The mostly SM-like Higgs, mostly . . .

This work is based on P. Draper, A. Ekstedt and H.E. Haber, in preparation

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2HDM

Potential

$$\begin{aligned}\mathscr{V} =& m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - [m_{12}^2 \Phi_1^\dagger \Phi_2 + \mathrm{h.c.}] + \tfrac{1}{2}\lambda_1 (\Phi_1^\dagger \Phi_1)^2 \\ &+ \tfrac{1}{2}\lambda_2 (\Phi_2^\dagger \Phi_2)^2 + \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) \\ &+ \left\{ \tfrac{1}{2}\lambda_5 (\Phi_1^\dagger \Phi_2)^2 + \left[\lambda_6 (\Phi_1^\dagger \Phi_1) + \lambda_7 (\Phi_2^\dagger \Phi_2)\right] \Phi_1^\dagger \Phi_2 + \mathrm{h.c.} \right\}\end{aligned}$$

Spectrum

$$\left\langle \Phi_i^0 \right\rangle = \frac{v_i}{\sqrt{2}}, \; v = \sqrt{v_1^2 + v_2^2} = \frac{2m_W}{g} = 246 \text{ GeV}, \; \tan\beta = \frac{v_2}{v_1}$$

$$h, \; H, \; A, \; H^\pm$$

Alignment

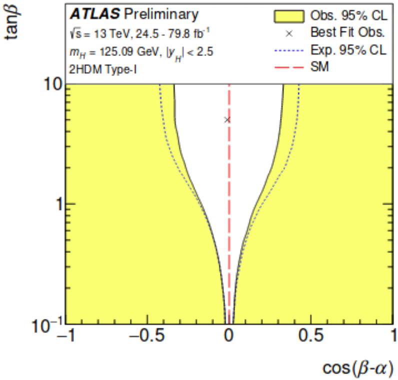
Higgs basis

$$\langle H_1 \rangle = \frac{v}{\sqrt{2}}, \ \langle H_2 \rangle = 0.$$

$$\begin{aligned}
\mathscr{V} = & Y_1 H_1^\dagger H_1 + Y_2 H_2^\dagger H_2 + Y_3 [H_1^\dagger H_2 + \mathrm{h.c.}] + \tfrac{1}{2} Z_1 (H_1^\dagger H_1)^2 \\
& + \tfrac{1}{2} Z_2 (H_2^\dagger H_2)^2 + Z_3 (H_1^\dagger H_1)(H_2^\dagger H_2) + Z_4 (H_1^\dagger H_2)(H_2^\dagger H_1) \\
& + \left\{ \tfrac{1}{2} Z_5 (H_1^\dagger H_2)^2 + \left[Z_6 (H_1^\dagger H_1) + Z_7 (H_2^\dagger H_2) \right] H_1^\dagger H_2 + \mathrm{h.c.} \right\}
\end{aligned}$$

CP-even scalars

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} c_{\beta-\alpha} & -s_{\beta-\alpha} \\ s_{\beta-\alpha} & c_{\beta-\alpha} \end{pmatrix} \begin{pmatrix} \sqrt{2} H_1^0 - v \\ \sqrt{2} H_2^0 \end{pmatrix}$$



Taken from ATLAS-CONF-2019-005, and assumes that h is SM-like

Alignment limit

Potential

$$\mathscr{V} = \ldots + \left\{ \frac{1}{2} Z_5 (H_1^\dagger H_2)^2 + \left[Z_6 (H_1^\dagger H_1) + Z_7 (H_2^\dagger H_2) \right] H_1^\dagger H_2 + \mathrm{h.c.} \right\}$$

Mass matrix

$$\mathscr{M}_{\mathrm{H}}^2 = \begin{pmatrix} Z_1 v^2 & Z_6 v^2 \\ Z_6 v^2 & m_A^2 + Z_5 v^2 \end{pmatrix}$$

Decoupling : $m_A^2 \gg (Z_1 - Z_5) v^2$

Alignment without Decoupling : $|Z_6| \ll 1$

Symmetry explanation

Potential

$$
\begin{aligned}
\mathscr{V} =& m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - [m_{12}^2 \Phi_1^\dagger \Phi_2 + \mathrm{h.c.}] + \tfrac{1}{2}\lambda_1 (\Phi_1^\dagger \Phi_1)^2 \\
& + \tfrac{1}{2}\lambda_2 (\Phi_2^\dagger \Phi_2)^2 + \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1) \\
& + \left\{ \tfrac{1}{2}\lambda_5 (\Phi_1^\dagger \Phi_2)^2 + \left[\lambda_6 (\Phi_1^\dagger \Phi_1) + \lambda_7 (\Phi_2^\dagger \Phi_2)\right] \Phi_1^\dagger \Phi_2 + \mathrm{h.c.} \right\}
\end{aligned}
$$

Symmetry	Φ_1	Φ_2
Π_2	Φ_2	Φ_1
$\mathrm{U}(1)_{PQ}$	$e^{-i\theta}\Phi_1$	$e^{i\theta}\Phi_2$

$Z_6 = 0$ if $\mathscr{V}$ is $\Pi_2 \otimes \mathrm{U}(1)_{\mathrm{PQ}}$ symmetric

$$
m_{11}^2 = m_{22}^2,\ \lambda_1 = \lambda_2
$$

$$
m_{12}^2 = \lambda_5 = \lambda_6 = \lambda_7 = 0
$$

Yukawa sector

Symmetry	Φ_1	Φ_2	q	$\bar{\mathrm{u}}$	$\bar{\mathrm{U}}$	U
Π_2	Φ_2	Φ_1	q	$\bar{\mathrm{U}}$	$\bar{\mathrm{u}}$	U
$\mathrm{U}(1)_{PQ}$	$e^{-i\theta}\Phi_1$	$e^{i\theta}\Phi_2$	q	$e^{-i\theta}\bar{\mathrm{u}}$	$e^{i\theta}\bar{\mathrm{U}}$	$e^{-i\theta}\mathrm{U}$

$$\mathscr{L}_{\mathrm{Yuk}} \supset y_t \left(q\Phi_2\bar{\mathrm{u}} + q\Phi_1\bar{\mathrm{U}} \right)$$
$$\mathscr{L}_{\mathrm{VL}} \supset M_U\bar{\mathrm{U}}\mathrm{U} + M_u\bar{\mathrm{u}}\mathrm{U}$$

Loop corrections

$$m_{12}^2 \sim \frac{3y_t^2 M_U M_u}{4\pi^2} \qquad m_{22}^2 - m_{11}^2 \sim -\frac{3y_t^2(M_U^2 - M_u^2)}{4\pi^2}$$

Mixing

$$c_{2\beta} = \varepsilon,\ \mathrm{R} = \frac{\lambda_3+\lambda_4}{\lambda_1}$$

$$c_{\beta-\alpha} \sim -(\mathrm{R}-1)\varepsilon\sqrt{1-\varepsilon^2}\,\frac{m_h^2}{m_H^2}$$