$\ell\ell\gamma\gamma$ events at LEP

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ABSTRACT

The results of studies on the $\ell\ell\gamma\gamma$ events with high $\gamma\gamma$ mass from the L3 experiment at LEP is reported. A clustering of events with $\gamma\gamma$ invariant mass around 60 GeV is observed. The clustering could come from decay of a heavy particle, however, QED fluctuation cannot be ruled out. More data are needed to ascertain the origin of these events.

1. INTRODUCTION

During the running period of April 1990- Aug. 1992, the L3 group at LEP has found four $\ell\ell\gamma\gamma$ events with high $\gamma\gamma$ invariant mass. The $\gamma\gamma$ invariant mass of these 4 events clustered around 60 GeV, clearly distinguished from the expectation of QED radiation[1]. Three of the events are $\mu\mu\gamma\gamma$ events, and one of them is $ee\gamma\gamma$ event.

Original motivation to search for these event was to search for high mass new particles decaying into one or more photons, taking advantage of the special resolution of the L3 detector for the electron, photon and muons. Good resolution make the identification and reconstruction of the new particle straight-forward and accurate.

Since the announcement of these events, more Z^0 events are collected and the total luminosity is increased from 27 pb^{-1} to 43 pb^{-1}. The status of the search for high mass $\ell\ell\gamma\gamma$ events with the increased luminosity, and other related searches is reported in the following sections.

2. EVENT SELECTION

Fig. 1 shows the 4 discovered $\ell\ell\gamma\gamma$ events from L3. The events show very clear and distinctive signature of two leptons and two photons, and no hadronic activity. The measured energy of all 4 events are consistent with the beam energy. Table 1 lists important parameters of these events. We notice that the recoil masses calculated from the lepton pairs agrees very well with the invariant masses of the photon pairs, indicating that there is no missing particles.

Event	$M_{\gamma\gamma}$ (GeV)	$M_{\ell\ell}$ (GeV)	M^{rc} (GeV)	$\theta^1_{\gamma\ell}$ (deg.)	$\theta^2_{\gamma\ell}$ (deg.)
1	58.8 ± 0.6	27.1 ± 1.4	58.0 ± 3.5	18.2 ± 0.3	45.9 ± 0.3
2	59.0 ± 0.6	25.3 ± 0.4	59.7 ± 1.0	55.0 ± 0.3	92.4 ± 0.3
3	62.0 ± 0.6	20.0 ± 0.4	61.5 ± 1.1	8.8 ± 0.3	100.6 ± 0.3
4	60.0 ± 0.6	17.9 ± 0.2	59.9 ± 0.7	11.4 ± 0.3	20.8 ± 0.3

Table 1 Important parameters of the four high photon mass events. M^{rc} is the recoil mass from the lepton pairs, $\theta^1_{\gamma\ell}$ is the smallest angle between a lepton and a photon, and $\theta^2_{\gamma\ell}$ is the angle between the remaining lepton and photon.

The selection of these events is based on identified leptons and photons by the L3 detector. The L3 detector[2] consists of, from inside out, a central tracking chamber (TEC), BGO electromagnetic calorimeter, the Hadron calorimeter, and the Muon chambers. The whole detector is enclosed in a large magnetic volume of 0.51 Tesla field. BGO electromagnetic calorimeter measures electron and photon with momentum resolution of 1.2% above 5 GeV. The muon chambers measure the muons with 2.5% resolution at 45 GeV. Hadronic jets are measured by the calorimeters with 10% resolution.

The electrons and photons are identified by the shower shape of the energy deposit in the BGO crystal. The shower profile has to agree with that of the testbeam measurements.

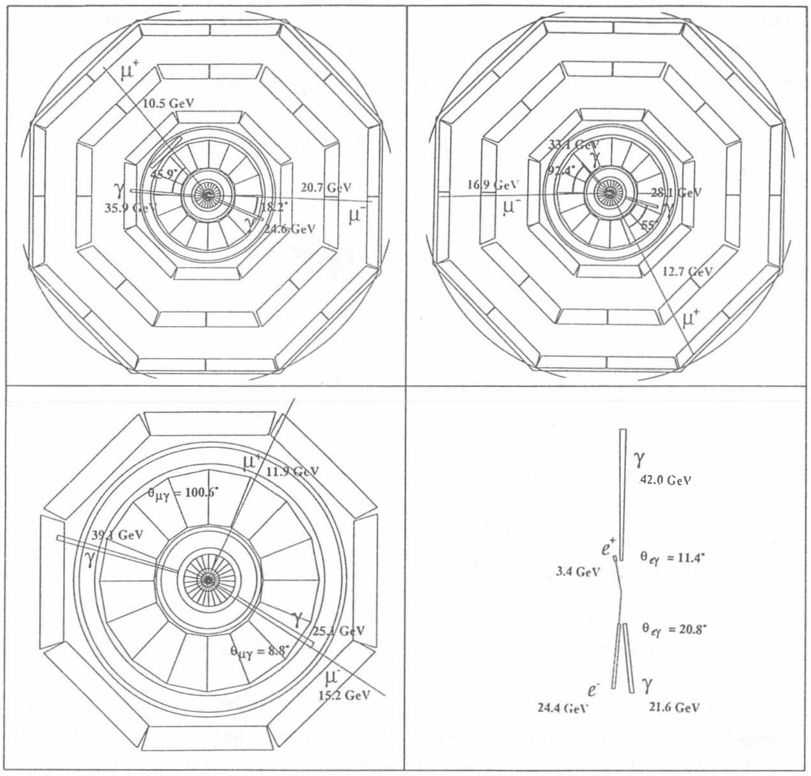


Fig. 1 The four events found with high photon invariant mass.

Furthermore, the energy deposit in the hadron calorimeters within 7 degrees of the electromagnetic shower center has to be less than 10% of the electromagnetic shower energy. The electromagnetic shower is identified as an electron if there is a TEC track within 20 mrad of the bump, otherwise it is identified as a photon. The muons are identified by a track in the muon chamber, matched with a TEC track. The energy of the muon is required to be greater than 3 GeV and the track has to pass through less than 100 mm from the interaction point. Taus are identified as narrow jets in the TEC and in the hadronic calorimeter.

To select $\ell\ell\gamma\gamma$ events, we require 2 identified lepton and two identified photons. The electrons are limited in the Barrel region ($|\cos\theta| < 0.74$) to avoid t-channel process. The muons are identified within the fiducial volume of the muon chambers ($|\cos\theta| < 0.8$). Photons are accepted in the whole fiducial volume of BGO ($|\cos\theta| < 0.9$). To avoid shower overlapping, we further require that the angle between the electrons and the photons , $\theta_{\gamma e}$, be larger than 8°. The angle between muon and photon are required to be larger than 5°. Since τ can decay to hadronic jet, the γ - τ separation, $\theta_{\gamma\tau}$, is required to be larger than 15°.

Assuming that the 4 particles are generated with unity matrix element, i.e., the phase space distribution, the acceptance of $ee\gamma\gamma$, $\mu\mu\gamma\gamma$, and $\tau\tau\gamma\gamma$ events are 35%, 38%, and 33%, respectively.

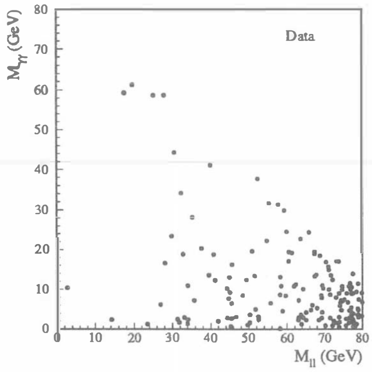


Fig. 2 $M_{\gamma\gamma}$ versus $M_{\ell\ell}$ for $\ell\ell\gamma\gamma$ events.

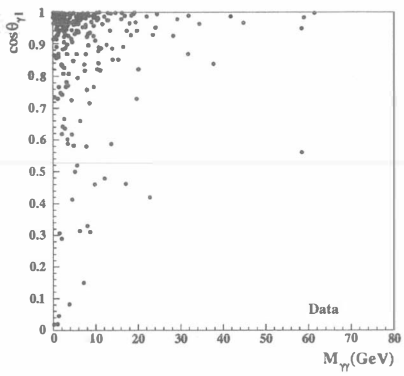


Fig. 3 $\cos\theta_{\gamma\ell}$ versus $M_{\gamma\gamma}$ for $\ell\ell\gamma\gamma$ events.

The whole data sample from 1990 to 1992 LEP physics runs are used in the selection. The total luminosity is 43 pb^{-1}, corresponding to 1.5 million produced Z^0s. Figure 2 shows the distribution of $M_{\gamma\gamma}$ versus $M_{\ell\ell}$ of all the accepted $\ell\ell\gamma\gamma$ events. Four high $\gamma\gamma$ mass events are far away from the rest of the events, and their mass clustered around 60 GeV. Fig. 3 shows the distribution of $\cos\theta_{\gamma\ell}$ versus $M_{\gamma\gamma}$ for the same events.

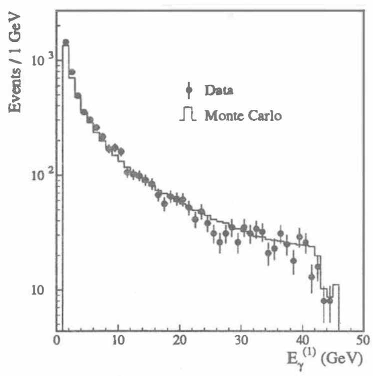
3. BACKGROUND EXPECTATIONS

Hard photons can produce from the Z decays via initial or final state radiation. These radiation, however, does not produce clustered photon invariant mass. We therefore studied the QED radiation and compare the kinematic distribution from QED calculation to the observed events. The probability that the four high mass events coming from QED fluctuation can then be estimated.

Several QED calculations and Monte-Carlo simulations exist for the process:

$$e^+e^- \to \ell^+\ell^- + \mathrm{n}(\gamma)(\ell \neq e)$$

YFS3 Monte-Carlo program, by Jadach and Ward[3], treats the soft and collinear photon by YFS[4] exponentiation to all orders of α. The hard, isolated photons are implemented to α^2



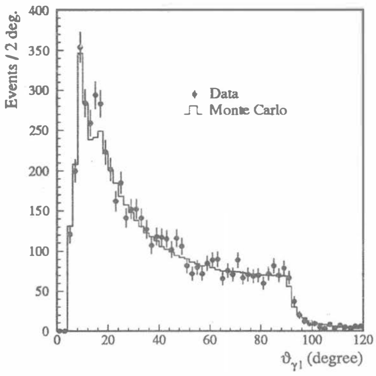


Fig. 4 Energy of the most energetic photon in $\ell\ell n(\gamma)$ events.

Fig. 5 Angle between the most energetic photon and the closest lepton in $\ell\ell n(\gamma)$ events.

order. Matrix element calculation of this process to α^2 order are carried out separately by Stirling[5], Summers[6], Martinez[7], and others. For hard and isolated photon production, these two approach should predict the same cross section. Predictions of $M_{\gamma\gamma}$ distribution by different programs agrees to better than 10% [8]. In the L3 analysis, YFS3 is used for QED backgrounds calculations.

To determine the validity of these simulations, we compared the predicted $\ell\ell n(\gamma)$ production rates with the collected events. Table 2 shows the comparison of the number of $\ell\ell n\gamma$ events in the data and predicted by the Monte-Carlo program. The number of events in the Monte-Carlo prediction is normalized to 43 pb^{-1}, corresponding to 1.6 million produced Z^0.

	Data Sample				MC (YFS3) Expectation			
n	$een\gamma$	$\mu\mu n\gamma$	$\tau\tau n\gamma$	$\ell\ell n(\gamma)$	$een\gamma$	$\mu\mu n\gamma$	$\tau\tau n\gamma$	$\ell\ell n(\gamma)$
n$\geq$ 1	2412	2270	1150	5832	2203	2338	1062	5604
n$\geq$ 2	94	109	41	244	76	94	29	199

Table 2. Number of $\ell\ell n(\gamma)$ events in data sample and from MC (YFS3) expectation, out of 1.6 million produced Z^0.

Fig. 4 shows the comparison of the energy of the most energetic photon in $\ell\ell n(\gamma)$ events. The distribution is well described by the QED calculation. Fig. 5 shows the angle between the most energetic photon and the closest lepton, $\theta_{\gamma\ell}$. Again, the distribution agrees well. Fig. 6 shows the energy of the second photon, $E_\gamma^{(2)}$, in two photon events. The distribution agrees well in the low energy region, while the four high mass events with $E_\gamma^{(2)} > 20$ GeV is in excess of the expectation from QED. The invariant mass of the photon pairs in $\ell\ell\gamma\gamma$

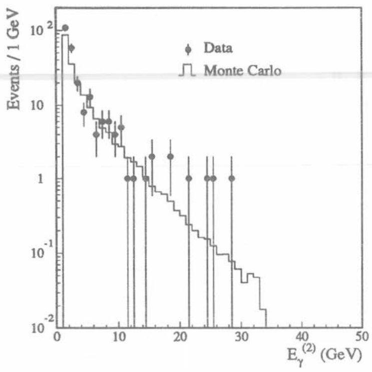


Fig. 6 Energy of the second energetic photon in $\ell\ell n(\gamma)$ events.

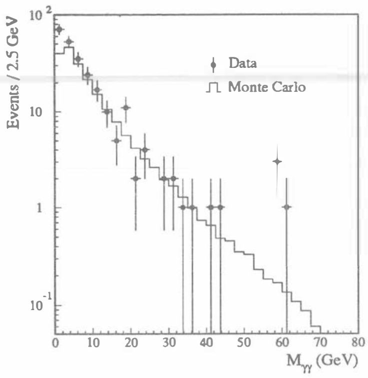


Fig. 7 Invariant mass of photon pairs in $\ell\ell\gamma\gamma$ events.

events is shown in fig. 7. Here again the expectation of QED radiation agrees well with the data at low mass region. Four events clustered at 60 GeV is clearly in disagreement with the prediction.

We conclude that the QED prediction is in agreement with the data for both the normalization and the distributions of energy and angle, except for the four events clustered around 60 GeV $\gamma\gamma$ mass. We then calculate the probability for this clustering to happen in the following way: 1 million "runs" of $\ell\ell\gamma\gamma$ events are generated. Number of events in each "run" is determined by a poisson distribution whose average value equals to the observed number of events. We then count the number of cases which has 4 or more events with invariant masses $M_{\gamma\gamma}$ clustered in a 5 GeV mass bin, and $M_{\gamma\gamma} > 50$ GeV. We found that the probability of such happening is of the order of $O(10^{-2})$.

4. RELATED SEARCHES

Assuming that the photon pair in the $\ell\ell\gamma\gamma$ events are from the decay of a heavy particle X, which couples to the Z or the virtual photon from e^+e^- annihilation, one would also expect to see $\nu\nu\gamma\gamma$ and $qq\gamma\gamma$ events, with clustered photon mass. One can also assume that X decays to leptons and quarks in addition to photon pairs, then 4 lepton and $\ell\ell qq$ events with recoil mass from $\ell\ell$ pair near 60 GeV should be observed. These channels are also looked for from the L3 data.

Signature of $\nu\nu\gamma\gamma$ events is two acollinear photons with isolated momentum imbalance. The acceptance assuming phase space distribution is 64%. From all the L3 data, we found no $\nu\nu\gamma\gamma$ event with $M_{\gamma\gamma} > 10$ GeV.

$qq\gamma\gamma$ events are looked for by searching for hadronic events with two energetic and isolated photons. Again no events are found with $M_{\gamma\gamma} > 40$ GeV, with an acceptance of $\sim 35\%$.

Four fermion events are expected in the Z data, mainly through initial and final state radiation. These events are look for by identified isolated leptons. $e^+e^- \rightarrow \ell\ell\ell'\ell'$ (ℓ, $\ell' = e$, μ), $e^+e^- \rightarrow eeqq$, and $e^+e^- \rightarrow \mu\mu qq$ processes have been searched for. These searches showed that the invariant mass and recoil mass distributions of the lepton pairs are in good agreement with the standard model prediction. No excess of events with 60 GeV mass has been observed[9].

5. CONCLUSION

$\ell\ell$n(γ) events have been studied by the L3 group in searching for new phenomena. The Monte-Carlo predictions are overall in good agreement with the measurements, except four $\ell\ell\gamma\gamma$ events with clustered photon pair mass around 60 GeV. These events could come from decay of a 60 GeV particle. However, the fluctuation from QED cannot be ruled out. We are waiting for more data from LEP to ascertain the origin of these events.

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