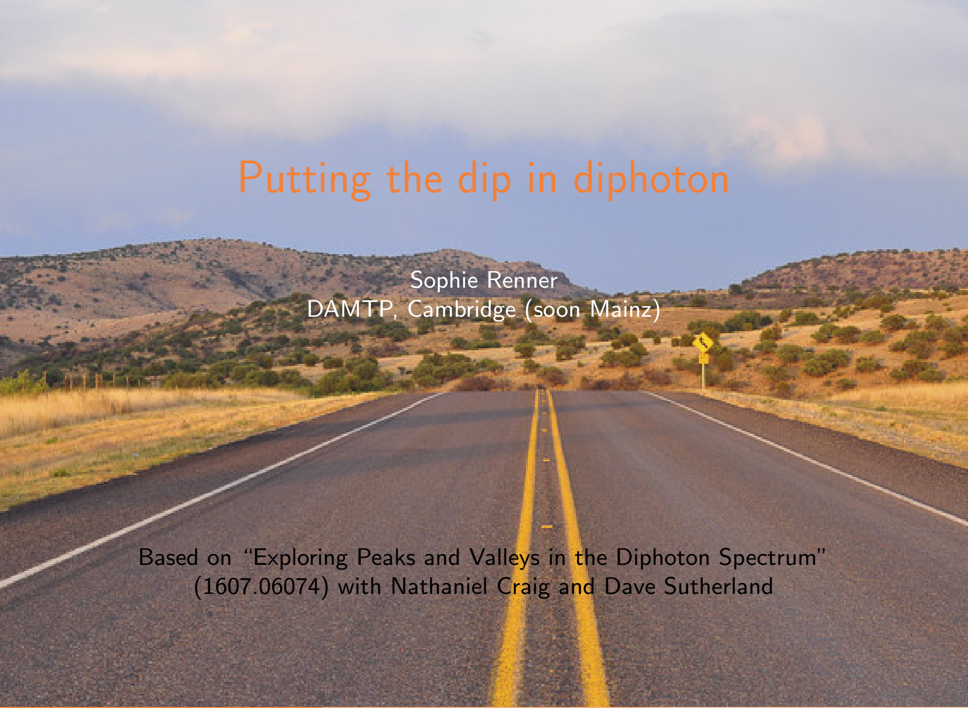

Putting the dip in diphoton

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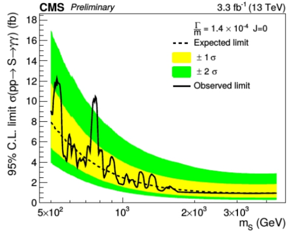
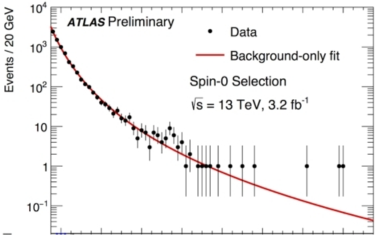
Based on "Exploring Peaks and Valleys in the Diphoton Spectrum" (1607.06074) with Nathaniel Craig and Dave Sutherland

Outline

- There was a bump in diphotons
- Fits were done to find the preferred "mass", "width" and "cross-section" of a possible resonance
- But how might resonance-continuum interference affect these numbers?
- And can we use interference effects to deduce the most likely "spin"?
- Obviously we now know that the bump was just a statistical fluctuation of the background
- Can we learn anything for if and when it happens again (and for real)?
- Can we dip-hunt as well as bump hunt?

The diphoton bump: ATLAS and CMS fits to 2015 data





CMS:

- Best fit with 13 TeV data $\sim$ 760 GeV
- Preference for a narrow width
- 2.85σ local significance ($< 1\sigma$ global)

ATLAS:

- Best fit with 13 TeV data $\sim$ 750 GeV
- Preference for a $\sim$ 45 GeV width
- 3.6σ local significance (2σ global)

Particle explanations

- Spin 0 (scalar or pseudoscalar) or spin 2
- qq initiated or gg initiated
- wide or narrow

Effective Lagrangians:

$$
\begin{aligned}
\mathcal{L}_{0^{++}} &\supset -\frac{1}{\Lambda_g}\phi G^{\mu\nu}G_{\mu\nu} - \frac{1}{\Lambda_\gamma}\phi F^{\mu\nu}F_{\mu\nu} - c_q\phi\overline{q}q; \\
\mathcal{L}_{0^{-+}} &\supset -\frac{1}{\Lambda_g}\phi G^{\mu\nu}\tilde{G}_{\mu\nu} - \frac{1}{\Lambda_\gamma}\phi F^{\mu\nu}\tilde{F}_{\mu\nu} - ic_q\phi\overline{q}\gamma^5 q; \\
\mathcal{L}_{2^{++}} &\supset -\frac{1}{\Lambda_T}\phi_{\mu\nu}\left[-F^{\mu\lambda}F^{\nu}_{\lambda} + \frac{1}{4}g^{\mu\nu}F^2 - G^{\mu\lambda}G^{\nu}_{\lambda} + \frac{1}{4}g^{\mu\nu}G^2\right. \\
&\qquad \left. + \frac{1}{2}i\overline{q}(\gamma^\mu\partial^\nu + \gamma^\nu\partial^\mu)q - ig^{\mu\nu}\overline{q}\not{\partial}q\right].
\end{aligned}
$$

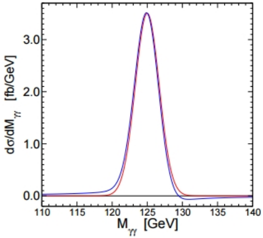
Signal-background interference

$$P = \frac{A}{\hat{s} - M^2 + i\Gamma\sqrt{\hat{s}}}$$

- Calculate interference for each scenario using helicity amplitudes
- A, M, Γ all free parameters

At $\sqrt{s} = 13$ TeV and $\sqrt{\hat{s}} = 750$ GeV, the background is mostly $q\bar{q}$ initiated contributions $\Longrightarrow$ interference effects will be largest in $q\bar{q}$ initiated signals

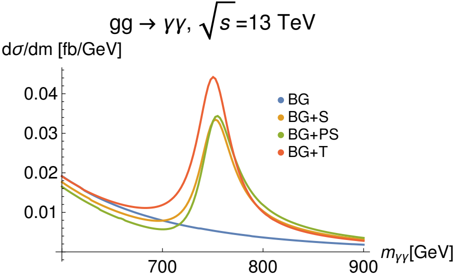
Lots of previous work on interference effects in Higgs to gamma gamma (eg. hep-ph/0302233, 1208.1533), but the very narrow width of the Higgs means effects are small

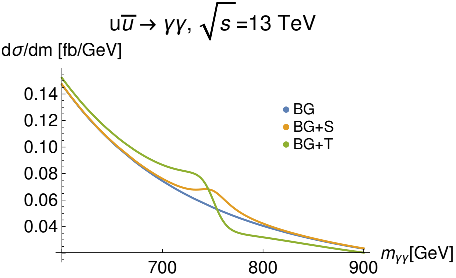


Other papers focus on effects of interference in the interpretation of the 750GeV excess, using benchmark models (eg 1601.00006, 1605.00542)

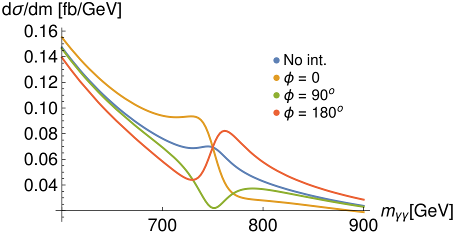
Bumps with interference

No phase:





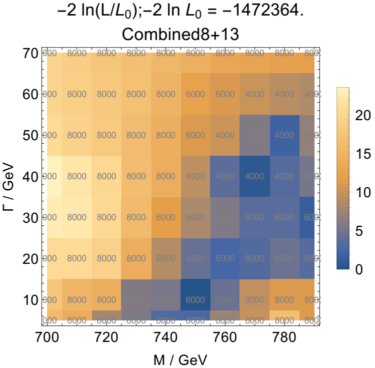
Spin 2 qq initiated with phases:



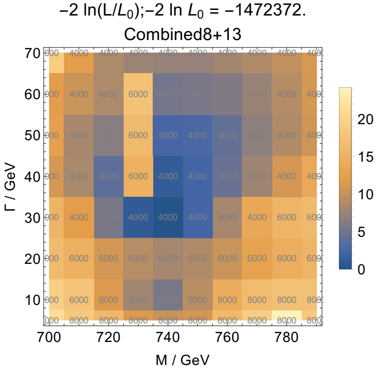
In the EFT no phases are possible in couplings due to hermiticity of effective lagrangian

Using $M = 750$ GeV, $\Gamma = 40$GeV

Fits with interference: spin 2 qq-initiated



With interference

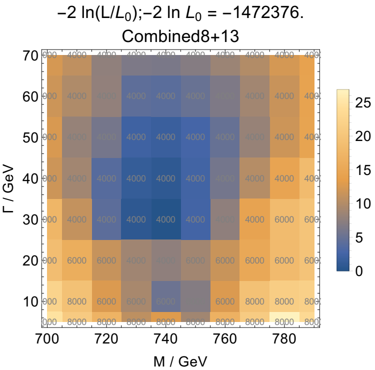


Without interference

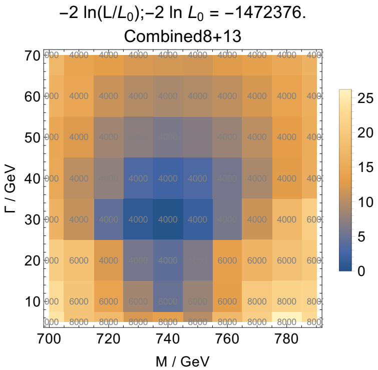
Big change: due to

- Dominance of qq initiated background (large interfering background $\implies$ large interference effects)

Fits with interference: spin 2 gg-initiated



With interference

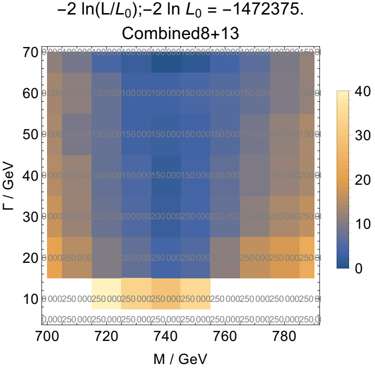


Without interference

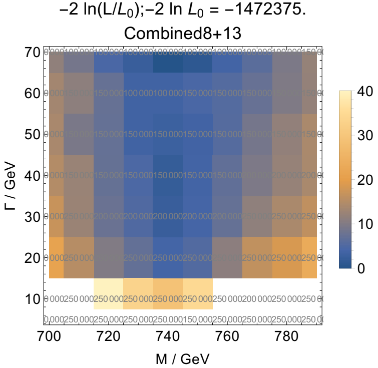
Some change: due to

- Relative suppression of gg- initiated background

Fits with interference: spin 0 *qq* - initiated



With interference

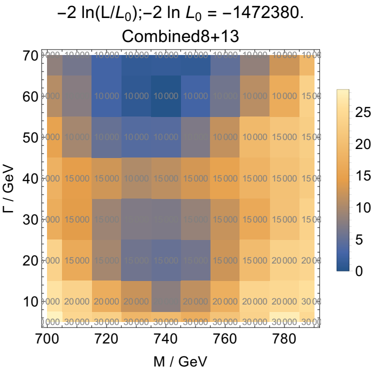


Without interference

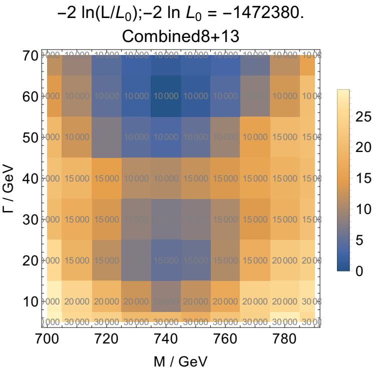
No change: due to

- No interference at LO

Fits with interference: spin 0 gg - initiated:



With interference

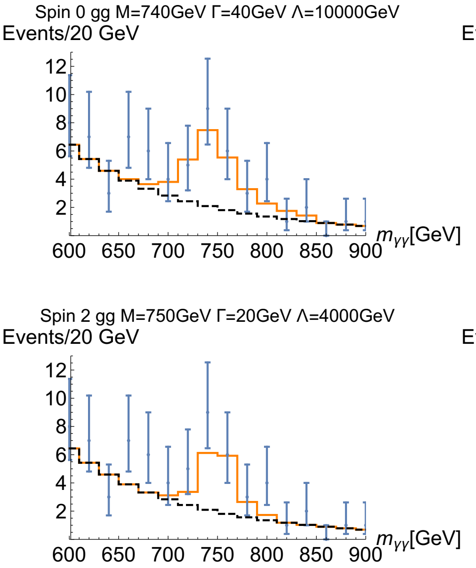


Without interference

V little change change: due to

- PDF suppression of gg background compared to qq

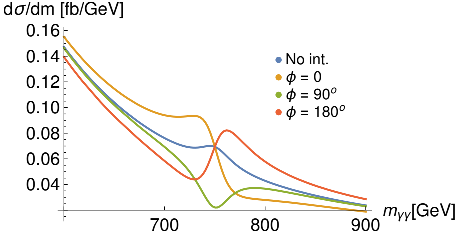
Best fits for each scenario



These are fits to 13 TeV 2015 ATLAS data (their "Spin 0" dataset)

Peak-dip hunting? Dip hunting?

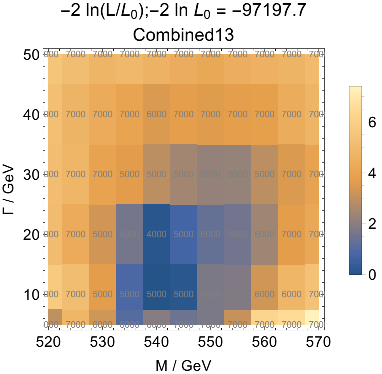
We have found that in diphotons, spin 2 qq-initiated resonances can look very different from a bump:

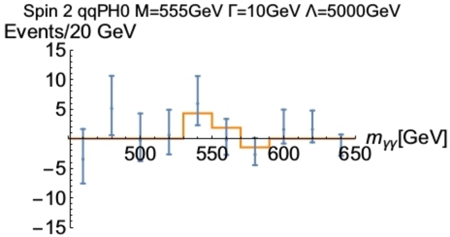


NB This can be the case in other final states and for different quantum numbers too, mostly dependent on size of interfering background (eg. in $gg \to S \to tt$, see *eg* 1608.07282 and many other refs)
$\implies$ for WIDE resonances, other shapes are possible, which could be missed by simple bump hunting

Peak-dip hunting

Slight peak-dip structure in ATLAS and CMS diphoton spectrum (pre-2016, 13TeV) at 550GeV - what happens when you try to fit a spin 2 resonance?

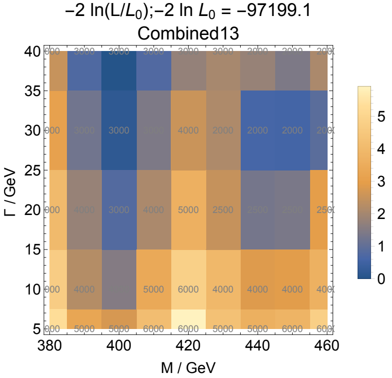


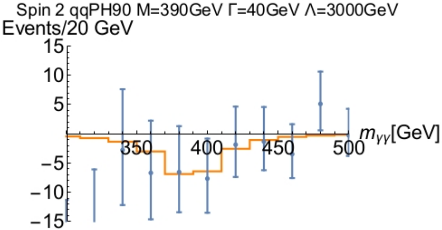


Can produce a slightly improved fit to the data $\Delta\chi^2 \sim 6$ compared to BG only

Dip hunting

Slight dip in ATLAS and CMS diphoton spectrum (pre-2016, 13TeV)
Try to fit a dip *i.e.* with a phase of 90 degrees in the amplitude A





Can produce a slightly improved fit to data $\Delta\chi^2 \sim 5$ compared to BG only

Summary

- In some cases, interference matters
- This depends on: spin, width, initial state, values of the PDFs at the resonance, whether there is interference at LO...
- Seems to be especially important in the diphoton channel for high mass spin 2 particles produced from $q\bar{q}$
- Lessons for resonance searching in diphotons at the LHC:
  - Best fits of mass, width, amplitude can be affected
  - Possible to get some info on likely spin by looking at shape
  - Consider looking for other shapes in the data