Higgs-like resonant signals in a no-universal 2HDM

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Outline

1. why another Z'+2HDM model?(I am stealing the question of the C. Yaguna presentation)
2. Low energy and collider constraints
3. Higgs-like resonant signals

why another Z'+2HDM model?(I am stealing the question of the C. Yaguna presentation)

- Recently, several anomalies have been reported in searches of high-mass scalar resonances in proton-proton collisions at the LHC. The 2HDMs are the most straightforward extensions of the Standard Model that can explain these observations, it is interesting knowing if the recent reported Higgs-like 2σ-signals overlap with the scalar spectrum of the preferred parameter space of the 2HDM.
- We found an interesting SM+2HDM+U(1)' non-universal model. In spite to be non-universal, with this model it is possible generating the CKM and PMNS matrices, which it is non-trivial for this kind of models.
- In this model, the FCNC of the scalar sector cancels automatically.

- This model is constructed by imposing the breaking pattern $SU(3)_C \otimes SU(2)_L \otimes U(1) \otimes U(1) \rightarrow SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ by requiring that both of the high energy $U(1)$ charges contribute in a non-trivial way (neither of them is inert) to the hipercharge Y. I.e., this is an example of two non-universal models combining to obtain a universal one. Under this assumption, we only found a UNIQUE solution by assuming the fermion content as that of the standard model plus three right-handed neutrinos. i.e., this is an interesting benchmark model.
- In building this model, it was clear that adding Majorana mass terms enforces universality in most cases on the high-energy $U(1)$ charges. This feature can shed light on the origin of universality in the SM.

fermion content of the model and Z' chiral charges

f	$\nu_{1,2}$	ν_3	$e_{1,2}$	e_3	$u_{1,2}$	u_3	$d_{1,2}$	d_3
$g_{Z'}\tilde{\epsilon}_f^L$	$-z$	$-z$	$-z$	$-z$	$\frac{1}{3}z$	$\frac{1}{3}z$	$\frac{1}{3}z$	$\frac{1}{3}z$
$g_{Z'}\tilde{\epsilon}_f^R$	$-y$	$-x$	$y-2z$	$x-2z$	$-y+\frac{4}{3}z$	$-x+\frac{4}{3}z$	$y-\frac{2}{3}z$	$x-\frac{2}{3}z$

Table: Chiral couplings between the fermion sector and the Z' gauge boson. the scalar fields Φ_1 and Φ_2, their Z' couplings are given by $z-y$ and $z-x$, respectively.

Why is it not trivial to obtain mixing matrices for quarks and leptons in a non-universal model?

Z' charge	d	s	b
$-q$	$-\frac{1}{3}z$	$-\frac{1}{3}z$	$-\frac{1}{3}z$
d_R	$y-\frac{2}{3}z$	$y-\frac{2}{3}z$	$x-\frac{2}{3}z$
Q_{ϕ_1}	$z-y$	$z-y$	$z-y$
$-q+d_R+Q_{\phi_1}$	0	0	$x-y$

Z' charge	d	s	b
$-q$	$-\frac{1}{3}z$	$-\frac{1}{3}z$	$-\frac{1}{3}z$
d_R	$y-\frac{2}{3}z$	$y-\frac{2}{3}z$	$x-\frac{2}{3}z$
Q_{ϕ_2}	$z-x$	$z-x$	$z-x$
$-q+d_R+Q_{\phi_2}$	$y-z$	$y-z$	0

With this charge assignment it is possible to fill the four Dirac mass matrices for the up-like quarks, down-like quarks, charged leptons, and the neutrinos, with the same pair of Higgs doublets ϕ_1 and ϕ_2

EWPD and FCNC

- Electroweak Precision data (EWPD) constraints on the y and z parameters (green and orange continuous lines in the left panel of Figure 1), obtained using the GAPP package [1, 2], which includes low-energy weak neutral current experiments and Z-pole observables.
- As our model is non-universal, it has two possible sources of FCNC: the non-universal couplings of the Z' and the couplings of the SM fermions to two scalar doublets. Since the charges of the first two families are equal, we can ignore constraints from observables with flavor changes between quarks and leptons of the first two families, such as: K^0-$\bar{K}^0$-mixing, μ-e conversion, etc. In our case, one of the strongest constraints on the parameters comes from B^0-$\bar{B}^0$-mixing. Figure 1 shows the upper limits on the y and z parameters at a 95% confidence level

FCNC in the scalar sector

if the right-handed SM fermion is a singlet under the gauge group and if each right-handed SM singlet fermion couples to only one Higgs doublet (there is no problem if the scalar doublet has non-zero couplings to several right-handed fermions.), then there are no FCNC for the scalar sector; i.e., The two Higgses have different quantum numbers. (explanation by RM).

Collider Constraints

- For the process $\bar{q}q \longrightarrow Z' \longrightarrow \ell^+\ell^-$, ATLAS reports upper limits on the fiducial cross-section times the $Z' \to \ell^+\ell^-$ branching from searches of high-mass dilepton resonances (dielectron and dimuon) during Run 2 of the Large Hadron Collider (LHC) at a center-of-mass energy of $\sqrt{s} = 13$TeV and an integrated luminosity of 139fb^{-1}. From these constraints, we obtain upper limits on the y and z couplings corresponding to the green dashed and orange dotted lines in the left-handed plot in Figure 1. These limits are obtained from the intersection of the theoretical cross-section [3, 4, 5, 6] with the 95% CL upper limit on the cross-section reported by the ATLAS collaboration [7] (the green continuous line in the right plot Figure 1).

Low energy and collider constraints

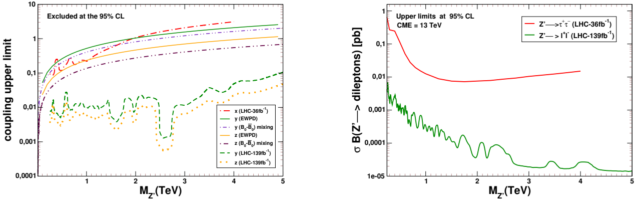

Figure: Left: Upper limit on the model parameters x, y, z. Right: 95% CL upper limits on the fiducial Z' production cross-section times the $Z' \to \ell^+\ell^-$ branching [7] (green continuous line) and the corresponding upper limits on the Z' decaying to $\tau\overline{\tau}$ pairs [8] (red continuous line).

Analysis of Higgs-like resonant signals

- Light neutral scalar Higgs with a mass $M_{H1} \approx 95$ GeV [9]
- charged Higgs around $M_{C^\pm} \approx 130$ GeV [10]. For the charged Higgs, in [11] a detailed analysis of the phenomenological implications of a new resonance with a three sigma significance was studied.
- An excess of events was also found in channels involving the productions of SM gauge bosons, $\gamma\gamma$ and $Z\gamma$ (for further analysis, look in [12] and references therein). This analysis provides a good indication of new scalar resonances decaying into two photons with invariant masses of 95 GeV [13] and 152 GeV [12].

Higgs-like resonances

- Other excesses over the expected value in the SM for dibosons are reported at 680 GeV [14], which are compatible with the excess in $\gamma\gamma$ and $b\bar{b}$ reported by the CMS collaboration [15].
- Recently, a deviation from the background-only expectation occurred for high scalar resonances with masses $(575, 200)$ GeV and a local (global) significance of 3.5 (2.0) standard deviations, as reported by the ATLAS collaboration [16]. It is important to stress that this analysis shows good agreement with the background-only hypothesis for the masses $(650, 90)$ GeV, where CMS reported an excess with a local (global) significance of 3.8 (2.8) standard deviations [15].

Higgs potential

The most general scalar potential consistent with the gauge symmetry $SU(2)_L \otimes U(1)_\alpha \otimes U(1)_\beta$ is:

$$\begin{aligned} V(\Phi_1,\Phi_2,\sigma) = {} & \mu_1^2\,|\Phi_1|^2 + \mu_2^2\,|\Phi_2|^2 + \mu_\sigma^2\,|\sigma|^2 + \lambda_1\,|\Phi_1|^4 + \lambda_2\,|\Phi_2|^4 + \lambda_\sigma\,|\sigma|^4 \\ & + \lambda_3\,|\Phi_1|^2|\Phi_2|^2 + \lambda_4\,|\Phi_1^\dagger\Phi_2|^2 + \lambda_{1\sigma}\,|\Phi_1|^2|\sigma|^2 + \lambda_{2\sigma}\,|\Phi_2|^2|\sigma|^2 \\ & + \text{linear term in } \sigma \text{ (or quadratic term in } \sigma) \;, \end{aligned} \tag{1}$$

where a linear interaction term in σ results in a cubic interaction term of the form

$$\mu\left[(\Phi_1^\dagger\Phi_2)\sigma + \text{h.c.}\right]$$

Here μ is a real parameter with mass dimensions. It is also possible to choose the $U(1)$ charge of σ such that we obtain a quartic term,

$$\lambda\left[(\Phi_1^\dagger\Phi_2)\sigma^2 + \text{h.c.})\right] \;.$$

In this case, the coupling λ is dimensionless.

Distribution of the scalar mass for a potential with a cubic term

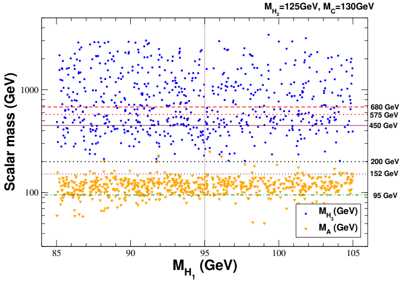

Figure: Distribution of the scalar mass M_{H_3} (the blue round points) and the pseudoscalar M_A (orange triangle points) for a scalar potential including the cubic term $\mu\Phi_1^\dagger\Phi_2\sigma + \text{h.c.}$. In this term, μ has mass dimensions and takes values in the range $(-77.3, 0)$ GeV. We vary the dimensionless in the range $[-1.5, 1.5]$, and $250\text{GeV} < v_\sigma < 2000$ GeV. And $\sqrt{v_1^2 + v_2^2} = v = 246.24$ GeV and $v_2 \gg v_1$.

Distribution of the scalar mass for a potential with a quartic term

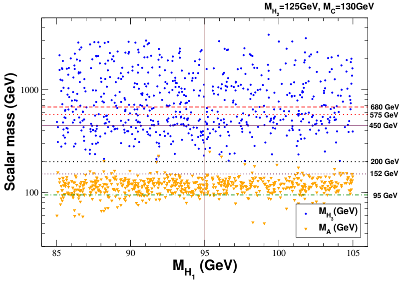

Figure: Distribution of the scalar mass M_{H_3} (the blue round points) and the pseudoscalar M_A (orange triangle points) for a scalar potential including the quartic term $\lambda \Phi_1^\dagger \Phi_2 \sigma^2 + \text{h.c.}$. In this term, λ is dimensionless and takes values in the range $(-0.44, 0)$ GeV. We vary the dimensionless in the range $[-1.5, 1.5]$, and $250\text{GeV} < v_\sigma < 2000$ GeV. And $\sqrt{v_1^2 + v_2^2} = v = 246.24$ GeV and $v_2 \gg v_1$.

Conclusions

- In this work, we assume that the SM is a low energy effective theory of a more fundamental theory characterized by a gauge symmetry of the form $SU(3)_C \otimes SU(2)_L \otimes U(1)_\alpha \otimes U(1)_\beta$, and whose particle content is that of the SM extended with three right-handed neutrinos, a second Higgs doublet and a scalar singlet. Additionally, we impose that both $U(1)$ charges are non-universal and contribute non-trivially to the SM hypercharge,
- In this model, generating all the mass matrix elements with only two Higgs doublets is possible. From this, it is possible to adjust the model to reproduce the CKM and PMNS mixing matrices. This feature is highly non-trivial for non-universal scenarios and represents a great advantage of this model.
- It is important to mention that to maintain the non-universality condition, it was preferable to avoid Majorana mass terms (in our model, the constraints on the $U(1)$ charges arising from the Majorana mass terms, in the vast majority of cases, tend to generate universality). So, in our model, there is a link between Majorana masses and Universality.

Conclusions

- From the assumptions of our work, as well as the collider, electroweak and flavor constraints, we also conclude that for a model with two non-inert Abelian symmetries at low energies ($M_{Z'} < 5$ TeV), only the residual symmetry $T_{3R}(3)$,
- Models with couplings to the first and second families are strongly constrained, so that only Z' couplings below 0.1 are possible, i.e., $g_{Z'}\tilde{\epsilon}_{L,R} < 0.1$. For a Z' coupling to the third family, it is possible to have Z' charges such that $g_{Z'}\tilde{\epsilon}_{L,R} \sim 1$ for Z' masses above 2 TeV.
- Our work analyzes some Higgs-like anomalies recently reported by the ATLAS and CMS collaborations [12]. To this end, we show the distribution of 400 solutions in the M_{H_1}, M_{H_3} and M_{H_1}, M_A planes. These results are shown in Figures 3 and **??**. This analysis concludes that explaining some of the observed anomalies within the model is possible.
- We show that the scalar sector FCNC cancel if each right-handed fermion couples only to a single Higgs doublet (although the scalar doublet can have non-zero couplings with several right-handed fermions). This will be the case as long as the right-handed fermions are singlets of the gauge grou

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