Radiative corrections to Higgs coupling constants in two Higgs doublet models

MARIKO KIKUCHI in Univ. of Toyama

Collaborators:
Shinya Kanemura (Univ. of Toyama),
Kei Yagyu (National Central Univ.)

S. Kanemura, M. Kikuchi, K. Yagyu, Physics Letters B731 (2014) 27-35

The 37th General Meeting of ILC Physics Subgroup
2014/06/21

Contents

- Introduction

(Higgs couplings as a probe of new physics)

- Two Higgs doublet models
- The pattern of Yukawa couplings deviations from SM predictions
- Calculations of Higgs coupling constants at 1 loop level
- Summary

Introduction

- A Higgs boson was discovered, but are there only one Higgs boson ?
- There is a possibility of an extended Higgs sector.
- We should determine the shape of the Higgs sector.

Relations between Higgs sectors and new physics scenario

B-L Gauge, Dark Matter, ⋯	● Φ + S (Singlet)
MSSM, Dark Matter, m_ν (Radiative Seesaw), ⋯	● Φ + Φ (Doublet)
m_ν (Type II Seesaw), ⋯	● Φ + Δ (Triplet)

The shape of the Higgs sector is a probe of new physics

Physics of *h* (SM-like Higgs boson)

- SM-like Higgs coupling constants can deviate from predictions of SM by new physics effects.

  → A pattern of the deviations depend on the Higgs sector !

- Higgs coupling constants can be measured with high precision by future collider experiments(ILC).

- We determine the Higgs sector by comparing precision measurements with precise calculation with radiative corrections.

⇒ **We can determine new physics !!**

Precision measurements of Higgs couplings × **Theoretical predictions at loop level** = **Testing models**

Two Higgs doublet models

Φ_1, Φ_2 (isospin doublets)

In general, there is the possibility to cause FCNCs.

To avoid FCNCs, Φ_1 and Φ_2 should have different quantum numbers each other.

Discrete Z_2 symmetry

$$\Phi_1 \to +\Phi_1$$
$$\Phi_2 \to -\Phi_2$$

4 types of Yukawa interactions

Barger, Hewett, Phillips(1990), Aoki, Kanemura, Tsumura, Yagyu(2009), Logan, Su, Haber, ⋯.

Type I | Type II | Type X | Type Y

MSSM | Radiative seesaw

Higgs potential

$$\Phi_i = \begin{pmatrix} \omega_i^+ \\ \phi_i \end{pmatrix}, \quad \phi_i = \frac{1}{\sqrt{2}}(h_i + v_i + z_i).$$

- CP invariance & softly broken Z_2

Broken scale of Z_2 sym.

$$M^2 = \frac{m_3^2}{\sin\beta\cos\beta}$$

$$V_{\rm THDM} = m_1^2|\Phi_1|^2 + m_2^2|\Phi_2|^2 - m_3^2(\Phi_1^\dagger\Phi_2 + \text{h.c.})$$
$$+ \frac{1}{2}\lambda_1|\Phi_1|^4 + \frac{1}{2}\lambda_2|\Phi_2|^4 + \lambda_3|\Phi_1|^2|\Phi_2|^2 + \lambda_4|\Phi_1^\dagger\Phi_2|^2 + \frac{1}{2}\lambda_5\left[(\Phi_1^\dagger\Phi_2)^2 + \text{h.c.}\right].$$

- Mass eigenstates

$$\begin{pmatrix} h_1 \\ h_2 \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix}\begin{pmatrix} H \\ h \end{pmatrix}, \quad \begin{pmatrix} z_1 \\ z_2 \end{pmatrix} = \begin{pmatrix} \cos\beta & -\sin\beta \\ \sin\beta & \cos\beta \end{pmatrix}\begin{pmatrix} z \\ A \end{pmatrix},$$
$$\begin{pmatrix} \omega_1^+ \\ \omega_2^+ \end{pmatrix} = \begin{pmatrix} \cos\beta & -\sin\beta \\ \sin\beta & \cos\beta \end{pmatrix}\begin{pmatrix} \omega^+ \\ H^+ \end{pmatrix}.$$

h, — SM-like Higgs

$H, A, H^\pm$ — Extra Higgs

- Parameters(8)

$v^2 = v_1^2 + v_2^2 = (246\text{GeV})^2$, $\quad \tan\beta = \frac{v_2}{v_1}$

$m_h, m_H, m_A, m_{H+}, v, \alpha, \beta, M^2$

Higgs coupling measurements at ILC

Which couplings can we obtain accurate data from ?

h-couplings can be measured typically by O(1) % !!

All couplings are important !

Gauge couplings *hVV*

All types of Yukawa couplings *hff*

	ILC(250)	ILC(500)	ILC(1000)	ILC(LumUp)
$\sqrt{s}$ (GeV)	250	250+500	250+500+1000	250+500+1000
L (fb^{-1})	250	250+500	250+500+1000	1150+1600+2500
$\gamma\gamma$	18 %	8.4 %	4.0 %	2.4 %
gg	6.4 %	2.3 %	1.6 %	0.9 %
WW	4.8 %	1.1 %	1.1 %	0.6 %
ZZ	1.3 %	1.0 %	1.0 %	0.5 %
$t\bar{t}$	–	14 %	3.1 %	1.9 %
$b\bar{b}$	5.3 %	1.6 %	1.3 %	0.7 %
$\tau^+\tau^-$	5.7 %	2.3 %	1.6 %	0.9 %
$c\bar{c}$	6.8 %	2.8 %	1.8 %	1.0 %
$\mu^+\mu^-$	91%	91%	16 %	10 %
$\Gamma_T(h)$	12 %	4.9 %	4.5 %	2.3 %
hhh	–	83 %	21 %	13 %
BR(invis.)	< 0.9 %	< 0.9 %	< 0.9 %	< 0.4 %

ILC WHITE PAPER 1303.3570.

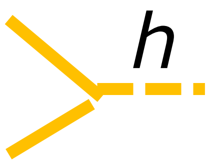
Deviations at tree level

- Gauge couplings (*hWW, hZZ*)

$$= \sum_i \frac{g^2}{2} v_i h_i W^+ W^-$$

$$\kappa_W \equiv \frac{g_{hWW(2HDM)}}{g_{hWW(SM)}} = \sin(\beta - \alpha)$$

- Yukawa couplings (*htt, hbb, hττ*)



$$= \frac{m_f}{v_i} h_i f f$$

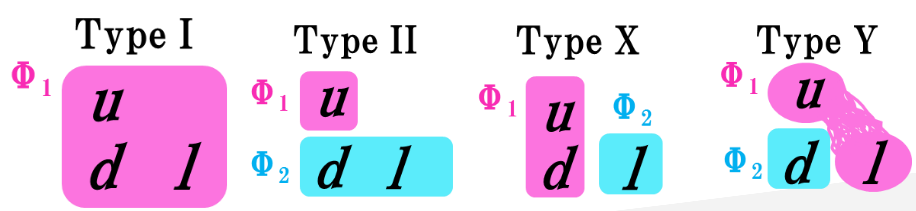
$$\kappa_f = \frac{\cos\alpha}{\sin\beta}, \text{ or } -\frac{\sin\alpha}{\cos\beta}$$

Mixing of fields

$$\begin{pmatrix} h_1 \\ h_2 \end{pmatrix} = \begin{pmatrix} c_\alpha & -s_\alpha \\ s_\alpha & c_\alpha \end{pmatrix} \begin{pmatrix} H \\ h \end{pmatrix}$$

Mixing of VEVs

$$\tan\beta = \frac{v_2}{v_1}, \quad v^2 = v_1^2 + v_2^2$$



Deviations at tree level

- Gauge couplings (*hWW, hZZ*)

$$= \sum_i \frac{g^2}{2} v_i h_i W^+ W^-$$

$$\kappa_W \equiv \frac{g_{hWW(2HDM)}}{g_{hWW(SM)}} = \sin(\beta - \alpha)$$

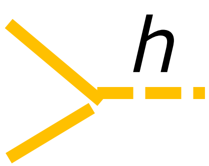
SM like limit

$$\kappa_V = \sin(\beta - \alpha) \rightarrow 1$$

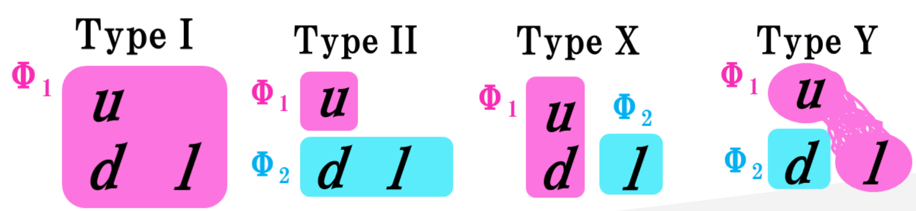
In this case

$$\kappa_f = \frac{\cos\alpha}{\sin\beta} \left(, -\frac{\sin\alpha}{\cos\beta}\right) \rightarrow 1$$

- Yukawa couplings (*htt, hbb, hττ*)



$$= \frac{m_f}{v_i} h_i f f$$



$$\kappa_f = \frac{\cos\alpha}{\sin\beta}, \text{ or } -\frac{\sin\alpha}{\cos\beta}$$

Yukawa couplings have a characteristic pattern in deviation.

Deviations at tree level

- Gauge couplings (*hWW, hZZ*)

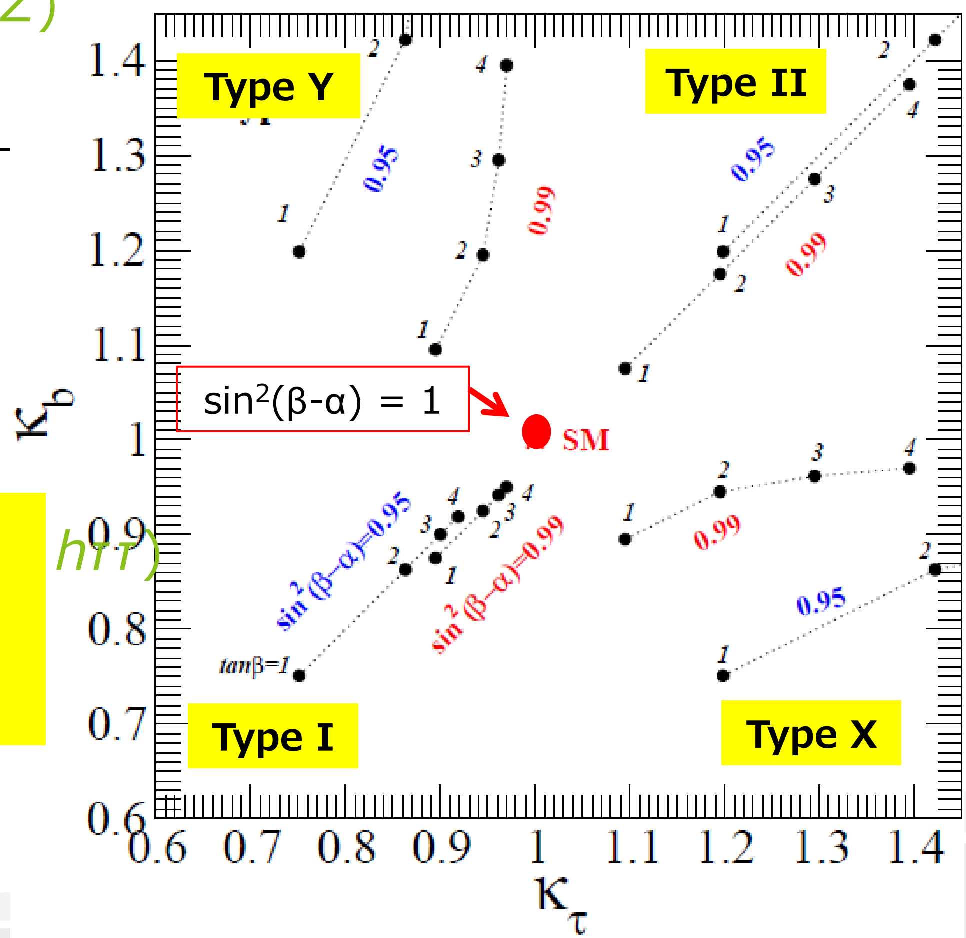
$$= \sum_i \frac{g^2}{2} v_i h_i W^+ W^-$$

$$\kappa_W \equiv \frac{g_{hWW(2HDM)}}{g_{hWW(SM)}} = \sin(\beta - \alpha)$$

We can discriminate all types, if $\sin^2(\beta-\alpha)$ slightly differs from unity.

hττ)

$$\kappa_f = \frac{\cos\alpha}{\sin\beta}, \text{ or } -\frac{\sin\alpha}{\cos\beta}$$

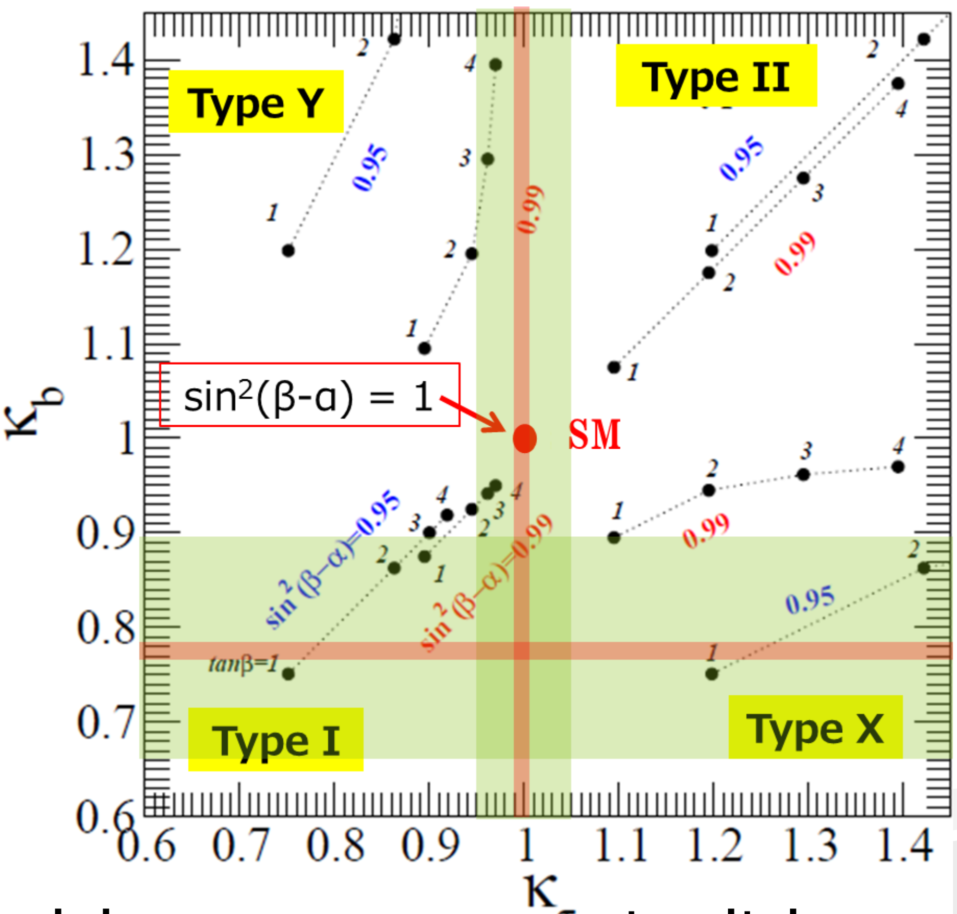


Deviations at tree level

Coupling measurements

LHC3000fb^{-1}
hττ 5.4 %
hbb 11 %

ILC1TeV
hττ 0.9 %
hbb 0.7%



To compare with future precision measurements, it is essentially important to evaluate loop contributions.

Renormalized couplings

$$\hat{\Gamma}_{hff}(p_1^2, p_2^2, q^2) = \Gamma_{hff}^{\text{tree}} + \delta\Gamma_{hff} + \Gamma_{hff}^{\text{1PI}}(p_1^2, p_2^2, q^2)$$

- Counter terms

$$\delta\Gamma_{hff} = -i\frac{m_f}{v}\xi_h^f\left[\frac{\delta m_f}{m_f} + \delta Z_V^f + \frac{1}{2}\delta Z_h + \frac{\delta\xi_h^f}{\xi_h^f} + \frac{\xi_H^f}{\xi_h^f}(\delta C_h + \delta\alpha) - \frac{\delta v}{v}\right]$$

$$-\frac{\cos\alpha}{\sin\beta}(\cot\beta\delta\beta + \tan\alpha\delta\alpha) \quad \textbf{or} \quad -\frac{\sin\alpha}{\cos\beta}(\tan\beta\delta\beta + \cot\alpha\delta\alpha)$$

- Deviations and scale factors at 1 loop level

$$\Delta\hat{\Gamma}_{hff} = \frac{\hat{\Gamma}_{hff}(p_1, p_2, q)_{THDM} - \hat{\Gamma}_{hff}(p_1, p_2, q)_{SM}}{\hat{\Gamma}_{hff}(p_1, p_2, q)_{SM}}$$

$$\hat{\kappa}_f \equiv \frac{\hat{\Gamma}_{hff}(m_f^2, m_f^2, m_h^2)_{\text{THDM}}}{\hat{\Gamma}_{hff}(m_f^2, m_f^2, m_h^2)_{\text{SM}}}$$

κ_τ vs κ_b at 1 loop level

◆ Scan analysis

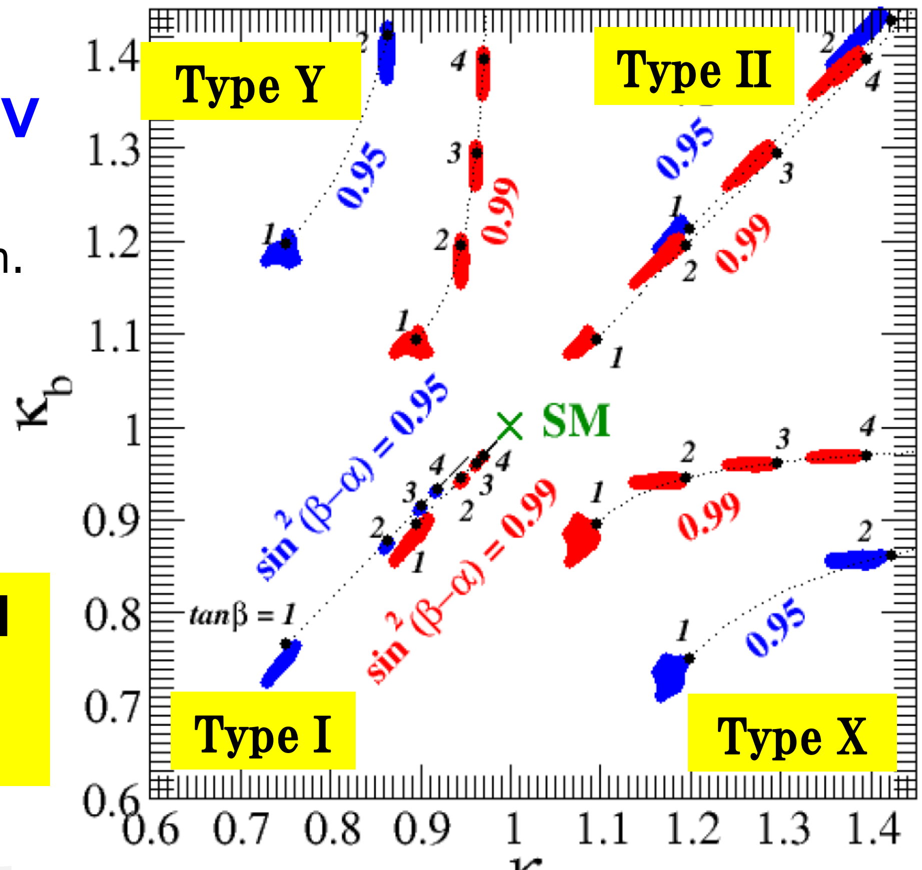
100 GeV ≤ $m_{H+,\ H,\ A}$ ≤ 1000GeV
0 ≤ M ≤ $m_{H+,\ H,\ A}$

→ Soft breaking scale of Z_2 sym.

◆ Constraints

- Perturbative unitarity
- Vacuum stability

***hff* couplings can be modified as large as several % from tree level predictions.**



$\cos(\beta - \alpha) \leq 0$

κ_τ vs κ_b at 1 loop level

- ◆ Scan analysis

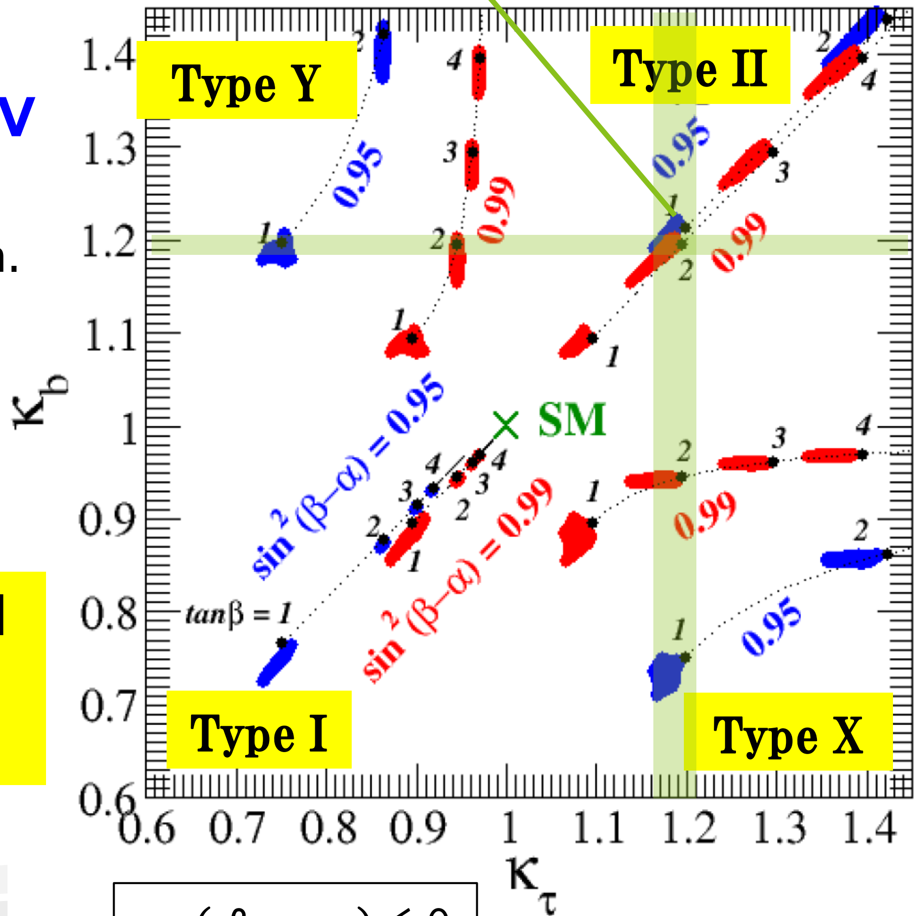
100 GeV ≤ $m_{H+,\ H,\ A}$ ≤ 1000GeV
0 ≤ M ≤ $m_{H+,\ H,\ A}$

→ Soft breaking scale of Z_2 sym.

- ◆ Constraints
  - Perturbative unitarity
  - Vacuum stability

***hff* couplings can be modified as large as several % from tree level predictions.**

Measurement accuracy at ILC500



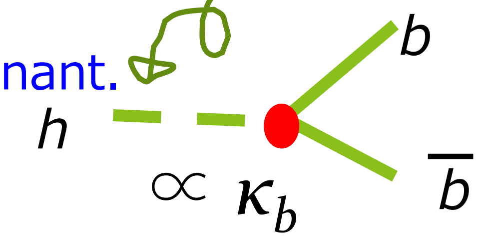
$\cos(\beta - \alpha) \leq 0$

$R_{\gamma\gamma}$

Precision at LHC300fb^{-1} 15%

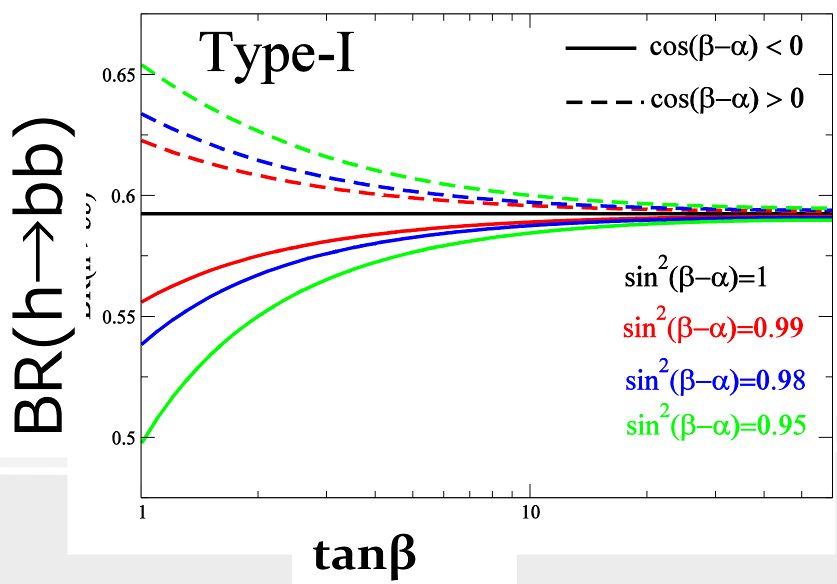
$$R_{\gamma\gamma} \equiv \frac{\sigma(gg\to h)_{\mathrm{THDM}} \times BR(h\to\gamma\gamma)_{\mathrm{TDHM}}}{\sigma(gg\to h)_{\mathrm{SM}} \times BR(h\to\gamma\gamma)_{\mathrm{SM}}} = \frac{\sigma_{\mathrm{THDM}} \times \Gamma(h\to\gamma\gamma)_{\mathrm{THDM}} \times \Gamma(ALL)_{\mathrm{SM}}}{\sigma_{\mathrm{SM}} \times \Gamma(h\to\gamma\gamma)_{\mathrm{SM}} \times \Gamma(\mathrm{ALL})_{\mathrm{THDM}}}$$

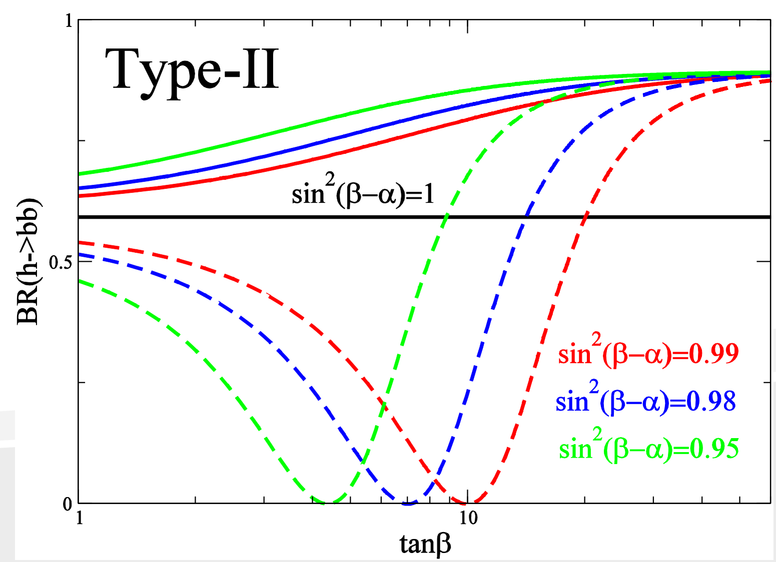
Contribution of h→bb is dominant.



Type I, X $\kappa_b \propto \sin(\beta-\alpha) + \cot\beta \cos(\beta-\alpha)$

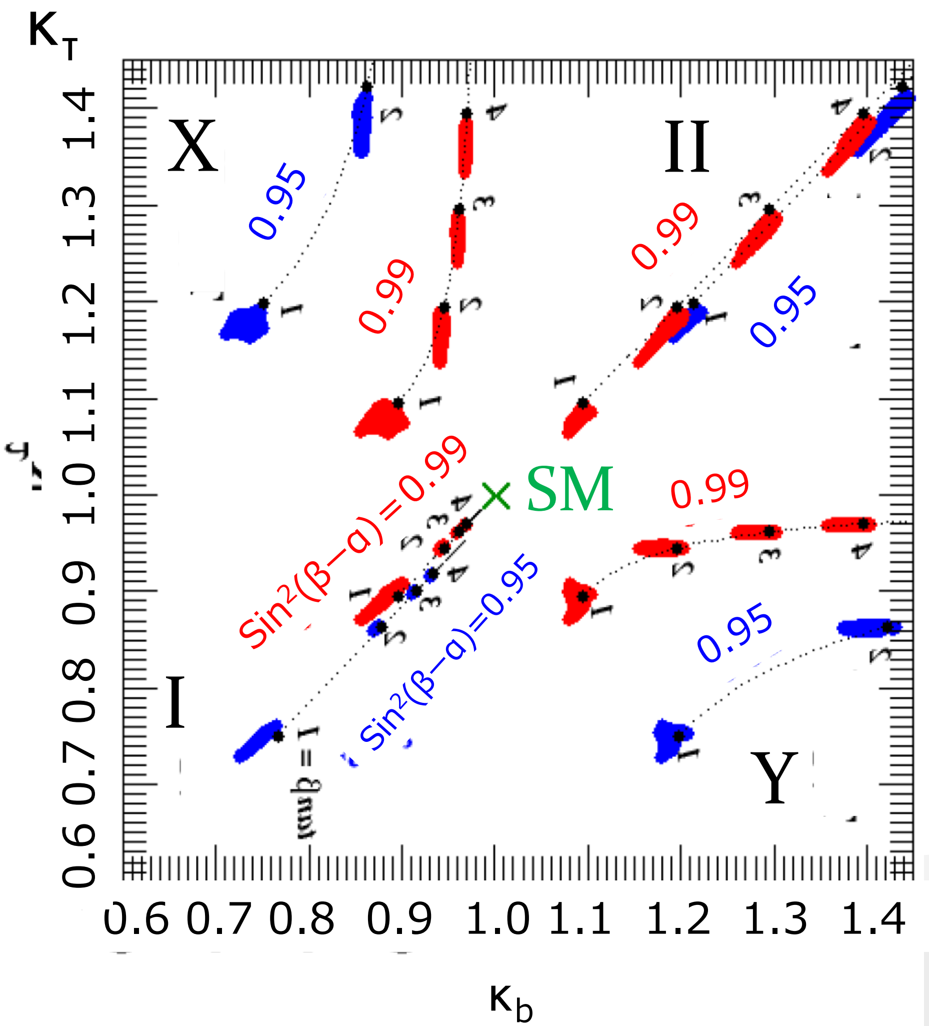
Type II, Y $\kappa_b \propto \sin(\beta-\alpha) - \tan\beta \cos(\beta-\alpha)$

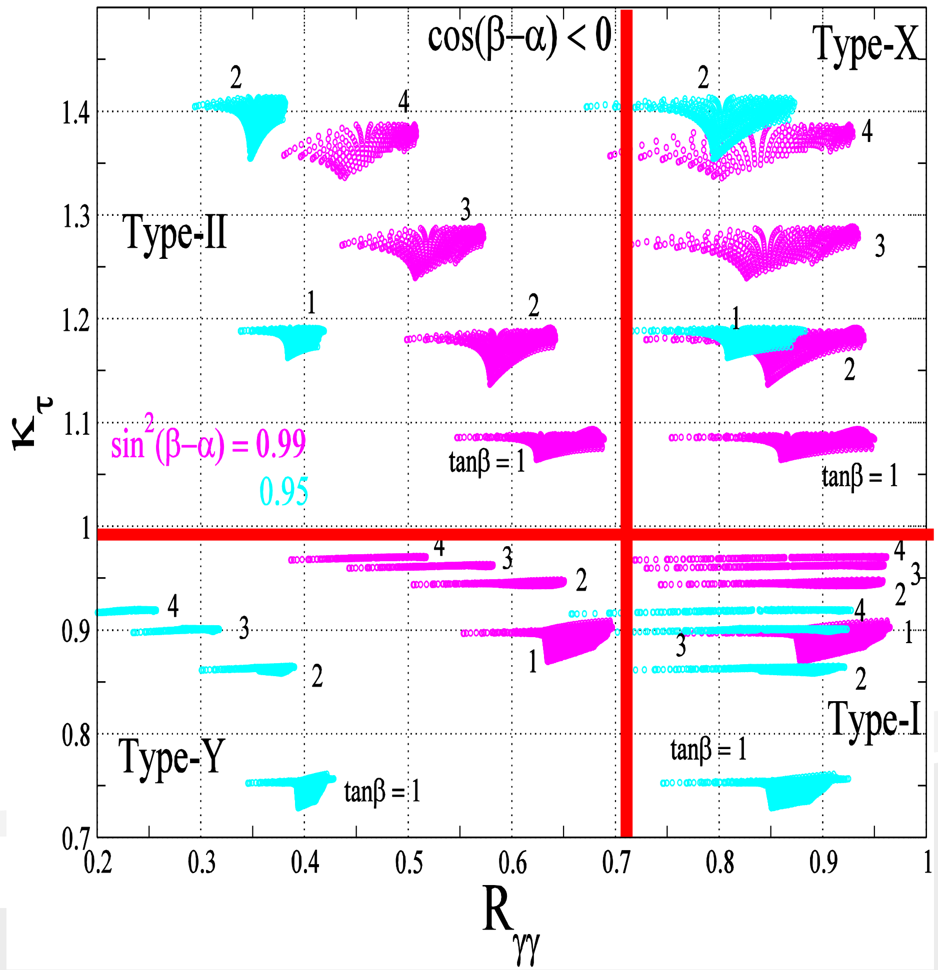




K_f vs $R_{\gamma\gamma}$

We may check the pattern in deviation of *hbb* by evaluating $R_{\gamma\gamma}$.





Summary

- In this talk, we focused on 2HDMs with softly broken Z2 symmetry, and calculate all Yukawa couplings including electroweak radiative corrections.

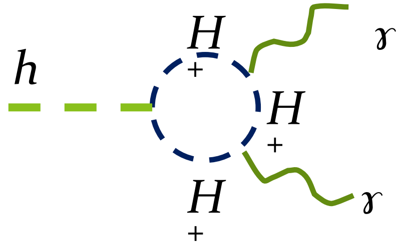
- Since Yukawa couplings can deviate by several % from tree predictions by extra Higgs loop corrections, we should take into account these contributions when we compare theory predictions with ILC data.

- The characteristic pattern in deviations does not change even including radiative corrections. Namely, we can discriminate the type of 2HDMs when gauge couplings *hWW(hZZ)* slightly deviate (as long as $K_W \simeq 0.99$) from SM predictions.

- Furthermore, by comparing loop corrections with precision data, we may obtain information of inner parameters.

	Z_2 charge							Mixing factor								
	Φ_1	Φ_2	Q_L	L_L	u_R	d_R	e_R	ξ_h^u	ξ_h^d	ξ_h^e	ξ_H^u	ξ_H^d	ξ_H^e	ξ_A^u	ξ_A^d	ξ_A^e
Type-I	+	−	+	+	−	−	−	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\cot\beta$	$-\cot\beta$	$-\cot\beta$
Type-II	+	−	+	+	−	+	+	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\cot\beta$	$\tan\beta$	$\tan\beta$
Type-X	+	−	+	+	−	−	+	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\cot\beta$	$-\cot\beta$	$\tan\beta$
Type-Y	+	−	+	+	−	+	−	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\cot\beta$	$\tan\beta$	$-\cot\beta$

$h \to \gamma\gamma$

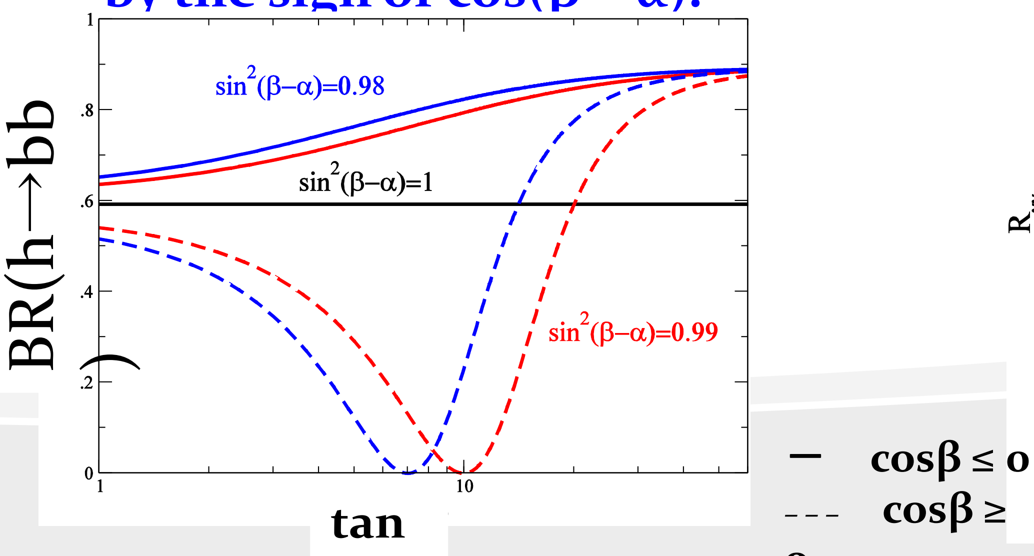


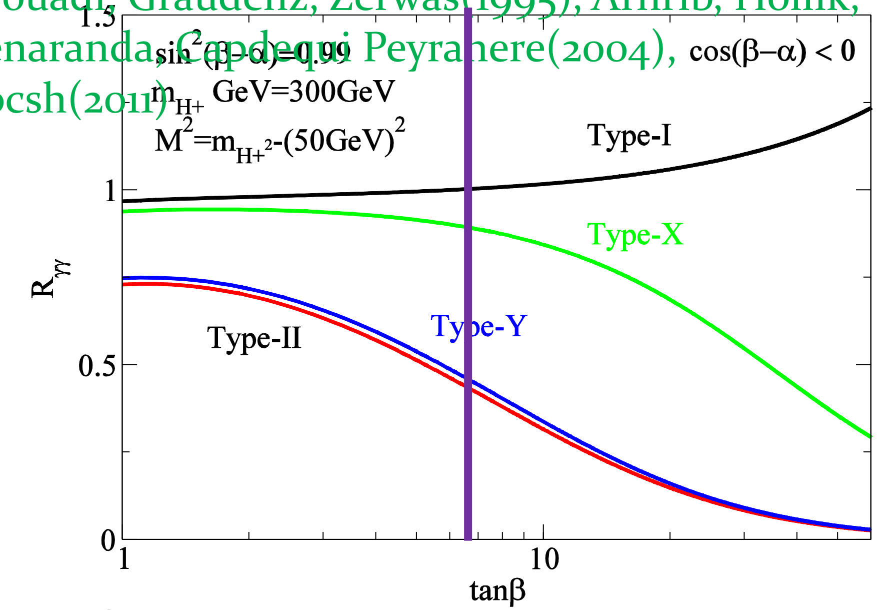
Zeppenfeld, Kinnunen, Nikitenko, Richter-Was(2000),
Ginzburg, Krawczyk, Osland(2001), Spira, Djouadi, Graudenz, Zerwas(1995), Arhrib, Hollik, Penaranda, Capdequi Peyranere(2004), Pocsh(2011)

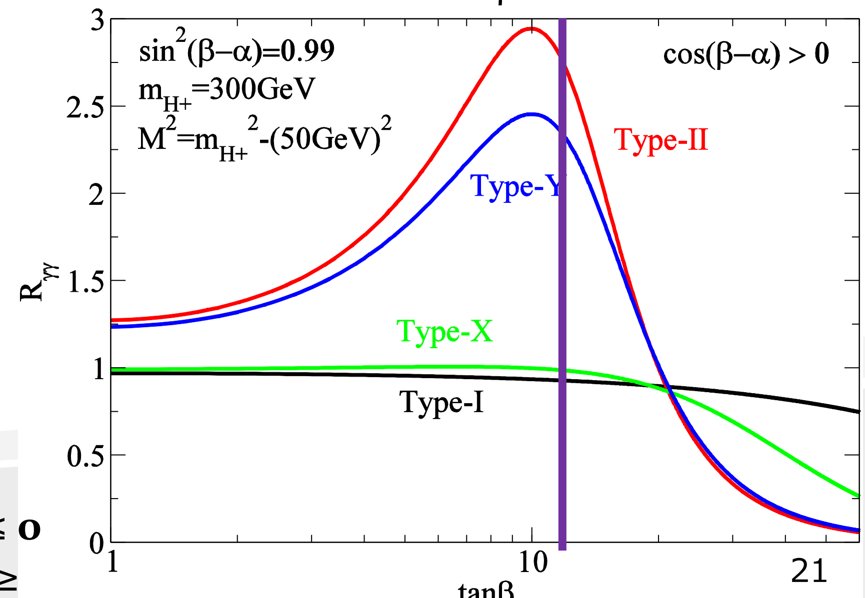
$$R_{\gamma\gamma} \equiv \frac{\sigma(gg\to h)_{2HDM} \times BR(h\to\gamma\gamma)_{2HDM}}{\sigma(gg\to h)_{SM} \times BR(h\to\gamma\gamma)_{SM}}$$

ATLAS 1.2 – 1.8 , CMS 0.3 – 1.3

- ◆ ***Rɤɤ* depends on types of Yukawa interaction.**
- ◆ **Magnitudes of *Rɤɤ* are different by the sign of cos(β − α).**







Kanemura, Kikuchi, Yagyu(2013)

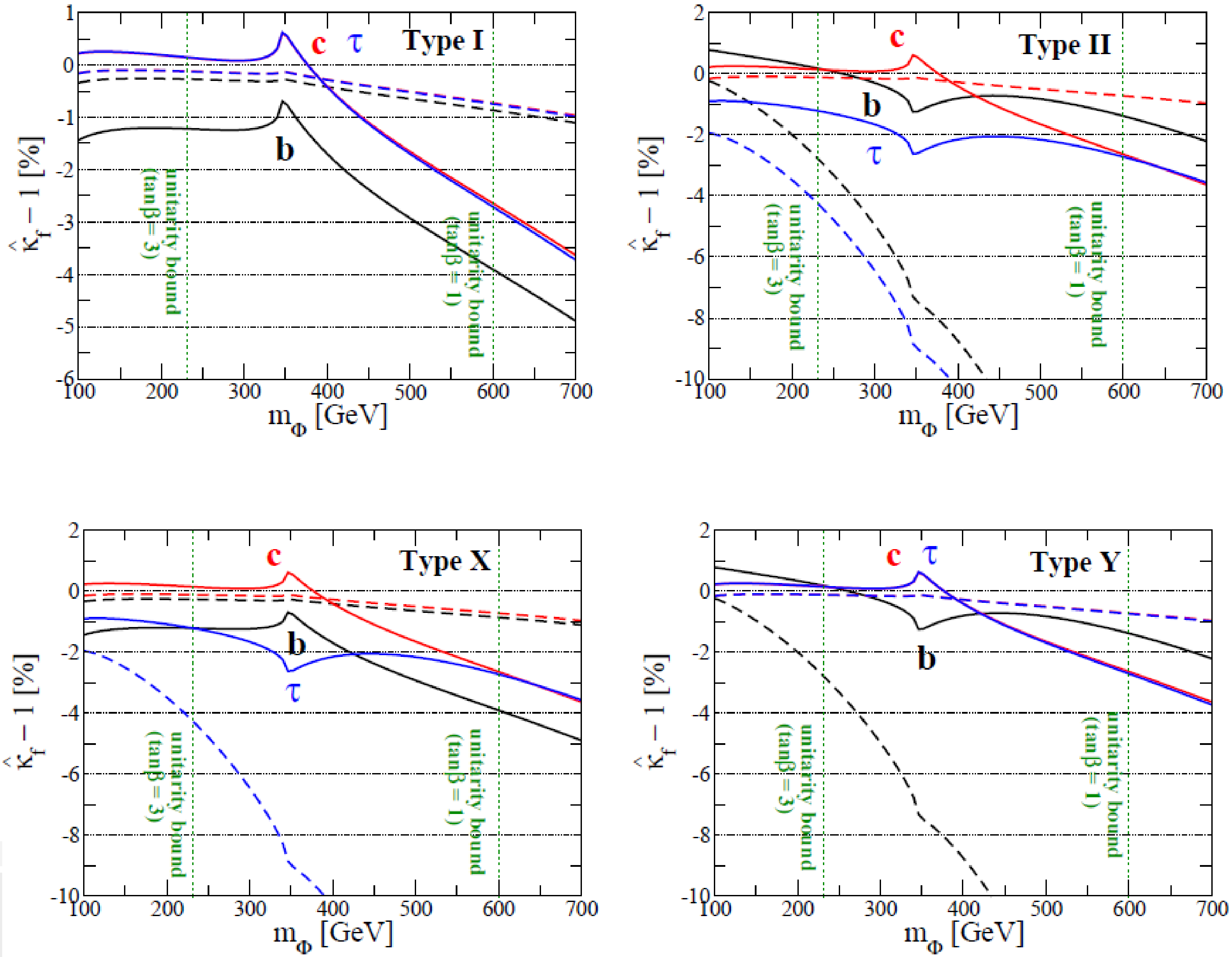
$\sin^2(\beta-\alpha)=1$

— $\tan\beta=1$

--- $\tan\beta=3$

Deviations in *hff*

$M=0$



Deviations in *htt*

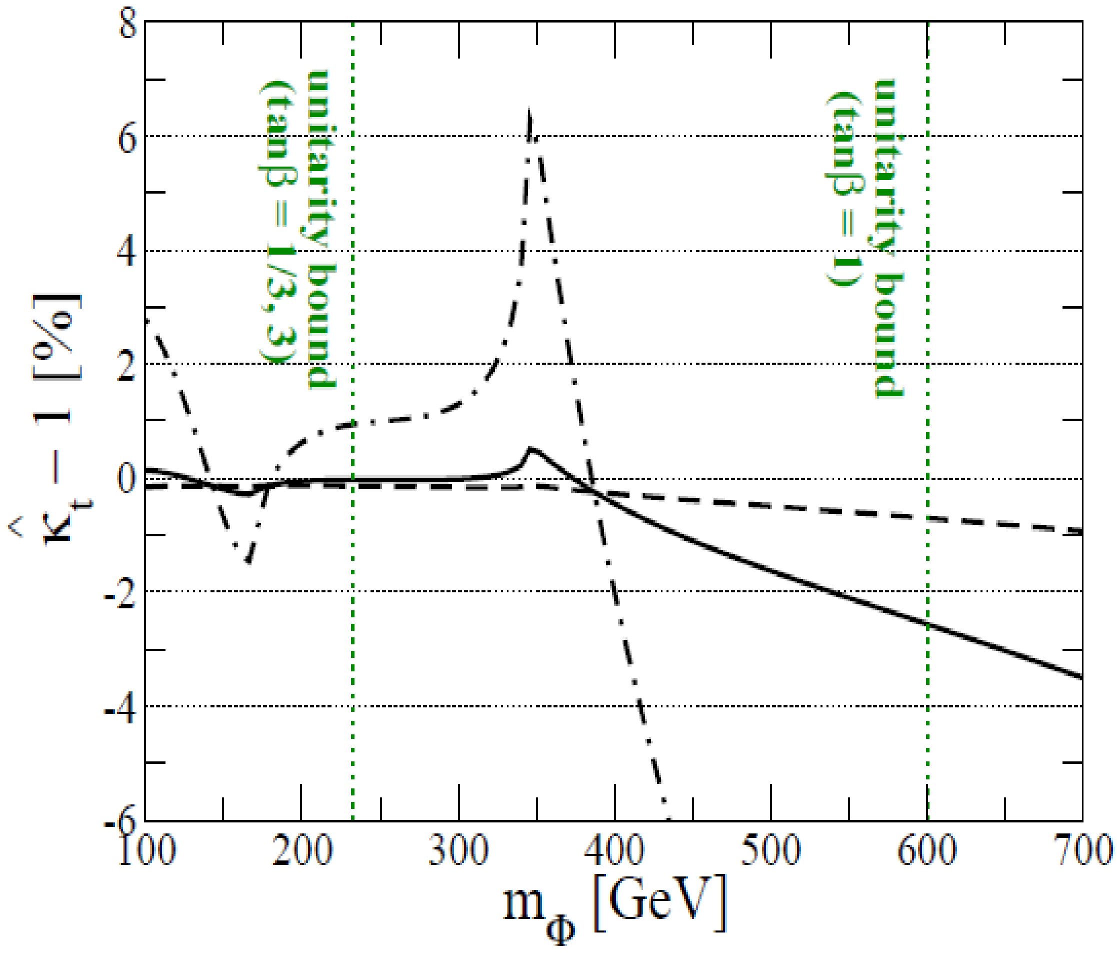
$\sin^2(\beta-\alpha)=1$

— $\tan\beta=1$

- - - $\tan\beta=3$

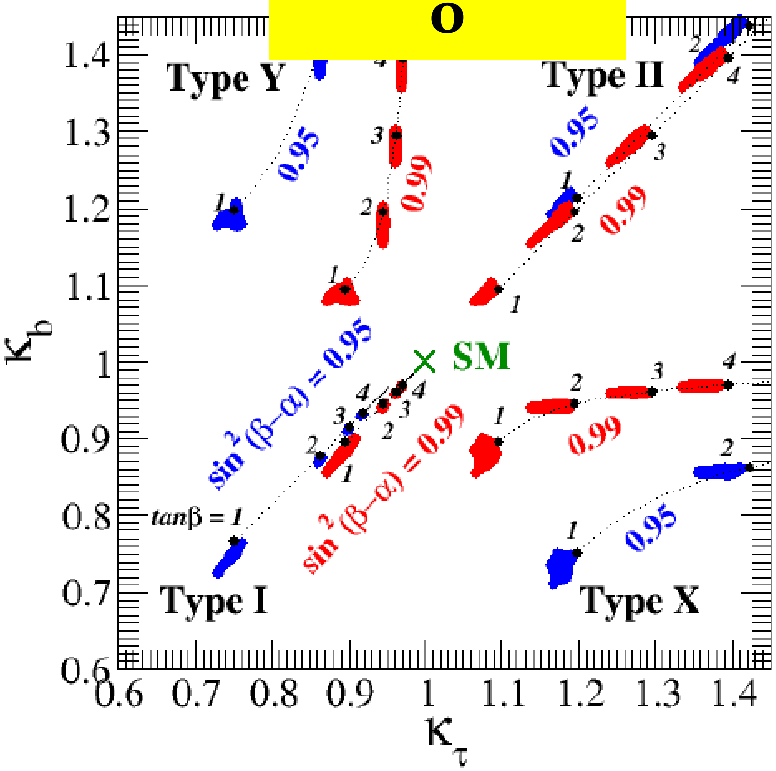
***M* = 0**

Kanemura, Kikuchi, Yagyu(2013)

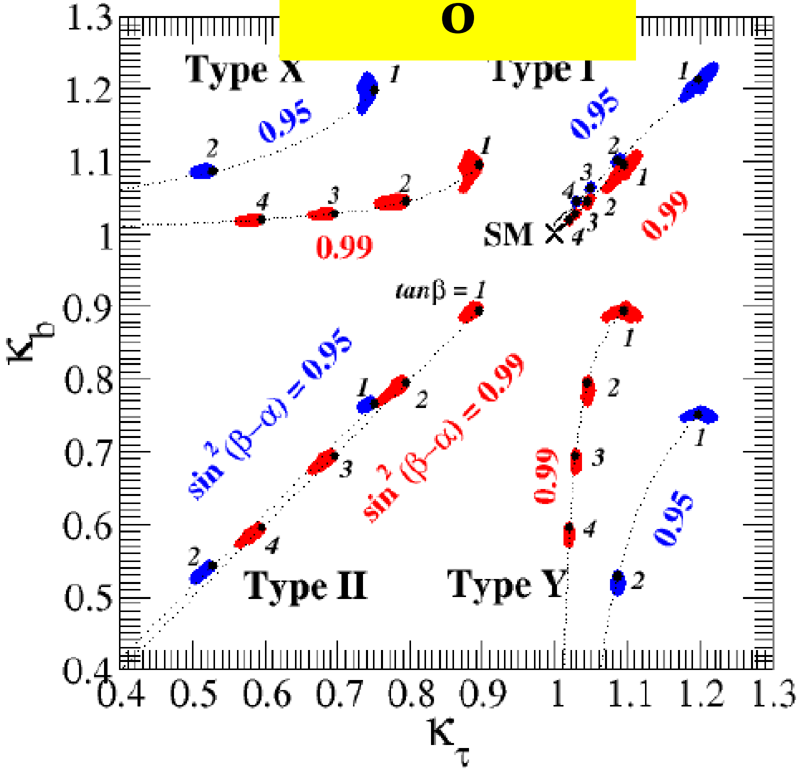


κ_b VS κ_τ

cos(β-α) < 0

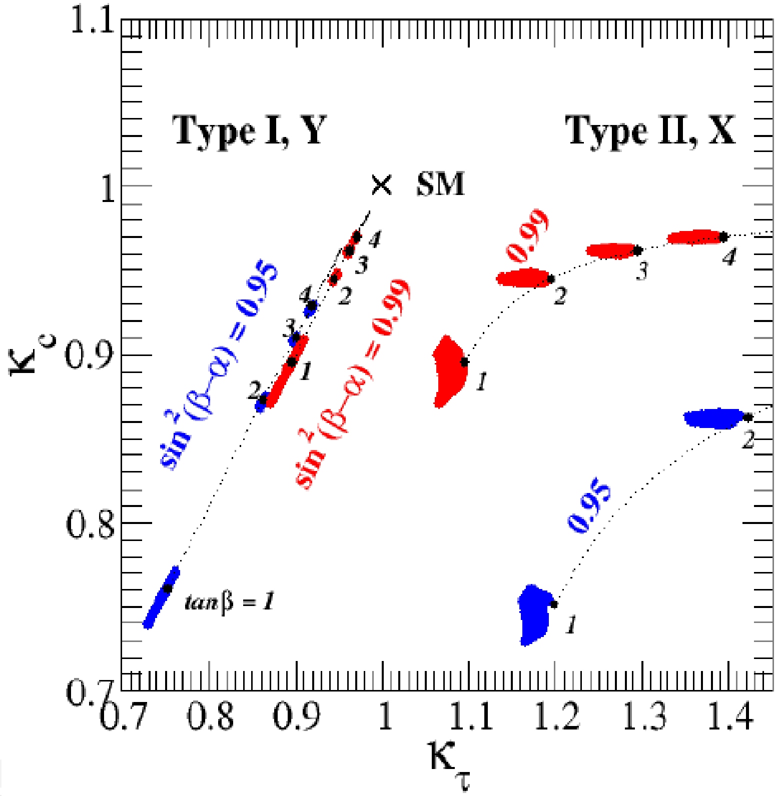


cos(β-α) > 0

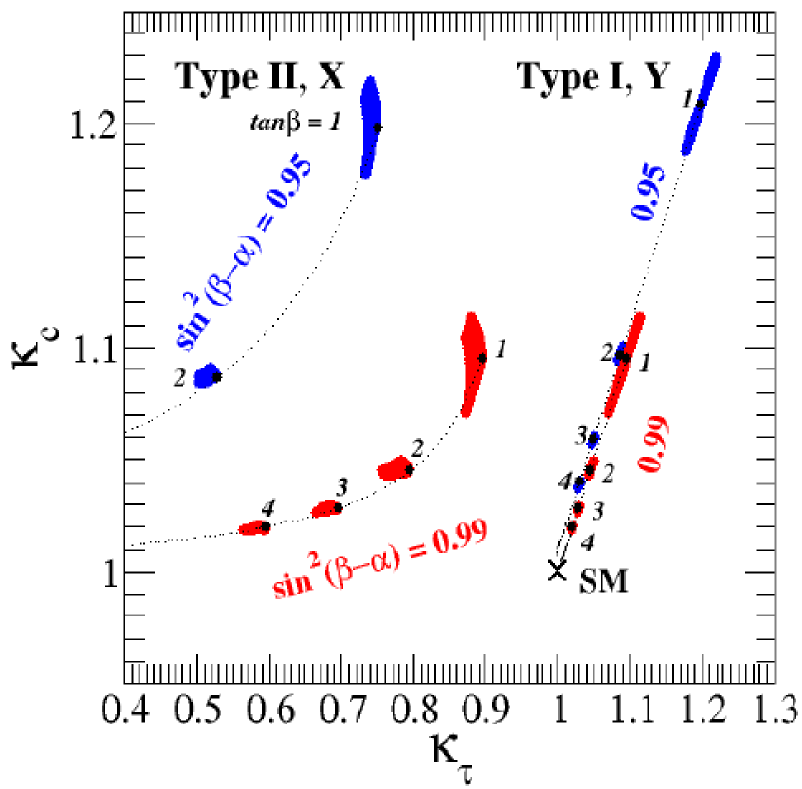


κ τ VS κ c

cos(β-α) <

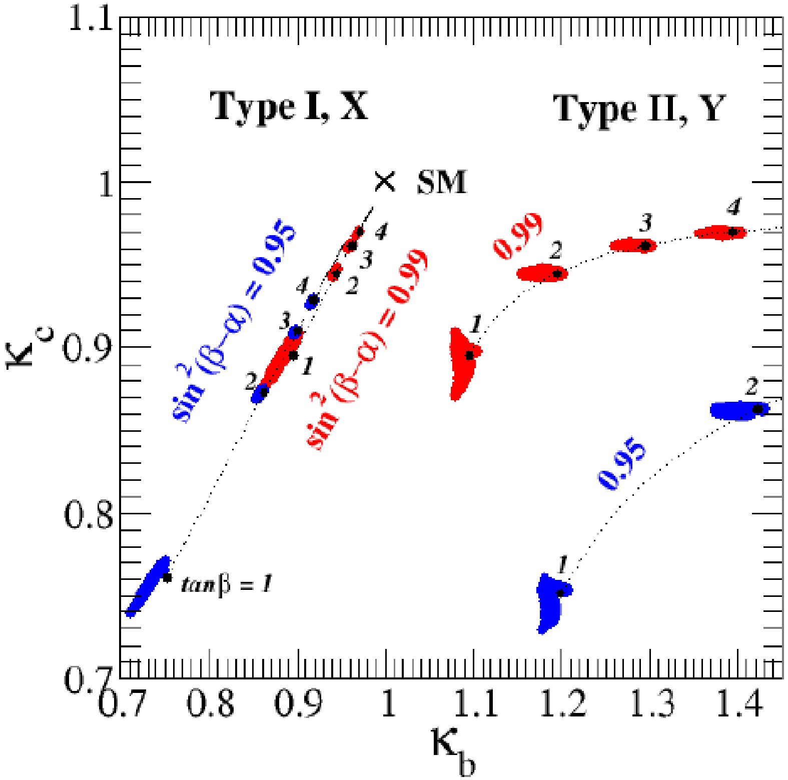


cos(β-α) >

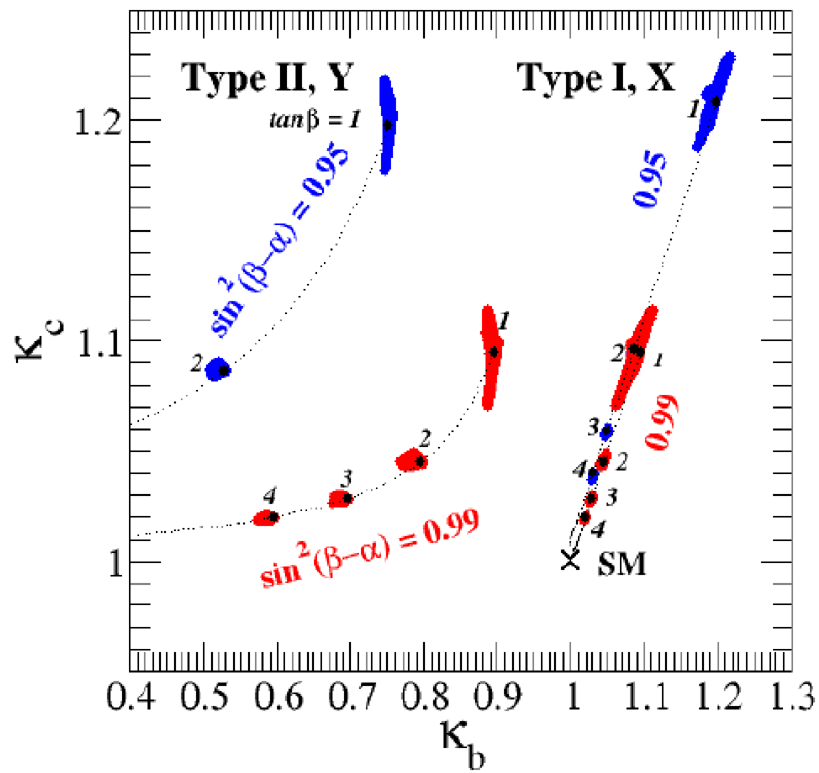


κ_b VS κ_c

cos(β-α) <



cos(β-α) >



SM like limit

$\sin^2(\beta-\alpha) = 1$, $m_{H+} = m_A$
$= m_H = m_\Phi$

ξ_A^u	ξ_A^d	ξ_A^e
$\cot\beta$	$-\cot\beta$	$-\cot\beta$
$\cot\beta$	$\tan\beta$	$\tan\beta$
$\cot\beta$	$-\cot\beta$	$\tan\beta$
$\cot\beta$	$\tan\beta$	$-\cot\beta$

$$\hat{\Gamma}^{\rm THDM}_{hff}(m_f^2, m_f^2, m_h^2)$$

$$\simeq \hat{\Gamma}^{\rm SM}_{hff}(m_f^2, m_f^2, m_h^2) + \frac{m_f}{v}\frac{1}{16\pi^2}\left\{\frac{2m_{f'}^2}{v^2}\xi_A^d \cot\beta\Big[(m_h^2 - 2m_f^2)C_{12}(m_{f'}, m_\Phi, m_{f'})\right.$$

$$+ (2m_{f'}^2 - m_f^2)C_0(m_{f'}, m_\Phi, m_{f'}) + v\lambda_{\Phi\Phi h}C_0(m_\Phi, m_{f'}, m_\Phi)\Big]$$

$$+ 4\lambda_{\Phi\Phi h}^2\frac{d}{dp^2}B_0(p^2; m_\Phi, m_\Phi)\Big|_{p^2=m_h^2} - \frac{6m_t^2}{v^2}I_f\xi_A^f \cot\beta B_0(m_\Phi^2; m_t, m_t)$$

$\delta\beta_h$

$$+\frac{6m_t^4}{v^2(m_\Phi^2 - m_h^2)}I_f\xi_A^f \cot\beta\left[\left(4 - \frac{m_h^2}{m_t^2}\right)B_0(m_h^2; m_t, m_t) - \left(4 - \frac{m_\Phi^2}{m_t^2}\right)B_0(m_\Phi^2; m_t, m_t)\right]$$

$$\left.+\frac{6\lambda_{\Phi\Phi h}\lambda_{\Phi\Phi H}}{m_\Phi^2 - m_h^2}I_f\xi_A^f\left[B_0(m_h^2; m_\Phi, m_\Phi) - B_0(m_\Phi^2; m_\Phi, m_\Phi)\right]\right\},$$

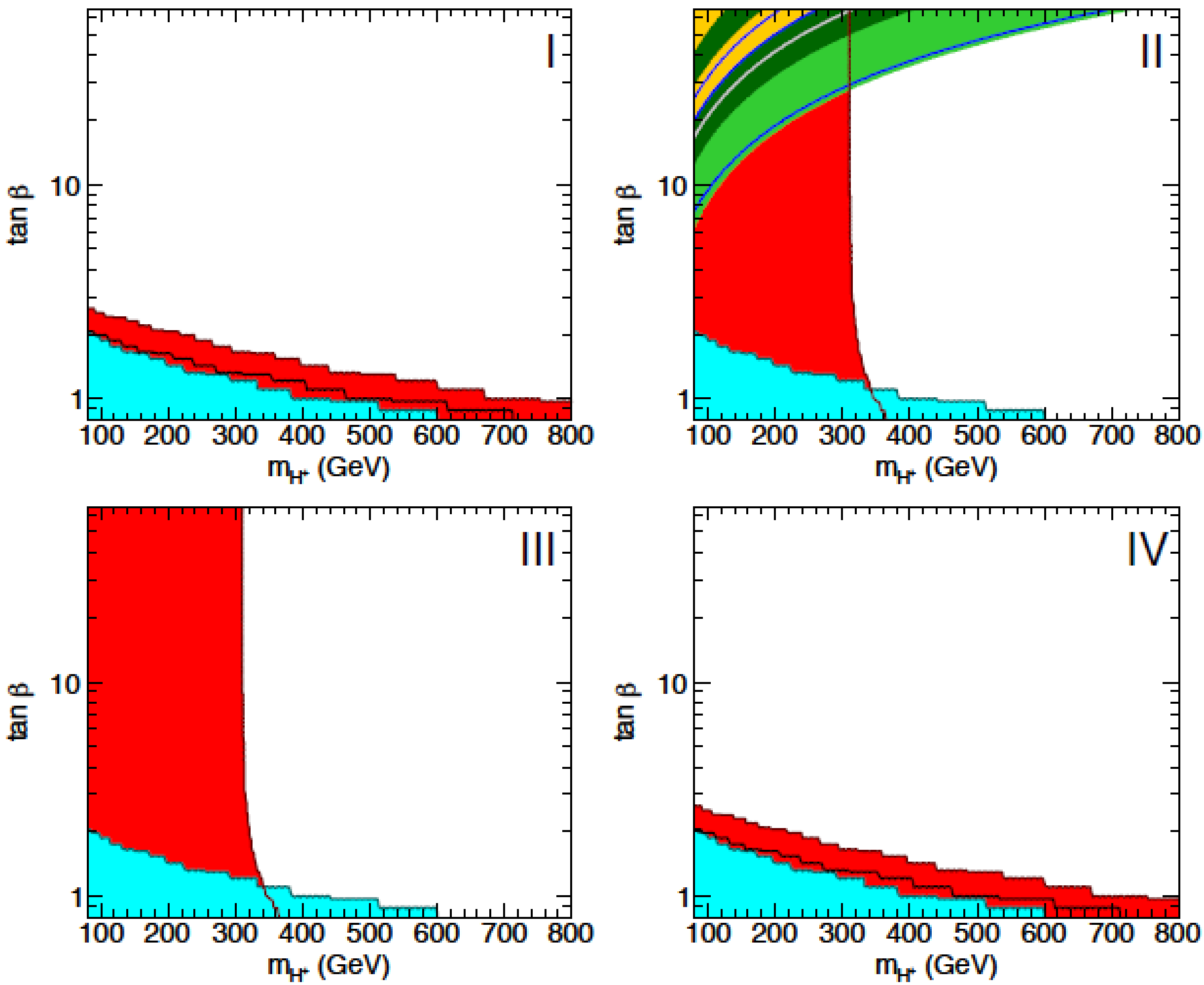
δC_h

$$\lambda_{\Phi\Phi h} = \frac{m_h^2 + 2m_\Phi^2 - 2M^2}{v}, \quad \lambda_{\Phi\Phi H} = \frac{M^2 - m_\Phi^2}{v}\cot 2\beta$$

Characteristic of couplings

	2HDM	Higgs triplet model
hff Yukawa couplings	<table><tr><th></th><th>c</th><th>b</th><th>τ</th></tr><tr><td>I</td><td>↓</td><td>↓</td><td>↓</td></tr><tr><td>II</td><td>↓</td><td>↑</td><td>↑</td></tr><tr><td>X</td><td>↓</td><td>↓</td><td>↑</td></tr><tr><td>Y</td><td>↓</td><td>↑</td><td>↓</td></tr></table> cos(β-α)<0 Each type has a different pattern of deviations.	① $v_\Delta / v_\phi \ll 1$ → Mixing is very small. ②Fermion don't couple to Δ. Deviations are very small
hVV Gauge couplings	＜Multi-doublet model＞ $g_{hVV} = g_{hVV}{}^{SM} \times \kappa_{hVV}$ κ_{hVV} = -sinα cosβ + cosα sinβ $\kappa_{hVV} \leqq 1$	Gauge couplings can be larger than SM predictions because of CG coefficient. κ_{hWW} = cosβ cosα + √2 sinβ sinα $\kappa_{hVV} \geqq 1$ is possible

Constraints from flavor experiments



$b \to s\gamma$

B_0–B_0 mixing

$D_s \to \tau\nu_\tau$

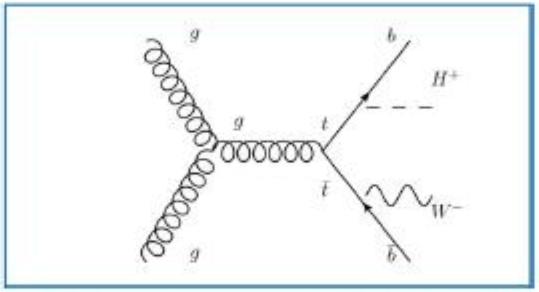
$D_s \to \mu\nu_\mu$

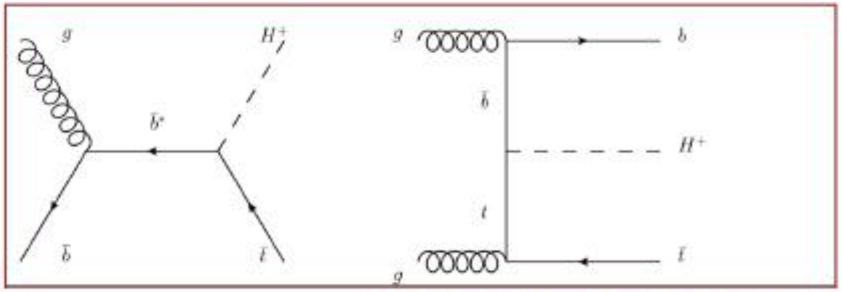
$B \to D\tau\nu_\tau$

Charged Higgs

- Search for H->τν , using assumption B(H->τν=1)
- Different channels dominate depending on m_H/m_t

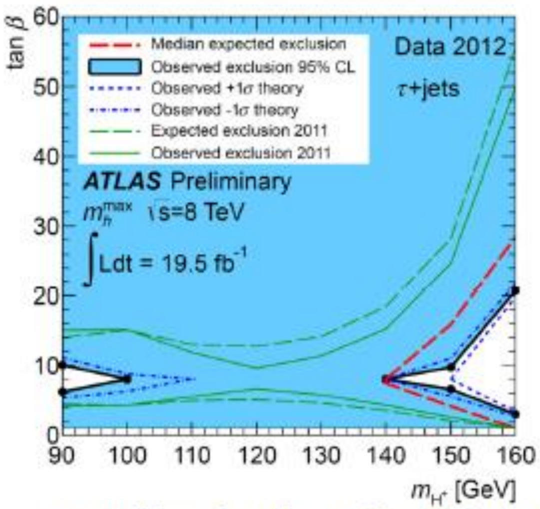
ATLAS-CONF-2013-09



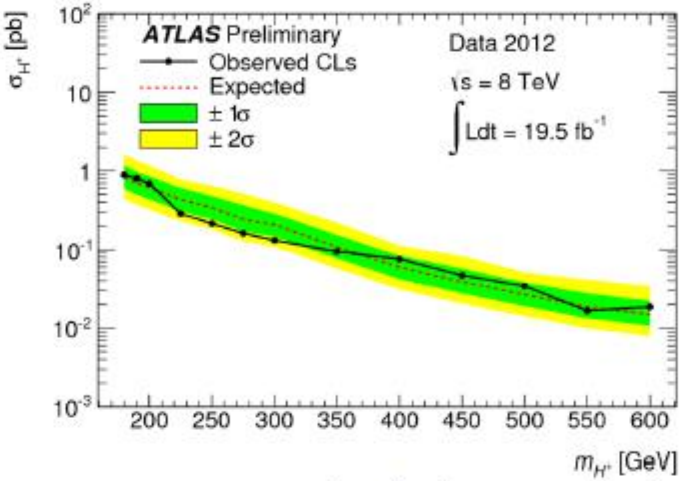


Light Higgs (m_H<m_t), tt->HbWb

Heavy Higgs (m_H>m_t)



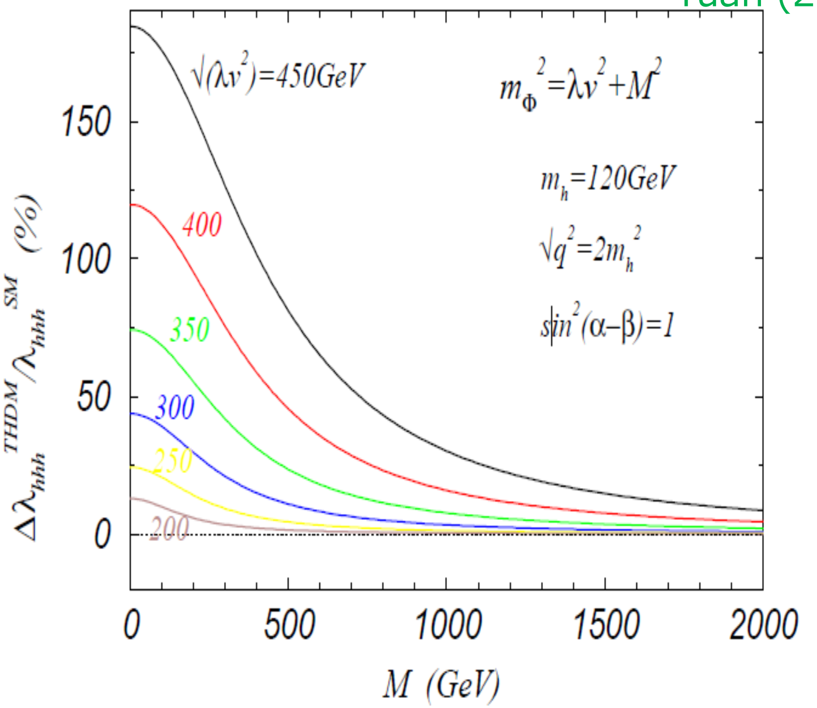
Branching fraction B(t->Hb),0.24-2.1%

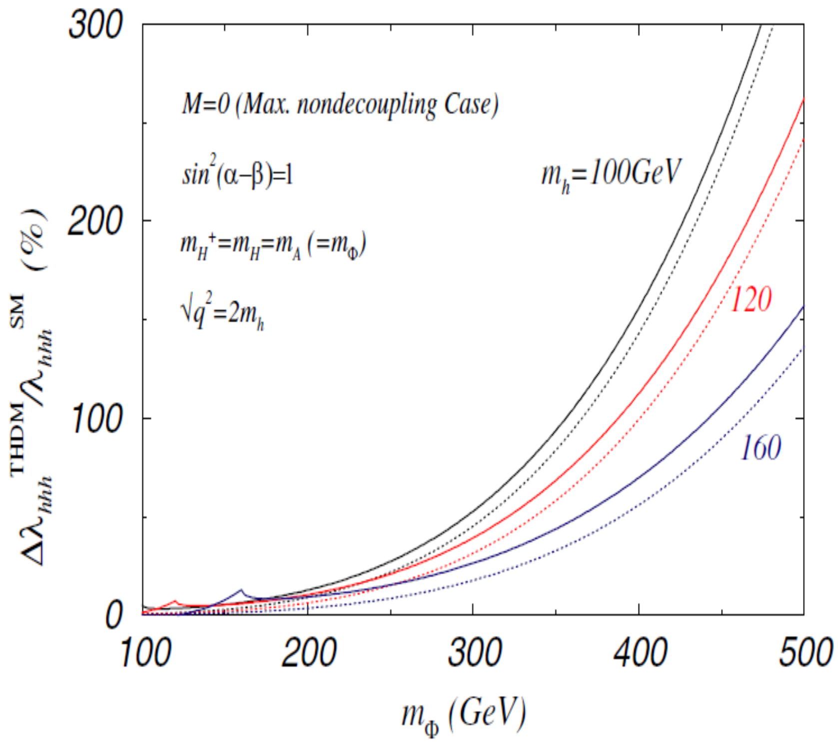


tH cross section limits:0.017-0.9pb

2HDM の *hhh*結合

Kanemura, Okada, Senaha, Yuan (2004)





$$m_\Phi^2 = \lambda v^2 + M^2$$

h coupling constants

- $m_X \propto g_X\, v$ in the SM

- If the Higgs sector is extended, $\cdots$

Coupling constants of *h* deviate from SM predictions by

- Field mixing
- Extra Higgs loop contributions

We may distinguish the Higgs sector by using the pattern of deviation of couplings.

$$\Delta\Gamma_{hff} \equiv \frac{\Gamma_{hff}^{\mathrm{THDM}} - \Gamma_{hff}^{\mathrm{SM}}}{\Gamma_{hff}^{\mathrm{SM}}}$$