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Scalar explanation of diphoton excess at LHC

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Abstract

Inspired by the diphoton signal excess observed in the latest data of 13 TeV LHC, we consider either a 750 GeV real scalar or pseudo-scalar responsible for this anomaly. We propose a concrete vector-like quark model, in which the vector-like fermion pairs directly couple to this scalar via Yukawa interaction. For this setting the scalar is mainly produced via gluon fusion, then decays at the one-loop level to SM diboson channels $gg, \gamma\gamma, ZZ, WW$. We show that for the vector-like fermion pairs with exotic electric charges, such model can account for the diphoton excess and is consistent with the data of 8 TeV LHC simultaneously in the context of perturbative analysis.

1. Introduction

The first data at the 13 TeV Large Hadron Collider (LHC) was released on December 15 2015 [1,2]. It shows an excess in diphoton final state at the invariant mass $M \simeq 750$ GeV, with local significance of order 3.9 σ and 2.6 σ for ATLAS and CMS, respectively. In contrast, no excesses in the Standard Model (SM) diboson channels such as $\gamma\gamma$, ZZ, WW, ZW, dilepton and dijet were seen in the old data of 8 TeV LHC [3–11].

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Table 1
Matters and their SM quantum numbers in the vector-like quark model. Another fermion doublet $\tilde{\Psi}$ is added to make sure that the model is free of gauge anomaly.

Matters	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$
ϕ	$\mathbf{1}$	$\mathbf{1}$	0
$\Psi = (\psi_1, \psi_2)^T$	$\mathbf{3}$	$\mathbf{2}$	q_ψ
$\tilde{\Psi} = (\tilde{\psi}_1, \tilde{\psi}_2)^T$	$\bar{\mathbf{3}}$	$\bar{\mathbf{2}}$	$-q_\psi$

If the diphoton excess is indeed a hint of some new physics beyond SM, for an on-shell decay to diphoton it should be due to either spin-0 or spin-2 scalar ϕ. To explain the observed excess, the cross section $\sigma(pp \to \phi \to \gamma\gamma)$ is required to satisfy the signal strength of order,

$$\sigma(pp \to \phi \to \gamma\gamma)\,|_{\sqrt{s}=13\ \text{TeV}} \simeq (8 \pm 3)\ \text{fb}. \tag{1.1}$$

Such SM singlet scalar which is responsible for the excess has stimulated extensive interests, see Ref. [12–54].

In this paper, we propose a concrete vector-like quark model, in which the vector-like fermion pairs directly couple to ϕ via tree-level Yukawa interaction. Under our setup, ϕ is mainly produced via gluon fusion, then decays at the one-loop level to SM diboson channels $gg, \gamma\gamma, ZZ, WW$, with the colored vector-like fermion pair running in the Feynman loop. For the vector-like fermion pairs with exotic electric charges, such model can account for the diphoton excess, and is consistent with the data of 8 TeV LHC simultaneously in the context of perturbative analysis.

This paper is organized as follows. In Sec. 2 we address the matter content in the vector-like quark model, define the parameter space, and summarize the experimental limits on ϕ and vector-like quark at the 8 TeV LHC. In Sec. 3 we explore the parameter space for ϕ either being a real scalar or pseudo-scalar. Finally, we conclude in Sec. 4.

2. The vector-like quark model

2.1. The model

In order to reproduce the on-shell decay $\phi \to \gamma\gamma$, which is a loop process for the SM singlet ϕ, we directly couple ϕ to a fermion doublet Ψ, the latter of which is a subsector of vector-like quark model as defined in Table 1. In this table, another fermion doublet $\tilde{\Psi}$ is added in order to evade the gauge anomaly problem.

For simplicity, we assume that the mass $M_{\tilde{\Psi}}$ for $\tilde{\Psi}$ is obviously larger than the mass M_Ψ for Ψ. Below the mass scale $M_{\tilde{\Psi}}$ the effective Lagrangian in the new physics is described by,[1]

$$\mathcal{L}_{\text{BSM}} = \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m_\phi^2\phi^2 + i\bar{\Psi}\gamma^\nu D_\nu\Psi - M_\Psi\bar{\Psi}\Psi + \mathcal{L}_{\text{Yukawa}}, \tag{2.1}$$

where

$$\mathcal{L}_{\text{Yukawa}} = \begin{cases} y\phi\bar{\Psi}\Psi, & \text{(scalar)}, \\ iy\phi\bar{\Psi}\gamma_5\Psi, & \text{(pseudo-scalar)}. \end{cases} \tag{2.2}$$

[1] The effective Lagrangian as analyzed in the previous version of this manuscript is a simplification of this concrete one.