Radiative corrections to Higgs decays in various extended Higgs models

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Outline

- Introduction
  - Motivation
  - H-COUP program
- Renormalization
  - Renormalizations of THDMs
  - Gauge dependence for scalar mixings
- Calculation of Higgs decays at NLO
  - Numerical results for Higgs branching ratios
- Summary

Motivation

- Property of the Higgs boson has been measured at the LHC.
  - Measurements of mass, *hVV* couplings, *hff* couplings, etc.
  - Current measurements are consistent with predictions of the SM.
- The structure of Higgs sector remains unknown.
  - SM Higgs sector :
  - But, there is still a possibility of extended Higgs sectors

Number and multiplet?

$\Phi + S$ (Singlet)

$\Phi_1 + \Phi_2$ (Doublet)

$\Phi + \Delta$ (Triplet)

Symmetry?

Discrete symmetry

Custodial symmetry

etc.

- Relation between BSM phenomena and extended Higgs sectors

→ Testing extended Higgs sectors is essential for exploring NP.

Our approach

Our approaches to the determination of the shape of the Higgs sector is following:

Precise calculations
$\Phi + S, \quad \Phi_1 + \Phi_2,$
$\Phi + \Delta, \ldots$

Precise measurements
HL-LHC, ILC, CLIC
FCC-ee, CEPC, etc.

Observables for the Higgs boson :
cross section, branching ratio, coupling, etc

Determination of the shape of the Higgs sector

→ We studied on radiative corrections to branching ratios in 6 different extended Higgs models.

Setup

We treat 6 simple extended Higgs models.

- **Higgs singlet models (HSM)**

The potential has shift invariance → $< S > = 0$
$[\ S \to S + v_s'\ ]$

$$V(\Phi, S) = m_\Phi^2|\Phi|^2 + \lambda|\Phi|^4 + \mu_{\Phi S}|\Phi|^2 S + \lambda_{\Phi S}|\Phi|^2 S^2 + t_S S + m_S^2 S^2 + \mu_S S^3 + \lambda_S S^4$$

Physical state : *h, H*   Free parameter : $m_H,\ \cos\alpha,\ m_s^2,\ \mu_S,\ \lambda_S$

SM-like Higgs ↗   ↖ CP -even Higgs

- **Two Higgs doublet models (THDMs)**

[softly broken Z_2 symmetry]
→ 4types of Yukawa int.

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

Physical state : $h, H, A, H^\pm$ Free parameter : $m_H, m_A, m_{H^\pm}, s_{\beta-\alpha}, t_\beta, M^2 (= m_3^2/(s_\beta c_\beta))$

- **Inert doublet model (IDM)**

[exact Z_2 symmetry]
→ Dark matte candidate

$$V_{IDM} = V_{THDM}\ \ (\ m_3^2 \to 0,\ \ < \Phi_2 > \to 0\ )$$

Physical state : $h, H, A, H^\pm$ Free parameter : $m_H, m_A, m_{H^\pm}, \lambda_2, m_2$

Higgs couplings

$$\kappa_X = \frac{g(hXX)^{EX.}}{g(hXX)^{SM}}$$

HSM : $\kappa_V = \kappa_f = \cos\alpha$

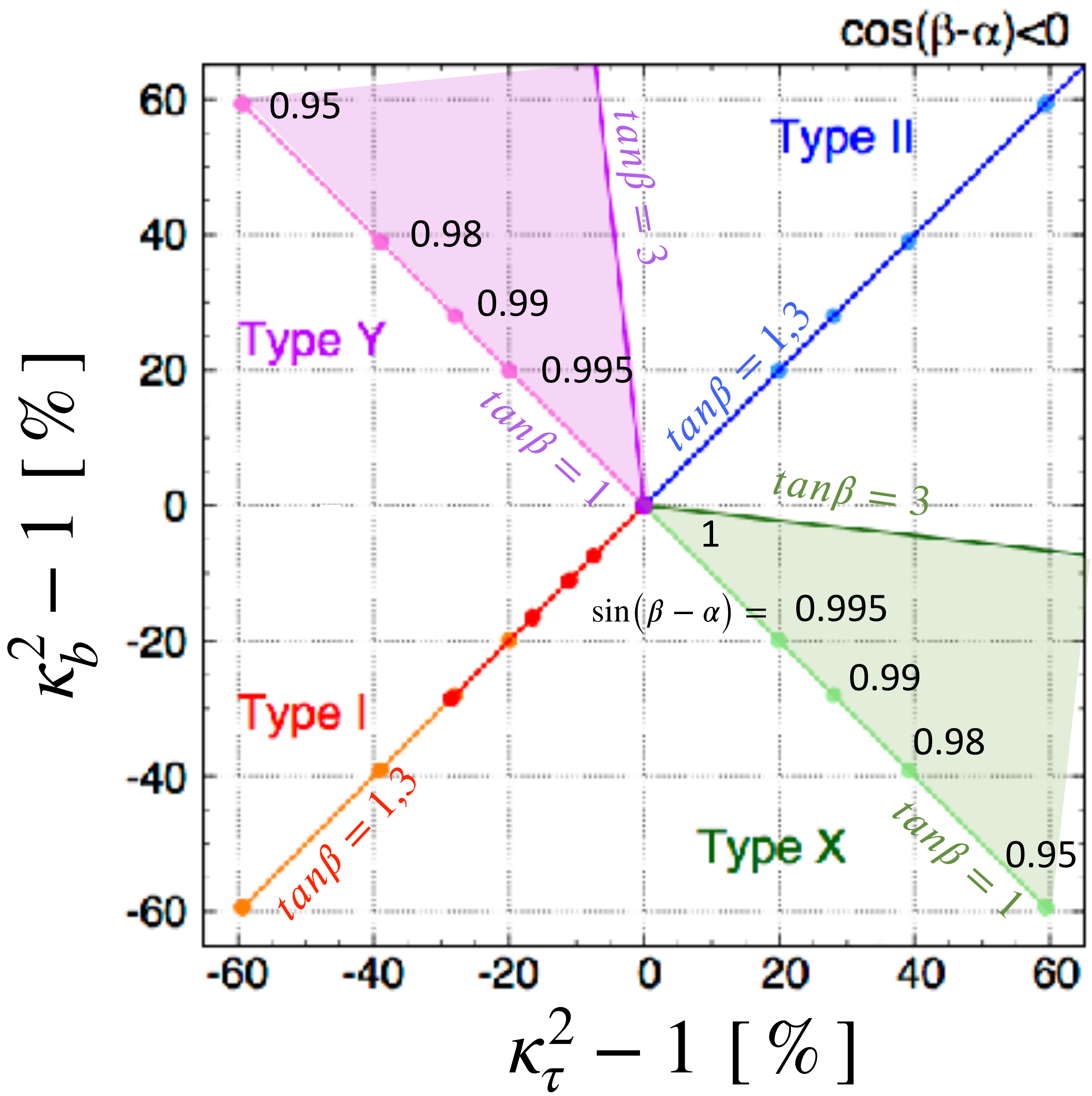
THDMs : $\kappa_V = \sin(\beta - \alpha)$, $\kappa_f = \sin(\beta-\alpha) + \xi_f \cos(\beta-\alpha)$

	ξ_u	ξ_d	ξ_e
Type-I	$\cot\beta$	$\cot\beta$	$\cot\beta$
Type-II	$\cot\beta$	$-\tan\beta$	$-\tan\beta$
Type-X	$\cot\beta$	$\cot\beta$	$-\tan\beta$
Type-Y	$\cot\beta$	$-\tan\beta$	$\cot\beta$

IDM : $\kappa_V = \kappa_f = 1$

Model discrimination by couplings

Ex.) THDM Type I, II, X, and Y



[Kanemura, Tsumura, Yagyu, Yokoya, PRD90 (2014) 075001]

$$\kappa_f = \sin(\beta - \alpha) - \xi_f \cos(\beta - \alpha)$$

	ξ_u	ξ_d	ξ_e
Type-I	$\cot\beta$	$\cot\beta$	$\cot\beta$
Type-II	$\cot\beta$	$-\tan\beta$	$-\tan\beta$
Type-X	$\cot\beta$	$\cot\beta$	$-\tan\beta$
Type-Y	$\cot\beta$	$-\tan\beta$	$\cot\beta$

Each extended Higgs model can give different pattern of deviations

Nondecoupling effects

In the alignment limit, the heavy Higgs masses can be commonly expressed as:

$$m_\Phi^2 \simeq M^2 + \lambda_i v^2 \qquad (\Phi = H, A, H^\pm)$$

$$M^2 = \begin{cases} 2m_s & \text{(HSM)} \\ m_3^2/s_\beta c_\beta & \text{(THDMs)} \\ \mu_2^2 & \text{(IDM)} \end{cases}$$

There are two cases for large m_Φ^2 :

(1) $M^2 \gg \lambda_i v^2 \longrightarrow m_\Phi^2 \simeq M^2$

Loop contributions of Φ decouple, obeying decoupling theorem.

[T. Appelquist, J. Carazzone, PRD 11 (1975) 2856]

$$\kappa_X - 1 \simeq -\frac{1}{16\pi^2}\frac{1}{6}\sum_\Phi \frac{1}{m_\Phi^2} + \dots$$

(2) $M^2 \ll \lambda_i v^2 \longrightarrow m_\Phi^2 \simeq \lambda_i v^2$

Nondecoupling effects can be obtained.

$$\kappa_X - 1 \simeq -\frac{1}{16\pi^2}\frac{1}{6}\sum_\Phi \frac{m_\Phi^2}{v^2} + \dots$$

Nondecoupling effects

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Nondecoupling effects can be obtained.

$$\kappa_X - 1 \simeq -\frac{1}{16\pi^2}\frac{1}{6}\sum_\Phi \frac{m_\Phi^2}{v^2}$$

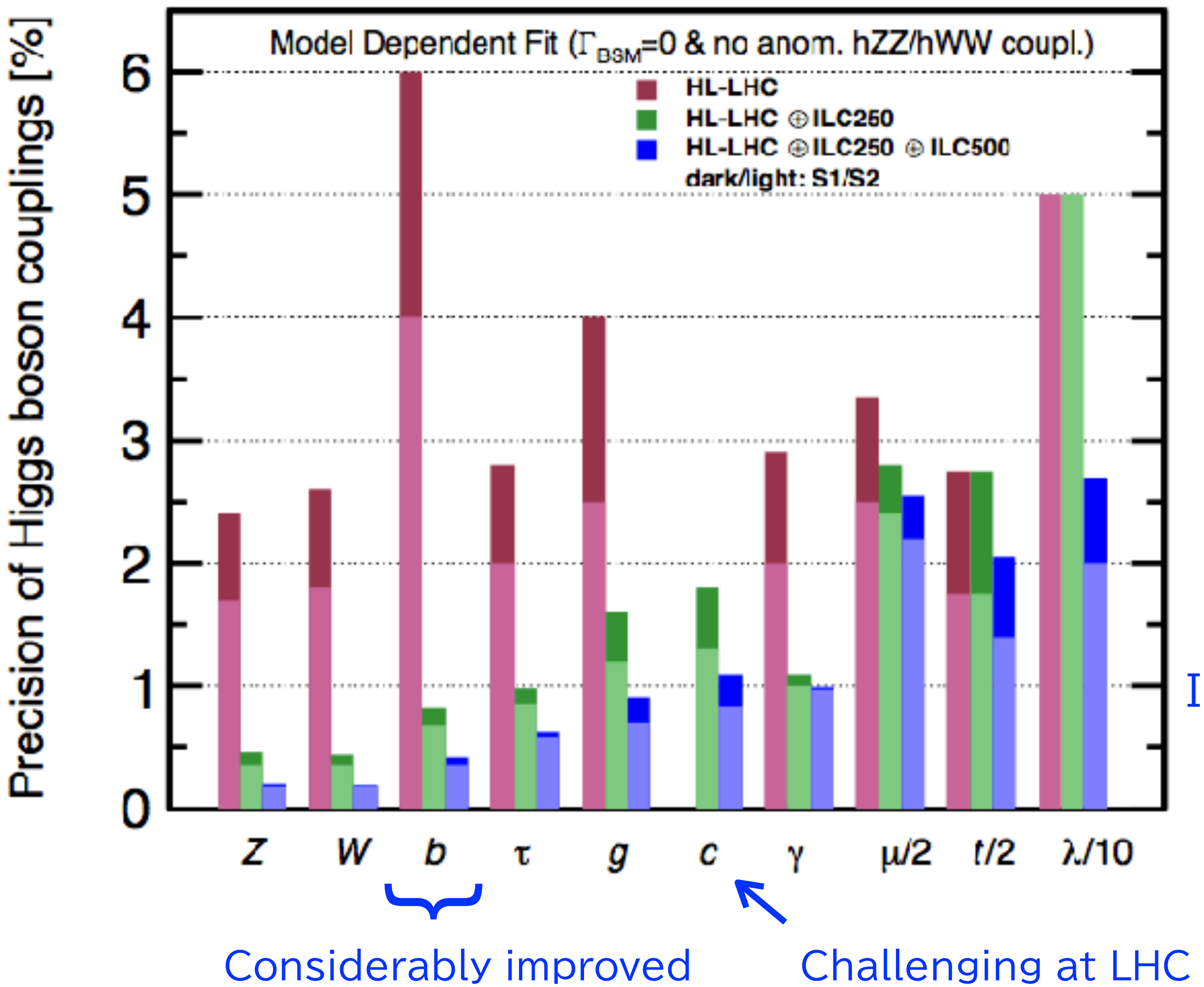
In the case of THDMs, maximally

~ 2.5% for *hVV* [Kanemura, Okada, Senaha, Yuan, PRD70,115002]

~ 5% for *hff* [Kanemura, Kikuchi, Yagyu, PLB731, 27]

Measurements accuracy of the Higgs couplings (prospect)

[arXiv:1901.09829]



HL -LHC: $\mathcal{O}(1)\,\%$

ILC: $\mathcal{O}(1) \sim \mathcal{O}(0.1)\,\%$

- Sensitivity of most of couplings are improved by the ILC.
- Loop effects of extra Higgs is comparable with future sensitivities.

  → Evaluation of Higher order corrections is necessary.

Couplings → branching ratios

While the experimental data of Higgs couplings are not directly compared with predictions of models, the branching ratios can be done :

- Higgs couplings

Exp. data $\longleftrightarrow$ κ factors / Wilson coefficients $\longleftrightarrow$ Models

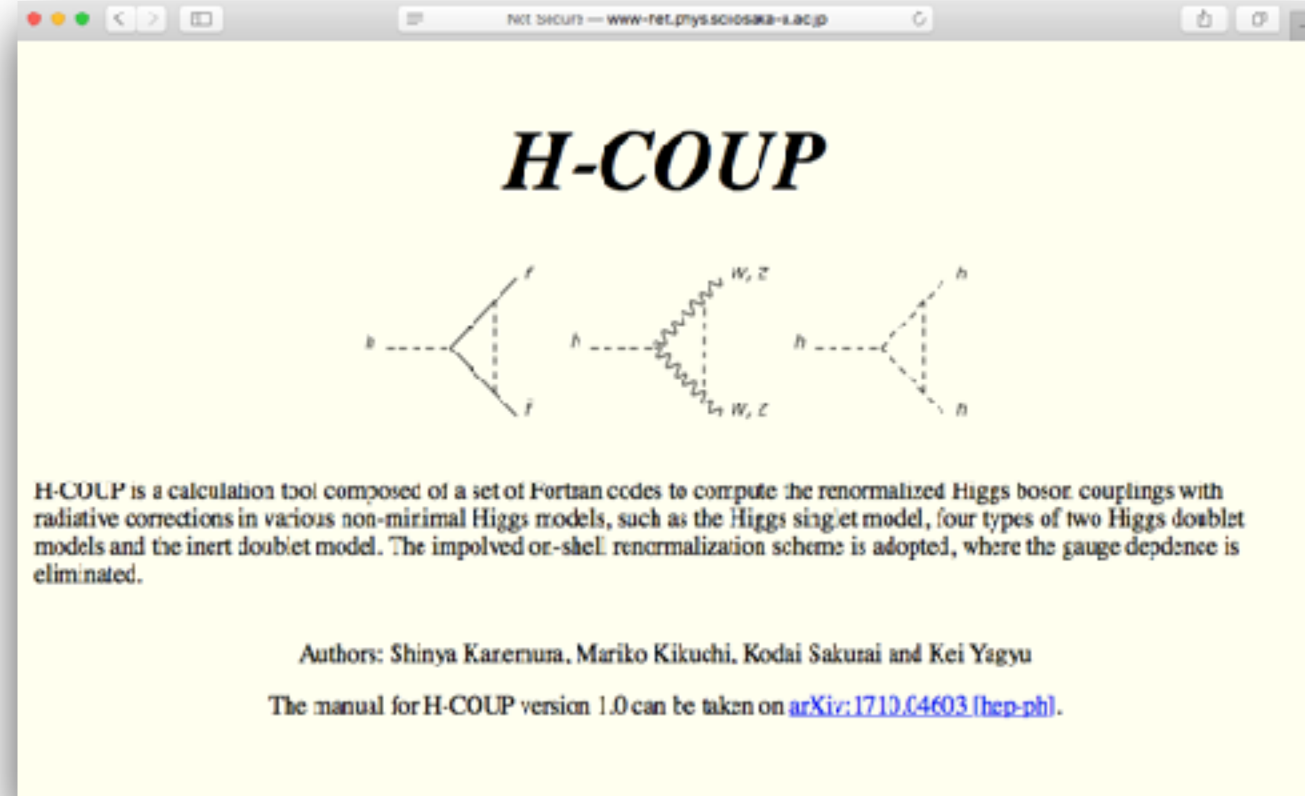
- Branching ratios

Exp. data $\xleftrightarrow{\text{Directly compared}}$ Models

Public tools

Here is a list of public tools to compute the Higgs decays for extended Higgs models.

- (ewN)**2HDECAY** : [M. Krause, M. Mühlleitner, M. Spira, 1810.00768][M. Krause, M. Mühlleitner, 1904.02103]
  - Model: 2HDMs, N2HDMs
  - Calculations of two-body-Higgs decays with full 1-loop EW and state-of-the-art QCD corrections in 17 renormalization scheme for mixing parameters
- **Prophecy4f** : [L. Altenkamp, S. Dittmaier, H. Rzehak,JHEP 1803 (2018) 110]
  - Model: SM,2HDMs, HSM
  - h → WW/ZZ → 4 fermions with NLO QCD and NLO EW corrections
- **RECOLA2** : [A. Denner, J. N. Lang, S. Uccirati, CPC 224(2018)346]
  - Model: 2HDMs, HSM
  - Calculation to NLO amplitude for any process
- **2HDMC** : [D. Eriksson, J. Rathsman, O. Stal CPC. 181 (2010) 189]
  - Model: 2HDMs
  - Calculations of decays of Higgs bosons with NLO QCD
- **SHDECAY** : [R. Costa, M. Mühlleitner, M. Sampaio, R. Santos, JHEP 06 (2016) 034]
  - Model: HSM (real and complex)
  - Calculations of decays of Higgs bosons with NLO QCD
- **H-COUP** : [Kanemura, Kikuchi, KS, Yagyu, CPC 233 (2018) 134]
  [Kanemura, Kikuchi, Mawatari, KS, Yagyu, 1910.12769]



H-COUP1.0(13.10.18~)

Model:

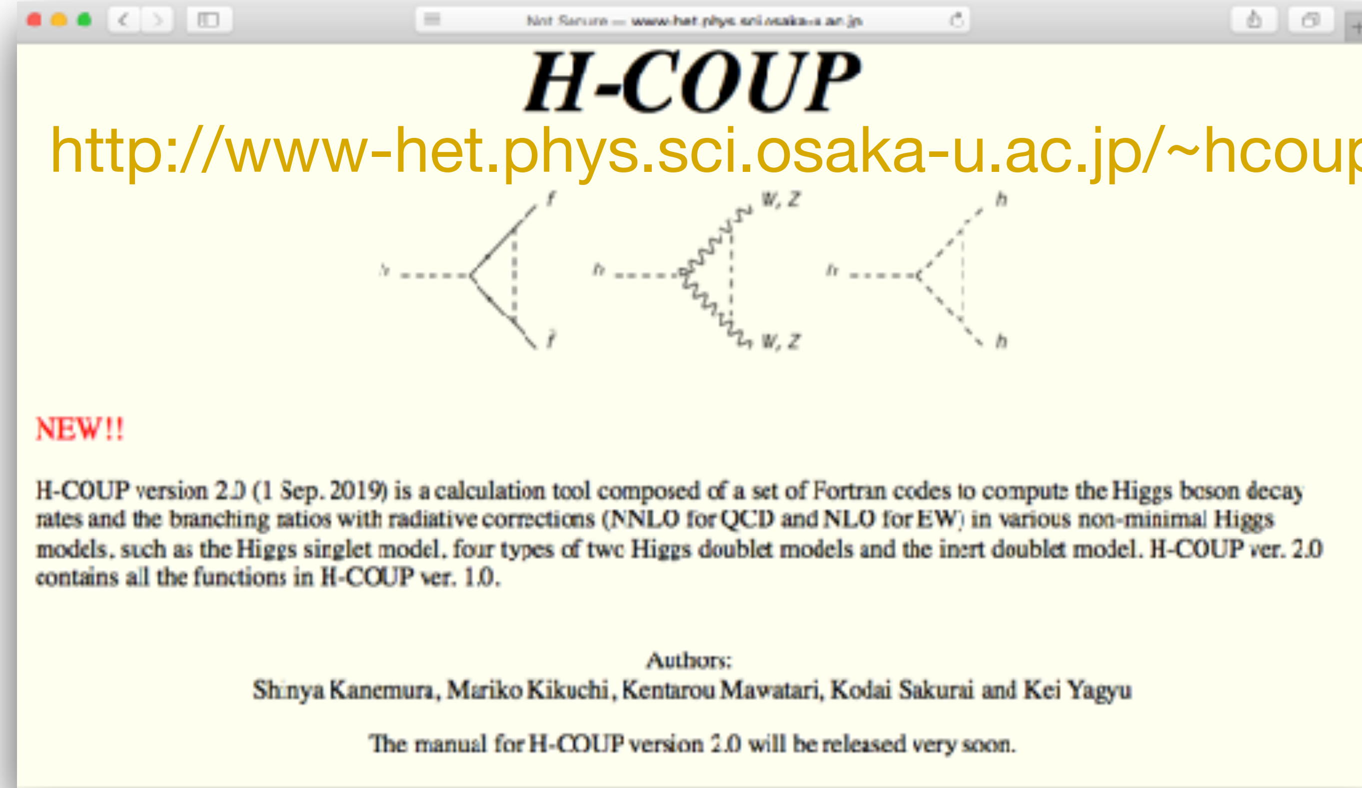
- Singlet extension of the SM
- 4 types of 2HDMs
- Inert doublet model

Evaluation:

- Higgs vertex functions (at 1-loop)

$$\hat{\Gamma}^{\mu\nu}_{hVV} = \hat{\Gamma}^{1}_{hVV} g^{\mu\nu} + \hat{\Gamma}^{2}_{hVV} \frac{p_1^{\mu} p_2^{\nu}}{m_V^2} + i \hat{\Gamma}^{3}_{hVV} \epsilon^{\mu\nu\rho\sigma} \frac{p_{1\rho} p_{2\sigma}}{m_V^2},$$

$$\begin{aligned} \hat{\Gamma}_{hff} = {} & \hat{\Gamma}^{S}_{hff} + \gamma_5 \hat{\Gamma}^{P}_{hff} + \not{p}_1 \hat{\Gamma}^{V1}_{hff} + \not{p}_2 \hat{\Gamma}^{V2}_{hff} \\ & + \not{p}_1 \gamma_5 \hat{\Gamma}^{A1}_{hff} + \not{p}_2 \gamma_5 \hat{\Gamma}^{A2}_{hff} + \not{p}_1 \not{p}_2 \hat{\Gamma}^{T}_{hff} + \not{p}_1 \not{p}_2 \gamma_5 \hat{\Gamma}^{PT}_{hff} \end{aligned}$$



http://www-het.phys.sci.osaka-u.ac.jp/~hcoup/

H-COUP1.0(13.10.18~)

Model:

- Singlet extension of the SM
- 4 types of 2HDMs
- Inert doublet model

Evaluation:

- Higgs vertex functions (at 1-loop)

H-COUP2.0(03.09.19~)

Model:

Same as ver. 1.0

Evaluation:

- Higgs vertex functions (at 1-loop)
- New – Higgs branching ratios (with NLO EW and NNLO QCD)

Feature of the H-COUP:

- All decay processes for the Higgs boson with Higher order corrections can be evaluated in the same renormalization scheme for various models.
- Form factors of renormalized Higgs bosons can be evaluated.

In this talk

By using **H-COUP**, We have evaluated Higgs BRs with full 1-loop corrections in 6 different models.

The predictions can be directory compared with exp. data

Open questions:

- how is decoupling property of additional Higgs bosons for BRs?
- What is pattern of deviations from the SM for BRs for each model?

▶ We show size of additional Higgs boson loop cont. for BRs.

▶ We discuss if various extended Higgs models are discriminated by using precise measurements of Higgs BRs.

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Renormalization of the Higgs sector

We have used improved on-shell renormalization scheme in calculations for EW corrections for Higgs decay rates. [S. Kanemura, M. Kikuchi, KS, K. Yagyu, PRD96,035014]

Ex.) Higgs potential in the THDMs

$$\Phi_i = \begin{pmatrix} w_i^+ \\ \frac{1}{\sqrt{2}}(h_i + i z_i) \end{pmatrix} \quad (i = 1,2)$$

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

1. Count number of parameters and fields in Lagrangian:

- Parameters in Higgs potential ： 8

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

- Tadpoles ：2

  $T_h,\ T_H$

- Fields of Higgs sector ： 8

  $h,\ H^\pm,\ H,\ A,\ G^0,\ G^\pm$

[Kanemura, Senaha, Okada Yuan, PRD70 (2004) 115002]

2. Shift parameters and fields to introduce counter terms as same number these:

- Parameter shift : $(\varphi = h, H^{\pm}, H, A)$

$$m_\varphi \to m_\varphi + \delta m_\varphi,\ M \to M + \delta M,\ \alpha \to \delta\alpha,\ \beta \to \delta\beta,$$

$$T_h \to T_h + \delta T_h, T_h \to T_H + \delta T_H$$

- Field shift :

$$\begin{pmatrix}\varphi_1\\ \varphi_2\end{pmatrix} \to \begin{pmatrix}1+\delta\frac{1}{2}Z_{\varphi_1} & \delta C_{\varphi_1\varphi_2}+\delta\theta\\ \delta C_{\varphi_1\varphi_2}-\delta\theta & 1+\frac{1}{2}\delta Z_{\varphi_2}\end{pmatrix}\begin{pmatrix}\varphi_1\\ \varphi_2\end{pmatrix}, \qquad (\varphi_1,\varphi_2,\theta) = (H,h,\alpha),\ (G^0,A,\beta)\ \text{or}\ (G^{\pm},H^{\pm},\beta)$$

→ We get 19 counter terms :

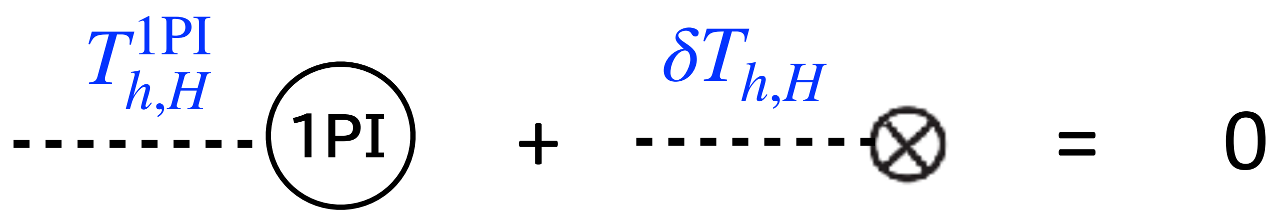
$$\delta v,\ \delta m_h^2,\ \delta m_H^2,\ \delta m_A^2,\ \delta m_{H^\pm}^2,\ \delta M^2,\ \delta\alpha,\ \delta\beta, \delta T_h, \delta T_H$$

$$\delta Z_h\ ,\ \delta Z_H,\ \delta Z_A,\ \delta Z_{H^\pm},\ \delta Z_{G^0},\ \delta Z_{G^\pm},\ \ \delta C_{Hh},\ \delta C_{GA},\ \delta C_{G^+H^-}$$

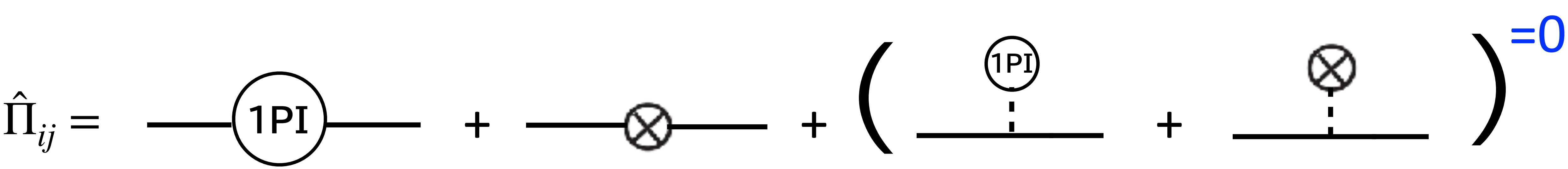
3. Set renormalization conditions:

Renormalization of tadpoles

- Standard scheme [W.F.L. Hollik, Fortschr. Phys. 38 (1990) 165.]



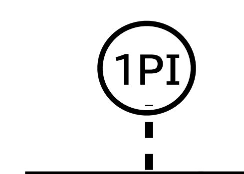
  - Tadpole contributions don't appear in self-energy for vector boson and fermion.



  - Counter terms for physical parameters (e.g., mass) are gauge-dependent.

Note: This is not a problem as longs as physical quantities are gauge independent.

- (Alternative) tadpole scheme [J. Fleischer and F. Jegerlehner, PRD23, 2001 (1981)]
  - In addition to above conditions, Shift of VEV is performed: $v_i \to v_i + \Delta v_i, \ (i = 1,2)$

→ Tadpole contributions appear in self-energy for all fields: $\hat{\Pi}^{\mathrm{Tad}}_{ij} = \hat{\Pi}_{ij} +$ 

→ Gauge invariance for CT is restored.

We showed that $\Gamma^{\mathrm{Tad}}_{h\to XX} = \Gamma^{\mathrm{Stand.}}_{h\to XX}$ → We use the standard scheme.

[Kanemura, Kikuchi, KS, Yagyu, PRD96,035014]

Renormalization of mass, WFR and mixing angles

δm_Φ : $\hat{\Pi}_{\varphi\varphi}(m_\varphi^2) = 0$ (Φ =h, H , A , $H^\pm$)

δZ_Φ : $\frac{d}{dp^2}\hat{\Pi}_{\varphi\varphi}(p^2)\big|_{p^2=m_\varphi^2} = 0$ (Φ =h, H , A , $H^\pm$,$G^\pm$,G^0)

$\delta\alpha, \delta\beta, \delta C_{\Phi 1 \Phi 2}$: $\hat{\Pi}_{\phi_1\phi_2}(m_{\phi_1}^2) = \hat{\Pi}_{\phi_1\phi_2}(m_{\phi_2}^2) = 0$ ({Φ_1, Φ_2 }={H, h} , {G^0,A} , {$H^\pm$,$G^\pm$})

Renormalization of another quantities

δv : This counter term is determined in gauge sector.

δM : It is determined such as UV divergence in *hhh* vertex becomes zero.

- In this way, with above renormalization conditions, all counter terms are determined.

  → any renormalized quantities are UV finite .

- Gauge dependence appears in the renormalization of the scalar mixing angles (even if in tadpole scheme). [Yamada, PRD64(2001)036008]

  → Physical quantities also become gauge dependent .

Gauge dependence on mixing angles

We consider unrenormalized mass matrix at the 1-loop in R_ξ gauge :

$$M_{Hh} = \begin{pmatrix} m_h^2 + \Pi_{hh}^{\mathrm{Tad}} & \Pi_{Hh}^{\mathrm{Tad}} \\ \Pi_{Hh}^{\mathrm{Tad}} & m_H^2 + \Pi_{HH}^{\mathrm{Tad}} \end{pmatrix}$$

$$\partial_\xi M_{Hh} = \begin{pmatrix} (p^2 - m_h^2)\tilde{\Pi}_{hh}^{\mathrm{Tad}} & (2p^2 - m_h^2 - m_H^2)\tilde{\Pi}_{Hh}^{\mathrm{Tad}} \\ (2p^2 - m_h^2 - m_H^2)\tilde{\Pi}_{Hh}^{\mathrm{Tad}} & (p^2 - m_H^2)\tilde{\Pi}_{HH}^{\mathrm{Tad}} \end{pmatrix}$$

Diagonal elements : $\hat{\Pi}_{hh}^{\mathrm{Tad}}(m_h^2) = \hat{\Pi}_{HH}^{\mathrm{Tad}}(m_H^2) = 0$

→ δm_h^2, δm_H^2 are gauge independent.

Off-diagonal elements : $\hat{\Pi}_{Hh}^{\mathrm{Tad}}(m_h^2) = \hat{\Pi}_{Hh}^{\mathrm{Tad}}(m_H^2) = 0$

→ $\delta\alpha$, $\delta\beta$ are gauge dependent.

→ amplitudes for Higgs process with $\delta\alpha$, $\delta\beta$ are also gauge dependent [M. Krause, R. Lorenz, M. Muhlleitner, R. Santos, H. Ziesche, JHEP 09 (2016) 143]

Pinch technique

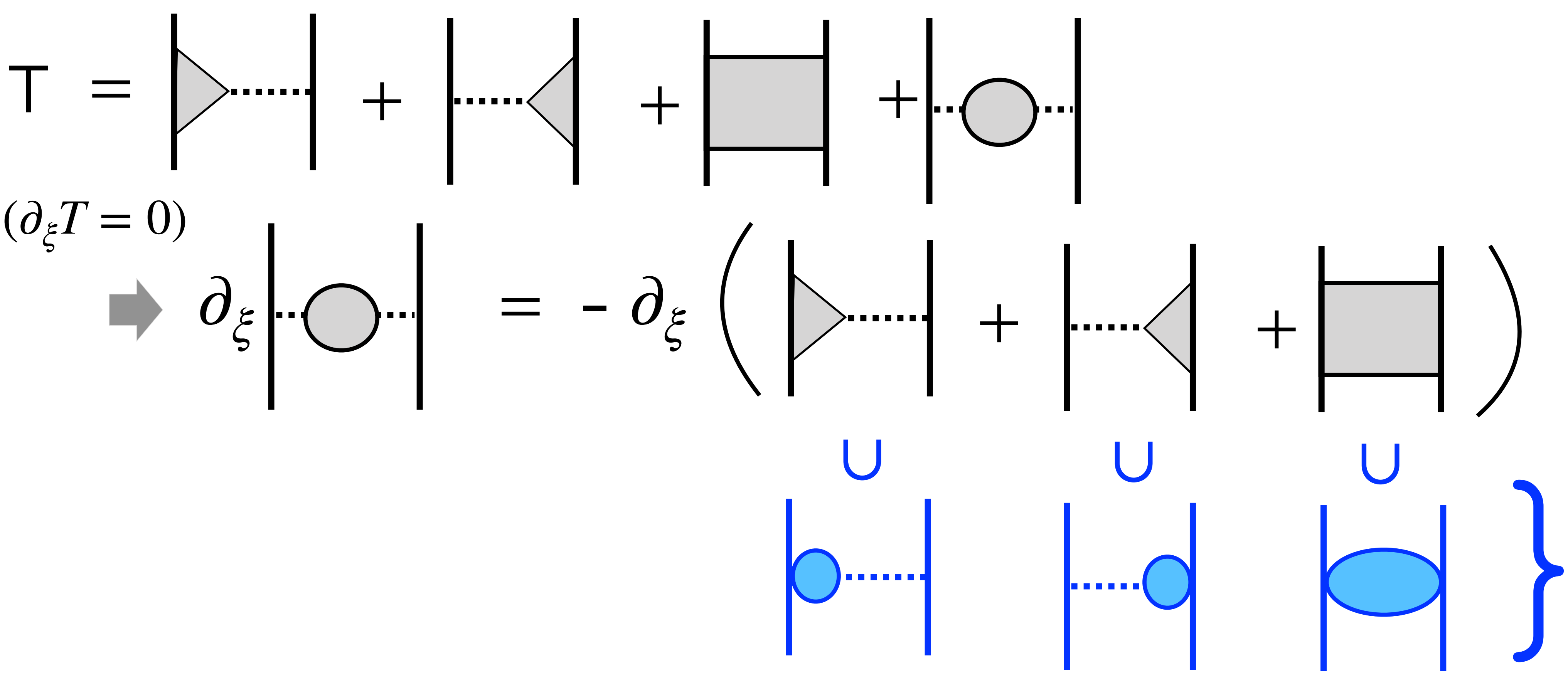
- In order to remove the gauge dependence in $\delta\alpha,\ \delta\beta$ we utilize pinch technique [J. Papavassiliou, PRD50, 5958]

Basic idea: $\Pi^{\mathrm{Tad}}_{Hh} \rightarrow \underbrace{\Pi^{\mathrm{Tad}}_{Hh} + \Pi^{PT}_{Hh}}_{}$ (in $\delta\alpha,\ \delta\beta$) $\Rightarrow$ $\partial_\xi \delta\alpha = 0,\ \partial_\xi \delta\beta = 0$

Pinch terms

- Pinch terms can be extracted as follows:

  Considering S-matrix of 2 →2 fermions scattering



Self-energy like cont. (=pinch terms)

In this way, we can get gauge independent mixing counter terms.

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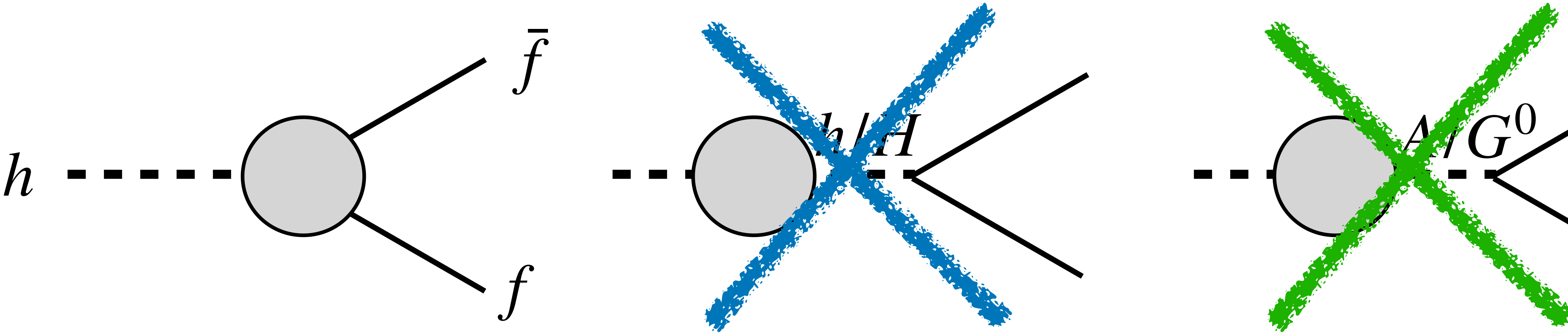
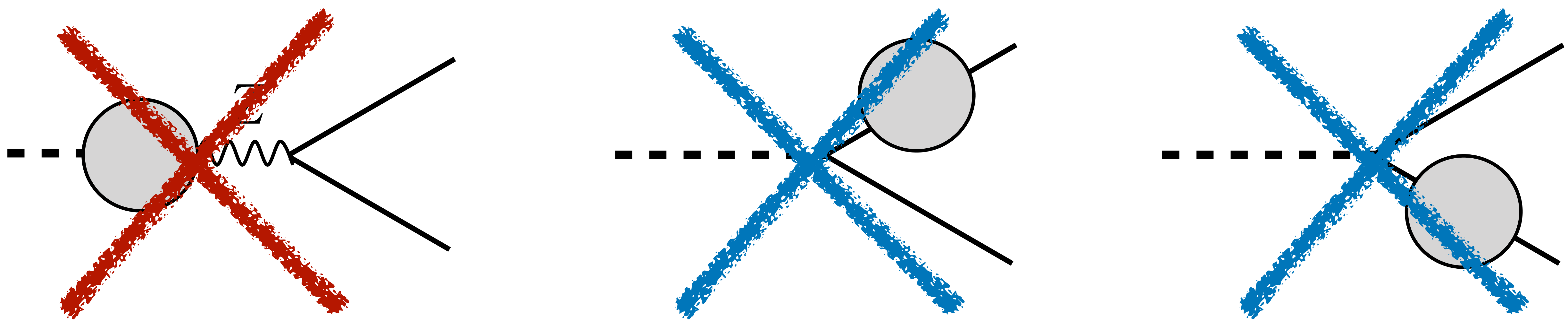
One-loop calculation of Higgs decay rates

Virtual corrections for $h \to ff$:

CP-conservation





Slavnov-Taylor identity

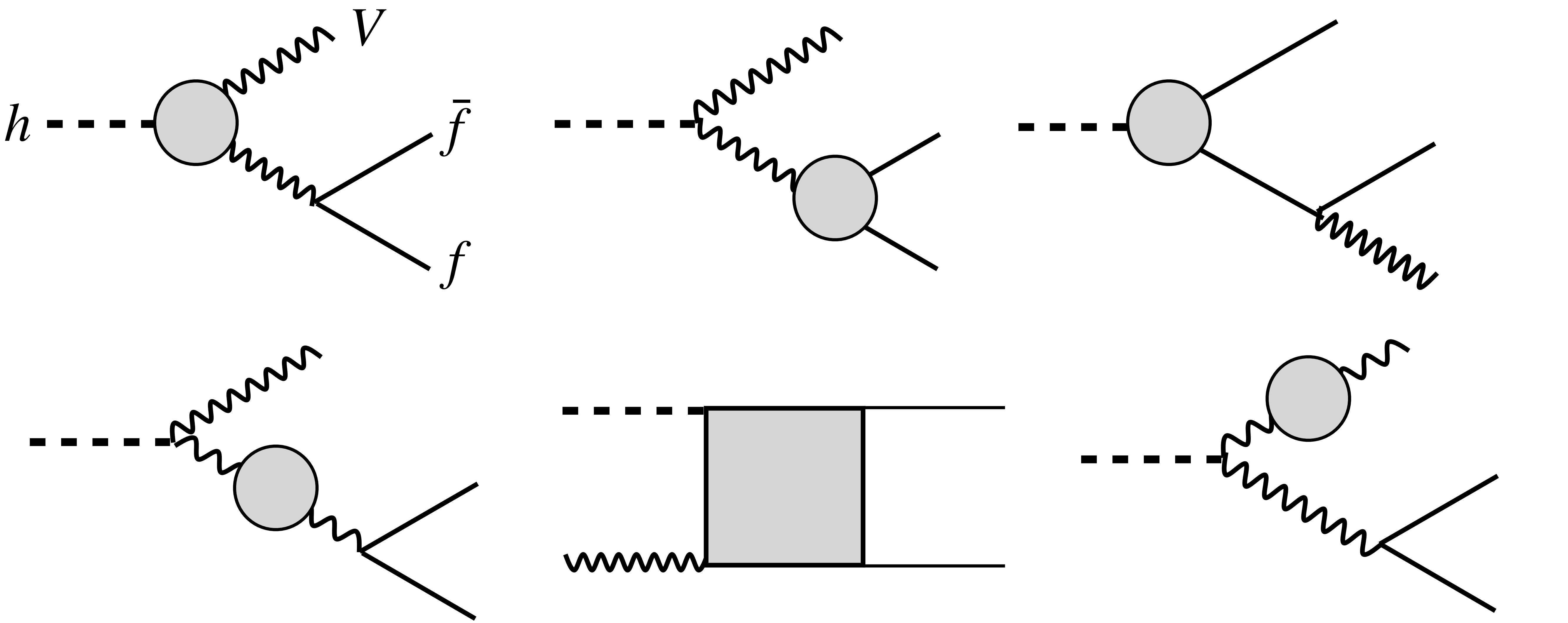
[K. E. Williams, H. Rzehak, G. Weiglein, Eur.Phys.J. C71 (2011) 1669]

$$\Pi_{hG} + i m_Z \Pi_{hZ} = 0$$

On-shell condition

$$\hat{\Pi}_{hh'}, \hat{\Pi}_{hH'}, \hat{\Pi}_{ff} = 0$$

Virtual corrections for $h \to VV^* \to Vf\bar{f}$: (V=Z,W)



- For renormalization of WFR for the weak gauge boson, we do not impose that the residue is a unity. It is expressed as in terms of WFR for γ and γ-Z mixing.

  [W.F.L. Hollik, Fortschr. Phys. 38 (1990) 165.]

- IR structure between $h \to ZZ^*$ and $h \to WW^*$ are different.

  $h \to ZZ^*$: Only Vff vertex contains photon loop diagrams.

  $h \to WW^*$: All diagrams contain photon loop diagrams.

IR divergence for h→WW*

- In order to get IR finate results for h→WW*, real photon emissions are needed. For the evaluation we make use of phase space slicing method. [B. Harris, J. Owens, ,PRD65(2002)094032]

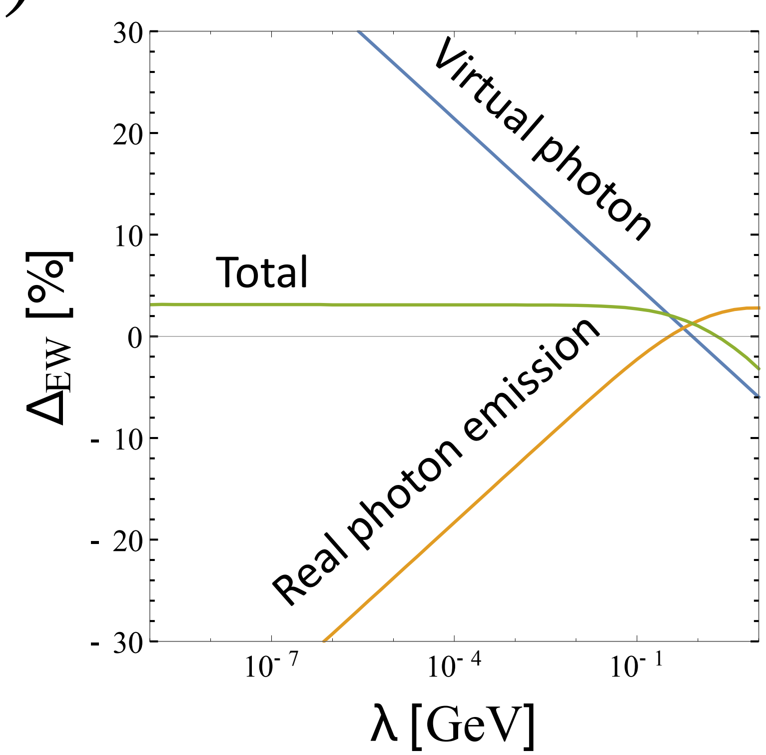
$$\Gamma\left(h \to Wff'\gamma\right) = \Gamma\left(h \to Wff'\gamma\right)[\lambda, \mathrm{m}_f, \mathrm{m}_{f'}, \Delta E]^S + \Gamma\left(h \to Wff'\gamma\right)\left[m_f, m_{f'}, \Delta E\right]^H$$

ΔE: cut off parameter, λ: regulator of soft div. $m_f, m_{f'}$: regulator of collinear div.

- Adding contributions of the real photon to that of virtual photon, soft divergence and collinear divergence are cancelled.

$$\Gamma(h \to Wff') + \Gamma(h \to Wff'\gamma) = (\text{IR finite})$$

→ We numerically checked the cancellation.



Higgs branching ratios at the 1-loop

HSM, IDM

$$\mathrm{BR}(h \to XX) \simeq \frac{\cancel{\kappa_X^2}\,\Gamma(h \to XX)^{\mathrm{LO}}(1 + \Delta_{SM}^{\mathrm{EW,QCD}} + \cancel{\Delta_{NP}^{\mathrm{EW}}})}{\cancel{\kappa_X^2}\,\Gamma_h(1 + \Delta_{SM}^{\mathrm{EW,QCD}} + \cancel{\Delta_{NP}^{\mathrm{EW}}})}$$
$$\simeq \mathrm{BR}(h \to XX)^{\mathrm{SM}}$$

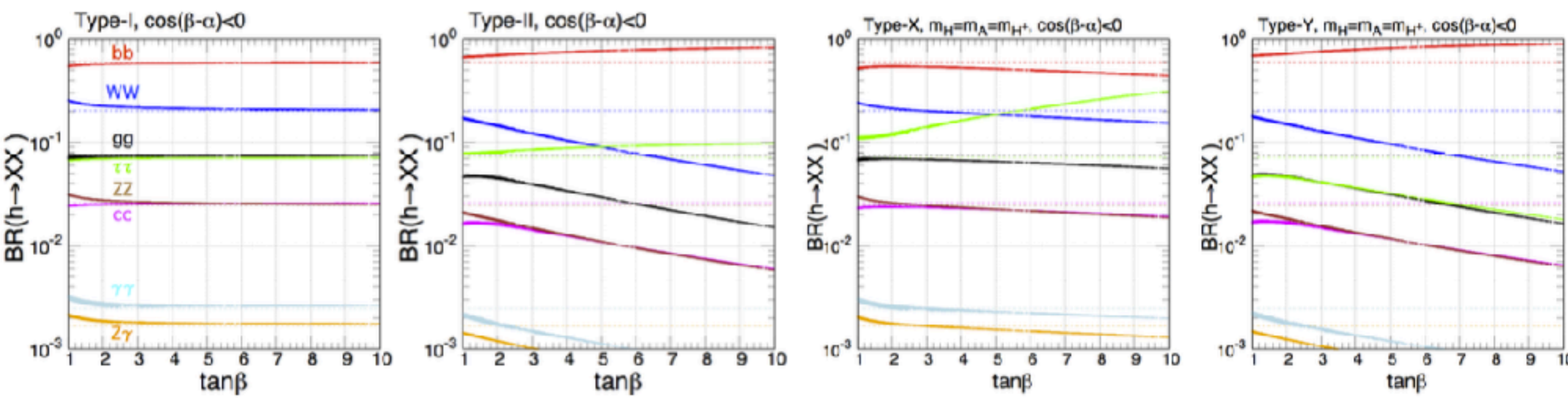
κ_X : Scaling factor

Δ_{EW}^{NP} : Loop contributions of additional Higgs bosons

Typical values of deviation from the SM is about 0.5%.

But, total decay rates deviate with few %.

THDMs [Kanemura, Kikuchi, Mawatari ,KS, Yagyu]



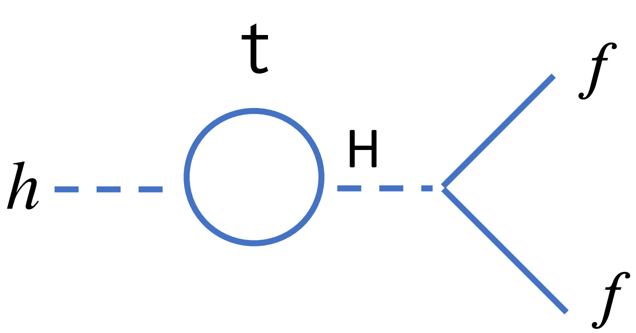
Cause of deviations from SM : ① Mixing, loop effect of additional Higgs

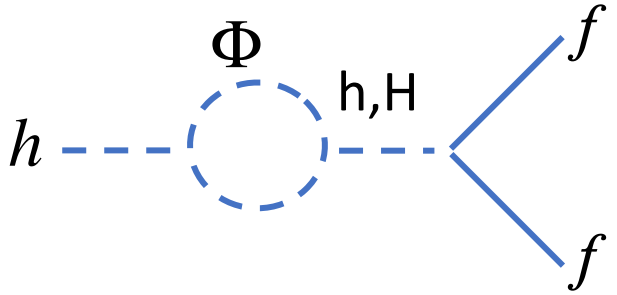
② Correlation of each mode

Higgs branching ratios at the 1-loop

In order to more clearly see the magnitude of additional Higgs bosons loop contributions, we evaluate the deviations in the branching ratios in 2HDMs.

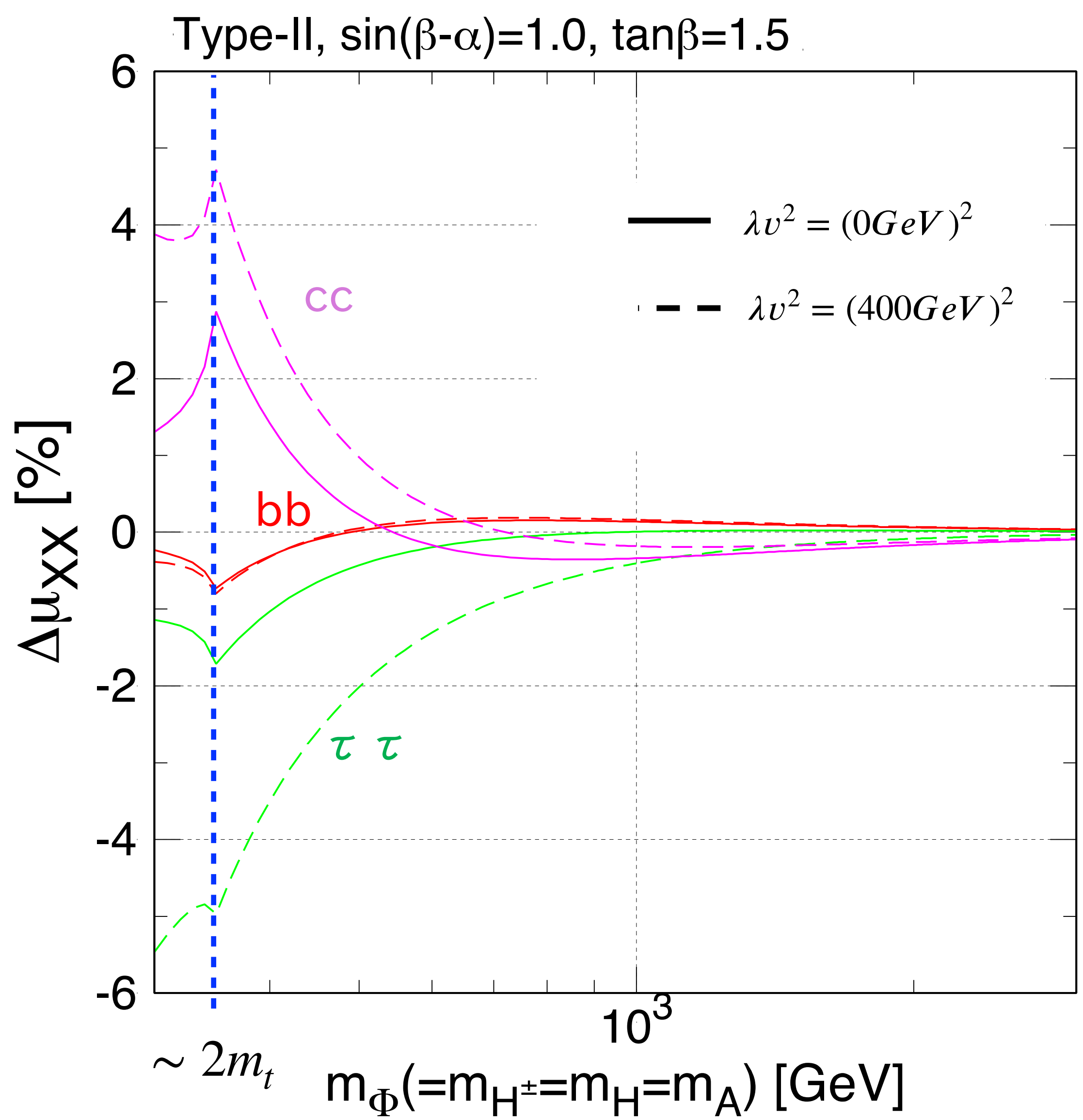
Typical graph :





$$\sim -\frac{1}{16\pi^2}\frac{1}{6}\sum_{\Phi}\frac{m_{\Phi^2}}{v^2}\left(1-\frac{M^2}{m_\Phi^2}\right)^2$$

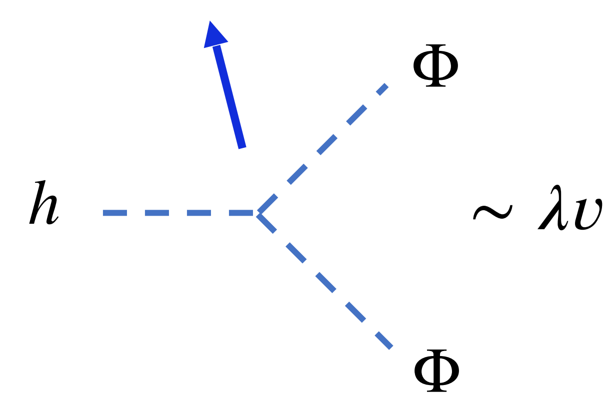
[Kanemura, Kikuchi, Mawatari ,KS, Yagyu]



Deviations from SM :

$$\Delta\mu_{XX} = \frac{\mathrm{BR}(h\to XX)_{NP}}{\mathrm{BR}(h\to XX)_{SM}} - 1$$

$$\lambda v^2 \equiv m_\Phi^2 - M^2$$



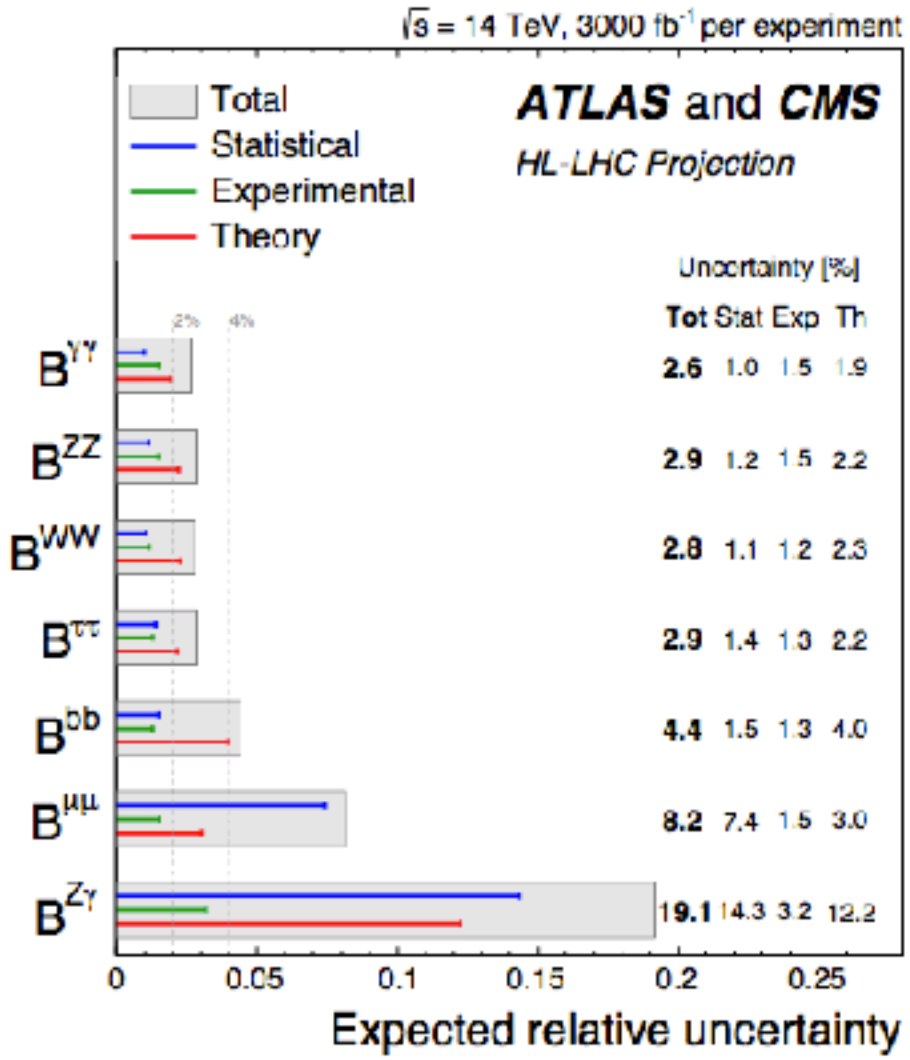
$m_\Phi \gg v$: Additional Higgs loop contributions decouple.

$m_\Phi \sim v$: Non-decoupling effect can be appeared at few %.

Discrimination of the models

We discuss whether 6 different models are discriminated by precise measurements of Higgs branching ratios.

HL-LHC [1902.00134]



ILC [1710.07621]

	1σ	2σ
$B^{\gamma\gamma}$	13%	26%
B^{ZZ}	6.7%	13.4%
B^{WW}	1.9%	$\boxed{3.8\%}$
$B^{\tau\tau}$	1.4%	2.8%
B^{bb}	0.89%	1.78%
$B^{\mu\mu}$	27%	54%

We consider situations that B^{WW} are measured with few % accuracy at the ILC.

→We studied three cases:

①: $\Delta\mu_{WW} = 0 \pm 4\,\%$ ②: $\Delta\mu_{WW} = 5 \pm 4\,\%$ ③: $\Delta\mu_{WW} = -5 \pm 4\,\%$

Case ① : $\Delta\mu_{WW} = 0 \pm 4\,\%$

$$\Delta\mu_{XX} = \frac{\mathrm{BR}(h \to XX)_{NP}}{\mathrm{BR}(h \to XX)_{SM}} - 1$$

[Kanemura, Kikuchi, Mawatari ,KS, Yagyu]

- Plot of color :
  Predictions of each model

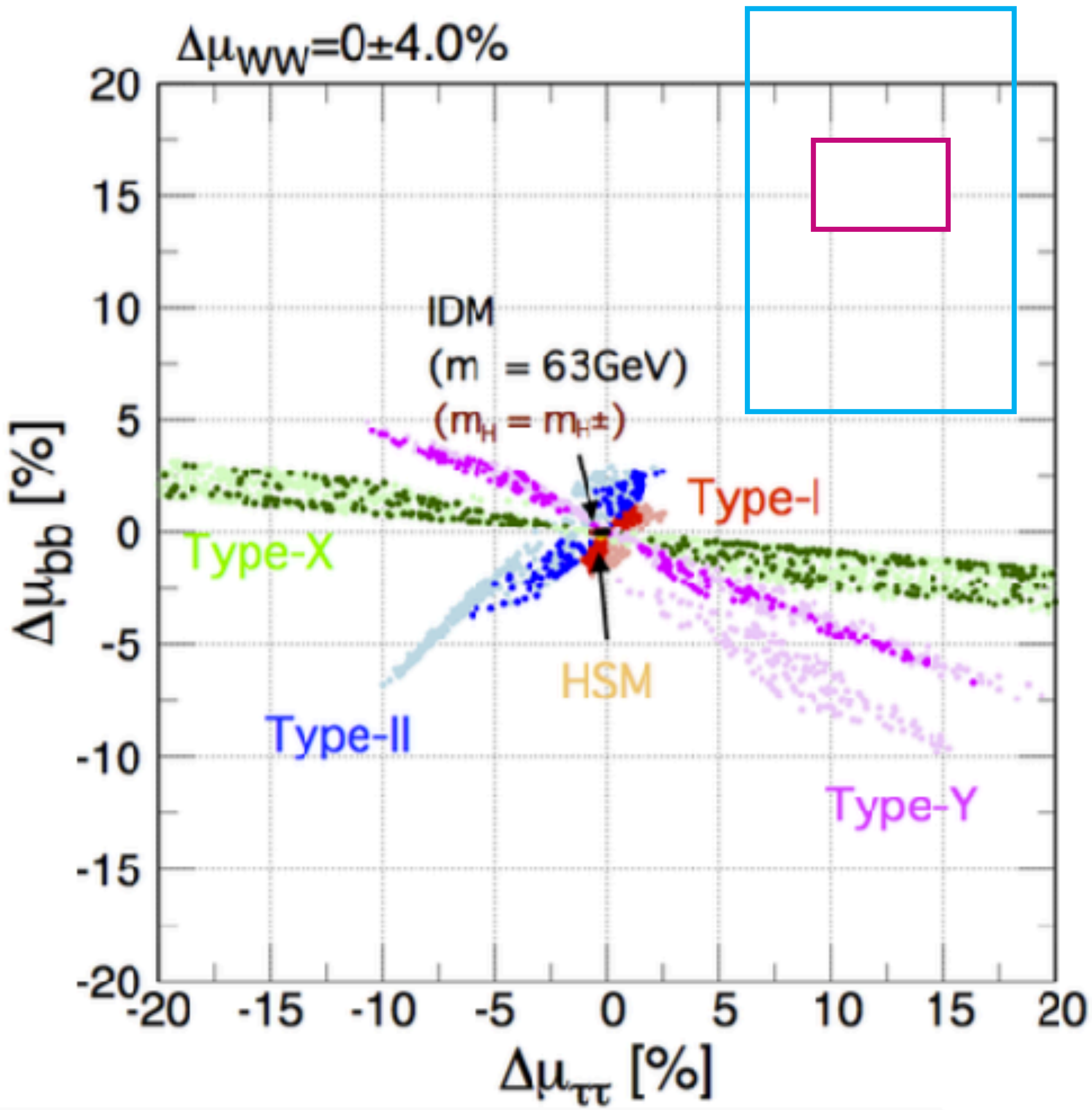
- Brightness of color :
  Value of m_Φ

  - Lighter colors: $m_\Phi < 600\mathrm{GeV}$
  - Darker colors: $m_\Phi > 600\mathrm{GeV}$

Lower bound from $b \to s\gamma$
(for Type-II,Y)

HL-LHC(2σ):
[ATLAS, CMS,1902.00134]

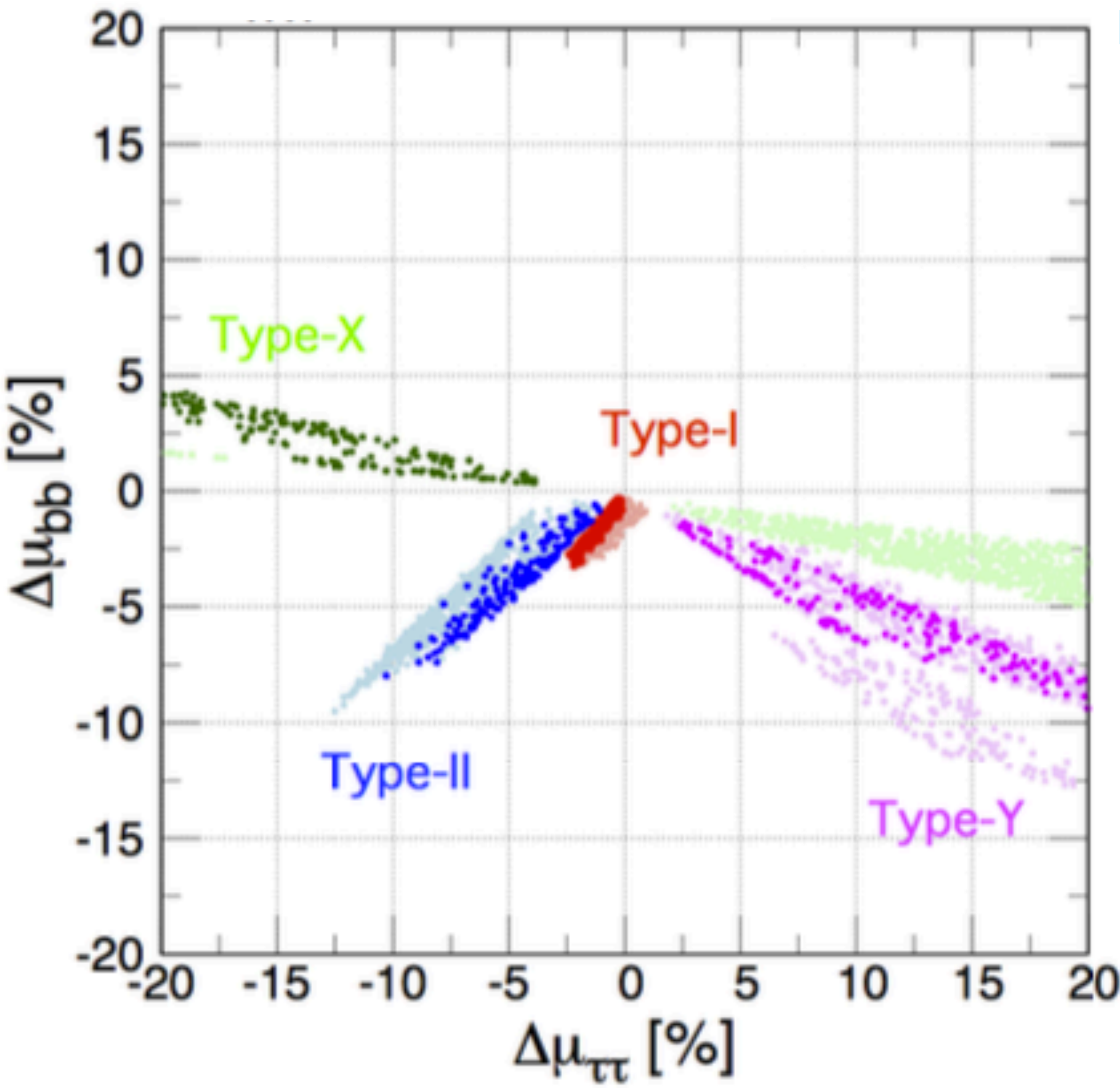
ILC(2σ):
[T. Barlow et al. 1710.07621]



If $|\Delta\mu_{\tau\tau}| \gtrsim 5\,\%$, 4 types of THDMs can be separated.

Case ②: $\Delta\mu_{WW} = 5 \pm 4\,\%$

[Kanemura, Kikuchi, Mawatari ,KS, Yagyu]

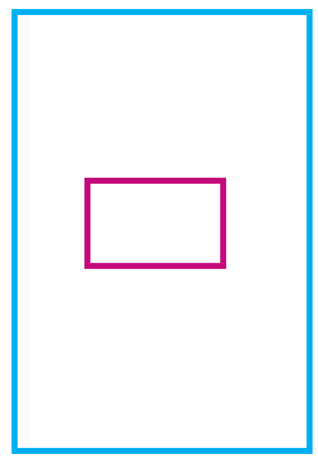


HL-LHC(2σ):

[ATLAS, CMS,1902.00134]

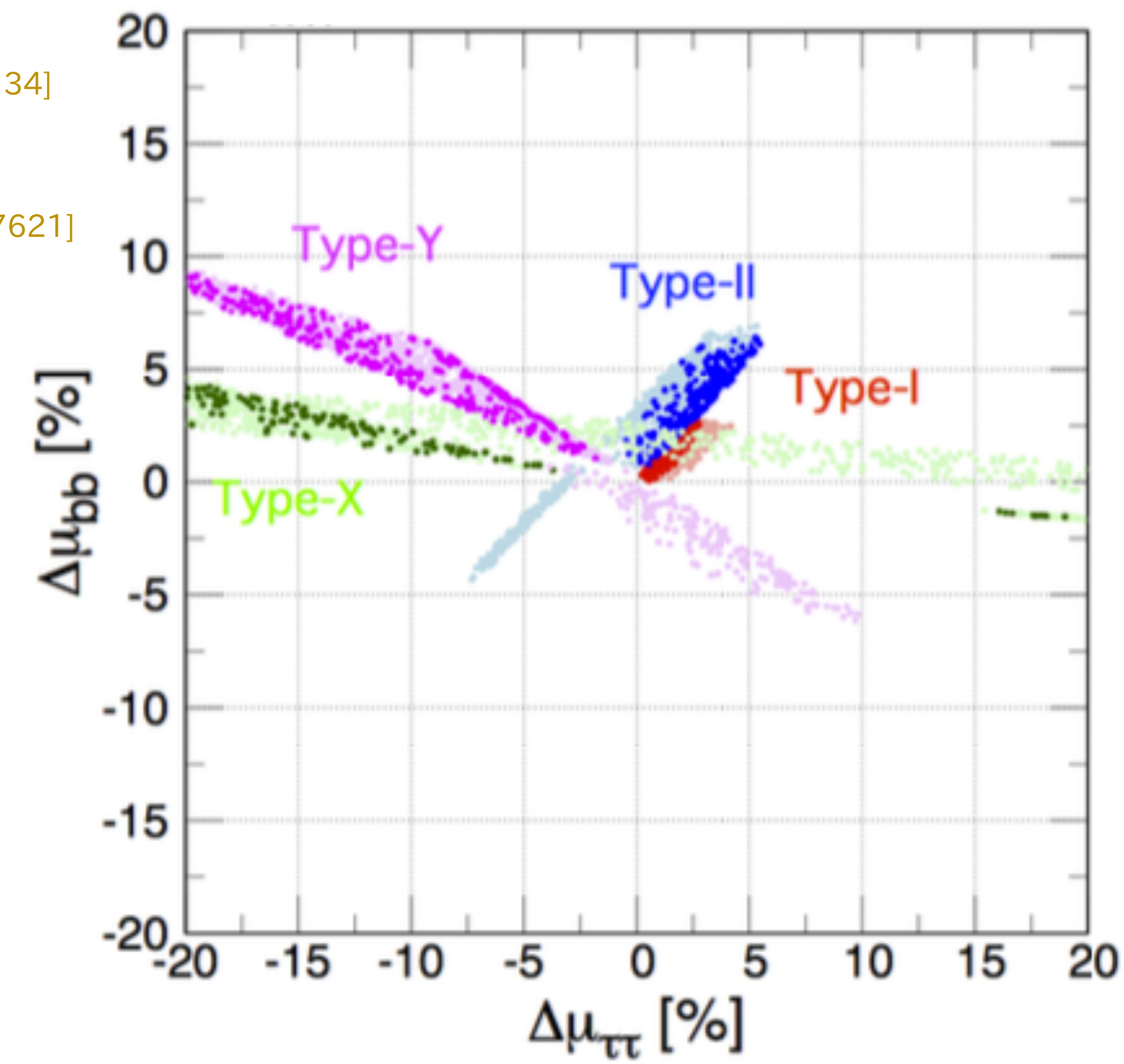
ILC(2σ):

[T. Barlow et al. 1710.07621]



Case ③: $\Delta\mu_{WW} = -5 \pm 4\,\%$

[Kanemura, Kikuchi, Mawatari ,KS, Yagyu]



- In both case, HSM and IDM are already excluded.
- In case② models predictions of 2HDMs are completely separated.
- In case③, if m_Φ>600 GeV, we can distinguish all models

Summary

- We evaluated Higgs branching ratio with full 1-loop corrections in various extended Higgs models by H-COUP.
- the branching ratios will be precisely measured in the future collider experiments such as the HL-LHC and the ILC.
- We investigated the deviations from the SM in the 3 cases:

	Constraint for $\Delta\mu_{WW}$	Discriminations of models
①	$\Delta\mu_{WW} = 0 \pm 4\,\%$	Possible (if $\lvert\Delta\mu_{\tau\tau}\rvert \gtrsim 5\,\%$)
②	$\Delta\mu_{WW} = 5 \pm 4\,\%$	Possible
③	$\Delta\mu_{WW} = -5 \pm 4\,\%$	Possible (if m_Φ>600 GeV)

→In any case, there are situations all models can be discriminated.