EXCITED LEPTONS AND LEPTOQUARKS AT LEP

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I summarise the search for excited leptons and leptoquarks in e^+e^- collisions at centre-of-mass energies up to 202 GeV, using the data taken by the Aleph, Delphi, L3 and Opal detectors. No evidence is found for their existence. Limits at the 95% confidence level are set on the mass and the couplings.

1 Excited leptons

The existence of excited leptons would provide evidence for fermion substructure. Composite models could explain the number of families and make the fermion masses and weak mixing angles calculable [2].

The interactions of excited leptons are studied with the model described in Reference [2]. This model assumes spin 1/2, and isospin doublets with left and right handed components.

$$\mathrm{L}^* = \begin{pmatrix} \nu^* \\ \ell^* \end{pmatrix}_L + \begin{pmatrix} \nu^* \\ \ell^* \end{pmatrix}_R$$

Excited leptons can be produced in pairs or singly. Pair production, $e^+e^- \to L^*L^*$, proceeds mainly through s-channel Z/γ exchange. The coupling between a gauge boson and a pair of excited leptons is determined by their isospin and hypercharge. Therefore, the cross section for pair production depends only on the centre of mass energy, $\sqrt{s}$, and the mass of the excited lepton, m_*. In the case of single production of excited leptons, $e^+e^- \to L^*L$, the cross section also depends on the effective coupling parameters f/Λ and f'/Λ (associated with the SU(2) and U(1) gauge groups of the Standard Model) which determine the strength of the L^*LV interaction ($V = \gamma$, Z or W).

Once an excited lepton has been produced, it is expected to decay immediately into a standard lepton and a gauge boson, $L^* \to LV$. The decay fractions depend on the ratio f/f'.

The t-channel exchange of a virtual excited electron can contribute to photon pair production, $e^+e^- \to \gamma\gamma$. This process is sensitive to the existence of an excited electron with mass above the kinematical limit for single production.

Excited leptons are searched for at LEP in all the experimental topologies corresponding to the dominant decay modes [1]. In all selections, the number of observed events in data is consistent with the Standard Model expectation. From pair production searches, lower limits on the masses of excited leptons are obtained by Aleph, Delphi ($\sqrt{s} \leq 189$ GeV), L3 and Opal ($\sqrt{s} \leq 202$ GeV), as shown in Table 1. All values are close to the kinematical limit ($m_* = \sqrt{s}/2$).

Table 1. Opal and L3 95% confidence level lower mass limits for excited leptons.

L^*	95% CL Mass Limit (GeV)			
	$f = f'$		$f = -f'$	Any $\frac{f}{f'}$
	L3	OPAL	L3	L3
e^*	100.1	100.1	96.2	96.0
μ^*	100.3	100.1	96.2	96.2
τ^*	99.9	100.0	96.2	94.9
ν_e^*	99.3	99.5	99.5	98.5
ν_μ^*	99.4	99.5	99.5	98.5
ν_τ^*	93.9	91.9	99.4	92.7

Searches for single production of excited leptons are performed by Aleph ($\sqrt{s} \leq 189$ GeV), Delphi, L3 and Opal ($\sqrt{s} \leq 202$ GeV). Since no signal is found, upper limits on the coupling constant f/Λ are obtained in the

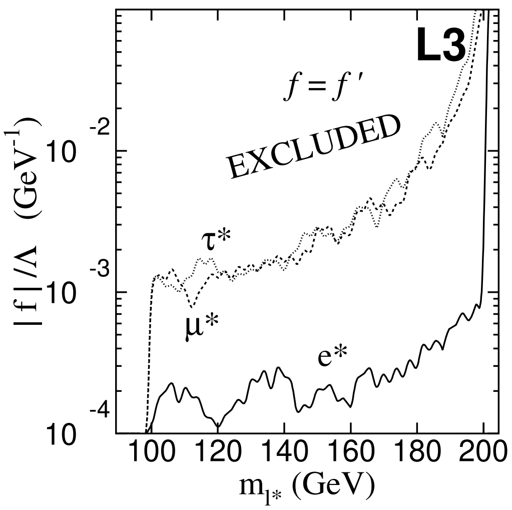

Figure 1. L3 95% confidence level upper limit on the coupling constant f/Λ, as a function of the excited lepton mass for e*, μ^* and τ^* with $f = f'$.

range from 10^{-4} GeV^{-1} to 1 GeV^{-1} as a function of the mass of the excited lepton, up to $m_* \simeq \sqrt{s}$. In Figure 1 the L3 limits on f/Λ for the case of charged excited leptons are shown. Similar limits are obtained for excited neutrinos. Upper limits to the coupling constant are obtained assuming different scenarios, $f = f'$ and $f = -f'$, and also independently from the coupling scenario.

Excited electrons are searched for indirectly, measuring the $e^+e^- \to \gamma\gamma$ differential cross section, by Aleph, L3 ($\sqrt{s} \leq 189$ GeV), Delphi and Opal ($\sqrt{s} \leq 202$ GeV), They find no significant deviation from the Standard Model. Upper limits are obtained on the coupling constant f/Λ, in the $f = f'$ scenario, in the range from 10^{-3} GeV^{-1} to 10^{-2} GeV^{-1} as a function of the mass of the excited electron, up to $m_* \simeq 400$ GeV.

2 Leptoquarks

Quarks and leptons show an apparent symmetry with respect to the family and multiplet structure of electroweak interactions. This symmetry is realised in some theories beyond the Standard Model, which predict the existence of new bosonic fields, called leptoquarks (LQs), mediating interactions between quarks and leptons [3].

These particles carry baryon and lepton number and therefore decay into a lepton and a quark. They have color, electric charge and weak isospin, and couple to the standard gauge bosons. Assuming dimensionless interactions with Standard Model fermions and gauge invariance, there could be 9 scalar states, S, and 9 vector states, V, grouped in two singlets, two doublets and a triplet of isospin. Only the mass, m_{LQ}, and the coupling to fermions, λ, remain as free parameters. Leptoquarks are searched for at the LEP e^+e^- collider [1].

Pair production, $e^+e^- \to$ LQ LQ, proceeds mainly through s-channel Z/γ exchange, Figure 2. In the case of scalar leptoquarks the coupling to gauge bosons is determined by their quantum numbers, and the cross section depends only on the centre of mass energy, $\sqrt{s}$, and the mass of the leptoquark, m_{LQ}. In the case of single production of leptoquarks, $e^+e^- \to$ e q LQ, Figure 2, the cross section also depends on the coupling between leptoquark, electron and quark. At LEP, first generation leptoquarks (coupling to fermions of the first generation) could be produced singly with mass close to the centre of mass energy, $m_{\mathrm{LQ}} \simeq \sqrt{s}$.

Once a leptoquark has been produced, it decays immediately into a lepton and a quark (provided that $\lambda > \mathcal{O}(10^{-6})$).

Pair produced leptoquarks are searched for by Delphi, L3 ($\sqrt{s} \simeq 91$ GeV) and Opal ($\sqrt{s} \leq 202$ GeV) in the three possible experimental signatures: *jet jet* ℓ ℓ, *jet jet* ℓ ν and *jet jet* ν ν. First generation singly produced leptoquarks are searched for by Aleph, L3 ($\sqrt{s} \simeq 91$ GeV), Opal ($\sqrt{s} \leq 189$ GeV) and Delphi ($\sqrt{s} \leq 202$ GeV), in the two possible experimental signatures: *jet* ℓ and *jet* (monojet). Note that in single production the leptoquark is produced in association with an electron and a quark which are lost in the

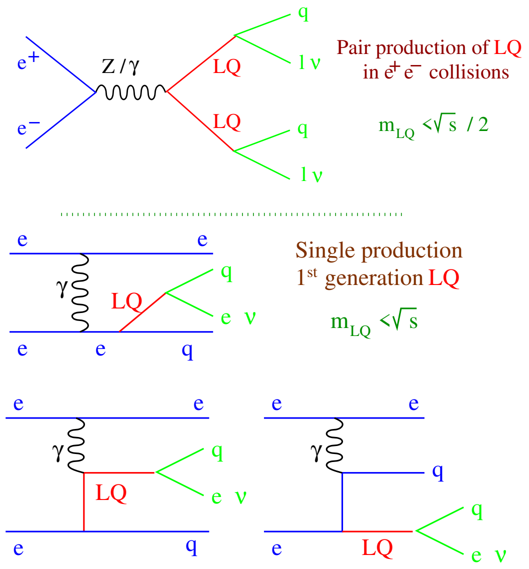

Figure 2. Feynman diagrams for leptoquark production in e^+e^- interactions.

beam pipe, and only the decay products of the leptoquark may be detected.

In all selections, the number of observed events in data is consistent with the Standard Model expectation. From pair production searches, lower mass limits on scalar leptoquarks are obtained by Opal, as shown in Table 2. From single production searches upper limits are obtained on the coupling constant λ in the range from 0.05 to 1.0 as a function of m_{LQ} up to $m_{\mathrm{LQ}} \simeq \sqrt{s}$.

Table 2. Opal 95% confidence level lower mass limits for scalar leptoquarks (GeV).

LQ	1^{st} gen.	2^{nd} gen.	3^{rd} gen.
S_0	44.2	44.2	41.4
$\tilde{S}_0$	94.7	96.4	95.2
$S_{1/2}$	88.5	88.9	89.4
	95.6	97.0	96.1
$\tilde{S}_{1/2}$	83.3	83.3	83.3
	90.5	94.6	93.1
S_1	91.7	91.7	91.7
	44.2	44.2	43.2
	96.0	97.4	96.5

The t-channel exchange of a virtual leptoquark can contribute to hadron production, $e^+e^- \to q\bar{q}$. This process is sensitive to the existence of leptoquarks with masses above the kinematical limit for single production. Aleph, Delphi, Opal ($\sqrt{s} \leq 189$ GeV) and L3 ($\sqrt{s} \leq 202$ GeV), search for leptoquarks indirectly, measuring the $e^+e^- \to q\bar{q}$ differential cross section. They find no significant deviation from the Standard Model. Assuming $\lambda = \sqrt{4\pi\alpha}$, Aleph and L3 lower bounds on leptoquark masses are shown in Table 3.

Table 3. L3 and Aleph 95% confidence level lower mass limits for leptoquarks (GeV).

Leptoquark	L3	ALEPH
$S_0(L/R)$	413 / 322	380 / 56
$\tilde{S}_0(R)$	84	128
$S_{1/2}(L/R)$	64 / 117	120 / 99
$S_1(L)$	208	319
$V_0(L/R)$	584 / 136	618 / 137
$\tilde{V}_0(R)$	288	331
$V_{1/2}(L/R)$	202 / 183	144 / 169
$\tilde{V}_{1/2}(L)$	145	105
$V_1(L)$	394	515

References

1. Opal Collab. G. Abbiendi *et al.*, Abstracts 127, 128, 151, 185, 199, 215, 236, 237 and 238;
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2. K. Hagiwara *et al.*, Z. Phys. **C29** (1985) 115.
3. M. Tanabashi, Eur. Phys. J. **C15** (2000) 294.