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Prospects for a Precision Timing Upgrade of the CMS PbWO Crystal Electromagnetic Calorimeter for the HL-LHC

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The upgrade of the Compact Muon Solenoid (CMS) crystal electromagnetic calorimeter (ECAL), which will operate at the High Luminosity Large Hadron Collider (HL-LHC), will achieve a timing resolution of around 30 ps for high energy photons and electrons. We will discuss the benefits of precision timing for the ECAL event reconstruction at HL-LHC. Simulation studies on the timing properties of PbWO crystals, as well as the impact of the photosensors and the readout electronics on the timing performance, will be presented. Test beam studies, including new results from 2017, on the timing performance of PbWO crystals with various photosensors and readout electronics will be shown.

Summary

The electromagnetic calorimeter (ECAL) of CMS is currently operating at the LHC. The instantaneous luminosity during the current LHC Run2 is in the range of up to 2×10^{34} $cm^{-2}s^{-1}$ in routine operation. With an upgrade at the end of the decade, the High-Luminosity LHC (HL-LHC) will increase the instantaneous luminosity by about a factor of 2 to 5 from current levels. The goal of the HL-LHC is to accumulate a total of at least 3 ab^{-1} of data.

Particular challenges at HL-LHC are the harsh radiation environment, the increasing data rates and the extreme level of pileup events, up to 200 simultaneous proton-proton collisions. The pileup mitigation may be substantially improved by means of precision time-tagging of calorimeter clusters, by associating them to primary vertices via 4D triangulation. We will discuss in detail the timing performance requirements for such a 4D triangulation technique and how it can be achieved with the upgraded CMS ECAL.

We review the design and R\&D studies for the HL-LHC CMS ECAL crystal calorimeter upgrade for which the lead tungstate $PbWO_4$ crystals, the Avalanche Photo-Diode (APD) photodetectors with their respective motherboards as well as the overall mechanical structure of the ECAL barrel will remain unchanged. The readout electronics will be replaced to cope with the higher bandwidth and latency required for operation at the HL-LHC and will enable the calorimeter to achieve a timing resolution of around 30 ps for high-energy photons.

The upgraded very front-end (VFE) electronics will achieve this timing performance by shortening the shaping time from the current 43 ns to 20 ns and increase the digitization rate from 40 MHz to 160 MHz. The VFE will employ re-designed ASICs to optimize shaping time and sampling to reduce the impact of noise, out-of-time pileup, and anomalous isolated large signals in the APDs. Pulse shaper and preamplifier ASIC options we are currently investigating include Trans Impedance Amplifiers (TIA) and a further iteration of the current architecture (MGPA, CR-RC) as an alternative, optimized for a 130 nm process, faster shaping and additional rejection logic for anomalous signals. As digitzers we consider multi-channel ADCs with 12-bit resolution at a higher sampling rate of 160 MHz, which benefits, in particular, the timing resolution. Prototype boards with the above design criteria are currently undergoing lab and test beam measurements. We will present results from these test beam measurements - including new ones from 2017 - with a prototype utilizing a 5x5 matrix of CMS ECAL PbWO4 crystals with readout electronics following the design path described above. Different digitization speeds were emulated offline to demonstrate the requirements for the final choice of the readout.

We will also discuss in detail extensive simulation studies on the optimization of the shaping time and sampling rate to achieve optimal timing performance. We will also show simulation studies and further test beam measurements on the timing properties of large-size scintillating crystals, as used in the CMS ECAL. These studies illustrate that for the performance targets we envision indeed the photodetector and readout chain are the limiting factors for the timing performance.

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