DIPHOTON SCALAR RESONANCE SEARCH IN THE $\gamma\gamma + 1\mu$ CHANNEL

EVENT SELECTION, SCALE FACTOR STUDIES , BACKGROUND STUDY AND CHARACTERISATION *WITH* $\mathcal{L} = 164\ FB^{-1}$ *OF ATLAS DATA*

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

08 JULY 2026

OVERVIEW

- Introduction
- Physics Motivation
- 2HDM+S and Triplet Model33
- $\gamma\gamma + 1\mu$ channel

1st Pillar

- Analysis Strategy & Dataset Samples
- Event Selection Overview
- Cutflow Outcomes (CR and SR)
- Scale Factor Studies

2nd Pillar

- Kinematic Distributions (CR and SR)
- Data/MC agreement
- Summary and Future Work

3rd Pillar

Credit:
http://people.physics.tamu.edu/kamon/research/refColliders/LHC/LHC_is_back.html

ATLAS EXPERIMENT

INTRODUCTION

The Standard Model (SM)

- Our best description of fundamental particles and three of the four forces: electromagnetic, weak, and strong (gravity is not included)
- Built on quantum field theory: matter particles (quarks, leptons) interact via force-carrying bosons (γ, W±, Z, gluons)
- The Brout-Englert-Higgs mechanism (1964) was proposed to explain electroweak symmetry breaking and the origin of particle mass, predicting a new scalar boson, the Higgs boson
- Extremely well-tested: the SM has withstood decades of precision measurements at LEP, Tevatron, and the LHC

Why Beyond the Standard Model (BSM)?

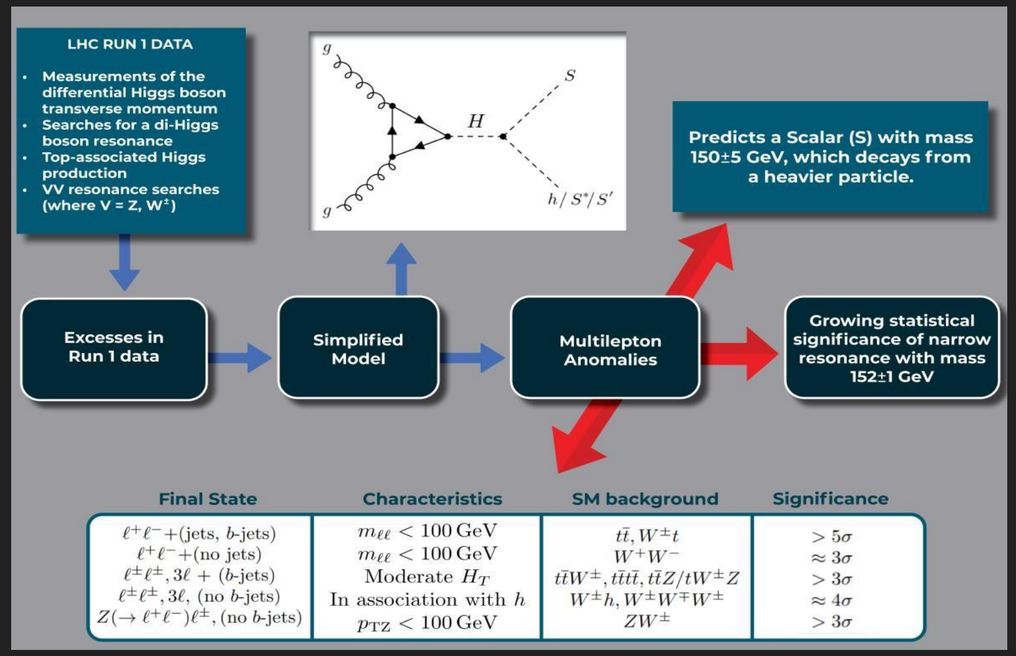
- The SM, despite its success, is known to be incomplete: it does not account for dark matter, neutrino masses, matter–antimatter asymmetry, or gravity
- Since the 2012 discovery, precision studies of the 125 GeV Higgs boson's couplings and production modes have continued, alongside searches for additional scalar states
- Large excesses across Run 1/Run 2 measurements (differential Higgs p_T, di-Higgs searches, top-associated Higgs production, VV resonances, multi-lepton final states) hint at physics beyond a single SM-like Higgs
- These excesses motivate extended Higgs-sector models 2HDM+S and Higgs triplet models collectively referred to here as HBSM (Higgs Beyond the Standard Model) scenario.

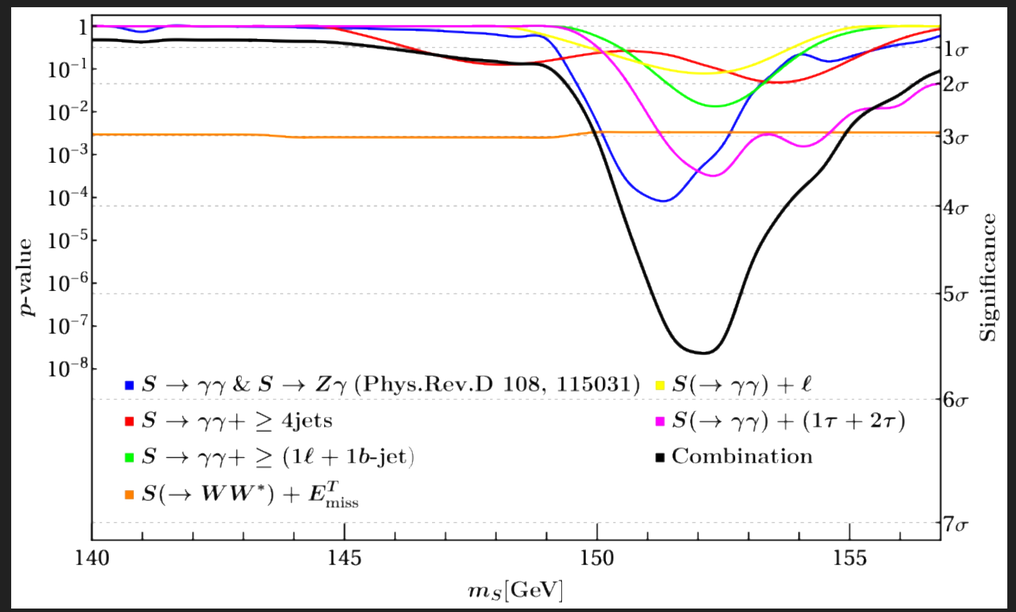
4 July 2012: ATLAS and CMS independently announced discovery of a new boson with mass ≈125 GeV, consistent with the long-sought SM Higgs boson completing the SM particle content.

ATLAS EXPERIMENT

PHYSICS MOTIVATION (Multilepton Anomalies)

- Run 1 ATLAS data showed a cluster of large excesses across several distinct measurements: differential Higgs pT, di-Higgs resonance searches, top-associated Higgs production, and VV resonance searches (V = Z, W±).
- These excesses motivated a simplified model: a heavy particle produced via gluon fusion and decaying as $H \to Sh$.
- Independently, multilepton final states across Run 2 and early Run 3 have shown a pattern of anomalies significances ranging from ~3σ to >5σ across five distinct final states
- That model predicts a scalar with mass 150 ± 5 GeV, produced in association with a heavier state.
- This Analysis uses Run 3 ATLAS data alongside with phenomenological input to probe the Run 2 excesses and cross-check the predicted 152 GeV peak.
- This is the mass region this analysis targets searching for the same scalar in the multilepton final states, where the associated lepton gives an independent production handle and a different background composition than the inclusive diphoton channel.

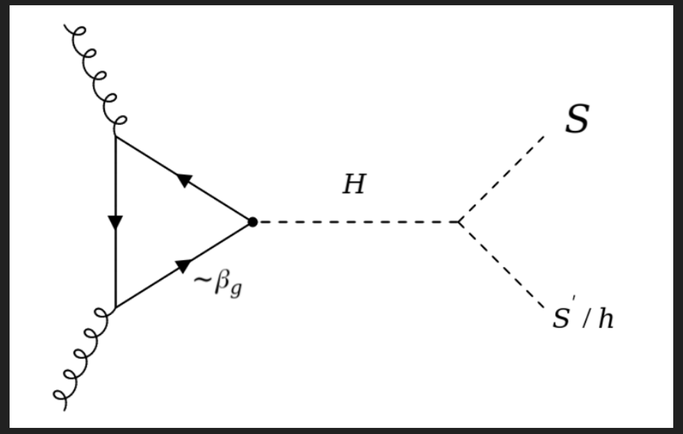




Reference: J.Phys.G 45 (2018) 11, 115003

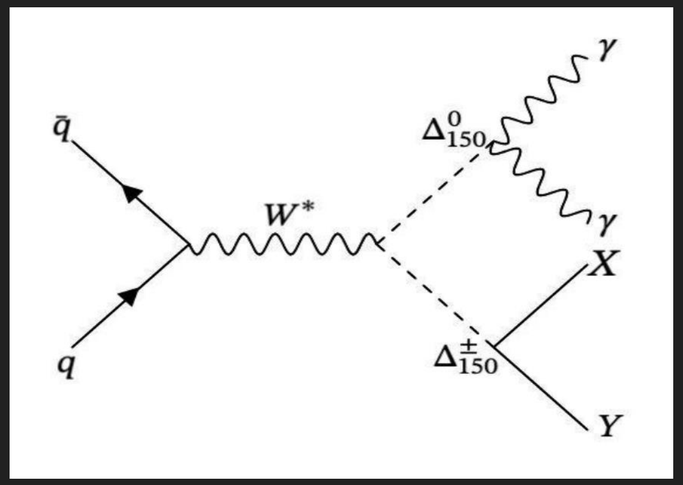
Models: 2HDM+S and Triplet

2HDM+S Model



- Heavy CP-even scalar H produced via ggF (top-quark loop, scaling factor $\tilde{\beta}_g$ relative to SM)
- H decays to a pair of lighter scalars: $H \to Sh$ or $H \to S'h$, with $m_H = 250$ GeV, $m_S \approx 152\ GeV$
- Introduced to explain multi-lepton and diphoton excesses at the LHC (von Buddenbrock et al.)
- Key coupling: $\beta_g^2 \approx 1.38 \pm 0.22$, giving $\tan^2\beta \approx 0.72 \pm 0.12$

Triplet Model



- Charged/neutral triplet scalars (Y = 0) produced via Drell-Yan: $q\bar{q} \to W^* \to \Delta^0_{150}\,\Delta^{\pm}_{150}$
- $\Delta^0_{150} \to \gamma\gamma$, consistent with the diphoton $\approx 152\ GeV$ excess
- $\Delta^{\pm}_{150}$ decays dominantly to W±Z

Reference: *S. von Buddenbrock et al., "Constraints on a 2HDM with a singlet scalar and implications in the search for heavy bosons at the LHC," arXiv:1809.06344 [hep-ph]*

ATLAS EXPERIMENT

Why $\gamma\gamma + 1\mu$ Channel

Target Channels

$\gamma\gamma + 0\ell + 1\tau$

$\gamma\gamma + 0\ell + 2\tau$

$\gamma\gamma + 1\ell + 1\tau$

$\gamma\gamma + 2\ell + 0\tau$

$\gamma\gamma + 1\mu + 0\tau_{had}$

$\gamma\gamma + 1\ell + 1b$

2HDM+S decay chain

gg → H → (S → γγ)(S'/h → X)

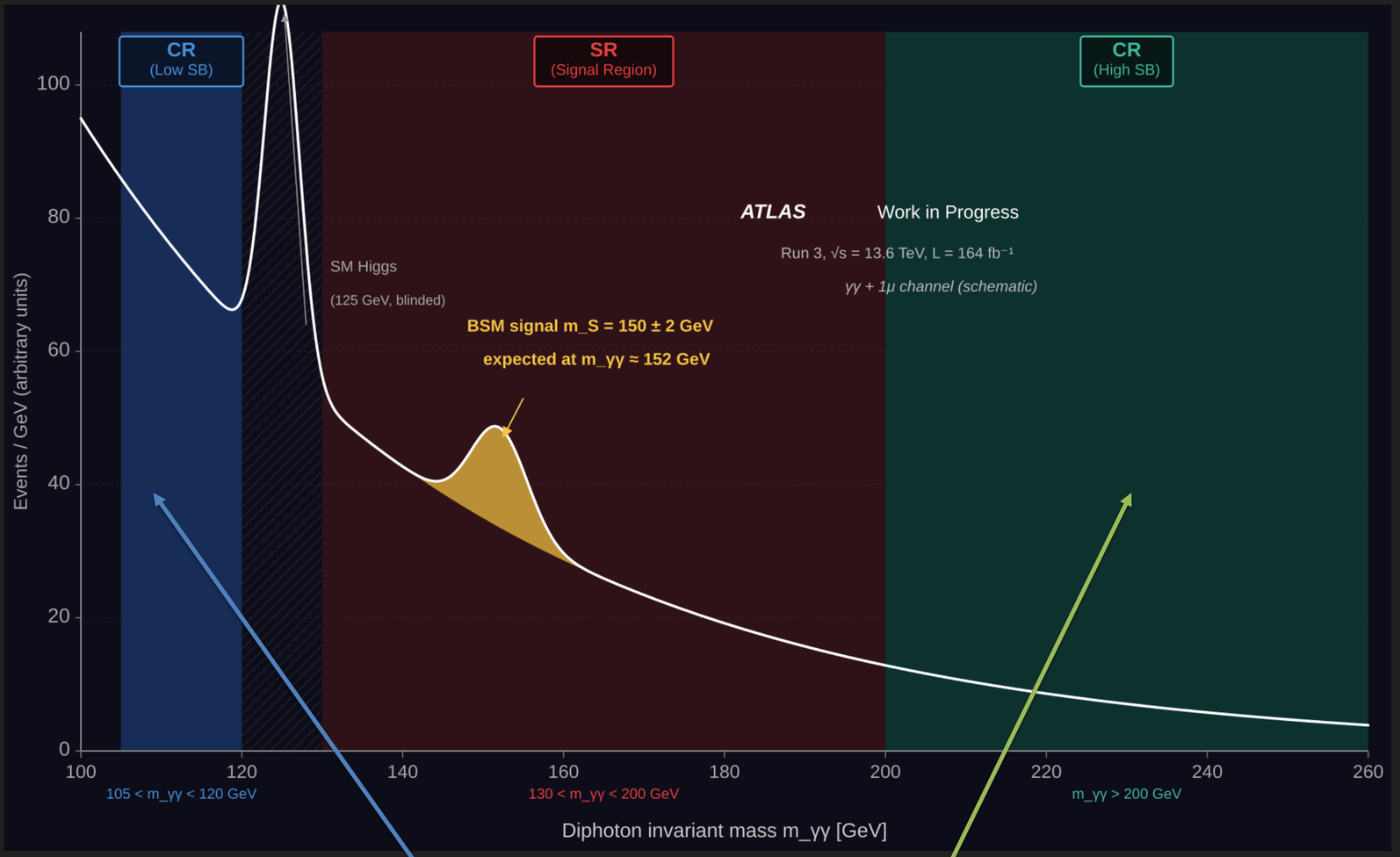
m_H = 250 GeV, m_s ≈ 152 GeV benchmark; the diphoton resonance ($S \to \gamma\gamma$) anchors event reconstruction.

- The companion scalar S'/h decays to $b\bar{b}$, $\tau^+\tau^-$or WW*, populating the different $\ell/\tau/b$ categories in the table at left
- $\boldsymbol{\gamma\gamma + 1\mu + 0\tau_{had}}$ isolates events where S'/h produces exactly one reconstructed muon, either prompt or from heavy-flavour decay, with no hadronic τ, a clean, low-background slice of the decay chain
- Muons give a clean tag: low fake rates and high reconstruction purity, vs. electrons/jets faking leptons or τ_{had} **misidentification**.
- $1\mu + 0\tau_{had}$ requirement strongly suppresses $\gamma\gamma jets$ and Drell-Yan/diphoton continuum backgrounds
- Mass scan covers the low-mass S'/h region: H 250–400 GeV, S 150–275 GeV, S'/h 95–125 GeV

Reference: *S. von Buddenbrock et al., "Constraints on a 2HDM with a singlet scalar and implications in the search for heavy bosons at the LHC," arXiv:1809.06344 [hep-ph]; S. Ashanujjaman, S. Banik, G. Coloretti, A. Crivellin, S. P. Maharathy, B. Mellado, "Anatomy of the real Higgs triplet model," JHEP 04 (2025) 003, arXiv:2411.18618 [hep-ph]; S. Ashanujjaman, A. Crivellin, S. P. Maharathy, B. Mellado, "Searching for a Charged Higgs Boson in Top-Quark Decays via the WZ Mode," arXiv:2509.07094 [hep-ph].*

ATLAS EXPERIMENT

ANALYSIS STRATEGY: MASS REGIONS



Sideband Regions

CR : Control Region (Low Sideband)

105 < $m_{\gamma\gamma}$ < 120 GeV

Data-driven scale-factor derivation for the irreducible $V\gamma\gamma$/ $t\bar{t}\gamma\gamma$backgrounds.

SR : Signal Region (blinded)

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

Background MC characterisation; encloses the expected signal at $m_{\gamma\gamma}$ ≈ 152 GeV. Data blinded until unblinding approval.

CR : Validation Region (High Sideband)

$m_{\gamma\gamma}$ > 200 GeV

Kinematic Data/MC validation of the CR-derived scale factor; independent cross-check, not used in the SF fit.

Strategy: derive SFs in sideband region, keep SR blinded — 120–130 GeV excluded to avoid the SM Higgs.

ATLAS EXPERIMENT

Dataset, Monte Carlo Samples, and Event selection overview

Dataset and Monte Carlo Samples

Campaign	Data Taking	$\mathcal{L}$ [fb^{-1}]
mc23a	2022	29.3
mc23d	2023	26.7
mc23e	2024	107.9
Combined	**Run 3**	**163.9**

Signal Samples

Signal	Status	Relevancy
$\gamma\gamma\tau\tau$	**Request Completed**	Benchmark
$\gamma\gamma + 1\ell$	**Request On-going**	High statistics
$\gamma\gamma + 2\ell$	**Request On-going**	High statistics

Background Samples

Process	Samples	Why Relevant to $\gamma\gamma + 1\mu$
$\gamma\gamma$+jets	FASTSIM + FULLSIM	Dominant background before muon selection. Fake muons entering the signal region.
$V\gamma\gamma$	FULLSIM	Prompt diphoton production with genuine leptons.
$t\bar{t}\gamma\gamma$	FULLSIM	Top pair production with prompt muons. Contains additional jets and b-jets.
Single Higgs	FULLSIM	Associated Higgs production with similar final states.

Trigger Chains

Year	Trigger Chains
2022	HLT_2g50_loose_L12EM20VH HLT_g35_medium_g25_medium_L12EM20VH HLT_2g22_tight_L12EM15VHI
2023	HLT_2g50_loose_L12eEM24L HLT_g35_medium_g25_medium_L12eEM24L HLT_g45_medium_g20_medium_L1eEM40L_2eEM18L HLT_2g22_tight_L12eEM18M
2024	HLT_g45_medium_g20_medium_L1eEM40L_2eEM18L HLT_g35_medium_g25_medium_L12eEM24L **(currently in use)**

Event Selection Overview

Photons	Requirements
Number of objects	2
Leading photon	$p_T > 35$ GeV
Sub-leading photon	$p_T > 25$ GeV
Pseudorapidity	$\lvert\eta\rvert < 2.37$ excluding $1.37 < \lvert\eta\rvert < 1.52$
Relative transverse momenta	$p_T/m_{\gamma\gamma} > 0.35$ $p_T/m_{\gamma\gamma} > 0.25$
Identification & Isolation	Tight FixedCutLoose

Muons	Requirements
Number of objects	1
Transverse momentum	$p_T > 10$ GeV
Pseudorapidity	$\lvert\eta\rvert < 2.5$
Identification & Isolation	Medium PflowLoose
Transverse Impact parameter	$\left\lvert \frac{d_0}{\sigma_{d_0}} \right\rvert < 3$
Longitudinal Impact parameter	$\lvert z_0 \sin\theta \rvert < 0.5$ mm

Vetoes
Electrons (=0)
Taus (=0)
b-jets (=0)

ATLAS EXPERIMENT

Cutflow Results for Control Regions (2022-2024)

Table 8: Cutflow — Control Region — Low-mass Sideband, combined.

Selection Step	Signal	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$	Single Higgs	Total Bkg.	Data
1) Initial Events	64.84	297,698.58	9,549.34	291.02	1,294.53	308,833.46	8,261,057
2) PASS_Trigger	64.84	297,698.58	9,549.34	291.02	1,294.53	308,833.46	8,261,057
3) Pass diphoton trigger matching	64.84	297,698.58	9,549.34	291.02	1,294.53	308,833.46	8,261,057
4) Photon ID/Iso (Tight_FixedCutLoose)	47.03	205,224.18	5,095.39	177.17	943.06	211,439.81	1,687,402
5) Photon eta & crack veto	46.75	204,290.60	5,067.83	176.26	939.04	210,473.72	1,680,076
6) $p_T(\gamma_1)$>35 GeV & $p_T(\gamma_2)$>25 GeV	46.74	203,915.70	5,045.74	176.17	938.60	210,076.21	1,663,158
7) $p_T(\gamma_1)/m_{\gamma\gamma}$>0.35 & $p_T(\gamma_2)/m_{\gamma\gamma}$>0.25	42.07	149,261.66	4,295.59	147.46	841.69	154,546.40	1,459,845
8) $m_{\gamma\gamma}$>105 GeV	41.79	89,583.05	1,496.51	97.99	841.05	92,018.60	308,254
9) Low-mass SB (105<$m_{\gamma\gamma}$<120 GeV)	0.03	33,089.78	403.95	34.92	19.27	33,547.91	137,476
10) $N_{b\text{-jets}} = 0$	0.03	32,740.86	395.33	7.60	18.78	33,162.57	135,462
11) $\gamma\gamma$ + 1μ, veto taus & electrons (0e, 0τ, 1μ)	0.00	20.02	97.28	2.13	0.22	119.66	214

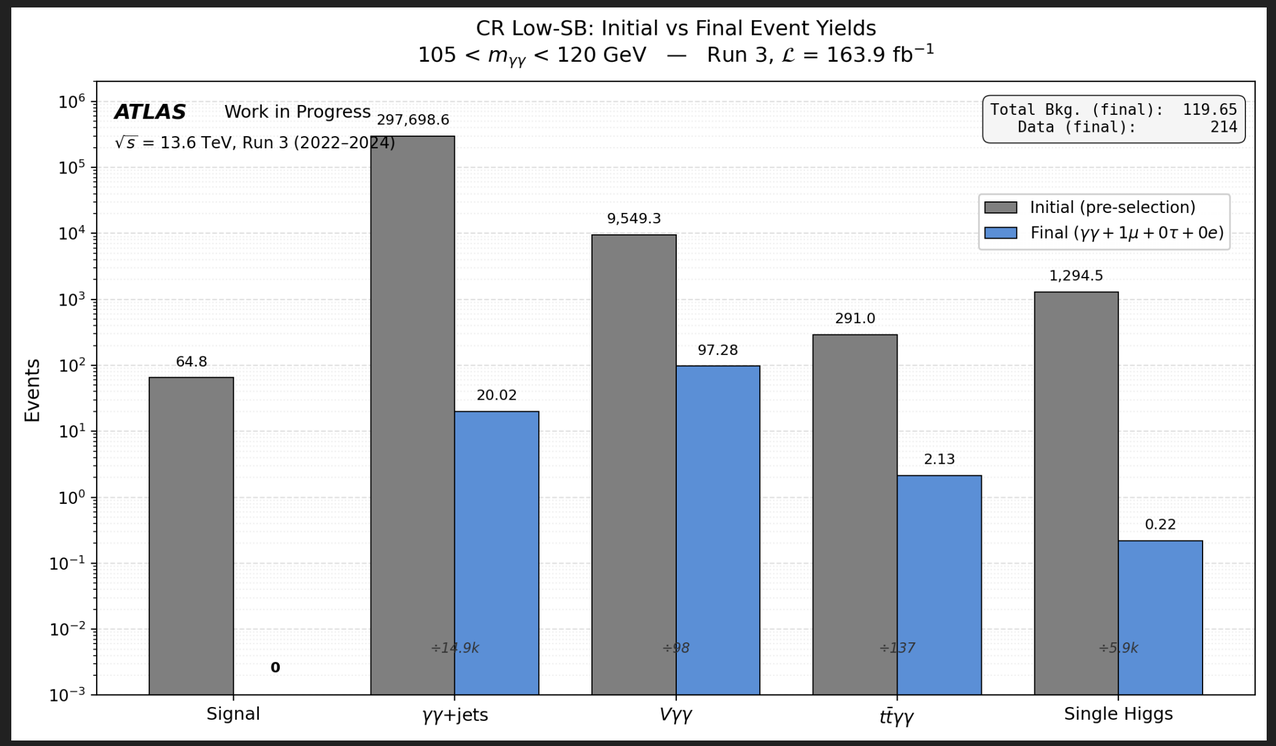
$105GeV < m_{\gamma\gamma} < 120GeV$

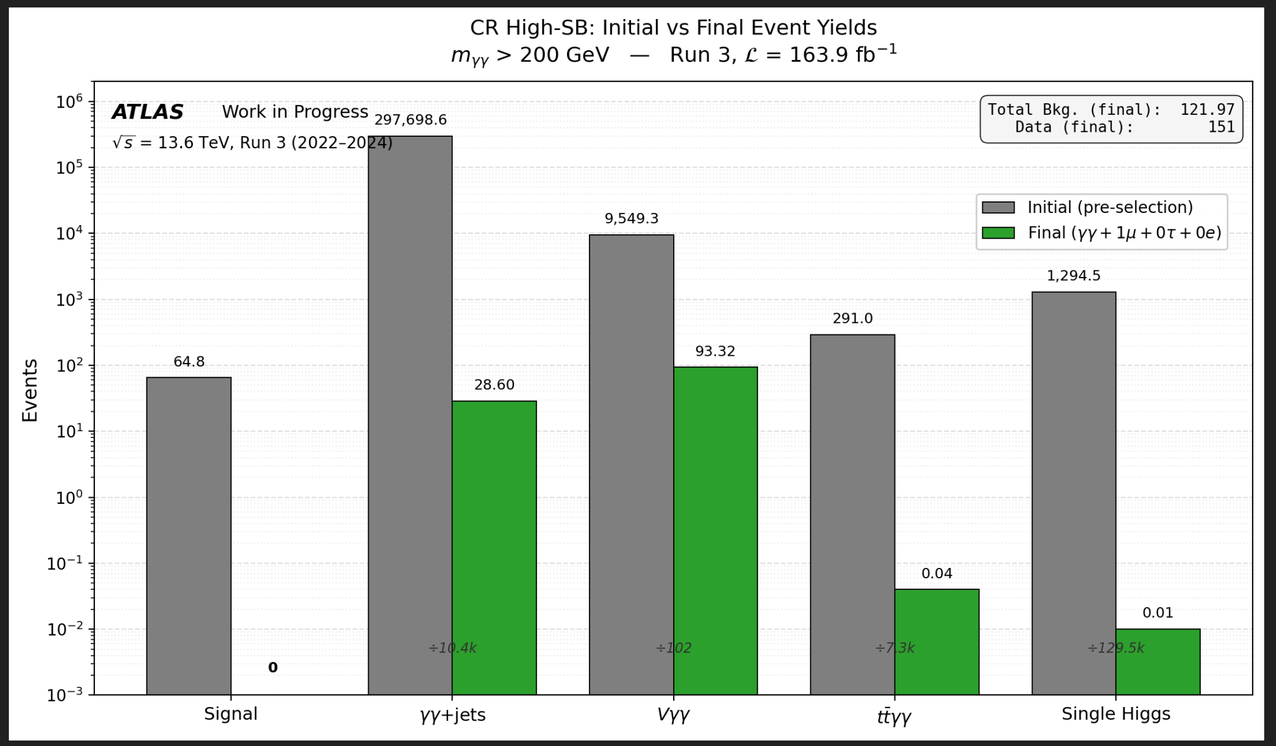
Table 12: Cutflow — Control Region — High-mass Sideband, combined.

Selection Step	Signal	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$	Single Higgs	Total Bkg.	Data
1) Initial Events	64.84	297,698.58	9,549.34	291.02	1,294.53	308,833.46	8,261,057
2) PASS_Trigger	64.84	297,698.58	9,549.34	291.02	1,294.53	308,833.46	8,261,057
3) Pass diphoton trigger matching	64.84	297,698.58	9,549.34	291.02	1,294.53	308,833.46	8,261,057
4) Photon ID/Iso (Tight_FixedCutLoose)	47.03	205,224.18	5,095.39	177.17	943.06	211,439.81	1,687,402
5) Photon eta & crack veto	46.75	204,290.60	5,067.83	176.26	939.04	210,473.72	1,680,076
6) $p_T(\gamma_1)$>35 GeV & $p_T(\gamma_2)$>25 GeV	46.74	203,915.70	5,045.74	176.17	938.60	210,076.21	1,663,158
7) $p_T(\gamma_1)/m_{\gamma\gamma}$>0.35 & $p_T(\gamma_2)/m_{\gamma\gamma}$>0.25	42.07	149,261.66	4,295.59	147.46	841.69	154,546.40	1,459,845
8) $m_{\gamma\gamma}$>105 GeV	41.79	89,583.05	1,496.51	97.99	841.05	92,018.60	308,254
9) High-mass SB ($m_{\gamma\gamma}$>200 GeV)	0.02	12,202.83	303.26	0.73	0.38	12,507.19	16,081
10) $N_{b\text{-jets}} = 0$	0.02	11,957.51	294.95	0.16	0.28	12,252.90	15,577
11) $\gamma\gamma$ + 1μ, veto taus & electrons (0e, 0τ, 1μ)	0.00	28.60	93.32	0.04	0.01	121.96	151

$m_{\gamma\gamma} > 200GeV$

ATLAS EXPERIMENT





CR: Low sideband mass

CR: High sideband mass

- **$\gamma\gamma$+jets is crushed by a factor of (15,000×) from ~298k initial down to 20 events, driven by the 1μ requirement killing jet-fake muons**
- **$V\gamma\gamma$ dominates the final composition (~97 events out of 120 total background) because its prompt muons survive selection efficiently.**
- **$V\gamma\gamma$ still dominates (~93 events) because it has a broad, slowly-falling $m_{\gamma\gamma}$ spectrum.**

ATLAS EXPERIMENT

Scale Factor studies to normalize the irreducible backgrounds

$$\mathrm{SF} = \frac{N_{\mathrm{Data}} - N_{\gamma\gamma+\mathrm{jets}} - N_{\mathrm{SingleHiggs}}}{N_{t\bar{t}\gamma\gamma} + N_{V\gamma\gamma}}$$

$$\sigma_N^2 = \sigma_{\mathrm{data}}^2 + \sigma_{\gamma\gamma+\mathrm{jets}}^2 + \sigma_{\mathrm{SingleH}}^2, \quad (3)$$

$$\sigma_D^2 = \sigma_{t\bar{t}\gamma\gamma}^2 + \sigma_{V\gamma\gamma}^2. \quad (4)$$

The SF uncertainty is then obtained by combining the relative uncertainties on the numerator and denominator,

$$\sigma_{\mathrm{SF}} = \mathrm{SF}\sqrt{\left(\frac{\sigma_N}{N}\right)^2 + \left(\frac{\sigma_D}{D}\right)^2}. \quad (5)$$

Derived from the full γγ+1μ-selected sideband yields per the internal collaboration 2024 Note.

Table 1: Per-year SF in the combined sideband after $\gamma\gamma + 1\mu$ selection.

Quantity	**2022**	**2023**	**2024**	**Combined**
Luminosity $[\mathrm{fb}^{-1}]$	29.3	26.7	107.9	163.9
Data	64	51	250	365
$V\gamma\gamma$	36.877 ± 0.403	31.293 ± 0.286	122.423 ± 0.824	190.593 ± 0.961
$t\bar{t}\gamma\gamma$	0.409 ± 0.009	0.349 ± 0.008	1.413 ± 0.015	2.172 ± 0.020
$\gamma\gamma$+jets	17.056 ± 1.472	14.486 ± 1.032	17.076 ± 3.829	48.618 ± 4.230
Single Higgs	0.038 ± 0.003	0.033 ± 0.002	0.161 ± 0.008	0.231 ± 0.009
Scale Factor	1.2580 ± 0.2186	1.1529 ± 0.2283	1.8796 ± 0.1320	1.6401 ± 0.1018
Rel. uncertainity	17.4%	19.8%	7.0%	6.2%

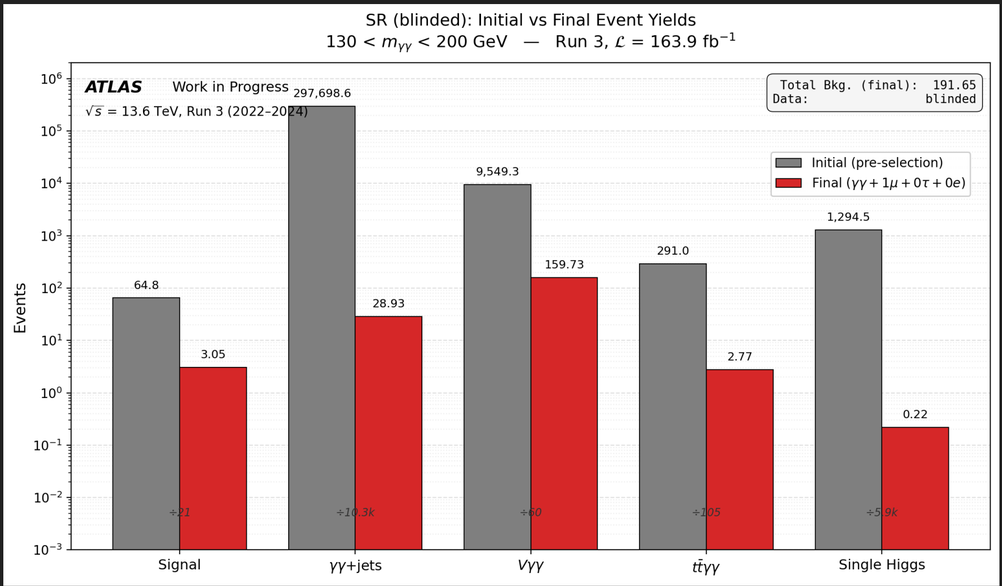
Credit: Arnav Chauhan

ATLAS EXPERIMENT

Cutflow Results for Signal Region(2022-2024)

Table 20: Cutflow — Signal Region (SR) — Blinded, combined.

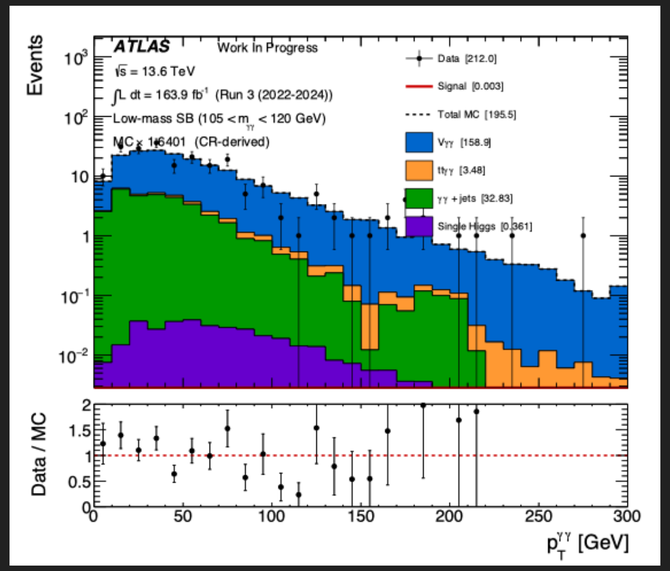
Selection Step	Signal	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$	Single Higgs	Total Bkg.	Data
1) Initial Events	64.84	297,698.58	9,549.34	291.02	1,294.53	308,833.46	**Blinded**
2) PASS_Trigger	64.84	297,698.58	9,549.34	291.02	1,294.53	308,833.46	**Blinded**
3) Pass diphoton trigger matching	64.84	297,698.58	9,549.34	291.02	1,294.53	308,833.46	**Blinded**
4) Photon ID/Iso (Tight_FixedCutLoose)	47.03	205,224.18	5,095.39	177.17	943.06	211,439.81	**Blinded**
5) Photon eta & crack veto	46.75	204,290.60	5,067.83	176.26	939.04	210,473.72	**Blinded**
6) $p_T(\gamma_1) > 35$ GeV & $p_T(\gamma_2) > 25$ GeV	46.74	203,915.70	5,045.74	176.17	938.60	210,076.21	**Blinded**
7) $p_T(\gamma_1)/m_{\gamma\gamma} > 0.35$ & $p_T(\gamma_2)/m_{\gamma\gamma} > 0.25$	42.07	149,261.66	4,295.59	147.46	841.69	154,546.40	**Blinded**
8) $m_{\gamma\gamma} > 105$ GeV	41.79	89,583.05	1,496.51	97.99	841.05	92,018.60	**Blinded**
9) $130 < m_{\gamma\gamma} < 200$ GeV	41.73	31,682.35	596.74	44.96	22.16	32,346.21	**Blinded**
10) $N_{b\text{-jets}} = 0$	40.52	31,238.84	582.48	9.51	21.54	31,852.38	**Blinded**
11) $\gamma\gamma + 1\mu + \mu$ quality (Medium ID, $\lvert d_0/\sigma_{d_0}\rvert < 3$, $\lvert z_0 \sin\theta\rvert < 0.5$ mm), $0e$, 0τ	3.05	28.93	159.73	2.77	0.22	191.66	**Blinded**

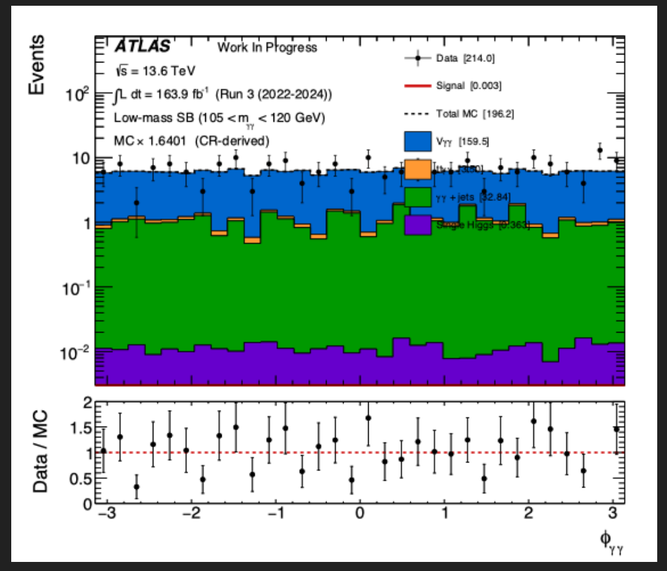


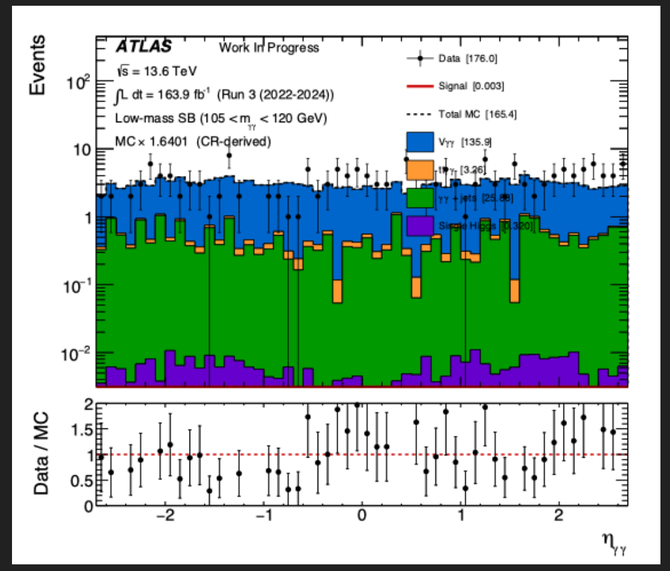
- **Signal survives at 3.05 events by a factor ~20× loss from initial, but note this uses the $\gamma\gamma\tau\tau$ benchmark; proper $\gamma\gamma + 1\mu$ MC will improve this substantially.**
- **$V\gamma\gamma$ dominates strongly at ~160 events because the 70 GeV mass window is 4–5× wider than the sidebands.**
- **$\gamma\gamma$ +jets suppressed by ~10,000× to just 29 events the 1μ + 0τ + 0e vetoes are doing the heavy lifting**

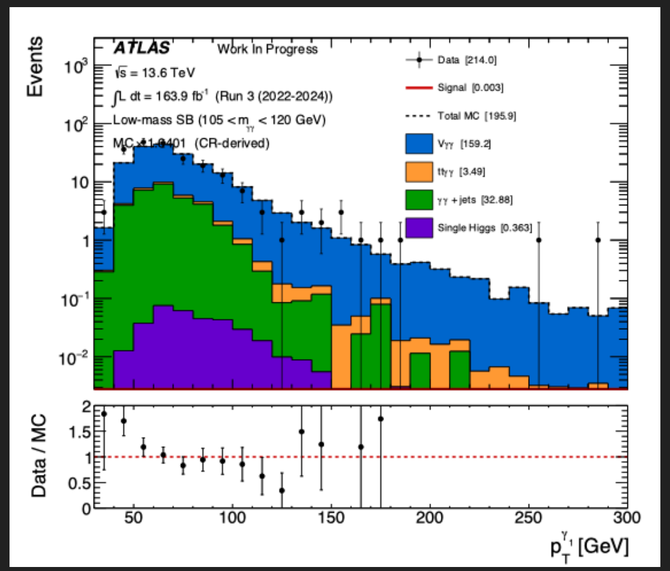
ATLAS EXPERIMENT

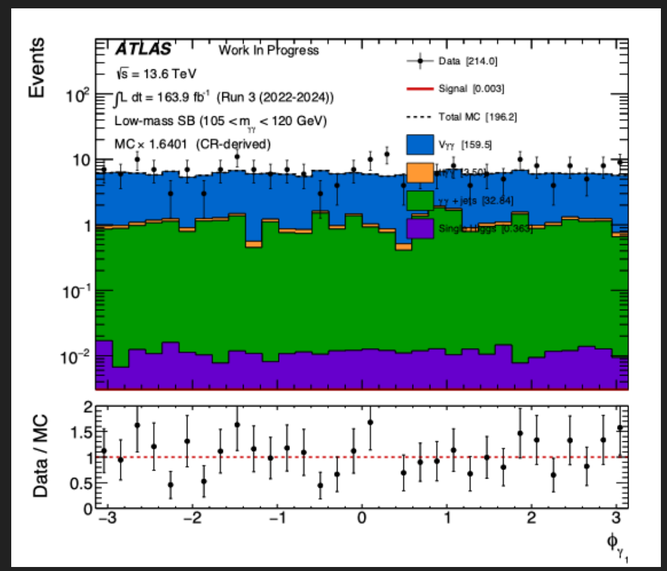
CR: Low sideband mass kinematic distributions (2022-2024)

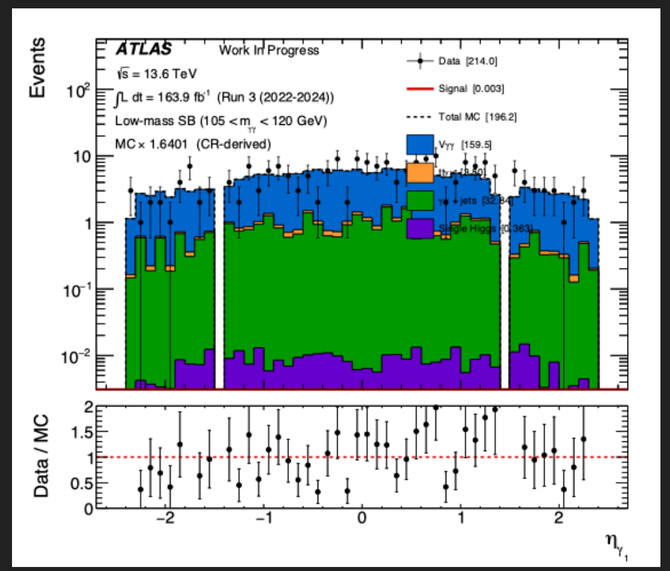






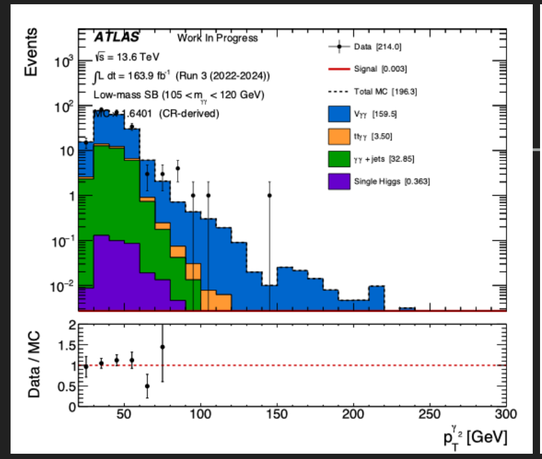


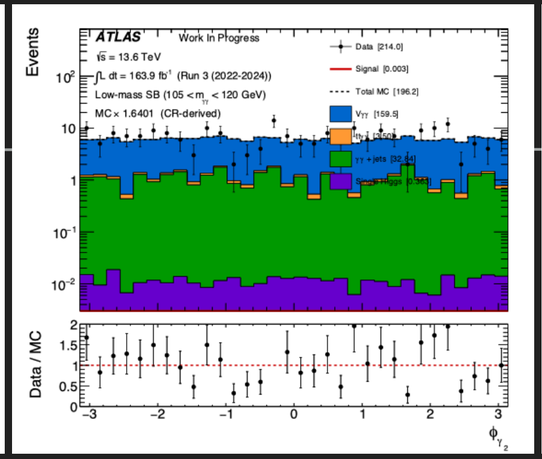


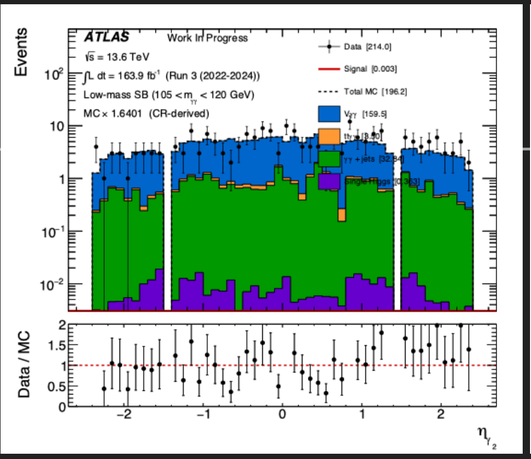


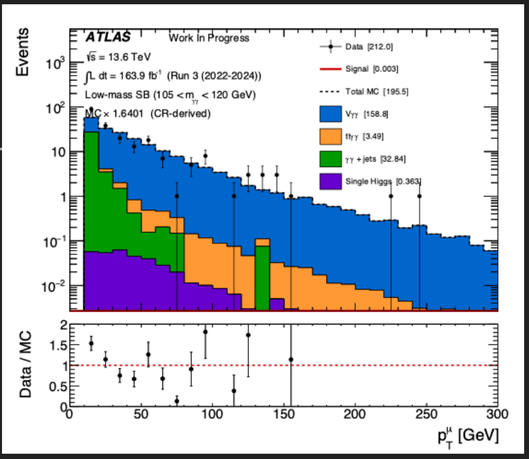
- $p_T(\gamma\gamma)$ falls smoothly from ~50 GeV. No anomalous high-pT tail.
- $\eta(\gamma\gamma)$ symmetric around zero .No detector asymmetry
- $\phi(\gamma\gamma)$ flat as expected for an azimuthally isotropic collision
- Leading $p_T(\gamma_1)$ peaks higher than sub-leading consistent with the asymmetric $p_T/m_{\gamma\gamma}$ cuts (0.35 vs 0.25)

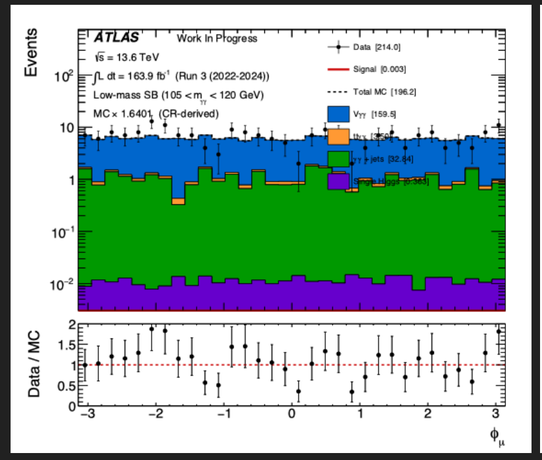
ATLAS EXPERIMENT

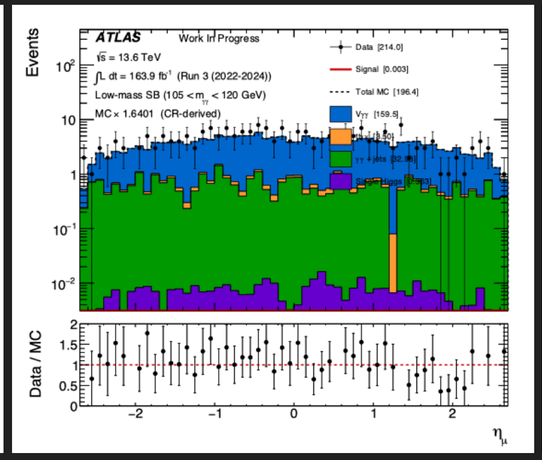


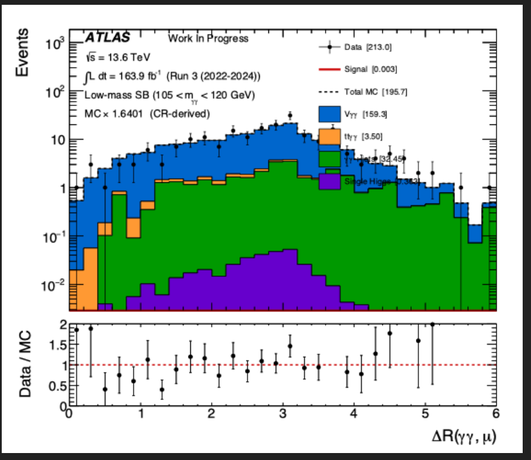


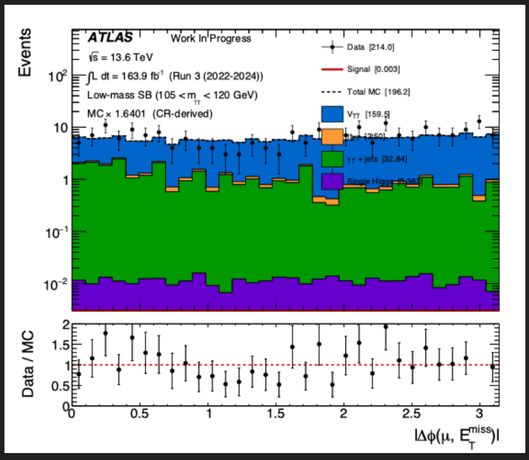


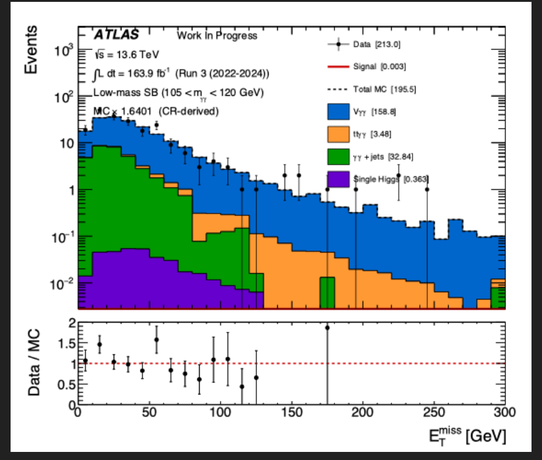






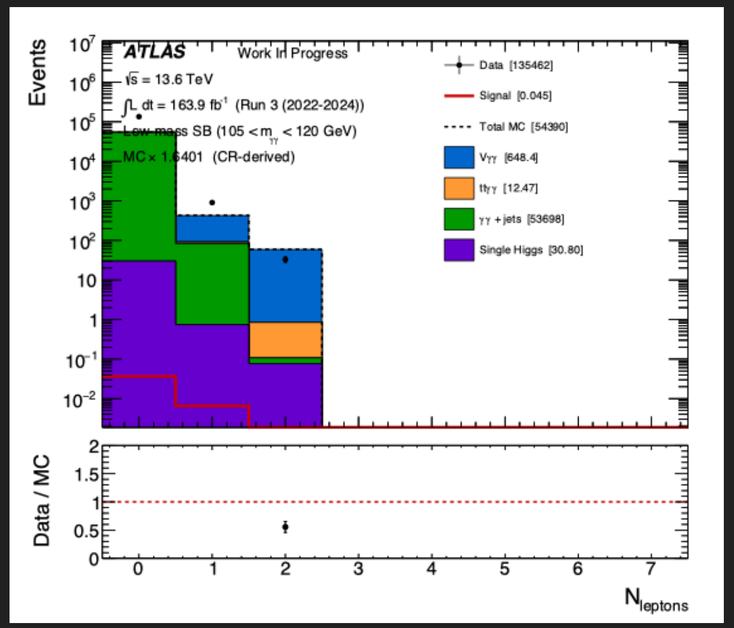




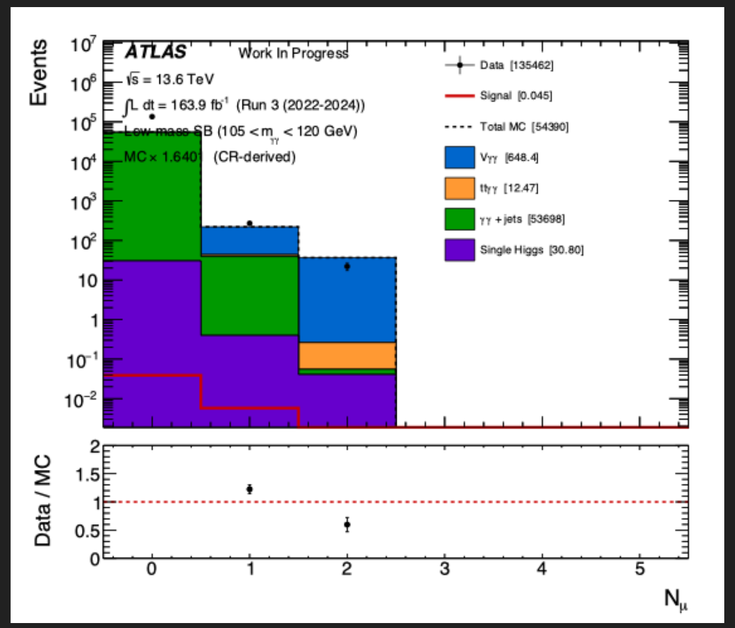


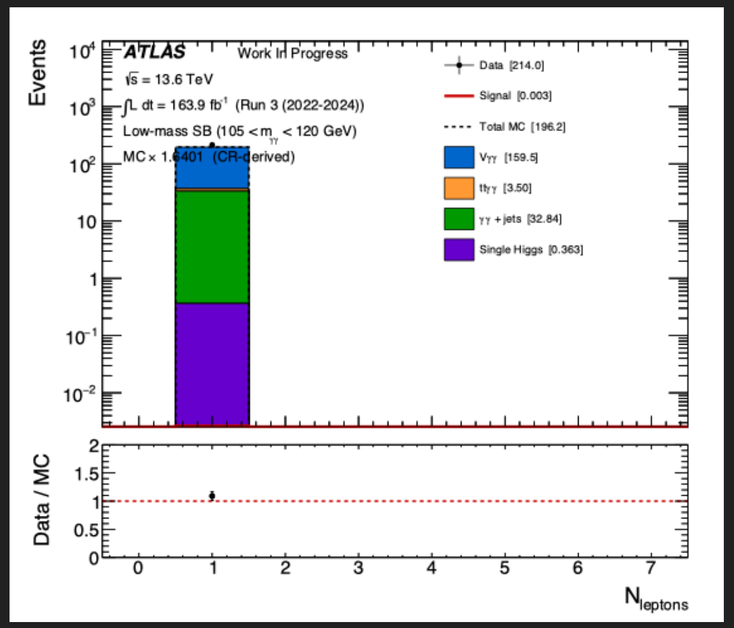
- $p_T(\mu)$ peaks around 15–25 GeV then falls consistent with $W \rightarrow \mu\nu$ kinematics dominating $V\gamma\gamma$
- $\eta(\mu)$ covers |η| < 2.5 as required good coverage across the tracker acceptance
- $\Delta(\gamma\gamma, \mu)$ peaks near π, the muon is back-to-back with the diphoton system, consistent with a resonant decay topology, not a photon-conversion or FSR configuration
- |Δφ(μ, MET)| is roughly flat, mixture of W-boosted (peak at 0) and unboosted topologies smearing across the range
- MET tail extends to ~150 GeV dominated by W → μν neutrinos in the Vγγ background

ATLAS EXPERIMENT

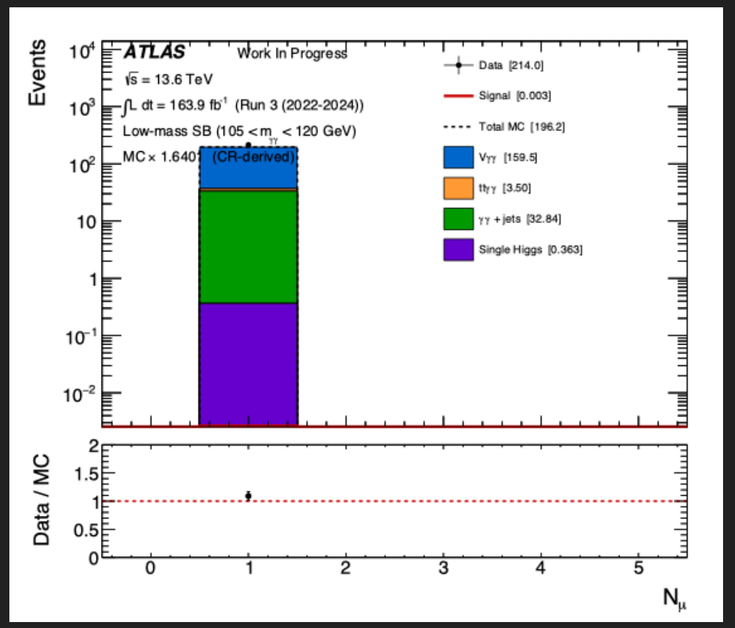


Before $\gamma\gamma + 1\mu$ selection



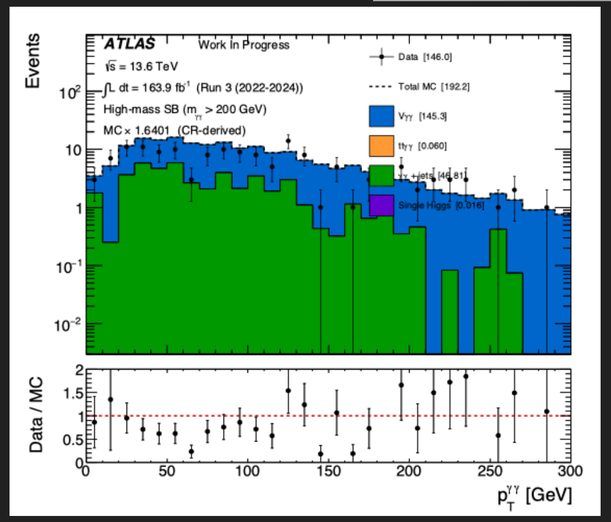


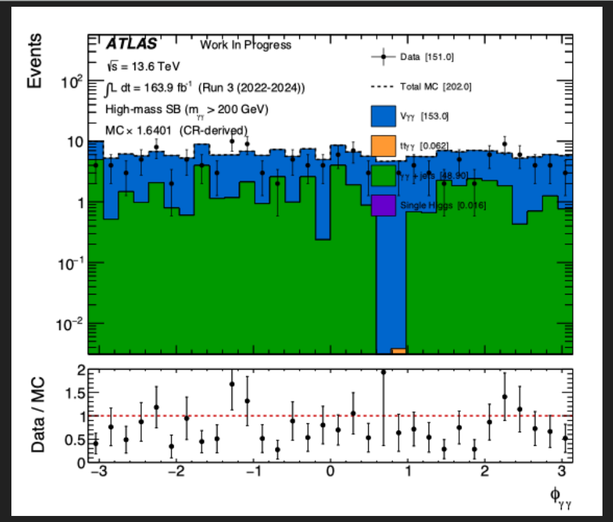
After $\gamma\gamma + 1\mu$ selection

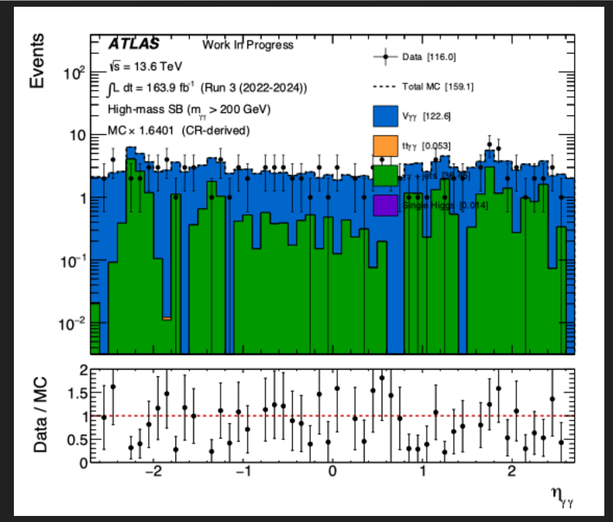


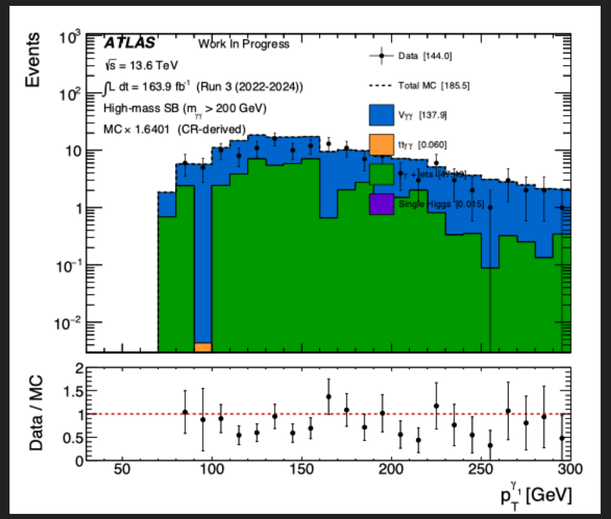
ATLAS EXPERIMENT

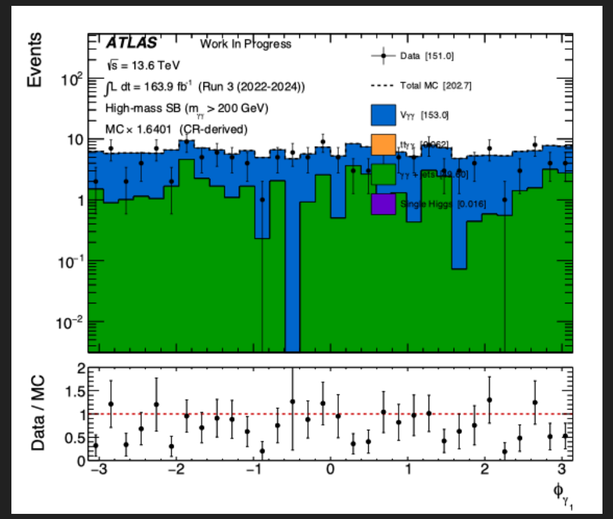
CR: High sideband mass Kinematic Distribution (2022-2024)

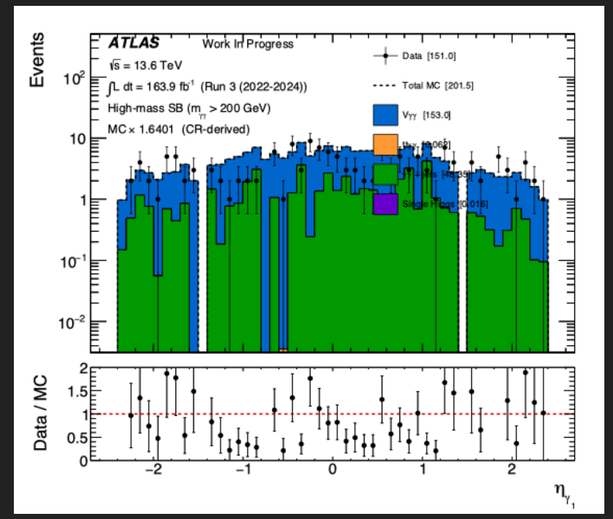








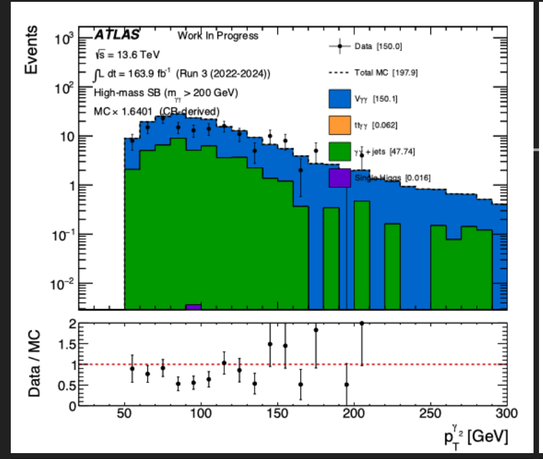


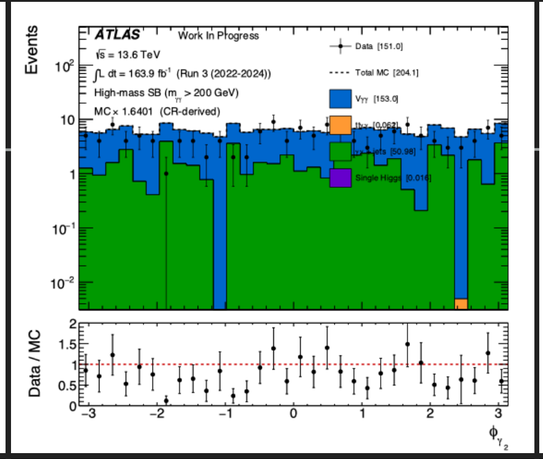


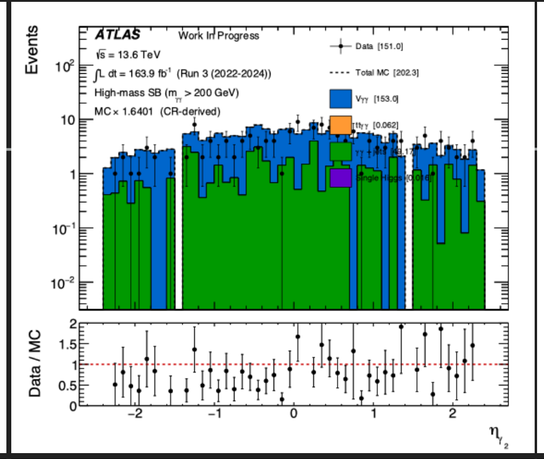
What changes vs. Low-SB:

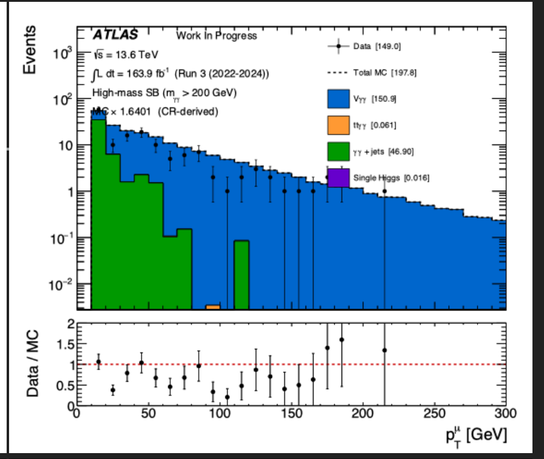
- **Green** (γγ+jets) becomes visible again in the stack the mγγ > 200 GeV window has a larger continuum contribution
- **Orange** ($t\bar{t}\gamma\gamma$) essentially disappears top-pair diphoton dies above 200 GeV
- **Purple** (Single Higgs) is invisible no SM Higgs contribution this far from 125 GeV

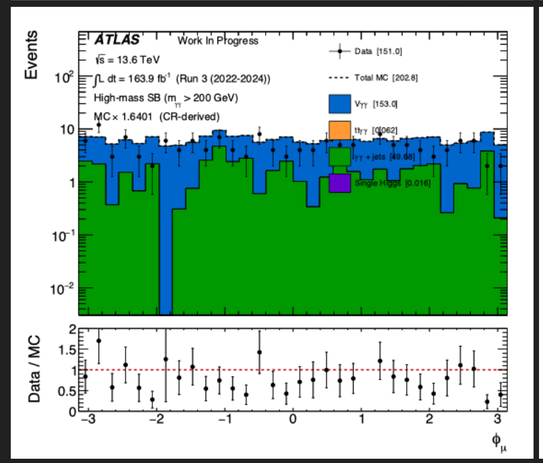
ATLAS EXPERIMENT

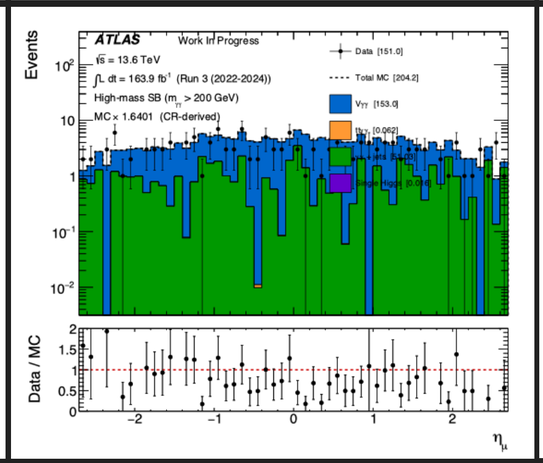


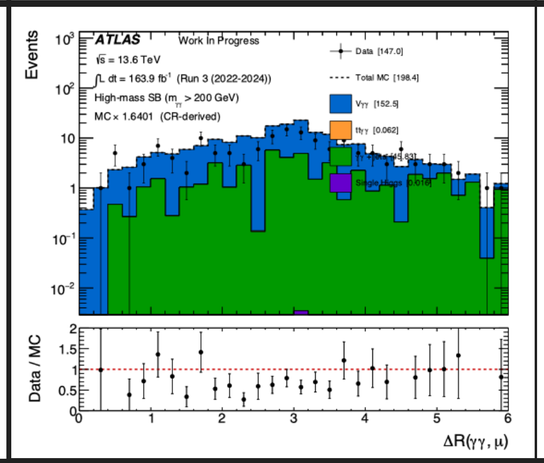


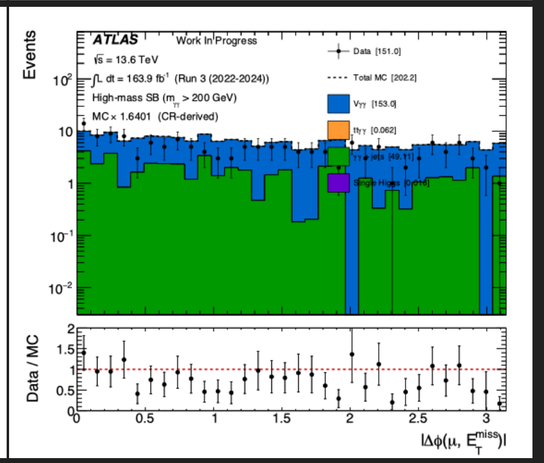


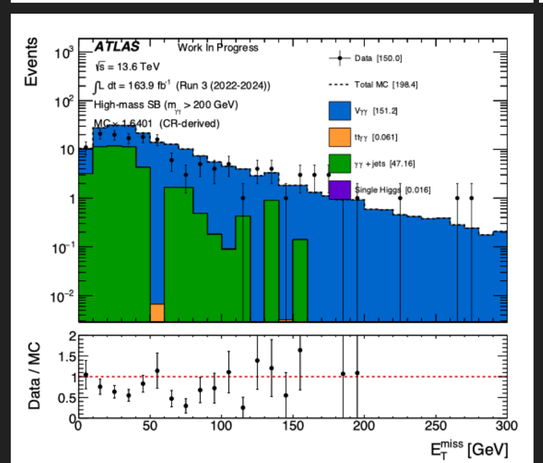




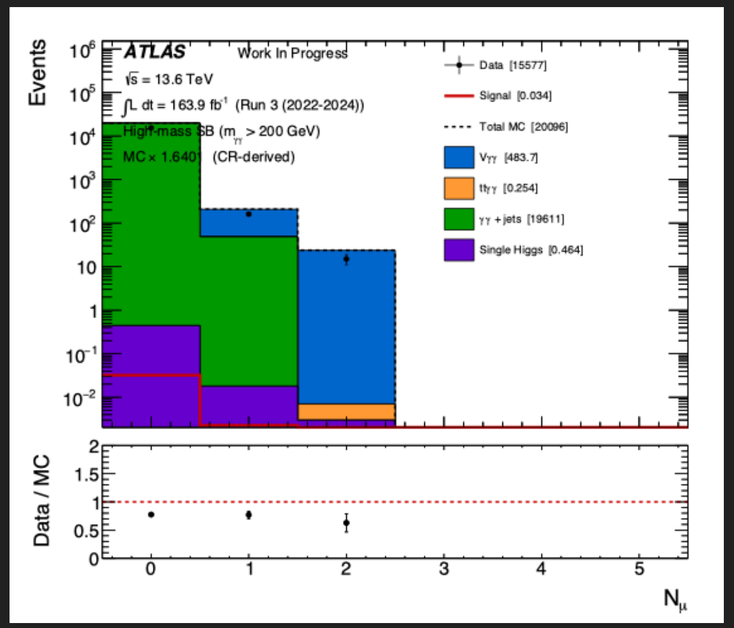




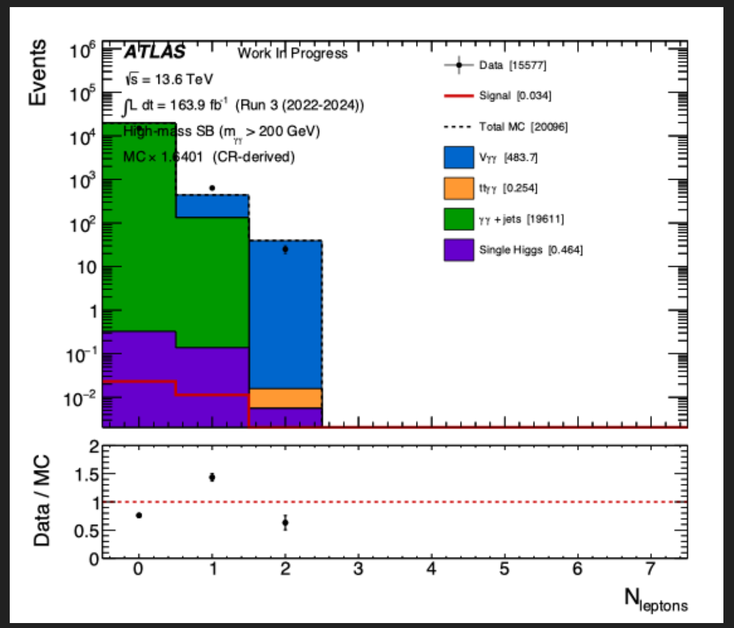


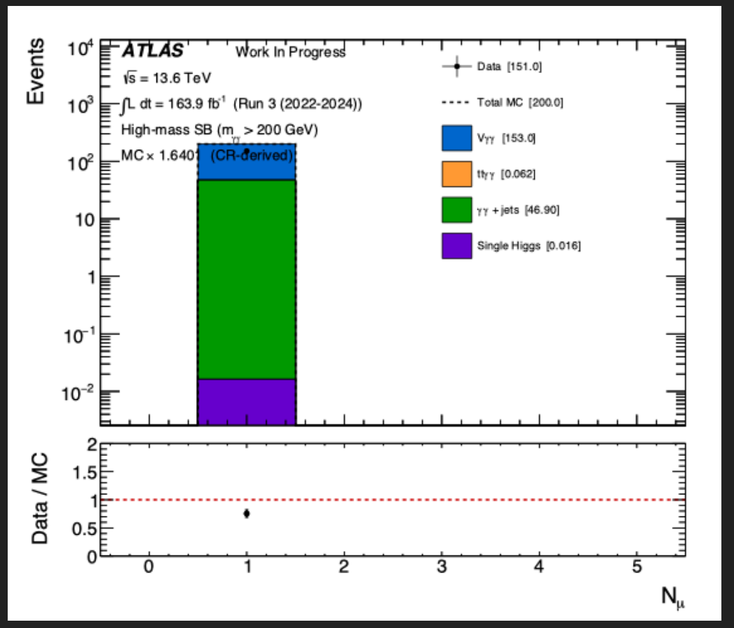


ATLAS EXPERIMENT

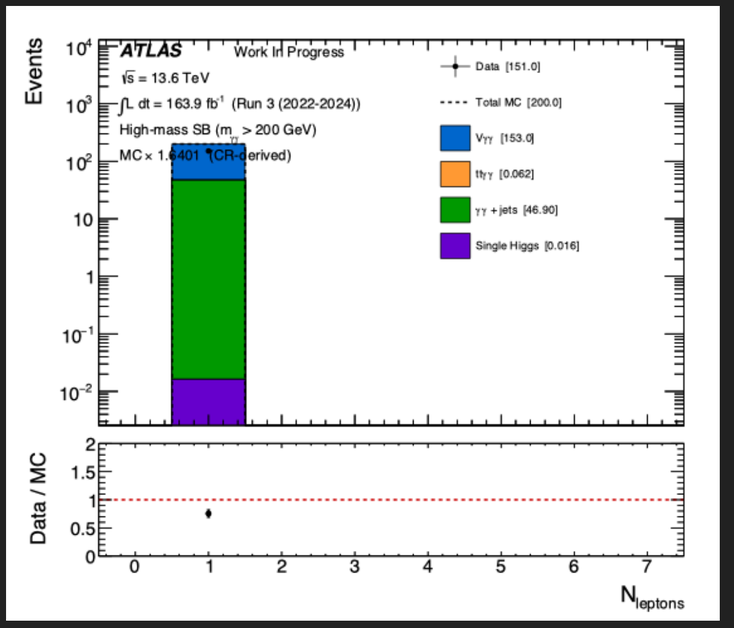


Before $\gamma\gamma + 1\mu$ selection



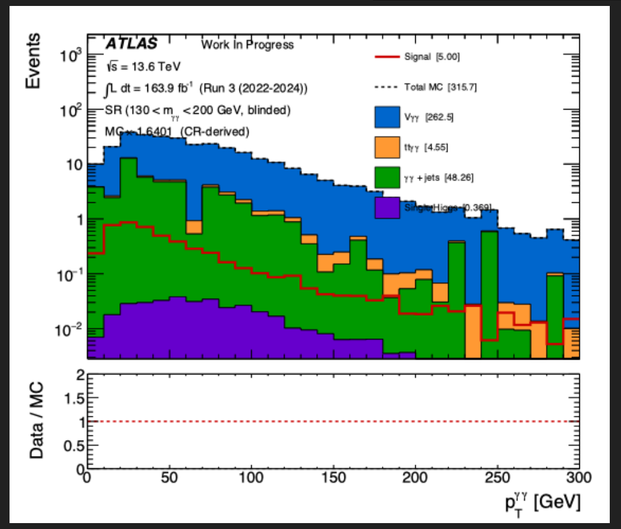


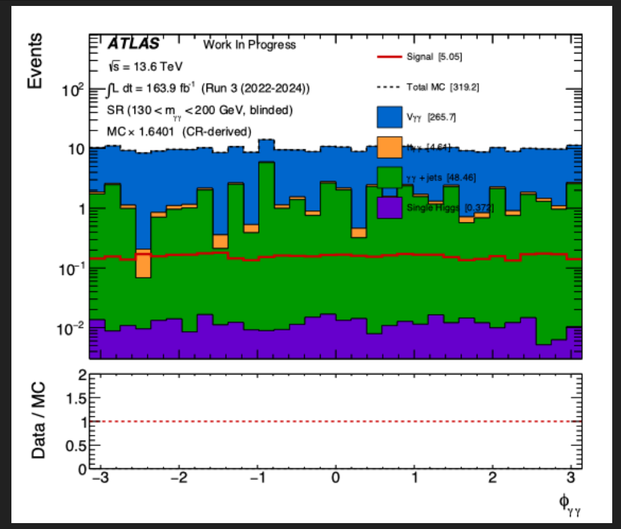
After $\gamma\gamma + 1\mu$ selection

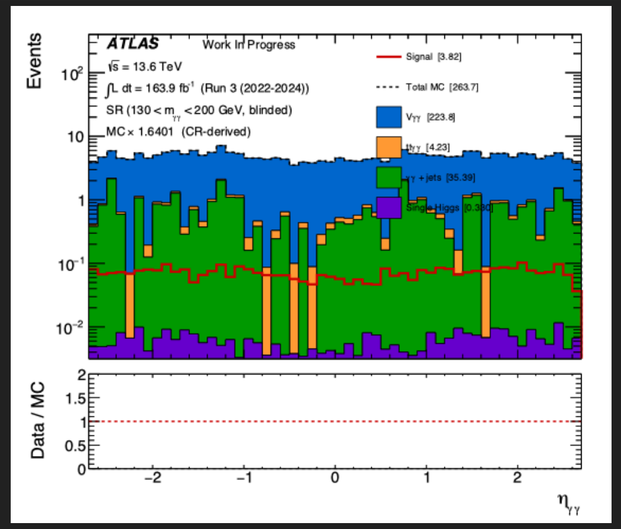


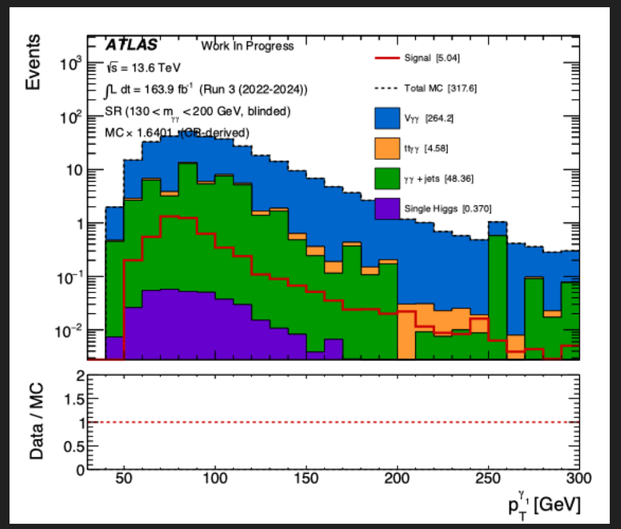
ATLAS EXPERIMENT

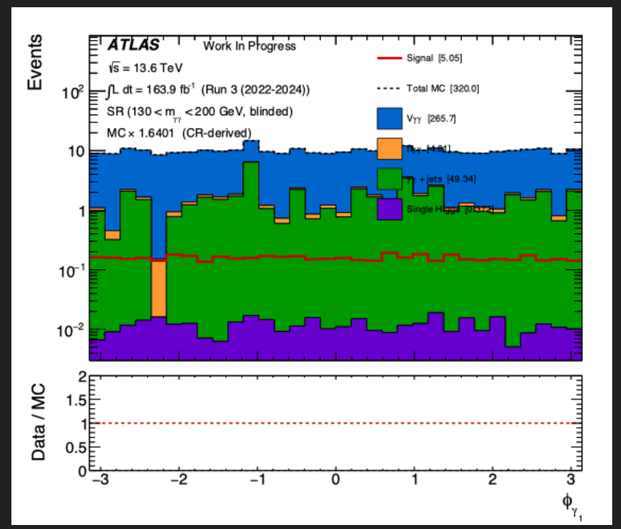
SR: Kinematic Distributions (2022-2024)

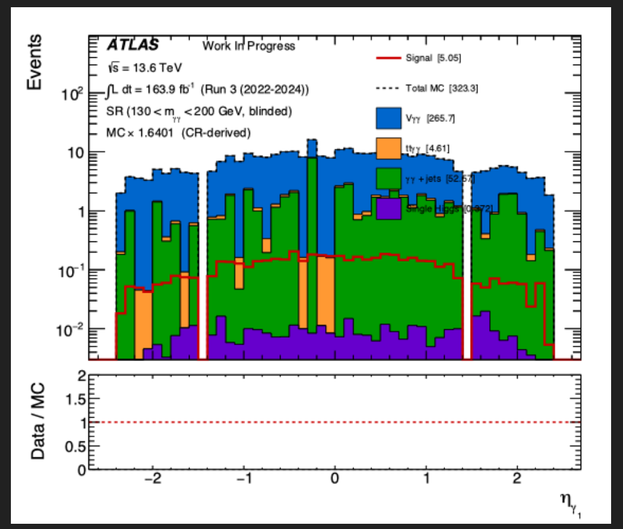






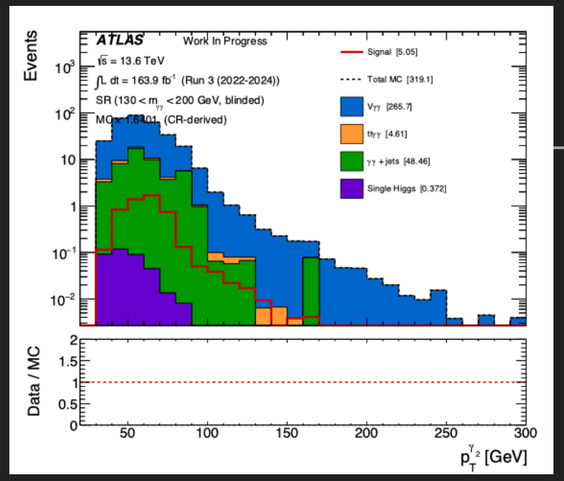


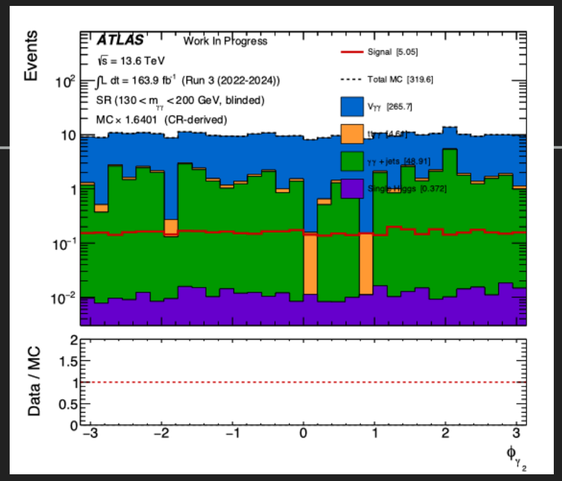


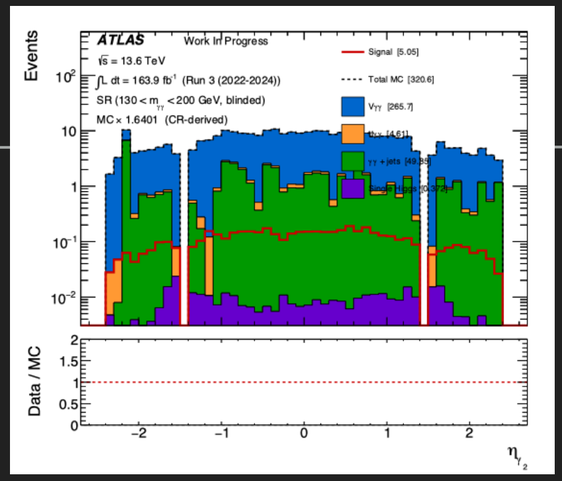


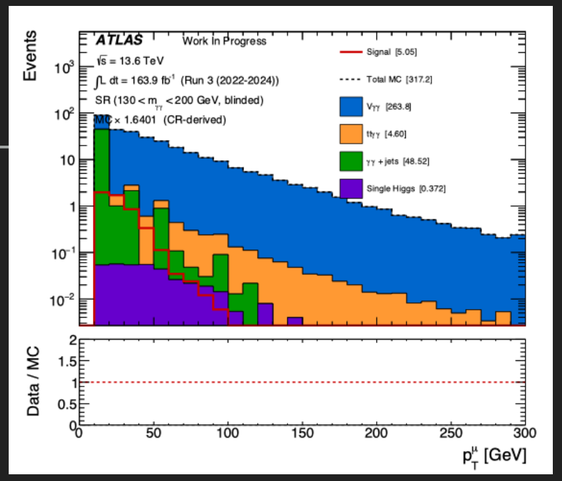
- $V\gamma\gamma$ dominates strongly
- $\gamma\gamma$+jets contributes but suppressed by the muon requirement
- $t\bar{t}\gamma\gamma$ and Single Higgs are minor contributors

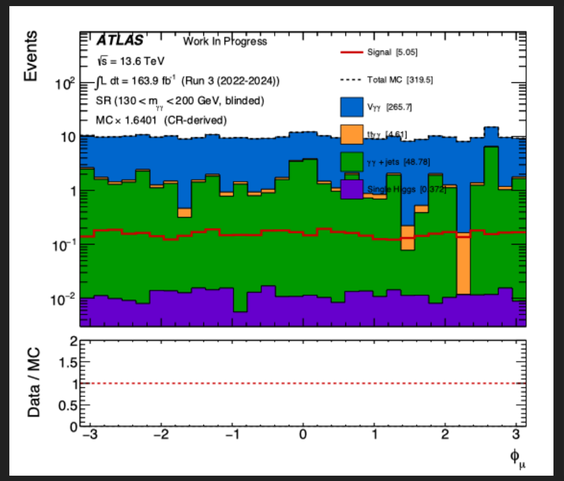
ATLAS EXPERIMENT

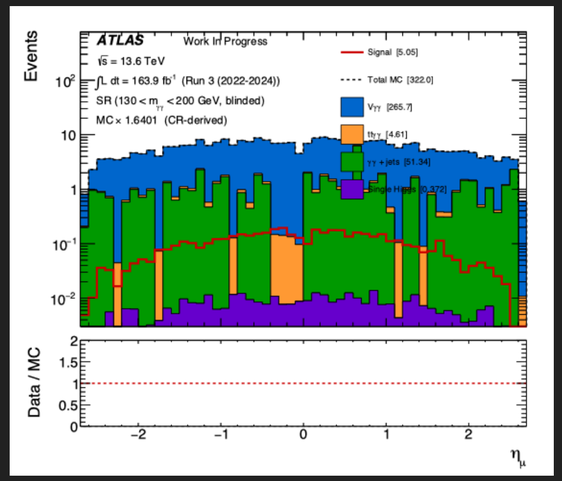


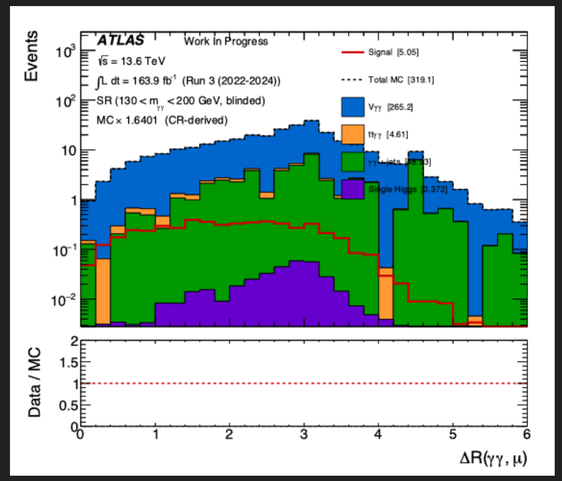


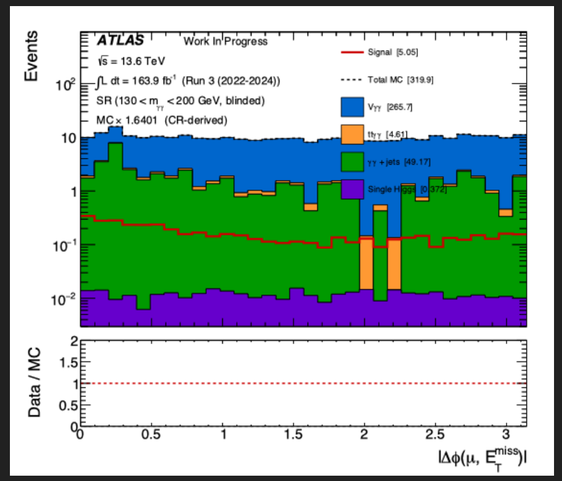


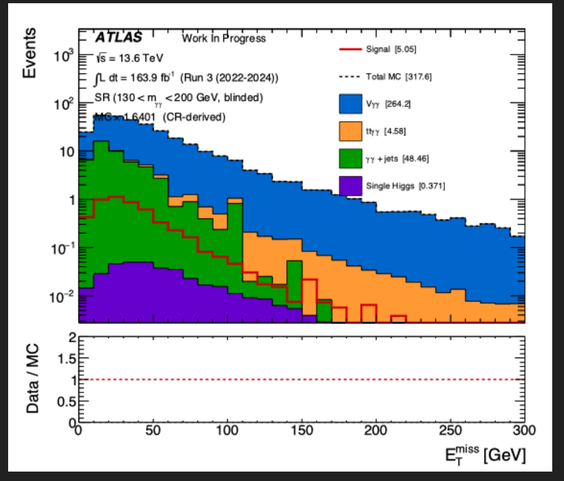




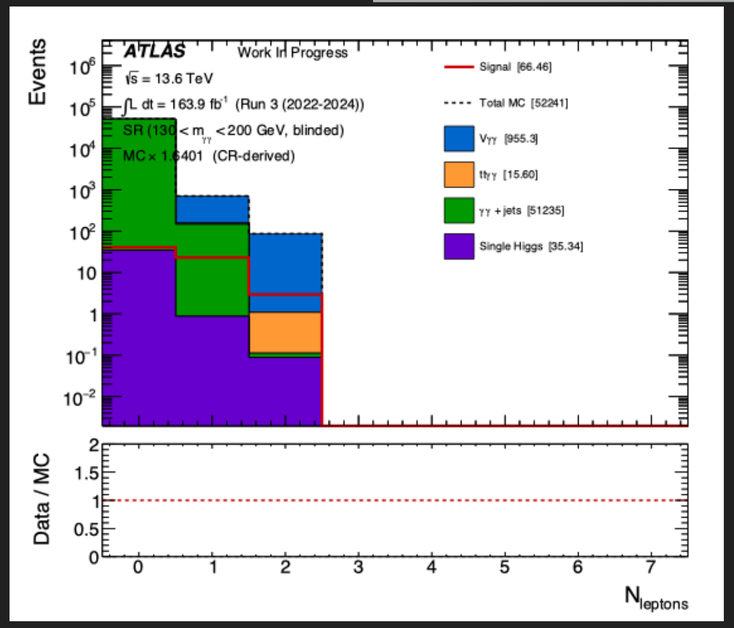




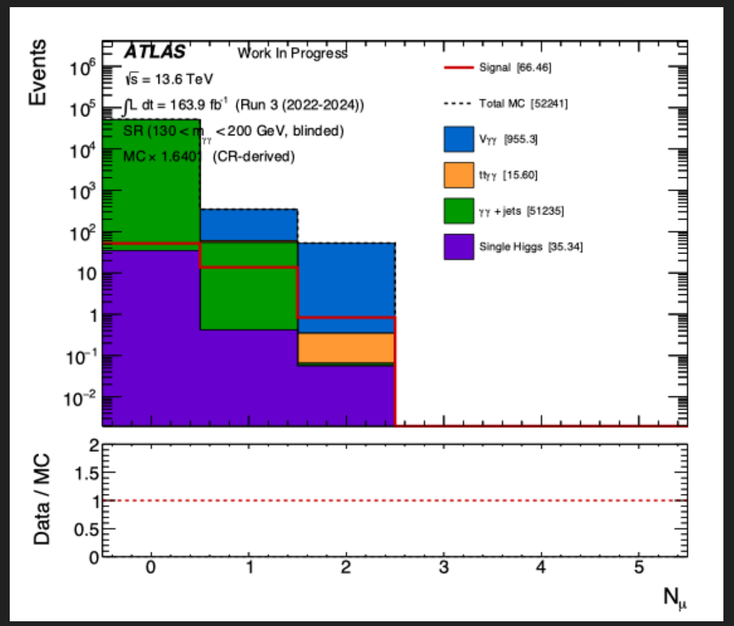


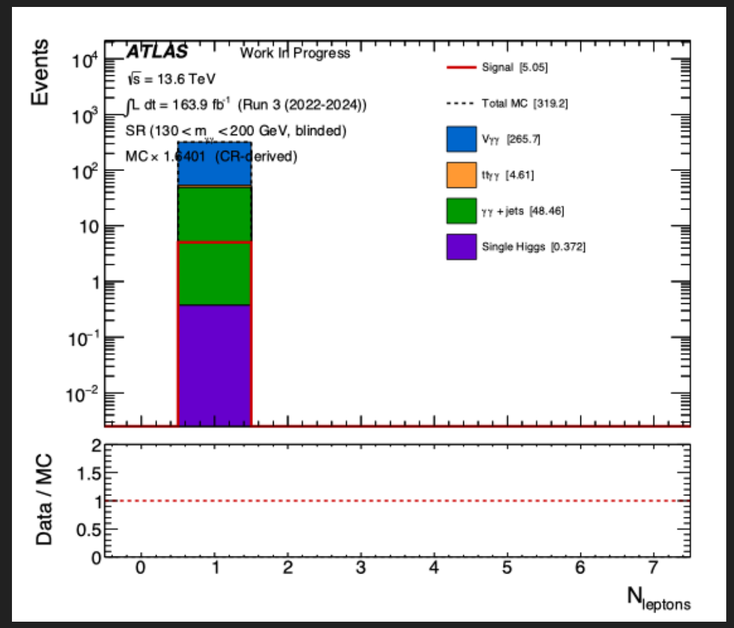


ATLAS EXPERIMENT

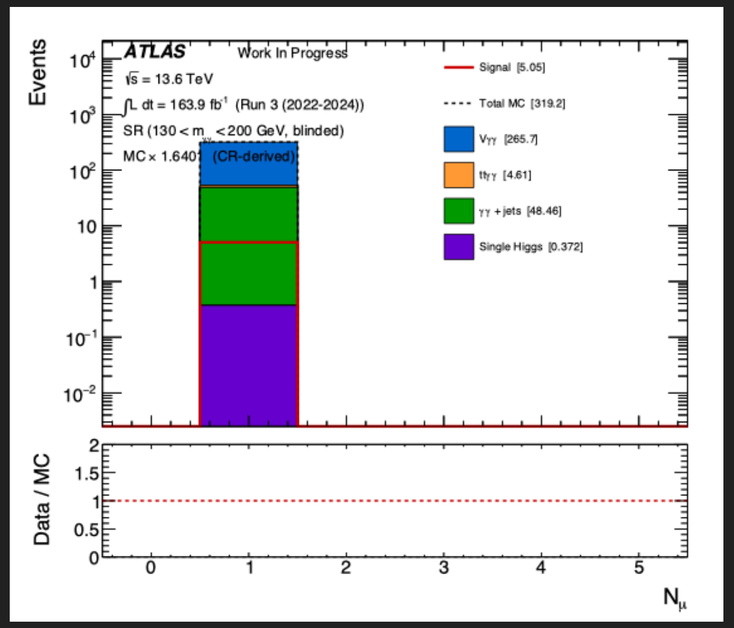


Before $\gamma\gamma + 1\mu$ selection





After $\gamma\gamma + 1\mu$ selection



ATLAS EXPERIMENT

Key Conclusions: Kinematic Distributions

CR: Low-mass sideband

105 < $m_{\gamma\gamma}$ < 120 GeV

- Data/MC flat within uncertainty across all p_T , η, ϕ variables ($\gamma\gamma$, γ_1, γ_2, μ)
- $V\gamma\gamma$dominates the SF-corrected background composition
- No evidence of shape mismodelling after SF correction

VR: High-mass sideband

$m_{\gamma\gamma}$ > 200 GeV

- $\gamma\gamma$+jets dominates before muon selection; agreement holds without large deviations
- Validates that the CR-derived SF extrapolates across the sideband
- Acts as an independent cross-check, not used in the SF fit

SR (blinded)

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

- 1μ+ 0τ selection sharply suppresses $\gamma\gamma$+jets (≈ 1000× reduction from initial to final cutflow step)
- $V\gamma\gamma$ becomes the dominant background after lepton/tau vetoe

Cross-cutting: $\Delta R(\gamma\gamma, \mu)$ and $|\Delta\phi(\mu, \text{MET})|$ show the muon is well-separated from the diphoton system in all regions, consistent with the expected topology and not suggestive of photon-conversion or FSR-dominated configurations .

ATLAS EXPERIMENT

DATA/MC AGREEMENT

Kinematics checked (CR, 2022–2024 combined)

- Diphoton system: $p_T(\gamma\gamma), \eta(\gamma\gamma), \phi(\gamma\gamma)$
- Leading/sub-leading photons: $p_T(\gamma_1)$, $p_T(\gamma_2)$, $\eta(\gamma_{1,2}), \phi(\gamma_{1,2})$
- Muon: $p_T(\mu), \phi(\mu), \eta(\mu)$
- Correlation / MET: $\Delta R(\gamma\gamma, \mu)$, $|\Delta\phi(\mu, MET)|$, MET (E_T)

Findings

- After applying the combined $\gamma\gamma$ +1μ-derived scale factor (SF = 1.6401 ± 0.1018) to $V\gamma\gamma/t\bar{t}\gamma\gamma$, Data/MC is consistent with unity within statistical uncertainty across all distributions
- No significant shape mismodelling in any variable ratio panels are flat and stable across p_T, η, ϕ
- High-mass sideband (VR, $m_{\gamma\gamma} > 200\ GeV$) serves as an independent validation: agreement here confirms the low-mass-derived SF generalises across the sideband

Caveat under investigation

Per-year breakdown shows the 2024 (mc23e) $\gamma\gamma$+jets yield/luminosity in the sideband is anomalously low relative to 2022/2023 (0.1583 vs. ≈ 0.54–0.58 fb^{-1}, see backup).

Currently does not bias the combined SF beyond its quoted 6.2% uncertainty, but is being followed up.

Signal region

- SR is used to study and characterise MC background shapes/normalisation; data in the SR remains blinded pending unblinding

ATLAS EXPERIMENT

SUMMARY AND FUTURE WORK

Summary

- Established a γγ + 1μ + 0τ event selection for a model-independent search, using the 2HDM+S ($m_H = 250\ \mathrm{GeV}, m_S \approx 152\ GeV$) and Higgs Triplet Model as benchmark scenarios to guide the analysis, based on $\mathcal{L}$ = 163.9 fb^{-1} of Run 3 data (mc23a+d+e).
- Derived a data-driven scale factor for the irreducible $V\gamma\gamma$ / $t\bar{t}\gamma\gamma$ backgrounds from the γγ+1μ sideband: combined SF = 1.6401 ± 0.1018 (6.2% uncertainty)
- Demonstrated good Data/MC agreement across CR and VR kinematic distributions after SF correction, with flat ratio panels and no significant shape mismodelling
- Characterised the blinded SR cutflow: 1μ + 0τ selection suppresses $\gamma\gamma$+jets by ≈ 1000×, leaving $V\gamma\gamma$ as the dominant background
- Identified an anomalously low 2024 (mc23e) $\gamma\gamma$ +jets sideband yield, currently within the quoted SF uncertainty but under investigation

Future Work

- Resolve the anomalous 2024 (mc23e) $\gamma\gamma$+jets sideband yield and confirm its impact on the combined scale factor
- Complete outstanding signal sample requests ($\gamma\gamma$ +1ℓ, $\gamma\gamma$ +2ℓ) to extend coverage beyond the $\gamma\gamma\tau\tau$ benchmark
- Extend background estimation: closure tests, additional single-Higgs processes, and cross-checks against ANA-HDBS-2019-04-INT1
- Work on Muon working point optimization, Explore the significance Z of the available WPs.
- Build on DSCB and background modelling, and spurious signal studies.
- Perform Fake factor Studies.

ATLAS EXPERIMENT

Poem by Dylan Thomas

THANK YOU. KE YA LEBOGA!!!

ATLAS EXPERIMENT

Back up Slides

Anomalous 2024 Scale Factor: Cutflow Evidence

Table 2: CR event yields after preselection, and yield normalised by luminosity (fb^{-1}).

Year	Luminosity	Data	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$
2022	29.3	23707.0	18935.683	130.788	1.441
2023	26.7	23942.0	17497.560	112.581	1.256
2024	107.9	103390.0	8265.132	446.912	5.059
Yield / Luminosity					
2022	29.3	809.11	646.27	4.464	0.0492
2023	26.7	896.70	655.34	4.217	0.0470
2024	107.9	958.20	**76.60**	4.142	0.0469

Table 3: CR event yields after the $\gamma\gamma + 1\mu$ cutflow, and yield normalised by luminosity (fb^{-1}).

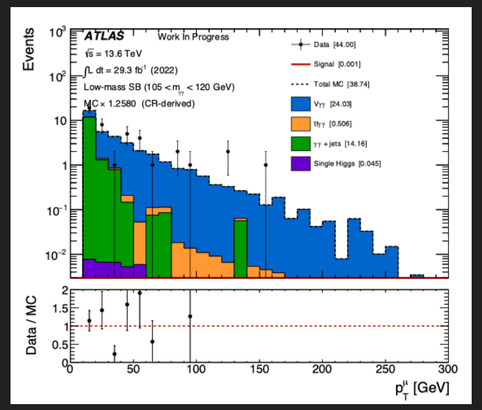
Year	Luminosity	Data	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$
2022	29.3	64.0	17.056	36.877	0.410
2023	26.7	51.0	14.486	31.293	0.350
2024	107.9	250.0	17.077	122.423	1.413
Yield / Luminosity					
2022	29.3	2.184	0.5821	1.2586	0.0140
2023	26.7	1.910	0.5425	1.1720	0.0131
2024	107.9	2.317	**0.1583**	1.1346	0.0131

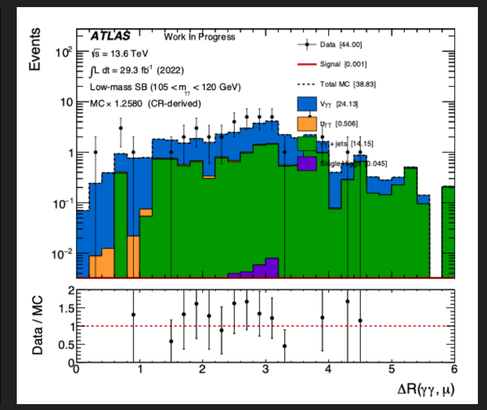
ATLAS EXPERIMENT

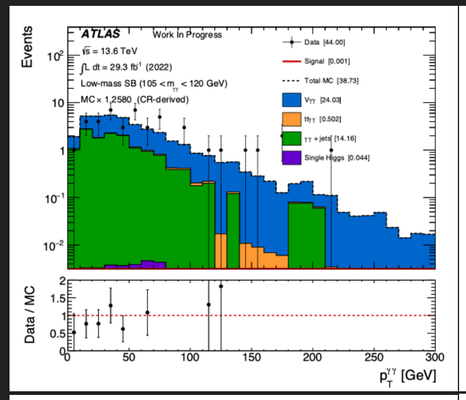
CR: Low Sideband mass (2022)

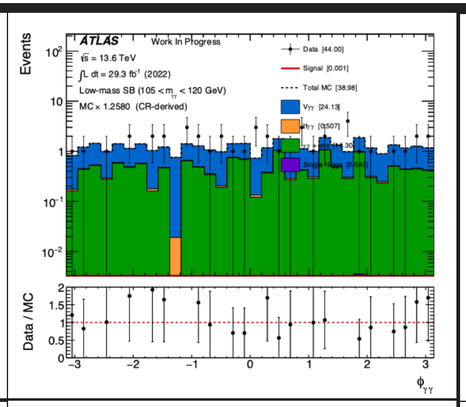
Table 5: Cutflow — Control Region — Low-mass Sideband, mc23a.

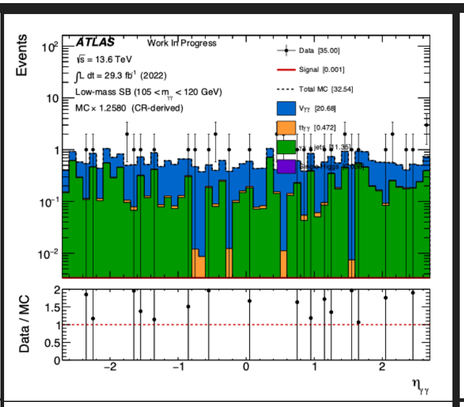
Selection Step	Signal	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$	Single Higgs	Total Bkg.	Data
1) Initial Events	12.35	127,288.82	1,739.16	53.36	216.30	129,297.65	1,235,725
2) PASS_Trigger	12.35	127,288.82	1,739.16	53.36	216.30	129,297.65	1,235,725
3) Pass diphoton trigger matching	12.35	127,288.82	1,739.16	53.36	216.30	129,297.65	1,235,725
4) Photon ID/Iso (Tight_FixedCutLoose)	9.18	87,211.66	969.39	33.58	161.02	88,375.66	266,489
5) Photon eta & crack veto	9.12	86,848.86	964.34	33.42	160.37	88,006.98	265,395
6) $p_T(\gamma_1)$>35 GeV & $p_T(\gamma_2)$>25 GeV	9.11	86,663.58	960.85	33.40	160.30	87,818.13	262,847
7) $p_T(\gamma_1)/m_{\gamma\gamma}$>0.35 & $p_T(\gamma_2)/m_{\gamma\gamma}$>0.25	8.20	69,686.07	817.86	28.05	143.13	70,675.11	231,225
8) $m_{\gamma\gamma}$>105 GeV	8.15	38,300.88	284.18	18.60	143.02	38,746.67	47,688
9) Low-mass SB (105<$m_{\gamma\gamma}$<120 GeV)	0.01	17,214.57	77.11	6.62	2.94	17,301.24	21,646
10) $N_{b\text{-jets}} = 0$	0.01	17,029.00	75.44	1.42	2.86	17,108.71	21,318
11) $\gamma\gamma$ + 1μ, veto taus & electrons (0e, 0τ, 1μ)	0.00	11.25	19.18	0.40	0.04	30.87	44

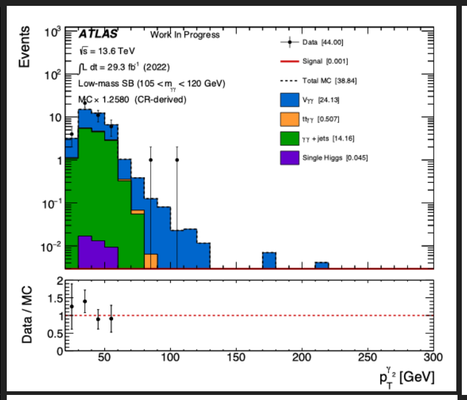


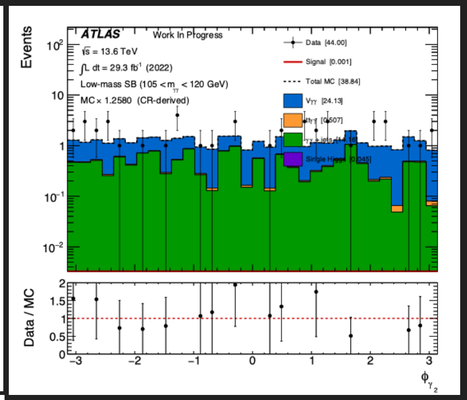


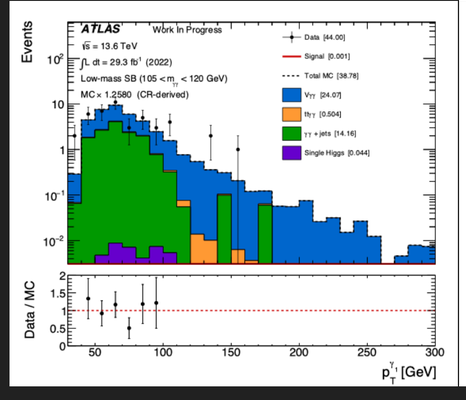


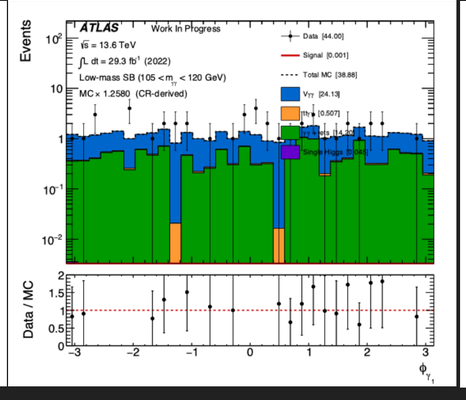


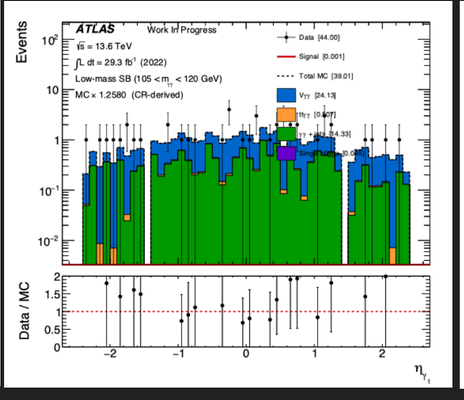


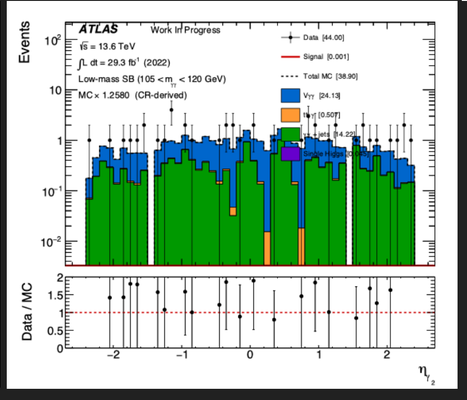










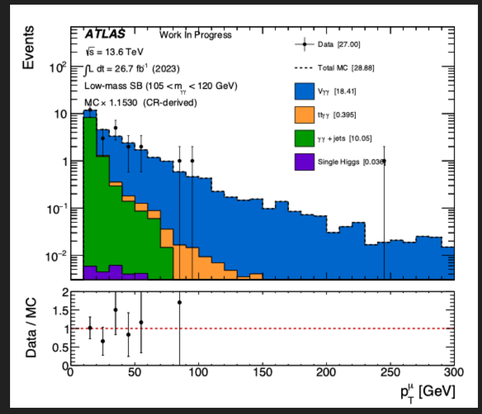


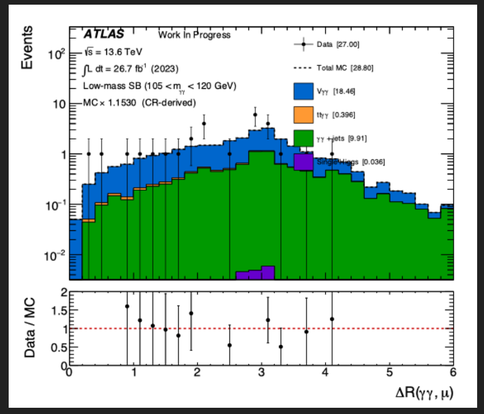
ATLAS EXPERIMENT

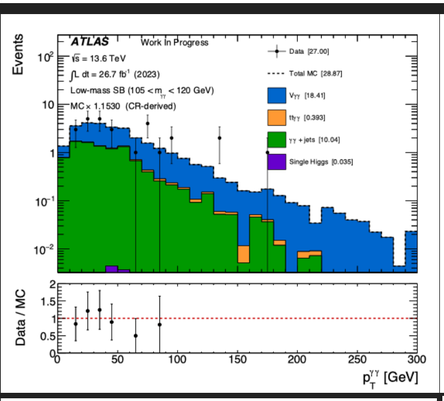
CR: Low sideband mass (2023)

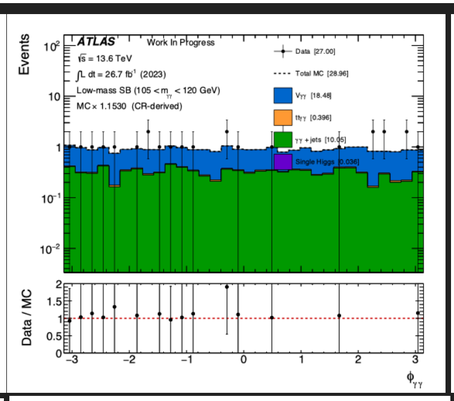
Table 6: Cutflow — Control Region — Low-mass Sideband, mc23d.

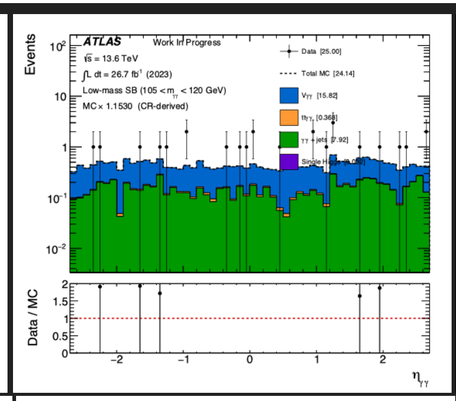
Selection Step	Signal	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$	Single Higgs	Total Bkg.	Data
1) Initial Events	10.50	118,475.92	1,516.21	46.59	203.48	120,242.20	1,302,690
2) PASS_Trigger	10.50	118,475.92	1,516.21	46.59	203.48	120,242.20	1,302,690
3) Pass diphoton trigger matching	10.50	118,475.92	1,516.21	46.59	203.48	120,242.20	1,302,690
4) Photon ID/Iso (Tight_FixedCutLoose)	7.61	79,485.26	815.61	28.53	148.65	80,478.05	269,892
5) Photon eta & crack veto	7.57	79,132.63	811.33	28.39	148.01	80,120.36	268,655
6) $p_T(\gamma_1)$>35 GeV & $p_T(\gamma_2)$>25 GeV	7.57	78,970.90	808.15	28.37	147.94	79,955.37	265,832
7) $p_T(\gamma_1)/m_{\gamma\gamma}$>0.35 & $p_T(\gamma_2)/m_{\gamma\gamma}$>0.25	6.82	63,931.18	688.78	23.85	132.77	64,776.58	232,914
8) $m_{\gamma\gamma}$>105 GeV	6.78	35,707.99	242.90	15.94	132.67	36,099.49	48,468
9) Low-mass SB (105<$m_{\gamma\gamma}$<120 GeV)	0.00	15,838.18	65.99	5.70	2.88	15,912.74	21,965
10) $N_{b\text{-jets}} = 0$	0.00	15,675.26	64.55	1.23	2.81	15,743.84	21,620
11) $\gamma\gamma + 1\mu$, veto taus & electrons ($0e$, 0τ, 1μ)	0.00	8.71	16.03	0.34	0.03	25.12	27

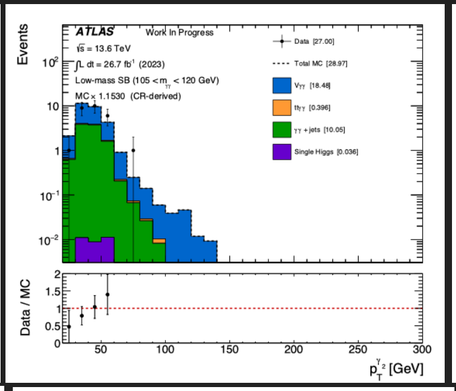


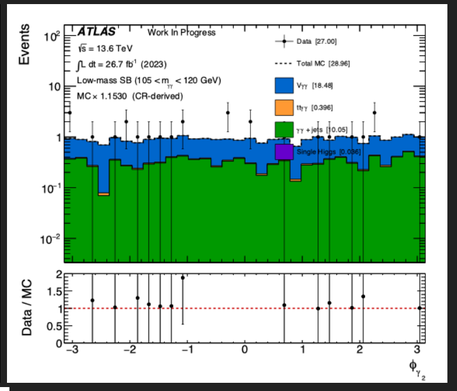


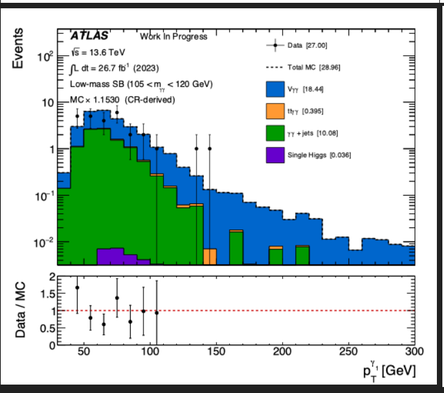


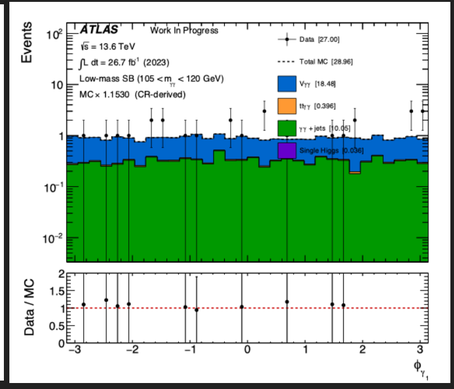


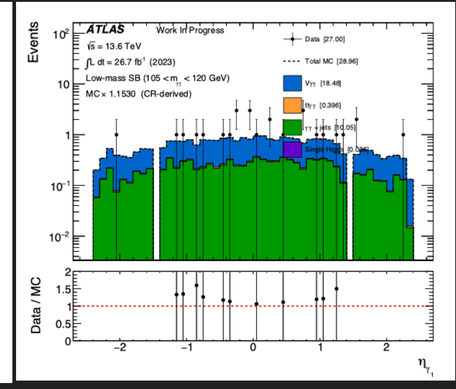


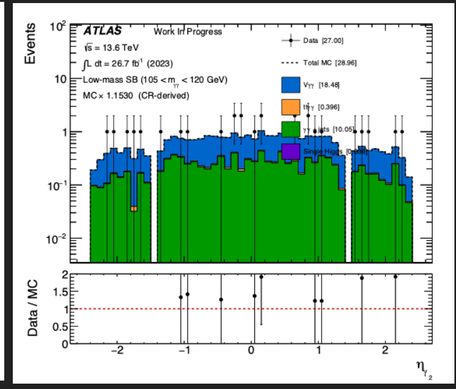










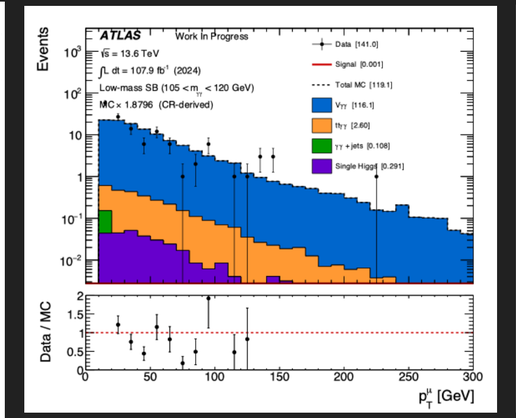


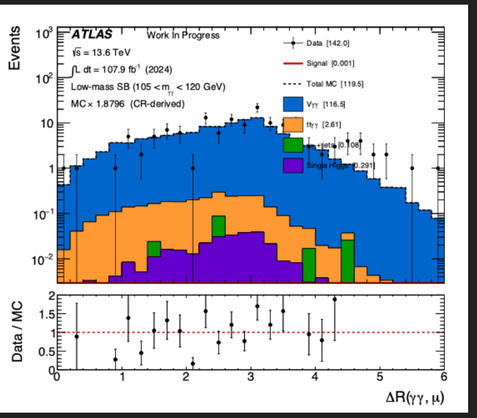
ATLAS EXPERIMENT

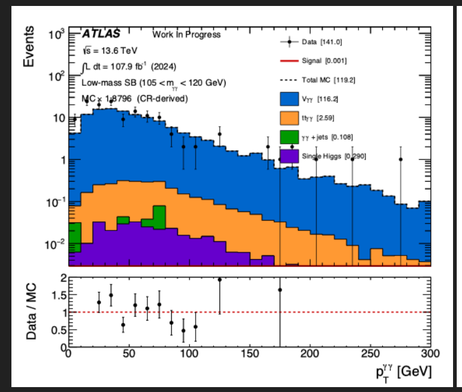
CR: Low sideband mass (2024)

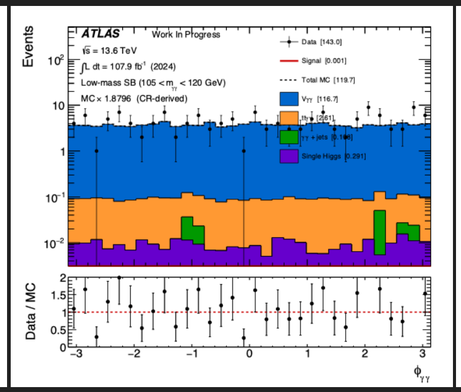
Table 7: Cutflow — Control Region — Low-mass Sideband, mc23e.

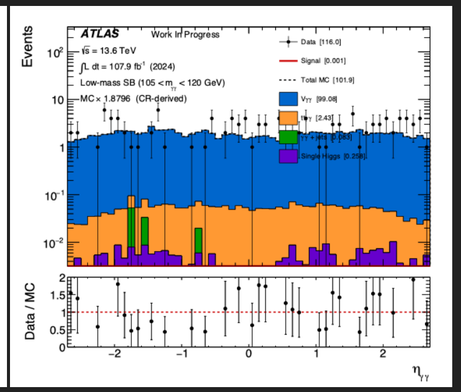
Selection Step	Signal	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$	Single Higgs	Total Bkg.	Data
1) Initial Events	42.00	51,933.84	6,293.96	191.07	874.76	59,293.62	5,722,642
2) PASS_Trigger	42.00	51,933.84	6,293.96	191.07	874.76	59,293.62	5,722,642
3) Pass diphoton trigger matching	42.00	51,933.84	6,293.96	191.07	874.76	59,293.62	5,722,642
4) Photon ID/Iso (Tight_FixedCutLoose)	30.24	38,527.25	3,310.39	115.05	633.40	42,586.10	1,151,021
5) Photon eta & crack veto	30.06	38,309.10	3,292.16	114.45	630.66	42,346.38	1,146,026
6) $p_T(\gamma_1)$>35 GeV & $p_T(\gamma_2)$>25 GeV	30.06	38,281.21	3,276.74	114.39	630.36	42,302.71	1,134,479
7) $p_T(\gamma_1)/m_{\gamma\gamma}$>0.35 & $p_T(\gamma_2)/m_{\gamma\gamma}$>0.25	27.05	15,644.42	2,788.95	95.55	565.79	19,094.71	995,706
8) $m_{\gamma\gamma}$>105 GeV	26.87	15,574.18	969.44	63.45	565.36	17,172.44	212,098
9) Low-mass SB (105<$m_{\gamma\gamma}$<120 GeV)	0.01	37.03	260.86	22.60	13.45	333.93	93,865
10) $N_{b\text{-jets}} = 0$	0.01	36.60	255.34	4.95	13.12	310.02	92,524
11) $\gamma\gamma$ + 1μ, veto taus & electrons (0e, 0τ, 1μ)	0.00	0.06	62.06	1.39	0.15	63.66	143

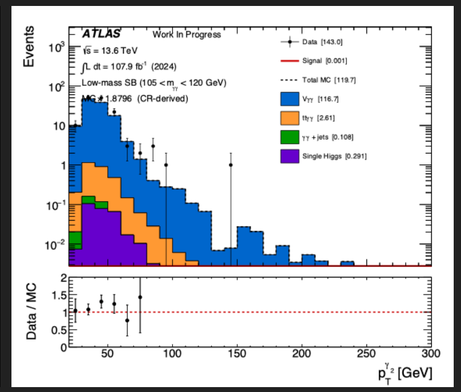


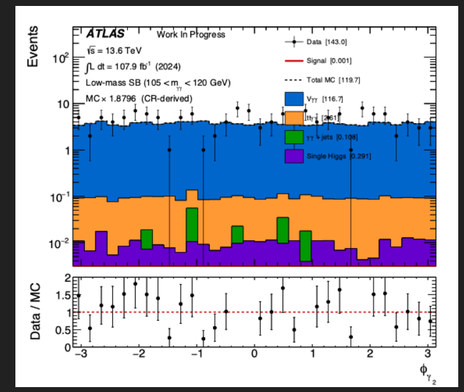


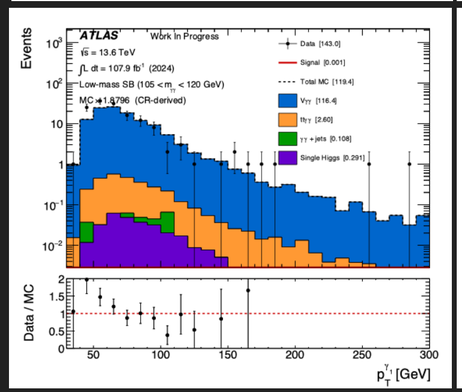


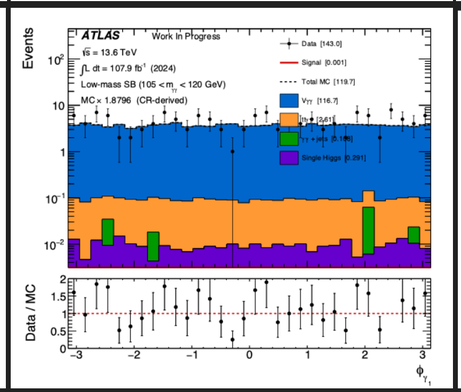


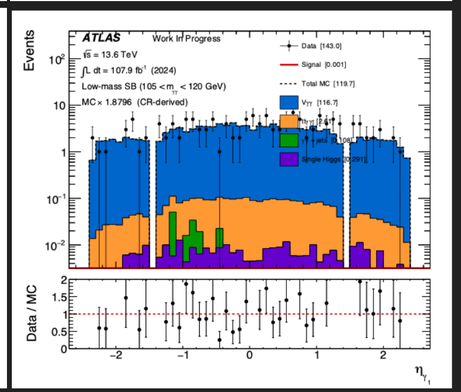


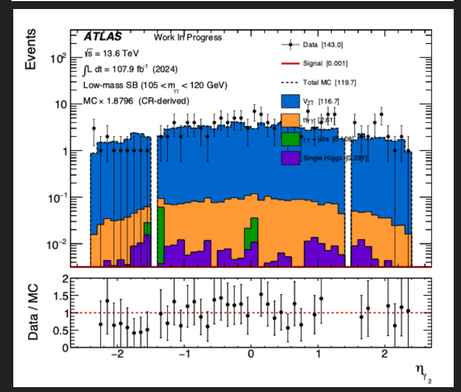










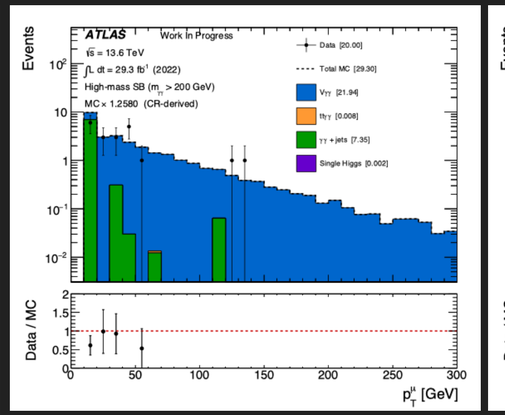


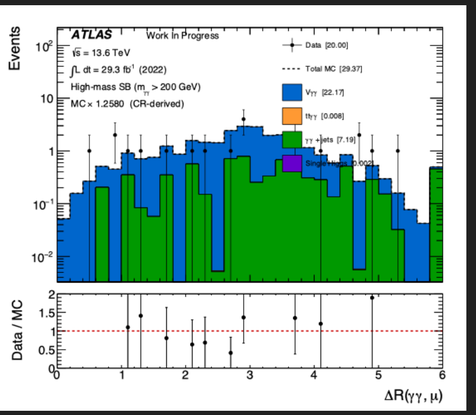
ATLAS EXPERIMENT

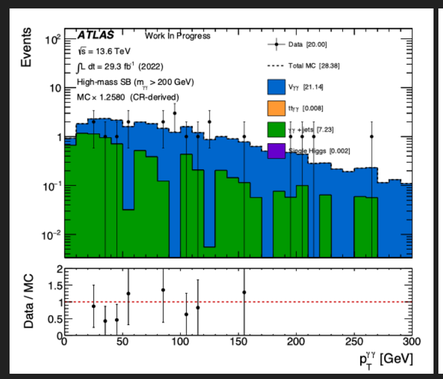
CR: High sideband mass (2022)

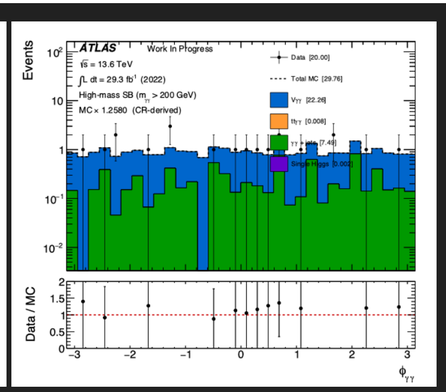
Table 9: Cutflow — Control Region — High-mass Sideband, mc23a.

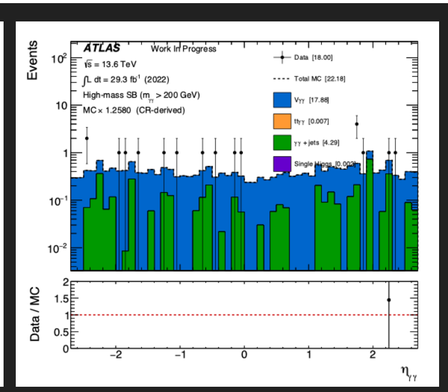
Selection Step	Signal	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$	Single Higgs	Total Bkg.	Data
1) Initial Events	12.35	127,288.82	1,739.16	53.36	216.30	129,297.65	1,235,725
2) PASS_Trigger	12.35	127,288.82	1,739.16	53.36	216.30	129,297.65	1,235,725
3) Pass diphoton trigger matching	12.35	127,288.82	1,739.16	53.36	216.30	129,297.65	1,235,725
4) Photon ID/Iso (Tight_FixedCutLoose)	9.18	87,211.66	969.39	33.58	161.02	88,375.66	266,489
5) Photon eta & crack veto	9.12	86,848.86	964.34	33.42	160.37	88,006.98	265,395
6) $p_T(\gamma_1)$>35 GeV & $p_T(\gamma_2)$>25 GeV	9.11	86,663.58	960.85	33.40	160.30	87,818.13	262,847
7) $p_T(\gamma_1)/m_{\gamma\gamma}$>0.35 & $p_T(\gamma_2)/m_{\gamma\gamma}$>0.25	8.20	69,686.07	817.86	28.05	143.13	70,675.11	231,225
8) $m_{\gamma\gamma}$>105 GeV	8.15	38,300.88	284.18	18.60	143.02	38,746.67	47,688
9) High-mass SB ($m_{\gamma\gamma}$>200 GeV)	0.01	1,949.07	56.90	0.14	0.07	2,006.18	2,471
10) $N_{b\text{-jets}} = 0$	0.01	1,906.68	55.35	0.03	0.05	1,962.10	2,389
11) $\gamma\gamma$ + 1μ, veto taus & electrons (0e, 0τ, 1μ)	0.00	5.80	17.70	0.01	0.00	23.51	20

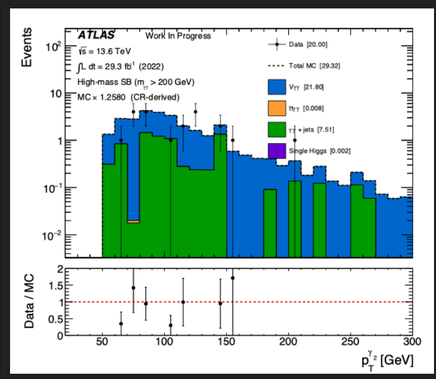


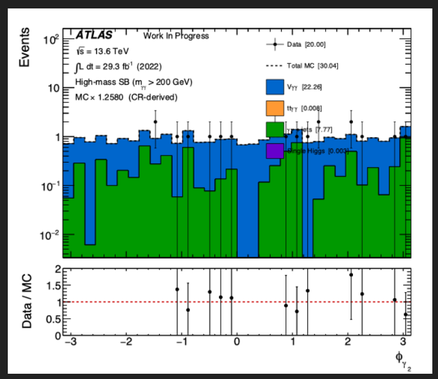


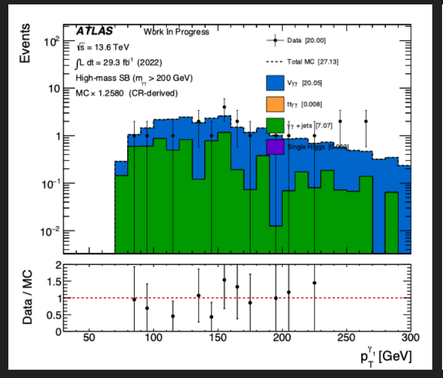


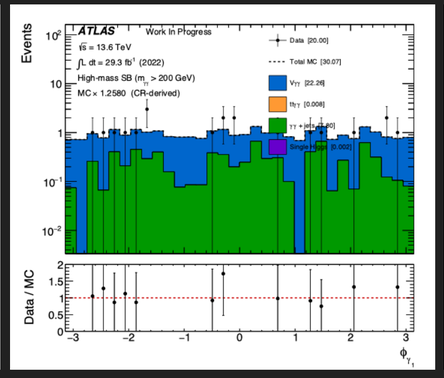


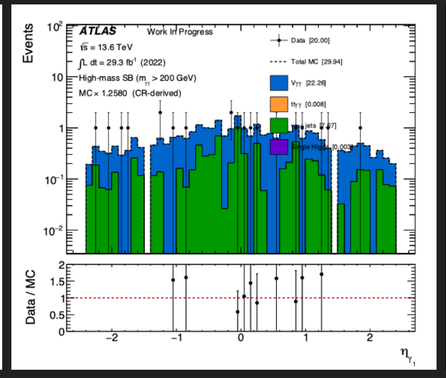


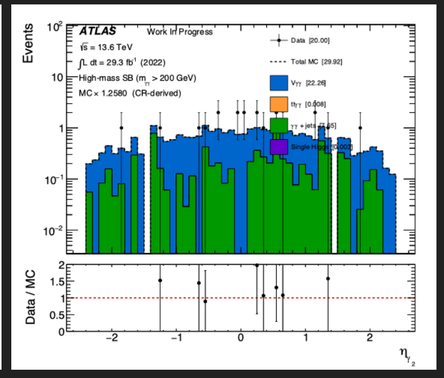










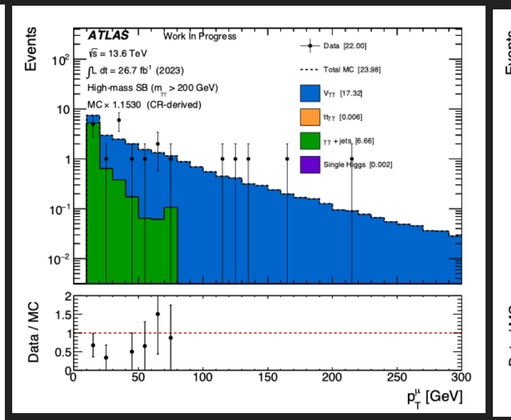


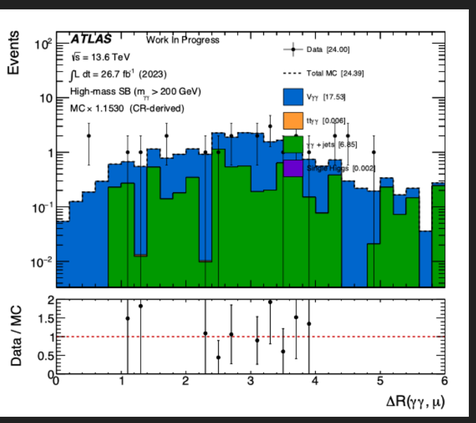
ATLAS EXPERIMENT

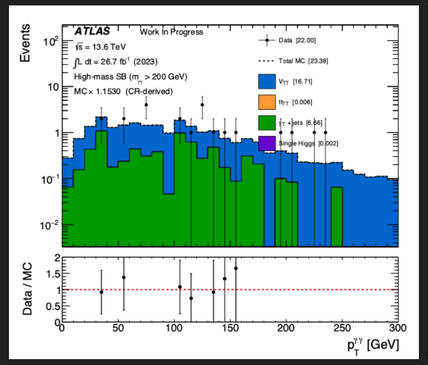
CR: High sideband mass (2023)

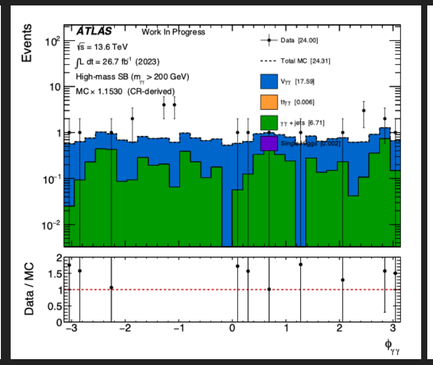
Table 10: Cutflow — Control Region — High-mass Sideband, mc23d.

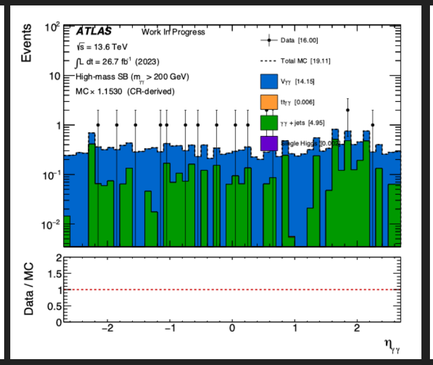
Selection Step	Signal	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$	Single Higgs	Total Bkg.	Data
1) Initial Events	10.50	118,475.92	1,516.21	46.59	203.48	120,242.20	1,302,690
2) PASS_Trigger	10.50	118,475.92	1,516.21	46.59	203.48	120,242.20	1,302,690
3) Pass diphoton trigger matching	10.50	118,475.92	1,516.21	46.59	203.48	120,242.20	1,302,690
4) Photon ID/Iso (Tight_FixedCutLoose)	7.61	79,485.26	815.61	28.53	148.65	80,478.05	269,892
5) Photon eta & crack veto	7.57	79,132.63	811.33	28.39	148.01	80,120.36	268,655
6) $p_T(\gamma_1)$>35 GeV & $p_T(\gamma_2)$>25 GeV	7.57	78,970.90	808.15	28.37	147.94	79,955.37	265,832
7) $p_T(\gamma_1)/m_{\gamma\gamma}$>0.35 & $p_T(\gamma_2)/m_{\gamma\gamma}$>0.25	6.82	63,931.18	688.78	23.85	132.77	64,776.58	232,914
8) $m_{\gamma\gamma}$>105 GeV	6.78	35,707.99	242.90	15.94	132.67	36,099.49	48,468
9) High-mass SB ($m_{\gamma\gamma}$>200 GeV)	0.00	1,860.37	49.39	0.11	0.06	1,909.93	2,382
10) $N_{b\text{-jets}} = 0$	0.00	1,822.30	48.03	0.02	0.05	1,870.41	2,322
11) $\gamma\gamma$ + 1μ, veto taus & electrons (0e, 0τ, 1μ)	0.00	5.77	15.26	0.01	0.00	21.04	24

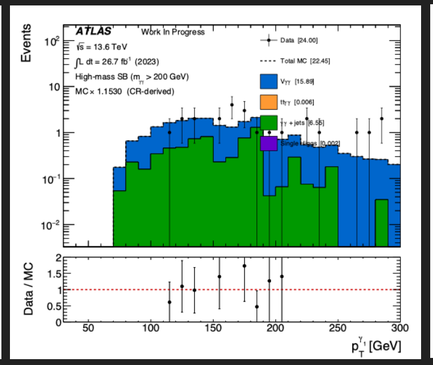


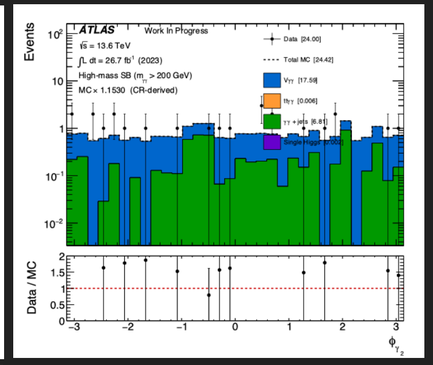


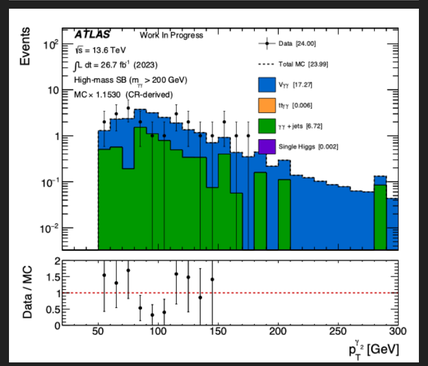


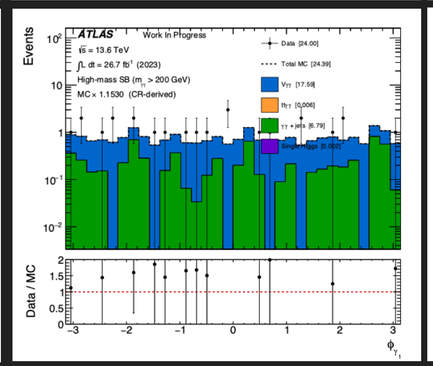


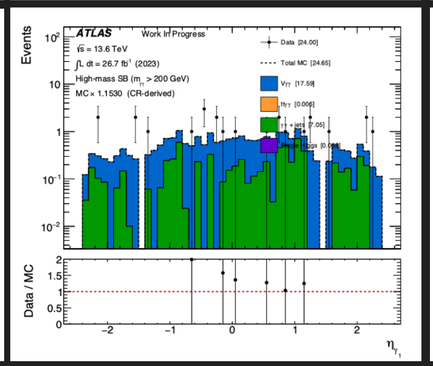


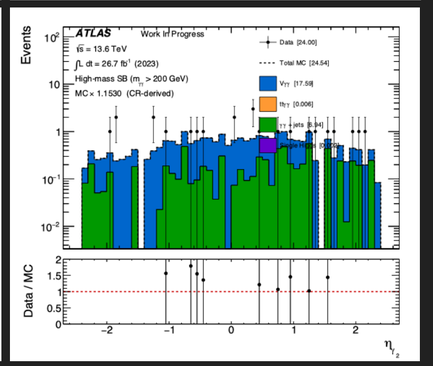








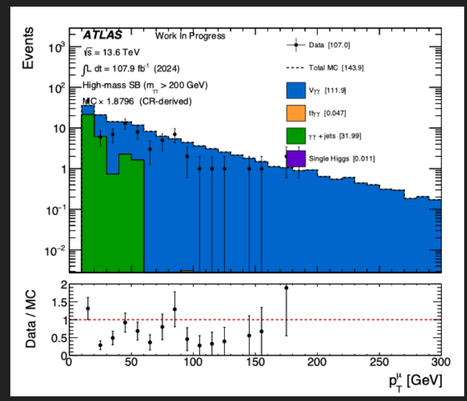


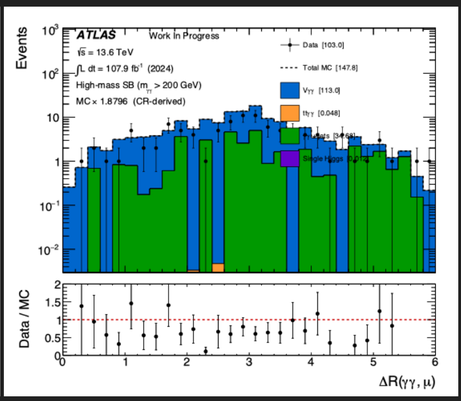


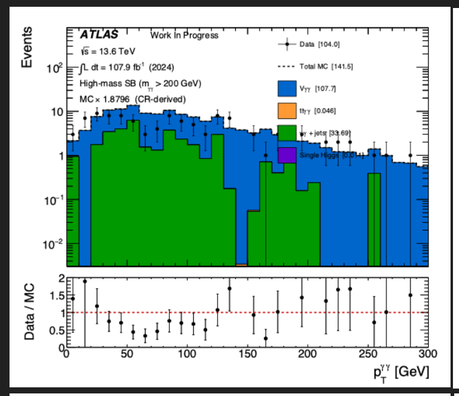
CR: High sideband mass (2024)

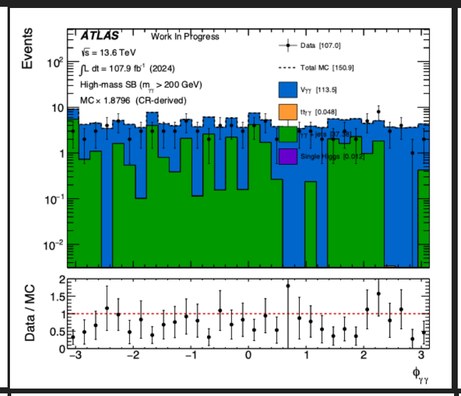
Table 11: Cutflow — Control Region — High-mass Sideband, mc23e.

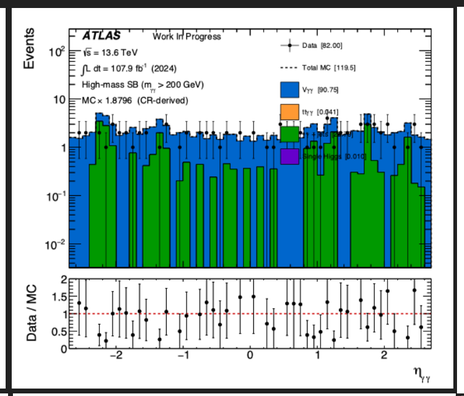
Selection Step	Signal	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$	Single Higgs	Total Bkg.	Data
1) Initial Events	42.00	51,933.84	6,293.96	191.07	874.76	59,293.62	5,722,642
2) PASS_Trigger	42.00	51,933.84	6,293.96	191.07	874.76	59,293.62	5,722,642
3) Pass diphoton trigger matching	42.00	51,933.84	6,293.96	191.07	874.76	59,293.62	5,722,642
4) Photon ID/Iso (Tight_FixedCutLoose)	30.24	38,527.25	3,310.39	115.05	633.40	42,586.10	1,151,021
5) Photon eta & crack veto	30.06	38,309.10	3,292.16	114.45	630.66	42,346.38	1,146,026
6) $p_T(\gamma_1)$>35 GeV & $p_T(\gamma_2)$>25 GeV	30.06	38,281.21	3,276.74	114.39	630.36	42,302.71	1,134,479
7) $p_T(\gamma_1)/m_{\gamma\gamma}$>0.35 & $p_T(\gamma_2)/m_{\gamma\gamma}$>0.25	27.05	15,644.42	2,788.95	95.55	565.79	19,094.71	995,706
8) $m_{\gamma\gamma}$>105 GeV	26.87	15,574.18	969.44	63.45	565.36	17,172.44	212,098
9) High-mass SB ($m_{\gamma\gamma}$>200 GeV)	0.02	8,393.40	196.96	0.47	0.25	8,591.09	11,228
10) $N_{b\text{-jets}} = 0$	0.01	8,228.53	191.57	0.11	0.19	8,420.39	10,866
11) $\gamma\gamma$ + 1μ, veto taus & electrons (0e, 0τ, 1μ)	0.00	17.02	60.36	0.03	0.01	77.41	107

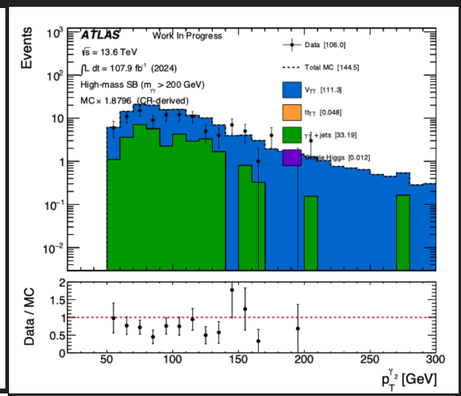


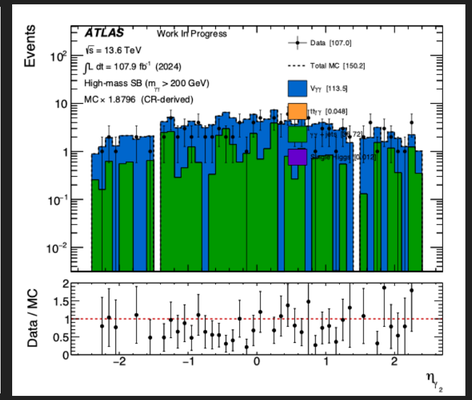


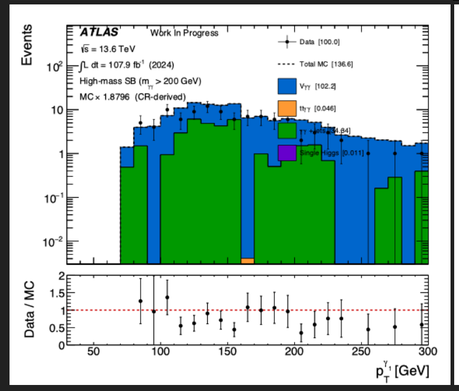


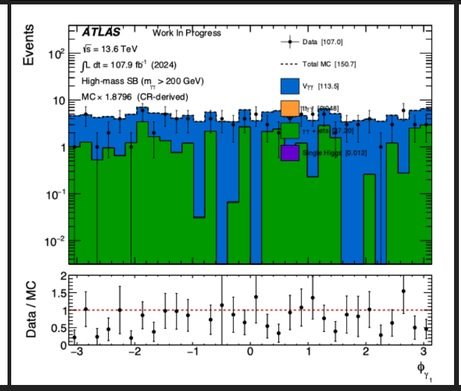


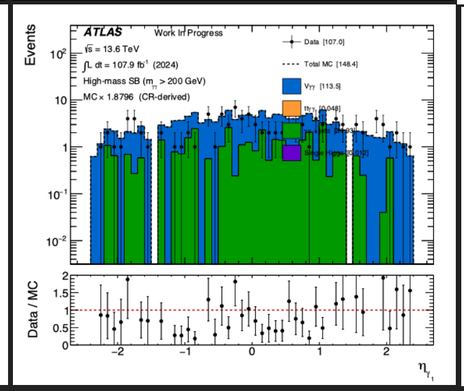


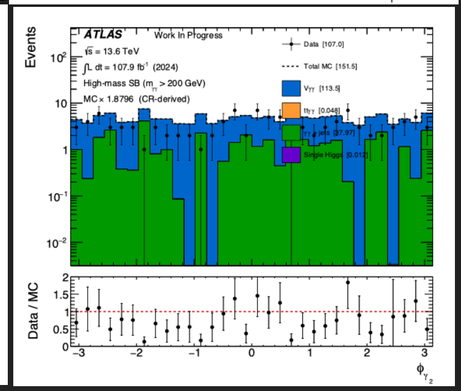










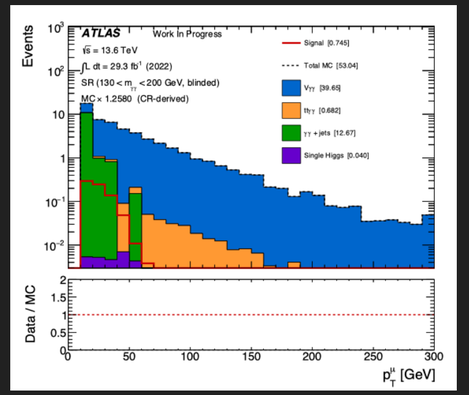


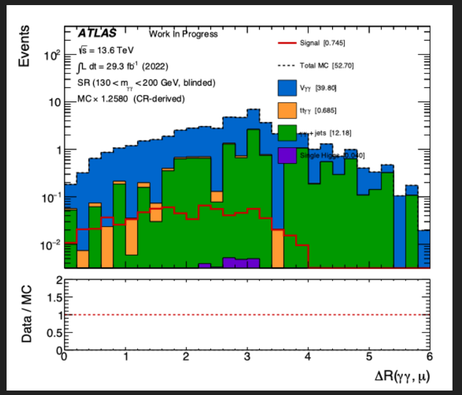
ATLAS EXPERIMENT

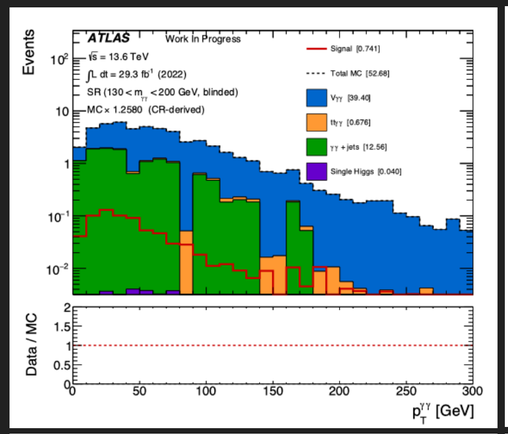
SR: Kinematic Distribution (2022)

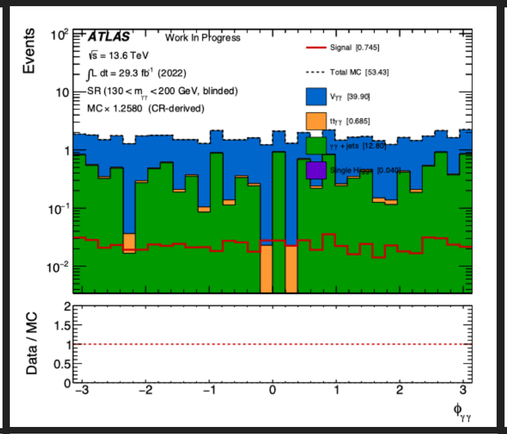
Table 17: Cutflow — Signal Region (SR) — Blinded, mc23a.

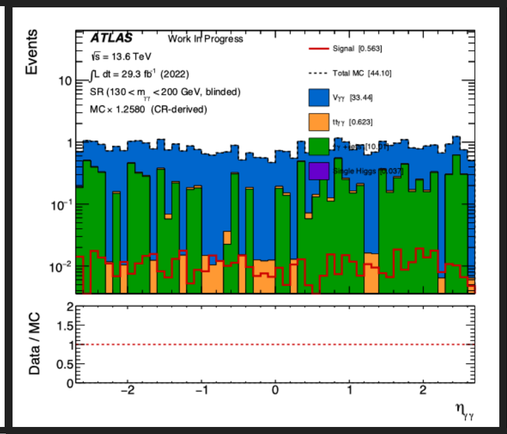
Selection Step	Signal	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$	Single Higgs	Total Bkg.	Data
1) Initial Events	12.35	127,288.82	1,739.16	53.36	216.30	129,297.65	**Blinded**
2) PASS_Trigger	12.35	127,288.82	1,739.16	53.36	216.30	129,297.65	**Blinded**
3) Pass diphoton trigger matching	12.35	127,288.82	1,739.16	53.36	216.30	129,297.65	**Blinded**
4) Photon ID/Iso (Tight_FixedCutLoose)	9.18	87,211.66	969.39	33.58	161.02	88,375.66	**Blinded**
5) Photon eta & crack veto	9.12	86,848.86	964.34	33.42	160.37	88,006.98	**Blinded**
6) $p_T(\gamma_1) > 35$ GeV & $p_T(\gamma_2) > 25$ GeV	9.11	86,663.58	960.85	33.40	160.30	87,818.13	**Blinded**
7) $p_T(\gamma_1)/m_{\gamma\gamma} > 0.35$ & $p_T(\gamma_2)/m_{\gamma\gamma} > 0.25$	8.20	69,686.07	817.86	28.05	143.13	70,675.11	**Blinded**
8) $m_{\gamma\gamma} > 105$ GeV	8.15	38,300.88	284.18	18.60	143.02	38,746.67	**Blinded**
9) $130 < m_{\gamma\gamma} < 200$ GeV	8.13	12,598.28	113.29	8.52	3.21	12,723.30	**Blinded**
10) $N_{b\text{-jets}} = 0$	7.93	12,424.64	110.62	1.78	3.13	12,540.16	**Blinded**
11) $\gamma\gamma + 1\mu + \mu$ quality (Medium ID, $\lvert d_0/\sigma_{d_0}\rvert < 3$, $\lvert z_0 \sin\theta\rvert < 0.5$ mm), $0e$, 0τ	0.58	9.49	30.93	0.53	0.03	40.98	**Blinded**

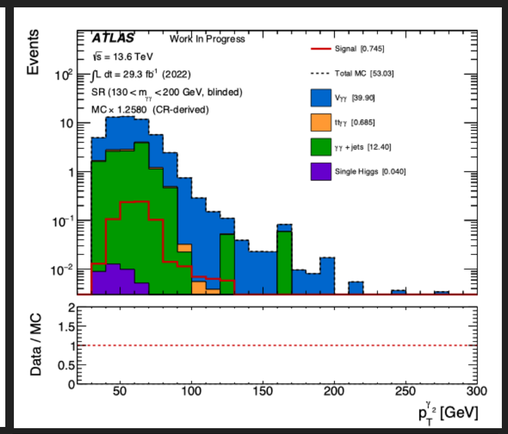


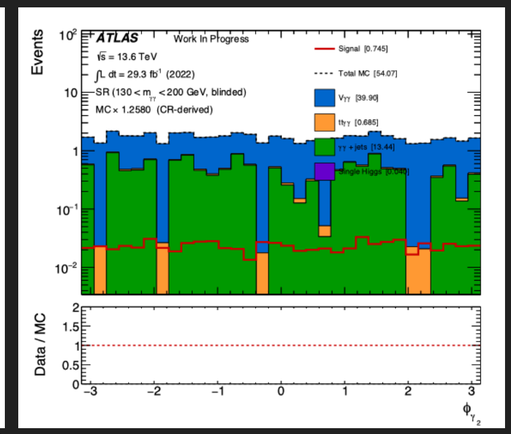


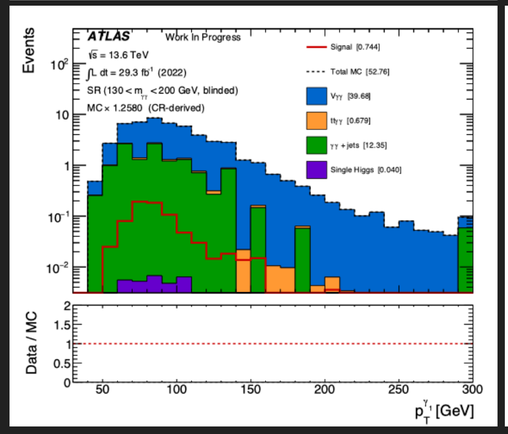


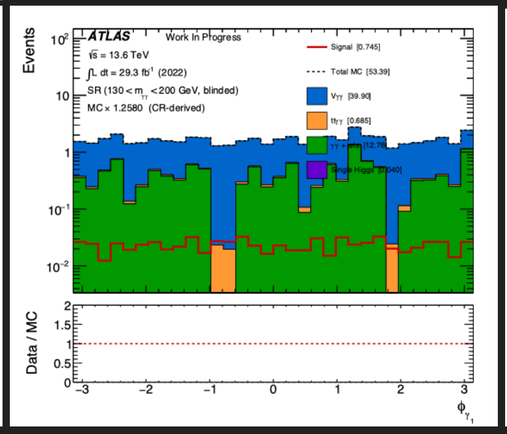


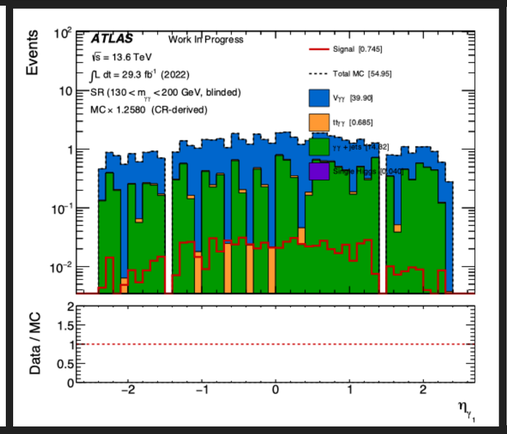


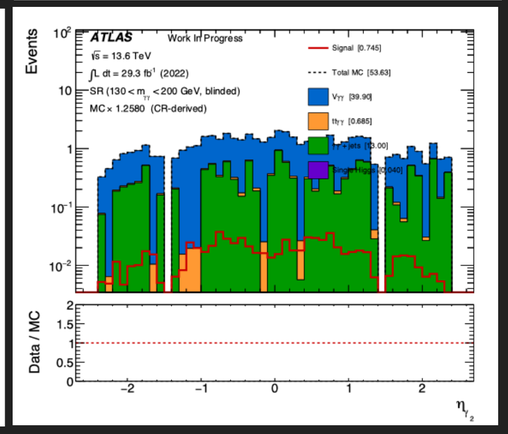










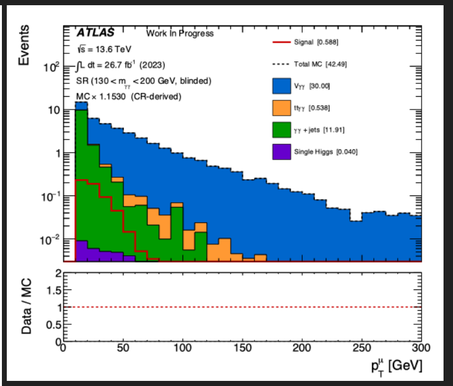


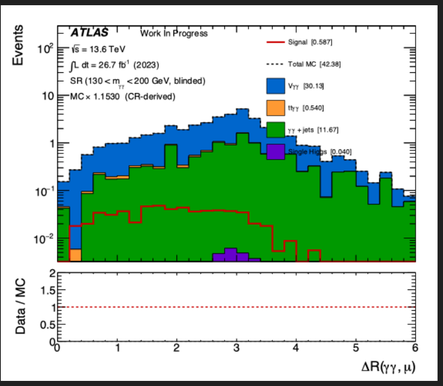
ATLAS EXPERIMENT

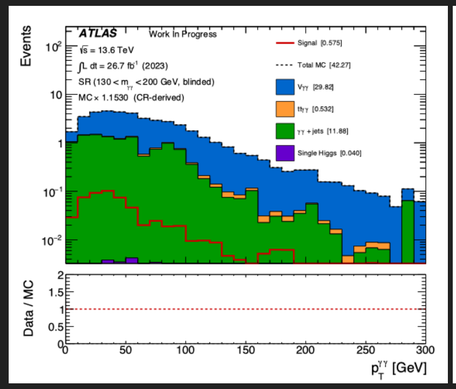
SR: kinematic Distribution (2023)

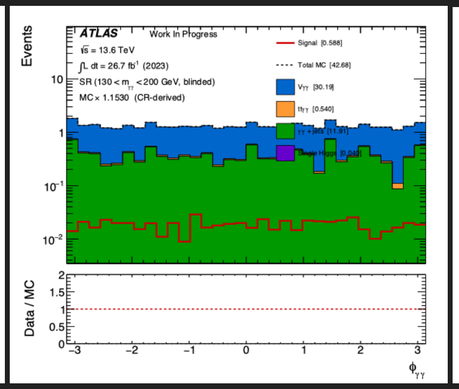
Table 18: Cutflow — Signal Region (SR) — Blinded, mc23d.

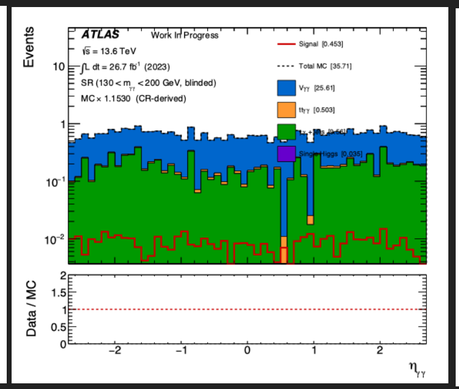
Selection Step	Signal	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$	Single Higgs	Total Bkg.	Data
1) Initial Events	10.50	118,475.92	1,516.21	46.59	203.48	120,242.20	**Blinded**
2) PASS_Trigger	10.50	118,475.92	1,516.21	46.59	203.48	120,242.20	**Blinded**
3) Pass diphoton trigger matching	10.50	118,475.92	1,516.21	46.59	203.48	120,242.20	**Blinded**
4) Photon ID/Iso (Tight_FixedCutLoose)	7.61	79,485.26	815.61	28.53	148.65	80,478.05	**Blinded**
5) Photon eta & crack veto	7.57	79,132.63	811.33	28.39	148.01	80,120.36	**Blinded**
6) $p_T(\gamma_1) > 35$ GeV & $p_T(\gamma_2) > 25$ GeV	7.57	78,970.90	808.15	28.37	147.94	79,955.37	**Blinded**
7) $p_T(\gamma_1)/m_{\gamma\gamma} > 0.35$ & $p_T(\gamma_2)/m_{\gamma\gamma} > 0.25$	6.82	63,931.18	688.78	23.85	132.77	64,776.58	**Blinded**
8) $m_{\gamma\gamma} > 105$ GeV	6.78	35,707.99	242.90	15.94	132.67	36,099.49	**Blinded**
9) $130 < m_{\gamma\gamma} < 200$ GeV	6.77	11,955.88	96.16	7.32	3.32	12,062.68	**Blinded**
10) $N_{b\text{-jets}} = 0$	6.57	11,792.86	93.85	1.51	3.23	11,891.45	**Blinded**
11) $\gamma\gamma + 1\mu + \mu$ quality (Medium ID, $\lvert d_0/\sigma_{d_0}\rvert < 3$, $\lvert z_0 \sin\theta\rvert < 0.5$ mm), $0e$, 0τ	0.51	10.24	25.89	0.46	0.03	36.63	**Blinded**

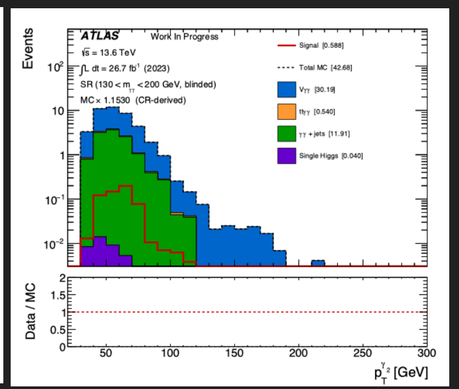


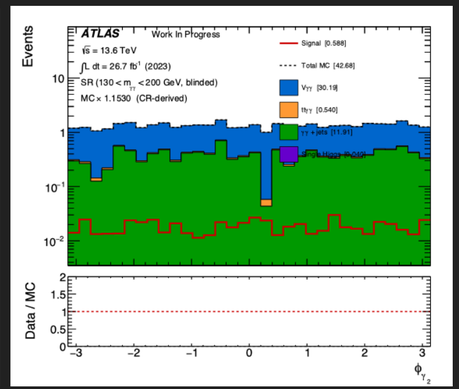


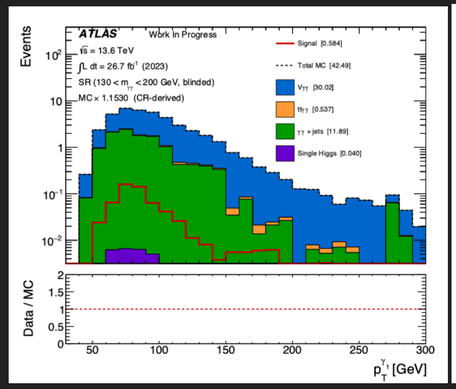


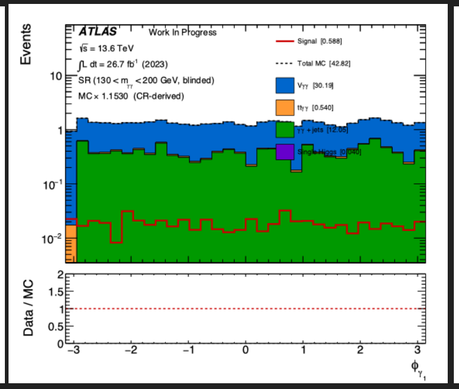


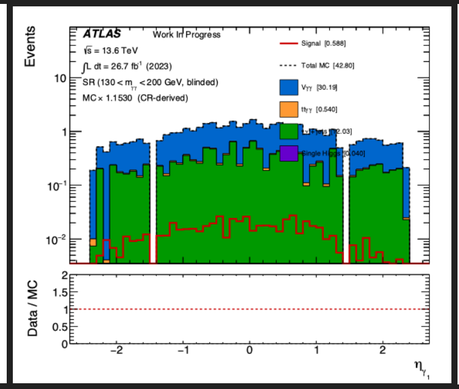


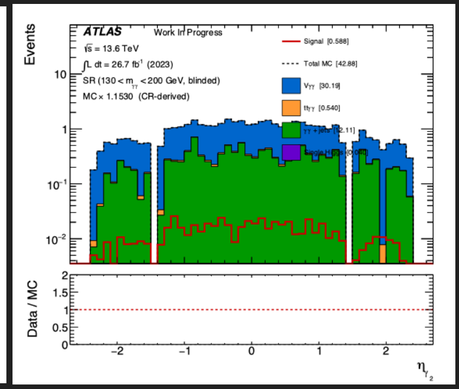










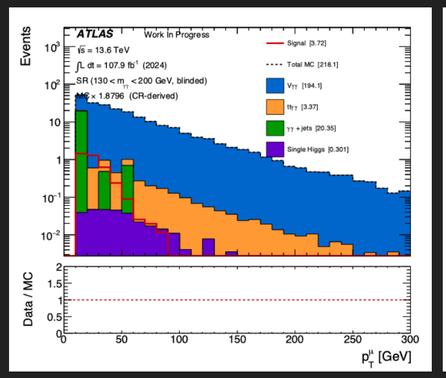


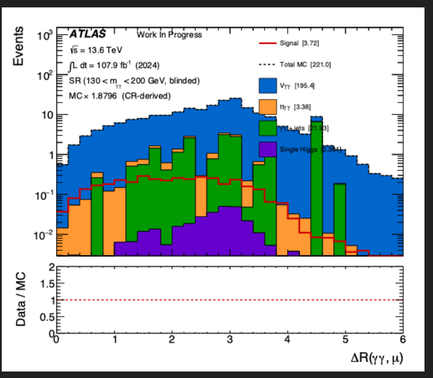
ATLAS EXPERIMENT

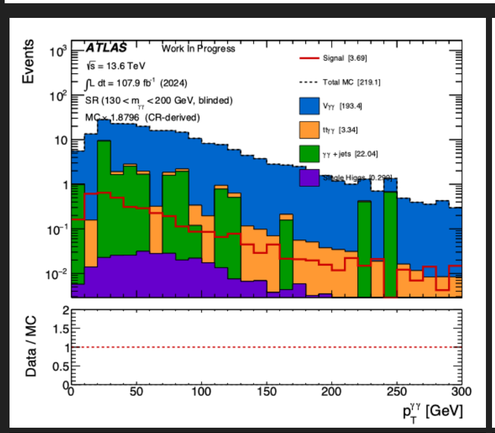
SR: Kinematic Distribution (2024)

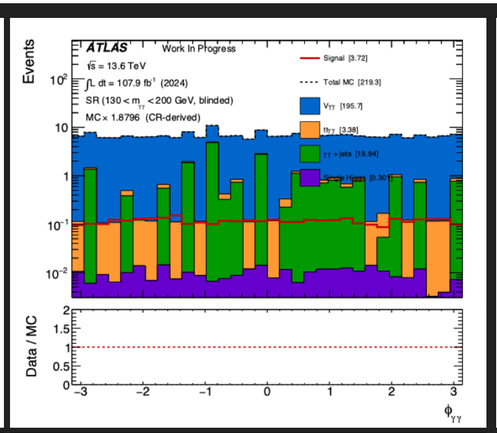
Table 19: Cutflow — Signal Region (SR) — Blinded, mc23e.

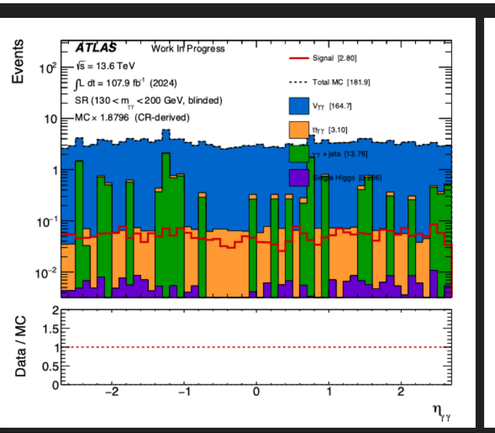
Selection Step	Signal	$\gamma\gamma$+jets	$V\gamma\gamma$	$t\bar{t}\gamma\gamma$	Single Higgs	Total Bkg.	Data
1) Initial Events	42.00	51,933.84	6,293.96	191.07	874.76	59,293.62	**Blinded**
2) PASS_Trigger	42.00	51,933.84	6,293.96	191.07	874.76	59,293.62	**Blinded**
3) Pass diphoton trigger matching	42.00	51,933.84	6,293.96	191.07	874.76	59,293.62	**Blinded**
4) Photon ID/Iso (Tight_FixedCutLoose)	30.24	38,527.25	3,310.39	115.05	633.40	42,586.10	**Blinded**
5) Photon eta & crack veto	30.06	38,309.10	3,292.16	114.45	630.66	42,346.38	**Blinded**
6) $p_T(\gamma_1) > 35$ GeV & $p_T(\gamma_2) > 25$ GeV	30.06	38,281.21	3,276.74	114.39	630.36	42,302.71	**Blinded**
7) $p_T(\gamma_1)/m_{\gamma\gamma} > 0.35$ & $p_T(\gamma_2)/m_{\gamma\gamma} > 0.25$	27.05	15,644.42	2,788.95	95.55	565.79	19,094.71	**Blinded**
8) $m_{\gamma\gamma} > 105$ GeV	26.87	15,574.18	969.44	63.45	565.36	17,172.44	**Blinded**
9) $130 < m_{\gamma\gamma} < 200$ GeV	26.82	7,128.19	387.30	29.12	15.62	7,560.24	**Blinded**
10) $N_{b\text{-jets}} = 0$	26.02	7,021.34	378.02	6.22	15.19	7,420.77	**Blinded**
11) $\gamma\gamma + 1\mu + \mu$ quality (Medium ID, $\lvert d_0/\sigma_{d_0}\rvert < 3$, $\lvert z_0 \sin\theta\rvert < 0.5$ mm), $0e$, 0τ	1.96	9.20	102.92	1.78	0.16	114.05	**Blinded**

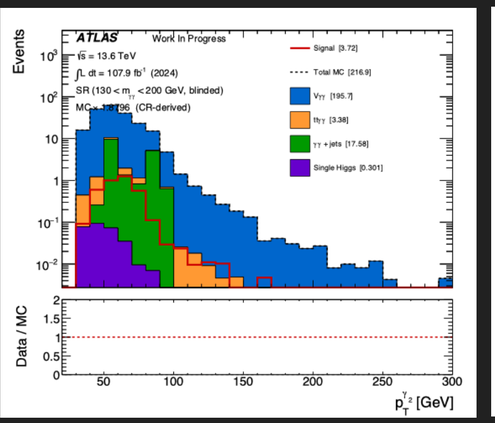


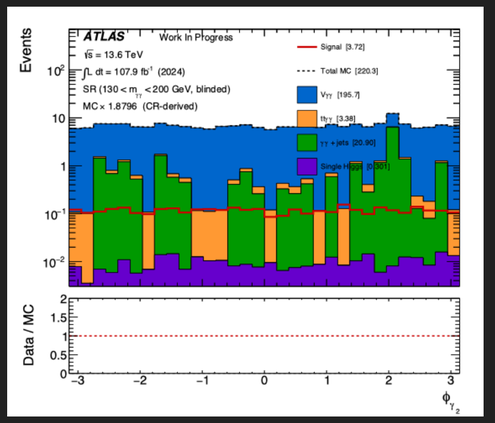


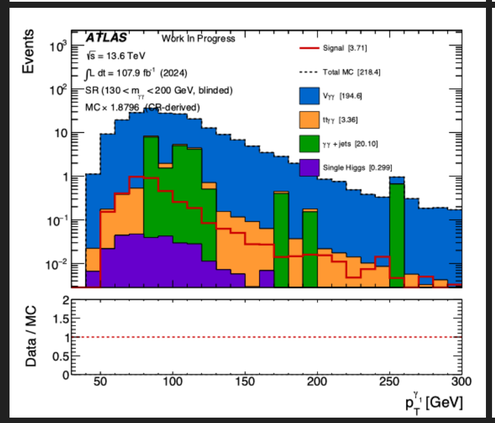


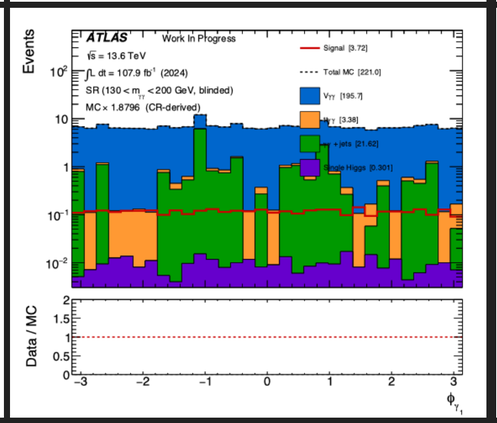


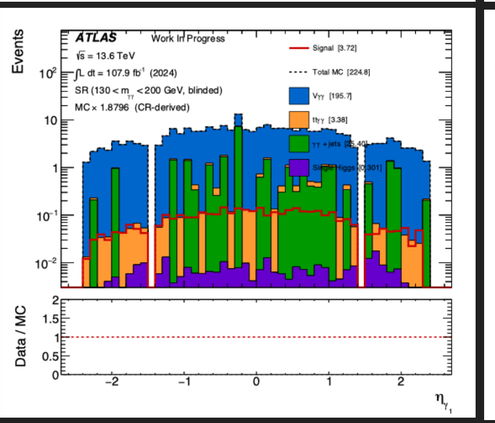


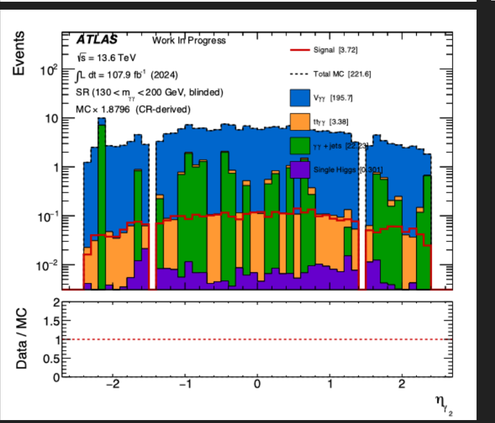












ATLAS EXPERIMENT

Fake Factors Studies for the Muon channel (2022 data)

2. Region Definition

The following WP were used :

1. Medium_PflowLoose_VarRad
2. Tight_NonIso

Region definitions:

A	=	Passes Medium ID	&	Tight Iso
B	=	Fails Medium ID	&	Passes Tight Iso
C	=	Passes Medium ID	&	Fails Tight Iso
D	=	Fails Medium ID	&	Tight Iso

3. Yield Calculation

- Fake Muon = Yield in region (B * C) / D
- yyjets is enriched in fakes so we ignore it.
- Prompt MC = Signal + Vyy + ttyy + Single H
- If (Data - Prompt MC) < 0. Consider the yield to be 0 in the region.

4. Error Calculation

- Relative poisson uncertainty : $\frac{\sigma_{data}}{N} = \frac{1}{\sqrt{N}}$
- Weighted MC uncertainty : $\sigma_{MC} = \sqrt{\sum_i w_i^2}$
- Uncertainty in region yields : $\sqrt{\sigma_{data}^2 + \sigma_{MC}^2}$
- Error in fake prediction : $N_{fake} \times \sqrt{(\frac{\sigma_B}{B})^2 + (\frac{\sigma_C}{C})^2 + (\frac{\sigma_D}{D})^2}$

5. Region Yields and Fake Muon Estimation

Process	A	B	C	D	Fake Muons
Data	38.000 ± 6.164	6.000 ± 2.449	1.000 ± 1.000	2.000 ± 1.414	3.000 ± 3.873
yyjets	2.630 ± 0.633	9.691 ± 0.675	1.060 ± 0.247	2.459 ± 0.481	4.179 ± 1.304
Signal	0.478 ± 0.016	0.010 ± 0.002	0.021 ± 0.003	0.010 ± 0.002	0.020 ± 0.007
Vyy	25.951 ± 0.310	0.326 ± 0.046	1.178 ± 0.067	0.455 ± 0.041	0.845 ± 0.149
ttyy	0.454 ± 0.010	0.020 ± 0.002	0.023 ± 0.002	0.008 ± 0.001	0.059 ± 0.012
SingleHiggs	0.028 ± 0.002	0.001 ± 0.000	0.001 ± 0.000	0.001 ± 0.000	0.001 ± 0.001
Data - MC	11.089 ± 6.172	5.644 ± 2.450	0.000 ± 1.002	1.527 ± 1.415	0.000 ± 1.608

6. Check for Region Definition

Comparing yields in final cutflow with yields in region A+B+C+D to see there is any correlation.

DATA

Final cutflow	=	47
A+B+C+D	=	47

MC PER PROCESS

Process	Final Cut	ABCD Sum
Signal	0.519	0.519
Vyy	27.910	27.910
ttyy	0.504	0.504
yyjets	15.841	15.841
SingleHiggs	0.030	0.030
TotalMC	44.804	44.804

Muon fake rates obtained using previous version of the 2022 dataset(MC and Data). 2023 and 2024 were still in preparation.

Credit: Arnav Chauhan

ATLAS EXPERIMENT