EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

CERN-PPE/93-75
30 April 1993

Search for high mass photon pairs in $e^+e^- \rightarrow f\bar{f}\gamma\gamma$ ($f = e,\ \mu,\ \tau,\ \nu,\ q$) at LEP

The ALEPH Collaboration ‡

Abstract

The result of a search for high mass photon pairs from the processes $e^+e^- \rightarrow f\bar{f}\gamma\gamma$ ($f = e,\ \mu,\ \tau,\ \nu$ and q) with the ALEPH detector is reported. The result for $f = e, \mu$ and τ is to be compared with the observation of 4 events by the L3 Collaboration with invariant masses, $M_{\gamma\gamma}$, of the two photons near 60 GeV. From a data sample approximately twice as large taken from 1990 to 1992, 6 events are found with $M_{\gamma\gamma}$ distributed between 50 GeV and 72 GeV, while 4.9 events are expected from a QED calculation. There is no evidence for a mass peak; only one event ($\mu^+\mu^-\gamma\gamma$) at $M_{\gamma\gamma} = 59.4 \pm 0.2$ GeV is compatible with the L3 observation. In addition, for $M_{\gamma\gamma} > 50$ GeV, no event is found for $e^+e^- \rightarrow q\bar{q}\gamma\gamma$ and only one event is found consistent with $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$; this event has $M_{\gamma\gamma} = 58.5 \pm 1.9$ GeV. High mass photon pair events have also been searched for in $\gamma\gamma$ collisions. This allows one to set an upper limit of 50 MeV for the width of an assumed resonance decaying to photon pairs.

(Submitted to Physics Letters B)

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[12]Supported by the US Department of Energy, contract DE-FG05-87ER40319.
[13]Supported by the NSF, contract PHY-8451274.
[14]Supported by the US Department of Energy, contract DE-FC0S-85ER250000.
[15]Supported by SLOAN fellowship, contract BR 2703.
[16]Supported by the Bundesministerium für Forschung und Technologie, Fed. Rep. of Germany.
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1 INTRODUCTION

The observation of four events, one $e^+e^-\gamma\gamma$and three $\mu^+\mu^-\gamma\gamma$, each with two energetic photons and an invariant mass $M_{\gamma\gamma}$ of the photon pair close to 60 GeV was reported by the L3 Collaboration at LEP [1] in the reactions

$$e^+e^- \rightarrow \ell^+\ell^-(n\gamma)\ (\ell = e, \mu, \tau)$$

where $n > 1$. Their data sample comes from 950K produced Z and the $M_{\gamma\gamma}$of these four events are, respectively, 58.8, 59.0, 60.0 and 62.0 GeV with a mass resolution of 0.6 GeV. No other events were observed above $M_{\gamma\gamma} = 35$ GeV. In addition, no events of the type $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$ for $M_{\gamma\gamma} > 10$ GeV and $e^+e^- \rightarrow q\bar{q}\gamma\gamma$ for $M_{\gamma\gamma} >$ 40 GeV were found. The searches for $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$ and $q\bar{q}\gamma\gamma$ are motivated by a hypothetical process Z$\rightarrow$ Z*R where R is a resonance decaying into two photons with $M_{\gamma\gamma} \approx 60$ GeV and Z* is a virtual Z decaying into $\ell^+\ell^-, \nu\bar{\nu}$ or $q\bar{q}$.

This letter reports a similar analysis carried out by the ALEPH collaboration with a data sample of about twice the L3's (1.8 million produced Z, corresponding to 1.25 million hadronic events). High mass photon pairs have been looked for in $e^+e^- \rightarrow \ell^+\ell^-\gamma\gamma$ ($\ell^\pm = e^\pm$, $\mu^\pm$ and $\tau^\pm$), $q\bar{q}\gamma\gamma$ and $\nu\bar{\nu}\gamma\gamma$. The observed rate of $e^+e^- \rightarrow \ell^+\ell^-\gamma\gamma$ is also compared with a QED calculation for $M_{\gamma\gamma}$> 50 GeV.

A resonance R decaying to $\gamma\gamma$ pairs must also be produced in $\gamma\gamma$ collisions; therefore an upper limit for the width Γ_R of this hypothetical resonance can be set by searching for high mass photon pairs in the two-photon process

$$e^+e^- \rightarrow e^+e^-\ \mathrm{R, with\ R} \rightarrow \gamma\gamma$$

where the final state e^+ and e^- are not detected.

2 THE ALEPH DETECTOR

The ALEPH detector has been described in detail elsewhere [2]. Charged tracks are measured over the range $|\cos\theta| < 0.966$, where θ is the polar angle, by an inner cylindrical drift chamber (ITC) and a large cylindrical time projection chamber (TPC). These chambers are contained in a magnetic field of 1.5 Tesla and together measure the momentum of charged particles with a resolution of $\delta p/p = 0.0008p$ (GeV/c)$^{-1}\oplus$ 0.003 [3]. Since 1991, a double-sided silicon vertex detector has been added providing two three-dimensional measurements of charged tracks with a resolution of approximately $15\mu m$, allowing a momentum resolution of $\delta p/p = 0.0006p$ (GeV/c)$^{-1}$ for high momentum particles. The electromagnetic calorimeter (ECAL), which surrounds the TPC and is inside the coil of the superconducting solenoid, is used to measure electromagnetic energy and, together with the TPC, to identify electrons. The ECAL has an energy resolution for electromagnetic showers of $\sigma_E/E = 0.017 \oplus 0.19/\sqrt{E}$ (with E in GeV) and an angular resolution of about 2 mrad for 45 GeV photons. It covers an angular range of $|\cos\theta| < 0.98$ and is finely segmented into projective towers, each subtending a solid angle of approximately 12 mrad by 12 mrad. These towers are read out in three longitudinal stacks corresponding to thicknesses of approximately 4, 9 and 9 radiation lengths. The lateral and longitudinal segmentation is used for electron and photon identification. The hadron calorimeter (HCAL) is composed of the iron of the magnet return yoke interleaved with 23 layers of streamer tubes which are also used for muon identification, and is surrounded by the muon chambers, an additional two layers of streamer tubes that cover the same angular range as the HCAL. The muon chambers are read out by cathode strips both parallel and perpendicular to the tubes. Therefore each layer provides a three-dimensional coordinate for charged tracks which penetrate the 7.5 interaction lengths of material between the interaction point and the muon chambers.

3 $e^+e^-\gamma\gamma$and $\mu^+\mu^-\gamma\gamma$EVENTS

Events with e^+ and e^- or μ^+ and μ^- accompanied by at least two photons, each with energy greater than 1 GeV are selected. In addition, the following conditions have to be fulfilled:

- The polar angles θ with respect to the beam direction for the $e^\pm$ and $\mu^\pm$ are required to satisfy $|\cos\theta| < 0.95$ and for the photons $|\cos\theta| < 0.90$.
- The momenta of $e^\pm$ or $\mu^\pm$ are greater than 1.5 GeV.
- The angle $\theta_{e\gamma}$ between an electron (or positron) and a photon is greater than 8^o. The angle $\theta_{\mu\gamma}$ between a muon and a photon is greater than 5^o.
- The total energy of the events is greater than $0.75\sqrt{s}$.

The $\theta_{e\gamma}$ and $\theta_{\mu\gamma}$ cuts are chosen to be the same as in the L3 analysis. The cut in total energy is to eliminate $e^+e^- \to \tau^+\tau^-\gamma\gamma$ events.

The identification of electrons and muons is detailed in references [4]. The photons are obtained from either isolated ECAL clusters [5] or converted electron pairs. In the case of electrons, in order to take bremsstrahlung into account, the energy of the associated ECAL cluster is used in place of the measurement from the central tracking chambers if the ECAL cluster energy is larger.

The two photon invariant mass ($M_{\gamma\gamma}$) distribution for the 48 selected $e^+e^- \to \mu^+\mu^-\gamma\gamma$ and $e^+e^- \to e^+e^-\gamma\gamma$ events for $M_{\gamma\gamma} > 20$ GeV is given in Fig.1. There are 6 events above 50 GeV. To calculate the mass and its error of each event, a 3C fit [6] is performed using energy and momentum conservation as constraints and allowing one photon from initial state radiation to be emitted along the beams. Only one event with $M_{\gamma\gamma} = 59.4$ GeV is compatible within resolution with the cluster of four events seen by L3 near 60 GeV. The masses and errors of the events with $M_{\gamma\gamma} > 50$ GeV are listed in Table 1 and shown in Fig. 2. The error on the mass, as shown in Table 1, differs from event to event due to the different kinematic configuration of each event.

In the L3 analysis the momenta of the leptons ($e^{\pm}$ or $\mu^{\pm}$) are required to be greater than 3 GeV and the polar angles of e, μ and γ with respect to the beam are required to be $|\cos\theta| < 0.9$ for photons, $|\cos\theta| < 0.74$ for electrons and $|\cos\theta| < 0.81$ for muons. Only four of the ALEPH events (events 1, 3, 4 and 6) satisfy these requirements.

4 $\tau^+\tau^-\gamma\gamma$ EVENTS

Events with two oppositely charged particles or four charged particles with a net charge of zero are selected. In the case of four charged particles, the invariant mass of three of the particles is required to be less than the τ mass and the three tracks are assumed to be the three-prong decay products of a τ. In each event at least two photons are required, each with energy greater than 1 GeV. In addition, the following conditions have to be fulfilled:

- The polar angles θ with respect to the beam direction for the charged particles and for the photons are required to have $|\cos\theta| < 0.95$ and $|\cos\theta| < 0.90$ respectively.
- The momentum of each charged particle is greater than 1.5 GeV.
- The angle $\theta_{\gamma\tau}$ between the charged particle (or the vector sum of the momenta of the three charged particles) and the photon is greater than 15^o. The 15^o is chosen to be the same as the L3 cuts.
- In the case of two charged particles, to take into account the missing neutrinos in the τ decays, the total charged energy is required to be smaller than $0.6\ (\sqrt{s} - E_{2\gamma})$ where $E_{2\gamma}$ is the sum of the energies of the two photons.

No candidates with $M_{\gamma\gamma} > 40$ GeV are found. The error on the invariant mass of the two photons is estimated to be about 1.9 GeV at $M_{\gamma\gamma} \sim 60$ GeV.

5 QED PREDICTION FOR $e^+e^- \rightarrow \ell^+\ell^-\gamma\gamma$ EVENTS

The observed rate of $e^+e^- \rightarrow \ell^+\ell^-\gamma\gamma$ ($\ell^{\pm} = e^{\pm}$, $\mu^{\pm}$ and $\tau^{\pm}$) is compared with a QED calculation[7] for $M_{\gamma\gamma} > 50$ GeV. This Monte Carlo calculation includes t-channel diagrams and incorporates full α^2 matrix elements. However, it has a limitation that there are no more than two photons in the final state. Since for the topology defined by the cuts, most of the events correspond to double photon emission in the final state, radiative corrections in the initial state are taken into account by multiplying the result of the calculation by an effective factor 0.74, as recommended in [7]. Integrating over the angular and momentum acceptance this calculation gives an expectation of 4.9 events. The calculation is estimated to be accurate to about 15%. Since 6 events are seen in $e^+e^- \rightarrow \ell^+\ell^-\gamma\gamma$ ($\ell^\pm = e^\pm$, $\mu^\pm$ and $\tau^\pm$) for $M_{\gamma\gamma} > 50$ GeV, there is no significant excess for $M_{\gamma\gamma} > 50$ GeV.

6 $\nu\bar{\nu}\gamma\gamma$ EVENTS

Motivated by the possibility that the L3 observation is a resonance R as mentioned in the introduction, one can search for the process Z$\rightarrow$ Z*R where R $\rightarrow \gamma\gamma$ and Z* $\rightarrow \nu\bar{\nu}$ with M_R near 60 GeV .

Events with no charged tracks and two and only two photons with energy greater than 1 GeV, are selected. For each photon, it is required that $|\cos\theta| < 0.9$. For the background process $e^+e^- \rightarrow \gamma\gamma(\gamma)$ where the transverse momenta of the two photons balance each other, the energies E_1 and E_2 of each of the incoming e^+ and e^- are calculated from the measurements of the directions and energies of the photons in the final state. Here E_1 and E_2 are calculated approximately as follows: $(E_1 + E_2)$ equals the sum of the energies of the two observed photons and $(E_1 - E_2)$ equals the unbalanced momentum along the beam direction. For the $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma$ process, E_1 and E_2 calculated this way will be much smaller, due to the missing neutrinos. In order to remove the background from $e^+e^- \rightarrow \gamma\gamma(\gamma)$, it is required that both E_1 and $E_2 < 40$ GeV. To remove background events $e^+e^- \rightarrow e^+e^-\gamma\gamma$ where both e^+ and e^- go down the beam pipe and are not detected, it is required that $|\Sigma\vec{P}_\perp| > 1$ GeV and $\theta_{acop} > 2^o$. Here $|\Sigma\vec{P}_\perp|$ is the magnitude of the vector sum of the momenta of the photons perpendicular to the beam direction and the acoplanarity angle θ_{acop} is 180^o minus the angle between the two photons in the $r-\phi$ plane (the plane perpendicular to the beam direction). The reason for this $|\Sigma\vec{P}_\perp|$ cut at a relatively low value is that, due to the large $M_{\gamma\gamma}$, the missing energy of the event is relatively low.

Only one event with $M_{\gamma\gamma} > 20$ GeV is found at $M_{\gamma\gamma} = 58.5 \pm 1.9$ GeV. It is observed that this event also has a third photon with energy 0.6 GeV which is below the 1 GeV cut defined a priori. The event has a missing transverse momentum with respect to the beam direction ($= |\Sigma\vec{P}_\perp|$) of 2.3 GeV and the acoplanarity angle (θ_{acop}) between the two photons is 7^o. If the event is interpreted as one of the backgrounds given above the photons seen must be accompanied by two other photons or electrons at small angles. These particles are calculated to have energies of 8.5 and 22 GeV respectively. In order to be undetected the particle which balances the 2.3 GeV missing $P_\perp$ has to go through a crack of the small angle calorimeter. Due to the lack of higher order generator, the expected background can not be estimated.

The above selection criteria give an efficiency of about 61% in detecting Z $\rightarrow$Z*R (Z* $\rightarrow \nu\bar{\nu}$ and R $\rightarrow \gamma\gamma$, where R is assumed to be a narrow resonance). This is estimated from a Monte Carlo simulation assuming the spin of R to be zero and $M_{\gamma\gamma} = 60$ GeV. If the 4 events observed by L3 near $M_{\gamma\gamma} \sim 60$ GeV come from such resonance R, then, one expects to see about 14 events in $e^+e^- \rightarrow \nu\bar{\nu}$ R (R $\rightarrow \gamma\gamma$). Only one such event is observed in our data.

7 $q\bar{q}\gamma\gamma$ EVENTS

Events which satisfy the hadronic event selection [8] are accepted. In addition, it is required that there are at least two isolated photons each with energy greater than 1 GeV. The isolation criterion is that within a 15° cone around the photon there is less than 1 GeV charged energy. Again, the polar angles of the photons with respect to the beam direction are required to have $|\cos\theta| < 0.9$.

Fig. 3 shows the distribution of $M_{\gamma\gamma}$in these selected events. There is no candidate for $M_{\gamma\gamma} > 50$ GeV. Using the same argument as in the preceeding section, one expects 42 events in $e^+e^- \rightarrow q\bar{q}\gamma\gamma$ using an efficiency of 52% for the process Z$\rightarrow$Z* R (Z* $\rightarrow q\bar{q}$ and R $\rightarrow \gamma\gamma$) obtained by Monte Carlo simulation.

8 UPPER LIMIT FOR Γ_R

A broad resonance decaying into $\gamma\gamma$ should also be produced in $\gamma\gamma$ interactions. In the equivalent photon approximation[9], the number of expected events N_R in the channel $e^+e^- \rightarrow e^+e^-\gamma\gamma$ with $\gamma\gamma \rightarrow$ R $\rightarrow \gamma\gamma$ can be expressed as

$$N_R = \mathcal{L}_{e^+e^-}\sigma(e^+e^- \rightarrow e^+e^-R, R \rightarrow \gamma\gamma)$$

where $\sigma(e^+e^- \rightarrow e^+e^-\mathrm{R}, \mathrm{R} \rightarrow \gamma\gamma) = \int \sigma_{\gamma\gamma\rightarrow R} L_{\gamma\gamma} dM_{\gamma\gamma}$.

The $\gamma\gamma \rightarrow$ R cross-section can be expressed as :

$$\int \sigma_{\gamma\gamma\rightarrow R} dM_{\gamma\gamma} = \frac{4\pi^2(2J+1)}{m_R^2}\Gamma_R B_{R\rightarrow\gamma\gamma}$$

For a spin J particle this gives [10]

$$\sigma(e^+e^- \rightarrow e^+e^-R, R \rightarrow \gamma\gamma) = \left(\frac{\alpha}{2\pi}\log\frac{s}{4{M_e}^2}\right)^2 \frac{(2J+1)8\pi^2\Gamma_R B^2_{R\rightarrow\gamma\gamma}}{sM_R} F\left(\frac{{M_R}^2}{s}\right)$$

where

$$F(\omega) = \frac{1}{\omega}\left[(2+\omega)^2 \log\frac{1}{\omega} - 2(1-\omega)(3+\omega)\right]$$

In these events, the outgoing electrons tend to remain undetected in the beam pipe. The topology to be searched for is therefore a pair of energetic acollinear photons.

Preselection of $\gamma\gamma$ events is performed demanding at least two ECAL clusters each with $|\cos\theta| \leq 0.95$ and energy greater than $20.0 \times \left(\frac{\sqrt{S}}{91.25}\right)$ GeV. The angle in space between the two most energetic clusters is required to be greater than 100° and there are to be no charged tracks in the event. To distinguish the signal final state from the background QED process $e^+e^- \rightarrow \gamma\gamma(\gamma)$ the energies E_1 and E_2 of each of the incoming particles are calculated by measuring the direction and energy of the photons in the final state as explained in section 6. The signal lies on a hyperbola in the E_1, E_2 plane whereas the background distribution lies predominantly in 2 bands at E_1, E_2 = beam energy as shown in Fig.4. A cut at less than 40 GeV on the energy of each of the incoming particles is thus introduced to further suppress the QED background. Following this cut only 20 events remain. The distribution of the $\gamma\gamma$ invariant masses of these events is distributed between 38 GeV and 77 GeV. The selection efficiency for the "signal" Monte Carlo is 50% compared with 1.2% for the standard QED process.

In the invariant mass band of 5 GeV around 60 GeV, 3 events are observed compared with 4.4 predicted from the QED process $e^+e^- \rightarrow \gamma\gamma(\gamma)$. This corresponds to a limit of 4.9 events at 95% CL from which one derives an upper limit on $\Gamma_R B^2_{R\rightarrow\gamma\gamma}$ of

$$\Gamma_R B^2_{R\rightarrow\gamma\gamma} < 2.9\ MeV.$$

It is necessary to obtain a lower limit on $B_{R\rightarrow\gamma\gamma}$ in order to place a constraint on Γ_R alone. Since the hypothetical resonance R has been suggested from the observation of $ee\gamma\gamma$ and $\mu\mu\gamma\gamma$ events [1] then an estimate of the branching ratios of R can be made by searching in our data for events of the type $e^+e^- \rightarrow e^+e^-$ R and $e^+e^- \rightarrow \mu^+\mu^-$R, where R is an object with mass 60 ± 2.5 GeV which decays to a pair of quarks, leptons or invisible particles (i.e. essentially all other plausible decay modes). The topologies of these searches correspond to the standard Higgs searches performed by ALEPH [11]. The exact value of the cuts used have been updated for the analysis of the 1991-1992 data [12]. Their selection cuts are tuned to reject the main backgrounds as appropriate in each specific channel (e.g. isolation cuts to reject double leptonic decays of $b\bar{b}$ in the case of $q\bar{q}$ decays); however, in all these selections a high efficiency for an isotropically decaying resonance is achieved.

No events are seen in the $\ell^+\ell^- q\bar{q}$ channels and one event is seen in each of the channels $\ell^+\ell^-\ell^+\ell^-$ and $\ell^+\ell^-\nu\bar{\nu}$ with a recoil mass to the $\ell^+\ell^-$ pairs compatible with the 60 ± 2.5 GeV range defined above. From these two events one can place an upper limit at 95% CL

$$B(Z \to e^+e^-R, \mu^+\mu^-R) \times (1 - B(R \to \gamma\gamma)) \leq 7.1 \times 10^{-6}$$

The remaining branching ratio product $B(Z \to e^+e^-R, \mu^+\mu^-R) \times B(R \to \gamma\gamma)$ is not quoted in [1]. However, it has recently [13] been given, assuming all 4 events from L3 originate from R,

$$B(Z \to e^+e^-R, \mu^+\mu^-R) \times B(R \to \gamma\gamma) \approx 6.7 \times 10^{-6}$$

Taking into account statistical fluctuations on the $\ell\ell\gamma\gamma$ rate, one derives $B_{R\to\gamma\gamma} > 0.41$. This value can be combined with the limit on $\Gamma_R B^2_{R\to\gamma\gamma}$ to give

$$\Gamma_R < 17\ MeV$$

at 95% CL. The argument can be generalized for the case where two of the four L3 $\ell\ell\gamma\gamma$ events around 60 GeV are interpreted as background with two interpreted as coming from the R decay, the limit then becomes 50 MeV. In both cases the limits are smaller than the typical mass resolution for R decaying into $\gamma\gamma$. Therefore only events compatible within the experimental mass resolution are relevant when discussing the possibility of a resonance R.

9 CONCLUSION

From a sample of data corresponding to 1.25 million hadronic Z, six events have been observed in the process $e^+e^- \to \ell^+\ell^-\gamma\gamma$ ($\ell^\pm = e^\pm$ and $\mu^\pm$) with invariant mass $M_{\gamma\gamma}$ of the two photons distributed between 50 and 72 GeV. While there is no evidence of a mass peak, one event ($M_{\gamma\gamma} = 59.4 \pm 0.2$ GeV) is compatible with the masses of the cluster of events observed by the L3 Collaboration near $M_{\gamma\gamma} =$ 60 GeV. A QED Monte Carlo calculation gives 4.9 events compared with 6 seen. For $M_{\gamma\gamma} > 50$ GeV one candidate is found in the search for $e^+e^- \to \nu\bar{\nu}\gamma\gamma$ with $M_{\gamma\gamma} = (58.5 \pm 1.9)$ GeV while no candidate is found for $e^+e^- \to q\bar{q}\gamma\gamma$. From a search for the two photon process $e^+e^- \to e^+e^-$ R, (R $\to \gamma\gamma$), an upper limit for Γ_R is derived to be 50 MeV where Γ_R is the width of a hypothetical resonance R corresponding to the events observed by L3 near $M_{\gamma\gamma} \sim 60$ GeV.

Acknowledgements

It is a pleasure to thank our colleagues from the SL division for the operation of LEP. We are indebted to the engineers and technicians at CERN and at our home institutes for their contributions to ALEPH's success. Those of us not from member states thank CERN for its hospitality.

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	Type	$M_{\gamma\gamma}(3c)$ GeV	E(rad) GeV	$(\theta_{l\gamma})_{min}$
1	$e^+e^-\gamma\gamma$	54.7 ± 1.0	1.05 ± 0.71	66.5°
2	$e^+e^-\gamma\gamma$	55.6 ± 0.4	0.30 ± 0.69	13.1°
3	$\mu^+\mu^-\gamma\gamma$	59.4 ± 0.2	0.15 ± 0.15	30.3°
4	$e^+e^-\gamma\gamma$	62.8 ± 0.4	0.08 ± 0.29	23.8°
5	$\mu^+\mu^-\gamma\gamma$	63.4 ± 0.3	1.00 ± 0.20	12.9°
6	$e^+e^-\gamma\gamma$	71.3 ± 0.3	0.06 ± 0.38	12.5°

Table 1: The invariant mass ($M_{\gamma\gamma}$) and its error for each of the 6 $\ell^+\ell^-\gamma\gamma$events with $M_{\gamma\gamma}$> 50 GeV. The values are obtained from a 3C fit. E(rad) is the fitted energy of the initial state radiation. $(\theta_{l\gamma})_{min}$ is the minimum angle between a lepton and a photon in an event.

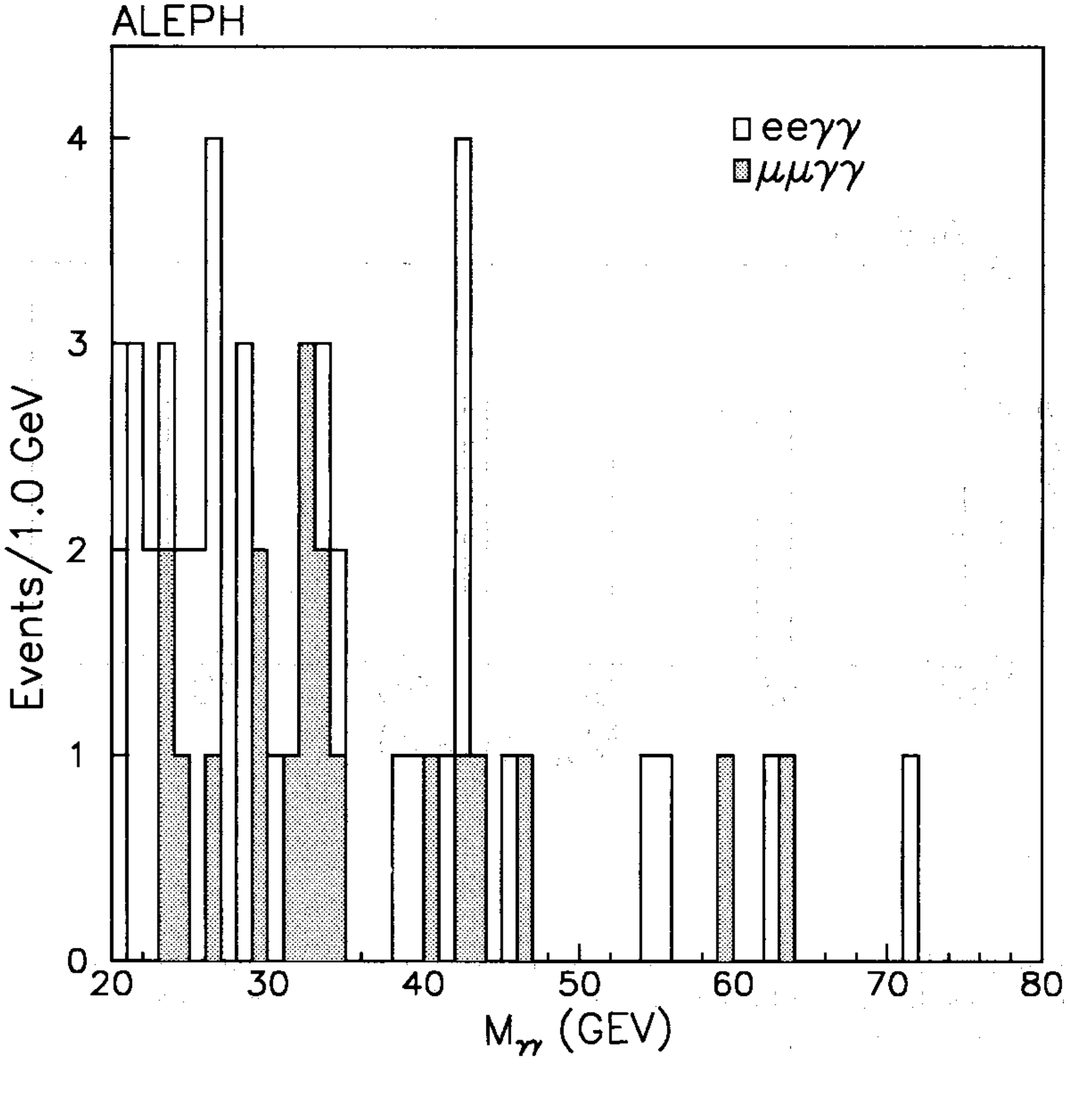

Figure 1: The two photon invariant mass ($M_{\gamma\gamma}$) distribution for $e^+e^- \rightarrow e^+e^-\gamma\gamma$(white) and $\mu^+\mu^-\gamma\gamma$(shaded) for $M_{\gamma\gamma}$> 20 GeV.

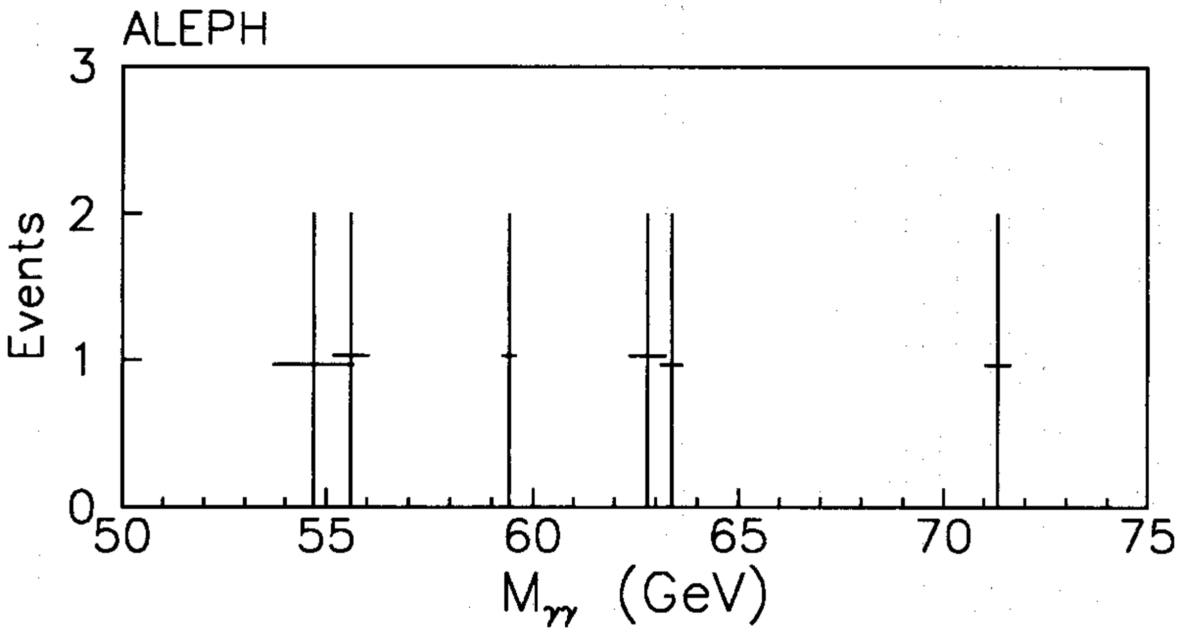

Figure 2: The event-by-event display of the two photon invariant masses and their errors determined by a 3C fit for $M_{\gamma\gamma}>$ 50 GeV. The processes are from $e^+e^- \to e^+e^-\gamma\gamma$and $\mu^+\mu^-\gamma\gamma$.

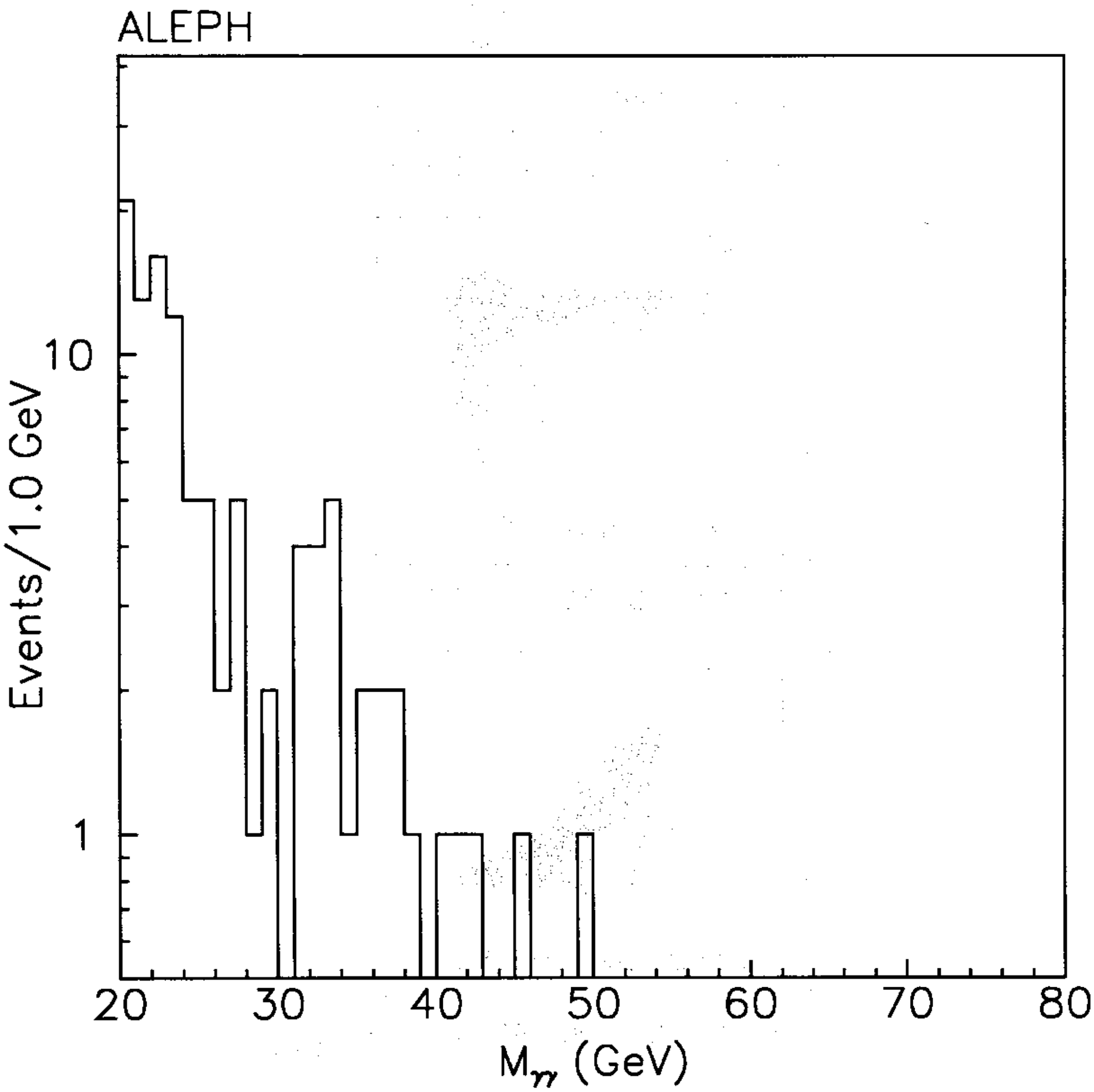

Figure 3: The two-photon invariant mass ($M_{\gamma\gamma}$) distribution for $M_{\gamma\gamma}$> 20 GeV from the search of the process $e^+e^- \rightarrow q\bar{q}\gamma\gamma$.

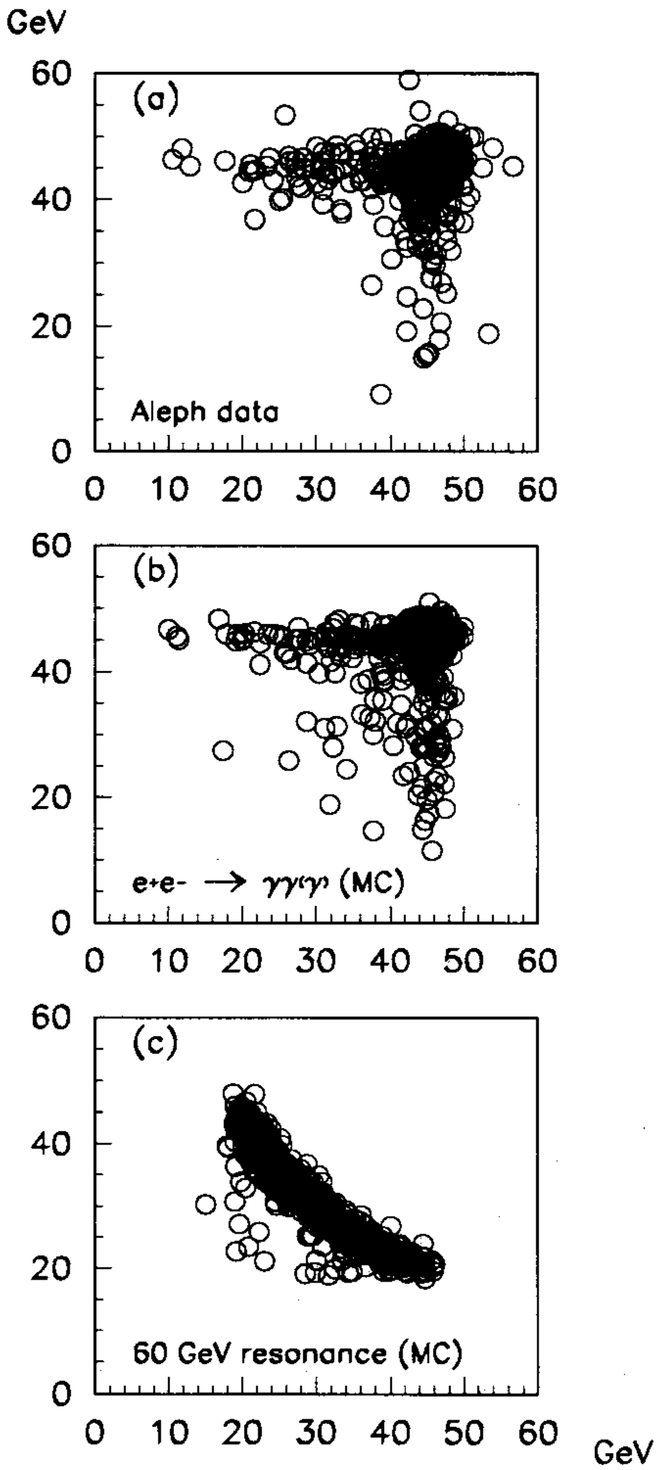

Figure 4: The E_1 *vs* E_2 distribution for (a) the ALEPH data, (b) process $e^+e^- \rightarrow \gamma\gamma(\gamma)$ Monte Carlo, and (c) Monte Carlo simulated $\gamma\gamma$ decay of a 60 Gev resonance R.