A search for long lived ALPs that decay into diphoton, and SCT studies for Run 3

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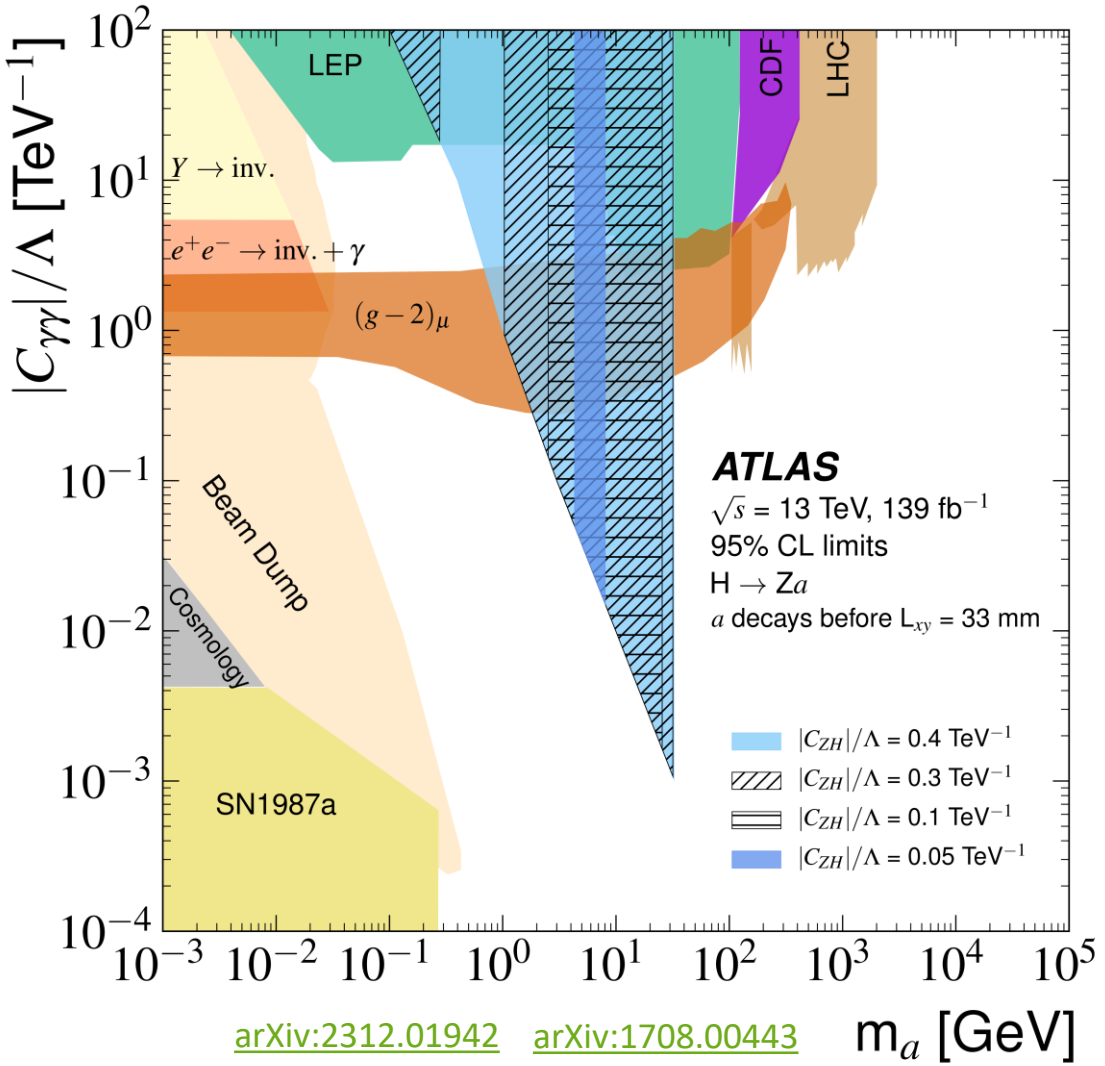
Axion like particles (ALPs)

- ALPs are a generalisation of the QCD axion.
- In contrast, ALPs mass and couplings to other particles are free parameters.
  - Determined by experiment.
- ALPs are hypothetical light particles that may be a component of the dark sector.
- The strong CP problem - why does the strong force conserve CP symmetry when predictions suggest otherwise.
- ALPs could solve the strong CP problem by dynamically suppressing CP-violating effects.
  - Via a new ‘axion field’.
- Could explain the $(g\text{-}2)_\mu$ anomaly through their interactions with the EM field.



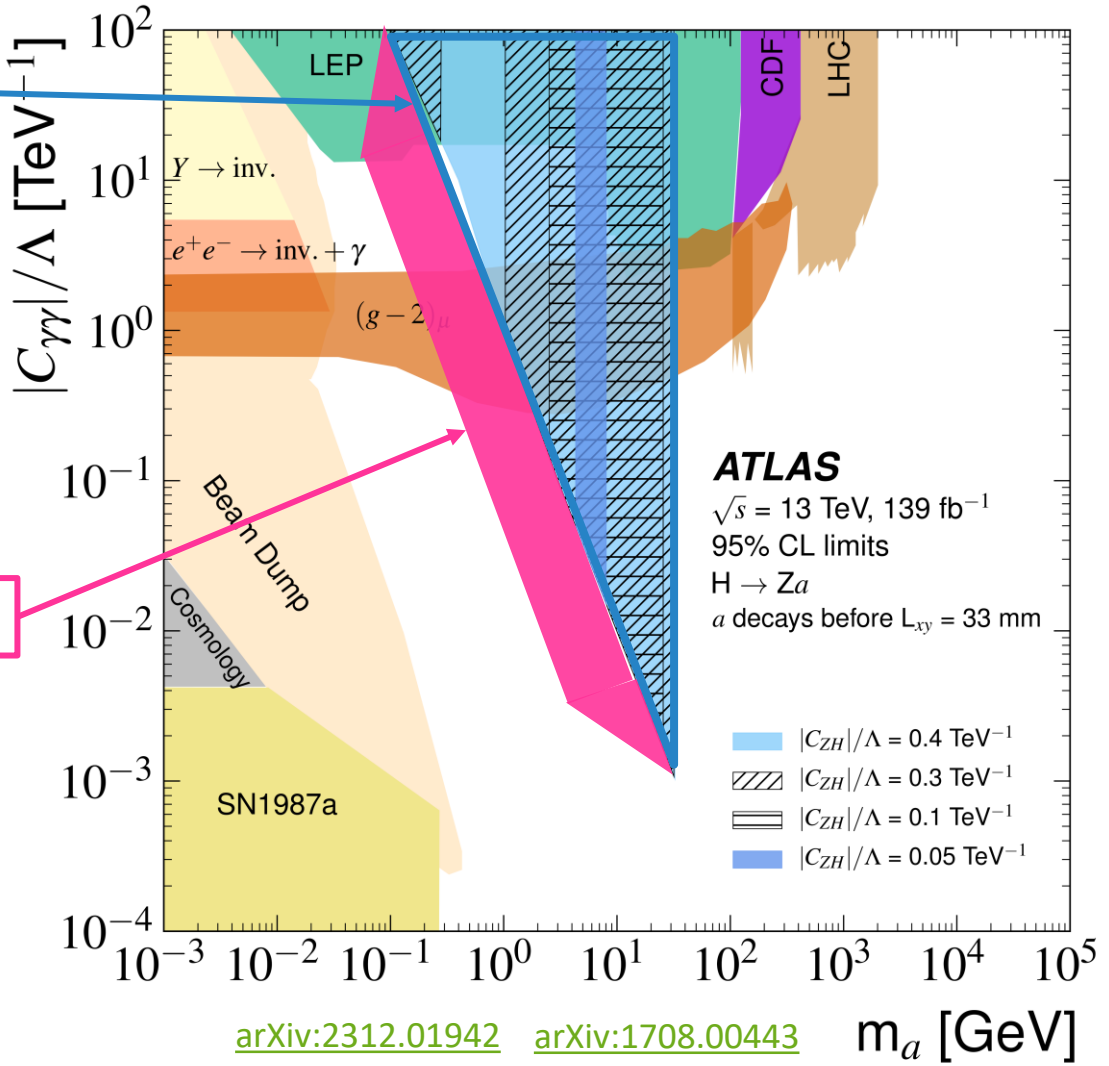
arXiv:2312.01942 arXiv:1708.00443

Search for long lived ALPs that decay into diphoton

- ALPs can decay promptly or be long lived.
- Probes ALP coupling to SM in phase space unreachable by non-collider experiment.
- If the (g-2)$_\mu$ anomaly is due to new particles instead of uncertainties in the theory, ATLAS can probe that region.
- ALPs mass range: 0.1-35 GeV.

ALP prompt region

ALP displaced region



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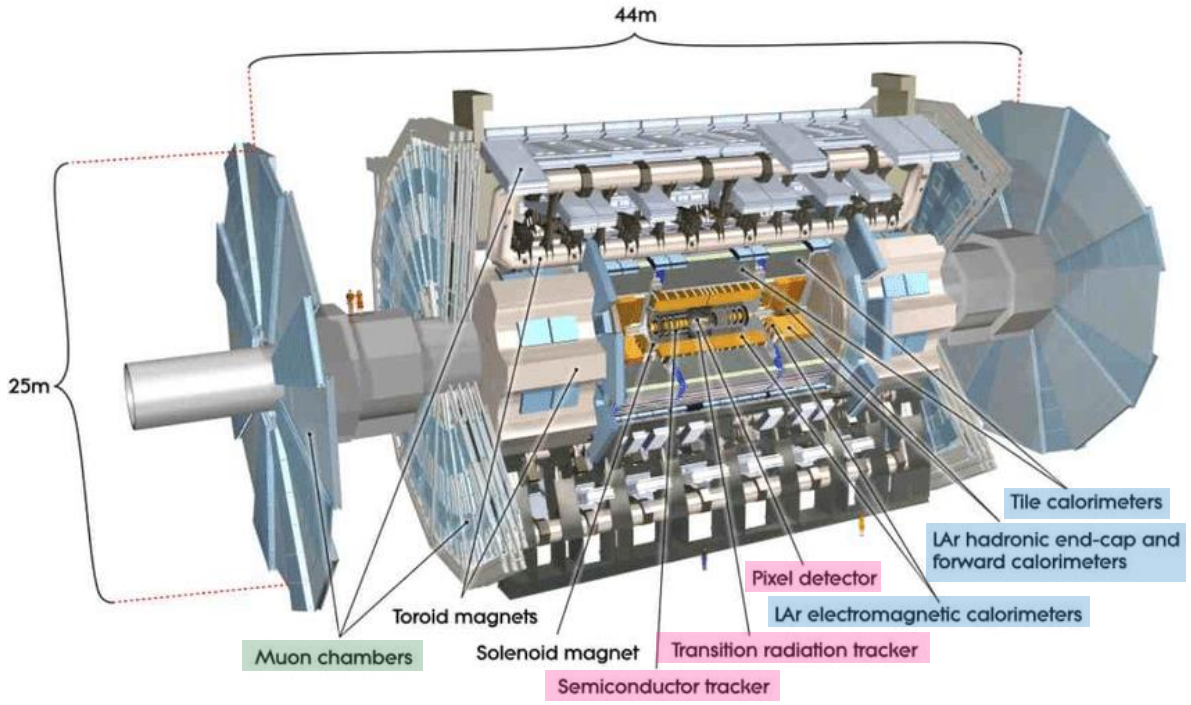
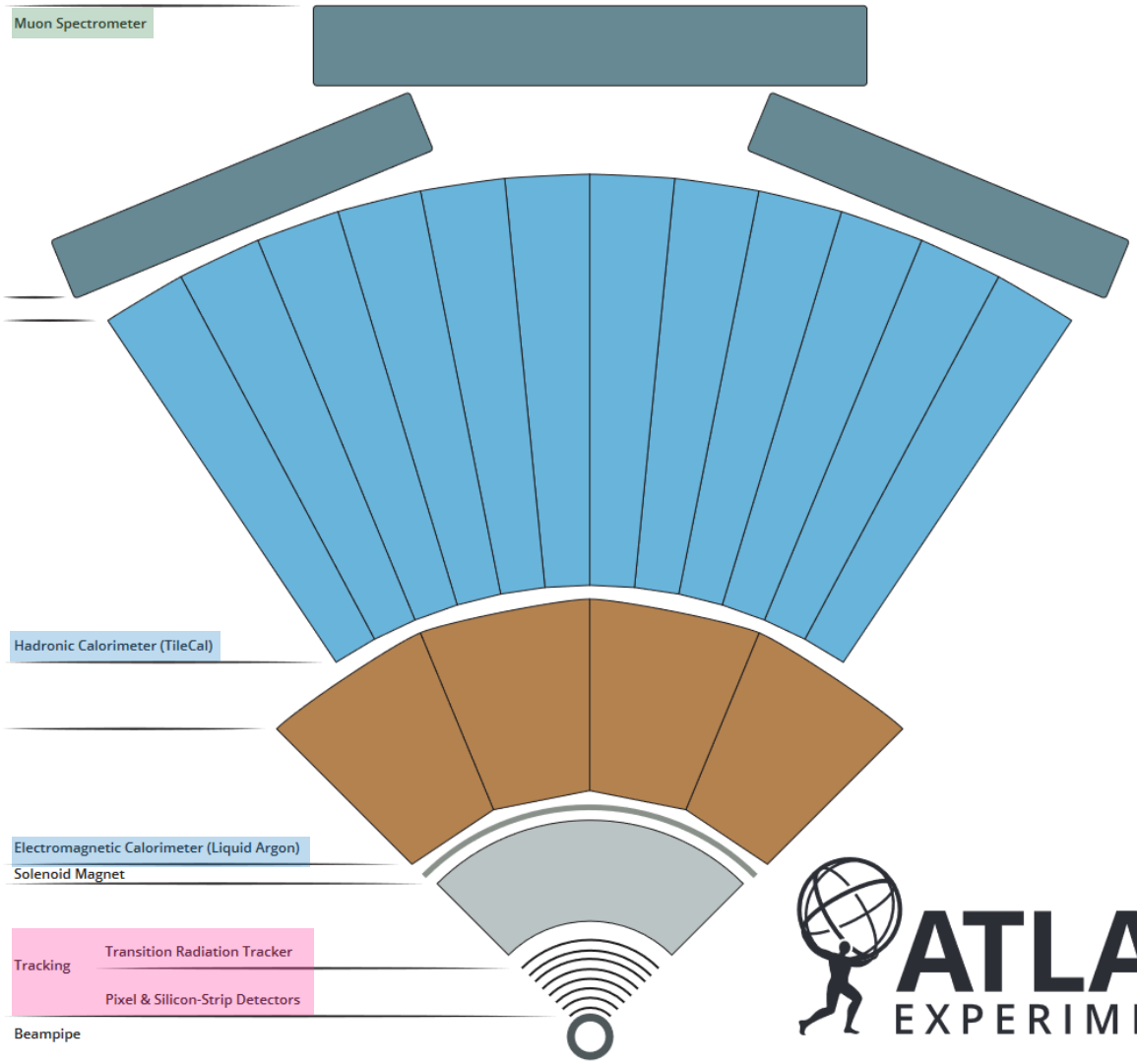
ATLAS detector





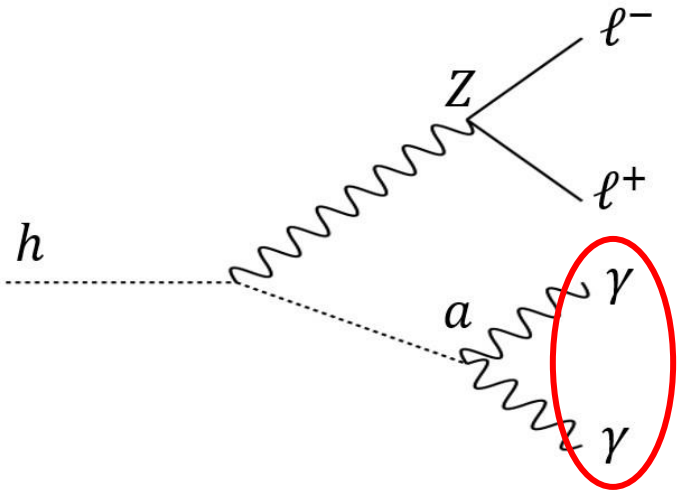
The ATLAS detector is made up of:

- Inner detector (ID) for tracking.
- Electromagnetic (ECAL) and hadronic (HCAL) calorimeters for energy deposits.
- Muon spectrometer for detecting muons.

Signature

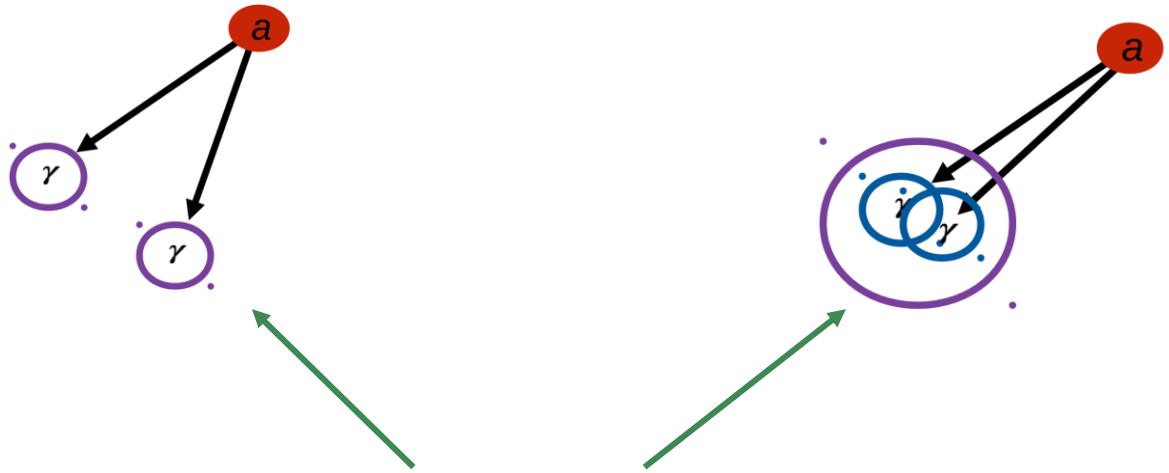
A powerful way to look for ALPs at high mass, is through exotic decays of the 125 GeV Higgs boson.

- Both ggF and VBF Higgs production considered.
- Focus on h->Za.
- Backgrounds: Z+jets, Z+gamma.



Signature has one photon if photons are collimated enough

Analysis strategy



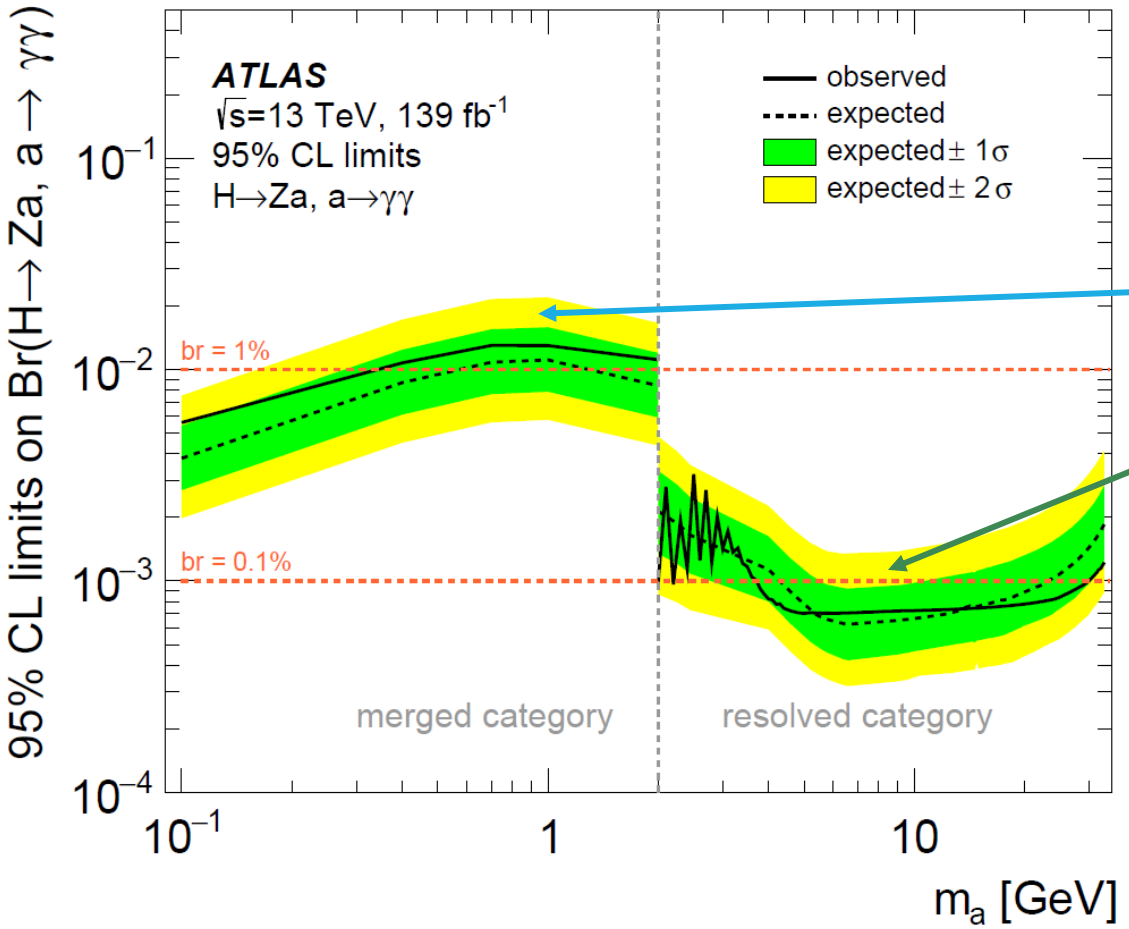
Photons can either be reconstructed as resolved or merged.

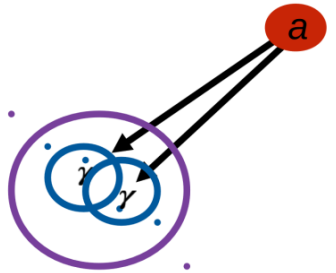
- At low mass points, the ALP is more boosted, therefore the photons are more merged.

Trigger on the Z boson → Use a photon tagger for signal/background discrimination → Define signal and control region Cut and count analysis

Prompt analysis: summary

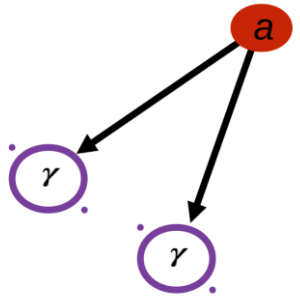
- Search for h->Za using Run 2 data (arXiv:2312.01942).
- Two selection categories depending on how collimated the photon pair are; merged category and resolved category.
- Backgrounds: Z+jets, Z+gamma.
- CMS search: arXiv:2311.00130





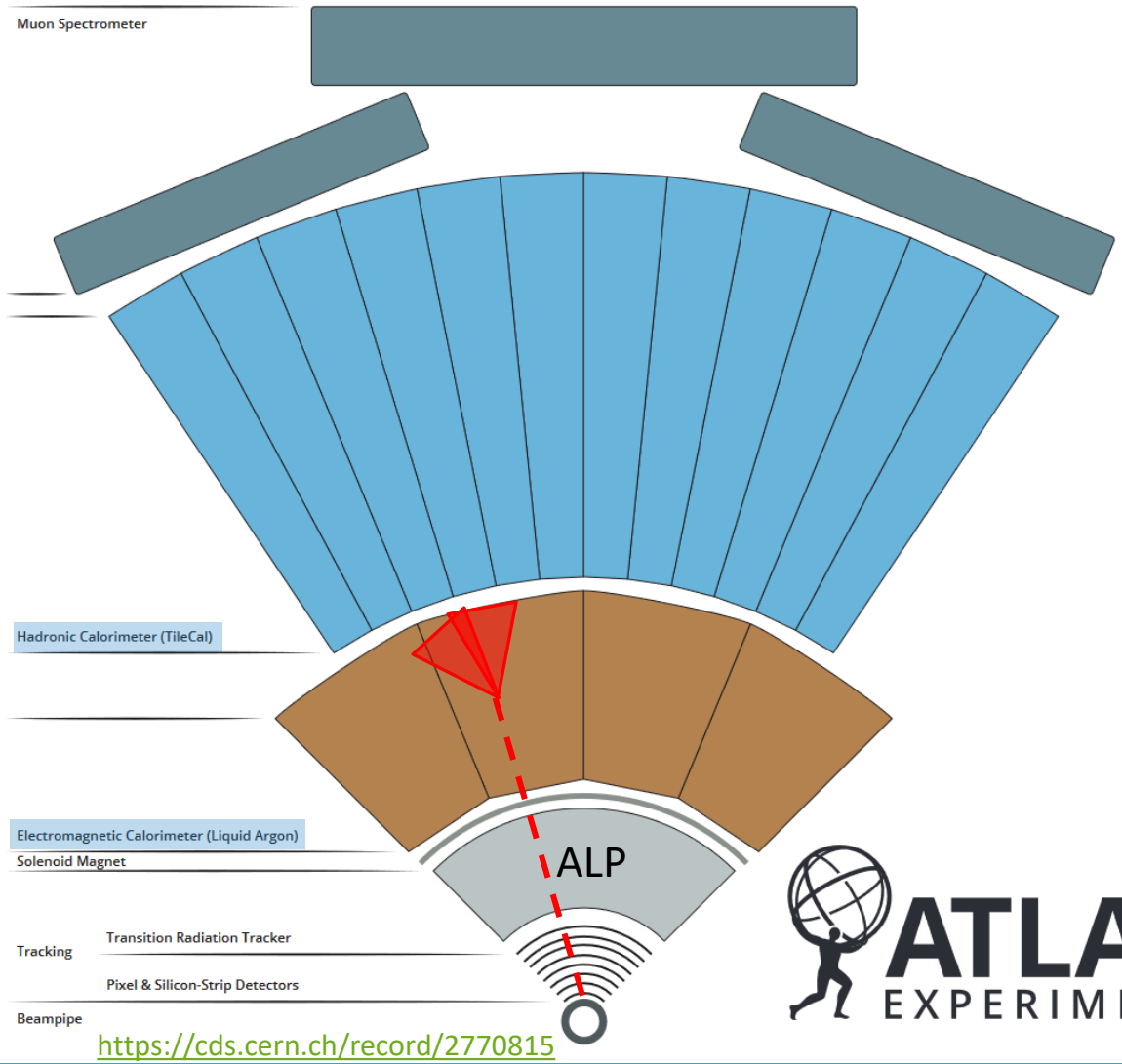
Merged category wins for mA < 2 GeV

Resolved category wins for mA > 2 GeV



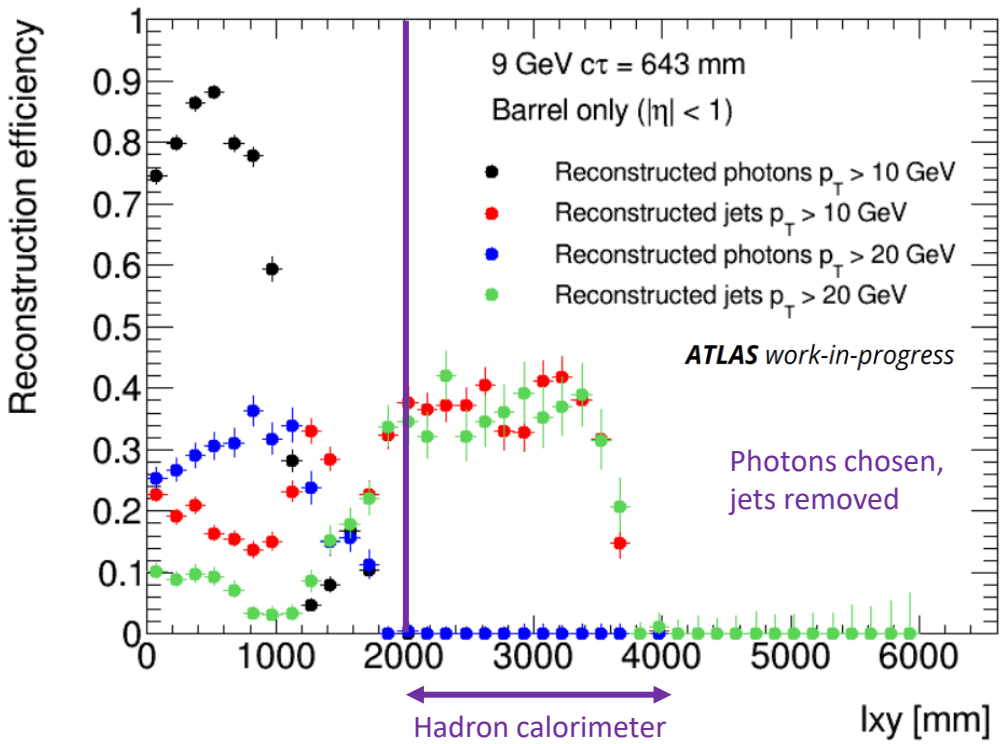
Long lived signature

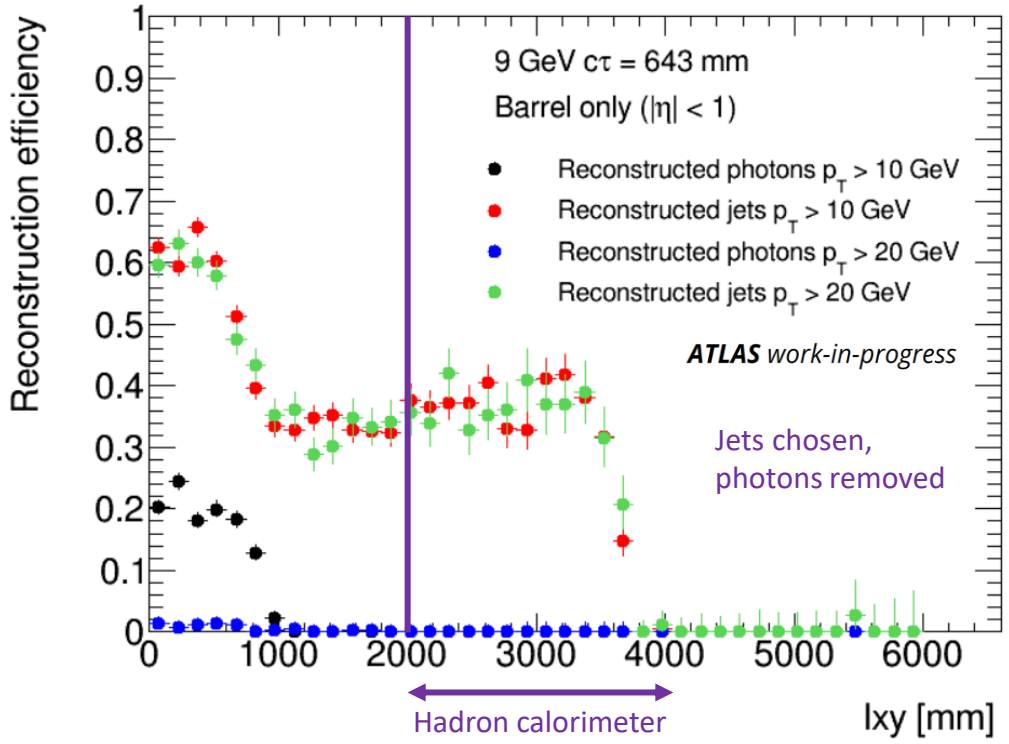
- Lifetime of ALPs -> 0-3800 mm.
- Displaced secondary vertex.
- Decay inside calorimeters.
  - Highly collimated photon pairs in ECAL.
  - Possible that energy is only deposited in last layers of calorimeters.
- Photon standard reconstruction is not built to reconstruct collimated γ pairs.
- ALP decay photons won't pass the usual identification criteria (or will be reconstructed as one γ).
- Cannot use photon objects -> jet based analysis.



https://cds.cern.ch/record/2770815

Reconstruction efficiency



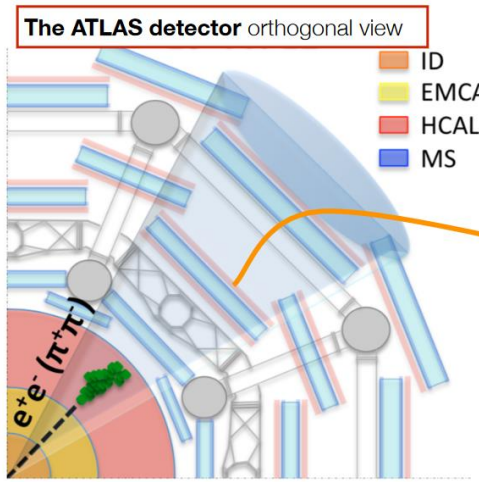


- Reconstructed photons (jets) are the photons (jets) with the smallest ΔR with respect to Truth photons.
- ΔR is the difference in the pseudorapidity-azimuthal angle space.
- The majority of reconstructed photons are lost when decay length passes the electromagnetic calorimeter.
- Jets are usually removed for photons if they are close in ΔR.
- Current studies -> Testing how removing photons for jets affects the reconstruction efficiency.
- Can move to a jet-based analysis.

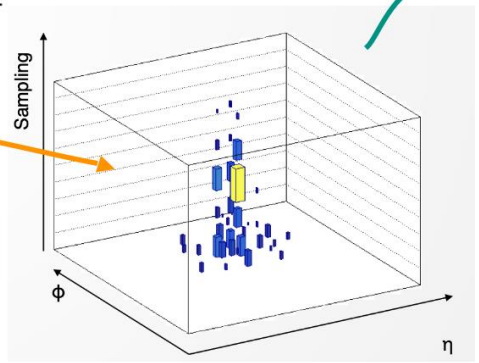
Photon tagging

Photons from displaced decays can be reconstructed using:

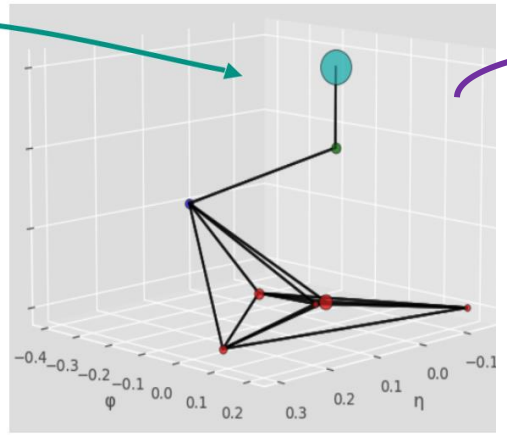
- A neural network, e.g. using the same approach as in arXiv:2206.12181 and extending it to GNN.
- Shower shapes in the calorimeter layers of the ATLAS detector.

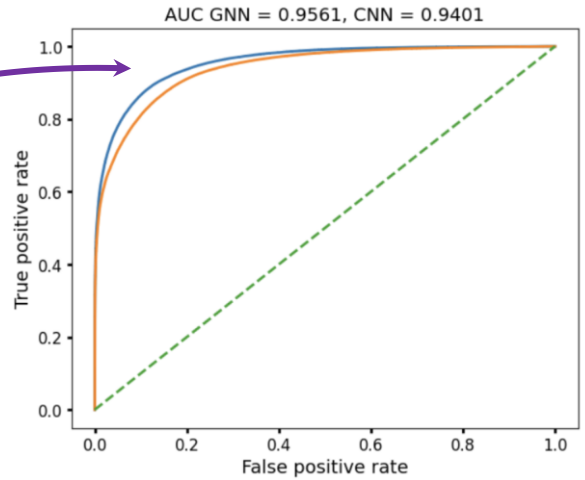


CNN



GNN

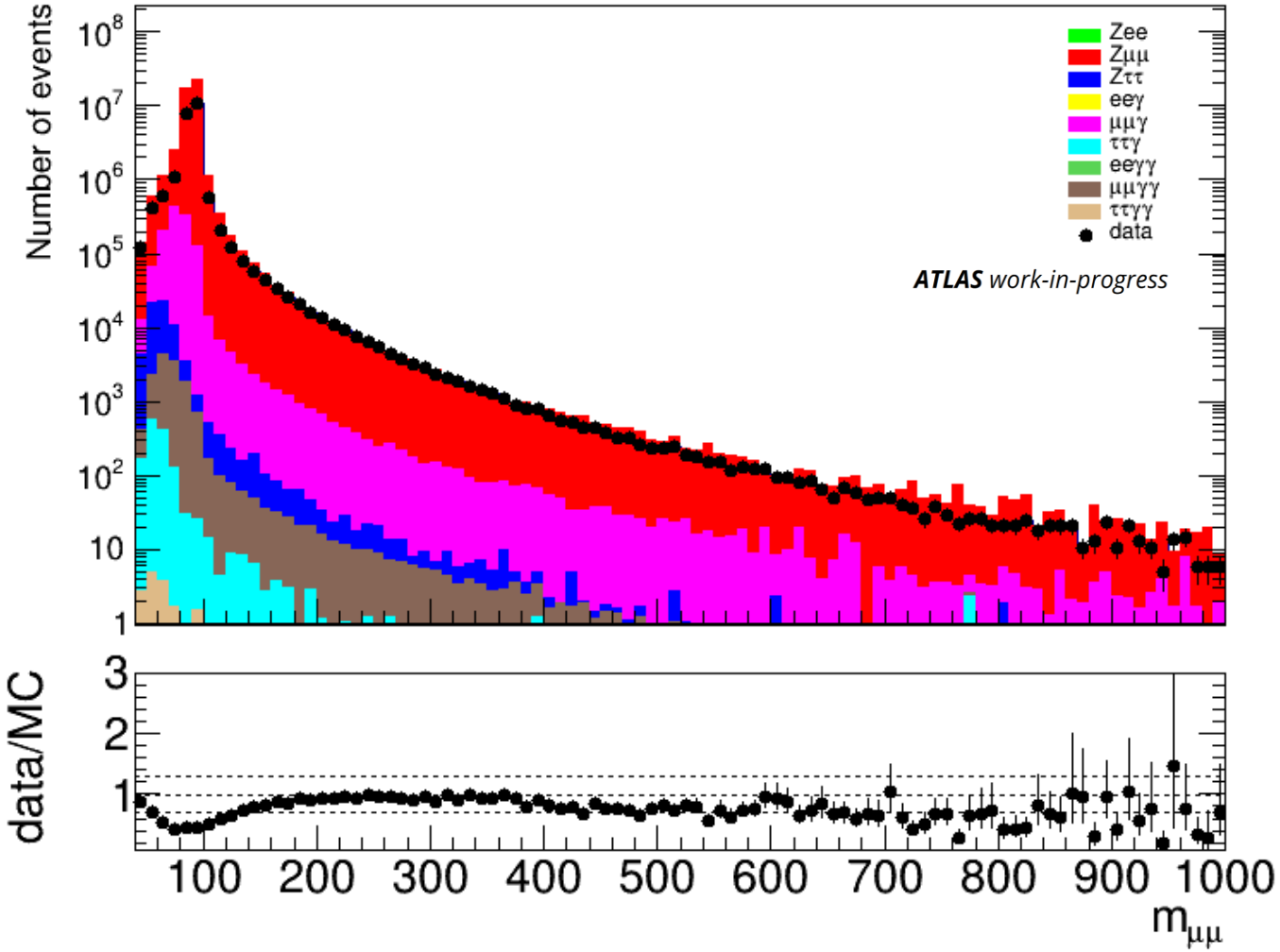




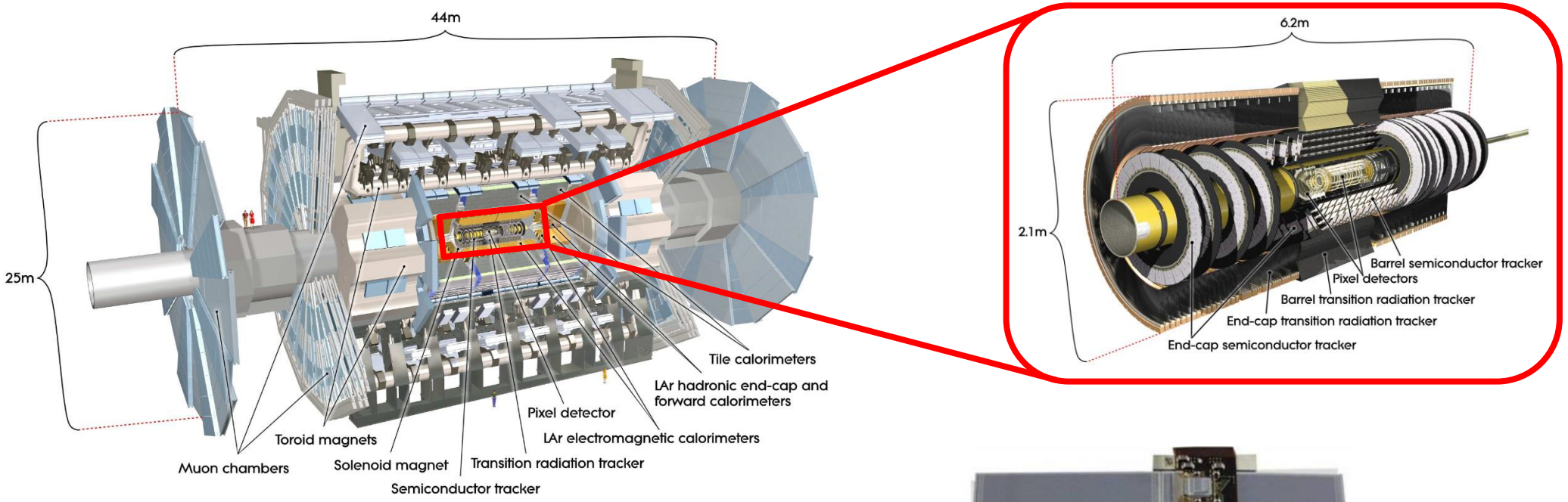
- CNN -> very sparse images -> sub-optimal.
- GNN -> fully optimised and out-performs CNN model on all performance metrics tested.

Next steps

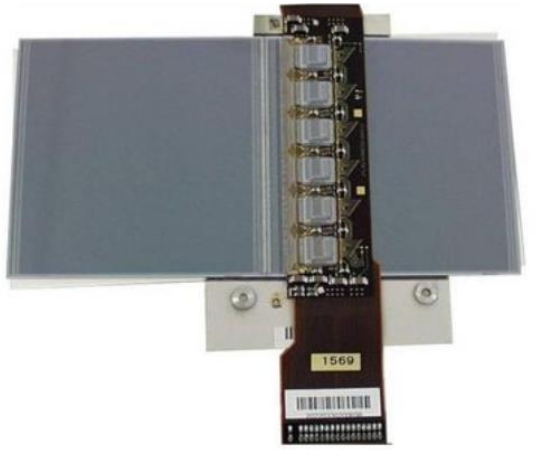
- SM background estimates.
- Backgrounds: Z+jets, Z+gamma.
- First look at di-muon events shows reasonable good data/MC agreement.
- Using Run 3 data.
- MC used to define event selection and optimisation maximising the Signal significance.



The ATLAS Semiconductor Tracker (SCT)



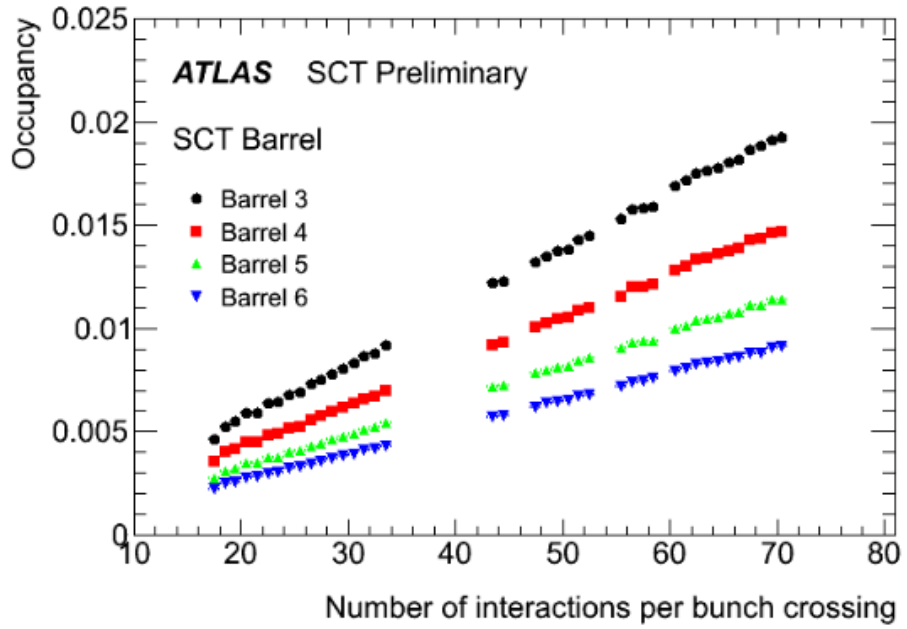
- Located in the ATLAS Inner Detector.
  - Between Pixel and TRT.
- 4 barrel layers and 2 endcaps with 9 disks each.
  - 4088 silicon-strip modules.
- A charged particle produces a hit on each layer which are combined into 3D spacepoints.

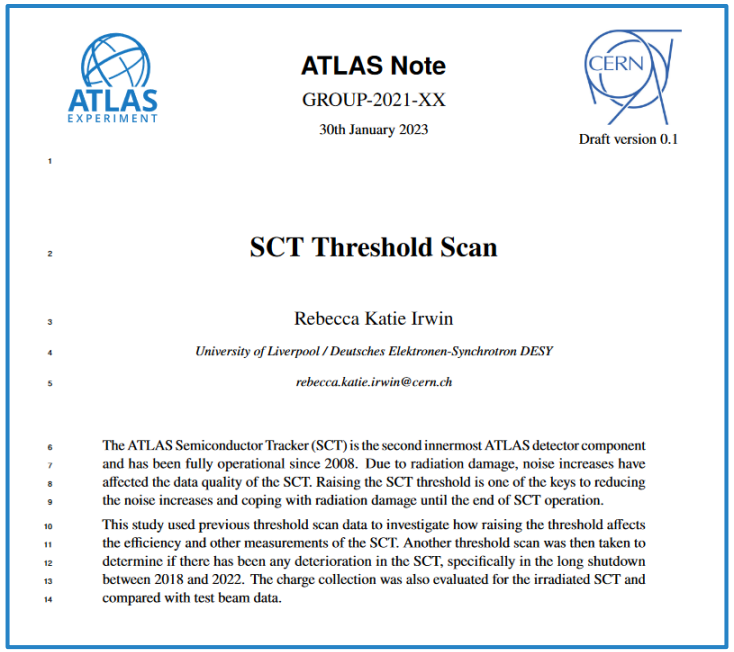


Barrel Module
10.1016

Ageing of the SCT and radiation effects

SCT Public Results





ATLAS EXPERIMENT

ATLAS Note

GROUP-2021-XX

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CERN

Draft version 0.1

SCT Threshold Scan

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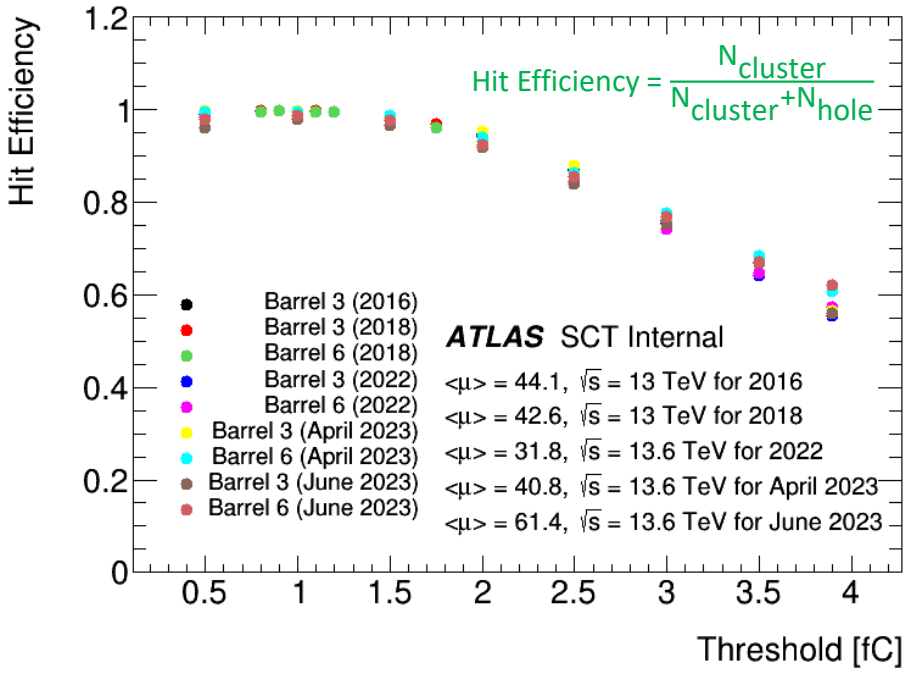
The ATLAS Semiconductor Tracker (SCT) is the second innermost ATLAS detector component and has been fully operational since 2008. Due to radiation damage, noise increases have affected the data quality of the SCT. Raising the SCT threshold is one of the keys to reducing the noise increases and coping with radiation damage until the end of SCT operation.

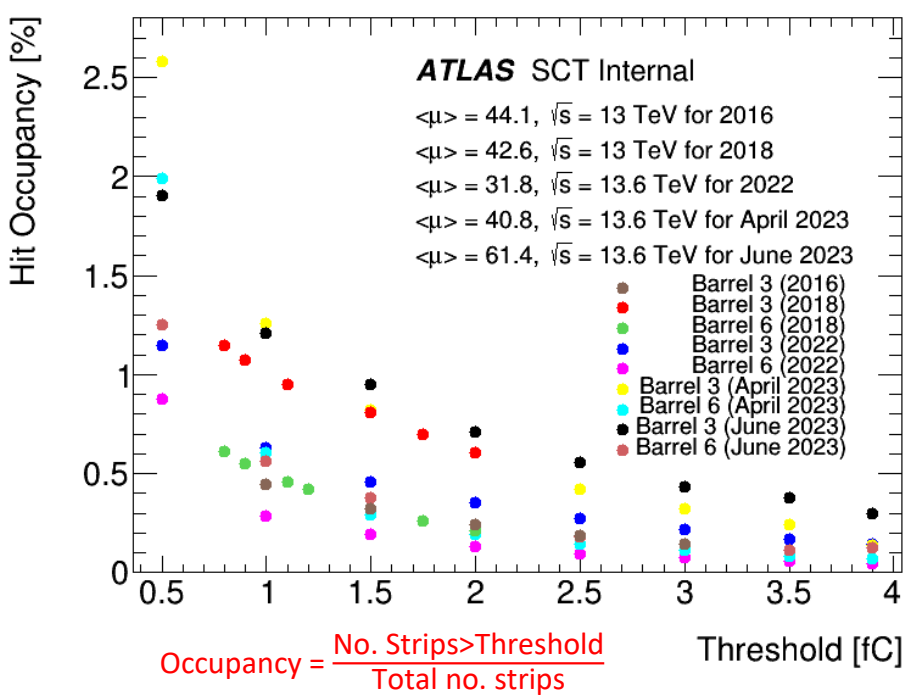
This study used previous threshold scan data to investigate how raising the threshold affects the efficiency and other measurements of the SCT. Another threshold scan was then taken to determine if there has been any deterioration in the SCT, specifically in the long shutdown between 2018 and 2022. The charge collection was also evaluated for the irradiated SCT and compared with test beam data.

- SCT Sensors irradiated by particles with energy ranging from thermal neutrons to the TeV-scale.
- The SCT uses binary readout, where a “hit” is registered if the charge on a strip exceeds a configurable threshold (currently 1fC).
- Raising the SCT threshold from 1fC is one of the keys to reducing occupancy and coping with radiation damage, however it decreases efficiency.
- Optimal threshold maintains efficiency > 99% and occupancy < 1.5%.
- Full note documenting this study written in January 2023.

Threshold Scan

- Special runs have been acquired to scan various thresholds (Threshold scans).
- Five threshold scans were studied to determine if there has been any deterioration in the SCT, specifically in the long shutdown between 2018 and 2022.
- The results from the recent threshold scans shows no deterioration in efficiency from the long shutdown, or any increase in occupancy.
- The SCT threshold does not need to be increased from its binary threshold of 1 fC before the end of Run 3.



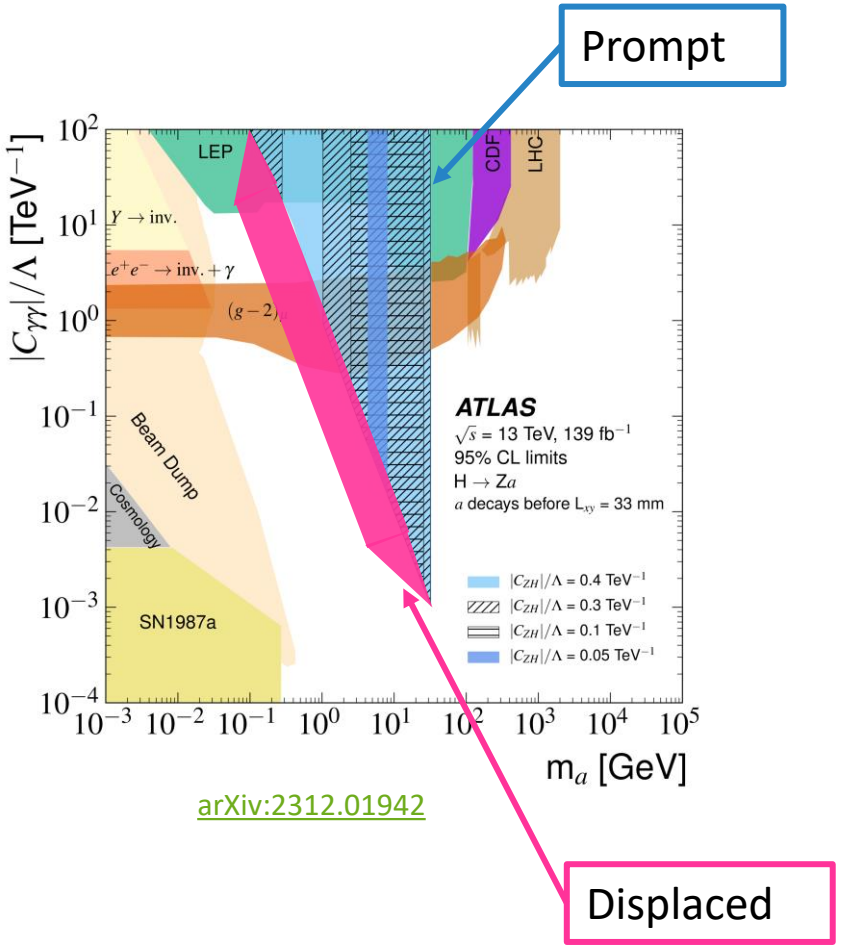


- The June 2023 scan has a much higher pile-up than April 2023, to compare with the 2018 scan.
- The same increase in occupancy with pile-up was not seen.

Summary

The slides summarised worked carried out for ATLAS in the detector (SCT) and analysis, which will be the work of my thesis.

- The SCT threshold does not currently need to be increased from 1 fC.
- Build on top of the prompt analysis a search for displaced decays in di-photon pairs.
- Preliminary studies for very-displaced ALPs decay show low efficiency in reconstructing ALPs decay products as standard photons or jets.
- Dedicated ID procedures being developed, studying reconstruction tools.
- Targeting early Run 3 publication and legacy paper with full Run 3 and Run 2 datasets.
- First results expected end of 2024.



arXiv:2312.01942

Back-up

Further SCT studies

- The median charge is equivalent to the threshold value at 50% Hit Efficiency.
- The median charge is higher for higher η index as expected, as at higher η index particles pass through a longer distance in the silicon and have more charge deposited in the SCT to pass the threshold value.
- The 2018 median charge values are not accurate due to the shorter threshold range in the efficiency plot previously shown.
- The most recent scan is looking at how changing the HV affects the efficiency and occupancy.