Search the SM Higgs boson to bb, $\tau\tau$, WW, ZZ with 4.7 fb^{-1} of CMS data

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1 Introduction

The Standard Model (SM) of particle physics is the theory of the strong and electroweak interactions. It has been soundly confirmed by a variety of direct and indirect measurements performed over the last decades. By introducing a certain number of scalar degrees of freedom, the mass of the gauge bosons and of the fermions can be generated via the Brout–Englert–Higgs (BEH) mechanism. In its minimal version, the BEH mechanism implies the existence of one physical neutral boson with $J^{\rm CP} = 0^{++}$, the so–called "Higgs boson", whose mass (M_H) is a free parameter of the theory. Theoretical arguments constrain M_H to be bounded from above by about 700 GeV (see e.g. Ref. [1]). Assuming the SM predictions of the electroweak observables, the precision measurements hint at a rather light Higgs boson, $M_H \approx 100$ GeV. Direct searches at LEP2 measure a 95% CL lower bound on M_H at 114.4 GeV [2]. Depending on its mass, the Higgs boson decays predominanlty to b–quarks and τ–leptons ($M_H \lesssim 135$ GeV) or to a pair of massive gauge bosons ($M_H \gtrsim 135$ GeV). At the LHC, the main production mechanisms, ordered by importance, are gluon–gluon fusion (GGF), vector–boson fusion (VBF), and associated production with a gauge boson (VH), or heavy quarks (bbH, ttH).

A detailed description of the CMS apparatus can be found in Ref. [3]. A particle–flow technique is deployed for the offline reconstruction of collision events. The list of reconstructed "particle–flow particles" is then used to build higher–level objects, like jets, b–tag discriminators, or the semileptonic decays of tau leptons (τ_h). The missing transerse energy ($\vec{E}_T^{miss}$) is defined as the negative vector sum of all particles transverse momenta.

The analyses presented in this talk are based on up to 4.7 fb^{-1} of LHC data collected throughout 2011 at a center–of–mass energy of 7 TeV, with a peak instantaneous luminosity of $3.5 \cdot 10^{33}$ cm^{-2}s^{-1}, and an average of 9 pile–up interactions per bunch crossing.

2 Higgs searches

2.1 $H \to b\bar{b}$

A search for the SM Higgs boson decaying to a pair of b–quarks, and produced in association with a gauge boson $V = W, Z$, is documented in Ref. [4]. Events are selected online requiring electron/muon triggers, or large E_T^{miss}, depending on which of five exclusive final state of the vector V is tagged. A pair of b–tagged jets is required offline. The di–jet system is required to have transverse momentum in excess of 150 GeV. The main SM backgrounds consist of $V + bb$ (dominant), V+light quarks, di–boson, and $t\bar{t}$. They are normalized from background–enriched sidebands. The interpretation of the results is performed using a multivariate analysis ("BDT"), cross–checked with a cut–based one. A counting experiment of events with a score of the BDT above a given threshold is used to set exclusion limits. No evidence of a signal over the SM background is found. The observed (expected) exclusion limit at 95% CL on the cross–section of a SM–like Higgs boson is 4.3 (5.7) times the SM prediction for $M_H = 125$ GeV.

2.2 $H \to \tau^+\tau^-$

For $M_H \lesssim 145$ GeV, the decay into a pair of tau leptons [5] provides an important discovery channel for the SM Higgs boson, allowing in principle for a direct measurement of the Higgs coupling to leptons. Three final states are considered: when both taus decay leptonically, one into a muon plus neutrinos and the other into an electron plus neutrinos ($\tau_e\tau_\mu$), or when one tau decays leptonically and the other semileptonically ($\tau_e\tau_h$, $\tau_\mu\tau_h$). Depending on the jet content, events are classified into a "VBF"–like, a "Boosted", and a "0/1–jet" category. The dominant background ($Z \to \tau\tau$) is estimated from $Z \to \mu\mu$ data events, where the muons are replaced with simulated tau leptons. The second largest source of background comes from events where a jet is misidentified as a tau (W+jets, QCD). The di–tau mass is reconstructed from the visible tau momenta and $\vec{E}_T^{miss}$, using a likelihood–based technique; the resulting di–tau mass resolution is at most 20%. A binned shape analysis of the di–tau mass spectrum is performed for the statistical interpretation of the results. The observation is consistent with the background–only hypothesis. The observed (expected) exclusion limit at 95% CL on the cross–section of a SM–like Higgs boson is 3.6 (2.3) times the SM prediction for $M_H = 125$ GeV.

2.3 $H \to W^+W^- \to \ell^+\nu\ell^-\nu$

A search for the SM Higgs boson decaying to W bosons in the fully–leptonic final state is documented in Ref. [6]. Events with a pair of opposite–charge, isolated and high–

p_T leptons (electrons or muons) are considered. The Drell–Yan and $t\bar{t}$ backgrounds are reduced by a cut on the "projected" $\vec{E}_T^{miss}$ and a b–tag veto, respectively. The largest background comes from the WW continuum, whose contribution is calibrated from sidebands or normalized to the theoretical NLO cross–section, depending on the value of M_H under test. Subleading backgrounds come from $t\bar{t}$, W+jets and Drell–Yan, and are estimated from sidebands. Events are further split into a 0–jet, 1–jet and 2–jets category, the latter optimized for the VBF production mode. For the first two categories, a BDT classifies events as signal or background like, depending on the event kinematics. The output of the BDTs is used in a shape analysis. The SM Higgs boson is ruled out in the range $[129, 270]$ GeV, compared with an expectation of $[127, 270]$ GeV in the background–only hypothesis.

2.4 $H \to ZZ \to \ell^+\ell^- q\bar{q}$

The final state $H \to ZZ \to \ell^+\ell^- q\bar{q}$, with $q = u, d, c, s, b$, has the largest branching ratio among the $H \to ZZ$ decays [8]. To enhance the statistical power, events are categorized depending on the number of b–tagged jets. To reduce the dominant Z+jets background, the analysis exploits an angular likelihood and a quark/gluon likelihood discriminator. A shape analysis of the four–body mass spectrum is performed, with a data–driven parametrization of the background template. Two separate analyses are optimized for the $[130, 164]$ GeV and for the $[200, 600]$ GeV range. The observed limit is consistent with the background–only expectation in the full search range.

2.5 $H \to ZZ \to \ell^+\ell^- \nu\nu$

A search for the Higgs boson in the $H \to ZZ \to \ell^+\ell^- \nu\nu$ final state is documented in Ref. [7]. In addition to a pair of isolated and opposite–sign electrons or muons, the E_T^{miss} is required to be in excess of 70 GeV. The largest background comes from events with genuine leptons and missing energy, namely $t\bar{t}$ and WW, followed by WZ, ZZ and Drell–Yan di–lepton production with instrumental E_T^{miss}. The dominant backgrounds are estimated from data sidebands with opposite–flavor leptons. A binned shape analysis of the transverse mass distribution of the di–lepton and $\vec{E}_T^{miss}$ allows to exclude the SM Higgs boson at 95% CL in the range $[270, 440]$ GeV.

2.6 $H \to ZZ \to \ell^+\ell^- \tau^+\tau^-$

A search for the Higgs boson decaying to a pair of Z bosons in the $2\ell 2\tau$ final state is documented in Ref. [9]. A total of eight independent channels from combinatorial association of the two Z boson final states are simultaneously analyzed. The dominant background is represented by the ZZ continuum, which is normalized to the measured inclusive Z cross–section, scaled by the $\sigma(ZZ)/\sigma(Z)$ theoretical ratio. The residual backgrounds come from misidentified leptons and are estimated from data using the fake rate method. A binned shape analysis of the visible four–body mass is used to set limits. The upper limit on the cross section is approximately between a factor four and seven larger than the SM cross section in the range $[190, 500]$ GeV, consistent with the background–only expectation.

3 Conclusions

A search for the SM Higgs boson in six different final states, using up to 4.7 fb^{-1} of CMS data at $\sqrt{s} = 7$ TeV, has been presented. The analyses presented here target the "low mass resolution" channels. The SM Higgs boson is excluded at 95% CL over large intervals of M_H in both the intermediate and high mass range. A moderate excess in the low–mass range, with a maximal local significance of about 2σ, is observed from the combination of the $\ell^+\nu\ell^-\nu$, $b\bar{b}$, and $\tau^+\tau^-$ channels.

References

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