Flavored Multi-Higgs models

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Outline

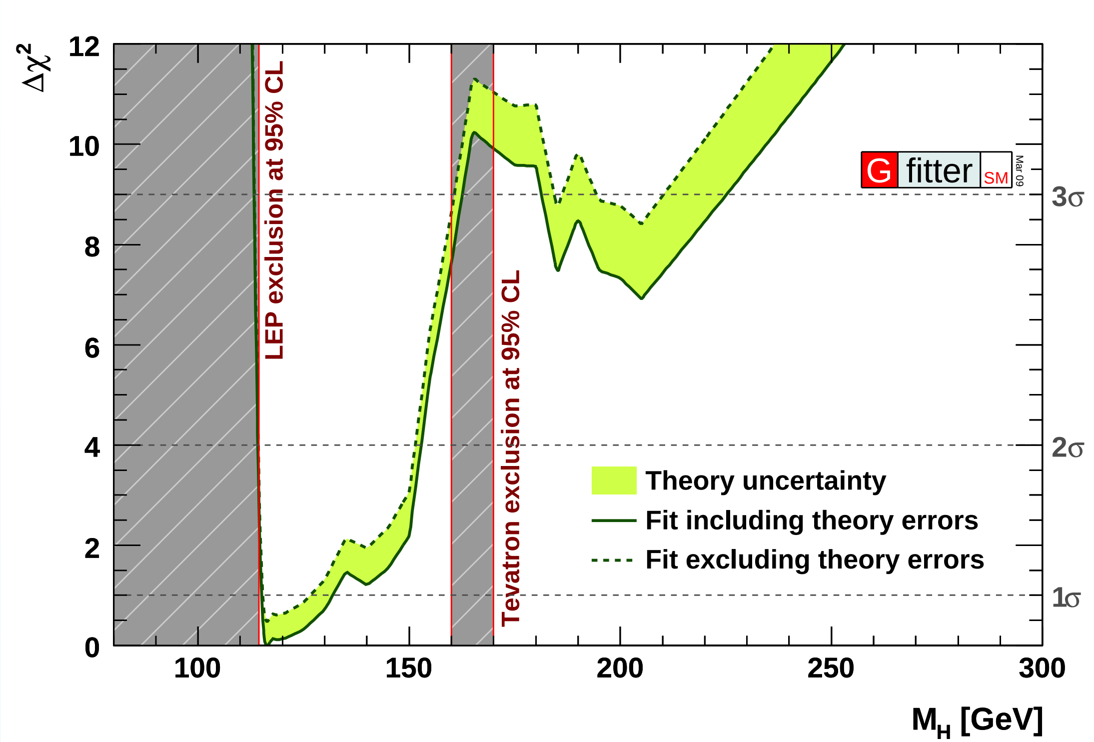
1. Scalars- Motivation
2. A more flavored Higgs sector?
3. A 3 Higgs doublet Model (3HDM)
4. Phenomenology:
   Low Energy Constraints and Colliders Signals
5. Conclusions.

1.1 Electroweak symmetry breaking

- Within the SM, SSB in needed for $SU(2)_L \times U(1)_Y \to U(1)_{em}$,
- In the Minimal Model with one doublet: $\Phi = (\phi^+, \phi^0)$, an scalar particle remmains, the Higgs boson,
- The distinctive characteristic of the Higgs boson is that it couples to the mass of the particles,
- Rad. Corrs. prefere a light Higgs, with a mass of order of the EW scale ($m_{\phi_{SM}} \simeq v$).
- LHC is already probing the Higgs sector of the SM, (most interesting time I have seen in physics in my life, so far)

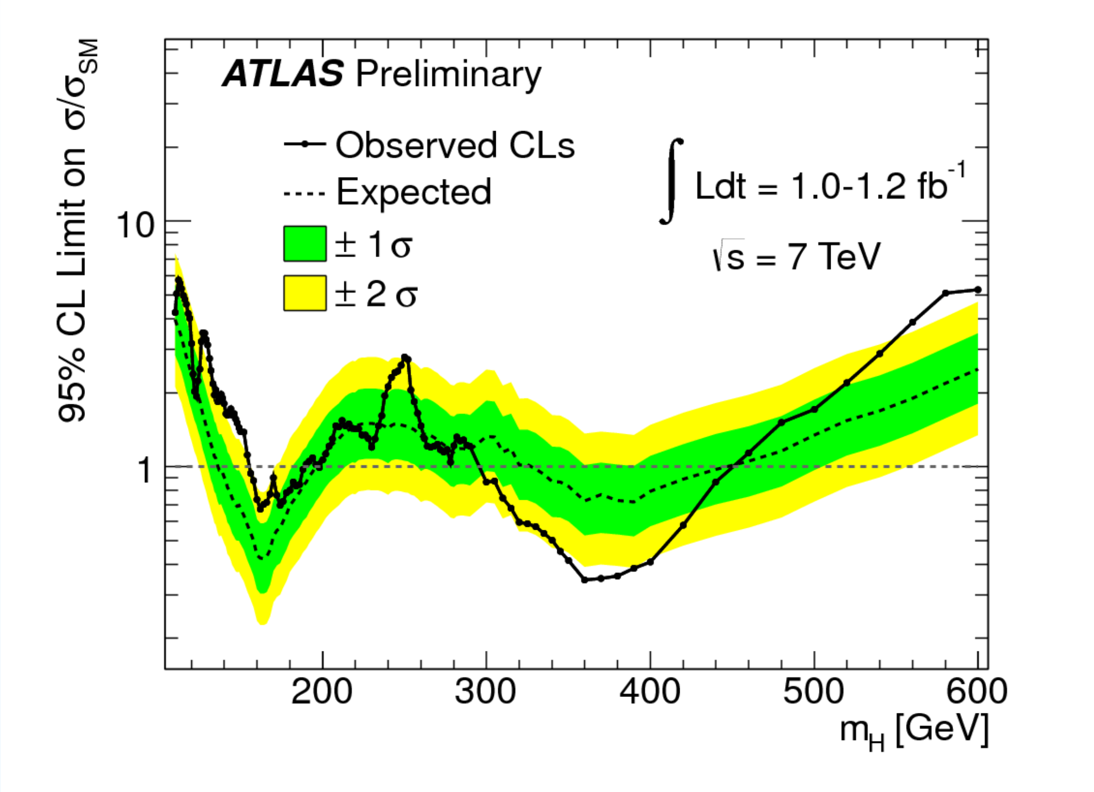
In "Why I would be very sad if a Higgs boson is discovered", H. Georgi argues that one should distinguish between the Higgs Mecanism and the Higgs boson,

1.2 Higgs mass limits



1.3 The LHC Great Results

1.3b Higgs search at LHC - ATLAS



1.4 Scenarios of New Physics

There are open problems in the SM:

- Large/Little hierarchy problem,
- Neutrino masses,
- Strong CP problem,
- Dark Matter,
- Cosmological constant (Dark energy),
- Some deviations from the SM (a few std. dev.),
  e.g. Δa_μ, etc.
- Aesthetical questions,

They all suggest the need for New Physics.

1.5 Scenarios of New Physics

Models of New Physics often $\rightarrow$ Multi-Scalar spectrum:

- Hierarchy problem
  SUSY $\rightarrow$ Two-Higgs doublet model
- Neutrino masses
  Radiative $\rightarrow$ Higgs triplets
  LR models $\rightarrow$ Higgs triplets, doublets and bi-doublets,
- Strong CP problem
  Pecce-Quinn $\rightarrow$ Two-Higgs doublet model,
- Dark Matter
  Inert HM $\rightarrow$ Scalar DM,

1.6 Multi-Higgs models

Multi-Higgs models are usefull, cheap, economical.....and takes you almost everywhere.

2.1 Hierarchy-first paradigm

There seems to be good reasons to think that,

- New Physics associated with hierarchy problem has an scale of O(TeV),
- Threfore, this new physics will show up first at LHC,
- However, LHC needs to find the Higgs first,
  "In order to explore new countries in another continent you need to know first that the continent exists" (G.S.)
- Further, possible that new flavor physics is not far (or unrelated) with physics of hierarchy problem,
- Models with low-flavor scale can be constructed,
  Q. The standard LHC search for Higgs gets modified?

2.2 Higgs and Flavor

- The SM Higgs boson knows about flavor but only to a certain extent, i.e. it distinguish the generations through the diagonal fermion masses,
- But in extentions of the SM one could get a "more flavored Higgs sector", where the Higgs couples with fermions of different families.
- IN fact, adding another Higgs doublet could induce plenty of flavor signals,
  When both Higgs doublets in 2HDM couple to all types of fermions, FCNC are induced at tree-level,
- Low-energy FCNC processes imposse strong constraints on the possible Higgs-fermion couplings.

2.3 Dealing with Flavor problem

- Decoupling,
- Natural Flavor Conservation,
- Minimal Flavor Violation,
- Mass Textures,
- Alignment,

Flavor symmetries could be used in some of those scenarios,

But what works for 2HDM may not for NHDM...

3.1 Models with 3 Higgs models doublets

- Here, we are interested in multi-Higgs doublet models which reproduces the fermion masses and mixing angles.
- Flavor symmetries are used to get correct fermion mass matrices,
- We focus on models with 3 Higgs doublets, where Higgs doublets are charged under a flavor symmetry.
- We look for textures/scenarios that can pass all constraints,
- Then, look for distinguish new Higgs signals at LHC,

3.2 Yukawa lagrangian in 3HDM

In our model $\Phi_{1,2,3}$ couple to both d- and u-type quarks:

- Flavor violating Neutral Higgs interactions are induced at tree-level,
- Fermion mass textures are needed to keep under control FCNC,
  A particular non-hermitic NNI texture arise from the flavor simmetry,
- However, it is possible to find other textures,
  From Minimal Flavor violation $\rightarrow$ Fritszch -like textures,
- Interesting to study Higgs phenomenology (flavor and LHC),

3.3 Flavor Symmetry- Abelian

Flavor symmetry under which the fields in the model are charged as:

Q_1	Q_2	Q_3	u_1	u_2	u_3	d_1	d_2	d_3	H_1	H_2	H_3
$-a$	$-b$	0	a	b	0	$-2b$	$-a-b$	$-b$	$a+b$	b	0

The charges are chosen so that $|a| \neq \{|b/2|, |b|, |2b|\}$.

After spontaneous breaking of the electroweak symmetry, Φ_1, Φ_2 and Φ_3 acquire vevs (v_1, v_2, and v_3, in obvious notation, and where we assume CP-even vevs). Thus, $\phi_a^0 = \frac{1}{\sqrt{2}}(v_a + \phi_{Ra}^0 + i\phi_{Ia}^0)$.

3.4 Mass matrices

The resulting mass matrices are of the form (non-Hermitic Fritzsch-like):

$$M_u^0 = \begin{pmatrix} 0 & v_1 y_{12}^u & 0 \\ v_1 y_{21}^u & 0 & v_2 y_{23}^u \\ 0 & v_2 y_{32}^u & v_3 y_{33}^u \end{pmatrix} \, , \quad M_d^0 = \begin{pmatrix} 0 & v_2 y_{12}^d & 0 \\ v_2 y_{21}^d & 0 & v_3 y_{23}^d \\ 0 & v_1 y_{32}^d & v_2 y_{33}^d \end{pmatrix} \, ,$$

Only small deviations from hermiticity are needed in order to fit fermion masses and CKM (Branco et al)

3.5 FCNC problem

The mass matrices are of the form:

$$M_f^0 = \begin{pmatrix} 0 & A_f & 0 \\ A_f' & 0 & B \\ 0 & B_f' & C_f \end{pmatrix} ,$$

Then, Higgs-fermion couplings are of the form (Cheng-Sher):

(1) $$(hf_if_j) \simeq \frac{1}{v_i}\sqrt{m_i m_j}$$

which are known to have acceptable FCNC, but...

3.6 Fermion mass Diagonalization

- Split the full mass matrix: $M_f^0 = H_f^0 + \Delta M_f$,

(2) $$\bar{M}_f = O_L^f M_f^0 O_R^{f\dagger}$$

- Perform diagonalization of the hermitic part (H_f^0), with $O_L^f = O_R^f = O_f$,
- Approximate full diagonalzation: $O_L^f = O_f(1+X)$, $O_R^f = O_f(1-X)$, with X obtained pert.

3.7 Higgs-fermion couplings

- $$\mathcal{L}_{(Y_f)_{ij}} = \frac{1}{2}\bar{f}_i \left([(\Lambda_b^f)_{ij} + \Lambda_b^{f*})_{ji}] + [(\Lambda_b^f)_{ij} - \Lambda_b^{f*})_{ji}]\gamma_5 \right) f_j h_b^0 + h.c.$$
(3)
- When we neglect the phases we obtain:

(4)
$$\mathcal{L}_{(Y_f)_{ii}} = \bar{f}_i \left([(\Lambda_b^f)_{ii}] \right) f_j h_b^0 + h.c.$$

3.8 FC Higgs couplings

We can further write the conefficients Λ's as follows:

(5)
$$(\Lambda_a^f)_{ii} = g_{sm}^{fi}\chi_{ia}^f = \frac{m_{fi}}{v}\chi_a^f$$

(6)
$$\begin{aligned}
\chi_a^s &= U_{1a}\frac{v}{v_1} \\
\chi_a^b &= U_{2a}\frac{v}{v_2} - U_{1a}\frac{vm_s}{v_1 m_b} \\
\chi_a^c &= 2U_{2a}\frac{v}{v_2} + U_{3a}\frac{v}{v_3} \\
\chi_a^t &= U_{3a}\frac{v}{v_3} - 2U_{2a}\frac{vm_c}{v_2 m_t} \\
\chi_a^\mu &= U_{1a}\frac{v}{v_1} \\
\chi_a^\tau &= U_{2a}\frac{v}{v_2} - U_{1a}\frac{vm_\mu}{v_1 m_\tau}
\end{aligned}$$

3.9 FV Higgs couplings

For top-charm-higgs coupling we find:

$$\mathcal{L}_{h_a tc} = \bar{t}\left([(\Lambda_a^u)_{\bar{t}c}]\right) c h_a^0 + h.c. \tag{7}$$

We can further write the coefficients Λ's as follows:

$$(\Lambda_a^u)_{\bar{t}c} = \frac{\bar{m}_{ct}}{v}\chi_{tc}^a \tag{8}$$

where $\chi_{ct}^a = \frac{v}{v_3}U_{3a}$.

3.10 Higgs-Gauge interactions

The interaction of the Higgs particles with the W and Z gauge bosons are obtained from the covaraint derivative, which also produce the corresponding masses,

(9)
$$\mathcal{L}_{hWW} = g m_W \chi_a^W W^{+\mu} W_\mu^- h_a^0 + h.c.$$

χ_a^W is given in terms of the vevs v_i and the Higgs rotation matrix U_{ab} as follows:

(10)
$$\chi_a^W = \frac{v_1}{v} U_{1a} + \frac{v_2}{v} U_{2a} + \frac{v_3}{v} U_{3a}$$

4.1 The Higgs spectrum of 2HDM-III

- The Higgs potential is constrained by the symmetry, (But we assume CP conservation),
- Masses and mixing angles are obtained numerically.
- In general we find that the model requires:
  $v_1, v_2 << v_3 \simeq v_{sm}$,
  $v = v_{sm} = (v_1^2 + v_2^2 + v_3^2)^{1/2}$,
- CP-even neutral Higgs bosons h_1^0, h_2^0, h_3^0, with $m_{h1} < m_{h2} < m_{h3}$,

$$\phi_R^0 = U_{ab} h_b^0 \tag{11}$$

- CP-odd neutral Higgses A_1^0, A_2^0,
- Pair of Charged Higgs $H_1^\pm, H_2^\pm$,
  Contribution to $b \to s + \gamma$?

4.2 Light-Higgs scenarios:

A summary of the resulting Higgs-fermion couplings is shown in the next table.
We have taken a set of parameters with $v_1 = 7GeV$, which give $m_{h1} = 92.2$ GeV

v_2 [GeV]	χ^1_{cc}	χ^1_{tt}	χ^1_{ss}	χ^1_{bb}	$\chi^1_{\mu\mu}$	$\chi^1_{\tau\tau}$	χ^1_{WW}
10	38.5	-0.29	21.9	18.8	21.9	17.9	0.09

(These cases may have problems with FCNC, K-K mixing mainly)

4.3 Heavy Higgs scenario

- Another set of parameters, with $v_1 = 10$ GeV, $v_2 = 20$ GeV,
- Heavier Higgs bosons are obtained,
  e.g. $m_{h1} = 186.3$ GeV, $m_{h2} = 236.5$ GeV, $m_{h3} = 292.2$ GeV
- Higgs bosons have reduced couplings with gauge bosons, so it is not clear how LHC recent bounds apply,
- All bounds on FCNC are satisfied,

5. Conclusions

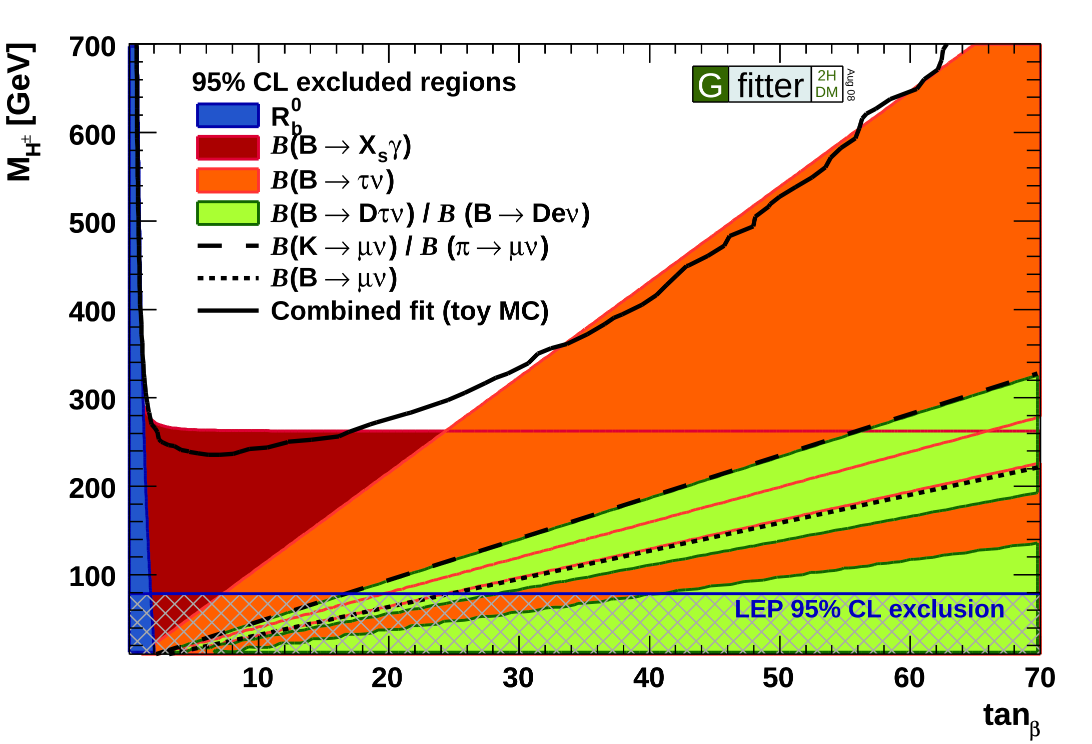
- We have studied a 3HDM,
- The structure of one model favors a lighht neutral Higgs boson, with enhanced coupling to the fermions of the second generation, as well as the b-quark and the tau lepton.
- In such case the production of the Higgs through charm fusion receives a significant enhancement.
- Another relevant signal is the associated production of the Higgs boson with b-pairs, with the Higgs decaying into b-pairs, tau pairs or even into muon pairs.
- need to identify scenarios that satisfy all the constraints (work in progress),

3.x Higgs and Flavor

Rare B decays have been used to constrain the Neutral and Charged Higgs sector in THDM (and BSM)

- $B.R.(B \to X_s + \gamma)_{exp.} = (3.55 \pm 0.24)x10^{-4}$:
  (SM prediction: $B.R. = (3.15 \pm 0.23)x10^{-4}$)
- $B.R.(B_s \to \mu\mu)_{exp.} \leq 5.8x10^{-8}$:
  (SM prediction:$B.R.(B_s \to \mu\mu) = 3x10^{-9}$)
- $B \to \tau\nu$, $B \to \mu\nu$,
- $B \to D\tau\nu$
- $\tau \to \mu\nu\nu$

3.y Flavor and Higgs



1.2b Higgs B.R.'s

1.2c Higgs cross sections

2.x 4-Texture - 2HDMIII

(12) $$M^q = \begin{pmatrix} 0 & C_q & 0 \\ C_q^* & \tilde{B}_q & B_q \\ 0 & B_q^* & A_q \end{pmatrix} \qquad (q = u, d) \ ,$$

(13) $$\left[\tilde{Y}_n^q\right]_{ij} = \frac{\sqrt{m_i^q m_j^q}}{v} \ [\tilde{\chi}_n^q]_{ij} = \frac{\sqrt{m_i^q m_j^q}}{v} \ [\chi_n^q]_{ij} \ e^{i\vartheta_{ij}^q}$$