Two loop corrections to the Higgs self-coupling in classical scale invariant models

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J. Braathen, S. Kanemura, MS. arxiv:2011.07580 [hep-ph]. JHEP to appear.

1. Introduction

The successful but problematic SM

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Alignment without decoupling scenarios

$$\delta R \equiv \frac{\lambda_{hhh}^{\rm BSM} - \lambda_{hhh}^{\rm SM}}{\lambda_{hhh}^{\rm SM}}$$

(1) Extended Higgs models

1 loop : $\lambda_{hhh}^{(1)} \sim \frac{M_S^4}{16\pi^2 v^3}\left(1-\frac{M^2}{M_S^2}\right)^3$ — decoupling (large M), non-decoupling (small M)

δR can be $\mathcal{O}$(100%).

[S. Kanemura, Y. Okada, E. Senaha, C.-P. Yuan. PRD70]

($M_S^2 = M^2 + \lambda_S v^2$, M_S : additional scalar mass, M : mass parameter)

2 loop : Further ∼+20% deviation.

[J. Braathen, S. Kanemura, PLB796]

(2) Extended Higgs models with classical scale invariance (CSI)

1 loop : $\lambda_{hhh}^{(1)} = \frac{5M_h^2}{v^2} = \frac{5}{3}\lambda_{hhh}^{\rm SM\,tree}$ [K. Hashino, S. Kanemura, Y. Orikasa. PLB752]

Model independent non-decoupling effect.

2 loop : How large, model dependent? Our work

- Necessary for precise prediction.
- Important to distinguish models by precise test at future colliders.

2. Model and calculation

(detail : Backup)

Example CSI O(N) singlet scalar model

$$V = \lambda|\Phi|^4 + \lambda_{\Phi S}|\Phi|^2\vec{S}^2 + \frac{1}{4}\lambda_S(\vec{S}^2)^2$$

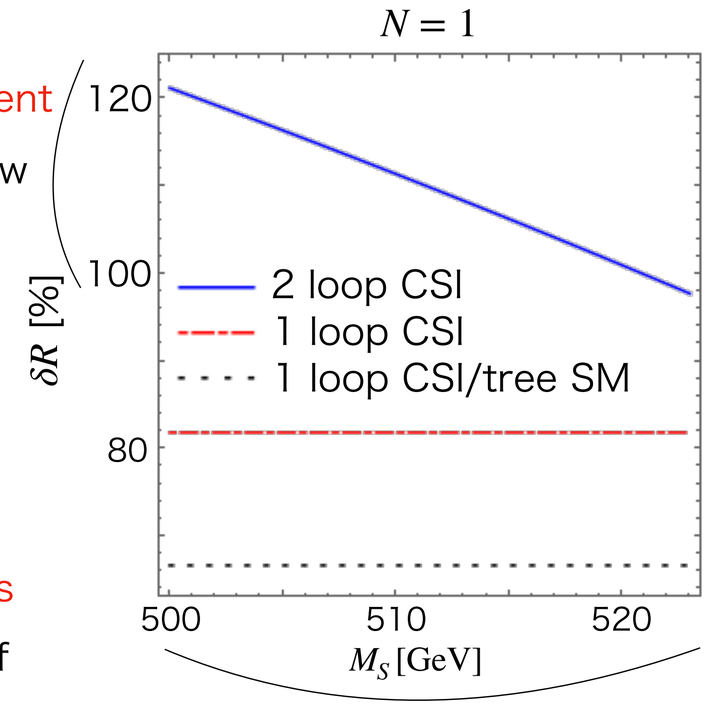
Φ : SM Higgs doublet

$\vec{S}$: Additional scalars $\vec{S} = (S_1, \ldots, S_N)$

3. Result

(N=4, other model : Backup)

- $\lambda_{hhh}^{\rm CSI}$ is model dependent because of 2 loop new contributions.
- Further ∼+20% deviation from 1 loop result.
- λ_S, M_S(related to $\lambda_{\Phi S}$) is restricted because of
  (1) Conditions to cause electroweak symmetry breaking by radiative corrections to the potential.
  (2) Perturbative unitarity.



4. Summary

λ_{hhh} at two loop in CSI theories is model dependent and deviate ∼+100% from the SM prediction.

Backup1

(1) General form of effective potential at two loop (in $\overline{\mathrm{MS}}$ scheme)

$$V_{eff}(h) = A(v+h)^4 + B(v+h)^4 \ln\frac{(v+h)^2}{Q^2} + C(v+h)^4 \ln^2\frac{(v+h)^2}{Q^2}$$

Two loop new contribution

(A, B, C : model dependent coefficients)

(2) Conditions to cause EWSB radiatively

$$0 = \left.\frac{\partial V_{eff}(h)}{\partial h}\right|_{h=0}, \quad m_h^2 = \left.\frac{\partial^2 V_{eff}(h)}{\partial h^2}\right|_{h=0} > 0 \longrightarrow$$

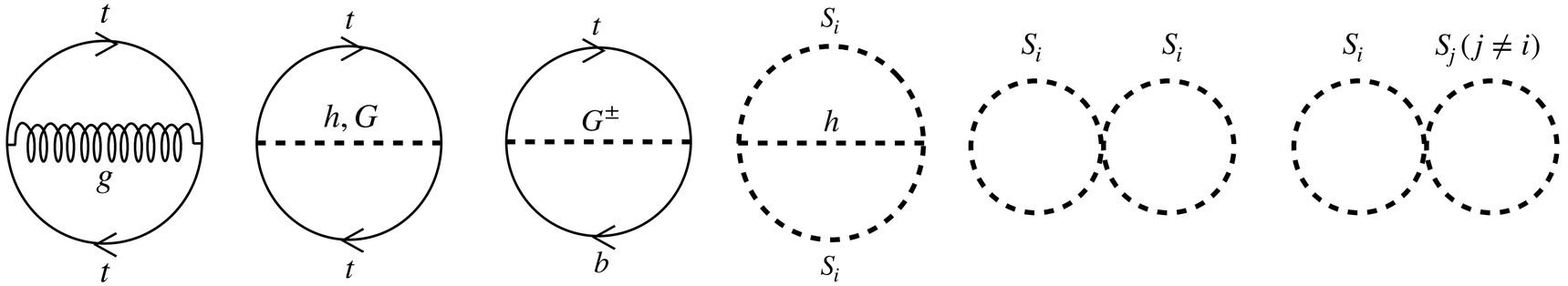
Restrictions on A, B, C

(3) Calculation and result of the Higgs triple coupling

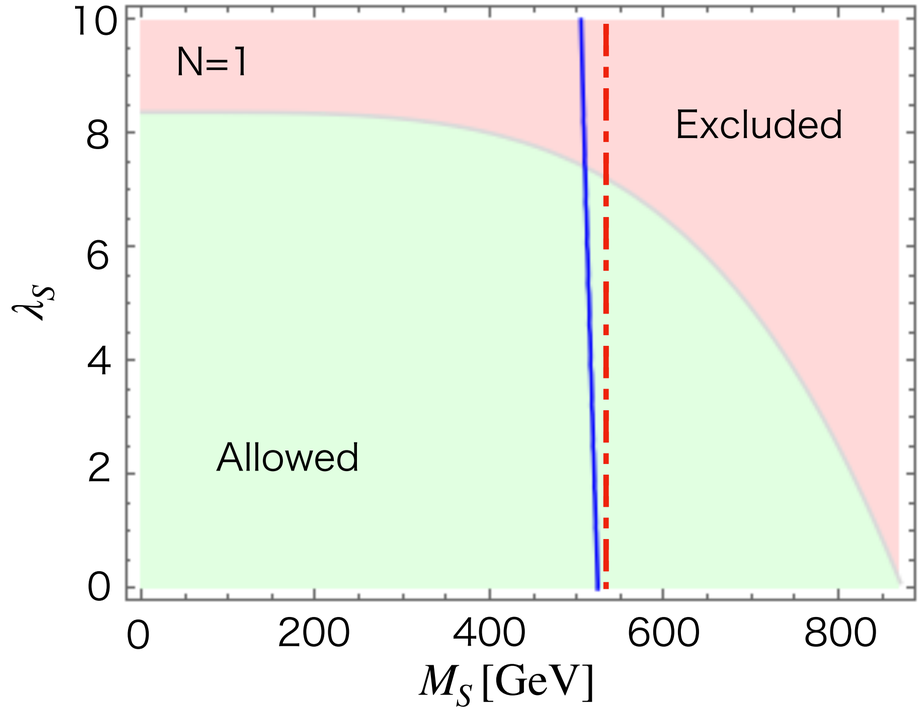
$$\lambda_{hhh} = \left.\frac{\partial^3 V_{eff}(h)}{\partial h^3}\right|_{h=0} = \frac{3m_h^2}{v} + 32Cv$$

Model dependent effect

(4) Two loop contributions to the effective potential in CSI O(N) singlet scalar model

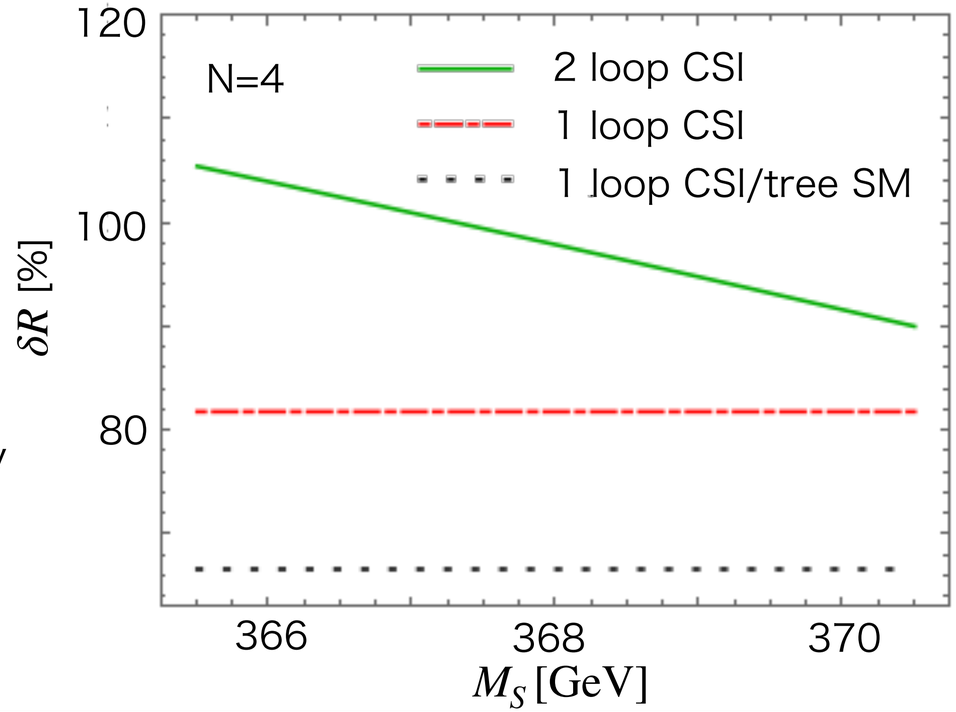


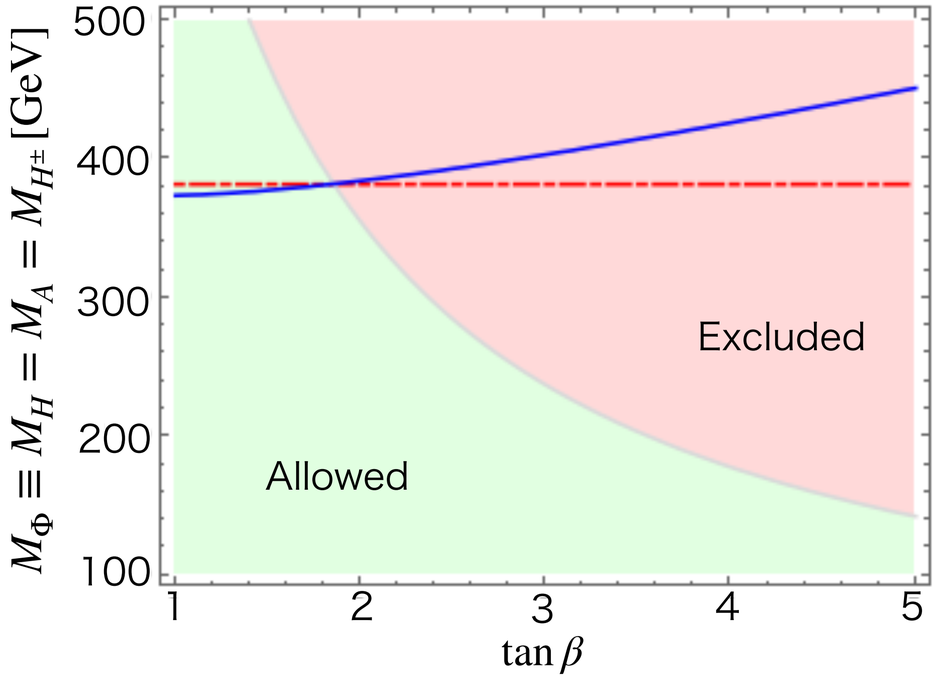
Backup2



CSI O(N)

Tree level unitarity
2 loop CSI
1 loop CSI





CSI 2HDM

Tree level unitarity
2 loop CSI
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