Search for Standard Model Higgs boson using the $H \to ZZ \to 2l2\nu$ channel in pp collisions at CMS

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Abstract. A search for the Standard Model (SM) Higgs boson in pp collisions at the LHC at a center-of-mass energy of 7 TeV is presented. The results are based on a data sample corresponding to an integrated luminosity of 1.6 fb^{-1} recorded by the CMS experiment. The search is conducted in the decay channel $H \to ZZ \to 2l2\nu$. No excess is observed in the transverse mass distributions. Limits are set on the production of the Higgs boson in the context of the Standard Model and in the presence of a sequential fourth family of fermions with high masses.

1 Introduction

The search for the SM Higgs boson and its discovery are central to the goals of the experiments at the LHC. The primary production mechanism of the Higgs at the LHC is gluon fusion with the small contribution from vector boson fusion. This note presents search for SM Higgs boson in the $H \to ZZ \to 2l2\nu$ channel which is sensitive to Higgs searches in the high mass range ($250 - 600 GeV/c^2$). The braching fraction of this decay channel is about six times higher than that of golden channel $H \to ZZ \to l^- l^+ l^- l^+$. This may lead to better sensitivity to SM Higgs boson production at higher masses, where background can be effectively suppressed kinematically.

2 Event Selection

Since, this analysis is carried out for Higgs mass above $250 GeV/c^2$ so $H \to ZZ \to 2l2\nu$ event is characterized by the presence of a boosted Z boson decaying to e^+e^- or $\mu^+\mu^-$ and large missing transverse energy (MET) arising from the decay of the other Z boson into neutrinos. Muons are measured with the silicon tracker and the muon system [3]. Further identification criteria based on the number of hits in the tracker and muon system, the fit quality of the muon track and its consistency with the primary vertex, are imposed on the muon candidates to reduce fakes. Electrons are detected in the ECAL as energy clusters and as tracks in the tracker [4]. These reconstructed electrons are further required to pass certain identification criteria based on the ECAL shower shape, track-ECAL cluster matching and consistency with the primary vertex. 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 endcap, $1.44 < |\eta| < 1.57$, is excluded. Events are selected such that there are two well-identified, isolated, opposite charge leptons of the same flavor with $p_T > 20 GeV/c$ that form an invariant mass consistent with Z mass. With this selection the principal backgrounds in this analysis are:

- Z**+jets**: with fake missing transverse energy due to jet mismeasurement and detector effects.
- **Non-Resonant**(i.e., events without a Z resonance): top decays, fully leptonic WW decays, W+jets with a fake lepton.
- **Irreducible**: electroweak ZZ pair production and fully leptonic decays of WZ pairs.

The other selection variables which are used in this analysis are as follows-

- **B-tagging and soft-muon veto**: Since top quark events contain b-jets,this background can be suppressed by vetoing events with at least one b-tagged jet. B jets are tagged using "Track Counting High Efficiency" (TCHE) algorithm [5] which uses displaced track in a jet to compute a b-tagging discriminator. In addition to the b-jet veto, a soft muon veto is applied to further suppress top events in which b-quarks decay leptonically [6].
- **Third lepton veto**: In order to suppress the WZ background in which the both W,Z decay leptonically, events are required to have exactly two leptons in the event with $p_T > 10 GeV/c$.
- **MET**: Particle flow MET [7] is used in the analysis. The hard cut on MET mainly suppresses Drell-Yan background which has very less real missing energy.
- $\Delta\phi(MET, jet)$: To suppress backgrounds with MET coming from jet mis-measurements, events in which the MET is aligned with a jet are removed using a cut on $\Delta\phi(MET, jet)$ variable.
- **Transverse mass of Higgs**(M_T): Signal events have a narrower M_T distribution. A two-sided cut is applied on the M_T variable to further separate signal with respect to the background.

The details of the cut values are in Table1. MET, $\Delta\phi(MET, jet)$, M_T cuts are Higgs mass dependent Table2. The cuts for these variables have been optimized with GARCON [8].

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Table 1. Event selection cuts.

Cut	Cut Value
Lepton p_T	$p_T > 20$GeV/c
Z mass window	$\|m_{ll} - 91.1876\| \leq 15$GeV/$c^2$
Z p_T	$Zp_T > 25$GeV/c
b-tag veto	TCHE discriminator < 2
$\Delta\phi(MET, jet)$	see Table 2
MET	see Table 2
M_T	see Table 2

Table 2. Higgs mass-dependent $\Delta\phi(MET, jet)$, MET (GeV), and M_T (GeV/c^2) cuts optimized using GARCON.

$M_H(GeV/c^2)$	$\Delta\phi(MET, jet)$	MET	M_T
250	> 0.62	> 69	> 216 AND < 272
300	> 0.28	> 83	> 242 AND < 320
350	> 0.14	> 97	> 267 AND < 386
400	> -	> 112	> 292 AND < 471
450	> -	> 126	> 315 AND < 540
500	> -	> 141	> 336 AND < 600
550	> -	> 155	> 357 AND < 660
600	> -	> 170	> 377 AND < 720

3 Background Estimation

ZZ/WZ backgrounds are modeled using simulation, while the remaining backgrounds (Z+jets and all non-resonant ones) are estimated using the data-driven methods descibed below.

3.1 Z+jets Estimation

Photon+jets (γ+jets) events are used to estimate the Z+jets events in data because both processes have same MET response from detector and γ+jets have higher cross section than that of Z+jets. Re-weighting of γ+jets data is done event-by-event, so that the p_T spectrum of photon agrees with the observed dilepton p_T spectrum. An additional reweighting is done to match the jet multiplicity between γ+jets and dilepton events in the 0 and 1 jet bins (jets with $p_T > 30$ GeV/c are considered). Then, a mass sampled from a fit to the observed Z mass spectrum is assigned to each photon. The yield of γ+jets events is normalized to the observed yield of dilepton events. The transverse mass M_T is computed and the full analysis selection is applied to the weighted γ+jets events. This procedure produces an accurate model of the MET distribution in Z+jets as can be seen in Fig1 and Fig2.

3.2 Top/WW/W+jets Estimation

To estimate the non-resonant background using data, events with final state comprising of $e^+\mu^-/e^-\mu^+$ pairs and passing the full analysis selection are used. The non-resonant background in the $e^+e^-/\mu^-\mu^+$ final states is estimated by applying a scale factor (α) to these events:

$$N_{\mu\mu} = \alpha_\mu \times N_{e\mu}, N_{ee} = \alpha_e \times N_{e\mu} \quad (1)$$

This scale factor α is computed from the sidebands (SB) to the Z peak (40GeV/c^2 $< m_H <$ 70GeV/c^2 and 110GeV/c^2 $< m_H <$ 200GeV/c^2) using the following relations:

$$\alpha_\mu = \frac{N^{SB}_{\mu\mu}}{N^{SB}_{e\mu}}, \alpha_e = \frac{N^{SB}_{ee}}{N^{SB}_{e\mu}} \quad (2)$$

where N^{SB}_{ee}, $N^{SB}_{\mu\mu}$ and $N^{SB}_{e\mu}$ are events in the sidebands in the e^+e^-, $\mu^+\mu^-$ and $e^+\mu^-/e^-\mu^+$ final states respectively, passing all the analysis requirements that are independent of the Higgs mass (with the exception of anti-btag) and MET>70 GeV. This method cannot distinguish between the non-resonant background and $H \to WW \to 2l2\nu$ events, which are very small. Table3 and Table4 list the predicted yields for the non-resonant backgrounds with integrated luminosity of $1.6 fb^{-1}$. Statistical uncertainties on these estimates are also quoted.

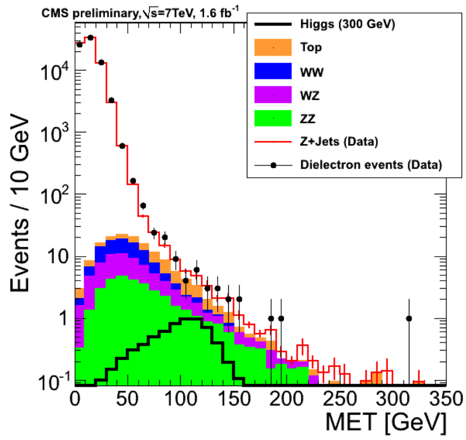

Fig. 1. MET spectrum of di-electron events and re-weighted single photon events in $1.6 fb^{-1}$.

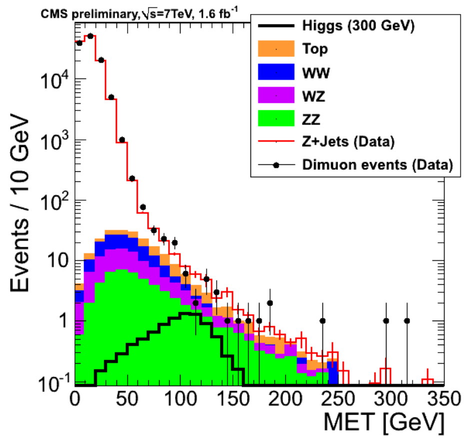

Fig. 2. MET spectrum of di-muon events and re-weighted single photon events in $1.6 fb^{-1}$.

4 Systematics and Results

The systematic uncertainies are summarized in Table5.
No evidence of SM Higgs boson production is found in

Table 3. Electron Channel: yields from $1.6 fb^{-1}$ data for non-resonant backgrounds.

m_H	Predicted Yields	MC Prediction
250	12±2±2	12±1
300	4.0±0.7±1.3	4.5±0.5
350	1.8±0.3±0.9	1.1±0.2
400	0.44±0.07±0.44	0.51±0.14
500	0	0.21±0.10
600	0	0

Table 4. Muon Channel: yields from $1.6 fb^{-1}$ data for non-resonant backgrounds.

m_H	Predicted Yields	MC Prediction
250	16±2±3	15±1
300	5.3±0.6±1.8	6.2±0.5
350	2.3±0.3±1.2	1.8±0.3
400	0.58±0.07±0.58	0.49±0.13
500	0	0.059±0.043
600	0	0

$H \to ZZ \to 2l2\nu$ channel with integrated luminosity of $1.6 fb^{-1}$. The 95% mean expected and observed C.L. upper limits on the cross section, $\sigma \times BR(H \to ZZ \to 2l2\nu)$, for masses in the range 250-600GeV/c^2 has been measured. Results are obtained using a CLs approach with a flat prior for the cross-section. The ratio R of the $\sigma_{upperlimit}$ to the σ_{SM} at 95% CL is shown in Fig.3. $\sigma_{upperlimit}$ as a function of the Higgs mass m_H at 95% CL has also been measured and is shown in Fig.4. With $1.6 fb^{-1}$, the SM Higgs with masses in the range 340-375 GeV/c^2 can be excluded at 95% CL.

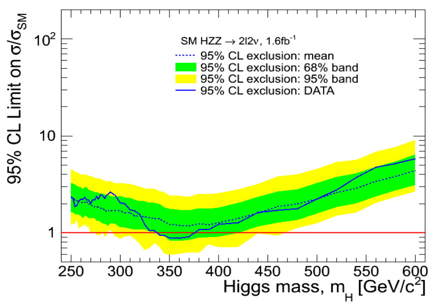

Fig. 3. 95% CL limit of the ratio of expected/measured cross section × BR over Standard Model for $1.6 fb^{-1}$ of data.

Table 5. Systematic uncertainties on the final event yields for both electron and muon final states.

Uncertainty	value,%
Luminosity	4.5
pdf, gluon-gluon initial state	6-11
pdf,quark-quark initial state	3.3-7.6
QCD scale,(ggH)	7.6-11
QCD scale,(VBF)	0.2-2
QCD scale,(ggZZ)	20
QCD scale,(qqVV)	5.8-8.5
Anti b-tagging	1-1.2
Lepton ID+Isolation	2
Lepton Momentum Scale	5(for 2e), 2(for 2μ)
Jet energy scale	1-1.5
PU effects	1-3
Trigger	1(for 2e), 2(for 2μ)
non-resonant backgrounds	7%(α)
Z+jets estimation from data	19-57%

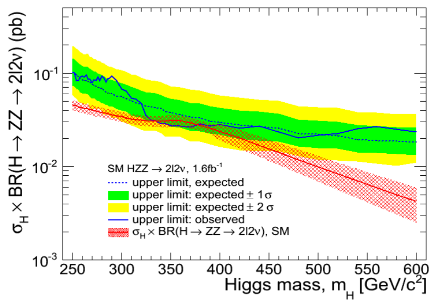

Fig. 4. Upper limit of the expected/measured cross section × BR over Standard Model for $1.6 fb^{-1}$ of data.

References

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