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Search for the standard model Higgs boson in the H→ZZ→ 4ℓ channel with CMS

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A search for the Higgs boson in the H $\rightarrow$ ZZ four-lepton decay channel, with each Z boson decaying to electrons or muons is presented. The dataset was recorded by the CMS detector at the LHC, corresponding to an integrated luminosity of 10.2 fb^{-1}, 5.1 fb^{-1} of data taken at 7 TeV center-of-mass energy and 5.2 fb^{-1} at 8 TeV. The search covers Higgs boson mass hypotheses in the range $110 < m_{\rm H} < 600$ GeV. An excess of events is observed in the low $m_{4\ell}$ mass range with mass around 126 GeV. The local excess with respect to the background expectation has a significance of 3.2σ and corresponds to a signal strength, $\sigma/\sigma_{\rm SMH}$, of 0.7$\pm$0.4. This result constitutes evidence for a new massive boson and its mass is measured to 125.6$\pm$1.2 GeV.

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1. Introduction

An important goal of the LHC physics program is to ascertain the mechanism of electroweak symmetry breaking, through which the W and Z bosons acquire mass. In the standard model (SM), this is achieved via the Higgs mechanism, which also predicts the existence of a scalar Higgs boson. On July 4, 2012, the observation of a new boson, with mass around 126 GeV and with properties compatible with those of a SM Higgs boson, was announced at CERN by the ATLAS and CMS collaboration [1, 2].

This presentation discusses the search for the SM Higgs boson in the H$\rightarrow$ZZ$\rightarrow 4\ell$ channel in pp collisions at $\sqrt{s}$ = 7 and 8 TeV [3], which contributes to the observation. The analysis uses pp collision data recorded by the CMS detector [4] at the LHC, corresponding to integrated luminosities of 5.1 fb^{-1} at $\sqrt{s}$ = 7 TeV and 5.3 fb^{-1} at $\sqrt{s}$ = 8 TeV. This search channel is often called the "Golden channel" due to its clean experimental signature of four isolated leptons, electrons or muons. The search relies critically on the reconstruction, identification, and isolation of leptons and benefits from excellent electron and muon resolution. It allows the reconstruction of a narrow resonance in the four lepton mass spectrum. The background sources include an irreducible contribution from direct ZZ production. Reducible background contributions stem from Z$b\bar{b}$ and $t\bar{t}$. Additional instrumental backgrounds arise from Z+jets and WZ+jets events where jets are misidentified as leptons.

Compared to the previous CMS analysis [5], this search combines the four-lepton mass with a discriminant exploiting the production and decay kinematics expected for the signal events. In addition, improvements of the lepton reconstruction and isolation are significant. The changes to the analysis strategy were deployed based on expected performance. Four-lepton events in the signal region were not used in the optimization to avoid biases.

2. Event Selection and Kinematic

Events with four isolated leptons, electrons or muons, are selected. The electrons are reconstructed within $|\eta| < 2.5$, and for $p_T > 7$ GeV. Muons are reconstructed within $|\eta| < 2.4$ and for $p_T > 5$ GeV. The Z candidates are formed from a pair of leptons of the same flavor and opposite charge. The pair with a reconstructed mass closest to the nominal Z boson mass (Z_1) is required to satisfy $40 < m_{Z_1} < 120$ GeV. The second Z boson candidates (Z_2) are formed from all remaining leptons and are require to satisfy $12 < m_{Z_2} < 120$ GeV. To ensure that selected events have leptons on the high-efficiency plateau for the trigger, at least one lepton is required to have $p_T > 20$ GeV and second $p_T > 10$ GeV. A minimum di-lepton mass requirement of 4 GeV is imposed on all opposite-charge lepton pairs to reduce backgrounds originating from low-mass hadron decays.

Five angles $(\theta^*, \Phi_1, \theta_1, \theta_2, \Phi)$ defined in Reference [6] and the masses of the lepton pairs, m_{Z_1} and m_{Z_2}, fully describe the decay kinematics of the four-lepton system. These observables provide significant discrimination between signal and background processes in addition to the four-lepton mass. A matrix element likelihood analysis (MELA) is used and a kinematic discriminant (KD) is constructed based on the probability ratio of the signal and background hypotheses. The likelihood ratio is defined for each value of $m_{4\ell}$.

PoS(ICHEP2012)052

3. Backgrounds

The ZZ background is evaluated from Monte-Carlo simulation. This includes the dominant process of $q\bar{q}$ annihilation, as well as gluon fusion. The theoretical uncertainties are computed as a function of $m_{4\ell}$, varying both the QCD renormalisation and factorization scales and the PDF set.

To estimate the reducible backgrounds, a Z+X background control region is defined. The background is estimated using the probability for a reconstructed object to pass the isolation and identification requirements. The contamination from WZ in these events is suppressed by requiring missing transverse energy below 25 GeV. The lepton misidentification probability is compared, and found compatible, with the one derived from MC simulation. The event rates measured in the background control region are extrapolated to the signal region.

4. Results

The number of candidates observed as well as the estimated background in the signal region are reported in Table 1, for the mass range of $100 < m_{4\ell} < 800$ GeV. The expected number of signal events is given for several Higgs boson mass hypotheses. The reconstructed four-lepton mass distribution is shown in Figure 1 and compared with the expectation from background processes. At low mass around $m_{4\ell} = m_Z$ the contribution of Z$\rightarrow 4\ell$ is observed. The measured distribution at higher mass is in agreement with the expectation dominated by the irreducible ZZ background.

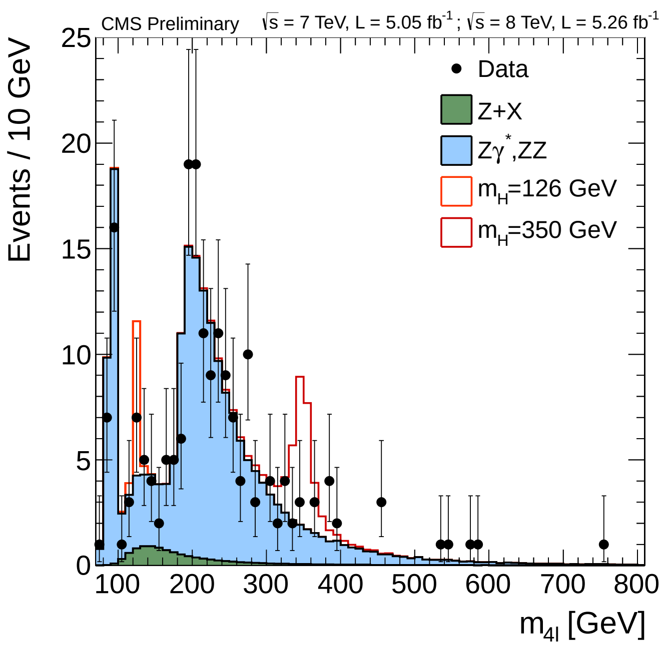

Figure 1: Distribution of the four-lepton reconstructed mass in full mass range.

The distributions of the MELA KD versus the four-lepton reconstructed mass $m_{4\ell}$ is shown for the selected events and compared to SM background and signal expectation in Figure 2. The comparison of the left and the right plot shows the discrimination between signal and background processes.

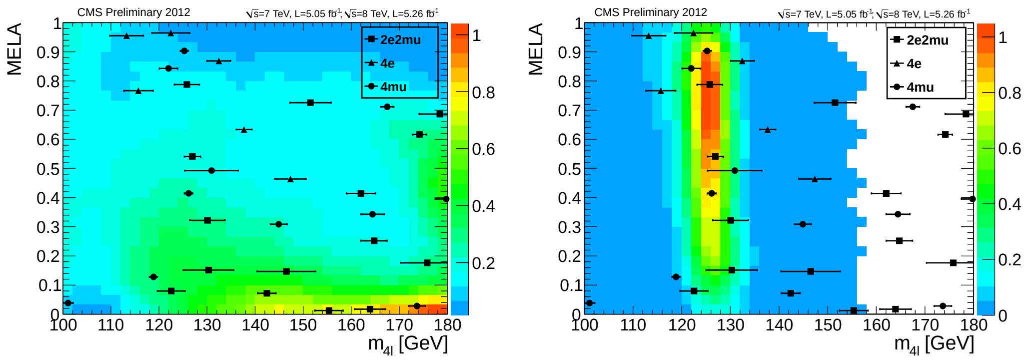

Figure 2: Distribution of the MELA KD versus the four-lepton reconstructed mass $m_{4\ell}$ in the low-mass region. The individual events are shown with their reconstructed mass uncertainties. The contours represent the expected relative density of background (left) and signal events (right).

The measured distributions are compared with the expectation from background processes, and exclusion limits at 95% CL on the ratio of the production cross section for the Higgs boson to the SM expectation are derived. For this, the ($m_{4\ell}$, KD) distributions of the selected events are split into six categories based on three final states and two running periods, 7 and 8 TeV. For each mass hypothesis, a simultaneous likelihood fit is performed of the six two-dimensional ($m_{4\ell}$, KD) distributions.

The upper limit on the ratio of the production cross section to the SM expectation is shown in Figure 3 (left). The SM Higgs boson is excluded at 95% CL in the range 131–525 GeV, except for the small range 162–172 GeV.

The local p-values in the low mass region are shown in Figure 3 (right). The minimum of the local p-value is found for the Higgs boson mass hypothesis of 125.6 GeV and corresponds to a local significance of 3.2σ. Both, the 2011 and 2012 datasets show an excess of similar strength in the same mass region. The average expected significance for a SM Higgs boson at this mass is

Table 1: Number of event candidates observed, compared to the mean expected background and signal rates for each final state. The results are given integrating the mass range from 100 to 800 GeV.

Channel	4e	4μ	$2e2\mu$	4ℓ
ZZ background	29.3 ± 3.4	49.0 ± 5.1	75.5 ± 8.0	153.7 ± 10.1
Z+X	$3.0^{+2.7}_{-1.9}$	$2.2^{+1.6}_{-1.3}$	$5.0^{+4.0}_{-3.0}$	$10.2^{+5.0}_{-3.8}$
All backgrounds	$32.3^{+4.4}_{-3.9}$	$51.2^{+5.3}_{-5.3}$	$80.5^{+9.0}_{-8.6}$	$163.9^{+11.3}_{-10.8}$
m_H = 200 GeV	8.3 ± 2.0	13.3 ± 2.7	21.6 ± 4.5	43.2 ± 5.6
m_H = 350 GeV	4.8 ± 1.2	7.5 ± 1.6	12.7 ± 2.9	24.9 ± 3.5
m_H = 500 GeV	1.7 ± 0.8	2.6 ± 1.2	4.4 ± 2.0	8.7 ± 2.4
Observed	32	47	93	172

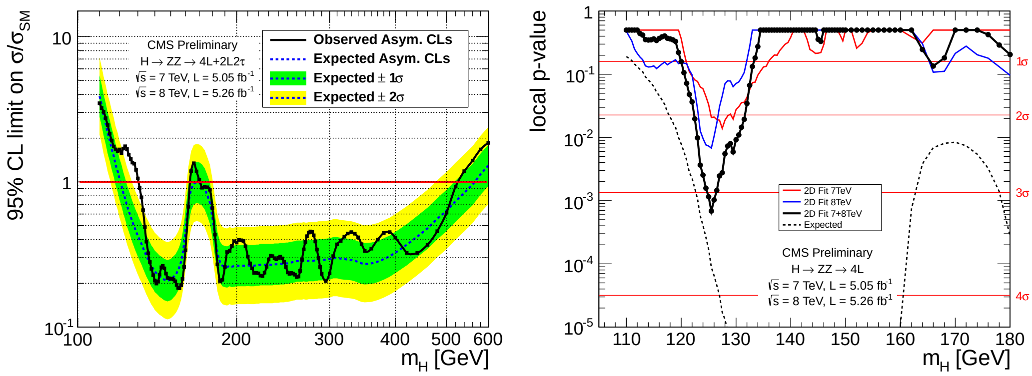

Figure 3: Observed and expected 95% CL upper limit (left) on the ratio of the production cross section to the SM expectation. The 68% and 95% ranges of expectation are shown with green and yellow bands, respectively. Significance of the local excess (right) with respect to the background expectation as a function of the Higgs boson mass in the mass range 110-180 GeV.

3.8σ. The distribution of the four-lepton reconstructed mass is shown in Figure 4 (left) in the low mass range. An unconstrained fit to the excess yields a mass of 125.6±1.2 GeV. Figure 4 (right) shows the 2D test statistic versus hypothesized Higgs boson mass m_H and signal strength $\sigma/\sigma_{\mathrm{SM\,H}}$ (right).

5. Summary

In summary, a search for the SM Higgs boson has been presented in the four-lepton channel, H$\to$ ZZ $\to 4\ell$. The measurements are interpreted by using the reconstructed four-lepton mass and a kinematic discriminant. The upper limit at 95% confidence level excludes the SM Higgs boson in the range 131–162 and 172–525 GeV, while the expected exclusion range is 121–570 GeV. An excess of events is observed in the mass range $120 < m_{4\ell} < 130$ GeV. The local excess with respect to the background has a significance of 3.2σ. The signal strength, $\sigma/\sigma_{\mathrm{SM\,H}}$, is measured

Table 2: Number of event candidates observed, compared to the mean expected background and signal rates for each final state. The results are given integrating the mass range from 110 to 160 GeV.

Channel	4e	4μ	$2e2\mu$	4ℓ
ZZ background	2.7 ± 0.3	5.7 ± 0.6	7.2 ± 0.8	15.5 ± 1.0
Z+X	$1.2^{+1.1}_{-0.8}$	$0.9^{+0.7}_{-0.6}$	$2.3^{+1.8}_{-1.4}$	$4.4^{+2.2}_{-1.7}$
All backgrounds	$3.9^{+1.1}_{-0.8}$	$6.6^{+0.9}_{-0.8}$	$9.5^{+2.0}_{-1.6}$	$19.9^{+2.4}_{-2.0}$
m_H = 120 GeV	0.8 ± 0.2	1.6 ± 0.3	1.9 ± 0.5	4.4 ± 0.6
m_H = 126 GeV	1.5 ± 0.5	3.0 ± 0.6	3.8 ± 0.9	8.3 ± 1.2
m_H = 130 GeV	2.1 ± 0.7	4.1 ± 0.8	5.4 ± 1.3	11.6 ± 1.6
Observed	6	6	9	21

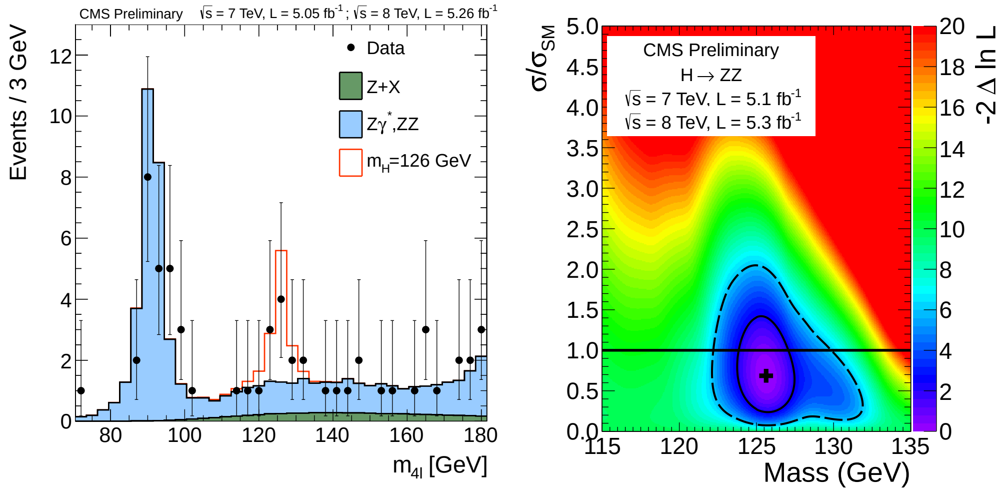

Figure 4: Distribution of the four-lepton reconstructed mass (left). 2D test statistic versus hypothesized Higgs boson mass m$_H$ and signal strength $\sigma/\sigma_{\mathrm{SM\,H}}$ (right). The cross indicates the best-fit values. The solid and dashed contours show the 68% and 95% CL ranges, respectively.

to 0.7±0.4. This result constitutes evidence for a new massive boson and its mass is measured to 125.6±1.2 GeV.

References

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