Possible implications of 750 GeV diphoton excess on BSM

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Based on arXiv:1601.00586
with Yuji Omura (Nogoya) and
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Data

$$\text{ATLAS}: M_X = 750\ \text{GeV}, \quad \sigma_{\text{fit}}(pp \to X \to \gamma\gamma) \approx 10 \pm 3\,\text{fb}; (95\%\ \text{CL}), \quad \Gamma_X \approx 45\,\text{GeV}$$

$$\text{CMS}: M_X = 760\,\text{GeV}, \quad \sigma_{\text{fit}}(pp \to X \to \gamma\gamma) \approx 9 \pm 7\,\text{fb}; (95\%\ \text{CL})$$

What would be this resonance
if the excess is confirmed ?

Let us consider a scalar case

Composite scenarios : not discussed here

Basic Ingredients

- New vectorlike fermions which are chiral under new U(1)' : non-decoupling effects on X->gg, gam gam
- Diphoton at 750 GeV = Higgs boson from U(1)' sym breaking, mostly a SM singlet scalar
- All the masses from dynamical (Higgs) mechanism
- New decay modes to enhance the total decay rate

Type-II 2HDM with U(1)H gauge symmetry

Ko, Omura, Yu: arXiv:1204.4588 [hep-ph]

Table 1: Matter contents in U(1)$'$ model inspired by E_6 GUTs. Here, i denotes the generation index: $i = 1, 2, 3$.

Fields	SU(3)	SU(2)	$U(1)_Y$	$U(1)'$	Z_2^{ex}
Q^i	**3**	**2**	1/6	−1/3	
u_R^i	**3**	**1**	2/3	2/3	
d_R^i	**3**	**1**	−1/3	−1/3	
L_i	**1**	**2**	−1/2	0	+
e_R^i	**1**	**1**	−1	0	
n_R^i	**1**	**1**	0	1	
H_2	**1**	**2**	−1/2	0	
H_1	**1**	**2**	−1/2	−1	+
Φ	**1**	**1**	0	−1	
D_L^i	**3**	**1**	−1/3	2/3	
D_R^i	**3**	**1**	−1/3	−1/3	
$\widetilde{H}_L^i$	**1**	**2**	−1/2	0	−
$\widetilde{H}_R^i$	**1**	**2**	−1/2	−1	
N_L^i	**1**	**1**	0	−1	

2HDM with U(1) Higgs

- 2HDM: one of the popular extensions of the SM Higgs sector
- Yukawa's and mass matrices cannot be diagonalized simultaneously —> neutral Higgs mediated FCNC prob.
- Natural Flavor Conservation : usually in terms of Z2

$$Z_2 : (H_1, H_2) \to (+H_1, -H_2).$$

TABLE I: Assignment of Z_2 parities to the SM fermions and Higgs doublets.

Type	H_1	H_2	U_R	D_R	E_R	N_R	Q_L, L
I	+	−	+	+	+	+	+
II	+	−	+	−	−	+	+
III	+	−	+	+	−	−	+
IV	+	−	+	−	+	−	+

$$V(H_1, H_2) = m_1^2 H_1^\dagger H_1 + m_2^2 H_2^\dagger H_2 + \frac{\lambda_1}{2}(H_1^\dagger H_1)^2 + \frac{\lambda_2}{2}(H_2^\dagger H_2)^2 + \lambda_3 H_1^\dagger H_1 H_2^\dagger H_2 + \lambda_4 H_1^\dagger H_2 H_2^\dagger H_1. \quad (4)$$

$$\Delta V = m_\Phi^2 \Phi^\dagger \Phi + \frac{\lambda_\Phi}{2}(\Phi^\dagger \Phi)^2 + (\mu H_1^\dagger H_2 \Phi + \text{h.c.}) + \mu_1 H_1^\dagger H_1 \Phi^\dagger \Phi + \mu_2 H_2^\dagger H_2 \Phi^\dagger \Phi, \quad (5)$$

Soft Z2 breaking is replaced by gauge sym breaking

Type-I extensions

Models are anomaly free without extra chiral fermions

TABLE II: Charge assignments of an anomaly-free $U(1)_H$ in the Type-I 2HDM.

Type	U_R	D_R	Q_L	L	E_R	N_R	H_1
$U(1)_H$ charge	u	d	$\frac{(u+d)}{2}$	$\frac{-3(u+d)}{2}$	$-(2u+d)$	$-(u+2d)$	$\frac{(u-d)}{2}$
$h_2 \neq 0$	0	0	0	0	0	0	0
$U(1)_{B-L}$	1/3	1/3	1/3	−1	−1	−1	0
$U(1)_R$	1	−1	0	0	−1	1	1
$U(1)_Y$	2/3	−1/3	1/6	−1/2	−1	0	1/2

See arXiv:1309.7256 for Higgs data analysis, arXiv:1405.2138 for DM (Ko,Omura,Yu)

A type-II extension has all the necessary ingredients

Table 1: Matter contents in U(1)′ model inspired by E_6 GUTs. Here, i denotes the generation index: $i = 1, 2, 3$.

Fields	SU(3)	SU(2)	$U(1)_Y$	$U(1)'$	Z_2^{ex}
Q^i	**3**	**2**	1/6	−1/3	
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d_R^i	**3**	**1**	−1/3	−1/3	
L_i	**1**	**2**	−1/2	0	+
e_R^i	**1**	**1**	−1	0	
n_R^i	**1**	**1**	0	1	
H_2	**1**	**2**	−1/2	0	
H_1	**1**	**2**	−1/2	−1	+
Φ	**1**	**1**	0	−1	
D_L^i	**3**	**1**	−1/3	2/3	
D_R^i	**3**	**1**	−1/3	−1/3	
$\widetilde{H}_L^i$	**1**	**2**	−1/2	0	−
$\widetilde{H}_R^i$	**1**	**2**	−1/2	−1	
N_L^i	**1**	**1**	0	−1	

Fermions : 27 of E6 (!!!)

Scalar Bosons : 2 Doublets + 1 Singlet

Yukawa couplings

The U(1)′-symmetric Yukawa couplings in our model are given by

$$V_y = y^u_{ij}\overline{u^j_R}H_1^\dagger i\sigma_2 Q^i + y^d_{ij}\overline{d^j_R}H_2 Q^i + y^e_{ij}\overline{e^j_R}H_2 L^i + y^n_{ij}\overline{n^j_R}H_1^\dagger i\sigma_2 L^i + H.c., \tag{16}$$

where σ_2 is the Pauli matrix. The Yukawa couplings to generate the mass terms for the extra particles are

$$V^{\rm ex} = y^D_{ij}\overline{D^j_R}\Phi D^i_L + y^H_{ij}\overline{\widetilde{H}^j_R}\Phi\widetilde{H}^i_L + y^N_{IJ}\overline{N^c_L}H_1^\dagger i\sigma_2\widetilde{H}^i_L + y'^N_{IJ}\overline{\widetilde{H}^i_R}H_2 N^j_L + H.c.\ . \tag{17}$$

Complex Scalar DM

One can introduce new $Z_2^{\rm ex}$-odd scalar field X with the $SU(3)_C\times SU(2)_L\times U(1)_Y\times U(1)_H$ quantum numbers equal to $(1,1,0;-1)$. Then the gauge-invariant Lagrangian involving X is given by

$$\begin{aligned}\mathcal{L}_X =\ & D_\mu X^\dagger D^\mu X - (m^2_{X0} + \lambda_{H_1X}H_1^\dagger H_1 + \lambda_{H_2X}H_2^\dagger H_2)X^\dagger X - \lambda_X(X^\dagger X)^2 \\ & - \left(\lambda''_{\Phi X}(\Phi^\dagger X)^2 + H.c.\right) - \lambda_{\Phi X}\Phi^\dagger\Phi X^\dagger X - \lambda'_{\Phi X}|\Phi^\dagger X|^2 \\ & - \left(y^D_{dX}\overline{d_R}D_L X + y^{\tilde H}_{LX}\overline{L}\widetilde{H}_R X^\dagger + H.c.\right)\end{aligned} \tag{18}$$

125 GeV Higgs Data

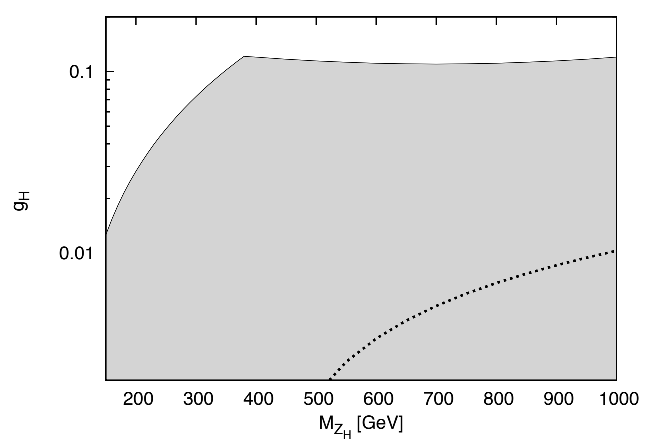
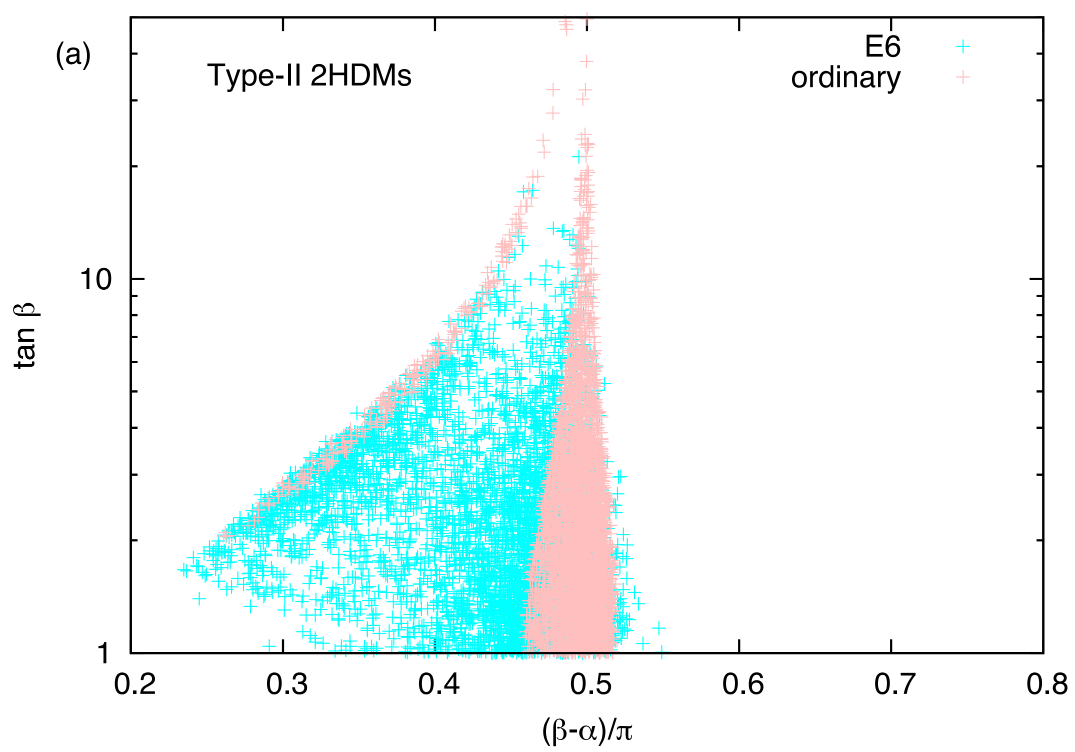


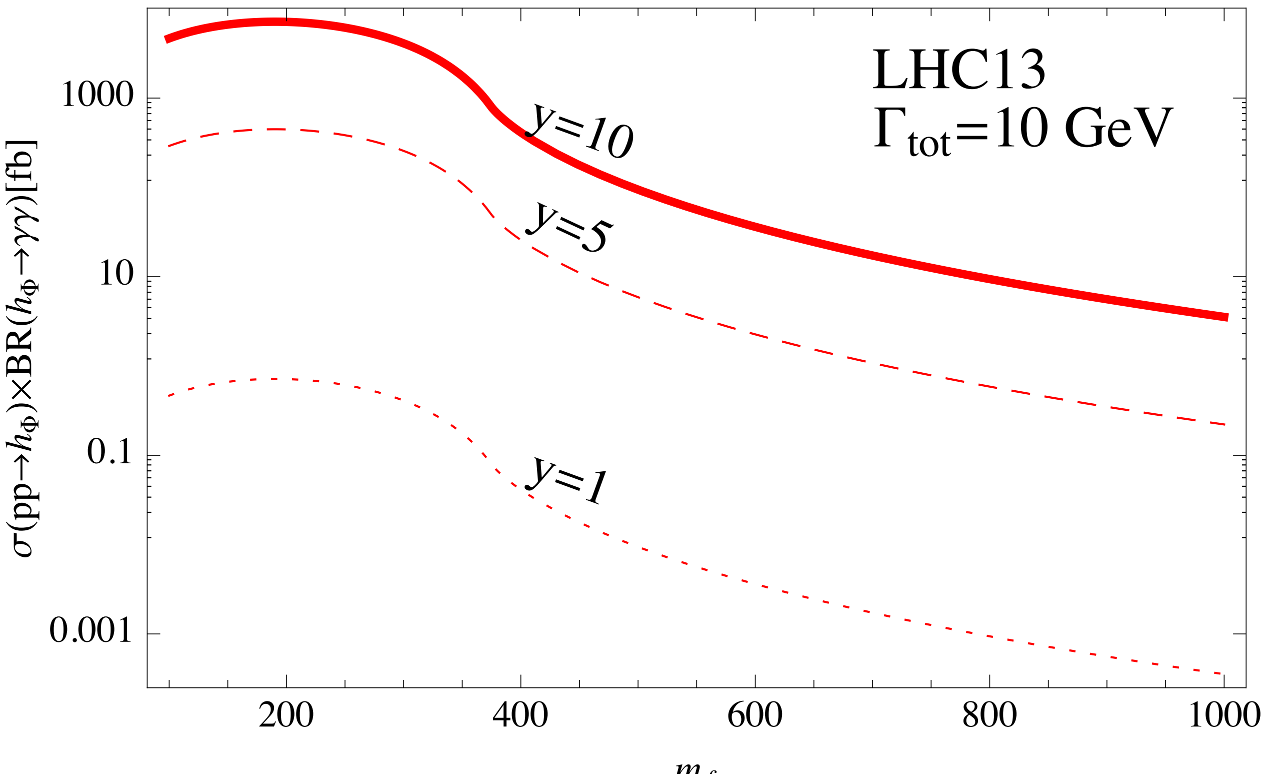
FIG. 1. M_{Z_H} and g_H in the type-II 2HDM$_{U(1)}$. The dot line is the upper bound on the $U(1)_\psi$ gauge boson, and the gray region is allowed for the $U(1)_H (\equiv U(1)_b)$ gauge boson.

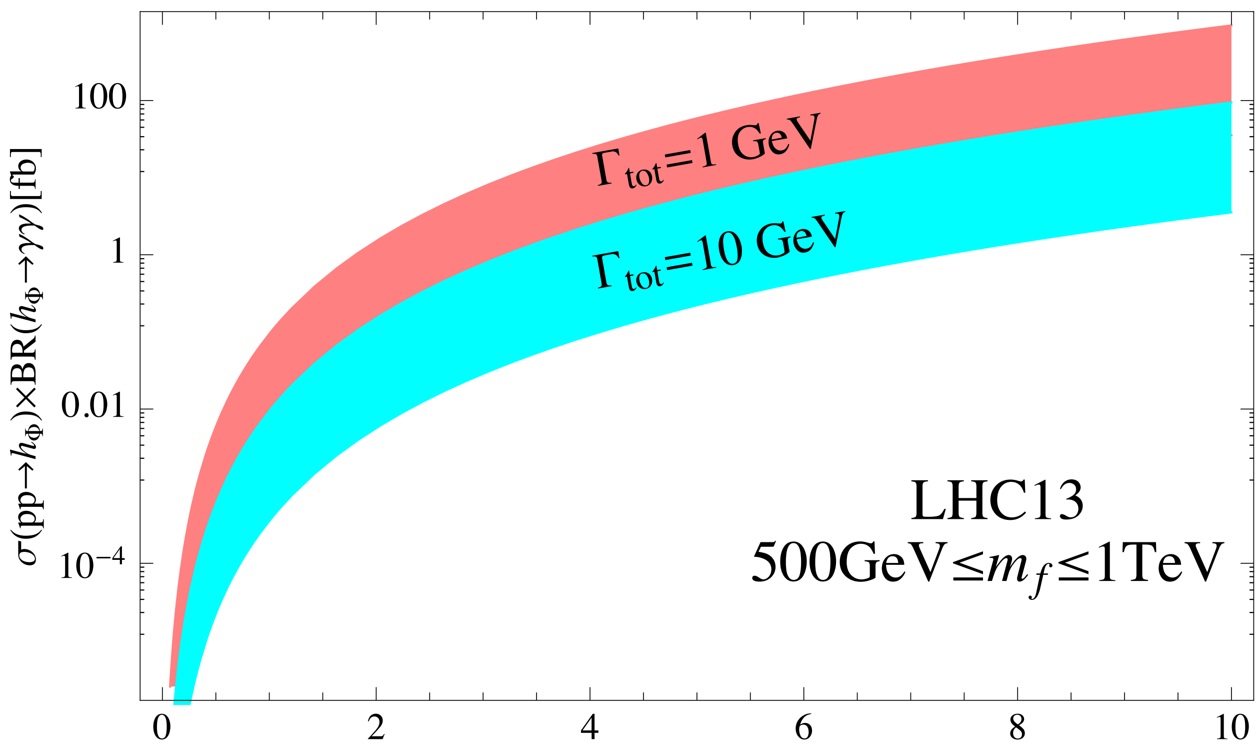


Qualtatively different from the ordinary Type-II 2HDM
arXiv:1502.00262 (Ko, Omura, Yu)

750 GeV Diphoton Excess

Ko, Omura, Yu, arXiv:1601.00586





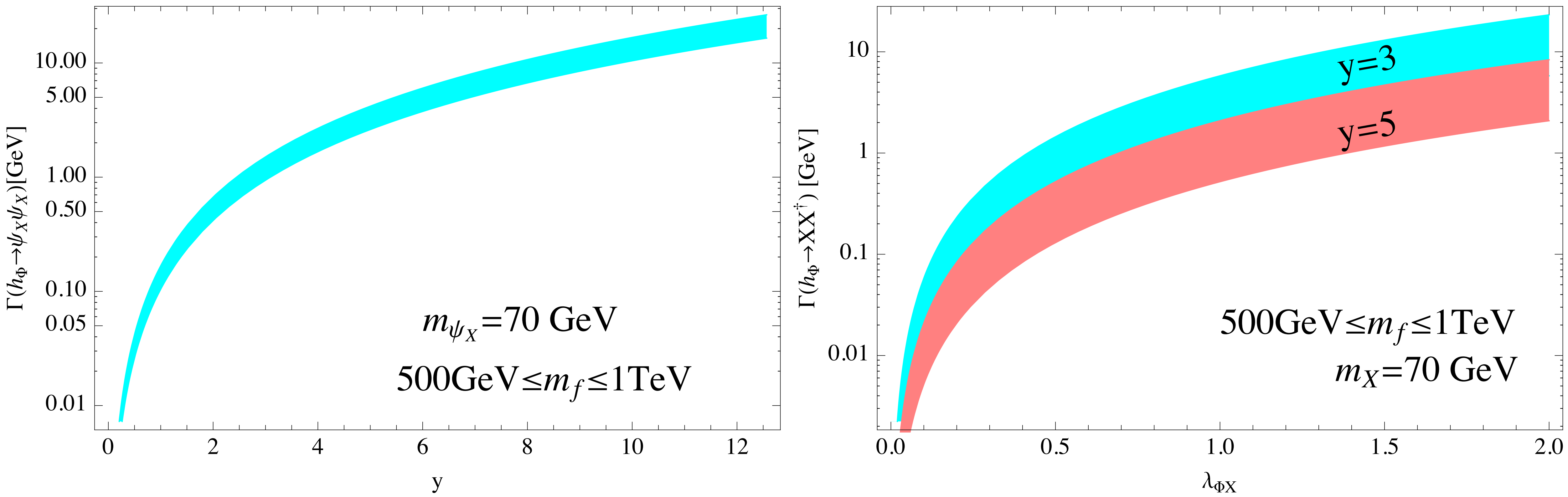


Figure 2: y vs. invisible decay width of h_Φ (GeV) in the fermionic DM scenario (left) and scalar DM scenario (right).The vector-like fermion mass is between 500 GeV and 1 TeV on the cyan and pink bands. The dark matter masses are 70 GeV in the both cases.

Constraints

final state f	σ at $\sqrt{s}=8\,\text{TeV}$ observed	expected	ref.	implied bound on $\Gamma(S\to f)/\Gamma(S\to\gamma\gamma)_{\text{obs}}$
$\gamma\gamma$	< 1.5 fb	< 1.1 fb	[6,7]	$< 0.8\ (r/5)$
$e^+e^- + \mu^+\mu^-$	< 1.2 fb	< 1.2 fb	[8]	$< 0.6\ (r/5)$
$\tau^+\tau^-$	< 12 fb	15 fb	[9]	$< 6\ (r/5)$
$Z\gamma$	< 4.0 fb	< 3.4 fb	[10]	$< 2\ (r/5)$
ZZ	< 12 fb	< 20 fb	[11]	$< 6\ (r/5)$
Zh	< 19 fb	< 28 fb	[12]	$< 10\ (r/5)$
hh	< 39 fb	< 42 fb	[13]	$< 20\ (r/5)$
W^+W^-	< 40 fb	< 70 fb	[14,15]	$< 20\ (r/5)$
$t\bar{t}$	< 550 fb	-	[16]	$< 300\ (r/5)$
invisible	< 0.8 pb	-	[17]	$< 400\ (r/5)$
$b\bar{b}$	$\lesssim 1$ pb	$\lesssim 1$ pb	[18]	$< 500\ (r/5)$
jj	$\lesssim 2.5$ pb	-	[5]	$< 1300\ (r/5)$

Rescaled Run I limits

[Franceschini et al, 1512.04933]

- Most can be evaded
- Monojet + missing ET ??

Conclusion

- Type II 2HDM + U(1) Higgs gauge symmetry : leptophobic U(1)' derived from E6
- Can accommodate the 750 GeV diphoton excess at qualitative level. Quantitatively ?? (Work in progress)
- A few more different models within the same ingredients are being studied now : Stay tuned
- A new playground for new gauge models (including DM)