Search for a Standard Model Higgs boson in the mass range 200–600 GeV in the $H \to ZZ \to \ell^+\ell^- q\bar{q}$ decay channel with the ATLAS detector

**ATLAS Collaboration**

**ABSTRACT**

A search for a heavy Standard Model Higgs boson decaying via $H \to ZZ \to \ell^+\ell^- q\bar{q}$, where $\ell = e$ or $\mu$, is presented. The search uses a data set of $pp$ collisions at $\sqrt{s} = 7$ TeV, corresponding to an integrated luminosity of 4.7 fb$^{-1}$ collected in 2011 by the ATLAS detector at the CERN LHC. No significant excess of events above the estimated background is found. Upper limits at 95% confidence level on the production of events per unit mass in a Higgs boson with a mass in the range between 200 and 600 GeV are derived. A Standard Model Higgs boson with a mass in the range $300 \text{ GeV} \leq m_H \leq 322 \text{ GeV}$ or $353 \text{ GeV} \leq m_H \leq 410 \text{ GeV}$ is excluded at 95% CL. The corresponding upper limit on the production of a Higgs boson with a mass in the range between 100 and 115 GeV is $1.4 \times 10^{-4}$ fb$^{-1}$.

1. Introduction

In the Standard Model (SM), the as-yet-unobserved Higgs boson gives mass to the weak vector bosons and other particles. Direct searches performed at the CERN Large Electron–Positron Collider (LEP) exclude a SM Higgs boson with mass $m_H$ less than 114.4 GeV [4]. Searches at the Fermilab Tevatron $p\bar{p}$ collider have excluded at 95% confidence level (CL) the production of a SM Higgs boson with mass $m_H$ less than 114.4 GeV [4]. Searches at the Fermilab Tevatron $p\bar{p}$ collider have excluded at 95% CL the regions 100–106 GeV and 147–179 GeV [5]. The ATLAS experiment at the LHC, which has an integrated luminosity of 4.7 fb$^{-1}$ collected in 2011, has excluded at 95% CL the regions 100–106 GeV and 147–179 GeV [5]. The corresponding upper limit on the production of a SM Higgs boson with a mass in the range between 200 and 600 GeV is $1.4 \times 10^{-4}$ fb$^{-1}$.

2. Data and Monte Carlo samples

The data used in this search were recorded by the ATLAS experiment during the 2011 LHC run with $pp$ collisions at $\sqrt{s} = 7$ TeV. They correspond to an integrated luminosity of approximately 4.7 fb$^{-1}$ after data quality selections to require that all systems used in this analysis were operational. The data were collected using single-lepton triggers with a transverse momentum ($p_T$) threshold of 20 to 22 GeV for electrons and 18 GeV for muons, supplemented with a dielectron trigger with a threshold of 12 GeV. The resulting trigger criteria are about 95% efficient in the muon channel and close to 100% efficient in the electron channel, relative to the selection criteria described below. Collision events are selected by requiring a reconstructed primary vertex with at least three associated tracks with $p_T > 0.4$ GeV. The average number of collisions per bunch crossing in this data sample is about nine.

The $H \to ZZ \to \ell^+\ell^- q\bar{q}$ signal is modelled with the POWHEG Monte Carlo (MC) event generator [10,11], which calculates separately the gluon and vector-boson fusion Higgs boson production mechanisms up to next-to-leading order (NLO). Generated signal events are hadronised with PYTHIA [12], interfaced to PHOTOS [13] to model final-state radiation and PHOJET [14,15] to simulate $\tau$ decays. The parton distribution function (PDF) is MRSTMCL [16]. The Higgs boson $p_T$ spectrum is reweighted to match Ref. [17], which provides QCD corrections up to NLO and QCD soft-gluon resummations up to next-to-next-to-leading logarithms. The small contribution from $Z$ boson decay to $\tau$ leptons is also included.
The Higgs boson production cross sections and decay branching ratios as well as their uncertainties, are taken from Refs. [18,19]. The predicted cross sections for the gluon fusion processes are based on calculations to next-to-next-to-leading order (NNLO) in QCD [20–25], and also include QCD soft-gluon resummations up to next-to-next-to-leading logarithms [26] and NLO electroweak (EW) corrections [27,28]. These results are compiled in Refs. [29–31] and assume factorisation between QCD and EW corrections. The cross sections for the vector-boson fusion processes are calculated with full NLO QCD and EW corrections [32–34] and approximate NNLO QCD corrections [35]. The uncertainty in the production cross section due to the choice of the QCD scale is $+3\%$ for the gluon fusion process and $\pm1\%$ for the vector-boson fusion process [18,19]. The uncertainty in the production cross section due to uncertainties in the PDFs and $\alpha_s$ is $\pm6\%$ for the gluon-initiated process and $\pm4\%$ for quark-initiated processes [36–40]. The Higgs boson decay branching ratio [41] to the four-fermion final state is calculated with PROPHETCVX [42,43]. The combined production cross section and decay branching ratio for the $H \rightarrow ZZ \rightarrow 4\ell$ channel ranges from $140\pm20\text{ fb}$ for $m_H = 200\text{ GeV}$ to $10\pm2\text{ fb}$ for $m_H = 600\text{ GeV}$.

The cross section calculations do not take into account the width of the Higgs boson, which increases from 1.4 GeV at $m_H = 200\text{ GeV}$ to 120 GeV at $m_H = 600\text{ GeV}$, and which is implemented through a relativistic Breit–Wigner line shape applied at the event generator level. It has been suggested [19,44–46] that effects related to off-shell Higgs boson production and interference with other SM processes may become sizeable for the highest masses ($m_H > 400\text{ GeV}$) considered in this search. Currently, in the absence of a full calculation for the different production mechanisms, a conservative estimate of the possible size of such effects is included as a signal normalisation systematic uncertainty parameterised as a function of $m_H$ as $1.5 \times m_H^2$ [TeV], for $m_H \geq 300\text{ GeV}$ [19].

The $Z$+light-jets background is modelled with the ALPGEN generator [47] with the CT10 PDF set [48], interfaced to HERWIG [49] for parton showers and hadronisation, while SHERPA [50] with the CT10 PDF set is used for $Z$+heavy-flavour events. Top quark production, both $t\bar{t}$ and single-top, is modelled using the MC@NLO generator [51] with the CT10 PDF set [38], interfaced to HERWIG for parton showers and hadronisation.

The SM $ZZ$ process is an irreducible background for $H \rightarrow ZZ$. The $q\bar{q} \rightarrow ZZ$ process (also WZ) is modelled using HERWIG with the MRSTMCL PDF set, interfaced to PHOTOS and TAUOLA. Alternative samples with PYTHIA and MC@NLO are used for systematics studies: HERWIG and PYTHIA use only leading-order matrix elements, but they can generate off-shell vector bosons, while MC@NLO generates only on-shell bosons. The $qq \rightarrow ZZ$ production cross section has been calculated up to NLO in QCD [52]. Due to the large gluon flux at the LHC, NNLO gluon pair quark-box diagrams ($gg \rightarrow ZZ$) are significant and the $qq$ cross section is increased by $6\%$ to account for this additional contribution [53].

Those simulations that use HERWIG for hadronisation use JIMMY [54] for the modelling of the underlying event, while PYTHIA and SHERPA implement their own underlying event model.

3. Event selection

The ATLAS detector [55] has a forward–backward symmetric cylindrical geometry. An inner tracking detector immersed in a 2 Tesla axial magnetic field covers $|\eta| < 2.5$ with silicon detectors and straw tubes. A liquid-argon electromagnetic calorimeter is divided into barrel ($|\eta| < 1.475$), endcap (1.375 < $|\eta| < 3.1$), and forward (3.1 < $|\eta| < 4.9$) regions. Hadronic calorimeters (using liquid argon or scintillating tiles as active materials) surround the electromagnetic calorimeter and cover $|\eta| < 4.9$. A muon spectrometer measures the deflection of muon tracks in the field of three large toroidal magnets and covers $|\eta| < 2.7$. A three-level trigger system selects events to be recorded for offline analysis.

The offline selection starts with the reconstruction of either a $Z \rightarrow ee$ or a $Z \rightarrow \mu\mu$ lepton pair. Electron and muon candidates must satisfy $p_T > 20\text{ GeV}$ and $|\eta| < 2.5$, in addition to standard ATLAS quality requirements [56–58], and must also be isolated from surrounding tracks. Electrons within a pair are required to have opposite charge, but this requirement is not imposed for electrons because larger energy losses from showering in material in the inner tracking detector lead to higher charge misidentification probabilities. The invariant mass of the lepton pair $m_{\ell\ell}$ must lie within the range 83–99 GeV, and events with any additional selected electrons or muons are rejected to reduce background from $WZ$ production where both bosons decay leptonically.

$H \rightarrow ZZ \rightarrow 4\ell$ decays contain a pair of jets from $Z \rightarrow q\bar{q}$ decay. Events are thus required to contain at least two jets with $p_T > 25\text{ GeV}$ and $|\eta| < 2.5$. Jets are reconstructed with the anti-$k_t$ algorithm [59] with radius parameter $R = 0.4$. They are calibrated using energy- and $\eta$-dependent correction factors based on MC simulation and validated with data [60]; this calibration includes effects of energy from additional proton–proton interactions. Jets within $\Delta R = 0.4$ of an electron or in which less than 75% of the momentum of the associated tracks originates from the primary vertex are rejected. The missing transverse momentum, with magnitude $E^{\text{miss}}_T$, is the (negative) vectorial sum of the transverse momenta of all cells in the calorimeters with $|\eta| < 4.9$, calibrated appropriately based on their identification as electrons, photons, $t\bar{t}$ leptons, jets, or unassociated calorimeter cells, and all selected muons in the event [61]. Calorimeter deposits associated with muons are subtracted from $E^{\text{miss}}_T$ to avoid double counting. Since no high-$p_T$ neutrinos are present in the signal, events are required to satisfy $E^{\text{miss}}_T < 50\text{ GeV}$, which primarily reduces the background from $t\bar{t}$ production.

Jets originating from $b$-quarks can be discriminated from other jets (“tagged”) based on the relatively long lifetime of hadrons containing $b$-quarks. This discrimination is important for this analysis because about 21% of signal events contain $b$-jets from $Z \rightarrow bb$ decay, while $b$-jets are produced less often (~2%) in the dominant $(Z \rightarrow \ell\ell) +$ jets background. A jet is tagged by taking the set of tracks associated with the jet and looking for either a secondary vertex or for tracks that have a significant impact parameter with respect to the primary event vertex [62]. This information is combined into a single discriminating variable and a selection is applied that gives an efficiency of about 70% (20%) for identifying true $b$-jets ($c$-jets) with a light-quark jet rejection of about 130 [63,64]. To optimise the expected sensitivity, the analysis is divided into “tagged” and “untagged” subchannels, containing events with exactly two and with fewer than two $b$-tags, respectively. Events with more than two $b$-tags (< 3% of the data sample with two $b$-tags) are rejected.

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1. ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis coinciding with the axis of the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upward. Cylindrical coordinates ($r, \phi$) are used in the transverse plane, $\phi$ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle $\theta$ as $\eta = -\ln(\tan(\theta/2))$. 


Events are required to have at least one candidate $Z \rightarrow q\bar{q}$ decay with dijet invariant mass $m_{jj}$ within 70–105 GeV in order to be consistent with a $Z$ boson decay. This selection is asymmetric around the $Z$ boson mass to account for non-Gaussian tails extending to lower masses. The jets forming a candidate must also be separated by $\Delta R > 0.7$, as the phase space region with jets close together is poorly modelled by MC simulation. For untagged events, all pairs of jets formed from the three highest-$p_T$ jets are considered. All such pairs are retained with unit weight, leading to the possibility of multiple candidates per event. The fraction of untagged events with multiple pairs retained is 13–16% (2–5%) for the low-$m_H$ (high-$m_H$) selection defined below. For tagged events, the two tagged jets are used to form the dijet invariant mass; their energies are scaled up by 5% to take into account the average energy scale difference between heavy- and light-quark jets. The resulting dijet invariant mass distributions are well described by the MC simulation, as shown in Fig. 1.

The selection criteria above define the “low-$m_H$” selection, which is applied when searching for a Higgs boson with $m_H < 300$ GeV. For higher Higgs boson masses, the $Z$ bosons from the $H \rightarrow ZZ$ decay have large momenta in the laboratory reference frame, decreasing the opening angles between their decay products. Accordingly, in addition to the low-$m_H$ selection, the following requirements are applied for $m_{jj} \geq 300$ GeV: the two jets must have $p_T > 45$ GeV and the azimuthal difference between the two leptons ($\Delta \phi_{\ell\ell}$) and the two jets ($\Delta \phi_{jj}$) must both be less than $\pi/2$. These criteria define the “high-$m_H$” selection.

Following this event selection, an $H \rightarrow ZZ \rightarrow \ell^+\ell^-q\bar{q}$ signal should appear as a peak in the invariant mass distribution of the $\ell\ell jj$ system, with $m_{\ell\ell jj}$ around $m_H$. To improve the Higgs boson mass resolution, the energies of the jets forming each dijet pair are scaled event-by-event by a single multiplicative factor to set the dijet invariant mass $m_{jj}$ to the nominal mass of the $Z$ boson. The resolution is improved by a factor of 2.4 at $m_H = 200$ GeV; the improvement decreases with increasing $m_H$ due to the increase in the natural width of the Higgs boson. The total efficiency for the selection of signal events is about 8% over most of the mass range.

The flavour composition of the $Z + \text{jets}$ sample is determined from three exclusive MC samples containing at least one true $b$-jet, at least one true $c$-jet, and all light jets, respectively. The relative normalisations of the three components are adjusted by fitting the distribution of the MC $b$-tagging discriminant to data.

To set the overall $Z + \text{jets}$ normalisation, the $m_{\ell\ell jj}$ distribution is compared between data and MC simulation for events in which the dijet invariant mass $m_{jj}$ is in sidebands of the $Z$ boson mass: 40–70 GeV or 105–150 GeV (see Figs. 2(a) and 2(b)). The numbers of events in the sidebands, after subtraction of the contribution from other background sources, are then used to derive scale factors to correct the normalisation of the $Z + \text{jets}$ MC simulation to that observed in the data. The scale factors are determined for the untagged channel separately for the low- and high-$m_H$ selections; the results agree within statistical uncertainties. In the tagged channel, there are too few events in the sidebands to determine the scale factor for the high-$m_H$ selection, hence the low-$m_H$ scale factor is used for both selections. Since the top quark background is not negligible, the $Z + \text{jets}$ MC normalisations are determined in a simultaneous fit to the $Z + \text{jets}$ control region and the corresponding top quark control region (see below). The overall data to MC scale factors for $Z + \text{jets}$ are approximately 0.9 for light-jets, 1.9 for $c$-jets, and 1.5 for $b$-jets.

In the $m_{jj}$ sidebands of the untagged low-$m_H$ selection, the $Z + \text{jets}$ MC simulation is about 3% above the data at $m_{\ell\ell jj} = 200$ GeV and about 1% below it at $m_{\ell\ell jj} = 300$ GeV (see Fig. 2(a)). Since similar results are seen for both the low and high mass sidebands, a linear fit to the ratio of data to MC simulation in the $m_{\ell\ell jj}$ sideband distribution is used to correct the prediction in the signal region. For the high-$m_H$ untagged selection and the tagged selections no difference between the data and MC distributions is seen within statistical uncertainties. Thus, no correction is applied to these samples, but similar fits to the ones described above are used to evaluate systematic uncertainties on the $Z + \text{jets}$ $m_{\ell\ell jj}$ shape.

The second most significant background is top quark production, which is most important in the tagged channel. The shapes of the relevant kinematic distributions are taken from MC simulation and the normalisation from data, using the top quark control region defined by the $m_{\ell\ell}$ sidebands 60–76 GeV or 106–150 GeV, with the $E_T^{\text{miss}}$ selection reversed. Figs. 2(c) and 2(d) show the $m_{jj}$ distributions for these control regions for the untagged and tagged selections respectively; good agreement is found after scaling up the MC prediction by about 5% for the untagged selection and 20% for the tagged selection. The contribution to this background from the production of single top quarks is negligible.

![Fig. 1. Distributions of the invariant mass of selected dijet pairs, $m_{jj}$, for the data and the MC simulation, in the untagged (left) and tagged (right) samples, which contain fewer than two $b$-jets and exactly two $b$-jets respectively. Scale factors and corrections described in Section 4 have been applied. The signal has been scaled up by a factor of 100 for the $m_{jj}$ case to be more visible. The vertical lines show the range of the $m_{jj}$ selection.](image-url)
As in Ref. [8], the small irreducible background from diboson (ZZ and WZ) production is estimated directly from MC simulation. The background due to multijet events in which jets are misidentified as isolated electrons is estimated from data using a sample of events containing electron candidates that fail the selection requirements but pass loosened requirements. The multijet background to the muon channel was found to be negligible. The background from W+jets production was also found to be negligible.

5. Systematic uncertainties

The theoretical uncertainties on the Higgs boson production cross section from Refs. [18,19] are 15–20% for the gluon fusion process and 3–9% for the vector-boson fusion process, depending on the Higgs boson mass. As mentioned in Section 2, an additional uncertainty $\propto m_H^3$ is applied for $m_H \geq 300$ GeV. The selection efficiency uncertainty due to the production process modelling is estimated by varying parameters of the signal MC simulation, including the amount of initial- and final-state radiation, the factorisation and normalisation scales, and the underlying event model; a further comparison uses PYTHIA instead of POWHEG. This procedure gives a 3% (12%) uncertainty for the low- (high-) $m_H$ selection.

The uncertainty on the procedure used to determine the normalisation of the $Z$+jets background, described in Section 4, is evaluated by comparing the scale factors obtained from the upper or lower sideband separately. It is taken as the difference between the scale factors or the statistical uncertainty, whichever is larger. This procedure gives 1.7% for the low-$m_H$ untagged selection, 2.2% for the high-$m_H$ untagged selection, and 5.5% for both tagged selections. The uncertainty in the flavour composition of the $Z$+jets background is estimated by varying the relative fraction of $Z+c$-jets by $\pm 30\%$ as determined by altering the selection criteria applied in the fitting procedure described in Section 4. An uncertainty due to the modelling of the $m_{\ell\ell}$, $m_{jj}$ shape as described in Section 4 is also applied. Additional uncertainties on the shape of the $Z$+jets background are estimated by finding variations of the MC $m_{jj}$ and $Z$ boson $p_T$ distributions that sufficiently cover any differences between MC simulation and data in the $m_{jj}$ sidebands.

The uncertainty on the procedure used to determine the normalisation of the $t\bar{t}$ background is derived from the statistical uncertainties on the normalisation scale factors. It is found to be 2.7% for the untagged selection and 4.0% for the tagged selection. The diboson cross sections have a combined 5% QCD scale and PDF uncertainty [19]; adding an additional 10% uncertainty, corresponding to the maximum difference seen between MC@NLO and K-factor scaled PYTHIA results, yields an overall uncertainty of 11% on the diboson background normalisation. A 50% systematic uncertainty is assigned to the normalisation of the multijet background in the electron channel by comparing the result of fitting the $m_{\ell\ell}$ distribution before and after the requirement of at least two jets. An overall 3.9% uncertainty from the integrated luminosity [65,66] is added to the uncertainties on all MC processes that are not normalised from data (i.e. excluding $Z$+jets and top quark production), correlated across all samples.
Table 1

The expected numbers of signal and background candidates in the $H \rightarrow ZZ \rightarrow \ell^+\ell^-q\bar{q}$ channel, along with the numbers of candidates observed in data, for an integrated luminosity of 4.7 fb$^{-1}$. The low-$m_H$ analysis is applied when searching for a Higgs boson with $m_H < 300$ GeV and the high-$m_H$ analysis for $m_H \geq 300$ GeV. The first error indicates the statistical uncertainty, the second error the systematic uncertainty.

<table>
<thead>
<tr>
<th></th>
<th>Untagged</th>
<th>High-$m_H$</th>
<th>Tagged</th>
<th>High-$m_H$</th>
</tr>
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<tr>
<td></td>
<td>Low-$m_H$</td>
<td>High-$m_H$</td>
<td>Low-$m_H$</td>
<td>High-$m_H$</td>
</tr>
<tr>
<td>$Z + \text{jets}$</td>
<td>$36,190 \pm 80 \pm 640$</td>
<td>$1450 \pm 14 \pm 35$</td>
<td>$239 \pm 6 \pm 15$</td>
<td>$11 \pm 1 \pm 2$</td>
</tr>
<tr>
<td>Top</td>
<td>$85 \pm 3 \pm 10$</td>
<td>$7.1 \pm 0.7 \pm 0.8$</td>
<td>$23 \pm 1 \pm 3$</td>
<td>$1.9 \pm 0.4 \pm 0.5$</td>
</tr>
<tr>
<td>Multijet</td>
<td>$15 \pm 0 \pm 8$</td>
<td>$0.2 \pm 0.0 \pm 0.1$</td>
<td>$&lt; 0.1$</td>
<td>$&lt; 0.1$</td>
</tr>
<tr>
<td>$WZ$</td>
<td>$348 \pm 0 \pm 47$</td>
<td>$25 \pm 1 \pm 3$</td>
<td>$22 \pm 1 \pm 4$</td>
<td>$2.3 \pm 0.3 \pm 0.4$</td>
</tr>
<tr>
<td>Total background</td>
<td>$37070 \pm 80 \pm 670$</td>
<td>$1530 \pm 14 \pm 37$</td>
<td>$285 \pm 6 \pm 18$</td>
<td>$15 \pm 1 \pm 2$</td>
</tr>
<tr>
<td>Data</td>
<td>$36,898$</td>
<td>$1444$</td>
<td>$286$</td>
<td>$18$</td>
</tr>
<tr>
<td>Signal</td>
<td>$m_H = 200$ GeV</td>
<td>$118 \pm 2 \pm 19$</td>
<td>$6.4 \pm 0.4 \pm 1.3$</td>
<td>$2.1 \pm 0.2 \pm 0.4$</td>
</tr>
<tr>
<td>$m_H = 300$ GeV</td>
<td>$24.3 \pm 0.7 \pm 4.1$</td>
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<tr>
<td>$m_H = 400$ GeV</td>
<td>$40.5 \pm 0.5 \pm 6.4$</td>
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<tr>
<td>$m_H = 500$ GeV</td>
<td>$18.5 \pm 0.2 \pm 3.1$</td>
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<td>$m_H = 600$ GeV</td>
<td>$6.3 \pm 0.1 \pm 1.1$</td>
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</table>

Fig. 3. The invariant mass of the $\ell\ell jj$ system for both the untagged (a, c) and tagged (b, d) channels, for the low-$m_H$ (top row) and high-$m_H$ (bottom row) selections. The hatched band represents the systematic error on the total background prediction. Examples of the expected Higgs boson signal for $m_H = 200$ and 400 GeV are also shown; in the untagged plots (a, c), the signal has been scaled up by a factor of five to make it more visible.

Contributions to systematic uncertainties also arise from detector effects, including the lepton and jet trigger and identification efficiencies, the energy or momentum calibration and resolution of the leptons and jets, and the $b$-tagging efficiency and mistag rates. These detector-related uncertainties are applied to all MC processes. The dominant uncertainty on the tagged sample comes from the $b$-tagging efficiency and corresponds to an average uncertainty of 9% on the signal [63,64]. For the untagged sample, the uncertainties on the jet energy scale and resolution contribute 3% and 4% respectively to the uncertainty on the signal [60].

The normalisations of the $Z + \text{jets}$ and top quark backgrounds are redetermined for each systematic variation following the procedures described in Section 4.

6. Results

Table 1 shows the numbers of candidates observed in data for each of the four selections compared with the background expectations. Fig. 3 shows the $m_{\ell\ell jj}$ distributions for both the tagged and untagged channels for the low- and high-$m_H$ selections.
No significant excess of events above the expected background is seen; the smallest p_0 value is 0.15 at m_H = 540, where p_0 represents the probability that a background-only experiment would yield a result that is more signal-like than the observed result. Upper limits are set on the SM Higgs boson cross section at 95% CL as a function of mass, using the CL_s modified frequentist formalism with the profile likelihood test statistic [67, 68]. This method is based on a likelihood that compares, bin-by-bin using Poisson statistics, the observed m_{eff} distribution to either the expected background or the sum of the expected background and a mass-dependent hypothesised signal. The tagged and untagged channels, which contribute approximately equally across the m_H range, are combined by forming the product of their likelihoods; systematic uncertainties, with their correlations, are incorporated as nuisance parameters. Fig. 4 shows the resulting upper limit on the cross section for Higgs boson production and decay in the channel H → ZZ → ℓ⁺ℓ⁻q̅q̅ relative to the Standard Model cross section as a function of the hypothetical Higgs boson mass. The discontinuity in the limit at m_H = 300 GeV is due to the transition between the use of the low- and high-m_H selections. Since the high-m_H selection is a very small subset of the low-m_H selection, there is little correlation between the observed limits on either side of the boundary.

7. Summary

A search for the SM Higgs boson in the decay mode H → ZZ → ℓ⁺ℓ⁻q̅q̅ has been performed in the Higgs mass range 200 to 600 GeV using 4.7 fb⁻¹ of √s = 7 TeV pp data recorded by the ATLAS experiment at the LHC. No significant excess over the expected background is found. A Standard Model Higgs boson is excluded at a 95% CL within the range 300 GeV < m_H < 322 GeV and 353 GeV < m_H < 410 GeV. The corresponding expected exclusion range is 351 GeV < m_H < 404 GeV at 95% CL.

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References

56 Department of Physics, Hampton University, Hampton, VA, United States
57 Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, MA, United States
58 (a) Kurchatov-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; (b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany
59 Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan
60 Department of Physics, Indiana University, Bloomington, IN, United States
61 Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
62 University of Iowa, Iowa City, IA, United States
63 Department of Physics and Astronomy, Iowa State University, Ames, IA, United States
64 Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
65 KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
66 Graduate School of Science, Kobe University, Kobe, Japan
67 Faculty of Science, Kyoto University, Kyoto, Japan
68 Kyoto University of Education, Kyoto, Japan
69 Department of Physics, Kyushu University, Fukuoka, Japan
70 Instituto de Fisica La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
71 Physics Department, Lancaster University, Lancaster, United Kingdom
72 (a) INFN Sezione di Lecce; (b) Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
73 Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
74 Department of Physics, Jozef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
75 School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
76 Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
77 Department of Physics and Astronomy, University College London, London, United Kingdom
78 Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
79 Physiska institutionen, Lunds universitet, Lund, Sweden
80 Department of Fisica Teorica C-15, Universidad Autónoma de Madrid, Madrid, Spain
81 Institut für Physik, Universität Mainz, Mainz, Germany
82 School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
83 CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
84 Department of Physics, University of Massachusetts, Amherst, MA, United States
85 Department of Physics, McGill University, Montreal, QC, Canada
86 School of Physics, University of Melbourne, Victoria, Australia
87 Department of Physics, The University of Michigan, Ann Arbor, MI, United States
88 Department of Physics and Astronomy, University of Michigan, East Lansing, MI, United States
89 (a) INFN Sezione di Milano; (b) Dipartimento di Fisica, Università di Milano, Milano, Italy
90 B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus
91 National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Belarus
92 Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, United States
93 Group of Particle Physics, University of Montreal, Montreal, QC, Canada
94 P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia
95 Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia
96 Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia
97 Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
98 Department of Physics, Universita' di Milano, Milano, Italy
99 Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
100 Nagasaki Institute of Applied Science, Nagasaki, Japan
101 Graduate School of Science, Nagoya University, Nagoya, Japan
102 (a) INFN Sezione di Napoli; (b) Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy
103 Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, United States
104 Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands
105 Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands
106 Department of Physics, Northern Illinois University, DeKalb, IL, United States
107 Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia
108 Department of Physics, New York University, New York, NY, United States
109 Ohio State University, Columbus, OH, United States
110 Faculty of Science, Okayama University, Okayama, Japan
111 Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK, United States
112 Department of Physics, Oklahoma State University, Stillwater, OK, United States
113 Palacký University, RCPITM, Olomouc, Czech Republic
114 Center for High Energy Physics, University of Oregon, Eugene, OR, United States
115 LAT, Université Paris-Sud and CNRS/IN2P3, Orsay, France
116 Graduate School of Science, Osaka University, Osaka, Japan
117 Department of Physics, University of Oslo, Oslo, Norway
118 Department of Physics, Oxford University, Oxford, United Kingdom
119 (a) INFN Sezione di Pavia; (b) Dipartimento di Fisica, Università di Pavia, Pavia, Italy
120 Department of Physics, University of Pennsylvania, Philadelphia, PA, United States
121 Petersburg Nuclear Physics Institute, Gatchina, Russia
122 (a) INFN Sezione di Pisa; (b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
123 Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA, United States
124 (a) Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal; (b) Departamento de Fisica Teorica y del Cosmos and CAFFE, Universidad de Granada, Granada, Spain
125 Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic
126 Faculty of Mathematics and Physics, Charles University in Prague, Prague, Czech Republic
127 Czech Technical University in Prague, Prague, Czech Republic
128 State Research Center Institute for High Energy Physics, Protvino, Russia
129 Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
130 Physics Department, University of Regina, Regina, SK, Canada
131 Ritsumeikan University, Kusatsu, Shiga, Japan
132 (a) INFN Sezione di Roma I; (b) Dipartimento di Fisica, Università La Sapienza, Roma, Italy

87

Also at Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIF, Lisboa, Portugal.

Also at Faculdade de Ciencias and CFNUL, Universidade de Lisboa, Lisboa, Portugal.

Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom.

Also at TRIUMF, Vancouver, BC, Canada.

Also at Department of Physics, California State University, Fresno, CA, United States.

Also at Novosibirsk State University, Novosibirsk, Russia.

Also at Fermilab, Batavia, IL, United States.

Also at Department of Physics, University of Coimbra, Coimbra, Portugal.

Also at Department of Physics, UASLP, San Luis Potosi, Mexico.

Also at Università di Napoli Parthenope, Napoli, Italy.

Also at Institute of Particle Physics (IPP), Canada.

Also at Department of Physics, Middle East Technical University, Ankara, Turkey.

Also at Louisiana Tech University, Ruston, LA, United States.

Also at Departamento de Fisica and CEITITC of Facultade de Ciencias e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal.

Also at Department of Physics and Astronomy, University College London, London, United Kingdom.

Also at Group of Particle Physics, University of Montreal, Montreal, QC, Canada.

Also at Department of Physics, University of Cape Town, Cape Town, South Africa.

Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.

Also at Institut fur Experimentalphysik, Universitat Hamburg, Hamburg, Germany.

Also at Manhattan College, New York, NY, United States.

Also at School of Physics, Shandong University, Shandong, China.

Also at CPPM, Aix-Marseille Universite and CNRS/IN2P3, Marseille, France.

Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China.

Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.

Also at Dipartimento di Fisica, Universita La Sapienza, Roma, Italy.

Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l’Univers), CEA Saclay (Commissariat a l’Energie Atomique), Gif-sur-Yvette, France.

Also at Department of Physics, University of California at San Diego, La Jolla, CA, United States.

Also at Institute of Pure and Applied Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8571, Japan.

Also at Department of Physics, University of Toronto, Toronto, ON, Canada.

Also at Department of Physics and Astronomy, York University, Toronto, ON, Canada.

Also at Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; 
Also at Faculté des Sciences, Université Mohammed V-Agdal, Rabat, Morocco.

Also at School of Physics, University of the Witwatersrand, Johannesburg, South Africa.

Also at Physics Department, Royal Institute of Technology, Stockholm, Sweden.

Also at Department of Physics and Astronomy, University of Johannesburg, Johannesburg; 
Also at School of Physics, University of the Witwatersrand, Johannesburg, South Africa.

Also at Department of Physics, Stockholm University; 
Also at The Okazaki Klin Centre, Stockholm, Sweden

Also at Physics Department, University of Cincinnati, Cincinnati, OH, United States.

Also at Department of Physics, University of Illinois, Urbana, IL, United States.

Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.

Also at Department of Physics, University of Cape Town, Cape Town, South Africa.

Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom.

Also at Dipartimento di Fisica, Università Roma Tre, Roma, Italy.

Also at Physics Department, Simon Fraser University, Burnaby, BC, Canada.

Also at SLAC National Accelerator Laboratory, Stanford, CA, United States.

Also at Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic.

Also at Department of Physics, Tokyo Institute of Technology, Tokyo, Japan.

Also at Institute of Pure and Applied Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8571, Japan.

Also at Science and Technology Center, Tufts University, Medford, MA, United States.

Also at Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia.

Also at Department of Physics and Astronomy, University of California Irvine, Irvine, CA, United States.

Also at INFN Padova, C. di Udine, INFN Trieste; 
Also at Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy.

Also at Department of Physics, University of Illinois, Urbana, IL, United States.

Also at Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden.

Also at Istituto di Fisica Corpuscolare (IFC) and Departamento de Fisica Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IBMB-CNEN), Universitat de Valencia and CSIC, Valencia, Spain.

Also at Department of Physics, University of British Columbia, Vancouver, BC, Canada.

Also at Department of Physics and Astronomy, University of Victoria, Victoria, BC, Canada.

Also at Department of Physics, University of Warwick, Coventry, United Kingdom.

Also at Waseda University, Tokyo, Japan.

Also at Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel.

Also at Department of Physics, University of Wisconsin, Madison, WI, United States.

Also at Fakultat für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany.

Also at Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany.

Also at Department of Physics, Yale University, New Haven, CT, United States.

Also at Yerevan Physics Institute, Yerevan, Armenia.

Also at Domaine Scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France.

Also at Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy.

Also at Dipartimento di Fisica, Università di Roma Tre, Roma, Italy.

Also at Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies – Université Hassan II, Casablanca; 
Also at Centre National de l’Energie des Sciences Techniques Nucleaires, Rabat; 
Also at Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA, Marrakech; 
Also at Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; 
Also at Faculté des Sciences, Université Mohammed V-Agdal, Rabat, Morocco.

Also at Fermilab, Batavia, IL, United States.

Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France.

Also at School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China.

Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan.

Also at Dipartimento di Fisica, Università La Sapienza, Roma, Italy.

Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l’Univers), CEA Saclay (Commissariat a l’Energie Atomique), Gif-sur-Yvette, France.