The Endcap Calorimeter of CMS for HL-LHC: the HGCAL

ICHEP2020

on behalf of the CMS Collaboration
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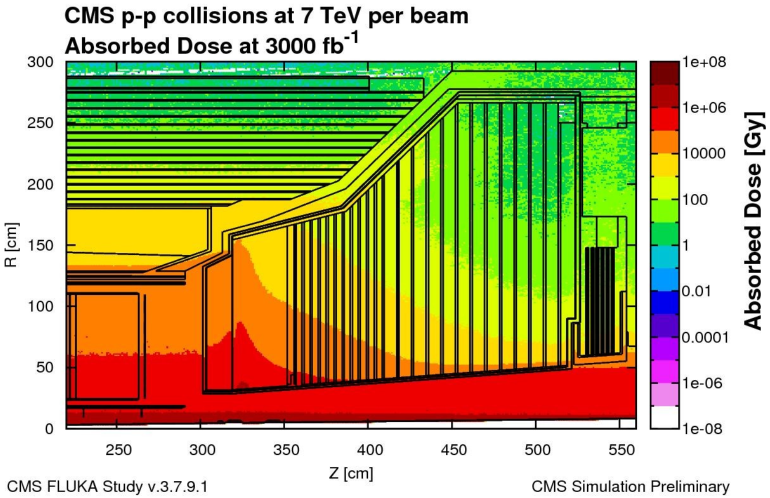
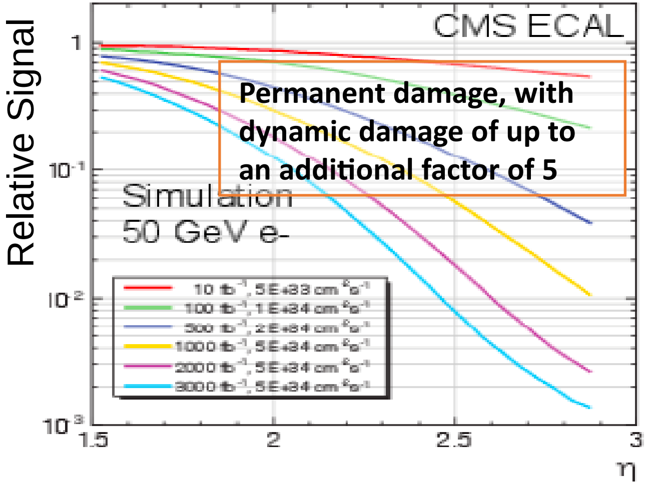
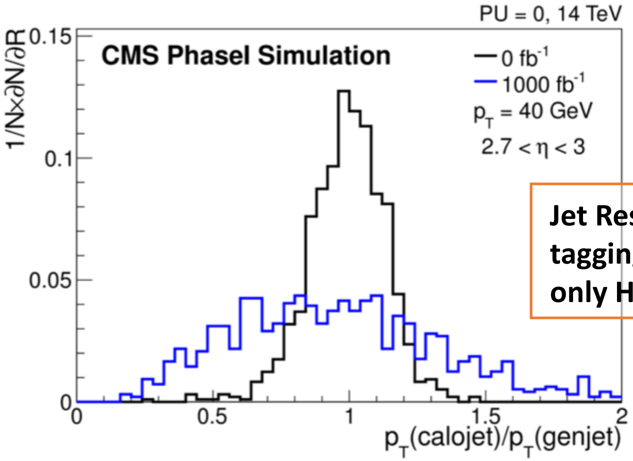
Motivation for the Endcap Calorimeter Replacement

- Radiation-induced darkening is reducing the signal from the current scintillator-based endcap calorimeters
  - Up to 90% signal loss in some regions
  - HL-LHC will require good operation with radiation loads 10-20x higher



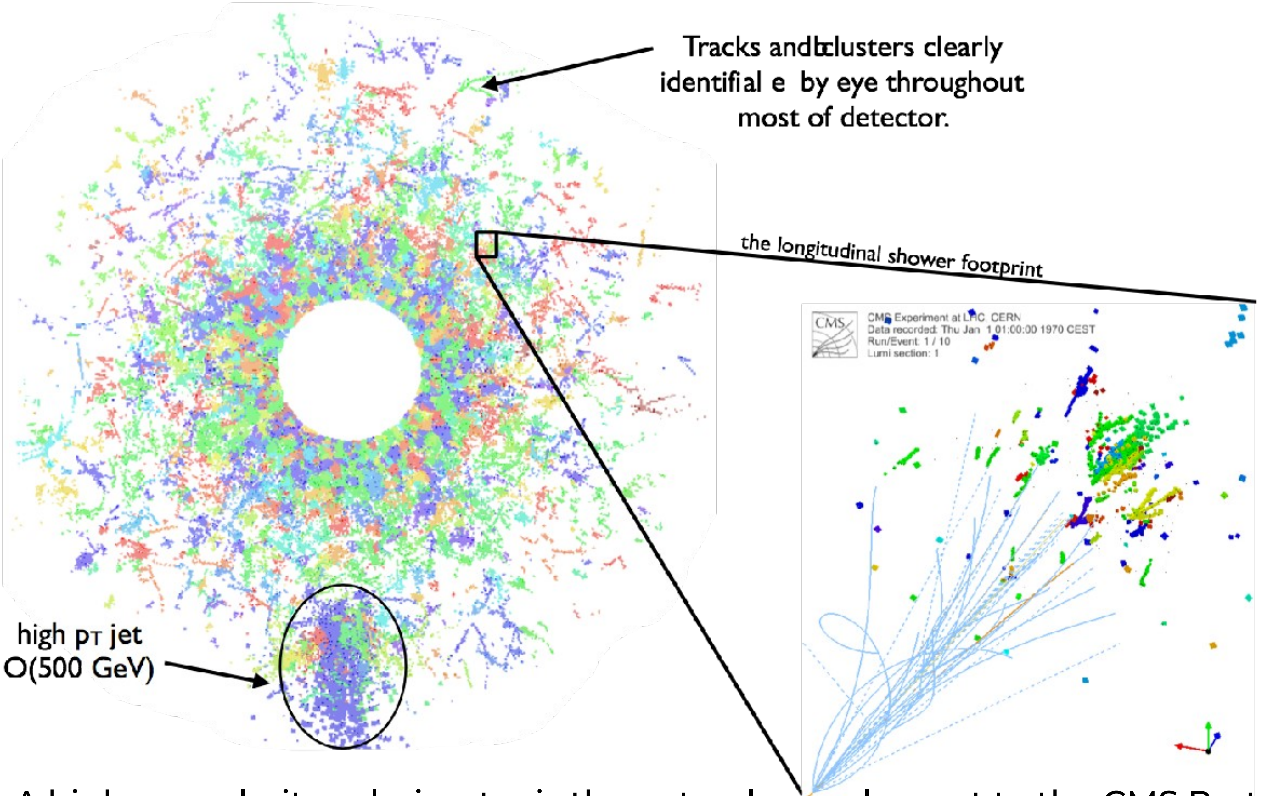


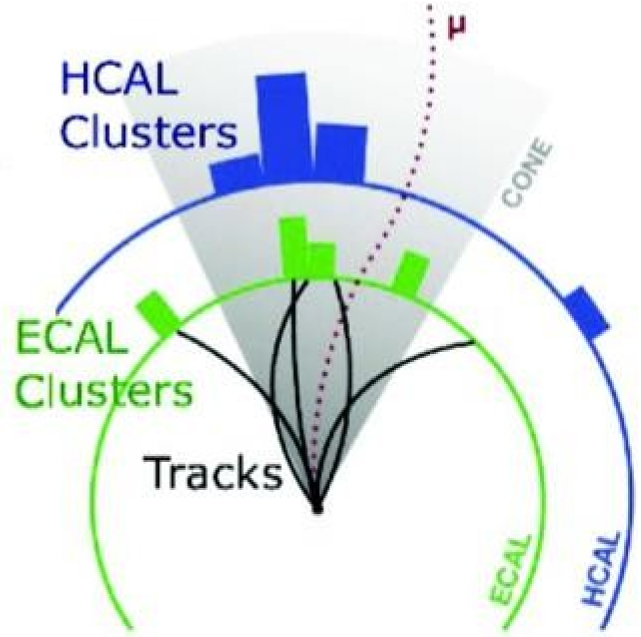
Permanent damage, with dynamic damage of up to an additional factor of 5



Jet Resolution for Higgs tagging jets considering only HCAL signal loss

High-Granularity and Particle Flow



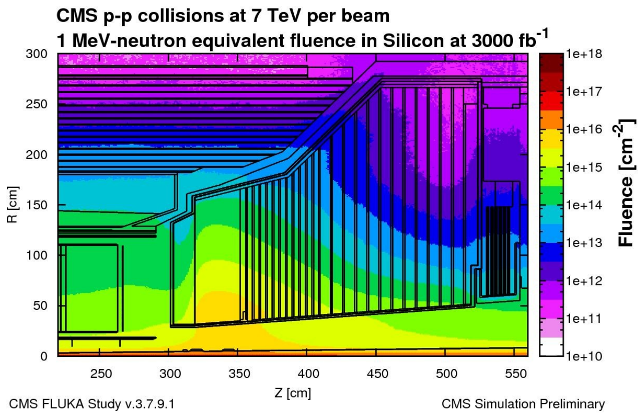


A high-granularity calorimeter is the natural complement to the CMS Particle Flow reconstruction technique which aims to optimize reconstruction (and pile-up suppression) by clearly associating tracks and clusters to individual particles

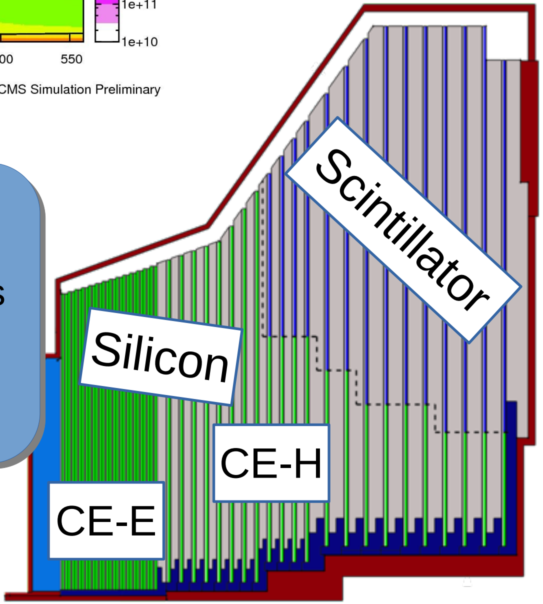
- In the HL-LHC CMS detector, tracking will cover the full endcap calorimeter

Detector Design

- Active Elements:
  - Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
  - Scintillating tiles with SiPM readout in low-radiation regions of CE-H
  - "Cassettes": multiple modules mounted on cooling plates with electronics and absorbers
- Key Parameters
  - 215 ton/endcap, full system at -30C
  - 620 m^2 of silicon sensors in 30k modules
    - 6M Si channels, 0.5 or 1 cm^2 cell size
  - 400 m^2 of scintillator in 4k boards
    - 240k scintillator channels, 4-30 cm^2 cell size



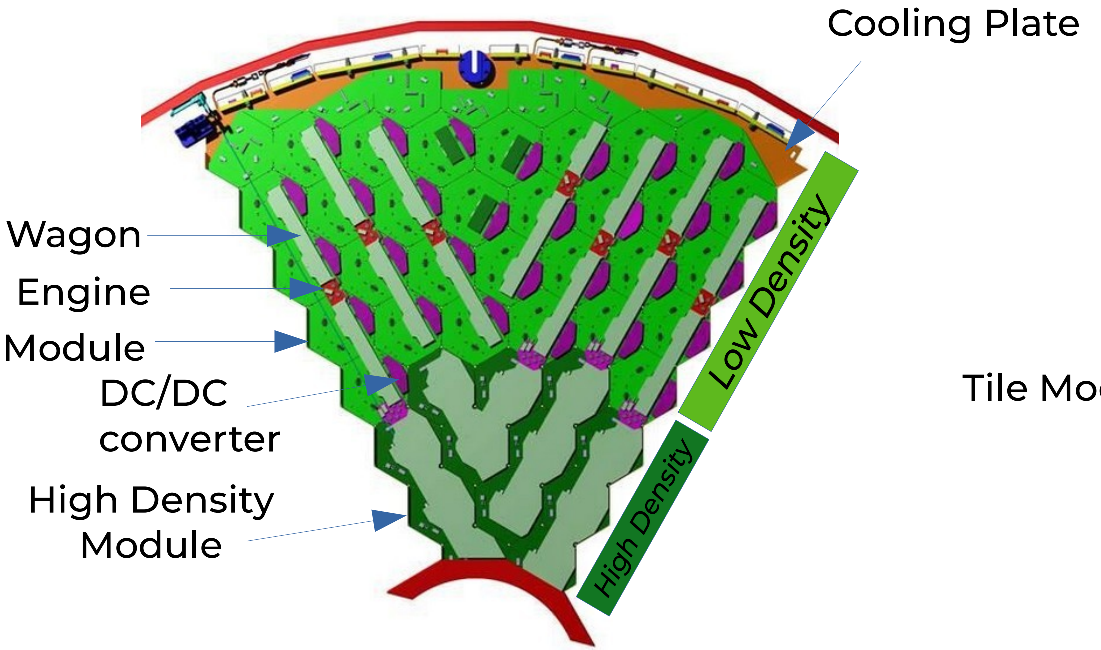
EM section (CE-E)
28 layers, 25 X0, ~1.3λ
Cu, CuW, Pb absorbers
HAD section (CE-H)
22 layers, ~8.5λ
Steel, Cu absorbers

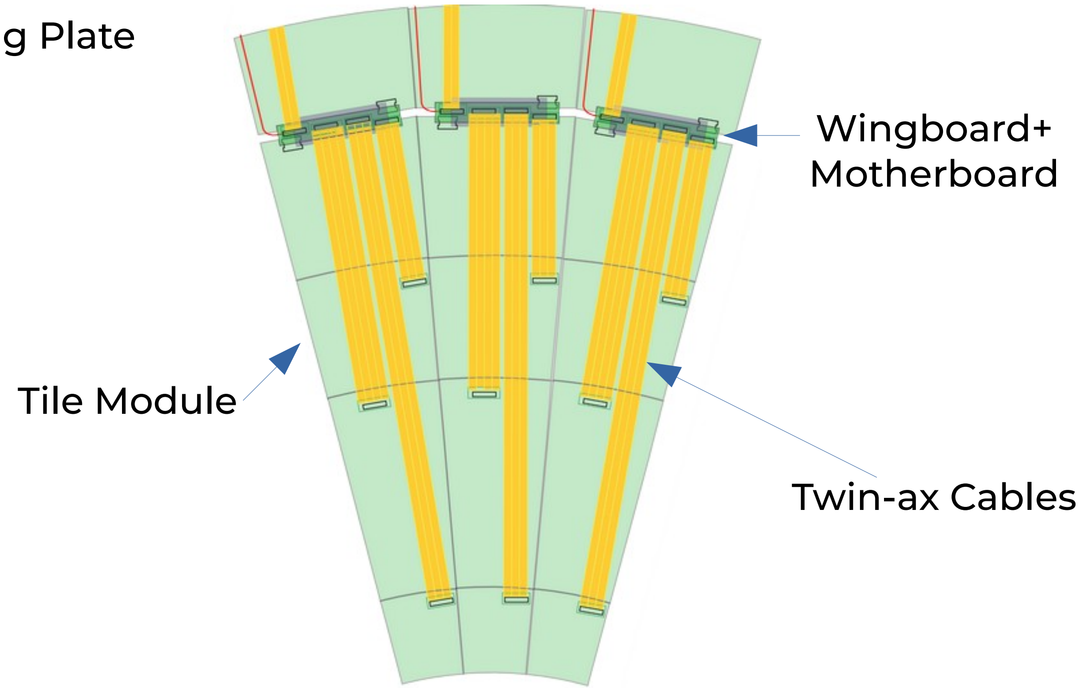


Components

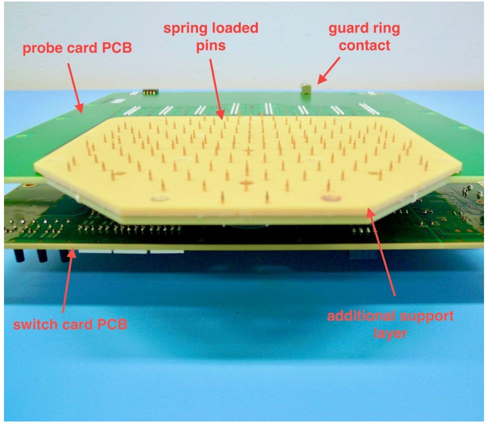
Detector is organized into cassettes made of a cooling plate with silicon and scintillator modules mounted on it

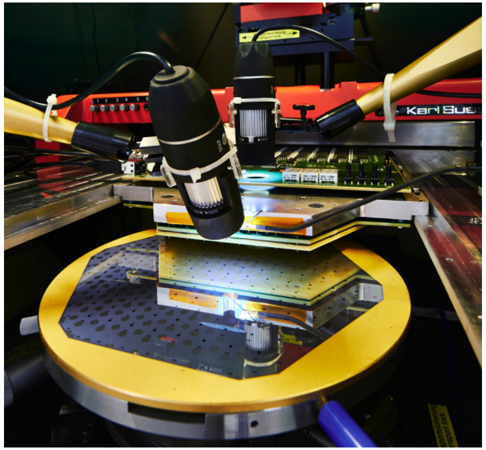
Front-end electronics located on the modules, with readout and control through the engine/wagon motherboard system



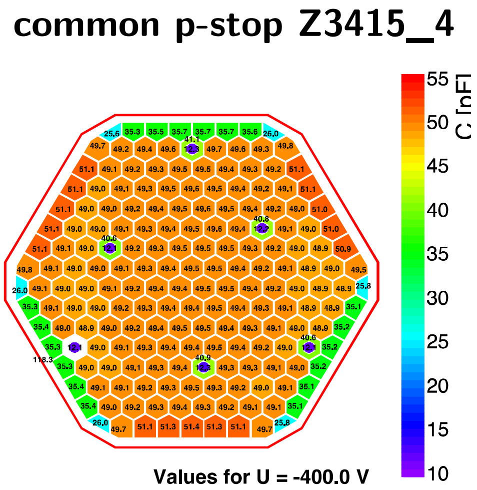


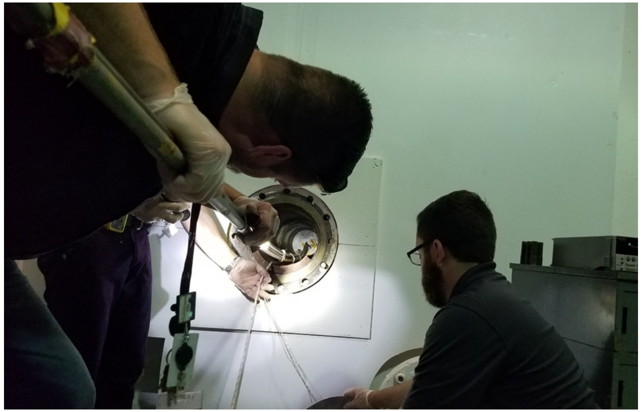
Silicon Sensors



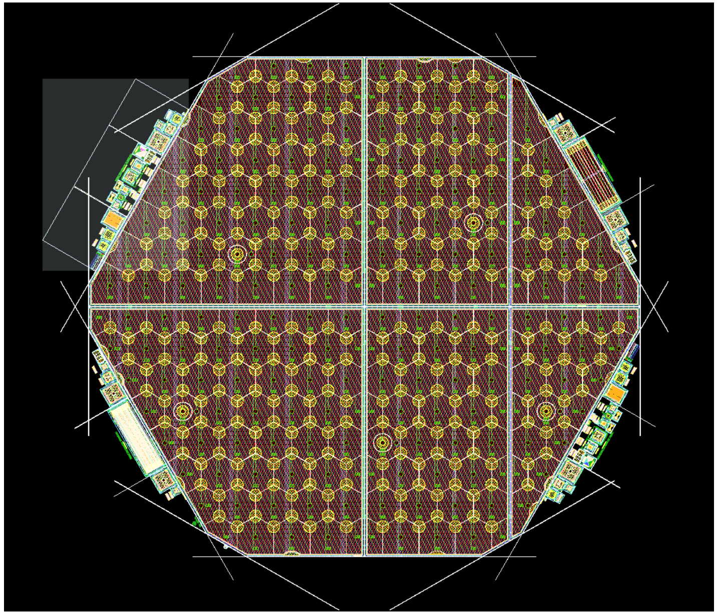


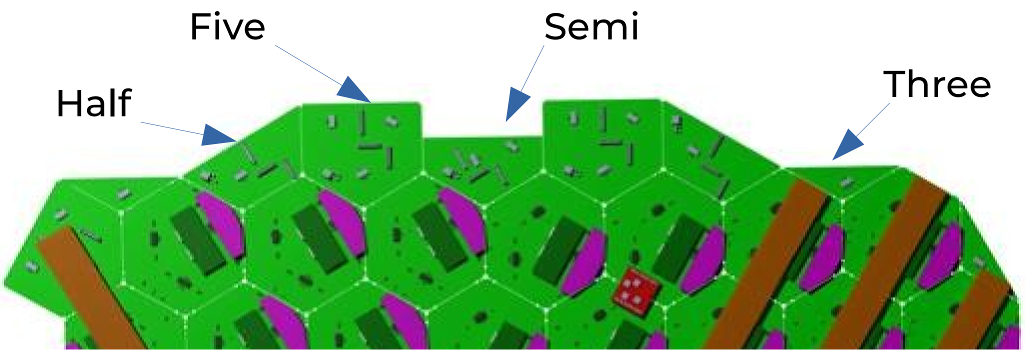
- Silicon sensors are first use of 8" technology for large-scale HEP sensors
  - Hexagonal geometry to maximize use of wafer area
  - Generally performing as expected, some "teething" challenges with commissioning new wafer lines
- Comprehensive test program including full-sensor tests with custom probe cards and reactor-based neutron irradiations
  - Also studying process-quality-control structures produced on the edges of the wafers

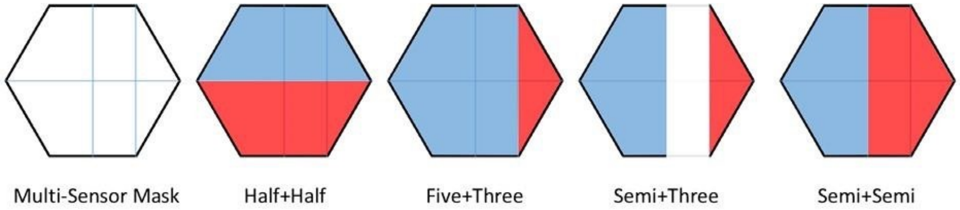




- The inner and outer envelopes of the detector are circles
- To improve the filling along the edge, we use partial sensors of various types to fill in the gap
    - Designed a common mask which allows us to produce various different partial sensors from the same production of wafers by dicing the wafer along different lines

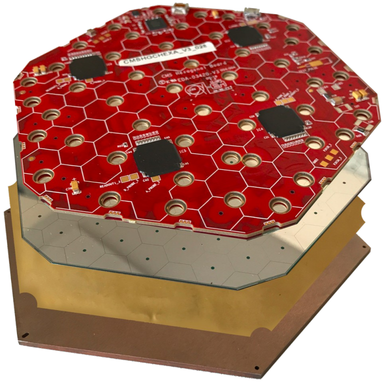


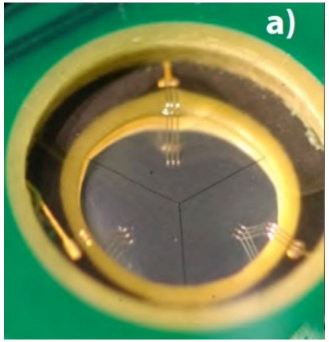


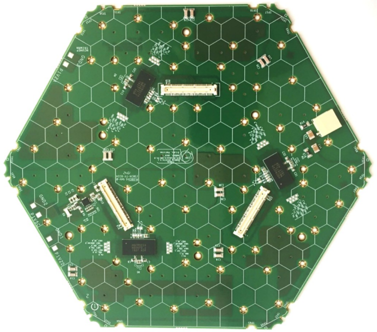


Silicon Modules

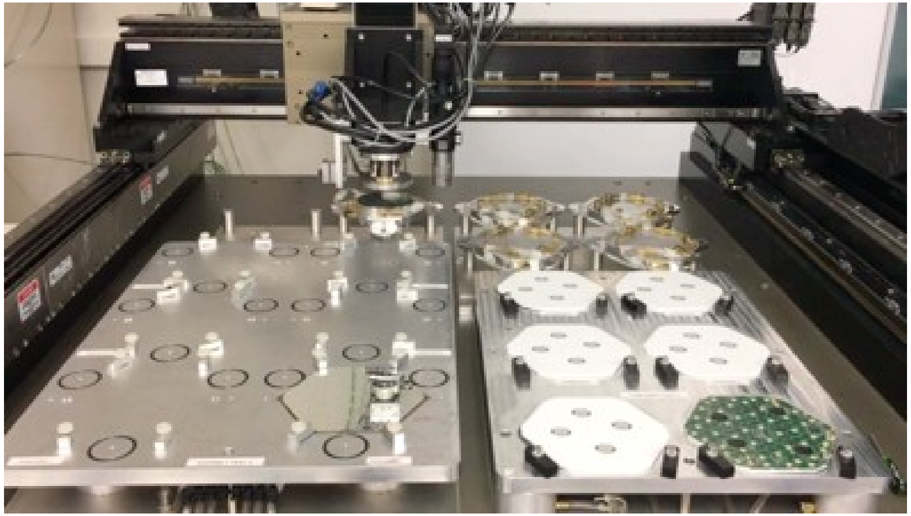
- Robust module constructed from a baseplate, insulating layer, silicon sensor, and readout PCB



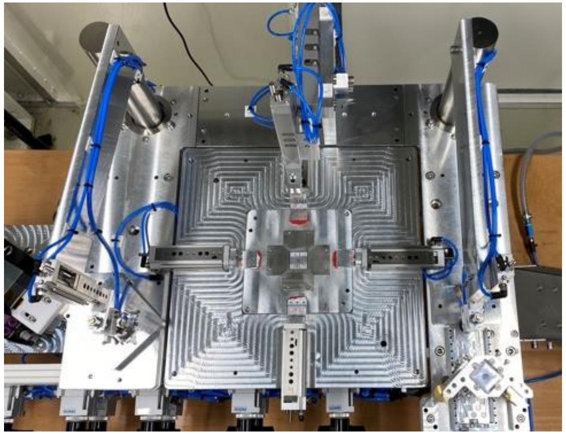


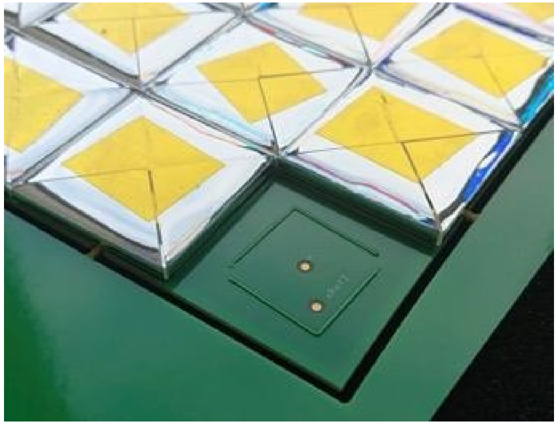


- Automated assembly process using gantry and robotic wirebonder developed at UCSB
  - Highly-repeatable, being replicated to five additional module assembly centers worldwide

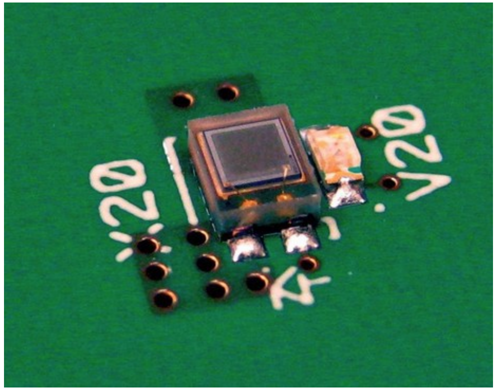


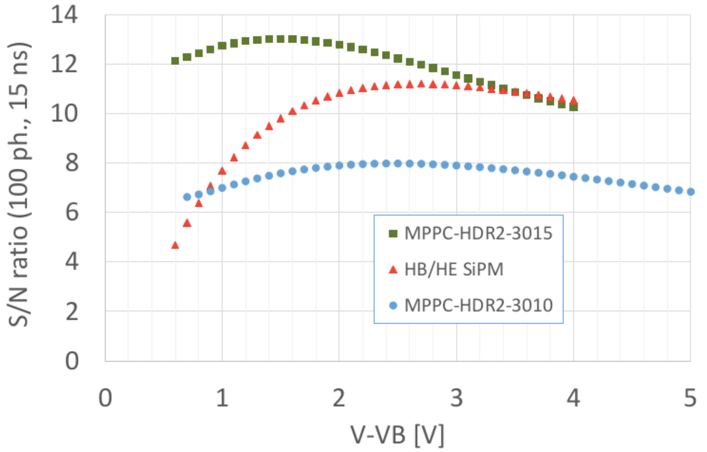
Tiles and SiPMs





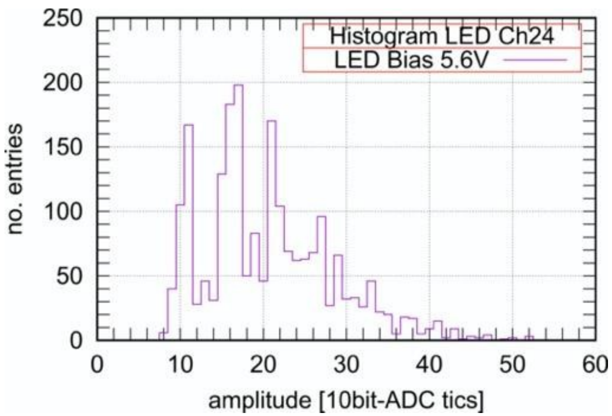
- Scintillator tiles will be produced using both injection molding and machining of cast scintillator
  - Tiles will be wrapped with ESR foil in an automated wrapping machine which can adapt to the 25 different sizes of tiles required
- SiPM photodetectors have been produced which provide sufficient signal-to-noise over the life of the experiment

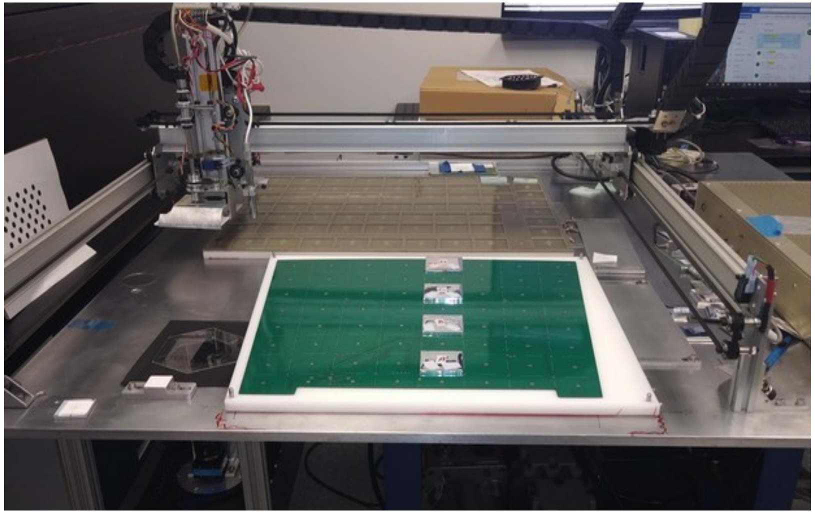


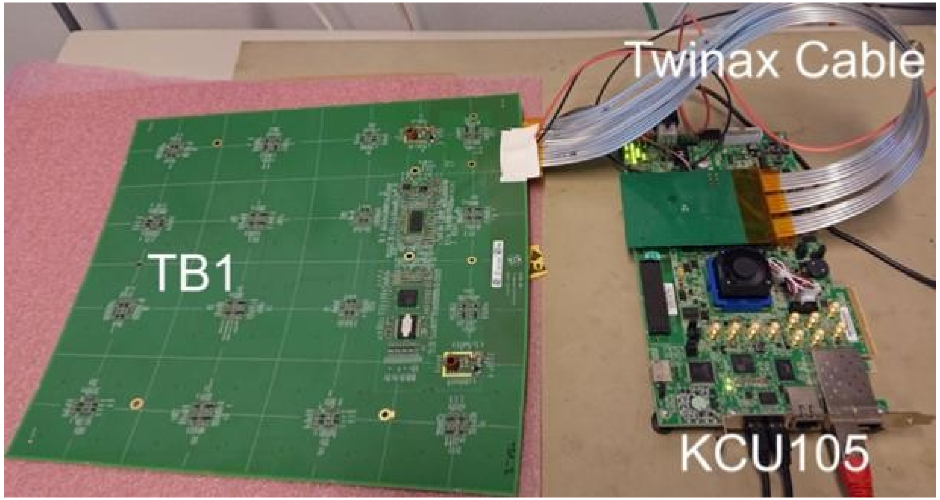


Tile Modules

- Tile modules constructed by automated pick-and-place of tiles onto tile PCB containing the SiPMs, readout chip, and other components
- First single photo-electron spectra recently obtained using tile PCB with HGCROCV2 ASIC

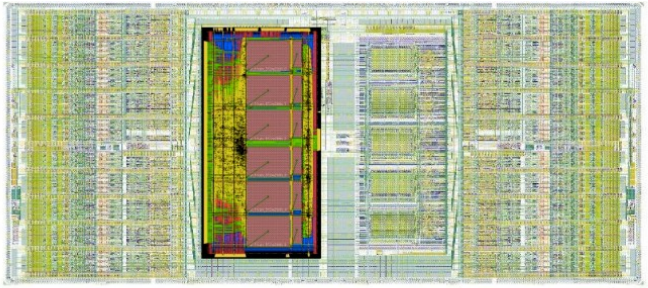






Electronics and Motherboards

- HGCROCV2 ASIC received in late 2019
  - Operating well including radiation tolerance
  - V3 with full DAQ rate capabaility is under final design currently
- Concentrator ASICs (trigger and DAQ) are nearing completion for submission in the Fall/Winter
- Prototypes of all key electronics boards are underway or complete
  - Engines, wagons, wingboards, DC/DC converters, etc



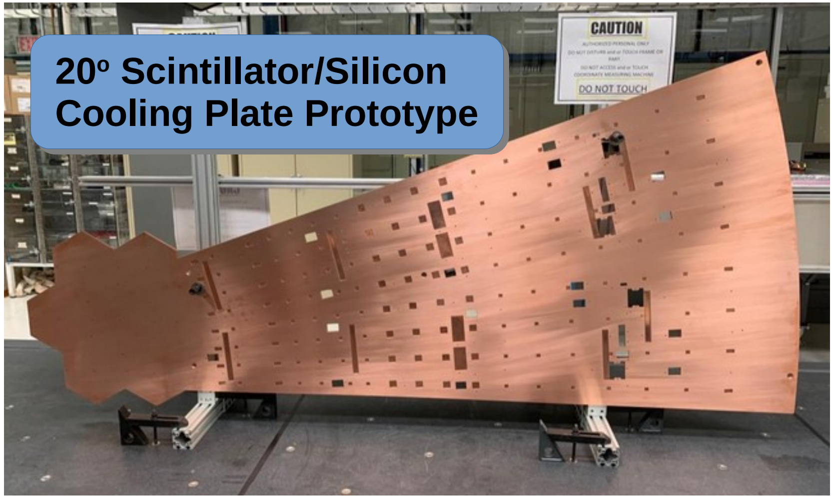
V3 HGCROC

Photo of Engine V2
Coming Here

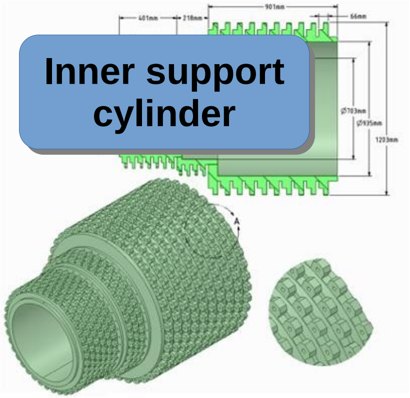
Wagon

Cassettes and Mechanics

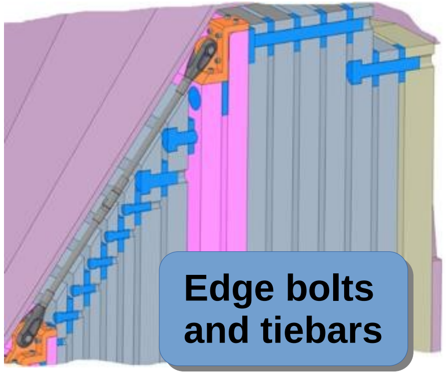
- Hadron absorber design now in a very advanced state
  - Production expected to start in 2021
- Cassette design and manufacture well-advanced
  - Multiple prototypes produced for both CE-E and CE-H, including the section of CE-H with scintillator, which is the most complex case



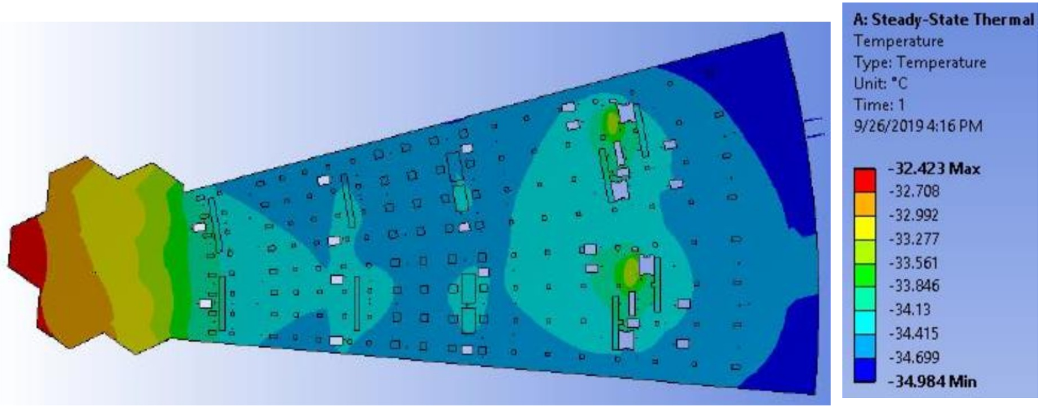
20º Scintillator/Silicon Cooling Plate Prototype

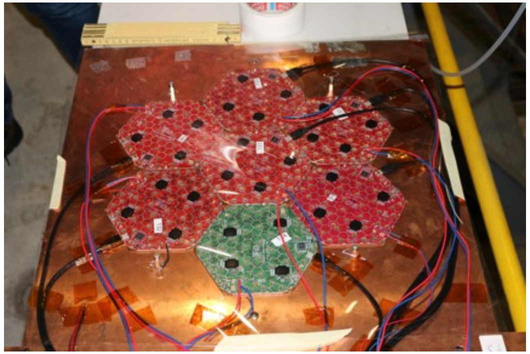


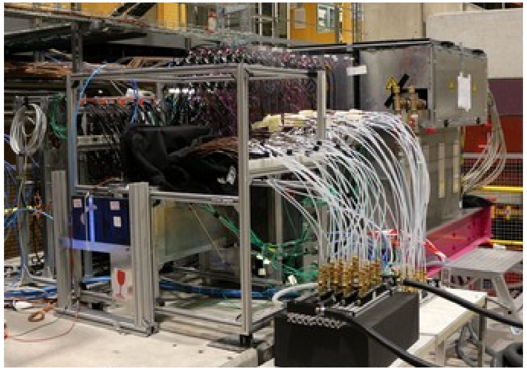
Inner support cylinder



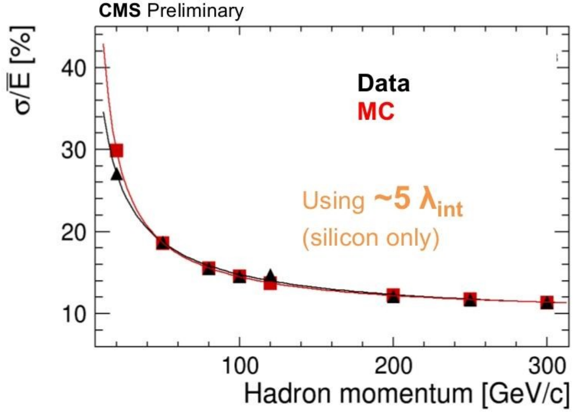
Edge bolts and tiebars

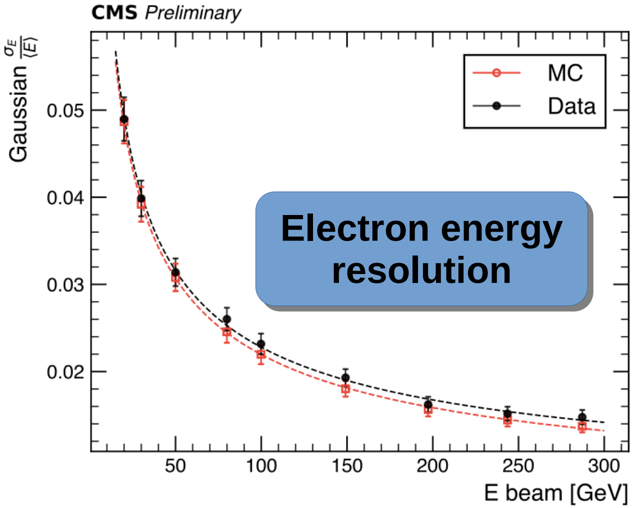


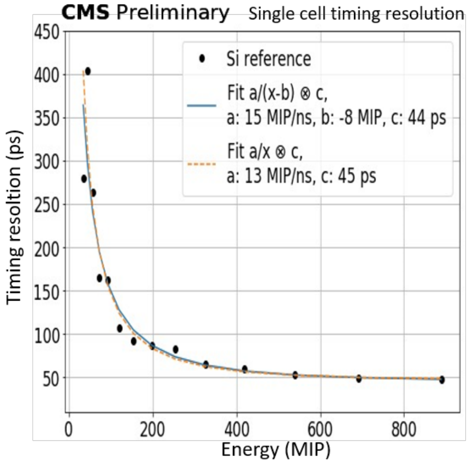




- 28 EM layers, 12 silicon HAD layers, 39 scintillator layers from CALICE AHCAL
- Measured electrons, pions, and muons with energies from 20 GeV to 300 GeV
- Papers under preparation/in final collaboration review



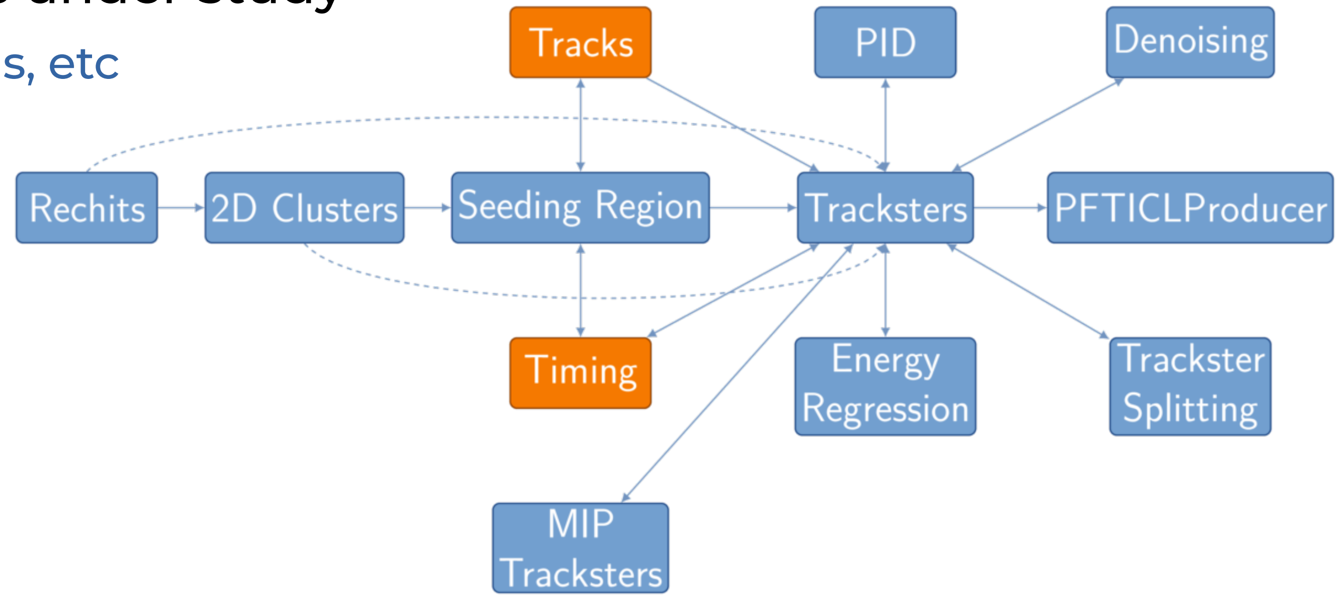




Reconstruction

- TICL – The Iterative CLustering
- Improvements on pattern recognition towards full particle flow performance
- Advanced techniques under study
  - Machine-learning, GPUs, etc

See talk by Jingyu Zhang



Summary

- HGCAL: where highly granular calorimetry comes to life at the energy frontier
  - Building on many previous developments
- Now vigorously prototyping towards the fully-engineered design
  - Exciting adventure at every single step!
  - Some efforts have been delayed by COVID effects, but the team has been working hard to advance those aspects which are less-affected
- System tests now underway with fully-functional front end electronics
  - Moving towards the full engineering design review in 2021