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Search for a high mass diphoton resonance using the ATLAS detector

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A search for new spin-0 resonances decaying into two photons in the ATLAS experiment at the LHC is described. The analysis is based on pp collision data at $\sqrt{s}$=13 TeV corresponding to integrated luminosities of 3.2 fb^{-1} and 12.2 fb^{-1} recorded in 2015 and 2016, respectively. A deviation from the Standard Model background-only hypothesis corresponding to 3.4 standard deviations is observed in the 2015 data for a resonance mass hypothesis of 730 GeV. No significant excess at such mass over the background expectation is observed in the 2016 data. Limits on the production cross section times branching ratio to two photons of such resonances are reported.

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1. Introduction

New high-mass states decaying into two photons are predicted in many extensions of the Standard Model (SM). The diphoton final state provides a clean experimental signature with excellent invariant mass resolution and moderate backgrounds.

Using 3.2–3.3 fb^{-1} of $\sqrt{s} = 13$ TeV proton–proton (pp) collision data recorded in 2015 at the CERN Large Hadron Collider (LHC), the ATLAS and CMS Collaborations reported an excess in the diphoton invariant mass spectra with respect to the SM continuum background near the mass value of 750 GeV [1, 2]. The searches were performed using two benchmark signal models, the lightest Kaluza–Klein [3] spin-2 graviton excitation (G^*) of a Randall–Sundrum (RS) [4] model or a spin-0 resonance (X). The ATLAS results in Ref. [1] correspond to a global significance of about two standard deviations.

An update of this search is given in Ref. [5] and summarised below. The analysis follows closely the description given in Ref. [1], but limited to the spin-0 resonance search analysis. Both the 2015 and 2016 pp collision datasets are used, corresponding to a total integrated luminosity of 15.4 fb^{-1}.

2. Description of the analysis

The search uses events from pp collisions recorded by the ATLAS detector [6] using a diphoton trigger with a signal efficiency close to 99% for events fulfilling the final event selection. Photon candidates, reconstructed from clusters of energy deposited in the electromagnetic calorimeter and tracks and conversion vertices reconstructed in the inner detector, are required to fullfil tight identification criteria based primarily on shower shapes in the calorimeter. To further reject the background from jets misidentified as photons, the photon candidates are required to be isolated using both calorimeter and tracking detector information.

The transverse energy is required to be $E_{\mathrm{T}} > 0.4 \cdot m_{\gamma\gamma}$ for the photon with the highest E_{T} and $E_{\mathrm{T}} > 0.3 \cdot m_{\gamma\gamma}$ for the photon with the second-highest E_{T}, for a given value of the diphoton invariant mass $m_{\gamma\gamma}$, thus selecting events in which the photons are preferentially emitted in the central part of the detector. Only events with $m_{\gamma\gamma} > 150$ GeV are retained. With these requirements, 35891 events are selected in the data. The selected sample mainly consists of events from diphoton production, with an estimated purity of $(90^{+3}_{-10})\%$.

Simulated Monte Carlo (MC) samples are used to optimize the search strategy and to study background sources. The invariant mass distribution of the diphoton pair for the signal is expected to peak near the assumed mass of the new particle, with a spread given by the convolution of its intrinsic decay width with the experimental resolution, which varies from 2.3 GeV at a mass of 200 GeV to 15 GeV at a mass of 2 TeV. A double-sided Crystal Ball (DSCB) function, with a Gaussian core and power-law functions describing the low and high mass sidebands is used to model the experimental resolution of the reconstructed invariant mass. The parameters of the DSCB function are obtained from fits to the invariant mass distributions of simulated narrow-width signal samples. The signal mass distribution for any value of the mass and width hypothesis is obtained by a convolution of the intrinsic detector resolution with the predicted line-shape distribution of the resonance that combines a Breit-Wigner function, the parton luminosity and the matrix element, calculated using an effective field theory approach at next-to-leading order in QCD.

The estimate of the background $m_{\gamma\gamma}$ contribution in the selected sample is based on a fit using the following functional form, with parameters determined from the data:

$$f_{(k)}(x;b,\{a_k\}) = N(1-x^{1/3})^b x^{\sum_{j=0}^{k} a_j (\log x)^j}, \tag{2.1}$$

where $x = m_{\gamma\gamma}/\sqrt{s}$, b and a_k are free parameters, and N is a normalization factor. The mass distribution from data is fitted in the range above 180 GeV, and the search range for the signal is 200–2400 GeV. To validate the choice of this functional form and to derive the corresponding uncertainties, the method detailed in Ref. [7] is used to check that the form is flexible enough to accommodate different physics-motivated underlying distributions. The simplest choice $k = 0$ is adopted. The bias related to the choice of functional form for a narrow-signal hypothesis varies from 18 events at 200 GeV to 0.012 events at 2400 GeV. For larger hypothesized signal widths, the signal is integrated over a wider mass range and the background uncertainty is larger, varying from 117 events at 200 GeV to 0.35 events at 2400 GeV, for a hypothesized signal with a relative width Γ_X/m_X of 10%.

The numbers of estimated signal and background events are obtained from maximum-likelihood fits of the $m_{\gamma\gamma}$ distribution of the selected events. The function used to describe the data can be written as

$$N_S(\sigma_S) f_S(m_{\gamma\gamma}) + N_B f_B(m_{\gamma\gamma}), \tag{2.2}$$

where N_S is the fitted number of signal events, $f_S(m_{\gamma\gamma})$ is the normalized invariant mass distribution for a given signal hypothesis, N_B is the fitted number of background events and $f_B(m_{\gamma\gamma})$ is the normalized invariant mass distribution of the background events. The fitted number of signal events is related to the assumed signal cross section times branching ratio to two photons (σ_S) in the fiducial acceptance via the integrated luminosity and the total efficiencies of the event reconstruction, identification and isolation criteria, which ranges from 66% for a particle with a mass of 200 GeV to 74% for a mass of 700 GeV and is almost constant above 700 GeV.

Uncertainties in the signal parameterization, in the detector efficiency correction factors for the signal and in the signal extraction are included in the fit via nuisance parameters, constrained with Gaussian or log-normal penalty terms. The compatibility with the background-only hypothesis when testing a given signal hypothesis (m_X, α) is estimated using the local p-value (p_0) based on the profile likelihood ratio test statistic under the asymptotic approximation. Global significance values are computed to account for the trial factors given by the search range with a large number of background-only pseudo-experiments. The expected and observed 95% confidence level (CL) exclusion limits on the cross section times branching ratio to two photons are computed using a modified frequentist approach.

3. Results and conclusion

The 2015 data and simulated samples, used in Ref. [1], have been reprocessed with the same reconstruction software as used for the 2016 data processing, which includes small improvements in the reconstruction and selection of converted photons and in the photon energy calibration. Figure 1 shows the diphoton invariant mass distribution together with the background-only fit, for events selected in the full dataset.

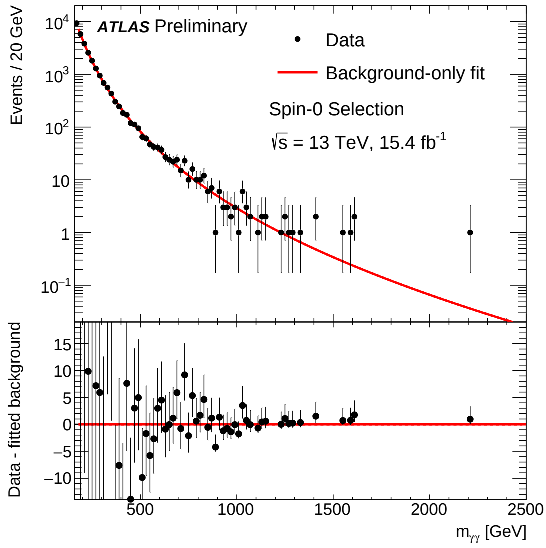
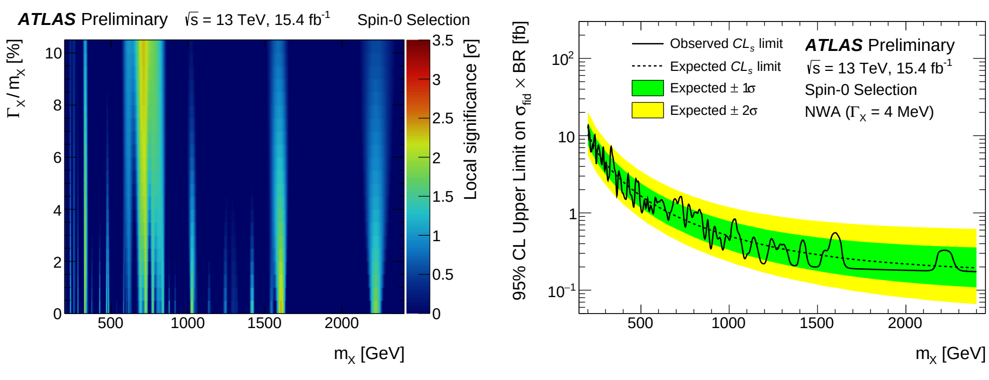


Figure 1: Distribution of the diphoton invariant mass of the selected events, together with the background-only fit. The difference between the data and this fit is shown in the bottom panel. The arrow shown in the lower panel indicates a values outside the range with more than one standard deviation. There is no data event with $m_{\gamma\gamma} > 2500$ GeV. Extracted from Ref. [5].



(a) (b)

Figure 2: (a) Compatibility, in terms of local significance σ, with the background-only hypothesis as a function of the assumed signal mass and relative width for a spin-0 resonance. (b) Upper limits on the fiducial cross section times branching ratio to two photons at $\sqrt{s} = 13$ TeV of a spin-0 particle as a function of its mass m_X for a narrow-width signal (NWA) with Γ_X = 4 MeV. Both figures were extracted from Ref. [5].

The compatibility with the background-only hypothesis is computed as a function of the hypothesized resonance mass and width, as shown in Figure 2a. The largest deviation over the background-only hypothesis is observed at a mass of 1600 GeV for an assumed narrow width, corresponding to a local significance of 2.4 standard deviations. In the 700–800 GeV mass range, where the largest deviation from the background-only hypothesis is observed in the reprocessed 2015 dataset, the largest local significance is 2.3 standard deviations for a mass near 710 GeV and a relative width of 10%. The global significance of these excesses is less than one standard deviation.

Figure 2b shows the limits on the signal fiducial cross section times branching ratio to two photons for a spin-0 particle as a function of the assumed signal mass for a narrow-width signal.

References

[1] ATLAS Collaboration, *Search for resonances in diphoton events at $\sqrt{s} = 13$ TeV with the ATLAS detector*, *JHEP* **09** (2016) 001, [1606.03833].

[2] CMS Collaboration, *Search for resonant production of high-mass photon pairs in proton-proton collisions at $\sqrt{s} = 8$ and 13 TeV*, *Phys. Rev. Lett.* **117** (2016) 051802, [1606.04093].

[3] T. Appelquist, A. Chodos and P. Freund, *Modern Kaluza-Klein theories*, vol. 65 of *Frontiers in Physics*. Addison-Wesley, 1987.

[4] L. Randall and R. Sundrum, *A Large mass hierarchy from a small extra dimension*, *Phys. Rev. Lett.* **83** (1999) 3370, [hep-ph/9905221].

[5] ATLAS Collaboration, "Search for scalar diphoton resonances with 15.4 fb^{-1} of data collected at $\sqrt{s}$=13 TeV in 2015 and 2016 with the ATLAS detector." ATLAS-CONF-2016-059, 2016.

[6] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.

[7] ATLAS Collaboration, *Measurement of Higgs boson production in the diphoton decay channel in pp collisions at center-of-mass energies of 7 and 8 TeV with the ATLAS detector*, *Phys. Rev. D* **90** (2014) 112015, [1408.7084].

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