Triple Higgs coupling effect on $h \to b\bar{b}$ and $h \to \tau^+\tau^-$ in the 2HDM

Jaouad EL Falaki

In collaboration with

Abdesslam Arhrib, Rachid Benbrik, Wolfgang Hollik

Université Abdelmalek Essaadi
Faculté des Sciences et Techniques
Département des Mathématiques
Tanger

April 24, 2017

Plan de la présentation

- The best known motivation is supersymmetry.

- The best known motivation is supersymmetry.

- The generation of CP violation.

- The best known motivation is supersymmetry.

- The generation of CP violation.

- Some motivations come from axion models.

- The best known motivation is supersymmetry.
- The generation of CP violation.
- Some motivations come from axion models.
- the generation of the baryon asymmetry of the Universe.

Z_2 symmetric CP-conserveing 2HDM:

$$
\begin{aligned}
V_{\mathrm{THDM}} &= m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - m_{12}^2 \left(\Phi_1^\dagger \Phi_2 + \Phi_2^\dagger \Phi_1 \right) \\
&+ \frac{\lambda_1}{2} (\Phi_1^\dagger \Phi_1)^2 + \frac{\lambda_2}{2} (\Phi_2^\dagger \Phi_2)^2 \\
&+ \lambda_3 (\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4 \left| \Phi_1^\dagger \Phi_2 \right|^2 \\
&+ \left\{ \frac{\lambda_5}{2} \left(\Phi_1^\dagger \Phi_2 \right)^2 + \left(\Phi_2^\dagger \Phi_1 \right)^2 \right\}
\end{aligned}
$$

- 5 Higgs bosons: H^+, H^-,2 CP-even h^0, H^0 and 1 CP-odd A^0.
- 7 free parameters:
  m_A, m_h, m_H, $m_{H\pm}$, α, $tan\beta$ and $m12^2$

Types of 2HDM:

	2HDM-1	2HDM-2	2HDM-3	2HDM-4
up	Φ_2	Φ_2	Φ_2	Φ_2
down	Φ_2	Φ_1	Φ_1	Φ_2
lepton	Φ_2	Φ_1	Φ_2	Φ_1

Theoretical Constraints:

- Stability conditions on λ_i:

  The scalar potential is bounded from below only if the following conditionss are satisfied.

$$\lambda_{1,2} > 0; \lambda_3 > -\sqrt{\lambda_1\lambda_2}, \lambda_3 + \lambda_4 - |\lambda_5| > -\sqrt{\lambda_1\lambda_2}$$

- Perturbativity and Unitarity conditions

Experimental Constraints:

- Limits from $b \to s\gamma$ in 2HDM-2.
- The ρ parameter constraint.
- The signal strength :

$$\mu_{xx} = \frac{\sigma(gg \to h^0)^{2HDM}\Gamma(h^0 \to xx)^{2HDM}}{\sigma(gg \to h^0)^{SM}\Gamma(h^0 \to xx)^{SM}}$$

- Some contributions that don't exist in the SM:

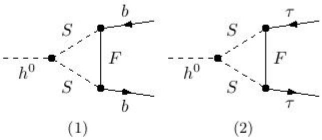

Figure: S stands for $H^{\pm}$, A^0, H^0 and F represents (b, t) for $h \to b\bar{b}$ and τ for $h \to \tau^+\tau^-$

- At one-loop order the amplitude can be written as follows,

$$\mathcal{M}_1 = -\frac{igm_f}{2m_W}\sqrt{Z_h}\left[\xi_h^f(1+\Delta\mathcal{M}_1) + \xi_{H^0}^f\Delta\mathcal{M}_{12}\right] \tag{1}$$

Where

$$\Delta\mathcal{M}_1 = V_1^{hf\bar{f}} + \delta(hf\bar{f}) \tag{2}$$

$$\Delta\mathcal{M}_{12} = \frac{\Sigma_{hH^0}(m_h^2)}{m_h^2 - m_{H^0}^2} - \delta\alpha\,,$$

$$Z_h = \left[1 + \widehat{\Sigma}'_h(m_h^2)\right]^{-1}\,. \tag{3}$$

- At one-loop order the decay width of the Higgs-boson into $b\bar{b}$ and $\tau^+\tau^-$ is given by the following expressions:

$$\begin{aligned}\Gamma_1(h \to f\bar{f}) &= \frac{N_C G_F m_f^2}{4\sqrt{2}\pi}\beta^3 m_h\,(\xi_h^f)^2\,Z_h\left[1 - \Delta r + 2\Re(\Delta\mathcal{M}_1)\right] \\ &= \Gamma_0(h \to f\bar{f})Z_h\left[1 - \Delta r + 2\Re(\Delta\mathcal{M}_1)\right], \qquad (4)\end{aligned}$$

  where $\beta^2 = 1 - 4m_f^2/m_h^2$.
- The central part of the computation is thus the determination of $\Delta\mathcal{M}_1$.
- We used the on-shell scheme for determination of the counterterms, with the exception that the field renormalization constants for the two Higgs doublets are determined in the MS scheme.

We can derive from the potential the following triple Higgs couplings:

$$\begin{aligned}
\lambda_{hhh}^{2HDM} &= \frac{-3e}{2m_W s_W s_{2\beta}^2}\left[(2c_{\alpha+\beta} + s_{2\alpha}s_{\beta-\alpha})s_{2\beta}m_h^2 - 4c_{\beta-\alpha}^2 c_{\beta+\alpha}m_{12}^2\right] \\
\lambda_{hH^0H^0}^{2HDM} &= \frac{1}{2}\frac{e s_{\beta-\alpha}}{m_W s_W s_{2\beta}^2}\left[(m_h^2 + 2m_{H^0}^2)s_{2\alpha}s_{2\beta} - 2(3s_{2\alpha} + s_{2\beta})m_{12}^2\right] \\
\lambda_{hH^+H^-}^{2HDM} &= \frac{1}{2}\frac{e}{m_W s_W}\left[(m_h^2 - 2m_{H^+}^2)s_{\beta-\alpha} - \frac{2c_{\beta+\alpha}}{s_{2\beta}^2}(m_h^2 s_{2\beta} - 2m_{12}^2)\right] \\
\lambda_{hA^0A^0}^{2HDM} &= -\frac{1}{2}\frac{e}{m_W s_W}\left[(2m_{A^0}^2 - m_h^2)s_{\beta-\alpha} + \frac{2c_{\beta+\alpha}}{s_{2\beta}^2}(m_h^2 s_{2\beta} - 2m_{12}^2)\right]. \qquad (5)
\end{aligned}$$

In the decoupling regime, with $\alpha \to \beta - \pi/2$, these couplings become:

$$
\begin{aligned}
\lambda_{hhh}^{2HDM} &= \frac{-3e}{2m_W s_W} m_h^2 = \lambda_{hhh}^{SM}, \\
\lambda_{hH^0H^0}^{2HDM} &= \frac{e}{m_W s_W}\left[\left(\frac{2m_{12}^2}{s_{2\beta}} - m_{H^0}^2\right) - \frac{m_h^2}{2}\right], \\
\lambda_{hH^+H^-}^{2HDM} &= \frac{e}{m_W s_W}\left[\left(\frac{2m_{12}^2}{s_{2\beta}} - m_{H^+}^2\right) - \frac{m_h^2}{2}\right], \\
\lambda_{hA^0A^0}^{2HDM} &= \frac{e}{m_W s_W}\left[\left(\frac{2m_{12}^2}{s_{2\beta}} - m_{A^0}^2\right) - \frac{m_h^2}{2}\right].
\end{aligned}
\tag{6}
$$

- To parameterize the quantum corrections, we define the following one loop ratios:

$$\Delta_{bb} = \frac{\Gamma_1^{2HDM}(h \to b\bar{b})}{\Gamma_1^{SM}(h \to b\bar{b})}, \quad \Delta_{\tau\tau} = \frac{\Gamma_1^{2HDM}(h \to \tau^-\tau^+)}{\Gamma_1^{SM}(h \to \tau^-\tau^+)}. \tag{7}$$

these 2 ratios will take the following form:

$$\Delta_{ff} = \frac{Z_h(1 - \Delta r^{2HDM} + 2\Re(\Delta\mathcal{M}_1^{2HDM}))}{(1 - \Delta r^{SM} + 2\Re(\Delta\mathcal{M}_1^{SM}))}, \quad f = b, \tau \tag{8}$$

- An other observable that could help in distinguishing between models is the ratio of branching fractions given by:

$$R = BR(h \to bb)/BR(h \to \tau^+\tau^-) \tag{9}$$

$$\frac{R^{\text{2HDM}}}{R^{\text{SM}}} = \frac{\Delta_{bb}}{\Delta_{\tau^+\tau^-}} \tag{10}$$

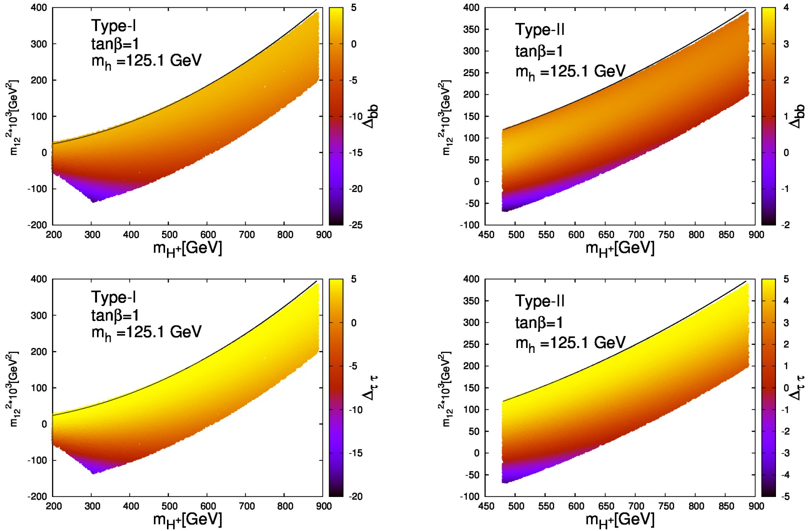

Figure: Scatter plot in the decoupling limit for Δ_{ff} in the plane (M_{H^+}, m_{12}^2) in four types of THDMs.

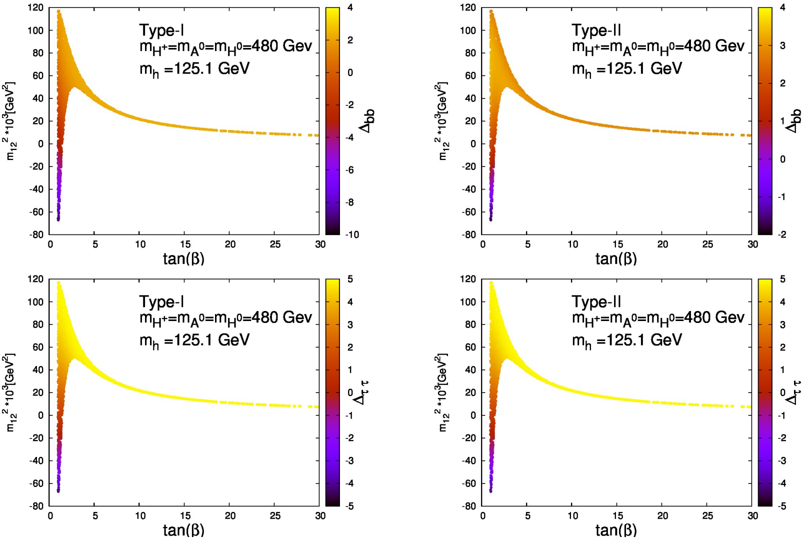

Figure: Scatter plot in the decoupling limit for Δ_{ff} in the plane $(tan\beta, m_{12}^2)$ in four types of THDMs.

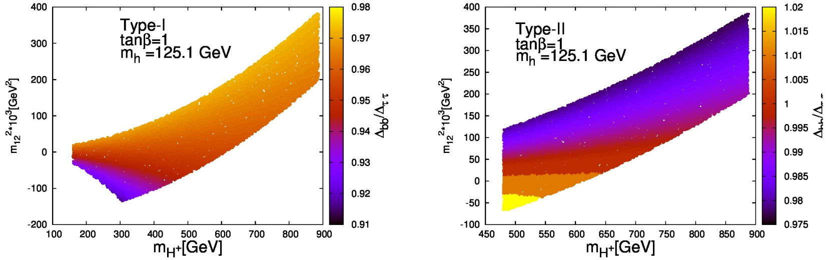

Figure: Scatter plot in the decoupling limit for $\frac{R^{2HDM}}{R^{SM}}$ in the plane (M_{H^+}, m_{12}^2) in the type 1 and 2.

- the numerical evaluation of the Higgs boson couplings at the one-loop in some extensions of the SM is essentially important to find out the structure of the Higgs sector.
- Precision Measurements of $h \to b\bar{b}$ and $h \to \tau^+\tau^-$ can be used to distinguish between THDM and SM.