Search for Exotica at LEP

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Abstract: In year 2000 four LEP experiments (ALEPH, DELPHI, L3 and OPAL) have collected data at various centre-of-mass energies between 202 and 209 GeV. The typical collected integrated luminosity per experiment is about 220 pb^{-1}. This paper describes recent LEP results on indirect and direct searches for contact interactions, additional heavy neutral gauge boson $\mathrm{Z}^{'}$, leptoquarks, gravity in extra dimensions and technicolour. All discussed results include the data obtained in year 2000.

1. Contact Interactions

Contact interactions provide a general framework to describe new interactions. Following reference [1], contact interactions are parameterized by an effective Lagrangian, $\mathcal{L}$, which is added to the Standard Model (SM) Lagrangian and has the form:

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

where e and f are the chiral projections of the fermion spinors, g is effective coupling, Λ is an energy scale, which is equivalent to the mass of the exchanged particle, δ_{ef} is equal to 1 for the $\mathrm{e}^+\mathrm{e}^-$ final state, otherwise is 0. The parameters η_{ij} determine the type of chiral coupling of the four fermions. By convention, the compositeness scale Λ is defined such that the unknown coupling constant satisfies $g^2/4\pi = 1$ and that the largest $|\eta_{ij}| = 1$. The different models are defined by the values of the parameters η_{ij} as shown in Table 1. The $\pm$ signs denote positive and negative interference with the SM amplitudes, respectively.

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

Table 1: Different models of contact interactions.

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Contact interactions would affect the cross section and forward-backward asymmetry measurements in fermion pair production. Since there are no significant deviations from the SM predictions, limits on Λ are derived. Table 2 shows the limits on the scale Λ for $e^+e^- \rightarrow \ell\ell(\mu^+\mu^-$ and $\tau^+\tau^-)$ and $e^+e^- \rightarrow b\bar{b}$ final states [2, 4, 7, 8, 9]. Slightly lower limits are obtained for $c\bar{c}$-quarks.

Model	$\ell\ell$		$b\bar{b}$	
	Λ^-	Λ^+	Λ^-	Λ^+
LL	9.8	16.5	9.3	11.8
RR	9.4	15.8	2.2	7.9
LR	16.5	26.2	9.9	13.6
RL	14.0	21.7	11.6	14.9
VV	8.5	11.2	3.1	5.5
AA	8.5	11.2	7.0	2.5
V0	13.5	22.9	11.0	14.0
A0	13.2	15.6	6.4	4.0

Table 2: 95% CL lower limits in TeV on the scale Λ for $\ell\ell$ and bb final states, combined from all LEP experiments.

2. New Heavy Neutral Gauge Boson Z$'$

Additional heavy neutral vector bosons are predicted in many theories, like E_6 models, left-right symmetric models and Sequential SM extension model. In e^+e^- annihilation the lightest one can affect the cross section and asymmetry measurements even if its mass is larger then $\sqrt{s}$. Fits are made to the mass of Z$'$ and to the mixing angle between the two bosonic fields, $\Theta_{ZZ'}$, using the cross section and asymmetry measurements from LEP1 and LEP2.

This is done using models obtained from E_6 GUTs or left-right gauge group. In both cases a mixing angle, denoted as Θ_6 or α_{LR}, respectively, appears. Specific choices of Θ_6 mixing angle are defined as $\chi(\Theta_6 = 0)$, $\psi(\Theta_6 = \pi/2)$ and $\eta(\Theta_6$ =-arctan$(\sqrt{5/3}))$ models. In the left-right symmetric model the coplings g_L and g_R are assumed to be equal. In the Sequential SM extension model Z$'$ has the same couplings as the SM Z boson. No evidence is found for the existence of Z$'$ in any of the models. The mass limits obtained in the single LEP experiments and from LEP combined data are shown in Table 3 for different models [2, 7, 8, 9].

Model	single exp.	LEP combined
χ	460 - 684	715
ψ	275 - 336	480
η	330 - 450	450
LR	412 - 469	860
SSM	656 -1280	2090

Table 3: 95% CL lower limits in GeV on $m_{Z'}$ from the single LEP experiments and from LEP combined data.

3. Leptoquarks

These particles carry baryon and lepton numbers. They have colour, electric charge and weak isospin, and couple to the standard gauge bosons. Assuming dimensionless interactions with SM fermions and gauge invariance, there could be 9 scalar states, S, and 9 vector states, V, grouped in two singlets,

Scalar LQ type	single exp.	LEP comb.
$S_0(L) \rightarrow eu$	530 - 632	789
$S_0(R) \rightarrow eu$	103 - 410	639
$\tilde{S}_0(R) \rightarrow ed$	112 - 170	210
$S_{1/2}(L) \rightarrow e\bar{u}$	90 - 179	190
$S_{1/2}(R) \rightarrow e\bar{u}, e\bar{d}$	149 - 158	240

Table 4: 95% CL lower mass limits in GeV for scalar leptoquarks.

two doublets and a triplet of isospin. Only the mass, m_{LQ}, and the coupling to fermions, λ, remain as free parameters.

In the process $e^+e^- \to q\bar{q}$, leptoquarks of the first generation can be exchanged in the t-channel or u-channel and can modify the hadronic cross section. Therefore, the comparison of the cross section measurement with theoretical predictions allows one to set upper limits on the leptoquarks couplings as a function of its mass, m_{LQ}. For a coupling $g = \sqrt{4\pi\alpha}$, where α is the fine-structure constant, mass limits can be derived. The results for these lower bounds on first generation leptoquark masses are shown in Tables 4 and 5 for scalar and vector leptoquark states, respectively [2, 4, 7].

Vector LQ type	single exp.	LEP comb.
$V_{1/2}(L) \to ed$	167 - 230	305
$V_{1/2}(R) \to eu, ed$	199 - 340	227
$\tilde{V}_{1/2}(L) \to eu$	120 - 156	176
$V_0(L) \to e\bar{d}$	750 - 829	1070
$V_0(R) \to e\bar{d}$	147 - 148	167
$\tilde{V}_0(R) \to e\bar{u}$	350 - 409	497
$V_1(L) \to e\bar{u}, e\bar{d}$	470 - 620	664

Table 5: 95% CL lower mass limits in GeV for vector leptoquarks.

4. Gravity in Extra Dimensions

The large extra dimensions are introduced to solve the hierarchy problem of the Standard Model by lowering the Planck scale, M_{Pl}, to the TeV scale. These models assume δ extra space dimensions of range R and a fundamental scale M close to the electroweak scale. These parameters are linked to M_{Pl} (which is not fundamental any more but becomes merely an effective scale in 3-dimensional space) by the relation $M_{Pl}^2 \sim R^\delta M^{\delta+2}$. Models with δ=1 have already been excluded by $\sim 1/r^2$ tests of the gravitational force. $\delta \geq 2$ is tested at LEP either directly by searching for the graviton G in the reaction $e^+e^- \to \gamma G$ or indirectly via virtual graviton effects on $e^+e^- \to f\bar{f}$, $\gamma\gamma$ rates and distributions.

	ALEPH		DELPHI		L3	
δ	M (TeV)	R (cm)	M (TeV)	R (cm)	M (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	$5.2 \cdot 10^{-12}$

Table 6: 95% CL lower limits in TeV on the mass scale M from direct search for the graviton G in the reaction $e^+e^- \to \gamma G$.

The effect of direct graviton emission, $e^+e^- \to \gamma G$, leads to single photon plus missing energy final state. The negative results of this search can be expressed in terms of limits on the scale M as shown in Fig. 6 [3, 5].

Among the many difermion and diboson final states tested for presence of virtual graviton effects at LEP, the most sensitive channels involve dielectron, e^+e^-, and diphoton, $\gamma\gamma$, final states, especially the e^+e^- final state where the inteference between t-channel photon exchange and graviton exchange is expected to be large. No significant deviations are found from the SM predictions and the extracted lower limits on the mass scale M are shown in Table 7 [4, 8, 9, 10].

	Process	ALEPH	DELPHI	L3	OPAL
$M(\lambda = +1)$ (TeV)	e^+e^-	1.32	-	1.06	1.00
$M(\lambda = -1)$ (TeV)	e^+e^-	0.88	-	0.98	1.15
$M(\lambda = +1)$ (TeV)	$\gamma\gamma$	-	0.82	0.83	0.83
$M(\lambda = -1)$ (TeV)	$\gamma\gamma$	-	0.91	0.99	0.89

Table 7: 95% CL lower limits in TeV on the mass scale M from indirect searches in $e^+e^- \to e^+e^-$, $\gamma\gamma$ final states.

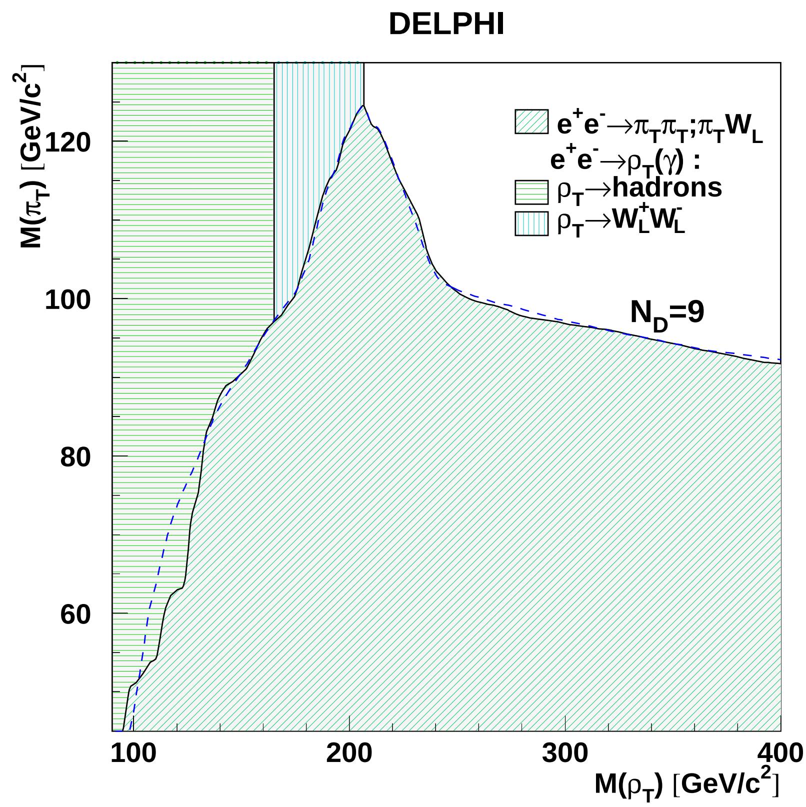

Figure 1: 95% CL excluded mass region in the (m_{π_T},m_{ρ_T}) plane.

5. Technicolour

Technicolour provides electroweak symmetry breaking dynamically by strong interactions of gauge bosons. Recent extension of technicolour models, the so-called "topcolour assisted working technicolour", avoids the discrepances with electroweak precision measurements, flavour-changing neutral current predictions and the large mass of the top quark, and predicts technicolour scalar π_T and vector meson ρ_T, which can be light enough to be observed at LEP2. DELPHI [6] searched for these particles in the following channels:

- $e^+e^- \to \rho_T \to$ hadrons
- $e^+e^- \to \rho_T \to W_L W_L$
- $e^+e^- \to \rho_T \to W_L \pi_T,\ \pi_T \pi_T$

Good agreement is observed with the SM expectation in all channels. This is translated into an excluded region at 95% CL in the (m_{π_T},m_{ρ_T}) plane as shown in Figure 1. The ρ_T production is excluded for $m_{\rho_T} < 206.7$ GeV.

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References

[1] E.J. Eichten, K.D. Lane and M.E. Peskin, *Phys. Rev. Lett.* **50** 811 (1983).

[2] LEP2FF/01-01

[3] ALEPH 2001-010 CONF 2001-007.

[4] ALEPH 2001-019 CONF 2001-016.

[5] DELPHI 2001-082 CONF 510.

[6] DELPHI 2001-086 CONF 514.

[7] DELPHI 2001-094 CONF 522.

[8] L3 Note 2647.

[9] OPAL Physics Note PN 469.

[10] OPAL Physics Note PN 471.