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Search for the Standard Model Higgs boson decay to $\mu^+\mu^-$ with the ATLAS detector

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ABSTRACT

A search is reported for Higgs boson decay to $\mu^+\mu^-$ using data with an integrated luminosity of 24.8 fb^{-1} collected with the ATLAS detector in pp collisions at $\sqrt{s} = 7$ and 8 TeV at the CERN Large Hadron Collider. The observed dimuon invariant mass distribution is consistent with the Standard Model background-only hypothesis in the 120–150 GeV search range. For a Higgs boson with a mass of 125.5 GeV, the observed (expected) upper limit at the 95% confidence level is 7.0 (7.2) times the Standard Model expectation. This corresponds to an upper limit on the branching ratio BR($H \to \mu^+\mu^-$) of 1.5×10^{-3}.

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1. Introduction

The Standard Model (SM) describes a wide range of particle physics phenomena to a high degree of precision. In the SM, the Brout–Englert–Higgs (BEH) mechanism [1–3] spontaneously breaks the electroweak (EW) gauge symmetry and generates masses for the W and Z gauge bosons as well as for the charged fermions via Yukawa couplings [4–6]. In searches for the Higgs boson predicted by the BEH mechanism, the ATLAS and CMS Collaborations have discovered a new particle, via decays into gauge bosons [7,8], with a mass of approximately 125.5 GeV and measured properties consistent with those predicted by the SM [9–12].

Higgs boson decays to $b\bar{b}$, $\tau^+\tau^-$ and $\mu^+\mu^-$ can be measured at the LHC with their SM branching ratios proportional to the squares of the fermion masses. The SM branching ratio for the $H \to \mu^+\mu^-$ decay is 21.9×10^{-5} for a Higgs boson mass (m_H) of 125 GeV [13,14]. The $H \to \mu^+\mu^-$ decay has a clean final state signature that allows a measurement of the Higgs boson coupling to second-generation fermions. The dominant irreducible background is the $Z/\gamma^* \to \mu^+\mu^-$ process, which has an approximately three orders of magnitude higher production rate compared to that of the expected signal.

In this Letter a search for the $H \to \mu^+\mu^-$ decay of the SM Higgs boson is presented. This search for the presence of a narrow $H \to \mu^+\mu^-$ resonance, with a signal width determined by experimental resolution, is performed by fitting the invariant mass distribution in the 110–160 GeV region. This range allows determining background shape and normalisation and setting a limit on the dimuon decay of the SM Higgs boson with a mass of 125.5 GeV. Section 2 gives a description of the experimental setup and summarises the data sample and Monte Carlo (MC) simulation samples used to model the signal process and to develop an analytical model for the background processes. Sections 3 and 4 describe the event selections and categorisation. Analytical models used to describe invariant mass distributions for signal and background processes are discussed in Section 5, and systematic uncertainties are detailed in Section 6. The results are presented in Section 7.

2. Experimental setup, data and simulated samples

This search is performed on the data sample recorded in 2011 and 2012 by the ATLAS detector in pp collisions at the LHC at $\sqrt{s} = 7$ and 8 TeV, respectively. ATLAS [15] is a general-purpose particle detector with a cylindrical geometry and consists of several subdetectors surrounding the interaction point and covering almost the full solid angle.[1] The trajectories and momenta of charged particles are measured within the pseudorapidity range of $|\eta| < 2.5$ by multi-layer silicon pixel and microstrip detectors as well as a transition radiation tracker. The tracking system is immersed in a 2 T magnetic field produced by a superconducting solenoid, and is surrounded by a high-granularity

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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 along 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, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$.

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liquid-argon (LAr) electromagnetic sampling calorimeter covering $|\eta| < 3.2$. An iron and scintillator tile hadronic calorimeter provides coverage in the range $|\eta| < 1.7$. The LAr calorimeters also provide measurements of electromagnetic and hadronic energy deposits in the region $1.5 < |\eta| < 4.9$. The muon spectrometer surrounds the calorimeters and consists of three large air-core superconducting magnets with a toroidal field of 0.5 T in the barrel region and 1 T in the forward regions, and a system of precision tracking chambers; it provides coverage for $|\eta| < 2.7$. The muon spectrometer also includes fast detectors for triggering covering $|\eta| < 2.4$.

Events were recorded with a trigger [16] requiring at least one muon candidate with transverse momentum $p_T > 18$ GeV for 7 TeV data and $p_T > 24$ GeV for 8 TeV data. This trigger is approximately 70% efficient for muons with $|\eta| < 1.05$ and approximately 90% efficient for muons with $|\eta| > 1.05$. The differences in the efficiency are mostly due to the different geometrical acceptance of the muon trigger system in these regions. For 8 TeV data, events were also recorded with a dimuon trigger requiring at least two muon candidates with transverse momenta of $p_T > 18$ GeV and $p_T > 8$ GeV. After applying data quality requirements, the total integrated luminosity of the selected data sample is 4.5 ± 0.1 fb^{-1} for 7 TeV data and 20.3 ± 0.6 fb^{-1} for 8 TeV data. The associated systematic uncertainties are summarised in Section 6.

At the LHC, SM Higgs boson production is dominated by the gluon fusion (ggF) process with the next two most important contributions arising from the vector boson fusion (VBF) process and production in association with vector bosons (VH). The signal MC samples are generated in 5 GeV steps of the Higgs boson mass from 120 GeV to 150 GeV. The ggF and VBF samples are generated at next-to-leading-order (NLO) in QCD with POWHEG [17,18] with the parton showering modelled by PYTHIA8 [19] for the 8 TeV samples and PYTHIA [20] for the 7 TeV samples. The CT10 [21] parton distribution functions (PDFs) are used in POWHEG, with the ATLAS Underlying Event Tune, AU2 [22]. The ggF Higgs boson p_T spectrum in POWHEG is tuned to agree with the prediction from HRES [23,24]; this procedure shifts the Higgs boson p_T spectrum to slightly smaller values. The VH samples are generated with PYTHIA8, using AU2 and the CTEQ6 [25] PDFs.

The predicted SM Higgs boson cross-sections and branching ratios are compiled in Refs. [13,14,26]. The cross section for the ggF process is calculated at next-to-next-to-leading-order (NNLO) [27–32] in QCD and NLO electroweak (EW) corrections are applied [33,34], assuming that the QCD and EW corrections factorise. The cross section for the VBF process is calculated with full NLO QCD and EW corrections [35–37] and approximate NNLO QCD corrections [38]. The cross section for the VH process is calculated at NNLO [39,40] in QCD, and NLO EW radiative corrections [41] are applied. The branching ratios for $H \to \mu^+\mu^-$ decays as a function of m_H are calculated using HDECAY [42].

The following MC event generators are used to simulate background processes: ALPGEN [43] + HERWIG [44] for W + jets, MC@NLO [45] + HERWIG for $t\bar{t}$, tW and tb, ACERMC [46] + PYTHIA for tqb, POWHEG + PYTHIA8 for Z/γ^* and $q\bar{q} \to WW$, gg2WW [47] + HERWIG for $gg \to WW$, POWHEG [48] + PYTHIA for WZ and ZZ and MADGRAPH [49,50] + PYTHIA for $W\gamma^*$. WW, WZ, ZZ and $W\gamma^*$ production are referred to as diboson production later in the text. In addition, contributions from W boson production in association with one or more jets (W + jets), where one of the jets is misidentified as a muon, are estimated using a data control region containing same-sign dimuon events as described in Ref. [9].

The signal and background MC samples are processed through the ATLAS detector simulation [51] based on GEANT4 [52], followed by the same reconstruction algorithms that are used for collision data. The effects arising from multiple collisions in the same or neighbouring bunch crossings (pile-up) are included in the MC simulation, matching the pile-up conditions of the selected data sample.

3. Event selection

Events are required to contain at least one reconstructed pp collision vertex candidate with at least three associated tracks each with $p_T > 0.4$ GeV. The vertex with the largest sum of p_T^2 of tracks is considered to be the primary vertex. Muon candidates [53] are reconstructed by matching tracks in the inner detector to tracks reconstructed in the muon spectrometer. In addition to stringent track quality requirements imposed for muon identification, the muon tracks must be consistent with having originated from the primary vertex. All selected muon candidates are required to be within $|\eta| < 2.5$. Muon candidates must pass track and calorimeter isolation requirements that scale with the p_T of the muon track. The isolation is calculated as the scalar sum of the p_T of additional tracks or the E_T of calorimeter energy deposits within cone of radius $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta^2)} = 0.3$ around the muon track, normalised by p_T^μ. For 8 TeV data, each muon with $p_T^\mu > 20$ (15) GeV is required to have a normalised track isolation smaller than 0.12 (0.08) and a normalised calorimetric isolation less than 0.30 (0.18). For 7 TeV data, equivalent values for $p_T^\mu > 15$ GeV are 0.15 and 0.2 for track and calorimetric isolation, respectively. Due to different pile-up conditions, different isolation criteria are used for 7 TeV and 8 TeV data.

Jets are reconstructed from clusters of calorimeter cells using the anti-k_t algorithm [54,55] with a radius parameter of 0.4. The selected jets must satisfy $E_T > 25$ GeV for $|\eta| < 2.4$ and $E_T > 30$ GeV for $2.4 \leq |\eta| < 4.5$. Muon candidates overlapping with the selected jets within a cone of radius $\Delta R = 0.4$ are removed from the analysis. In the pseudorapidity range $|\eta| < 2.5$, jets originating from b-quarks are identified using a b-tagging algorithm [56,57] with an efficiency of approximately 80%, determined from $t\bar{t}$ MC events, and with a misidentification rate for selecting light-quark or gluon jets of less than 1%. The missing transverse momentum [58], E_T^{miss}, is the magnitude of the vector sum of the p_T of muons, electrons, photons, jets and clusters of calorimeter cells with $|\eta| < 4.9$ not associated with these objects.

Corrections are applied to simulated MC samples in order to account for differences between data and MC simulation for the trigger and identification efficiency and for the muon momentum scale and resolution. The trigger and reconstruction efficiency corrections are measured using $Z \to \mu^+\mu^-$ events and are found to be within 2% of unity. The muon momentum corrections are determined by comparing the reconstructed invariant mass distribution of $Z \to \mu^+\mu^-$ events in data with that from simulated events; these corrections are within 0.1% of unity.

$H \to \mu^+\mu^-$ candidate events are selected by requiring exactly two oppositely charged muons with transverse momentum $p_T^{\mu_1} > 25$ GeV and $p_T^{\mu_2} > 15$ GeV for the leading and subleading muon, respectively. Selected events must contain at least one muon identified by the trigger system within a cone of radius $\Delta R = 0.15$ centred on the reconstructed muon candidate. The dominant background in this search is $Z/\gamma^* \to \mu^+\mu^-$ production, followed by smaller backgrounds from single and pair production of top quarks and diboson processes. To suppress backgrounds from top quark pair production and diboson processes, events are required to have $E_T^{miss} < 80$ GeV. The dimuon invariant mass distribution $m_{\mu^+\mu^-}$ and the dimuon transverse momentum $p_T^{\mu^+\mu^-}$ for data and MC events passing all the selection requirements so far are shown in Fig. 1. The number of expected signal events for $m_H = 125$ GeV, the expected background contributions, and the number of observed data events in the $m_{\mu^+\mu^-}$ region from 122.5 to 127.5 GeV

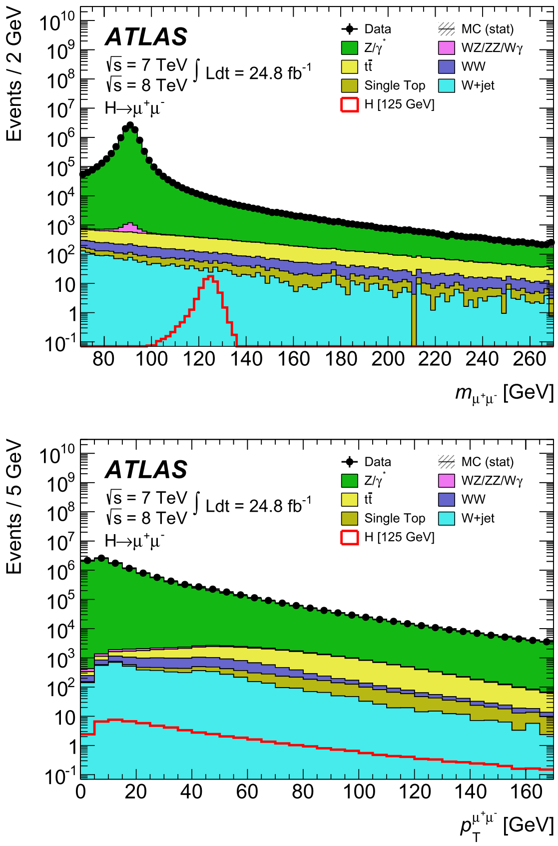

Fig. 1. The distribution of the dimuon invariant mass (top) and dimuon momentum (bottom) for 7 TeV and 8 TeV data with all the selection requirements described in Section 3. The expected signal is shown for $m_H = 125$ GeV.

are shown in Table 1. The MC background yields are given to illustrate the expected background composition. The selection efficiency times acceptance for signal events with $m_H = 125$ GeV after all selection criteria described thus far is approximately 55%.

The expected background processes produce smooth $m_{\mu^+\mu^-}$ distributions in the search window, allowing the total background normalisation and shape in each category to be derived from fitting the data as described in Section 5. The $m_{\mu^+\mu^-}$ distribution is examined in the range 110–160 GeV. This range is larger than the 120–150 GeV search window in order to account for signal resolution effects and to allow sufficient sidebands for background normalisation.

4. Event categorisation

To increase sensitivity to the Higgs boson signal, the selected events are separated into seven mutually exclusive categories with different signal-to-background ratios based on their muon pseudorapidity (η_μ), $p_T^{\mu^+\mu^-}$, and VBF dijet signature. Events produced in the VBF process are characterised by two forward jets with little hadronic activity between them. The VBF category is thus defined by requiring the events to have at least two jets with an invariant mass greater than 500 GeV, $|\eta_{\text{jet}_1} - \eta_{\text{jet}_2}| > 3$ and $\eta_{\text{jet}_1} \times \eta_{\text{jet}_2} < 0$. In events with more than two jets, those with the highest p_T are used in the selection. Events with at least one jet identified as originating from a b-quark are excluded from the VBF category.

The events that are not selected for the VBF category are classified using $p_T^{\mu^+\mu^-}$. Signal events have on average larger values of $p_T^{\mu^+\mu^-}$ than the Z/γ^* background events. Therefore, the remaining events are separated into three $p_T^{\mu^+\mu^-}$ categories: low (< 15 GeV), medium (15–50 GeV) and high (> 50 GeV). To further improve the search sensitivity, each of these three categories is also subdivided into a central category with $|\eta_{\mu_1}| < 1$ and $|\eta_{\mu_2}| < 1$ and a non-central category containing all remaining events. This value for the η_μ boundary has been chosen by scanning a range of η_μ values and selecting a value with the highest signal sensitivity. The muon momentum measurement for the central muons is more precise, producing a narrower $m_{\mu^+\mu^-}$ distribution for signal events in the central category and thus resulting in a higher overall signal sensitivity. Table 2 shows the signal event yields, $N_S/\sqrt{N_B}$ ratios, approximate signal width and results of the fits to the data, described in Section 5, for all analysis categories.

Table 1
Number of expected signal events for $m_H = 125$ GeV, number of expected background events predicted by the MC simulation, and number of observed data events within a window of $|m_H - m_{\mu^+\mu^-}| \leq 2.5$ GeV after all selection criteria are applied. Only statistical uncertainties are given. The theoretical systematic uncertainty on the dominant Z/γ^* background is about 4%. The MC background yields are given to illustrate the expected background composition.

	7 TeV	8 TeV
Signal (125 GeV)	5.6 ± 0.1	32.7 ± 0.2
Z/γ^*	3110 ± 40	$16\,660 \pm 270$
$WZ/ZZ/W\gamma$	2.2 ± 0.2	12.3 ± 0.7
$t\bar{t}$	75.6 ± 1.8	509.2 ± 2.7
WW	23.2 ± 0.5	123.3 ± 1.6
Single top	7.2 ± 0.9	54.5 ± 0.6
W + jets	3.2 ± 1.5	38 ± 4
Total Bkg.	3220 ± 40	$17\,390 \pm 270$
Observed	3344	17 745

Table 2
Expected signal yields (N_S) for $m_H = 125$ GeV and the ratio $N_S/\sqrt{N_B}$ using the simulated MC background yields (N_B) within a window of $|m_H - m_{\mu^+\mu^-}| \leq 2.5$ GeV for each of the event categories under study. In addition, the full width at half maximum (FWHM) of the signal $m_{\mu^+\mu^-}$ distribution, modelled as described in Section 5, is given. Also shown are χ^2/ndof of the standalone fits to the $m_{\mu^+\mu^-}$ distribution in each category using models described in Section 5. The 7 TeV VBF category does not include a sufficient number of events to compute a meaningful χ^2 value. The goodness of fit for the background description in this category was verified using MC simulation to ensure that the background model provides a consistent description of the 7 TeV and 8 TeV VBF categories.

$\sqrt{s}$ [TeV]	Category	N_S	$\frac{N_S}{\sqrt{N_B}}$	FWHM [GeV]	χ^2/ndof
8	non-cen. low $p_T^{\mu^+\mu^-}$	6.1	0.07	6.6	49.8/48
8	cen. low $p_T^{\mu^+\mu^-}$	2.6	0.06	5.5	52.8/48
8	non-cen. medium $p_T^{\mu^+\mu^-}$	10.4	0.15	6.6	45.1/48
8	cen. medium $p_T^{\mu^+\mu^-}$	4.7	0.13	5.6	36.7/48
8	non-cen. high $p_T^{\mu^+\mu^-}$	5.5	0.13	7.2	26.7/48
8	cen. high $p_T^{\mu^+\mu^-}$	2.6	0.10	6.0	32.3/48
8	VBF	0.8	0.09	7.0	18.6/19
7	non-cen. low $p_T^{\mu^+\mu^-}$	1.0	0.03	6.8	42.0/48
7	cen. low $p_T^{\mu^+\mu^-}$	0.5	0.03	5.3	43.5/48
7	non-cen. medium $p_T^{\mu^+\mu^-}$	1.8	0.06	6.9	41.2/48
7	cen. medium $p_T^{\mu^+\mu^-}$	0.8	0.05	5.5	34.4/48
7	non-cen. high $p_T^{\mu^+\mu^-}$	0.9	0.05	7.5	60.0/48
7	cen. high $p_T^{\mu^+\mu^-}$	0.5	0.05	5.9	56.2/48

5. Signal and background models

Analytical models are used to describe the $m_{\mu^+\mu^-}$ distributions for signal and background processes. The simulated samples detailed in Section 2 are used to develop background models which are designed to describe essential features of the background $m_{\mu^+\mu^-}$ distributions, dominated by Z/γ^*, while having sufficient flexibility to describe different categories and to absorb potential differences between data and MC simulation.

The background model selected to describe the $m_{\mu^+\mu^-}$ distribution for the $p_T^{\mu^+\mu^-}$ categories is the sum of a Breit–Wigner (BW) function convolved with a Gaussian function (GS), and an exponential function divided by x^3:

$$P_B(x) = f \cdot \left[\mathrm{BW}(M_{\mathrm{BW}}, \Gamma_{\mathrm{BW}}) * \mathrm{GS}\left(\sigma_{\mathrm{GS}}^{\mathrm{B}}\right)\right](x) + (1-f) \cdot C \cdot e^{A \cdot x}/x^3, \quad (1)$$

where x represents $m_{\mu^+\mu^-}$ and f represents the fraction of the BW component when each individual component is normalised to unity. C is an overall normalisation coefficient. The $\sigma_{\mathrm{GS}}^{\mathrm{B}}$ parameters in each category are fixed to the average $m_{\mu^+\mu^-}$ resolution in that category as determined from the MC simulation of Z/γ^*. The background model for the VBF category is the product of a Breit–Wigner and an exponential function:

$$P_B(x) = \mathrm{BW}(M_{\mathrm{BW}}, \Gamma_{\mathrm{BW}}, x) \cdot e^{A \cdot x}. \quad (2)$$

For all categories, the BW parameters are fixed to $M_{\mathrm{BW}} = 91.2$ GeV and $\Gamma_{\mathrm{BW}} = 2.49$ GeV. The parameters f, A and the overall background normalisation are determined from fits to the data, as shown in Fig. 2 for the central medium $p_T^{\mu^+\mu^-}$ category. Similar fit quality is observed for all other categories.

The signal model is obtained from simulated Higgs boson signal samples, where contributions from the ggF, VBF and VH Higgs boson production processes are added together. This model is the sum of a Crystal Ball (CB)[2] and a Gaussian function:

$$P_S(x) = f_{\mathrm{CB}} \cdot \mathrm{CB}(x, m, \sigma_{\mathrm{CB}}, \alpha, n) + (1 - f_{\mathrm{CB}}) \cdot \mathrm{GS}\left(x, m, \sigma_{\mathrm{GS}}^{\mathrm{S}}\right), \quad (3)$$

where x represents $m_{\mu^+\mu^-}$ and f_{CB} represents the fraction of the CB contribution when each individual component is normalised to unity. The parameters α and n define the power-law tail of the CB distribution. The parameters σ_{CB} and $\sigma_{\mathrm{GS}}^{\mathrm{S}}$ denote the widths of the CB and GS distributions, respectively. The parameters m, σ_{CB} and $\sigma_{\mathrm{GS}}^{\mathrm{S}}$ are determined from the fits to the simulated Higgs boson samples. In order to improve stability of the fits, the remaining parameters f_{CB}, α and n are fixed to values determined from empirical tests where a range of possible values have been tested. Fig. 3 shows how the signal model reproduces the simulation for the medium $p_T^{\mu^+\mu^-}$ category for the expected signal dimuon mass distributions. Similar fit quality is obtained for all other categories. The signal model parameters are linearly interpolated in steps of 1 GeV between the generated signal samples.

To derive the results presented in Section 7, a binned maximum likelihood fit to the observed $m_{\mu^+\mu^-}$ distributions in the range 110–160 GeV is performed using the sum of the signal and background model. The fit is done simultaneously in all seven categories with separate distributions for 7 TeV and 8 TeV data. Free fit parameters include the background model fit parameters described earlier and an overall background normalisation in each category. The signal model parameters are fixed in the fit to data except for the $H \to \mu^+\mu^-$ signal strength μ_S defined such that $\mu_S = 0$ corresponds to the background-only hypothesis and $\mu_S = 1$ corresponds to the SM $H \to \mu^+\mu^-$ signal hypothesis.

[2] A Gaussian function with a power-law tail.

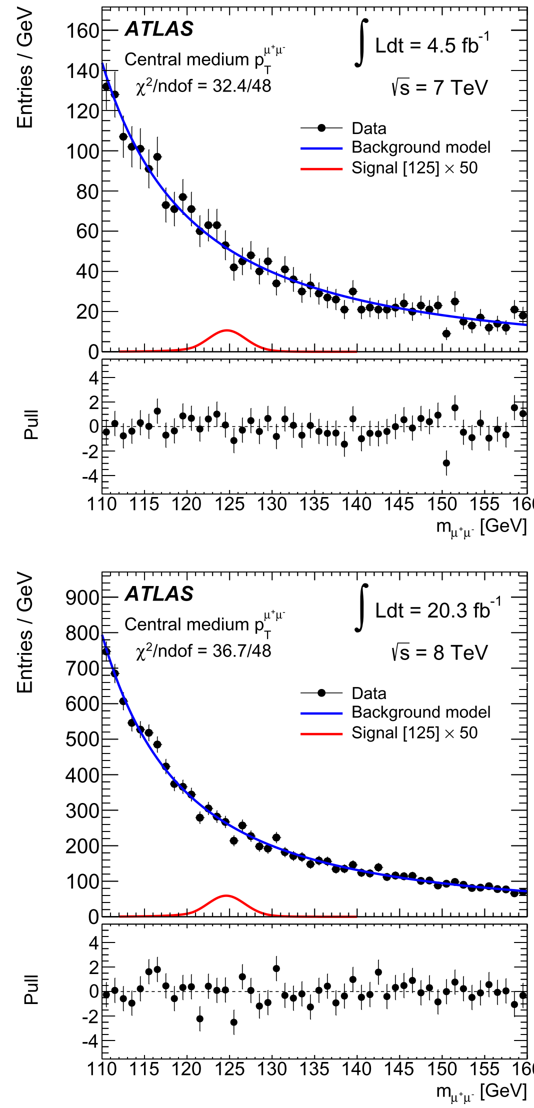

Fig. 2. The background model fits to the $m_{\mu^+\mu^-}$ distribution for the central medium $p_T^{\mu^+\mu^-}$ category for 7 TeV (top) and 8 TeV (bottom) data. The statistical uncertainties are given for the data points. The expected signal is shown for $m_H = 125$ GeV and is scaled by a factor of 50.

Table 3
Main sources of experimental and theoretical uncertainty on the signal yield, excepting the error from mismodelling bias. "QCD scale" indicates the theoretical uncertainty on the Higgs boson production due to missing higher-order corrections estimated by varying the QCD renormalisation and factorisation scales, while "PDFs + α_s" indicates uncertainty due to parton distribution functions, as described in Refs. [13,14]. The ranges for the uncertainties cover the variations among different categories and data-taking periods.

Source (experimental)	Uncertainty (%)
Luminosity	±1.8 (7 TeV), ±2.8 (8 TeV)
Muon efficiency	±1
Muon momentum res.	±1
Muon trigger	±1.5
Muon isolation	±1.1
Pile-up reweighting	±1
Jet energy scale	$^{+3.4}_{-4.5}$ (VBF)
Source (theory)	**Uncertainty (%)**
Higgs boson branching ratio	±7
QCD scale	±8 (ggF), ±1 (VBF, VH)
PDFs + α_s	±8 (ggF), ±4 (VBF, VH)
ggF uncert. in VBF	±22
Multi-parton inter. in VBF	±9 (ggF), ±4 (VBF)

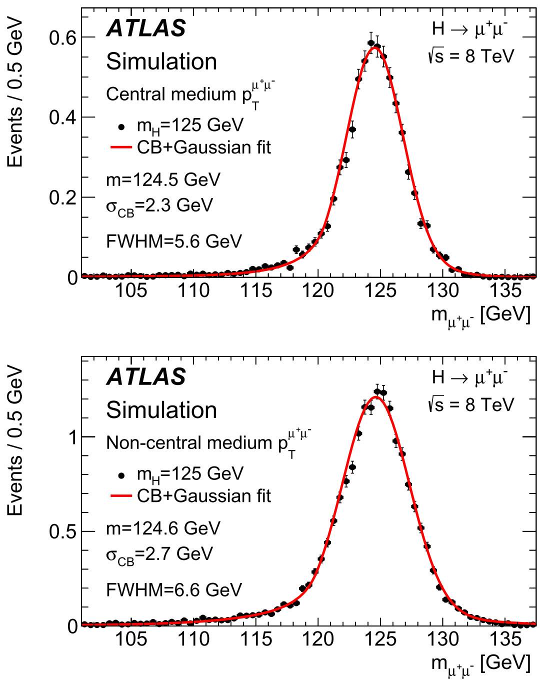

Fig. 3. The signal model fit to the $m_{\mu^+\mu^-}$ distribution for the central (top) and non-central (bottom) simulated Higgs boson events for $m_H = 125$ GeV in the medium $p_T^{\mu^+\mu^-}$ category for $\sqrt{s} = 8$ TeV.

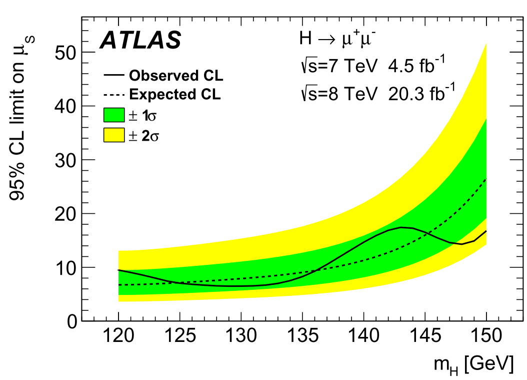

Fig. 4. Observed (solid) and expected (dashed) 95% CL upper limits on the $H \to \mu^+\mu^-$ signal strength as a function of m_H over the mass range 120–150 GeV. The dark- and light-shaded regions indicate the $\pm 1\sigma$ and $\pm 2\sigma$ uncertainty bands on the expected limit, respectively.

6. Systematic uncertainties

The main theoretical and experimental sources of uncertainty on the number of expected signal events are shown in Table 3. The uncertainty on the integrated luminosity is ±1.8% for 7 TeV data [59] and ±2.8% for 8 TeV data; it is obtained following the same methodology as that detailed in Ref. [59], from a preliminary calibration of the luminosity scale derived from beam-separation scans performed in November 2012.

Sources of experimental uncertainty include the efficiency of the muon trigger, reconstruction, identification, and isolation requirements, as well as the muon momentum scale and resolution. Uncertainties on the jet energy scale and resolution affect the selection of jets used in the VBF category definitions. Smaller uncertainties arise from pile-up and the primary vertex selection. The total experimental uncertainty on the predicted signal yield is a sum in quadratures of the individual uncertainties. Shape variations of the signal distributions are negligible.

Table 4
Observed and expected 95% CL upper limits on the $H \to \mu^+\mu^-$ signal strength μ_S for different values of m_H.

m_H [GeV]	120	125	130	135	140	145	150
Obs.	9.5	7.1	6.5	8.3	14.7	16.5	16.8
Exp.	6.7	7.2	7.9	9.1	11.3	16.0	26.6

The theoretical uncertainties on the production and $H \to \mu^+\mu^-$ decay of a SM Higgs boson of mass $m_H = 125$ GeV are taken from Refs. [13,14]. The uncertainty on the relative populations of the $p_T^{\mu^+\mu^-}$ categories, due to the uncertainty on the description of the Higgs boson p_T spectrum arising from missing higher-order corrections, is determined by varying the QCD renormalisation, factorisation and resummation scales used in the HRES program. To evaluate these uncertainties, the scales are independently varied up and down by a factor of two while keeping their ratio between 0.5 and 2.0. The ggF contribution to the VBF category has large uncertainties due to missing higher-order corrections; they are estimated using the method described in Ref. [26]. The uncertainties associated with the modelling of multi-parton interactions (MPI) are estimated by turning off the MPI modelling in the event generation, according to the recommendations in Ref. [26].

In addition to the samples described in Section 2, samples of the dominant Z/γ^* background are generated with POWHEG + PYTHIA8 and parameterised with a detector response measured using simulated MC events. These samples contain approximately 170 times more events than expected in the data and are used to validate the background models and to derive systematic uncertainties due to potential mismodelling bias. This bias is estimated by fitting the parametrised signal plus background model to the simulated $m_{\mu^+\mu^-}$ background distribution in the mass range 110–160 GeV where the signal strength μ_S is a free parameter. The bias is then defined as the root mean square of the signal yield obtained from the fit for Higgs boson masses in the range 120–150 GeV. This uncertainty varies from 3% to 20% of the statistical uncertainty on the signal strength μ_S, depending on the selection category and data-taking period.

7. Results and conclusions

The statistical procedure used to interpret the data is summarised in Ref. [7]. The observed data is consistent with the expected backgrounds and no evidence for a signal is found. Upper limits are computed on the signal strength μ_S using a modified frequentist CL_s method [60,61] based on a Poisson log-likelihood ratio statistical test.

The observed and expected 95% confidence level (CL) limits on the $H \to \mu^+\mu^-$ signal strength are shown in Fig. 4. Table 4 summarises the observed and expected limits for different values of m_H. Including the systematic uncertainties described in Section 6 changes the expected limit by approximately 2% for $m_H = 125$ GeV.

To conclude, a search for Higgs boson decay to $\mu^+\mu^-$ in 24.8 fb^{-1} of pp collisions at $\sqrt{s} = 7$ and 8 TeV at the LHC has been performed with the ATLAS experiment. The observed data is consistent with the expected backgrounds. No evidence for a signal is observed and upper limits are set on the signal strength as a function of the Higgs boson mass. For a SM Higgs boson with a mass of 125.5 GeV, the observed (expected) limit on the signal strength μ_S at the 95% CL is 7.0 (7.2) times the SM prediction. Assuming a Higgs boson mass of 125.5 GeV and the SM production cross section, which is allowed to vary within its uncertainty, the 95% CL upper limit on the $H \to \mu^+\mu^-$ branching ratio is 1.5×10^{-3}.

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