

# Collaborating at a distance: operations centres, tools, and trends

**Erik E Gottschalk**

Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

E-mail: erik@fnal.gov

**Abstract.** Successful operation of the LHC and its experiments is crucial to the future of the worldwide high-energy physics program. Remote operations and monitoring centres have been established for the CMS experiment in several locations around the world. The development of remote centres began with the LHC@FNAL ROC and has evolved into a unified approach with distributed centres that are collectively referred to as “CMS Centres Worldwide.” An overview of the development of remote centres for CMS will be presented, along with a synopsis of collaborative tools that are used in these centres today and trends in the development of remote operations capabilities for high-energy physics.

## 1. Introduction

As international research groups in high-energy physics continue to grow in size, there is a growing need to develop capabilities for remote participation in daily operations of experimental facilities. The next big project that involves a large fraction of the international high-energy physics community is the Large Hadron Collider (LHC), a particle accelerator and collider with a 27-kilometer circumference located at CERN. The LHC provides colliding particle beams for several particle physics experiments. One of these experiments is the Compact Muon Solenoid (CMS), which has 3000 scientists and engineers collaborating on this one experiment. A second experiment, named ATLAS, has a comparable number of scientists and engineers. Two other experiments, named ALICE and LHCb, have fewer people, but each one has approximately 1000 researchers. The large number of people working in these international collaborations is unprecedented in scientific research, as are the logistics of commissioning and operating experimental facilities with collaborations of this size. For CMS, remote operations capabilities are expected to help streamline operations. The development of these capabilities began at Fermilab with the LHC@FNAL Remote Operations Center (usually referred to as the “ROC”) and has evolved into a collection of multiple remote operations and monitoring centres referred to as “CMS Centres Worldwide” [1].

The goal is to develop remote operations capabilities that will enable remote participation in daily operations from anywhere in the world. One aspect of remote operations is *remote monitoring* of accelerators and experiments. This capability is not new, since remote monitoring has been done routinely for more than ten years. The new focus is on developing remote operations capabilities that exploit new communications technologies and collaborative tools that are able to function in an environment with ever-increasing emphasis on cybersecurity. As projects and international collaborations grow in size, the overall goal for the field of high-energy physics is to involve larger numbers of people with expertise that is essential to the success of a

project, while working towards improving the effectiveness and efficiency of accelerator and experiment operations. The belief that everybody who contributes to operations must be physically present in one location, such as a control room, is no longer tenable in a field that involves numerous people from all over the world with wide-ranging expertise working towards a common goal. Specific goals for remote operations include the need for *safeguards* that prevent people who are working at remote locations from causing problems or interfering with operations; *secure access* to information that is available in control rooms and operations centres; *collaborative tools* to enable remote participation; and *remote shifts* to streamline operations.

To address the need for remote operations and remote participation in both the LHC and CMS, Fermilab built the LHC@FNAL ROC. Construction was completed in February 2007, and since that time the ROC has been used for numerous activities and events, most of which are described in section 2. Here I briefly mention one particular event that exemplifies the close ties that have developed between Fermilab and CERN as a result of having built the ROC. The event occurred at CERN on September 10, 2008. The occasion was the LHC First Beam Day, the world's largest scientific media event since the moon landing. At Fermilab the event began shortly after midnight in the atrium of Wilson Hall, which on this occasion appeared to be an extension of CERN. Activities at CERN captivated and enlivened an audience of over 400 people, including members of the press, who gathered at the ROC to participate in what turned out to be a tremendous success at circulating beams in the LHC. Figure 1 shows a photograph that was taken of the crowd that gathered in the early hours of the morning in front of the ROC. The ROC is located at the top of the photograph with a large public display that was showing what was happening at CERN via a satellite feed, a streaming video feed, and a high-definition



**Figure 1.** A photograph of the crowd that gathered in front of the ROC at two o'clock Central Time on September 10, 2008. (Courtesy of Wayne Baisley)

videoconferencing connection. A few hours later, after beam had successfully circulated in the LHC, a live video feed originating in the ROC was broadcast worldwide from CERN as part of the television coverage that day. Using high-definition videoconferencing equipment in the ROC, Fermilab's Director, Dr. Pier Oddone, surrounded by representatives from the U.S. Department of Energy, National Science Foundation, Argonne National Laboratory, CMS, and a group of high school students congratulated CERN's Director General, Dr. Robert Aymar, on the successful circulation of beam in the LHC. Remote participation in important media events such as this requires considerable planning, testing, and cooperation. While most of the planning for this event was done at CERN, the ROC provided a focal point for coordinating joint activities that involved both CERN and Fermilab. Without the ROC, Fermilab would not have attempted to host its own press event, and would not have participated remotely in the excitement occurring at CERN that day.

Besides providing a focus for remote participation in the LHC First Beam Day, the ROC has played an important role for numerous events and activities associated with the LHC and CMS, even before operations have begun at CERN. It has also served as a precursor for other CMS Centres around the world. Section 2 describes the original concept for the ROC, evolution of the concept, development of the ROC, and the development of CMS Centres Worldwide. In building the foundation for multiple distributed CMS Centres, we have made several significant contributions to the development of new remote operations capabilities. These contributions are described in section 3, along with an overview of collaborative tools that are used in CMS Centres today.

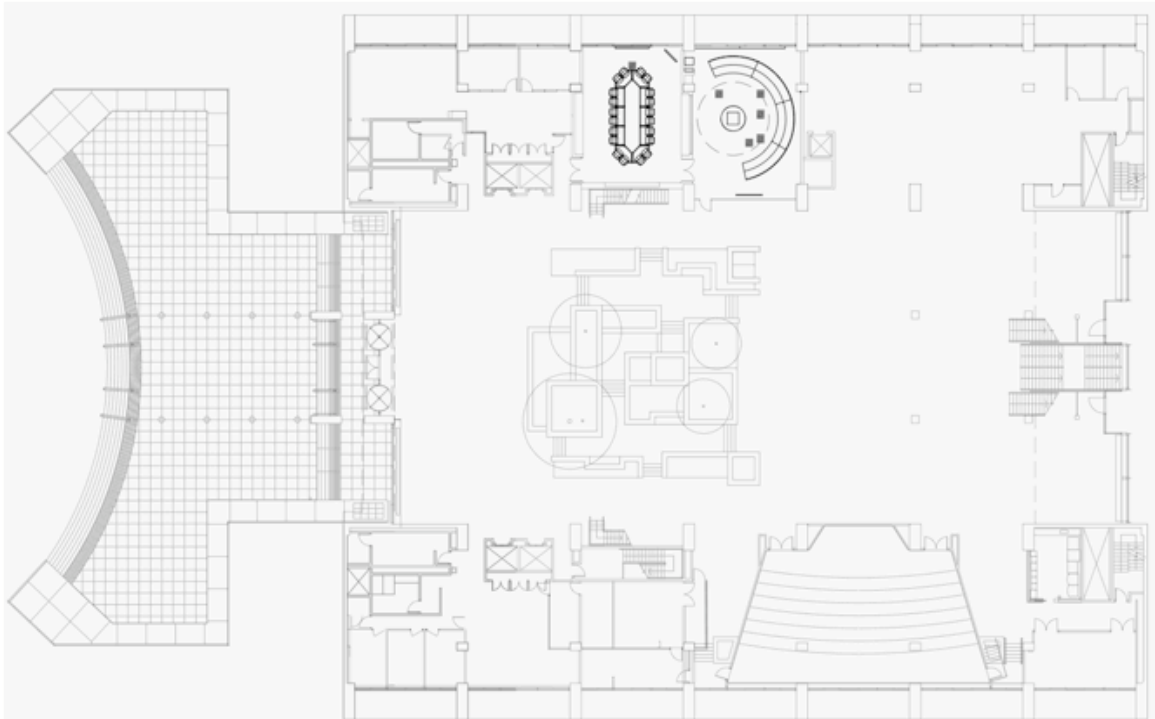
## **2. Operations centres**

The original concept that was developed for the LHC@FNAL Remote Operations Center in 2005 was that the ROC would help scientists and engineers working on the LHC and CMS contribute their expertise to commissioning and operations activities at CERN. At the time we envisioned three functions for the ROC. First, it would be a place that would provide access to data and data-analysis tools in a manner similar to what is available in controls rooms at CERN. With this capability members of the LHC community would be able to participate remotely in accelerator and experiment activities. Second, the ROC would serve as a communications conduit between CERN and members of the LHC community located in North America. The third function envisioned for the ROC was education and outreach. The idea was that visitors would be able to see involvement in LHC activities, and they would be able to see how future international projects would benefit from the development of remote operations capabilities. For instance, the ROC was viewed as a prototype for exploring the capabilities that would be needed for remote operations of a future International Linear Collider.

In many ways the ROC evolved the way we envisioned it in 2005. However, there were some noteworthy developments that we did not anticipate. For instance, while we anticipated that the ROC could serve as a model for other remote operations centers in high-energy physics, we did not anticipate that the ROC would lead to a multitude of distributed CMS Centres all over the world. All of these centres are collectively referred to as "CMS Centres Worldwide." Similarly, our initial focus for developing communications capabilities in 2005 was on establishing reliable communications between the ROC and CERN. In the context of multiple operations and monitoring centres the communications capabilities must be augmented to satisfy the need for communication between *all* CMS Centres. With regard to outreach, we were surprised to discover that interest in the ROC and its association with the LHC was greater than we had anticipated. This encouraged us to become more active in promoting outreach activities. Consequently, we started to play an active role in organizing events, and in participating in the organization of large-scale events, such as the LHC First Beam Day.

The following sections begin with a brief description of the location and layout of the ROC. This provides the context for subsequent sections that explain how the ROC is used today, how it

has evolved from its original concept, and how it has served as a precursor for CMS Centres Worldwide.



**Figure 2.** Floor plan of the first floor of Fermilab’s Wilson Hall. The ROC and associated conference room are located in the two rooms at the top and center of the floor plan. The ROC is the room on the right with consoles arranged in a semicircle, and the conference room is adjacent to the ROC and to the left.

### 2.1. Location and layout

The ROC is located at Fermilab on the first floor of Wilson Hall. Figure 1 shows a view of the area in front of the ROC, and figure 2 shows a floor plan with the ROC and the associated conference room at the top and center of the figure. The floor plan shows the main entrance to Wilson Hall on the left, a staircase to the main auditorium on the right, and shows an open area to the left of the staircase that is occupied by the Fermilab cafeteria. Due to this prominent location, the ROC has become a focal point for LHC and CMS outreach at Fermilab, which was one of the original functions envisioned for the ROC.

Figure 2 also shows the layout of the ROC. The layout consists of four consoles that are arranged in a semicircle around a center table. Each console consists of two workstations. At the midpoint of the semicircular arrangement of consoles is a television screen (see figure 6) that is permanently connected to a high-definition videoconferencing system linked to the CMS Control Room, CMS Centre at CERN, and the CMS Centre at DESY. This high-definition video link is an important aspect of the communications link that exists between the major CMS Centres and is described in section 2.4. A large screen that is referred to as the “Public Display,” is partially visible in figure 1, and is drawn as a small horizontal line beneath the semicircle in figure 2. The Public Display is important for outreach and it has a wide viewing angle so that it is easily visible on the first floor of Wilson Hall, as shown in figure 3.

To the left of the ROC is a conference room. An important feature of the ROC (and one that was incorporated in the design of the CMS Centre at DESY) is a large window between the ROC and the conference room so that people in the conference room can see displays in the ROC,

especially when both rooms are being used for operations. The large window in the ROC has switchable privacy glass, which provides an option to use the conference room for meetings that require a greater degree of privacy for which a view through the glass is not desired. The conference room is equipped with a high-definition (HD) videoconferencing system. This was the first HD system installed at Fermilab, and although the use of HD systems in high-energy physics is still relatively new, these systems are becoming more common as lower priced systems become available. The significance of this particular HD system is that it was used for the dedication of the ROC (see section 2.4) to establish a reliable transatlantic communications link between the ROC, the CERN Control Centre (CCC), and the surface building in Cessy, France, where the CMS detector was being assembled at the time. This particular event was noteworthy in that it set the stage for the use of high-definition videoconferencing for the LHC First Beam Day.

## 2.2. Evolution of the concept

The concept for a *joint* remote operations center for members of the CMS collaboration and for accelerator scientists and engineers working on projects related to the LHC evolved at Fermilab for several reasons. Probably the main reason is that Fermilab has considerable expertise in constructing, commissioning and operating both a hadron collider and the experiments that operate in a collider environment. With expertise in both areas, members of the accelerator community and of the experimental high-energy physics community saw advantages to having access to a remote operations center that would help them apply their expertise to LHC and CMS activities at CERN.

There are several other reasons why Fermilab was instrumental in developing the ROC. Fermilab has had several projects with direct involvement in the LHC. For example, Fermilab accelerator scientists and engineers have built components for the LHC, Fermilab is a collaborating institution in the LHC Accelerator Research Program (LARP) [2], and accelerator scientists, engineers and software professionals are developing software for the LHC controls system. This software development effort, which is unique to Fermilab, is a collaborative effort where the software development is directed by the LHC Controls Group in CERN's Accelerators and Beams Department (CERN-AB), and the LHC Operations Group helps to determine what software is needed and establishes priorities.

These projects have spanned many years and having a remote operations center was viewed as a way to help facilitate work that must, after all, be integrated with work that is being done at CERN. In particular, LARP was interested in remote participation in LHC studies, in training people before they travel to CERN to work on the LHC, and in providing remote support for LHC accelerator components built in the United States. For software development the desire was to develop software for the LHC controls system without having to send many of the Fermilab developers to CERN.

In addition to the work that is being done on the LHC, Fermilab has had, and continues to have, significant involvement in construction, commissioning, operations, and upgrade activities for CMS. Moreover, Fermilab is the host institution for CMS in the United States, it hosts the LHC Physics Center (LPC) for US-CMS, and it is a Tier-1 grid-computing center for CMS. With regard to remote operations, the LPC had been planning for many years to establish a remote operations center that would provide the physical space and the tools that CMS would need for remote monitoring of data quality. To this end a prototype remote operations center was established in 2005 on the 11<sup>th</sup> floor of Fermilab's Wilson Hall. This operations center was used successfully for participation in testbeam activities and experiment commissioning activities at CERN. Since planning for the ROC began in 2005 and we were well aware of the LPC's plans to do remote monitoring of data quality, we began to discuss with CMS and US-CMS Management whether we should expand the role of the ROC to include remote shifts for CMS. At the time this was viewed by some people as a way to take advantage of the time difference between Europe

and the United States to have more people involved in monitoring data quality and monitoring other aspects of CMS operations, especially in the middle of the night at CERN.

The concept for a joint LHC and CMS remote operations center evolved from the early planning stages in 2005 to become an important part of Fermilab's involvement in both the LHC and CMS. However, for accelerator scientists and engineers working on the LHC, the ROC has not yet managed to satisfy many of the goals that people had envisioned. For example, current methods for accessing LHC data, software, documentation, and other types of information at CERN have discouraged several talented people from contributing their expertise to work on the LHC, due in part to CERN's approach to cybersecurity. This is unfortunate, but also somewhat understandable with respect to the challenge that CERN faces in protecting itself against cyberattacks. In contrast, the ROC is used for many different aspects related to CMS. The ROC is used for CMS detector commissioning, data operations, data quality monitoring, trigger monitoring, Fermilab Tier-1 monitoring, and participation in special events. As mentioned before, the ROC has also served as a precursor for the development of CMS Centres at CERN and DESY, and serves as a model for operations and monitoring centres that are being established at CMS institutions around the world.

### 2.3. Development of the ROC

The development of the ROC proceeded through several phases. The first phase started in 2005 with the development of requirements for a Fermilab remote operations center. The requirements were reviewed later that year, which led to revised version of the requirements. The second phase consisted of site visits to find out how other projects built control rooms and, if applicable, how they incorporated remote operations capabilities into daily operations. In the third phase we designed the remote operations center and developed a project management plan with cost and schedule estimates. The fourth phase consisted of building the operations center. After construction was completed, we made adjustments to include additional capabilities as we learned from experience how the ROC was being used. This section describes the development phases, and section 2.4 describes noteworthy events that led up to the current arrangement of multiple CMS Centres distributed around the world.

The development of requirements began in May 2005 after we formed a task force that included members from every division (Accelerator, Computing, Particle Physics, and Technical Divisions) at Fermilab, CMS, LARP, CERN Accelerators and Beams Department (CERN-AB), and the University of Maryland. This task force had an advisory board that included members from ATLAS, Brookhaven National Laboratory, CERN-AB, CERN Physics Department, CERN Technical Support Department, Boston University, Cornell University, University of Michigan, University of Toronto, and the University of Wisconsin. We consulted with people working in the field of fusion energy physics, and with people working on the CDF, D0, MINOS, and MiniBoone experiments at Fermilab. Concepts that influenced our ideas for the ROC came from reports written by a task force that studied the proposal by Professor Albrecht Wagner for a Global Accelerator Network (GAN) [3]. We also credit two individuals who influenced our efforts: Dr. Dan Green, who envisioned a remote operations center for CMS, and Dr. Alvin Tollestrup, who envisioned a remote operations center for accelerator scientists and engineers.

We consulted with CMS and US-CMS Management, as well as LARP and LHC machine groups to develop requirements and prepare a list of activities for the ROC. Our list included the following activities:

- participate in CMS and LHC shifts;
- participate in CMS and LHC data monitoring and analysis;
- develop and test new monitoring capabilities;
- provide access to data, data summaries, and analysis results;
- provide training in preparation for shift activities at CERN;
- and assist in communications between CERN and experts in North America.

In addition to these activities, an important aspect of the ROC was the idea that accelerator and experiment experts would be working in close proximity to each other in the ROC and would be able to share their insights on commissioning and operating the LHC and CMS. The task force developed requirements for the ROC, which were reviewed in July 2005. The review provided useful feedback and recommendations that were taken into consideration as we worked on the requirements. The final version of the requirements document was completed March 24, 2006 [4].

During the latter half of 2005 the task force visited nine sites to find out how other projects built control rooms. Projects that had remote operations capabilities were especially important to us in our planning for the ROC. The task force visited the following sites, with dates of the site visits indicated in the list:

- Technology Research, Education, and Commercialization Center (August 25, 2005);
- Gemini Observatory control room in Hilo, Hawaii (September 20, 2005);
- Jefferson Lab's Machine Control Center (September 27, 2005);
- Hubble Space Telescope control rooms (October 25, 2005);
- National Ignition Facility control room (October 27, 2005);
- General Atomics' DIII-D tokamak control room (October 28, 2005);
- Spallation Neutron Source control room (November 15, 2005);
- Advanced Photon Source control room (November 17, 2005);
- European Space Operations Centre (December 7, 2005).

After the task force completed the project management plan for the ROC (including cost and schedule estimates), we received funding for construction. Construction started on September 13, 2006, and was completed February 14, 2007. Figure 3 shows a view of the completed ROC. The Public Display, shown in the photograph, is used primarily for outreach and special events.



**Figure 3.** A photograph of the ROC on the first floor of Wilson Hall after construction was completed on February 14, 2007. (*Fermilab Photo*)

#### 2.4. The ROC as a precursor for CMS Centres Worldwide

During the construction phase of the ROC an effort began at CERN to develop requirements for a CMS operations centre that would be located at CERN. This effort was motivated in part by construction of the ROC at Fermilab, and it was motivated by concerns that the CMS detector and control room (located in Cessy France) are not close to CERN's main site at Meyrin. There were concerns that CMS collaborators working in Cessy would not have ready access to support staff, office space, meeting rooms, and other amenities that would otherwise be available in Meyrin. Furthermore, the CMS Control Room was not designed to be large enough to accommodate a large number of people for experiment commissioning and operations, especially during the initial startup of the LHC when many more people are needed to bring the experiment online. Therefore, in preparation for CMS commissioning and operations a Requirements and Technical Assessment Group (RTAG) was assembled to develop requirements for the "CMS Centre at CERN." Dr. Lucas Taylor led this effort, which produced a requirements document [5] on March 16, 2007 and subsequently a design for the CMS Centre.

As the design of the CMS Centre progressed, a close working relationship developed between those of us working on the ROC and those who were working on the CMS Centre, especially with regard to planning for future cooperation that would benefit CMS operations. The cooperation between the two centres turned out to be particularly important for the successful dedication of the ROC on October 22, 2007. For this event, which involved several dignitaries at CERN and at Fermilab, close cooperation between the two laboratories was needed to coordinate planning and rehearsals. For this event a high-definition (HD) videoconferencing connection was established between the ROC, the LHC control centre at CERN, and the building in Cessy that was being used to assemble detector components for CMS. The HD videoconferencing system was used so



**Figure 4.** A photograph taken on the occasion of the LHC@FNAL Dedication on October 22, 2007. CERN's Director General, Dr. Robert Aymar, is visible on the Public Display giving his speech with part of the CMS detector visible behind him. (*Fermilab Photo*)



that invited speakers at Fermilab and at CERN could be seen and heard by audiences assembled at both locations. Dignitaries who participated in the “Dedication of the LHC@FNAL Remote Operations Center” and gave speeches included: Dr. Ray Orbach (Department of Energy Under Secretary for Science), Dr. Robert Aymar (CERN Director General), Dr. Joseph Dehmer (National Science Foundation Division Director), Dr. Jim Virdee (CMS Spokesperson), Dr. Lyn Evans (LHC Project Manager), Dr. Joel Butler (US-CMS Program Manager), and Dr. Pier Oddone (Fermilab Director). Figure 4 shows a photograph of several dignitaries at Fermilab watching and listening to Dr. Aymar, who is visible on the Public Display with part of the CMS detector visible in the background. Before the speeches, participants at CERN were given a virtual tour of the ROC using the HD videoconferencing system. Multiple cameras and microphones were used so that participants at CERN could take part in the tour of the ROC that had been arranged for Under Secretary Orbach.

While this event was an important milestone for the ROC, it was also a precursor for the use of HD videoconferencing for large-scale press events involving multiple sites located in different countries. The successful use of HD videoconferencing for the dedication of the ROC led to the planning of the far more ambitious use of this technology for the LHC First Beam Day (as described in section 1). For this event, HD videoconferencing systems were used to connect all of the LHC experiment control rooms, the CMS Centre at CERN, the CERN Globe, and the ROC to the CERN Control Centre, where most of the attention was focused on individuals who were attempting to circulate beam in the LHC. Most of the planning for the HD videoconferencing part of this event was done by Dr. Lucas Taylor and members of the CERN-IT Department. Figure 5



**Figure 5.** A photograph of a screen showing HD videoconferencing connections for the LHC First Beam Day on September 10, 2008. (Courtesy of Wayne Baisley)

shows several sites that were connected by HD video during the event. After the LHC First Beam Day, other events were organized using HD videoconferencing to connect multiple sites. For example, the LHC Grid Fest on October 3, 2008 was an event that announced the readiness of the Worldwide LHC Computing Grid, and on October 16, 2008 we used HD videoconferencing to join in the celebration of the completion of the CMS Centre at DESY.

The primary use for HD videoconferencing for CMS is for day-to-day operations. On February 6, 2008 we established the first permanent video link (see figure 6) between the ROC and the CMS Centre at CERN. The idea behind installing a permanent connection was that this would make it much easier for people working in the ROC and in the CMS Centre to see each other and communicate with each other. In the ROC we refer to the video connection as “the window to CERN.” The high-resolution video of the HD system is so good that one can easily recognize people working in the CMS Centre, thereby encouraging communication. This is very much like encouraging the spontaneous exchange of ideas that occurs when members of a team meet each other in a hallway while working in offices that are located on the same floor of a building. The audio quality of the HD system is also very good. We usually mute the microphones at each end of the video link to avoid interfering with discussions unnecessarily at the other end, and only “unmute” a microphone when one needs to talk to somebody at the other end. With regard to reliability we refer to the video link as being “permanent” since the systems are never intentionally disconnected. However it does happen that a video connection is occasionally “dropped” due to network outages. To make the video connection more reliable, we have recently installed automated procedures for some of the systems to detect the occurrence of



**Figure 6.** A photograph of the television screen in the ROC showing the permanent high-definition videoconferencing connection to the CMS Centre that was first established February 6, 2008.

a dropped video connection. When this happens the system is automatically reconnected.

While construction of the CMS Centre at CERN was underway, a new initiative to build a CMS Centre in Germany was being discussed at DESY. One week after the dedication of the ROC in October 2007, Professor Albrecht Wagner, Chairman of the DESY Board of Directors, visited Fermilab and expressed his interest in constructing a remote operations center at DESY for LHC experiments. Shortly after that, Professor Rolf-Dieter Heuer, Research Director for particle and astroparticle physics at DESY at the time (and now Director General of CERN), visited Fermilab and also discussed his ideas for a remote operations center at DESY. These discussions developed into a plan to proceed with the construction of a CMS Centre at DESY. Dr. Guenter Eckerlin led this effort, and Figure 7 shows the CMS Centre after construction was completed. The permanent high-definition videoconferencing connection is visible on the television screen in the photograph. This connects DESY to the CMS Control Room, the CMS Centre at CERN, and the ROC at Fermilab.

Even before the CMS Centre at DESY was completed, several people at a number of CMS collaborating institutions were beginning to ask about establishing CMS Centres at their home institutions. This expression of interest was very much a grass roots movement that led to new CMS Centres that were established at various institutions as part of what is now called “CMS Centres Worldwide.” To help facilitate the construction of these new CMS Centres around the world, Lucas Taylor wrote a four-page document to provide information on the essential elements that are needed for a CMS Centre, the cost of equipment, and guidelines for software and



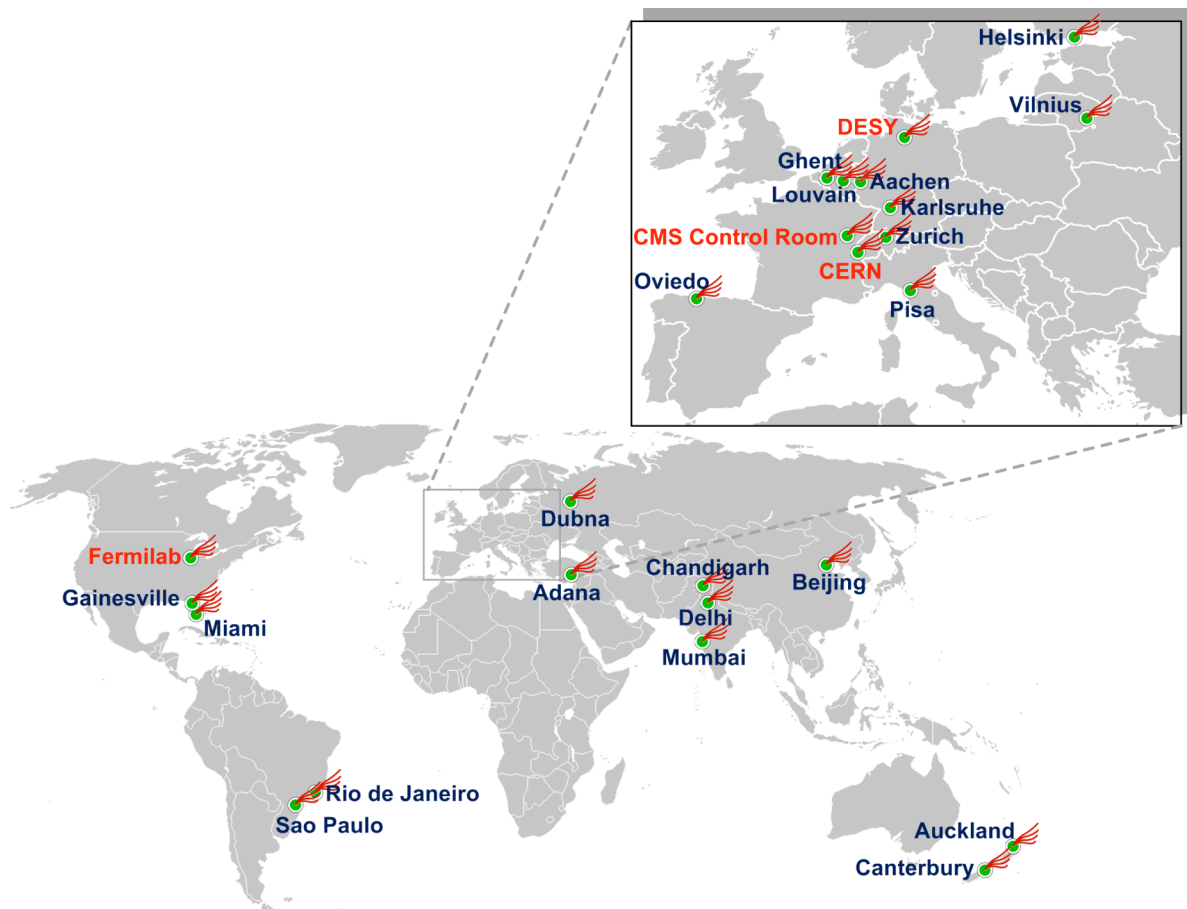
**Figure 7.** A photograph of the CMS Centre at DESY. The high-definition videoconferencing system that connects DESY to the CMS Control Room, the CMS Centre at CERN, and the ROC is visible on the left. (Courtesy of Dr. Guenter Eckerlin)

videoconferencing. One of the collaborative tools that helps to connect distributed CMS Centres to each other is the Ci2i (see eye to eye) web application [6]. This tool is used to provide capabilities for remote viewing of displays, mapping of monitoring information to local or remote displays, configuring computing hardware, managing group accounts and user privileges, and planning of CMS operations. A second web application, called “CMS-TV,” works together with Ci2i to provide information for education and outreach.

The interest in establishing CMS Centres around the world and the information and tools that are available to help CMS collaborators establish their own centre has led to a rapid growth in the number of centres worldwide. Figure 8 shows a map with locations of currently operating CMS Centres, and centres that will be established in the near future. Locations shown in red identify the major centres at CERN, DESY, and Fermilab.

### 3. Collaborative tools and trends

Collaborative tools are an important aspect of remote operations, since the tools make it possible for people to collaborate when they are not in the same physical location. In general, one can think of a collaborative tool as any system, either hardware or software, that makes it possible for people to share or exchange information. Collaborative tools include communications technologies such as telephones, videoconferencing systems, instant messaging and e-mail. There



**Figure 8.** Locations of CMS Centres around the world (as of April 2009), including currently operating centres and centres that will be established in the near future. The major centres are shown in red and include the CMS Control Room, the CMS Centre at CERN, the CMS Centre at DESY, and the ROC at Fermilab. (Courtesy of Lucas Taylor)

are collaborative tools that provide remote access to computing systems, such as secure shell (SSH), virtual private network (VPN), remote desktop services, virtual network computing (VNC) for desktop sharing, and web-based tools to access information or run applications. Other types of tools provide capabilities that let people exchange files, work collaboratively on developing software, engage in online discussions, save files in document repositories, and record information in electronic logbooks. Needless to say, there are many collaborative tools available today, and new tools are being developed all the time. For remote operations in high-energy physics it is important to keep in mind that collaborative tools need to provide *safeguards* and *secure access to information*, so that people working at remote locations can contribute to accelerator or experiment operations without interfering in these operations. Tools that do not satisfy these requirements will, in time, be disfavored as the emphasis on cybersecurity continues to grow.

While working on developing remote operations capabilities for the LHC and CMS, we have introduced several significant innovations that contribute to improved collaboration in an operations environment. Some of these innovations have been briefly mentioned in previous sections. Several of them were specifically designed to provide safeguards, provide secure access to information, or both.

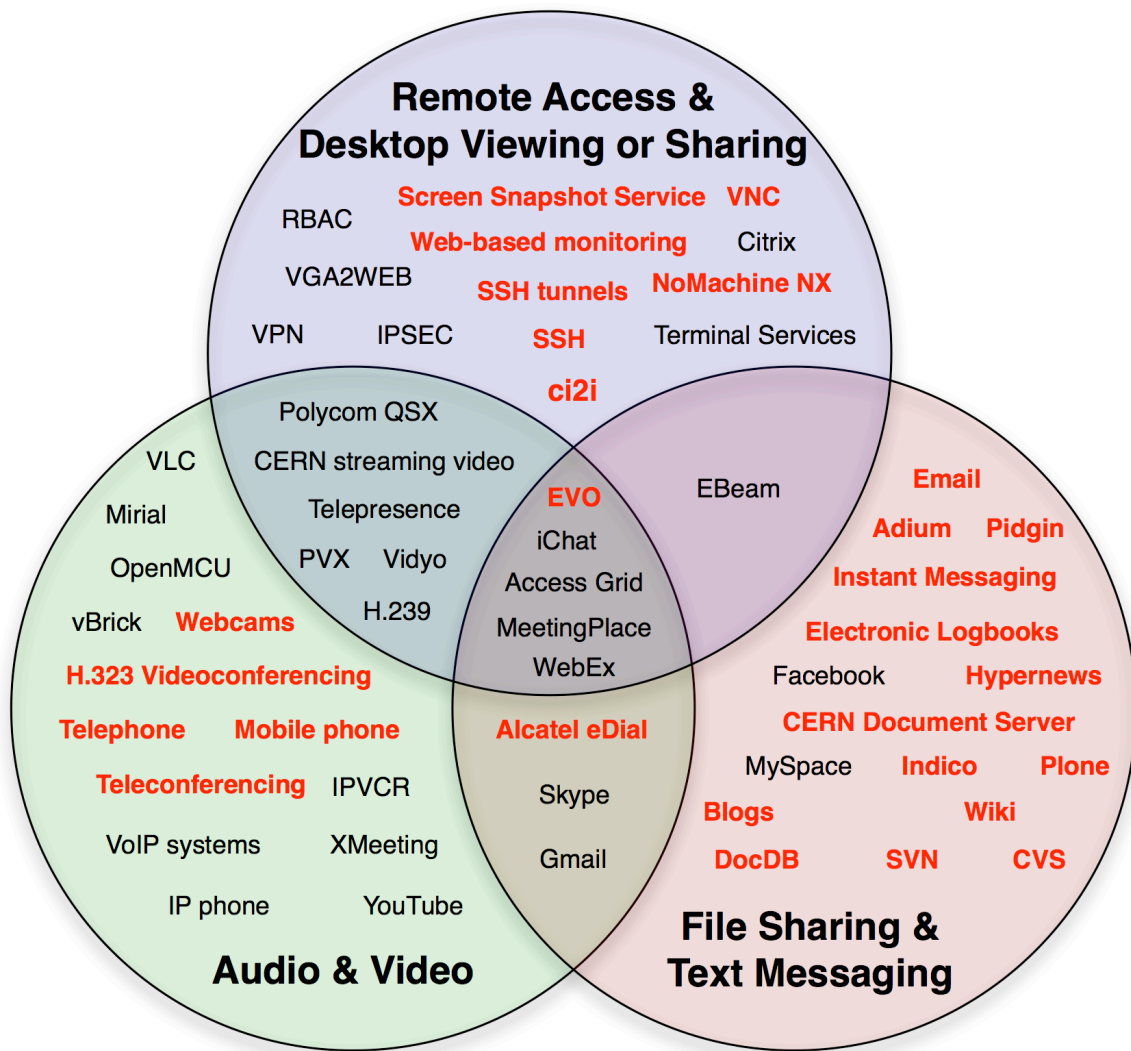
The first significant contribution that we made to remote operations is Role-Based Access Control (RBAC) [7] for the LHC accelerator controls system. RBAC contributes to safety and security by preventing unauthorized access to the accelerator controls system. The main idea behind RBAC is to give people the ability to perform functions based on their roles and their location. For the ROC we were interested in helping with the development of RBAC at CERN, since RBAC would give us the ability to run the LHC controls system software at Fermilab with safeguards that would limit our access to monitoring capabilities for the LHC (or limit our access to control capabilities for some types of monitoring instruments). This way we could use the same monitoring capabilities that would be used at CERN without having to develop special capabilities at Fermilab, and we would be able to train people in the use of the LHC controls system before they traveled to work at CERN. Initial discussions regarding our participation in helping with the development of RBAC for the LHC began in 2005, while we were working on requirements for LHC remote operations at Fermilab. RBAC was considered to be an important contribution, so a joint CERN/FNAL software development effort (referred to as LAFS) was initiated. RBAC development was completed in 2008, and is now used to control all access to the LHC controls system.

A second significant contribution that we have made to remote operations is a collaborative tool that is called Screen Snapshot Service [8]. This tool addresses concerns about secure access to information by enabling *remote viewing* of computer screens without allowing *remote control* of the computers in a control room, operations, or monitoring center. Screen Snapshot Service is an application that periodically captures and forwards computer desktop images to a central web server. The web server provides access to these desktop images so that interested observers at remote locations can see the screen content. The tool is not intended as a substitute for remote monitoring applications (for example, applications used to monitor CMS data quality), but is used in situations where someone wants to show their desktop without having to use a desktop sharing application, which often requires additional measures to establish secure connections to a remote system.

A third significant contribution named Ci2i (see eye to eye) was briefly mentioned in section 2.4. Ci2i provides an innovative way for collaborators to see computer screens in a control room, operations, or monitoring center using an approach that differs from the Screen Snapshot Service. Ci2i is typically used to manage the monitoring information displayed on an upper row of screens in a CMS Centre, as shown in figure 7. For example, a person sitting at a desk can use the lower row of screens for any work they need to do, while the monitoring information displayed on the upper row of screens is managed using Ci2i, usually for a specific subsystem in CMS. Ci2i

requires that the information that is displayed has a fully-qualified uniform resource locator (URL), which is the case for most of the web-based monitoring information in CMS. By managing the screen content on the upper row of displays using Ci2i, anybody in CMS can see what is being displayed at a specific desk in a CMS Centre. A thumbnail view of desktop images is provided for navigation so that one can see the content of all displays in a particular CMS Centre, or one can see the content for a particular CMS subsystem in all CMS Centres. In some cases, for example for proprietary applications where a fully-qualified URL is not available, one can use the Screen Snapshot Service to produce a URL that can then be used by Ci2i. Besides providing remote viewing capabilities and managing screen content, Ci2i provides the ability to manage group accounts and user privileges in a CMS Centre, configure computer hardware in the centre, and provide capabilities for planning CMS operations. A second web application that uses the screen content management capabilities of Ci2i is called “CMS-TV,” which cycles through a series of URLs to display information about CMS for education and public outreach.

A fourth contribution to remote operations capabilities in CMS is the use of high-definition videoconferencing, which has had an impact on the way people located in different CMS Centres



**Figure 9.** A Venn diagram showing collaborative tools that are currently used in the ROC (shown in red), tools we have considered using, or tools we are evaluating for LHC and CMS operations.

work together. For example, the CMS data operations group has found that the permanent high-definition video link between major CMS Centres has contributed to improved communication between members of the group. A description of how these permanent video links have helped can be found in these conference proceedings [9]. As the number of CMS Centres continues to grow, we will use EVO [10,11] to link the growing number of institutional CMS Centres to the major CMS Centres, and to each other. The plan is to have specific EVO sessions dedicated to particular subsystems in CMS.

In addition to the contributions that we have made to remote operations capabilities for CMS, we find that many different collaborative tools are used in CMS Centres today. Figure 9 shows diagram of collaborative tools that are currently used in the ROC, tools that we have considered using, and tools we are evaluating for LHC and CMS operations. Tools that are currently used in the ROC are shown in red. The diagram shows collaborative tools grouped into three categories: audio and video tools; file sharing and text messaging tools; and tools for remote access and desktop sharing or viewing. For effective communication and collaboration in an operations environment one needs at least one tool from each category, or one can use tools that are associated with more than one category. For example, EVO stands out as one tool that covers all three categories. For CMS we find that an effective combination of tools for operations consists of web-based monitoring tools for remote access to information; telephone or videoconferencing for communication; and instant messaging, electronic logbooks and wikis for text-based messaging and documentation. This particular combination of tools seems to satisfy most of the needs for CMS at this time. However, the CMS operations environment is evolving, so for now people are relying on a wide assortment of tools that may be consolidated over time.

Figure 9 shows some of the trends that have developed in the use of collaborative tools in the CMS operations environment. While the figure is specific to CMS, it also exemplifies general trends in the use of collaborative tools in high-energy physics. For example, with regard to the *audio and video* category of tools there are numerous choices for collaboration, but the only tools that we tend to use consistently are telephones, teleconferencing, H.323 videoconferencing, and EVO. There is a growing awareness that the use of video is superior to audio-only tools in an operations environment, and that audio and video are both superior to a reliance on text-based tools alone. Furthermore, reliable communication is important. This means that standard telephones with international calling capabilities (not voice-over-IP phones) are essential (for now), and that videoconferencing systems need automatic reconnection capabilities to be useful in an operations environment. With regard to the *file-sharing and text-messaging* category it is noteworthy that there are many, many tools for exchanging and recording textual information. We find that individual groups, or subgroups, select particular tools to collaborate with others in their group without regard for communication in the collaboration as a whole. A more unified approach to collaborative tools would be helpful. The emphasis should be on selecting specific tools (not necessarily introducing new tools), integrating these tools, and establishing a more homogeneous work environment.

The third category in figure 9, *remote access and desktop sharing or viewing*, is particularly important for effective collaboration, and it is also the category that faces the most challenges as more and more emphasis is placed on cybersecurity. Tools in this category tend to be scrutinized more carefully for security loopholes, and tend to be shut down when security concerns arise. As mentioned previously, CMS relies heavily on web-based monitoring tools, the Screen Snapshot Service, and Ci2i as ways of making information available in a secure manner to collaborators who are not physically located at CERN. The emphasis is on making as much information as possible available on the web. This is an effective approach. However, information that is not easily accessible invariably introduces concerns about remote access and secure access to information. Collaborative tools in this category that address these concerns, work reliably, are easy to use, and are secure will undoubtedly be a valuable contribution to future remote operations capabilities.

#### 4. Summary

With the LHC, a new era begins in high-energy physics at the energy frontier. Not only is the LHC the first “discovery machine” to be built in decades, it also heralds a change in the way high-energy physics experiments operate at this frontier. The unprecedented size of the large international research teams that are needed to commission and operate a new generation of experiments demands a new approach to harnessing the wide-ranging expertise of so many people working towards a common goal. For the CMS experiment, the development of remote operations capabilities is expected to help streamline operations by making the overall operation of the experiment more efficient and more effective. Moreover, experimental physics data will be processed globally by the LHC computing grid, and this approach to data processing will naturally feed back and influence the way in which experiments operate. Building on previous successes, most notably the World Wide Web, a new goal for high-energy physics is to develop capabilities that will give remote collaborators the ability to participate in daily operations from anywhere in the world.

To help scientists and engineers in North America engaged in LHC and CMS activities at CERN, Fermilab designed and built the LHC@FNAL Remote Operations Center. Planning for the ROC was done in a way that would encourage others to view the ROC as a model for future projects requiring remote operations capabilities. The ROC served as a precursor for the CMS Centre at CERN and the CMS Centre at DESY, however, we did not anticipate that this would eventually lead to a multitude of distributed CMS Centres all over the world, as is the case today. A new project, “CMS Centres Worldwide,” was initiated within the CMS Collaboration to assist collaborators who want to build a CMS Centre at their home institution. This is done by providing guidance on how to establish a centre, and providing collaborative tools to link CMS Centres to each other. While we have made several significant contributions to the development of new collaborative tools, more work will surely be done to make collaboration at a distance ubiquitous in high-energy physics.

In recognition of the dedicated work required to organize and achieve the successful outcome of several noteworthy events, especially the LHC First Beam Day, I wish to thank the members of our distributed, collaborative team: Knut Bjorkli (CERN), Joao Fernandes (CERN), Guenter Eckerllin (DESY), Reinhard Eisberg (DESY), Sheila Cisco (Fermilab), and Lucas Taylor (Northeastern University).

Fermilab is operated by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the United States Department of Energy.

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