750 GeV Diphoton excess from Gauged $B-L$ Symmetry

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Abstract

We show that the recently observed 750 GeV diphoton excess at LHC can be due to the decay of a $SU(2)_L$ singlet scalar particle having 3 units of charge under gauged $B-L$ symmetry. Such a particle arises as an essential ingredient of recently studied gauged $B-L$ extension of the Standard Model with unconventional charge assignment for right handed neutrinos. Apart from being one of the simplest extensions of the Standard Model, the model also contains a dark matter candidate and Dirac neutrinos with naturally small masses.

I. INTRODUCTION

The ATLAS and CMS collaborations at the LHC have recently reported an excess of events in the invariant mass distribution containing two photons at $\sqrt{s} = 13$ TeV [1–3]. The ATLAS Collaboration [2], with 3.2 fb^{-1} data, has reported an excess of 3.9σ at diphoton invariant mass around 750 GeV. The significance reduces to 2.3σ once the Look Elsewhere Effect is included. This corresponds to an excess in signal $\sigma(pp \to \gamma\gamma)$ of about (10 ± 3 fb) with a best fit width ~ 45 GeV. The value of the experimental acceptance in ATLAS is about 0.4.

The CMS collaboration has also found an excess in diphoton events with local significance 2.6σ [3] at $\sqrt{s} = 13$ TeV with 2.6 fb^{-1} data at mass around 750 GeV. This significance reduces to 2.0σ if large width (~ 45 GeV) is assumed. This translates to an excess in signal cross section $\sigma(pp \to \gamma\gamma)$ of about (6 ± 3 fb).

These excess events do not have any significant missing energy, leptons or jets associated with them. No excess of events have been found in ZZ, dilepton, dijet channels in the same invariant mass region for new data. Although this excess could well be a statistical fluctuation, it has drawn significant attention as it can also arise from decay of new particle with mass around 750 GeV [4].

If the observed diphoton excess indeed corresponds to decay of a hitherto unknown particle then this will be the first confirmation of new physics beyond the Standard Model (SM). If the observed excess is due to a resonance it has to be a boson and it cannot be a spin-1 particle [5, 6]. This leaves the possibility of it being either a spin-0 or spin-2 particle. If it is indeed a new particle then one must wonder what kind of new physics incorporates it. This issue can only be settled by looking at various possible new physics scenarios that can potentially lead to such a particle. It is generally expected that this new physics will also be related to other open problems in high energy physics which do not have a satisfactory explanation within SM. Chief among them is the problem of neutrino masses (and their relative smallness) and the nature of dark matter. It will be quite satisfying if the observed new particle has a natural connection with the models addressing at least one of these issues. In this work we assume this resonance to be a spin-0 particle and look at one such promising model based on gauge $B-L$ symmetry. This model was recently proposed to explain the smallness of neutrino mass if neutrinos are Dirac particles and also has an interesting dark matter candidate [7–9].

The gauged $B-L$ symmetry is one of the simplest and most well studied extension of SM. In SM, Baryon number B and Lepton number L are accidentally conserved classical symmetries. However, both B and L currents are anomalous and only the combination $B-L$ is anomaly free. In the conventional gauged $B-L$ model, the

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$B-L$ symmetry is promoted to an anomaly free gauge symmetry by addition of three right handed neutrinos ν_R^i each transforming as -1 under the $U(1)_{B-L}$. It was shown that if this $B-L$ symmetry is spontaneously broken by a $SU(2)_L$ singlet scalar χ_2 having two units of $B-L$ charge, then the right handed neutrinos can acquire a Majorana mass term M_R proportional to the vacuum expectation value (vev) u_2 of the singlet scalar. Moreover if the $B-L$ breaking scale is far greater than the electroweak scale then the right handed neutrinos acquire a large mass leading to a natural implementation of Type I seesaw mechanism. However, in this scenario the $B-L$ breaking scale is expected to be very high (same as seesaw scale) and it is very difficult to test this model at LHC.

Recently, another simple choice of $B-L$ charges for right handed neutrinos which leads to anomaly free $U(1)_{B-L}$ gauge symmetry has been proposed. Unlike the previous case, here the three right handed neutrinos transform as $\nu_R^i = (+5, -4, -4)$ under $B-L$ symmetry [7, 10]. It was shown that such a charge assignment can lead to Dirac neutrinos with naturally small masses if the $B-L$ symmetry is spontaneously broken by a $SU(2)_L$ singlet scalar χ_3 transforming as ~ 3 under $U(1)_{B-L}$ symmetry. This new $B-L$ model can also have a candidate for long lived scalar dark matter if two new singlet scalars transforming as $\chi_2 \sim 2$ and $\chi_6 \sim -6$ under $U(1)_{B-L}$ symmetry are added to it [9]. Unlike the conventional $B-L$ model, here the $B-L$ breaking scale need not be high and can be well within the reach of LHC. This opens up the possibility of testing various features of this model in the present run of LHC. Moreover, the dark matter in this model has a significant interaction with the nuclei and can be detected in present or near future dark-matter direct-search experiments. We refer the interested readers to [7–9] for further details. Thus, apart from providing a explanation for the nature and small masses for neutrinos as well as a candidate for dark matter, various aspects of this new $B-L$ model are quite testable both in colliders and dark matter direct detection experiments. Furthermore, as we will discuss in the subsequent sections, owing to presence of singlet scalars, this model is ideally suited to explain the recently observed 750 GeV diphoton excess and the aim of this paper is to look at this possibility in details.

The plan of the paper is as follows. In Section II we look at the details of the gauged $B-L$ symmetry model which is a slightly extended version of the previously discussed model. We show that the modified model is also free of anomalies. In Section III we look at the details of the scalar and Yukawa sectors and identify a viable candidate which can explain the observed 750 GeV diphoton excess. In Section IV we discuss the production and decay of the 750 GeV particle and compare our computation with the experimental results. We finally conclude in V.

II. THE GAUGE $B-L$ SYMMETRY MODEL

As mentioned before, the anomaly free gauged $B-L$ model with unconventional $B-L$ charges for right handed neutrinos [7, 8] was originally constructed to obtain Dirac neutrinos with naturally small masses. It was further extended in [9] to accommodate a long lived dark matter particle. The $SU(2)_L$ singlet scalars of the model are required to break the gauge $B-L$ symmetry and we show in this work, that a linear combination of these scalar can be a viable candidate for 750 GeV resonance, whose decay can provide a possible explanation for the recently observed diphoton excess [2, 3]. In this work we study a slightly extended version of the model discussed in [9], where we have also included two $SU(2)_L$ singlet vector "quarks" $X_{L,R}, Y_{L,R}$. Although they are $SU(2)_L$ singlets, these exotic quarks do carry $SU(3)_c$ colour charge as well as $U(1)_Y$, $U(1)_{B-L}$ charges. The $SU(3)_c \times SU(2)_L \times U(1)_Y$ and $U(1)_{B-L}$ charge assignment for the fermions in the model are as follows:

Fields	$SU(3)_c \times SU(2)_L \times U(1)_Y$	$U(1)_{B-L}$	Fields	$SU(3)_c \times SU(2)_L \times U(1)_Y$	$U(1)_{B-L}$
Q_L^i	$(3, 2, \frac{1}{3})$	$\frac{1}{3}$	L_L^i	$(1, 2, -1)$	-1
u_R^i	$(3, 1, \frac{4}{3})$	$\frac{1}{3}$	l_R^i	$(1, 1, -2)$	-1
d_R^i	$(3, 1, -\frac{2}{3})$	$\frac{1}{3}$	ν_R^1	$(1, 1, 0)$	5
ν_R^2	$(1, 1, 0)$	-4	ν_R^3	$(1, 1, 0)$	-4
N_L^i	$(1, 1, 0)$	-1	N_R^i	$(1, 1, 0)$	-1
X_L	$(3, 1, \frac{4}{3})$	3	X_R	$(3, 1, \frac{4}{3})$	0
Y_L	$(3, 1, -\frac{4}{3})$	-3	Y_R	$(3, 1, -\frac{4}{3})$	0

TABLE I: The $SU(3)_c \times SU(2)_L \times U(1)_Y$ and $U(1)_{B-L}$ charge assignment for the fermions. Here $i = 1, 2, 3$ represents the three generations.

In Table I apart from the SM particles we have also included three right handed neutrinos ν_R^i, three $SU(2)_L$ singlet heavy fermions $N^i_{L,R}$ (as in the previous model [9]) and two pair of exotic "quarks" $X_{L,R}$, $Y_{L,R}$ which carry color and electromagnetic charges but are singlet under $SU(2)_L$.

The charge assignment for the scalars in this model (which are same as in [9]) are as follows:

Fields	$SU(3)_c \times SU(2)_L \times U(1)_Y$	$U(1)_{B-L}$	Fields	$SU(3)_c \times SU(2)_L \times U(1)_Y$	$U(1)_{B-L}$
$\Phi = (\phi^+, \phi^0)^T$	$(1, 2, 1)$	0	χ_2	$(1, 1, 0)$	2
χ_3	$(1, 1, 0)$	3	χ_6	$(1, 1, 0)$	-6

TABLE II: The $SU(3)_c \times SU(2)_L \times U(1)_Y$ and $U(1)_{B-L}$ charge assignment for the scalars.

In Table II, $\Phi = (\phi^+, \phi^0)^T$ is the usual $SU(2)_L$ doublet scalar and χ_i are $SU(2)_L$ singlet scalars. The new fermions introduced in the model can potentially lead to anomalies. Thus, it is important to ensure that the model is anomaly free. The new particles can induce following triangular anomalies:

$$[SU(3)_c]^2\, U(1)_{B-L} \quad \rightarrow \quad \sum_q (B-L)_{q_L} - \sum_q (B-L)_{q_R} \tag{1}$$

$$[SU(2)_L]^2\, U(1)_{B-L} \quad \rightarrow \quad \sum_l (B-L)_{l_L} + 3 \sum_q (B-L)_{q_L} \tag{2}$$

$$[U(1)_Y]^2\, U(1)_{B-L} \quad \rightarrow \quad \sum_{l,q} \left[Y^2_{l_L} (B-L)_{l_L} + 3\, Y^2_{q_L} (B-L)_{q_L} \right] - \sum_{l,q} \left[Y^2_{l_R} (B-L)_{l_R} + 3\, Y^2_{q_R} (B-L)_{q_R} \right] \tag{3}$$

$$U(1)_Y\, [U(1)_{B-L}]^2 \quad \rightarrow \quad \sum_{l,q} \left[Y_{l_L} (B-L)^2_{l_L} + 3\, Y_{q_L} (B-L)^2_{q_L} \right] - \sum_{l,q} \left[Y_{l_R} (B-L)^2_{l_R} + 3\, Y_{q_R} (B-L)^2_{q_R} \right] \tag{4}$$

$$[U(1)_{B-L}]^3 \quad \rightarrow \quad \sum_{l,q} \left[(B-L)^3_{l_L} + 3\, (B-L)^3_{q_L} \right] - \sum_{l,q} \left[(B-L)^3_{l_R} + 3\, (B-L)^3_{q_R} \right] \tag{5}$$

$$[\text{Gravity}]^2\, [U(1)_{B-L}] \quad \rightarrow \quad \sum_{l,q} \left[(B-L)_{l_L} + 3\, (B-L)_{q_L} \right] - \sum_{l,q} \left[(B-L)_{l_R} + 3\, (B-L)_{q_R} \right] \tag{6}$$

It has already been shown in [7] that for the case when exotic quarks X, Y are not present, the model is completely anomaly free. It can also be easily seen that the addition of the X, Y quarks does not spoil the anomaly cancellation and hence the model remains anomaly free.

III. THE SCALAR AND YUKAWA SECTORS

In this section we look at the details of the scalar and Yukawa sector of our model and identify the candidate for 750 GeV resonance. The scalar potential of our model is given by

$$\begin{aligned} V &= -\mu_0^2(\Phi^\dagger\Phi) + m_2^2(\chi_2^*\chi_2) - \mu_3^2(\chi_3^*\chi_3) - \mu_6^2(\chi_6^*\chi_6) + \frac{1}{2}\lambda_0(\Phi^\dagger\Phi)^2 + \frac{1}{2}\lambda_2(\chi_2^*\chi_2)^2 + \frac{1}{2}\lambda_3(\chi_3^*\chi_3)^2 + \frac{1}{2}\lambda_6(\chi_6^*\chi_6)^2 \\ &+ \lambda_{02}(\chi_2^*\chi_2)(\Phi^\dagger\Phi) + \lambda_{03}(\chi_3^*\chi_3)(\Phi^\dagger\Phi) + \lambda_{06}(\chi_6^*\chi_6)(\Phi^\dagger\Phi) + \lambda_{23}(\chi_2^*\chi_2)(\chi_3^*\chi_3) + \lambda_{26}(\chi_2^*\chi_2)(\chi_6^*\chi_6) \\ &+ \lambda_{36}(\chi_3^*\chi_3)(\chi_6^*\chi_6) + [\frac{1}{2}f_{36}(\chi_3^2\chi_6) + h.c.] + [\frac{1}{6}\lambda'_{26}(\chi_2^3\chi_6) + h.c.], \end{aligned} \tag{7}$$

The Minimum of V is given by:

$$V_0 = -\mu_0^2 v^2 - \mu_3^2 u_3^2 - \mu_6^2 u_6^2 + \lambda_0 \frac{v^4}{2} + \lambda_3 \frac{u_3^4}{2} + \lambda_6 \frac{u_6^4}{2} + \lambda_{03} u_3^2 v^2 + \lambda_{06} u_6^2 v^2 + \lambda_{36} u_3^2 u_6^2 + f_{36} \frac{u_3^2 u_6}{2}, \tag{8}$$

where $\langle\phi^0\rangle = v, \langle\chi_3\rangle = u_3, \langle\chi_6\rangle = u_6$, are the vev of the scalar fields. Moreover, just like in [9], here also the singlet scalar χ_2 does not acquire any vev i.e. $\langle\chi_2\rangle = 0$. The minimum of V is determined by

$$\begin{aligned}
\mu_0^2 &= \lambda_0 v^2 + \lambda_{03} u_3^2 + \lambda_{06} u_6^2, && (9)\\
\mu_3^2 &= \lambda_3 u_3^2 + \lambda_{03} v^2 + \lambda_{36} u_6^2 + f_{36} u_6, && (10)\\
\mu_6^2 &= \lambda_6 u_6^2 + \lambda_{06} v^2 + \lambda_{36} u_3^2 + \frac{f_{36} u_3^2}{2u_6}. && (11)
\end{aligned}$$

Since $\langle \chi_2 \rangle = 0$, there is one dark-matter scalar boson χ_2 with mass given by

$$m_{\chi_2}^2 = m_2^2 + \lambda_{02} v^2 + \lambda_{23} u_3^2 + \lambda_{26} u_6^2. \tag{12}$$

There is also one physical pseudoscalar boson

$$A = \sqrt{2} Im(2u_6 \chi_3 + u_3 \chi_6)/\sqrt{u_3^2 + 4u_6^2} \tag{13}$$

with mass given by

$$m_A^2 = -f_{36}(u_3^2 + 4u_6^2)/2u_6. \tag{14}$$

There are three physical scalar bosons spanning the basis $[h, \sqrt{2}Re(\chi_3), \sqrt{2}Re(\chi_6)]$, with 3×3 mass-squared matrix given by

$$M^2 = \begin{pmatrix} 2\lambda_0 v^2 & 2\lambda_{03} u_3 v & 2\lambda_{06} u_6 v \\ 2\lambda_{03} u_3 v & 2\lambda_3 u_3^2 & 2\lambda_{36} u_3 u_6 + f_{36} u_3 \\ 2\lambda_{06} u_6 v & 2\lambda_{36} u_3 u_6 + f_{36} u_3 & 2\lambda_6 u_6^2 - f_{36} u_3^2/2u_6 \end{pmatrix}. \tag{15}$$

A. Simplifying Scenario

The mass matrix in Eq. 15 can be diagonalized to give three CP even scalars which will be linear combinations of Φ, χ_3, χ_6 scalars. However for sake of illustration, we look at a special case of the generic mass matrix in Eq. 15 which takes a simple form if we assume

$$\begin{aligned}
2\lambda_0 v^2 &= a^2 & \Rightarrow \lambda_0 &= \frac{a^2}{2v^2}\\
4\lambda_{03} u_3 v &= ab & \Rightarrow \lambda_{03} &= \frac{ab}{4u_3 v}\\
4\lambda_{06} u_6 v &= ab & \Rightarrow \lambda_{06} &= \frac{ab}{4u_6 v}\\
2\lambda_3 u_3^2 &= b^2 & \Rightarrow \lambda_3 &= \frac{b^2}{2u_3^2}\\
4\lambda_{36} u_3 u_6 + 2f_{36} u_3 &= b^2 & \Rightarrow f_{36} &= \frac{1}{2\,u_3}\left(b^2 - 4\lambda_{36} u_3 u_6\right)\\
2\lambda_6 u_6^2 - \frac{f_{36} u_3^2}{2u_6} &= b^2 & \Rightarrow \lambda_6 &= \frac{1}{2u_6^2}\left(b^2 + \frac{f_{36} u_3^2}{2u_6}\right)
\end{aligned} \tag{16}$$

where a and b are two independent parameters. With these simplifying assumptions, the mass matrix of Eq. 15 becomes

$$\begin{pmatrix} a^2 & \frac{ab}{2} & \frac{ab}{2} \\ \frac{ab}{2} & b^2 & \frac{b^2}{2} \\ \frac{ab}{2} & \frac{b^2}{2} & b^2 \end{pmatrix} \tag{17}$$

The eigenvalues of the mass matrix in Eq. 17 are given by

$$\begin{aligned}
\Sigma_1 &= \frac{1}{4}\left(2a^2 + 3b^2 - \sqrt{4a^4 - 4a^2b^2 + 9b^4}\right) \\
\Sigma_2 &= \frac{b^2}{2} \\
\Sigma_3 &= \frac{1}{4}\left(2a^2 + 3b^2 + \sqrt{4a^4 - 4a^2b^2 + 9b^4}\right)
\end{aligned} \tag{18}$$

The masses of the scalars are then given by

$$m_1 = \sqrt{2\Sigma_1}\,, \quad m_2 = \sqrt{2\Sigma_2}\,, \quad m_3 = \sqrt{2\Sigma_3} \tag{19}$$

with one scalar having the mass same as the 125 GeV resonance and another having mass 750 GeV. For sake of definiteness we will identify the first eigenstate with the 125 GeV scalar (henceforth called "Higgs") and the second eigenstate as 750 GeV scalar i.e. we demand $m_1 = 125$ GeV and $m_2 = 750$ GeV. The mass of the third scalar then depends on the value of a and b. Solving for a and b we find that $a = 108.5$ GeV and $b = 750$ GeV leads to desired masses for m_1 and m_2 scalars. The mass of the third scalar m_3 then becomes $m_3 = 1.30$ TeV.

The masses of the pseudoscalar, dark matter and Z' are dependent on the value of other free parameters e.g. the value of vevs u_3, u_6, the $U(1)_{B-L}$ coupling g_X as well as on the quartic coupling of scalars λ_{ij}. We also like to note that in the simplified mass matrix of Eq. 17, not all of λ_{ij} are independent parameters owing to Eq. 16. The mass of dark matter χ_2 is also dependent on the additional parameter m_2^2 and the quartic couplings λ_{i2}; $i = 0, 3, 6$. Thus for a large range of parameter space, we can also have heavy Z' (as required by constraints from LUX dark matter direct detection experiment [9, 11]) and the dark matter $m_{\chi_2} \sim 100$ GeV along with a heavy pseudoscalar.

B. Higgs Coupling to SM Gauge Bosons

In Section III A, we showed that in a simplified mass matrix, one of the scalar combinations can be identified with the 125 GeV Higgs recently discovered at LHC. The recent data from both ATLAS and CMS experiments suggest that this scalar has couplings very similar to SM Higgs couplings with the SM gauge bosons. In this section we show that in our model also, there exists a decoupling limit where one of the scalars will have almost SM like couplings with the SM gauge bosons.

For sake of simplicity we will work with the simplified mass matrix of Eq. 17. The mass matrix mixes $\phi_0^R, \chi_3^R, \chi_6^R$ states with each other. This matrix can be diagonalized by an orthogonal matrix with the diagonal matrix corresponding to the masses of the three physical scalars as shown in Eq. 18. The physical scalars are then given by

$$\begin{aligned}
h &= \cos\theta\,\phi_0^R - \sin\theta(\chi_6^R + \chi_3^R) = 125\,\text{GeV} \\
H_1 &= (\chi_6^R - \chi_3^R) = 750\,\text{GeV} \\
H_2 &= \sin\theta\,\phi_0^R + \cos\theta(\chi_6^R + \chi_3^R)
\end{aligned} \tag{20}$$

where $\tan 2\theta = \dfrac{2\sqrt{2}ab}{3b^2 - 2a^2}$. It is clear from Eq. 20 that as $\sin\theta \to 0$, h couplings to SM gauge bosons become SM like. For the case of $a = 108.5$ GeV and $b = 750$ GeV we find that $\cos\theta = 0.997$ $\sin\theta = 0.069$. This implies that in our model the couplings of the scalar h of mass 125 GeV with W, Z gauge bosons are almost SM like. The small deviations from the SM like couplings are well within the experimental limits [12]. It should be noted that in this limit the other scalars as well as the Z' boson can be made heavy (assuming all couplings to be $\mathcal{O}(1)$) in congruence with the experimental bounds for these particles [9].

C. The Yukawa Sector

Apart from its coupling to the scalars, χ_3 has following Yukawa couplings

$$\mathcal{L}_{\chi_3} \;=\; f_X\,\bar{X}_L X_R \chi_3 \,+\, f_Y\,\bar{Y}_L Y_R \chi_3^* + + f_N\,\bar{N}_L \nu_R^{2,3} \chi_3 \,+\, h.c. \tag{21}$$

As evident from Eq. 21 both quarks X, Y acquire mass after spontaneous breaking of $B-L$ symmetry and the masses are proportional to the vev u_3 of χ_3. The Yukawa coupling of χ_3 translates into Yukawa coupling of the scalar $H_1 \equiv \chi_3 - \chi_6$. The Yukawa couplings of other scalars with fermions are same as in [9] and we refer the interested reader to [9] for further details. Owing to the coupling of χ_3 with quarks X, Y; the 750 GeV scalar H_1 can be efficiently produced through gluon-gluon fusion at LHC. The production and decay of this scalar are discussed in details in the next section.

IV. PRODUCTION AND DECAY OF H_1

In this section we look at the details of the production and decay channels for the 750 GeV scalar at the LHC. In particular, we show that the decay of this scalar to two photons can lead to the observed diphoton excess. Moreover, as we will show, the decay of H_1 to SM fermions and the Higgs are suppressed thus explaining the non-observation of any excess in other channels.

Since, χ_3 couples to quarks X, Y through its Yukawa couplings Eq. 21, therefore, at LHC $H_1 = (\chi_6^R - \chi_3^R)$ can be efficiently produced by gluon-gluon fusion through triangular loop involving X, Y. If both X, Y are heavier than $\frac{m_{H_1}}{2}$ then the tree level decay of H_1 to both X, Y is kinematically forbidden. In such a case its decay to two photons through triangular loop involving X, Y as shown in fig 1, can be significant leading to the observed anomaly in diphoton channel.

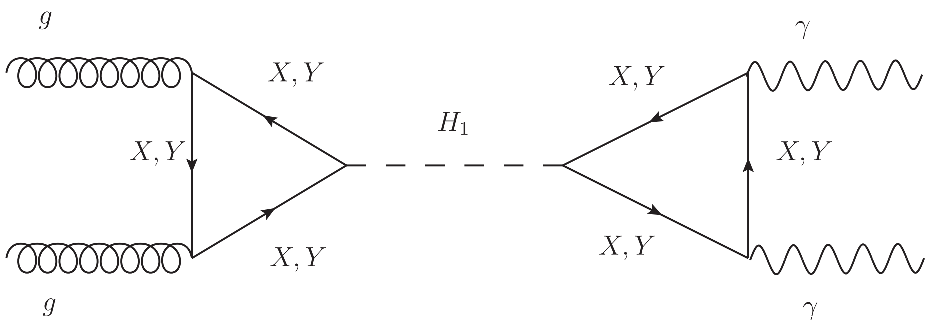

FIG. 1: Production and decay of 750 GeV scalar to two photons.

Apart from its decay to two photons, H_1 can also decay into a pair of gluons or Higgs (h) as shown in fig. 2 and fig 3 respectively.

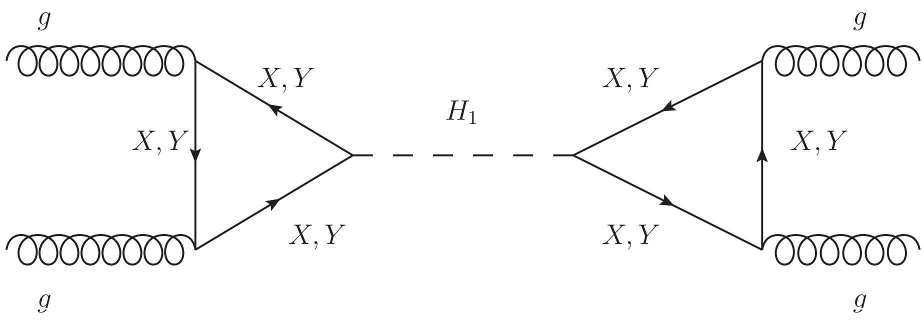

FIG. 2: Production and decay of 750 GeV scalar to two gluons.

Since the SM like Higgs (h) couples to both χ_3 and χ_6 with same coupling strength, this will result in cancellation of its interaction strength with $H_1 \equiv \chi_3 - \chi_6$, resulting in very small $H_1 hh$ coupling. Hence the $H_1 \to hh$ decay will

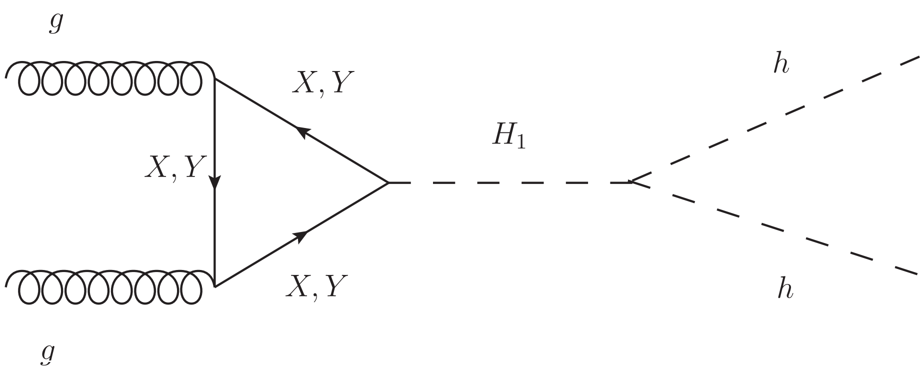

FIG. 3: Production and decay of 750 GeV scalar to two Higgs. Owing to negligible H_1hh coupling, this decay mode is highly suppressed.

be vanishingly small. Furthermore, since H_1 is primarily a mixed state of $SU(2)_L$ singlets χ_3 and χ_6 as shown in Eq. 20 therefore it has negligible coupling to SM fermions as well as W and Z gauge bosons. Therefore, its decay in other channels like dilepton, dijet and diboson is extremely suppressed. This observation is also in congruence with the experimental results which show lack of any statistically significant excess in these channels.

Thus the only prominent decay modes of interest are $H_1 \to \gamma\gamma$ and $H_1 \to gg$. The decay widths of H_1 in these modes are given as,

$$\Gamma(H_1 \to \gamma\gamma) = \frac{\alpha^2 m_{H_1}}{64\pi^3} \left| 2N_c \sum_{i=X,Y} f_i Q_i^2 \sqrt{\tau_i}(1 + (1-\tau_i) f(\tau_i) \right|^2 , \quad (22)$$

$$\Gamma(H_1 \to gg) = \frac{\alpha_s^2 m_{H_1}}{32\pi^3} \left| 2 \sum_{i=X,Y} f_i \sqrt{\tau_i}(1 + (1-\tau_i) f(\tau_i) \right|^2 , \quad (23)$$

where $\tau_i = \frac{4m_i^2}{m_{H_1}^2}$ with m_i, Q_i being corresponding fermion (X, Y) masses and electromagnetic charges respectively. The f_i s here denote fermion Yukawa couplings with the scalar H_1 whereas α_s, α denote strong and electromagnetic interaction gauge coupling strengths. N_c is the color factor which is 3 for the quarks. The $f(\tau_i)$ for our case, where $m_{X,Y} > m_{H_1}/2$ is given as

$$f(\tau_i) = (\sin^{-1}[\frac{1}{\sqrt{\tau_i}}])^2. \quad (24)$$

Thus, H_1 is an ideal candidate to explain the observed diphoton excess and lack of significant excess in other decay channels.

A. Numerical Results

In this section we present the numerical results and the allowed parameter range for the masses of the quarks X, Y and the Yukawa coupling which can explain the excess observed at the LHC in the diphoton channel. For this part we have used MadGraph5aMC@NLO[13] with NN23LO1 PDF set[14] to obtain the numerical estimates taking K factor of 1.5 into account for NLO correction [15].

As mentioned before, there are only two important decay modes for H_1 namely $H_1 \to \gamma\gamma$ and $H_1 \to gg$, both going through triangle loops involving X, Y quarks as shown in Fig 1 and Fig. 2 respectively. Since, both g and γ couple to the quarks through gauge interactions so their interaction strengths are fixed, and are proportional to α_s, α, the strong and electromagnetic coupling constants respectively. Hence, in our model the production and decay rate of H_1

depends on only two free parameters, the masses of X, Y quarks and the Yukawa coupling between H_1 and quarks. Moreover, since the quarks X, Y acquire mass through the vev of χ_3 so the Yukawa coupling can be equivalently replaced by the vev u_3 as a free parameter.

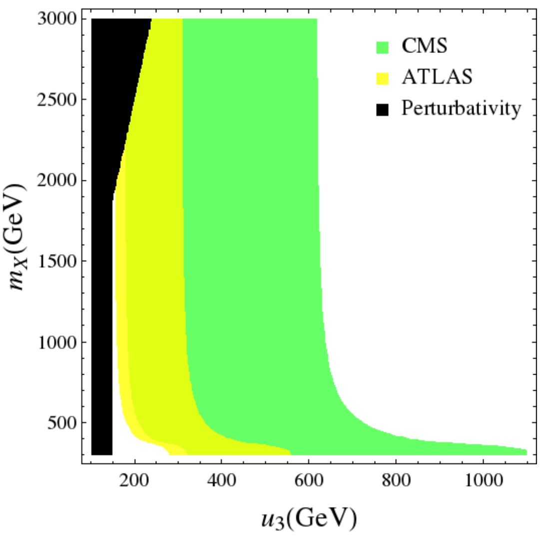

FIG. 4: The allowed m_X - u_3 range corresponding to CMS (green) and ATLAS (yellow) ranges with 95% confidence level. The black shaded region is excluded by the perturbativity constraints.

In Fig. 4 we show the allowed ranges of the exotic quark masses and the value of the vev, $\langle \chi_3 \rangle = u_3$, that can explain the observed 750 GeV diphoton excess for both the CMS and ATLAS experiments within 95% confidence level. In obtaining the numerical results, for simplicity we assume that the masses of the exotic quarks X, Y are degenerate i.e. $m_X = m_Y$ and treat them as a single parameter m_X. We have also required that all the couplings in our model remain perturbative. The region of the parameter space excluded due to non-perturbativity of the couplings is explicitly shown in Fig. 4.

Since, neither experiment has seen any hint or anomalous excess in any channel for masses below 750 GeV, we further require that all the other new particles (except dark matter) should be sufficiently massive. Thus we require that the mass of the pseudoscalar $m_A > 1$ TeV. The mass of other CP even scalar H_2 is also greater than 1 TeV as obtained in Section III B. We have kept the mass of the dark matter $\chi_2 \sim 100$ GeV. Also, we limit the mass of the Z' boson $m_{Z'} > 12$ TeV which is well above the dark matter direct detection constraints from the LUX experiment[9, 11].

We also impose the 8 TeV exclusion limits for the heavy scalars (CP-odd or CP-even) of mass 750 GeV in all other channels. As mentioned before, the scalar H_1 that we are considering here, does not couple to SM fermions at tree level. Therefore the limits given in [16] can be easily satisfied. Moreover, the scalar is a neutral SU(2) singlet. So it can couple to ZZ, $Z\gamma$ only through triangle loop of the exotic fermions. As the exotic fermions are SU(2) singlet even the $H_1 \to WW$ decay through the triangle loop is not possible. So the limits presented in [17] do not put any extra constraint on the model. The coupling $H_1 hh$ is also negligibly small and $\sigma(pp \to H_1 \to hh)$ is well under the experimental limit [18]. Finally we have required that the H_1 decay to gluons through the process $pp \to H_1 \to gg$ should be within experimental 95% confidence limit i.e. $\sigma_{gg} < 2.5$ pb[19]. Our model predicts a cross section of σ_{gg} below this value. Thus the 750 GeV excess can be understood in our model as the decay of H_1 to a pair of photons.

V. CONCLUSIONS

The recently observed 750 GeV diphoton excess has drawn significant attention as it could be the first signs of new physics at LHC. Although it is too early to conclude that this is a definite sign of new physics but nonetheless it raises an intriguing possibility that it might originate from decay of a hitherto unknown particle. In this work we have looked at the extended gauged $B - L$ symmetry model with unconventional charges for the right handed neutrinos as a possible candidate new physics model to explain the 750 GeV excess. The model was originally constructed to obtain Dirac neutrinos with naturally small masses and also has a long lived dark matter particle.

Unlike the conventional gauged $B-L$ symmetry model where the $B-L$ scale is expected to be quite high, being related with the seesaw scale, in our model the $B-L$ scale can be well within the LHC range thus opening up the possibility of testing its various aspects at LHC.

We have looked at the possibility that the observed diphoton excess can arise due to decay of the scalar particle H_1 into two photons. This scalar in our model is predominantly composed of the singlet scalars χ_3 and χ_6 which are essential ingredients of the model. They are required in order to spontaneously break the gauged $B-L$ symmetry as well as to obtain Dirac neutrinos with small masses. We have further shown that the model not only explains the diphoton excess but also satisfies all the other experimental constraints like non-observation of any excess in dilepton, dijet and diboson channels. It also has a 125 GeV particle h which has almost SM Higgs like couplings to the other SM particles and satisfies all the other experimental constraints for the 125 GeV scalar. Moreover, since in our model h is predominantly composed of the $SU(2)_L$ doublet scalar with very small admixture from $SU(2)_L$ singlet scalars, it naturally explains why the 125 GeV particle has almost SM like couplings.

Thus to conclude, the gauged $B-L$ model considered here appears to be a promising candidate for new physics. It has all the right ingredients to explain not only the 750 GeV diphoton excess but all the other experimental results both for the 750 GeV resonance as well as the 125 GeV resonance. Moreover, the model also connects the observed new physics with the already well know and long standing problems of neutrino masses and dark matter and attempts to provide a unifying solution to all of them. Also, it has several testable predictions like existence of heavier particles in ~ 1 TeV range, Dirac nature of neutrinos and candidate for dark matter. These aspects can be tested in future run of LHC as well as in dark matter direct detection experiments and in various neutrino physics experiments.

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