The New Compact 341 Model: Higgs Decay Modes

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Abstract. New developments in the anomaly free compact 341 model are discussed and the higgs bosons decay modes are studied taking into account the contributions of new fermions, gauge bosons and scalar bosons predicted by the model. It is shown from signal strengths and the branching ratios of the various decay modes analysis and the LHC constraints that there is a room for this extended BSM model and it is viable.

1. Introduction

Despite all successes of the standard model, many questions remained unsolved and not well understood like dark matter, neutrinos oscillation, matter anti-matter asymmetry etc... Trying to find a solution to those problems, one needs to extend the standard model and go beyond (BSM). The most proposed model on the literature are the ones with two-Higgs doublets (THDM)[1], supersymmetry [2], 331, extra dimensions [3] and 341 gauge models [4, 11].

Among those extensions, we focus on a model which is based on the $SU(3)_C \otimes SU(4)_L \otimes U(1)_N$ gauge symmetry (denoted by 341 model for a short hand). This model has new particles like exotic quarks, new gauge bosons $K_0, K'_0, K^{\mp}, X^\mp, V^{++}, Y^{\mp}, Z_0' \text{ and } Z''$. Moreover, the 341 model has a very specific arrangement of the fermions into generations; for leptons, one has both right and left handed helicities arranged in the same multiplet. In order to make the model anomaly free, the second and (4) third quarks families has to belong to the conjugate 4* fundamental representation of the fermions into generations; for leptons, one has both right and left handed helicities arranged in the same multiplet. In this compact 341 model, we have a minimum of three scalars quartets[8] and after SSB which is achieved via three steps, one ends up with three CP even neutral higgses $h_1, h_2 \text{ and } h_3$ and eight CP odd massive higgs $h_1^\pm, h_2^\mp, h_3^\pm$. 

In this paper, we focus on the analysis of the neutral Higgs decays modes and discuss the signal strengths and the branching ratios of the various decay modes as well as the LHC constraints and show that there is a room for this extended BSM model and it is viable. In section 2 we present a brief review of the theoretical model. In section 3 we give the various analytical expressions of the partial decays width which we have derived using the new Feynman rules of the model. Finally, in section 4 we give our numerical results concerning the signal strength of the various higgses branching ratios, after imposing the self consistency and compatibility constraints on the scalar potential of the model like triviality, unitarity, vacuum stability and non-ghost conditions, make comparison with the signal strengths of the recent experimental data reported by ATLAS, CMS and combined ATLAS+CMS and draw our conclusions.
2. The theoretical model

The gauge group structure of the model is $SU(3)_C \otimes SU(4)_L \otimes U(1)_Y$ and the electric charge operator $\tilde{Q}$ is defined as [9]:

$$\tilde{Q}/e = \frac{1}{2} \left( T_3 - \frac{1}{\sqrt{3}} T_8 - \frac{4}{\sqrt{6}} \gamma \right) + N$$

where:

$$\lambda_3 = \text{diag}(1, -1, 0, 0) \quad \lambda_8 = \frac{1}{\sqrt{3}} \text{diag}(1, 1, -2, 0) \quad \lambda_{15} = \frac{1}{\sqrt{6}} \text{diag}(1, 1, 1, -3).$$

The fermions content of this model is as follows [2]: for the leptons (resp. quarks) denoted by $L_aL$ and $Q_{1L}$, $Q_{iL}$ respectively one has,

$$f_{aL} = \begin{pmatrix} \nu_a \\ l_a \\ \nu_a^c \\ \ell_a^c \end{pmatrix} \sim (1, 4, 0), \quad Q_{1L} = \begin{pmatrix} u_1 \\ d_1 \\ u_1^c \\ d_1^c \end{pmatrix} \sim (3, 4, 2, 3), \quad Q_{iL} = \begin{pmatrix} d_i \\ u_i \\ d_i^c \\ u_i^c \end{pmatrix} \sim (3, 4^*, -1, 3)$$

Where $a=1,2,3$ and $i=2,3$. Here $U_1$, $J_1$, $D_i$ and $J_i$ are exotic quarks with electric charges $\frac{2}{3}$, $\frac{1}{3}$, $\frac{-1}{3}$ and $\frac{-2}{3}$ respectively. Right-handed quarks transform as $u_{1R}(3, 1, \frac{2}{3})$, $d_{1R}(3, 1, -\frac{1}{3})$, $U_{1R}(3, 1, \frac{2}{3})$, $J_{1R}(3, 1, \frac{5}{3})$, $u_{iR}(3, 1, \frac{2}{3})$, $d_{iR}(3, 1, -\frac{1}{3})$, $D_{iR}(3, 1, \frac{-1}{3})$, $J_{iR}(3, 1, -\frac{2}{3})$. The most general scalar potential with a $Z_3$ discrete symmetry in the compact 341 model is given by [3]:

$$V(\eta, \rho, \chi) = \mu_0^2 \eta^\dagger \eta + \mu_\rho^2 \rho^\dagger \rho + \mu_\chi^2 \chi^\dagger \chi + \lambda_1 (\eta^\dagger \eta)^2 + \lambda_2 (\rho^\dagger \rho)^2 + \lambda_3 (\chi^\dagger \chi)^2 + \lambda_4 (\eta^\dagger \rho^\dagger \rho \eta)^2 + \lambda_5 (\eta^\dagger \eta^\dagger \eta^\dagger \chi \chi \eta)^2$$

$$+ \lambda_6 (\eta^\dagger \rho^\dagger \rho \chi \chi \eta)^2 + \lambda_7 (\rho^\dagger \eta^\dagger \eta \rho \rho)^2 + \lambda_8 (\chi^\dagger \eta^\dagger \eta \rho \rho)^2 + \lambda_9 (\rho^\dagger \rho \chi \chi \rho).$$

Where $\mu_{\mu_\rho_\chi}$ are the mass dimension parameters and $\lambda_S = 1$ are dimensionless coupling constants. The scalars quadruplets $\eta$, $\rho$ and $\chi$ (which are necessary to generate masses) are given by the following quartets:

$$\eta = \begin{pmatrix} \eta_0^- \\ \eta_1^- \\ \eta_1^0 \\ \eta_1^+ \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{2}} (R_{\eta_1} + i I_{\eta_1}) \\ \frac{1}{\sqrt{2}} (v_{\eta_1} + R_{\eta_2} + i I_{\eta_2}) \end{pmatrix} \sim (1, 4, 0),$$

$$\rho = \begin{pmatrix} \rho_0^+ \\ \rho_1^- \\ \rho_1^0 \\ \rho_1^+ \\ \rho_2^+ \\ \rho_2^+ \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{2}} (v_{\rho} + R_{\rho} + i I_{\rho}) \\ \frac{1}{\sqrt{2}} (v_{\rho} + R_{\rho} + i I_{\rho}) \end{pmatrix} \sim (1, 4, 1),$$

$$\chi = \begin{pmatrix} \chi_0^- \\ \chi_1^- \\ \chi_1^0 \\ \chi_1^+ \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{2}} (v_{\chi} + R_{\chi} + i I_{\chi}) \\ \frac{1}{\sqrt{2}} (v_{\chi} + R_{\chi} + i I_{\chi}) \end{pmatrix} \sim (1, 4, -1).$$

The reason to choose the $\eta$ quadruplet developing VEV only in the only in the 3rd component is to avoid mixings between ordinary quarks and exotic ones. Imposing the tadpole conditions:

$$\mu_1^2 + \lambda_1 v_\eta^2 + \frac{1}{2} \lambda_2 v_\rho^2 + \frac{1}{2} \lambda_5 v_\chi^2 = 0, \quad \mu_2^2 + \lambda_3 v_\rho^2 + \frac{1}{2} \lambda_4 v_\eta^2 + \frac{1}{2} \lambda_6 v_\chi^2 = 0$$
\[ \mu^2 + \lambda_3 v^2 + 1/2 \lambda_5 v_\eta^2 + 1/2 \lambda_6 v_\rho^2 = 0 \]  

helps to find the CP-even neutral scalars mass matrix in the basis \((R_\rho, R_\chi, R_\eta)\), whose eigenvalues are \([7]\):

\[
M_{h_1}^2 = \frac{\lambda_2 v_\rho^2 + \lambda_3 \lambda_5^2 + \lambda_6 (\lambda_1 \lambda_6 - \lambda_4 \lambda_5)}{\lambda_5^2 - 4 \lambda_1 \lambda_3} v_\rho^2, \quad M_{h_2}^2 = c_1 v_\chi^2 + c_2 v_\rho^2 \approx c_1 v_\chi^2, \quad M_{h_3}^2 = c_3 v_\chi^2 + c_4 v_\rho^2 \approx c_3 v_\chi^2. \tag{5}
\]

representing the masses of the physical scalars \(h_1, h_2\) and \(h_3\) respectively (the lightest neutral scalar \(h_1\) is identified as SM like Higgs boson) and eigenstates:

\[
h_1 = R_\rho, \quad h_2 = a R_\chi + b R_\eta, \quad h_3 = c R_\chi + d R_\eta \tag{6}
\]

where

\[
a = \frac{\lambda_1 - \lambda_3 - \sqrt{(\lambda_1 - \lambda_3)^2 + \lambda_5^2}}{\lambda_5^2 - 4 \lambda_1 \lambda_3}, \quad b = \frac{\lambda_5}{\lambda_5^2 - 4 \lambda_1 \lambda_3},
\]

\[
c = \frac{\lambda_1 - \lambda_3 + \sqrt{(\lambda_1 - \lambda_3)^2 + \lambda_5^2}}{\lambda_5^2 - 4 \lambda_1 \lambda_3}, \quad d = \frac{\lambda_5}{\lambda_5^2 - 4 \lambda_1 \lambda_3}. \tag{7}
\]

The SSB steps are:

\[
SU(4)_L \otimes U(1)_N \rightarrow v_\chi \quad SU(3)_L \otimes U(1)_X, \quad SU(3)_L \otimes U(1)_X \rightarrow v_\eta \quad SU(2)_L \otimes U(1)_Y,
\]

\[
SU(2)_L \otimes U(1)_Y \rightarrow v_\rho \quad U(1)_{QED}.
\]

Here stands for the weak isospin quantum number and the VeVs are such that \(\sim 246\) GeV, \(v_\eta \sim \mathcal{O}(\text{TeV})\) and \(v_\chi \sim \mathcal{O}(\text{TeV})\) \((v_\chi \sim v_\eta\) The masses of the charged gauge bosons in this model are:

\[
M_{W^\pm}^2 = \frac{g_L^2}{4} v_\rho^2, \quad M_{K^0, K^\prime}^2 = \frac{g_L^2}{4} v_\eta^2, \quad M_{X^\pm}^2 = \frac{g_L^2}{4} v_\chi^2, \quad M_{V^\pm}^2 = \frac{g_L^2}{4} (v_\rho^2 + v_\chi^2),
\]

\[
M_{Y^\pm}^2 = \frac{\alpha}{4} (v_\eta^2 + v_\chi^2). \tag{9}
\]

and of the neutral ones:

\[
M_y = 0, \quad M_Z^2 = \frac{g_L^2 v_\rho^2}{4 c_W^2}, \quad M_{Z'}^2 = \frac{g_L^2 v_\eta^2}{4 c_W^2}, \quad M_{Z''}^2 = \frac{g_L^2 v_\chi^2 (1 - 4 s_W^2) + h_W^2}{8 v_\rho^2 (1 - 4 s_W^2)}. \tag{10}
\]

where

\[
W^\pm = \frac{(W_\mu^1 \mp i W_\mu^2)}{\sqrt{2}}, \quad K^0, K^\prime = \frac{(W_\mu^4 \mp i W_\mu^5)}{\sqrt{2}}, \quad K_\mp = \frac{(W_\mu^6 \mp i W_\mu^7)}{\sqrt{2}}, \tag{11}
\]

and

\[
X^\mp = \frac{(W_\mu^0 \mp i W_\mu^{10})}{\sqrt{2}}, \quad V^\pm = \frac{(W_\mu^{11} \mp i W_\mu^{12})}{\sqrt{2}}, \quad Y^\mp = \frac{(W_\mu^{13} - i W_\mu^{14})}{\sqrt{2}}. \tag{12}
\]

Here, \(\cos \theta = c_w, \sin \theta = s_w\) and \(h_W = 3 - 4s_w^2\). It is worth to mention that, the most attractive phenomenological features of the model is that in addition to the reproduction of all phenomenological success of SM, it has only 03 families of quarks and leptons and computation of the of U(1) gauge group running coupling shows the presence of a Landau pole at a scale around 5 TeV. This implies the existence of a natural cut off for the model around the TeV scale and therefore solving hierarchy problem. Moreover, this cut off can be used to implement fermions masses that are not generated by Yukawa couplings including neutrinos masses and consequently one has a natural Dark matter candidate.
3. Higgs decays modes in the compact 341 model

To determine the different SM Higgs-like branching ratios, we have derived all the Feynman rules of the various vertices within the compact 341 model [7, 8] and get explicit analytical expressions of the various $h_1$ partial decay widths channels. The main Feynman diagrams contributing to the neutral Higgs (denoted by in fig.1) double photon production ($h_1 \rightarrow \gamma\gamma$) are displayed in Fig.1.

![Figure 1](image)

**Figure 1.** The one-Loop diagrams contributing to $h \rightarrow \gamma\gamma$ decay modes.

The partial decay width is shown to have the following form:

$$
\Gamma(h_1 \rightarrow \gamma\gamma) = \frac{\alpha^2 m_{h_1}^3}{1024 \pi^3} \sum_V \frac{g_{VV}^2}{m_V^2} Q_V^2 A_1(\tau_V) + \sum_f \frac{2 g_{ff}^2}{m_f^2} Q_f^2 N_{e,f} A_\frac{1}{2}(\tau_f) + \sum_f \frac{g_{SS}^2}{m_S^2} Q_S^2 N_{e,S} A_0(\tau_S)|^2
$$

(13)

Straightforward but lengthy calculations using the new derived Feynman vertices leads also to:

$$
\begin{align*}
\Gamma_{341}(h_1 \rightarrow ll) &= \frac{g^2}{32 \pi} \frac{m_l^2}{m_{W}^2} m_{h_1} \left(1 - \frac{4 m_l^2}{m_{h_1}^2}\right)^{\frac{3}{2}}, \\
\Gamma_{341}(h_1 \rightarrow b\bar{b}) &= \frac{3 g^2}{32 \pi} \frac{m_b^2}{m_{W}^2} m_{h_1} \left(1 - \frac{4 m_b^2}{m_{h_1}^2}\right)^{\frac{3}{2}}, \\
\Gamma(h_1 \rightarrow \gamma Z) &= \frac{\alpha^2 m_{h_1}^3}{512 \pi^3} \left(1 - \frac{M_Z^2}{M_{h_1}^2}\right)^{\frac{3}{2}} \frac{2}{u \sin \theta_W} A_{SM} + \mathcal{A}^2, \\
\Gamma_{341}(h_1 \rightarrow W^*W) &= \frac{3 g^4}{512 \pi^3} \frac{m_{h_1}}{m_{W}}, \\
\Gamma_{341}(h_1 \rightarrow Z^*Z) &= \frac{g^4 g_{h_1 ZZ}^2}{2048 \pi^3 C_W m_{h_1}} F\left(\frac{m_Z}{m_{h_1}}\right) \left(\sum_{j=\text{quarks}} (g_{jV}^2 + g_{jA}^2) + \sum_{l=\text{leptons}} (g_{lV}^2 + g_{lA}^2)\right),
\end{align*}
$$

(14)

where $\tau_i = 4 m_i^2/m_{h_1}^2$, $V, f$ and $S$ refer to Spin1, Spin$\frac{1}{2}$ and Spin0 particles respectively. The loop functions are given by:

\[ \mathcal{A}_{SM} \]
\[ A_1(x) = -x^2 \left( 2x^{-2} + 3x^{-1} + 3(2x^{-1} - 1)f(x^{-1}) \right), \quad A_2(x) = 2x^2 \left( x^{-1} + (x^{-1} - 1)f(x^{-1}) \right), \]

\[ A_0(x) = -x^2 \left( x^{-1} - f(x^{-1}) \right). \]  

(15)

with

\[ f(x) = \begin{cases} \arcsin^2 \sqrt{x} & \text{for } x \geq 1, \\ \frac{1}{4} \left( \ln \left( \frac{1+\sqrt{1-x^{-1}}}{1-\sqrt{1-x^{-1}}} \right) - 4\pi \right)^2 & \text{for } x < 1. \end{cases} \]  

(16)

Similarly,

\[ \mathcal{A} = \frac{g_{hVV}}{m_V^2} g_{ZVV} \tilde{A}_1(\tau_V, \lambda_V) + \tilde{N}_{c,f} \frac{4N_cQ_f}{m_f^2} g_{h_{Vff}}(g_{Zff}^L + g_{Zff}^R) \tilde{A}_2(\tau_f, \lambda_f) \]

\[- \frac{2N_cQ_S}{m_S^2} g_{hSSgZSS} \tilde{A}_0(\tau_S, \lambda_S), \]

(17)

with

\[ \tilde{A}_1(x, y) = 4(3 - \tan^2 \theta_W) I_2(x, y) + \left( (1 + 2x^{-1}) \tan^2 \theta_W - (5 + 2x^{-1}) \right) I_1(x, y), \]

\[ \tilde{A}_2(x, y) = I_1(x, y) - I_2(x, y), \quad \tilde{A}_0(x, y) = I_1(x, y), \]

(18)

where

\[ I_1(x, y) = \frac{xy}{2(x-y)} + \frac{x^2y^2}{2(x-y)^2} \left( f(x^{-1}) - f(y^{-1}) \right) + \frac{x^2y}{(x-y)^2} \left( g(x^{-1}) - g(y^{-1}) \right), \]

\[ I_2(x, y) = \frac{-xy}{2(x-y)} \left( f(x^{-1}) - f(y^{-1}) \right). \]

\[ g(x) = \begin{cases} \sqrt{x^{-1}} - \arcsin \sqrt{x} & \text{for } x \geq 1, \\ \frac{1-x^{-1}}{2} \left( \ln \left( \frac{1+\sqrt{1-x^{-1}}}{1-\sqrt{1-x^{-1}}} \right) - 4\pi \right) & \text{for } x < 1. \end{cases} \]

and

\[ F(x) = -|1 - x^2| \left( \frac{47}{2} x^2 - \frac{13}{2} + \frac{1}{x^2} - \frac{3}{2}(1 - 6x^2 + 4x^4) \ln(x) + \frac{3(1 - 8x^2 + 20x^4)}{\sqrt{4x^2 - 1}} \arccos \left( \frac{3x^2 - 1}{2x^3} \right). \]  

(19)

Here \( \mathcal{A}_{SM} \) represents the SM contribution, \( \lambda_i = 4m_i^2/m_Z^2 \) and \( g_{hVV}, g_{ZVV}, g_{h_{Vff}}, g_{Zff}^L, g_{Zff}^R, g_{hSS}, g_{hVV} \) are couplings constants. Here, \( Q_V, Q_f, Q_S \) are electric charges of the vectors, fermions and scalars and \( N_{c,f} : N_{c,S} \) are the number of fermion and scalar colors respectively. It is very important to mention that the SM contribution of the diphoton decay channel comes essentially from the one loop top quark and the gauge bosons W. However, in the 341 Model, beside the W and the top quark, it includes the new heavy gauge bosons \( K_1^\pm \) and \( V^{\pm\mp} \),
and the charged higgs bosons $h_{1}^{\pm}$, $h_{2}^{\pm}$ and $h_{3}^{\pm}$ (there is no direct coupling between the exotic quarks and the Higgs like-boson $h_{1}$). Regarding $h_{2}$ and $h_{3}$ higgs bosons, the expressions of most of the various decay widths are the same as the ones of the higgs $h_{1}$ except that the couplings are different and replace $m_{h_{1}}$ by $m_{h_{2}}$ or $m_{h_{3}}$. Among the interesting new decay modes, one has $h_{2} \rightarrow h_{1}h_{1}$, $h_{3} \rightarrow h_{1}h_{1}$, $h_{3} \rightarrow h_{2}h_{2}$ and $h_{3} \rightarrow h_{2}h_{1}$ with the corresponding decay width:

$$\Gamma_{341}(h_{2} \rightarrow h_{1}h_{1}) = \frac{1}{16\pi m_{h_{2}}} (g_{h_{2}h_{1}h_{1}})^{2} \left(1 - \frac{4m_{h_{1}}^{2}}{m_{h_{2}}^{2}}\right)^{\frac{1}{2}},$$

$$\Gamma_{341}(h_{3} \rightarrow h_{1}h_{1}) = \frac{1}{16\pi m_{h_{3}}} (g_{h_{3}h_{1}h_{1}})^{2} \left(1 - \frac{4m_{h_{1}}^{2}}{m_{h_{3}}^{2}}\right)^{\frac{1}{2}},$$

$$\Gamma_{341}(h_{3} \rightarrow h_{2}h_{2}) = \frac{1}{16\pi m_{h_{3}}} (g_{h_{3}h_{2}h_{2}})^{2} \left(1 - \frac{4m_{h_{2}}^{2}}{m_{h_{3}}^{2}}\right)^{\frac{1}{2}},$$

$$\Gamma_{341}(h_{3} \rightarrow h_{2}h_{1}) = \frac{1}{16\pi m_{h_{3}}} (g_{h_{3}h_{2}h_{1}})^{2} \left(\frac{m_{h_{2}}^{4}}{m_{h_{3}}^{2}} - \frac{2m_{h_{2}}^{2}m_{h_{3}}^{2}}{m_{h_{3}}^{2}} - 2m_{h_{2}}^{2} + \frac{m_{h_{1}}^{4}}{m_{h_{3}}^{2}} - 2m_{h_{1}}^{2} + m_{h_{3}}^{2}\right)^{\frac{1}{2}},$$

(20)

where

$$g_{h_{2}h_{1}h_{1}} = v_{\chi} \left(\frac{\lambda_{6}}{2} \gamma + \frac{\lambda_{4}}{2} v_{\eta} \alpha\right), \quad g_{h_{3}h_{1}h_{1}} = v_{\chi} \left(\frac{\lambda_{6}}{2} \sigma + \frac{\lambda_{4}}{2} v_{\eta} \beta\right),$$

$$g_{h_{3}h_{2}h_{2}} = \frac{\lambda_{5}}{2} \left(v_{\chi} (\alpha^{2} \sigma + 2\alpha \beta \gamma) + v_{\eta} (\beta \gamma^{2} + 2\alpha \gamma \sigma)\right), \quad g_{h_{3}h_{2}h_{1}} = \lambda_{4}v_{\rho} \alpha \beta + \lambda_{6}v_{\rho} \gamma \sigma. \quad (21)$$

The parameters $\alpha$, $\beta$, $\gamma$ and $\sigma$ are functions of the potential parameters $\lambda$’s (see refs. [7, 8]). It is worth to mention that in the decay modes $h_{2} \rightarrow \gamma \gamma$ and $h_{2} \rightarrow Z \gamma$, one has additional contributions of exotic fermions, charged scalars and the new gauge bosons (for more details see refs. [7, 8]).

4. Numerical results and conclusions
We have calculated the signal strength for each individual decay channel in the context of the compact 341 model, as in order to reproduce the experimental results (e.g. $m_{h_{1}} \sim 126$ GeV etc...), one has to take as inputs $v_{\chi} \sim v_{\eta} \sim 2$ TeV (because of the fact that 341 model has a Landau pole at a round the TeV scale), $m_{\text{exotic quarks}} \sim 750$ GeV (from the LHC experimental data concerning the lower bounds on exotic quarks), $m_{h_{2}} \sim 700$ GeV and for gauge bosons see table I. Moreover, other inputs are the scalar potential couplings $\lambda$’s selected from a random number generator and a Monte Carlo simulation after putting the self consistency constraints. In fact, we have obtained a confidence band due to the variations of the couplings within the allowed parameter space region after imposing the noghost, perturbative unitarity, triviality and stability conditions. Table 2 shows the results of the signal strength experimental data of ATLAS, CMS, combined ATLAS+CMS and the predictions of the compact 341 model. Figs 2 and 3 display the signal strengths for various decay modes compared to the ATLAS, CMS and the combined ATLAS+CMS run2 data 13 14. Notice that the predictions of the 341 model are fairly good and compatible with the run2 experimental data. This is a confirmation and a proof of the viability of the 341 BSM model.
Table 1. Masses of gauge bosons in compact 341 model.

| Gauge boson | Mass TeV |
|-------------|----------|
| Z           | 0.091    |
| Z'          | 0.79     |
| Z''         | 2.2      |
| W±          | 0.08     |
| K°, K±      | 0.65     |
| K±          | 0.655    |
| X±          | 0.655    |
| V±±         | 0.655    |
| Y±          | 0.92     |

Table 2. Signal strength data of ATLAS, CMS, ATLAS+ CMS and compact 341 model.

| Decay channel | ATLAS      | CMS        | ATLAS+CMS  | The compact 341 model |
|---------------|------------|------------|------------|-----------------------|
| µγγ           | 1.15±0.27  | 1.12±0.25  | 1.16±0.20  | 1.03                  |
| µZZ           | 1.51±0.39  | 1.05±0.27  | 1.31±0.27  | 1.17                  |
| µWW           | 1.23±0.23  | 0.91±0.24  | 1.11±0.18  | 0.99                  |
| µττ           | 1.41±0.30  | 0.89±0.31  | 1.12±0.25  | 0.99                  |
| µbb           | 0.62±0.37  | 0.81±0.45  | 0.69±0.29  | 0.99                  |

Figure 2. Signal Strengths for various decay modes compared to the ATLAS and CMS run2 data.
Figure 3. Signal Strengths for various SM like higgs decay modes compared to the combined ATLAS-CMS run2 data

Regarding the heavy higgses $h_2$ and $h_3$, the branching ratios (BR) for the various mode channels are shown in figs.3 and 4. We have used a Monte Carlo simulation taking into account the theoretical constraints mentioned before. We have checked that there is no big effect regarding the ambiguity in the choice of the renormalization parameter. For the higgs $h_2$, the dominant decay mode is $h_2 \rightarrow h_1 h_1$ where the branching ratio $\text{BR}(h_1 h_1)$ is $\sim 0.98$ and it is a decreasing function of $\gamma$. This could be a good signal for the 341 model regarding the double higgs production process at the LHC (more study is under investigation) aiming to measure the Higgs self-coupling and learn about new physics. It is important to mention that measuring the Higgs self couplings directly probes the structure of the Higgs potential and any deviation of the coupling value implies BSM physics, also it is important for the vacuum meta stability. Since the Higgs is unstable, we need to hunt for its decay products like $b\tau^+\tau^-$, $bbW^+W^-$, $bb\gamma\gamma$, $bbbb$ etc., and reconstruct it from them although the background is very important. To do so and minimize the background, we use some searches strategies like jet substructure techniques, unboosted and Boosted searches like exploiting the event kinematic differences between signal and background, generalize transverse mass cuts to pair production and increase luminosity etc., in order to gain sensitivity in the main higgs decay channels then, reconstruct the semi-invisible particle decays and so on. What are the implications of the di-higgs beyond the standard model physics (BSM) and its relevance to it? how can BSM physics alter SM di-higgs phenomenology? It is worth to mention that important resonant and non resonant enhancements are possible in a large varieties of BSM models. In the compact 341 model, one can have non resonant enhancement at large transverse momentum due to new loop contributions of exotic quarks and extra heavy gauge bosons or scalars and/or new (on-shell) resonances like the CP even higgs $h_2$ where its decay to $h_1 h_1$ is the dominant channel (new states induce large deviations in
inclusive cross section and differential distributions). In this case, one can separate the SM and BSM contributions using cuts on the invariant mass of the $h_1 h_1$ besides allowing to bound and reconstruct $\tan \beta = v_\eta / v_\chi$. For the decay mode $h_2 \rightarrow Z\gamma$, one gets a $\text{BR}(Z\gamma) \sim 0.1$, however for $h_2 \rightarrow ZZ$, the branching ratio $\text{BR}(ZZ)$ is very small $\sim 10^{-32}$ and has a big slope as a function of $m_{h_2} \in [0.7, 1.0]$ TeV (see fig.4). For the Higgs $h$ and contrary to $h$ the dominant decay modes are $h_3 \rightarrow ZZ$, $h_3 \rightarrow X^+ X^-$ and $h_3 \rightarrow V^{++} V^{--}$ where $\text{BR}(ZZ) \in [0.12, 0.45]$, $\text{BR}(X^- X^+) \in [0.257, 0.261]$ and $\text{BR}(V^{++} V^{--}) \in [0.24, 0.245]$ respectively when $m_{h_3} \in [0.45, 1.8]$.
However, for the decay modes \( h_3 \rightarrow h_1 h_1 \), \( h_3 \rightarrow J \bar{J} \) the branching ratios are \( \sim O(10^{-2}) \). Finally, for the \( h_3 \rightarrow \gamma \gamma \) and \( 3 \rightarrow b \bar{b} \), the branching ratios are very small \( \sim O(10^{-5}) \) (for more details see refs.\[7\]–[8]).

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