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Radiative corrections to the Higgs boson couplings in the model with an additional real singlet scalar field

Shinya Kanemura [a], Mariko Kikuchi [a,*], Kei Yagyu [b]

[a] *Department of Physics, University of Toyama, 3190 Gofuku, Toyama 930-8555, Japan*
[b] *School of Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ, United Kingdom*

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Abstract

We calculate renormalized Higgs boson couplings with gauge bosons and fermions at the one-loop level in the model with an additional isospin singlet real scalar field. These coupling constants can deviate from the predictions in the standard model due to tree-level mixing effects and one-loop contributions of the extra neutral scalar boson. We investigate how they can be significant under the theoretical constraints from perturbative unitarity and vacuum stability and also the condition of avoiding the wrong vacuum. Furthermore, comparing with the predictions in the Type I two Higgs doublet model, we numerically demonstrate how the singlet extension model can be distinguished and identified by using precision measurements of the Higgs boson couplings at future collider experiments.

1. Introduction

Although a Higgs boson was discovered by the LHC experiments in 2012 [1,2], the structure of the Higgs sector and the physics behind the Higgs sector remain unknown. Deep understanding for the Higgs sector is a key to explore new physics beyond the standard model (SM).

The minimal Higgs sector of the SM satisfies the current LHC data [3,4], while most of non-minimal Higgs sectors do so as well. As there is no theoretical reason to choose the minimal

* Corresponding author.
E-mail address: kikuchi@jodo.sci.u-toyama.ac.jp (M. Kikuchi).

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form of the Higgs sector like in the SM, there are many possibilities for extended Higgs sectors which contain additional scalar isospin multiplets. In principle, there are infinite kinds of extended Higgs sectors. However, particular importance exists in the second simplest Higgs sectors, where only one isospin multiplet is added to the SM Higgs sector, such as a model with an additional singlet, doublet or triplet scalar field. There are many new physics models which predict one of these extended Higgs sectors such as the $B-L$ extended SM with the $B-L$ symmetry breaking [5] which contains an additional singlet scalar field, the minimal supersymmetric SM [6,7] whose Higgs sector has the two Higgs doublets, and the model for the Type II seesaw mechanism [8] which can generate Majorana neutrino masses by introducing a complex triplet Higgs field, and so on. These second simplest Higgs sectors can also be regarded as low-energy effective theories of more complicated Higgs sectors.

How can we test extended Higgs sectors by experiments? Obviously direct discovery of the second Higgs boson is manifest evidence for extended Higgs sectors. By detailed measurements of such a particle, we can determine the structure of the Higgs sector. On the other hand, we can also test extended Higgs sectors by precisely measuring low energy observables such as those in flavor physics [9], electroweak precision observables [10], etc. As additional observables we can consider a set of coupling constants of the discovered Higgs boson. In general, a pattern of deviations in these observables strongly depends on the effects of extra Higgs bosons and other new physics particles, so that we may be able to fingerprint extended Higgs sectors and new physics models if we can detect a special pattern of the deviations at future experiments [11–17].

After the Higgs boson discovery, coupling constants of the discovered Higgs boson with SM particles became new observables to be measured as precisely as possible at current and future colliders. Currently the measured accuracies for the Higgs boson couplings are typically of the order of 10% [3,4]. They will be improved drastically to the order of 1% or even better at future lepton colliders, such as the International Linear Collider (ILC) [11,18], the Compact LInear Collider (CLIC) [19] and Future e^+e^- Circular Collider (FCCee). Therefore, these future electron–positron colliders are idealistic tools for fingerprinting Higgs sector and new physics models via precise measurements of the Higgs boson couplings. In order to compare theory predictions with such precision measurements, calculations with higher order corrections are clearly necessary.

One-loop corrected Higgs boson couplings have been calculated in two Higgs doublet models (THDMs) with various Yukawa interactions [15,16,20], in the inert doublet model (IDM) [21,22] and in the Higgs triplet model (HTM) [17,23,24]. In addition, decay rate of loop induce processes hgg, $h\gamma\gamma$ and $h\gamma Z$ have been investigated in THDMs [25–28], the IDM [29] and the HTM [30–33].

In this paper, we calculate one-loop corrections to the Higgs boson couplings with gauge bosons and with fermions in the model with a real isospin singlet scalar field (HSM) [34–39]. The renormalized couplings can deviate from the SM predictions due to the mixing effect and the one-loop contributions of the extra neutral scalar boson. The one-loop contributions are calculated in the on-shell scheme. We numerically investigate how they can be significant under the theoretical constraints from perturbative unitarity and vacuum stability and also the conditions of avoiding the wrong vacuum. Furthermore, we compare the results with the predictions at the one-loop level in the THDM with Type I Yukawa interactions [15,16]. We study how the HSM can be distinguished from these models and identified by using precision measurements of the Higgs boson couplings at future collider experiments.

This paper is organized as follows. In Sec. 2, we define the HSM, and briefly review the tree level properties to fix notation. In Sec. 3, we present our calculational scheme for one-loop cor-