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Measurement of the Higgs boson properties in the diphoton final state with the ATLAS detector

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Summary. — Properties of the Higgs boson are measured in the two-photon final state using 36.1 fb^{-1} of proton-proton collision data recorded at $\sqrt{s} = 13$ TeV by the ATLAS experiment at the Large Hadron Collider. Cross-section measurements for the production of a Higgs boson through the main production processes are reported. Furthermore, the production of the Higgs boson decaying to two isolated photons in a fiducial region closely matching the experimental selection of the photons is measured. Finally the measurement of the mass of the Higgs boson in the $H \to \gamma\gamma$ decay channel and its combination with the $H \to ZZ^* \to 4\ell$ decay channel is reported.

1. – Introduction

On July 4th, 2012, the ATLAS [1] and CMS [2] Collaborations announced the observation of a new particle [3, 4] using proton-proton collision data collected at center-of-mass energies $\sqrt{s} = 7$ TeV and 8 TeV at the CERN Large Hadron Collider (LHC). Subsequent measurements of its properties were found to be consistent with the expectation of the Standard Model (SM) Higgs boson [5] with a mass $m_H = 125.09 \pm 0.21$ (stat.) ± 0.11 (syst.) GeV [6].

Based on the data collected by the ATLAS detector at $\sqrt{s} = 13$ TeV during 2015 and 2016 new measurements were carried out using an integrated luminosity of 36.1 fb^{-1}. In particular this paper focuses on the measurements performed in the Higgs boson decay channel in two photons. This decay channel is a particularly attractive way to study the properties of the Higgs boson since, despite the small branching ratio, $(2.27 \pm 0.07) \times 10^{-3}$ for $m_H = 125$ GeV, a reasonably large signal yield can be obtained thanks to the high photon reconstruction and identification efficiency at the ATLAS experiment. Furthermore, due to the excellent photon energy resolution of the ATLAS calorimeter, the signal can be observed as narrow peak in the diphoton invariant mass distribution ($m_{\gamma\gamma}$) above a large falling continuum background from SM $\gamma\gamma$, $\gamma+$ jet and di-jet events.

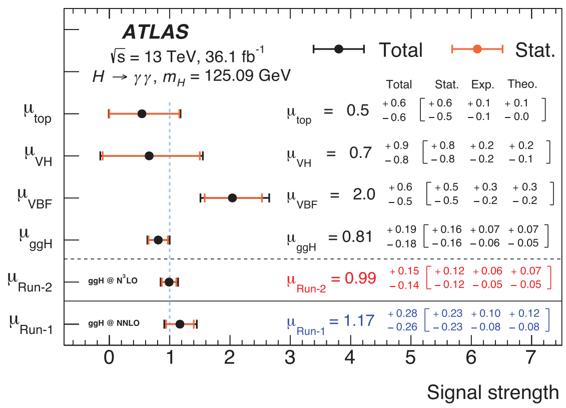

Fig. 1. – Summary of the signal strengths measured for the different production processes (ggH, VBF, VH and top) and globally ($\mu_{\text{Run-2}}$), compared to the global signal strength measured at 7 and 8 TeV ($\mu_{\text{Run-1}}$). The black and orange error bars show the total and statistical uncertainties. Uncertainties smaller than 0.05 are displayed as 0.0 [8].

The Higgs boson mass and signal yield can be measured from a fit to the $m_{\gamma\gamma}$ distribution of the selected events.

2. – Measurement of total production cross-sections and signal strengths

The measurements presented here are based on data selected using a diphoton trigger requiring two photons with transverse energy above 35 GeV and 25 GeV. Events are selected if the leading and the subleading photon candidates have $E_T/m_{\gamma\gamma} > 0.35$ and 0.25, respectively, and satisfy tight identification criteria and isolation criteria based on calorimeter and tracking information. Finally, the data are divided into 31 categories to maximize the sensitivity to different production modes and the different regions of the simplified template cross-sections [7].

The results are then obtained from a maximum-likelihood fit of a signal-plus-background model of $m_{\gamma\gamma}$ to data. The shape of the diphoton invariant mass distribution of the signal is modelled from Monte Carlo samples using a double-sided Crystal Ball function, *i.e.*, a Gaussian function in the peak region with power-law functions in both tails, while the background is parametrised with a functional form directly fitted on the data, and selected in order to minimise the potential bias on the fitted signal.

The signal strengths, *i.e.*, the ratios of the measured number of Higgs boson signal events to the SM predictions for each production mode, are shown in fig. 1. A global signal strength μ is measured assuming the ratios between different production processes to be as predicted by the SM: $\mu = 0.99^{+0.12}_{-0.12}$ (stat.) ${}^{+0.06}_{-0.05}$ (syst.)${}^{+0.07}_{-0.05}$ (theo.) [8], well compatible with the SM expectation.

Measurements of simplified template cross-sections are also reported. All results are in agreement with the SM expectations.

3. – Measurement of fiducial integrated and differential cross-sections

The measurement of fiducial integrated and differential cross-sections provides an alternative way to study the properties of the Higgs boson and to search for physics beyond the SM. The fiducial volumes are defined to closely model the detector-level photon and object selections. The cross-section (σ) in a fiducial integrated region, and the differential cross-section ($\mathrm{d}\sigma/\mathrm{d}x$) in a bin of variable x, are given by: $\sigma = \frac{N^{\mathrm{sig}}}{c\int L\mathrm{d}t}$ and $\frac{\mathrm{d}\sigma}{\mathrm{d}x} = \frac{N^{\mathrm{sig}}}{c\Delta x\int L\mathrm{d}t}$, where N^{sig} is the number of selected signal events, $\int L\mathrm{d}t$ is the integrated luminosity of the data set, c is a correction factor that accounts for detector inefficiencies and resolution, and Δx is the bin width of the differential variable.

The cross-section for $pp \to H \to \gamma\gamma$ measured in the diphoton fiducial region is $\sigma_{\mathrm{fid}} = 55 \pm 9$ (stat.) $\pm\, 4$ (syst.) $\pm\, 0.1$ (theo.) fb, which is to be compared with the SM prediction of 64 ± 2 fb [8].

Results are presented also as differential cross-section in bin of several variables (*i.e.*, number of jets, p_{T}^{H}, y^{H}, $|\cos\theta^{*}|$, etc.) that can probe the jet kinematic description, the spin and CP of the Higgs boson, and that are sensitive to perturbative QCD calculations, modelling of high-p_{T} quark and gluon emission. All measured differential cross-sections are compared to SM predictions and no significant deviation is observed.

4. – Measurement of the mass

The mass of the Higgs boson has been measured from a fit to the invariant mass spectra in different data categories of the $H \to \gamma\gamma$ decay channel based on the latest calibration of photon energy. The measured value of the Higgs boson mass is $m_H = 124.93 \pm 0.40$ GeV [9]. This result is combined with a similar measurement performed in the $H \to ZZ^{*} \to 4\ell$ decay channel. From the combination of these two channels, the mass is measured to be $m_H = 124.86 \pm 0.27$ GeV. This result is in good agreement with the average of the ATLAS and CMS Run 1 measurements. The results from each of the four individual measurements, as well as various combinations, along with the LHC Run 1 result, are summarised in fig. 2.

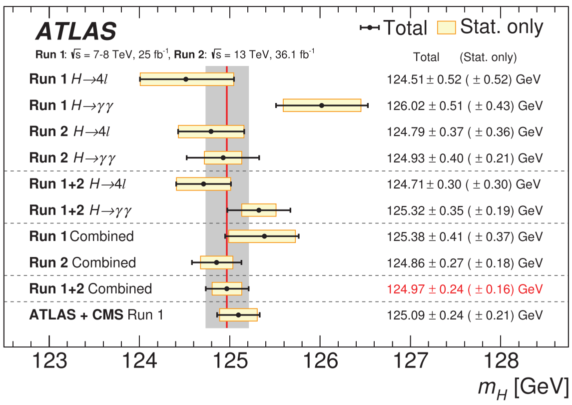

Fig. 2. – Summary of the Higgs boson mass measurements from the individual and combined analyses, compared with the combined Run 1 measurement by ATLAS and CMS [6]. The statistical-only (horizontal yellow-shaded bands) and total (black error bars) uncertainties are indicated. The (red) vertical line and corresponding (grey) shaded column indicate the central value and the total uncertainty of the combined ATLAS Run 1 + 2 measurement, respectively [9].

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