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Optimising the High Granularity Calorimeter trigger primitives for machine learning based particle identification in the CMS Level-1 trigger

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As part of its upgrade for the High-Luminosity LHC (HL-LHC) , the CMS experiment is deploying a novel High Granularity Calorimeter (HGCAL) in the endcap regions. Designed with fine segmentation in both longitudinal and transverse directions, HGCAL will be the first calorimeter specifically optimised for particle-flow reconstruction to operate at a colliding-beam experiment. The calorimeter data will be part of the Level-1 Trigger (L1T) system of the CMS and, together with tracking information, will enable the use of particle-flow techniques in the trigger decision. The unprecedented granularity of the HGCAL leads to approximately six million sensor channels, from which around one million trigger cells (TCs) are derived for real-time processing at 40 MHz. This represents a significant challenge in terms of data manipulation and processing for the trigger system, given the stringent constraints on hardware resources. The HGCAL trigger primitive generation (TPG) system reconstructs 3D energy clusters from the particle showers and forwards them to the central L1T for particle identification. However, due to bandwidth limitations, only a subset of cluster features can be transmitted, thus making their optimisation an essential design decision.

To address this hardware limitation, we employ Boosted Decision Trees (BDTs) to optimise the primitives, specifically to classify photons and electrons against hadronic objects from jets and overlapping interactions. A multi-objective optimisation strategy is applied to balance identification performance with the hardware cost of feature encoding. The trained models are then compiled into FPGA-ready designs using Conifer, a toolchain to convert machine learning models into hardware description, and are evaluated in simulation to study the impact of feature choice on latency and FPGA resource usage. These developments are essential to fully exploit the full physics potential of the HL-LHC by enabling robust and efficient real-time particle identification in CMS. This talk will present an overview of these optimisation studies and their implications.

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