Development of Integrated Cooling Solutions for the CALICE AHCAL

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The CALICE Analog Hadron Calorimeter (AHCAL), originally developed to meet the design requirements of the proposed International Linear Collider (ILC), used power pulsing to manage heat dissipation within the calorimeter. While the CALICE activities are being continued within the DRD Calo collaboration, the AHCAL is being adapted to meet the demands of a potential Future Circular Collider (FCC). In this new context, power pulsing is no longer a viable option, and an integrated cooling system must be developed. This abstract outlines the differences between the ILC and FCC requirements, reviews the existing CALICE AHCAL design, and describes the approach for implementing a new cooling solution for the upgraded detector.

1 Linear vs. Circular Collider

One of the key differences between the ILC and the FCC comes from their fundamentally different accelerator concepts. The ILC, as a linear collider, features a relatively low bunch crossing rate of about 5 Hz. Its bunch trains are roughly 1 ms long, which allows the electronics of the AHCAL to be switched off for the remaining 199 ms between bunch trains. This results in a duty cycle of only about 1%, making power pulsing an effective method for limiting heat dissipation. In contrast, circular colliders such as FCC-type colliders operate with an almost continuous collision environment and a much higher bunch crossing rate. For comparison, the LHC at CERN runs at about 40 MHz. Such conditions require the AHCAL electronics to remain active continuously, leading to a significantly higher average power dissipation. Therefore, the thermal load can no longer be managed by power pulsing, making an integrated cooling system necessary.

2 CALICE AHCAL

The CALICE AHCAL is a highly granular sampling calorimeter originally developed to meet the requirements of the ILC. Such high granularity is motivated by the Particle Flow approach, where individual particles inside complex hadronic showers are reconstructed by combining information from the tracker and calorimeter systems. This method aims to achieve the best possible jet energy resolution by assigning the measurement of charged particles to the tracker while relying on the calorimeter primarily for neutral hadrons and photons. To make this separation feasible, calorimeters must provide a very fine spatial resolution, which drives the need for detectors like the AHCAL. A physics prototype with approximately 22000 readout channels has already been constructed and successfully tested. The detector uses the so-called SiPM-on-tile technology, in which plastic scintillator tiles are individually read out by silicon photomultipliers (SiPMs) directly coupled to the tile surface. The basic building block of the AHCAL is the HCAL Base Unit (HBU), a printed circuit board (PCB) with 144 readout channels. On one side of the PCB, the scintillator tiles and SiPMs are mounted, while the front-end electronics are located on the opposite side. In the ILC prototype, cooling of the calorimeter was achieved through power pulsing. The plans for developing an integrated cooling system are described in the next section.

3 Development of an Integrated Cooling System for the AHCAL

The development of an integrated cooling system for the AHCAL began with a detailed thermal characterization of the calorimeter's readout electronics. Initial measurements were performed using an infrared camera to map the temperature distribution across a single HBU. Based on these measurements, a dedicated dummy board will be designed to replicate the observed thermal profile, replacing the ASICs with heat-generating components such as voltage regulators. This dummy board will serve as a test platform for evaluating different cooling strategies. As an initial step, only water-based cooling concepts will be investigated. Among the approaches to be studied are heat extraction through the board's ground plane and the use of an additional copper plate for thermal conduction. In the latter case, parameters such as copper thickness, contact pressure, material choice, and other mechanical and thermal factors will be systematically investigated. A particular challenge is to implement an effective cooling system while preserving the existing mechanical design and compactness of the CALICE AHCAL modules, so that the upgrade does not compromise the detector's structure. The results from these measurements will be used as input for a dedicated thermal simulation, which will support the design and optimization of the final cooling system for the upgraded AHCAL.