Department of Energy/
National Science Foundation
Review Committee Report

on the

Technical, Cost, Schedule, and
Management Review

of the

U.S. LHC CMS DETECTOR PROJECT

June 2002

EXECUTIVE SUMMARY

The Department of Energy (DOE) and the National Science Foundation (NSF) conducted a review of the U.S. CMS Construction project on June 5-6, 2002. The review was undertaken at the request of the co-Chairpersons of the U.S. Large Hadron Collider (LHC) Joint Oversight Group, Dr. John R. O'Fallon, Director, DOE Division of High Energy Physics, and Dr. John W. Lightbody, Jr., Physics Division, NSF Mathematical and Physical Sciences Directorate. The Review Committee was charged to assess technical progress in each subsystem, progress towards completing the U.S. deliverables on schedule, newly revised plans for pre-operations (2002-2004), adequacy of the updated cost to complete and project contingency.

The Compact Muon Solenoid (CMS) will be a large, general-purpose detector used to observe very high energy proton-proton collisions at the LHC, now under construction at CERN, the European Laboratory for Particle Physics, near Geneva, Switzerland. The detector is being built by a large international collaboration, including over 335 U.S. physicists from 35 universities and Fermi National Accelerator Laboratory. The U.S. CMS collaborators comprise twenty percent of the CMS collaboration and will provide a comparable fraction of the detector components. U.S. physicists are participating in many aspects of the detector design and fabrication, including important management roles.

The U.S. has taken responsibility for well-defined CMS detector subsystems and collaborating on other items defined as CMS common projects. The U.S. has management responsibilities within the international CMS collaboration for the Hadron Calorimeter, the end cap muon system, and the trigger.

Since the last review in May 2001, the U.S. CMS project continues to make excellent technical progress toward completing the deliverable items before the end of FY 2005. As reported at the end of April 2002, the project is 69 percent complete. It is expected that the U.S. scope will be completed in time to meet CMS requirements.

U.S. CMS maintains a Total Project Cost (TPC) estimate of $167.25 million. The project cost baseline includes a 53 percent overall contingency for the remaining work. The total contingency amount appears to be reasonable and adequate to complete the project. Overall, cost and schedule performance indices suggest the project is slightly behind schedule and is under-running costs. However, cost and schedule variances are well understood and are proactively monitored by management.

Overall the schedule is reasonable and schedule progress has been good. The Committee supports the Project's decision and actions to maintain the baseline schedule despite the CERN LHC schedule slippage. All disks of the Endcap Iron were completed and erected in the CMS assembly area in mid-March 2002 on budget and cost—a job well done. However, several subcommittees identified technical issues that create schedule risk for several components. Many of these potential delays are known by the project team and have been quantified and documented.

Overall, the project appears to be making good progress. The strong management team is to be commended for their exemplary application of established project management tools. There is a close working relationship between the U.S.CMS project, the CMS collaboration leadership, and CERN.

The DOE and NSF conducted a review of the U.S. LHC Research Program maintenance and operations (M&O) component on April 9-11, 2002. While additional attention was devoted to scrubbing the requirements and costs associated with the activities necessary to maintain and operate the detector equipment, the Committee believes the collaboration must review each CMS maintenance and operation element in greater detail with intent to reduce the overall M&O budget.

In conclusion, the U.S. CMS construction project continues to make impressive technical progress and to maintain an adequate contingency budget. The Committee urges the project to maintain its excellent technical progress and to work with other collaborators in a manner to make certain that U.S. and collaboration physicists deliver a detector that is functional for the intended physics research purposes. Success will depend in large part on the execution of an effective end game plan that guides the project transition from construction through assembly and installation to start-up operations. The design and implementation of the end game plan will be a major focus of the next full review.

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1. INTRODUCTION

The Large Hadron Collider (LHC), a hadron-hadron collider to be installed in the LEP tunnel at the CERN Laboratory (the European Laboratory for Particle Physics outside Geneva, Switzerland), will be a unique facility for basic research. It will provide the world's highest energies to probe the structure of matter and the forces that control it. CERN has committed itself to the construction of the LHC Accelerator with start-up projected in the year 2006. The CMS detector will be one of two large, general purpose detectors designed to find and study a wide variety of new phenomena made possible by the unprecedented LHC proton-proton collision energies and intensities.

The U.S. scientific community has strongly and repeatedly recommended United States involvement in the LHC program. Recommendations received bipartisan support in Congress and the Administration. On December 8, 1997 the U.S. Department of Energy (DOE), the National Science Foundation (NSF), and CERN signed an agreement for U.S. participation in the LHC program, including U.S. participation in CMS.

The LHC will be the highest energy accelerator in the world for many years following its completion. It will provide two proton beams, circulating in opposite directions, at an energy of 7 TeV each. These beams will collide with an event rate 1,000 times higher than that presently achieved at the Tevatron proton/anti-proton collider, currently the world's most energetic proton accelerator (nearly 1 TeV per beam) at Fermi National Accelerator Laboratory (Fermilab) outside Chicago. Two large detectors, CMS (Compact Muon Solenoid) and ATLAS (A Toroidal LHC Apparatus) will detect and record the results of interesting collisions. These detectors will be among the largest and most complex devices for experimental research ever undertaken, and the events that they record are expected to point to exciting, even revolutionary advances in the current understanding of matter and forces.

The CMS detector will be roughly 22 meters in length, 15 meters in diameter, and 12,500 metric tons in weight. Its central feature is a huge, high field (4 Tesla) solenoid, 13 meters in length, and 6 meters in diameter. Its "compact" design, will be big enough to contain the electromagnetic and hadron calorimetry, and makes possible a superb muon detection system. CMS will be one of the most complex scientific instruments ever built. DOE and NSF are working with the collaboration to maximize use of scarce resources by cooperative efforts within the broader high energy physics community in areas of commonality of functions, especially in networking and database management.

The CMS collaboration is exploring new ground in the management of large international scientific undertakings, involving scientists from 141 institutions in 31 nations. With DOE and NSF supporting over 335 CMS scientists from 36 U.S. institutions, the U.S. group comprises 20 percent of the full collaboration and plans to provide a comparable portion of the detector. U.S. physicists are participating in many aspects of the detector, including important management roles.

In an April 17, 2002 memorandum (Appendix A), Dr. John R. O'Fallon, Director, DOE Division of High Energy Physics, and Dr. John W. Lightbody, NSF Mathematical and Physical Sciences Directorate, requested the Office of Science Construction Management Support Division to conduct a review of the U.S. effort on the CMS detector.

Daniel R. Lehman of the Construction Management Support Division, chaired the DOE/NSF Review Committee for U.S. CMS. The Committee was organized into six subcommittees with members drawn from DOE national laboratories, U.S. universities, and DOE. In addition, there were observers from DOE, NSF, and CERN. The Committee membership and subcommittee structure are found in Appendix B. The review took place June 5-6, 2002, at Fermilab (see Review Agenda in Appendix C).

2. TECHNICAL SYSTEMS EVALUATIONS

2.1 Endcap Muon (WBS 1.1)

2.1.1 Findings

The Committee finds no major technical risks in the Endcap Muon (EMU) project. The EMU project is approximately 70 percent complete. The project BCWP is $26.5 million and the estimate-to-complete (ETC) is $12.3 million. The assigned contingency on the ETC is 48 percent, which is adequate for this subproject. The costs are under control for this subproject. Over half of the ETC resides in materials and supplies (M&S).

The production of cathode strip chamber (CSC) panels is nearly complete and CSC assembly is proceeding according to the schedule. Installation of on-chamber electronics and chamber certification at the FAST sites has started slowly but there is comfortable schedule float.

The on-chamber electronics are in production. Some of these electronics are nearly completed while others are just starting. All on-chamber electronics should be available by October 2003.

The design and prototyping of the peripheral crate electronics seems to be complete. The start of the off-chamber electronics production depends on radiation tests and a beam test in LHC-like beam conditions. This beam test has been postponed by CERN from fall 2002 until spring 2003.

CSC installation at SX5 should begin at CERN in November 2002. It appears above ground installation can proceed quickly. The planned vertical slice tests are critical pre-commissioning tests.

Good progress in developing a strong alignment system was presented. However, the design has not yet converged. The DCOPS development is not finished and will incur schedule risk if not completed by early 2003.

2.1.2 Comments

The EMU group is to be commended for its excellent progress.

The electronics group should develop a backup plan to ensure the LHC-like beam test does not jeopardize the completion of the off-chamber electronics.

The muon group has increased the scope of their deliverables in various ways (e.g., engineering work on the infrastructure at CERN and the vertical slice-tests), but these appear to be beneficial to the success of the EMU detector.

The Committee endorses the re-scoping of the ME3 alignment system.

Detailed M&O plans remain under discussion. It appears at least some of M&O costs are dedicated to maintaining a standing army.

2.1.3 Recommendations

1. Work with CERN to ensure the LHC-like beam test has high priority.

2. Complete a detailed M&O plan and identify personnel to support that plan by December 2002.

2.2 Hadron Calorimeter (WBS 1.2)

2.2.1 Findings

Significant progress has been made in all areas of this subproject. Production of some components is now complete. However, production of several key components is either just getting started or will only be starting in the next few months. In almost all cases where production is not yet well underway the schedule is tight for a variety of follow-on tasks, including beam calibrations of calorimeter modules, full testing of the vertical slice, and ultimately completion of surface installation on schedule.

The current estimate-to-complete is $10.5 million. In the last year a draw on contingency of $2.9 million has been made beyond scope changes. A scope increase of $600 K was offset by a cost decrease of the same amount for removal of layer 0 readout. The remaining cost increases are $800 K for cost overrun in the optics factory, $150 K for test stands, $400 K for electrical engineering and $200 K for additional hybrid photo-diode (HPD) development and testing costs, $200 K for increased optical costs and remainder for a variety of smaller tasks.

No new bottoms-up contingency analysis has been performed in the last year. Based on the last analysis and progress in the last year the contingency estimate remains at 45 percent of the estimate-to-complete.

Good progress has been made in all areas of this project. The hadron calorimeter barrel (HB) megatile production is now complete. Production of HB absorber wedges is complete and installation of megatiles into the wedges is nearing completion. Barrel readout boxes are now in production. Other readout box designs are nearing completion. HPD production and testing is getting started. HV and bias supplies for the HPDs are well into the prototyping phase. All electronics designs are nearing completion with substantial prototype systems under test. Initial demonstrations of the wire-source calibration have been made. A significant focused effort is underway aimed at SPS test beam calibration of some wedges this summer.

Technical concerns remain on the long-term stability of the production HPDs. However, there is no choice but to proceed, using additional contingency where necessary to address any future problems. Production HPDs that meet specifications have been delivered. No fundamental technical issues remain in the final design or production of readout boxes but design is not yet finished on endcap hadron (HE) or outer hadron calorimeter (HO). Production and assembly is now scheduled to happen rapidly over the next year. Front-end electronics boards have been completely prototyped but production has not yet begun. The QIE application specific integrated circuits (ASIC) production run is scheduled for July and requires increase in clock speed from 35 MHz to 40 MHz. This appears to present schedule risk but not to have substantial technical risk. A potential holdup is CERN production of the necessary optical coupling units (GOLs). Readout crate electronics prototypes are coming into existence but timescales are very tight. Small-scale demonstrations of calibration hardware appear successful but await larger-scale demonstration on modules at the CERN SPS test beam. Nominally adequate spares of all components are already assigned as part of the construction project.

The project is starting to make a transition from construction to operations. The stretched-out schedule for completion of LHC and CMS has presented schedule and manpower difficulties for the U.S. HCAL construction project. Important short-term operations activities includes a vertical slice test beginning in 2003 on the surface at CERN. Additional longer-term M&O tasks have been identified which address commissioning and maintenance of essential engineering and technical expertise between 2005 and 2007.

2.2.2 Comments

The status of the subproject is generally in good shape. Good progress has been demonstrated in all areas. Some schedule delays have occurred but float does exist for all remaining tasks. However, the schedule remains very tight for most areas of the remaining Hadron Calorimeter project. Management should act aggressively to push production forward on remaining tasks on the current schedule and not permit additional delays to accumulate. Doing so may require additional significant contingency use over the next year. The current base costs appear to be reasonably accurate and complete and the several technical and schedule risks which remain argue in favor of the relatively high 45 percent contingency. This is due to the fact that although the project is already very far into production, most of the remaining work is either very early in its production phase or not even yet into production. The contingency use in the last year on mature production tasks is relatively large and the Committee believes this shows that management must be aggressive on cost containment in all future production at the same time as they push for keeping the schedule. The two are not mutually exclusive.

The Hadron Calorimeter testing plan is well developed and appropriate. Large system tests are very important for devices of this complexity. Both the beam test at CERN this summer and the vertical slice test starting in the spring 2003 are important tasks needed for the progress of the Hadron Calorimeter. The group should allocate sufficient resources to guarantee the success of these exercises.

There is no choice but to proceed expeditiously with HPD production. It is fully possible that additional long-term stability problems will be identified but there appears to be little risk that the current production tubes will suffer massive failures. In addition, there is simply no alternative. Although substantial effort is already planned for understanding long-term stability, it appears that even more investment in this direction is justified. Finally, substantial contingency should be reserved at this point to permit flexibility in the future should stability problems be identified.

Given the relative difficulty of replacing components in readout boxes, the current plans for testing these complete systems seems somewhat small and appears to be determined more by the need to keep the schedule given the lateness of this production than any other factor. The nominal allowed failure rate of approximately one box per ten years may require more commissioning testing than is currently allocated.

The M&O plans and costs presented appear to be adequate to meet the needs through 2007 and to maintain expertise. The Committee noted that one major problem is not just money to keep manpower available but tasks to keep manpower adequately intellectually engaged in the current "operations desert" between 2005 and 2007. The Committee believes that it will be of interest to explore task sharing with other subsystems in that timescale in order to keep staff adequately engaged and perhaps minimize the total number of personnel required across the entire project. M&O manpower estimates beyond 2007 (eight FTEs) seem high for steady state operation.

2.2.3 Recommendations

1. Aggressively bring all remaining tasks into production and require that nascent production tasks reach full production rate rapidly.

2. CMS management must work with CERN to promptly produce GOL units to ensure availability of sufficient electronics for the vertical slice test.

3. Increase testing aimed to determine long-term stability of HPDs.

4. Consider means of increasing burn-in tests of complete readout boxes.

2.3 Trigger and Data Acquisition (WBS 1.3)

2.3.1 Findings and Comments

Impressive technical progress has been made in both the trigger and data acquisition systems. Both systems have a realistic design based on experience with similar systems.

Excellent progress has been made on five custom digital ASIC's needed for the calorimeter trigger. Second generation prototype calorimeter boards using the ASIC's are being tested, and it should be clear within the next year whether they satisfy CMS requirements. Redesign of the muon trigger has not only improved the performance of the design so that it meets the specifications for trigger latency, but also vastly simplifies the system, so that the track finder can fit into a single crate.

The Technical Design Report for data acquisition is in draft form, but the design is very far advanced and should be complete by the May 2001 DOE/NSF review into one that is soundly based on experience, simulation, and prototypes.

Beneficial occupancy of the underground counting room (USC55) is not scheduled until 2005, so much of the data acquisition and trigger commissioning will have to take place before final installation. The slice test on the surface is an essential part of the commissioning program, and both trigger and data acquisition systems will benefit greatly from participating in it.

2.3.2 Recommendations

1. Support for additional software engineering should be considered for the data acquisition project in 2003 and 2004 before support from operations ramps up in 2005.

2. Support for an additional physicist for trigger software development should be considered to replace reduced support in the base program for this effort, well in advance of the slice test.

2.4 Electromagnetic Calorimeter (WBS 1.4)

2.4.1 Findings

Progress since the May 2001 DOE/NSF review has been mixed. U.S. deliverables include the photo-sensors, avalanche photodiodes (APDs); the floating-point preamplifier (FPPA); the analog-to-digital converter (ADC); the optical link between the electronics buried in the detector and the off-detector electronics; and the monitor laser and switching system. This subsystem is about 60 percent complete.

Delivery of APDs from Hamamatsu has reached the full production rate of 5,000 per month. More than 32,000 (approximately 25 percent) APDs have been received. A screening method was developed about the time of the May 2001 DOE/NSF review. Rejection criteria were established that are expected to limit the failure rate of these devices to less than 1 to 1,000 over the detector lifetime. About five percent of the APDs are rejected; they are replaced at no cost by the vendor. The cost increase in this task was due to the addition of another technician to the qualification team.

The last round of FPPA submissions, received before the May 2001 DOE/NSF review, had multiple problems: noise levels four times the required level, pulse shape distortion and non-linearity, gain errors, and marginal timing of the output pulse. Investigation of performance details and extensive, improved simulation indicate that the first three of these are due to on-chip parasitic resistance. The last problem required output driver redesign to reduce settling time.

The design work for a new submission has been completed. The FPPA was reviewed earlier this year. Another review will be held this month before submitting the design at the end of June for another run. If chips from this submission behave well, production can begin in February 2003. However, the scheme for testing the production run chips must be redeveloped because Intersil, the manufacturer, decided not to participate in this process. Options include package testing at LBNL, at Fermilab, or in Europe. A large FPPA cost increase covers the work done by the LBNL engineering team.

The FPPA has moved onto CMS's critical path: there is time for only one more chip submission before the installation of the calorimeter is affected. Two backup plans have been considered. Both make use of deep sub-micron technology. In the first plan the FPPA is modified so that the output of the four gain ranges are each fed into individual deep-sub-micron process (DSM) ADCs. The second plan proposes complete redesign of the FPPA in DSM technology.

The order for the radiation-hard off-the-shelf ADC (AD4092) has been held up pending resolution of the FPPA problem. During this time the Electromagnetic Calorimeter group is considering development of a DSM ADC in order to reduce substantially the cost of the ADC.

There has been a complete redesign of the optical data links in order to reduce costs substantially. This scheme, which was adopted in March 2002, makes maximum use of components developed for the tracker system. Instead of the one link per crystal of the previous design, this design has three fibers for a trigger super-tower of 25 crystals. A new data store and trigger primitive generator chip must be designed. The new plan reduces the fiber-optic links from about 91,500 to approximately 12,000, reduces the number of receiver boards, and cuts on-detector power dissipation. The new design team includes developers from the tracker links group. The addition of an engineer has increased this item's cost. The DMILL control chip was removed from the project.

The U.S. ECAL group has been asked to take on the low voltage power supplies. There have also been requests to take on the remaining 50 percent of the links project costs, as well as all the ADC costs. These requests to ameliorate CMS ECAL cost increases are under consideration.

The monitor laser system has continued to make good progress. The monitor test bench was completed. The first laser was installed at CERN in August. The second laser and its switches are under construction and will be installed at CERN in autumn of this year. A long wavelength (approximately 700 nm) laser was investigated, though not added to the U.S. scope. This task is on schedule and budget.

Due to the FPPA problems, the super-module calibration scheme has been altered. It is expected that in the limited beam time available after FPPA production begins, it will not be possible to fully calibrate all the super-modules and endcap Ds with beam.

The plans and costs for M&O in the years 2002-2005 are reasonable. Though the group would like to participate in the slice test, this may prove difficult. Manpower is now quite limited. If this state continues, the team needs to concentrate its effort on the beam tests that occur directly before the slice tests. The estimated cost-to-complete, as well as the contingency appear reasonable for the current scope.

2.4.2 Comments

The approach adopted to solve the FPPA problem by detailed and complete study of the prototype chips, with extensive review before submissions, is the right way to proceed, rather than the less systematic method of the past. A concern with this approach is that excessive conservatism may introduce more delay than is necessary. The Committee is encouraged by the team's efforts in development of backup plans. The scenario in which a new DSM ADC is attached to outputs of each of the FPPA gain ranges is deemed to be the most likely to succeed, and should be devoted the largest share of effort. In order to limit schedule risk, the team should begin the task of adapting the FPPA design for this possibility. The ADC effort, which is worth pursuing for the cost savings independent of its use in solving the FPPA problem, is likely to yield results on a relatively short time scale. The team should also consider devoting more effort to the full DSM solution design effort. Exposure to delays must be limited. Finally, the group must quickly develop a detailed testing plan. Making use of facilities and expertise at Fermilab, if available, is a good option.

It is late in development process to be entering into a redesign of the fiber optical link system. Nevertheless, this is the right choice because of the substantial savings that are expected to result, even though there is increased risk of multi-channel failures. By adapting an established design and adding an experienced, and enthusiastic design team, the Committee feels that this effort is likely to succeed.

Taking on the low-voltage power supplies is a natural fit for the U.S. effort. However, because of the U.S. Electromagnetic Calorimeter chronic engineering shortage, this task should only be taken on if manpower can be added to this effort as it was added to the optical link development.

The laser calibration system is in good shape. The long wavelength laser is a necessary addition to the calibration system. The best time to procure and install this system is now, while the laser team is still together and focused on this effort.

2.4.3 Recommendations

1. Limit schedule risk by initiating design work to adapt the FPPA for use with multiple ADCs.

2. Identify and leverage facilities and expertise within the collaboration for chip testing to contain costs and avoid schedule slippage.

2.5 Forward Pixels (WBS 1.5)

2.5.1 Findings

The Forward Pixel subproject is 26 percent complete, with a contingency of $3.2 million, which is 60 percent of the estimated cost to complete. This subproject is in the later stages of development, and not yet a construction project.

Substantial progress has occurred on the sensors, on the ASIC’s (Application Specific Integrated Circuits), and on the VHDI’s (Very High Density Interconnect flex circuits).

A sensor design that passes the TDR specification is available. A substantial number of prototype sensors is available, and a pre-production submission is planned during the next year.

The ROC (Read Out Chip), which is on the Pixel critical path, was submitted to the producer in December 2001, about five months past the milestone from the March 2001 DOE/NSF review. The ROC’s, produced with the DMILL process, were returned in March 2002, and preliminary testing has been done. Preliminary testing has shown that these ROCs are functional, although some performance issues have been uncovered. About 240 ROC’s on 3.5 wafers are now available for incorporation into prototypes.

The TBM (Token Bit Manager) and PLL (Phase Lock Loop) ASIC segments were produced with the ROC, with the DMILL process. Preliminary testing has shown that the TBM and PLL are functional, although power consumption is a bit high and the maximum clock speed is a bit lower than expected.

The ROC, as well as the TBM and PLL segments will be transferred from DMILL to 0.25 micron, which will bring integrated circuit-related delay to a total of nearly one year.

Two European bump-bonding vendors (IZT and AMS) have been qualified by ATLAS and ALICE, for eight-inch wafers using the 0.25 micron process. These vendors appear capable of performing CMS bonding. BTEV and CMS are working with a third vendor in the U.S. (MCNC).

Project manpower (less faculty) has increased from six FTE in 2001 to eleven FTE in 2002. One Electronics Engineer was lost at Fermilab. A further increase in manpower to 17 FTE is planned in 2003, and 19 FTE are planned in 2004.

A detailed plan for Pre-Operations and M&O has been formulated.

2.5.2 Comments

The Committee commends the Pixel group and particularly the subsystem manager for clear and informative presentations and documentation.

The relatively high proportion of contingency is appropriate for this subproject, because this subproject is on the cutting edge of technology advancement, with many associated risks.

The ROC is the responsibility of PSI (Paul Scherrer Institute), so the U.S. Forward Pixel group does not have control over the ROC schedule. Communication is not strong between International CMS Project Management and the U.S. Forward Pixel group.

Minimum specifications for the ROC do not appear to have been decided. There is risk that added functionality for the ROC will continue to be developed, consequently, delaying the completion of system aspects of the Pixel project.

The ROC's, TBM's, and DLL's delivered so far will be extremely useful for the development of system aspects of the Pixel project. Systems tests should occur during the next year. More planning will be necessary to insure success of the systems tests.

The pixel dimensions might change from 150 by 150 microns to 150 by 100 microns. There has been no top-to-bottom evaluation of system consequences of this change, as recommended in the May 2001 DOE/NSF review.

The loss of one Fermilab electrical engineer puts the systems tests planned for the next year at risk of delay.

Substantial work on the mechanics and cooling for the Forward Pixels occurred, although a successful design for the multipurpose support and cooling structure is not yet in hand.

It is probable that the current Forward Pixel construction schedule will extend beyond 2005, by about one year. The difficulty of finishing Pixel construction by 2005 has been noted in previous reviews. The Pixel detector is not on the International CMS detector critical path, because the detector will function initially without the Pixel detector, and the Pixel detector can be installed or removed in a relatively short time period (about one month).

The manpower resources specified for long-term M&O are close to the manpower resources utilized at the peak of construction. The M&O manpower level is justified by regular replacement of radiation-damaged components, difficulty of technology and the logistics of working at CERN. The M&O manpower looks comfortable.

2.5.3 Recommendations

1. Establish and adhere to a minimum specification for the ROC, by November 2002.

2. Improve communications concerning pixel specifications and schedule among International CMS Management, U.S. CMS Management, and the U.S. Forward Pixel group.

3. Make a detailed plan, by August 2002, with reportable milestones for the upcoming systems tests. Identify adequate manpower to successfully complete these tests.

4. Develop a realistic long-term schedule for the Forward Pixel construction, and identify the resources needed to meet that schedule.

2.6 Common Projects (WBS 1.6)

2.6.1 Findings and Comments

All disks of the Endcap Iron were completed and erected in the CMS assembly area in mid-March 2002, on budget and on schedule. Job well done. This accomplishment is due to good management, good design, and good workmanship from those who were involved. Photogrammetry shows that the mounts for the CSC of the Forward Muon System were located with an accuracy of 0.2-0.3 mm, requiring no corrective adjustment for the CSC mount mechanism.

Approximately $5 million saved in this Endcap contract under WBS 1.6 was applied to the procurement of superconductor and pure aluminum stabilizer for the CMS magnet. The superconducting material and aluminum stabilizer were co-extruded, and delivered to ANSALDO of Italy.

2.7 Silicon Tracker (WBS 1.8)

2.7.1 Findings

The Silicon Tracker subproject is 16 percent complete, with a contingency of $1.6 million, which is 57 percent of the estimated cost to complete. This subproject consists of assembly from parts produced outside the U.S., and testing, qualification, and installation of the assembled modules.

One assembly robot (gantry) is operating at Fermilab, and another is undergoing installation at University of California, Santa Barbara (UCSB). Kulicke and Soffa (K&S) Model 8090 wirebonders are available at both Fermilab and UCSB.

Six modules were made at Fermilab, and they have passed quality standards. These modules were used in a recent test beam, in part to study the phenomenon of highly ionizing events.

One LabView-based DAQ system, and one DAQ system consisting of the official CMS readout stream are running at Fermilab. These systems have been validated by comparisons of results with CERN systems.

Commencement of production module assembly has been delayed by about nine months due to problems with the hybrid circuits.

Project manpower (less faculty) has increased from 1 FTE in 2001 to 11 FTE in 2002, consisting mainly of physicists, not technical staff. A manpower increase to nearly 16 FTE, consisting mainly of technicians, is planned in 2003. A subsequent increase to 36 FTE is planned in 2004.

2.7.2 Comments

The Committee commends the Silicon Tracker group for their informative presentations.

There is little cost exposure from the recent experience of hybrid delay, because there is very little manpower currently paid from project funds. The capacity of Fermilab and the UCSB sites and the planned resources appear sufficient to assemble the modules as long as further delays from all part deliveries stay less than about one year. Even further delays beyond one year would probably require round-the-clock shifts to maintain the schedule, with added costs covered by contingency.

The hybrid causing the recent delay does not employ risky technology. Similar hybrids have been successfully produced and used in numerous silicon projects.

The recent ramp-up of manpower has been substantial. Achieving the increase planned between 2003 and 2004 will be challenging. The M&O manpower estimates look comfortable.

2.7.3 Recommendations

1. Develop backup strategies to handle late arrival of parts.

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3. COST ESTIMATE

3.1 Findings

The U.S. CMS total project cost remains at $167.25 million. As reported at the end of April 2002, the project is 69 percent complete. Contingency as a percentage of remaining work is 53 percent. Table 3-1 compares the cost estimate from the May 2001 review to this review.

Table 3-1. U. S. CMS Cost Estimate

WBS	System or Item	U.S. CMS Baseline Comparison		
		April 2001 Base Cost (AY$K)	April 2002 Base Cost (AY$K)	Difference
1.1	End Cap Muon (EMU)	35,995	38,885	2,890
1.2	Hadron Calorimeter (HCAL)	38,336	41,082	2,746
1.3	Trigger/Data Acquisition (Tridas)	13,747	12,391	-1,328
1.4	Electromagnetic Calorimeter (ECAL)	9,861	12,136	2,275
1.5	Forward Pixels (FPIX)	6,756	7,234	478
1.6	Common Projects (CP)	23,000	23,000	0
1.7	Project Office (PO)	7,569	6,642	-927
1.8	Silicon Tracker (SiTkr)	3,325	3,353	28
U.S. CMS Total Estimated Cost (AY$)		138,674	144,692	6,018
Contingency		28,576	22,558	-6,018
U.S. CMS Total Project Cost (AY$)		167,250	167,250	0

Overall cost and schedule performance trends indicate the project is slightly behind schedule and is under-running costs. The cost performance is primarily influenced by delays in receiving invoices. Cost and schedule variances are well understood and are proactively monitored by management and routinely discussed with subsystem managers.

The bottoms-up sum of subsystem installation tasks is $4.75 million. U.S. CMS management suggested that the contingency associated with these tasks should be 50-100 percent.

3.2 Comments

The U.S. CMS management team is to be commended for exemplary use of fundamental project management tools.

The Committee supports U.S. CMS management's assessment of the degree of uncertainty associated with the installation tasks and encourages the project to establish and maintain a level of contingency at the higher end of the range suggested.

The U.S. CMS overall contingency situation is adequate to complete the project. The Committee agrees that the first priority use of contingency is to complete the U.S. deliverables (on schedule). Supporting the CMS International needs for completing the detector is an appropriate secondary use, however, the project team should not allow pressure from CMS International to make premature decisions regarding contingency allocation.

U.S. CMS management has identified several potential uses of project contingency (AC/DC converters, Muon alignment system, re-scoping DAQ) that mutually benefit CMS International and U.S. CMS. The Committee supports these proposals.

One recommendation at the March 2001 DOE/NSF review was to perform a detailed contingency analysis for all work remaining and commissioning work. Efforts were made to complete this task, but a comprehensive analysis of all components was not completed. The recommendation regarding preparation of a revised estimate to complete is satisfied.

3.3 Recommendations

1. Complete the detailed contingency analysis that was started, but not completed by all subsystems and present findings for the entire project at the next Quarterly Project Review.

4. SCHEDULE and FUNDING

4.1 Findings

CMS is preparing a new schedule that is expected to be approved at the next LHC review that will incorporate a one-year slip in overall project end date. The U.S. CMS intends to maintain their current schedule and milestones. Several areas of schedule risk have been identified by the project, and are summarized in Table 4-1.

Table 4-1. Summary of U. S. CMS Schedule Concerns

Subproject	Delay (Days)
EMU – Services	~ 20
HCAL – Readout Boxes	~ 40-60
HCAL – Front-End Electronics	~ 40
HCAL – Trigger/DAQ and Supplies	~ 80-100
HCAL – PMT's and Boxes	~ 100
Trigger – RCT Boards	~ 65
ECAL – ADC's	~ 40
FPIX – HDI/VHDI Electronics	~ 140*
SiTrkr – Electronics Test Equipment	~ 20*

* The U.S. effort in FPIX and SiTrkr are dependent on delivery of foreign parts. The projected delays are for these subsystems are off the critical path and are less than the projected slip in the overall LHC schedule.

The recommendation from the March 2001 DOE/NSF review to develop a mechanism to communicate and resolve issues with CMS International management has been addressed.

4.2 Comments

Overall the U.S. CMS schedule is reasonable. Frequent schedule updates provide excellent planning and project execution information for U.S. CMS project and subproject teams.

Technical and schedule risk still exist within the Forward Pixel subsystem. The Silicon Tracker schedule is at some risk because the U.S. collaboration relies on its European counterparts for delivery of many of the components necessary for assembly at the U.S. facilities. The Committee believes that the forward pixel may well slip beyond FY 2005 project end date.

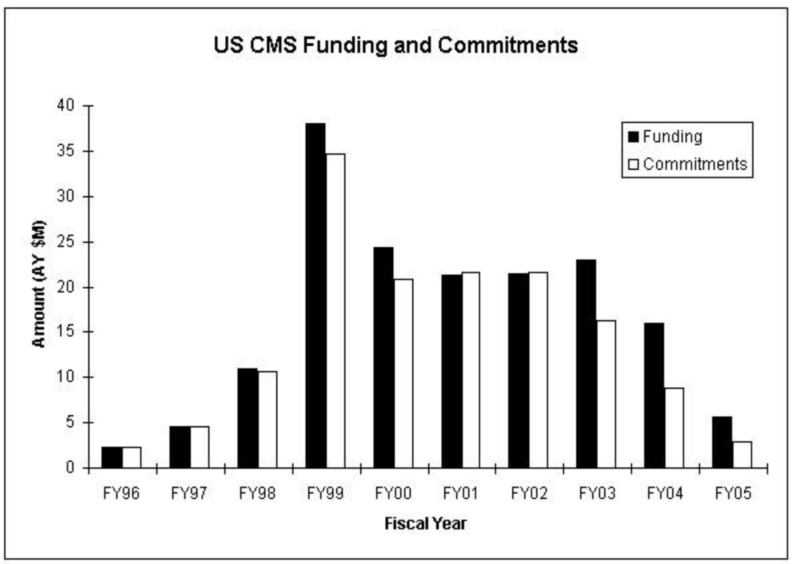
While many subsystem schedule delays will not show up on the CMS International critical path, delays that push the U.S. CMS deliverables out beyond FY 2005 will jeopardize completing the project on schedule.

The potential revisions to the CMS schedule (Version 33) would push installation of some U.S. CMS deliverables into FY 2006 and perhaps beyond. This is an area that needs to be addressed with the funding agencies (see recommendation in Section 5, Management).

The current funding profile is provided in Figure 4-2.

Figure 4-2. U.S. CMS Funding and Commitments

	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	Total
Funding	2.30	4.62	10.95	38.03	24.26	21.23	21.40	22.91	15.98	5.56		167.25
Commitments	2.30	4.62	10.72	34.74	20.83	21.67	21.53	16.25	8.87	2.89	0.28	144.69



4.3 Recommendation

1. Re-evaluate the subproject schedules considering the comments and concerns expressed in other sections in this report and present results at the next Quarterly Project Review.

5. MANAGEMENT (WBS 1.7)

5.1 Findings

Due to a technical problem arising from the delivery of superconducting cable from industry, the completion date of the LHC machine has been delayed by about one and a half year. CERN is also facing severe funding difficulties, mostly arising from the overrun in cost of the LHC machine and the detector construction. This new schedule and the mid-term budget plan are expected to be adopted formally by the CERN Council at its June 2002 meeting. In spite of this delay, the U.S. CMS group intends to continue the current pace of the construction work aiming at an early completion of deliverables listed in the current baseline agreement by the end of September 2005.

Since the March 2001 DOE/NSF review, the U.S. CMS project has made significant technical progress toward completing the deliverable items before the end of FY 2005. The change in cost to complete these items has been relatively small. The overall schedule appears to be consistent with the goal stated above, though some subsystem reviewers expressed minor schedule concerns. In most cases, installation of equipment in the final underground experimental hall will take place in FY 2006.

The International CMS management expects additional contributions of 54 MCHF to mitigate a funding shortfall of 62.7 MCHF. U.S. CMS is assessed for 12.8 MCHF (approximately $7 million) toward this contribution. CMS has developed approximately $20 million of their staging and saving plan, which will be discussed at the International CMS meeting next week. This staging will have little impact on the physics at the initial luminosity expected at the LHC. This staging includes savings of about 8 MCHF by giving up about one half of DAQ bandwidth. This leaves about 27.7 MCHF to be raised later for the high luminosity upgrade. Hopefully, additional collaborators will be found who can fund this upgrade.

The project completion definition for the purpose of the hand-off to M&O phase, which was presented to DOE in the earlier M&O review, was discussed. In addition, the respective subsystem managers presented the hand-off plan for each subsystem.

5.2 Comments

The Committee would like to commend the presenters and the U.S. CMS management for their frank and open description of the present status of the U.S CMS project and the status of the International CMS. The U.S. CMS project has continued to make excellent progress toward the completion of subsystems on the baseline schedule. Because of the delay in the completion of the CMS cavern, the installation of the detector in the underground location will not take place before September 30, 2005, the anticipated date for Critical Decision 4, Approve Start of Operations. The cost increase since the May 2001 DOE/NSF review is minimal.

The International CMS has a good management structure, and recently supplemented it's strength with a Technical Coordination group, which is to oversee the technical progress of the subsystems and coordinate the integration of the detector. Likewise, the U.S. CMS has a good management structure that is staffed by experienced and competent people and outfitted with good project management tools.

The delay in the completion of the CMS cavern and the LHC machine will provide extra time between the completion of the detector subsystems and their installation in the final location. The Committee applauds CMS's plan to assemble the detector slices above ground where easy and efficient access can be made, and to carry out a slice test.

It appears that the present level of contingency is sufficient to complete the scope of the U.S. CMS deliverables. The highest priority for future contingency use should be to ensure the timely completion of the U.S. CMS scope. To the extent that contingency funds will be freed up by the completion of components on the base budget, the committee endorses U.S. CMS taking on additional tasks for the common good of International CMS overall.

The U.S. CMS has begun the process of scrubbing the estimate for the physics research-funding request (the sum of Pre-Operations, M&O, Computing, etc.) that was presented in the April 2002 M&O review, addressing the detailed needs of each subsystem, and applying an additional management challenge. The result is a reduction of the research-funding estimate from $53.9 to 37.9 million for the period of FY 2002-FY 2005, and from $34.7 to 31.2 million for FY 2007.

This scrubbed funding scenario allows only for bare bones procurement of computing equipment, reaching about 20 percent of the full compute power needed for full luminosity operation in 2008 and 100 percent in 2009. The Committee observes that this level of computing power is sufficient in the early stage of the program. The Committee is pleased to note that this scrubbed funding, will still allow CMS to do frontier physics in the first year of collisions.

DOE and NSF have supported the U.S. LHC detector projects jointly with a funding ratio of about three to one. Continued funding from NSF, as well as DOE for maintenance and operation of U.S. CMS is critical for a sound physics program.

During the fall 2000, the International CMS management has made a difficult technology choice for the outer barrel tracker that could have had adverse consequences. It is commendable that U.S. CMS has stepped in by establishing two Silicon Tracker "ROD"-assembly lines, one at Fermilab and the other at University of California, Santa Barbara in order to minimize the schedule risk that could have arisen from this decision. The U.S. CMS group is ready for assembly, and is presently waiting for the arrival of parts from Europe.

There appears to be some technical areas (e.g., Forward Pixels) where the communication between the International CMS management and the U.S. CMS managers needs to be strengthened.

Fermilab has carried out a Director's Review, chaired by Ed Temple, of the CMS project on April 30 and May 1, 2002. This review selected a few critical subsystems and studied these in depth. This type of review is very useful.

Fermilab intends to continue its oversight role of CMS to include Software and Computing (SWC), Maintenance and Operation (M&O), and Upgrade R&D phases. The Fermilab Computing Division has provided space for the SWC effort on the ninth floor, and the Particle Physics Division is pursuing a plan to make the entire eleventh floor of Wilson Hall available to U.S. CMS. The eleventh floor should accommodate the current Fermilab U.S. CMS group, an additional 60 visitors, and a Virtual Control Room for CMS.

The situation with the Electromagnetic Calorimeter FPPA is highly critical. Because of the potential for significant cost and schedule impact, there is a need for close management attention. While the next chip submission is scheduled to occur shortly and has received much scrutiny, the committee supports U.S. CMS's efforts to start developing a work around plan.

5.3 Recommendations

1. Conduct a combined, three-day review of U.S. CMS Construction and Pre-operations in one year with a mini review in six months.

2. Refine the U.S. CMS End-Game plan so that it is fully consistent with the International CMS End-Game plan and present an interim report at the next mini review and a full report at the next full review.

3. Work with the agencies to refine the definition of project completion and present the result at a mini review in six months.

4. Work with the agencies to decide how to handle the part of the construction activities (i.e., in cavern installation) that are anticipated to spill over into FY 2006. The final resolution must be presented at the next full review.