Search for a high mass diphoton resonance using the ATLAS detector

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On behalf of the ATLAS Collaboration

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Outline

• LHC and Atlas detector
• Identification and reconstruction of photons
• Analysis Models and Results from 7 and 8 TeV
• 13 TeV analyses:
  ▪ Analysis strategy
  ▪ Event selection
  ▪ Signal and Background modeling
  ▪ Results
• Conclusion and prospects
ATLAS experiment at LHC

- pp collisions
- Run-1: 7 and 8 TeV (20 fb\(^{-1}\))
- Run-2: 3.2 fb\(^{-1}\) (2015)

arXiv:1606.03833 (June 13\(^{th}\))
Photon Reconstruction and Identification

- Clean signature
- Good mass resolution of diphoton system
- Moderate level of background (prompt $\gamma\gamma$)

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- $\gamma$ from energy deposits in the ECAL
- Tracks to determine electron or $\gamma$ candidate
- Calorimeter Energy resolution: 1.2%
- $\gamma$ cluster reconstruction eff. $\sim$ 100%

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- $\gamma$ ID: tight and loose selections
- Tight ID efficiency:
  - 85% at $E_T \sim 50$ GeV
  - 95% at $E_T \sim 200$ GeV
- Isolation Energy in the CALO in a cone of
  $\Delta R = (\Delta \phi^2 + \Delta \eta^2)^{0.5} = 0.4$
- Track Isolation variable ($p_T^{iso}$) in a cone of
  $\Delta R = 0.2$
Resonances in diphoton channel at 8 TeV in BSM (Spin 0) Higgs searches


No significant excess found up to 600 GeV

Spin 0 heavier Higgs (> 125 GeV)

- Several extensions of Higgs sector foresee additional scalar States
- Narrow resonance

\(m_X\) [GeV]
Resonances in diphoton channel
7 and 8 TeV in Graviton (Spin 2) analyses


Performed in Randall Sundrum (RS) or ADD (Large Extra Dimension) models

- Additional dimensions where only gravity propagates \(\rightarrow\) Reduced effective value of the Planck scale in the SM brane

- For the RS Graviton the coupling with the SM, \(k/M_{pl}\) is proportional to the width of the resonance

Graviton \(m_{G^*}\) excluded to 2.66 TeV for \(k/M_{pl}=0.1\)

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Analysis Strategy for the 13 TeV 2015 data

- **Spin 0:**
  - Extended Higgs sector in mass range [200 GeV;2 TeV] and widths up to 10% of $m_X$ ($\Gamma_X/m_X < 0.1$)
  - Signal modeled using Powheg-Box+Pythia 8
  - Background modeled using data-driven method, smooth function fitted to data

- **Spin 2:**
  - Randall-Sundrum model with graviton excitation $G^*$ in mass range [500 GeV;5 TeV] and dimensionless coupling $k/M_{pl}$ ranging from 0.01 to 0.1 (13 TeV $\rightarrow$ 0.3); $\Gamma_{G^*}=1.44(k/M_{pl})^2 m_{G^*}$
  - Signal modeled using Pythia 8
  - Background modeled using MC template method built from Sherpa LO multi-leg, MC reweighed by fixed order NLO QCD

- Signal + Background fit the $m_{\gamma\gamma}$ distribution

- Statistical treatment: test the Background (B) only hypothesis over the S+B hypothesis on data

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13 TeV Analyses: Event Selection

- 2 $\gamma$ of highest $p_T$ in $|\eta|<2.37$
- Diphoton trigger: 35 and 25 GeV $E_T$ threshold
- Spin-2: $p_{\gamma T}> 55$ GeV
- Spin-0: $p_{\gamma T}/M_{\gamma\gamma}> 0.4$ (0.3) Leading (subleading) $\gamma$
- Calorimeter En. Isolation $< 0.022 p_{\gamma T} + 2.45$ GeV
- Tracking $p_T$ Isolation $< 0.05 p_{\gamma T}$
- Primary vertex selected using the $\gamma$ pointing technique
Purity of the selected diphoton sample

Checked with:
- 4x4 matrix method
- 2x2 sidebands method

**ATLAS**

$\sqrt{s}=13$ TeV, 3.2 fb$^{-1}$
Spin-2 Selection

- Data yield
- Estimated $\gamma\gamma$ yield
- Estimated $\gamma+j_j$ yield
- Estimated $j_j$ yield

**ATLAS**

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

- Data yield
- Estimated $\gamma\gamma$ yield
- Estimated $\gamma+j_j$ yield
- Estimated $j_j$ yield

94$^{+3}_{-7}$ %

93$^{+3}_{-8}$ %
Signal Modeling

Convolution of detector resolution described by a DSCB (Double-Sided Crystal Ball)

Spin 2:
with Breit-Wigner-like on the mass line shape of RS graviton model

Spin 0:
With mass line shape of Higgs-like particles using PowHeg-box+Pythia8
Spin 2: Background Modeling (1)

Irreducible background

- Fully simulated Sherpa multi-leg LO $m_{\gamma\gamma}$
- Normalized to data at low mass [200,500] GeV
- The NLO QCD parton-level calculation Diphox is used to describe the shape of the mass spectrum of the irreducible $\gamma\gamma$ background
- The result from Diphox is used to reweight the Sherpa in Fullsim samples

$\rightarrow m_{\gamma\gamma}$ shape uncertainties:
- PDF eigenvector variations: 40% at 3.5 TeV
- PDF choice: up to 5%
- parton-level photon isolation modelling: up to 10%
- QCD renormalisation and factorisation scale: up to 5%
Spin 2: Background Modeling (2)

- Reducible background is $\gamma j$, $j\gamma$, $jj$ (leading, sub-leading)
- Shape from reducible background in anti-tight $\gamma$ ID
- Normalization from fit to Isolation distributions in control regions at low mass [200,500] GeV

Dominated by PDFs
Parton-level Isolation cut in Diphox

Total uncertainty
Spin 0: Background Modeling

$m_{\gamma\gamma}$ shape is a function fit on data

$$f_{(k)}(x; b, \{a_k\}) = N(1 - x^{1/3})^b x^a$$

- Fit function chosen from S+B fit to background template only, built using $\gamma\gamma$ Sherpa MC and $\gamma j/jj$ from a control sample data $\rightarrow$ fitted S (spurious signal)
- $S < 20\%$ of the statistical uncertainty on the fitted signal yield

Spurious signal found in background $\sim 20$ to 0.04 events from 200 GeV to 2 TeV
Diphoton Mass distributions
13 TeV – 2015 data

Spin-2 Selection
\( \sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1} \)

Spin-0 Selection
\( \sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1} \)
Significances
scan in the mass-width plane

Largest deviation at 750 GeV
and coupling $k/\tilde{M}_{pl} = 0.23$ (57 GeV)
Local $\sigma = 3.8$; Global $\sigma = 2.1$

Largest deviation at 750 GeV
and $\Gamma_x/m_x = 6\%$ (45 GeV)
Local $\sigma = 3.9$; Global $\sigma = 2.1$

Global significance: called also, the look elsewhere effect:
Search in a large bi-dimensional phase space ($k/\tilde{M}_{pl}$, $m_x$) or ($\Gamma_x$, $m_x$).
Background-only MC toys were used in
$\rightarrow m_x$ range: [500,2000] GeV; $k/\tilde{M}_{pl}$ range: [0.01,0.3]; $\Gamma_x$ range: [0%,10%]

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Checks of kinematic distributions in excess region and side bands
Graviton Searches with RS Model

Limits Settings

- Observed limits are compared with theory prediction (red line)
- $m_{G^*}$ excluded to 3.4 TeV for $k/M_{pl}=0.1$ (2.66 TeV@8TeV)
Conclusion & Prospects

- Observation of an excess at 750 GeV @ Global significance of 2.1 $\sigma$ @ 13TeV
- Limit settings for the RS Graviton mass up to 3.4 TeV @ 13TeV (2.66@8 TeV)
  
  arXiv:1606.03833

- More to come with 2016 data → ICHEP 2016
Back-up
Diphoton Mass distributions
13 TeV – 2015 data

ATLAS

- Data

\textbf{Spin-2 Selection}
\bar{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1}

ATLAS

- Data

\textbf{Spin-0 Selection}
\bar{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1}
<table>
<thead>
<tr>
<th>Investigated signal region</th>
<th>Background from</th>
<th>Background from</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MC extrapolation</td>
<td>functional form</td>
</tr>
<tr>
<td>( m = 750 \text{ GeV}, T/m = 6% )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>720–780 GeV, spin-2 selection</td>
<td>20.1 ± 0.3 ± 0.7</td>
<td>21.9 ± 1.2 ± 0.4</td>
</tr>
<tr>
<td>720–780 GeV, spin-0 selection</td>
<td>6.7 ± 0.1 ± 0.4</td>
<td>6.8 ± 0.7 ± 0.3</td>
</tr>
<tr>
<td>( m = 1500 \text{ GeV}, T/m = 6% )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1440–1560 GeV, spin-2 selection</td>
<td>1.14 ± 0.02 ± 0.09</td>
<td>1.51 ± 0.27 ± 0.08</td>
</tr>
<tr>
<td>1440–1560 GeV, spin-0 selection</td>
<td>0.32 ± 0.01 ± 0.04</td>
<td>0.33 ± 0.11 ± 0.04</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>Spin-2 search</th>
<th>Spin-0 search</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal mass resolution (mass dependent)</td>
<td>((30-60)%)</td>
<td>((40-60)%)</td>
</tr>
<tr>
<td>Signal photon identification (mass dependent)</td>
<td>(\pm2-3)%</td>
<td></td>
</tr>
<tr>
<td>Signal photon isolation (mass dependent)</td>
<td>(\pm2-1)%</td>
<td>(\pm4-1)%</td>
</tr>
<tr>
<td>Signal production process</td>
<td>N/A</td>
<td>(\pm3-6)%</td>
</tr>
<tr>
<td>Trigger efficiency</td>
<td>(\pm0.6)%</td>
<td></td>
</tr>
<tr>
<td>Luminosity</td>
<td>(\pm5.0)%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>13 TeV</th>
<th>Spin-2 Selection</th>
<th>Spin-0 Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass for the largest excess</td>
<td>Free width</td>
<td>Narrow width</td>
</tr>
<tr>
<td></td>
<td>750 TeV</td>
<td>770 TeV</td>
</tr>
<tr>
<td>Width over mass for the largest excess</td>
<td>8%</td>
<td>-</td>
</tr>
<tr>
<td>Local significance</td>
<td>3.8</td>
<td>3.3</td>
</tr>
<tr>
<td>Global significance</td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>8 TeV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local significance (at 13 TeV best-fit)</td>
<td>-</td>
<td>1.9</td>
</tr>
</tbody>
</table>

| 8 TeV - 13 TeV Compatibility                            |                   |
|---------------------------------------------------------|                   |
| Gluon-gluon scaling (4.7)                               | 2.7               | 2.2               | 1.2               | 1.5               |
| Quark-antiquark scaling (2.7)                            | 3.3               | 2.4               | 2.1               | 2.0               |
Checks of kinematic distributions in excess region and side bands

Spin 0
Limits are in terms of the fiducial cross section and they are within the expected error bands (except for 750 GeV bump)
Diphoton Mass distributions of the 8 TeV re-analyzed data

No Excess found

2 \sigma significance is found at 750

<table>
<thead>
<tr>
<th>Analysis</th>
<th>13 TeV ( \sigma ) local</th>
<th>13 TeV ( \sigma ) global</th>
<th>8 TeV compatibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scalar</td>
<td>3.9 ( \sigma )</td>
<td>2 ( \sigma )</td>
<td>1.2 ( \sigma ) (gg) – 2.1 ( \sigma ) (qq)</td>
</tr>
<tr>
<td>Graviton</td>
<td>3.8 ( \sigma )</td>
<td>2.1 ( \sigma )</td>
<td>2.7 ( \sigma ) (gg) – 3.3 ( \sigma ) (qq)</td>
</tr>
</tbody>
</table>