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Neutrino catalyzed diphoton excess

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Abstract

In this paper we explain the 750 GeV diphoton resonance observed at the run-2 LHC as a scalar singlet $\mathbb{S}$, that plays a key role in generating tiny but nonzero Majorana neutrino masses. The model contains four electroweak singlets: two leptoquarks, a singly charged scalar and a neutral scalar $\mathbb{S}$. Majorana neutrino masses might be generated at the two-loop level as $\mathbb{S}$ gets nonzero vacuum expectation value. $\mathbb{S}$ can be produced at the LHC through the gluon fusion and decays into diphoton with charged scalars running in the loop. The model fits perfectly with a narrow width of the resonance. Constraints on the model are investigated, which shows a negligible mixing between the resonance and the standard model Higgs boson.

1. Introduction

The standard model (SM) of particle physics fits perfectly with almost all the experimental observations in the elementary particle physics. But there are still hints of new physics beyond the SM. The discovery of the neutrino oscillations has confirmed that neutrinos are massive and lepton flavors are mixed [1], which provided the first evidence for physics beyond the SM. An attractive approach towards understanding the origin of small neutrino masses is using the dimension-five Weinberg operator [2]

$$\frac{1}{4}\kappa_{gf}\overline{\ell_{Lc}^{C}}^{g}\varepsilon_{cd}H_d\ell_{Lb}^{f}\varepsilon_{ba}H_a+\text{h.c.} \tag{1}$$

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where ℓ_L is the left-handed lepton doublet, H is the SM Higgs, κ is a symmetric matrix with a mass dimension of -1, ε is the 2-dimensional antisymmetric tensor, $a,\ b,\ c$ and d are $SU(2)$ indices, g and f are flavor indices, C means charge conjugation. This operator, which might come from integrating out some new superheavy particles, gives Majorana masses to active neutrinos after the spontaneous breaking of the electroweak symmetry. A simple way to realize the Weinberg operator is through the tree-level seesaw mechanisms [3–5]. But the canonical seesaw scales are usually too high to be accessible by colliders. Many TeV-scale seesaw mechanisms were proposed motivated by the testability, some of them give rise to the Weinberg operator at the loop level.

Both ATLAS [6] and CMS [7] Collaborations presented a summary of the first LHC results obtained from proton–proton collisions at $\sqrt{s} = 13$ TeV on December 15 2015, which show a hint of an excess in the diphoton channel at invariant mass around 750 GeV. The local statistical significance is 3.6σ and 2.6σ for ATLAS and CMS respectively. The best fit width of the resonance given by ATLAS is about 45 GeV and the corresponding cross section is (10 ± 3) fb, while the CMS result favors a narrow width, whose corresponding cross section is (6 ± 3) fb. During the Moriond 2016 conference, ATLAS and CMS [8] updated their diphoton resonance searches. The statistical significance of the resonance is increased up to 3.9σ for the ATLAS experiment with looser photon selection cuts, and 2.9σ for the CMS experiment with combined data sets of 0 T and 3.8 T magnetic field. CMS also showed the 8 TeV + 13 TeV combined results with a local statistical significance about 3.4σ and the best fit width about 0.1 GeV. Currently, this diphoton resonance could be anything, including nothing, but if confirmed, it would be another hint of new physics beyond the SM. According to the Landau–Yang theorem [9,10], this resonance can only be spin-0 or spin-2 bosonic state.[1] The heavy quarks and/or gluon fusion production of the resonance are favored, because the run-1 LHC [11,12] at $\sqrt{s} = 8$ TeV did not see significant excess at 750 GeV. It is intriguing to investigate the physics behind this excess as done in a bunch of papers [13–52]. Especially it would be more interesting if a new physics can explain both the diphoton excess and other unsolved problems of the SM, such as non-zero neutrino masses.

In this paper, we explain both the diphoton excess and the active neutrino masses in a concrete model. The model extends the SM with four scalar singlets: one neutral scalar $\mathbb{S}$ transforming as $(1,\ 1,\ 0)$ under the SM gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$, one singly charged scalar Θ transforming as $(1,\ 1,\ 1)$ and two leptoquarks Φ and Ω transforming as $(\bar{3},\ 1,\ 4/3)$ and $(\bar{3},\ 1,\ 1/3)$. Θ interacts with the left-handed lepton doublets, Ω interacts with the left-handed lepton doublets and quark doublets, Φ interacts with the right-handed leptons and down-type quarks. In addition there is a quartic interaction of the type $\hat{\lambda}\mathbb{S}\Phi^\dagger\Omega\Theta$ + h.c., where $\hat{\lambda}$ is dimensionless coupling. In this way Majorana neutrino masses can be generated at the two-loop level as $\mathbb{S}$ gets vacuum expectation value (VEV). Elements of neutrino mass matrix are proportional to the charged lepton and down-type quark masses, and are suppressed by the loop factor. Thus one can naturally derive the electron-volt scale Majorana neutrino masses with new particles at the TeV scale. Furthermore, the observed 750 GeV diphoton excess may be explained as the scalar $\mathbb{S}$, which can be produced at the LHC through the gluon fusion. The ratio of $\Gamma(\mathbb{S} \to gg)/\Gamma(\mathbb{S} \to \gamma\gamma)$ is about $\mathcal{O}(25)$, which is the typical character of this model. The narrow width of $\mathbb{S}$ can be naturally realized in this model, while a broad width of $\mathbb{S}$ may be realized

[1] Actually if one of the photon jet in the diphoton signal was constructed by highly boosted photons coming from the decay of a light scalar, the observed diphoton signal could also be explained by a vector resonance [52], which is interesting but beyond the reach of this paper.