Searches for scalar resonances in the $\gamma\gamma + 0\ell 1\tau$ final state at $\sqrt{s} = 13.6$ TeV with ATLAS Run 3 data using background modelling, spurious-signal testing, and DSCB signal parameterisation

ATLAS Analysis Team

Arnav Chauhan, Francesco Curcio, Mukesh Kumar, Rachid Mazini, Bruce Mellado, Karabo Mosala, Njokweni Mbuyiswa, Baballo-Victor Ndhlovu, Chinedu Jude Nnaji, Kgothatso Tshepo Ntumbe, Phuti Rapheeha, Nidhi Tripathi, Vuyolwethu Kakancu, Sijing Zhang,

Speaker: **Thapelo Gerry Leboho**,

Annual SAIP Conference • 6–10 July 2026 • University of the Western Cape

Motivation · Why this search

The anomalies came first

- Multi-lepton anomalies appeared in **LHC Run 1** and were strengthened in **Run 2**.
- Excesses in Higgs p_T^h, di-Higgs, and $t\bar{t}h$-like production.

Predicted, then found

- A $\sim$ 150 GeV scalar was **predicted before** the di-photon excess,not post-hoc.
- Combined significance grew: $3.9\sigma \to 4.7\sigma \to 5.4\sigma$.

A coherent 152 GeV excess

- Seen together in $\gamma\gamma$ and WW, *but not* ZZ.
- Strongest in single-τ, E_T^{miss}, four-jet, $\geq 1\ell + \geq 1$ b-jet ($\approx 3\sigma$ each).
- Corroborated by triboson rates (WWZ, WZZ, WWW).

Why our channel

- Explained by the $Y = 0$ real Higgs triplet (ΔSM): Δ^0 and $\Delta^\pm$ with fixed couplings.
- $\Delta^0 \to \gamma\gamma$, $\Delta^\pm \to \tau\nu \Rightarrow \gamma\gamma + 0\ell\, 1\tau$: a **statistically independent** test.
- The 2HDM+S Model also gives a stong motivation for the study of this channel

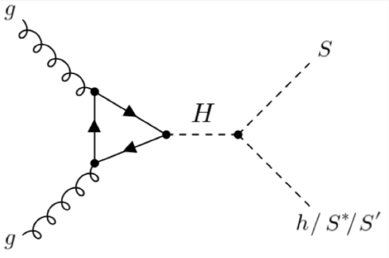
Refs: 1901.05300 • 2503.16245 (5.4σ) • 2411.18618 (ΔSM) • ATLAS 2405.20040 • triboson 2605.01488.

Motivation · The simplified model

A heavy scalar H ($\approx$270) decays to a lighter scalar S ($\approx$150 GeV):

$$gg \to H \to S\,S', \quad S\,h, \quad hh.$$

- Fixing the mass from the anomalies gives $m_S = 150 \pm 5$ GeV.
- Predicts final states with $\ell^+\ell^- + E_T^{\text{miss}}$, b-jets and photons.
- Later UV-completed by the $Y = 0$ real Higgs triplet (ΔSM).



$gg \to H \to S\,S'/S\,h/hh$

Final states predicted by the 2017 simplified model.

Refs: von Buddenbrock *et al.* 1901.05300 • $m_H = 272^{+12}_{-12}$ GeV 1506.00612 • growing excess 2503.16245.

The $\gamma\gamma + 0\ell\, 1\tau_{\text{had}}$ search(Analysis Strategy)

1. Final state

- Two tight photons + exactly one hadronic τ, no light leptons.
- Sensitive to scalar production with a τ in association.
- Run 3 data luminosities: 29.3 fb^{-1} (2022), 27.2 fb^{-1} (2023)

2. Backgrounds

- Continuum $\gamma\gamma$+jets (dominant), plus $V\gamma\gamma$, $t\bar{t}\gamma\gamma$ and single-Higgs.
- Jet$\rightarrow\tau$ fakes estimated in a data-driven way.

3. Background modelling

- $\gamma\gamma$+jets normalised to data via a control-region scale factor.
- Fake-τ estimated with the fake-factor method.

4. Signal & test

- Double-sided Crystal Ball parameterisation of the signal line-shape.
- Spurious-signal test to bound the background-model bias.

Signal region $130 < m_{\gamma\gamma} < 200$ **GeV is blinded** (all studies use sideband control regions)

The $\gamma\gamma + 0\ell\,1\tau$ cutflow, step by step

Every selection removes a background while retaining the $\gamma\gamma + 0\ell 1\tau$ topology.

Result: a clean $\gamma\gamma + 0\ell 1\tau$ sample — the final-state signature of the search.

1	**All events** — *every recorded collision*
2	**Trigger requirement** — *di-photon trigger fired*
3	**Two Tight_FixedCutLoose photons** — *tight photon ID*
4	$\|\eta\| < 2.37$, **crack veto** — *EM-cal crack removed*
5	$p_T(\gamma_1) \geq 35,\ p_T(\gamma_2) \geq 25$ GeV — *photon p_T*
6	$p_T/m_{\gamma\gamma} > 0.35\,(0.25)$ — *relative-p_T cut*
7	$m_{\gamma\gamma} > 105$ GeV — *diphoton mass*
8	**Control region** — *sideband either side of blinded window*
9	**Electron veto** — *reject baseline electron*
10	**Muon veto** — *reject baseline muon*
11	**pass_0l1tau** — *zero leptons, one hadronic τ*
12	**tau_passesOR** — *τ survives overlap removal*
13	$E_T^{miss} > 35$ GeV — *missing transverse energy*

Cutflow to the control region: 2022 (pre scale-factor)

Selection	**Data**	$\gamma\gamma$+jets	$t\bar{t}\gamma\gamma$	$V\gamma\gamma$	Single-H	Signal
All events (no cuts)	1235725	127288.8	53.36	1739.16	216.30	12.35
Trigger requirement	1235725	127288.8	53.36	1739.16	216.30	12.35
Two Tight_FixedCutLoose photons	266489	87211.7	33.58	969.39	161.02	9.18
$\lvert\eta\rvert < 2.37$, crack veto	265395	86065.9	33.13	955.61	158.88	9.04
$p_T(\gamma_1) \geq 35$, $p_T(\gamma_2) \geq 25$ GeV	262847	85884.0	33.11	952.19	158.81	9.04
$p_T/m_{\gamma\gamma} > 0.35\,(0.25)$	231225	69062.2	27.82	810.35	141.80	8.13
$m_{\gamma\gamma} > 105$ GeV	47688	37987.0	18.46	282.46	141.69	8.09
Control region: 105–120 or 200–300	31960	25164.7	9.96	150.63	138.47	0.02
Electron veto	31692	25137.9	6.54	104.53	133.15	0.01
Muon veto	31583	25114.2	2.83	51.77	127.07	0.01
pass_0l1tau	29507	23644.4	2.62	46.28	121.12	0.01
tau_passesOR (0l1tau)	29507	23644.4	2.62	46.28	121.12	0.01
$E_T^{\text{miss}} > 35$ GeV	6115	5008.75	1.78	25.78	29.75	0.01

Cutflow to the control region: 2023 (pre scale-factor)

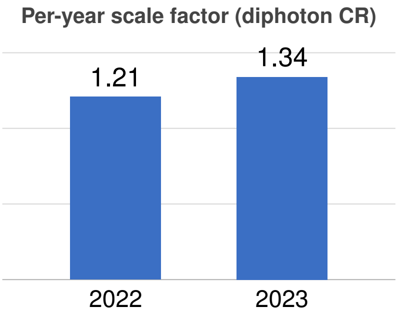
Selection	**Data**	$\gamma\gamma$+jets	$t\bar{t}\gamma\gamma$	$V\gamma\gamma$	Single-H	Signal
All events (no cuts)	1302690	118475.9	46.59	1516.21	203.48	10.50
Trigger requirement	1302690	118475.9	46.59	1516.21	203.48	10.50
Two Tight_FixedCutLoose photons	269892	79485.3	28.53	815.61	148.65	7.61
$\|\eta\| < 2.37$, crack veto	268655	78415.7	28.14	804.08	146.62	7.51
$p_T(\gamma_1) \geq 35$, $p_T(\gamma_2) \geq 25$ GeV	265832	78257.1	28.12	800.96	146.55	7.51
$p_T / m_{\gamma\gamma} > 0.35\,(0.25)$	232914	63355.2	23.65	682.52	131.52	6.77
$m_{\gamma\gamma} > 105$ GeV	48468	35411.9	15.82	241.45	131.42	6.73
Control region: 105–120 or 200–300	32130	23255.9	8.51	129.14	128.11	0.01
Electron veto	31917	23231.0	5.66	90.33	123.64	0.01
Muon veto	31816	23209.3	2.53	45.75	118.47	0.00
pass_0l1tau	29646	21693.7	2.33	41.09	112.37	0.00
tau_passesOR (0l1tau)	29646	21693.7	2.33	41.09	112.37	0.00
$E_T^{miss} > 35$ GeV	6673	4950.15	1.61	22.77	29.47	0.00

Monte-Carlo $\gamma\gamma$+jets scale factor estimation

METHOD

$$\text{SF} = \frac{N_{\text{data}} - (V\gamma\gamma + \text{single-H} + t\bar{t}\gamma\gamma)}{N_{\gamma\gamma+\text{jets}}}$$

Measured in the $m_{\gamma\gamma}$ sidebands; $\gamma\gamma$+jets is run unscaled, so the ratio is a clean normalisation.



Stable, physical normalisation

- **SF $\approx$ 1.2-1.3**, consistent across years.
- The MC continuum needs only a modest data-driven correction.
- Per-campaign matching: 2022 to mc23a, 2023 to mc23d, each normalised to its own luminosity.
- A fake-factor (FF) correction will be layered on top discussed later.

High-mass region $200 < m_{\gamma\gamma} < 300$ GeV: 2022 (post scale-factor)

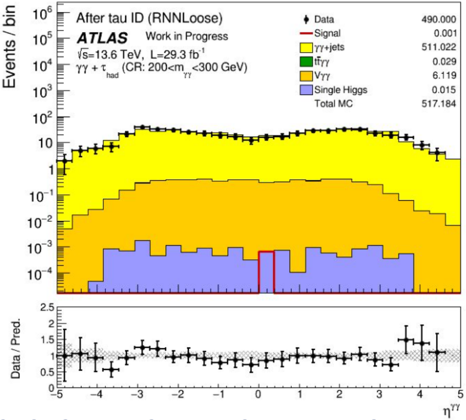
Selection	Data	$\gamma\gamma$+jets	$t\bar{t}\gamma\gamma$	$V\gamma\gamma$	Single-H	Signal
All events (no cuts)	1235725	154019.47	53.36	1739.16	216.30	12.35
Trigger requirement	1235725	154019.47	53.36	1739.16	216.30	12.35
Two Tight_FixedCutLoose photons	266489	105526.11	33.58	969.39	161.02	9.18
$\lvert\eta\rvert < 2.37$, no crack veto	265395	104139.71	33.13	955.61	158.88	9.04
$p_T(\gamma_1) \geq 35$, $p_T(\gamma_2) \geq 25$ GeV	262847	103919.63	33.11	952.19	158.81	9.04
$p_T/m_{\gamma\gamma} > 0.35\,(0.25)$	231225	83565.30	27.82	810.35	141.80	8.13
$m_{\gamma\gamma} > 105$ GeV	47688	45964.25	18.46	282.46	141.69	8.09
Control region: $200 < m_{\gamma\gamma} < 300$	2032	1971.82	0.10	37.61	0.04	0.00
Electron veto	1957	1965.18	0.07	24.46	0.03	0.00
Muon veto	1941	1960.33	0.04	10.19	0.03	0.00
pass_0l1tau	1893	1914.92	0.04	9.37	0.03	0.00
tau_passesOR (0l1tau)	1893	1914.92	0.04	9.37	0.03	0.00
$E_T^{\text{miss}} > 35$ **GeV**	490	511.02	0.03	6.12	0.01	0.00

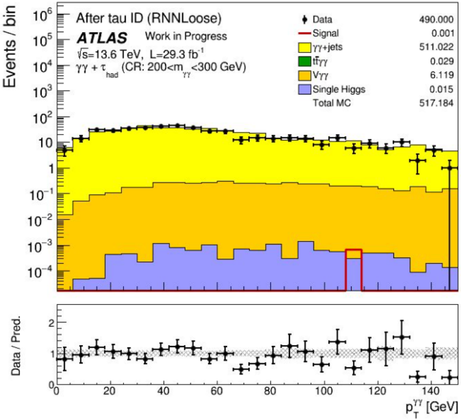
High-mass region $200 < m_{\gamma\gamma} < 300$ GeV: 2023 (post scale-factor

Selection	Data	$\gamma\gamma$+jets	$t\bar{t}\gamma\gamma$	$V\gamma\gamma$	Single-H	Signal
All events (no cuts)	1302690	158757.73	46.59	1516.21	203.48	10.50
Trigger requirement	1302690	158757.73	46.59	1516.21	203.48	10.50
Two Tight_FixedCutLoose photons	269892	106510.25	28.53	815.61	148.65	7.61
$\|\eta\| < 2.37$, no crack veto	268655	105077.03	28.14	804.08	146.62	7.51
$p_T(\gamma_1) \geq 35$, $p_T(\gamma_2) \geq 25$ GeV	265832	104864.48	28.12	800.96	146.55	7.51
$p_T/m_{\gamma\gamma} > 0.35\,(0.25)$	232914	84895.98	23.65	682.52	131.52	6.77
$m_{\gamma\gamma} > 105$ GeV	48468	47451.91	15.82	241.45	131.42	6.73
Control region: $200 < m_{\gamma\gamma} < 300$	1981	2101.72	0.08	32.59	0.04	0.00
Electron veto	1935	2094.04	0.06	21.55	0.03	0.00
Muon veto	1911	2086.59	0.03	9.29	0.03	0.00
pass_0l1tau	1859	2033.72	0.03	8.57	0.03	0.00
tau_passesOR (0l1tau)	1859	2033.72	0.03	8.57	0.03	0.00
$E_T^{\text{miss}} > 35$ **GeV**	533	566.48	0.02	5.52	0.02	0.00

Data/MC agreement in the high-mass control region ($200 < m_{\gamma\gamma} < 300$ GeV)

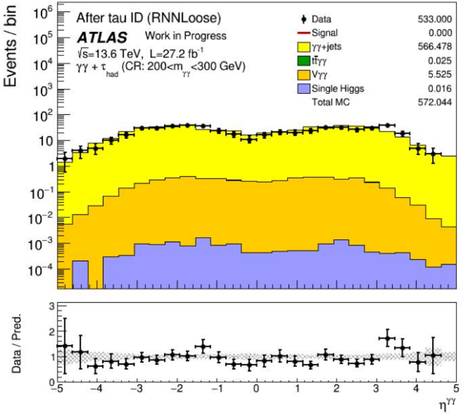
Diphoton ($\gamma\gamma$) kinematic distribution – 2022 data

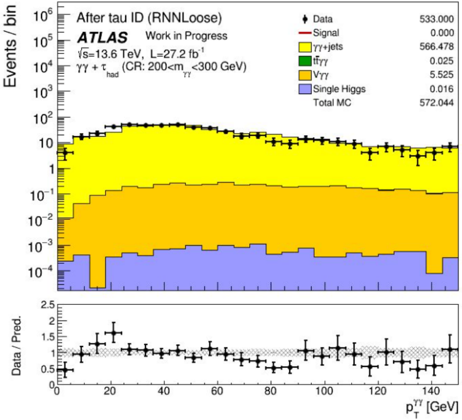




Data/MC agreement in the high-mass control region ($200 < m_{\gamma\gamma} < 300$ GeV)

Diphoton ($\gamma\gamma$) kinematic distribution – 2023 data

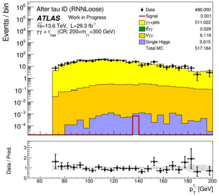


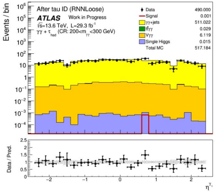


Data/MC agreement in the high-mass control region ($200 < m_{\gamma\gamma} < 300$ GeV)

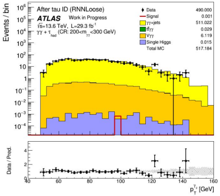
Leading & sub-leading photon kinematics – 2022 data

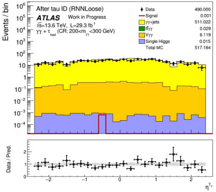
Leading γ_1





Sub-leading γ_2

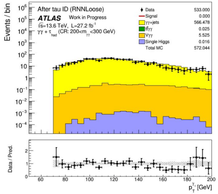


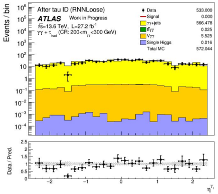


Data/MC agreement in the high-mass control region ($200 < m_{\gamma\gamma} < 300$ GeV)

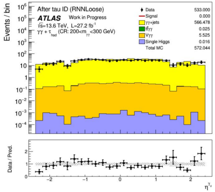
Leading & sub-leading photon kinematics – 2023 data

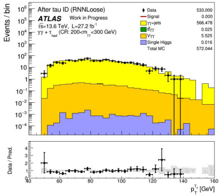
Leading γ_1





Sub-leading γ_2

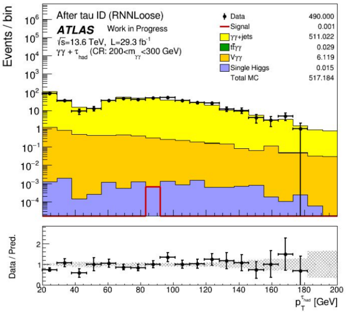




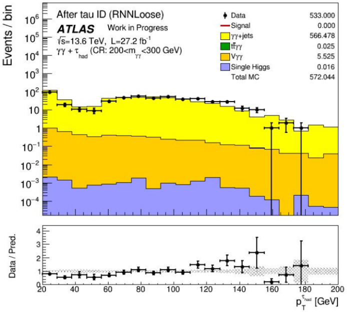
Data/MC agreement in the high-mass control region ($200 < m_{\gamma\gamma} < 300$ GeV)

With the scale factor applied, the data-driven background reproduces the control-region kinematics after τ identification (RNNLoose), shown across the previous slides. Here: the τ transverse momentum for both years.

τ p_{T} — 2022



τ p_{T} — 2023



How the “fake factor” estimates the $\gamma\gamma$+jets scale factor

The method

- **FF** $= N_{\text{ID}}/N_{\text{anti-ID}}$, a data-driven estimate of the jet$\to\tau$ fake yield.
- Binned in τ p_T, prong multiplicity and pileup.
- The SF currently absorbs **two things at once**: the true $\gamma\gamma$+jets normalisation *and* the jet$\to\tau$ fakes the MC mis-models.
- The FF estimates those fakes directly, so the SF no longer has to.

Effect on the scale factor

- **Current:** $\text{SF} = \dfrac{N_{\text{data}} - N_{V\gamma\gamma} - N_H - N_{t\bar{t}\gamma\gamma}}{N_{\gamma\gamma+\text{j}}}$
- **With FF:**
$$\text{SF}' = \frac{N_{\text{data}} - N_{V\gamma\gamma} - N_H - N_{t\bar{t}\gamma\gamma} - N_{\text{fake-}\tau}}{N_{\gamma\gamma+\text{j}}}$$

Three ways it improves the SF

1. **Decouples the measurement.** With fakes estimated separately, the SF measures only the genuine $\gamma\gamma$+jets normalisation - not a blend of continuum and mis-modelled τ fakes.
2. **Stabilises it across years.** The jet$\to\tau$ fake rate varies with pileup and jet composition; a pileup-binned FF absorbs that, so the residual SF moves less between 2022/2023.
3. **Improves closure.** Background $=$ SF-scaled continuum $+$ FF-estimated fakes, a more complete model flattens data/prediction toward 1, tightening the SF uncertainty and the spurious-signal bound.

Spurious-signal test on our background model

1. Build the significance template

- Data-driven background: SF-scaled $\gamma\gamma$+jets + FF-estimated jet$\to\tau$ fakes.
- Used as a signal-free Asimov $m_{\gamma\gamma}$ distribution in the sidebands.

2. Fit signal + background

- Fit the background-only template with the candidate form + a signal DSCB of free normalisation.
- The fitted signal yield *is* the spurious signal.

3. Scan the test mass

- Repeat across the mass range (around the 152 GeV region).
- Map N_{spurious} vs the hypothesised resonance mass.

4. Apply the acceptance rule

- Require $|N_{\text{spurious}}| < 10$–$20\%$ of the fitted-signal statistical uncertainty.
- If a function fails: assign a systematic or pick a better form.

Outcome: a validated background shape and a quantified model-bias term - the prerequisite for a credible result once unblinded.

DSCB parameterisation of our signal MC

1. Fit the signal MC

- Fit the reconstructed $m_{\gamma\gamma}$ with a **double-sided Crystal Ball** (DSCB).
- Gaussian core captures the detector resolution.
- Power-law tails capture energy loss / mis-measurement.

2. Extract the parameters

- Core: $\mu,\ \sigma$; tails: $\alpha_{\text{low}}, n_{\text{low}}, \alpha_{\text{high}}, n_{\text{high}}$.
- Cross-check fastsim vs. fullsim gives a consistent shape.

3. Parameterise vs. mass

- Map each parameter as a smooth function of the resonance mass.
- Gives an interpolated signal template at *any* test mass.
- Feeds the spurious-signal test and the final fit.

Status: DSCB parameterisation is the *next* signal-modelling step, not yet implemented; shown here as planned work.

Background model in place; signal-side methods to follow

Done

Per-year cutflows -2022 & 2023 validated on v2 ntuples; 130–200 GeV window blinded.

$\gamma\gamma$**+jets SF** -1.21 (2022), 1.34 (2023): stable, physical normalisation.

Data/MC validation - flat data/prediction across $p_T^{\gamma\gamma}$, η and photon kinematics.

Fake-factor estimator -coded and validated; awaiting to be implemented.

Work to be implemented

DSCB signal parameterisation

Fit the signal MC (DSID 562134) $m_{\gamma\gamma}$ line-shape with a double-sided Crystal Ball; parameterise $\mu, \sigma, \alpha/n$ versus resonance mass.

Spurious-signal test

Fit the signal-free background template and scan the test mass; bound $|N_{\text{spurious}}| <$ 10–20% of the stat. uncertainty before un-blinding.

Thank you

Questions welcome