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Recent results on the Higgs boson searches in the $\gamma\gamma$ and Zγ decay channels with the ATLAS detector

L. Carminati
Università di Milano e INFN, Sezione di Milano - Milano, Italy

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Summary. — In this paper the latest results on the search for a Higgs boson decaying into photon pairs and Zγ with the ATLAS detector are reviewd. The presented measurements are based on 4.8 fb^{-1} of integrated luminsity collected in 2011 at a center of mass energy of 7 TeV and 20.7 fb^{-1} collected in 2012 at a center of mass energy of 8 TeV.

PACS 14.80.Bn – Standard-model Higgs bosons.

1. – Introduction

The 4th of July 2012, both ATLAS and CMS experiments announced the observation of a new boson [1, 2]. Since then more statistic has been integrated and more precise studies of the properties of the new particle have been performed with improved analysis techniques. In fact, after the assessment of the discovery, it is now of primary importance the understanding of the nature of this new particle and in particular the compatibility of the measured contribution of the different production modes, the couplings and the spin with the SM predictions. Along this line, the search for rare Higgs decays like in the Zγ channel is now important to improve our understanding of the Higgs sector of the Standard Model.

2. – H $\rightarrow \gamma\gamma$ analysis

2·1. *Event selection.* – In this analysis [3] we look for two photon candidates with transverse energies larger than 40 and 30 GeV for the leading and sub-leading photons respectively, and both need to be within the fiducial calorimeter region of $|\eta| < 2.37$. Photon candidates are required to be isolated and to pass tight identification requirements on the electromagnetic shower shape variables [4]. The photon energy calibration is obtained from a detailed simulation of the detector geometry separately for converted and unconverted photons and refined by applying η-dependent correction factors determined *in situ* from $Z \rightarrow e^+e^-$ events [5]. For an accurate measurement of the diphoton invariant

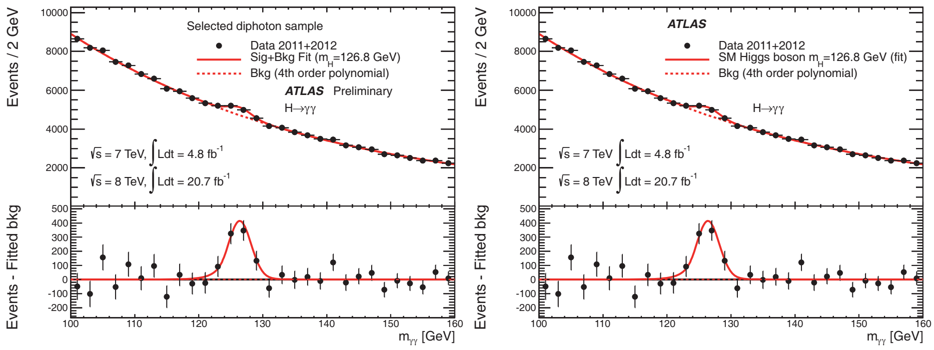

Fig. 1. – Left: invariant mass distribution of diphoton candidates for the combined $\sqrt{s} = 7\,\mathrm{TeV}$ and $\sqrt{s} = 8\,\mathrm{TeV}$ data samples. The result of a fit to the data of the sum of a signal component fixed to $m_H = 126.8\,\mathrm{GeV}$ and a background component described by a fourth-order Bernstein polynomial is superimposed. The bottom inset displays the residuals of the data with respect to the fitted background component. Right: the observed local p_0 value as a function of m_H for the combination of $\sqrt{s} = 7\,\mathrm{TeV}$ and $\sqrt{s} = 8\,\mathrm{TeV}$ data for the inclusive case (black) and for the analysis using categories (red). The expected local p_0 under the SM Higgs boson signal plus background hypothesis is shown by the dashed curves.

mass, the precise location of the diphoton production vertex is necessary: the diphoton production vertex is selected among all the reconstructed primary vertices using a Neural Network algorithm which combines the photon pointing obtained from the calorimeter standalone with several tracking quantities. A total of 118893 (23788) collisions events at 8 TeV (7 TeV) were selected with a diphoton invariant mass between 100 and 160 GeV. The fraction of genuine diphoton events, estimated with data driven techniques, is found to be $(75^{+3}_{-4})\%$.

2˙2. *Event categorization*. – The selected events are divided into 14 exclusive categories based on event properties. The categories differ in signal-to-background ratio as well as invariant mass resolution and thus increase the sensitivity of the measurement. Three of the 14 categories are designed to maximize the number of Higgs candidates from associated production by requiring an additional lepton, large missing energy or two low mass jets respectively. A multivariate analysis is performed to improve the sensitivity to Vector Boson Fusion process which is characterised by two forward jets with little hadronic activity between the two jets. The remaining events are classified in 9 non-overlapping categories based on the conversion status, η region and P_{Tt} [3] of the diphoton system.

2˙3. *Results*. – The invariant mass distribution of diphoton candidates for the combined $\sqrt{s} = 7\,\mathrm{TeV}$ and $\sqrt{s} = 8\,\mathrm{TeV}$ inclusive data sample is shown in fig. 1 (left). The observed local p_0 values, as well as the expected p_0 values corresponding to a SM Higgs boson signal plus background hypothesis, are also shown in fig. 1 (right) as a function of m_H in the inclusive case and in the case where event categories are used. The largest local significance is found to be 7.4σ at $m_H = 126.5\,\mathrm{GeV}$, where the expected significance is 4.1σ. The largest observed (expected) local significance for the inclusive analysis is $6.1(2.9)\sigma$.

In order to estimate the mass of the observed new particle, the parameter of interest in the test statistic is changed to m_H, and the signal strength parameter μ is treated

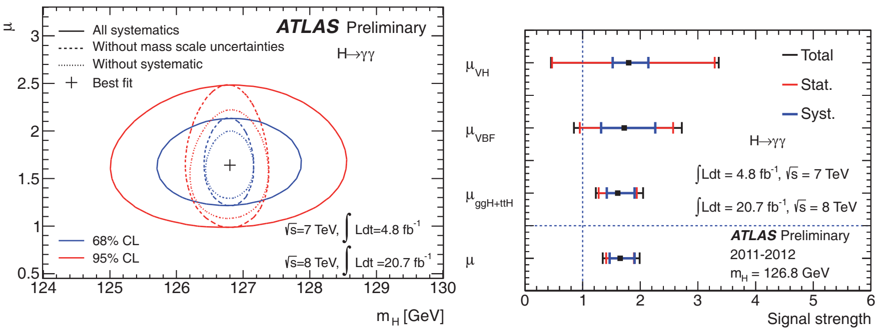

Fig. 2. – Left: the best-fit values of m_H and μ, and their 68% (blue) and 95% (red) CL contours. Results when photon energy scale systematic uncertainties are removed (dashed), and results when all systematic uncertainties are removed (dotted), are also shown. Right: measured signal strengths $\mu_{ggF+ttH}$, μ_{VBF} and μ_{VH} for the different hgg production modes, as well as overall strength μ.

as a free parameter in the fit. The best-fit m_H value is found to be 126.8 GeV, and its statistical and systematic uncertainties are ± 0.2 GeV and ± 0.7 GeV, respectively. The dominant contribution to the systematic uncertainty comes from the uncertainties on the photon energy scale. The best-fit values of the signal strength μ and m_H are shown in fig. 2 (left) where the effect of the systematic uncertainties on the photon scale is also reported. At the best-fit value $m_H = 126.8$ GeV, μ is found to be $1.65^{+0.34}_{-0.30}$ ($^{+0.24}_{-0.24}$(stat) and $^{+0.25}_{-0.18}$(syst)). The compatibility in the signal strength parameter between the data and the SM Higgs boson signal plus background hypothesis is found to be at the 2.3σ level.

A simultaneous fit is also performed to determine the signal strengths $\mu_{ggF+ttH}$, μ_{VBF} and μ_{VH}: the best-fit values as shown in fig. 2 (right) are $\mu_{ggF+ttH} \times B/B_{SM} = 1.6^{+0.3}_{-0.3}(\text{stat})^{+0.3}_{-0.2}(\text{syst})$, $\mu_{VBF} \times B/B_{SM} = 1.7^{+0.8}_{-0.8}(\text{stat}){+}^{+0.5}_{-0.4}(\text{syst})$ and $\mu_{VH} \times B/B_{SM} = 1.8^{+1.5}_{-1.3}(\text{stat})^{+0.3}_{-0.3}(\text{syst})$.

Studies of the spin of the new Higgs-like boson have been performed in the H $\rightarrow \gamma\gamma$ channel using 20.7 fb^{-1} of pp collision data at a centre-of-mass energy of 8 TeV recorded in 2012 by the ATLAS detector [6]. The SM spin-0 hypothesis is compared to a graviton-like spin-2 model with minimal couplings, where the spin-2 signal is produced via gluon fusion or quark-antiquark annihilation. The separation has been studied as a function of the fraction of gg and q$\bar{\text{q}}$ modes in the production. The data are generally in good agreement with the spin-0 hypothesis while a spin-2 resonance produced by gluon fusion is excluded at 99% CL. For decreasing fractions of gluon fusion production of the spin-2 signal in favour of q$\bar{\text{q}}$ production, the expected separation between spin-0 and spin-2 is reduced, reaching a minimum when the gluon fusion contribution is at 25%. The observed spin-2 rejections for these configurations do not exceed 95% CL.

Finally, the fiducial cross section (σ_{fid}) for the production of the observed particle at a mass of 126.8 GeV was measured with the $\sqrt{s} = 8$ TeV data for isolated photons in the pseudorapidity region $|\eta| < 2.37$ and with transverse energies of $E^1_\gamma > 40$ GeV and $E^2_\gamma > 30$ GeV for the leading and subleading photons, respectively. The measured value is $\sigma_{fid} \times \text{BR} = 56.2 \pm 10.5(\text{stat}) \pm 6.5(\text{syst}) \pm 2.0(\text{lumi})$ fb, compatible with the SM Higgs prediction.

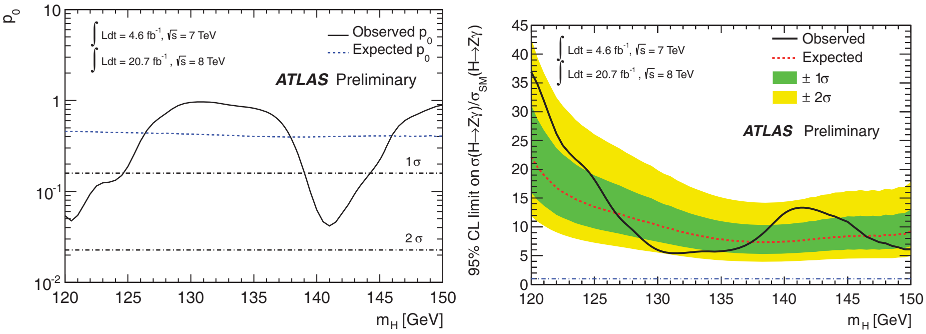

Fig. 3. – Left: expected (dashed blue line) and observed (solid black line) p_0 (compatibility of the data with the background-only hypothesis) as a function of the Higgs boson mass, using $4.6\,\mathrm{fb}^{-1}$ of pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ and $20.7\,\mathrm{fb}^{-1}$ of pp collisions at $\sqrt{s} = 8\,\mathrm{TeV}$. Right: observed 95% CL limits (solid black line) on the production cross section of a SM Higgs boson decaying to $\mathrm{Z}\gamma$, as a function of the Higgs boson mass. The median expected 95% CL exclusion limits (dashed red line) are also shown. The green and yellow bands correspond to the $\pm 1\sigma$ and $\pm 2\sigma$ intervals.

3. – $\mathrm{H} \to \mathrm{Z}\gamma$ analysis

After the discovery of the new Higgs-like boson, the observation (exclusion) of the $\mathrm{H} \to \mathrm{Z}\gamma$ decay is important to improve our understanding of the nature of Higgs mechanism and the measurement of the decay rate can provide insight into models beyond the SM [7]. This is a rare decay: for a Higgs boson mass of 125 GeV the predicted cross section times branching ratios into electrons and muons, is about 1.8(2.3) fb at 7(8) TeV, roughly similar to that of $\mathrm{pp} \to \mathrm{H} \to \mathrm{ZZ}^* \to 4\mathrm{l}$ and only 5% of that of $\mathrm{pp} \to \mathrm{H} \to \gamma\gamma$. The main backgrounds originate from $\mathrm{Z} + \gamma$ events, either from diboson production in the t, u channels (also referred to as initial-state-radiation), from final-state-radiation (FSR) in radiative Z boson decays ($\mathrm{Z} \to \mathrm{ll}\gamma$) or from parton-to-photon fragmentation, and production of a Z boson in association with jets, followed by a $\mathrm{Z} \to \mathrm{ll}$ decay, and misidentification of a jet as a photon. Although the background level for $\mathrm{H} \to \mathrm{Z}\gamma$ is reduced compared to $\mathrm{H} \to \gamma\gamma$, it is orders of magnitude higher than that for $\mathrm{H} \to \mathrm{ZZ}^* \to 4\mathrm{l}$.

3˙1. *Event selection.* – In this analysis we look for events with an opposite sign same flavour lepton pair (electrons or muons) with a mass compatible with the one of the Z boson accompanied by an isolated photon. Leptons are required to have a transverse momentum greater than 10 GeV, while photon candidates minimum p_T is set to 15 GeV. Electron and photon candidates should satisfy a set of identification criteria that require the longitudinal and transverse shower profiles to be consistent with those expected for electromagnetic showers. Both leptons and photons candidates are required to be isolated. Photon candidates that are within $\Delta R < 0.3$ of a selected electron or muon candidate are also rejected, thus suppressing background from FSR $\mathrm{Z}+\gamma$ events. Finally, to suppress events from FSR $\mathrm{Z} \to \mathrm{ll}\gamma$, the di-lepton invariant mass is required to be larger than the PDG value of the Z boson mass minus 10 GeV. This requirement also reduces the contribution to the signal from internal photon conversions in $\mathrm{H} \to \gamma\gamma$ to a negligible level. After applying all selection criteria, the number of $\mathrm{H} \to \mathrm{Z}\gamma$ candidate events in the $\sqrt{s} = 8\,\mathrm{TeV}$ ($\sqrt{s} = 7\,\mathrm{TeV}$) data sample is 13978 (1927) in the $\mathrm{Z} \to \mathrm{ee}\gamma$ channel and 16678 (2621) in the $\mathrm{Z} \to \mu\mu\gamma$ channel.

3˙2. *Results*. – The expected and observed p_0 values are shown in fig. 3 (left) as a function of the Higgs boson mass. Using the full 2011 and 2012 ATLAS data, corresponding to $4.6\,\text{fb}^{-1}$ of pp collisions at $\sqrt{s} = 7\,\text{TeV}$ and $20.7\,\text{fb}^{-1}$ of pp collisions at $\sqrt{s} = 8\,\text{TeV}$, the expected p_0 ranges between 0.40 and 0.46 for $120 < m_H < 150\,\text{GeV}$, corresponding to significances around 0.25σ. The observed p_0 distribution is compatible with the data being composed of background only. The smallest p_0 (0.042), corresponding to a significance of 1.61σ, occurs for a mass of 141 GeV. The expected p_0 at $m_H = 125\,\text{GeV}$ is 0.443, corresponding to a significance of 0.14σ, while the observed one is 0.188 (0.89σ). The expected and observed limits on the production cross sections are shown in fig. 3 (right).

4. – Conclusion

Measurements of the mass and couplings of the new Higgs-like boson in the two photon decay channel with the ATLAS detector at the LHC have been discussed. The proton-proton collision datasets used correspond to integrated luminosities of $4.8\,\text{fb}^{1}$ collected at $\sqrt{s} = 7\,\text{TeV}$ and $20.7\,\text{fb}^{-1}$ collected at $\sqrt{s} = 8\,\text{TeV}$. The updated measurements benefit from an increased data sample and an improved analysis. The measured value of the mass is $126.8 \pm 0.2(\text{stat}) \pm 0.7(\text{syst})\,\text{GeV}$ and the fitted signal strength μ is found to be $1.65 \pm 0.24(\text{stat})^{+0.25}_{-0.18}(\text{syst})$ which corresponds to a 2.3σ deviation from the SM prediction. Measurements of the signal strength in different production processes and a fiducial cross section for the observed particle have also been measured. The spin of the new particle is studied by comparing the data to the SM Higgs boson and specific spin-2 models. The data favours the SM spin-0 state over the tested spin-2 models. Limits have also been placed on the observation of the Higgs decay into Zγ consistent with the SM expectations.

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