Exotic Zγ Search with the ATLAS Detector and Implication to the 750 GeV γγ Excess

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Content

• The 750 GeV excess: VBF Production?
• $Z\gamma/W\gamma$ exotic search at 8 TeV
• $Z\gamma$ exotic search at 13 TeV
• Implication to the 750 GeV $\gamma\gamma$ excess
• Conclusions

With the latest results presented in Moriond 2016
The 750 GeV Excess

- The exciting news that the ~750 GeV excess at 13 TeV (2015) LHC collisions with both the ATALS and CMS detectors.

- The first up to >3σ BSM excess

\[ \text{spin-0 or spin-2?} \]

\[ \text{real } \gamma \text{, collimated } \gamma \text{ or fake } \gamma? \]

\[ \text{ggF or VBF productions?} \]

In the NWA search, an excess of 3.6σ (local) is observed at a mass hypothesis of minimal \( p_0 \) of 750 GeV
VBF v.s. Simplicity

- SM-like 750 GeV Higgs: \( \frac{\sigma_{VBF}}{\sigma_{ggF}} \approx \frac{620 \text{ fb}}{220 \text{ fb}} \sim \frac{1}{3} \), \( \frac{(\rightarrow gg)}{(\rightarrow gg)} = \frac{2.55 \times 10^{-4}}{1.2} \), so \( d\mathcal{L}_{pp}^{VBF} / d\mathcal{L}_{pp}^{ggF} = \frac{3}{2} \cdot 10^{-4} \)

- Minimal BSM: 2HDM, Georgi-Machacek triplet model... fail (custodial symmetry) \( c_{\nu\nu} \mu \nu_T, c_{gg} \mu \nu \), unless introducing huge number of charge scalars

- SM+new gauge symmetries: VBF (simpler) v.s. ggF (new quarks/leptons)

- dim-5 effective couplings of scalars/axions:
  \[
  \kappa_s \frac{\ell_s}{4\pi} \phi^X \quad G^a_\mu \tilde{G}^{a\mu} + \kappa_w \frac{\ell}{4\pi} \phi \quad B_\mu \tilde{B}^\mu + \quad W^c_\mu \tilde{W}^{c\mu}
  \]

  if \( g \sim 0 \) no underlying colored particle, VBF is dominant, otherwise VBF cannot compete with ggF

  using effective W/Z approximation

  \[
  \hat{\sigma}_{in \rightarrow \Phi,incl.m^2}\frac{\Gamma_\gamma}{\Gamma_\gamma + \Gamma_{other}} \quad \frac{d\mathcal{L}}{dm^2_\Phi} \sim \frac{\Gamma_{in}}{m_\Phi} \frac{\Gamma_\gamma}{\Gamma_\gamma + \Gamma_{other}} \quad \frac{d\mathcal{L}}{dm^2_\Phi}
  \]
SM-like 750 GeV Higgs: \[ \frac{\sigma_{VBF}}{\sigma_{ggF}} \approx \frac{620 \text{ fb}}{220 \text{ fb}} \sim \frac{1}{3}, \quad \frac{(\rightarrow gg)}{(\rightarrow gg)} = \frac{2.55 \times 10^{-4}}{1.2}, \quad \text{so} \quad \frac{d\mathcal{L}_{pp}^{VBF}}{d\mathcal{L}_{pp}^{ggF}} = \frac{3}{2} \times 10^{-4} \]

Atlas: no other activity, Jet multiplicity

\[ m_\Phi = [700-840] \text{ GeV} \]

using effective W/Z approximation

\[ \dot{\sigma}_{in\rightarrow\Phi,inc} \frac{m_\Phi^2}{\Gamma_{\gamma\gamma} + \Gamma_{\text{other}}} \frac{d\mathcal{L}}{dm^2_{\Phi}} \sim \frac{\Gamma_{\text{in}}}{m_\Phi} \frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma} + \Gamma_{\text{other}}} \frac{d\mathcal{L}}{dm^2_{\Phi}} \]

effective scalar with MadGraph5 at parton level, using the fiducial cuts:

\[ \text{N}_{\text{jets}} = \text{[0-10]} \]

We cannot exclude the VBF yet due to low statistics!
13 TeV Run2 started in 2015 and 2016!

Luminosities in physics

- 20.3 fb\(^{-1}\) (8 TeV, 2012) peak luminosity \(7.7 \times 10^{33}\)
- 3.2 fb\(^{-1}\) (13 TeV 2015) Good data
- Atlas recorded 6.0 fb\(^{-1}\) until 21 June and \(~10\) fb\(^{-1}\) in 2016!!

Models of hard process -> MC generator -> detector simulation

Day in 2016

- 22/04
- 30/05
- 08/07

Total Integrated Luminosity [fb]

- Total Delivered: 11.7 fb\(^{-1}\)
- Total Recorded: 10.6 fb\(^{-1}\)

Move from parton-level to particle-level cross section measurements in well-defined fiducial regions

PDFs

Parton showering

Matrix Element

Parton level

Fragmentation

Particle level

Detector level
Effective Model for the $Z\gamma$ Exotic Search

- Model-independent, depend on spin(-1 & -0) and CP (NWA)
- A new search for spin-0 $Z\gamma$ resonance up to 2TeV using the generic effective dimension-5 phenomenological model of the singlet scalar as a benchmark

$$ L_{\text{eff}} = c_g \frac{4^{\uparrow} \leq S}{\kappa} \phi G_{\mu}^{a} G_{\mu}^{a} + c_W \frac{4^{\uparrow} \leq \text{em}}{\kappa} \sin^2 \theta_W \phi W_{\mu}^{a} W_{\mu}^{a} + c_B \frac{4^{\uparrow} \leq \text{em}}{\kappa} \cos^2 \theta_W \phi B_{\mu}^{a} B_{\mu}^{a} $$

- Large vector-like fermions of new strong dynamics and electroweak run in the loops underly the couplings and thus can be estimated in NDA (and only ggF)

- Set (a): $c_g = c_W = -c_B = 1/4\pi$ for the n-loop corrections $c_V \leq O(1)/4\pi$.

- Set (b): $c_g = 1/2\pi$, $c_W = -c_B = 1/\pi$ when $c_V \leq a_f \sqrt{N_c}$, $N'_c = 4$ and $a_f = 2$

- Scale $\Lambda = 6$TeV. $m_Q = 750$GeV.

Phys.Lett. B738, 428
Using the LO Higgs process in MadGraph5 interfaced to Pythia8 with MSTW2008LO to simulate the signals for singlet scalar

**Event Selection**

<table>
<thead>
<tr>
<th>Cuts applied in the $Z\gamma$ searches</th>
<th>$e^+e^-\gamma$</th>
<th>$\mu^+\mu^-\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton $p_T$</td>
<td>$p_T^e &gt; 25\text{GeV}$</td>
<td>$p_T^\mu &gt; 25\text{GeV}$</td>
</tr>
<tr>
<td>Lepton $\eta$</td>
<td>$</td>
<td>\eta_e</td>
</tr>
<tr>
<td>Boson mass</td>
<td>$[65, 115]\text{GeV}$</td>
<td>$[65, 115]\text{GeV}$</td>
</tr>
<tr>
<td>$l$ track isolation</td>
<td>$&lt; 0.15$</td>
<td>$&lt; 0.15$</td>
</tr>
<tr>
<td>$l$ calo isolation</td>
<td>$&lt; 0.20$</td>
<td>$&lt; 0.30$</td>
</tr>
<tr>
<td>Photon $E_T$</td>
<td>$E_T &gt; 40\text{GeV}$</td>
<td>$\Delta R(l,\gamma) &gt; 0.7$</td>
</tr>
<tr>
<td></td>
<td>$</td>
<td>\eta_\gamma</td>
</tr>
</tbody>
</table>

- Uncertainties from the expected limits
- Set (a) no sensitivity
- Set (b) excluded in the range $[200, 1180]\text{GeV}$
- All fluctuations within the $2\sigma$ band

Phys.Lett. B738, 428
**Zγ Exotic Search at 13 TeV of 2015 Data**

- **Search for a spin-0 resonance with larger mass range**
- **Both leptonic and hadronic Z decay modes are analyzed at 13 TeV**

<table>
<thead>
<tr>
<th>leptonic channel \ $(Z\gamma \rightarrow l^+l^-\gamma)$</th>
<th>hadronic channel \ $(Z\gamma \rightarrow q\bar{q}\gamma)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon: $P_T &gt; 0.3 \times M_{\text{ll}}$, where $M_{\text{ll}} &gt; 200$ GeV</td>
<td>Photon selection: $P_T &gt; 200$ GeV</td>
</tr>
<tr>
<td>2 leptons (e+e-/μ+μ-) selection:</td>
<td>Boosted large-R jet selection:</td>
</tr>
</tbody>
</table>
|   - $|d0|, |\eta|$ cut, $P_T (>10$ GeV), Medium ID, Isolation |   - anti-kt, $R=1.0$, $P_T (>200$ GeV), $|\eta|<2$
|   - $Z$ mass window |   - $Z$-boson-tagged |
| Main background: $Z+\gamma, Z+\text{Jet}$ | Main background: $\gamma+\text{Jet}$ |

- **Fit in 0.2-1.6 TeV**, signal search in 0.25 -1.5 TeV
  - Signal: **Double-sided crystal ball**
  - Background: analytic parametrization
  - Largest deviation: **Local $Z0 = 2\sigma$ at 350$\text{GeV}$**

- **Fit in 0.64-3 TeV**, signal search in 0.7-2.75 TeV
  - Signal: **Crystal ball + Gaussian**
  - Background: analytic parametrization
  - Largest deviation: **Local $Z0 = 1.8\sigma$ at 1.9$\text{TeV}$**

*Moriond 2016*
Exotic Search at 13 TeV of 2015 Data

- Signal: POWHEG-BOX+Pythia8 with effective scalar model

- dominant by statistic uncertainties
- Leptonic channel:
  - $\gamma/e$ resolution (4.0-0.5%), spurious signal (3.0-2.0%), Luminosity (0.5%)
- Hadronic channel:
  - jet mass resolution (4.3-2.1%) & jet energy resolution (5.3-1.0%)

ATLAS-CONF-2016-010 (Moriond 2016)
Implication to the 750 GeV $\gamma\gamma$ excess

- Can we make constraints on the models of 750 GeV resonance using the $Z\gamma$ search? The effective Lagrangian is for singlet

$$ L_{\text{eff}} = c_g \phi G^a G_{\mu \nu} + c_W \phi W^a W_{\mu \nu} + c_B \phi B_{\mu \nu} $$

- We can constrain only parameters $c_B, c_W$ but not $c_g$

- The 13 TeV limit $\sim 40$ fb, roughly same as that extrapolated from 8 TeV observed limit

- $ZZ$ search is too loose to constrain any parameter

- $Z\gamma$ search and $WW$ search are essential constraints

the exclusion limit of 8 TeV rescaled to 13 TeV rates

<table>
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<th>Final State</th>
<th>95% CL U.L. on $\sigma \times \text{BR}$ [fb]</th>
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<td>$WW$ (gluon fusion)</td>
<td>174</td>
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<td>$ZZ$ (gg prod.)</td>
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<td>$Z\gamma$</td>
<td>42</td>
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$$ g_{gg} = \kappa_g \frac{\alpha_s}{4\pi}, $$

$$ g_{ww} = \kappa_W \frac{\alpha_{em}}{4\pi s_w^2}, $$

$$ g_{zz} = \frac{\alpha_{em}}{4\pi} \left( \kappa_W \frac{c_w^2}{s_w^2} + \kappa_B \frac{s_w^2}{c_w^2} \right), $$

$$ g_{\gamma\gamma} = \frac{\alpha_{em}}{4\pi} c_w s_w \left( \kappa_W \frac{c_w^2}{s_w^2} - \kappa_B \frac{s_w^2}{c_w^2} \right), $$

$$ g_{\gamma\gamma} = \frac{\alpha_{em}}{4\pi} \left( \kappa_W + \kappa_B \right). $$
Implication to the 750 GeV $\gamma\gamma$ excess

- Can we make constraints on the models of 750 GeV resonance using the $Z\gamma$ search? The effective Lagrangian is for singlet

$$L_{\text{eff}} = c_g \frac{4 \phi G_{\mu \nu} G^{\mu \nu}}{\kappa} + c_W \frac{4 \phi \mathcal{W}_{\mu \nu} \mathcal{W}^{\mu \nu}}{\sin^2 \sqrt{W}} + c_B \frac{4 \phi B_{\mu \nu} B^{\mu \nu}}{\cos^2 \sqrt{W}}.$$

- $Z\gamma$ search and $WW$ search are essential constraints

$$c_B < (3.6226 \sim 2.5833)|c_W| \quad c_B > (0.03867 \sim 0.4689)|c_W|$$

- We can also constrain the models that the resonance is not singlet, but more complicated

- The data we need to find it in $Z\gamma$ channel?

The exclusion limit of 8 TeV rescaled to 13 TeV rates

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arXiv:1512.04928
We consider the tension between VBF production and simpleness of the 750 GeV excess

We use an EFT model to search for the heavy exotic resonance of Z boson+photon in leptonic channels at 8 TeV at ATLAS

The same search for the heavy scalar resonance of Z boson+photon in both leptonic and hadronic channels at 13 TeV is presented

We use the exotic $Z\gamma$ search to constrain the EFT parameters of the scalar 750 GeV resonance
Thank you!
Backup: Model Parameter Constraint of 8TeV

Only exclusions on the two particular parameter sets were attained from data. However, the coupling coefficients $c_V$ can be any values below the upper bounds. We can go further to constrain the parameter space.

- Only cross sections $\sigma_{th}(c_V; m_\phi, \cdots)$ are needed
- High-dimensional parameter space: assuming constraint $c_W = -c_B$
- Interesting parameters: $c \equiv c_g = \sqrt{N_c}$ and ratio $\rho = c_g / c_W = 1 / a_f$
- Two special $\rho_a = 1$ and $\rho_b = 1/2$, constraint of $c$