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Mitigation of Anomalous APD signals in the CMS ECAL

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We describe the observation and mitigation of anomalous, large signals, observed in the barrel part of the CMS Electromagnetic Calorimeter during proton collisions. Laboratory and beam tests, as well as simulations, have been used to understand their origin. They are ascribed to direct energy deposition by particles in the avalanche photodiodes used for light readout. A reprogramming of the front-end electronics has allowed a majority of these anomalous signals to be identified and rejected at the first (hardware) trigger level with minimum impact on physics performance. Further rejection is performed in the high-level (software) trigger and offline analyses.

Summary

The CMS electromagnetic calorimeter (ECAL) is designed to provide excellent energy resolution in the harsh radiation environment of the LHC. The ECAL comprises 75848 lead tungstate ($PbWO_4$) crystals, organised into a barrel and two endcaps, providing coverage to $|\eta|=3.0$. Scintillation light emitted by the crystals is converted to electrical signals by photodetectors glued to their rear faces. Avalanche photodiodes (APDs) and Vacuum Phototriodes (VPTs) are used in the ECAL Barrel and Endcaps respectively.

Anomalous signals, consisting of isolated large signals, have been observed in the ECAL Barrel during LHC proton-proton collisions data-taking in CMS during 2009-11. These deposits, termed "ECAL spikes"are observed to occur at a rate proportional to the intensity of the proton beams. As a consequence, they present issues for triggering CMS at high luminosity and must be eliminated from physics analyses in order to prevent large biases in the energies of reconstructed electrons, photons and jets.

The spikes are understood to be associated with particles (produced in pp collisions) striking the APDs and very occasionally interacting to produce secondaries that cause large anomalous signals through direct ionization of the silicon. This hypothesis has been checked by studying the APD response via laboratory and test beam studies, and the development of Monte Carlo simulations where the APDs are treated as active volumes.

These "spikes" can induce large trigger rates at both the level-1 (hardware) trigger (L1) and the high-level (software) trigger (HLT) if not removed from the trigger decision. On average, one spike with transverse energy > 3 GeV is observed per 370 minimum bias triggers in CMS. At high luminosity these would be the dominant component of the 100kHz CMS L1 trigger rate bandwidth.

Spike-like energy deposits are prevented from triggering CMS by exploiting the programmability of the ECAL front-end electronics: a new 1-bit flag was implemented to indicate the likelihood of the topology of the energy deposits being due to real EM deposits or spikes. The strip Fine-Grained Veto Bit (sFGVB), computed per trigger tower (5x5 crystal array), flags spike-like energy deposits by comparing the energies recorded for each channel to a configurable threshold, distinguishing between an isolated energy deposit (a single crystal above threshold) and an EM energy deposit (multiple crystals above threshold). If the sFGVB detects a spike-like energy deposit, the trigger tower energy is set to zero.

In addition to topological cuts, similar to the sFGVB, spikes and EM showers have different signal pulse shapes. Since a spike is produced by a particle directly hitting the APD, the decay constant of scintillation light (~ 10 ns) is not present. When the pulse is fitted to extract the timing of the signal, the spikes generally appear early. An offline cut on the signal timing of ±3 ns is > 90% efficient at removing spike pulses, with a negligible impact on EM energy deposits.

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