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Nuclear Physics B 915 (2017) 206–223

NUCLEAR PHYSICS B

www.elsevier.com/locate/nuclphysb

Extending two Higgs doublet models for two-loop neutrino mass generation and one-loop neutrinoless double beta decay

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Received 10 November 2016; accepted 2 December 2016

Available online 6 December 2016

Editor: Hong-Jian He

Abstract

We extend some two Higgs doublet models, where the Yukawa couplings for the charged fermion mass generation only involve one Higgs doublet, by two singlet scalars respectively carrying a singly electric charge and a doubly electric charge. The doublet and singlet scalars together can mediate a two-loop diagram to generate a tiny Majorana mass matrix of the standard model neutrinos. Remarkably, the structure of the neutrino mass matrix is fully determined by the symmetric Yukawa couplings of the doubly charged scalar to the right-handed leptons. Meanwhile, a one-loop induced neutrinoless double beta decay can arrive at a testable level even if the electron neutrino has an extremely small Majorana mass. We also study other experimental constraints and implications including some rare processes and Higgs phenomenology.

1. Introduction

The massive and mixing neutrinos have been confirmed by the precise measurements on the atmospheric, solar, accelerator and reactor neutrino oscillations [1]. This fact implies the need

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http://dx.doi.org/10.1016/j.nuclphysb.2016.12.001

for new physics beyond the $SU(3)_c \times SU(2)_L \times U(1)_Y$ standard model (SM). On the other hand, the cosmological observations have indicated that the neutrino masses should be in a sub-eV range [1]. In order to understand the small neutrino masses, people have proposed various ideas, among which the tree-level seesaw [2–5] mechanism is very popular [2–12]. However, the seesaw will not be easy to verify unless it is not at a naturally high scale. Alternatively, the neutrinos can acquire their tiny masses at loop order [13–45]. These models for the radiative neutrino mass generation contain additionally charged scalars so that they may be tested at colliders.

In principle the neutrinos can have a Majorana nature [46] since they do not carry any electric charges. One hence can expect a neutrinoless double beta decay ($0\nu\beta\beta$) [47] process mediated by the Majorana electron neutrinos. This $0\nu\beta\beta$ process is determined by one unknown parameter m_{ee}, i.e. the 1–1 element in the Majorana neutrino mass matrix, so that it can be seen in the running and planning experiments unless the m_{ee} parameter is big enough [48,49]. However, there are other possibilities for a $0\nu\beta\beta$ process [5,10,50–60]. For example, some left-right symmetric models for a linear seesaw of tree-level neutrino mass generation can offer a nonconventional tree-level $0\nu\beta\beta$ process with an testable lifetime, which simply depends on the scale of the left-right symmetry breaking rather than the details of the Majorana neutrino mass matrix [61]. One may also consider other models which accommodate an observable $0\nu\beta\beta$ process at tree level and then give a negligible contribution to the neutrino masses at loop order [62]. These $0\nu\beta\beta$ processes, which are related to quite a few arbitrary parameters, thus can be free of the constraint from the neutrino mass matrix [63–65].

It should be interesting if an enhanced $0\nu\beta\beta$ process originates from a tiny m_{ee}. Some people have realized this scenario [37–45]. In a realistic model [37], after the SM Higgs doublet develops a vacuum expectation value (VEV) for spontaneously breaking the electroweak symmetry, a Higgs triplet without any Yukawa couplings can acquire an induced VEV up to a few GeV, meanwhile, its doubly charged component can mix with a doubly charged scalar singlet. Thanks to the gauge interactions, a two-loop induced Majorana neutrino mass matrix then can have a structure fully determined by the symmetric Yukawa couplings of the doubly charged scalar singlet to the right-handed leptons. As for the $0\nu\beta\beta$ process, it can appear at tree level through the same Yukawa interactions and the related gauge interactions.

In this paper we shall extend some two Higgs doublet models [66], where the Yukawa couplings for the charged fermion mass generation only involve one Higgs scalar, to generate the required neutrino masses and the enhanced $0\nu\beta\beta$ process. Specifically we shall introduce two scalar singlets among which one carries a singly electric charge while the other one carries a doubly electric charge. The singly charged scalar without any Yukawa couplings has a cubic term with the two Higgs scalars. The doubly charged scalar has the Yukawa couplings with the right-handed leptons, besides its trilinear coupling with the singly charged scalar. After the electroweak symmetry breaking, we can obtain a dominant Majorana neutrino mass matrix at two-loop and a negligible one at three-loop level. The symmetric Yukawa couplings of the doubly charged scalar to the right-handed leptons can fully determine the structure of the neutrino mass matrix. The $0\nu\beta\beta$ processes can be induced at tree, one-loop and two-loop level. The amplitudes of these $0\nu\beta\beta$ processes are all proportional to the electron neutrino mass. The one-loop $0\nu\beta\beta$ process can arrive at an observable level even if the electron neutrino mass is extremely small. We will also study other experimental constraints and implications including some rare processes and Higgs phenomenology.