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Search for a SM Higgs boson in the $H \to Z^*Z \to \ell^+\ell^- q\bar{q}$ channel in the mass range 120 - 180 GeV with the ATLAS Detector at $\sqrt{s} = 7$ TeV

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Abstract. A summary of the first study is given for the decay channel $H \to Z^*Z \to \ell^+\ell^- q\bar{q}$ ($\ell = e, \mu$) in the Higgs boson mass range 120 - 180 GeV, using the pp collision data collected by the ATLAS experiment at $\sqrt{s} = 7$ TeV at the LHC. Data driven methods to estimate the background and new techniques to improve the mass resolution of the hadronic Z boson decay are used. Events with 0 or 1 b-jets and events with 2 b-jets are treated as separated channels. No significant excess of events above the estimated background is observed; upper limits at 95% C.L. on the Higgs production cross section are derived.

1 Introduction

The search for the Higgs boson is one of the major benchmark of the Large Hadron Collider (LHC) physics programme and recently both ATLAS [1] and CMS [2] Collaborations have reported the observation of a new particle in the search for the SM Higgs boson with a mass of approximately 125 GeV and a significance in excess of 5 σ. In this analysis the decay channel $H \to Z^*Z \to \ell^+\ell^- q\bar{q}$ is studied in the low mass range of the ZZ^* system, namely between 120 GeV and 180 GeV [3]. The ATLAS Collaboration has reported previously results on this channel in the high mass range between 200 GeV and 600 GeV [4].

2 Data and Monte Carlo samples

The dataset used in this analysis was recorded by the ATLAS detector [5] during the 2011 pp collision data-taking corresponding to 4.7 fb^{-1} of integrated luminosity using both a single-lepton and a dilepton trigger. The data are required to satisfy a certain number of conditions to ensure stable and good performances of the detector during the data acquisition.

The $H \to Z^*Z \to \ell^+\ell^- q\bar{q}$ signal is simulated applying a matrix element method for gluon fusion and vector-boson fusion (VBF) production mechanism. The Higgs boson production cross-sections and the decay branching ratios are taken from Ref. [6] and Ref. [7].

Several processes have the same final state of the analyzed decay channel and contribute to the total background. The main background originates from Z+jets events and, at low invariant mass, from Drell-Yan dilepton production plus multiple jets (DY+jets). The $t\bar{t}$, single top quark, Wt processes also contribute significantly to the background. For all these processes (Z+jets, DY+jets and top) the shape is taken from MC simulations (Alpgen, MC@NLO, etc.) but the normalization is constrained from data as described in Sec. 5. Diboson production and W+jets give a lower contribution and are modelled with the MC simulations only. The QCD multijet production is evaluated applying data-driven techniques and is described in Sec. 5. The cross sections of the simulated samples are fixed at the higher order calculations available. The generated events are fully simulated using the ATLAS detector simulation. Additional pp interactions originated from the same or nearby bunch-crossing (pile-up) are also included in the simulations.

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3 Event reconstruction

Electrons are reconstructed from electromagnetic calorimeter clusters matched to a track in the inner detector (ID) by using the standard ATLAS sliding window algorithm. The electron candidates are required to satisfy a certain number of conditions on the track-cluster matching, the electromagnetic shape and the track quality to ensure an high rejection of QCD multijet production. This set of criteria defines the ATLAS standard “tight++” electron quality. Muons are reconstructed by matching a track from the inner detector to a full or a segmented track reconstructed in the muon spectrometer. Leptons are preselected requiring $p_T > 7$ GeV and $|\eta| < 2.5$ (2.47 for electrons) corresponding to the limit of the angular acceptance of the ATLAS tracking system. To reject leptons originated by jets (decay in flight of B-hadrons inside the jet, etc.), lepton candidates are required to be isolated imposing that the sum of the inner detector track momenta (excluding the track associated to the candidate) in a cone $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.2$ around the lepton to be less than 10% of the momenta of the candidate itself.

Jets are reconstructed with the anti-k_t algorithm with distance parameter $R = 0.4$ and they are calibrated using η- and energy-dependent correction factors. Jets are selected by requiring $p_T > 20$ GeV and $|\eta| < 2.5$. Consistency with primary vertex is defined by requiring at least the 75% of the summed momenta of the tracks associated to the jets to originate from the primary vertex. The identification of the bottom-originated jets (b-jet) is based on the ATLAS b-tagging algorithm at a working point at 70% of b-tagging efficiency in $t\bar{t}$ events which corresponds to a light quark jet rejection of about 140. The missing transverse energy (E_T^{miss}) is calculated from calorimeter cell with $|\eta| < 4.9$ and muons reconstructed in the muon spectrometer.

4 Event selection

The analysis strategy, to enhance the expected signal significance with respect to the expected background, is designed to search for a pair of same-flavour opposite-sign leptons, consistent with an off-mass shell Z^* boson decay, and then search for a pair of jets, with an invariant mass consistent with the Z boson mass.

The single-lepton and the dilepton trigger used in this analysis are the ones with the lower unprescaled p_T threshold, 18 GeV for single-muon and 20 GeV (raised to 22 GeV in the second half of the data taking to account for the higher instantaneous luminosity) for single-electron. In the dilepton trigger case the thereshold are set to 10 GeV and 12 GeV for dimuon and dielectron respectively.

Events are selected requiring exactly two opposite-sign same-flavour leptons. To be kinematically consistent with the firing trigger p_T threshold, in the dilepton trigger case both muons (electrons) must have a $p_T > 12$ (14) GeV whereas in the single lepton trigger case at least one lepton must have a $p_T > 20$ GeV. To reduce the Z+jets background contribution, the dilepton invariant mass is required to be in the range $20 < m_{\ell\ell} < 76$ GeV, consistent with a leptonic (off-mass shell) Z^* boson decay. The imposition of an upper limit on $E_T^{miss} < 30$ GeV, reduces primarily the $t\bar{t}$ process contribution. In the signal processes about 22% of events contains b-jets originated from the $Z \rightarrow b\bar{b}$ decay whereas b-jet contribution in the DY processes is 20 times lower ($O(1\%)$). Thus an enhancement in the signal significance is achievable splitting the events in two different subchannels: the "untagged" subchannel, collecting events with 0 or 1 b-tagged jet, and the "tagged" subchannel, collecting events with exactly 2 b-jets. Events with more than two b-tagged jets (less than 0.1% of the total) are rejected.

The dijet invariant mass is calculated in the tagged channel using the momenta of the two b-tagged jets. In the untagged channel, because there is not an upper limit on the number of selected jets, the jet pair used for the Higgs mass reconstruction is chosen with χ^2 minimization by using, as a constraint, the well known Z boson mass and allowing the jet energies to vary within the uncertainties. All possible jet pairs are exploited and the one with the minimum χ^2 is chosen for the final analysis. A signal region (SR, $60 < m_{jj} < 115$ GeV) is defined by using the dijet invariant mass m_{jj} of the selected pair of jets.

The efficiency of the described selection for all $H \rightarrow Z^*Z \rightarrow \ell^+\ell^-q\bar{q}$ signal events, including $Z \rightarrow \tau^+\tau^-$, ranges from 1.4% to 6% for the untagged channel and from 0.1% to 0.5% for the tagged one, depending on the Higgs boson mass considered. Efficiency increases with the Higgs boson mass up to a maximum around $m_H = 170$ GeV, falling at higher values of Higgs mass because of the proximity of the threshold for two real Z boson production for which this analysis is not optimal.

The final Higgs signal search is performed by looking for a peak above the background expectation in the $m_{\ell\ell jj}$ invariant mass distributions.

5 Backgrounds

The dominant background in this analysis is the DY dilepton + jets production with significant contribution from $t\bar{t}$ and QCD multijet events. These backgrounds are estimated and checked using data-driven methods.

For DY+jets processes, the overall normalization and the $m_{\ell\ell jj}$ shape uncertainty are estimated by using two sideband regions, whereas for processes of top quark production, dominated by $t\bar{t}$ events, a different control region is defined by requiring $E_T^{miss} > 40$ GeV. The evaluated scale factors, which scale the MC distributions to the one observed in data, are all compatible with unity within the uncertainties. The QCD multijet processes give a significant contribution in the low region dilepton invariant mass region but it is very difficult to simulate. Therefore two different data-driven methods are applied to estimate either the size and the shape of this background: the "ABCD" and the "template fit" methods, as described in Ref. [3]. The shape is taken from data in a multijet dominated and signal free region.

6 Systematic uncertainties

The main contributions to the experimental systematic uncertainties, which are primarily detector-related, arise: from the jet energy scale ($4 - 8\%$) in the untagged channel and from the b-tagging efficiency (10%) in the tagged channel. For backgrounds with normalization estimated exclusively through MC simulations a fully correlated uncertainty of 3.9% on the integrated luminosity is taken into account. The theoretical uncertainties, in the considered Higgs mass range, on the Higgs boson production cross sections [6] [7] are $15 - 20\%$ for the dominant gluon fusion process and $3 - 9\%$ for the VBF process.

7 Results

The search for a Higgs boson resonance is performed by comparing the $m_{\ell\ell jj}$ distributions, i.e. the reconstructed Higgs boson mass, of the experimental data to the expected background. The final distribution for the reconstructed Higgs mass for the muon channel are shown in Fig. 1 for both the untagged and the tagged channel. Distributions for electron channel are similar.

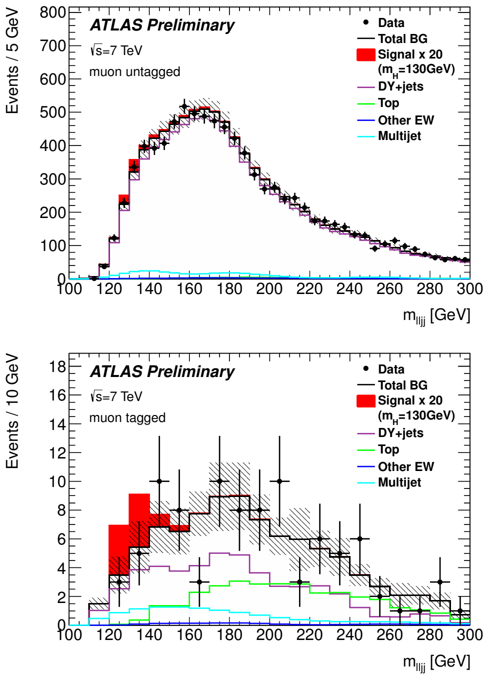

Figure 1. The invariant mass of the $\ell\ell jj$ system for both the untagged (top) and the tagged channels for the muon channel. The hatched band represents the systematic uncertainty on the total background. The predicted signal for a SM Higgs boson with $m_H = 130$ GeV is also shown. [3]

The resolution on the reconstructed Higgs mass $m_{\ell\ell jj}$ distribution in signal events is predicted to be around 3 GeV for $m_H = 120-130$ GeV after applying the constraint on the dijet invariant mass. Above the nominal Higgs mass value, a long tail is also present because of the hadronic decay of the off-shell Z^* boson. The $m_{\ell\ell jj}$ distribution of the background has conversely a very broad shape, peaking around 170 GeV and with a width of about 40 GeV.

No significant excess of observed events with respect to expectation from background is observed. Limits at 95% Confidence Level (CL), shown in Fig. 2, are set on the Higgs boson cross section normalized to SM predicted cross section as a function of the hypothesized Higgs boson mass, by using the CL_S modified frequentist formalism [8].

8 Summary

A study of the $H \to Z^*Z \to \ell^+\ell^- q\bar{q}$ decay channel has been performed extending the previous analysis of the same final state performed for the search of a Higgs boson in the high mass range. The results are based on 4.7 fb^{-1} of pp collisions data collected by the ATLAS detector at $\sqrt{s} = 7$ TeV during 2011. In the mass range considered in this study, the best expected sensitivity using the full dataset collected by ATLAS at $\sqrt{s} = 7$ TeV is obtained around $m_H = 145$ GeV with an expected upper limit corresponding to 4.1 times the SM Higgs cross section. The

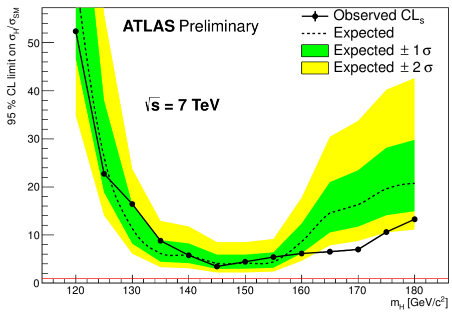

Figure 2. The expected (dashed line) and observed (solid line) upper limits on the total cross section divided by the expected Standard Model Higgs boson cross section, calculated using the CL_s method at 95%. The green and yellow bands indicate the expected limits with $\pm1\sigma$ and $\pm2\sigma$ fluctuations, respectively. The red line shows the Standard Model value of 1. [3]

best observed limit is also obtained around $m_H = 145$ GeV corresponding to 3.5 times the SM cross section. The sensitivity around the mass of the recently discovered Higgs boson-like particle at 125 GeV is limited: the expected limit is 22 times the SM cross section.

References

[1] ATLAS Collaboration, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, Phys. Lett. **B 716**, 1-29 (2012)

[2] CMS Collaboration, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, Phys. Lett. **B 716**, 30-61 (2012)

[3] ATLAS Collaboration, *Study of the channel $H \to Z^*Z \to \ell^+\ell^- q\bar{q}$ in the mass range 120-180 GeV with the ATLAS Detector at $\sqrt{s}$=7 TeV*, ATLAS-CONF-2012-163 (2012)

[4] ATLAS Collaboration, *Search for a Standard Model Higgs boson in the mass range 200-600 GeV in the $H \to ZZ \to llqq$ decay channel*, Phys. Lett. **B 717**, 70-88 (2012), `arXiv:1206.2443 [hep-ex]`

[5] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST **3**, S08003 (2008)

[6] LHC Higgs Cross Section Working Group, S. Dittmaier, C. Mariotti, G. Passarino, and R. Tanaka (Eds.), *Handbook of LHC Higgs cross sections: 1. Inclusive observables. CERN-2011-002* (2011), `arXiv:1101.0593 [hep-ph]`

[7] LHC Higgs Cross Section Working Group, S. Dittmaier, C. Mariotti, G. Passarino, and R. Tanaka (Eds.), *Handbook of LHC Higgs Cross Sections: 2. Differential distributions. CERN-2012-002* (2012), `arXiv:1201.3084 [hep-ph]`

[8] A. L. Read, *Presentation of search results: The CL(s) technique*, J. Phys. G **28**, 2693-2704 (2002), `arXiv:1007.1727 [physics.data-an]`