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# Update on the search for excited fermions at LEP

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# Update on the search for excited fermions at LEP

**S. Andringa, P. Gonçalves, A. Onofre,**
**R. Paiva, L. Peralta, M. Pimenta and B. Tomé**
LIP-IST-FCUL Lisboa, Portugal

**M. Espírito Santo**
CERN, CH-1211 Geneva 23, Switzerland

**C. Matteuzzi**
INFN Milano, Italy

**Abstract**

A search for excited leptons and quarks with the DELPHI detector at LEP is reported. The data analysed correspond to an integrated luminosity of about 153 pb$^{-1}$, taken in 1998 at an $e^+e^-$ centre-of-mass energy of 189 GeV. The search for pair-produced excited fermions establishes 95% confidence level mass limits. The search for singly produced excited leptons and quarks establishes upper limits on the ratio of the coupling of the excited fermion to its mass ($\lambda/m_{f^*}$) as a function of the mass.

This note updates the search for excited fermions in DELPHI reported in [1]. The analysis follows closely the previous one and therefore this note contains basically the updated plots and tables. The statistics corresponds to an integrated luminosity of 153 pb$^{-1}$ at $\sqrt{s} = 189$ GeV and all results are preliminary.

The single production of excited fermions could proceed via $s$-channel $\gamma$ and $Z$ exchange. Important additional t-channel contributions would arise for excited electron and for excited electronic neutrino production. In this case the unexcited beam particle is emitted preferentially at low polar angle and often goes undetected in the beam pipe.

Pair production of charged excited fermions in $e^+e^-$ collisions could proceed via $s$-channel $\gamma$ and $Z$ exchanges while for excited neutrinos only $Z$ exchange contributes. Although $t$-channel contributions are also possible, they correspond to double de-excitation, and give a negligible contribution to the overall production cross-section [2].

Excited fermions could decay by radiating a $\gamma$, $Z$ or $W$. For excited quarks, the gluon radiation transition is also possible, becoming in general the most important decay mode. The decay branching ratios are functions of the $f$, $f'$ and $f_s$ coupling parameters of the model [2]. The mean lifetime of excited fermions with masses above 20 GeV/$c^2$ is predicted to be less than $10^{-15}$ seconds in all the cases studied.

The process $e^+e^- \rightarrow \gamma\gamma(\gamma)$ can be used to probe compositeness at LEP and thus complement the excited electron direct searches for the mass region above the kinematical threshold [3].

Excited fermion events were generated according to the cross-sections defined in [2], involving $\gamma$ and $Z$ exchange. The hadronization and decay processes were simulated by JETSET 7.4 [4]. The initial state radiation effect was included at the level of the generator.

The event selection was performed in three stages. In the first level, very general selection criteria were applied and the events were classified according to the number of jets and of isolated leptons and photons. In the second level, differing selection criteria were applied to each topology. Finally, whenever possible, event flavour tagging was performed, based on the identification of the final state leptons and on other (topology dependent) characteristics of the event. Details on each selection level are given in reference [1]. Only small adjustments were made with respect to the previous analysis. At the different selection levels and topologies, fair agreement between data and SM expectation was found.

The numbers of excited fermion candidates, as well as the SM expectations, are summarized in table 1 for the different excited fermion types and decay modes.

Signal simulation studies allowed the determination of the efficiency and the mass resolution for each situation, and they were found to be similar to the obtained in the previous analysis.

The limits were computed using the method described in [5]. For the single production of excited fermions the cross-sections are a function not only of the mass of the excited particle but also of the ratio of the coupling of the excited fermion to its mass. 95% confidence level (CL) upper limits on the ratio $\lambda/m_{f^*}$ as a function of the $f^*$ mass were derived. Figures 1 and 2 show these limits for the excited leptons assuming $f = f'$ and $f = -f'$ respectively. Figures 3(a) and 3(b) show the limits on the single production of excited quarks, namely limits on $\lambda/m_{q^*}$ multiplied by the branching ratio of the $q^*$ into q$\gamma$ and into q$g$ respectively. These limits were obtained assuming up-type excited quarks. For down-type excited quarks the cross section limits are about 15% higher in the studied

| channel | $e$ | $\mu$ | $\tau$ |
|---|---|---|---|
| $\ell^* \to \ell\gamma$ | 144(128±6) | 28(37±2) | 62(49±4) |
| $\ell^* \to \nu W$ | 38(42±3) | 22(21±2) | 12(14±1) |
| $\ell^* \to \ell Z$ | 87(96±4) | 52(51±3) | 86(81±4) |
| $\nu^* \to \nu\gamma$ | 3(0.7) | | |
| $\nu^* \to \ell W$ | 34(38±3) | 18(17±2) | 33(30±3) |
| $\nu^* \to \nu Z$ | 13(9±1) | | |
| $q^* \to q\gamma$ | 292(336±8) | | |
| $q^* \to qg$ | 248(258±8) | | |
| $\ell^* \to \ell\gamma$ | 2(0.2±0.2) | 0(0.4±0.2) | 5(0.9±0.3) |
| $\ell^* \to \nu W$ | 68(58±4) | | |
| $\nu^* \to \nu\gamma$ | 8(3.8±0.5) | | |
| $\nu^* \to \ell W$ | 10(13±1.6) | 8(8±0.9) | 42(47±3) |

Table 1: Number of excited fermion candidates for the different decay channels. The numbers in brackets correspond to the simulated SM background expectations. Channels below the double line correspond to the pair production.

mass region due to the lower expected production cross-section.

The lower limits at 95% CL on the masses of pair produced excited leptons are given in table 2 for both $f = f^{'}$ and $f = -f^{'}$ assumptions.

| | $e^*$ | $\mu^*$ | $\tau^*$ |
|---|---|---|---|
| $f = f^{'}$ | 94.1 | 94.1 | 93.3 |
| $f = -f^{'}$ | 84.0 | 84.0 | 84.0 |

| | $\nu_e^*$ | $\nu_\mu^*$ | $\nu_\tau^*$ |
|---|---|---|---|
| $f = f^{'}$ | 93.6 | 93.7 | 89.5 |
| $f = -f^{'}$ | 93.7 | 93.7 | 93.7 |

Table 2: Lower limits (in GeV/$c^2$) at 95 % CL on the excited lepton masses from the pair production modes.

Figure 4 shows the limit on the excited electron production for $f = f^{'}$ obtained by combining the result of the direct search (figure 1(a)) with the indirect result from the search for deviations in the $e^+e^- \to \gamma\gamma(\gamma)$ differential cross-section. We can thus extend the result to regions above the kinematic limit.

# References


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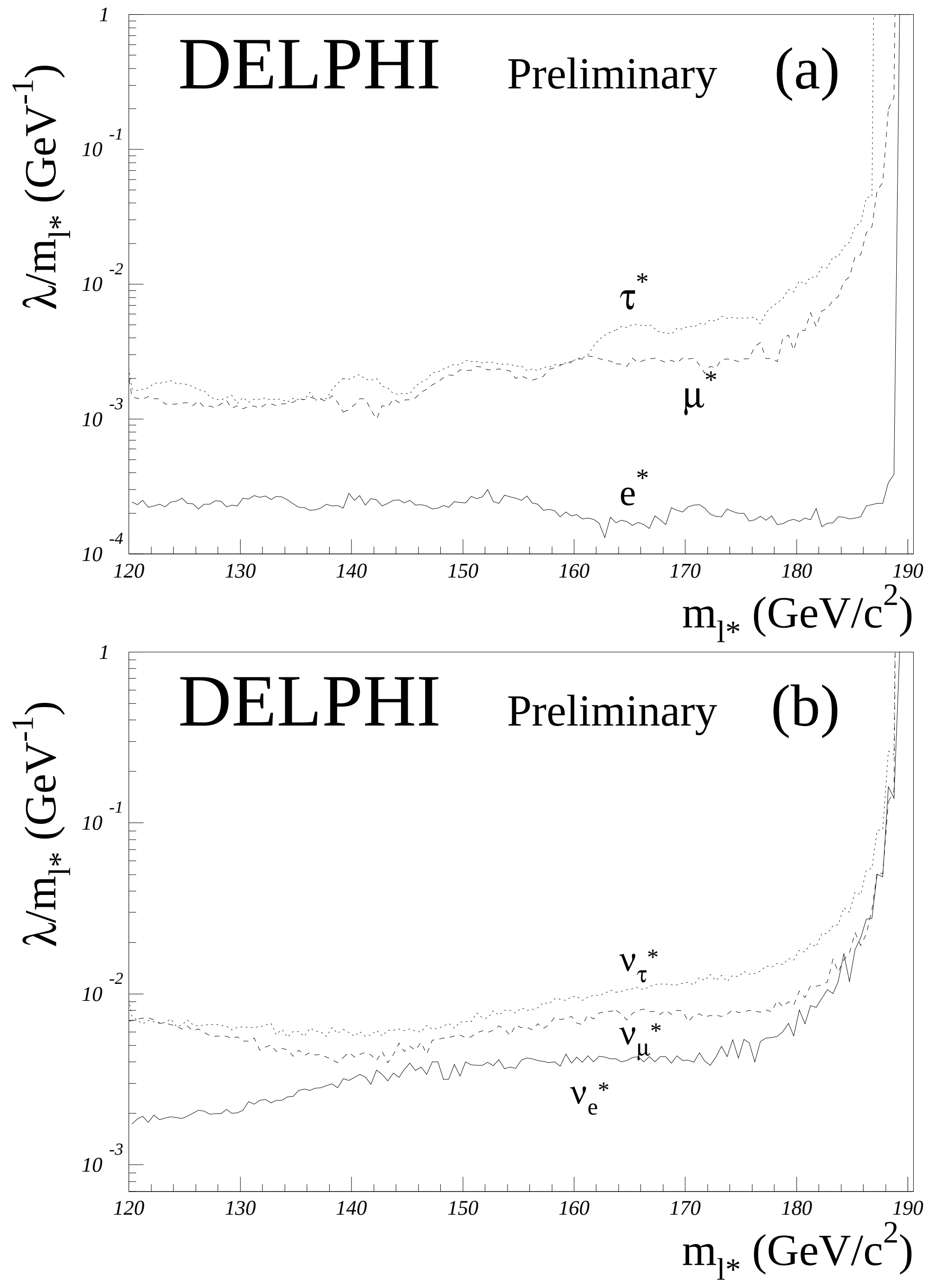
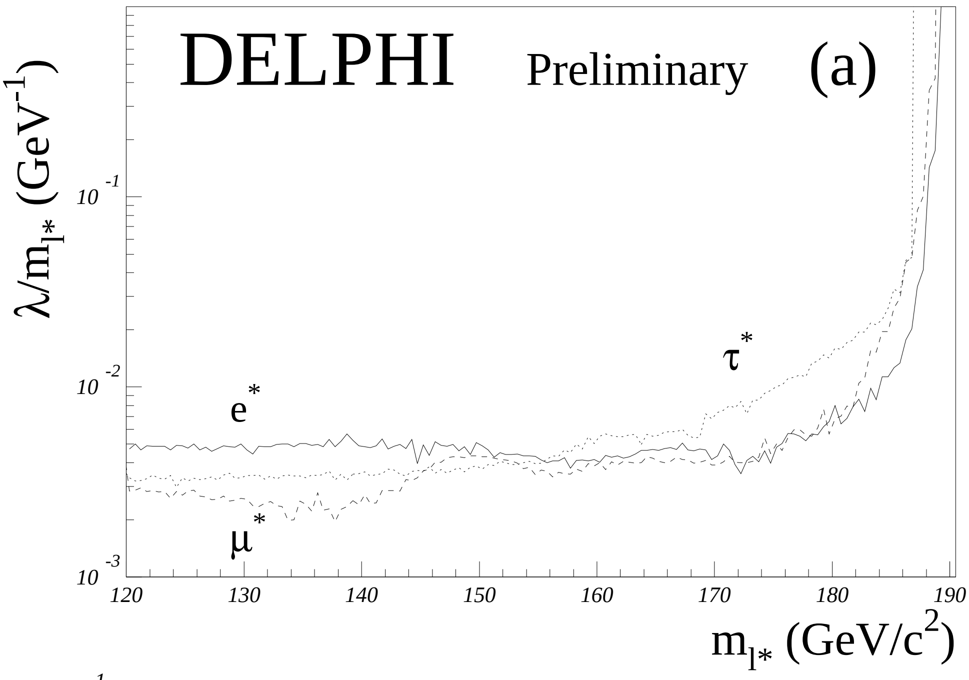



Figure 1: Results on single production of excited charged **(a)** and neutral **(b)** leptons assuming $f = +f'$. The lines show the upper limits at 95% CL on the ratio $\lambda/m_{\ell^*}$ between the coupling of the excited lepton and its mass as a function the mass.



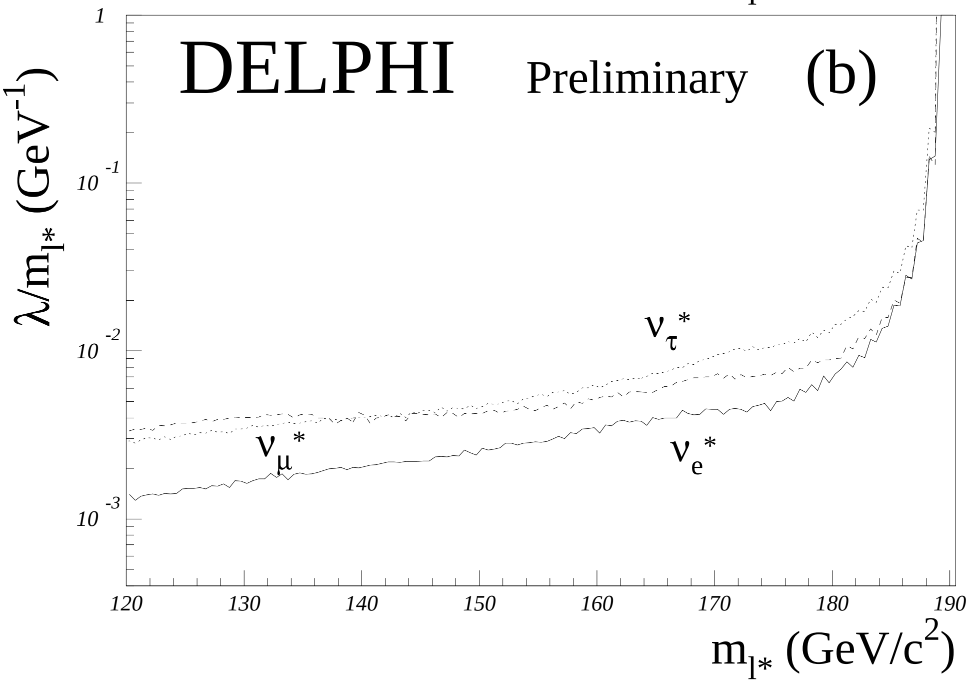




Figure 2: As figure 1, but for $f = -f'$.

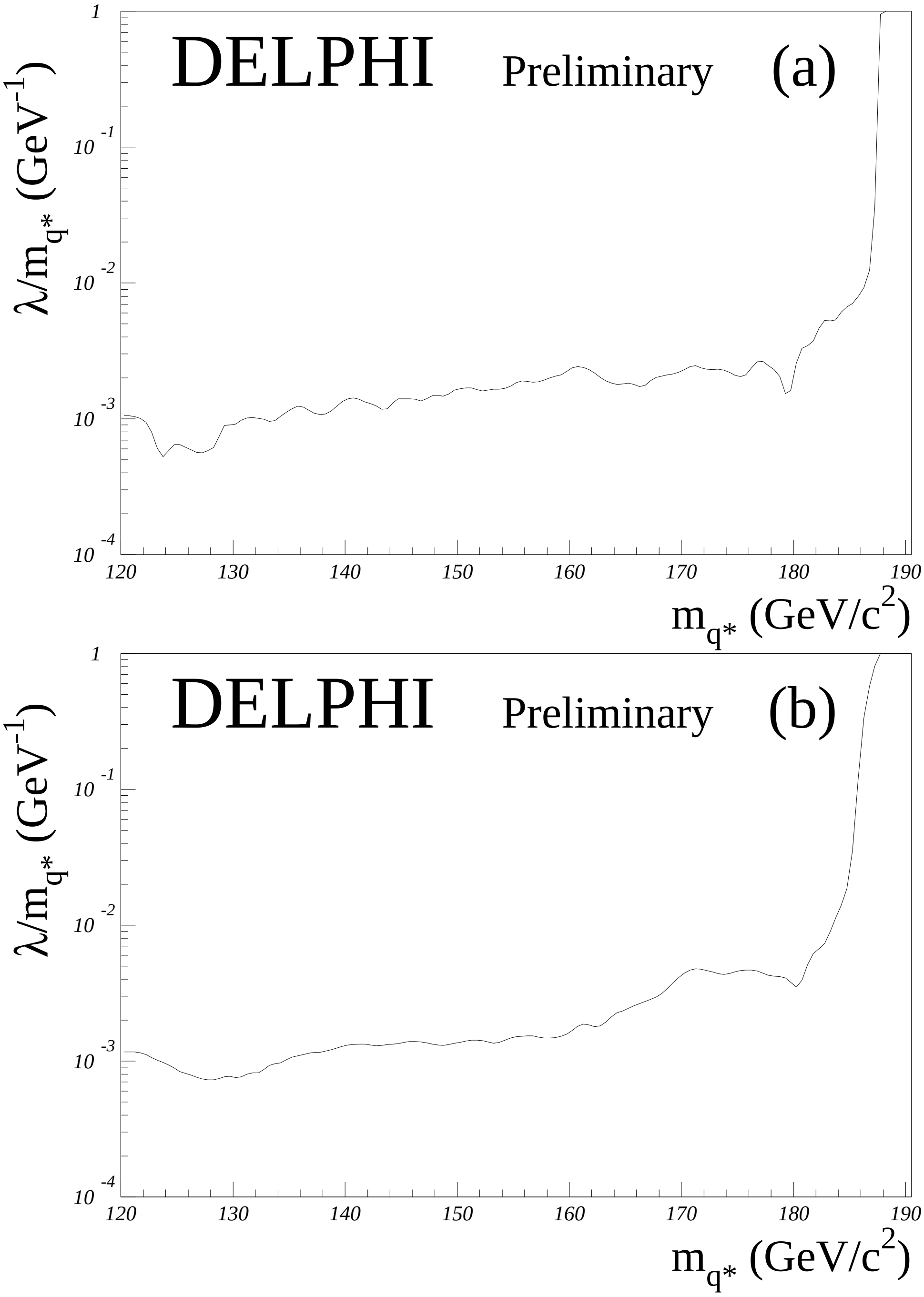



Figure 3: Results on single production of excited quarks assuming a branching ratio of 100% for the photon **(a)** or the gluon **(b)** decay modes. The lines show the upper limits at 95% CL on the ratio $\lambda/m_{q^*}$ between the coupling of the excited quark and its mass as a function of the mass.

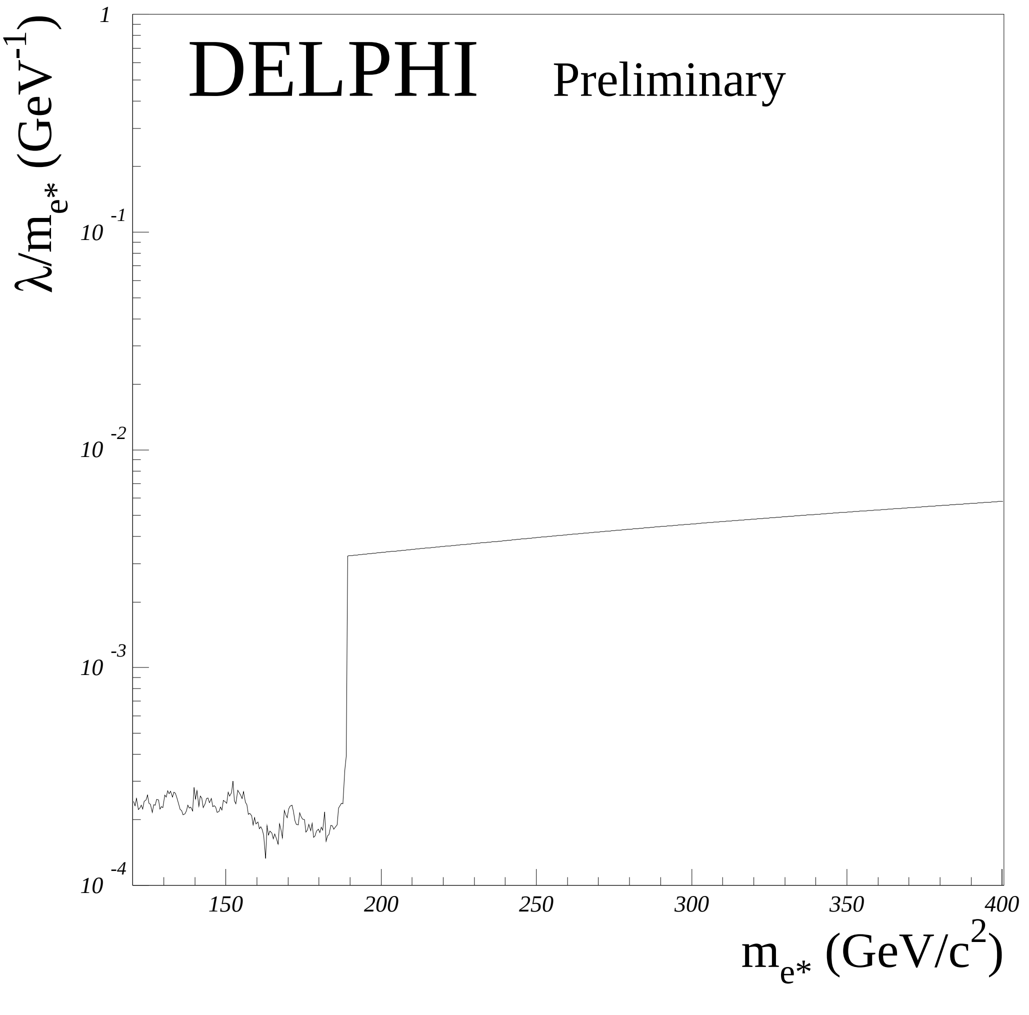



Figure 4: Combined excited electron limits for $f = f'$ from direct and indirect searches. The line shows the upper limits at 95% CL on the ratio $\lambda/m_{e^*}$ between the coupling of the excited electron and its mass as a function of the mass. Up to the kinematic limit the result is dominated by the single production direct search. Above this value the limit it is the one coming from the indirect search using $e^+e^- \to \gamma\gamma$.