PROCEEDINGS OF SCIENCE

CMS Commissioning

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The process of commissioning the CMS experiment and its status by the end of September 2008 is briefly summarized.

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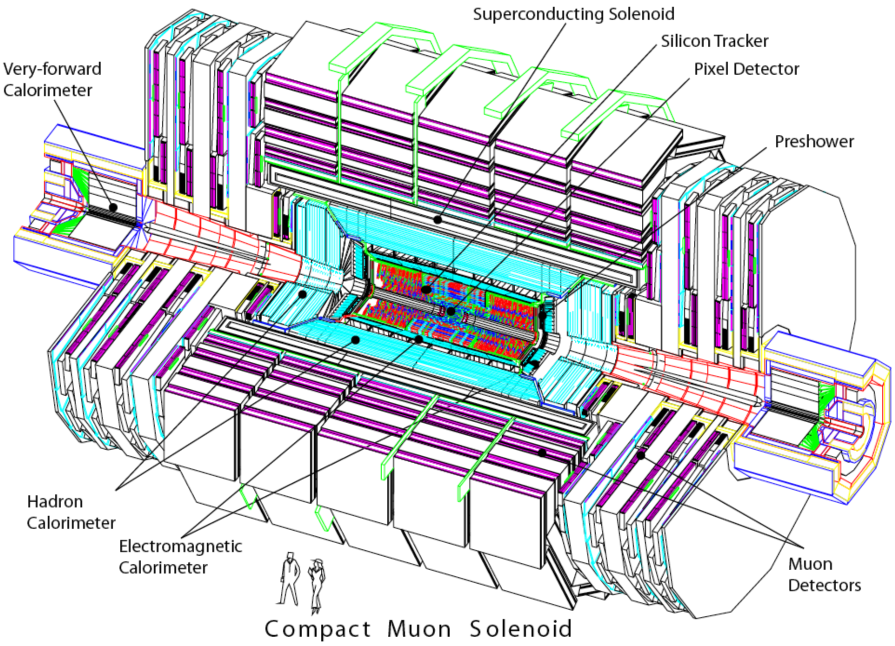

Figure 1: The layout of the CMS experiment with main sub-detector components labeled.

1. Introduction

The CMS (Compact Muon Solenoid) is a multi-purpose experiment at the CERN LHC. The design of the CMS detector is driven by the use of a large superconducting solenoid with the nominal magnetic field strength of 4 T (Figure 1). The size of the magnet, with 6 m diameter and 13 m length, allows to accommodate the inner tracking system and the calorimetry. The magnetic flux is returned through a 10 kt iron yoke, comprising 5 wheels and 2 endcaps, housing the muon detector system.

The inner tracking system consists of 3 central layers of pixel and 10 layers of strip silicon sensors. The strip tracking system is divided into 4 layers of inner and 6 layers of outer barrel systems and 3 inner and 9 outer disks. The tracking system provides a good granularity and precision to deal with the high track multiplicities.

The electromagnetic calorimeter (ECAL) uses lead tungstate crystals and the scintillation light is detected by silicon avalanche photo-diodes in the barrel part and vacuum photo-triodes in the endcaps. The electromagnetic calorimeter is surrounded by the brass-scintillator sampling hadron calorimeter (HCAL) equipped by hybrid photo-diodes capable to operate in the high axial magnetic field. Both calorimeters cover the pseudorapidity range of $|\eta| < 3$ and provide signals for the Level-1 trigger. The hadron calorimetry is completed by the hadron outer detector for the measurement of deep penetrating shower tails and a quartz fiber forward calorimeter which provides a coverage of pseudorapidity up to $|\eta| < 5$.

The muon detectors are organized into 4 stations separated by the iron of the magnet return yoke with the total thickness of 1.5 m. The aluminum drift tube technology is used in the barrel

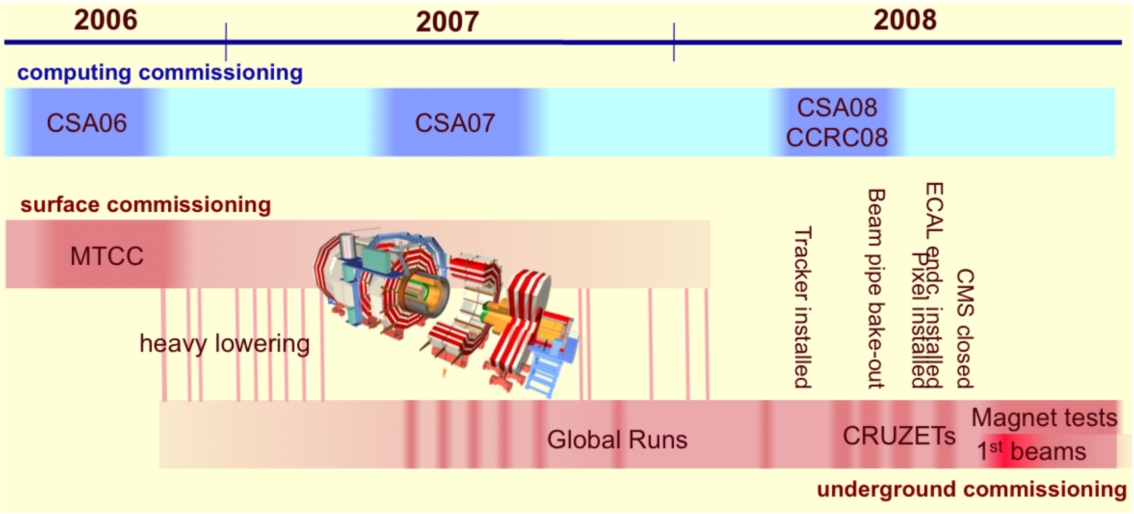

Figure 2: Overview of global CMS commissioning activities.

region (DT) and cathode strip chambers (CSC) in the endcaps both complemented by resistive plate chambers (RPC) providing a redundancy in the muon detection. The muon system covers hermetically the pseudorapidity range of $|\eta| < 2.4$. All 3 muon detection systems participate in the Level-1 trigger.

A more detailed description of the CMS apparatus can be found in [1]. The physics potential of the CMS experiment is described in [2].

A large part of the commissioning activities of the individual sub-detector systems was performed during the construction and assembly in various test beams, integration facilities and in situ in the surface hall and the experimental cavern. This report concentrates on CMS-wide global commissioning activities outlined in Figure 2.

2. Surface commissioning

CMS performed its first global commissioning exercise in the surface hall during August-November 2006. The main goal of this campaign, called the MTCC (Magnet Test and Cosmic Challenge), was to fully test the solenoid magnet while the experiment was still located in the surface assembly building. As a part of the exercise, a vertical slice of most important detector components (pilot silicon tracking system, ECAL, HCAL, barrel and endcap muon chambers) was operated to record the cosmic ray signal with and without the magnetic field. The magnet was ramped to several field strengths from 2 T to nominal 4 T including tests of fast discharges. After collecting about 200 million cosmic muon events, the central detectors were removed and the field maps for different field values measured to a precision of 10^{-4}.

The MTCC confirmed that the large CMS solenoid is fully operational. The measurements of the central field map are used in the simulation and reconstruction software. The data collected during the MTCC provided an important feedback for the calibration and alignment procedures. The behavior of the detectors in the magnetic field was verified by comparing their performance

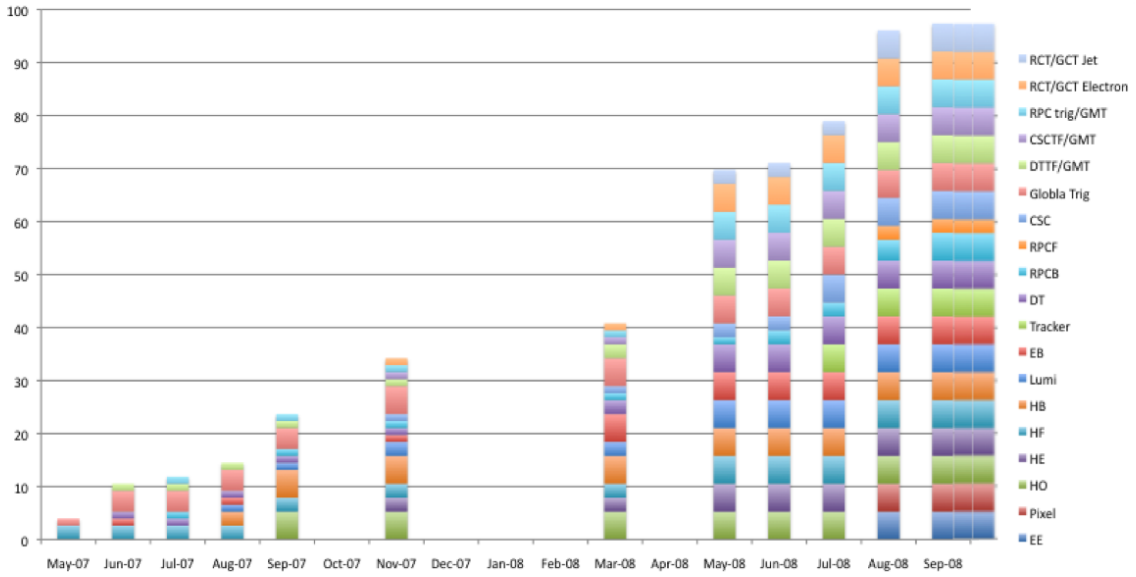

Figure 3: Participation of sub-detectors and trigger components in the global commissioning campaigns.

with and without field and was checked with the simulations. The data was recorded using the global trigger and data acquisition system. A full analysis of the cosmic muon charge ratio was performed and published [3]. In this sense, the MTCC represented a first global commissioning test of the CMS at all levels, from the data taking up to the the physics analysis.

3. Underground commissioning

Soon after the central heavy elements of CMS have been lowered into the experimental cavern a series of centrally driven data taking efforts, called the Global Runs, was initiated. The Global Runs started in May 2007 and were performed in intervals of 1-2 months with a duration of a few days. They were planned and introduced dynamically in order not to disturb but rather complement the ongoing detector installation and local commissioning activities. In this way, the complexity of the system gradually grew as can be seen on Fig. 3.

The goals of Global Run campaigns were:

- Integrate parts of CMS into the data acquisition process as soon as they become available.
- Test the trigger at all levels and the trigger throttling mechanism using cosmic triggers as well as high rate random triggers.
- Introduce a 24/7 shift operation and collect experience in running the experiment.
- Develop and test the Data Quality Monitoring (DQM) system.
- Exercise the data transfer to the CMS Analysis Facility (CAF) and various tiers of CMS computing system, the prompt reconstruction, alignment and calibration.

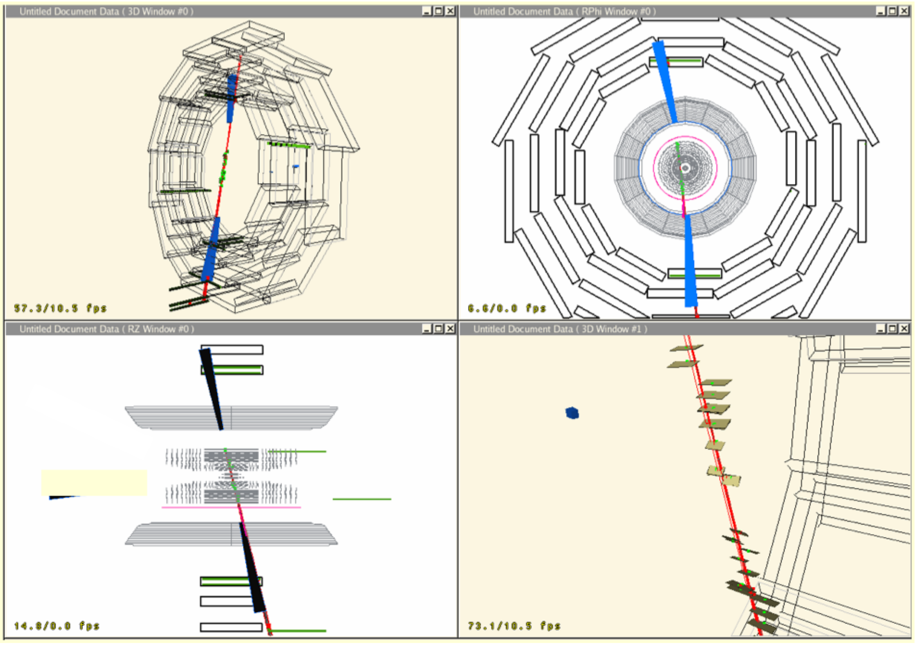

Figure 4: Event display showing a global track reconstructed from a cosmic ray signal in the silicon tracker and muon chambers associated with the calorimeter signal.

- Use the collected data to understand the trigger timing and quality, read-out synchronization and detector performance using inter-system correlations.

The main cosmic ray trigger was provided by the muon chamber trigger system operating in a special timing mode compensating for the time-of-flight of cosmic muons through the detector. The calorimeter trigger was commissioned using m.i.p. signals in both calorimeters.

Starting from May 2008 the Global Runs changed character. The majority of the detector and trigger components have been integrated by then. Four exercises, called the CRUZETs (Cosmic RUn at Zero Tesla), with a duration of about a week every month, took advantage from the improved data taking stability and collected substantial statistics of cosmic ray data for calibration and alignment studies. About 300 million cosmic events have been collected during this commissioning phase. During the four CRUZET runs the silicon tracker and the endcap ECAL were fully integrated so that in August 2008 practically all CMS, except one RPC endcap, was able to take data. Fig. 4 shows a fully reconstructed global track based on the silicon tracker and muon detector data associated with signal in the ECAL and HCAL. The reconstruction of such objects demonstrates a whole component chain correctly working: the trigger and data acquisition, the read out synchronized between different detector components, a proper use of the calibration and alignment in the tracking and reconstruction software.

At the end of August 2008 the magnet yoke of CMS has been closed in order to start the underground magnet commissioning. A field strength of 3T has been reached by the end of August. Then the program was suspended because the onset of LHC operations required the solenoid to be off. The tests resumed after the limited 2008 beam operations and after addressing certain

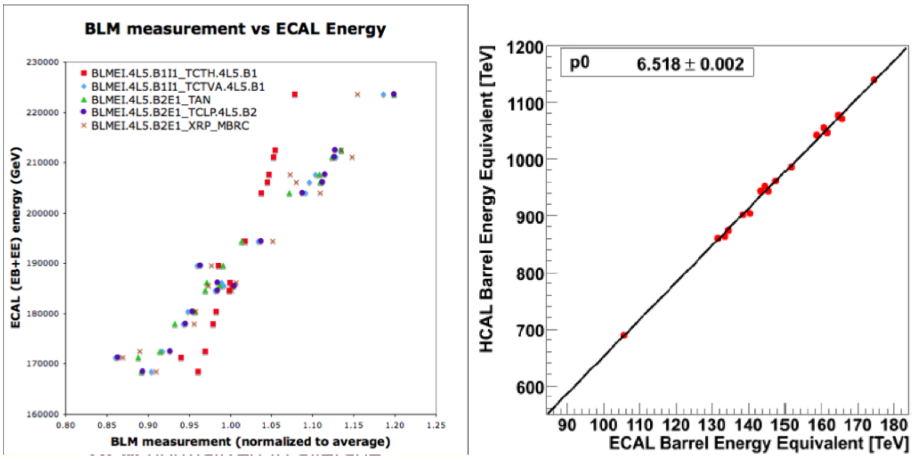

Figure 5: Correlation of beam splash energy deposits between ECAL and Beam Loss Monitors (left) and ECAL and HCAL (right).

mechanical effects of the fringe field on some external components, and the solenoid successfully reached its operating point of 3.8T. [1].

4. Underground commissioning with LHC beams

First of a series of LHC operation tests was to transport the pilot beam through individual sectors and dump it on the collimator ~ 150 m upstream from the experiment. This yielded a splash of a few 10^5 particles illuminating the detector at the same time. Based on a few tens of such events CMS was able to time-in very quickly special beam related triggers: the trigger based on the beam pick-up detectors, the beam halo trigger based on the endcap muon chambers and the forward hadron calorimeter trigger. In addition, these events firing almost all detector channels turned out to be useful for improving the internal detector synchronization and for occupancy and bad channel studies. The energy deposits in the calorimeters, reaching the equivalent of $100-1000$ TeV, have been correlated with the signal from the Beam Loss Monitors (BLM) placed in several locations between collimators and the experiment (Fig. 5). The Beam Conditions Monitors protecting central tracker parts were also tested.

During all of the LHC operations CMS was able to keep a very high data taking efficiency. This allowed to collect large amount of beam halo tracks in the endcap muon system used for alignment and timing studies. The performance of the beam halo trigger was checked and a comparison of the data with simulations has been performed. The cleanness of the RF-captured beam was studied using the endcap muon chambers and calorimeters.

5. Computing commissioning

The amount of data collected by CMS during the cosmic ray tests was not sufficient to exercise

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[1] During October and November 2008 a full month continuous cosmic run - CRAFT (Cosmic Run at Four Tesla) - yielded about 300 million cosmic triggers at 3.8 T.

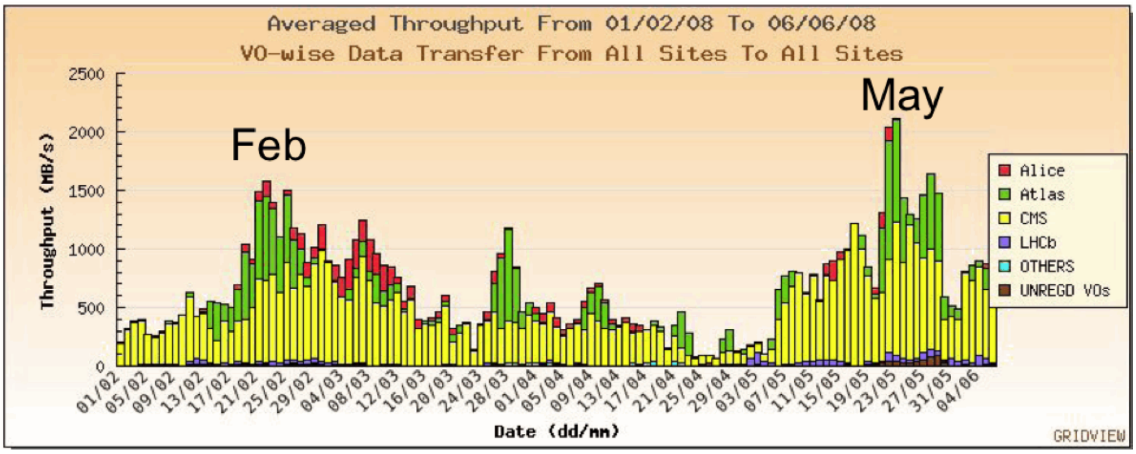

Figure 6: Data transfer throughput during Common Computing Readiness Challenge showing contributions of individual LHC experiments.

the CMS data handling system to its capacity at LHC rates. Every year since 2006 (Fig. 2) CMS undertook a dedicated stress test (CSA - Computing, Software and Analysis challenge) of the computing model using generated data. Last such test in February and May 2008 was organized CERN wide as a Common Computing Readiness Challenge (CCRC). During this test the whole CMS grid was used. A sustained export of 600 MB/s during a whole week targeted by this campaign was exceeded with peaks above 1 GB/s (Fig. 6). All workflows including a full range of alignment and calibration tasks, prompt reconstruction and re-reconstruction, skimming and data analysis were successfully exercised in real time.

6. Conclusions

The integration and commissioning process of CMS culminated at the beginning of September 2008 when LHC started operations. CMS was ready to take data with practically the entire apparatus. The whole infrastructure including detectors, trigger, data acquisition, data quality monitoring, data handling, calibration and alignment workflows up to the reconstruction and analysis was in place. Further commissioning efforts will focus on improving the efficiency and stability of data taking, automating failure detection, recovering dead channels and commissioning of the preshower detector.

References

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