JHEP PROCEEDINGS
International Europhysics Conference on HEP

Searches for Higgs Bosons Beyond the Standard Model at LEP (Part B): Fermiophobia, Anomalous couplings, Invisible and Charged Higgs.

M.Isabel Josa*
CIEMAT, Avda. Complutense 22, E-28040 Madrid
E-mail: Isabel.Josa@ciemat.es

On behalf of LEP collaborations

Abstract: Experimental results from the four LEP experiments on the search for Higgs bosons in extensions beyond the Standard Model are reviewed.

1. Introduction

The electroweak symmetry breaking is described in the Standard Model (SM) through a complex doublet Higgs field. After symmetry breaking the complex field results into the Higgs boson physical state. Searches for the SM Higgs done by the four LEP experiments allowed to set a LEP combined lower limit to the SM Higgs boson mass of 114.1 GeV (95% CL) [1].

Extensions to the SM that include more than one Higgs doublet produce a very rich spectrum of physical Higgs bosons. LEP experiments have performed a formidable experimental research program exploring several extensions of the SM and the different Higgs scenarios proposed in them. In the following I will restrict to the following searches: fermiophobia and anomalous couplings, invisible Higgs and charged Higgs.

All LEP experiments have reported on the analysis of 2000 data. No evidence of Higgs production was found, and combining with data from previous years mass limits were quoted. The LEP combined values, as calculated by the LEP Higgs working group [2], were also submitted. A review of experimental searches in other extensions of the SM can be found elsewhere in these proceedings [3].

All results presented in this paper are preliminary.

*Speaker.

2. Fermiophobia

In the SM the decay of the Higgs boson to photons proceeds through charged particle loops, making its branching ratio of the order of 10^{-3} over a wide range of Higgs masses. Particular choices of the parameters in Two Higgs Doublet Models (THDM) result in a suppression of the fermionic decay modes. In purely fermiophobic models the preferred Higgs decay mode is $\mathrm{H} \to \gamma\gamma$ for a Higgs mass $\lesssim m_\mathrm{Z}$. For Higgs masses above 100 GeV, $\mathrm{H} \to \mathrm{W}^{(*)}\mathrm{W}^{(*)}$ becomes dominant. It is therefore meaningful to perform a search of such *fermiophobic* decay modes at LEP energies.

Many fermiophobic models suggest a Higgs production rate not very different from the SM one. The production mechanism is the Higgstrahlung process $\mathrm{e}^+\mathrm{e}^- \to \mathrm{HZ}$. A "benchmark" fermiophobic model is therefore defined to have SM production rates but with the fermionic decay channels closed. The search channels are then $\mathrm{e}^+\mathrm{e}^- \to \mathrm{HZ} \to \gamma\gamma\mathrm{f}\bar{\mathrm{f}}$, $\mathrm{f} = \mathrm{q}, \nu, \ell$. The main signature is the presence of two isolated, energetic and central photons The fact that the Higgs boson is produced in association with a Z is exploited in the analysis by requiring that the recoil mass to the two-photon system be consistent with the Z mass. Figure 1 shows the two-photon invariant mass for the full LEP data including the signal of a Higgs boson with $m_\mathrm{H} = 100$ GeV. The fermiophobic Higgs mass limits computed by the experiments with the full statistics [4], [5], [6], [7] are summarized in table 1. The LEP combined [8] limit is also given.

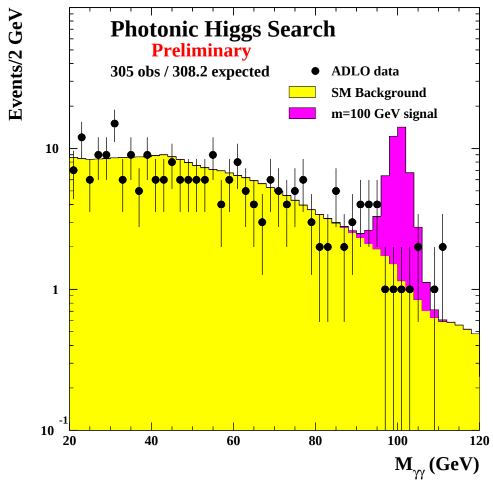

Figure 1: Two-photon invariant mass distribution for all fermiophobic candidates. Signal prediction is for $m_\mathrm{H} = 100$ GeV.

Mass limit (GeV)	ALEPH	DELPHI	L3	OPAL	LEP comb.
Observed	105.4	103.4	104.1	105.5	108.2
Expected	Not quoted	105.1	104.9	106.4	109.0

Table 1: Fermiophobic Higgs mass limits reported by the experiments and LEP combined limit.

3. Anomalous couplings

The SM can be extended via a linear representation of the $\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$ symmetry breaking. The lowest order representation leads to the SM. At higher order new interactions between the Higgs boson and the gauge bosons become possible, the strength of these new interactions given by the so called *anomalous* couplings. An enhancement of particular

Higgs production and decay mechanisms may therefore happen. L3 performs a search of the direct production channels $e^+e^- \rightarrow H\gamma$ and $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-H$ with the subsequent decay $H \rightarrow \gamma\gamma$, that is, final states with three photons or longitudinally unbalanced events with two photons. Higgs anomalous couplings are excluded for Higgs masses below 112 GeV (95% CL) [9].

4. Invisible Higgs

Several scenarios propose the existence of invisible decay channels of the Higgs, such as $H \rightarrow SS$ (S is a scalar with $m_S < \frac{1}{2}m_H$), $H \rightarrow \chi\chi$ if the χ is light enough or $H \rightarrow JJ$ in models with Majorons (J).

The experimental search [10], [11], [12], [7] assumes the Higgsstrahlung production process: $e^+e^- \rightarrow HZ, H \rightarrow$ invisible, $Z \rightarrow q\bar{q}$. The search is similar to the SM process $e^+e^- \rightarrow b\bar{b}\nu\bar{\nu}$ but without any requirements on b-tag. The fact that the hadronic mass should be consistent with m_Z is used as a constraint.

In the hypothesis of a branching ratio $H \rightarrow$ invisible equal to 1 a limit on the ratio $\xi = \sigma(e^+e^- \rightarrow HZ)/\sigma_{SM}(e^+e^- \rightarrow HZ)$ versus m_H is calculated (Figure 2).

Assuming a SM production cross section ($\xi = 1$) a mass limit for a purely invisibly decaying Higgs boson can be set. The LEP combined limit [13] is $m_{H_{inv}} >$ 114.4 GeV at 95% CL.

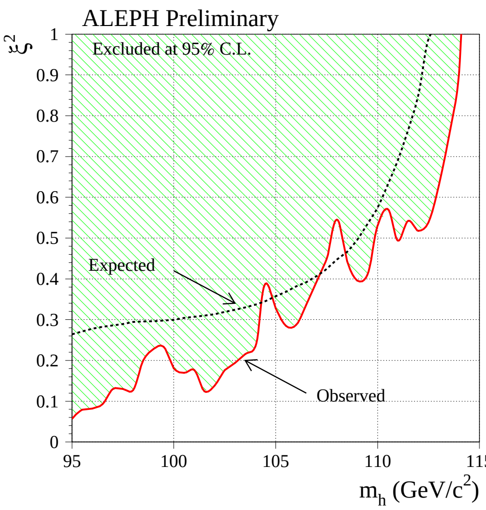

Figure 2: Excluded region in the parameter ξ versus m_H in ALEPH.

5. Charged Higgs

Models such as THDM predict the existence of a pair of charged Higgs, their phenomenology depending on the specific choices of the Higgs couplings to fermions.

A model independent search for charged Higgs is done by the four LEP experiments [14], [15], [16], [7]. The experimental assumptions are that charged Higgs are produced in pairs, decay to the heaviest fermions, i.e. $H \rightarrow \tau\nu_\tau$ and $H \rightarrow c\bar{s}$, and those two channels saturate the decay width. The branching fraction ($H \rightarrow \tau\nu_\tau$) is left as a free parameter in the analysis. The dominant background to this process is W-pair production, with exactly the same final state topology. Two important differences are exploited to reject this background: the polar angle of the boson and the τ polarization, as the spin configuration is different for a spin=0 particle (the Higgs boson) and a spin=1 particle (the W boson). In the semileptonic ($H^+H^- \rightarrow \tau^+\nu_\tau c\bar{s}$) and fully hadronic ($H^+H^- \rightarrow c\bar{s}\bar{c}s$) channels a kinematical fit with energy-momentum conservation and equal mass constraints is applied.

Figure 3 shows the Higgs reconstructed mass distribution for the semileptonic channel from DELPHI [15]. L3 reports an excess of events at $m_{\rm H} = 68$ GeV in the fully hadronic (Figure 4) and semileptonic channels [16]. The excess is maximum (4.2 σ) for a BR($\rm H \to \tau\nu_\tau$) = 0.1. This excess is not confirmed by the other experiments. The charged Higgs mass limits quoted by the experiments are summarized in table 2 together with the LEP combined value [17].

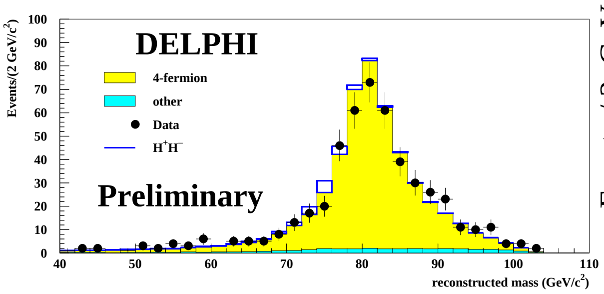

Figure 3: Reconstructed charged Higgs mass distribution in the semileptonic channel from DELPHI. Signal prediction is for $m_{\rm H} = 75$ GeV and BR($\rm H \to \tau\nu_\tau$)=0.5.

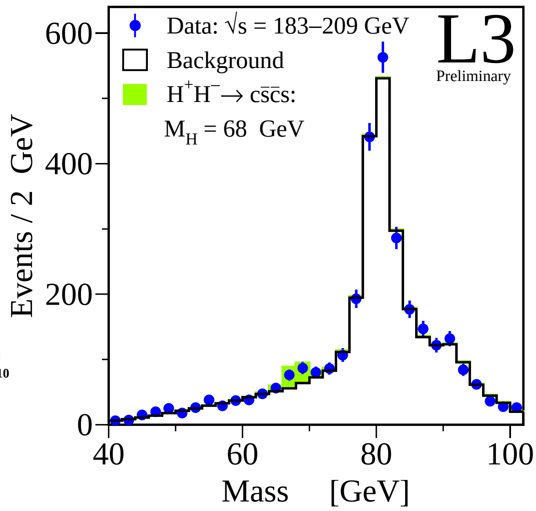

Figure 4: Reconstructed charged Higgs mass distribution in the fully hadronic channel from L3. Signal prediction is for $m_{\rm H} = 68$ GeV and BR($\rm H \to \tau\nu_\tau$)=0.

BR($\rm H \to \tau\nu_\tau$)		ALEPH	DELPHI	L3	OPAL	LEP comb.
0.	Observed	80.7	Not quoted	77.2	76.2	81.0
	Expected	78.1	Not quoted	77.1	77.1	80.2
1.	Observed	83.4	Not quoted	85.2	84.5	89.6
	Expected	86.9	Not quoted	84.6	86.5	92.1
Any BR	Observed	78.0	73.8	66.9	72.2	78.6
	Expected	76.9	75.4	76.0	74.5	78.8

Table 2: Charged Higgs mass limits (GeV) from the individual experiments and LEP combined limit. The lower value quoted by L3 is due to the excess of events at 68 GeV.

In the particular case of Type I THDM the decay $\rm H^\pm \to W^{*\pm}A^0$ is the dominant one (when kinematically accessible) for $\tan\beta > 1$ (β is the ratio of the vacuum expectation values of the two doublets). Its branching ratio depends on both $\tan\beta$ and the relative difference between $\rm H^\pm$ and $\rm A^0$ masses. OPAL has performed a search for such a signal in the $\rm H^+H^- \to W^{*+}A^0W^{*-}A^0 \to q\bar{q}'b\bar{b}q''\bar{q}'''b\bar{b}$, $\rm H^+H^- \to W^{*+}A^0W^{*-}A^0 \to \ell\nu b\bar{b}q\bar{q}'b\bar{b}$ (where $\ell = {\rm e}, \mu, \tau$) and $\rm H^+ \to W^{*+}A^0 \to q\bar{q}'b\bar{b}$, $\rm H^- \to \tau\nu_\tau$ channels. Limits in the $m_{\rm A^0}$ versus $m_{\rm H^\pm}$ plane are set for different values of $\tan\beta$ [7].

6. Summary

LEP experiments have extended their search of the Higgs boson much beyond the Standard Model. No evidence for any Higgs has been found. This allows to set the following limits:

- A lower mass limit on fermiophobic Higgs to 108.2 GeV (95% CL).
- Higgs anomalous couplings are excluded for Higgs masses below 112 GeV (95% CL).
- A lower mass limit on invisible Higgs to 114.4 GeV (95% CL).
- A lower mass limit on charged Higgs to 78.6 GeV (95% CL), independent of $BR(H \to \tau\nu_\tau)$.
- Limits on 2HDM parameter space from the search $H^\pm \to W^{*\pm}A^0$.

References

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