Search for new phenomena in high-mass diphoton final states with the ATLAS detector

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2017 Division of Particles and Fields Meeting
August 1, 2017
Introduction

• Search for phenomena in the diphoton final state are presented
  • Observable is diphoton invariant mass

• Using 37fb$^{-1}$ data collected in 2015+2016
  • result updated from 15fb$^{-1}$ (ATLAS-CONF-2016-059)

• Three benchmark models are studied:
  • Extended Higgs sector, spin-0 resonance
  • Randall-Sundrum graviton, spin-2 resonance
  • ADD scenario, spin-2 non-resonant
Event Selection

- Preselection:
  - $E_{T\gamma,1} > 40$ GeV, $E_{T\gamma,2} > 30$ GeV
  - $|\eta^\gamma| < 2.37$ excluding $1.37 < |\eta^\gamma| < 1.52$

- Tight photon identification
  - using EM calorimeter shower shapes
  - Photon isolation (track and calorimeter based)

<table>
<thead>
<tr>
<th>Spin-0 Selection</th>
<th>Spin-2 Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{T\gamma,1}/m_{\gamma\gamma} &gt; 0.4$, $E_{T\gamma,2}/m_{\gamma\gamma} &gt; 0.3$</td>
<td>$E_{T\gamma,1} &gt; 55$ GeV, $E_{T\gamma,2} &gt; 55$ GeV</td>
</tr>
<tr>
<td>$m_{\gamma\gamma} = 200$-2700 GeV</td>
<td>$m_{\gamma\gamma} = 500$-2700 GeV</td>
</tr>
</tbody>
</table>
Signal Modeling

- Double-sided crystal ball for spin-0 and spin-2 resonance model
- Parametrized as function of $m_{\gamma\gamma}$ and width

**ATLAS Simulation**

$\sqrt{s} = 13$ TeV, $X \rightarrow \gamma\gamma$

Spin-0 Selection
$m_X = 800$ GeV
$\Gamma_X/m_X = 6\%$

Spin-2 Selection
$m_{G^*} = 1000$ GeV
$k/\tilde{M}_{Pl} = 0.20$ ($\Gamma_{G^*}/m_{G^*} = 5.8\%$)

**arXiv:1707.04147**
Signal Modeling

- Primary sources of uncertainty on signal yield
- Mass resolution is 17-38% (28-36%) for spin 0 (spin 2) resonance
- The combined uncertainty (minus resolution) is less than 6% on signal yield

<table>
<thead>
<tr>
<th>Uncertainty source</th>
<th>Spin-0 resonance [%]</th>
<th>Spin-2 resonance [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal mass resolution</td>
<td>17–38</td>
<td>28–36</td>
</tr>
<tr>
<td>Signal photon identification efficiency</td>
<td>1.3–3.0</td>
<td>2.6–3.1</td>
</tr>
<tr>
<td>Signal photon isolation efficiency</td>
<td>1.1–1.3</td>
<td>1.2–1.4</td>
</tr>
<tr>
<td>Signal width dependence</td>
<td>2.8</td>
<td>2.9</td>
</tr>
<tr>
<td>Trigger efficiency</td>
<td></td>
<td>0.4</td>
</tr>
<tr>
<td>Total uncertainty in signal yield</td>
<td>4.6–5.4</td>
<td>5.3–5.5</td>
</tr>
</tbody>
</table>

arXiv:1707.04147
Background Model - spin 0

- Fit to smooth function for $m_{\gamma\gamma} > 180$ GeV
  - $m_{\gamma\gamma} > 150$ GeV when fitting to 2015 data alone

- Bias from choice of function shown in table below as “spurious signal” and used as systematic on background estimate
  - required to be $< 30\%$ of statistical uncertainty on fitted signal yield

<table>
<thead>
<tr>
<th></th>
<th>Narrow Width</th>
<th>10% width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spurious signal</td>
<td>74-(6x10^{-3}) events</td>
<td>195-(4x10^{-2}) events</td>
</tr>
</tbody>
</table>
Background Model - spin 2

- Monte Carlo template (binned in 5 GeV)
  - $\gamma\gamma$ shape taken from Diphox NLO
  - parton level isolation requirement used as systematic
- $\gamma j/j\gamma + jj$ shape taken from data driven techniques
- relative normalization from data-driven technique

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**ATLAS**

$\sqrt{s} = 13$ TeV, 36.7 fb$^{-1}$

Spin-2 Selection

- Data yield
- Estimated $\gamma\gamma$ yield
- Estimated $\gamma j/j\gamma$ yield
- Estimated $jj$ yield

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**Relative uncertainty**

<table>
<thead>
<tr>
<th>$\gamma\gamma$ fraction</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1</th>
<th>1.2</th>
<th>1.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative uncertainty</td>
<td>1.0</td>
<td>1.2</td>
<td>1.0</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
</tr>
</tbody>
</table>

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Manuel Silva (Wisconsin)  
DPF 2017

**arXiv:1707.04147**
Fitted Invariant Mass

ATLAS

- Data
- Background-only fit

Spin-0 Selection
\(\sqrt{s} = 13\text{ TeV}, 36.7\text{ fb}^{-1}\)

Spin-2 Selection
\(\sqrt{s} = 13\text{ TeV}, 36.7\text{ fb}^{-1}\)

Data - fitted background

arXiv:1707.04147
Observed Significance - Spin 0

\[ \sqrt{s} = 13 \text{ TeV}, 36.7 \text{ fb}^{-1} \]

\[ \Gamma_X / m_X [\%] \]

\[ m_X [\text{GeV}] \]

\[ \text{Local significance} \]

\[ \text{Global significance} \]

Largest Observed Significance \( m_{YY} = [650, 800 \text{ GeV}] \)

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Local Significance</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>3.3(\sigma), 736 GeV, 8%</td>
<td>-</td>
</tr>
<tr>
<td>2016</td>
<td>1.8(\sigma), 780 GeV, NWA</td>
<td>-</td>
</tr>
<tr>
<td>15+16</td>
<td>2.6(\sigma), 730 GeV, NWA</td>
<td>0.0(\sigma), 730 GeV, NWA</td>
</tr>
</tbody>
</table>

\( \sigma \) indicates standard deviation.

\( \text{NWA} \) indicates No Work Available.

\textbf{arXiv:1707.04147}
Observed Significance - Spin 2

\[ \sqrt{s} = 13 \text{ TeV}, \ 36.7 \text{ fb}^{-1} \]

Spin-2 Selection

\[ k/M_{Pl} \]

\[ m_{G^*} [\text{GeV}] \]

Largest Observed Significance \( m_{\gamma\gamma} = [650, 800 \text{ GeV}] \)

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<thead>
<tr>
<th>Dataset</th>
<th>Local Significance</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>3.2(\sigma), 742 GeV, 0.28</td>
<td>-</td>
</tr>
<tr>
<td>2016</td>
<td>2.8(\sigma), 698 GeV, 0.05</td>
<td>-</td>
</tr>
<tr>
<td>15+16</td>
<td>3.0(\sigma), 708 GeV, 0.30</td>
<td>0.8(\sigma), 708 GeV, 0.30</td>
</tr>
</tbody>
</table>

arXiv:1707.04147
Results for resonances

- Spin-0 resonance limits
  - 11.4 fb at 200 GeV, 0.1 fb at 2700 GeV @ NWA
- Spin-2 resonance limits
  - 4.6 fb at 500 GeV, 0.1 fb at 500 GeV @ \( k/M_{Pl} = 0.1 \)

\[ m_X \text{ [GeV]} \]

\[ m_{G^*} \text{ [GeV]} \]
Results for non-resonant search

• Counting experiment implemented for $m_{\gamma\gamma} > 2.24$ TeV
• Observed: 4 events
• Expected: $4.3 \pm 1.0$
• Limits set on $M_S$ from 5.7-8.1 TeV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ADD formalism</th>
<th>GRW</th>
<th>Hewett positive</th>
<th>HLZ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$n = 3$</td>
<td>$n = 4$</td>
</tr>
<tr>
<td>Without K-factor</td>
<td>$M_S$ observed limit [TeV]</td>
<td>6.8</td>
<td>6.1</td>
<td>8.1</td>
</tr>
<tr>
<td>With K-factor</td>
<td>$M_S$ observed limit [TeV]</td>
<td>7.2</td>
<td>6.5</td>
<td>8.6</td>
</tr>
</tbody>
</table>

arXiv:1707.04147
Conclusion

• A search for high-mass phenomena in the diphoton channel was presented

• Observed significance is 2.6\(\sigma\) (3.0\(\sigma\)) for heavy Higgs (RS graviton) resonance search and globally found to be 0.0\(\sigma\) (0.8\(\sigma\))

• Limits on ADD model are 5.7-8.6 TeV for ultraviolet cutoff scale \(M_S\) depending on the number of extra-dimensions

• Paper submitted to PLB (arXiv:1707.04147)
Thank you!
Observed Significance

- Observed significance for narrow width scenario in spin-0 and spin-2 resonance analysis
- Computed separately for 2015, 2016, and 15+16 datasets
Patron level isolation uncertainty

- Fit to low-mass sideband events in diphox
- Uncertainty from fit used as systematic in background model for spin-2