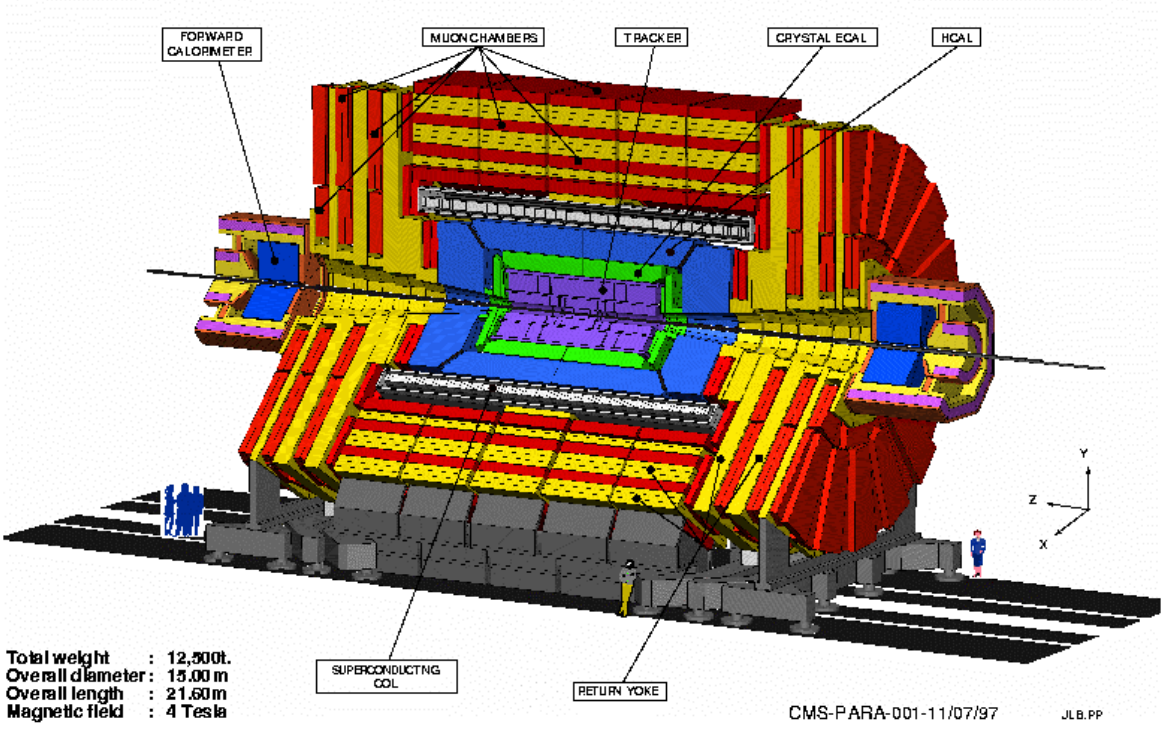
U.S. CMS

Operations Program

Management Plan



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Submission and Approvals

This Management Plan defines the plans, organization, systems and relevant interfaces for the U.S. CMS Operations Program for the CMS Experiment as part of the Large Hadron Collider (LHC) at the European Laboratory for Nuclear Research (CERN). The U.S. role in the operation and exploitation of the CMS detector is funded jointly by the U.S. Department of Energy and the National Science Foundation.

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US CMS Operations Program Management Plan (Revision 6.0)
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1. INTRODUCTION

1.1 Overview and Scope of the U.S. CMS Operations Program Management Plan

This document is the Operations Program Management Plan (OPMP) that U.S. participants in the Compact Muon Solenoid (CMS) experiment will follow to meet the technical, cost, and schedule objectives of the U.S. CMS Operations Program. This Management Plan defines the plans, organization, systems and relevant interfaces for the U.S. CMS role in the operation of the CMS experiment as part of the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN). The U.S. role in the operation and exploitation of the CMS detector is funded jointly by the U.S. Department of Energy (DOE) and the National Science Foundation (NSF) and is referred to as the U.S. CMS Operations Program (OP).

This OPMP covers the commissioning, operation and maintenance of the CMS detector, including research and development for detector improvements and upgrades, the US contribution to CMS software and computing infrastructure, and the development of the analysis infrastructure that will allow U.S. collaborators to participate in the data analysis of the CMS experiment. However, the actual performance of the physics analysis itself is not within the purview of this program but belongs to the Proton Research Program within the Office of High Energy Physics (OHEP) of the DOE and the Elementary Particle Physics Program (EPP) of the Physics Division of the National Science Foundation. The R&D activities necessary to modify CMS to ensure that CMS is always able to fully exploit the physics opportunities of the LHC, including improvements to the existing detectors to make them more maintainable and provide enhanced physics capability and to enable them to cope with higher luminosities planned for the LHC after several years of operation, are included in the Operations Program. However, the actual implementation of the larger upgrades, as opposed to repairs and modest improvements, will be carried out in one or more "construction projects" that will be managed separately.

This OPMP also describes the linkage of the Operations Program to external entities including the CMS Collaboration, the U.S. CMS Collaboration, and such entities as the Worldwide LHC Computing Grid (WLCG) and the Open Science Grid (OSG). The relationship between the OP, DOE, NSF and the host laboratory, Fermilab (FNAL) is also described.

This OPMP establishes the technical scope, cost and schedule to which the OP will be managed and against which the performance of the OP will be measured. The OPMP defines the highest level Work Breakdown Structure (WBS) for the program and presents a corresponding organizational structure. The OPMP also describes the management control mechanisms, configuration and changes in management, and reporting requirements. Although the OP is not a project, many of the procedures appropriate to a project will be followed where applicable. Notable exceptions are that earned value reporting will not be used and detailed scheduling will be applied only where appropriate to an ongoing operations program.

The mission of the Detector Operations task (DO) is to commission the parts of the CMS detector for which the U.S. is responsible and to provide the means to align and calibrate it so that physics results may be extracted quickly. Thereafter the DO task aims to operate the detector, to maintain it in good working order, to collect high quality data, and to write and maintain the low level programs needed to verify detector performance. R&D for detector upgrades also resides within the DO task. Additionally, the OP includes all efforts related to the U.S. CMS Software & Computing Operations (SCO) task, whose mission is to develop and operate the U.S. share of the software and computing resources necessary to process CMS data expeditiously and to enable U.S. physicists to fully participate in the physics of CMS. The OPMP also discusses "Common Operations" (CO). These are parts of the program's activities that are either common to both DO or SCO or that don't fall within the definition of either of them, but relate to the interaction between the U.S. Program and the CMS experiment as a whole. The DO and SCO programs, together with Common Operations, form the three parts the U.S. CMS Operations Program that are managed as a single coherent entity.

The mission of the Operations Program may be expressed in terms of the following four sets of objectives: scientific, technical, schedule, and cost.

1.1.1 Scientific Objectives

The CMS Detector is a general purpose colliding beam detector designed to study proton on proton collisions with center of mass energy approaching 14 TeV and a peak luminosity approaching $10^{34}cm^{-2}s^{-1}$ at the LHC located at CERN near Geneva, Switzerland. The LHC has sufficient energy and luminosity (collision rate) to explore parton-parton collisions with energies of more than a Tera-electron Volt (TeV) in the center of mass. At these energies the physics of

electroweak symmetry breaking should be manifest and physics "beyond the Standard Model" should be observed. It is the goal of CMS to discover this physics and study it in depth. CMS is expected to operate at the LHC for twenty or more years. Over this period, several upgrades to the LHC will increase the peak and integrated luminosity by another factor of 3-5 over the original design goals. The CMS detector will need to be upgraded to exploit these increases.

1.1.2 Technical Objectives

The overall dimensions of the CMS detector are immense, with a length of 21.6m (with Forward Hadron Calorimeters excluded), a diameter of 15.0m, and a total weight of 12,500 metric tons. Its central feature is a high field (4 Tesla) solenoid of 13m length and 2.95m radius. CMS is one of the most complex scientific instruments ever built. The detector has about 100 million readout channels and can generate data at a rate of more than 300 Mbytes/s. The U.S. funding agencies and the U.S. participants in CMS have taken responsibility through this program to operate the deliverables specified in the U.S. CMS Detector Construction Project[1] and to contribute proportionally to the common activities of the CMS experiment.

For detector subsystems, the U.S. CMS strategy is an extension of its contribution to the construction of CMS, where it took leadership roles in particular areas where the U.S. had expertise and interest, assuming responsibilities for major deliverables. Based on this, the U.S. has major responsibilities for the maintenance, operation, and R&D for upgrades for the Endcap Muon Cathode Strip Chambers (EMU /CSC), the Hadron Calorimeter (HCAL), and the Forward Pixel (FPIX) System. For each of the projects in which it plays a dominant role the U.S. team has responsibility for vertical integration, which is for carrying out all necessary hardware and software activities to enable physicists to use the device in data analysis. For these subsystems, the U.S. has considerable autonomy and flexibility in optimizing resources and schedule for maintenance and operation of U.S. deliverables. For still other systems, in which it plays a significant but not a dominant role, the Electromagnetic Calorimeter (ECAL), the Silicon Strip Detector (SiTRK), Trigger (TRIG), and Data Acquisition (DAQ), the U.S. carries out a fair share of the work and bears an appropriate share of the financial burden based on a combination of what it delivered to the project, on annual agreements, and on sharing formulas long in use at CERN and accepted by the U.S. funding agencies in their MOU with CERN[2].

For software and computing, the U.S. has made commitments to CMS to support a Tier-1 Computing Center and a number of Tier-2 Centers, the total being proportional to its share of the production computing and simulation[3]. An important technical objective is the provision of a fair share of the core software to support the alignment, calibration and monitoring of the detector and to contribute to software systems supporting the production computing including reconstruction, simulation, data management, data processing, and the analysis framework and basic toolkit. These are linked to the U.S. share of PhD physicists in CMS.

The OP provides the hardware infrastructure for physics analysis by hosting physics data sets at Tier-2 centers for analysis job submission, and supports the final analysis steps through assistance to university groups who want to set up Tier-3 systems. In addition the OP provides a Computer Analysis Facility (CAF) at FNAL to augment the university-based Tier-3s. These facilities contain large amounts of storage that will provide for rapid access to datasets for analysis by U.S. physicists. The OP also provides facilities for training U.S. physicists in the use of the computing systems and data analysis software, including the resources at the Tier-3 sites.

The OP provides additional services, such as remote control rooms and videoconferencing, to enable U.S. collaborators who wish to participate in CMS, but cannot go to CERN, to carry out their obligations within the U.S. This includes the facilities to take remote shifts at Fermilab. The OP also provides administrative and logistics support at CERN for U.S. people doing work for the program.

The OP also supplies the resources and facilities necessary to participate in R&D for future detectors that can operate at higher luminosities and sustain higher radiation doses envisioned for the LHC upgrade. It also provides for R&D into the new computing hardware and new software techniques that will permit the analysis of the additional, and more complex, data that will be collected at an upgraded LHC.

1.1.3 Schedule Objectives

The OP will do its part to ensure that CMS is ready to extract the maximum physics return from the available luminosity and energy. The U.S. should meet all commitments for maintenance of detectors during shutdowns in a manner fully consistent with the overall planning of CMS.

Computer facilities should be delivered, debugged and commissioned according to schedules agreed to by U.S. CMS and the WLCG, taking into account the most up-to-date running schedules and projections of luminosity. Similarly, software deliverables should conform to the schedules set by the CMS Offline Software Coordinator. In this way, the schedule for the detector operations and software and computing operations of the OP are kept aligned with the CMS and LHC schedules.

1.1.4 Cost Objectives

The fundamental cost objective is to optimize the use of U.S. CMS funds to achieve the scientific, technical and schedule objectives described above.

The U.S. participants in the CMS Collaboration have taken responsibility to operate and maintain the parts of the CMS detector that the U.S. built. This is done by engineers and technicians supported by the Operations Program and by physicists supported by the DOE and NSF physics research programs.

U.S. physicists comprise about 35% of all the Ph.D. physicists on CMS. This number is commonly used at CERN to define the sharing of responsibilities within scientific collaborations. The host laboratory, Fermilab, is the site of a "Tier-1" computing center for CMS. This is the largest amongst the seven CMS Tier-1 centers. The hardware and most of the staff for this Tier-1 is provided by the OP. In addition, seven "Tier-2" centers are sited at U.S. CMS universities, and supported largely by the OP.

Similarly, U.S. physicists are responsible for 35% of all the shift work and maintenance and operations tasks associated with the detector and the production computing. The U.S. is also expected to provide support for its appropriate share of senior managers of detector operations and computing and software operations tasks in CMS, which often requires relocation or frequent travel to CERN, and to contribute its proper share to M&O Category A and M&O Category B (described below).

1.2 Goals and Scope of the Detector Operations (DO) Task

The goals and scope of the Detector Operations task are the following: operation of the CMS detector at high efficiency for accumulation of physics data; maintenance and improvement

of the CMS detector to insure high quality of the data; and upgrade of the CMS detector so that CMS is fully capable of exploiting the luminosity provided by the LHC.
A description of the DO Work Breakdown Structure (WBS) is provided in Appendix 1.

The CMS detector is a complex device and requires expert personnel and specialized hardware and software to maintain it and to operate it so as to maximize its data collection efficiency. Working with CMS detector managers, the U.S. CMS Detector Operations management team identifies needs and provides resources for detector maintenance. This includes hardware repairs, software and firmware upgrades, maintenance of sufficient spares and analysis and resolution of problems as they arise. Detector maintenance also includes the development and improvement of hardware and software for detector alignment and calibration. In addition, to maintaining the detector itself, this task includes maintenance of the detector infrastructure, including power, cooling, controls and safety systems.

Detector Operation includes also the essential R&D necessary to ensure that the CMS detector will continue to meet and exceed the CMS design specification as the luminosity of the LHC increases or to add critical new capabilities to exploit the LHC discovery potential. The DO supports R&D on the systems that the U.S. has helped to construct.

1.3 Goals and Scope of the Software and Computing Operations (SCO)

The goal of the U.S. CMS Software and Computing effort is to provide the software and computing resources needed to enable U.S. physicists to fully participate in the physics program of CMS and to provide a share to the software and computing resources needed by the CMS experiment for central computing tasks.

A key element in achieving this goal is to develop and maintain the software and to construct, upgrade and operate the facilities to provide an integrated software and computing environment that meets the U.S. commitment to provide a fair share of CMS' computing resources and enables central roles for U.S. scientists in CMS data analysis. This includes provision of resources and facilities for participation by U.S. CMS physicists, especially those who wish to remain based in the U.S., in all analysis efforts and activities of interest to them.

The SCO provides services and facilities to U.S. CMS and the whole of CMS through a Tier-1 regional computing center and a central analysis facility (CAF) at Fermilab, and a set of Tier-2 centers at U.S. universities. Efforts are provided by the computing organization at

Fermilab, by U.S. universities. Services and facilities provided to U.S. CMS at Tier-1 and Tier-2 centers must integrate with the local organizations providing them, making optimal use of and exploiting synergies and economies of scale with other local, national and global computing activities.

Significant data analysis will take place external to CERN. The U.S. goals are consistent with that policy by marshaling U.S. national resources to support the analysis activities of U.S. physicists on CMS. The U.S. expects to do this in a cost effective way by leveraging the knowledge, talent, and experience with HEP computing within U.S. universities and Fermilab. U.S. based facilities and services must couple smoothly to CERN central computing and other Tier-1 and Tier-2 regional computing centers.

The SCO effort is closely coordinated with the international CMS Offline and Computing Projects that cover the software and computing aspects of the operation, calibration and upgrade of the CMS detector the storage, access and processing of event data, including simulated data, event reconstruction and analysis, and the computing infrastructure and application software services for the above.

The SCO provides resources to solve special problems related to the geographical separation of U.S. physicists from the site of the experiment and to differences in standards and practices between the U.S. and CERN.

The SCO provides core framework and infrastructure software services, and the facilities to support data reconstruction, simulation and physics analysis. This does not include development of the actual reconstruction software, nor the software for specific physics analyses, much of which will be written by physicists, although providing technical support for this software is part of the scope of the SCO.

The detailed Level 2 WBS for Software and Computing is given in Appendix 2.

1.4 Goals and Scope of the Common Operations Task

Common Operations (CO) are parts of the program's activities that are either common to both DO and SCO or that don't fall within the definition of either of them, but relate to the interaction between the U.S. Program and the CMS experiment as a whole.

These include such items as the staffing and activities of the main Program Office at Fermilab as well as the Branch office that handles NSF funds and the Office at CERN. It also

provides the funds for collaborative tools such as videoconferencing. It provides resources and management for the Remote Operations Center at Fermilab that enables people to take some CMS shifts at Fermilab so that they do not have to travel to CERN. It provides funds for education and outreach. The detailed Level 2 WBS is given in Appendix 3.

The Operations Program Manager acts as the Level 1 Manger for the CO task. The Operations Program Deputy Manager functions as the Deputy Level 1 Manager. The Management Reserve account is administered under this task.

1.5 Operations Program Management Plan Evolution

This OPMP will be reviewed and revised, as required, to reflect new developments or agreements among the participants. Revisions will be endorsed by the U.S. CMS Operations Program Manager, the U.S. CMS Operations Program Deputy Manager, the Fermilab Director or designee, the DOE/NSF program management, and approved by the U.S. LHC Joint Oversight Group (JOG).

1.6 Reference Documents

Additional documentation related to agreements that support the U.S. CMS Collaboration in its work on the CMS detector, are listed in Appendix 4. Copies of all associated documents, reside in the U.S. CMS Program Office at Fermilab.

2. Organization Breakdown Structure and Work Breakdown Structure

2.1 Organization Breakdown Structure

The Organization Breakdown Structure (OBS) of U.S. CMS Operations Program is given in Figure 1

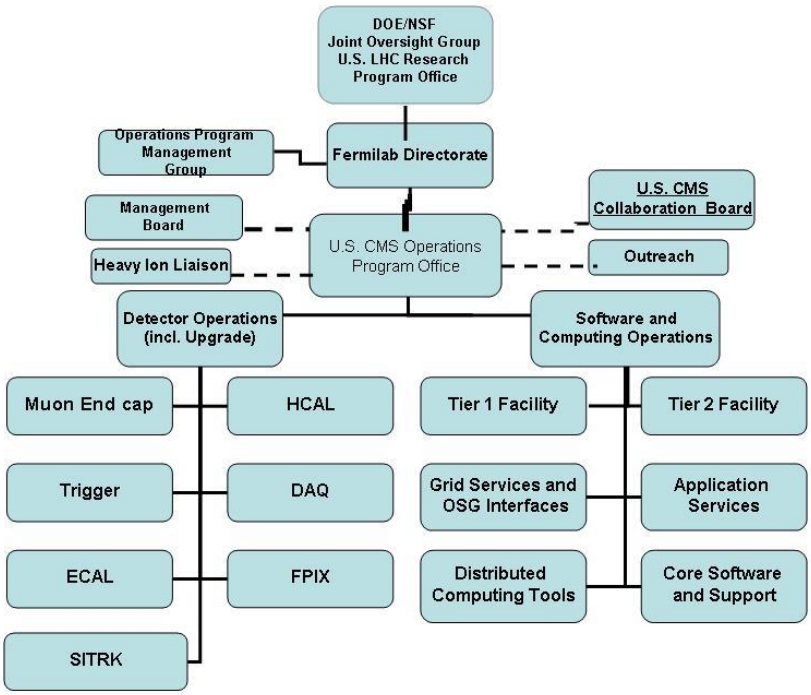


Figure 1: Organization Breakdown Structure of the U.S. CMS Operations Program

The U.S. CMS Operations Program Office includes the Operations Program Manager and Deputy Manager and represents the management functions in the OBS. The boxes that are above the Program Office represent the linkage of the OP to external U.S. management and oversight, including the funding agencies, DOE and NSF; Fermilab oversight functions at the host laboratory, including the Directorate and the Operations Program Management Group (OPMG); and the CMS physicists in the U.S. as represented by the U.S. CMS Collaboration Board

The boxes that are below the U.S. CMS Operations Program Office box describe the internal organization of the Operations Program. Each of the two main subtasks, Detector Operations and Software and Computing Operations has its own Level 1 manager. They each organize their subtasks hierarchically. Figure 1 shows the organizations only to Level 2.

The Detector Operations Level 1 subtask includes the seven detector subsystems in which the U.S. participates. The Software and Computing Operations Level 1 subtask includes the hardware and support and operation for the Tier 1 and Tier 2 centers and four activities related to software development and support.

In order to ensure coordination between the U.S. efforts on Heavy Ions, supported by DOE Nuclear Physics, and the HEP efforts, the OP has established a liaison between it and the Heavy Ion community. The Heavy Ion Liaison provides direct interaction with the OP.

The Operations Program Office manages the entire program. The purpose of the Program Office is to provide the management of the project, the interactions of the project with external entities, and the support of U.S. collaborators at CERN and in the U.S. A schematic of the Program Office is given in Fig. 2. The Program Office is run by the OPM and OPDM.

As stated in section 1.2, the Detector Operations subtask includes responsibility for the Detector Upgrade R&D. Upgrade R&D is conducted through the Detector Operations subproject and uses its staff, management, and technical and scientific personnel to execute its mission. The Upgrade R&D Coordinator works with the Detector Operations Manager to execute the approved R&D program. Since that program also must be aligned with the CMS Upgrade R&D, the Upgrade R&D Coordinator also reports on the international aspects of the program directly to the Operations Program Manager and therefore appears in the Program Office organization chart.

Figure 1 does not show the linkages of the OP with the (international) CMS Collaboration. These linkages exist at every level of the OP and are described below.

2.2 Work Breakdown Structure (WBS)

The OBS is aligned with the Work Breakdown Structure shown in Figure 3 . The Level 2 tasks under Detector Operations include the seven connected to subdetectors and one additional task, Detector Support that includes resources for activities that are shared among more than one subdetector. The Level 2 Tasks under Software and Computing Operations each have a Level 2 manager. The items listed under Common Operations are management functions that are carried out by the staff of the Program Office under the direction of the Operations Program Manager and Operations Program Deputy Manager. The OPM and OPDM act as Level 1 Managers for CO.

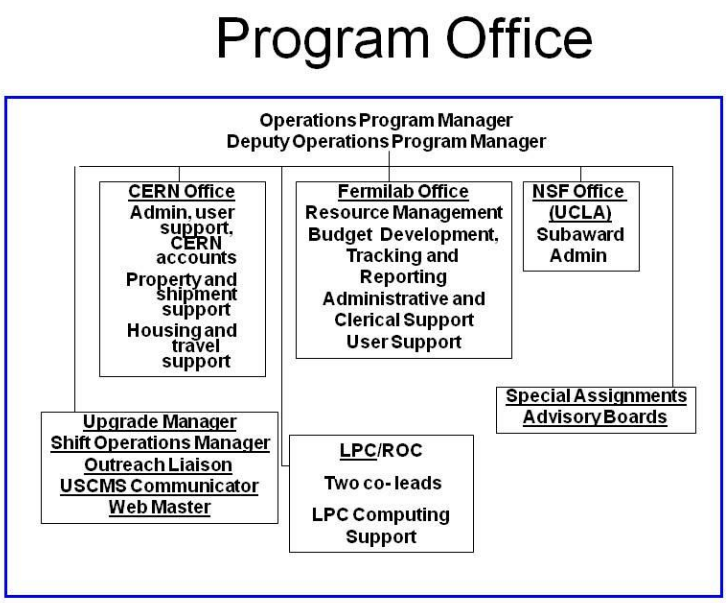


Figure 2: Organization of the U.S. CMS Program Office

Appendices 1, 2, and 3 contain brief descriptions of each Level 2 task for Detector Operations, Software and Computing Operations, and Common Operations respectively. Activities in DO and SCO are the defined scope of the respective subtasks based on extensive discussion and agreement with CMS, the U.S. Funding Agencies, CERN, U.S. universities, and other stakeholders. Activities assigned to Common Operations are those that are either common to DO or SCO or do not logically belong to either of them but are, nevertheless, necessary to manage the program.

The Management Reserve is called out as a WBS activity in Common Operations. It is managed by the OPM and OPDM through the change control process, described below, which is a tool that the program managers use to optimize resource allocation across the whole program.

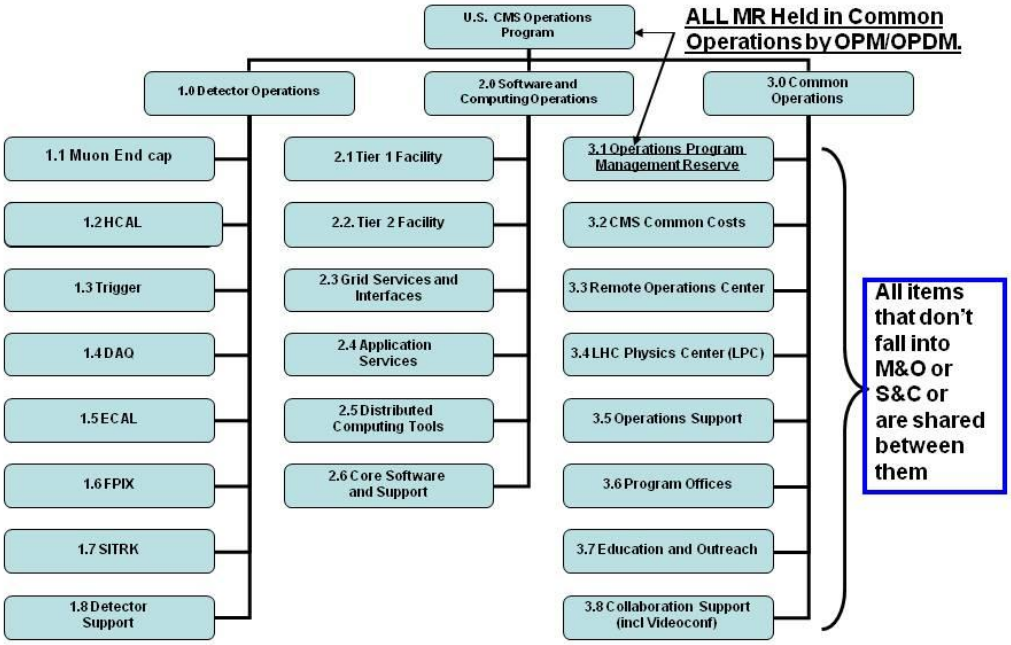


Figure 3: Work Breakdown Structure U.S. CMS Operations Program

3. Relationship of the U.S. CMS Operations Program to the CMS Collaboration and to the U.S. CMS Collaboration

The overall responsibility for the exploitation of the CMS detector resides with the CMS Collaboration, consisting of approximately 1400 PhD physicists more than 600 graduate students, and several hundred engineers, computer scientists and technicians from 38 countries and more than 165 institutions. The U.S. participation in CMS is part of the international CMS Collaboration, and currently consists of 460 PhD level scientists, over 225 graduate students, and about 150 engineers, technicians, and computing professionals from 47 universities in the U.S. and Puerto Rico and 2 national laboratories, as shown in Appendix 5.

The U.S. CMS Operations Program functions within the context of the internationally funded CMS experiment located at CERN. The general responsibilities of the U.S. participants and CERN as the Host Laboratory for the CMS experiment are described in the Protocol signed by CERN, DOE and NSF[4] and in a related CERN document[5] .

3.1 The International CMS Collaboration and its Management

The CMS detector ranks among the most ambitious and challenging technical endeavors ever undertaken by the scientific community. The CMS approach to this challenge is to base most of the CMS governance on the collaborating institutions rather than on national blocks.[6] This is true especially in areas relating to scientific and programmatic issues. However, funding in most nations is provided through government funds from national funding agencies. Therefore, CMS also recognizes national funding agencies in areas concerning finances and related policies. The organization of the CMS Collaboration is described in the CMS Constitution and is shown schematically in Appendix 6.

Within CMS, the principal organizational entity is the Collaboration Board (CB), consisting of one voting representative from each collaborating institution, regardless of size[7] or national origin. The CB is the overall governing body of the CMS experiment, and must ratify all policy and technical decisions and all official appointments to CMS positions. The Chairperson of the CB is elected by the members of the CB and, along with the Deputy Chairperson, serves a non-renewable two-year term.

The Collaboration Board elects a Spokesperson who is responsible to CERN and to CMS for carrying out the CMS program. The spokesperson may serve only for one two year term.

The spokesperson is assisted in carrying out the executive function by the CMS Management Board (MB) and the Executive Board (EB). The CMS spokesperson is advised on financial matters by the Finance Board (FB). The roles and interactions of these boards are described in the CMS Constitution.

The MB, through the Spokesperson, is responsible for directing the CMS experimental program and for formulating policy. The U.S. has a regional representative on the CMS MB.

The CMS Finance Board is chaired by the CMS Resource Manager and reports to the CMS spokesperson. It consists of the resource manager, the Spokesperson and Deputy Spokesperson(s), the resource manger of each major CMS subsystem, and a representative of each funding agency that supplies resources to CMS. It develops and proposes policy on M&O A and M&O B funds (described in section 5), special assessments to deal with one-time demands on resources, and the level of scientific effort that is necessary to operate CMS and obtain physics results. It monitors the status of the budget and proposes actions to resolve funding shortfalls. The OP has two representatives who keep the DOE and NSF informed of all issues.

CERN management has the ultimate responsibility for CMS, and CMS reports to it through the spokesperson. The LHC Resources Review Board (RRB), with representatives from the constituent funding agencies, acts as an oversight board and liaison to CERN management to ensure that the CMS collaboration has sufficient resources to operate and maintain the detector, to take and analyze the data, and to produce physics results in a timely fashion The RRB meets twice each year. Two “Scrutiny Groups” (SG), one for Detector Operations and one for Computing (CSG) provide support to the RRB. The SGs interact closely with CMS to monitor spending and evaluate proposed budgets and funding sources for the upcoming CERN fiscal year. In the spring, the RRB discusses the initial proposal for the budget for the upcoming year and reviews expenditures from the previous year. The final budget with additional input from the SGs is discussed and approved at the fall RRB. DOE and NSF each have a representative on the RRB. The U.S. nominates members for both Scrutiny Groups.

3.2 The U.S. CMS Collaboration

The U.S. CMS Collaboration is a voluntary, self-organized group consisting of all CMS scientists from U.S. institutions that have been admitted to the CMS experiment at the CERN LHC. It is governed by the U.S. CMS Constitution[8] prepared by an elected committee. The key body is the U.S. CMS Collaboration Board, which has a member from each U.S. CMS institution. The U.S. CMS Collaboration Board elects a Chairperson to represent the collaboration in its interactions with other organizations. The mission of the U.S. Collaboration includes an interest and participation in nearly all activities of the U.S. CMS Operations Program. However, the scope of the U.S. CMS Collaboration's interest and activities extends beyond the scope of the OP and includes such areas as physics analysis.

The DOE and NSF recognize the significance of this organization as a means of receiving information and advice on various aspects of the performance of the U.S. CMS Operations Program. The Collaboration Board plays a role in the appointment of the U.S. CMS Operations Program Manager and the Operations Program Deputy Manager. U.S. funding agencies include the CB Chairperson in reviews and at meetings of the Joint Oversight Group (described below).

Since the U.S. CMS Operations Program interacts with the same physicists who belong to the U.S. CMS Collaboration, the U.S. CMS OP relies on it for structured input to its activities and uses it to develop consensus for its policies where appropriate.

The U.S. CMS Collaboration Board Chairperson acts as a key adviser to the OP. He/she organizes and chairs meetings of the full Collaboration Board or its advisory committee to seek input to decisions or concurrence where appropriate. The Chairperson serves on internal committees of the OP. Fermilab includes the Chairperson in the Operations Program Management Group, discussed below.

The U.S. CMS Operations Program reports to and is responsible to the DOE and the NSF. They provide management oversight to the Operations Program. The Operations Program considers the Collaboration as acting in an advisory capacity, seeks to build consensus through it, but is not bound by decisions it may make since it receives its overall direction and instruction from the DOE and NSF. However, as part of their oversight, the funding agencies are likely to request input from the U.S. CMS Collaboration since they are key stakeholders in the program.

4. Management and Oversight Organization, Roles, and Responsibilities

4.1 Program Oversight Organization Structure

4.1.1 U.S. Department of Energy (DOE) and National Science Foundation (NSF)

The DOE and NSF have negotiated and signed a joint agreement and protocols with CERN for U.S. participation in the construction, operation, and physics programs of the ATLAS (A Toroidal LHC ApparatuS) and CMS (Compact Muon Solenoid) detectors[9] [10] .

Program oversight for the U.S. CMS Operations Program is the responsibility of the U.S. Department of Energy (DOE) and the National Science Foundation (NSF), under the general purview of a U.S. LHC Joint Oversight Group (JOG), with specific responsibilities as described in the Operations Program Execution Plan[11] (OPEP). The DOE has delegated responsibility for the U.S. CMS OP to the Office of High Energy Physics within the Office of Science. The NSF has delegated responsibility for the U.S. CMS OP to the Division of Physics in the Directorate for the Mathematical and Physical Sciences. These two divisions of DOE and NSF together provide oversight through the JOG[12].

DOE and NSF have requested, via the JOG, that the Fermi National Accelerator Laboratory (Fermilab, FNAL), in Batavia, Illinois act as the Host Laboratory and assume management responsibilities for the U.S. CMS OP[13] exercised through the DOE and NSF-appointed Operations Program Manager and Operations Program Deputy Manager. Fermilab is a DOE laboratory operated by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the United States Department of Energy.

4.1.2 U.S. LHC Joint Oversight Group (JOG)

The DOE and NSF established the U.S. LHC Joint Oversight Group as the highest level of joint oversight of the U.S. LHC Operations Program. The JOG establishes programmatic guidance and direction for the U.S. CMS OP and coordinates DOE and NSF policy and procedures as they apply to U.S. CMS. The OPEP lists the specific responsibilities.

4.1.3 U.S. LHC Program Manager and Associate Program Manager

The U.S. LHC Program Manager and Associate Program Manager are Federal employees (or their equivalents) who manage the Operations Program for the funding agencies. The OPEP lists the specific responsibilities.

4.1.4 Fermilab Site Office

The Office of Science (SC) Fermi Site Office (FSO) is the responsible DOE office at Fermilab that administers the management and operating contract and provides day-to-day oversight of the laboratory. FSO receives direction on Fermilab programmatic management from the SC Office of High Energy Physics (OHEP), and other support upon request from the SC Integrated Support Center. OHEP will coordinate with FSO to identify and establish any FSO functions or management systems needed to support program activities, such as establishing Federal project oversight for future upgrade projects.

4.1.5 Host Laboratory (Fermilab) Organization

The DOE and NSF have jointly assigned management oversight for the U.S. CMS OP to the Fermi National Accelerator Laboratory (Fermilab), in Batavia, Illinois. A U.S. CMS Program Office has been formed, with its principal office sited at Fermilab, and has been charged with meeting the technical, cost, and schedule objectives of the U.S. CMS OP.

The use of Fermilab facilities and services, as is the case with the use of assets at any U.S. CMS institution, shall be agreed upon via a MOU with the appropriate organization, which could be the Operations Program or a U.S. CMS Institution. The use of these resources will follow procedures consistent with the Fermilab's current policies. To the extent agreed by Fermilab, the OP will receive support from the Laboratory through contributions in: accounting and Budgeting; Environment, Safety and Health, (ES&H); Human Resources; Legal issues; Facilities Management; Quality Assurance; and Information and Business Services.

All support functions are provided through Fermilab's normal organizational lines of authority and responsibility, according to agreed upon priorities. Services may include those provided to Fermilab's U.S. CMS group or to other U.S. CMS institutions. Within the framework of the MOU, specific items are negotiated annually by Fermilab (as host laboratory)

by the U.S. CMS OPM and OPDM and by the collaborating U.S. CMS institutions. The annual Statement of Work (SOW) will specify the commitments and associated estimated costs.

4.1.6 Fermilab Director

The Fermilab Director has management oversight responsibility to ensure that the OP effort is well managed, that technical progress proceeds in a timely way, that technical and financial problems are identified and properly addressed, and that an adequate management organization is in place. Specific responsibilities include, but are not restricted to:

1. providing oversight and coordination of the OP and ensuring compliance with all DOE and NSF rules and regulations in the execution of OP activities;
2. in consultation with the U.S. CMS Collaboration, appointing the OPM and DOPM, subject to the concurrence of the Joint Oversight Group;
3. establishing an advisory structure for the OP for the purpose of monitoring both management and technical progress for all OP activities;
4. ensuring that the U.S. CMS OPM has adequate staff and support, and that the U.S. CMS management systems at Fermilab are matched to the needs of the program;
5. consulting regularly with the OPM to ensure timely resolution of management challenges;
6. reviewing and concurring with the annual institutional Statements of Work (SOW) for the U.S. CMS collaborating institutions that specify the deliverables to be provided and the resources available at each institution;
7. ensuring that accurate, complete reporting to DOE and NSF is provided in a timely manner;
8. ensuring that there is effective communication and cooperation between the Operations Program and the U.S. CMS Collaboration; and
9. reviewing and approving significant program changes as prescribed in this document.

The responsibilities of the Fermilab Director are further described in a letter of joint appointment from DOE and NSF to the Fermilab Director, dated November 30, 1997[14]. The Fermilab Director may delegate certain responsibilities and authorities to a duly appointed Fermilab staff member, typically a Deputy or Associate Director and referred to hereafter in the document as “designee” or DD.

4.1.7 Fermilab Director or Designee (DD)

The DD is responsible for management oversight of the OP. The U.S. CMS OP Manager reports to the DD. The DD must concur with the Memorandum of Understanding between CERN and U.S. CMS and with the Statements of Work between the U.S. CMS OP and the collaborating U.S. institutions. In addition, the OP Management Plan and annual budget require the approval of the DD, DOE and NSF.

4.1.8 Operations Program Management Group (OPMG)

To exercise management oversight for the OP, an Operations Program Management Group (OPMG) is organized and convened by Fermilab. The DD chairs the OPMG. The OPMG will include members from Fermilab, the Operations Program line management (the OPM, OPDM the SCO and DO managers, and Upgrade Coordinator), with OPMG meetings attended by members of the U.S. LHC Program Office as appropriate. The Chairperson of the U.S. CMS Collaboration Board is a member of the OPMG, ensuring communication of issues, including those that could impact on the scientific output, to or from the U.S. CMS Collaboration. External consultants and stakeholders are added as deemed necessary by the DD.

The OPMG reviews the quarterly reports of the OP. The OPMG meets regularly in order to provide routine interactions with OP management. The OPMG identifies actions to be undertaken to achieve the goals of the OP, including allocation of both financial and human resources. As necessary, the OPMG is used as a review board to assess critical areas of the OP.

4.2. U.S. CMS Operations Program Management Roles and Responsibilities

4.2.1 Overview of the Roles and Responsibilities of the OPM and OPDM

Figure 1 shows the management structure of the U.S. CMS Operations Program. The U.S. CMS Operations Program Manager (OPM) has overall responsibility to provide programmatic coordination and management for the work performed at the participating institutions to meet the objectives of the OP. He/she is assisted in this task by an Operations Program Deputy Manager (OPDM). The OPM and the OPDM are referred to as the Level 0 (L0) Program Managers. They are supported by the SCO Level 1 (L1) Manager, who is responsible for the Software and Computing tasks, and the L1 Detector Operations Manager, who is responsible for detector-related tasks. The OPM acts as the L1 Manager for Common Operations

and the OPDM acts as Deputy. Level 2 Managers of the Operations Program are appointed by the SCO and DO Managers for each of their major subsystems.

U.S. CMS planning and management functions are conducted in close communication and cooperation with overall CMS management. The U.S. OPM and OPDM maintain close contact with the CMS Spokesperson and the relevant CMS Project Managers and Coordinators. The DO and SC Level 1 managers and their Level 2 Managers maintain close contact with their counterparts in the international organization.

The OPM, with the assistance of the OPDM, presides over the development of the annual spending plan that determines the initial allocation of funds to the SCO, DO, and CO tasks, in light of funding guidance provided regularly by the DOE and NSF. The model used for planning the program captures all U.S. CMS commitments to international CMS and must support the approved global CMS schedule. Commitments of each institution to the OP are explicit, as defined in annual U.S. CMS Statements of Work (SOW). Subcontracts, e.g., Purchase Orders (PO's) in the case of DOE funding or subawards in the case of NSF funding are issued to institutions in agreement with their respective SOWs, either for SCO, DO, or CO (Common Operations) deliverables.

For DOE funds, Management Reserve (MR) is not included in the initial budgets allocated to the DO or SC tasks but is instead allocated by the OPM from a central fund based on change requests throughout the fiscal year. However, in the process of creating the annual spending plan, the DO and SC Managers identify items where MR may be needed along with estimated amounts. This provides the OPM with good information and maximum flexibility as decisions on change requests are acted on throughout the fiscal year. The OPM and OPDM provide updated information on possible requests for MR to DOE and NSF throughout the year so that they are well informed when change requests are generated that need agency approval.

Management reserve is not generally held for NSF funds. Adjustments may be made either by changing the scope of program deliverables or in some cases the schedule. Also, if needed, shifting of funds between categories may be requested by a funding change request from the Principal Investigator to the NSF Program Director.

Regarding the Operations Program Manager and Operations Program Deputy Manager, it is anticipated that one be from Fermilab (or a guest scientist with a Fermilab appointment) and the other from a U.S. CMS university. Therefore, in addition to duties traditionally associated

with managing a program, the university-based physicist will serve as a conduit for communications of special interest to the universities, both to and from the line management. In the following, it has been assumed that the OPM is a Fermilab employee and that the ODPM is a staff member at a collaborating university. Clearly, the OPM may be a university employee, while the OPDM may be a Fermilab employee. In either case, DOE financial responsibility resides with the FNAL employee, while NSF financial responsibility resides with the university employee.

4.2.2 The U.S. CMS Operations Program Manager (OPM)

The U.S. CMS Operations Program Manager (OPM) has overall responsibility for coordination and management of the U.S. CMS OP. The OPM represents the U.S. CMS OP in interactions with CMS management, CERN, DOE, NSF, Fermilab and the U.S. collaborating universities. Specific responsibilities of the OPM include, but are not restricted to:

1. providing general administration, planning, organization and control on a day-to-day basis of the execution of the OP technical scope on schedule and within the authorized budget;
2. consulting with the Fermilab Director or designee on the appointment of the OPDM and the SCO and DO L1 managers;
3. establishing and maintaining, with the support of Fermilab management, a U.S. CMS Operations Program Office with appropriate support services;
4. allocating Management Reserve to deal with unforeseen issues in a manner consistent with the U.S. CMS change control process;
5. maintaining close communication with the Fermilab Director or designee, and with the U.S. LHC Program Office, on progress of U.S. CMS, and reporting promptly any problems that may benefit from the joint efforts of the OPM, OPDM , Fermilab and LHC Program Office;
6. serving as the DOE link-person to the CMS Finance Board and as an advisor to the DOE/NSF on the Resources Review Board;
7. ensuring that ES&H and QA/QC activities are managed effectively; and
8. making periodic reports to the JOG and at reviews of the OP conducted by the LHC Program Office on the status and issues of the OP and publishing a quarterly report on the activities, issues, performance and fiscal status of the OP.

4.2.3 U.S. CMS Operations Program Deputy Manager

The Operations Program Deputy Manager (OPDM) reports to the OPM in the line management. The OPDM represents the OPM in all OP functions when the OPM is not available.

In addition, the university-based OPDM will serve as the Principal Investigator or a co-Principal Investigator for the NSF Cooperative Agreement covering funding of the Operations Program. In this capacity, this individual will be responsible for ensuring that the NSF Operations Program funds are allocated in a manner consistent with the decisions of the OPM. Much of the work of the Operations Program will be carried out or overseen by physicists funded from the Physics Research Programs of NSF and DOE. Thus, the university-based manager will stay in contact with the program officers in each of the agencies in order to coordinate support of university groups. Specific responsibilities of the OPDM include, but are not restricted to:

1. acting as NSF Administrator for the Cooperative Agreement (CA) under which the NSF funds its share of the OP;
2. establishing and managing the NSF Program Office at the Responsible University that distributes and tracks funds from the NSF CA to U.S. CMS universities;
3. approving the overall NSF budget and associated SOWs;
4. supporting the OPM in the overall management coordination, integration, and planning for the OP, with respect to NSF/DOE funds;
5. tracking and reporting NSF funding to the U.S. CMS Program Office in a timely manner;
6. acting as the point of contact between the university programs of NSF and DOE and the OP;
7. acting as the U.S. CMS advocate for the university groups within the program;
8. representing the OP to external committees, such as HEPAP, FRA/URA and other reviews, in matters specifically related to the universities;
9. serving as the NSF link-person to the CMS Finance Board and as an advisor to the DOE/NSF on the Resources Review Board;
10. ensuring that ES&H and QA/QC activities are managed effectively; and
11. participating in the definition and execution of a plan for education and outreach.

4.2.4 Level 1 Managers: Software and Computing Operations Manager (SCOM) and Detector Operations Manager (DOM)

The Level 1 (L1) managers represent U.S. CMS Software and Computing in interactions with the OPM, OPDM, CMS management, CERN, DOE, NSF, Fermilab, the collaborating universities, and related external organizations (e.g. the WLCG and OSG) and external R&D projects. They report to the OPM and OPDM and through them to DOE and NSF. The L1 managers have authority to negotiate, subject to the required approvals, on behalf of the OP with collaborating institutions and with Fermilab for collaboration or laboratory resources.

The L1 managers are responsible for completing the work plan by achieving the approved scope within budget and on schedule. They must also ensure that the deliverables of the SCO and DO conform to the technical specifications that are set for them. Finally, they are responsible for doing this in a manner consistent with CMS software and computing, technical, and scientific policy. During their tenure, the L1 managers will be members of Fermilab's staff.

Specific responsibilities of the L1 managers include, but are not restricted to:

1. developing and executing the baseline work plan for SCO or DO especially with respect to budget, personnel requirements, schedule, metrics and milestones;
2. appointing a deputy if deemed necessary to assure management continuity during periods when the L1 manager is absent or unavailable and appointing the Level 2 (L2) managers;
3. developing or adopting general technical and quality assurance standards to which deliverables must conform. For the SCOM, this includes making sure that U.S. CMS software and facilities conform to applicable CMS and CERN standards and practices. For the DOM, this includes ensuring that deliverables conform to applicable safety and quality assurance standards at all locations where they will operate;
4. negotiating and signing U.S. CMS Institutional Statements of Work (SOWs) representing annual agreements between the OP and each U.S. collaborating institution specifying the funding to be provided by the OP and the deliverables to be provided by the institution;
5. allocating resources within SCO or DO. Allocations are largely set by the annual work plan and budget but adjustments are often necessary during the year.
6. reporting variances from the scope, schedule or cost estimates to the OPM and OPDM and developing action plans for dealing with them;

7. exercising change control authority as described in this plan and bringing change issues that exceed their authority to the attention of the OPM and OPDM;
8. establishing technical advisory committees where appropriate; and
9. ensuring that ES&H and QA/QC activities are managed effectively.

Additional responsibilities of the SCOM include:

- establishing and maintaining the organization of U.S. CMS Software and Computing, within the Fermilab Computing Division and within the U.S. CMS Program Office, required to manage procurements, maintain schedules, submit reports, develop budgets, carry out quality assurance, maintain the work plan and the record of all revisions to it; and
- developing a technology-tracking plan, in conjunction with the Level 2 managers and with similar efforts at CERN. The tracking plan should allow the SCO to take advantage of new, more cost-effective technologies that may arise during the period of its execution.

Additional responsibilities of the DOM include:

- working with the U.S. CMS Upgrade Coordinator to establish and oversee a viable R&D program for the upgrade of the parts of the CMS detector for which the OP is responsible.

4.2.5 Upgrade Coordinator

The U.S. CMS effort on upgrade R&D makes use of the "normal" detector project management and personnel to avoid having a parallel organization for the upgrade and to ensure that priorities can be properly established between ongoing operations and upgrade R&D efforts. The U. S. CMS Upgrade R&D Coordinator organizes the U.S. CMS Upgrade R&D Program of the OP and coordinates the U. S. CMS Upgrade effort with the CMS Upgrade R&D Program and a variety of joint LHC upgrade programs and various external programs of CERN, the DOE and the NSF. The Upgrade R&D Coordinator therefore also has an appointment to the Program

Office as an adviser to the OPM on the overall balance of R&D funding and on aspects of the upgrade R&D program that is external to U.S. CMS. Specific responsibilities of the Upgrade Coordinator include, but are not restricted to

1. appointing, with the concurrence of the OPM and OPDM, the U.S. CMS Upgrade Steering Committee that provides advice concerning priorities in the U. S. CMS R&D program;
2. soliciting R&D proposals from U. S. CMS institutions for R&D to improve the capability of CMS to exploit the physics opportunities of the LHC;
3. developing a prioritized the U. S. CMS R&D plan in consultation with the U.S. CMS Upgrade Steering Committee;
4. recommending to the DOM the R&D budget including the institution-by-institution funding allocations for carrying out specific, agreed upon activities for the R&D program;
5. negotiating and signing SOWs for activities related to Upgrade R&D;
6. identifying shortfalls in the budget, developing plans to deal with them and preparing the appropriate change requests to submit to the DOM;
7. working with CMS, the OPM, OPDM, and DOM to set up reviews of the progress of Upgrade activities carried out by U.S. CMS institutions;
8. periodically reporting on CMS Upgrade R&D status and issues to DOE and NSF; and
9. ensuring that ES&H and QA/QC activities are managed effectively.

4.3 Method of Appointment of Key Managers and Terms of Service

Table 1 shows the participants and their roles in the appointment or reappointment of the managers of the OP. Also shown are the durations of the terms of the initial appointments. All appointments are renewable with terms being negotiated as part of the reappointment process but in no case extending for a duration longer than that of the initial appointment.

4.4 The Role of the U.S. CMS Operations Program Office (PO)

The day-to-day control of the U.S. CMS OP will be facilitated by the U.S. CMS Operations Program Office (PO). This office consists of the OPM, OPDM, and administrative support personnel. The PO includes administration functions that are located at the Central Program Office (FPO) at Fermilab, a branch (NPO) office to track NSF disbursements, and a branch office at CERN (CPO) to support U.S. activities at CERN.

4.4.1 Fermilab Central Program Office (FPO)

The Fermilab Central Program Office tracks all DOE expenditures and invoices directly. It works with the NSF Branch Office to track all NSF expenditures, and with the CERN Branch Office to monitor financial transactions at CERN and with CMS. It is the responsibility of the FPO to integrate all the information from across the whole program to report on overall OP costs and on the financial and technical state of the OP.

Position	Initial Term	Renew-able	Concur	Appoint	Consult
OPM	5	Y	JOG	FNAL DIR	U.S. CMS CB, other stakeholders
OPDM	5	Y	JOG	FNAL DIR	U.S. CMS CB, OPM, other stakeholders
SCOM	2	Y		FNAL DIR	U.S. CMS CB, OPM, OPDM, other stakeholders
DOM	2	Y		FNAL DIR	U.S. CMS CB, OPM, OPDM, other stakeholders
Upgrade Coordinator	2	Y		FNAL DIR	U.S. CMS CB, OPM, OPDM, other stakeholders
Level 2 Manager (S&C, DO)	2	Y	OPM, OPDM	SCOM, DOM,	Stakeholders
Level 3 Manager (S&C, DO)	2	Y		SCOM, DOM	Stakeholders

Table 1: responsibilities for appointing key OP Managers

The FPO will maintain all official documentation for the OP and ensure that the U.S. CMS Collaboration, the DOE and the NSF, are fully informed of the latest developments, action items, and/or changes that affect the OP or the overall LHC research Program. Within the OP, the SCO and DO managers report performance and status of their respective programs to the PO on a quarterly basis. The PO coordinates the production of the quarterly report. Administrative functions include but are not restricted to:

1. providing monthly summaries of budgets, costs, and obligations for the U.S. CMS OP;
2. aiding and coordinating the Fermilab Purchase Orders using DOE funding support and any other subcontracts to provide consistency with the approved Level 2 budgets;
3. monitoring and reporting on OP transactions at CERN;
4. ensuring that the quarterly report provides accurate statement of obligations and budgets and assembling and distributing the final version;
5. administering the change control process and maintaining a log of all change requests and their disposition;
6. acting as liaison between the OP and Fermilab's Business Services Section.
7. acting as liaison between the OP and CMS Resource Management at CERN
8. assisting in the preparation of budget-planning documents, projections, and financial reports;
9. producing ad-hoc reports of requisitions, purchase orders, and procurements;
10. producing ad-hoc reports and queries, as necessary, to track effort charged to the OP; and
11. overseeing all U.S. CMS procurements, including ProCard purchases, and providing gate-keeping oversight of the requisition process.

4.4.2 NSF Branch Office (NPO)

The U.S. CMS Operations Program Office includes a Responsible University (RU) which administers NSF Funds. The OPDM acts as Administrator for NSF funds and is responsible for administration, disbursement, and reporting on the use of NSF funds in accordance with the NSF Cooperative Agreement (CA) with the RU. A "branch office" is maintained by the RU to handle the distribution of and accounting for funds provided by the NSF. The NSF Administrator is a member of the Operations Program Management Group. Should the OPM be university based

and the OPDM be Fermilab based, the financial responsibility for NSF funds still will reside with the university based administrator.

As a member of the program management team, the NSF Administrator (OPDM) reports to the U.S. CMS OPM and under his/her direction, arranges for the appropriate procurement instrument (e.g. subaward) to be issued from the RU to the respective U.S. CMS participating institutions. Disbursement and utilization of funds provided by the NSF for U.S. CMS are subject to this management plan and the change control and reporting procedures herein defined. The annual Statement of Work (SOW) describes a work plan for each institution that is consistent with the scope of the OP. Subawards issued by the RU authorize expenditures in a manner consistent with the approved SOW for each institution. The NSF funded institutions invoice the RU and provide information on how the amounts correspond to WBS numbers. OPDM approval is required before invoices are paid. The RU tracks and records all NSF funds disbursed on behalf of U.S. CMS and reports this information monthly to the U.S. CMS Program Office at Fermilab.

4.4.3 CERN Branch Office (CPO)

A branch office of the U.S. CMS Program Office is located at CERN to facilitate activities of U.S. CMS OP at CERN and with CMS. Administrative functions include but are not restricted to:

1. serving as liaison to CERN financial officers with regard to OP transactions at CERN;
2. acting as liaison for U.S. CMS participants in the OP on communications, computing and database support with CERN and CMS;
3. acting as liaison between the OP and CERN Accounting;
4. acting as liaison for U.S. visitors to CERN and CMS;
5. expediting travel, housing, computing support and shipping requests from U.S. CMS collaborators at CERN; and
6. supporting U.S. CMS collaborators who come to CERN for long and short term stays to work by providing information and assistance on obtaining registration, training, and services.

5. Meeting U.S. CMS Obligations to the CMS Experiment

U.S. CMS has major responsibilities within CMS for both detector operations and for facilities for data processing and data access. In many cases, there are direct agreements between CMS management and the U.S. CMS Operations Program to support equipment or software that the U.S. contributed and which it is natural, efficient and appropriate for the U.S. to perform. For areas that are the collective responsibility of all CMS collaborators, CERN has well established procedures for determining the appropriate budget level for each nation and for distributing responsibility. The Scrutiny Process and the approval process in the RRB, discussed above, is intended to ensure that CMS has adequate operating funds to execute its program, that the requested funds are carefully scrubbed and therefore not excessive, and that the funds are used appropriately and effectively to accomplish the approved scope.

Generally speaking, CMS assesses costs for common projects using the formula that each funding agency will pay a fraction of the total cost proportional to the fraction of Ph.D. physicists supported by that funding agency. It is the intention that this defines the set of Ph.D. authors whose names will appear on all CMS physics papers for that year[15]. Payment of a person's common fund obligation is one of several requirements for authorship on CMS papers.

Information on the number of PhDs supported by each funding agency is obtained by CMS through an annual request to each institutional representative to update a database containing information on the number of PhDs and the tasks they each will work on for the upcoming year. U.S. CMS works closely with CMS to make sure that all U.S. representatives respond, that the information is correct and complete, and that each person who is included can meet all the other requirements for authorship that are under the purview of the OP.

5.1 Maintenance and Operation Category A Funds (M&O A)

M&O A supports a standard set of activities that benefit the entire CMS collaboration. There is a basic list of activities that evolve over time. There may also be short-term additions to deal with short term projects[16]. The final budget is established in late summer of each year by CMS through the CMS Finance Board and is approved in the October RRB.

5.2 Maintenance and Operations Category B Funds (M&O B)

M&O B refers to funds that are needed to carry out basic maintenance and operations of CMS subdetectors, the Trigger and Data Acquisition systems, and the offline software. M&O B budgets are generally borne by the group responsible for the subdetector or subtask. Assessment of funds within the group is based on fraction of Ph.D. authors from each nation (or institution). The M&O B funding for each subdetector in which the U.S. is involved is included in the corresponding U.S. CMS Level 2 budget.

5.3 Commitment of computing resources through the WLCG

All nations and institutions of CMS are required to provide a fair share of the computing resources needed to process the data from collisions recorded by CMS. Many of these resources will be remote from the CERN campus and interconnected via high speed network links. The computing resources, CPU, disk storage, and tape storage, are organized in "Tiers", each with its own function as described in the CMS Computing Technical Design Report.

The U.S. CMS Operations Program contributes one large Tier1 and 7 Tier-2s to the WLCG to provide its fair share of CMS computing resources. Pledges are made each year for the coming year based on DOE and NSF budget guidance and subject to modification when the actual budget is finally established. Non-binding "goals" are set for the subsequent two years.

U.S. CMS works within CMS to establish the computing needs based on the CMS analysis model and projections of the amount of data expected given the LHC operations schedule. These computing needs are reviewed by the CERN Resources Computing Scrutiny Group (CRSG), in which the U.S. funding agencies are represented.

5.4 Experiment Services and Pledges (ESP)

Experiment Services and Pledges (ESP) cover personnel to perform the many tasks needed to operate and maintain the CMS detector, computing, and software. Examples include physicist effort required to align and calibrate the detectors, to take shifts, to constantly monitor the data quality, to maintain the flow of reconstruction, simulation and production of data sets for physics analysis, to verify their correctness, and to carry out the R&D for upgrades. These activities do not include "physics analysis". Engineering and technician support is required to troubleshoot and fix problems in the detector or the electronics.

6. Scheduling and Milestones

The OP has an ongoing mission focused on detector operations and data processing at U.S. Tier 1 and Tier 2 computing facilities. In addition, it is charged with carrying out R&D for future detector upgrades and for new facilities and approaches to software and computing. This makes it different from a "project" with a defined deliverable and an overall deadline. Therefore, it has been acknowledged by the JOG that detailed scheduling and Earned Value Management are not the most appropriate tools for tracking the progress of the diverse activities of the OP.

Nevertheless, there are "projects" within the overall "program". A shutdown of the LHC provides an opportunity to do detector maintenance. This requires intervention in the detector and may require the CMS detector to be opened. This requires detailed CMS-wide planning which constitutes a large project that needs to be rigorously planned, scheduled and coordinated. The U.S. is typically responsible for several activities within this larger project. There are also smaller individual tasks that are complex enough to benefit from detailed planning. We therefore take a graded approach to scheduling, applying detailed planning for complex projects; employing milestones for simpler ones; and relying on metrics for ongoing tasks.

Milestones will be monitored at a frequency appropriate to the individual projects by the DOM and the SCOM. They may choose to divide responsibility within their projects into lower level milestones that are the responsibility of the personnel assigned to those projects. The will summarize the status of recent and upcoming milestones in the quarterly reports.

7. Change Control Process and Use of Management Reserve

7.1 Change Control Graded Approval Matrix

Change Control is exercised in the areas of technical scope and cost using a graded approach. Technical change requests are proposals to modify existing detector, computing, or software components so that they meet baseline requirements, add some new capability that has been determined to be necessary for reliable operations, or add a new capability that extends the performance of CMS in some new direction considered desirable for the CMS physics program. Technical change requests usually need to be endorsed by CMS through its normal decision making process. The U.S. process is directed at the evaluation and approval of the use of U.S.

resources to undertake an activity that has been approved by CMS or an activity that is totally within the purview of the U.S. and does not require CMS approval. All new projects and initiatives are subject to change control and therefore to DOE and NSF approval. Technical change requests often require funding that is then subject to the cost portion of the change control process. The level of approval for the change depends on the nature of the change and the cost since the cost is subject to the same approvals established in Table 2.

Cost change requests are proposals for additional funds to achieve approved objectives that cannot be accomplished within their original (or revised) funding. Acceptance of the change request will require the redistribution of funds within or between tasks or the allocation of funds from the Management Reserve. The level of approval depends on the magnitude of the change and is shown in Table 2.

	U.S. CMS Detector Operations or Software and Computing Manager	U.S. CMS Operations Program Manager and/or Deputy	Fermilab Director or designee	DOE/NSF LHC Program Manager
Technical	Any increase or decrease in subsystem scope or physics performance of a subsystem, including tradeoffs among subdetectors. Any new component or device.	Any increase or decrease in subsystem scope or physics performance of a subdetector, including tradeoffs among subdetectors. Any new component or device.	Any increase or decrease in subsystem scope or physics performance of a subdetector, including tradeoffs among subdetectors. Any new component or device.	Significant changes in subsystem scope or physics performance of a subdetector. Any new component or device.
Cost	Any change in a U.S. CMS subsystem budget greater than $10,000 at WBS Level 2 that can be handled by reallocating fund s within the L1 projects	Any change in a US CMS subsystem budget greater than $20,000 at WBS Level 2 or any amount that requires allocation of Management Reserve	Any change in a US CMS subsystem OP budget greater than $35,000 at WBS Level 2.	Any change in a US CMS subsystem OP budget greater than $50,000 at WBS Level 2.

Table 2: Change Control matrix

7.2 Generation and Processing of Change Requests

Once the funding allocations are set in any given fiscal year, changes to the total funding for any L1 subsystem can only come from a corresponding change in the management reserve. Any such change in funding must be requested by the relevant L2 Manager and generally requires the approval of the corresponding L1 manager. Approval of large changes shall be guided by the needs of the entire Operations Program and shall require the approval of the OPM, subject to the thresholds described in Table 2.

8. Program Reporting, Communications and Review

The objective of the reporting activity is to provide for the collection, integration and transmission of information needed for managing and monitoring the OP.

For this purpose, the OPM produces a quarterly report on the status, progress and ongoing issues relevant to the OP. The report includes a description of technical progress of the OP, including international issues, financial information, the allocation of Management Reserve, and performance as measured by milestones and metrics.

A requirement of the Cooperative Agreement through which the NSF portion of the US CMS operations program is funded is the submission of an annual report. This report is prepared by the OPDM in consultation with the Operations Program Manager and university Principle Investigators. Progress and financial information in the reporting year is provided for each university group funded through sub awards.

To facilitate good communication and coordination between the OP and the U.S. funding agencies, regularly scheduled meetings and reviews are conducted, including:

- Meetings of the JOG (twice per year);
- Biweekly LHC Operations Meetings with reports from U.S. CMS concerning status and issues for the two most recent weeks. These meetings include the LHC Program Office, the Proton Research Program of DOE, and the leadership of U.S. CMS and U.S. ATLAS;
- Informal chats between the CMS OPM and OPDM and the representatives of DOE and NSF (approximately every two weeks); and
- Reviews as specified by DOE/NSF. Typically these include an annual review, with external reviewers, of all aspects of the U.S. CMS Operations Program, including DO and SCO, as well as internal reviews.

9. Safety Program

The ES&H program in the U.S. CMS Operations Program is complicated because work may occur in any of the U.S. CMS institutions and most items that are produced will eventually

be sent to CERN. U.S. personnel will similarly be located at U.S. institutions and at CERN. Therefore, in many cases, multiple safety standards may apply to the work.

9.1 CERN

CERN is the host laboratory and site of the CMS experiment. All equipment delivered to CERN must comply with the applicable CERN safety requirements and standards and must be operated according to CERN's established procedures. All U.S. CMS physicists who work at CERN are required to register at the CERN Users' Office. In doing so, they become unpaid members of the CERN staff and all CERN safety rules and responsibilities apply to them.

Safety at CERN is defined by a series of documents produced by the Safety Policy Committee, known as SAPOCO. Individual responsibility is a key part of the CERN Program. The responsibility of individuals as stated in the CMS Constitution and derived from the SAPOCO is that, "Members of the CERN personnel, fellows, associates, registered visitors, students, apprentices, contractors and temporary labour personnel, are accountable for the observance of the safety rules to their immediate supervisors or to other persons specifically appointed to be responsible for safety issues relating to their work." The CMS policy for safety is described and updated in the safety website[17].

The CMS Constitution describes the role of the CMS Technical Coordinator. In Section 5.4 of that document, it states that the Technical Coordinator "holds overall responsibility in terms of safety during installation and operation of the experiment up to its dismantling" in accordance with the CERN Safety Policy Manual, SAPOCO[18] 42, revision, November 2006. All work in CMS is organized into Work Packages. When Work Packages are planned, safety issues, including specification of the procedures to be followed, training that is required, and an evaluation of the risks and hazards are specified. The leader of the Work Package is responsible for seeing that the work, including all aspects related to ES&H, is carried out according to the plan.

The CMS Constitution and the CERN Safety Policy specify the role of the "Group Leader in Matters of Safety" (GLIMOS). According to the Constitution, "The GLIMOS has executive authority to ensure the safety of the experiment by delegation from the PH Department Leader and the CMS Technical Coordinator. He/she has complete authority over personnel and equipment in all matters that concern safety of the experiment, irrespective of the institute

affiliation of personnel or the ownership of equipment." This means that U.S. CMS project leaders or their engineers must contact the GLIMOS to ensure that they are taking into account all applicable safety standards and rules in designing and building equipment to be operated at CERN. The GLIMOS has access to resources and advice to assist collaborators in meeting CERN safety requirements. In many cases, applicable standards are very similar in the U.S. and at CERN. However, this is not always the case.

CMS conducts reviews at key stages in the design and production of equipment and when equipment is put into operation. These reviews include ES&H issues and are a key part of the process of ensuring ES&H compliance.

CERN provides general and site specific training for a variety of tasks. U.S. CMS collaborators are required to identify the required training and obtain it. Subdetector Project Managers are the best source of information on the training required to work on their subsystems. Run Coordination specifies the training required for general shift work.

9.2 U.S. Collaborating Institutions

Work performed for U.S. CMS at U.S. collaborating institutions must be carried out in accordance with the safety requirements of those institutions. Work must be carried out so that devices produced can be successfully operated and meet all regulatory requirements at all locations where they are needed.

9.3 Fermilab

Fermilab is the U.S. CMS host institution and provides facilities to U.S. CMS for the integration and testing of equipment produced for CMS before shipment to CERN. Fermilab has a comprehensive, documented safety program based on the Fermilab ES&H Manual (FESHM)[19]. Safety at Fermilab is integrated in the line management and into everyone's daily activities. Line managers are responsible for the actions of all the people reporting to them and this extends through the hierarchy down to the individual worker who is responsible for his/her own actions.

If equipment built in a U.S. CMS institution, including Fermilab, is to be brought to Fermilab and operated, then it must conform to FNAL ES&H requirements. Fermilab requires safety evaluations for all equipment operated on its site and has reviews for any equipment that is to be operated unattended (Operational Readiness Review).

Equipment must conform to the requirements at the locations where it is operated. Given the possibility of different ES&H requirements at CERN and at Fermilab, it should be standard practice to attempt to satisfy the strictest applicable requirement so that the device can operate in conformance with safety rules at either place, even if it is not anticipated to be operated at both locations.

9.4 U.S. Funding Agencies

The DOE and NSF have undertaken some specific initiatives with respect to the safety of U.S. personnel at CERN.

9.4.1 Information Page

The U.S. funding agencies maintain a web site "Safety at CERN – Information for U.S. Personnel" at http://www.uscms.org/pdfs/Safety_at_CERN.pdf

This document describes the general safety procedures that U.S. people must follow at CERN. It also includes references and lists of contacts for CERN, CMS, U.S. CMS, and DOE. The page is maintained by the DOE Office of High Energy Physics with the assistance of U.S. CMS.

9.4.2 Tripartite consultation on safety issues

In order to promote mutual understanding, share best practices and keep communications channels open, CERN, U.S. CMS and U.S. ATLAS have initiated direct consultations between the head of the CERN Safety Policy Committee, the head of the Fermilab ES&H section representing Fermilab in its role as U.S. CMS host institution, and the head of ES&H at Brookhaven Laboratory representing BNL in its role as U.S. ATLAS host institution. The CMS GLIMOS also participates in these interactions.

9.5 Safety Incident Reporting in CMS

In March 2007, CMS adopted a notification procedure for reporting serious incidents, as determined by CMS management. The Institutional Representative from every CMS institution in the world will be kept informed about the details of such an incident and any follow-up. In addition, CMS will also inform the funding agencies through the Finance Board. The OPM and

the OPDM are members of the CMS Finance Board. The OPM or OPDM will inform the head of ES&H at FNAL, as well as the U.S. LHC Program Manager and Associate.

10. Quality Assurance Program

The first goal of quality assurance is that devices that are intended for insertion in the CMS detector or are used for maintaining the detector must meet CMS and CERN requirements and standards. Similarly, computing installations, whether local to CERN or at remote sites, must meet all performance and throughput requirements. Software deliverables must also satisfy all the requirements. This means that CMS and U.S. CMS must agree to the final requirements documents, specifications, and technical designs for work carried out by the OP for CMS. This is done through the responsible CMS Coordinator interacting with the relevant U.S. CMS managers. The line responsibility for this in CMS flows down from the CMS Coordinator (Technical Coordinator, Offline Coordinator, or Computing Coordinator). However, work that originates in the U.S. and is used in the U.S. exclusively or is used in both the U.S. and CERN must also conform to DOE /NSF safety and quality standards. This duality presents challenges to the overall Quality Assurance Program in U.S. CMS. Fortunately, the CERN/CMS and Fermilab/U.S. CMS programs are very similar in their goals and implementation. Central to the process are clear, agreed upon requirements and specifications and rigorous reviews at key parts of the process. Also, various European and U.S. codes and standards are now very similar. More details on quality assurance are given elsewhere[20].

Appendix 1: Detector Operations Work Breakdown Structure

This appendix describes the Work Breakdown Structure for Detector Operations to Level 2. For each Level 2 element, a list of participating institutions is provided. This is necessarily a snapshot and changes with time are possible. For each of the detector subsytems described below, detector operations includes support of personnel to maintain the detector, including both mechanical and electronics systems. The supported personnel perform repairs and updates to firmware and software. There are Detector Control Systems and Detector Safety Systems that require support and maintenance. Power, cooling and alignment systems must also be maintained. Detector operations also includes support for calibration and alignment activities, both hardware and software.

1.11 Endcap Muon System (EMU/CSC)

Carnegie Mellon, FIT, Florida, FNAL, Northeastern, Northwestern, Ohio State, Purdue, Rice, Texas A&M,, UC Davis, UCLA, UC Riverside, Wayne State, Wisconsin

The CMS Endcap muon detector has both Resistive Plate Chambers (RPCs) and Cathode Strip Chambers (CSCs) in the endcap region. This WBS element includes only the Cathode Strip Chambers for which the U.S. has substantial responsibility. The CSC system consists of 468 Cathode Strip Chambers each with six anode wire planes interleaved among seven cathode panels. The wires run azimuthally and define a track's radial coordinate. The strips run lengthwise at constant $\Delta\phi$ width. There are about 250K cathode strip channels and 200K anode wire group channels.

1.12 Hadron Calorimeter (HCAL)

Boston, Brown, Caltech, Fairfield, FIT, FIU, FNAL, FSU, Iowa, Kansas, Maryland, Minnesota, Mississippi, Northeastern, Northwestern, Notre Dame, Princeton, Purdue, Rochester, Rockefeller, TTU, UC Riverside, UIC

The CMS Hadron Calorimeter consists of four subdetectors summarized in the following table:

Name	Composition	Photodetector	η range	# channels
HB (Barrel)	Brass absorber + scintillator tile	Hybrid Photodiode (HPD)	0.000 ~ 1.393	2,592
HE (Endcap)	Brass absorber + scintillator tile	HPD	1.305 ~ 3.000	2,592
HF (Forward)	Iron absorber + Quartz fibers	PMT	2.853 ~ 5.191	1,728
HO (Outer)	Scintillator Tile (outside of solenoid	HPD	0.000 ~ 1.305	2,160

1.13 Trigger

Boston, Brown, Cornell, Florida, FNAL, Kansas State, Purdue Rice, Rockefeller, Texas A&M, UC Davis, UCLA, UCSB, UIC, Wisconsin

The LHC provides proton-proton and heavy-ion collisions at a crossing frequency of 40 MHz. The trigger system performs the reduction of this rate to a rate manageable for data recording. The rate is first reduced by the Level-1 Trigger. It consists of custom-designed programmable electronics with a design output rate limit of 100 kHz. The Level-1 Trigger uses coarsely segmented data from the calorimeters and muon systems. The second stage of the trigger is the High-Level Trigger (HLT) which consists of software running on a filter farm of about one thousand commercial processors. The HLT has access to the complete read-out data and can therefore perform complex calculations similar to those made in the off-line analysis software. The HLT reduces the rate to a few hundred Hz.

1.14 Data Acquisition System (DAQ)

FNAL, MIT, UC San Diego, UCLA

The Data Acquisition system has three functional blocks:

- The Data-to-Surface system acquires data from the detector front-end electronics.
- The Readout Builder system assembles the events from the read-out fragments.

- The Filter Farm runs the High-Level Trigger software to select events of interest.

The HLT was previously mentioned in the Trigger description. The HLT software is the responsibility of the Trigger groups while the Filter Farm (hardware) is the responsibility of the DAQ groups.

1.15 Electromagnetic Calorimeter (ECAL)

Caltech, Cornell, Kansas State, Minnesota, Northeastern, Notre Dame, Rutgers, Virginia

The CMS electromagnetic calorimeter of CMS (ECAL) is a hermetic homogeneous calorimeter made of 61,200 lead tungstate (PbWO4) crystals mounted in the central barrel region, closed by 7,324 crystals in each of the two endcaps. A preshower detector is placed in front of the endcaps crystals. Avalanche photodiodes (APDs) are used as photodetectors in the barrel and vacuum phototriodes (VPTs) in the endcaps.

1.16 Forward Pixel Detector (FPix)

Colorado, Cornell, FNAL, Iowa, Johns Hopkins, Kansas, Mississippi, Nebraska, Northwestern, Princeton, Puerto Rico, Purdue, Purdue Calumet, Rice, Rochester, Rutgers, SUNY-Buffalo, Tennessee, UC Davis, Vanderbilt

The Forward Pixel Detector consists of two disks at each end of CMS, at z = 34 and 46 cm. The structure has 24 blades in each disk and seven detector modules per blade (four on front and three on back of the blade). The pixel size is 100μm ×150μm and the detector has about 18 million channels.

1.17 Silicon Strip Tracker (SiTrk)

Brown, FNAL, Kansas, MIT, Rochester, UCSB, UC Riverside, UC San Diego, UIC

The radial region of CMS between 20 cm and 116 cm is occupied by the silicon strip tracker. It is composed of three different subsystems: the Tracker Inner Barrel and Disks (TIB/TID); the Tracker Outer Barrel (TOB) and the Tracker Endcaps (TEC). The Tracker Inner Barrel and Disks (TIB/TID) extend in radius towards 55 cm and are composed of four barrel layers, supplemented by three disks at each end. The TIB/TID is surrounded by the Tracker

Outer Barrel (TOB). It has an outer radius of 116 cm and consists of six barrel layers. The TOB extends in *z* between ±118 cm. Beyond this *z* range, the Tracker EndCaps (TEC+ and TEC- where the sign indicates the location along the z axis) cover the region 124 cm < |*z*| < 282 cm and 22.5 cm < |*r*| < 113.5 cm. Each TEC is composed of nine disks, carrying up to seven rings of silicon micro-strip detectors. In addition, the modules in the first two layers and rings, respectively, of TIB, TID, and TOB as well as rings 1, 2, and 5 of the TECs carry a second micro-strip detector module which is mounted back-to-back with a stereo angle of 100 mrad in order to provide a measurement of the second co-ordinate (*z* in the barrel and *r* on the disks). This tracker layout ensures at least ≈ 9 hits in the silicon strip tracker in the full range of $|\eta| < 2.4$ with at least ≈ 4 of them being two-dimensional measurements. The CMS silicon strip tracker has a total of 9.3 million strips and 198 m^2 of active silicon area.

1.18 Detector Support

This WBS element includes items of importance for the detector that because of their global nature do not fit logically into one of the other WBS Level 2 elements. This part of the WBS has been used to support personnel working on databases, low voltage power, cooling and installation.

Appendix 2: Software & Computing Work Breakdown Structure

2.1 Tier-1 Facility

The Tier-1 Facilities Task takes care of all aspects of operating and upgrading the Fermilab computing facility, which includes the Tier-1 center and the LPC-CAF analysis facility with their substantial CPU, data storage, and data access systems.

The Tier-1 delivers a list of services for data storage and transfers, for job submission and monitoring, etc, working as part of the Fermilab Computing Division. The Tier-1 facility area also oversees and is engaged in developing software required to carry out its mission, in particular in the area of mass storage management, integration and interfaces, and high performance and reliable data servers. Other facility services include security, facility space planning, and license management. It interfaces with the user community that uses the analysis facility and is involved in user education and training. It also interacts and provides expertise and

guidance to the Tier-2 facilities area and the Open Science Grid. It provides services for all other areas like servers, and help with data operations.

2.2 Tier-2 Facilities

The Tier-2 facilities Task coordinates all activities across the currently seven regional computing centers at Caltech, MIT, Purdue U., UC San Diego, U. Florida, U. Nebraska, UW Madison. These sites had been selected after a call for proposal to all US institutions in Feb. 2005, and funding started in FY05. The Tier-2 centers function as components of the distributed CMS computing system, and the Fermilab Tier-1 center has specific responsibilities for US CMS Tier-2 centers, like data distribution and serving and centralized support.

This area provides a managed framework for building, upgrading and operating the Tier-2 environment and for its funding. Each Tier-2 center supports physics analysis for US CMS members and event simulation production, and hosts datasets on its storage systems for collaboration-wide use. The Tier-2 center is part of the WLCG and a CMS site in the OSG Consortium.

For each site, procurements (hardware specifications, vendors, schedules, etc.), the computing environment (Operating Systems, Grid tools and services, etc) and operating priorities (resources allocation by function, by user, etc) are being coordinated with the rest of U.S. CMS. While this does not mean that uniformity in any of these areas will be required, it does mean that some uniformity may be required and that there will be thresholds in procurement levels, configuration changes and capacity allocations above which approval of the Tier-2 Facilities Manager and the US CMS Software and the SCOM will be required.

The OP provides resources so that sites can acquire and install computing hardware (storage systems, networking equipment and computational nodes) and perform system administration and operational support. A detailed yearly procurement plan for each facility is worked out between the site managers and the Tier-2 Facilities L2 manager, addressing the agreed resource requirements and the funding envelope.

The sites are responsible for maintaining the necessary computing services and software stack for proper functioning as a Tier-2 site. These include (but are not limited to) the OSG services, monitoring services, data-transfer and data-management software, and CMS software. The sites deploy new versions of existing services, and new services, as necessary for proper operation. They are supporting the CMS-wide and WLCG-wide performance monitoring and the

OSG accounting services and are fully engaged in CMS-wide system tests and eventual performance and reliability campaigns. The schedules and milestones for these activities are part of the WBS.

2.3 Grid Services and Interfaces

The Grid Services and Interfaces area includes all development and operational aspects of Grid middleware and Grid services and the interfaces to CMS-specific application services with the Grid infrastructure. Grid services at CMS regional centers are run run by the Open Science Grid, and the Grid Services and Interfaces area interacts with OSG and CMS sites on behalf of U.S. CMS to facilitate the successful running of the CMS distributed computing infrastructure.

Much of the development work is done off-project under the guidance and with collaboration of this area, for tasks like integration between CMS services and Grid services, for accounting and monitoring services etc.

U.S. CMS makes resources accessible to the Open Science Grid, which provides for the sharing of U.S. CMS and other VO owned Grid resources subject to policy and agreements, making opportunistic and shared use of the Open Science Grid resources. The Open Science Grid is providing a framework for collaboration with other Grid-enabled sites, including US Atlas Tier-1 and Tier-2 centers and other laboratories and university computing centers. The Grid Services and Interfaces area facilities this collaboration and interacts with other projects like the WLCG etc.

2.4 Application Services

The Application Services area coordinates the U.S. efforts to develop, integrate, commission, and operate the set of services for Data Management and Workflow Management.

2.5 Distributed Computing Tools

The Distributed Computing Tools area is responsible for computing and software services that pertain to the distributed nature of the CMS computing environment. This involves the services

for large-scale movement of Petabytes of data between the regional centers in the worldwide grid, services for sharing of distributed computing resources for production processing and analysis job submission, and all operational aspects of running these services. The area also takes care of research, development, integration, and deployment of software to support these activities in the U.S. It also has operational responsibility for simulation production tools, and is participating in the CMS Analysis Operations task. In addition this area also coordinates the integration component of the DISUN Tier-2C Program, which is running out in 2010.

2.6 Core Software and Support

The Core Software and Support area is responsible for providing the US share to the CMS offline software efforts. The US has specific responsibility for general software architecture, for the core application framework and for software supporting the Event Data Model, for event visualization, for performance measurements and improvements, for software releases, packaging, and distribution.

The area also supports physicists writing code with software development expertise, architectural help

Appendix 3: Common Operations Work Breakdown Structure

3.1 Operation Program Management Reserve Allocation

This task is the allocation of management reserve by the Program Manager and Deputy based on the change control process described above. Funds are transferred from this task to the appropriate tasks in the Detector Operations and Software and Computing or into one of the Common Operations tasks listed below.

3.2 CMS Common Fund Costs

M&O Category A payments from the U.S. CMS Operations Program to the CMS experiment are distributed from the account associated with this task. CMS requests lists of physicists, engineers and computer scientists who are going to be authors of physics papers for the next year from CMS institutional representatives to the collaboration board. Since inclusion in the list also implies commitment to carry out activities to support the operation and maintenance of the CMS detector and computing infrastructure, the U.S. CMS Program Manager and the Deputy evaluate the proposed M&O A lists provided by the U.S. institutional representatives to the CMS Collaboration Board. They make sure that each institution can satisfy the requirements for service that are implied by persons they have included in the list. They provide the completed list to the DOE and NSF LHC Program Managers.

3.3 U.S. CMS Remote Operations Center

The Remote Operations Center, or ROC, located in the atrium of Wilson Hall at Fermilab provides a location where U.S. CMS physicists can take certain kinds of shifts on the CMS experiments. Currently, Data Quality Monitoring shifts can be taken. Shifts taken at the ROC count towards CMS service work (ESP). U.S, CMS physicists who choose to do this avoid the expense and inconvenience of travelling to CERN to carry out their obligations. This task includes the equipment of the ROC and its maintenance; personnel to develop tools that make operations, including remote operations, convenient and useful in CMS; personnel to provide training in shift operations; and personnel to make sure that the required information is available to the ROC.

3.4 LHC Physics Center

The LHC Physics Center (LPC) at Fermilab offers support for U.S. CMS members who wish to participate in the CMS data analysis without necessarily having to spend large amounts of time at CERN. The LPC is jointly funded by the U.S. CMS Operations Program and Fermilab through its CMS Center.

The LPC has experts on nearly every aspect of CMS analysis, CMS physics objects, and data operations. It also provides training in the use of CMS software and facilities. In addition, it maintains a Computer Analysis Facility for the entire U.S. CMS community to support physicists at the LPC or at U.S. institutions who do not have adequate local resources to support their data analysis efforts. The LPC works closely with the CMS Physics Office at CERN to coordinate the activities at the LPC with those at CERN so that LPC activities are aligned with the rest of CMS. The LPC has a detailed governance document. There are two LPC coordinators appointed by the Fermilab Director with the assistance of a selection committee that has international CMS participation. The LPC coordinators run the LPC program with the help of \the LPC Management Board. An LPC Advisory Board reports to the Fermilab Director and the U.S. CMS Operations Program.

3.5 Operations Support

This is mainly salary and other support (COLA, travel) for U.S. CMS members and some non-U.S. CMS members who are contributing to aspects of CMS that do not fall into the elements of M&O or S&C. These include COLA and in some cases teaching buyouts for U.S. physicists who are asked to serve as CMS Project Managers or carry out other special international-level functions for the detector, software or computing. This constitutes the fair share of U.S. CMS contribution to the overall management of CMS operations. This task also supports a few expert consultants who are available to help generally on CMS.

3.6 Program Offices

This task provides for salary support, M&S and travel for the staffs of the three program offices of U.S. CMS: the main program office at Fermilab, the Program Office at CERN, and the NSF Program Office at UCLA.

3.7 Education and Outreach

This task pays for the activities of the U.S. CMS Outreach coordinator. (S)he allocates funds to various international CMS education and outreach activities and also supports some

activities specific to the U.S. This task also provides travel support for the U.S. CMS Communicator and salary support for the U.S. CMS web master.

3.8 Collaboration Support

This task provides support for special tools needed to facilitate the participation of U.S. CMS members in CMS. This has included videoconferencing support and collaborative tools. It has also included support for an additional post doc for the independently (NSF) funded PIRE postdoc. The PIRE program contributes directly to the Pixel R&D program for U.S. CMS.

Appendix 4: Reference Documents

1. General Conditions for Experiments Performed at CERN (April 1989) – Defines the roles and responsibilities of CERN, as the Host Laboratory, and the CMS Collaboration.
2. U.S. CMS Collaboration Letter of Intent (September 1995) – Proposal for U.S. participation in the construction of the CMS Detector.
3. CMS Constitution (September 1996) – Organization, structure, and management systems governing the CMS Collaboration.
4. International Cooperation Agreement between CERN, DOE and NSF (December 1997) – Defines the program of work, responsibilities and funding for the U.S. participation in the LHC.
5. MOU between U.S. CMS and U.S. Collaborating Institution (June 1998) – Defines the program of work, responsibilities and funding for the U.S. institution's participation in the U.S. CMS Project.
6. U.S. CMS Project Management Plan rev. 1 (December, 2002) – Plan describing the management of the U.S. CMS Detector Construction Project.
7. The U.S. LHC Project Execution Plan rev. 1 (October, 2002) – Mission need, scope and goals of U.S. participation in the LHC, and description of management and executive processes governing the U.S. LHC effort.

8. MOU between DOE and NSF concerning the LHC (December 1999) – Communication and coordination of funding agencies as it applies to U.S. participation in the LHC.
9. U.S. CMS Constitution (June 2000) – Organization, structure, and management systems governing the U.S. CMS Collaboration.
10. U.S. CMS Technical Baseline Document (October 2002) – Controlled document that describes the technical scope of the U.S. CMS Project.
11. MOU for M&O with CERN
12. U.S. CMS S&C Program Management Plan (2004) – http://uscms.fnal.gov/pub/pmp/Software_Computing/
13. U.S. CMS M&O Program Management Plan (2004) – http://uscms.fnal.gov/pub/pmp/Maintenance_Operations/
14. Letter, JOG to: FNAL Director re: U.S. CMS Program Management (November 7, 2003).
15. U.S. Research Program for the Large Hadron Collider, Research Program Execution Plan, January 2005.

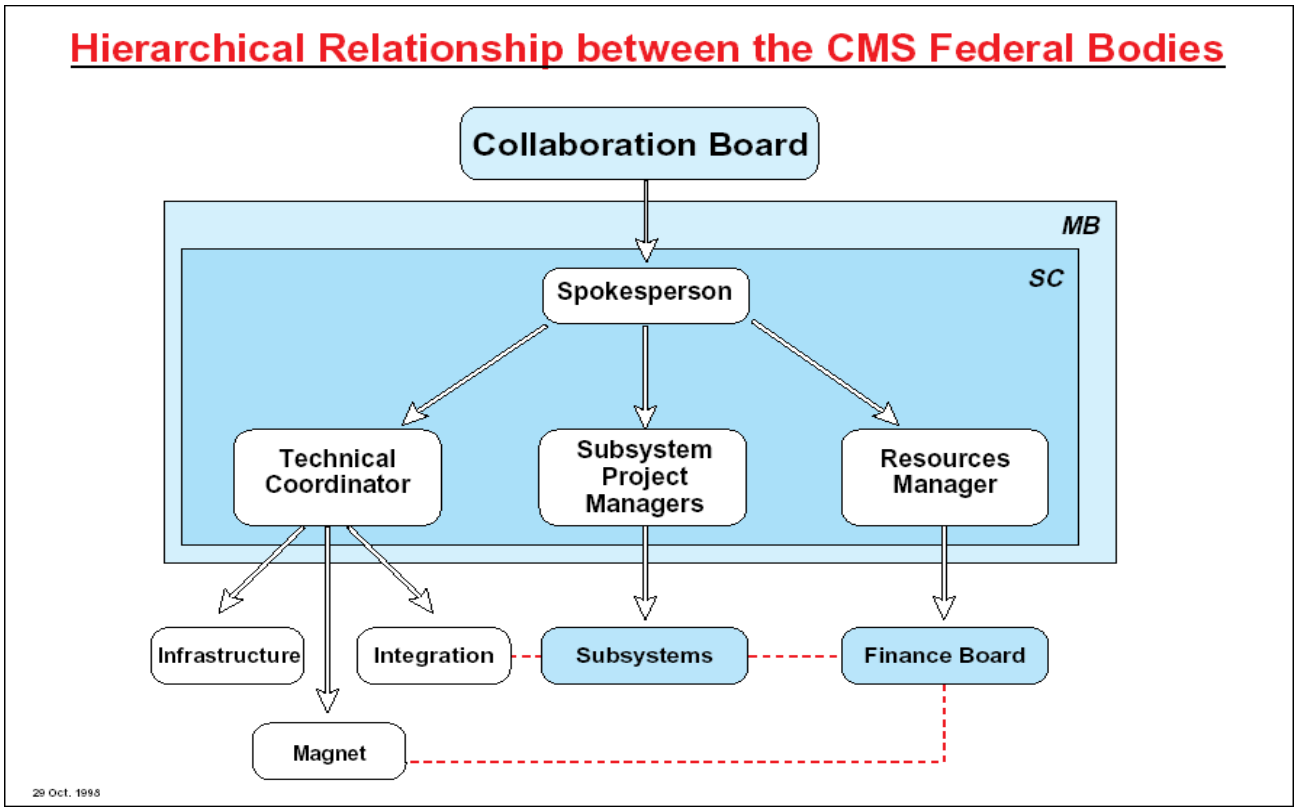
Appendix 5: U.S. CMS Collaborating Institutions

Institution	**Agency Support**
Boston University	DOE
Brown University	DOE
University of California at Davis	DOE
University of California at Los Angeles	DOE
University of California at Riverside	DOE
University of California at San Diego	DOE
University of California at Santa Barbara	DOE
California Institute of Technology	DOE
Carnegie Mellon University	DOE
University of Colorado	DOE
Cornell Unversity	NSF
Fairfield University	DOE
Fermi National Accelerator Laboratory*	DOE
University of Florida	DOE
Florida Institute of Technology	DOE
Florida International University	NSF
Florida State University	DOE
University of Illinois at Chicago	NSF
University of Iowa	DOE
Johns Hopkins University	NSF
University of Kansas	NSF
Kansas State University	DOE
Lawrence Livermore National Laboratory	DOE
University of Maryland	DOE
Massachusetts Institute of Technology	DOE
University of Minnesota	DOE
University of Mississippi	DOE
University of Nebraska-Lincoln	NSF
State University of New York at Buffalo	NSF
Northeastern University	NSF
Northwestern University	DOE
University of Notre Dame	NSF
Ohio State University	DOE
Princeton University	DOE
University of Puerto Rice - Mayguez	DOE
Purdue University - Bloomington	DOE
Purdue University - Calumet	NSF
Rice University	DOE
University of Rochester	DOE
Rockefeller University	DOE
Rutgers University	NSF
University of Tennessee	DOE
Texas A&M University	DOE
Texas Tech University	DOE
Vanderbilt University	NSF

University of Virginia	DOE
Wayne State University	DOE
University of Wisconsin at Madison	DOE

* Designated as Host Laboratory for the U.S. CMS Operations Program

Appendix 6: CMS Executive Hierarchy



Appendix 7: GLOSSARY

ATLAS (A Toroidal LHC Apparatus) – A general-purpose particle detector to be installed at Point 1 of the LHC ring. Distinctive features of ATLAS are a large volume, air-core toroidal magnet providing good momentum resolution and sign discrimination for muons and a fine-grained liquid argon electromagnetic calorimeter.

AY$ (Actual Year Dollars). Dollars in the year spent. Allows the project to estimate out year expenditures while considering escalation estimates. The U.S. CMS project uses the inflation estimates for energy research projects as recommended by the DOE.

BA (Budget Authority). Cumulative funds currently allocated and authorized by the Department of Energy and the National Science Foundation that may be committed and spent by U.S. CMS institutions for project-related activities.

CERN (European Organization for Nuclear Research) – An intergovernmental organization established by Convention signed in Paris on 1 July 1953, revised on 17 January 1971. Also known as the European Organization of Particle Physics.

CERN Team Account – An accounts receivable service contract between a U.S. institution and CERN used to purchase goods and services at CERN.

CMS (Compact Muon Solenoid) – A general-purpose particle detector to be installed at Point 5 of the LHC ring. A distinctive feature of CMS is a high field solenoid surrounding a precision tracker providing high precision spatial information for decay vertices and particle tracking.

Host Laboratory – A designated DOE laboratory that has management oversight responsibilities for U.S. LHC Accelerator, U.S. ATLAS, or U.S. CMS activities.

JOG (DOE/NSF Joint Oversight Group) – The combined DOE/NSF operating group for the U.S. LHC Program. The Director of the DOE Division of High Energy Physics and the Director of the NSF Division of Physics serve as co-chairs of the JOG.

LHC (Large Hadron Collider) – A particle accelerator at CERN that will collide two counter-rotating beams of protons, each with energy of up to 7 trillion electron volts (TeV). The beams will collide at four

intersection points at which appropriate particle detectors will be located. The accelerator will be fed by an existing cascade of lower-energy accelerators.

LHC Project – The activities by CERN to build the LHC accelerator and to contribute to the construction of, and to provide co-ordination and support for, the LHC experiments. (International Agreement, Article I, 1.5)

Management Reserve- The difference between planning commitments and budget authority, assessed for each fiscal year.

OBS (Organizational Breakdown Structure) – A hierarchical organization chart showing the chain of authority and responsibility for executing the program or project.

RRB (Resource Review Board) – An oversight board, with representatives of the concerned funding agencies and the CERN management, for each of the LHC detectors, ATLAS, CMS, which reviews and allocates resources required for the project to proceed on cost and schedule. The Co-Chairs of the U.S. DOE/NSF JOG are ex-officio members of the RRB.

SOW (Statement of Work). A non-binding annual agreement between a U.S. CMS collaborating institution and the U.S. CMS Research Program that describes the amount of work, along with related costs and resources needed to achieve the work, which that institution is responsible for in any given fiscal year.

Upgrade – Improvement or optimization in the capability or function of a detector or accelerator component, subsystem or system intended to enhance its physics productivity.

U.S. LHC Construction Project – U.S. participation in the construction of the LHC accelerator and in the design and fabrication of the ATLAS and CMS detectors. Funding in the amount of $450M has been provided in the DOE budget plan and $81M in the NSF budget plan. Details of the U.S. "deliverables" are found in the respective Project Management Plans.

U.S. LHC Program – U.S. participation in construction of the LHC Accelerator and construction and operation at CERN of the ATLAS and CMS detectors. The U.S. LHC Program has two components, the U.S. LHC Construction Project and the U.S. LHC Research Program.

U.S. LHC Operations Program – U.S. participation in the operation of the LHC detectors and in the physics investigations enabled by the detectors, following completion of the facility and commissioning of the detectors.

WBS (Work Breakdown Structure) – A method of hierarchically numbering tasks in a traditional outline numbering format. The WBS is used in US CMS to track all resources, schedules, and costs. A WBS# is one of the outline numbers that is used in the subproject for tracking.

Appendix 8: List of Abbreviations

Item	Definition
APM-DD	Agency Project Manager-Fermilab Director Designee
AY$	Actual Year Dollars (Spent)
BA	Budget Authority
CB	CMS Collaboration Board
CERN	European Organization for Nuclear Research
CH	DOE Chicago Operations Office
CMS	Compact Muon Solenoid
CO	Common Operations
CR	Change Request
DAQ	Data Acquisition
DO	Detector Operations
DOM	Detector Operations Manager
DOE	United States Department of Energy
DOE-OHEP	DOE Office of High Energy Physics
DOE-SC	U.S. DOE Office of Science
EH&S	Environment, Health and Safety
FB	CMS Finance Board
GLIMOS	Group Leader in Matters of Safety
FSO	U.S. DOE Fermi Site Office
Fermilab	Fermi National Accelerator Laboratory
FNAL	Fermi National Accelerator Laboratory
FRA	Fermi Research Alliance
IB	U.S. CMS Collaboration Institutional Board
JOG	Joint Oversight Group
LHC	Large Hadron Collider
L2M	WBS Level 2 Manager
L3M	WBS Level 3 Manager
LHCC	CERN LHC Committee
M&O	Maintenance and Operations
MB	CMS Management Board
MCHF	Million Swiss Franc
MOU	Memorandum of Understanding
NSF	National Science Foundation
MPO	Memorandum Purchase Order
OER	DOE Office of Energy Research
OPM	Operations Program Manager
PEP	U.S. LHC Project Execution Plan
OPDM	U.S. CMS Operations Program Deputy Manager

OPM	U.S. CMS Operations Program Manager
OPMG	Operations Program Management Group
OPMP	U.S. CMS Operations Program Management Plan
OSG	Open Science Grid
PO	U.S. CMS Program Office
QA	Quality Assurance
R&D	Research and Development
RRB	CERN LHC Resource Review Board
RU	Responsible University
SC	Steering Committee
S&C	Software and Computing
SCM	Software and Computing Manager
SG	Scrutiny Group
SOW	Statement of Work
URA	Universities Research Association
WBS	Work Breakdown Structure
WLCG	Worldwide LKHC Computing Grid

[1] Deliverables as specified in Construction Project
[2] MOU with CERN
[3] CMS Computing Technical Design Report
[4] Protocal between CERN, DOE, NSF

[5] Related CERN document to above
[6] Funding for CMS is, in most nations, funded by national funding agencies.CMS recognizes national blocks in issues relating to funding.
[7] All institutions that have been admitted to CMS can attend CMS CB meetings and constribute to the discussions.In order to cast a vote, the institution must have 5 PhD level participants in CMS. Small groups amy combine numbers to earn a single vote.
[8] U.S. CMS Constitution
[9] International Cooperative Agreement between CERN, DOE and NSF (December 1997)
[10] MOU for M&O with CERN

[11] U.S. Research Program for the Large Hadron Collider, Research Program Execution Plan, January 2005
[12] MOU between DOE and NSF concerning the LHC (Dececmber 1999)
[13] Letter, JOG to FNAL Director re: U.S. CMS Program Management (November 7, 2003)
[14] Letter to FNAL director (Nov 30, 1997)
[15] The actual author list of a paper may consist of Ph>D. Physicists who are not on the M&O A list for that year due to various carryover arrangements as people transition in and out of CMS. There are special rules for physicists who have retired from their positions. Graduate students who have met all other authorship requirements are included even though they do not pay M&O A.
[16] A recent example of this is thar the M&O A assessment will be increased for the next three years to permit the construction of needed maintenance facilities at the surface at Point 5. Thereafter, the ongoing maintenance costs for theses facilities will become a regular operating cost within the M&O A.
[17] http://cms-safety.web.cern.ch/cms-safety/.
[18] SAPOCO refers to the CERN Safety Policy Committee
[19] FESHM reference
[20] Document under development may be obtained from OPM