Department of Energy/Office of Science
Review Committee Report

on the

Technical, Cost, Schedule, and
Management Review

of the

LHC CMS DETECTOR UPGRADE PROJECT

August 2013

EXECUTIVE SUMMARY

A Department of Energy/Office of Science (DOE/SC) review of the LHC CMS Detector Upgrade project was conducted at the Fermi National Accelerator Laboratory (Fermilab) on August 26-27, 2013. The review was conducted by the Office of Project Assessment and chaired by Kurt Fisher, Office of Project Assessment (OPA) at the request of Dr. Michael Procario, Director, Facilities Division, Office of High Energy Physics. The purpose of the review was to evaluate the CMS Upgrade project's progress and readiness to proceed to Critical Decision (CD) 1, including technical areas, the overall cost, schedule, and management aspects of the project.

The Committee found that U.S. CMS Upgrade project design is well advanced, in most cases beyond CD-1 maturity and has a sound basis for establishing the cost and schedule range. The U.S. CMS project team has the appropriate skills mix and management experience.

The Committee recommended that the project proceed to CD-1 after addressing the review recommendations and emphasized that the project team should continue to maintain close communications with the collaboration members and CERN to ensure that all interdependent activities proceed as planned.

Technical

The Committee noted that the replacement of the present photo-sensors with Silicon photo-multipliers (SiPMs) will allow increased granularity for the Hadron Calorimeter (HCAL) readout of the The Barrel and Endcap Hadron Calorimeter (HB/HE) within the physical, optical, and services constraints in the existing detector. The Charge Integration and Encode (QIE)10/QIE11 readout chip provides improved precision, sufficient dynamic range, and 0.5ns signal timing to allow identification of background signals. However, the production schedule is delayed by over a year following the Electronics System Review (ESR). The Committee judged that the collaboration should monitor this situation closely and consider options to mitigate this risk.

The Committee judged that it will be important to complete the planned test of a full Readout Box with both neutrons and hadrons. Monitoring the stability of the signal from a laser light pulser is planned and is an essential part of this test. It was noted that the current HCAL design uses a GigaBit Transceiver chip (GBTX) designed by CERN. The HCAL appears to be the only CMS detector system using this chip and delays in the schedule have already been encountered. This work needs to be closely monitored and alternatives considered.

The Committee acknowledges that the proposed Forward Pixel Detector (FPIX) upgrades implements significant cost reduction measures over the original detector, such as using a single module everywhere, going to six-inch wafers, and using a cost effective U.S. bump bonding vendor. The schedule identified installation of the FPIX in March 2017 during the proposed (not yet officially approved and scheduled) Extended Technical Stop. However, some component purchases are delayed to FY 2016 by limited funding in FY 2015, compressing schedule and reducing schedule contingency. A pilot run involving eight modules will be installed in 2014-2015, too late to inform the production, but early enough to review aspects of the installation and commissioning of the project in 2017.

For the scope of the Level 1 Trigger the phased approach to allow simultaneous operation of the current system and the new system mitigates many potential risks. There was not any significant increase in cost due to this concept. The Committee was informed that one of the issues identified with higher luminosity was the increased rate of single event upsets (SEUs). While the ability to directly reduce SEUs is outside the scope of this project, they have adequate plans for detecting and mitigating the effects of SEUs.

Cost and Schedule

It was noted that the cost contingency is time-phased in the project schedule and appears reasonable at 39% of to-go costs. However, the FY 2014 contingency appears low at 18%. The Committee judged that the cost estimate is sufficiently detailed and mature for this stage of the project. The Basis of Estimate (BOE) needs to be reviewed to ensure all backup documentation is included. The Committee's random sampling indicated some material quantities were not included. The schedule contingency appears reasonable for this stage of the project. The preliminary resource loaded schedule is well-developed and detailed but appears sub-optimal due to funding constraints.

Project Management

In the Committee's opinion the technical design of the CMS Upgrade project is well advanced, in most cases beyond CD-1 maturity. The design provides a good basis for establishing cost and schedule range, and therefore a good foundation for proceeding to CD-1 approval.

The U.S. CMS project team has excellent management experience and skill level, and is capable of producing a technical, cost and schedule baseline. Project governance in terms of

technical specifications and laboratory-university should be discussed in more detail at CD-2. The project objectives developed in coordination with the international CMS collaboration are very specifically defined. No substantive cost de-scope options were provided by CMS.

The project's KPPs (both objective and threshold) require optimization between CMS requirements, the U.S. CMS Operations Program and the project, which may not be ideal as currently defined (particularly in Trigger and HCAL).

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1. INTRODUCTION

The Compact Muon Solenoid (CMS) detector operates at the Large Hadron Collider (LHC) at CERN. The CMS Detector and the other general purpose detector ATLAS, were conceived to study proton-proton (and lead-lead) collisions at a centre-of-mass energy of 14 TeV (5.5 TeV nucleon-nucleon) and at luminosities up to 10^{34} cm^{-2} s^{-1} (10^{27} cm^{-2} s^{-1}). At the core of the CMS detector sits a high-magnetic-field and large-bore superconducting solenoid surrounding an all-silicon pixel and strip tracker, a lead-tungstate scintillating-crystals electromagnetic calorimeter, and a brass-scintillator sampling hadron calorimeter. The iron yoke of the flux-return is instrumented with four stations of muon detectors covering most of the 4π solid angle. Forward sampling calorimeters extend the pseudorapidity coverage to high values ($|\eta| \leq 5$) assuring very good hermeticity. The overall dimensions of the CMS detector are a length of 21.6 m, a diameter of 14.6 m, and a total weight of 12,500 tons.

The LHC provides access to new physical phenomena, some predicted by promising theoretical models, which would manifest themselves as heretofore unobserved states, including supersymmetric particles, manifestations of technicolor or extra dimensions, new gauge bosons, or evidence of compositeness of quarks or leptons. The recent discovery of a Higgs-like boson at CERN was a striking achievement, representing a multi-decade world-wide scientific campaign to understand the basic forces that govern our physical world. Its observation offers the opportunity to further study the origin of electroweak symmetry breaking and other elemental phenomena through precision measurements of the Higgs-like boson's properties, including its couplings to other particles, self-couplings, and rare decays.

The U.S. participation in the CMS experiment has been crucial to its success. The U.S. CMS collaboration, with 48 institutions, about 430 Ph.D. physicists, almost 250 graduate students, and nearly 200 engineers, technicians, and computer scientists is the largest national group in the CMS collaboration. U.S. groups have made significant contributions to nearly every aspect of the detector throughout all phases including construction, installation, and preparation for data-taking. Approximately 700 physicists from U.S. institutions conduct research as collaborators in CMS. They are supported as part of the DOE High Energy Physics research program; the National Science Foundation (NSF) Elementary Particle Physics Program; and the U.S. CMS Operations Program, which is jointly funded by DOE and NSF.

The high energy and luminosity available at the LHC offers the best opportunities for exploration of new physics beyond the Standard Model (SM) and for making precision measurements of properties of known phenomena. The LHC began operations in 2009 and has

delivered over 5 fb^{-1} of data to CMS with luminosities peaking at $3x10^{33}$ cm^{-2} s^{-1} at a center-of-mass energy of 7 TeV. This corresponds to one-third of its design luminosity and half of its design energy. In 2012, the LHC continued its operation at a slightly higher center-of-mass energy of 8 TeV and delivered an additional 20 fb^{-1} to each experiment, which allowed both the CMS and ATLAS experiments to discover the Higgs boson in July 2012. The repair of the splices in the LHC is being planned during a long shutdown in 2013-2014. This will allow the LHC to operate at its design parameters with a center of mass energy of approximately 14 TeV and peak luminosities of 10^{34} cm^{-2} s^{-1} when data taking resumes in 2015.

The next long shutdown is being planned for 2018 after which peak luminosities are expected to reach 2-3 x 10^{34} cm^{-2} s^{-1} corresponding to 50 to 80 interactions per crossing (pile-up) with 25 ns bunch spacing operation. In order to preserve adequate detector performance in this high luminosity environment, and hence the discovery potential, significant detector improvements are required. The LHC U.S. CMS Detector Upgrade Project (CMS Upgrade) is designed to enhance the detector capability for the high luminosity data run (Phase I) that is scheduled to begin in 2019. Upgrades to the accelerator during the preceding year-long shutdown in calendar year (CY) 2018 will result in delivered instantaneous luminosity that exceeds the original luminosity design specifications of 10^{34} $cm^{-2}s^{-1}$ by a factor of 2-3.

Upgrades are needed to three detectors where the U.S. played a leadership role in the original construction: the Pixelated Inner Tracking (Pixel) Detector, the Hadron Calorimeter (HCAL) Detector, and the Trigger (L1Trig).

- **Pixel:** The pixel detector plays a key role in the identification of primary vertices, secondary vertices, and secondary tracks. These elements are essential for the efficient identification of long-lived particles, such as *b* quarks, and for the search for new physics at the LHC. The upgrade of the Pixel detector is driven by radiation damage, caused by particles produced at the collision point. The upgraded Pixel Detector would replace the degraded present detector while being itself more radiation tolerant to future damage. In addition the upgrade is driven by the data loss at peak luminosity due to the increased number of tracks per crossing at the expected higher luminosities. The new detector and associated electronics greatly reduce the data loss problem and will enable the expanded tracking information to enhance track reconstruction. The implementation of the upgraded Pixel Detector would improve all aspects of the CMS tracking.

- **HCAL:** The HCAL upgrade will implement depth segmentation to cope with the higher luminosities. This is achieved by using a new photo-detector, the Silicon Photomultiplier (SiPM), that provides the high gain needed for segmentation; and new electronics, required to read-out the increased data stream and to provide enhanced information to the upgraded Regional Calorimeter Trigger (RCT). In

addition, the front end electronics provides precise timing information that is needed to handle “out-of-time” pileup that becomes important especially with 25 ns bunch spacing and is also crucial for rejecting various rare background events (from cosmic rays and machine background) in the search for new physics.

- **L1 Trig:** The present CMS trigger will need significant modifications to operate at the higher LHC luminosity. Due to the increased occupancy of each crossing the current L1 Trig system will experience degraded performance. Rebuilding the RCT and the Endcap Muon Trigger using new technologies addresses the peak instantaneous luminosity, high pile-up, and overall efficiency.

The excellent performance of the LHC in 2011 and 2012 has demonstrated its ability to deliver luminosity that exceeds expectations and it is therefore prudent to plan for higher than anticipated luminosity and pile-up conditions. The experience gained from ongoing analysis of data taken at lower luminosities, and from special high pile up runs produced by the LHC machine group, along with studies of simulated data for expected higher luminosities, has helped CMS plan for upgrades at the higher luminosity that will be needed to search for new physics with high efficiency. The overall CMS physics program can only succeed if the necessary upgrades are implemented; thereby ensuring that high efficiency for expected physics is maintained as energy and luminosity increase beyond current design.

The CMS detector including U.S. supplied components were not designed for and are not capable of handling the higher data rates of the LHC expected in 2018 and beyond without the planned upgrades.

As with the U.S. participation in the construction of the original CMS detector, the CMS Upgrade will be funded jointly by DOE and NSF. The scope will be divided between the agencies in a manner that minimizes the inter-agency dependencies. The fractional cost sharing will be approximately 75% DOE and 25% NSF. DOE approved Critical Decision (CD) 0, Approve Mission Need, for the CMS Upgrade on September 18, 2012.

In preparation for DOE approval of CD-1, Approve Alternative Selection and Cost Range an independent review was conducted on August 26-27, 2013 at Fermi National Accelerator Laboratory (Fermilab), in order to assess conceptual designs, proposed alternatives, and cost range. The review was conducted by the DOE Office of Project Assessment, with the participation of technical experts. The goal of the review was to evaluate whether the project is prepared to begin preliminary design. In addition to a general assessment of progress, current status, and the identification of potential issues, the Committee was asked to address the following specific items:

1. Conceptual Design: Is the conceptual design sound and likely to meet the MIE project's technical performance requirements most efficiently and effectively? Do the conceptual design report and supporting documentation adequately justify the stated cost range and project duration?

2. Project Scope: Are the project's scope and specifications sufficiently defined to support preliminary cost and schedule estimates?

3. Cost and Schedule: Are the cost and schedule estimates credible and realistic for this stage of the project? Do they include adequate scope, cost and schedule contingency?

4. Management and ES&H: Is the project being appropriately managed at this stage? Does the proposed project team have adequate management experience, design skills, and Laboratory support to produce a credible technical, cost and schedule baseline? Are ES&H aspects being properly addressed and are future plans sufficient given the projects current stage of development?

5. Documentation: Is the prerequisite documentation required for approval of CD-1 complete?

2. TECHNICAL STATUS

2.1 Hadron Calorimeter

2.1.1 Findings

The CMS Upgrade Hadron Calorimeter (HCAL) is proposed to allow the HB/HE calorimeter system to continue to perform at high efficiency in the expected higher than design luminosity of the LHC by replacing the current photosensors by SiPMs, and increasing the readout granularity and providing signal timing to mitigate the impact of pileup.

The proposed HCAL upgrade will mitigate the impact of radiation damage to the calorimeter scintillator for an integrated luminosity of 500fb-1by providing increased depth granularity and minimum ionizing particle (MIP) calibration to allow correction of the scintillator response as a function of time/dose.

The proposed upgrade will address backgrounds associated with the current photo-sensors and the sensitivity of the Hybrid Photo Detectors (HPD) to magnetic fields by replacing them with Silicon Photomultipliers and thereby also solve the problem of low and unstable gain in the present photo-sensors.

2.1.2 Comments

SiPMs are recently developed devices which have not been widely used in high radiation environments. U.S. CMS has done extensive testing and the results appear very promising. A number of vendors are available and the performance of their devices continues to improve but the performance is already at an acceptable level.

It will be important to complete the planned test of a full Readout Box in the CERN IRRAD facility with both neutrons and hadrons. Monitoring the stability of the signal from a laser light pulser is planned and is an essential part of this test. It is important that this test cover the MIP signal region to insure the in situ calibration capability of HB/HO.

It will also be important to complete the tests of a section of the calorimeter using these devices and the full readout chain, as planned at CERN in July 2015.

The planned system test in a high radiation environment is presently planned for summer 2015. This appears late compared to the planned construction start date. The collaboration should consider options for moving up this test, emphasizing in particular the high radiation environment aspect of it.

2.1.3 Recommendations

1. Include unit counts for deliverables in Basis of Estimate text narrative at Level 3.

2. Finalize the Conceptual Design Report.

3. Proceed with CD-1 approval.

2.2 Forward Pixel Detector

2.2.1 Findings

Without upgrades, the current CMS Pixel Detector will continue to lose efficiency after LS1 as the LHC luminosity exceeds 10^{34} cm^{-2} s^{-1}, seriously impacting physics performance. Specifically, track seeding, primary and secondary vertex reconstruction, and b-tagging will all be degraded.

The CMS Collaboration has developed an upgrade design to address this degradation, which is documented in the CMS technical proposal for an upgrade pixel system; the U.S. Conceptual Design Report (CDR) for the forward pixel (FPIX) upgrade is based on this document.

Performance and physics studies have been done for the full pixel system upgrade, barrel and forward, using the digital readout chip (PSI46dig). The impact of using the specialized higher rate chip (PSI46dig+), designed specifically for the Barrel Pixel (BPIX) inner barrel layer, was not presented.

The FPIX upgrade project involves only U.S. collaborators, no non-U.S. members; however, the project relies on CERN support for aspects that are contributed at no cost to the U.S. Also, the FPIX project relies on PSI to supply the Pixel Readout Chip, as well as test setups purchased by the FPIX project.

The FPIX upgrade project implements significant cost reduction measures compared to the original detector, such as using a single module everywhere, going to six-inch wafers, and using a cost effective U.S. bump bonding vendor.

The upgraded FPIX system comprises 44 million pixels on 672 modules, mounted on 12 half-disks; the upgrade increases the pixel layers from 3 to 4.

The schedule is designed for installation in March 2017. However, some component purchases are not made until FY 2016 due to limited funding in FY 2015. This late purchasing schedule compresses the remaining schedule and reduces schedule contingency. The FPIX installation goal of March 2017 would use the proposed (not yet officially approved and scheduled) Extended Technical Stop.

A pilot run involving eight modules will be installed in 2014-2015, too late to inform the pixel module production, but early enough to shake down aspects of the installation and commissioning of the project in 2017.

The FPIX upgrade project management did not initially present possible areas of scope contingency during the review, but in break out discussions possible scope contingency items were identified.

The risk analysis presented identifies three risks to the project. Several other risks have been considered and consolidated into this shortened list.

2.2.2 Comments

The FPIX project team brings a large experience base to the project based on their significant role in the original CMS pixel project and current CMS pixel system.

Given the performance objectives, the scope is appropriate and the conceptual design is complete. The Committeee looks forward to further performance studies, particularly with the higher rate inner barrel chip (PSI46dig+) included. The FPIX performance margin is not completely clear presently given the BPIX/FPIX integrated presentations of performance.

The design is well documented in the conceptual design report with reasonable cost estimates.

Building in scope contingency could have an impact on the half disk and half cylinder assembly sequences.

During review, additional risks beyond those presented were identified and discussed.

Even though the number of spares is large, the module yield assumption (85%) is aggressive.

The qualification period for initial production modules in 2015 (approximately 2-3 months) is not currently shown in the schedule.

Delayed purchase of components due to limited funding in FY 2015 adds schedule risk.

2.2.3 Recommendations

4. Plan to advance component purchases by applying contingency when (and if) it becomes available in order to protect schedule float.

5. Consider using a more conservative module yield assumption for CD-2.

6. Address in the schedule for CD-1 the addition of an explicit qualification time for the first batch of module production.

7. Consider exchanging flip-chip assemblies with European BPIX colleagues in 2014/2015, to assemble FPIX modules using BPIX flip chip assemblies in the module production ramp-up stage, and vice-versa.

8. Broaden risk analysis to ensure more comprehensive understanding for CD-2. As an example of an additional risk that should be considered, what if the pilot run reveals needed minor hardware modifications?

9. Subject to addressing the schedule issue of recommendation 6 above, the Forward Pixel Detector project is ready for CD-1 approval.

2.3 Level 1 Trigger

2.3.1 Findings

The Level 1 Trigger (L1 Trig) is needed to respond to the increased data rate from CMS, which will result from both the increase in energy and increase in luminosity. A consequence of the luminosity increase is the number of events per crossing also increases, which places additional demands on the trigger system.

There are two major components to the L1 Trig Upgrade. The first is to increase the momentum and angular resolution of the muon trigger and the second is to increase the granularity of the calorimeter trigger. The conceptual design is sound and likely to meet the project's (Major Item of Equipment of MIE) technical performance requirements most efficiently and effectively. The Conceptual Design Report (CDR) and supporting documentation adequately justify the stated cost range and project duration.

The phased approach to allow simultaneous operation of the current system and the new system mitigates many potential risks. There was not any significant increase in cost due to this concept.

Prototypes for all major boards have been made. The project's scope and specifications are sufficiently defined to support preliminary cost and schedule estimates.

The prerequisite documentation required for CD-1approval is complete.

2.3.2 Comments

In the plenary session presentation, one of the issues identified with higher luminosity was the increased rate of single event upsets. While the ability to directly reduce single event upsets (SEU) is outside the scope of this project, they have adequate plans for detecting and mitigating the effects of SEUs.

The infrastructure needed to build and test the electronics at each institution is well matched to the task. The number of boards and crates is matched to the test stand needs.

The performance of the L1 Trig system has been adequately measured with a combination of data from high intensity special runs and validated Monte Carlo simulation.

Legacy computer support to ensure that design tools are available for the duration of CMS operation needs to be implemented.

2.3.3 Recommendation

10. Proceed with CD-1 approval.

3. COST and SCHEDULE

3.1 Findings

CMS PROJECT STATUS as of July 2013		
Project Type	MIE	
CD-1	Planned: FY14Q1	Actual:
CD-2	Planned: FY14Q2	Actual:
CD-3	Planned: FY14Q4	Actual:
CD-4	Planned: FY20Q1	Actual:
TPC Percent Complete	Planned: 5 %	Actual: 5 %
TPC Cost to Date	$ 1.25M	
TPC Committed to Date	$ 1.375M	
TPC	$ 33.25M	
TEC	$ 25.75M	
Contingency Cost (w/Mgmt Reserve)	$ 9.0M	39% to go
Contingency Schedule on CD-4b	14 months	25%
CPI Cumulative	N/A	
SPI Cumulative	N/A	

The CMS Upgrade project prepared a detailed resource-loaded schedule with 2,243 activities and 428 milestones to achieve the project scope. The schedule includes appropriate NSF activities except for specific NSF pre-operations activities that extend beyond DOE Key Performance Parameters (KPP). There are no planning packages in the schedule. The project schedule includes 14 months of contingency to CD-4 (approximately 25%), as well as at least six-months schedule contingency to the needed by dates at CERN. Level 2 and Level 3 milestones include six months and three months of schedule contingency, respectively. Subproject schedules and critical paths are largely independent with a link at CD-3 and two linkages between HCAL and Trigger.

The proposed CD-1 cost range is $29.2-$35.9 million. The preliminary DOE Total Project Cost (TPC) is $33.2 million including $6.213 million estimate uncertainty contingency and $2.4 million risk-based contingency. Total project contingency is approximately $9 million (approximately 39% of to-go costs). The base estimate is 48% materials and services (M&S) and 52% labor. The NSF contribution is estimated at $13.5 million based on the proposal. Institution specific escalation rates are under negotiation.

The project includes $923K in scope contingency associated largely with the objective KPPs. Other opportunities were identified during the review.

3.2 Comments

The cost contingency is time-phased in the project schedule and appears reasonable at 39% of to-go costs. The FY 2014 contingency appears low at 18%. The cost estimate is sufficiently detailed and mature for this stage of the project. However, the BOE should be reviewed to ensure that all backup is included. A sampling indicated some material quantities were not included. The schedule contingency appears reasonable for this stage of the project. The preliminary resource loaded schedule is well-developed and detailed but appears sub-optimal due to funding constraints.

3.3 Recommendations

11. Prior to CD-1, review the BOE to ensure quantities are accurate.

12. Proceed with CD-1 approval.

4. MANAGEMENT

4.1 Findings

The CMS Upgrade project is part of a larger multi-national upgrade of the CMS detector to address increasing demands for LHC luminosity and “pileup”.

The project scope includes upgrades to three subsystems: the Hadron Calorimeter; Forward Pixels; and Trigger. These subsystems are jointly funded by DOE (MIE) and an NSF Cooperative Agreement (CA).

All the prerequisite documentation for CD-1 was available for review by the Committee, including, but not limited to:

- Preliminary Project Execution Plan (PEP)
- Risk Management Plan and Risk Registry
- ES&H Plan and Integrated Safety Management (ISM)
- All necessary National Environmental Policy Act (NEPA) documentation.

The CMS Upgrade preliminary PEP includes a defined set of threshold KPPs (minimum) and objective KPPs (desired).

An Integrated Project Team (IPT) has been in place since December 2012 and meets biweekly. A Joint Oversight Group (JOG) has been established to coordinate shared DOE and NSF responsibilities.

Fermilab is the lead U.S. laboratory responsible for the management and coordination of the CMS Upgrade effort and its 30 participating U.S. universities.

The U.S. CMS Project Manager (Joel Butler) and Deputy Project Manager (Erik Gottschalk) plan to transition out of their positions after CD-1. Fermilab has recently hired a new U.S. CMS Project Manager (Steve Nahn) who will transition into the lead role, and a Deputy Project Manager is being recruited. Aaron Dominguez (NSF-funded) will continue to serve as Deputy Project Manager and will be responsible for managing the NSF institutions and contributions.

A five-year NSF proposal for $13.5 million has been submitted for the Phase-1 upgrades of the FPIX, HCAL, and L1 Trig and is under review.

Critical documentation is controlled via CMS document management system (docdb).

4.2 Comments

Overall, the project is making good progress. The technical design of the CMS Upgrade project is well advanced, and in many areas beyond CD-1 maturity. The maturity of the design provides a good basis for establishing cost and schedule range, and therefore a good foundation for proceeding to CD-1 approval. It should be noted that early R&D efforts within the U.S. CMS Operations Program have allowed the upgrade design to rapidly converge on a sound technical approach.

The CMS Upgrade project team has excellent management experience and skill level and is capable of producing a technical, cost, and schedule baseline.

The project governance, particularly around the management of technical specifications and laboratory-university oversight and coordination was not discussed in sufficient detail at the CD-1 review. This should be further refined and discussed in more detail at the CD-2 review.

The project objectives developed in coordination with the international CMS collaboration are very specifically defined. No substantive cost descope options were identified by U.S. CMS.

The project's KPPs (both objective and threshold) require optimization between CMS requirements, the U.S. CMS Operations Program and the project, which may not be ideal as currently defined (particularly in L1Trig and HCAL). These should be revisited prior to CD-2.

The PEP describes system and value engineering processes, which do not reflect actual CMS practice. Consider implementing whatever system and value engineering processes are described then document the processes being performed.

4.3 Recommendations

13. Prior to CD-2, work closely with DOE, NSF and CMS, to refine the project's KPPs to find the appropriate balance between the CMS Upgrade and U.S. CMS Operations.

14. Prior to CD-2, work closely with DOE and NSF, in considering a split CD-3a/b so that long-lead procurements can be ordered early while the final design continues or, in the case that the designs are all well in hand, a combined CD-2/3 to ensure the same.

15. Prior to CD-2, update the governance plan for the scientific workforce (as needed by the project), and Partner/University oversight in the Project Management Plan (PMP).

16. Prior to CD-2, consider updating the PEP to address comments on value engineering and system engineering.

17. Prior to CD-2, the BOE should be revisited to adequately address the complexities of the respective product at each level of integration, as well as allow for potential volatility in manufacturing costs (particularly in out-years).

18. Prior to CD-1, update CD-1 documentation to reflect recommendations of this report, as well as typographical errors (e.g., Table 1 of the PMP), and finalize the CDR.

19. Proceed with CD-1 approval.

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APPENDIX A

CHARGE MEMORANDUM

Department of Energy
Office of Science
Washington, DC 20585

MAY 30 2013

MEMORANDUM FOR DANIEL LEHMAN, DIRECTOR
OFFICE OF PROJECT ASSESSMENT

FROM: MICHAEL PROCARIO
DIRECTOR, FACILITIES DIVISION
OFFICE OF HIGH ENERGY PHYSICS

SUBJECT: REQUEST TO CONDUCT CD-1 REVIEW OF THE LHC-CMS DETECTOR UPGRADE PROJECT

I request that you conduct an Independent Project Review of the "LHC-CMS Detector Upgrade" MIE Project on August, 26-27, 2013 at Fermilab, in order to assess conceptual designs, proposed alternatives, and cost range in preparation for Critical Decision CD-1. The purpose of this review is to determine if the LHC CMS Detector Upgrade Project has fulfilled the requirements for CD-1, "*Approve Alternative Selection and Cost Range*" and if it is ready to request CD-1 approval.

The objective of the LHC CMS Detector Upgrade Project is to enable CMS to fully exploit the physics opportunities offered by the LHC for exploration of new physics and to make precision measurements of properties of known phenomena. The "LHC CMS Detector Upgrade Project" received CD-0, "*Approve Mission Need*" on September 18, 2012, with a preliminary Total Project Cost in the range $22 million to $34 million and estimated completion date of December 2018. By the end of 2012, the LHC delivered about 25 fb^{-1} of data, to the CMS experiment. Planned upgrades to the LHC to be installed in 2018 will produce 2-3 times the instantaneous luminosity currently delivered by the machine. Upgrades are needed to the Pixelated Inner Tracking (Pixel) Detector, the Hadron Calorimeter (HCAL) Detector and Trigger to take advantage of the increased luminosity.

In your review, please evaluate whether the Project is prepared to begin preliminary design. In addition to a general assessment of progress, current status and the identification of potential issues, the committee should address the following specific items:

1. Conceptual Design: is the conceptual design sound and likely to meet the MIE project's technical performance requirements most efficiently and effectively? Do the conceptual design report and supporting documentation adequately justify the stated cost range and project duration?
2. Project Scope: Are the project's scope and specifications sufficiently defined to support preliminary cost and schedule estimates?
3. Cost and Schedule: are the cost and schedule estimates credible and realistic for this stage of the project? Do they include adequate scope, cost and schedule contingency?

4. Management and ES&H: Is the project being appropriately managed at this stage? Does the proposed project team have adequate management experience, design skills, and Laboratory support to produce a credible technical, cost and schedule baseline? Are ES&H aspects being properly addressed and are future plans sufficient given the projects current stage of development?
5. Documentation: Is the prerequisite documentation required for approval of CD-1 complete?

Dr. Simona Rolli is the program manager for the LHC-CMS Detector Upgrade Project in this office and will serve as the OHEP contact person for the review.

We appreciate your assistance in this matter. As you know, these reviews play an important role in our program. I look forward to receiving your Committee's report, within 60 days of the review's conclusion.

Sincerely,

Michael Procario, Director
Facilities Division
for High Energy Physics

cc: Patricia Dehmer, SC-2
James Siegrist, SC-25
Simona Rolli, SC-25
Steven Webster, FNAL Site Office
Pier Oddone, FNAL Director

APPENDIX B

REVIEW PARTICIPANTS

Department of Energy / Office of Science Review (CD-1) of the
LHC CMS Upgrade Project
August 26-27, 2013

Kurt Fisher, DOE/SC, Chairperson

SC1
HCal—Hadron Calorimeter (WBS 1.2)

* Jim Proudfoot, ANL
Jim Pilcher, U. of Chicago

SC2
Forward Pixel Detector (WBS 1.3)

* Jim Brau, Oregon
Maurice Garcia-Sciveres, LBNL

SC3
Level 1 Trigger (WBS 1.4)

* Myron Campbell, U. of Michigan
Charlie Young, SLAC
Luciano Ristori, FNAL

SC4
Cost and Schedule

* Ethan Merrill, DOE/SC
Gail Penny, DOE/BHSO

SC5
Project Management (WBS 1.1)

* Mark Reichanadter, SLAC
Michael Levi, LBNL
Mark Palmer, FNAL

Observers

Jim Siegrist, DOE/SC
Mike Procario, DOE/SC
Simona Rolli, DOE/SC
Pepin Carolan, DOE/FSO
Steve Webster, DOE/FSO

LEGEND

SC Subcommittee
* Chairperson

Count: 13 (excluding observers)

APPENDIX C

REVIEW AGENDA

Department of Energy / Office of Science Review (CD-1) of the
LHC CMS Detector Upgrade Project
August 26-27, 2013

AGENDA

Monday, August 26, 2013—Wilson Hall Comitium and One West

8:00 am	DOE Executive Session—Comitium (WH2SE)	Fisher
9:00 am	Welcome—One West (WH1W)	TBD
9:10 am	CMS Upgrade Project Overview and Highlights	Butler
9:30 am	CMS Upgrade Project Management: Resources, Planning and Priorities	Gottschalk
10:00 am	Break	
10:20 am	HCal—Hadron Calorimeter (WBS 1.2)	Mans
11:00 am	Forward Pixel Detector (WBS 1.3)	Johns
11:40 am	Level 1 Trigger (WBS 1.4)	Smith
12:20 pm	Lunch	
1:00 pm	Subcommittee Breakout Sessions	
	— Management, Cost and Schedule	Comitium (WH2SE)
	— HCal	Black Hole (WH2NW)
	— Pixel	Snake Pit (WH2SE)
	— Trigger	Racetrack (WH7X)
3:30 pm	Break	
4:00 pm	Subcommittee Executive Sessions	
5:00 pm	DOE Full Committee Executive Session	Fisher
6:30 pm	Adjourn	

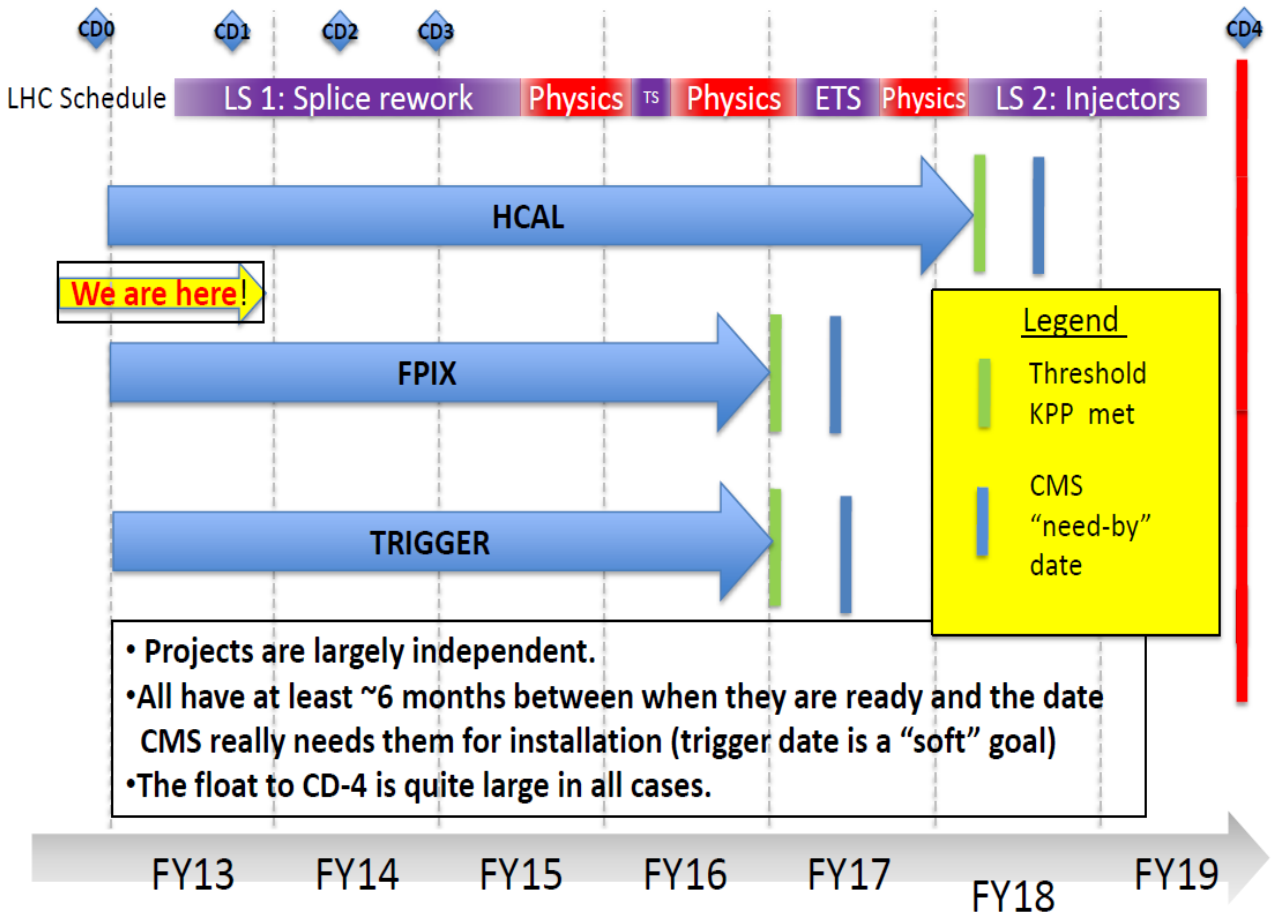
Tuesday, August 27, 2013

8:00 am	Subcommittee Breakout Sessions	
11:00 am	Break	
11:30 am	Subcommittee Breakout Sessions	
12:30 pm	Lunch	
1:30 pm	DOE Executive Session Dry Run—Comitium	Fisher
3:00 pm	Closeout Presentation to CMS Upgrade Project Team—One West	Fisher
4:00 pm	Adjourn	

APPENDIX D

SCHEDULE CHART

U.S. CMS Preliminary Project Schedule



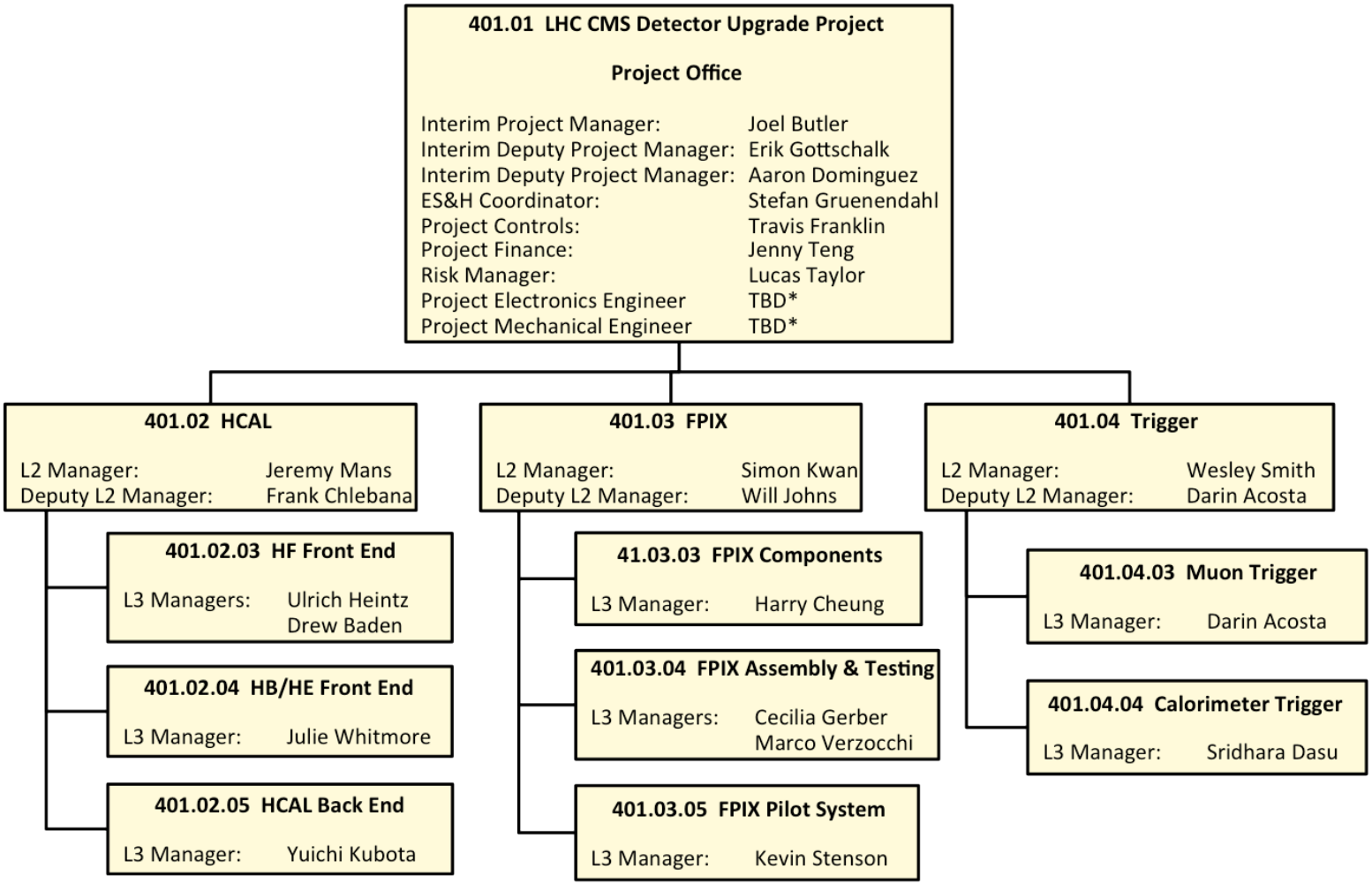
APPENDIX E

FUNDING TABLE

U.S. CMS Pre-CD-1 Funding Profile ($M)

Fiscal Year beginning w/CD-0	2013	2014	2015	2016	2017	2018	2019	Total
OPC - R&D								0
OPC - Design	1.5	6						7.5
TEC - MIE			7.75	9.5	8.5			25.75
TEC - Construction								0
Total Project Cost	1.5	6	7.75	9.5	8.5	0	0	33.25

APPENDIX F

MANAGEMENT CHART

CMS Upgrade Organization