Department of Energy
Office of Science
Washington, DC 20585

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MEMORANDUM FOR: JAMES SIEGRIST
ASSOCIATE DIRECTOR
OF THE OFFICE OF SCIENCE
FOR HIGH ENERGY PHYSICS

FROM: STEPHEN W. MEADOR
DIRECTOR
OFFICE OF PROJECT ASSESSMENT

SUBJECT: Final Report on the DOE/SC Review of the CMS-U Project, October 2015

Attached for your consideration and use is the final report on the Department of Energy/Office of Science review of the CMS Detector Upgrade (CMS-U) project. The CMS-U review was conducted on October 14-15, 2015, at the Fermi National Accelerator Laboratory in Batavia, Illinois.

If you have any questions or would like to discuss the report further, please contact me.

Attachment

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U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Project Assessment
Review Report on the

LHC CMS Detector Upgrade Project

at Fermi National Accelerator Laboratory

October 2015

EXECUTIVE SUMMARY

A Department of Energy/Office of Science (DOE/SC) review of the Compact Muon Solenoid (CMS) Detector Upgrade project was conducted on October 16-17, 2015 at Fermi National Accelerator Laboratory. The review was conducted by the Office of Project Assessment (OPA), and chaired by Kurt Fisher, OPA, at the request of Michael Procario, Director, Facilities Division for High Energy Physics. The purpose of the review was to evaluate the CMS-U project's progress since the approval of Critical Decision (CD) 2/3, Approve Performance Baseline and Start of Construction, including technical aspects, the overall cost, schedule, and management aspects.

The Committee found that the CMS-U project design proceeded well since the CD-2/3 review. The U.S. CMS-U project team has the appropriate skills mix and management experience, ans made significant advancements since the previous review.

Technical

Hadron Calorimeter (HCAL)

The Hadron Calorimeter (HCAL) schedule is driven by the needs of the CMS experiment, and the desire to both spread-out the installation work in the cavern and to provide CMS the best possible instrument on the earliest timescale.

The complete HCAL Forward (HF) work will not be possible in the upcoming shutdown, because [international] CMS management does not believe the photomultiplier tube box can be reworked in this window. In addition, the late Versatile Twin-Transmitter **(**VTTx**)** delivery schedule from CERN makes it likely that other tasks will slip as well. This will have trickle-down effects, such as delaying and shortening the time for system integration. None of this puts CD-4 at risk, and even in the worst case, all three subtasks can complete their installation during Long Shutdown 2.

Forward Pixel Detector (FPIX)

The plan for the Forward Pixel Detector (FPIX) sub-project will complete the construction of the FPIX hardware to be installed at CERN in January 2017 during the Extended Technical Stop.

The FPIX pilot detector, consisting of eight modules installed in CMS with the current pixel detector, revealed a serious jitter issue that the project team has worked to overcome. This has resulted in delays in port card production and a new Token Bit Manager (TBM) fabrication. In addition, testing of the TBM has been extended.

The production of High Density Interconnects (HDI) has experienced a low yield rate. Recent improvements in yield are encouraging. This is a now a critical component in the schedule. The FPIX project team has focused attention on strategies to deal with this problem including the enlistment of multiple vendors.

The presented plan, to produce five full half cylinders is very likely to allow for the successful completion of the FPIX Objective Key Performance Parameters (KPPs); however, completion in time for the installation during the extended technical stop is less certain. Additional electronics engineering may help alleviate this concern.

The lack of spare mechanical components in the current plan provides little capability to respond to mechanical failures that could result in significant schedule delay. The Committee recommended that the FPIX sub-project team should proceed urgently with multiple HDI vendor procurement.

Level 1 Trigger (L1T)

The physics motivation for the Level 1 Trigger (L1T) upgrade continues to be strong and the hardware production is largely complete. Significant progress has been made on firmware and software. CMS is currently running in-situ tests of vertical slices in parallel with the legacy system. Impressive progress has been made in the last year, and project is in excellent shape overall. The L1T project team should update the risk registry to include MTF7 board from the first production run, and continue monitoring remaining firmware and software tasks.

Cost and Schedule

The total DOE funding profile is $33.217 million. The cost contingency is $5.773 million or 48.1 % of the "to-go" work. This equates to 33% on costs to go. The CD-4 date is planned for December 2019.

There are ten months of schedule contingency to CD-4. Schedule contingency can be increased by an additional five months if the Objective KPP for HCAL is dropped from the project plan. The Project Manager conducts an Estimate at Completion (EAC) analysis on a monthly basis. Variance Analysis Reports (VARs) are detailed and provide useful information to project team. The Corrective Action Log tracks all corrective actions to closure.

Management

The Committee noted that the project has been making excellent progress since CD-2/3, and its progress and status is well quantified, traceable, and on track for CD-4. Where specific challenges exist, the individual sub-projects are pursuing mitigation strategies and executing a well-defined Baseline Change Request (BCR) process, as necessary. A sufficient amount of project contingency remains, and there is now room in the budget to more aggressively approach contingency to both ensure timely project completion, and to work to optimize overall CMS physics output.

Project risks appear to be under control and active risks are being effectively managed.
The risk assessment is being maintained to reflect the current project status, and no risks are apparent, which could seriously jeopardize any of the Threshold KPPs for the project.

The interdependence of the National Science Foundation (NSF) and DOE deliverables is well understood, and the project is being managed with close attention being paid to each agency's requirements.

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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 (A Toroidal LHC Apparatus), 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 discovery in 2012 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 Department of Energy (DOE) High Energy Physics (HEP) 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 $3\text{x}10^{33}$ 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 announce the discovery of the Higgs boson in July 2012. The repair of the splices in the LHC was performed during a Long Shutdown in 2013-2014. This now allows 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} , with data taking having resumed in 2015.

The next Long Shutdown is being planned for 2019-2020 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 (CMS-U) project is designed to enhance the detector capability for the high luminosity data run (Phase I) that is scheduled to begin in 2021. Upgrades to the accelerator during the preceding shutdown will result in delivered instantaneous luminosity that exceeds the original luminosity design specifications of 10^{34} $cm^{-2}s^{-1}$ by a factor of two or three.

Upgrades are needed to three detectors where the U.S. played a leadership role in the original construction: the Forward Pixel Detector (FPIX), the Hadron Calorimeter (HCAL) Detector, and the Trigger (L1T).

Pixelated Inner Tracking (Pixel) Detector—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 FPIX is driven by radiation damage, caused by particles produced at the collision point. The upgraded FPIX 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 FPIX would improve all aspects of the CMS tracking.

Hadron Calorimeter (HCAL) Detector—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" pile-up 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.

Level 1 Trigger (L1T)—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 L1T 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 2020 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% from DOE and 25% from NSF. DOE approved Critical Decision (CD) 0, Approve Mission Need, for the CMS Upgrade on September 18, 2012, and CD-1, Approve Alternative Selection and Cost Range, on October 17, 2013; CD-2/3, Approve Performance Baseline and Start of Construction, on November 12, 2014.

As part of project oversight, a Project Independent Review was held at Fermilab on October 14-15, 2015. The review was conducted by the DOE Office of Project Assessment, with the participation of technical experts.

2. TECHNICAL SYSTEMS EVALUATIONS

2.1 Hadron Calorimeter

2.1.1 Findings

Hadron Calorimeter (WBS 401.02)

This project has three subprojects: replacing the HF (forward) front-end electronics, replacing the HE (endcap) and HB (barrel) front-ends, including photosensors, and replacing the Hadron Calorimeter (HCAL) counting room electronics. The project is scheduled so that necessary detector access occurs during the next technical stop (the 2016 Year End Technical Stop) for the HF, the extended technical stop for the HE and Long Shutdown 2 for the HB.

A key element for multiple subprojects is the Versatile Twin-Transmitter (VTTx) optical links, produced at CERN. While some units have been delivered, the earliest possible date for bulk delivery is now the end of October, which is close to the need-by date to meet this schedule.

HF Front-End (WBS 401.02.03)

This WBS is planned to replace the front-end electronics of the HF calorimeter to improve the rejection of spurious signals, through additional timing information and segmented photomultiplier tube (PMT) signals. This upgrade also improves the radiation tolerance of the electronics and increases the readout bandwidth. The installation of the upgrade is currently planned for the year-end-technical-stop (YETS) of 2015-16. CMS-U does not support the rework the PMT box of the HF detector before 2016-17. This is needed to take full advantage of the front-end electronics upgrade.

HB and HE Front-Ends (WBS 401.02.04)

The upgrade to the HE and HB systems will eliminate high amplitude noise and improve the calibration stability. A system of silicon photomultipliers (SiPMs) with associated readout electronics will be installed on the detector. This upgrade will also provide improved segmentation information from the calorimeters. The vendor for the HE SiPMs has been chosen and production is underway. A substantial preproduction system has been built and performance demonstrated in a test beam study. The electronics use the VTTx part but there is more time available for delivery than in the case of the HF calorimeter. The plans call for installation of the HE front-end upgrade during the extended YETS of 2016-17.

The schedule calls for installation of the HB front-end upgrade in 2019. Since the HB calorimeter is planned to serve as part of the Phase 2 detector and because radiation requirements for the HB SiPMs are more severe than for HE, more attention is being given to the radiation tolerance of the SiPMs for HB. Interactions continue with vendors and the preproduction devices are planned for January 2017.

HCAL Back-End (WBS 401.02.05)

The back-end electronics are located in an underground counting room and receives digital signals from the on-detector front-end electronics. It is identical for the HF, HE, and HB calorimeters. A version using a link speed of 1.6 Gbps is now installed in CMS for use with the existing calorimeter systems, while a version with a link speed of 4.8 Gbps is in an advanced state of development. The difference is only in firmware. Over 80% of the work has been completed.

2.1.2 Comments

Hadron Calorimeter (WBS 401.02)

The schedule is driven by the needs of the CMS experiment, and the desire to both spread out the installation work in the cavern and to provide CMS the best possible instrument on the earliest timescale. Meeting this schedule will automatically meet the CD-4 milestone well before the schedule.

The complete HF work will not be possible in the upcoming shutdown, because [international] CMS management does not believe the PMT Box can be reworked in this window. In addition, the late VTTx delivery schedule from CERN makes it likely that other tasks will slip as well. This will have a trickle-down effect, such as delaying and shortening the time for system integration. None of this puts CD-4 at risk, and even in the worst case, all three subtasks can complete their installation during Long Shutdown 2.

Should the VTTx delivery slip again, the HCAL schedule will be substantially impacted. U.S. CMS management should continue to work with CERN to avoid this. If this becomes unavoidable, the new schedule will likely have later component installation.

Subproject management makes good use of Project Management tools and has used and is using them to actively manage the project and not merely as a report-writing tool.

HF Front End (WBS 401.02.03)

As noted in earlier reviews, the goals of this HF upgrade are worthwhile. Good progress is being made to prepare the hardware. Unfortunately an important element of the front-end boards, the VTTx chip used for the optical output link, has not yet been delivered in quantity. This may delay the burn-in and system testing. The goal of installation during the upcoming YETS may be at risk. Installation of the hardware during the YETS of 2016-17 is likely if it cannot be done in 2015-16. This would not place either the Threshold or Objective Key Performance Parameters (KPPs) at risk.

HB and HE Front Ends (WBS 401.02.04)

Good progress is being made on the HE front-end system. The project team is on track to meet cost and schedule milestones, as well as installation windows. The HB SiPMs are still in a development stage but the downstream readout electronics is identical to that of the HE system.

The Committee judged that there is sufficient time and good justification for optimizing the choice of SiPMs.

HCAL Back End (WBS 401.02.05)

Good progress is being made on the back-end electronics. The group is on track to meet cost and schedule milestones. The Committee supported the strategy of installing the new system in parallel with the existing system.

2.1.3 Recommendations

None.

2.2 Forward Pixel Detector

2.2.1 Findings

The target of the Forward Pixel Detector (FPIX) project is to complete the construction of the FPIX hardware to be installed at CERN in January 2017 during the Extended Technical Stop.

The FPIX pilot detector, consisting of 8 modules installed in CMS with the current pixel detector, revealed a serious jitter issue that the project team has worked to overcome. This has resulted in delays in port card production and a new Token Bit Manager (TBM) fabrication. In addition testing of the TBM has been extended.

The yield of the High Density Interconnects (HDI) is low from the existing vendor. Alternate vendors have been solicited and batches ordered for qualification. This remains a schedule risk, nevertheless it is expected that the HDI production rate can be brought to necessary levels using alternate vendors. The next batch from the first vendor is due in late October. The timescale of the alternate vendors including HDI qualification is longer.

There are delays in the fabrication of the module and system components that show a shift of approximately three months in the availability of a first production full module/electronics chain. This delay is mitigated by the incorporation of a faster production throughput that should, if realized, allow the delivery to meet the schedule. The first half cylinder is now expected to be completed in December.

The yields of the readout chips and other custom ASICS already fabricated, as well as the flip chip assembly process appear to be sufficient to meet the required number of assembled modules and half disks assuming the presented yield expectations.

The mechanics budget has increased by $500K. This is attributed to a known under-estimate that was not propagated into the baseline cost and schedule documentation as estimates were not yet available. After the new work was added to the baseline through Baseline Change Control, the mechanics has been performing to the new schedule.

The FPIX project critical path now runs through the modules/electronics rather than through the mechanics, as was the case during CD-2/3 review, even though the mechanics themselves have been lagging behind schedule.

There are three months of reported schedule contingency between the FPIX scheduled completion and the CERN "need-by" date in the optimistic scenario. The realistic scenario shows only one month. There are opportunities for improvement as the electronics issues are resolved.

The available contingency, based on the analysis presented, appears to be sufficient to complete the FPIX project successfully, if the delays that have been experienced so far do not continue.

2.2.2 Comments

Near-term Level 4 and 5 milestones are mostly shown as late by a few months. This is explained as both out of order fabrication (as measured by the existing baseline) and real delays. The schedule and build rates as presented shows that there is time to meet the delivery date. This new plan should be monitored carefully as it pushes important system integration milestones later into the schedule where there is less time to deal with any problems that arise.

The production of High Density Interconnects (HDI) has experienced a low yield. Recent improvements in yield are encouraging. This is now a critical component in the schedule. The FPIX team has focused attention on strategies to deal with this problem including the enlistment of multiple vendors.

The presented plan to produce five, full half cylinders is very likely to allow for the successful completion of the FPIX Objective KPP; however, completion in time for the installation during the extended technical stop is less certain. Additional electronics engineering may help alleviate this concern.

The lack of spare mechanical components in the current plan provides little capability to respond to mechanical failures that could result in significant schedule delay.

The estimate to complete (ETC) has been updated to reflect the findings above and appears to be complete and credible.

The Baseline Change Requests (BCRs) that are planned appear to be reasonable and fit with the newly presented plan for meeting the delivery schedule.

The risks appear to have been properly assessed and mitigation plans are in place.

The bump bonding contract has been delayed due to issues in contract arrangements. This should be resolved as soon as possible. The critical path runs through the module assembly.

It appears that there may be some flexibility in the scheduling of the extended technical stop. The project may wish to coordinate with the Barrel pixels and CMS and CERN management to provide schedule adjustments if necessary and possible.

2.2.3 Recommendations

1. Proceed urgently with multiple HDI vendor procurement.

2. Proceed with the fabrication of an increased number of spare mechanical components.

3. Increase engineering resources dedicated to the electronics.

2.3 Level 1 Trigger

2.3.1 Findings

The Level 1 Trigger upgrade is well motivated. Given the increases in LHC beam energy, luminosity and pileup, the legacy trigger system would need very high thresholds in order to have a tolerable trigger rate. The upgraded trigger restores the physics performance of the CMS detector with improved momentum resolution of the muon trigger and increased processing granularity of the calorimeter trigger.

Hardware production is largely complete, and many components have been installed and checked out. For example, all optical Serial Link Boards (oSLB) and optical Receiver Mezzanines (oRM) have been connected in the electromagnetic calorimeter, optical splitters are in place driving both the legacy HTR and the new uHTR in HCAL, and EMUTF production is complete.

There has been significant progress on firmware and software as well, and vertical slices of both the calorimeter and the muon triggers are being operated in situ in parallel with the legacy trigger system. The Stage 1 calorimeter upgrade has progressed sufficiently that the legacy GCT was retired in August. The muon trigger system has successfully transmitted muon candidates during a recent LHC fill to the uGMT. Rates are as expected, although detailed comparisons of events between MTF7 and uGMT are still to be made.

Fourteen MTF7 boards in the initial production run of twenty boards passed quality control. They are sufficient for the muon trigger and another production run is being launched to provide spares.

This Threshold KPP is expected to be accomplished by September 2016, three months ahead of the milestone date. The Objective KPP is expected to be complete by March 2017, consistent with the milestone date.

2.3.2 Comments

Progress since CD-2/3 has been impressive, and the Level 1 Trigger project is in excellent shape overall.

The failure of six boards in the first production run of twenty MTF7 board does not by itself jeopardize the project since they will be replaced in a second production run. However, there may be latent issues with the accepted boards after extensive use. The risk registry will be updated to track this topic.

The remaining tasks are primarily firmware and software in nature. The project should continue to monitor these tasks closely to ensure on-time completion of the project.

The ETC is credible, and the performance metrics for the current year are appropriate. The risk registry is accurate pending completion of MTF7 tem above. Contingency is adequate, and there are no significant risks.

2.3.3 Recommendations

None.

3. COST and SCHEDULE

3.1 Findings

PROJECT STATUS (as of Aug 2015)		
Project Type	Major Item of Equipment	
CD-1	Planned: 10/18/2013	Actual: 10/17/2013
CD-2	Planned: 11/12/2014	Actual: 11/12/2014
CD-3	Planned: 11/13/2014	Actual: 11/12/2014
CD-4	Planned: 12/30/2019	Actual:
TPC Percent Complete	Planned: 58.8 %	Actual: 55.4 %
TPC Cost to Date - as of Aug 2015	$ 15,069K	
TPC Committed to Date	$ 16,003K	
TPC	$ 33,217K	
TEC [OPC & TEC was revised post-CD2/3]	$ 21,516K	
Contingency Cost (w/Mgmt Reserve)	$ 5,773K	48.1 % to go
Contingency Schedule on CD-4b	10 months	19.2 %
CPI Cumulative	0.99	
SPI Cumulative	0.94	

The CMS-U Critical Decision (CD) 0, Approve Mission Need was obtained on August 28, 2012; CD-1, Approve Alternative Selection and Cost Range on October 17, 2013; and CD-2/3, Approve Performance Baseline and Start of Construction on November 12, 2014. The project's Total Project Cost (TPC) is $33.217 million, which includes $5.773 million contingency or 48% on the cost to go. The cost contingency is comprised of cost estimate uncertainty ($4.491 million) and risk based contingency ($1.181 million). The project is currently 55% complete. The proposed funding profile for the estimated TPC is shown in Table 3-1. The DOE budget will rise from $7.5 million in FY 2015 to a peak level of $9.5 million in FY 2016. The National Science Foundation (NSF) is co-funding the project, contributing 26.5% of the project's $45.200 million combined total TPC cost.

Table 3-1. DOE Funding Profile

Fiscal Year	2013	2014	2015	2016	2017	2018	2019	Total
OPC - Design	1.50	6.25	3.75					12.00
TEC - MIE			3.75	9.50	8.00			21.25
Total DOE	1.50	6.25	7.50	9.50	8.00	0.00	0.00	33.25

The Resource Loaded Schedule has 3,727 activities and 613 milestones. In FY 2015, half of the project tasks and a third of the milestones were completed. There are ten months of schedule contingency to CD-4. Schedule contingency can be increased by additional five months if the Objective KPP for HCAL is dropped from the project plan. Change requests are being managed, and to date, there have been 85 BCRs processed (approved or rejected) and 37 BCRs processed since the CD-2/3 ESAAB.

Project status reporting and performance monitoring are in place and operating. The monthly monitoring output consist of a detailed monthly report, Earned Value Management (EVM) report (CPR1), and Estimate at Completion (EAC) Analysis. The monthly report covers project milestone status, EVM, contingency management, configuration management, and change control board actions, and discussion of any other issues relevant to project performance. Project activities are statused each month by the Control Account Managers (CAMs) and Level-2 system managers using a standardized turn-around report. Variance Analysis Reports (VARs) are produced for control accounts that exceed established higher level threshold limits, and describe variance, impact, and corrective action.

Risk management is in place and operating. Since baselining the project at CD-2/3, there were seven opportunities realized and four retired, and there were nine threats managed and 24 retired. About $1 million of cost contingency has been used since change control inception on $17.7 million (51% of project completion). The current risk registry consists of 35 threats (7 ranked high) and 12 opportunities. The value of current risks is $1,181 thousand at a Monte Carlo summation of 90% confidence level. The project has $5,773 thousand of cost contingency available to cover current risks and the remaining $12 million of cost to go.

Key project management documents were made available for this review including: Responsibility Assignment Matrix (RAM), Work Authorization Documents (WADs), Contract Performance Report (CPR) Format 1, VARs. The RAM consists of 10 CAMs responsible for 14 control accounts. The WADs that formalize the CAMs scope of work and resources are issued to each CAM.

The project has reset the practice baseline at CD-2/3 approval to aligned the Baseline Cost of Work Scheduled (BCWS), Baseline Cost of Work Performed (BCWP) and Actual Cost of Work Performed (ACWP). Known as SPA-reset, this action was documented in BCR57. FNAL's EVM System was recertified following a successful EVMS Surveillance Review conducted in December 2014.

3.2 Comments

Project status reporting and performance monitoring are adequate for user needs. The Estimate to Complete (ETC) is updated and credible. Monthly EAC Analysis were provided, the most recent analysis dated August 2015 concluded that the difference between EAC and Budget at Completion (BAC) is less than 1% and an indicator that the total cost should not surpass the total funding. It is clear the Project Manager and the Integrated Project Team are paying close attention to the EVM and taking corrective actions when needed. The EAC is part of the monthly reporting to DOE. The Project Manager conducts an EAC Analysis on a monthly basis.

VARs are detailed and provide useful information to project team. The Corrective Action Log tracks all corrective actions to closure. Each CAM has a clear understanding of their subsystem scope and has defined goals and metrics. The project team is knowledgeable and the CAMs have ownership of their schedules. The system managers are familiar with concepts of early completion date and schedule contingency. In August 2015 the cumulative schedule variance of FPIX Component-Electronics (WBS 401.03.03.02) is -16% and concerning. However, the project team is confident that the completion of the detector will not be affected.

The current cost and schedule are consistent with the baseline. However, the Project Execution Plan (PEP) should be revised to reflect the current Other Project Costs (OPC) and Total Estimate Costs (TEC) distribution. The TEC presented during the review is $286 thousand higher than the recorded TEC in the PEP as a result of some activities being re-planned due to the FY 2015 continuing resolution. Minor data inconsistencies exist between the information provided to the Committee and the August 2015 monthly report, which should be reconciled. The financial status of the project is accurately represented in the most recent monthly reports. The DOE program office receives a tailored monthly report with focused coverage.

The risk analysis is being updated to accurately reflect the risks that remain in completing the project. The project has an effective and detailed risk management process. Based on Monte Carlo simulations, the cost and schedule contingencies appear more than adequate to cover remaining risks. The DOE cost contingency ($5,773 thousand) appears more than adequate to cover current risks and the remaining. The simulation at 90% confidence level estimated the finish date to be February 2019 or ten months to CD-4. The 90% confidence level is conservative, but it is a standard FNAL practice for covering risk. The contingency log list all change requests and their impact (increase/decrease) on contingency. This is an appropriate way to track the use of cost contingency. There are no significant current risks that are jeopardizing CD-4. None of the risks drive the technical completion or CD-4 dates.

3.3 Recommendation

4. The revised OPC/TEC distribution needs to be corrected in the PEP by the end of first quarter FY 2016.

4. PROJECT MANAGEMENT

4.1 Findings

Regular meetings are being held by the project, including weekly internal technical meetings, Project Management Group (PMG) and Performance Oversight Group (POG) meetings with the Laboratory, and IPT meetings.

The CPI in all areas of the project is running very near 1. The SPI, on the other hand, is noticeably <1 in several cases.

The management team is fully staffed. Robust transition plans were described where staff replacements required. New management staff was added where critical path efforts required further support—for example, in the FPIX assembly and testing.

A risk management process was presented. No single remaining identified risk has the potential to fully draw down the project contingency.

4.2 Comments

The project has been making excellent progress since CD-2/3. Its progress and status is well quantified and traceable, and on track for CD-4.

The schedule for each of the subsystems appears robust, with no apparent outstanding issues that will inhibit project completion to CD-4. The necessary resources appear to be available to successfully execute the project through CD-4.

Detailed CPI and SPI tracking of individual sub-projects appear very reasonable for this stage in the project. Where specific challenges exist, the individual sub-projects are pursuing mitigation strategies and executing a well-defined BCR process. The RC to ETC ratio appears very robust. The ETC is updated and credible, and the proposed annual goals and performance metrics for the current year are suitable as effective indicators of performance in the coming year.

A sufficient amount of project contingency remains, and this should address any remaining risks and take the project through completion. There is now room in the budget to support a more aggressive approach toward contingency usage, which could be aimed at both ensuring timely project completion and optimizing overall CMS physics output.

Project risks appear to be under control and active risks are being effectively managed. The risk assessment is being maintained to reflect the current project status, and no risks are apparent which could seriously jeopardize any of the Threshold KPPs for the project. Where specific risk threats have been realized, the relevant managers have aggressively worked the problem and suitable BCRs have been processed.

The project team—managers at all levels, CAMs, technical personnel—is strong, highly engaged, and well integrated, and demonstrates a keen commitment to the U.S. CMS Phase I

project and its successful execution and completion. The management structure and resources are adequate to deliver the proposed technical scope within stated performance by CD-4, both overall and from the point of view of individual DOE and NSF awardees.

The Project Manager is fully engaging the entire management team in the project management and tracking tools, and they are being embraced by all of the managers. The tools are being used extensively and to advantage to monitor and evaluate project progress, and, where possible, to anticipate problems that might arise. The laboratory has also provided an effective means of implementing its project tools that enables the project management team.

Meetings internal to the project, and with the laboratory and the agencies, are held with appropriate frequency and regularity to facilitate project progress, to obtain input and/or address issues that might require broader discussion, and to keep all of the personnel and stakeholders properly informed.

The laboratory demonstrates an appropriately strong level of support of, and engagement with, the project and its needs for its successful realization.

The project is being managed with close attention paid to the requirements of each agency. The management of the NSF Cooperative Agreement and the subcontracts with the NSF awardees are being well managed and properly tracked. The interdependence of the NSF and DOE deliverables is well understood, and being appropriately managed.

The project is to be commended for having created a culture of open communication, both internally and with all the relevant stakeholders, including the Laboratory and the agencies. This is a notable feature of the project, and a significant component of its success to date.

While it does not influence overall project completion and CD-4, the project team should consider sharpening its planning to help ensure that the FPIX schedule is maintained, and to enhance the probability of its timely completion by the CERN need-by date. This might include generating a more detailed staffing plan that focuses on the FPIX production end game, and the anticipatory use of contingency up front to develop a complementary technical labor pool with the appropriate expertise.

4.3 Recommendation

5. Continue to explore options for accelerating delivery of the FPIX.

Appendix A Charge Memo

Department of Energy
Washington, DC 20585

AUG 27 2015

MEMORANDUM FOR: STEPHEN MEADOR, DIRECTOR
OFFICE OF PROJECT ASSESSMENT

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

SUBJECT: Request to Conduct Independent Review of the LHC-CMS DETECTOR UPGRADE PROJECT

I am writing to request that your Office conduct an Independent Project Review of the LHC CMS Detector Upgrade Project, at Fermi National Accelerator Laboratory (FNAL) on October 14–15, 2015. This project is performed in partnership with the National Science Foundation (NSF). The purpose of the review is to evaluate the progress made by the project since the previous CD-2/3 review. In accordance with the approved Project Execution Plan, the Earned Value (EV) and schedule data are reported monthly in PARS and to the respective Program Managers and Federal Project Director.

As part of assessing the project's progress and status of the remaining activities, your committee should focus on the following questions:

1. Management: Is the management structure and resources adequate to deliver the proposed technical scope within stated performance by CD-4, both overall and from the point of view of individual DOE and NSF awardees?

2. Estimate to Complete: Is the Estimate to Complete updated and credible? Are the proposed annual goals and performance metrics for the current year suitable as effective indicators of performance in the coming year?

3. Cost & Schedule: Are the current project cost and schedule projections consistent with the approved baseline cost and schedule? Are the technical and financial status of the project accurately represented in the most recent monthly reports, reflecting project milestone status, EVM, risk and contingency management, configuration management and change control board actions, EH&S, and discussion of any other issues relevant to project performance from the point of view of awardees and sub-awardees?

4. Risk: Has the risk analysis been updated to accurately reflect the risks that remain in completing the project? Is the contingency still adequate for the risks? Are there any

significant risks that jeopardize CD-4 completion and require high level management attention?

As Program Manager for the LHC-CMS Detector Upgrade Project, Dr. Simona Rolli will serve as the Office of High Energy Physics contact person for this 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.

Sincerely,

Michael Procario
Director, Facilities Division
for High Energy Physics

cc: Patricia Dehmer, SC-2
James Siegrist, SC-25
Simona Rolli, SC-25
Mark Coles, NSF

Nigel Lockyer, FNAL Director
Mike Lindgren, FNAL Chief Project Officer
Steve Nahn, FNAL Project Manager
Alan Harris, FSO, Federal Project Director
Michael Weis, FSO Site Office Manager

Appendix B Review Committee

DOE/SC Status Review of the
LHC CMS Upgrade Project
October 14-15, 2015

Kurt Fisher, DOE/SC, Chairperson

SC1
HCal—Hadron Calorimeter (WBS 1.2)

* Tom LeCompte, ANL
Jim Pilcher, U of Chicago

SC2
Forward Pixel Detector (WBS 1.3)

* Jim Brau, Oregon (first day only)
Leo Greiner, LBNL

SC3
Level 1 Trigger (WBS 1.4)

* Charlie Young, SLAC
Kevin Pitts, U of Illinois

SC4
Cost and Schedule

* Frank Gines, DOE/ASO
Penka Novakova, BNL
Ray Won, DOE/OPA

SC5
Project Management (WBS 1.1)

* Jon Kotcher, BNL
Mark Palmer, FNAL

Observers

Jim Siegrist, DOE/SC
Mike Procario, DOE/SC
Simona Rolli, DOE/SC
Alan Harris, DOE/FSO
Pepin Carolan, DOE/FSO
Mark Coles, NSF

LEGEND

SC Subcommittee
* Chairperson

Count: 12 (excluding observers)

Appendix C Review Agenda

DOE/SC Review of the
LHC CMS Detector Upgrade Project
October 14-15, 2015

AGENDA

Wednesday, October 14, 2015—Wilson Hall, in the Comitium

8:00 am	DOE Full Committee Executive Session—**Comitium (WH2SE)**.....K. Fisher
9:00 am	Welcome—**One West** ..... N. Lockyer
9:10 am	CMS Upgrade Project Overview ..... S. Nahn
10:00 am	Break—**Outside One West**
10:20 am	Hadron Calorimeter (WBS 401.2) .....J. Mans
11:00 am	Pixel (WBS 401.3) ..... W. Johns
11:40 am	Trigger (WBS 401.4) .....W. Smith
12:20 pm	Lunch—**2nd Floor Crossover**
12:50 pm	Reviewer Photo—**Atrium**
1:00 pm	Subcommittee Breakout Sessions
	—Management—**Comitium (WH2SE)**
	—HCAL—**Snake Pit (WH2NE)**
	—Pixel—**Black Hole (WH2NW)**
	—Trigger—**Theory (WH3NE)**
3:30 pm	Break—**Outside Comitium**
4:00 pm	Subcommittee Executive Session—**Comitium**
5:00 pm	DOE Full Committee Executive Session.....K. Fisher
6:30 pm	Adjourn

Thursday, October 15, 2015

9:00 am	Question and Answer Session—**Comitium (WH2SE)**
10:15 am	Break—**Outside Comitium**
10:30 am	Committee Report Writing
12:00 pm	Lunch
1:00 pm	DOE Full Committee Executive Session Dry Run ..... K. Fisher
3:00 pm	Break—**Outside Comitium**
3:30 pm	Closeout Presentation**—One West**
4:30 pm	Adjourn

Appendix D CMS Management Chart

LHC CMS Detector Upgrade Project

LHC CMS Detector Project Organization

*Jeremy Mans moving to another phase. Replacement Paulo Rumerio (AL), deputy HCAL for int'l CMS, taking over after this review, and has been shadowing JM since February

401.01 LHC CMS Detector Upgrade Project

Project Office

Project Manager:	Steve Nahn
Deputy Project Manager:	Aaron Dominguez
Deputy Project Manager:	Lucas Taylor
ESH&Q Coordinator:	Stefan Gruenendahl
Project Controls:	Bill Freeman
Project Finance:	Jenny Teng
Risk Manager:	Lucas Taylor
Project Electronics Engineer	Michael Matulik
Project Mechanical Engineer	Greg Derylo

401.02 HCAL

L2 Manager: Jeremy Mans*
Deputy L2 Manager: Frank Chlebana

- **401.02.03 HF Front End** — L3 Manager: Ulrich Heintz
- **401.02.04 HB/HE Front End** — L3 Manager: James Hirschauer
- **401.02.05 HCAL Back End** — L3 Manager: Yuichi Kubota

401.03 FPIX

L2 Manager: Will Johns
Deputy L2 Manager: Marco Verzocchi

- **401.03.03 FPIX Components** — L3 Manager: Harry Cheung
- **401.03.04 FPIX Assembly & Testing** — L3 Manager: Cecilia Gerber; L3 Manager: Petra Merkel
- **401.03.05 FPIX Pilot System** — L3 Manager: Karl Ecklund

401.04 Trigger

L2 Manager: Wesley Smith
Deputy L2 Manager: Darin Acosta

- **401.04.03 Muon Trigger** — L3 Manager: Ivan Furic
- **401.04.04 Calorimeter Trigger** — L3 Manager: Sridhara Dasu