H-COUP: Higgs Precision Calculations and New Developments toward Ver. 4

Kei Yagyu

Tokyo U. of Science



Based on H-COUP Collaboration:

M. Aiko (Miyakonojo Coll.), S. Kanemura (U. of Osaka), M. Kikuchi (Saga U.)

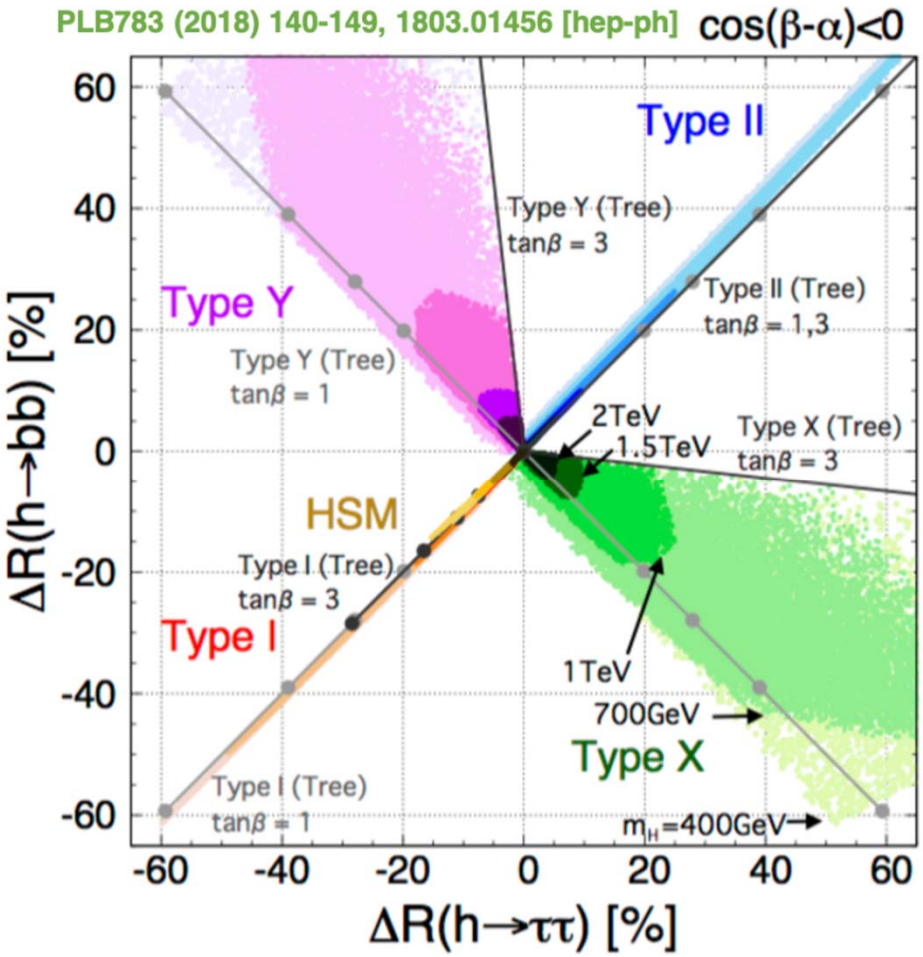
K. Sakurai (Tsuruoka Coll.), S. Taniguchi (U. of Osaka)

LCWS2026, KEK Nov. 12th, 2026

Why H-COUP?

Higgs sector as a probe of BSM

- Deviations indirectly tell us information of BSM



Kanemura, Kikuchi, Mawatari, Sakurai, KY (2018)

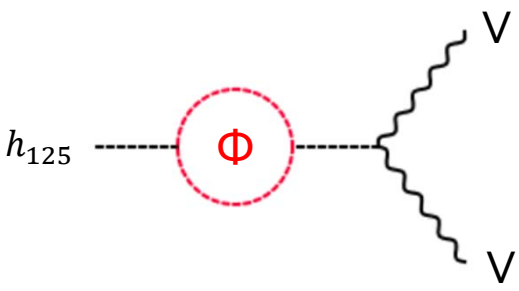
- Pattern of deviations
  → BSM Higgs structure

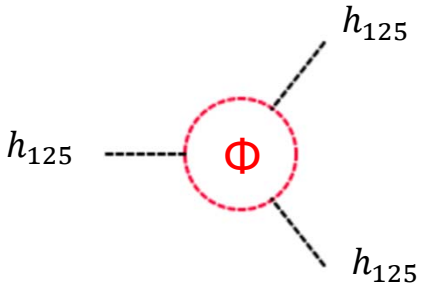
- Size of deviations
  → BSM mass scale

Why Precision Calculations?

- Higgs precise calculations are inevitable.

$$\Delta\kappa_X \equiv \frac{g_{hXX}^{\rm NP}}{g_{hXX}^{\rm SM}} - 1$$





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

$$\Delta\kappa_V \simeq \frac{1}{16\pi^2}\frac{m_\Phi^2}{v^2}\left(1-\frac{M^2}{m_\Phi^2}\right)^2 \underset{M^2/m_\Phi^2 \ll 1}{\sim} \mathcal{O}(1)\%$$

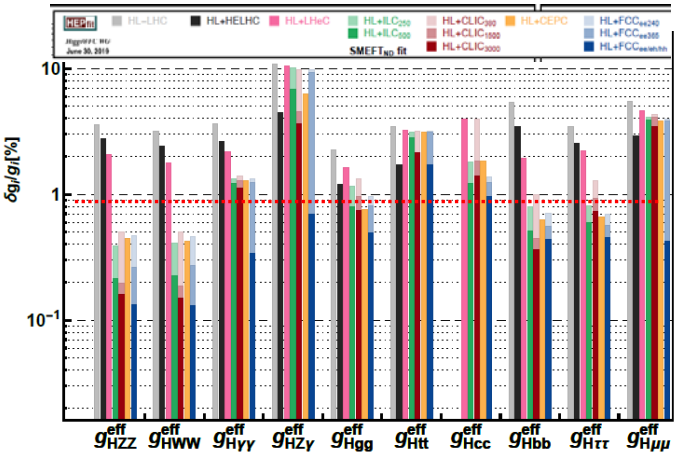
$$\Delta\kappa_h \simeq \frac{1}{16\pi^2}\frac{m_\Phi^4}{v^4}\left(1-\frac{M^2}{m_\Phi^2}\right)^3 \underset{M^2/m_\Phi^2 \ll 1}{\sim} \mathcal{O}(100)\%$$

- Nondecoupling-loop effects lead to sizable deviations even in the Higgs alignment limit.

- Permille level measurements are realized at Higgs factories.

H-COUP realizes such precise calculations!

1905.03764 [hep-ph]



1%

What is H-COUP?

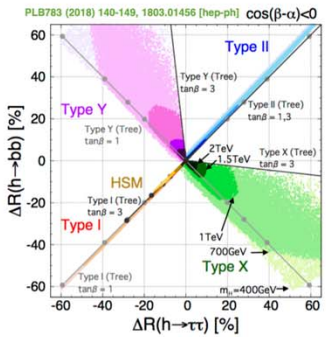
Google H-COUP

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

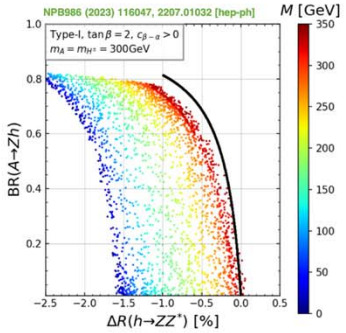
H-COUP is a package of Fortran codes to calculate Higgs observables including radiative corrections in various extended Higgs models.



H-COUP



SM-like Higgs boson
One can study the new physics effects in the SM-like Higgs boson decays with higher-order corrections by using H-COUP. Various extended Higgs models can be distinguished by comparing them on the same footing.



Additional Higgs bosons
H-COUP calculates decay rates of additional Higgs bosons with higher-order corrections. The correlation with the SM-like Higgs boson measurements can be studied.

Downloads

- H-COUP version 3.0 : [HCOUP-3.0.zip] [The manual for H-COUP ver. 3 is here]

H-COUP needs a Fortran compiler (gfortran is recommended) and LoopTools (www.feynarts.de/looptools/).

H-COUP Project

Kanemura, Kikuchi, Sakurai, KY, 1710.04603 (H-COUP v1)
Kanemura, Kikuchi, Sakurai, Mawatari, KY, 1910.12769 (H-COUP v2)
Aiko, Kanemura, Kikuchi, Sakurai, KY, 2311.15892 (H-COUP v3)

2nd simplest models

	h_{125} couplings	h_{125} decays & BRs	H decays & BRs
Higgs singlet model			
2HDMs (Type-I, II, X, Y)			
Inert doublet model			
Complex triplet model			
Real triplet model			
Georgi-Machacek model			

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H-COUP Project

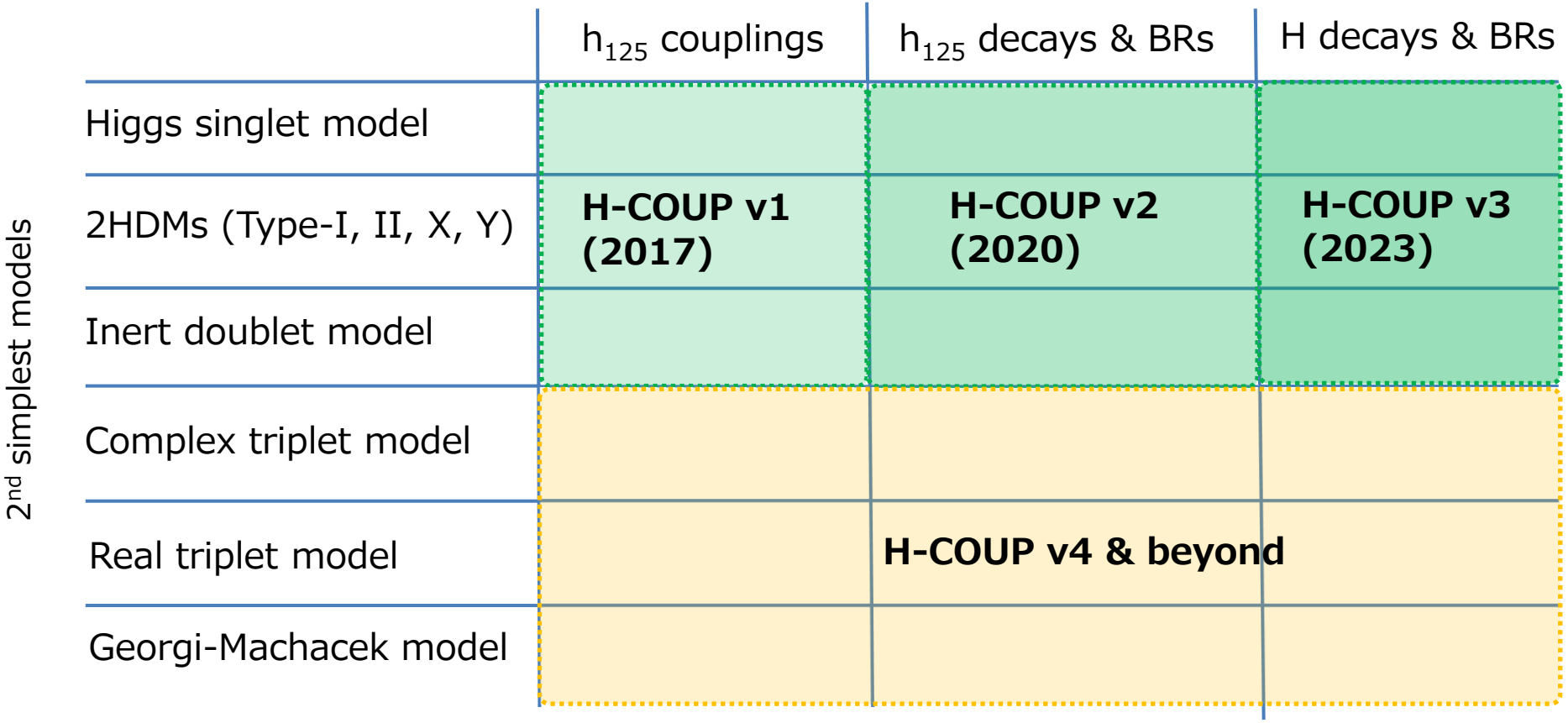
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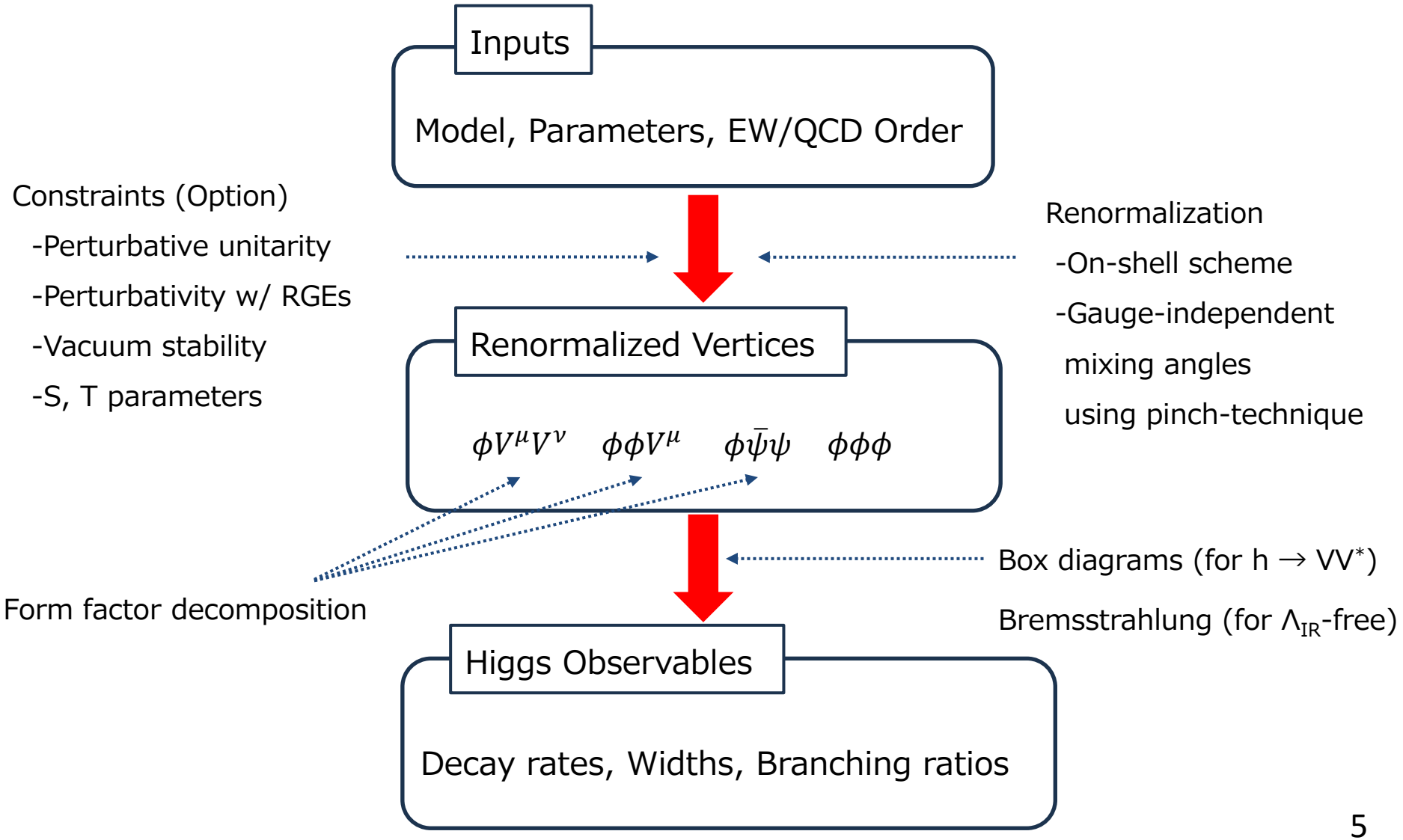
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Structure of H-COUP



Recent Developments

Models with Isospin Triplets

Complex Triplet Model

$$\begin{pmatrix}\phi^+\\ \phi^0\end{pmatrix},\quad \begin{pmatrix}\Delta^{++}\\ \Delta^{+}\\ \Delta^{0}\end{pmatrix}$$

$$\rho_{\text{tree}} \sim 1 - 2\frac{\langle\Delta^0\rangle^2}{\langle\phi^0\rangle^2}$$

$$\kappa_W, \kappa_Z > 1$$

Aoki, Kanemura, Kikuchi, KY, 1211.6029

Aiko, Kanemura, Kikuchi, Sakurai, Taniguchi, KY, 2601.15983

Real Triplet Model

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$$\rho_{\text{tree}} \sim 1 + 2\frac{\langle\xi^0\rangle^2}{\langle\phi^0\rangle^2}$$

$$\kappa_W > 1$$

→ See talk by K. Sakurai (Thu. morning)

Aiko, Kanemura, Kikuchi, Sakurai, Taniguchi, KY, 2611.04857

Georgi-Machacek Model

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Custodial bi-triplet

$$\rho_{\text{tree}} = 1 \quad \text{with } \langle\Delta^0\rangle = \langle\xi^0\rangle$$

$$\kappa_W, \kappa_Z > 1$$

- Alignment w/o decoupling is not possible ($\kappa_V \to 1$ means $M_\Delta \to \infty$)
- 4 EW inputs are required for EW renormalization : $\{\alpha_{\text{em}}, m_Z, G_F, X\}$
  - -Effective weak mixing angle $(\sin\theta_{\text{eff}})$ *Blank, Hollik 9703392 , Kanemura, Yagyu 1201.6287*
  - -Mixing between NG boson & Higgs boson (e.g., A-G^0) *Aoki, Kanemura, Kikuchi, KY 1201.6287*
  - -T parameter *Chiang, Kuo,, KY 1804.02633*

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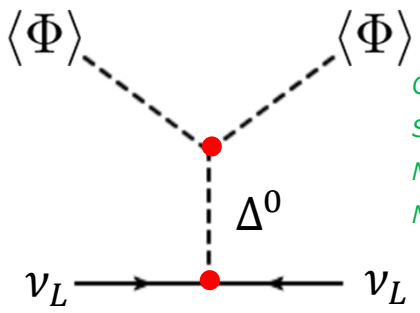
Complex Higgs Triplet Model (CHTM)

- Scalar content $\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}, \quad \Delta = \begin{pmatrix} \Delta^{++} \\ \Delta^+ \\ \Delta^0 \end{pmatrix}$

  ➡ $H^{\pm\pm}$, $H^{\pm}$, H^0, A^0, h_{125}

- Neutrino mass $\quad \mathcal{L} \supset Y_\Delta \, LL\Delta$

  $m_\nu = Y_\Delta \, v_\Delta$



Cheng, Li (1980)
Schechter, Valle (1980)
Maag, Wetterich (1981)
Mohapatra, Senjanovic (1981)

Type-II seesaw mechanism

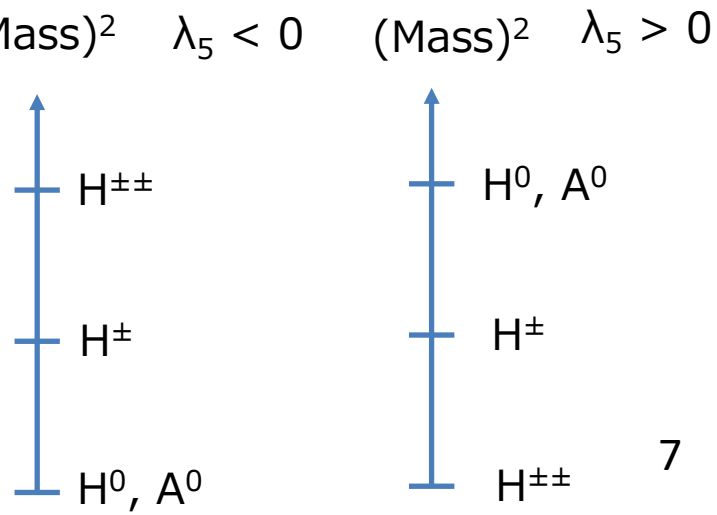
- Parameters $\{m_{H^{\pm\pm}}, m_{H^\pm}, m_A, m_H, m_h, \alpha, v_\Delta, v\}$

  H^0 - h^0 mixing angle

- Mass formulae ($v_\Delta / v \ll 1$)

$$m^2_{H^{\pm\pm}} \simeq m^2_A - \frac{\lambda_5}{2} v^2,$$
$$m^2_{H^\pm} \simeq m^2_A - \frac{\lambda_5}{4} v^2,$$
$$m^2_H \simeq m^2_A$$

$V \supset \lambda_5 \Phi^\dagger (\sigma^a \Delta^a)(\sigma^a \Delta^a)^\dagger \Phi$

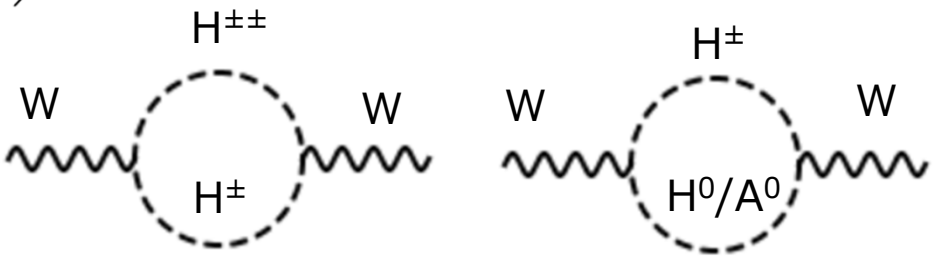


W boson mass

- Renormalized W mass

$$m_W^2 \simeq (m_W^2)_{\rm SM}\left(1-\frac{2v_\Delta^2}{v^2}+\frac{c_W^2}{s_W^2}\Delta\rho\right)$$

$$\Delta\rho \sim \frac{\sqrt{2}G_F}{3\pi^2}(m_{H^\pm}-m_A)^2$$



Tree: m_W ↓, Loop: m_W ↑

- Constraint on the triplet VEV

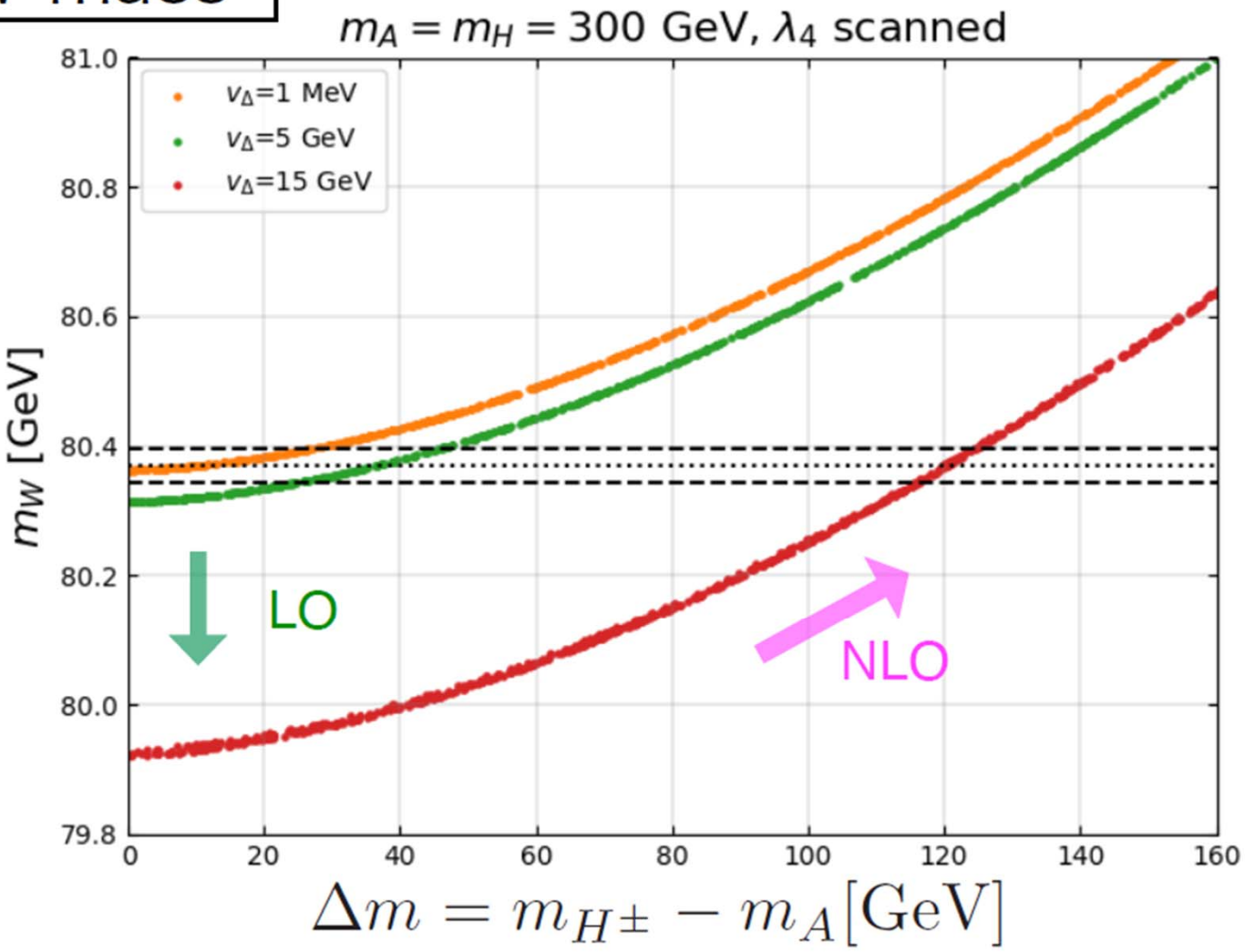
・LO $v_\Delta \lesssim 6.9\ \text{GeV}\ (95\%\ \text{CL})$ $\rho_{\rm exp} = 1.0003 \pm 0.0019$

from STU fit

・NLO Dependent on the mass splitting

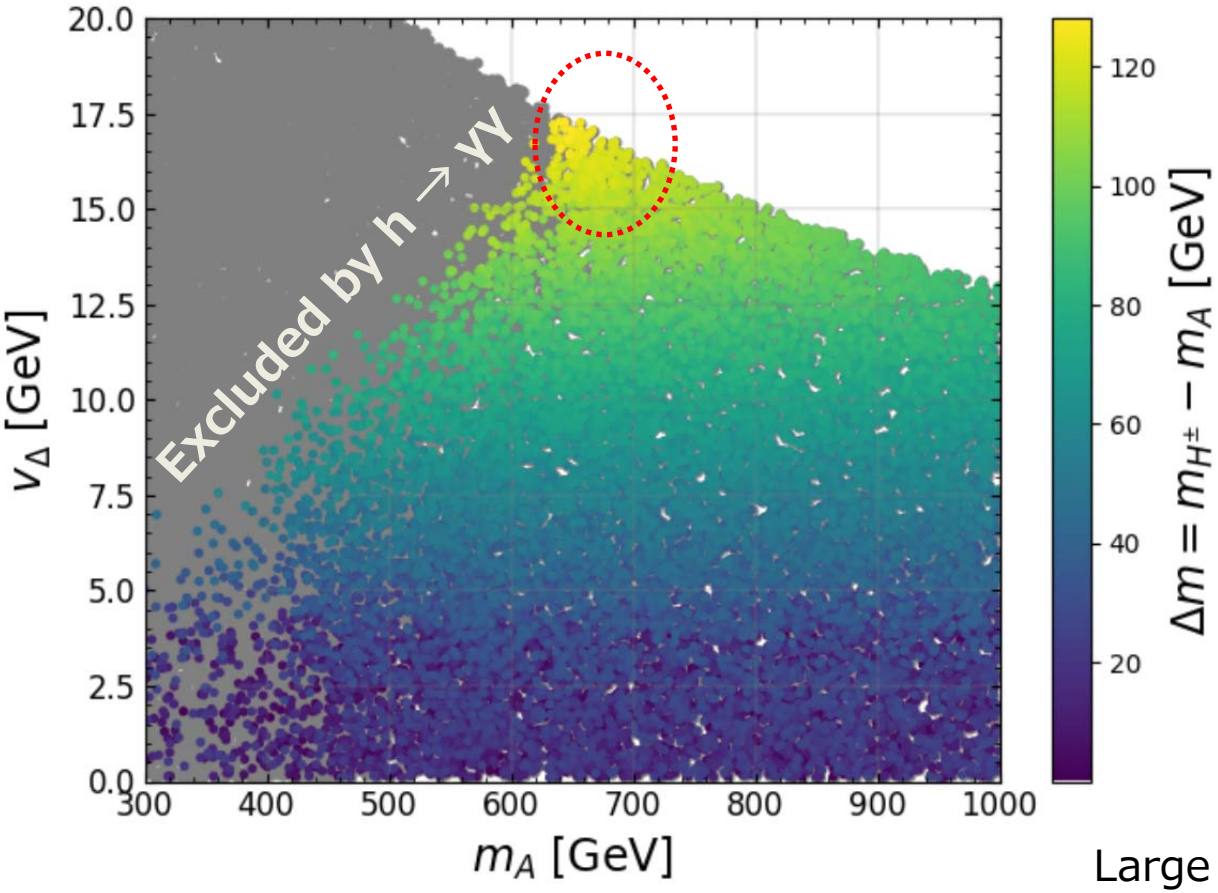
Aiko, Kanemura, Kikuchi, Sakurai, Taniguchi, KY 2601.15983 (JHEP)

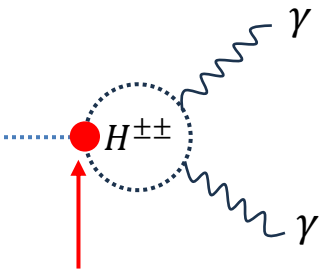
W mass



Large v_Δ is allowed for a large mass difference.

Constraints ($H^{\pm\pm}$ heaviest case)





$\lambda_{H^{++}H^{--}h} \lesssim -\frac{4\Delta m^2}{v}$

Vacuum stability

m_W

Large v_Δ → Large Δm → Large $|\Delta\kappa_\gamma|$

$$v_\Delta \lesssim 17.5\ \text{GeV}$$

h → ZZ* vs h → τ τ

$$\Delta R(h \to XX) = \frac{\Gamma_{h\to XX}}{\Gamma^{\rm SM}_{h\to XX}} - 1$$

Aiko, Kanemura, Kikuchi, Sakurai, Taniguchi, KY 2601.15983 (JHEP)

CHTM ($H^{\pm\pm}$ heaviest)

300 GeV ≤ m_A ≤ 1 TeV, 0 ≤ Δm ≤ 150 GeV, 0 < λ_4 < 4π

$\Delta m = m_{H\pm} - m_A$

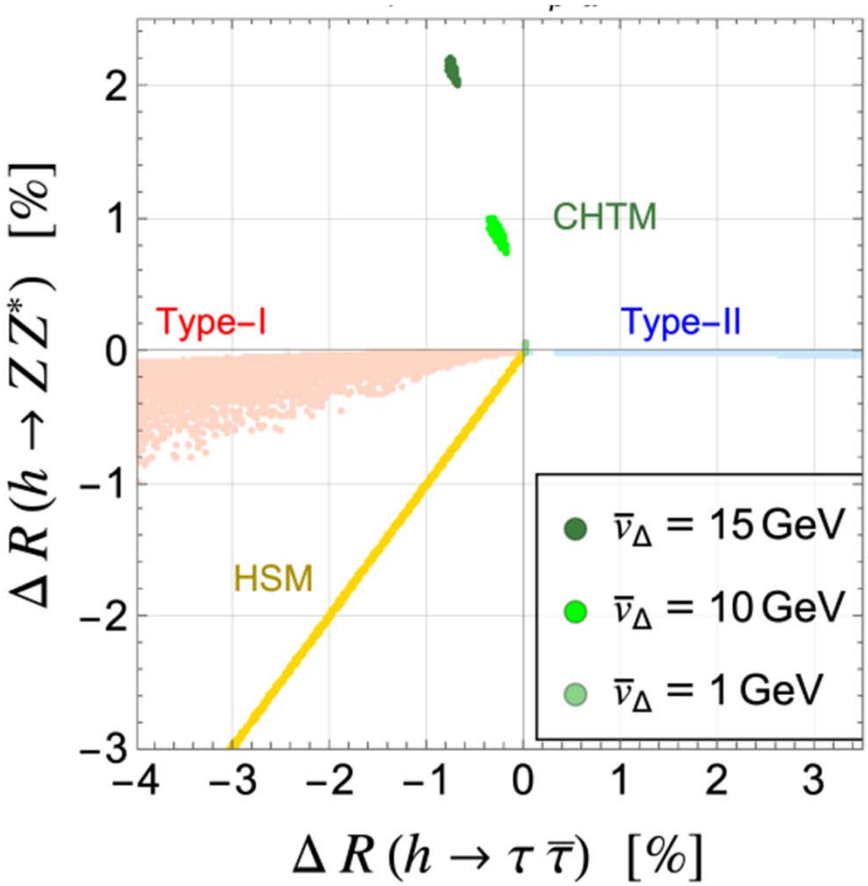
2HDM: 0.99 ≤ sin(β-α) ≤ 1, cos(β-α)<0, 1.5 ≤ tanβ ≤ 10, 0 ≤ M ≤ m_H + 500 GeV,

400 GeV ≤ m_H ≤ 1 TeV (Type-I), 800 GeV ≤ m_H ≤ 1 TeV (Type-II)

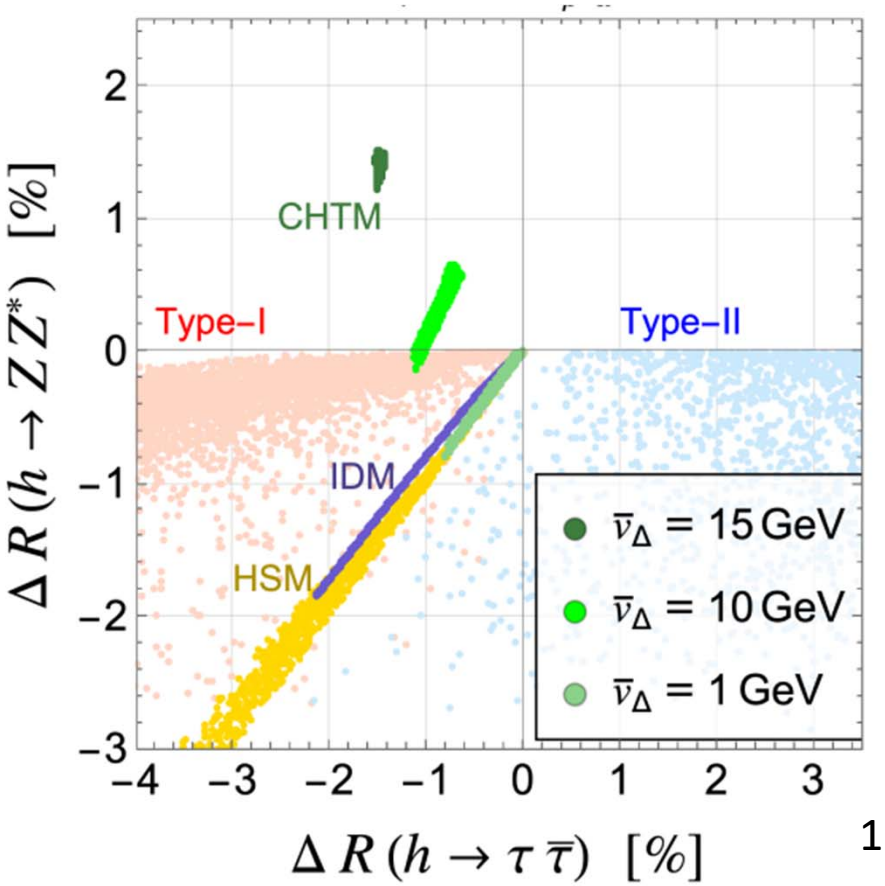
HSM: 0.95 ≤ cosα ≤ 1, 0 m_s ≤ m_H + 500 GeV, 400 GeV ≤ m_H ≤ 1 TeV

IDM: 100 GeV < $m_{H\pm}$ < 1 TeV, m_H = 60 GeV (DM), $m_A = m_{H\pm}$, μ_2^2 = 3581 GeV²

LO



NLO



h → ZZ* vs h → γγ

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Aiko, Kanemura, Kikuchi, Sakurai, Taniguchi, KY 2601.15983 (JHEP)

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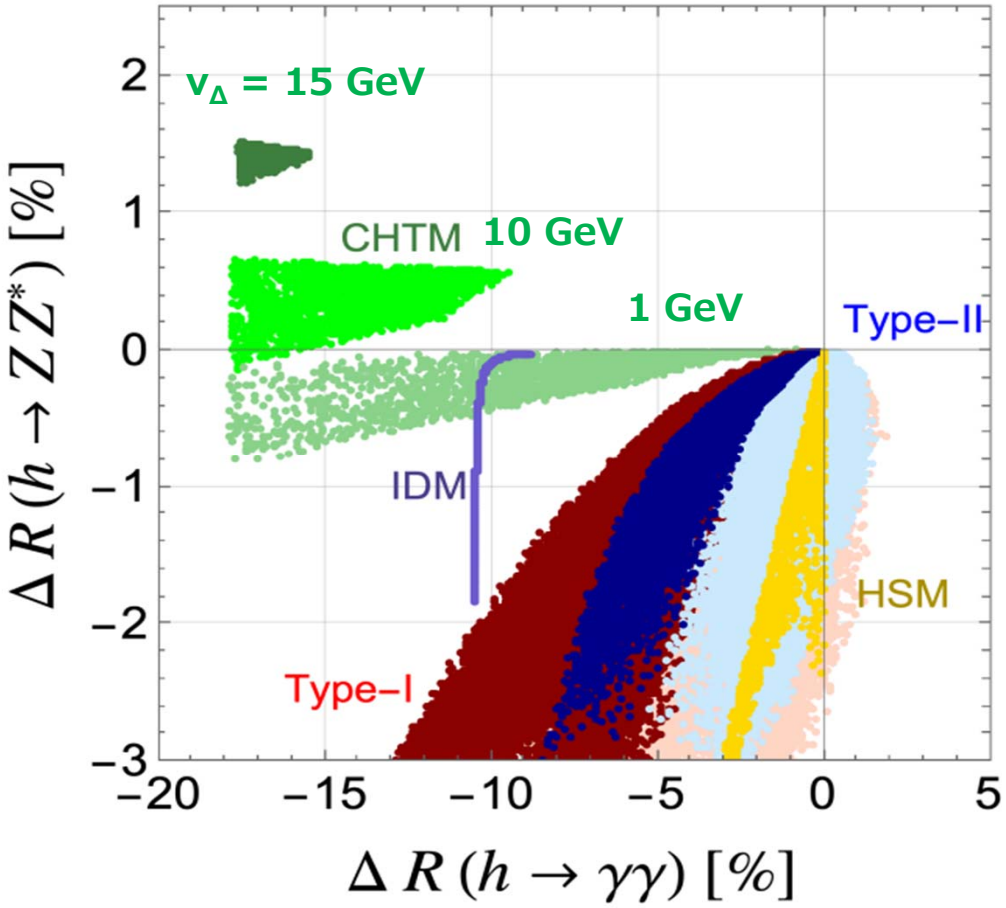
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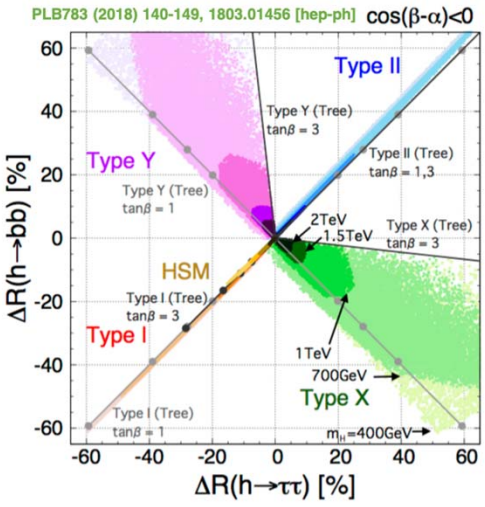


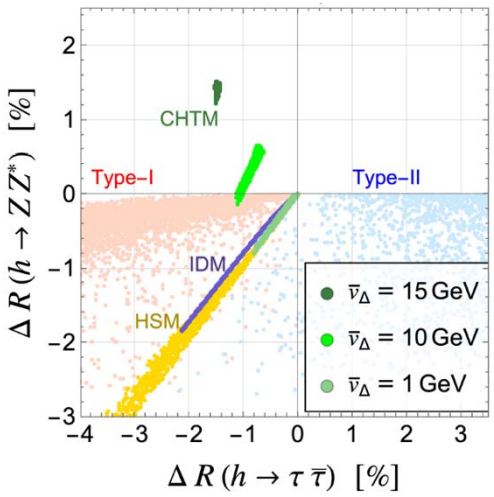
h → ZZ* : NLO

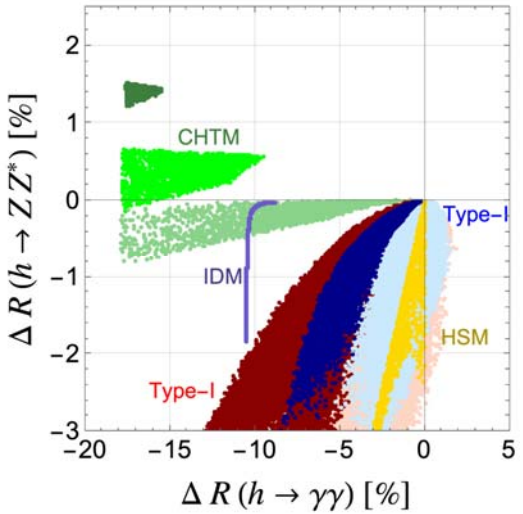
h → γγ : LO

Summary

- Why H-COUP → To compare future Higgs precise measurements
  To extract BSM Higgs structure & BSM mass scale
- What is H-COUP → Higgs observables computed at one-loop level in various extended Higgs sectors.
- Recent developments toward Ver. 4
  → Implementing CHTM and RHTM (see talk by Sakurai).

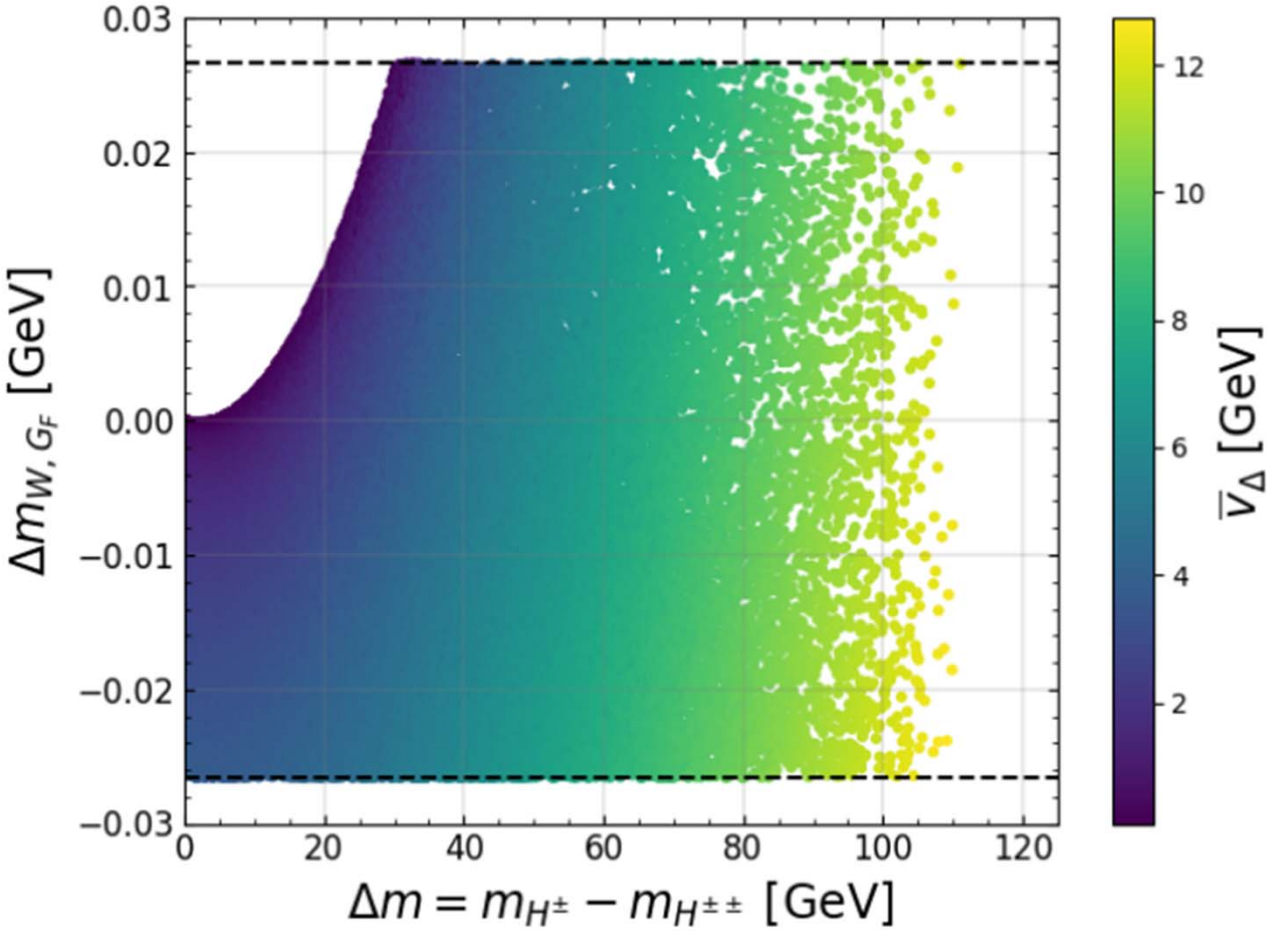




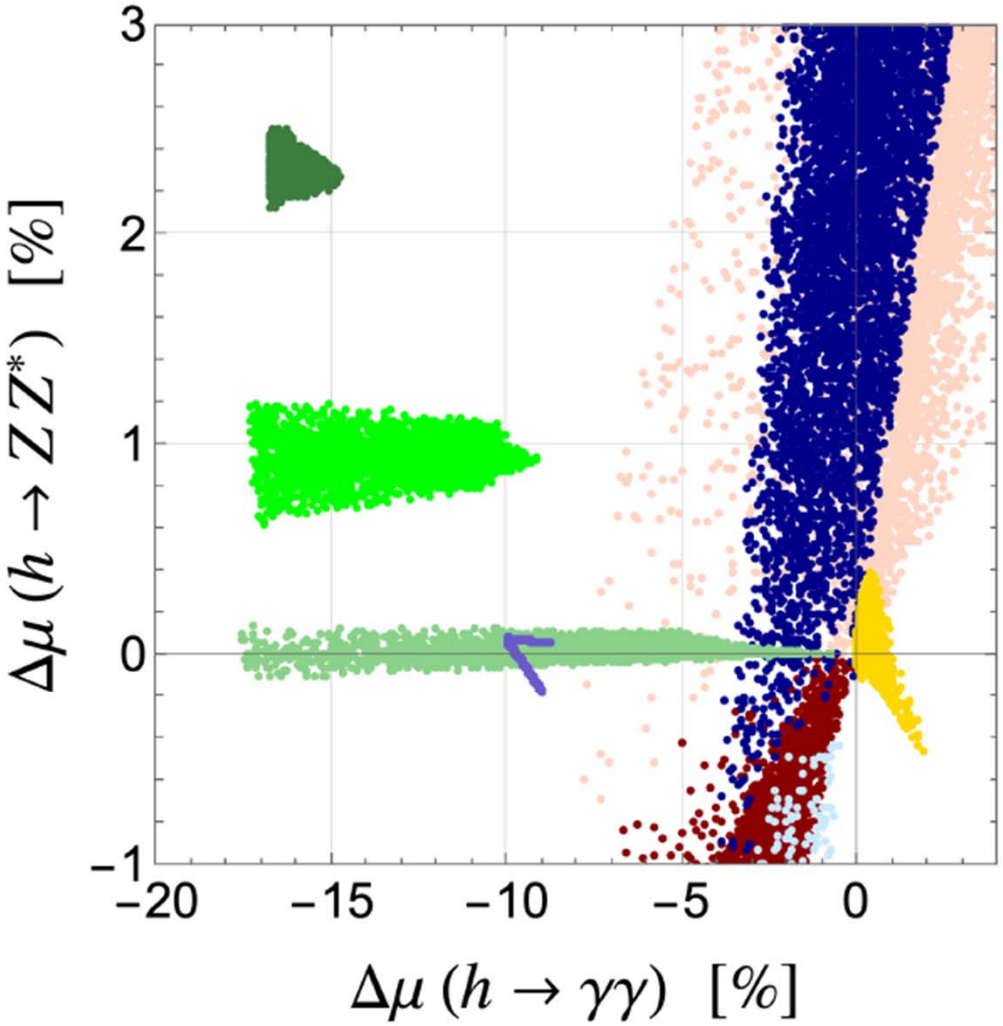


Backup

Constraints ($H^{\pm\pm}$ lightest case)



Ratio of the BRs ($H^{\pm\pm}$ heaviest case)

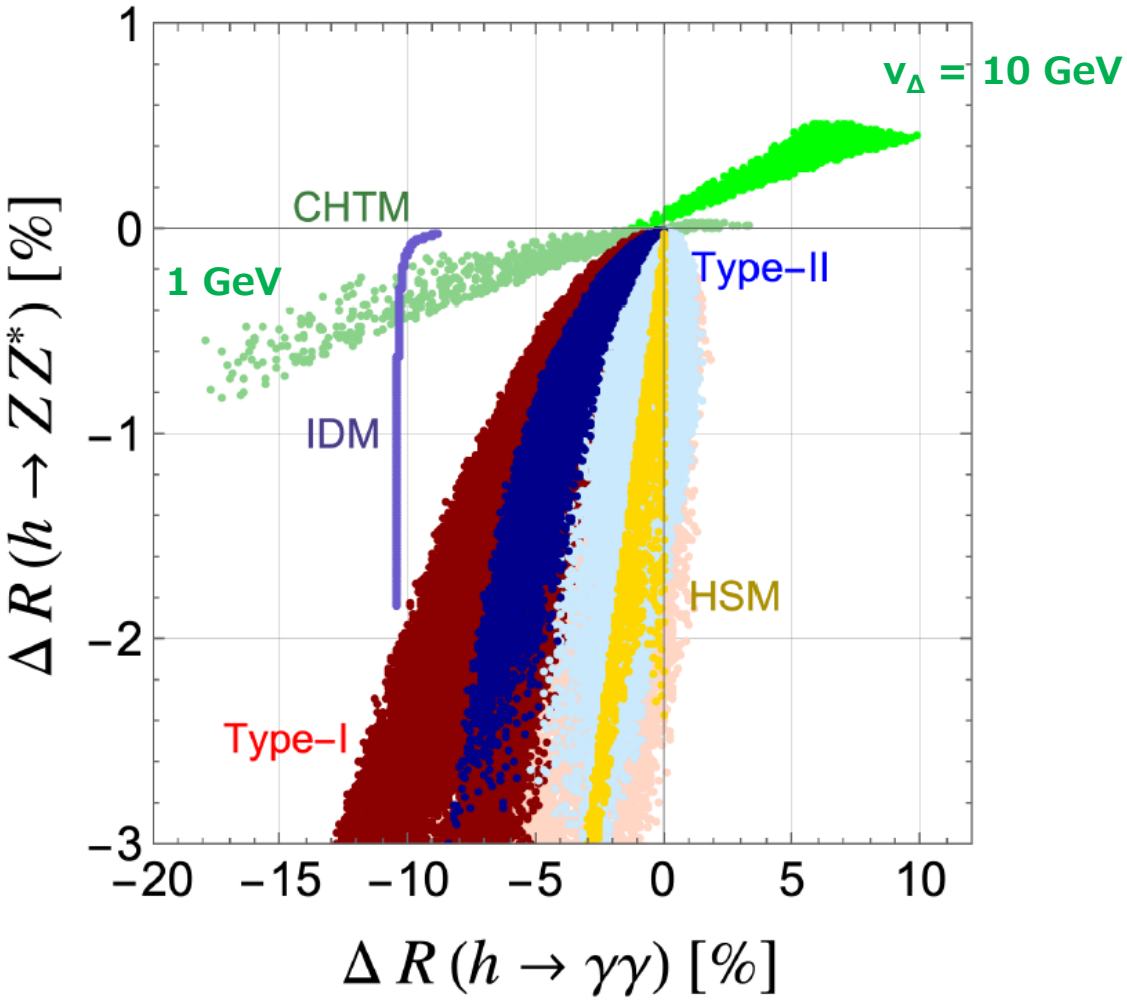


$$\Delta\mu(h \to XX) = \frac{\mathrm{BR}(h \to XX)^{\mathrm{NP}}}{\mathrm{BR}(h \to XX)^{\mathrm{SM}}} - 1$$

Lightest $H^{\pm\pm}$ case

Aiko, Kanemura, Kikuchi, Sakurai, Taniguchi, KY 2601.15983 (JHEP)

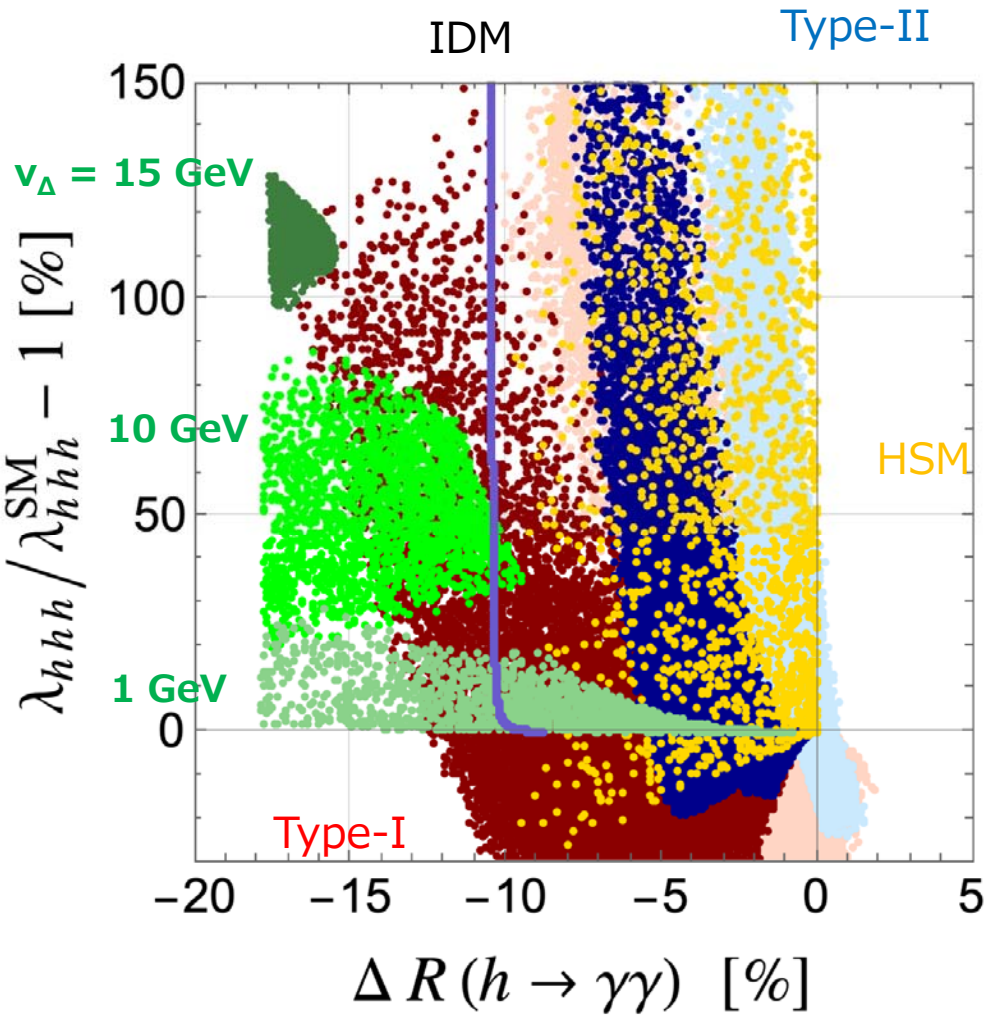
LS: $400\ \text{GeV} \leq m_{H^{\pm\pm}} \leq 1000\ \text{GeV},\ -5 \leq \bar{\lambda}_4 \leq 4\pi,\ 0 \leq \Delta m \leq 150\ \text{GeV},$



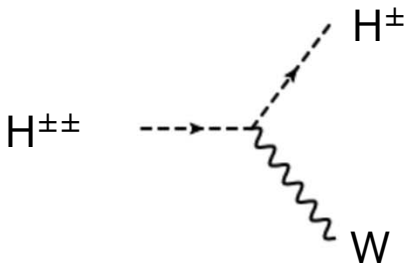
hhh vs h → γγ

Aiko, Kanemura, Kikuchi, Sakurai, Taniguchi, KY 2601.15983 (JHEP)

hhh (NLO), h → γγ (LO), $H^{\pm\pm}$ heaviest

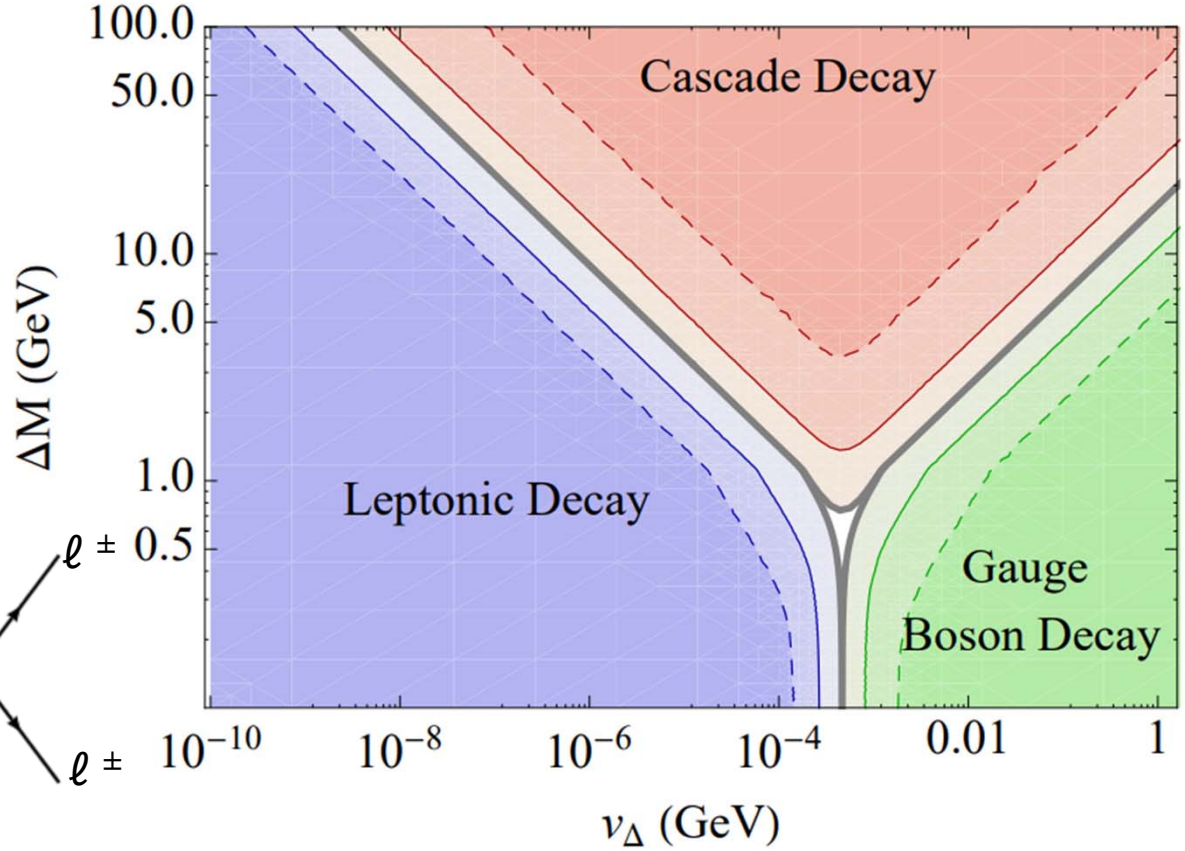


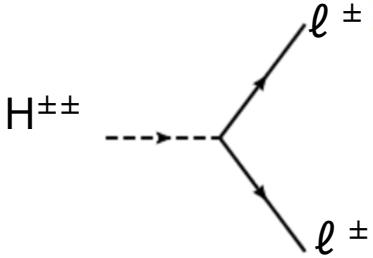
Scenarios

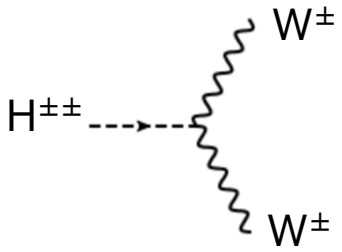


$$\Delta M = m_{H^{\pm\pm}} - m_{H^{\pm}}$$

Melfo, Nemevsek, Nesti, Senjanovic, Zhang (1108.4416; PRD)

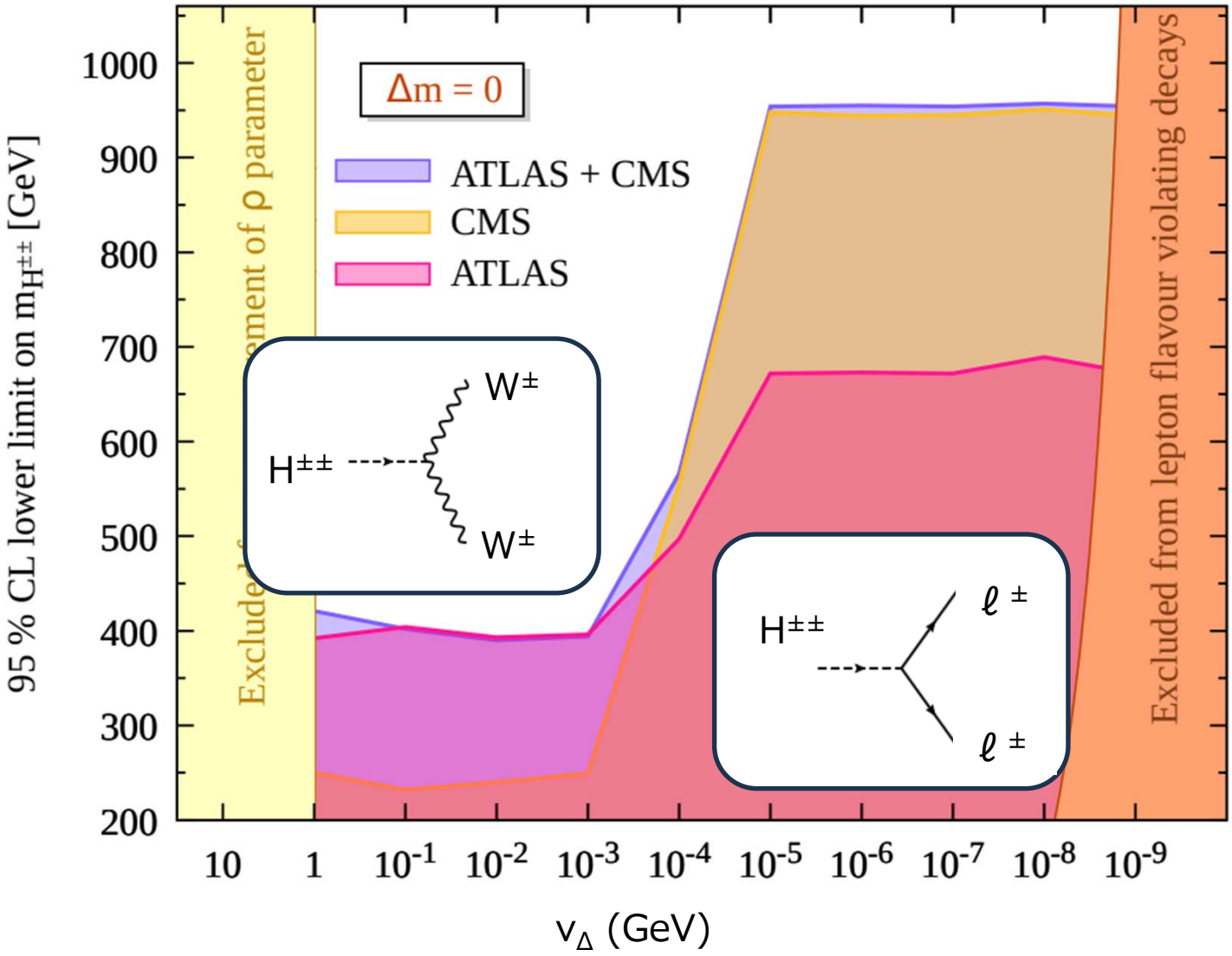




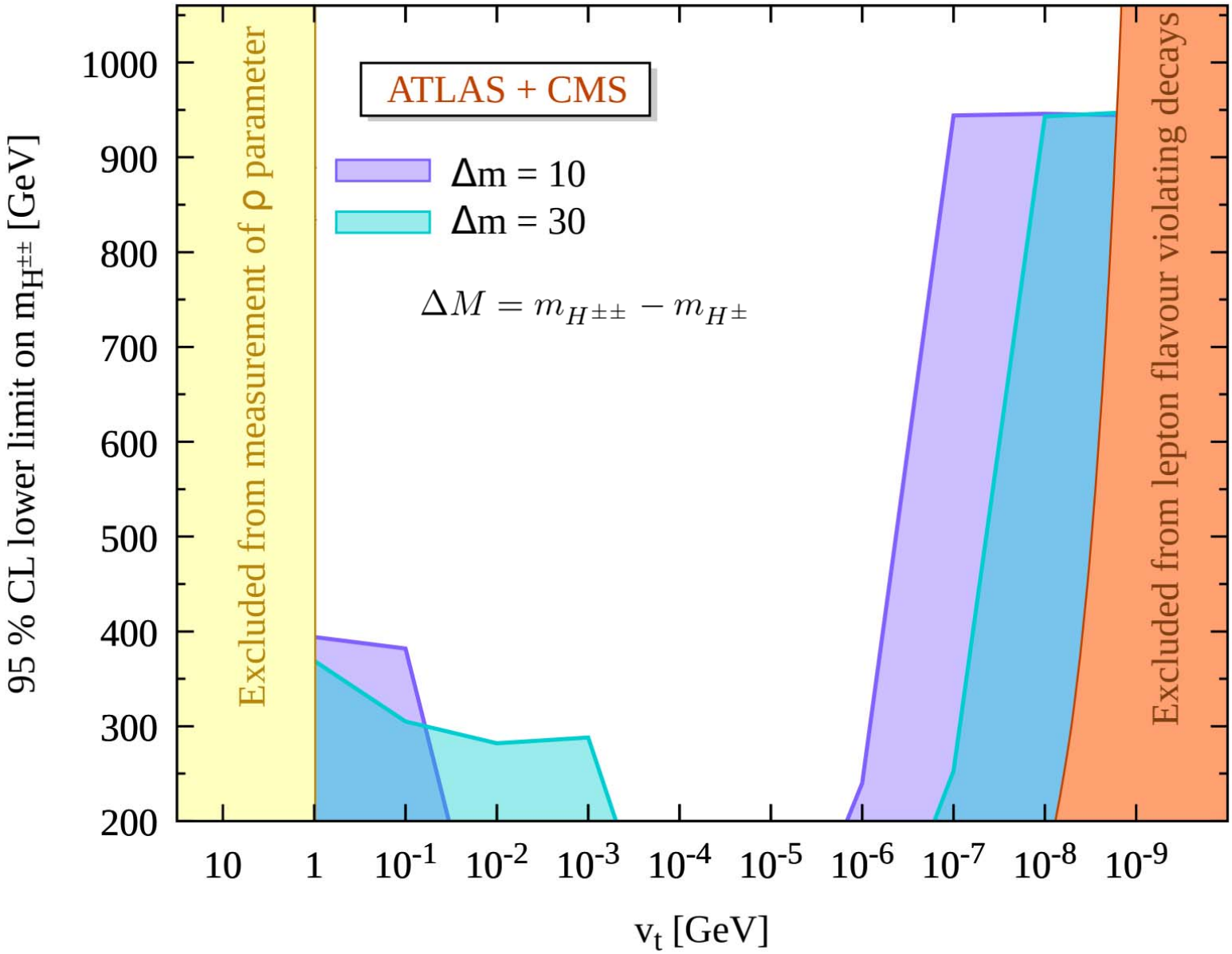


Scenarios

Ashanujjaman, Ghosh (2108.10952; JHEP)



Ashanujjaman, Ghosh (2108.10952; JHEP)



Higgs potential

- Most general Higgs potential

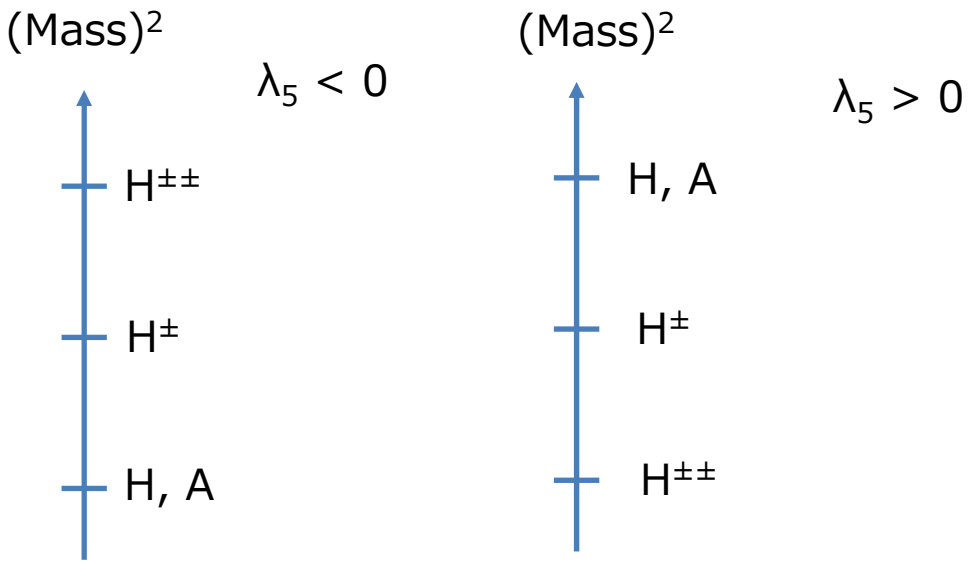
$$V(\Phi,\Delta) = m^2\Phi^\dagger\Phi + M^2(\Delta^\dagger\Delta) + [\mu\Phi^T i\sigma_2\Delta^\dagger\Phi + \text{h.c.}]$$
$$+ \lambda_1(\Phi^\dagger\Phi)^2 + \lambda_2[(\Delta^\dagger\Delta)]^2 + \lambda_3[(\Delta^\dagger\Delta)^2] + \lambda_4(\Phi^\dagger\Phi)(\Delta^\dagger\Delta) + \lambda_5\Phi^\dagger\Delta\Delta^\dagger\Phi$$

8 parameters

$$\Big\{m_{H^{\pm\pm}}, m_{H^\pm}, m_A, m_H, m_h, \alpha, \beta'(\beta), v\Big\}$$

- Mass formulae (@ $v_\Delta/v \ll 1$)

$$m^2_{H^{\pm\pm}} \simeq m^2_A - \frac{\lambda_5}{2}v^2,$$
$$m^2_{H^\pm} \simeq m^2_A - \frac{\lambda_5}{4}v^2,$$
$$m^2_H \simeq m^2_A$$



- Decoupling limit

$$m^2_A \simeq M^2 \simeq \frac{\mu v^2_\phi}{\sqrt{2}v_\Delta}$$

$M^2 \to \infty$ ($v_\Delta \to 0$)

Complex Higgs Triplet Model (CHTM)

- Scalar content $\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}, \quad \Delta = \begin{pmatrix} \frac{\delta^+}{\sqrt{2}} & \delta^{++} \\ \delta^0 & -\frac{\delta^+}{\sqrt{2}} \end{pmatrix}$

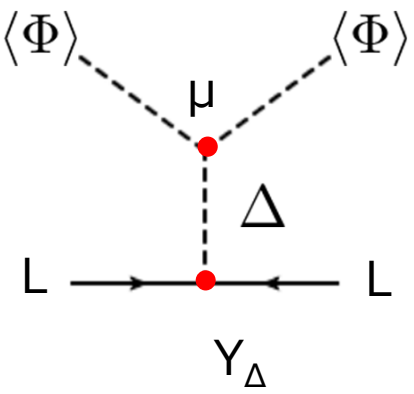
$$\begin{pmatrix} \phi^\pm \\ \delta^\pm \end{pmatrix} = \begin{pmatrix} c_\beta & -s_\beta \\ s_\beta & c_\beta \end{pmatrix} \begin{pmatrix} G^\pm \\ H^\pm \end{pmatrix}, \quad \begin{pmatrix} \mathrm{Im}\,\phi^0 \\ \mathrm{Im}\,\delta^0 \end{pmatrix} = \begin{pmatrix} c_{\beta'} & -s_{\beta'} \\ s_{\beta'} & c_{\beta'} \end{pmatrix} \begin{pmatrix} G^0 \\ A \end{pmatrix}$$
$$\begin{pmatrix} \mathrm{Re}\,\phi^0 \\ \mathrm{Re}\,\delta^0 \end{pmatrix} = \begin{pmatrix} c_\alpha & -s_\alpha \\ s_\alpha & c_\alpha \end{pmatrix} \begin{pmatrix} h \\ H \end{pmatrix}$$
$$\tan\beta = \frac{\sqrt{2}v_\Delta}{v_\phi}, \quad \tan\beta' = \frac{2v_\Delta}{v_\phi}$$

➡ $H^{\pm\pm}$, $H^\pm$, H^0, A^0, h_{125}

- Type-II seesaw mechanism

Cheng, Li (1980)
Schechter, Valle (1980)
Maag, Wetterich (1981)
Mohapatra, Senjanovic (1981)

$$\mathcal{L}_{\mathrm{CHTM}} \supset -Y_\Delta \overline{L}_L \cdot \Delta L_L - \mu \Phi^\dagger \cdot \Delta \Phi + \mathrm{h.c.}$$



$$m_\nu \sim Y_\Delta v_\Delta$$

- ρ parameter

$$\rho_{\mathrm{tree}} = \frac{m_W^2}{m_Z^2 \cos^2\theta_W} = \frac{v_\phi^2 + 2v_\Delta^2}{v_\phi^2 + 4v_\Delta^2} \simeq 1 - \frac{2v_\Delta^2}{v^2}$$

$$v_\Delta \lesssim 6.9\ \mathrm{GeV}\ (95\%\ \mathrm{CL})$$

- hVV couplings

$$\kappa_W = c_\beta c_\alpha + \sqrt{2} s_\beta s_\alpha \qquad \kappa_Z = \frac{c_{\beta'} c_\alpha + 2 s_{\beta'} s_\alpha}{\sqrt{1 + s_\beta^2}}$$

➡ $\kappa_{W,Z} \gtrsim 1$

Reno. of the potential parameters

Aoki, Kanemura, Kikuchi, KY (1211.6029; PRD)

- We apply the on-shell scheme.
  - 8 (13) CTs from potential parameter (wavefunction) shift.
  - 20 on-shell conditions + 1 EW condition for the VEV.

$$\hat{\Pi}_{\varphi\varphi}(p^2 = m_\varphi^2) = 0 \quad (\varphi = H^{\pm\pm}, H^\pm, H, A, h) \Rightarrow \text{5 conditions}$$

$$\frac{d}{dp^2}\hat{\Pi}_{\phi\phi}(p^2)\Big|_{p^2=m_\phi^2} = 0 \quad (\phi = H^{\pm\pm}, H^\pm, H, A, h, G^\pm, G^0) \Rightarrow \text{7 conditions}$$

$$\hat{\Pi}_{\phi\phi'}(p^2 = m_\phi^2) = \hat{\Pi}_{\phi\phi'}(p^2 = m_{\phi'}^2) = 0 \quad (\phi\phi' = G^\pm H^\pm, G^0 A, hH) \Rightarrow \text{5 conditions}$$

$$\text{w/o } \hat{\Pi}_{G^\pm H^\pm}(m_{H^\pm}^2) = 0$$

$$(\delta R + \delta Z)^\dagger = \delta R + \delta Z \Rightarrow \text{3 conditions}$$

Denner, Sack (1990)

Kanemura, Okada, Seaha, Yuan (0408364; PRD)

- Pinch technique applied to δα, δβ′

  (to remove gauge dependence)

Cornwall (1990)

Papavassiliou (1994)

Krause, Lorenz, Muhlleitner, Santos, Ziesche (1605.04853; JHEP)

Aoki, Kanemura, Kikuchi, Sakurai, KY (1705.05399; PRD)