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Search for diphoton events with large missing transverse momentum in 7 TeV proton–proton collision data with the ATLAS detector

ATLAS Collaboration*

A search for diphoton events with large missing transverse momentum has been performed using proton–proton collision data at √s = 7 TeV recorded with the ATLAS detector, corresponding to an integrated luminosity of 4.8 fb⁻¹. No excess of events was observed above the Standard Model prediction and model-dependent 95% confidence level exclusion limits are set. In the context of a generalised model of gauge-mediated supersymmetry breaking with a bino-like lightest neutralino of mass above 50 GeV, gluinos (squarks) below 1.07 TeV (0.87 TeV) are excluded, while a breaking scale Λ below 196 TeV is excluded for a minimal model of gauge-mediated supersymmetry breaking. For a specific model with one universal extra dimension, compactification scales 1/R < 1.40 TeV are excluded. These limits provide the most stringent tests of these models to date.

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free parameters. For the squark–bino GGM model all squark masses are treated as degenerate except the right-handed up-type squarks whose mass is decoupled (set to inaccessibly large values). For the gluino–bino model all squark masses are decoupled. For both configurations all other sparticle masses are also decoupled, leading to a dominant production mode at $\sqrt{s} = 7$ TeV of a pair of squarks in one case and a pair of gluinos in the other case. These would decay via short cascades into the bino-like neutralino NLSP. Jets may be produced in the cascades from the gluino and squark decays. Further model parameters are fixed to $c_{\text{NLSP}} < 0.1$ mm and $\tan\beta = 2$; for this GGM scenario, restricted to the region of parameter space for which the NLSP is the bino-like neutralino, the final-state phenomenology relevant to this search is only weakly dependent on the value of $\tan\beta$ [4]. The decay into the wino-like neutralino NLSP is possible and was studied by the CMS Collaboration [29].

3. Extra dimensions

UED models postulate the existence of additional spatial dimensions in which all SM particles can propagate, leading to the existence of a series of excitations for each SM particle, known as a Kaluza–Klein (KK) tower. This analysis considers the case of a single UED, with compactification radius (size of the extra dimension) $R \approx 1$ TeV$^{-1}$. At the LHC, the main UED process would be the production via the strong interaction of a pair of first-excitation-level KK quarks and/or gluons [30]. These would decay via cascades involving other KK particles until reaching the lightest KK particle (LKP), i.e. the first-excitation-level KK photon $\gamma^*$. SM particles such as quarks, gluons, leptons and gauge bosons may be produced in the cascades. If the UED model is embedded in a larger space with $N$ additional ev$^{-1}$-sized dimensions accessible only to gravity [31], with a $(4 + N)$-dimensional Planck scale ($M_P$) of a few TeV, the LKP would decay gravitationally via $\gamma^* \rightarrow \gamma + G$. $G$ represents a tower of eV-squared graviton states, leading to a graviton mass between 0 and $1/R$. With two decay chains per event, the final state would contain $\gamma\gamma + E_{\text{miss}}$, where $E_{\text{miss}}$ results from the escaping gravitons. Up to $1/R \sim 1$ TeV, the branching ratio to the diphoton and $E_{\text{miss}}$ final state is close to 100%. As $1/R$ increases, the gravitational decay widths become more important for all KK particles and the branching ratio into photons decreases, e.g. to 50% for $1/R = 1.5$ TeV [7].

The UED model considered here is defined by specifying $R$ and $\Lambda$, the ultraviolet cut-off used in the calculation of radiative corrections to the KK masses. This analysis sets $\Lambda$ such that $\Delta R = 20$ [32]. The $\gamma^*$ mass is insensitive to $\Lambda$, while other KK masses typically change by a few per cent when varying $\Delta R$ in the range 10–30. For $1/R = 1.4$ TeV, the masses of the first-excitation-level KK photon, quark and gluon are 1.40 TeV, 1.62 TeV and 1.71 TeV, respectively.

4. Simulated samples

For the GGM model, the SUSY mass spectra were calculated using SUSPECT 2.41 [34] and SDECAY 1.3 [35]; for the SPS8 model, the SUSY mass spectra were calculated using ISAJET 7.80 [36]. The Monte Carlo (MC) SUSY signal samples were produced using Herwig++ 2.5.1 [37] with MRST2007 LO* [38] parton distribution functions (PDFs). Signal cross sections were calculated to next-to-leading order (NLO) in the strong coupling constant, including the resummation of soft gluon emissions at next-to-leading-logarithmic accuracy [39–43]. The nominal cross sections and the uncertainties were taken from an envelope of cross-section predictions using different PDF sets and factorisation and renormalisation scales, as described in Ref. [44]. In the case of the UED model, cross sections were estimated and MC signal samples generated using the UED model as implemented at leading order (LO) in PYTHIA 6.423 [45,33] with MRST2007 LO* PDFs.

The “irreducible” background from $W(\rightarrow \ell\nu) + \gamma\gamma$ and $Z(\rightarrow \nu\nu) + \gamma\gamma$ production was simulated at LO using MadGraph 4 [46] with the CTEQ6L1 [47] PDFs. Parton showering and fragmentation were simulated with PYTHIA. NLO cross sections and scale uncertainties were implemented via multiplicative constants ($K$-factors) that relate the NLO and LO cross sections. These have been calculated for several restricted regions of the overall phase space of the $Z(\rightarrow \nu\nu) + \gamma\gamma$ and $W(\rightarrow \ell\nu) + \gamma\gamma$ processes [48,49], and are estimated to be $2.0 \pm 0.3$ and $3 \pm 3$ for the $Z(\rightarrow \nu\nu) + \gamma\gamma$ and $W(\rightarrow \ell\nu) + \gamma\gamma$ contributions to the signal regions of this analysis, respectively. As described below, all other background sources are estimated through the use of control samples derived from data.

All samples were processed through the GRANT4-based simulation of the ATLAS detector [50,51]. The variation of the number of pp interactions per bunch crossing (pile-up) as a function of the instantaneous luminosity is taken into account by overlaying simulated minimum bias events according to the observed distribution of the number of pile-up interactions in data, with an average of $\sim 10$ interactions.

5. ATLAS detector

The ATLAS detector [52] is a multi-purpose apparatus with a forward–backward symmetric cylindrical geometry and nearly $4\pi$ solid angle coverage. Closest to the beamline are tracking devices comprising layers of silicon-based pixel and strip detectors covering $|\eta| < 2.5$ and straw-tube detectors covering $|\eta| < 2.0$, located inside a thin superconducting solenoid that provides a 2 T magnetic field. Outside the solenoid, fine-granularity lead/liquid-argon electromagnetic (EM) calorimeters provide coverage for the electromagnetic and hadronic energy. A muon spectrometer comprising eight toroidal coils, tracking chambers, and detectors for triggering surrounds the calorimeter system. A presampler, covering $|\eta| < 1.8$, is used to correct for energy lost upstream of the EM calorimeter. An iron/scintillating-tile hadronic calorimeter covers the region $|\eta| < 1.7$, while a copper/liquid-argon medium is used for hadronic calorimeters in the end-cap region $1.5 < |\eta| < 3.2$. In the forward region $3.2 < |\eta| < 4.9$ liquid-argon calorimeters with copper and tungsten absorbers measure the electromagnetic and hadronic energy. A muon spectrometer consisting of three superconducting toroidal magnet systems each comprising eight toroidal coils, tracking chambers, and detectors for triggering surrounds the calorimeter system.

6. Reconstruction of candidates and observables

The reconstruction of converted and unconverted photons and of electrons is described in Refs. [53] and [54], respectively. Photon candidates were required to be within $|\eta| < 1.81$, and to be outside the transition region $1.37 < |\eta| < 1.52$ between the barrel and end-cap calorimeters. Identified on the basis of the characteristics of the longitudinal and transverse shower development in the EM calorimeter, the analysis made use of both “loose” and “tight” photons [53]. In the case that an EM calorimeter deposition was identified as both a photon and an electron, the photon candidate was discarded and the electron candidate retained. In addition,

1 ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upward. Cylindrical coordinates $(r, \phi)$ are used in the transverse plane, $\phi$ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle $\theta$ as $\eta = -\ln \tan(\theta/2)$.
converted photons were re-classified as electrons if one or more candidate conversion tracks included at least one hit from the pixel layers. Giving preference to the electron selection in this way reduced the electron-to-photon fake rate by 50–60% (depending on the value of $\eta$) relative to that of the prior 1 fb$^{-1}$ analysis [11], while preserving over 70% of the signal efficiency. Finally, an “isolation” requirement was imposed. After correcting for contributions from pile-up and the deposition ascribed to the photon itself, photon candidates were removed if more than 5 GeV of transverse energy was observed in a cone of $\sqrt{(\Delta \eta)^2 + (\Delta \phi)^2} < 0.2$ surrounding the energy deposition in the calorimeter associated with the photon.

The measurement of the two-dimensional transverse momentum vector $p_T^{miss}$ (and its magnitude $E_T^{miss}$) was based on energy deposits in calorimeter cells inside three-dimensional clusters with $|\eta| < 4.9$ and was corrected for contributions from muons, if any [55]. The cluster energy was calibrated to correct for the different response to electromagnetically- and hadronically-induced showers, energy loss in dead material, and out-of-cluster energy. The contribution from identified muons was accounted for by adding in the energy derived from the properties of reconstructed muon tracks.

Jets were reconstructed using the anti-$k_t$ jet algorithm [56] with radius parameter $R = 0.4$. They were required to have $p_T > 20$ GeV and $|\eta| < 2.8$ [57].

Two additional observables of use in discriminating SM backgrounds from potential GMSB and UED signals were defined. The total visible transverse energy $H_T$ was calculated as the sum of the magnitude of the transverse momenta of the two selected photons and any additional leptons and jets in the event. The photon–$E_T^{miss}$ separation $\Delta \phi(\gamma, E_T^{miss})$ was defined as the azimuthal angle between the missing transverse momentum vector and either of the two selected photons, with $\Delta \phi_{min}(\gamma, E_T^{miss})$ the minimum value of $\Delta \phi(\gamma, E_T^{miss})$ of the two selected photons.

7. Data analysis

The data sample, corresponding to an integrated luminosity of $(4.8 \pm 0.2)$ fb$^{-1}$ [58,59], was selected by a trigger requiring two loose photon candidates with $E_T > 20$ GeV. To ensure the event resulted from a beam collision, events required to have at least one vertex with five or more associated tracks. Events were then required to contain at least two tight photon candidates with $E_T > 50$ GeV, which MC studies suggested would provide the greatest separation between signal and SM background for a broad range of the parameter space of the new physics scenarios under consideration in this search. A total of 10 455 isolated $\gamma\gamma$ candidate events passing these selection requirements were observed in the data sample. The $E_T$ distributions$^2$ of the leading and sub-leading photon for events in this sample are shown in Figs. 1 and 2. Also shown are the $E_T$ spectra obtained from GGM MC samples for $m_{\tilde{g}} = 1000$ GeV and $m_{\tilde{\chi}} = 450$ GeV, from SPBS MC samples with $\Lambda = 190$ TeV, and from UED MC samples for $1/R = 1.3$ TeV, representing model parameter values near the expected exclusion limits. Figs. 3 and 4 show the $H_T$ and $\Delta \phi_{min}(\gamma, E_T^{miss})$ distributions of selected diphoton events, with those of the same signal models overlaid.

To maximise the sensitivity of this analysis over a wide range of model parameters that may lead to different kinematic properties, three different signal regions (SRs) were defined based on the observed values of $E_T^{miss}$, $H_T$ and $\Delta \phi_{min}(\gamma, E_T^{miss})$. SR A, optimised for gluino/squark production with a subsequent decay to a high-mass bino, requires large $E_T^{miss}$ and moderate $H_T$. SR B, optimised for gluino/squark production with a subsequent decay to a low-mass bino, requires moderate $E_T^{miss}$ and large $H_T$. SR C, optimised for the electroweak production of intermediate-mass gaugino pairs that dominates the SPBS cross section in this regime, requires moderate $E_T^{miss}$ but makes no requirement on $H_T$. In addition, a requirement of $\Delta \phi_{min}(\gamma, E_T^{miss}) > 0.5$ was imposed on events in SR A and C; for the low-mass bino targeted by SR B, the separation between the photon and gravitino daughters of the bino is too slight to allow for the efficient separation of signal from background through the use of this observable. The selection requirements of the three SRs are summarised in Table 1. Of the three SRs, SR A provides the greatest sensitivity to the UED model, and is thus the SR used to test this model.

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$^2$ An excess of events relative to a smoothly-falling distribution of the leading-photon spectrum was observed for $E_T < 285$ GeV. Searching over the range 100 GeV $< E_T < 500$ GeV, a significance of 1.8 was found using BumpHunter [60], while the local significance was found to be 3.1$\sigma$. No correlation between the excess and the LHC running period or luminosity was observed. A comparison of other observables (e.g. diphoton mass, $E_T^{miss}$, leading-photon $\eta$, $\Delta \phi(\gamma_1, \gamma_2)$) between the excess and sideband regions exhibited no appreciable differences. It was concluded that the observed excess of events is compatible with a statistical fluctuation.
tributions from the SPS8 MC sample with \( \Lambda \) and C, respectively. After imposing the final m
m
m
matical uncertainty only) together with the spectra from simulated GGM (\( \Lambda = 190 \) TeV), and UED (1/R = 1.3 TeV) samples after the diphoton requirement. The signal samples are scaled by a factor of 100 for clarity.

Fig. 3. The \( H_T \) spectrum of \( \gamma\gamma \) candidate events in the data (points, statistical uncertainty only) together with the spectra from simulated GGM (\( m_3 = 1000 \) GeV, \( m_{\tilde{\chi}} = 450 \) GeV), SPS8 (\( \Lambda = 190 \) TeV), and UED (1/R = 1.3 TeV) samples after the diphoton requirement. The signal samples are scaled by a factor of 100 for clarity.

Fig. 4. The minimum \( \Delta\phi(\gamma, E_T^{\text{miss}}) \) spectrum of \( \gamma\gamma \) candidate events in the data (points, statistical uncertainty only) together with the spectra from simulated GGM (\( m_3 = 1000 \) GeV, \( m_{\tilde{\chi}} = 450 \) GeV), SPS8 (\( \Lambda = 190 \) TeV), and UED (1/R = 1.3 TeV) samples after the diphoton requirement. The signal samples are scaled by a factor of 100 for clarity.

Table 1

<table>
<thead>
<tr>
<th>SR A</th>
<th>SR B</th>
<th>SR C</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_T^{\text{miss}} &gt; )</td>
<td>200 GeV</td>
<td>100 GeV</td>
</tr>
<tr>
<td>( H_T &gt; )</td>
<td>600 GeV</td>
<td>1100 GeV</td>
</tr>
<tr>
<td>( \Delta\phi_{\text{min}}(\gamma, E_T^{\text{miss}}) &gt; )</td>
<td>0.5</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 2 shows the numbers of events remaining after several stages of the selection. A total of 117, 9 and 7293 candidate events were observed to pass all but the \( E_T^{\text{miss}} \) requirement of SR A, B and C, respectively. After imposing the final \( E_T^{\text{miss}} \) requirement, no events remained for SR A and B, while two events remained for SR C.

Fig. 5 shows the \( E_T^{\text{miss}} \) distribution for SR C, the expected contributions from the SPS8 MC sample with \( \Lambda = 190 \) TeV, and estimated background contributions from various sources (described below).
estimate of 0 events with a 90% confidence-level (CL) upper limit of less than 1.01 and 1.15 background events for SR A and SR B, respectively.

To improve the constraint on the estimated background for SRs A and B, a complementary method making use of $H_T$ sidebands of the QCD control sample was employed. The $H_T$ requirement applied to the QCD templates of SR A and B was relaxed in three steps: to 400 GeV, 200 GeV and 0 GeV for the SR A control sample, and to 800 GeV, 400 GeV and 200 GeV for the SR B control sample. For each SR, the $E_T^{\text{miss}}$ distribution of each of these relaxed control samples was scaled to the diphoton sample. For each SR, the $E_T^{\text{miss}}$ distribution of each of these relaxed control samples was scaled to the diphoton sample. For each SR, the $E_T^{\text{miss}}$ distribution of each of these relaxed control samples was scaled to the diphoton sample. For each SR, the $E_T^{\text{miss}}$ distribution of each of these relaxed control samples was scaled to the diphoton sample. 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Table 3

<table>
<thead>
<tr>
<th>SR</th>
<th>QCD</th>
<th>Electroweak</th>
<th>$W(\rightarrow \ell \nu) + \gamma \gamma$</th>
<th>$Z(\rightarrow \nu \bar{\nu}) + \gamma \gamma$</th>
<th>Total</th>
<th>Observed events</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.07 ± 0.00 ± 0.07</td>
<td>0.03 ± 0.03 ± 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>0.10 ± 0.03 ± 0.07</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0.27 ± 0.00 ± 0.27</td>
<td>0.09 ± 0.05 ± 0.02</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>0.36 ± 0.05 ± 0.27</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>0.85 ± 0.30 ± 0.71</td>
<td>0.80 ± 0.16 ± 0.22</td>
<td>0.18 ± 0.13 ± 0.18</td>
<td>0.27 ± 0.09 ± 0.04</td>
<td>2.11 ± 0.37 ± 0.77</td>
<td>2</td>
</tr>
</tbody>
</table>

After applying corresponding selection requirements on $H_T$, $\Delta \phi_{\text{min}}(\gamma, E_T^{\text{miss}})$ and $E_T^{\text{miss}}$, a total of 1, 3 and 26 electron–photon events were observed for SRs A, B and C, respectively. After multiplying by the $\eta$-dependent electron-to-photon mis-reconstruction probability, the resulting EW background contamination was estimated to be 0.03 ± 0.03, 0.09 ± 0.05 and 0.80 ± 0.16 events for SRs A, B and C, respectively, where the uncertainties are statistical only.

The systematic uncertainty on the determination of the electron-to-photon mis-reconstruction probability is assessed by performing an independent tag-and-probe analysis with looser electron $T$ and identification requirements. Differences with the nominal tag-and-probe analysis are taken as systematic uncertainty on the EW background estimate, resulting in relative systematic uncertainties of ±6.9%, ±7.1% and ±10.0% for SRs A, B and C, respectively. MC studies suggest that approximately 25% of the EW background involves no electron-to-photon mis-reconstruction, and thus are not accounted for with the electron-photon control sample. These events, however, typically involve a jet-to-photon mis-reconstruction (for example, an event with one radiated photon and a hadronic $\tau$ decay with an energetic leading $\pi^0$ mis-reconstructed as a photon), and are thus potentially accounted for in the QCD background estimate. A relative systematic uncertainty of ±25% is conservatively assigned to the EW background estimates for all three SRs to account for this ambiguity. The resulting EW background estimates for the three SRs, along with their uncertainties, are compiled in Table 3.

The contribution of the irreducible background from the $Z(\rightarrow \nu \bar{\nu}) + \gamma \gamma$ and $W(\rightarrow \ell \nu) + \gamma \gamma$ processes was estimated using MC samples. It was found to be negligible for SRs A and B, and estimated to be 0.46 ± 0.16 ± 0.19 events for SR C, where the first uncertainty is due to the limited number of events in the MC sample and the second to the uncertainty on the applied $K$-factor. These estimates, along with the resulting estimates for the total background from all sources, are reported in Table 3.

The contamination from cosmic-ray muons, estimated using events triggered in empty LHC bunches, was found to be negligible.

9. Signal efficiencies and systematic uncertainties

Signal efficiencies were estimated using MC simulation. GGM signal efficiencies were estimated over an area of the GGM parameter space that ranges from 800 GeV to 1300 GeV for the gluino or squark mass, and from 50 GeV to within 10 GeV of the gluino or squark mass for the neutralino mass. For SR A the efficiency increases smoothly from 1.2% to 25% for $m_{\tilde{g}}$, $m_{\tilde{q}}$ = (800, 50) GeV to (1300, 1280) GeV, but then drops to 20% for the case for which the gluino and neutralino masses are only separated by 10 GeV. For SR B the efficiency increases smoothly from 2.8% to 26% for $m_{\tilde{g}}$, $m_{\tilde{q}}$ = (800, 790) GeV to (1300, 50) GeV. The SPS8 signal efficiency in SR C increases smoothly from 5.9% ($A = 100$ TeV) to
chosen reference points: (UED) samples. A conservative systematic uncertainty of filtered multijet samples and photons from signal (GGM, SPS8 and selection. To estimate the systematic uncertainty due to the un-

21% ($\Lambda = 250$ TeV). For SR A the UED signal efficiency increases smoothly from 28% ($1/R = 1.0$ TeV) to 37% ($1/R = 1.5$ TeV).

The various relative systematic uncertainties on the GGM, SPS8 and UED signal cross sections are summarised in Table 4 for the chosen reference points: $(m_\chi, m_{\tilde{g}}) = (1000, 450)$ GeV for GGM, $\Lambda = 190$ TeV for SPS8, and $1/R = 1.3$ TeV for UED. The uncertainty on the luminosity is $\pm 3.9\%$ [58,59]. The efficiency of the required diphoton trigger was estimated using a single photon trigger according to [62], yielding $99.8\pm 0.2\%$ for events passing the diphoton selection. To estimate the systematic uncertainty due to the unknown composition of the data sample, the trigger efficiency was also evaluated on MC events using mis-reconstructed photons from filtered multijet samples and photons from signal (GGM, SPS8 and UED) samples. A conservative systematic uncertainty of $\pm 0.5\%$ was derived from the difference between the obtained efficiencies. Uncertainties on the photon selection, the photon energy scale, and the detailed material composition of the detector, as described in Ref. [61], result in an uncertainty of $\pm 4.4\%$ for the GGM, SPS8 and UED signals. The uncertainty due to the photon isolation requirement was estimated by varying the energy leakage and the pile-up corrections independently, resulting in an uncertainty of $\pm 0.9\%$, $\pm 0.2\%$ and $\pm 0.4\%$ for the GGM, SPS8 and UED signals, respectively. The influence of pile-up on the signal efficiency, evaluated by scaling the number of pile-up events in the MC simulation by a factor of 0.9 (chosen to reflect the range of uncertainty inherent in estimating and modelling the effects of pile-up), leads to a systematic uncertainty of $\pm 0.8\%$ (GGM), $\pm 0.5\%$ (SPS8) and $\pm 0.5\%$ (UED). Systematic uncertainties due to the $E_{T}^{miss}$ reconstruction, estimated by varying the cluster energies and the $E_{T}$ reconstruction, are treated as Gaussian-distributed nuisance parameters in the maximum likelihood fit, resulting in observed upper limits of 3.1, 3.1 and 4.9 events for SRs A, B and C, respectively. In the context of the GGM model, these limits translate into 95% upper limits on the visible cross section for new physics, defined by the product of cross section, branching ratio, acceptance and efficiency for the different SR definitions, of 0.6, 0.6 and 1.0 fb, respectively. As for background uncertainties, uncertainties on the luminosity, acceptance and efficiency are taken into account as Gaussian-distributed nuisance parameters in the maximum likelihood fit. Because the observed numbers of events are close to the expected numbers of background events for all three SRs, expected limits on the numbers of events from and visible cross section for new physics are, to the quoted accuracy, identical to the observed limits.

10. Results

No evidence for physics beyond the SM was observed in any of the SRs. Based on the numbers of observed events in SR A, B and C and the background expectation shown in Table 3, 95% CL upper limits are set on the numbers of events in the different SRs from any scenario of physics beyond the SM using the profile likelihood and CLs prescriptions [64]. Uncertainties on the background expectation are treated as Gaussian-distributed nuisance parameters in the maximum likelihood fit, resulting in observed upper limits of 3.1, 3.1 and 4.9 events for SRs A, B and C, respectively. In the context of the GGM model, these limits translate into 95% upper limits on the visible cross section for new physics, defined by the product of cross section, branching ratio, acceptance and efficiency for the different SR definitions, of 0.6, 0.6 and 1.0 fb, respectively. As for background uncertainties, uncertainties on the luminosity, acceptance and efficiency are taken into account as Gaussian-distributed nuisance parameters in the maximum likelihood fit. Because the observed numbers of events are close to the expected numbers of background events for all three SRs, expected limits on the numbers of events from and visible cross section for new physics are, to the quoted accuracy, identical to the observed limits.

Limits are also set on the GGM squark and gluino masses as a function of the bino-like neutralino mass, making use of the SR (A or B) that provides the most stringent expected limit for the given neutralino mass. Figs. 6 and 7 show the expected and observed lower limits on the GGM gluino and squark masses, respectively, as a function of the neutralino mass. Three observed-limit contours are shown, corresponding to the nominal assumption for the SUSY production cross section as well as those derived by
reducing and increasing the cross section by one standard deviation of theoretical uncertainty (the combined uncertainty due to the PDFs and renormalisation and factorisation scales). For comparison the lower limits on the GGM gluino mass from ATLAS [1] based on 1 fb\(^{-1}\) from 2011 are also shown.

Including all sources of uncertainty other than the theoretical uncertainty, 95% CL upper limits on the cross section of the SP58 model are derived from the SR C result and displayed in Fig. 8 for the range \(\Lambda = 100–250\) TeV along with the overall production cross section and its theoretical uncertainty. For illustration the cross-section dependence as a function of the lightest neutralino mass in the GGM model with a bino-like lightest neutralino NLSP (the grey area indicates the region for which the squark mass is less than the bino mass, which is not considered here). The other sparticle masses are assumed to be decoupled. Further model parameters are \(\tan \beta = 2\) and \(c_{\text{NLSP}} < 0.1\) mm.

Fig. 7. Expected and observed 95% CL lower limits on the squark mass as a function of the neutralino mass in the GGM model with a bino-like lightest neutralino NLSP (the grey area indicates the region for which the squark mass is less than the bino mass, which is not considered here). The other sparticle masses are assumed to be decoupled. Further model parameters are \(\tan \beta = 2\) and \(c_{\text{NLSP}} < 0.1\) mm.

Fig. 8. Expected and observed 95% CL upper limits on the sparticle production cross section in the SP58 model, and the NLO cross-section prediction, as a function of \(\Lambda\) and the lightest neutralino and chargino masses. Further SP58 model parameters are \(M_{\text{mass}} = 2\Lambda\), \(N_1 = 1\), \(\tan \beta = 15\) and \(c_{\text{NLSP}} < 0.1\) mm. Limits are set based on SR C.

Fig. 9. Expected and observed 95% CL upper limits on the KK particle production cross section times branching ratio to two photons in the UED model, and the LO cross-section prediction times branching ratio, as a function of \(1/R\) and the KK quark (Q\(^*\)) and KK gluon (g\(^*\)) masses. The ±1σ expected-limit error band overlaps the observed limit contour and is too narrow to be distinguished. No error is shown for the UED cross section since the cross-section calculation is available only to LO (see text for further discussion). The UED model parameters are \(N = 6\), \(M_D = 5\) TeV and \(AR = 20\). Limits are set based on SR A.

Computed at LO, in the limit calculation degrades the limit on \(1/R\) by a few GeV.

11. Conclusions

A search for events with two photons and substantial \(E_{T}\text{miss}\), performed using 4.8 fb\(^{-1}\) of 7 TeV pp collision data recorded with the ATLAS detector at the LHC, is presented. The sensitivity to different new physics models producing this final state was optimised by defining three different signal regions. No significant excess above the expected background is found in any signal region. The results are used to set model-independent 95% CL upper limits on possible contributions from new physics. In addition, under the GGM hypothesis, considering cross sections one standard deviation of theoretical uncertainty below the nominal value, a lower limit on the gluino/squark mass of 1.07 TeV/0.87 TeV is determined for bino masses above 50 GeV. Under similar assumptions, a lower limit of 196 TeV is set on the SUSY-breaking scale \(\Lambda\) of the SP58 model. Considering nominal values of the leading-order UED cross section, a lower limit of 1.40 TeV is set on the UED compactification scale \(1/R\). These results provide the most stringent tests of these models to date.

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ATLAS Collaboration

1 School of Chemistry and Physics, University of Adelaide, Adelaide, Australia
2 Physics Department, SUNY Albany, Albany, NY, United States
3 Department of Physics, University of Alberta, Edmonton, AB, Canada
4 (a) Department of Physics, Ankara University, Ankara, (b) Department of Physics, Dumlupinar University, Kayseri; (c) Department of Physics, Gaziev University, Ankara; (d) Division of Physics, TOBB University of Economics and Technology, Ankara, (e) Turkish Atomic Energy Authority, Ankara, Turkey
5 LAP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France
6 High Energy Physics Division, Argonne National Laboratory, Argonne, IL, United States
7 Department of Physics, University of Arizona, Tucson, AZ, United States
8 Department of Physics, The University of Texas at Arlington, Arlington, TX, United States
9 Physics Department, University of Athens, Athens, Greece
10 Physics Department, National Technical University of Athens, Zografou, Greece
11 Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
12 Instituto de Física d'Altes Energies and Departament de Física de la Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain
13 (a) Institute of Physics, University of Belgrade, Belgrade, (b) Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
14 Department for Physics and Technology, University of Bergen, Bergen, Norway
15 Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, CA, United States
16 Department of Physics, Humboldt University, Berlin, Germany
17 Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland
18 School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
19 (a) Department of Physics, Bogazici University, Istanbul; (b) Division of Physics, Dogus University, Istanbul; (c) Department of Physics Engineering, Gaziantep University, Gaziantep;
20 (a) Department of Physics, Istanbul Technical University, Istanbul, Turkey
21 (a) INFN Sezione di Bologna; (b) Dipartimento di Fisica, Università di Bologna, Bologna, Italy
22 Physikalisches Institut, University of Bonn, Bonn, Germany
23 Department of Physics, Boston University, Boston, MA, United States
24 (a) Universidad Federal do Rio de Janeiro COPPE/EE/IF, Rio de Janeiro; (b) Federal University of Juiz de Fora (UFJF), Juiz de Fora; (c) Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei; (d) Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil
25 Physics Department, Brookhaven National Laboratory, Upton, NY, United States
26 (a) National Institute of Physics and Nuclear Engineering, Bucharest; (b) University Politehnica Bucharest, Bucharest; (c) West University in Timisoara, Timisoara, Romania
27 Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
28 Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom