A.6 Calorimeter Endcap QA Plans

A6.1 Calorimeter Endcap Scope

The Calorimeter Endcap (CE) detector is an array of silicon sensors and scintillator tiles readout by SiPM photodetectors embedded in an absorber matrix to form a sampling calorimeter. These detectors operate within a high-radiation environment inside the CMS magnet. The showers initiated in the absorbers are sampled through ionization in small cells to determine particle energies and provide trigger information for electrons, photons, taus, and jets in the endcap region. The design entails the use of silicon modules and scintillator tile-modules. Silicon modules include a silicon sensor, a PCB-baseplate, and a readout PCB hosting custom ASICs. Scintillator tile-boards include scintillator tiles wrapped in ESR foil, SiPMs, and a readout PCB hosting custom ASICs and LEDs. Modules and tile-modules are mounted onto cooling plates to form cassettes and connected to motherboards for data and trigger concentration.

The US CE subproject is integrated with international CMS with respect to shared designs, procurements, and module production. Deliverables for the US effort include silicon modules and scintillator tile-modules integrated onto cassette cooling plates; development, production, and test of the concentrator ASIC; procurement and test of a portion of the powering system. As part of the objective project scope, the subproject includes integration of the cassettes into the absorber and surface commissioning of the calorimeter.

The US CE WBS for deliverables is

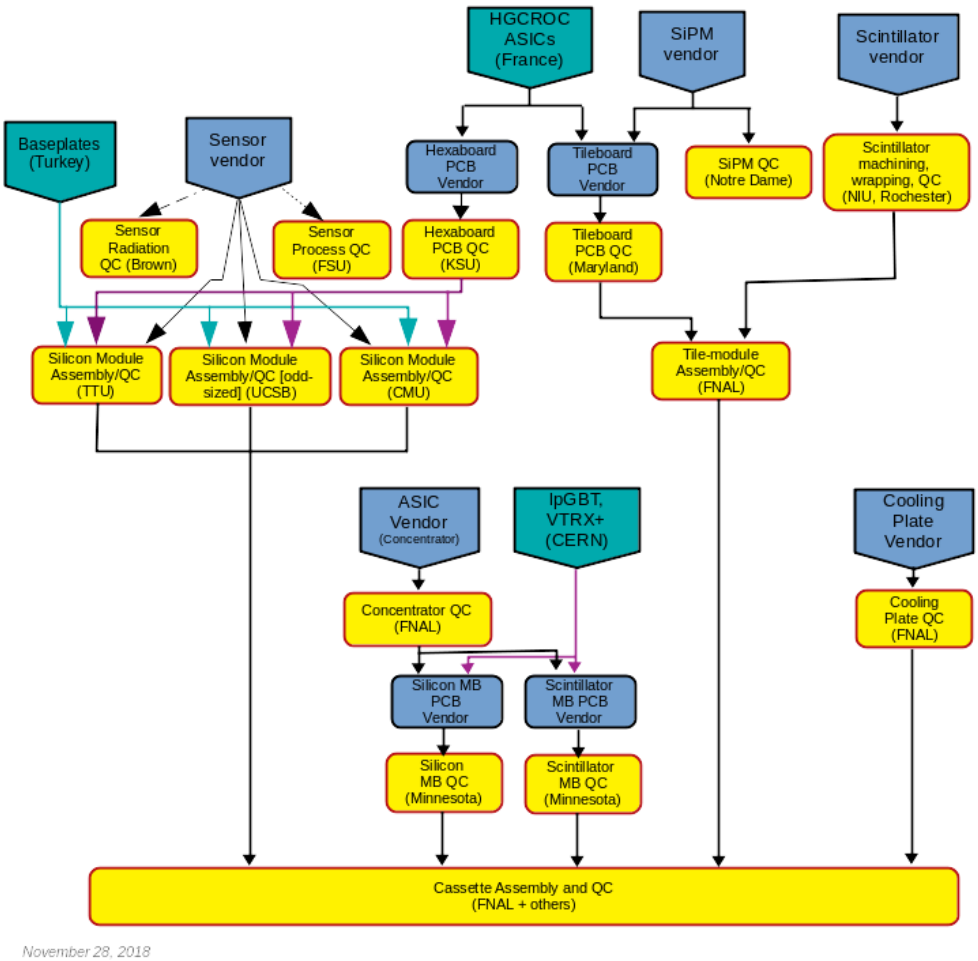
- 402.4.2 Management
  - Travel for organizational meetings and misc M&S
  - Integration and commissioning activities at CERN
- 402.4.3 Sensors
  - Procurement of Sensors, Setup-up and Execution of QC
- 402.4.4 Modules
  - QC of module baseplates
  - Production and QC of module readout PCBs
  - Setup of module fabrication sites
  - Production and QC of silicon modules
- 402.4.5 Cassettes
  - Production and QC of cooling plates
  - Procurement and QC of cassette interfaces and cables
  - Design, Procurement, and QC of silicon sensor motherboards
  - Setup of cassette fabrication sites
  - Production and QC of cassettes
- 402.4.6 Scintillator Calorimeter
  - Production and QC of wrapped scintillator tiles
  - Procurement and QC of SiPM photodetectors
  - Procurement and QC of tile-module PCBs
  - Production and QC of tile-modules
  - Design, Procurement, and QC of scintillator motherboards
- 402.4.7 Electronics and Services
  - Design, Procurement, and QC of the Concentrator ASIC
  - Procurement and QC of detector power systems

A6.2 Calorimeter Endcap Organization

US CMS CE reports to the international CE subsystem manager. The US is one of 18 entities (CERN, countries, funding agencies) that provide some subset of the Calorimeter Endcap deliverables. The US CE effort is homogeneously intertwined with the international CMS with respect to design validation, shared procurements organized through CERN to guarantee consistency, and fabrication in parallel, all coordinated and overseen by CMS Calorimeter Endcap. U.S. team members are embedded in the Calorimeter Endcap international organization: members of the U.S. team include the deputy subsystem technical coordinator, co-coordinators for the module construction, scintillator calorimetry, cassettes, and on-detector electronics. There are organization charts for CMS and US-CMS that define clear roles and responsibilities, as well as official channels for communication (see the Preliminary Project Management Plan for the HL-LHC CMS Detector Upgrade Project, CMS Document 13104).

The U.S. CE project planning and schedule are maintained independently from the CMS schedule, with deliverables to and from the U.S. project represented as external milestones. Key external interfaces are with CERN on procurements of silicon sensors and common electronics components (ASICS), with CE collaborators responsible for mechanical structures and DAQ, and with the receivers of U.S. CE deliverables.

Components for silicon module and tile-module assembly are delivered from vendors, acceptance tested, and used to build modules, which then are distributed to cassette integration centers. The overall scheme is shown in Figure 1.



Interfaces and decisions on requirements, design decisions for both components and assembly procedures and equipment, and required testing are handled at the international level because of the shared design and fabrication. Design and fabrication plans, including Quality Assurance, are discussed and decided under the international CMS organization with participation from all countries. Multiple parallel discussions at every level of the WBS occur at frequent meetings, weekly or biweekly. Participants, including U.S. project members, present, discuss and debate the current topic – design, fabrication plan, quality assurance level, prototyping result, etc. The decisions arising from these meetings, typically after several iterations, are presented to a broader audience, usually in dedicated week-long workshops that occur three times per year. These workshops include upper level management and other non-management team members, and are the forum where decisions are further scrutinized and either rejected, with a request for further investigation, or accepted. In this way consensus about what is being built and how it will be validated is reached. It is expected that all stakeholders will follow this consensus.

The collaboration Information and decisions are passed further up the management chain to CMS Technical Coordination and undergo CMS Step reviews, usually including reviewers external to CMS, for review and concurrence.

A6.3 Participating Institutions

The US CMS CE subproject leverages existing experience and expertise at participating institutes and has already instituted cross-site exchanges to spread knowledge and expertise. CE institutions bring the following experience/expertise to the project:

- UCSB: Facility used to construct current CMS tracker modules
- Iowa: Expertise on CMS HCAL mechanics and construction
- Notre Dame: Lead developer of SiPMs for CMS HCAL Phase 1 upgrades
- Fermilab: Experience on developing CMS, CDF calorimeters, SiDet facility with CO2 cooling system used for current forward pixel detector, history of many integrated detector projects in CMS and Tevatron experiments
- Minnesota: Developed Phase 1 HCAL readout electronics
- NIU: Leading group in CALICE for development of SiPM-on-tile readout technique

The following table lists the 19 participating institutions that will be performing work for U.S. CMS and indicates which will likely require site visits for validation of capability to meet requirements and readiness for production work.

Table A-6.3.1 –Participating Institution Activities for US Calorimeter Endcap

Institution	L3 Subcomponent	Activity
DOE Responsibility		
Brown	Sensor	Sensor prototype and production QC
Fermilab	Sensor	Sensor design
Florida State	Sensor	Sensor production QC
Kansas State	Module PCB	Module readout PCB procurement and QC
Carnegie Mellon	Modules	Mechanical and electrical assembly and QC of silicon modules
Texas Tech	Modules	Mechanical and electrical assembly and QC of silicon modules

UCSB	Modules	Mechanical and electrical assembly and QC of silicon modules
Baylor*	Modules/Tile-modules	Development of, support for firmware and software for module and tile-module test systems deployed at production sites
NIU	Scintillator Tiles	Procurement, wrapping and QC of scintillator tiles
Rochester*	Scintillator Tiles	Involvement in wrapping and QC of scintillator tiles at NIU/FNAL
Notre Dame	SiPM	Procurement and QC of SiPMs
Maryland	Scintillator PCBs	Procurement and QC of tile-module readout PCBs
Fermilab	Tile-modules	Mechanical assembly and QC of scintillator tile-modules
FSU	Scintillator MB	Development, production, and QC of scintillator motherboards
Fermilab	Concentrator	Development, procurement, and QC of concentrator ASIC
FIT*	Concentrator	Studies in support of concentrator ASIC
MIT*	Concentrator	Studies in support of concentrator ASIC
Northwestern*	Concentrator	Studies in support of concentrator ASIC
Minnesota	Power systems	Procurement and QC of power supplies
Fermilab	Cooling Plates	Design, procurement, QC of cooling plates
Brown	Cooling Tubes	Design, production(bending), QC of cooling tubes
Alabama*	Cooling Plates	QC of cooling plates at FNAL
Minnesota	Silicon MB	Development, production, and QC of silicon motherboards
Iowa*	Cassette interface	Procurement and QC of cassette interface components
Fermilab	Cassette	Mechanical and electrical assembly, QC of cassettes
Iowa*	Cassette	Participate in assembly, QC of cassettes
Fairfield*	Cassette	Participate in assembly, QC of cassettes
Northwestern*	Cassette	Participate in assembly, QC of cassettes

*No site visit needed due to work being performed under the QA plan/procedure for another site or due to the nature of the work.

A6.4 Planned QA Activities

All QA aspects of the U.S. HL LHC CMS Detector Upgrade Project will be handled in accordance with the rules and procedures laid out in the Project-wide Quality Assurance Plan CMS-doc-13093. Current detailed plans for QA/QC activities are found in the Calorimeter Endcap QA Activities Spread Sheet (QAP, CMS-doc-13093, under Other Documents). The QA activities are linked to Technical Requirements established through the CMS review and approval process and recorded in the 402.4 Calorimeter Endcap Requirements and Interfaces, CMS Document 13447. While U.S. CE is responsible for creating and following QA plans and processes for work at its sites, those plans must incorporate the international CMS QA plans and procedures approved by the collaboration to support of standardization across projects and to ensure proper integration across interfaces. QA plans/procedures for CE U.S. sites are developed in collaboration with the cognizant international CE WBS lead and the site representative and are reviewed and approved by the CE L2 lead and the U.S. QA Coordinator. The U.S. CE team works with the CMS CE technical coordinator and project office on planning QA and validation of CMS requirements.

U.S. CE QA activities fall into the following areas, with a few examples:

- Quality Assurance = processes to prevent substandard fabrication
    - Sensors: Designing test structures into wafers for “Process Quality Control” to test sensor composition

    - Electronics: design/fabrication of test systems for module PCBs, tile-modules, concentrator ASIC, motherboard to verify quality
    - Prototype/Preproduction/Production cycles
        - Two full-integration cycles including all aspects of vertical integration
- Quality Control = actions to detect substandard fabrication
    - Sensor and SiPM: Sensor Quality Control and Irradiation tests
    - Modules and tile-modules: Acceptance tests of components, final module burn-in tests
    - Cassettes: thermal cycling and burn-in tests of fully-assembled cassettes

More examples and details can be found in the quality activities spreadsheet for the CE.

A6.5 Design Validation:

In all areas of the Calorimeter Endcap, there are several planned iterations of prototyping and validation of prototype performance before/after irradiation where appropriate, including test beam performance. Initial validation work has been undertaken using small-scale testbeam modules and thermal mockups of full cassettes. Two full cycles of end-to-end integration are planned throughout the project, including all areas from sensors and SiPMs to modules and tile-module. to motherboards and cassettes. In each major system, the development and validation of the necessary test equipment to ensure quality is part of the required deliverables before full-scale production can begin.

Internationally, the CMS constitution specifies reviews under the aegis of Technical Coordination at many points along the fabrication path, as described in section 4, and is subject to internal annual reviews run by the collaboration with outside reviewer participation, independent of project progression, as well as the bi-annual HL LHC review run by CERN management. The Calorimeter Endcap successfully completed Step 2, approval of the TDR and Cost and Schedule baseline, in the HL LHC review process in April of 2018 (Calorimeter Endcap TDR, CMS-doc-13384) and expects to follow the normal progression of internal CMS review procedures (Electronic System/Engineering Design Review, Production Readiness Review, Manufacturing Progress Review, Installation Readiness Review) as the project progresses.

A6.6 Production Verification:

All components will be checked first by the vendor as part of the Quality Control specifications in the contract, with contracts written such that only satisfactory parts are paid for/delivered. Vendor QC will be cross checked by visual inspection and, where appropriate, functional testing by the project team at the Sensor QC and Module Assembly sites. Items which do not conform will be graded as such and segregated from conforming components, to be either discarded or used in dedicated tests/mock-ups where the lack of functionality does not affect the test.

The institutional sites where fabrication of components will take place will be required to follow the International CMS designs and procedures, which applies to all participants independent of local institutional QA programs. To be approved for assembly of production components, all assembly centers will have to demonstrate to the CMS group that they can meet the requirements by reliably by assembling multiple sample components to specifications. Module production is coordinated across the full international project under the leadership of the UCSB group of US CMS, while tile-module production is led by the DESY group in international CMS. Fermilab leads the cassette integration process for hadronic cassettes.

In addition, U.S. subproject production site responsibles will follow the process described in the U.S. CMS QAP to validate demonstrated site capability for CMS designs and procedures after the prototyping campaign and to review/approve site QA plans/procedures. By default, the Institute PI serves as the QA point of contact for each site but may delegate that to the engineering or technical staff responsible for the daily operations. Site visits by the L2 Lead and the QA Coordinator will occur before the start of production. Continuous monitoring of the yield of recent fabrications will be performed by the assembly site personnel as well as L3 and L2 management

throughout the production, with site follow-up visits If the yield becomes unsatisfactory. Weekly reports to L2 management of production throughput based on the standardized verification program will be used to judge progress as the production ensues.

In areas where the deliverable is part of the detector, acceptance tests of all components are planned to occur before integration into composite structures. Final acceptance tests and extended performance tests of the assembled composite structures/systems are also planned. The QA Activities spreadsheet lists the entities responsible for performing the acceptance tests, including integrated performance tests on assembled subsystems.

A6.7 Document/Record Storage:

Project designs, plans, and reports shared between the U.S., other CMS CE detector stakeholders, and CERN engineering are maintained by the international organization, through the CERN Engineering Design Management System (EDMS), the CMS Document Database, or an online “e-space” built for collaborative work. These systems are meant to be the repository of the authoritative latest design and can have notification/approval mechanisms such that all stakeholders can be aware of and/or approve design changes