

A search for the Higgs boson in $H \rightarrow ZZ^{(*)}$ mode with the CMS detector

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The results from a search for the SM Higgs Boson in the channels $H \rightarrow ZZ \rightarrow 4l$, $2l2\nu$ and $2l2j$ with the CMS detector using data accumulated in the 2010 and 2011 running of the LHC at $\sqrt{s} = 7$ TeV are presented.

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1. Introduction

The production of SM Higgs bosons followed by the decay $H \rightarrow ZZ^{(*)}$ is expected to be the main discovery channel at the CERN LHC pp collider for a wide mass range. In the following the decay channels $H \rightarrow ZZ^{(*)} \rightarrow 2l2j$, $2l2\nu$ and $4l$ are presented. The analyses use data corresponding to an integrated luminosity of $> 1 \text{ fb}^{-1}$ recorded by the CMS detector during 2010 and 2011 in pp collisions at $\sqrt{s} = 7 \text{ TeV}$ from the LHC. The search covers Higgs boson mass (m_H) hypotheses of $110 < m_H < 600 \text{ GeV}/c^2$ with an expected sensitivity varying between one and five times the standard model cross section at 95% Confidence Level (CL) over most of the mass range.

2. $H \rightarrow ZZ \rightarrow 2l2j$

The analysis uses data collected during 2011, corresponding to an integrated luminosity of $1.00 \pm 0.06 \text{ fb}^{-1}$ [3]. The selection to discriminate between signal and background events is based on kinematic and topological quantities, which include the angular spin correlations of the decay products. The events are classified according to probability of the jets to originate from quarks of light or heavy flavor or from gluons. The m_{ZZ} distributions of selected events are split into six categories based on the b -tag type and the lepton flavor, see Fig 1(left). The background distribution is parameterized with an empirical probability function with normalization obtained from the m_{jj} sideband distribution rescaled to the m_{jj} signal region. No evidence for a SM-like Higgs boson has been found and upper limits on the production cross section for the SM Higgs boson have been set in the range of masses between $225 \text{ GeV}/c^2$ and $600 \text{ GeV}/c^2$, see Fig 1(right).

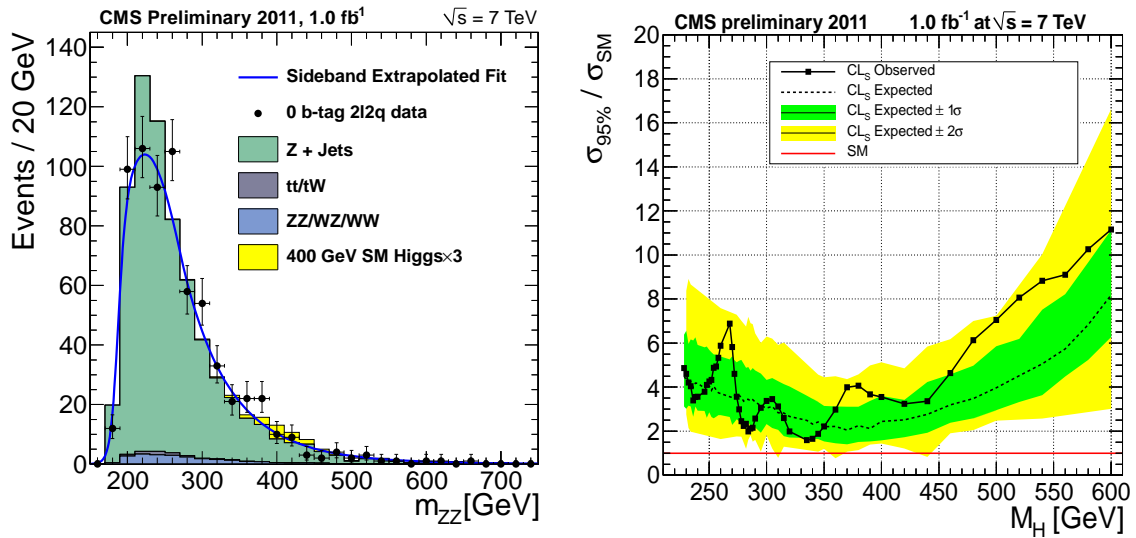


Figure 1: (left) The m_{ZZ} invariant mass distribution after final selection 0 b -tag category. Points represent the data, shaded histograms represent the signal and background expectations. (right) The mean expected and the observed upper limits at 95% CL on $\sigma(pp \rightarrow H + X) \times \mathcal{B}(ZZ \rightarrow 2l2j)$ for a Higgs boson in the mass range $225\text{-}600 \text{ GeV}/c^2$, using the CL_s approach. The samples correspond to an integrated luminosity of 1.0 fb^{-1} .

3. $H \rightarrow ZZ \rightarrow 2l2\nu$

The analysis uses data collected during 2011, corresponding to an integrated luminosity of $1.10 \pm 0.07 \text{ fb}^{-1}$ [2]. If the mass of the Higgs boson is much larger than twice the mass of the Z boson, each Z boson is produced with a substantial transverse momentum. Consequently, a $2l2\nu$ event is characterized by the presence of a boosted Z boson decaying to an e^+e^- or $\mu^+\mu^-$ pair and large missing transverse energy (MET) arising from the decay of the other Z boson decaying into neutrinos. Events are selected such that there are two well-identified, isolated, opposite charge leptons of the same flavor with $p_T > 20 \text{ GeV}$ that form an invariant mass consistent with the Z mass vetoing events with at least one b-tagged jet or a third lepton. An high MET threshold and additional cuts on the $\Delta\phi(\text{MET};\text{jet})$ and the transverse Higgs mass variables (M_T) are imposed to further separate signal with respect to the backgrounds. No excess is observed in the ZZ transverse mass, see Fig 2(left), and upper limits on the production cross section for the SM Higgs boson have been set in the range of masses between $250 \text{ GeV}/c^2$ and $600 \text{ GeV}/c^2$, see Fig 2(right).

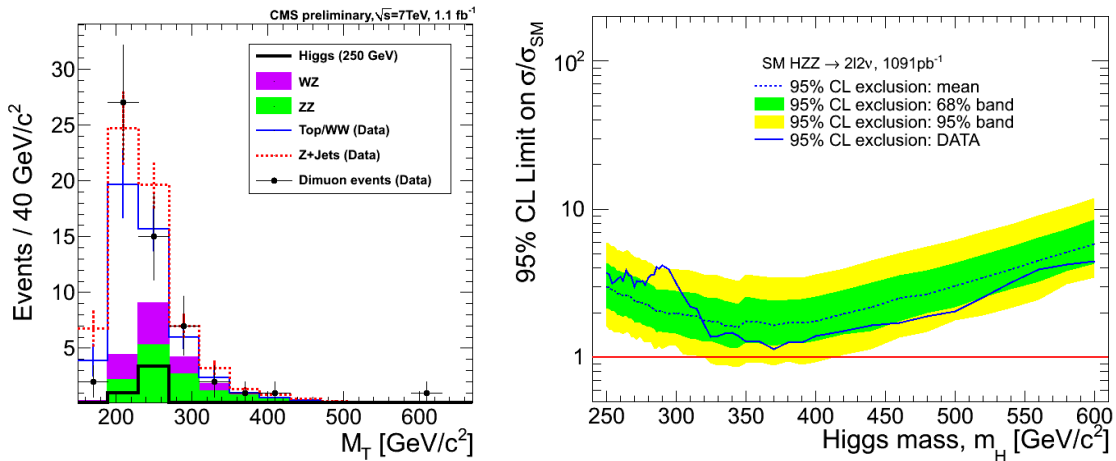


Figure 2: (left) The M_T distribution of events passing the selection. Points represent the data, shaded histograms represent the signal and background expectations. (right) The mean expected and the observed upper limits at 95% CL on $\sigma(pp \rightarrow H + X) \times \mathcal{B}(ZZ \rightarrow 2l2\nu)$ for a Higgs boson in the mass range 250-600 GeV/c^2 , using the CL_s approach. The samples correspond to an integrated luminosity of 1.1 fb^{-1} .

4. $H \rightarrow ZZ^{(*)} \rightarrow 4l$

The analysis uses data collected during 2010 and 2011, corresponding to an integrated luminosity of $1.13 \pm 0.07 \text{ fb}^{-1}$ [1]. The search relies solely on the measurement of leptons and the analysis achieves high lepton reconstruction, identification and isolation efficiencies for a $ZZ^{(*)} \rightarrow 4\ell$ system, composed of two pairs of same flavour and opposite sign isolated leptons, e^+e^- or $\mu^+\mu^-$. Two strategies are developed: one is focusing on the search of the Higgs boson with masses lower than twice the Z boson mass (baseline selection), the other dedicated to high Higgs boson masses and to the measurement of the ZZ cross section (high-mass selection). The background sources

comprise an irreducible 4ℓ contribution from $ZZ^{(*)}$ production, a reducible background contributions come from $Zb\bar{b}$ and $t\bar{t}$ where the final states contain two isolated leptons and two b jets giving rise to secondary leptons, and instrumental backgrounds from Z +jets or multiple jets in QCD hard interactions where jets are misidentified as leptons. Fifteen events are observed in the $2e2\mu$, $4e$ and 4μ channels while 14.4 ± 0.6 events are expected from standard model background processes. The distribution of events is compatible with the expectation from the standard model continuum production of Z boson pairs from $q\bar{q}$ annihilation and gg fusion. No clustering of events is observed in the measured $m_{4\ell}$ mass spectrum, see Fig. 3(left). Six of the events are below the kinematic threshold of two on-shell Z 's ($m_H < 180 \text{ GeV}/c^2$), while 1.9 ± 0.1 background events are expected. The probability that the background fluctuates to the observed number of events is 1.3%. Using the high-mass selection which contains eight events, a total cross section for a pair of Z bosons in the mass range $60 < m_Z < 120 \text{ GeV}/c^2$ has been measured to be in agreement with the predicted value. Upper limits obtained at 95% CL on the cross section \times branching ratio for a Higgs boson with standard model-like decays exclude cross sections from about one to two times the expected standard model cross section for masses in the range $180 < m_H < 420 \text{ GeV}/c^2$ see Fig. 3(right). Upper limits obtained in the context the standard model with a fourth fermion family, exclude a Higgs boson with a mass in the ranges 138 - $162 \text{ GeV}/c^2$ or 178 - $502 \text{ GeV}/c^2$ at 95% CL.

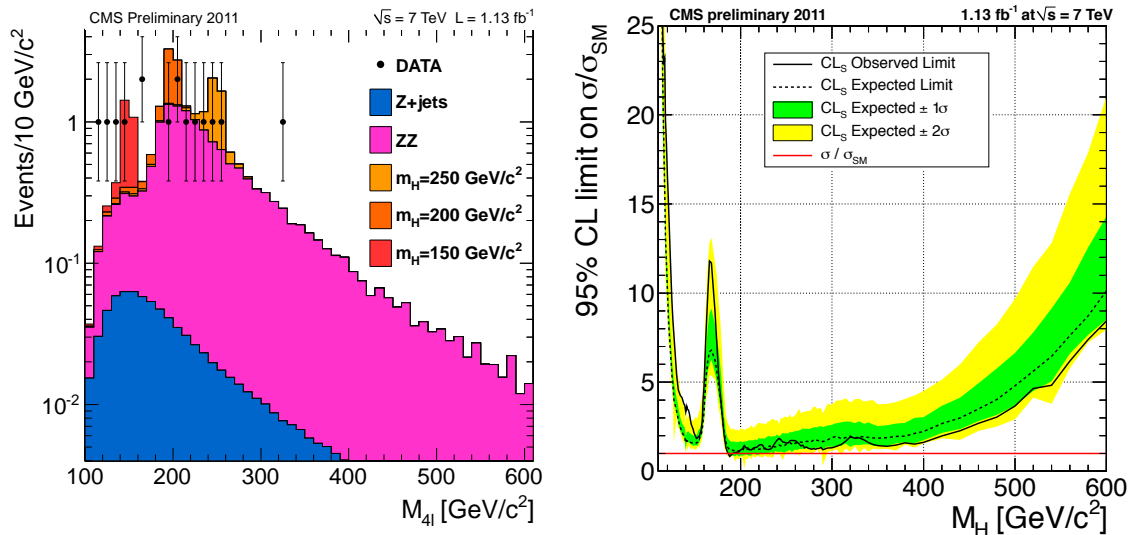


Figure 3: (left) Distribution of the four-lepton reconstructed mass for the baseline selection in the sum of the 4ℓ channels. Points represent the data, shaded histograms represent the signal and background expectations. (right) The mean expected and the observed upper limits at 95% CL on $\sigma(pp \rightarrow H + X) \times \mathcal{B}(ZZ \rightarrow 4\ell)$ for a Higgs boson in the mass range 110 - $600 \text{ GeV}/c^2$, using the CL_s approach. The samples correspond to an integrated luminosity of 1.13 fb^{-1} .

5. Conclusion

The results of a search for a standard model Higgs boson produced in pp collisions at $\sqrt{s} = 7 \text{ TeV}$ and decaying in $ZZ^{(*)}$ have been presented for the first time. In absence of a signifi-

cant clustering of candidates at any given mass, upper limits obtained at 95% CL on the cross section \times branching ratio for a Higgs boson with standard model-like decays are derived.

References

- [1] CMS Collaboration. "Search for a Standard Model Higgs boson in the decay channel $H \rightarrow ZZ^{(*)} \rightarrow 4l$ ". *CMS Physics Analysis Summary*, CMS-PAS-HIG-11-004, 2011.
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