EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

L3 Note 2580
July 3, 2000

Search for a Higgs Boson Decaying into Two Photons in e^+e^- Interactions at center-of-mass energies up to 202 GeV at LEP

The L3 Collaboration

Abstract

A search is performed for a Higgs boson, decaying into two photons, using the L3 data collected at center-of-mass energies between 192 GeV and 202 GeV, corresponding to an integrated luminosity of 233.2 pb^{-1}. The process $\mathrm{e^+e^-} \rightarrow \mathrm{hZ} \rightarrow \gamma\gamma\mathrm{q\bar{q}}$ is considered. The observed data are found to be consistent with the expected background from Standard Model processes. Limits on the branching fraction of the Higgs boson decay into two photons as function of the Higgs mass are derived assuming a Standard Model production rate. A lower limit on a fermiophobic Higgs mass is also derived. These results are preliminary.

Submitted to the *XXXth International Conference on High Energy Physics*
July 27 - August 2, 2000, Osaka, Japan

1 Introduction

In the Standard Model the decay of a Higgs boson h $\rightarrow \gamma\gamma$ occurs at the one loop level and the branching fraction is small [1]. For example, for Higgs masses in the range 80 $< M_h$ $<$ 110 GeV, this decay rate lies between 0.1% to 0.2%. However, several extended models predict enhancements of this branching fraction [2]. In Two Higgs Doublet models of Type I, for example, in which only one Higgs doublet couples to fermions, a fermiophobic Higgs may arise which couples at tree level only to the gauge bosons. Such a Higgs is expected to decay dominantly into a pair of photons if its mass is below 90 GeV [3].

We have searched for a Higgs boson produced in association with a Z, $e^+e^- \rightarrow$ hZ, followed by the decay h $\rightarrow \gamma\gamma$, in the hadronic decay mode of the Z boson.
All results reported in this note are preliminary.

2 Data and Monte Carlo Samples

The data were collected by the L3 detector [4] in 1999. The integrated luminosity is 233.2 pb^{-1} at centre of mass energies ranging between 192 GeV and 202 GeV.

The Standard Model Higgs signal cross section is calculated using the HZHA generator [5]. For efficiency studies, samples of Higgs events were generated using KK2f [6] for Higgs masses between 50 and 110 GeV, with a mass step of at most 10 GeV. A total of 4K events per Higgs mass value were generated. For the background studies the following Monte Carlo programs were used: KK2f ($\mathrm{e^+e^-} \rightarrow \mathrm{q\bar{q}}(\gamma)$, $\mathrm{e^+e^-} \rightarrow$ ZZ and $\mathrm{e^+e^-} \rightarrow \mathrm{Ze^+e^-}$), KORALW [7] ($\mathrm{e^+e^-} \rightarrow \mathrm{W^+W^-}$), and PHOJET [8] ($\mathrm{e^+e^-} \rightarrow \mathrm{e^+e^-q\bar{q}}$).

The L3 detector response is simulated using the GEANT 3.15 program [9], which takes into account the effects of energy loss, multiple scattering and showers in the detector. GHEISHA is used to simulate hadronic interactions in the detector.

3 Analysis Procedures

A two fold cut-based selection is performed aiming to select events with photons and to identify the Z in its hadronic decay mode. This gives rise to $\gamma\gamma\mathrm{q\bar{q}}$ final state.

Photons are clusters in the electromagnetic calorimeter (BGO) with an energy greater than 1 GeV and a shower shape compatible with that of an electromagnetic shower. This means that the ratio of energies deposited in a 3×3 crystal matrix and in a 5×5 crystal matrix, centred on the shower axis, is greater than 0.95. The energy deposition in the hadron calorimeter must not exceed 20% of the energy deposited in the electromagnetic calorimeter.

In addition clusters must not be associated with a charged track within 50 mrad in the plane perpendicular to the beam axis. To reduce the contamination from photons from initial state radiation we require the polar angle of the photons to be in the range $45° < \theta < 135°$ or $25° < \theta < 35°$ or $145° < \theta < 155°$ which corresponds to the barrel and end-cap regions of the BGO. This defines the acceptance region for our analysis.

To ensure that the photons arise from the decay of a heavy resonance we require the energy of the photon candidates to be larger than 10 GeV.

3.1 The hadronic channel

The signature for the $q\bar{q}\gamma\gamma$ final state is a pair of isolated photons and two jets in the event. To select these events we first apply a hadronic preselection requiring high multiplicity events with the number of tracks larger than 6 and more than 15 calorimetric clusters; the visible energy normalised to the center-of-mass energy is required to be bigger than 0.5; the energy imbalances parallel and perpendicular to the beam direction, normalised to the visible energy, are required to be below 0.4. In order to reduce the background from the two-photon interaction events, we require the energy in a 30° cone around the beam pipe normalised to the visible energy to be less than 0.5.

From this sample we select further those events which contain at least two photons. All other particles were clustered in two jets using the DURHAM jet algorithm [10]. To reject photons coming from neutral hadron decays we require them to be isolated: the energy in a 10° cone around the photon direction must be less than 1.5 GeV and in a 20° cone less than 3.5 GeV. The number of charged tracks and calorimeter clusters in a 20° cone around the photon direction must be below 4. The opening angle between the photons must be larger than 50° and the angle $\theta_{\gamma\mathrm{jet}}$ between the photon direction and the nearest jet must to be greater than 25°. To illustrate the agreement between data and simulated events we show the energy spectrum of the most energetic photon in Figure 1 and the distribution of the polar angle for the most energetic photon in Figure 2 for data collected at $\sqrt{s} = 202$ GeV, background and a Higgs signal with the mass $m_h = 95$ GeV, before applying the cut on the respective quantity.

We also perform a five-constraint kinematic fit which imposes the conservation of the total energy and momenta and requires the mass of the two jets to be consistent to the Z mass. This consistency is obtained by requiring the χ^2 of the kinematic fit to be less than 100. In addition it reduces the $e^+e^- \rightarrow q\bar{q}(\gamma)$ process where a neutral hadron from the Z decay mimics a photon or a photon in the final state is emitted; in both cases the recoil mass against the photons would be smaller than the Z mass.

The efficiency of this analysis for selecting $\gamma\gamma q\bar{q}$ events variates between 40% to 45%. The number of data events and of the backgrounds after the preselection, selection and kinematic fit is presented in Table 1. The total number of events selected in the data is 14 while 12.6 are expected from the Standard Model processes. As estimated from MC simulations, almost all of the remaining background comes from the process $e^+e^- \rightarrow q\bar{q}(\gamma)$.

4 Results and upper limits

Since we do not observe any signal in the data with respect to the expected background we evaluate the confidence level of the absence of the Higgs signal in our data.

The Bayesian confidence level for a given number of expected signal events can be calculated with the formula [11]

$$1 - C.L. = \frac{\int_{\sigma}^{\infty} \mathcal{L}(s,b)ds}{\int_{0}^{\infty} \mathcal{L}(s,b)ds}.$$

The binned likelihood is defined using the reconstructed di-photon mass spectrum for the hypothetical signal, background and observed data:

$$\mathcal{L}(s,b) = \prod_{i=1}^{n_{bin}} \frac{e^{-(s_i+b_i)}(s_i+b_i)^{d_i}}{d_i!},$$

where s_i, b_i and d_i are the number of signal, background and data events in each bin of the reconstructed Higgs mass distribution.

The reconstructed di-photon invariant mass is shown in Figure 3 for all the center-of-mass energies combined.

Figure 4 shows the measured upper limits on the B(h$\rightarrow \gamma\gamma$) as a function of m_{h} assuming a Standard Model rate for the hZ production. We have included in the calculation the sensitivities and the candidates from our search at $\sqrt{s}$ = 189 GeV. On the same figure is shown the theoretical prediction for the B(h$\rightarrow \gamma\gamma$) for a fermiophobic Higgs as calculated with the program HDECAY [12] and switching off the couplings with the fermions. From the intersection of this curve with the exclusion contour we derive a lower limit of 99.2 GeV for the mass of a fermiophobic Higgs.

Acknowledgements

We wish to express our gratitude to the CERN accelerator division for the excellent performance of the LEP machine. We acknowledge with appreciation the effort of all engineers, technicians and support staff who have participated in the construction and maintenance of this experiment.

References

[1] J. Ellis, M.K. Gaillard and P.V. Nanopoulos, Nucl. Phys. **B 106** (1976) 292.

[2] K. Hagiwara, R. Szalapski, D. Zeppenfeld, Phys. Lett. **B 318** (1993) 155; K. Hagiwara and M.L. Stong, Z. Phys. **C 62** (1994) 99; A.G. Akeroyd, Phys. Lett. **B 368** (1996) 89; A. Stange, W. Marciano and S. Willenbrock, Phys. Rev. **D 49** (1994) 1354; H. Haber, G. Kane and T. Sterling, Nucl. Phys. **B 161** (1979) 493; J.F. Gunion, R. Vega and J. Wudka, Phys. Rev. **D 42** (1990) 1673.

[3] Marco A. Diaz and Thomas J. Weiler, preprint hep-ph/9401259; L. Brücher and R. Santos, preprint hep-ph/9907434; L. Brücher and R. Santos, preprint hep-ph/0002027.

[4] L3 Collab., B. Adeva *et al.*, Nucl. Instr. and Meth. **A 289** (1990) 35;
M. Chemarin *et al.*, Nucl. Instr. and Meth. **A 349** (1994) 345;
M. Acciarri *et al.*, Nucl. Instr. and Meth. **A 351** (1994) 300;
G. Basti *et al.*, Nucl. Instr. and Meth. **A 374** (1996) 293;
I.C. Brock *et al.*, Nucl. Instr. and Meth. **A 381** (1996) 236;
A. Adam *et al.*, Nucl. Instr. and Meth. **A 383** (1996) 342.

[5] P.Janot, "The HZHA generator", in "Physics at LEP2", Eds. G.Altarelli, T.Sjöstrand and F.Zwirner, CERN 96-01 (1996) Vol.2, 309.

[6] S. Jadach, B.F.L. Ward and Z. Was, Preprint CERN-TH/99-235, hep-ph/9912214.

[7] M.Skrzypek *et al.*, Comp.Phys.Comm. **94** (1996) 216; M.Skrzypek *et al.*, Phys.Lett. **B372** (1996) 289.

[8] R.Engel, Z.Phys. **C66** (1995) 203; R.Engel, J.Ranft and S.Roesler, Phys.Rev. **D52** (1995) 1459.

[9] R.Brun *et al.*, preprint CERN DD/EE/84-1 (Revised 1987); H.Fesefeldt, RWTH Aachen Report PITHA 85/02 (1985).

[10] S. Bethke *et al.*, Nucl. Phys. **B 370** (1992) 310.

[11] V.F. Obratsov, Nucl. Instr. Meth. **A 316** (1993) 388, and the references therein.

[12] A. Djouadi, J. Kalinowski and M. Spira, Preprint hep-ph/970448.

Cut	Data	ΣBkg.	$q\bar{q}(\gamma)$	WW	$q\bar{q}e\nu$	Ze^+e^-	ZZ
$\sqrt{s} = 192$							
Preselection	1309	1305.2	885.7	336.5	52.7	9.05	21.3
$N_\gamma \geq 2$ + photon requirements	2.	2.6	2.5	0.03	0.004	0.01	0.02
5C Kinematic Fit	0	1.6	1.56±0.3	0.	0.001	0.01	0.02
$\sqrt{s} = 196$							
Preselection	3463	3525.9	2326.0	956.1	150.7	27.2	65.7
$N_\gamma \geq 2$ + photon requirements	8.	6.7	6.5	0.14	0.02	0.03	0.03
5C Kinematic Fit	5.	4.3	4.27±0.6	0.02	0.003	0.02	0.02
$\sqrt{s} = 200$							
Preselection	3283.	3282.9	2118.7	926.9	146.5	25.2	65.7
$N_\gamma \geq 2$ + photon requirements	7.	6.8	6.5	0.2	0.01	0.03	0.03
5C Kinematic Fit	6.	4.8	4.7±0.6	0.03	0.003	0.02	0.02
$\sqrt{s} = 202$							
Preselection	1451.	1489.6	959.4	420.2	67.	12.4	30.6
$N_\gamma \geq 2$ + photon requirements	3.	2.7	2.6	0.07	0.004	0.04	0.02
5C Kinematic Fit	3.	1.9	1.9±0.4	0.01	0.	0.01	0.02

Table 1: Number of events expected from Standard Model physics precesses compared to the observed number of events in the data, after the selection steps. The MC expectations are normalised to the integrated luminosity.

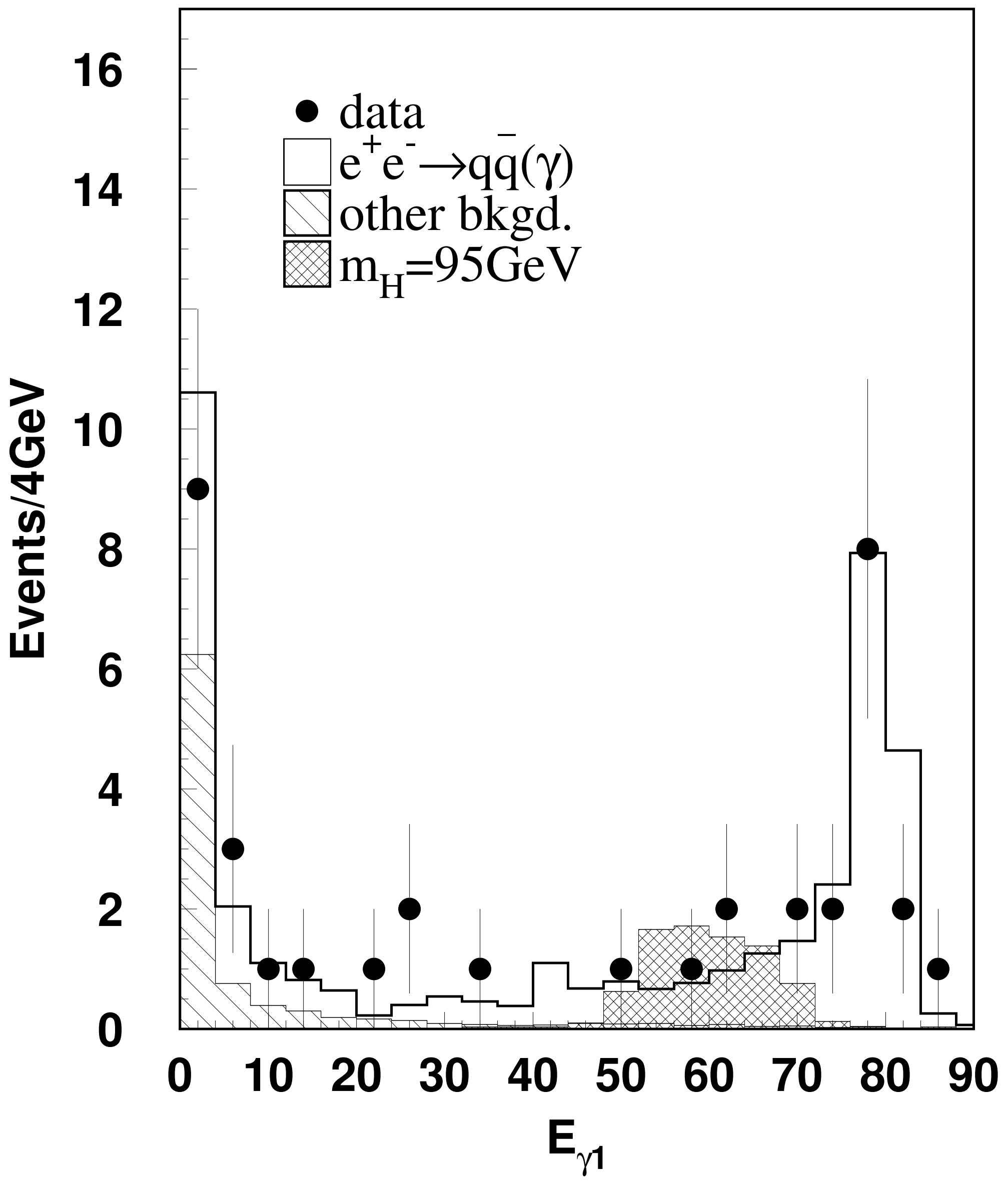

Figure 1: Distribution of the energy spectrum for the most energetic photon for data collected at $\sqrt{s} = 202$ GeV, background and a 95 GeV Higgs signal arbitrarily normalised.

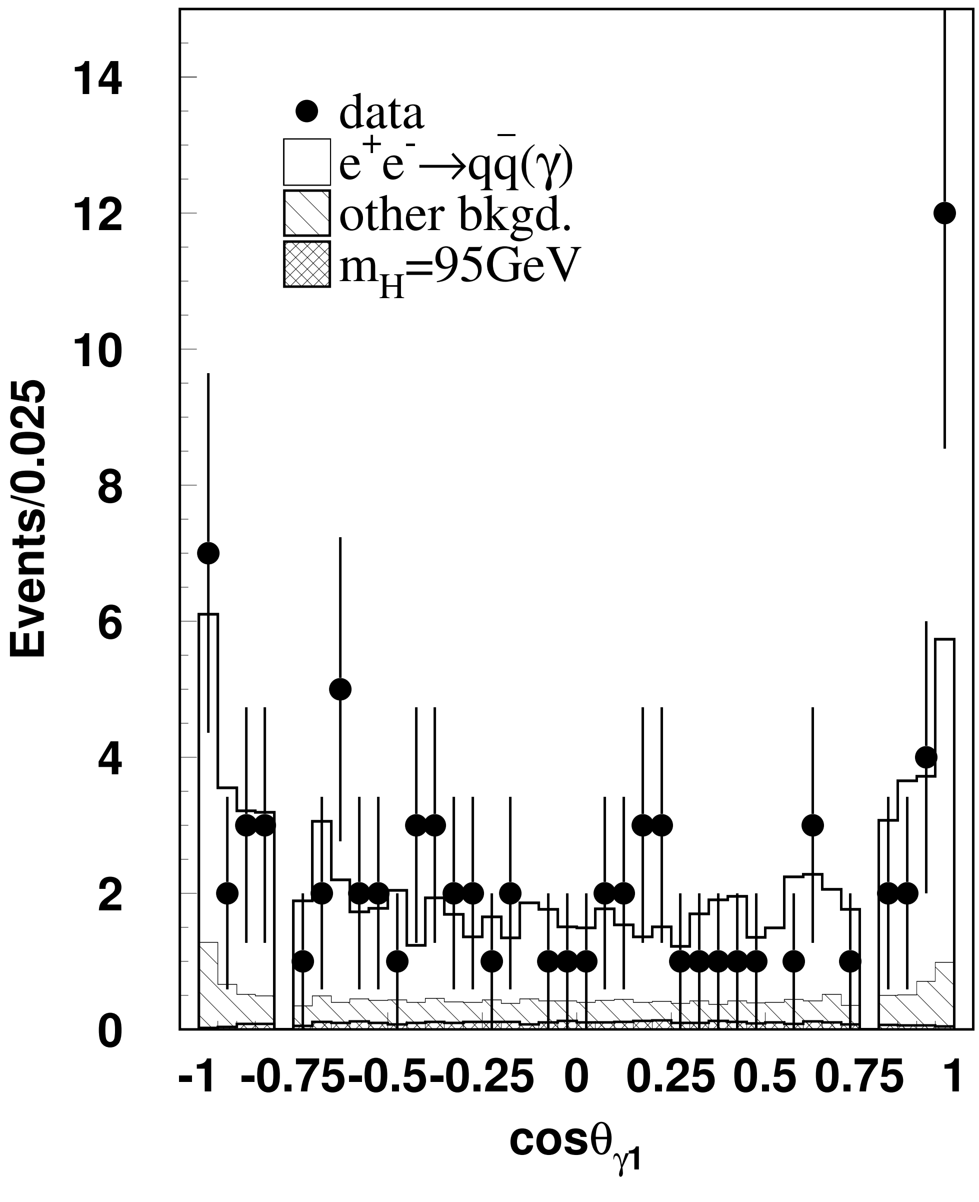

Figure 2: Distributions of the cosine of the polar angle of the most energetic photon for data collected at $\sqrt{s} = 202$ GeV, background and a 95 GeV Higgs signal arbitrarily normalised.

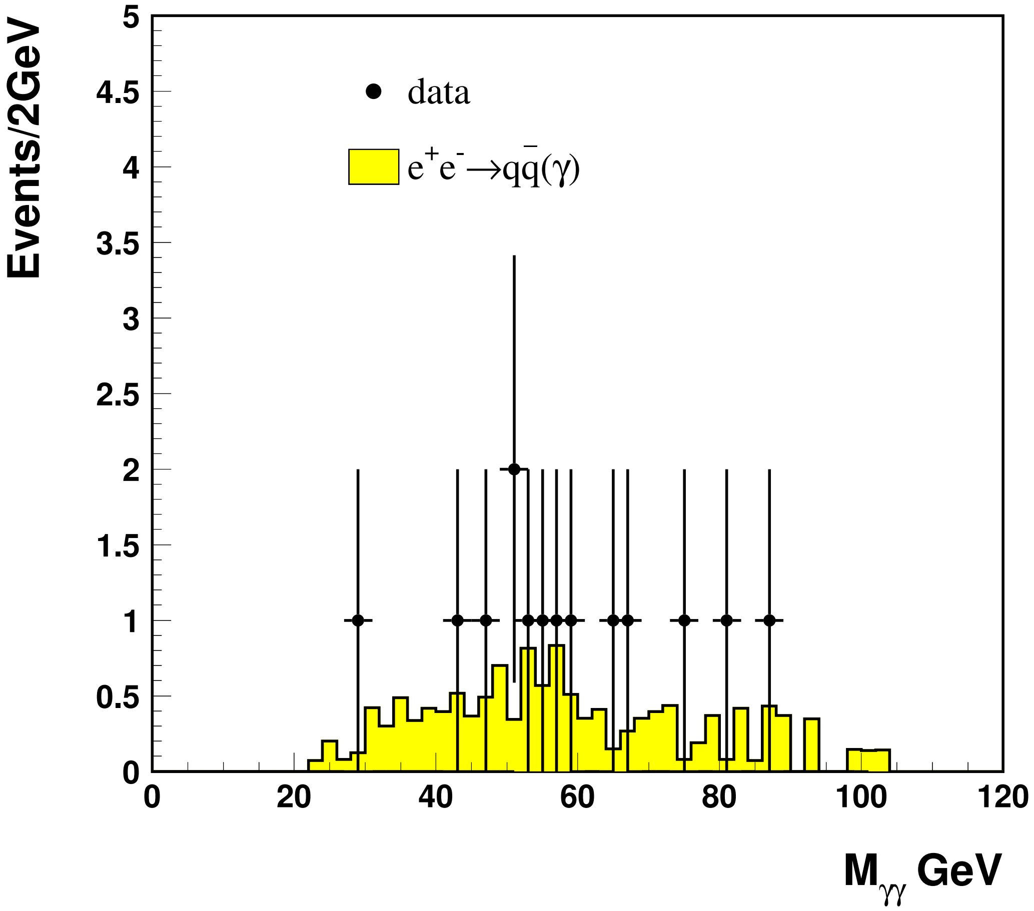

Figure 3: Distribution of the di-photon invariant mass for the combined data at all center-of-mass energies.

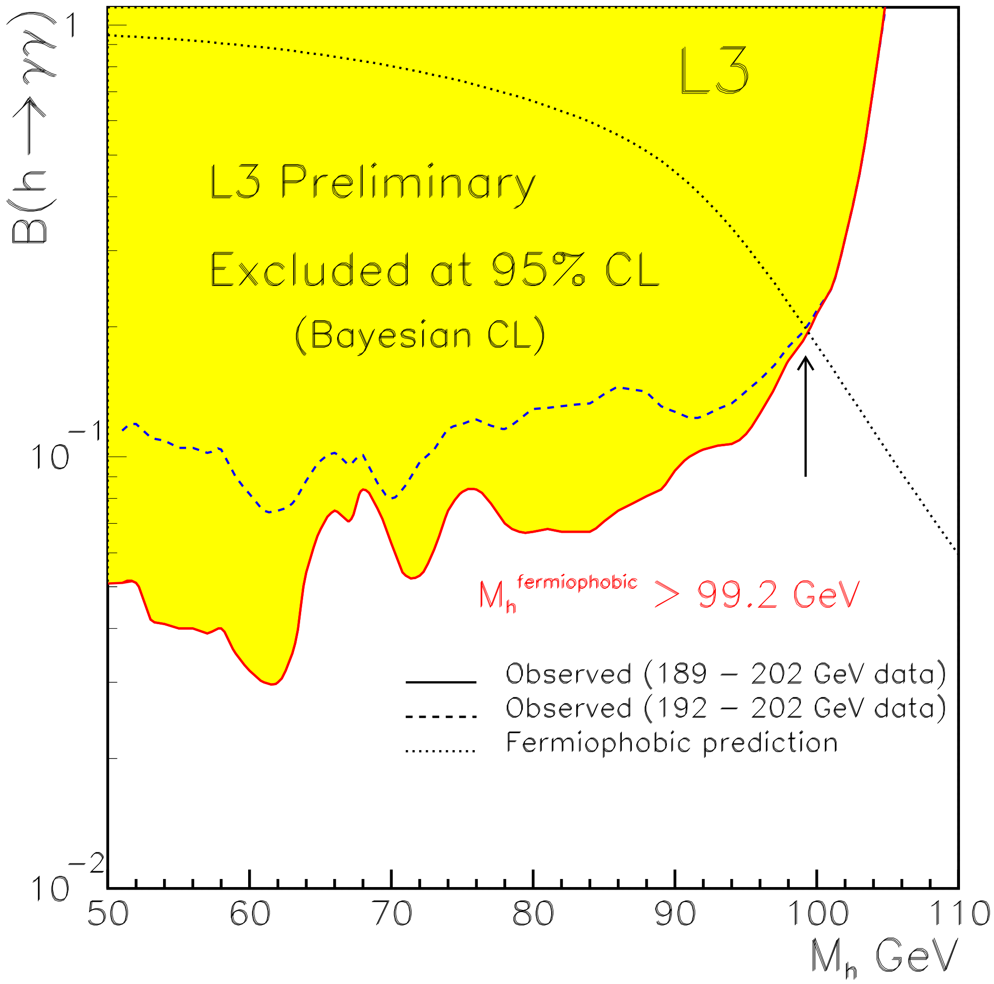

Figure 4: 95% C.L. upper limit on B(h→ $\gamma\gamma$) as a function of the Higgs mass together with the theoretical prediction in the fermiophobic limit. The yellow contour is obtained with the combined 189 - 202 GeV data, while the dashed curve shows the upper limits obtained with the 1999 data only.