Search for new physics in high mass diphoton events: CMS results.

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Motivation

Looking for fully reconstructed resonances at higher center-of-mass energy is the golden way to new particle discoveries.

- LHC Run2: new data taken at $\sqrt{s} = 13$ TeV

Statistically significant peak over a smooth background.

- Very clear signature
- Experimentally robust
- Small systematic effects
- Model independent probe to new physics
Past discoveries

J/Psi

Z

Higgs
The CMS Collaboration

1700 physicists, 700 students, 950 engineers/technicians, 180 institutions from 43 countries
Standard Model with CMS

Dec 2015

CMS Preliminary

Production Cross Section, $\sigma$ [pb]

All results at: http://cern.ch/go/pNg7
1) Define the event selection: 2 isolated photons
   ✓ must be loose and model-independent

2) Reconstruct the \( \gamma \gamma \) invariant mass
\[
M = \sqrt{2E_1 E_2 (1 - \cos\theta)}
\]
   ✓ photon reconstruction
   ✓ energy resolution and scale
   ✓ dedicated vertex identification technique

3) Signal extraction
CMS Electromagnetic Calorimeter

Lead Tungstate (PbWO$_4$) homogeneous crystal calorimeter

- 75848 PbWO$_4$ crystals
- Barrel (EB): $|\eta| < 1.48$
- Endcaps (EE): $1.48 < |\eta| < 3$
- APD/VPT photodetectors

Design energy resolution: 
~0.5% for $E(\gamma) > 100$ GeV

Critical issues:
- Transparency loss due to radiation damage
- Precision of in-situ calibration
Stable energy scale achieved after laser correction in prompt reconstruction

Barrel:

- average signal loss ~6%
- RMS stability ~0.15%

Relative crystals response to laser light vs time

Crystal transparency loss
Prompt reconstruction used for the analysis.

**Significant improvement in energy resolution with new calibrations:**
- barrel: resolution ~Run1
- endcaps: still worse (statistical precision)

Energy scale and resolution checked in data => analysis-level corrections applied
Photon clustering

Photon = energy deposits in clusters of ECAL crystals
✓ clustering optimized to have the best energy resolution

Reconstruction and selection strategies:
✓ tuned on simulation and validated in data
✓ main control samples: Z->ee and Z->μμγ
Diphoton event display

\[ m(\gamma\gamma) = 745 \text{ GeV} \]
## High mass diphoton searches

<table>
<thead>
<tr>
<th>Ref</th>
<th>Title</th>
<th>$M_X$ [GeV]</th>
<th>$\sqrt{s}$ [TeV]</th>
<th>$\mathcal{L}$ [fb$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS-PAS-EXO-15-004</td>
<td>Search for new physics in high mass diphoton events in proton-proton collisions at $\sqrt{s} = 13$ TeV</td>
<td>500-4500</td>
<td>13</td>
<td>2.6</td>
</tr>
<tr>
<td>PLB 750 (2015) 494–519</td>
<td>Search for diphoton resonances in the mass range from 150 to 850 GeV in pp collisions at $\sqrt{s} = 8$ TeV</td>
<td>150-850</td>
<td>8</td>
<td>19.7</td>
</tr>
<tr>
<td>CMS-PAS-EXO-12-045</td>
<td>Search for high-mass diphoton resonances in pp collisions at $\sqrt{s} = 8$ TeV with the CMS Detector</td>
<td>500-3000</td>
<td>8</td>
<td>19.7</td>
</tr>
</tbody>
</table>
1) Define the event selection: 2 isolated photons
2) Reconstruct the $\gamma\gamma$ invariant mass:
3) Signal extraction

Some considerations:

✓ Analysis built on SM Higgs search experience
  ✓ same methods used
✓ Only solid techniques exploited
  ✓ nothing very fancy for this first round
✓ Selection developed before looking to the data:
  ✓ cut based selection
  ✓ fully blind analysis

=> Goal: have a robust analysis up to high $p_T$
Simple event selection

- HLT: 2 photons, $p_T > 60$ GeV
- Offline selection:
  - $p_T > 75$ GeV
  - ECAL fiducial region
  - dedicated photon selection (isolation, H/E, shower shape)
- 2 event categories:
  - EBEB: both $\gamma$ in the barrel
  - EBEE: one $\gamma$ in EB, one in EE
  - events with $2\gamma$ in EE discarded

Zee to check efficiencies

- data/MC scale factors compatible with 1, constant at high $p_T$

Zee and high mass DY to check scale and resolution

- results compatible within 0.5%
Backgrounds

Direct $\gamma\gamma$ SM production irreducible

Dijet and $\gamma+$jet production reducible

Background composition measured in data using template fits

**Dominant contribution:** 2 prompt photons

**QCD and photon+jets:**

$<10\%$ ($20\%$) in EEBEB (EBEE)
Mass spectra

Selected event $m_{\gamma\gamma}$ spectra in the two categories
Signal modelling

- **Shape of the signal**: combination of the intrinsic width of the resonance and the ECAL detector response.
- **Benchmark model**: spin2 RS Graviton
  - scan of two parameters (mass and effective coupling) chosen a priori
  - mass range: 500-4500 GeV
  - scan of the coupling: 0.01-0.2 → \( \Gamma_G/m_G = 0\%-6\% \)
- **Detector response modeled on fully simulated signal sample with negligible intrinsic width**

<table>
<thead>
<tr>
<th>( m_G ) (GeV)</th>
<th>category</th>
<th>( \bar{\kappa} )</th>
<th>FWHM (GeV)</th>
<th>( \bar{\kappa} )</th>
<th>FWHM (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>EBEB</td>
<td>0.01</td>
<td>14</td>
<td>0.2</td>
<td>36</td>
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<tr>
<td>500</td>
<td>EBEE</td>
<td>0.01</td>
<td>22</td>
<td>0.2</td>
<td>42</td>
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<tr>
<td>1000</td>
<td>EBEB</td>
<td>0.01</td>
<td>27</td>
<td>0.2</td>
<td>74</td>
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<tr>
<td>1000</td>
<td>EBEE</td>
<td>0.01</td>
<td>43</td>
<td>0.2</td>
<td>85</td>
</tr>
</tbody>
</table>
Background modelling

Background $m_{\gamma\gamma}$ shape:
- parametric fit to data $f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b \cdot \log(m_{\gamma\gamma})}$ (several function tested)
- model coefficients: nuisance parameters in the hypothesis test

Background fit accuracy determined using MC
- possible mis-modelling: <1/2 of background statistical uncertainty
- extra uncertainty: signal-like component added to the model
Expected and observed limits on Graviton cross section x diphoton BR (ATL-PHYS-PUB-2011-11 / CMS NOTE-2011/005):

- \( m_G < 1.3/3.8 \) TeV excluded (\( k = 0.01/0.2 \))
- Excluded range in agreement with expectations
- Observed limit deviation from expected due to excess in data
Largest excess for $m_G=760$ GeV in the narrow width hypothesis

Local significance 2.6 $\sigma$

- Significance reduced to 1.2 $\sigma$ when accounting for Look Elsewhere Effect in $m_G$ (E. Gross and O. Vitells, arXiv:1005.1891v3)

- LEE in $k$ further decreases significance
Spin hypothesis

Spin 2 vs Spin 0: different acceptance and categories weight but analysis not much sensitive to these differences

8 TeV analysis: limit shape is quite similar
Combination with 8 TeV results in narrow width hypothesis
✓ different acceptance and categorizations
✓ most sensitive 8 TeV analysis in each mass range considered

Likelihood of fits to S+B hypothesis vs 13 TeV equivalent cross-section:
✓ 8 TeV limits scaled by xsec ratio
✓ S=RS Graviton, \( m_G = 750 \text{ GeV}, k=0.01 \)
  ✓ production: 90% gg, 10% qqbar
  ✓ \( \frac{\text{xsec}(8\text{TeV})}{\text{xsec}(13\text{TeV})} = 1/4.2 = 0.24 \)

• **Compatible equivalent cross-sections within uncertainties**
• **13 TeV result not in contradiction with 8 TeV**
$m_G < \sim 1.5 \text{ TeV}: \text{combined limits } 20\text{-}30\% \text{ better than single inputs}$

Largest excess for $m_G = 750 \text{ GeV}$

✓ local significance $\sim 3\sigma$
✓ reduced to $< 1.7\sigma$ accounting for LEE

**8-13 \text{ TeV combination}**
Outlook

- Observed diphoton mass spectrum in agreement with Standard Model expectations
- Strongest constraint on production cross-section set
- Simple and robust analysis strategy

- Modest excess for mass ~760 GeV
  - local significance of 2.6 $\sigma$ assuming narrow width signal
  - global significance of <1.2 $\sigma$
  - still consistent with 8 TeV search
Few more months (~10 fb\(^{-1}\) @ 13 TeV) to determine the origin of this excess: statistical fluctuation or manifestation of new physics?