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Search for Standard Model Higgs boson in the decay channel $H \to ZZ \to l^+l^-q\bar{q}$ at CMS

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Abstract. A search for the Standard Model Higgs boson decaying to two Z bosons with a subsequent decay to a final state with two leptons and two quark jets, $H \to ZZ \to l^+l^-q\bar{q}$, is presented. Data corresponding to an integrated luminosity of 1.6 fb^{-1} of LHC proton–proton collisions at the centre-of-mass energy of 7 TeV were collected and analysed by the CMS experiment. 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 the probability of the jets to originate from quarks of light or heavy flavour or from gluons. No evidence for a Higgs boson is found and upper limits on the Higgs boson production cross-section are set in the range of masses between 226 and 600 GeV/c^2.

Keywords. CMS; Higgs.

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1. Introduction

The search for the Standard Model (SM) Higgs boson in a wide range of masses, from 120 to 600 GeV/c^2, is of high priority in experiments at Large Hadron Collider (LHC). In this note an optimized search for SM Higgs boson decaying to two Z bosons with a subsequent decay to two leptons and two quark jets, $H \to ZZ \to l^+l^-q\bar{q}$ is presented. The branching fraction of this decay channel is about 20 times higher than that of $H \to ZZ \to l^-l^+l^-l^+$. This may lead to better sensitivity to SM Higgs boson production at higher masses, where background can be effectively suppressed kinematically.

2. Event selection

The decay chain $H \to ZZ \to l^+l^-q\bar{q}$ is fully reconstructed, where charged leptons $l^{\pm}$ are either muons or electrons and quarks are reconstructed as jets in the CMS detector. Muons are measured with the all-silicon tracker and the muon system. Electrons are detected in the ECAL as energy clusters and as tracks in the tracker. Both muons and electrons are required to have p_{T} greater than 40 GeV/c and 20 GeV/c for the leading and

Table 1. Table showing the cuts on various likelihood variables.

Variable	0 b-Tag	1 b-Tag	2 b-Tag
Angular LD	$> 0.55+0.00025 m_{ZZ}$	$> 0.302+0.000656 m_{ZZ}$	> 0.5
Quark-gluon LD	> 0.10	–	–
$2 \ln \lambda(\not{E}_{\mathrm{T}})$	–	–	< 10

subleading lepton. They are measured in pseudorapidity range $|\eta| < 2.4$ for muons and $|\eta| < 2.5$ for electrons, though for electrons the transition range between the barrel and end-cap, $1.44 < |\eta| < 1.57$, is excluded. The details of electron and muon identification are described in [1]. Jets are reconstructed with the particle flow (PF) algorithm [2]. Jets are required to have $p_{\mathrm{T}} > 30$ GeV/c and $|\eta| < 2.5$. Invariant masses of dileptons and dijets are constructed to suppress mainly Z+jets and $t\bar{t}$ backgrounds with cuts like 75 GeV/c^2 $< m_{jj} <$ 105 GeV/c^2 and 70 GeV/c^2 $< m_{ll} <$ 110 GeV/c^2. Jets from the hadronization of bottom quarks are tagged by track counting high efficiency (TCHE) b-tagging algorithm. The data are split into three b-tag categories: one jet is b-jets with medium and second jet with loose requirements, events not selected in 2 b-tag region are categorized as 1 b-tag with loose tag requirements, and 0 b-tag category contains all the remaining events. The composition of the expected signal and background varies significantly among the three categories. Other selection variables are as follows:

(a) *Angular likelihood*: This variable exploits the five decay angles of $gg \rightarrow H \rightarrow ZZ \rightarrow l^+l^-q\bar{q}$ process [3]. Cut values for three categories are listed in table 1.
(b) *Quark-gluon likelihood*: Based on the fact that gluons couple more than quarks to strong field and hence they form wider jets. So, a discriminant can be made to discriminate between quark and gluon jets. The cut is applied only in the case of 0 b-jet category.
(c) *Likelihood ratio discriminant* λ: This provides a measure of the missing transverse energy significance based on the ratio of likelihoods of the hypothesis that the event presents a real missing transverse energy $\not{E}_{\mathrm{T}}$ equal to the value measured with the PF algorithm, and the null hypothesis $\not{E}_{\mathrm{T}} = 0$.

3. Background estimation and systematics

The analysis technique was chosen to rely on data side-bands to take into account the discrepancies between data and simulation. Background is estimated from m_{jj} side-bands, defined as 60 GeV/c^2 $< m_{jj} <$75 GeV/c^2 or 105 GeV/c^2 $< m_{jj} <$130 GeV/c^2. In order to minimize systematic uncertainties from the theoretical calculations and detector effects, the expected number of background events, $N_{\mathrm{bkg}}(m_{ZZ})$, is obtained from the number of events in the side-bands, $N_{\mathrm{sb}}(m_{ZZ})$, as follows:

$$N_{\mathrm{bkg}}(m_{ZZ}) = N_{\mathrm{sb}}(m_{ZZ}) \times \frac{N_{\mathrm{bkg}}^{\mathrm{sim}}(m_{ZZ})}{N_{\mathrm{sb}}^{\mathrm{sim}}(m_{ZZ})} = N_{\mathrm{sb}}(m_{ZZ}) \times \alpha(m_{ZZ}), \qquad (1)$$

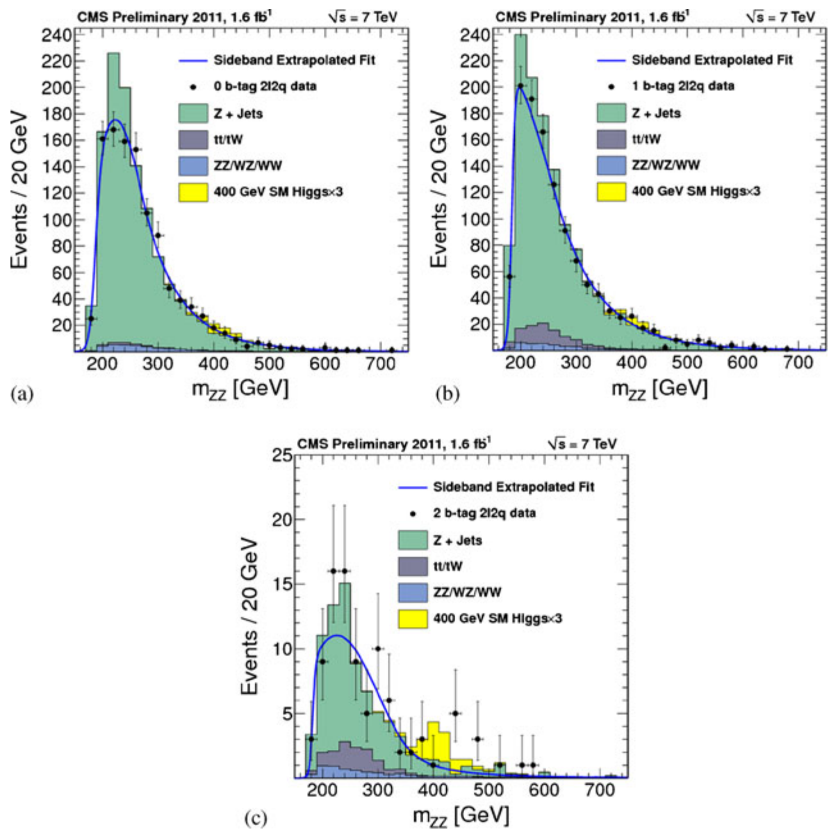

Figure 1. The m_{ZZ} invariant mass distribution after the final selection in three categories. **(a)** $0b$-tag, **(b)** $1b$-tag and **(c)** $2b$-tag.

where $\alpha(m_{ZZ})$ is the ratio of the expected number of background events in the signal and side-band regions obtained from simulation. The results of the side-band extrapolation procedure are shown as solid curves in figure 1. Additional information about the $t\bar{t}$ background is provided either by m_{ll} side-bands or by the mixed-flavour $e^{\pm}\mu^{\pm}jj$ sample, with otherwise identical selections. The main systematic uncertainties on signal normalization are from lepton energy scale, resolution, selection and trigger, jet resolution and efficiency, pile-up, heavy-quark flavour tagging and quark-gluon discrimination, $\not{E}_{\mathrm{T}}$, Higgs production mechanism, LHC luminosity, Higgs cross-section and branching fractions.

4. Results

The exclusion limits of the SM Higgs boson in the channel $H \to ZZ \to l^+l^-q\bar{q}$ are approaching those of the SM expectation. In the absence of the Higgs boson, these limits are expected to reach the SM expectation with the increased LHC luminosity. A limit on

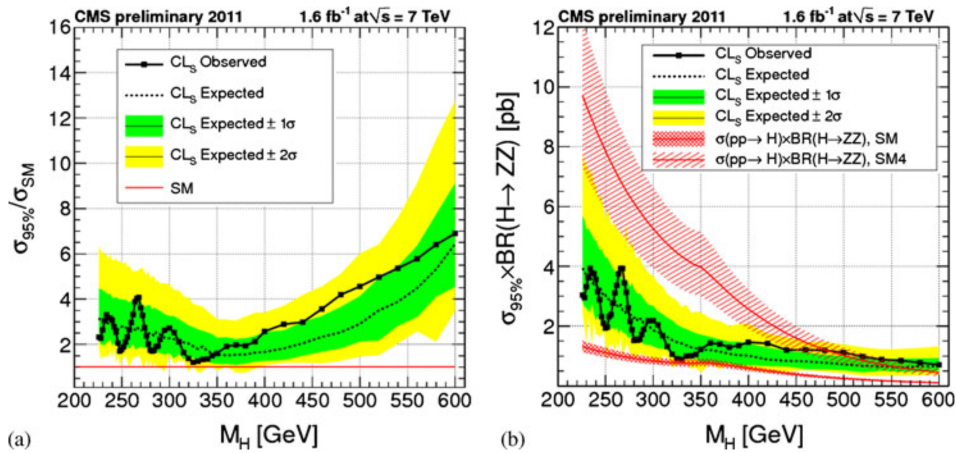

Figure 2. Observed (dashed) and expected (solid) 95% CL upper limit on the ratio of the Higgs boson production cross-section to SM expectation and upper limit on $\sigma \times \mathrm{BR}(H \to ZZ)$ using 1.6 fb^{-1} of data obtained with the CL$_s$ technique. **(a)** Ratio of Higgs production cross-section to SM expectation and **(b)** upper limit on Higgs cross-section.

the ratio of SM Higgs boson production cross-section to the SM expectation and upper limit on Higgs cross-section are shown in figure 2.

References

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