Interpreting the 750 GeV diphoton excess in minimal extensions of Two-Higgs-Doublet models

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Abstract

It is shown that the 750 GeV diphoton excess can be explained in extensions of Two-Higgs-Doublet Models that do not involve large multiplicities of new electromagnetically charged states. The key observation is that at moderate and large $\tan \beta$ the total decay width of the 750 GeV Higgs is strongly reduced as compared to the Standard Model. This allows for much more economical choices of new states that enhance the diphoton signal to fit the data. In particular, it is shown that one family of vector-like quarks and leptons with SM charges is enough to explain the 750 GeV diphoton excess. Moreover, such charge assignment can keep the 125 GeV Higgs signal rates exactly at the SM values. The scenario can interpret the diphoton excess provided that the total decay width of a hypothetical resonance that would be measured at the LHC turns out to not exceed few GeV.
1 Introduction

The ATLAS and CMS collaborations reported recently an excess in the diphoton mass distribution around 750 GeV [1, 2]. Local significances of these excesses are somewhat above 3σ at ATLAS and slightly less than 3σ at CMS. While global significance of this excess is not yet large enough to celebrate discovery of New Physics, it is the most significant excess observed simultaneously at ATLAS and CMS in searches for New Physics at the LHC so far. Thus, it is tempting to interpret this signal in extensions of the Standard Model (SM).

There are many ways how to explain the 750 GeV excess by New Physics [3]. Among candidates for a new resonance there are singlets coupled to vector-like fermions [4]-[20], composite states [21]-[30], states originating from reduction of extra dimensions [31]-[32], axions [33]-[34] or sgoldstinos [35]-[37].

Some authors speculate also on a possible link of this new resonance to a dark matter particle [39]-[45]. Here, we assume that the 750 GeV diphoton excess is due to new Higgs boson(s) in Two-Higgs-Doublet Model (2HDM) [46]. Such interpretations of the diphoton signal were already presented in Refs. [47, 48, 49]. In those articles the main focus was on small values of tan β with dominant contribution to production of a 750 GeV states in gluon fusion coming from a top quark loop. It has been shown, however, that in order to fit the diphoton signal 2HDM must be extended by additional new states with large multiplicities and/or large exotic electromagnetic charges.

In the present paper we investigate a possibility to fit the 750 GeV diphoton excess in extensions of 2HDMs with moderate and large tan β. At first sight, it might seem to be not a good choice of parameter space because at large tan β top quark contribution to gluon fusion is strongly suppressed. However, since new states have to be added anyway to 2HDMs to enhance 750 GeV Higgs decays to diphotons it is reasonable to assume that these new states also carry colour charge and contribute to the 750 GeV Higgs production via gluon fusion. In such a case top quark contribution to gluon fusion is no longer necessary and tan β can be large. The main advantage of large tan β is that the total decay width of the 750 GeV Higgs is suppressed in this regime. This allows for much smaller diphoton decay width of the 750 GeV Higgs to explain the excess. Moreover, if the excess is due to narrow resonance produced in gluon fusion, preferred signal rate of this resonance is about 6 fb, as compared to 11 fb for a resonance with total decay width of 45 GeV [9]. Due to larger diphoton signal rate the wide resonance hypothesis is in bigger tension with LHC run-1 data [9] (see also Ref. [50]). On the other hand, in the narrow resonance hypothesis, the best-fit point from 13 TeV data is consistent with constraints from the run-1 data. Nevertheless, the best-fit point in a global fit to all diphoton data shifts downwards to about 3 fb.

We investigate possible size of the suppression of the total decay width of the 750 GeV Higgses in Type-I and Type-II 2HDM and show that it is large enough to fit the diphoton excess with rather small multiplicities of new particles. In particular, we demonstrate that one family of vector-like quarks and leptons with SM charges is enough to explain the 750 GeV diphoton excess. By construction, this scenario can interpret the diphoton excess provided that the total decay width of a hypothetical resonance that would be measured at the LHC turns out to not exceed few GeV.

1It has also been suggested that the excess may not originate from a 750 GeV resonance [38].
2 Suppression of a Higgs total decay width in 2HDMs and enhanced 750 GeV diphoton signal

The total decay width of a 750 GeV Higgs in the SM is about 247 GeV \[51\]. The main decay channels are into \(WW\), \(ZZ\) and \(t\bar{t}\) with the corresponding branching ratios of about 59\%, 29\% and 12\%, respectively. As a consequence of large total decay width, \(\text{BR}(H \rightarrow \gamma\gamma)\) is only \(2 \times 10^{-7}\). Since the SM production cross-section for the 750 GeV Higgs, dominated by gluon fusion rate, is about 0.74 pb \[51\], it is clear that if the 750 GeV resonance is a Higgs it must have totally different properties than in the SM.

In 2HDMs there are three physical neutral Higgs bosons, two CP-even and one CP-odd, that originate from two Higgs doublets, \(H_u\) and \(H_d\). Two important parameters of this class of models are \(\tan\beta = \frac{v_u}{v_d}\), the ratio of vacuum expectation values of the doublet neutral components, \(H_0^u\) and \(H_0^d\), and angle \(\alpha\) which parametrizes the mixing between the two CP-even states:

\[
H_0^u = \cos\alpha h + \sin\alpha H, \quad H_0^d = -\sin\alpha h + \cos\alpha H.
\] (1)

In the present work, we identify \(h\) with the 125 GeV Higgs, while \(H\) is a candidate for the 750 GeV resonance. We focus on the so-called alignment limit \(\alpha = \beta - \pi/2 \[52\]. In such a case \(h\) has exactly the same couplings as the SM Higgs while \(H\) couples to the SM fermions but not to the gauge bosons. This is motivated, in part, by the fact that the LHC 125 GeV Higgs data agree quite well with the SM prediction \[53\]. More importantly, in the alignment limit the total decay width of \(H\) is generically much smaller than in the SM. In particular, for \(\tan\beta = 1\), when the \(H\) couplings to the SM fermions are the same as in the SM, the total decay width is about 30 GeV. Similar decay width has CP-odd scalar, which has the same couplings to SM particles as \(H\) in the alignment limit. In spite of vanishing couplings to gauge bosons, the branching ratios of \(H\) and \(A\) to diphoton are of order \(10^{-5}\), much too small to explain the 750 GeV excess.

In the most widely studied Type-I and Type-II 2HDMs, the correct magnitude of the 750 GeV diphoton signal could be, in principle, adjusted by choosing appropriately small value of \(\tan\beta\). This is because the effective gluon coupling of \(H/A\) is proportional to the coupling to top quark which is rescaled by a factor \(1/\tan\beta\), as compared to the SM. However, such possibility is experimentally excluded since \(t\bar{t}\) production from \(H/A\) decays would be too large.

The remaining possibility is to assume that there exist new electromagnetically charged particles that modify \(\Gamma(H/A \rightarrow \gamma\gamma)\). In Ref. \[47\] it was shown that it is indeed possible to fit the 750 GeV excess using decays of degenerate \(H\) and \(A\) to \(\gamma\gamma\) enhanced by vector-like leptons. However, in such a case the price to pay is very high multiplicity of vector-like leptons. Moreover, in order not to spoil the 125 GeV Higgs decays into photons fine cancellation in the amplitude between the contributions from different vector-like leptons is required. In an explicit example presented in Ref. \[47\] \(\tan\beta = 1\) was used, for which the model is at the verge of exclusion by the LHC searches for \(H \rightarrow t\bar{t}\).

We focus instead on larger values of \(\tan\beta\) since they allow to reduce \(\Gamma(H/A \rightarrow t\bar{t})\), hence also the total decay width. The reduction of the \(H/A\) couplings to top quarks results also in decrease of the gluon fusion production cross-section. Therefore, in this case new particles should exist that carry colour charge that are responsible for large enough production cross-
Figure 1: Left panel: Enhancement of the total decay width of the 750 GeV CP-even (solid lines) and CP-odd (dashed lines) Higgs in Type-II 2HDM in the alignment limit $\alpha = \beta - \pi/2$, with respect to the 750 GeV SM Higgs. Right panel: the total decay width in GeV in the same case as in the left panel. Difference between the CP-even and CP-odd Higgs comes from a different phase space suppression in $H/A \rightarrow t\bar{t}$.

section of $H/A$, however, as we will see with much smaller multiplicity than for $\tan \beta = 1$. Since couplings of $H$ and $A$ to bottom quarks are different in type-I and type-II 2HDMs we discuss these models separately in the following subsections.

2.1 Type-II 2HDM

In type-II 2HDM, in which the Higgs sector is that of MSSM, the couplings of $H$ and $A$ to bottom quarks are proportional to $\tan \beta$. For the SM Higgs with mass of 750 GeV the decay width into top quarks is about 2900 times larger than that into bottom quarks [51]. This implies in Type-II 2HDM that those decay widths equalize at $\tan \beta \approx 7.3$. At this value of $\tan \beta$ the total decay width of $H$ is minimized and equals around 1 GeV, as can be seen in the left panel of Figure 1. Hence, it is smaller by more than two orders of magnitude than for the SM Higgs with the same mass, and by a factor of 30 as compared to the $\tan \beta = 1$ case. However, $\text{BR}(H \rightarrow \gamma\gamma)$ is not enhanced because reduced $H$ coupling to top quarks reduces also the top contribution to $\Gamma(H \rightarrow \gamma\gamma)$. The same applies to the decays of the CP-odd Higgs. Moreover, the cross-section for production of $H$ and $A$ via gluon fusion is suppressed by $1/(\tan \beta)^2$. Nevertheless, this can be fixed by introducing new particles that are both electromagnetically and coloured charged. The 2HDMs do not have coloured particles in the spectrum but they can be treated as simplified models of some more complete models where such particles are present. For the sake of demonstration, we consider the model proposed in Ref. [47] but with both vector-like
quarks and leptons. The key feature of that model is that up-type and down-type vector-like fermions couple to \( H_u \) and \( H_d \), respectively. In consequence, contributions from different types of vector-like fermions to the amplitude for Higgs decaying to photons/gluons have different dependence on the mixing angle \( \alpha \): \[ A_{\text{VLF}}^\Phi(gg) \sim A_{\text{top/bottom}}^\Phi(gg) + \sum_i^n \left[ \sin \alpha \frac{v g_{u_i}}{m_{u_i}} A_{1/2}^\Phi(\tau_{u_i}) + \cos \alpha \frac{v g_{d_i}}{m_{d_i}} A_{1/2}^\Phi(\tau_{d_i}) \right], \] for \( \Phi = H, A \) in the alignment limit (\( \alpha = \beta - \pi/2 \)), while for \( \Phi = h \) \( \sin \alpha \to \cos \alpha \) and \( \cos \alpha \to -\sin \alpha \) should be substituted in the above formulae. In the above formula \( \nu_i \) (\( l_i \)) correspond to up-type (down-type) vector-like leptons. The form factors for spin-1/2 fermions \( A_{1/2}^\Phi(\tau) \) with \( \tau = \frac{M_\Phi^2}{4m_i^2} \), as well as SM contributions from top, bottom and \( W \) boson can be found e.g. in Ref. [59]. The form factors are maximized for \( \tau \approx 1 \), in the limit \( \tau \to 0 \) they approach values of order one, while in the limit \( \tau \to \infty \) they go to zero (but rather slowly). Moreover, the form factors are typically slightly larger for CP-odd than for CP-even Higgses. It is important to note that for all Higgses top quark dominates the contribution to gluon fusion from the SM particles. While in the \( h \to \gamma\gamma \) amplitude, dominant \( W \) boson contribution interferes destructively with subdominant (but non-negligible) top contribution.

From the perspective of the diphoton excess the most interesting region is the one with \( \tan \beta \) around 6 to 8, where the total decay width of \( H \) and \( A \) is minimal. In this region the contributions from SM particles to gluon fusion and \( \gamma\gamma \) amplitude are strongly suppressed. Therefore, in order to explain the 750 GeV diphoton signal some of the new particles must carry colour and electromagnetic charge. However, due to suppressed total decay width only few new particles are required, in contrast to the \( \tan \beta = 1 \) case considered in Ref. [47]. In what follows we assume that there is only one family of vector-like quarks and leptons with the same pattern of charges as the SM fermions:

\[
\begin{pmatrix}
 l' \\
 l'' \\
 u' \\
 u'' \\
 v'_L \\
 v'_R \\
 t'_L/R \\
 t''_L/R
\end{pmatrix}_{L/R}, \quad
\begin{pmatrix}
 b'_L/R \\
 b''_L/R \\
 \nu'_L/R \\
 \nu''_L/R \\
 \nu'_L/R \\
 \nu''_L/R \end{pmatrix}_{L/R}.
\]

We assume that the mixing between the vector-like fermions and the SM fermions is negligible. As emphasized in Ref. [47], it is crucial to introduce both \' and \'' states to have gauge invariant Yukawa interactions for the vector-like fermions. Hence, \( n = 2 \) should be used in the formulae \[ (2)-(3) \] for the amplitudes. In these formulae \( g_i \) are the Yukawa couplings of the vector-like fermions in the mass basis. They are functions of the Yukawa couplings and explicit mass terms for the vector-like fermions in the interactions basis. For simplicity, we assume that \( g_i \) are free parameters. The key feature of this model is a different \( \alpha \)-dependence of the vector-like contributions to the gluon fusion and \( \gamma\gamma \) amplitudes for \( h \) and \( H/A \). This implies that if

\[ ^2 \text{Phenomenology of vector-like fermions and their impact on Higgs production and decays were investigated e.g. in Refs. [54]-[58].} \]
contributions from vector-like up-type and down-type fermions interfere constructively in the 
\( H/A \) amplitudes, in the \( h \) amplitudes they interfere destructively. In general, it is not possible 
to exactly cancel vector-like fermion contributions simultaneously in \( h \to \gamma\gamma \) and \( h \to gg \) 
amplitudes. However, it follows from eqs. (2)-(3) with \( \sin \alpha \to \cos \alpha \) and \( \cos \alpha \to -\sin \alpha \) that 
such cancellation is possible for some combinations of masses, couplings and charges if both 
vector-like quarks and leptons couple to the Higgs. In order to better illustrate this fact let 
us assume for simplicity that 
\[
-\frac{g_u}{m_d} A_{1/2}(\tau_u) \tan \beta = \frac{g_d}{m_u} A_{1/2}(\tau_d)
\]
for all vector-like quarks and leptons (with \( u \to \nu \) and \( d \to l \)). In such a case the vector-like fermion contribution to 
the gluon fusion amplitude production for the 125 GeV Higgs vanishes in the alignment limit, 
according to eq. (2) for \( \Phi = h \). On the other hand, the vector-like fermion contribution to the 
\( h \to \gamma\gamma \) amplitude vanishes if:
\[
N_u^c Q_u^2 - N_d^c Q_d^2 + Q_\nu^2 - Q_l^2 = 0.
\]
Interestingly, the above condition is fulfilled if vector-like fermions have the same pattern of 
charges as the SM fermions.

In our numerical examples we fix \(-g_u \tan \beta = g_d = 1\) for all vector-like fermions. There 
are two important consequences of using this relation. First: the 125 GeV Higgs production is 
exactly the same as in the SM. Second: for moderate and large \( \tan \beta \) couplings of all Higgses to 
up-type vector-like fermions are suppressed. We also take, for simplicity, all vector-like quarks 
and leptons equal to \( m_{V_{LQ}} \) and \( m_{V_{LL}} \), respectively. If, in addition, \( m_{V_{LL}} = m_{V_{LQ}} \) 
the \( h \to \gamma\gamma \) rate is also exactly the same as in the SM. However, even if vector-like quarks 
are not degenerate with vector-like leptons the \( h \to \gamma\gamma \) rate is still in good agreement with 
the LHC Higgs data if \( \tan \beta \) is not small. This follows from the fact that \( h \) couplings to 
up-type (down-type) vector-like fermions are suppressed by \( g_u (\cos \beta) \) and only one family of 
vector-like fermions is introduced to explain the 750 GeV excess. Notice also that the condition 
\(-g_u \tan \beta = g_d \) implies that for moderate and large \( \tan \beta \) only down-type vector-like fermions 
give non-negligible contribution to the gluon fusion and \( \gamma\gamma \) amplitudes for \( H \) and \( A \).

In the left panel of Fig. 2 we present dependence of the sum of diphoton signal rates from 
\( H \) and \( A \) decays, \( \sigma_{H/A} \times BR(H/A \to \gamma\gamma) \), on \( \tan \beta \) for \( m_{V_{LL}} = 400 \) GeV and several values 
of \( m_{V_{LQ}} \). We assume that \( H \) and \( A \) are degenerate with mass of 750 GeV. Note that due to 
particular values of form-factors the diphoton signal from \( A \) decays is larger by a factor of five 
or more than that from \( H \) decays. It can be seen that the 750 GeV diphoton signal is much 
larger for \( \tan \beta \) around 7 than for small \( \tan \beta \) and can be of order \( \mathcal{O}(1) \) fb for \( m_{V_{LQ}} = 800 \) 
GeV. In order to get 4 fb one needs \( m_{V_{LQ}} \sim 500 \) GeV. The latter values may be in tension with 
the LHC constraints for vector-like quarks, which are, however, model dependent and it is 
beyond the scope of the present paper to investigate them in detail. Note, also, that \( m_{V_{LQ}} \) can 
be larger for larger values of \( g_d \). Notice also that despite the fact that vector-like quarks are not 
degenerate with vector-like leptons the diphoton signal of the 125 GeV Higgs is very close to 
the SM prediction for moderate and large \( \tan \beta \), as explained before. In the right panel of Fig. 2 
we present the 750 GeV diphoton signal in the plane \( m_{V_{LQ}}, m_{V_{LL}} \) for optimal value \( \tan \beta = 7 \)
. It can be seen, in particular, that lowering \( m_{V_{LL}} \) to 375 GeV, which is a minimal value for 
which \( H/A \) decays to vector-like fermions may not increase the total decay width, allow for 
increase of \( m_{V_{LQ}} \) by about 150 GeV keeping the same cross-section and Yukawa couplings.
Figure 2: $\sigma_{H/A} \times \text{BR}(H/A \rightarrow \gamma\gamma)$ (solid lines) and BR($h \rightarrow \gamma\gamma$) normalized to SM (dashed lines) in Type-II 2HDM with one family of vector-like fermions (4) with $-g_u\tan\beta = g_d = 1$. In the left panel, dependence on $\tan\beta$ is shown for $m_{VLL} = 400$ GeV and blue, red, green lines (from top to bottom) correspond to $m_{VLQ} = 500, 600, 800$ GeV, respectively. In the right panel, $\tan\beta = 7$ while $m_{VLL}$ and $m_{VLQ}$ are varied. The numbers on solid (dashed) contours in the red (green) square boxes correspond to $\sigma_{H/A} \times \text{BR}(H/A \rightarrow \gamma\gamma)$ in fb (BR($h \rightarrow \gamma\gamma$)) normalized to SM.

Notice also that for this value of $\tan\beta$ deviations from the SM prediction for the $h \rightarrow \gamma\gamma$ rate are at the level of few percent at most. Of course, in order to relax requirements on the masses of vector-like fermions and Yukawa couplings one can include additional copies of vector-like fermions (4) or to use bigger charges for vector-like quarks and/or leptons. However, in the latter case one should keep in mind that the production and/or decays of the 125 GeV Higgs might be affected.

Let us also discuss constraints on this scenario from direct searches for heavy Higgs bosons in the $\tau\tau$ final state performed at the LHC. An upper limit for the production cross-section times $\tau\tau$ branching fraction of a 750 GeV scalar boson at 13 TeV is about 60 fb [60]. In Fig. 3 we present dependence of the $\tau\tau$ signal rates from $H$ and $A$ decays on $\tan\beta$ for several values of $m_{VLQ}$. It can be seen that $\tan\beta$ is constrained from above by the $\tau\tau$ search. The constraint on $\tan\beta$ is stronger for lighter vector-like quarks because this makes the gluon fusion production cross-section of heavy Higgses larger. Nevertheless, even for $m_{VLQ} = 500$ GeV values of $\tan\beta \lesssim 5$, which correspond to the diphoton signal of up to 4 fb (cf. Fig. 2), are allowed by the current data. The tension between the diphoton signal and the constraints from the $\tau\tau$ search can be relaxed by reducing $H/A$ production cross-section while increasing branching.

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3Even though $b\bar{b}$ branching fraction of $H/A$ is larger than the $\tau\tau$ one, the $b\bar{b}$ channel is experimentally much more challenging so constraints from $\tau\tau$ channel are stronger.
fraction to diphoton which can be realized, for example, by taking the heavy Higgs couplings to vector-like leptons larger than those to vector-like quarks. In any case the interesting part of parameter space will be probed in near future by searches in the $\tau\tau$ channel.

2.2 Type-I 2HDM

Let us now consider Type-I 2HDM in which the $H/A$ couplings to bottom quarks are scaled by $1/\tan\beta$, similarly as the corresponding couplings to top quarks. In consequence, the total decay width of $H/A$ does not have a minimum as a function of $\tan\beta$, as can be seen from Figure 4. For very large values of $\tan\beta$ the total decay width of $H/A$ tends to $\Gamma(h \to gg)$. For the SM 750 GeV Higgs $\Gamma(H \to gg) \approx 0.06$ GeV corresponding to BR($H \to gg) \approx 2.5 \times 10^{-4}$ which means that for strongly suppressed top quark Yukawa coupling the total decay width can be suppressed by a factor of 4000. Due to larger form factor for $A$ for strongly suppressed top quark Yukawa coupling the total decay width of $A$ is suppressed by about 2700. Suppressed top quark Yukawa coupling leads to even stronger suppression of $\Gamma(h \to gg)$. However, in order to have large enough $H/A$ production cross-section to explain the 750 GeV excess new coloured particle must enhance the $H/A$ effective coupling to gluons to a similar level as the top quark loop does in the SM. In the narrow width approximation, that we use throughout this paper and is fully justified, $\sigma(gg \to H/A) \sim \Gamma(H/A \to gg)$ so one should not expect $\Gamma(H/A \to gg)$ to be smaller than $O(0.01)$ GeV. Assuming the SM value for $\Gamma(H/A \to gg)$, the total decay width vary most rapidly up to $\tan\beta \approx 20$ for which $\Gamma(H/A \to tt) \approx \Gamma(H/A \to gg)$.

Figure 3: $\sigma_A \times \text{BR}(A \to \tau\tau)$ (solid lines) and $\sigma_H \times \text{BR}(H \to \tau\tau)$ (dashed lines) in Type-II 2HDM with one family of vector-like fermions [4] with $-g_u \tan\beta = g_d = 1$ as a function of $\tan\beta$. Blue, red, green lines (from top to bottom) correspond to $m_{V_{LQ}} = 500, 600, 800$ GeV, respectively. Horizontal black dotted line corresponds to the experimental upper bound from ATLAS [60].
Figure 4: The same as in Fig. 1 but for Type-I 2HDM. $\Gamma(H/A \rightarrow gg)$ is fixed to the SM value. Difference between the CP-even and CP-odd Higgses comes from a different phase space suppression in $H/A \rightarrow t\bar{t}$ (significant for smaller $\tan \beta$) and different form factors in the $\Gamma(H/A \rightarrow gg)$ amplitude (important for large $\tan \beta$).

In order to demonstrate consequences for the 750 GeV diphoton signal we choose the same model for vector-like fermions as for the Type-II 2HDM. The results are shown in Figure 5. From the left panel it can be seen that the 750 GeV diphoton rate increases indefinitely with $\tan \beta$. Moreover, the diphoton signal can have correct magnitude to fit the 750 GeV excess, without invoking very large Yukawa couplings or small masses for vector-like quarks. For example in the case of $\tan \beta = 30$, presented in the right panel of Figure 5 with the same assumptions about Yukawa couplings as in the Type-II 2HDM examples, masses of vector-like quarks can be above 1 TeV even if the vector-like lepton masses are far away from the kinematic threshold and $H/A \rightarrow \gamma\gamma$ decays are not enhanced by a large value of the form factor. Moreover, the $h \rightarrow \gamma\gamma$ rate is within one percent from the SM prediction.

3 Conclusions

We have investigated a possibility that a tentative 750 GeV diphoton excess reported by ATLAS and CMS is the first signal of heavier Higgs bosons in 2HDMs. While it is not possible to fit this excess in a pure 2HDM, it is possible to do it when new particles are coupled to the Higgs sector. For $\tan \beta \sim 1$, even in the alignment limit, large multiplicity of new states with exotic electromagnetic charges are preferred to fit the excess. Apart from aesthetic arguments, larger multiplicities of states are more likely to affect the production and decays of the 125 GeV, that are subject to strong LHC constraints, thus complicating model building. In order to avoid large multiplicity of new particles, small total decay width is preferred. In the context of 2HDM, the total decay width is suppressed for $\tan \beta$ significantly above one, due to suppression of the top...
Yukawa coupling. In the Type-II 2HDM, the biggest suppression of the total decay width, as compared to the SM, is about 250 which is obtained for $\tan \beta$ around 7. In the Type-I 2HDM, the total decay width decreases monotonically with $\tan \beta$, approaching for very large $\tan \beta$ the decay width into gluons which is typically few times $10^{-4}$ smaller than the total decay width of the SM 750 GeV Higgs.

Due to large suppression of the total decay width it is possible to fit the 750 GeV excess with a small number of new particles. However, in contrast to small $\tan \beta$ case, at least one of these particles must carry colour charge, otherwise gluon fusion cross-section would be strongly suppressed due to smallness of the top Yukawa coupling. As a proof of concept, we have shown that adding to 2HDMs one family of vector-like quarks and leptons with the corresponding SM fermion charges is enough to fit the 750 GeV excess. Moreover, for such choice of vector-like fermions charges their total contribution to the 125 GeV Higgs signal rates can vanish. While in the Type-II model new fermions must have relatively large Yukawa couplings and masses close to the experimental bounds, in the Type-I model parameters are not strongly constrained provided that $\tan \beta$ is large enough. We should emphasize that the 750 GeV excess is expected to be fitted also in many other extensions of 2HDMs without introducing large multiplicities of new states.

In the regions of $\tan \beta$ considered in this paper the total decay width of $H/A$ is around or below 1 GeV. The ATLAS 13 TeV data shows some preference for much larger width of about 30 GeV. Even though CMS and 8 TeV data do not support this interpretation it is worth pointing out that in the presented scenario single wide resonance preferred by the ATLAS 13 TeV data can be mimicked by $H$ and $A$ with masses that differ by few tens of GeV. In such a case $H$
and $A$ contribute to different bins in the ATLAS analysis improving the fit to the ATLAS 13 TeV data. Nevertheless, if the diphoton signal is real future LHC data will discriminate this hypothesis against single wide resonance.

If the future LHC data confirm that the 750 GeV diphoton excess is due to a new resonance one of the next steps will be to measure its CP properties. In 2HDM the diphoton signal from CP-odd Higgs decays is stronger than from the CP-even one. Nevertheless, CP-even state can by its own explain the excess, which is especially simple in extensions of the Type-I 2HDM.

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