Radiative corrections to $h \to f\bar{f}$ in the 2HDM

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Plan de la présentation

Motivations for 2HDMs

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- the generation of the baryon asymmetry of the Universe.

Brief review on 2HDM

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:
  $m_A, m_h, m_H, m_{H\pm}, \alpha, tan\beta$ 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 :

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

- xx=ZZ,$\gamma\gamma$, W^+W^-,$\tau^+\tau^-$

Higgs self coupling effects on $h \to b\bar{b}$ and $h \to \tau^+\tau^-$ in the THDM

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

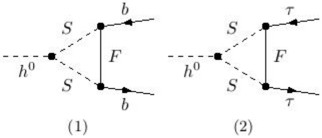

Figure: S stands for $H^\pm$, A^0, H^0 and F represents (b, t) for $h \to b\bar{b}$ and τ for $h \to \tau^+\tau^-$

Higgs self coupling effects on $h \to b\bar{b}$ and $h \to \tau^+\tau^-$ in the THDM

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

$$\mathcal{M}_1 = -\frac{igm_b}{2M_W c_\beta}\sqrt{Z_{h^0}}\,[s_\alpha\,(1+\Delta\mathcal{M}_1) + s_\alpha\,\Delta\mathcal{M}_{12}] \qquad (1)$$

with $s_\alpha = \sin\alpha$, $c_\beta = \cos\beta$, and

$$\begin{aligned} \Delta\mathcal{M}_1 &= V_1^{h^0 b\bar{b}} + \delta(h^0 b\bar{b})\ ,\ \ \Delta\mathcal{M}_{12} = \frac{\Sigma_{hH}(M_{h^0}^2)}{M_{h^0}^2 - M_{H^0}^2} - \delta\alpha\,, \\ Z_{h^0} &= \left[1 + \widehat{\Sigma}'_{h^0}(M_{h^0}^2)\right]^{-1}\,. \end{aligned} \qquad (2)$$

Higgs self coupling effects on $h \to b\bar{b}$ and $h \to \tau^+\tau^-$ in the THDM

The Higgs-boson decay width is then given by the expression

$$\Gamma_1(h^0 \to b\bar{b}) = \frac{N_C G_F m_b^2}{4\sqrt{2}\pi} \frac{s_\alpha^2}{c_\beta^2} M_{h^0} Z_{h^0} \left[1 + 2\Re(\Delta\mathcal{M}_1)\right] . \quad (3)$$

- 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 $\overline{\mathrm{MS}}$ scheme.

Higgs self coupling effects on $h \to b\bar{b}$ and $h \to \tau^+\tau^-$ in the THDM

$$\begin{aligned}
\delta Z_{\Phi_1}^{\overline{\mathrm{MS}}} &= \frac{-g^2\Delta}{32\pi^2 m_W^2}\{\frac{1}{c_\beta^2}(m_e^2 + m_\mu^2 + m_\tau^2 + (m_b^2 + m_d^2 + m_s^2)N_C)\} + \frac{\Delta}{2(4\pi)^2}(3g^2 + g'^2)\,, \\
\delta Z_{\Phi_2}^{\overline{\mathrm{MS}}} &= \frac{-g^2\Delta}{32\pi^2 m_W^2}\{\frac{N_C}{s_\beta^2}(m_c^2 + m_t^2 + m_u^2)\} + \frac{\Delta}{2(4\pi)^2}(3g^2 + g'^2)\,, \qquad (4)
\end{aligned}$$

the h^0 field-renormalization constant is a linear combination of (4), which determines the derivative of the renormalized self-energy

$$\widehat{\Sigma}'_{h^0}(M_{h^0}^2) = \Sigma'_{h^0}(M_{h^0}^2) + (\delta Z_{\Phi_1}^{\overline{MS}} \sin^2\alpha + \delta Z_{\Phi_2}^{\overline{MS}} \cos^2\alpha)\,, \qquad (5)$$

The vertex counterterm $\delta(h^0 b\bar{b})$ in (2) is given by

$$\delta(h^0 b\bar{b}) = \frac{\delta m_b}{m_b} + \delta Z_V^b + \frac{\delta v_1}{v_1}\,, \qquad (6)$$

Higgs self coupling effects on $h \to b\bar{b}$ and $h \to \tau^+\tau^-$ in the THDM

$$\frac{\delta m_b}{m_b} + \delta Z_V^b = \Sigma_S^b(m_b^2) - 2m_b^2\left[\Sigma_S'^b(m_b^2) + \Sigma_V'^b(m_b^2)\right] \tag{7}$$

$$\begin{aligned} 2\frac{\delta v}{v} &= \cos^2\beta\,\delta Z_{\Phi_1}^{\overline{\rm MS}} + \sin^2\beta\,\delta Z_{\Phi_2}^{\overline{\rm MS}} \\ &+ \Sigma'_{\gamma\gamma}(0) + 2\frac{s_W}{c_W}\frac{\Sigma_{\gamma Z}(0)}{M_Z^2} - \frac{c_W^2}{s_W^2}\frac{\Re\Sigma_{ZZ}(M_Z^2)}{M_Z^2} + \frac{c_W^2 - s_W^2}{s_W^2}\frac{\Re\Sigma_{WW}(M_W^2)}{M_W^2}. \end{aligned} \tag{8}$$

Higgs self coupling effects on $h \to b\bar{b}$ and $h \to \tau^+\tau^-$ in the THDM

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

$$\lambda^{THDM}_{h^0H^0H^0} = \frac{e s_{\beta-\alpha}}{2m_W s_W s^2_{2\beta}}\left[(m^2_{h^0} + 2m^2_{H^0}) s_{2\alpha} s_{2\beta} - (3s_{2\alpha} + s_{2\beta}) m^2_{12}\right]$$

$$\lambda^{THDM}_{hH^+H^-} = \frac{e}{2m_W s_W}\left[(m^2_{h^0} - 2m^2_{H^-}) s_{\beta-\alpha} - \frac{2c_{\beta+\alpha}}{s^2_{2\beta}}(m^2_{h^0} s_{2\beta} - m^2_{12})\right]$$

$$\lambda^{THDM}_{hA^0A^0} = -\frac{e}{2m_W s_W}\left[(2m^2_{A^0} - m^2_{h^0}) s_{\beta-\alpha} + \frac{2c_{\beta+\alpha}}{s^2_{2\beta}}(m^2_{h^0} s_{2\beta} - m^2_{12})\right]$$

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

$$\begin{aligned}
\lambda^{THDM}_{h^0 H^0 H^0} &= -\frac{g}{2m_W}\left[m^2_{h^0} + 2\left(m^2_{H^0} - m^2_{12}/s_{2\beta}\right)\right] \\
\lambda^{THDM}_{h^0 H^+ H^-} &= -\frac{g}{2m_W}\left[m^2_{h^0} + 2\left(m^2_{H^-} - m^2_{12}/s_{2\beta}\right)\right] \\
\lambda^{THDM}_{h^0 A^0 A^0} &= -\frac{g}{2m_W}\left[m^2_{h^0} + 2\left(m^2_{A^0} - m^2_{12}/s_{2\beta}\right)\right]
\end{aligned}$$

To parameterize the quantum corrections, we will define the following observables:

$$\Delta_{bb} = \frac{\Gamma_{thdm}(h \to b\bar{b})}{\Gamma_{born}(h \to b\bar{b})}, \quad \Delta_{\tau\tau} = \frac{\Gamma_{thdm}(h \to \tau^-\tau^+)}{\Gamma_{born}(h \to \tau^-\tau^+)}$$

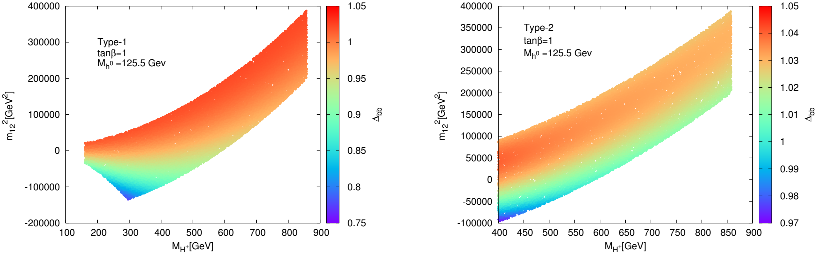

Figure: Scatter plot in the decoupling limit for Δ_{bb} in the plane (M_{H^+}, m_{12}^2) in the type 1 and 2, right column shows the size of the corrections to the $b\bar{b}$ decay width of h.

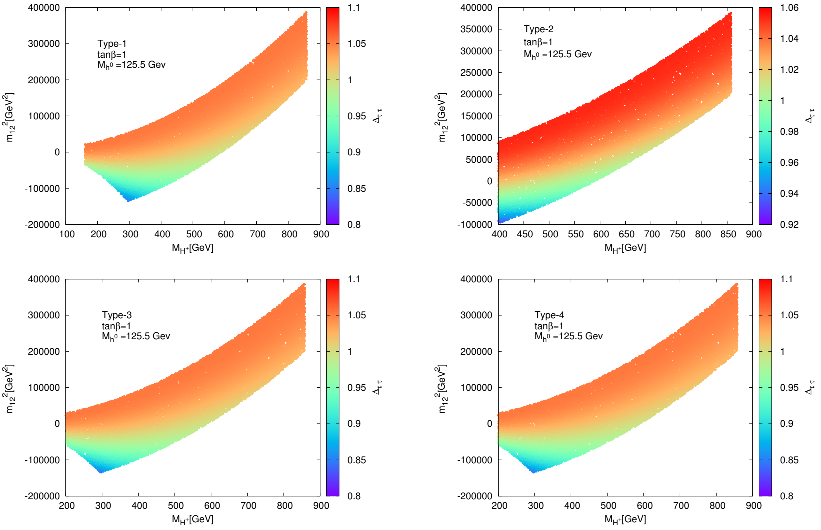

Figure: Scatter plot in the decoupling limit for $\Delta_{\tau\tau}$ in the plane (M_{H^+}, m_{12}^2) in four types of THDMs.

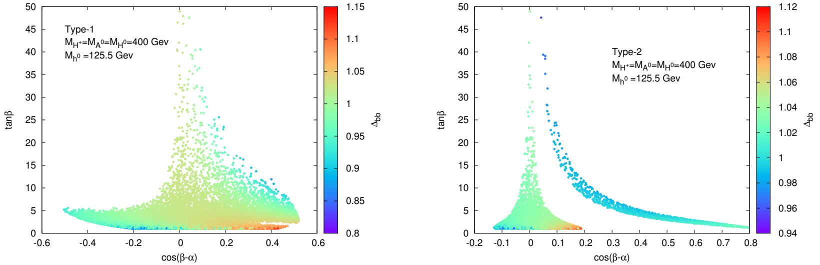

Figure: Scatter plot for Δ_{bb} in the plane $(cos(\beta-\alpha), tan\beta)$ in the type 1 and 2, right column shows the size of the corrections to the $b\bar{b}$ decay width of h.

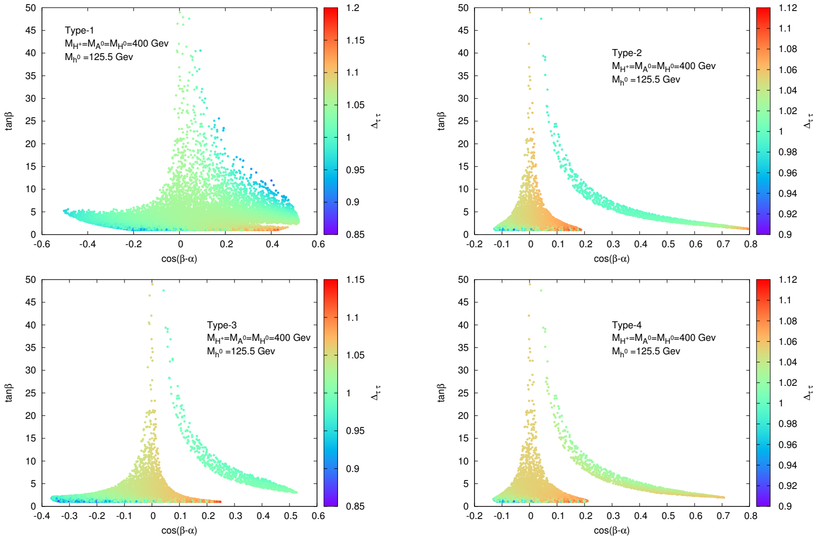

Figure: Scatter plot for $\Delta_{\tau\tau}$ in the plane $(cos(\beta - \alpha), tan\beta)$ in four types of THDMs, right column shows the size of the corrections to the $\tau^-\tau^+$ decay width of h_0.

- Precision Measurements of $h \to b\bar{b}$ and $h \to \tau^+\tau^-$ can be used to distinguish between THDM and SM.

- 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 by using the future precision data.