Higgs Triplets at LEP2

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Abstract

In the Standard Model it is possible that the electroweak symmetry is broken by a non-minimal Higgs sector containing representations other than just doublets. We explore the most popular model with Higgs triplets which may contain scalar bosons in the range of LEP2. We find that the model's exotic nature would help to distinguish it from other more conventional Higgs sectors.
1 Introduction

It is well known that the Standard Model (SM) requires a Higgs sector to break the electroweak symmetry. Complex Higgs doublets (and singlets) are the most natural way of achieving this because they force the $\rho$ parameter ($= M_W^2 / [M_Z^2 \cos^2 \theta_W]$) to be equal to one at tree level [1]. With the present experimental value measured to be $1.0004 \pm 0.0022 \pm 0.002$ [2], such a tree level result is desirable. The minimal SM consists of one doublet, although this may not be nature’s choice and much can be found in the literature concerning the two-Higgs-doublet model (2HDM) [1].

However, it may be that higher representations contribute to symmetry breaking and in this paper we consider an extended Higgs sector containing triplets. Our analysis is strictly ‘non-minimal SM’ i.e. we assume no other new particles apart from Higgs bosons. We note that many extensions of the SM require triplet Higgs representations (e.g. left-right symmetric models), though triplets can be considered purely in the context of the non-minimal SM. One must be careful not to deviate from the experimental value of $\rho \approx 1$ and this can be achieved in various ways. Let us consider the general formula for $\rho$ at tree level,

$$\rho = \frac{\sum_{T,Y} [4T(T + 1) - Y^2] |V_{T,Y}|^2 c_{T,Y}}{\sum_{T,Y} 2Y^2 |V_{T,Y}|^2} .$$

(1)

Here $V_{T,Y}$ is the vacuum expectation value of the neutral Higgs field member of the particular representation with total isospin $T$ and hypercharge $Y$. The parameter $c_{T,Y}$ is 1 (1/2) for a complex (real) representation. One can see that $\rho = 1$ requires

$$(2T + 1)^2 - 3Y^2 = 1 .$$

(2)

As already mentioned, this is satisfied by any number of doublets ($T = 1/2, Y = \pm 1$) to which any number of singlets ($T = Y = 0$) can be added. The next simplest representation to try is a triplet ($T = 1$). In order to have a neutral member, one is only allowed to have hypercharge values of $Y = 0, \pm 2$, and from Eq. (2) it is clear that $\rho = 1$ is not satisfied. However, it is still possible to avoid this problem by a number of means. Consider the case of a doublet together with a triplet. The requirement of $\rho \approx 1$ can be obtained if the vacuum expectation value (VEV) of the triplet is very small compared to that of the doublet. Given the above experimental measurement of $\rho$, we find that

$$|V_{1,Y}|/|V_{1/2,1}| \leq 0.03 ,$$

(3)

with $Y = 0, \pm 2$. Therefore the triplet would play a very minor role in electroweak symmetry breaking. Of course this is a possible scenario but leads one to wonder why nature chose such a representation at all.\footnote{We recall that the motivation for Higgs bosons in the SM is for them to have a non-zero VEV (i.e. to break the electroweak symmetry). Therefore introducing Higgs bosons with very small VEVs seems contradictory and unnatural.} A more attractive option which has
found favour in the literature [1], [3], [4], [5] is to combine one doublet with one real
\((T = 1, Y = 0)\) triplet and one complex \((T = 1, Y = 2)\) triplet. From Eq. (1) it is
easily shown that \(\rho = 1\) can be maintained at tree level if the VEVs of the triplet fields
are equal. Denoting \(V_{1,0} = V_{1,2} = b\) and \(V_{1/2,1} = a/\sqrt{2}\), we find that \(M_W^2 = \frac{1}{4}g^2v^2\) with
\(v^2 \equiv a^2 + 8b^2 = (246\text{ GeV})^2\). There is no constraint on \(b\) (apart from \(8b^2 \leq v^2\)) which
is in contrast to the previous case of one triplet and a doublet. Therefore it is possible
that the triplets play a major role in symmetry breaking and this model (henceforth
to be called HTM) seems theoretically more favourable.

The rest of the paper is organised as follows. In Section 2 we present a brief review
of the HTM while Section 3 deals with current constraints on its parameters. In
Section 4 we study the prospects for detection at LEP2, using the most natural values
for arbitrary parameters. Distinguishing this model from other Higgs representations
is an important issue and is thus covered in detail. Finally, Section 5 contains our
conclusions.

2 The Model

We give here a brief description of the model first proposed by Georgi and Machacek
[3]. A detailed phenomenological account appears in Ref. [4].

The Higgs fields take the form

\[
\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}, \quad \chi = \begin{pmatrix} \chi^0 & \xi^+ & \chi^{++} \\ \chi^- & \xi^0 & \chi^+ \\ \chi^- & \xi^- & \xi^{0*} \end{pmatrix}
\]

(4)

i.e. one complex doublet \((Y = 1)\), one real triplet \((Y = 0)\), and one complex triplet
\((Y = 2)\). The value \(\rho = 1\) is maintained at tree level by giving the \(\chi^0\) and \(\xi^0\) fields
the same VEV, \(\langle \chi^0 \rangle = \langle \xi^0 \rangle = b\). We also take \(\langle \phi^0 \rangle = a/\sqrt{2}\) and from this it can be
shown that \(v^2 \equiv a^2 + 8b^2\). It is convenient to introduce a doublet-triplet mixing angle
\((0 \leq \theta_H \leq \pi/2)\) defined by

\[
\cos \theta_H \equiv \frac{a}{\sqrt{a^2 + 8b^2}}, \quad \sin \theta_H \equiv \sqrt{\frac{8b^2}{a^2 + 8b^2}}.
\]

(5)

We will also use the following combinations of fields:

\[
\phi^0 \equiv \sqrt{\frac{1}{2}} (\phi^0_H + i\phi^0_I), \quad \chi^0 \equiv \sqrt{\frac{1}{2}} (\chi^0_H + i\chi^0_I),
\]

\[
\nu^\pm \equiv \sqrt{\frac{1}{2}} (\chi^\pm + \xi^\pm), \quad \zeta^\pm \equiv \sqrt{\frac{1}{2}} (\chi^\pm - \xi^\pm).
\]
The physical states are classified according to their transformation properties under the custodial SU(2). There exists a fiveplet $H_5^{++}$, a threeplet $H_3^{+,0}$, and two singlets, $H_1^0$ and $H_1^{0'}$, with each member of a particular multiplet being degenerate in mass at tree level. Their respective compositions are (with $c_H = \cos \theta_H$, $s_H = \sin \theta_H$)

\begin{align*}
H_5^{++} &= \chi^{++}, \quad H_5^+ = \zeta^+, \quad H_5^0 = \sqrt{\frac{1}{3}}(\sqrt{2}\zeta^0 - \chi_R) ; \\
H_3^+ &= c_H \psi^+ - s_H \phi^+, \quad H_3^0 = c_H \chi_l^0 + s_H \phi_l^0 ; \\
H_1^0 &= \phi_R^0, \quad H_1^{0'} = \sqrt{\frac{1}{3}}(\sqrt{2}\chi_R^0 + \xi^0).
\end{align*}

(6) (7) (8)

According to the phase conventions $H_5^{-} = (H_5^{++})^*$, $H_5^{-} = -(H_5^+)^*$, and $H_3^{-} = -(H_3^+)^*$. Mixing is possible between $H_1^0$ and $H_1^{0'}$, varying from zero to maximal depending on the parameters in the Higgs potential. It is conventional in the literature [4] to adopt the language of zero mixing purely for the sake of simplicity. However in this paper we show that by assuming natural values for the parameters in the Higgs potential, and using the bound on $\sin \theta_H$ (from considering the $Z \rightarrow b\bar{b}$ vertex), this mixing is negligible. Hence results will be presented using $H_1^0$ and $H_1^{0'}$ as mass eigenstates.

We will decouple the triplet fields (in the matrix $\chi$) from the fermions in the HTM. The only possible coupling (by gauge invariance) to the fermions would be the $Y = 2$ triplet field to the lepton-lepton channel. However, Ref. [4] shows that such couplings would give a mass for neutrinos. With the current very stringent constraints on neutrino masses [2], such couplings are only significant phenomenologically for very small values of $\sin \theta_H$ (much less than 0.1) [4]. Recalling that the motivation for this model is that $\sin \theta_H$ should be significant (i.e. the triplet fields play a sizeable role in electroweak symmetry breaking) it seems contradictory to consider the case of a very small $\sin \theta_H$. Hence our point of view is that even if a Higgs-lepton-lepton coupling exists it will have no phenomenological impact. Therefore we will not consider it and decouple the triplet fields from all fermions. It follows that all members of the 5-plet and $H_1^{0'}$ are ‘fermiophobic’ at tree level, because they consist purely of triplet fields. They will still couple to gauge bosons (from the kinetic energy term in the Lagrangian) and to other Higgs bosons (from the scalar potential). The 3-plet members, $H_3^\pm$ and $H_3^0$, are respectively equivalent to $H^\pm$ and $A^0$ of the 2HDM (Model I) with the replacement $\cot \beta \rightarrow \tan \theta_H$ in the Feynman rules. The $H_1^0$ plays the role of the minimal SM Higgs in the limit of $\sin \theta_H \rightarrow 0$. A full list of Feynman rules for this model appears in Ref. [4].

\[^2\text{Here we take 'natural' to mean equal.}\]
3 Constraints on Parameters

Precision measurements of the process $Z \to b\bar{b}$ impose the strongest bound on $\sin \theta_H$. Virtual charged scalars with tree level fermion couplings contribute to this decay i.e. $H^\pm$ in the 2HDM and $H_3^\pm$ in the HTM. Ref. [6] shows that this vertex constrains $|\cot \beta| \leq 0.8$ in the 2HDM, which corresponds to $|\tan \theta_H| < 0.8$ (or $|\sin \theta_H| \leq 0.63$) in the HTM. This constraint is for a top quark mass of 180 GeV and $m_{H_5} \leq 200$ GeV.

We are not aware that this bound is considered in the literature, and recent papers still consider the case of $|\sin \theta_H| \to 1$. We note that $|\sin \theta_H| \leq 0.06$ is equivalent to $|V_{\text{trip}}|/|V_{\text{doub}}| \leq 0.03$ (see Eq. 3). Therefore it is in the spirit of the model to only consider $|\sin \theta_H| > 0.1$ (say). The maximum value of $|\sin \theta_H| = 0.63$ allows $|V_{\text{trip}}|/|V_{\text{doub}}| = 0.4$, showing that the triplets could still play a significant role in electroweak symmetry breaking.

The other arbitrary parameters in the model are of course the masses of the Higgs bosons. From the Higgs potential we can write down the following tree level values [4], with $\lambda_i$ being a Higgs self coupling constant and $v^2 = (246 \text{ GeV})^2$:

$$m_{H_5}^2 = 3(\lambda_5 s_H^2 + \lambda_4 c_H^2)v^2, \quad m_{H_3}^2 = \lambda_4 v^2.$$  \hspace{1cm} (9)

As mentioned earlier, all members of a particular multiplet are degenerate in mass. In general, $H_1^0$ and $H_2^0$ can mix according to the mass-squared matrix

$$M = \begin{pmatrix} 8c_H^2(\lambda_1 + \lambda_3) & 2\sqrt{6}s_Hc_H\lambda_3 \\ 2\sqrt{6}s_Hc_H\lambda_3 & 3s_H^2(\lambda_2 + \lambda_3) \end{pmatrix} v^2.$$  \hspace{1cm} (10)

There exists two mass eigenstates denoted by $\psi_1$ and $\psi_2$ with $m_{\psi_1} > m_{\psi_2}$:

$$m_{\psi_1, \psi_2}^2 = \frac{1}{2} \left[ M_{11} + M_{22} \pm \sqrt{(M_{11} - M_{22})^2 + 4M_{12}^2} \right].$$  \hspace{1cm} (11)

As we can see the mixing vanishes in the limit of $\lambda_3 \to 0$ and this scenario is usually considered in the literature. However, it is our aim to keep natural values for $\lambda_i$ and we will present results for the case of them all being equal (we see these as being the most natural values). From now on we will employ a set of units in which $\lambda_1 = 1$.

Figure 1 shows the masses of $\psi_1$ and $\psi_2$ in this unit system as a function of $\theta_H$. From the constraint on $\sin \theta_H$, one finds $\theta_H < 0.67$ rads (or 38.7º). From figure 1 it is apparent that $10v^2 \leq m_{\psi_1} \leq 16v^2$, and $0 \leq m_{\psi_2} \leq 1.5v^2$. Hence there exists a natural, tree level hierarchy of masses:

$$m_{\psi_1}^2 = 10v^2 \to 16v^2, \quad m_{H_5}^2 = 3v^2, \quad m_{H_3}^2 = v^2, \quad m_{\psi_2}^2 = 0 \to 1.5v^2.$$  \hspace{1cm} (12)

The compositions of $\psi_1$ and $\psi_2$ are given by

$$\psi_1 = H_1^0 \sin \alpha + H_1^0 \cos \alpha,$$

$$\psi_2 = H_1^0 \cos \alpha - H_1^0 \sin \alpha.$$  \hspace{1cm} (13)
with the mixing angle obtained from
\[ \sin 2\alpha = \frac{2M_{12}}{\sqrt{(M_{11} - M_{22})^2 + 4M_{12}^2}}. \] (15)

Figure 2 shows how \( \sin 2\alpha \) varies with \( \theta_H \). It is clear that the bound \( \theta_H \leq 0.67 \) rads forces the value of \( \sin 2\alpha \) to be \( < 0.1 \). This strongly constrains \( \alpha \) to the region \( \leq 2.9^\circ \) or \( \geq 87.1^\circ \). In the former case \( \sin \alpha \leq 0.05 \) and \( \cos \alpha = 0.999 \to 1 \). From Eqs. (13, 14) it is then clear that \( \psi_1 \) is effectively \( H_1^0 \) with \( \psi_2 \) equal to \( H_1^{0'} \). The converse is true for \( \alpha \geq 87.1^\circ \). Therefore very little mixing is present and so we can treat \( H_1^{0'} \) and \( H_1^0 \) as mass eigenstates to a very good approximation.

Now that we know the composition of all the mass eigenstates and their Feynman rules, could some of the Higgs bosons be light enough to lie in the energy range of LEP2 (i.e. an \( e^+e^- \) collider with \( \sqrt{s} = 175 \to 200 \) GeV)? We must first consider the current lower bounds on their masses from both direct/indirect searches. By ‘indirect’ searches we mean measuring processes that are sensitive to the Higgs sector. The most important process of this kind is the decay \( b \to s\gamma \) which can proceed by emitting a virtual \( H_3^\pm \) (for a general review of how this decay is sensitive to new physics see Ref. [7]). Recently the first measurement of its branching ratio was announced by the CLEO collaboration, with the value [8]
\[ \text{BR}(b \to s\gamma) = (2.32 \pm 0.57 \pm 0.35) \times 10^{-4}. \] (16)

This measurement sets a lower limit \( (M_H \geq 260 \text{ GeV}) \) on the mass of \( H^\pm \) (2HDM, Model II), taking it out of the range of LEP2. However, as shown in Refs [7], [9], no lower bound can be obtained for the \( H^\pm \) (2HDM, Model I). Recalling that \( H_3^\pm \) obeys the same phenomenology as this latter charged scalar with the substitution \( \cot \beta \to \tan \theta_H \), the \( H_3^\pm \) may also be in the range of LEP2.

The other charged scalars in this model (\( H_5^{\pm\pm} \) and \( H_5^\pm \)) are fermiophobic at tree level and so do not contribute to this decay. Hence no indirect mass bound can found for them. For neutral scalars, direct bounds from \( e^+e^- \) colliders are stronger.

The current LEP limits on these particles are as follows [2]:
\[ m_{H_5^{\pm\pm}} \geq 45.6 \text{ GeV}, \] (17)
\[ m_{H_5^{\pm}}, m_{H_5^\pm} \geq 41.7 \text{ GeV}, \] (18)
\[ m_{H_5^0} \geq 22.0 \text{ GeV}. \] (19)

Eqs. (17, 18) are obtained by searching for \( e^+e^- \to \gamma\gamma, Z^\star \to H^+H^-, H^+H^-; \) Eq. (19) uses the process \( e^+e^- \to Z^\star \to H_0^0H_3^0 \), with \( H_0^0 \) being another neutral Higgs. Limits for \( H_1^0, H_1^{0'} \) and \( H_5^0 \) (which can couple to vector bosons) are best obtained by searching for \( e^+e^- \to Z^\star \to ZH_0^0 \) (at higher collider energy \( W^+W^- \) and \( ZZ \) fusion
become important). From Ref. [4] we have the following ratios for this cross section, with $\phi^0$ being the minimal SM Higgs:

$$H_5^0 : H_1^0 : H_2^0 : \phi^0 = \frac{4}{3} s_H^2 : \frac{8}{3} t_H^2 : c_H^2 : 1.$$  \hspace{1cm} (20)

The bound on $m_{\phi^0}$ is $\geq 63.5$ GeV [2], and so the bounds on $H_5^0$, $H_1^0$ and $H_2^0$ will tend to be less due to $s_H < 0.63$ ($s_H^2 < 0.39$). Ref. [2] states that for a cross-section $\geq 0.1$ times that of the $\phi^0$, the bound is $\geq 40$ GeV.

There is one caveat to the lower limit for $H_5^{\pm\pm}$. The current searches have assumed $H^{\pm\pm} \rightarrow t^\pm t^\pm$ [10], [11] which is the decay for a doubly charged scalar of a left-right symmetric theory. The $H_5^{\pm\pm}$ in the model we are studying would decay to via $W^* W^*$ to $l^\pm l^\pm \nu \nu$ (for masses in the range of LEP2) [4], [12]. This would provide a way of distinguishing between the two models, but also suggests that the $\geq 45.6$ GeV limit (Eq. 17) may not be relevant for our analysis. However, we expect $H_5^{\pm\pm}$ and $H_8^{\pm}$ to have very similar masses (equal at tree level) and so the $\geq 41.7$ GeV bound (Eq. 18) could loosely be used for both. This argument can also be applied to the 3-plet, thus allowing us to discard the result $m_{H_5^0} \geq 22.0$ GeV (Eq. 19) in favour of $m_{H_5^0} \geq 41.7$ GeV (Eq. 18).

4 Phenomenology at LEP2

We next investigate the prospects for detection of the Higgs bosons at LEP2, for which we will assume $\sqrt{s} = 175 \rightarrow 200$ GeV. Using the mass hierarchy (Eq. 12) as a guide, we will consider in turn the possible combinations of Higgs bosons in range at this collider. Distinguishing the HTM from other models is an important issue and is discussed below. Measuring the value of sin $\theta_H$ is also desirable, in order to see to what extent the triplets contribute to electroweak symmetry breaking.

Case 1: Here we consider only $\psi_2$ to be in the discovery range, i.e. $m_{\psi_2} \leq \sqrt{s} - 100$ GeV. As mentioned in Section 3, $\psi_2$ will be (to a good approximation) entirely $H_1^0$ or $H_2^0$ depending on the value of the mixing angle ($\alpha$).

a) $\psi_2 = H_1^0$: The production process here would be $Z^* \rightarrow Z H_1^0$. From Eq. (20) we see that the rate would be quite large ($c_H^2 \geq 0.61$) and so detection should not be a problem ($H_1^0 \rightarrow b \bar{b}$ is expected to be the strongest decay channel for $m_{H_1^0} \leq 100$ GeV). Its suppressed production rate could be a way of distinguishing it from $\phi^0$, though we must remember that a light $h^0$ from a 2HDM [1] would also have the same signature. However, some evidence that we have a non-minimal Higgs sector could be obtained.

\footnote{Assuming the production mechanism $e^+ e^- \rightarrow Z^* \rightarrow Z \psi_2$.}
b) $\psi_2 = H_1^{0'}$: Again one uses the Higgs bremsstrahlung process $Z^* \to Z H_1^{0'}$. The rate (see Eq. (20)) is $\sin\theta_H$ dependent but could be slightly above that for $\phi^0$ when $s_{2H} = 0.39$ (its maximum value). If produced in sufficient quantities then we must search for the decays of this fermiophobic Higgs. Ref. [13] analyses such decays and concludes that the dominant channels for masses below 90 GeV would be to $\gamma \gamma$ or $f \bar{f}$, both induced at one loop. The $\gamma \gamma$ channel would provide an excellent signature and could have a large branching ratio. Also, the one loop fermionic decays would certainly not be all $b\bar{b}$. Therefore even if this $f \bar{f}$ channel did dominate, $b$-tagging could distinguish $H_1^{0'}$ from $\phi^0$. However, a fermiophobic Higgs is also possible in the 2HDM (Model I) with the mixing angle $\alpha$ fine-tuned to equal $\pi/2$. In principle, there still exists a parameter space that could distinguish between the two. The $Z-Z'$-Higgs coupling for this latter boson is $Z-Z'-\phi^0$ strength with a suppression factor of $\sin(\beta - \alpha)$. With $\alpha = \pi/2$ we have $\sin(\beta - \alpha) = - \cos \beta$, and from the constraint $|\cot \beta| \leq 0.8$, one finds a production cross section $\geq 0.39$ that of the $\phi^0$. From Eq. (20) we see that this cross section for $H_1^{0'}$ is $\sin\theta_H$ dependent and so could be significantly less than 0.39. This suppression would distinguish $H_1^{0'}$, though the number of events may not be sufficient for detection. However, we conclude that if such a fermiophobic Higgs is found, it is more likely to be from the HTM (as the 2HDM requires fine-tuning for fermiophobia).

Case 2: Here we consider only the 3-plet to be in range. The $H_3^{\pm}$ would be produced by pair production, $e^+e^- \to \gamma^*, Z^* \to H^+H^-$. Singly charged scalars from the 2HDM (Model I and I') and general multi-doublet model (MHDM) are also possible at this collider and a full phenomenological study appears in Ref. [9]. Distinguishing $H_3^{\pm}$ from $H_3^\pm$ (2HDM, Model I) is impossible due to their identical couplings. However, detection would be proof of a non-minimal Higgs sector.

The $H_3^0$ cannot be produced by $Z^* \to Z H_3^0$, being equivalent to $A^0$ in the 2HDM (Model I). Its production at $e^+e^-$ colliders must wait until the $Z^* \to H_3^0 H_1^0$, $H_3^0 H_1^{0'}$ processes become available (see case 3).

Case 3: This case combines the above analyses, considering both the 3-plet and $\psi_2$ to be accessible.

a) $\psi_2 = H_1^0$: A new production channel is now available, that of $Z^* \to H_3^0 H_1^0$. The cross section is well known [1], [4], and a review of the detection techniques appears in Ref. [14]. If substantial enough, this process would suggest the triplet model (a pair of degenerate Higgs bosons, $H_3^0$ and $H_3^\pm$). Without this option one would observe just $H_3^\pm$ and $H_1^0$, which would look like a 2HDM (Model I or I') (as mentioned earlier).

b) $\psi_2 = H_1^{0'}$: Again the presence of $Z^* \to H_3^0 H_1^{0'}$ is useful in suggesting we have the triplet model. Without it, $H_3^\pm$ and $H_1^0$ could look like the 2HDM (Model I) with
a fine-tuned mixing angle. However, case 1(b) explains that we could perhaps infer that we have the triplet model.

Case 4: Now we include the members of the 5-plet. This situation has rich phenomenology and should readily identify the HTM. The most spectacular evidence would be that of \( H_5^{\pm \pm} \). The pair production cross-section would be four times that of the singly charged Higgs bosons, yielding > 350 events for \( m_{H^\pm} \leq 80 \text{ GeV} \) at \( \sqrt{s} = 200 \text{ GeV} \). The dominant decay channel would be to \( W^* W^* \) [4], [12], (the 5-plet members are fermiophobic) yielding a four fermion final state. The cleanest signature would \( l l \nu \nu \) and this decay could distinguish (see Section 3) \( H_5^{\pm \pm} \) from the doubly charged scalar of a left-right symmetric model, the latter decaying to \( l l \). A review of the detection techniques can be found in Refs. [10], [11].

Many other production processes become available with the introduction of the 5-plet. These are \( H_5^+ H_5^- \), \( H_5^{\pm} H_3^\mp \), \( H_5^0 H_3^0 \), \( Z H_5^0 \) and \( H_5^{\mp} W^\mp \). The \( H_5^0 \) would be produced in pairs (standard process for charged scalars), singly by the exotic vertex \( H_5^\mp W^\mp Z \), and by \( Z^* \to H_5^\mp H_5^\mp \). Ref. [15] shows that the dominant decay of \( H_5^0 \) would be to \( W^\pm Z^* \). This vertex is exclusive to higher Higgs representations and is not present in models with just doublets. The \( H_5^0 \) would be produced by \( Z^* \to Z H_5^0 \), \( H_5^0 H_3^0 \). Being fermiophobic also, its decays are similar to those of \( H_1^0 \).

The best processes for measuring the contribution of the triplets to electroweak symmetry breaking will be \( \cos \theta_H \) dependent (recalling that \( c_H^2 \geq 0.61 \)). The ones likely to give most events are \( Z^* \to Z H_1^0 \) (which is proportional to \( c_H^2 \)) and \( Z^* \to H_1^0 H_1^0 \) (proportional to \( \frac{5}{2} c_H^2 \)).

5 Conclusions

We have studied the most popular model containing Higgs triplets (HTM) in the context of the non-minimal Standard Model. Such a representation is possible, not being in conflict with current experimental data (most notably the measurement of \( \rho \approx 1 \)).

Various exotic Higgs bosons with reasonable cross sections are predicted (i.e. doubly charged and fermiophobic bosons), all of which escape the mass bounds from \( b \to s \gamma \). Therefore they can be searched for at LEP 2. Making use of a natural mass hierarchy obtained from the Higgs potential, we considered in turn the possible combinations of Higgs bosons in range at this collider. If light enough (\( \leq 80 \text{ GeV} \)), detection of \( H_5^{\pm \pm} \) would be straightforward and a strong signature of the HTM. Otherwise, distinguishing this model from other non-minimal representations is not so easy. The discovery of one of the fermiophobic Higgs bosons (the lightest likely to be \( \psi_2 \) composed mainly of \( H_1^0 \)), and/or a pair of bosons roughly degenerate in mass (\( H_1^0 \) and \( H_5^\pm \)) would be indicators but not conclusive evidence.
A Next Linear Collider (NLC) with $\sqrt{s} = 500 \to 1000$ GeV would enable heavier Higgs bosons to be produced, should LEP2 be insufficiently energetic. Decays to lighter Higgs bosons would no longer be negligible and so detection methods must change accordingly. However, all the production processes mentioned above would be relevant, with new ones also becoming significant (such as vector boson fusion for both neutral and charged scalars). A general outline of detection prospects at such a collider appears in Ref. [4]. Ref. [16] examines production processes using the exotic $H_5^{\pm} W^\mp Z$ vertex as an alternative way of distinguishing the HTM. However, $s_H^2 \approx 1$ is required to detect this vertex, and given the constraint $s_H^2 \leq 0.39$ this method seems difficult.

Prospects at high energy hadron colliders have also been discussed, see for example Ref. [4]. Usually such work focuses on $H_5^{\pm}$ [17], with relatively little attention given to the fermiophobic neutral Higgs bosons ($H_1^0$, $H_2^0$). We recall that discovery of one of these latter scalars would suggest the HTM, though the main production process of gluon fusion via a fermion loop would be absent. Work in this direction is currently being undertaken.

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References


Figure Captions

[1] The squared masses of $\psi_1$ and $\psi_2$ in units of $v^2 = (246 \text{ GeV})^2$ as a function of $\theta_H$ ($\lambda_1 = 1$ is assumed). The experimentally allowed region lies to the left of the vertical line $\theta_H = 0.67$ radians.

[2] The mixing angle $\sin 2\alpha$ as a function of $\theta_H$. The experimentally allowed region lies to the left of the vertical line $\theta_H = 0.67$ radians.