Search for Resonances in Diphoton Events with $3.2\text{fb}^{-1}$ at $\sqrt{s}=13$ TeV

in ATLAS

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What are we looking for?

- Spin 0 Scalar, Higgs-like?

- Mass Range 200-2000 GeV with a $\Gamma$ of up to 10% of the mass (@ $m_S=800$ GeV, $\Gamma$ up to 80 GeV)

- Search based on $gg$ (VBF, $ttH$ and $VH$ cross checked)
What are we looking for?

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- Search based on gg (VBF, ttH and VH cross checked)

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SPECIFIC MODEL: Spin 2 Graviton

- Use Randall-Sundrum model graviton as benchmark

- Search 500-5000 GeV with

$$\Gamma_{G^*} = 1.44 \left( \frac{\kappa}{\bar{M}_{p\ell}} \right)^2 m_{G^*}$$

- Production via gg and qq

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@800 GeV $\Delta m(Det) \sim 10$ GeV

Main physics difference is the angular distribution of the Photons in the DiPhoton rest frame, which is isotropic for a scalar, and forward enriched for Graviton
What are we looking for?

Irreducible BG

Diphox NLO (parton level)
OR
SHERPA multi-leg LO (fully simulated)

For spin 2 -MC, Correct SHERPA with DIPHOX
For spin 0 - Functional fit, DATA based, validated with SHERPA
What are we looking for?

Irreducible BG

born

box

Reducible BG

fake photons from jets: $j\gamma, \gamma j'jj$

Require
Tight isolated Photons reducing fakes rate by an order of magnitude
• Identification performed by applying cuts on the shape of the electromagnetic shower in the calorimeter, and the fraction of energy deposited in the hadronic calorimeter.

• Photon ID is $\eta$ and conversion dependent

• Calorimeter granularity allows to separate photons from pions

Efficiency:
85% ($E_T=50\text{GeV}$)-95%($E_T=200\text{GeV}$)

Uncertainty:
$\pm1\%$ - $\pm5\%$ for $E_T > 50\text{GeV}$

$\eta$ & $E_T$ dependent (uncertainty measured MC vs DATA)
Tight Isolation is used for reducible BG rejection (fake photons)

Both **calorimeter isolation** and **track isolation** ARE required.

- Calo isolation $E_T^{\text{ISO}} \rightarrow$
  - sum of $E_T$ of energy clusters within $\Delta R = 0.4$
  - Ignore $\Delta\eta \times \Delta\phi = 0.125 \times 0.125$ centered on photon
  - Subtract out-of-cone energy from isolation
  - $E_T - 0.022 E_T < 2.45$ GeV

- Track isolation $\rightarrow$
  - scalar sum of track $p_T$ ($p_T > 1$ GeV) within $\Delta R = 0.2$ & consistent with selected primary vertex
  - $p_{T,\text{iso}} < 0.05 E_T$

**PHOTON ISOLATION**

Isolation efficiency: 90 - 96% ($E_T=100-500$)
Isolation uncertainty: 1-2%
• Using sophisticated methods (Matrix & Sidebands) we estimate the BG composition \((\gamma_j, j\gamma, jj)\).

• The resulting **inclusive purity** is \(Purity_{\gamma\gamma} = 93^{+3}_{-8}\%\).

Similar purity for the spin 2 analysis.
Trigger & Pre-Cuts

Trigger: $p_T > 35 \ (25)$ GeV for leading (subleading) photon.

Tight photon ID with
$E_T^{\gamma 1} > 40$ GeV, $E_T^{\gamma 2} > 30$ GeV (“baseline”)

2 Isolated Photons
**Spin 2**

$E_{T}^{\gamma_{1}} > 55 \text{GeV}, E_{T}^{\gamma_{2}} > 55 \text{GeV}$. Preserve acceptance at high mass.

**Spin 0**

Optimized for Higgs-like signal: $E_{T}^{\gamma_{1}} > 0.4 m_{YY}, E_{T}^{\gamma_{2}} > 0.3 m_{YY}$. $+20\%$ significance for $m_X > 600 \text{ GeV}$.

$\cos \theta^* = \frac{\sinh(\eta_{\gamma_{1}} - \eta_{\gamma_{2}})}{\sqrt{1 + (p_{T}^{\gamma_{1}}/m_{\gamma\gamma})^2}} \cdot \frac{2 p_{T}^{\gamma_{1}} p_{T}^{\gamma_{2}}}{m_{\gamma\gamma}^2}$

**Graph**

*ATLAS Simulation*  
- Spin-2 Selection  
- Spin-0 Selection  
- $X \rightarrow \gamma\gamma$, $m_X = 750 \text{ GeV}$  
- $G^* \rightarrow \gamma\gamma$, $m_{G^*} = 750 \text{ GeV}$  
- Sherpa $\gamma\gamma$, $700 \text{ GeV} < m_{\gamma\gamma} < 800 \text{ GeV}$

Spin 0 cuts will reduce the sensitivity to the Graviton signal.
Determining the Background

Monte Carlo simulation (Spin 2) vs Functional Form (Spin 0)

- **Correct multi-leg LO SHERPA (fully simulated) with NLO Diphox**

- **Search goes up to 5000 GeV-> Shape from MC, Normalisation from Data**

- **Reducible BG determined from DATA, extrapolated with function to high m_{\gamma\gamma}**

All methods to obtain background (MC and data based) are giving consistent results
Determining the Background (Spin 2 MC)

Monte Carlo simulation (Spin 2)

- Price of MC in uncertainties
- PDF and Renormalisation Scale QCD (Irred) takes off to 35% @ 3500 GeV
- Isolation uncertainty (due to parton level matching with full simulation)
Determine the BG (spin 0 functional form)

- Use the following functional form:
  \[ f_{k;d}(x; b, \{a_k\}) = (1 - x^d)^b x^{\sum_{j=0}^{k} a_j \log(x)^j} \]
  \[ x = m_{\gamma\gamma} / \sqrt{s} \]

- Use statistical chi^2 based test to determine the number of d.o.f. \( k = 0 \)
  \[ f_0(x; b, a_0) = (1 - x^{1/3})^b x^{a_0} \]
  - 2 shape d.o.f. (+Normalization)

- Validate with MC (Sherpa based + reducible BG template)

- Fit s+b with b-only template. The resulting “signal” is considered spurious. We require spurious signal <20% b-uncertainty

7391 (2878) events for \( m_{\gamma\gamma} > 150 \) (200) GeV

![Graph](image-url)
Cross checks (Kinematic Distributions)

\[
\cos \theta^* (\text{beam, forward going photon})
\]

- Data (600 GeV < $m_{\gamma\gamma}$ < 700 GeV)
- Data (700 GeV < $m_{\gamma\gamma}$ < 840 GeV)
- Data ($m_{\gamma\gamma}$ > 840 GeV)
- Sherpa (600 GeV < $m_{\gamma\gamma}$ < 700 GeV)
- Sherpa (700 GeV < $m_{\gamma\gamma}$ < 840 GeV)
- Sherpa ($m_{\gamma\gamma}$ > 840 GeV)

$n_{jets}$

$E_T$

$p_T(\gamma\gamma)$
Cross checks (Kinematic Distributions)

- ATLAS
- $\sqrt{s} = 13 \text{ TeV}, \ 3.2 \text{ fb}^{-1}$
- Spin-0 Selection

- $1/N \cdot dN/d\eta_{\text{jets}}$
- $1/N \cdot dN/dp_T^{\gamma\gamma}$
- $1/N \cdot dN/dE_T^{\text{miss}}$
- $1/N \cdot dN/d\cos\theta_{\gamma\gamma}$
RESULTS

Spin 0

7391 (2878) events for $m_{\gamma\gamma} > 150$ (200) GeV

Spin 2

5066 events for $m_{\gamma\gamma} > 200$ GeV

ATLAS

Data

Background-only fit

Spin-0 Selection

$\sqrt{s} = 13$ TeV, 3.2 fb⁻¹

Spin-2 Selection

$\sqrt{s} = 13$ TeV, 3.2 fb⁻¹

Events / 20 GeV

Data - fitted background

$m_{\gamma\gamma}$ [GeV]

$\Delta m_{\gamma\gamma}$ [GeV]

$\Delta S / \Delta \ln m_{\gamma\gamma}$

Local significance $[\sigma]$

$S / N$ vs $m_{\gamma\gamma}$

Events / 20 GeV

Data - fitted background

$m_{\gamma\gamma}$ [GeV]

$\Delta m_{\gamma\gamma}$ [GeV]

$\Delta S / \Delta \ln m_{\gamma\gamma}$

Local significance $[\sigma]$

$S / N$ vs $m_{\gamma\gamma}$
Interpreting the Result

Spin 0

Largest significance

\( m_X \sim 750 \text{GeV}, \Gamma_X \sim 45 \text{GeV}(6\%) \)

Local \( Z = 3.9\sigma \)

Any peak with \( Z > 3.9\sigma \) with \( m=200-2000 \) will draw our attention

\[
P_{\text{global}}(u) \approx p_{\text{local}}(u) + E(n_{u_0})e^{-\frac{u_0-u}{2}}
\]

- \( p_{\text{local}} = 5 \cdot 10^{-5} \)
- \( u_0 = 0 \)
- \( n_{u_0} = 7 \pm 2.6 \)
- \( u = Z^2 = 3.9^2 = 15.2 \)
- \( P_{\text{global}} = 5 \cdot 10^{-5} + (7 \pm 2.6)e^{-15.2/2} = (2.2 - 4.8)10^{-3} \)
- \( Z_{\text{global}} \sim 2.7 \pm 0.1\sigma \)

The LEE is even stronger when you consider another dimension (the width range (0-10%\( m \)) should also be taken into account.)
Interpreting the Result

Spin 2

2D Scan

Largest significance

$m_X \sim 750\text{GeV}, \Gamma_X \sim 45\text{GeV}(6\%)$

Local $Z = 3.9\sigma$

$m = 200-2000\text{ GeV}$

$\Gamma_X / m_X = 0-10\%$

Use toys or asymptotic formula from


arXiv:1105.4355

$Z_{\text{local}} = 3.9\sigma$

$Z_{\text{global}} = 2.1\sigma$

2.1$\sigma$ is not something to write home about
Spin 2

Largest significance

\[ m_G \sim 750\text{GeV}, \frac{k}{M_{Pl}} \sim 0.23 \]
\[ (\Gamma_G \sim 57 \text{GeV} \sim 7\% m_G) \]

Local \( Z = 3.8\sigma \)

Any peak with \( Z > 3.8\sigma \)
with \( m = 500-2000 \) will draw our attention

\[ P_{global}(u) \approx P_{local}(u) + E(n_{u_0})e^{-\frac{u_0-u}{2}} \]

\[ p_{local} = 7 \cdot 10^{-5} \]
\[ u_0 = 0 \]
\[ n_{u_0} = 3 \]
\[ u = Z^2 = 3.8^2 = 14.4 \]
\[ P_{global} = 7 \cdot 10^{-5} + (3 \pm 1.7)e^{-14.4/2} \]
\[ Z_{global} \sim 2.8^{+0.2}_{-0.1}\sigma \]

The LEE is even stronger when you consider another dimension
(the coupling \( k/M_{PL} \) range (0.01-0.3) should also be taken into account)
2D Scan

Largest significance

\[ m_G \sim 750 \text{GeV}, \kappa/M_{\text{Pl}} \sim 0.23 \]

\[ (\Gamma_G \sim 57 \text{ GeV}\sim7\%m_G) \]

Local \( Z = 3.8\sigma \)

m=500-2000 GeV
k/M_{PL}=0.01-0.3

Use toys or asymptotic formula from
arXiv:1105.4355

\[ Z_{\text{local}} = 3.8\sigma \]

\[ Z_{\text{global}} = 2.1\sigma \]

2.1\sigma is not something to write home about
LIMITS ON fiducial $\sigma \times \text{BR} \text{ spin } 0 \ (|\eta| < 2.37)$

$\sigma \times \text{BR} < 35 \text{ fb} \ @ m_s = 200 \text{ GeV}$

$\sigma \times \text{BR} < 1 \text{ fb} \ @ m_s = 2000 \text{ GeV}$
\[ \sigma = \sigma \left( m_{G^*}, \frac{\kappa}{M_{PL}} \right) \]

**One Can Derive Lower Bounds on** \( m_{G^*} \) **for given** \( \kappa / M_{PL} \)

\[ m_{G^*} > 1.5 - 4.1 \text{ TeV for} \quad \kappa / M_{PL} = 0.01 - 0.30 \]
CONCLUSIONS: Where do we go from here?
CONCLUSIONS: Here? (establishing a signal!)

[Graph showing p-value vs. m_x [GeV] with ATLAS collaboration details and significance levels marked.]
CONCLUSIONS: OR

![Graph showing p-values vs. mass (m_x) for ATLAS results.](image)

- **ATLAS**
  - \( \sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1} \)
  - NWA
  - Spin-0 Selection

![Diagram with p-values and mass (m_x) axis.](image)
CONCLUSION: Elsewhere?
where the wild roses grow, since, all beauty must die  
(N. Cave)
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where the wild roses grow, since, all beauty must die  (N. Cave)

THANK YOU
BACKUP