Searching for Diphoton Resonances in Association with Leptons in the Mass Range 130 – 200 GeV with the ATLAS detector

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Motivation: Why this search?

The Timeline

Nature Rev.Phys. 6 (2024) 5, 294-309

2015
Run 1 excesses
Motivating anomalies
Diboson final states

2016
Simplified di-boson model
predicting multi-lepton excesses
Eur.Phys.J.C 76 (2016) 10, 580

2017/2018
Multi-lepton anomalies in Run 1
Prediction of m_S=150±5 GeV
in association with leptons/jets/MET
J.Phys.G 45 (2018) 11, 115003

2019
Multi-lepton anomalies
verified in Run 2
JHEP 10 (2019) 157

2021
First narrow excess at 151.5±1
GeV with jets/leptons/MET
reaching 3.9$\boldsymbol{\sigma}$
Phys.Rev.D 108 (2023) 11, 115031

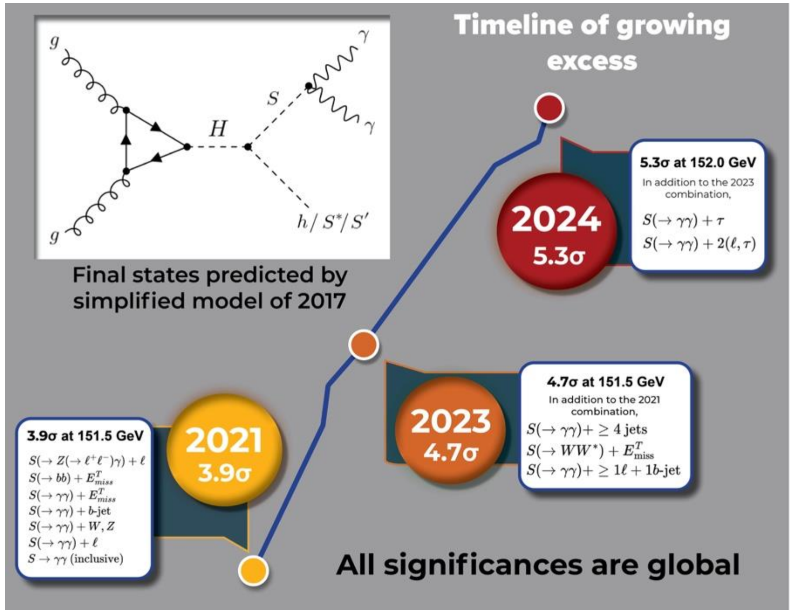
2025
Narrow excess at 152±1
GeV with 5.3$\boldsymbol{\sigma}$
with leptons/jets/MET
2503.16245

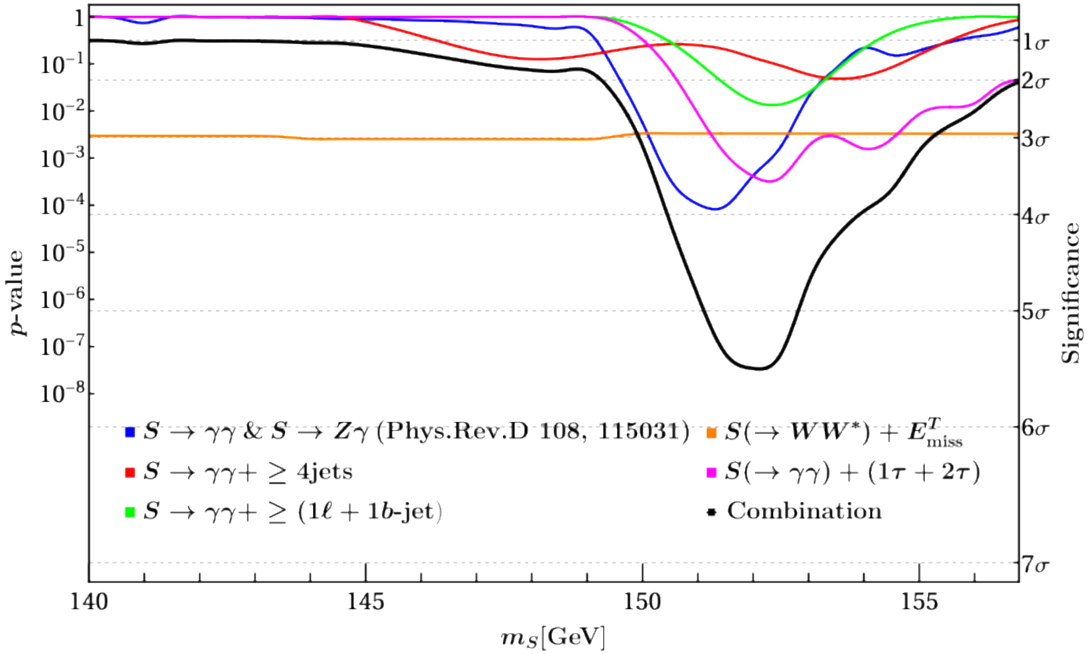
Current work continues to accumulate excesses at 152 ± 1 GeV and explores a Y = 0 triplet leading to triboson excesses.

Current Picture

2021 (Group 1)	2023 (Group 2)	2025 (Group 3)
$\gamma\gamma + E^T_{\text{miss}}$ [20, 43] $\gamma\gamma + W, Z$ [46, 47] $\gamma\gamma + b$-jet [48, 49] $\gamma\gamma + 2b$-jets [52] $Z(\to \ell^+\ell^-)\gamma + 1\ell, jj$ [53]	$\gamma\gamma + \geq (1\ell + 1b\text{-jet})$ [44] $\gamma\gamma + \geq 4$ jets [44] $WW^* + E^T_{\text{miss}}$ [50, 51]	$\gamma\gamma + \tau$ [45] $\gamma\gamma + 2(\ell, \tau)$ [45]

S. Battacharya et al. 2503.16245

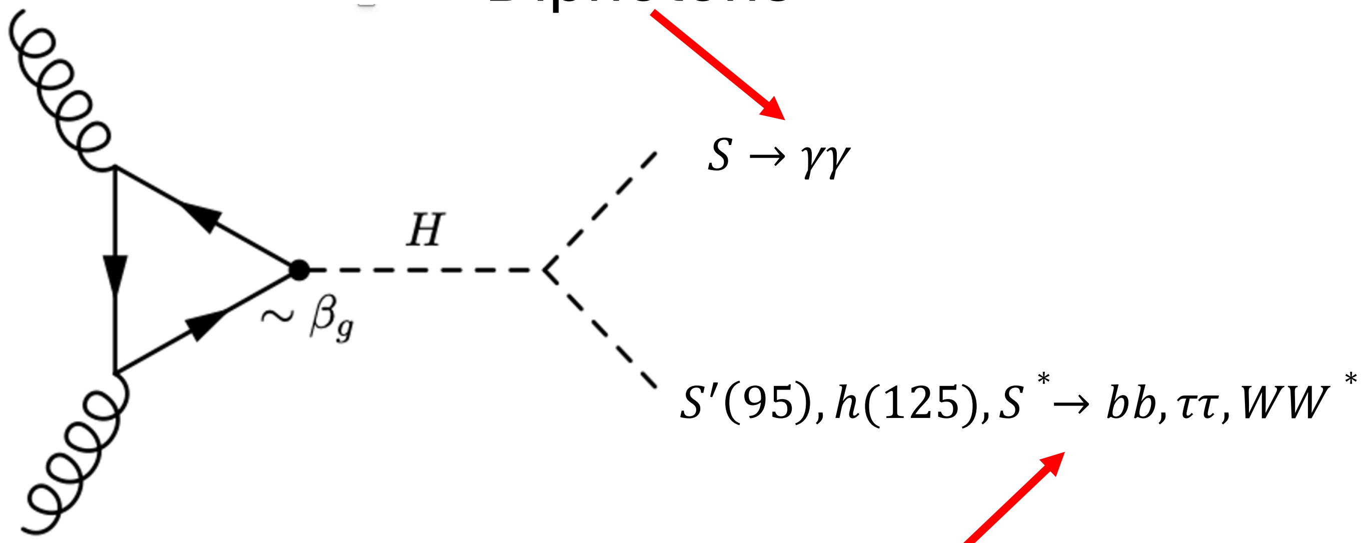




Physics Picture: What can explain the 152 GeV excess?

Models to motivate diphoton searches in association with b-jets, tau-jets, leptons (e/μ) and jets

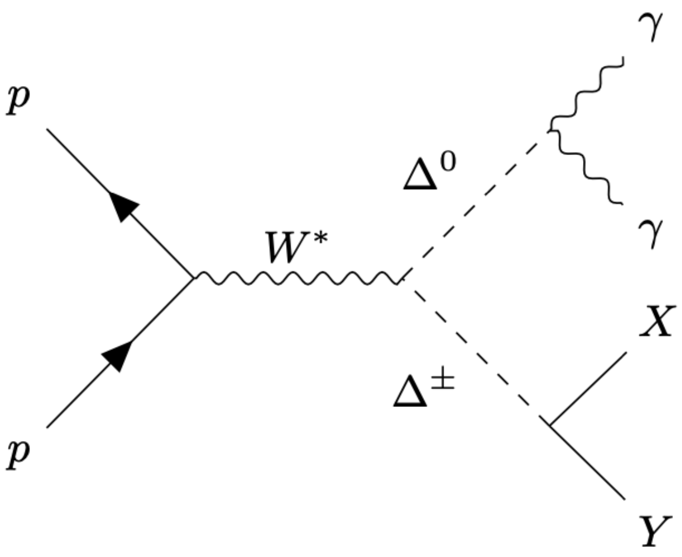
Diphotons



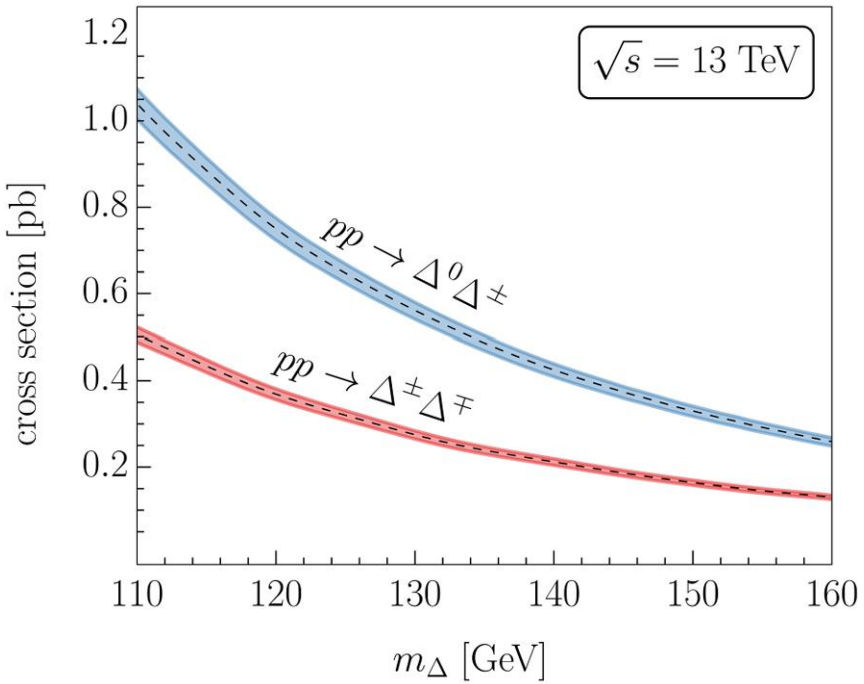
Source of b-jets, taus, leptons, jets

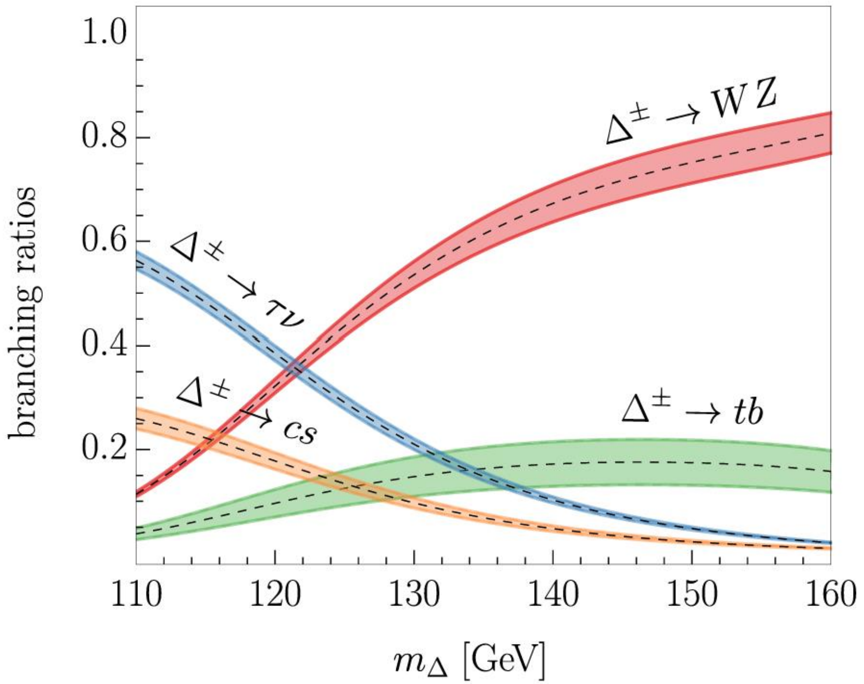
2HDM+S model, *Eur.Phys.J.C* 76 (2016) 10, 580

Triplet model predicts Δ^0 in association with tau-jets, leptons (e/μ), MET and jets
Charged scalars, $\Delta^{\pm}$ decay into $\tau^{\pm}\nu$, ZW$^{\pm}$ and t*b

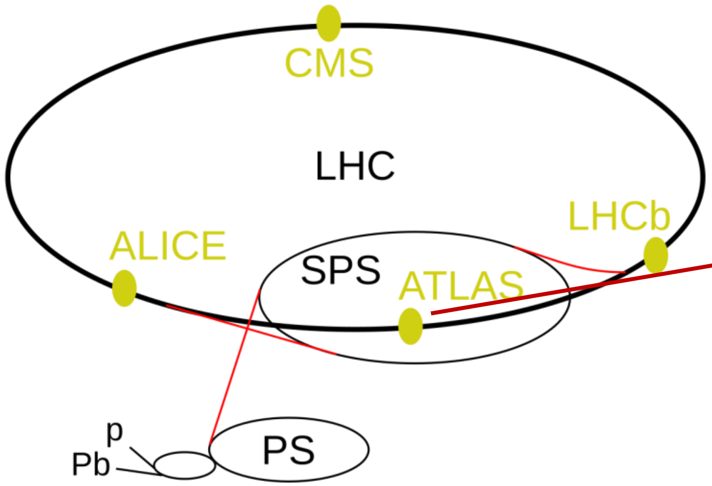


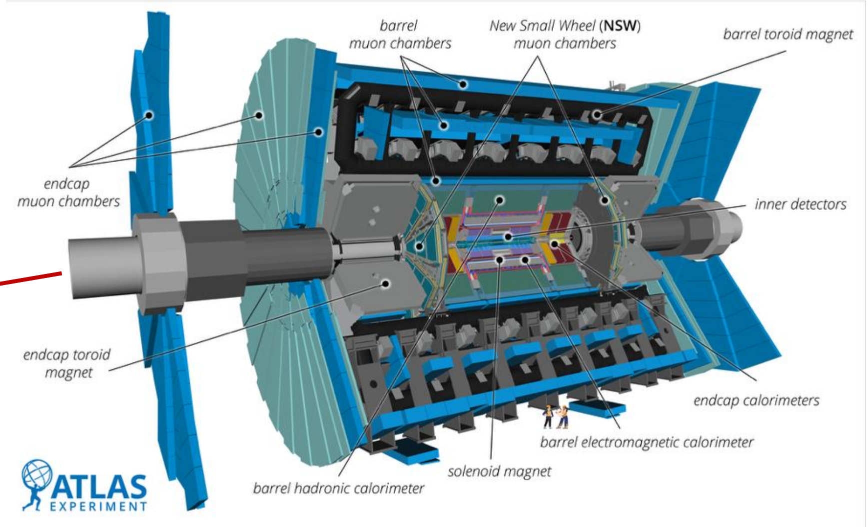
Triplet model:
JHEP 2025, 003 (2025).





LHC and ATLAS experiment



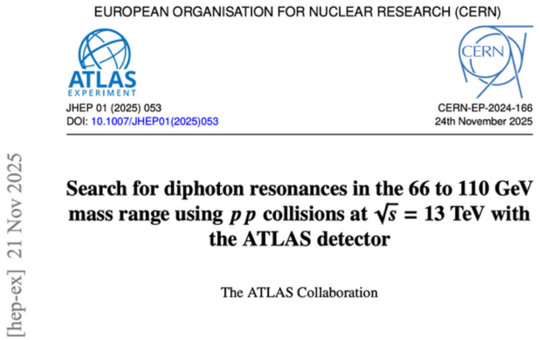


- Proton-proton (pp) collisions
- 13.6 TeV centre-of-mass energy
  - Allowing for creation of new particles
- Up to $2 \times 10^{34} \mathrm{cm}^{-2} \mathrm{s}^{-1}$ instantaneous luminosity

- The largest detector at the LHC
- Tests the Standard Model and searches for new physics
- **Tracking detectors:** Inner detector and the muon spectrometer
- **Calorimeters:** Electromagnetic and Hadronic

Gap in Current Searches in ATLAS

- ATLAS searches for diphoton production have focused on two mass windows
  - Low-mass 66 - 110 GeV
  - High-mass 200-3500 GeV


EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

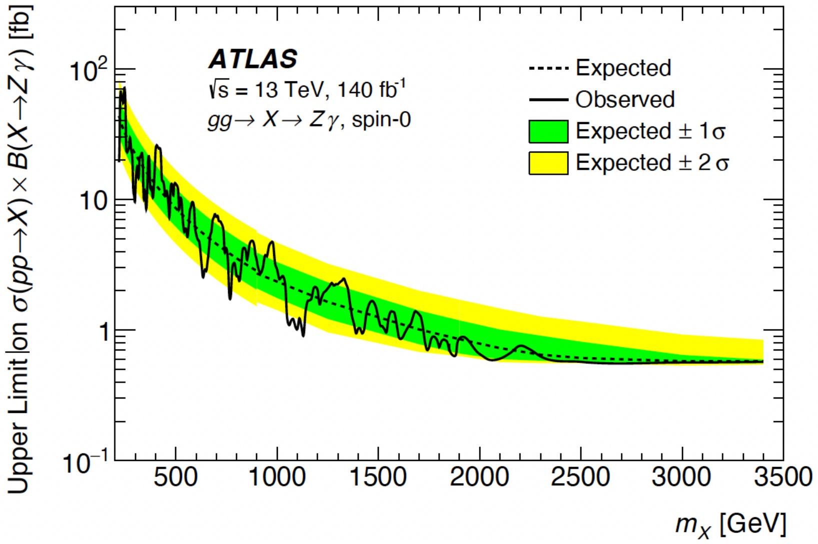
JHEP 01 (2025) 053
DOI: 10.1007/JHEP01(2025)053

CERN-EP-2024-166
24th November 2025

[hep-ex] 21 Nov 2025

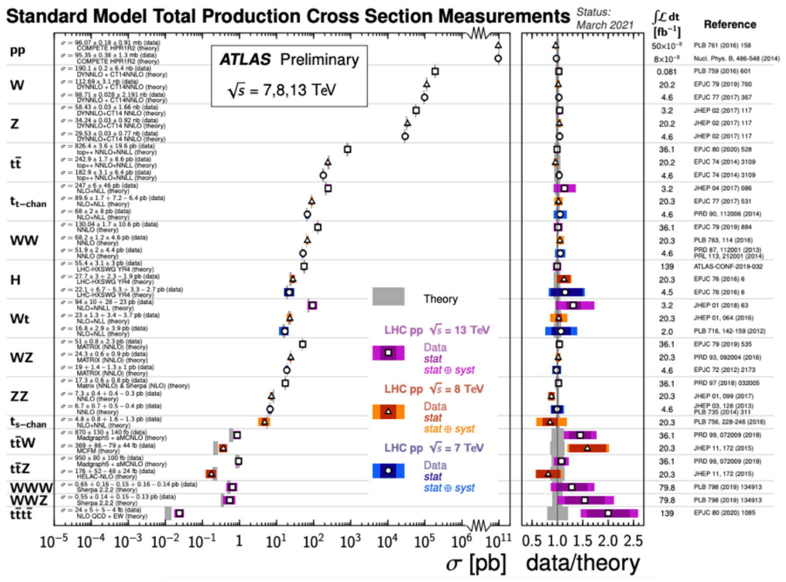
Search for diphoton resonances in the 66 to 110 GeV mass range using pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

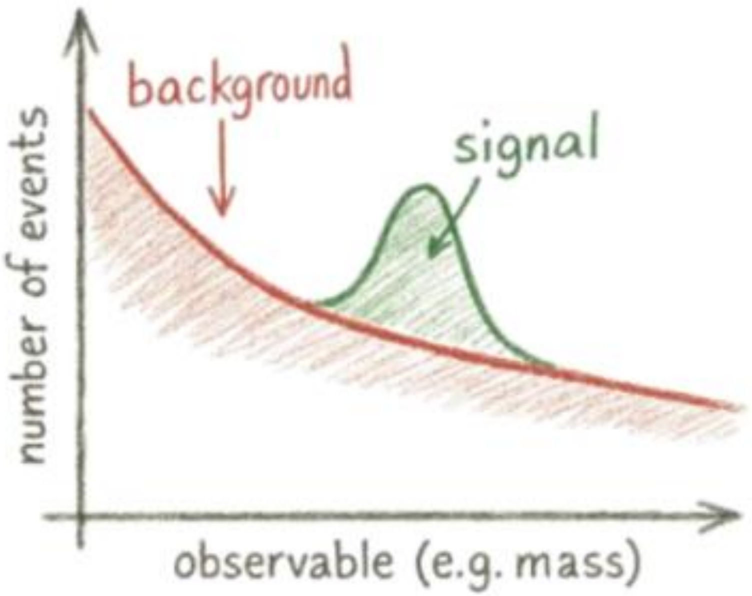
The ATLAS Collaboration



- Such an intensive resonant diphoton search has not been conducted in the mass range **130 - 200 GeV**, where we come in

Analysis strategy





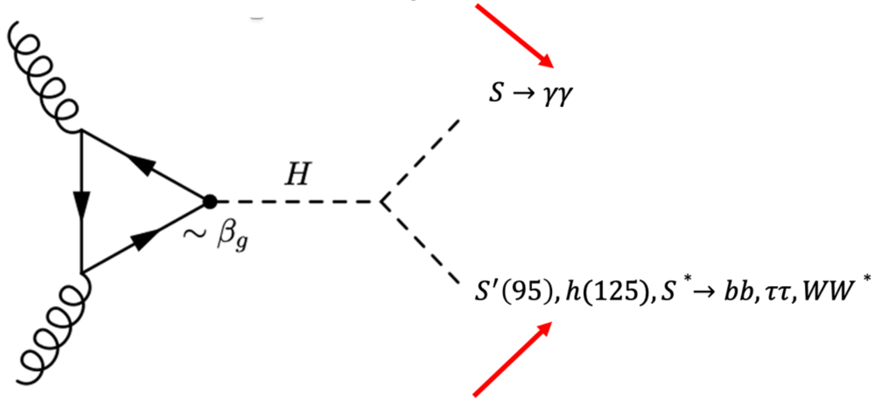
- Large success of the SM so far at the LHC and no clear evidence of BSM physics from direct searches
- The search is designed to be model-independent and interpretation-ready

- Reconstruct invariant mass spectra and perform fits
- Aim is to identify discrepancies between SM prediction and collected data
- Set limits on production cross-section × branching ratio

Channels of Interest

Final State	2HDM+S	Real Triplet Model
$\gamma\gamma + \tau_{had}$	Yes	Yes
$\gamma\gamma + e/\mu$ (b-veto)	Yes	Yes
$\gamma\gamma + e/\mu +$ b-jet	Low Cross-section	Yes
$\gamma\gamma + 2\ell$	Yes	Yes
$\gamma\gamma + 2\tau_{had}$	Yes	Yes

Di-photons



Source of b-jets, taus, leptons, jets

$\gamma\gamma$ + X search will be start soon

Analysis Toolkit

Ntupling frameworks

- Easyjet (Athena-based)
  - ➢ Produce a tree of vectors
- FastFrames to produce flat ntuples

Signal/background fitting and spurious signal studies

- xmlAnaWSBuilder
- HGam Core

Limit extraction

- QuickFit

Object and Event Selection

Diphoton Selections

- Triggers
  - HLT_2g50_loose_L12EM20VH
  - HLT_g35_medium_g25_medium_L12EM20VH
  - HLT_2g22_tight_L12EM15VHI
- Two Loose and non Isolated photons
- 1.37 <$|\eta|$< 1.52 rejected and $|\eta|$ ≤ 2.37

Leptons

- Electrons:
  - $p_T >$ 10 GeV, 1.37 <$|\eta|$< 1.52 rejected and $|\eta|$ ≤ 2.37 passing the MediumDNNLoose working point (WP)
- Muons
  - $p_T >$ 10 GeV, $|\eta|$ ≤ 2.5 and MediumPFlow WP
- Taus
  - $p_T >$ 25 GeV, 1.37 <$|\eta|$< 1.52 rejected and $|\eta|$ ≤ 2.37

Data and Simulated Samples

- Dominant backgrounds
  - $pp \to V\boldsymbol{\gamma\gamma}$
  - $pp \to \boldsymbol{\gamma\gamma + jets}$
  - $pp \to \boldsymbol{\gamma\gamma\ t\bar{t}}$
  - Standard Model Single Higgs background processes
- Signal Samples
  - Processes: $\gamma\gamma + 2\mathrm{l}, \gamma\gamma + 2\mathrm{b}$
  - Produced at different mass points
    - Enable us to parameterize signal shape parameters

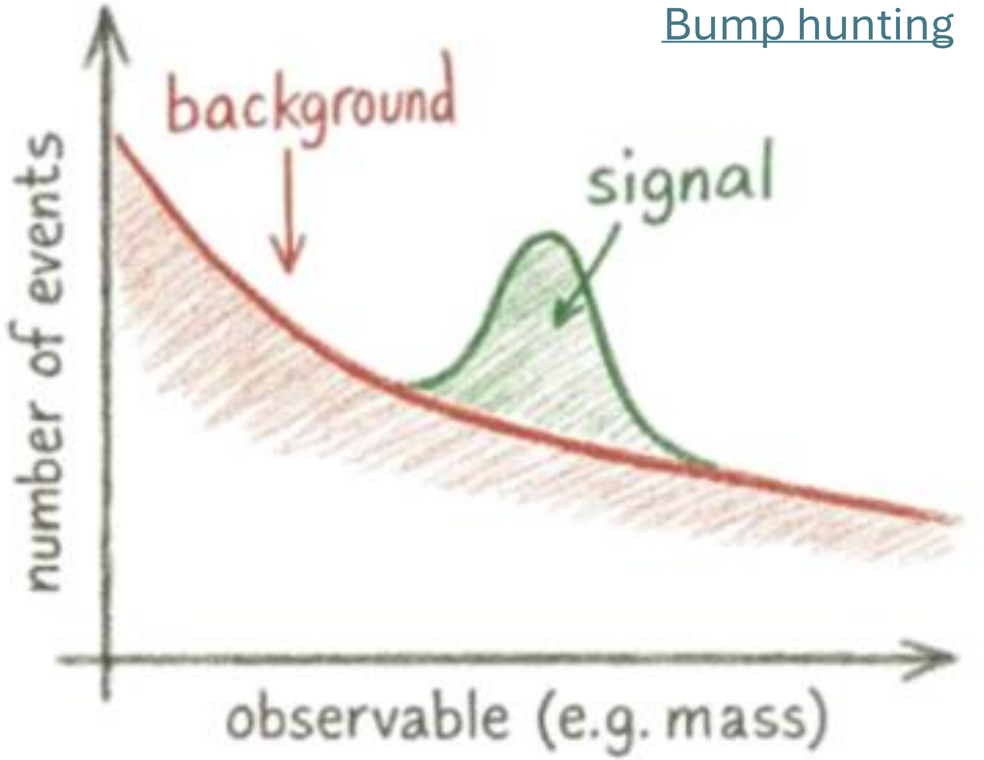
Data Sample

- proton-proton collisions @ 13.6 TeV
- Collected by the ATLAS detector
- Integrated luminosity: $\int \mathcal{L} = 164\ \mathrm{fb}^{-1}$ (Good for Physics)
  - 2022: $29.3\ \mathrm{fb}^{-1}$
  - 2023: $26.7\ \mathrm{fb}^{-1}$
  - 2024: $107.9\ \mathrm{fb}^{-1}$
- Monte Carlo samples are generated to have the same pile-up shape as data, for a given year
  - See Njokweni's talk

Signal and Background Modelling

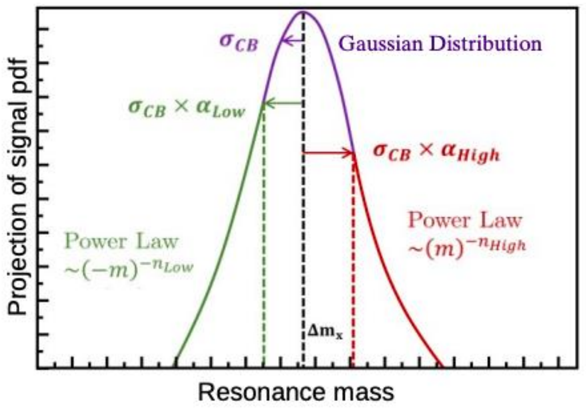
- The statistical analysis is performed using a **signal + background fit** to the $m_{\gamma\gamma}$ distribution in data
- The **true background shape is unknown** in data
- Any mismatch between the true background and the chosen analytic model can introduce a **bias in the fitted signal yield**
- This bias is referred to as the **spurious signal**

Bump hunting



Signal Modelling

- The signal is modelled using a **Double-Sided Crystal Ball (DSCB)** function



- The DSCB combines:
  - a Gaussian core to describe the detector resolution
  - power-law tails to model energy-loss and reconstruction effects
- The fitted DSCB parameters are parameterised as functions of the resonance mass

Background Modelling

- The non-resonant diphoton background is described using smooth analytic functions
- Candidate functional families include
  - Exponentials
  - Bernstein Polynomials
  - Power Laws
- The background model is fitted to the $m_{\gamma\gamma}$ spectrum over the search region

$$130 < m_{\gamma\gamma} < 200 \text{ GeV}$$

- Perform spurious signal studies to select a functional form with the smallest spurious signal

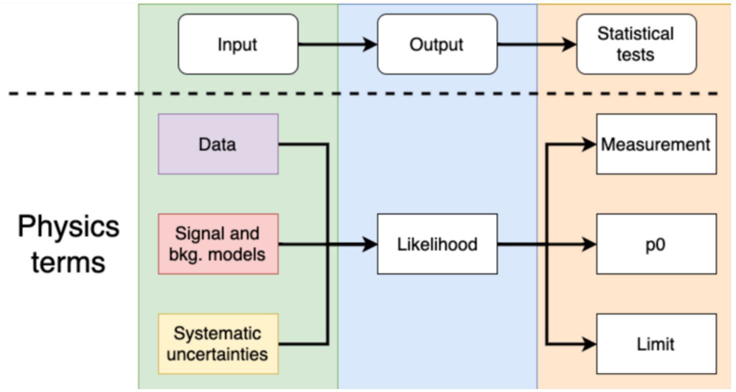
Analysis philosophy: use the simplest background model that accurately describes the background while minimising fit-induced bias.

Statistical Fits

- Statistical models are constructed using the [xmlAnaWSBuilder]
  - signal and background models
  - systematic uncertainties as nuisance parameters
  - correlations between uncertainties across channels

The statistical inference is performed using **QuickFit**:

  - maximises the profile likelihood
  - profiles nuisance parameters
  - evaluates the compatibility of the data with the background-only and signal-plus-background hypotheses.



- Expected Output:
  - Search for localised excesses above the expected background
  - Determine the statistical significance of any observed deviation
  - If no significant excess is observed, set upper limits at **95% confidence level upper limits** on

$$\sigma(pp \to X) \times \mathcal{B}(X \to \gamma\gamma + \text{multi leptons})$$

Impact and Outlook

Publication strategy

- Proceeding towards publication with the channels mentioned above
- The analysis will use partial Run 3 data

Build up on the current analysis for a “second round”

- Full Run 3 dataset
- Include MET channels and two b-jets

- Ongoing Work
  - Background composition studies
  - Fake estimation studies

Summary

Current Work

- Search for a narrow diphoton resonance produced in association with leptons using partial **ATLAS Run 3** data.
- Focus on the **130–200 GeV** mass region, motivated by recent phenomenological studies and complementary to existing ATLAS searches.

Ongoing Work

- Background composition studies
- Data-driven fake photon and fake lepton estimation
- Validation of the statistical model and systematic uncertainties.

Future Programme

- Extend the analysis to the **full Run 3 dataset**
- Incorporate additional final states:
  - Missing transverse energy (MET),
  - Two **b**-jet channels,
  - Other complementary signatures.