Higgs Phenomenology in the Two-Singlet Model.

Larbi Rahili[1], Jamal Ouaali[2]

[1] FS, Ibn Zohr University, Agadir, Morocco.

[2] FPBM, Sultan Moulay Slimane University, Beni-Mellal, Morocco

AIM

The SM plus two real (SM2S) is an extension of the Standard Model which provides a coherent explanation for the Dark Matter problem

- The SM plus two real, neutral scalar singlets and with a reflection symmetry on each of those singlets. Let SM2S denote this model, which we treat in section.
- This extension is severely constrained by unitarity, boundedness from below.
- It satisfies the experimental constraints, it gives a rich phenomenology with the addition of additional scalar bosons.
- New physics requires extensive areas of Higgs. and its effects on the masses of heavy Higgs bosons.

Introduction

Although the Standard Model has been tested with great precision and in agreement with the experimental results, some gaps suggest that this is not the fundamental theory of Nature. In fact the Standard Model does not explain :

- The existence of three generations of quarks and leptons.
- The lack of mixing between quarks and leptons.
- The oscillation of neutrinos.
- the problem of Dark Matter (DM).
- ... Hence the need to move towards a theory beyond the Standard Model. Theoretical physics offers several solutions that partly answer these questions, most of them based on extensions to the Standard Model. Our study model is : the Standard Model plus two Singlets

The Standard Model plus two Singlets

In this model, we extend the Standard Model with two real scalar fields S_1 and S_2. The part of the Lagrangian that includes the fields S_1, ϕ and S_2 is written as follows :

$$\mathcal{L} = (D_\mu\phi)^+(D^\mu\phi) + \partial_\mu S_1\partial^\mu S_1 + \partial_\mu S_2\partial^\mu S_2 - V(\phi, S_1, S_2)$$

where :

$$\begin{aligned} V(\phi, S_1, S_2) = &\mu^2\phi^+\phi + m_1^2 S_1^2 + m_2^2 S_2^2 \\ &+\frac{\lambda}{2}(\phi^+\phi)^2 + \frac{\lambda_1}{2}S_1^4 + \frac{\lambda_2}{2}S_1^4 \\ &+\eta(S_1S_2)^2 + \phi^+\phi(\xi_1 S_1^2 + \xi_2 S_2^2) \end{aligned}$$

After the spontaneous electroweak symmetry breaking, the Higgs doublet and triplet fields acquire their vacuum expectation values v_d and v_t respectively,

$$\langle S_1\rangle = \frac{v_1}{\sqrt{2}}, \ \langle S_2\rangle = \frac{v_2}{\sqrt{2}} \text{ and } \ \phi = \begin{pmatrix} 0 \\ \frac{v_d}{\sqrt{2}} \end{pmatrix}$$

Extended Higgs sector : Three CP_{even} neutral scalars (h_1, h_2 and h_3)

Procedure

Let the VEV of S_1 be v_1 and let the VEV of S_2 be v_2. Then, the vacuum stability conditions are

$$\mu^2 = -(\frac{\lambda}{2}v^2 + \xi_1 v_1^2 + \xi_2 v_2^2)$$
$$m_1^2 = -(\lambda_1 v_1^2 + \eta v_2^2 + \frac{1}{2}v^2\xi_1)$$
$$m_2^2 = -(\lambda_2 v_2^2 + \eta v_1^2 + \frac{1}{2}v^2\xi_2)$$

Using previous conditions. The neutral scalar and pseudo-scalar mass matrices are given by:

$$M^2_{CP_{even}} = \begin{pmatrix} \lambda v^2 & \sqrt{2}vv_1\xi_1 & \sqrt{2}vv_2\xi_2 \\ \sqrt{2}vv_1\xi_1 & 2\lambda_1 v_1^2 & \sqrt{2}v_1v_2\eta \\ \sqrt{2}vv_2\xi_2 & \sqrt{2}v_1v_2\eta & 2\lambda_2 v_2^2 \end{pmatrix}$$

One diagonalizes the real symmetric matrix M^2 as

$$M^2_{CP_{even}} = R^T diag(M_1^2, M_2^2, M_3^2)$$

where R is a 3×3 orthogonal matrix that may be parameterized as

$$R = \begin{pmatrix} c_1 & s_1c_3 & s_1s_3 \\ -s_1c_2 & c_1c_2c_3 + s_2s_3 & c_1c_2s_3 - s_2c_3 \\ -s_1s_2 & c_1s_2c_3 - c_2s_3 & c_1s_2s_3 + c_2c_3 \end{pmatrix}$$

Experimental Constraints

μ parameter:

To study the effects of ATLAS and CMS measurements on SM2S, we take into account experimental data from the observed cross section times branching ratio divided by the corresponding SM predictions for the various channels, i.e. the signal strengths of the Higgs boson defined by ;

$$\mu_i^f = \frac{\sigma_i^{SM2S}(h)Br^{SM2S}(h\to f)}{\sigma_i^{SM}(h)Br^{SM}(h\to f)}$$

where $\sigma(i\to h)$ denotes the Higgs boson production cross section through channel i and $Br(h\to f)$ the Br for the Higgs decay $h\to f$

Masses of Higgs bosons :

The above mentioned constraints are then imposed onto a set of randomly generated points in the ranges:

$$130GeV \le M_2 \le 1500GeV, \ \ 150GeV \le M_3 \le 1600GeV$$
$$10GeV \le v_1 \le 1500GeV, \ \ 10GeV \le v_2 \le 1500GeV$$

In this work we call that boson h_1 is the Higgs boson observed at the LHC, with $M_1 \sim 125GeV$. Where we have defined the Higgs hi fields so that their masses satisfy the following inequalities :

$$M_1 < M_2 < M_3$$

Theoretical Constraints

The SM2S Higgs potential parameters have to obey several constraints originating from theoretical requirements.

BFB:

$$\lambda > 0\,,\ \lambda_1 > 0\,,\ \lambda_2 > 0$$
$$a_1 \equiv \xi_1 + \sqrt{\lambda\lambda_1} > 0$$
$$a_2 \equiv \xi_2 + \sqrt{\lambda\lambda_2} > 0$$
$$a_3 \equiv \eta + \sqrt{\lambda_1\lambda_2} > 0$$
$$a_4 \equiv \sqrt{\lambda\lambda_1\lambda_2} + \xi_1\sqrt{\lambda_2} + \xi_2\sqrt{\lambda_1} + \eta\sqrt{\lambda} + 2\sqrt{a_1a_2a_3} > 0$$

Unitarity:

$$|\lambda| < 4\pi\,,\ |\xi_1| < 2\pi\,,\ |\xi_2| < 2\pi$$
$$|\eta| < \pi\,,\ |x_{1,2,3}| < 8\pi$$

and the eigenvalues $x_{1,2,3}$, which are the real roots of the cubic polynomial

$$\begin{aligned} &x^3 + 3x^2(\lambda + 2(\lambda_1+\lambda_2)) + 2x(2\eta^2 - 9\lambda(\lambda_1+\lambda_2) \\ &-18\lambda_1\lambda_2 + 2\xi_1^2 + 2\xi_2^2) + \lambda(-12\eta^2 + 108\lambda_1\lambda_2) + 16\eta\xi_1\xi_2 \\ &-24(\lambda_2\xi_1^2 + \lambda_1\xi_2^2) = 0 \end{aligned}$$

Results

A remarkable result of our numerical work is that there is an upper bound on the mass $\sqrt{M_2}$, even if the VEVs v_1 and v_2 are allowed to be as high as 100 TeV-and, correspondingly. The mass $\sqrt{M_3}$ also grows to a value of that order- the mass $\sqrt{M_2}$ remains much smaller. In figure Down we depict the upper bound on $\sqrt{M_2}$ as a function of c_1: when $c_1 \to 1$ the upper bound disppears, *i.e.* it tends to infinity.

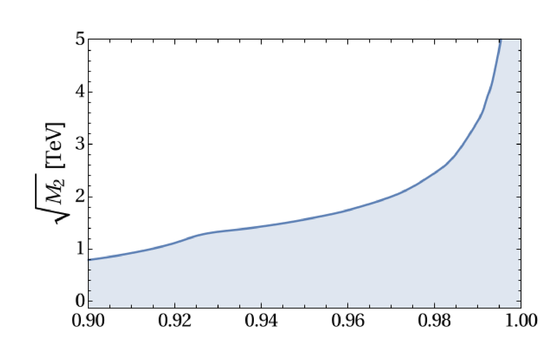

Figure: The upper on the mass of the second-lightest scalar $\sqrt{M_2}$ *versus* $\cos\alpha_1$ in the SM2S

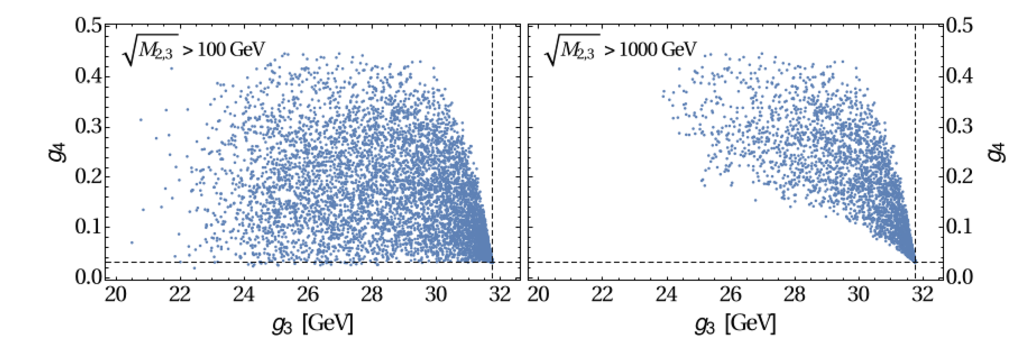

Figure: Scatter plots of the four-Higgs coupling g_4 *versus* the three-Higgs coupling g_3 in the SM2S. The dashed lines mark the values of both coupling in the SM.

....Results

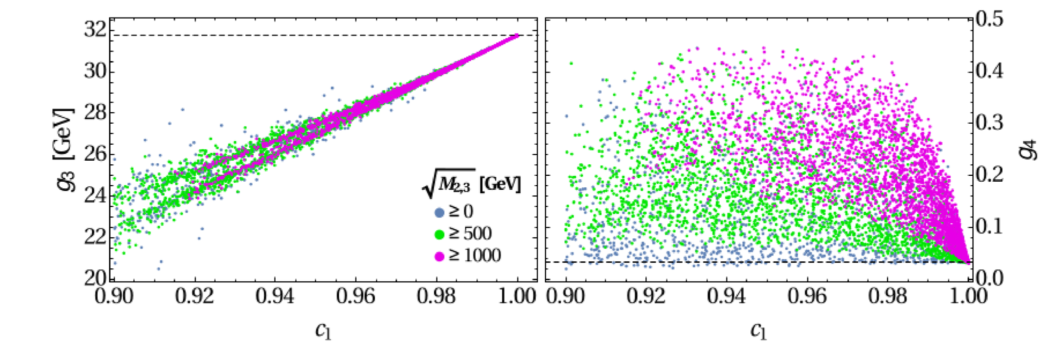

Figure: Scatter plots the three-Higgs coupling g_3 (left panel) and of the four-Higgs coupling g_4 (right panel) *versus* $\cos\alpha_1$ in the SM2S. The dashed lines mark the values of the coupling in the SM.

Higgs boson disintegration in SM2S

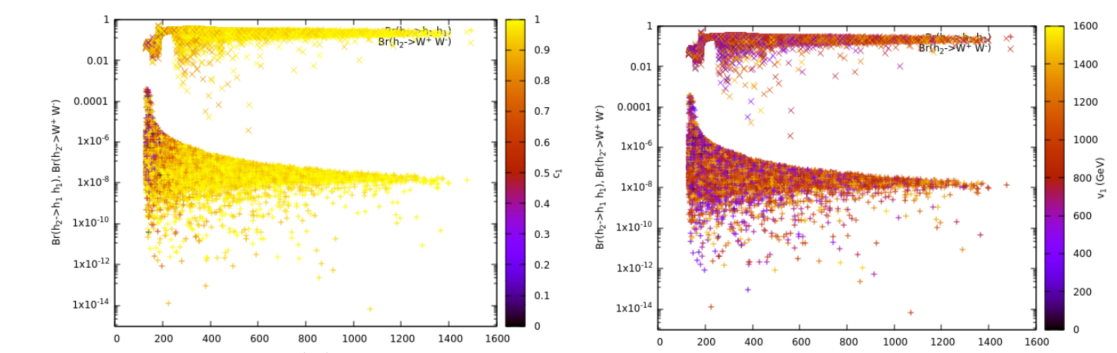

Figure: $Br(h_2\to h_1h_1)(+)$ and $Br(h_2\to W^+W^-)(\times)$ as function of m_{h_2} et $\cos(\alpha_1)$ (left), and also according to m_{h_2} et v_1 (right)

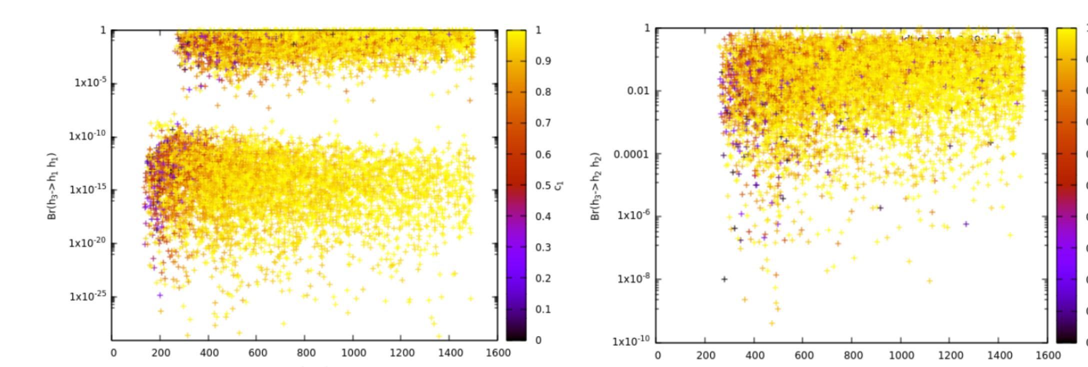

Figure: $Br(h_3\to h_1h_1)$ (left), $Br(h_3\to h_2h_2)$ (right) versus m_{h_3} et c_1

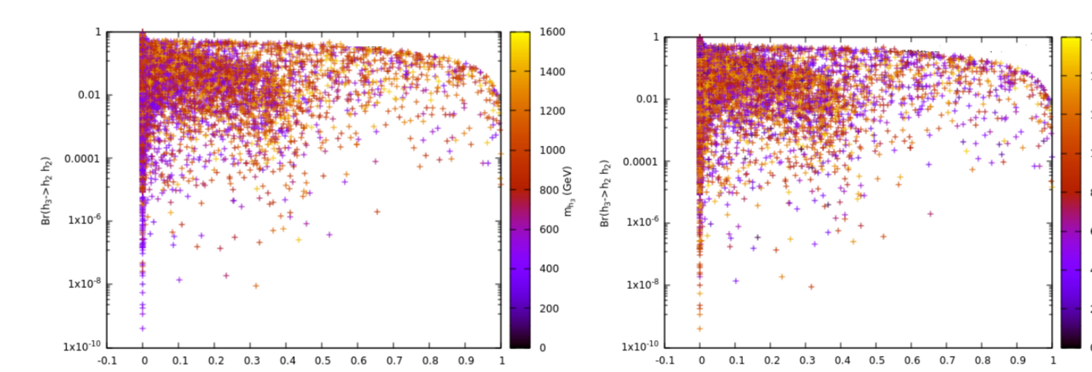

Figure: Correlations between $Br(h_3\to h_1h_1)$ and $Br(h_3\to h_2h_2)$ versus M_3 (left), and v_3 (right)

References

end of studies' project, Master of Modern Physics, USMS, FPBM, Morocco

Email: rahililarbi@gmail.com j.ouaali96@gmail.com