Physics Letters B 710 (2012) 519–537

Contents lists available at SciVerse ScienceDirect

Physics Letters B

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Search for diphoton events with large missing transverse momentum in 1 fb^{-1} of 7 TeV proton–proton collision data with the ATLAS detector ☆

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ARTICLE INFO

Article history:
Received 17 November 2011
Received in revised form 3 February 2012
Accepted 16 February 2012
Available online 22 February 2012
Editor: H. Weerts

ABSTRACT

A search for diphoton events with large missing transverse momentum has been performed using 1.07 fb^{-1} of proton–proton collision data at $\sqrt{s} = 7$ TeV recorded with the ATLAS detector. No excess of events was observed above the Standard Model prediction and 95% Confidence Level (CL) upper limits are set on the production cross section for new physics. The limits depend on each model parameter space and vary as follows: $\sigma <$ (22–129) fb in the context of a generalised model of gauge-mediated supersymmetry breaking (GGM) with a bino-like lightest neutralino, $\sigma <$ (27–91) fb in the context of a minimal model of gauge-mediated supersymmetry breaking (SPS8), and $\sigma <$ (15–27) fb in the context of a specific model with one universal extra dimension (UED). A 95% CL lower limit of 805 GeV, for bino masses above 50 GeV, is set on the GGM gluino mass. Lower limits of 145 TeV and 1.23 TeV are set on the SPS8 breaking scale Λ and on the UED compactification scale $1/R$, respectively. These limits provide the most stringent tests of these models to date.

1. Introduction

This Letter reports on the search for diphoton ($\gamma\gamma$) events with large missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$) in 1.07 fb^{-1} of proton–proton (pp) collision data at $\sqrt{s} = 7$ TeV recorded with the ATLAS detector in the first half of 2011, extending a prior study performed with 36 pb^{-1} [1]. The results are interpreted in the context of three models of new physics: a general model of gauge-mediated supersymmetry breaking (GGM) [2–4], a minimal model of gauge-mediated supersymmetry breaking (SPS8) [5], and a model positing one universal extra dimension (UED) [6–8].

2. Supersymmetry

Supersymmetry (SUSY) [9–14] introduces a symmetry between fermions and bosons, resulting in a SUSY partner (sparticle) with identical quantum numbers except a difference by half a unit of spin for each Standard Model (SM) particle. As none of these sparticles have been observed, SUSY must be a broken symmetry if realized in nature. Assuming R-parity conservation [15,16], sparticles have to be produced in pairs. These would then decay through cascades involving other sparticles until the lightest SUSY particle (LSP) is produced, which is stable.

In gauge-mediated SUSY breaking (GMSB) models [17–21] the LSP is the gravitino $\tilde{G}$. GMSB experimental signatures are largely determined by the nature of the next-to-lightest SUSY particle (NLSP), which for a large part of the GMSB parameter space is the lightest neutralino $\tilde{\chi}_1^0$. Should the lightest neutralino have similar couplings as the SM U(1) gauge boson, also referred to as “bino” in this case, the final decay in the cascade would predominantly be $\tilde{\chi}_1^0 \to \gamma\tilde{G}$, with two cascades per event, leading to final states with $\gamma\gamma + E_{\mathrm{T}}^{\mathrm{miss}}$, where $E_{\mathrm{T}}^{\mathrm{miss}}$ results from the undetected gravitinos.

Searches for GMSB performed at the Tevatron [22,23] were optimized to be sensitive to a minimal GMSB model (SPS8) [5]. To reduce the number of free parameters in this model, several assumptions are made. These assumptions lead to a mass hierarchy in which squarks and gluinos are much heavier than the lightest neutralino and chargino $\tilde{\chi}_1^{\pm}$. The SUSY breaking mass scale felt by the low-energy sector, Λ, is the only free parameter of the SPS8 model. The other model parameters are fixed to the following values: the messenger mass $M_{\mathrm{mess}} = 2\Lambda$, the number of copies of $5 + \bar{5}$ SU(5) messengers $N_5 = 1$, the ratio of the vacuum expectation values of the two Higgs doublets $\tan\beta = 15$, and the Higgs sector mixing parameter $\mu > 0$. The NLSP is assumed to decay promptly ($c\tau_{\mathrm{NLSP}} < 0.1$ mm). At the present LHC energy the main contribution to the production cross section in the SPS8 model is via gaugino pair production, i.e. production of $\tilde{\chi}_2^0\tilde{\chi}_1^{\pm}$ or $\tilde{\chi}_2^0\tilde{\chi}_2^0$ pairs. The contribution from gluino and/or squark pairs is below 10% of the production cross section due to their high masses. Besides the two photons and the two gravitinos, jets, leptons, and gauge bosons may be produced in the cascades. This Letter presents the first limits on the SPS8 model at the LHC. Furthermore, a GGM SUSY model is considered in which the

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doi:10.1016/j.physletb.2012.02.054

gluino and neutralino masses are treated as free parameters. The other sparticle masses are fixed at ~ 1.5 TeV, leading to a dominant production mode at $\sqrt{s} = 7$ TeV of a pair of gluinos via the strong interaction that would decay via cascades into the bino-like neutralino NLSP. Jets may be produced in the cascades from the gluino decays if kinematically allowed. Further model parameters are fixed to $\tan\beta = 2$ and $c\tau_{\mathrm{NLSP}} < 0.1$ mm. The decay into the wino-like neutralino NLSP is possible and was studied by the CMS Collaboration [24].

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) $R \approx 1\ \mathrm{TeV}^{-1}$. At the LHC, the main UED process would be the production via the strong interaction of a pair of first-level KK quarks and/or gluons [25]. These would decay via cascades involving other KK particles until reaching the lightest KK particle (LKP), i.e. the first level KK photon γ^*. 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 [26], with a $(4+N)$-dimensional Planck scale (M_D) of a few TeV, the LKP would decay gravitationally via $\gamma^* \to \gamma + G$. 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 $\gamma\gamma + E_{\mathrm{T}}^{\mathrm{miss}}$, where $E_{\mathrm{T}}^{\mathrm{miss}}$ results from the escaping gravitons. Up to $1/R \sim 1$ TeV, the branching ratio to the diphoton and $E_{\mathrm{T}}^{\mathrm{miss}}$ 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 Λ, the ultraviolet cut-off used in the calculation of radiative corrections to the KK masses. This analysis sets Λ such that $\Lambda R = 20$. The γ^* mass is insensitive to Λ, while other KK masses typically change by a few per cent when varying ΛR in the range 10–30. For $1/R = 1200$ GeV, the masses of the first-level KK photon, quark, and gluon are 1200, 1387 and 1468 GeV, respectively [27]. Further details of the model are given in Ref. [1].

4. Simulated samples

For the GGM model, the SUSY mass spectra were calculated using SUSPECT 2.41 [28] and SDECAY 1.3 [29]. The Monte Carlo (MC) signal samples were produced using PYTHIA 6.423 [30] with MRST2007 LO* [31] parton distribution functions (PDF). Cross sections were calculated at next-to-leading order (NLO) using PROSPINO 2.1 [32,33]. For the SPS8 model, the SUSY mass spectra were calculated using ISAJET 7.80 [34]. The MC signal samples were produced using HERWIG++ 2.4.2 [35] with MRST2007 LO* PDF. NLO cross sections were calculated using PROSPINO. In the case of the UED model, MC signal samples were generated using the UED model as implemented at leading order (LO) in PYTHIA [27].

The "irreducible" background from $(W \to \ell\nu)\gamma\gamma$ and $(Z \to \nu\nu)\gamma\gamma$ production was simulated at LO using MadGraph 4 [36] with CTEQ6L1 [37] PDF. Parton showering and fragmentation were simulated with PYTHIA. NLO cross sections and scale uncertainties from Refs. [38,39] were used. In all cases the underlying event was simulated within the respective generator.

All samples were processed through the GEANT4-based simulation [40] of the ATLAS detector [41]. In addition, the signal samples were overlaid with simulated minimum bias events to model the average number of six pp interactions per bunch crossing (pile-up) experienced during the considered data-taking period. More details may be found in Ref. [1].

5. ATLAS detector

The ATLAS detector [42] is a multi-purpose apparatus with a forward–backward symmetric cylindrical geometry and nearly 4π solid angle coverage. Closest to the beamline are tracking devices comprised of layers of silicon-based pixel and strip detectors covering $|\eta| < 2.5$[1] and straw-tube detectors covering $|\eta| < 2.0$, located inside a thin superconducting solenoid that provides a 2 T magnetic field. The straw-tube detectors also provide discrimination between electrons and charged hadrons based on transition radiation. Outside the solenoid, fine-granularity lead/liquid-argon (LAr) electromagnetic (EM) calorimeters provide coverage for $|\eta| < 3.2$ to measure the energy and position of electrons and photons. In the region $|\eta| < 2.5$, the EM calorimeters are segmented into three layers in depth. The second layer, in which most of the EM shower energy is deposited, is divided into cells of granularity of $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$. The first layer is segmented with finer granularity to provide discrimination between single photons and overlapping photons coming from the decays of neutral mesons. 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 copper and liquid-argon technology is used for hadronic calorimeters in the end-cap region $1.5 < |\eta| < 3.2$. In the forward region $3.2 < |\eta| < 4.5$ liquid-argon calorimeters with copper and tungsten absorbers measure the electromagnetic and hadronic energy. A muon spectrometer consisting of three superconducting toroidal magnet systems, tracking chambers, and detectors for triggering surrounds the calorimeter system.

6. Object reconstruction

The reconstruction of converted and unconverted photons and of electrons is described in Refs. [43] and [44], respectively.

Converted photons have EM calorimeter clusters matched to tracks coming from a conversion vertex. A conversion vertex is either a vertex that has two tracks with large transition radiation in the straw-tube detector and an invariant mass of the two tracks consistent with a massless particle, i.e. a photon, or one track with large transition radiation that has no associated hits in the pixel layer closest to the beam line. Electrons have a track matched to the EM calorimeter cluster, and the track must have hits in the silicon detectors, momentum not smaller than one tenth the cluster energy, and transverse momentum of at least 2 GeV. Clusters matched to neither a track or tracks coming from a conversion vertex nor an electron track as described above are classified as unconverted photons. A heuristic using the pixel hits closest to the beam line and the track momenta is applied to choose between the photon and electron interpretation in cases where the object can be both.

[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,ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$.

Photon candidates were required to be within $|\eta| < 1.81$, the value being chosen by an optimization of the signal acceptance versus background rejection, and to be outside the transition region $1.37 < |\eta| < 1.52$ between the barrel and the end-cap calorimeters. The analysis used "loose" and "tight" photon selections [43]. The loose photon selection includes a limit on the fraction of the energy deposit in the hadronic calorimeter as well as a requirement that the transverse width of the shower, measured in the middle layer of the EM calorimeter, be consistent with the narrow shape expected for an EM shower. The tight photon selection additionally uses shape information from the first layer to distinguish between isolated photons and photons from the decay of neutral mesons.

The reconstruction of E_T^{miss} is based on energy deposits in calorimeter cells inside three-dimensional clusters with $|\eta| < 4.5$ and is corrected for contributions from muons, if any [45]. The cluster energy is calibrated to correct for the non-compensating calorimeter response, energy loss in dead material, and out-of-cluster energy.

Jets were reconstructed using the anti-k_t jet algorithm [46] with four-momentum recombination and radius parameter $R = 0.4$ in η–ϕ space. They were required to have $p_T > 25$ GeV and $|\eta| < 2.8$.

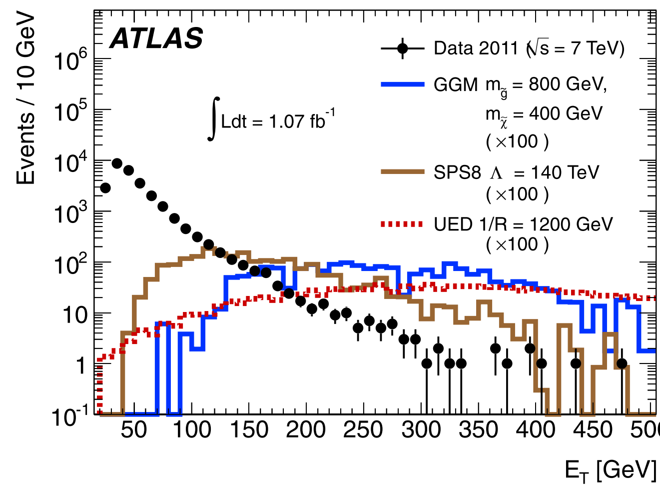

Fig. 1. The E_T spectrum of the leading photon in the $\gamma\gamma$ candidate events in the data (points, statistical uncertainty only) together with the spectra from simulated GGM ($m_{\tilde{g}}, m_{\tilde{\chi}_1^0} = (800, 400)$ GeV), SPS8 ($\Lambda = 140$ TeV), and UED ($1/R = 1200$ GeV) samples, prior to the application of the $E_T^{miss} > 125$ GeV cut. The signal samples are scaled by a factor of 100 for clarity.

7. Data analysis

The data sample, corresponding to an integrated luminosity of (1.07 ± 0.04) fb^{-1}, was selected by a trigger requiring two loose photon candidates with a transverse energy (E_T) above 20 GeV. In the offline analysis events were retained if they contained at least two tight photon candidates with $E_T > 25$ GeV. In addition, a photon isolation cut was applied, whereby the E_T deposit in a cone of radius 0.2 in the η–ϕ space around the centre of the cluster, excluding the cells belonging to the cluster, had to be less than 5 GeV. The E_T was corrected for leakage from the photon energy outside the cluster and for soft energy deposits from pile-up interactions. A cut of $E_T^{miss} > 125$ GeV [1] defined the signal region. Preference was given to a common signal region for the three models considered.

A total of 27 293 $\gamma\gamma$ candidate events were observed passing all selections except the E_T^{miss} cut. The E_T distribution of the leading photon for events in this sample is shown in Fig. 1. Also shown are the E_T spectra obtained from GGM MC samples for $m_{\tilde{g}} = 800$ GeV and $m_{\tilde{\chi}_1^0} = 400$ GeV, from SPS8 MC samples with $\Lambda = 140$ TeV, and from UED MC samples for $1/R = 1200$ GeV, representing model parameters near the expected exclusion limit. After the $E_T^{miss} > 125$ GeV cut, 5 candidate events survived.

8. Background estimation

Following the procedure described in Ref. [1], the contribution to large E_T^{miss} diphoton events from SM sources can be grouped into two primary components and estimated with dedicated control samples using data. The first of these components, referred to as "QCD background" for brevity, arises from a mixture of processes that include $\gamma\gamma$ production as well as γ + jet and multijet events with at least one jet mis-reconstructed as a photon. The second background component is due to $W + X$ and $t\bar{t}$ events, where mis-reconstructed photons can arise from electrons and jets, for which final-state neutrinos produce significant E_T^{miss}.

In order to estimate the QCD background from $\gamma\gamma$, γ + jet, and multijet events, a "QCD control sample" was extracted from the diphoton trigger sample by selecting events for which at least one of the photon candidates does not pass the tight photon identification. Electrons were vetoed to remove contamination from $W \to e\nu$ decays. The QCD background contamination in the signal region $E_T^{miss} > 125$ GeV was obtained from this QCD template after normalizing it to data in the region $E_T^{miss} < 20$ GeV. This gives a QCD background expectation in the signal region of 0.8 ± 0.3(stat) events. An alternate model for the QCD background was obtained using a sample of dielectron events, with no jets, selected by requiring two electrons with $E_T > 25$ GeV and $|\eta| < 1.81$ and an invariant mass consistent with the Z boson mass. As confirmed by MC simulation, the E_T^{miss} spectrum of this $Z \to ee$ sample with no additional jets, which is dominated by the calorimeter response to two genuine EM objects, accurately represents the E_T^{miss} spectrum of SM $\gamma\gamma$ events. This spectrum was normalized in the same way as the QCD control sample. An uncertainty of 0.6 events was assigned as the systematic uncertainty on the background prediction from the relative fractions of $\gamma\gamma$, γ + jet, and multijet events using the difference between the background estimates obtained using the QCD and the $Z \to ee$ templates, yielding the result of 0.8 ± 0.3(stat) ± 0.6(syst) events. The E_T^{miss} spectra of the QCD background and the $\gamma\gamma$ sample are shown in Fig. 2.

The second significant background contribution, from $W + X$ and $t\bar{t}$ events, was estimated via an "electron–photon" control sample composed of events with at least one photon and one electron, each with $E_T > 25$ GeV, and scaled by the probability for an electron to be mis-reconstructed as a tight photon, as estimated from a study of the Z boson in the ee and $e\gamma$ sample. The scaling factor varies between 5% and 17% as a function of η, since it depends on the amount of material in front of the calorimeter. Events with two or more photons were vetoed from the control sample to keep it orthogonal to the signal sample. In case of more than one electron, the one with the highest p_T was used. The E_T^{miss} spectrum for the scaled electron–photon control sample is shown in Fig. 3, where it is compared to the expected contributions from various background sources as computed from MC simulation. The electron–photon control sample has a significant contamination from $Z \to ee$ events, in which one electron is mis-reconstructed as a photon, and from QCD processes mentioned above. Both of these contaminations must be subtracted in order to extract the contribution to the E_T^{miss} distribution from events with genuine E_T^{miss}, such as $W + X$ and $t\bar{t}$. The contribution from QCD and $Z \to ee$ events was estimated by normalizing the QCD control sample to the scaled electron–photon E_T^{miss} distribution in the re-

Table 1
Number of observed $\gamma\gamma$ candidates in various E_T^{miss} ranges in the data, as well as the expected numbers of SM background events estimated from the QCD and electron–photon control samples and, for the irreducible $Z(\to \nu\bar{\nu}) + \gamma\gamma$ and $W(\to \ell\nu) + \gamma\gamma$ processes, from MC simulation. Also shown are the expected numbers of signal events from GGM with $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (800, 400)$ GeV, SPS8 with $\Lambda = 140$ TeV, and UED with $1/R = 1200$ GeV. The uncertainties are statistical only. The $E_T^{miss} < 20$ GeV region (first row) is used to normalize the QCD background to the number of observed $\gamma\gamma$ candidates.

E_T^{miss} range [GeV]	Data events	Predicted background events				Expected signal events		
		Total	QCD	$W/t\bar{t}(\to e\nu) + X$	Irreducible	GGM	SPS8	UED
0–20	20881	–	–	–	–	0.20 ± 0.05	0.22 ± 0.04	0.02 ± 0.01
20–50	6304	5968 ± 29	5951 ± 28	13.3 ± 8.1	3.55 ± 0.35	0.45 ± 0.08	1.53 ± 0.10	0.11 ± 0.01
50–75	86	87.1 ± 3.3	60.9 ± 2.8	25.2 ± 1.7	1.01 ± 0.16	0.48 ± 0.08	2.19 ± 0.12	0.14 ± 0.01
75–100	11	14.7 ± 1.2	6.7 ± 0.9	7.4 ± 0.8	0.52 ± 0.10	0.75 ± 0.10	2.09 ± 0.11	0.15 ± 0.01
100–125	6	4.9 ± 0.7	1.6 ± 0.4	3.0 ± 0.5	0.32 ± 0.08	1.20 ± 0.12	2.53 ± 0.13	0.29 ± 0.02
>125	5	4.1 ± 0.6	0.8 ± 0.3	3.1 ± 0.5	0.23 ± 0.05	17.2 ± 0.5	12.98 ± 0.28	9.67 ± 0.11

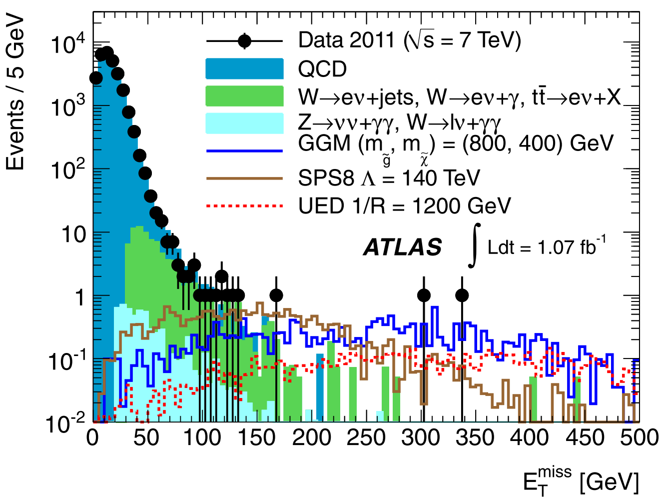

Fig. 2. E_T^{miss} spectra for the $\gamma\gamma$ candidate events in data (points, statistical uncertainty only) and the estimated QCD background (normalized to the number of $\gamma\gamma$ candidates with $E_T^{miss} < 20$ GeV), the $W(\to e\nu) + \text{jets}/\gamma$ and $t\bar{t}(\to e\nu) + \text{jets}$ backgrounds as estimated from the electron–photon control sample, and the irreducible background of $Z(\to \nu\bar{\nu}) + \gamma\gamma$ and $W(\to \ell\nu) + \gamma\gamma$. Also shown are the expected signals from GGM ($m_{\tilde{g}}, m_{\tilde{\chi}_1^0} = (800, 400)$ GeV), SPS8 ($\Lambda = 140$ TeV), and UED ($1/R = 1200$ GeV) samples.

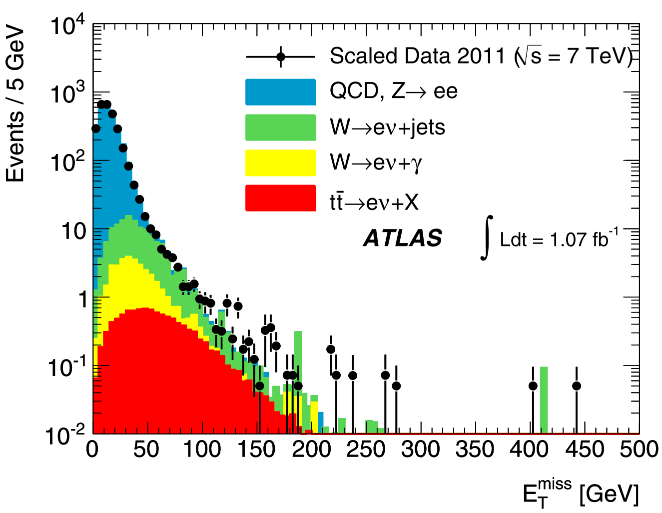

Fig. 3. E_T^{miss} spectrum for the electron–photon control sample in data (points, statistical uncertainty only), normalized according to the probability for an electron to be mis-reconstructed as a tight photon, compared to the expected backgrounds displayed by components (stacked histograms). For the purpose of this comparison, the expected contributions from $W(\to e\nu) + \text{jets}/\gamma$ and $t\bar{t}(\to e\nu) + \text{jets}$ events are taken from MC simulation.

gion $E_T^{miss} < 20$ GeV where they dominate, as shown in Fig. 3. This distribution was then subtracted from the scaled electron–photon control sample, yielding a prediction for the contribution to the high-E_T^{miss} diphoton sample from $W + X$ and $t\bar{t}$ events. This procedure led to an estimate of the background from $W + X$ and $t\bar{t}$ production of 3.1 ± 0.5(stat) events in the signal region. A systematic uncertainty of 0.06 events was assigned by using the $Z \to ee$ template in place of the QCD template when subtracting the contamination due to $Z \to ee$ and QCD processes. The contribution from WW events to the electron–photon control sample was estimated using MC simulation and found to be negligible.

A parallel study using MC samples of $W(\to e\nu) + \text{jets}/\gamma$ and $t\bar{t}(\to e\nu) + \text{jets}$, rather than the electron–photon control sample, gave an estimate of 1.8 ± 1.2(stat) background events. The difference was taken as an estimate of the systematic uncertainty, yielding the result of $3.1 \pm 0.5(\text{stat}) \pm 1.4(\text{syst})$ events. Also included in the quoted systematic uncertainty is the relative uncertainty ($\pm 10\%$) on the probability for an electron to be mis-reconstructed as a photon.

A small irreducible background of $0.23 \pm 0.05(\text{stat}) \pm 0.04(\text{syst})$ events from $Z(\to \nu\bar{\nu}) + \gamma\gamma$ and $W(\to \ell\nu) + \gamma\gamma$ events was estimated from MC simulation. The systematic uncertainty accounts for variations in the factorization and renormalization scales in the NLO calculations. The contamination from cosmic-ray muons was found to be negligible.

Fig. 2 shows the E_T^{miss} spectrum of the selected $\gamma\gamma$ candidates, superimposed on the estimated backgrounds. Table 1 summarizes the number of observed $\gamma\gamma$ candidates, the expected backgrounds, and three representative GGM, SPS8, and UED signal expectations, in several E_T^{miss} ranges. No indication of an excess at high E_T^{miss} values, where the signal is expected to dominate, is observed.

9. Signal efficiencies and systematic uncertainties

The GGM signal efficiency was determined using MC simulation over an area of the GGM parameter space that ranges from 400 GeV to 1200 GeV for the gluino mass, and from 50 GeV to within 20 GeV of the gluino mass for the neutralino mass. The efficiency increases smoothly from 5.5% to 31% for $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (400, 50)$ GeV to $(1200, 1100)$ GeV. The SPS8 signal efficiency increases smoothly from 9.2% ($\Lambda = 80$ TeV) to 29.4% ($\Lambda = 220$ TeV). The UED signal efficiency, also determined using MC simulation, increases smoothly from 48.9% ($1/R = 1000$ GeV) to 52.6% ($1/R = 1500$ GeV).

The various relative systematic uncertainties on the GGM, SPS8, and UED signal cross sections are summarized in Table 2 for the chosen GGM, SPS8, and UED reference points. The uncertainty on the luminosity is 3.7% [47,48]. The trigger efficiency of the required diphoton trigger was estimated from the efficiency of the corresponding single photon trigger, which was estimated using a bootstrap method [49]. The result is $99.92^{+0.04}_{-0.18}\%$ for events passing

Table 2
Relative systematic uncertainties on the expected signal yield for GGM with $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0}) = (800, 400)$ GeV, SPS8 with $\Lambda = 140$ TeV, and UED with $1/R = 1200$ GeV. No PDF and scale uncertainties are given for the UED case as the cross section is evaluated only to LO.

Source of uncertainty	Uncertainty		
	GGM	SPS8	UED
Integrated luminosity	3.7%	3.7%	3.7%
Trigger	0.6%	0.6%	0.6%
Photon identification	3.9%	3.9%	3.7%
Photon isolation	0.6%	0.6%	0.5%
Pile-up	1.3%	1.3%	1.6%
E_T^{miss} reconstruction and scale	1.7%	5.6%	0.7%
LAr readout	1.0%	0.7%	0.4%
Signal MC statistics	2.9%	2.3%	1.8%
Total signal uncertainty	6.6%	8.3%	6.0%
PDF and scale	31%	5.5%	–
Total	32%	10%	6.0%

all selections except the final E_T^{miss} cut. 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 (SUSY and UED) samples. A conservative systematic uncertainty of 0.6% 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. [1], result in an uncertainty of 3.9% for the GGM and SPS8 signals and 3.7% for the UED signal. The uncertainty from the photon isolation was estimated by varying the energy leakage and the pile-up corrections independently, resulting in an uncertainty of 0.6% for GGM and SPS8 and 0.5% for UED. The influence of pile-up on the signal efficiency, evaluated by comparing GGM/SPS8 (UED) MC samples with different pile-up configurations, leads to a systematic uncertainty of 1.3%(1.6%). Systematic uncertainties due to the E_T^{miss} reconstruction, estimated by varying the cluster energies within established ranges and the E_T^{miss} resolution between the measured performance and MC expectations, contribute an uncertainty of 0.1% to 12.4% (GGM), 1.7% to 13.8% (SPS8), and 0.5% to 1.5% (UED). A systematic uncertainty was also assigned to account for temporary failures of the LAr calorimeter readout during part of the data-taking period, which was not modeled in the MC samples. Electrons and photons were removed from the afflicted area, but jets, being larger objects, were not. Jet energy corrections were therefore applied. Varying these corrections over their range of uncertainty results in systematic uncertainties of 1.0%, 0.7%, and 0.4% for GGM, SPS8, and UED, respectively. Added in quadrature, the total systematic uncertainty on the signal yield varies between 6.3% and 15% (GGM), 6.2% and 15% (SPS8), and 5.8% and 6.0% (UED).

The PDF uncertainties on the GGM (SPS8) cross sections were evaluated by using the CTEQ6.6M PDF error sets [50] in the PROSPINO cross section calculation and range from 12% to 44% (4.7% to 6.6%). The factorization and renormalization scales in the NLO PROSPINO calculation were increased and decreased by a factor of two, leading to a systematic uncertainty between 16% and 23% (1.7% and 6.7%) on the expected cross sections. The different impact of the PDF and scale uncertainties of 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 [51] PDF error sets in the LO cross section calculation and are about 4%. The scale of α_s in the LO cross section calculation was increased and decreased by a factor of two, leading to a systematic uncertainty of 4.5% and 9%, respectively. NLO calculations are not yet available, but are expected to be much larger than the PDF and scale uncertainties. Thus, 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 given separately.

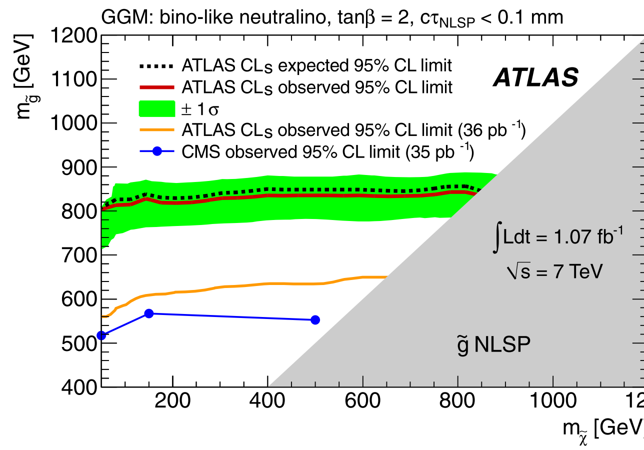

Fig. 4. Expected and observed 95% CL lower limits on the gluino mass as a function of the neutralino mass in the GGM model with a bino-like lightest neutralino NLSP (the grey area indicates the region where the NLSP is the gluino, which is not considered here). The other sparticle masses are fixed to ~ 1.5 TeV. Further model parameters are $\tan\beta = 2$ and $c\tau_{NLSP} < 0.1$ mm. The previous ATLAS [1] and CMS [52] limits are also shown.

10. Results

Based on the observation of 5 events with $E_T^{miss} > 125$ GeV and a background expectation of $4.1 \pm 0.6(\text{stat}) \pm 1.6(\text{syst})$ events, a 95% CL upper limit is set on the number of events in the signal region from any scenario of physics beyond the SM using the profile likelihood and CL_s method [53]. The result is 7.1 events at 95% CL.

Further, 95% CL upper limits on the cross sections of the considered models are calculated, including all systematic uncertainties except for theory uncertainties, i.e. PDF and scale. In the GGM model the upper limit on the cross section is (22–129) fb, where the larger value corresponds to $m_{\tilde{g}}, m_{\tilde{\chi}_1^0} = (400, 50)$ GeV. For $m_{\tilde{\chi}_1^0} \geqslant 150$ GeV, the limit is below 30 fb, reaching 22 fb for heavy neutralino masses. Fig. 4 shows the expected and observed lower limits on the GGM gluino mass as a function of the neutralino mass. For comparison the lower limits from ATLAS [1] and CMS [52] based on the 2010 data are also shown. The total systematic uncertainty includes the theory uncertainties, which are dominant. Excluding the PDF and scale uncertainty in the limit calculation would improve the observed limit on the gluino mass by ~10 GeV.

In the SPS8 model the cross section limit is $\sigma < (27\text{–}91)$ fb as shown in Fig. 5, corresponding to $\Lambda = 220\text{–}80$ TeV. For illustration the cross section dependence as a function of the lightest neutralino and chargino masses is also shown. A lower limit on the SPS8 breaking scale $\Lambda > 145$ TeV at 95% CL is set including the theory uncertainties, i.e. PDF and scale uncertainties, in the total systematic uncertainty.

For the UED model the cross section limit is $\sigma < (15\text{–}27)$ fb for $1/R = 1000\text{–}1500$ GeV. Fig. 6 shows the limit on the cross section times branching ratio for the UED model, which is $\sigma < (13\text{–}15)$ fb. For illustration the cross section dependence as a function of the KK quark and KK gluon masses is also shown. A lower limit on the UED compactification scale $1/R > 1.23$ TeV at 95% CL is set. In this case PDF and scale uncertainties are not included when calculating

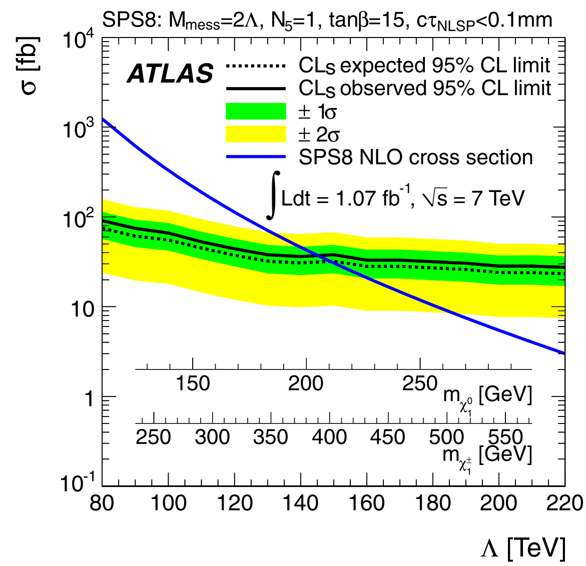

Fig. 5. Expected and observed 95% CL upper limits on the sparticle production cross section in the SPS8 model, and the NLO cross section prediction, as a function of Λ and the lightest neutralino and chargino masses. Further SPS8 model parameters are $M_{\text{mess}} = 2\Lambda$, $N_5 = 1$, $\tan\beta = 15$, and $c\tau_{\text{NLSP}} < 0.1$ mm.

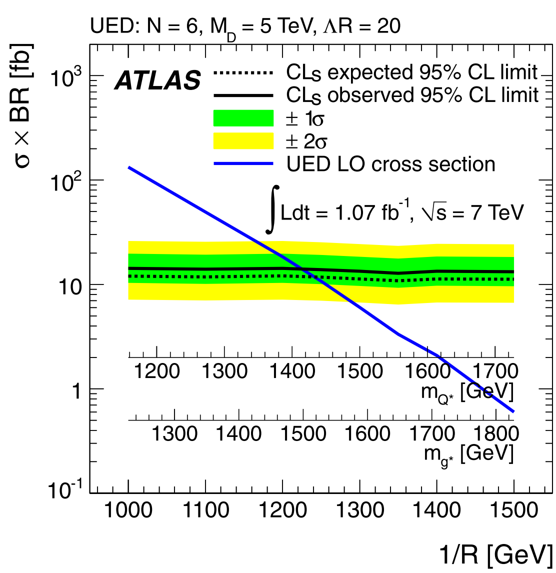

Fig. 6. Expected and observed 95% CL upper limits on the KK particle production cross section times branching fraction to two photons in the UED model, and the LO cross section prediction times branching fraction, as a function of $1/R$ and the KK quark (Q^*) and KK gluon (g^*) masses. The UED model parameters are $N = 6$, $M_D = 5$ TeV, and $\Lambda R = 20$.

the limits. Including PDF and scale uncertainties computed at LO degrade the limit on $1/R$ by a few GeV.

11. Conclusions

A search for events with two photons and $E_T^{\text{miss}} > 125$ GeV, performed using 1.07 fb^{-1} of 7 TeV pp collision data recorded with the ATLAS detector at the LHC, found 5 events with an expected background of $4.1 \pm 0.6(\text{stat}) \pm 1.6(\text{syst})$. The results are used to set a model-independent 95% CL upper limit of 7.1 events from new physics. Upper limits at 95% CL are also set on the production cross section for three particular models of new physics: $\sigma < (22\text{–}129)$ fb for the GGM model, $\sigma < (27\text{–}91)$ fb for the SPS8 model, and $\sigma < (15\text{–}27)$ fb for the UED model. Under the GGM hypothesis, a lower limit on the gluino mass of 805 GeV is determined for bino masses above 50 GeV. A lower limit of 145 TeV is set on the SPS8 breaking scale Λ, which is the first limit on the SPS8 model at the LHC. A lower limit of 1.23 TeV is set on the UED compactification scale $1/R$. These results provide the most stringent tests of these models to date, significantly improving upon previous best limits of 560 GeV [1] for the GGM gluino mass, 124 TeV [23] for Λ in SPS8, and 961 GeV [1] for $1/R$ in UED, respectively.

Acknowledgements

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF, DNSRC and Lundbeck Foundation, Denmark; ARTEMIS, European Union; IN2P3-CNRS, CEA-DSM/IRFU, France; GNAS, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT, Greece; ISF, MINERVA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTD, Serbia; MSSR, Slovakia; ARRS and MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA) and in the Tier-2 facilities worldwide.

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