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Searches for extra dimensions, gauge mediated SUSY and exotics at LEP

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The results of searches for several type of physics beyond the Standard Model using data from the four LEP experiments are presented. In the absence of any excess signal events seen in the data limits are placed on the existence of extra-dimensions, gauge mediated supersymmetry and some exotic states.

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1 Introduction

LEP was the large electron positron collider at CERN. This accelerator ran from 1989 to 2000 producing e^+e^- collisions at $\sqrt{s} = 91 - 208$ GeV in the four detectors around the ring. Each of the detectors was used to measure the parameters of the Z boson precisely and that of other standard model parameters. The large number of Z decays and other measurements allow accurate tests of the standard model and constrain new physics processes that would cause deviations from the standard model predictions.

Searches for new particles were performed by direct searches and indirectly using the precision measurements. A brief overview of a few of these searches is presented here.

2 The LEP experiments

The 4 LEP experiments, ALEPH, DELPHI, L3 and OPAL, use different technologies based around the same basic detector design, as described in [1, 2, 3, 4]. They all rely on precise vertexing with silicon detectors around the beam pipe, tracking charged particles within a solenoidal magnetic field and measuring energy deposited in the electro-magnetic and hadronic calorimeters and around the outside of the calorimeters dedicated muon detectors.

3 Extra Dimensions

One possible solution to the problem of quantising gravity is to add additional dimensions to the 3+1 space-time dimensions assumed in the standard model [5, 6, 7]. These extra dimensions are finite in size and so will have quantised energy states within them. Gravitons, the particle that mediates the gravitational force, propagates in these compactified extra dimensions. This can solve the hierarchy problem, which is the very large scale difference between the Plank scale ($M_{Pl} \sim \mathcal{O}(10^{18-19})$ GeV) and the electro-weak scale ($M_{EW} \sim \mathcal{O}(10^{2-3})$ GeV). In a space with $D = \delta + 4$ dimensions the Planck mass, M_D, will be modified by the extra-dimensions. If the extra dimensions are of size R

$$G_N^{-1} = 8\pi R^{\delta} M_D^{2+\delta}, \tag{1}$$

where G_N is the Newtonian gravitational constant.

In an e^+e^- collider at electro-weak scales a signature of this process is the production a photon with a graviton, $e^+e^- \to G\gamma$. The graviton can not be detected and the visible decay is a single photon and missing energy and momentum. In the ALEPH data there was no excess seen in the single photon distribution over the expected SM backgrounds, see Figure 1. The largest possible size extra dimension is a function of the number of assumed extra dimensions. Assuming 2 extra dimensions, which gives the least stringent

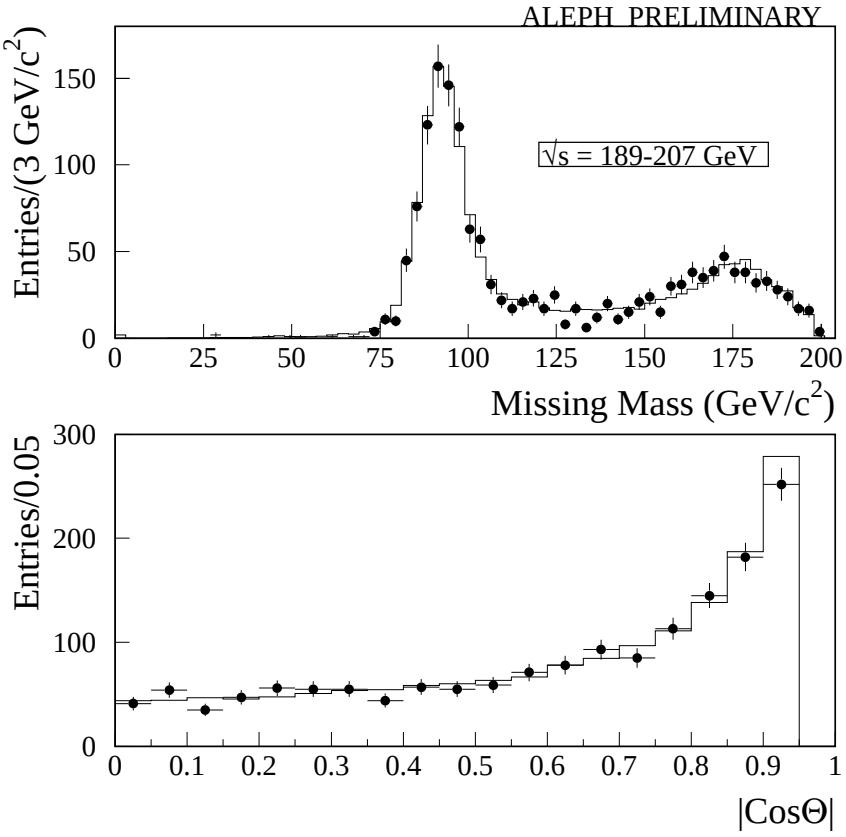

Figure 1: ALEPH data (points) and SM expectation (line) for the missing mass and $|\cos\theta|$ distributions.

size limit, they must be smaller than 0.29 mm at 95% confidence which is equivalent to a lower bound of 1.28 TeV on M_D, see reference [8] for the complete analysis.

Another signature is the modification of the 2 fermion production processes through a virtual graviton, $e^+e^- \to G^* \to \overline{f}f$. Comparisons of the standard model distributions and those with corrections for the extra dimensions can be made with the data. The largest effect will be seen in Bhabha scattering:

$$\frac{d\sigma}{d\cos\theta} = A(s,t) + \frac{\lambda}{M_s^4}B(s,t) + \frac{\lambda^2}{M_s^8}C(s,t), \tag{2}$$

where s is the square of the centre-of-mass energy, $t = -\frac{1}{2}s(1-\cos\theta)$ with $\cos\theta$ the electron scattering angle. A is the SM term, B is the interference term and C is the graviton exchange term. M_s is a mass scale related to M_D and λ is a parameter that depends on the theory. Using OPAL data and fitting for ee, $\mu\mu$, $\tau\tau$, $\gamma\gamma$ and ZZ distributions a measurement of $\lambda/M_s^4 = 0.31 \pm 0.39\text{TeV}^{-4}$ was made, see reference [9] for the complete

analysis.

4 Gauge mediated SUSY breaking

Minimal supersymmetry models (MSSM) assume that supersymmetry is broken in the gravitational sector at high scale (>> 1 TeV). If supersymmetry is broken by gauge forces (GMSB) then the gravitino will be a light particle, $M_{\tilde{G}} < 1\,\mathrm{eV}/c^2$, and the lightest supersymmetric particle. Decays of the next to lightest supersymmetric particle (NLSP) to the gravitino are possible and may have a significant life time ($c\tau > 10$ cm). NLSP signatures in three lifetime ranges are shown in Table 1.

NLSP Lifetime		sleptons	neutralinos
Short	($c\tau < 10$ cm)	Acoplanar leptons	Acoplanar photons
Medium	(5 cm $< c\tau <$ 10 cm)	Track kinks	Single non-pointing photons
Long	($c\tau > 2$ m)	Heavy stable charged particles (dE/dx)	Invisible

Table 1: GMSB signatures with a slepton or neutralino NLSP

4.1 Two photons and missing energy

The search for excess two acoplanar photons and missing energy constrains the neutralino pair production cross-section in the case of rapid decay to gravitinos and photons. Using the LEP combined data a limit on the production cross-section for neutralino pairs can be set. Figure 2 for an example data and background comparison and corresponding limits, see reference [10, 11] for a discussion of the complete analyses.

4.2 Heavy stable charged particles

Heavy particles decaying with a distance of greater than 10 m will be seen as tracks with very high specific ionisation along their path and will pass through the muon chamber when leaving the detectors. In DELPHI the additional information given by the Čerenkov detectors is an additional discriminant. These particles can be the signature of several types of new physics including stable lepton species, see section 5, NLSP states in GMSB or MSSM states with small R-parity violating couplings. Figure 3 shows the DELPHI data and Monte Carlo prediction for several stable charged particle masses for dE/dx and

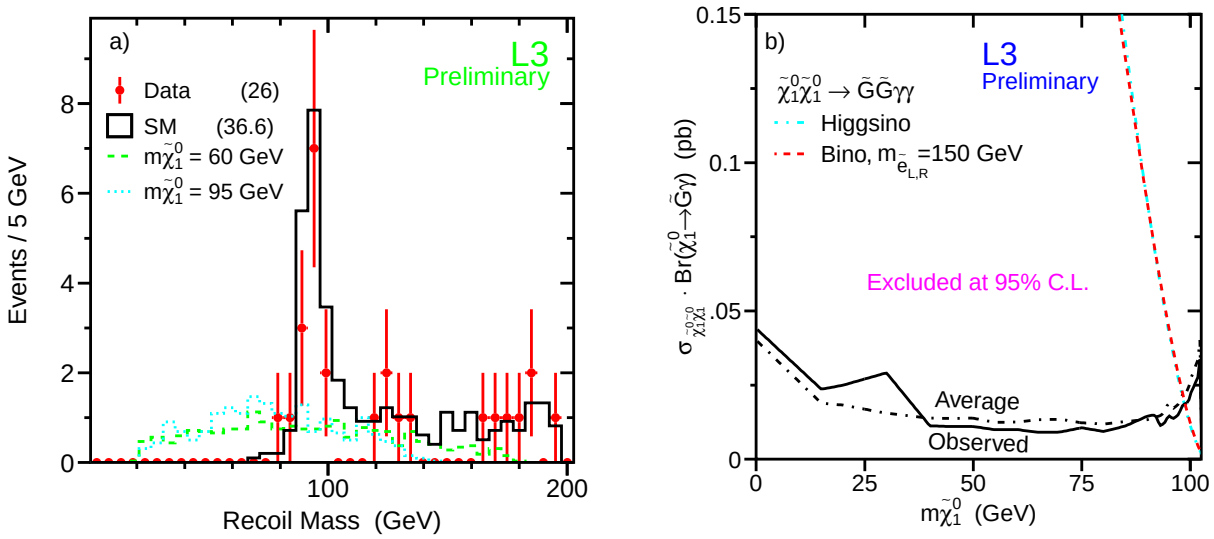

Figure 2: Plot a: L3 data and SM background predictions for the recoil mass from two photon events, two different mass neutralino predictions are also shown. Plot b: the cross-section $\times$ branching ratio exclusions for $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to \tilde{G}\tilde{G}\gamma\gamma$ and the cross-sections for two extreme case neutralino mixings.

Čerenkov angles, for a full analysis see [12]. This data allows the setting of a cross-section limit as a function of the mass of the proposed particle, for stable smuons or staus the limit corresponds to 97.4(97.1) GeV for left(right) handed sleptons [12]. For selections production the t-channel processes depend on the masses of the neutralinos and so a general limit can not be set.

4.3 Track kink searches

If a particle has a decay length of the order of the size detector it will be characterised by decays in the bulk of the detector, characterised by a kink in the track. Backgrounds to these topologies are usually caused by nuclear interactions, where a track elastically collides with a nucleus, and cosmic rays in which particles, predominantly muons, arriving out of time with a beam crossing are reconstructed in the wrong positions. These searched when combined with the long and short lifetime searches can completely cover the parameter space with a slepton NLSP. The limits set by the OPAL data is that for all lifetimes cross-sections of larger than 0.1 pb are excluded for each of the three slepton flavours, see Reference [13] for a complete discussion of the analysis.

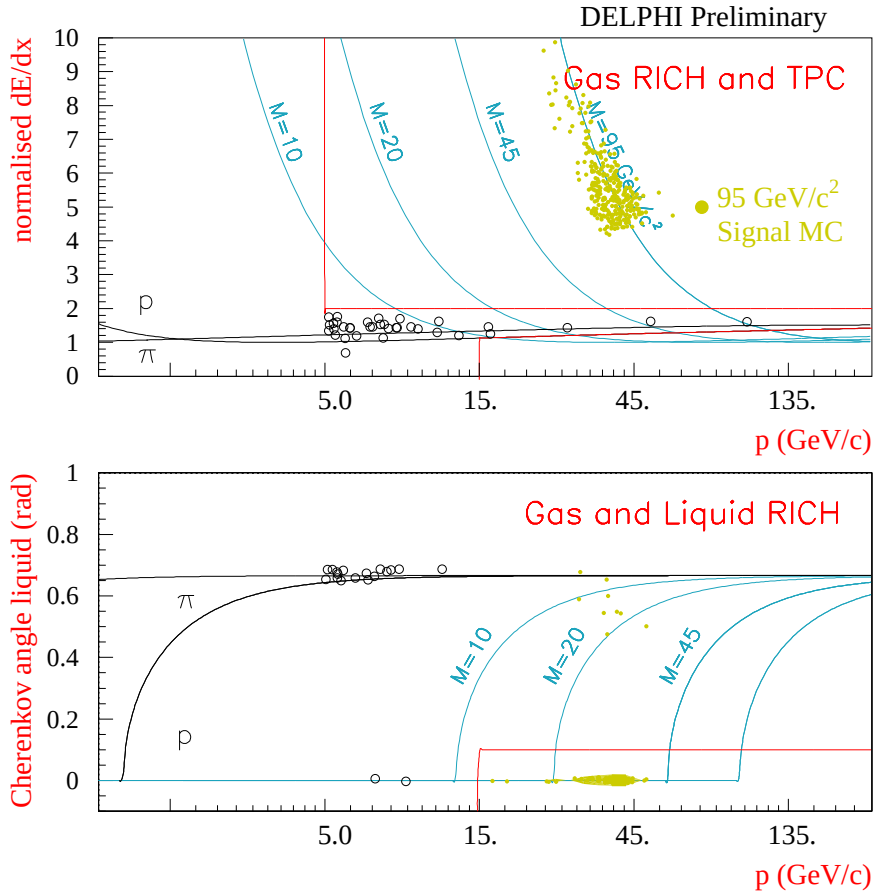

Figure 3: Normalised dE/dx and Čerenkov angle distributions for DELPHI data and predictions for several signal heavy lepton masses.

5 Exotic Leptons

Exotic leptons can be of several types depending on the extension to the standard model assumed. They can be classified according to their $SU(2) \times U(1)$ quantum numbers [14]. Three possible cases are

Sequential leptons [15]: a fourth family of standard model leptons is assumed,

Vector leptons [16]: which are vector particles and occur in left and right handed Iso-spin doublets,

Mirror leptons [17]: which have opposite chiral properties to the SM leptons.

Using the data collected by the L3 experiment with the assumptions that the charged current mode dominates, which is valid for the kinematically accessible regions, and a

short ($< 1\,\mathrm{cm}$) lifetime or long lifetime the limits set are listed in Table 2. Reference [18] has a complete discussion of the analysis and limits set.

	Sequential	Vector	Mirror
$L^0 \to \tau\mathrm{W}$ (Dirac)	90.3	99.3	90.3
$L^0 \to \tau\mathrm{W}$ (Majorama)	80.5	–	80.5
$L^\pm \to \nu\mathrm{W}$	100.8	101.2	100.5
$L^\pm \to L^0\mathrm{W}$	101.9	102.1	101.9
Stable $L^\pm$	102.6	102.6	102.6

Table 2: Lower limits in GeV/c^2 on the masses of exotic lepton species set using the L3 data.

6 Technicolor

Technicolor [19] is an alternative to the Higgs mechanism for electro-weak symmetry breaking. A new charge which is similar to the colour charge in QCD is proposed. This would be carried by a set of new particles called technifermions. It is the breaking of the chiral symmetry associated to these which gives masses to the Standard Model bosons. The simplest models are ruled out by precision electro-weak measurements [20] and so more complex models that avoid these limits are proposed. One way is to require that the coupling parameter changes more slowly with scale that that of QCD, rather than a running parameter it is described as a walking one. The most basic technicolor model used to set exclusions in LEP searches is the straw man model [21], in this model the lightest technicolor vector mesons could be seen at LEP.

The two channels used to search for technicolor decays are

$$\mathrm{e^+e^-} \to \rho_T^0/\omega_T^0 \to \pi_T^+\pi_T^- \to b\overline{q}\overline{b}q' \tag{3}$$

$$\mathrm{e^+e^-} \to \rho_T^0/\omega_T^0 \to \pi_T^0\gamma \to b\overline{b}\gamma \tag{4}$$

which are resonant production processes. The cross-section is much greater if $M(\rho_T^0/\omega_T^0) \sim \sqrt{s}$, although there is some sensitivity at other centre-of-mass energies through radiative events and by producing virtual techinparticles. Cross-section limits on the processes listed above are shown in Figure 4 [22]. Limits are set using both OPAL and DELPHI data on possible parameters of the see references [22, 23] for a complete discussion of the analysis and limits.

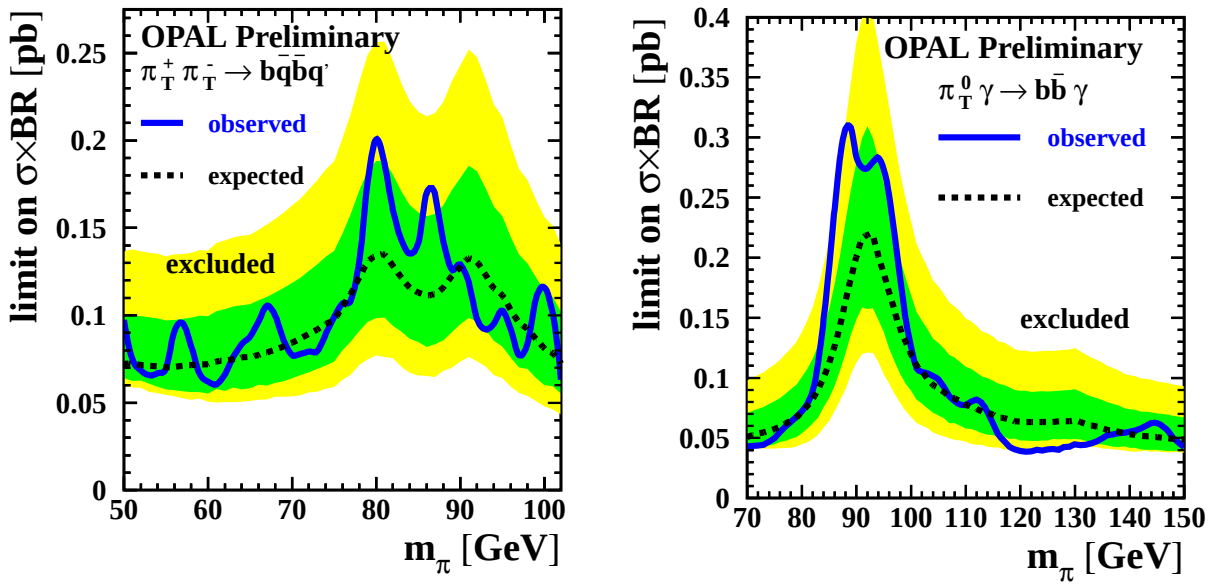

Figure 4: Limits set with the OPAL data on two topologies for technicolor production. The blue curve is the upper limit on technicolor production, the dashed curve is the expected limit and the green and yellow bands are the 1σ and 2σ curves around this.

7 Conclusions

The data taken from 1989–2000 by the four LEP experiments have been analysised and many searches for physics beyond the standard model have been performed. So far there has been no evidence for any such process. This is only a partial survey of the large number of direct and indirect searches performed by the LEP collaborations.

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