Glue to light signal of a new particle

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arXiv:1512.08221
Events / 40 GeV

\[ \sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1} \]
CMS

$\sigma B(X \rightarrow \gamma \gamma)_{95\% CL}$ (pb)

$\Gamma_X = 0.1 \text{ GeV}; \text{ spin-0}$

- Observed
- Expected ± 1σ
- Expected ± 2σ

$m_X$ [GeV]
Pros and Cons: Signal of New Physics?

Pro
- Diphoton channel is very clean
- Repetition of Higgs discovery
- Both in ATLAS and CMS

Con
- Excess is close to the event tail
- Not in ttbar, jj, ll
- So many 2 sigma bumps in CMS
- Strong coupling is necessary (cross section*Br is too big)
- No motivated BSM can explain it
- Not seen at Run I

We have to wait for six months (2016 summer) or a year

Independently of the result, it would be a great opportunity for postdocs and students

It can also stimulate some ideas
Excess of events from 700 ~ 800 GeV (a few 10s events)

750 GeV peak with 45 GeV width fits the best (narrow width is consistent)

ATLAS : 3.6 sigma
CMS : 2.6 sigma
from 1601.03153

<table>
<thead>
<tr>
<th>Background function</th>
<th>Free width</th>
<th>NWA</th>
</tr>
</thead>
<tbody>
<tr>
<td>( y = (1-x^{1/3})^b x^{a_0} )</td>
<td>3.9( \sigma )</td>
<td>3.6( \sigma )</td>
</tr>
<tr>
<td>( y = (1-x^{1/3})^b x^{a_0+a_1\log x} )</td>
<td>2.9( \sigma )</td>
<td>2.6( \sigma )</td>
</tr>
<tr>
<td>( y = (1-x^{1/3})^b (x^{c_0} + x^{a_0+a_1\log x}) )</td>
<td>2.0( \sigma )</td>
<td>2.0( \sigma )</td>
</tr>
</tbody>
</table>

omitted zero event bins

from 1601.07330

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<thead>
<tr>
<th>Background function</th>
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<th>Free-width</th>
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</thead>
<tbody>
<tr>
<td><strong>Fixed normalisation</strong></td>
<td></td>
<td></td>
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<tr>
<td>( k = 0 )</td>
<td>4.2( \sigma )</td>
<td>4.9( \sigma )</td>
</tr>
<tr>
<td>( k = 1 )</td>
<td>3.4( \sigma )</td>
<td>3.7( \sigma )</td>
</tr>
<tr>
<td>( k = 2 )</td>
<td>3.4( \sigma )</td>
<td>3.7( \sigma )</td>
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<tr>
<td><strong>Free normalisation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( k = 0^{\dagger} )</td>
<td>3.4( \sigma )</td>
<td>3.6( \sigma )</td>
</tr>
<tr>
<td>( k = 1 )</td>
<td>3.5( \sigma )</td>
<td>3.8( \sigma )</td>
</tr>
<tr>
<td>( k = 2 )</td>
<td>3.4( \sigma )</td>
<td>3.6( \sigma )</td>
</tr>
<tr>
<td>ATLAS reported</td>
<td>3.6( \sigma )</td>
<td>3.9( \sigma )</td>
</tr>
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</table>
Physics of ambulance chasing

One success in 2012 Dec.: precursor of Higgs discovery

Many other failures:
- Many B physics anomalies
- Tevatron $W^+dijet$
- Dimuon charge asymmetry
- Top $A_{FB}$
- DAMA/LIBRA
- CoGeNT
- PAMELA
- 140 GeV Higgs ($WW^*$)
- BICEP2
More than 150 papers attempting to explain the excess considers a 750 GeV singlet scalar resonance.

The motivation of the paper 1512.08221 is to suggest a model independent search strategy for colored and charged (new) particle in diphoton channel at LHC.

Direct search (vector-like fermions $> 600 \sim 900$ GeV, sfermions $> 600$ GeV) highly depends on the decay channels but there is a loop diagram independently of the decay channels.
ATLAS \( \sqrt{s} = 8 \text{ TeV}, 20.3 \text{ fb}^{-1} \)

Observed 95% CL mass limit [GeV]

\begin{align*}
350 & \quad 400 \\
450 & \quad 500 \\
550 & \quad 600 \\
650 & \quad 700 \\
750 & \quad 800
\end{align*}

from 1505.04306
CMS Searches for New Physics Beyond Two Generations (B2G)

95% CL Exclusions (TeV)

Excluded Mass (TeV)

- ttbar+MET, scalar (semilep)
- ttbar+MET, scalar (dil)
- t+MET, scalar (had)
- t+MET, vectorial (had)
- bH (hadronic)
- tW (semilep)
- tW (multilep)
- bH (multilep)
- bZ (multilep)
- tH (hadronic)
- tH (vectorial)
- tH (gamma gamma)
- bH (hadronic)
- bZ (hadronic)
- bZ (multilep)
- bZ (dilep)
- bZ (mixed)
- tW (hadronic)
- tW (all)
- bH (all)

Displaced tops
Excited tops
Resonances

CMS 8 TeV 20 fb-1
Any new colored/charged particle will contribute to the loop of $gg \rightarrow \gamma \gamma$. 

\[ C = NS_2Q^2 \]
When the invariant mass is twice of the loop particle mass, on-shell enhancement is visible in the loop amplitude. It is a consequence of rapid rising of imaginary part and related change of the real part amplitude.

Loop amplitude has tensor indices and physics is clear after the polarization sum.

Instead scalar example would be illustrative.
Figure 1. The absolute value of the fermion Loop-function corrections for scalar and pseudoscalar as defined in Eq. (2.5).

In Fig. 1 we show the absolute values of these loop-function corrections as a function of the VLQ mass $M$ for a 750 GeV scalar particle. This demonstrates the size of near-threshold enhancement for the loop induced couplings. Comparing to the value of unity in large $M$, the loop function could be enlarged to $1.5(2.5)$ and $1.4(1.7)$ for VLQ mass $M = 375$ GeV and 400 GeV, respectively, for scalar (pseudoscalar). As we shall see later, the signal requires large values of loop induced scalar to gluon pair and to diphoton coupling. This near-threshold effect is helpful in pushing up the cut-off scale of the theory. This motivates our benchmark VLQ mass of 1000 GeV and 400 GeV. The former represents asymptotic values of loop function for large mass; the latter represents the case where threshold effect is important without opening up the tree-level two-body decays to VLQ pairs.

Before moving on to numerical studies of the diphoton excess, we want to comment on alternative choices of the effective Lagrangian. Conventionally we use the set of higher-dimensional operators assuming the preservation of SM gauge symmetries $SU(3)_c \times SU(2)_L \times U(1)_Y$. It is not only a plausible requirement for most beyond stand model extensions, but also enables us to see the links between various modes after electroweak symmetry breaking. In such basis, the most relevant operators are $O_B$ and $O_W$. Our coefficient is in fact proportional to Wilson coefficient $c_B \cos^2 \theta_W + c_W \sin^2 \theta_W$. Furthermore, these operators also induce $S \rightarrow ZZ, Z \gamma$ and $WW$ decays with explicit parametric dependence. Consequently, the future measurement of these relevant channels will provide new insight about the underlying theory, see discussions in e.g. Refs [7,13,81,88]. However, our choice of parameterization does capture the essential physics for the diphoton anomaly, avoiding introducing more parameters.

This is due to our consistent choice of the coefficients in Eq. (2.2), Eq. (2.3) and Eq. (2.4).

These operators are defined by replacing the $F_F$ in operators in Eq. (2.2) with $B_B$ and $W_W$ in the unbroken phase of electroweak gauge symmetry, and similarly for the pseudoscalar.
In the following analysis, selection efficiency is assumed to be 100%.

Signal cross section as a function of the loop particle (scalar) mass.

- $M_s = 100$ GeV
- $M_s = 200$ GeV
- $M_s = 300$ GeV
- $M_s = 400$ GeV
- $M_s = 500$ GeV
- $M_s = 600$ GeV
- $M_s = 700$ GeV

$C_S = 10$
Signal cross section as a function of the loop particle (fermion) mass
*Background is subtracted with the usual fitting function

**Scalar**

350 GeV (top loop)  
700 GeV (new particle)  

**Fermion**

C\(_S\) = 10, 20  
C\(_F\) = 5, 8

Best fit (red) and small color/charge (blue)
Upper limit on $C$ (scalar) and expected upper limit

Interference is important
Interference is important

Upper limit on $C$ (fermion) and expected upper limit

LHC 13, 3.2 fb$^{-1}$

ATLAS (3.2 fb$^{-1}$)
Model independent upper bounds on colored and charged particles are obtained from diphoton channel at LHC.

It can compete with the monojet search bounds.
Working in progress 1

Observation of ttbar threshold from diphoton spectrum
(in collaboration with KCMS group in SNU)
Bound state can give comparable effects if the constituent particle lives long enough.

Interesting interference effect is expected from loop diagram and bound state.

Double counting issue should be correctly addressed to interpolate different regions of parameter space.