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Searches for Higgs Bosons Decaying into Photons: Combined Results from the LEP Experiments

Abstract

This note describes combined results of searches for Higgs bosons decaying into photons carried out by the four LEP collaborations: ALEPH, DELPHI, L3, and OPAL. The analyses use data collected in e^+e^- collisions at centre-of-mass energies between 88 and 209 GeV. Combining the results of these analyses, a lower bound of 109.7 GeV is set at the 95% confidence level for the "benchmark" fermiophobic Higgs boson.

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1 Introduction

In the Standard Model (SM), the branching fraction for $h^0 \to \gamma\gamma$ is too small to permit its observation at LEP energies. However, in particular formulations of 2-Higgs Doublet Models (2HDM) and other models, the Higgs coupling to fermions can be small and the Higgs bosons therefore decay preferentially to pairs of bosons. These are the so-called "fermiophobic" Higgs bosons (see, e.g., references [1, 2]).

The fermiophobic models are indeed parameter dependent, but in a large class of the models the fermiophobic h^0 is produced with near-Standard Model strength. Therefore, we define a "benchmark" fermiophobic Higgs boson with Standard Model production rates and decays, but with the fermionic channels closed. To model Higgs boson production, the four LEP experiments are using the code HZHA [3] and/or HDECAY [4]. The bosonic branching fractions obtained in the benchmark model are shown in Figure 1. The code HDECAY gives a slightly lower di-photon branching ratio than HZHA. In the interest of conservatism, we use the HEDAY branching fractions in our calculations of the exclusion limits.

To obtain the limits, the fermiophobic LEP Higgs Working Group uses the frequentist confidence levels using the code of Reference [5]. This technique includes the estimated systematic errors and the expected signal shape in setting test-mass dependent limits on Higgs boson decays to photon pairs. To obtain the limits shown in their individual publications, the four LEP collaborations use statistical methods different from the one used by the LHWG. These methods have been shown to agree with the LHWG method to within 0.5 GeV on all mass limits.

The LEP limits on the fermiophobic Higgs boson mass will be shown to exceed 100 GeV, where Figure 1 indicates preferred decay into WW. One LEP experiment [6] has set limits on the WW mode, but this channel is not considered in the present combination.

2 Searches for h^0Z^0 with $h^0 \to \gamma\gamma$

The ALEPH [7], DELPHI [8], L3 [9], and OPAL [10] analyses are described in journal articles or CERN preprints. All of the LEP experiments search for hadronic, leptonic, and missing energy (neutrino) decay modes of the associated Z boson in the production channel $e^+e^- \to h^0Z^0$. The ALEPH experiment does not discriminate between Z decay modes; rather, it performs a "global" analysis which focusses on identifying the di-photon state. DELPHI, L3, and OPAL seek to identify the hadronic ($Z^0 \to q\bar{q}$), leptonic ($Z^0 \to \ell^+\ell^-$), and missing energy ($Z^0 \to \nu\bar{\nu}$) classes.

The LEP data from energies just below the Z resonance to the highest LEP-2 energy of 209 GeV can be used for this combined search. The energies and Z decay modes used by the 4 LEP experiments are summarized in Table 1. Note that in some instances the collaborations do not include in their searches the data collected over the entire range of $\sqrt{s}$. The greatest sensitivity to new physics for very low di-photon masses comes from the large amount of LEP1 data, which both ALEPH and OPAL include in their analyses. However, OPAL does not present results for $M_{\gamma\gamma}$ below 20 GeV because discrepancies are observed at lower masses in the various LEP1-era generators for the background simulations both for double-ISR and for neutral hadron content in jets; therefore, only the results for the mass range common to all the experiments are included in Table 1 and the subsequent figures.

	ALEPH	DELPHI	L3	OPAL	SUM
Modes	global	$q\bar{q}$,$\ell^+\ell^-$,$\nu\bar{\nu}$	$q\bar{q}$,$\ell^+\ell^-$,$\nu\bar{\nu}$	$q\bar{q}$,$\ell^+\ell^-$,$\nu\bar{\nu}$	
$\sqrt{s}$ (GeV)	$88-209$	$183-209$	$189-209$	$88-209$	$88-209$
Candidates	23	54	62	124	263
Background	30.8	51.6	72.0	135.2	289.6
Benchmark limit (GeV)	104.5	104.3	104.7	105.3	109.7
Expected limit (GeV)	–	104.6	105.4	105.9	109.4

Table 1: Parameters of the photonically-decaying Higgs searches. 95% confidence level lower limits on the mass of a benchmark fermiophobic Higgs boson are shown.

Figure 2 shows the di-photon mass for all candidate events. The distribution appears to be reasonably well modelled by the SM background processes. In the figure, only the di-photon mass range common to all four experiments is shown. The candidates passing the selection cuts for all three decay topologies are shown in Table 1 for the individual experiments; in each case the observed rate is consistent with, though somewhat lower than, the background rate calculated from SM physics generators. The level of this discrepancy is consistent with other comparisons of single and double photon ISR modelling to LEP data. Figure 3 shows the distributions for $1-\mathrm{CL}_b$ for each experiment individually, and for the sum of the DELPHI, L3, and OPAL experiments. ALEPH is not included in these plots because they do not use background subtraction in their analysis and therefore the background uncertainties are not available. These distributions can only be calculated within our statistical framework at test masses for which an expected signal is supplied; this explains why the L3 region is limited to 50−115 GeV.

The selected events are used to set an upper limit on the di-photon branching ratio of particles produced in association with a Z^0. Figures 4 and 5 show the 95% CL upper limit on $B(\mathrm{h}^0 \to \gamma\gamma) \times \sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{h}^0\mathrm{Z}^0)/\sigma(\mathrm{SM})$ obtained by the individual experiments and by combining the candidate events from the four experiments. The L3 inputs to the LHWG only cover the mass range $50-115$ GeV which gives rise to a kink at 50 GeV in the expected limit. The mass at which $\mathrm{B}(\mathrm{h}^0\to\gamma\gamma)=1$ is excluded at the 95% C.L. is 117.2 GeV.

Also shown in the Figures (and in Figure 1) is the $\mathrm{h}^0\to\gamma\gamma$ branching ratio in the Standard Model computed using HDECAY [4] with the fermionic couplings switched off. The benchmark fermiophobic lower mass limit is obtained where the predicted branching ratio crosses the upper-limit curve. Table 1 shows the limits obtained for the individual experiments using the statistical method of the LHWG; in all cases the LHWG values are within 0.5 GeV of the values reported by the individual experiments. No value is obtained for the ALEPH expected limit because no uncertainty on the background estimate is available.

For the combined data from the four experiments, the 95% CL lower mass limit for a benchmark fermiophobic Higgs boson is set at 109.7 GeV. The median limit one would expect to obtain in an ensemble of experiments in the absence of a signal is 109.4 GeV. In order to calculate the expected limit including the ALEPH data, a systematic uncertainty of $10-20\%$ for the ALEPH background simulation was assumed; the expected limit thus obtained is not very sensitive to the systematic uncertainty assumed in the statistical procedure. Had we used HZHA instead of HDECAY to calculate the Higgs boson branching fractions, the lower bound on the mass would have come out higher by about 0.6 GeV.

References

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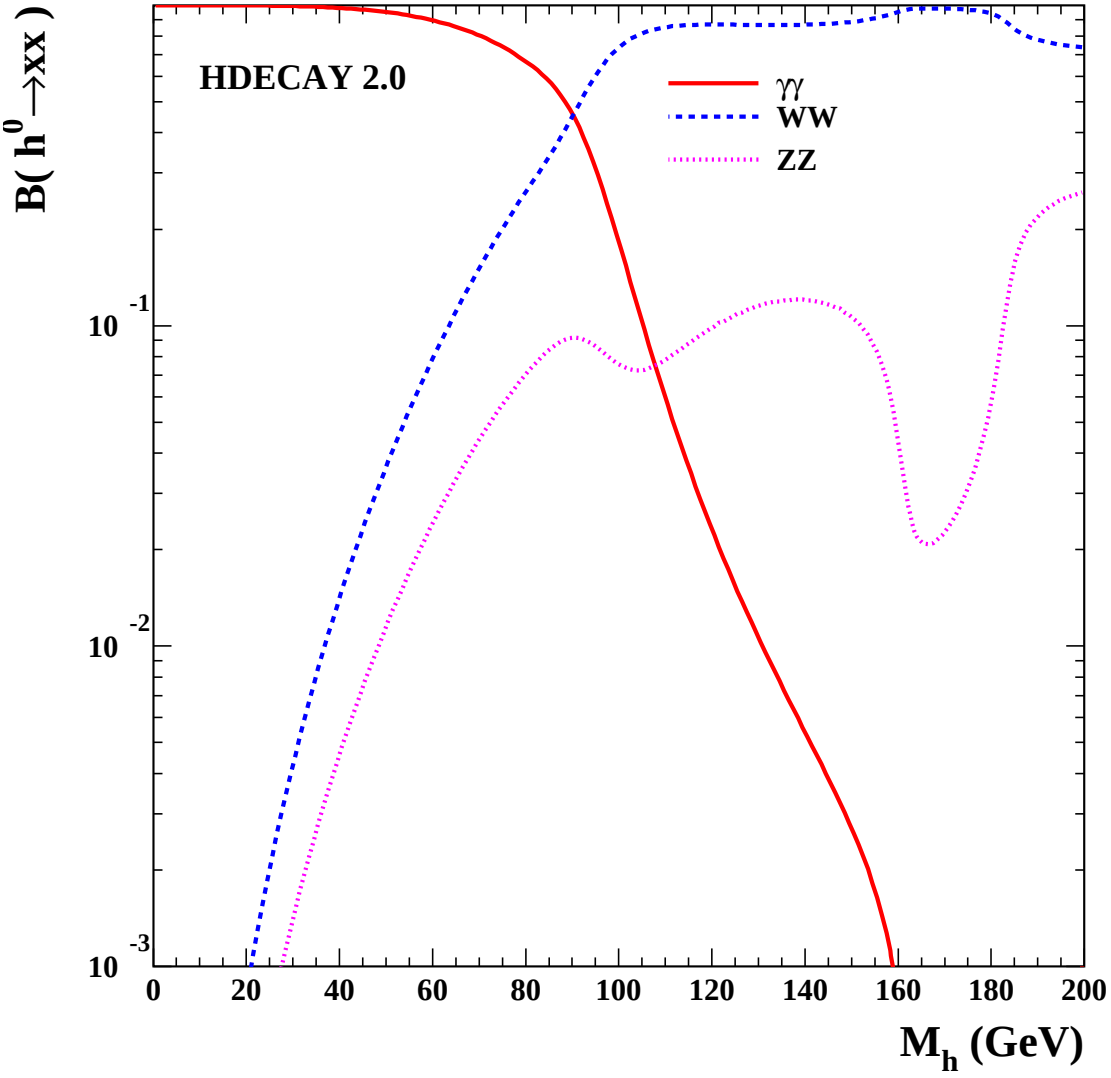

Figure 1: Branching fraction of benchmark fermiophobic Higgs boson into boson pairs as calculated with HECAY2 [4].

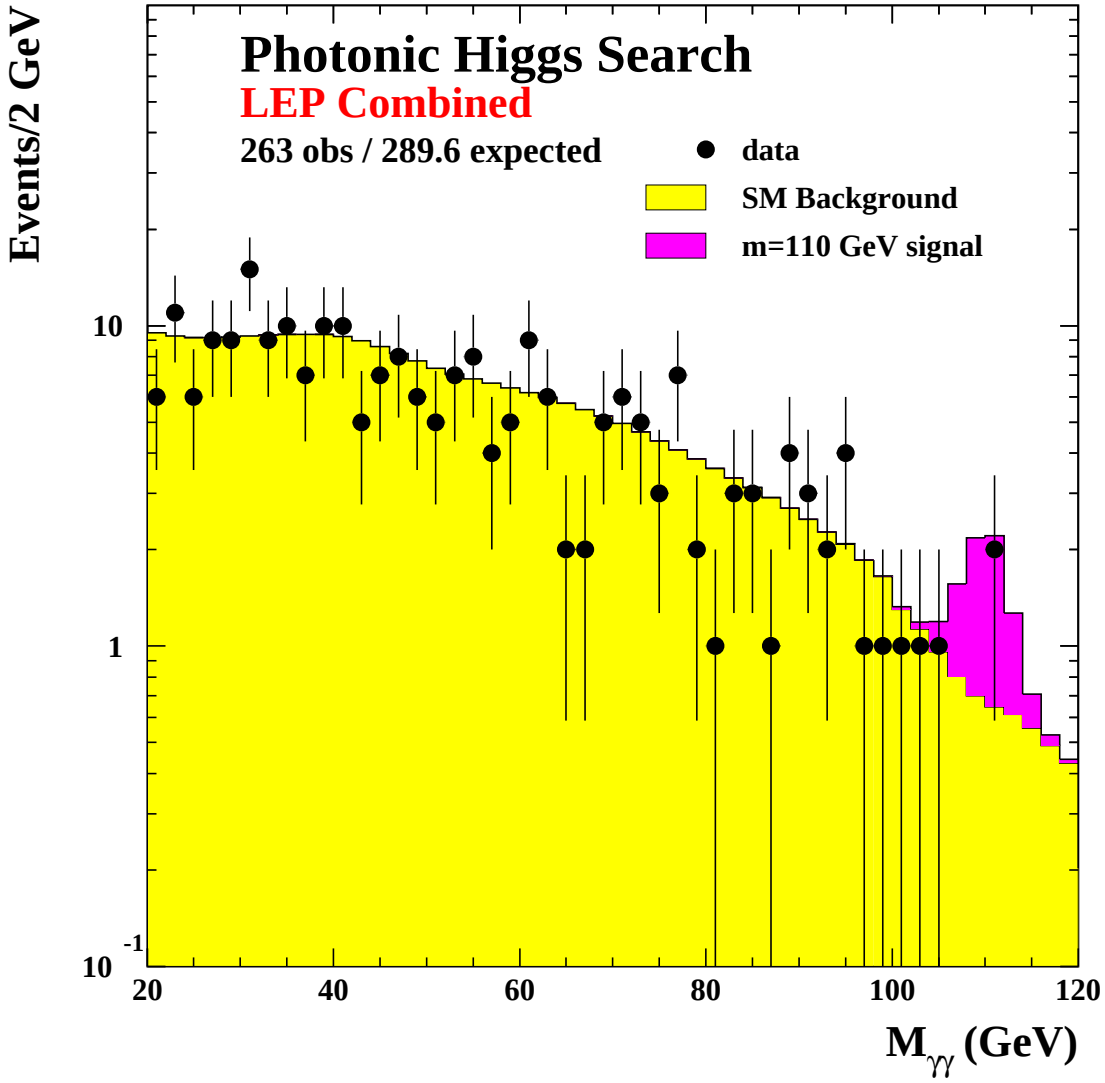

Figure 2: Distribution of di-photon masses for the LEP experiments combined. The expected background from all SM sources is indicated by the lightly shaded histogram. The signal expected for a benchmark fermiophobic Higgs boson of mass 110 GeV is shown by the dark shaded histogram.

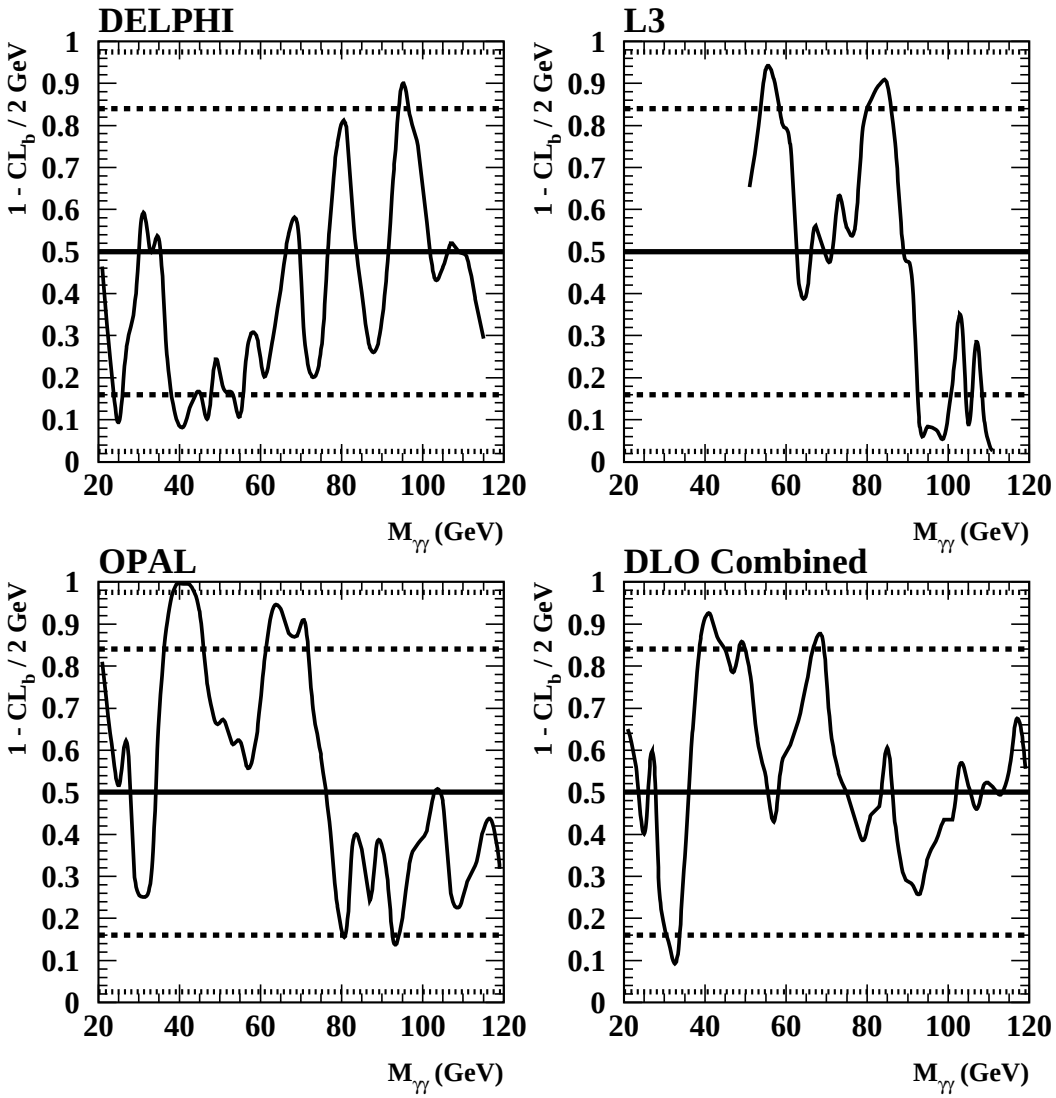

Figure 3: Distributions of $1 - \mathrm{CL}_b$ for the individual experiments, and for the DLO combined data. The dashed lines indicate the 1σ level; the dotted lines indicate the 2σ level.

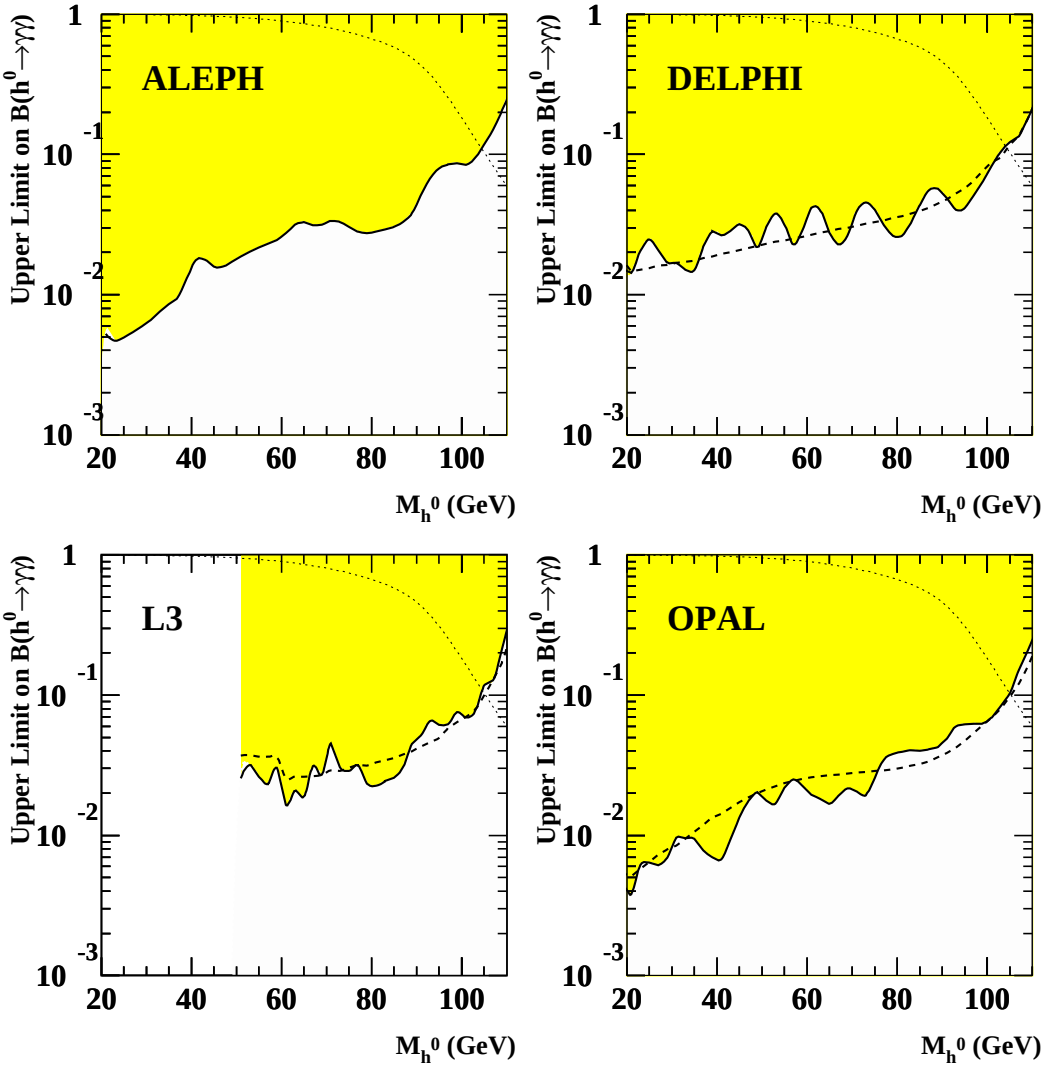

Figure 4: Individual experimental limits on fermiophobic Higgs bosons for the photonic decay mode. The 95% confidence level upper limit on $B(\mathrm{h}^0 \to \gamma\gamma) \times \sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{h}^0\mathrm{Z}^0)/\sigma(\mathrm{SM})$ is shown as a function of Higgs mass; the dark shaded regions are excluded. The median expected limits are indicated by the dashed curves, except for ALEPH (where no background systematic is available). Also shown (dotted line) is the branching fraction obtained for the benchmark fermiophobic model.

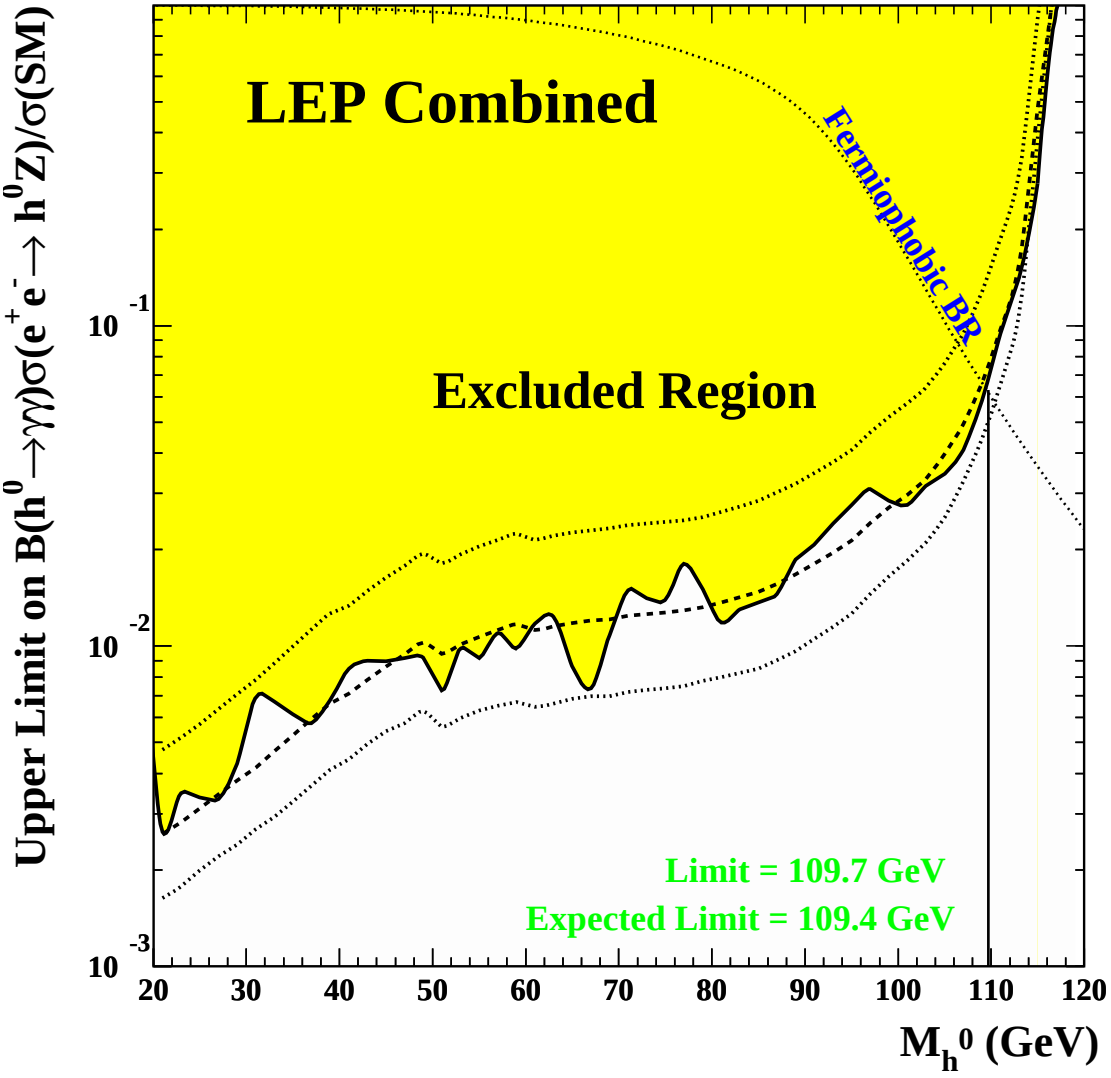

Figure 5: Combined LEP experimental limits for Higgs bosons decaying into di-photons. The 95% confidence level upper limit on $B(\mathrm{h}^0 \to \gamma\gamma) \times \sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{h}^0\mathrm{Z}^0)/\sigma(\mathrm{SM})$ is shown as a function of Higgs mass. Also shown (dotted line) is the branching fraction obtained for the benchmark fermiophobic model. The median expected limits and the $\pm 2\sigma$ confidence level region are denoted by the dashed curves. The combined limit is indicated by the vertical line.