Wish you were here (The SM Higgs and beyond)

J. Lorenzo Diaz Cruz [a]

jldiaz@fcfm.buap.mx

FCFM-BUAP and DUAL-CP IHEP

(Mexico)

[a] MWPF 2011, Leon

Outline

1. Scalars- History and Motivation
2. SM Higgs search at LHC (then what?)
3. New Physics and the Higgs sector
4. Multi-Higgs doublet Models
   3-higgs doublet model with flavour:
   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,

2. Why call it *THE HIGGS*???

From J. Ellis (at Higgs Hunting 2011, Orsay)

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium
(Received 26 June 1964)

It is of interest to inquire whether gauge vector mesons acquire mass through interaction[1]; by a gauge vector meson we mean a Yang-Mills field[2] associated with the extension of a Lie group from global to local symmetry. The importance of this problem resides in the possibility that strong-interaction physics originates from massive gauge fields related to a system of conserved currents.[3] In this note, we shall show that in certain cases vector mesons do indeed acquire mass when the vacuum is degenerate with respect to a compact Lie group.

those vector mesons which are coupled to currents that "rotate" the original vacuum are the ones which acquire mass [see Eq. (6)].

We shall then examine a particular model based on chirality invariance which may have a more fundamental significance. Here we begin with a chirality-invariant Lagrangian and introduce both vector and pseudovector gauge fields, thereby guaranteeing invariance under both local phase and local γ_5-phase transformations. In this model the gauge fields themselves may break the γ_5 invariance leading to a mass for the original Fermi field. We shall show in this case

GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

G. S. Guralnik,† C. R. Hagen,‡ and T. W. B. Kibble
Department of Physics, Imperial College, London, England
(Received 12 October 1964)

In all of the fairly numerous attempts to date to formulate a consistent field theory possessing a broken symmetry, Goldstone's remarkable theorem[1] has played an important role. This theorem, briefly stated, asserts that if there exists a conserved operator Q_i such that

$$[Q_i, A_j(x)] = \sum_k t_{ijk} A_k(x),$$

and if it is possible consistently to take $\sum_k t_{ijk} \times \langle 0|A_k|0\rangle \neq 0$, then $A_j(x)$ has a zero-mass particle in its spectrum. It has more recently been observed that the assumed Lorentz invariance essential to the proof[2] may allow one the hope of avoiding such massless particles through the introduction of vector gauge fields and the consequent breakdown of manifest covariance.[3] This, of course, represents a departure from the assumptions of the theorem, and a limitation on its applicability which in no way reflects on the general validity of the proof.

In this note we shall show, within the framework of a simple soluble field theory, that it is possible consistently to break a symmetry (in the sense that $\sum_k t_{ijk}\langle 0|A_k|0\rangle \neq 0$) without requiring that $A(x)$ excite a zero-mass particle. While this result might suggest a general procedure for the elimination of unwanted massless bosons, it will be seen that this has been accomplished by giving up the global conservation law usually

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BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

At Warsaw 2011 conference it was called "The Scalar".

2.b 4 lines worth for a Nobel

In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these particles (which would be absent if their mass were zero) go over into the Goldstone bosons when the coupling tends to zero. This phenomenon is just the relativistic analog of the plasmon phenomenon to which Anderson[3] has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal plasmon modes of finite mass when the gas is charged.

presented elsewhere.

It is worth noting that an essential feature of the type of theory which has been described in this note is the prediction of incomplete multiplets of scalar and vector bosons.[8] It is to be expected that this feature will appear also in theories in which the symmetry-breaking scalar fields are not elementary dynamic variables but bilinear combinations of Fermi fields.[9]

3. Higgs mechanism

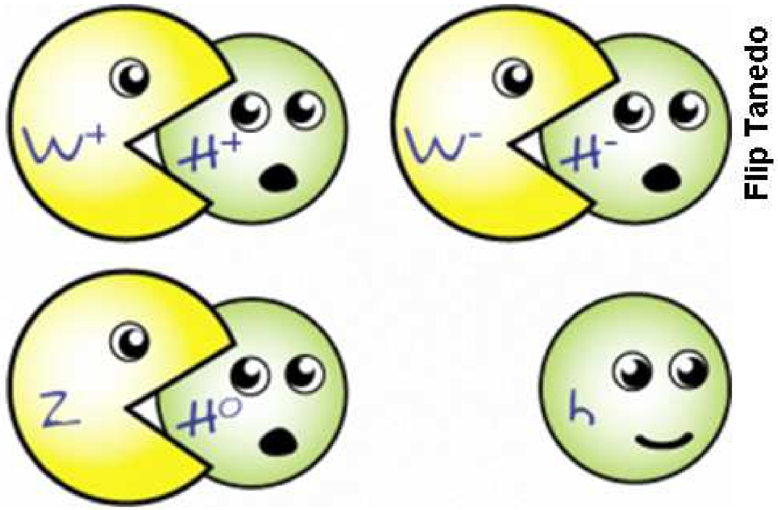
But part of the Higgs multiplet has been observed,

10 octubre 2011

El bosón de Higgs y sus tres hermanos "difuntos"

Archivado en: Bosón de Higgs,Ciencia,Física,Noticias,Physics,Science — emulenews @ 22:59

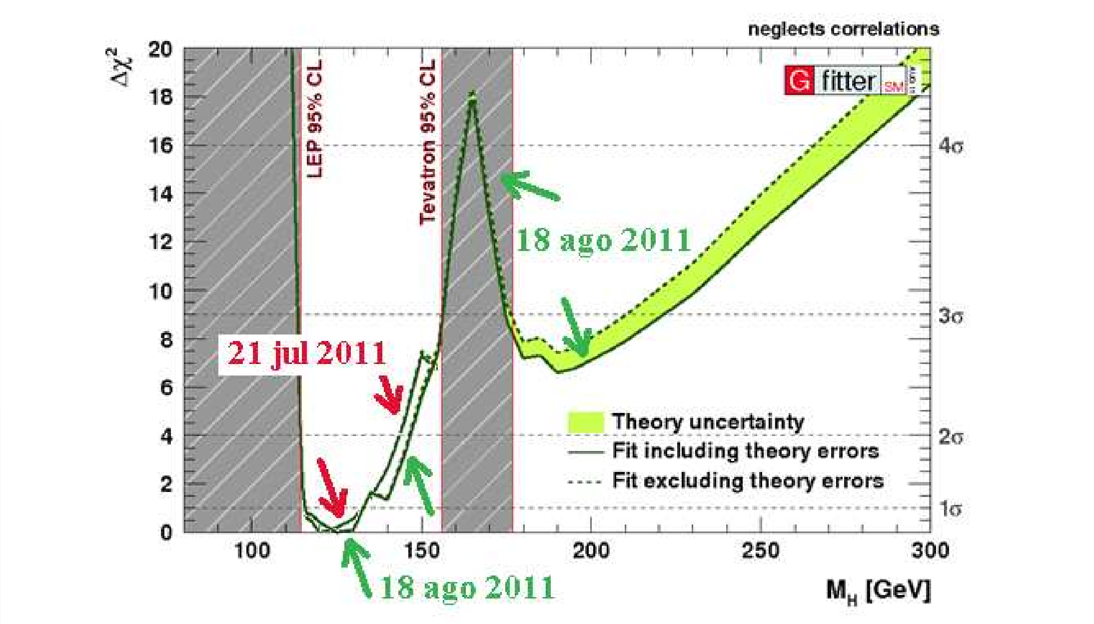
Tags: Bosón de Higgs, Ciencia, curiosidades, Física, física teórica, partículas elementales



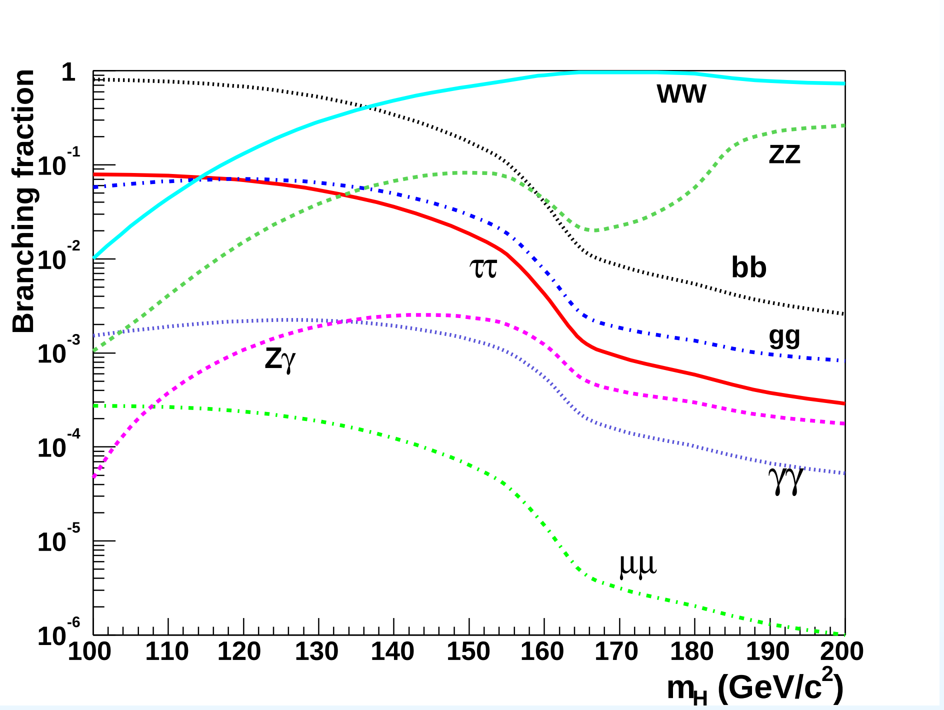
It remamins to test that the 4th component (h) exists, and whether it forms a doublet, as minimal model predicts

2.1 The LHC Great Results

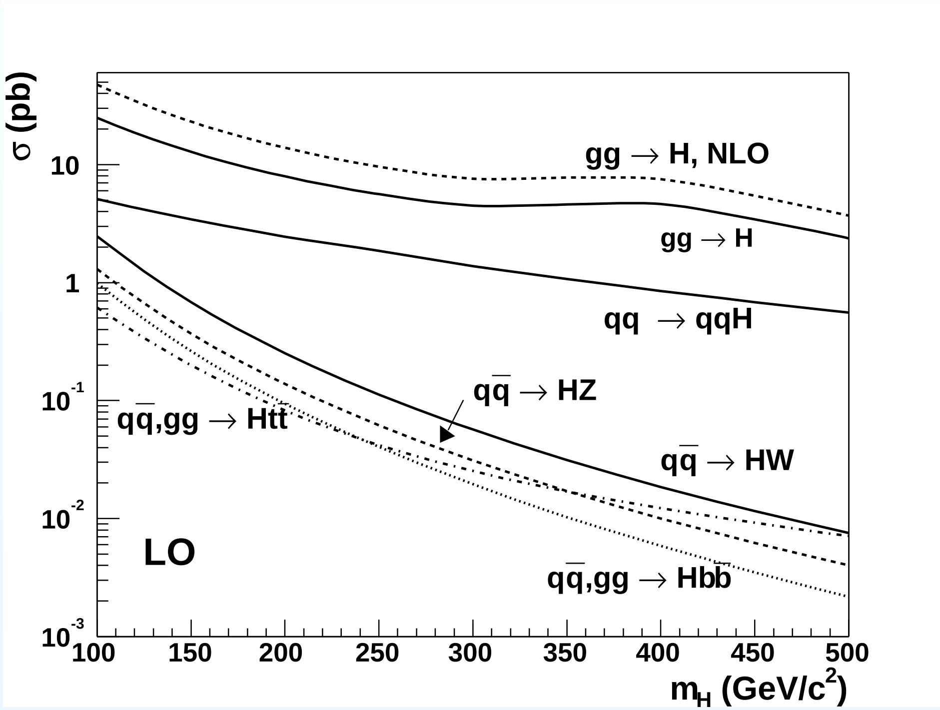
2.2 Where is the Higgs?



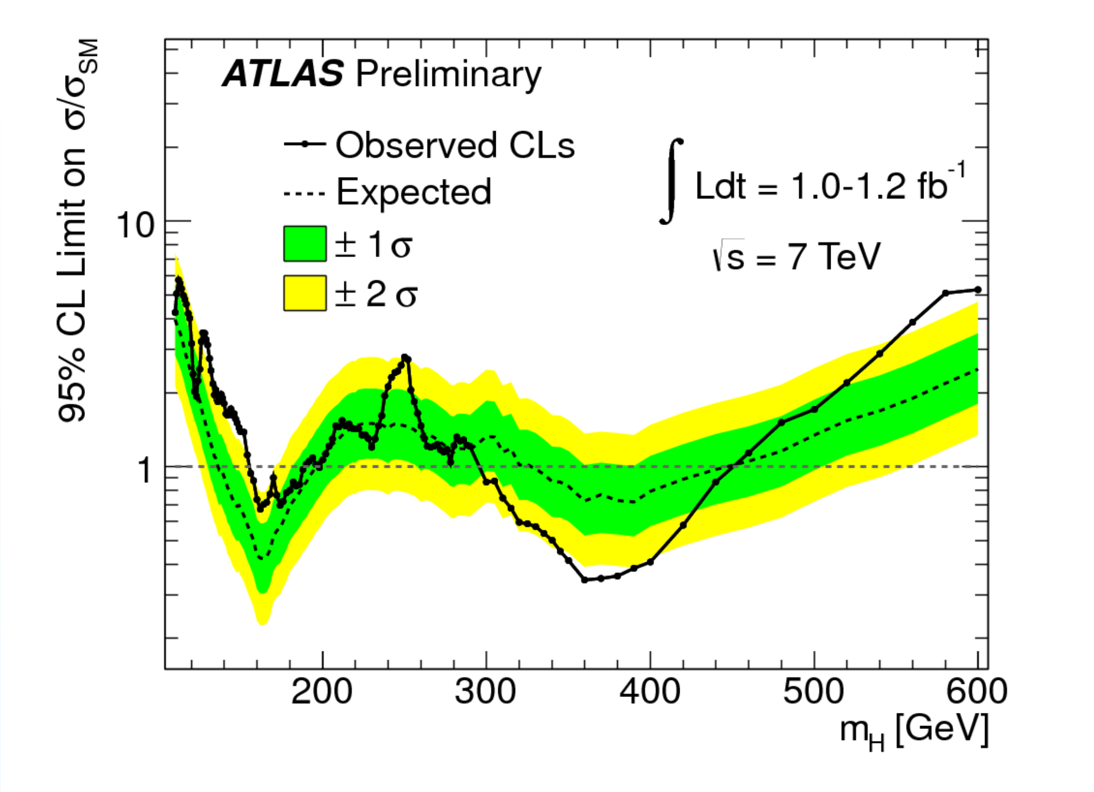
2.3 The LHC Great Results



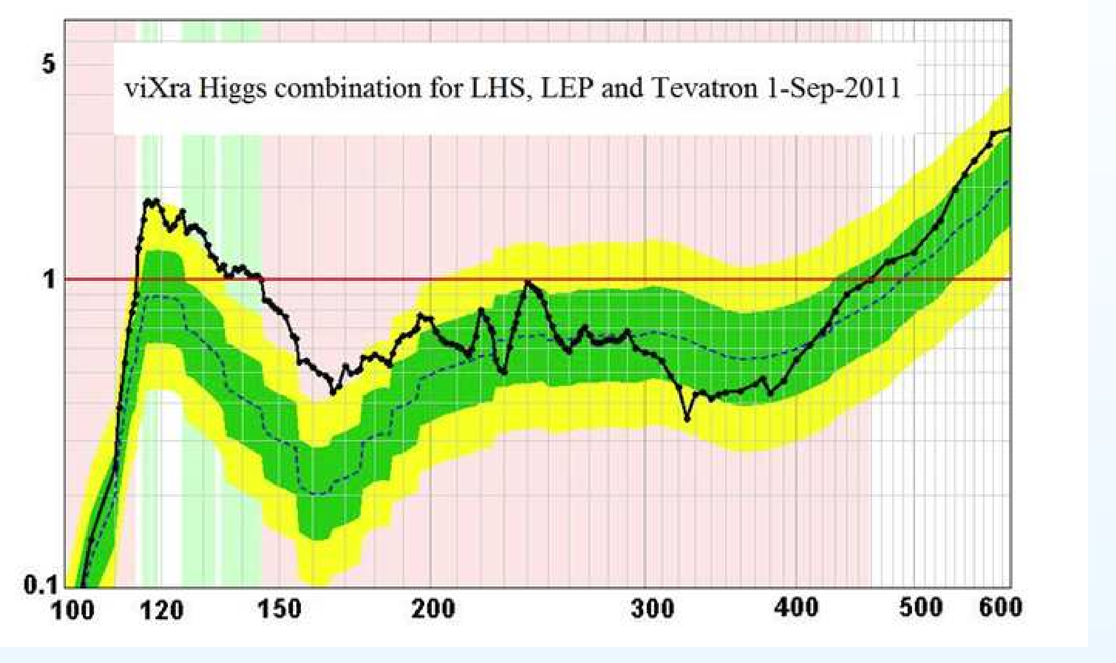
2.4 The LHC Great Results



2.5 Higgs search at LHC - ATLAS



2.6 Unofficial combined results



3.1 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,

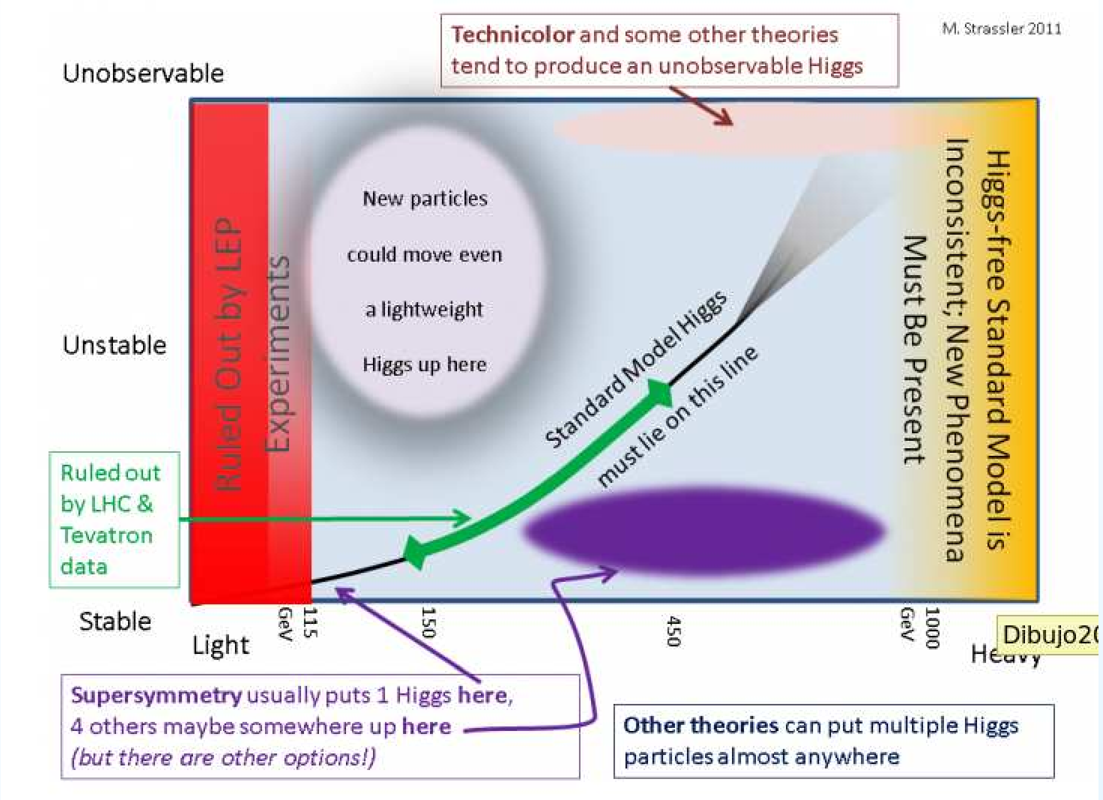
They all suggest the need for New Physics.

3.2 Scenarios of New Physics

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

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

3.3 To Higgs or not to Higgs?



3.4 NLC needed to test Higgs properties

En "La mula de Francis":

El mecanismo de Higgs tiene múltiples ventajas técnicas desde el punto de vista matemático en una teoría gauge, destacando que es renormalizable a todos los órdenes (no conozco ningún otro mecanismo alternativo para el que esté demostrado que lo sea) y que es genérico para cualquier unificación de campos gauge (cualquier ruptura espontánea de simetrías gauge). Cualquier otro mecanismo dinámico de ruptura de la simetría que explique la transición de fase electrodébil (hay muchísimas propuestas) debe coincidir con todo detalle con el mecanismo de Higgs en la escala de energías de dicha transición de fase (difiriendo solo a energías mucho más altas). Esta coincidencia requiere un ajuste fino de sus parámetros; dependiendo de la teoría concreta el ajuste es más fino o menos fino, pero el principio de la navaja de Ockham prefiere la explicación que no requiere ningún ajuste fino, cuando la hay, y en este caso la hay, es el mecanismo de Higgs. Un parámetro de este tipo es el parámetro rho de Veltman (1980), exactamente la unidad en el mecanismo de Higgs (a primer orden en la teoría de perturbaciones), pero que difiere de ella en teorías alternativas. Otro parámetro es el introducido por los mexicanos Diaz-Cruz y Lopez-Falcon, también igual a la unidad en el mecanismo de Higgs pero que difiere de ella en otras teorías.

4. Multi-Higgs models

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

4.1 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 verify 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?

4.2 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.

4.3 Dealing with Flavor problem in NHDM

- 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...

4.4 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, work on how to distinguish new Higgs signals at LHC,

4.5 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),

4.6 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, $\phi_a^0 = \frac{1}{\sqrt{2}}(v_a + \phi_{Ra}^0 + i\phi_{Ia}^0)$.

4.7 Mass matrices

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

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

Shining and Twisted textures, resp.

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

4.8 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):

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

which are known to have acceptable FCNC, but $1/v_i$ factors may give extra enhancement,

4.9 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.

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

4.11 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)
$$\begin{aligned}
\chi_a^s &= U_{1a}\frac{v}{v_1} \\
\chi_a^b &= U_{2a}\frac{v}{v_2} - U_{1a}\frac{vm_s}{v_1 m_b} \\
\chi_a^c &= 2U_{2a}\frac{v}{v_2} + U_{3a}\frac{v}{v_3} \\
\chi_a^t &= U_{3a}\frac{v}{v_3} - 2U_{2a}\frac{vm_c}{v_2 m_t} \\
\chi_a^\mu &= U_{1a}\frac{v}{v_1} \\
\chi_a^\tau &= U_{2a}\frac{v}{v_2} - U_{1a}\frac{vm_\mu}{v_1 m_\tau}
\end{aligned}$$

4.12 FV Higgs couplings

For top-charm-higgs coupling we find:

(7) $$\mathcal{L}_{h_a tc} = \bar{t}\,([(\Lambda^u_a)_{\bar{t}c}])\, c h^0_a + h.c.$$

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

(8) $$(\Lambda^u_a)_{\bar{t}c} = \frac{\bar{m}_{ct}}{v}\chi^a_{tc}$$

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

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

4.14 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
  $m_{h1} < m_{h2} < m_{h3}$,

$$\phi_R^0 = U_{ab} h_b^0 \quad (11)$$

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

4.15 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)

4.16 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

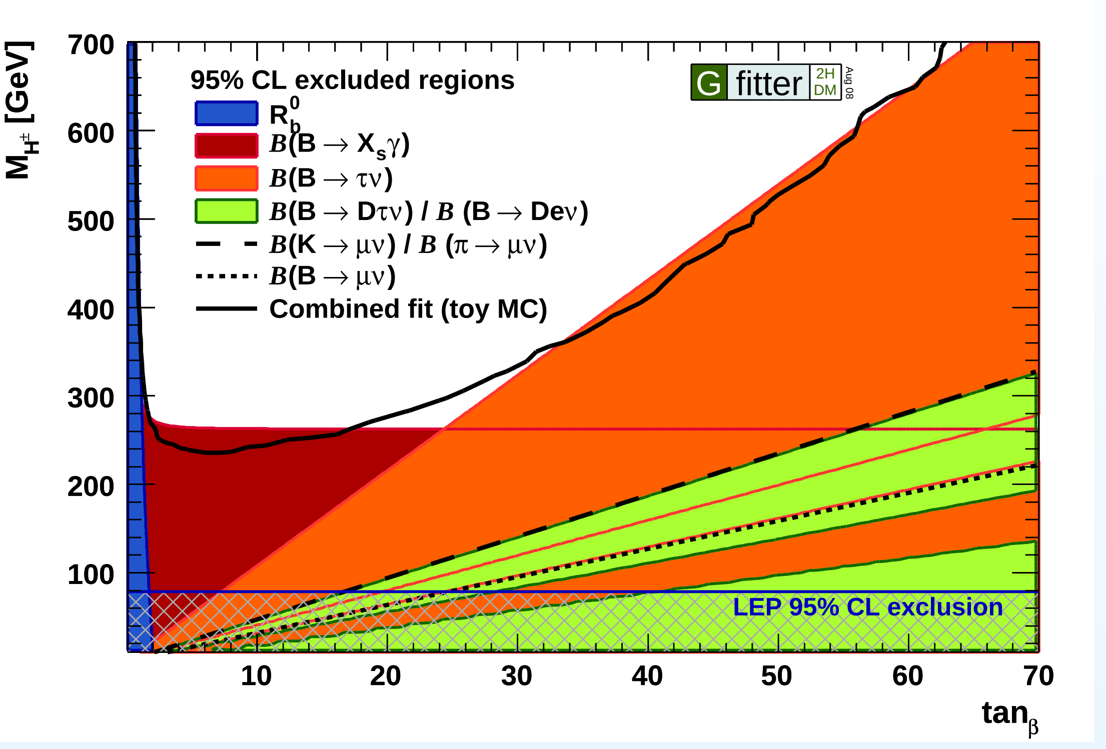
- The Higgs is the Higgs,
- LHC will show us the way,
- A 3HDM can give different Higgs phenomenology:
  Production of the Higgs through charm fusion receives a significant enhancement,
  Associated production of the Higgs boson with b-pairs, with the Higgs decaying into b-pairs, tau pairs or even into muon pairs, is also relevant

3.x Higgs and Flavor

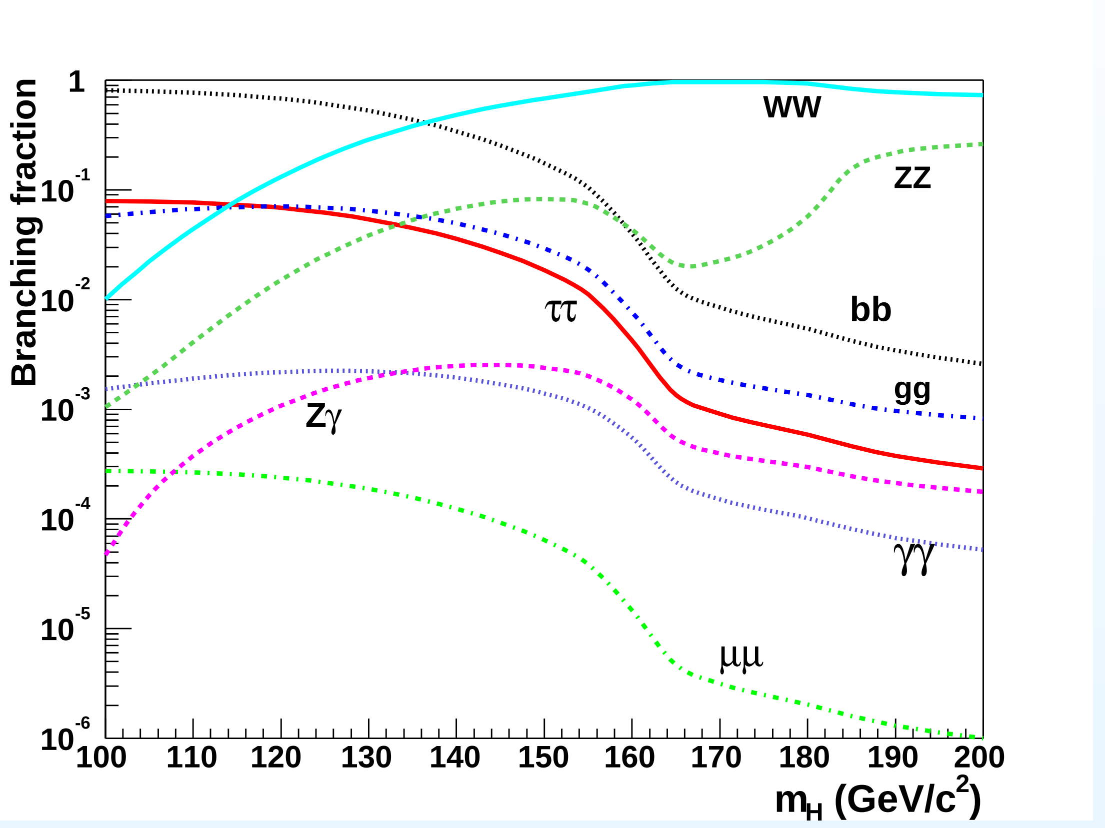
Rare B decays have been used to constrain the Neutral and Charged Higgs sector in THDM (and BSM)

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

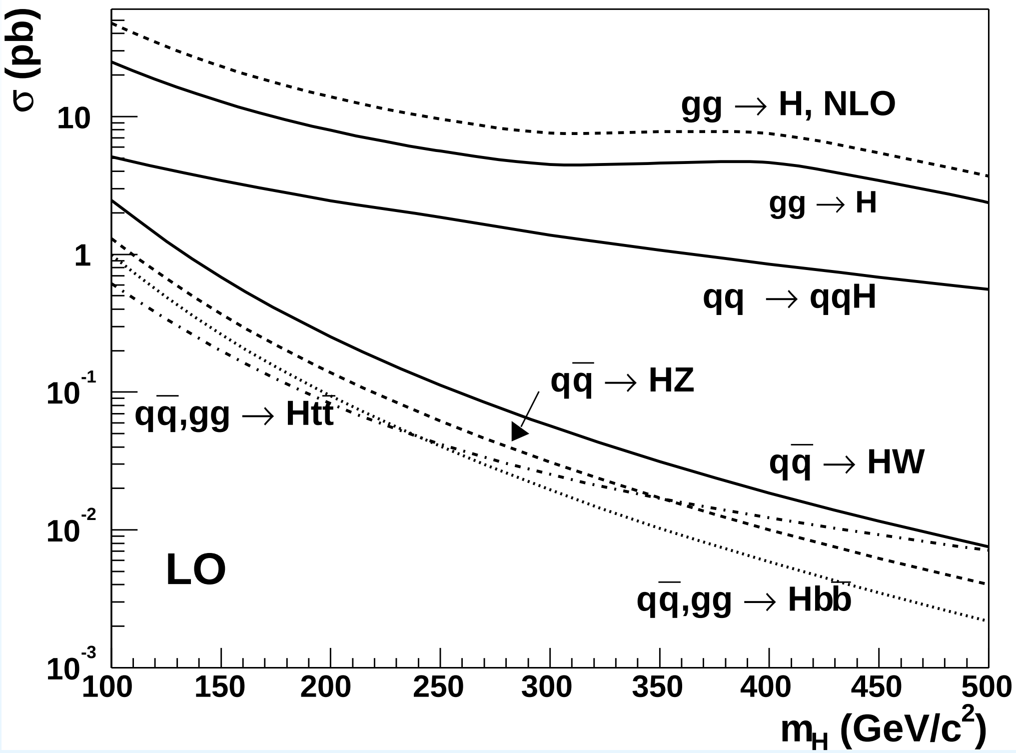
3.y Flavor and Higgs



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