PROCEEDINGS OF SCIENCE

ATLAS search for ALPs that decay into diphoton at the LHC

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A search for axion-like particles (ALPs) decaying into diphotons using the ATLAS detector is presented. ALPs, hypothetical light particles potentially part of a hidden sector, are investigated in the context of Higgs boson decays. The study focuses on a Higgs boson decaying to a Z boson and an ALP, with the Z boson decaying leptonically. For prompt ALP decays, a dedicated analysis targeting events with two leptons and two collimated photons (either merged or resolved) has been completed and published. Ongoing studies examine scenarios where ALPs are long-lived and predominantly decay within the calorimeter volume, resulting in displaced photons that require specialised identification techniques. This proceeding summarises current findings and future prospects of these ALP searches.

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This proceeding presents a search for axion like particles (ALPs, a) produced in association with a Z boson from Higgs decays, $h \to Za$. ALPs are hypothetical light particles that may be a component of the dark sector. Unlike the QCD axion, ALPs have masses and couplings to other particles that are free parameters determined by experiments. They offer potential solutions to the strong CP problem by dynamically suppressing CP-violating effects through a new "axion field" and could also account for the muon $g-2$ anomaly via their interactions with the electromagnetic field. ALPs can either decay promptly or be long-lived. The ATLAS detector [1] at the LHC [2] can probe ALP couplings to the Standard Model within a phase space unreachable by non-collider experiments. If the muon $g-2$ anomaly is due to new particles rather than theoretical uncertainties, ATLAS can explore this region. The mass range for ALPs in ATLAS spans from 0.1 to 35 GeV.

A powerful way to search for ALPs in this mass range is through exotic decays of the 125 GeV Higgs boson, considering both gluon-gluon fusion (ggF) and vector boson fusion (VBF) Higgs production mechanisms. This analysis focuses on the decay channel $h \to Za$, with the primary backgrounds being Z + jets and $Z + \gamma$. The signature for this analysis is two leptons and two collimated photons (Figure 1). Depending on the ALP's boost, the photon pair from the ALP decay can be reconstructed as either two distinct photons (resolved) or a single photon (merged). At low masses (less than 2 GeV), the ALP is more boosted, resulting in more merged photons. The analysis strategy begins with triggering on the Z boson, followed by using a photon tagger to discriminate between signal and background. The signal and control regions are then defined through a cut-and-count analysis.

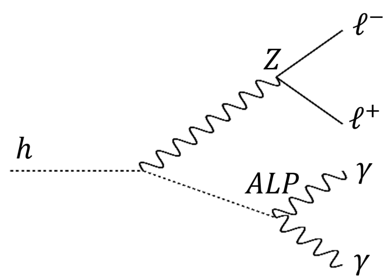
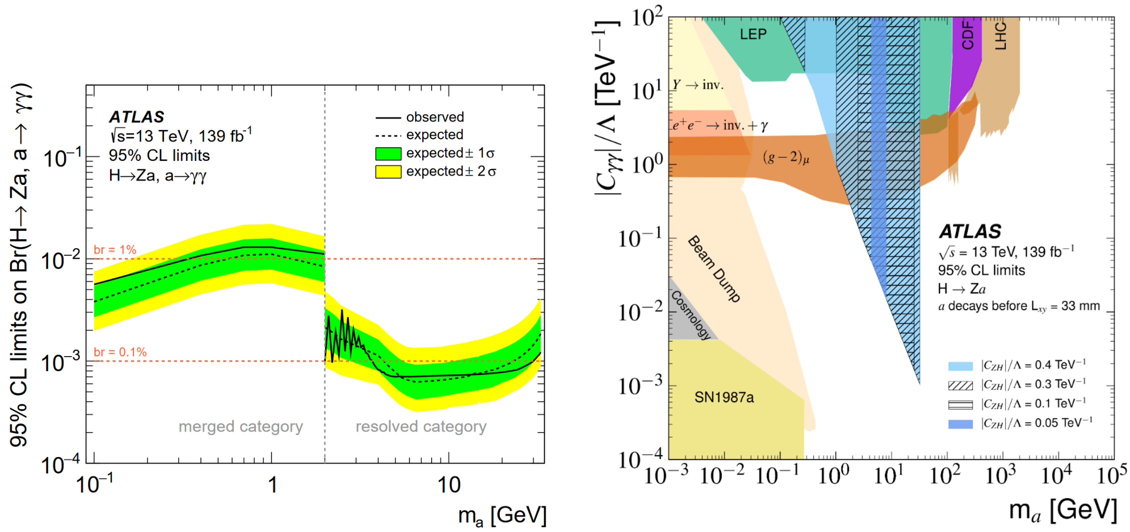


Figure 1: ALP produced in association with a Z boson from a Higgs decay.

The prompt version of this analysis, using Run 2 data, has been completed. This search for $h \to Za$ employed two selection categories based on the collimation of the photon pair: merged and resolved. Figure 2(a) illustrates the sensitivity for merged and resolved photons in the ALP mass regions selected for each category. The 95% upper limits for these categories in the prompt analysis are also interpreted in terms of the ALP mass and effective coupling to photons, as shown in Figure 2(b).

Ongoing studies are investigating scenarios where ALPs are long-lived, with sizeable lifetimes resulting in decay lengths ranging from 0 to 3800 mm. In these cases, the photons from ALP decays can exhibit a displaced secondary vertex, decaying within the calorimeters. These photons are highly collimated and may deposit energy primarily in the last layers of the ATLAS calorimeters. Standard photon reconstruction algorithms are not designed to handle displaced photons, meaning that photons from ALP decays may not meet the usual identification criteria or may be reconstructed as a single photon. The long-lived ALP study aims to extend the prompt exclusion contours shown



(a) (b)

Figure 2: (a) Expected and observed 95% CL upper limits on the branching ratio of $h \to Za$, multiplied by the branching ratio of $a \to \gamma\gamma$, as a function of the a particle mass in the merged and resolved categories. (b) Reach in mass vs coupling to photons for various experiments, including ATLAS observed 95% CL exclusion contours limits for different values of the Higgs coupling to Za, where the ALP is prompt [3].

in Figure 2(b) to cover these new scenarios.

In conclusion, building on the published prompt $h \to Za$ analysis, an extension to investigate long-lived ALPs is planned. Dedicated identification procedures are being developed to enhance the analysis of long-lived ALPs, focusing on improving reconstruction tools. These efforts aim to further our understanding and detection capabilities of ALPs within the ATLAS experiment.

References

[1] ATLAS Collaboration, *JINST* **3** (2008) S08003.

[2] L. Evans and P Bryant, *JINST* **3** (2008) S08001.

[3] ATLAS Collaboration, *Phys. Lett. B* **850** (2024) 138536.