Closeout Presentation

Director's Review of US-CMS HL-LHC Upgrades

February 2-4, 2016

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Executive Summary

The US-CMS HL-LHC Upgrade Project was reviewed to evaluate the state of the overall planning and readiness for presentation of the project plans to the DOE and NSF. The focus of the review was technical, cost, schedule, management, and ES&H readiness for meeting funding agency expectations for a project at this stage. The review took place over three days from February 2-4, 2016 and included both plenary and parallel sessions for breakouts and provided ample time for discussion. The review charge, the agenda, and the committee membership can be found in Appendices A, B, and C, respectively.

The US-CMS HL-LHC Upgrade Project is an ambitious technical undertaking with multiple high-level stake-holders including NSF, DOE, and International CMS. The scope of work presented by the US-CMS HL-LHC upgrade project is well motivated by the physics priorities of CMS for high-luminosity LHC running scheduled to begin in 2026 and is well integrated with the International CMS upgrade plan. The US-CMS project includes well defined contributions from both NSF and DOE, each of which represent a significant contribution to the International CMS HL-LHC detector upgrade and each of which are fundamental to achieving the required physics performance. The Design & Scope, Cost &Schedule, Project Management, and ESH&Q aspects of the US-CMS HL-LHC Upgrade Project have been developed to an appropriate level for this stage of the project. Although additional work remains, the US-CMS HL-LHC Upgrade Project is on track to develop a conceptual design that meets or exceeds the expectations for the upcoming NSF CDR and DOE CD-1 reviews.

The committee thanks the US-CMS HL-LHC Upgrade Project team for providing all the relevant material for this review and for taking the time to address our questions and concerns. The project team has the expertise and experience to successfully deliver the proposed NSF and DOE scope on schedule and within budget. We wish them the best of luck in this exciting endeavor.

Introduction

A Director's Progress Review of the US-CMS HL-LHC Upgrade Project was held on February 2-4, 2016 at Fermi National Accelerator Laboratory. The purpose of this review was to inform the laboratory about the state of the overall planning and readiness for presentation of the project plans to the DOE and NSF. The focus of this review was cost, schedule, management, ES&H, and technical readiness for meeting funding agency expectations for a project at this stage. The DOE has provided a preliminary budget profile scenario and the project anticipates receiving Critical Decision 0 (CD-0) approval in early 2016. NSF has scheduled a Conceptual Design Review (CDR) in March 2016 in anticipation of eventual construction funding through the Major Research Equipment and Facilities Construction (MREFC) account.

This Final Report provides the assessments of the Project's design of technical deliverables and project management. Each section is generally organized by Answers to Charge Questions, Findings, Comments and Recommendations. Findings are statements of fact that summarize noteworthy information presented during the review. The Comments are judgment statements about the facts presented during the review and are based on reviewers' experience and expertise. The Comments are to be evaluated by the Project Team and actions taken as deemed appropriate. Recommendations are statements of actions that should be addressed by the Project Team. The US-CMS HL-LHC Upgrade Project is to present responses to recommendations to the Laboratory Management. The recommendations will be tracked to closure. Documented status of the Project's resolution of the recommendations will need to be available for future reviews.

The Appendices contain the reference materials for this review. The Charge for this review is shown in Appendix A. The review was conducted per the agenda shown in Appendix B. The Reviewers' assignments and contact information are noted in Appendix C.

6.0 Common Findings, Comments, and Recommendations

Findings

The US-CMS HL-LHC Upgrade Project (hereafter, "the Project") has defined a management structure and has named the key leadership positions in the Project Office and the L2 and most L3 sub-project leaders.

A WBS has been developed down to level-4 or better across all sub-systems and is used to develop a resource-loaded cost and schedule.

Well-defined rules are used to assign contingency associated with the uncertainty in M&S and Labor estimates. The rules employ a graded approach that assigns a larger contingency for tasks whose planning is less mature.

A high-level risk analysis has been completed and is used to estimate risk-based cost and schedule contingency.

The Project has or will soon implement Risk Management, Interface Management, and QA/QC Management processes based on existing policies and practices that have been used successfully at CERN and Fermilab.

The Project has an ES&H Coordinator in the Project Office who is responsible for ensuring all work at all the participating institutions in performed in a safe manner.

A draft NSF PEP exists that includes all the required elements.

Comments

The Project leadership team has the expertise and experience to successfully execute the proposed plan.

While, the cost and schedule estimates appear to be sound and meet or exceed the expected level of maturity for this stage of a project, the schedule contingency should be more clearly articulated.

The assigned contingency is appropriate for this stage of the project.

The NSF and DOE scope are each well motivated by the science requirements and each represent a significant contribution to the International CMS HL-LHC Upgrade. While the NSF and DOE scope are each well defined and distinct, this was not always communicated clearly.

The connection between the Science Requirements and the proposed technical scope of work was not clearly articulated.

While the project appears to be on track in all the aspects reviewed here, this did not come across in many of the presentations that were made, but instead required some detailed back-and-forth between the committee and the Project team.

Recommendations

1. Prior to the NSF CDR Review, develop a plan so that the R&D, OPC, TEC, and MREFC scope each fits within the guidance provided.

2. Prior to the NSF CDR Review, clearly document the connection between the high-level technical features of the proposed scope of work and the high priority HL-LHC science goals. Comparisons of the expected performance with and without the upgrade can provide powerful motivation. Be quantitative where possible.

3. Prior to the NSF CDR Review, work with all speakers so that their presentations address the charge questions and requirements flow-down in a clear and concise way and to ensure they can speak to all aspects of project management (ie. Cost, Schedule, Interface Control, Risk, QA/QC, and ESH Management).

2.0 Technical Systems

2.1 Trigger

Subcommittee Lead: Hal Evans
Subcommittee Members: Kirsten Tollefson

Charge Questions:

- Have the project's performance requirements been sufficiently defined and do they flow down from the overall CMS plan?

  Yes. The information is largely there, but needs to be presented in a crisper way.

- Are the conceptual designs sound and likely to meet the performance requirements?

  Yes.

- Do the designs capture the entire scope and are they adequately defined to support the cost and schedule estimates?

  Yes.

- Is there an adequate plan for design reviews?

  Yes.

- Is the R&D plan appropriate to mitigate technical risk on the project's timescale?

  Yes.

Findings

We are commenting on two areas of US CMS scope: the L1 Trigger system, at WBS Level-2 (402.06), and the Track Trigger, a Level-3 item (402.02.05) in the Tracker project

- There are three Level-3 areas in the US scope for the L1 Trigger system
  - the Calorimeter Trigger, supported by the DOE
  - the Muon Trigger, supported by the NSF
  - the Global Correlator, supported by the NSF
- Cost and effort estimates are based on experience with electronics being designed and built in the US for the Phase-1 CMS upgrades. Each of the three systems could use very similar electronics to what is being developed for Phase-1.

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- This Phase-1 effort serves as the basis for R&D for the HL-LHC L1 Trigger system and specific plans exist for studies associated with HL-LHC requirements.
- There are two options for US scope in the Track Trigger and an additional option that is being developed and led by the UK
    - an Associative Memory (AM) based architecture, based on the CDF SVT and the ATLAS FTK. If chosen this scope would be supported by the DOE.
    - an all-FPGA "Tracklet" based approach. If chosen, this scope would be supported by the NSF
    - The decision point on how to move forward with a Track Trigger concept, based on comparisons of hardware demonstrators, is scheduled for early 2017.
- An extensive R&D program in the US is ongoing that has already addressed many of the major issues required to be understood for the technical decision. This R&D program, for both US options, has clear plans for providing the input needed to resolve remaining questions needed for the decision.

Comments

- In all of the elements of the US trigger system scope, the group demonstrated a technical understanding and readiness well beyond that required for a Conceptual Design Review.
- Preparation of budgets that fit within the NSF and DOE guidelines would be helpful for the CDR for both Track Trigger decision (Tracklets via NSF or AM via DOE) as that requires swapping of projects (L1 Trigger vs. Track Trigger) between NSF and DOE.
- Exact level of responsibilities of the US for the hardware and effort for each system were not always clearly presented. For example, it was not initially clear that the US is responsible for 100% of the Track Trigger design but will only pay for 50% of the production boards.
- The group's strategy for presenting technical information was at a too detailed level for the CDR, given that the schedule and audience will be different there than at the Director's Review.
- There is a risk that a crisp down-select to a single Track Trigger technology may not be taken in time for the PDR. The group is in a good position to minimize this risk given there leadership roles within the CMS Trigger Upgrade project.
- The trigger system presents a good opportunity to prepare a few specific, numerical examples of requirements flow down involving to US CMS scope..

Recommendations

4. **Prior to the NSF CDR, the division of NSF vs. DOE parts of the L1 Calorimeter and Global Correlator Triggers must be clearly defined and articulated.**

2.2 Tracker

Subcommittee Lead: Jason Nielsen

Subcommittee Members: Gaston Gutierrez

Charge Questions:

- Have the project's performance requirements been sufficiently defined and do they flow down from the overall CMS plan?

  Maybe. The performance requirements have been defined based on the main science requirements for the project, but needs to be more clearly articulated.

- Are the conceptual designs sound and likely to meet the performance requirements?

  Yes. At the conceptual level, the project designs are technically sound and achieve the performance requirements.

- Do the designs capture the entire scope and are they adequately defined to support the cost and schedule estimates?

  Yes. The designs fully capture the US-CMS scope. The cost and schedule estimates are complete and advanced. The estimates are derived from past experience with similar projects.

- Is there an adequate plan for design reviews?

  Yes. The CMS collaboration requires all projects to undergo multiple internal design and system reviews at different stages of the projects. For example, the projects undergo Engineering Design Reviews, Electronic System Reviews, and Procurement Readiness Reviews, based on the entire project scope.

- Is the R&D plan appropriate to mitigate technical risk on the project's timescale?

  Yes. There are clear R&D plans, appropriate for mitigating risk, for both the forward pixel and outer tracker projects. It is important that this R&D be supported to inform the upcoming technical decisions and to maintain the risk-mitigating backup strategies as needed.

Findings

We are commenting on the forward pixel detector (FPIX), at WBS Level-3 (402.02.03), and the outer tracker system (OT), at WBS Level-3 (402.02.04) both in the Tracker project. The tracker trigger (402.02.05) is discussed in Sec. 2.1 Trigger.

- The FPIX project is entirely in the NSF scope while the OT project is entirely within the DOE scope.

- The module assembly concept for the forward pixel system is similar to the Phase 1 forward pixel project currently under construction. The proposed assembly procedures are similar, and the schedule and costing are based on the experience with the Phase 1 project. Many of the institutes and personnel will have gained experience on the Phase 1 project. The schedule and costing seem reasonable for the new version of the forward pixels.

- The mechanical design for the forward pixel project -- including the disk assembly, CO_2 cooling, and support cylinder -- is similar to the Phase 1 project. Refining this design will require continued engineering support, but the technical risk is manageable.

- The design of the main pixel readout chip (ROC) for the forward pixel system currently follows two paths. The first path is based on a synthesis of design blocks from the RD53 collaboration, and the second path is a design from PSI in Switzerland. US-CMS has formed a committee to recommend how to proceed with the pixel ROC. More development will be needed to produce a functioning ROC that can operate at high speeds and high radiation environment required for forward pixel detectors at the HL-LHC.

- The design of the pixel sensors is still under development. The three options presented were: 1) 3-D sensors, 2) thin planar n-on-n sensors, and 3) thin planar n-on-p sensors. A decision on the technology will be made in the next year, and the mechanism and criteria for the decision still need to be defined.

- The outer tracker project is a large and complex project. US CMS collaborators are responsible for a part of the project. Production of the large number of modules required has necessitated a careful planning of the overall schedule.

- There are three separate sensor designs required for the outer tracker: 2S strip sensor, PS strip sensor, and PS pixel sensor. All three designs are essentially fixed, and prototypes have been characterized. Sensors from additional vendors are being tested, with the potential of reducing production costs and mitigating risk associated with a single vendor. Initial tests indicate that the sensors meet requirements after being irradiated to doses expected at HL-LHC.

- There are a total of six ASICs to be developed for the outer tracker project. These chips require custom development because of requirements like the track trigger and the high rate environment. We believe that none of these chip designs carries any great technical risk.

- The module assembly plans for the outer tracker were presented in detail. The assembly procedures are well defined. A time estimate for producing 2000 2S modules was presented, and the estimate of 2 years for complete production is credible. The PS production requires 4000 modules, and a timeline for the complete production was not clearly presented.

- There is good progress in the design and prototyping of the mechanical mounting and cooling structure for the outer tracker planks. The cooling prototyping benefits from the CO_2 cooling experience gained from the Phase 1 forward pixel project. The plans for assembling modules into planks are progressing well, but the site of the final plank mounting is unknown.

Comments

- We feel that the performance requirements flowing from the science goals have been developed in a careful way, but it would be helpful if they were presented in a concise and clear manner.

- There are a large number of PS modules to be produced in the US. We did not see a clear long-term production schedule taking into account the available production facilities and equipment.

- Many important technical decisions remain to be taken in the next two years. These include the FPIX sensor technology and the pixel size. It was not clear how these decisions will be made and on what basis the various options will be evaluated. Continue working with International CMS to develop a plan for making this decision.

Recommendations

5. Prior to the DOE CD-1 review develop a production schedule for the PS modules in the US.

2.3 Muons

Subcommittee Lead: Tom LeCompte

Subcommittee Members: Dmitri Denisov

Charge Questions:

- Have the project's performance requirements been sufficiently defined and do they flow down from the overall CMS plan?

  Yes.

- Are the conceptual designs sound and likely to meet the performance requirements?

  Yes.

- Do the designs capture the entire scope and are they adequately defined to support the cost and schedule estimates?

  Yes. The designs are as developed as they can be at this point, given the state of the integration, particularly in the Endcap region. We believe the contingency is adequate for this level of uncertainty, which supports the cost estimate.

- Is there an adequate plan for design reviews?

  Yes. At this stage of the project, the most critical reviews are scheduled. Plans for more detailed reviews are under development.

- Is the R&D plan appropriate to mitigate technical risk on the project's timescale?

Yes, when the Operations program is considered. See Findings and Comments.

Findings

We are commenting on the Endcap Muons at WBS Level-2 (402.05), which includes the CSC (402.05.03) and GEM (402.05.04) sub-projects at WBS Level-3.

- This subproject is 100% funded by the NSF. The (project) cost of the subproject is $5.95M with an overall contingency of $2.26M (38%).

- The installation of the GEMs is intended to preserve triggerability in the forward region in the HL-LHC environment. This project provides the electronics for these detectors, as well as for forward CSCs. The requirements for these upgrades are driven by the speed of the data links relative to the occupancy of the detector and the L1 trigger rate, and the acceptance of muons from the ZZ* decay of the Higgs boson.

- The proposed CSC and ME0/GE21 electronics are similar to the existing CSC readout, and prototypes exist of GEM optohybrid boards. The optical links are commercial off the shelf technology.

- Each major component is reviewed at least three times: at the TDR stage, the EDR stage and pre-production. Lower-level reviews are intended to be scheduled, but that schedule is under development.

- The Endcap integration envelope is not yet finalized. The ME0 mechanical design cannot be finalized before this. That, in turn, has implications for the electronics (mechanical board design and possibly channel count).

- The radiation hardness for the existing CSC electronics has been established. These tests will be repeated for Phase 2 CSC production electronics.

- The gas and chamber aging activity has moved out of this subproject and into the CMS Operations Program. The present gas mixture includes CF_4, a known greenhouse gas, and its purchase or use may be regulated in the future. This activity is intended to be supported at the ~$150K/year level.

Comments

- The presentation of the relationship between physics requirements and performance requirements should be more quantitative and focused. This information exists, but in future presentations should be presented in a crisp and clear manner in one or two dedicated slides.

- Based on similarity with previous systems and R&D prototypes, the committee believes that the design will achieve the necessary performance. The subcommittee drilled down on several items and found the cost and schedule estimates to be reasonable.

- We encourage the development of a more detailed review schedule.

- We emphasize the importance of clear and well-understood boundaries between subprojects. The boundary between this subproject and the detectors and the boundary between this subproject and Trigger & DAQ are particularly important.

- Radiation hardness tests for ME0 and GE2/1 electronics, similar to that for the CSC, should be done by 2020.

- The gas and chamber aging studies in the Operations program is high priority, and an important part of CMS's risk mitigation strategy. Given the impact, the level of funding seems appropriate.

Recommendations

none

2.4 Calorimeter

Subcommittee Lead: James Proudfoot

Subcommittee Members: Julie Whitmore

We are commenting on the Barrel Calorimeter project at WBS Level-2 (402.03), which includes the ECAL (402.03.03) and HCAL (402.02.04) sub-projects, and the Endcap Calorimeter, at WBS Level-2 (402.04), which includes the Sensors/Modules (402.04.03), Cassettes (402.04.04), BH Active (402.04.05), and Electronics & Services (402.04.06) sub-projects. We have a separate sub-section below for Barrel ECAL, Barrel HCAL, and the Endcap Calorimeter.

Some general comments:

- There is an abundance of experience embodied in the Calorimeter management and technical teams. The team has extensive technical experience working on the ECAL and HCAL original construction and Phase 1 Upgrades. The management team has experience navigating the complexities inherent in a multi-institute U.S. effort collaborating in an international context, and can manage the range of issues that naturally arise in such a project, drawing on previous lessons learned.

- The interdependence of the NSF and DOE deliverables is well understood and being appropriately managed. The project is being managed with close attention paid to the requirements of each agency.

- A high level summary of US deliverables for separately NSF and DOE was difficult to extract from the material presented.

Barrel ECAL:

Charge Questions:

- Have the project's performance requirements been sufficiently defined and do they flow down from the overall CMS plan?

  Yes. The project goals have been defined along with the technical motivation. The goals follow from the CMS plan to maintain the physics performance of the present detector in HL-LHC.

- Are the conceptual designs sound and likely to meet the performance requirements?

  Yes. The conceptual design for the upgrade of the BEE to provide increased granularity to the trigger and to provide a latency sufficient to meet the requirement for the upgrade track trigger is sound. It is based on incremental development of existing technology and techniques using to a large extent modern high performance FPGAs.

- Do the designs capture the entire scope and are they adequately defined to support the cost and schedule estimates?

  Yes. The design captures the full scope to support the cost and schedule. However, external dependencies such as associated with the disassembly of the current FE and associated technical risk should be documented as part of a complete plan.

- Is there an adequate plan for design reviews?

  Yes. The CMS management, US NSF and DOE agency reviews and ad hoc internal technical reviews provide a sufficient review requirement.

- Is the R&D plan appropriate to mitigate technical risk on the project's timescale?

  Yes. Key areas of technical risk comprise the FEE (not a US deliverable), availability and radiation tolerance of the lpGBtx, and the possibility of noise in analog circuitry from the DC2DC switch convertors. These are not part of the US scope. No critical technical risks directly associated with US scope were identified.

Findings

- The ECAL sub-project is entirely part of the NSF scope.

- The proposed HL-LHC upgrade to the Barrel ECAL is to increase the granularity of the information provided to the trigger from 5x5 cells to 1x1 cells, to reduce the operating temperature of the APDs, to increase the trigger latency to 12.5usec from 6.4usec and to provide electronics capable of a maximum Level 1 accept rate of 750kHz compared to the Phase 1 limit of 150kHz. The full US scope of this upgrade is funded by NSF.

- The increased trigger granularity is motivated by the need to provide improve track matching with the planned track trigger, to provide improved rejection of noise signals and for the rejection of energy from additional interactions (pileup).

- The reduced operating temperature of the APDs is motivated by the need to reduce the increase of noise due to radiation damage

- The increased trigger latency is required to meet the latency of the planned track trigger

- The maximum Level 1 accept rate is required to allow CMS to have comparable performance in the HL-LHC as for Run 2 luminosity conditions

- The US groups propose to contribute to the upgrade of the back end electronics, which comprise all electronics boards and firmware required to process calorimeter data from the front end readout and transmit it to the CMS trigger and data acquisitions systems.

- An external dependency for the ECAL FE electronics is the delivery of the lpGBtx ASIC that is being developed by CERN. The lpGBtx delivery schedule drives the ECAL upgrade critical path.

- A VFE/FE/BE demonstrator of the ECAL electronics readout chain is scheduled for the end of 2017.

- The US CMS Calorimeter Upgrade Level 2 is also the International CMS ECAL Upgrade Coordinator

- The end date of the US-CMS ECAL Upgrade is currently defined as the successful testing of the calorimeter FE and BE electronics installed in CMS.

Comments

- The ECAL team is to be complimented on presenting a well defined plan to upgrade the back end readout electronics of the barrel ECAL. The Calorimeter team has extensive experience working on the ECAL and HCAL detectors. Many team members have experience from original construction of the ECAL and HCAL and from Phase 1 upgrades of the HCAL.

- The use of common boards whose function is defined by different firmware in separate logic blocks of a high performance FPGA is a well conceived approach to optimize use of resources and is likely to provide a cost effective solution for the DCC, TCC, and CCS boards.

- Although the performance requirements have been stated, the justification based on the spikes in the APDs was not provided in a sufficiently quantitative manner. The justification was not connected to the physics goals: the limitation on trigger rate impacted by the spike rate should be characterized in the context of trigger thresholds and physics acceptance.

- Timing resolution of ~30ps is apparently a goal in the project. This is intrinsically a responsibility of international CMS who has the responsibility of developing the VFE. This is a concern from the view of diluting the effort on US defined scope beyond defining the interface to the FE. The ECAL team should consider re-evaluating their level of participation in this area in the light of limited R&D funding.

- The US CMS Calorimeter management team should continue to maintain close communication with International CMS Calorimeter management to ensure that the risks of major design modifications triggered by external changes are minimized.

- The US CMS Calorimeter management should re-evaluate the start date and duration of the firmware development to minimize exposure to changes in external interfaces, obsolete parts and technology.

- The connection between physics capability and the required noise signal rejection was unclear.

Recommendations

6. **Prior to NSF CDR, explore the possibility of redefining the definition for project completion to be the successful delivery and testing of the FE and BE electronics at CERN for the ECAL barrel in order to remove external dependencies of the NSF project on the CERN schedule.**
7. **Prior to DOE CD-1, document external dependencies and responsibilities associated with ECAL dis-assembly.**

Barrel HCAL

Charge Questions:

- Have the project's performance requirements been sufficiently defined and do they flow down from the overall CMS plan?

  Yes, the scintillator tile light level drop from radiation damage is sufficient to motivate replacement of the inner 6 layers of the HCAL barrel megatiles. Without this upgrade VBS physics and all physics using the measurement of missing Et would be severely compromised.

- Are the conceptual designs sound and likely to meet the performance requirements?

  Yes. The conceptual design is sound. The majority of the detector upgrade can be accomplished using scintillators with radiation tolerance of 2MRad, which is commercially available. Two options exist for instrumenting the regions of high radiation dose. The downselect process was not given, but the milestone for this decision was given as 2016.

- Do the designs capture the entire scope and are they adequately defined to support the cost and schedule estimates?

Yes, the design of replacement of scintillation tiles captures the entire scope of the required detector upgrade. The project should consider whether the installation of the megatiles should be an on-project activity. (See question below regarding disassembly and re-assembly).

- Is there an adequate plan for design reviews?

  Yes.

- Is the R&D plan appropriate to mitigate technical risk on the project's timescale?

  Yes. A reasonable R&D plan was presented, but with a very aggressive timescale.

Findings

- The US scope for the HCAL barrel upgrade is to replace the inner 6 layers of scintillator in the subdetector because of loss of light due to radiation damage. This is a DOE project.

- The Scintillator and WLS fiber R&D for the HCAL Barrel upgrade is budgeted for ~$60k per year from 2016-2019. Test beams, irradiation exposures and for the CASTOR test facility is budgeted for ~$50k per year from 2016-2019.

- The end date of the US CMS Barrel Upgrade project is currently defined as the installation of megatiles in CMS.

Comments

- The Calorimeter team has extensive experience working on the HCAL. Many team members have experience building the detector during the original construction of CMS. The calorimeter team has experience installing megatiles in HCAL in situ during the original construction. Team members are encouraged to transfer valuable/subtle installation knowledge to younger team members to ensure successful installation of megatiles during the Long Shutdown 3 (LS3) in FY23.

- The highest schedule risk for the HCAL Barrel (and Backing Calorimeter) upgrade is radiation hard scintillator and WLS fiber development. A material that meets the requirements has not yet been identified for those regions of the detector experiencing the highest radiation dose. US CMS Project Management should consider re-evaluating the R&D funding level to accelerate the development process to ensure successful development of materials that meet their requirements by FY17 in preparation for the TDR.

- The longitudinal segmentation implemented in the Phase 1 upgrade is an indirect dependency on the HL-LHC upgrade. The calorimeter team should maintain close communication with the Phase 1 upgrade group to insure that the combination of layers for Phase 1 does not adversely impact the number of layers to be replaced in the HL-LHC upgrade.

Recommendations

8. Prior to DOE CD-1, define the R&D milestones to address the path to a final design.

9. Prior to DOE CD-1, work with International CMS to define the process to be used for the down select of the scintillator option for the regions of the calorimeter exposed to the highest radiation doses.

10. Prior to DOE CD-1, explore the possibility of redefining the project's KPP for project completion to be the successful delivery and testing of megatiles at CERN for the HCAL Barrel Subsystem. This change would remove the external dependence of the DOE project from CERN schedule.

Endcap Calorimeter

Charge Questions:

- Have the project's performance requirements been sufficiently defined and do they flow down from the overall CMS plan?

  Yes. The performance of the endcap ECAL is justified on the basis of the H->gamma gamma decay. The resolution of the endcap hadronic calorimeter system is justified on the basis of the identification and reconstruction of jets from VBS.

- Are the conceptual designs sound and likely to meet the performance requirements?

  Yes. The basic conceptual design is well defined and sound. Some details remain to be optimized: sampling frequency as needed for particle flow reconstruction, and timing as needed for pileup mitigation.

- Do the designs capture the entire scope and are they adequately defined to support the cost and schedule estimates?

  Yes.

- Is there an adequate plan for design reviews?

  Yes

- Is the R&D plan appropriate to mitigate technical risk on the project's timescale?

  Yes. A key element is a demonstrator to be exposed in high energy beams at Fermilab and CERN in 2016.

Findings

- The endcap calorimeter comprises a Si/W/Cu electromagnetic calorimeter (EE), a Si/W/Cu Front hadron calorimeter (FH) and a scintillator/brass backing calorimeter (BH). The US scope comprises silicon sensors, modules, cassettes and mechanical and interfaces infrastructure for the EE and FH. For the BH the US scope comprises the scintillator, WLS fiber and readout electronics. This is a DOE project.

- The calorimeter team is taking advantage of the extensive expertise within US-CMS in the design and construction of Si detectors. The team has attracted groups with this expertise to participate in the EE and FH efforts.

- The decision on the location of the thermal shield between FH and BH impacts the calorimeter boundaries, mechanical supports and services. The calorimeter envelope impacts the boundaries and scope of the muon upgrade.

- Off detector readout/DAQ (FED) system for the entire endcap calorimeter is a US deliverable. This effort is combined with the Barrel ECAL and HB readout project. Cost sharing for FED work – Design work is being done by NSF.

- A beam test of EE is planned for spring 2016 and a beam test of a full EE+FH in late 2016.

- Sensor R&D is a global CMS responsibility and the decision on choice of sensor (dependent on sensor type, radiation tolerance, vendor; 8in vs 6in wafer) will be taken by international CMS prior to the TDR. US Cost is based conservatively on the 6in wafer which can provide sufficient radiation hardness. There are no internal risks for the sensors, the choice of disk size is an external dependency for the module mechanics.

- Module R&D is focused on the development of a mass production scheme to build modules (jigs, glue deposition, wire bonding, layout). The approach builds on the production of modules for tracker and is advanced through collaborations with groups who had experience in this construction. This is a solid design, well understood and straightforward procedures.

- Cassettes production is a well defined scope (all for FH); R&D is ongoing to reduce complexity and improve integration. Cassettes are horizontal when inserted initially into the absorber structure, The mechanical components and assembly uses generally conventional engineering with no severe tolerances.

- The backing calorimeter design plan is to use scintillator. Several options are being considered: with or without wave-shifting fiber, with direct readout by a SiPM, warm or cold.

- The calorimeter team presented a number of options for scope reduction: using stainless steal rather than brass for the BE absorber (not part of the US scope but has consequences), replacing an FH layer or removing one entirely could realize approximately $1M in cost reduction.

Comments

- The cost of the cassette base plate was estimated by comparison to similar assemblies (analogy). The calorimeter team should review the plate design and cost in terms of number of threaded holes and pins used.

- Cost saving should be presented as an opportunity arising from ongoing R&D.

- The calorimeter team is considering moving the location of the DC-DC regulators to the inner edges of the modules. The team should give consideration to reliability and serviceability if they pursue this option.

- The calorimeter team should continue to work with International CMS to develop plans for scope and schedule contingency.

Recommendations

11. Prior to DOE CD-1, work with International CMS to define the decision path and criteria for the down-select of the backing calorimeter design options.

12. Prior to DOE CD-1, work with International CMS to define interfaces and responsibilities between the calorimeter and muon systems.

13. Prior to DOE CD-1, define interface responsibilities for the readout electronics funded both by NSF and DOE.

3.0 Project Management

3.1 Cost and Schedule

Subcommittee Lead: Rich Marcum

Subcommittee Member: Suzanne Saxer, Mike Gardner

Charge Questions:

- Are the cost and schedule estimates credible and realistic?

  Yes.

- Do the estimates meet the funding agency targets?

  No. The NSF option #1 exceeds the guidance by $200k. The DOE TEC estimate exceeds the guidance by $16M.

- Are the estimating methodologies clearly defined and appropriate?

  Yes.

- Has adequate cost, scope and schedule contingency been identified to account for risk?

  Yes.

- Are assumptions used in the estimates, such as support from the core research program, realistic?

  Yes.

Findings

- The project cost estimate is well developed and includes all anticipated project scope. The estimates incorporate anticipated cost escalation and contingencies.

- The cost estimate is organized following the detailed Work Breakdown Structure (WBS).

- The project cost estimates presented at the review are:
  - NSF Option 1 – $75.2M including 50% contingency and risk.
  - NSF Option 2 - $74.6M including 49% contingency and risk.
  - DOE Option 1 - $148.6M including 45% contingency and risk.
  - DOE Option 2 - $140.9M including 44% contingency and risk.

- The project has a detailed resource loaded schedule, traceable to the BOEs, that is appropriate for a CDR-level review.

- The NSF estimate "Option 1 Tracklet" is $200K above the guidance. The DOE TEC option 1 estimate exceeds the guidance by $16.1M.

- The BOE's are not uniform and there is not a project document, such as a cost book, that allows a cost trace to be performed. The L2 managers were able to trace the numbers from the BOE's back to the resource loaded schedule.

- The BOEs do not clearly address NSF estimate categories.

- Because of the two funding sources and internal requirements, the project has a significant number of reviews.

- The Project uses Merlin as its RLS tool.

Comments

- Considering the PEP is a high level regulatory document, the WBS dictionary in the PEP may be at too low of a level. Consider limiting the WBS dictionary in the PEP to level 2 or 3.

- When discussing DOE funding, focusing on only TEC gives a less favorable outlook then looking at the TPC. Consider how to present budget/funding profiles taking advantage of the project's history of cost savings.

Closeout Presentation

- The project cost estimate, as presented, is well developed, and provides adequate contingency based on the maturity of the design. The project cost estimate provides a reasonable forecast of the total project cost.

- BOE's should be standardized across the Project in a manner that will facilitate the development and maintenance of the formal project RLS. If possible, it should be developed so that it satisfies both NSF and DOE requirements including NSF estimate categories.

- Language used to present Options shown above promotes confusion as they seem to cross descriptive boundaries. For example, descriptions on presentation slides are not consistent.

- The project should consider developing a

- The project should consider identifying the “critical” or “longest” path.

- The project should continue to develop the schedule interdependencies (internal and external).

- The project appears to have a good schedule, for this phase of the project. The team also demonstrates a comprehensive understanding and ownership of the schedule.

- The project should migrate the schedule and cost estimate to Primavera P6 / Cobra which will allow the use of lab standard rates and overheads in advance of the DOE CD-1 review.

- To meet NSF and DOE targets, consider reduction of scope or contingency as needed. Then develop a prioritized list of candidates for scope enhancements and reductions that can be deployed to manage contingency as the project progresses.

- The Project should consider the use of cost codes to identify NSF and DOE work in the schedule.

- Presentation cost tables did not always trace back to high-level bullets in the presentation, which added an element of confusion (e.g. avoid $k vs. $M on same slide, totals on tables should add to bulleted dollar amounts).

Recommendations

14. Prior to the NSF CDR review scrub the existing BOEs so that they have a uniform presentation and are tailored to the NSF charge while still meeting the DOE requirements.

15. Prior to the NSF CDR review prepare a cost book to demonstrate the traceability between the BOEs and the resource-loaded schedule.

16. At NSF CDR, present the critical or longest path, critical procurements, schedule dependencies, and schedule float/margin to demonstrate the project’s knowledge and use of the schedule.

17. **The required Project Controls resources need to be identified soon in order to be ready for a DOE CD-1 review by the end of this year. Work with the relevant stakeholders to identify a workable solution.**

3.2 ESH&Q

Subcommittee Lead: Madelyn Wolter

Charge Questions:

- Is ES&H being appropriately addressed for this stage of the project?

  Yes – The HL-LHC CMS Detector Upgrade Project ESH&Q Coordinator has developed a credible conceptual plan to address Environment, Safety and Health (ESH) concerns and Human Performance Improvement (HPI) initiatives throughout the process of the Phase II upgrades. Quality Assurance (QA) and Quality Control (QC) will be handled separately by the different projects for each subsystem.

Findings

- The overall plan for incorporating ESH in this project has been well thought out. The plan includes visits with facility ESH representatives to go over their responsibilities for: implementing ESH and HPI initiatives in all work performed at the facility on a routine basis; keeping track of facility specific safety training, procedures and protocols; and reporting on ESH through the appropriate reporting lines. There is a plan to create a tracking tool that will keep a record of incidents, near-misses, etc. throughout the entire project, combining reports from laboratories, universities and other facilities. There is a strong drive to promote a living ESH culture throughout the many subsystems and facilities. This is already apparent as the subsystems are already addressing potential ESH risks and possible mitigations.

- Several R&D efforts will be conducted at different facilities, at both the university and laboratory level. These R&D efforts will mainly be concerned with general safety (i.e., slip/trip hazards, cranes, flammable gas, high voltage, radioactive sources, etc.). It has been said that personnel will follow established facility-specific safety training, procedures and protocols for the work. It is planned that overseeing these aspects will be the responsibility of the facility ESH representative, giving reports through the appropriate reporting line.

- Periodic safety reports, specifically mentioned by the CSC Off-Chamber Electronics subsystem, are reported at various meetings and through the US FA, International Project and International CMS reporting lines. Similar reporting techniques are planned to occur in all subsystems.

Comments

- While it was stated that various safety training records, procedures, protocols, etc. would be given to the ESH Coordinator, it was not mentioned how these documents would be saved. It is encouraged that a dedicated location be established early on in the project to keep track of all documents.

- It was stated that each facility would have an ESH representative. It is encouraged to establish and document these representatives and their communication lines early in the project to ensure all members are adequately integrating safety in all aspects of the project.

- The ESH Coordinator plans to incorporate safety awareness presentations during management meetings as well as general personnel meetings, it is suggested that Lessons Learned from the Phase I upgrades, various Phase II subsystems, and R&D efforts be incorporated in these presentations.

- The ESH Coordinator plans to develop a tracking tool that will keep a record of all ESH related "events" and will incorporate laboratory and university personnel. Reporting requirements are understood for laboratories, such as Fermilab and CERN, and for universities, but a better understanding is needed for NSF reporting requirements. At the moment, NSF does not have any reporting requirements, but this can change over time. Periodic reviews of the NSF reporting requirements is encouraged to ensure compliance.

- Several documents, such as the QA/QC Plan, Preliminary Hazard Analysis Report, facility-specific procedures and protocols, and Standard Operating Procedures, have not yet been created. Continuing ESH&Q review is encouraged as documents become available.

- The muon subsystem has identified the possibility of the European Union banning CF_4 before LHC is complete. It has created a test-group to look into suitable alternatives. These alternative should be thoroughly reviewed, and should not affect the overall project requirements. It is encouraged to restrict the use of CF_4 and use a suitable alternative from the start, if possible.

Recommendations

none

3.3 Management

Subcommittee Lead: Brenna Flaugher
Committee Member: Doug Glenzinski

Charge Questions:

- Is the project appropriately staffed and being effectively managed at this stage?

  Yes, the project management and staffing build on the experience with previous successful CMS construction projects. All major leadership roles are filled with experienced and dedicated people. The Project Office needs to identify a Project Controls lead soon (cf. Sec. 3.1) and should fill the remaining vacancies on the timescale of the DOE CD-1 review.

- Are the roles, responsibilities, and contributions of DOE, NSF, and International CMS defined and appropriate?

  Yes, aside from the small piece of scope discussed in Sec. 2.4 Endcap Calorimeter Finding. The NSF and DOE roles are clearly defined and appropriate. There remains an option for redistribution of a small piece of scope. The decision will be made in consultation with international CMS, NSF and DOE.

- Have management plan documents been developed?

  Yes. A draft PEP for NSF exists as well a CMS HL-LHC technical proposal and a CMS scoping document and a Risk Management plan. The technical proposal and the scoping document provide information that is well advanced for a project at this stage in the DOE approval process. The risk management plan is well beyond the level expected for a DOE project at this stage. Additional management planning (e.g. Interface, QA/QC) will utilize existing CERN and Fermilab policies and processes.

- Do the NSF CDR and NSF Project Execution Plan fulfill the NSF's expectations for conceptual design?

  Yes. The documents appear to be comprehensive and complete.

- Is there a credible plan for systems engineering functions such as requirements management, interface control, and QA?

  Yes. Systems engineering is handled at the level on International-CMS management. The project is developing a plan for using this system. Interface control documents have not been developed between the subsystems yet, but there seems to be a reasonable level of understanding of the issues within the project management.

- Are the projected resources sufficient to complete design, construction, and installation and are these resources likely to be available when needed?

No, not as presented. The project presented cost estimates that were higher than the guidance, but there appears to be flexibility in the estimates, contingency, and scope that could be used to meet the guidance. The FTE resources needed for construction will build on the resources already on staff at multiple institutions. The growth needed for construction is not excessive and is distributed over a number of institutions so that no one institution has to increase by a large factor.

- Are critical procurements sufficiently understood and coordinated across the organizations involved?

  Yes. Detailed lists of procurements above $500k were presented. For the DOE piece these are mainly for sensors for the outer tracker and occur at a rate of 1-2 per year starting in 2019. The peak number of large procurements (5) totals nearly $10M and occurs in 2021. The first procurement of outer tracker sensors is scheduled for 2018 and is anticipated to be the only item requested for CD3a approval. For NSF procurements the FPIX sensors are the largest components. The NSF procurements occur at the rate of about 1-2 per year starting in 2020, with the peak (4 procurements totaling about $4.5M) occurring in 2022.

- Is the risk management system in place and appropriate? Have risks been adequately identified?

  Yes. A very thorough plan is in place. 18 medium/high risks have been identified: 15 threats, and 3 opportunities. A quantitative risk analysis with Monte Carlo modeling is being developed and was used to estimate the required risk-based contingency. The estimates have been cross checked with other projects at Fermilab and show good consistency. A plan for refining risk analysis is well developed.

Findings

- In general, the mapping of science requirements to the technical designs was not clearly articulated.
- System engineering is handled at the International CMS level. The project is beginning to develop a plan for using this system.
- The bottom up estimates for the funding need for the DOE R&D and TEC was above the guidance. The estimates for the NSF work were presented as slightly above the guidance.
- The R&D needs are reviewed once a year and redistributed according to priorities defined by project management. Project management expressed confidence that this process would result in an R&D program in FY16/17 that would fit within the guidance.
- There is some scope contingency within the project.
- The effort for the subprojects is distributed across multiple institutions.
- The project has as estimate of the resources needed for the construction and how this will ramp up from the current levels.
- Installation and commissioning is included in some sub-projects and not in others. Integration and assembly at CERN is generally included.

- The project is working with a schedule deadline of being ready to install during CERN Long Shutdown #3 (LS3). Project management is actively monitoring the highest schedule risk items. Although these have 1.5-2 years of schedule float at this time, it is still early in the R&D and technical development.

- R&D on the ROC needed for FPIX is not under project control. This design is a deliverable of International CMS. The HL-LHC upgrade project management is tracking it through common milestones.

- There is a review process at CERN in addition to the NSF and DOE reviews

- A strong, experienced, active and enthusiastic management team is in place. There is a well defined scope for the vast majority of NSF and DOE parts of the upgrade and these are jointly managed through the HL-LHC project. The NSF and DOE parts of the project are distinct and have separate managers with clear lines of authority and responsibilities.

- A list of major (>$500k) procurements has been identified. These are clearly separated by funding source and subproject and distributed across the construction project.

- A high-level risk analysis has been performed: 18 medium/high risks: 15 threats, and 3 opportunities have been identified and are being tracked. Monte Carlo modeling has given a preliminary estimate of 12.6M$ cost risk contingency and 30 months of schedule contingency. The estimates have been cross-checked with other projects at Fermilab and show good consistency.

Comments

- Preparing a concise summary of the science requirements and their connection to the technical requirements for the HL-LHC upgrade would make managing design decisions and R&D choices easier to explain to the relevant agencies, reviewers and interested management structures. Presenting a high level discussion of the flow down from science goals to technical designs in the plenary talks would help frame and motivate the overall scope.

- The high level dependencies between 1) NSF and DOE subprojects, 2) NSF and International CMS, 3) DOE and international CMS were not clearly presented.

- The Level 2 managers did not appear to be sufficiently engaged in the Systems Engineering processes (e.g. development of Interface Control documents).

- The scope contingency and the associated costing appear to be well understood by the project manager and deputy project manager but were not clearly presented.

- It was hard to tell from the material presented where the ramp-ups in technical effort were going to occur and if any one institution was going to have to initiate a major hiring effort.

- The technical end of the construction subprojects are not consistently defined across the subprojects and with ATLAS. General practice is that projects should end before potential delays in the CERN schedule impact the project completion.

- Closely monitor external dependencies that might significantly impact schedule contingency (e.g. the R&D on the ROC needed for FPIX or the lpGBTx).

Closeout Presentation

- The connection and interleaving between the CERN technical reviews, the NSF and DOE reviews was not clearly presented.

- The technical end of the subprojects and their due dates within the LS3 was not clearly presented. Doing so would make the schedule float and potential critical path more obvious.

- Frequent communication between ATLAS and CMS US-CMS project management is occurring and we encourage it to continue.

- For the presentations to the different funding agencies, consider further highlighting the roles of people funded by that agency (e.g. in International CMS).

- The risk analysis is advanced for this stage of the project. The plan for refining the risk analysis is well developed.

Recommendations

18. **Prior to the NSF CDR, prepare separate labor profiles for the NSF and DOE scopes of work including how the effort is distributed among the participating institutions. Where significant hiring will be needed, prepare a plan for addressing these needs.**

19. **Clearly present the high-level dependencies between NSF-DOE, NSF-CMS, and DOE-CMS for the NSF CDR.**

20. **Clearly identify the schedule float for each sub-project for the NSF CDR.**

4.0 Appendices

A. Charge

B. Agenda

C. Review Committee Contact List and Writing Assignments

Appendix A

Charge

Director's Review of US-CMS HL-LHC Upgrades

February 2-4, 2016

To: Mike Lindgren, Chief Project Officer

From: Nigel Lockyer, Director

Subject: Director's Progress Review of the US-CMS HL-LHC Upgrade Project

Please organize and conduct a Director's Review on February 2-4, 2016 to assess the US-CMS HL-LHC (a.k.a. Phase II) Upgrade Project. Upgrades to the CMS detector at the LHC will be needed for the future High Luminosity LHC running period, scheduled to start in 2026 and last about 10 years. These upgrades will be installed during Long Shutdown 3, which is scheduled to last for 30 months, starting in January 2024. The DOE has provided a preliminary budget profile scenario and the project anticipates receiving Critical Decision 0 (CD-0) approval in early 2016. NSF has scheduled a Conceptual Design Review (CDR) in March 2016 in anticipation of eventual construction funding through the Major Research Equipment and Facilities Construction (MREFC) account.

Closeout Presentation

This Director's review is to inform the laboratory about the state of the overall planning and readiness for presentation of the project plans to the DOE and NSF. The focus of this review is cost, schedule, management, ES&H, and technical readiness for meeting funding agency expectations for a project at this stage. The review committee should respond to the following questions:

1. **Design and Scope.** Have the project's performance requirements been sufficiently defined and do they flow down from the overall CMS plan? Are the conceptual designs sound and likely to meet the performance requirements? Do the designs capture the entire scope and are they adequately defined to support the cost and schedule estimates? Is there an adequate plan for design reviews? Is the R&D plan appropriate to mitigate technical risk on the project's timescale?
2. **Cost and Schedule.** Are the cost and schedule estimates credible and realistic? Do the estimates meet the funding agency targets? Are the estimating methodologies clearly defined and appropriate? Has adequate cost, scope and schedule contingency been identified to account for risk? Are assumptions used in the estimates, such as support from the core research program, realistic?
3. **Management.** Is the project appropriately staffed and being effectively managed at this stage? Are the roles, responsibilities, and contributions of DOE, NSF, and International CMS defined and appropriate? Have management plan documents been developed? Do the NSF CDR and NSF Project Execution Plan fulfill the NSF's expectations for conceptual design? Is there a credible plan for systems engineering functions such as requirements management, interface control, and QA? Are the projected resources sufficient to complete design, construction, and installation and are these resources likely to be available when needed? Are critical procurements sufficiently understood and coordinated across the organizations involved? Is the risk management system in place and appropriate? Have risks been adequately identified?
4. **Environment, Safety, and Health.** Is ES&H being appropriately addressed for this stage of the project?

The committee is asked to present a draft of their report at the review closeout and to issue the final report within two weeks of the review's conclusion.

Nigel Lockyer

Director

Fermi National Accelerator Laboratory

Appendix B

Agenda

Director's Review of US-CMS HL-LHC Upgrades

February 2-4, 2016

ReadyTalk Information for Plenaries and Closeout Session:
Toll-Free Dial-In: 866-740-1260; Access Code: 5571684#

Appendix C

Review Committee Contact List and Writing Assignments

Director's Review of US-CMS HL-LHC Upgrades
February 2-4, 2016

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