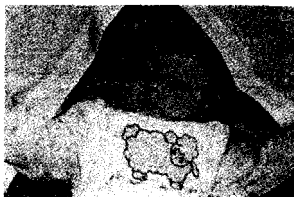# SEARCH FOR NON-SM HIGGSES AT LEP

AURA ROSCA

Institut für Physik, Invalidenstr. 110,
D-10115 Berlin, Germany

The four LEP experiments, ALEPH, DELPHI, L3 and OPAL, have searched for Higgs bosons predicted by a large number of extensions of the Standard Model. Flavor independent searches are presented for the $h^0 Z^*$ process in which the h^0 decays hadronically. Search results are also presented for fermiophobic Higgs bosons, invisibly decaying Higgs bosons, charged Higgs bosons and the neutral Higgs bosons in the MSSM.

1 Introduction

Since we have no experimental evidence for the Standard Model (SM) Higgs particle, we must test more complicated scenarios beyond the SM. Several extensions of the SM introduce additional Higgs doublets and singlets[1]. In this work we present results on the 2HDM Higgses. The 2HDM is a minimal extension of the SM, in the sense that only one additional doublet is introduced in the theory. After the symmetry is broken the Higgs spectrum consists of five particles: two CP-even neutral scalars (h^0 and H^0), a CP-odd neutral scalar (A^0) and a charged pair ($H^\pm$). The properties of the Higgs bosons are defined by six free parameters: four Higgs masses, the ratio of the vacuum expectation values of the two fields, $\tan\beta$, and the mixing angle in the neutral CP-even sector, α. The Higgs couplings with the bosons and fermions control Higgs production and decays. Particularly, the Higgs couplings with the fermions must be limited, in order to suppress FCNCs (Flavor Changing Neutral Currents) at the tree level. There are exactly two possibilities for the Higgs boson to couple to the fermions: only one doublet couples with fermions, and the other does not couple to quarks or leptons, and this determines the structure of the 2HDM of Type I; or one doublet couples to down-type fermions, and the second doublet couples with the up-type fermions, and this determines the structure of the 2HDM of Type II.
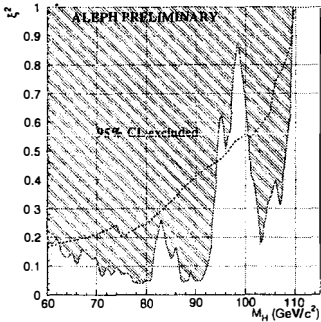
27

Figure 1: The expected (dashed line) and observed (hatched) 95% C.L. excluded ξ^2 as a function of the Higgs boson mass.
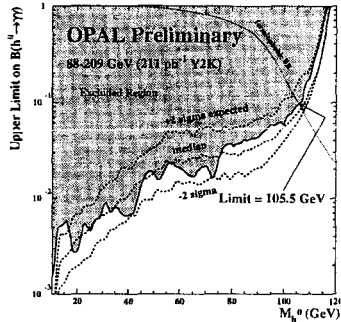

Figure 2: The expected (dashed line) and observed (shaded) 95% C.L. upper limit on the BR(h$\rightarrow \gamma\gamma$) assuming SM production cross section.

2 Search for the Higgs bosons beyond the SM

2.1 Flavor independent searches

For certain regions of the parameter space the Higgs boson decay into a pair of b$\bar{\text{b}}$ quarks can be suppressed with respect to the SM values, while decays to charm quark or gluon pairs are enhanced. Therefore, flavor independent searches have been performed. The experiments have updated their search for a scalar boson which is produced in association with the Z^0 and which decays hadronically with a BR $= 1$. These analyses use the same topologies as for the SM Higgs boson search, but do not make use of the b-tag. In the absence of a signal, the results are usually given in terms of excluded regions in the plane m_h versus a SM cross section scaling factor, ξ^2. As an example we show in Fig. 1 the results obtained by the ALEPH collaboration combining energies up to 209 GeV [2]. A Higgs boson produced with the SM cross section and decaying hadronically with a BR $= 1$ is ruled out by ALEPH up to the mass of 109.4 GeV. Similar results have been obtained by the OPAL collaboration [3].

2.2 Fermiophobic decays

Fermiophobic decays due to suppressed couplings between the Higgs bosons and the fermions can appear in several non-minimal models, as for example 2HDM of Type I. At masses below 90 GeV the Higgs boson decays dominantly into $\gamma\gamma$, while at higher masses it decays mostly into WW* and ZZ*. The four LEP experiments searched for a photonically decaying Higgs boson produced in association with a Z^0 and leading to the following final states: $\gamma\gamma$q$\bar{\text{q}}$, $\gamma\gamma\nu\bar{\nu}$, $\gamma\gamma\ell^+\ell^-$. Since no indication for a signal was found in the data, the negative search result is given in terms of upper limits of the BR($h^0 \rightarrow \gamma\gamma$), assuming a SM production cross section for the Higgs boson. The limits are shown in Fig. 2 for the OPAL collaboration [3]. In the fermiophobic model, the observed mass limit is 105.5 GeV. Similar results have been obtained by the other collaborations [4].

2.3 Invisible decays

Invisible Higgs boson decays can appear in different models as MSSM, majoron models, models with extra-dimensions, etc. At LEP energies it can be produced via the Higgs-Strahlung mechanism, $e^+e^- \rightarrow h^0Z^0$, followed by the decay of h^0 into undetectable final states. The signatures
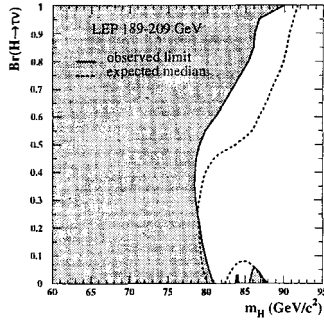
Figure 3: The expected (dashed line) and observed (full) 95% C.L. bounds on $m_{H^\pm}$ as a function of the branching ratio BR($H^+ \rightarrow \tau^+\nu_\tau$). The shaded area is excluded at 95% C.L.
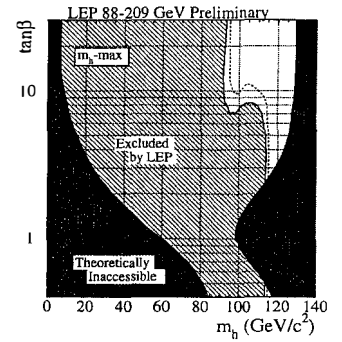
Figure 4: The MSSM 95% C.L. exclusion for the m_h-max scenario. The excluded (hatched) and theoretically forbidden (shaded) regions as a function of the MSSM parameters are shown. The expected (dashed line) bound is also present.

for such processes are either 2 jets and missing energy in the event, or a lepton pair and missing energy. The analyses make use of the kinematic constraint $m_{f\bar{f}} \approx m_Z$. No excess with respect to the SM is observed in the data. The results are expressed as excluded regions in the plane m_h versus ξ^2, with ξ^2 defined as the ratio of the Higgs boson production cross section times the branching fraction for the invisible Higgs decay, normalized to the SM cross section. For $\xi^2=1$ the lower limit on the mass of an invisibly decaying Higgs boson is set by ALEPH at 114.1 GeV[5]. Similar results have been obtained by the other collaborations[3,6].

2.4 Charged Higgs Bosons

Charged Higgs bosons are predicted in 2HDMs. At LEP energies, they are produced in pairs, with a cross section which depends only on the Higgs boson mass. The branching ratios are not predicted by the model. Possible decay modes are $q\bar{q}$, $\tau\nu_\tau$ and W^*A^0. In 2HDM of Type II it is assumed that the first two fermionic decay modes are the only possible ones. The searches cover all the possible final states: four jet final state, the semileptonic and fully leptonic final states. The mass limits are expressed as a function of BR($H^+ \rightarrow \tau^+\nu_\tau$). The main background is from the process $e^+e^- \rightarrow W^+W^-$ which sets the scale for the limits in the hadronic and semileptonic searches. Negative search results are shown in Fig. 3 combining the data from the four LEP experiments at energies up to 209 GeV[7]. The lowest mass limit obtained at BR($H^+ \rightarrow \tau^+\nu_\tau$)=0.4 is 78.5 GeV, with a median expectation of 78.9 GeV. A small excluded "island" appears in Fig. 3 for BR($H^+ \rightarrow \tau^+\nu_\tau$)=0, where the search sensitivity above the W^+W^- background peak becomes sufficient to exclude this small region. In 2HDM of Type I, at high $\tan\beta$, the decay mode $H^\pm \rightarrow W^{\pm *}A^0$ can become dominant, with a branching ratio which depends on $\tan\beta$ and the mass difference between the charged Higgs and the CP-odd neutral Higgs. The OPAL collaboration carries out such a search by considering new decay modes[3]. Results are expressed as excluded regions in the ($m_{H^\pm}, m_A$) plane[3].

2.5 Neutral Higgs Bosons in the MSSM

The MSSM is a 2HDM of Type II. The Higgs boson production cross sections and the branching ratios depend on the model parameters. We use a constrained model with only seven parameters: the mass scale of the sfermions M_{SUSY}, the gaugino mass parameter M_2, the supersymmetric

Table 1: Limits on m_h-max and no-mixing scenarios.

Scenario	m_h limit (GeV)	m_A limit (GeV)	Excluded $\tan\beta$
m_h-max	91.0	91.9	$0.5 < \tan\beta < 2.4$
no-mixing	91.5	92.2	$0.8 < \tan\beta < 9.6$

Higgs mass parameter μ, the triliniar coupling of the Higgs boson to the squarks A, the ratio of the vacuum expectation values of the two fields, the mass of the CP-odd neutral scalar m_A and the gluino mass m_g. These parameters are further set to specific values which define three benchmark scans. In the no-mixing scenario, the parameter which controls the mixing in the stop sector, $X_t = A - \mu\cos\beta$, is chosen to be zero. The other parameters are chosen to be $M_{SUSY} = 1$ TeV, $M_2 = 200$ GeV, $\mu = $ -200 GeV and $m_g = 800$ GeV and the scan is done over $0.4 < \tan\beta < 50$ and 4 GeV$< m_A <$1 TeV. For the case of the maximal mixing in the stop sector, $X_t = 2M_{SUSY}$ and the other parameters take the same values as before. The maximum mass value of the h^0 is a function of $\tan\beta$. In the third scenario, called the large-μ scenario, the parameters are chosen such as to emphasize points in the parameter space where the Higgs decay mode into a b$\bar{\text{b}}$ pair is not dominant. These values are: $M_{SUSY} = 400$ GeV, $M_2 = 400$ GeV, $\mu = $ -1 TeV and $m_g = 200$ GeV.

The two Higgs production mechanisms, the Higgs-Strahlung process, and the h^0A^0 associate production, vary in relative importance as a function of $\tan\beta$. The h^0Z^0 production is dominant at low $\tan\beta$ and the MSSM phenomenology reduces to the SM one, while the h^0A^0 production becomes dominant at high $\tan\beta$. The dominant decays of the h^0 and A^0 Higgs bosons are into a pair of b-quarks and a pair of tau leptons. However, for several choices of parameters, the decays $h^0 \to A^0A^0$, $h^0 \to c\bar{c}$, $h^0 \to gg$ and $h^0 \to W^+W^-$ can become important.

No evidence for a signal was found in the data. The negative results are presented as excluded regions in the planes $[m_h, \tan\beta]$, $[m_A, \tan\beta]$, $[m_h, m_A]$ or $[m_{H^\pm}, \tan\beta]$. The 95% C.L. excluded region for the m_h-max scenario is shown in Fig. 4 combining the data from the four LEP experiments at energies up to 209 GeV [8]. The lower limits on the Higgs masses and the excluded $\tan\beta$ ranges for the m_h-max and no-mixing scenarios are summarized in Tab. 1.

Acknowledgments

References

1. S. Dawson *et al.*, The Physics of the Higgs Bosons: Higgs Hunter's Guide", (Addison Wesley, 1989).
2. ALEPH 2001-021 CONF 2001-018.
3. OPAL Note PN472.
4. ALEPH 2001-015 CONF 2001-012, L3 Note 2652.
5. ALEPH 2001-008 CONF 2001-005.
6. DELPHI 2001-025 CONF 466, L3 Note 2593.
7. LEP Higgs Working Group (LHWG) Note 2001-1, ALEPH 2001-029 CONF 2001-023, DELPHI 2001-031 CONF 472, L3 Note 2653, OPAL Note TN680.
8. LHWG Note 2001-2, ALEPH 2001-032 CONF 2001-024, DELPHI 2001-032 CONF 473, L3 Note 2656, OPAL Note TN682.