Search for pairs of highly collimated groupings of photons with the ATLAS detector

https://arxiv.org/abs/1808.10515

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Higgs Couplings 2018, 29 Nov. 2018

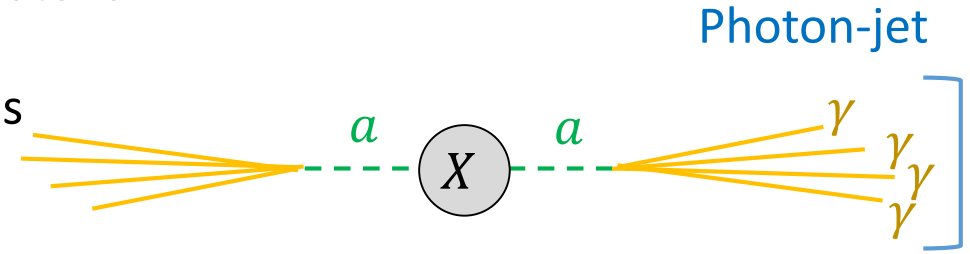
ICEPP The University of Tokyo

ATLAS EXPERIMENT

Introduction to photon-jets

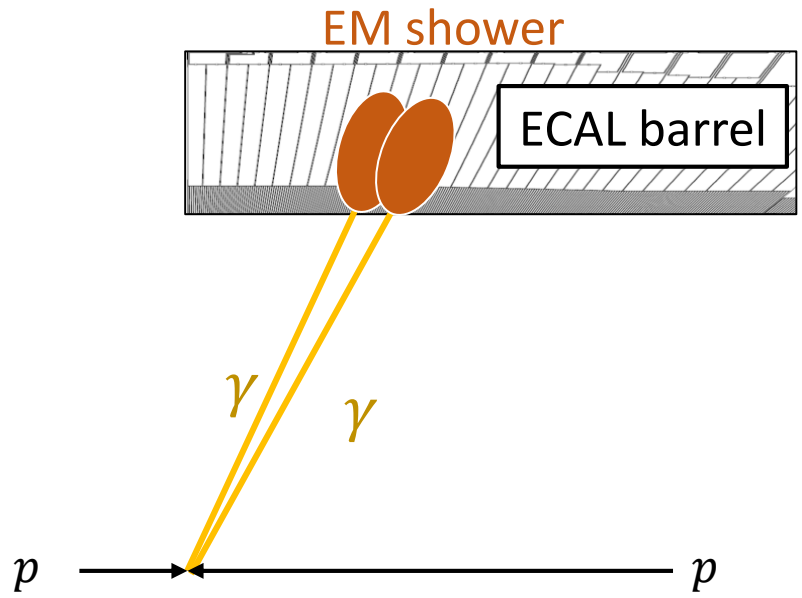
"Photon-jet": Grouping of collimated photons

- Boosted particle decaying into photons leads to a photon-jet



- Cascade decay : heavy resonance (X) --> light resonances (a) --> photons

- For $m_X > 200$ GeV and $m_a \sim$ a few GeV, a photon-jet leads to one EM cluster

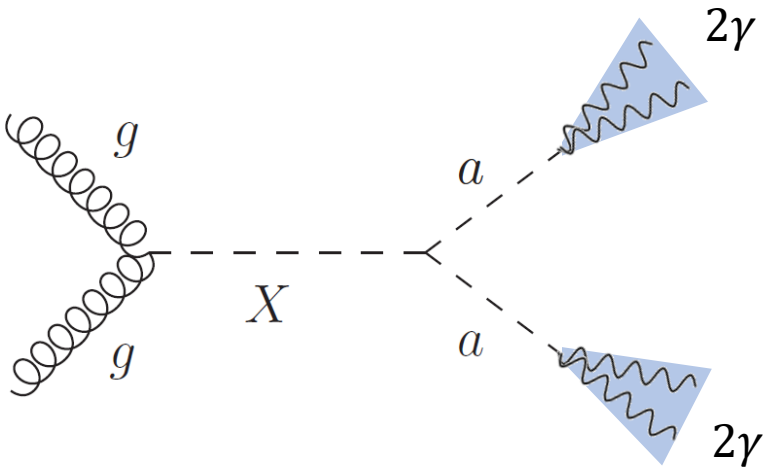


- New experimental signature possibly arising from new physics!

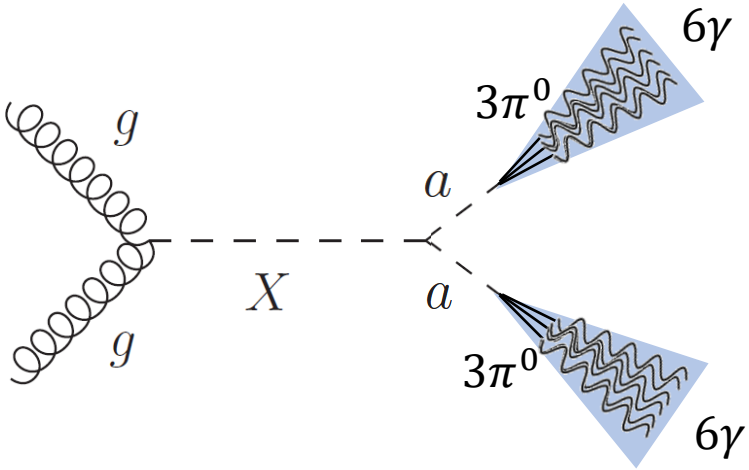
Signal models

- Model-independent search for heavy scalar $\rightarrow aa \rightarrow$ photons
  - Extended Higgs sector (heavy scalar + light pseudoscalar)
  - Diaxion resonance

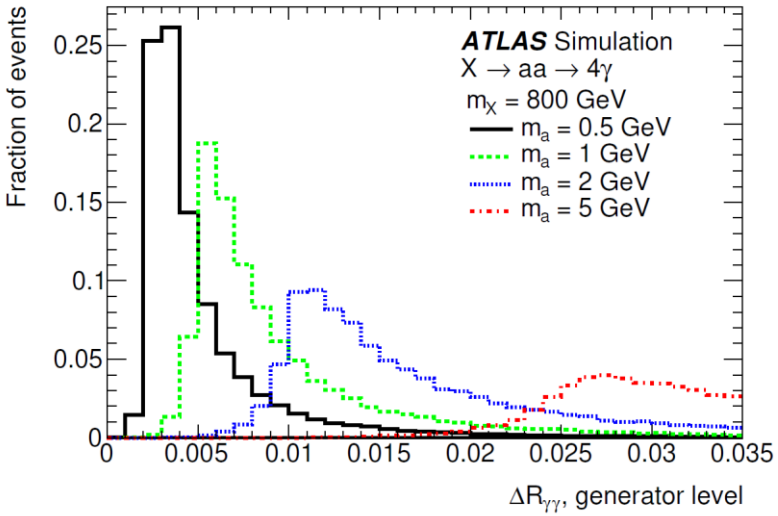
Photon-jet with 2 photons



Photon-jet with 6 photons



Experimental signature

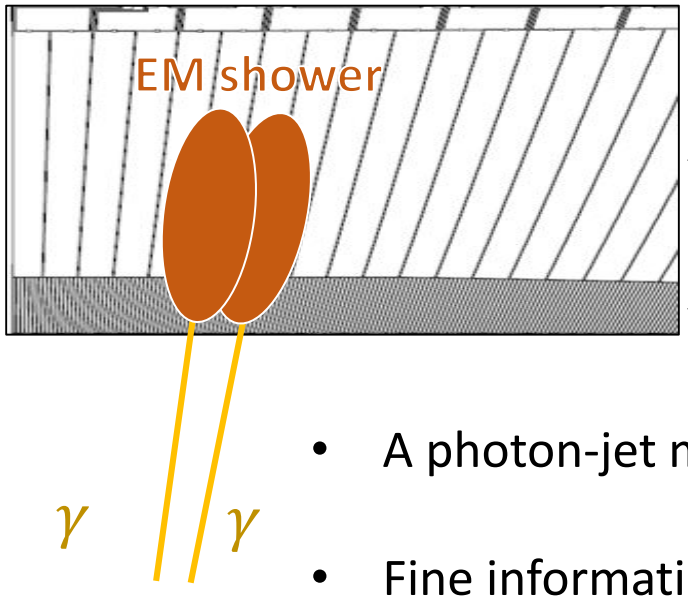


Spread of photons in photon-jet
~ roughly proportional to $\frac{m_a}{m_X}$

E.g. for $X \to aa \to 4\gamma$,

$\Delta R_{\gamma\gamma} \sim 4 \cdot \frac{m_a}{m_X}$

($\because \Delta R_{\gamma\gamma} \sim \frac{2}{\gamma_a}$, where γ_a : Lorentz factor of a)

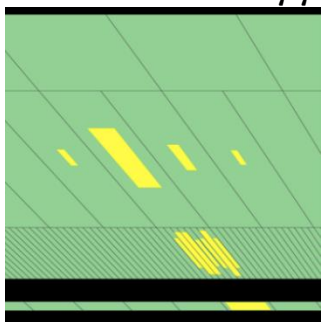


← ECAL 2nd layer ($\Delta\eta = 0.025$ at $\eta = 0$)

← ECAL 1st layer ($\Delta\eta = 0.003$)

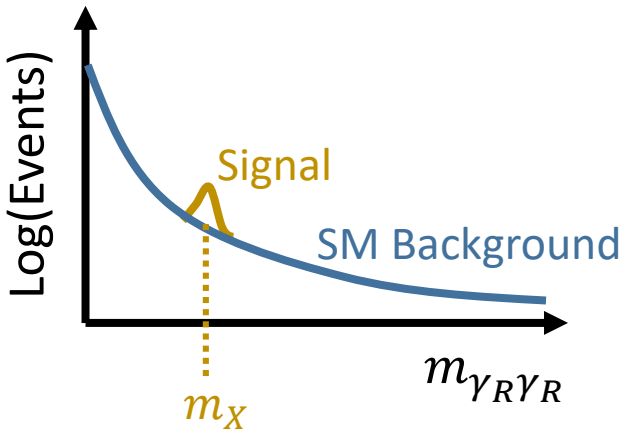
- A photon-jet may be reconstructed as one photon
- Fine information of shower shape in 1st layer is utilized in the analysis

Similar to $\pi^0 \to \gamma\gamma$



Analysis overview

- 2015-2016 ATLAS 37 fb^{-1} dataset
- Select events containing two reconstructed photon clusters with high-E_{T}
  → Search for resonance decaying to pair of photon-jets
- Two event categories based on EM shower shape
- Resonance search in the reconstructed diphoton mass $m_{\gamma_R\gamma_R}$
  ("γ_R" : symbol for reconstructed photon)
  - $S + B$ fit to mass spectrum
  - Background: $\gamma\gamma$, γj, and jj
    (j: hadronic jet)
- First result!

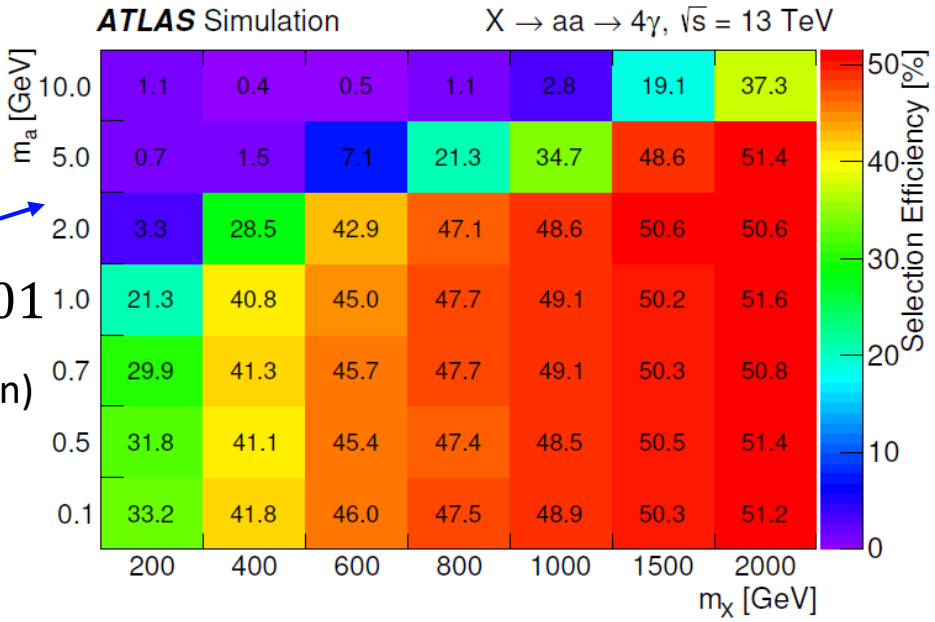


Event selection

- Select events with two high-E_{T} reconstructed photons from diphoton trigger

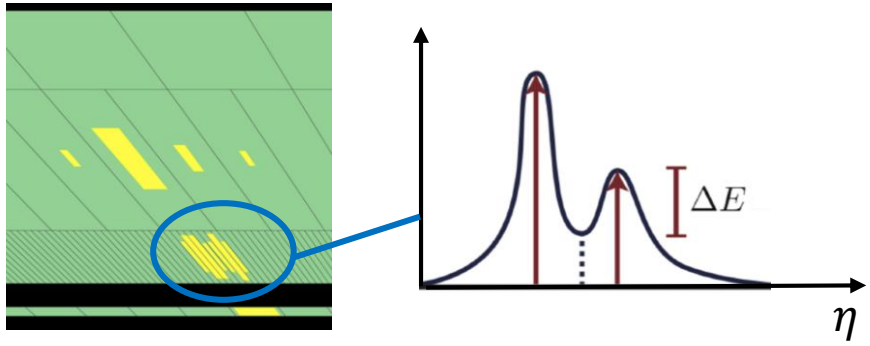
- Photon ID
  - Very loose selection compared to the standard ATLAS photon selection
  - Increase selection efficiency by factor $\lesssim 10$
- E_{T} cut $\left(E_{\mathrm{T},1} > 0.4 m_{\gamma_R \gamma_R},\ E_{\mathrm{T},2} > 0.3 m_{\gamma_R \gamma_R}\right)$
- Isolation cut (track & calorimeter)

Low efficiency above $\frac{m_a}{m_X} > 0.01$ due to photon trigger (+ isolation)



Event categorization

- Use shower shape variable
- "ΔE" : relative size of the 2nd peak



"low-ΔE category"

- 2 leading reconstructed photons with low ΔE

  Threshold: 100-500 MeV (η dependent)

- Sensitive to $\frac{m_a}{m_X} \lesssim 0.002$

  (i.e. smaller photon spread)

"high-ΔE category"

- At least 1 leading reconstructed photon with high ΔE

- Sensitive to $0.002 \lesssim \frac{m_a}{m_X} < 0.01$

  (i.e. larger photon spread)

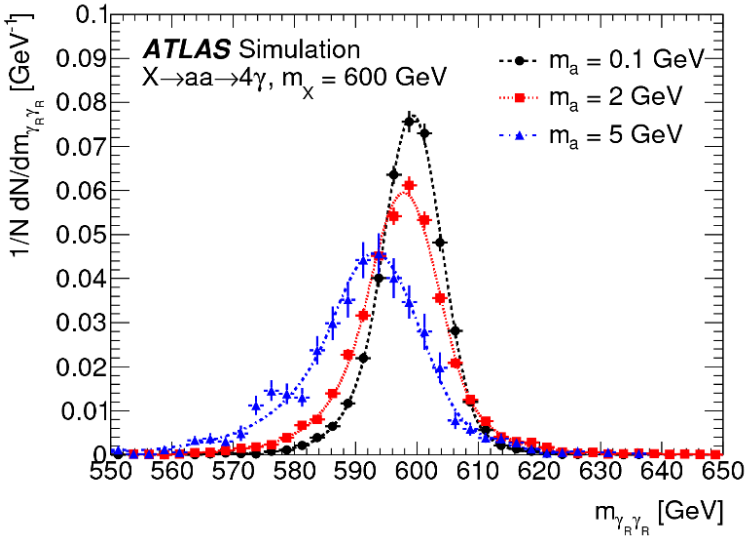
Smaller background yield ($\sim$ 1/8 of the other)

- Background $\gamma\gamma$ rejected by ΔE cut
- γj and jj rejected by isolation and photon ID

Signal and background modelling

Signal modelling

- Assume narrow-width resonance
- Use double-sided Crystal-Ball function
  (i.e. Gaussian core + exponential tails)



Background modelling

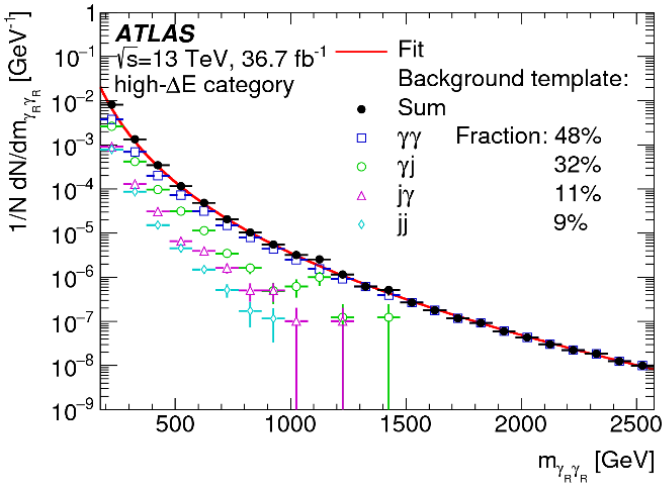
- Function fit with free parameters (Inclusive for all background components)

$$f(x;a,b,c) = (1-\sqrt{x})^{a} \cdot x^{b+c\log x} \qquad \left(x = \frac{m_{\gamma_R\gamma_R}}{\sqrt{s}}\right)$$

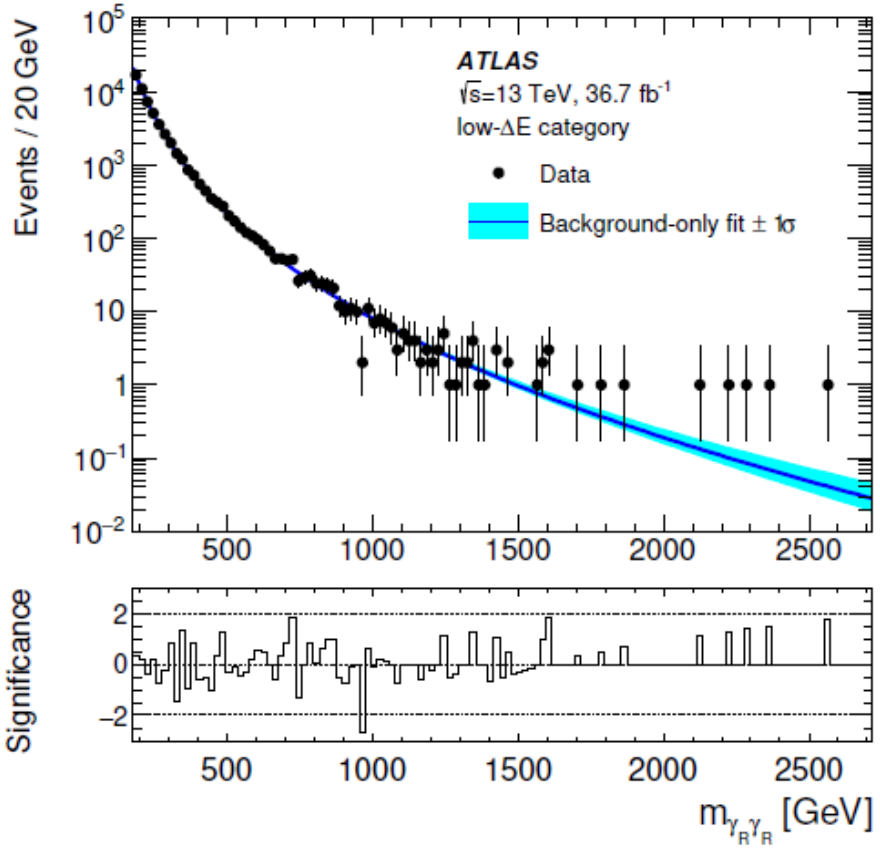
- Validation performed using background templates
  (“Spurious Signal” method)

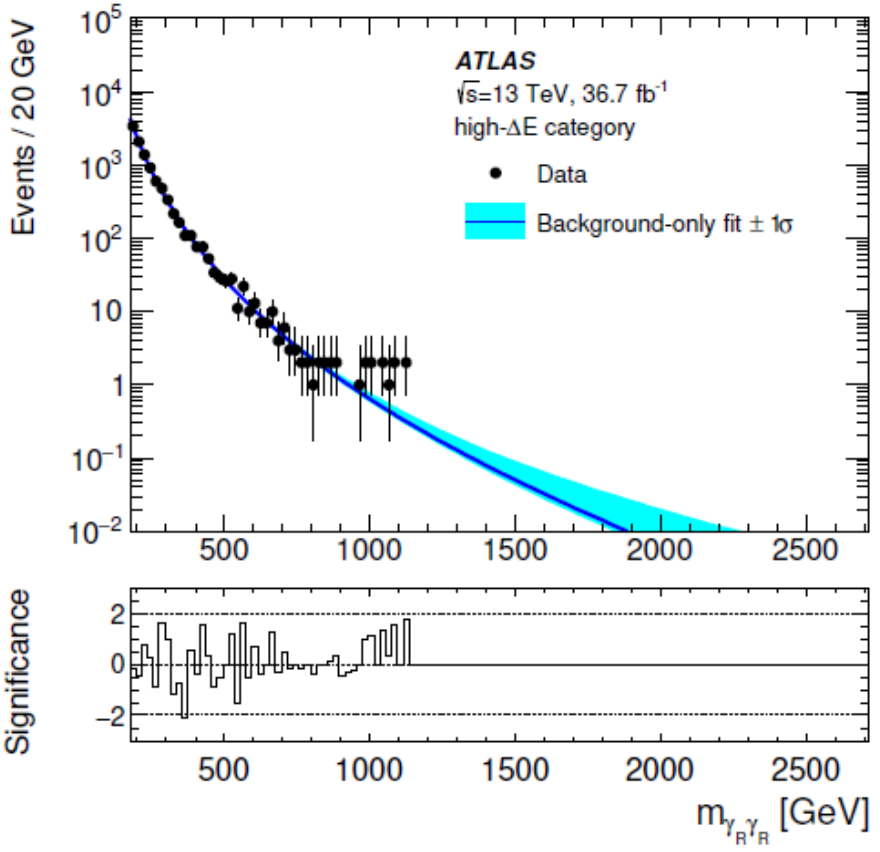
Templates: $\gamma\gamma$ LO MC (Sherpa)

γj and jj Data control region
(defined by inverting isolation)



Results



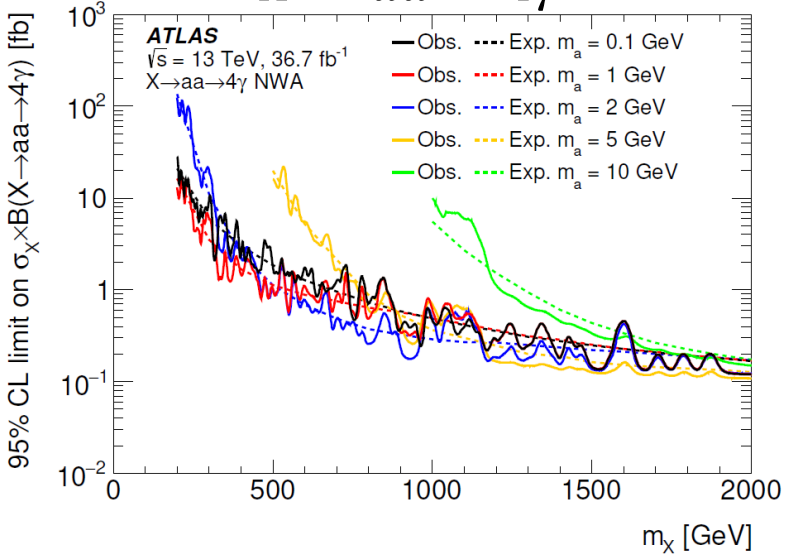


No significant excess observed

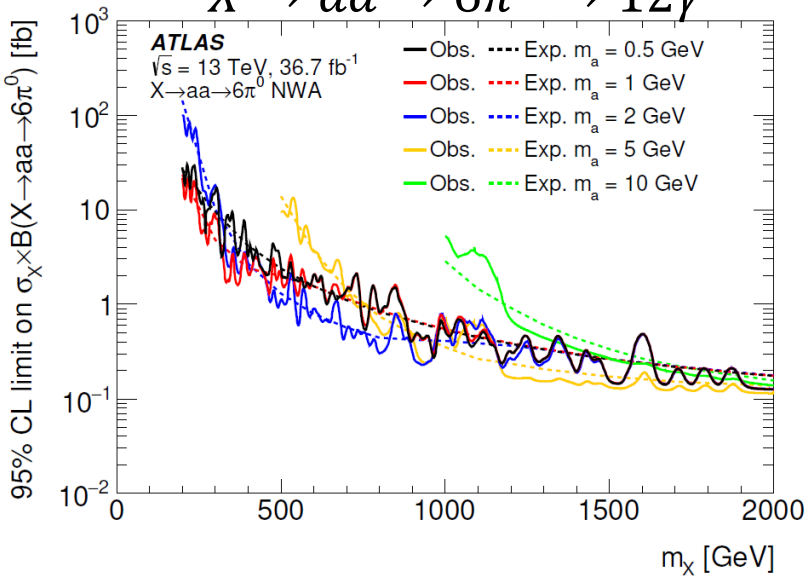
(Largest local significance = 2.7σ)

Results

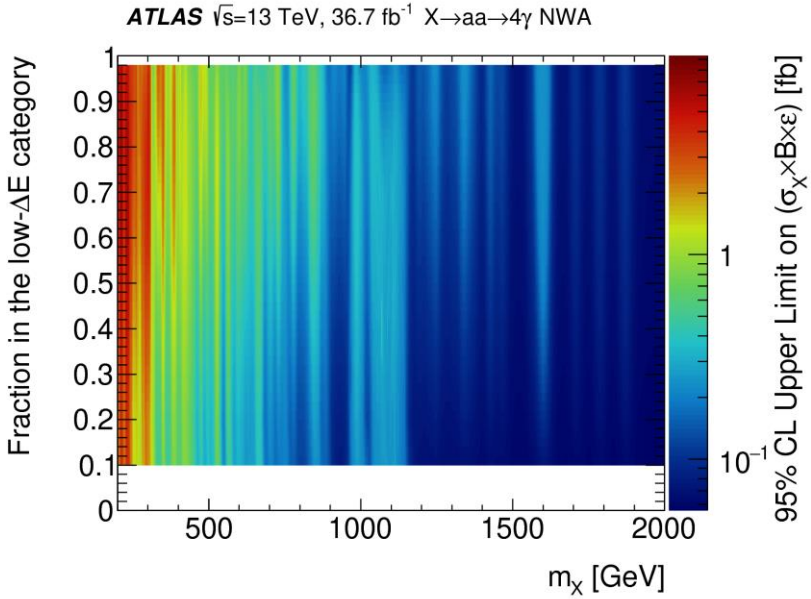
$X \to aa \to 4\gamma$



$X \to aa \to 6\pi^0 \to 12\gamma$



For $m_X > 600$ GeV and $m_a < 2$ GeV, upper limits in the range 0.2-2 fb



Model-independent limit

- Limit on visible cross-section as a function of m_X and category fraction
- Using data in HEPData (in preparation), this can be used for reinterpretation

Summary

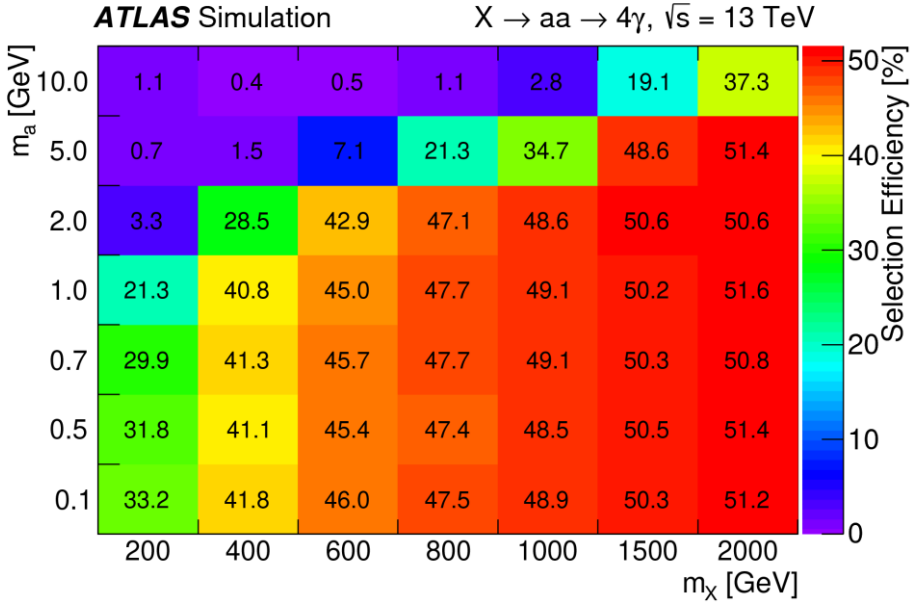
- Search for heavy resonance decaying into pair of photon-jets
- New experimental signature!
- Motivated from several models e.g. extended Higgs sector

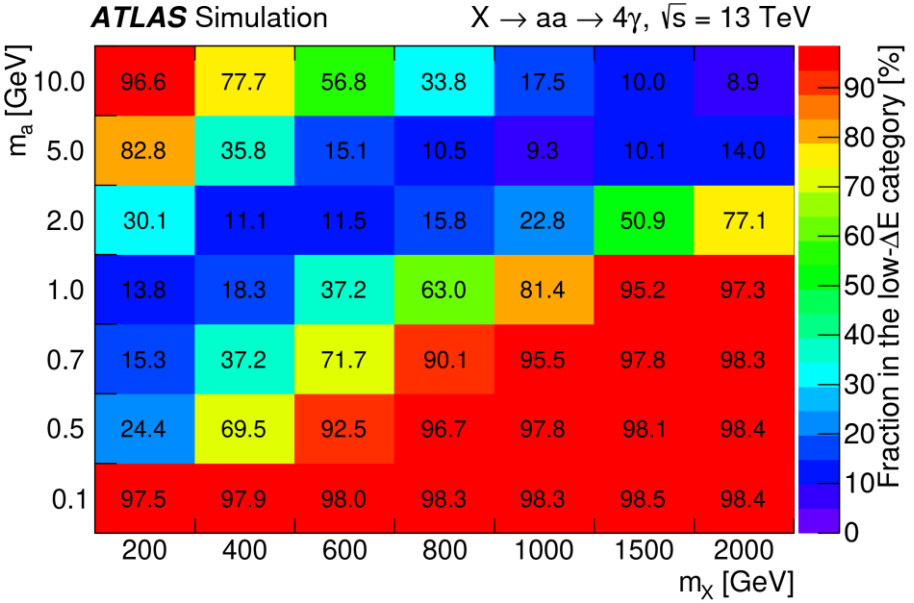
- No significant excess observed
- Upper limits on cross-section times branching ratios are set for wide range of mass parameters
- Model-independent limit on visible cross-section

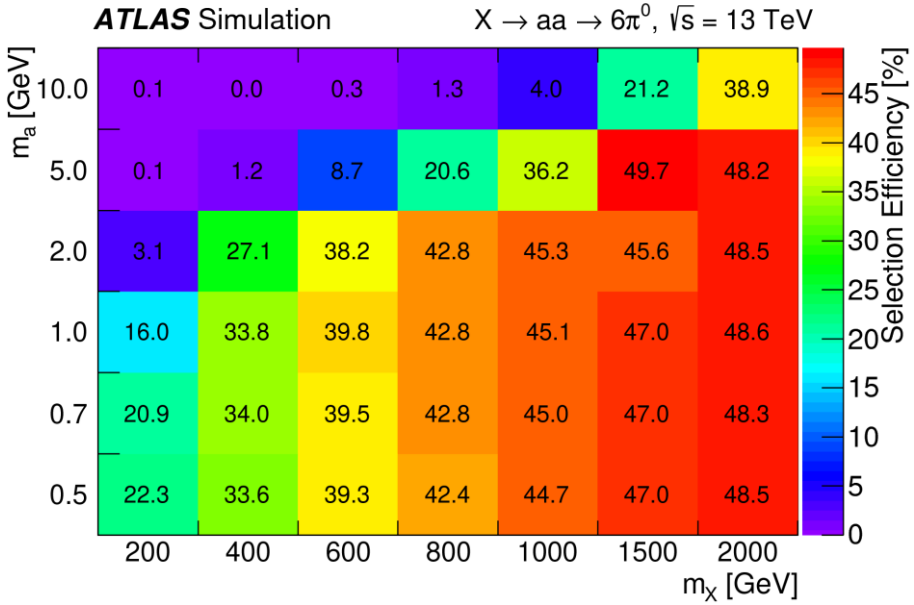
- First result for this search

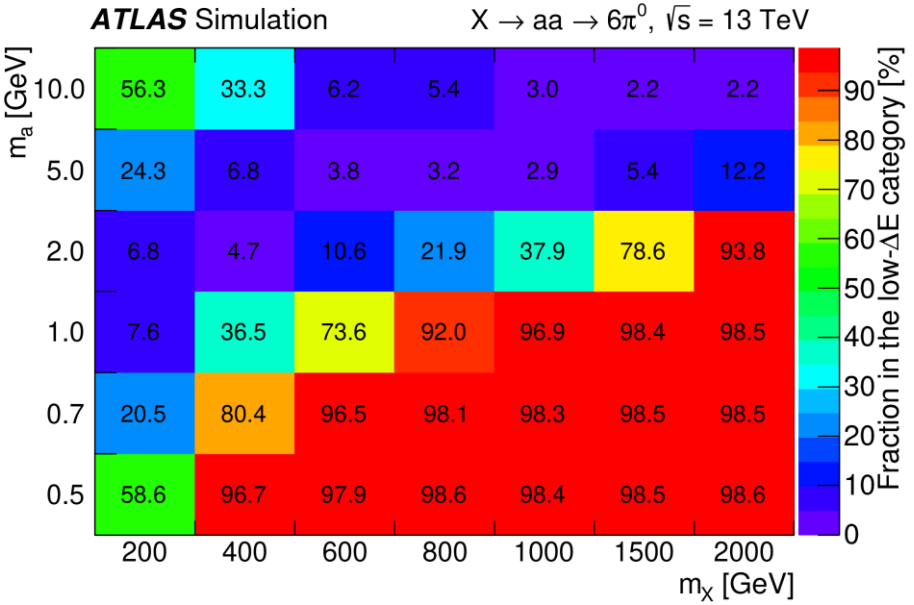
Backup

Selection efficiency and category fraction





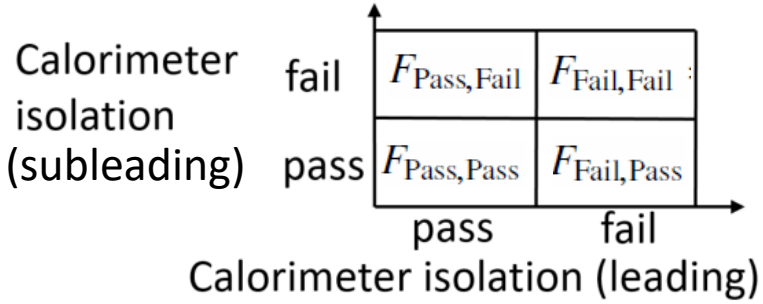




Background composition measurement

Matrix method is used:

- Data events are divided into 4 regions based on calorimeter isolation cuts



- Composition of $\gamma\gamma, \gamma j, j\gamma, jj$ is evaluated from following equation

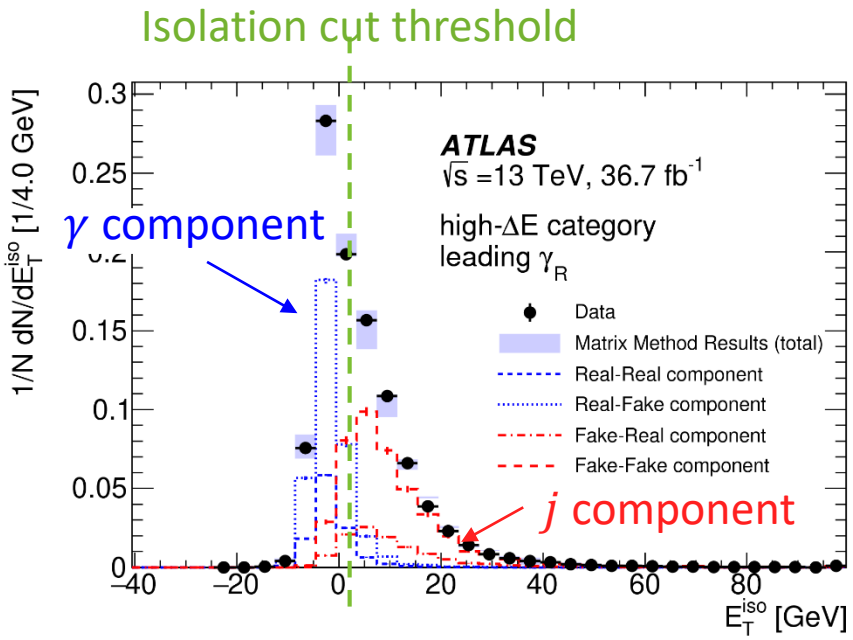
$$\begin{pmatrix} F_{\text{Pass,Pass}} \\ F_{\text{Pass,Fail}} \\ F_{\text{Fail,Pass}} \\ F_{\text{Fail,Fail}} \end{pmatrix} = \begin{pmatrix} \varepsilon_1\varepsilon_2 & \varepsilon_1 f_2 & f_1\varepsilon_2 & f_1 f_2 \\ \varepsilon_1(1-\varepsilon_2) & \varepsilon_1(1-f_2) & f_1(1-\varepsilon_2) & f_1(1-f_2) \\ (1-\varepsilon_1)\varepsilon_2 & (1-\varepsilon_1)f_2 & (1-f_1)\varepsilon_2 & (1-f_1)f_2 \\ (1-\varepsilon_1)(1-\varepsilon_2) & (1-\varepsilon_1)(1-f_2) & (1-f_1)(1-\varepsilon_2) & (1-f_1)(1-f_2) \end{pmatrix} \begin{pmatrix} F_{\gamma\gamma} \\ F_{\gamma j} \\ F_{j\gamma} \\ F_{jj} \end{pmatrix}$$

Evaluation of calorimeter isolation cut efficiency:

- Efficiency of photons (ε) evaluated using LO $\gamma\gamma$ MC (Sherpa)
- Efficiency of hadronic jets (f) evaluated using data CR inverting photon ID

Background composition results

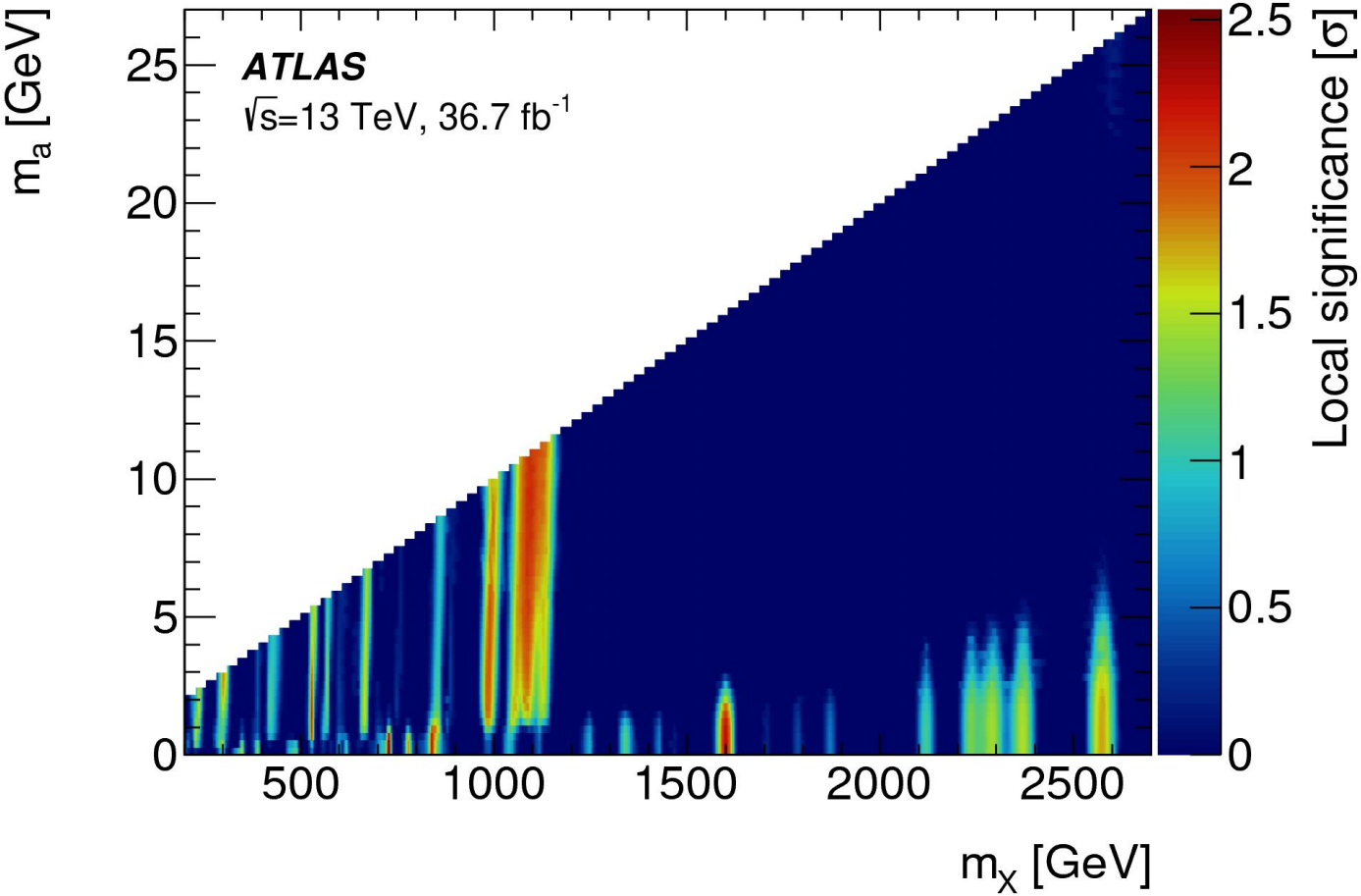
	Low-ΔE category	High-ΔE category
$\gamma\gamma$	$0.930^{+0.027}_{-0.031}$	0.48 ± 0.16
γj	$0.051^{+0.021}_{-0.018}$	$0.32^{+0.08}_{-0.09}$
$j\gamma$	$0.014^{+0.004}_{-0.005}$	$0.108^{+0.001}_{-0.016}$
jj	$0.005^{+0.006}_{-0.003}$	$0.09^{+0.09}_{-0.05}$



Validation plot:

- Shows the agreement of γ and j isolation templates and data
- Components are added with composition in the table

p_0 scan result



Upper limits as a function of m_a/m_X