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# Search for Rare Z Decays at LEP

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**Abstract**

We discuss preliminary results of the LEP experiments on rare or forbidden Z decays. The present sensitivity to the branching ratios is about $10^{-5} - 10^{-6}$. Results on searches for lepton flavor violation and decays with photons in the final state are presented here.

## 1. Introduction

In this note we consider Z decays that are either forbidden or have expected branching ratios that are very small in the framework of the Standard Model [1]. In many models involving new physics such rare decays can be enhanced, and become observable at LEP, when one takes into account new couplings. Therefore, their observation can be interpreted as the manifestation of new physics.

In the following section we review the search for lepton flavor violation and decays with the photons in the final state.

## 2. Lepton flavor violating decays

In the Standard Model lepton flavor is conserved. However, there is no gauge principle requiring this conservation. Different models, beyond the Standard Model, allow processes which violate lepton flavor conservation. In theories where such violation arises through mixing with new particles [2], the branching ratios for processes, e.g. $Z \to \mu\tau$, have been calculated to be as large as $10^{-4}$ in certain models. All four LEP experiments have searched [3] for $Z \to e\tau$, $Z \to \mu\tau$. Here, recent L3 results, including 1993 data, are reported.

The expected experimental signature is an electron or a muon with an energy close to the beam energy recoiling against a different type of lepton or hadrons from tau decay. Background arises from Standard Model leptonic final states and can be divided into two classes : (i) incorrectly reconstructed $e^+e^-$ and $\mu^+\mu^-$ events; (ii) $\tau^+\tau^-$ events with one or both of the taus decaying into an electron or a muon which carries almost all the energy of the tau. Good electron and muon energy resolution is essential to reduce the latter background while retaining a high detection efficiency. This is demonstrated in figure 1 from the L3 experiment showing the muon energy for data, background and expected signal, normalised to the beam energy. The limits on the branching ratios were obtained with a maximum likelihood fit. The normalised energy distribution for data was fitted by the sum of the background prediction plus signal contribution and the following bounds at the 95% confidence level were obtained :

$$Br(Z \to e\tau) < 8.7 \times 10^{-6}$$

$$Br(Z \to \mu\tau) < 11 \times 10^{-6}$$

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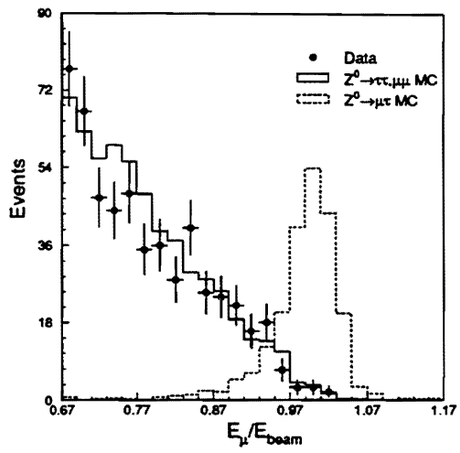


**Figure 1.** The L3 distribution of the normalised muon energy for the data, background and signal Monte Carlo $Z \to \mu\tau$. The signal normalisation is arbitrary.

## 3. Search for Z decays into a photon plus a meson

Within the context of the Standard Model, Z decays to a single photon plus either a single pseudoscalar or a single vector meson are expected to be rare. However, the magnitudes of the branching ratios for such Z decays are theoretically disputed and estimates range over many orders of magnitude, $10^{-4}$ – $10^{-11}$. Hence, experimental results will aid clarification of this dispute. If observable, such Z decays would yield useful information regarding strong interaction dynamics and quite possibly imply new physics.

Two methods can be used for the above searches : one can look for the charged decay modes of a meson or for the neutral ones. For the first case the experimental signature is the following one : an isolated photon, with an energy close to the beam energy, in one hemisphere of the detector associated with a narrow jet along the opposite direction. For Z decays into pure neutral final states one can look for a possible deviation of the measured $e^+e^- \to \gamma\gamma(\gamma)$ cross section from the QED prediction at Z energies, which can be interpreted as evidence for rare or forbidden Z decays, such as $Z \to \gamma\gamma(\gamma)$, $\gamma\pi^0$, $\gamma\eta$, $\gamma\omega$, all of which have a similar experimental signature since the neutral decay of a high energy meson is not distinguished from the passage of a single photon. This possibility was tested by analyzing the dependence of the total $e^+e^- \to \gamma\gamma(\gamma)$ cross section on the cente-of-mass energy. To obtain the upper limits on such rare decays the cross section was fitted to the sum of the QED prediction plus a Z decay contribution, given by a Breit-Wigner line shape.

The updated L3 (with 1993 statistics) and DELPHI (with 1992 statistics) results are shown in table 1.

| decay mode | L3 limit | search mode | DELPHI limit | search mode |
|---|---|---|---|---|
| $Z \to \gamma\gamma$ | 5.2 | | 5.5 | |
| $Z \to \gamma\pi^0$ | 5.2 | | 5.5 | |
| $Z \to \gamma\eta$ | 4.0 | charged | 8.0 | neutral |
| $Z \to \gamma\eta'$ | 1.7 | charged | | |
| $Z \to \gamma J/\psi$ | 1.9 | charged | | |
| $Z \to \gamma\omega$ | | | 65. | neutral |
| $Z \to \gamma\gamma\gamma$ | 0.8 | | 1.7 | |

**Table 1.** 95% confidence level upper limits on rare Z decays in units of $10^{-5}$.

## 4. $Z \to \gamma\gamma\gamma$

In the Standard Model the branching ratio of $Z \to \gamma\gamma\gamma$ is of the order of $10^{-9}$. However, if Z is composite it can couple to photons and gluons through its charged and coloured constituents. In some models [5] the decay $Z \to \gamma\gamma\gamma$ can have a branching ratio as high as $10^{-4}$. The main background for this search comes from the QED radiative process $e^+e^- \to \gamma\gamma\gamma$. Figure 2 shows the distribution of the least energetic photon for data, signal and QED background (the 10 GeV cut was applied) from the L3 experiment. The obtained 95% confidence level limit is

$$Br(Z \to \gamma\gamma\gamma) < 8.1 \times 10^{-6}$$

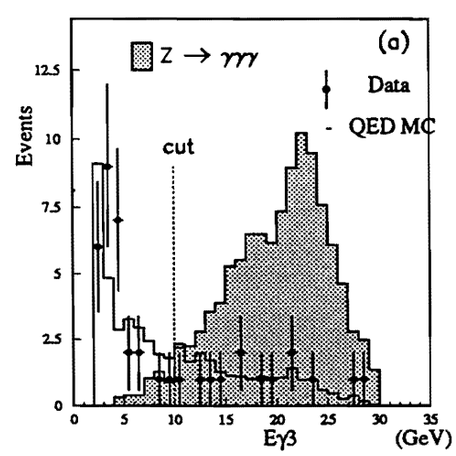


**Figure 2.** Energy of the least energetic photon for data, QED background and composite signal $Z \to \gamma\gamma\gamma$. The signal normalisation is arbitrary.

The $\gamma\gamma\gamma$ final state can be also used for the search for anomalous production of high mass photon pairs in $e^+e^- \rightarrow \gamma\gamma\gamma$ events. This search is motivated by the L3 collaboration's observation of four events of the type $e^+e^- \rightarrow \ell^+\ell^-\gamma\gamma$ with an invariant mass of the two photons clustering around 60 GeV [6]. If a new resonance X were produced in assosiation with a virtual photon, which could explain the $\ell^+\ell^-$ in the $e^+e^- \rightarrow \ell^+\ell^-\gamma\gamma$ events of L3 collaboration and the absence of $\nu\nu\gamma\gamma$ events, then it may also be produced in association with a real photon leading to a final state with three photons. The main background to this search is the QED process $e^+e^- \rightarrow \gamma\gamma\gamma$. The L3 collaboration has updated the results on this search with 1993 statistics (totall 65 $pb^{-1}$). The results are presented in figure 3. No significant structure was observed in the distribution of invariant mass of the two photons. The probability of the four events, shown in the upper left corner, to originate from QED process is about 4%.

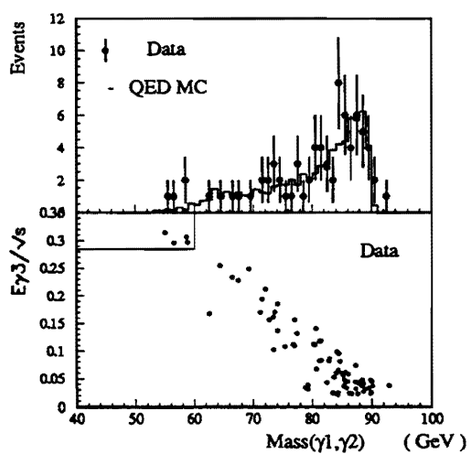


**Figure 3.** Upper picture : the distribution of invariant mass of the two photons for data and QED background. Down picture : The distribution of invariant mass of the two photons versus the energy of the least energetic photon for data.

Large couplings of magnetic monopoles to Z's and $\gamma$'s were predicted in [7]. Therefore, one can search for virtual-monopole effects in the $\gamma\gamma\gamma$ final state. The characteristic features of the photons produced through the monopole loop are the following : (i) all 3 photons are energetic; (ii) they are not peaked in the forward region, as in the case of QED process. Using the theoretical predictions [7], the L3 95% confidence level upper limit

$$Br(Z \rightarrow \gamma\gamma\gamma) \; < \; 8.1 \times 10^{-6}$$

can be translated into the mass limit of magnetic monopole

$$Mass\ of\ magnetic\ monopole \; > \; 0.51\ Tev$$

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