Electronics design in contribution to CMS's HGCAL upgrade

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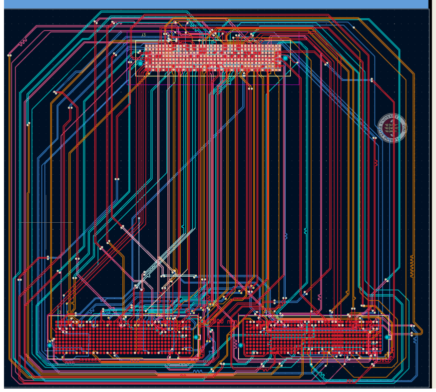
ABSTRACT

This project aims to enhance CERN's Large Hadron Collider (LHC) by designing and constructing an adapter board using computer-aided design (CAD) for the Compact Muon Solenoid (CMS) High Granularity Calorimeter (HGCAL) upgrade. The HGCAL, crucial for precise event reconstruction and particle identification, requires integration with motherboards to process and send data that comes from the individual cells of the calorimeter. To validate these motherboards, simulated calorimeter cell output is needed from an evaluation board. The adapter board, designed for this project using CAD, facilitates this integration by translating electrical connections from the evaluation board to the motherboard, enabling simulation of physics events. Through development using KiCAD PCB design software, the reliability and efficiency of the motherboard hardware is validated before implementation in the experimental setup, helping to ensure the success of the CMS HGCAL upgrade.

FIG. 1 Final Board Design



INTRODUCTION

The Large Hadron Collider is the world's largest and most powerful particle accelerator.

- A particle accelerator is a very large machine (LHC is roughly 17 miles in circumference) that is used to accelerate small particles, such as protons or electrons, to incredibly high speeds.
- Particles are then purposefully collided, and the data gathered from the collisions is useful in studying physics pertaining to the fundamental workings of the universe.
- LHC is currently being updated into its high luminosity phase, which will greatly increase the number of particle collisions with the collider.

FSU's High Energy Physics Group is a longtime contributor to one of the main experiments at the LHC, the Compact Muon Solenoid.

- CMS is a particle detector weighing roughly 14,000 metric tons.
- CMS bends particles (using a solenoid magnet), identifies tracks, measures energy, and detects muons.

A calorimeter is a device used to measure the energy of particles produced in collisions.

- It does this by absorbing particles and measuring the energy deposited.
- The High Granularity Calorimeter upgrade for the CMS experiment will bring improved accuracy and capabilities for particle detection at CMS.
- HGCAL is specifically upgrading the endcap calorimeters to cope with the higher luminosity expected from LHC updates.

The electronics design in this research project contributes to the HGCAL upgrade by helping to validate the functionality and design of the motherboard.

- Motherboards serve an important function within HGCAL by, among other things, facilitating data readout and control functions.
- Data comes from individual cells of the calorimeter known as silicon sensors.

Since the CMS weighs 14,000 tonnes and is also in Switzerland/France, it is not practical to validate the motherboard's functionality by installing it in the CMS.

- Functionality is instead being verified by simulating the output from the CMS to the motherboards by using a specialized testing "computer," the Xilinx ZCU.
- The goal of this research project lies in enabling communication between said ZCU (simulator of the CMS signals/outputs) and the motherboard,
- This requires the design of a printed circuit board (PCB) in order to "translate" the signals from the ZCU to the motherboards.

METHODS

KiCad, an open-source computer aided design (CAD) software, was used in the design of the PCB. The adapter PCB was first laid out as a schematic based off a spreadsheet and then as a final board design (FIG. 1).

For a design to be successful, the different connector types between the ZCU and motherboard had to be reconciled with one another. To begin the process of pairing the pins of both devices, the specifications of both had to be read to identify the capabilities/bandwidth of the pins. This was important because a mismatch could mean signal loss or data corruption.

After noting the specifications of each, a spreadsheet was created that recorded the matchup for each of the 400 motherboard pins to the ZCU. Using that spreadsheet, a one-dimensional schematic of the connections was made. The schematic is important because the software uses data from it to link pins together as well as differential pairs (differential pairing of signals helps to ensure signal integrity).

With the schematic finished, the final design step could go ahead within the PCB editor. The PCB editor is different from the schematic because it is multi-dimensional as PCBs have several layers. In this case, there are 6 distinct layers each represented in figure 1 with their own color. Each line is called a trace, which will eventually be copper on the board ready to carry electrical signals. Traces on the same layer cannot intersect one another, so they had to be routed around each other or put on a separate layer altogether if their paths crossed using vias.

The principle method of detection for HGCAL depends on two kinds of sensors, silicon sensors as well as scintillators/SiPMs.

The silicon sensors are to be used in the higher radiation areas of HGCAL (closer to the center) while the scintillators/SiPMs will be used in areas where radiation hardness is not as big a priority. This is a cost saving measure as the full silicon sensors are more costly to manufacture. They are superior to the scintillators not only because of their improved radiation hardness, but also because of their improved spatial and energetic resolution as compared to scintillators/SiPMs.

Silicon sensors have an advantage because they operate based on ionization. When charged particles travel through the material, they directly create an electrical signal corresponding to the energy deposited by the particle.

On the other hand, the scintillators/SiPMs work because the scintillators become excited by charged particles and then emit photons that the SiPMs convert into electrical signals. This is a disadvantage because resolution can be lost due to light scattering between the scintillator emitting the photons and the SiPMs detecting them.

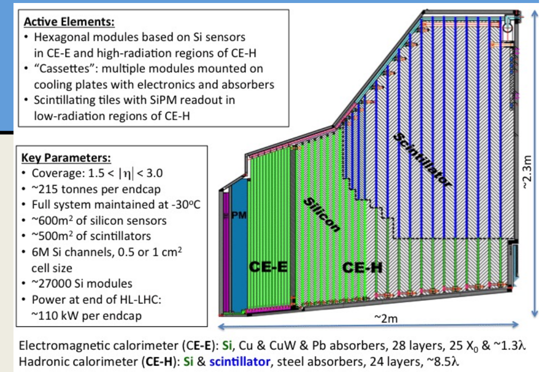


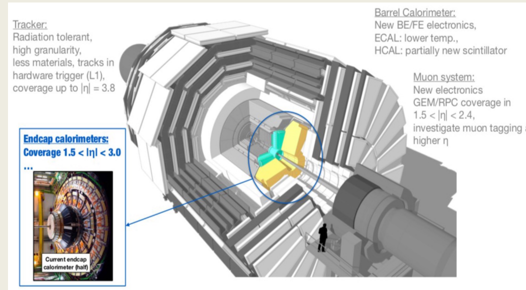
FIG. 2 Internal layout of HGCAL

RESULTS

Specific results from this project are still pending as both the adapter boards and motherboards they will help to validate have not yet been completely assembled. However, the adapter board design has been manufactured.

HGCAL will result in significantly better event reconstruction of electromagnetic and hadronic particle showers (showers are what occur when particles collide) using its silicon sensors as well as its scintillators/SiPM combos.

FIG. 3 Diagram of the Compact Muon Solenoid with position of HGCAL highlighted



CONCLUSIONS

The HGCAL upgrade will allow the CMS experiment to cope with higher luminosities and detect with higher resolutions than ever before, enabling new and better experiments. This project is one small part of helping to get HGCAL up and running by validating components that will eventually end up in the CMS.

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