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The 750 GeV diphoton excess at the LHC and dark matter constraints

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Abstract

The recent reported 750 GeV diphoton excess at the 13 TeV LHC is explained in the framework of effective field theory assuming the diphoton resonance is a scalar (pseudoscalar) particle. It is found that the large production rate and the broad width of this resonance are hard to be simultaneously explained if only visible final states are considered. Therefore an invisible decay channel to dark matter (DM) is strongly favored by the diphoton resonance with a broad width, given a large coupling of the new scalar to DM. We set constraints on the parameter space in this scenario using the results from LHC Run 1, DM relic density, and DM direct and indirect detection experiments. We find that the DM searches can exclude a large portion of the parameter regions accounting for the diphoton excess with a broad width.

1. Introduction

A great success of LHC Run 1 is the discovery of the 125 GeV Higgs boson in the Standard Model (SM). With a higher collision energy of 13 TeV, LHC Run 2 is ideal for probing heavy ex-

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otic particles in new physics beyond the Standard Model (BSM). Recently, the CMS and ATLAS Collaborations have reported their results based on Run 2 data with an integrated luminosity of $\sim 3\ \mathrm{fb}^{-1}$ [1–3]. As the majority of Run 2 searches have not detected exotic signatures, their results have been used to set limits on BSM models, most of which are stronger than those from Run 1 searches. Some anomalies found in Run 1, such as the ~ 2 TeV diboson excess, have not yet been confirmed by the latest Run 2 searches [3].

However, some surprising results have been provided from diphoton resonance searches. Based on a data set of $3.2\ \mathrm{fb}^{-1}$, the ATLAS Collaboration found an excess in the diphoton invariant mass distribution around 750 GeV, with a local (global) significance of 3.9σ (2.3σ) [1]. A fit to data suggested that this excess could be due to a resonance with a width of about 45 GeV. A similar excess at ~ 760 GeV has also been reported by the CMS Collaboration based on $2.6\ \mathrm{fb}^{-1}$ data, with a lower local (global) significance of 2.6σ (1.2σ) [2]. Both collaborations claimed that this excess was not excluded by Run 1 data, because of the large uncertainties in this energy range.

This excess may be just due to statistical fluctuation, as many other disappeared anomalies in high energy physics experiments. Future LHC searches with more data are required to confirm its existence. Undoubtedly, if it is true, it would become the beginning of an epoch of BSM physics. According to the Landau–Yang theorem [4,5], a particle decaying into two photons cannot be of spin-1, implying that this 750 GeV resonance should be either a spin-0 or spin-2 particle. Spin-2 tensor fields can be realized in BSM physics related to gravity. For instance, this particle may be an excitation of the graviton in the Randall–Sundrum model. However, this kind of interpretations suffer stringent constraints [2].

Many studies on the diphoton excess assuming a scalar or pseudoscalar resonance have appeared soon after the reports [6–43]. This resonance, which is denoted as ϕ hereafter, can be realized as an axion or composite Higgs boson in models with new strong dynamics, as well as an exotic Higgs boson with weak coupling. The cross section of the $pp \to \phi \to \gamma\gamma$ signal is of $\mathcal{O}(10)\ \mathrm{fb}^{-1}$. In general, Higgs-photon couplings induced by top and W loops are suppressed. Therefore, heavy Higgs bosons in ordinary two Higgs doublet models (including Higgs bosons in the MSSM) could not account for this excess with such a large production rate [35,38,40]. Thus the excess may suggest the existence of new charged and colored particles coupled to ϕ. Furthermore, the broad width of ~ 45 GeV suggested by the ATLAS analysis is also a challenge for model building. On the other hand, the CMS fit seems to favor a narrower width, but the signal significance is too low. Nevertheless, current data with low statistics could not give a final conclusion.

In this work, we attempt to provide an interpretation of the diphoton excess in the context of effective field theory. We find that in order to explain the diphoton production rate, large ϕ couplings to gluons and photons are required. Considering the constraints from resonance searches of LHC Run 1, it is challenging to achieve a broad decay width, if only the visible decay final states, such as dijet, $\gamma\gamma$, ZZ, and WW, are taken into account. This implies that there may be some invisible decay channels. An appealing and interesting possibility is that ϕ can decay into dark matter (DM) particles, which compose $\sim 26\%$ of the Universe energy but leave no energy deposit in the ATLAS and CMS detectors. Thus it is straightforward to assume a scenario where ϕ is a portal between DM and SM particles, i.e., DM particles interact with SM particles through the ~ 750 GeV scalar (pseudoscalar) particle.

Constraints on this scenario are investigated in this work. We consider the limits from the LHC monojet search [44], the DM relic density measurement [45], DM direct detection results from the LUX experiment [46], and indirect detection results from the Fermi-LAT [47–49] and