The Compact Muon Solenoid Experiment
Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

26 June 2013 (v2, 01 July 2013)

Searches for Exotic Higgs decays in CMS

Adrian Perieanu for the CMS Collaboration

Abstract

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 will be presented.

Presented at *DIS 2013 XXI. International Workshop on Deep-Inelastic Scattering and Related Subjects*

Searches for exotic Higgs decays with the CMS detector

Adrian Perieanu*

on behalf of the CMS Collaboration

I. Physikalisches Institut B, RWTH-Aachen

E-mail: adrian.perieanu@cern.ch

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.

*XXI International Workshop on Deep-Inelastic Scattering and Related Subject -DIS2013,
22-26 April 2013
Marseilles, France*

*Speaker.

1. Introduction

The properties of the discovered Higgs boson [1, 2] by the ATLAS and CMS collaborations are in a continuous 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 ratio 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.

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 MeV¹ and up to a pseudorapidity² $|\eta| < 2.5$. A p_T resolution of 1% at 100 GeV is achieved. The energy resolution achieved by ECAL is $3\%/\sqrt{E_T/\text{GeV}}$ while in HCAL it is $100\%/\sqrt{E_T/\text{GeV}}$. 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].

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.

¹In 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 $H^+ \rightarrow c\bar{s}$ 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 $\text{BR}(a_1 \rightarrow \mu^+\mu^-)$ for the case $2m_\mu < m_{a_1} < 2m_\tau$. The search for the a_1 boson with multimMuon final state can be performed analysing the data for the $h_{1,2} \rightarrow 2a_1$ decay [17] or the direct production $gg \rightarrow a_1 \rightarrow \mu^+\mu^-$ [18].

In the $h_{1,2} \rightarrow 2a_1$ 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 contribution is measured. In Fig. 3 the observed limits for the $h_{1,2} \rightarrow 2a_1$ search are shown for various m_{a_1} hypotheses and compared with the prediction when a 7.7% branching ratio is assumed for $(a_1 \rightarrow \mu^+\mu^-)$.

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 from the $\Upsilon(nS)$ resonances. In these ranges the

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.

search has a relatively flat background. Events selected with a 6 GeV transverse 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.

4. Minimal Type II Seesaw Model

In extensions of the SM which include the see-saw 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.

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 BSM channels to 64% assuming electroweak bosons couplings to be bound by to SM expectation to be less or equal to 1. This motivates to

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

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

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.

continue the searches in the MSSM model especially at low values of $\tan\beta$ and in NMSSM with various decay modes of the CP -odd light Higgs boson a_1 even though no signal was found so far.

References

- [1] CMS Collaboration, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, *Phys. Lett.* **B716** (2012) 30-61.
- [2] ATLAS Collaboration, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, *Phys. Lett.* **B716** (2012) 1-29.
- [3] CMS Collaboration, *Measurements of the properties of the new boson with a mass near 125 GeV*, CMS-PAS-HIG-13-005.
- [4] S. L. Glashow, *Partial-symmetries of weak interactions*, *Nucl. Phys.* **22** (1961) 579.
- [5] S. Weinberg, *A model of leptons*, *Phys. Rev. Lett.* **19** (1967) 1264.
- [6] A. Salam, *Weak and electromagnetic interactions*, N. Svartholm, ed., p. 367. Almqvist & Wiskell, 1968. Proceedings of the eighth Nobel symposium.
- [7] CMS Collaboration, *The CMS experiment at the CERN LHC*, *JINST* **3** S08004.
- [8] CMS Collaboration, *Particle-Flow Event Reconstruction in CMS and Performance for Jets, Taus and MET*, CMS-PAS-PFT-09-001.
- [9] M. Cacciari, G. P. Salam and G. Soyez, *The Anti-k(t) jet clustering algorithm*, *JHEP* **0804** 063.
- [10] I. Aitchinson, *Supersymmetry and the MSSM: An Elementary Introduction*, [hep-ph/0505105].
- [11] S. Martin, *A Supersymmetry Primer*, [hep-ph/9709356].
- [12] CMS Collaboration, *Search for Neutral MSSM Higgs Bosons in the $\mu^+\mu^-$ final state with the CMS experiment in pp Collisions at $\sqrt{s} = 7$ TeV*, CMS-PAS-HIG-12-011.
- [13] CMS Collaboration, *Search for a Higgs boson decaying into a b -quark pair and produced in association with b quarks in proton-proton collisions at 7 TeV*, *Phys. Lett.* **B722** (2013) 207.
- [14] CMS Collaboration, *Higgs to tau tau (MSSM)*, CMS-PAS-HIG-12-050.
- [15] CMS Collaboration, *Search for a light charged Higgs boson in top quark decays in pp collisions at $\sqrt{s} = 7$ TeV*, *JHEP* **07** (2012) 143.
- [16] M. Maniatis, *The next-to-minimal supersymmetric extension of the standard model reviewed*, *Int. J. Mod. Phys.* **A 25** (2010) 3505.
- [17] CMS Collaboration, *Search for a non-standard-model Higgs boson decaying to a pair of new light bosons in four-muon final states*, [arXiv:1210.7619].
- [18] CMS Collaboration, *Search for a light pseudoscalar Higgs boson in the dimuon decay channel in pp collisions at $\sqrt{s} = 7$ TeV*, [arXiv:1206.6326].
- [19] M. Magg and C. Wetterich, *Neutrino mass problem and gauge hierarchy*, *Phys. Lett.*, **B94** (1980) 61.
- [20] CMS Collaboration, *A search for a doubly-charged Higgs boson in pp collisions at $\sqrt{s} = 7$ TeV*, *Eur. Phys. J.* **C72** (2012) 2189.
- [21] CMS Collaboration, *Search for the standard model Higgs boson in the Z boson plus a photon channel in pp collisions at $\sqrt{s} = 7$ and 8 TeV*, CMS-PAS-HIG-13-006.