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Search for the Standard Model Higgs boson with ATLAS

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Summary. — Preliminary results are presented on the search for the Standard Model Higgs boson with the ATLAS experiment. These results are based on datasets corresponding to an integrated luminosity of 4.6 to 4.9 fb^{-1} of pp collision data collected at $\sqrt{s} = 7\,\mathrm{TeV}$ at the LHC. All search channels are reviewed. More emphasis is given to the channels sensitive to a low mass Higgs boson. The combined result is also discussed.

PACS 14.80.Bn – Standard-model Higgs bosons.

1. – Introduction

One of the primary goals of the Large Hadron Collider (LHC) research programme is the understanding of the electroweak symmetry breaking (EWSB) mechanism. In the Standard Model (SM) the EWSB is achieved via the Higgs mechanism [1-3] with the introduction of a new scalar field, the so called Higgs boson. The Higgs mechanism generates the mass of all SM particles, and fixes the couplings of the Higgs boson with SM particles to be proportional to their masses. However, it does not predict the mass of the Higgs boson m_H, which remains a free parameter in the SM. For a given m_H hypothesis, the cross section in the various production modes and the branching ratio in the different channels can be predicted [4].

In 2011, the LHC delivered an integrated luminosity of 5.6 fb^{-1} of proton-proton (pp) collisions at a centre-of-mass energy of 7 TeV to the ATLAS detector. In the same period, the instantaneous peak luminosity reached values up to $3.6\times10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ corresponding to about 24 pp-interaction per bunch crossing (pile-up). In these conditions ATLAS has collected a dataset of 4.9 fb^{-1} with a data taking efficiency close to 90%. The analyses in the individual Higgs search channels are based on an integrated luminosity between 4.6 fb^{-1} and 4.9 fb^{-1}, depending on the data quality requirements specific to each channel.

This contribution describes the preliminary results on the search for the SM Higgs boson with the ATLAS experiment using the 2011 dataset. The analyses in the various channels are presented, giving more relevance to those sensitive to the low-m_H region. The results of the combination of the individual channels is also discussed.

2. – Higgs search strategies

A combined search for the Higgs boson has been performed by ATLAS in the range of masses 110–600 GeV exploiting the different decay modes. Two mass regions can be identified depending on the Higgs decay channel: $m_H < 135\,\text{GeV}$ and $m_H > 135\,\text{GeV}$. The former is dominated by the Higgs decays in $H \to b\bar{b}$ and $H \to \tau^+\tau^-$. However, due to the large continuum background, the $pp \to H$ and $pp \to qqH$ production modes cannot be exploited, leaving these channels only accessible in the $pp \to VH$ production mode (with $V = W^\pm$ or Z) loosing about a factor of 15 in the production cross section. Despite the small branching ratio, the $H \to \gamma\gamma$, $H \to ZZ^*$, and $H \to WW^*$ are the most sensitive channels in the low m_H region thanks to the good diphoton and dilepton mass resolution and the higher $pp \to H$ production cross section. In the high-m_H region the most sensitive channels are $H \to ZZ$ and $H \to WW$.

2˙1. *Higgs searches in the high-mass region.* – The most sensitive mode in the high-m_H region is the $H \to ZZ \to \ell^+\ell^-\nu\nu$ [5]. To achieve best sensitivity the selection is different depending on the m_H hypotheses above and below 280 GeV and the two lepton flavours (e, μ). The $\ell^+\ell^-$ invariant mass is required to be within 15 GeV from the Z-boson mass. The transverse invariant mass of the dilepton and missing transverse energy E_T^{miss} system is used as a discriminant variable. The observed exclusion limit at the 95% confidence level [6] (CL) ranges from 260 GeV and 460 GeV, while the range 320–560 GeV is expected to be excluded in the absence of a signal. The analysis in the $H \to ZZ \to \ell^+\ell^- q\bar{q}$ channel is described in ref. [7]. The event selection is optimized separately in the regions above and below $m_H = 300\,\text{GeV}$. To profit from the sizable fraction of Z's decaying into a pair of b-quarks in the signal, the analysis is further divided into two categories depending on the number of b-tagged jets. The invariant mass of the $\ell^+\ell^- q\bar{q}$ system is used as a discriminant variable with $m_{\ell^+\ell^-}$ constrained to the Z mass. The observed exclusion limit at the 95% of CL ranges from 360 GeV and 400 GeV, while the ranges 300–310 GeV and 360–400 GeV are expected to be excluded in the absence of a signal. The search in the $H \to WW \to \ell^+\nu^- q\bar{q}$ has also been updated [8], and presented elsewhere [9].

2˙2. *Higgs searches in the low mass region.* – The search for the Higgs boson in the low m_H region is articulated in five individual analyses identified by the Higgs decay products, and namely: $H \to WW^{(*)} \to \ell\nu\ell\nu$, $H \to ZZ^{(*)} \to \ell^+\ell^-\ell^+\ell^-$, $H \to \gamma\gamma$, $H \to b\bar{b}$, $H \to \tau\tau$, with the first two decay channels also sensitive in the high m_H range. The search in the $H \to WW^* \to \ell^+\nu\ell\nu$ [10] channel, discussed elsewhere [9], provides the highest sensitivity wide range of hypothesized Higgs masses.

2˙2.1. $H \to ZZ^{(*)} \to \ell^+\ell^-\ell^+\ell^-$. The $H \to ZZ^{(*)} \to \ell^+\ell^-\ell^+\ell^-$ channel represents a very clean signature to search for the Higgs boson, the analysis is described in ref. [11]. For $m_H \geq 200\,\text{GeV}$ the only background is the irreducible ZZ process, while for lower masses there is a small additional contamination from the reducible $Zb\bar{b}$, Z+jets, and $t\bar{t}$. The latter contamination is directly extracted from data control samples. This channel is characterized by a very good invariant mass resolution of 1.5% to 2%, and benefits from the high lepton reconstruction and identification efficiency. In addition, a high signal efficiency is ensured by the low transverse energy cut of 7 GeV on the

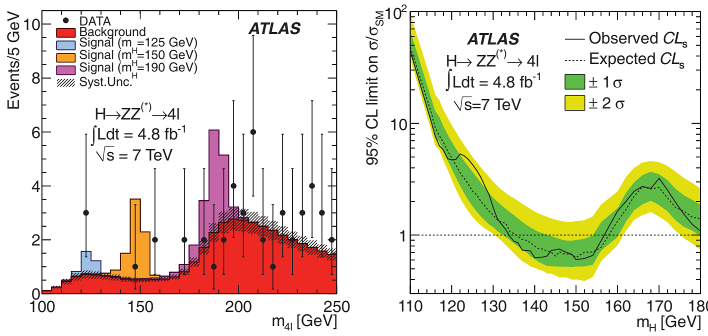

Fig. 1. – Left: Invariant four-lepton mass distribution. Right: Observed and expected 95% CL limits on the SM Higgs boson production in the decay channel $H \to WW^{(*)} \to \ell\nu\ell\nu$.

subleading leptons. The mass of one dilepton pair is required to be compatible with that of the Z boson, while a m_H-dependent cut is applied on the second pair. To optimize the sensitivity the analysis is performed in 4 sub-categories based on the lepton flavour. Figure 1 (left) shows the $m_{4\ell}$ spectrum, the corresponding exclusion limit is shown in fig. 1 (right). The observed exclusion covers the mass regions 134–156 GeV, 182–233 GeV, 256–265 GeV, and 268–415 GeV. The expected exclusion ranges are 136–157 GeV and 184–400 GeV. The most significant upward deviations from the background-only hypothesis are observed for $m_H = 125\,\text{GeV}$ with a local significance of 2.1σ, $m_H = 244\,\text{GeV}$ with a local significance of 2.2σ, and $m_H = 500\,\text{GeV}$ with a local significance of 2.1σ. Once the look-elsewhere-effect (LEE) [12] is considered, none of the observed local excesses is significant.

2˙2.2. $H \to \gamma\gamma$. Despite a very small branching ratio of about 0.2% the $H \to \gamma\gamma$ channel offers the best sensitivity for $m_H < 120\,\text{GeV}$. The diphoton selection has been optimized such as to suppress the reducible photon-jet and jet-jet background, more details on the analysis are given in ref. [13]. The irreducible diphoton production accounts for about 70% of the total backgrounds contamination in the probed mass region of 100–150 GeV. The analysis is divided into 9 sub-categories based on the photon pseudorapidity, conversion status and $p_{Tt}^{\gamma\gamma}$, *i.e.* the component of the diphoton p_T orthogonal to the diphoton thrust axis. The excellent diphoton invariant mass resolution of 1% to 2% allows for the search of a narrow diphoton invariant mass peak over the continuum background. The inclusive invariant diphoton mass spectrum is shown in fig. 2 (left) together with the total expected background contribution. The background contributions are estimated separately in each sub-category from an exponential fit to the diphoton invariant mass spectrum, while the signal shape is modelled by the sum of a Crystal Ball and a Gaussian function. 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. 2 (right). A SM Higgs boson is excluded at the 95% CL in the mass ranges of 113–115 GeV and 134.5–136 GeV. The largest excess with respect to the background-only hypothesis is observed at 126.5 GeV with a local significance of 2.8σ. The corresponding global significance is 1.5σ after accounting for the LEE in the entire mass range explored with this decay channel.

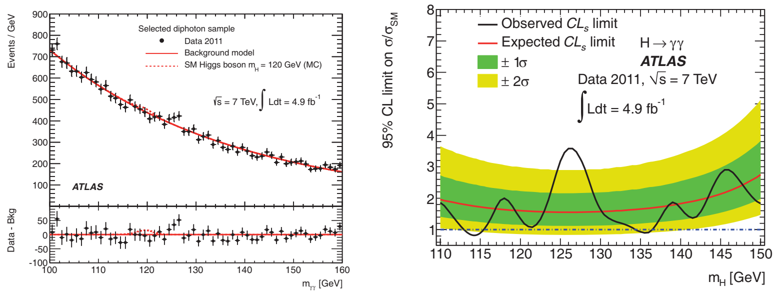

Fig. 2. – Left: Invariant diphoton mass distribution. Right: Observed and expected 95% CL limits on the SM Higgs boson production in the decay channel $H \to \gamma\gamma$.

2˙2.3. $H \to b\bar{b}$. The analysis of the $H \to b\bar{b}$ channel is described in ref. [14]. The search is divided in 11 sub-categories based on the decay mode of the associated vector boson and its transverse momentum p_T^V. The highest sensitivity is reached in the bins with the highest p_T^V where there is a better signal-to-background ratio. The dominant background processes are the W/Z+jets, $t\bar{t}$, diboson, and multi-jet production. The shape of all but the last process are modeled with simulation, while the multi-jet shape and all background contributions are extracted from control regions in data. The exclusion limit is extracted by fitting the b-tagged dijet invariant mass. The observed upper limits at the 95% CL on the SM Higgs boson production vary from of 2.7 at 110 GeV to 5.3 at 130 GeV times the SM cross section.

2˙2.4. $H \to \tau\tau$. The $H \to \tau\tau$ analysis [15] is based on both the leptonic an hadronic decay modes of the two τ leptons. For best sensitivity the search is divided in 12 categories based on the lepton flavour and jet multiplicity, as well as topological cuts intended to separate the contribution from the vector boson fusion and the associated production modes. The reconstructed mass shape of the dominant $Z \to \tau^+\tau^-$ background contribution is estimated by substituting muons from Z decay in data in simulated tau-lepton events. The normalization of this background is obtained from the simulation. The other backgrounds with misidentified leptons or jets are evaluated on data control samples. The $\tau\tau$ invariant mass is used to extract the limit, inferring the neutrino momentum with different techniques depending on the channel. The observed upper limits at the 95% CL on the SM Higgs boson production, in units of SM cross section, vary from of 2.9 at 100 GeV to 11.9 at 150 GeV.

3. – Combination

The results of the combination of all individual channels is given in ref. [16]. The SM Higgs boson with a mass in the range 120–555 GeV is expected to be excluded at the 95% CL or higher. The observed 95% CL exclusion regions are 110.0–117.5 GeV, 118.5–122.5 GeV, and 129–539 GeV. The mass region 130–486 GeV is excluded at the 99% CL. The mass region around $m_H = 126$ GeV cannot be excluded due to an observed excess of events compared to the expected background contribution. The p_0-values in the given mass region are shown in fig. 3 for individual channels and their combination. The most significant excesses are observed in the two channels with high mass resolution, $H \to \gamma\gamma$ and $H \to ZZ^{(*)} \to \ell^+\ell^-\ell^+\ell^-$. The largest combined local significance of the

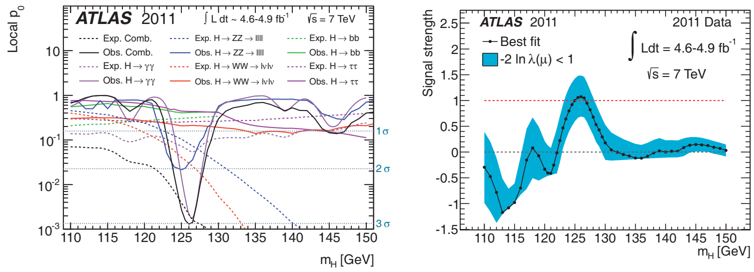

Fig. 3. – Left: Local p_0-value for the individual channels and their combination. Right: The best-fit signal strength $\mu = \sigma/\sigma_{SM}$ as a function of the Higgs boson mass hypothesis.

observed excess is 2.5σ, while the expected significance in the presence of a SM Higgs boson with $m_H = 126\,\text{GeV}$ is 2.9σ. The global probability for such an excess to occur anywhere in the entire explored Higgs boson mass region is approximately 30%. The excess corresponds to the best-fit signal strength μ of approximately $0.9^{+0.4}_{-0.3}$, which is compatible with the signal strength expected from a SM Higgs boson at that mass, as shown in fig. 3.

4. – Conclusions

The whole dataset of *pp* collisions collected by ATLAS in 2011 has been used to search for the SM Higgs boson in the m_H range from 110–600 GeV combining several decay modes. A SM Higgs boson is excluded at the 95% CL in a wide mass range. The exclusion was not possible for m_H around 126 GeV, due to an observed excess of events at the local significance level of 2.5σ. More data collected in 2012 will be needed to better understand the origin of the described excess.

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