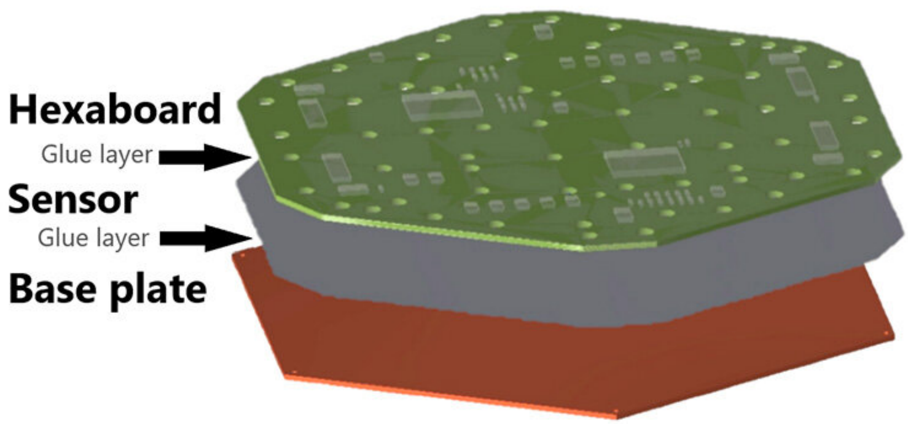
Prototype particle detectors project smashes milestone

February 1 2023



Credit: Carnegie Mellon University

Carnegie Mellon University physicists in Pittsburgh are one step closer to building new particle detectors for the Compact Muon Solenoid (CMS) experiment at CERN's Large Hadron Collider (LHC).

A team led by John Alison, an assistant professor in physics, and Manfred Paulini, a professor of physics and the Mellon College of Science associate dean for faculty and graduate affairs, has successfully built and tested prototypes for the High-Granularity Calorimeter (HGC), an upgrade to the current CMS detector. On the one hand, building functional prototypes is a major milestone several years in the making. On the other hand, the milestone is the first step in a manufacturing project that will take place over the next three years.

"CMS can be thought of as a large 3D camera that records the products of the proton-proton collisions provided by the LHC," Alison said. "For example, images collected from the detector were used to discover the Higgs boson in 2012."

Since the discovery of the Higgs boson, a major focus of the particle physics has been in studying the properties of the Higgs boson in detail and searching for new particles not predicted by the standard model of particle physics. Comparing measurements to predictions will allow new theories to be tested but more data is needed.

The LHC has a 15-year program to increase the total number of proton collisions by a factor of 20. This program requires collecting more data faster and comes at a significant cost: increased radiation. In addition to producing new exotic states of matter—like the Higgs boson—LHC proton collisions produce large amounts of ionizing radiation. This radiation is similar to that produced by a nuclear reactor and is damaging to people and the instrumentation that makes up the detector.

Built almost 20 years ago, the current CMS detector was not designed to handle the amount of radiation damage anticipated during future LHC runs. New, upgraded detectors are needed both to improve the quality of the recorded images and cope with the more challenging radiation environment. This is where the High-Granularity Calorimeter upgrade comes in.

Big Data gets bigger

The HGC will replace current CMS detectors in regions that face the most radiation. A next-generation imaging calorimeter, the HGC will significantly increase the precision with which the LHC collisions are imaged. The number of individual measurements per picture will increase from about 20,000 in current detectors to about 6 million in the HGC. The measurements of individual particles will go from the handful of numbers that the current detector provides to a high-resolution 3D movie of how the particles interact when traversing the detector.

The HGC will be built in the next five years, and Carnegie Mellon is playing a leading role in its construction. The HGC will be composed of 30,000 20-centimeter hexagonal modules. The modules—essentially radiation tolerant digital cameras—will be tiled to form wheels several meters in diameter. The wheels will then be stacked to form the full 3D detector. In total, the HGC will require 600 square meters of active silicon sensors.

Alison, Paulini and Valentina Dutta, a new assistant professor in physics, will build and test 5,000 of these modules in Wean Hall laboratory with the help of engineers, technicians and students. The remaining modules will be produced by CMS collaborators at UC Santa Barbara and Texas Tech University in the U.S., and by groups in China, India and Taiwan. Each module consists of a silicon sensor attached to a printed circuit board housing readout electronics and to a base plate, which provides overall stability.

Module construction will be performed with a series of automated robots that use pattern-recognition algorithms for assembly and then the required approximately 500 electrical connections per module are established. After a series of testing at CMU the modules are tiled onto wheels at Fermilab—a particle physics lab outside of Chicago—and then sent to CERN in Switzerland for installation in the CMS detector.

The production of the first working modules this fall was part of a qualifying exercise in which the various assembly centers demonstrated that they are ready and able to build the high-quality modules needed by HGC.

The CMU group established a class 1,000 clean room on the eighth floor of Wean Hall, expanding an existing space used by the medium-energy physics group. They have installed and commissioned an 8,000-pound gantry robot to attach the different module layers and an automated wire bonder to make the electrical connections within the modules. The prototype modules allowed the group to test its automated assembly procedures and exercise the full production chain.

"It is great to see our group achieving this qualification milestone," Paulini said. "I had been working diligently for some years to bring this project to CMU since it also offers opportunities for graduate and especially undergraduate students to obtain hands-on instrumentation experience working in our lab during the semester or for summer research."

Producing a handful of modules to specification is just the beginning. During full-scale module production—starting in 2024—CMU will produce 12 modules per day until early 2026. A major challenge in ramping throughput will be recruiting and onboarding local talent.

"To meet production needs we have to grow the group with hiring four more full-time technicians and engineers who will work on the daily production line," said Jessica Parshook, the lead engineer for Carnegie Mellon's project team.

Developing and implementing reliable test procedures for quality control is another major challenge going forward. The production pipeline requires several days to build each module. Catching and fixing any flaws in production quickly will be critical. Postdoctoral fellows and graduate students will create most of the assembly and quality control procedures that will provide opportunities for a significant number of CMU undergraduates to get hands-on experience testing modern particle physics detectors.

"Our efforts here could lead to the next big discovery in physics and that excites me," said Sindhu Murthy, a doctoral student in physics. "In these early stages of setting up production, I get to see the different aspects of an engineering project of this scale. It's a great experience and a privilege to contribute to this upgrade. I'm always thinking about how we can optimize module assembly so that everything goes as planned."

Alison, Dutta and Paulini said that recent advances in image processing from machine learning will be crucial in assuring quality control during production.

"This work, a mix of computer science, machine learning and robotics, is a perfect fit for CMU and we plan to tap into resources throughout the university," Alison said.

Provided by Carnegie Mellon University

Citation: Prototype particle detectors project smashes milestone (2023, February 1) retrieved 26 April 2024 from https://phys.org/news/2023-02-prototype-particle-detectors-milestone.html