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Design Studies for the Phase II Upgrade of the CMS Barrel Electromagnetic Calorimeter

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The High Luminosity LHC (HL-LHC) aims to reach the unprecedented integrated luminosity of 3 ab-1 with an instantaneous luminosity up to 5x10ˆ34 cm2 s-1. This poses stringent requirements on the radiation resistance of detector components and on the latency of the trigger system. The barrel region of the CMS Electromagnetic Calorimeter will be able to retain the current lead tungstate crystals and avalanche photodiode detectors which will meet the performance requirements throughout the operational lifetime of the HL-LHC. The new front-end electronics and very front-end system required at high luminosities will be described.

Summary

The barrel region of the CMS electromagnetic calorimeter (ECAL) is a homogeneous and hermetic calorimeter made of 61200 lead tungstate scintillating crystals. Each crystal is read out by a pair of silicon avalanche photodiodes (APDs) operating at gain 50 and at a temperature of 18°C.

The CMS ECAL was designed to cope with the harsh LHC radiation environment for 10 years, up to an integrated luminosity of 500˜fb^{-1}. After 2025, the high luminosity phase of the LHC (HL-LHC) will begin, with the goal of recording data corresponding to an integrated luminosity of 3000 fb^{-1} in 10 years, with an instantaneous luminosity of up to $5\times10^{34}\text{cm}^{-2}\text{s}^{-1}$,
almost a factor of 5 higher than during LHC Run2.
This will give rise to approximately 140 overlapping events per bunch crossing (pileup). In order to preserve good trigger acceptance in these conditions, the CMS Level-1 Trigger will exploit signals from the tracker, requiring a longer latency (up to 12.5˜μs) and a higher trigger rate. The existing ECAL readout is incompatible with these requirements, and the front-end and off-detector electronics must therefore be replaced.

Recent developments in radiation hard optical links will permit the amplification, digitization and transmission of data from all ECAL readout channels to new off-detector electronics, where processors are capable of processing these data with more complex and better-performing algorithms than are currently possible. This will allow the exploitation of the full ECAL granularity at the Level-1 trigger. Such an upgrade will improve the rejection of anomalous signals (spikes) which are caused by direct ionization in the APDs, as well as mitigating pileup effects.

The luminosity increase poses significant challenges to the on-detector components. In particular the APDs are subject to hadron damage. Recent irradiation studies have shown that the APDs will remain operational, however the dark current increases linearly with the neutron fluence.
The radiation induced noise becomes the dominating effect limiting the ECAL energy resolution for photons from Higgs boson decays after an integrated luminosity of about 1200 fb^{-1}. It is planned to operate the detector at a lower temperature of 8°C to mitigate this effect.

The new ASICs for pulse amplification, shaping and digitisation must also be less sensitive to dark current. Several possibilities are being explored: using CR-RC shaping as presently implemented, with shorter shaping time, using a charge-integrating ADC, or digitizing the signal with a faster sampling rate. These new ASICs will significantly improve the spike suppression capability, exploiting the characteristic differences between scintillation signals and spikes. The on-detector readout will also be designed with the aim of exploiting the timing resolution of the crystals, in order to discriminate between energy deposits coming from different overlapping events based on their time-of-flight.

The status of design studies for the upgraded ECAL electronics for HL-LHC based on simulations, laboratory tests, and test beam measurements will be discussed.

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