in the world for the heavy neutrino masses above ≈ 80 GeV.

4 Excited Leptons and Quarks

Excited fermions are natural consequence of models where the standard leptons are composite rather then elementary particles [6]. 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.

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

Type	Coupling	Decay	L3 189	OPAL 183 + 189(40 pb^{-1})	DELPHI 183
e*	$f = f'$	Photonic	94.2	94.1	90.7
μ^*	$f = f'$	Photonic	94.2	94.1	90.7
τ^*	$f = f'$	Photonic	94.2	94.0	89.7
e*	$f = -f'$	Charged	93.0	91.3	81.3
μ^*	$f = -f'$	Charged	93.0	91.3	81.3
τ^*	$f = -f'$	Charged	93.0	91.3	81.3
ν_e^*	$f = f'$	Charged	94.1	92.8	87.3
ν_μ^*	$f = f'$	Charged	94.1	93.6	88.0
ν_τ^*	$f = f'$	Charged	92.2	90.5	81.0
ν_e^*	$f = -f'$	Photonic	94.1	93.2	90.0
ν_μ^*	$f = -f'$	Photonic	94.1	93.2	90.0
ν_τ^*	$f = -f'$	Photonic	94.1	93.2	90.0

At e^+e^- colliders, excited fermions would be produced in pairs ($e^+e^- \to f^*f^*$, through s-channel) or singly ($e^+e^- \to ff^*$, through s-channel, and additionally through t-channel, but only for first generation excited leptons). For pair production, the maximum mass of excited fermion 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 $\sqrt{s} = 189$ 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 $\lambda/m_{\ell^*} = f/\sqrt{2}\Lambda$, although in general it could be more complicated.

Searches for excited leptons ℓ^* were performed using two potential decay modes: $\ell^{\pm *} \to \ell^\pm\gamma$, $\ell^{\pm *} \to \nu W^\pm$, for charged excited leptons, and $\nu^* \to \nu\gamma$, $\nu^* \to \ell^\pm W^\mp$ 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.

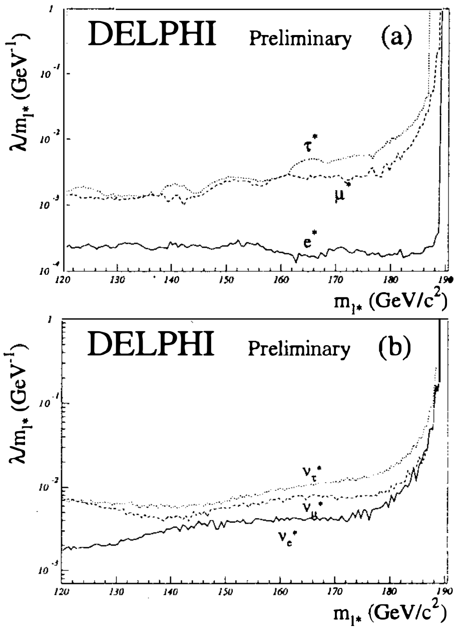

Figure 3: Single production of excited charged leptons (a) and excited neutrinos (b) : the lines show the compositeness limits at 95% C.L. of the ratio of the coupling of the excited lepton to the mass ($\lambda/m_{\ell^{\pm *}}$) as a function of the mass for electron, muon and tau generations, and for combination of couplings $f = f'$.

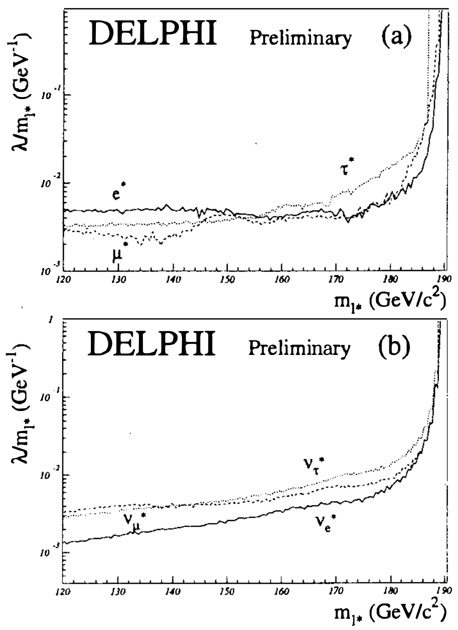

Figure 4: Single production of excited charged leptons (a) and excited neutrinos (b) : the lines show the compositeness limits at 95% C.L. of the ratio of the coupling of the excited lepton to the mass ($\lambda/m_{\ell^{\pm *}}$) as a function of the mass for electron, muon and tau generations, and for combination of couplings $f = -f'$.

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 3 and Figure 4. Similar limits were obtained by L3 and OPAL. DELPHI has also searched for singly produced excited quarks for two decay modes: $q \to qg$ and $q \to q\gamma$. No signal was found and similar coupling limits as for excited leptons ($\sim 10^{-3}$) were obtained.

5 Conclusion

No evidence for new heavy fermions has been found at LEP at $\sqrt{s}$ = 183 and 189 GeV. New lower limits on their masses have been set, which are significantly (by ~ 15 GeV) higher than 1998 Particle Data Group limits.

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