PROCEEDINGS OF SCIENCE

Search for low mass Higgs-boson like resonances at CMS

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A search is performed on the 8 TeV LHC data for additional scalars and pseudoscalar with masses below the newly discovered higgs boson h(125). These searches are motivated within several BSM theories, most significantly extensions of the non mininal extensions of the MSSM like the NMSSM, where additional scalar and pseudoscalar states are expected. The mass range from 250 MeV to 110 GeV is explored with different final states. The current status of these searches will be reviewed and prospects will be given to extend these searches in the Run2 of the LHC.

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1. Introduction

The discovery of a Higgs boson with a mass close to 125 GeV has been a major milestone in the understanding of the origin of the elementary particle masses [1] [2] [3]. All the properties of this boson appear to be in accord with the Standard Model (SM) at the current level of precision [4] [5]. However, the SM cannot address several crucial issues such as the hierarchy problem or the nature of dark matter [6]. Theories beyond the Standard Model (BSM) have been proposed to address these questions. Many of them predict an extended Higgs sector, possibly with an additional low-mass (below 125 GeV) scalar or pseudoscalar.

Two-Higgs doublet models (2HDM) are a simple extension of the SM [7]. They feature two doublet fields ϕ_1 and ϕ_2, giving rise after $SU(2)_L$ symmetry breaking to five physical states : two scalar (h and H, with $m_h < m_H$), one pseudoscalar (A) and two charged ($H^{\pm}$) Higgs bosons. There are four distinct types of 2HDM, depending on which doublet the quarks and leptons couple to. The main parameters of the models are the two doublets vacuum expected values ratio $\tan\beta$ and the mixing angle α of the two scalar bosons. In the "alignment limit" [8], one can obtain a SM-like scalar H or h compatible with the discovered Higgs boson $h(125)$ and an additional low-mass scalar h or pseudoscalar A.

Supersymmetric models [9] also predict extended Higgs sectors. First, the Minimal Supersymmetric Standard Model (MSSM),which is a type II 2HDM, features 5 Higgs bosons. However, within this model the existence of a low-mass Higgs boson is strongly disfavoured, both theorically and experimentally. The Next-To-Minimal Supersymmetric Standard Model (NMSSM) is a simple extension of the MSSM, addressing the μ problem of the latest model. It consists in adding a singlet field S to the two doublets, resulting in the existence of seven physical states : three scalar (h_1, h_2 and h_3, with $m_{h_1} < m_{h_2} < m_{h_3}$), two pseudoscalar ($a_1$ and a_2) and two charged ($H^{\pm}$) Higgs bosons [10]. It is possible to identify h_1 or h_2 with the discovered Higgs boson $h(125)$ and obtain an additionnal low-mass scalar h_1 or pseudoscalar a_1. This light boson would preferentially have a large singlet mixture, resulting in suppressed couplings to vector bosons, preventing its discovery in classical channels so far.

Other BSM theories also motivates the search for a low-mass Higgs boson, such as dark-SUSY models [11] or general 2HDM+S [12].

In this document we review a set of searches for a light Higgs boson performed by the CMS experiment [13] with the 8 TeV dataset. The explored mass range goes from 0.25 to 110 GeV. The $\gamma\gamma$, $\tau\tau$, bb and $\mu\mu$ channels are considered, the classical Higgs boson searches channel ZZ and WW being forbidden kinematically. We split these searches according to two general strategies : the search for a direct production of the scalar or pseudoscalar with possibly additional objects, and the search for a pair production from the decay of a heavier Higgs boson, which could be $h(125)$. We denote a light scalar, which could be h of the 2HDM or h_1 of the NMSSM, by h and a light pseudoscalar, which could be A of the 2HDM or a_1 of the NMSSM, by a.

2. Search for a direct production

2.1 $h \to \gamma\gamma$

A search for a new scalar decaying into two photons is performed for a diphoton invariant mass in the range between 80 and 110 GeV [14]. Both 2HDM and NMSSM allow the existence of such a particle with a sizeable cross-section times branching ratio in the diphoton channel, up to 3.5 times the one expected for a SM Higgs boson in the case of the NMSSM [15]. The analysis extends the method developed in CMS for the observation and the measurement of the properties of the SM-like Higgs boson discovered in 2012 [16]. It searches for a localized excess of diphoton events over a smoothly falling background due to prompt diphoton production and to events with at least one jet misidentified as a photon. Additionally, despite the application of an electron veto, a remaining contribution due to the Drell-Yan process, with the electrons misidentified as photons, needs to be added to the background model. To achieve the best sensitivity, the events are separated into four classes obtained from a multivariate classifier. The expected and observed limits on the product of the cross-section times branching ratio into two photons are presented (fig.1). No significant excess with respect to the expected limit is observed. The observed limit ranges from 75 fb at the mass hypothesis of 80 GeV to 42 fb at a mass of 110 GeV. The highest excess has a significance of 1.9 σ for a mass of 98 GeV.

2.2 $a + bb \to \tau\tau + bb$

A search for a light pseudoscalar Higgs boson decaying to a pair of τ leptons, produced in association with a bb pair, is performed [17]. Pseudoscalar boson masses between 25 and 80 GeV are probed. Three di-tau final states are considered : $\mu\tau_h$, $e\tau_h$ and $e\mu$. The main backgrounds are $t\bar{t}$ pairs, W+jets and QCD multijets. No evidence for a pseudoscalar boson is found and upper

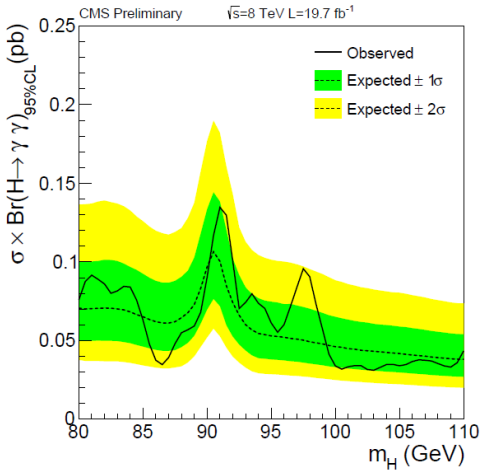

Figure 1: Expected and observed exclusion limits (95% CL) on the product of the cross-section times branching ratio into two photons in the asymptotic CLs approximation

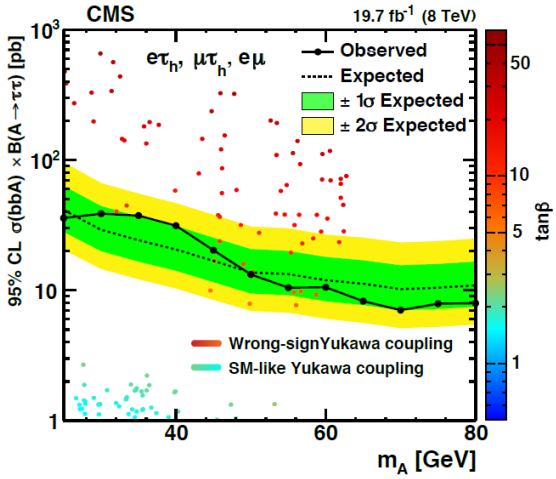

Figure 2: Expected cross sections for Type II 2HDM, superimposed on the expected and observed combined limits from the $a + bb \to \tau\tau + bb$ search

limits are set on the production cross section times branching fraction to τ pairs between 7 and 39 pb at the 95% confidence level (fig.2). This search excludes a pseudoscalar Higgs boson with mass below 80 GeV, in Type II 2HDM, with negative Yukawa couplings to down-type fermions (red points). It is not sensitive yet to exclude pseudoscalars with SM-like Yukawa couplings (blue points).

2.3 $h+X \to bb+X$

A search for a light scalar Higgs boson produced in supersymmetric cascades and decaying to a pair of b quarks is performed [18]. The search is made in the context of the NMSSM, considering two benchmark points : the "modified P4" benchmark scenario and the "decoupled squarks" case [19] [20]. The type of process considered is the pair production of coloured supersymmetric partners, decaying to neutralinos and charginos, and subsequently into a light scalar h_1 and the lightest supersymmetric particle (LSP). Additionally a high hadronic activity is expected due to the squarks and gluinos decays to quarks. Therefore, the signature of the event is a pair of b quarks coming from the decay of h_1 plus, denoted by X, large missing energy and at least two very energetic jets. Scalar masses between 30 and 110 GeV are probed. The signal model is composed by a model independant h_1 resonance and a model dependant non-resonant SUSY component. No indication of a signal is observed. Limits are set on the cross section of h_1-only production times the branching fraction into $b\bar{b}$. Moreover, results are interpreted within the NMSSM benchmark scenarios. Limits are set on the NMSSM cross section times branching fraction into $b\bar{b}$ together with the prediction of the modified P4 scenario (fig.3), and limits on NMSSM parameters in the decoupled squarks scenario are obtained.

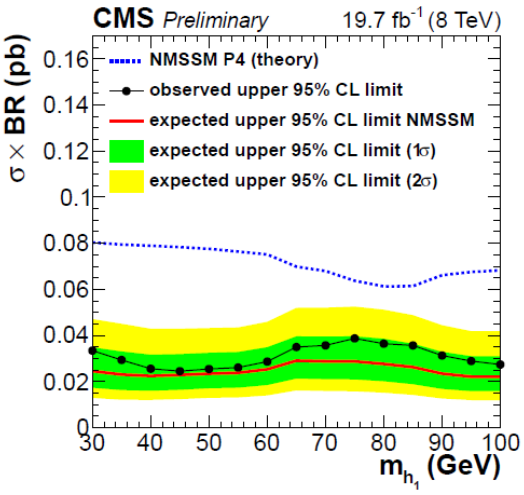

Figure 3: Upper limits for the light Higgs boson production cross section times branching fraction, for the $h+X \to bb+X$ search, in comparison to the theoretical expectations from the NMSSM P4 scenario

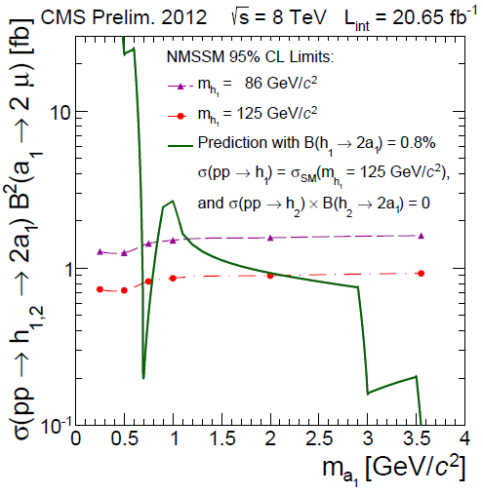

Figure 4: 95% CL upper limits as functions of m_{a_1}, for the NMSSM case, on $\sigma(pp \to h_{1,2} \to 2a_1 \times BR^2(a_1 \to 2\mu)$. The limits are compared to the predicted rate obtained using a simplified scenario from [21]

3. Search for a pair production

3.1 $H \to aa/\gamma_D\gamma_D \to 4\mu$

A search for a non-Standard-Model Higgs boson decay to a pair of new light bosons, each of which decaying into the $\mu^+\mu^-$ final state, is performed [22]. Two specific scenarios are considered : the NMSSM, with muons coming from the decays of a pair of light pseudoscalars a_1, and the dark-SUSY, with muons coming from the decays of a pair of dark photons γ_D. The expected signature is two boosted pairs of oppositely charged muons isolated from the rest of the event activity. The anaysis strategy is to search for an excess of events in the signal region, defined as a the 2D dimuon pairs space ($m_{\mu\mu1}$,$m_{\mu\mu2}$), with $m_{\mu\mu1}$ close to $m_{\mu\mu2}$ and $0.25 < m_{\mu\mu} < 3.55$ GeV. No excess of events is observed, and a model-independent upper limit on the product of the cross section times branching fraction times acceptance is derived. Results are then interpreted in terms of the NMSSM (fig.4) and dark-SUSY scenarios.

3.2 $h(125) \to aa/hh \to 4\tau$

Searches for non-standard decays of a Standard Model-like Higgs boson to a pair of light scalar or pseudoscalar bosons, each of which decaying into a highly boosted pair of τ, are performed [23] [24]. Two complementary analyzes are dedicated to this search. Both of them look for two well separated same-sign muons, each coming for a muonic decay of a τ in each pair, in order to reduce the background. The first analysis [23] covers a mass range for the a / h boson of 4 to 8 GeV. A boosted pair of tau is reconstructed from a muon with an oppositely-charged track nearby. The second analysis [24] covers a mass range of 5 to 15 GeV. A boosted pair of tau is reconstructed from the CMS standard hadronic τ reconstruction algorithm (HPS) [25], requiring the presence of a muon in the seeding jet. Two categories are built, based on the amount of missing transverse energy (MET), in order to be sensitive not only to gluon fusion (ggh) and vector boson fusion (VBF) production modes but also to associated production with a vector boson (VH). Both

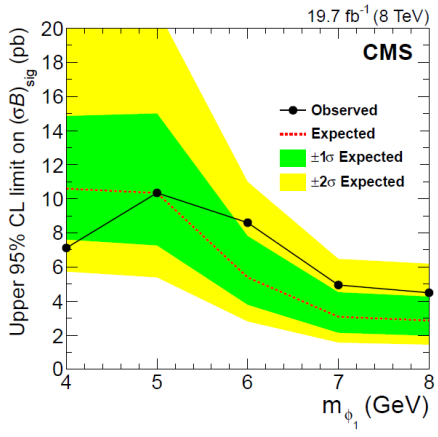

Figure 5: The observed and expected upper limits on $\sigma \times BR(h(125) \to \phi_1\phi_1 \to 4\tau)$ at 95% CL, as a function of the light boson mass [23]

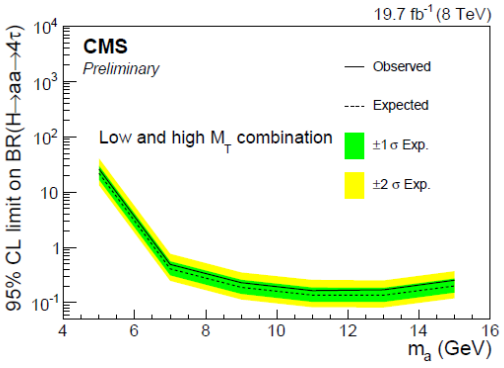

Figure 6: Expected and observed 95% C.L. limits on the branching ratio $BR(h(125) \to aa \to 4\tau)$. Combination of low and high MT bins [24]

analyzes observe no excess of events, and upper limits are set on the cross section times branching fraction (fig.5) and on the branching fraction (fig.6) for the considered process.

3.3 $h(125) \to aa \to \mu\mu bb$

A search for exotic decays of a Higgs boson $h(125)$ to a pair of new light bosons a, where one of the light bosons decays to a pair of muons and the other one decays to a pair of b quarks, is performed [26]. Both 2HDM and NMSSM predict a sizeable branching fraction for this process, up to 2.10^{-3} for NMSSM. The analysis covers a mass range for the pseudoscalar a of 25 to 65 GeV. Only ggh production mode is considered. The sensitivity of the search to the signal is extracted using a fit to the dimuon mass distribution. No statistically significant excess of event is observed and upper limits are set on the cross section times branching ratio (fig.7) and on the branching ratio itself for the considered process.

3.4 $h(125) \to aa \to \mu\mu\tau\tau$

A search for the exotic decay of the Higgs boson $h(125)$ to a pair of light pseudoscalar bosons a is performed in the final state with two muons and two taus [27]. One motivation for this search are two-Higgs-doublet models extended with a complex singlet (2HDM+S). Masses of the pseudoscalar boson between 20 and 62.5 GeV are probed. Five di-tau decay channels are considered : ee, $\mu\tau_h$, $e\tau_h$, $e\mu$ and $\tau_h\tau_h$. The sensitivity of the search to the signal is extracted using a fit to the dimuon mass distribution. No indication of a signal is observed. Results are interpreted in the context of general 2HDM+S. First, upper limits are set on the cross section times $BR(h(125) \to aa) \times BR(a \to \tau\tau)^2$, using the 2HDM+S relation between $BR(a \to \mu\mu)$ and $BR(a \to \tau\tau)$. Then, upper limits are set on the cross section, normalized to the SM, times $BR(h(125) \to aa)$ for the four types of 2HDM+S, in function of $\tan\beta$. The best sensitivity, with

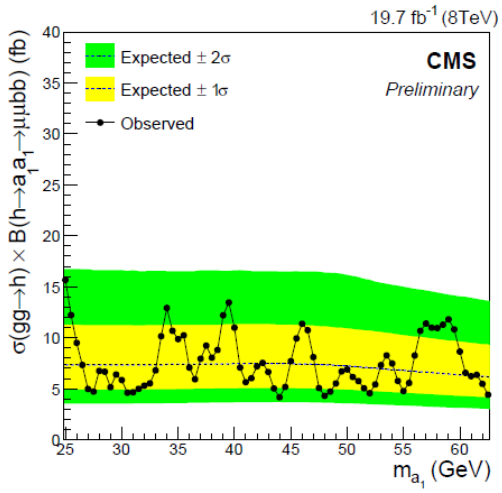

Figure 7: Observed and expected upper limits at 95% CL on the Higgs boson production times $BR(h(125) \to aa \to \mu\mu bb)$

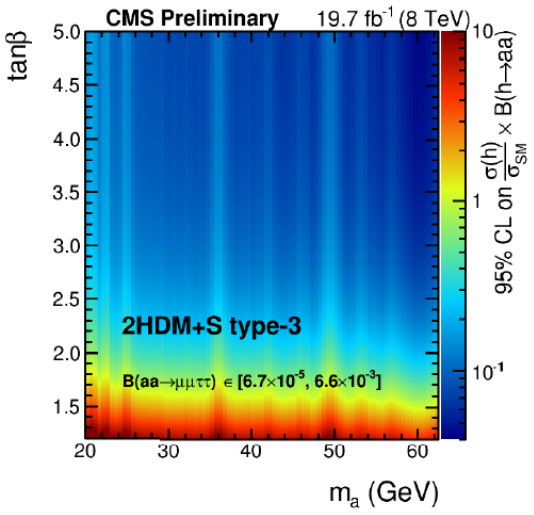

Figure 8: Observed upper limits at 95% CL on $\sigma(h(125))/\sigma_{SM} \times BR(h(125) \to aa)$ for the combination of all di-tau final states in 2HDM+S type-3

a limit on $BR(h(125) \to aa)$ between 4 and 15 %, is achieved for the 2HDM+S type III, called "lepton-specific" (fig.8).

4. Conclusion

Several low-mass scalar and pseudoscalar searches have been performed in CMS during run I in the range [0.25,110] GeV. Both direct and pair production have been considered. No evidence for new particle production has been observed. The results are interpreted in terms of several BSM theories, including 2HDM and NMSSM. Wide parameter space regions of these models have been excluded and benchmark scenarios have been ruled out.

All the presented searches are being continued with run II data. Several improvements to the analyzes are foreseen, such as dedicated triggers or the consideration of new production modes and final states. In addition, the sensitivity to BSM models will beneficiate from the increase of the luminosity and the center of mass energy.

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