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High Mass Photon Pairs in $\ell^+\ell^-\gamma\gamma$ Events in ALEPH

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INTRODUCTION

The observation of four events, one $e^+e^-\gamma\gamma$ and three $\mu^+\mu^-\gamma\gamma$, with the invariant mass of the photon pairs close to 60 GeV was reported by L3 at LEP [1] in the reactions

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

A similar analysis has been carried out with the ALEPH detector at LEP. For the purpose of direct comparison with L3, and for completeness, the analysis has been done in two ways:

1. Follow the L3 event selection and the L3 acceptance.

2. Enlarge the acceptance to include events where $\ell^+\ell^-$ are detected by the end caps.

Data taken in 1990, 1991 and 1992 are analyzed corresponding to a total of about 1.8 million produced Z° decays. The relevant resolutions of the ALEPH detector for this analysis are

$$\frac{\Delta E}{E} = \frac{19\%}{\sqrt{E}} + 1\% \quad \text{(E in GeV)}$$

for electrons and photons detected in the electromagnetic calorimeter, and

$$\frac{\Delta p}{p} = 0.006p + 0.003 \quad \text{(P in GeV/c)}$$

for charged particles detected by the central tracking devices.

The angular resolution for photons is about 2mrad and for charged particles is about 0.4mrad and 0.6mrad for θ and ϕ respectively. In order to optimize the mass resolution of the invariant mass of the two photons in the process

$$e^+e^- \rightarrow \ell^+\ell^-\gamma\gamma,$$

a 3-C fit is performed using the energy and momentum conservation as constraints and allowing a soft photon from initial state radiation to be emitted along the beams. This gives a mass resolution of about 300 to 700 MeV at $M_{\gamma\gamma}$ around 60 GeV.

EVENT SELECTION

(A) Analysis with the L3 acceptance

Following as close as possible the event selection used by the L3 analysis, the following cuts are used:

Photon energy $E_\gamma > 1.0$ GeV and $|\cos\theta| < 0.9$
Electron energy $E_e > 3.0$ GeV and $|\cos\theta| < 0.74$
Muon momentum $P_\mu \geq 3$ GeV and $|\cos\theta| < 0.81$
Angle between electron and photon $\theta_{e\gamma} > 8°$
Angle between muon and photon $\theta_{\mu\gamma} > 5°$
The total energy of the events $> 0.6\sqrt{S}$

PCPA and GAMPEC are used to identify photons. Electrons and muons are identified using QEIDO and QUIDO respectively. In addition, converted electron pairs are treated as photons. In the case of electrons, in order to take into account the bremsstrahlung, the energy of an associated electromagnetic calorimeter (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 $e^+e^- \rightarrow \mu^+\mu^-\gamma\gamma$ and $e^+e^- \rightarrow e^+e^-\gamma\gamma$ is given in Fig. 1 for $M_{\gamma\gamma} > 20$ GeV. Among the 25 events, there are 4 events above 50 GeV. Only one event with $M_{\gamma\gamma} = 59.4 \pm 0.2$ GeV is compatible within resolution with the cluster of three events seen by L3 near 59 GeV. (The three events of L3 are: $M_{\gamma\gamma} = 58.8 \pm 0.6$ GeV, 59.0 ± 0.6 GeV and 60.0 ± 0.6 GeV). The properties of these events with $M_{\gamma\gamma} > 50$ GeV are listed in Table 1 and Table 2 (events 1, 3, 4 and 6), along with additional events selected using a larger acceptance (events 2 and 5) as described below.

(B) Analysis with a larger acceptance to include ALEPH endcaps

To include the detection of electrons and muons using the ALEPH endcaps of the electromagnetic calorimeters and muon chambers, the following cuts are used:

Photon energy $E_\gamma \geq 1.0$ GeV and $|\cos\theta| < 0.95$
Electron energy $E_e \geq 3.0$ GeV and $|\cos\theta| < 0.95$
Muon momentum $P_\mu \geq 1.5$ GeV and $|\cos\theta| < 0.95$
Angle between electron and photon $\theta_{e\gamma} > 8°$
Angle between muon and photon $\theta_{\mu\gamma} > 5°$
The total energy of the events $> 0.6\sqrt{S}$

The two photon invariant mass ($M_{\gamma\gamma}$) distribution for $e^+e^- \rightarrow \mu^+\mu^-\gamma\gamma$ and $e^+e^- \rightarrow e^+e^-\gamma\gamma$ for this enlarged acceptance is shown in Fig. 2 for $M_{\gamma\gamma} > 20$ GeV. Among the 47 events, there are 6 events above 50 GeV as listed in Table 1 and Table 2.

$M_{\gamma\gamma}$ RESOLUTION

The error of $M_{\gamma\gamma}$ for each event above 50 GeV is given in Table 1 from the 3-C fit as mentioned before, and is also shown in Fig. 3. The errors differ from event to event due to the different kinematic configuration of each event. In general, the resolution of $M_{\gamma\gamma}$ is σ = 350 MeV and σ = 680 MeV for $\mu^+\mu^-\gamma\gamma$ and $e^+e^-\gamma\gamma$ respectively. These numbers are obtained by performing the 3-C fit on the Monte Carlo events simulated in the ALEPH detector from the process $Z^\circ \rightarrow Z^*H$, where $Z^* \rightarrow \ell^+\ell^-$ and $H^\circ \rightarrow \gamma\gamma$ with $M_{\gamma\gamma}$ = 60 GeV.

An additional check of the mass resolution event by event is to use the kinematics of each event as input to a Monte Carlo simulation program. The same event passes through the ALEPH detector simulation program 100 times and the mass resolution for that event is obtained from the two-photon mass distribution after a 3-C fit. The results are consistent with the mass errors given in Table 1.

COMPARISON WITH OTHER LEP EXPERIMENTS

A comparison of the mass distribution for $M_{\gamma\gamma} > 50$ GeV is shown in Fig. 4 for L3 [1], ALEPH, DELPHI and OPAL [2]. For ALEPH, only one event with $M_{\gamma\gamma} = 59.4 \pm 0.2$ GeV is compatible within resolution with the cluster of three events given by L3 near 59 GeV.

ACKNOWLEDGEMENT

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REFERENCES

[1] L3 Collaboration, CERN-PPE/92-152, 16 September, 1992; to be published in Physics Letters B.
[2] U. Amaldi, J. LeFrançois, and A. Michelini, presentations at a CERN seminar, 26 November, 1992.

TABLE 1

Properties of the events in $e^+e^- \rightarrow \ell^+\ell^-\gamma\gamma$ after a 3-C fit for events with $M_{\gamma\gamma} > 50$ GeV

	Event	Type	$M_{\gamma\gamma}$ GeV	E (rad) GeV	$(\theta_{\ell\gamma})_{MIN}$	$M_{\ell\ell}$(GeV)
1	8652-968	eeγγ	54.7±1.0	1.05±0.71	66.5°	35.4±0.9
2	12765-6401	eeγγ	55.6±0.4	0.30±0.69	13.1°	31.2±0.6
3	15260-4200	μμγγ	59.4±0.2	0.15±0.15	30.3°	17.6±0.1
4	16328-3835	eeγγ	62.8±0.4	0.08±0.29	23.8°	14.1±0.5
5	8854-2228	μμγγ	63.4±0.3	1.00±0.20	12.9°	12.5±0.6
6	16250-8436	eeγγ	71.3±0.3	0.06±0.38	12.5°	14.2±0.3

$M_{\gamma\gamma}$ = Invariant mass of the two photons
E(rad) = Energy of the initial state radiation
$(\theta_{\ell\gamma})_{MIN}$ = The smallest angle between a lepton and a photon
$M_{\ell\ell}$ = Invariant mass of the two leptons

1	8652-968	e+	e -	γ	γ
	E(GeV)	20.3	15.7	22.7	32.4
	Theta	88.5 °	97.9 °	25.0 °	138.1 °
	phi	166.0°	10.0°	129.8°	306.6 °
	Pair Mass (GeV)	Mee=35.4+-0.9		Mgg=54.7+-1.0	
2	12765-6401	e+	e -	γ	γ
	E(GeV)	21.7	12.8	21.8	34.6
	Theta	145.0 °	66.9 °	135.8°	30.7°
	phi	177.2°	5.5 °	191.9°	5.1 °
	Pair Mass (GeV)	Mee=31.2+-0.6		Mgg=55.6+-0.4	
3	15260-4200	μ+	μ–	γ	γ
	E(GeV)	4.5	22.6	35.5	28.7
	Theta	103.8°	99.4°	77.2 °	95.7°
	phi	113.1°	351.9°	127.6°	269.5°
	Pair Mass (GeV)	Mμμ=17.6+–0.1		Mgg=59.4+-0.2	
4	16328-3835	e+	e -	γ	γ
	E(GeV)	5.4	19.8	28.0	35.8
	Theta	65.5 °	66.1°	88.9 °	106.5°
	phi	38.2 °	301.6°	33.5 °	185.1°
	Pair Mass (GeV)	Mee=14.1+-0.5		Mgg=62.8+-0.4	
5	8854-2228	μ+	μ–	γ	γ
	E(GeV)	23.2	1.8	24.9	37.8
	Theta	105.7 °	65.8°	101.2 °	76.8 °
	phi	11.7 °	168.7°	316.8 °	161.8°
	Pair Mass (GeV)	Mμμ=12.5+–0.6		Mgg=63.4+-0.3	
6	16250-8436	e+	e -	γ	γ
	E(GeV)	16.2	3.5	32.5	40.4
	Theta	86.4°	117.2°	38.3 °	127.5°
	phi	77.4°	256.7°	62.7 °	248.3°
	Pair Mass (GeV)	Mee=14.2+-0.3		Mgg=71.3+-0.3	

Table 2

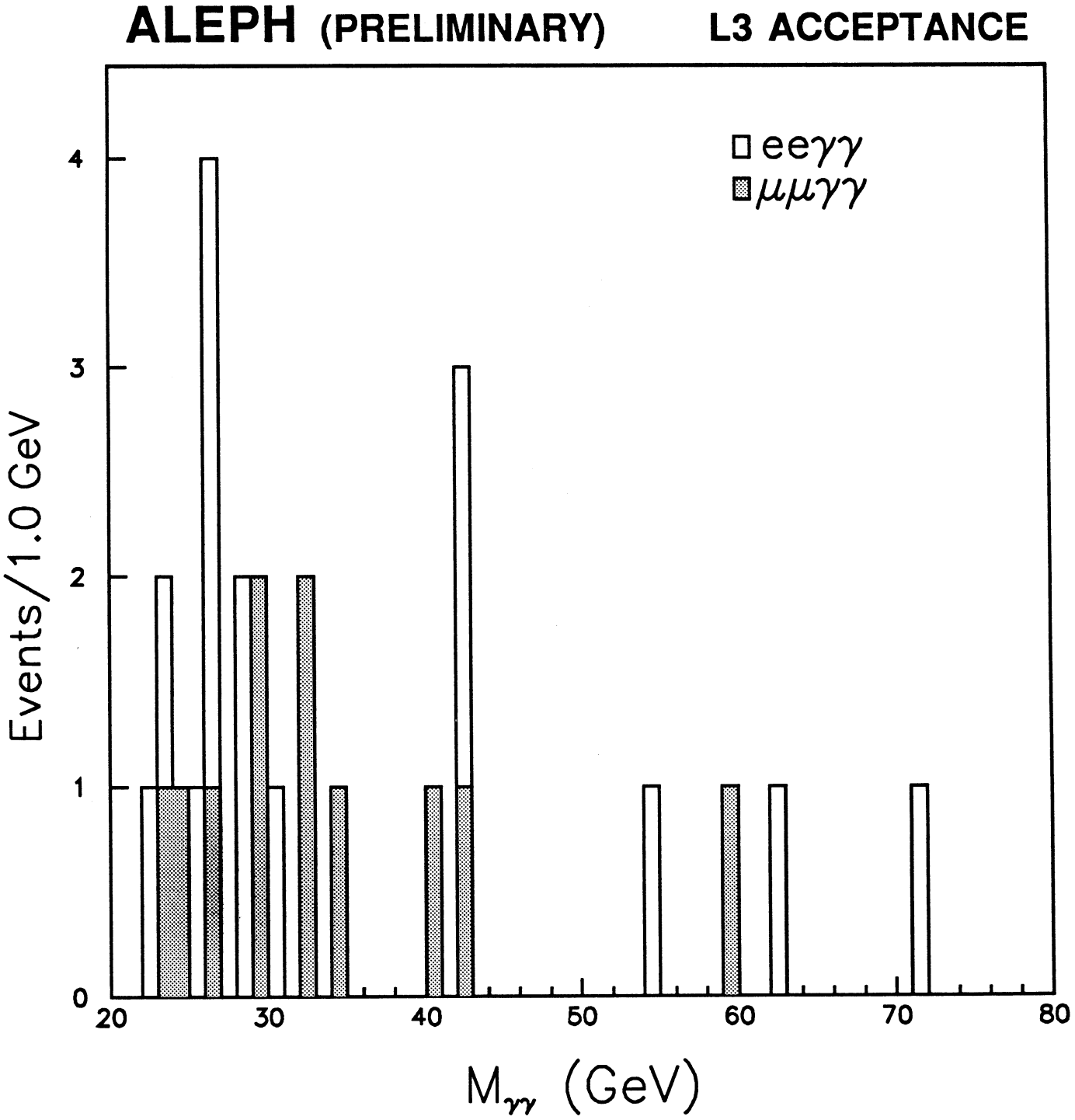

ALEPH (PRELIMINARY)
L3 ACCEPTANCE
eeγγ
μμγγ
Events/1.0 GeV
0
1
2
3
4
20
30
40
50
60
70
80
$M_{\gamma\gamma}$ (GeV)

FIG. 1

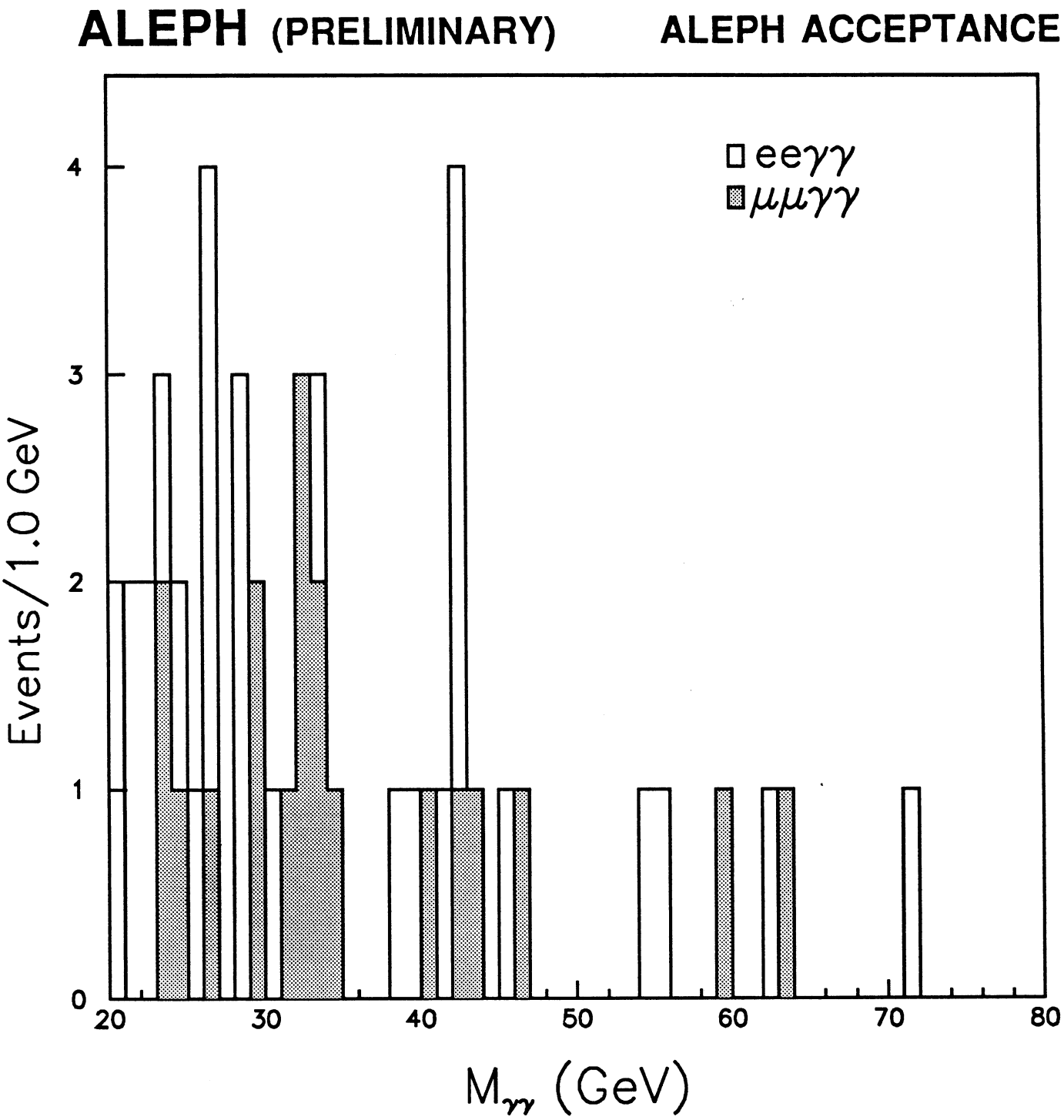
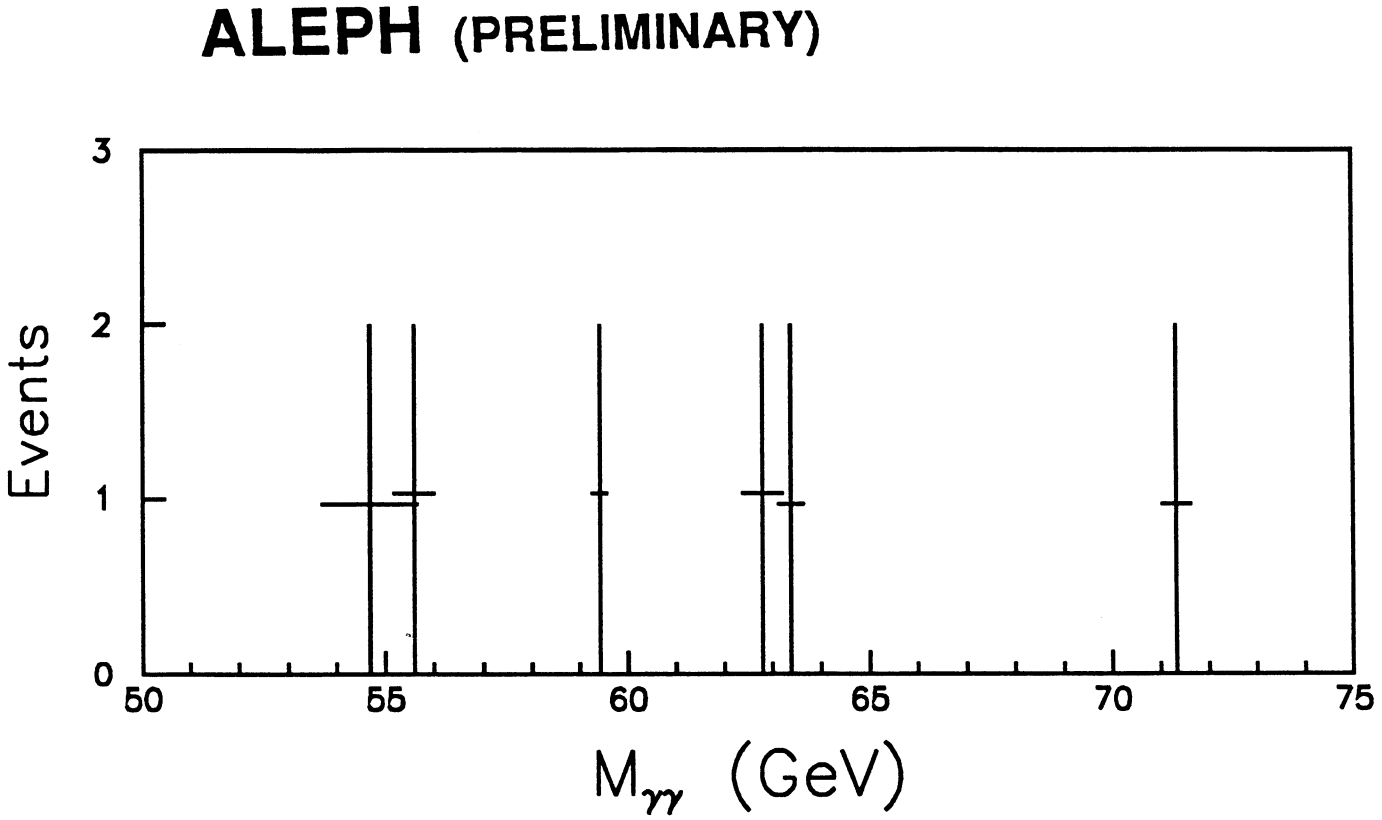

ALEPH (PRELIMINARY)
ALEPH ACCEPTANCE
eeγγ
μμγγ
Events/1.0 GeV
0
1
2
3
4
20
30
40
50
60
70
80
Mγγ (GeV)

FIG. 2



	Type	Mγγ GeV (3C)	E (rad) GeV	$\theta\,(\ell\gamma)_{MIN}$
1	eeγγ	54.7±1.0	1.05±0.71	66.5°
2	eeγγ	55.6±0.4	0.30±0.69	13.1°
3	μμγγ	59.4±0.2	0.15±0.15	30.3°
4	eeγγ	62.8±0.4	0.08±0.29	23.8°
5	μμγγ	63.4±0.3	1.00±0.20	12.9°
6	eeγγ	71.3±0.3	0.06±0.38	12.5°

FIG. 3

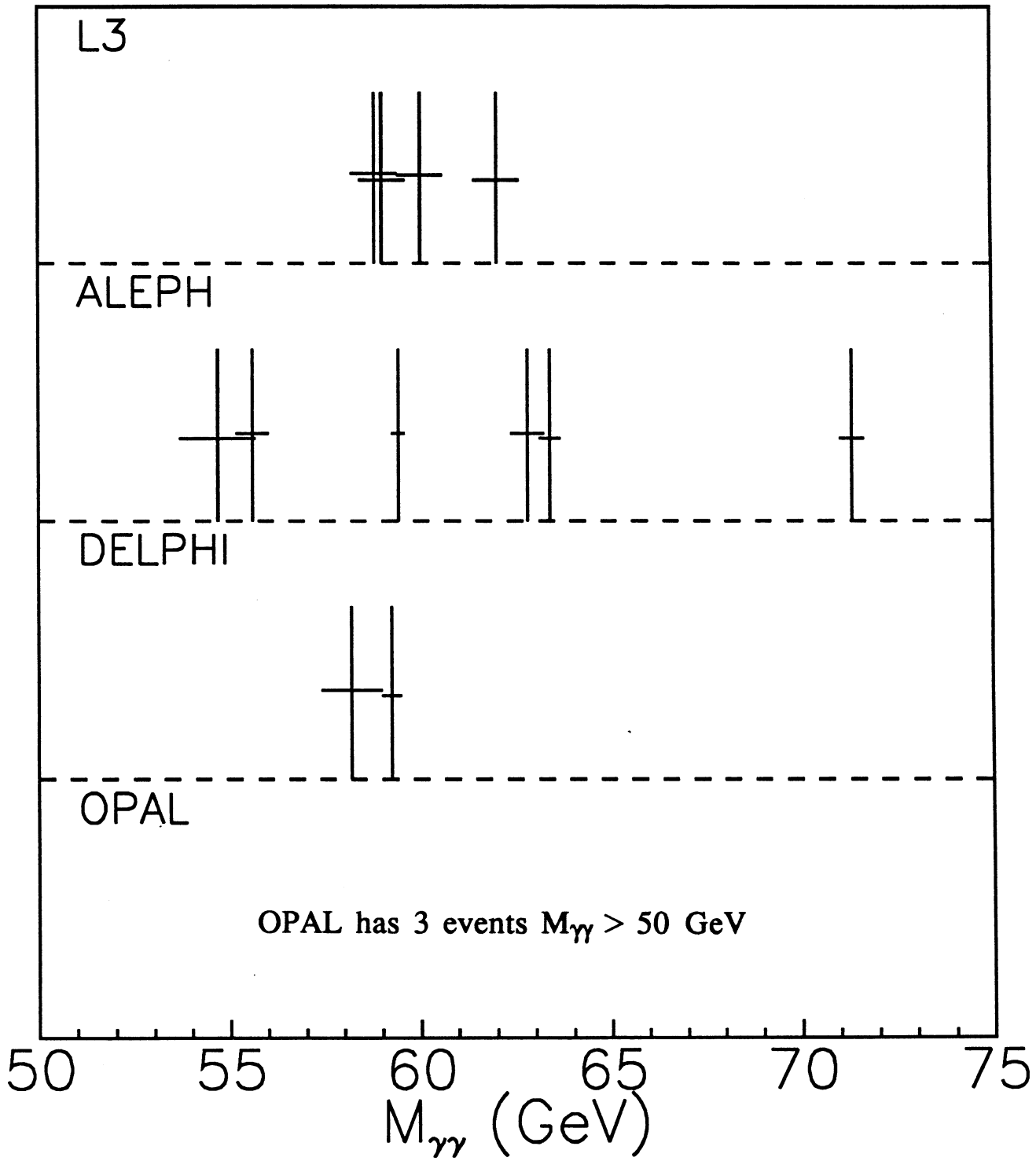

L3
ALEPH
DELPHI
OPAL
OPAL has 3 events $M_{\gamma\gamma} > 50$ GeV
50
55
60
65
70
75
$M_{\gamma\gamma}$ (GeV)

FIG. 4