A Resolution of the Flavor Problem of Two Higgs Doublet Models wit h an Extra $U(1)_H$ Symmetry for Higgs Flavor

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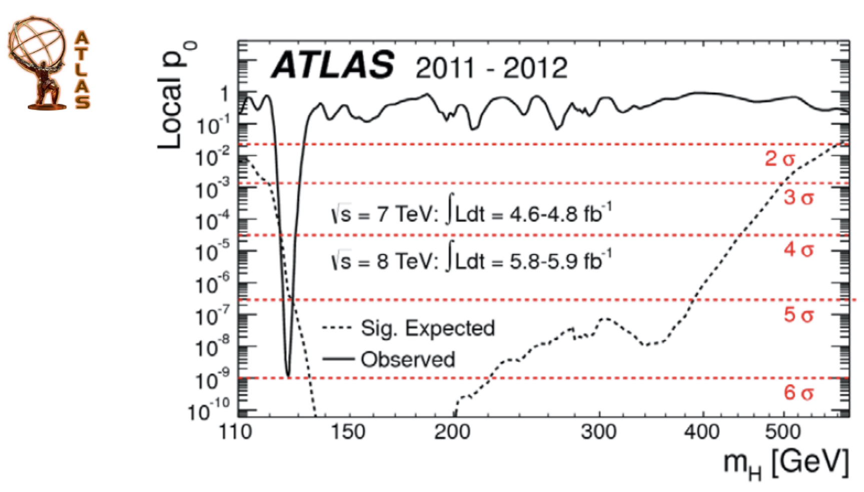
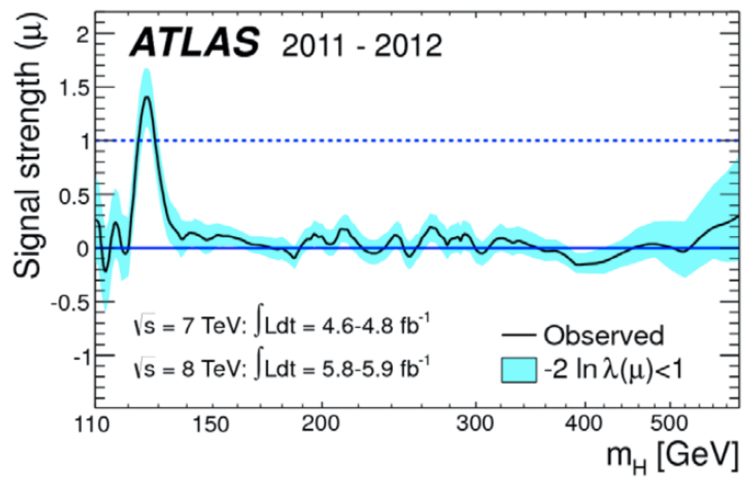
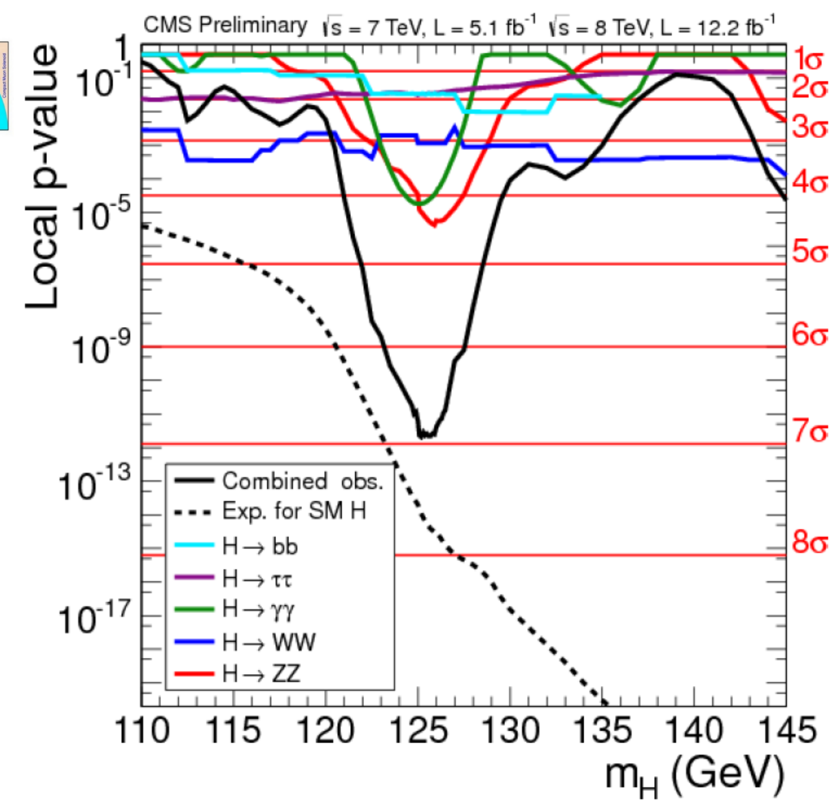
KIAS

Motivation♪

Discovery of the scalar boson at the LHC♪







SM Higgs or not?♪

- Higgs sector : the least understood part of the SM.♪
- Discovery of Higgs-like excess at the LHC address♪
  – does there exist extra Higgs boson? ♪
- Multi-Higgs scenario may be motivated by SUSY or GU T.♪

Two Higgs Doublet Model♪

- One of the simplest extension of the SM Higgs sector.♪
- In general, suffers from Flavor changing processes.♪

$$\{(V_L^{d\dagger} y_1^d V_R^d)_{ij}\cos\alpha + (V_L^{d\dagger} y_2^d V_R^d)_{ij}\sin\alpha\} H_1 \bar{D}_L^i D_R^j$$

- One sector must couple with one Higgs.♪

2HDMs♪

Z_2 symmetry♪

- A simple way to avoid FCNC problems is to assign an a d hoc Z_2 symmetry (called Natural Flavor Conservation).♪

$$Z_2 : (H_1, H_2) \to (+H_1, -H_2).$$

Assignment of Z_2 parities to the SM fermions and Higgs doublets.

Type	H_1	H_2	U_R	D_R	E_R	N_R	Q_L, L
I	+	−	+	+	+	+	+
II	+	−	+	−	−	+	+
III	+	−	+	+	−	−	+
IV	+	−	+	−	+	−	+

Generic problems of 2HDMs♪

- It is well known that discrete symmetry could generate a domain well problem when it is spontaneously broken.♪
- Usually the Z_2 symmetry is assumed to be broken softly by a dim-2 operator, $H_1^\dagger H_2$ term.♪
- The origin of such a discrete symmetry is not clear at all .♪

Potential in typical 2HDMs♪

$$V(H_1,H_2) = m_1^2 H_1^\dagger H_1 + m_2^2 H_2^\dagger H_2 + \frac{\lambda_1}{2}(H_1^\dagger H_1)^2 + \frac{\lambda_2}{2}(H_2^\dagger H_2)^2 + \lambda_3 H_1^\dagger H_1 H_2^\dagger H_2 + \lambda_4 H_1^\dagger H_2 H_2^\dagger H_1$$
$$+ BH_1^\dagger H_2 + \lambda_5 (H_1^\dagger H_2)^2 + h.c.$$

➡ Z_2 odd and source of pseudoscalar mass.♪

Gauged $U(1)_H$♪

- propose to replace the Z_2 symmetry by a new $U(1)_H$ symmetry a ssociated with Higgs flavors (h_1 ⊠ h_2).♪

$$V(H_1,H_2) = m_1^2 H_1^\dagger H_1 + m_2^2 H_2^\dagger H_2 + \frac{\lambda_1}{2}(H_1^\dagger H_1)^2 + \frac{\lambda_2}{2}(H_2^\dagger H_2)^2 + \lambda_3 H_1^\dagger H_1 H_2^\dagger H_2 + \lambda_4 H_1^\dagger H_2 H_2^\dagger H_1$$

- The massless mode is eaten by the $U(1)_H$ gauge boson. ♪
- include a singlet scalar Φ ($h_\Phi = h_1 - h_2$). ♪

$$\Delta V = m_\Phi^2 \Phi^\dagger\Phi + \frac{\lambda_\Phi}{2}(\Phi^\dagger\Phi)^2 + (\mu H_1^\dagger H_2 + h.c.) + \mu_1 H_1^\dagger H_1 \Phi^\dagger\Phi + \mu_2 H_2^\dagger H_2 \Phi^\dagger\Phi$$

Source of pseudoscalar mass♪

Models♪

Type-I 2HDM♪

Charge assignments of an anomaly-free $U(1)_H$ in the Type-I 2HDM.

Type	U_R	D_R	Q_L	L	E_R	N_R	H_1
$U(1)_H$ charge	u	d	$\frac{(u+d)}{2}$	$\frac{-3(u+d)}{2}$	$-(2u+d)$	$-(u+2d)$	$\frac{(u-d)}{2}$
$h_2 \neq 0$	0	0	0	0	0	0	0
$U(1)_{B-L}$	1/3	1/3	1/3	−1	−1	−1	0
$U(1)_R$	1	−1	0	0	−1	1	1
$U(1)_Y$	2/3	−1/3	1/6	−1/2	−1	0	1/2

- (u,d)=(0,0): ♪
  – Z_H is fermiophobic and Higgsphilic.♪
  – $H^\pm W^{\mp} Z_H$ is the main source of production of Z_H.♪
- (u,d)=(1/3,1/3): ♪
  – $U(1)_H = U(1)_{B-L}$, but Z_H gets mass from H_2 and Φ.♪
- (u,d)=(1,−1): ♪
  – $U(1)_H = U(1)_R$, and Z_H couples only with the RH fermions .♪
- (u,d)=(2/3,−1/3): ♪
  – $U(1)_H = U(1)_Y$.♪
  – If $h_2 \neq h_1$, h_2 does not couple with the SM fermions at tr ee level, but eventually interacts with the SM fermions thr ough a Z_H loop.♪

Type-II 2HDM♪

$$V_y = y_{ij}^U \bar{Q}_{Li} \tilde{H}_1 U_{Rj} + y_{ij}^D \bar{Q}_{Li} H_2 D_{Rj} + y_{ij}^E \bar{L}_i H_2 E_{Rj} + y_{ij}^N \bar{L}_i \tilde{H}_1 N_{Rj} + h.c.$$

U_R	D_R	Q_L	L	E_R	N_R	H_1	H_2
u	0	0	0	0	u	u	0

- Requires extra chiral fermions for cancellation of gauge anomaly .♪

$U(1)_H^3$

	$SU(3)$	$SU(2)$	$U(1)_Y$	$U(1)_H$
q_{Li}	3	1	2/3	$\hat{Q}_L = u + \hat{Q}_R$
q_{Ri}	3	1	2/3	$\hat{Q}_R$
n_{Li}	1	1	0	$\hat{n}_L = u + \hat{n}_R$
n_{Ri}	1	1	0	$\hat{n}_R$

$U(1)_Y U(1)_H^2$

\+ Two SM vector-like pairs♪

- The mass term of extra fermions are given by♪

$$V_m = y_{ij}^q \overline{q_{Li}} q_{Rj} \Phi + y_{ij}^n \overline{n_{Li}} n_{Rj} \Phi + y_1^l \overline{l'_{L1}} l'_{R1} \Phi + y_2^l \overline{l'_{L2}} l'_{R2} \Phi^\dagger + \text{h.c.}$$

- forbid mixting terms which may cause FCNC such as♪ $m_{ij}\bar{q}_{Li}U_{Rj}$ or $\lambda_{ij}\Phi\bar{q}_{Li}U_{Rj}$ for appropriate $U(1)_H$ charge assignment.♪

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)_H$
l_{L1}	1	2	-1/2	Q_L
l_{R1}	1	2	-1/2	Q_R
l_{L2}	1	2	-1/2	$-Q_L$
l_{R2}	1	2	-1/2	$-Q_R$

- $U(1)_H$ forbids mixing with the S M fermions. ♪
- neutral fermion could be a can didate for CDM.♪

Conclusions♪

- We proposed a new resolution of th e Higgs mediated FCNC problem in 2 HDM with gauged $U(1)_H$.♪
- easily realize "Natural Flavor Con-se rvation" for proper $U(1)_H$ assignment.♪
- Type-I cases which do not require e xtra fermions.♪
- must add extra chiral fermions for a nomaly free in most of cases.♪
  – CDM can be realized.♪
- easy to extend to Type-III and IV ca ses.♪
- Details of phenomenology would be♪ type-dependent.♪

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