A vectophobic 2HDM in the light of the LHC

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Accidental Symmetries

### The Custodial Symmetry

**SM**

Accidental symmetry of the scalar potential

$$SU(2)_L \times SU(2)_R \xrightarrow{SSB} SU(2)_V$$

Broken by $Y_b \ll Y_t$

Protects the tree-level mass relation

$$\rho = \frac{M_W^2}{M_Z^2 \cos^2 \theta_W} = 1$$

**2HDM**

$$\Phi_1 \ni \begin{cases} G^+ \\ G^0 \\ G^- \end{cases} \oplus \{h^0 + \frac{\nu}{\sqrt{2}}\};$$

$$\Phi_2 \ni \begin{cases} H^+ \\ A^0 \\ H^- \end{cases} \oplus \{H^0\} \text{ or } \begin{cases} H^+ \\ H^0 \\ H^- \end{cases} \oplus \{A^0\}$$

### The Flavour Symmetry

**SM**

Accidental symmetry of the matter lagrangian

$$U(3)^3 = U(3)_Q \times U(3)_u \times U(3)_d$$

Broken by $Y_{u,d} \neq 0$.

Flavour Conservation in NC

**2HDM**

$$\mathcal{L}_{Yukawa} = -\bar{Q}_L(Y_d \Phi_1 + Z_d \Phi_2)d_R - \bar{Q}_L(Y_u \tilde{\Phi}_1 + Z_u \tilde{\Phi}_2)u_R$$

$Y_{u,d} = \text{SM-like, } Z_{u,d} \text{ generate FCNC } (A^0, H^0)$

MFV $\Rightarrow$ Sources of Flavour Violation $= \text{SM } (Y_{u,d})$

$\Rightarrow$ Suppressed FCNCs

$$Z_d = \{\delta_0 + \delta_1 Y_u Y_u^\dagger + \delta_2 (Y_u Y_u^\dagger)^2\} Y_d$$

$$Z_u = \{v_0 + v_1 Y_u Y_u^\dagger + v_2 (Y_u Y_u^\dagger)^2\} Y_u$$
Figure: $\mathcal{B}(B_s \rightarrow \mu^+ \mu^-)$ as a function of the $H^0$ and $A^0$ masses
Diphoton channel: $H^0$ and $A^0$ are vectophobic ($g_{HVV} = g_{AVV} = 0$ with $V = W^\pm, Z^0$)

$$R = \frac{\sigma \times B(H^0, A^0 \rightarrow \gamma\gamma)}{\sigma \times B(h^0 \rightarrow \gamma\gamma)^{SM}}$$

Two possible hierarchies

1. $m_{A^0(H^0)} < m_{H^0(A^0)} \approx m_{H^\pm} < m_{h^0}$
   $$m_{h^0} > 2m_{H^0(A^0)}$$
   one resonance in the diphoton channel
   no resonance in the $W^+W^-$ and $Z^0Z^0$ decays

2. $m_{h^0}, m_{A^0(H^0)} < m_{H^0(A^0)} = m_{H^\pm}$
   two resonances in the diphoton channel
   one in the $W^+W^-$ and $Z^0Z^0$ decays

$W^+W^-$ and $Z^0Z^0$ production and decay observations $\rightarrow$ crucial!!!
THANK YOU!
$\Delta F = 2$ mixings

Tree-level $A^0$ and $H^0$ mediated FCNC $\Rightarrow (Z_d)_{ij} = 4G_F\delta_1(V^*_tiV_{tj})m_t^2\frac{m_{d_j}}{v}$

\begin{align*}
\langle \bar{M}^0 | H_{eff}^{\Delta F=2} | M^0 \rangle &\simeq \langle \bar{M}^0 | H_{eff}^{\Delta F=2} | M^0 \rangle^{SM} \left[ 1 + 16\pi^2\delta_1^2 m^2_M \left( \frac{1}{m_{H^0}^2} - \frac{1}{m_{A^0}^2} \right) \right] \\
x &= \frac{2m_t^4}{m_W^2v^2S_0(x_t)}
\end{align*}

Figure: $\epsilon_K$ and $\Delta M_s$ as a function of the $H^0$ and $A^0$ masses
$B_s \rightarrow \mu^+ \mu^-$ decay

SM operator $Q_A = (\bar{b}_L \gamma^\mu s_L)(\bar{\mu}\gamma_\mu \gamma_5 \mu)$; new operators

\[
\begin{align*}
H^0 & \rightarrow Q_S = m_b (\bar{b}_R s_L)(\bar{\mu}\mu) \\
A^0 & \rightarrow Q_P = m_b (\bar{b}_R s_L)(\bar{\mu}\gamma_5 \mu)
\end{align*}
\]

**Figure:** The $B_s \rightarrow \mu^+ \mu^-$ branching ratio as a function of the $H^0$ and $A^0$ masses

\[
\begin{align*}
\mathcal{B}(B_s \rightarrow \mu^+ \mu^-) = \mathcal{B}(B_s \rightarrow \mu^+ \mu^-)^{SM} \left[ \left( 1 + m^2_{B_s} \frac{C_P}{C_A} \right)^2 + \left( 1 - \frac{4m^2_\mu}{m^2_{B_s}} \right) m^4_{B_s} \frac{C^2_S}{C^2_A} \right]
\end{align*}
\]

\[
C_{S(P)} = \frac{\Delta}{m^2_{H^0(A^0)}} ; \quad \Delta = \frac{4\pi^2 \delta_1 \lambda_0 m^2_t}{M^2_W}
\]
Diphoton signal at the LHC

$H^0$ and $A^0$ are vectophobic $g_{HVV} = g_{AVV} = 0$ with $V = W^\pm, Z^0$

$$R = \frac{\sigma \times B(H^0, A^0 \to \gamma\gamma)}{\sigma \times B(h^0 \to \gamma\gamma)^{SM}}$$

$R_{H^0/h^0}(m_{H^0} = 0 \to 125 \text{ GeV}) = (0.12 \to 0.08)$

$R_{A^0/h^0}(m_{A^0} = 0 \to 125 \text{ GeV}) = (0.59 \to 0.44)$

Two possible hierarchies

1. $m_{A^0(H^0)} < m_{H^0(A^0)} \approx m_{H^\pm} < m_{h^0}$
   with $m_{h^0} > 2m_{H^0(A^0)}$

2. $m_{h^0}, m_{A^0(H^0)} < m_{H^0(A^0)} = m_{H^\pm}$

Role of Higgs $W^+W^-$ and $Z^0Z^0$ production and decay observations

**Figure:** The ratio $R$ as a function of the $H^0$ and $A^0$ masses