General Particle Searches at LEP

Wolfgang Lohmann

DESY Zeuthen & CERN

- Contact Interactions
- Z'
- Heavy Leptons
- Technicolour

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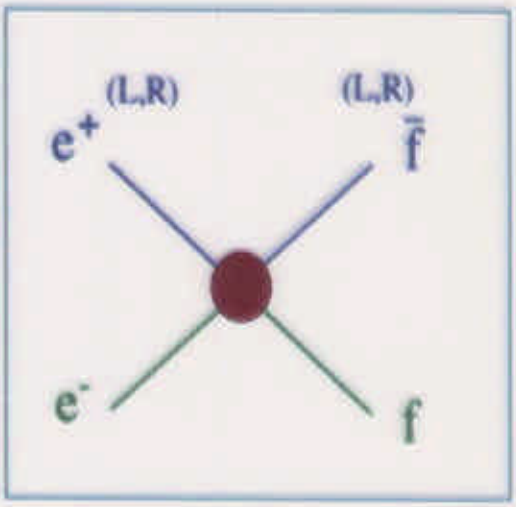
contact interactions

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

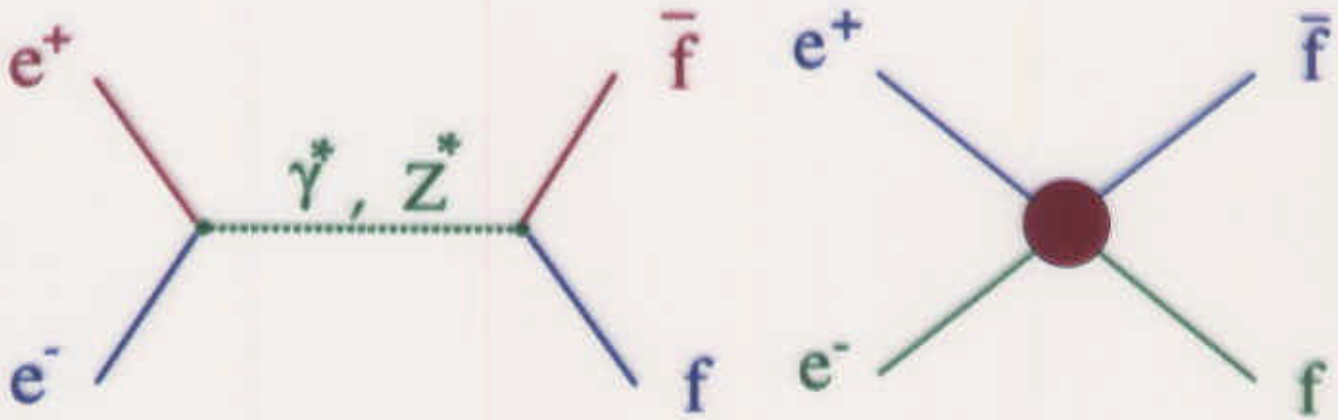
free parameter: Λ



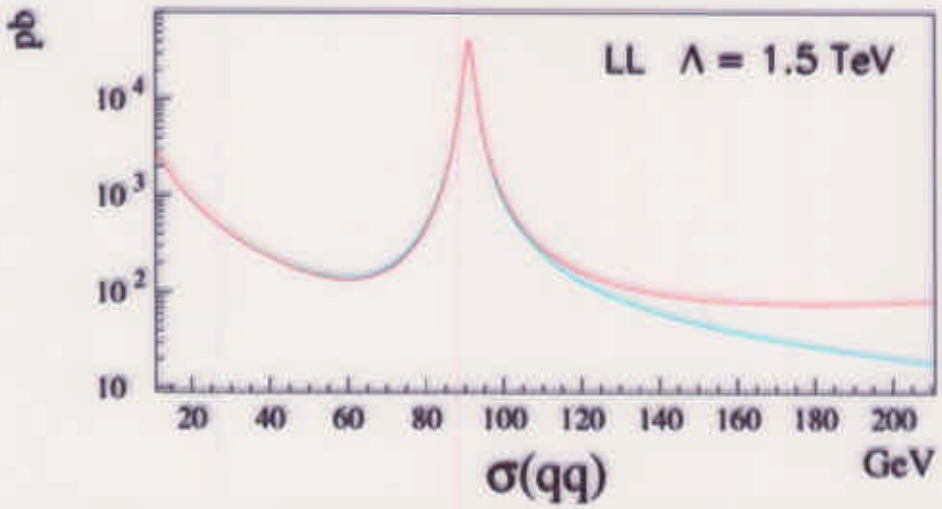
Model	LL	RR	LR	RL	VV	AA	V0	A0
η_{LL}	±1	0	0	0	±1	±1	±1	0
η_{RR}	0	±1	0	0	±1	±1	±1	0
η_{LR}	0	0	±1	0	±1	∓1	0	±1
η_{RL}	0	0	0	±1	±1	∓1	0	±1

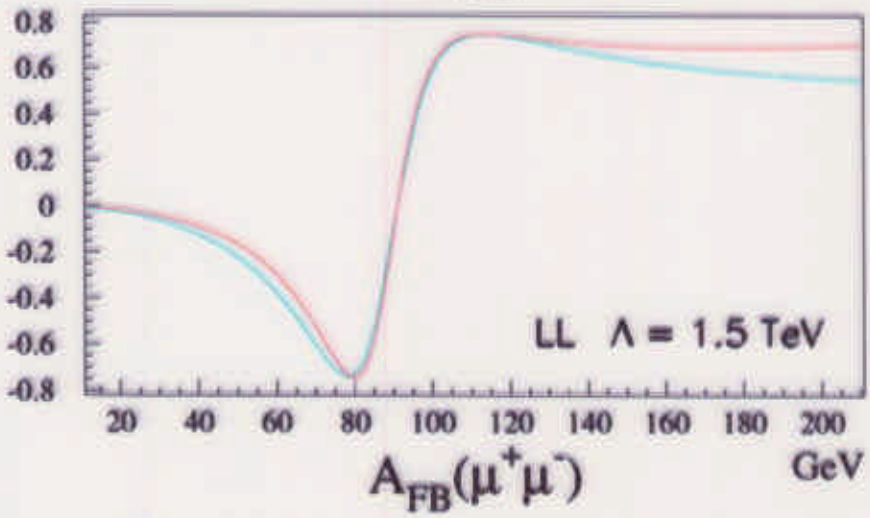
Study done for $e^+e^- \to f\bar{f}$, with $f = e, \mu, \tau$ or q
(where $q\bar{q}$ is $u\bar{u}$, $d\bar{d}$, or $b\bar{b}$).

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



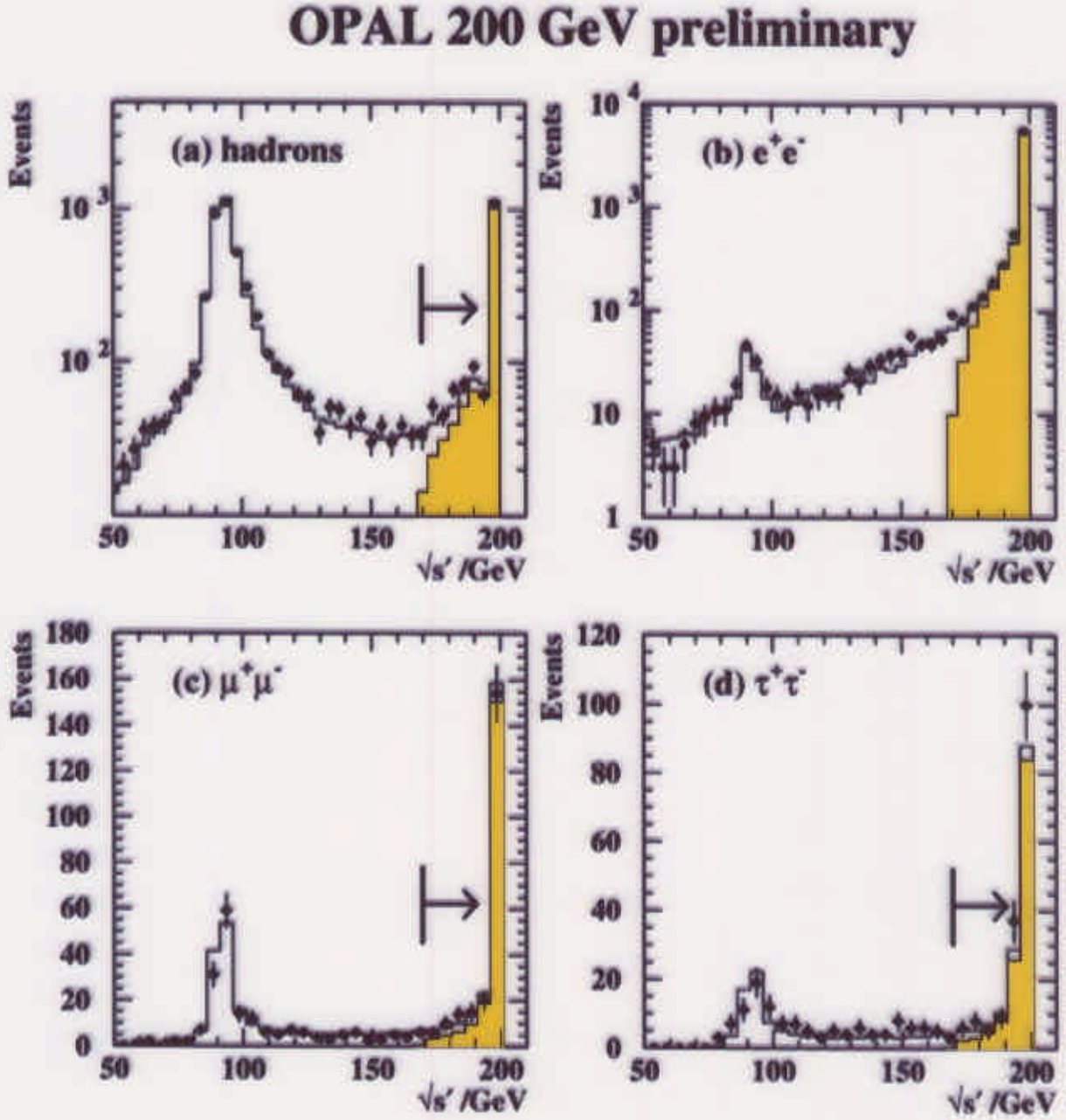
$$\frac{d\sigma}{dcos\theta} = \frac{d\sigma^{SM}}{dcos\theta} + c_2(s, cos\theta)\frac{1}{\Lambda^2} + c_4(s, cos\theta)\frac{1}{\Lambda^4}$$





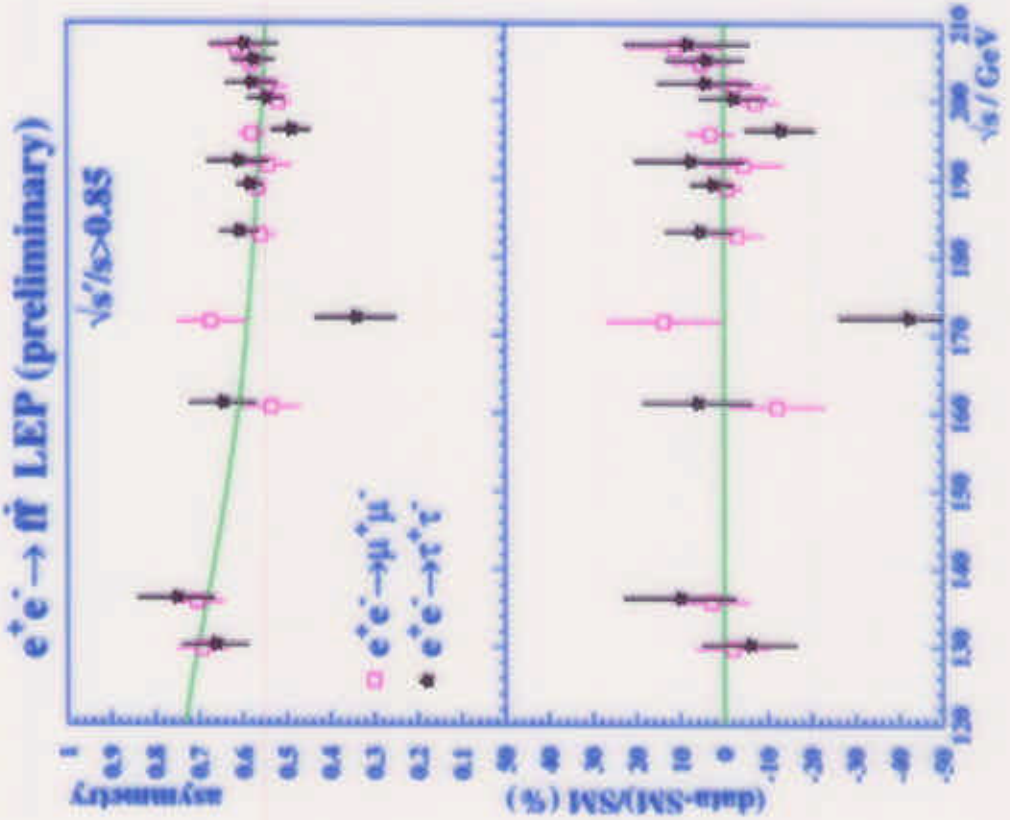
All LEP experiments analysed data taken between $\sqrt{s} = 130$ GeV and $\sqrt{s} = 202$ GeV ($\approx 490\ pb^{-1}$)

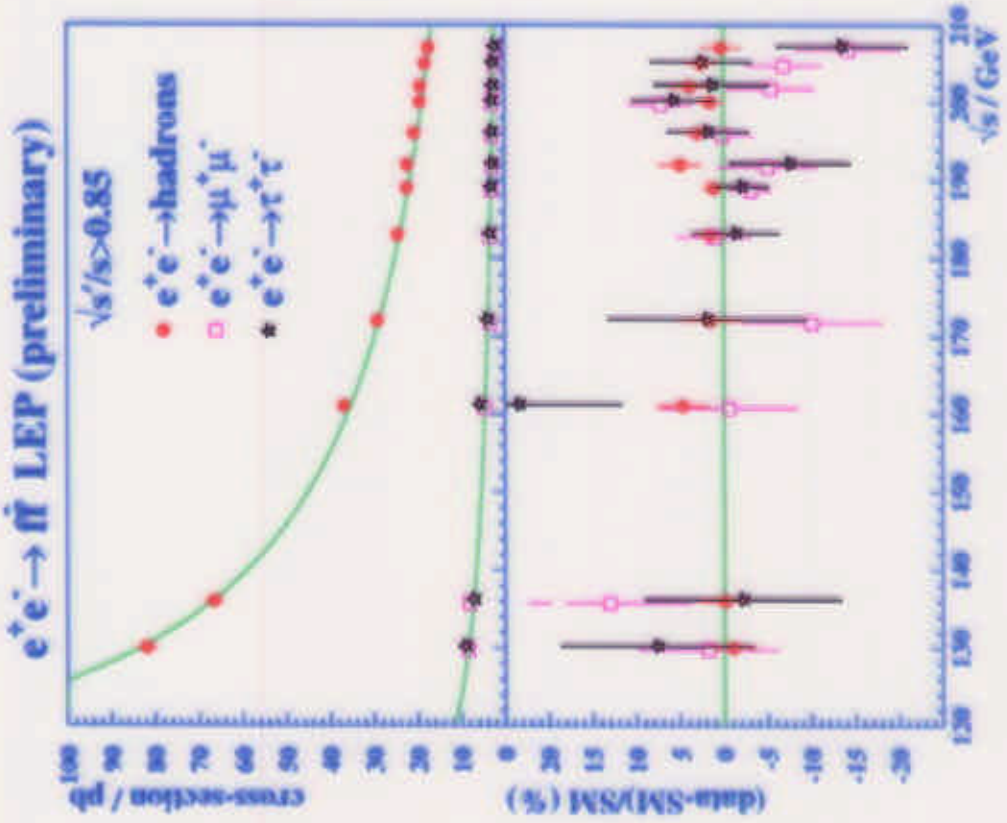
e.g. OPAL



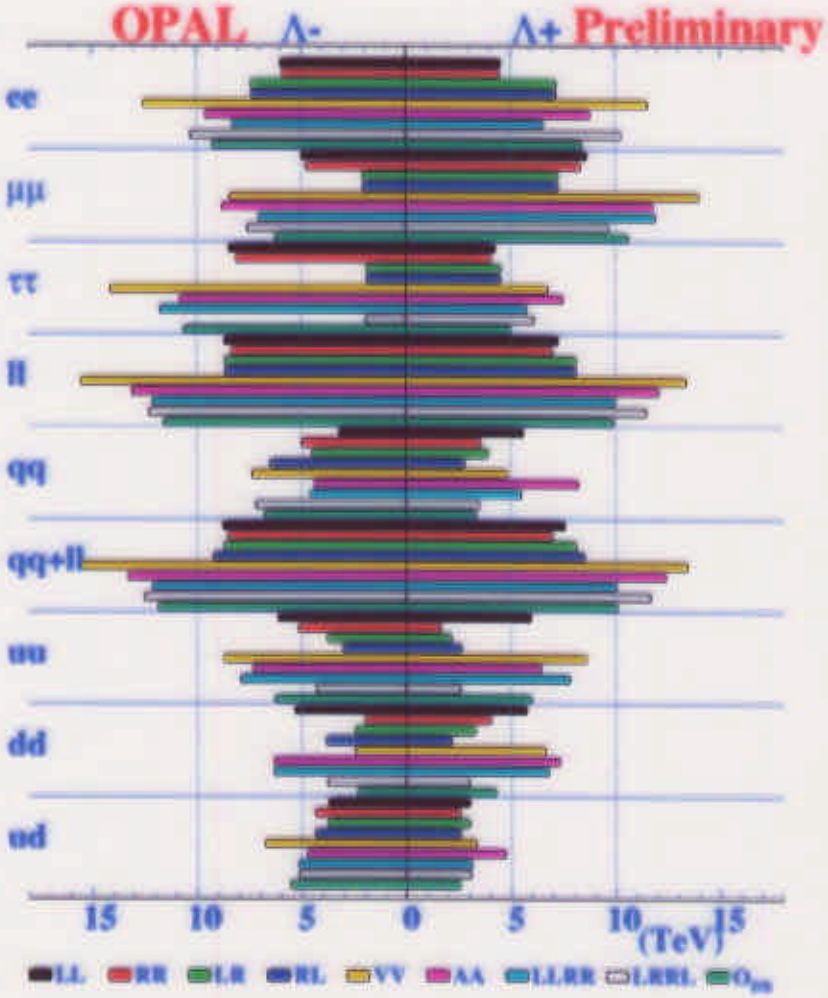
(only the high $\sqrt{s'}$ part of the spectra is interesting!)

Cross sections and F-B Asymmetries, LEP combined





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

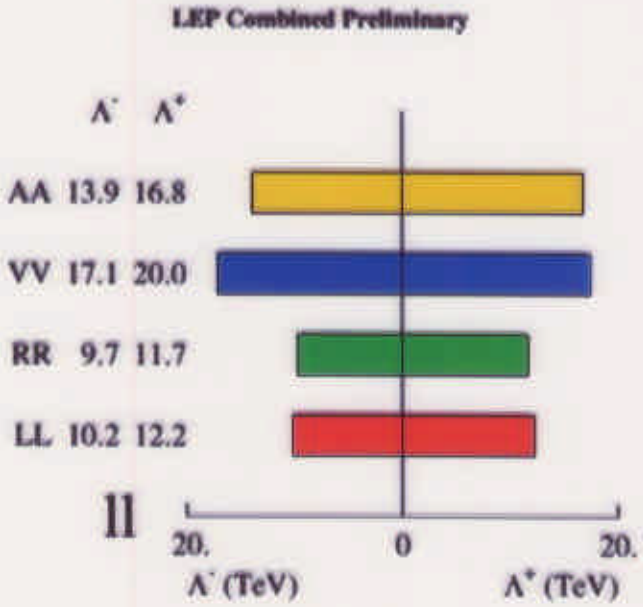
lowest limits:

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

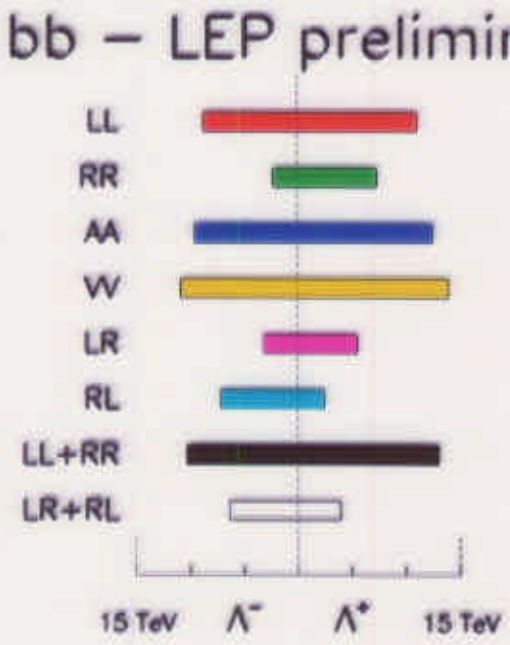
$10^{-17} - 10^{-18} cm$

LEP combined results

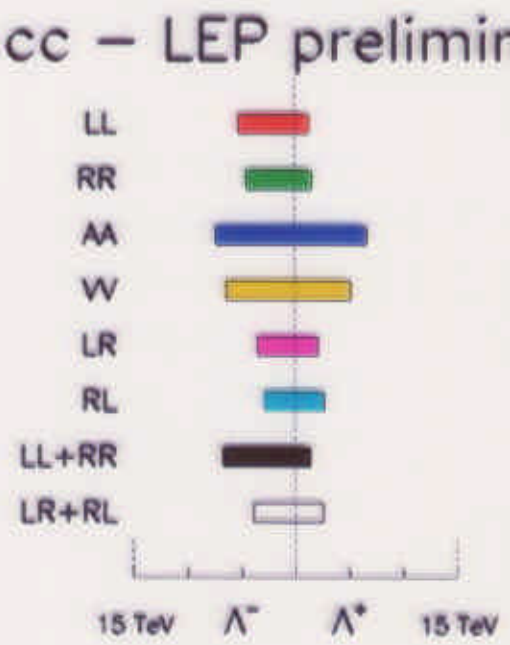
leptons



b-quarks

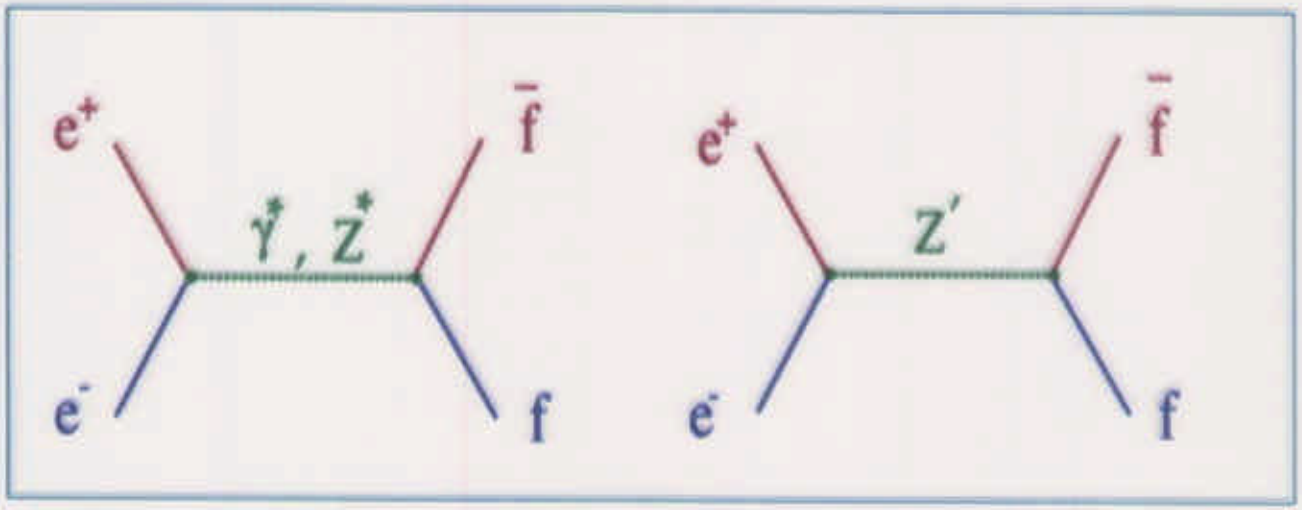


c-quarks



Generic ansatz to consider an additional boson Z':

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



particularity: Z, Z' mixing;

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

θ_M is bounded from LEP1 measurements to very small values.

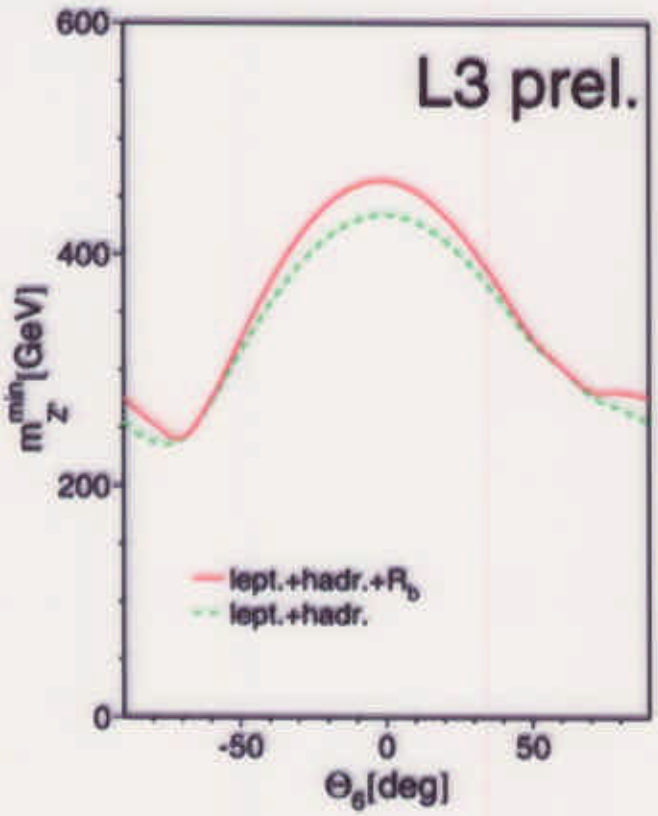
$$\sigma(e^+e^- \to f\bar{f}) = \sigma_{\gamma\gamma} + \sigma_{\gamma Z} + \sigma_{ZZ} + \sigma_{\gamma Z'} + \sigma_{ZZ'} + \sigma_{Z'Z'}$$

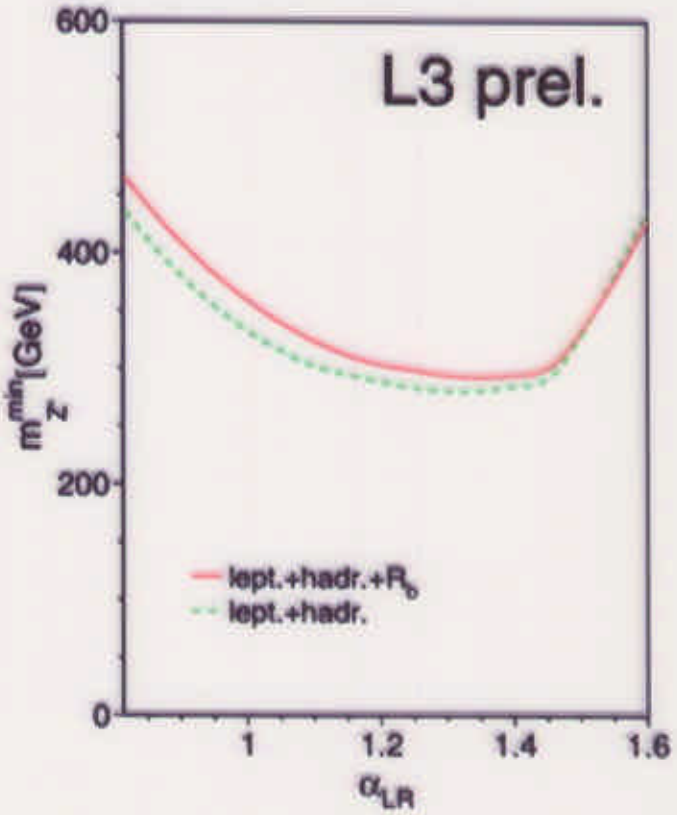
Couplings to fermions fixed using models

extra gauge boson Z'

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

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





- 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

extra gauge boson Z'

All LEP experiments exploited cross sections and A_{FB}

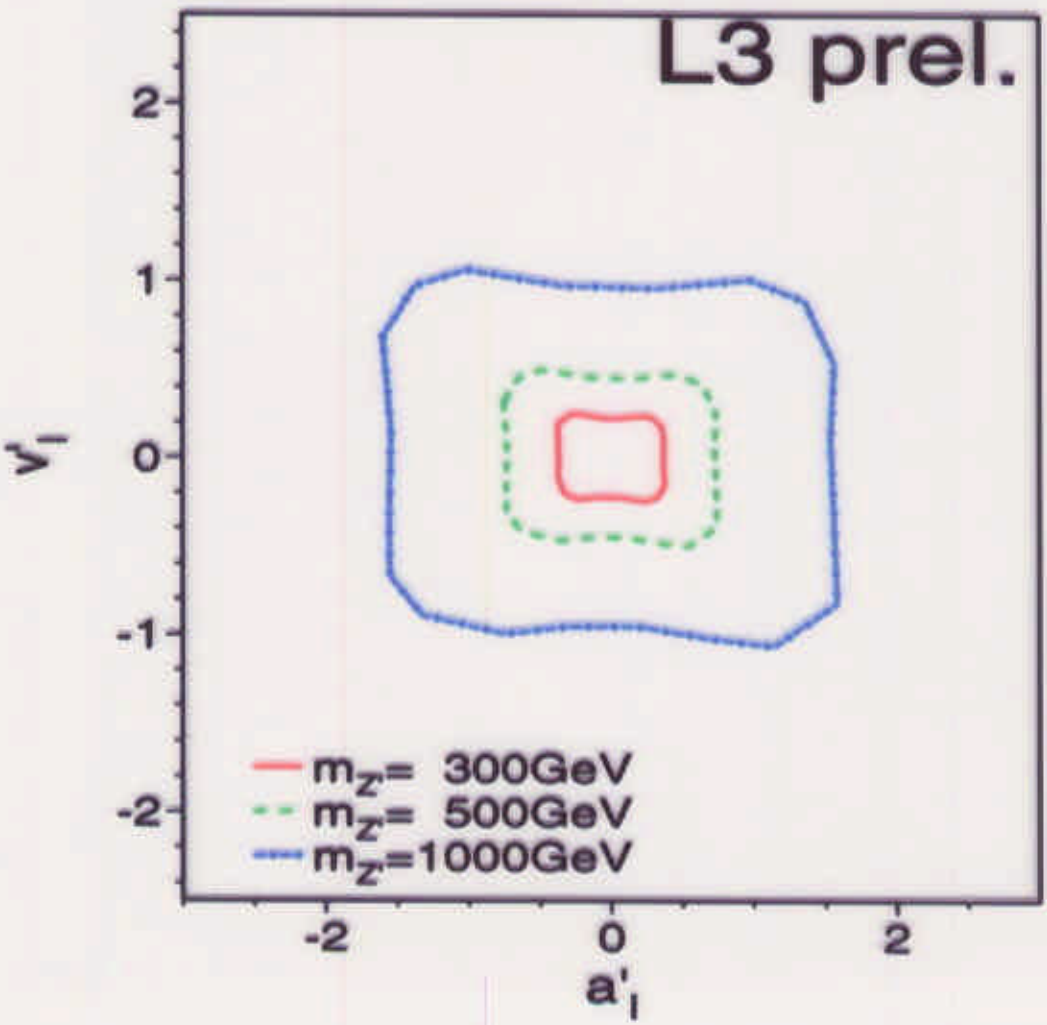
model	$M_{Z'}$ lower limit, GeV single experiments	LEP combined
χ	460 - 753	679 *
ψ	275 - 410	600
η	315 - 486	425
LR	360 - 635	
SSM	700 - 1170	

*S. Riemann, DESY-Z.

Model independent studies

$a'_\ell, v'_\ell, \theta_M$ and $m_{Z'}$ free parameters

$\ell = e, \mu, \tau$, assuming universality

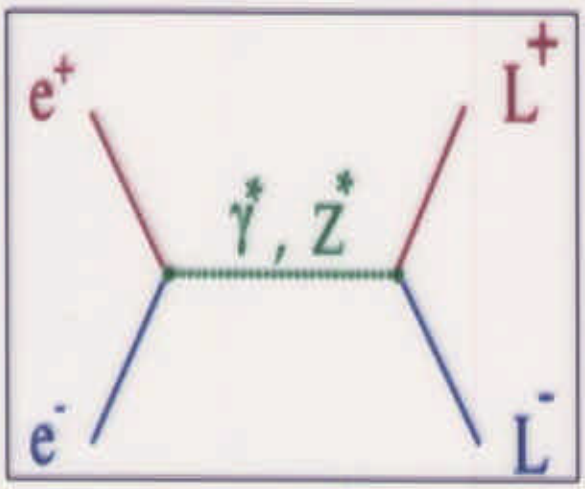


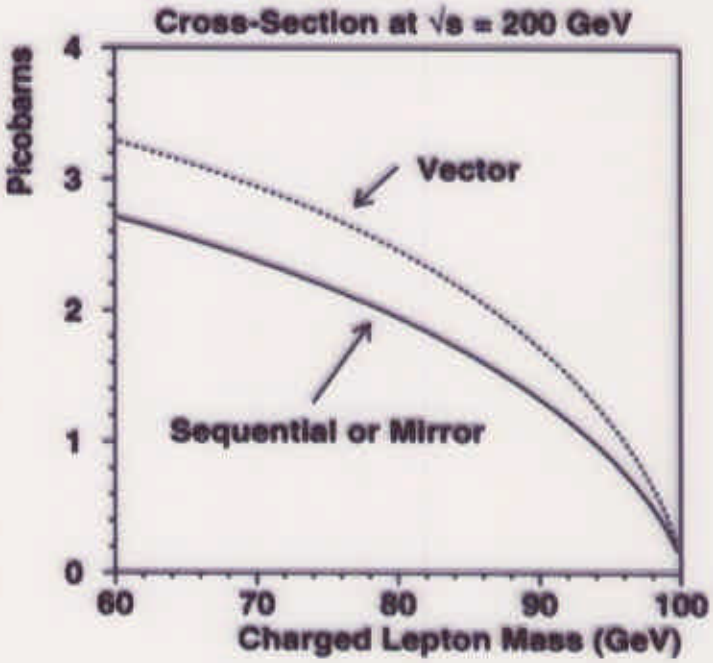
new fermions

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: $L^0\bar{L}^0 \to \ell^+\ell^- WW \to \ell^+\ell^-\ 4jets$

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

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

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

$L^+L^- \to N_L\bar{N}_L WW \to N_L\bar{N}_L\ 4jets$

new leptons

Signatures

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

- 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
$L^0 \to e\,W$	96.9 - 97.1	85.7	88	76
$L^0 \to \mu\,W$	96.7 -99.4	88.0	88.1	76
$L^0 \to \tau\,W$	89 - 96	79.6	71.1	53.8

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

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

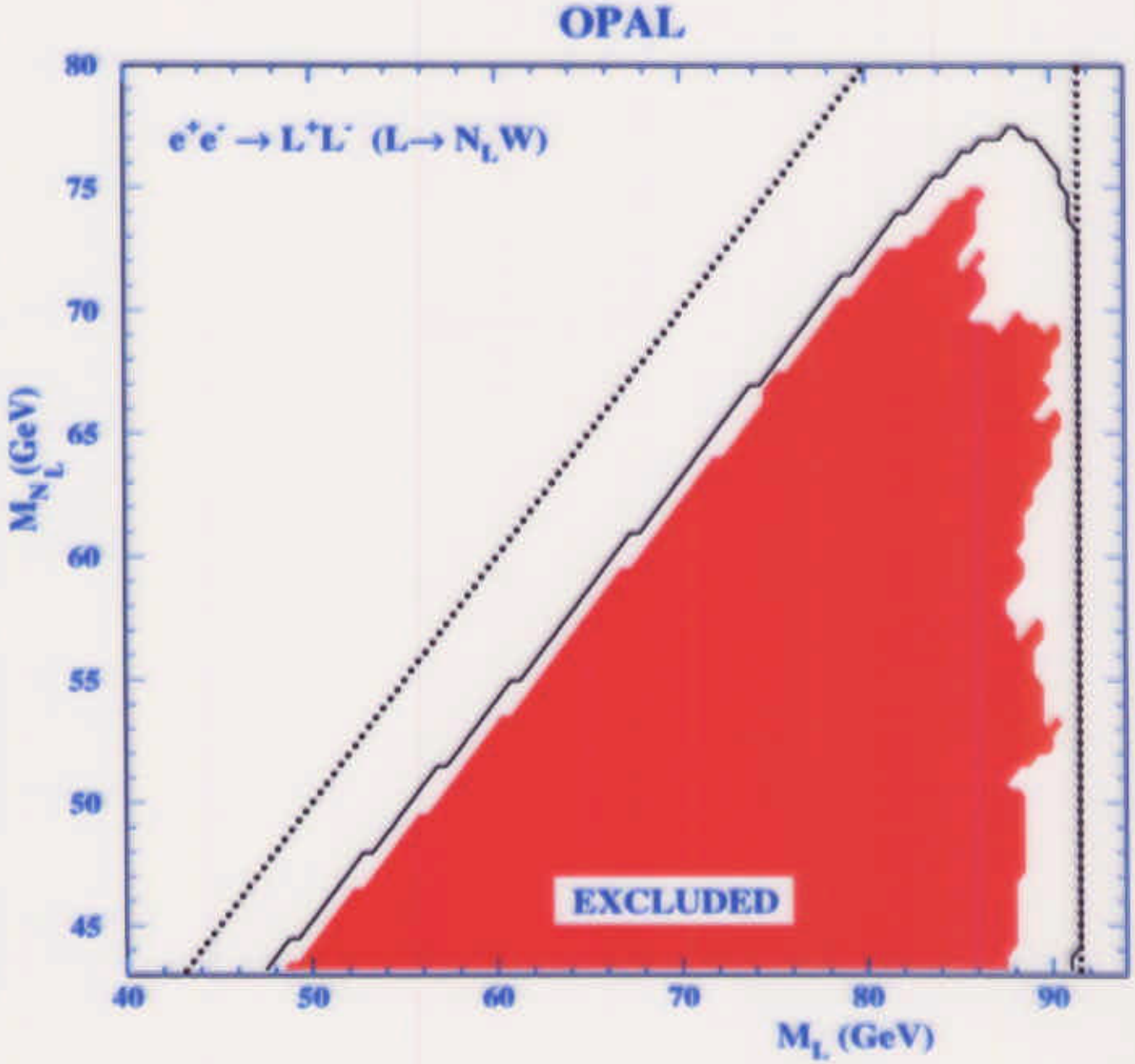
mass limits (in GeV)

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

new leptons

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

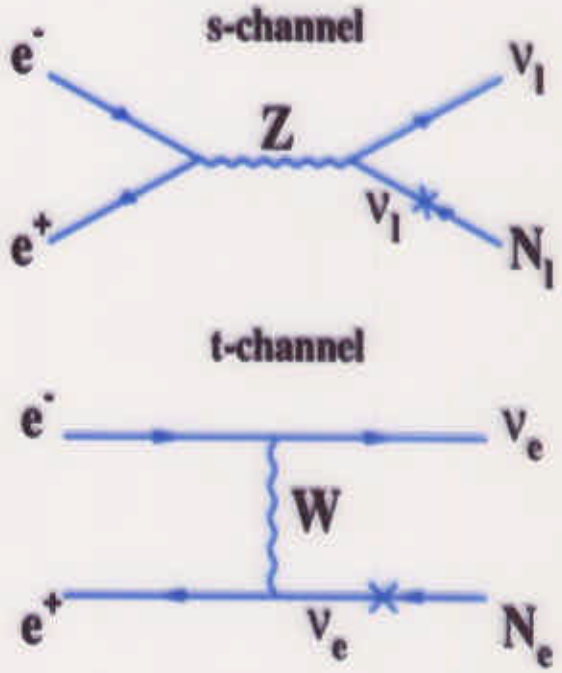
- 2 acoplanar jets
- missing momentum



singlet neutrino

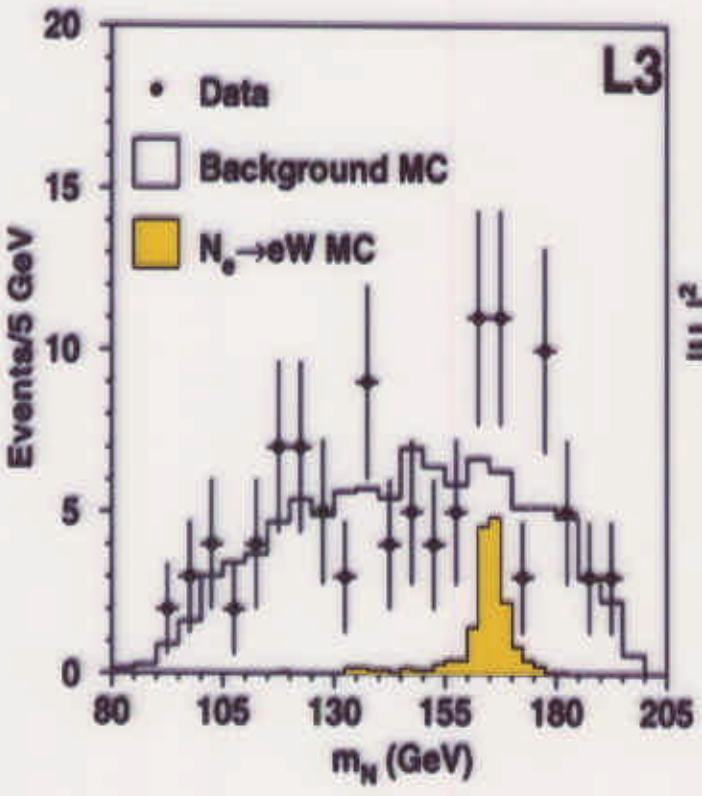
$e^+e^- \to N_e\nu_e$

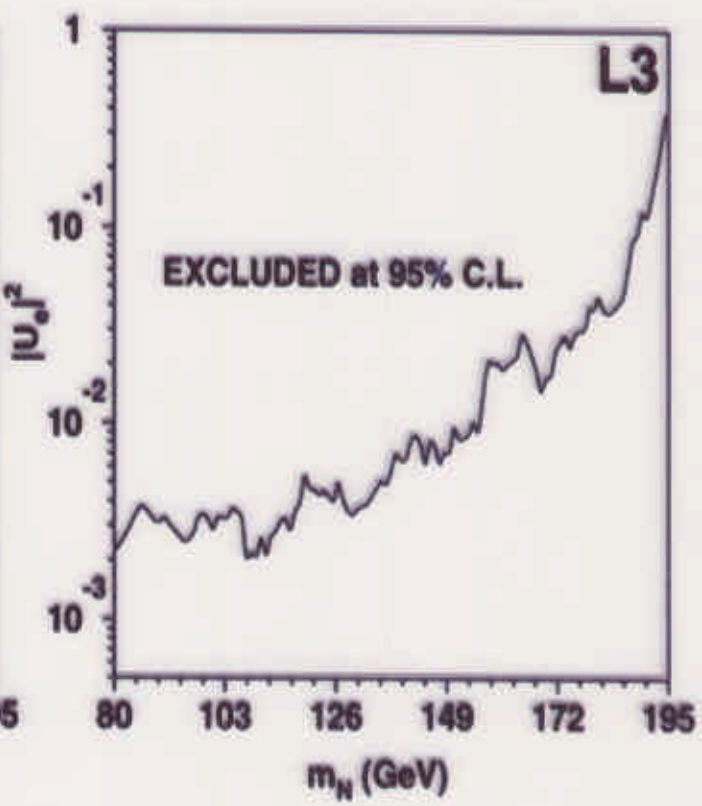
$N_e \to W^- e^+$



- one isolated electron
- 2 acoplanar jets
- missing momentum

$m_N > 100$ GeV → 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

$e^+e^- \to \rho_T^{(*)}$	$\to \pi_T\pi_T$	$\to b\bar{c}c\bar{b}$
	$\to W_L\pi_T$	$\to q\bar{q}'c\bar{b}$
	$\to W_LW_L$	$\to$ 4jets, 2jets ($\ell\nu$), 2 ($\ell\nu$)
	$\to f\bar{f}$	
	$\to \pi_T^0\gamma$	$\to b\bar{b}\gamma$

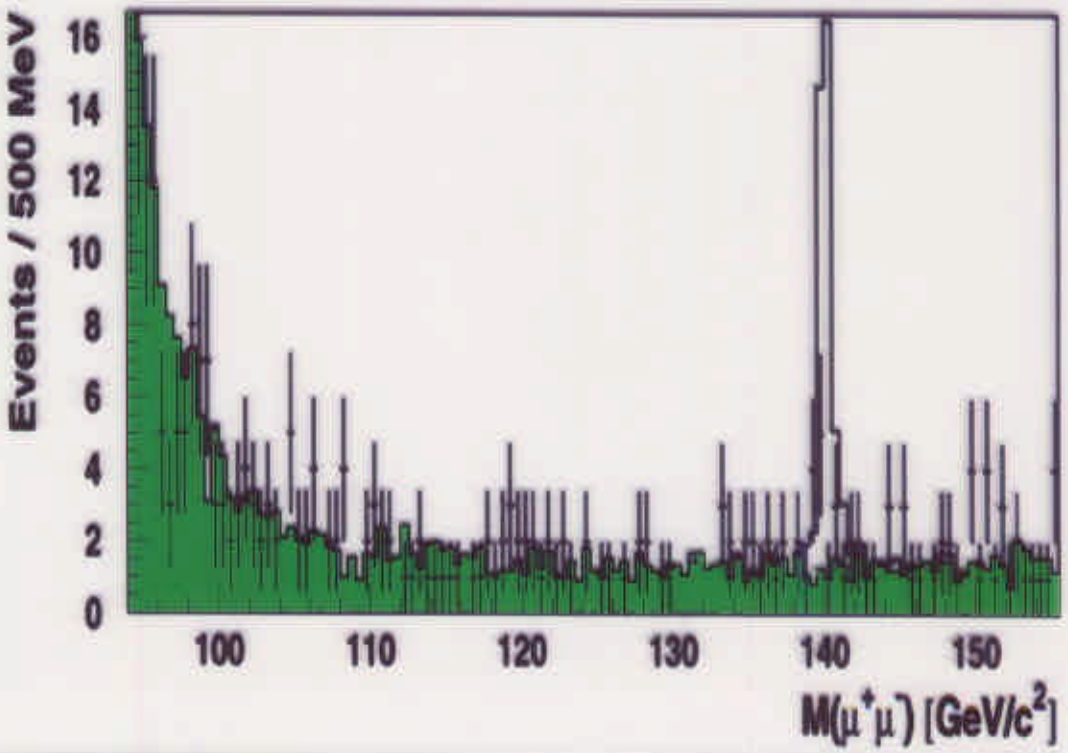
consider $m_{\rho_T} \lesssim m(X, \pi_T)$, where $X = W_L, \pi_T$

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

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

$\rho_T \to \mu^+\mu^-$

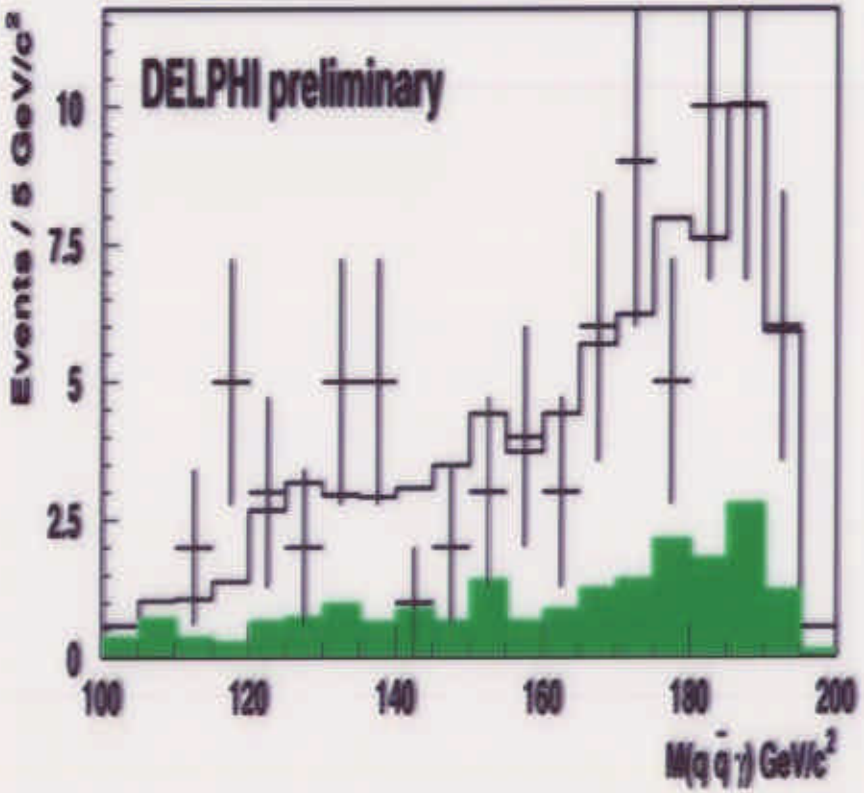
Delphi,
$\mathcal{L} \sim 460\ pb^{-1}$
$\sqrt{s} > 160$ GeV

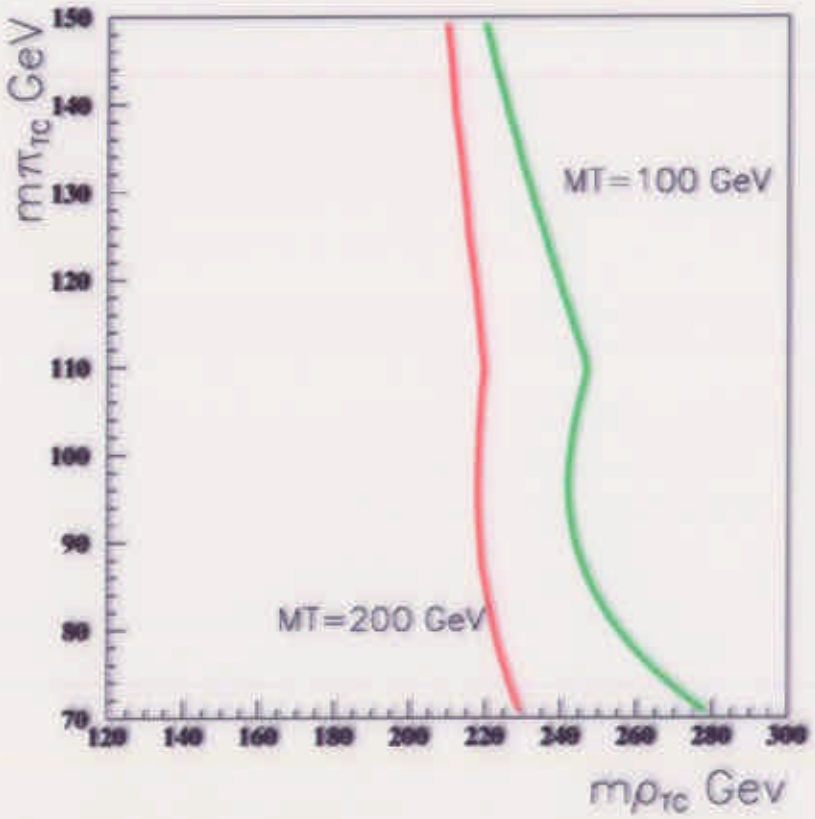


$\rho_T \to \pi_T^0 \gamma \to b\bar{b}\gamma$

- two b-jets
- one isolated photon

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

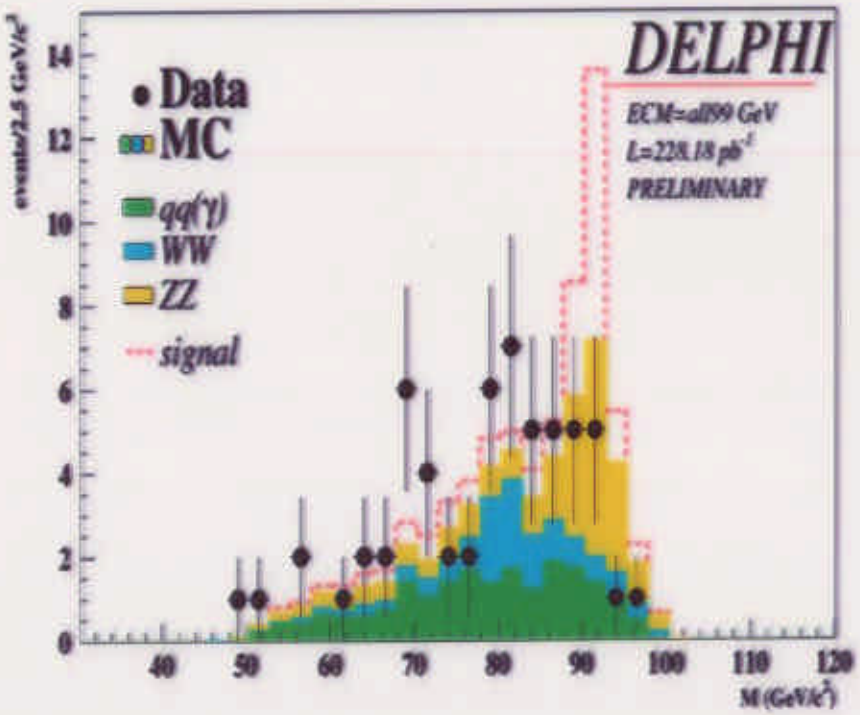


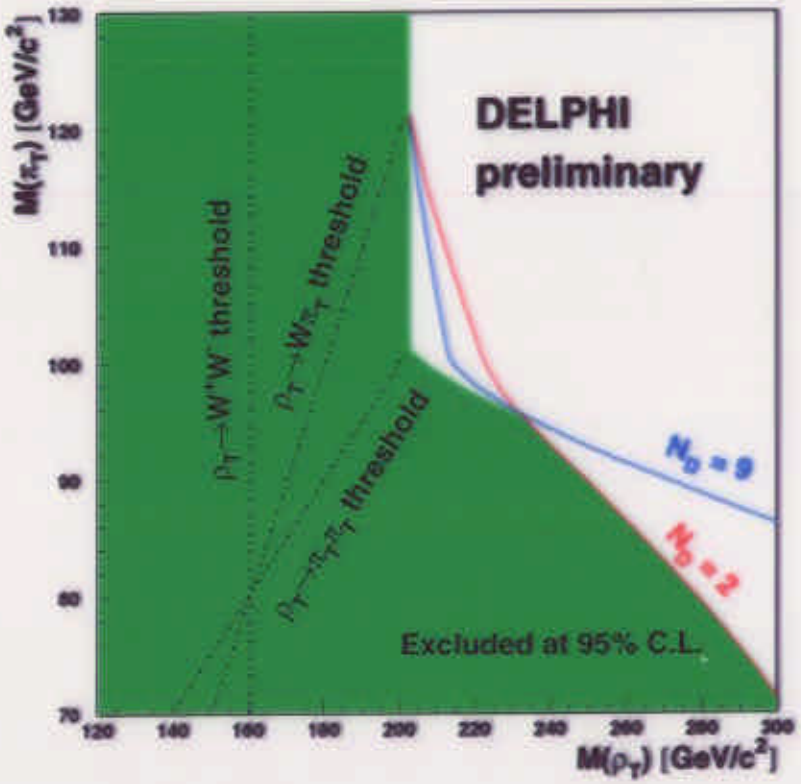


$\rho_T^{(8)} \to (W_L \pi_T), (\pi_T \pi_T) \to q\bar{q}b\bar{b}$

- four jets
- high b-quark probability

$\mathcal{L} \simeq 230\ pb^{-1}$, $192 \le \sqrt{s} \le 202$





$\rho_T \to \tilde{\pi}_T \tilde{\pi}_T \sim \cos^4 \chi$

$\to W_L \tilde{\pi}_T \sim 2\cos^2 \chi \sin^2 \chi$

exclusion contour valid for any mixing angle χ

$\chi = 1/N_D$

beginning of 2000 DELPHI reportaed an excess in the mass $m(e^+e^-)$ from $e^+e^- \to q\bar{q}e^+e^-$

OPAL checked the phenomenon: