DELPHI 97-82 CONF 68
28 July, 1997

Search for neutral Higgs bosons in two-doublet models at LEP1 and LEP2 energies

Preliminary

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Abstract

Most Higgs bosons searches assume MSSM constraints for hZ and hA couplings and h and A decays. In this note this type of search is reinterpreted in a more general framework, assuming a two-doublet model with CP not necessarily conserved and h or A not predominantly decaying into $b\bar{b}$.

Paper submitted to the LP'97 Conference
Hamburg, July 28 - August 1st

1 Introduction

Recent upgrades in the LEP energy have increased the kinematical domain for neutral Higgs boson searches. Results [1] have been presented in the Standard MSSM scheme, where high constraints between parameters (i.e. masses and mixing angles) are imposed.

At LEP1, DELPHI has already published a search in the more general scheme of the two doublet model [2]. In this note we extend this analysis to the high energy data, taking into account the possibility of non b decays and $h \to AA$ topology. The present search is restricted to Higgs bosons with masses above 10 GeV/c^2. The light boson region requires a large set of specific searches which were performed with LEP1 data [3].

Finally, inspired by [4], the present search takes into account the possibility of CP violation which allows the contribution of 3 channels: hA, hZ and AZ.

2 Two Higgs Doublet Model

A CP conserving two Higgs doublet model predicts the existence of two neutral CP–even Higgs bosons, h and H ($m_h < m_H$), one neutral CP–odd Higgs A, and a charged Higgs pair, $H^{\pm}$. The results on Higgs boson searches presented in [1] can be translated into exclusions of the parameter space in this model.

The two main production channels for neutral Higgs bosons at LEP energies are the so called "bremsstrahlung" diagram and the associated production: $e^+ e^- \to Z^* \to h\ Z$ and $e^+ e^- \to Z^* \to h\ A$ respectively.

The cross sections for both processes can be written as function of the standard Higgs boson cross section and the neutrino cross section from the Z:

$$\sigma_{hZ} = \sin^2(\alpha - \beta)\ \sigma_{h_{SM}Z}$$

$$\sigma_{hA} = \frac{1}{2}\lambda^3\left(1, \frac{m_h^2}{s}, \frac{m_A^2}{s}\right)\ \cos^2(\alpha - \beta)\sigma_{\nu\bar{\nu}}$$

where α and β are the mixing angles in the two doublet scheme, $s = E_{CM}^2$ and λ the following phase space factor: $\lambda(x, y, z) = \sqrt{(x - y - z)^2 - 4yz}$. Radiative corrections are included in the α angle and taken into account in the calculations.

These expressions clearly indicate the complementarity of the two processes. Besides, if one of them is experimentally out of reach for a given set of masses, no exclusion is possible since mixing angles could always be such that the other process is suppressed below detectability.

2.1 CP Conservation

In the CP–conserving two Higgs doublet model, the h and H bosons are mixtures of the real parts of the neutral Higgs fields, while A derives from the imaginary components not eaten by Z. One finds that the coupling strengths are in this case: $C_{hZ} = \sin\,(\alpha - \beta)$ and $C_{hA} = \cos\,(\alpha - \beta)$.

The exclusion plot in figure 1 is obtained in the following way: for each m_h and m_A values the number of expected events for the channels hA and hZ is calculated using the cross sections, integrated luminosities, branching ratios and efficiencies quoted in [1]. This number depends obviously on the factors C_{hZ} and C_{hA} , being necessary to perform a minimization of the number of events with respect to these factors, taking into account the sum rule $C^2_{hZ} + C^2_{hA} = 1$ (see appendix for details).

The change in the slope for values of m_h below 20 GeV/c^2 is due to the fact that for so light Higgses, the decay products of h are emitted close to each other, so that the usual cuts are less efficient. It has been checked (with a simplified simulation) that the efficiency is reduced by a factor of 2 in the dominant hadronic channels.

The dashed line represents the frontier below which the $h \to AA$ decay is open. To study this channel a few dedicated samples were simulated in order to control, with the same cuts as in the previous analysis, the final efficiencies, which resulted in lower values than in the other region (35% efficiency for $hA \to AAA$ events with $m_h = 63$ GeV/c^2 and $m_A = 20$ GeV/c^2; 11% for $hZ \to AA\nu\bar{\nu}$ events and 20% final efficiency for $hZ \to AAq\bar{q}$ events). Nevertheless, when $m_A < 20$ GeV/c^2 the effect of a large boost, mentioned previously for h, appears again, and the topology $h \to AA$ becomes similar to $h \to b\bar{b}$ so that the standard efficiencies are recovered.

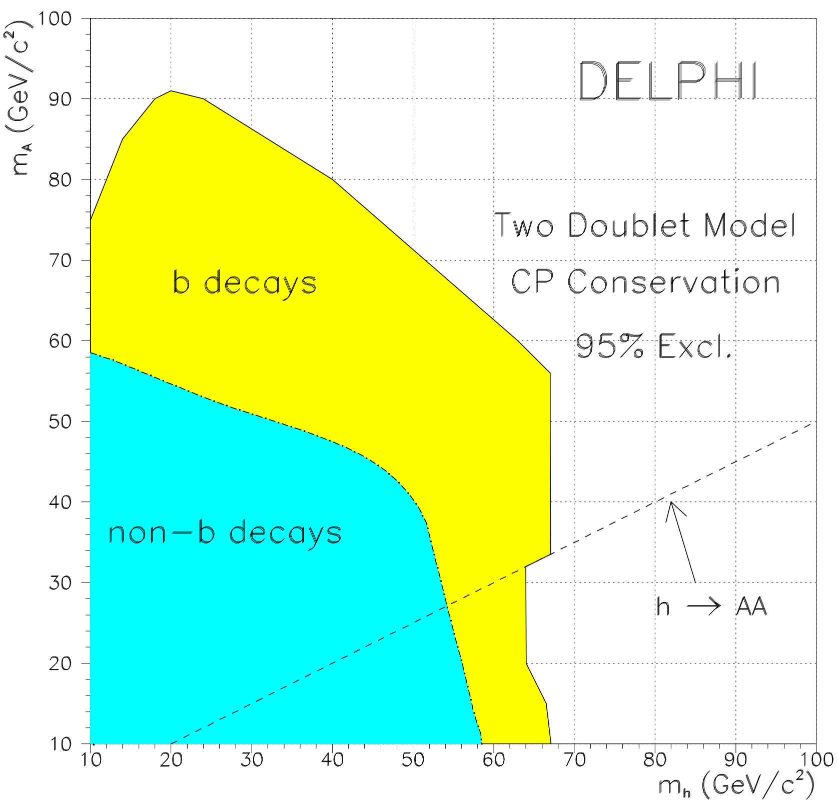

Figure 1: Excluded regions at the 95% CL in the CP–conserving model with dominant b–decays (light grey) and dominant non–b decays (dark grey).

The case of non–b decays has also been studied, using the selections of [1] except those referring to b–tagging, that were removed. This takes care of a scenario with $tan\beta < 1$ which would allow a dominant decay of the Higgs boson into $c\bar{c}$ (see [2]). Table 1 shows the number of events remaining, background and efficiencies at this level of the analysis. The exclusion plot is shown in figure 1. Most of the exclusion domain is provided by the LEP1 precision measurements presented in [5] (an upper bound has been derived on any additional contribution due to new physics on the total width $\Delta\Gamma_Z < 14\ MeV$ at the 95 % CL) and direct search LEP1 results shown in [2], while LEP2 gives an additional exclusion in the region $m_h \sim m_A \sim 45\ GeV/c^2$.

	136 GeV		161 GeV		172 GeV	
	data	MC	data	MC	data	MC
hA	13	9.3	12	11.6	15	15.4
hZ	-	-	25	26.4	41	54.2

Table 1: Number of events and background without b tag cuts.

2.2 CP Violation

CP violation in the SUSY sector is an opened possibility and may even be necessary in the electroweak baryogenesis scenario (see for instance [6] and references therein). The violation leads to three neutral Higgs bosons with undefined CP properties. It is shown in [4] that the previous sum rule valid in the CP–conserving case can be extended to the CP–violating model, giving the relation: $C^2_{hZ}+C^2_{AZ}+C^2_{hA}=1$ [1], which, together with the results in [1], allow to calculate the minimum number of events for each point (m_h, m_A), –with an extended procedure similar to the one used previously, and thus, the excluded region at 95% CL shown in figure 2. One can appreciate in this figure that the open $A \to hh$ decay mode gives a perfect symmetry to the $h \to AA$ decay due to the new AZ channel.

[1] and also $C^2_{hZ}+C^2_{HZ}+C^2_{hH}=1$

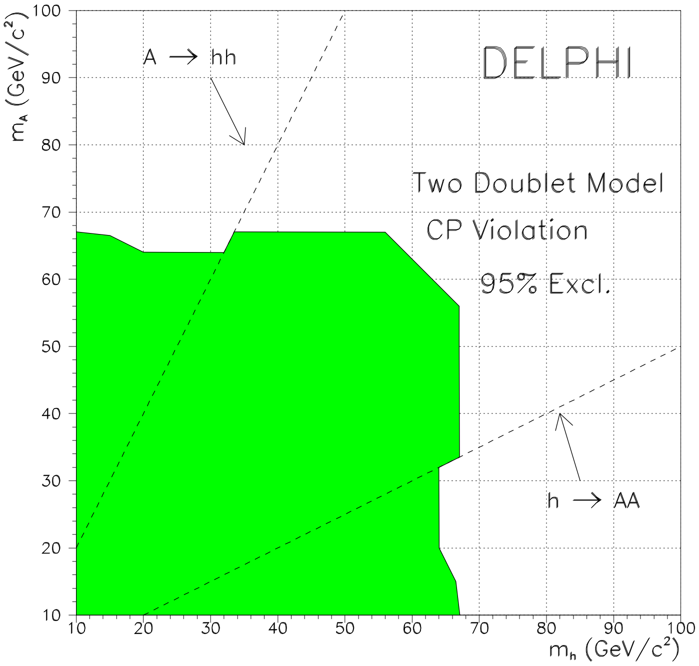

Figure 2: Excluded regions at the 95% CL in the non CP–conserving model.

3 Conclusions

The analysis presented in this note shows that it is possible to exclude a large region of Higgs boson masses even relaxing the standard assumptions made in the MSSM scenario. There is a significant improvement in the excluded regions with respect to [2] for the case of CP–conservation.

4 Appendix

The expected number of events from hA and hZ channels can be written as:

$$N = A\cos^2(\beta - \alpha) + B\sin^2(\beta - \alpha)$$

were A and B represent the remaining factors appearing in the cross section expressions. This can be seen as:

$$N = (A - B)C_{hA}^2 + B$$

The minimum number of events for each (m_h, m_A) point is then:

$$\min(N) = \begin{cases} B & \text{if B<A} \\ A & \text{if A<B} \end{cases}$$

Thus, a point in the (m_h, m_A) plane will be excluded if min(A,B)>L, being L the 95% CL limit in the number of events corresponding to that point.

References

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