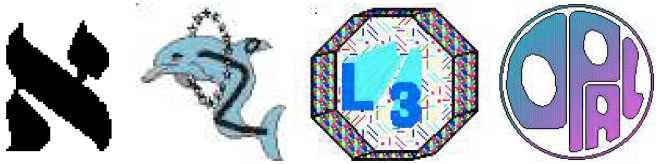
Moriond EW week
9-16 March 2002

Other Exotica searches at LEP

Paolo Giacomelli - INFN Bologna
on behalf of the 4 LEP experiments



Topics

- Excited Leptons
- Leptoquarks
- Heavy Leptons
- Single Top quark
- Technicolor
- Lepton Flavor Violation
- Conclusions

Caveat: No excess of events compared to SM expectation

 95% CL limits

LEP2 data summary

Year	Nominal Energy GeV	Actual Energy GeV	Luminosity pb^{-1}
1995	130	130.2	~ 3
	136	136.2	~ 3
	133*	133.2	~ 6
1996	161	161.3	~ 10
	172	172.1	~ 10
	167*	166.6	~ 20
1997	130	130.2	~ 2
	136	136.2	~ 2
	183	182.7	~ 50
1998	189	188.6	~ 170
1999	192	191.6	~ 30
	196	195.5	~ 80
	200	199.5	~ 80
	202	201.6	~ 40
2000	205	204.9	~ 80
	207	206.7	~ 140

Typical luminosities and center-of-mass energies of data collected by each LEP experiment

These data will be the highest center-of-mass energies collected at an e^+e^- collider for quite some time…

Total of ~700 pb^{-1} per experiment at LEP2 energies

Excited Leptons

The existence of three families of quarks and leptons is a strong motivation for substructures.

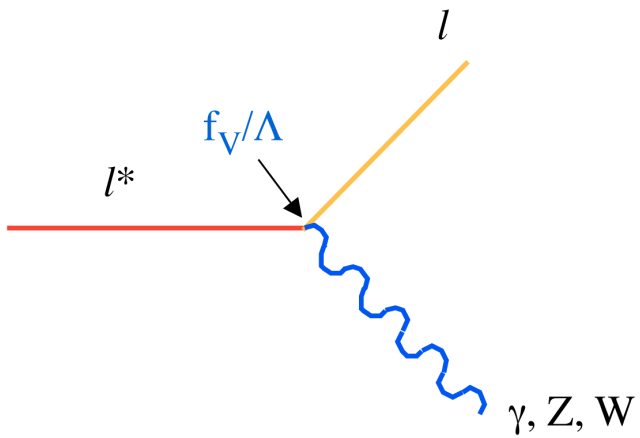
In composite models, quarks, leptons and gauge bosons are composite with an associated energy scale Λ.

At $E_{c.m.} << \Lambda$, one could get manifestations of these new constituents through anomalous decay modes, anomalous electric and magnetic multipoles, excited fermions, leptoquarks and contact terms.

Production

Excited leptons can be pair produced in e^+e^- collisions, $e^+e^- \rightarrow l^* \bar{l}^*$ or singly produced, $e^+e^- \rightarrow l\bar{l}^*$.

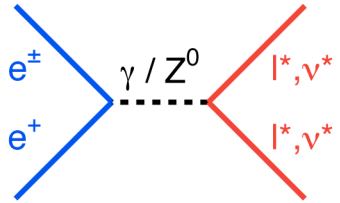
Decay



Topologies

eeγγ, μμγγ, ττγγ, eeWW, νννγ (pair production)
eeγ, μμγ, ττγ, νeW and ννγ (single production)

Excited Leptons

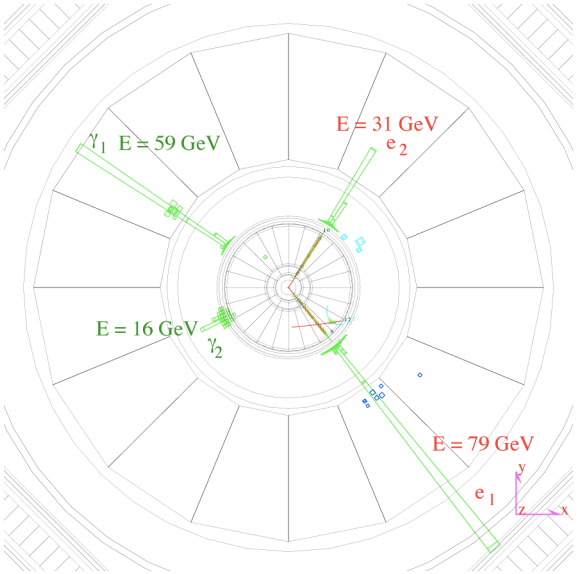


$$\ell^* \to \ell\gamma, \ell Z, \nu W$$
$$\nu^* \to \nu\gamma, \nu Z, \ell W$$

$e^+e^- \to e^*e^* \to ee\gamma\gamma$

m(e_1 ,γ_2) = 60 GeV m(e_2 ,γ_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			

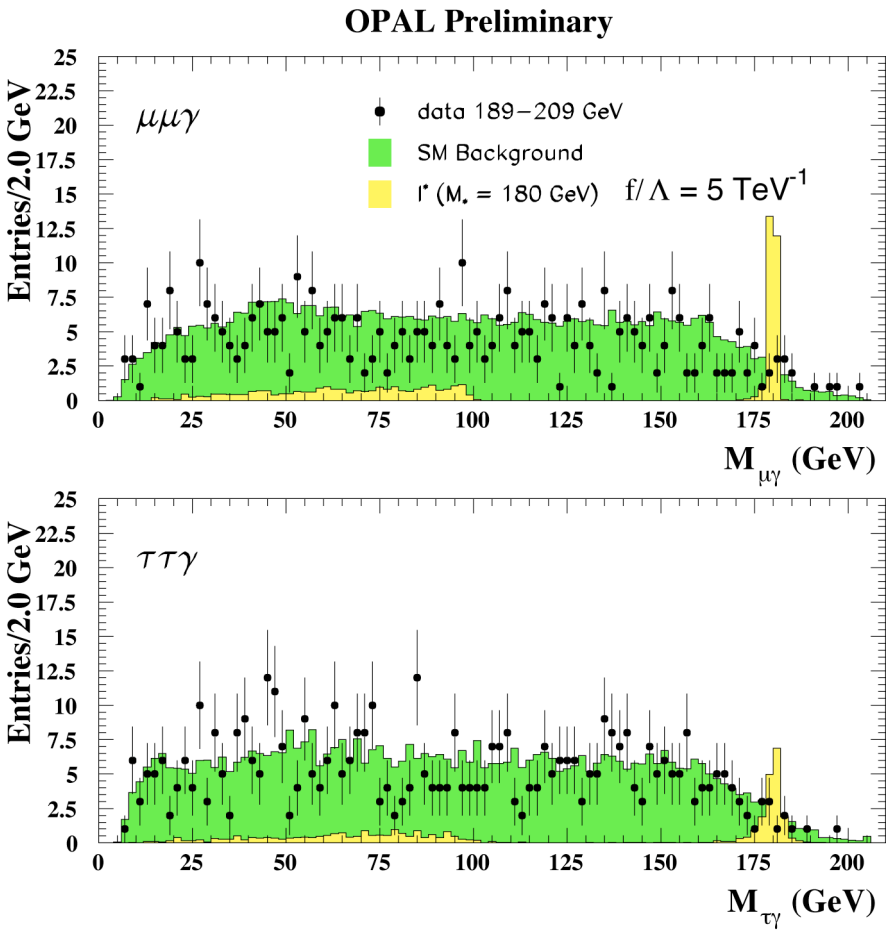
	95% CL Mass Limit (GeV)						
	$f = f'$				$f = -f'$		Coupl. Ind.
	DELPHI	**OPAL**	**L3**	**ALEPH**	**DELPHI**	**L3**	**L3**
e^*	103.0	102.9	100.1	94.3	98.0	96.2	96.0
μ^*	103.1	102.9	100.3	94.3	98.0	96.2	96.2
τ^*	102.2	102.8	99.9	94.3	98.0	96.2	94.9
ν_e^*	102.0	99.5	99.3	94.2	102.7	99.5	98.5
ν_μ^*	102.4	99.5	99.4	94.2	102.8	99.5	98.5
ν_τ^*	95.3	91.9	93.9	94.2	102.8	99.4	92.7

$\sqrt{s}$ = 189- 209 GeV ($\approx 170\ \mathrm{pb}^{-1}$)
$\sqrt{s}$ = 192-202 GeV
$\sqrt{s}$ = 189-208 GeV
$\sqrt{s}$ = 189 GeV

Excited Leptons

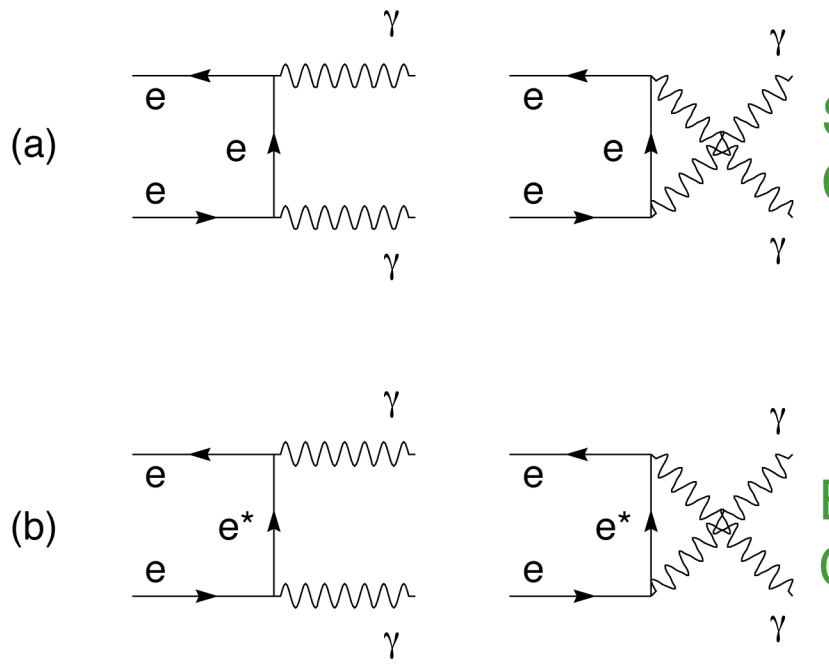
Single production

Look for peaks in invariant mass distributions



Excited Leptons

Indirect Searches for Excited Leptons

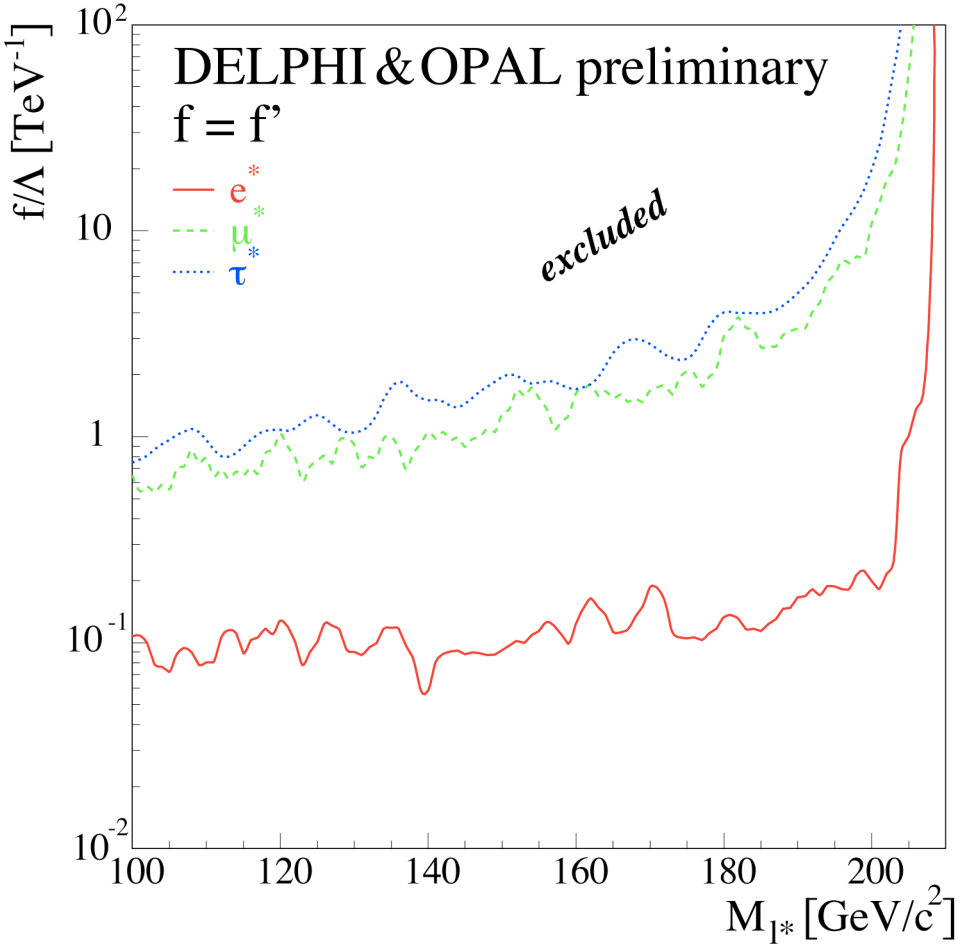


Standard Model Contributions

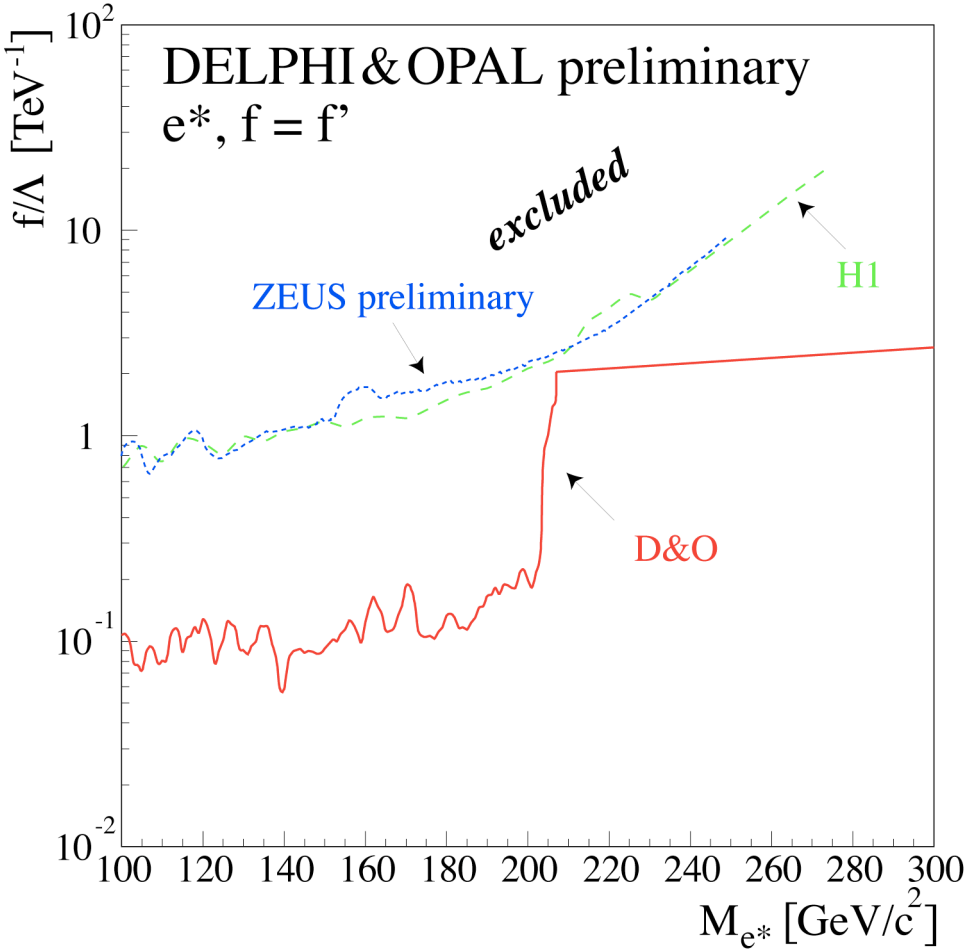
Excited Electron Contributions

Excited Leptons

Direct Searches



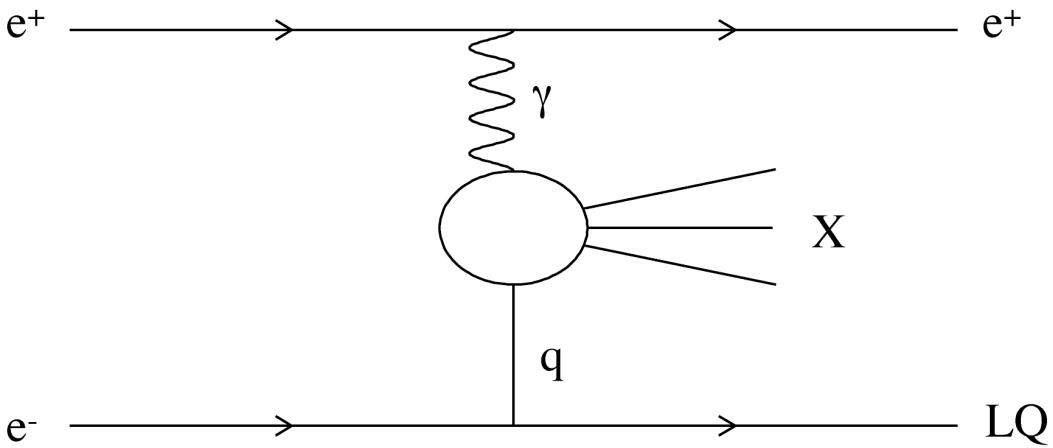
Indirect Searches



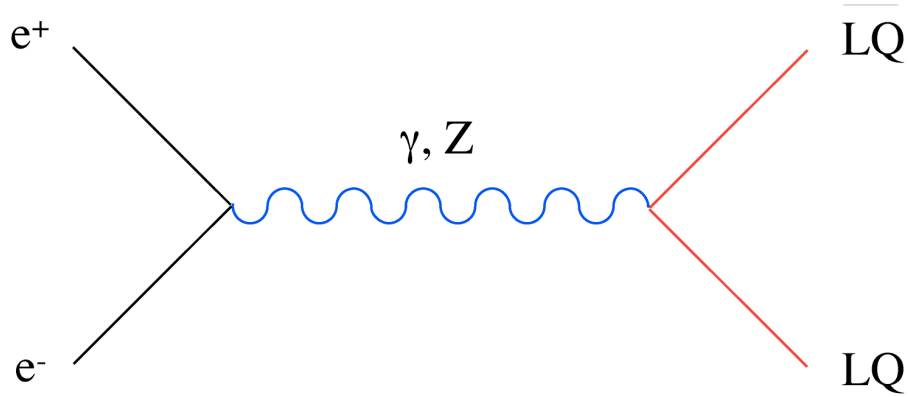
Leptoquarks

Leptoquarks are predicted in some composite models. They carry both baryon and lepton number and mediate interactions between quarks and gluons.

Single Production



Pair Production

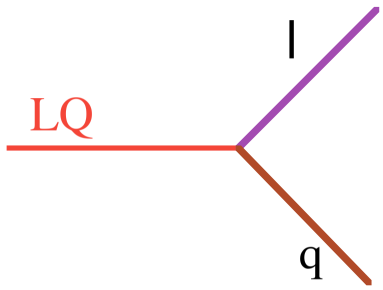


Assume LQ interaction { Dimensionless, SU(3)xSU(2)xU(1), B and L conservation } ⟹ 9 scalars and 9 vectors

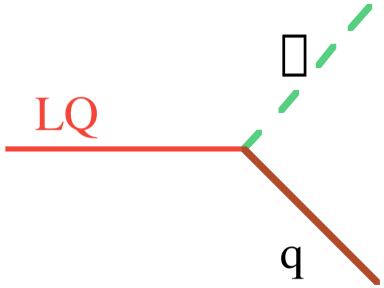
Leptoquarks

Predicted by some composite models

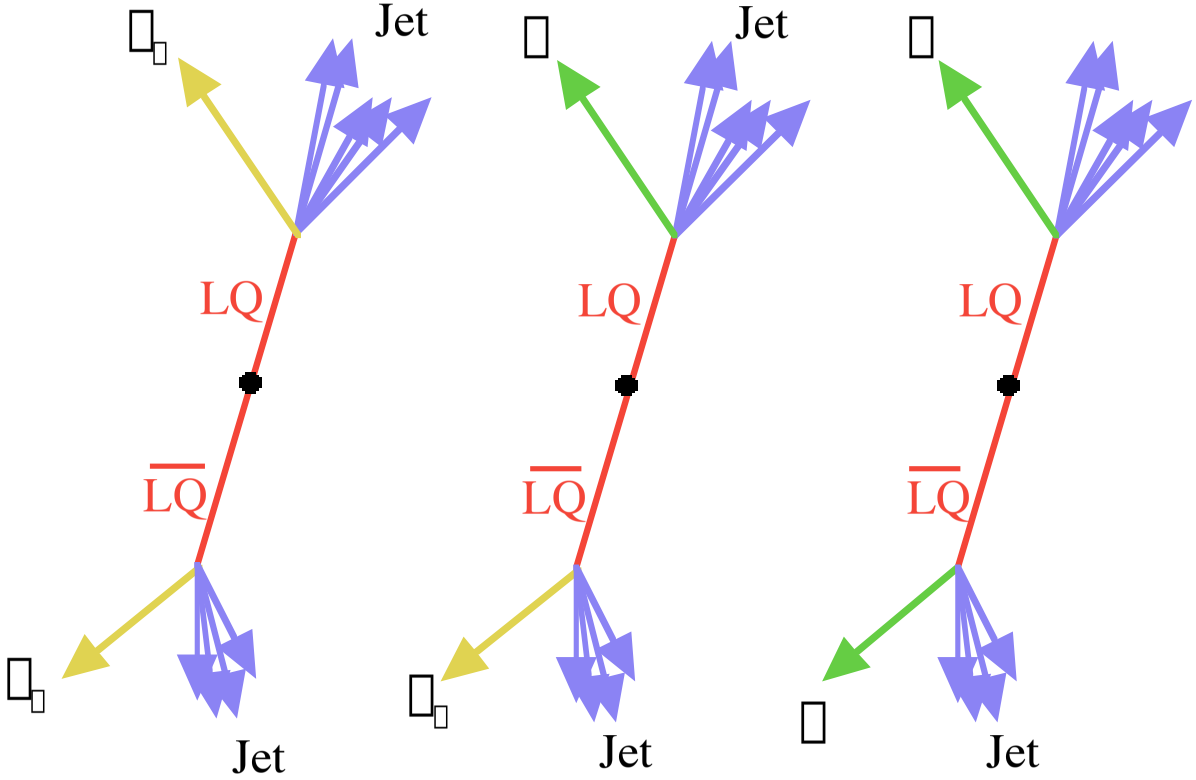
Decays



BR = □

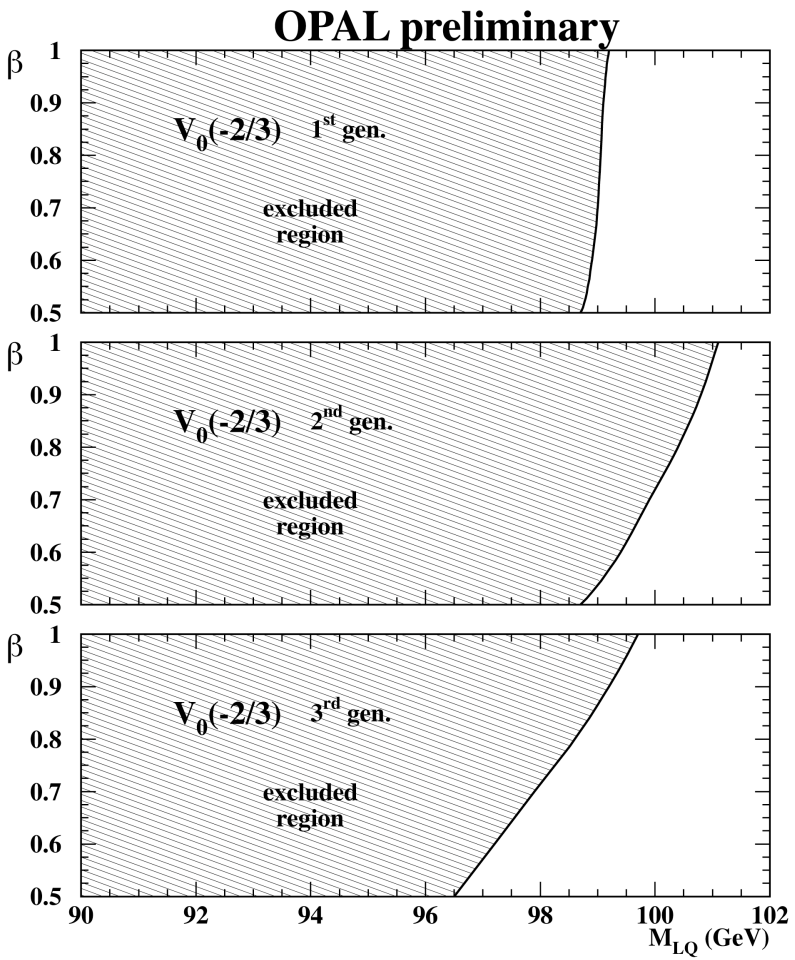


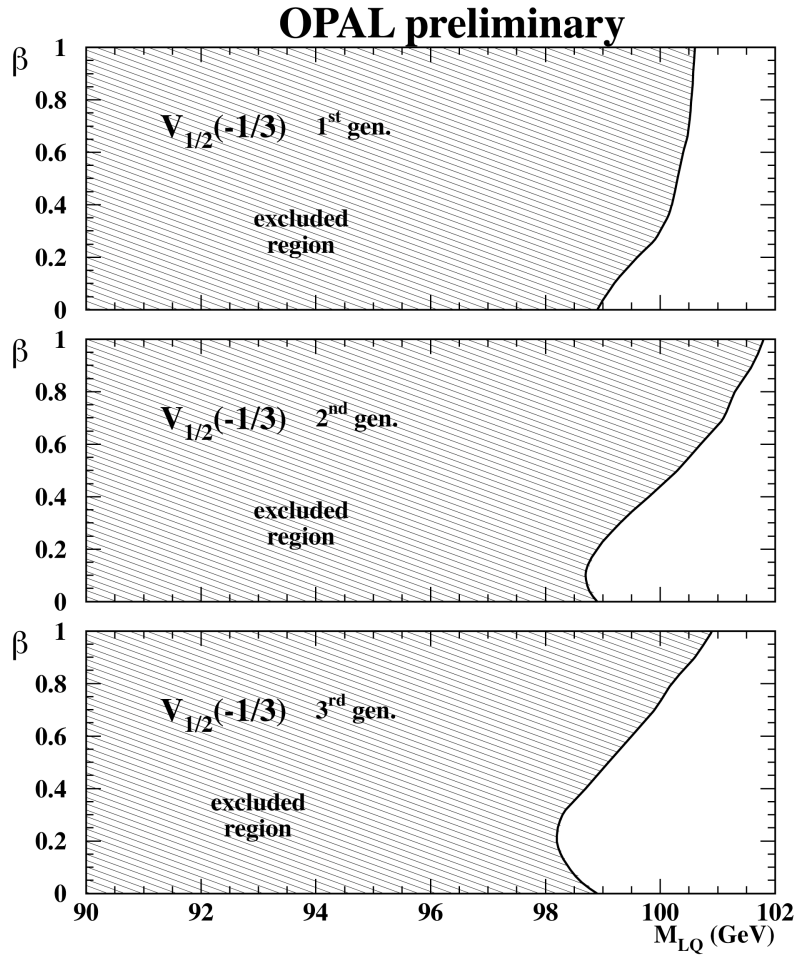
BR = 1 - □



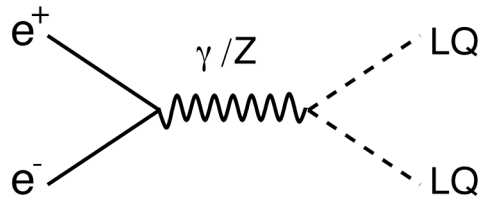
Leptoquarks pair production

Vector Leptoquarks

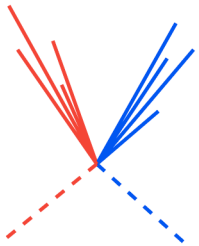




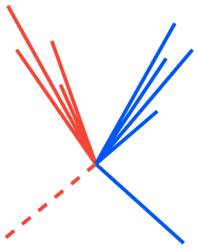
Leptoquarks pair production



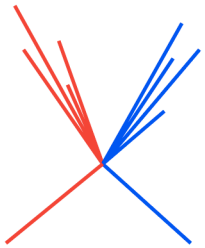
- Independent of $g_{R,L}$
- All LQ generations
- LQ with large coupling to neutrinos can be studied



$qq\nu\nu$



$qql\nu$

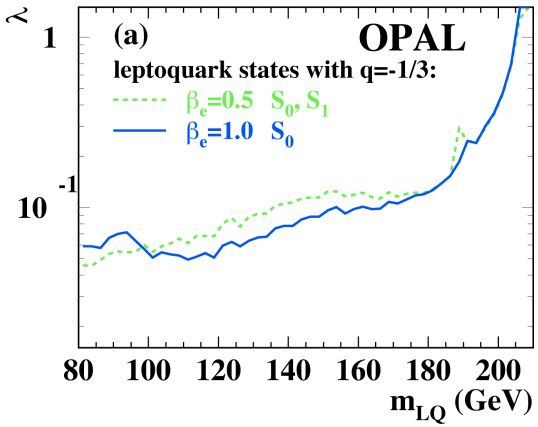


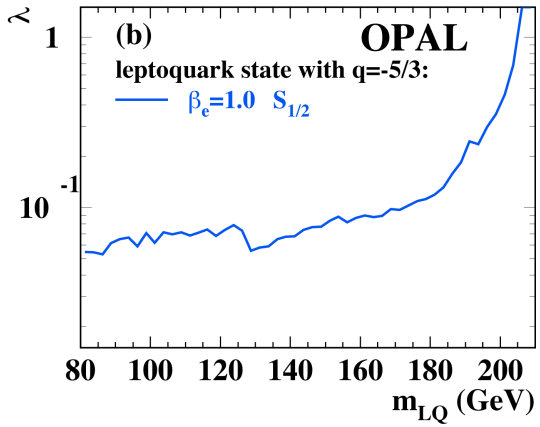
$qqll$

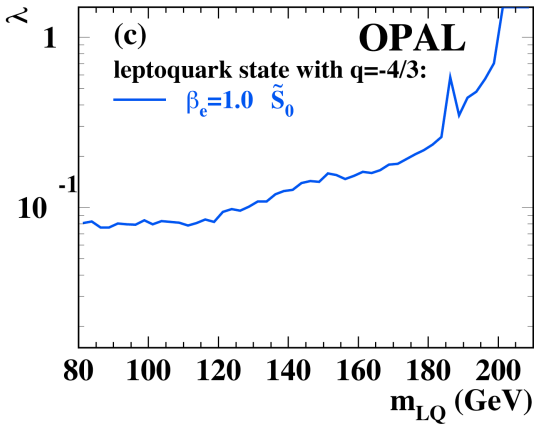
		OPAL 200-209 GeV Mass limits (GeV)		
LQ	Q_{em}	1^{st}	2^{nd}	3^{rd}
$\tilde{S}_0$	-4/3	97.6	100.3	98.2
$S_{\frac{1}{2}}$	-2/3	90.9	90.4	87.2
	-5/3	98.7	100.8	99.2
$\tilde{S}_{\frac{1}{2}}$	+1/3	76.5	76.5	76.5
	-2/3	93.9	98.6	94.9
S_1	+2/3	94.7	94.7	94.7
	-4/3	99.2	101.1	99.6
V_0	-2/3	98.7	98.7	96.5
$\tilde{V}_0$	-5/3	101.7	> 102	101.8
$V_{\frac{1}{2}}$	-1/3	98.9	98.7	98.2
	-4/3	101.3	> 102	101.5
$\tilde{V}_{\frac{1}{2}}$	+2/3	98.3	98.3	98.3
	-1/3	99.9	101.4	100.3
V_1	+1/3	100.7	100.7	100.7
	-2/3	98.7	98.7	96.5
	-5/3	101.9	> 102	> 102

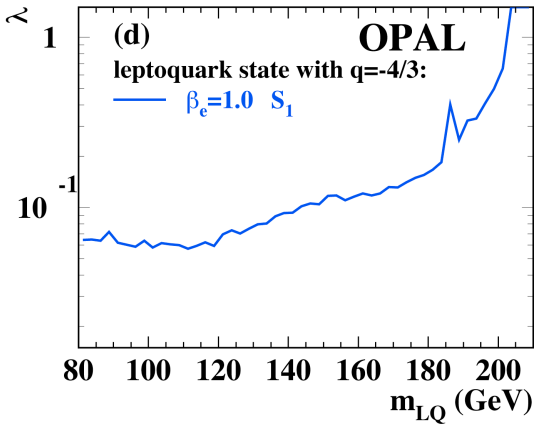
Leptoquarks single production

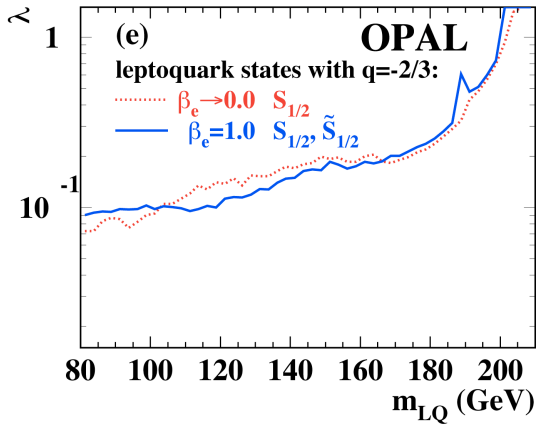
Scalar LQs





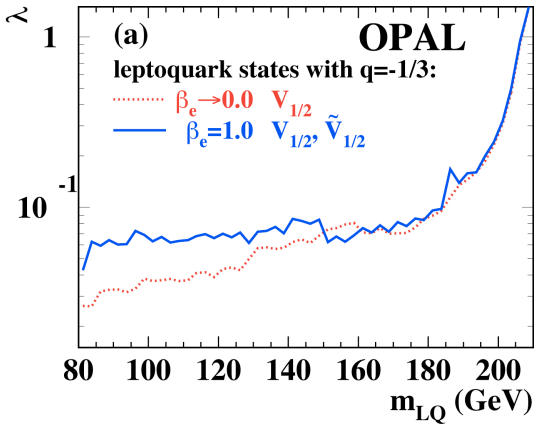


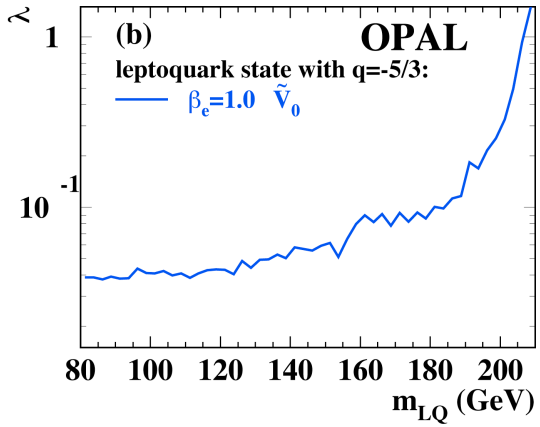


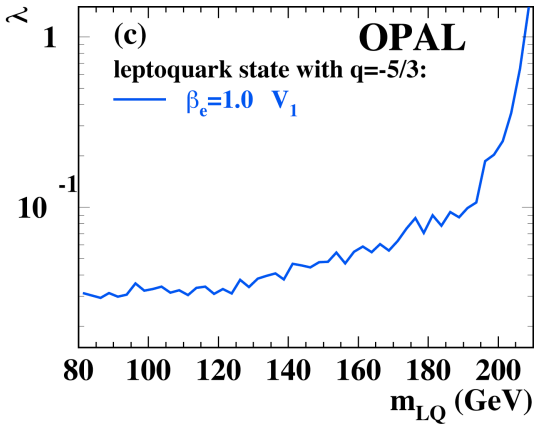


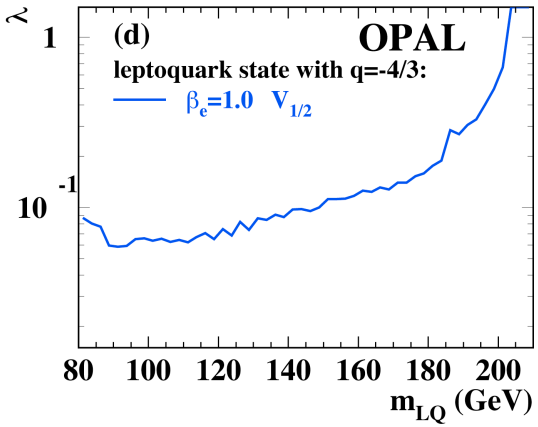
Leptoquarks single production

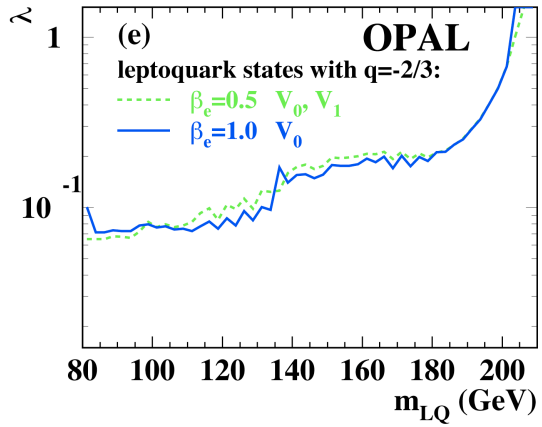
Vector LQs





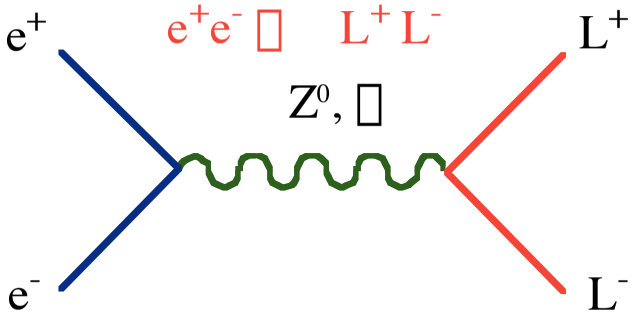


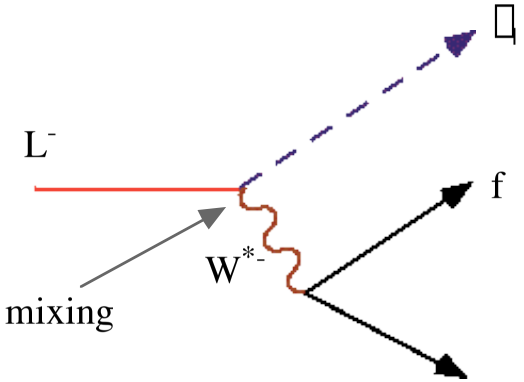




Heavy Leptons

Production

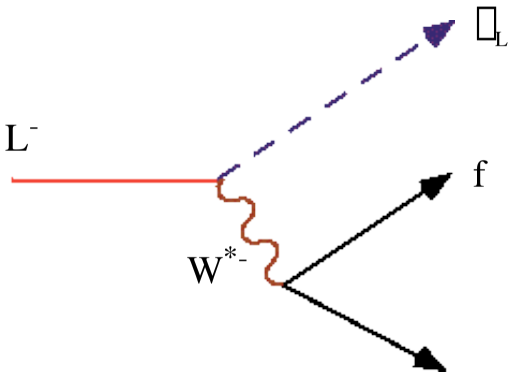




$m_L < m_{\gamma_L}$

decays through mixing

Decay



$m_L > m_{\gamma_L}$

γ_L stable

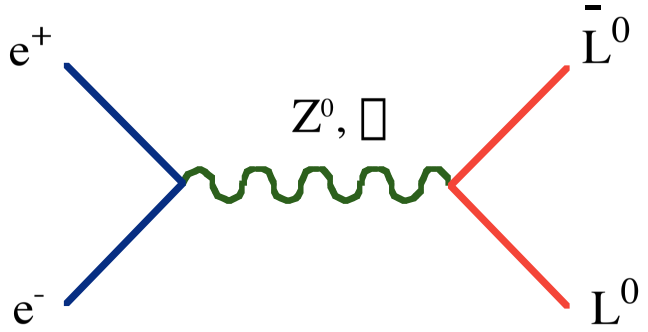
Topologies

Jets and missing energy, Jets + leptons and missing energy. In the second case there is even more missing energy.

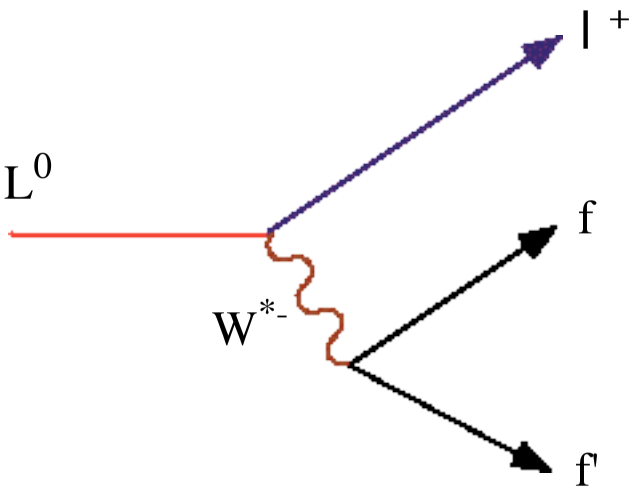
Neutral Heavy Leptons

Production

$e^+e^- \to L^0\bar{L}^0$



Decay



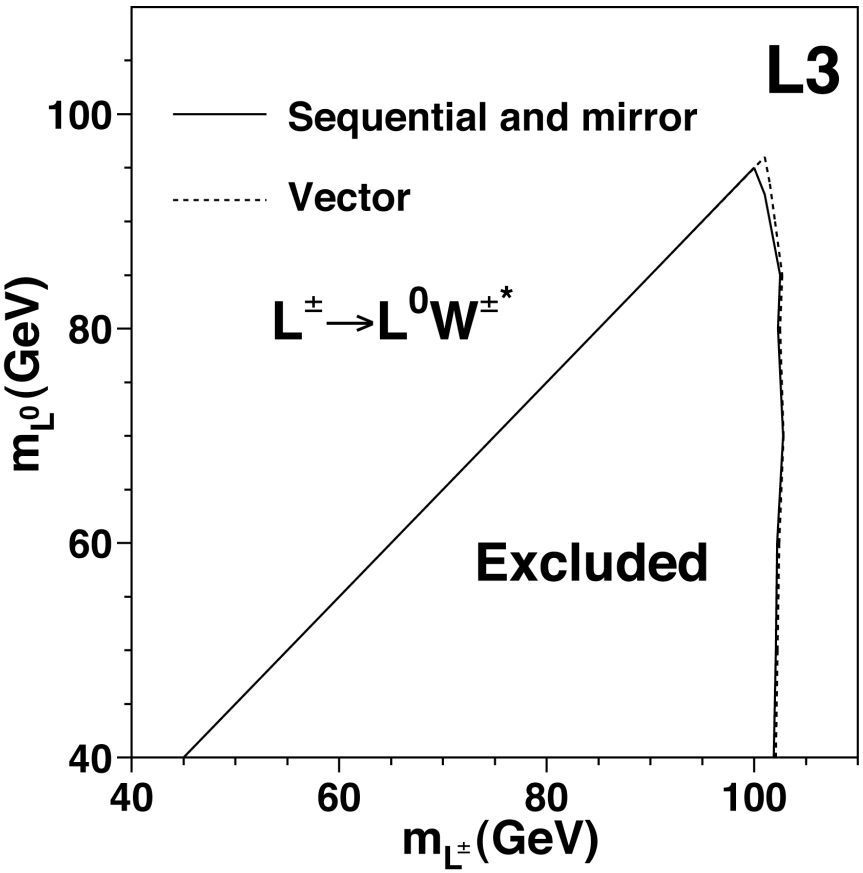
Topology

Isolated leptons plus jets.

Heavy Leptons

$e^+e^- \to L^0\bar{L}^0$

Decay mode	Model	Dirac	Majorana
$L^0 \to eW$	Sequential	101.3	89.5
	Vector	102.6	-
	Mirror	100.8	89.5
$L^0 \to \nu W$	Sequential	101.5	90.7
	Vector	102.7	-
	Mirror	101.0	90.7
$L^0 \to qW$	Sequential	90.3	80.5
	Vector	99.3	-
	Mirror	90.3	80.5



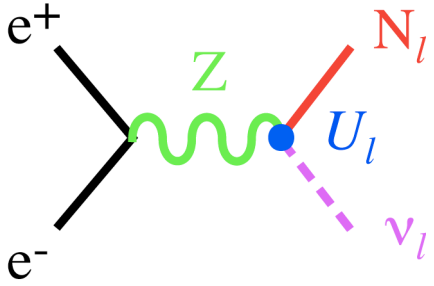
$e^+e^- \to L^+L^-$

Decay mode	Model	Dirac
$L^{\pm} \to \nu W$	Sequential	100.8
	Vector	101.2
	Mirror	100.5
$L^{\pm} \to L^0 W$	Sequential	101.9
	Vector	102.1
	Mirror	101.9
Stable	Sequential	102.6
	Vector	102.6
	Mirror	102.6

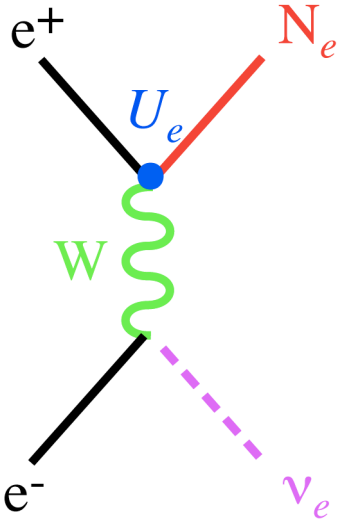
Neutral Heavy Leptons

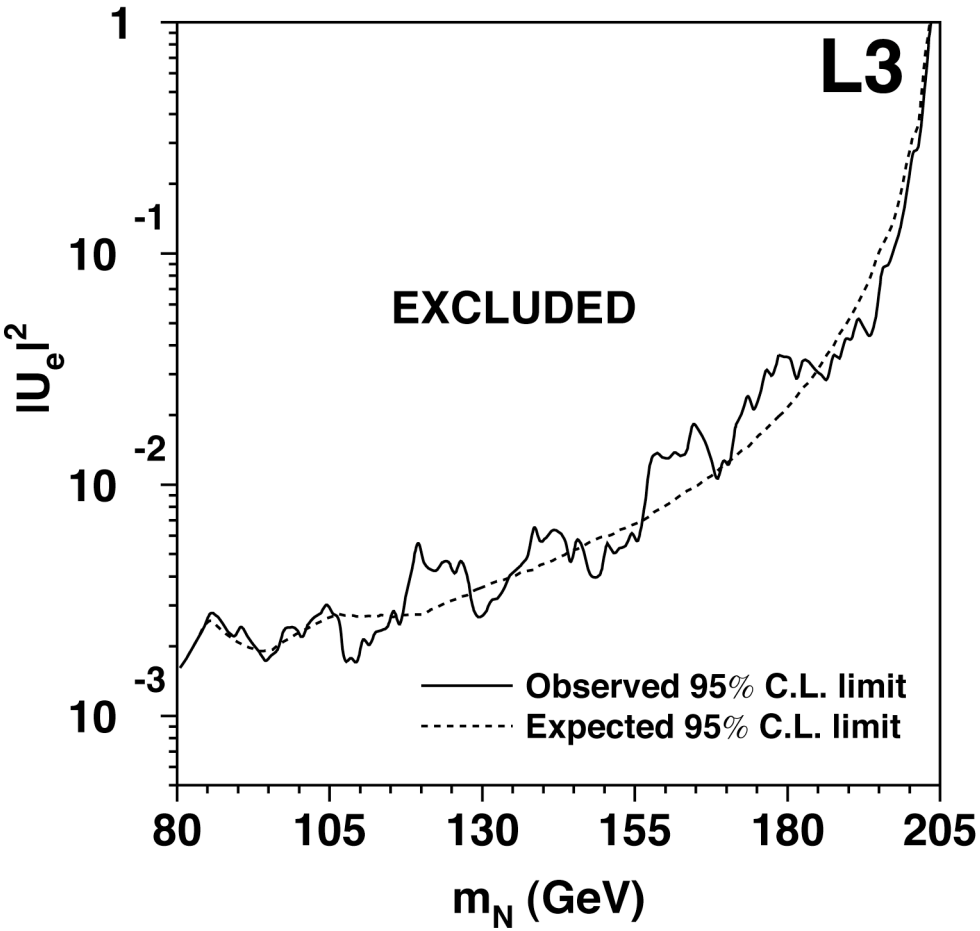
Isosinglet heavy Neutrino

s-channel



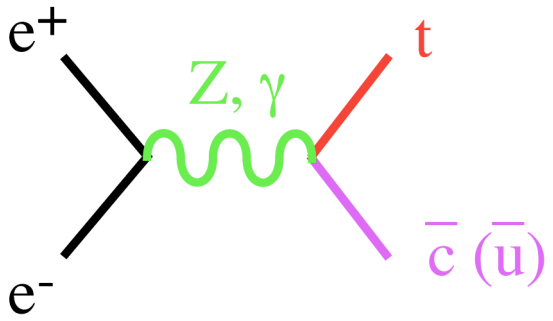
t-channel





U_l mixing amplitude with light neutrinos

Single Top quark



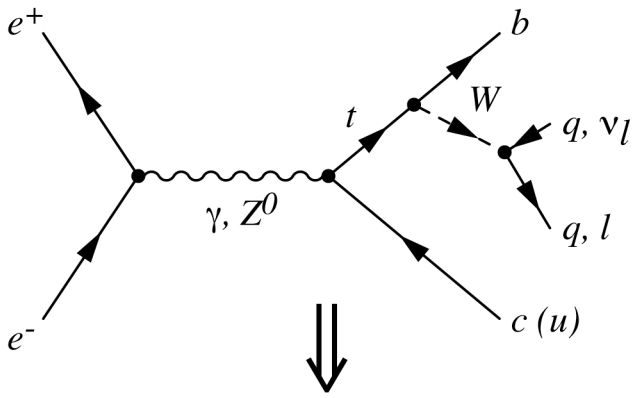
FCNC are absent in the SM at tree level.
Even at one-loop level they are severely suppressed.

SM: Single Top production ≈ 10^{-19} fb
At LEP2 energies

We can use single Top quark production as a probe for new physics!

Several extensions of the SM could enhance the production of single Top quarks at LEP.

Single Top quark



Coupling Parameters κ_Z and κ_γ

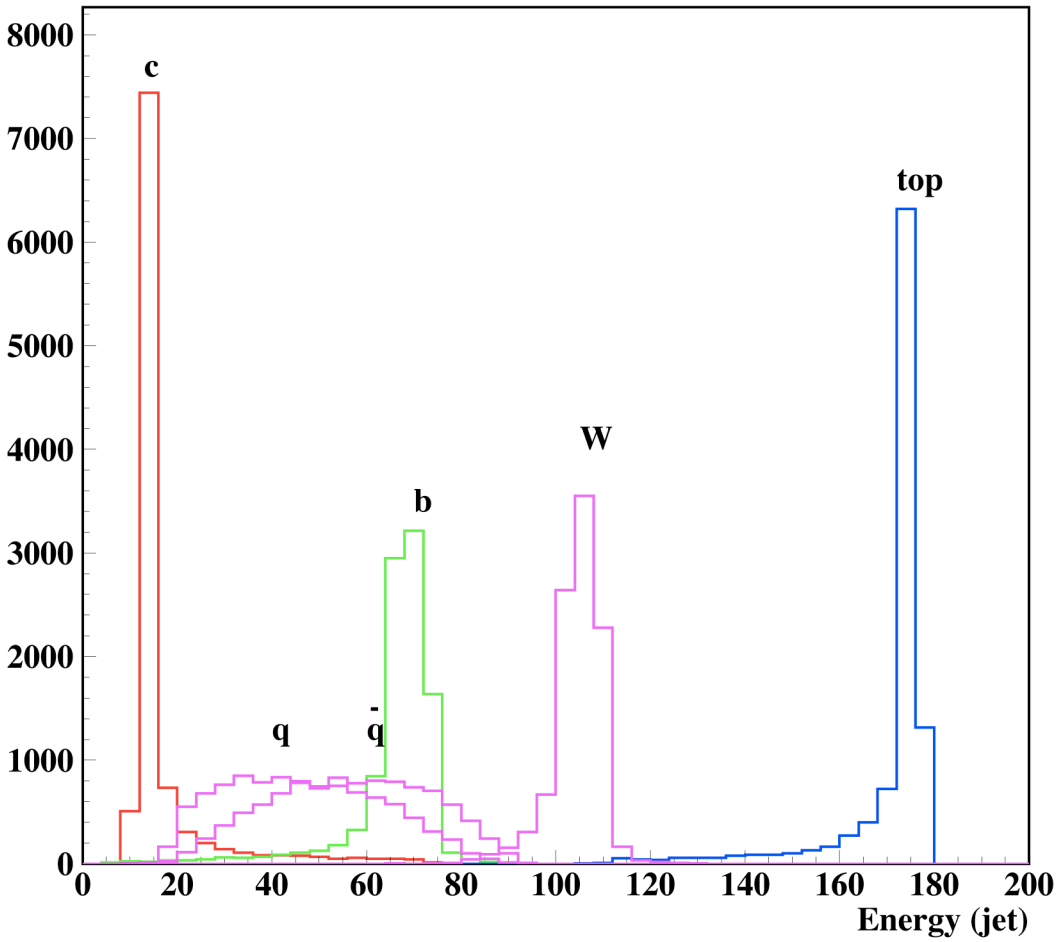
$$E_t \cong m_t$$

$$E_W \cong \frac{m_t^2 + m_W^2 - m_b^2}{2m_t}$$

$$E_b \cong \frac{m_t^2 - m_W^2 + m_b^2}{2m_t}$$

$$E_{c\,(u)} \cong \sqrt{s} - m_t$$

Characteristic kinematics



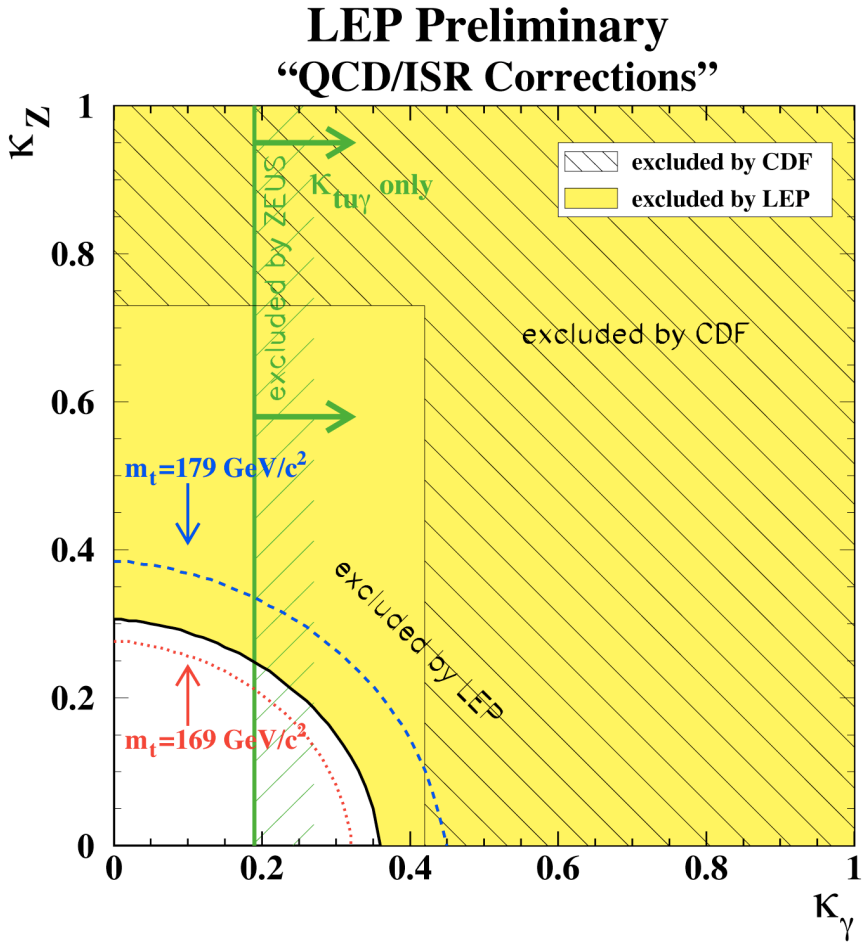
Single Top quark

Cross-section limits at each center-of-mass energy

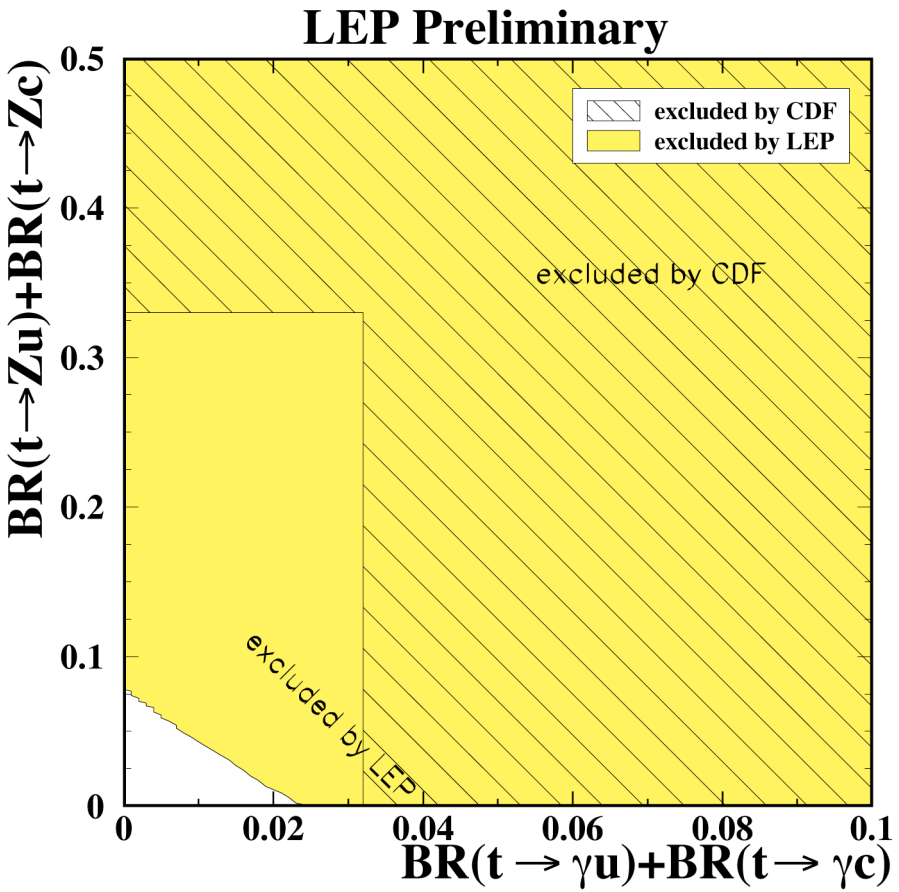
Preliminary LEP combination

Combination A+D+L+O [cross-section UL in pb]						
Label (GeV)	$m_{top} = 169\ GeV/c^2$		$m_{top} = 174\ GeV/c^2$		$m_{top} = 179\ GeV/c^2$	
	$\sigma_{95}^{obs.}$	$\sigma_{95}^{exp.}$	$\sigma_{95}^{obs.}$	$\sigma_{95}^{exp.}$	$\sigma_{95}^{obs.}$	$\sigma_{95}^{exp.}$
189	0.15	0.14	0.11	0.11	0.13	0.13
192	0.41	0.39	0.38	0.33	0.42	0.36
196	0.38	0.24	0.36	0.20	0.39	0.22
200	0.26	0.24	0.21	0.21	0.24	0.20
202	0.31	0.40	0.30	0.35	0.27	0.35
205	0.27	0.28	0.22	0.25	0.23	0.24
207	0.19	0.20	0.17	0.18	0.15	0.17

Single Top quark



Exclusion in the plane of Anomalous couplings



Exclusion in the plane of Branching Fractions

Technicolor

• *Provides a scheme to generate W/Z masses. EW symmetry broken dynamically by strong interactions of gauge bosons.*

• *Introduces new technifermions*

$$\begin{pmatrix} T_V \\ T_D \end{pmatrix}$$ *which obey a QCD-like*

Interaction with an effective scale $\Lambda_{TC} >> \Lambda_{QCD}$

• *At* Λ_{TC} *, TC interation becomes strong* $\Rightarrow$ *techniquark condensates replace non zero VEV of Higgs field:*

$$<\bar{T}T> = F_\pi \sim 246\ GeV$$

• *Extensions are worked out to solve problems:*

• *These extensions call for a large number* N_D *of technidoublets* $\Rightarrow$ *additional scalar* (π_T, π'_T) *and vector* (ρ_T, ω_T) *mesons which can be light enough to be observed at LEP2.*

Technicolor

$e^+e^- \to \gamma_T \to f\bar{f}$ (below WW threshold)

$e^+e^- \to \gamma_T \to W^+W^-$ (above WW threshold)

$\gamma_T \to W^\pm \pi_T^\pm, \pi_T^0 \gamma$

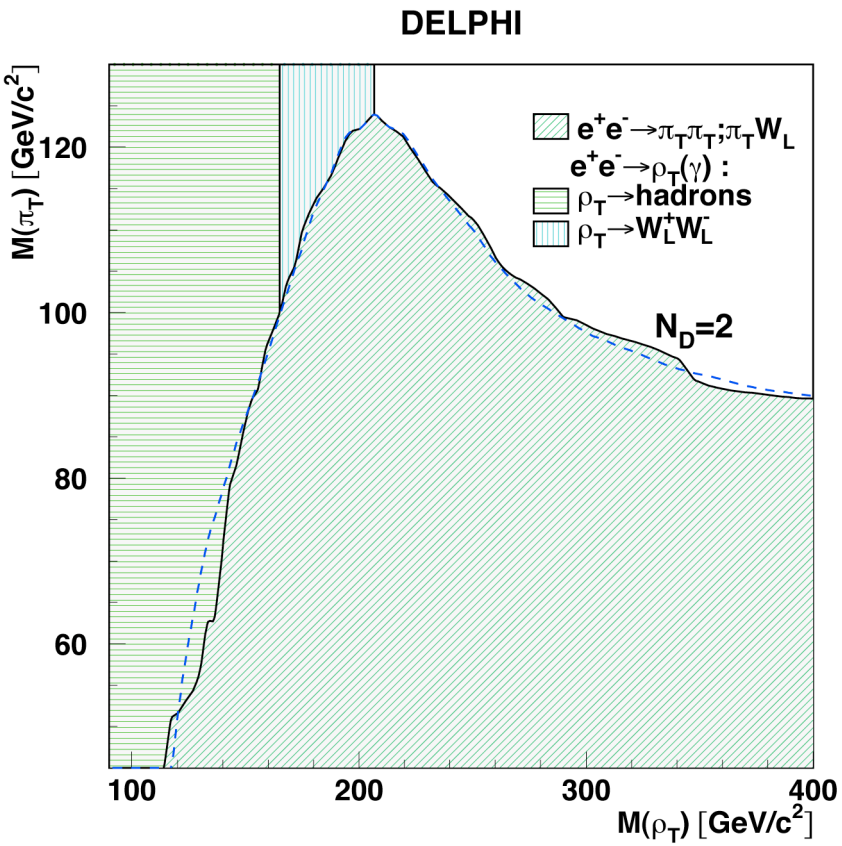
$\gamma_T \to \pi_T^- \pi_T^+$

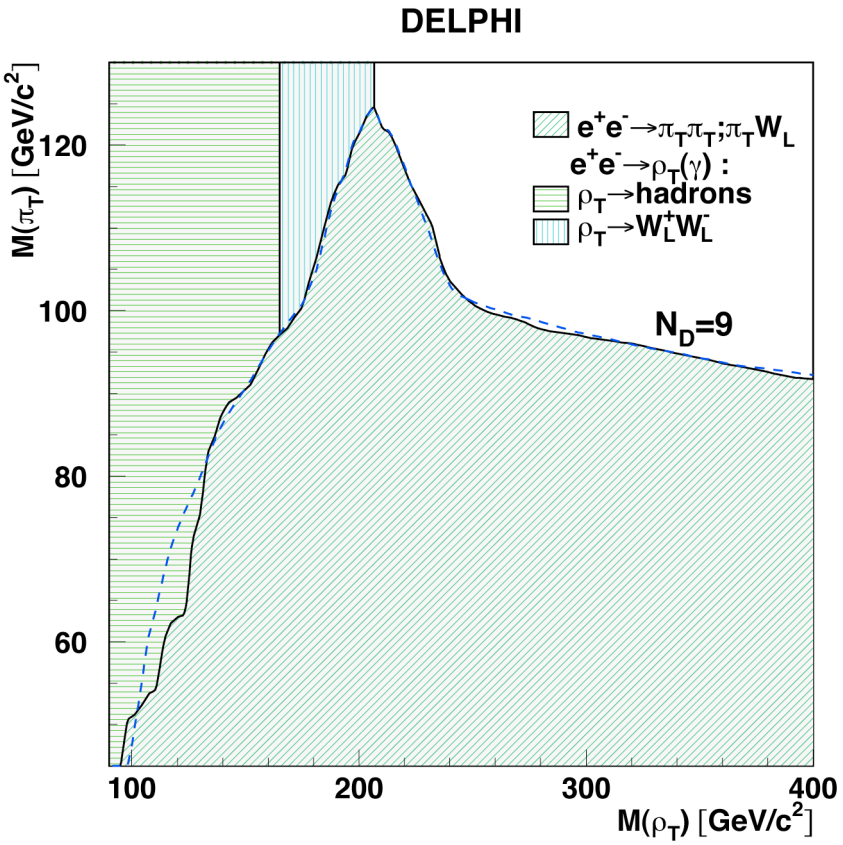
Important decays $\pi_T^+ \to \bar{b}c, \bar{b}u$

Technicolor

No significant contribution of technicolor production is observed

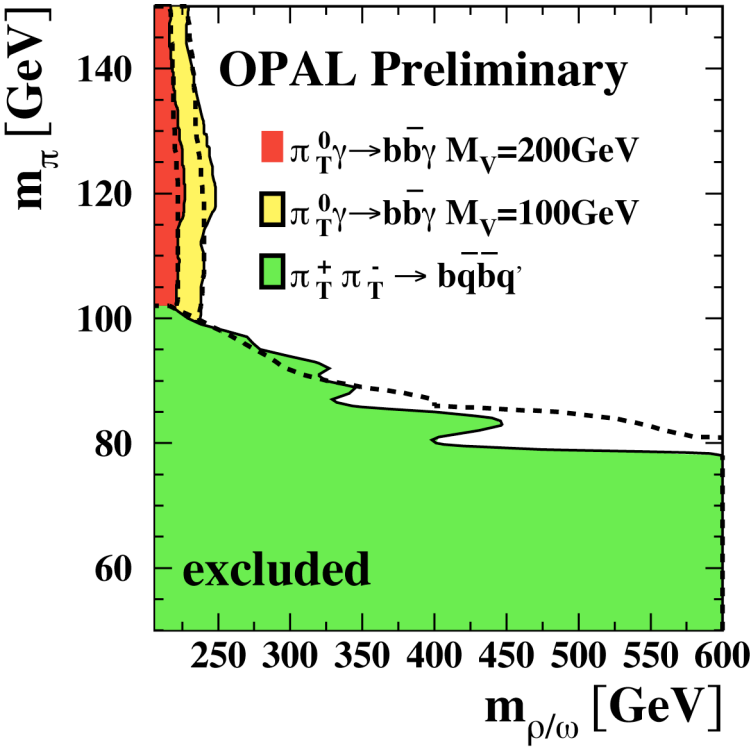
95% CL exclusion region in the (M_{π_T}, M_{ρ_T}) plane

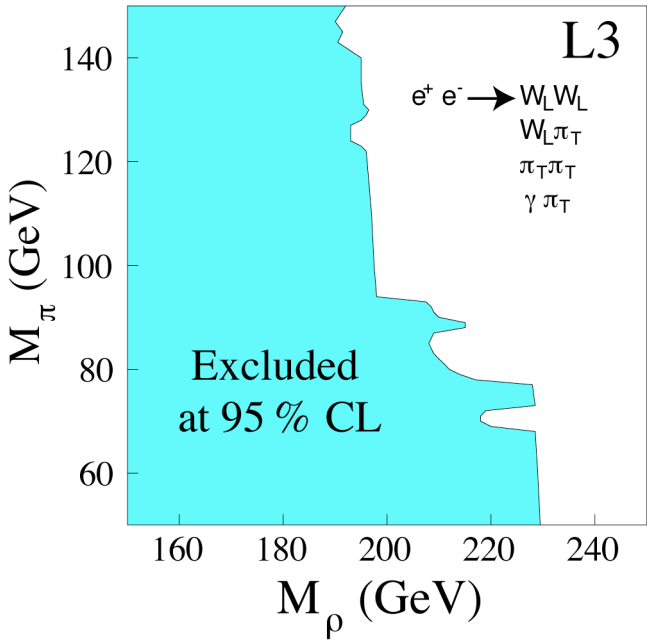




$M_{\pi_T^\pm} > 89.1$ (79.8) N_D=9 (N_D=2)

Technicolor



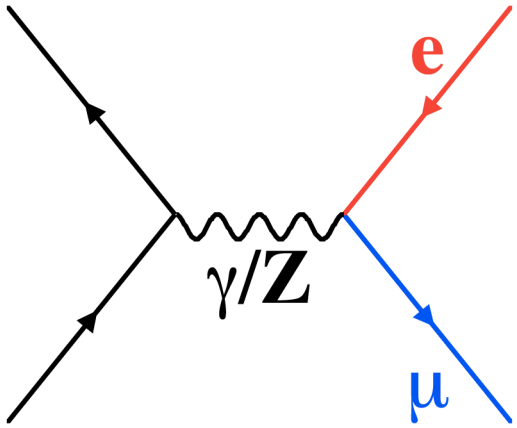


$N_D = 9$, $(Q_U + Q_D) = 5/3$

$M_{\pi_T^\pm} > 62.0$ (77.0) N_D=2 (N_D=9)

Lepton Flavor Violation

Phys.Lett. B519 (2001) 23



LFV possible via ν oscillations or SUSY
no measurable effects at LEP2 predicted

search for events with 2 leptons, of different flavor
ll' in barrel, no additional photons
no missing momentum (apart from τ decay)

type	ε	Data	MC	$e^+ e^-$	$\mu^+ \mu^-$	$\tau^+ \tau^-$	other
$e\mu$	56%	1	0.019	0	0	0.015	0.004
$e\tau$	24%	5	5.01	4.55	0.02	0.52	0.004
$\mu\tau$	22%	11	14.3	0.02	5.90	8.40	0

1-prong hadron misidentification rate: e: 3% μ: 1.6%

Summary

- *LEP has been a great success until its very end*
- *A broad spectrum of new particle searches have been and are still actively pursued… but no indication for Physics beyond the SM*
- *Results are interpreted in various models*
- *Existing limits have been extended:*

  ⇨ *plenty of results (final and preliminary) using all the data collected at LEP*

  LEP exotica working group combining results on:

  single top, excited leptons, technicolor

- *We are working towards FINAL LEP results, most should be ready for the summer*
- *Apologies for results which I did not have time to show*
- *Many thanks to my LEP colleagues who helped me to prepare this talk*