

Searches for the Standard Model Higgs Boson with the ATLAS Detector

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The most recent results for searches for the Standard Model Higgs boson at a center-of-mass energy of $\sqrt{s} = 7$ TeV using 4.9 fb^{-1} of data collected with the ATLAS detector at CERN's Large Hadron Collider are presented.

1 Introduction

In the Standard Model (SM) of particle physics the Higgs mechanism is responsible for breaking electroweak symmetry, thereby giving mass to the W and Z bosons. It predicts the existence of a heavy scalar boson, the Higgs boson, with a mass that can not be predicted by the SM. Direct searches for the Higgs Boson were performed at the LEP experiments and yielded a direct mass limit of $m_H > 114.4 \text{ GeV}$ ¹ and at the Tevatron excluding the region $156 < m_H < 177 \text{ GeV}$ ². Indirect limits have been placed on the Higgs boson mass by the LEP, SLD and Tevatron experiments from electroweak precision measurements³. The SM fit yields a best value of $m_H = 94_{-24}^{+29}$ ⁴. The corresponding upper limit on the Higgs mass at 95% CL is $m_H < 152 \text{ GeV}$.

2 Search Channels

In contrast to the combination of searches presented in [5] all analyses now use the full dataset of 4.9 fb^{-1} recorded in 2011, as shown in Tab. 1 which also indicates the mass range of the analysis. To enhance the sensitivity, the analysis channels under study are divided into sub-channels with different signal to background ratios or with a different sensitivity to various systematic uncertainties. In the following the search channels are described.

2.1 $H \rightarrow \gamma\gamma$

Despite the low branching ratio ($\approx 0.2\%$) the diphoton decay mode is one of the most important channels in the search for the SM Higgs boson in the low mass region. The analysis separates events into nine independent categories based on the pseudo-rapidity of the photons, whether it was reconstructed as a converted or unconverted photon, and on the momentum component of the diphoton system transverse to the thrust axis (p_{T_i}). The diphoton invariant mass $m_{\gamma\gamma}$ is used as a discriminating variable to distinguish signal and background, to take advantage of the mass resolution of approximately 1.4% for m_H around 120 GeV. The distribution of $m_{\gamma\gamma}$ in the data is fit to a smooth function to estimate the background. Figure 1 (left) shows the inclusive invariant mass distribution of the observed candidates, summing over all categories.

| Higgs Decay channel | Additional Sub-Channels | m_H Range [GeV] | L [fb $^{-1}$] | Ref. |
|---|---|-------------------|-----------------|------|
| low- m_H , good mass resolution | | | | |
| $H \rightarrow \gamma\gamma$ | 9 sub-channels ($p_{T,t} \otimes \eta_\gamma \otimes$ conversion) | 110-150 | 4.9 | [6] |
| $H \rightarrow ZZ \rightarrow \ell\ell'\ell'$ | { $4e, 2e2\mu, 2\mu2e, 4\mu$ } | 110-600 | 4.8 | [7] |
| low- m_H , limited mass resolution | | | | |
| $H \rightarrow WW \rightarrow \ell\nu\ell\nu$ | { $ee, e\mu, \mu\mu$ } \otimes {0-jet, 1-jet, VBF} | 110-300-600 | 4.7 | [8] |
| $VH \rightarrow b\bar{b}$ | $Z \rightarrow \nu\bar{\nu}$ $W \rightarrow \ell\nu$ $Z \rightarrow \ell\ell$ | 110-130 | 4.6 | [9] |
| $H \rightarrow \tau^+\tau^- \rightarrow \ell\ell 4\nu$ | { $e\mu$ } \otimes {0-jet} \oplus {1-jet, VBF, VH} | 110-150 | 4.7 | [10] |
| $H \rightarrow \tau^+\tau^- \rightarrow \ell\tau_{\text{had}}3\nu$ | { e, μ } \otimes {0-jet} \otimes { $E_T^{\text{miss}} \geq 20$ GeV} | 110-150 | 4.7 | [10] |
| $H \rightarrow \tau^+\tau^- \rightarrow \tau_{\text{had}}\tau_{\text{had}}2\nu$ | \oplus { e, μ } \otimes {1-jet, VBF} | 110-150 | 4.7 | [10] |
| high- m_H | | | | |
| $H \rightarrow ZZ \rightarrow \ell\nu\bar{\nu}$ | { $ee, \mu\mu$ } \otimes {low pile-up, high pile-up} | 200-280-600 | 4.7 | [11] |
| $H \rightarrow ZZ \rightarrow \ell\ell q\bar{q}$ | {b-tagged, untagged} | 200-300-600 | 4.7 | [12] |
| $H \rightarrow WW \rightarrow \ell\nu q\bar{q}'$ | { e, μ } \otimes {0-jet, 1-jet} | 300-600 | 4.7 | [13] |

Table 1: Summary of the individual channels under study in ATLAS and contributing to the combination.

2.2 $H \rightarrow ZZ^{(*)} \rightarrow \ell^+\ell^-\ell^+\ell^-$

In this search the events are categorised according to the lepton flavour combinations. The main irreducible $ZZ^{(*)}$ background is estimated using Monte Carlo simulation and the reducible Z +jets is estimated from control regions in the data. The mass resolutions are approximately 1.5% in the four-muon channel and 2% in the four-electron channel for $m_H \sim 120$ GeV. The four-lepton invariant mass is used as a discriminating variable and its distribution for events selected after all cuts shown in Fig.1 on the right side.

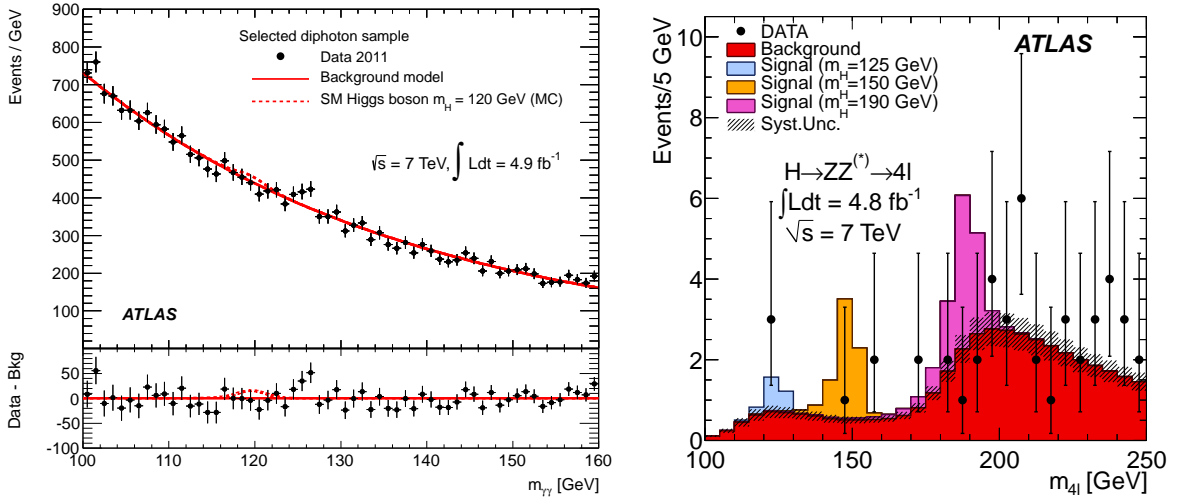


Figure 1: Distributions of the reconstructed invariant mass for the selected candidate events and for the total background and signal expected in the $H \rightarrow \gamma\gamma$ (left) and the $H \rightarrow ZZ^{(*)} \rightarrow \ell^+\ell^-\ell^+\ell^-$ (right).

2.3 $H \rightarrow WW^{(*)} \rightarrow \ell^+\nu\ell^-\bar{\nu}$

The analysis is separated into 0-jet, 1-jet and 2-jet categories as well as according to lepton flavour. The main backgrounds are estimated from the data using control regions and extrapolating into the signal region using Monte Carlo simulation. As a discriminating variable the WW transverse mass (m_T) distribution is used, which is shown for events with 0-jets and 1-jets in Fig. 2 on the left and right side, respectively.

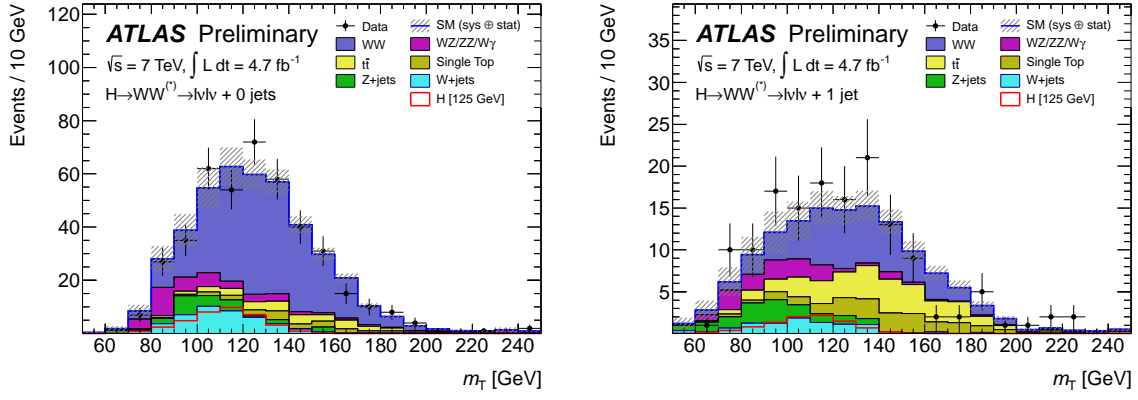


Figure 2: Distributions of the reconstructed transverse mass for the selected candidate events and for the total background and signal expected in the $H \rightarrow WW^{(*)} \rightarrow \ell^+ \nu \ell^- \bar{\nu}$ channel for events with 0-jets (left) and 1-jets (right).

2.4 $ZH \rightarrow \ell^+ \ell^- b \bar{b}$, $WH \rightarrow \ell \nu b \bar{b}$, $ZH \rightarrow \nu \bar{\nu} b \bar{b}$

All three analyses require exactly two b -tagged jets and the invariant mass of the two b -jets, m_{bb} , is used as a discriminating variable. To increase the sensitivity of the search, the m_{bb} distribution is examined in sub-channels with different signal-to-background ratios. In the searches with one or two charged leptons, the division is made according to four bins in transverse momentum of the reconstructed vector boson. The individual channels are not broken into distinct lepton-flavour categories.

2.5 $H \rightarrow \tau \tau \rightarrow \ell^+ \ell^- 4\nu$, $H \rightarrow \tau \tau \rightarrow \ell \tau_{had} 3\nu$, $H \rightarrow \tau \tau \rightarrow \tau_{had} \tau_{had} 2\nu$

In the $H \rightarrow \tau^+ \tau^-$ channel any combination of events with leptonic decaying taus or hadronic decaying taus are considered. For the $H \rightarrow \tau \tau \rightarrow \tau_{had} \tau_{had} 2\nu + \text{jet}$ channel and $H \rightarrow \tau \tau \rightarrow \ell^+ \ell^- 4\nu$ channel as a discriminating variable the $\tau \tau$ invariant mass is used and estimated using the collinear approximation. As a discriminating variable in the $H \rightarrow \tau \tau \rightarrow \ell \tau_{had} 3\nu$ channel a Missing Mass Calculator technique is used to estimate the ditau invariant mass which does not assume a strict collinearity between the visible and invisible decay products of the tau leptons.

2.6 $H \rightarrow ZZ \rightarrow \ell^+ \ell^- \nu \bar{\nu}$, $H \rightarrow ZZ \rightarrow \ell^+ \ell^- q \bar{q}$, $H \rightarrow WW \rightarrow \ell \nu q \bar{q}'$

The $H \rightarrow ZZ \rightarrow \ell^+ \ell^- \nu \bar{\nu}$ is split into two lepton flavour categories and analysed in the mass range from 200 to 600 GeV and is sensitive to a SM Higgs boson in the range of $260 \leq m_H \leq 490$ GeV. The $H \rightarrow ZZ \rightarrow \ell^+ \ell^- q \bar{q}$ analysis is divided into events where the two jets are b -tagged and into events with less than two b -tags. This analysis is expected to exclude a SM Higgs boson in the range of $360 \leq m_H \leq 400$ GeV at the 95% CL. In the $H \rightarrow WW \rightarrow \ell \nu q \bar{q}'$ channel the $\ell \nu q \bar{q}'$ mass distribution is used as a discriminating variable imposing mass constraints on both W bosons. The analysis reaches the best sensitivity of two times the SM Higgs boson cross section around $m_H = 400$ GeV.

3 Combination

The combination procedure is based on the profile likelihood ratio test statistic. The signal strength, μ , is defined as the ratio of a given Higgs boson production cross section (σ) to its SM value (σ_{SM}), $\mu = \sigma / \sigma_{SM}$. Exclusion limits are based on the CL_s prescription¹⁴; a value of μ is regarded as excluded at the 95% (99%) CL when CL_s takes on the corresponding value. Figure 3 (left) shows the expected and observed limits from the individual channels as described

above entering the combination. For the low mass region (below $m_H < 150$ GeV) the combined 95% CL exclusion limits¹⁵ on μ are shown in Fig. 3 (right) as a function of m_H . An excess of events is observed near $m_H \sim 126$ GeV in the $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ^{(*)} \rightarrow \ell^+\ell^-\ell^+\ell^-$ channels, both of which provide fully reconstructed candidates with high-resolution in invariant mass.

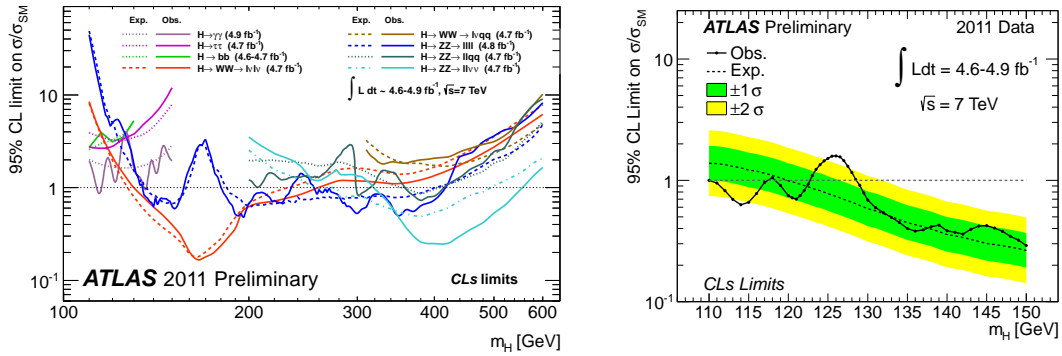


Figure 3: Left: The observed (solid) and expected (dashed) 95% CL cross section upper limits for the individual search channels as a function of the Higgs boson mass. Right: The observed and expected 95% CL combined upper limits on the SM Higgs boson production cross as a function of m_H in the low mass range.

4 Conclusions

The full dataset recorded in 2011 by the ATLAS experiment has been used to update searches for the SM Higgs boson. A Higgs boson with a mass in the ranges from 110.0 GeV to 117.5 GeV, 118.4 GeV to 122.7 GeV, and 128.6 GeV to 529.3 GeV is excluded at the 95% CL, while in the absence of a signal the range 119.8 GeV to 567 GeV is expected to be excluded. Between 130 GeV and 486 GeV the exclusion is even at the 99% CL. Around m_H of 126 GeV an excess of events is observed with a local significance of 2.5σ . The expected significance in the presence of a SM Higgs boson at that mass hypothesis is 2.8σ . The global probability for such an excess to occur anywhere in the explored Higgs boson mass region is estimated to be approximately 30%, in the range not excluded at the 99% CL, it amounts to approximately 10%.

References

1. R. Barate *et al*, *Phys. Lett. B* **565**, 61 (2003).
2. CDF and D0 Collaborations, arXiv:1203.3774.
3. Tevatron Electroweak Working Group, August 2009, <http://tevewwg.fnal.gov/>.
4. LEP Electroweak Working Group, March 2012, <http://lepewwg.web.cern.ch/LEPEWWG/>.
5. ATLAS Collaboration, *Phys. Lett. B* **710**, 49 (2012).
6. ATLAS Collaboration, *Phys. Rev. Lett.* **108**, 111803 (2012).
7. ATLAS Collaboration, *Phys. Lett. B* **710**, 383 (2012).
8. ATLAS Collaboration, ATLAS-CONF-2012-012, <http://cdsweb.cern.ch/record/1429660>.
9. ATLAS Collaboration, ATLAS-CONF-2012-015, <http://cdsweb.cern.ch/record/1429664>.
10. ATLAS Collaboration, ATLAS-CONF-2012-014, <http://cdsweb.cern.ch/record/1429662>.
11. ATLAS Collaboration, ATLAS-CONF-2012-016, <http://cdsweb.cern.ch/record/1429665>.
12. ATLAS Collaboration, ATLAS-CONF-2012-017, <http://cdsweb.cern.ch/record/1429666>.
13. ATLAS Collaboration, ATLAS-CONF-2012-018, <http://cdsweb.cern.ch/record/1429667>.
14. A. L. Read *J. Phys.* **G28** (2002) 2693–2704.
15. ATLAS Collaboration, ATLAS-CONF-2012-019, <http://cdsweb.cern.ch/record/1430033>.