SEARCH FOR THE STANDARD MODEL HIGGS BOSON WITH THE ATLAS DETECTOR

CATERINA PIZIO

On behalf of the ATLAS Collaboration

Università and INFN Milano
via Celoria 16, Milano, Italy
E-mail: caterina.pizio@cern.ch

The experimental results of the search for the Standard Model Higgs boson with the ATLAS detector at the Large Hadron Collider are reported. They are based on pp collision data collected in 2011 and 2012 with an integrated luminosity of up to 4.9 fb^{-1} at $\sqrt{s} = 7$ TeV and 5.9 fb^{-1} at $\sqrt{s} = 8$ TeV, respectively. The search combines several Higgs boson decay channels in a wide range of Higgs boson masses from 110 GeV to 600 GeV. A Standard Model Higgs boson is excluded at the 95% confidence level in the mass ranges from 110.0 to 122.6 GeV and from 129.7 to 558 GeV, while the range from 110 to 582 GeV is expected to be excluded in the absence of a signal. An excess of events is observed around 126.5 GeV with a local significance of 5.0 σ.

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1 Introduction

The Higgs mechanism [1] provides a general framework to explain the observed masses of the W and Z gauge bosons through electroweak symmetry breaking. Within the Standard Model (SM), this mechanism implies the existence of a scalar boson, the Higgs boson, with an a priori unknown mass (m_H). The existence of the Higgs boson in the mass regions with $m_H < 114.4$ GeV and 147 GeV$< m_H <$177 GeV is excluded at the 95% CL by the LEP [3] and Tevatron [4] experiments, respectively. In the following, the latest results from direct searches for the SM Higgs boson with the ATLAS detector [2] at the Large Hadron Collider (LHC) are presented. They are based on pp collision data recorded in 2011 with an integrated luminosity of up to 4.9 fb^{-1} at a center-of-mass

energy of $\sqrt{s} = 7$ TeV and on data recorded in 2012 with an integrated luminosity of up to 5.9 fb^{-1} at $\sqrt{s} = 8$ TeV for $H \to \gamma\gamma$ and $H \to ZZ \to 4l$ searches.

2 Analysis and results on individual channels

The search for the SM Higgs boson is performed in the mass range from 110 GeV to 600 GeV combining all the search channels summarised in Table 1. In the following the individual analyses are outlined.

Table 1: Individual channels for the SM Higgs boson search with the corresponding number of subchannels, explored range of m_H, integrated luminosity and references to public documentation.

Search channel	Nr. of subchannels	m_H range (GeV)	L (fb^{-1})	Reference
$H \to \gamma\gamma$	10	110-150	4.9+5.9	[5]
$H \to \tau\tau$	12	110-150	4.7	[6]
$VH, H \to bb$	11	110-130	4.7	[7]
$H \to WW^{(*)} \to l\nu l\nu$	9	110-600	4.7	[8]
$H \to ZZ^{(*)} \to 4l$	4	110-600	4.8+5.9	[9]
$H \to ZZ \to ll\nu\nu$	4	200-600	4.7	[10]
$H \to ZZ \to lljj$	2	200-600	4.7	[11]
$H \to WW \to l\nu jj$	9	300-600	4.7	[12]

2.1 Searches using the full statistics (2011+2012 data)

- $H \to \gamma\gamma$ [5]
  Despite the very small branching ratio of about 0.2%, this decay channel provides the highest sensitivity for the Higgs boson search in the low m_H region in ATLAS. The event selection requires two isolated, high transverse momentum photons. Selected events are separated into ten independent subchannels. The categorisation is based on photon pseudorapidity, conversion status, the momentum component of the diphoton system transverse to the thrust axis and the presence of 2 jets for the vector boson fusion (VBF) production mode. The diphoton invariant mass

is used as a discriminating variable to separate signal from background, to take advantage of the good mass resolution of approximately 1.4% for $m_H \sim 120$ GeV. The background is parametrized by an analytic function for each category, where the normalization and the shape are obtained from fits to $m_{\gamma\gamma}$ distribution. The signal shape is modeled by the sum of a Crystal Ball and a Gaussian function. The invariant mass distribution of the observed candidates, summing over all categories, is shown in Fig. 1 (top left). The observed and expected exclusion limits at the 95% CL on the Higgs boson production in units of the SM cross section are shown in Fig. 1 (top right). A SM Higgs boson is excluded at the 95% CL in the mass ranges of 113-115 GeV and 134.5-136 GeV. An excess with respect to the background-only hypothesis is observed at 126.5 GeV with a local significance of 4.5 σ.

- $H \to ZZ \to 4l$ [9]
  The Higgs boson decay into four-leptons provides a clean signature with a very low level of background. The channel is characterised by high experimental invariant mass resolution of $\sim 2\%$ up to m_H=350 GeV. A high signal efficiency is ensured by a high lepton reconstruction and identification efficiency. The mass of one dilepton pair is required to be between 50 and 106 GeV, while an m_H- dependent invariant mass cut is applied on the second lepton pair. The analysis is divided into four subchannels based on lepton flavours. Fig. 1 (bottom left) shows the inclusive four-lepton invariant mass distribution after all selection cuts. In the m_H region 125±5 GeV a total of 13 candidate events are observed while 5.1 ± 0.8 candidates are expected from background processes. The corresponding 95% CL exclusion limit is shown in Fig. 1 (bottom right). The observed exclusion covers the mass regions from 131 to 162 GeV and from 170 to 460 GeV. The expected exclusion ranges are 124 to 164 GeV and 176 to 500 GeV. The most significant upward deviation from the background-only hypothesis is observed for m_H= 125 GeV with a local significance of 3.4 σ.

2.2 Searches using 2011 data

- $H \to \tau^+\tau^-$ [6]
  The search in this channel considers all combinations of leptonic and semileptonic (hadrons + neutrino) decay modes of the τ-leptons. Events are separated into twelve subchannels based on the lepton flavour, jet multiplicity and on event topologies characteristic for the VBF and VH signal production mechanisms. The

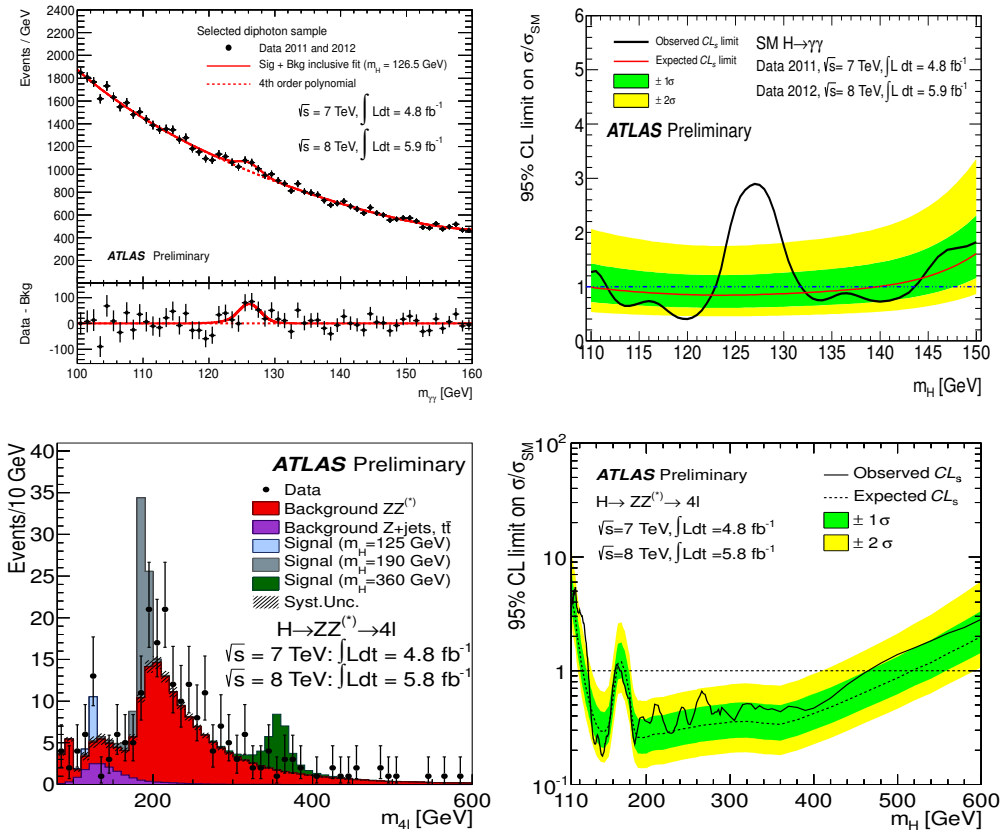

Figure 1: Invariant diphoton mass distribution, overlaid with the total background from the fit to all sub categories [5](top left). Invariant four-lepton mass distribution of the selected candidates compared to the background expectation [9](bottom left). Observed and expected 95% CL limits on the SM Higgs boson production in the $H \to \gamma\gamma$[5] (top right) and $H \to ZZ \to 4l$ [9] (bottom right) decay channels normalised to the predicted SM cross section as a function of m_H.

$\tau\tau$ invariant mass distribution used for the limit setting is reconstructed using the effective mass, collinear approximation or a Missing Mass Calculator [13] technique. The 95% CL exclusion limit on the SM Higgs boson production is shown in Fig. 2

(top left).

- VH, $H \to b\bar{b}$ [7]
  The search for $H \to b\bar{b}$ events in the VH production mode is divided eleven sub-channels based on the decay mode of the associated vector boson and its transverse momentum. The exclusion limits shown in Fig. 2 (top right) are set based on the b-jet pair invariant mass distribution.

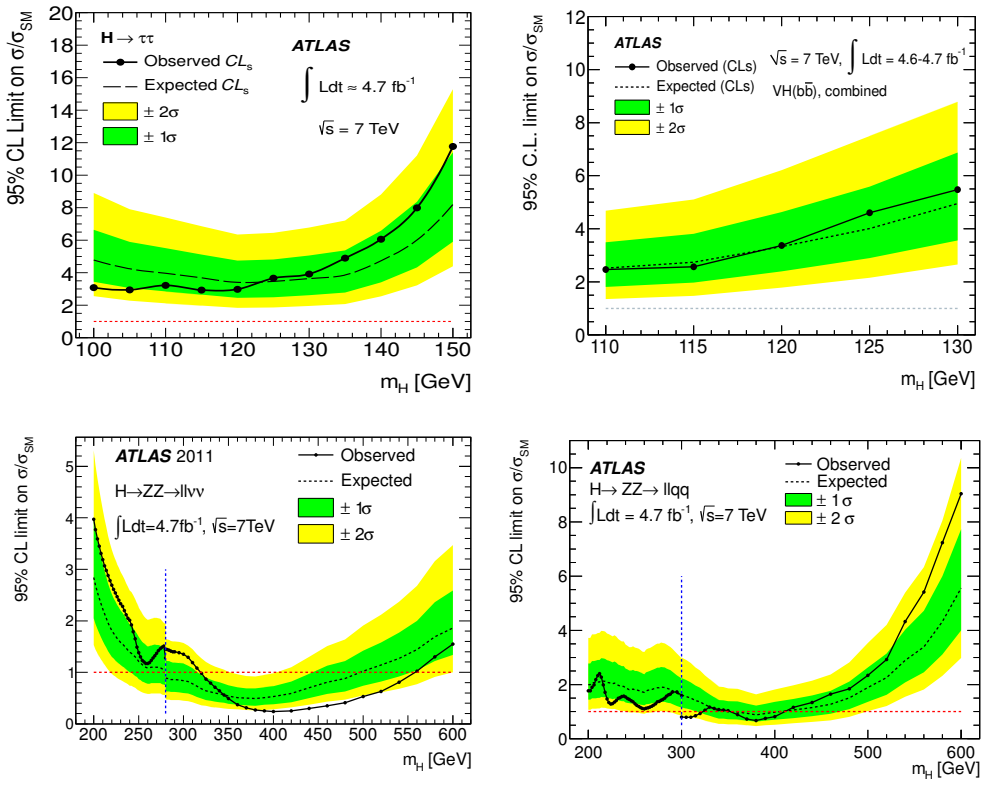

Figure 2: Observed and expected 95% CL limits on the SM Higgs boson production in the $H \to \tau^+\tau^-$ [6] (top left), $H \to b\bar{b}$ [7] (top right), $H \to ZZ \to ll\nu\nu$ [10] (bottom left) and $H \to ZZ \to lljj$ [11] (bottom right) decay channels normalised to the predicted SM cross section as a function of m_H.

- $H \to ZZ \to ll\nu\nu$ [10]
  This decay channel provides high sensitivity in the high-m_H region due to the high transverse momenta of leptons and neutrinos from the Z boson decays. The search is performed separately in $ee\nu\nu$ and $\mu\mu\nu\nu$ subchannels, both separated for low and high pile-up environment. The transverse mass distribution is used for the limit setting. The observed (expected) exclusion limit at the 95% CL covers the mass range from 320 to 560 GeV (260 to 490 GeV), as shown in Fig. 2 (bottom left).

- $H \to ZZ \to lljj$ [11]
  For this analysis two subchannels are considered, one with the two jets tagged as b-jets and one with less than two b-jets. The exclusion limit based on the m_{lljj} invariant mass distribution is shown in Fig. 2 (bottom right). Expected exclusion limit at the 95% CL covers the mass range from 360 to 400 GeV, while the observed upper limit excludes the mass range from 300 to 310 GeV and 360 to 400 GeV.

- $H \to WW \to l\nu jj$ [12]
  This channel is separated into six subchannels based on the lepton flavour and the jet multiplicity. The invariant mass of the dijet pair must be compatible with the W boson mass and a mass constraint $m_{l\nu} = m_W$ is applied to determine the z-component of the neutrino momentum. The discrimination variable is $m_{l\nu jj}$ invariant mass distribution. Fig. 3 (top left) shows the observed (expected) exclusion limit at the 95% CL.

- $H \to WW^{(*)} \to l\nu l\nu$ [8]
  The Higgs boson search in this channel provides the highest sensitivity in a wide mass range. Nine subchannels are considered: $ee\nu\nu$, $\mu\mu\nu\nu$ and $e\mu\nu\nu$, each separated according to the jet multiplicity (0-2) into final states. The transverse mass distribution is used for the limit setting. The 95% CL exclusion limit is shown in Fig. 3 (top right).

3 Combined results

The results of the statistical combination of all individual search channels are summarised in Ref. [14]. The expected and observed limits obtained are shown in Fig. 3 (bottom). SM Higgs boson masses between 110 and 582 GeV are expected to be excluded at the 95% CL or higher. The observed 95% CL exclusion regions range from 110 to 122.6 GeV and from 129.7 GeV to 558 GeV. The mass regions between 117 and 121.7 GeV and

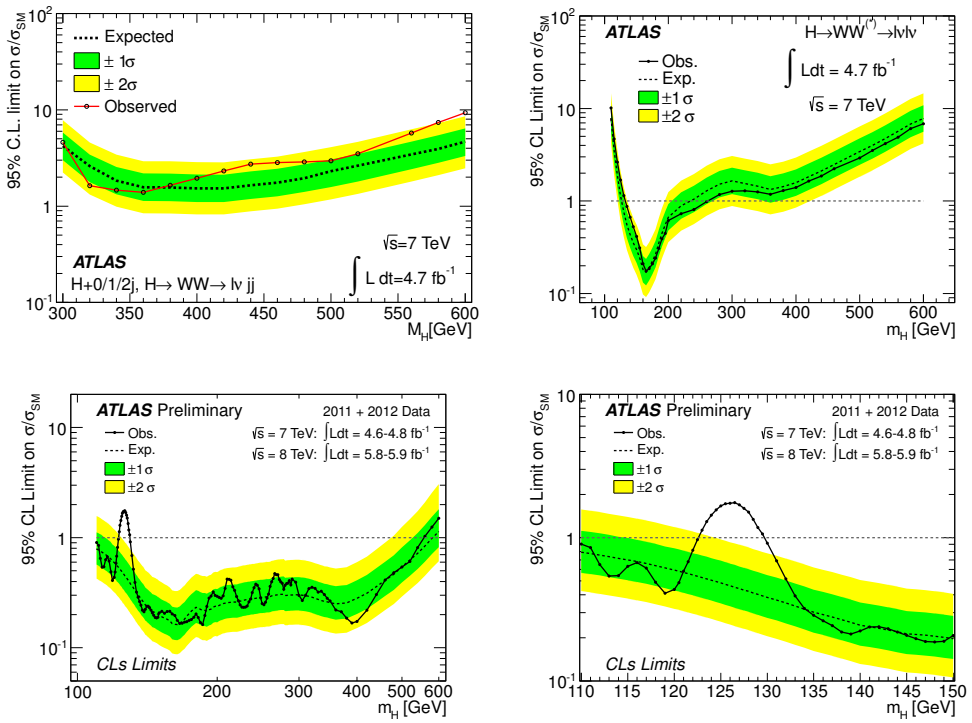

Figure 3: Observed and expected 95% CL limits on the SM Higgs boson production in the $H \to WW \to l\nu jj$ [12] (top left) and $H \to WW \to l\nu l\nu$ [8] (top right) decay channels and for the combination of all channels [14] in the full mass range (bottom left) and zoomed in to the low-mass region (bottom right) normalised to the predicted SM cross section as a function of m_H.

between 130.7 and 523 GeV are excluded at the 99% CL. An excess of events compared to the expected background contribution is observed at m_H=126.5 GeV, driven by the two high mass resolution channels: $H \to \gamma\gamma$ and $H \to ZZ \to 4l$. The combined local significance of the observed excess is 5 σ, while the expected significance in the presence of a SM Higgs boson with $m_H = 126.5$ GeV is 4.6 σ.

4 Summary

The full dataset of pp collision data recorded with the ATLAS detector at the LHC in 2011 has been analysed in search for the SM Higgs boson, combining several Higgs boson decay channels in the m_H range from 110 to 600 GeV. For $H \to \gamma\gamma$ and $H \to ZZ \to 4l$ preliminary results are obtained using also 2012 data with 5.9 fb^{-1} of integrated luminosity. A SM Higgs boson is excluded at the 95% CL in a wide mass range. At m_H=126.5 GeV an excess of events is observed correspondent to a local significance of 5 σ.

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