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The 126 GeV Higgs Boson in a general MSSM model with explicit CP-violation

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Abstract

In this work, we use the results from Higgs searches in the $\tau\bar{\tau}$ and $\gamma\gamma$ decay channels at LHC and indirect bounds as BR($B \to X_s\gamma$) to constrain the parameter space of a generic MSSM Higgs sector. In particular, we include the latest CMS results to look for additional Higgs states with masses up to 1 TeV. We show that the $\tau\bar{\tau}$ channel is the best and most accurate weapon in the hunt for new Higgs states beyond the Standard Model. We obtain that recent experimental results rule out additional neutral Higgs bosons in a generic MSSM below 300 GeV for any value of $\tan\beta$ and that, for instance, values of $\tan\beta$ above 30 are only possible for Higgs masses above 600 GeV. ATLAS stored data have the potential to render this bound obsolete in the near future.

Keywords: Higgs Physics, Beyond Standard Model, Supersymmetric Standard Model

1. Introduction

This work is a summary of the analysis carried out in Ref.[1] where the authors studied the possibility of having a light Higgs similar to the discovered boson at the LHC within a generalised MSSM model with CP violation. The final goal was to gain understanding about the nature of the observed resonance at 126 GeV, in addition to, looking for some signatures from which the existence of new particles, such as extra Higgs states, might be inferred. Our strategy consisted of analysing the compatibility between some key experimental signatures coming from the latest LHC results on Higgs observables and indirect constraints at low energy, making use of a semi-analytic approach complementing the usual general scans. This way we obtained a better understanding of the phenomenology being able, at the same time, to neatly exclude wide regions without the risk of missing small areas with unexpected cancellations. More details about the calculations can be found in Ref.[2].

The framework of our analysis is a generic MSSM model defined at the electroweak scale with explicit CP Violation. The lightest Higgs was designated to be the measured boson and hence its mass was fixed at 126 GeV. The rest of the model parameters were treated as free and independent, only constrained by experimental data. In this sense, this scheme can be thought of as the most general one since it encompasses all possible MSSM realisations due to the absence of theoretical assumptions. For instance, we do not impose the correct EWSB and, therefore, the Higgs masses, mixings and even the μ term have no settled values. In fact, they are taken to vary in a determined range during the scan. Consequently, this studio can be contemplated as the most conservative in view of the fact that we scrutinize all the allowed areas in the parameter space, even when some of these points may not be possible in a complete model.
The Higgs sector in consideration is the usual type II 2HdM where CP-violating phases are introduced. Then, the neutral Higgses will be a mixture between the scalar and pseudoscalar states. The two scalar doublets in the Lagrangian are:

$$\Phi_1 = \begin{pmatrix} \frac{1}{\sqrt{2}}(v_1 + \phi_1 + ia_1) \\ \phi_1^- \end{pmatrix} \qquad \Phi_2 = e^{i\xi} \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}(v_2 + \phi_2 + ia_2) \end{pmatrix}$$

where v_1 and v_2 are the Higgs vacuum expectation

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values.
The mass matrix for the physical states can be written on the basis (ϕ_1, ϕ_2, a), with $a = a_1 \sin\beta + a_2 \cos\beta$, as:

$$\mathcal{M}_H^2 = \begin{pmatrix} M_S^2 & M_{SP}^2 \\ M_{PS}^2 & M_P^2 \end{pmatrix} \quad (1)$$

where the M_{SP}^2 element reflects the size of the scalar-pseudoscalar mixing. From here it is clear that the mass matrix will not be diagonal. However, it is always possible to find a unitary matrix, $\mathcal{U}$, which diagonalises it in the following way:

$$\mathcal{U} \cdot M_H^2 \cdot \mathcal{U}^T = Diag\left(m^2_{h^0_1}, m^2_{h^0_2}, m^2_{h^0_3}\right) \quad (2)$$

2. Experimental Results

In this analysis, we use two main collections of experimental data to constrain the parameter space: one associated to Higgs observables and, the other, consisting in indirect processes such as $B \to X_s\gamma$, $B_s \to \mu^+\mu^-$ and the top decay, $t \to H^+b$. The diphoton channel is one of the main channels for the observed Higgs signal at the LHC while, in contrast, the $\tau\bar{\tau}$ channel plays the most important role constraining the presence of additional MSSM Higgs-states. In both cases the magnitude used to present the results is the signal strength, defined as:

$$\mu_X = \frac{\sigma(pp \to h) \times BR(h \to X)}{\sigma(pp \to h)_{SM} \times BR(h \to X)_{SM}} \quad (3)$$

where $\mu_x = 0$ corresponds to background-only hypothesis while $\mu_x = 1$ is associated to a SM Higgs signal. For the $\gamma\gamma$ decay channel, the measured signal strength by ATLAS [3] and CMS [4] is:

$$\mu_{\gamma\gamma}^{ATLAS} = 1.6 \pm 0.3 \qquad \mu_{\gamma\gamma}^{CMS} = 0.78^{+0.28}_{-0.26} \quad (4)$$

and the combined result at 2σ will be:

$$0.75 \le \mu_{\gamma\gamma}^{LHC} \le 1.55 \quad (5)$$

Considering the $\tau\bar{\tau}$ decay channel, the strongest bound for masses up to 150 GeV is set by CMS [5], Fig.1, with data samples of 4.9 fb^{-1} at 7 TeV and 19.4 fb^{-1} at 8 TeV. For masses above that, there is a previous study carried out by ATLAS [6] with 4.9 fb^{-1} at 7 TeV for masses up to 500 GeV, Fig.2, and a more recent analysis by CMS [7], Fig.3 and Fig.4, with masses up to 1 TeV with 4.9 fb^{-1} at $\sqrt{s}$ = 7 TeV and 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV. As the ATLAS bound is expected to be improved shortly, we focused our attention on the latest CMS limits. Herein the dominant Higgs production mode is specified: in Fig.3, where no b-tagged jet is required, the most sensitive channel is the gluon fusion process whereas in Fig.4, where at least one b-tagged jet is required, the production will be mainly given in association with b-quarks.

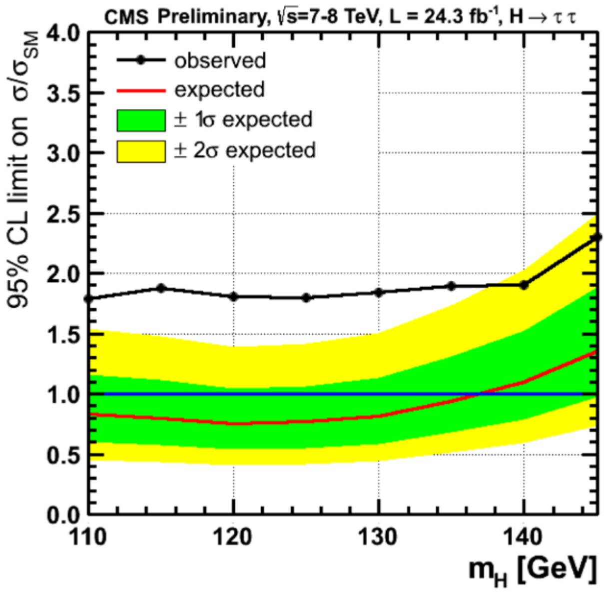

Figure 1: CMS combined observed 95% C.L. upper limit on the signal strength parameter together with the expected limit for the $\tau\bar{\tau}$ channel.

Concerning the flavour decays, $B_s \to \mu^+\mu^-$ is one of the low energy processes included in the analysis. In this case, the latest experimental results come from LHCb [8, 9] with 1.1 fb^{-1} at 8 TeV and 1.0 fb^{-1} at 7 TeV and CMS [10]:

$$\text{BR}(B_s \to \mu^+\mu^-) = (2.9^{+1.1}_{-1.0}) \times 10^{-9} \quad (6)$$

$$\text{BR}(B_s \to \mu^+\mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9} \quad (7)$$

Another important indirect constraint is $B \to X_s\gamma$. Its experimental value is provided by BaBar and Belle B-factories and CLEO [11, 12, 13, 14, 15, 16] being the HFAG [17, 18] current world average for $E_\gamma > 1.6$ GeV:

$$\text{BR}(B \to X_s\gamma) = (3.43 \pm 0.21 \pm 0.07) \times 10^{-4} \quad (8)$$

so that at 95% C.L. the valid range will be:

$$2.99 \le \text{BR}(B \to X_s\gamma) \times 10^4 \le 3.87 \quad (9)$$

Finally, there is a convenient light charged-Higgs studio performed by ATLAS [19] with masses up to 150 GeV which we also incorporated in the analysis, Fig.5.