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Search for pair production of unstable heavy leptons in e^+e^- collisions at centre–of–mass energies of 161 and 172 GeV

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Abstract

Data collected at centre–of–mass energies between 161 and 172 GeV by ALEPH at LEP, corresponding to an integrated luminosity of 21.8 pb^{-1}, are analysed to search for pair-production of charged and neutral heavy leptons. No evidence for a signal has been found, and new limits on production cross-sections and on masses of sequential leptons have been set. For instance, unstable charged heavy leptons with masses less than 85 GeV/c^2 are excluded at 95% C.L. for mass differences from the associated neutral heavy lepton greater than 20 GeV/c^2.

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1 Introduction

The existence of new charged heavy leptons $L^{\pm}$ and neutral heavy leptons N is suggested in a large set of models [1]. They can appear in doublets (L,N) or in weak isosinglets, possibly mixing with the first three generations. One example of the former scenario is the extension of the known particle spectrum by an additional (heavy) fermion generation, including the so–called sequential leptons. Neutral heavy leptons can be of Dirac- or Majorana-type, which in this context mainly affects the size and $\sqrt{s}$-dependence of the production cross section.

This article presents searches for heavy, unstable charged and neutral leptons, updating the results obtained at $\sqrt{s} = 130 - 136$ GeV [2] with new results from data collected by ALEPH at $\sqrt{s} = 161.3$ GeV, 170.3 GeV and 172.3 GeV. Section 2 describes the search for neutral heavy leptons decaying via mixing into one of the known charged leptons. Section 3 deals with the search for charged heavy leptons, decaying into their isopartner or (via mixing) into light neutrinos.

2 Neutral heavy leptons

Neutral heavy leptons might be detectable in e^+e^- collisions if they mix with one of the three known generations. Assuming the mixing angle is large enough for the heavy lepton to decay within $O(1$ cm), this analysis considers the three possible decay modes $N \to eW^*$, $N \to \mu W^*$ and $N \to \tau W^*$. Pair production of these heavy leptons leads to final states with two leptons plus neutrinos, leptons or jets from the decays of the virtual W bosons. Since similar topologies have been considered in a search for supersymmetry with R-parity violation via an LLE coupling [3], the selections for multileptons plus missing energy and final states with leptons plus hadrons applied in that search have been used as a basis for this analysis. For heavy lepton decays into electrons or muons, some of these selections have been retuned by requiring the presence of at least two leptons of identical flavour, with a total energy of at least 20 GeV. By tightening these requirements, it is possible to relax others on leptonic energy and event shape variables.

As the missing energy requirement applied in the SUSY search is inefficient for heavy lepton final states with two hadronic W decays, two new selections have been defined for decays into electrons or muons and taus, respectively. After requiring a minimum of twelve charged particle tracks and a visible mass of at least $85\%\sqrt{s}$ (for taus $60\%\sqrt{s}$), events are accepted if they contain at least two identified electrons or muons with a total energy of more than 25 GeV. For taus, where the latter requirement cannot be used, events are clustered into six jets, and selected if the jet with the minimum number of charged particle tracks contains exactly one, and the jet with the second smallest number of tracks has less than three charged particle tracks. In addition, the acollinearity of the event, as obtained by using the thrust axis to divide the event into two hemispheres and measuring the angle between the two hemisphere momenta, must be less than 170°.

For both selections, background from $q\bar{q}$ and W^+W^- is suppressed by requiring large values for the event shape variables y_4 and y_5, defined as the minimum Durham scale between jets after clustering to four and five jets, respectively. After rejecting events with initial state radiation, most of the background surviving the e/μ selection consists of events from ZZ^* and can be further reduced by requiring a minimum invariant mass of 10 GeV/c^2 between the two identified leptons. For τ's, remaining background from W^+W^- is rejected by applying the veto described in [3].

Taking the inclusive combination of the retuned and new selections, neutral heavy leptons with masses around 70 GeV/c^2 are selected with efficiencies of about 50% for decays into electrons, 65% for muons and 27% for taus. The systematic error of 3% relative, dominated by the statistical error on the efficiency due to limited Monte Carlo statistics, has been taken into account by lowering the efficiency by one standard deviation. The total background expected amounts to 0.85 events for electrons, 0.45 events for muons and 1.5 events for taus, with some overlap between the three channels. In the data, a total of three events are accepted. Two events pass the τ-selection (one of which is shared with the e-selection) and a third event passes the μ-selection. The former two have already been selected by the search for supersymmetry with R-parity violation and are consistent with coming from ZZ^* and W^+W^- (cf. [3]), whereas the latter can be interpreted as a $W^+W^- \to \mu\nu q\bar{q}$ event.

In combination with the results from [2], the absence of any signal has been used to set upper limits on the cross-section for pair production of neutral heavy leptons, conservatively counting the observed events as signal without subtracting background. The results are shown in Fig. 1a for Dirac and in Fig. 1b for Majorana neutrinos. Corresponding mass limits can be derived, and are summarised in Section 4. Since events with the neutral leptons decaying into $e\mu$, $e\tau$ or $\mu\tau$ are selected by the τ-selection with efficiencies between those for $\tau\tau$ and $\mu\mu$, the limit given for $\tau\tau$ corresponds to the overall worst case.

3 Charged heavy leptons

New charged leptons could decay via W-exchange into a lighter neutral heavy lepton or (for non-zero mixing angles) into one of the known neutrinos. The present analysis assumes that in the former case the neutral lepton escapes detection, and in the latter case the mixing angle is large enough for the lepton to decay within O(1 cm). In both cases, the final states from the decay of pair-produced heavy charged leptons are very similar to the topologies defined in search for charginos in the context of supersymmetry with R-parity conservation [4]. The corresponding selections have been used here, replacing the mass of the chargino and the lightest neutralino with the mass of the charged heavy lepton and the neutral heavy lepton (or neutrino), respectively. For masses of around 75 GeV/c^2, heavy leptons decaying into light neutrinos are selected with efficiencies of about 23%. Efficiencies for charged leptons decaying into heavy neutral leptons are 60%

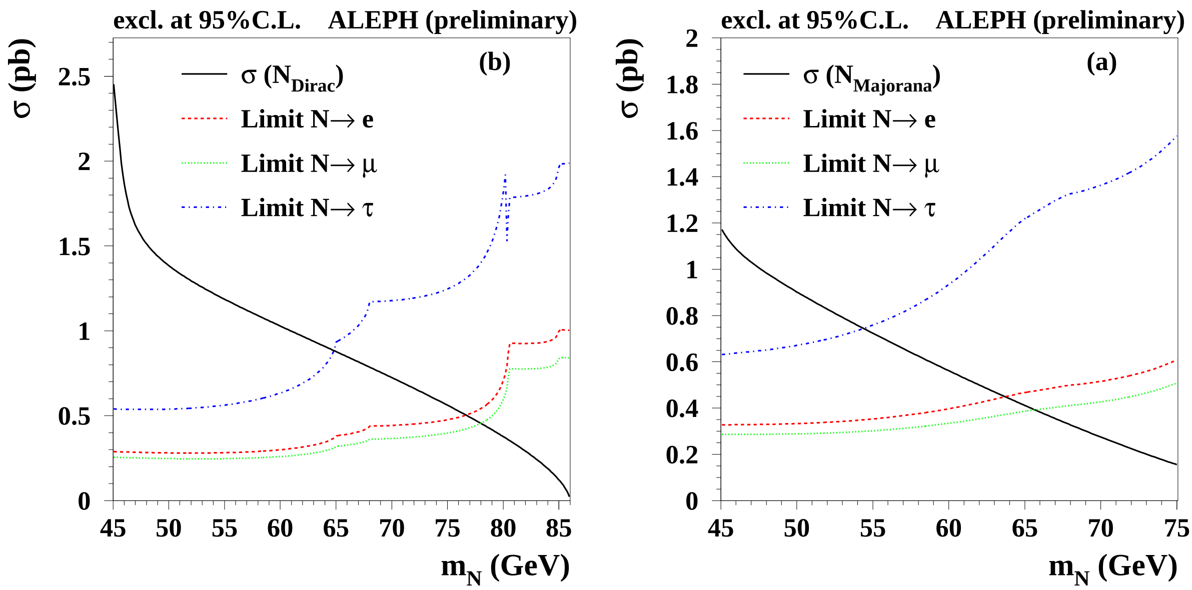

Figure 1: The cross-sections for heavy Dirac-neutrinos (a) and heavy Majorana-neutrinos (b) at $\sqrt{s} = 172$ GeV, in comparison with the limits set for the three different decay modes.

for (m_{L},m_{N})=(85,55) and 16% for (85,80). As reported in [4], no excess of events with respect to the expectation from Standard Model processes was observed. Limits on production cross-sections of charged heavy leptons can be set, as shown in Fig. 2a for the decay into light neutrinos. For charged leptons decaying into heavy neutral leptons, a large part of the kinematically accessible region in the ($m_{\mathrm{L}}, m_{\mathrm{N}}$) plane can be excluded at 95% confidence level (see Fig. 2b).

4 Conclusions

The data collected by ALEPH in 1996 have been used to search for pair-production of new, unstable heavy leptons. Since no evidence for a signal has been found, limits have been set on the production cross-sections. These cross-section limits can be translated into limits on the masses of sequential leptons:

- $m_{\mathrm{L}} > 85$ GeV/c^2 for $\mathrm{L}^{\pm}$ decaying into a stable N and $m_{\mathrm{L}} - m_{\mathrm{N}} > 20$ GeV/c^2.
- $m_{\mathrm{L}} > 75.5$ GeV/c^2 for $\mathrm{L}^{\pm}$ decaying into light neutrinos.
- $m_{\mathrm{N}} > 76.5$ (78.0, 65.0) GeV/c^2 for $\mathrm{N}_{\mathrm{Dirac}}$ decaying into electron (muon, tau).
- $m_{\mathrm{N}} > 63.5$ (65.6, 54.5) GeV/c^2 for $\mathrm{N}_{\mathrm{Majorana}}$ decaying into electron (muon, tau).

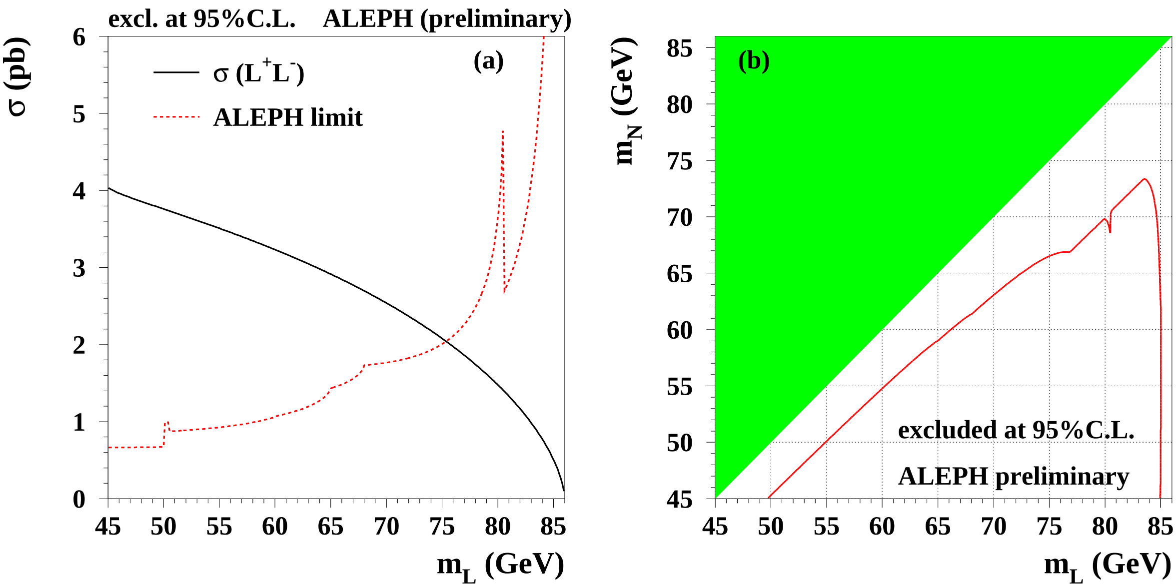

Figure 2: The cross-section for pair-production of heavy charged leptons at $\sqrt{s}$ = 172 GeV in comparison with the limit set for decays into light neutrinos (a); excluded region in the $(m_{\mathrm{L}}, m_{\mathrm{N}})$ plane for decays into heavy neutral leptons (b).

These limits extend the mass regions excluded at $\sqrt{s} = 130 - 136$ GeV [2] and $\sqrt{s}$ = 161 GeV [5].

5 Acknowledgements

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