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


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ATLAS Collaboration

1. Introduction

This Letter reports on a search for diphoton (γγ) events with large missing transverse momentum (E_T^{miss}) in 4.8 fb^{-1} of proton–proton (pp) collision data at √s = 7 TeV recorded with the ATLAS detector at the Large Hadron Collider (LHC) in 2011, extending and superseding a prior study performed with 1 fb^{-1} detector at the LHC in 2011, extending large missing transverse momentum (E_T) in proton (p) collision data. 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.
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 $eV$-sized dimensions accessible only to gravity [31], with a $(4 + N)$-dimensional Planck scale ($M_D$) of a few TeV, the LKP would decay gravitationally via $\gamma^* \rightarrow \gamma + G$. $G$ represents a tower of $eV$-spaced graviton states, leading to a graviton mass between 0 and 1/R. With two decay chains per event, the final state would contain $\gamma + E_{\text{miss}}^{\gamma\gamma}$, where $E_{\text{miss}}^{\gamma\gamma}$ results from the escaping gravitons. Up to 1/R $\sim$ 1 TeV, the branching ratio to the diphoton and $E_{\text{miss}}^{\gamma\gamma}$ 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 $\approx$ 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 $\Lambda = 20$ [32]. The $\gamma^*$ mass is insensitive to $\Lambda$, while other KK masses typically change by a few per cent when varying $\Lambda R$ in the range 10–30. For 1/R $\approx$ 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 [33].

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 emission 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 $W(\rightarrow l\nu) + \gamma\gamma$ 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 $W(\rightarrow l\nu) + \gamma\gamma$ processes $\gamma\gamma$, and are estimated to be 2.0 $\pm$ 0.3 and 3 $\pm$ 3 for the $Z(\rightarrow \nu\nu) + \gamma\gamma$ and $W(\rightarrow l\nu) + \gamma\gamma$ 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 GEANT4-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 $|\eta| < 3.2$ to measure the energy and position of electrons and photons. 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 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 $|\eta| < 3.2$ to measure the energy and position of electrons and photons. 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.
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 [1], 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 $p_T^{\text{miss}}$ (and its magnitude $E_T^{\text{miss}}$) 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–$E_T^{\text{miss}}$ separation $\Delta \phi(\gamma, E_T^{\text{miss}})$ was defined as the azimuthal angle between the missing transverse momentum vector and either of the two selected photons, with $\Delta \phi_{\text{min}}(\gamma, E_T^{\text{miss}})$ the minimum value of $\Delta \phi(\gamma, E_T^{\text{miss}})$ 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 analysis. A total of 10 455 isolated $\gamma\gamma$ candidate events passing these selection requirements were observed in the data sample. The $E_T$ and sub-leading photon 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 $E_T^{\text{miss}}$, $H_T$ and $\Delta \phi_{\text{min}}(\gamma, E_T^{\text{miss}})$. SR A, optimised for gluino/squark production with a subsequent decay to a high-mass bino, requires large $E_T^{\text{miss}}$ and moderate $H_T$. SR B, optimised for gluino/squark production with a subsequent decay to a low-mass bino, requires moderate $E_T^{\text{miss}}$ and large $H_T$. SR C, optimised for the electroweak production of intermediate-mass gaugino pairs that dominates the SPS8 cross section in this regime, requires moderate $E_T^{\text{miss}}$ but makes no requirement on $H_T$. In addition, a requirement of $\Delta \phi_{\text{min}}(\gamma, E_T^{\text{miss}}) > 0.5$ 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.
tributions from the SPS8 MC sample with A and C, respectively. After imposing the final tical uncertainty only) together with the spectra from simulated GGM (m = 1000 GeV, m = 450 GeV), SPS8 (A = 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 γγ candidate events in the data (points, statistical uncertainty only) together with the spectra from simulated GGM (m_{γ} = 1000 GeV, m_{γ} = 450 GeV), SPS8 (A = 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 $Δ\phi(γ, E_{T}^{miss})$ spectrum of γγ candidate events in the data (points, statistical uncertainty only) together with the spectra from simulated GGM (m_{γ} = 1000 GeV, m_{γ} = 450 GeV), SPS8 (A = 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
Definition of the three SRs (A, B and C) based on the quantities $E_{T}^{miss}$, $H_{T}$ and $Δ\phi_{min}(γ, E_{T}^{miss})$.

<table>
<thead>
<tr>
<th>SR</th>
<th>$E_{T}^{miss}$</th>
<th>$H_{T}$</th>
<th>$Δ\phi_{min}(γ, E_{T}^{miss})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&gt; 200 GeV</td>
<td>&gt; 100 GeV</td>
<td>&gt; 125 GeV</td>
</tr>
<tr>
<td>B</td>
<td>&gt; 600 GeV</td>
<td>&gt; 1100 GeV</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>&gt; 0.5</td>
<td>&gt; 0.5</td>
<td>&gt; 0.5</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 $E_{T}^{miss}$ requirement of SR A, B and C, respectively. After imposing the final $E_{T}^{miss}$ requirement, no events remained for SR A and B, while two events remained for SR C.

Fig. 5 shows the $E_{T}^{miss}$ distribution for SR C, the expected contributions from the SPS8 MC sample with A = 190 TeV, and estimated background contributions from various sources (described below).

Following the procedure described in Ref. [61], the contribution to the large $E_{T}^{miss}$ diphoton sample from SM sources can be grouped into three primary components. The first of these, referred to as “QCD background”, arises from a mixture of processes that include γγ production as well as γ + jet and multijet events with at least one jet mis-reconstructed as a photon. The second background component, referred to as “EW background”, is due to W + X and tX events (here “X” can be any number of photons or jets) for which mis-reconstructed photons arise from electrons and jets, and for which final-state neutrinos produce significant $E_{T}^{miss}$. The QCD and EW backgrounds were estimated via dedicated control samples of data events. The third background component, referred to as “irreducible”, consists of W and Z bosons produced in association with two real photons, with a subsequent decay into one or more neutrinos.

To estimate the QCD background from γγ, γ + jet, and multijet events, a “QCD control sample” was selected from the diphoton trigger sample by selecting events for which at least one of the photon candidates passes the loose but not the tight photon identification. Events with electrons were vetoed to remove contamination from W → ev decays. The $H_{T}$ and $Δ\phi_{min}(γ, E_{T}^{miss})$ requirements associated with each of the three SRs were then applied, yielding three separate QCD samples, or “templates”. An estimate of the QCD background contamination in each SR was obtained from imposing the $E_{T}^{miss}$ requirement associated with the given SR upon the corresponding QCD template, after normalising each tem-plate to the diphoton data with $E_{T}^{miss} < 20$ GeV from the given SR. This yielded a QCD background expectation of 0.85 ± 0.30(stat) events for SR C. No events above the corresponding $E_{T}^{miss}$ requirement were observed for the A and B control samples, yielding an
The expected number of $\gamma\gamma$ events for each of the three signal regions. The uncertainties are statistical, arising from the limited numbers of events in the control samples, and systematic, the details of which are given in the text. For the irreducible background, the statistical uncertainty is due to limited numbers of events in the corresponding MC samples.

<table>
<thead>
<tr>
<th>SR A</th>
<th>SR B</th>
<th>SR C</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCD</td>
<td>0.07 ± 0.00 ± 0.07</td>
<td>0.27 ± 0.00 ± 0.27</td>
</tr>
<tr>
<td>Electroweak</td>
<td>0.03 ± 0.03 ± 0.01</td>
<td>0.09 ± 0.05 ± 0.02</td>
</tr>
<tr>
<td>$W(\rightarrow \ell v\nu) + \gamma\gamma$</td>
<td>$&lt; 0.01$</td>
<td>$&lt; 0.01$</td>
</tr>
<tr>
<td>$Z(\rightarrow \ell\ell\nu\nu) + \gamma\gamma$</td>
<td>$&lt; 0.01$</td>
<td>$&lt; 0.01$</td>
</tr>
<tr>
<td>Total</td>
<td>0.10 ± 0.03 ± 0.07</td>
<td>0.36 ± 0.05 ± 0.27</td>
</tr>
<tr>
<td>Observed events</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The contamination from cosmic-ray muons, estimated using MC samples and triggered events 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 $(m_{\tilde{g}}, m_{\tilde{\chi}}) = (800, 50)$ 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 $(m_{\tilde{g}}, m_{\tilde{\chi}}) = (800, 790)$ GeV to $(1300, 50)$ GeV. The $\mu$-SPH signal efficiency in SR C increases smoothly from 5.9% ($A = 100$ TeV) to
The various relative systematic uncertainties on the GGM, SPS8 and UED signal cross sections are summarised in Table 4 for the chosen reference points: \((m_{\tilde{g}},m_{\tilde{b}}') = (1000, 450)\) GeV for GGM, \(\Lambda = 190\) TeV for SPS8, and \(1/\sqrt{S} = 1.3\) 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 \(99.8\pm0.2\%\) 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 \(E_T^{miss}\) resolution between the measured performance and MC expectations \([55]\), contribute an uncertainty of \(\pm 0.1/0.5\%\) to \(\pm 5.3/16.1\%\) (GGM, SPS8 A/B), \(\pm 1.6\%\) to \(\pm 9.7\%\) (SPS8) and \(\pm 0.9\%\) to \(\pm 2\%\) (UED). Systematic uncertainties due to the \(H_T\) reconstruction, estimated by varying the energy scale and resolution of the individual objects entering \(H_T\), are below \(\pm 0.3\%\) (GGM, SPS8 A), \(\pm 0.1\%\) to \(\pm 7.3\%\) (GGM, SPS8 B) and \(\pm 0.1\%\) to \(\pm 1.1\%\) (UED). The systematic uncertainties from \(E_T^{miss}\) and \(H_T\) are taken to be fully correlated. Added in quadrature, the total systematic uncertainty on the signal yield varies between \(\pm 6\%\) and \(\pm 20\%\) (GGM), \(\pm 6\%\) and \(\pm 15\%\) (SPS8), and \(\pm 6\%\) and \(\pm 7\%\) (UED).

The PDF and scale uncertainties on the GGM and SPS8 yields is related to the different production mechanisms in the two models (see Section 2). In the case of UED, the PDF uncertainties were evaluated by using the MSTW2008 LO \([63]\) PDF error sets in the LO cross-section calculation and are about \(\pm 4\%\). The scale of \(\alpha_s\) in the LO cross section calculation was increased and decreased by a factor of two, leading to a systematic uncertainty of \(\pm 4.5\%\) and \(\pm 9\%\), respectively. NLO calculations are not yet available, so the LO cross sections were used for the limit calculation without any theoretical uncertainty, and the effect of PDF and scale uncertainties on the final limit is discussed separately.

### Table 4

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GGM</td>
</tr>
<tr>
<td>Integrated luminosity</td>
<td>3.9%</td>
</tr>
<tr>
<td>Trigger</td>
<td>0.5%</td>
</tr>
<tr>
<td>Photon identification</td>
<td>4.4%</td>
</tr>
<tr>
<td>Photon isolation</td>
<td>0.9%</td>
</tr>
<tr>
<td>Pile-up</td>
<td>0.8%</td>
</tr>
<tr>
<td>(E_T^{miss})</td>
<td>3.9%</td>
</tr>
<tr>
<td>(H_T)</td>
<td>0.0/2.1%</td>
</tr>
<tr>
<td>Signal MC statistics</td>
<td>3.0%</td>
</tr>
<tr>
<td>Total signal uncertainty</td>
<td>7.6/7.1%</td>
</tr>
<tr>
<td>PDF and scale</td>
<td>31%</td>
</tr>
<tr>
<td>Total</td>
<td>32%</td>
</tr>
</tbody>
</table>

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

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 CL\(_S\) 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 limits 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

\[\tan \beta < 0.1\text{mm}\]
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 and chargino masses. Further SP58 model parameters are \(M_{\text{miss}} = 2\Lambda, N_{11} = 1, \tan\beta = 15\) and \(\sigma_{\text{NLSP}} < 0.1\) mm. Limits are set based on SR C.

Fig. 9 shows the limit on the cross section times branching ratio for the UED model as a function of the compactification scale \(1/R\). For comparison the lower limits on the UED model parameters are \(M_{\text{miss}} = 2\Lambda, N_{11} = 1, \tan\beta = 15\) and \(\sigma_{\text{NLSP}} < 0.1\) mm. Limits are set based on SR A.

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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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 \(\sigma_{\text{NLSP}} < 0.1\) 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 \(M_{\text{miss}} = 2\Lambda, N_{11} = 1, \tan\beta = 15\) and \(\sigma_{\text{NLSP}} < 0.1\) 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 \(N = 6, M_0 = 5\) TeV and \(AR = 20\). Limits are set based on SR A.
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