Fermiophobic Higgs Bosons at LEP

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This work describes the results of the searches for a Higgs boson decaying into gauge bosons carried out by the four LEP collaborations: ALEPH, DELPHI, L3 and OPAL. A lower bound of 109.7 GeV is set at 95% confidence level on the mass of a fermiophobic Higgs boson decaying into photons. This mass limit can be extended by considering the Higgs decay mode into weak bosons. Such a combination has been done by the L3 collaboration which extended the fermiophobic mass by 5 GeV.

1. Introduction

Photonic final states from the process $e^+e^- \rightarrow Zh \rightarrow Z\gamma\gamma$ do not occur in the Standard Model at the tree level, but may be present at a low rate due to charged weak boson and top quark loops. Very specific models can lead to an enhancement of the $h\rightarrow \gamma\gamma$ rate, such as the fermiophobic 2 Higgs doublet models of type I [1], where all fermions are assumed to couple to the same scalar field, and the couplings can thus be suppressed simultaneously by appropriate parameter choices.

Since there are several possible models which predict fermiophobic Higgs bosons, the LEP Higgs working group (LHWG) defined the so-called "benchmark fermiophobic model" where the production cross-section is the same as in the Standard Model, and the couplings of the Standard Model Higgs to fermions are removed, resulting in increased branching fractions into gauge bosons. A fermiophobic Higgs in the benchmark model decays predominantly via the process $h\rightarrow \gamma\gamma$ if its mass is below 90 GeV, while at higher masses it decays mostly via the processes $h\rightarrow WW^*, ZZ^*$.

2. Photonic Higgs decays

A fermiophobic Higgs can be produced in e^+e^- collisions at the energies available at LEP by the Higgs-Strahlung mechanism in the s-channel, $e^+e^- \rightarrow Zh$, where the Higgs boson is radiated off an intermediate Z boson. For the case of photonic decays, this results in three categories of possible final states with different topologies, efficiencies and background rates:

1. the hadronic final state, involving two high energy photons and two jets from the hadronic decay of the Z;
2. the missing energy final state, involving two high energy acoplanar photons and two neutrinos;
3. the dilepton final state, involving two high energy photons and two high energy leptons.

For all the channels, the major background is the double radiative Z production.

Table 1
Results of the $h\rightarrow \gamma\gamma$ search.

Experiment	Data	Bkgd.	Mass limit (GeV)
ALEPH	23	30.8	105.4
DELPHI	54	51.6	104.1
L3	62	72.0	105.4
OPAL	124	135.2	105.5
SUM	263	289.6	109.7

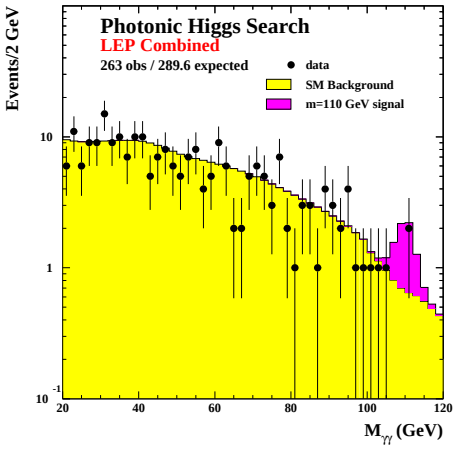

Figure 1. Distribution of the reconstructed diphoton invariant mass for all final states combined. The combined LEP data are shown together with the background and a Higgs boson signal with mass $m_{\mathrm{h}} = 110$ GeV.

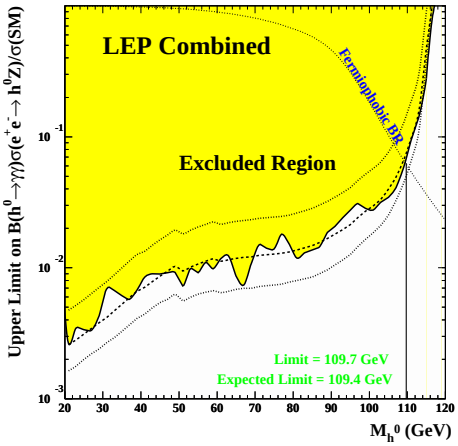

Figure 2. Excluded values at 95% confidence level of BR(h→ $\gamma\gamma$)×$\sigma(\mathrm{e^+e^-} \to \mathrm{Zh})/\sigma_{\mathrm{SM}}$ as a function of the Higgs mass, in the fermiophobic model. The expected (dashed line) 95% confidence limit and the theoretical prediction (dotted line) are also presented.

The searches used data samples collected in $\mathrm{e^+e^-}$ collisions at centre-of-mass energies between 88 and 209 GeV. The ALEPH [2], DELPHI [3], L3 [4] and OPAL [5] analyses are described in journal articles or CERN preprints.

The results of the analyses are summarised in Table 1, where we list the number of observed events, the estimated background and the lower mass limit set at 95% confidence level for the benchmark fermiophobic Higgs boson.

The distribution of the di-photon invariant mass is shown in Figure 1 for the combined data from the four LEP experiments. No excess with respect to the Standard Model predictions is observed in the data. In the absence of a signal, the results are given in terms of upper limits on the BR(h→ $\gamma\gamma$) at 95% confidence level, assuming a Standard Model production cross section for the Higgs boson. The LEP combined limits are shown in Figure 2. In the fermiophobic model, the observed mass limit is 109.7 GeV.

3. Decay into weak bosons

In the case Higgs decays via the process h→ WW* or ZZ*, and considering all the Z and W decay modes, there are nine possible channels. From these the L3 [7] collaboration analysed the following six: Zh→ $\mathrm{q\bar{q}q\bar{q}q\bar{q}}$, Zh→ $\mathrm{q\bar{q}q\bar{q}}\ell\nu$, Zh→ $\mathrm{q\bar{q}}\ell\nu\ell\nu$, Zh→ $\nu\nu\mathrm{q\bar{q}q\bar{q}}$, Zh→ $\nu\nu\mathrm{q\bar{q}}\ell\nu$ and Zh→ $\ell^+\ell^-\mathrm{q\bar{q}q\bar{q}}$, covering a total of 92% of the h→ WW* branching fraction. Of these the qqqq$\ell\nu$ final state has the largest sensitivity.

The background in these channels comes from a variety of Standard Model processes, including W pair production, Z pair production and $\mathrm{q\bar{q}}$ events.

The number of selected events in 336.4 pb^{-1} of data collected at center-of-mass energies from 199 GeV up to 209 GeV is 566 and 568.3 events are expected from the Standard Model processes. Since no indication for a signal was found in the data, the negative search result is given in terms of upper limits on the branching fraction BR(h→ WW*) as a function of the Higgs mass. The limits are shown in Figure 3. A fermiophobic Higgs boson decaying to weak bosons is excluded for 83.8 GeV $< m_{\mathrm{h}} <$ 104.2 GeV with a region between 88.9 GeV $< m_{\mathrm{h}} <$ 89.4 GeV which can be excluded only at 93% confidence level.

Model-independent fermiophobic results can be derived by scanning the relative branching frac-

tions of h→ $\gamma\gamma$ and h→ WW*, assuming

$$\mathrm{BR}(h \to \gamma\gamma)+\mathrm{BR}(h \to WW^*)+\mathrm{BR}(h \to ZZ^*) = 1.$$

The search results are presented as excluded regions in the plane [BR(h→ $\gamma\gamma$),m_h] and are shown in Figure 4. The solid line crossing the excluded area gives the predicted value of BR(h→ $\gamma\gamma$) for the benchmark fermiophobic model. In the benchmark model, the 95% confidence level for a fermiophobic Higgs mass is set at 108.3 GeV, with an expected limit of 110.7 GeV. This result represents a significant extension of the mass limit of 105.3 GeV obtained by the L3 collaboration from the search in the photonic decay mode. The 95% confidence level mass limit, valid for any value of BR(h→ $\gamma\gamma$) and assuming a Standard Model production cross section is set at 107 GeV.

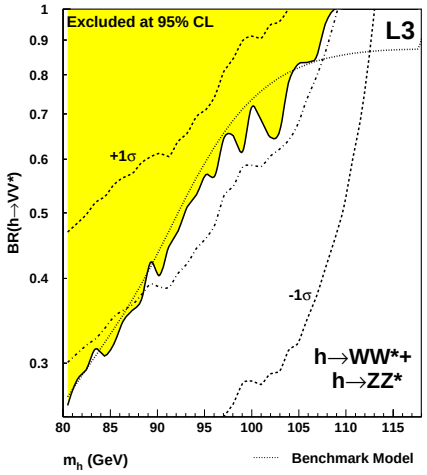

Figure 3. Excluded values at 95% confidence level of BR(h→ WW*) as a function of the Higgs mass in the fermiophobic model. The expected 95% confidence level limit (dot-dash line) and the theoretical prediction (dotted line) are also presented.

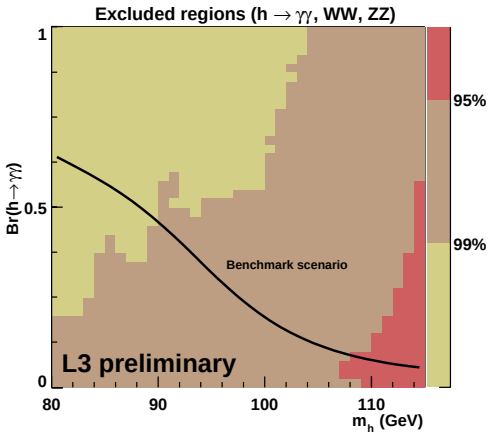

Figure 4. Excluded area at 95% confidence level in the (BR(h→ $\gamma\gamma$),m_h) plane. The solid line gives the prediction of the benchmark fermiophobic model.

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