Searches for Exotica at LEP

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EPS HEP 2001, July 12-18, 2001,Budapest

- Contact Interactions
- Extra Gauge Bosons
- Leptoquarks
- Extra Dimensions
- Technicolour

LEP2 Dataset

All result include 2000 data:

$\sqrt{s} =$ 202-209 GeV

Luminosity/Experiment $\approx$ 220 pb^{-1}

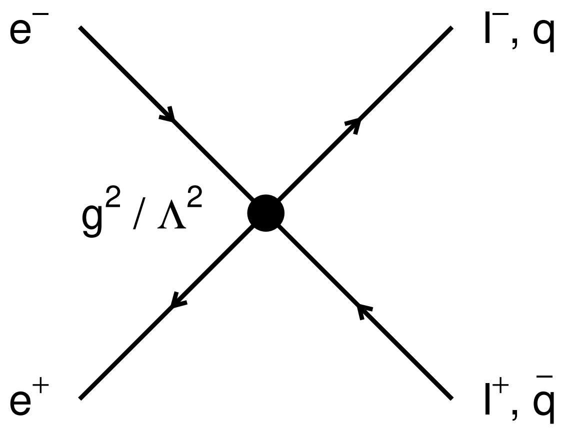
All results are preliminary

Contact Intractions

General framework to describe new interactions with typical energy scale $\Lambda \gg \sqrt{s}$.

Effective Lagrangian for C.I.:

$$\mathcal{L} = \frac{1}{1+\delta_{ef}} \sum_{i,j=\mathrm{L,R}} \eta_{ij} \frac{g^2}{\Lambda_{ij}^2} (\bar{\mathrm{e}}_i \gamma^\mu \mathrm{e}_i)(\bar{f}_j \gamma_\mu f_j)$$



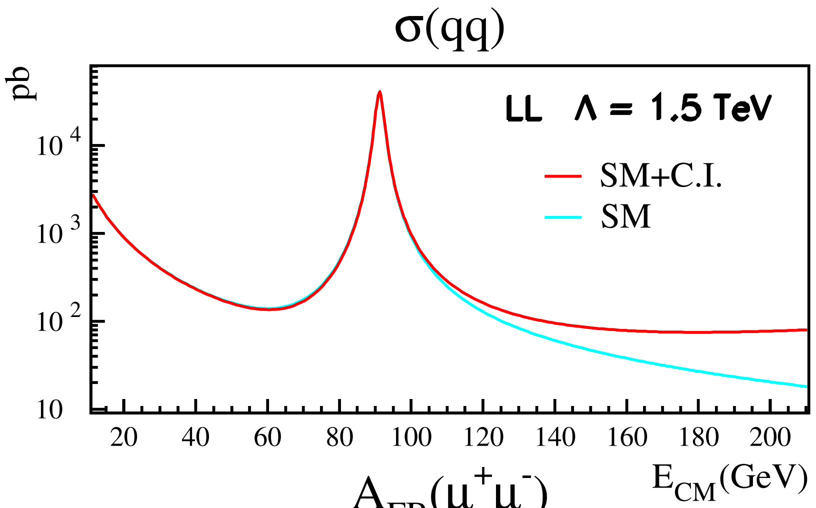
- g - effective coupling constant
- Λ - Energy scale, which is equivalent to the mass of the exchanged particle
- $\delta_{ef} = 1$ for $\mathrm{e}^+\mathrm{e}^-$ final state, otherwise 0
- η_{ij} - Helicity amplitudes, chosen to be 0 or 1
- Λ values quoted assuming $g^2/4\pi = 1$

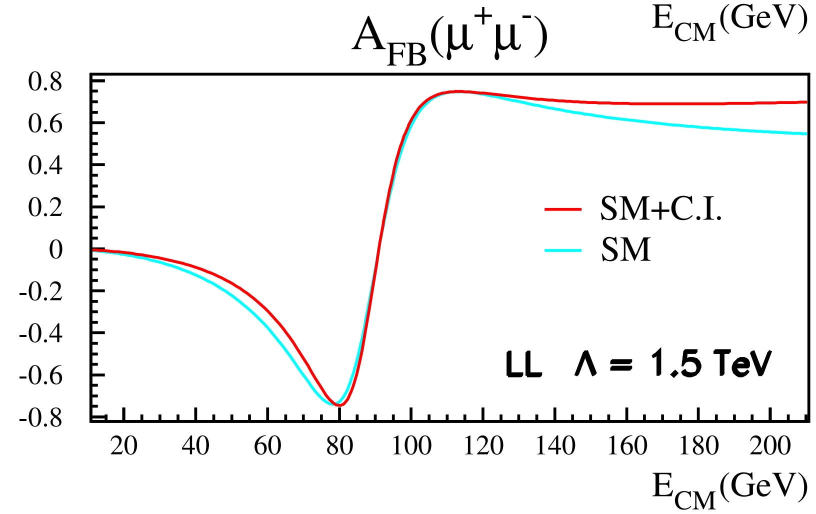
Contact Intractions

η_{ij} defines C.I. model:

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

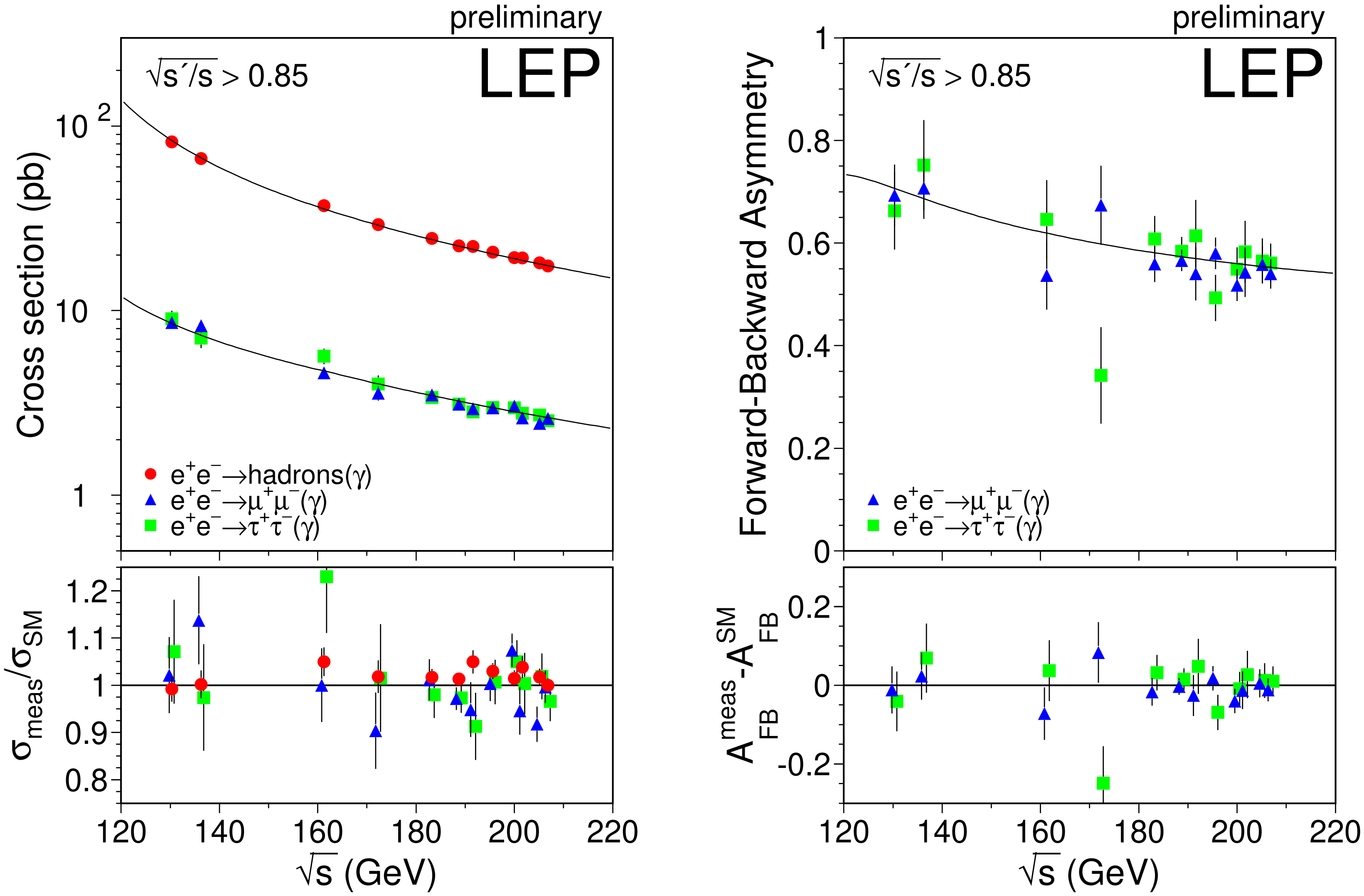
Models VV, AA, V0 and A0 are parity conserving, and LL, RR, LR and RL are parity violating



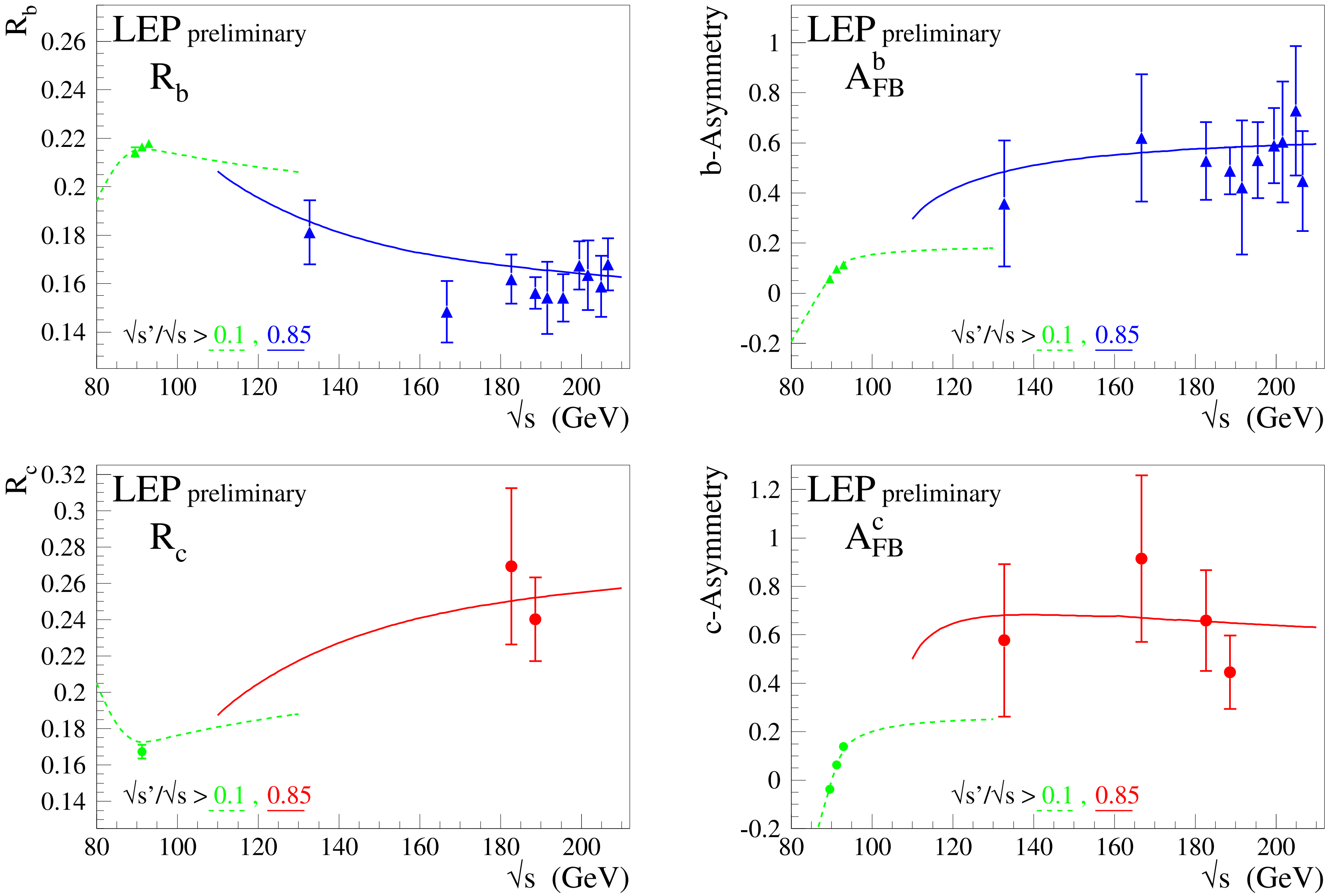


Contact interactions would affect cross section and asymmetries

Fermions Pair - σ_{tot} and A_{FB}



Heavy Flavours

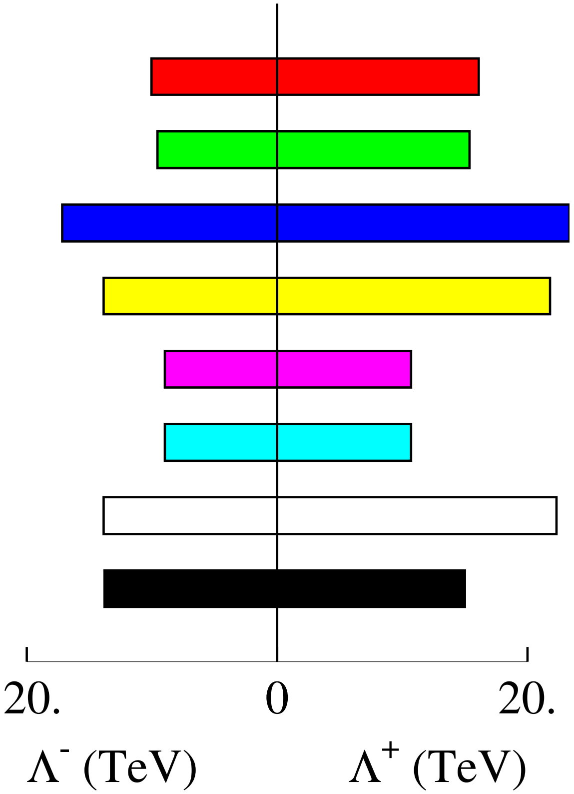


Limits on Energy Scale Λ

LEP Combined Preliminary

	Λ^-	Λ^+
LL	9.8	16.5
RR	9.4	15.8
VV	16.5	26.2
AA	14.0	21.7
RL	8.5	11.2
LR	8.5	11.2
V0	13.5	22.9
A0	13.2	15.6

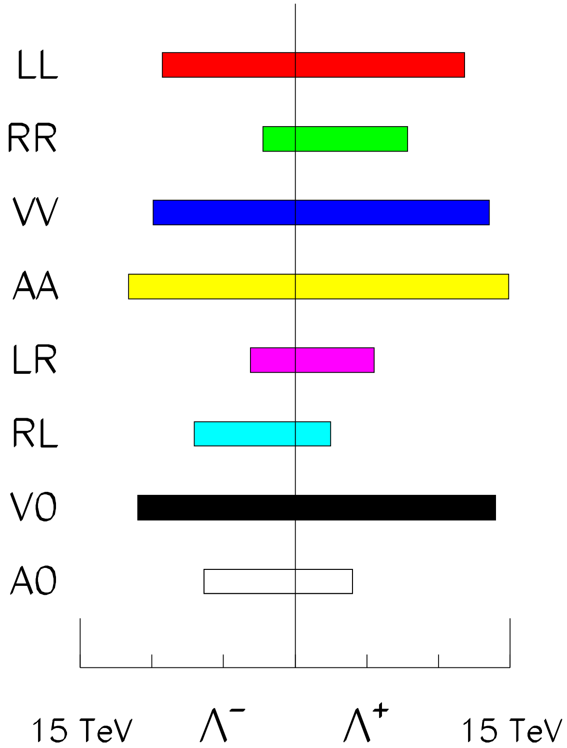
ll



$\mu^+\mu^- + \tau^+\tau^-$ final states

bb - LEP Combined preliminary

Λ_-	Λ_+
9.3	11.8
2.2	7.9
9.9	13.6
11.6	14.9
3.1	5.5
7.0	2.5
11.0	14.0
6.4	4.0



Indirect Search for Z$^{'}$

Generic ansatz to consider additional boson Z$^{'}$:

$$\mathcal{L} = eA_\mu J^\mu_\gamma + gZ_\mu J^\mu_Z + g^{'} Z^{'}_\mu J^\mu_{Z'}$$

Z-Z$^{'}$ mixing:

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

$$\tan^2\theta_M = \frac{m_0^2 - m_\mathrm{Z}^2}{m_{\mathrm{Z}'}^2 - m_0^2}, m_0 = \frac{m_W}{\rho\cos\theta_W}$$

E_6 models:

$J^\mu_{Z'} = J^\mu_\chi \cos\Theta_6 + J^\mu_\psi \sin\Theta_6$

- χ model - $\Theta_6 = 0$
- ψ model - $\Theta_6 = \pi/2$
- η model - $\Theta_6 =$ -arctan$\sqrt{5/3}$

Left-right symmetric models:

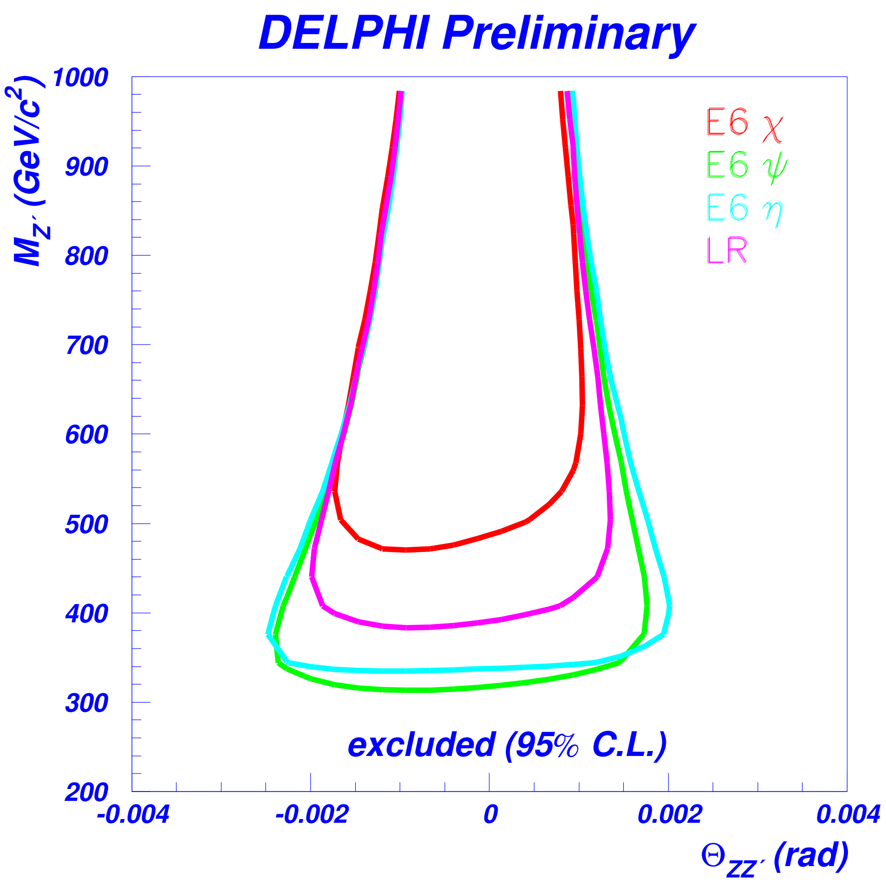
$J^{LR} = \alpha_{LR} J^\mu_{3R} - \frac{1}{2\alpha_{LR}} J^\mu_{B-L}$

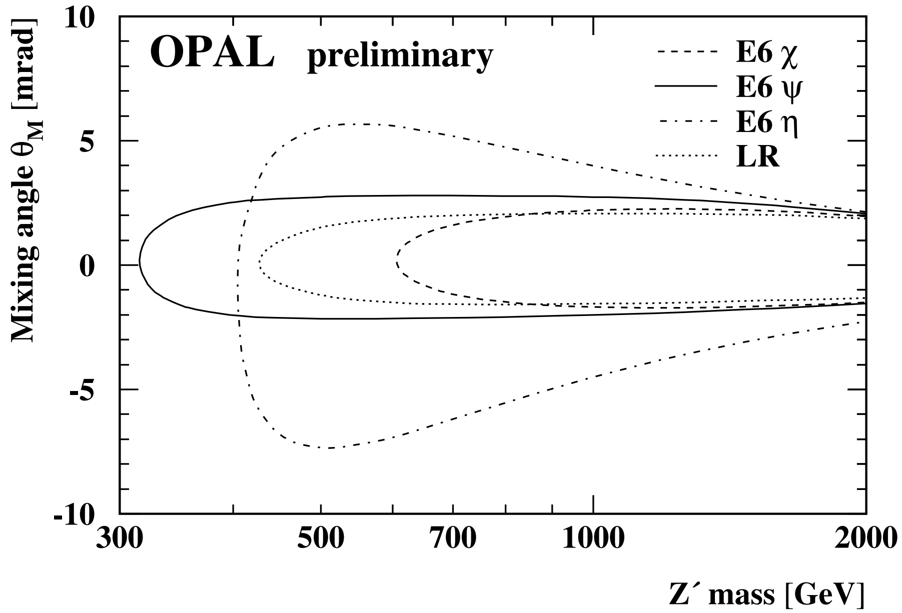
$\alpha_{LR} = \sqrt{\frac{\cos^2\theta_W - \sin^2\theta_W}{\sin^2\theta_W} \cdot \frac{g_L}{g_R}}$

- LR model - $g_L = g_R$

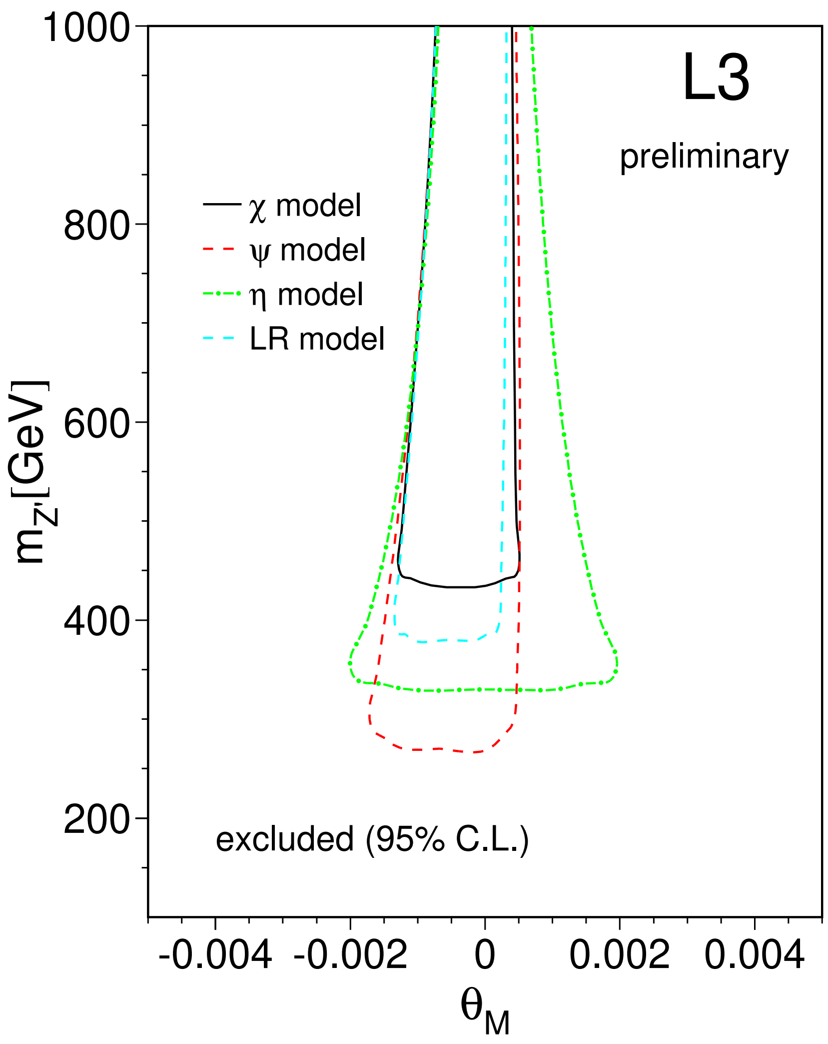
Sequential SM model: Z$^{'}$ couplings equal to SM Z couplings

Results on Indirect Z' Search





Results on Indirect Z$'$ Search



Limits on $m_{Z'}^{min}$ [GeV]

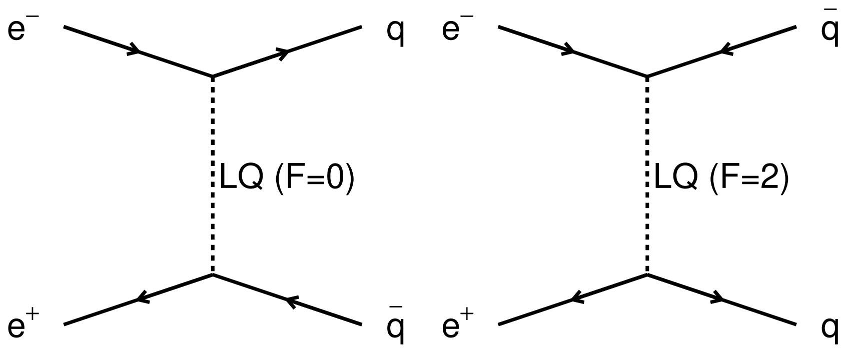
Model	DELPHI	L3	OPAL	LEP(ADLO)
χ	503	460	684	715
ψ	336	275	334	480
η	353	330	450	450
LR	412	450	469	860
SSM	656	1280		2090

Hadronic and leptonic cross-sections and leptonic forward-backward asymmetry were used to fit the data to Z$'$ models

Indirect Search For Leptoquarks

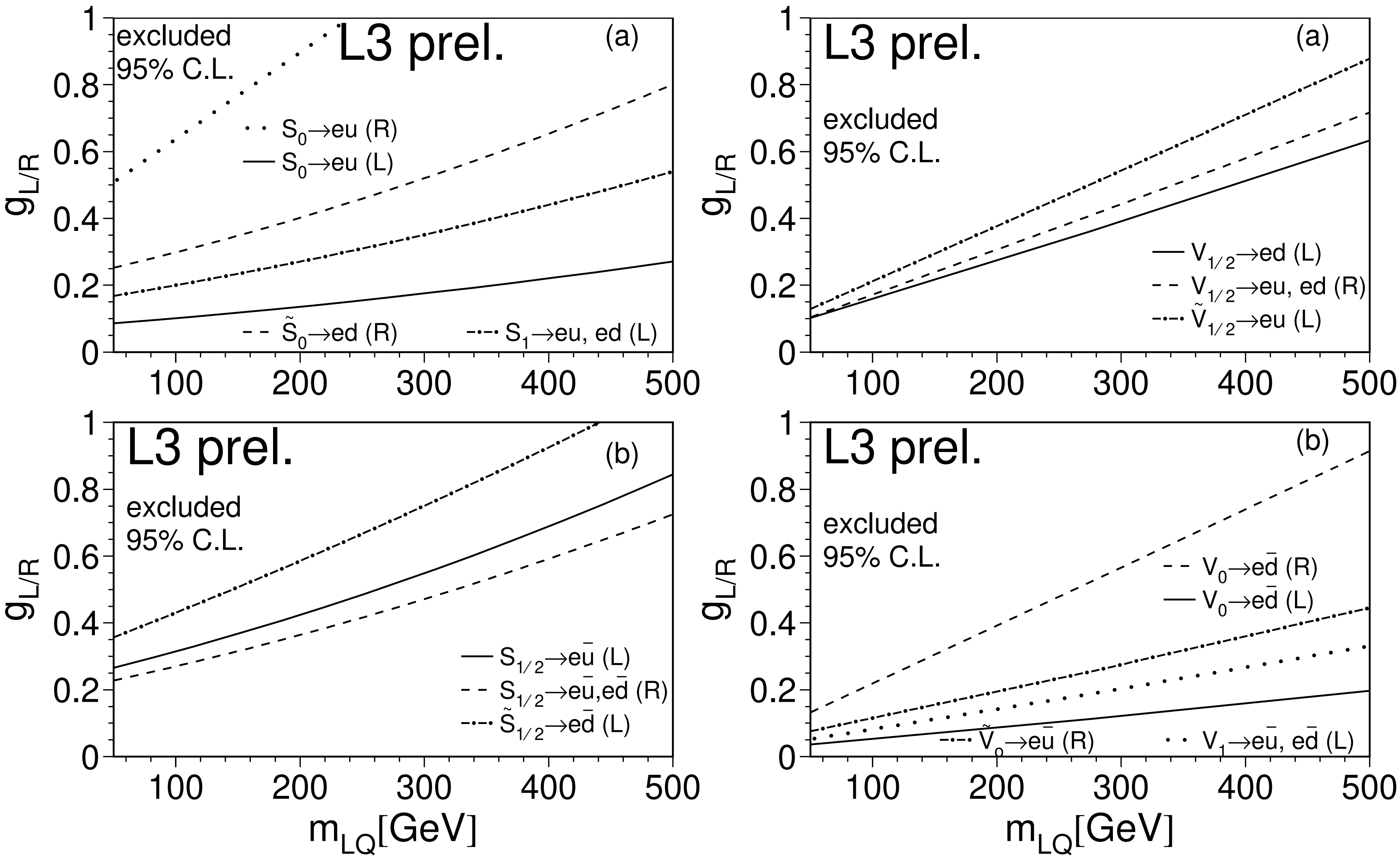
Leptoquarks (LQ) appear in many extensions of SM as a consequence of the symmetry between leptons and quarks.

- Carry both baryon and lepton numbers, $F = L + 3B$
- Conserve B and L
- Have spin 0 or 1 (Scalar S_I or vector V_I LQ)
- Couplings to quak-lepton pairs are flavour-diagonal
- Couple either to left- or right-handed quarks



At LEP, the t- and u-channel exchanges of first generation LQ can modify the hadronic cross section $\Longrightarrow$ comparison of the measurement with theoretical predictions allows to set upper limits on the LQ's couplings as a function of its mass, m_{LQ}.

Indirect Limits on the Leptoquark Couplings



Indirect Limits on the Leptoquark Masses

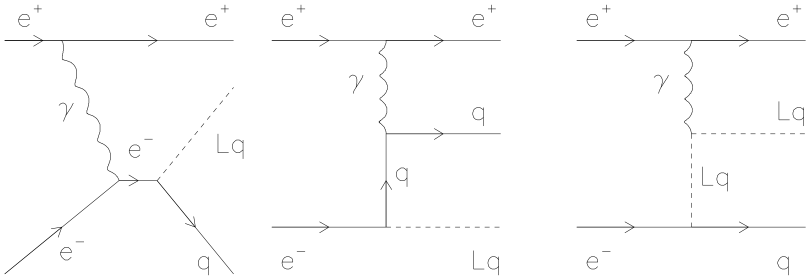
Limits on the m_{LQ} [GeV] (assume: $g_{L,R} = \sqrt{4\pi\alpha_{em}}$)

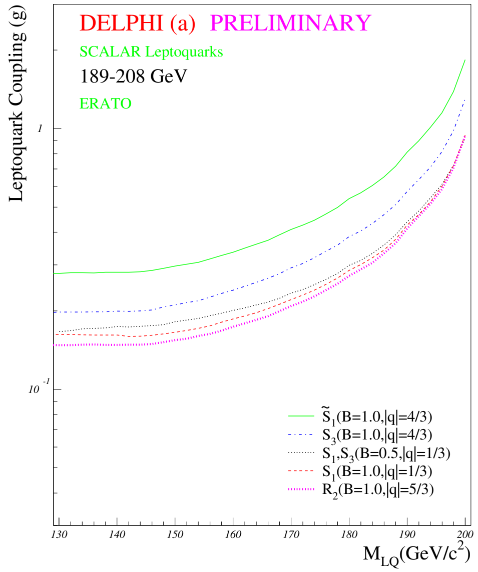
Scalar LQ type	ALEPH	L3	LEP (ADLO)
$S_0(L) \to eu$	632	530	789
$S_0(R) \to eu$	103	410	639
$\tilde{S}_0(R) \to ed$	170	112	210
$S_1(L) \to eu, ed$	387	254	364
$S_{1/2}(L) \to e\bar{u}$	179	90	190
$S_{1/2}(R) \to e\bar{u}, e\bar{d}$	158	149	240
$\tilde{S}_{1/2}(L) \to e\bar{d}$	-	-	-
$V_{1/2}(L) \to ed$	167	230	305
$V_{1/2}(R) \to eu, ed$	340	199	227
$\tilde{V}_{1/2}(L) \to eu$	120	156	176
$V_0(L) \to e\bar{d}$	829	750	1070
$V_0(R) \to e\bar{d}$	147	148	167
$\tilde{V}_0(R) \to e\bar{u}$	409	350	497
$V_1(L) \to e\bar{u}, e\bar{d}$	620	470	664

Direct Search for Leptoquarks

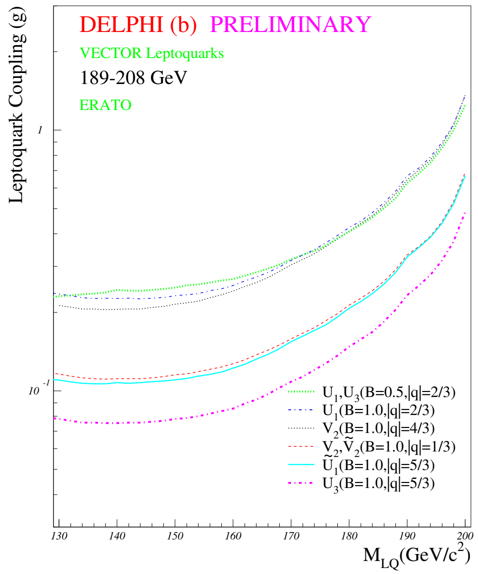
Production of single LQ

$$e^+e^- \to e\ q\ L_q$$





- Charged decay mode $L_q \to e^{\pm}q$
  - Isolated electron
- Neutral decay mode $L_q \to \nu q$
  - Monojet



Extra Dimensions: Motivation

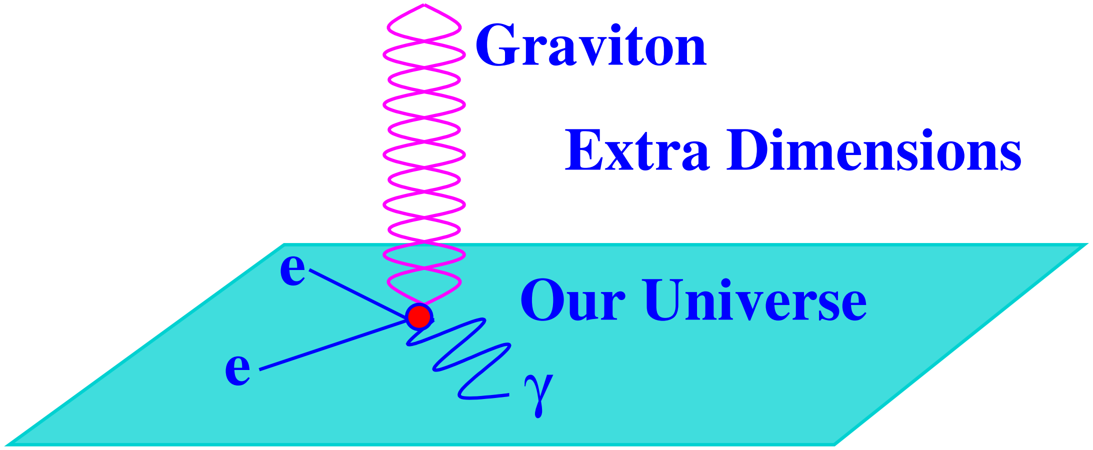
- Relative weakness of gravity with respect to other fundamental forces, $M_{\mathrm{Pl}} = \sqrt{\frac{1}{G_{\mathrm{N}}}} \sim 10^{18}\ \ \mathrm{GeV}$.
- Alternative to this scenario:
  - Gravity propagates in compactified higher dimensional space
  - SM particles are confined to usual 3+1 space-time dimension
- Reduction of effective quantum gravity scale, $M_D \approx \Lambda_{EW}$

$$\frac{1}{G_{\mathrm{N}}} = M_{\mathrm{Pl}}^2 = 8\pi R^{\delta} M_D^{\delta+2} \qquad M_D^{\delta+2} \propto M_{\mathrm{Pl}}^2 / R^{\delta}$$

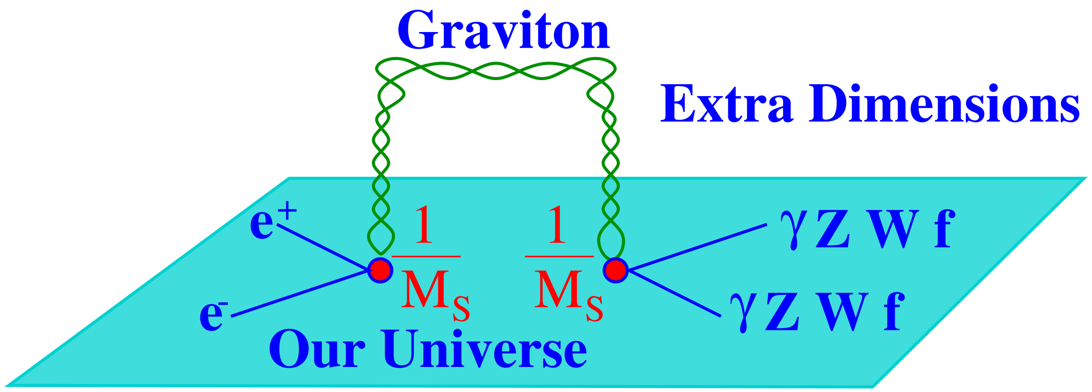
  - δ number of extra dimensions,
  - R radius of the compactified space,
  - M_D a new fundamental scale of gravity.
- Hierarchy problem is solved

Extra Dimensions: Search Strategy

Direct Search: single photon + missing energy.



Indirect Search: Look for deviations from $(d\sigma/d\Omega)_{SM}$.

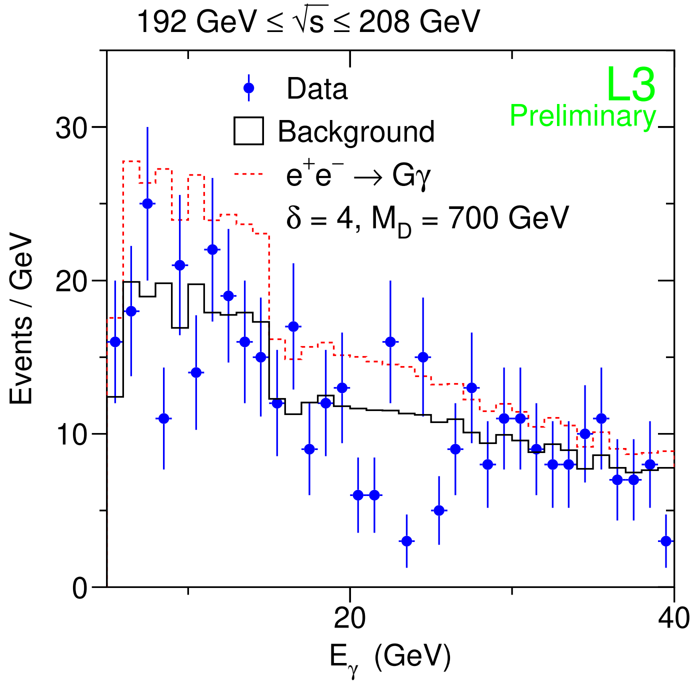


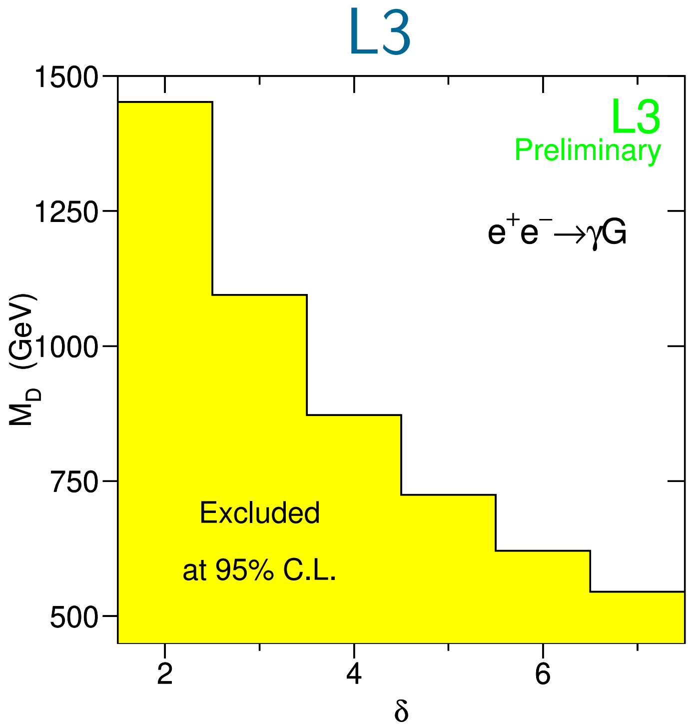
Direct Search: Single Photons

$$e^+e^- \rightarrow \gamma\, G^*$$

$$\frac{d^2\sigma}{dx_\gamma d\cos\theta_\gamma} = \frac{\alpha}{32s}\frac{\pi^{\delta/2}}{\Gamma(\delta/2)}\left(\frac{\sqrt{s}}{M_D}\right)^{\delta+2} f(x_\gamma, \cos\theta_\gamma)$$

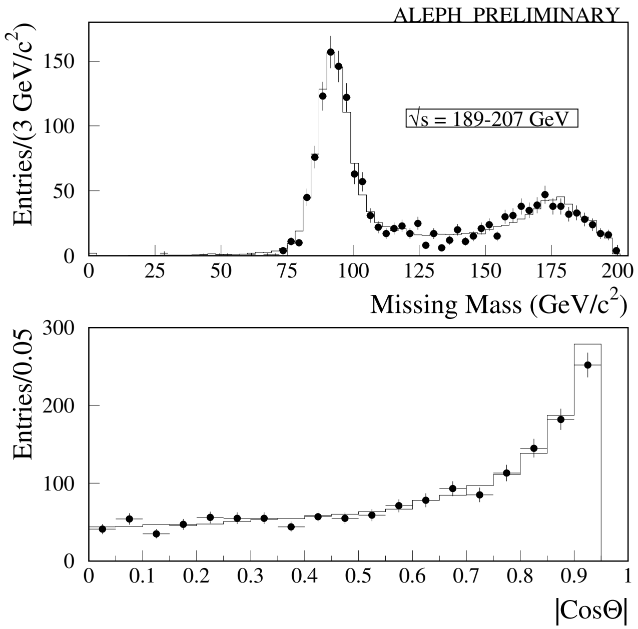
The cross section increases with smaller photon energies and angles.



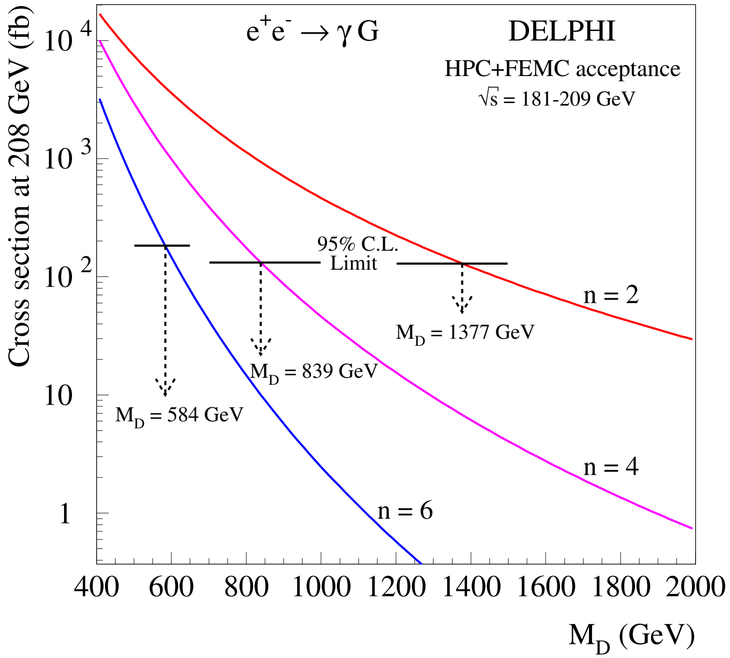


Direct Search: Single Photons

ALEPH



DELPHI



	ALEPH		DELPHI		L3	
δ	M_D (TeV)	R (cm)	M_D (TeV)	R (cm)	M_D (TeV)	R (cm)
2	1.28	$2.9 \cdot 10^{-2}$	1.38	$2.5 \cdot 10^{-2}$	1.45	$2.3 \cdot 10^{-2}$
4	0.78	$1.4 \cdot 10^{-9}$	0.84	$1.3 \cdot 10^{-9}$	0.87	$1.2 \cdot 10^{-9}$
6	0.57	$5.6 \cdot 10^{-12}$	0.58	$5.4 \cdot 10^{-12}$	0.61	$5.2 \cdot 10^{-12}$

Indirect Search: $e^+e^- \to \gamma\gamma$

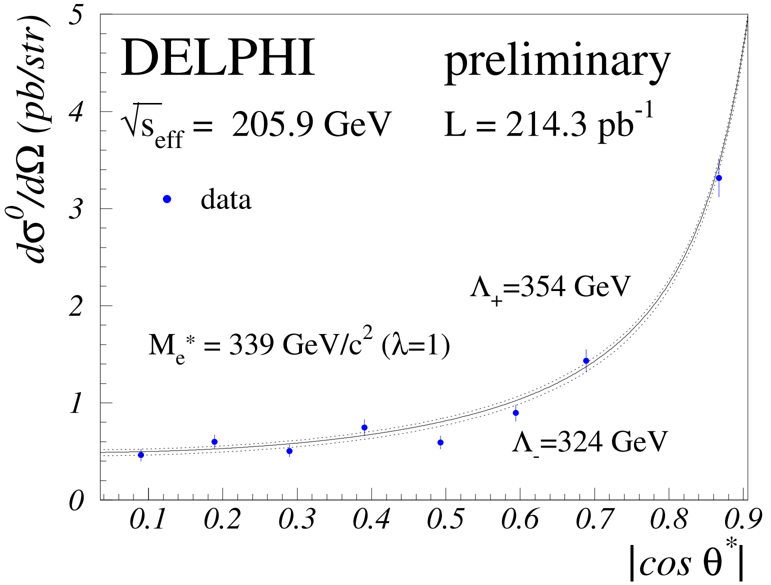
Virtual Graviton exchange: $e^+e^- \to G^* \to \gamma\gamma$

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{s}\frac{(1+\cos^2\theta)}{(1-\cos^2\theta)}$$

$$-\frac{\alpha\lambda s}{2\pi M_S^4}\left(1+\cos^2\theta\right)$$

$$+\frac{\lambda^2 s^3}{16\pi^2 M_S^8}\left(1+\cos^2\theta\right)\left(1-\cos^2\theta\right)$$

M_S – a new scale for the gravity



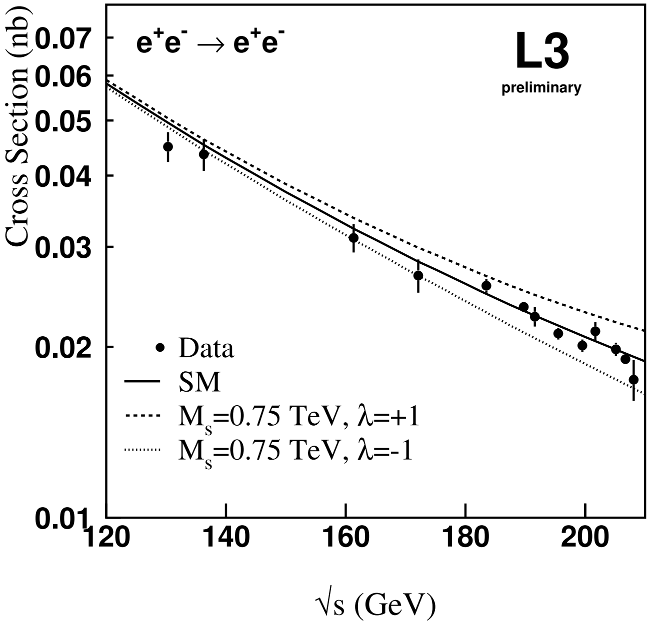
$$\cos\theta^* = \left|\sin\left(\tfrac{\theta_1-\theta_2}{2}\right)/\sin\left(\tfrac{\theta_1+\theta_2}{2}\right)\right|$$

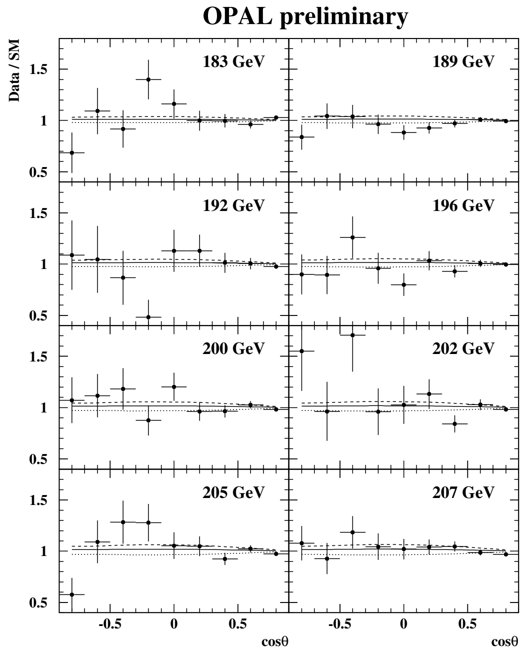
	DELPHI	L3	OPAL
$M_S(\lambda=+1)$ (TeV)	0.82	0.83	0.83
$M_S(\lambda=-1)$ (TeV)	0.91	0.99	0.89

Indirect Search: $e^+e^- \to e^+e^-$

$$e^+e^- \to G^* \to e^+e^-$$

Bhabha scattering is most sensitive to LSG effects as compared to other two-fermion processes at LEP. Interference between t-channel photon exchange and graviton exchange is expected to be large.





	L3	OPAL
$M_S(\lambda = +1)$ (TeV)	1.06	1.00
$M_S(\lambda = -1)$ (TeV)	0.98	1.15

-0.5 0 0.5 -0.5 0 0.5

Technicolour

- Scaled up version of QCD
  - New fields: Technifermions T, coupled to W, Z
  - New interaction: Technicolour: ($\Lambda_{TC} \gg \Lambda_{QCD}$)
- Electroweak symmetry broken dynamically. Alternative to Higgs mechanism: avoids elementary scalar in the theory
- Extensions are worked out to solve some problems:
  - Flavour-changing neutral currents
  - Precision measurements of electroweak quantities (STU)
  - Mass of top quark
- Recent extension is "topcolour assisted working technicolour" (TC2)
- Predicts technicolour scalar π_{T} and vector meson ρ_{T}, which can be light enough to be observed at LEP2

Technicolour

The direct search for the technicolour production at LEP2

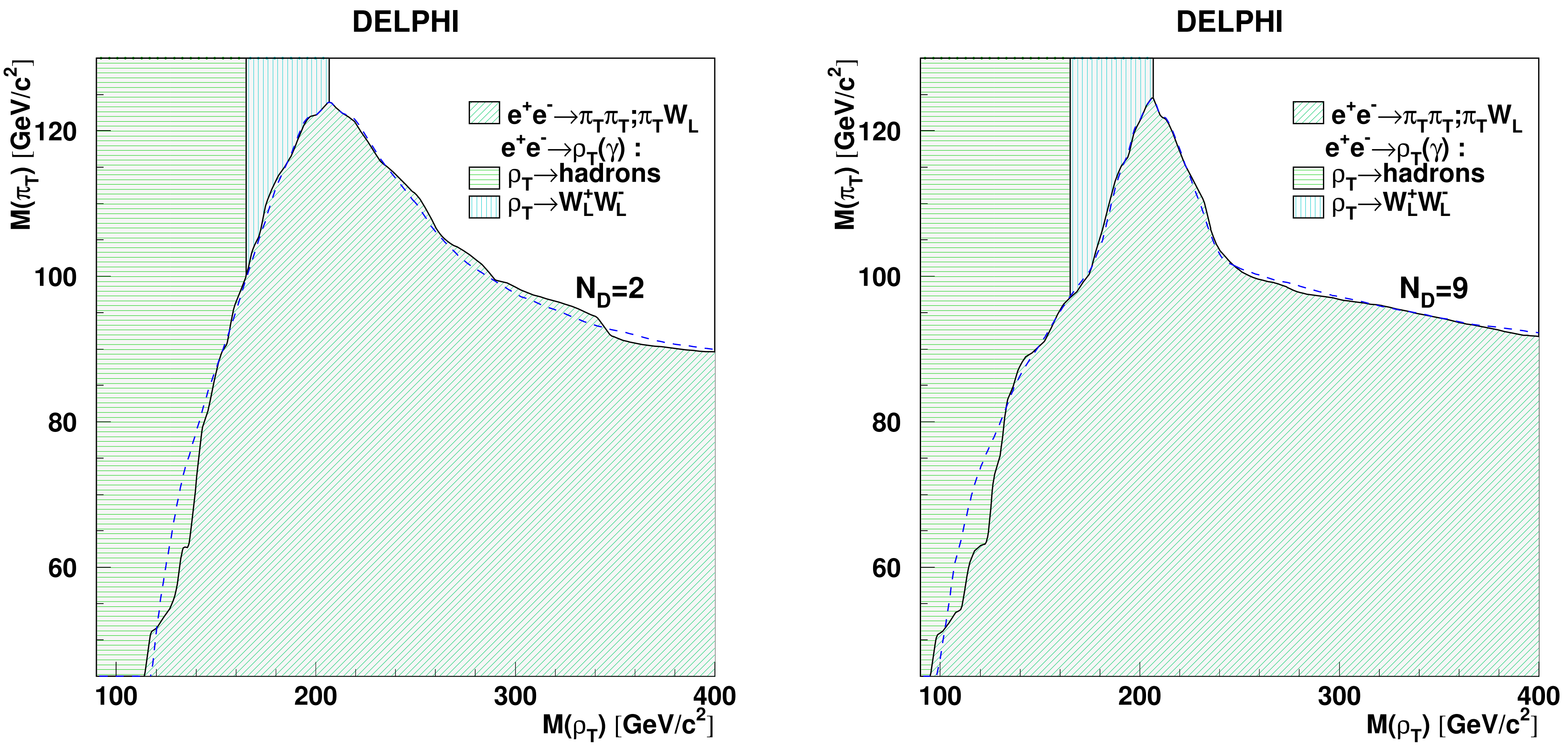
Below WW threshold:

- $\mathbf{e^+e^- \longrightarrow \boldsymbol{\rho}_T \longrightarrow hadrons\ (q\bar{q},\ \boldsymbol{\pi}_T\boldsymbol{\pi}_T)}$
  - Peak in the hadronic mass distribution

Above WW threshold:

- $\mathbf{e^+e^- \longrightarrow \boldsymbol{\rho}_T \longrightarrow W_L W_L}$
  - Comparison with expected WW cross section
- $\mathbf{e^+e^- \longrightarrow \boldsymbol{\rho}_T \longrightarrow W_L \boldsymbol{\pi}_T,\ \boldsymbol{\pi}_T\boldsymbol{\pi}_T}$
  - $\pi_T^+ \to \bar{b}c,\ \bar{b}u$ (∼90%)
  - B-tagging important

Technicolour



Excluded at 95% CL: 90 GeV $< m_{\rho_T} <$ 206.7 GeV

Conclusion

- No evidence for Exotica at LEP
- LEP Limits will be finalized soon, but we do not expect surprises.
- Goal: produce LEP combined results (agreed by all collaborations).