Searching for long lived axion like particles through Higgs boson decays using ATLAS calorimeters

Axion Like Particles (ALP)

The original Axion was postulated as a solution to the strong CP problem in 1977. The idea is to raise the θ prefactor of the CP-violating term in QCD to a field with a new global symmetry (U(1) Peccei-Quinn) which moves θ to a low value.
A **spontaneous breaking** (SSB) of this **symmetry results** in a pseudo-Nambu–Goldstone **boson called the Axion**.

$$L_\theta = \theta \frac{g^2}{32\pi^2} G^{\mu\nu}\widetilde{G}_{\mu\nu} \rightarrow L_a = \frac{a}{f_a}\frac{g^2}{32\pi^2} G^{\mu\nu}\widetilde{G}_{\mu\nu}$$

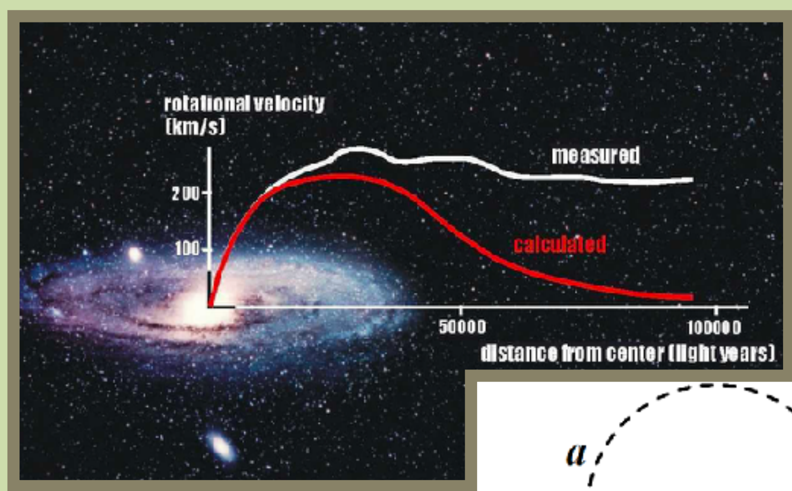
ALPs are particles following the same mechanism but **universalized to any theory** with U(1) SSB.
This yields a larger parameter space for the particle and thus a wider window of phenomenologies giving possible explanations to several modern physics problems, such as **dark matter's nature** or the **muon's g-2** 4.2 sigma deviation from SM predictions, while offering a vast range of experimental search strategies from cosmology to collider experiments.

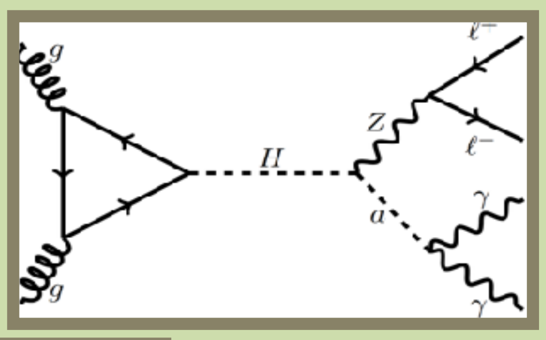
Production mechanism at the LHC

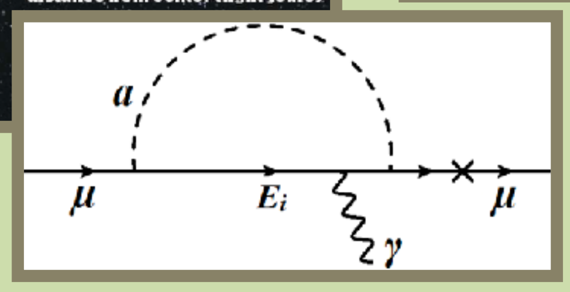
Exotic Higgs decay can produce ALPs $\quad h \rightarrow Za \quad h \rightarrow aa$

The resulting ALPs, if massive enough, can decay into pairs of leptons, **photons** or gluons.

Light axions can have a long life-time. $\quad \Gamma_{a\rightarrow\gamma\gamma} = 4\pi\alpha^2 m_a^3 \left(\frac{C^{eff}_{\gamma\gamma}}{\Lambda}\right)^2$







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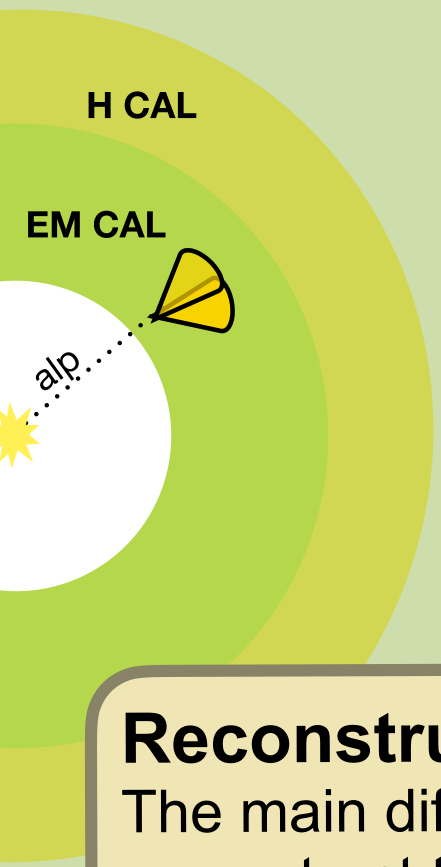
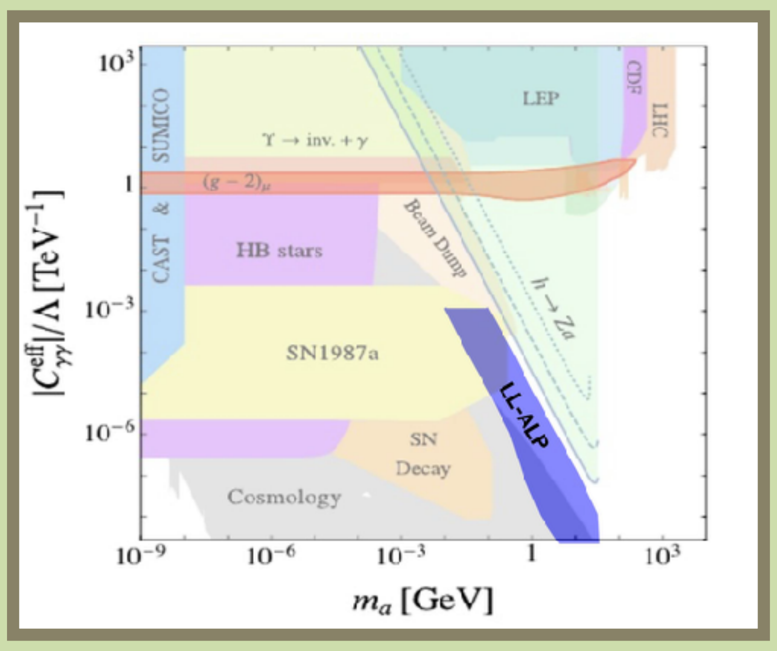




Axion Like Long Lived Particles

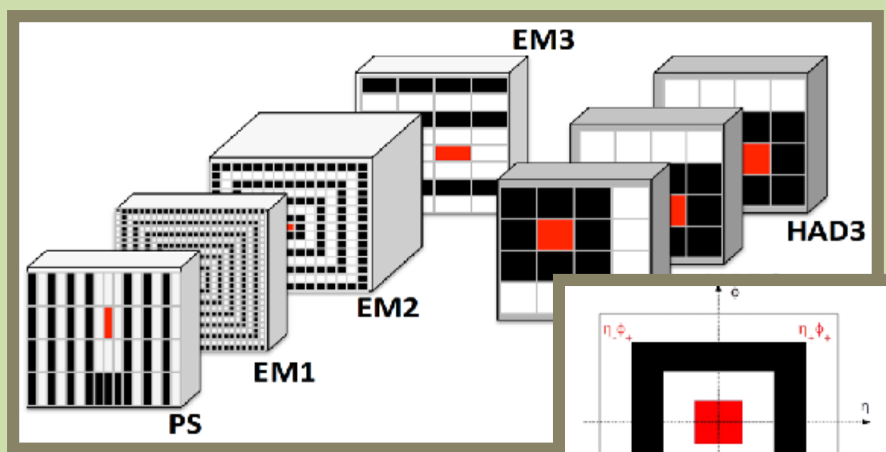
Covers a blank region of the parameter space

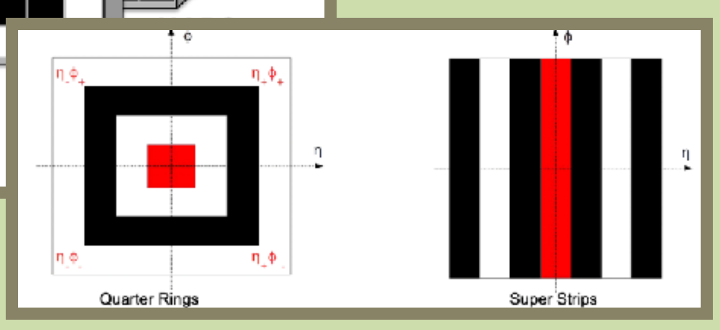
Interesting channel to exploit due to **unique signal** characteristics.
displaced vertices; timing shift; trackless jets; **unusual shower shapes**

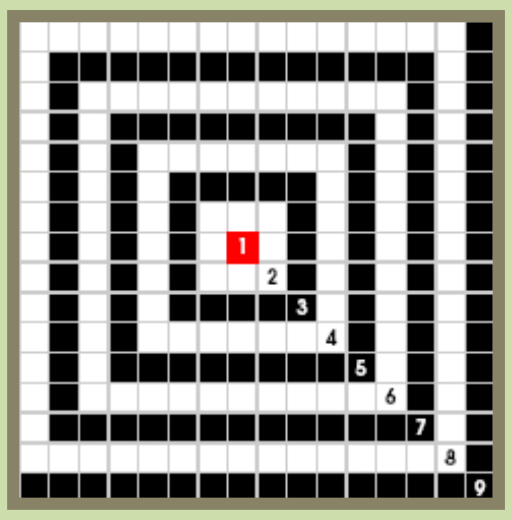
Decay inside the calorimeter : highly collimated photon pairs, miss-identification of photons

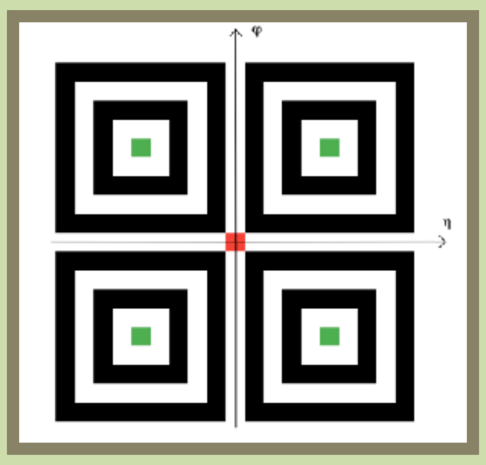
Reconstruction of merged pairs of photons

The main difficulty of such an analysis is in the identification and reconstruction of the late photon pairs as standard methods will reconstruct them as jets or as one photon. **New identification strategies** are being developed to separate these events from real single photons and QCD-jets. (improve pi0 reconstruction)
Note that the search is based around a **new phenomenology** that can be applied to **multiple LLP models.**









Calorimetry study

In ATLAS a set of shower shape (SS) variables, built from calorimeter cells, are used to identify e/gamma and separate them from QCD-jets. These were constructed for prompt events thus are inefficient for this situation.
New SS variables with different **topologies** are needed :

- Focused on the shower's center
- Not symmetrical by construction
- Efficient for photon identification / reconstruction

Alternative low level calorimeter **variables** : **Rings**

- Cells energy summed in concentric ring shapes around the barycenter
- Used for electrons and photon triggering (under dev)
- Can be modified to more **complex topologies** (asymmetrical rings)

Using and **modifying the ring approach** we can develop a technique that identifies merged photons coming from LLP. With a high enough resolution calo-only vertex pointing could be implemented.

Analysis status and perspectives

A **tool** was built to access low level calorimetry info, **build rings + extensions around jets ROI** and reconstructs the events to a physics analysis format level.
Studying background rejection possibilities by exploiting the Lund Jet Plane properties and differences regarding QDC and EM jets.
Machine-Learning algorithms using these variables are to be developed and tested for identification efficiency on MC simulations.
The resulting optimized code will be run on run2 and run3 data and provide final exclusion limits.

This method could be **ported to the trigger level** which would allow for **model-independent searches** of late diphoton systems.

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