IOP Joint APP, HEPP and NP Conference

# Search for long lived ALPs that decay into diphoton in Run 3

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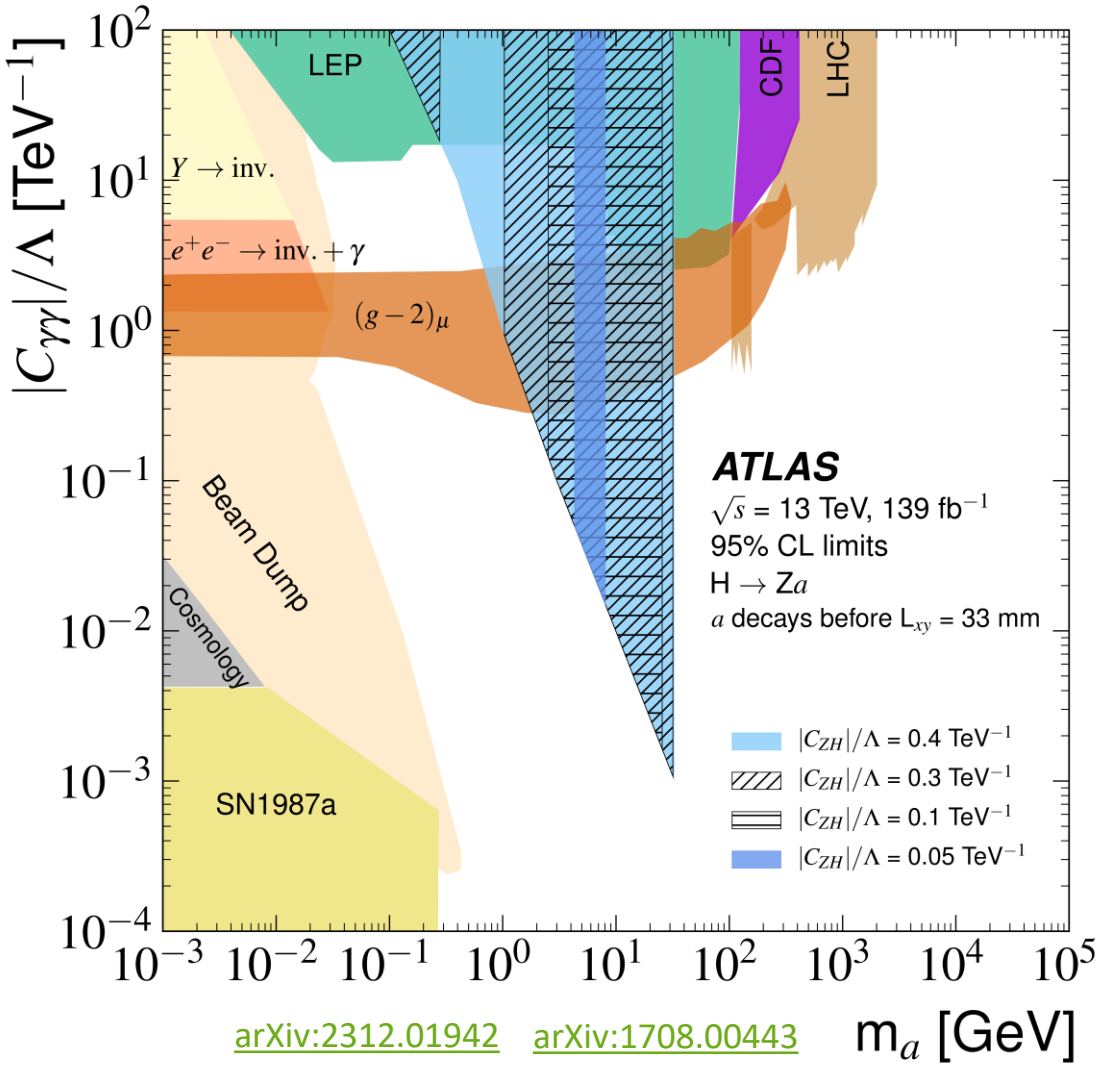
# Axion like particles (ALPs)

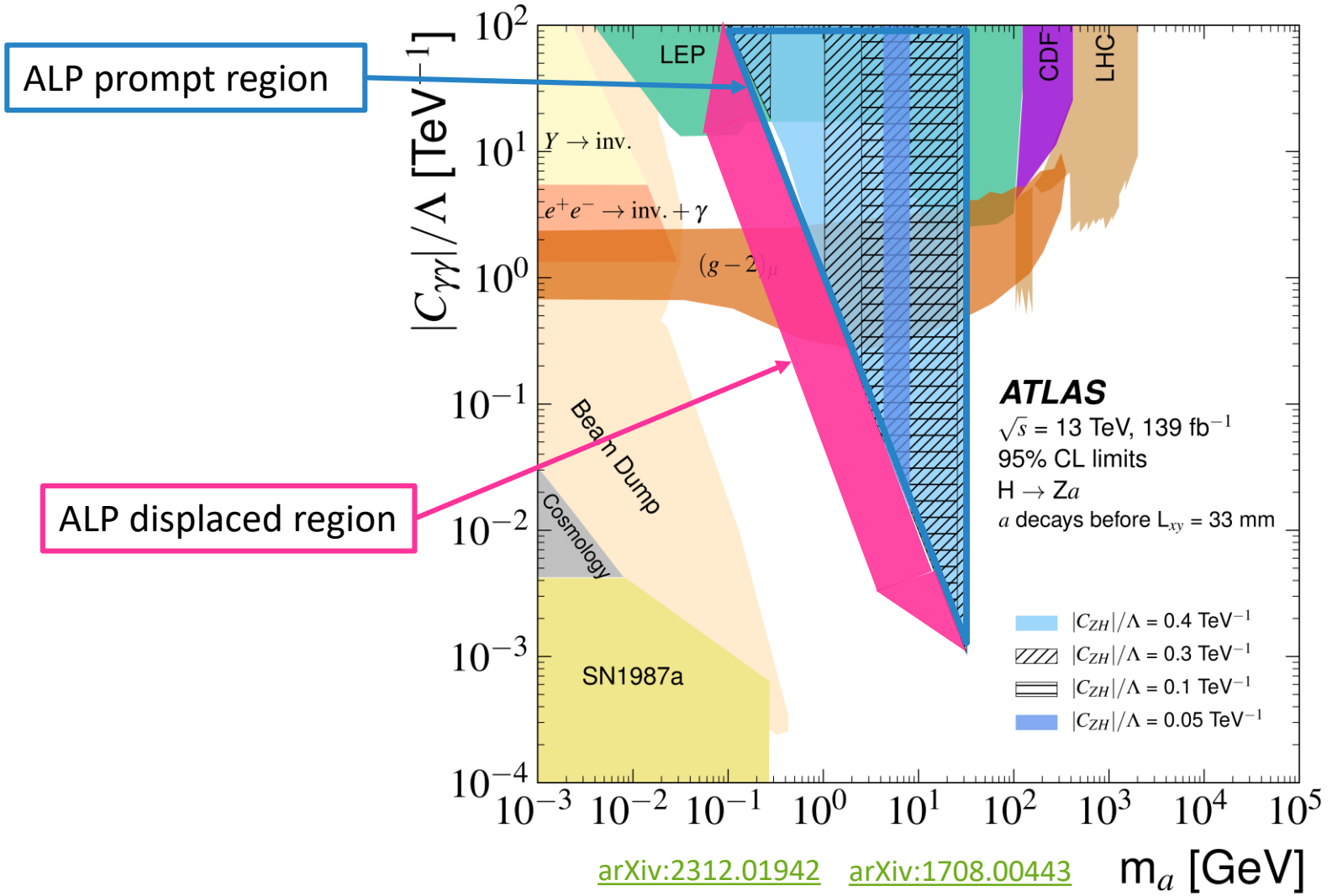
- ALPs are a generalisation of the QCD axion.
- In contrast, ALPs mass and couplings to other particles are free parameters.
  - Determined by experiment.
- ALPs are hypothetical light particles that may be a component of the dark sector.
- The strong CP problem - why does the strong force conserve CP 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.

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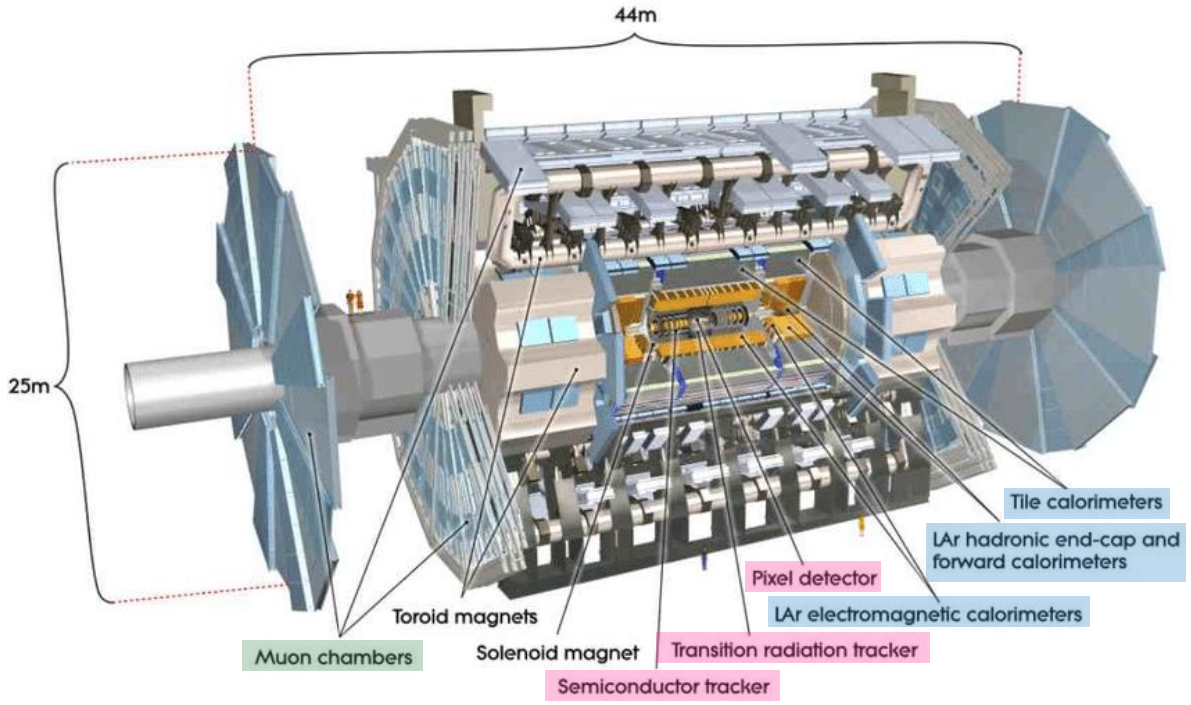
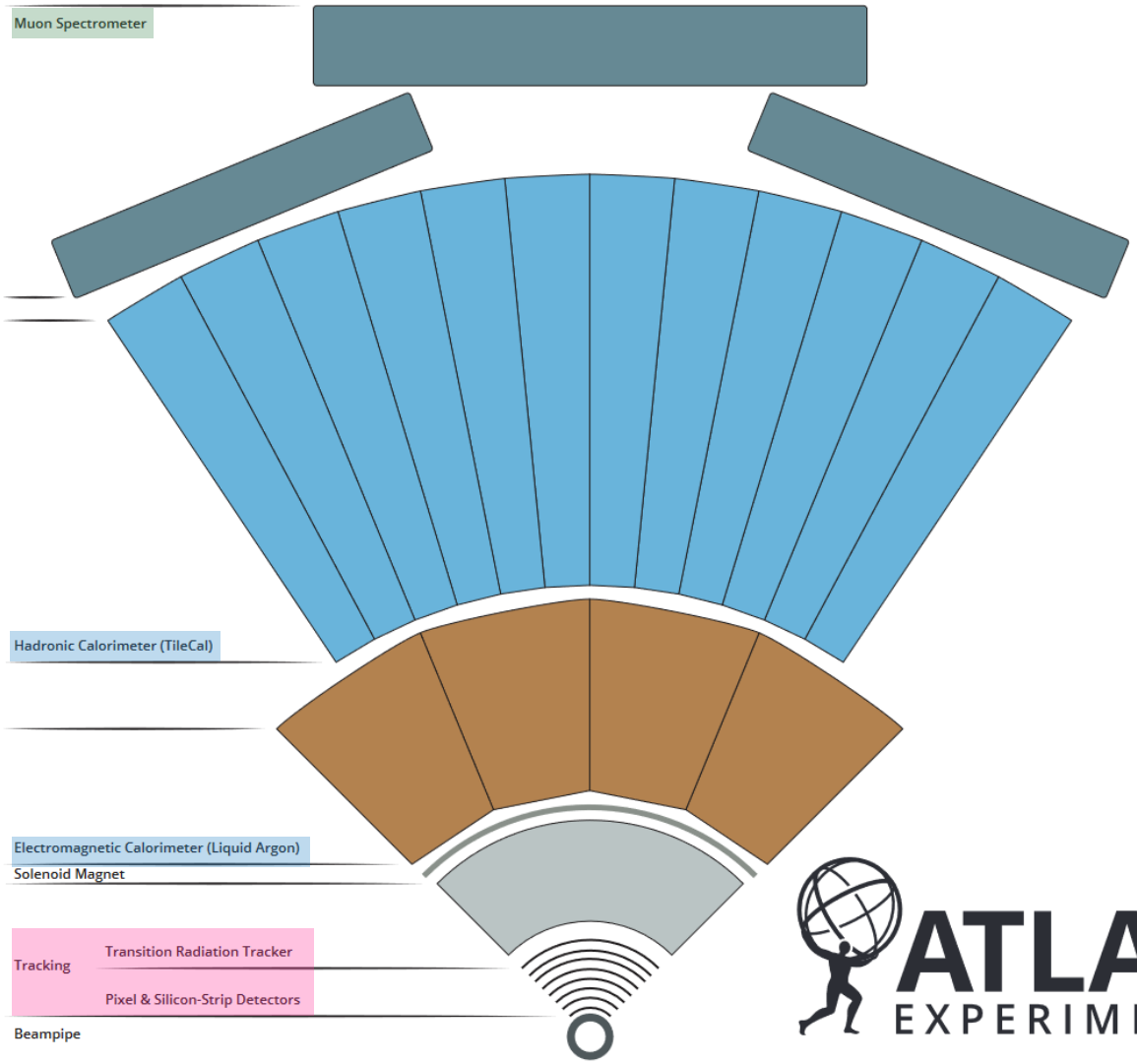
# ATLAS detector



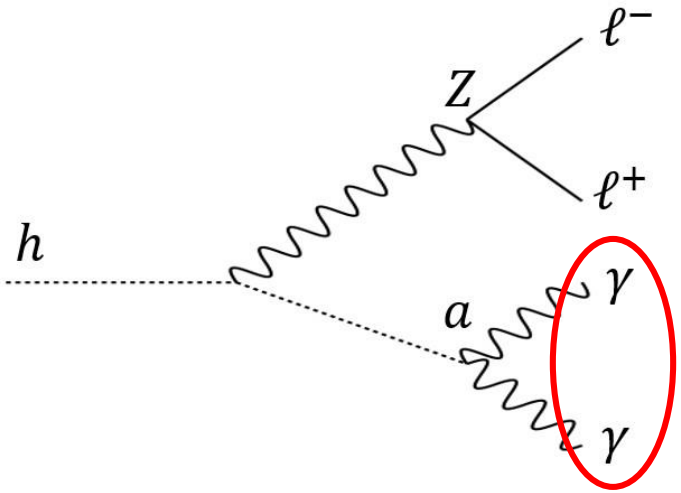

The ATLAS detector is made up of:

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

# Signature

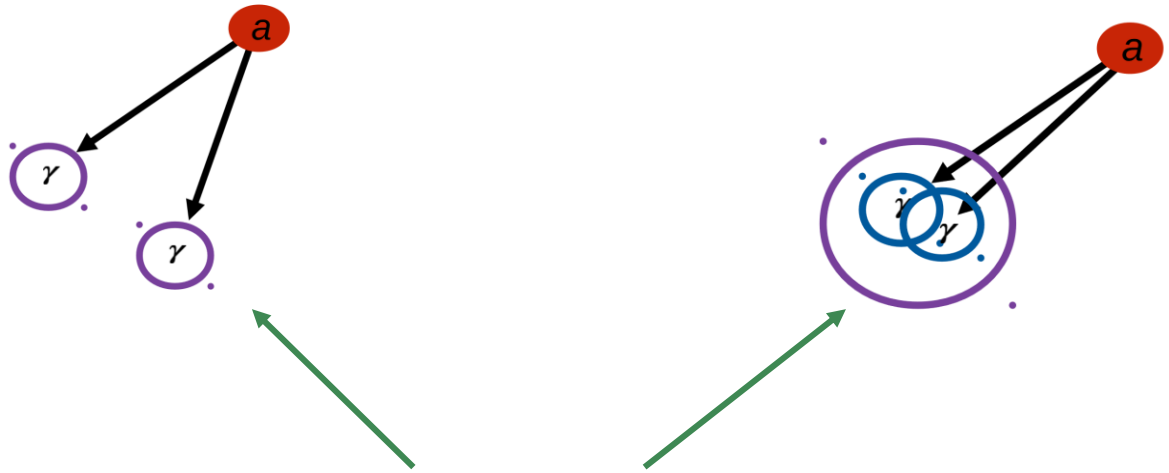
A powerful way to look for ALPs at high mass, is through exotic decays of the 125 GeV Higgs boson.

- 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



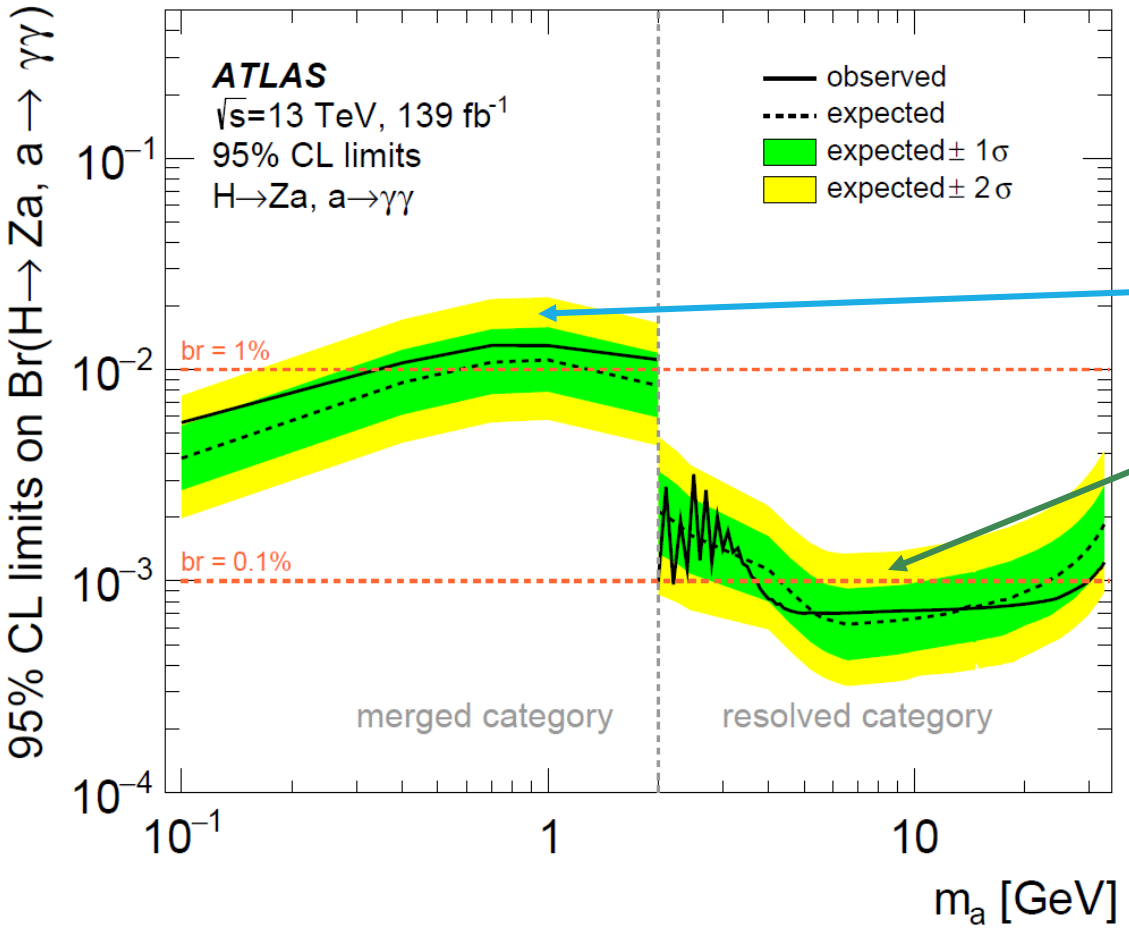

Photons can either be reconstructed as resolved or merged.

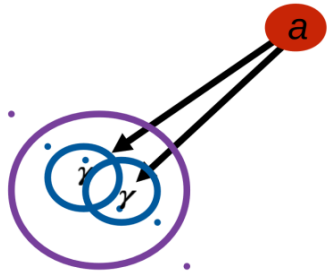
- At low mass points, the ALP is more boosted, therefore the photons are more merged.

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

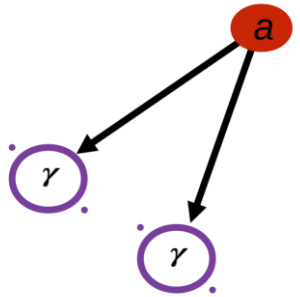
- Search for h->Za using Run 2 data (arXiv:2312.01942 ).
- Two selection categories depending on how collimated the photon pair are; merged category and resolved category.
- Backgrounds: Z+jets, Z+gamma.
- CMS search: arXiv:2311.00130



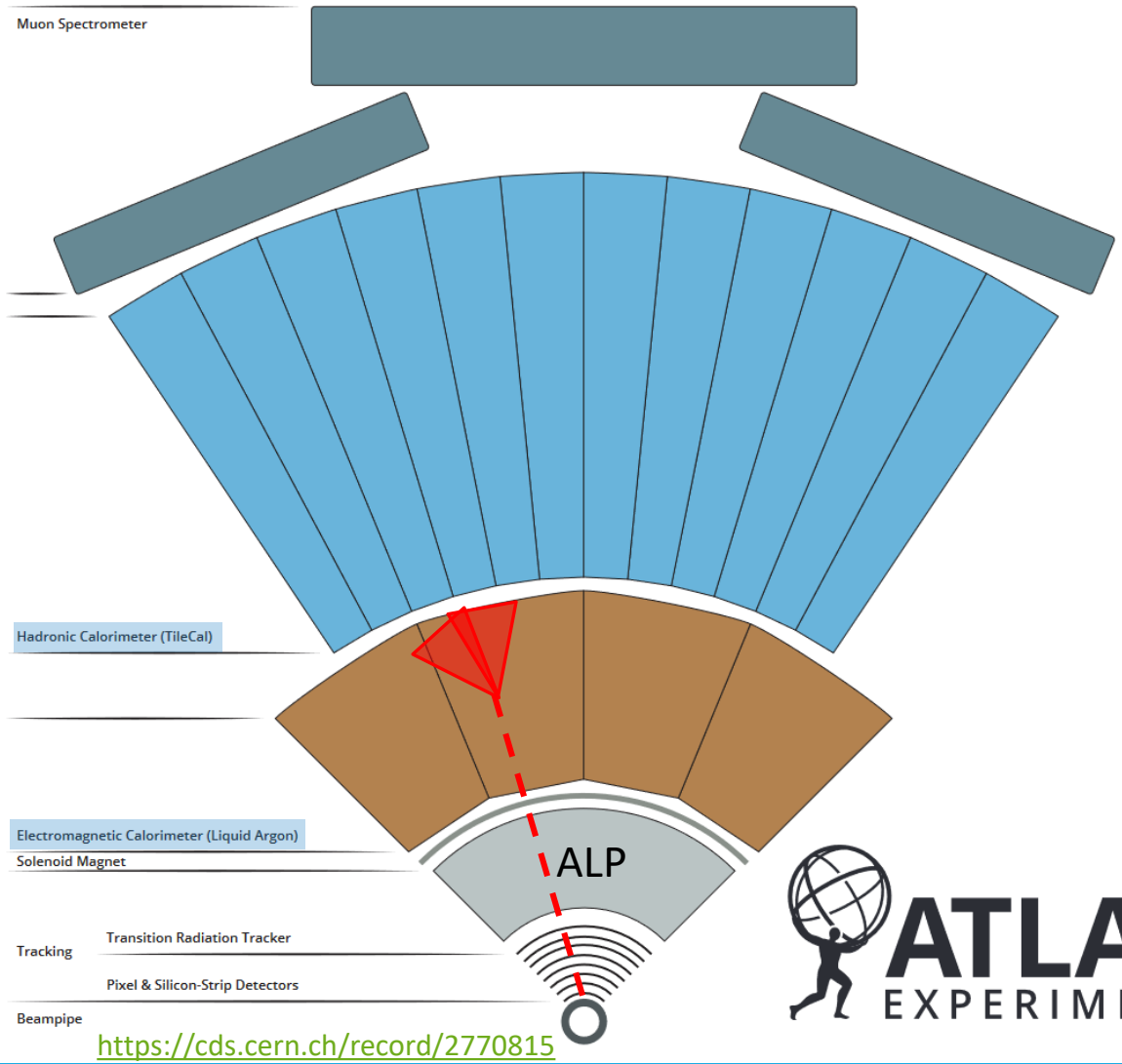

Merged category wins for mA < 2 GeV

Resolved category wins for mA > 2 GeV



# Long lived signature

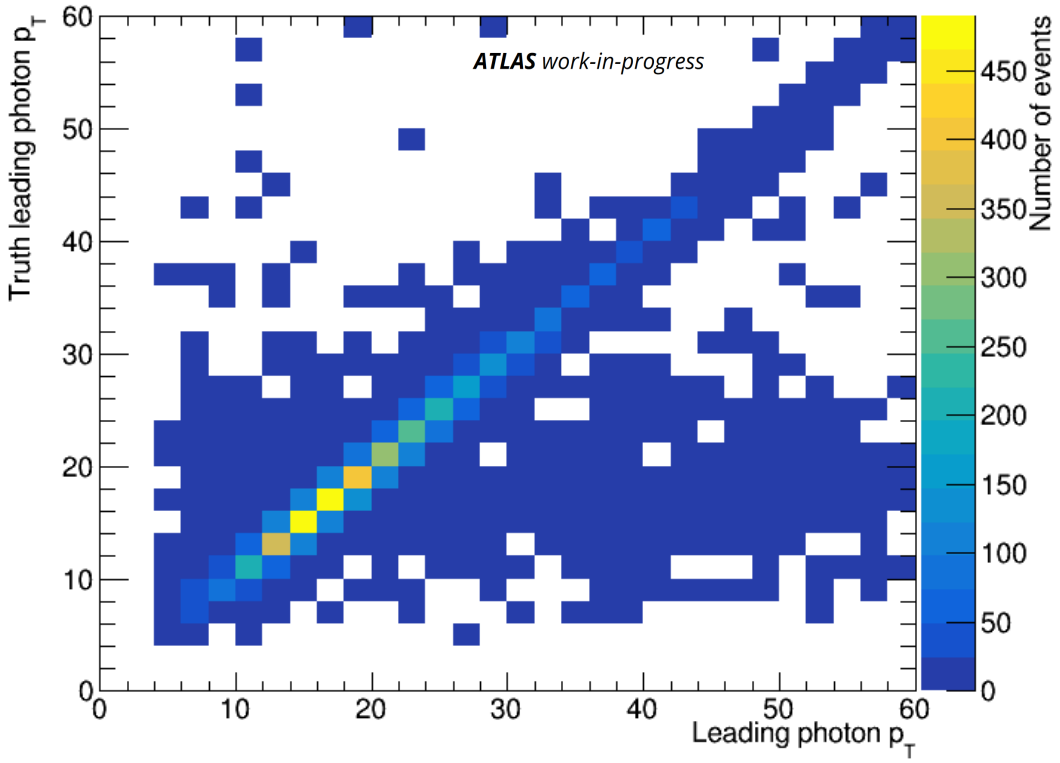
- Lifetime of ALPs -> 0-3800 mm.
- Displaced secondary vertex.
- Decay inside calorimeters.
  - Highly collimated photon pairs in ECAL.
  - Possible that energy is only deposited in last layers of calorimeters.
- Photon standard reconstruction is not built to reconstruct collimated γ pairs.
- ALP decay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



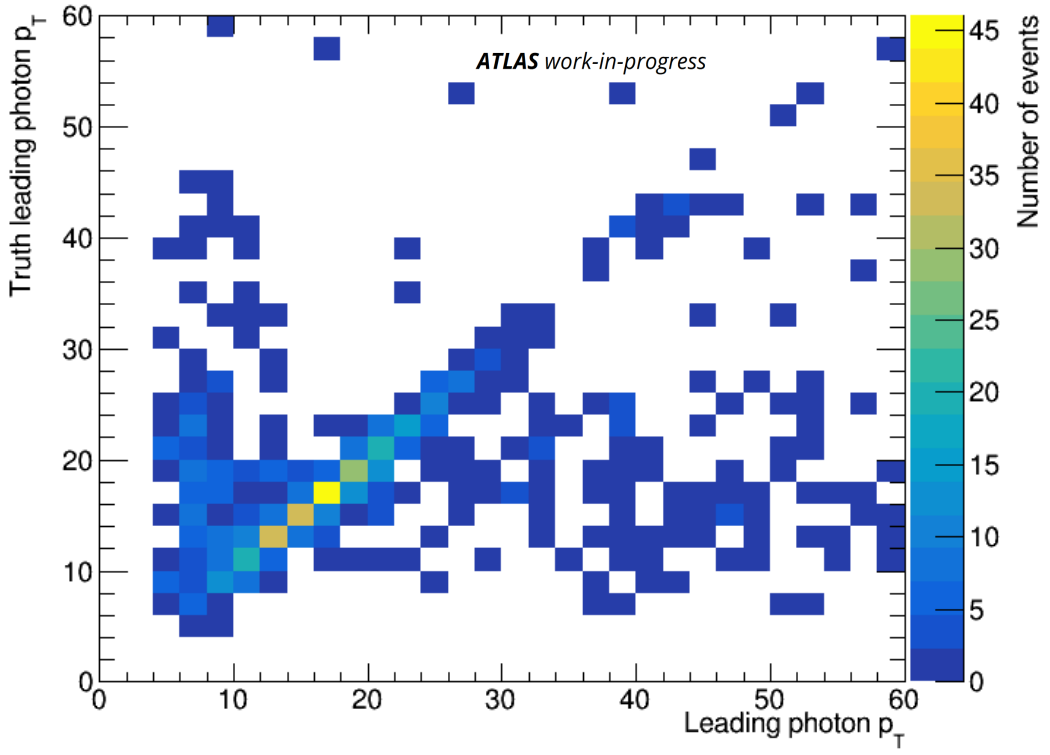

https://cds.cern.ch/record/2770815

# Particle-level and detector-level photon $p_T$ correlation

9 GeV prompt

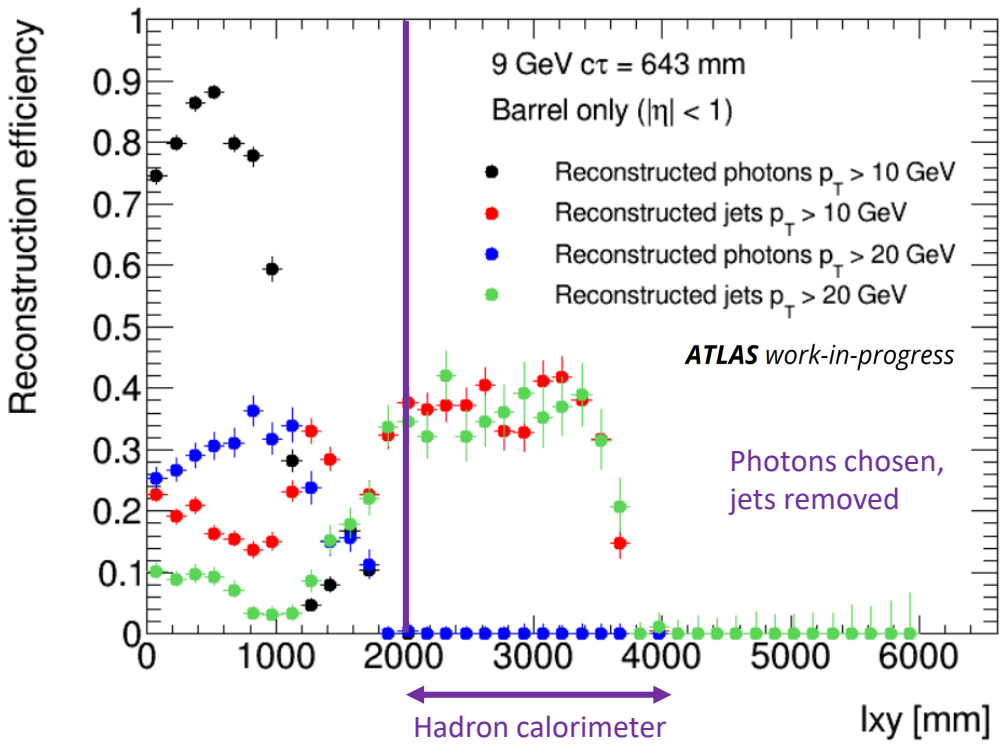


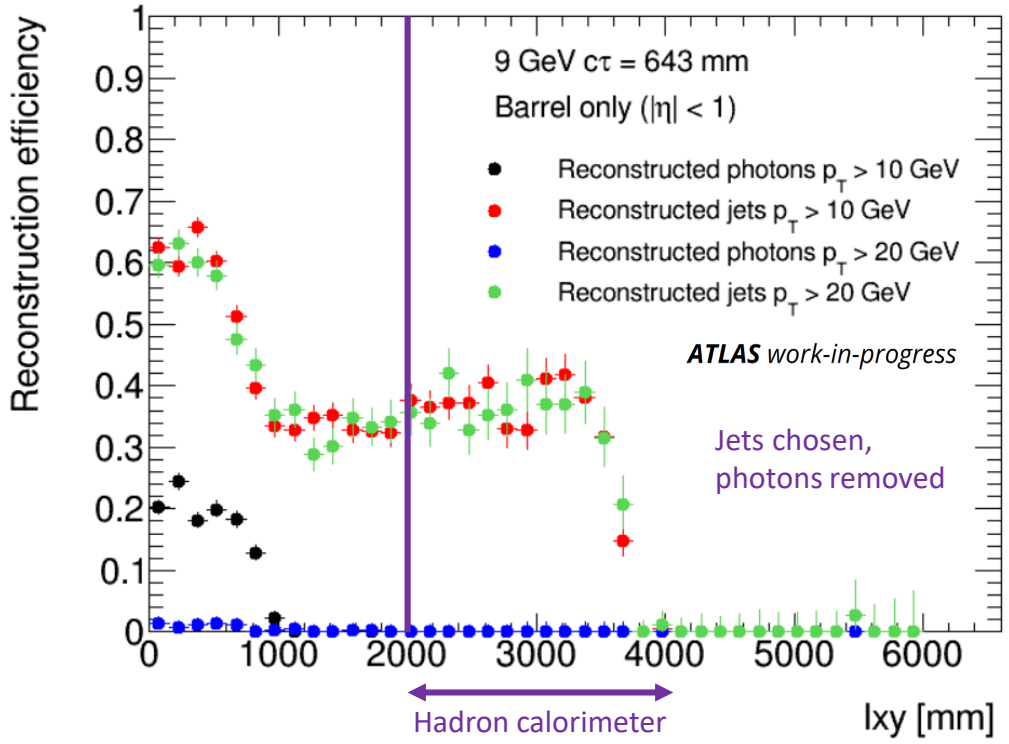

9 GeV cτ = 6430 mm




- For very displaced photons, the correlation between particle-level (truth) and detector-level (reconstructed) photon pT decreases greatly.

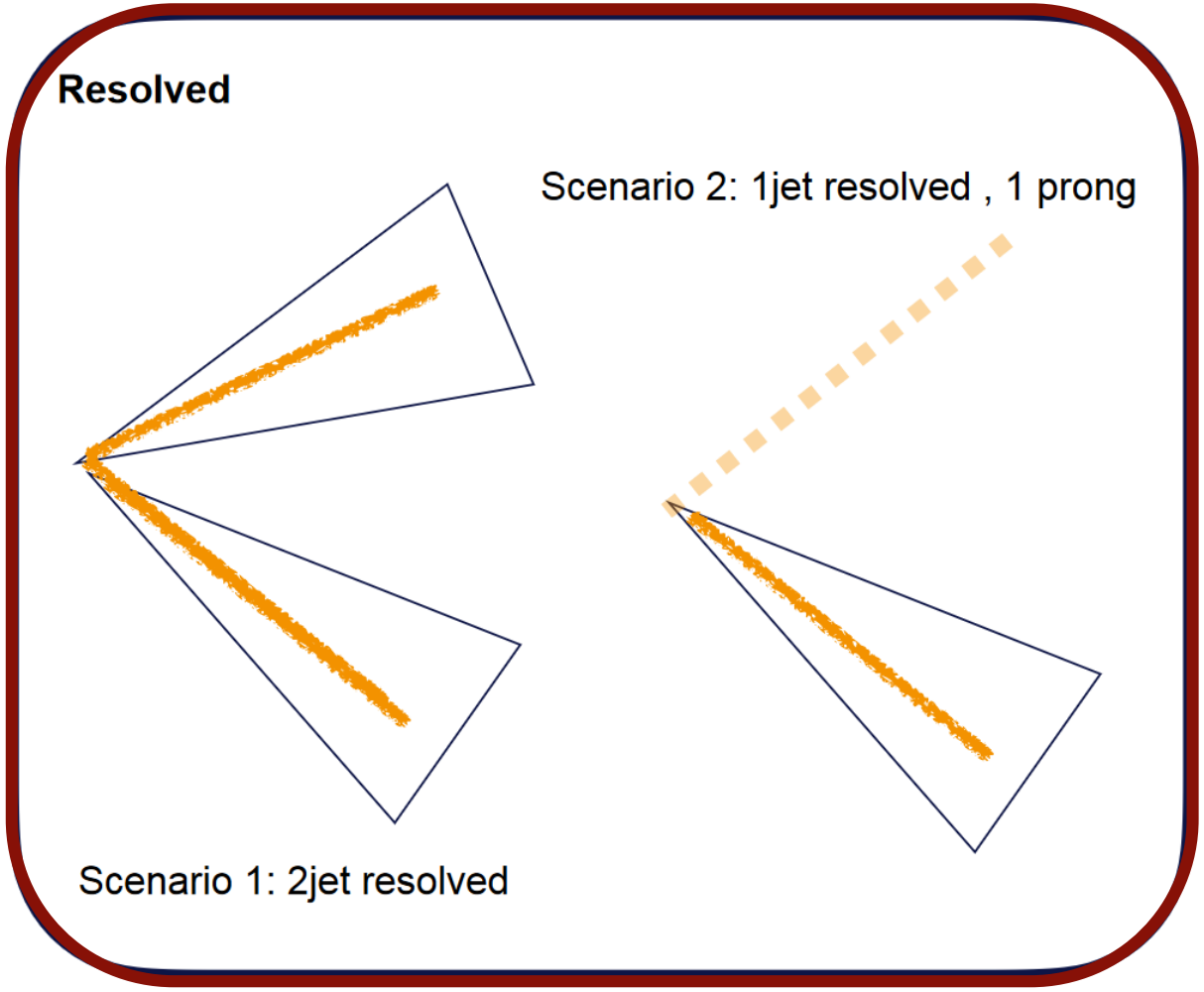
# Reconstruction efficiency

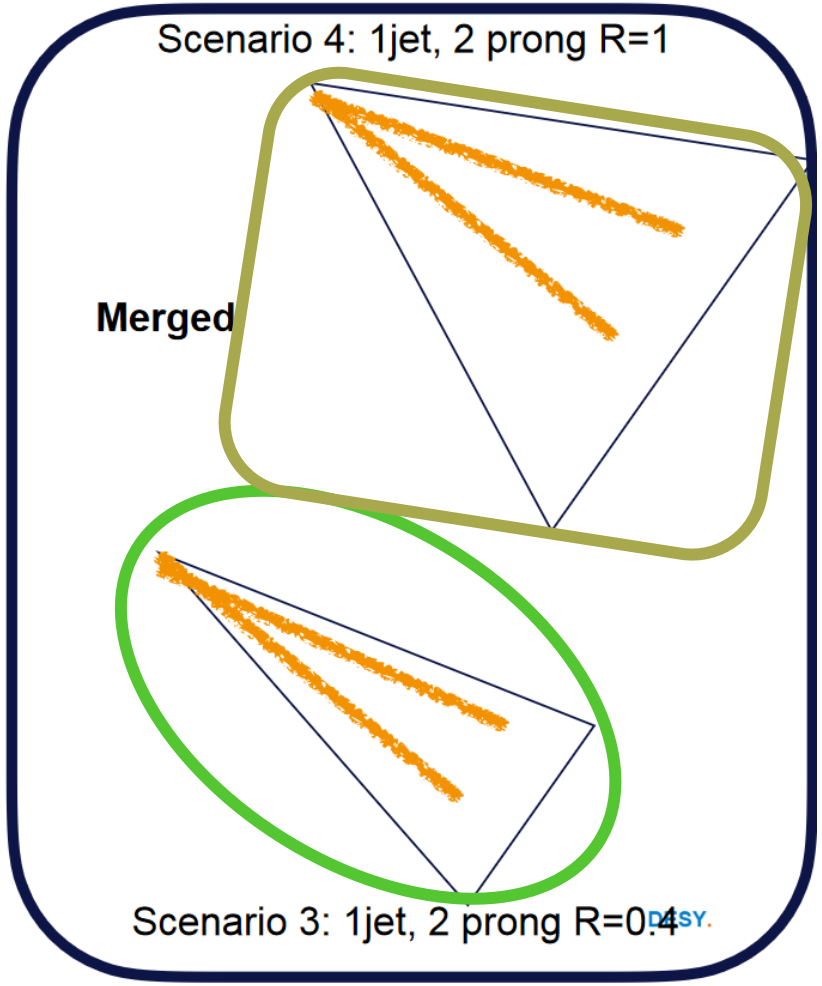



- Reconstructed photons (jets) are the photons (jets) with the smallest ΔR with respect to Truth photons.
- ΔR is the difference in the pseudorapidity-azimuthal angle space.
- The majority of reconstructed photons are lost when decay length passes the electromagnetic calorimeter.
- Jets are usually removed 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.

# Reconstructing photons as jets, 4 scenarios



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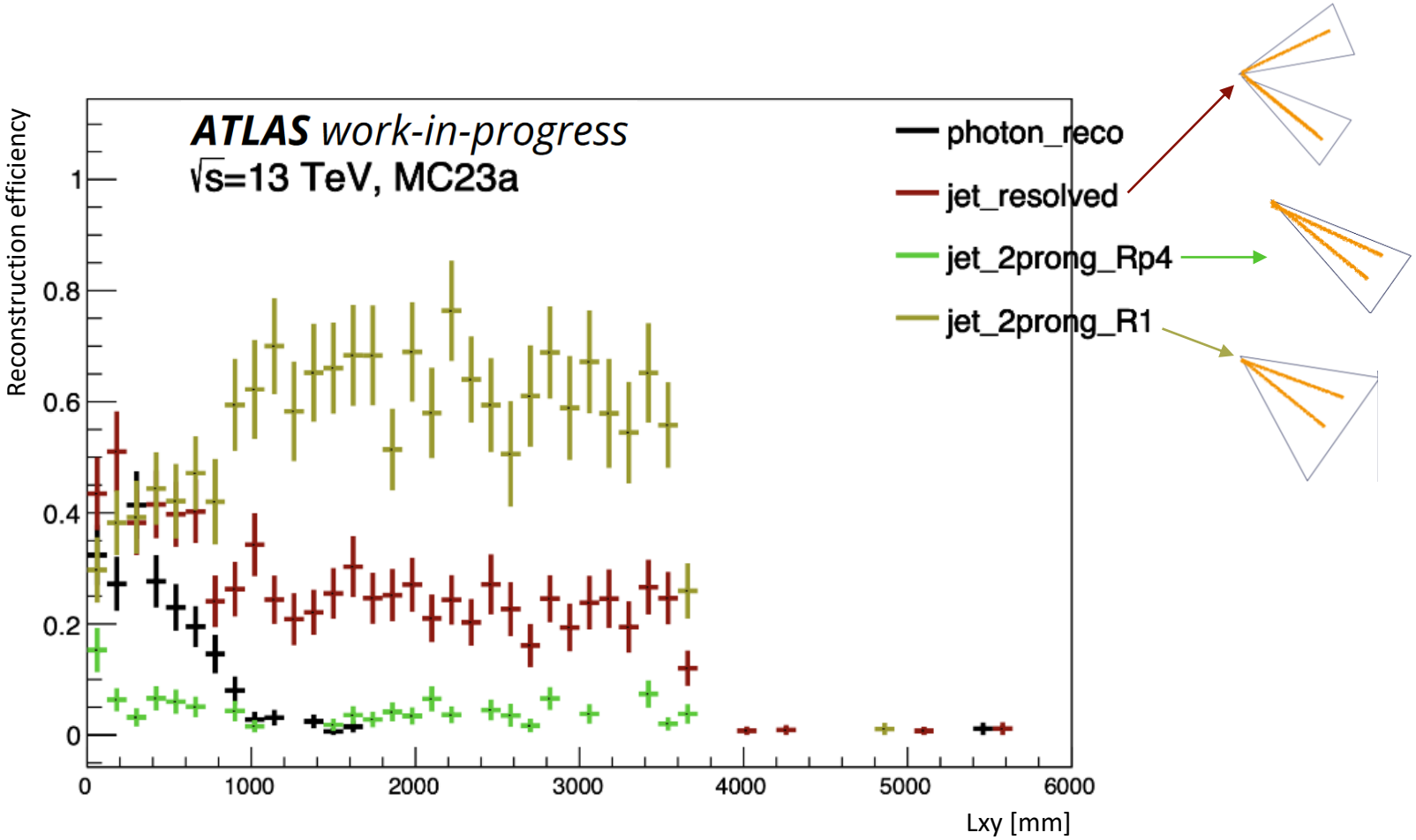
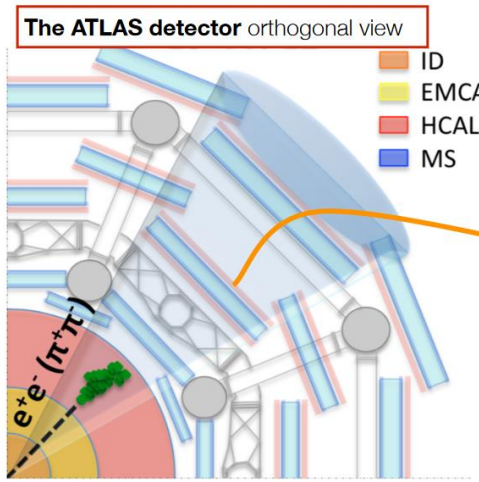



- 2 prong contribution in standard R=0.4 jet not significant.
- Effect seems to be quite significant in R=1 jet.
- Using a large R jet could lead to significant increase in reconstruction efficiency.

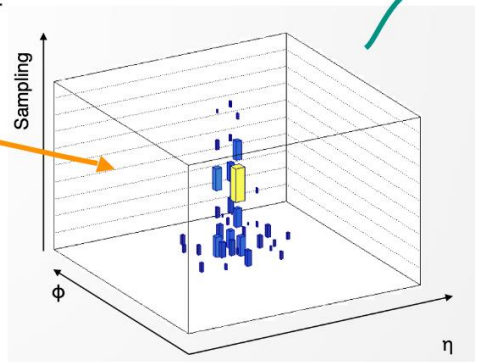
# Photon tagging

Photons from displaced decays can be reconstructed using:

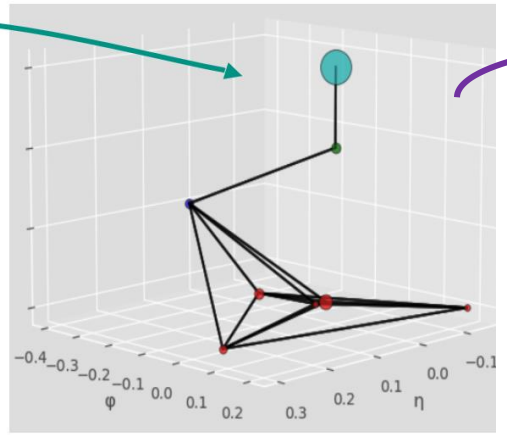
- A neural network, e.g. using the same approach as in [arXiv:2206.12181](arXiv:2206.12181) and extending it to GNN.
- Shower shapes in the calorimeter layers of the ATLAS detector.

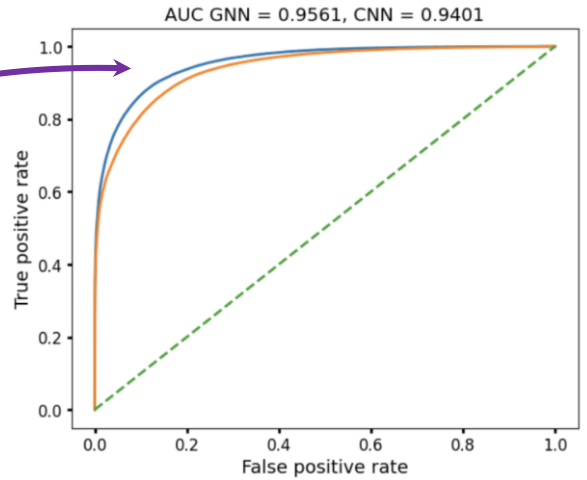



CNN




GNN

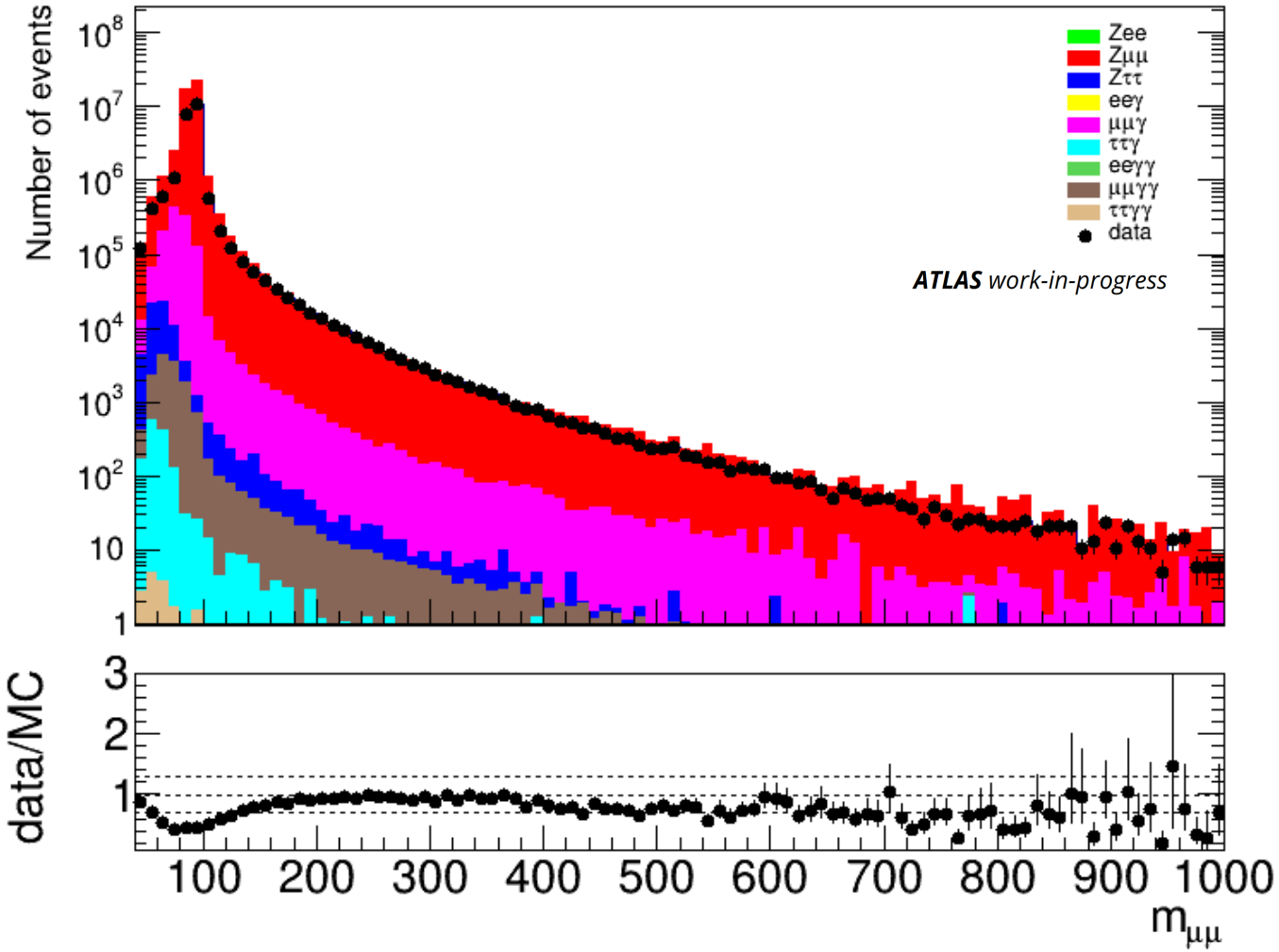



- CNN -> very sparse images -> sub-optimal.
- GNN -> fully optimised and out-performs CNN model on all performance metrics tested.

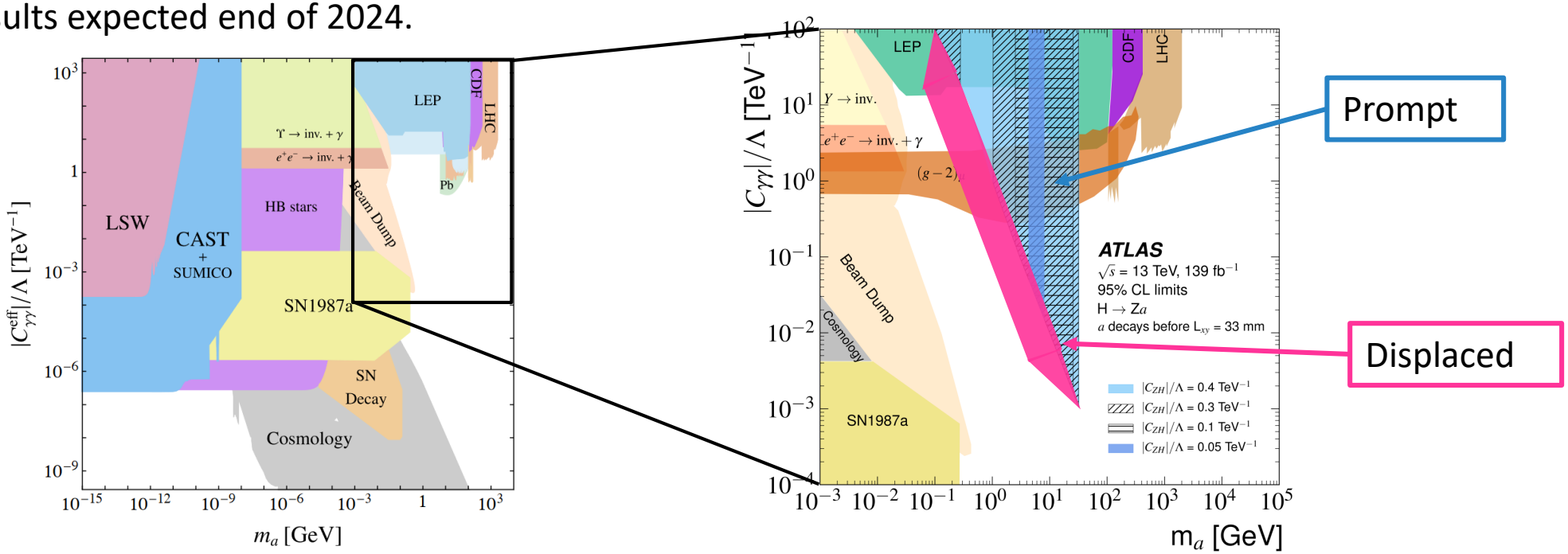
# Next steps

- 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.



# Summary

- 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.
- Looking into data/MC background correlation for electrons.
- Targeting early Run 3 publication and legacy paper with full Run 3 and Run 2 datasets.
- First results expected end of 2024.

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