General Particle Searches at LEP

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DESY Zeuthen & CERN

- Contact Interactions
- Z'
- Heavy Leptons
- Technicolour

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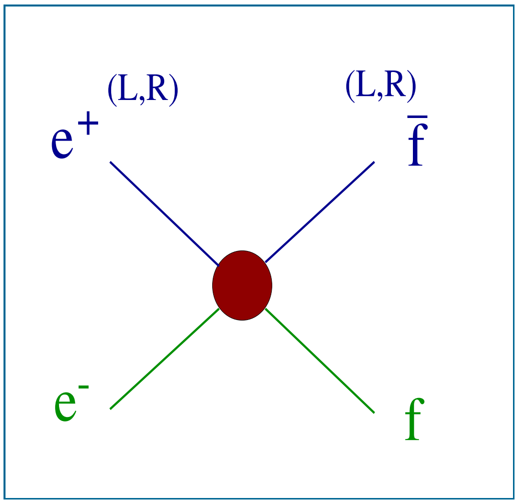
contact interactions

Generic ansatz to describe contact interactions:

$$\mathcal{L} \sim \eta_{(L,R)} \frac{g^2}{\Lambda^2} \sum_{L,R} (\bar{e}\gamma^{\nu} e)(\bar{f}\gamma_{\nu} f)$$

conventions: $g^2/4\pi = 1$; L,R specified by a model

free parameter: Λ

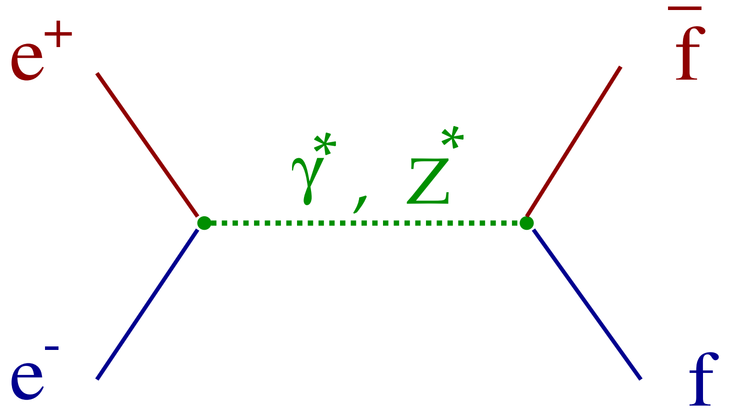


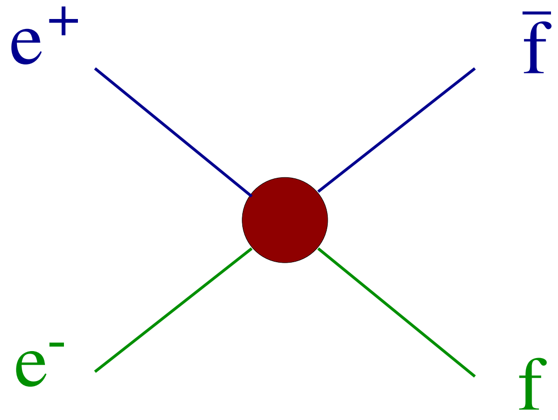
Model	LL	RR	LR	RL	VV	AA	V0	A0
η_{LL}	± 1	0	0	0	± 1	± 1	± 1	0
η_{RR}	0	± 1	0	0	± 1	± 1	± 1	0
η_{LR}	0	0	± 1	0	± 1	∓ 1	0	± 1
η_{RL}	0	0	0	± 1	± 1	∓ 1	0	± 1

Study done for $\mathrm{e^+e^-} \rightarrow \mathrm{f\,\bar{f}}$, with $\mathrm{f} = \mathrm{e}, \mu, \tau$ or q (where $\mathrm{q\bar{q}}$ is $\mathrm{u\bar{u}}$, $\mathrm{d\bar{d}}$, or $\mathrm{b\bar{b}}$).

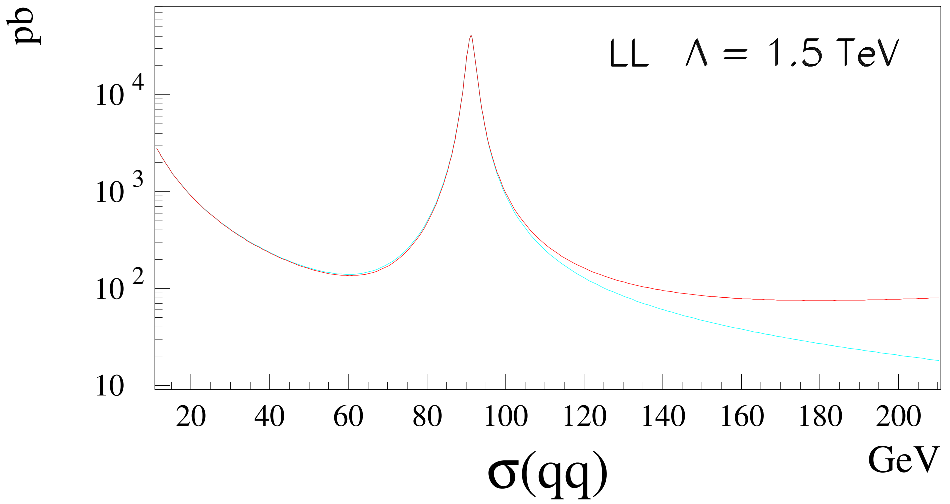
contact interactions

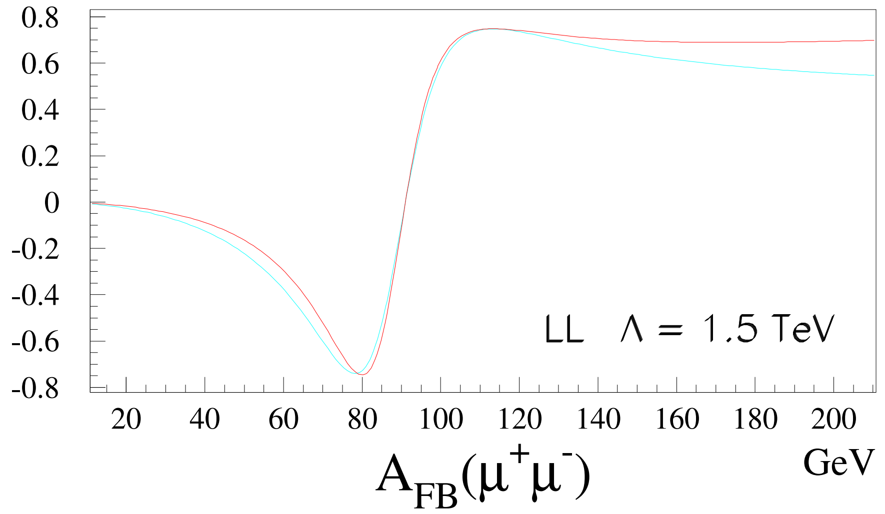
probe σ_{tot} and A_{FB} of $e^+e^- \longrightarrow f\bar{f}$





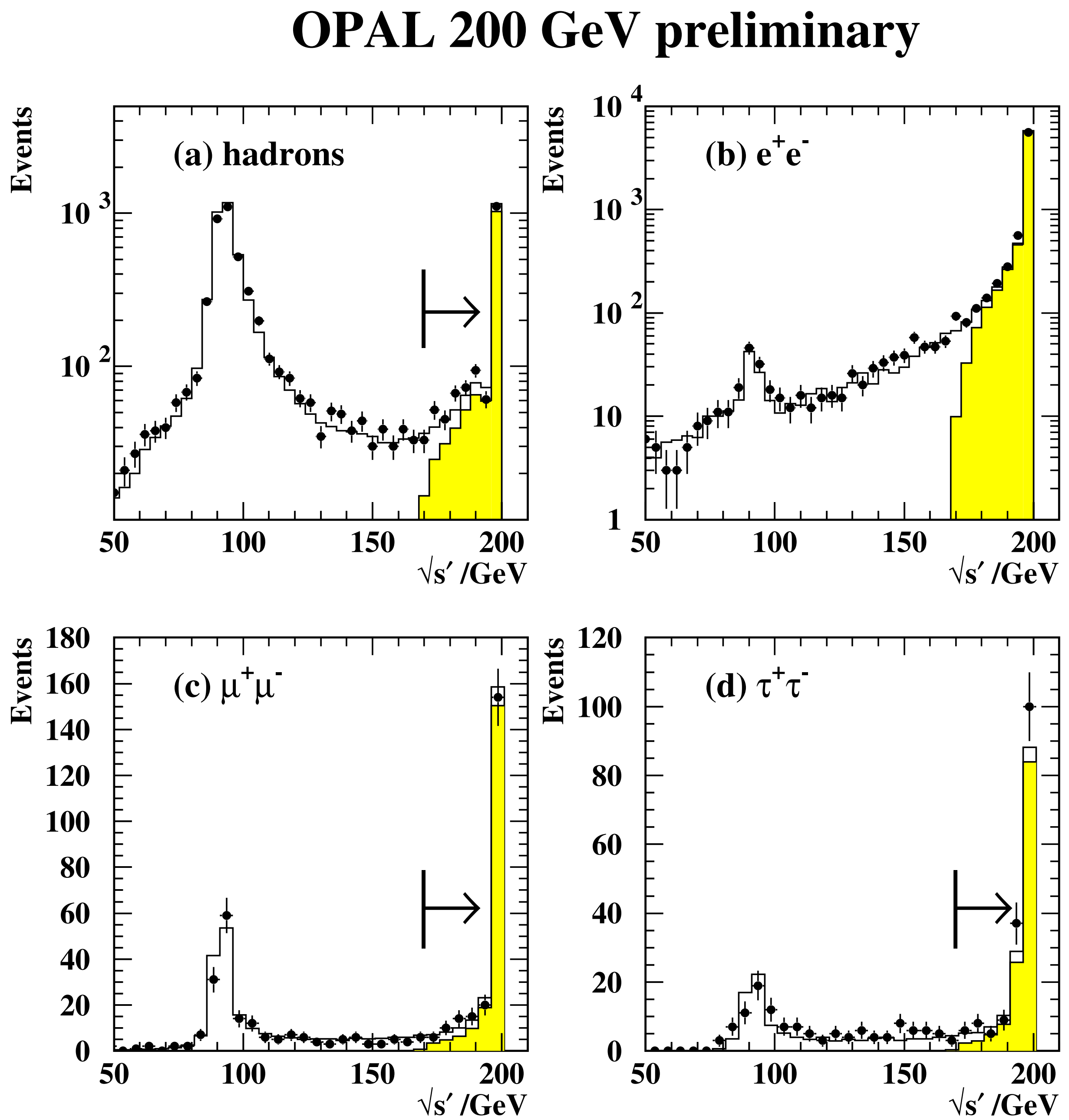
$$\frac{d\sigma}{dcos\theta} = \frac{d\sigma^{SM}}{dcos\theta} + c_2(s, cos\theta)\frac{1}{\Lambda^2} + c_4(s, cos\theta)\frac{1}{\Lambda^4}$$





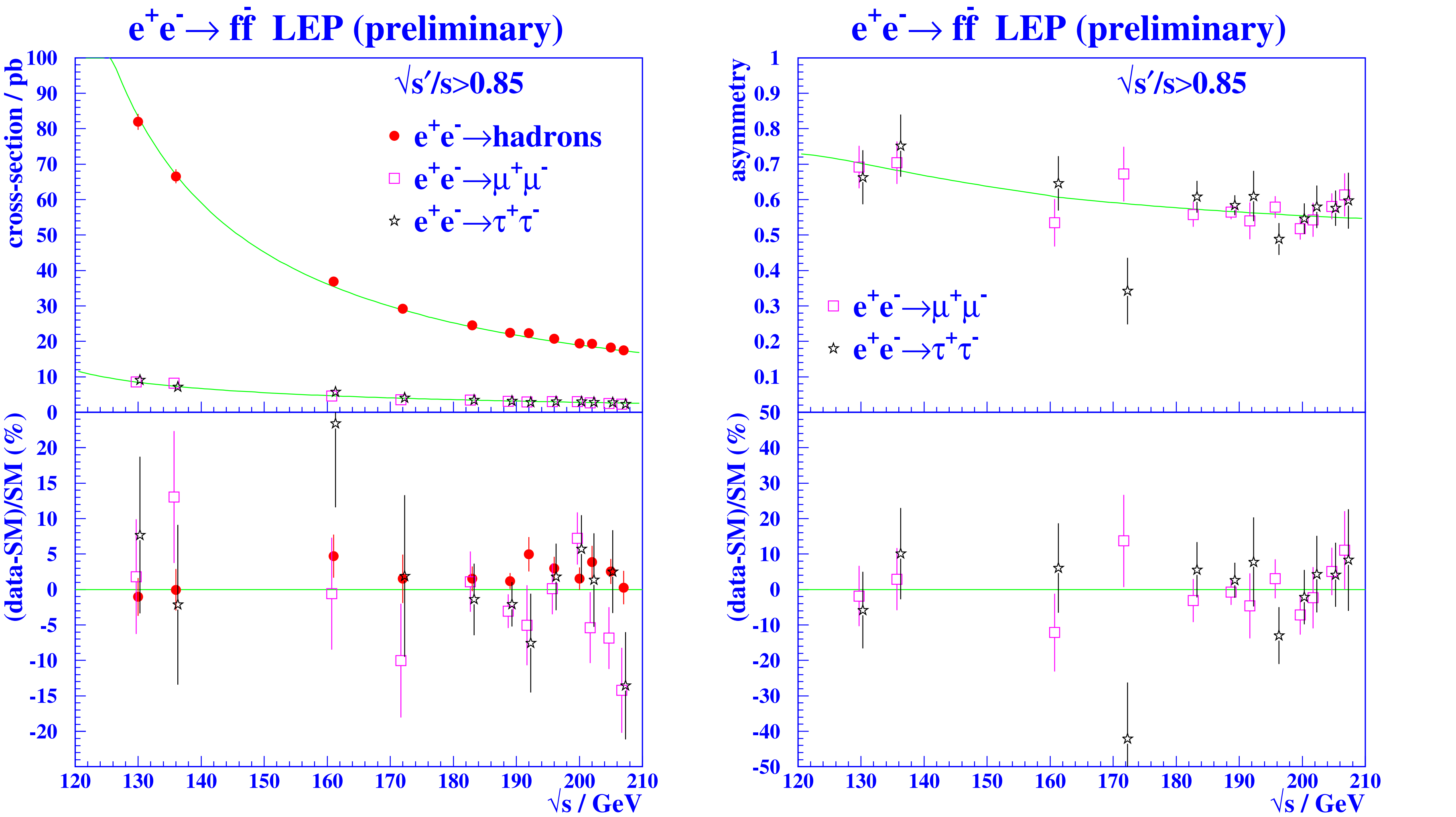
All LEP experiments analysed data taken between $\sqrt{s}$ = 130 GeV and $\sqrt{s}$ = 202 GeV ($\approx$ 490 pb^{-1})

e.g. OPAL



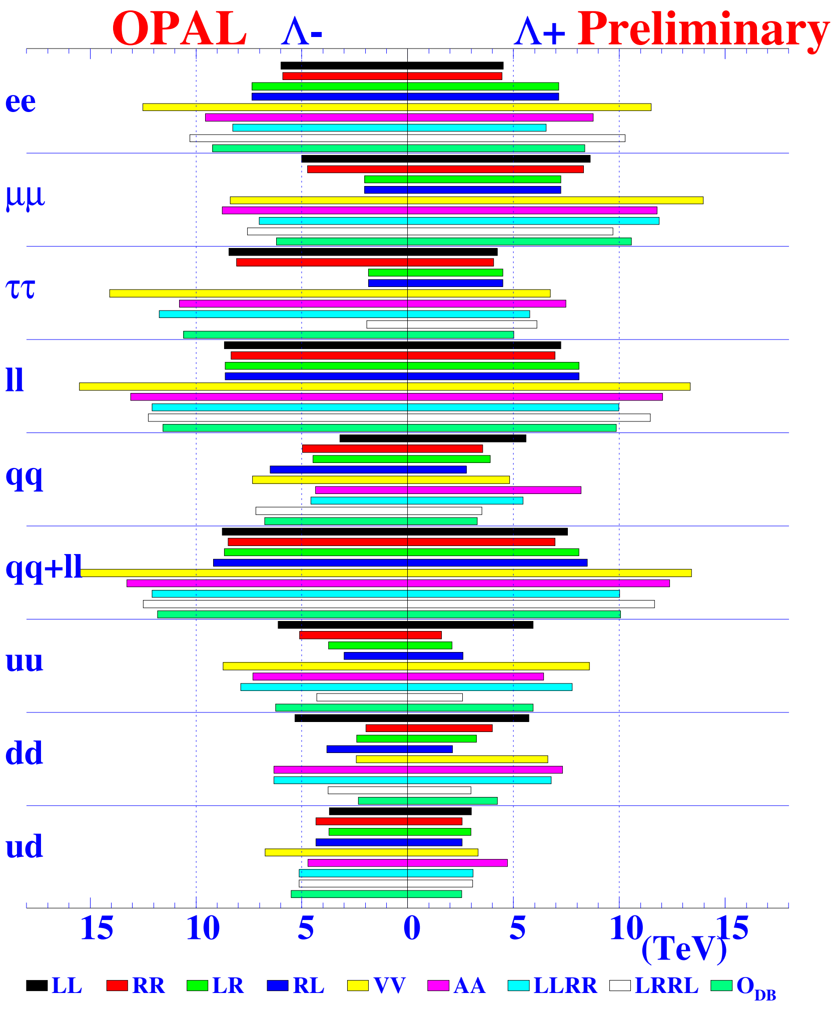
(only the high $\sqrt{s'}$ part of the spectra is interesting!)

Cross sections and F-B Asymmetries, LEP combined



contact interactions

results from single experiments



highest limits:

final state	model	Λ (TeV)
$\ell^+\ell^-$	VV	17.8
$q\bar{q}$	AA	11.2
$u\bar{u}$	VV	12.9
$d\bar{d}$	AA	9.8
$f\bar{f}$	VV	17.9

lowest limits:

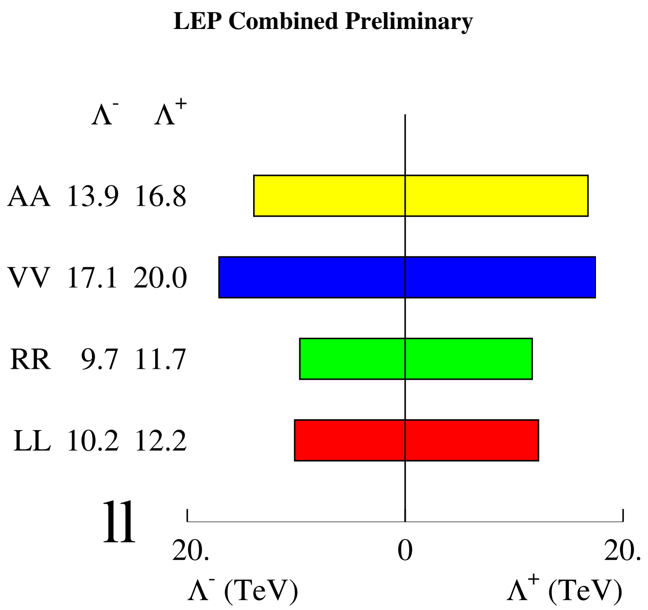
final state	model	Λ (TeV)
$\ell^+\ell^-$	RR	5.9
$q\bar{q}$	RL	2.7
$u\bar{u}$	RR	1.5
$d\bar{d}$	RR	1.8
$f\bar{f}$	RR	5.5

$$10^{-17} - 10^{-18} cm$$

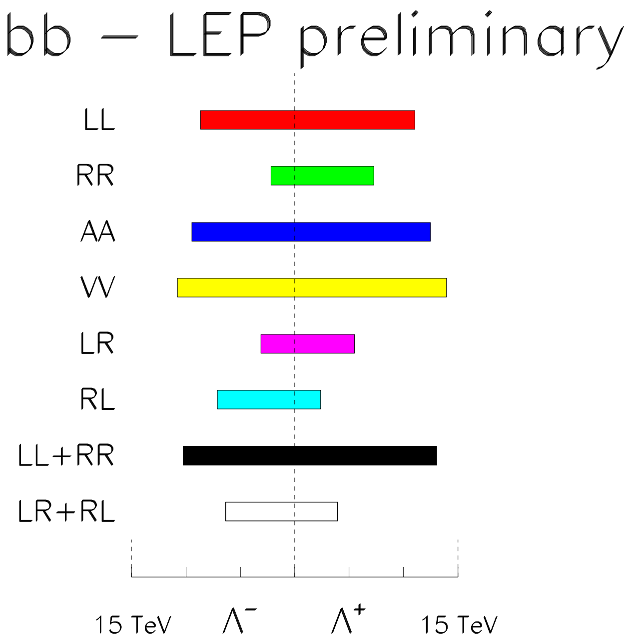
contact interactions

LEP combined results

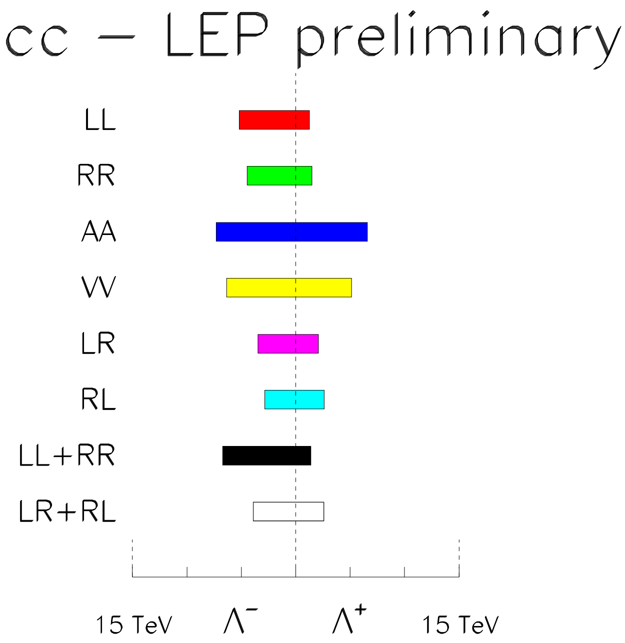
leptons



b-quarks



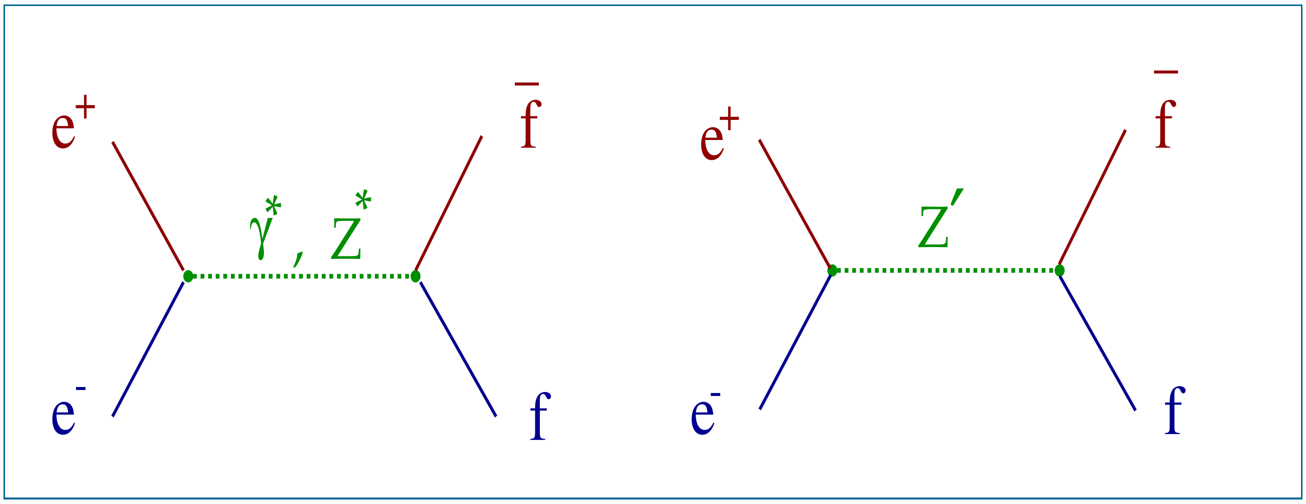
c-quarks



extra gauge boson Z'

Generic ansatz to consider an additional boson Z':

$$\mathcal{L} \sim eA_\mu J^\mu_{(\gamma)} + gZ_\mu J^\mu_{(Z)} + gZ'_\mu J^\mu_{(Z')}$$



particularity: Z, Z' mixing;

$$\begin{pmatrix} Z \\ Z' \end{pmatrix} = \begin{pmatrix} \cos\theta_M & \sin\theta_M \\ -\sin\theta_M & \cos\theta_M \end{pmatrix} \begin{pmatrix} Z^0 \\ Z^{0\prime} \end{pmatrix}$$

θ_M is bounded from LEP1 measurements to very small values.

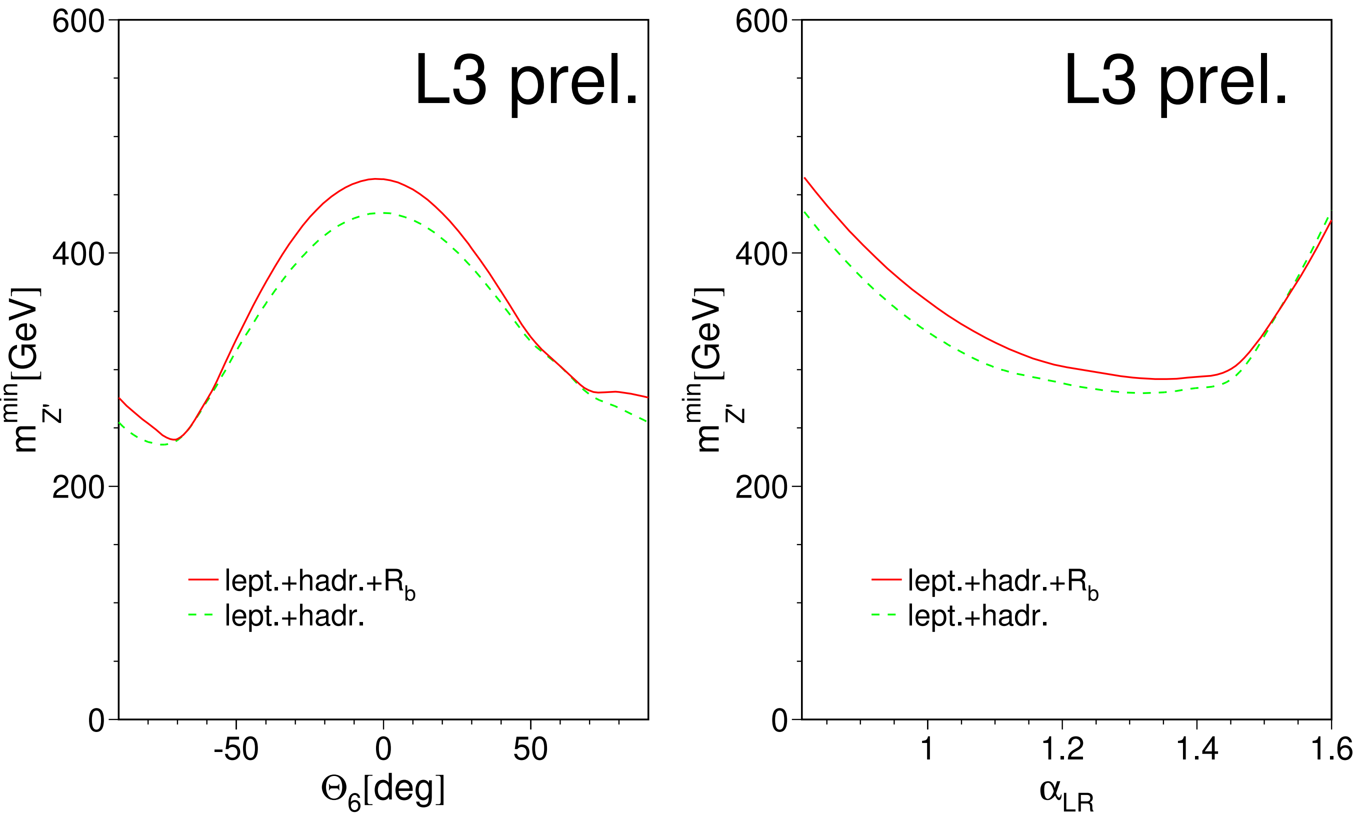
$$\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{f}\,\bar{\mathrm{f}}\,) = \sigma_{\gamma\gamma} + \sigma_{\gamma Z} + \sigma_{ZZ} \boxed{+\sigma_{\gamma Z'} + \sigma_{ZZ'} + \sigma_{Z'Z'}}$$

Couplings to fermions fixed using models

extra gauge boson Z'

E6 models: $\boxed{J^{\mu}_{Z'} = J^{\mu}_{\chi}\cos\Theta_6 + J^{\mu}_{\psi}\sin\Theta_6}$

L-R models: $\boxed{J_{LR} = \alpha_{LR} J^{\mu}_{3R} - \frac{1}{2\alpha_{LR}} J^{\mu}_{B-L}}$



- χ model: Θ_6=0
- ψ model: Θ_6=π/2
- η model: Θ_6=$-\arctan\sqrt{(5/3)}$
- LR model: $g_L = g_R$

SSM: Z' couplings equal the SM Z couplings

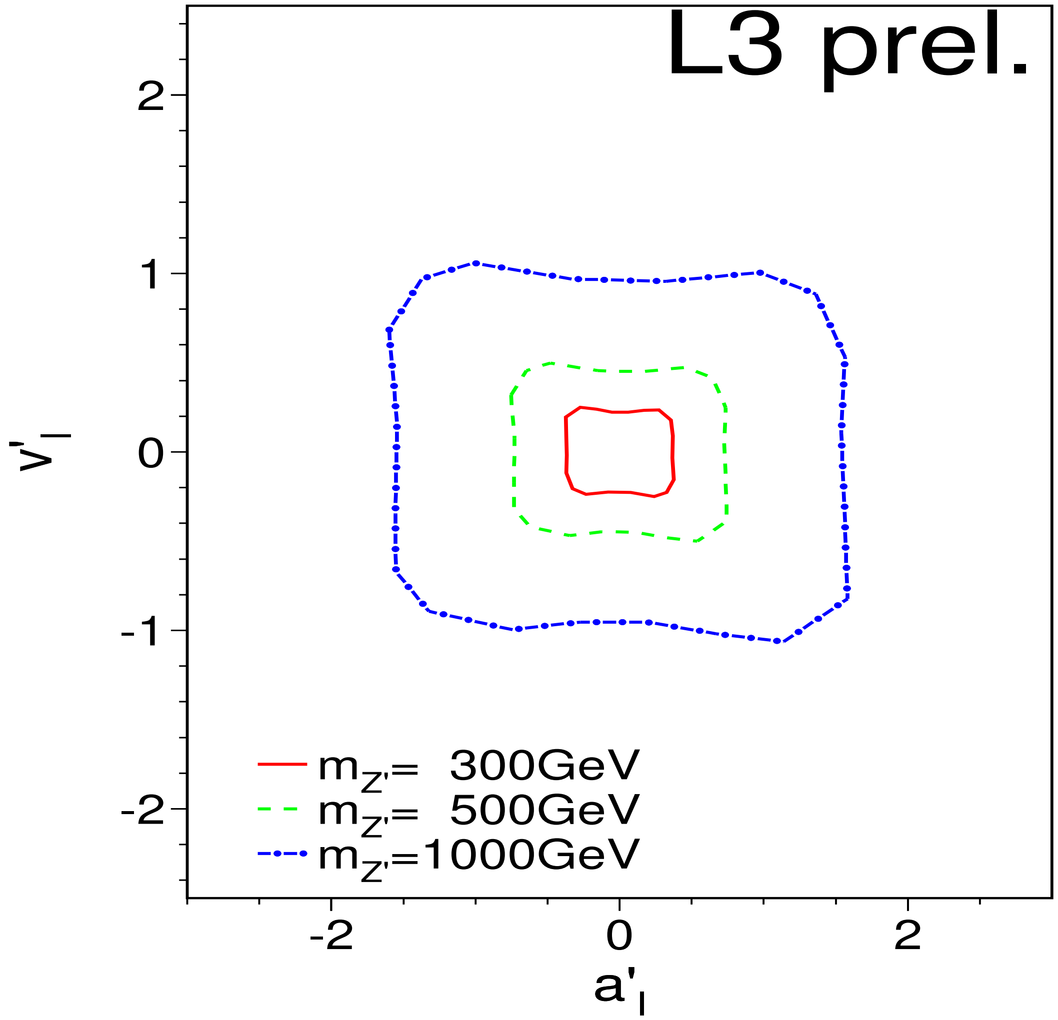
All LEP experiments exploited cross sections and A_{FB}

model	$M_{Z'}$ lower limit, GeV single experiments	LEP combined
χ	460 - 753	679[a]
ψ	275 - 410	600
η	315 - 486	425
LR	360 - 635	
SSM	700 - 1170	

[a] from S. Riemann, DESY-Zeuthen

Model independent studies

$a'_\ell, v'_\ell, \theta_M$ and $m_{Z'}$ free parameters; ℓ = e, μ, τ; universality

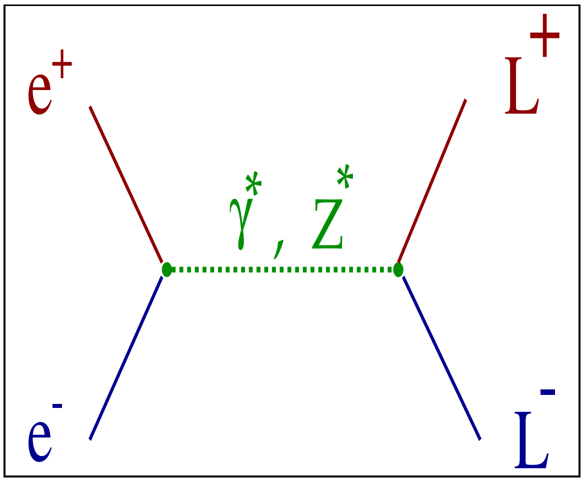


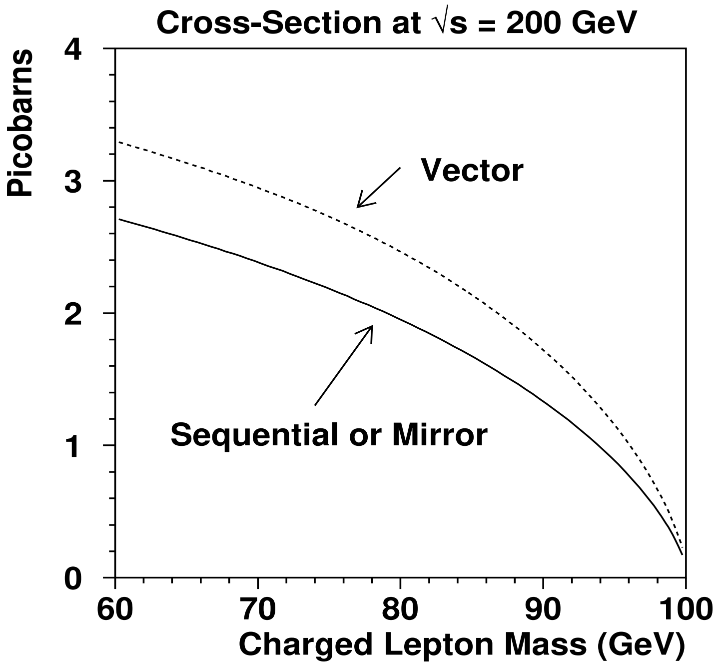
new fermions

categories:

- sequential: quantum numbers like SM fermions
- mirror: chiral properties opposite to SM
- vector: L,R couplings equal
- singlet neutrinos

Leptons





neutral leptons L^0: $\mathrm{L}^0\bar{\mathrm{L}}^0 \rightarrow \ell^+\ell^- WW \rightarrow \ell^+\ell^-\ 4jets$

$\rightarrow \ell^+\ell^-\ell\nu\ 2jets$

charged leptons $\mathrm{L}^\pm$: $\mathrm{L}^+\mathrm{L}^- \rightarrow \nu_e\bar{\nu}_e WW \rightarrow \nu_e\bar{\nu}_e\ 4jets$

$\rightarrow \nu_e\bar{\nu}_e\ell\nu\ 2jets$

$\mathrm{L}^+\mathrm{L}^- \rightarrow \mathrm{N_L}\bar{\mathrm{N}}_\mathrm{L} WW \rightarrow \mathrm{N_L}\bar{\mathrm{N}}_\mathrm{L}\ 4jets$

new leptons

Signatures

$L^0\bar{L}^0 \rightarrow \ell^+\ell^- WW, \;\; \ell = e, \mu, \tau$

- two isolated leptons of the same family
- hadronic jets(2-4)

No signal found!

lower mass limits (in GeV) from OPAL and L3

decay	L3		OPAL	
	Dirac	Majorana	Dirac	Majorana
$L^0 \rightarrow e\, W$	96.9 - 97.1	85.7	88	76
$L^0 \rightarrow \mu\, W$	96.7 -99.4	88.0	88.1	76
$L^0 \rightarrow \tau\, W$	89 - 96	79.6	71.1	53.8

$L^+\bar{L}^- \rightarrow \nu_e\bar{\nu}_e WW$

- one isolated electron or muon and two jets, or
- no lepton and four jets
- missing momentum
- W mass constraint for two-jet invariant masses

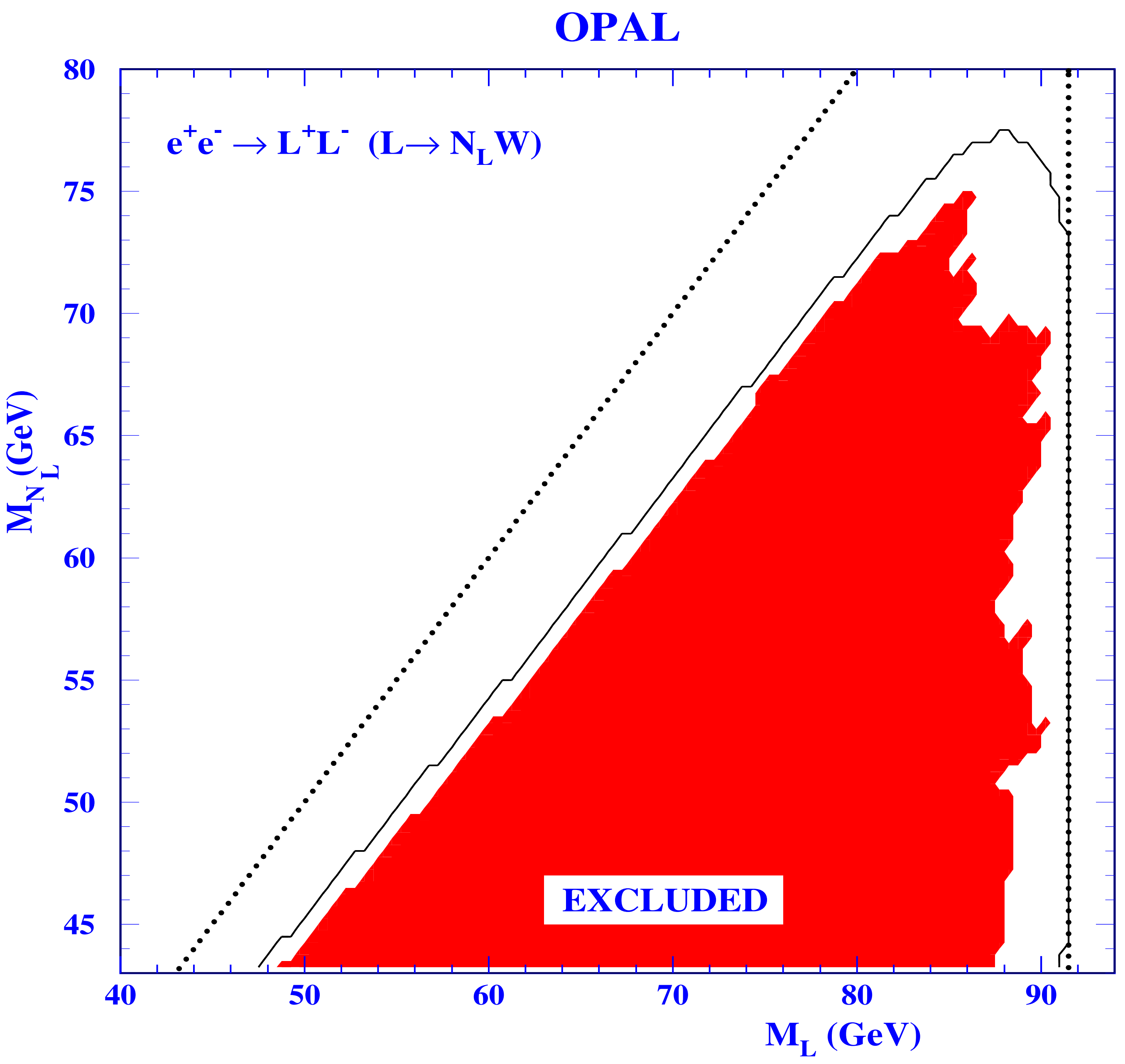
mass limits (in GeV)

decay	L3	OPAL
$L^\pm \rightarrow \nu_e\, W$	98.7 - 99.1	84.1

new leptons

$L^+\bar{L}^- \rightarrow N_L\bar{N}_L WW$

- 2 acoplanar jets
- missing momentum

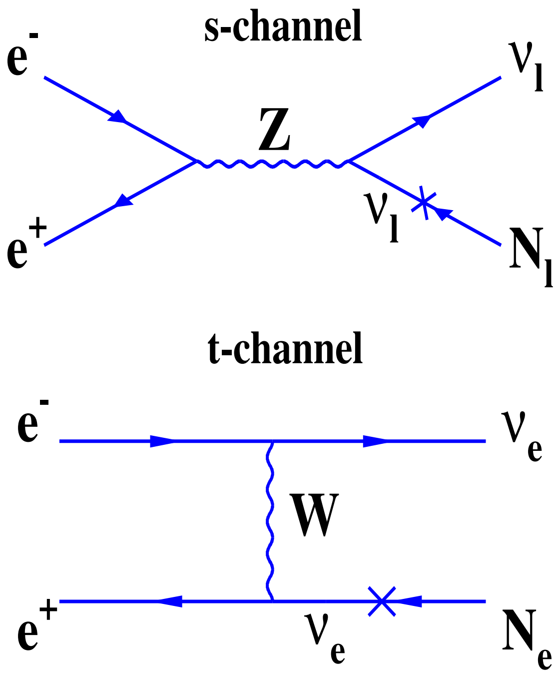


singlet neutrino

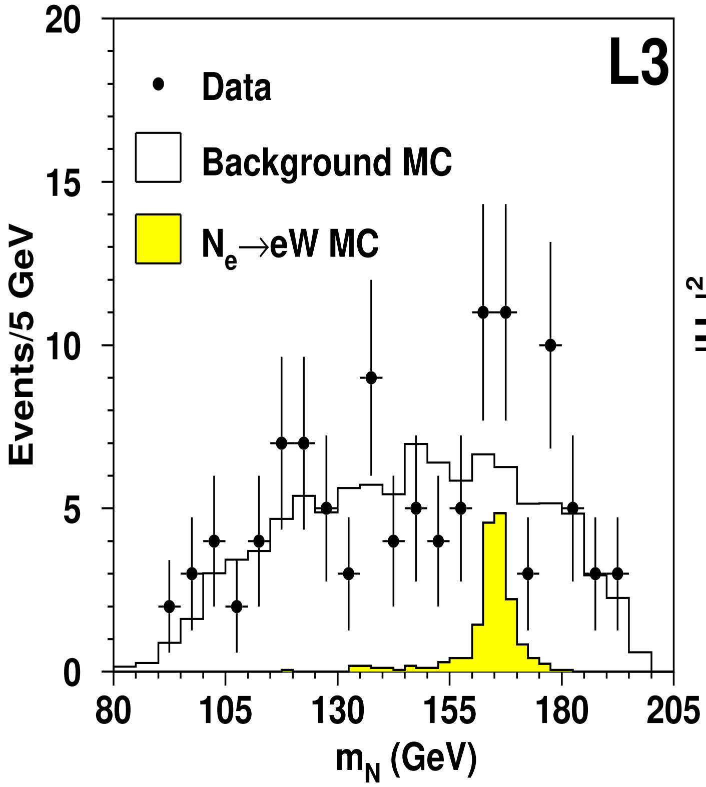
$\boxed{e^+e^- \rightarrow \mathrm{N}_e\nu_e}$

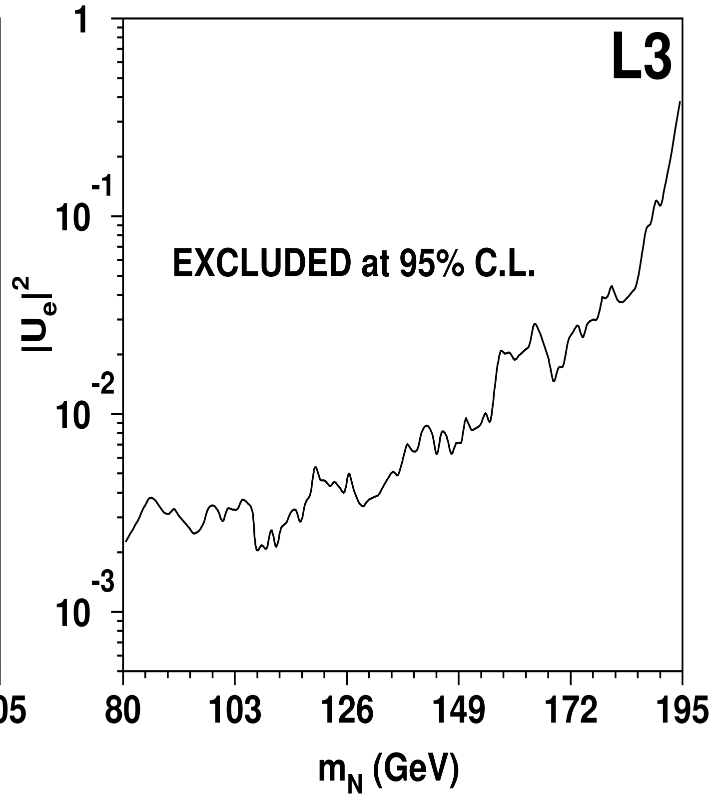
$\mathrm{N}_e \rightarrow W^-e^+$

- one isolated electron
- 2 acoplanar jets
- missing momentum



$m_\mathrm{N} > 100$ GeV $\rightarrow$ exploit W mass constraint
limits on the mixing parameter U_e





Technicolor

TC breaks electroweak symmetry dynamically by strong interactions of gauge bosons

recent extensions- 'walking technicolour' -
additional scalar (π_T) and vector (ρ_T) mesons

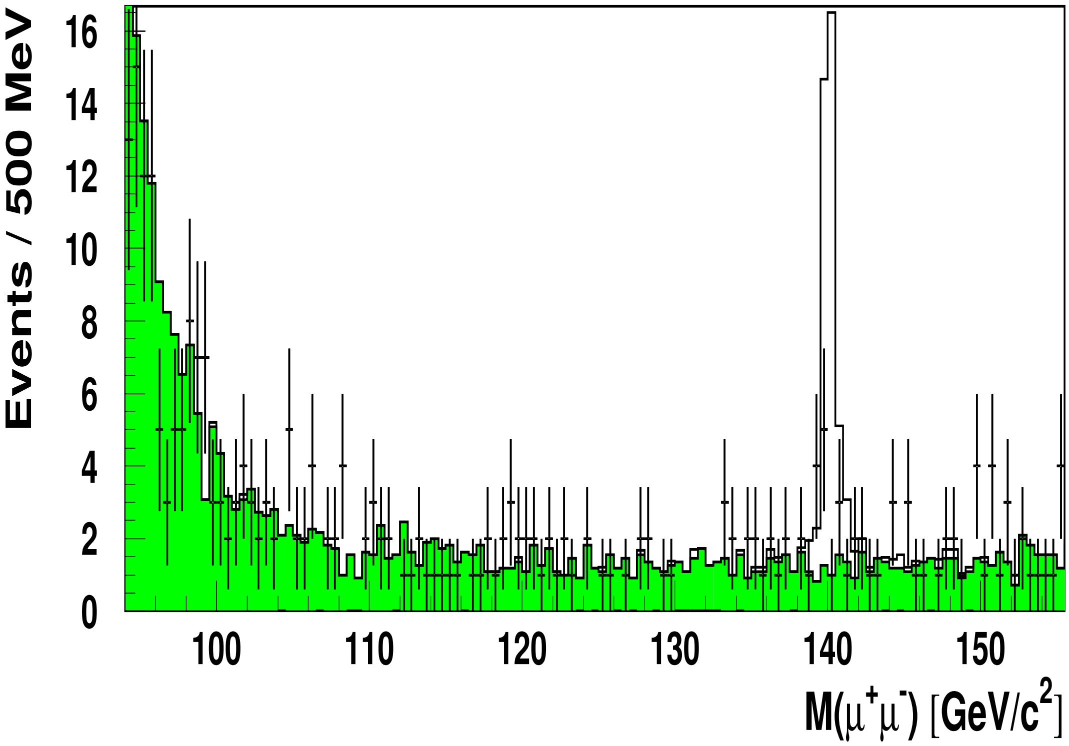
$$
\begin{array}{lll}
e^+e^- \rightarrow \rho_T^{(*)} & \rightarrow \pi_T\pi_T & \rightarrow \mathrm{b\bar{c}c\bar{b}} \\
 & \rightarrow W_L\pi_T & \rightarrow \mathrm{q\bar{q}'c\bar{b}} \\
 & \rightarrow W_LW_L & \rightarrow \text{4jets, 2jets } (\ell\nu),\ 2\ (\ell\nu) \\
 & \rightarrow \mathrm{f\bar{f}} & \\
 & \rightarrow \pi_T^0\gamma & \rightarrow \mathrm{b\bar{b}}\gamma
\end{array}
$$

consider $m_{\rho_T} < m(X, \pi_T)$, where $X = W_L, \pi_T$

$$\boxed{e^+e^- \rightarrow \rho_T^{(*)} \rightarrow W_LW_L}$$

for $m_{\rho_T} < \sqrt{s}$: cross section a few pb, excluded by $e^+e^- \rightarrow W^+W^-$ cross section measurements

$\boxed{\rho_T \rightarrow \mu^+\mu^-}$
DELPHI,
$\mathcal{L} \sim 460pb^-1$
$\sqrt{s} = 160$ GeV

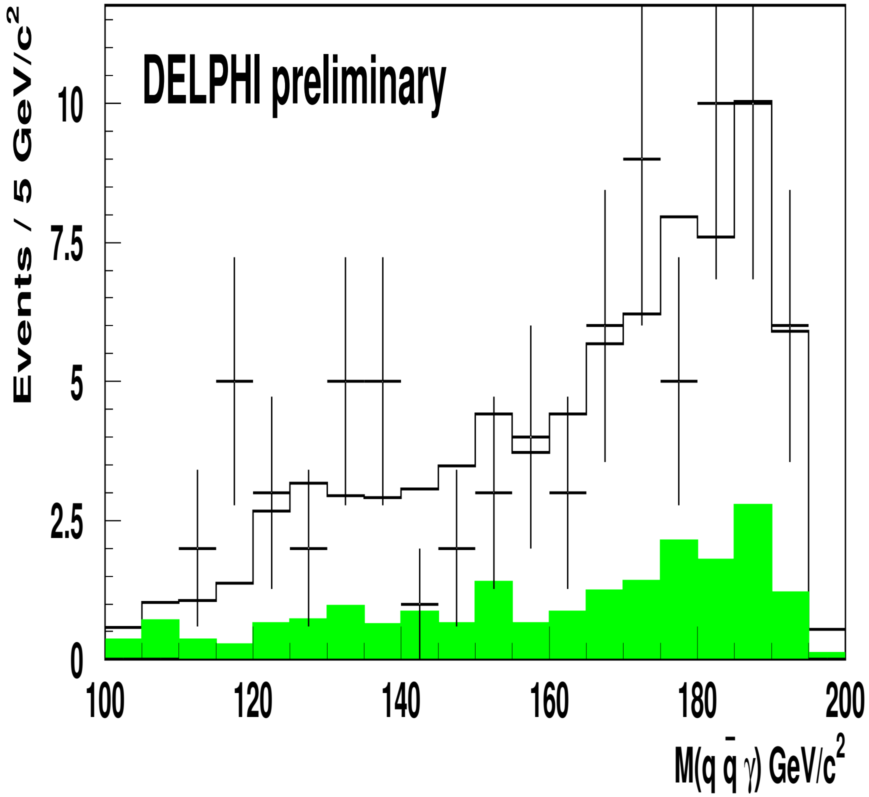


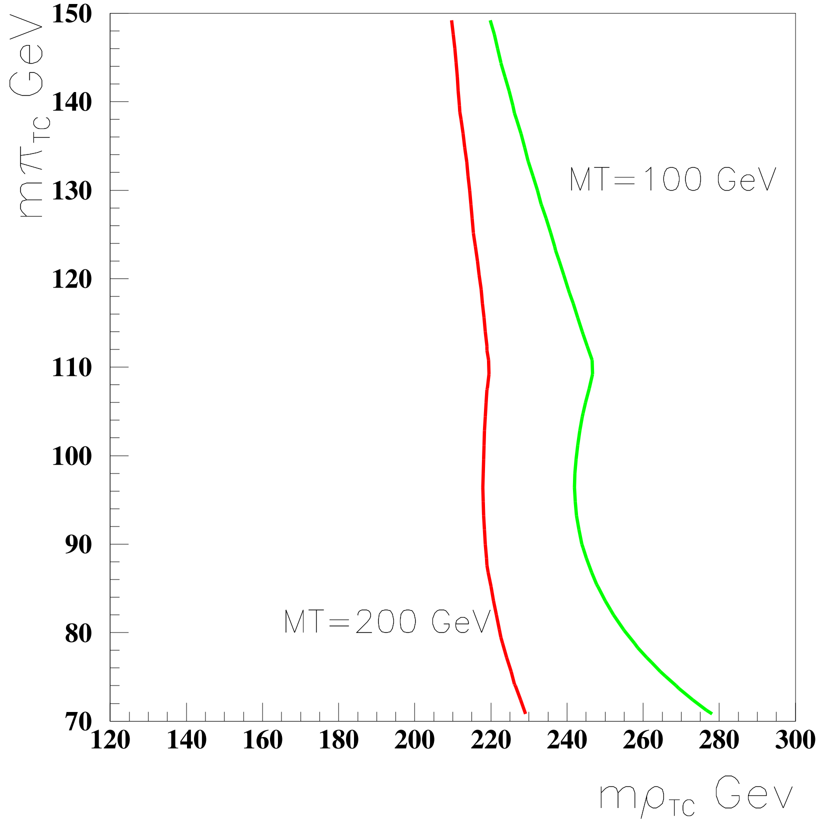
Technicolor

$\boxed{\rho_T \rightarrow \pi_T^0 \gamma \rightarrow \mathrm{b\bar{b}}\gamma}$

- two b-jets
- one isolated photon

for $m_{\rho_T} > \sqrt{s}$ - limit (with some model assumptions)



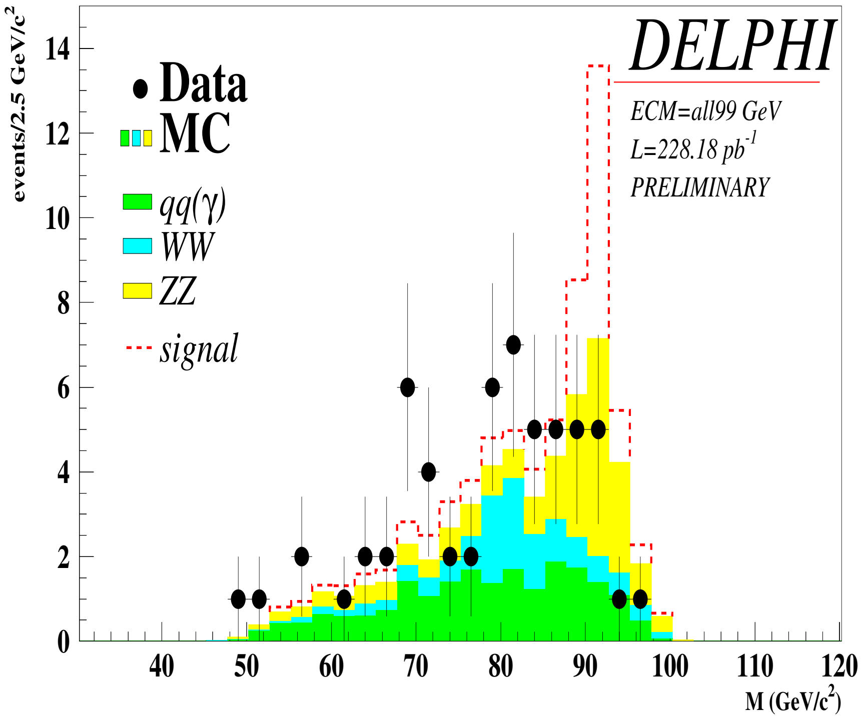


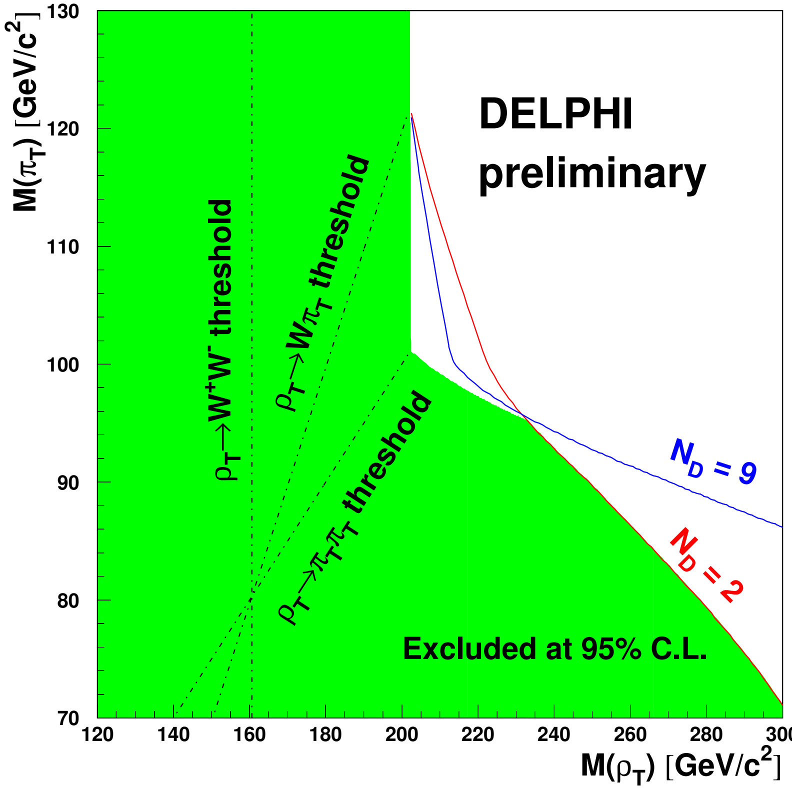
Technicolor

$$\boxed{\rho_T^{(*)} \rightarrow (W_L\pi_T), (\pi_T\pi_T) \rightarrow \mathrm{q\bar{q}b\bar{b}}}$$

$\mathcal{L} \sim 230pb^{-1}, 192 \leq \sqrt{s} \leq 202$ **GeV**

- four jets
- high b-quark probability





exclusion contour valid for any mixing angle χ,

where $\rho_T^{(*)} \rightarrow W_L\pi_T \sim \cos^4\chi$ and $\rho_T^{(*)} \rightarrow \pi_T\pi_T \sim 2\cos^2\chi\sin^2\chi$

beginning of 2000 DELPHI reported an excess in the mass $m(e^+e^-)$ from $e^+e^- \rightarrow q\bar{q}e^+e^-$ at about 55 GeV

OPAL checked the phenomenon: