Radiative corrections to Higgs to Higgs decays in extended Higgs models

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Work in progress

Introduction

- Although the discovered Higgs is SM-like Higgs, there remains a lot of mysteries in the Higgs sector.
  It is possible to consider a variety of extended Higgs sectors.

- Relations between Higgs structure and New physics

New physics pheno.	variety of extended Higgs sectors
DM, m_ν, Baryon asymmetry, Inflation, …	Φ+ X (+…) Elementary ? composite ? Dynamics of symmetry breaking, …

⇒Direction of New physics is related to Higgs sector.

- Minimal one? Or Non-minimal one ?

Φ

Φ+S(singlet), Φ+Φ, Φ+Δ(triplet), …

ρ=1 ρ≠1

Considering EW rho parameter data,
we study Φ+S (HSM), Φ+Φ (THDM, IDM) as priority.

Additional Higgs search

Additional Higgs bosons (H, A, $H^{\pm}$)

- Direct searches @LHC

  $H \to hh$,
  $A \to Zh$,
  $H \to WH^{+}$,…

  In this talk, we will show necessity of studies of radiative corrections for BR(H, A, H^{+}) in direct search.

- Indirect searches by precision measurement of h_{125}
  - Deviations from SM predictions of h_{125}-couplings
  - New physics effects

H-COUP

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

Kanemura, MK, Mawatari, Sakurai, Yagyu (2019)

★ Precisely calculate BR(h_{125}) including radiative corrections in order to compare to future precision data

- Processed : $h \to ff$, $h \to VV$, $h \to \gamma\gamma$, … (EW-NLO, QCD-NNLO)

★ We can compare results of several models.

- Models : SM, HSM, THDM(I, II, X, Y), IDM

Tools about Higgs processes of extended Higgs models

- 2HDECAY : [M. Krause, M. Mühlleitner, M. Spira]
- Prophecy4f : [A. Denner, S. Dittmaier, A. Mück]
- sHDECAY : [R. Costa, M. Mühlleitner, M. Sampaio, R. Santos] など

provided by other group

Two Higgs doublet model

THDM ★Softly broken Z2 sym. → 4 types of Yukawa interactions
★CP-conserving ★Mass eigenstates h_{125}, H, A, $H^{\pm}$
★Unknown parameters m_H m_A m_{H+} α β M^2

- Couplings of h_{125}

$$\kappa_V = \frac{g_{hVV}^{\mathrm{THDM}}}{g_{hVV}^{SM}} = \sin(\beta-\alpha) \rightarrow 1$$ Higgs alignment limit

Other Higgs couplings (hff, hhh) approach to predictions in SM.

- "Alignment"

(Higgs) alignment limit ・・・ $\sin(\beta-\alpha)=1$
(Higgs) near alignment ・・・ $\sin(\beta-\alpha) \simeq 1$

- Couplings of additional CP-even Higgs (*H*)

Couplings with SM particles Higgs alignment limit

HWW, HZZ

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

Hff

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

$$\kappa_f^H = \cos(\beta-\alpha) + \tan\beta\,\sin(\beta-\alpha) \rightarrow \tan\beta$$

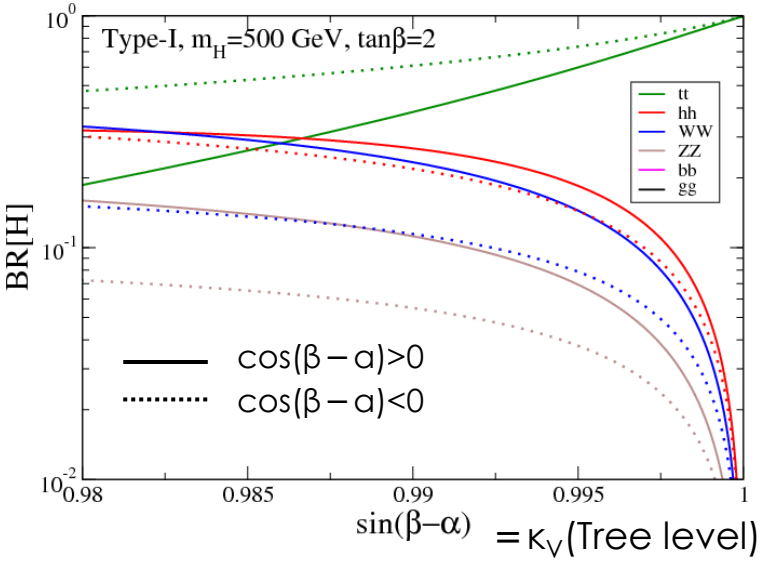
	I	II	X	Y
U-クォーク				
d-クォーク				
荷電レプトン				

Hhh

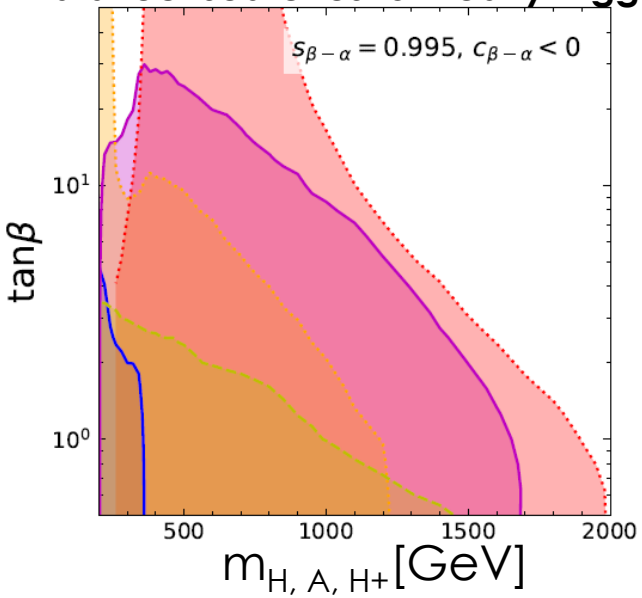
$$\lambda_{Hhh} = -\frac{\cos(\beta-\alpha)}{2v\sin 2\beta}\left\{(2m_h^2+m_H^2-3M^2)\sin 2\alpha + M^2\sin 2\beta\right\} \rightarrow 0$$

Decay modes at near alignment

Decay BR of *H*



Regions expected to be excluded (95%CL) via direct searches for heavy Higgs bosons at HL-LHC



Aiko, Kanemura, MK, Mawatari, Sakurai, Yagyu [2020]

Tree level analysis

- BRs(H) drastically change by slightly changing values of mixing parameter
- Higgs to Higgs decays are (next to-)main decay modes at near alignment regions

To do

- Better evaluation of κ_V ($\sin(\beta-\alpha)$)→ *h*125 decay with loop effects (by H-CO
- Calculate BR of additional Higgs boson with radiative corrections.

We will show results of $H \to hh$ decay

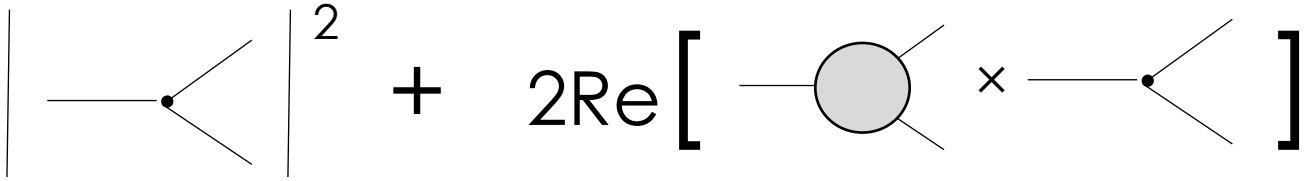
For study of H^+ decay, K. Sakurai will talk on Friday

Calculations of EW-corrections

- Decay modes $H \to hh,\ H \to tt,\ H \to bb,\ H \to cc,\ H \to \tau\tau,\ H \to WW,\ H \to ZZ$

- EW-corrections

$$\Gamma_{NLO}[H \to XX] = \left| \quad \right|^2 + 2\mathrm{Re}\left[\quad \times \quad \right]$$



Calculations Loop diagram

Same calculation scheme as that of H-COUP(h_{125})

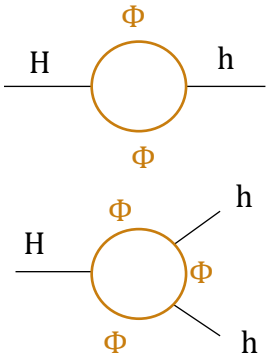
- ★UV div. → On-shell renormalizations
- ★Gauge dependence → Remove by Pinch technic
- ★IR div. via photon loop diagrams → Cancel by real photon emission (H→ff, H→WW)

Behavior of loop corrections

- EW 1-loop corrections

★ cos(β-a)

Cos(β-a) > 0 ⇒increase、 Cos(β-a) < 0⇒decrease



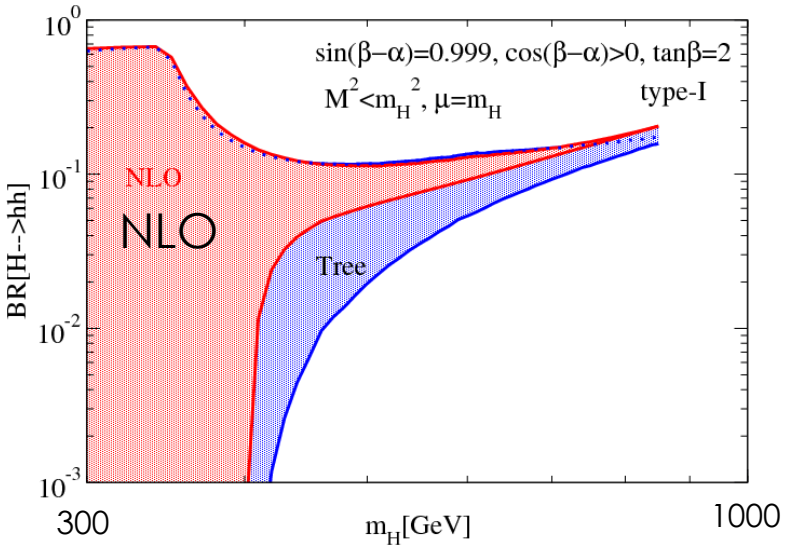
★balance btw m_H and M $\quad m_\Phi{}^2 \cong \lambda' v^2 + M^2$ Scalar coupling

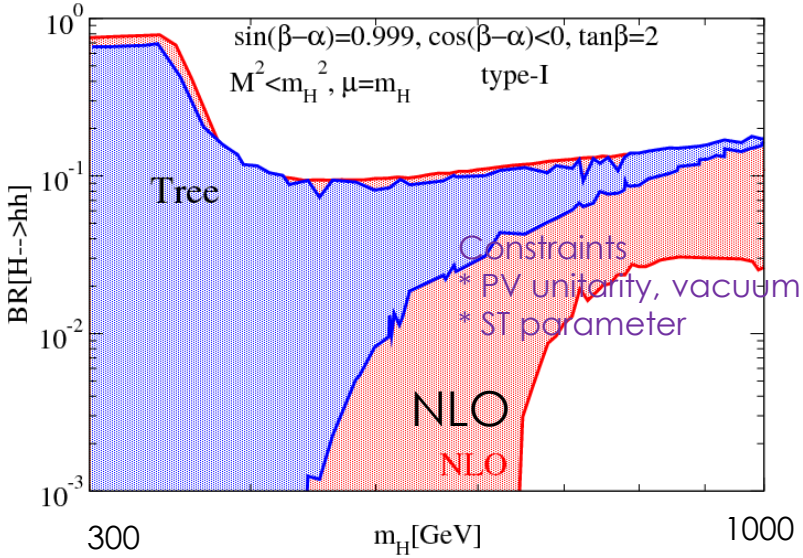
(Φ = $H^\pm$, A, H)

$M^2 \simeq m_\Phi^2$ ・・・ |Loop corrections| is small

$M^2 \ll m_\Phi^2$ ・・・Loop effects can be significant by Non-decoupling effect.

★tanβ （|Loop corrections| become large as tanβ becomes large.）





Case with mass differences

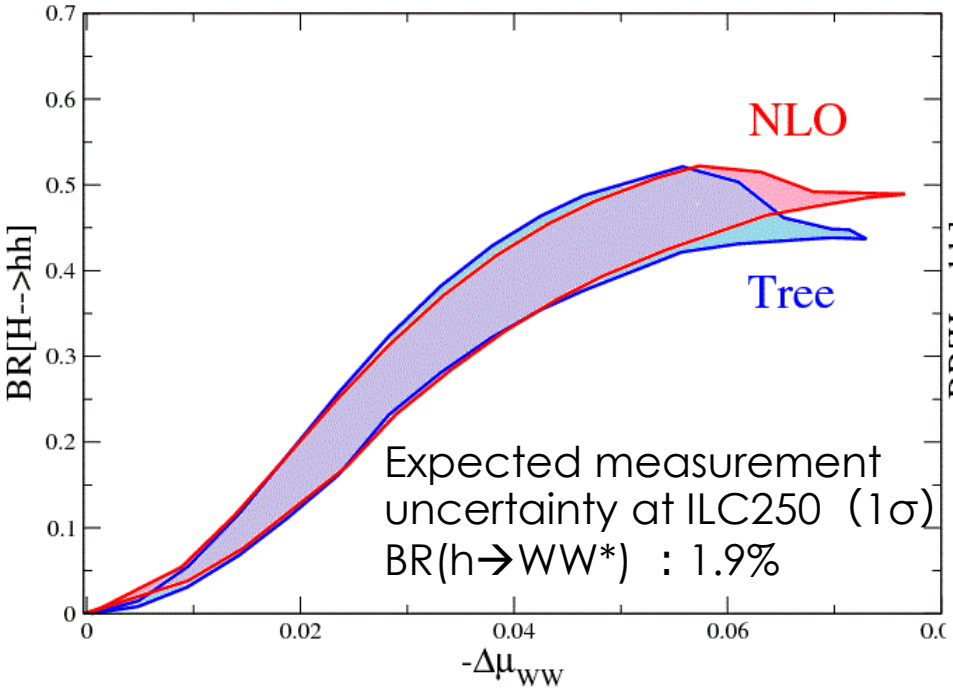
$$\Delta\mu_{WW} \equiv \frac{\mathrm{BR}^{\mathrm{NLO}}_{\mathrm{THDM}}[h \to WW^*]}{\mathrm{BR}^{\mathrm{NLO}}_{\mathrm{SM}}[h \to WW^*]} - 1$$

VS

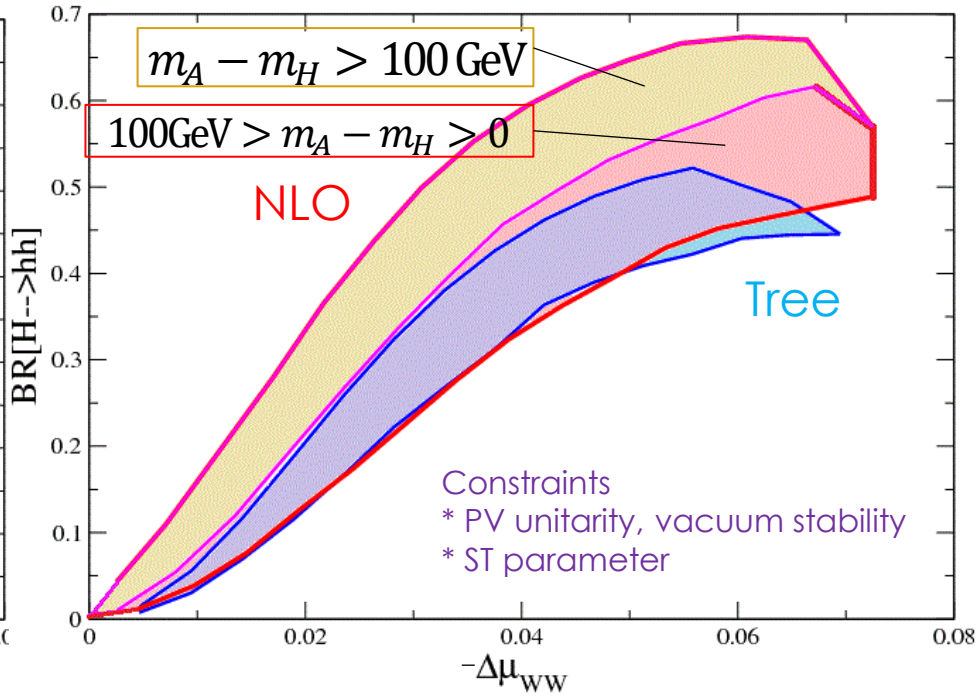
$$\mathrm{BR}^{\mathrm{NLO}}_{\mathrm{THDM}}[H \to hh]$$

$$m_H = 500\ \mathrm{GeV}, \tan\beta = 3, \cos(\beta - \alpha) > 0$$

$m_H = m_A = m_{H^+}$



$m_A = m_{H^+} > m_H$



BR[H→hh] can typically increase by about 10% from LO calculations by including EW-loop effects.

⇒ (Expected) excluded regions by direct searches can be modified.

Summary

- Precisely calculating *h*125 processes with radiative corrections is essential task, because they will be compare with precision measurements.

  Q : How about processes of additional Higgs bosons?

  A : Yes !!

- We calculate BR(H) with NLO corrections.
- BR(H→hh) can typically increase by about 10% via EW-radiative corrs.

The NLO corrections can affect (expected) excluded regions.
Studies of radiative corrections for additional Higgs boson's processes are essentially important.

- We will incorporate calculations of BR[H,A,H^+] into H-COUP Next version.