The hidden Higgs model at the NLC

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Abstract

We investigate the influence of massless scalar singlets on Higgs signals at the NLC. An exclusion bound is presented which restricts large regions of the parameter space but on the other hand implies that for strong interactions between the Higgs boson and the singlet fields of the hidden sector, detection of such a non standard Higgs signal can become impossible.

1. Introduction

Understanding of the electroweak symmetry breaking mechanism is one of the main tasks in particle physics. The determination of its nature would be a break-through in our knowledge about matter. So it is important to think about alternatives to the Standard Model Higgs sector. Various such extensions are available. Maybe the best motivated one is the supersymmetrized Standard Model with its important phenomenological implication of a light Higgs boson and which allows a consistent frame for grand unified theories. Another well understood extension – though in its minimal version disfavoured by the precision experiments at LEP – are technicolor theories. Though these theories avoid fundamental scalars, a rich bosonic spectrum of techniquark condensates may exist. Thus in both theories, as long as they do not occur in their minimal form, light bosonic matter could be present modifying the standard Higgs signals we are looking for at present and future colliders. If such bosons appear as singlets under the Standard Model gauge group, they do not feel the color or electroweak forces, but they can couple to the Higgs particle. As a consequence radiative corrections to weak processes are not sensitive to the presence of singlets in the theory, because no Feynman graphs containing singlets appear at the one–loop level. Since effects at the two–loop level are below the experimental precision, the presence of a singlet sector is not ruled out by any of the LEP1 precision data. The only connection to such a hidden sector is a possible Higgs–singlet coupling, leading to a nonstandard invisible Higgs decay. The invisible decay of the Higgs boson with a narrow width leads to relatively sharp missing energy signals, well known from discussions on Majoron models [2]. However a strongly coupled hidden sector could lead to fast Higgs decay and thereby to wide resonances. This would disturb the signal to background ratio if necessary cuts are imposed.

To check the influence of a hidden sector we will study the coupling of a Higgs boson to an O(N) symmetric set of scalars, which is one of the simplest possibilities, introducing only a few extra parameters in the theory. The effect of the extra scalars is practically the presence of a possibly large invisible decay width of the Higgs particle. When the coupling is large enough the Higgs resonance can become wide even for a light Higgs boson. It was shown earlier that there will be a range of parameters, where such a Higgs boson can be seen neither at LEP nor at the LHC [1, 2].

In the next section we will introduce the model together with its theoretical constraints and in the last section we will discuss exclusion limits at the NLC.

2. The model

The scalar sector of the model consists of the usual Higgs sector coupled to a real N–component vector $\vec{\varphi}$ of scalar fields, denoted by phions in the following. The Lagrangian density is given by,

$$\begin{aligned}\mathcal{L} &= -\partial_\mu\phi^+\partial^\mu\phi - \lambda(\phi^+\phi - v^2/2)^2 - 1/2\,\partial_\mu\vec{\varphi}\partial^\mu\vec{\varphi} - 1/2\,m^2\,\vec{\varphi}^2 \\ &\quad -\kappa/(8N)\,(\vec{\varphi}^2)^2 - \omega/(2\sqrt{N})\ \vec{\varphi}^2\,\phi^+\phi\end{aligned}$$

where ϕ is the standard Higgs doublet. Couplings to fermions and vector bosons are the same as in the Standard Model. The ordinary Higgs field acquires the vacuum expectation value $v/\sqrt{2}$. For positive ω the $\vec{\varphi}$–field acquires no vacuum expectation value. After spontaneous symmetry breaking one is left with the ordinary Higgs boson, coupled to the phions into which it decays. Also the phions receive an induced mass from the spontaneous symmetry breaking which is suppressed by a factor $1/\sqrt{N}$. If the factor N is taken to be large, the model can be analysed with $1/N$–expansion techniques. By taking this limit the phion mass remains small, but as there are many phions, the decay width of the Higgs boson can become large. Therefore the main effect of the presence of the phions is to give a large invisible decay rate to the Higgs boson. The invisible decay width is given by

$$\Gamma_H = \frac{\omega^2 v^2}{32\pi M_H} = \frac{\omega^2(\sin\theta_W\cos\theta_W M_Z)^2}{32\pi^2\alpha_{em}M_H} \quad .$$

The Higgs width is compared with the width in the Standard Model for various choices of the coupling ω in Fig. 1. The model is different from Majoron models [2], since the width is not necessarily small. The model is similar to the technicolor–like model of Ref. [4].

Consistency of the model requires two conditions. One condition is the absence of a Landau pole below a certain scale Λ. The other follows from the stability of the vacuum up to a certain scale. An example of such limits is given in Fig. 2, where $\kappa = 0$ was taken at the scale $2m_Z$, which allows for the widest parameter range. The regions of validity up to a given scale Λ are sandwiched between the lower–left and the upper–right contour lines in the figure. The first stem from instability of the vacuum, the second from the presence of a Landau pole at that scale.

To search for the Higgs boson there are basically two channels, one is the standard decay, which is reduced in branching ratio due to the decay into phions. The other is the invisible decay, which rapidly becomes dominant, eventually making the Higgs resonance wide (see Fig. 1). In order to give the bounds we neglect the coupling κ as this is a small effect. We also neglect the phion mass. For other values of the phion mass the bounds can be found by rescaling the decay widths with the appropriate phase space factor. Now we confront this two dimensional parameter space with the experimental potential of the NLC.

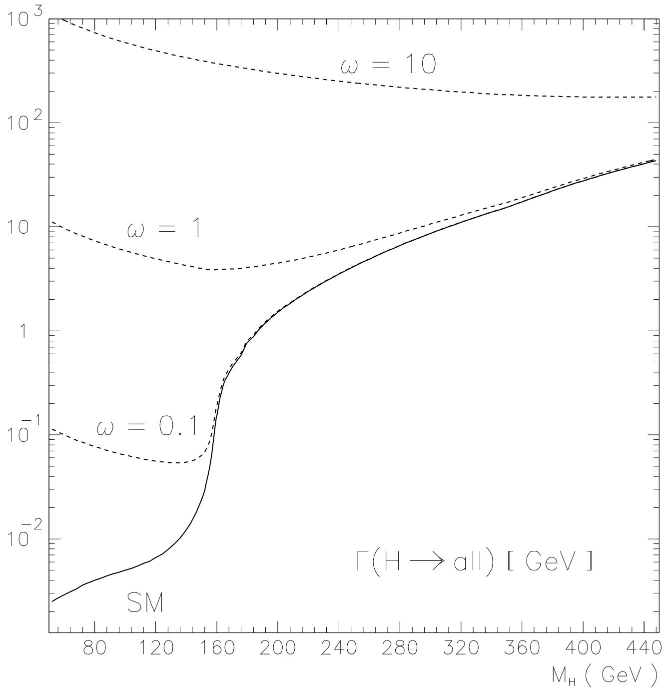

Figure 1: *Higgs width in comparison with the Standard Model.*

3. NLC bounds

At the NLC the upper limits on the couplings in the present model come essentially from the invisible decay, as the branching ratio into visible particles drops with increasing φ–Higgs coupling (ω), whereas for small ω one has to consider visible Higgs decays, too. Since the main source for Higgs production, the WW–fusion process, can not be used to look for invisible Higgs decay, one is in principle left with the Higgsstrahlung und ZZ–fusion reaction. For energies up to 500 GeV the Higgsstrahlungs cross section is dominant and is of comparable size to the ZZ–fusion process even if one is folding in the branching ratio $B(Z \to e^+e^-, \mu^+\mu^-)$. The possibility to tag an on–shell Z boson via a leptonic system which is extremely useful for the discrimination of possible backgrounds makes Higgsstrahlung to be the preferred production mechanism. Thus we only have considered reactions containing an on shell Z boson with its decay into e^+e^- or $\mu^+\mu^-$. One should be aware that a few events from the huge WW background may survive [3], but that the $Z\nu\nu$ background is dominant after imposing the cuts defined below. Then the signal cross section is the well known Higgsstrahlungs cross section modified by the non standard Higgs width due to phion decay. With the invariant mass of the invisible phion system, s_I, it has the form:

$$\sigma_{(e^+e^- \to Z + \not{E})} = \int ds_I \, \sigma_{(e^+e^- \to ZH)}(s_I) \, \frac{\sqrt{s_I} \quad \Gamma(H \to \not{E})}{\pi((M_H^2 - s_I)^2 + s_I \, \Gamma(H \to \mathrm{All})^2)}$$

We calculated the $Z\nu\nu$ background with the standard set of graphs for Z production (ZZ–production, WW–fusion and Z initial, final state radiation) by a Monte Carlo program

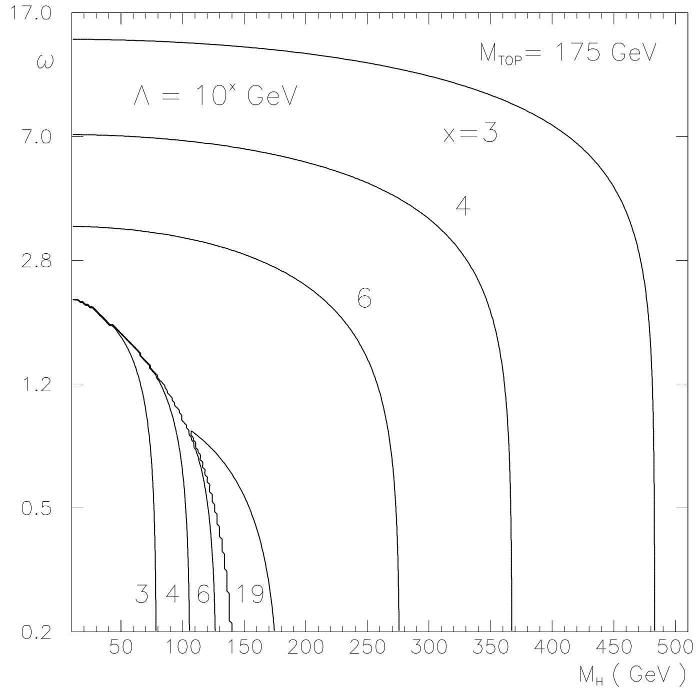

Figure 2: *Theoretical limits on the parameters of the model in the ω vs. M_H plane. The contour lines correspond to the cutoff scales $\Lambda = 10^{19}$, 10^6, 10^4 and 10^3 GeV.*

(see Ref. [5]). To reduce the background we used the fact that the angular distribution of the Z–boson for the signal peaks for small values of $|\cos\theta_Z|$ in contrast to the background. Thus we imposed the cut $|\cos\theta_Z| < 0.7$. Because we assume the reconstruction of the on-shell Z–boson we use the kinematical relation $E_Z = (s + M_Z^2 - s_I)/(2\sqrt{s})$ between the Z energy and the invariant mass of the invisible system to define a second cut. Since the differential cross section $d\sigma/ds_I$ contains the Higgs resonance at $s_I = M_H^2$, we impose the following condition on the Z energy:

$$\frac{s + M_Z^2 - (M_H + \Delta_H)^2}{2\sqrt{s}} < E_Z < \frac{s + M_Z^2 - (M_H - \Delta_H)^2}{2\sqrt{s}}$$

For the choice of Δ_H a comment is in order. As long as the Higgs width is small, one is allowed to use small Δ_H, which reduces the background considerably keeping most of the signal events. But in the case of large φ–Higgs coupling, ω, one looses valuable events. To compromise between both effects we took $\Delta_H = 30$ GeV.

For the exclusion limits we assumed an integrated luminosity of $20\,fb^{-1}$. To define the 95% confidence level we used Poisson statistics similar to the description of Ref. [2]. The result is given in Fig. 3. One notices the somewhat reduced sensitivity for $M_H \simeq M_Z$ due to a resonating Z boson in the ZZ background. For larger values of M_H the limit stems from the other $Z\nu\nu$ backgrounds with W bosons in the t–channel and kinematical constrains. For large ω the signal ceases to dominate over the background because the Higgs peak is smeared out to an almost flat distribution.

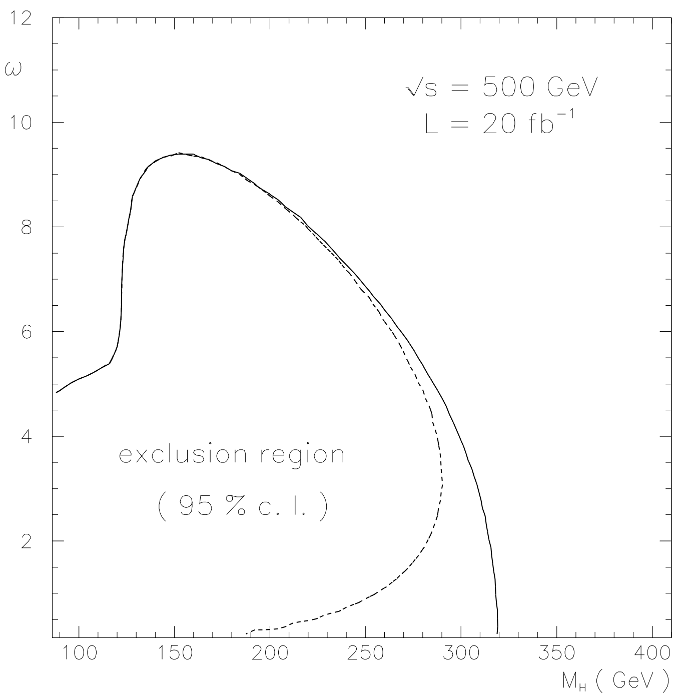

Figure 3: *Exclusion limits at the NLC due to Higgs searches. The dashed line corresponds to the invisible, the full line to all Higgs decay modes.*

We conclude from this analysis that the NLC can put further limits on the parameter space of our invisible Higgs model. Note that within the kinematic range very strong limits on ω can be set. Again there is a range where the Higgs boson will not be discovered, even if it does exist in this mass range. This has already been shown for the Higgs search at LEP and also holds true for the heavy Higgs search at LHC. We see that a sufficiently wide nonstandard Higgs resonance would make it very difficult to test the mechanism of electroweak symmetry breaking at future colliders.

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