Search for resonances decaying to photon pairs in 3.2 fb^{-1} of *pp* collisions at √s=13 TeV with the ATLAS detector

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ATLAS EXPERIMENT

17.12.2015

Enigmass
The enigma of mass

lapp

Outline

Introduction

Ingredients to search for a resonance

- Selection optimised for best significance
- Background modeling
- Signal parameterization
- Apply ingredients to get:
  - discovery p-value
  - cross-section $\times$ BR limit

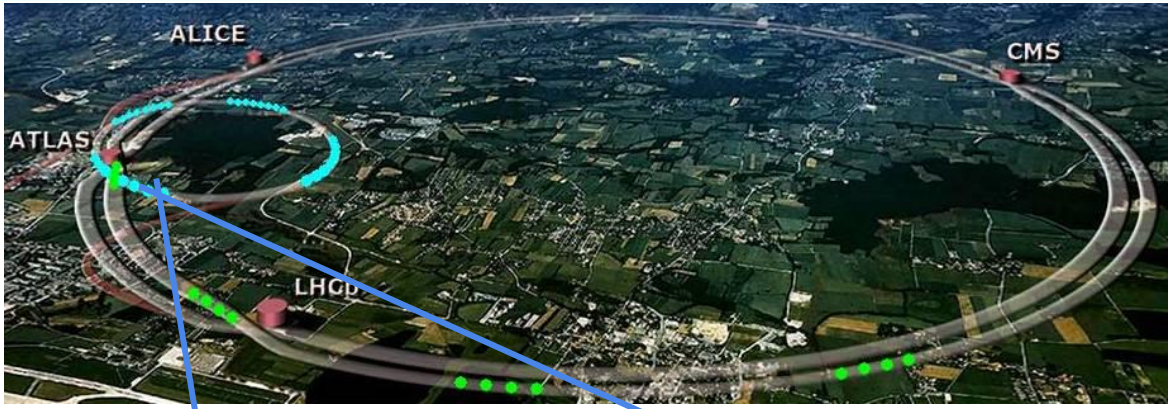
Results

Introduction

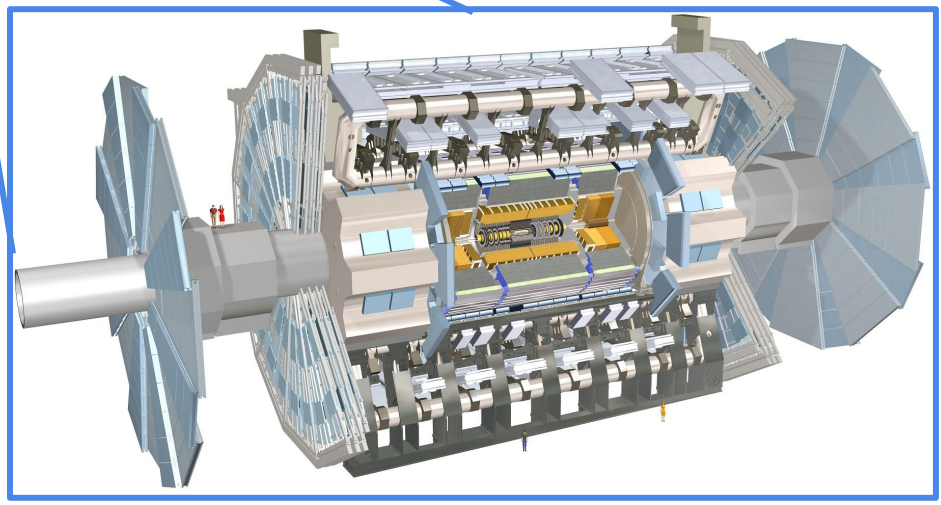
ATLAS

(A Toroidal LHC ApparatuS)

general-purpose detector:



- search for new physics
- test predictions of the Standard Model (including the Higgs boson)



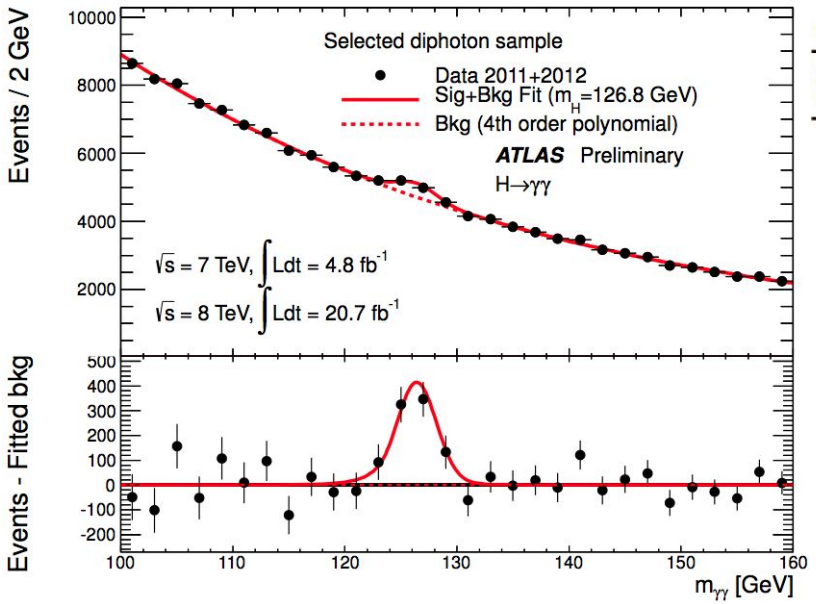
The Nobel Prize in Physics 2013

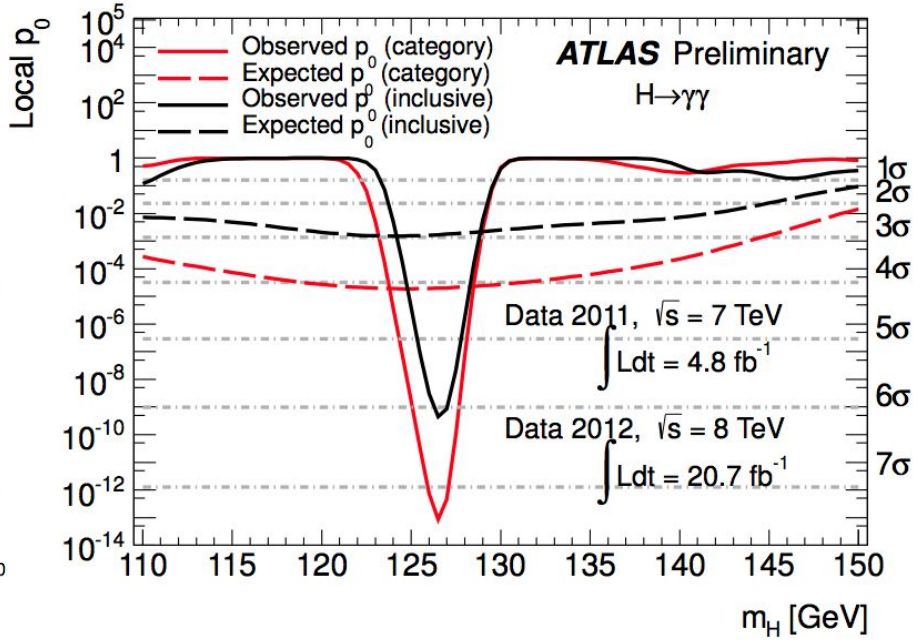
François Englert, Peter Higgs

"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the **ATLAS** and CMS experiments at CERN's Large Hadron Collider"

Search for a resonance

In 2012, THE ATLAS & CMS collaborations presented the observation of a new resonance:
particle compatible with the SM Higgs boson



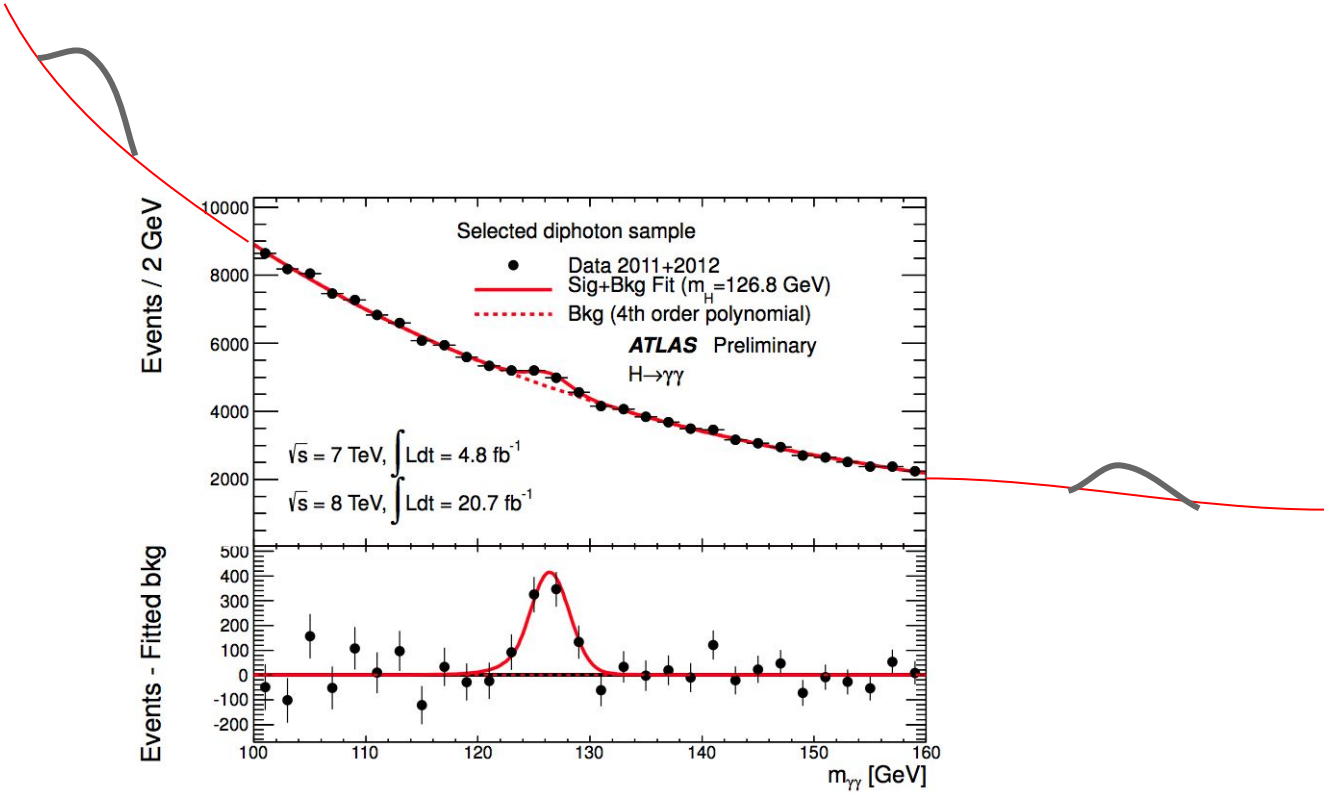


p_0 - local significance, probability of background to generate a signal-like excess

Search for a resonance

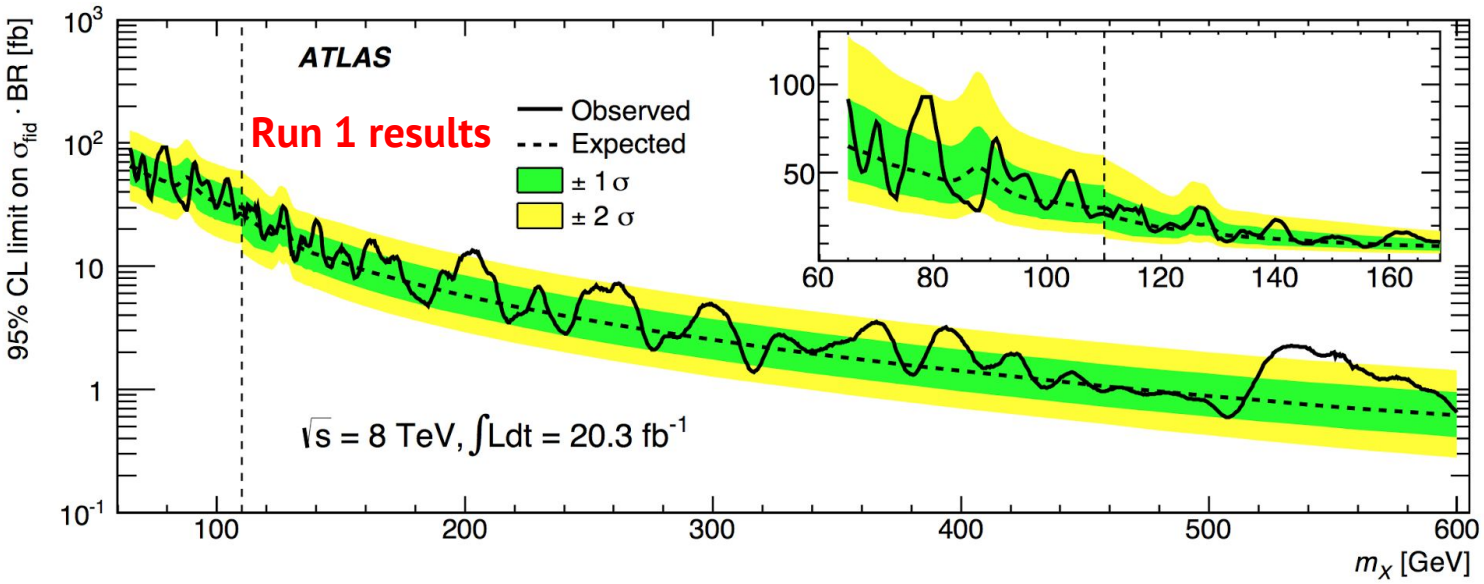
What if there are more of them?

Additional diphoton resonances foreseen by model with an extended Higgs sector, like 2HDM



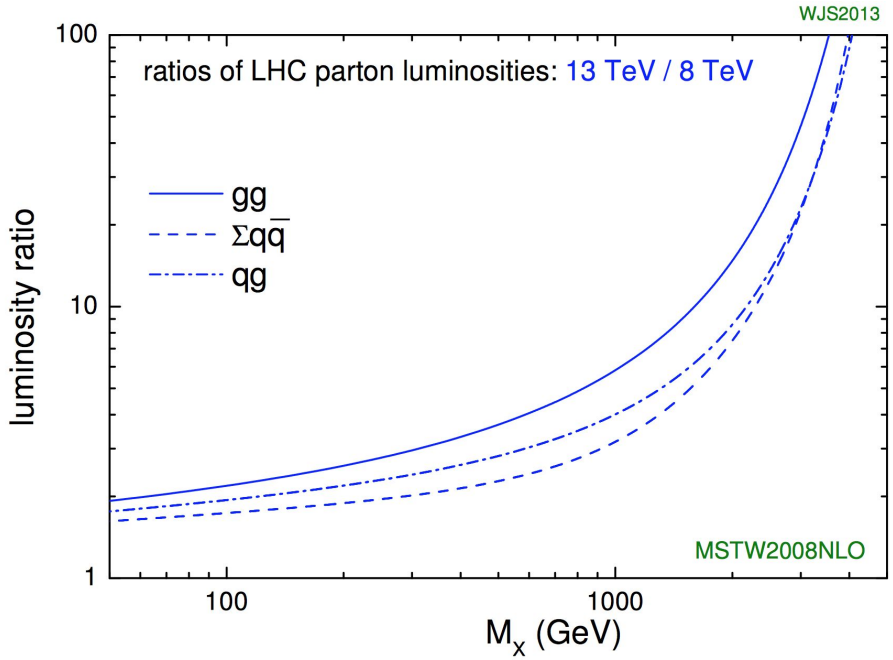
Search for a resonance

Limits were set for Run 1 - no excess found up to 600 GeV.



Search for a resonance

Cross Section increases in Run 2, and we are **searching again!**



During LHC run 1, ATLAS collected: 4.8 fb^{-1} @ 7 TeV

20.7 fb^{-1} @ 8 TeV

In 2015, ATLAS has collected and validated 3.2 fb^{-1} @ 13 TeV

The number of expected events *N* is proportional to luminosity and cross section σ

$$N_{process}^{Events} = L * \sigma_{process}$$

Search for a resonance in Run 2

ATLAS NOTE

ATLAS-CONF-2015-081

December 15, 2015

Search for resonances decaying to photon pairs in 3.2 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

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Analysis Team

34 authors

~15 active contributors

6 of them from LAPP

Critical contributions and leading role of LAPP ATLAS Team!

Marco - the analysis contact and main editor of the note

I'm co-editor

The results are public, note can be found here

Search for a resonance in Run 2

In collected diphoton candidates we have combination of photon-photon , photon-jet and jet-jet events (where jet(s) faking a photon).

1) Select events with a pair of photon candidates, applying selection criteria to maximize a significance and obtain high photon purity
2) The selected events contains events from direct $\gamma\gamma$, γj, jj production (and possibly a new resonance ?)
3) The background is continuous and its shape can be parametrized
4) The possible signal is parameterized with various natural width hypothesis
5) Data are fitted with the sum of the background + a possible signal (“3+4”)

Search for a resonance in Run 2

- Selections
  - optimized to have largest significance (S/√B) at high mass for scalar Higgs-like resonance (spin 0, narrow width)
  - typical prompt photon purity >90%
  - **frozen** before unblinding the data

We require

- basic preselections
  - trigger (HLT_g35_medium_g25_medium)
  - in precision detector acceptance $|\eta|<2.37$ (excluding transition region between the barrel and the end-cap calorimeters)
  - photon's E_T greater than 25 GeV
- Shower shape requirements "tight" photons (after this step we select pair of photons)
- Calorimeter and track-based isolation (topoetcone40 < 0.022* E_T + 2.45 GeV && ptcone20 < 0.05* p_T)
- **Relative p_T cuts: $E_T^{\gamma_i}/m_{\gamma\gamma}$ > 0.4/0.3 (leading/subleading)**

Search for a resonance in Run 2

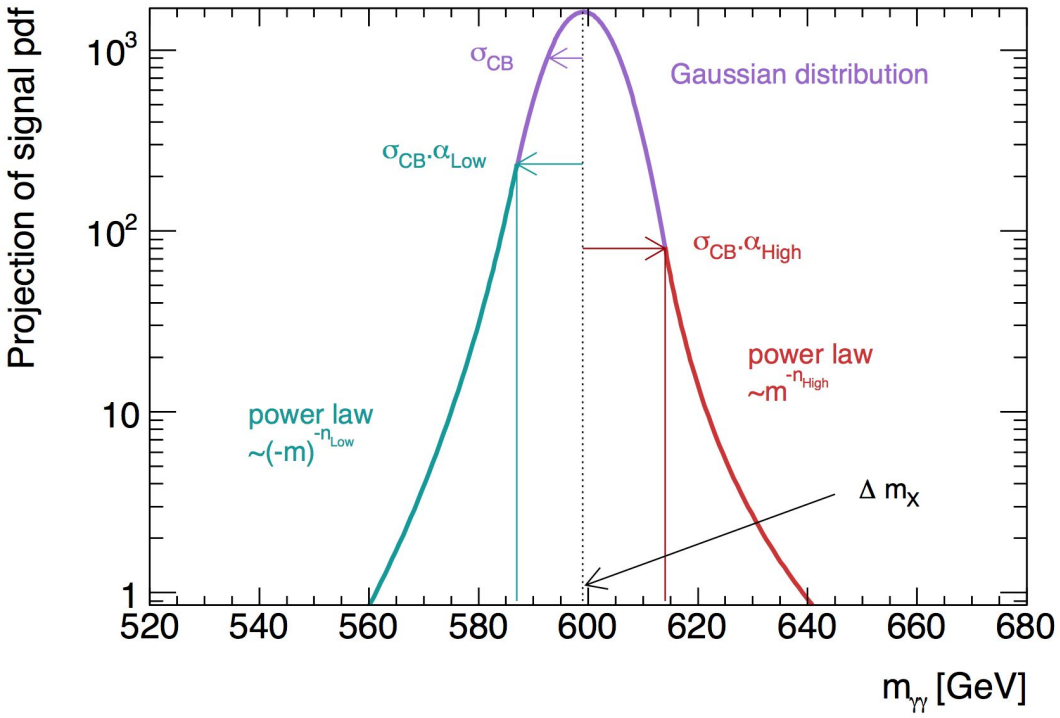
- Background modeling
  - Use analytical form to describe the background shape

$$f_{k;d}(x; b, \{a_k\}) = (1 - x^d)^b x^{\sum_{j=0}^{k} a_j \log(x)^j} \qquad x = \frac{m_{\gamma\gamma}}{\sqrt{s}}$$

  - Choose simplest function that fits all MC samples: d=1/3, k=0
  - Bias on the fitted signal induced by function required to be smaller than 20% of expected background statistical uncertainty
  - Choice of background modeling validated on partially unblinded data with large bins, unnecessity of additional dof been verified with F-test
- Signal parameterization
  - Narrow Width Approximation, natural width negligible wrt to detector resolution
  - Large Width - different widths with up to 10% of the resonance mass (up to 25% for validation purpose)

Signal parametrization

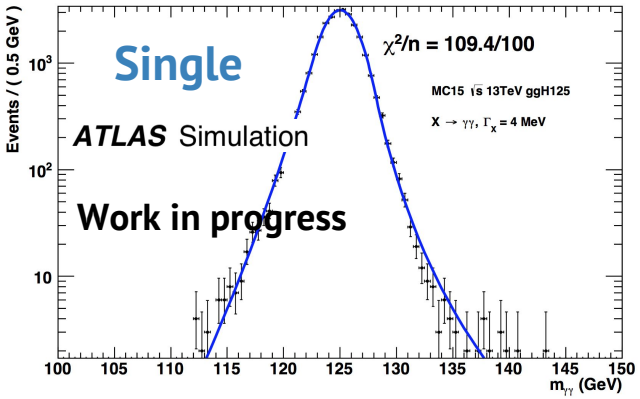
Parametrize signals with Double-Sided Crystal Ball (DSCB) function using simulation:

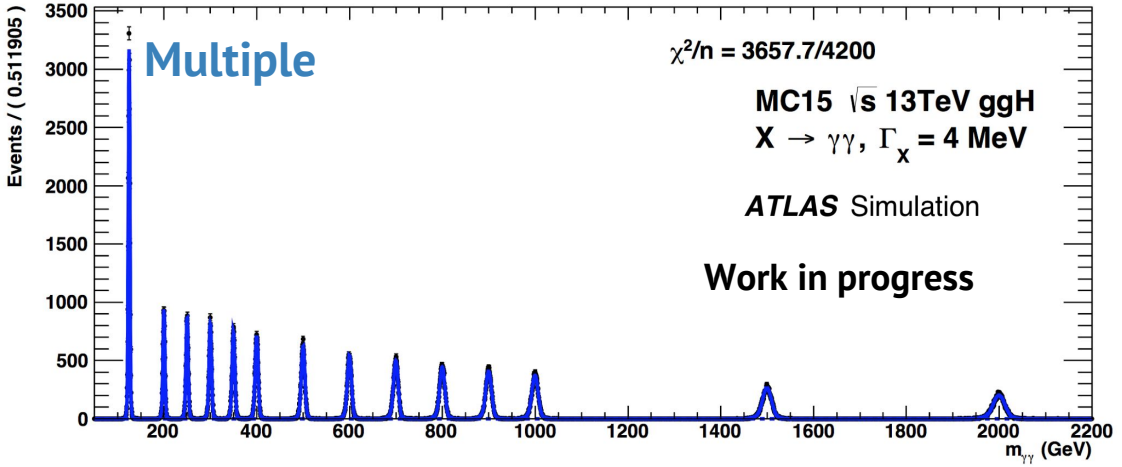


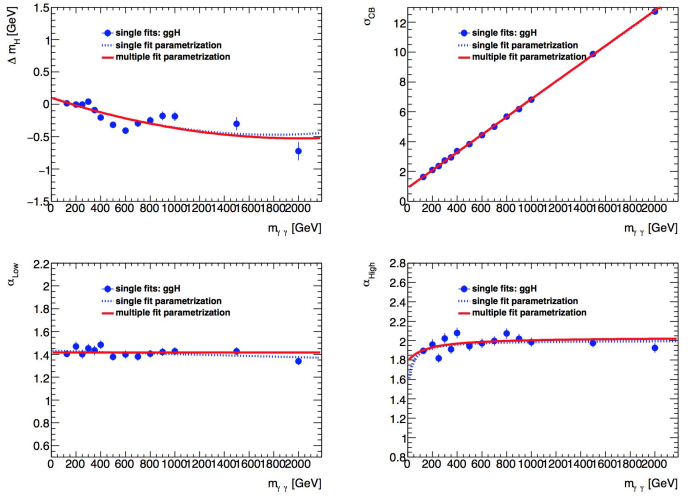
MC signal samples produced for several mass points in **Narrow Width Approximation**
Parametrization derived on those points and provide function to continuously cover all the mass range

Signal parametrization

An unbinned fit of the $m_{\gamma\gamma}$ distribution of all the events passing the selection cuts







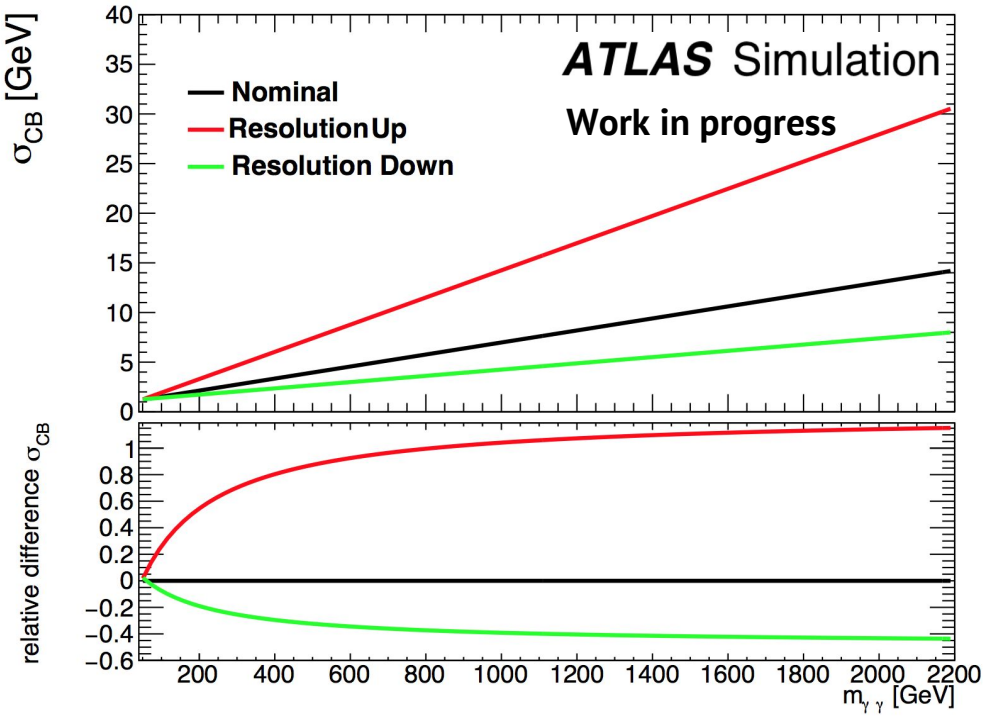
The double-sided Crystal Ball function is defined as

$$N \cdot \begin{cases} e^{-t^2/2} & \text{if } -\alpha_{Low} \geq t \geq \alpha_{High} \\ \dfrac{e^{-0.5\alpha_{Low}^2}}{\left[\frac{\alpha_{Low}}{n_{Low}}\left(\frac{n_{Low}}{\alpha_{Low}} - \alpha_{Low} - t\right)\right]^{n_{Low}}} & \text{if } t < -\alpha_{Low} \\ \dfrac{e^{-0.5\alpha_{High}^2}}{\left[\frac{\alpha_{High}}{n_{High}}\left(\frac{n_{High}}{\alpha_{High}} - \alpha_{High} + t\right)\right]^{n_{High}}} & \text{if } t > \alpha_{High}, \end{cases}$$

where $t=\Delta m_X/\sigma_{CB}$, $\Delta m_X = m_X - \mu_{CB}$, N is a normalisation parameter, μ_{CB} is the peak of the Gaussian distribution, σ_{CB} represents the width of the Gaussian part of the function, α_{Low} (α_{High}) is the point where the Gaussian becomes a power law on the low (high) mass side, n_{Low} (n_{High}) is the exponent of this power law

Systematics

- We aim for model independent search, thus impact of choice of production mode (ggH, VBF, ZH, WH, ttH) was tested and estimated as negligible with injection test
- Dominant contribution from resolution variations included in Signal+Background fit as nuisance parameter (NP)



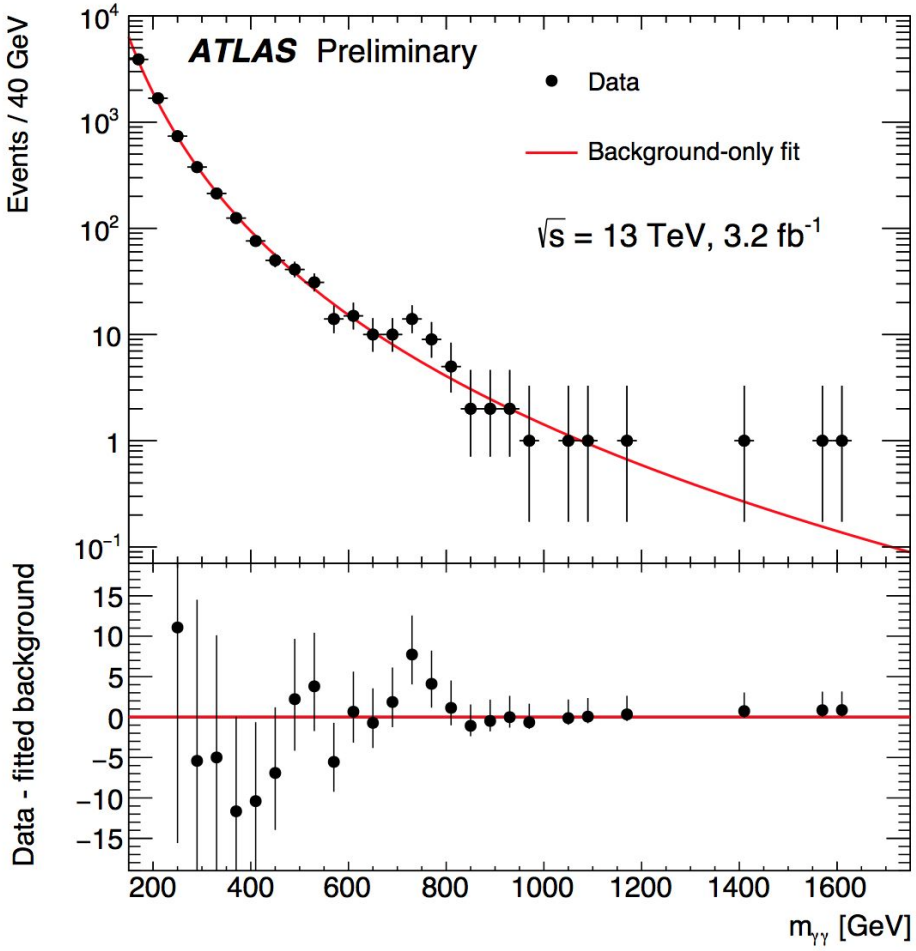
Search for a resonance

When all ingredients are ready:

- Look at the data - we select 3.2 fb^{-1} for 2015 dataset, with all ATLAS subdetectors operational
- Present the search (p_0 plot)
- Publish results of the search
  - Discovery p-value and excess(es) characterisation, if any
  - cross-section $\times$ BR limit, if no significant excess is observed

Background only fit

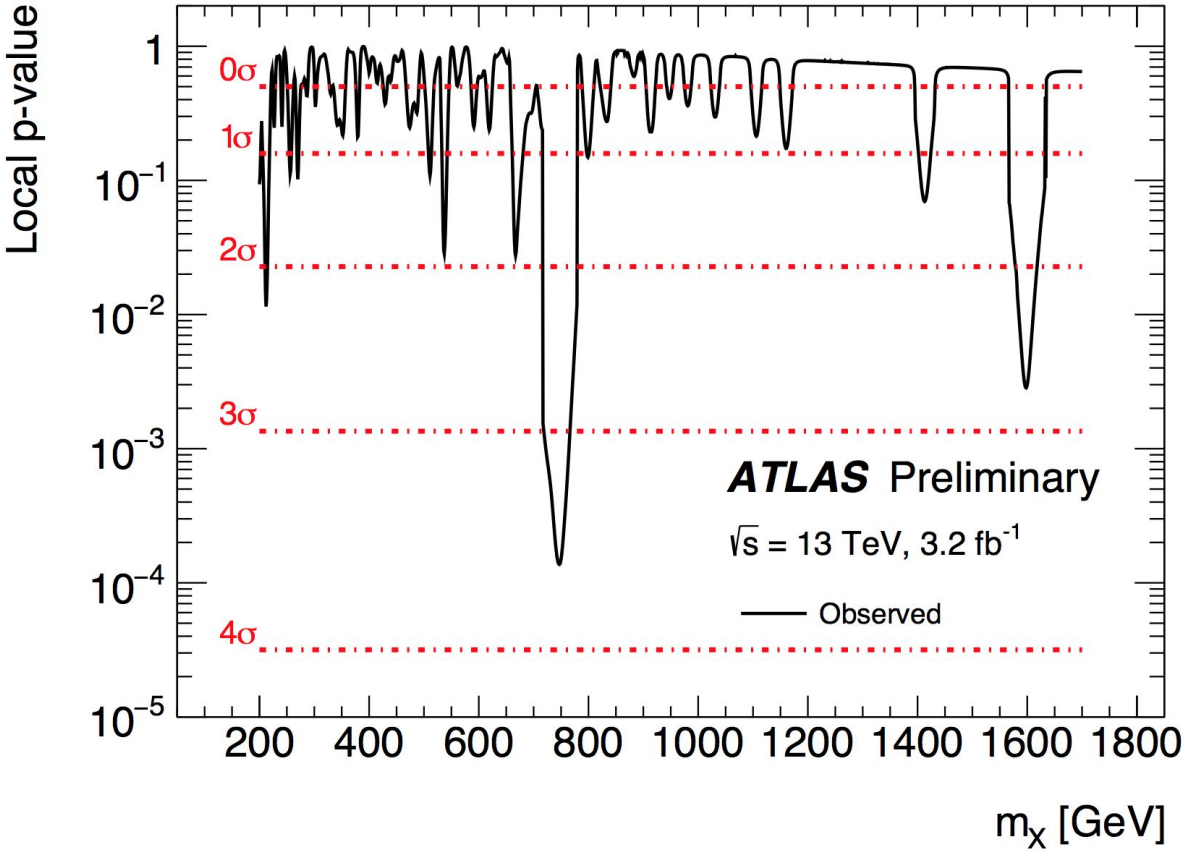
Invariant mass distribution of the selected diphoton events.



Background unbinned fit for 3.2 fb^{-1} in 2015 dataset

Background only fit

p-value for the background-only hypothesis p_0 as a function of the mass m_X of a probed NWA resonance



local p-value at minimum 3.6σ around 750 GeV

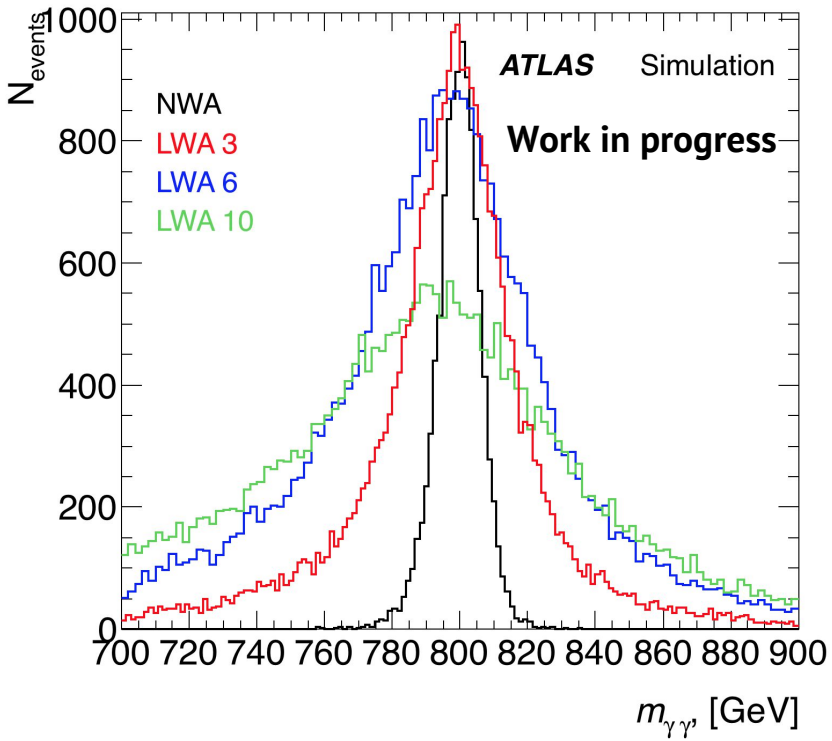
Compute Look-elsewhere effect: global p-value at the 2σ level

~1.5 σ pull of the resolution NP at 750 GeV

LWA signal parametrization

- Generate large-width signal shape using
  - the PowHeg Higgs lineshape with $\alpha=\Gamma_X/m_X$ up to 25%
  - Correction terms for parton luminosity
- Convolute with DSCB to account for detector resolution
- Parameterize as a function of m_X with another DSCB, as for the narrow-width case for α=3, 6, 10, 15, 20, 25%
- Interpolate linearly in α

The largest deviation from the background-only hypothesis is observed for a mass around 750 GeV and $\alpha \simeq$ 6%, corresponding to a width Γ of about 45 GeV



restrict the signal to an interval around the peak to avoid problems with interference for large widths

Excess region

The events in region [700,800] GeV are scrutinized:

- No detector or reconstruction effect or any indication of anomalous background contamination observed
- The kinematic properties studied wrt side bands and no significant difference is observed.

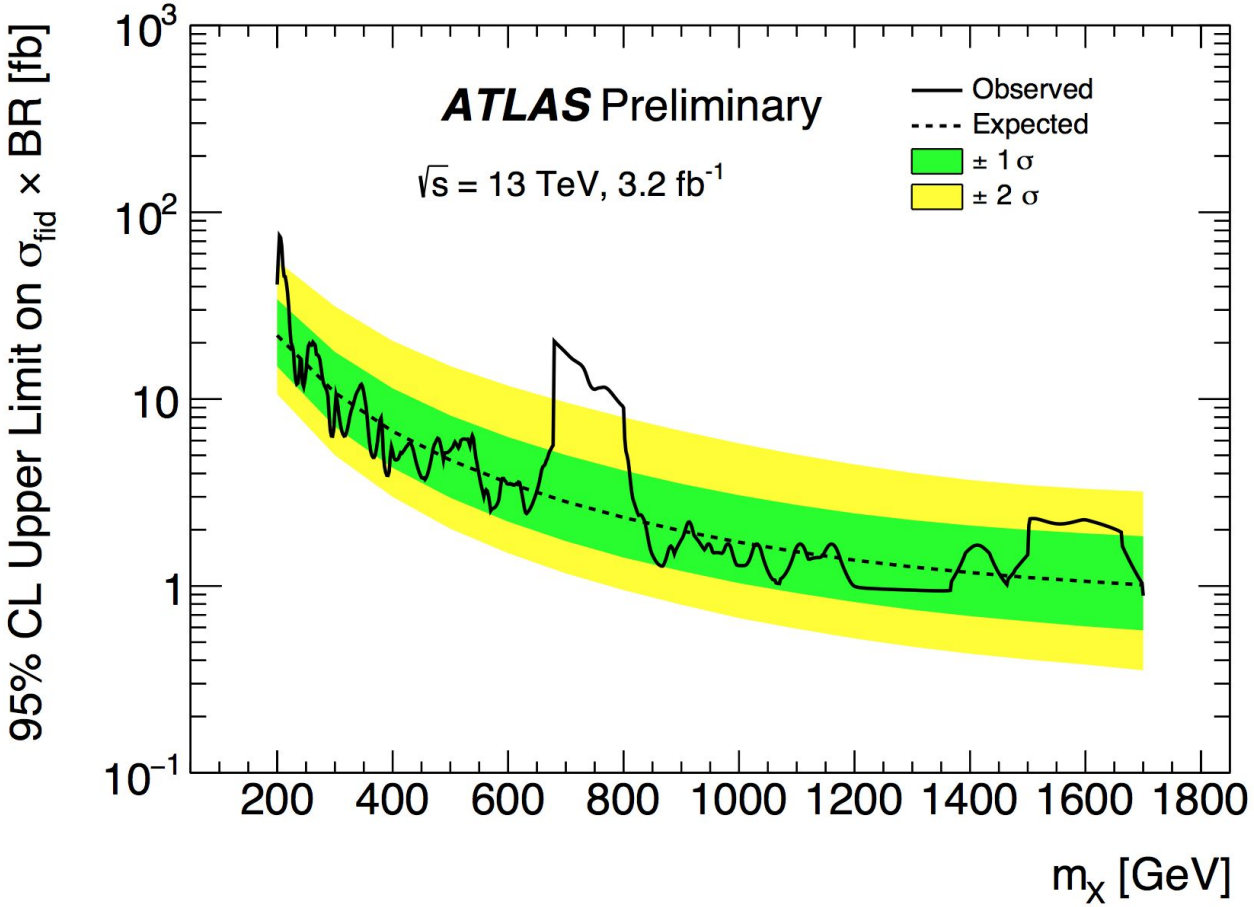
~500 plots in cross-check supporting documentation

	Significance	
Signal Model	local	global
NWA	3.6 σ	2.0 σ
LWA 6%	3.9 σ	2.3 σ

The compatibility between the results in 8 TeV and 13 TeV estimated for NWA and LWA6%. Results are compatible within 2.2 and 1.4 σ for the two width hypotheses respectively.

Limit

Expected and observed upper limits on $\sigma_{fiducial} \times BR(X \rightarrow \gamma\gamma)$ expressed at 95% CL, as a function of the assumed value of the narrow-width scalar resonance mass

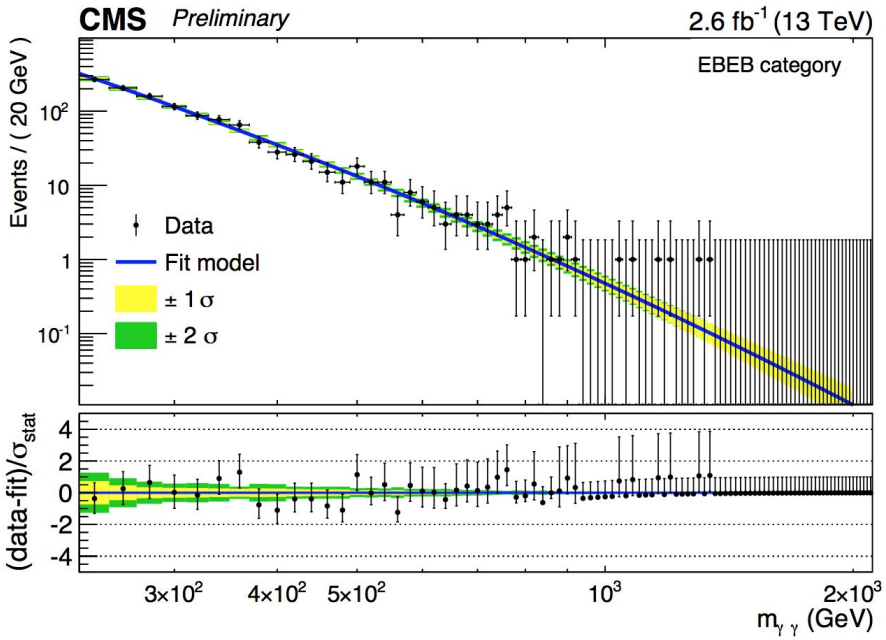


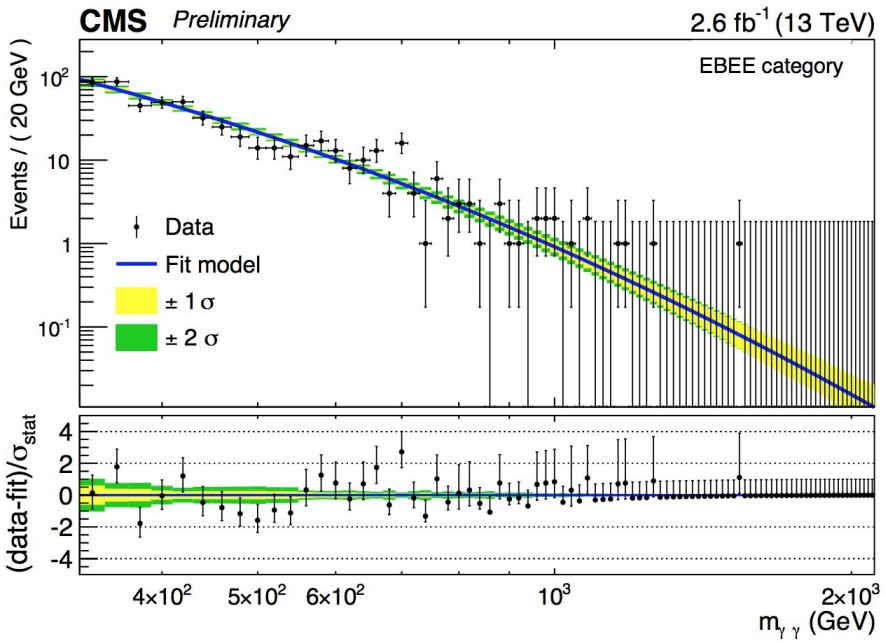
CMS results

Diphoton search in range 0.5-4.5 TeV, using **2.6 fb^{-1}** , targeting for:

- spin 2 graviton-like resonances, wrt scalar in ATLAS analysis
- fixed E_T cuts, compared to relative selections in ATLAS analysis
- split to detector-based categories, compared to inclusive ATLAS search

produce p_0 scan and limit in NWA and LWA approach





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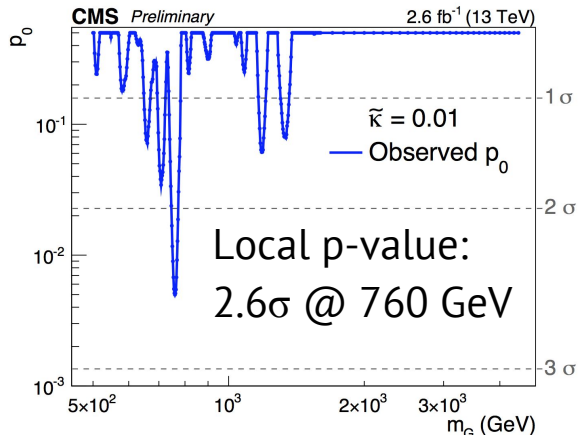
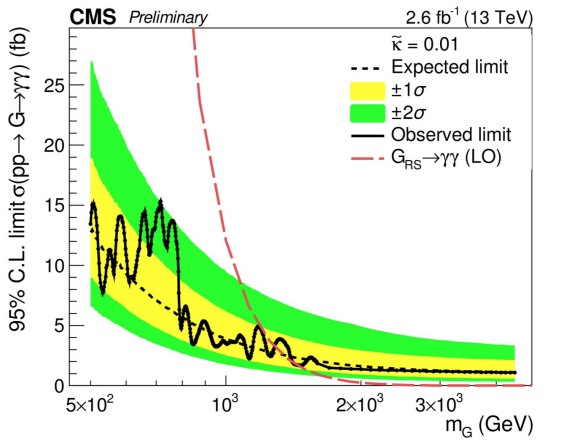
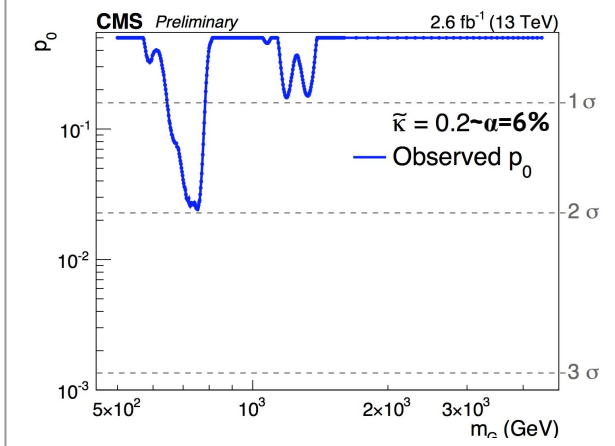
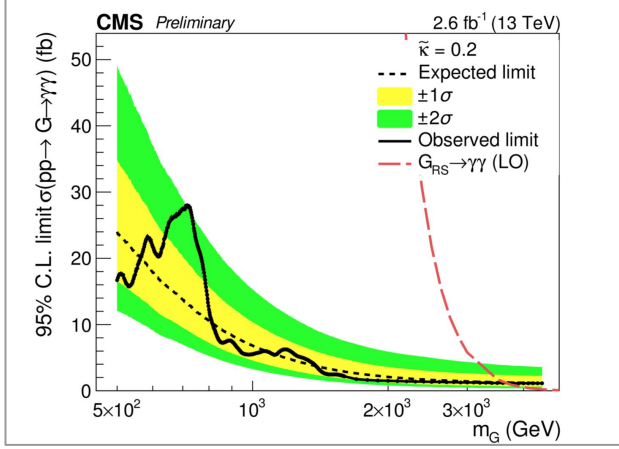
Narrow width





Large width





Excess region ATLAS and CMS

Both experiments have excess in same region.

ATLAS has another ongoing diphoton search, graviton-oriented as CMS's one

For now:

	Significance, local(global)	
Signal Model	ATLAS (3.2fb^{-1}) @750 GeV	CMS (2.6fb^{-1}) @760 GeV
NWA	3.6(2.0) σ	2.6(1.2) σ
LWA 6%	3.9(2.3) σ	1.9(-) σ

Wait for next year data, to make situation clear

First beam circulation in LHC expected end of March 2016

First stable beams scheduled to end of May - beginning of June

The « nominal expected integrated luminosity » in 2016 is 30 fb^{-1}

Seminar

To Do

After publication

Resonance in social networks, in press

[Le Monde]

[The wire]

After publication

And in scientific world. Appeared publications on arXiv more than 20 in 2 days

December 2015: the Gold Rush			
0	ATLAS and CMS	seminar	15 Dec 2015 15-17
1	K. Harigaya, Y. Nomura, 7 pages	1512.04850	v1: 15 Dec 2015 16:47:58 v2: 16 Dec 2015 08:19:11
2	Y. Mambrini, G. Arcadi, A. Djouadi, 9 pages	1512.04913	15 Dec 2015 20:05:04
3	M. Backovic, A. Mariotti, D. Redigolo, 17 pages	1512.04917	15 Dec 2015 20:26:16
4	A. Angelescu, A. Djouadi, G. Moreau, 15 pages	1512.04921	15 Dec 2015 20:32:58
5	Y. Nakai, R. Sato, K. Tobioka, 6 pages	1512.04924	15 Dec 2015 20:39:32
6	S. Knapen, T. Melia, M. Papucci, K. Zurek, 20 pages	1512.04928	15 Dec 2015 20:44:08
7	D. Buttazzo, A. Greljo, D. Marzocca, 16 pages	1512.04929	15 Dec 2015 20:49:36
8	A. Pilaftsis, 6 pages	1512.04931	15 Dec 2015 20:50:27
9	R. Franceschini, G. Giudice, J.F. Kamenik, M. McCullough, A. Pomarol, R Rattazzi, M. Redi, F. Riva, A. Strumia, R. Torre, 32 pages	1512.04933	15 Dec 2015 20:53:14
10	S. Di Chiara, L. Marzola, M. Raidal, 5 pages	1512.04939	15 Dec 2015 20:59:17
11	T. Higaki, K.S. Jeong, N. Kitajima, F. Takahashi, 8 pages	1512.05295	16 Dec 2015, 19:36:36
12	S.D. McDermott, P. Meade, H. Ramani, 6 pages	1512.05295	16 Dec 2015, 20:48:16
13	J. Ellis, S.A.R. Ellis, J. Quevillon, V. Sanz, T. You, 36 pages	1512.05327	16 Dec 2015, 20:49:44
14	M. Low, A. Tesi, L.T. Wang, 23 pages	1512.05328	16 Dec 2015, 20:50:26
>14	4 more		16 Dec 2015

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