Have ATLAS and CMS discovered a new boson at 750 GeV decaying in two photons?

Search for diphoton resonances in 13 TeV data

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CP3 - UC Louvain

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Disclaimer

NO

WE HAVEN'T DISCOVERED ANYTHING

but then, what is the current fuss about?

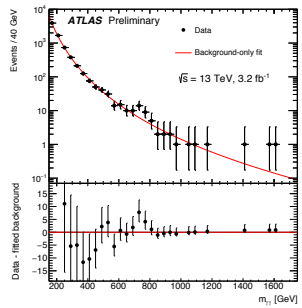
CERN end-of-the-year 'jamboree'

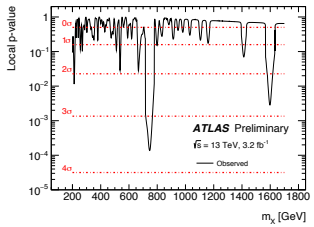
ATLAS and CMS physics results from Run 2

- In brief: two experiments see *somewhat* an incompatibility with the background-only hypothesis at around 750 GeV when looking for resonances in the $m_{\gamma\gamma}$ spectrum
  - "the latter stirs theorists' imagination, even if some experimentalists deplore the fact"
  - ATLAS: 2 slides out of 51; 1 analysis out of 26 ATLAS-CONF-2015-081
  - CMS: 3 slides out of 54; 1 analysis out of 33 CMS-PAS-EXO-15-004
- Besides, it's just plot'n'fit $m_{\gamma\gamma}$, how hard can it be? Why so cautious?

Search for a **Two Photons Resonance** (II)

Results: Events with mass in excess of 200 GeV are included in **unbinned fit**



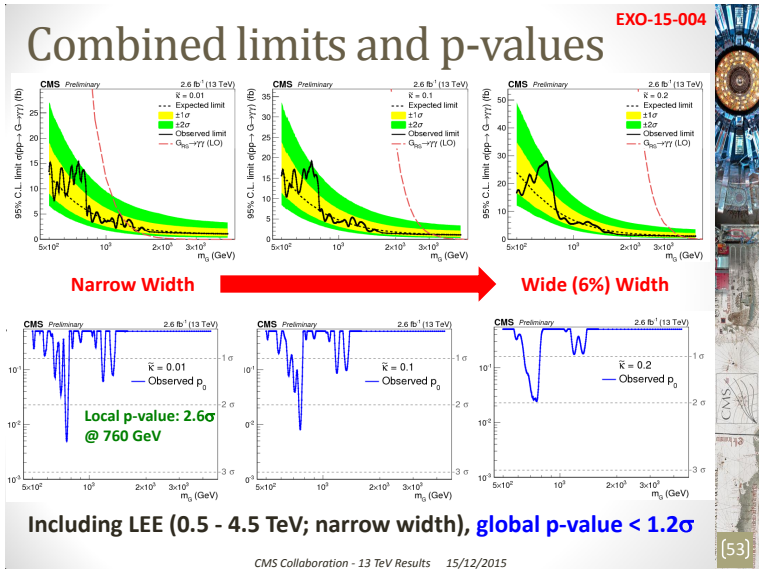


- **In the NWA search**, an excess of **3.6σ** (local) is observed at a mass hypothesis of minimal p_0 of 750 GeV
- Taking a LEE in a mass range (fixed before unblinding) **of 200 GeV to 2.0 TeV** the global significance of the excess is **2.0σ**

In the NWA fit the resolution uncertainty is profiled in the NWA fit and is pulled by 1.5σ

The data was then fit under a **LW hypothesis** yielding a width of approximately 45 GeV (Approx. 6% of the best fit mass of approximately 750 GeV)

- As expected the local significance increases to **3.9σ**
- Taking into account a LEE in mass and width of up to **10%** of the mass hypothesis of **2.3σ** (Note: upper range in resolution fixed after unblinding)



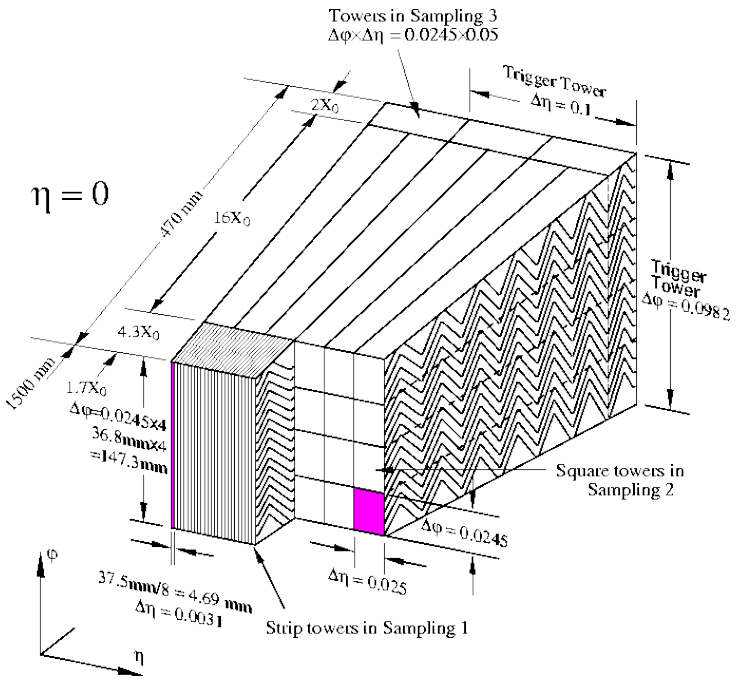
Plan & disclaimer

1. About photons
2. About the analyses
3. About the results

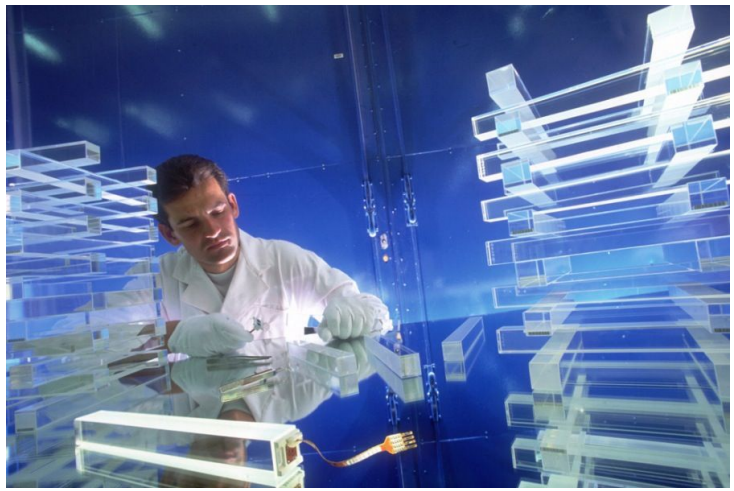
Beware it's not possible to present correctly so much so quickly,
I took shortcuts :)

A brief history on photons I: calorimeters

ATLAS: 3 layers liquid LAr



CMS: 1 layer crystal $PbWO_4$



Why is this important?

- Typical energy resolution form: $\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$
  - **Calibration affects high energy photons**
  - The more homogeneous and dense, the better the energy collection

A brief history on photons II: reconstruction, calibration

ATLAS: new IBL, calibration from simulation

- new layer in the pixel (IBL)
- new clustering consistent in between electrons, unconverted and converted photons
- calibration from $Z \rightarrow ee$ at 8 TeV reconstructed à la RunII

CMS: changes in reconstruction, preliminary calibration

- Crystal inter-calibration from Run I: aka preliminary calibration ('prompt-reco')
- Laser corrections well understood (darkening of crystals with radiation dose)
- Clustering of energy deposits now also fully part of particle flow
- Dedicated regression in case of very high energy photons (can saturate electronics)

New detector, new reconstruction, new strategies

A brief history on photons III: identification, performance

Common items

- new trigger paths and design
- shower-shape data/mc corrections
- reoptimized tight photon identification
  - Fight against neutral meson decays ($\pi_0, \rho, ... \rightarrow \gamma\gamma$)
  - photon conversions $\gamma \rightarrow e^+ e^-$
  - new pile-up and bunch-crossing conditions
  - longitudinal granularity helps
- use of calorimeter and track/charged (PF) isolations

New center of mass energy, new data-taking conditions (PU, BX), new high-level objects

Analyses: selection

ATLAS

- diphoton trigger: $E_T > 35$ GeV, $E_T > 25$ GeV, loose identification, $\epsilon > 99\%$ for $m_X > 200$ GeV
- vertex assignment from NN: 80 to 95% efficiency
- no categorisation
- MC simulation:
  - $\gamma\gamma$: SHERPA (NLO?), x-check with DIPHOX (NLO)
  - γjet: SHERPA
- $\frac{p_T(\gamma_1)}{m_{\gamma\gamma}} > 0.4$, $\frac{p_T(\gamma_2)}{m_{\gamma\gamma}} > 0.3$
- $\epsilon_{ID} > 90(85)\%$ for (un)converted photons

CMS

- diphoton trigger: $E_T > 60$ GeV, loose identification, $\epsilon = 100\%$ for $m_X > 500$ GeV
- highest $p_T^{\gamma\gamma}$ candidate
- EBEB (EBEE) categories
- MC simulation:
  - $\gamma\gamma$: SHERPA (NLO), x-check with 2γNNLO
  - γjet: MADGRAPH5
  - jj: PYTHIA8
- $p_T > 75$ GeV, $m_{\gamma\gamma} > 230(320)$ GeV for EBEB (EBEE)
- $\epsilon_{ID} > 90(85)\%$ for EBEB (EBEE)
- many x-checks, no changes

Analyses: high level corrections

ATLAS

- Definition of a fiducial volume for computing limits on fiducial production cross-section, and associated correction factors

CMS

- Photon energy scale residual shift
- Data/MC scale factors from $Z \rightarrow ee$
- Residual corrections to the scale factors from back to back DY$\rightarrow ee$

Analyses: signal modeling

$$m_{\gamma\gamma} = \sqrt{2 \cdot E_1 E_2 \cdot cos(\gamma_1, \gamma_2)}$$

- Important: energy resolution AND correct vertex assignment
- Signal distribution is (intrisic shape $\otimes$ detector response)

ATLAS

- SM Higgs-like boson, 5 prod. modes, 4 MeV width, $m_X \in [200, 2000]$ GeV
- Interference with $gg \to \gamma\gamma$ neglected / small
- ggF, VBF with POWHEG (NLO?), VH, ttH with PYTHIA8
- detector resolution modeled with double-sided Crystal-Ball
- intrisic lineshape from POWHEG, $\alpha = \frac{\Gamma}{m_X} \in [1, 10]\%$

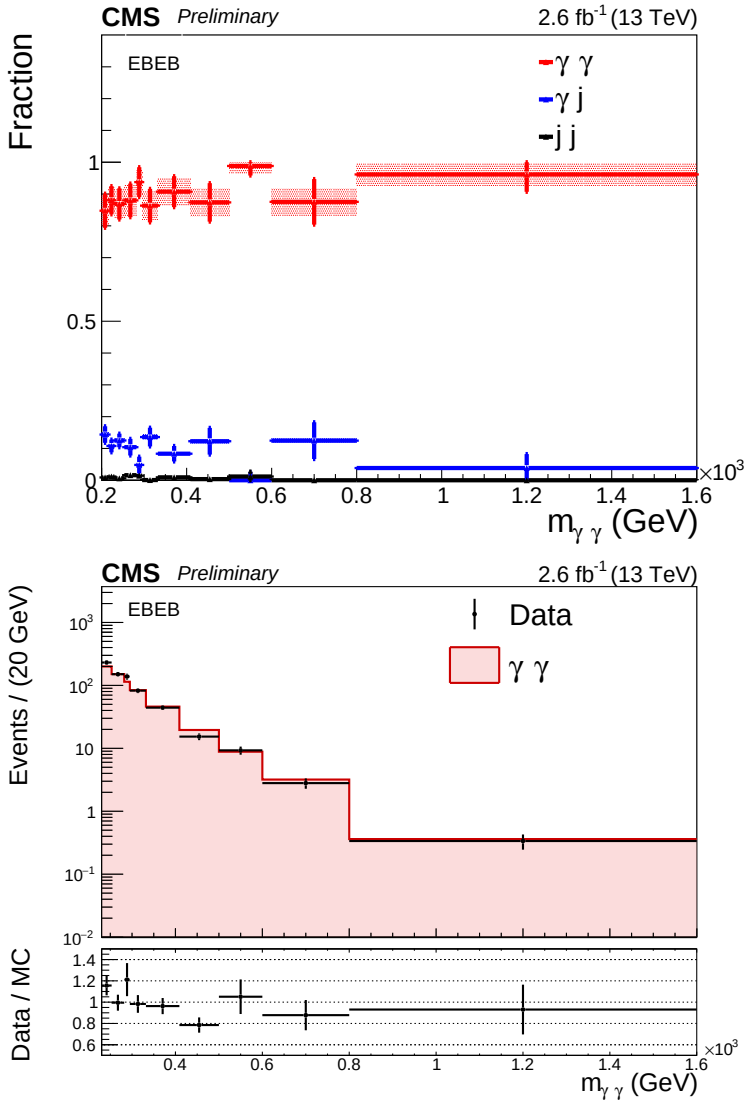
CMS

- RS graviton with PYTHIA8 (LO), $\tilde{\kappa} \in [0.01, 0.2]$, $m_X \in [500, 4500]$ GeV
- 9 fully simulated mass hypotheses
- Interpolation with 125 GeV spacing with PYTHIA8 samples using moment morphing

Analyses: background modeling (I)

CMS

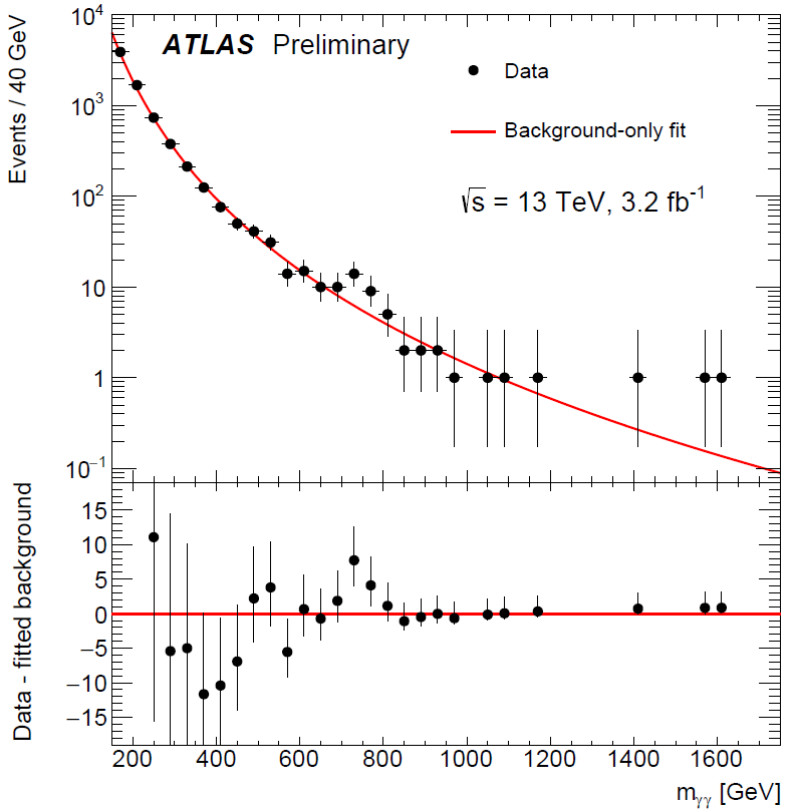
- $f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b\cdot \log(m_{\gamma\gamma})}$
- Background composition from a 2D template fit on relaxed charged hadron isolation; k-NN matching with analysis selection using k-NN: $\gamma\gamma$ background dominant
- Prediction from SHERPA rescaled to 2γNNLO compared with data: good agreement
- Uncertainty on bkg parametrization increased until median of the pull from pseudo-experiments below 0.5



Analyses: background modeling (II)

ATLAS

- $f_{(k)}(x; b, \{a_k\}) = (1 - x^{1/3})^b \cdot x^{\sum_{j=0}^{k} a_j (\log x)^j}$, where $x = \frac{m_{\gamma\gamma}}{\sqrt{s}}$
- F-test indicates choice $k = 0$
- Bias studies: bias on fitted signal yield in the background-only hypothesis required to be $< 0.2\times$ the statistical uncertainty
- potential presence of a signal elswhere than in the mass hypothesis studied does not bias the shape
- $\gamma\gamma$ purity measured from data-driven methods à la $\frac{d\sigma(\gamma\gamma)}{dX}$



Analyses: systematic uncertainties

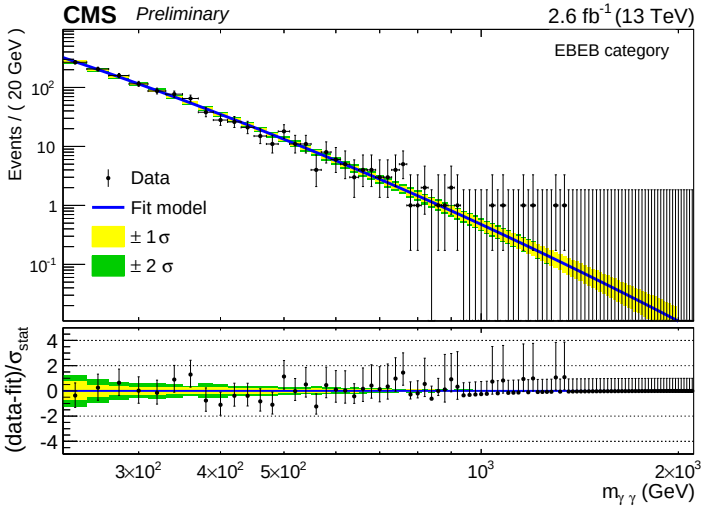
ATLAS

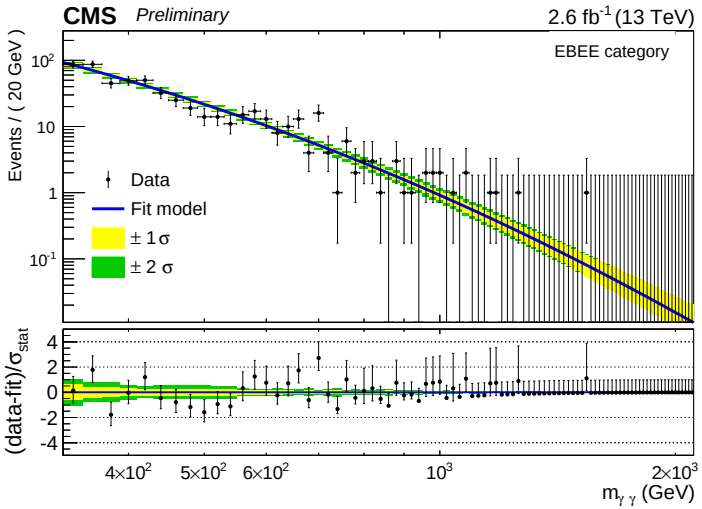
Source	Uncertainty
Background modeling °•	
Spurious signal	$2-10^{-3}$ events, mass-dependent
Background fit	$\leq 50\%$–$\leq 20\%$ of the total signal yield uncertainty, mass- and signal-dependent
Signal modeling °•	
Photon energy resolution	$^{+[55-110]\%}_{-[20-40]\%}$, mass-dependent
Signal yield •	
Luminosity	$\pm 5\%$
Trigger	$\pm 0.63\%$
C_X *factors* •	
Photon identification	$\pm(3$–$2)\%$, mass-dependent
Photon isolation	$\pm(4.1$–$1)\%$, mass-dependent
Production process	$\pm 3.1\%$

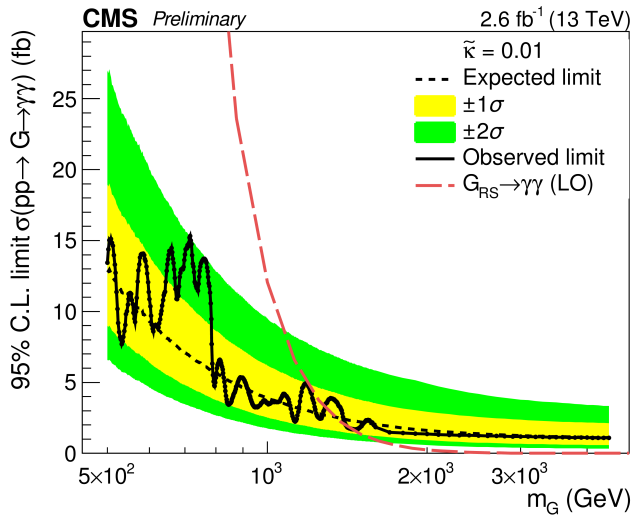
CMS

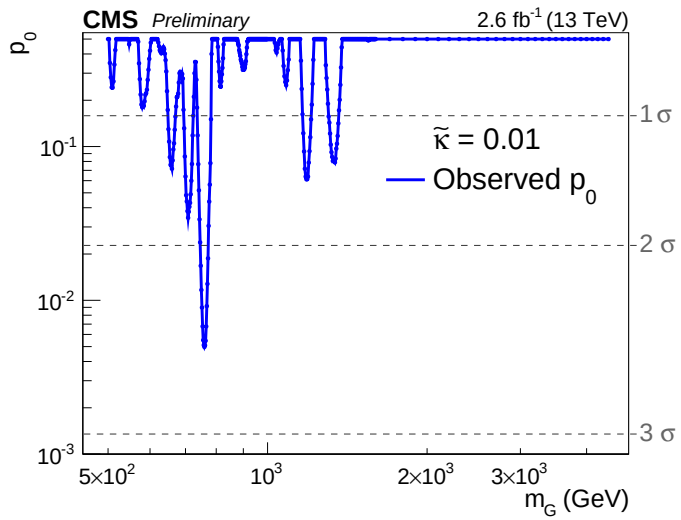
- Integrated luminosity: 4.6%
- Trigger and photon ID: 10%
- PDF: 6%
- Photon energy scale: 1%

The results: CMS



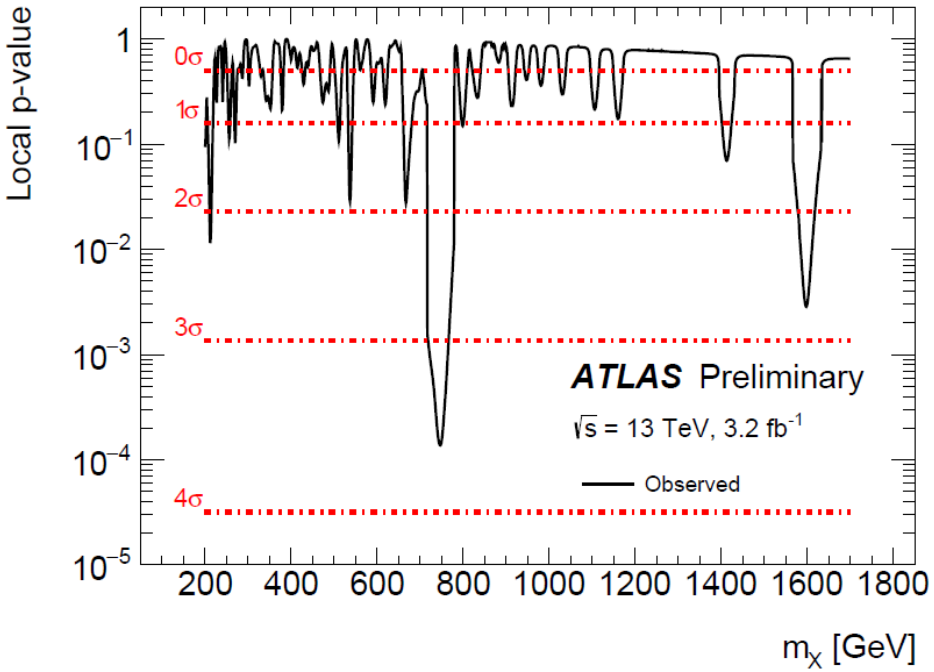


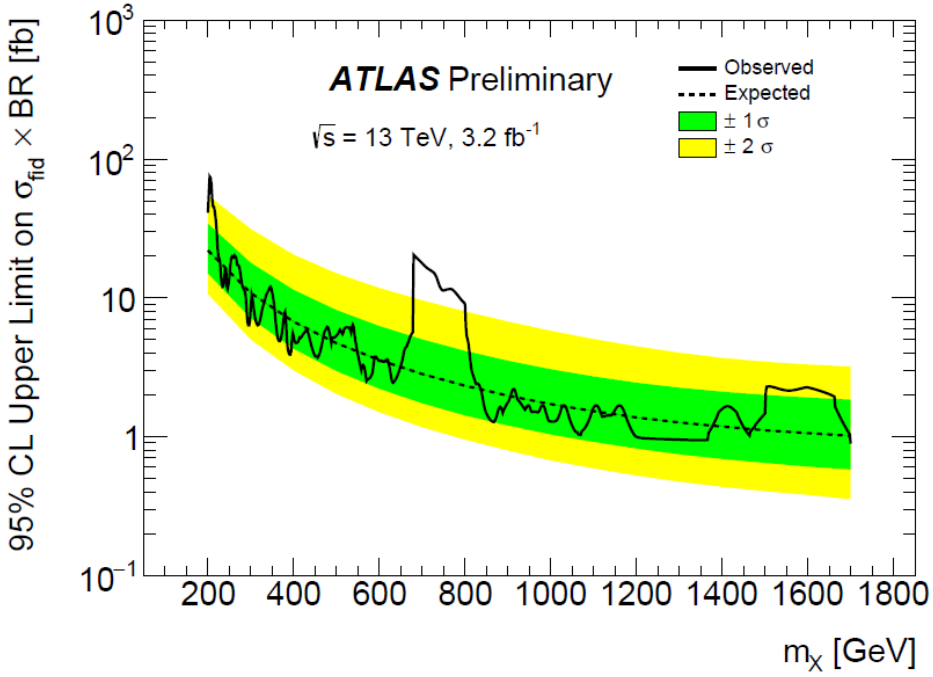




Largest excess for $m_X = 760$ GeV and $\tilde{\kappa} = 0.01$: 2.6 σ
Decrease to 1.2 σ taking LEE on mass hypotheses into account

The results: ATLAS



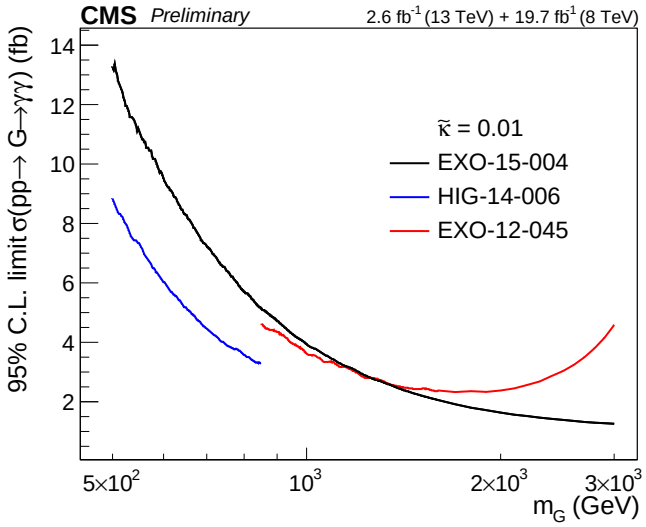


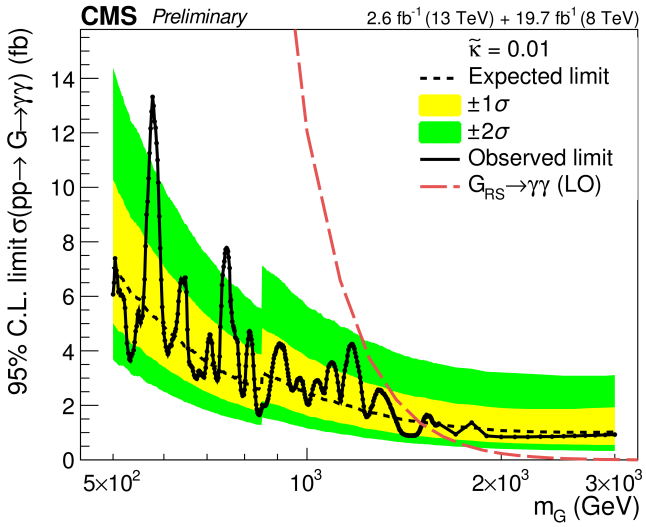
Largest excess for $m_X = 750$ GeV for narrow width: 3.6 σ
Decrease to 2.0 σ taking LEE on mass and width hypotheses

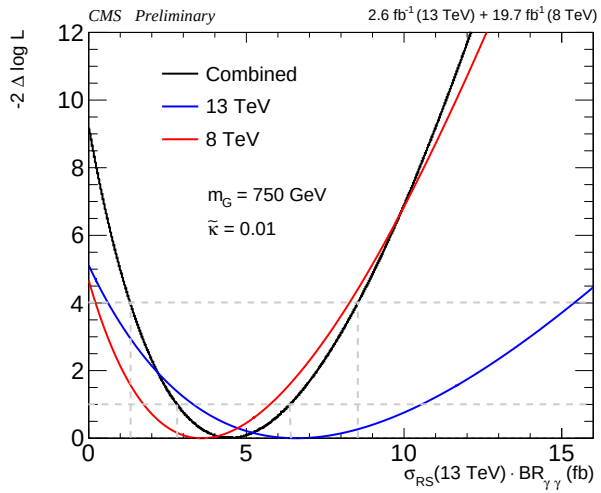
A $\sim 1.5\sigma$ pull on photon energy resolution nuisance observed: excess broader than experimental resolution:

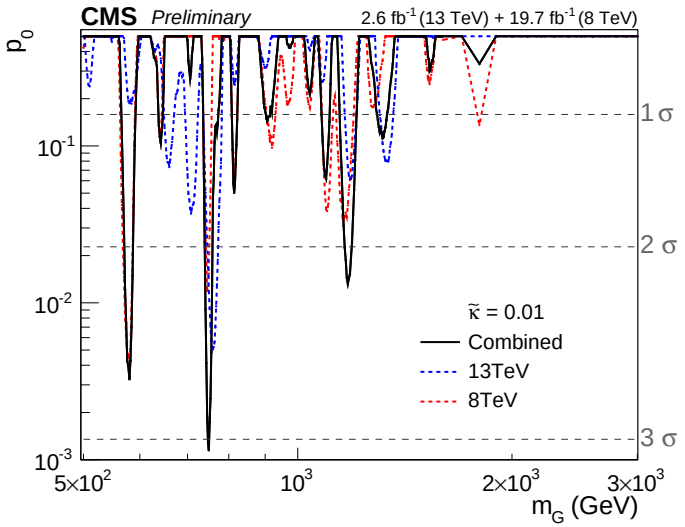
$m_X = 750$ GeV and $\alpha = 6\%$ ($\Gamma = 45$ GeV): 3.9σ local (2.3σ global)

Bonus track: CMS combination









Largest excess at $m_X = 750$ GeV with $\approx 3\sigma$ local (1.7σ global)
Cross sections at 8 and 13 TeV are compatible

The facts

- CMS sees a 3 (1.7) σ local (global) excess at $m_X = 750$ GeV
- ATLAS sees a 3.9 (2.3) σ local (global) excess at $m_X = 750$ GeV

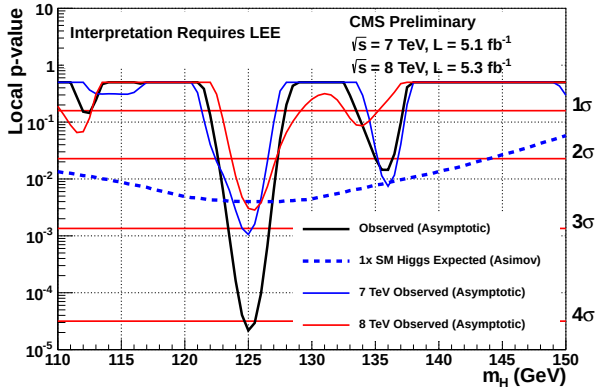
Why so cautious?

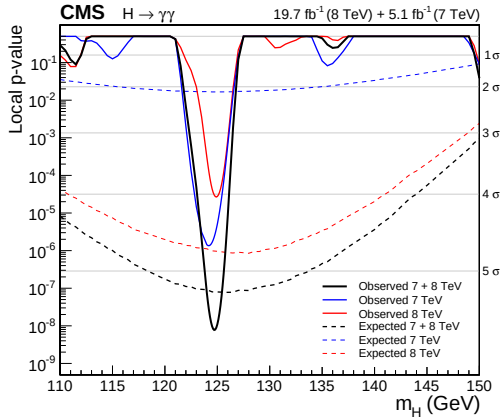
- Two very different analyses
- Two different signal hypotheses
- Brand new data-taking conditions
- Not final calibrations
- Brand new objects
- New MC techniques (NLO is the new standard)
- etc.
- Need time to digest it all
  - these are ***preliminary*** results for a reason :)

Really?

YES: remember CMS SM Higgs to $\gamma\gamma$ search (photons, again, btw):

- July 4th, 2012 (yeah! discovery! happy!)
- Run I legacy paper 2 years later: signal strength **decreased** between 7 and 8 TeV :(
  - Yet we added 4 times more data, updated to state-of-the-art calibration, polished understanding of objects and conditions, improve sizeably analysis techniques...





(I could also mention ATLAS did not see much Higgs at 13 TeV yet...
In CMS we didn't dare looking so soon)

So?

According to our recent understanding of our new detector and data, our best ATLAS (CMS) preliminary bump in searches for scalar (RS graviton) bumps in two photons have 3% (10%) chances to be (un)lucky statistical fluctuations

BACKUP

ATLAS

- $\sigma_{CB} = 2$ GeV at $m_X = 200$ GeV
- $\sigma_{CB} = 13$ GeV at $m_X = 2$ TeV

CMS

m_G (GeV)	category	$\tilde{\kappa}$	FWHM (GeV)	$\tilde{\kappa}$	FWHM (GeV)
500	EBEB	0.01	14	0.2	36
500	EBEE	0.01	22	0.2	42
1000	EBEB	0.01	27	0.2	74
1000	EBEE	0.01	43	0.2	85
2000	EBEB	0.01	54	0.2	147
2000	EBEE	0.01	76	0.2	163
3000	EBEB	0.01	96	0.2	225
3000	EBEE	0.01	110	0.2	254
4000	EBEB	0.01	121	0.2	320
4000	EBEE	0.01	150	0.2	326