Preparing for Diphoton Resonance Searches in the Leptonic, 0-τ Final States: Event Selection and Background Characterization Using ATLAS Run 3 Data

ATLAS EXPERIMENT

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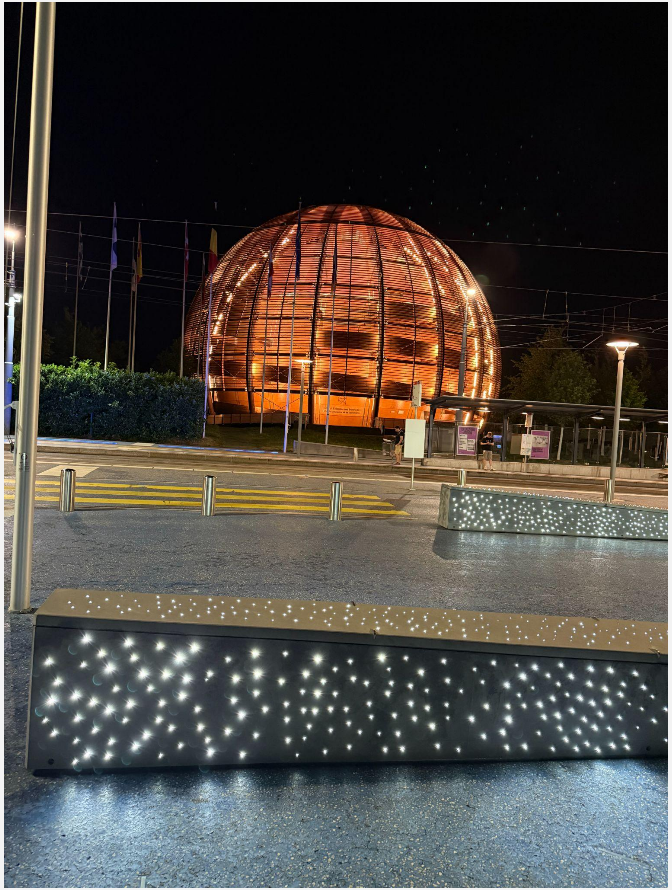
iThemba LABS Laboratory for Accelerator Based Sciences

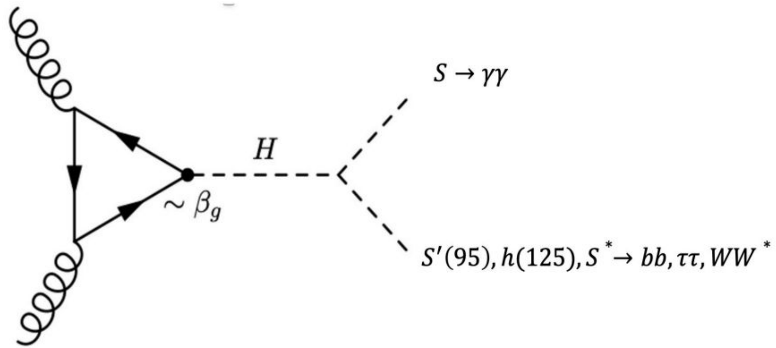
Outline

- Final State Motivation
- Analysis Framework
- Background Characteristics
- Event Selection Strategy
- Object Kinematics from Background
- Conclusion



Final State Motivation

- **Physics Motivation**
  - ❑ Sensitive to extended Higgs sector models like **2HDM+S** (arXiv:1606.01674 **[hep-ph]**) **(see Vuyolwethu Kakancu presentation)**
  - ❑ Also aligns with ATLAS searches in similar final states
    - ➢ $bb\gamma\gamma$ (arXiv:2404.12915 **[hep-ex]**)
    - ➢ $\ell\ell\gamma\gamma$ (arXiv:2405.20926 **[hep-ex]**)
  - ❑ Predicted decay,
    - ➢ $H \rightarrow SS'$, with
    - ➢ $S \rightarrow \gamma\gamma$,
    - ➢ $S' \rightarrow WW, \tau\tau, bb$



- **Final States**
  - ❑ Signatures :**γγ+1ℓ , γγ+2ℓ**, with 0 hadronic taus
  - ❑ Clean, fully reconstructable, low background
  - ❑ High photon and lepton ID efficiency in ATLAS
- **Why γγ+1ℓ, γγ+2ℓ , 0-τ?**
  - ❑ Avoids hadronic reconstruction complications
  - ❑ Suppresses backgrounds like $t\bar{t}\gamma\gamma$
  - ❑ Focus on leptonic decays of WW^*

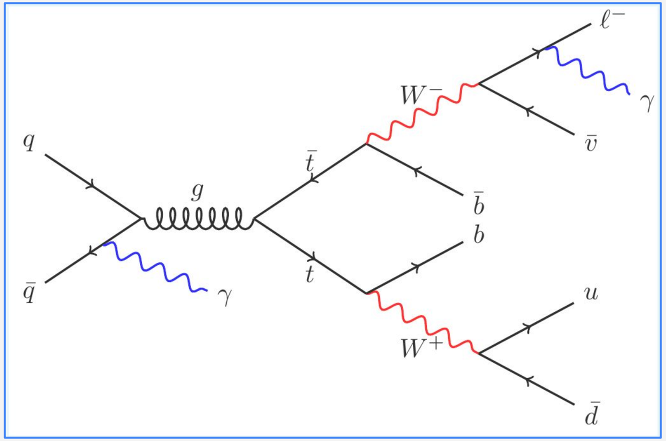
Analysis Framework (Easyjet)

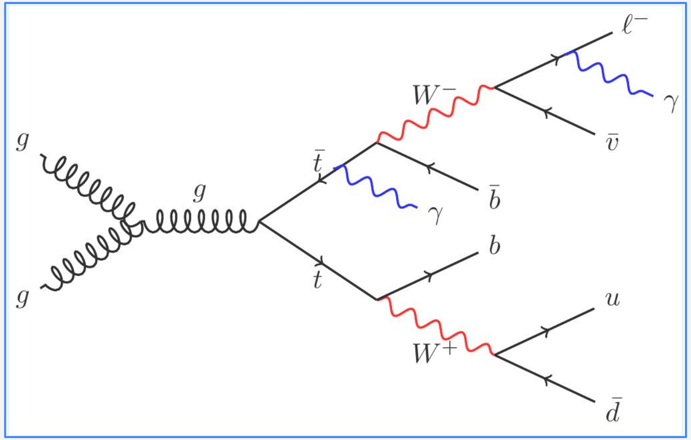
- **Framework**
  - Easyjet https://gitlab.cern.ch/easyjet/easyjet

- **Purpose**
  - Ensures reproducibility,
  - standardized object definitions
  - and integration with official recommendations
  - Ntuple production
- **Implemented so far**
  - Photon and Lepton object definitions using ATLAS-recommended ID and Isolation
  - Tau veto (no hadronic taus)
  - Event-level selection logic
  - Output configuration for:
    - Histograms (kinematics, ID, Isolation)
    - Cutflows
- **Advantages**
  - Scalable for addition final states (e.g $\gamma\gamma$+1ℓ+b, $\gamma\gamma$+1τ, $\gamma\gamma$+2τ)
  - Easy integration with signal once available.

Background Characterization

- **Dominant background(and why?)**
  - ❑ Produces **two real leptons** from W→ℓν decays of the top quarks
  - ❑ Two **real photons** from
    - ➢ Final state radiation (FSR)
    - ➢ Initial state radiation (ISR)
    - ➢ Radiative top decays

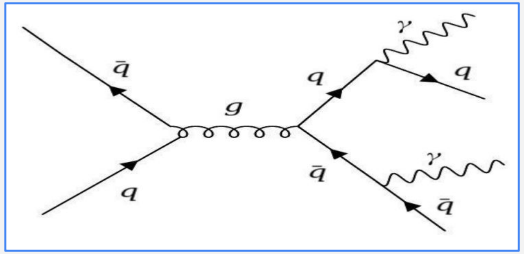




Credit:Observation of t̄tγγ production at $\sqrt{s}$ =13 TeV with the ATLAS detector arXiv:2506.05018 **[hep-ex]**

- Final states **mimics signal** topology: **γγ+1ℓ, γγ+2ℓ , 0-τ**

- **Why it is critical in this phase?**
  - Signal MC is **not yet available**, so all current studies are **based on background.**
  - **Used to:**
    - Validate event selection and cuts,
    - Produce kinematic distributions,
    - Test trigger thresholds,
    - Prepare for signal-region optimization.
  - Helps in shaping expectations for control region definitions later.



- **Other relative backgrounds**
  - γγ+jj:
    - Events with **two prompt photons** plus additional jets can mimic signal if jets overlap or produce fake leptons.
    - Requires careful modeling and understanding, especially when no τ's are present.
    - need more information for minimization and fake rates.

Event Selection for $\gamma\gamma$+1ℓ, 0-τ

- **Photon selection**
  - Require = 2
  - ID: Loose
  - Isolation: FixedCutLoose
  - Primary and Secondary
    - $p_T \geq 35$ GeV (leading)
    - $p_T \geq 25$ GeV (subleading)
    - $|\eta| < 2.37$ $(1.37 < |\eta| < 1.52)$
- **Electron selection**
  - Require =1
  - ID: MediumLH
  - Isolation: Loose
  - Primary
    - p_T >10 GeV (minimum)
    - $|\eta| < 2.5$
- **Muon selection**
  - Require = 1
  - ID: Medium
  - Isolation: Loose
  - Primary
    - $p_T > 10$ GeV (minimum)
    - $|\eta| < 2.5$
- **Triggers**

```
selection:
  chains:
    '2022':
    - 'HLT_g35_medium_g25_medium_L12EM20VH'
    - 'HLT_2g50_loose_L12EM20VH'
    - 'HLT_2g22_tight_L12EM15VHI'
    '2023':
    - 'HLT_g35_medium_g25_medium_L12eEM24L'
    - 'HLT_2g50_loose_L12eEM24L'
    - 'HLT_g45_medium_g20_medium_L1eEM40L_2eEM18L'
    - 'HLT_2g22_tight_L12eEM18M'
    '2024':
    - 'HLT_g35_medium_g25_medium_L12eEM24L'

scale_factor:
  doSF: false
```

Event Selection for γγ+2ℓ, 0-τ

- **Photon selection**
  - Require = 2
  - ID: Loose
  - Isolation: FixedCutLoose
  - Primary and Secondary
    - $p_T \geq 35$ GeV (leading)
    - $p_T \geq 25$ GeV (subleading)
    - $|\eta| < 2.37$ $(1.37 < |\eta| < 1.52)$
- **Electron selection**
  - Require = 2
  - ID: MediumLH
  - Isolation: Loose
  - Primary and Secondary
    - $p_T > 10$ GeV (minimum)
    - $|\eta| < 2.5$
- **Muon selection**
  - Require = 2
  - ID: Medium
  - Isolation: Loose
  - Primary and Secondary
    - $p_T > 10$ GeV (minimum)
    - $|\eta| < 2.5$
- **Sum of the two leptons**
  - Require = 2
  - ID: MediumLH(electrons), Medium(muons
  - Isolation: Loose

Table 1: Event selection breakdown from MC23a samples.

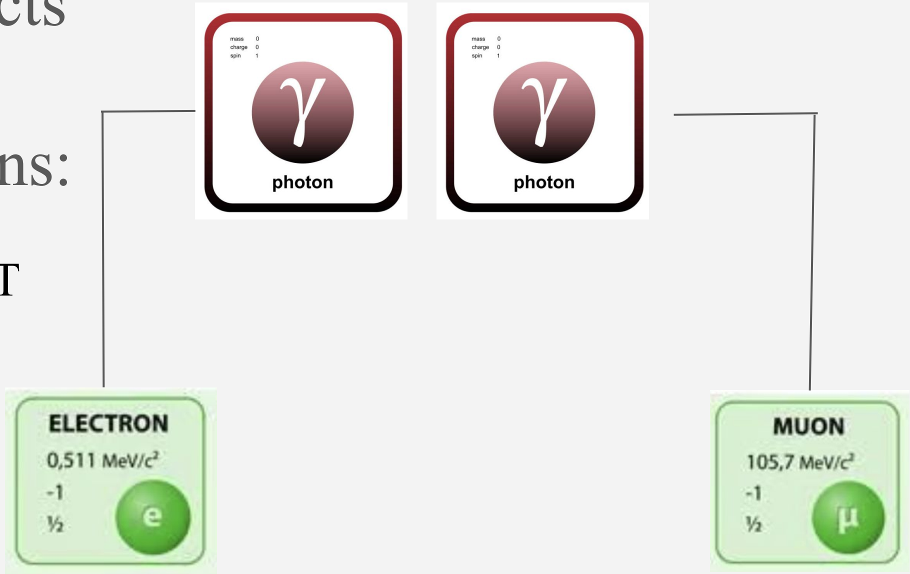
	$\gamma\gamma jj$	$\bar{t}t\gamma\gamma$
Number of Preselected events	2.24199×10^6	534144
Events passing the trigger	2.24199×10^6	534144
Cut: $\gamma\gamma + 1\ell$	1184	275872
Cut: $\gamma\gamma + 2\ell$	1	25830

Table 2: Cutflow Comparison for the $\gamma\gamma + 1\ell$ and $\gamma\gamma + 2\ell$ Final States

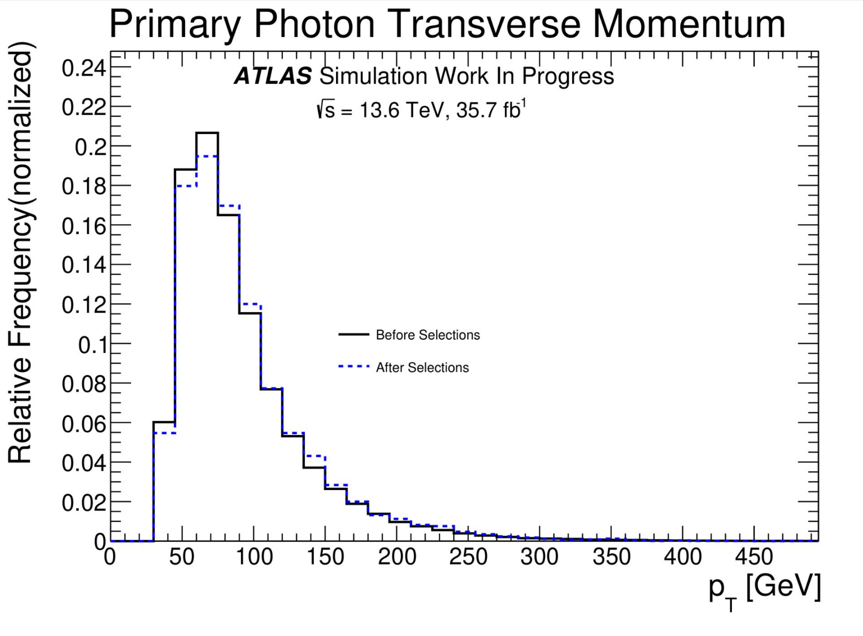
Cut Description	$\gamma\gamma + 1\ell$		$\gamma\gamma + 2\ell$	
	Events Passed	**Efficiency**	**Events Passed**	**Efficiency**
Total events	534144	1.0	534144	1.0
Pass Photon ID	405764	0.76	405764	0.76
Pass Photon Isolation	405764	0.76	405764	0.76
Pass Photon Selections	405558	0.76	405558	0.76
Pass Electron Selections	392068	0.73	392068	0.73
Pass Muon Selections	392068	0.73	392068	0.73
Final Selection (1ℓ or $2\ell + 0\tau$)	201682	0.38	19028	0.036

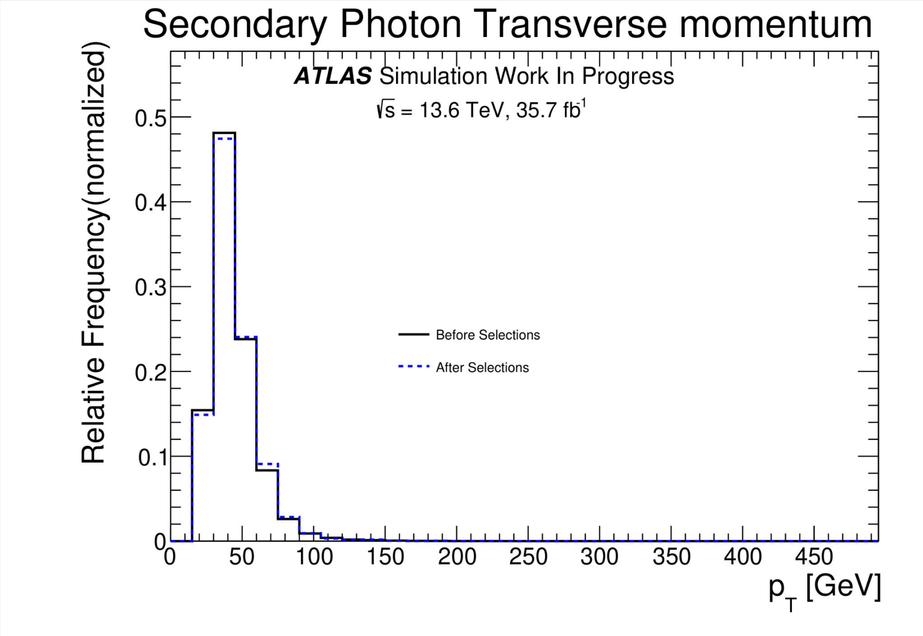
Objects Kinematics for $\gamma\gamma$+1ℓ, 0-τ

- Distribution Results for our objects
- Look at:
  - ❑ Photons, Electrons, and Muons:
    - ➢ Transverse momentum, p_T
    - ➢ Pseudorapidity, η
    - ➢ Azimuthal angle, φ

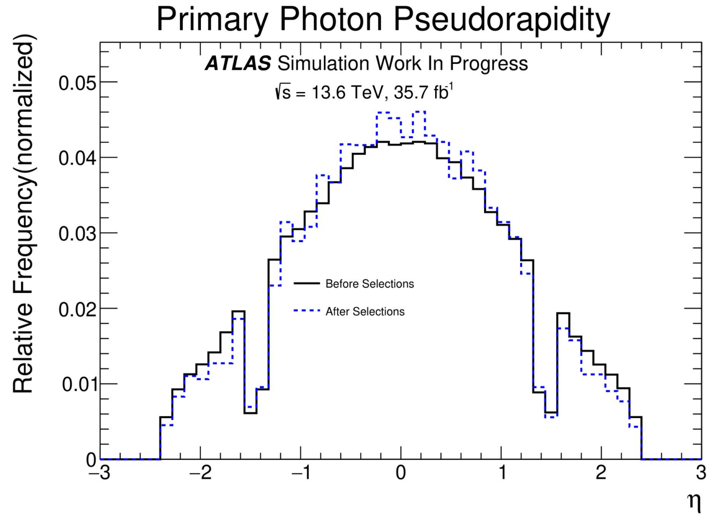


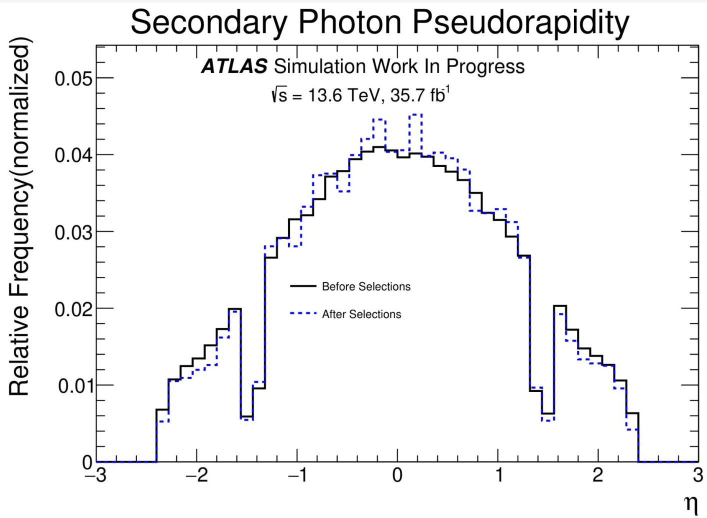
PHOTONS





- Photon p_T distributions match expected cuts.
- By increasing the bin size for clear visuality, the peak for the primary photon after the cut selection is reduced.


Primary Photon Pseudorapidity
ATLAS Simulation Work In Progress
√s = 13.6 TeV, 35.7 fb1
Before Selections
After Selections
Relative Frequency(normalized)
η


Secondary Photon Pseudorapidity
ATLAS Simulation Work In Progress
√s = 13.6 TeV, 35.7 fb1
Before Selections
After Selections
Relative Frequency(normalized)
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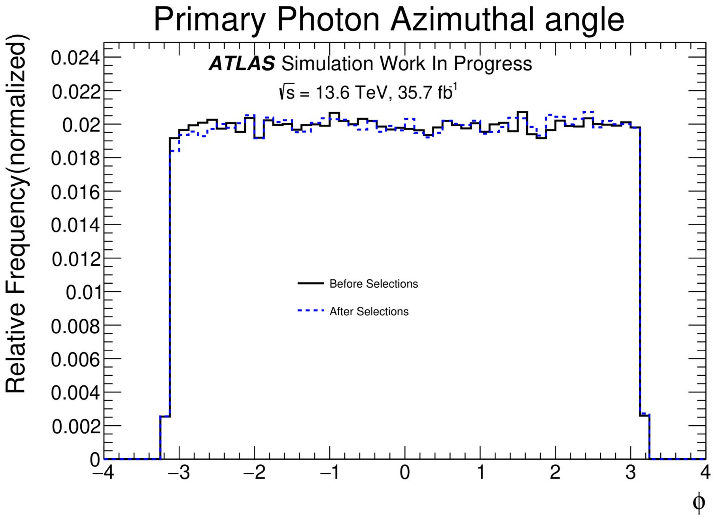
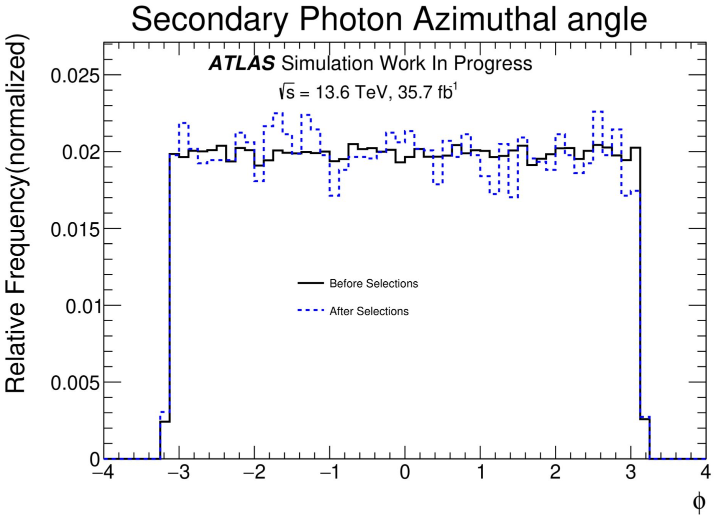
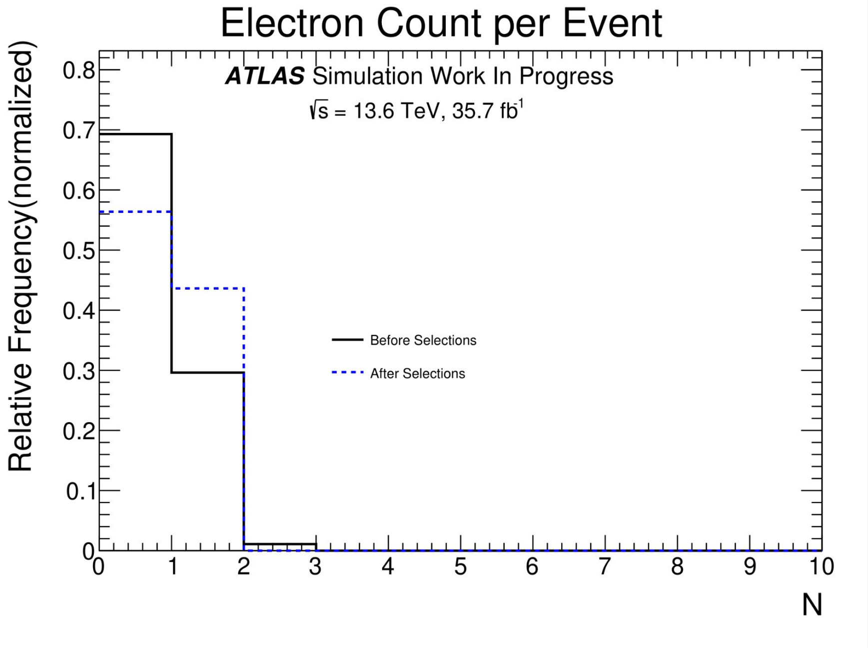
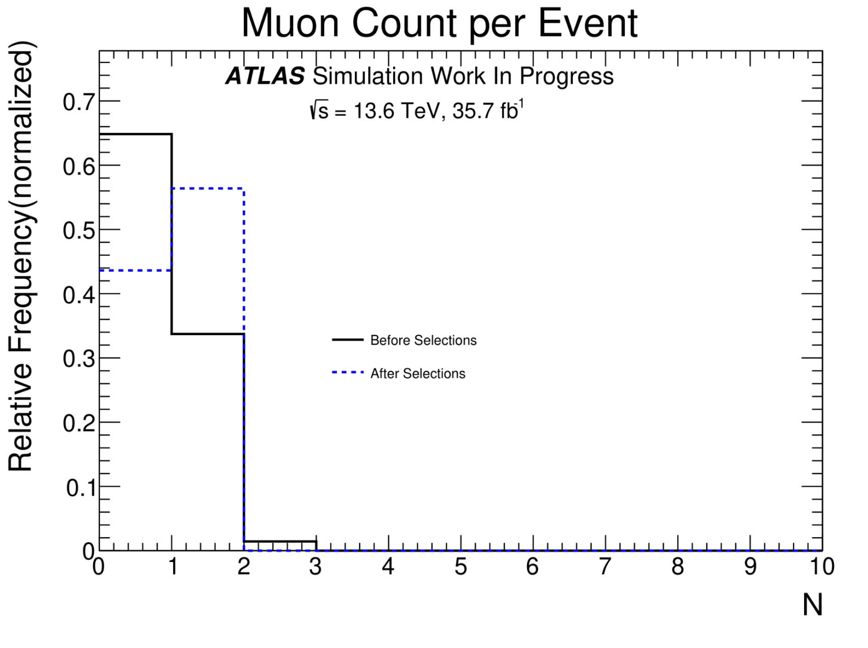

Primary Photon Azimuthal angle
ATLAS Simulation Work In Progress
√s = 13.6 TeV, 35.7 fb1
Before Selections
After Selections
Relative Frequency(normalized)
ϕ

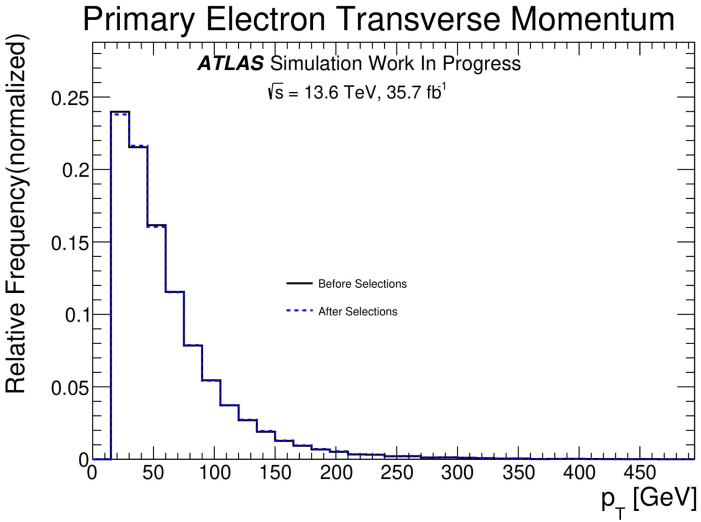

Secondary Photon Azimuthal angle
ATLAS Simulation Work In Progress
√s = 13.6 TeV, 35.7 fb1
Before Selections
After Selections
Relative Frequency(normalized)
ϕ

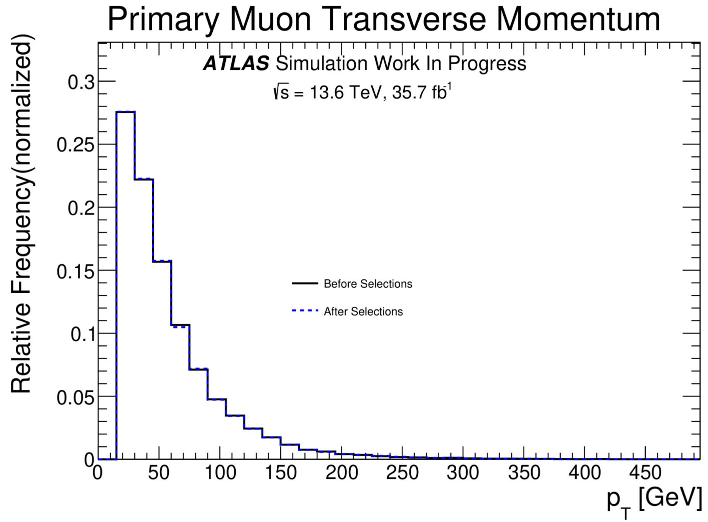
ELECTRONS AND MUONS($\gamma\gamma$+1ℓ, 0-τ)





- Looking at electrons and muons, we see more events with muons than electrons.
- In fact, over 50% of the events have zero electrons.
- This is expected due to better muon reconstruction and ID efficiency.


Primary Electron Transverse Momentum
ATLAS Simulation Work In Progress
√s = 13.6 TeV, 35.7 fb-1
Relative Frequency(normalized)
Before Selections
After Selections
p_T [GeV]


Primary Muon Transverse Momentum
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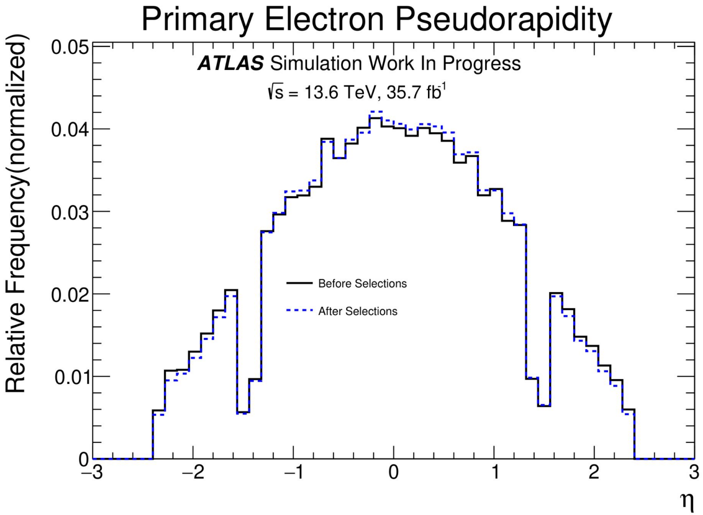
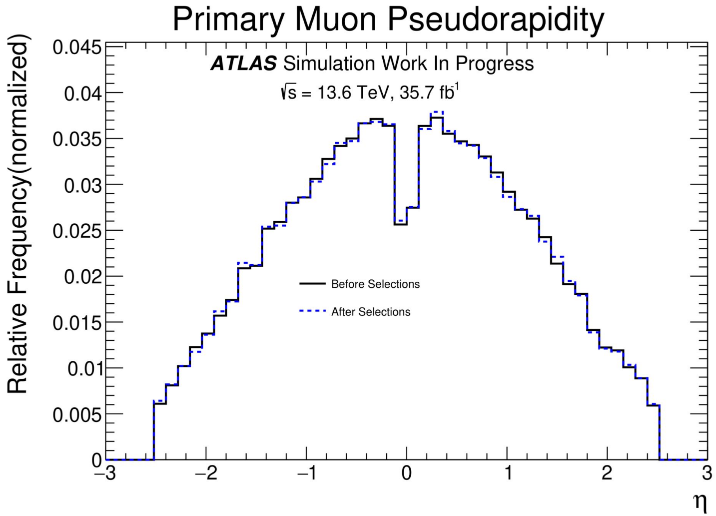
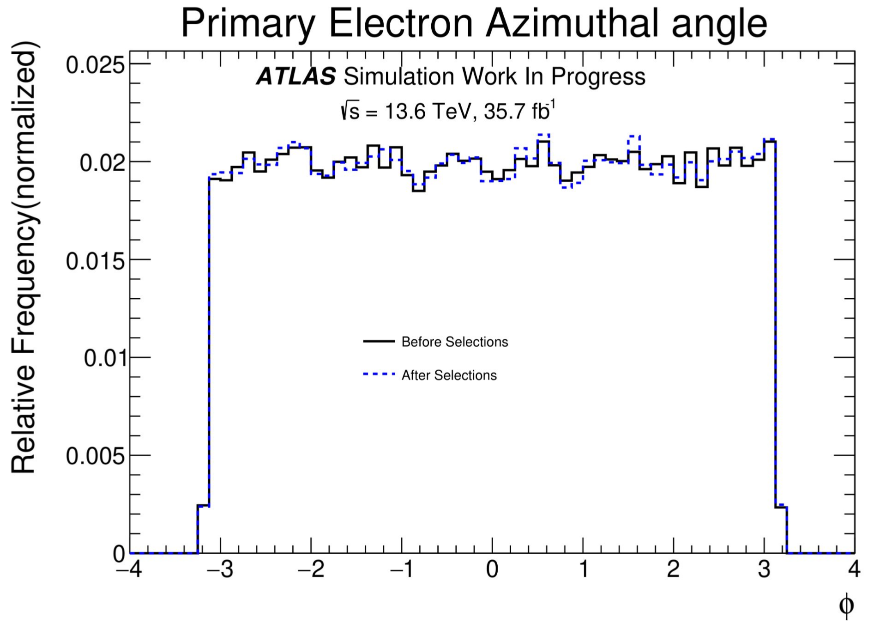
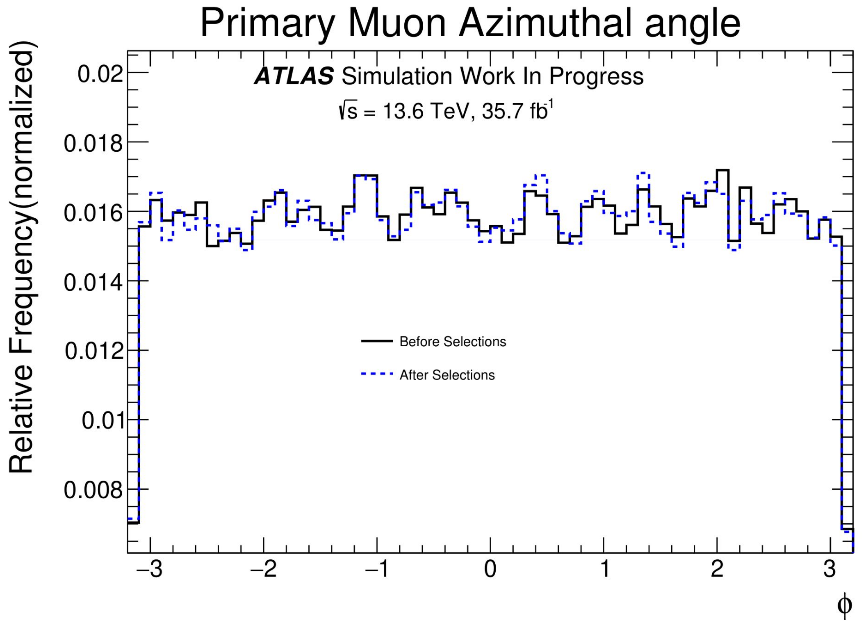
√s = 13.6 TeV, 35.7 fb-1
Relative Frequency(normalized)
Before Selections
After Selections
p_T [GeV]


Primary Electron Pseudorapidity
ATLAS Simulation Work In Progress
√s = 13.6 TeV, 35.7 fb-1
Relative Frequency(normalized)
Before Selections
After Selections
η

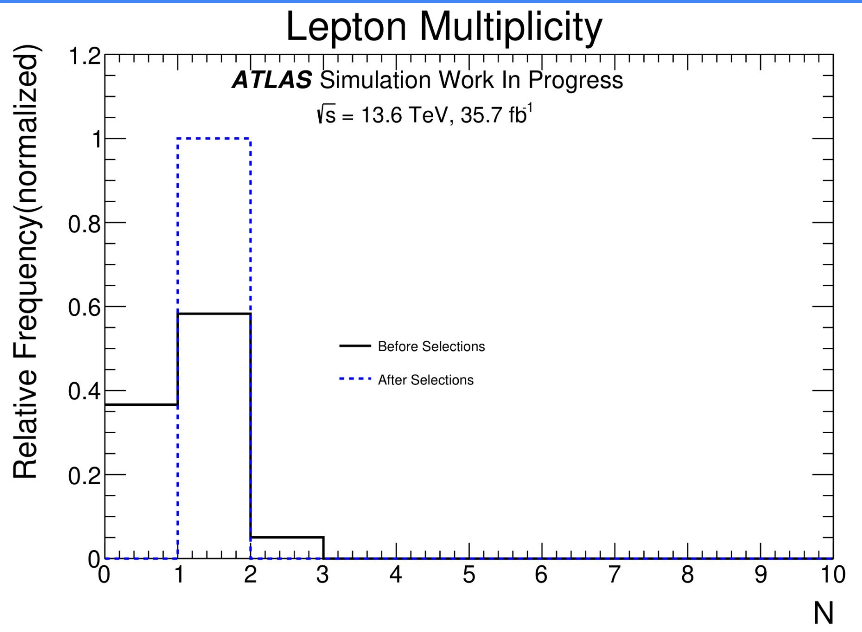

Primary Muon Pseudorapidity
ATLAS Simulation Work In Progress
√s = 13.6 TeV, 35.7 fb-1
Relative Frequency(normalized)
Before Selections
After Selections
η

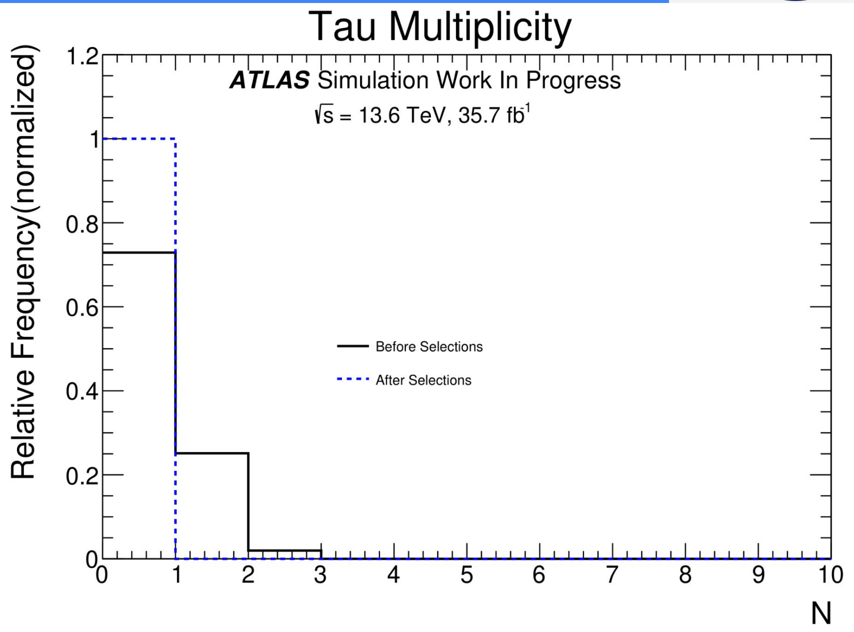




- φ distributions for primary electrons and muons show slight asymmetries could be due to detector geometry, background topology, or selection effects.
- These observations are based on **background sample** used and will be cross-checked once the **signal MC becomes available**.

Total Number of Leptons for γγ+1ℓ, 0-τ

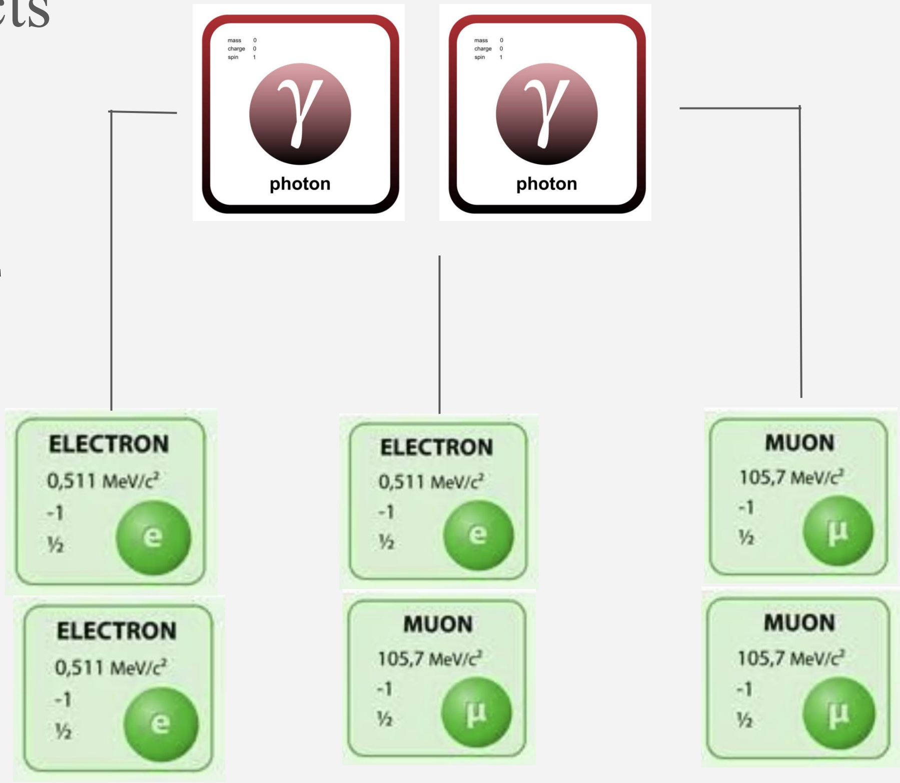




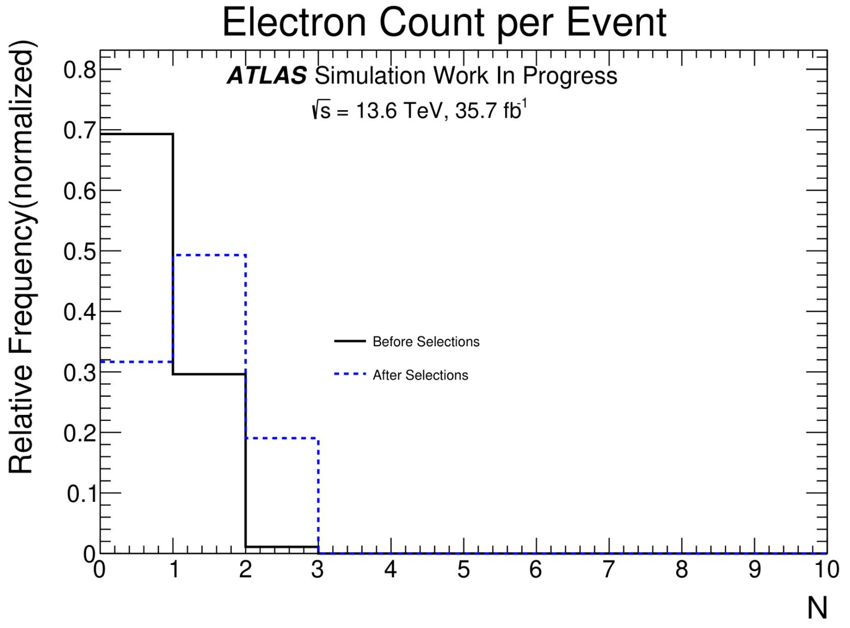
- Total lepton multiplicity peaks cleanly at 1, which confirms that our selection is correctly isolating γγ+1ℓ events.
- Tau multiplicity peaks at 0 as required confirms effective tau veto in both γγ+1ℓ and γγ+2ℓ selections.

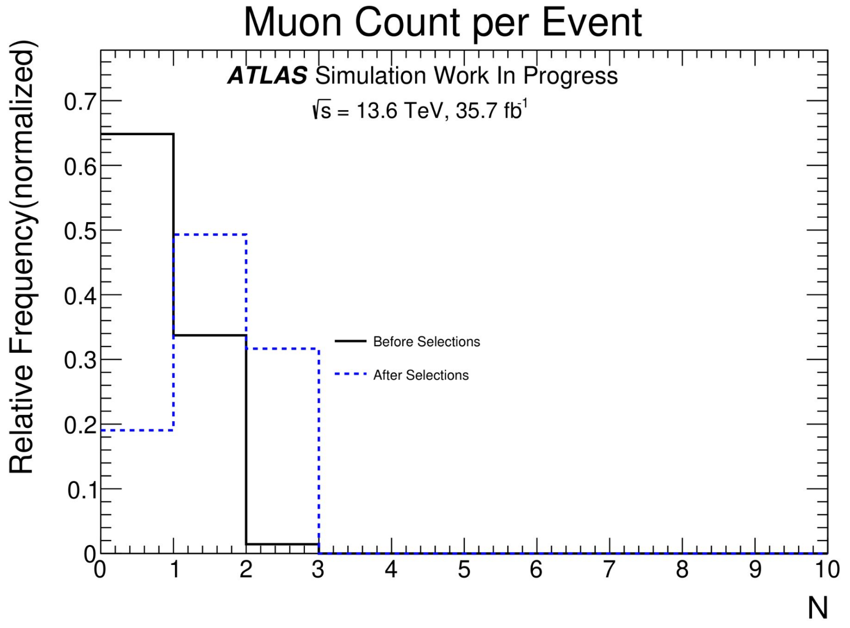
Objects Kinematics for $\gamma\gamma+2\ell$, 0-τ

- Distribution Results for our objects
- Look at:
  - ❑ Electrons and Muons:
    - ➢ Transverse momentum, p_T
    - ➢ Pseudorapidity, η
    - ➢ Azimuthal angle, φ
  - ❑ Primary and Secondary

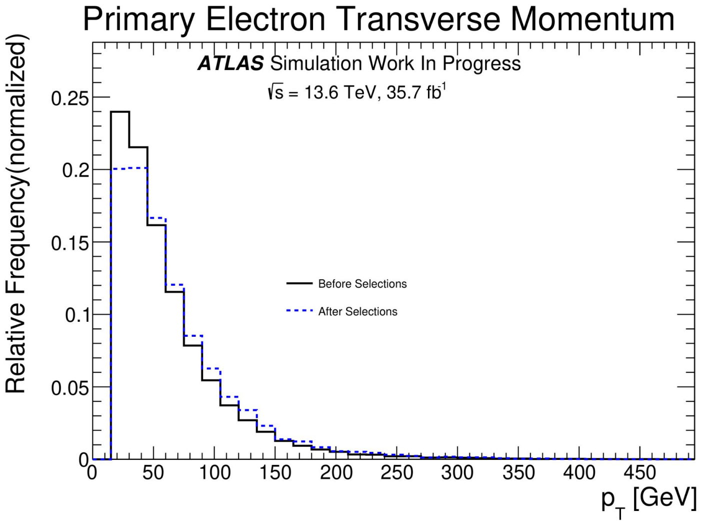


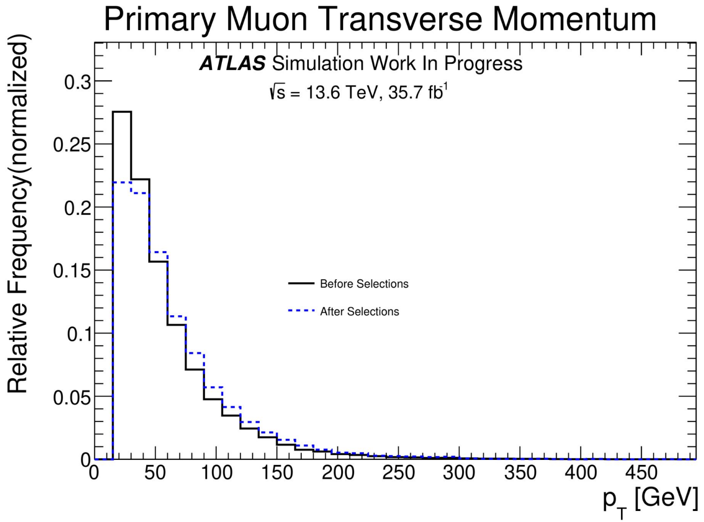
ELECTRONS AND MUONS($\gamma\gamma+2\ell$, 0-τ)





- Events with one electron and one muon are evenly distributed after selection.
- Events with two muons occur more frequently than those with two electrons.
- There is a ~10% higher rate of events with zero electrons compared to zero muons.


Primary Electron Transverse Momentum
ATLAS Simulation Work In Progress
$\sqrt{s}$ = 13.6 TeV, 35.7 fb^{1}
Before Selections
After Selections
Relative Frequency(normalized)
p_T [GeV]


Primary Muon Transverse Momentum
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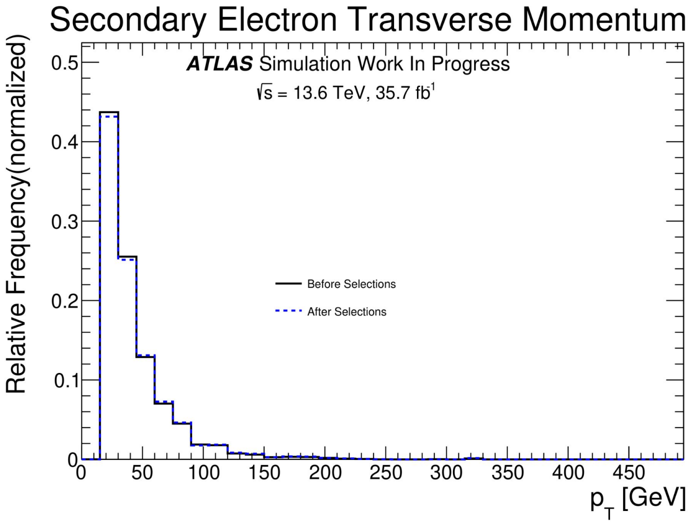
Before Selections
After Selections
Relative Frequency(normalized)
p_T [GeV]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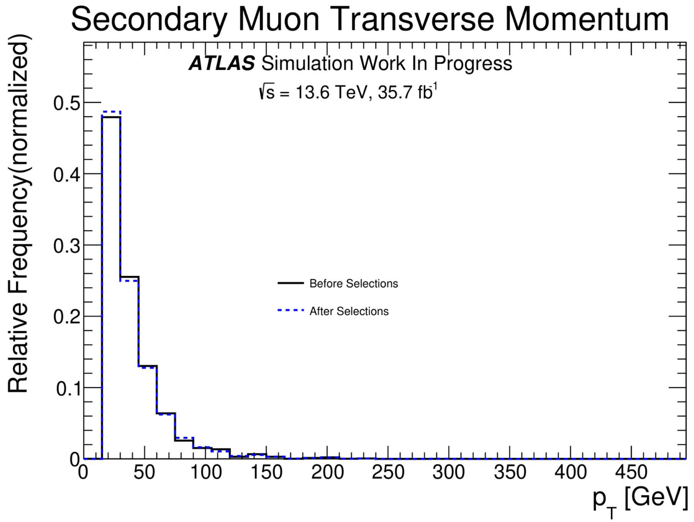
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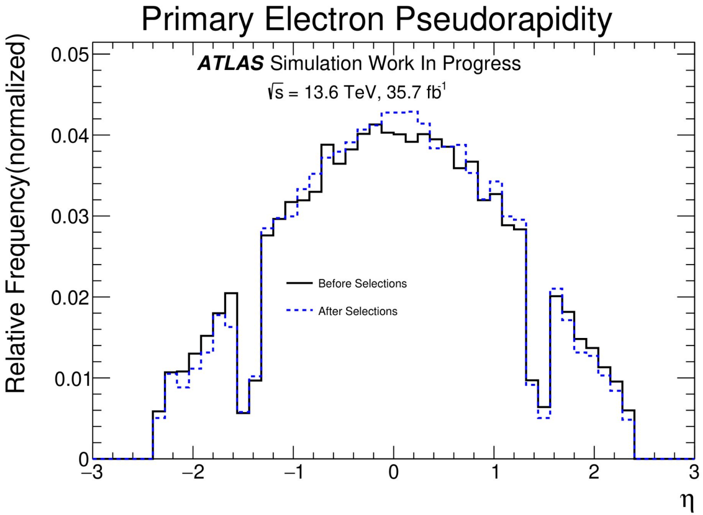
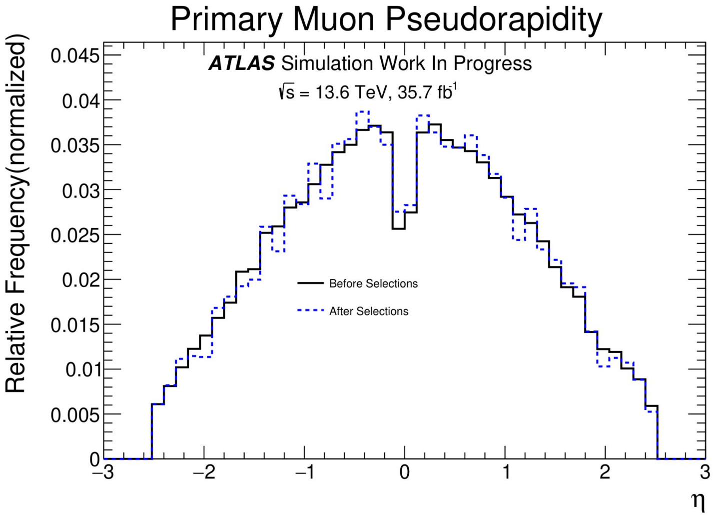

Primary Electron Pseudorapidity
ATLAS Simulation Work In Progress
$\sqrt{s}$ = 13.6 TeV, 35.7 fb^{1}
Before Selections
After Selections
Relative Frequency(normalized)
η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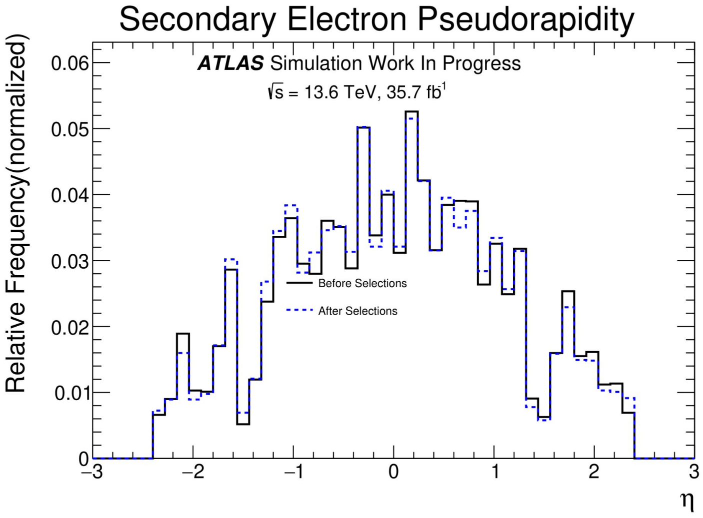
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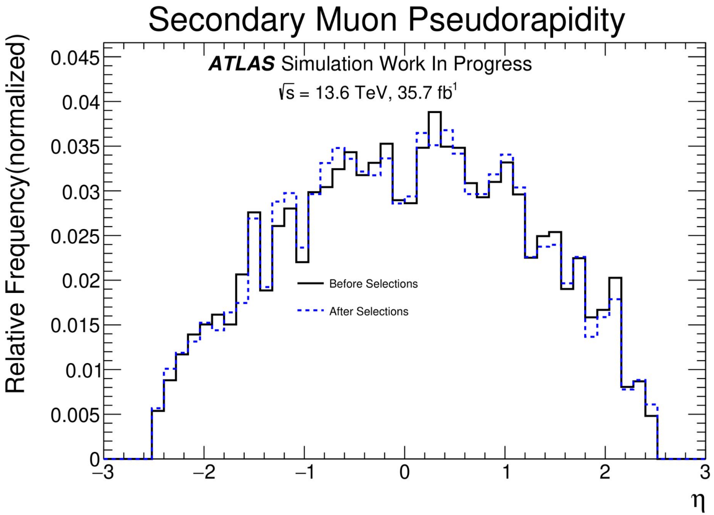
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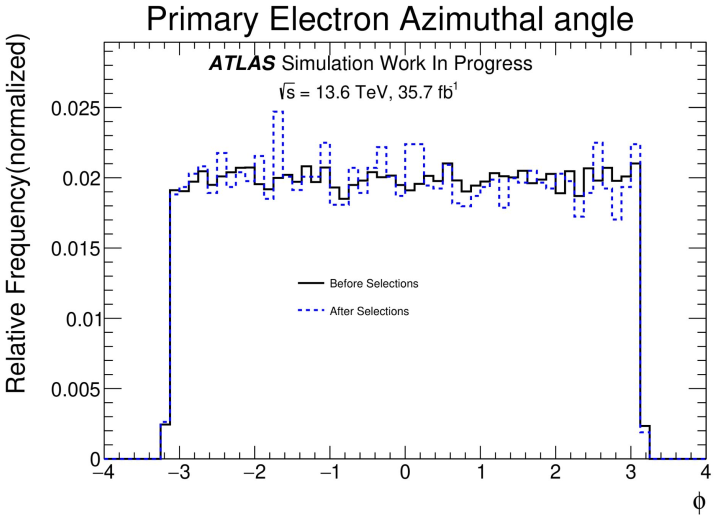
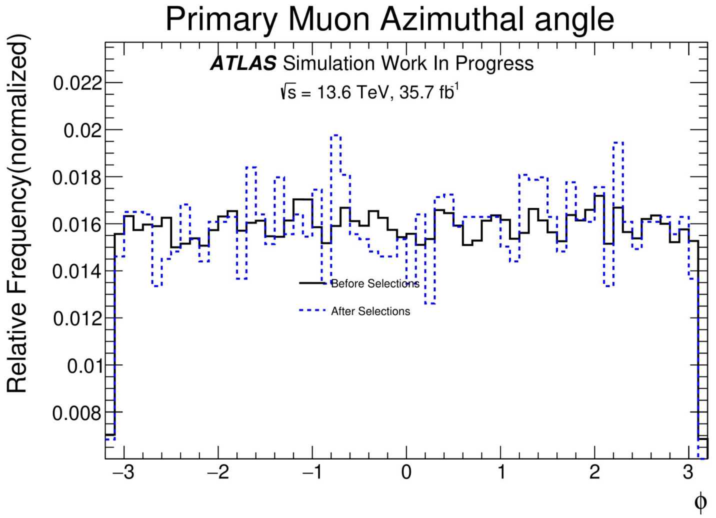

Primary Electron Azimuthal angle
ATLAS Simulation Work In Progress
√s = 13.6 TeV, 35.7 fb1
Before Selections
After Selections
Relative Frequency(normalized)
ϕ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Before Selections
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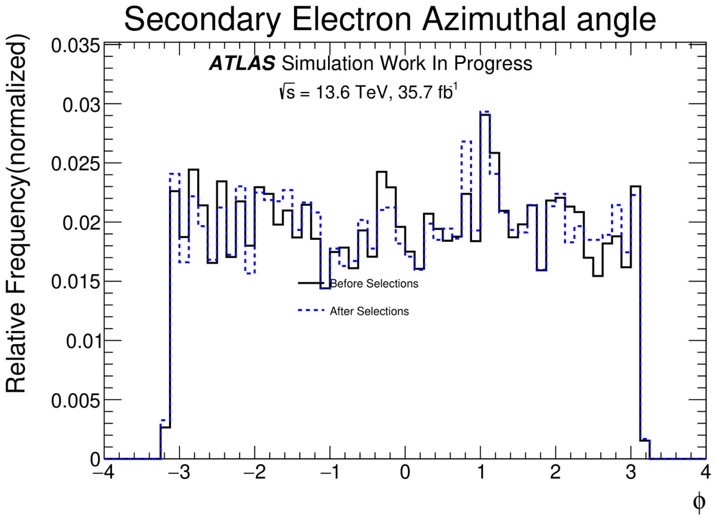
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ATLAS Simulation Work In Progress
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Before Selections
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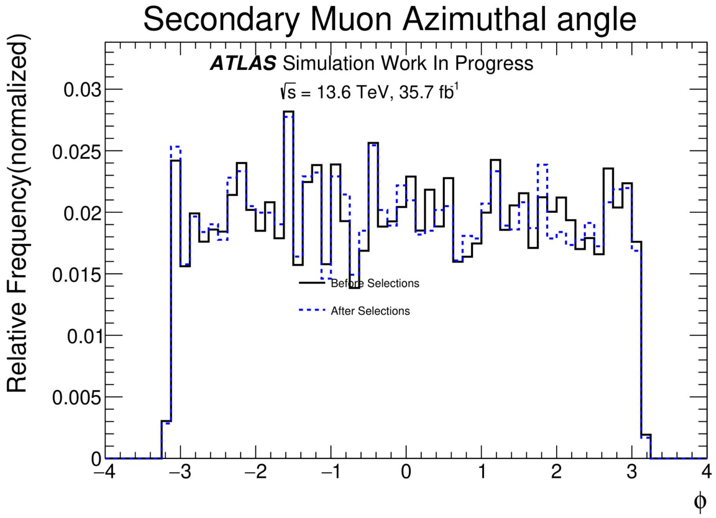
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Before Selections
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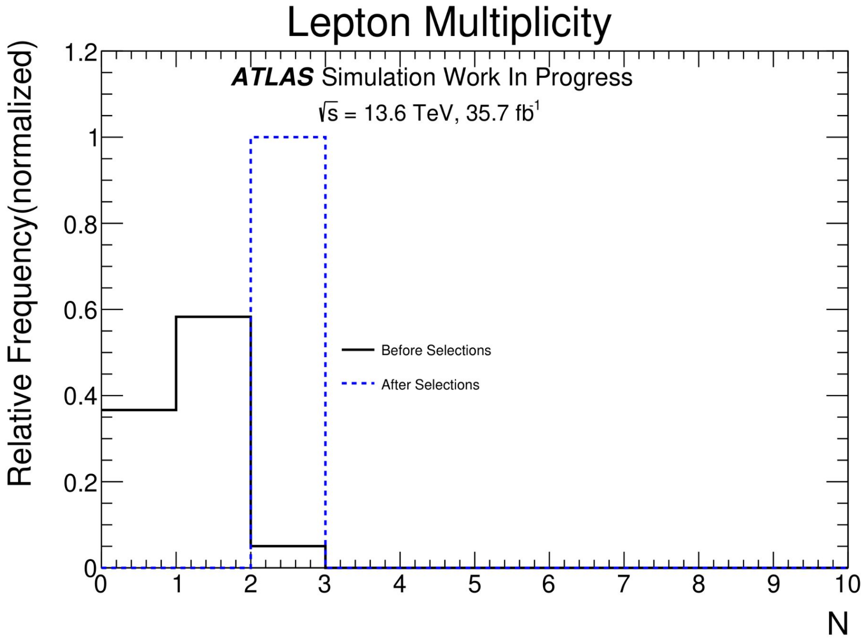
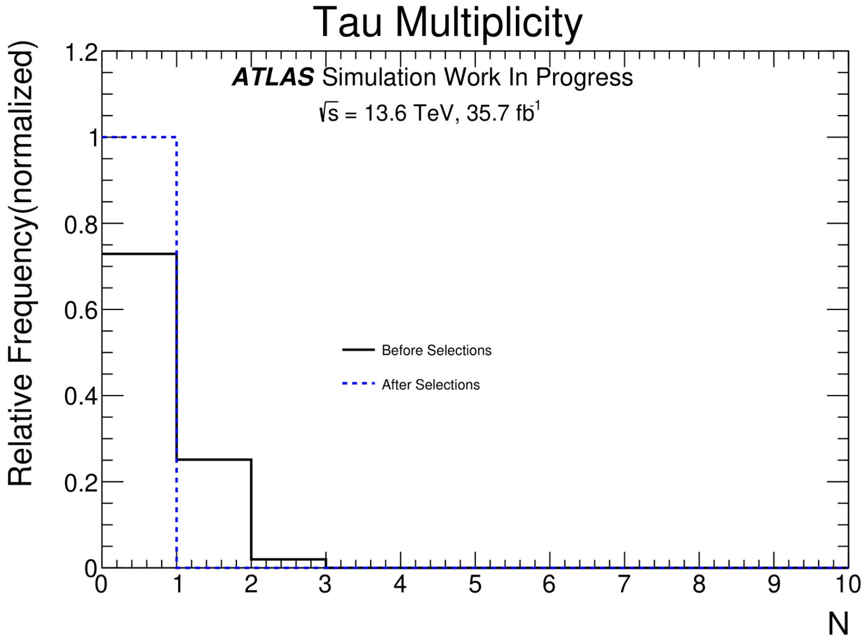
Total Number of Leptons for γγ+2ℓ, 0-τ





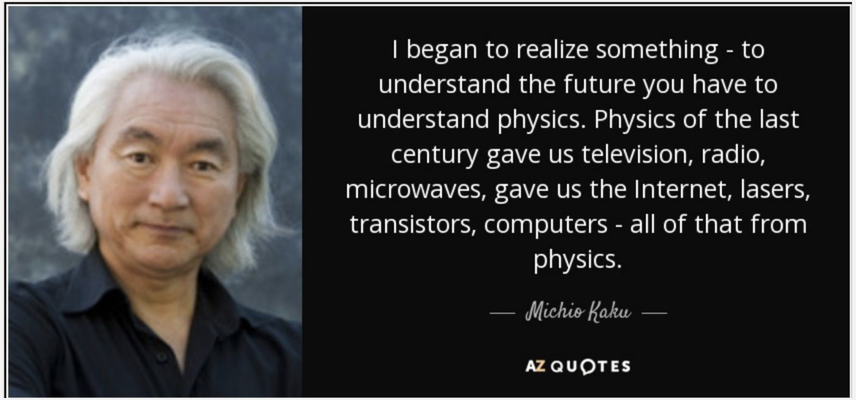
- Total lepton multiplicity peaks cleanly at 2, which confirms that our selection is correctly isolating γγ+2ℓ events.

Conclusion

- Presented preliminary study of **γγ+1ℓ** and **γγ+2ℓ**, **0-τ** final states using MC23 background samples.
- Event selection strategy successfully implemented using **EasyJet framework**, with consistent photon and lepton kinematics.
- Clean lepton and tau multiplicity distributions confirm correct selection logic and tau veto.
- Object-level kinematic distributions show expected behavior, with some variations offering insights into background topology and detector effects.
- Current results serve as a foundation for validating selection cuts and preparing control regions.

Future Work

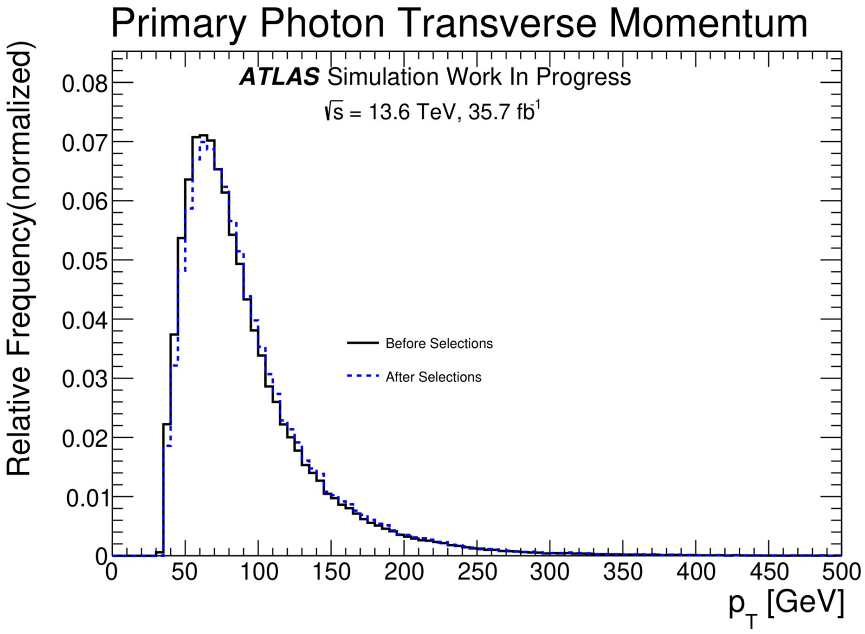
- Extend analysis to include all relevant backgrounds for both final states.
- Explore fake rates and reducible backgrounds involving jets and non-prompt leptons.
- Integrate signal MC samples (upon availability) and proceed with optimization of signal regions and sensitivity studies.

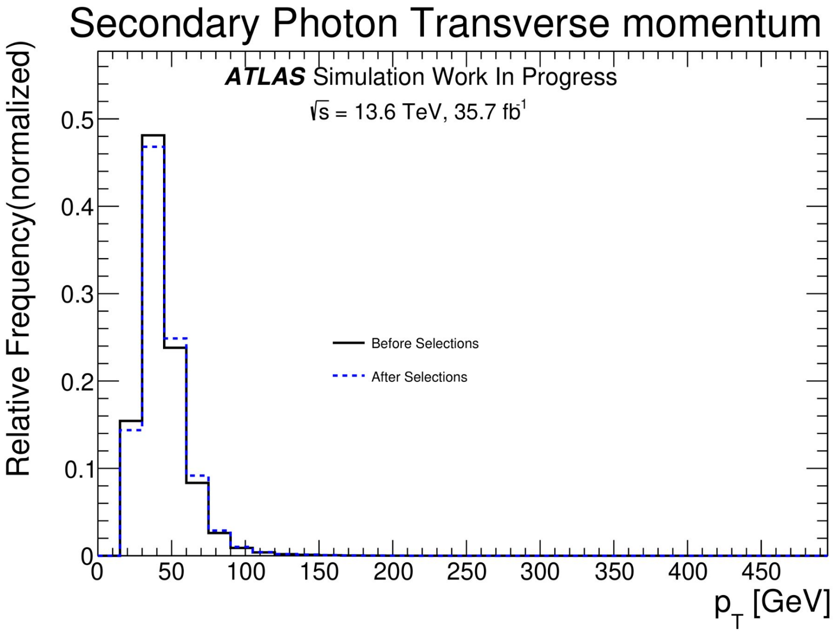


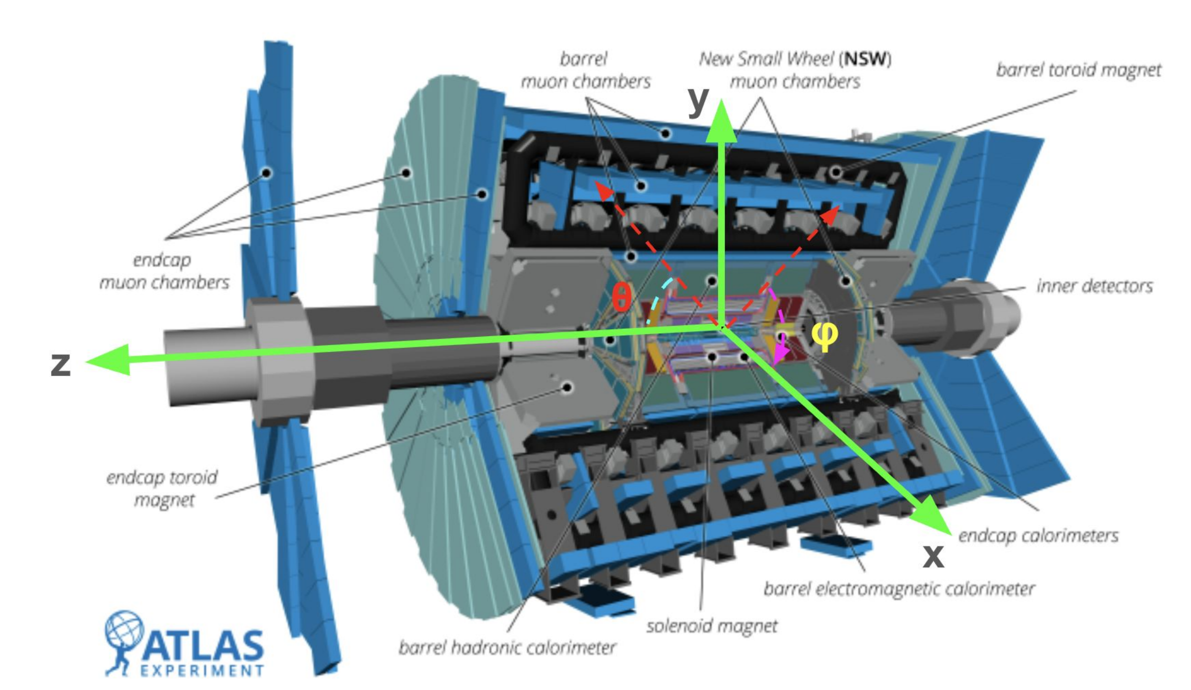
Thank You!!

Backup slides

PHOTONS (5GeV BIN WIDTH)







Pseudorapidity

$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$

- $\theta=90^0$, sharp dip near $|\eta|\approx 0$ in both distributions for the primary and secondary muons
- muons move almost perfectly **perpendicular to the beamline**, exiting through the **central barrel region**.
- But in that region, there's a **mechanical gap** between the top and bottom halves of the **barrel muon chambers**, where detector coverage is reduced.

Triggers Used

```yaml
selection:
  chains:
    '2022':
    - 'HLT_g35_medium_g25_medium_L12EM20VH'
    - 'HLT_2g50_loose_L12EM20VH'
    - 'HLT_2g22_tight_L12EM15VHI'
    '2023':
    - 'HLT_g35_medium_g25_medium_L12eEM24L'
    - 'HLT_2g50_loose_L12eEM24L'
    - 'HLT_g45_medium_g20_medium_L1eEM40L_2eEM18L'
    - 'HLT_2g22_tight_L12eEM18M'
    '2024':
    - 'HLT_g35_medium_g25_medium_L12eEM24L'

scale_factor:
  doSF: false
```

2022 Triggers

- HLT_g35_medium_g25_medium_L12EM20VH: Two photons (35 GeV & 25 GeV, medium ID) + an electron leg
- HLT_2g50_loose_L12EM20VH: Two photons >50 GeV, loose ID + electron leg
- HLT_2g22_tight_L12EM15VHI: Two photons >22 GeV, tight ID + tighter isolation

2023 Triggers

- HLT_g35_medium_g25_medium_L12eEM24L: Same photon config as 2022, updated electron leg (L12eEM24L)
- HLT_2g50_loose_L12eEM24L: Two loose photons >50 GeV + updated electron leg
- HLT_g45_medium_g20_medium_L1eEM40L_2eEM18L: One photon > 45 GeV & another > 20 GeV + combination of high and moderate electron triggers
- HLT_2g22_tight_L12eEM18M: Two tight photons > 22 GeV + moderate electron leg

2024 Triggers

- HLT_g35_medium_g25_medium_L12eEM24L: Same as in 2023, possibly for early testing or limited config.

Scale Factor Section

- doSF: False:
  - ❑ No trigger scale factors are applied in this setup
  - ❑ Appropriate for **MC-only studies**
  - ❑ Scale factors will be relevant **once data is included**

Detailed Information

Objects	Extra Working Points (WPs)
Photons	Tight, FixedcutLoose Tight, NonIso Loose, FixedCutLoose
Electrons	MediumDNN TightLH Loose_VarRad
Muons	PflowLoose_VarRad