The charged Higgs Boson of the two Higgs Doublet model type III

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Recently there are experimental reports from D0 and CDF collaborations searching for a particular signature of new physics in the framework of the Two Higgs Doublet Model (2HDM) type III, specifically looking for charged Higgs bosons. We present a review of the analysis done in the region $M_{H^+} > m_t$ by D0 collaboration and we take into account the previous bounds obtained on the parameter space of the model. We use the ratio R_σ for the region $M_{H^+} < m_t$.

One possible simple extension of the SM is by adding a new Higgs doublet and it is called the two Higgs Doublet Model (2HDM). This extension has the following direct consequences: it increases the scalar spectrum and it gives a more generic pattern of the Flavor Changing Neutral Currents (FCNC). FCNC at tree level can be consider a problem that was solved in the earlier versions of the two Higgs Doublet Model (2HDM type I and II) by imposing a discrete symmetry that restricts each fermion to be coupled at most to one Higgs doublet. But if the discrete symmetry is not imposed then FCNC at tree level remains, it is the so-called two Higgs Doublet Model type III. In the 2HDM-III, for each type quark, up or down type, there are two Yukawa couplings. One of the Yukawa couplings is in charge of generates the quark masses and the other one produces the flavor changing couplings at tree level. The two complex scalar fields correspond to eigth degrees of freedom, where three of them are identified as Goldstone bosons and are absorbed as longitudinal components to the $W^\pm$ and Z bosons giving mass to the weak bosons. The remaining degrees of freedom are interpreted as five physical states: two neutral scalars h^0 and H^0, a pseudo-scalar A^0, and a pair of charged Higgs bosons $H^\pm$.

While it may be hard to distinguish any one of these neutral Higgs bosons of the 2HDM-III from that one of the SM, the charged $H^\pm$ pair carry a distinctive hall-mark of this kind of new physics. Hence the charged Higgs boson plays a very important role in the search of new physics beyond the SM.

We will consider a general 2HDM-III where the Higgs doublets can couple with the up and down quark sector at the same time because there is not any discrete symmetry. In 2HDM-III there is a global symmetry which can make a rotation of the Higgs doublets and fix one VEV equal to zero. In such a way, $v_1 = v$ and $v_2 = 0$, and the mixing parameter $\tan\beta = v_2/v_1$ can be eliminated from the Lagrangian. If the parameter $\tan\beta$ is eliminated from the Lagrangian, we have the usual 2HDM type III [5], and the Lagrangian of the charged sector is given by

$$-\mathcal{L}^{III}_{H^\pm ud} = H^+\bar{U}[K\xi^D P_R - \xi^U K P_L]D + h.c. \tag{1}$$

where K is the Cabbibo-Kobayashi-Maskawa (CKM) matrix and $\xi^{U,D}$ the flavour changing matrices.

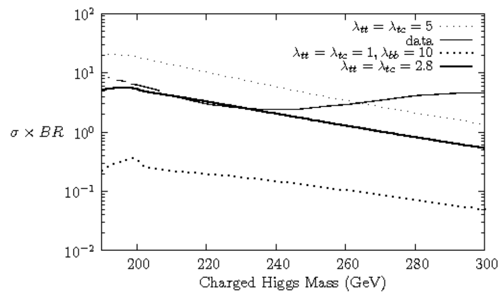

Figure 1: The cross section times branching fraction versus the charged Higgs boson for different scenarios in the type III 2HDM

For a better study of the FCNC processes, Cheng, Sher and Yuang (CSY) [2] propose an anzats for the Yukawa matrices. It is based on the SM $\phi f \bar{f}$ couplings and states that

$$\xi^{ij} \equiv \frac{\sqrt{m_i m_j}}{v} \lambda_{ij} \, .$$

This is an ansatz for the Yukawa texture matrices looking for a phenomenological similarity with SM couplings. This anzats obeys to the fact that couplings between fermions and the Higgs particle in the SM are proportional to the mass of the fermion. Parameters λ_{ij} could change the hierarchy between fermionic couplings and because of this it is expected that they would be ~ 1. Some restrictions over the λ_{ij} and the ξ_{ij} parameter sets have been found in literature, summarized in table 1 [3].

Parameter	Range
$\xi^2_{\mu\tau}$	$[7.62\times10^{-4} : 4.44 \times 10^{-2}]$
$\xi_{\tau\tau}$	$[-1.8\times10^{-2} : 2,2 \times 10^{-2}]$
$\xi_{\mu\mu}$	[-0.12:0.12]
$\xi_{\mu e}$	[-0.39:0.39]
λ_{bb}	[-6:6]
λ_{tt}	$[-\sqrt{8} : \sqrt{8}]$

Table 1: Experimental constraints over the ξ and λ matrices

The analysis presented by D0 collaboration [1] for the type III 2HDM has followed the analysis done in reference [4] assuming that the parton level is important to enhance the cross section, if λ_{tc} is bigger than one. The experimental analisis have used $\lambda_{tc} = 5$. Further, they assumed the parameter λ_{tt} in the charged Higgs decay vertex, to be equal to λ_{tc}. About this last point, we should mention that Atwood, *et. al.* in reference [5] have already shown that the assumption $\lambda_{ij} = \lambda$ is not in agreement with the low energy phenomenology and on the other hand, it has been shown [3] that perturbation theory validity requires that $\lambda_{tc} \leq 2.8$. From this point we aim to explore scenarios allowed in the 2HDM-III space parameters, with the additional simplification that in this model $\tan\beta$ is a spureous parameter. The experimental D0 collaboration report the observed limits on the production cross section (pb) times the branching fraction $\sigma(q\bar{q}' \to H^+) \times B(H^+ \to t\bar{b})$. These limits are shown in Fig. 1 labeled as data. We have used the program CompHEP to evaluate the charged Higgs boson production and decays, $q\bar{q}' \to H^+ \to t\bar{b} \to W^+ b\bar{b} \to l^+ \nu b\bar{b}$ where l represents an electron or muon. The expected limits using the same values of the λ_{ij} in the charged Higgs boson mass range 180 to 300 GeV are plotted in Fig. 1. In addition, in Fig. 1 are shown the predictions

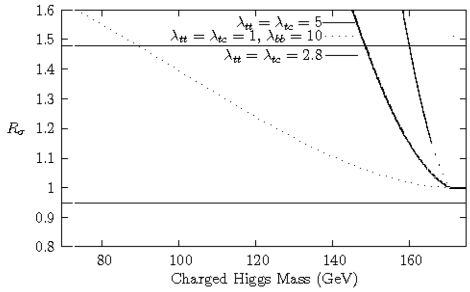

Figure 2: The ratio R_σ with the experimental limits from D0 collaboration and different values of the space parameter in the framework of the type III 2HDM

taken $\lambda_{tc} = 2.8, 1$, $\lambda_{tt} = 2.8, 1$ and $\lambda_{bb} = 0, 10$. These values of λ_{ij} are allowed for the phenomenology according to the table 1. We conclude that restrictions on the parameter space of the type III 2HDM are not too stronger. We notice that in the case $\lambda_{ij} = 5$ only charged Higgs masses above around 264 GeV are allowed and for values $\lambda_{tt} = 2.8$ the charged Higgs boson mass should be bigger than 230 GeV. Finally, in the region $M_{H^+} < m_t$, we have used the reported measurements of the ratio $R_\sigma = \sigma(p\bar{p} \to t\bar{t})_{l+jets}/\sigma(p\bar{p} \to t\bar{t})_{dilepton}$. We have shown the results in Fig. 2.

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