Radiative corrections to the Higgs coupling constants in the Higgs triplet model

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Introduction

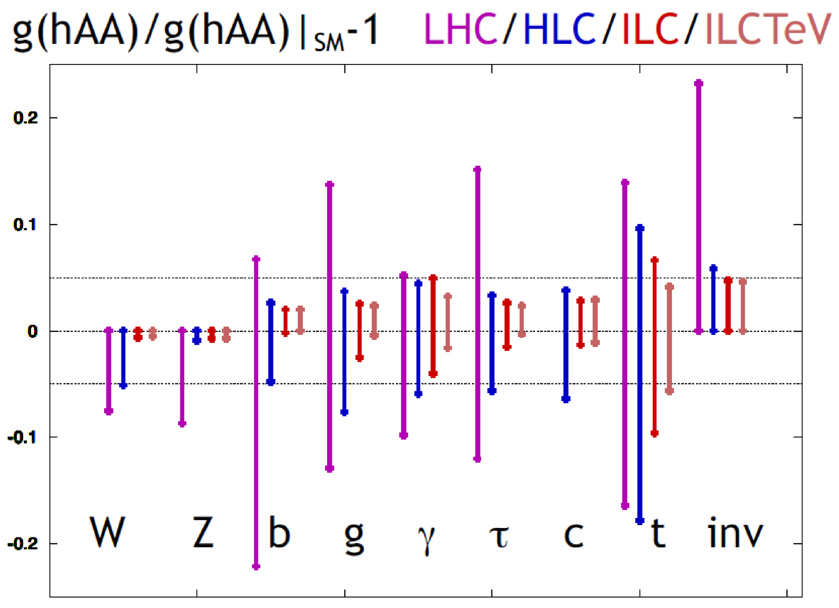
- The Higgs boson with a mass of about 126 GeV was discovered at LHC in 2012.
  ➡ What kind of the Higgs sector ? ・・・ Standard Model(SM) ?, THDM ?, others ?
- Why is determining the Higgs sector important ? = New physics beyond the SM
- In order to determine the Higgs sector ・・・

LHC : $\sqrt{s}$=14 TeV, L=300fb^{-1}
HLC : $\sqrt{s}$=250 GeV, L=250fb^{-1} in ILC
ILC : $\sqrt{s}$=500 GeV, L=500fb^{-1} in ILC
ILCTeV : $\sqrt{s}$=1000 GeV, L=1000fb^{-1}

Precision measurement × **Theoretical prediction at loop level**

- We then focus on the Higgs triplet model(HTM) which can generate tiny neutrino masses .
  NEW We define the on-shell renormalization scheme.
  NEW We evaluate deviations in coupling constants of the SM like Higgs boson from the SM values at the 1 loop level. ($h \to \gamma\gamma$, hWW, hZZ, hhh)

M. E. Peskin (2012)



Conclusion

- Deviations are detectable at ILC. → New physics can be explored by coupling calculation with radiative corrections and precision measurement.

I. Model

T. P. Cheng, L. F. Li (1980) ; J. Schechter, J. W. F. Valle (1980); G. Lazarides, Q. Shafi , C. Wetterich (1981); R. N. Mohapatra, G. Senjanovic (1981); M. Magg, C. Wetterich (1980).

	$SU(2)_L$	$U(1)_Y$	$U(1)_L$
Φ	2	1/2	0
Δ	3	1	-2

$$\Phi = \begin{bmatrix} \phi^+ \\ \frac{1}{\sqrt{2}}(\phi + v_\phi + i\chi) \end{bmatrix} \qquad \Delta = \begin{bmatrix} \frac{\Delta^+}{\sqrt{2}} & \Delta^{++} \\ \Delta^0 & -\frac{\Delta^+}{\sqrt{2}} \end{bmatrix}$$

$$\Delta^0 = \frac{1}{\sqrt{2}}(\delta + v_\Delta + i\eta)$$

➢ Gauge interaction

$$\mathcal{L}_{\rm kin} = (D_\mu\Phi)^\dagger(D^\mu\Phi) + {\rm Tr}[(D_\mu\Delta)^\dagger(D^\mu\Delta)]$$

$$\Rightarrow \quad m_W^2 = \frac{g^2}{4}(v_\phi^2 + 2v_\Delta^2), \quad m_Z^2 = \frac{g^2}{4\cos^2\theta_W}(v_\phi^2 + 4v_\Delta^2) \quad ,$$

$$\rho_{tree} \equiv \frac{m_W{}^2}{m_Z{}^2\cos^2\theta_W} = \frac{v_\phi{}^2 + 2v_\Delta{}^2}{v_\phi{}^2 + 4v_\Delta{}^2} \quad (\simeq 1 - 2\frac{v_\Delta{}^2}{v_\phi{}^2}) \; .$$

➢ Higgs potential

$$V(\Phi,\Delta) = m^2\Phi^\dagger\Phi + M^2{\rm Tr}(\Delta^\dagger\Delta) + \left[\mu\Phi^T i\tau_2\Delta^\dagger\Phi + {\rm h.c.}\right]$$
$$+ \lambda_1(\Phi^\dagger\Phi)^2 + \lambda_2\left[{\rm Tr}(\Delta^\dagger\Delta)\right]^2 + \lambda_3{\rm Tr}[(\Delta^\dagger\Delta)^2] + \lambda_4(\Phi^\dagger\Phi){\rm Tr}(\Delta^\dagger\Delta) + \lambda_5\Phi^\dagger\Delta\Delta^\dagger\Phi$$

Mass eigenstates $H^{\pm\pm}$, $H^\pm$, A, H, h
triplet like Higgs bosons SM like Higgs boson

II. Mass hierarchy

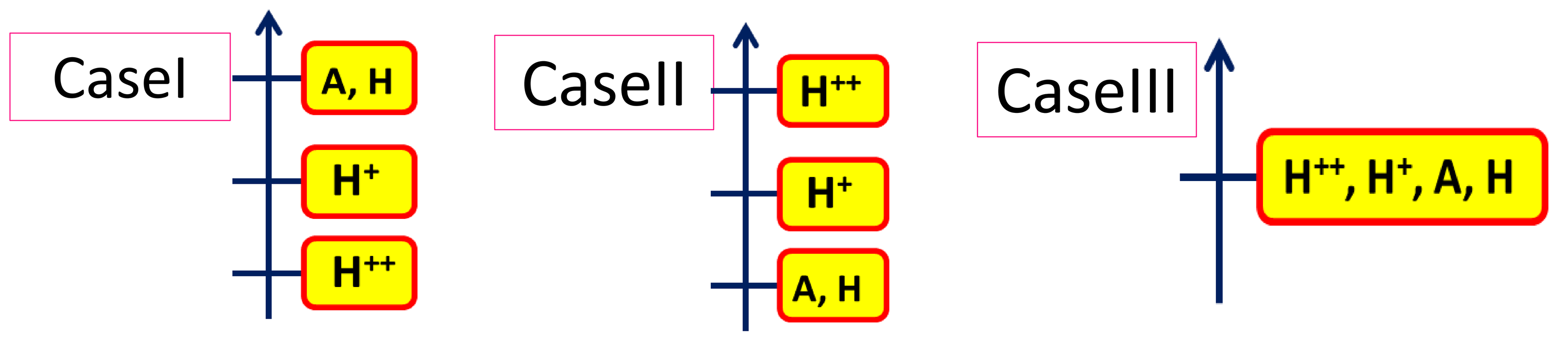
$$\rho = \frac{v_\phi{}^2 + 2v_\Delta{}^2}{v_\phi{}^2 + 4v_\Delta{}^2}, \; \rho_{exp} \simeq 1.0008 \quad \Rightarrow \quad v_\Delta{}^2 \ll v_\phi{}^2$$

Experimentally constrained !!

In the limit of $v_\Delta{}^2/v_\phi{}^2 \to 0$,

$$m_{H^{++}}^2 - m_{H^+}^2 = m_{H^+}^2 - m_A^2 \quad \left(= -\frac{\lambda_5}{4}v^2\right), \quad m_A^2 = m_H^2 \;\; (= M_\Delta^2).$$

There are three mass hierarchy $\quad \Delta m = m_{H^\pm} - m_{lightest}$



$\Delta m = m_{H^\pm} - m_{H^{\pm\pm}}$ $\qquad \Delta m = m_{H^\pm} - m_A$ $\qquad \Delta m = 0$

The phenomenology in triplet fields depends on the mass hierarchy.
M. Aoki, S. Kanemura, K. Yagyu (2012).

III. Renormalization

T. Blank, W. Hollik (1998), S. Kanemura, K. Yagyu (2012), P. H. Chankowski, S. Pokorski, J. Wagner, (2007); M. -C. Chen, S. Dawson, C. B. Jackson, Phys. Rev. D 78, 093001 (2008).

➢ In the gauge sector

- Parameters ・・・ m_W , m_Z , $\sin\theta_W$, G_F , α_{em} .
- Input parameters ・・・

<SM>
Three input parameters are required to be fixed from experiments.
m_W , m_Z , α_{em}

$$G_F = \frac{\pi\alpha_{em}}{\sqrt{2}m_W^2\sin^2\theta_W} \qquad \sin^2\theta_W = 1 - \frac{m_W^2}{m_Z^2},$$

<HTM>
We need four input parameters.
m_W , m_Z , α_{em},
β'(CP-odd mixing angle)

$$\cos\theta_W{}^2 = \frac{2m_W{}^2}{m_Z{}^2(1+\cos\beta'^2)}$$

$$\delta\bar{s}_W^2 = -\delta\bar{c}_W^2 = \frac{2m_W^2}{m_Z^2(1+c_{\beta'}^2)}\left(\frac{\delta m_Z^2}{m_Z^2} - \frac{\delta m_W^2}{m_W^2} - \frac{2s_{\beta'}c_{\beta'}}{(1+c_{\beta'}^2)}\delta\beta'\right)$$

- Renormalization conditions
  $\delta m_W{}^2$ ・・・ $\Pi_{WW}[m_W{}^2] = 0$,
  $\delta m_Z{}^2$ ・・・ $\Pi_{ZZ}[m_Z{}^2] = 0$, $\delta\beta'$ ・・・ renormalization in $V(\Phi,\Delta)$,
  $\delta\alpha$ ・・・ $ee\gamma$ vertex on-shell conditions .

➢ In $V(\Phi,\Delta)$

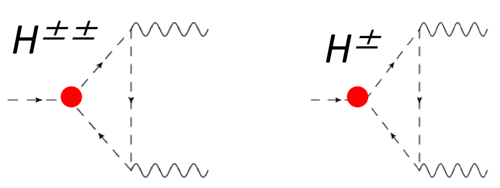
(α: CP-even mixing angle, β: charged mixing angle)

- Parameters ・・・ v, α, β, β', $m_{H^{\pm\pm}}$, $m_{H^\pm}$, m_A, m_H, m_h
- Renormalization conditions(on-shell condition)
  $\delta m_\varphi{}^2$ ・・・ $\Pi_{\varphi\varphi}[m_\varphi{}^2] = 0$,
  δv ・・・ from EW renormalization, $v^2 = \frac{m_W{}^2\sin^2\theta_W}{\pi^2\alpha_{em}}$,
  $\delta\alpha$ ・・・ $\Pi_{Hh}[m_h{}^2] = 0, \Pi_{Hh}[m_H{}^2] = 0$,
  $\delta\beta$ ・・・ $\delta\beta = \frac{1+s_\beta^2}{\sqrt{2}}\delta\beta'$,
  $\delta\beta'$ ・・・ $\Pi_{AG}[m_A{}^2] = 0, \Pi_{AG}[m_G{}^2] = 0$.

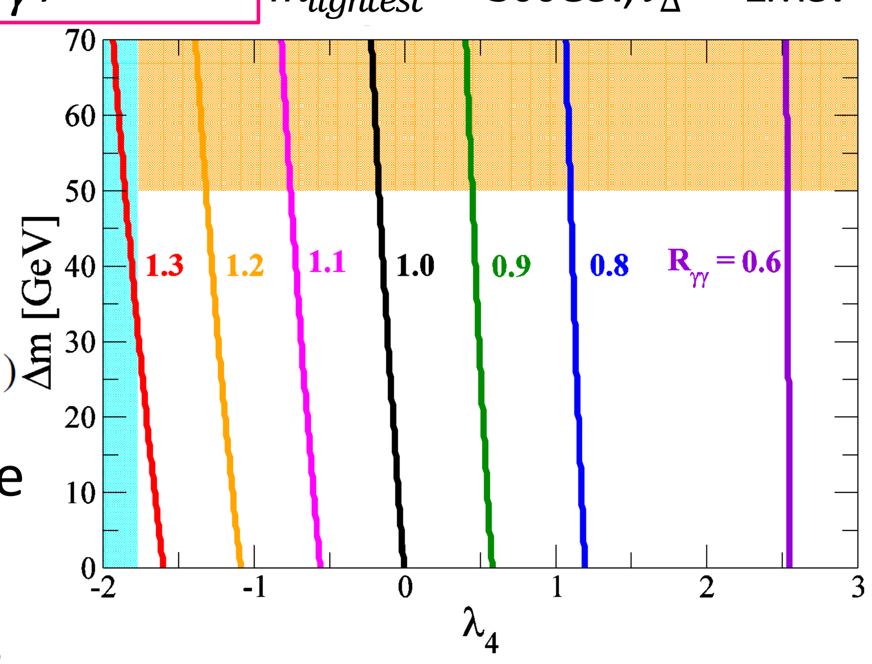
IV. Results

➢ $h \to \gamma\gamma$

diagrams of triplet field effects



$$\lambda_{hH^{++}H^{--}} \simeq -v\lambda_4, \qquad \lambda_{hH^+H^-} \simeq -\frac{v}{2}(2\lambda_4 + \lambda_5)$$



We evaluate ratios event rates in the HTM of those in the SM,

$$R_{\gamma\gamma} \equiv \frac{\sigma(gg \to h)_{\rm HTM} \times {\rm BR}(h \to \gamma\gamma)_{\rm HTM}}{\sigma(gg \to h)_{\rm SM} \times {\rm BR}(h \to \gamma\gamma)_{\rm SM}} \; .$$

In the allowed region from EW data and vacuum stability, $R_{\gamma\gamma}$ can be 0.6 – 1.3 in Case I, II.

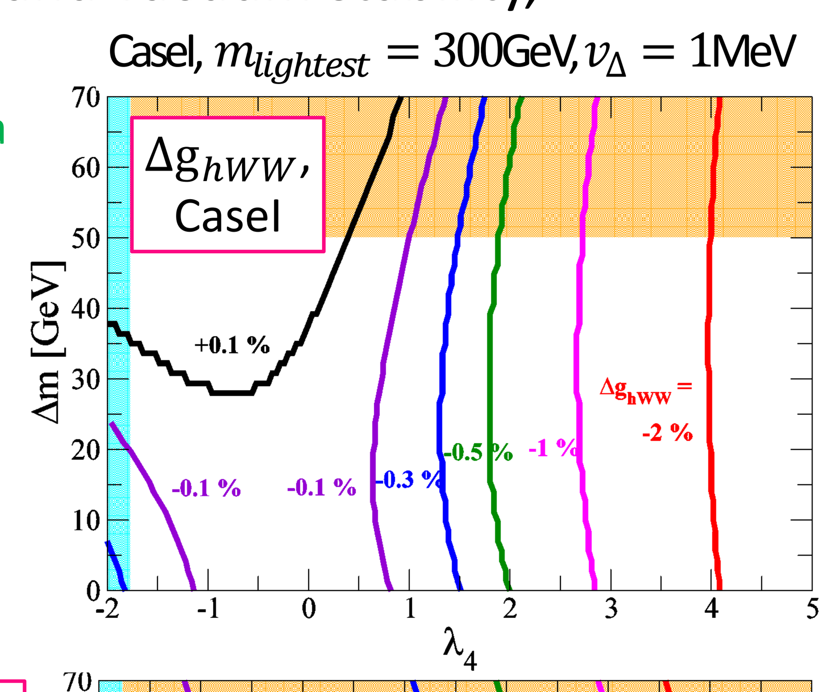
A. Arhrib, R. Benbrik, M. Chabab, G. Moultaka (2012); A. G. Akeroyd, S. Moretti (2012);

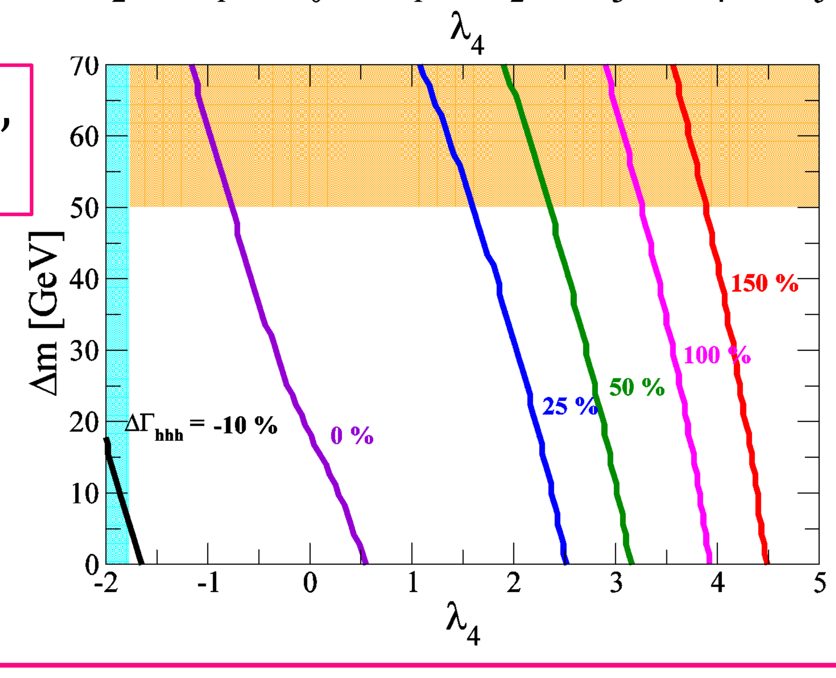
➢ Renormalized coupling

Deviations of coupling constants of h from the SM prediction

$$\Delta g_{hVV} = \frac{{\rm Re}M_1^{hVV} - {\rm Re}M_1^{hVV}({\rm SM})}{{\rm Re}M_1^{hVV}({\rm SM})} \quad ,$$

$$\Delta\Gamma_{hhh} \equiv \frac{{\rm Re}\Gamma_{hhh} - {\rm Re}\Gamma_{hhh}^{\rm SM}}{{\rm Re}\Gamma_{hhh}^{\rm SM}} \quad .$$





In the allowed region from EW data and vacuum stability, Δg_{hVV} can be -2.0 – +0.1 %, $\Delta\Gamma_{hhh}$ can be -10 - +150% in Case I, II.