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The Compact Muon Solenoid Experiment

Conference Report

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Status of CMS Commissioning

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Abstract

The status of the installation of the detectors for the CMS experiment and the global commissioning campaign by May 2008 are summarized.

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Status of CMS Commissioning

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1. – Overview

The Compact Muon Solenoid (CMS) experiment is constructed as a general-purpose experiment with excellent particle identification capability able to capitalize on the rich physics program of the LHC, and its design is described in more detail in [1]. The expected performance of the detector systems and the overall capability for LHC physics studies is covered in [2]. The construction phase of CMS is essentially complete, and currently the experiment is in its final stages of installation in preparation for LHC collisions later in 2008. An illustration of its components is shown in fig. 1. The detectors are preassembled into complete structures for rapid installation given the relatively late availability of the underground collision hall.

There are 3 detector technologies for the detection of muons, and all participate in the Level-1 trigger: drift-tubes (DT) in the central region ($|\eta| < 1.2$), cathode strip chambers (CSC) in the endcaps ($|\eta| > 0.9$), and resistive plate chambers (RPC) throughout barrel and endcap. There are nearly 1 million electronics channels in total, and all chambers are installed and cabled on the steel return yoke wheels and disks now located in the collision cavern. The muon systems provide for standalone momentum measurements.

Calorimetry is provided by lead tungstate crystals for electromagnetic showers and a brass-scintillator plate calorimeter for the barrel and endcap regions for hadronic showers. Both calorimeters are placed inside the volume of the 4T solenoid and the barrel and endcap compartments cover the range in pseudorapidity $|\eta| < 3$. A hadron outer detector composed of scintillator is placed outside the barrel HCAL region for penetrating shower detection. A quartz fiber forward calorimeter system provides for coverage in the region $3 < |\eta| < 5$.

The installation status is that all hadron calorimeter (HCAL) components are installed and cabled as are all crystals of the electromagnetic calorimeter (ECAL) barrel

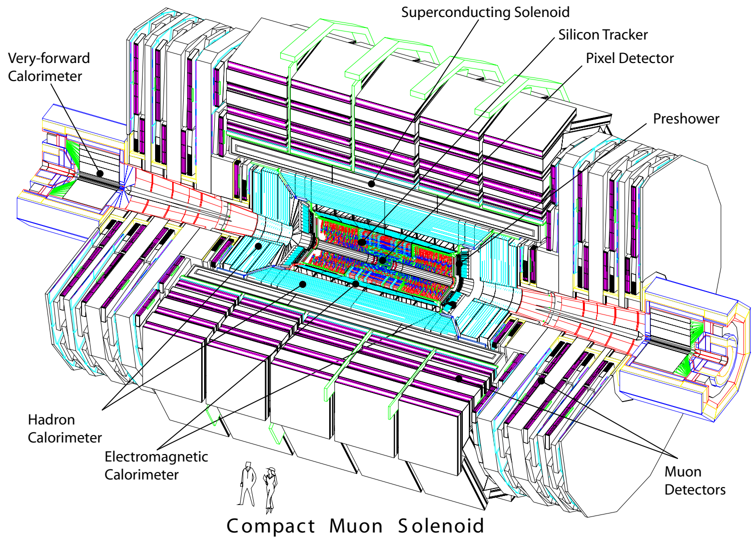

Fig. 1. – The CMS experiment with major detector systems labelled.

region (61K crystals arranged into 36 “supermodules”). The crystals in these supermodules have been intercalibrated in the lab using cosmic muons to a precision of 1.5–2.5%, and 25% of the crystals have been intercalibrated in a testbeam to a precision of 0.3%. The crystals comprising the endcap electromagnetic calorimeters are foreseen to be installed in July 2008.

The inner tracking volume is comprised entirely of silicon strip and pixel sensors. The strip tracker is composed of more than 15 000 sensor modules (11 million channels) covering over 200 m^2 of surface area and divided into several major compartments: inner and outer barrel structures (4 and 6 layers, respectively), and inner and outer disks (3 and 9 disks respectively). Construction and assembly was completed in 2007, and a series of operational tests with approximately 20% of the system was performed during the first half of 2007 in a dedicated Tracker Integration Facility (TIF). Results from recorded cosmic muons indicated a signal-to-noise of greater than 25 for the sensor modules, and a layer efficiency for single cosmic muons of better than 99.7%.

After the TIF exercise, the entire strip tracker was transported and installed into the experiment in December 2007 (fig. 2), and cabling was completed in March 2008. The pixel detector consists of 3 barrel layers and 2 endcap disks and has a total of 66 million channels. The construction and assembly of the forward pixel system is complete and ready for installation. The barrel pixel system was just completed in July 2008 and both compartments are ready for installation.

All central hardware for the Level-1 trigger has been installed and cabling is complete. Currently the jet trigger is undergoing commissioning. In the data acquisition (DAQ) and high-level trigger area, all underground service cavern components and the data links to the surface processor farm are complete. The event builder storage managers are ready, and the last computers ordered for the 2008 LHC run are being installed and tested at the time of this writing.

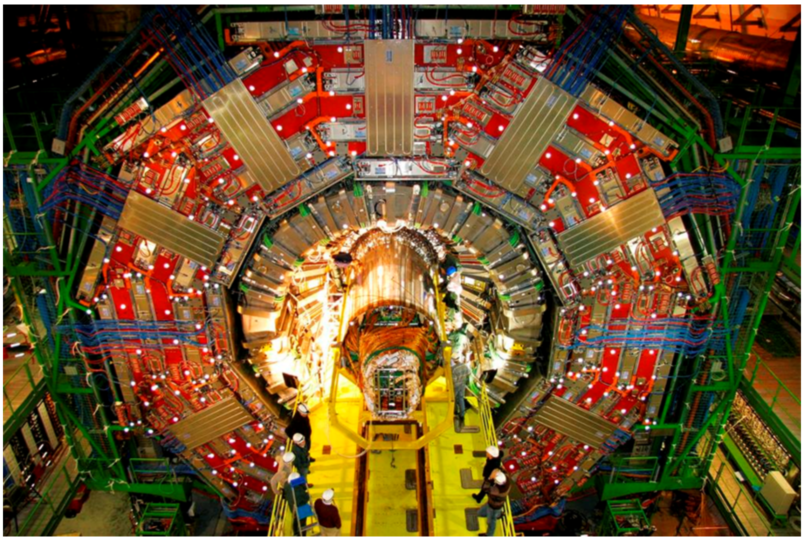

Fig. 2. – The installation of the CMS silicon strip tracker in December 2007.

2. – Installation

The lowering of the heavy elements of CMS into the collision cavern began in November 2006 starting with the forward calorimeters and followed shortly thereafter by the $+z$ endcap steel disks and barrel wheels onto which the muon detectors are mounted. In February 2007 the central yoke and cryostat were lowered, and by January 2008 the last heavy elements of the $-z$ endcap were lowered.

The campaign to install services to the detectors within the central portion of CMS included the installation or more than 200 km of cables and optical fibers (about 6000 cables). Additionally, more than 20 km of cooling pipes (about 1000 pipes) also were installed. The whole enterprise took place over a 5 month period and required more than 50 000 man-hours of effort.

The cabling of the silicon strip tracker was completed in March 2008, and the final cooling for it was operational by June after a switch to a commercial refrigeration system. The central beam pipe has been installed and bake-out was completed in June as well. A trial closure test of the $+z$ endcap with the central portion of CMS was successfully demonstrated, as was a trial insertion test of the pixel tracking system in May.

The current schedule for CMS foresees closure of the experiment in August 2008 in preparation for LHC beams. As of the time of this report, the final major components have just been installed: both ECAL endcaps and the pixel tracking system.

3. – Global Commissioning

3˙1. *MTCC*. – The large solenoid of CMS was fully tested while it was in the surface assembly hall during August–November 2006. A slice of the major detector subsystems were operated to record data concurrently with this test. The exercise[3], called the Magnet Test and Cosmic Challenge (MTCC), provided important commissioning and operational experience. The magnet was ramped to several field strengths up to the

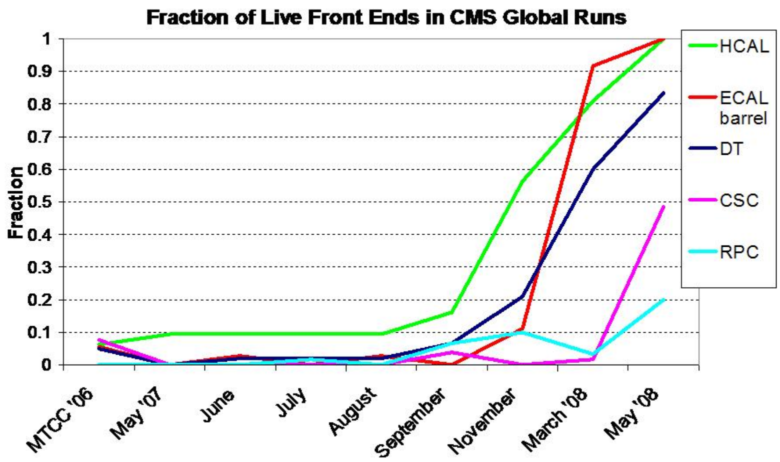

Fig. 3. – Fraction of CMS detector systems participating in global commissioning exercises.

operating value of 4T, and fast discharges were commissioned. Concurrently with the magnet test, about 7% of the muon detection systems, 22% of HCAL, 5% of ECAL, a pilot silicon strip tracking system, and the global trigger and data acquisition were successfully operated together for purposes of collecting data. In a second phase of the exercise, the ECAL and pilot tracker were removed and the central magnetic field was mapped using a specially designed mapping device to a statistical precision of 10^{-4}, which is now available in the offline simulation and reconstruction software. In total, approximately 200 million cosmic muon events were recorded for purposes of calibration, alignment, and detector performance studies. Recently a measurement of the cosmic muon charge ratio from these data was published[4]. The conclusion of MTCC coincided with the start of the the installation into the underground cavern as described above.

3˙2. *Global Runs.* – Since May 2007, 3-10 consecutive days monthly or bimonthly have been devoted to global commissioning exercises using the installed detectors and electronics, ultimately using final power and cooling in the underground experiment and service caverns. These "global runs" balance the need to continue installation and local commissioning activities with the need for global system tests, and were preceded by subsystem to DAQ connectivity and functionality tests. Prior to each global run a detailed list of goals was established which was in turn translated into a working plan which is discussed at a daily planning meeting. The scale of the global runs to-date is illustrated in fig. 3, which shows the fraction of the listed detector systems powered and participating in the read-out.

We began the underground commissioning campaign with just one forward calorimeter, the Global Trigger, and a "mini-DAQ" in May 2007; but by August we demonstrated the synchronization of an ECAL supermodule to cosmic muons triggered by the drift tube muon system. In September we achieved the same using the hadron calorimeter and the RPC muon system. Generally the availability of power, cooling, and gas limited the

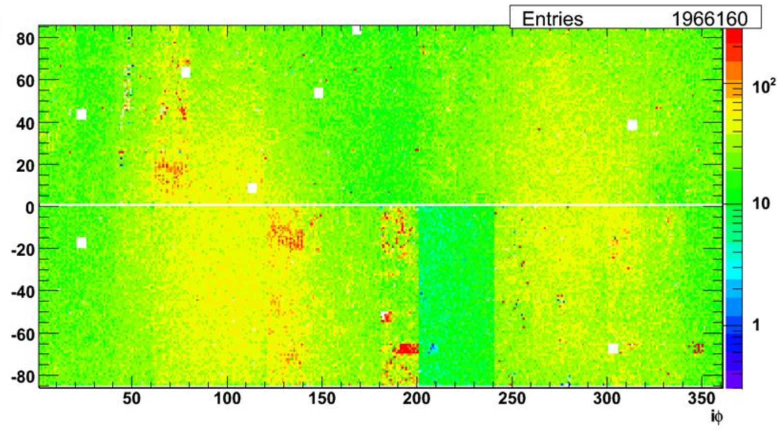

Fig. 4. – ECAL crystal occupancy map for cosmic muons clusters. The map uses an internal labeling convention for eta while phi is measured in degrees. Empty boxes are masked trigger towers, and hot areas are known noisy channels.

scope of the commissioning exercises. However, by the time of the November-December 2007 Global Run, with final services installed, we began operating large fractions of the experiment as indicated in fig. 3.

Most recently in May 2008, a week-long exercise known as the Cosmic Run at Zero Tesla (CRUZET) concluded quite successfully with the accumulation of more than 30 million cosmic triggers. This global commissioning exercise reached new heights as all 5 wheels of the DT muon system participated in the trigger and readout along with the entire $+z$ endcap of the CSC muon system and 20% of the barrel RPC muon system. Moreover, all components of the HCAL and all 36 supermodules comprising the barrel ECAL participated. The latter is illustrated in fig. 4 which shows the ECAL crystal occupancy for 2 million reconstructed cosmic muon clusters recorded during this commissioning exercise. The sinusoidal dependence of the cosmic flux is clearly visible. Some supermodules intentionally left noisy as a diagnostic tool are also visible, as are several masked trigger towers. An event display of a single cosmic muon leaving tracking hits in the DT and RPC muon systems and associated energy deposits in ECAL and HCAL is shown in fig. 5, demonstrating the inter-synchronization of these systems.

The Level-1 muon triggers during CRUZET exercise provided a trigger rate of about 250 Hz, and minimum ionizing particle triggers based on both ECAL and HCAL were tested. For online processing and filtering, more than 500 processors were deployed for the High Level Trigger which were used to select enriched samples of cosmic muons pointing to the central region of CMS and to test a prototype LHC trigger menu. Data were promptly reconstructed at the Tier-0 computing centre at CERN to create high-level physics objects with a latency of less than 1 hour and transferred to the CMS Analysis Facility (CAF) at the CERN Meyrin site and to several Tier-1 and Tier-2 centres worldwide (also with a latency of hours) for prompt analyses by teams of physicists. Data quality monitoring of the Tier-0 reconstruction output in addition to the standard online monitoring at the control room was provided.

The silicon tracking systems were not yet ready for this latest global commissioning

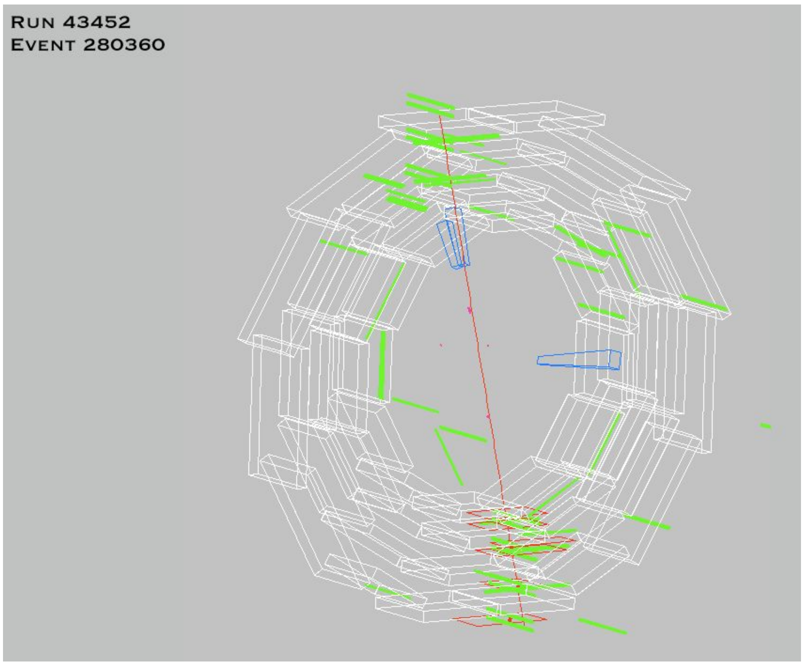

Fig. 5. – An event display of a cosmic muon recorded during the CRUZET exercise with a track reconstructed using the DT and RPC muon system data and with associated energy deposits in the HCAL and ECAL.

run(1) due to ongoing installation and cooling work, but operational experience with these systems in past global runs was gained using a few sensor modules installed in a box and located in the collision cavern. These small devices were configured and readout using the final data acquisition electronics, and integration with the rest of the CMS readout was achieved and detector noise was studied.

3·3. *Data Handling Commissioning.* – As noted in the previous section, the global run commissioning data logged by the experiment is processed at the Tier-0 computing centre at CERN and exported to 7 Tier-1 centres worldwide. This has not fully stressed the design limits of the CMS computing model because only a fraction of the experiment has so far been operated, and because the rate and detector occupancy from cosmic ray events are low. In order to fully test the data handling model, CMS has organized several data challenges to load the system. The most recent test was part of the LHC-wide Common Computing Readiness Challenge (CCRC), which took place during May 2008 (with a pre-challenge during February). A principal aim was to operate all LHC experiments simultaneously to understand the interferences and limitations in advance of LHC data operations. CMS prepared sizable simulated datasets reflective of early LHC data and then processed these datasets as for real LHC data using offline reconstruction software. The data were then exported to the Tier-1 and Tier-2 computing centres whose

(1) Since the time of this report, in a third phase of CRUZET that took place during July 2008, 75% of the strip tracker was successfully incorporated into a global run.

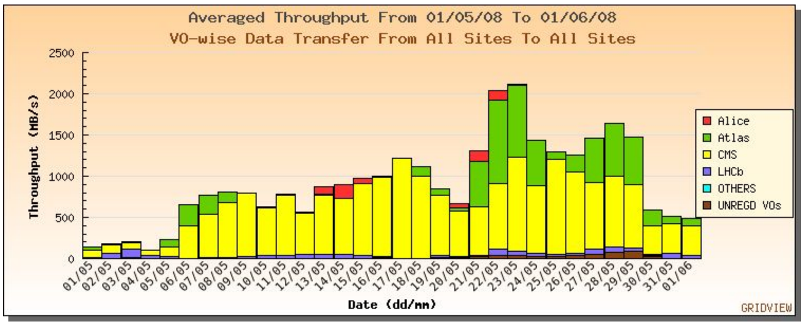

Fig. 6. – Data transfer bandwidth out of CERN in MB/s to computing grid sites during the LHC-wide Common Computing Readiness Challenge, broken down by LHC experiment.

data links had been pre-commissioned. The sustained export bandwidth by CMS (fig. 6) to these centres exceeded the target of 600 MB/s and had a peak bandwidth exceeding 1GB/s. A total of 3.6 PB was moved between CMS grid sites during May. All workflows anticipated to be needed to process data were conducted, such as prompt calibration and alignment jobs to derive improved calibration constants for reconstruction and data skims for physics analyses. Use was made of the CAF at CERN by teams of physicists to demonstrate prompt turn-around on these activities.

3˙4. *Summary.* – The odyssey of building CMS is nearly over with the installation of its final detector components in preparation for this year's LHC run. As part of the commissioning campaign, ever-increasing slices of the experiment have been operated simultaneously using final services as part of a sequence of "global runs." The data handling model, based on a tiered set of computing centres, has also been commissioned in a series of data challenges. The success of these endeavours gives the CMS collaboration confidence that it is ready for LHC operations in 2008!

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