Search for extra dimension in the diphoton final state with ATLAS

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on behalf of the Atlas collaboration

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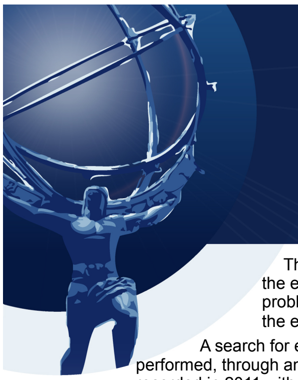


The large difference between the Planck scale and the electroweak scale, known as the hierarchy problem, has been addressed in some models through the existence of extra spatial dimensions.

A search for evidence of extra spatial dimensions has been performed, through an analysis of the diphoton final state in data recorded in 2011 with the ATLAS detector at the Large Hadron Collider.

The analysis uses data corresponding to an integrated luminosity of 2.12 fb^{-1} of $\sqrt{s}$ = 7 TeV proton-proton collisions. The diphoton invariant mass spectrum is observed to be in good agreement with the expected Standard Model (SM) background. The results set 95% CL lower limits on the fundamental Planck scale in the context of the Arkani-Hamed, Dimopoulos, Dvali (ADD) model and on the lightest Kaluza Klein (KK) excitation mass in the context of the Randall-Sundrum (RS) model. **The results are the most stringent limits to date on these two extra dimension models.**

The Arkani-Hamed, Dimopoulos, Dvali (ADD) Model (PLB,429,263):

✓n flat additional dimensions compactified in which only gravity propagates. The Planck scale (M_D) is related to the compactification radius (R). Resolving the hierarchy problem requires small values of 1/R which lead to an almost continuum spectrum of KK gravitons states

✓ Exchange of virtual gravitons can be parameterized by the strength of gravity $\eta_G = F/M_S^4$ with M_S the Ultra-Violet cutoff of the KK spectrum. F is a dimensionless parameter with several definitions depending of the theoretical formalism.

$$\mathcal{F} = 1, \text{ (GRW)};$$

$$\mathcal{F} = \begin{cases} \log\left(\frac{M_S^2}{\hat{s}}\right) & n = 2 \\ \frac{2}{n-2} & n > 2 \end{cases}, \text{ (HLZ)};$$

$$\mathcal{F} = \pm\frac{2}{\pi}, \text{ (Hewett)}.$$

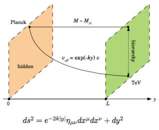
The Randall-Sundrum Model (PRL,83:3370-3373):

✓ 5 dimensions bounded by 2 (3+1) branes

✓ SM localized on one brane, gravity penetrates all dimensions

✓ Series of massive graviton (KK Tower) is produced

✓ The model can be expressed in term of k/M_{PL} and M_G mass of the lightest KK excitation



$$ds^2 = e^{-2k|y|}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$

Trigger and Event Selection

✓ Trigger : 2 clusters, E_T>20 GeV (fully efficient for high mass events passing the offline analysis cuts)

✓ At least one primary vertex with at least three tracks

✓ 2 photon candidates :

- E_T> 25 GeV
- $|\eta|<2.37$ excluding $1.37<|\eta|< 1.52$ (the transition region of the EM calorimeter)
- Satisfying identification (ID) criteria based on hadronic leakage and lateral shower shapes in the EM calorimeter. The fine granularity of the first sampling allows to achieve a high purity.
- Calorimetric cone isolation less than 5 GeV. The cone size is of $dR=\sqrt{d\eta^2+d\Phi^2}=0.4$

✓ This selection is orthogonal to the ATLAS dielectron analysis (http://arxiv.org/abs/1108.1582)

→ **6846 diphoton candidates with $m_{\gamma\gamma}$ > 140 GeV**

ATLAS Detector *(JINST S08003 (2008))*

The Atlas detector is composed of 3 majors subsystems (calorimeters, inner tracker and muon spectrometer). This analysis relies on the inner tracker and the calorimeter.

1) Inner Tracking Detector

- Silicon pixel, Silicon strips, transition radiation detectors
- Immersed in homogeneous 2 T magnetic field
- $|\eta|$ < 2.5

Reconstruct vertices and charged particles tracks

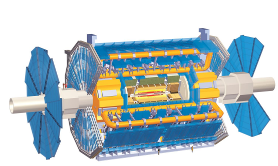
2) Calorimeters

- liquid argon-lead sampling for electromagnetic part
- scintillating tiles-iron sampling (central),

liquid argon-copper/tungsten ($|\eta|$ > 1.7) for the hadronic part

- $|\eta|$ < 4.9

Measure the energy of the electrons, positrons and photons and quantify the shower shape



Signal Modeling

✓ **ADD signal:**

- SHERPA1.2.3 *(T. Gleisberg et al., JHEP 02,007 (2009))*+CTEQ6.6 PDFs *(P. M. Nadolsky et al., PRD78,013004 (2008))*
- k factor = 1.7±0.1
- Acceptance varies for the various ADD scenarios, from ~20% for M_S=1.5 TeV to ~15% for M_S=3 TeV
- Selection efficiency around 70% for events in the detector acceptance

✓ **Randall Sundrum signal:**

- PYTHIA6.424 *(T. Sjöstrand et al., CPC. 135,238 (2001))*+MRST2007LOMOD PDFs *(A. Sherstnev et al., EPJ. C55,553 (2008))*
- k factor = 1.75±0.1
- The product acceptance*efficiency goes from 53% to 60% increasing with graviton mass
- Invariant mass theoretical shapes modeled by a Breit-Wigner with increasing width from 8 GeV to 30 GeV, varying as square of k/M_{PL}
- Detector response modeled by a double sided Crystal-Ball.

Background Evaluation

✓ **The largest background is the irreducible SM γγ production**

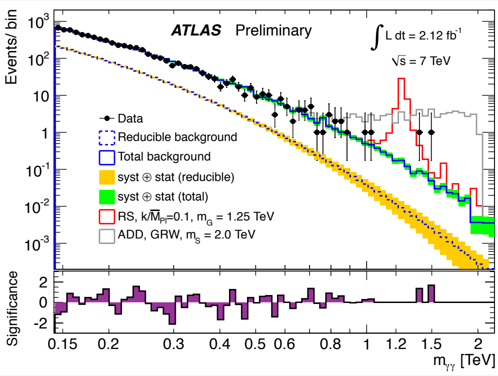
- Shape determined with PYTHIA reweighted by DIPHOX *(T. Binoth et al., E.P.J. C16,311 (2000).)* next to leading-order (NLO) cross-sections predictions

✓ **The second significant background arises from a different physics object (electron or jet) misidentified as a photon.**

- The Drell-Yan production has been verified to be very small and has been neglected above 140 GeV
- The γ+jet and dijet background shapes are determined on background enriched samples obtained by reverting the ID criteria
- The background shape is then extrapolated at high mass

✓ **The fraction of each background has been determined by a 2D template fit method using the isolation variable for each photon *(arXiv:1108.5895v1 (2011), submitted to PLB.)***

✓ **The total background is normalized to the data in the [140,400] GeV region (ADD and RS have been excluded in this region by previous searches)**



Observed invariant mass distribution of diphoton events, with the predicted SM background and example of expected signal of RS and ADD models

Systematic Uncertainties

✓ Signal uncertainties:

- Listed in the table
- EM energy scale and resolution are negligible.
- PDFs : 10-15% for ADD, 5-10% for RS

Systematic Source	Signal (%)
Luminosity	3.7
Trigger Efficiency	2.5
MC statistics	1.0
Photon Efficiency and ID	4.3
Pileup	2.5
Bunch Crossing ID	1.0

✓ Background uncertainties:

- The irreducible background shape uncertainty is obtained by varying the scales of the models and the PDFs in DIPHOX
- The reducible shape uncertainty is obtained by fitting different sub-samples with the functional form used to model the reducible background
- The purity uncertainty is obtained by varying the control samples

Background uncertainty (%)	
140 GeV < $M_{\gamma\gamma}$ < 400 GeV	~ 2
$M_{\gamma\gamma}$ ~ 700 GeV	~ 15
$M_{\gamma\gamma}$ ~ 2 TeV	~ 20

Event display of the highest mass γγ candidate

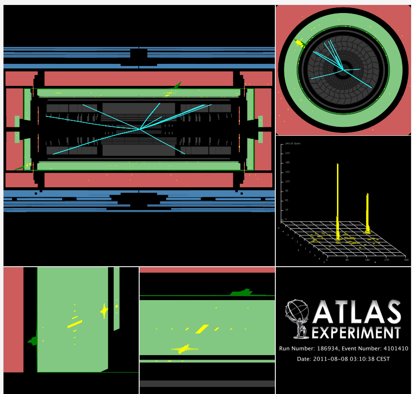
✓ $M_{\gamma\gamma}$=1.49 TeV, the two photons are converted

✓ Leading photon:

- p_T = 520 GeV
- η = -1.6 , Φ = -0.58
- Isolation = -0.13 GeV

✓Sub-leading photon:

- p_T = 470 GeV
- η = 0.34 , Φ = 2.58
- Isolation = 1.72 GeV



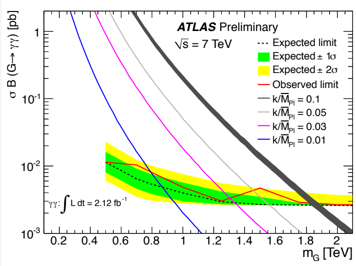
Limit setting

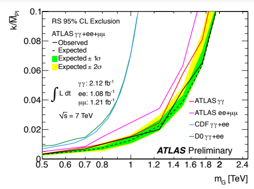
✓ A 95% CL upper limit has been set signal cross-section*Branching ratio using a Bayesian approach with a flat prior on the cross section

✓ The cross section limit is converted into a mass limit using the theoretical dependence

✓ The result is combined with the dilepton channels (Accepted by PRL, arXiv:1108.1582). See poster by Daniel Hayden

→RS





k-Factor Value	Channel(s) Used	95% CL Limit [TeV] $k/\overline{M}_{Pl}$ Value 0.01	0.03	0.05	0.1
1	$G\to\gamma\gamma$	0.74	1.26	1.41	1.79
	$G\to\gamma\gamma/ee/\mu\mu$	0.76	1.32	1.47	1.90
1.75	$G\to\gamma\gamma$	0.79	1.30	1.45	1.85
	$G\to\gamma\gamma/ee/\mu\mu$	0.80	1.37	1.55	1.95

✓ A 95% CL upper limit is set on the signal cross-section using a counting experiment approach

✓ The result is translated into upper limits on the parameter M_S

→ADD

k-factor Value	GRW	Hewett Pos	Hewett Neg	HLZ $n=3$	$n=4$	$n=5$	$n=6$	$n=7$
1	2.73	2.44	2.16	3.25	2.73	2.47	2.30	2.17
1.7	2.97	2.66	2.27	3.53	2.97	2.69	2.50	2.36

Results

○ The presence of any significant deviation from the SM in the γγ invariant mass spectrum is excluded with the BUMPHUNTER*(G. Choudalakis, arXiv:1101.0390v2 (2011))* (The p-value of the largest observed discrepancy is 0.28)

○ A 95% CL lower limits is set on the fundamental Planck scale between **2.36** and **3.53 TeV** in the context of various ADD models

○ A 95% CL lower limits on the lightest RS graviton mass is set between **0.79** and **1.85 TeV**, for coupling from **0.01 to 0.1**.

○ Combining with previously published ATLAS results from the dielectron and dimuon final states, limits on the RS graviton mass for k/M_{PL}= **0.01 (0.1)** are **0.80 (1.95) TeV**