# Reconstructing long-lived particles in the CMS High-Granularity Calorimeter at the Level-1 trigger

## Scientific context

The high-luminosity phase of the LHC (HL-LHC) is planned to start in 2029 with a target integrated luminosity of 3000fb$^{-1}$. For the HL-LHC, the CMS collaboration decided to replace the end-cap calorimeters with a new radiation-resistant and highly granular detector (HGCAL). The high granularity of this detector and the high luminosity pose severe challenges in terms of data volume on the trigger system of the experiment, a two-stage online system which selects collision events of interest to be recorded. It is particularly true for the first stage of the trigger system, the Level-1 (L1) trigger, which is based on custom electronics boards and takes as input data coming from the detector at an event rate of 40 MHz.

The purpose of the HGCAL trigger subsystem is to reconstruct clusters of energy deposited in the detector in three dimensions and to classify these reconstructed clusters. This task needs to be done with a tight latency constraint of a few microseconds, which requires to make simplifications in the way 3-dimensional clusters are built. Among these simplifications, it is assumed that particles originate from the center of the detector and travel along straight lines. Although this simplification has only a marginal impact on the reconstruction of particles originating from a vertex close to the center of the detector, it can make the reconstruction of long-lived particles fail. Long-lived particles (LLP) are particles with long lifetimes predicted by some scenarios beyond the standard model (BSM). It results that their decay products can originate from largely displaced vertices, and the shapes of the resulting showers in the detector can then be significantly different compared to those originating from the beam spot.

## Internship project

During this internship, the reconstruction of LLP decay products in the HGCAL at the L1 trigger will be studied. This study will be based on existing clustering algorithms and possible changes will be investigated in view of improving the reconstruction of LLPs.

The first task will consist in studying standard figures of merits such as the reconstruction efficiency and the energy resolution of the LLP decay products. For this task, state of the art reconstruction algorithms developed for the L1 trigger will be used.

The second task will consist in investigating possible changes to the existing algorithms in order to improve the reconstruction of LLPs. Special care will be taken in order to minimize the implementation complexity of these changes and to take into account hardware constraints at the L1 trigger.

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An additional task could be pursued if time allows. It would consist in developing a classification algorithm in order to identify showers originating from displaced vertices. For this task, machine learning algorithms such as boosted decision trees and neural networks could be used.

## Host team at the Laboratoire Leprince-Ringuet

The CMS group at LLR is a founding member of the CMS collaboration. It has designed, built, and is responsible for the operation of the L1 trigger for the electromagnetic calorimeter (ECAL). It has also designed the calorimeter mechanics and contributed to the front-end readout electronics. It has major involvement in particle reconstruction and identification with the e/gamma and tau Physics Object Groups, and contributed to the development of the Particle Flow event reconstruction. It is among the leading protagonists within the CMS collaboration in diboson, multiboson and Higgs physics, as well as in heavy ions physics.

The group is also strongly involved in the development of the future HGCAL for the HL-LHC, in particular on its mechanical design, on the generation of the L1 trigger primitives, and on the development of offline reconstruction algorithms. In addition, it is participating in the beam tests of the detector prototypes.

## Other information

This internship is intended for students at the M1 or M2 level.

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