Search for Heavy and Excited Fermions at $\sqrt{s}$ = 183-189 GeV at LEP2

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Representing the LEP Collaborations

Recontres de Moriond, March 17, 1999

Extensions of the Standard Model

It is widely believed that Standard Model, although extremely successful at the present energy scale, is not the final Theory.

There are two basic approaches for the extension of the Standard Model:

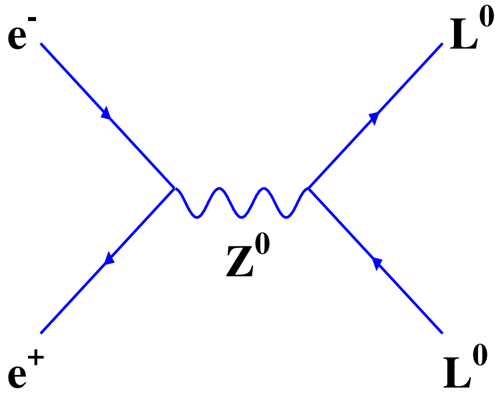
- Enlarge the symmetries : SUSY, Strings, GUT models (E_6, SO(10))
  - new supersymmetric particles
  - new heavy fermions
  - new gauge boson Z'
- Go to a deeper level of elementaries : composite models
  - excited fermions
  - contact terms

Outline

Search for :

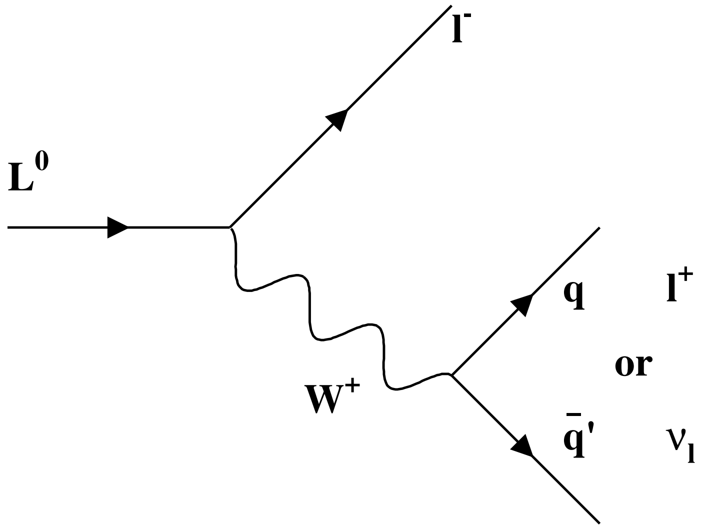
- Unstable Sequential Leptons
- Stable Charged Sequential Leptons
- Singlet Heavy Neutrino
- Excited Leptons
- Excited Quarks

3 Unstable Neutral Heavy Sequential Lepton



Decay Modes:

$L^0 \rightarrow l^{\mp}(e, \mu, \tau) W^{\pm}$



Mixing (coupling) with ν_e, ν_μ, ν_τ large enough for short decay path:

$$L_{decay} = \beta\gamma c\tau_{L^0} \sim\mid U_\ell \mid^{-2} M_{L^0}^{-6} \leq 1 \text{ cm} \Rightarrow$$

$$\mid U_\ell \mid^2 > \mathcal{O}(10^{-12}) \text{ for } M_{L^0} \approx \text{80-90 GeV}$$

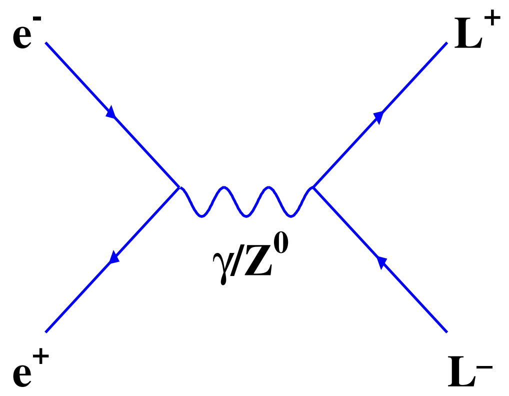
Signature :

Isolated energetic leptons

Isolated tracks

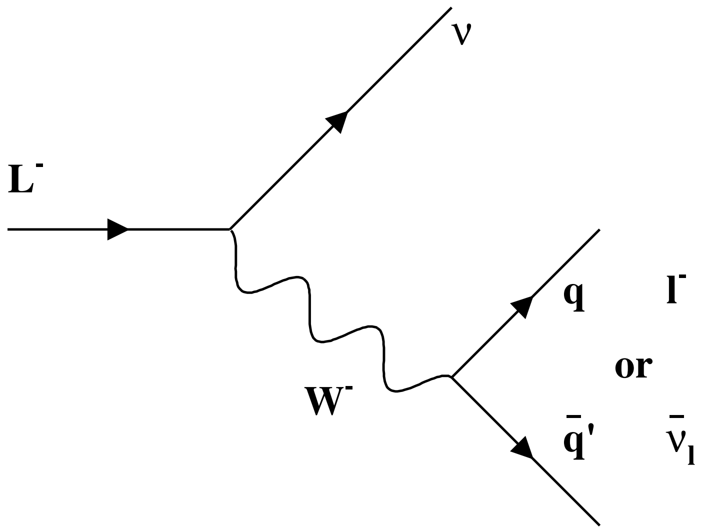
Large hadronic activity

Unstable Charged Heavy Sequential Lepton



Decay Modes :

$L^- \rightarrow \nu W^-$



Signature:

- Missing energy
- Momentum imbalance
- Isolated lepton plus jets

Severe background from WW process

Unstable Heavy Sequential Leptons

$$\sqrt{s} \; = \; 189 \; GeV$$

L3: Integrated Luminosity = 176 pb^{-1}

Number of candidates and expected background:

Channel	Data	Background	Efficiency
$L^0 \to e^\pm W^\mp$	6	7.2	$\sim$ 34%
$L^0 \to \mu^\pm W^\mp$	1	1.2	$\sim$ 32%
$L^0 \to \tau^\pm W^\mp$	33	32.3	$\sim$ 17-24%

Channel	Data	Background	Efficiency
$L^\pm \to \nu W^\mp$	71	76.5	$\sim$ 18%

Good agreement between the number of candidates and expected background

- Similar analysis by OPAL gives no excess

Unstable Heavy Sequential Leptons

95% C.L. Lower Mass Limits in GeV/c^2

Neutral Heavy Lepton (Dirac type)

Decay mode	L3 161-189 GeV	OPAL 183-189 GeV	DELPHI 183 GeV
$L^0 \to e$W	92.4	93.4	76.5
$L^0 \to \mu$W	93.3	92.9	79.5
$L^0 \to \tau$W	83.3	80.1	60.5

Neutral Heavy Lepton (Majorana type)

$L^0 \to e$W	81.8	84.9
$L^0 \to \mu$W	84.1	83.4
$L^0 \to \tau$W	73.5	62.6

Unstable Charged Heavy Lepton

$L^\pm \to \nu_\ell W^\mp$	92.4	91.3*	78.3

* - 40 pb^{-1} of data collected at $\sqrt{s} = 189\ GeV$ were analyzed

Stable Charged Heavy Sequential Lepton

Search strategy:

- Pair production of new stable charged heavy leptons would appear as two back to back charged tracks in the detector.
- If $m_{L^\pm}$ close to E_{beam} $\Longrightarrow$ small kinetic energy $\Longrightarrow$ $L^\pm$ tracks with large dE/dx
- dE/dx information from tracking chamber is used to search for stable charged heavy lepton

No signal found at $\sqrt{s} = 183 - 189\ GeV$

	L3	OPAL
$L^\pm$-Stable/Long-lived	93.5	92.6*

* - 40 pb^{-1} of data collected at $\sqrt{s} = 189\ GeV$ were analyzed

Singlet Heavy Neutrino

Why?

- Isosinglet Neutral Heavy Leptons corresponding to right-handed neutrinos arise in many extensions of the Standard Model such as Grand Unified or Superstring Models

- No good theoretical basis for the absence of right-handed neutrino in the Standard Model

$$\text{SM}\quad \begin{array}{lllll} & \begin{pmatrix} e \\ \nu_e \end{pmatrix}_L & \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}_L & \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}_L & \text{isodoublets} \\ & e_R & \mu_R & \tau_R & \text{isosinglets} \\ ? & N_e & N_\mu & N_\tau & \text{New isosinglet} \end{array}$$

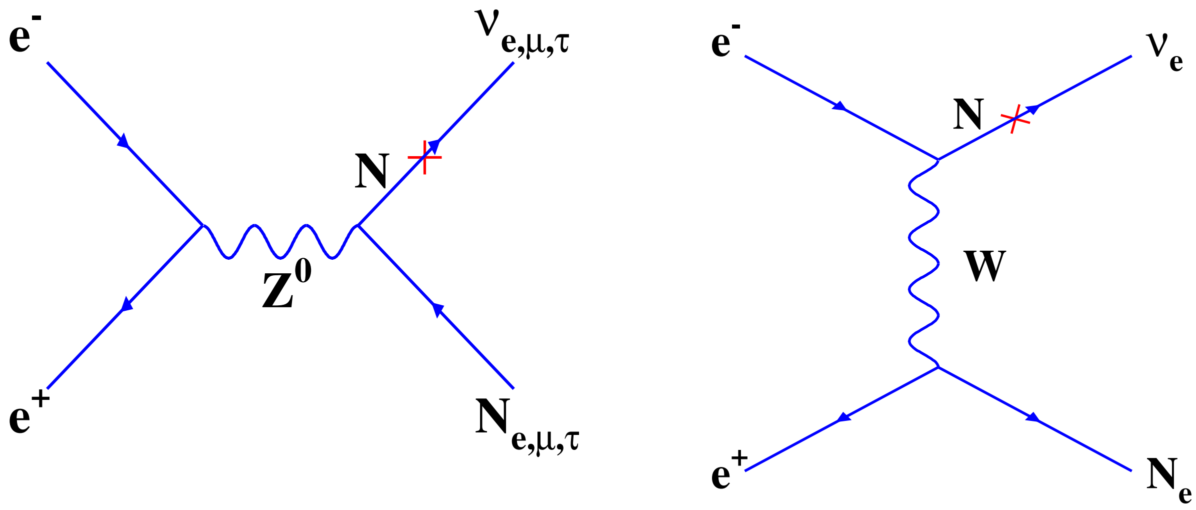
- Limits on the possible existence of such particles are still rather poor, especially for high masses

- One INHL is assumed to be associated with each generation of light neutrinos

Singlet Heavy Neutrino

PRODUCTION :

- Isosinglet Neutral Heavy Leptons (INHL) are produced via their mixing with the standard neutrinos. Main production mode is single production $\propto |U|^2$ ($\longrightarrow$ search up to M_Z)
  Pair production $\propto |U|^4 \Longrightarrow$ suppressed



- Additional contribution to the production cross section from t-channel diagram for first generation
  $\sigma_t(m_N) \approx 50 \times \sigma_s(m_N)$

- Cross section for the second and third generations are below observable level at LEP2 $\Longrightarrow$ study only the first generation case
  $\sigma_t \approx 0.24pb\ for\ m_N = 140\ GeV\ and\ |U|^2 = 0.01$
  W. Buchmuller and C. Greub, Nucl. Phys. B363 (1991) 345.

Singlet Heavy Neutrino

- Decays:

  $N_e \rightarrow e + W$

  $N_e \rightarrow \nu + Z$

- The dominant and most clean decay channel

  $N_e \rightarrow e + 2\ jets$

  Branching ratio $\approx$ 45-60%

- Invariant mass reconstruction, m$_N$ is possible

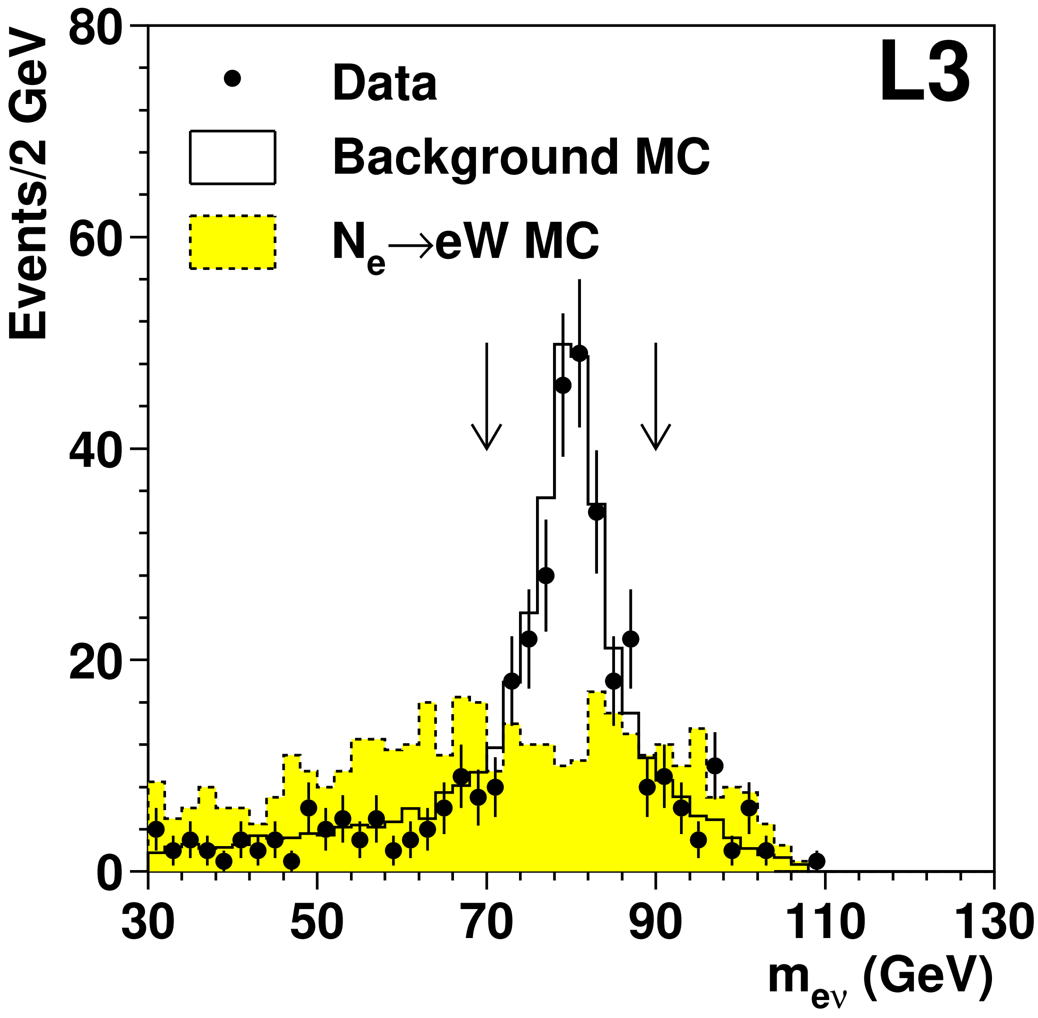
- Events are selected by requring an isolated electron plus hadronic activity

- Main background is WW production

- All LEP2 data are used in the analysis, $\sqrt{s} = 161 - 189\ GeV$

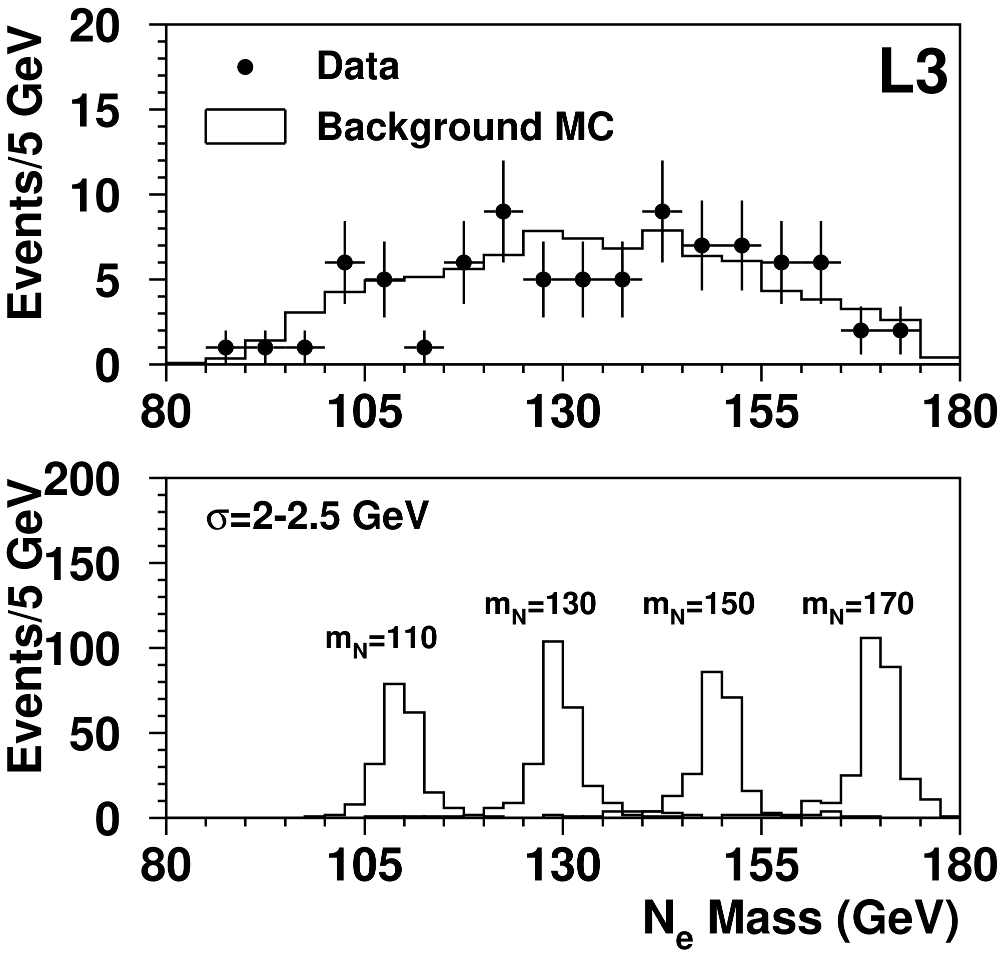
Singlet Heavy Neutrino

- To reject WW background we require that invariant mass of an electron and missing momentum is inconsistent with W mass
- Apply kinematical fit to improve the resolution



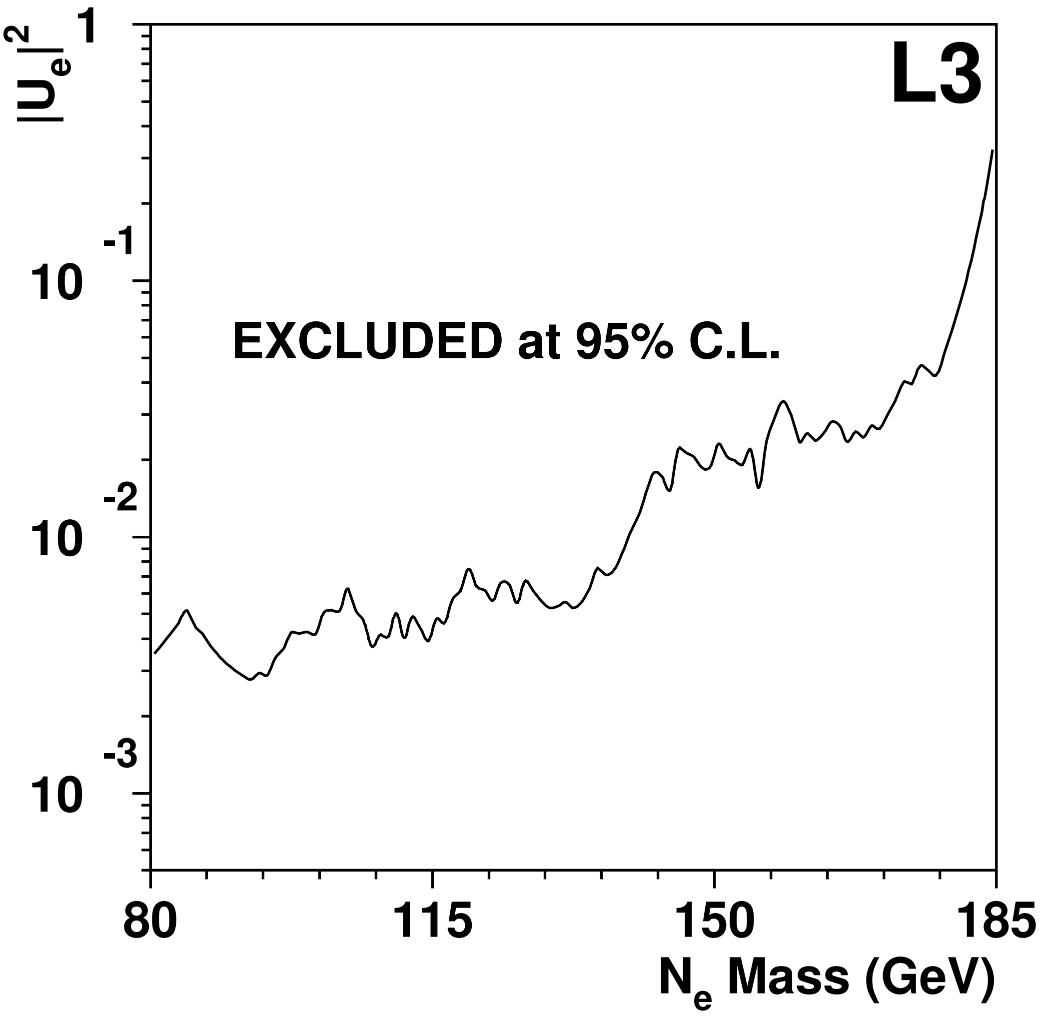
Singlet Heavy Neutrino

- No signal - good agreement beetween data and expected background
- Selection efficiency $\sim$ 30-40%
- To set a limit on the coupling constant, $|U_e|^2$, as a function of mass, use the number of events in data and expected background in mass range m $\pm$ 2σ_m



Singlet Heavy Neutrino

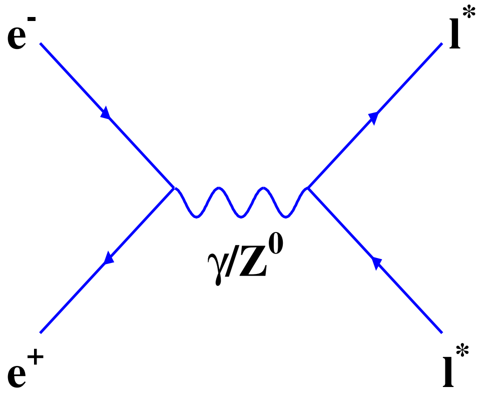
95% C.L. Upper Limits on Coupling Constant $|U_e|^2$



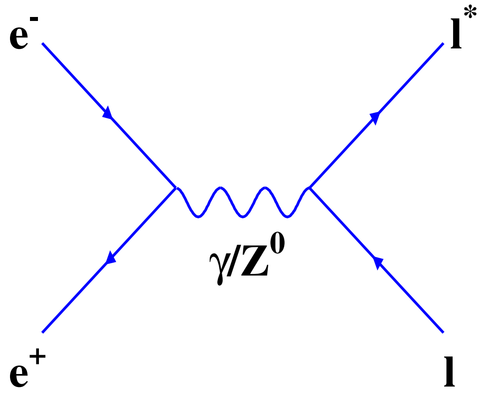
These limits are the first results for the masses of singlet heavy neutrino $\geq$ 80 GeV

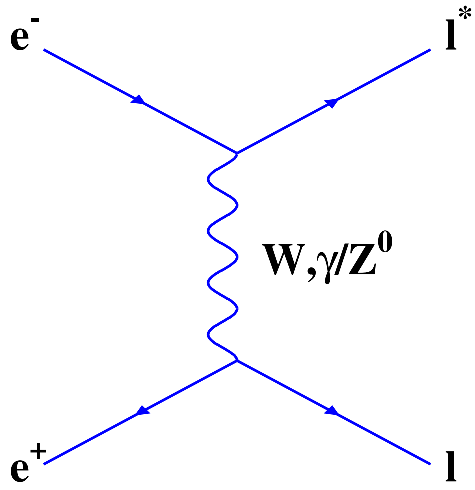
Excited Leptons

- Pair Production
  - e^*, μ^*, τ^* via s-channel $\gamma - Z$



- Single Production
  - $\mu\mu^*$, $\tau\tau^*$ via s-channel $\gamma - Z$
  - ee^* via s and t-channel $\gamma - Z$
  - Single production rates are suppressed by a factor of $1/\Lambda^2$

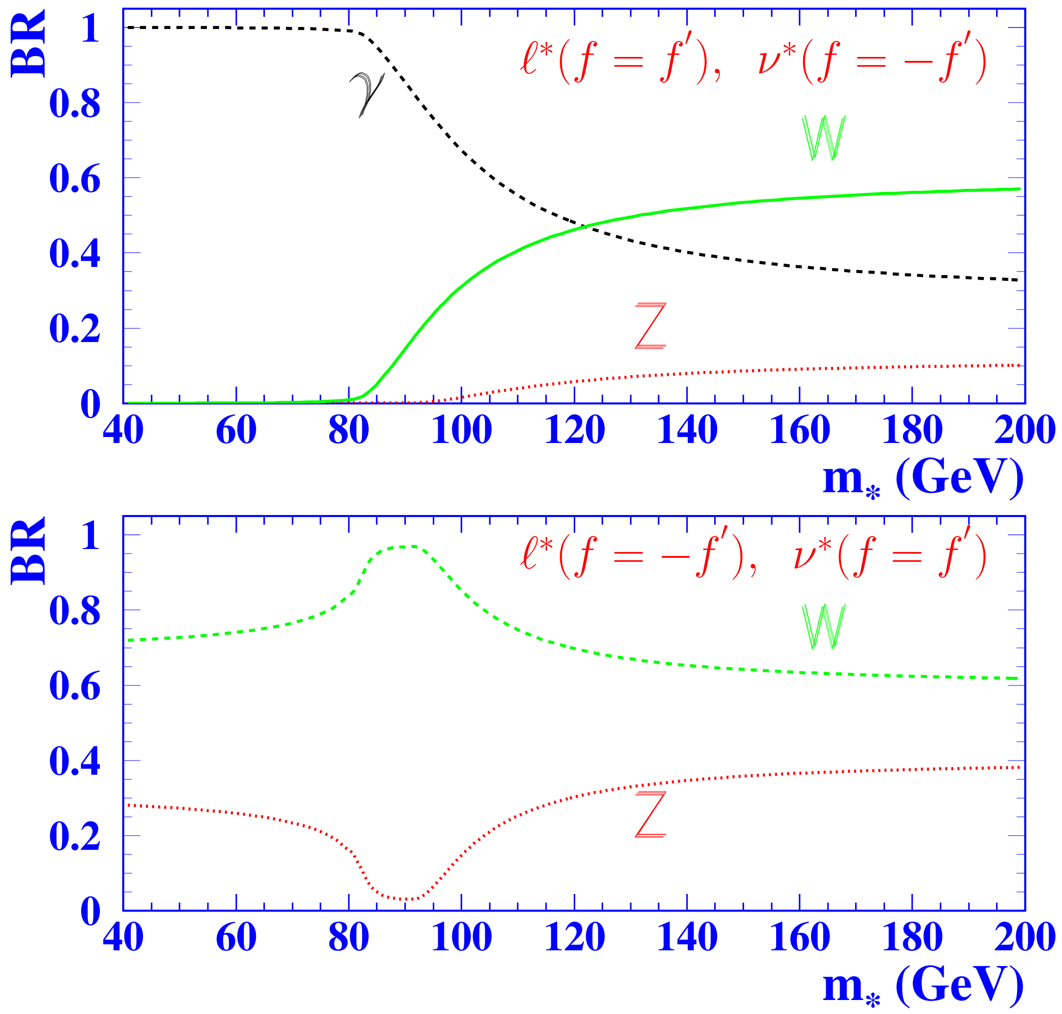




Excited Leptons

Decays of Excited Leptons

$$\mathcal{L}_{\ell^*\ell} = \frac{1}{2\Lambda}\bar{\ell}^*\sigma^{\mu\nu}[g f \frac{\tau}{2} W_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu}]\ l_L$$



Branching ratios depend on gauge group weights f, f'

Common settings: $f = f'$ and $f = -f'$

Pair Production of Excited Leptons

CC Decays: $\ell^*\ell^* \to \nu\nu WW \quad (f = -f')$

$\nu^*\nu^* \to \ell\ell WW \quad (f = f')$

γ Decays: $\ell^*\ell^* \to \ell\ell\gamma\gamma \quad (f = f')$

$\nu^*\nu^* \to \nu_\ell\nu_\ell\gamma\gamma \quad (f = -f')$

No signal was found

95% C.L. Lower Mass Limits in GeV/c^2

Type	Coupling	Decay	L3 189	OPAL 183 + 189*	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	92.4	92.8	87.3
ν_μ^*	$f = f'$	Charged	92.3	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

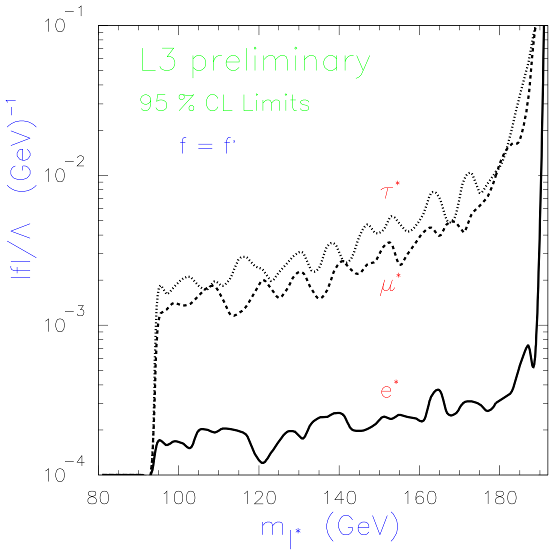
* - 40 pb^{-1} of data collected at 189 GeV were analyzed

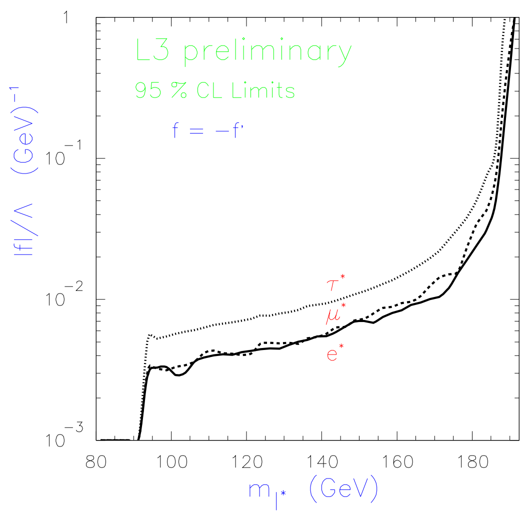
Single Production of Excited Leptons

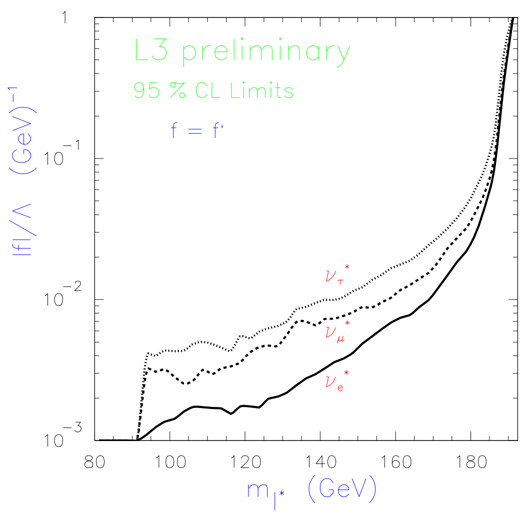
Upper Limits on f/Λ as a function of mass

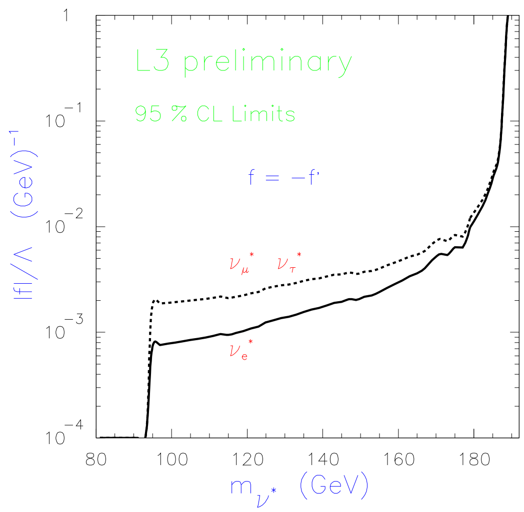
$\sqrt{s} = 189\ GeV$

L3 preliminary







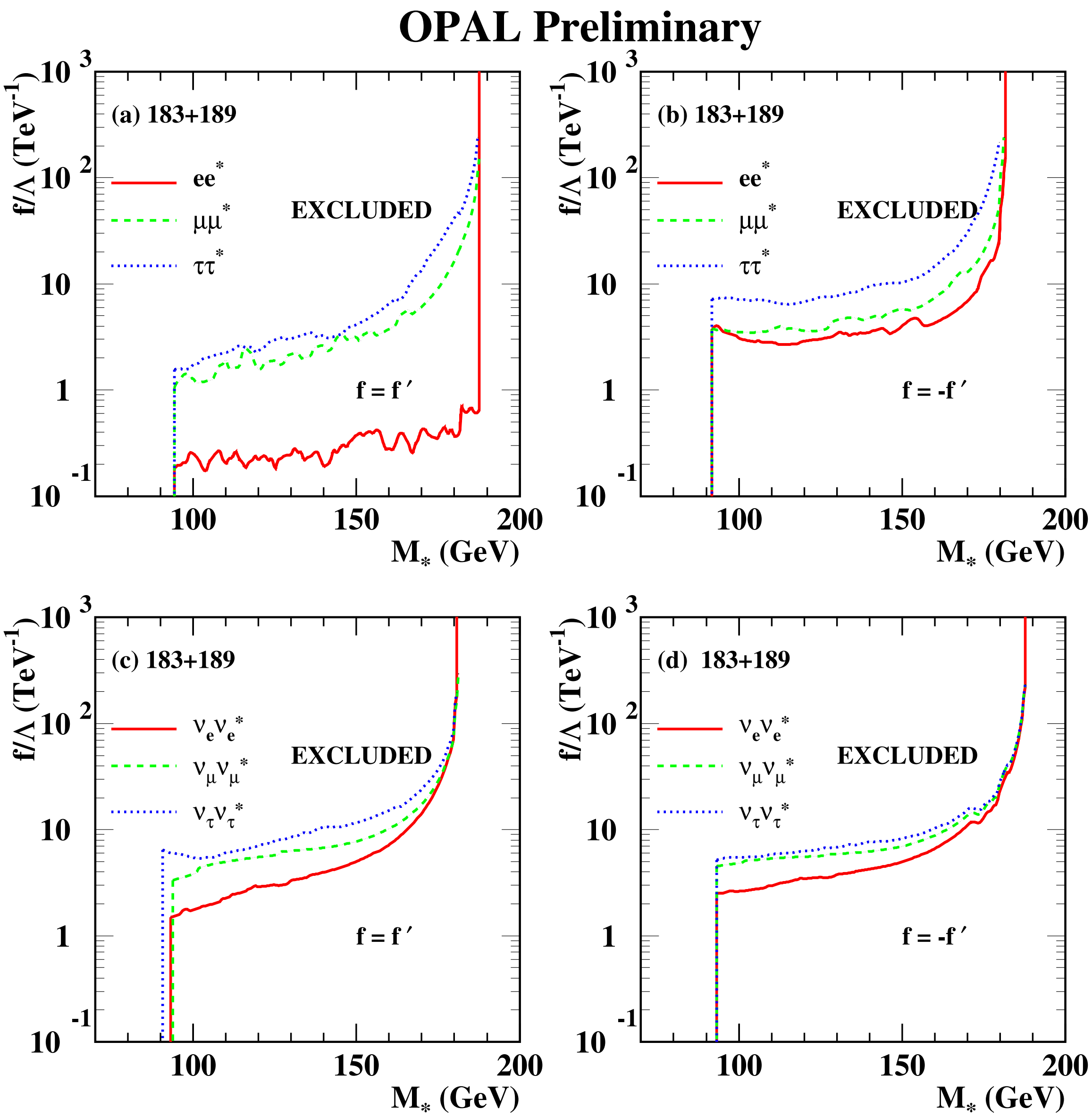


Single Production of Excited Leptons

Upper Limits on f/Λ as a function of mass

$$\sqrt{s} = 183 - 189\ GeV^*$$

* - 40 pb^{-1} of data collected at 189 GeV were analyzed



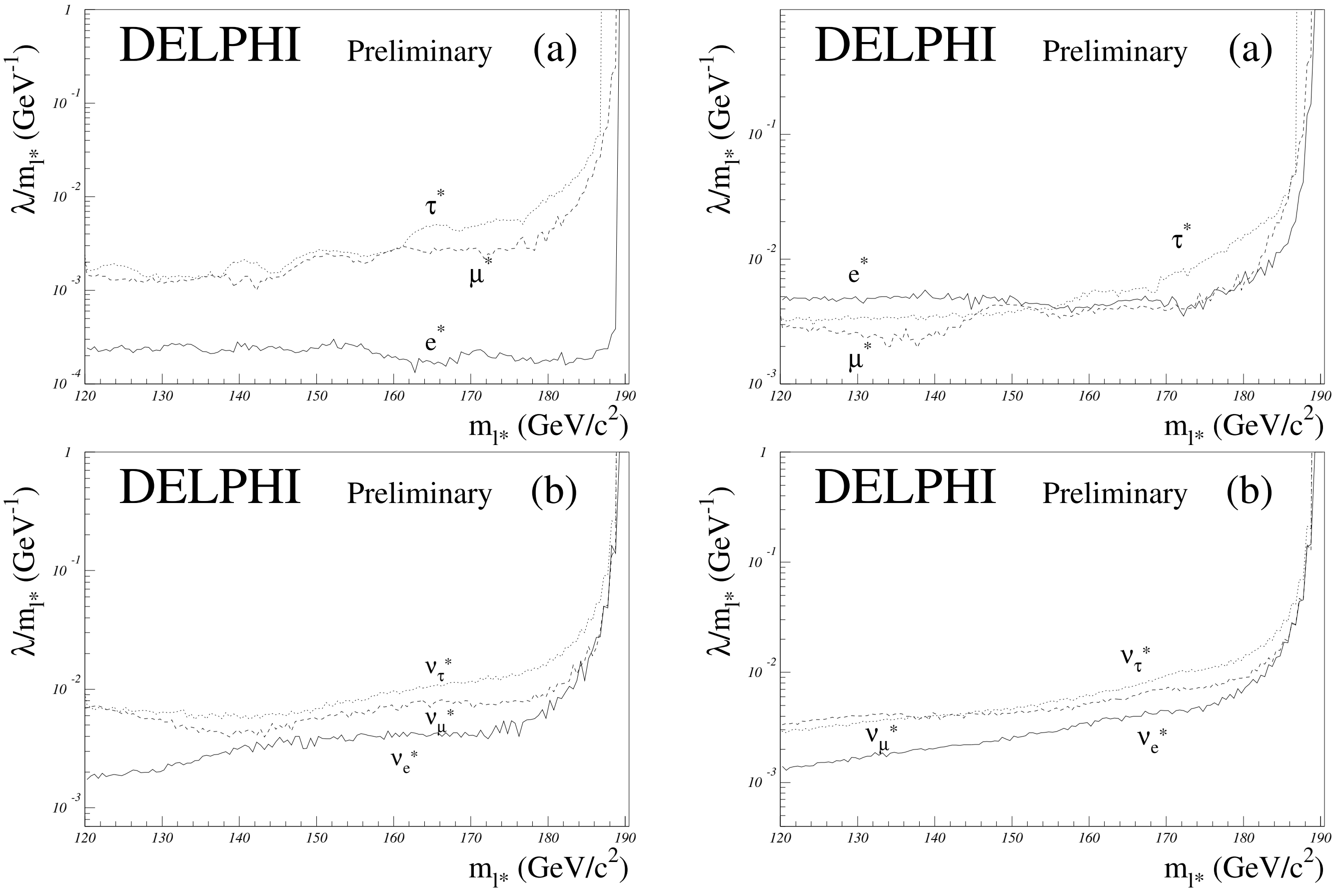
Single Production of Excited Leptons

Upper Limits on $\lambda/m_{l^*} \ = \ f/(\sqrt(2)\Lambda)$ as a function of mass

$\sqrt{s} = 189\ GeV$

DELPHI preliminary

$f \ = \ f'$ $\qquad\qquad$ $f \ = \ -f'$

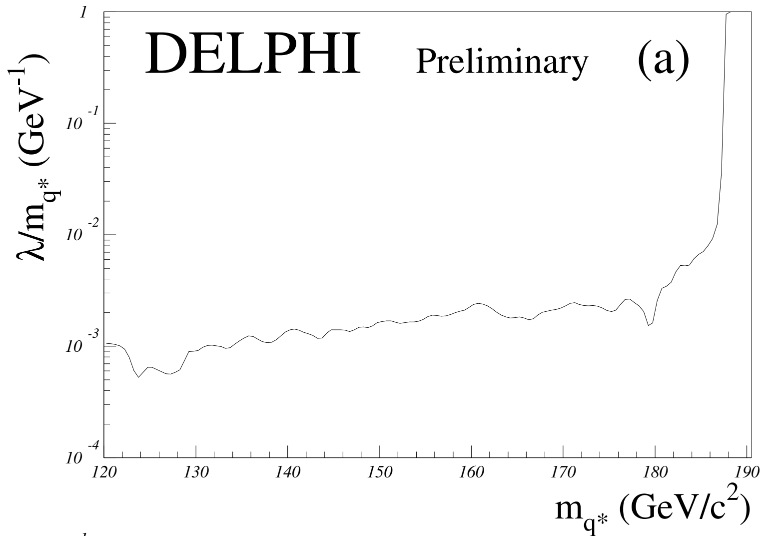


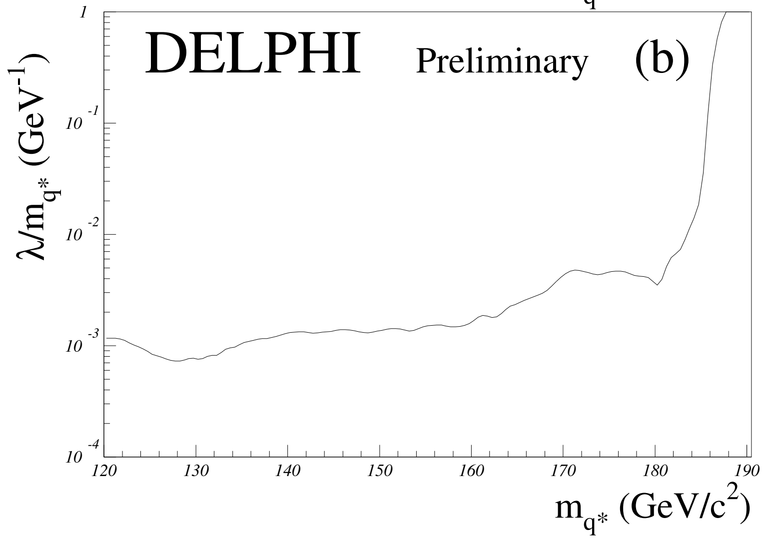
Single Production of Excited Quarks

$$\sqrt{s} = 161 - 183\ GeV$$

Decay mode	Data	Background	Efficiency m_q^*=170 GeV
$q^* \to q\gamma$	292	336 ± 8	31%
$q^* \to qg$	248	258 ± 8	19%

Assuming up-type excited quarks





Concusions

- No signal yet

- Searches at LEP2 from DELPHI, L3 and OPAL for
  - Unstable Heavy Neutal Leptons
  - Unstable Heavy Charged Leptons
  - Stable/Long-lived Heavy Charged Leptons
  - Singlet Heavy Neutrino
  - Excited Leptons
  - Excited Quarks

- Present limits are higher than 1998 PDG limits by $\sim$ 10-15 GeV