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Searches for new physics in photonic final states at LEP

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Abstract. A brief review of searches for physics beyond the Standard Model in photonic final states at LEP is given here. These include searches for supersymmetry, large extra dimensions and contact interactions. Recent results from all four LEP experiments are presented, including improved limits on the new scale of gravity for models with large extra dimensions and the most precise direct measurement of the number of light neutrino species. Status and prospects of the LEP combined searches are also discussed.

PACS. 13.66.Hk Production of non-standard model particles in e^+e^- interactions – 04.50.+h Gravity in more than four dimensions – 12.60.Jv Supersymmetric models – 12.60.-i Models beyond the standard model – 13.15.+g Neutrino interactions

1 Introduction

Photonic final states were produced at LEP via the reactions $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$ and $e^+e^- \to \gamma\gamma(\gamma)$, leading to two distinct topologies: single- and multi-photon events with missing energy and events with collinear photons (di-photons), respectively. These experimental signatures are also predicted by a wide variety of theories with physics beyond the Standard Model. Single- and multi-photon events can be used in direct searches for new neutral particles, such as graviton production in models with extra dimensions and neutralino and gravitino production processes in supersymmetry. Whereas in the di-photon topology, New Physics can manifest itself through deviations in the measured total and differential cross sections.

Results reviewed here are based on studies of the photonic final states by the four LEP collaborations, ALEPH, DELPHI, L3 and OPAL, using the highest centre-of-mass energy, $\sqrt{s}$, and luminosity LEP data samples collected in 1998-2000 at $\sqrt{s} = 189 - 208$ GeV with an integrated luminosity of about 650 pb^{-1} per experiment.

2 Single- and multi-photon signatures

2.1 Neutrino production

In the Standard Model of the electroweak interactions the reaction $e^+e^- \to \nu\bar{\nu}\gamma(\gamma)$ proceeds through s-channel Z exchange and t-channel W exchange, where the photons are radiated mainly from the incoming electrons and positrons. The distribution of the recoil mass to the photon system, M_{rec}, is expected to peak around the Z mass in the s-channel, whereas photons from the t-channel W exchange are expected to have a relatively flat energy distribution, peaked at low energies. A typical selection (L3)

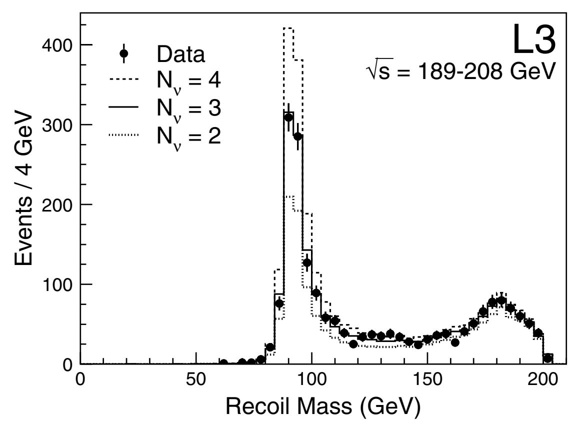

Fig. 1. The recoil mass spectrum of the single- and multi-photon events selected by L3 compared to the expected spectra for $N_\nu = 2, 3$ and 4

of single- and multi-photon events at LEP requires no charged tracks and the transverse momentum of the photon system, P_t^γ, greater than $0.02\sqrt{s}$. The purity of the selected $\nu\bar{\nu}\gamma(\gamma)$ sample is 99% and the selection efficiency is estimated to be about 71% [1].

The expected total and differential cross sections depend on the number of light neutrino families, N_ν. The M_{rec} spectrum of the single- and multi-photon events selected by the L3 experiment is shown in Fig. 1 together with the expectations for $N_\nu = 2, 3$ and 4. To determine N_ν a maximum likelihood fit is performed to the two-dimensional distribution of M_{rec} *vs.* $|\cos\theta_\gamma|$. Including lower energy data, N_ν is determined to be [1]

$$N_\nu = 2.98 \pm 0.05(stat) \pm 0.04(syst).$$

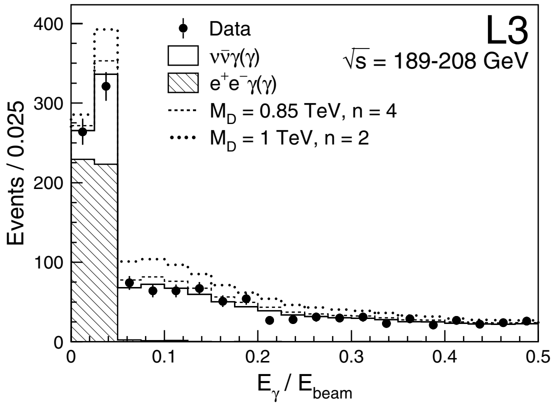

Fig. 2. Distribution of the ratio of the photon energy to the beam energy, for the single-photon sample selected by L3. Expected signals from the reaction $e^+e^- \to \gamma G$ are also shown

This result is more precise than the present world average of measurements relying on the single-photon method [2]. ALEPH [3] and DELPHI [4] have performed similar measurements of N_ν, which are also consistent with the Standard Model value of $N_\nu = 3$.

2.2 Searches for extra dimensions

Models with large extra dimensions [5] predict a gravity scale, M_D, as low as the electroweak scale, naturally solving the hierarchy problem. Gravitons, G, are then produced in e^+e^- collisions through the process $e^+e^- \to \gamma G$, and escape detection, leading to a single-photon signature.

All LEP experiments have performed searches for this reaction using selected samples of single-photon events. Since the photon energy spectrum from the graviton production is expected to be soft, the L3 experiment has also extended its standard single-photon selection to accept photons with P_t^γ as low as $0.008\sqrt{s}$ [1]. In the low P_t^γ region the Standard Model background is increased due to the reaction $e^+e^- \to e^+e^-\gamma(\gamma)$, where both electrons have a very low polar angle and cannot be detected. However, this effect is compensated by a significant increase in the accepted signal cross section. Effects of extra dimensions on the L3 photon energy spectrum are shown in Fig. 2.

A good agreement with the Standard Model expectation is observed and limits on the parameter M_D are derived from a fit to the photon energy and polar angle distributions. Recent limits obtained at LEP are detailed in Table 1. These are the best current collider limits for the number of extra dimensions below 6.

The presence of the brane in theories with extra dimensions creates additional degrees of freedom. Brane fluctuations in the extra-space directions would then manifest themselves as new stable particles, called "branons", π_{Br} [6]. If the brane tension is below the gravity scale, branons can be detected at LEP via the reaction $e^+e^- \to \pi_{Br}\pi_{Br}\gamma$, leading to a single-photon signature. The signal properties are similar to those of the graviton production process. L3 has limited branon masses to be above 103 GeV for a scenario with small brane tensions. Alternatively, under the assumption of light branon masses, brane tensions below 206 GeV are excluded [7].

Table 1. Lower limits at 95% C.L. on the gravitational scale, M_D, as a function of the number of extra dimensions, n, obtained by ALEPH [3], DELPHI [4] (preliminary) and L3 [1]

n	ALEPH	DELPHI M_D (TeV)	L3
2	1.26	1.36	1.50
4	0.77	0.82	0.91
6	0.57	0.59	0.65

2.3 Searches for SUSY

Single- and multi-photon events can be also produced by a variety of processes predicted in different models with supersymmetry (SUSY) [8]. These processes involve production and decays of neutralinos and gravitinos. No evidence for such models is observed and corresponding limits on SUSY parameters are given in [1,3,4]. Combined searches are also performed by the LEP SUSY Working group [9].

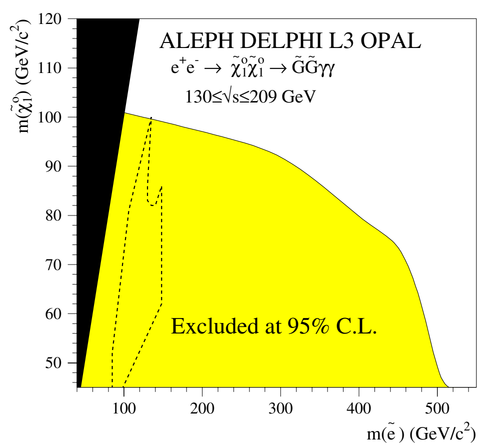

Fig. 3. Region excluded at 95% C.L. in the $m_{\tilde{\chi}_1^0}$ *vs.* $m_{\tilde{e}}$ plane. Overlaid is the region favored by the interpretation of the CDF event in the scalar electron scenario. This result is preliminary

In particular, a search for pair-production of neutralinos, each decaying into a photon and a gravitino, is motivated by an interpretation [10] of the rare $ee\gamma\gamma$ event observed by CDF [11]. This reaction, $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 \to \tilde{G}\gamma\tilde{G}\gamma$, is predicted by models with gauge-mediated SUSY breaking when the lightest and next-to-lightest supersymmetric particles are gravitino, $\tilde{G}$, and neutralino, $\tilde{\chi}_1^0$, respectively. The experimental signature of this process is very clean, involving events with two energetic acoplanar photons. No anomalous production of such events has been

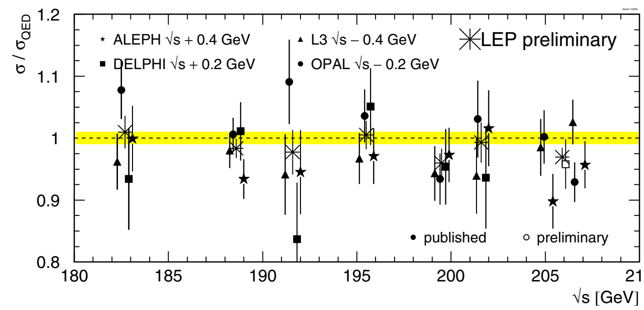

Fig. 4. The ratio of the measured and QED predicted cross sections of the process $e^+e^- \to \gamma\gamma(\gamma)$ as a function of $\sqrt{s}$

observed, and Fig. 3 shows the region excluded by LEP in the $m_{\tilde{\chi}^0_1}$ *vs.* $m_{\tilde{e}}$ plane, where $m_{\tilde{\chi}^0_1}$ and $m_{\tilde{e}}$ are the neutralino and scalar electron masses. The above interpretation of the rare CDF event is now excluded.

3 Collinear photons

Events with collinear photons are typically selected by requiring two energetic back-to-back photon candidates and no matching charged tracks. The cross section of this process has been measured by all four LEP collaborations [3, 12,13,14]. The individual measurements have been combined by the LEP Di-photon Working Group [15]. The measured total cross sections normalized to the QED predictions are shown in Fig. 4. To search for possible signs of new physics a global fit to the measured total and differential cross sections is performed. Good agreement with the Standard Model expectation is observed, and preliminary LEP combined limits have been derived in the context of several New Physics Models, some of which are described below.

The process $e^+e^- \to \gamma\gamma(\gamma)$ has a simple QED description at tree level, and provides a benchmark test of the QED at e^+e^- colliders. A simple and convenient way of parameterizing possible deviations from QED is the introduction of the cut-off parameters $\Lambda^{\pm}$. In a similar way, bounds on the mass scale of $e^+e^-\gamma\gamma$ contact interactions can be derived in terms of a parameter Λ_7. The corresponding 95% C.L. limits are:

$$\Lambda^+ > 392 \text{ GeV}, \quad \Lambda^- > 364 \text{ GeV}, \quad \Lambda_7 > 837 \text{ GeV}.$$

In models with extra dimensions, photon pair production via virtual graviton exchange can interfere with the Standard Model diagrams, leading to modifications of the differential cross section [1]. Deviations from QED can be then described in terms of a new mass scale, M_S, and a parameter $\lambda = \pm 1$, which gives the sign of the interference. The derived 95% C.L. limits are given by:

$$M_S(\lambda = +1) > 933 \text{ GeV}, \;\; M_S(\lambda = -1) > 1010 \text{ GeV}.$$

[1] It should be noted here, that searches for manifestations of extra dimensions are performed not only in photonic final states but in many other final state topologies [16].

4 Conclusions and discussions

Searches for New Physics in photonic states have been performed at LEP using the complete LEP data sample. These include searches for supersymmetry, large extra dimensions and deviations from QED. No evidence of such models is found. Constraints on various New Physics theories are set by the LEP experiments separately and by preliminary LEP combinations. Several search strategies and results have been briefly reviewed in this paper. Individual references should be consulted for details.

The LEP combinations are expected to be finalized in the near future, and an improvement in sensitivity of the LEP combined searches with single- multi-photon events is expected. The L3 experiment has also published the selection results in the form of Tables [1,13], which can be used to test future models involving photonic final states at LEP.

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