SIGNALS OF NON-MINIMAL HIGGS SECTORS*

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It is possible that the Standard Model possesses a non-minimal Higgs sector. We consider various extended Higgs models and highlight two distinctive signatures which may be of relevance at present colliders: a light charged scalar ($H^{\pm}$) and a fermiophobic neutral scalar (H_F).

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1. Introduction

The Standard Model (SM) [1] has proved remarkably successful to date in describing the particle interactions of nature. However, the theory requires that the electroweak symmetry is broken and an efficient way of accomplishing this is to introduce scalar particles (Higgs bosons) with non-zero vacuum expectation values (VEVs) [2]. Thus far no such particles have been detected and therefore it is prudent to explore all possible Higgs sectors. The minimal SM consists of one complex isospin Higgs doublet which after symmetry breaking predicts one physical neutral scalar (ϕ^0), although much can be found in the literature concerning extended models [3] *i.e.* the non-minimal SM[1]. Extended Higgs sectors with additional doublets/triplets always require exotic Higgs bosons with electric charge ($H^{\pm}$) and zero tree-level couplings to gauge bosons (A^0). Also, these models predict neutral scalars (h) which differ from ϕ^0 in their production cross sections and branching ratios. The above differences can studied at present and future colliders, with the aim of establishing whether a minimal or non-minimal Higgs representation is present. However, if it has been confirmed

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1 Defined by assuming no other new particles apart from Higgs bosons.

that a non-minimal Higgs representation exists, the question of which model is present (out of the many possible) still remains. In this paper we highlight two distinctive signatures which would indicate specific non-minimal representations; a light charged scalar ($H^{\pm}$) which could possibly be in the discovery range of LEP2, and a 'fermiophobic' Higgs (H_F) which contains no tree-level couplings to fermions. The paper is essentially a summary of our earlier work [4, 5] to which we refer the reader for a more detailed analysis. The paper is organized as follows. Section 2 reviews the various non-minimal models which are consistent with current experimental data. Section 3 shows that light charged scalars may exist and analyses their phenomenology at LEP2. Section 4 introduces the concept of fermiophobia, and examines the phenomenology of H_F at the Tevatron and LEP2. Finally, Section 5 contains our conclusions.

2. Non-minimal Higgs models

The most theoretically favourable non-minimal Higgs sectors are those that contain only doublet representations. These naturally preserve the relation [6, 7]:

$$\rho \equiv M_W^2/(M_Z^2 \cos^2\theta_W) \approx 1\,. \tag{1}$$

Suppression of flavour changing neutral currents can be obtained by requiring that each fermion type couples to not more than one Higgs doublet [8]. Models with triplets can also be considered and the most popular of these was proposed by Georgi and Machacek containing one doublet and two triplets [9, 10]. In this talk we shall concentrate on doublet models but will mention the above triplet model.

For a two-Higgs doublet model (2HDM) and a general multi-Higgs doublet model (MHDM) with N doublets, the Lagrangian for the charged Higgs sector can be written as the following: [11]

$$\mathcal{L} = (2\sqrt{2}G_F)(X\overline{U}_L V M_D D_R + Y\overline{U}_R V M_U D_L + Z\overline{N}_L M_E E_R)H^+ + \text{h.c.} \tag{2}$$

Here U_L, U_R (D_L, D_R) denote left- and right-handed up (down) type quark fields, N_L is the left-handed neutrino field, and E_R the right-handed charged lepton field. M_D, M_U, M_E are the diagonal mass matrices of the down type quarks, up type quarks and charged leptons respectively. V is the CKM matrix, and X, Y and Z are coupling constants that originate from the mixing matrix for the charged scalar sector. For the MHDM it is conventional to assume that one of the charged scalars is much lighter than the others and thus dominates the low-energy phenomenology[2]. The CP conserving

[2] In a model with N doublets there exists $(N-1)$ $H^{\pm}$s.

2HDM, which is usually considered in the literature [3], contains an important parameter

$$\tan\beta = v_2/v_1\,, \tag{3}$$

with v_1 and v_2 being real vacuum expectation values (VEVs) of the two Higgs doublets, $v_1^2 + v_2^2 = 246^2$ GeV^2 and $0 \leq \beta \leq \pi/2$. There are 4 variants of the 2HDM depending on how the doublets are coupled to the fermions. Their coupling constants are given in Table I [12].

TABLE I

The values of X, Y and Z in the 2HDM

	Model I	Model I′	Model II	Model II′
X	$-\cot\beta$	$-\cot\beta$	$\tan\beta$	$\tan\beta$
Y	$\cot\beta$	$\cot\beta$	$\cot\beta$	$\cot\beta$
Z	$-\cot\beta$	$\tan\beta$	$\tan\beta$	$-\cot\beta$

In the MHDM X, Y and Z are *arbitrary* complex numbers. It follows that combinations of parameters like XY^* have different values depending on the model under consideration, thus leading to phenomenological differences. This has important consequences, particularly when one calculates loop diagrams involving $H^\pm$.

3. Light charged scalars

Precision measurements of the process $b \to s\gamma$ impose the severest constraints on the mass of the charged scalar of the 2HDM (Models II and II′) and the decay has recently been observed for the first time by the CLEO Collaboration. The value for the branching ratio was measured to be [13]

$$\mathrm{BR}(b \to s\gamma) = (2.32 \pm 0.57 \pm 0.35) \times 10^{-4}\,, \tag{4}$$

which corresponds to

$$1 \times 10^{-4} \leq \mathrm{BR}(b \to s\gamma) \leq 4.2 \times 10^{-4} \quad (95\%\ cl)\,. \tag{5}$$

In the context of an extended Higgs sector the branching ratio (BR) is given by [14–17]:

$$\mathrm{BR}(b \to s\gamma) = C\left|\eta_2 + G_W(x_t) + (|Y|^2/3)G_W(y_t) + (XY^*)G_H(y_t)\right|^2\,, \tag{6}$$

where

$$C = \frac{3\alpha\eta_1^2 BR(B \to X_c l\nu)}{2\pi F_{\mathrm{ps}}(m_c^2/m_b^2)} \approx 3 \times 10^{-4}\,. \tag{7}$$

Here $F_{\text{ps}} \approx 0.5$ is a phase space factor, $\eta_1 \approx 0.66$ and $\eta_2 \approx 0.57$ are QCD correction factors, and the G functions are positive increasing:

$$G_W(x) = \frac{x}{12(1-x)^4}\left[(7-5x-8x^2)(1-x)+6x(2-3x)\ln(x)\right] ,$$

$$G_H(x) = -\frac{x}{6(1-x)^3}\left[(3-5x)(1-x)+2(2-3x)\ln(x)\right] ,$$

$$F_{\text{ps}} = 1-8x+8x^3-x^4-12x^2\ln(x) . \tag{8}$$

The dimensionless parameters x_t and y_t are defined by $x_t = m_t^2/M_W^2$ and $y_t = m_t^2/M_H^2$ with M_H being the mass of the charged Higgs. This calculation is purely 'SM + charged Higgs' and so assumes no SUSY particles in the loops. The diagrams which contribute to the process are essentially the same as those for the SM with the $W^\pm$ replaced by $H^\pm$. For a general review of how new physics affects this decay see Ref. [18].

Now in the 2HDM (Models II and II′) Table I shows that

$$XY^* = \tan\beta(\cot\beta)^* = 1 , \tag{9}$$

and so there is a $G_H(y_t)$ contribution to the branching ratio which does not depend on $\tan\beta$. Hence to keep the theoretical branching ratio below the bounds from experiment, the Higgs mass M_H (which appears in G_H) must be constrained. We therefore obtain a lower bound of $M_H > 260$ GeV. However this is *not* the case in 2HDM (Models I and I′). Here $XY^* = -\cot^2\beta$, and so the 2HDM contribution to the decay is $[G_W(y_t)/3 - G_H(y_t)]\cot^2\beta$. This is negative for all values of y_t and no bound on M_H independent of $\tan\beta$ can be found. Hence this $H^\pm$ could be in the range of LEP2. In the MHDM, the combination XY^* which appears in Eq. (6) is an arbitrary complex number. Hence there is the possibility of cancellation between the terms that depend on the MHDM parameters, and therefore no bound on M_H. With the expected energy of LEP2 ($\sqrt{s} = 180 \to 200$ GeV), the $H^\pm$ of the conventional version of the 2HDM (*i.e.* Model II) as well the $H^\pm$ of Model II′ is inaccessible, while both the lightest $H^\pm$ of the MHDM as well as the charged scalars of the 2HDM (Models I and I′) could possibly be found if $M_H \leq 90$ GeV. We note that in the minimal Supersymmetric extension (MSSM) of the SM, the $H^\pm$ here is constrained by theory to be $\geq M_W$. Thus detection is unlikely at LEP2 and so the observance of a light $H^\pm$ at this collider would be evidence against the MSSM.

In order to study the phenomenology of light $H^\pm$s at LEP2 we must investigate their BRs which will differ from model to model. Their values are given in Table II.

TABLE II

Branching ratios of $H^\pm$ for M_H in the LEP2 range

	Model I	Model I′	MHDM
BR($H^\pm \to cs$)	66%	$\leq 45\%$	0% → 100%
BR($H^\pm \to cb$)	1%	$\leq 0.9\%$	0% → 100%
BR($H^\pm \to \tau\nu_\tau$)	33%	$\geq 54\%$	0% → 100%

The bound $|Y| \leq 0.8$ for $M_H \leq 200$ GeV [11] causes the inequalities for the 2HDM (Model I′). The cb channel never exceeds more than a few percent in any 2HDM due to heavy CKM matrix suppression, although in the MHDM it can be significantly enhanced due to the greater freedom in X, Y and Z. Such an enhancement could have two important uses. It could increase the chance of detection if $M_H \approx M_W$ (when $W^\pm$ decays form a large background)[3], and also indicate that any detected $H^\pm$ is from the MHDM rather than from the 2HDM. Also, we note that another distinctive signature of the MHDM is a lack of $\tau\nu_\tau$ decays ($\ll 33\%$).

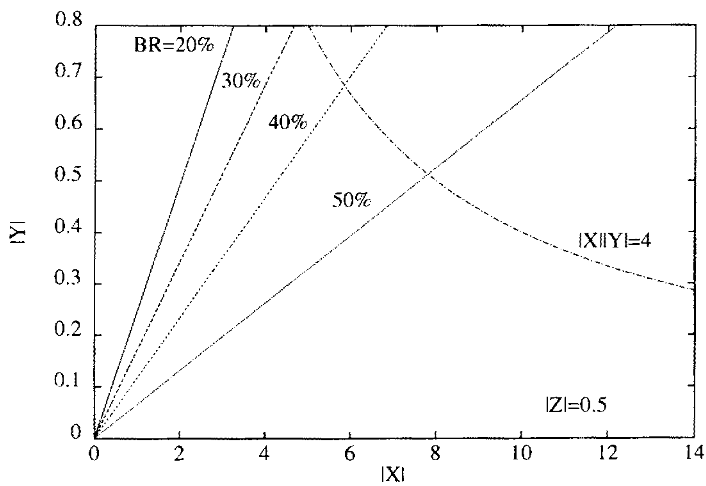

Fig. 1. Lines of constant branching ratio for the decay $H^+ \to c\bar{b}$ with $|Z| = 0$. The experimentally allowed region lies beneath the curve $|X||Y| = 4$.

[3] This was first observed in Ref. [11], but we will perform a full analysis of detection prospects in this difficult mass region.

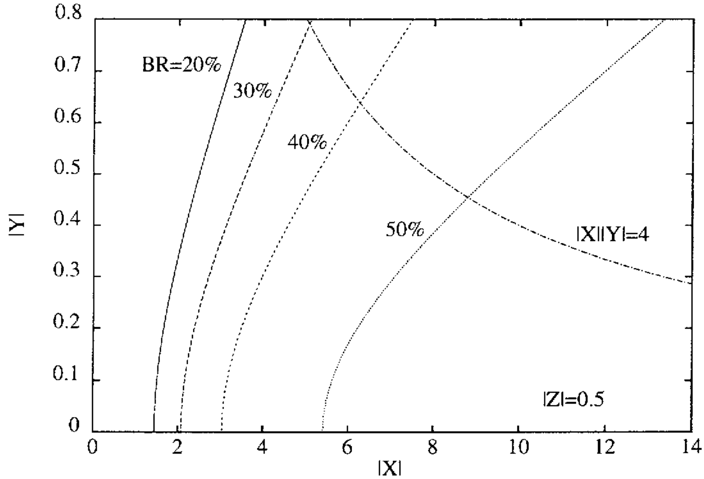

Fig. 2. Same as Figure 1 but with $|Z| = 0.5$.

Figures 1 and 2 show lines of constant branching ratio (BR) in the $|X|$, $|Y|$ plane for the $H^{\pm} \to cb$ channel, in the range 20% to 50%. For $M_H = 80$ GeV (which suffers from large $W^{\pm}$ backgrounds), regions below the curve $|XY| = 4$ [11] are allowed by current experimental data[4]. In Fig. 1 we have set $|Z| = 0$, and in Fig. 2 $|Z| = 0.5$. We see that there is a significant parameter space for large BR($H^{\pm} \to cb$), with low values of $|Y|$ and $|Z|$ being more favourable. This is in contrast to the charged scalars of the 2HDM (Models I and I′) which never reach more than BR$\sim$1% in the cb channel. Thus a significant BR($H^{\pm} \to cb$) signal would be a signature of a MHDM. Furthermore, because the $W^{\pm} \to cb$ decay is negligible (BR$\sim$0.05%), there is more chance in the MHDM of overcoming the W^+W^- background when $M_H \approx M_W$. As an alternative distinctive signature there is also a sizeable parameter space for a low BR($H^{\pm} \to \tau\nu_{\tau}$) in the MHDM, *i.e.* a 'leptophobic' Higgs. It can be shown [4] that this branching ratio is (not including cb decays for the moment)

$$\approx \frac{|Z|^2}{|Z|^2 + 2|Y|^2} \,. \tag{10}$$

Therefore, if $|Y| \geq 2|Z|$, the BR is $\leq 11\%$. The inclusion of the cb channel

[4] This bound is based on a previous (95%cl) upper limit for $b \to s\gamma$ (5.4×10^{-4}) since superseded by the new measurement from Eq. (4).

would decrease this further, and so we conclude that it is very possible to have a low number of $H^{\pm} \to \tau\nu_\tau$ decays in the MHDM. Recalling that the same BR for Model I and Model I$'$ must be greater than 33% and 54% respectively, this is in principle another way of distinguishing the MHDM from the other models.

If for any of the above models M_H *does* lie in the discovery range of LEP2, how would one search for it? Production in top decay, *i.e.* $e^+e^- \to \gamma^*, Z^* \to t\bar{t} \to H^+H^-b\bar{b}$, is obviously kinematically forbidden at LEP2. Therefore, we must rely on the annihilation process $e^+e^- \to \gamma^*, Z^* \to H^+H^-$. This has been studied extensively in the literature for the case of the 2HDM (see for example Ref. [19]). It is straightforward to show that the $Z\,H^+H^-$ and $\gamma\,H^+H^-$ couplings have the same strength in both the 2HDM and MHDM. For all the charged scalars that we will consider there exists an experimental lower bound from LEP of 41.7 GeV [6], obtained from a lack of signal from the process $e^+e^- \to \gamma^*, Z^* \to H^+\,H^- \to \tau\,\nu_\tau\tau\,\nu_\tau$. The number of expected events is shown in Fig. 3 as a function of M_H, where we have assumed an integrated luminosity of 500 pb^{-1} and two values for the collider energy. For $\sqrt{s} = 180$ GeV we expect approximately 350 events for M_H=45 GeV, decreasing to 51 events for M_H=80 GeV. For Higgs masses below M_W there should therefore be no problem in detection, the particle being detected as a peak in the jet-jet mass distribution, for example. Also, the scalar nature of the $H^{\pm}$ gives rise to a characteristic $\sin^2\theta$ angular dependence with respect to the beam direction. A review of the detection techniques for a light $H^{\pm}$ appears in Ref. [20]. Although this only considers the 2HDM (Model II), the results can be extended to the other cases. The potential problem arises when $M_H \approx M_W$. The W^+W^- production cross section ($\approx$ 20 pb) is considerably larger than that for H^+H^-. Table III shows the expected number of events for 500 pb^{-1} integrated luminosity and two different values of the collider energy $(\sqrt{s})^5$.

TABLE III

The expected number of W^+W^-, ZZ and H^+H^- events for 500 pb^{-1} integrated luminosity at LEP2.

	$\sqrt{s} = 180$ GeV	$\sqrt{s} = 200$ GeV
W^+W^-	9727	10191
ZZ	0	397
$H^+H^-(M_H = 80$ GeV$)$	51	91
$H^+H^-(M_H = 90$ GeV$)$	0	35

[5] We ignore below-threshold ZZ production at the lower energy.

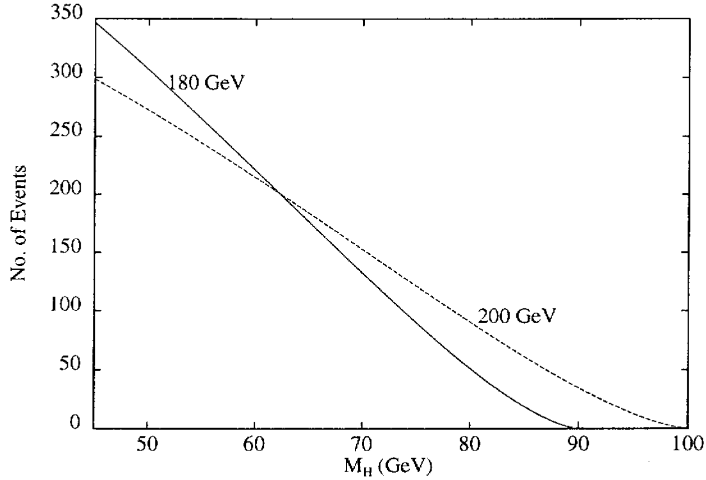

Fig. 3. Expected number of H^+H^- pairs produced with $\int \mathcal{L} = 500$ pb^{-1} at LEP2 as a function of M_H, for $\sqrt{s} = 180$ and 200 GeV.

Clearly detection of a $H^\pm$ will be impossible unless use is made of special decay channels. Exploiting an enhanced cb decay channel will be required if one is to detect $H^\pm$, since backgrounds from $(W^\pm \to cb)$ are very small (BR $\sim 0.05\%$). As we have already discussed, this is not an option for the 2HDM (Model I and I$'$) and so in their cases the $\tau\nu_\tau$ channel will have to be used. Given the large background, detection appears difficult. For the MHDM the prospects are much better due to the possibility of a significant branching ratio for the cb decay channel. The expected number of $cbcb$ events arising from H^+H^- production is $51 \times \left(\mathrm{BR}(H^\pm \to cb)\right)^2$, while for the mixed decays ($cbcs$, $cb\tau\nu_\tau$) we have similar expressions with an extra factor of two from permutations. In order to isolate these final states b-tagging will be necessary. Since this a standard technique for searching for the SM Higgs at LEP2, the efficiency will be quite high in practice, see for example Ref. [21]. The number of final states N_b containing at least one b quark is given by

$$\mathrm{N}_b = \mathrm{N}_{H^+H^-} \times \mathrm{BR}_{cb} \times (2 - \mathrm{BR}_{cb})\,. \tag{11}$$

For example, a $\mathrm{BR}(H^\pm \to cb)$ of 30% would give $\mathrm{N}_b = 26.0$ with 4.5 events containing two b quarks. The background N_b from W^+W^- is 9.7. Note that these numbers correspond to the idealized situation of 100% efficiency for detecting b quarks. However they should still be large enough to provide an observable signal assuming a more realistic tagging efficiency, see for example Ref. [21]. At the higher collider energy, $\sqrt{s} = 200$ GeV, ZZ production becomes a significant background, particularly if $M_H \approx M_Z$. For $M_H = 80$ GeV, there is an improved chance of detection with a maximum of 91 events. A BR($H^{\pm} \to cb$) of 30% for the MHDM would now give $N_b = 46.4$, with a background of 10.2 events from W^+W^-. Again, detection depends on the efficiency of b-tagging. If $M_H = 90$ GeV ($\approx M_Z$), the number of produced H^+H^- pairs is lower (≈ 35), and there is a large background from ZZ decays with $N_b(ZZ) = 110.8$. For the 2HDM (Model I and I′) the mass regions $M_H \approx M_W$ and $M_H \approx M_Z$ are problematic; in the former case there is no $H^{\pm} \to cb$ channel to exploit, and the latter suffers from there being too few $H^{\pm}$ pairs produced.

If a $H^{\pm}$ is found then can we infer the underlying Higgs model? As mentioned earlier, a sizeable $H^{\pm} \to cb$ signal would be a signature of the MHDM. For a mass comfortably below M_W a significant number of pairs will be produced. In this mass range, a branching ratio of 10% would probably be sufficient to produce a large enough N_b to tag, in excess of what could be expected from a 2HDM. For example, if $N_{H^+H^-} = 100$ (corresponding to $M_H \approx 75$ GeV at $\sqrt{s} = 180$ GeV), we find $N_b = 19.0$ compared to a maximum value of $N_b = 2.0$ for either 2HDM. Also, we recall that a lack of $H^{\pm} \to \tau\nu_\tau$ decays is another indicator of the MHDM. Eq. (10) shows that quite a large region of parameter space is available for a BR $\leq 10\%$ and this in principle would be a good discriminator. However, it remains to be seen if any variation in this channel for a $H^{\pm}$ can be distinguished at LEP2, given the strong background from $W^{\pm} \to \tau\nu_\tau$.

4. Fermiophobic Higgs bosons

The second special type of Higgs boson that we shall consider is a fermiophobic Higgs (H_F) (see Ref. [5] and references therein) which contains no tree-level coupling to fermions. Fermiophobia is only possible in the 2HDM (Model I) and in the MHDM. This becomes clear when we view the couplings in Table IV. We are interested here in the lighter of the two neutral, CP-even Higgs bosons (h).

TABLE IV

The fermion couplings of h in the 2HDM relative to those for the minimal SM Higgs boson (ϕ^0).

	Model I	Model I′	Model II	Model II′
$hu\bar{u}$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$
$hd\bar{d}$	$\cos\alpha/\sin\beta$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$-\sin\alpha/\cos\beta$
$he\bar{e}$	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$

Here α is a mixing angle used to diagonalize the CP-even mass matrix. From Table II we see that fermiophobia is only possible in Model I if $\cos\alpha \to 0$ [22]. We note that the heavier CP-even Higgs (H) in Model I would itself be fermiophobic if $\cos\alpha \to 1$. However this particle could be substantially heavier than h and so is not considered. From now on we shall label the fermiophobic Higgs in this model as being H_F. Therefore, it is apparent that fermiophobia is not possible in the MSSM since it requires Model II type couplings [3]. Hence searching for H_F is well motivated. The MHDM can also display fermiophobia in an analogous way, but we shall concentrate on the 2HDM (Model I).

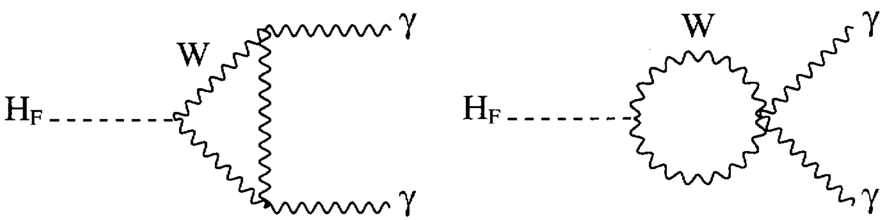

Fig. 4. Two-photon decay of H_F.

We now study the branching ratios (BRs) of H_F. Tree-level decays to fermions are obviously not allowed, and if $M_{H_F} \leq 80$ GeV then the only possible tree-level channels are $H_F \to W^*W^*$, Z^*Z^*, with '*' denoting an off-shell vector boson[6]. Since these latter decays are not very strong (the vector bosons being considerably off-shell) then one-loop mediated decays can compete and these are displayed in Fig. 4. For the case of $H_F \to \gamma\gamma$, the W mediated decays give the dominant contribution [3, 23] and only these are included. The one-loop decays to $f\overline{f}$ (which would dominantly be to $b\overline{b}$ [24]) are renormalization scheme dependent and it is conventional in the literature to consider an extreme fermiophobic Higgs with the renormalized $H_F \to f\overline{f}$ vertex set equal to zero [24, 25]. The BRs predicted by Refs. [24] and [25] agree and imply that the channel $H_F \to \gamma\gamma$ dominates for $M_{H_F} \leq 80$ GeV; at $M_{H_F} \approx 95$ GeV the tree-level process $H_F \to WW^*$ is equally likely as $H_F \to \gamma\gamma$, each having BR=45%. In contrast, for ϕ^0 and the lightest neutral CP-even scalar of the MSSM the branching ratio to two photons is of the order 0.1%. For higher M_{H_F} the vector boson channels dominate along with decays to other Higgs bosons ($H_F \to t\overline{t}$ is not allowed at tree-level). Therefore the distinctive fermiophobic signature of $H_F \to \gamma\gamma$

[6] Not including decays to other Higgs bosons which will be heavily off-shell also.

is disappearing for $M_{H_F} \geq 100$ GeV, and so we shall focus on the region of $M_{H_F} \leq 100$ GeV. For the heavier mass region (≥ 160 GeV) the only difference between the decays of H_F and ϕ^0 would be due to the presence of lighter Higgs bosons *e.g.* $h \to A^0 Z$. Ref. [24] studies the phenomenology of a fermiophobic Higgs at the Tevatron with ϕ^0 strength (*i.e.* minimal SM strength) couplings to vector bosons. This is not the case for the H_F that we are considering, whose couplings are given in Eq. (12) (expressed relative to those of ϕ^0):

$$hW^+W^- : -\cos\beta\,, \qquad hZZ : -\cos\beta\,. \tag{12}$$

We shall now consider the phenomenology of H_F at the Tevatron. For ϕ^0 the main production process is gluon-gluon fusion via a top quark loop [26]. This is not allowed for H_F and nor are any diagrams involving associated production with top quarks [27, 28]. Therefore, there remains two processes; associated production with vector bosons [29] and vector boson fusion [30]. However, Ref. [24] shows that the latter gives less events and so we shall focus on the former whose Feynman diagram is displayed in Fig. 5. As mentioned before Ref. [24] assumed minimal SM strength couplings to vector bosons for H_F; this is not the case for the H_F that we are considering and the production cross section will scale by $\cos^2\beta$ *i.e.* the square of the couplings in Eq. (12). Due to the bound $\cos^2\beta \leq 0.39$ [11] we see that h has at best a cross section 0.39 that of ϕ^0.

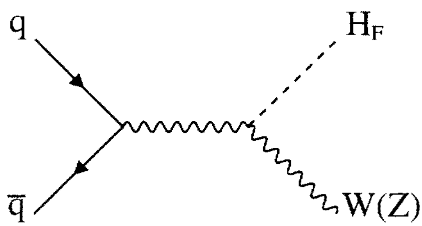

Fig. 5. The main production mechanism of H_F at the Tevatron.

We note that a H_F with ϕ^0 strength couplings to ZZ would have been seen at LEP if $M_{H_F} \leq 60$ GeV [31]. This lower bound will in be weaker when couplings are suppressed. The method of searching for H_F at the Tevatron is described in Ref. [24] and we shall briefly review it here. The photons from H_F act as a trigger for the events, and then various cuts are applied depending on whether the vector bosons decay hadronically or leptonically. For the leptonic decay it is shown that the main background ($W\gamma\gamma$ and $Z\gamma\gamma$) is negligible. Hence we only require a reasonable number of events

(≥ 3) in this channel for detection. For the hadronic decays of the vector bosons there is a background ($jj\gamma\gamma$)[7]. For this channel the WH_F and ZH_F signals are combined due to the invariant mass distribution being unable to separate the W and Z peaks. Table V shows the expected number of signal and background events[8] for 67 pb $^{-1}$ of data, which is the current data sample at the Tevatron. The numbers are for $\cos^2\beta = 0.39$.

TABLE V

Number of signal and background events for the process $q\bar{q} \to W^*(Z^*) \to H_F W(Z)$, with $H_F \to \gamma\gamma$ and $W \to l\nu$, $Z \to l\bar{l}$, $\nu\bar{\nu}$, or $W, Z \to jj$.

M_{H_F} (GeV)	WH/ZH (leptonic)	WH/ZH (jets)	$jj\gamma\gamma$
60	3.7/2.9	19.1	3.5
80	1.4/1.3	7.6	1.9
100	0.2/0.2	1.2	1.0

We see that $M_F \leq 60$ GeV can be probed (≥ 3 events in the leptonic channel and a $\geq 4\sigma$ signal in the hadronic channel). The coverage increases to $M_F \leq 80$ GeV with 140 pb^{-1}. It is probable that the Tevatron will be upgraded in luminosity with 2 fb^{-1} being possible by the year 2000. The increased number of events would allow heavier M_{H_F} to be probed. If $\cos^2\beta = 0.39$ one would expect ≥ 3 events in the leptonic channel for masses up to around 100 GeV. To probe beyond this mass region requires another large increase in luminosity due to the rapid weakening of BR ($H_F \to \gamma\gamma$). Therefore, the coverage would be superior to that of LEP2, the latter only being able to probe the region $M_{H_F} \leq \sqrt{s} - 100$ GeV if H_F has ϕ^0 strength couplings. For previous searches at LEP see Refs. [31, 32]. To end this discussion on H_F we must point out that fermiophobia arises more naturally in the aforementioned (Section 2) Higgs triplet model, and a discussion of the analogous phenomenology appears in Ref. [5].

5. Conclusions

We have discussed the phenomenology of light ($M_H \leq M_W$) charged Higgs scalars ($H^\pm$) and fermiophobic Higgs scalars (H_F) at LEP2 and the Tevatron. These particles may only arise in specific extended Higgs models, and in particular are not possible in the MSSM.

7 From processes like gg, $qq \to qq\gamma\gamma$.

8 The event numbers in all our tables are obtained from Ref. [24] with appropriate scaling for a particular Higgs model.

We showed that $H^{\pm}$s from the MHDM and the 2HDM (Model I and I′) may lie in the discovery range of LEP2, while those from the 2HDM (Models II and II′) cannot; masses from 41.7 GeV (current LEP lower bound) to $M_H < M_W$ will be covered successfully. For $M_H \approx M_W$, detection requires a branching ratio of $> 30\%$ for the $H^{\pm} \to cb$ decay, with b-tagging efficiencies around 50%. For $\sqrt{s} = 200$ GeV, a BR($H^{\pm} \to cb$) of 20% would be sufficient if $M_H \approx M_W$, but for $M_H \approx M_Z$ too few charged scalars are produced. We have shown that branching ratios of these magnitudes (or greater) *are* allowed in the MHDM, which is in contrast to the 2HDM. A distinctive signature of the $H^{\pm}$ would be a BR($H^{\pm} \to cb$) $> 10\%$. This would be sufficiently large to distinguish the MHDM from the 2HDM, given at least 100 or so pair production events. Another signature of the MHDM would be a BR($H^{\pm} \to \tau\nu_{\tau}$) $\leq 10\%$. It remains to be seen if this method could be exploited at LEP2. The above comments apply to the $H^{\pm}$ of the various 2HDM considered (Model I and I′) apart from the $M_H \approx M_W$ and $M_H \approx M_Z$ mass regions. Here detection seems difficult, as there is no significant $H^{\pm} \to cb$ decay to exploit.

For the fermiophobic Higgs, which is only possible in the MHDM and the 2HDM (Model I), we showed that the $H_F \to \gamma\gamma$ decay dominates for masses ≤ 90 GeV. Such a decay has a branching ratio of the order $\sim 0.1\%$ for the minimal SM Higgs (ϕ^0) and the lightest CP-even Higgs of the MSSM (h^{SUSY}). Backgrounds at the Tevatron are small and the detection of H_F is possible if its mass is less than 80 GeV; at an upgraded Tevatron ($L = 2$ fb^{-1}) the coverage is improved to ~ 100 GeV.

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