Characterisation of Low Gain Avalanche Diodes and Time Resolution Estimation

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The Large Hadron Collider (LHC) at CERN is scheduled to undergo a major upgrade to the High Luminosity-Large Hadron Collider (HL-LHC), which will significantly increase collision rates and particle flux. While this upgrade will expand the potential for new physics experiments and discoveries, it also introduces substantial experimental challenges. In particular, the large number of simultaneous collisions (pile-up) requires detectors capable of extremely precise timing measurements in order to accurately assign detected particles to their interaction vertices. To address this challenge, the HL-LHC will incorporate dedicated timing detectors. In the Compact Muon Solenoid (CMS) experiment, this will be in the form of the Minimum Ionising Particle Timing Detector (MTD), whose Endcap Timing Layer (ETL) will use Ultra-Fast Silicon Detectors (UFSDs) based on Low Gain Avalanche Diode (LGAD) technology.

LGAD sensors are thin silicon detectors that have an internal gain layer which amplifies the charge produced by ionising radiation through controlled avalanche multiplication. This internal gain enables fast signal rise times and improved timing resolution, making LGADs particularly well suited for precision timing applications. However, operation in the high-radiation environment of the HL-LHC introduces several challenges. Radiation damage increases leakage current in the sensors, which raises electronic noise and can degrade detector performance. A common strategy to mitigate this is to operate the detectors at low temperatures, where the reduced leakage current improves the signal-to-noise ratio and helps preserve timing performance.

This work investigates the timing performance of unirradiated Hamamatsu (HPK) UFSD3 LGAD sensors as a function of bias voltage and operating temperature. As part of this study, a dedicated low-temperature measurement setup was designed, constructed, and implemented to enable stable operation of the sensors. The system provides a controlled environment for detector testing over a temperature range from -5 °C up to room temperature and is intended to support quality control studies of LGAD devices.

Timing measurements were performed using a coincidence setup with a Sr-90 β source. The signals were read out using single-channel Santa Cruz boards, amplified, and recorded with a high-speed oscilloscope that was set to trigger when coincident signals were detected in the sensors. The recorded waveforms were then analysed to extract timing information. Two time-walk correction methods were implemented: Constant Fraction Discriminator (CFD) and Time-over-Threshold (ToT), and the final timing resolution values were compared.

The measurements show a clear dependence of the LGAD timing resolution on the operating temperature. Cooling the sensors from room temperature to -5 °C resulted in a measurable improvement in timing performance, with the resolution improving by approximately 10 ps. These results demonstrate the benefit of low-temperature operation for LGAD based timing detectors and provide insight into the optimisation of UFSD performance for future applications in timing systems.