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Search for a Resonant Scalar in the Diphoton Final State in Association with an electron with ATLAS Run-3 Data at the LHC

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Overview

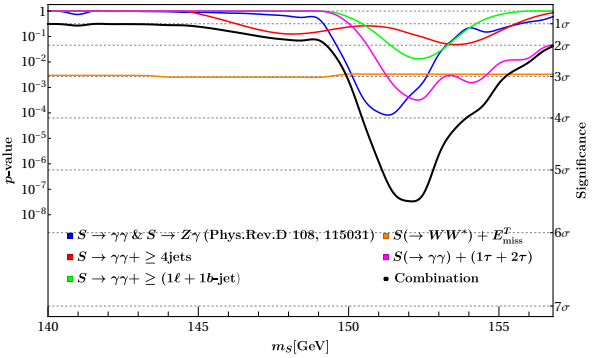
- Analysis Strategy & Model Description
- Background Processes
- Region Definitions
- Event Selections
- Working Point Selection
- Kinematic Distributions
- Conclusions

Di-Photon Resonance Searches

Multi-lepton anomalies

- Multi-lepton anomalies were observed at the LHC
- A simplified model predicts multi-lepton final states associated with these excesses.
- ATLAS Higgs-sideband studies suggest a possible narrow scalar resonance near 150 ± 5 GeV in $\gamma\gamma$ and $Z\gamma$ final states.
- This motivates the search for a possible scalar in the 130–200 GeV diphoton mass region [1].

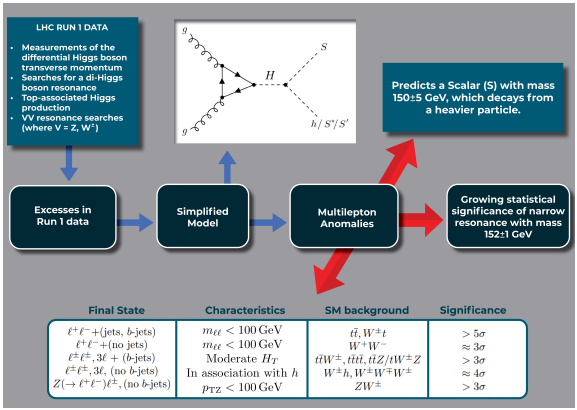
Candidate resonance



Model Description

- We are probing Beyond the Standard Model (BSM) physics using the 2HDM+S Model, supported by the multilepton anomalies observed at the LHC [2]
- We are interested in the final states:
  - $\gamma\gamma + 0\ell + 1\tau$
  - $\gamma\gamma + 0\ell + 2\tau$
  - $\gamma\gamma + 1\ell + 1\tau$
  - $\gamma\gamma + 2\ell + 0\tau$
  - $\gamma\gamma + 1\ell + 0\tau$ [focus]
  - $\gamma\gamma + 1\ell + 1b$
- The final state of focus in this specific study is:
  - $\gamma\gamma + e^{-} + 0\tau$

The 2HDM+S Topology



Background Processes

The single electron final state: $\gamma\gamma + 1e$

- **Reducible backgrounds**
  - $\gamma\gamma$+jets: jet, photon conversion, or non-prompt electron passes electron selection
  - Single Higgs: $H \to \gamma\gamma$ with an associated jet or non-prompt electron
- **Irreducible backgrounds**
  - $V\gamma\gamma$: dominated by $W\gamma\gamma \to e\nu\gamma\gamma$ and $Z\gamma\gamma \to ee\gamma\gamma$
  - $t\bar{t}\gamma\gamma$: one W boson decays as $W \to e\nu$
  - We use the full Run-3 Monte Carlo Data set in the 2022, 2023 and 2024 data taking periods

Weighting of the Events

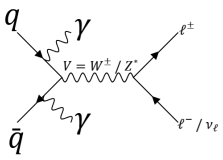
- Higgs diphoton branching ratio:

$$BR_{H\to\gamma\gamma} = 0.002270$$

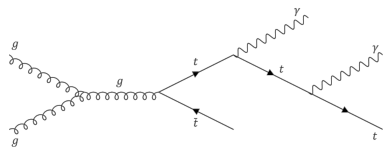
- The Higgs diphoton BR is applied to Single-Higgs:

$$N^{\mathrm{SH}}_{\gamma\gamma} = N_{\gamma_1}\epsilon^{\mathrm{effSF}}_{\gamma_1}\epsilon^{\mathrm{effSF}}_{\gamma_2}BR_{H\to\gamma\gamma}$$

Feynman diagrams



$V\gamma\gamma$



$t\bar{t}\gamma\gamma$

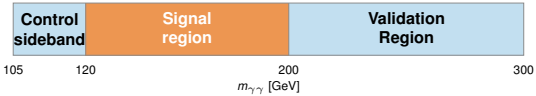
Region Definitions

Common event selection

- Start with events passing the diphoton trigger and trigger matching.
- Select events with exactly two good photons.
- Require photon quality:
  - `Tight` photon ID
  - `Loose` isolation
  - η acceptance and crack veto
- Apply photon p_T and $p_T/m_{\gamma\gamma}$ requirements.
- Focus on the clean electron final state:

$$\gamma\gamma + 1e + 0b + 0\mu + 0\tau$$

Region Selection



Control Region
105–120 GeV

Used to understand and constrain the background.

Signal Region
130–200 GeV

Region where the possible scalar signal is tested.

Validation Region
200–300 GeV

Used to validate selections with plots.

One clean $\gamma\gamma + e$ selection is used throughout; only the diphoton mass window changes.

Event Selections (Cutflow Table)

Weighted events by production mode

Event weighting

$$\text{Yield} = \text{per} - \text{event corrections} \times \underbrace{\frac{\sigma \times \text{genFiltEff} \times \mathcal{L}}{\sum w_{\text{generated}}}}_{\text{normalisation to data luminosity}}$$

Control Region Cutflow ($105 < m_{yy} < 120$ GeV)

Cut	Data	SingleHiggs	ttyy	Vyy	yyjets
All entries	8261057	570278.591	291.016	9549.337	297465.480
Two Photons	8261057	570278.591	291.016	9549.337	297465.480
Photon η acceptance	1680076	409812.203	174.716	5022.497	202418.924
Photon p_T thresholds	1663158	409623.459	174.627	5000.841	202051.390
p_T/m_{yy} thresholds	1459845	367339.980	146.230	4256.650	147873.021
$105 < m_{yy} < 120$ GeV region	137476	8414.420	34.607	400.552	32747.967
b-jet veto	135462	8203.006	7.535	392.018	32402.782

Signal Region Cutflow ($130 < m_{yy} < 200$ GeV)

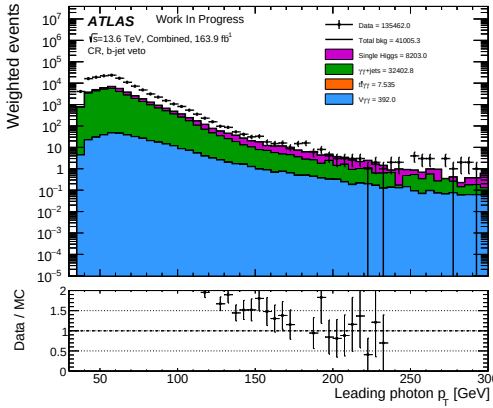
Cut	Data	SingleHiggs	ttyy	Vyy	yyjets
All entries	8261057	570278.591	291.016	9549.337	297465.480
Two Photons	8261057	570278.591	291.016	9549.337	297465.480
Photon η acceptance	1680076	409812.203	174.716	5022.497	202418.924
Photon p_T thresholds	1663158	409623.459	174.627	5000.841	202051.390
p_T/m_{yy} thresholds	1459845	367339.980	146.230	4256.650	147873.021
$130 < m_{yy} < 200$ GeV region	101776	9694.014	44.689	593.612	31446.340
b-jet veto	99828	9423.860	9.454	579.426	31005.998
exactly 1 electron	986	124.256	2.988	159.668	55.177
1 electron + 0μ + 0τ	797	102.110	2.359	139.792	49.783

Validation Region Cutflow ($200 < m_{yy} < 300$ GeV)

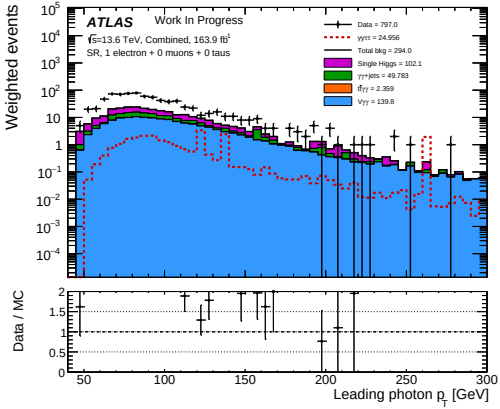
Cut	Data	SingleHiggs	ttyy	Vyy	yyjets
All entries	8261057	570278.591	291.016	9549.337	297465.480
Two Photons	8261057	570278.591	291.016	9549.337	297465.480
Photon η acceptance	1680076	409812.203	174.716	5022.497	202418.924
Photon p_T thresholds	1663158	409623.459	174.627	5000.841	202051.390
p_T/m_{yy} thresholds	1459845	367339.980	146.230	4256.650	147873.021
$200 < m_{yy} < 300$ GeV region	13352	115.848	0.536	200.202	10301.020
b-jet veto	12965	84.670	0.114	194.964	10111.945
exactly 1 electron	345	20.646	0.030	59.408	35.620
1 electron + 0μ + 0τ	289	16.445	0.023	53.666	36.589

Kinematic Distributions

Control Region Plot



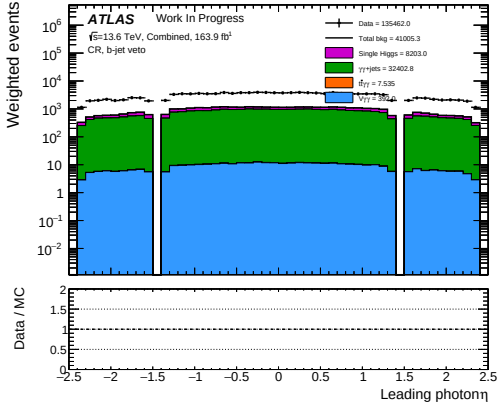
Signal Region Plot



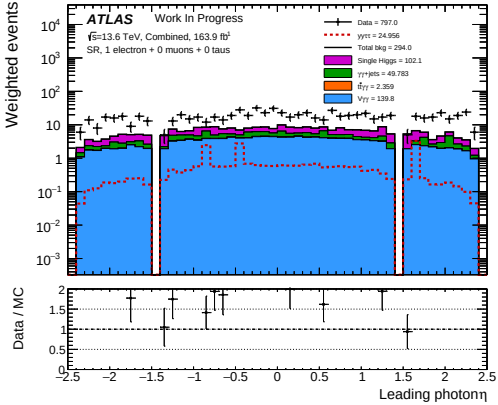
Comparison of the leading photon transverse momentum In the Control and Signal Regions

Kinematic Distributions

Control Region Plot



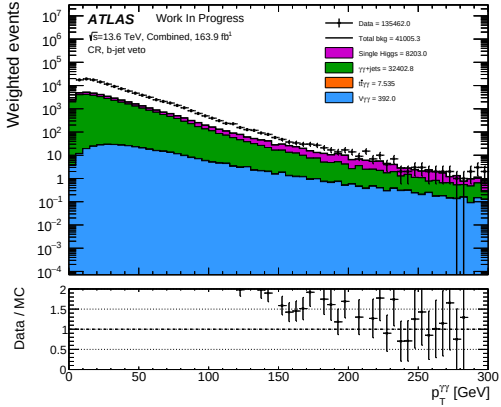
Signal Region Plot



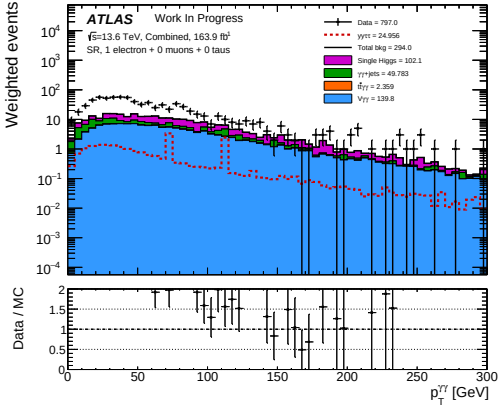
Comparison of the leading photon pseudorapidity In the Control and Signal Regions

Kinematic Distributions

Control Region Plot



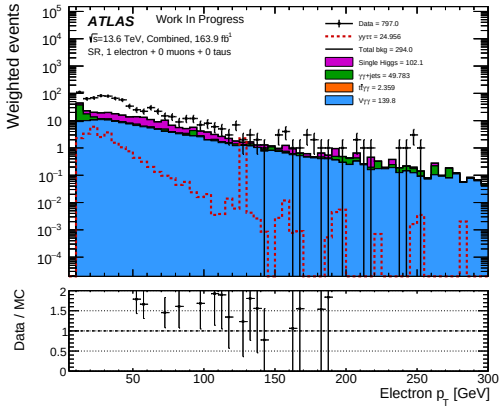
Signal Region Plot



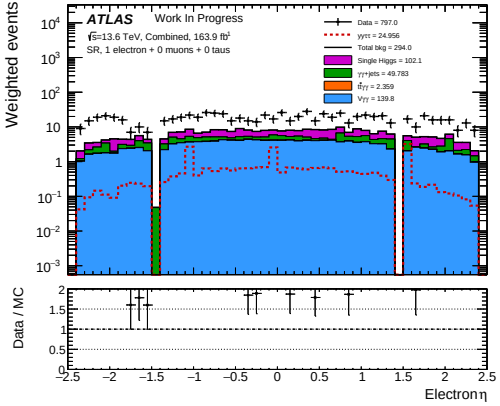
Comparison of the Diphoton transverse momentum In the Control and Signal Regions

Electron Kinematics in the Signal region

Transverse Momentum



Pseudorapidity



Conclusions

Summary

- A Run-3 $\gamma\gamma + e$ region study was developed for the resonant scalar search.
- Control, signal, and validation regions were defined using the diphoton mass window.
- Kinematic distributions were produced for the photons, diphoton system, and selected electron.
- The signal region keeps the final $1e + 0\mu + 0\tau$ selection for the search topology.

Future work

- Improve Data/MC agreement by deriving suitable scale factors in control regions.
- Optimise the electron selection in the signal region to improve sensitivity.
- Continue electron working-point studies and compare LH- and DNN-based selections.
- Validate the optimised selection in the validation region before applying it to the signal region.

The next step is to constrain the backgrounds and optimise the electron selection before extracting the final signal-region sensitivity.

Backup slides

References

[1] Andreas Crivellin et al. “Accumulating evidence for the associated production of a new Higgs boson at the LHC”. In: *Phys. Rev. D* 108.11 (2023), p. 115031. DOI: 10.1103/PhysRevD.108.115031. arXiv: 2109.02650 [hep-ph].

[2] Stefan von Buddenbrock et al. “The emergence of multi-lepton anomalies at the LHC and their compatibility with new physics at the EW scale”. In: *Journal of High Energy Physics* 2019.10 (Oct. 2019). ISSN: 1029-8479. DOI: 10.1007/jhep10(2019)157. URL: http://dx.doi.org/10.1007/JHEP10(2019)157.