New Physics and novel Higgs signals

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Abstract. We review some of the results of our recent work dealing with the novel type of Higgs signals that arise when one considers extensions of the standard model. We discuss first possible deviations on the Higgs couplings due to heavy particles, in the context of the MSSM and with large extra-dimensions. Then, we present several models where it is possible to induce flavor violating Higgs couplings, and probe them at future hadron colliders through the LFV Higgs decay $h \to \tau \mu$ or with rare top decays.

INTRODUCTION

The discovery of the Higgs boson is certainly one of the most cherished goals of present and future high-energy experiments. In fact, the reported bounds on the Higgs boson mass [1], together with data on neutrinos [2] and CP-violation with B-mesons [3], can be considered some of the most important recent results in Particle Physics, and are already helping us to shape our understanding of flavor physics and electroweak (EW) symmetry breaking. The Higgs boson mass is constrained by radiative corrections to lay in the range 110-185 GeV at 95 % c.l. [1]; such a light Higgs boson ($h$) is consistent with the prediction of weak scale SUSY, which has become one of the preferred extensions of the SM [4].

The characteristic Higgs boson couplings determine the strategies employed for its search at present and future colliders [5]. For instance, the Higgs-fermion couplings can be studied by open production of $t\bar{t}h, bbh$ at hadron colliders or NLC. However, the possible presence of heavy particles associated with physics beyond the SM, can induce corrections to such couplings, which can modify the SM predictions for Higgs production or decays. Heavy particles can also induce tree-level corrections, as it occurs in scenarios with large extra-dimensions, where the KK modes can contribute to the associated production of Higgs with $Z$ boson at NLC, as it will be discussed next.

Flavor violation is another phenomena that could be tested in the Higgs sector. The most widely studied scenarios for Higgs searches, assume that the Flavor-Conserving (FC) Higgs-fermion couplings only depend on the diagonalized fermion mass matrices, while flavor-violating (FV) Higgs transitions are absent or highly suppressed [6]. Indeed, within the SM the Higgs boson-fermion couplings are only sensitive to the fermion mass eigenvalues. However, if one considers extensions of the SM, it is possible to induce new flavored Higgs interactions. These new interactions could be tested through the lepton-flavour violating (LFV) Higgs decays, such as $h \to \tau \mu/\tau e$ [7], which can reach detectable levels in several models that will be discussed next; similarly, these FV scalar interactions can also be tested with the rare decays of the top quark.
DEVIATIONS OF THE HIGGS COUPLINGS AND HEAVY PARTICLES

Within the minimal standard model (SM), a light Higgs boson mass is favored by present data [1]. However one can show that the effect of new physics can modify the Higgs couplings with gauge bosons, in a manner that cancels the (virtual) Higgs contribution that appears in the analysis of EW radiative corrections, and thus allow heavier Higgs masses, up to about 600 GeV, that still could be accessible at future colliders. This was first proved using a model-independent effective lagrangian approach in Refs. [8]. Nevertheless, even after a Higgs signal will be seen, probably at the Tevatron and/or LHC, it will become crucial to measure its mass, spin and couplings, to elucidate its nature. In particular, the Higgs coupling to light fermions (\(b\bar{b}, c\bar{c}, \tau^+\tau^-\)) could be measured at next-linear collider (NLC) with a precision of a few percent [9], which can be used to constrain physics beyond the SM. For instance, higher-dimensional operators of the type \(\Phi^\dagger\Phi\bar{Q}_L\Phi b_R\) involving the third family, will generate corrections to the coupling \(h\bar{b}b\), which in turn will modify the dominant decay of the light Higgs, as well as the associated production of the Higgs with b-quark pairs. This effect was studied within the minimal SUSY SM (MSSM), and found to be detectable in the large \(\tan\beta\) regime [10, 11]. The Higgs sector of the MSSM includes two Higgs doublets, and the light Higgs boson (with mass bound \(m_h \leq 125\) GeV), is perhaps the strongest prediction of the model.

Any additional heavy particle that receives its mass from the SM Higgs mechanism, will also contribute to the 1-loop vertices, an effect that can be tested through Higgs production, such as the loop-induced gluon fusion production of Higgs bosons at hadron colliders, or through the decay into photon pairs (\(h \rightarrow \gamma\gamma\)). However, such heavy particles will also induce non-decoupling corrections to the tree vertices \(hff, hWW\) and \(hZZ\), which can affect the decay rate of detectable signatures [12].

Heavy particles can also induce tree-level corrections, as it occurs in scenarios with large extra-dimensions, which were proposed as an alternative solution to the hierarchy problem [13]. The location of the Higgs can be studied within the context of a model with two-Higgs doublets, one living in the brane, while the other penetrates the bulk. Due to this assignment, new vertices of the type \(hZZ_{KK}\) between the higgs (h), the Z boson and its KK resonances (\(Z_{KK}\)), arise in the model. These vertices in turn affect the Higgs phenomenology. For instance we found that the KK states contribute to the associated production of Higgs with Z boson, in a manner that suppresses the Higgs rates at LEP and Tevatron, while giving large enhancements on the cross-section at the future LHC and NLC [14].

FLAVOR-VIOLATING HIGGS COUPLINGS

New flavored Higgs interactions can be induced when one considers extensions of the SM, which either present a significant new source of flavor-changing transition or are aimed precisely to explain the pattern of masses and mixing angles of the quarks and leptons. Namely, when additional fields that have non-aligned couplings to the SM
fermions, i.e. which are not diagonalized by the same rotations that diagonalize the fermion mass matrices, and also couple to the Higgs boson, then such fields could be responsible for transmitting the structure of the flavor sector to the Higgs bosons, thereby producing a more flavored Higgs boson [15]. Depending on the nature of such new physics, we can identify two possibilities for flavor-Higgs mediation, namely:

• **RADIATIVE MEDIATION.** In this case the Higgs sector has diagonal couplings to the fermions at tree-level. However, the presence of new particles associated with extended flavor physics, which couple both to the Higgs and to the SM fermions, will induce corrections to the Yukawa couplings and/or new FCNC process at loop levels. Within the MSSM, it can be shown that flavor-Higgs mediation is of radiative type, and it communicates the non-trivial flavor structure of the soft-breaking sector to the Higgs bosons through gaugino-sfermion loops.

  1. As an illustration of the SUSY case, we have evaluated the slepton-gaugino contributions to the LFV Higgs-lepton vertices, with slepton mixing originating from the trilinear $A_l$-terms. The slepton mixing is constrained by the low-energy data, but it mainly suppress the FV’s associated with the first two family sleptons, and still allows the flavor-mixings between the second- and third-family sleptons, to be as large as $O(1)$. Thus, the general $6 \times 6$ slepton-mass matrix can be reduced down to a $4 \times 4$ matrix, involving only the smuon and stau sectors. Such pattern of large slepton mixing, and the resulting $h\tau\mu$ coupling can also be motivated by the large neutrino mixing observed with atmospheric neutrinos [2]. For this pattern of large trilinear $A$-terms, we find that bounds on $\tau - \mu$ transitions, allow the decay mode $h \rightarrow \tau \mu$, to reach a B.R. of the order $10^{-4}$, which enters into the domain of detectable signals [16].

  2. This reduction of sfermion mass matrices was discussed first for the squarks in ref. [17]. Similar mixing between the stop and scharm squarks, can be tested through the rare decays of the top quark [18]; for instance one finds that the decay $t \rightarrow ch$ reaches branching ratios of the order $10^{-3} - 10^{-4}$, which could be detected at future hadron colliders, such as LHC.

• **MIXING MEDIATION.** Modifications to the Higgs-flavor structure can also arise when additional particles (bosons or fermions) mix with the SM ones. These new interactions could then be transmitted to the Higgs sector, either through scalar-Higgs mixing or through mixing of SM fermions with exotic ones. Some models where this flavor-violating Higgs interactions appear are:

  1. In the general Two-Higgs doublet model (THDM-III) [19, 20], where large FV Higgs couplings are allowed, we obtain $B.R.(H \rightarrow \tau \mu/\tau e) \approx 10^{-1}$ [7], which can be detected at Tevatron Run-II and LHC [16].

  2. Along these lines we have also considered a multi-Higgs $E_6$-inspired model, supplemented with an abelian flavor symmetry, where similar rates for $h \rightarrow \tau \mu$ are obtained [15].

  3. We have also consider mixing between SM and exotic fermions, within the context of a LR model with mirror fermions [21] as a source of LFV , when
this is transmitted to the Higgs sector, it induces the decay \( h \rightarrow \tau \mu \) at detectable rates.

Thus, as a consequence of the presence of LFV Higgs interactions, the decay \( h \rightarrow \tau \mu \) can be induced at rates that could be detected at future colliders, such as Tevatron and LHC. Large LFV Higgs couplings could be the manifestation of a deeper link between the Higgs and flavor sectors.

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