The 750 GeV excess from photon-photon and quark-quark processes

Tanumoy Mandal

UPPSALA UNIVERSITET

In collaboration with U. Danielsson, R. Enberg, G. Ingelman
Based on arXiv:1601.00624

(Moriond QCD, March 20, 2016)
Excess is only seen in the diphoton channel
(Possibly no hard activities associated with diphoton)
Resonance may couple dominantly to photons
Coupling to gluons can be suppressed or absent

A photon-philic resonance?

A lot of model buildings and proposals to explain the resonance

“A Theory of Ambulance Chasing” predicted 310 papers by the June 1, 2016 [1603.01204]
Run-I vs Run-II data

A slight upward fluctuation around 750 GeV

Non-observation in Run-I data
Observation in Run-II data

A generic s-channel production

Ratio of signal events in Run-I and Run-II: Compatibility ratio

\[ xxF : \mathcal{R}_x \equiv \frac{N_{8}^{xx}}{N_{13}^{xx}} = \frac{\sigma_{8}^{xx} \times \varepsilon_{8}^{xx} \times L_{8}}{\sigma_{13}^{xx} \times \varepsilon_{13}^{xx} \times L_{13}}; \quad x = \{g, q, \gamma\} \]

Using NN23LO PDF

\[ \mathcal{R}_x = \{\mathcal{R}_g \approx 1.3; \mathcal{R}_{u,d} \approx 2.6; 1.6 \gtrsim \mathcal{R}_{s,c,b} \gtrsim 1.2; \mathcal{R}_{\gamma} \approx 3\} \]

For background \[ \mathcal{R}_B \approx 3.3 \]

Serious tension

Tension in the photon-fusion channel is slightly reduced
Photon fusion

1512.05751; 1512.05776; 1512.08502; 1601.00386; 1601.00638; 1601.01144; 1601.01571; 1601.01712; 1601.03772; 1601.07167; 1601.07187; 1602.02380; 1602.07574; 1601.07774; 1603.00287 ... more
Uncertainties in photon-flux

Photon-fusion contribution can be very large due to IR enhancement in the collinear limit (equivalent / Weizsacker-Williams photon approximation)

Cross section crucially depends on the proton form-factors

In the forward limit, IR singularities are cutoff by the finite size of the proton

Leading order computation is not a good approximation and one should take into account the large collinear logarithms properly for robust predictions

Compatibility ratio can vary a lot $R_\gamma \approx [1.7 \ - \ 3.3]$

Due to these uncertainties Run-I data might be compatible to the Run-II data
Examples of uncertainties

C. Csaki, J. Hubisz, S. Lombardo, J. Terning [1601.00638]

\[ \sigma_{13 \ TeV} = 10.8 \ \text{pb} \left( \frac{\Gamma}{45 \ \text{GeV}} \right) BR^2(R \to \gamma\gamma) \]

\[ \sigma_{8 \ TeV} = 5.5 \ \text{pb} \left( \frac{\Gamma}{45 \ \text{GeV}} \right) BR^2(R \to \gamma\gamma) \]


\[ \sigma_{13 \ TeV} = [1.7 \ \text{pb} - 3.6 \ \text{pb}] \left( \frac{\Gamma}{45 \ \text{GeV}} \right) BR^2(R \to \gamma\gamma) \]

\[ \sigma_{8 \ TeV} = [0.5 \ \text{pb} - 1.3 \ \text{pb}] \left( \frac{\Gamma}{45 \ \text{GeV}} \right) BR^2(R \to \gamma\gamma) \]

Why so different? Need to understand various issues in the photon-flux
Quark fusion

An extra hard photon in the final state

Significant fraction of events survive after selection cuts

Basic quark-fusion topology

Diphoton associated with an extra hard jet. Higher-order correction to s-channel ggF

An extra hard photon in the final state

Significant fraction of events survive after selection cuts
Varying EM coupling

Space-time varying EM coupling

Proposed by Jacob Bekenstein: a scalar with tiny mass \[ \text{[PRD 25, 1527 ('82)]} \]

\[
e = e_0 \epsilon(x); \quad \mathcal{L}_{K,E.}^\epsilon = \frac{\Lambda^2}{2 \epsilon^2} (\partial_\mu \epsilon)^2
\]

\[eA_\mu \rightarrow e_0 \epsilon A_\mu; \quad \epsilon = \exp(\varphi) \simeq 1 + \varphi; \quad \phi = \varphi \Lambda
\]

\[
\mathcal{L} = \frac{1}{2} (\partial_\mu \phi)^2 - \frac{1}{2} M_\phi^2 \phi^2 - \frac{1}{2 \Lambda} \phi F_{\mu\nu} F^{\mu\nu}
\]

Mass is free (we choose 750 GeV). OK with cosmology

A very "economical" and "predictive" model

Only one free parameter. No new particle is required

This scalar does not couple to gg, photon-Z, ZZ or WW
Decay modes

Tree-level effective vertex, no loop suppression

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>$\gamma\gamma$</th>
<th>$\gamma ff$</th>
<th>$\gamma\gamma ff$</th>
<th>$ffff$</th>
<th>$\gamma WW$</th>
<th>$\gamma\gamma WW$</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width (GeV)</td>
<td>8.393</td>
<td>2.672</td>
<td>0.610</td>
<td>0.208</td>
<td>0.447</td>
<td>0.022</td>
<td>12.35</td>
</tr>
<tr>
<td>BR (%)</td>
<td>67.95</td>
<td>21.63</td>
<td>4.94</td>
<td>1.68</td>
<td>3.62</td>
<td>0.18</td>
<td>-</td>
</tr>
</tbody>
</table>

$M_\phi = 750$ GeV; $\Lambda = 1$ TeV

- **BRs are independent of scale**, only depends on mass
- **Diphoton BR is as large as 68%** (a photon-philic scalar)
- **Total width can be large** depending on $\Lambda$, $\Gamma \sim 1/\Lambda^2$
- **s-channel gluon-fusion is not present** in this model
Due to various uncertainties total photon-fusion x-sec vary a lot

\[ \sigma(pp \rightarrow \gamma \gamma X)@13 \text{ TeV} \approx [0.4 \text{ pb} - 0.95 \text{ pb}] \left( \frac{1 \text{ TeV}}{\Lambda} \right)^2 \]

Work in progress @ THEP group, Uppsala university
Distributions

$p_T(\gamma_1)$

Disfavored from data?

$p_T(\gamma_2)$

$p_T(\gamma_3)$

$M(\gamma_1, \gamma_2)$
Recast limit

Searches are optimized for an s-channel resonance

To recast x-sec upper limit, one should take care cut-efficiencies

\[ \mathcal{N}_s = \sigma_s \times \epsilon_s \times \mathcal{L} = \left( \sum_i \sigma_i \times \epsilon_i \right) \times \mathcal{L} \]

i=all processes contributing to an experiment

<table>
<thead>
<tr>
<th>Category</th>
<th>$2\gamma + 0j$</th>
<th>$\geq 2\gamma + 0j$</th>
<th>$2\gamma + 0j$</th>
<th>$2\gamma + 1j$</th>
<th>$2\gamma + 2j$</th>
<th>$3\gamma + 0j$</th>
<th>$\geq 2\gamma + \geq 0j$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATLAS ($\phi\gamma$)</td>
<td>0.008</td>
<td>0.278</td>
<td>0.142</td>
<td>0.057</td>
<td>0.042</td>
<td>0.641</td>
<td>0.788</td>
</tr>
<tr>
<td>ATLAS ($\phi jj$)</td>
<td>0.0009</td>
<td>0.001</td>
<td>0.546</td>
<td>0.030</td>
<td>0.219</td>
<td>0.010</td>
<td>0.556</td>
</tr>
<tr>
<td>CMS ($\phi\gamma$)</td>
<td>0.036</td>
<td>0.323</td>
<td>0.247</td>
<td>0.086</td>
<td>0.063</td>
<td>0.704</td>
<td>0.957</td>
</tr>
<tr>
<td>CMS ($\phi jj$)</td>
<td>0.0009</td>
<td>0.001</td>
<td>0.750</td>
<td>0.035</td>
<td>0.291</td>
<td>0.013</td>
<td>0.763</td>
</tr>
</tbody>
</table>

$2\gamma + \geq 0j : \Lambda \approx 1.5$ TeV

$\geq 2\gamma + \geq 0j : \Lambda \approx 2$ TeV

Inclusion of elastic+inelastic photon-fusion contributions would modify the scale
Conclusions/Outlooks

- A photon-philic (68% BR) scalar is present in this model.
- Economical: one free parameter, no new particles needed.
- $\phi\gamma\gamma$ vertex is not loop-suppressed, large production rate.
- Total width can be large, about 12 GeV for $\Lambda = 1$ TeV.
- Observed excess can be explained for $\Lambda \approx 1.5 \sim 2$ TeV.
- Distinct signatures: a hard third photon (roughly in 40% events), resonance in $\gamma f f$ mass distribution (22% BR).
- Important to understand various uncertainties involved in the photon-fusion productions (work in progress).

THE ELECTROMAGNETIC-FORCE AWAKENS NOW?