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Singlet scalar resonances and the diphoton excess

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ABSTRACT

ATLAS and CMS recently released the first results of searches for diphoton resonances in 13 TeV data, revealing a modest excess at an invariant mass of approximately 750 GeV. We find that it is generically possible that a singlet scalar resonance is the origin of the excess while avoiding all other constraints. We highlight some of the implications of this model and how compatible it is with certain features of the experimental results. In particular, we find that the very large total width of the excess is difficult to explain with loop-level decays alone, pointing to other interesting bounds and signals if this feature of the data persists. Finally we comment on the robust $Z\gamma$ signature that will always accompany the model we investigate.

1. Introduction

The excess found in diphoton final states in the 13 TeV ATLAS and CMS data at 750 GeV [1,2] presents an interesting model-building challenge. (While this paper was in preparation a number of attempts at explaining the diphoton excess appeared [3].) ATLAS and CMS both characterize the events that make up their signal to have the same composition as the background in sidebands [1,2]. Therefore, we assume that this peak in the event spectrum comes from the direct production of a resonance rather than a cascade decay.

If the signal is caused by a resonance that decays to diphotons, the Landau–Yang theorem [4] restricts the spin of the resonance to 0 or 2. The spin 2 possibility was preliminarily investigated by CMS [2], and, though interesting, it is difficult to construct a model that satisfies all constraints. However, an example of a scalar resonance which decays to diphotons is already provided by the SM Higgs, illustrating that it is straightforward to construct a "cousin" of the Higgs to explain this excess.

Models of a scalar resonance which explain the excess can come from sectors with a wide variety of field content and quantum number assignments [3]. The simplest possibility which avoids many correlated bounds is a resonance that is a singlet under the Standard Model gauge group. This implies that the coupling to protons and photons is generated by loops of new non-Standard Model particles that are colored and charged.

As discussed in more detail below, the width of the excess preferred by ATLAS and CMS [1,2] immediately implies additional constraints on singlet models. The preferred fit from ATLAS has a width of 45 GeV [1] with a local significance of 3.9σ, although this represents only a marginal improvement over a narrow-width model. CMS slightly prefers a narrow width [2], but overall has a smaller number of events, which can be partially attributed to their lower luminosity. The model point favored by CMS data has a width of $\mathcal{O}(100\text{ MeV})$, with an excess of 2.6σ. However, CMS is compatible at a similar level of confidence with a width of 42 GeV. It should be noted that ATLAS, while compatible with narrow width, prefers a larger width for several reasons. In the narrow width model, ATLAS finds a pull based on marginalizing over the width. This indicates a resonance width larger than the experimental resolution of 5.3 GeV (we estimate this by a linear interpolation on the diphoton invariant mass resolution parameter listed in section 5 of [1]). Additionally, when comparing the excess between 13 TeV and 8 TeV, ATLAS finds that the narrow width is only compatible at the 2.2σ level whereas the larger width is compatible with a smaller 1.4σ tension. Given the limited data it is therefore still possible to have a narrow width (indicative, as we discuss below, of strictly loop-induced processes), but it is more experimentally favored to have a larger width.

This brings singlet models under some tension. The number of observed photons is given by

$$N_{\gamma\gamma} = \sigma_{\text{prod}} \times \frac{\Gamma_{\gamma\gamma}}{\Gamma_{\text{tot}}} \times \mathcal{L} \times \epsilon \times A, \tag{1}$$

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where σ_{prod} is the production cross section for $pp \to$ resonance, $\Gamma_{\gamma\gamma}$ is the partial width for the resonance to decay into photons, Γ_{tot} is the full width of the resonance, and $\mathcal{L}$, ϵ, A are the luminosity, efficiency, and acceptance of the experiment. The efficiency and acceptance are not explicitly given, but we find $A = 0.8$ by mimicking the ATLAS cuts with a MadGraph [5] parton level simulation; one can alternately estimate $\epsilon \times A = 0.4375$ by linearly extrapolating this factor from Sec. 6 of [1]. Given the relatively high object identification efficiencies, a reasonable range might be $0.4 \lesssim \epsilon \times A \lesssim 0.7$. We use $\epsilon \times A = 0.5$ in what follows, but our results may trivially be rescaled as desired. The characteristic size of $\Gamma_{\gamma\gamma}$ coming from a loop induced decay is

$$\Gamma_{\gamma\gamma} \sim \frac{\alpha_{\text{EM}}^2 m_S^3}{256\pi^3 m_L^2} \tag{2}$$

where m_S is the mass of the resonance and m_L is the mass of the charged particle in the loop responsible for coupling to photons. Assuming that no particles that couple the resonance to the SM via a loop provide tree-level decay modes for the resonance, and taking $\mathcal{O}(1)$ couplings, this provides a rough bound on the partial width into diphotons of $\Gamma_{\gamma\gamma} \sim \mathcal{O}(50)$ MeV. Therefore if Γ_{tot} is near the 45 GeV value preferred by ATLAS, in any model with a singlet scalar, the number of diphoton events is suppressed by $\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\text{tot}}} \lesssim \mathcal{O}(10^{-3})$. While this suppression is less severe than it would be for a copy of the Higgs of a similar mass, we show below that generating a large enough total event rate and cross section nevertheless provides some interesting tension even at large coupling. This provides opportunities for ATLAS and CMS to test this hypothesis in current data. This also provides bounds on the types of decay modes the resonance can have based on the earlier runs of the LHC.

2. The "Q L Model" and the excess

Assuming a singlet scalar S, we need to construct a model which couples the S to new non-Standard Model particles, allows for production in pp collisions, and leads to diphoton decays. The simplest way to achieve this is to couple S to a vector-like pair of fermions. The most economical model consists of adding a single pair of colored and hypercharged fermions, thus providing for loop-level couplings to gluons and photons. The ratio of these couplings will depend on the charges and masses of the loop particles. However, to provide for maximum freedom in separately adjusting the partial width of the resonance into gluons and photons, a more universal "module" will consist of a colored fermion pair and an uncolored but hypercharged pair. In principle a colored fermion pair could have hypercharge zero, but this leads to novel collider signatures [6] which are beyond the scope of this paper. Therefore we will look at a model where we introduce a vector like fermion Q with SM quantum numbers $(\mathbf{3},\mathbf{1})_{q_Q}$ and another called L transforming as $(\mathbf{1},\mathbf{1})_{q_L}$. This allows us to both dial the ratio of gluon and photon decays and later easily introduce decay modes for Q and L. The Lagrangian for S, Q, and L (excluding the decays of Q and L and their gauge interactions) is given by

$$\mathcal{L}_{QL} \supset \frac{1}{2} m_S^2 S^2 + y_Q \bar{Q} Q S + m_Q \bar{Q} Q + y_L \bar{L} L S + m_L \bar{L} L, \tag{3}$$

where we assume that $m_Q, m_L \geq m_S/2$. All S particles are produced as in Fig. 1, and decay as in Fig. 2.

Assuming for simplicity that $q_Q = 0$, so that the decay to gluons (photons) is mediated strictly by Q (L) particles, as in the top left and bottom panels of Fig. 2, the diphoton branching ratio is [7]

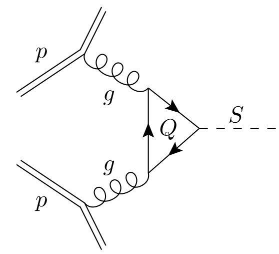

Fig. 1. Production of S particles from a loop of Q's.

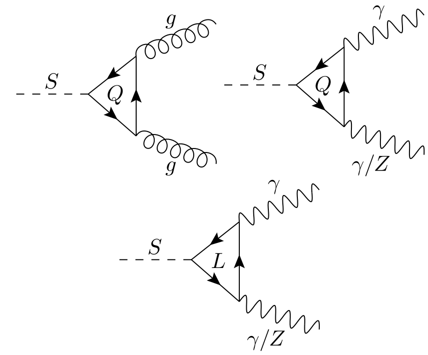

Fig. 2. Decay of S particles via loops of Q's and L's.

$$\begin{aligned}\text{Br}_{\gamma\gamma}^{QL} &= \frac{\Gamma(S \underset{L}{\to} \gamma\gamma)}{\Gamma(S \underset{L}{\to} \gamma\gamma) + \Gamma(S \underset{Q}{\to} gg)} \\ &= \frac{q_L^4 \alpha_{\text{EM}}^2 \left|A_{1/2}^L\right|^2 \epsilon_L^2}{q_L^4 \alpha_{\text{EM}}^2 \left|A_{1/2}^L\right|^2 \epsilon_L^2 + 2K\alpha_s^2 \left|A_{1/2}^Q\right|^2 \epsilon_Q^2},\end{aligned} \tag{4}$$

where "$\underset{i}{\to}$" means "via a loop of i particles;" $\epsilon_i \equiv y_i m_t / y_t m_i$; the ratio $\epsilon_Q^2/\epsilon_L^2$ is free but by assumption is less than 1; $A_{1/2}^i$ is a loop function [7][1]; K is the k-factor for the two gluon decay; and α_{EM}, α_s are the electromagnetic and strong fine structure constants. The number of diphoton events is

$$N_{\gamma\gamma}^{QL} \simeq \frac{\epsilon_{\text{eff}} \mathcal{L} \bar{\sigma} \epsilon_Q^2}{1 + \frac{460}{q_L^4} \frac{\epsilon_Q^2}{\epsilon_L^2} \frac{\left|A_{1/2}^Q\right|^2}{\left|A_{1/2}^L\right|^2}} \frac{\left|A_{1/2}^Q\right|^2}{\left|A_{1/2}^t\right|^2}, \tag{5}$$

where we define the Higgs production cross section as $\bar{\sigma}$, and rescale this to find the resonance production cross section using $K = 1.7$, $\alpha_{\text{EM}} \simeq 1/127$, and $\alpha_s \simeq 0.092$. As the $\text{Br}_{\gamma\gamma}$ increases (e.g., with increasing m_Q) it eventually asymptotes to 1, and inevitably the decrease in total rate of S production can no longer be accommodated by increasing $\text{Br}_{\gamma\gamma}$. In Fig. 3 we show the parameter space for this model, with $y_Q = 1$. We see that for generic couplings it is very easy to obtain the correct number of diphoton events. For $m_Q \lesssim 500$ GeV (which is probably bounded by direct searches for colored states; see below), there is limited sensitivity to m_Q. At larger m_Q the diphoton branching fraction is saturated at 1 while the total production of S's is decreased, contributing to a loss of signal.

[1] We define $A_{1/2}^i = \frac{2}{\tau_i^2}[\tau_i + (\tau_i - 1) f(\tau_i)]$, with $\tau_i = \frac{m_S^2}{4m_i^2}$ and $f(\tau) = \begin{cases} \arcsin^2(\sqrt{\tau}) & \tau \leq 1 \\ -\frac{1}{4}\left[\ln\left(\frac{1+\sqrt{1-\tau}}{1-\sqrt{1-\tau}}\right) - i\pi\right]^2 & \tau > 1 \end{cases}$ [7].

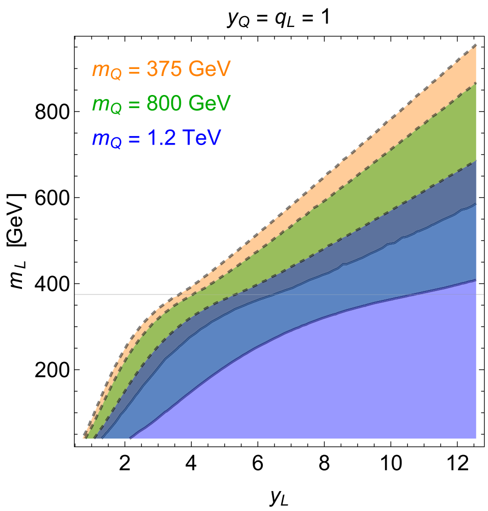

Fig. 3. Contours of $N_{\gamma\gamma}$ for the model in Eq. (5) with $y_Q = q_L = 1$. On the dashed (solid) lines we get 5 (15) events with $\mathcal{L} = 3.2\ \text{fb}^{-1}$ and $\epsilon \times A = 0.5$. The colored particle mass is fixed by the color coding; $m_Q = 375$ GeV is ruled out by direct searches, but is included for illustration. Below the faint solid line the S has on-shell decays to L. (For interpretation of the colors in this figure, the reader is referred to the web version of this article.)

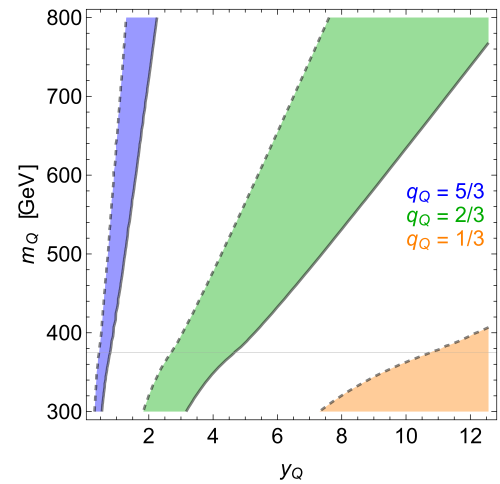

Fig. 4. Contours of $N_{\gamma\gamma}$ for the model in Eq. (7). On the dashed (solid) lines we get 5 (15) events with $\mathcal{L} = 3.2\ \text{fb}^{-1}$ and $\epsilon \times A = 0.5$. The quark electric charge is fixed by the color coding; $q_Q = 1/3$ is ruled out by direct searches, but is included for illustration. Below the faint solid line, the S has on-shell decays to Q. (For interpretation of the colors in this figure, the reader is referred to the web version of this article.)

As an interesting special example of the "QL Model," we can decouple the L by sending $m_L \to \infty$ and taking $q_Q \neq 0$. This has fewer free parameters (and is correspondingly more minimal) than the preceding model. The S will decay through Q loops to pairs of gluons and pairs of photons, as in the top row of Fig. 2, since $q_Q \neq 0$. We find

$$\mathrm{Br}^Q_{\gamma\gamma} \simeq \frac{9q_Q^4\,\alpha_{\mathrm{EM}}^2}{2K\alpha_s^2} \simeq \frac{1}{260}\left(\frac{q_Q}{2/3}\right)^4, \tag{6}$$

where we assume dijet events dominate. In this case, the number of diphoton events is approximately

$$N^Q_{\gamma\gamma} \simeq \frac{\epsilon_{\mathrm{eff}}\mathcal{L}\bar{\sigma}}{260}\left(\frac{y_Q m_t}{y_t m_Q}\right)^2\left(\frac{q_Q}{2/3}\right)^4 \frac{\left|A^Q_{1/2}\right|^2}{\left|A^t_{1/2}\right|^2}. \tag{7}$$

We show the parameter space for this model in Fig. 4 for a variety of choices of q_Q. Even in this very simple model, we are able to accommodate the observations at reasonable values of the couplings. This comes at the cost of a large number of dijet events fixed by the charge q_Q, which may only be borderline compatible with dijet searches. We address these searches in more detail below.

In the model of Eq. (3), the total width Γ_S is completely predicted by prohibiting tree-level decays. This width is the sum of the width to gluons via Q loops plus the width to γs and Zs via Q and L loops. We find

$$\begin{aligned}\Gamma_S &= \Gamma(S \underset{Q}{\to} gg) + \Gamma(S \underset{Q}{\to} \gamma\gamma/Z) + \Gamma(S \underset{L}{\to} \gamma\gamma/Z)\\ &\simeq 25\ \text{MeV}\,\epsilon_Q^2\left|A_{1/2}(\tau_Q)\right|^2 \times\\ &\quad\times\left[1+\left(9q_Q^4+q_L^4\frac{\epsilon_L^2\left|A_{1/2}(\tau_L)\right|^2}{\epsilon_Q^2\left|A_{1/2}(\tau_Q)\right|^2}\right)\Big/275\right],\end{aligned} \tag{8}$$

where we use $\Gamma_{Z\gamma} = 2t_W^2\Gamma_{\gamma\gamma}$, $\Gamma_{ZZ} = t_W^4\Gamma_{\gamma\gamma}$ with t_W the tangent of the Weinberg angle. Because $|A_{1/2}| \leq 2$ when on-shell decays are forbidden and $\epsilon_i \lesssim \mathcal{O}(1)$, we see that it is highly nontrivial for S to reproduce the observed width of $\Gamma_S \gg \mathcal{O}(\text{few GeV})$ via loop-level decays alone.

3. Implications of a broad width

As we have seen, the "QL Model" can account for the number of diphoton events observed in the excesses of ATLAS and CMS. However, the characteristic total width given in Eq. (8) is far too small to account for the full width if ATLAS's preliminary indications persist. It is useful therefore to augment the "QL Model" with some additional contribution to the partial width. We can then find bounds under the assumption that the total width is fixed as an experimental input,

$$\Gamma_{\mathrm{tot}} = \Gamma_{\gamma\gamma} + \Gamma_{\gamma Z} + \Gamma_{gg} + \Gamma_X \tag{9}$$

where X denotes some unknown final state and Γ_X is as large as necessary to get Γ_{tot} to match observations. It is trivial to generate an additional large partial width by introducing another particle that couples to S which allows for tree level decays. For now we will be agnostic about what this is and simply investigate the constraints on the "QL" sector by increasing the total width of S.

For Γ_{tot} we take two possibilities, $\Gamma_{\mathrm{tot}} = 5.3$ GeV and $\Gamma_{\mathrm{tot}} = 45$ GeV, which are the diphoton invariant mass resolution $\delta m_{\gamma\gamma}$ and the preferred value of the width from [1], respectively. As stated above, ATLAS has a preference for $\Gamma_{\mathrm{tot}} \gg \delta m_{\gamma\gamma}$. In Fig. 5 we plot the range of parameters that results in the S resonance giving between 5 to 15 diphotons in the limit of strong coupling between the S and the new fermions. As can be seen from Fig. 5, even in the limit of strong coupling there is essentially no parameter space in this model that can successfully allow for a width of 45 GeV and $N_{\gamma\gamma} = 15$ (although $N_{\gamma\gamma} = 5$ is easier to accommodate). Reducing the width to the experimental resolution allows for some additional parameter space, but note that this still requires strong coupling and fixes the mass of the QL both to be less than 800 GeV to account for the photons seen by ATLAS. This should allow for copious production of S particles at 13 TeV. This is to be contrasted with what was shown in the previous section where the colored particle mass could be well above a TeV and avoid other potential bounds. Additionally, the strong coupling limit can not be reduced very much away from 4π. To demonstrate this, in Fig. 5 we show that if we take the very optimistic width of 5.3 GeV and reduce the couplings only by a factor of π such that $y_Q = y_L = 4$, there is no viable parameter space remaining.

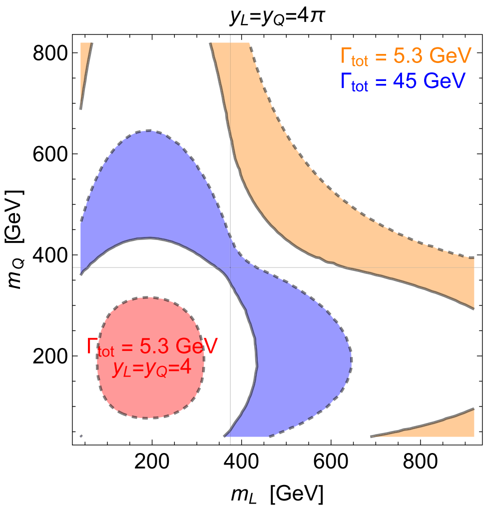

Fig. 5. Contours of $N_{\gamma\gamma}$ in the $m_L - m_Q$ plane for a fixed width. On the dashed (solid) lines, we get 5 (15) events with $\mathcal{L} = 3.2\ \text{fb}^{-1}$ and $\epsilon \times A = 0.5$, assuming the total width to be fixed to the amount suggested by the color coding. Below and to the left of the faint solid lines, the S has on-shell decays to the new fermions. The 5.3 GeV width is motivated by the diphoton invariant mass resolution at ATLAS [1]. (For interpretation of the colors in this figure, the reader is referred to the web version of this article.)

Table 1
Bounds from searches for mono-jet plus $\not{E}_T$ in 8 TeV data [8].

$\not{E}_T$ threshold [GeV]	$\sigma_{\text{invisible}}$ [pb]
250	3
300	1.78
350	0.75
400	0.65
450	0.52

If one postulates that the singlet scalar can be strongly coupled to fit the observed width, there will potentially be strong constraints depending on what final state X contributes to Γ_X. A simple model with a collider stable invisible fermion χ and a coupling $y_\chi S\bar{\chi}\chi$ would imply that Γ_X is an invisible width for S. However, these are already potentially constrained by mono-jet searches at 8 TeV. In [8], monojet events were analyzed in signal regions for events above different $\not{E}_T$ cuts starting at 250 GeV. To translate this into a bound on $\sigma(pp \to S \to \text{invisible})$ we perform the following analysis. We calculate an efficiency which gives the experimental acceptance for each signal region, and normalize against the production cross section for an S without an additional ISR jet:

$$\epsilon[p_T] = \left[\frac{\sigma(gg \to Sj)}{\sigma(gg \to S)}\right](p_T(j) > p_T). \tag{10}$$

We assume that $\not{E}_T = p_T(j)$, valid for large transverse momenta. Unfolding with respect to ϵ gives bounds at the 95% C.L. on $\sigma(pp \to S \to \text{invisible}) = \sigma(pp \to S) BF(S \to \text{invisible})$. We provide these bounds for each potential signal region in Table 1.

Given that the typical decay width for visible gluon and photon decay channels is less than a GeV but $\Gamma_{\gamma\gamma} \sim \mathcal{O}(5\ \text{MeV})$, accounting for a 45 GeV total width gives the requirement $\sigma(pp \to S \to \text{invisible}) \sim 9$ pb. Because the weakest possible bound on this model from [8] is 3 pb, the possibility for having the rest of the decay width be invisible is ruled out. If instead the width is assumed to be the experimental resolution, we require $\sigma(pp \to S \to \text{invisible}) > 1$ pb. This is compatible with the weaker bins of the analysis, but is ruled out by the higher MET regions. Therefore we conclude *that it is not viable to explain the large width by including only an invisible width for the* S: somehow an additional $\mathcal{O}(1)$ branching fraction must go into a visible final state that avoids all other direct bounds. Regardless, accounting for the larger width requires a much larger superstructure to be compatible with experimental constraints. The model must also be in a strong coupling region with light new colored and charged states.

4. Other experimental constraints

Here we examine additional limits and prospects with 8 TeV and 13 TeV searches in as model-independent a manner as possible.

$\gamma\gamma$ at 8 TeV: Assuming 15 events are observed at 13 TeV at 3.2 fb^{-1}, we find $\epsilon A\sigma_{\gamma\gamma}(13\ \text{TeV}) = 4.6$ fb. The gluon luminosity multiplier in going from 8 to 13 TeV is 4.7 [9], giving $\epsilon A\sigma_{\gamma\gamma}(8\ \text{TeV}) \simeq 1$ fb. For $\epsilon A = 0.5$ this gives $\sigma_{\gamma\gamma}(8\ \text{TeV}) \simeq 2$ fb. We find that this is not in conflict with the 8 TeV search [10], which requires $\sigma_{\gamma\gamma}(8\ \text{TeV}) \lesssim 4$ fb in the fiducial region at 95% confidence. This is possible because the increase in total luminosity from 8 to 13 TeV affects both the signal and background, but the $q\bar{q}$ luminosity multiplier (appropriate for background) from 8 to 13 TeV is only $\simeq 2$, smaller than the gluon luminosity multiplier.

$Z\gamma$ at 8 TeV: Figure 3c of [11] amusingly suggests a small bump near 750 GeV. In the fiducial region for $S \to Z\gamma \to \ell\ell\gamma$ the bound at 750 GeV is 0.26 fb. Unfolding with respect to the branching ratio for $Z \to \ell\ell = 0.034$ gives a bound on the fiducial cross section of $\sigma_{Z\gamma} = 7.6$ fb. For all the models we consider,

$$\frac{\sigma_{Z\gamma}}{\sigma_{\gamma\gamma}} = 2t_W^2 \simeq 0.6. \tag{11}$$

Comparing to the estimate above, we expect that the inclusive cross section is $\sigma_{Z\gamma}(8\ \text{TeV}) \sim 1.2$ fb, well below the fiducial 8 TeV bounds indicated. Furthermore, we find that taking the efficiency and acceptance into account of approximately 0.5 (0.7 from the identification efficiency [11] and approximately 0.7 for acceptance) $N_{Z\gamma} \lesssim 1$ at the current luminosity and energy, which is not observable.

Dijet bounds: The bound from [12] for a narrow width Breit–Wigner resonance produced via gluons with $\frac{\Gamma_{\text{BW}}}{M_{\text{BW}}} \simeq 0.05$ (we find that this provides stronger bounds than the updated search from [13]) gives $A\sigma_{jj} \le 1300$ fb. Unlike the $\gamma\gamma$ and $Z\gamma$ searches, the dijet rate is model-dependent. Since $\sigma_{jj} = \sigma_{\gamma\gamma}\Gamma_{gg}/\Gamma_{\gamma\gamma}$, we have $\Gamma_{gg}/\Gamma_{\gamma\gamma} \lesssim 1100$ assuming $A \sim 0.6$ from the relevant models in the dijet search [12]. This roughly corresponds to having $m_L \lesssim m_Q$ for $y_L \sim y_Q$ and $q_L \sim \mathcal{O}(1)$. For fixed total width this can be easily achieved. In the "QL Model" we have seen that the viable parameter space is not strongly dependent on m_Q, so m_Q can be pushed up to suppress the dijet cross-section as needed. In the "Q Model" we require sufficiently large electromagnetic charge, $q_Q \gtrsim 0.5$.

Heavy quarks: If the heavy quark Q decays inside the instrument, for a vector-like quark with $q_Q = 1/3, 2/3$, the bounds come from [14] and [15], requiring $m_Q \gtrsim 750$–920 GeV depending on the channel. If instead the quarks are long lived, [16,17] rule out $m_Q \le 500$ GeV. This is compatible with producing a sufficient number of diphoton events in our "QL Model".

Heavy leptons: If the heavy lepton L decays inside the instrument, the bounds depend on the decay channel. The bounds from [18] are somewhat weak, well below the requirement that S not delay directly to L. If instead the leptons are long lived, [19,20] rule out $m_L \leq 400$ GeV. Again, this is compatible with producing a sufficient number of diphoton events in our "$Q\,L$ Model".

5. Conclusions

We have demonstrated that a simple singlet scalar resonance with additional vector-like fermions charged under the Standard Model gauge group can account for the diphoton excess seen at ATLAS and CMS [1,2]. However, such a model shows tension with the large width preferred by ATLAS [1]. If the width is not a fluctuation, this implies that the dominant branching fraction for this resonance is into states other than dijet and diphoton. Additionally, for a large width to be compatible with the diphoton excess requires both large couplings and vector-like fermions with masses beneath the 750 GeV resonance. These fermions can be searched for directly depending on how the decays of the fermions are introduced in the model. However, these decay modes are not tied directly to the model for producing the diphoton excess, so searches for these consequences will be much more model dependent. Excitingly, we have further shown that the resonance must decay an $\mathcal{O}(1)$ fraction of the time into complicated visible sector states: a large invisible branching fraction to explain the width is ruled out by monojet searches.

A model-independent way to obtain additional evidence for this model is in the $Z\gamma$ final state, which is always coupled to the number of observed photons (the dijet final is also interesting but not as clean and can be suppressed). Regardless of large or small width, we can rescale the ATLAS 8 TeV search for $Z\gamma$ resonances [11] to predict the luminosity necessary for discovery. In this channel we expect $N_{\rm bgd} = 20 \times 2 \times \frac{3.2}{20.3} \times \frac{\mathcal{L}}{3.2\ \text{fb}^{-1}}$. For a 3σ discovery we find that we would need ~ 600 fb^{-1} of data. Therefore in the first 300 fb^{-1} we should expect hints in the $Z\gamma$ channel, and the high luminosity run of the LHC could definitively discover it in this channel. If this search was drastically improved so as to completely eliminate any backgrounds, observing 5 events (in a particular leptonic final state in $Z\gamma$) would still require at least ~ 50 fb^{-1} of integrated luminosity. Observation in $Z\gamma$ would help to single out this explanation if the diphoton resonance persists, given the paucity of additional signals that a singlet scalar generates.

While more sophisticated explanations may describe the new diphoton excess, the model proposed in this letter is economical and generic. It points to interesting searches (e.g., in $Z\gamma$ and dijet final states) and highlights interesting tensions (e.g., with forcing a large branching fraction to invisible final states). Additional signals of new physics should be aggressively investigated in the context of the model-independent bounds advocated here and in more complete UV frameworks.

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