Benchmarks regions where BGL 2HDM can have important light Higgs mediating Flavour Changing Processes

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Abstract

1 Introduction

We present a 2HDM scenario with CP conservation in the Higgs sector and flavour changing neutral currents at tree level, naturally suppressed in the quark sector by small V_{CKM} matrix elements. This is a crucial feature of this scenario which distinguishes it from the type II CP conserving 2HDM.

We have been studying 2HDM based on a class of renormalizable models, where the flavour structure of the couplings comes from a symmetry and therefore is stable under renormalization. As a result one is left with very few free parameters leading to a high degree of predictability.

Our work is based on a proposal put forward some time ago [1] by Branco, Grimus and Lavoura (BGL) who have pointed out that there is a symmetry which, when imposed on the Lagrangian, constrains the Yukawa couplings in such a way that FCNC do arise at tree level, but are entirely determined by the V_{CKM} matrix, with no other free parameters in the flavour sector. This symmetry also constrains the Higgs potential which coincides with that of type II 2HDM with no term in λ_5.

As a result, all Higgs mediated FCNC are suppressed by small entries of V_{CKM}. With this suppression, the neutral Higgs masses need not be too large. BGL models have been extended to the leptonic sector [2], their relation to Minimal Flavour Violation models has been studied [3] and their phenomenological implications have been recently analysed [4], [5], [6], [7].

In Ref. [7] we pursued the analysis of this class of models having in mind, in particular, the possibility that the 125 GeV Higgs discovered at the LHC could deviate from the SM Higgs, contributing to flavour violating rare Higgs and top decays, and putting bounds on such deviations in the context of this framework. In Ref [5] we had concentrated our study on the effects produced by the new Higgs fields and on the possibility that they may be detected soon at the LHC while at the same time assuming that the recently discovered Higgs field does not mediate FCNC. These two approaches are complementary and both are relevant for LHC physics. We should point out that the fact that these models are very constrained allows to obtain very interesting correlations which are important predictions of our models. The implementations studied in Ref. [7] are very interesting even in the case the new Higgs fields are heavy.

In section 2, we briefly mention the main features of our theoretical framework, for more details see Ref. [7]. In section 3, we present some benchmark like scenarios which will be analysed in more detail in a future work.

2 Theoretical framework

The quark Yukawa couplings of the Higgs field h can be denoted as:

$$\mathcal{L}_Y(\text{h, quarks} = Y_{ij}^d \ \bar{d}_{iL} d_{jR} h + Y_{ij}^u \ \bar{u}_{iL} u_{jR} h + \text{h.c.} \tag{1}$$

and similarly for the leptonic sector with the coefficients denoted by Y_{ij}^{ℓ}, and Y_{ij}^{ν}. BGL models have scalar FCNC either in the up or in the down quark sector but never in both. Likewise in the leptonic sector. Each of these class of models is labelled by a family index associated with a specific implementation of the BGL symmetry. For each index the FCNC are suppressed by a different row or column of V_{CKM}.

We call up-type models those with FCNC in the down sector and down-type those with FCNC in the up sector. More specifically, for $i \neq j$ we get the following flavour violating Yukawa couplings, for the different types of BGL models:
i) up type u_k model, with k fixed as 1 (u) or 2 (c) or 3 (t) where FCNC arise

in the down quark sector:

$$Y^d_{ij}(u_k) = -V^*_{ki}V_{kj}\left(\frac{m_{d_j}}{v}\right)\left(t+\frac{1}{t}\right)\cos(\alpha-\beta) \quad i \neq j, \text{ no sum in } k \tag{2}$$

ii) down type d_k model, with k fixed as 1 (d) or 2 (s) or 3 (b) where FCNC arise in the up quark sector:

$$Y^u_{ij}(d_k) = -V_{ik}V^*_{jk}\left(\frac{m_{u_j}}{v}\right)\left(t+\frac{1}{t}\right)\cos(\alpha-\beta) \quad i \neq j, \text{ no sum in } k \tag{3}$$

There are thirty six different BGL models grouped into four classes; (up-type, neutrino-type), (up-type, charged lepton type), (down-type, neutrino-type), (down-type, charged lepton type). For each class there are three different family indices for the quark sector and another three for the leptonic sector, making a total of nine different models for each class.

Once a particular BGL type model is chosen the relevant independent parameters are: $\tan\beta$, $(\alpha-\beta)$ and the scalar masses together with the type of suppression of the scalar FCNC, i.e, either a row or a column of the mixing matrix.

3 Benchmark scenarios in BGL

As far as the discovered Higgs-like scalar is concerned (h), the most relevant effect of these BGL models is the presence of Flavour Violating Yukawa couplings in the h particle. So we fix our benchmark scenarios by trying to maximise these new effects but in agreement with other low energy flavour constraints. Also we choose those scenarios where important signals can show up at LHC, although in some cases some of the observables could be more relevant for a future linear collider.

3.1 The (b,τ) model near decoupling

In reference [5] the low energy flavour phenomenology set important lower bounds on the masses of the new scalars at the same time that an important level of degeneracy was fixed by electroweak corrections and $D^0-\overline{D}^0$ mixing. So according to our recent analysis in reference [7] and also taking into account that in the decoupling limit [8] $c_{\beta\alpha} \sim O\left(\frac{v^2}{m_H^2}\right)$ we choose, in order to have important effects in rare top decays $(t \to hc, hu)$, the following parameters: $25 \leq \tan\beta \leq 100, |c_{\beta\alpha}| \leq 0.17$ and $m_H \sim m_A \sim m_{H^\pm} \geq 600GeV$. We expect $t \to hc$ at $\leq 10^{-2}$ and $t \to hu$ at 10^{-4}. These regions have been chosen in agreement with the results of our previous analyses as shown in Figure 1

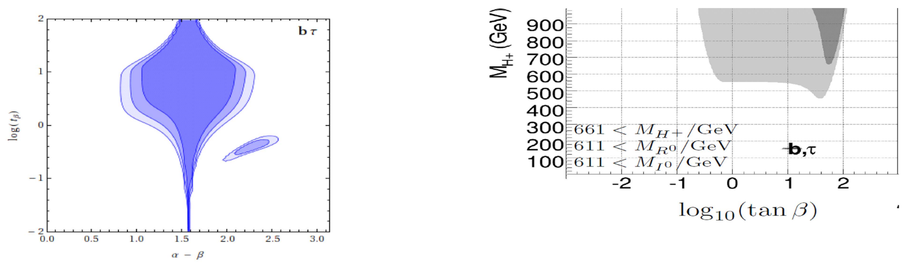


Figure 1:

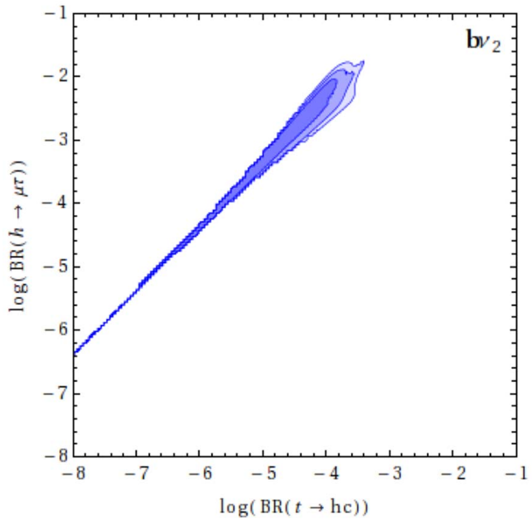
Diagonal couplings also change, Sizeable changes in $h \to b\bar{b}, \tau\bar{\tau}$ are expected.

3.2 The (t, ν_2) model with low new Higgs masses

This model has flavour changing coupling in the charged lepton sector incorporating therefore the new physics hint reported by CMS in the channel $h \to \mu\bar{\tau} + \tau\bar{\mu}$. Following the analyses in references [5], [7] we choose: $0.5 \leq \tan\beta \leq 3.5, |c_{\beta\alpha}| \leq 0.5$ and $m_H \sim m_A \sim m_{H^\pm} \geq 250GeV$. In this case we can have $h \to \mu\tau$ at a level near 10^{-2} together with other rare leptonic channels. A challenging process for LHC, better suited for ILC, is $h \to bs, bd$ that in this benchmark scenario can reach values around 3×10^{-3}. Important modifications also in $h \to b\bar{b}, \tau\bar{\tau}$.

3.3 The (b, ν_2) model near decoupling

This model has flavour changing coupling in the up quark and in the charged lepton sectors. It offers the possibility of rare top decays -to the Higgs-. Also the channel $h \to \mu\bar{\tau} + \tau\bar{\mu}$ appears at tree level. Following the analyses in references [5], [7] we choose: $1 \leq \tan\beta \leq 25, |c_{\beta\alpha}| \leq 0.17$, and $m_H \sim m_A \sim m_{H^\pm} \geq 600GeV$. In this case we can have $h \to \mu\tau$ at a level near 10^{-2} together with other leptonic channels. In the up quark sector the correlated constraint with $h \to \mu\tau$ reduces the rare decay rate of $t \to hc$ respect to our first benchmark scenario. This time the maximum value is around 6×10^{-4}. We show here in Figure 2 the kind of beautiful correlations one has in these scenarios. Important modifications also are present in the channels $h \to b\bar{b}, \tau\overline{\tau}$.



(h) $b\ \nu_2$

Figure 2:

4 Summary

In the following table we summarise the choosen benchmarks.

MODEL	$\lvert c_{\beta\alpha}\rvert$	$\tan\beta$	$m_H \sim m_A \sim m_{H^\pm}$	m_h	Interesting Channels
(b,τ)	≤ 0.17	$25 - 100$	≥ 600	125	$t \to hq, h \to b\bar{b}, \tau\overline{\tau}$
(t,ν_2)	≤ 0.5	$0.5 - 3.5$	≥ 250	125	$h \to \mu\overline{\tau}, q\bar{b}, \tau\overline{\tau}$
(b,ν_2)	≤ 0.17	$1 - 25$	≥ 600	125	$t \to hq, h \to \mu\overline{\tau}, b\bar{b}, \tau\overline{\tau}$

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