

Search for the scalar diphoton resonances produced in pp collisions with the ATLAS detector at the LHC

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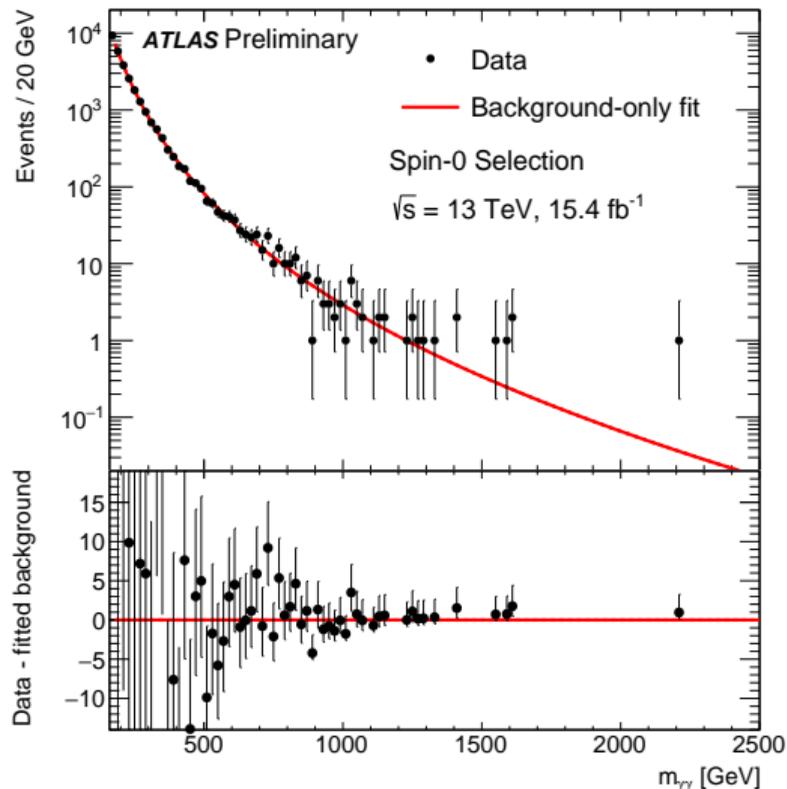
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Journées de Rencontre des Jeunes Chercheurs 2016
9 December 2016



Search for resonances decaying to two photons

- Spin-0 Selection:
search for Higgs-like resonances
- Data:
 $\sqrt{s} = 13 \text{ TeV}$, 3.2 fb^{-1} in 2015
and 12.2 fb^{-1} in 2016 (July)
- Background-only fit:
choose functional form $f(m_{\gamma\gamma})$
- Results



ATLAS Collaboration, ATLAS-CONF-2016-059 (2016)

The (NG)AEBHGHKMP Mechanism

- Gauge group of the Standard Model $SU(3)_C \times SU(2)_L \times U(1)_Y$

- Scalar field – complex doublet of $SU(2)$: $\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$

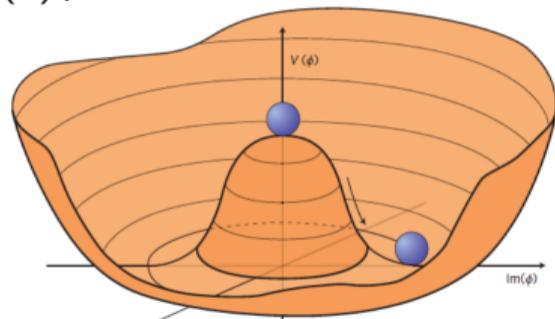
- In the unitary gauge $\phi = \begin{pmatrix} 0 \\ (v + \eta) / \sqrt{2} \end{pmatrix}$

Vacuum expectation value $v = \sqrt{\frac{-\mu^2}{\lambda}}$

Real scalar field η – the Higgs boson

⇒ No theoretical prediction for $m_H^2 = -2\mu^2$

- Discovered in 2012 by the ATLAS and CMS experiments: $m_H = 125 \text{ GeV}$, $J^P = 0^+$



$$V(\phi^\dagger \phi) = \mu^2 (\phi^\dagger \phi) + \lambda (\phi^\dagger \phi)^2$$

Beyond the Standard Model

- New resonances predicted in some models with an extended scalar sector, e.g. 2 Higgs Doublet Models (2HDMs):

$$V = m_{11}^2 \phi_1^\dagger \phi_1 + m_{22}^2 \phi_2^\dagger \phi_2 - m_{12}^2 (\phi_1^\dagger \phi_2 + \phi_2^\dagger \phi_1) + \frac{\lambda_1}{2} (\phi_1^\dagger \phi_1)^2 + \frac{\lambda_2}{2} (\phi_2^\dagger \phi_2)^2 + \lambda_3 (\phi_1^\dagger \phi_1) (\phi_2^\dagger \phi_2) + \lambda_4 (\phi_1^\dagger \phi_2) (\phi_2^\dagger \phi_1) + \frac{\lambda_5}{2} \left[(\phi_1^\dagger \phi_2)^2 + (\phi_2^\dagger \phi_1)^2 \right]$$

- Symmetry breaking \Rightarrow

5 physical scalars: neutral CP -even h and H , neutral CP -odd A , charged H^\pm

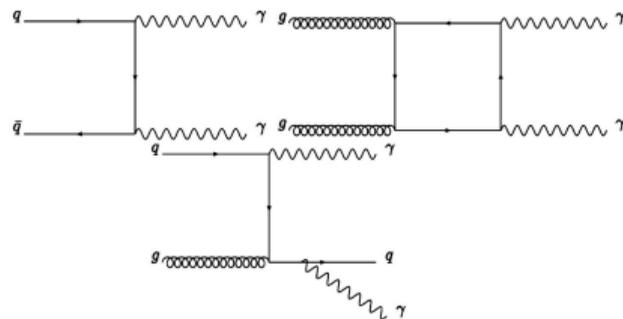
- “Physical” basis:

$$\begin{array}{c} \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, m_{11}^2, m_{22}^2, m_{12}^2 \\ \Updownarrow \\ m_h, m_H, m_A, m_{H^\pm}, \tan \beta, \sin(\beta - \alpha), v, m_{12}^2 \end{array}$$

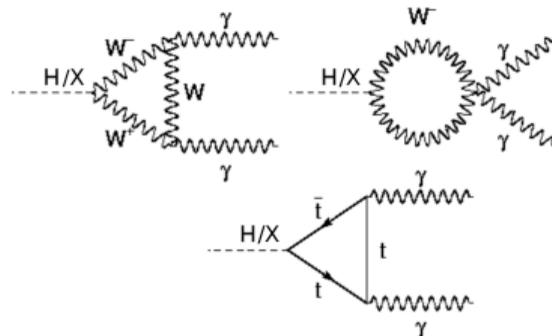
$v = 246$ GeV, $m_H = 125$ GeV; $m_h < m_H$, $\tan \beta = v_1/v_2$, α for $h \leftrightarrow H$ mixing

\Rightarrow 6 free parameters

Standard Model background



Scalar resonances decays

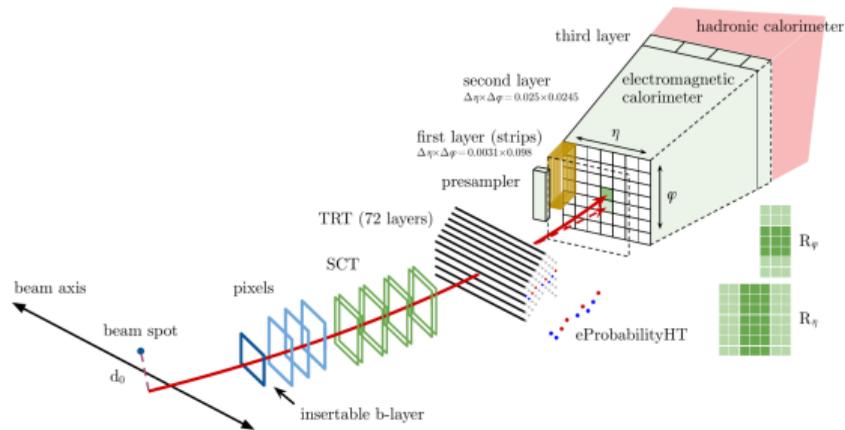
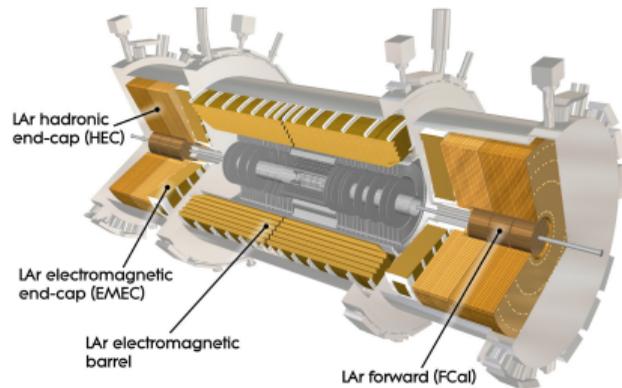


$$m_{\gamma\gamma}^2 = 2E_T^{\gamma 1} E_T^{\gamma 2} (\cosh \Delta\eta - \cos \Delta\phi)$$

Photons in the ATLAS LAr Calorimeter

- Clusters of cells in the calorimeter
- Identification based on shower shapes
- Unconverted: no matching tracks
Converted: > 1 track from $\gamma \rightarrow e^+e^-$

1st layer: high granularity strips



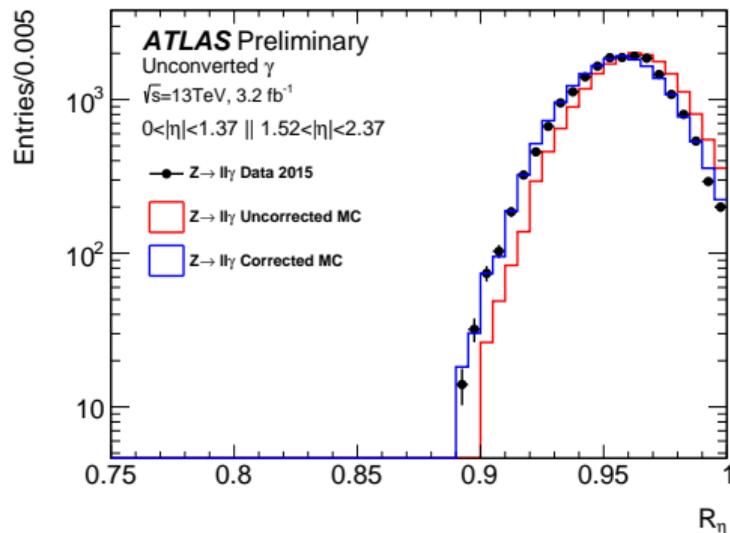
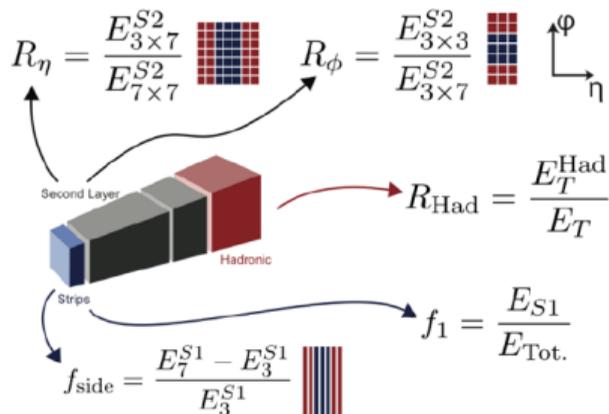
true photon



$\pi^0 \rightarrow \gamma\gamma$

Photon identification

Shape of EM shower in calorimeter cells \Rightarrow **set of cuts** on discriminating variables



Calorimeter isolation energy

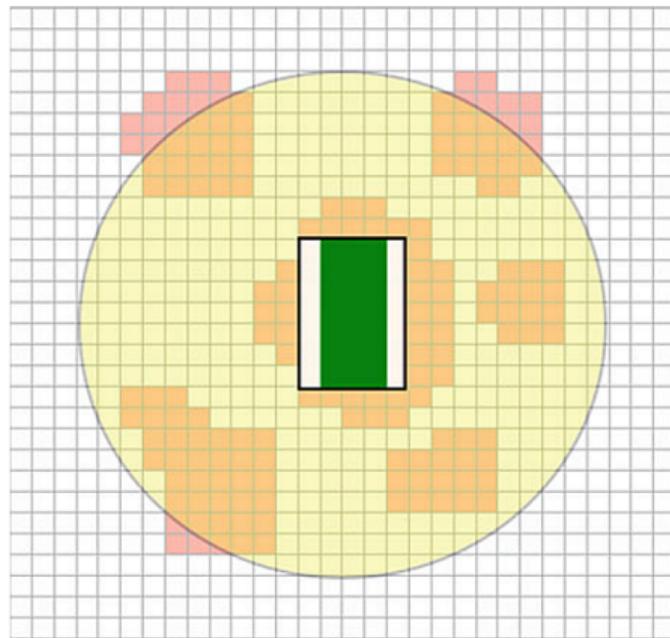
$$E_T^{\text{iso}} = \sum E_T^{\text{cone}} - \text{corrections:}$$

- 1) energy in center of photon cluster
- 2) small leakage into the isolation cone
- 3) ambient energy removal (pileup)

Selection on $E_T^{\text{iso}}/E_T \Rightarrow$

Aim to reject background from jets

So far used in offline analysis,
now implemented to photon triggers

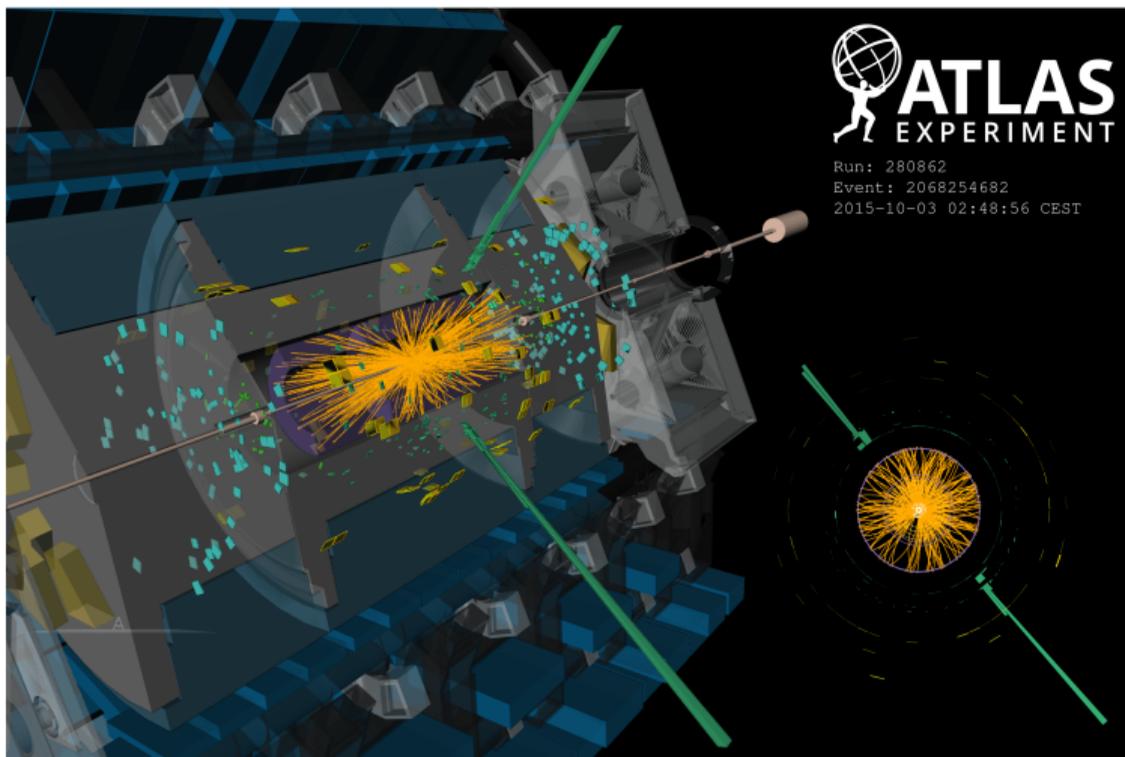


size of isolation cone:

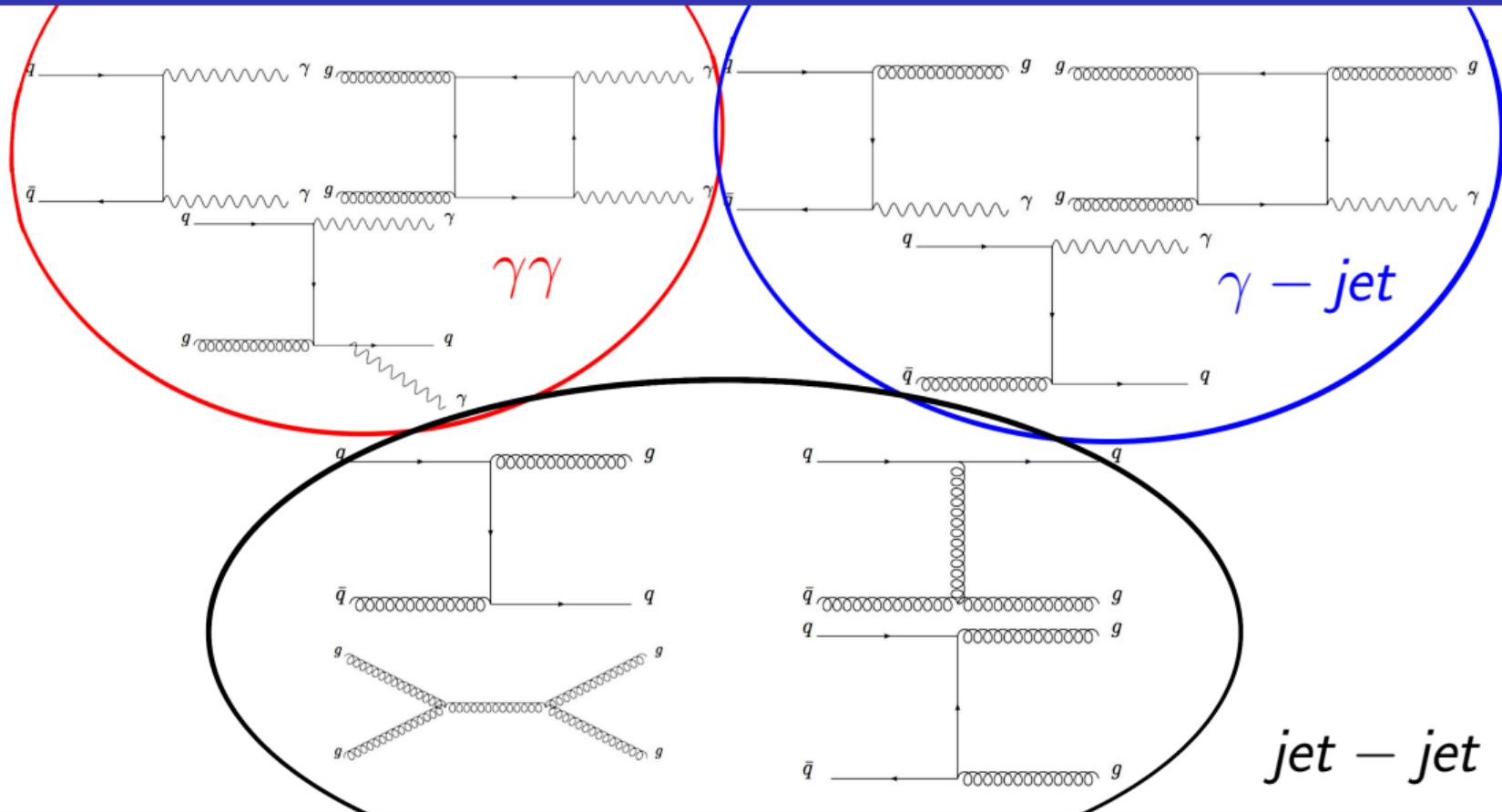
$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

Event selection

Photon candidates within $|\eta| < 2.37$ (excluding $1.37 < |\eta| < 1.52$) and fixed kinematic cuts

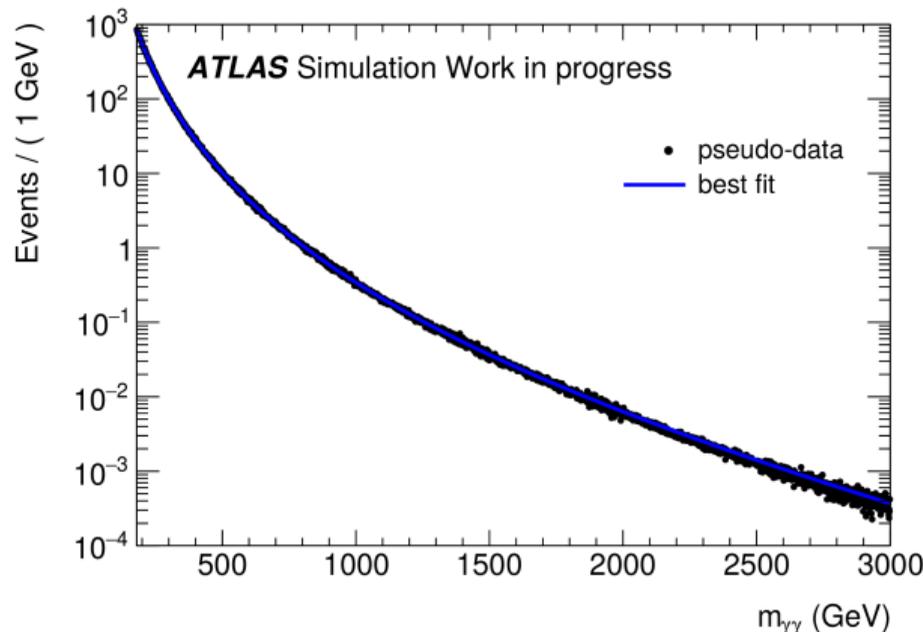


Diphoton background



Background modelling

- $\gamma\gamma$ simulated with SHERPA event generator
 - $\gamma - jet$ and $jet - jet$ estimated using data-driven methods
- } pseudo-data

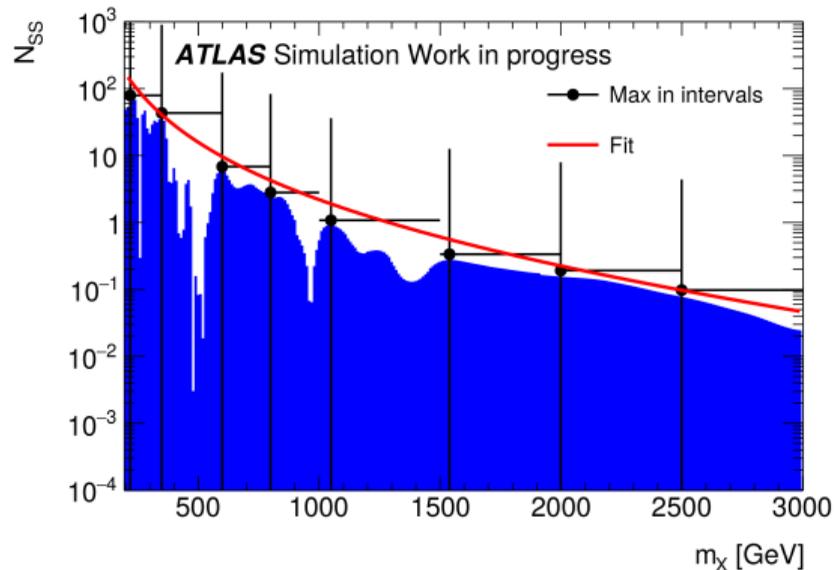
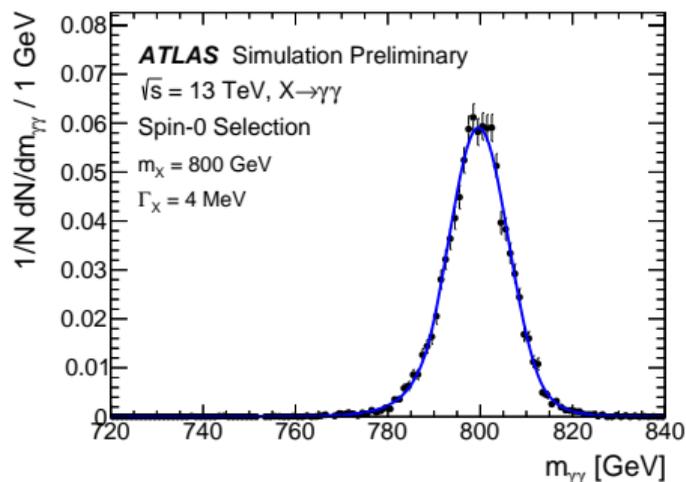


Functional form: $f_d(x; a, b) = (1 - x^d)^b x^a$, where $x = \frac{m_{\gamma\gamma}}{\sqrt{s}}$; a and b are free parameters

Functional form choice

- Procedure: fit pseudo-data using S+B model
⇒ include “spurious” signal – fit signal events with 10 GeV steps in $m_X > 200$ GeV

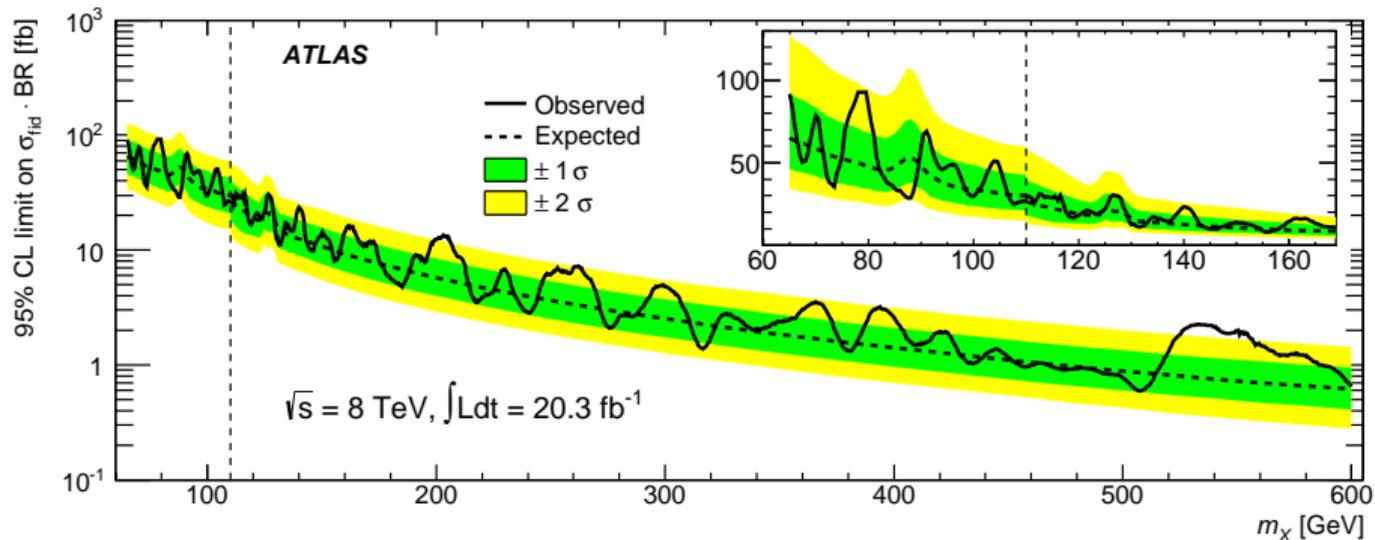
Signal mass distribution:



- Parameterized value of $N_{SS}(m_X)$ defines systematic uncertainty

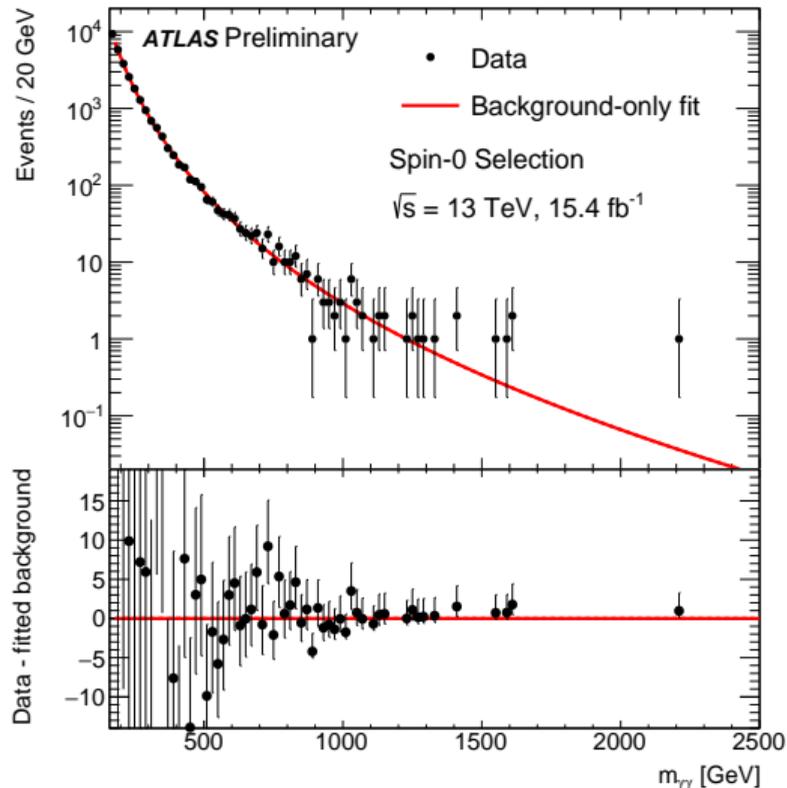
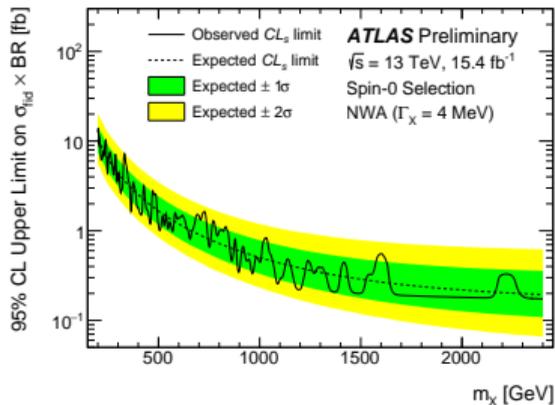
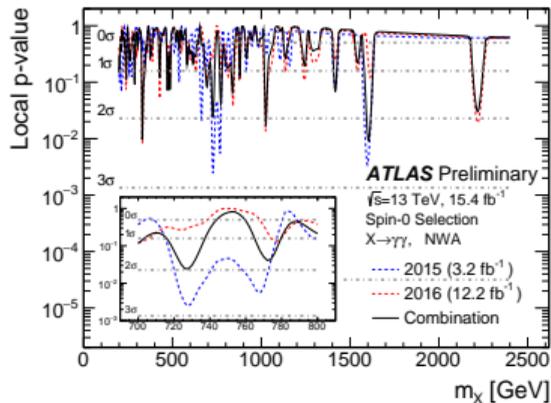
Results Run-1

Limits were set \Rightarrow no excess found at higher than 2.2σ significance level



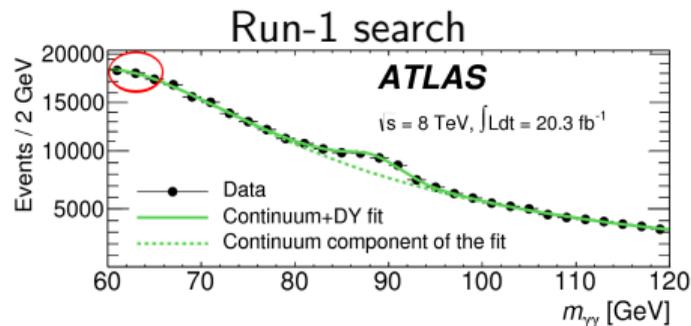
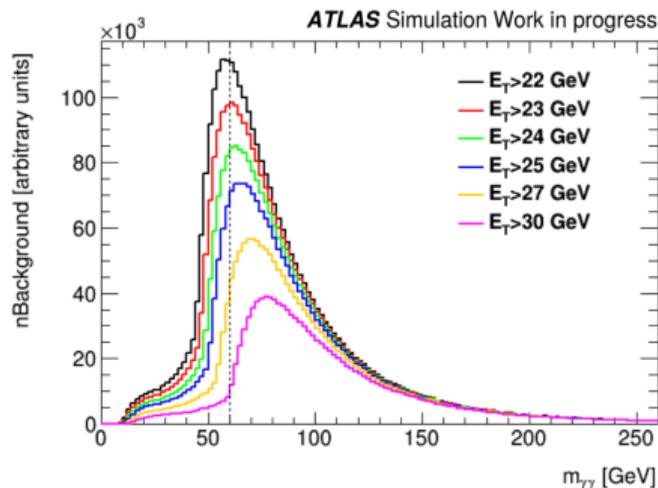
ATLAS Collaboration, Phys.Rev.Lett. 113 (2014) 171801

Results Run-2



ATLAS Collaboration, ATLAS-CONF-2016-059 (2016)

Low-mass resonances search in Run-2



Cuts on $E_T \Rightarrow$ spectrum turn-on at low $m_{\gamma\gamma}$

- Resonances search in the low-mass region: $m_{\gamma\gamma} < 100$ GeV
- LHC luminosity in 2017 $L = 2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

Diphoton trigger with $E_T > 20$ GeV:

expected	4.69 Hz
allowed	~ 3 Hz

Rate reduction: trigger only isolated photons (*ATLAS autorship qualification task*)

- Background modelling for diphoton resonances search in the full 2015+2016 dataset
- Diphoton low- E_T triggers rate reduction for data-taking in 2017

Outlook:

- Resonances search in the low-mass region ($m_X < 100$ GeV) with Run-2 data
- Search for associated production of scalar diphoton resonances with additional objects: jets, missing E_T , heavy quarks...

Thank you!