Precise calculations of Higgs branching ratios in extended Higgs models

[1905.XXXXX]

Kodai Sakurai (KIT ITP)

Karlsruher Institut für Technologie

Collaborators:
Shinya Kanemura (Osaka U.)
Kentarou Mawatari (Osaka U.)
Mariko Kikuchi (Kitakyusyu College)
Kei Yagyu (Osaka U.)

ITP seminar, 23.05.19

Outline

- Introduction
  - Precise calculations of Higgs observables
  - H-COUP program
- Calculation of Higgs decays at LO
  - Extended Higgs models
- Calculation of Higgs decays at NLO
  - Renormalization of THDMs
  - Branching ratios at the 1-loop
- Summary

Motivation

- Properties of the Higgs boson has been measured at the LHC.

  Mass, *hVV* couplings, *hff* couplings,⋯

Current measurements are consistent with predictions of the SM.

- The structure of Higgs sector remains unknown.
  - SM Higgs sector : Φ
  - But, there is still a possibility of extended Higgs sectors

Number and multiplet?

$\Phi + S$ (Singlet)

$\Phi_1 + \Phi_2$ (Doublet)

$\Phi_1 + \Phi_2$ (Triplet)

Symmetry?

Discrete symmetry

Custodial symmetry

etc.

- Shape of Higgs sector is closely related to new physics.

Beyond the SM

Supersymmetry

Composite Higgs

WIMP Dark matter

(radiative) Seesaw models

Electroweak baryogenesis

Higgs inflation

Muon g-2

Flavor anomaly

etc.

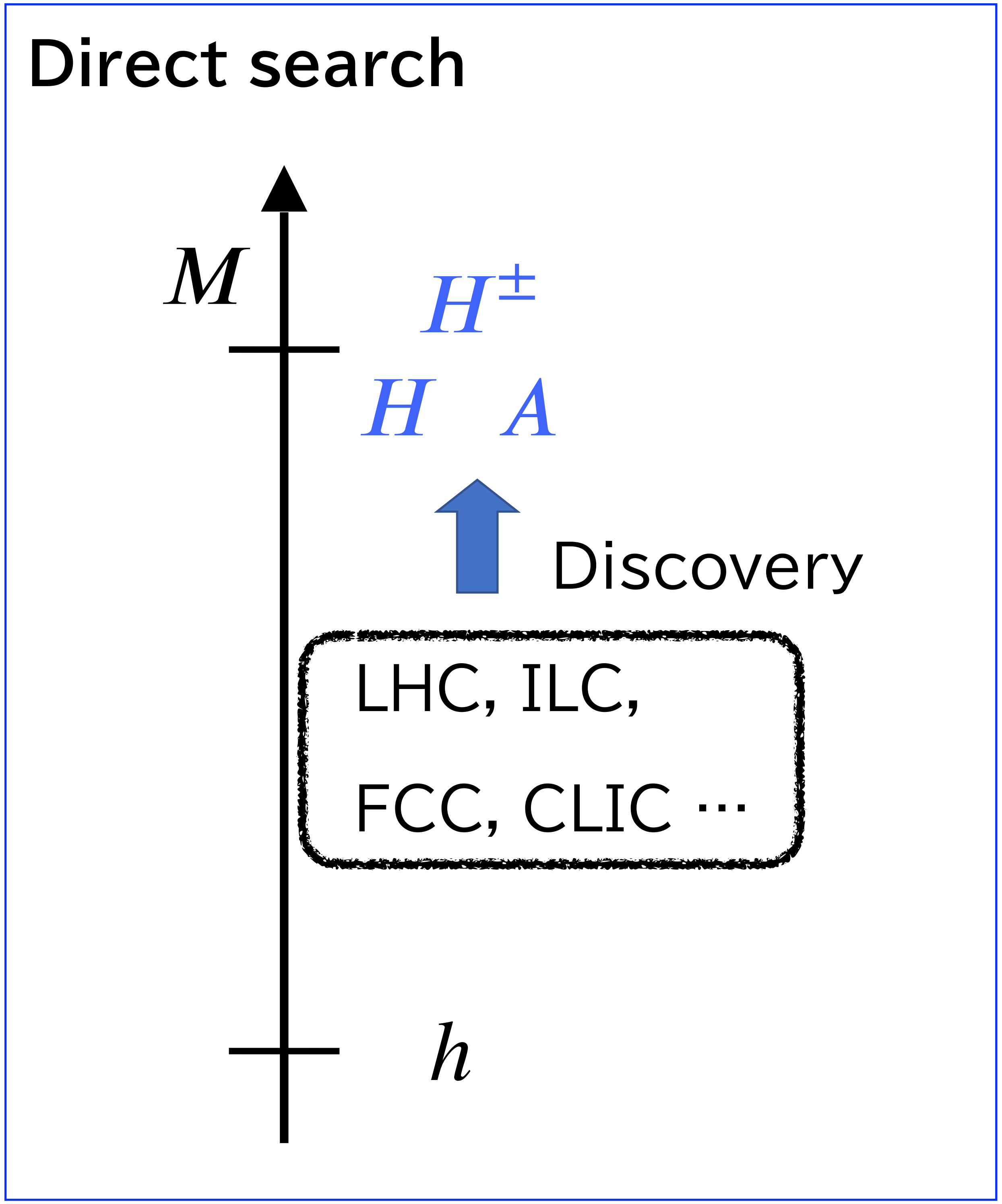
Introduce ↓ ↑ Narrow down

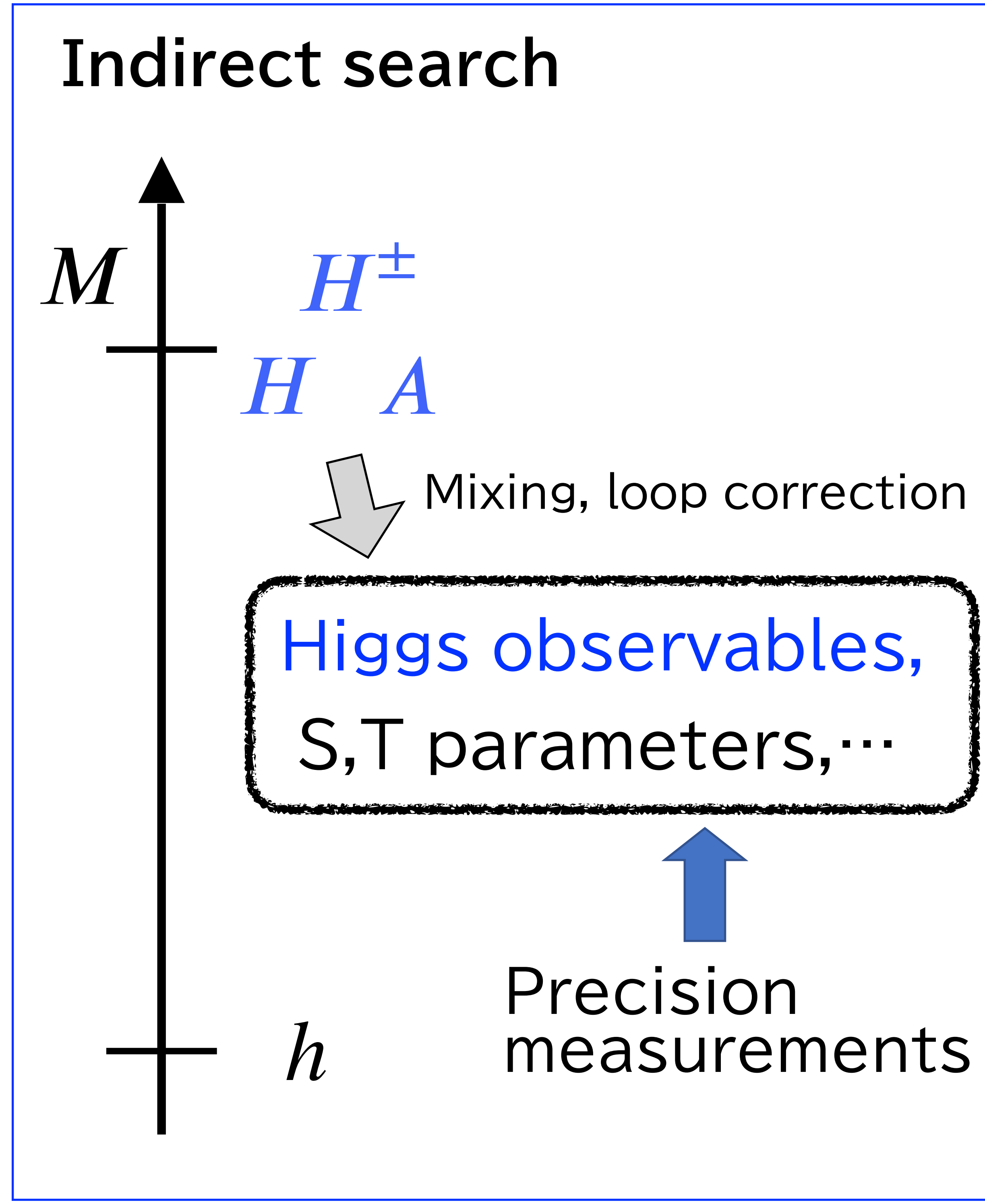
Non-minmal Higgs sectors

$\Phi + X$ (Singlet or doublet or triplet···) +...

Determination of the shape of the Higgs sector can give the information of new physics.

How is Higgs sector tested ?





Synergy of two searches is important.

Indirect search with Higgs precision measurements

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

Higgs observables :

$$\sigma(h \to XX), \;\; \mathrm{BR}(h \to XX), \;\; hXX$$

Precise calculations
HSM, THDMs,
ITM, IDM, etc.

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

Determination of the shape of the Higgs sector

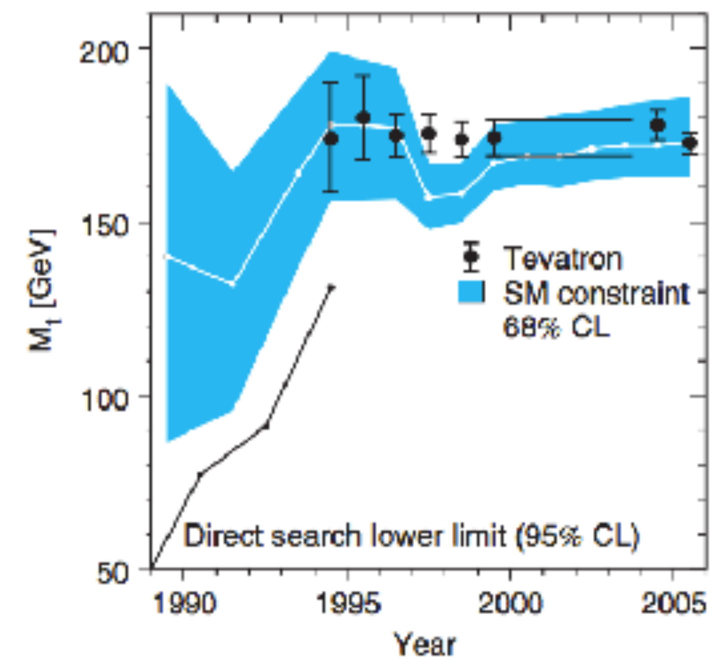
Impact of the precise measurements

Ex.) S, T parameter

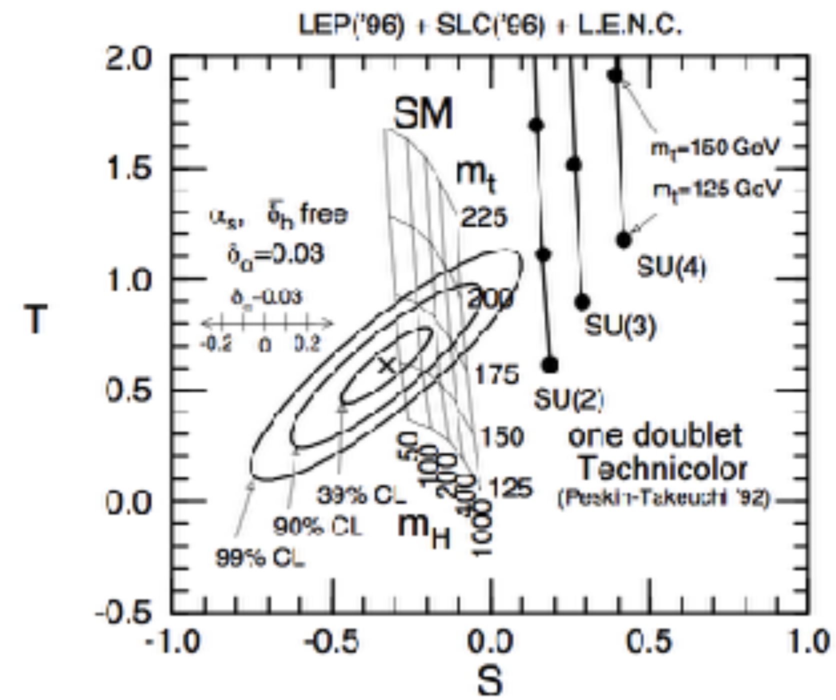
Top mass had been severely restricted before the discovery.

$$\alpha_{\rm EM} T \simeq \frac{3G_F}{8\sqrt{2}\pi^2}(m_t^2 - m_Z^2 s_W^2 \log\frac{m_h^2}{m_Z^2})$$

Non-decoupling effect



[Physics Reports 427(2006)257]

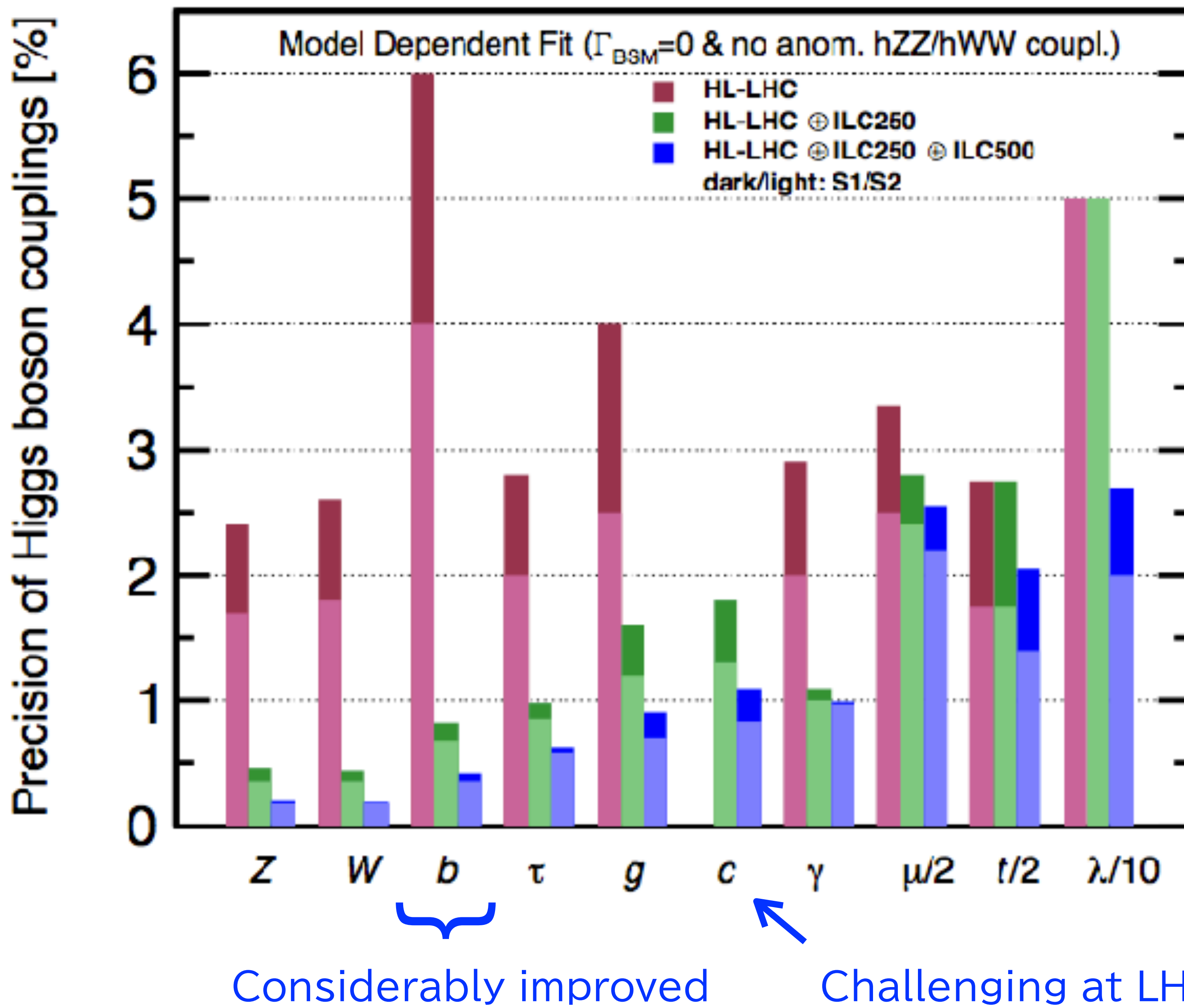


[Hagiwara, Haidt Matsumoto]

Same things can be applied to the Higgs physics.

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.
- In oder to compare with such precise measurements, we should evaluate theoretical predictions with radiative corrections.

H-COUP

We have calculated the Higgs observables included full 1-loop corrections in various extended Higgs models in the improved on-shell scheme.

H-COUP [Kanemura, Kikuchi, KS, Yagyu, CPC 233 (2018) 134]

Fortran program to evaluate loop-corrected Higgs observables in the improved on-shell scheme.

Model

- Higgs Singlet model
- Two Higgs doublet models
  Type I, II, X, Y
- Inert doublet model
- Higgs triplet model (v3.0?)

Observables

✓ *hff, hVV, hhh* vertex functions (v1.0)

✓ $\Gamma(h \to ff), \Gamma(h \to Vff), \Gamma(h \to \gamma\gamma),$ (v2.0)

$\Gamma(h \to Z\gamma), \Gamma(h \to gg),$

$\mathrm{BR}(h \to ff), \mathrm{BR}(h \to VV^*), \mathrm{BR}(h \to \gamma\gamma),$

$\mathrm{BR}(h \to Z\gamma), \mathrm{BR}(h \to gg)$

H-COUP ver. 2.0 will be published soon. [Kanemura, Kikuchi, KS, Mawatari, Yagyu]

Predictions for each model are evaluated in the same scheme

Another tools

2HDCAY :

[M. Krause, M. Mühlleitner, M. Spira, 1810.00768]
[M. Krause, M. Mühlleitner, 1904.02103]

- Model: THDMs, NHDMs
- Calculation of all Higgs decay rates 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,THDMs
- 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: THDMs, HSM
- Calculation to NLO amplitude for any process

You can make use of a lot of computation tools

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.

- Introduction
  - Precise calculations of Higgs observables
  - H-COUP program
- Calculation of Higgs decays at LO
  - Extended Higgs models
- Calculation of Higgs decays at NLO
  - Renormalization of THDMs
  - Branching ratios at the 1-loop
- Summary

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 : $m_H,\ \cos\alpha,\ m_s^2,\ \mu_S,\ \lambda_S$

- **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	$\cot\beta$	$-\tan\beta$	$\cot\beta$

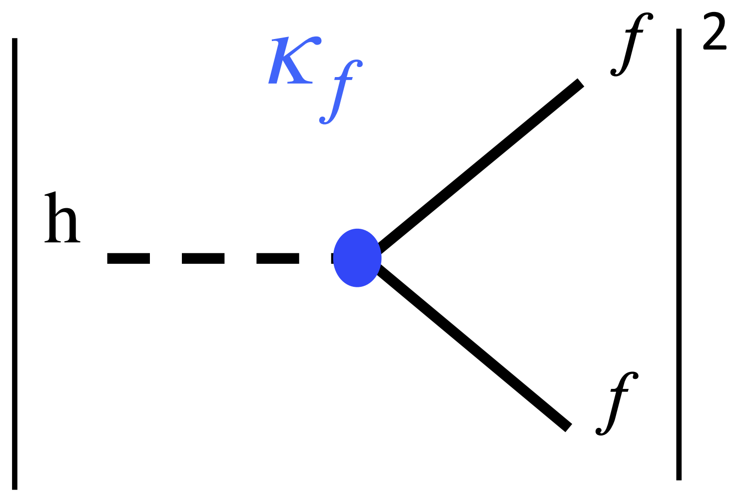
IDM : $\kappa_V = \kappa_f = 1$

Higgs decay rates at the LO

Deviations from the SM: $R(h\to XX) = \dfrac{\Gamma(h\to XX)_{EX.}}{\Gamma(h\to XX)_{SM}}$

$\mathrm{h}\to ff$

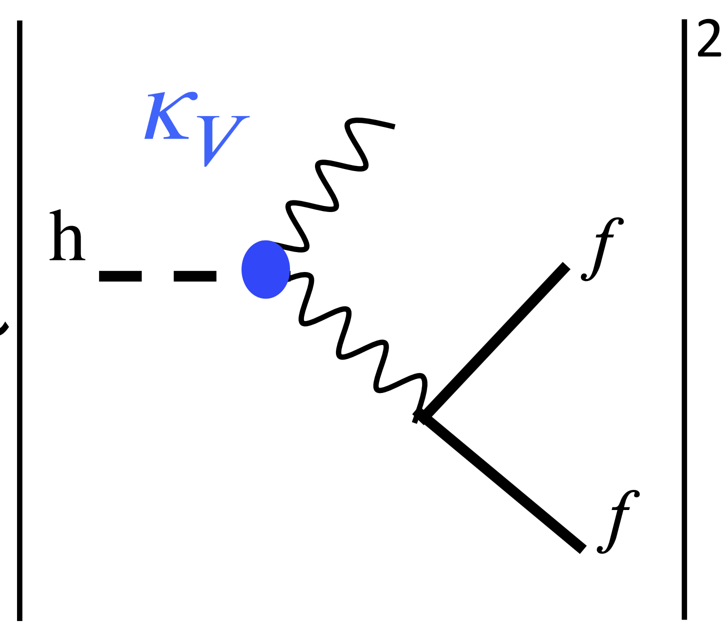
$\Gamma(\mathrm{h}\to ff) \sim$



$\Rightarrow\ R(h\to ff) = \kappa_f^2$

$\mathrm{h}\to VV^* \to Vff$

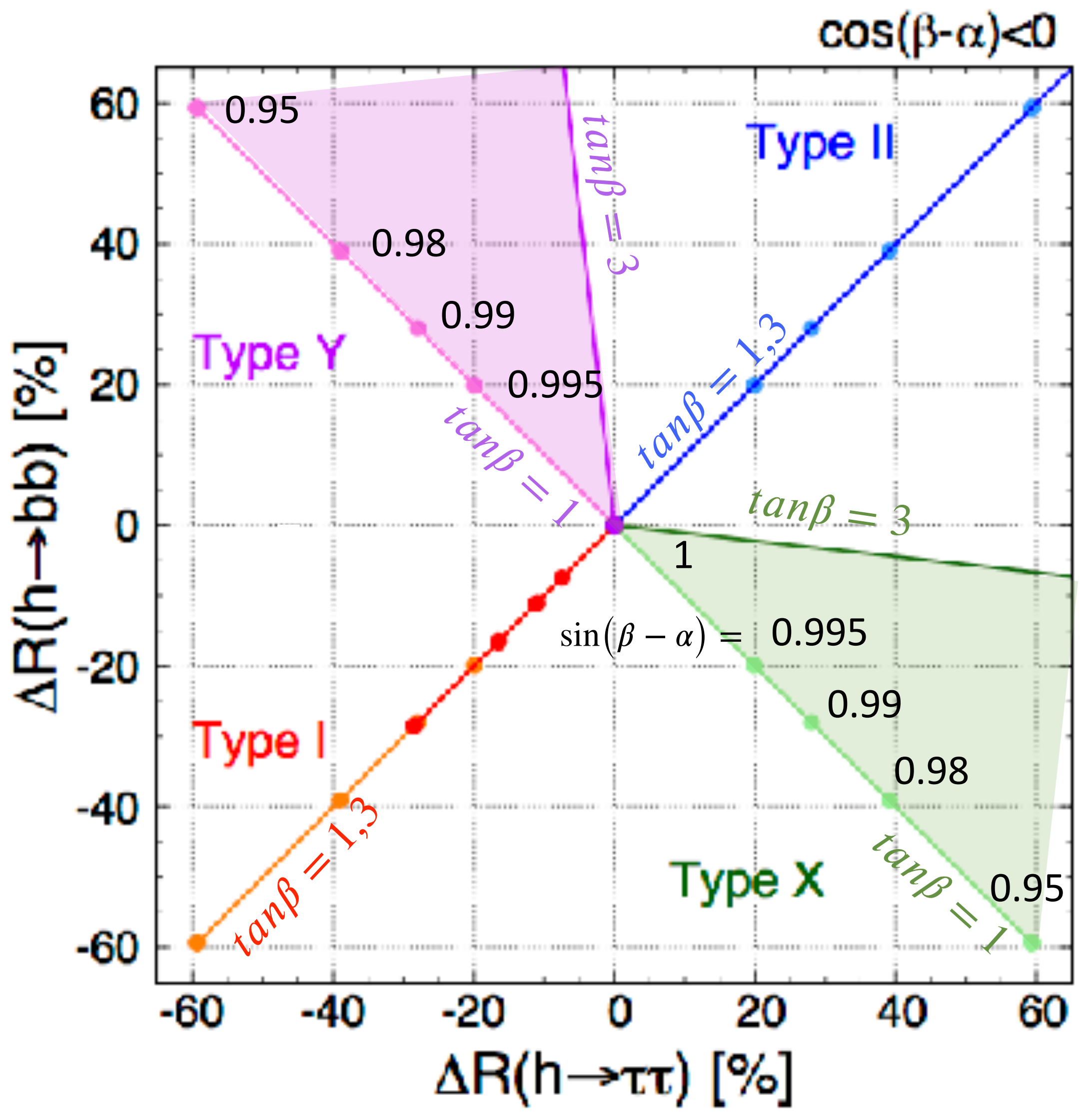
$\Gamma(\mathrm{h}\to VV^*) \sim$



$\Rightarrow\ R(h\to VV^*) = \kappa_V^2$

Deviations in Higgs decay rates

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



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

$$\Delta R_X = \frac{\Gamma(h \to XX)_{NP}}{\Gamma(h \to XX)_{SM}} - 1$$

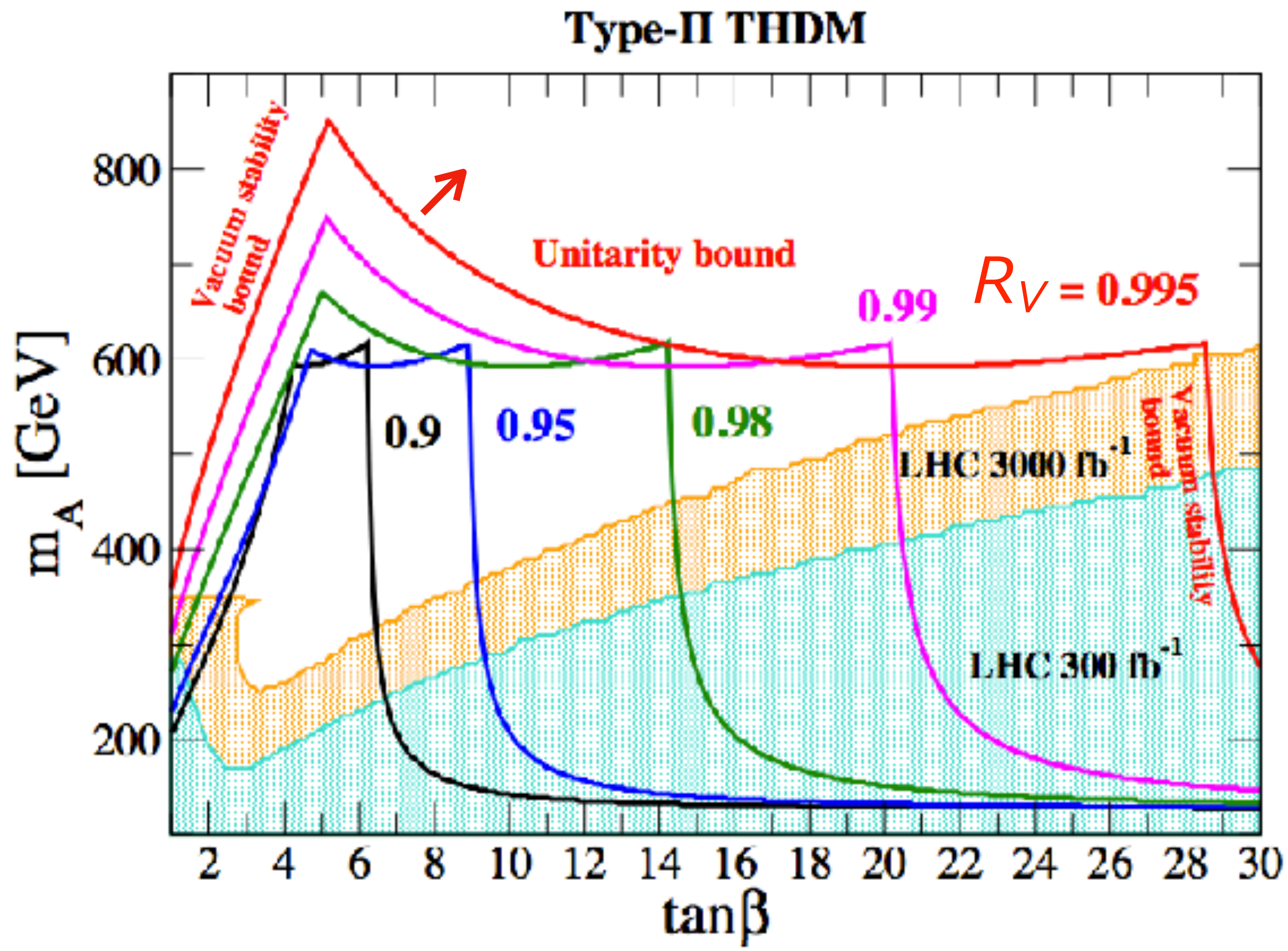
$$\Delta R(h \to f\bar{f})^{LO} = (\sin(\beta - \alpha) - \xi_f \cos(\beta - \alpha))^2 - 1$$

	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	$\cot\beta$	$-\tan\beta$	$\cot\beta$

We can discriminate 4 types of THDMs by the pattern of deviations

Synergy between direct search and indirect search

[arXiv:1310.0763]



Direct search of additional Higgs → Lower bound of m_Φ

Indirect search of Higgs decay rates → Upper bound of m_Φ

We can extract information of mass of additional Higgs boson by synergy between direct and indirect search

- Introduction
  - Precise calculations of Higgs observables
  - H-COUP program
- Calculation of Higgs decays at LO
  - Extended Higgs models
- **Calculation of Higgs decays at NLO**
  - Renormalization of THDMs
  - Branching ratios at the 1-loop
- Summary

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 THDM

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

1. Count number of parameters and fields in Lagrangian:

- Parameters in Higgs potential ： 8

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

- Fields of Higgs sector ： 6

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

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

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

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

- Field shift :

$$\begin{pmatrix} H \\ h \end{pmatrix} \to \begin{pmatrix} 1+\delta\frac{1}{2}Z_H & \delta C_{Hh}+\delta\alpha \\ \delta C_{Hh}-\delta\alpha & 1+\frac{1}{2}\delta Z_h \end{pmatrix} \begin{pmatrix} H \\ h \end{pmatrix},$$

$$\begin{pmatrix} G^0 \\ A \end{pmatrix} \to \begin{pmatrix} 1+\delta\frac{1}{2}Z_G & \delta C_{GA}+\delta\beta \\ \delta C_{GA}-\delta\beta & 1+\frac{1}{2}\delta Z_A \end{pmatrix} \begin{pmatrix} G^0 \\ A \end{pmatrix},$$

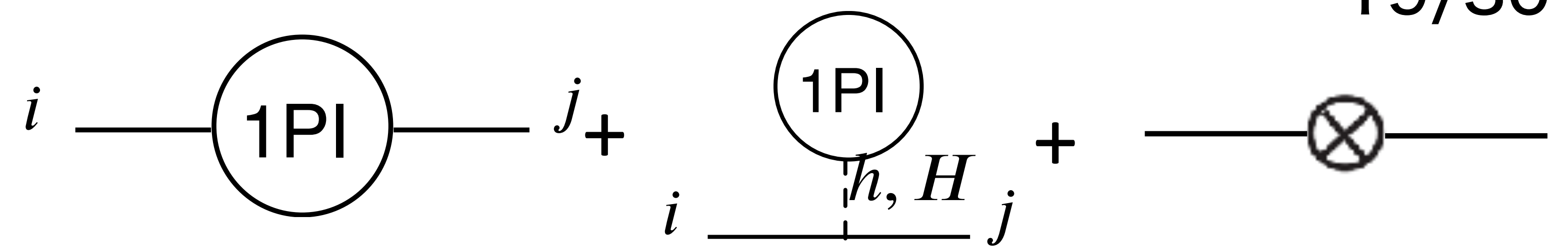
$$\begin{pmatrix} G^\pm \\ H^\pm \end{pmatrix} \to \begin{pmatrix} 1+\delta\frac{1}{2}Z_{G^\pm} & \delta C_{G^+H^-}+\delta\beta \\ \delta C_{G^+H-}-\delta\beta & 1+\frac{1}{2}\delta Z_{H^\pm} \end{pmatrix} \begin{pmatrix} G^\pm \\ H^\pm \end{pmatrix},$$

→ We get 17 counter terms :

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

$$\delta Z_h, \delta Z_H, \delta Z_A, \delta Z_{H^\pm}, \delta Z_{G^0}, \delta Z_{G^\pm},$$

$$\delta C_{Hh}, \delta C_{GA}, \delta C_{G^+H^-}$$

$\hat{\Pi}_{ij}(q^2) \equiv$ 

3. Set renormalization conditions as many as number of counter terms to determine these counter terms:

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} , {$H^\pm$,$G^\pm$})

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.

Gauge dependence on mixing angles

- Gauge dependence appears in the renormalization of the scalar mixing angles. [Yamada, PRD64(2001)036008]
- We consider unrenormalized mass matrix at the 1-loop in R_ξ gauge :

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

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

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

$\rightarrow$ $\delta m_h^2, \delta m_H^2$ are gauge independent.

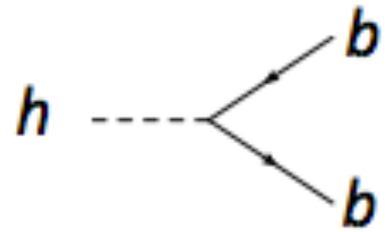
Off-diagonal elements : $\hat{\Pi}_{Hh}(m_h^2) = \hat{\Pi}_{Hh}(m_H^2) = 0$

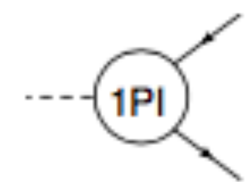
$\rightarrow$ $\delta\alpha, \delta\beta$ are gauge dependent.

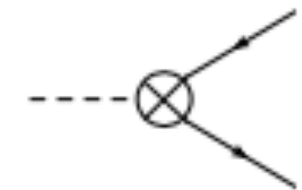
$\rightarrow$ Higgs process amplitudes with $\delta\alpha, \delta\beta$ are also gauge dependent [M. Krause, R. Lorenz, M. Muhlleitner, R. Santos, H. Ziesche, JHEP 09 (2016) 143]

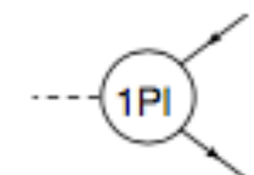
Ex.)Gauge dependence on h→bb

We can find that an amplitude for $h \to bb$ has a gauge dependence through only the counter term $\delta\beta$.

$\frac{\partial}{\partial \xi_Z}(hbb) = \frac{\partial}{\partial \xi_Z}($ 

$+$ 

$+$  $)$

$= \frac{\partial}{\partial \xi_Z}\left(-\frac{m_b}{v}\xi_h^u\left[\frac{1}{2}\delta Z_h + \delta Z_b + (t_\alpha \delta C_h - \cot\beta\,\delta\beta)\right] + \right.$ 

$\left.\right)$

The gauge dependence introduced by the δZ_i, δC_h is canceled by the contribution of 1PI diagrams. [P. Gambino, P. A. Grassi PRD62 (2000) 076002]

$$= \frac{\partial}{\partial \xi_Z}\left(\frac{m_c}{v}\xi_h^u\,[cot\beta\;\delta\beta]\right)$$

The gauge dependence come from $\delta\beta$ is only remained.

If we can remove the gauge dependence on the $\delta\beta$ (and $\delta\alpha$), in other wards, scalar mixing self energy, we can obtain gauge invariant results.

Pinch technique

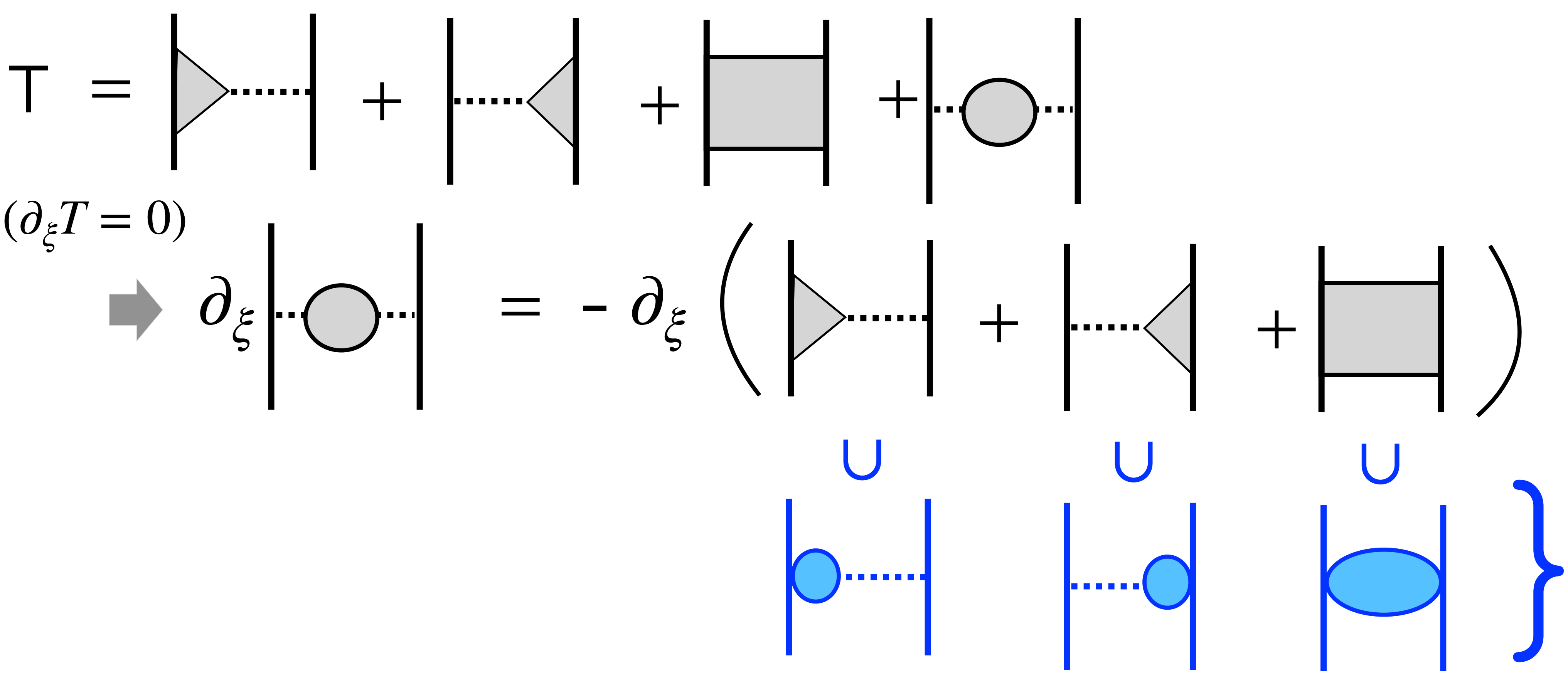
- In order to remove the gauge dependence in $\delta\alpha,\ \delta\beta$ we utilize pinch technique [J. Papavassiliou, PRD50, 5958]

Basic idea: $$\Pi_{Hh} \xrightarrow{(\text{in } \delta\alpha,\ \delta\beta)} \Pi_{Hh} + \Pi^{PT}_{Hh} \ \Rightarrow\ \partial_\xi \delta\alpha = 0,\ \partial_\xi \delta\beta = 0$$

Pinch terms

- Pinch terms can be extracted as follows:

Considering S-matrix of 2 →2 fermions scattering



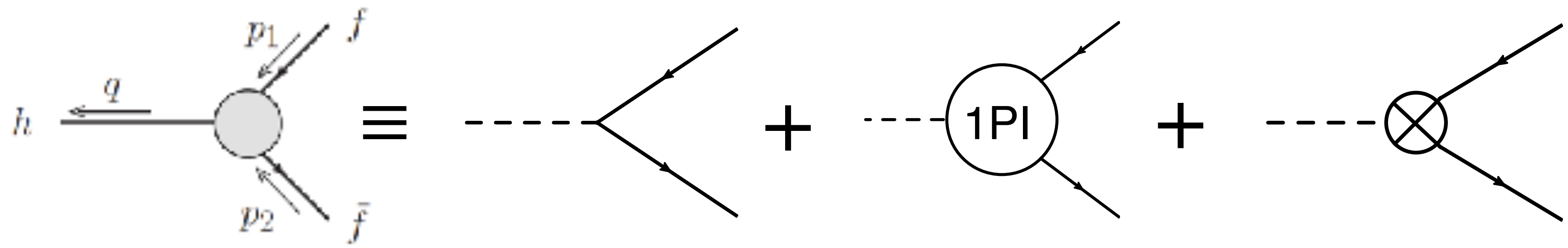
Self-energy like cont. (=pinch terms)

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

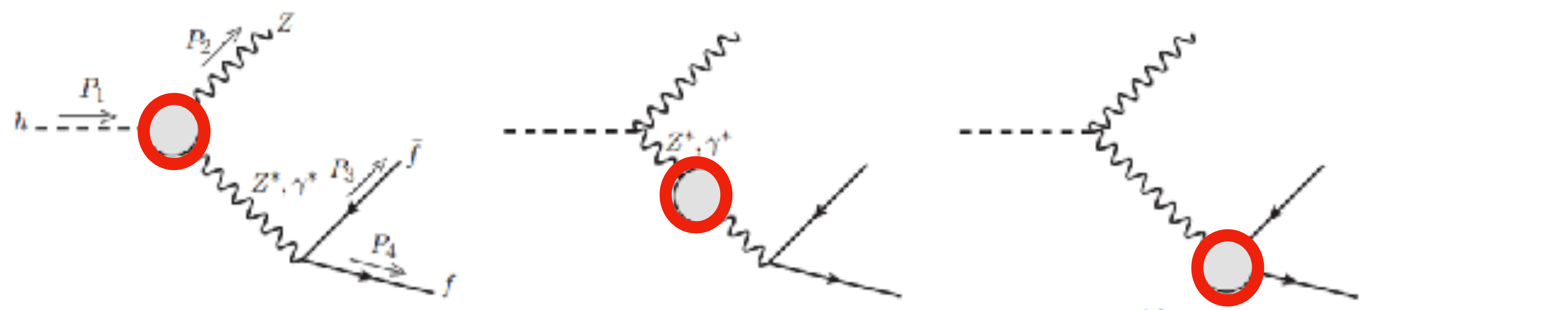
One-loop calculation of Higgs decay rates

By using **H-COUP**, we calculated Higgs decay rates at 1-loop

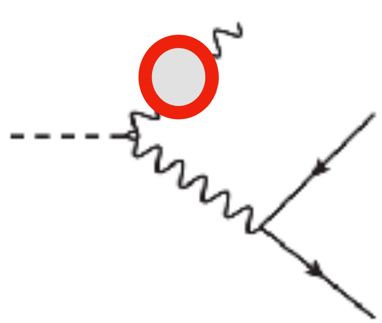
$h \to ff:$



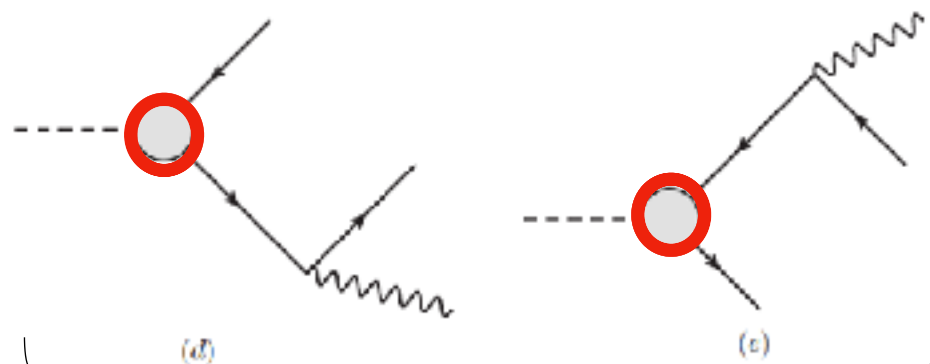
$h \to VV^*:$



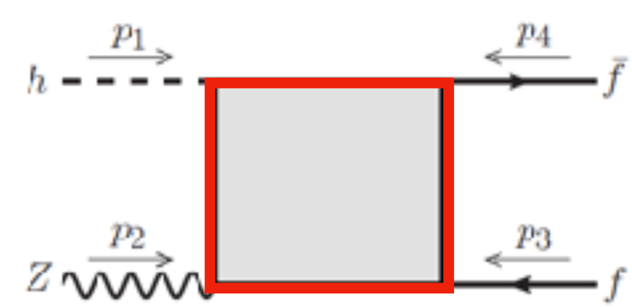
hVV vertex correction　Self-energy correction　*Vff* vertex correction



Wave function



hff vertex correction



Box diagram correction

- ✓ UV finiteness
- ✓ Gauge invariance
- ✓ IR finiteness

IR structure of $h \to VV^*$:

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

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

IR divergence for h→WW*

- In order to evaluate photon loop corrections for h→WW*(γ) we make use of phase space slicing method. [B. Harris, J. Owens, ,PRD65(2002)094032]

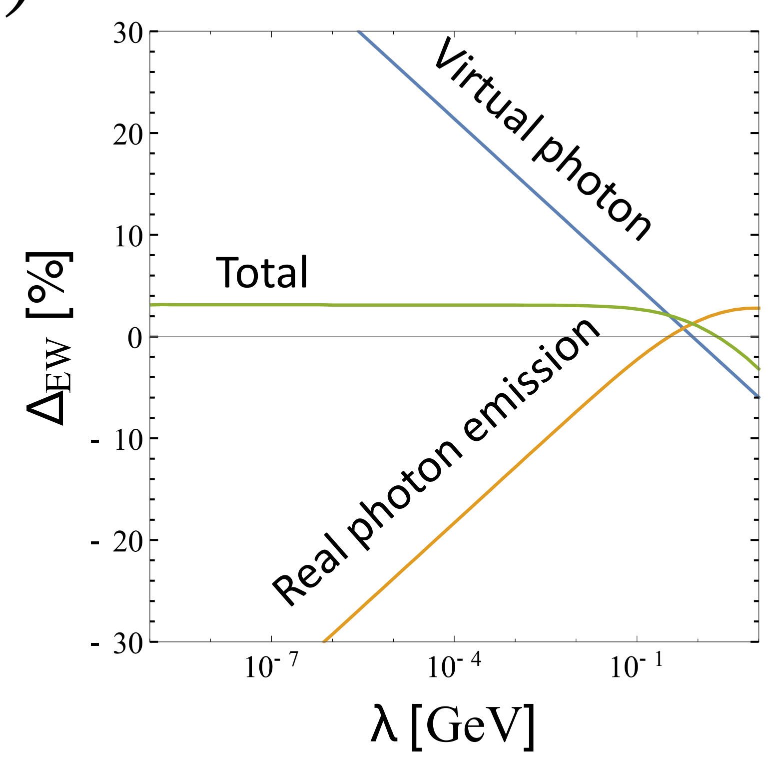
$$\Gamma\left(h \to Wff'\gamma\right) = \Gamma\left(h \to Wff'\gamma\right)[\lambda, \mathrm{m}_f, \mathrm{m}_{f'}, \Delta E]^S + \Gamma\left(h \to Wff'\gamma\right)\left[m_f, m_{f'}, \Delta E\right]^H$$

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

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

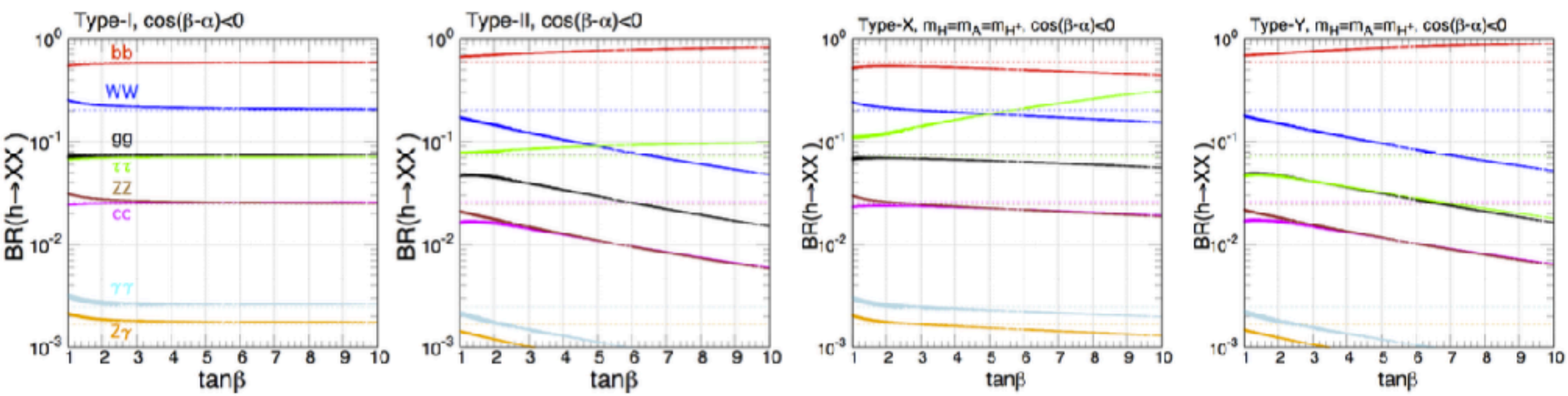
κ_X : Scaling factor

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, preliminary]



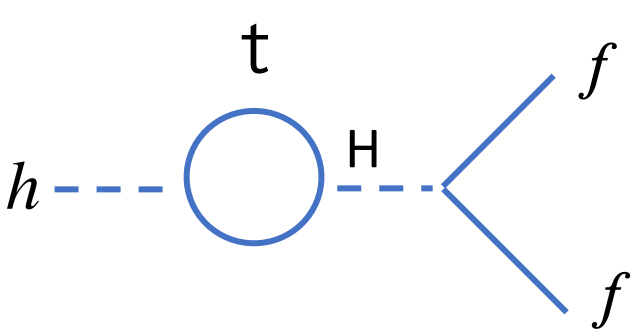
Cause of deviations from SM : ① Mixing, loop effect of additional Higgs

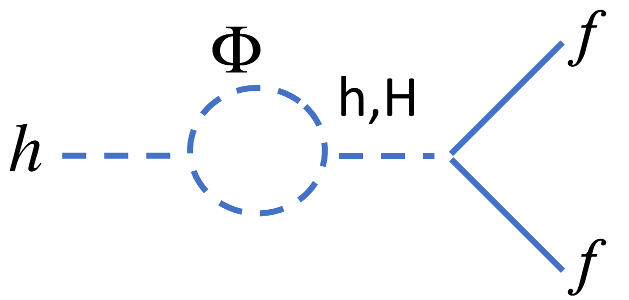
② Correlation of each mode

Higgs branching ratios at the 1-loop

We examined magnitude of additional Higgs boson loop contributions for Higgs branching ratios in 2HDMs

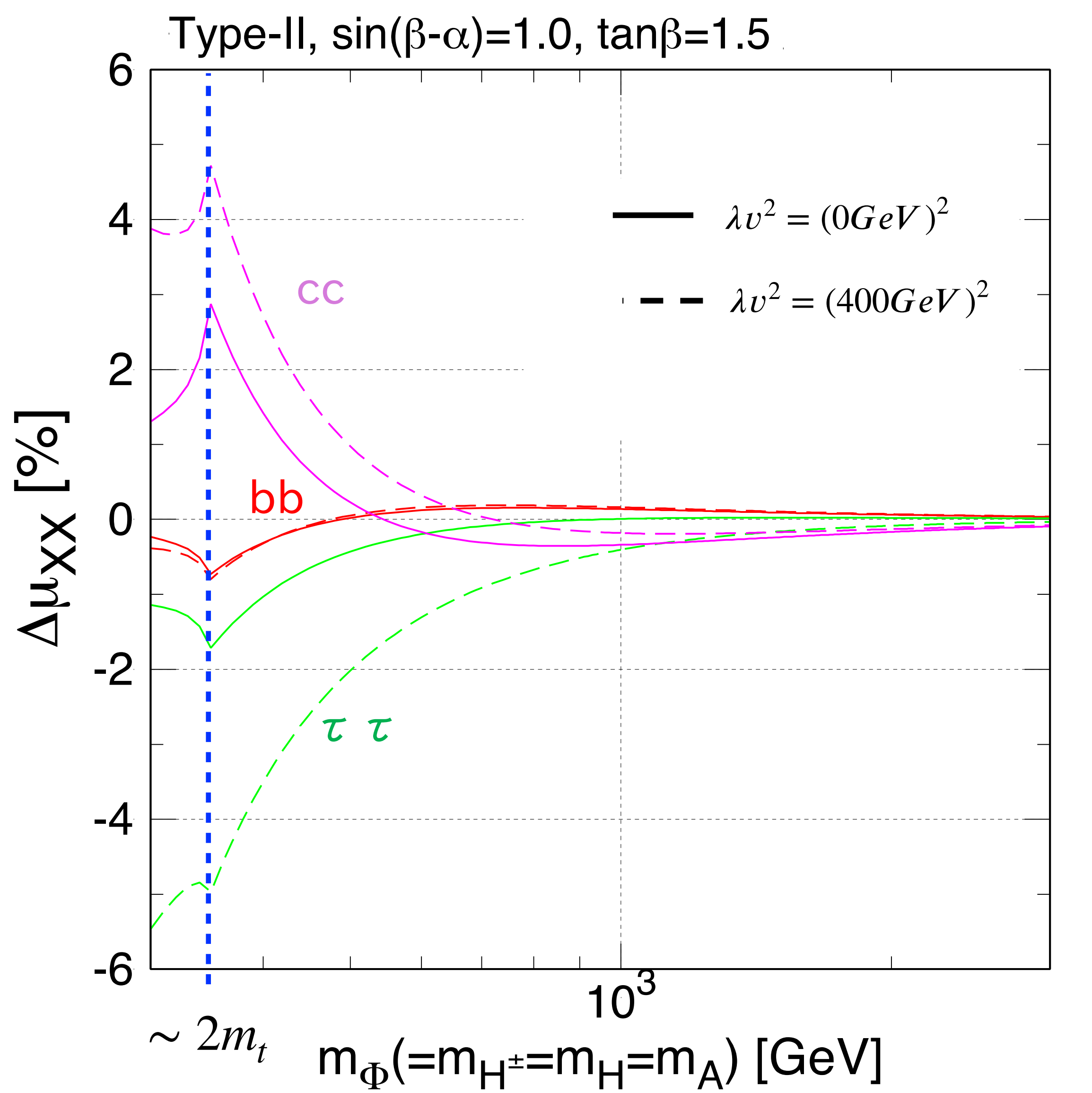
Typical graph :





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

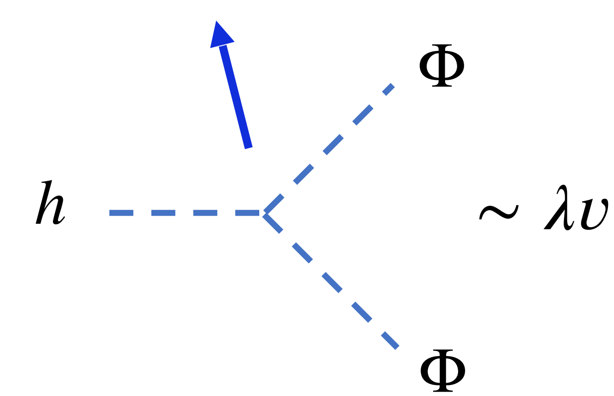
[Kanemura, Kikuchi, Mawatari ,KS, Yagyu, preliminary]



Deviations from SM :

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

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



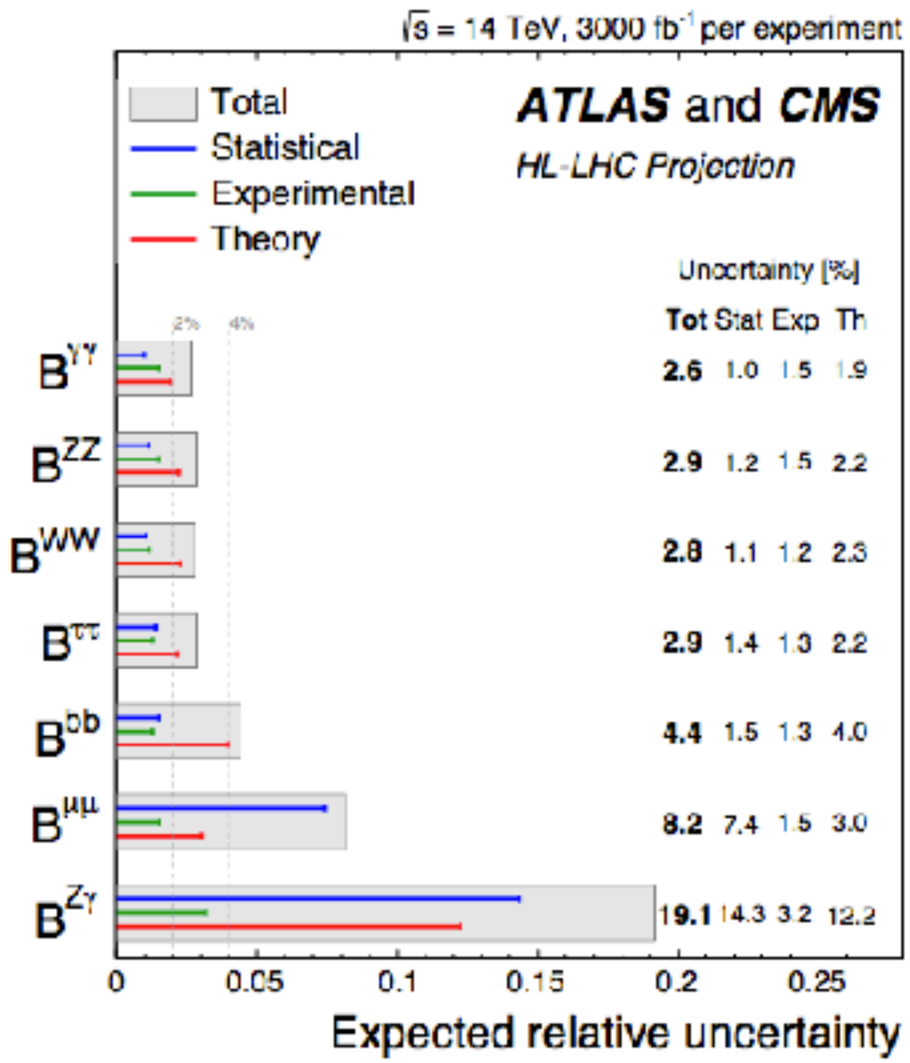
$m_\Phi \gg v$: Additional Higgs loop contributions decouple.

$m_\Phi \sim v$: 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%	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: $\Delta\mu_{WW} = 0 \pm 4\,\%$

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

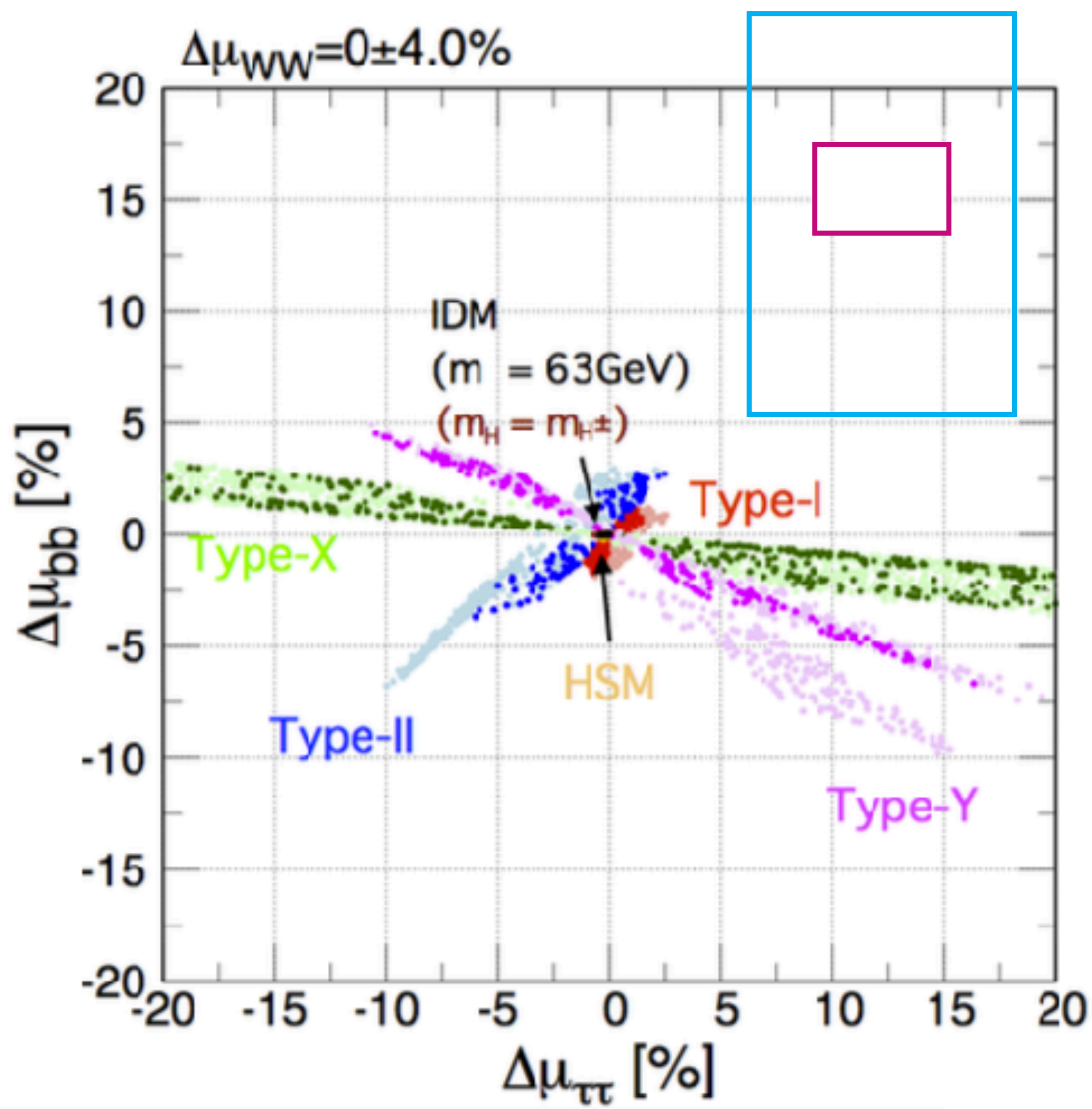
- Plot of color : Predictions of each model
- Brightness of color : Value of m_Φ
  - Lighter colors: $m_\Phi < 600\mathrm{GeV}$
  - Darker colors: $m_\Phi > 600\mathrm{GeV}$

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]

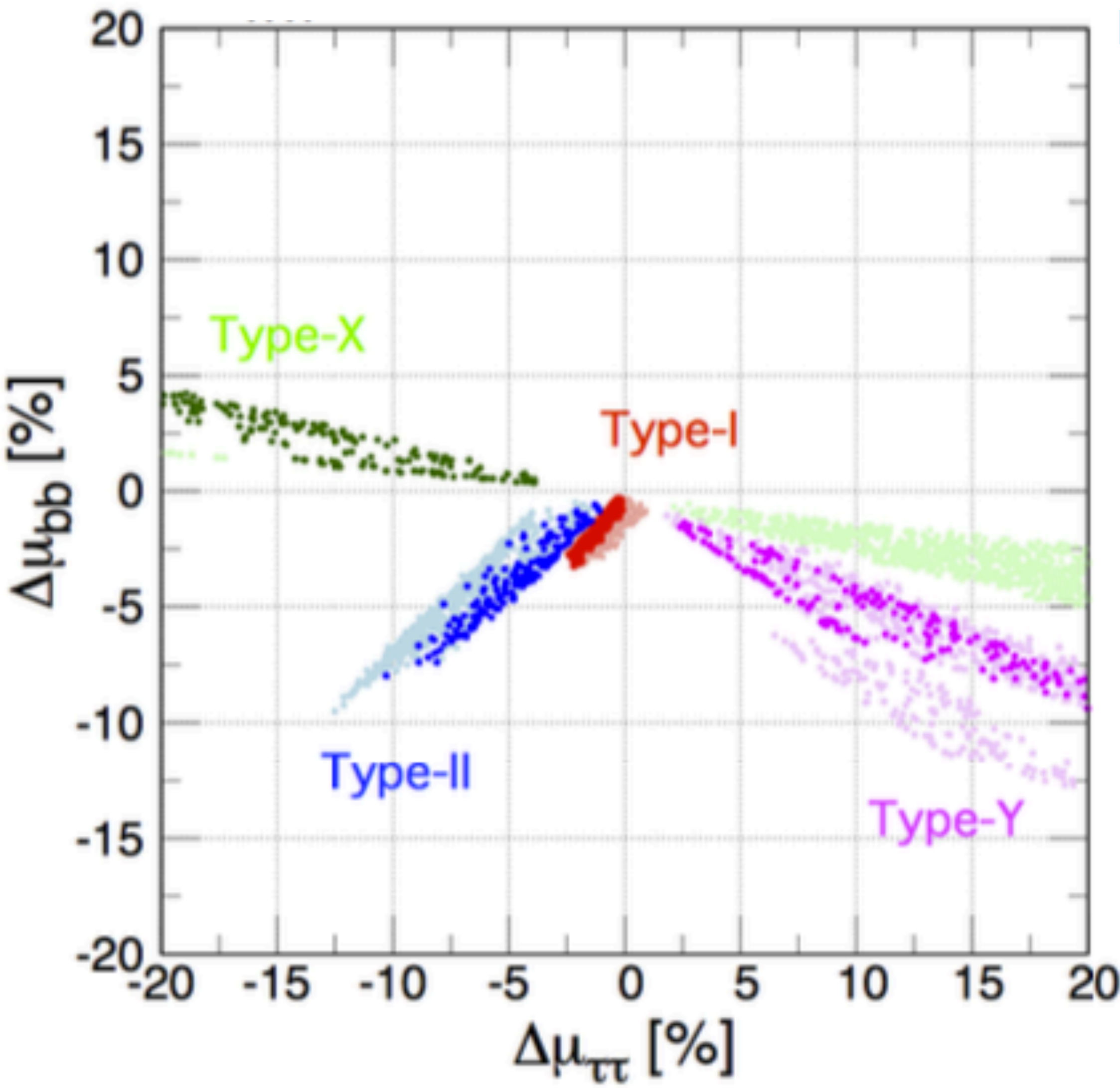
[Kanemura, Kikuchi, Mawatari ,KS, Yagyu, preliminary]



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, preliminary]

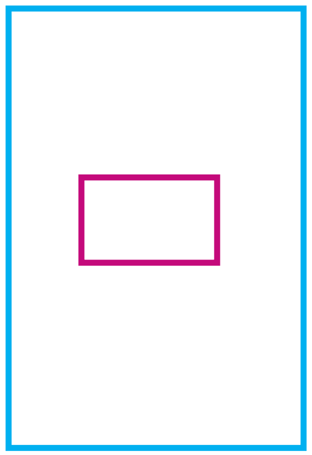


HL-LHC(2σ):

[ATLAS, CMS,1902.00134]

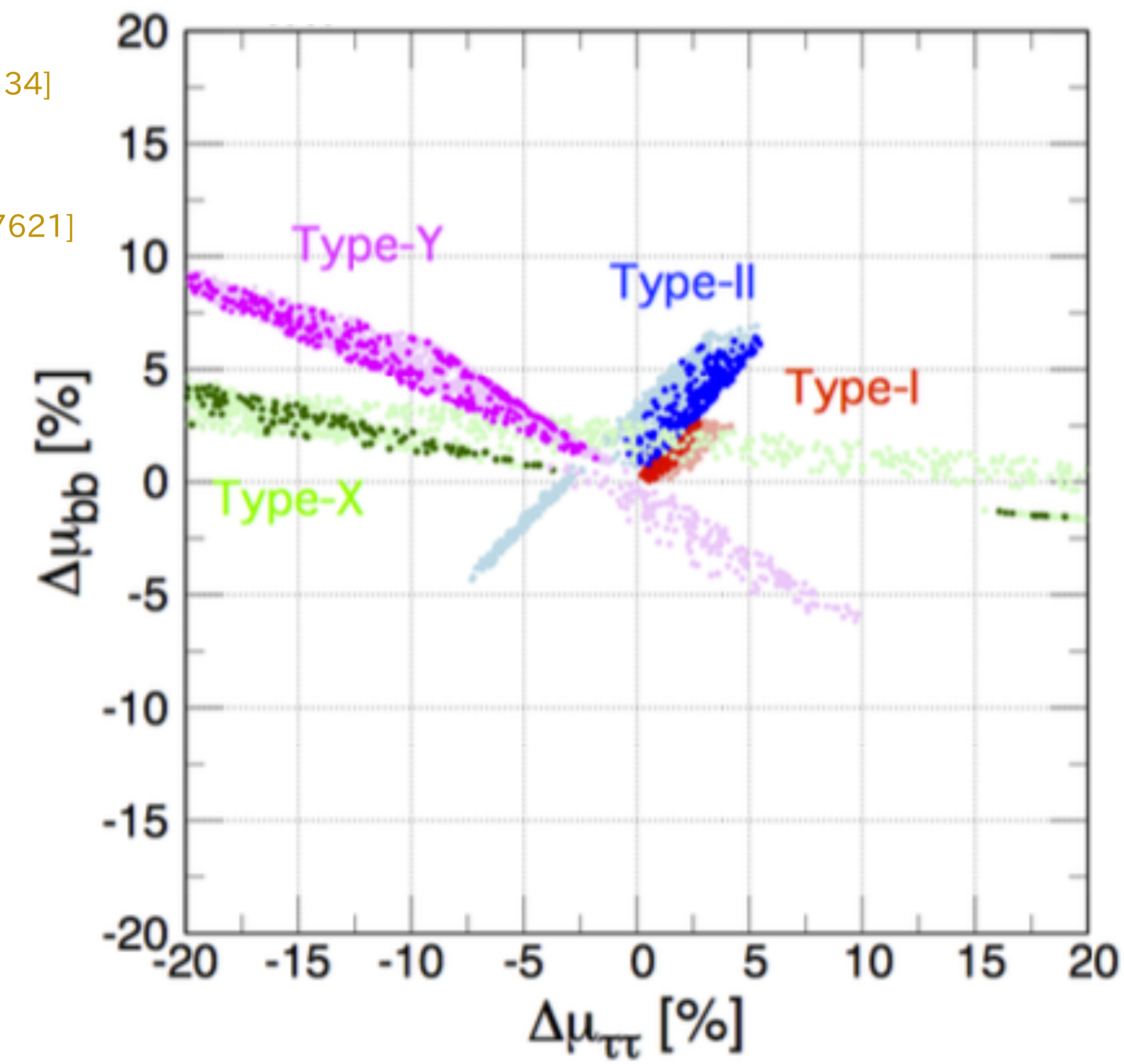
ILC(2σ):

[T. Barlow et al. 1710.07621]



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

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



- In both case, HSM and IDM are already excluded.
- In case② all models predictions 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.

- 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 $|\Delta\mu_{\tau\tau}| \gtrsim 5\,\%$)
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.