A.5 Outer Tracker Project QA Plans

A5.1 Outer Tracker Project Scope

The Outer Tracker (OT) detector is a subsystem within the international CMS Subdetector Upgrade Tracker Project. It is an array of silicon sensors that collects space points from the ionization of charged particle tracks, operating in a high radiation environment inside the CMS Calorimeters and Magnet. The space points are used to reconstruct particle trajectories and provide trigger information for charged particles (especially muons) above a transverse momentum threshold. The design entails the use of sensor doublets or ‘sandwiches’ to form modules: a pixel sensor-strip sensor sandwich for smaller radii forms a PS module, and a strip sensor-strip sensor (2S) sandwich forms a 2S module for larger radii. Pixel-Strip sensors (PS-s) and Strip-Strip sensors (2S) provide 1D information, pixelated sensors (PS-p) provide 2D information. Modules include sensors, ASICs, power and readout hybrids, spacers and mechanical support. Mechanics are similar for both modules although the sensors and electronics differ.

The U.S. OT subproject is integrated with international CMS with respect to shared designs, procurements, and module production. Deliverables for the U.S. effort include PS modules passed to Outer Tracker collaborators; PS modules assembled into planks and rings and integrated into the PS Flat Barrel structure; 2S modules; and the design/development of assembly procedures, assembly facilities, and test systems to support component and module QC. The development of the required radiation tolerant sensors and readout electronics is outside the scope of this project. The U.S. OT WBS for deliverables is

- 402.2.2 Management
  - Travel for Organizational Meetings and Misc. M&S
- 402.2.3 Sensors
  - Procurement of Sensors, Setup up and Execution of QC
- 402.2.4 Electronics
  - Oversight of MaPSA (bump bonding Ps-P sensors to MPA ASIC chip)
  - Design, Procurement of Component Test Systems
  - Outer Tracker Data Acquisition Firmware/Software
- 402.2.5 Module Assembly
  - Fabrication of Assembly sites, procurement of mechanical and electrical Components, Module Assembly
- 402.2.6 Mechanics
  - Fabrication of Plank and Ring Mechanical Structures
- 402.2.7 Integration
  - Loading of Modules onto Planks and Assembly of 3-layer Flat Barrel

A5.2 Outer Tracker Project Organization

U.S. CMS OT reports to the international CMS Subdetector Upgrade Coordinator for the L1 Upgrade Tracker Project, along with Inner Tracker (aka Pixels, U.S. NSF scope) and Track Trigger (part of U.S. Trigger/DAQ subproject, NSF and DOE scope)[1]. The U.S. is one of 11 entities – 10 countries plus CERN – that provide some subset of the Outer Tracker deliverables. The U.S. OT 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 Tracker. U.S. team members are embedded in the Tracker and CMS international organization: the U.S. team co-coordinates the System Test and Modules groups, as well as the CMS Upgrade Performance Studies" group. 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. OT 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 OT collaborators responsible for mechanical structures and DAQ, and with the receivers of U.S. OT deliverables.

Components for module assembly are delivered from vendors, acceptance tested, and used to build modules, which then are distributed to burn-in centers and finally integration centers to be built into larger structures. The overall scheme is shown in Figure 1. The U.S. flow, shown inside the red shape, starts at Brown and Rochester with sensor QA (not shown), which then feeds the East Coast (Brown, Rutgers, Princeton) and Fermilab module assembly centers, respectively. The PS modules from the East Coast centers feed DESY, Lyon, Louvain integration centers, and the 2S Modules the Strasbourg integration center. From Fermilab, the PS modules, in addition to being used in the Flat Barrel Assembly by the U.S., are sent to Lyon, while the 2S modules also go to Strasbourg.

[1] While there is one-to-one correspondence between the International and U.S. WBS elements for deliverables, the U.S. CMS organization does not map directly to the International CMS organization.

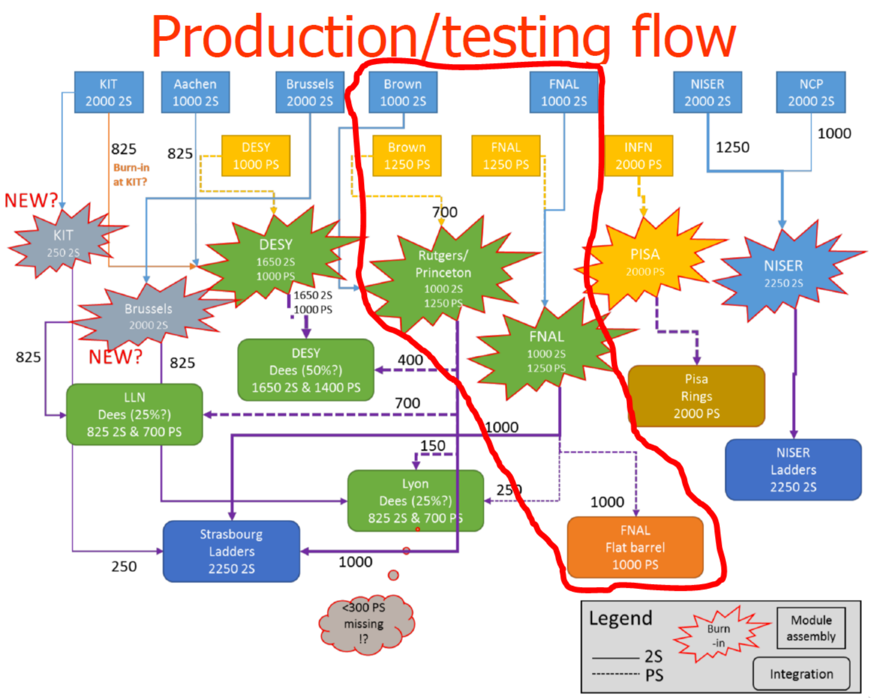

Figure 1: Proposed flow of Modules from Assembly to Burn-in to Integration

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 quarterly, which include upper level management and other non-management team members, 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.

A5.3 Participating Institutions

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

- Fermilab: SiDet facility used to construct D0, CDF, current CMS tracker, legacy and current Forward Pixel Detector
  - Symbiosis with LPC participants
- Princeton: Built Belle II Silicon Detector
- Rochester: D0, legacy CMS tracker construction and Operation
- Brown: D0 silicon, legacy Tracker operation, Phase 1 HCAL, FPIX assembly (@Purdue)
  - Supporting international CMS QA Manager and main module design guru
- Rutgers: legacy and current FPIX electronics
- UC Davis: Mechanics in legacy and current FPIX

The following table lists the 9 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-5.3.1 –Participating Institution Activities. Institutions in red italics indicate new institutions performing work in Outer Tracker.

Institution	L3 Subcomponent	Activity
DOE Responsibility		
Brown	Sensor	Sensor design and production QC
Rochester	Sensor	Sensor design and production QC
Brown	Modules	Mechanical assembly of modules
Princeton	Modules	Electrical assembly of modules
Rutgers	Modules	Electrical assembly of modules
Fermilab	Modules	Mechanical and Electrical assembly of modules
Fermilab	Integrated assembly	Plank and Layer assembly
UC Davis*	Mechanics, Materials testing	Validation of mechanical properties of substrates
Wayne State*	DAQ; Modules Machining	Participation in DAQ and test beam work at Fermilab; machining of jigs and fixtures for module assembly
Bethel*	Module Assembly	Participation in QA activities in Module Assembly at SiDet
Iowa*	Module Assembly	Participation in Module Assembly at SiDet

*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.

A5.4 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 Outer Tracker 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 402.2 Outer Tracker Requirements and Interfaces, CMS Document 13388. While U.S. OT 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 OT U.S. sites are developed in collaboration with the cognizant OT WBS lead and the site representative and are reviewed and approved by the OT L2 lead and the U.S. QA Coordinator. The U.S. OT team works with the assigned CMS Tracker QA Manager on planning QA and validation of CMS requirements.

U.S. OT 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 hybrids, MaPSAs, Modules to verify quality
  - Prototype/Preproduction/Production cycles
- Quality Control = actions to detect substandard fabrication
  - Sensor: Sensor Quality Control and Irradiation tests
  - Modules: Acceptance tests of components, final module burn-in tests

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

A5.4.1 Design Validation:

In all areas of the Outer Tracker, there are several planned iterations of prototyping and validation of prototype performance before/after irradiation where appropriate, including test beam performance. Several areas in Outer Tracker are almost completely Quality Assurance programs. For the Sensors, one of the major procurements in the HL-LHC project other than the actual procurement of the silicon sensors, the entire schedule is a plan to develop the procedures and testing infrastructure and then perform validation tests of the sensors, checking that they meet the specifications in terms of performance and radiation tolerance. In Electronics, the Test Systems L3 area is dedicated to the design of standardized test equipment and procedures to be used in all assembly sites for acceptance of components as well as validation of performance of the final assembled deliverable.

U.S. OT has passed an initial design review (See *report Sept 2017 Independent Outer Tracker Technical Review*, CMS-doc-13406), which established the main parameters and vetted the layout and sensor sandwich design through simulation. This report noted that QA for this project was well planned and executed. OT was also reviewed during the April 2018 HL LHC

CD-1 Director's Review (CMS-doc-13535), in which the only committee comment relevant to Quality Assurance was positive. Finally, the project was reviewed as part of the June 2018 DOE CD-1 review, but the remarks (predominantly positive) do not bear on Quality issues.

In order to prepare for the next step in the Critical Decision process, which is a CD 2/3 in the fall of 2020, a series of iterations of prototype module fabrication with increasingly mature components is underway, which provides both a development path for perfecting the construction methods but also a method for refining estimates before baseline and developing the QC infrastructure and methodology.

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 Outer Tracker successfully completed Step 2, approval of the TDR and Cost and Schedule baseline, in the HL LHC review process in December of 2017 (Tracker 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.

A5.4.2 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 QA 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.

Module production is coordinated by the CMS module group and the US activities are embedded into the work of this group. The CMS module group will approve the tooling and procedures to be used for assembly and publish the approved designs. 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 in the Outer Tracker, independent of local institutional QA programs. To be approved for assembly of production modules, all assembly centers will have to demonstrate to the CMS module group that they can meet the requirements by reliably by assembling five modules to specifications.

In addition, U.S. subproject production Leads 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.

A5.5 Document/Record Storage:

Project designs, plans, and reports shared between the U.S., other CMS Tracker 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. Implementation in EDMS is based on the 402.4 Endcap example and is ongoing.