High precision of $h \rightarrow b\bar{b}$ and $h \rightarrow \tau^+\tau^-$ in e^+e^- machine

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Outlines

- Introduction
- General 2HDM
- Renormalisation of e+e- ---> Z h
- Results and Discussion

Presentation

- We also examine $h^\circ, H^\circ \rightarrow b\bar{b}$ and $h^\circ, H^\circ \rightarrow \tau^+\tau^-$ whiche may receive large EW contribution from triple Higgs coupling which are absent in the SM.

- we propose 4 interesting benchmark scenarios of 2HDM for future colliders.

- It is found that for these benchmark scenarios, both EW and real emission corrections are sizable and could be measured at a future e^+e^- collider.

Introduction

- **LHC hase also mesured Higgs coupling $h \to b\bar{b}$ and $h \to \tau^+\tau^-$ via the process $pp \to ht\bar{t}$**

→ **The SM works well in the current Higgs data**

@HL-LHC: (LHC + High Luminosity) in the Run-2 (13 – 14 Tev)

Would be to improve all the measurements and to perform new ones $h \to \gamma Z$ as welle as the triple self-coupling of Higgs boson.

Uncertainty amelioreted:

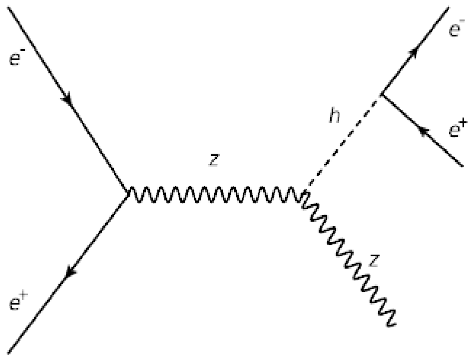
	$h \to b\bar{b}$	$h \to \tau^+\tau^-$
LHC	10% ----- 13%	6% ----- 8%
HL-LHC	4% ----- 7%	2% ----- 5%
LC (e+e–)	0,6%	1,3%

would be much smaller

- **In the SM :** EW-corrections decay { $h \rightarrow b\bar{b}$, $h \rightarrow \tau^+\tau^-$ } are also established
- The correction effects to distinguish between the Standard Model (SM) and various beyond-standard models (BSM)
- **In the 2HDM :** several studies have been carried to evaluate the EW-corrections to fermionics Higgs decay
- **@LHC :** The precision measurements of Higgs boson are arather challenging

(due the large theoritical uncertainties)

- **@LC (e+e−) :** can offer us precision measurements on the production and decay properties of Higgs boson.
- **For exemple :** Higgs-strahlung (process : $e^+e^- \rightarrow Zh$)
  - The dominant production channel for the Higgs boson at e+e− collider
  - with 240 ---- 250 Gev + Lumi (250 fb^{-1})
  - Higgs boson per year will be produced
  - Measurement of the Higgs coupling at % lev
  - @ILC experiment : Luminosity is expected tc



The General 2HDM

- Let us introduce two Higgs with opposite Hypercharge: ϕ_1 and ϕ_2
- After electroweak symmetry breaking 3 of their 8 degrees of freedom will be eaten by the W and Z, the other 5 remain physical.
- The Higgs spectrum contains now a charged Higgs ($H^\pm$), a pseudo-scalar Higgs (A), and two scalar Higgses (h, H)
- The neutral components of both Higgs doublets acquire a vacuum expectation value:

$$|\langle\phi_1\rangle| = \begin{pmatrix} 0 \\ v_1/\sqrt{2} \end{pmatrix} \qquad |\langle\phi_2\rangle| = \begin{pmatrix} v_2/\sqrt{2} \\ 0 \end{pmatrix}$$

- Additional parameters up to now:
  - $m_{H^\pm}$, m_A, m_H
  - $\tan\beta$ $\qquad \tan\beta = \frac{v_2}{v_1}$
  - α (mixing angle between H and h)

Scalar Sector

- two complex SU(2)L Higgs doublets

$$\Phi_1 = \begin{pmatrix} \omega_1^+ \\ \frac{v_1+\rho_1+i\eta_1}{\sqrt{2}} \end{pmatrix}, \qquad \Phi_2 = \begin{pmatrix} \omega_2^+ \\ \frac{v_2+\rho_2+i\eta_2}{\sqrt{2}} \end{pmatrix}$$

- non-vanishing vacuum expectation values (VEVs) v_1, v_2 with

$$v^2 := v_1^2 + v_2^2 \approx (246\ \mathrm{GeV})^2$$

- The most general 2HDM scalar potential which is invariant under $SU(2)_L \otimes U(1)_Y$ and possesses a soft Z_2 breaking term (m_{12}^2)

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

- Z_2 symmetry that forbids FCNC couplings at the tree level

Parameters

- 8 real-valued potential parameters:

  dimensionless $\lambda_i \; (i = 1, ..., 5)$

  mass-squared parameters m_{11}^2, m_{22}^2 and m_{12}^2

transformation to the Higgs mass basis via scalar mixing angles

α for the CP-even sector

β for the CP-odd and charged sectors

$$\tan\beta = \frac{v_2}{v_1}$$

- set of free parameters of the 2HDM

$$\left\{ m_{h^0},\ m_{H^0},\ m_{A^0},\ m_{H^\pm},\ \alpha,\ \beta,\ m_{12}^2,\ T_{h^0},\ T_{H^0},\ e,\ m_W,\ m_Z,\ m_\Psi \right\}$$

Yukawa Interaction for the 2HDM

- The most general Yukawa interactions can be written as follows:

$$-\mathcal{L}^{\text{2HDM}}_{\text{Yukawa}} = \overline{Q}_L Y_u \widetilde{\Phi}_2 u_R + \overline{Q}_L Y_d \Phi_d d_R + \overline{L}_L Y_\ell \Phi_\ell \ell_R + \text{h.c},$$

- the Yukawa interactions in terms of mass eigenstates of the neutral and charged Higgs bosons fields :

$$-\mathcal{L}^{\text{2HDM}}_{\text{Yukawa}} = \sum_{f=u,d,\ell} \frac{m_f}{v}\left(\xi_f^{h^0}\overline{f}fh^0 + \xi_f^{H^0}\overline{f}fH^0 - i\xi_f^{A^0}\overline{f}\gamma_5 f A^0\right) + \left\{\frac{\sqrt{2}V_{ud}}{v}\overline{u}\left(m_u\xi_u^{A^0}\text{P}_L + m_d\xi_d^{A^0}\text{P}_R\right)dH^+ + \frac{\sqrt{2}m_\ell\xi_\ell^{A^0}}{v}\overline{v_L}\ell_R H^+ + \text{h.c}\right\}$$

- Depending on the Z_2 assignment, we have four type of models

type	$\xi_u^{h^0}$	$\xi_d^{h^0}$	$\xi_l^{h^0}$	$\xi_u^{H^0}$	$\xi_d^{H^0}$	$\xi_l^{H^0}$	$\xi_u^{A^0}$	$\xi_d^{A^0}$	$\xi_l^{A^0}$
I	c_α/s_β	c_α/s_β	c_α/s_β	s_α/s_β	s_α/s_β	s_α/s_β	$\cot\beta$	$-\cot\beta$	$-\cot\beta$
II	c_α/s_β	$-s_\alpha/c_\beta$	$-s_\alpha/c_\beta$	s_α/s_β	c_α/c_β	c_α/c_β	$\cot\beta$	$\tan\beta$	$\tan\beta$
III	c_α/s_β	c_α/s_β	$-s_\alpha/c_\beta$	s_α/s_β	s_α/s_β	c_α/c_β	$\cot\beta$	$-\cot\beta$	$\tan\beta$
IV	c_α/s_β	$-s_\alpha/c_\beta$	c_α/s_β	s_α/s_β	c_α/c_β	s_α/s_β	$\cot\beta$	$\tan\beta$	$-\cot\beta$

Table 1: Yukawa coupling coefficients of the neutral Higgs bosons h^0, H^0, A^0 to the up-quarks, down-quarks and the charged leptons (u, d, ℓ) in the four 2HDM types.

These couplings follow from the scalar potential and are thus independent of the Yukawa types used; they are given by:

$$\lambda^{2HDM}_{h^0h^0h^0} = \frac{-3g}{2m_W s^2_{2\beta}}\left[(2c_{\alpha+\beta} + s_{2\alpha}s_{\beta-\alpha})s_{2\beta}m^2_{h^0} - 4c^2_{\beta-\alpha}c_{\beta+\alpha}m^2_{12}\right]$$

$$\lambda^{2HDM}_{H^0h^0h^0} = -\frac{1}{2}\frac{gc_{\beta-\alpha}}{m_W s^2_{2\beta}}\left[(2m^2_h + m^2_{H^0})s_{2\alpha}s_{2\beta} - 2(3s_{2\alpha} - s_{2\beta})m^2_{12}\right]$$

$$\lambda^{2HDM}_{h^0H^0H^0} = \frac{1}{2}\frac{gs_{\beta-\alpha}}{m_W s^2_{2\beta}}\left[(m^2_{h^0} + 2m^2_{H^0})s_{2\alpha}s_{2\beta} - 2(3s_{2\alpha} + s_{2\beta})m^2_{12}\right]$$

$$\lambda^{2HDM}_{h^0H^\pm H^\mp} = \frac{1}{2}\frac{g}{m_W}\left[(m^2_{h^0} - 2m^2_{H^\pm})s_{\beta-\alpha} - \frac{2c_{\beta+\alpha}}{s^2_{2\beta}}(m^2_h s_{2\beta} - 2m^2_{12})\right]$$

$$\lambda^{2HDM}_{h^0A^0A^0} = \frac{1}{2}\frac{g}{m_W}\left[(m^2_h - 2m^2_{A^0})s_{\beta-\alpha} - \frac{2c_{\beta+\alpha}}{s^2_{2\beta}}(m^2_h s_{2\beta} - 2m^2_{12})\right],$$

Theoretical Constraints

- The 2HDM has several theoretical constraints which we briefly address here.
- The scalar potential must satisfy conditions that guarantee that its bounded from below,

V2HDM ≥ 0 is satisfied for all directions of ϕ_1 and ϕ_2 components.

- This requirement imposes the following conditions on the coefficients λi

$$\lambda_1 > 0 \quad , \quad \lambda_2 > 0 \quad , \quad \lambda_3 + 2\sqrt{\lambda_1 \lambda_2} > 0 \quad , \quad \lambda_3 + \lambda_4 - |\lambda_5| > 2\sqrt{\lambda_1 \lambda_2}.$$

- we have indirect experimental constraints from B physics observables on 2HDM parameters such as tan β and the charged Higgs boson mass.

Benchmark points

BP's	α	$\tan\beta$	$m_h(GeV)$	$m_H(GeV)$	$m_A(GeV)$	$m_{H^\pm}$ (GeV)
BP1-h	-0.30	2.50	125	212	97.7	178
BP2-h	-0.77	1.00	125	694	512	592
BP1-H	1.46	4.45	95	125	170	135.5
BP2-H	1.24	2.50	95	125	616	611

BP's	$\lambda_{h^0h^0h^0}$	$\lambda_{H^0h^0h^0}$	$\lambda_{h^0H^0H^0}$	$\lambda_{h^0H^\pm H^\mp}$	$\lambda_{h^0A^0A^0}$
BP1-h	0.726	2.74	-257.48	-193.27	14.03
BP2-h	-0.79	-23.48	-184.6	-781.02	-63.67
BP1-H	-499.4	50.8	0.78	11.23	19.77
BP2-H	-238.2	-60.44	-0.55	150	152.2

Renormalization of e+e- $\longrightarrow$ Z h

- Calculations of higher order corrections in perturbation theory in general lead to ultra-violet (UV) divergences

- To eliminate these UV divergences consists in renormalization of the bare Lagrangian by redefinition of couplings and fields.

- For renormalization of the Higgs sector we take over the approach used in [20]*, which means on-shell renormalization.

(* [20] A. Arhrib, M. Capdequi Peyranere, W. Hollik and S. Penaranda, Phys. Lett. B 579 (2004) 361 doi:10.1016/j.physletb.2003.10.006 [hep-ph/0307391].)

- For the ho, Ho tadpoles, yielding zero for the renormalized tadpoles and thus v1,2 at the minimum of the potential also at one-loop order,

❑ The one-loop Feynman diagrams in 2HDM for simplicity , we draw ho → bb and ho → τ+τ− , where S stands for (H±, Ao, Ho, G±) for both decays while F represents (b,t) for ho → bb and (τ, ντ) for ho → τ+τ− (see .Fig. (1))

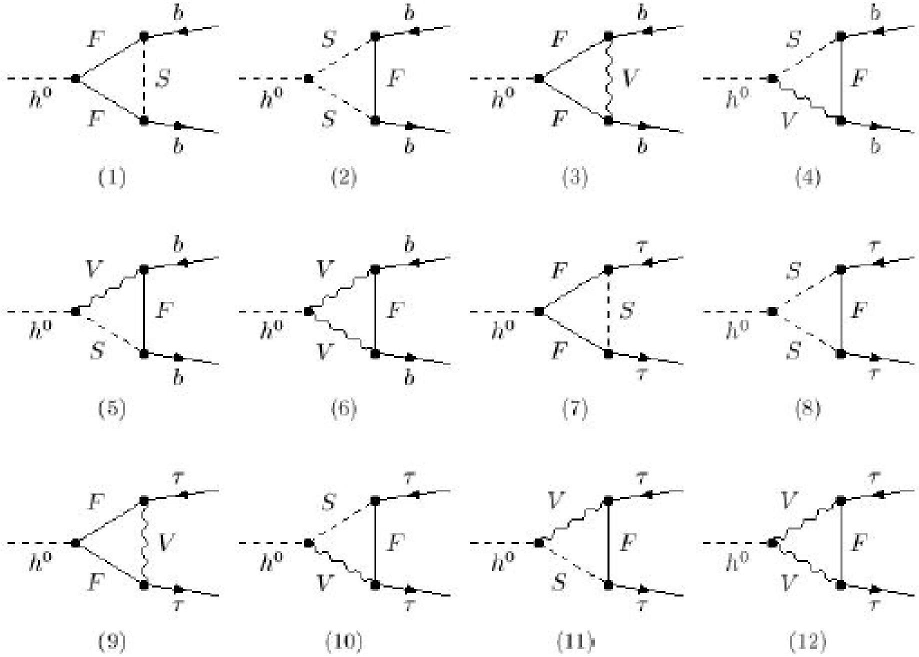


Figure 1: Generic one-loop 2HDM Feynman diagrams contributing to $\Gamma_1(h^0 \to b\bar{b})$ and $\Gamma_1(h^0 \to \tau^+\tau^-)$.

- To examine the deviation caused by the new physics, we will also evaluate the ratio of branching fractions of Higgs decays in the 2HDM
- To parameterize the quantum corrections, we define the following one-loop ratios:

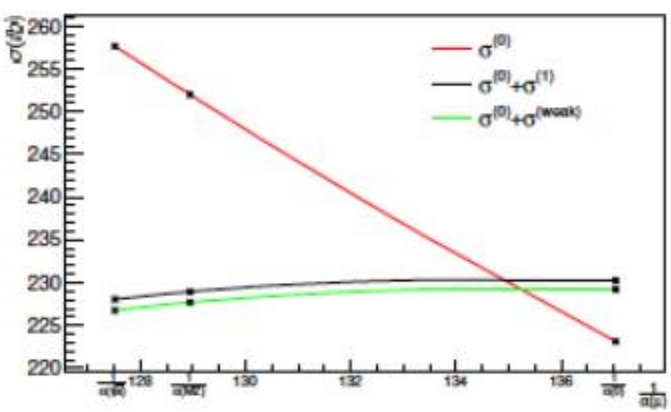
$$\Delta_{ff}(\phi) = \frac{\Gamma_1^{2HDM}(\phi \to f\bar{f})}{\Gamma_1^{SM}(h \to f\bar{f})} - 1,$$

- We have used an on-shell renormalization scheme for all parameters except for wave function renormalization of the Higgs doublet which has been done in the MS scheme.
- Using it (MS scheme), we also compute the decays h → b¯b and h → τ+τ− in the four types of 2HDM by including the EW corrections.

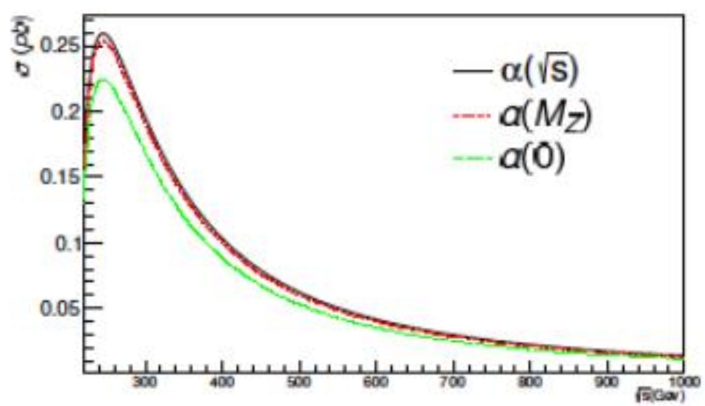
Discussions and conclusion

scheme	$1/\alpha(\mu)$	$\sigma^{(0)}$	σ^{weak}	$\sigma^{(1)}$	$\sigma^{(0)}+\sigma^{(1)}$
$\alpha(0)$	137.036	223.12(0)	6.09(0)	7.13(2)	230.25(2)
$\alpha(M_Z)$	128.943	252.00(0)	-24.33(0)	-23.07(2)	228.93(2)
$\alpha(\sqrt{s})$	127.515	257.68(0)	-30.92(0)	-29.63(2)	228.05(2)

Table 3. NLO SM results under different schemes at $\sqrt{s}=250$ GeV (in unit of fb)

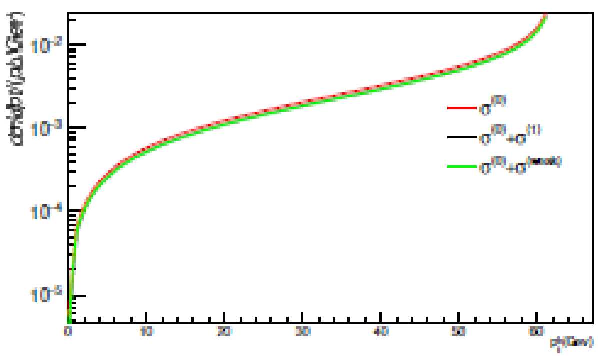


(a) μ dependence

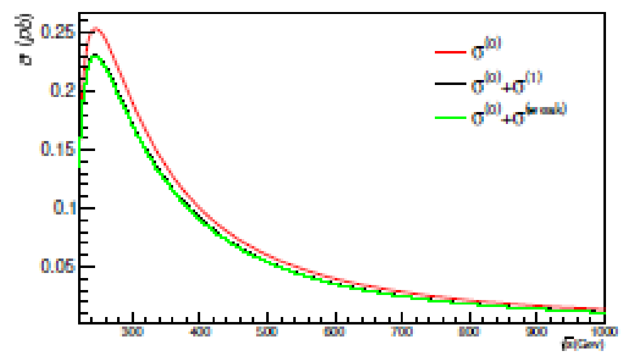


(b) $\sigma(s,\mu)$

- We proposed 4 benchmark scenarios of the 2HDM after taking into account the current Higgs data from the LHC.
- we have evaluated the radiative corrections to the process e+e– → Zh in the SM and in these 4 benchmark scenarios up to one-loop level.
- here we noticed that the real emission from the initial state can increase the cross section by a factor +0.5%.



(a) Distribution of $P_t(h)$



(b) $\sigma(s)$

❑ In this Figure, it is clear that by using precision measurements of the Higgs boson coupling, we can distinguish H-SM-like from h-SM-like in all types of 2HDM.

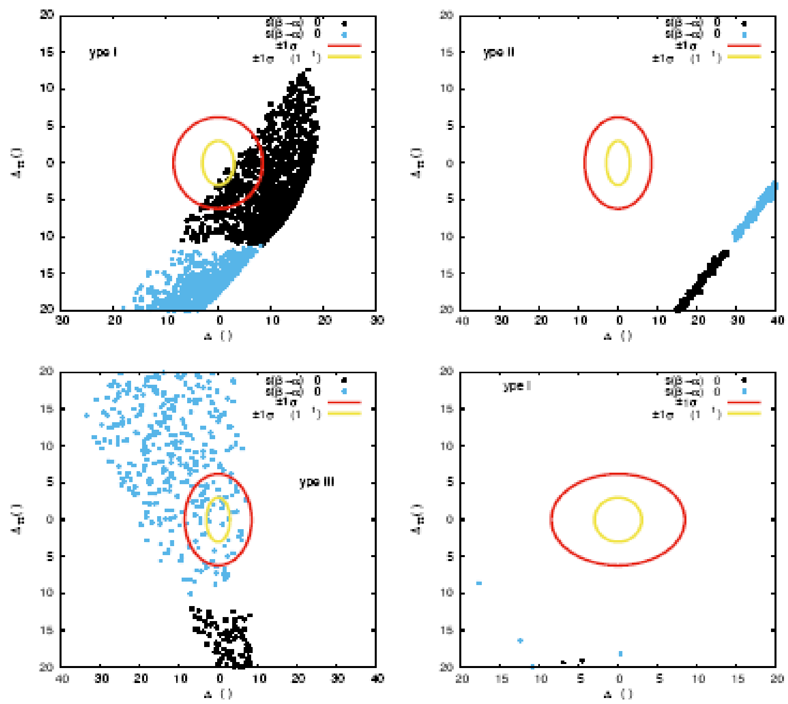


Figure 12: Correlation between relative precisions $\Delta_{\tau\tau}(h^0)$ and $\Delta_{bb}(h^0)$ in 2HDM. The ellipse show the 68% confidence regions for these couplings expected from the HL-LHC and CEPC [12].

❑ We note that the fiducial points in all types have a large radiative corrections which may be excluded by the sensitivity for $Hb\bar{b}$ and $H\tau\,\tau$ because the ratios of decay rate for the fermion are differents.

Thanks for your attention!

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