The HL-LHC and the ATLAS Hadronic Tile Calorimeter (TileCal).

TileCal is a sampling calorimeter composed of plastic scintillator tiles as active material interleaved with steel plates as absorber. The detector is divided in four cylindrical barrels composed of 64 wedge-shaped modules each (Figure 1). The scintillators in each module are grouped in pseudo-projective cells. Light from two sides of a cell is collected by wavelength shifting foams and read out by two photomultiplier tubes (PMTs).

The TileCal will have an instantaneous luminosity of 5 times the LHC nominal design value. The present TileCal read-out electronics will be incapable of dealing with the higher radiation levels and increased rates of pileup. R&D is ongoing aimed to replace a TileCal electronics with a improved design that will provide continuous digital read-out of all TileCal with lower electronic noise and better timing stability, therefore better energy resolution and less sensitivity to out-of-time pileup [1].

The TileCal read-out system for the HL-LHC.

TileCal read-out system for the HL-LHC [1] consists of two sections: on-detector and off-detector electronics. The on-detector system (Figure 2) will digitize two gains of the shaped analogue signal from each TileCal PMT at 40 MHz. The mechanics design is modularized in 896 Minidrivers (MDs), each MD (Figure 3) serves up to 12 channels by means of:

• 12 Photomultiplier (PMTs) to turn light pulses into electrical signals,
• 12 Front-End Boards (FEBs) to shape and condition the PMT signals,
• a Mainboard (MB) to digitize the two gains of each shaped PMT signal with a gain ratio of 1.13,
• a Daughterboard (DB) (Figure 4) to distribute LHC synchronized timing,
• commands and control signals to the front-end, and to continuously transmit the digital data from all the MB channels to the off-detector systems via multi-Gbps optical links.

The data is sent to the off-detector system (Figure 2) to be stored in pipelines, reconstructed and triggered-out by:
• Tile Preprocessors (TilePre)
• Trigger and DAQ interface (TDAQi)
• the ATLAS Front-End Link (FELIX)

Radiation tests results.

The design proved to withstand up to 20 kRad of TID, being enough to qualify it for the HL-LHC lifetime for the initially expected doses. New dose estimates were obtained by new simulations with updated geometry: the board has to be re-tested up to 72 kRad or 16 kRad with annealing.

The NIEL test was performed with a 52 MeV proton beam, hence the target fluence was achieved while simultaneously exposing the board to 76.2 kRad of equivalent TID. Therefore, the test was inconclusive and needs to be re-done in a facility capable of achieving the target fluence of 9.00 × 10^{11} n/cm² with neutrons.

The SEU rates in 4934 SEUs over a fluence of 2.05 × 10^{11} protons cm⁻², of which only 11 SEUs could not be corrected by the Xilinx Soft Error Mitigation (SEM) IP solution. The uncorrectable SEU rates predict that 1.4 ± 0.0% uncorrectable errors are expected per DB per year. With Xilinx SEM and the TMR, it is expected that correctable SEUs will not affect nominal runs.

The SEE tests showed that the Kintex Ultrascale+ 16 nm FinFET technology is susceptible to SEL with SEL-fluence rate increased from 2 × 10⁻¹¹ SEL-fluence rate at 58 MeV to 2.36 × 10⁻¹⁰ rate at 226 MeV protons (Figure 5).

The over-currents due to SEUs did not cause noticeable damage, however SEUs are not acceptable.

Conclusions.

The DB 5 cannot entirely fulfill the HL-LHC radiation requirements because of the design being incapable to mitigate the Kintex Ultrascale+ 16 nm FinFET process sensitivity to SEL appearances. DB 6 will migrate to a more SEL-resistant FPGA, add extra protection to SEL appearances and increase radiation tolerance by using conductive polymer capacitors. DB 6 must be tested for TID, NIEL and SEE to qualify it as mandated by ATLAS policies. DB 5 will further improve and optimize the already complete DB clocking scheme, DB 6 will add an extra layer of hardware control and monitoring to minimize single points of failure and allow mitigation of any unexpected issue appearances during nominal runs. Around 930 DBs will be produced as the contribution of Stockholm University to the HL-LHC era for TileCal.

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Relevant references.