Investigating new physics effects by loop corrected decays of the heavier CP-even Higgs boson

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arXiv:2203.08337 [hep-ph]

Introduction

- Clear evidence of New physics [DM, Neutrino mass, BAU, …]

- One of the important candidates is “Extended Higgs sector”.

  - There is no principle to require the minimal Higgs sector (the SM one).
  - In new physics models, the Higgs sector is often extended.

- Structure of Higgs sector is determined by new physics scenarios.

$\Rightarrow$ To clarify the structure of the Higgs sector is important in order to determine the direction of new physics

How to test extended Higgs sector

Various extended Higgs models

Φ+S(singlet), Φ+Φ, Φ+Δ(triplet), …

- **Additional Higgs bosons**

  H, A, $H^{\pm}$, $H^{\pm\pm}$, …

  ⇒ Direct searches at colliders (LHC, HL-LHC, ILC, CEPC, …)

- ***h_{125}*-couplings deviate via mixing effects**

  $\lambda_{hXX} = \kappa_X \lambda_{hXX}^{SM}$

  EX. *hWW (hZZ)*

  THDM(Φ+Φ) $\kappa_V = \sin(\beta - \alpha)$

  ⇒ Indirect tests by future precision measurements

Numerical program for determining Higgs Sector

H-COUP [éɪtʃ-kúː] *Aiko, Kanemura, MK, Mawatari, Sakurai, Yagyu*

Various observables
Couplings, BR, Γ, σ, …
h→VV, h→ff, h→γγ, …

Including radiative corr.

SM
HSM (Φ+S)
THDMs ($\Phi_1+\Phi_2$)
(Type-I, II, X, Y)
IDM (Φ+η)

Model Variations

×

Future precision data

HL-LHC,
ILC, CEPC, CLIC, …

the Higgs sector

【Other public tools】
2HDECAY : [M. Krause, M. Mühlleitner, M. Spira]
Prophecy4f : [A. Denner, S. Dittmaier, A. Mück]
sHDECAY : [R. Costa, M. Mühlleitner, M. Sampaio, R. Santos]

Done : Calculations of decays of ***h(125)***.
Next step : Calculations for decays of additional Higgs bosons ***(H, A, $H^{\pm}$)***

In this talk, we show new results of decays of H including loop corrections in THDM.

A, $H^{\pm}$ decays are discussed in Aiko-san's talk.

Two Higgs doublet model

THDM
- ∗ Softly broken Z_2 syms.
- ∗ CP conserving
- ∗ Mass eigenstates : h_{125}, H, A, $H^{\pm}$
- ∗ Parameters : m_H m_A m_{H+} α β M^2

■ Higgs Alignment

$\sin(\beta-\alpha) = \kappa_V \rightarrow 1$ ・・・ (Higgs) alignment limit
[Couplings of h are aligned to those of SM.]

LHC data indicate nearly-alignment "$\sin(\beta-\alpha) \simeq 1$".

■ Couplings of additional CP-even Higgs (H)

Couplings with SM particles

HWW, HZZ

$$\kappa_V^H = \frac{g_{HVV}^{NP}}{g_{hVV}^{SM}} = \cos(\beta-\alpha) \rightarrow 0$$

Higgs alignment limit

Hff

Type-I THDM

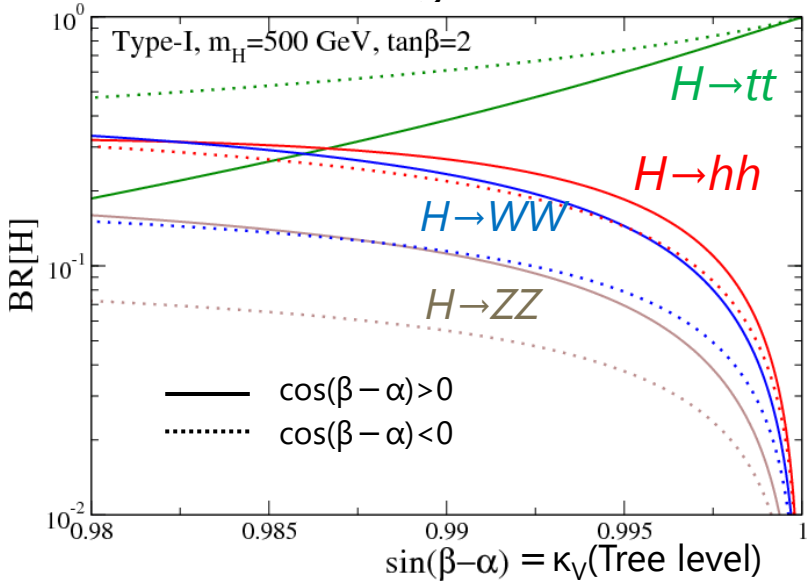
$$\kappa_f^H = \cos(\beta-\alpha) - \cot\beta \sin(\beta-\alpha) \rightarrow -\cot\beta$$

Hhh

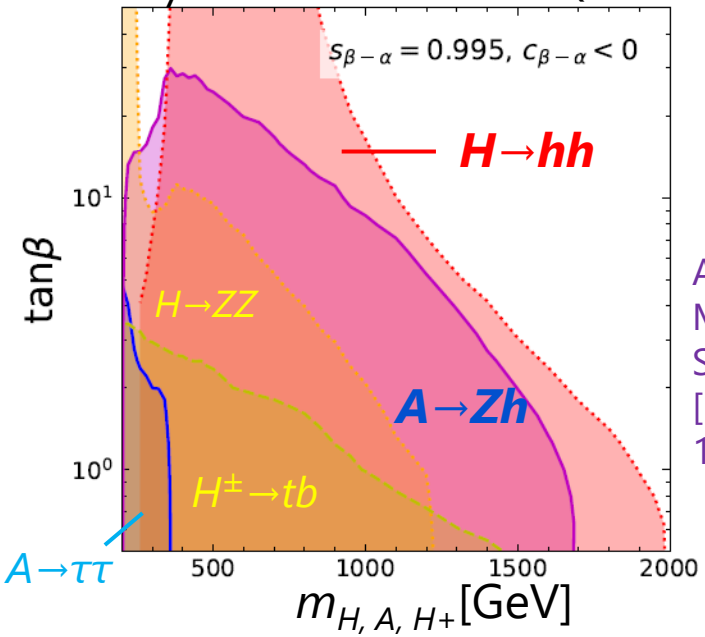
$$\lambda_{Hhh} = -\frac{\cos(\beta-\alpha)}{2v\sin 2\beta}\left\{(2m_h^2 + m_H^2 - 3M^2)\sin 2\alpha + M^2 \sin 2\beta\right\} \rightarrow 0$$

Decay modes in nearly-alignment

Branching ratio of H



Excluded region via heavy Higgs decay mode at HL-LHC (95%CL)



Aiko, Kanemura, MK, Mawatari, Sakurai, Yagyu [NPB966(2021) 115375]

From tree level analyses

- Slight variation in mixing parameters can significantly change BR[H].
- Wide parameter region is expected to be surveyed by "Higgs to Higgs decays" such as $H\to hh$ and $A\to Zh$.

To do

- Radiative corrections to both the discovered Higgs boson couplings and the decay BRs of additional Higgs bosons

We show the results for decays of H *with* $h\to WW^*$, hhh

Calculations of loop corrections

We calculate the full set of BRs of *H* with EW, scalar and QCD corrections.

- Numerical results

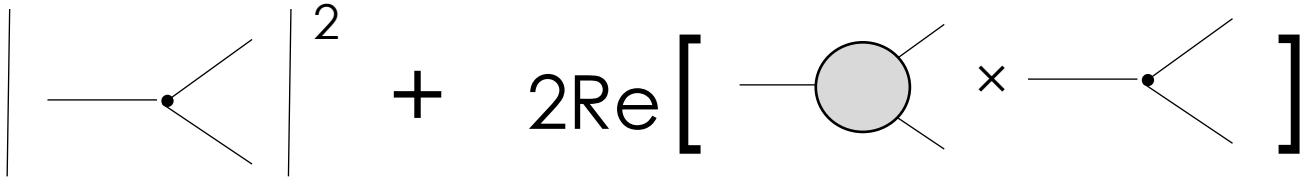
BR[$H \to hh$]

$$\Delta\mu_{WW} \equiv \frac{\mathrm{BR}^{\mathrm{NLO}}_{\mathrm{THDM}}[h \to WW^*]}{\mathrm{BR}^{\mathrm{NLO}}_{\mathrm{SM}}[h \to WW^*]} - 1$$

$$\Delta\lambda_{hhh} = \frac{\lambda^{THDM}_{hhh}}{\lambda^{sm}_{hhh}} - 1$$

- EW and scalar-NLO (Decay rate)

$\Gamma_{\mathrm{NLO}}[H \to XX]$ =



Calculations of loop diagrams

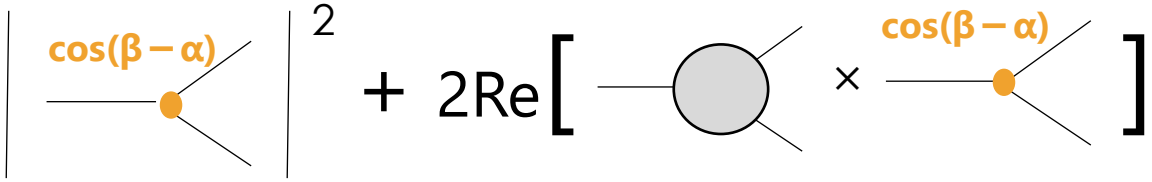
★UV divergence → On-shell renormalizations

★Gauge dependence → Pinch technique

- QCD corrections (for $H \to qq$, $H \to gg$, $H \to \gamma\gamma$, $H \to \gamma Z$)

MS-bar scheme（NNLO）

Loop corrections to Γ[$H \to hh$]

$\Gamma_{NLO}[H \to hh] =$ 

In nearly-alignment, cos(β − α) becomes the suppression factor

⇒ 1-loop contributions can be as large as Tree-level contribution.

★ cos(β-α)

cos(β-α) > 0 ・・・increase, cos(β-α) < 0 ・・・decrease

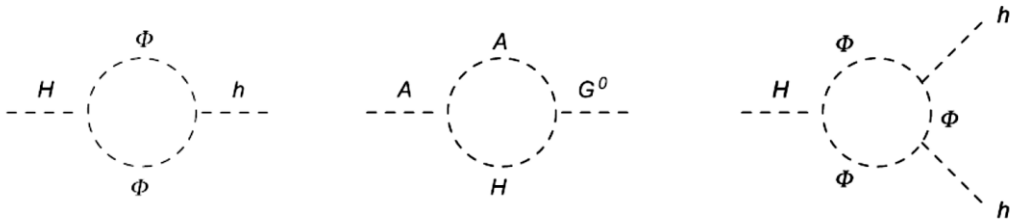
★ Decoupling? Or Non-decoupling?

$m_\Phi{}^2 \cong \lambda' v^2 + M^2$ Scalar self couplings ($\Phi = H^\pm, A, H$)

$M^2 \gg \lambda' v^2$ ・・・ Decoupling

$M^2 \simeq \lambda' v^2$ ・・・ Non-decoupling

Important bosonic loop diagrams



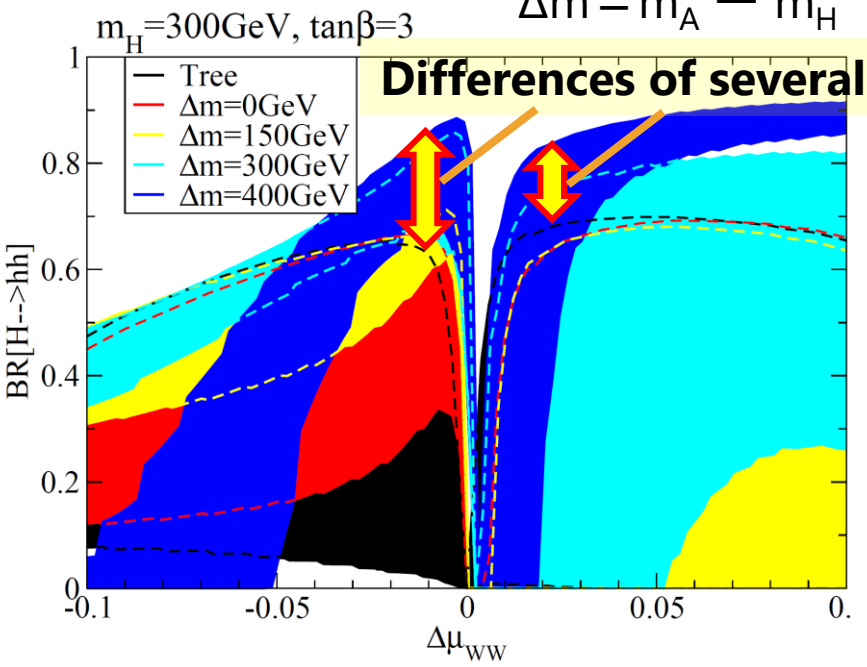
Correlation between $H \to hh$ and $h \to WW$

$$\Delta\mu_{WW} \equiv \frac{\mathrm{BR}^{\mathrm{NLO}}_{\mathrm{THDM}}[h \to WW^*]}{\mathrm{BR}^{\mathrm{NLO}}_{\mathrm{SM}}[h \to WW^*]} - 1$$

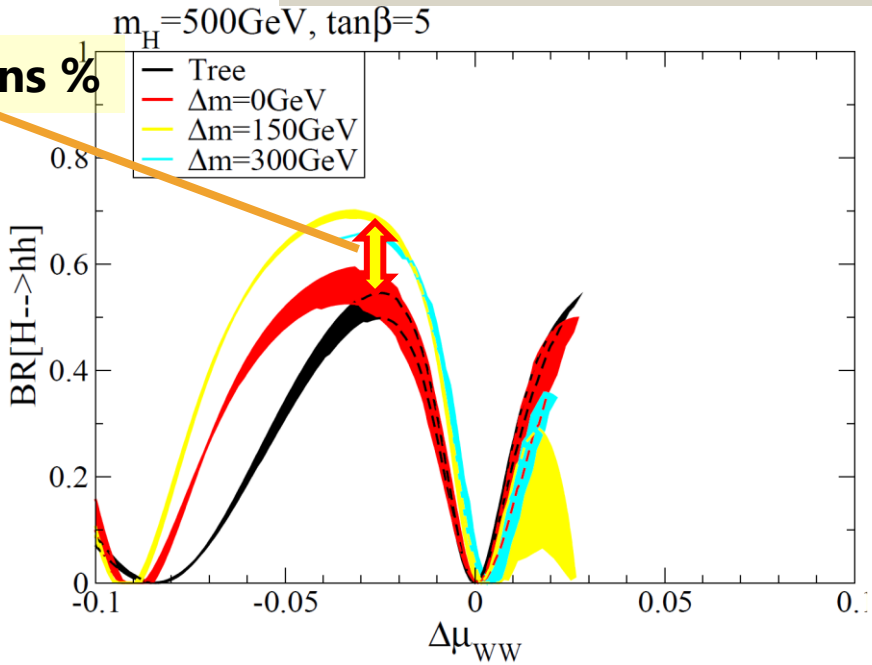
Current error-bar at CMS(1σ)
$\Delta\mu_{WW} = 0\ ^{+0.14}_{-0.13}$
Expected accuracy (ILC250)
BR($h \to WW^*$) : 0.019

Type-I THDM

$\Delta m = m_A - m_H$



Differences of several tens %



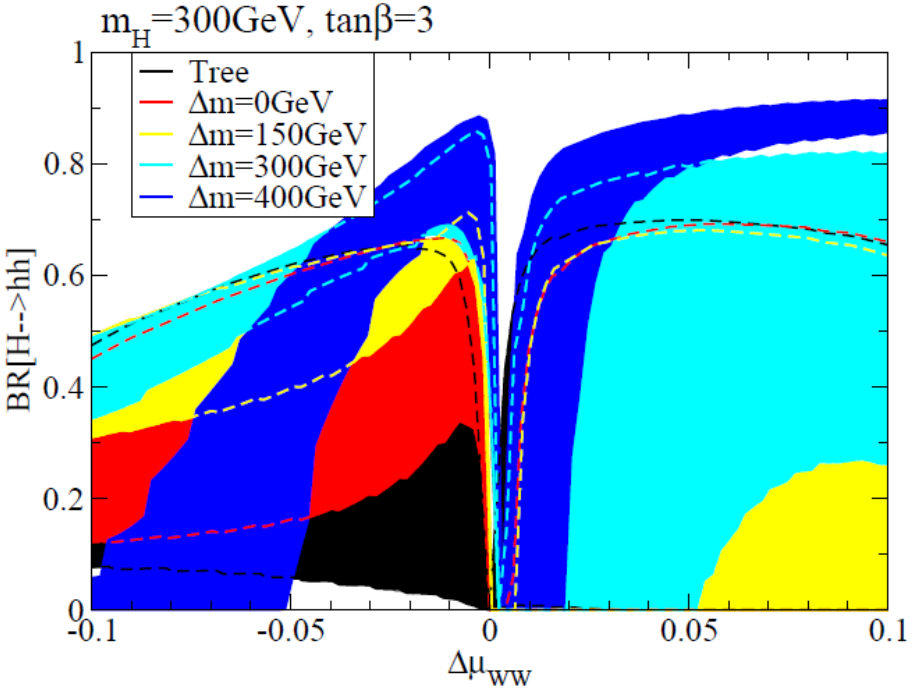
Kanemura, MK, Yagyu[2203.08337]

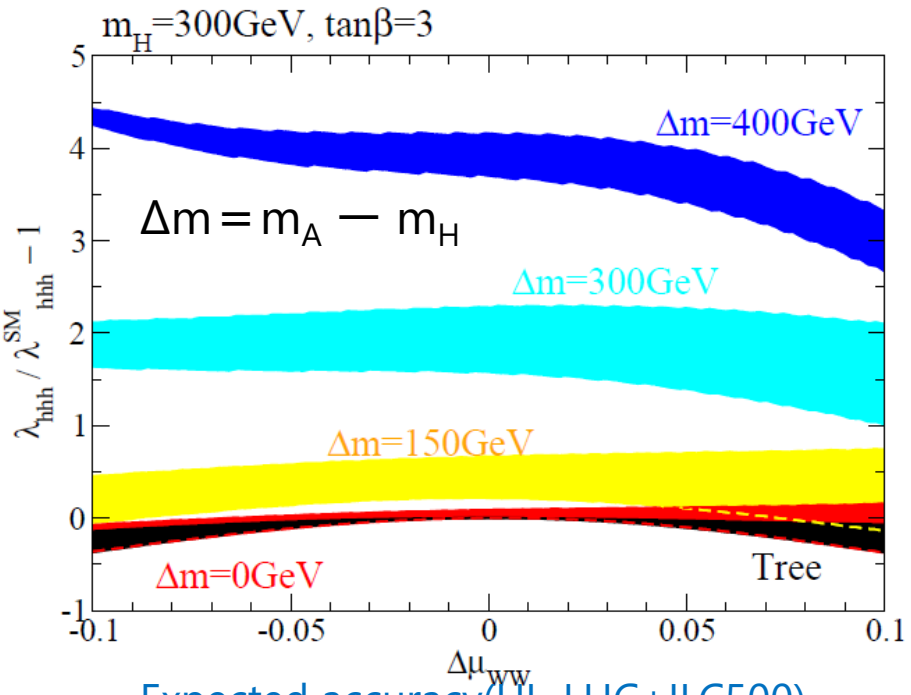
For Δm≠0, NLO corrections can change the tree level predictions by several tens %.

Radiative corrections to BR[H] are quite important.

Correlation between $H \to hh$ and hhh

Kanemura, MK, Yagyu[2203.08337]





Expected accuracy(HL-LHC+ILC500)

λ_{hhh} : 20 %

Fujii, et al. [1903.01629]

Radiative corrections to λ_{hhh} and BR[$H \to hh$] are correlated strongly

Since λ_{hhh} is important to test the scenario of EW baryogenesis,

$H \to hh$ may also be used to explore EW baryogenesis.

Conclusions

- We have computed the full set of decay rates of *H* with radiative corrections in the THDM.
- Radiative corrections to BR[H → hh] can drastically change its LO prediction due to non-decoupling effect of additional Higgs boson loops.
- Even in the case with very near alignment ($|\Delta\mu_{WW}| \sim 0.02$), $H \to hh$ can be the dominant decay mode.
- Radiative corrections to λ_{hhh} and BR[$H \to hh$] are correlated strongly.

Radiative corrections to decays of *H* is important for direct searches of additional Higgs bosons at future collider experiments such as HL-LHC.