Search for Heavy and Excited Leptons at LEP

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Outline

- Motivation
- Search for Heavy Leptons
    - Unstable
    - Stable/Long-lived
- Search for Excited Leptons
- Summary

Physics Beyond the Standard Model

Still many unanswered questions within the SM....

.... Nature might have chosen

Unification

GUT (E_6, SO(10))
SUSY
....

See-Saw Mechanism

$$m_{N_\ell} = m_\ell^2 / m_{\nu_\ell}$$

$$\text{if } m_{\nu_e} \sim 2 \text{ eV}$$

$$\Downarrow$$

$$m_{N_e} \sim 130 \text{ GeV}$$

Compositeness

Substructures at
scale $\Lambda \geq 1$ TeV

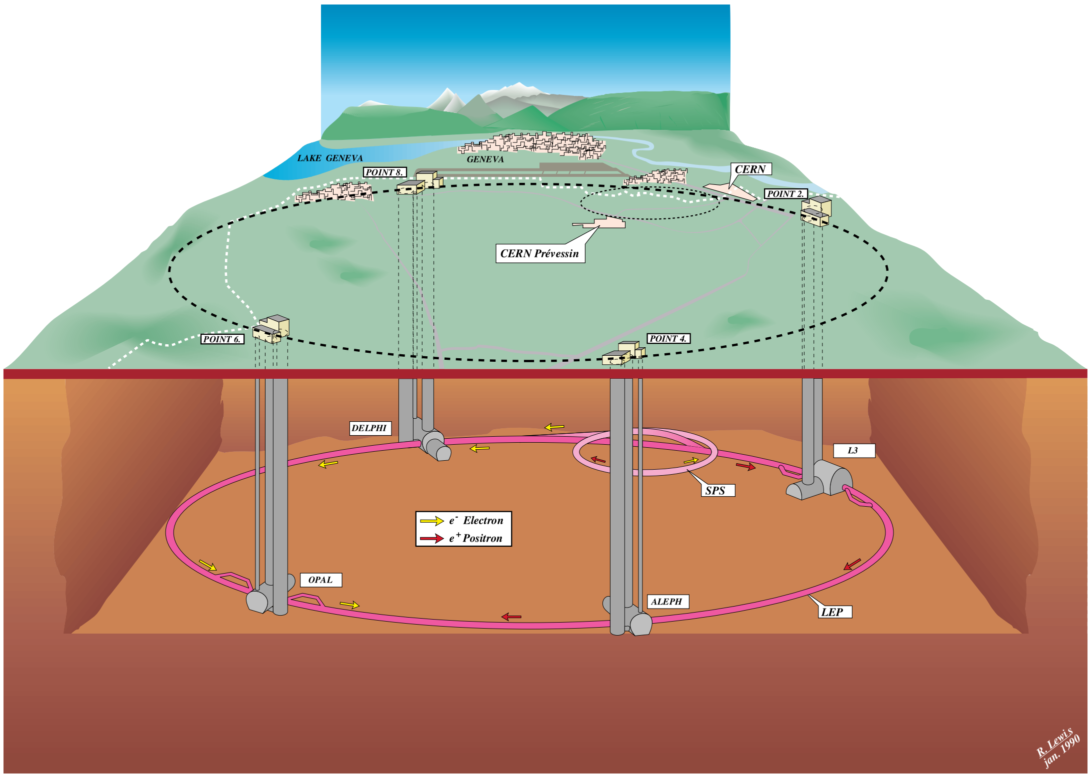
$$\Downarrow$$

Excited fermions

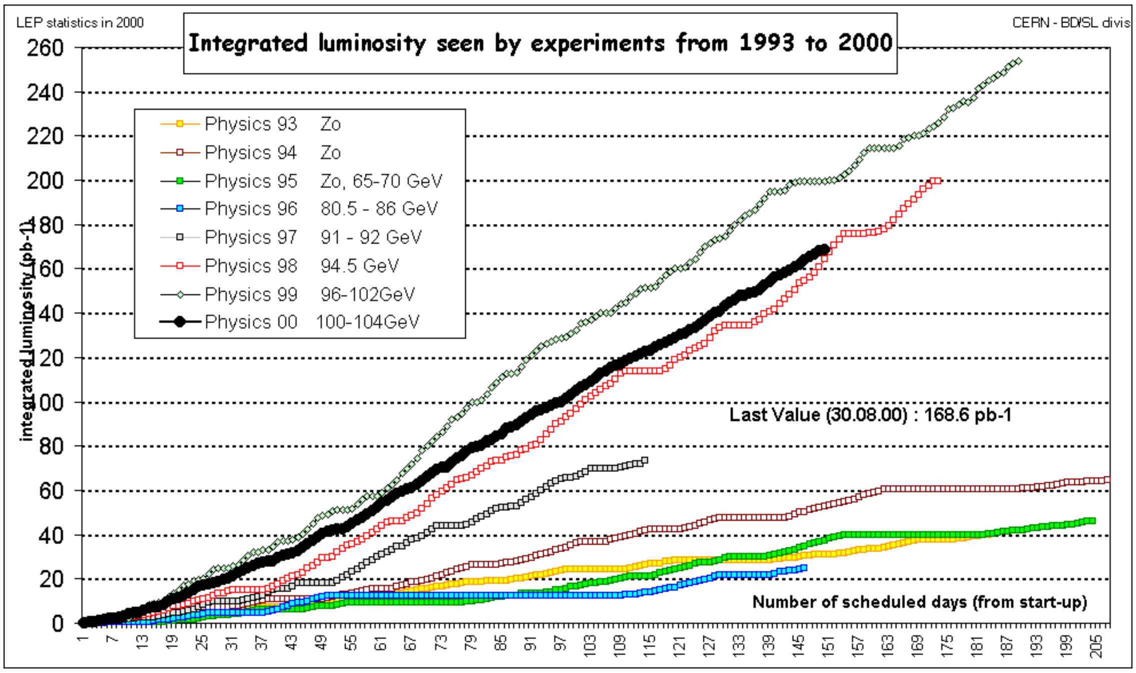
New Physics could be within TODAY's experimental reach

Large Electron Positron Collider

Circumference $\sim$ 27 km



Currently running at $\sqrt{s} \sim 207$ GeV



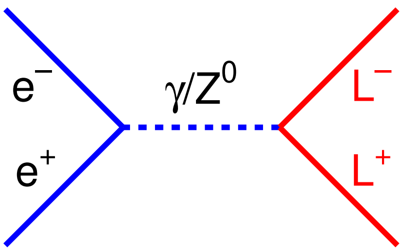
I - Heavy Leptons

- Can be **sequential**, **mirror** or **vector** leptons

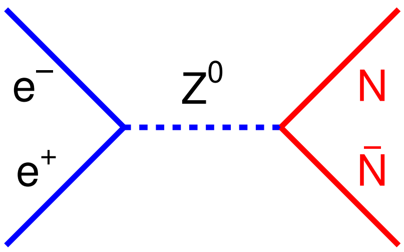
- Neutral Heavy Lepton $\nearrow$ **Dirac** $\searrow$ **Majorana**

- Mixing between heavy leptons and SM leptons severely constrained by LEP1 data and low-energy experiments. Thus, only consider **Pair production**.

Charged



Neutral



- Unstable Heavy Leptons can decay via CC or NC (except sequential leptons).

CC decays dominate $\Rightarrow$ only look for CC decays

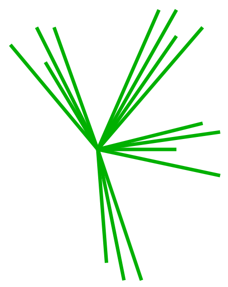
Heavy Unstable Charged Leptons

$$e^+e^- \longrightarrow L^+ L^-$$

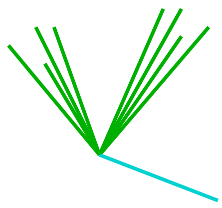
$$L^- \hookrightarrow \nu_\ell\, W^-,\quad W^- \hookrightarrow q\bar{q} \text{ or } \ell^-\bar{\nu}_\ell$$

$$L^+ \hookrightarrow \bar{\nu}_\ell\, W^+,\quad W^+ \hookrightarrow q\bar{q} \text{ or } \ell^+\nu_\ell$$

Topologies



Missing momentum + (jjjj)



Missing Momentum + (jj$\ell\nu$)

- Efficiency $\sim$ 20%
- Main background WW $\rightarrow$ qqqq and WW $\rightarrow$ qq$\ell\nu$

No Excess observed $\Rightarrow$ mass limit

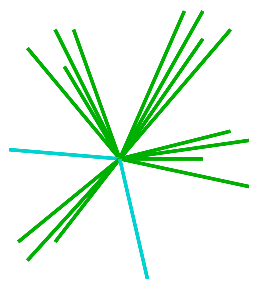
Heavy Unstable Neutral Leptons

$e^+e^- \longrightarrow N\bar{N}$

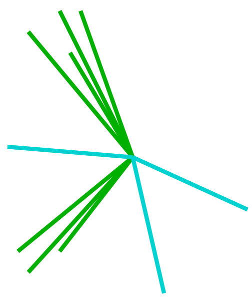
- $\hookrightarrow \ell^\pm W^\mp$
  - $\hookrightarrow q\bar{q}$ or $\ell^\mp \overset{(-)}{\nu}_\ell$
- $\hookrightarrow \ell^\mp W^\pm$
  - $\hookrightarrow q\bar{q}$ or $\ell^\pm \overset{(-)}{\nu}_\ell$

For Majorana N can have same sign leptons

Topologies



2 isolated leptons + (jjjj)



2 isolated leptons + (jj$\ell\nu$)

- Efficiency $\sim 35\%$
- Main background composed of multihadronic $q\bar{q}$, $\ell\ell qq$ and qqqq.

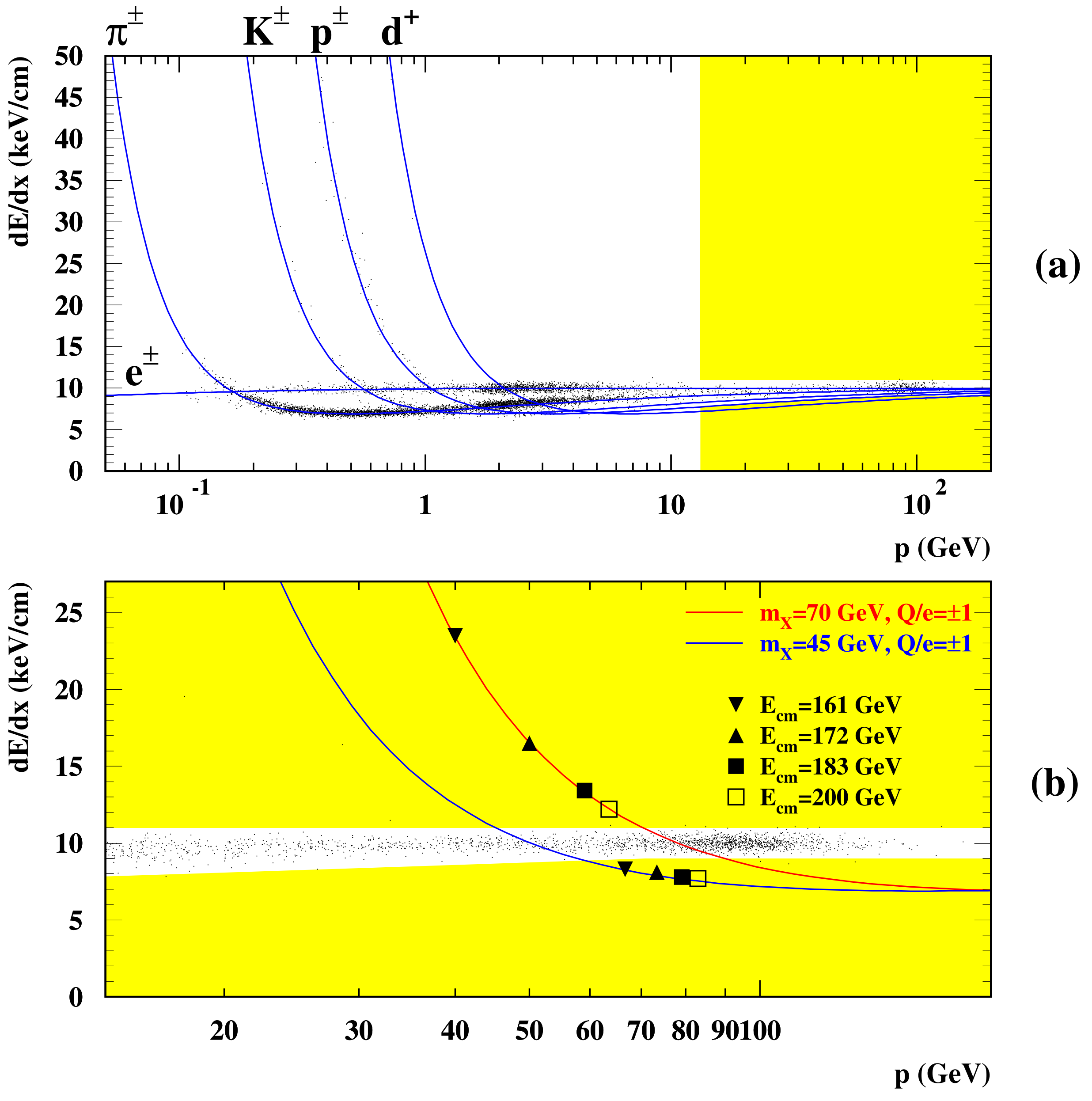
No Excess observed $\Rightarrow$ mass limit

Heavy Stable/Long-lived Charged Leptons

$$e^+e^- \to L^+L^-$$

- Look for two back-to-back charged tracks.
- Both tracks must have dE/dx outside SM range.
- In SM region, require both tracks to have low $\beta = p/E_{\mathrm{beam}}$

OPAL



Heavy Leptons Mass Limits

lower mass limit ~ 90 GeV

- Limits at 95% CL
- Preliminary results
- Data taken at $\sqrt{s}$ = 192-202 GeV (in 1999)

Channel		OPAL	L3
$N \to eW$	Dirac	97.8	97.1
	Majorana	88.8	85.7
$N \to \mu W$	Dirac	97.1	97.0
	Majorana	87.7	88.0
$N \to \tau W$	Dirac	78.9	89.0
	Majorana	67.5	79.6
$L^\pm \to \nu_\ell W^\pm$		$91.3^\dagger$	98.8
$L^\pm$ stable/long-lived		98.0	$93.5^\dagger$

$\dagger$ limits from $\sqrt{s} = 189$ GeV

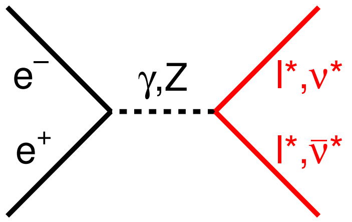
II - Excited Leptons

Stringent constraints from g-2 precision measurements

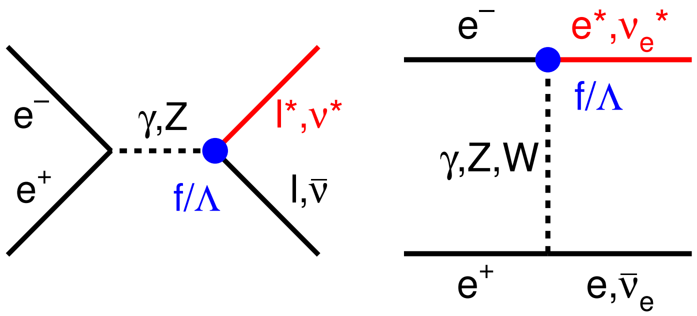
Generally assume $\begin{pmatrix} \nu_\ell^* \\ \ell^* \end{pmatrix}_{\rm L} \begin{pmatrix} \nu_\ell^* \\ \ell^* \end{pmatrix}_{\rm R}$; vector coupling $\ell^* \ell^* V$

$$\mathcal{L}_{\ell\ell^* V} = \underbrace{\frac{1}{2\Lambda}}_{\text{compositeness scale}} \bar{\ell}^* \sigma^{\mu\nu} \left[g \underbrace{f}_{\text{weight factors}} \frac{\boldsymbol{\tau}}{2} \mathbf{W}_{\mu\nu} + g' \underbrace{f'}_{\text{weight factors}} \frac{Y}{2} B_{\mu\nu} \right] \ell_{\rm L}$$

Pair production

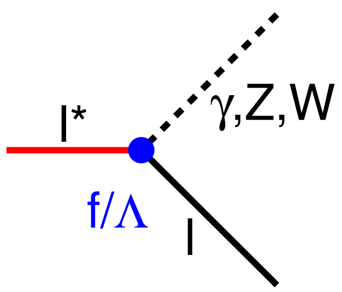


Single production



e^* produce forward

CC or NC Decay



Pair Production of Excited Leptons

$\ell^*\ell^* \to \ell\ell\gamma\gamma$

$\searrow \nu\nu WW$ (Same topology as Heavy Lepton)

$\nu^*\nu^* \to \nu\nu\gamma\gamma$

$\searrow \ell\ell WW$ (Same topology as Heavy Lepton)

No excess is found

$\Downarrow$

Lower mass limits are set

	95% CL Mass Limit (GeV)						
	$f = f'$				$f = -f'$		Coupl. Ind.
	L3	OPAL	DELPHI	ALEPH	L3	OPAL	L3
e^*	100.1	100.1	94.1†	94.3†	96.2	91.3†	96.0
μ^*	100.3	100.1	94.1†	94.3†	96.2	91.3†	96.2
τ^*	99.9	100.0	93.3†	94.3†	96.2	91.3†	94.9
ν_e^*	99.3	99.5	93.6†	94.2†	99.5	94.3†	98.5
ν_μ^*	99.4	99.5	93.7†	94.2†	99.5	94.3†	98.5
ν_τ^*	93.9	91.9	89.5†	94.2†	99.4	94.3†	92.7

Data up to $\sqrt{s} = 202$ GeV were analysed ($\dagger$ limits from $\sqrt{s} = 189$ GeV)

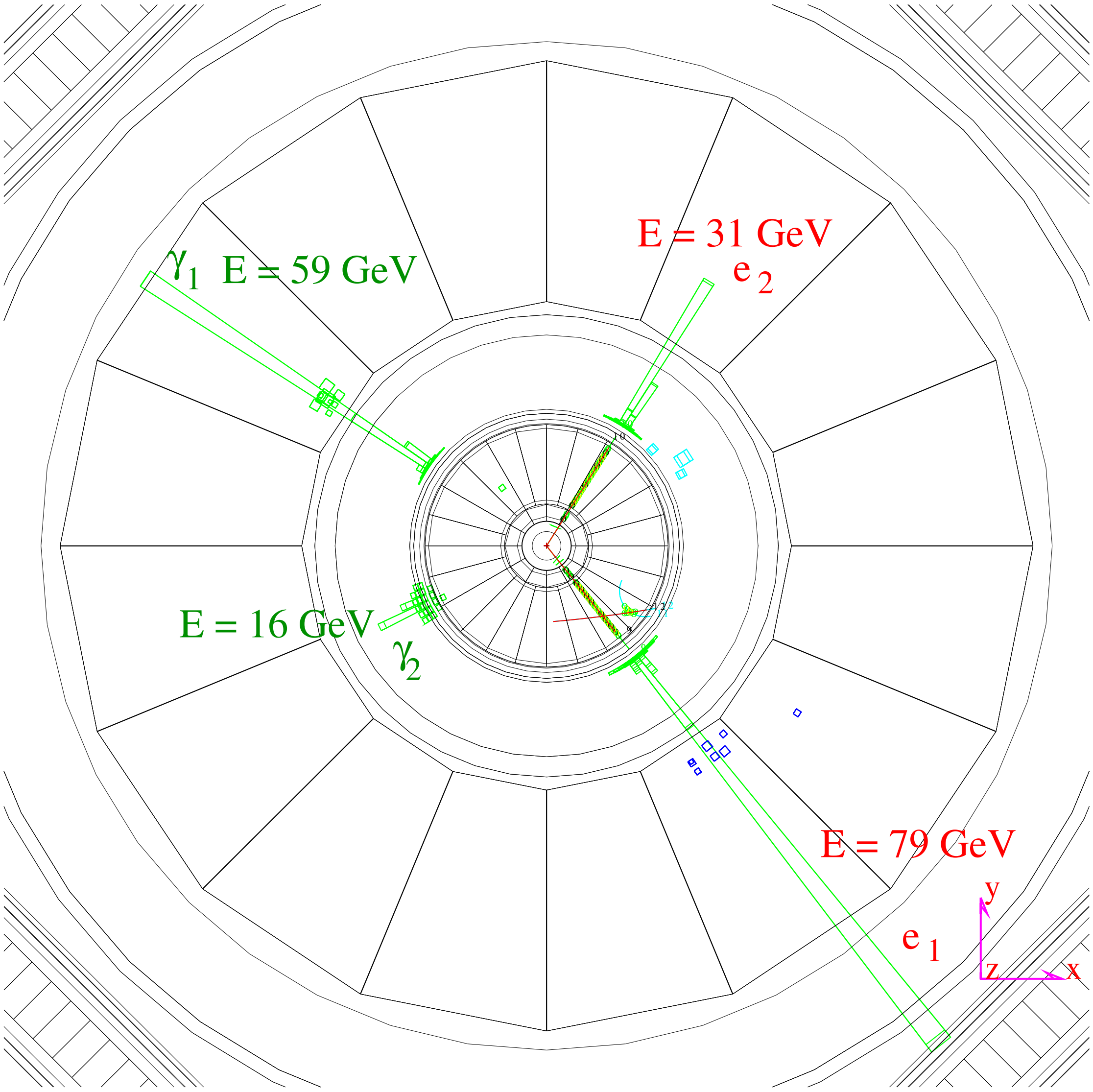
Excited Lepton **Candidate event**

$e^*e^* \longrightarrow ee\gamma\gamma$

Recorded by L3 at $\sqrt{s} = 200$ GeV

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

Run # 772501 Event # 3103 Total Energy : 189.50 GeV



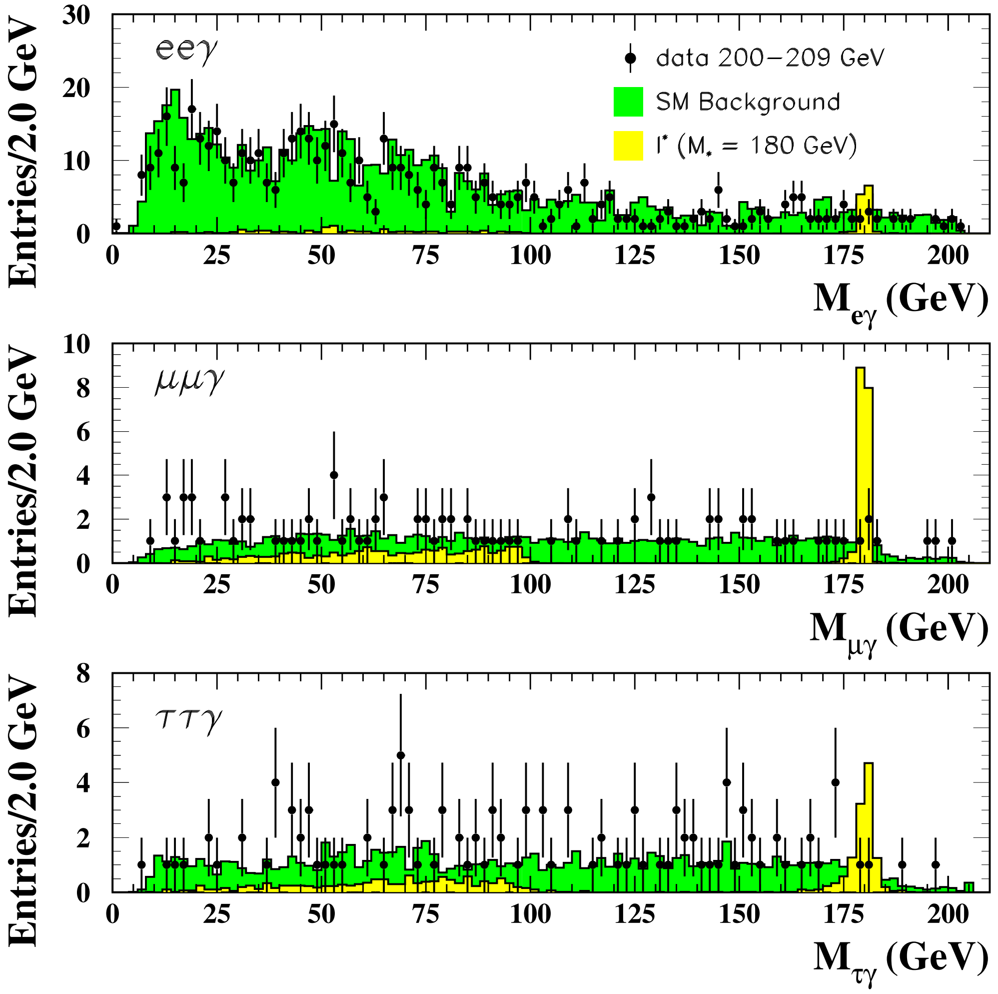
Transverse Imbalance : .0166		**Longitudinal Imbalance :** -.0202	
Thrust : .7979	**Major :** .2969	**Minor :** .2251	
Event DAQ Time : *990820 54953*			

Single Production of Excited Leptons

$$\boxed{\ell^*\ell} \begin{cases} \nearrow \ell\ell\gamma \\ \rightarrow \nu W \ell \\ \searrow Z\ell\ell \end{cases} \qquad \boxed{\nu^*\nu} \begin{cases} \nearrow \nu\nu\gamma \\ \rightarrow \ell W \nu \\ \searrow Z\nu\nu \end{cases}$$

Look for peaks in invariant mass distributions

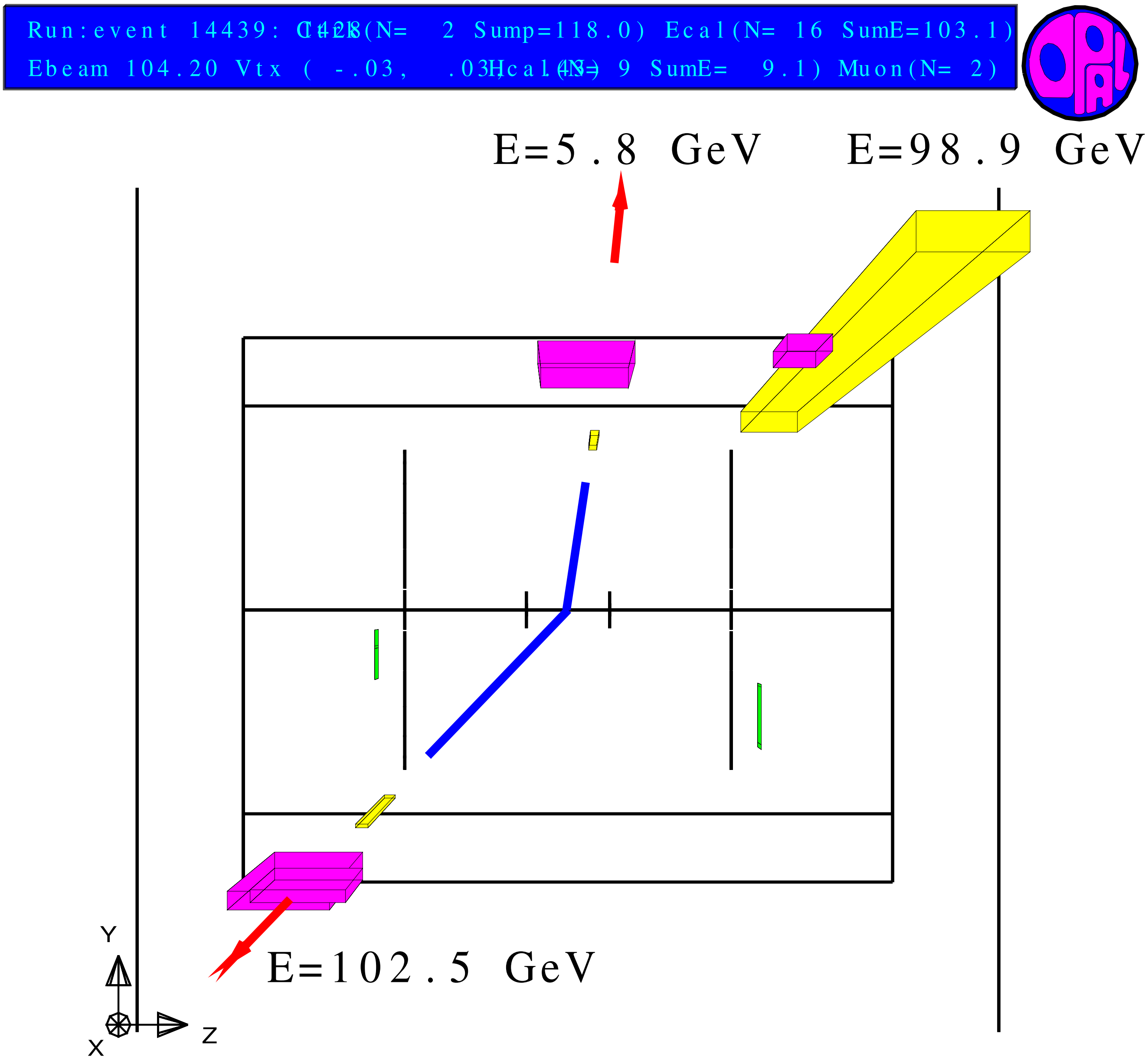
OPAL Preliminary



Excited Lepton **Candidate event**

$$\mu^{*}\mu \longrightarrow \mu\mu\gamma$$

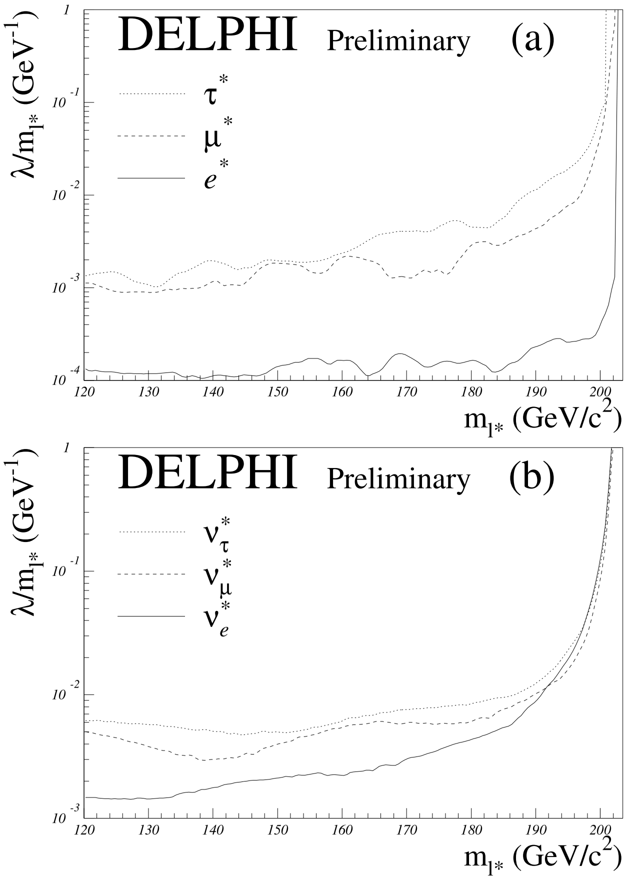
$$(\sqrt{s} = 208.4\ \mathrm{GeV},\ \mathrm{M}_{\mu^*} = 201.3\ \mathrm{GeV})$$

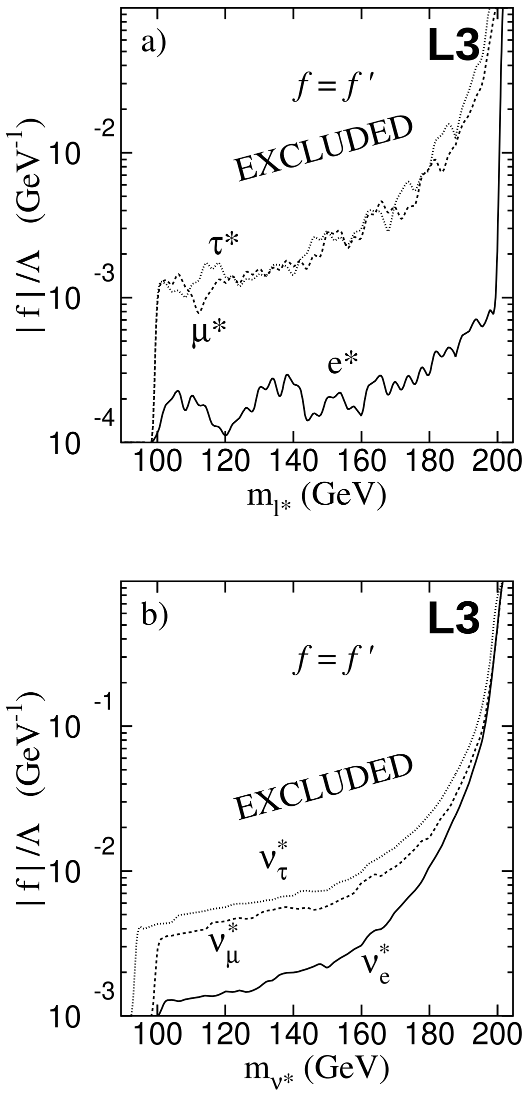


$$\mathrm{M}_{\mu\mu} = 46.0\ \mathrm{GeV}$$

Limits from Single Production of Excited Leptons

Upper limits on f/Λ as a function of excited lepton mass





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

$$f/\Lambda \lesssim \begin{array}{l} 0.1\ \mathrm{TeV}^{-1}\ (e^*) \\ 1\ \mathrm{TeV}^{-1}\ (\mu^*, \tau^*) \\ 5\ \mathrm{TeV}^{-1}\ (\nu^*) \end{array}$$

Summary

- LEP experiments search for Heavy and Excited Leptons
- No Excess has been observed in the data
- Still need to look at this year's data taken at the very highest energy
- More luminosity at $\sqrt{s} > 206$ GeV is expected in the next few weeks