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The CMS Magnet Test and Cosmic Challenge

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Abstract

During the second half of 2006 a first combined test of almost all sub-systems of the Compact Muon Solenoid (CMS) experiment at CERN's new Large Hadron Collider has been performed. This test has been carried out in a surface assembly hall prior to the currently ongoing installation in the underground experimental cavern. Partial configurations of the CMS sub-detectors have been successfully interfaced with a scaled-down setup of the central Data Acquisition and Run Control systems, with the Level-1 Trigger and with the Detector Control and Safety Systems. The superconducting solenoid has been stably operated at its design field strength of 4 T. Several millions of events were reconstructed, stored and transferred to the Tier-0 computing centre and to remote sites. The present paper reports this first operation of CMS as an integrated system.

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The CMS Magnet Test and Cosmic Challenge

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Abstract. During the second half of 2006 a first combined test of almost all sub-systems of the Compact Muon Solenoid (CMS) experiment at CERN's new Large Hadron Collider has been performed. This test has been carried out in a surface assembly hall prior to the currently ongoing installation in the underground experimental cavern. Partial configurations of the CMS sub-detectors have been successfully interfaced with a scaled-down setup of the central Data Acquisition and Run Control systems, with the Level-1 Trigger and with the Detector Control and Safety Systems. The superconducting solenoid has been stably operated at its design field strength of 4 T. Several millions of events were reconstructed, stored and transferred to the Tier-0 computing centre and to remote sites. The present paper reports this first operation of CMS as an integrated system.

1. Introduction

The Compact Muon Solenoid (CMS) [1] detector, which is currently being installed at CERN's new Large Hadron Collider, is expected to explore a broad range of new physics at the TeV scale. In order to cope with the schedule of civil engineering work for the underground experimental cavern, the detector has been constructed in a surface building over the past years. Thanks to a modular design, the individual detector elements, three disks in each end-cap region and five wheels in the barrel, can be lowered into the underground cavern individually. Each of these elements consists of an iron structure supporting the muon detectors, services and cables. The central barrel wheel further supports the 4 T superconducting solenoid into which the inner detectors are inserted.

Before lowering the detector elements, several major tests were performed on the surface during the second half of 2006. On the one hand, they concerned the commissioning of the superconducting coil, hence the name Magnet Test. On the other hand the CMS collaboration set itself the goal to operate roughly 1/20th of the CMS sub-detectors integrated with all central services and the Trigger and Data Acquisition Systems, using cosmic muons as a particle source. This major effort was named the Cosmic Challenge. The participating sub-detectors included a 60° sector of the Cathode Strip Chamber and Resistive Plate Chamber Muon Systems in one end-cap, a 60° sector and a 30° sector of the Drift Tube and Resistive Plate Chamber Muon Systems in two adjacent wheels of the barrel, two 80° sectors of the Barrel Hadronic Calorimeter, a 30° Sector of the Endcap Hadronic Calorimeter, two 20° modules of the Barrel Electromagnetic Calorimeter and a small setup of the Silicon Tracker containing parts of four barrel layers and one end-cap disk.

2. Magnet commissioning and the Cosmic Challenge Phase 1

The CMS magnet coil [2] is made from four layers of superconducting cable consisting of a core of superconducting NbTi embedded in pure Al and an Al alloy for reinforcement. The solenoid is contained in a cryostat which keeps its temperature at 4 K. The magnet was first cooled down to operating temperature in a very smooth operation during February 2006, taking care to keep temperature gradients small. After closing and interlocking the eleven detector elements, the magnet was powered with increasingly higher currents. After periods of constant magnetic field, the magnet was powered down using either the slow discharge method during which the solenoid stays at operating temperature or the fast discharge method during which superconductivity is lost and temperature increases by about 70 K. The nominal field strength of 4 T was reached at a current of 19.2 kA on August 22, 2006, setting a new world record for energy stored in a magnet of 2.5 GJ. During the following days, known as Cosmic Challenge phase 1, about 15 million cosmic events were taken with parts of all three Muon Systems, both Calorimeters and the Tracker at a field strength of 3.8 T.

3. Field Mapping

After this first phase, the detector was opened, the two innermost sub-detectors, the Tracker and the Electromagnetic Calorimeter, were removed and a field mapping device was installed in their place. This non-magnetic device was moved on rails along the z -direction (axis of the solenoid) by air-driven mechanics. It has two rotating arms in order to scan the field strength at different azimuths ϕ , each arm being equipped with five Hall probes at different radii. Additional NMR probes are located at the outermost radius ($r = 1.72$ m) of one arm and on the z -axis.

After closing the detector, the field in the inner detector volume was mapped at field strengths of 0 T, 2.5 T, 3.5 T, 3.8 T and 4 T with a granularity of 142 positions in z -direction and 48 positions in ϕ with a precision of the order of 10^{-4} . At the nominal field strength of 4 T, the measurements of the z -component of the magnetic field strength B_z show excellent agreement with a simulation model of the field strength ($\Delta B_z/B_z < 5 \times 10^{-4}$ for the central detector region $|z| < 2.5$ m). This is a key result of the magnet test, since the simulation model of the field strength will be used for reconstruction in all parts of CMS not directly mapped by the field mapper.

In parallel to the field mapping, cosmic data taking continued with the Muon Systems and the Hadronic calorimeter (Cosmic Challenge Phase 2).

4. Detector integration with Central Services, Trigger, Data Acquisition and Run Control

In order to test this substantial fraction of CMS sub-detectors, services such as Low and High Voltage, gas supplies and the Detector Control and Safety Systems had to be replicated on the surface.

A scaled-down Level-1 Trigger System [3] was installed in a counting room on the surface. The system included the full variety of components of the three Muon Triggers, the Global Muon Trigger and the Global Trigger and all types of components of the Calorimeter Trigger up to the Regional Calorimeter Trigger. The trigger was operated both in local and global mode. In local mode, the regional muon and calorimeter triggers generated trigger signals which were then distributed by a Local Trigger Controller. In global mode, which will be used in the final experiment, regional triggers send trigger objects all the way to the Global Trigger which then applies the trigger cuts and distributes the triggers. Trigger conditions were relaxed with respect to the final setting allowing for example single station muon triggers in the end-cap. Pointing triggers were used to select muons passing through the Tracker setup in the center of the detector. Depending on the trigger settings, the overall trigger rate from cosmic varied between 100 and 300 Hz.

Data acquisition needs were met by the pre-series DAQ system, a setup corresponding to about $1/16^{\text{th}}$ of the final CMS DAQ System [4], which had previously been installed next to the surface assembly hall in order to validate DAQ hardware and software. For the Cosmic Challenge, only part of this setup was utilized. The system included the full readout chain from the custom-built Front-end Readout Links, to the Myrinet Super-Fragment Builder, the Gigabit Ethernet Event Builder, the Event

Filter Farm and finally to a prototype Storage Manager which stored data on a local disk. From there, data were transferred to the Tier-0 Computing Center at CERN and to remote sites such as FNAL for quasi-online data-quality monitoring. On-site Data Quality Monitoring and Event Display received data directly from the Storage Manager. The average event size without zero suppression was 200 kB, about 1/5th of the final event size. The DAQ System also included the Trigger Throttling System, a fast feedback system used to throttle the trigger in case of front-end buffers filling up due to variations in trigger rate or back-pressure from the DAQ System.

All on-line software for the Trigger, DAQ and Detector Readout was controlled by the Central Run-Control System. Monitoring data from the Trigger and DAQ Systems were collected by a common monitoring framework.

5. Results

After an initial integration phase and successful synchronization of all detector components, cosmic muons were detected by all sub-detectors in coincidence. The detector was operated around the clock for several periods, most of them when the magnetic field was on. Data taking efficiency was good over long periods, especially when the field was on and operators made a big effort to quickly recover from errors. A total of 15 million events with field and 10 million events without were taken with all participating sub-detectors during the first phase of the Cosmic Challenge. This included about 5 k (6.5 k) tracks with (without) field hitting the Tracker setup. During the second phase, of the order of 100 million events were taken with the Muon Systems and the Hadronic Calorimeter at different magnetic field strengths.

Cosmic muon events were reconstructed with the CMS event reconstruction software CMSSW. Properties such as the distribution of the muon transverse momentum in the DT System were found to show good agreement with a Monte-Carlo simulation. The acquired data were used in many dedicated studies analyzing aspects such as the influence of the magnetic field on signal-to-noise ratios and pedestals, the influence of the field on detector alignment and the influence of the magnetic field on the drift velocity in the Drift-Tube chambers. In most cases results were as expected, but some problems were found such as increased cross-talk between Hybrid Photo-Diode pixels in the Outer Barrel Hadronic Calorimeter when the field was turned on. The latter problem was resolved by moving the Hybrid Photo-Diodes to a place with more suitable magnetic field conditions.

6. Summary

During the CMS Magnet Test and Cosmic Challenge in 2006, the CMS magnet was successfully commissioned to the nominal field strength of 4 T. The field in the inner detector volume was mapped with high accuracy. In parallel, a part of CMS was operated including almost the full variety of sub-detectors, readout electronics, Trigger and Data Acquisition components and central services. This important test has shown that the plethora of sub-systems of CMS indeed can be integrated and operated as a single experiment. Performing this test on the surface allowed some problems to be identified and corrected at an early stage. Work is now focusing on installation and commissioning of the full-scale system in the underground experimental cavern.

References

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