Excited leptons and leptoquarks at LEP

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- Excited leptons
- Leptoquarks
- Summary

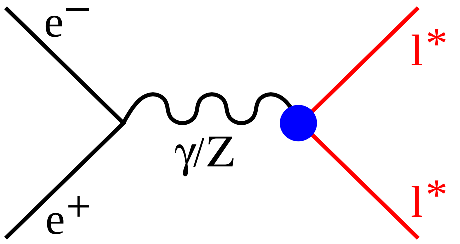
Introduction to excited leptons

- Excited fermions are expected in composite models. These models could explain the family problem and make the fermion masses calculable parameters.
- A well studied model, assumes spin 1/2, and isospin doublets with left and right handed components.

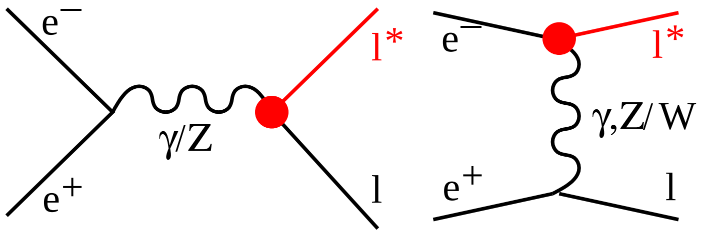
$$L^* = \begin{pmatrix} \nu^* \\ \ell^* \end{pmatrix}_L + \begin{pmatrix} \nu^* \\ \ell^* \end{pmatrix}_R$$

- They can be produced in pairs or singly.

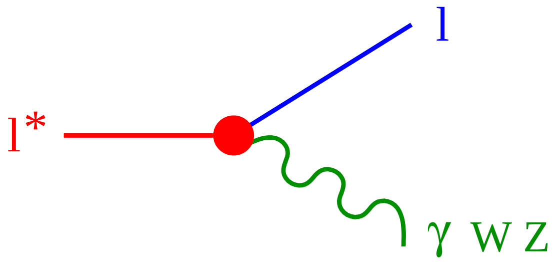
Pair production



Single production



- The cross section for pair production is determined by the charge and the isospin. It depends only on $\sqrt{s}$ and m_*.
- The cross section for single production depends on the effective couplings f and f' and m_*.
- An excited lepton decays immediately into a standard lepton plus a gauge boson (γ, W or Z).



Pair produced excited leptons have been extensively searched for in LEP, in many different signatures, corresponding to the dominant decay modes.

$\sqrt{s} \sim 200$ GeV	L3		OPAL	
Signal	Data	SM	Data	SM
$e^*e^* \rightarrow e\gamma e\gamma$	1	0.8	2	1.4
$\mu^*\mu^* \rightarrow \mu\gamma\mu\gamma$	1	0.5	0	0.7
$\tau^*\tau^* \rightarrow \tau\gamma\tau\gamma$	0	0.2	3	2.6

Data and SM expectation always agrees $\Longrightarrow$

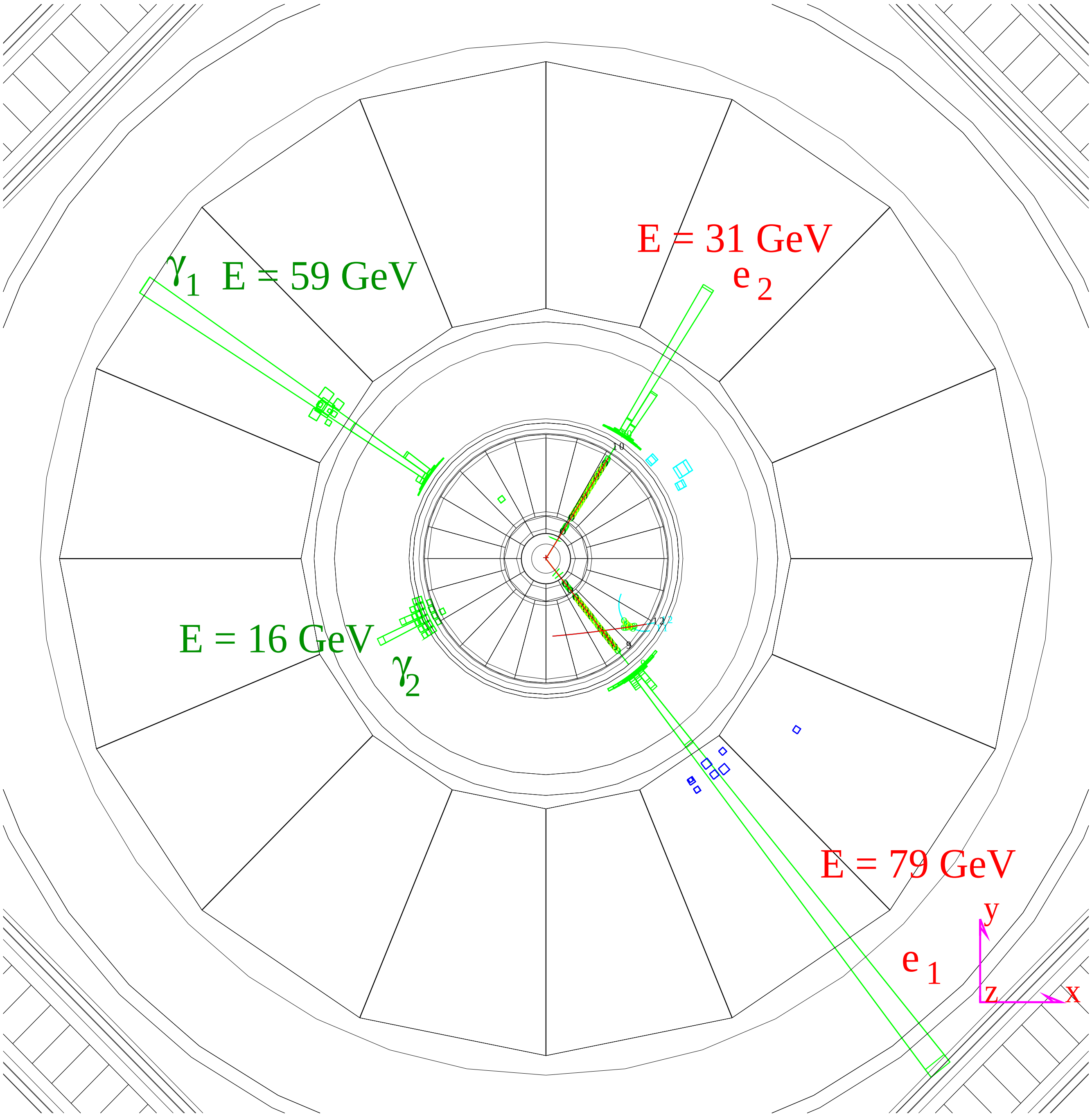
lower mass limits are set

Excited Lepton	95% CL Mass Limit (GeV)			
	$f = f'$		$f = -f'$	Coup. Indep.
	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

Candidate to e^*e^* production. L3 $\sqrt{s}$ = 200 GeV

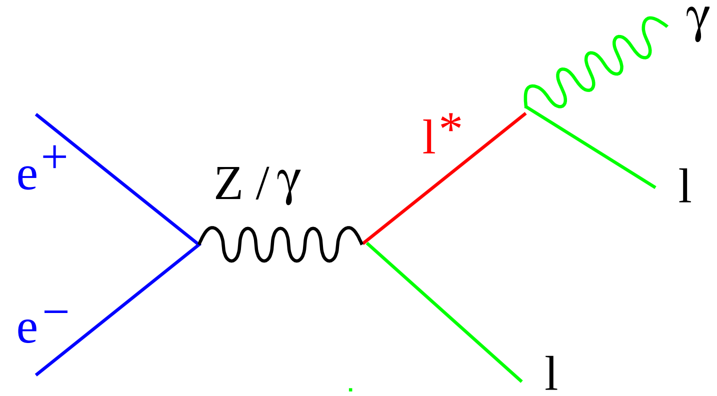
$m(e_1, \gamma_2) = 60$ GeV $\quad$ $m(e_2, \gamma_1) = 59$ GeV

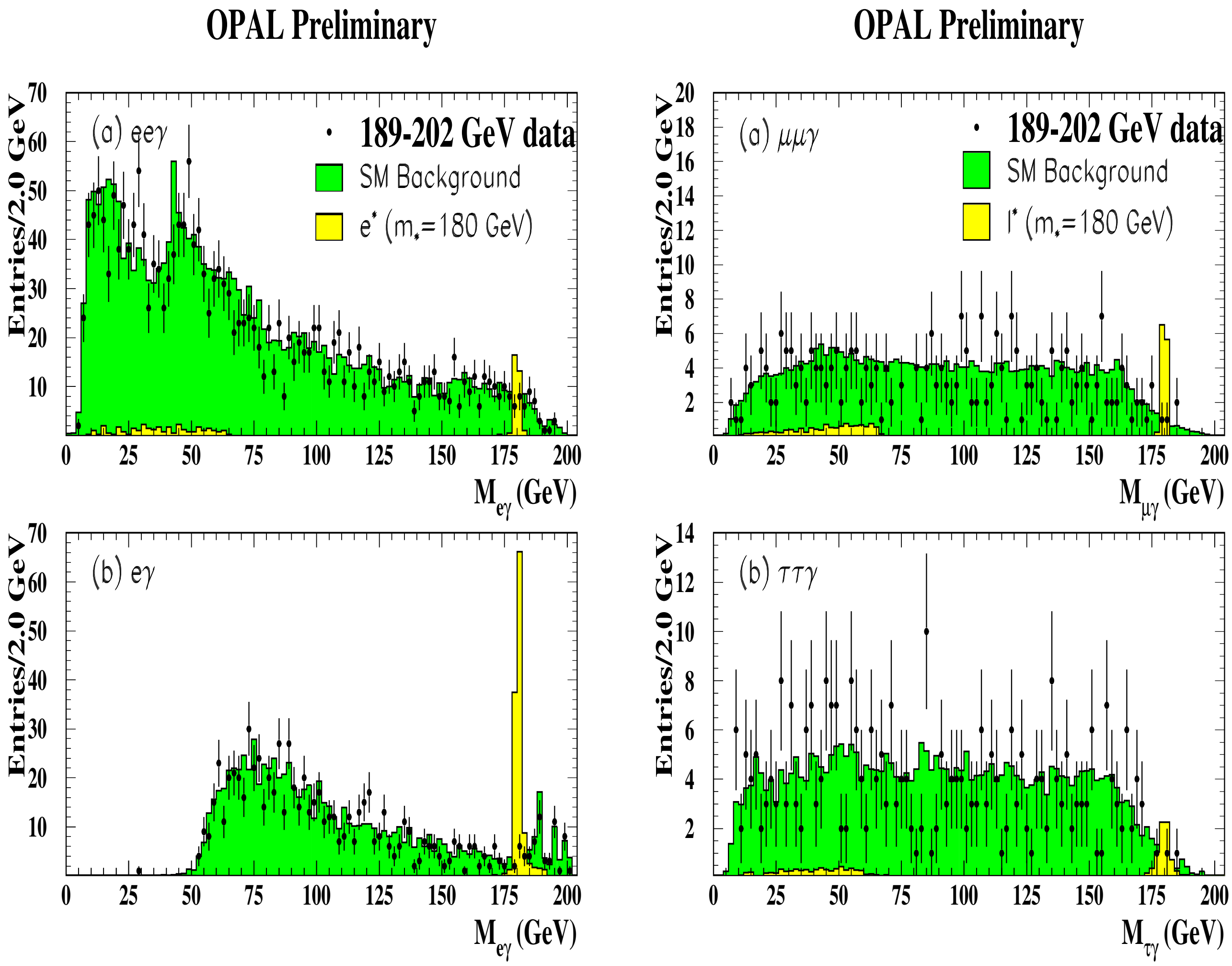
Run # 772501 Event # 3103 Total Energy : 185 GeV



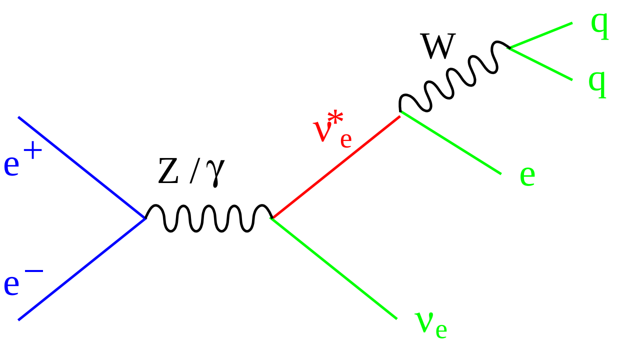
Single production of excited leptons

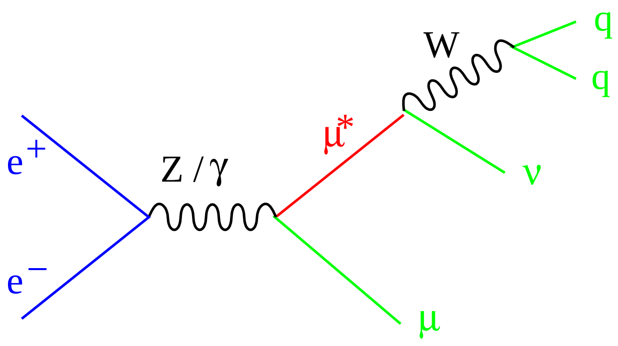
Experimental distributions from the $\ell\ell\gamma$ selection

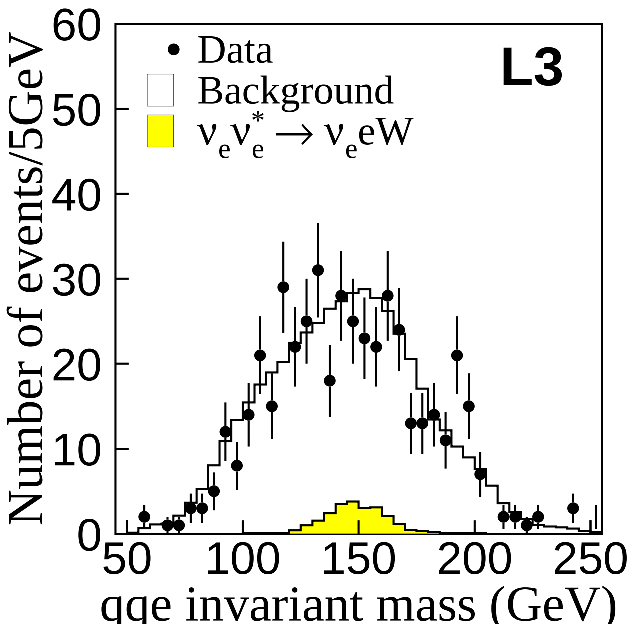


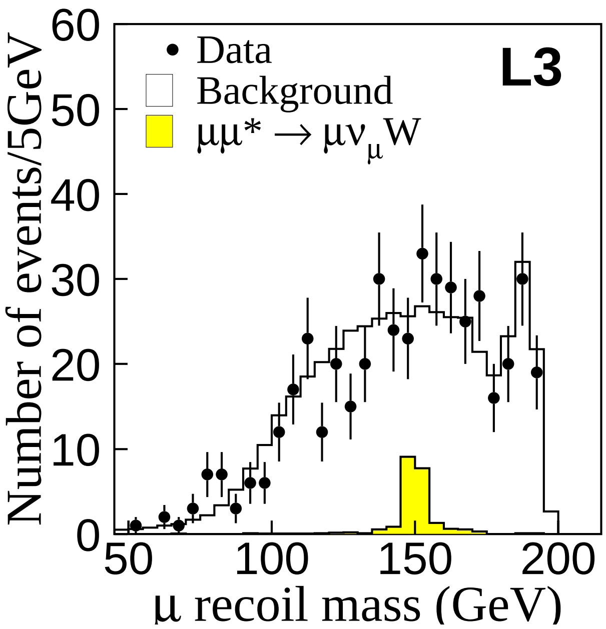


Experimental distributions from the $\ell\nu$W selection





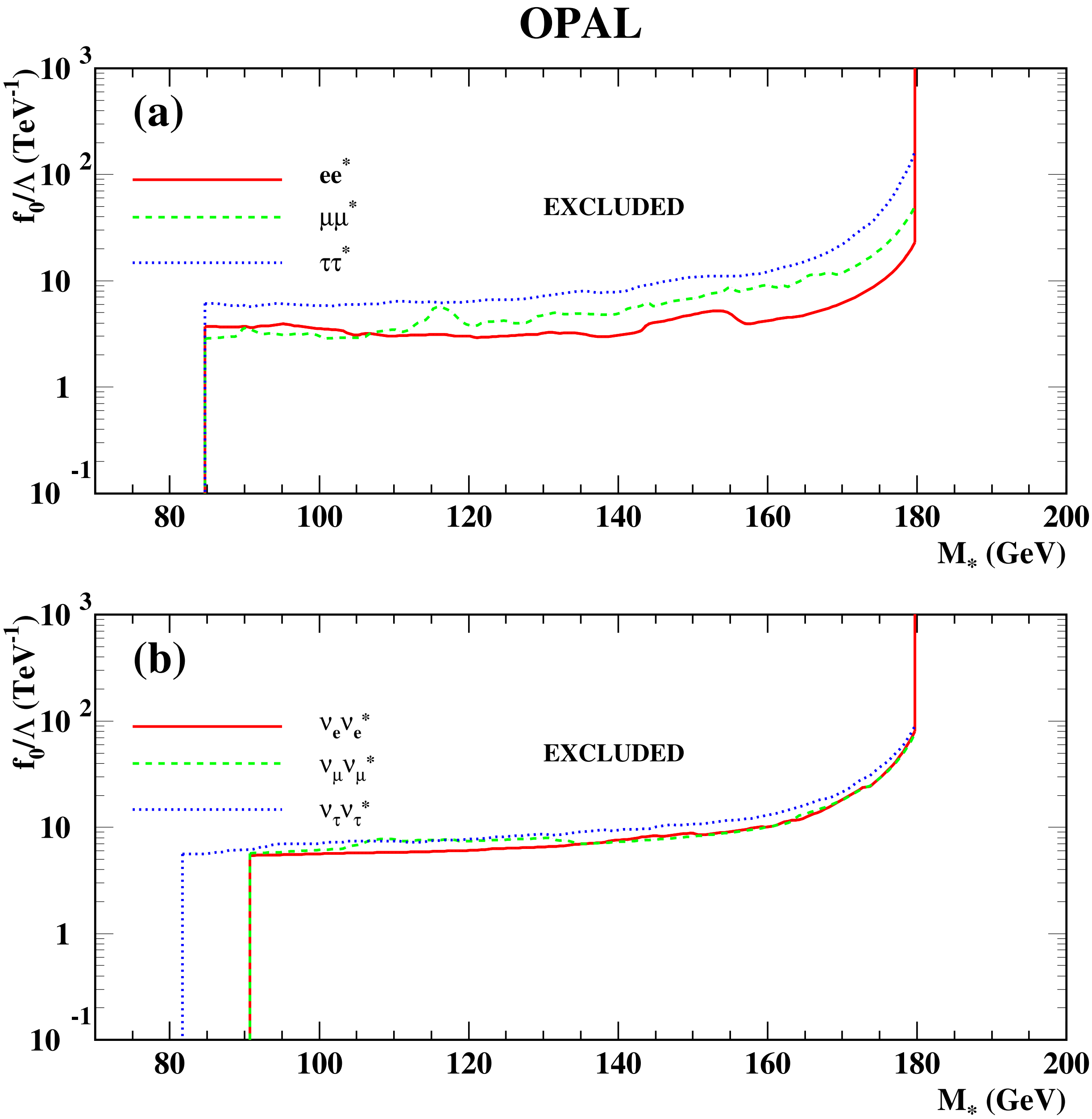




FROM SINGLE PRODUCTION SEARCHES

No excess in data is seen

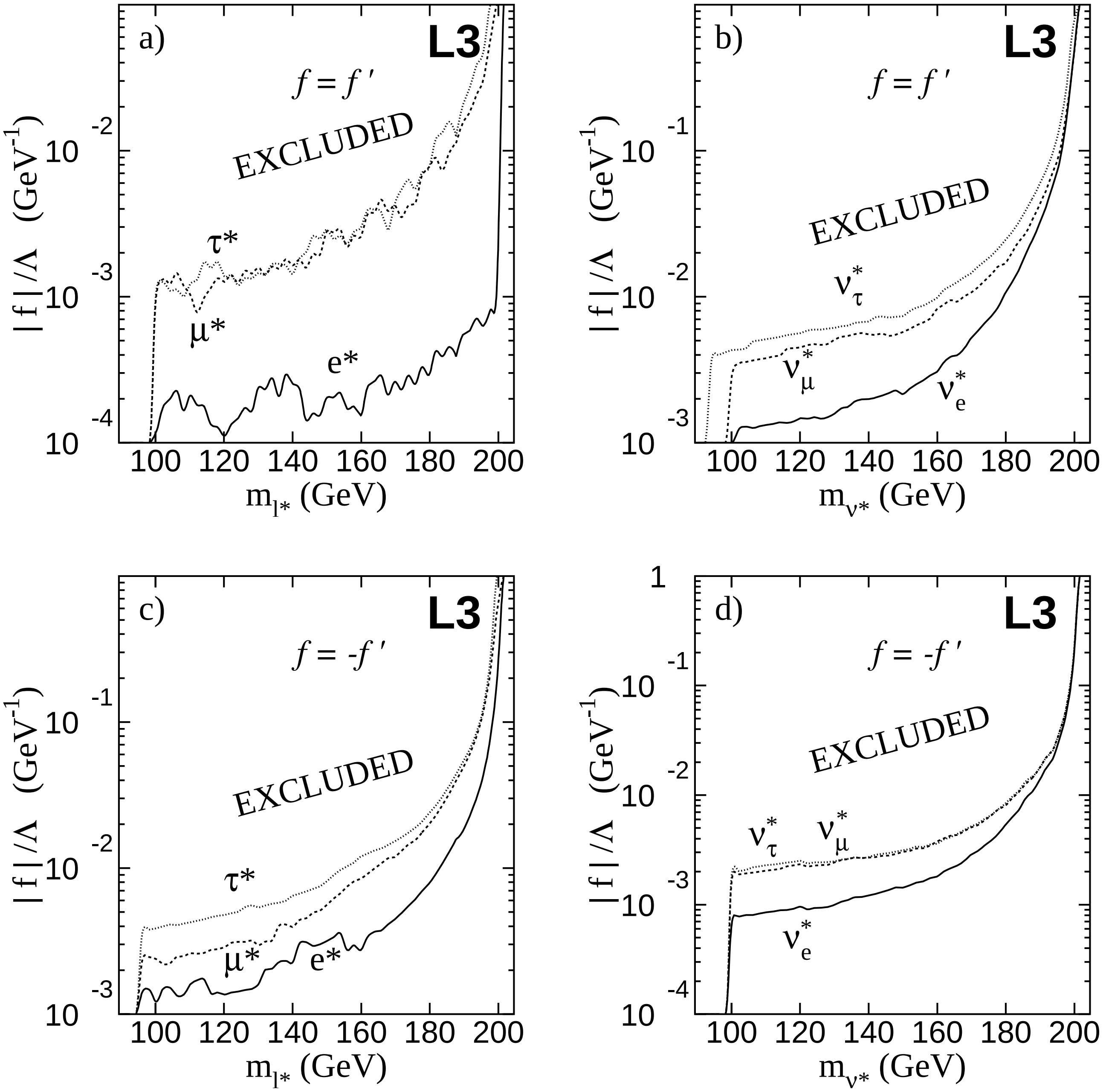
Limits are derived on $f_0/\Lambda = \sqrt{(f^2 + f'^2)/2}/\Lambda$ independently of the coupling assumption f/f'



(From data at $\sqrt{s} = 161 - 183$ GeV)

Limits to excited leptons

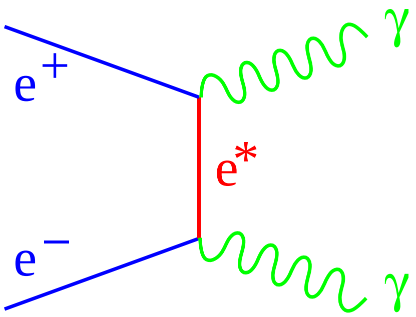
Including data at higher energies (192 – 202 GeV) and considering two particular scenarios ($f = f'$ and $f = -f'$) improved limits are derived on the coupling constant f/Λ



Similar limits are derived by DELPHI and OPAL

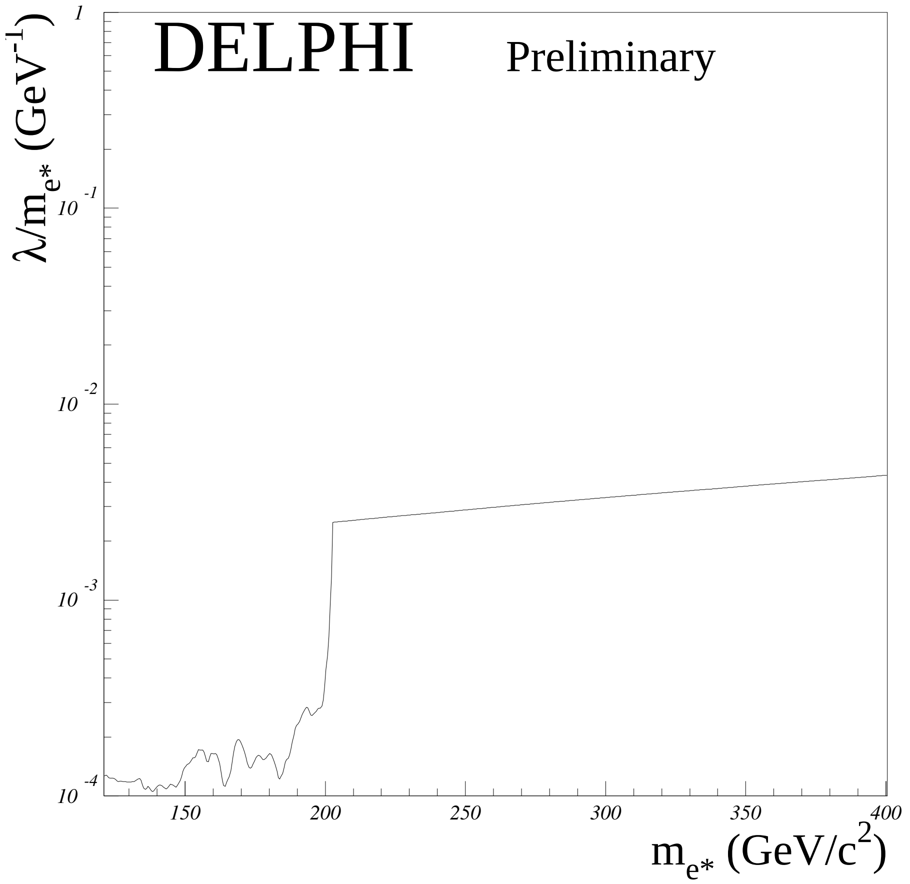
Indirect search for e*

The search for excited electrons is extended above the kinematical limit for single production $(m_* = \sqrt{s})$



Assuming the coupling strength of the $e^*e\gamma$ vertex equal to the standard $ee\gamma$ vertex, a mass limit to e^* is derived from the differential cross section for the process $e^+e^- \to \gamma\gamma(\gamma)$

OPAL $\sigma(e^+e^- \to \gamma\gamma(\gamma)) \Longrightarrow m_* > 316$ GeV at 95% C.L.

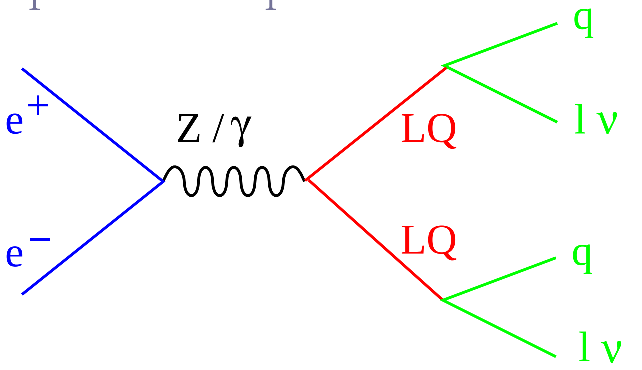


$(\sqrt{2}\lambda/m_* = f/\Lambda)$

Leptoquarks are new bosonic fields which mediate interaction between quark and leptons. They carry baryon and lepton number and therefore decay into a pair lepton - quark.

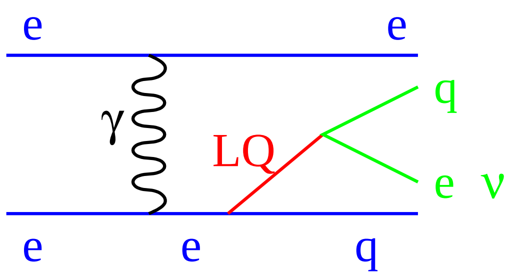
They have color, electric charge and weak isospin, and therefore couple to the standard gauge bosons.

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.



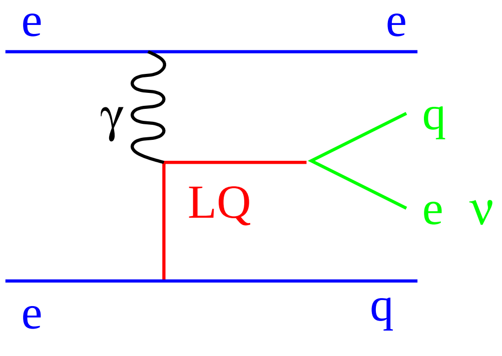
Pair production of LQ in e^+e^- collisions

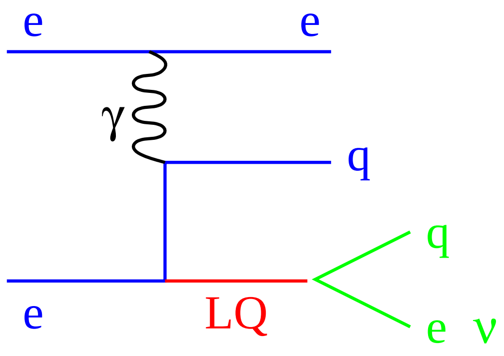
$m_{LQ} < \sqrt{s}/2$



Single production 1^{st} generation LQ

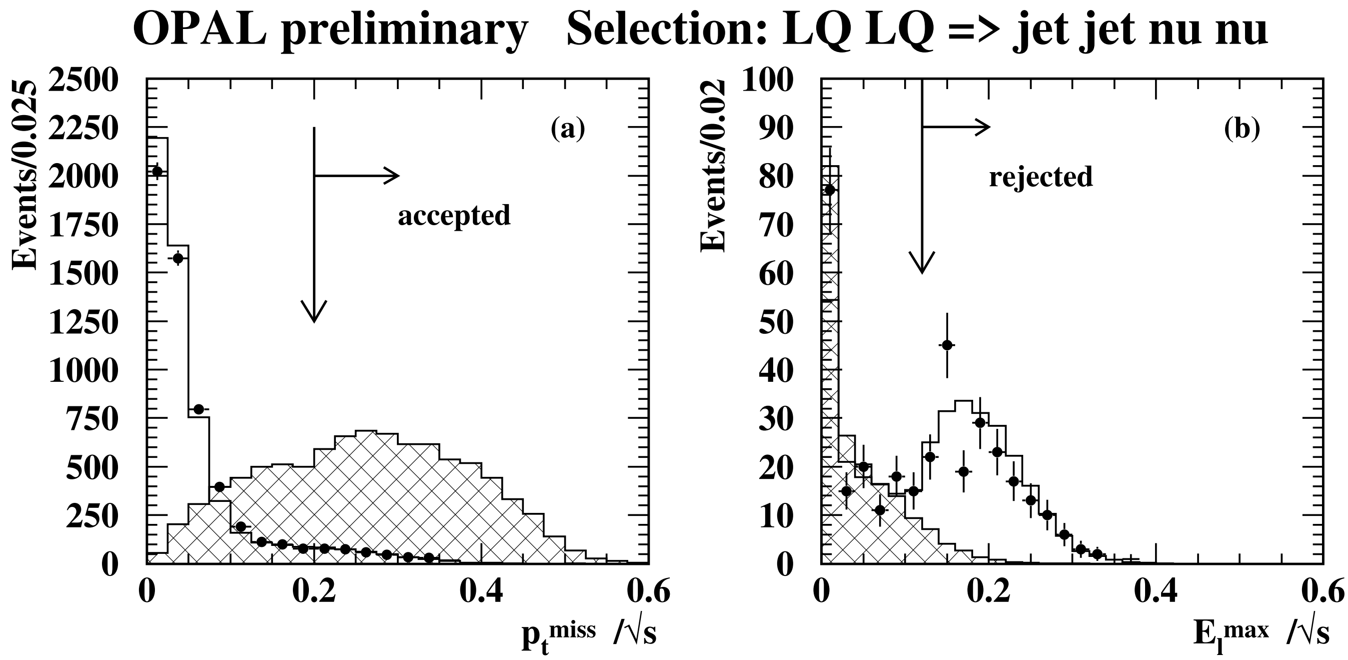
$m_{LQ} < \sqrt{s}$





Pair production of leptoquarks

Pair produced leptoquarks have been searched for in the Opal experiment at $\sqrt{s} = 189 - 202$ GeV in all their decay channels



No excess in Data $\Longrightarrow$ Mass limits are set on scalar leptoquarks

95% C.L. Mass limits (GeV)

LQ	Q_{em}	$Br(\mathrm{LQ} \to \ell q)$	1^{st} gen.	2^{nd} gen.	3^{rd} gen.
S_0	$-1/3$	[0.5,1.]	44.2*	44.2*	41.4*
$\tilde{S}_0$	$-4/3$	1.	94.7	96.4	95.2
$S_{1/2}$	$-2/3$	[0., 1.]	88.5	88.9	89.4
	$-5/3$	1.	95.6	97.0	96.1
$\tilde{S}_{1/2}$	$1/3$	0.	83.3	83.3	83.3
	$-2/3$	1.	90.5	94.6	93.1
S_1	$2/3$	0.	91.7	91.7	91.7
	$-1/3$	0.5	44.2*	44.2*	43.2*
	$-4/3$	1.	96.0	97.4	96.5

(*) Limits from LEP1

Single production of leptoquarks

Singly produced leptoquarks have been searched for in the Opal (189 GeV) and Delphi (192 − 202 GeV) experiments.

	OPAL		DELPHI	
Signal	Data	SM	Data	SM
$e^+e^- \to e\ q\ LQ \to e\ q\ e\ q$	21	22	6	6
$e^+e^- \to e\ q\ LQ \to e\ q\ \nu\ q$	7	9	5	4

No excess in Data $\Longrightarrow$

assuming coupling parameter to fermions $\lambda = \sqrt{4\pi\alpha_{em}}$

mass limits are set on first generation scalar and vector leptoquarks

95% C.L. Mass limits (GeV) on scalar LQ

Leptoquark	Q_{em}	$Br(LQ \to \ell q)$	OPAL	DELPHI
S_0	$-1/3$	0.5	158	180
		1.	163	180
$\tilde{S}_0$	$-4/3$	1.	149	158
$S_{1/2}$	$-2/3$	1.	121	155
	$-5/3$	1.	164	180
$\tilde{S}_{1/2}$	$1/3$	0.		
	$-2/3$	1.	121	155
S_1	$2/3$	0.		
	$-1/3$	0.5	158	180
	$-4/3$	1.	156	158

- Lower mass limits are also set on vector leptoquarks

95% C.L. Mass limits (GeV) on vector LQ

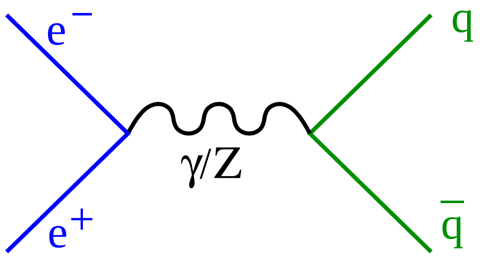
Leptoquark	Q_{em}	$Br(\mathrm{LQ} \to \ell \mathrm{q})$	OPAL	DELPHI
$\mathrm{V}_{1/2}$	$-1/3$	1.	176	188
	$-4/3$	1.	152	168
$\tilde{\mathrm{V}}_{1/2}$	$2/3$	0.		
	$-1/3$	1.	176	188
V_0	$-2/3$	0.5	149	171
		1.	151	170
$\tilde{\mathrm{V}}_0$	$-5/3$	1.	177	185
V_1	$1/3$	0.		
	$-2/3$	0.5	149	171
	$-5/3$	1.	182	185

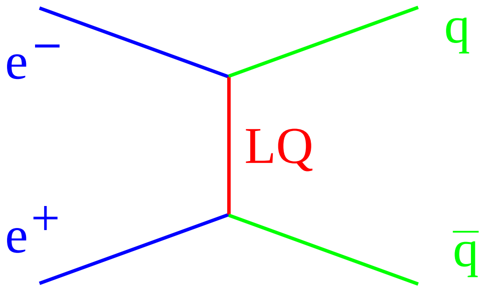
Indirect search for leptoquarks

The study of $\sigma(e^+e^-) \rightarrow q\bar{q}$ extends the sensitivity to leptoquarks above the kinematical limit for single production $(m_{LQ} = \sqrt{s})$

The t-channel LQ exchange diagrams would be an additional contribution to hadron production in LEP

SM hadron production





Assuming coupling parameter to fermions $\lambda = \sqrt{4\pi\alpha_{em}}$
mass limits are set on scalar and vector leptoquarks

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

Summary

- Excited leptons and leptoquarks have been searched for in pair production, single production and indirectly at LEP.

- No evidence for their existence has been found.

- From pair production searches, lower limits on the mass of excited leptons and leptoquarks have been set at the 95% confidence level.

- From single production and indirect searches upper limits to the couplings as a function of the mass have been derived.

- With the current LEP run at $\sqrt{s} = 208$ GeV the range of discovery potential has been extended around 3 GeV for pair production and 6 GeV for single production.
  In case no signal appears, limits will improved.