H-COUP: Exploring New Physics through Precision Calculations of Higgs Boson Decays

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Kanemura, Kikuchi, KS, Yagyu, CPC233 (2018),
Kanemura, Kikuchi, Mawatari, KS, Yagyu CPC257 (2020)
Aiko, Kanemura, Kikuchi, KS, Yagyu, CPC301 (2024)
Aiko, Kanemura, Kikuchi, KS,Taniguchi and Yagyu, JHEP05 (2026)

Kanemura,Kikuchi, KS, Taniguchi,Yagyu
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CEPC2026, Oct. 23rd, 2026

Introduction

Exploring the Higgs Sector

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

Numbers ?	Origion of ν masses?	
Representations?	CPV and baryogenesis?	
Symmetries?	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.

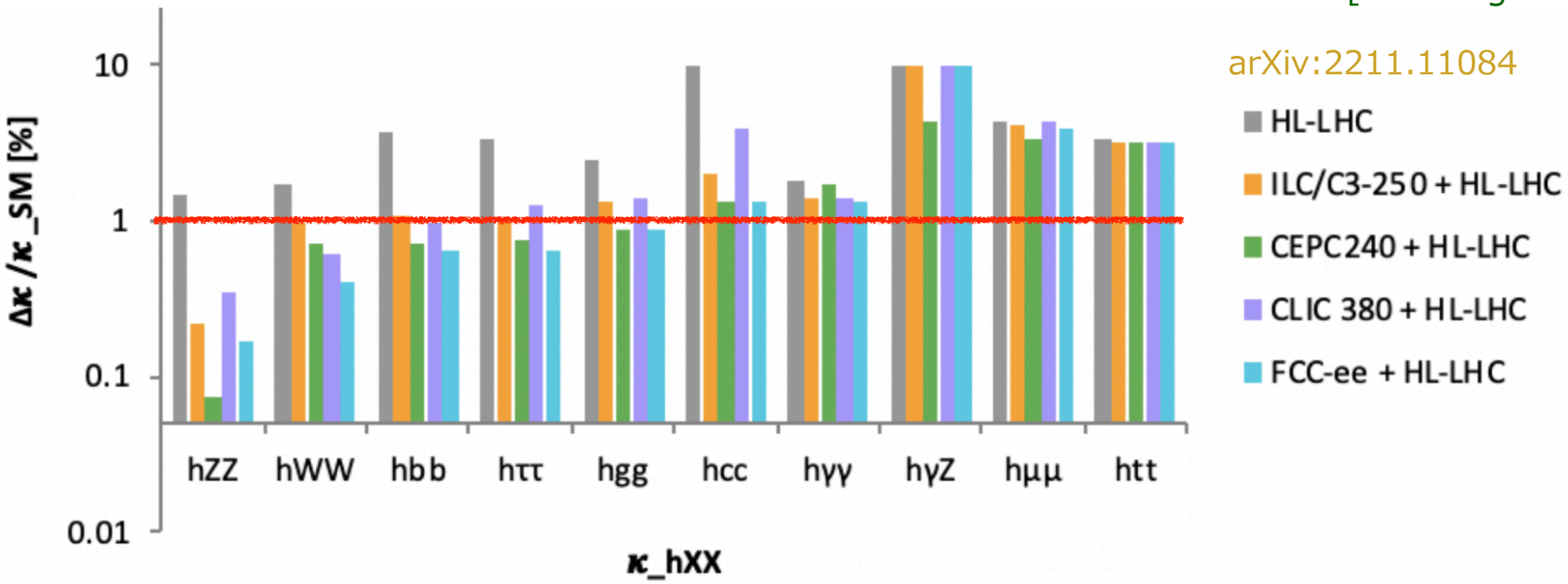
Current accuracy

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

E.g.) CEPC: hZZ 0.07%, hWW 0.4%, hbb 0.4%, hττ 0.5%
[arxiv.org2205.08553]



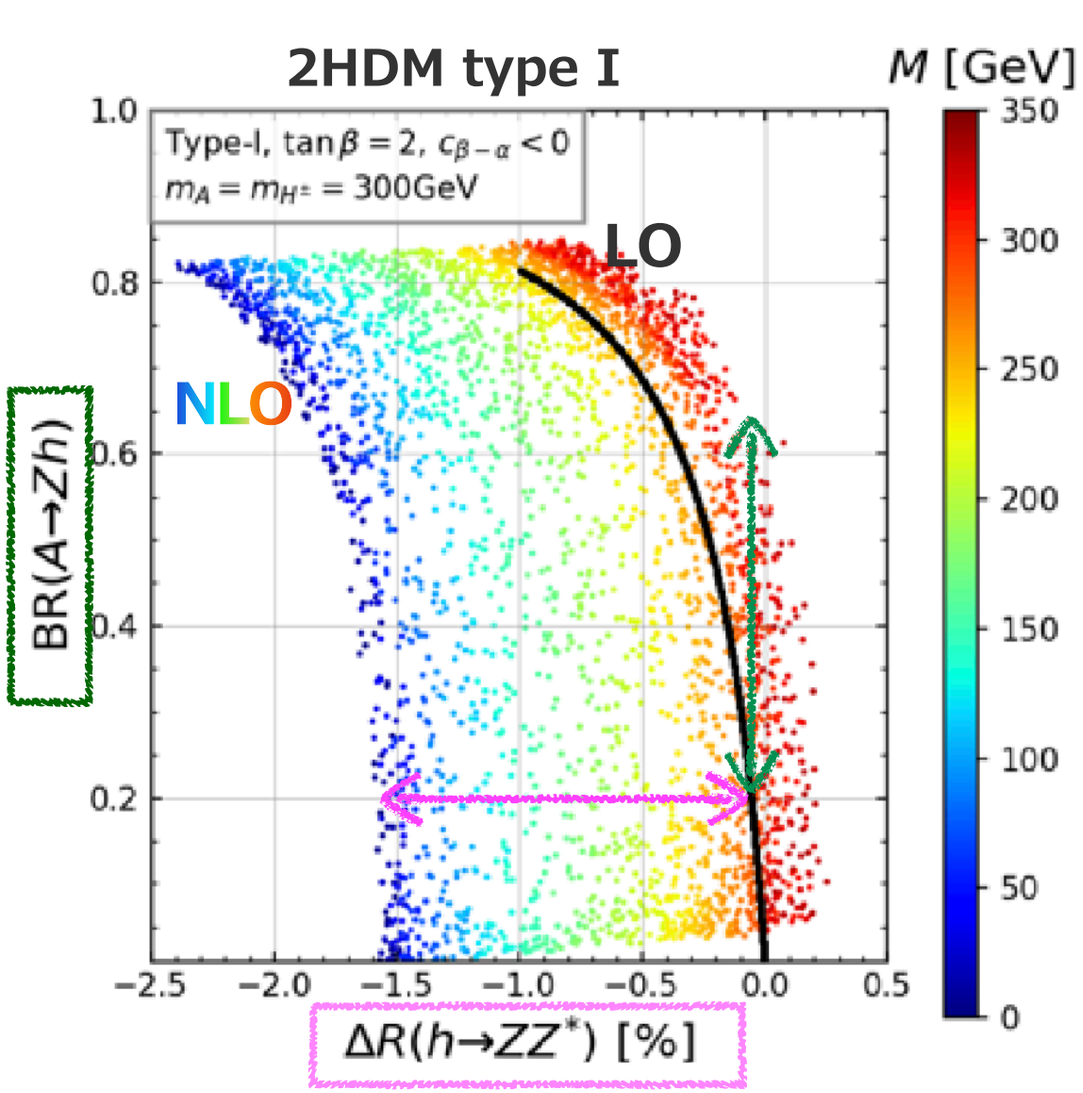
Imporatnce of radiative corrections

1. Higgs precision measurements

Radiative corrections are essential for predictions at the percent or sub-percent level.

2. Searches for additional Higgs bosons

Radiative corrections can significantly modify the decay properties of additional Higgs.



$$\Delta R(h \to ZZ^*) = \frac{\Gamma(h \to ZZ^*)_{NP}}{\Gamma(h \to ZZ^*)_{\mathrm{SM}}}$$

$\Delta R(h \to ZZ^*)$: ~0 [LO] → ~-1.5% [NLO]

$\mathrm{BR}(A \to Zh)$: ~0.2 [LO] → ~0.62 [NLO]

H-COUP

Kanemura, Kikuchi, KS, Yagyu, CPC233 (2018),
Kanemura, Kikuchi, Mawatari, KS, Yagyu CPC257 (2020)
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A program to evaluate radiative corrections to Higgs obsearvables

Processes

- Two-body decays and three-body decays of 125GeV Higgs
- Two-body decays of addional Higgs

Implemented models

- Higgs singlet model (HSM)
- Two-Higgs-doublet models (2HDMs) Type-I, II, X and Y
- Inert doublet model (IDM)

Features

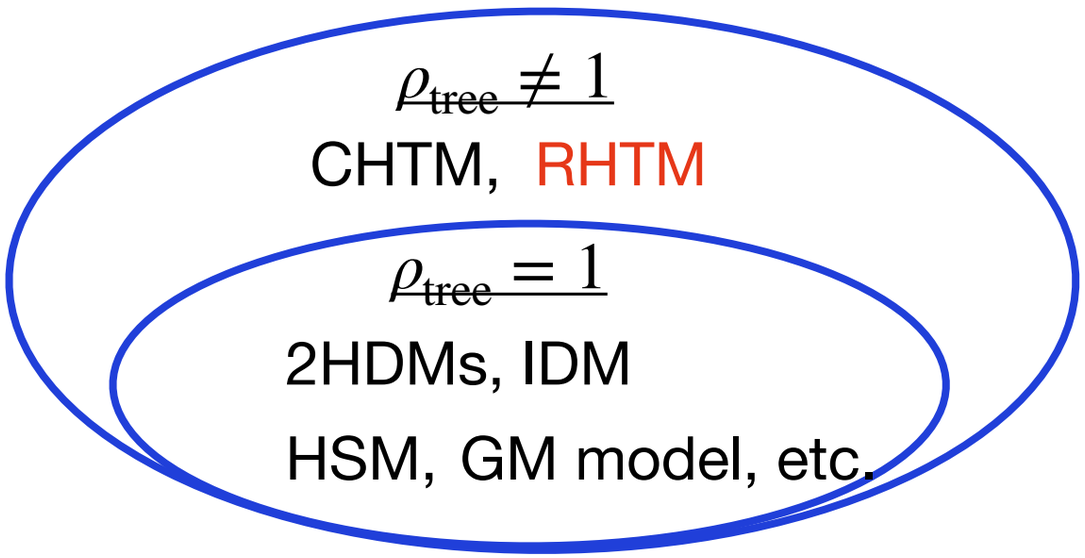
- Full 1-loop EW and higher-order QCD corrections
- Gauge-independent on-shell renormalization

Enables us to compare precise theoretical predictions among different models

Recent developments:

Extensions to Higgs triplet models

- Complex Higgs triplet model (CHTM)
- Real Higgs triplet model (RHTM) New!



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

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

Deviations in the Higgs boson decays at LO

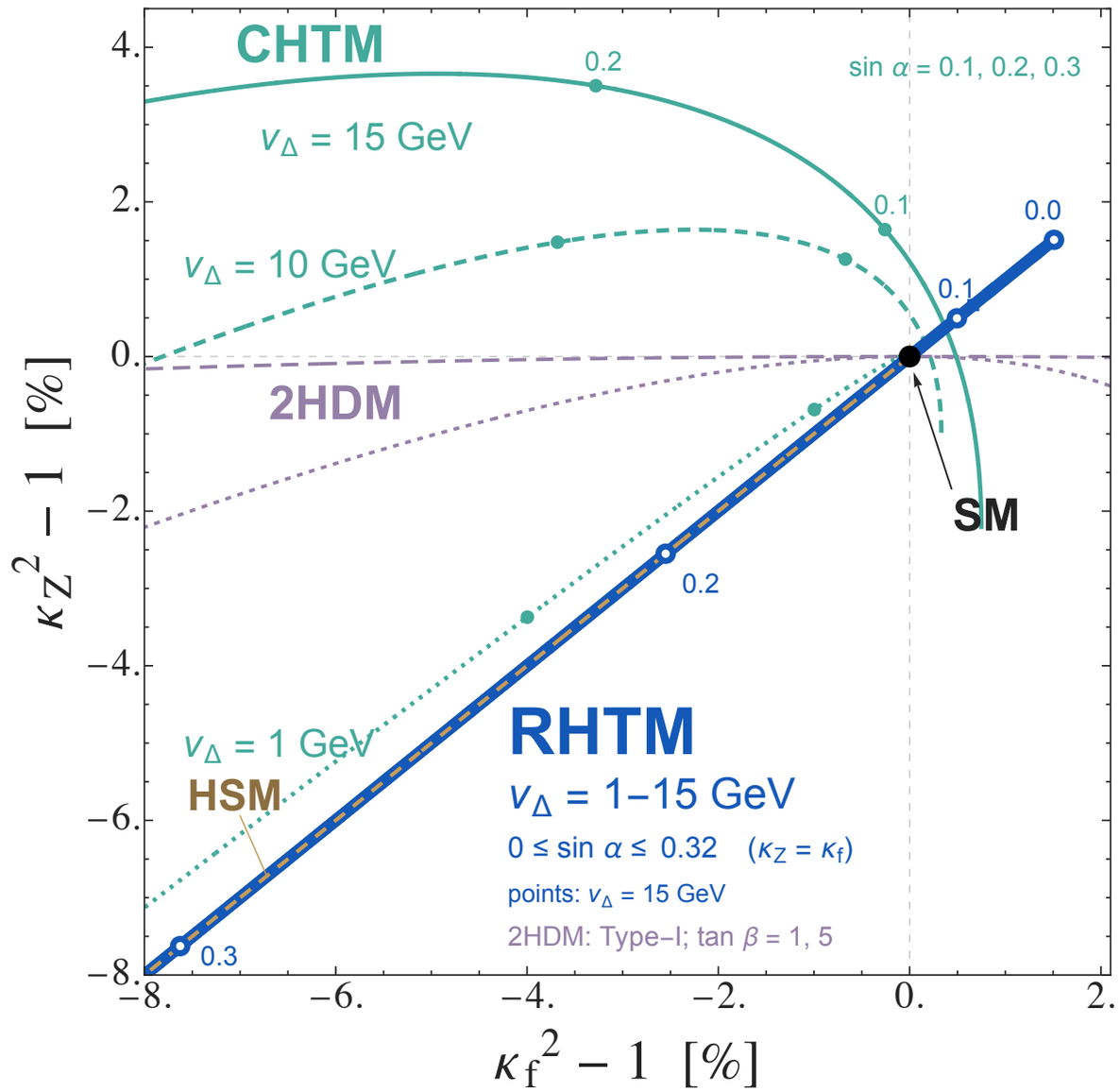
$$\kappa_Z^{\mathrm{RHTM}} = \kappa_f^{\mathrm{RHTM}} = \frac{\cos\alpha}{\cos\beta}$$

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

⟷ c.f) CHTM:

$$\kappa_Z^{\mathrm{CHTM}} = \frac{\cos\alpha\cos\beta' + 2\sin\alpha\sin\beta'}{\sqrt{1+\sin^2\beta}},$$

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



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

EW rho parameter

- ρ parameter deviate from a unity at tree-level ($\rho_{\rm exp} = 1.00031 \pm 0.00019$ [PDG2024])

$$\rho_{\rm tree} = \frac{v_\Phi^2 + 4v_\Delta^2}{v_\Phi^2} \simeq 1 + \frac{4v_\Delta^2}{v^2}$$

$\Delta\rho$: ↗

⟷ c.f) CHTM: $\rho_{\rm tree} = \dfrac{v_\Phi^2 + 2v_\Delta^2}{v_\Phi^2 + 4v_\Delta^2} \simeq 1 - \dfrac{2v_\Delta^2}{v^2}$ $\Delta\rho$: ↘

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

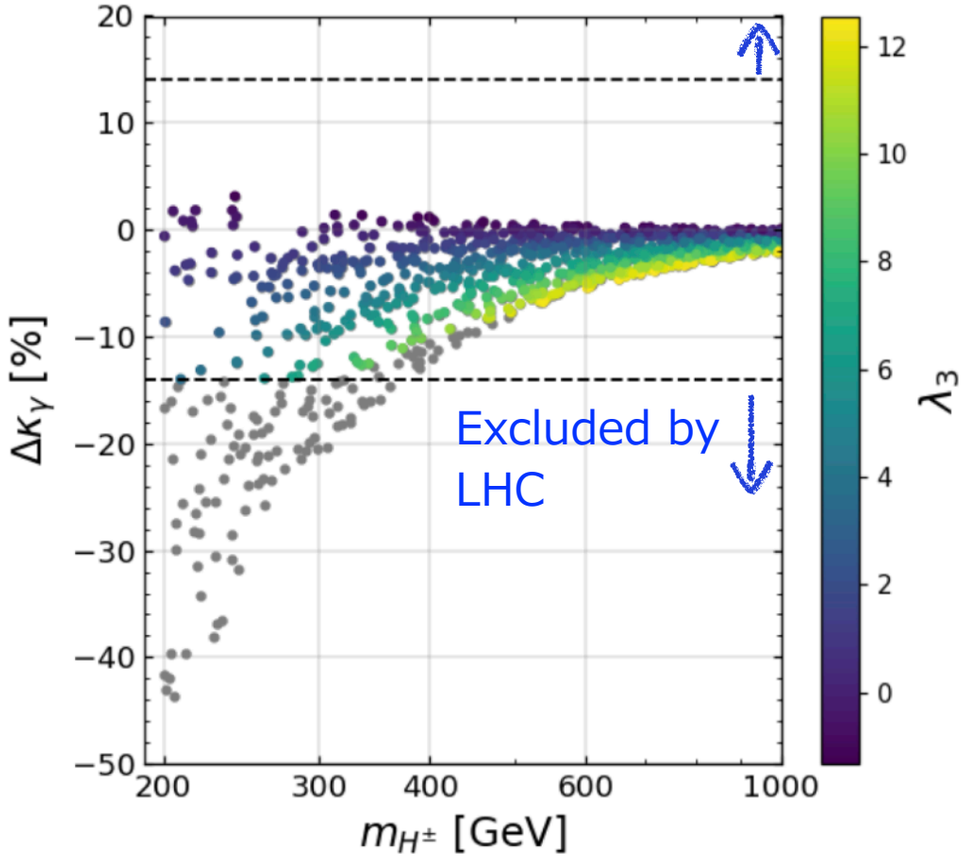
- Even if we include 1-loop corrections, similar results are obtained.

$$\rho\text{1-loop} \simeq \frac{\alpha_{\rm em}}{6\pi^2 v^2}\underbrace{(m_H - m_{H^\pm})^2}_{\propto v_\Delta^2}$$

Additional Higgs boson loop corrections to ρ are suppressed by v_Δ.

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.

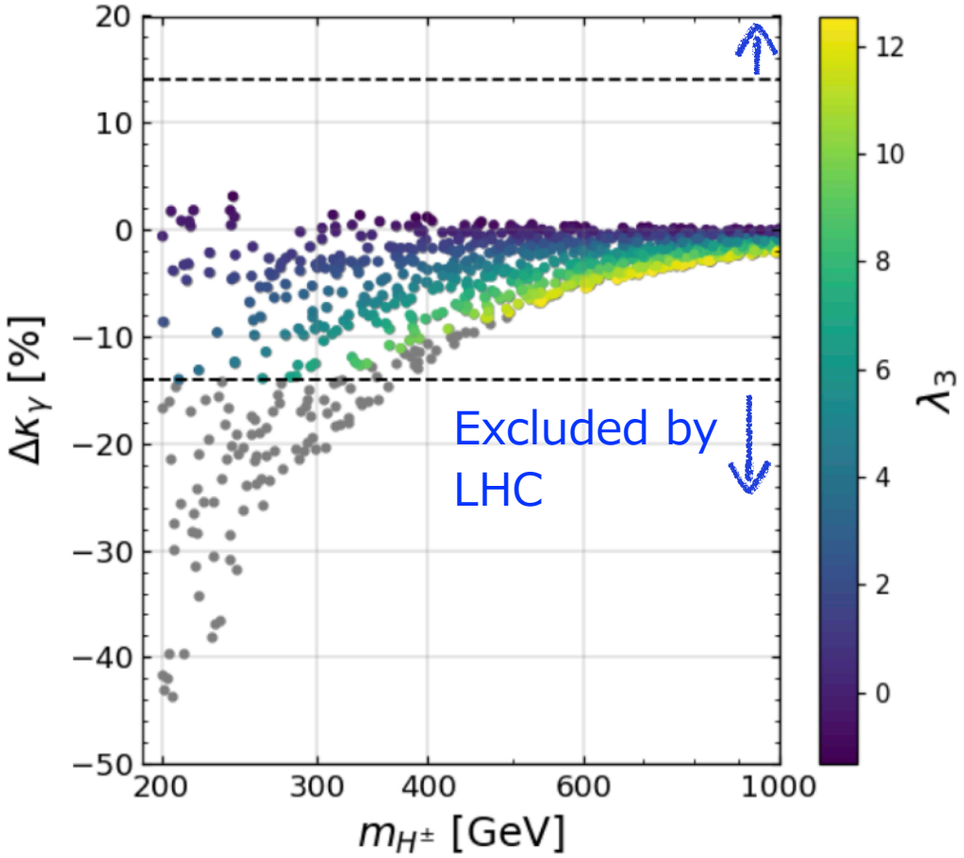
$$\Gamma_{h\to\gamma\gamma} = \frac{G_F \alpha_{\rm em}^2 m_h^3}{128\sqrt{2}\pi^3} \left| \frac{\lambda_3 v^2}{12 m_{H^\pm}^2} + (W, f \text{ loop}) \right|^2$$

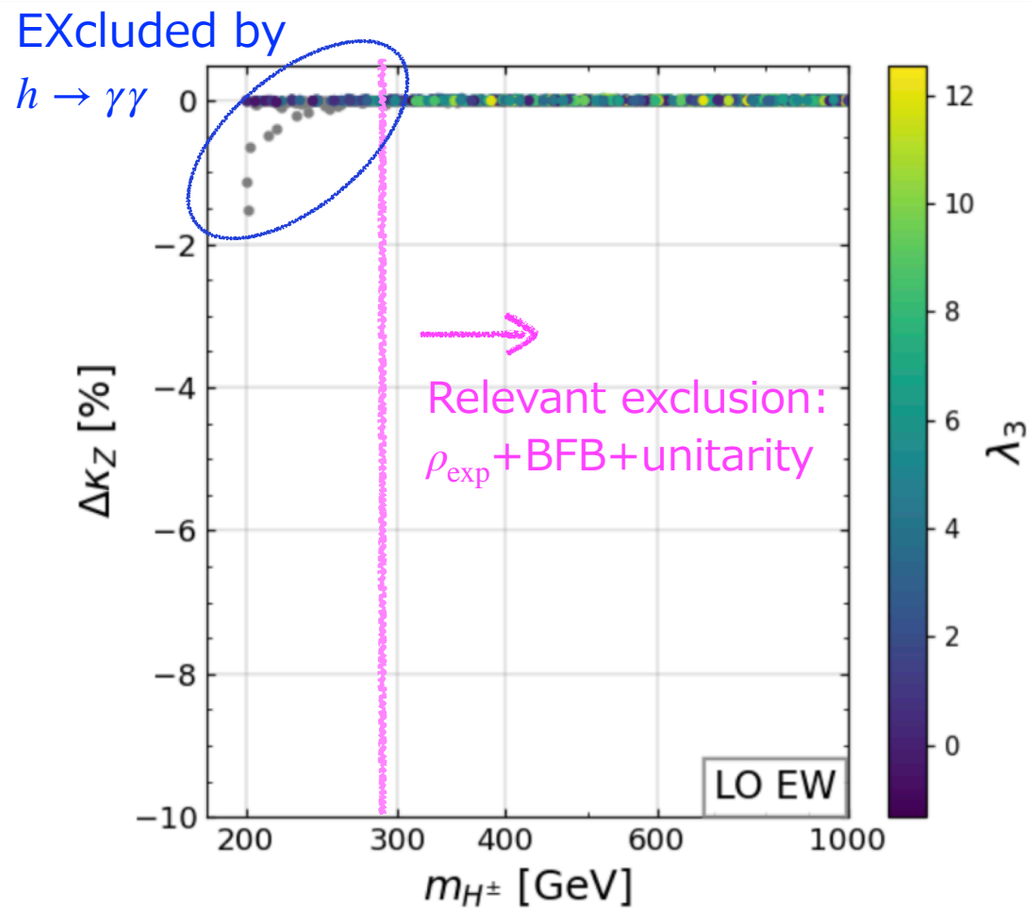
$$V_{RHTM} \supset \lambda_3 \Delta^2 \Phi^\dagger \Phi$$

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

Constraint from $h \to \gamma\gamma$

Aiko, Kanemura, Kikuchi, KS,
Tanighuchi, Yagyu, Preliminary





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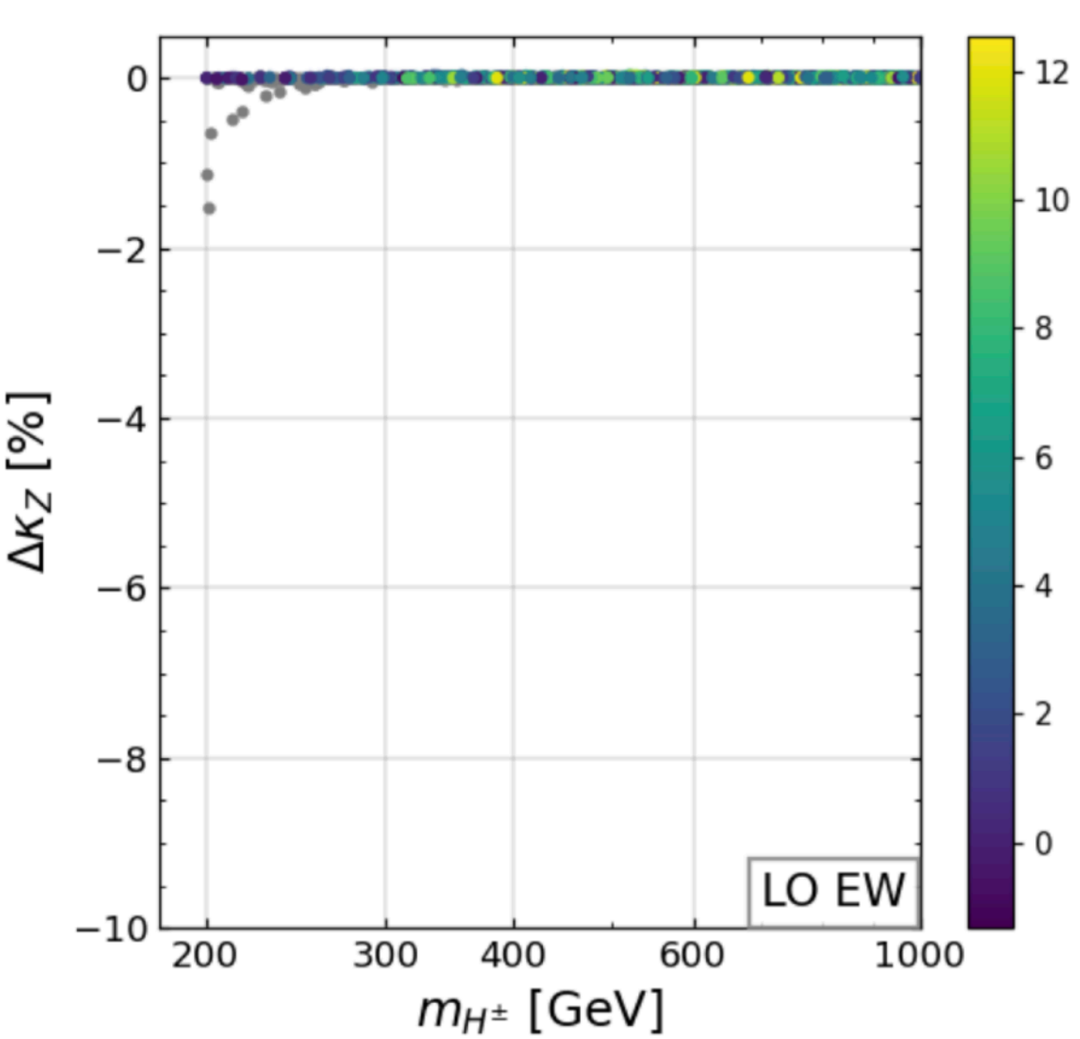
- Due to experimental constraints, <u>deviations in Higgs boson couplings is tiny</u>. $\Delta\kappa_Z \sim 0$

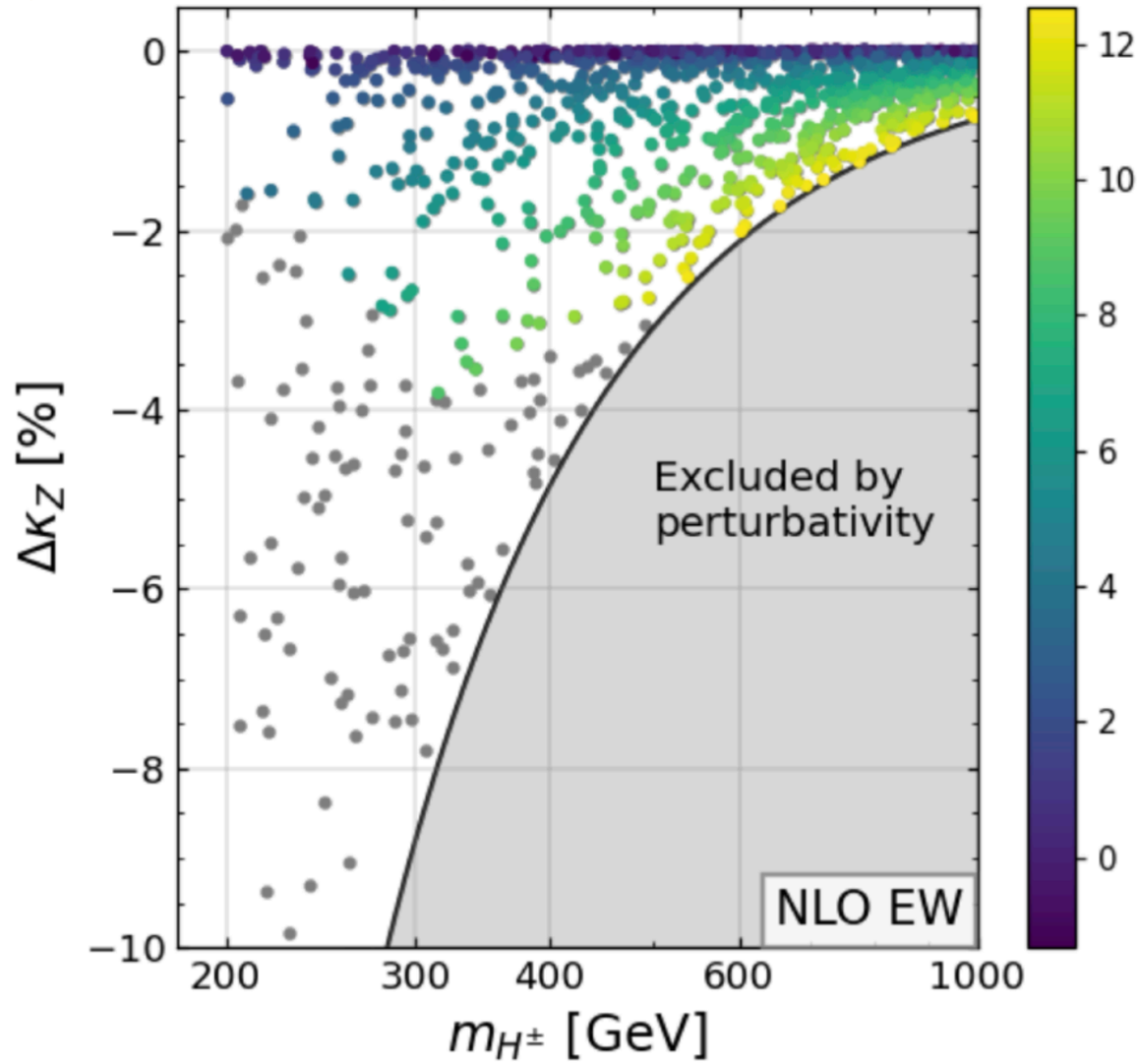
$$m_{H^\pm} \gtrsim v : s_\alpha \sim 4\frac{v_\Delta}{v} \ll 1, \qquad m_{H^\pm} \lesssim v : s_\alpha \sim -\lambda_3 \frac{v v_\Delta}{m_H^2} \sim -0.3 \quad [@\lambda_3 \sim 12\pi]$$

Excluded by $h \to \gamma\gamma$

Scalar loop corrections to h(125) decays

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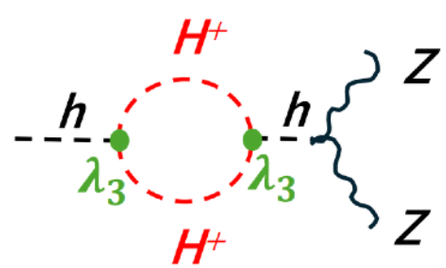
Additinal Higgs boson loop corrections shift $\Delta\kappa_Z$.

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

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

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

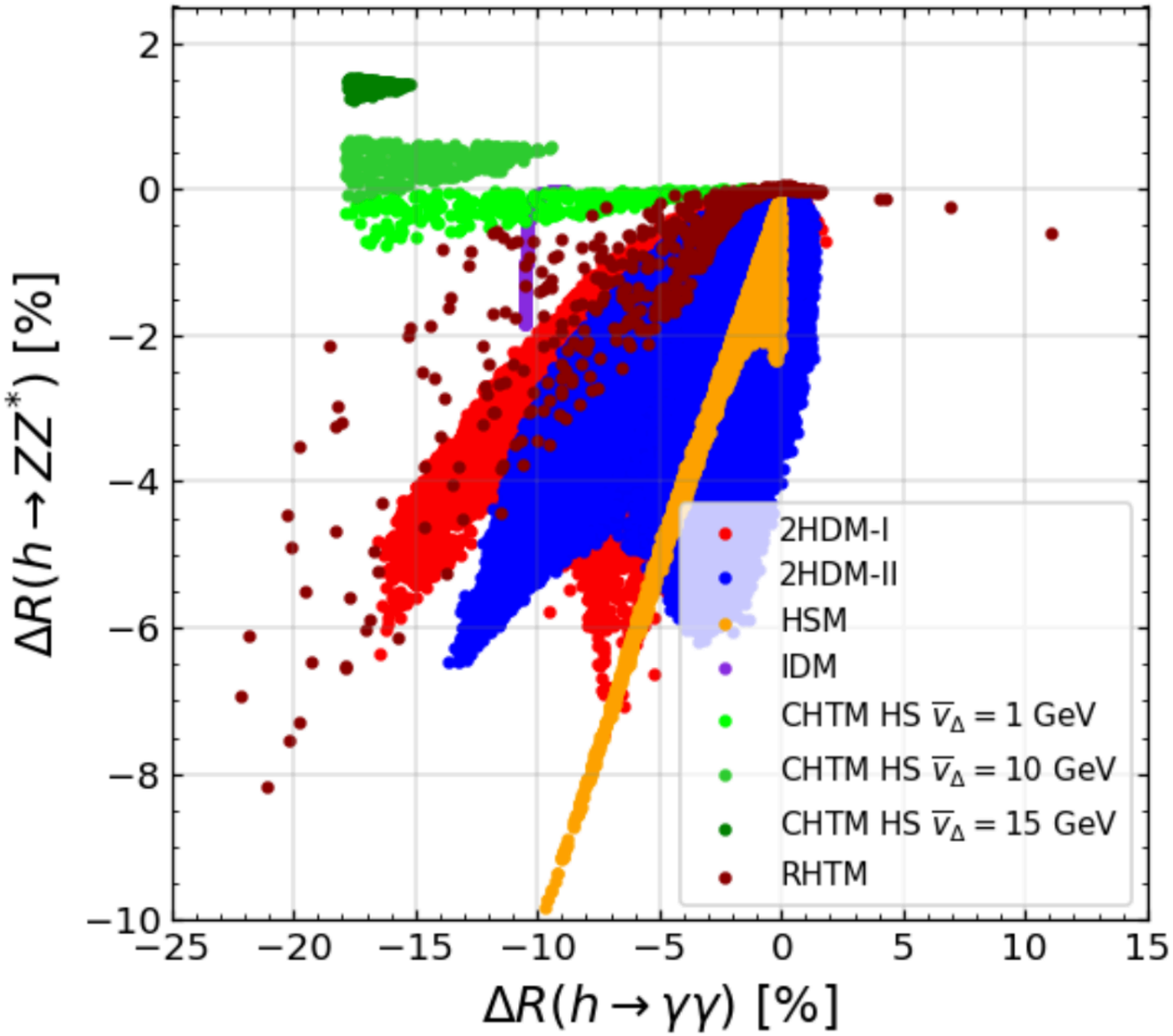
[Blas, et. al., JHEP01(2020)139]



Fingerprinting

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

Aiko, Kanemura, Kikuchi, KS, Tanighuchi, Yagyu, Preliminary



- $h \to \gamma\gamma$ 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 $\rho_{\text{tree}} \neq 1$.

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

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

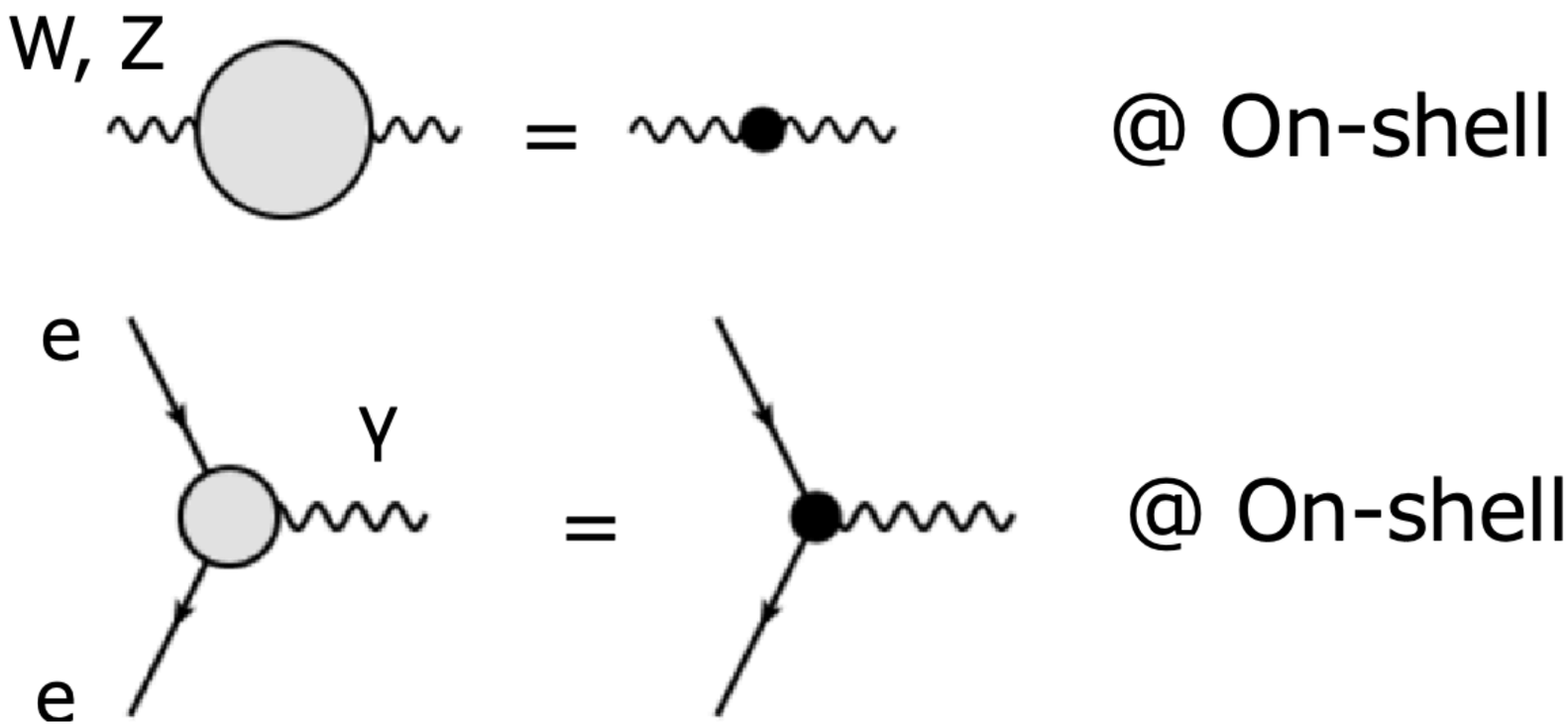
By comparing precise theoretical predictions with experimental results from future Higgs factory facilities, it becomes possible to test extended Higgs models.

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, $\alpha_{\rm em}(= e^2/(4\pi))$



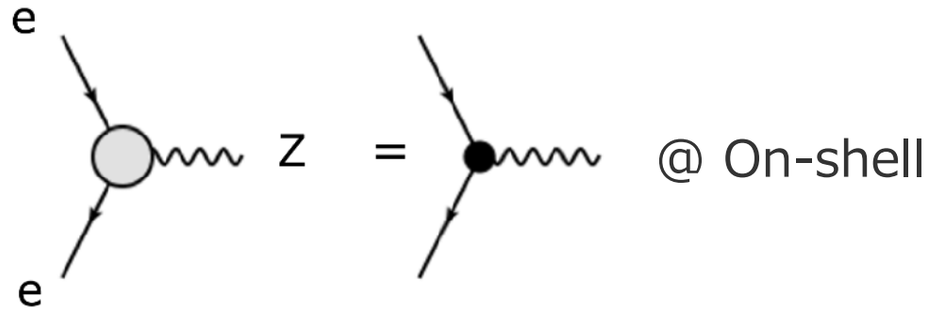
- RHTM case: (4 parameters : g, g', v, v_Δ,) $\rightarrow m_W$, m_Z, $\alpha_{\rm em}$, X

➡ 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.

Correlation in $h \to ZZ^*$ and $h \to \tau\tau$

