PROCEEDINGS OF SCIENCE

Searches for exotic Higgs decays with the CMS detector

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Results are presented from CMS on searches for Higgs-like particles in models beyond the Standard Model and searches for rare or exotic decays of the 125 GeV particle. Light Higgses as predicted in the NMSSM models are searched for. Decays of the 125 GeV Higgs-like particle into muons are explored and the most recent results are presented.

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1. Introduction

The properties of the discovered Higgs boson [1, 2] by the ATLAS and CMS collaborations collaborations are in a continous analysis process which combines the results of various decay channels. The last report on the combination of the Higgs standard model (SM) [4, 5, 6] decay modes [3] investigated with the CMS detector has improved the precision of the couplings estimation. In addition, an upper limit on the branching ration of the Higgs boson to decay into channels beyond the standard model (BSM) was calculated to be 64%, see Fig. 1. This upper limit is based on the assumption that the couplings to the electroweak bosons are bound by to SM expectation to be less or equal to 1. The $0 \leq BR_{BSM} \leq 0.64$ limits at 95% CL motivates to further search for exotic Higgs decays and BSM models.

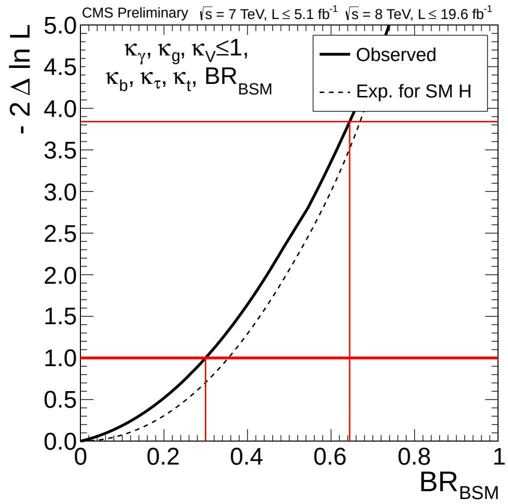

Figure 1: *The observed (solid line) and the expected (dashed line) median results in the presence of the standard model (SM) Higgs boson for the likelihood scan with respect to $BR_{BSM} = \Gamma_{BSM}/\Gamma_{tot}$ when the couplings to the electroweak bosons are assumed to be bound by the SM expectation.*

2. CMS Detector

The central feature of the CMS apparatus is a 13 m long superconducting solenoid with an internal diameter of 6 m, providing a 3.8 T magnetic field. Within the field volume are the silicon pixel and strip tracker, the crystal electromagnetic calorimeter (ECAL) and the brass/scintillator hadron calorimeter (HCAL). The tracks can be reconstructed with transverse momentum (p_T) as low as 100 MeV[1] and up to a pseudorapidity[2] $|\eta| < 2.5$. A p_T resolution of 1% at 100 GeV is achieved. The energy resolution achieved by ECAL is $3\%/\sqrt{E_T/\mathrm{GeV}}$ while in HCAL it is $100\%/\sqrt{E_T/\mathrm{GeV}}$. Muons are measured in gas-ionization detectors embedded in the steel return yoke. A detailed description of the CMS detector can be found elsewhere [7].

The analysed events are selected using a combination of electron, muon, tau and jets trigger objects. The particle flow (PF) algorithm [8] combines the information from all subdetectors and identifies the reconstructed particles as muons, electrons, photons and hadrons. The PF jets are then reconstructed with the anti-k_T jet algorithm [9] with the distance parameter of 0.5. The missing transverse energy is defined as the magnitude of the vector sum of the transverse momenta of the jets and the particles not associated with them.

3. MSSM and NMSSM Searches

The first model studied beyond the SM is its minimal supersymmetric extension (MSSM). In MSSM the Higgs sector contains the CP-odd neutral scalar A^0, two charged scalars $H^{\pm}$ and the two CP-even neutral scalars h^0 and H^0 [10, 11].

[1] In this paper the natural units system with $\hbar = c = 1$ is used.

[2] $\eta = -\ln[\tan(\theta/2)]$, where θ is the polar angle

3.1 Overview of MSSM Searches

The MSSM Higgs sector can be effectively described using m_{A^0}, the mass of the neutral scalar A^0, and $\tan\beta$, the ratio of the vacuum expectation values of the two doublets. In Fig. 2 the expected and the observed limits are shown for the dimuon, the $b\bar{b}$ and the ditau decay channel in the m_h^{max} scenario [12, 13, 14]. While for dimuon and $b\bar{b}$ decay modes, the $\tan\beta$ values are excluded up to 20 for m_{A^0} up to 200 GeV, the ditau decay channel search can exclude the $\tan\beta$ values up to 5. The search for charged Higgs [15] excludes $\tan\beta$ up to 16 for $m_{A^0} = 90$ GeV and 24 for 130 GeV. A precise measurement of the $\tan\beta$ can be obtained with the dimuon channel due to the mass

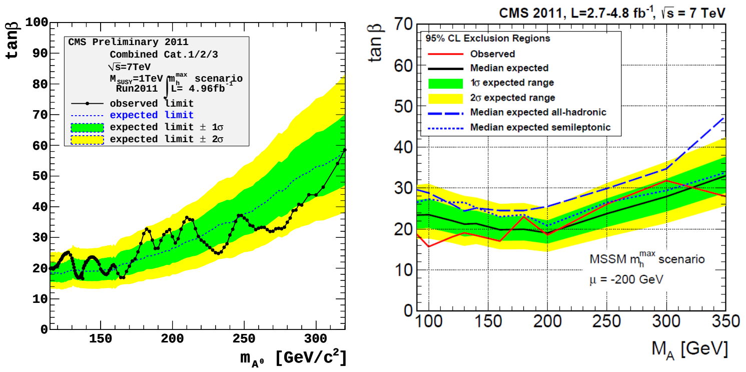

Figure 2: *The observed and the expected limits in the* $\tan\beta$ *vs.* m_{A^0} *plane for MSSM neutral Higgs bosons searches in the dimuon (left), the* $b\bar{b}$ *(middle) and ditau (right) decay channel with the CMS detector.*

invariant resolution. The ditau measurements are almost closing the phase space for $\tan\beta$ to a level where we need to start preparing decay modes as $H^+ \to c\bar{s}$ that are sensitive to $\tan\beta < 1$ values.

3.2 NMSSM Searches

In the next-to-MSSM model [16] (NMSSM) the *CP*-even Higgs bosons $h_{1,2}$ can decay via a new *CP*-odd light Higgs boson a_1. The model predicts a large BR$(a_1 \to \mu^+\mu^-)$ for the case $2m_\mu < m_{a_1} < 2m_\tau$. The search for the a_1 boson with multimuon final state can be performed analysing the data for the $h_{1,2} \to 2a_1$ decay [17] or the direct production $gg \to a_1 \to \mu^+\mu^-$ [18].

In the $h_{1,2} \to 2a_1$ search the main background contributions are from the $b\bar{b}$ and the double J/ψ productions. The $b\bar{b}$ final states with 4μ are estimated from data taking into account the muons momentum and their isolation, while the double J/ψ contibution is measured. In Fig. 3 the observed limits for the $h_{1,2} \to 2a_1$ search are shown for various m_{a_1} hypotheses and compared with the prediction when a 7.7% branching ratio is assumed for $(a_1 \to \mu^+\mu^-)$.

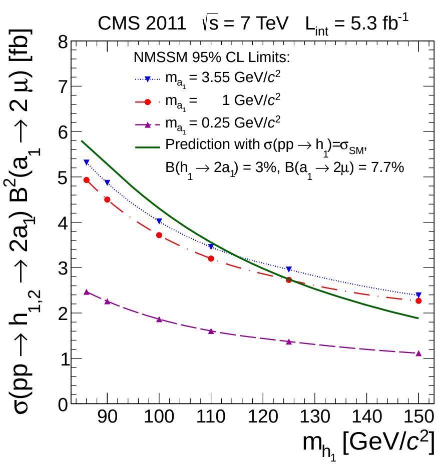

Figure 3: *The 95% CL upper limits from the* 4μ *final state search for the SM Higgs decaying into two pseudoscalars* a_1 *with various masses.*

The search for the direct a_1 production is performed in the 5.5 to 8.8 GeV and 11.5 to 14 GeV mass ranges to avoid the background contributions form the $\Upsilon(nS)$ resonances. In these ranges the search has a relatively flat background. Events selected with a 6 GeV tranverse momentum dimuon trigger and isolated reconstructed muons are analysed. No significant excess was observed in data, therefore the expected and observed limits at 95% CL shown in Fig. 4 for the two mass ranges were calculated.

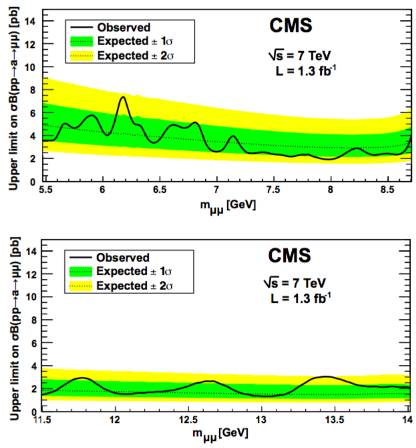

Figure 4: *The limits at 95% CL limits on $a_1 \to \mu^+\mu^-$ production in pp collisions at $\sqrt{s} = 7$ TeV for the dimoun invariant mass range 5.5 to 8.8 GeV (up) and 11.5 to 14 GeV (down).*

4. Minimal Type II Seesaw Model

In extensions of the SM which include the seesaw mechanism of type II [19], the doubly charged Higgs $\Phi^{\pm\pm}$ is member of the SU(2)$_L$ scalar triplet. The production of the $\Phi^{\pm\pm}$ boson is in pairs or in association with the charged Higgs boson.

The four and three leptons final states were studied optimising the analysis [20] with respect to the $\Phi^{\pm\pm}$ mass point. The following four benchmark points (BP) of the type II seesaw model were tested: a massless neutrino with normal mass hierarchies, with inverted mass hierarchies, degenerate neutrino mass spectrum (0.2 eV) and $\Phi^{\pm\pm}$ with equal branching ratios to each lepton generation. No signal was observed and therefore lower bounds on the $\Phi^{\pm\pm}$ mass between 383 and 408 GeV were set for the four BP. In addition, limits considering 100% branching fraction scenarios as shown in Fig. 5 for the $\mu^\pm\mu^\pm$ decay channel were calculated also for the $e^\pm e^\pm$, $\tau^\pm\tau^\pm$, $e^\pm\mu^\pm$, $e^\pm\tau^\pm$ and $\mu^\pm\tau^\pm$decay channels.

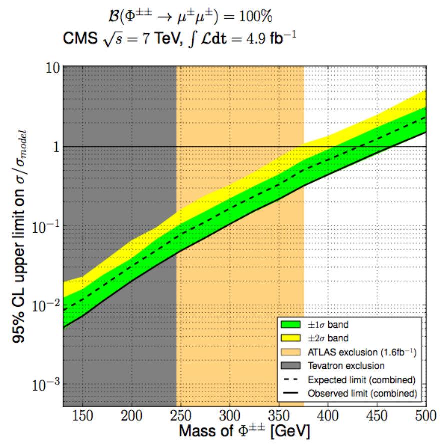

Figure 5: *The combined limits at 95% CL on the associated and pair production of $\Phi^{\pm\pm}$ for a $BR(\Phi^{\pm\pm} \to \mu^\pm\mu^\pm) = 100\%$.*

5. Higgs Rare Decays

In the category of Higgs rare decays one can consider all modes below the $\gamma\gamma$ channel. Decays channels as $Z^0\gamma$, $\mu^+\mu^-$ or e^+e^- are foreseen by the SM, but with a lower branching ratio than the $\gamma\gamma$ mode. Any signal excess observed in these modes relative to the SM predictions would point to an exotic model giving contribution to the observed rate. In Fig. 6 (left) the invariant mass spectrum of the $\ell^+\ell^-\gamma$ final state [21] is shown where the $\ell^+\ell^-$ are the dielectron and dimuon Z^0 decays. With the available statistics no signal was found and 94% CL limits, shown in Fig. 6 (right), were calculated.

6. Conclusion

The combination of the results on the SM Higgs decays available so far sets the upper limit on the branching ratio of the Higgs boson to decay into channels beyond the standard model to 64%. This motivates to continue the searches in the MSSM model especially at low values of

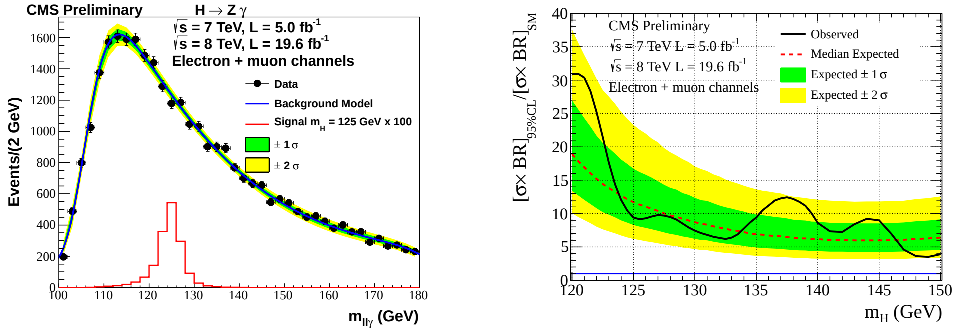

Figure 6: *The $m_{\ell\ell\gamma}$ invariant mass spectrum combined for $\sqrt{s} = 7$ and 8 TeV from the Z^0 decays into e^+e^- and $\mu^+\mu^-$. The expected signal ($\times 100$) is illustrated in red for a Higgs mass of 125 GeV.*

$\tan\beta$ and in NMSSM with various decay modes of the *CP*-odd light Higgs boson a_1 even though no signal was found so far.

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