Searches for "Other" Higgs Bosons at LEP

Mark J Oreglia[1]

[1] The Enrico Fermi Institute, The University of Chicago, Chicago 60637, USA
E-mail: m-oreglia@uchicago.edu

Abstract
Recent LEP searches for Higgs bosons in models other than the Minimal Standard Model and the Minimal Supersymmetric Standard Model are reviewed. Limits are presented for Higgs bosons decaying into diphotons or invisible particles, and for charged Higgs bosons.

1. Introduction

The Minimal Standard Model (MSM) incorporating a single Higgs doublet has one neutral Higgs boson with all decay rates specified by the theory. The dominant production mechanism at LEP is the Bjorken process $e^+e^- \rightarrow h^0Z^0$; a 95.2 GeV lower mass limit on the MSM h^0 is obtained by combining the results from the four LEP experiments analyzing data up to $E_{\rm cm}$=189 GeV [1].

In models employing more than one Higgs doublet or triplet fields, a rich spectrum of Higgs bosons occurs, with possibly large numbers of unknown decay parameters. For instance, the Minimal Supersymetric Standard Model (MSSM) is a two Higgs doublet model (2HDM) obtained with a particular choice of the couplings of the Higgs fields. This model has five Higgs particles in the form of three neutrals (one is CP odd) and a singly-charged pair. In more generality, there are four ways to couple the 2HDM fields to fermions and bosons (some authors classify these as model types I, I', II, and II').

In this brief review, I present results from LEP searches for Higgs bosons decaying in the context of models other than the MSM and MSSM.

2. Photonically Decaying Higgs Bosons

In the MSM, the Higgs boson can decay into a pair of photons by means of a W-loop. For a Higgs boson of mass 80 GeV, the diphoton branching fraction is 0.001, hence this mode is not visible at LEP. However, in non-minimal models, when the topology of the theory reduces the Higgs boson coupling strength to fermions, the diphoton mode can become large. An example of this is the "fermiophobic" Higgs boson [2] arising in the Type-I 2HDM. In this model, all the fermionic couplings to one of the Higgs neutrals have a factor $\cos\alpha/\sin\beta$, so that the appropriate choice of α turns off the fermionic couplings. In this theory, the lightest neutral boson is produced in e^+e^- collisions at MSM strength.

Very different theories can give rise to enhanced $H^0 \rightarrow \gamma\gamma$ rates, so it is important to present cross section limits in addition to model-specific Higgs boson mass limits. The list of theories having enhanced diphoton rates includes the 2HDM, the Higgs Triplet model, top-quark condensate models, models with extra dimensions, models with anomalous couplings, the hypercharge axion, etc.

Figure 1 shows the 95% CL upper limits on the production cross sections for $\sigma(e^+e^- \rightarrow XY) \times B(X \rightarrow \gamma\gamma) \times B(Y)$ obtained by OPAL [3] with data from $E_{\rm cm}$ up to 189 GeV; here, X can be a fermiophobic Higgs Boson and Y can be a scalar or vector particle. Factoring out the SM Higgs boson production cross section, OPAL obtains upper limits on the diphoton branching ratio (Figure 2); similar results have been contributed to this conference by ALEPH, DELPHI, and L3 [4].

3. Invisibly Decaying Higgs Bosons

In nonminimal models, the Higgs boson could decay into undetected particles such as a pair of SUSY particles. The Bjorken production mechanism allows searching for this mode by tagging the recoil Z^0. Backgrounds to this search arise primarilly from 4-fermion and WW processes.

The search results may be intrepreted by assuming that the invisibly-decaying Higgs boson is produced at the MSM rate modified by the factor ξ. All the LEP experiments have presented search limits to this conference [5]. The L3 plot of candidate events is shown in Figure 3. The ALEPH limits on ξ are shown in Figure 4.

4. Charged Higgs Bosons

Charged Higgs bosons can be pair-produced at LEP ($e^+e^- \rightarrow H^+H^-$). Models giving rise to singly-charged Higgs bosons are the 2HDM (including the MSSM), triplet models, and models with other extended Higgs sectors.

In the 2HDM, the pair-production rate is specified, however the $H^\pm$ decay couplings are not. The searches currently assume that $H^\pm \rightarrow c\bar{s}$ ("hadron mode") and $H^\pm \rightarrow \tau\nu_\tau$ ("lepton mode") are the dominant decays, and therefore BR($H^\pm \rightarrow \tau\nu_\tau$) is treated as a parameter of the theory. Akeroyd [7] suggests that $H^\pm \rightarrow W^* A^0$ is an important search channel for triplet models (and for 2HDM if $H^\pm$ is very massive).

All the LEP collaborations have submitted search updates to this conference [6]. The search results for $E_{\rm cm}$ up to 189 GeV are summarized in Table 1, where the mass limit shown is the lowest value of the 95% CL lower bound for any value of BR($H^\pm \rightarrow \tau\nu_\tau$). The exclusion regions for the various modes in the DELPHI analysis are shown in Figure 5. Also, for this conference, the LEP Higgs Working Group has combined the 189 GeV results from the four experiments, obtaining a lower mass bound of 77.3 GeV [1].

Table 1. LEP 95% CL lower mass limits for charged Higgs bosons. The expected limit is in parentheses.

Mode:	Data	Background	Limit (GeV)
ALEPH			65.5 (69.5)
hadron	263	295.4	
lepton	20	15.5	
mixed	19	22.6	
DELPHI			66.9 (66.5)
hadron	145	141.3	
lepton	15	15.8	
mixed	55	55.9	
L3			67.5 (70.2)
hadron	335	359.4	
lepton	30	32.5	
mixed	134	132.0	
OPAL			68.7 (68.5)
hadron	156	153.8	
lepton	31	26.2	
mixed	65	60.1	

References

[1] The LEP working group for Higgs boson searches, OPAL TN-614 (1999) (Tampere 6-49).
[2] A G Akeroyd, Phys. Lett. **B368** (1996) 89.
[3] OPAL Collab. CERN-EP/99-084 (1999) (accepted by Phys. Lett. B).
[4] ALEPH CONF 99-030 (Tampere 7-412); DELPHI CONF 99-72 (Tampere 7-116); L3 Note 2429 (1999) (Tampere 7-238).
[5] ALEPH CONF 99-008 (Tampere 7-413); DELPHI CONF 99-83 (Tampere 6-214); L3 Note 2435 (Tampere 7-237); OPAL PN 99-399 (1999) (Tampere 7-84).
[6] ALEPH CONF 99-044 (Tampere 7-414); DELPHI CONF 99-92 (Tampere 7-377); L3 Note 2379 (Tampere 7-236); OPAL PN 99-373 (Tampere 7-50).
[7] A G Akeroyd, Nucl. PHys. **B544** (1999) 557.

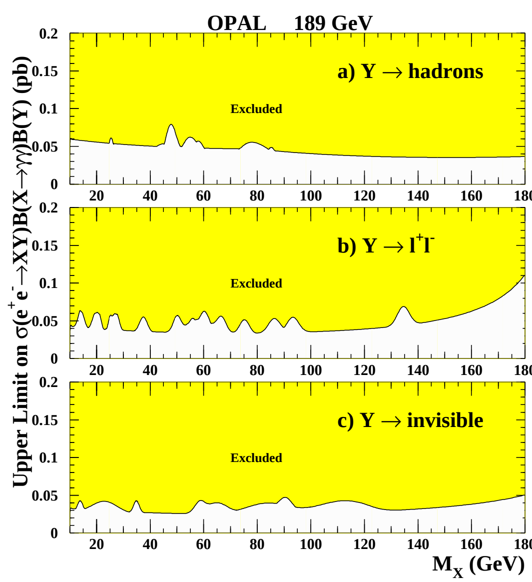

Figure 1. 95% confidence level upper limit on $\sigma(e^+e^- \rightarrow XY) \times B(X \rightarrow \gamma\gamma) \times B(Y)$ for the case where: a) Y decays hadronically, b) Y decays into any charged lepton pair and c) Y decays invisibly. The limits for each M_X assume the smallest efficiency as a function of M_Y such that $10 < M_Y < 180$ GeV and that $M_X + M_Y > M_Z$.

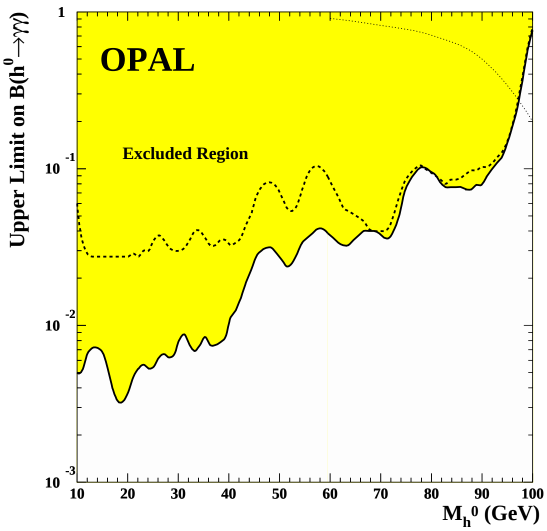

Figure 2. 95% confidence level upper limit on the branching fraction $B(\mathrm{h}^0 \to \gamma\gamma)$ for a Standard Model Higgs boson production rate. The shaded region, obtained with all LEP energies, is excluded; the dashed line shows the limit obtained with the 189 GeV data only. The dotted line is the predicted $B(\mathrm{h}^0 \to \gamma\gamma)$ assuming $B(\mathrm{h}^0 \to \mathrm{f\bar{f}})$=0. The intersection of the dotted line with the exclusion curve gives a lower limit of 96.2 GeV for the fermiophobic Higgs model.

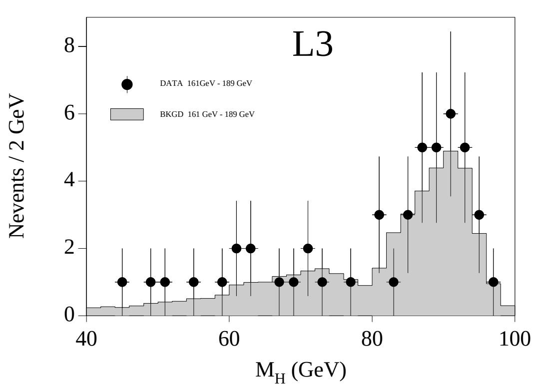

Figure 3. L3 candidate events for invisible Higgs decays in the data having E_{cm}=161–189 GeV.

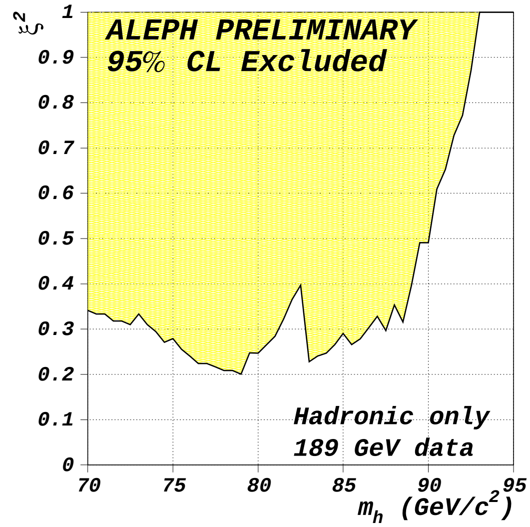

Figure 4. Excluded region of M_{h} vs ξ^2 for $\mathrm{e^+e^-} \to \mathrm{h^0Z^0}, \mathrm{Z^0} \to$ *hadrons*, with $\mathrm{h^0}$decaying invisibly.

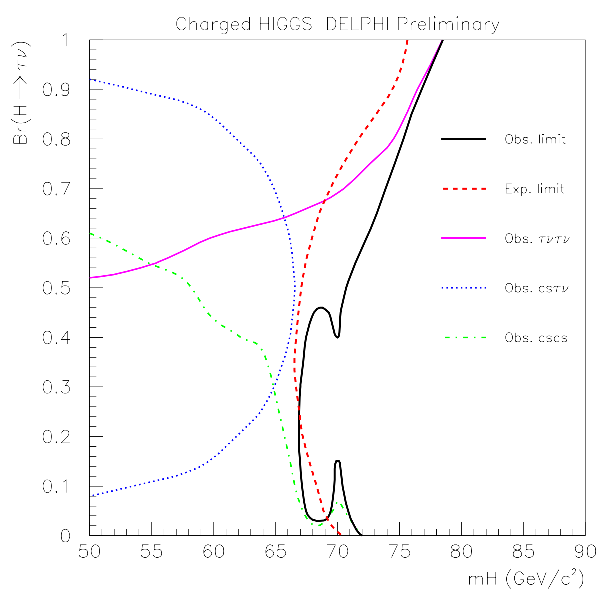

Figure 5. 95% CL observed and expected exclusion regions for $H^{\pm}$ obtained from a combination of the search results in the hadronic, leptonic, and mixed channels. The data are from E_{cm}=183 and 189 GeV.