A.4 Trigger/DAQ QA Plans

1.   Trigger/DAQ Scope

The CMS Trigger Systems Upgrade Project will analyze, accept, and reduce the data stream from the backend electronics of most of the CMS subdetectors for the most scientifically valuable events to 7.5 kHz. It provides the digital electronics, associated infrastructure, firmware, and software to replace the existing CMS Layer 1 (L1) Trigger and DAQ to enable higher data rates and to take advantage of technical advances. The U.S. Trigger/DAQ subproject consists of both NSF and DOE scope under combined, single management but with subcomponent deliverables held separately at WBS Level 3.

The DOE deliverables include design, production, and testing of:

- **electronics, firmware, and software for the L1 Barrel Calorimeter Trigger system (402.6.3)**
- **electronics, firmware, and software for the L1 Layer-1 Correlator Trigger system (402.6.5)**, and
- **hardware and software for the DAQ Storage Manager and Transfer System (402.6.6)**.

The NSF effort entails design, production, and testing of:
- **electronics, firmware, and software for the L1 Muon Trigger system (402.6.4)**, and
- **electronics, firmware, and software for the L1 Track Trigger system (402.6.7)**.

All U.S. deliverables involve off-detector electronics, including any related software, and are located outside the radiation zone. They are based on existing commercial parts housed in standard rack packaging. As such, they have no special requirements or anticipated technological risks beyond that of standard commercial electronics projects. The design efforts entail prototyping and testing the electronics using specified firmware, including slice-test demonstrators and algorithm performance studies. The production effort consists of procurements, assembly, and data simulation testing for electronics. For the DAQ Storage system, production involves procurement and assembly, software releases, and integrated testing with simulated data.

2.   Trigger Systems Organization

The U.S. CMS Trigger/DAQ upgrade project reports to the CMS Upgrade Coordinators for the L1 Trigger and the DAQ, who together are part of the CMS Trigger and DAQ Systems (TriDAS) Project. The CMS TriDAS Project consists of an Institutional Board and Chair, together with separate Project Managers that oversee the respective operations of the Trigger and the DAQ. The U.S. CMS Trigger/DAQ upgrade project also reports to the CMS Upgrade Coordinator for the Tracker, which formally hosts the CMS Track Trigger Project. Within those upgrade projects, the U.S. CMS Trigger/DAQ upgrade project partners with CERN, who provides the infrastructure (racks, crates, wiring, etc.) needed for installing the trigger electronics and data handling/storage system. It also

partners with other CMS Collaborating Institutions responsible for delivering all other remaining (not US scope) trigger components. The U.S. CMS Trigger/DAQ upgrade project works closely with the CMS TriDAS QA Coordinator and the CMS Electronics Coordinator, both of whom will be identified at the time of the TDR.

Key external interfaces exist with each subdetector whose back-end electronics provide inputs to the Trigger and DAQ systems. For the NSF effort, this entails close interface coordination with the Endcap Muon Detectors back-end electronics (US NSF), the Outer Tracker back-end electronics (not US scope), and Barrel Muon Detectors back-end electronics (not US scope). For the DOE, close interfaces are in place for inputs from the back-end electronics corresponding to the Barrel (US NSF) and Endcap Calorimeters (not US scope), as well as the inputs from the Muon Trigger (US NSF) and Track Trigger (US NSF) systems. The Layer-1 Correlator Trigger (US DOE) has an output interface to a Layer-2/Global Trigger component (not US scope). All trigger components have an interface to the DAQ (not US scope) and all have interfaces with CERN, who contributes M&S for the L1 trigger infrastructure (crates/fibers/patch panels).

The U.S. CMS Trigger/DAQ Upgrade Project participates in and also employs several effective means of communication to keep track of the project. In particular, the U.S. CMS Trigger/DAQ Upgrade Project is well placed within CMS: J. Berryhill is the current CMS Phase-2 Upgrade Coordinator for the L1 Trigger and Deputy Project Manager R. Cavanaugh was the previous Coordinator. The CMS L1 Trigger Upgrade Coordinator (Berryhill, Fermilab) reports to the CMS L1 Trigger Project Manager (A. Tapper, Imperial College), who is appointed by the CMS Spokesperson (R. Carlin, Padova) with endorsement by the TriDAS Institutional Board. The CMS L1 Trigger Upgrade Coordinator participates as a member of the CMS Upgrade Steering Group, organized by the CMS Upgrade Coordinator (F. Hartman, Karlsruhe; D. Contardo, Lyon). This tight coupling of leadership positions between U.S. CMS and CMS ensures that all U.S. CMS Trigger/DAQ activities are in lock-step coordination with CMS.

Under the CMS Coordination of Berryhill, the Phase-2 L1 Trigger Upgrade Group has instituted weekly meetings whose purpose is to track all L1 trigger upgrade activities, ensuring that algorithm development and performance studies meet the HL LHC science goals, and that engineering R&D as well as any assembly and technical work remain on track. That CMS group also organizes semi-annual workshops whose purpose is to report algorithm performance, track milestone progress, assess technical accomplishments, and formulate any updated plans for the next six months. The CMS Phase-2 L1 Trigger Upgrade Group also conducts weekly coordination meetings with all subgroup coordinators. CMS also maintains a standing Upgrade Steering Group Coordination meeting, organized weekly by CMS Upgrade Management with the various Detector Upgrade Coordinators including the L1 Trigger (represented by Berryhill).

In parallel, under the U.S. CMS Management of Berryhill, together with deputies R. Cavanaugh (DOE) and K. Ulmer (NSF), the U.S. CMS L1 Trigger/DAQ Upgrade Project conducts weekly coordination meetings with the L3 Trigger/DAQ Project Managers (S. Dasu, 402.06.03; D. Acosta, 402.06.04; N. Tran, 402.06.05; R. Mommsen, 402.06.06; P. Wittich, 502.06.07). In addition,

monthly U.S. CMS Trigger/DAQ engineering meetings are organized to track development of the Advanced Trigger Processor board and to coordinate infrastructure firmware and software development. Further, monthly U.S. CMS Trigger/DAQ scientific meetings are organized to track algorithm development for the Correlator Trigger. The L2 Trigger/DAQ Project Management team (Berryhill, Cavanaugh, Ulmer) participate in weekly general coordination meetings with the (DOE and NSF) U.S. CMS Project Office, and the same L2 Management team meets with the Project Office biweekly to discuss specific issues related to Trigger/DAQ. Finally, frequent ad hoc meetings, workshops, and reviews are conducted to address specific issues, including engineering development and progress, algorithm goals and performance, quality assurance and control, science and engineering requirements, internal and external interface specifications, and others.

Within the CMS TriDAS Upgrade Project (L1 Trigger and DAQ), decision points for design and technical choices, as well as any agreements regarding requirements and interface specifications are nominally achieved by consensus, based on outcomes of simulations and prototype demonstrators, with input from internal and external reviews, and will be documented in L1 Technical Design Report (Q4 2019) and the DAQ Technical Design Report (Q1 2021). If necessary, design choices and technical specifications can be made executively by CMS management with input provided by designated ad hoc committee and internal reviews. The U.S. CMS Trigger/DAQ Upgrade Project abides by the design and technical choices of CMS, including any requirements and interface specifications. All internal and external interface specifications are documented as technical notes and archived within the CMS DocDB document repository and described in the respective TDRs. Quality Assurance testing and inspections of pre-production electronics components for the Advanced Processor Trigger board is the responsibility of the U.S. CMS Trigger/DAQ Upgrade Project via the L2 and L3 Managers. Before the U.S. CMS Trigger/DAQ Upgrade Project may procure the final electronic components for production assembly of the Advanced Processor Trigger boards, the CMS L1 Trigger Upgrade Project must successfully pass a CMS instituted Electronics Systems Review, which verifies that all engineering requirements and interface specifications are met.

3.   Participating Institutions

The Trigger/DAQ Project has 16 participating institutions, all with past experience in supporting the construction of Trigger and DAQ components. Several of these institutions have responsibilities for more than one area. QA plans will be developed with each institution according to a graded approached. Four of these institutions, the University of Wisconsin, the University of Florida, Cornell University, and Boston University will also require ESH&Q site visits, since all four have significant and high consequence contributions to the design, the procurements, the assembly, and the testing of electronics, software, and firmware.

Table A-4.3.1 –Participating Institution Activities

Institution	L3 Subcomponent	Activity
DOE Responsibility		
Wisconsin	Calorimeter Trigger	HW, FW, SW engineering, algo development, procurement
Colorado	Correlator Trigger	FW, SW engineering, algorithm development
Fermilab		FW engineering, algorithm development
Florida		HW, FW, SW engineering, algorithm development
MIT		Algorithm development
Northwestern		Algorithm development
Texas A&M		FW, SW engineering, algorithm development
UIC		Algorithm development
Wisconsin		HW, FW, SW engineering, algo development, procurement
Fermilab	DAQ	Storage Manager specification, procurement, operations
MIT/Rice/UCSD		Storage Manager specification, operations
NSF Responsibility		
Boston	Track Trigger	HW, FW development, performance, demonstrator studies
Colorado		Track fitting, beyond the baseline algorithms
Cornell		HW, FW development, performance, demonstrator studies
Northwestern		Track fitting, performance, test stand studies, infra FW development
Notre Dame		Integer emulation studies, physics performance, system SW
Ohio State		Duplicate removal emulation, FW development
Rutgers		FW development, performance studies, beyond the baseline algorithms
Florida	Muon Trigger	Board design, algorithms, FW, SW
Northeastern		Monitoring, algorithms
Rice		Muon global sorter: algorithms, FW, board design
Texas A&M		Displaced muons: algorithms, FW
UCLA		Board design, algorithms, FW, SW

4.   Planned QA Activities

All QA aspects of the Trigger/DAQ HL LHC CMS Detector Upgrade Project will be handled in accordance with the *CMS Quality Assurance Plan (QAP)* CMS-doc-13093 for the scope of work under its control. Per the QAP, the QA activities follow the *Software Quality Assurance* section of the *Fermilab Quality Assurance Manual (12003,12090)* for firmware and software.

The Trigger/DAQ plans for QA are listed in the *Trigger/DAQ Quality Assurance Activities Spreadsheet* posted in the document stage database (DocDB) with the QAP. The QA activities are tied to the technical requirements contained in *402.6 Trigger and DAQ--Requirements and Interfaces* (CMS-doc-13318) and are intended to validate the design and verify that deliverables satisfy the requirements. The U.S. CMS Trigger/DAQ upgrade project is responsible for creating and following the QA plans for all specified requirements and to ensure proper integration across interfaces. The L2 and L3 managers of the U.S. CMS Trigger/DAQ upgrade project work with the assigned CMS QA Coordinator for TriDAS to ensure that all requirements and QA plans are consistent with CMS specifications.

A.4.3.1 Design Validation:

Designs for electronics and firmware will be verified by engineering analysis and demonstrations with prototypes and simulated data. Software and algorithms will be quality tested using measurement and analysis.

Trigger/DAQ has passed a set of initial design reviews:

- ▪ L1 Trigger Interim Technical Design Report (TDR) published and accepted by LHCC early 2018 (CMS-TDR-017)

- ▪ NSF preliminary design review passed (muon trigger, track trigger) Dec. 2017.

- ▪ DOE Critical Design Review 1 recommendation passed (calorimeter trigger, correlator trigger, DAQ storage) June 2018

Planned future CMS reviews include a CMS L1 Trigger TDR in 2020, a DAQ/HLT TDR in 2021, and a CMS Electronics Systems Review (ESR) stage-gate for L1 trigger construction in 2021. In addition, internal project design progress reviews are planned as the various component designs mature to provide design validation and verifications. Funding agency reviews of the project are scheduled for end of 2019 (FDR/CD2)

A4.3.2 Production Verification:

Trigger/DAQ prequalifies vendors through capability studies and or prototype and preproduction runs. While procurements will proceed through the University of Wisconsin, Cornell University, and Fermilab, all procurement procedures will follow the *Fermilab Procurement Manual*, with QA/QC plans and responsibilities determined and agreed to in advance of award. Experienced vendors are regularly qualified through R&D, pre-production, and production orders for board manufacture, parts ordering and board assembly. The University of Wisconsin and Cornell

University have long standing experience with vendors of required electronics, and Fermilab has long standing experience with required DAQ storage manager vendors.

For in-house fabrication, assembly, and testing, the U.S. CMS Trigger/DAQ upgrade project reviews the staff qualifications that perform the assigned work, the facility capabilities, and the training needs. The Universities of Wisconsin and Florida have a highly successful track record in L1 trigger construction and Cornell University has successfully demonstrated a prototyped track trigger. Fermilab has constructed and operated the DAQ storage manager since original construction. Each institution has a designated QA representative. A graded approach to the QA entails planning so that plans are created jointly by team members from the institution and the responsible L2/L3 lead, with review and approval by the Trigger/DAQ L2 lead and the QA Coordinator.

Component and assembly QC involve both qualification testing and inspections. Pre- and Initial-production runs of a few electronics boards will be partially assembled and tested before the full productions runs.

Th deliverables of the U.S. CMS Trigger/DAQ Upgrade Project include hardware, firmware, and software releases, all of which will go through thorough suites of tests at each participating institute according to their QA plans. Integrated testing using simulated data and demonstrators will be performed prior to shipping to CERN and hand-off to the installation group. A high-level summary of the integrated testing includes:

- Hardware testing and validation with tagged Firmware and Software by the Responsible Institute prior to final shipping (Validation repeated upon receipt at Electronics Integration Center at CERN)
- Storage and Memory validation through periodic playback against offline copies
- Optical connections validation through live continuous non-invasive monitoring (eye-diagrams) with on-board Zync applications for Xilinx.

5.   Document/Record Storage:

Trigger/DAQ documents are stored on the CMS DocDB site that is accessible to authorized project stakeholders. Hardware deliverables data and testing results are tracked in a spreadsheet, stored on the CMS DocDB site. Issues and handling of non-conforming parts are also tracked in the same spreadsheet. Testing/commissioning/production software and firmware are tracked in github repositories. The CMS Technical Coordinator has ultimate responsibility for managing all Trigger/DAQ documentation.