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Type-III two Higgs doublet model plus a pseudoscalar confronted with $h \to \mu\tau$, muon $g - 2$ and dark matter

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Abstract

In this work, we introduce an extra singlet pseudoscalar into the Type-III two Higgs doublet model (2HDM) which is supposed to solve a series of problems in the modern particle-cosmology. With existence of a light pseudoscalar, the $h \to \mu\tau$ excess measured at CMS and as well as the $(g-2)_\mu$ anomaly could be simultaneously explained within certain parameter spaces that can also tolerate the data on the flavor-violating processes $\tau \to \mu\gamma$ and Higgs decay gained at LHC. Within the same parameter spaces, the DM relic abundance is well accounted. Moreover, the recently observed Galactic Center gamma ray excess (GCE) is proposed to realize through dark matter (DM) pair annihilations, and in this work, the scenario of the annihilation being mediated by the pseudoscalar is also addressed.
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1. Introduction

Even though in the framework of a minimal extended Standard model (SM) with non-zero neutrino masses the leptonic flavor violation (LFV) process is almost unobservable for the smallness of neutrino masses which are experimentally confirmed [1]. Therefore, a direct search for

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the LFV processes would provide an ideal probe for new physics beyond SM, or in other words any observational anomaly may hint at its existence. Besides the B-factory, due to its high energy and luminosity, LHC is definitely the machinery for the exploration. A search for LFV has been performed by the CMS Collaboration via two channels $h \to \mu\tau_e$ and $h \to \mu\tau_h$, and a 2.4σ excess of the branching fraction $\text{BR}(h \to \mu\tau) = (0.84^{+0.39}_{-0.37})\%$) [2] is reported. If one could account such an excess as an anomaly, there should be some mechanisms which are obviously beyond SM, to be responsible for it. The Type-III two Higgs doublet model (2HDM) is one of them, because in the model a flavor-violating Yukawa interaction exists which may contribute to the LFV at tree level. The model has been explored extensively [3–11] to study this phenomenological observation. Furthermore, the Yukawa interaction contributes to the muon $g-2$ via one loop diagrams and thus would provide a possibility to explain the $(g-2)_\mu$ discrepancy [8,11,12]. Meanwhile, the flavor-changing Yukawa interaction would induce a substantial contribution to the radiative decay $\tau \to \mu\gamma$, thus the flavor-changing Yukawa interaction might be rigorously constrained by the available experimental data [9,11,12].

One of the main characteristics of the 21st century is that the cosmology has already become an accurate science and the corresponding observation must be combined with the precise measurements and new discoveries at the facilities on the Earth to testify the standing theories. The identity of dark matter (DM) and the interaction which determines the behavior of DM particles are the key point and searching for them is the most challenging job for both experimentalists and theorists of high energy physics and cosmologists.

Recently, the Fermi Large Area Telescope data show an excess of gamma-ray at energy of a few GeV coming from Galactic Center (GCE) [13–21]. To explain the observation, it is suggested that annihilation of DM particles weighing 30–70 GeV into $b\bar{b}$ is responsible for the GCE [22–24]. Even though there exist other proposals to explain the excess, such as a population of millisecond pulsars (MSP) [25,26] which might be responsible for GCE, it is not easy to explain the energy spectrum and spatial distribution of the GCE [27,28]. Thus in this work we discard the astrophysical source explanation [25–30] and focus on the DM scenario.

The dwarf galaxies are considered to be the cleanest sources for detecting gamma rays produced by DM annihilations, thus the data on gamma ray observed at Reticulum II [31–33] may imply existence of abundant DM at our galaxy. To be sure, we need to compute the cross section of DM annihilation in a model of particle physics. Meanwhile other cosmological phenomena must also be concerned, namely the DM annihilation cross section required by the new data should be of the same order as that determined by the thermal DM relic abundance.

However, the original Type-III 2HDM does not provide a natural explanation of the DM particle annihilation cross section. Thus we need to extend the model which can also accommodate the DM annihilation. It is noted that a pseudoscalar could mediate the annihilation of dark matter (DM) pair, meanwhile due to the small momentum transfer at t-channel, the interaction between the DM particles coming from the outer space and the nuclei in the detector is not affected by the existence of the new pseudoscalar, so that the DM particles may evade the direct search at not-much sensitive detectors. This idea has been implemented in various models [24,34–48]. It further motivates us to consider the DM explanation of the GCE, and introduce a Dirac fermion field serving as the DM candidate. In this work, we introduce a pseudoscalar a_0 into the Type-III 2HDM. The pseudoscalar does not directly couple to the SM particles, but it slightly mixes with the CP-odd Higgs which exists in the original Type-III 2HDM, thus it would effectively couple to SM via this mixing. Therefore the pseudoscalar can mediate an effective interaction between the DM $\chi\bar{\chi}$ and the SM fermions $b\bar{b}$.

Moreover, its introduction may bring up two more advantages as follows:

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