Search for narrow scalar $X \rightarrow \gamma\gamma$ in the mass range $65 - 600$ GeV with the ATLAS detector

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Abstract

A search for scalar narrow resonance $X$ decaying into two photons in the mass range $65 - 600$ GeV is performed using $20 \text{ fb}^{-1}$ of $pp$ collision data collected with the ATLAS detector at $\sqrt{s} = 8$ TeV at the Large Hadron Collider. The signal associated to the diphoton decay of the Higgs boson with a mass of 125.9 GeV is treated as a background. No significant evidence for an additional signal is observed. The result is presented as a model-independent limit on the production cross-section times the branching fraction $\text{BR}(X \rightarrow \gamma\gamma)$, in a fiducial volume where the reconstruction efficiency is independent of the event topology. The upper limits set extend over a considerably wider mass range than the limits previously set by the ATLAS and CMS collaborations.

Keywords: Higgs boson, diphoton resonance, ATLAS, LHC, $pp$ collisions

The scalar boson of mass $m_H \approx 126$ GeV, discovered at the LHC by ATLAS [1] and CMS [2], has properties compatible with those of the predicted Standard Model (SM) Higgs boson [3]. However, many models beyond the SM predict the existence of a second scalar particle with higher mass [4], while the NMSSM and 2HDM models [5] predict a new resonance with mass smaller than 126 GeV. The second resonance is expected to be narrow when its branching ratio to two photons is non-negligible. Therefore, the search for other Higgs-like states, presented here, focuses on a narrow resonance $X$ in a wide mass range of $65 < m_X < 600$ GeV.

The ATLAS experiment [6] at the Large Hadron Collider (LHC) is a multi-purpose experiment, covering a large range of pseudorapidity $|\eta| < 4.9$ and a full azimuth. It consists of an inner tracking detector covering the pseudorapidity range $|\eta| < 2.5$, surrounded by a thin superconducting solenoid, electromagnetic and hadronic calorimeters, large superconducting toroidal magnets and the muon spectrometer with end-caps.

This analysis was performed using 2012 proton-proton collision data at $\sqrt{s} = 8$ TeV, with a diphoton trigger requiring both photon candidates to have $E_T > 20$ GeV and medium shower shape criteria. The data must fulfill the standard data quality requirements, with all ATLAS systems operational, corresponding to the total integrated luminosity of $L = 20.3 \pm 0.6 \text{ fb}^{-1}$. Photon candidates are selected in a region of $|\eta| < 2.37$, and tight cuts are applied on shower shape variables to reduce the background composed of QCD jets with leading neutral hadrons decaying into photons. The photon candidates are required to be isolated, where the $p_T$ sum of all stable particles found within a cone of $\Delta R = \sqrt{\Delta \phi^2 + \Delta \eta^2} < 0.4$ around the candidate must be smaller than 6 GeV for $E_T > 80$ GeV and the same cut is applied on the quantity $I_{\text{calo}} = I_{\text{calo}} - 0.7\% (E_T - 80 \text{ GeV})$ for candidates with $E_T > 80$ GeV. In addition a cut on the track isolation $I_{\text{track}} = \sum p_{T\, \text{track}} > 1 \text{ GeV} < 2.6 \text{ GeV}$ within $\Delta R < 0.2$ excluding the conversion tracks and an offline cut of $E_T > 22$ GeV is applied.

The resonance with mass $m_X$ is considered narrow when its intrinsic width is smaller than 0.09 GeV + 0.01 $m_X$. This upper limit is defined such that the bias in the number of fitted signal events is smaller than 10%. The width of the new resonance is then dominated by the experimental resolution in the ATLAS de-
The resonance X is modelled using POWHEG [7, 8] interfaced with PYTHIA8 [9] MC SM Higgs samples produced via gluon-gluon fusion (ggF), for masses of 70 – 1000 GeV, simulated with a width of 4 GeV. Consequently, the width of the simulated peak is dominated by the detector resolution (mostly its constant term, especially at high masses). Low and high mass tails are present, due to miscalibration (energy loss before the calorimeter) or material mismodelling. The Double-sided Crystal Ball function (DSCB), chosen to describe the shape, consists of a Gaussian core and a power law tail on the low and high mass sides and has six free parameters [10]. All MC samples are fitted individually, and the six fit parameters are parameterized w.r.t. $m_X$ with an appropriate function (e.g. linear, quadratic). A categorized sample, containing several mass points, is then produced and simultaneously fitted. The shape of the parameters w.r.t. $m_X$ is, in the case of the multiple mass point fit, restricted by the parameterizations obtained from the single mass point fits. The two fitting methods (single and multiple) produce results in very good agreement and the parameterization obtained from the multiple fit method is used. The signal modelling was done separately for the categorized low-mass analysis and the inclusive high-mass analysis.

The low-mass background includes the continuum diphoton background with dominantly $\gamma\gamma$, $\gamma$-jet and jet-jet events and Drell-Yan (DY) production (both resonant ($Z$) and non-resonant). To increase the sensitivity, the sample was split into three categories according to the number of conversions: two converted (CC), two unconverted (UU) and one converted, one unconverted (CU). The resonant background mostly comes from the CC category. In each category, the resonance shape is described by a DSCB function, parameters of which are determined by a fit to a dielectron data sample, where the electrons must satisfy the same requirements as the selected photon candidates. Most of the misidentified electrons underwent large bremsstrahlung, therefore, the $m_{ee}$ distribution is wider and shifted to lower masses by up to 2 GeV compared to the $Z$ boson reconstructed from true electron pairs. The $m_{ee}$ distribution is therefore transformed by a shift in $E_T$ and a smearing in $\phi$. The obtained DY templates are normalized by factors computed from the $e \to \gamma$ fake rates, defined as the ratios of $e\gamma$ to $ee$ pairs measured in $Z \to ee$ data. The function describing the diphoton continuum background is a sum of Landau and an exponential distribution over the full $m_{\gamma\gamma}$ low-mass range. The bias on the signal yield induced by the choice of the functional form is required to be lower than 20% of the statistical uncertainty on the fitted signal yield for the background-only spectrum. This was studied on an Asimov dataset [11]. Figure 1 shows background-only fits to the data in the low-mass region.

The high-mass analysis describes the continuum
The ATLAS collaboration has published results of a search for the SM Higgs boson in the diphoton decay channel. The analysis uses data collected during the 2012 LHC run at a centre-of-mass energy of 8 TeV. The limit on the production cross-section times branching ratio (σfid ⋅ BR) for the SM Higgs boson is derived from the ggF samples, which ranges from 0.56 to 0.71 as a function of mX, ensuring model independence of the result. The statistical analysis of the data uses unbinned maximum likelihood fits. The DY and Higgs shapes and normalizations are allowed to float within their uncertainties. Only two excesses with 2.1 σ (mX = 201 GeV) and 2.2 σ (mX = 530 GeV) local significances above the background are observed, which is consistent with the absence of a new narrow resonance in full the mass range of 65 – 600 GeV. A 95% limit on σfid ⋅ BR(X → γγ) is computed as in [1] and shown in Figure 3. The systematic uncertainties are listed in Table 1. These results extend over a considerably larger range then previous searches done by ATLAS and CMS collaborations [17, 18], which only covered the range of 110 – 150 GeV.

### References

13. Differences in mH used here and in [14, 15] are covered by the energy scale uncertainties, listed in Table 1.

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Figure 3: Observed and expected 95% C.L. limit on the σfid ⋅ BR(X → γγ) as a function of mX in the range 65 < mX < 600 GeV. The discontinuity in the limit at mX (vertical dashed line) is due to the transition between the low-mass and the high-mass analyses. The green and yellow bands show the ±1σ and ±2σ uncertainties on the expected limit. The inset shows a zoom around the transition point.

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Table 1: Summary of the systematic uncertainties, 1 mass dependent, 2 category dependent, 3 factorization scale plus parton density function uncertainties [16].