One-loop corrections to the discovered Higgs boson decays in the real Higgs triplet model

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Aiko, Kanemura,Kikuchi, KS, Taniguchi,Yagyu 2611.04857

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Introduction

Exploring the Higgs Sector

- The 125 GeV Higgs boson was discovered in 2012.
- However, the structure of the Higgs sector remains unknown.

Numbers ?
Representations?
Symmetries?

Origion of ν masses?
CPV and baryogenesis?
Portal to Hidden sector?

etc.

How can we exlpore the Higgs sector

Direct searches	Indirect searches
Search for additional Higgs bosons	Probe deviations in the properties of h(125)
$pp \to H, A, H^{\pm}, \ldots$	$h \to VV^*, f\bar{f}, \gamma\gamma, \ldots$
LHC, HL-LHC	LHC, HL-LHC, ILC, CEPC, FCC-ee

Higgs precision mesurments

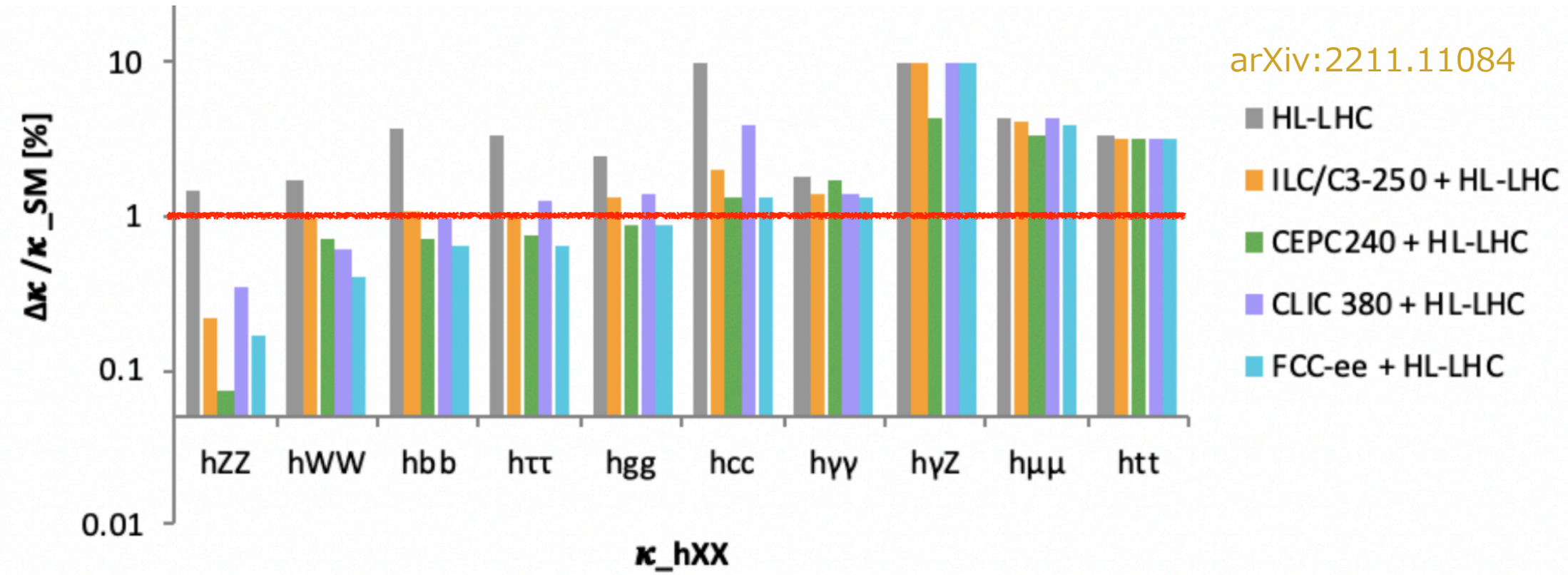
The precision of Higgs coupling measurements has improved since 2012.

Current accuracy

ATLAS: ATLAS-CONF-2025-006 (2025)
CMS: CMS-HIG-21-018 (2026)

Experiment	*hZZ*	*hWW*	*htt*	*hbb*	*hττ*	*hμμ*
ATLAS	5%	4%	5–6%	9%	6%	24–30%
CMS	6%	5–6%	6–7%	11–12%	7–8%	20–21%

Future expectation



Probe of Higgs secror by Higgs precision

$$\rho_{\text{tree}} = \frac{\sum_i [T_i(T_i+1) - Y_i^2] 2 |\langle \phi_i \rangle|^2}{\sum_i 2 Y_i^2 |\langle \phi_i \rangle|^2}$$

$$\rho_{\text{exp}} \simeq 1.0004$$

~~$\rho_{\text{tree}} \neq 1$~~

Complex triplet models

Real triplet models (RHTM)

~~$\rho_{\text{tree}} = 1$~~

2HDMs, IDM

HSM

GM model, etc.

Probe of Higgs secror by Higgs precision

$\rho_{\text{tree}} \neq 1$

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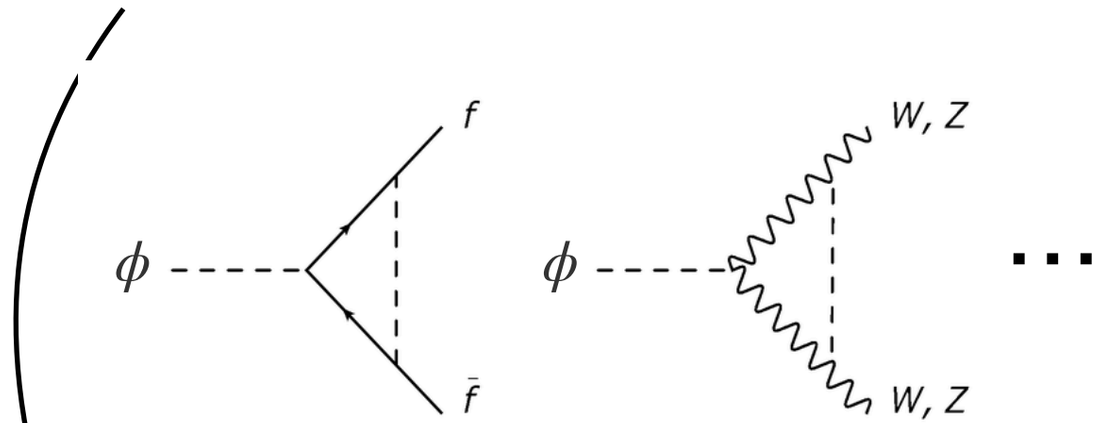
$\rho_{\text{tree}} = 1$

2HDMs, IDM

HSM

GM model, etc.

Precision calc.
of Higgs decays

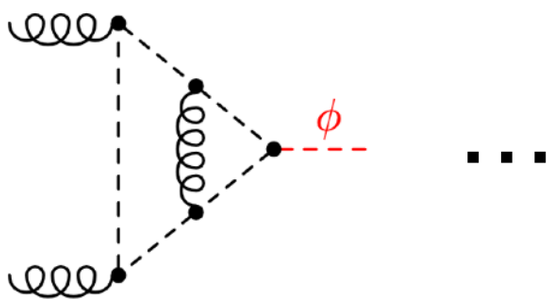


HCOUP Talk by K. Yagyu

(2HDECAY, EWsHDECAY, etc.)

SusHi, etc.

Precision calc. of
Higgs production



Probe of Higgs secror by Higgs precision

$\rho_{\text{tree}} \neq 1$

Complex triplet models

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Next target:

Triplet extenstions

This talk:
Impact of radiative corrections in RHTM

Real Higgs tripet models [1/2]

Scalar fields

$$\Phi = \begin{pmatrix} \phi^+ \\ \frac{1}{\sqrt{2}}(v_\phi + \phi + iG^0) \end{pmatrix}, \quad \Delta = \frac{1}{\sqrt{2}} \begin{pmatrix} \Delta^0 & \Delta^+ \\ \Delta^- & -\Delta^0 \end{pmatrix} \quad \text{with} \quad \Delta^0 = \frac{1}{\sqrt{2}}(v_\Delta + \delta),$$

$$\begin{pmatrix} \phi^\pm \\ \Delta^\pm \end{pmatrix} = R(\beta) \begin{pmatrix} G^\pm \\ H^\pm \end{pmatrix}, \quad \begin{pmatrix} \phi \\ \delta \end{pmatrix} = R(\alpha) \begin{pmatrix} h \\ H \end{pmatrix}$$

α, β: mixing angles

➡ 125 GeV Higgs : h, Addiaonal Higgs: $H, H^\pm$

Motivations

- Electroweak phase transitions S. Inoue, et. al., Phys.Rev.D 93 (2016) 015013. Y. Zhen Li, et. al. 2404.19197.
- Accommodation of excess light new Higgs boson (90~150GeV) S. Ashanujjaman, et. al., JHEP 04 (2025) 003.
- Ehancement of h and γ production in electron position collider A. Crivellin, et. al., Phys.Rev.D 108 (2023) 11, 115031.

S. Kanemura, K. Mawatari, KS, Phys.Rev.D 99 (2019) 3, 035023

Real Higgs tripet models [2/2]

Mass spectrum

Addiaitonal Higgs bosons are in quasi-degenerate:

$$m^2_{H^\pm} - m^2_H \simeq A v_\Delta \sim \mathcal{O}(1)\,\mathrm{GeV}^2 \qquad V_{RHTM} \supset A\Phi^\dagger\Delta\Phi$$

$A \to 0$, $O(3)_\Delta$ restoresd

[Ashanujjaman et al., JHEP 04 (2025) 003]

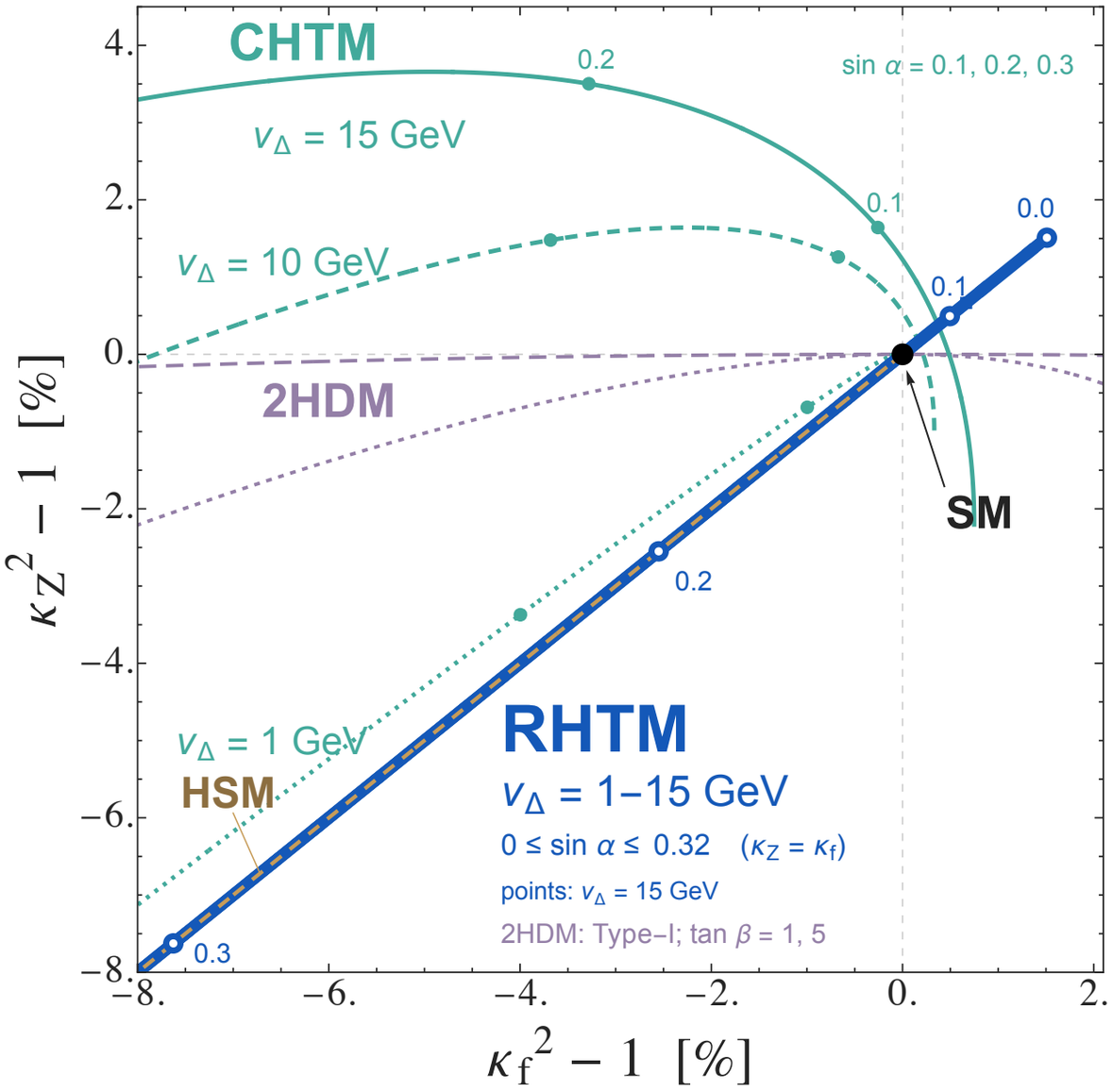
⟷ c.f) CHTM: $m^2_{H^\pm} - m^2_A \simeq m^2_{H^{\pm\pm}} - m^2_{H^\pm} \simeq -\frac{\lambda_5}{4}v^2 \sim \mathcal{O}(10^4)\,\mathrm{GeV}^2$

Alignment limit

$$\sin\alpha \sim \frac{v_\Delta}{v},\ \tan\beta = -2\frac{v_\Delta}{v_\phi} \longrightarrow \text{Alignment limit: } v_\Delta \to 0$$

$$[\kappa_Z^{\mathrm{RHTM}} = \kappa_f^{\mathrm{RHTM}} = \frac{\cos\alpha}{\cos\beta} \to 1]$$

Deviations in the Higgs boson decays at LO



$$k_X^2 \equiv \frac{\Gamma(h \to XX)^{\mathrm{RHTM}}}{\Gamma(h \to XX)^{\mathrm{SM}}}$$

RHTM

$$\kappa_Z^{\mathrm{RHTM}} = \kappa_f^{\mathrm{RHTM}} = \frac{\cos\alpha}{\cos\beta}$$

$$\left(\tan\beta = -\frac{2v_\Delta}{v_\phi}\right)$$

⟷ c.f) HSM:

$$\kappa_Z^{\mathrm{HSM}} = \cos\alpha \quad \kappa_f^{\mathrm{CSM}} = \cos\alpha$$

Unfortunately, RHTM overlaps with HSM and is close to CHTM with $v_\Delta = 1\mathrm{GeV}$.

Constraints

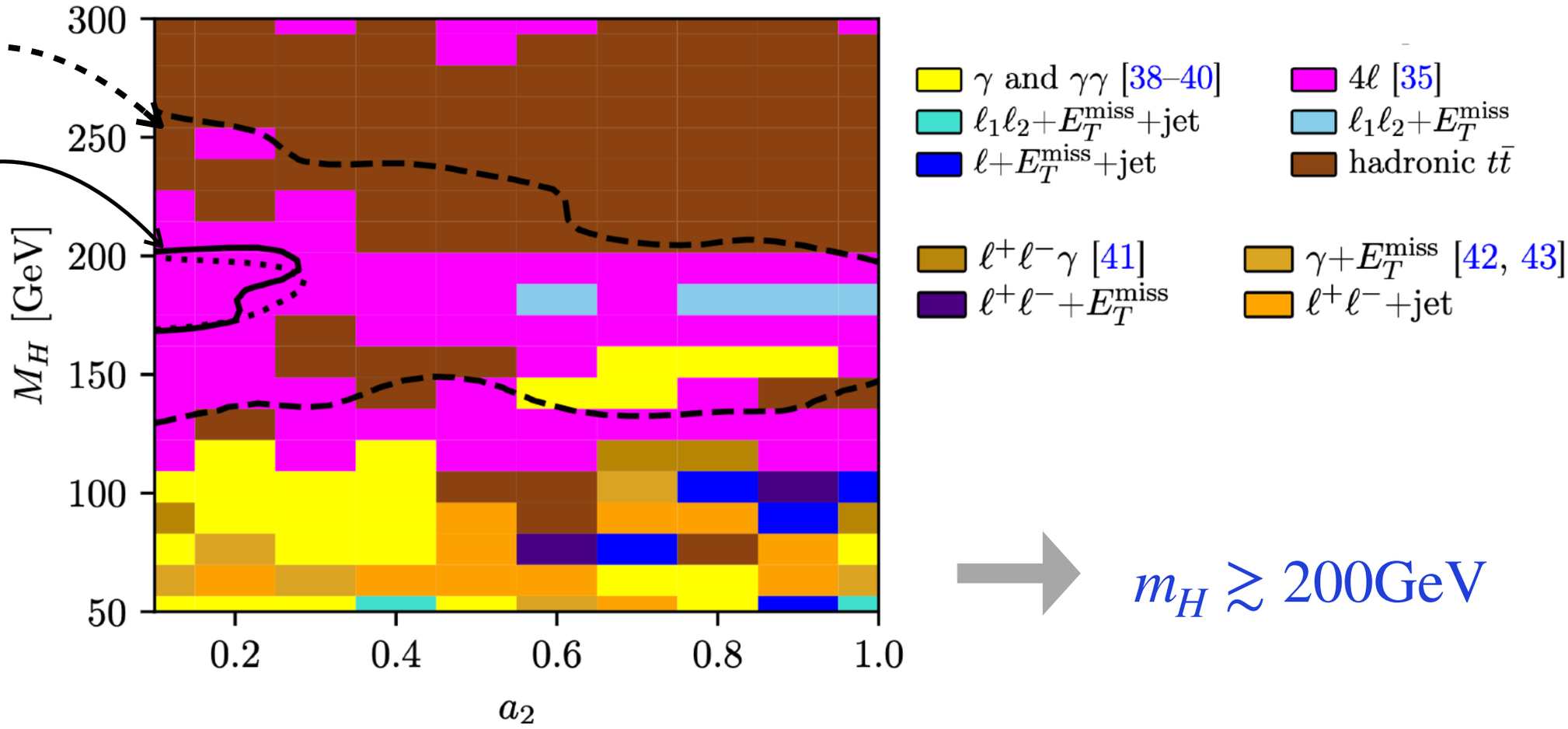
- Sarches of $H, H^{\pm}$

$V_{RHTM} \supset a_2 \Delta^2 \Phi^\dagger \Phi$

[J. Butterworth, Hridoy Debnath, et.al.,PRD109(2024)]

68% exclusion

95% exclusion



$\rightarrow$ $m_H \gtrsim 200\mathrm{GeV}$

- ρ parameter

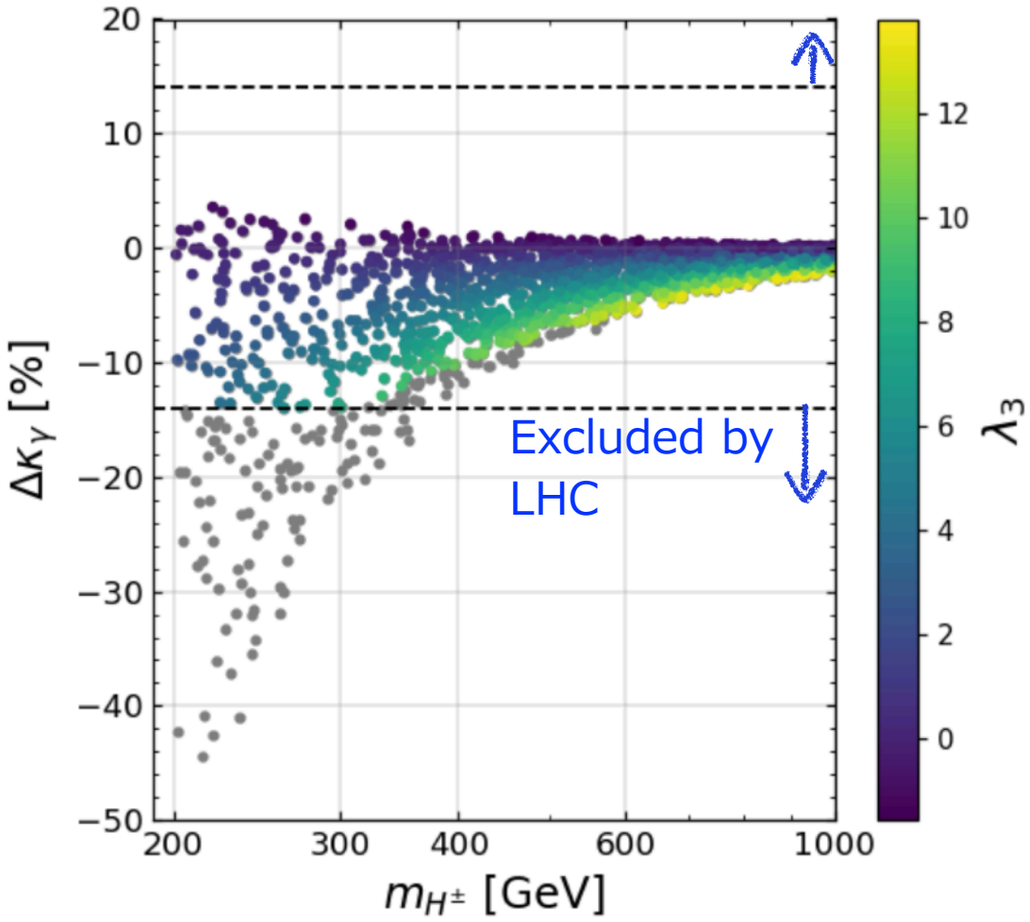
$$\rho_{\rm tree} = \frac{v_\Phi^2 + 4v_\Delta^2}{v_\Phi^2} \simeq 1 + \frac{4v_\Delta^2}{v^2}, \qquad \rho\,\text{1-loop} \simeq \frac{\alpha_{\rm em}}{6\pi^2 v^2}(m_H - m_{H^\pm})^2$$

$$(m_H - m_{H^\pm})^2 \propto v_\Delta^2$$

Constraint for triplet vev, $v_\Delta \ll v_\phi$ $\qquad v_\Delta \lesssim 2\mathrm{GeV}$

Constraint from $h \to \gamma\gamma$

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Tanighuchi, Yagyu, Preliminary



- Smaller $m_{H^\pm}$ larger Δk_γ. This is constrained by LHC.

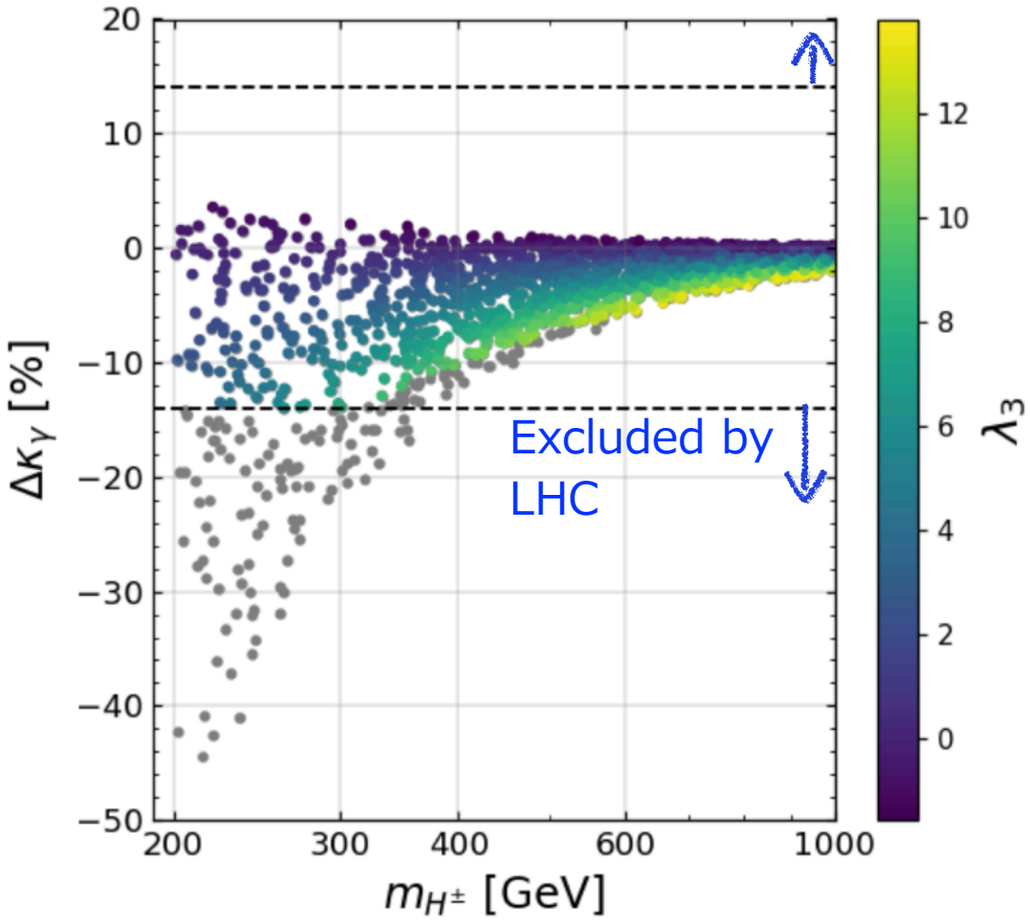
$$\Gamma_{h\to\gamma\gamma} = \frac{G_F \alpha_{\rm em}^2 m_h^3}{128\sqrt{2}\pi^3} \left| \frac{\lambda_3 v^2}{12 m_{H^\pm}^2} + (W, f \text{ loop}) \right|^2$$

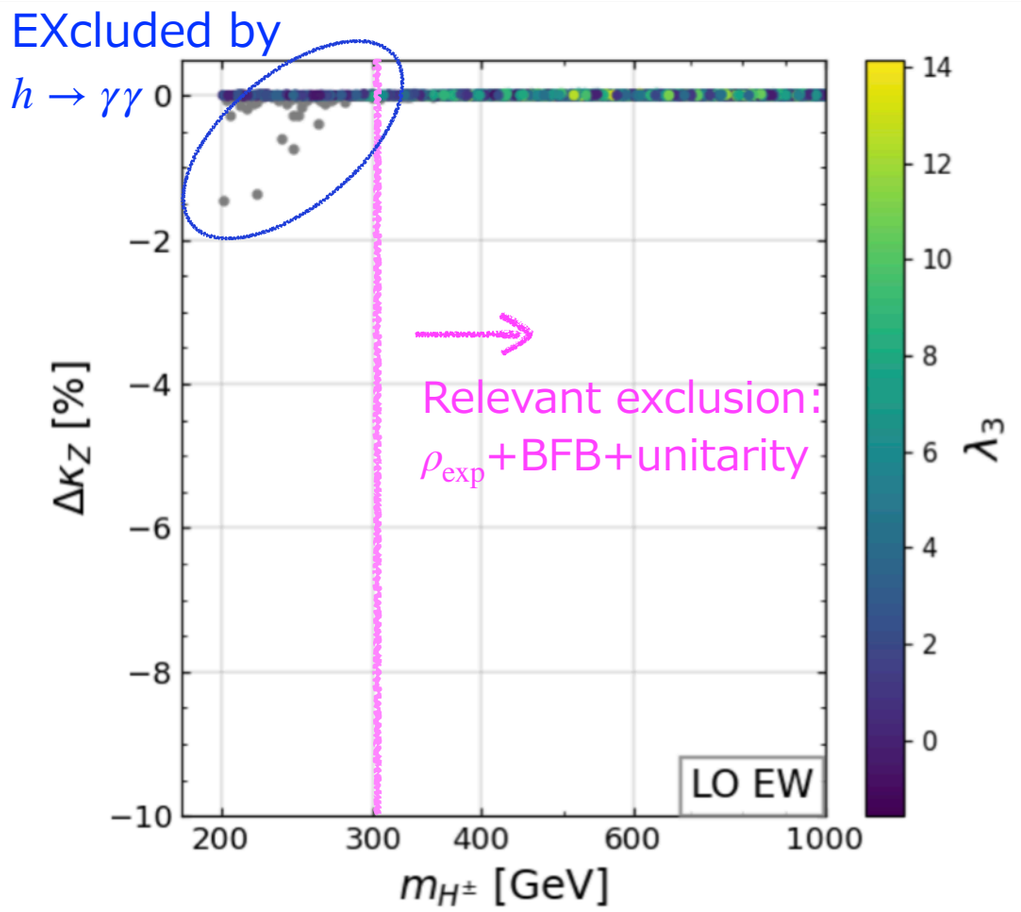
$$V_{RHTM} \supset \lambda_3 \Delta^2 \Phi^\dagger \Phi$$

Given $m_{H^\pm}$, maximum of λ_3 is determined.

Constraint from $h \to \gamma\gamma$

Aiko, Kanemura, Kikuchi, KS,
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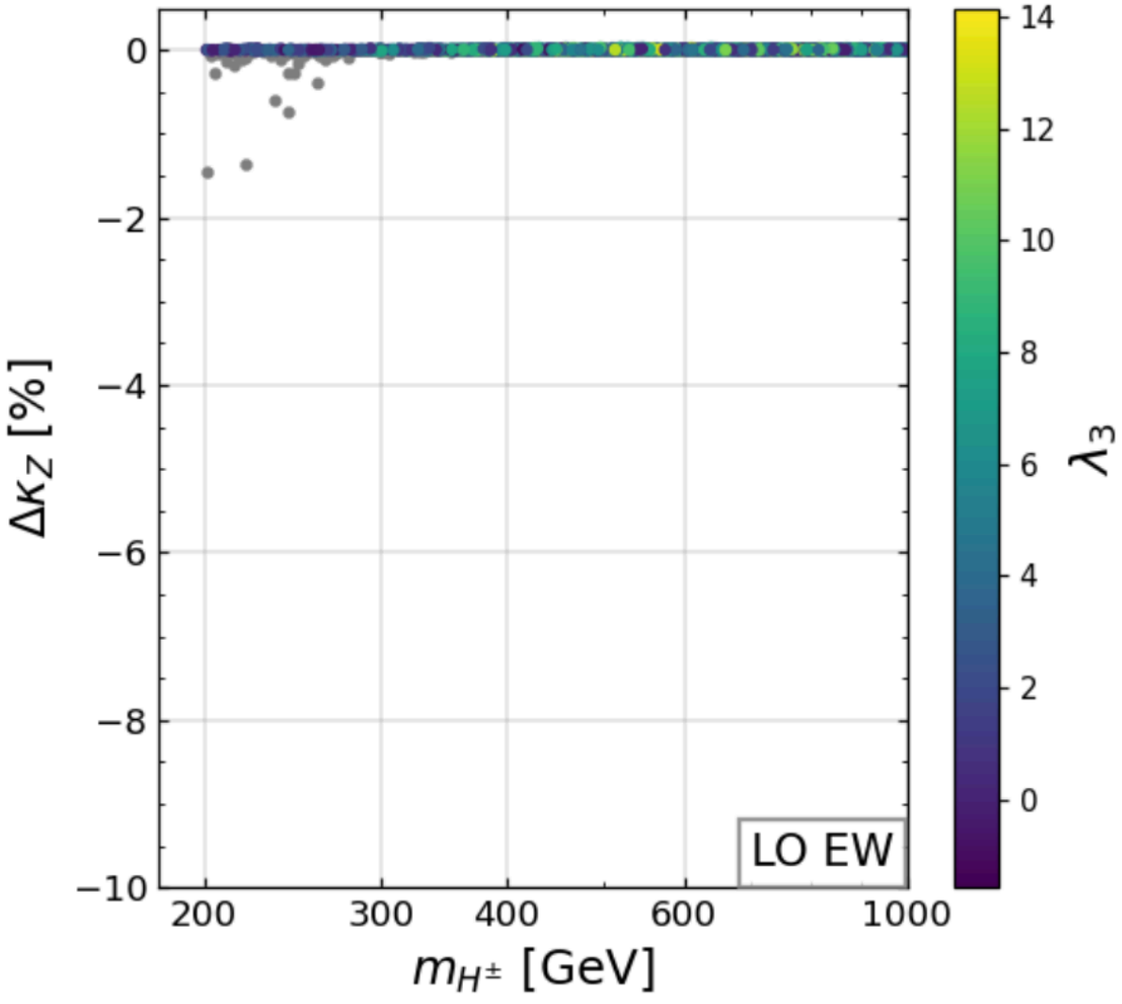
- Due to experimental constraints, deviations in Higgs boson decays are tiny. $\Delta\kappa_Z \sim 0$

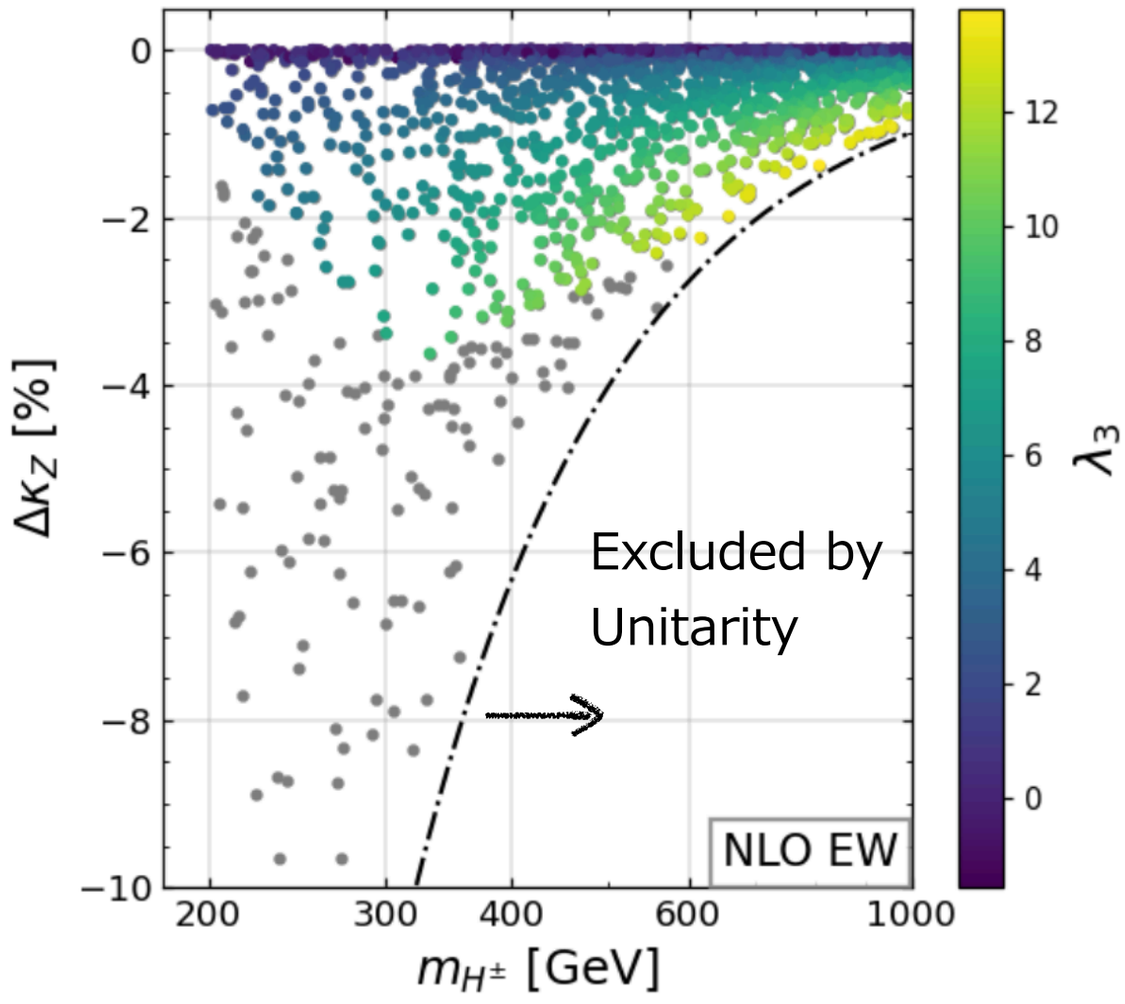
$$m_{H^\pm} \gtrsim v : s_\alpha \sim 4\frac{v_\Delta}{v} \ll 1, \qquad m_{H^\pm} \lesssim v : s_\alpha \sim -\lambda_3 \frac{v v_\Delta}{m_H^2} \sim -0.3 \quad [@\lambda_3 \sim 12\pi]$$

Excluded by $h \to \gamma\gamma$

Scalar loop corrections to h(125) decays

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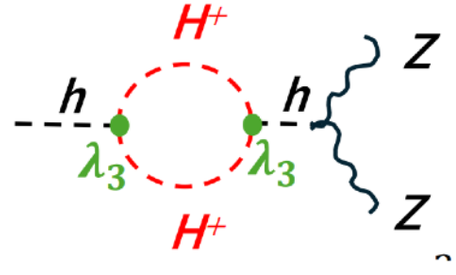
Additinal Higgs boson loop corrections shift $\Delta\kappa_Z$.

$$\kappa_Z^2 - 1 \approx -\frac{\lambda_3^2 v^2}{64\pi^2 m_{H^\pm}^2}.$$

$\Delta\kappa_Z$: ~0 [LO] → ~-4% [NLO]

⟷ e.g) $\Gamma(h \to ZZ^*)$~0.44% @ILC500

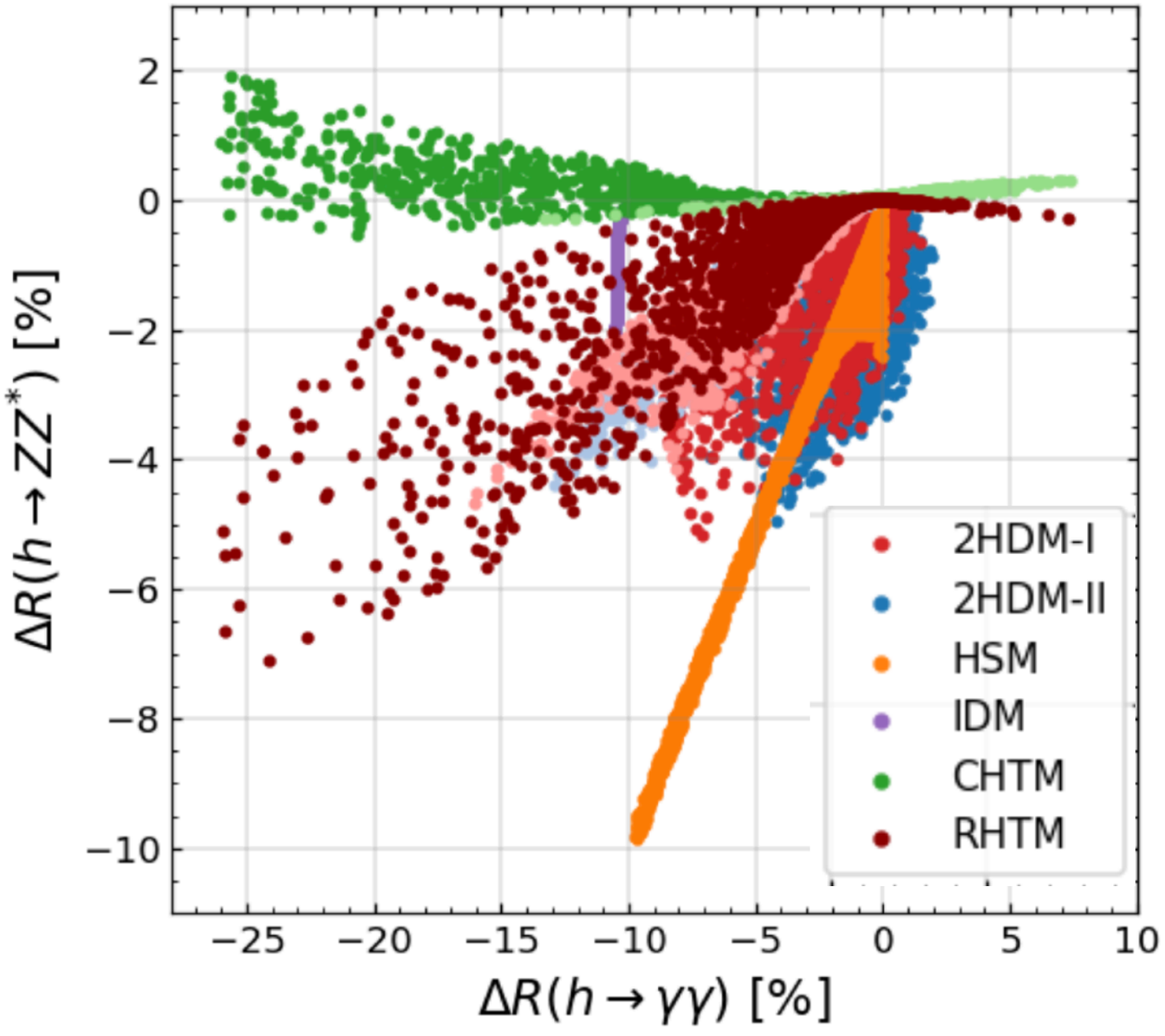
[Blas, et. al., JHEP01(2020)139]



Fingerprinting

$$\Delta R \equiv \frac{\Gamma(h \to XX)^{\rm RHTM}}{\Gamma(h \to XX)^{\rm SM}} - 1$$

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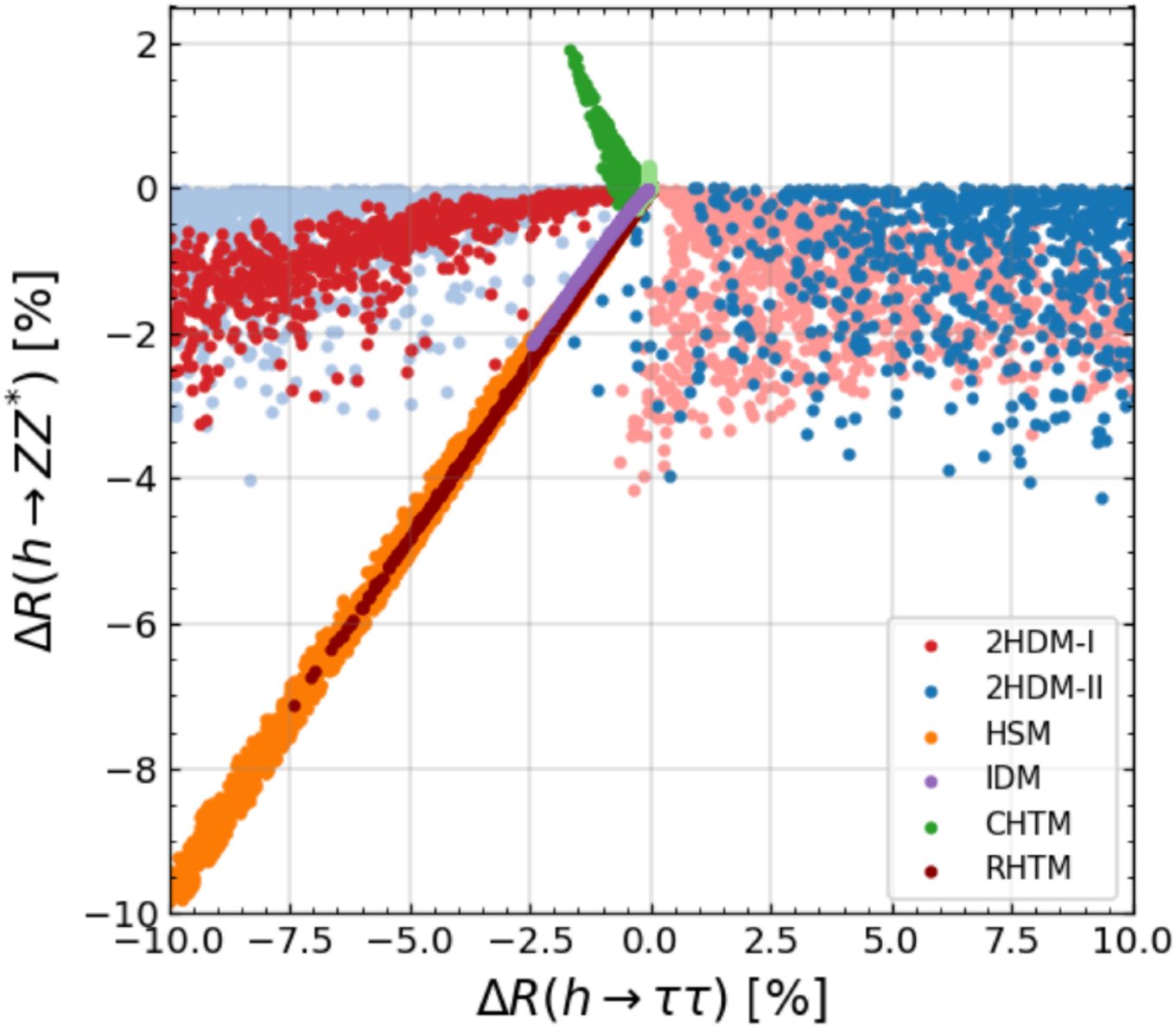


- $h \to \gamma\gamma$ vs $h \to ZZ^*$: the correlation is quite diffent from HSM and CHTM, refrecting the distinct structrutre of charged sector.

Fingerprinting

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Aiko, Kanemura, Kikuchi, KS, Tanighuchi, Yagyu.



- $h \to \gamma\gamma$ vs $h \to ZZ^*$: the correlation is quite diffent from HSM and CHTM, refrecting the distinct structrutre of charged sector.
- RHTM can be separated from 2HDMs in the $h \to \tau\tau$ vs $h \to ZZ^*$.

Summary

- We investigated the effects of NLO corrections to h(125) decays in the real Higgs triplet models (RHTM), which is a simple model with $\rho_{\rm tree} \neq 1$.

- The next version of H-COUP provides predictions in triplet extensions, including RHTM.

Talk by K. Yagyu
(Afternoon session)

- Loop corrections alter the predictions for h(125) decays with $\mathcal{O}(1)\,\%$.

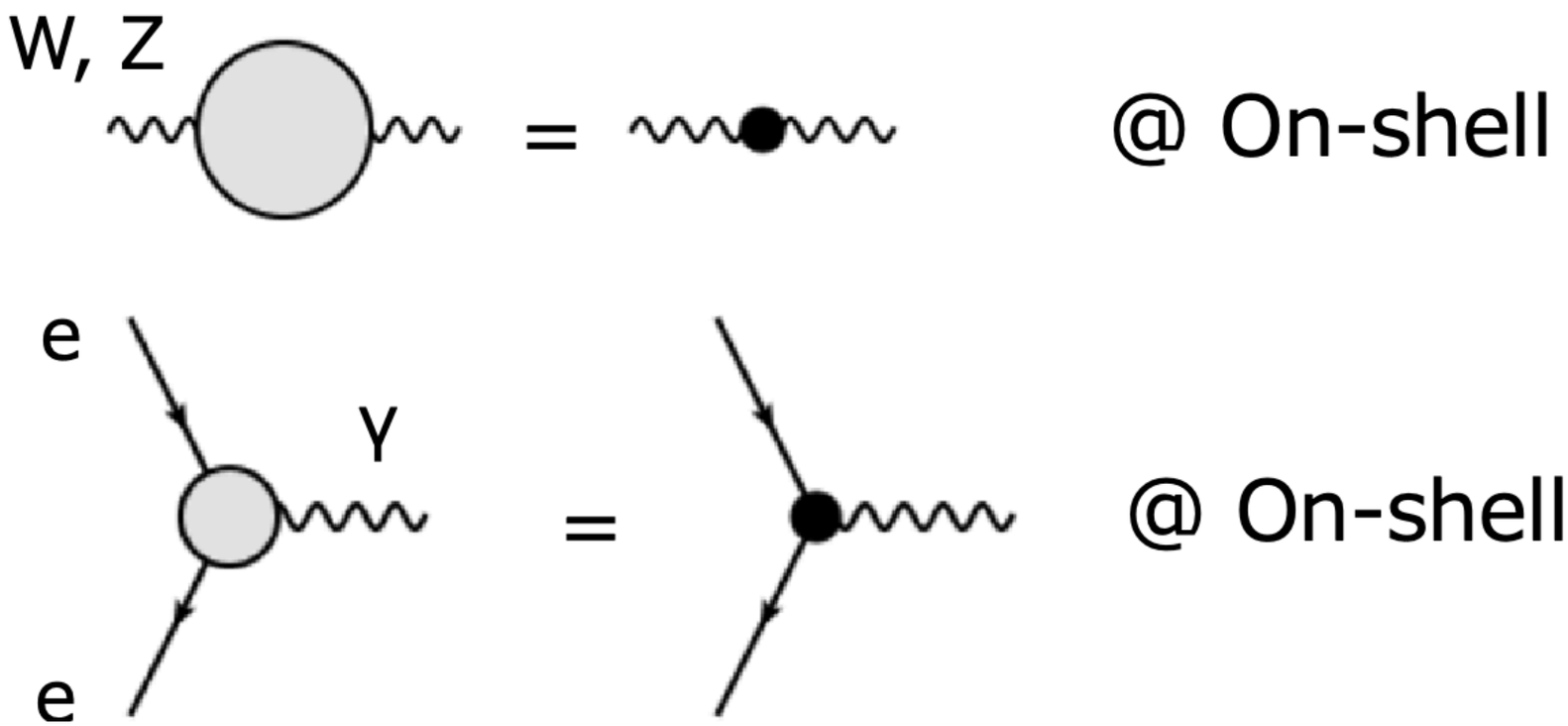
With the precise theoretical predictions, we can distinghuish RHTM from other extended Higgs models.

Buck up slide

Renormalization of gauge sector

[Sirlin (1980), Aoki et al. (1982), Hollik (1990), etc.]

- SM case （3 parameters g, g', v) $\rightarrow m_W$, m_Z, $\alpha_{\rm em}(= e^2/(4\pi))$



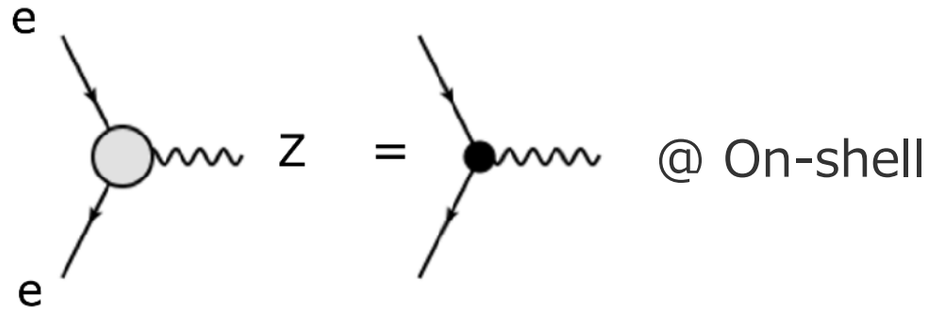
- RHTM case: (4 parameters : g, g', v, v_Δ,) $\rightarrow m_W$, m_Z, $\alpha_{\rm em}$, X

➡ There are several choice for the renormalization of the additional parameter (X)

Renorlaization of additional parameter

On-shell scheme 1 [Blank and Hollik (1998)]

- Renormalized parameter: m_W, m_Z, $\alpha_{\rm em}$, $(s_W^{f=e})^2$



- v_Δ is output parameter. The decoupling of the triplet field is not trivial (namely findg parameter point).
- The terms for cusdial symmetry violation appears at loop level. [M. Chen, S. Dawson, et. al. (2006)] There is no natural limit to realzie .

$v_\Delta \sim$ (The terms for cusdial symmetry violation)

On-shell scheme 2

- Renormalized parameter: m_W, m_Z, $\alpha_{\rm em}$, β



- off-diagonal components of the mass matirx for $(H^\pm, G^\pm)$ are proportional to v_Δ. $\beta' \to 0$ essentially corresponds to $v_\Delta \to 0$.

[Y. Yamada(2001)]

➡ We have develpoed scheme 2.

hhh coupling

