Searching for ALPs with light-by-light scattering

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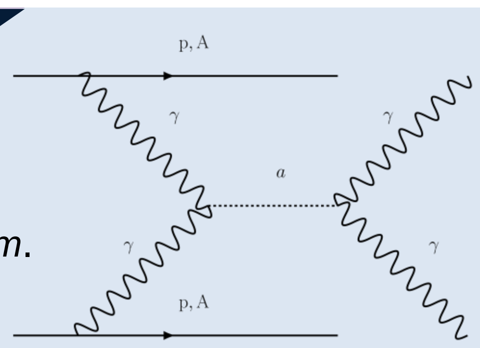
ALPs



Axions were first postulated by the Percei-Quinn theory to resolve the *strong CP problem*. This type of axions have small masses, may constitute ***cold dark matter***, and have been heavily constrained with helioscopes.

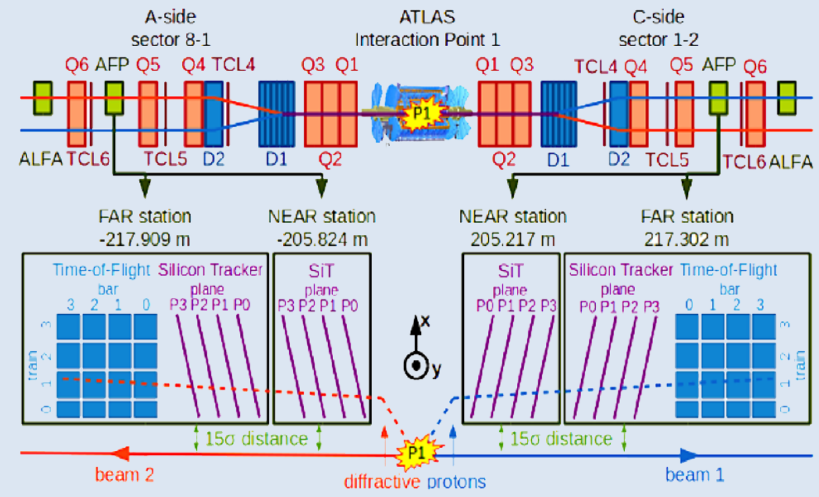
More generally, Axion Like Particles (ALPs) appear as pseudo *Nambu-Goldstone bosons* in theories with approximate global symmetries that are spontaneously broken.

$$\mathcal{L}^{+}_{eff} = \frac{1}{2f^2 m_a^2}\left(F_{\mu\nu}F^{\mu\nu}\right)^2$$

ALPs that couple mainly to photons have already been heavily constrained at sub-eV masses. Above this mass range, *collider searches become necessary*. Ultra-peripheral collisions of lead ions were used to constrain ALPs in the range between 1 and about 100 GeV, including limits imposed by *light-by-light scattering*. However, one can probe higher ALP masses (350 GeV to 2 TeV) by considering proton-proton collisions, and using the ATLAS Forward Proton Detector (AFP) to reduce the background.

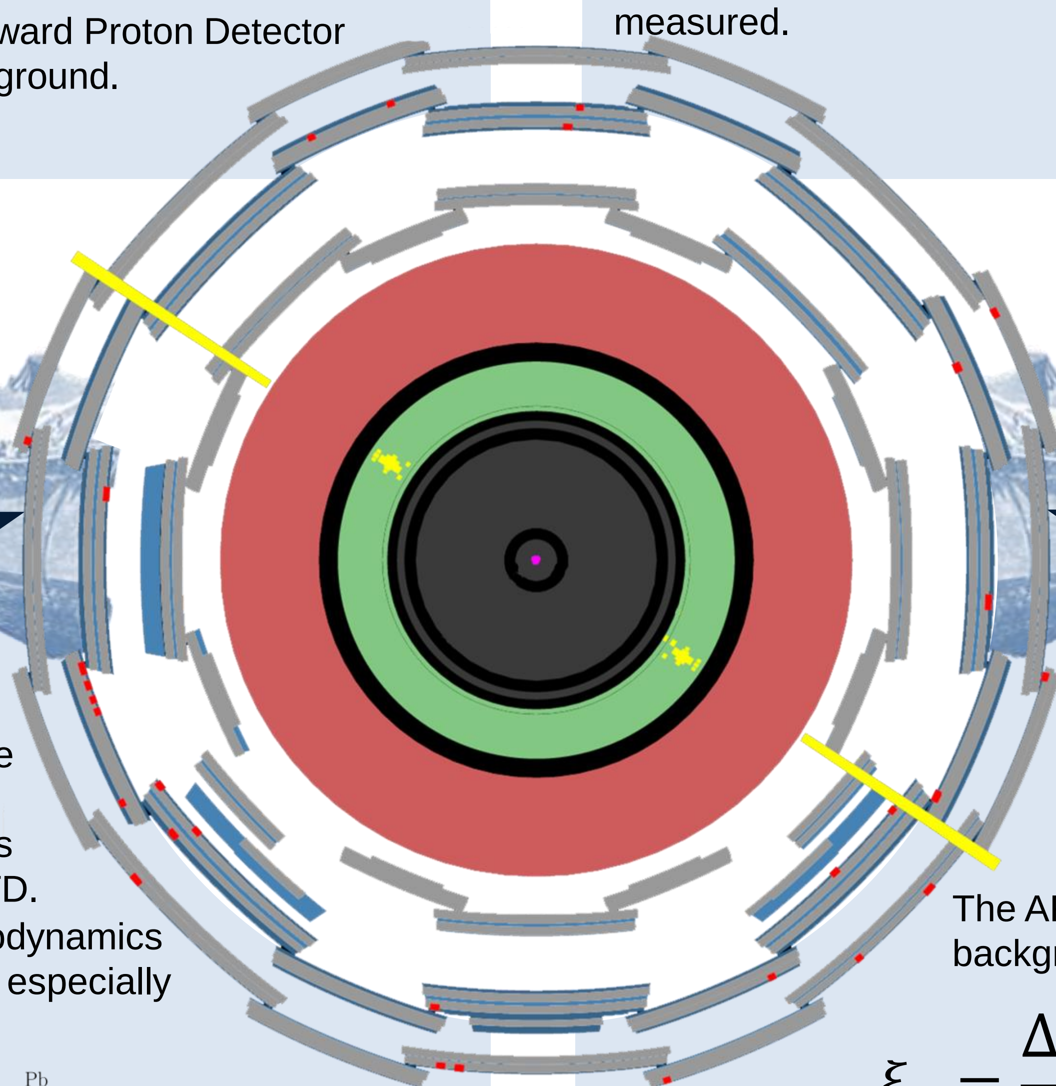
AFPs

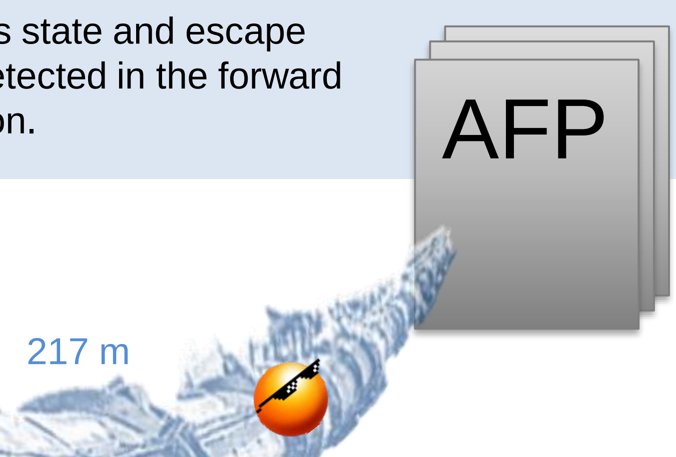
The AFP constitutes near-beam 3D-Si pixel tracking detectors that measure the momenta and emission angles of forward protons. The detector consist of two stations placed symmetrically with respect to the IP at the distance 205 and 217 m respectively. Each station contains horizontal Roman Pots. Protons that have lost a small fraction of their momentum are bent out of the beam envelope so that their trajectories are measured.



The proton(s) may either remain intact and then they can be detected in the AFP, or one/both can dissociate into a low mass state and escape undetected in the forward region.

The AFP 3D-Si sensors a resolution of $\sigma_x = 6$ μm and $\sigma_y = 30$ μm.

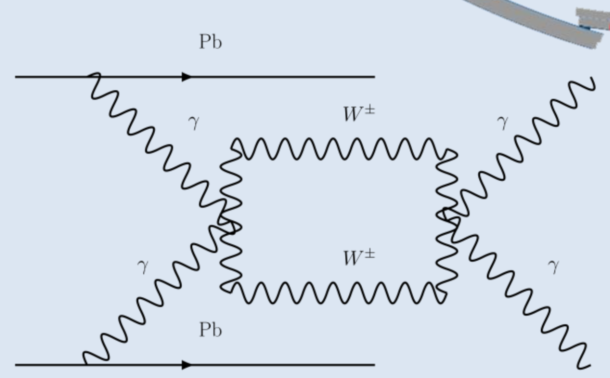




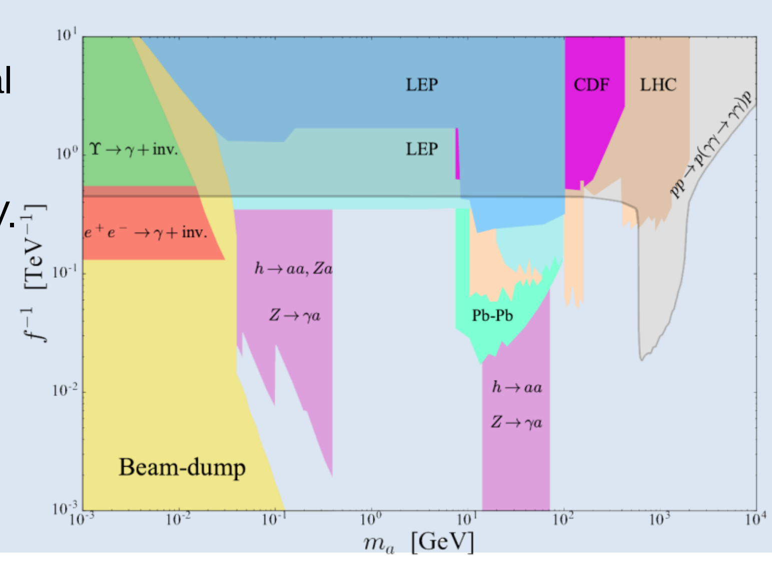
Motivation

In 2018, the first observation of 59 light-by-light scattering events was achieved with the ATLAS detector in led-led collisions. The measured cross-section for this process was determined to be 79±13±7±3 nb with 8.2 STD. This process is forbidden in classical electrodynamics and opens a new channel into new physics, especially high-mass ALP searches.

SM light-by-light scattering is mediated by a W box diagram, as shown on the right. It is theorised that another channel for this process could be mediated by an ALP, as shown above.



In the ALP search, the goal is to observe a resonance at high diphoton energies, between 350 GeV to 2 TeV. Highest predicted sensitivity is reached at approximately 1 TeV. The plot on the right shows the sensitivity reach as a function of ALP mass.

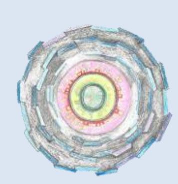


Method

Process is similar with SM light-by-light scattering in terms of selection and secondary backgrounds. However, in the ALP search, the SM light-by-light scattering becomes the dominating background.

The AFP detectors are used to reduce the background. This is done by matching their ξ values.

$$\xi_p = \frac{\Delta E}{E} \longleftrightarrow \xi_{\gamma\gamma} = \frac{m_{\gamma\gamma}}{\sqrt{s}} e^{-Y_{\gamma\gamma}}$$



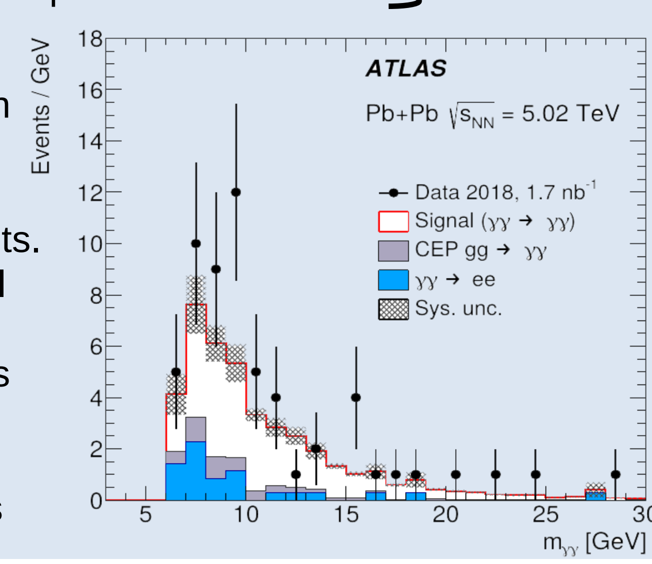
Exclusive diphoton event in the main detector.

A proton in each AFP, with their ξ value within 2-10% of the respective photon candidates.

Experi-mental signature

Analysis strategy:

- Selection of exclusive di-photon events in the central detector (similar to di-photons in figure).
- Application of photon quality cuts.
- Background study using control region.
- Using a data set which contains photon and AFP information.
- Extracting AFP information and studying the proton energy loss



References: arXiv:1803.10835 and arXiv:1904.03536.

ATLAS EXPERIMENT