1 Introduction

The Standard Model (SM) of particle physics [1–4] has been tested by many experiments over the last four decades and has been shown to successfully describe high energy particle interactions. However, the mechanism that breaks electroweak symmetry in the SM has not been verified experimentally. This mechanism [5–10], which gives mass to massive elementary particles, implies the existence of a scalar particle, the SM Higgs boson. The search for the Higgs boson, the only elementary particle in the SM that has not yet been observed, is one of the highlights of the Large Hadron Collider [11] (LHC) physics programme.

Direct searches at the CERN LEP \( e^+ e^- \) collider excluded the production of a SM Higgs boson with mass below 114.4 GeV at the 95% CL [12]. The combined searches at the Fermilab Tevatron pp collider have excluded the production of a Higgs boson with mass between 156 GeV and 177 GeV at the 95% CL [13].

In 2011, the LHC delivered to ATLAS [14] an integrated luminosity of 5.6 fb\(^{-1}\) of pp collisions at 7 TeV centre-of-mass energy. The ATLAS experiment collected and analysed an integrated luminosity corresponding to up to 4.9 fb\(^{-1}\) of data fulfilling all the data quality requirements to search for the SM Higgs boson. The Higgs boson is produced primarily through the gluon fusion process and the following decay modes are considered in the low mass region: \( H \to \gamma \gamma \), \( H \to ZZ(\ast) \to \ell^+ \ell^- \ell'^+ \ell'^- \), \( H \to WW(\ast) \to \ell^+ \nu \ell'^- \bar{\nu} \), \( H \to \tau^+ \tau^- \), \( H \to b \bar{b} \) where \( \ell \) denotes an electron or a muon.

2 Low Mass search Channels

All search analyses for a low mass Higgs are described in their respective references [15–19], while their combination is described in [20]. All the channels combined to search for the SM Higgs boson use the complete 2011 dataset passing the relevant quality requirements. In modes...
with a W or Z boson, an electron or muon is required for triggering. In the $H \rightarrow \tau^+\tau^-$ channel, almost all combinations of subsequent $\tau$ decays are considered.

- **$H \rightarrow \gamma\gamma$:** In this analysis, described in Ref [16], events are separated into nine independent categories of varying sensitivity. The categorization is based on the pseudorapidity of each photon, whether it was reconstructed as a converted or unconverted photon, and the momentum component of the diphoton system transverse to the diphoton thrust axis ($p_T$). The mass resolution is approximately 1.7% for $m_H \sim 120$ GeV.

- **$H \rightarrow ZZ^{(*)} \rightarrow \ell^+\ell^-\ell^+\ell^-$:** This analysis, described in Ref. [15], is performed for $m_H$ hypotheses in the 110 GeV to 600 GeV mass range. The expected background yield and composition are estimated using the MC simulation normalised to the theoretical cross section for $ZZ^{(*)}$ production and by methods using control regions from data for the $Z + \text{jets}$ and $t\bar{t}$ processes. Four categories of events are defined by the lepton flavor combinations and the four-lepton invariant mass is used as a discriminating variable. The typical mass resolutions for $m_H = 125$ GeV are 1.7 GeV, 1.7 GeV/2.2 GeV and 2.3 GeV for the $ZZ^{(*)}$ decaying into 4μ, 2e2μ/2μ2e and 4e sub-channels, respectively.

- **$H \rightarrow WW^{(*)} \rightarrow \ell^+\nu\ell^-\bar{\nu}$:** The updated analysis [17] is performed for $m_H$ values from 110 GeV up to 600 GeV. Events with two leptons are classified by the number of associated jets (0, 1 or 2), where the two-jet category has selection criteria designed to enhance sensitivity to the VBF production process. The events are further divided by the flavors of the charged leptons, ee, $e\mu$ and $\mu\mu$ where the mixed mode ($e\mu$) has a much smaller background from the Drell-Yan process. The samples are split according to the pile-up conditions and analyzed separately. Each sub-channel uses the WW transverse mass distribution, except for the 2-jets category, which does not use a discriminating variable.

- **$H \rightarrow \tau^+\tau^-$:** The analyses [18] are categorized by the decay modes of the two $\tau$ leptons, for $m_H$ hypotheses ranging from 110 GeV to 150 GeV (the leptonically decaying $\tau$ leptons are denoted $\tau_{lep}$ and the hadronically decaying $\tau$ leptons are denoted $\tau_{had}$). Most of these sub-channels are triggered using leptons, except for the fully hadronic channel $H \rightarrow \tau_{had}\tau_{had}$, which is triggered with specific double hadronic $\tau$ decay selections. All the searches using $\tau$ decay modes have a significant background from $Z \rightarrow \tau^+\tau^-$ decays, which are modeled using an embedding technique where $Z \rightarrow \mu^+\mu^-$ candidates selected in the data have the muons replaced by simulated $\tau$ decays. These embedded events are used to describe this background process.

- **$H \rightarrow b\bar{b}$:** The $ZH \rightarrow \ell^+\ell^-b\bar{b}$, $ZH \rightarrow \nu\bar{\nu}b\bar{b}$, and $WH \rightarrow \ell\nu b\bar{b}$ analyses [18] are performed for $m_H$ ranging from 110 GeV to 130 GeV. All three analyses require two $b$-tagged jets (one with $p_T > 45$ GeV and the other with $p_T > 25$ GeV) 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.

### 3 Combination results

The statistical procedure used to interpret the data is described in Refs. [20]. Exclusion limits are based on the $CL_s$ prescription [21]; a value of $\mu$ is regarded as excluded at 95% CL when $CL_s$ is less than 5%. The significance of an excess in the data is first quantified with the local $p_0$, the probability that the background can produce a fluctuation greater than or equal to the excess observed in data.

The expected and observed limits from the individual channels are shown in Fig. 1(a). The combined 95% CL exclusion limits on $\mu$ are shown in Fig. 1(b) as a function of $m_H$. The observed
exclusion regions range from 111.4 GeV to 116.6 GeV, from 119.4 GeV to 122.1 GeV, and from 129.2 GeV to 541 GeV at 95% CL under the SM ($\mu = 1$) hypothesis. The mass range 122.1 GeV to 129.2 GeV is not excluded due to the observation of an excess of events above the expected background. The observed local p-values, calculated using the asymptotic approximation, as a function of $m_H$ and the expected value in the presence of a SM Higgs boson signal at that mass are shown in Fig. 2. The largest significance is observed for $m_H=126$ GeV, where it reaches 3.0$\sigma$ with an expected value in the presence of a signal at that mass of 2.9$\sigma$. The effect of the energy scale systematic uncertainties (ESS) is an increase of approximately 30% of the corresponding local $p_0$, which leads to a decrease of the local significance to 2.9$\sigma$. The observed (expected) local significances for $m_H=126$ GeV are 2.8$\sigma$ (1.4$\sigma$) in the $H \rightarrow \gamma\gamma$ channel and 2.1$\sigma$ (1.4$\sigma$) in the $H \rightarrow ZZ^{(*)} \rightarrow \ell^+\ell^-\ell'^+\ell'^-$ channel.

Figure 2: The local probability $p_0$ for a background-only experiment to be more signal-like than the observation, for individual channels and the combination in the low mass range of 110–150 GeV. The full curves give the observed individual and combined $p_0$. The dashed curves show the median expected value under the hypothesis of a SM Higgs boson signal at that mass. The horizontal dashed lines indicate the $p_0$ corresponding to significances of 1$\sigma$, 2$\sigma$, and 3$\sigma$. Ref. [20].
4 Conclusions

A combined search for the Standard Model Higgs boson has been performed with the ATLAS detector in the $\sqrt{s} = 7$ TeV $pp$ collision data collected in 2011, corresponding to an integrated luminosity of 4.6-4.9 fb$^{-1}$. In the low mass region an excess is observed with a local significance of 2.9$\sigma$, in good agreement with the expected significance for a SM Higgs boson with $m_H=126$ GeV of 2.9$\sigma$.

References

17. ATLAS Collaboration. Search for the Standard Model Higgs boson in the $H \rightarrow WW^{(*)} \rightarrow \ell\ell\nu\nu$ decay mode with 4.7 fb$^{-1}$ of ATLAS data at $\sqrt{s} = 7$ TeV. *Phys.Lett.*, B716:62–81, 2012.