Operational experience with the CMS hadronic calorimeter system

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Abstract. The hadronic calorimeter (HCAL) of CMS was commissioned before and during the initial proton collisions in Large Hadron Collider. Various phases of HCAL commissioning were used to gain operational experience and prepare the detector for physics. In this note we briefly summarize the activities and outcomes from the commissioning studies.

1. Introduction
The CMS detector at CERN Larger Hadron Collider is built for Higgs particle and new physics searches by using various objects such as muons, electrons, photons, taus, jets, and missing transverse energy ($\not{E}_T$) [1, 2]. Hadronic calorimeter (HCAL), together with the electromagnetic calorimeter, is responsible for jet and $\not{E}_T$ measurements, and it will play very crucial role for new physics discovery program in CMS. HCAL is composed of various parts: The barrel (HB) and endcap (HE) calorimeters are outside the tracker and electromagnetic calorimeters, all of which are inside the magnet solenoid. They are made of brass absorber with scintillation tiles and wavelength shifting fibers. The outer hadron calorimeter (HO) situated behind the solenoid and have similar scintillation tile and wavelength shifter fibers. The forward hadron calorimeters (HF) are positioned 11.2 m away from the interaction point in both sides and they use quartz fiber technology with steel absorber. More details about the HCAL can be found in Ref.[1].

With the data from first 7 TeV collisions, the experiments will re-confirm Standard Model to demonstrate that the detectors are well understood. In parallel to that, tools for background estimations based on data driven methods will be refined and developed further. Before reaching its readiness, CMS detector has undergone various commissioning phases. In the last couple of years CMS experiment collected data from millions of cosmic ray muons. With this period we learnt how to operate HCAL as a part of the CMS experiment, and made different measurements which varies from timing adjustments to calibration of sub-detectors. Also, first circulating beams and beam shots on collimators in 2008 gave us different opportunities to prepare HCAL for physics. After the repair period in LHC, which was due to the electrical failure in LHC magnets, the protons were collided with 900 GeV and 2.36 TeV center of mass energies. On March 2010, a new world record was announced with 7 TeV collisions in LHC experiments, and at the end of April 2010 CMS collaboration announced that more than 1 nb$^{-1}$ of data were collected.

In all these milestones, HCAL collaboration made sure that the sub-detectors were operated in their highest performance, and they are ready for physics. In this report I will focus on what
Figure 1: The fraction of participation of seven sub-detectors in global runs during commissioning versus time. The unit of fraction is $\frac{1}{7} \times 100\%$ (left). The number of collected events triggered by cosmic ray muons versus days in CMS global runs (right)\cite{3}.

we learnt from cosmic muons, beam splashes and first collisions to operate HCAL to make it a better device for physics.

2. Monitoring HCAL status

HCAL is equipped with high-voltage, low-voltage, laser, LED, and radiation damage monitoring systems. High voltage and low voltage are continuously monitored through detector control system which is controlled by several PCs in the CMS control room. Relevant alarms and warnings are also installed to provoke actions to recover failures. The pedestal and timing parameters are downloaded to front-end electronics through database and control system. The pedestal values are periodically checked by using dedicated pedestal runs; actions are taken at the HCAL channel level if drifts from loaded pedestal values are observed. The timing of the HCAL channels are checked by using laser runs. For the detector noise studies, dedicated self-triggered events are also collected. These monitoring runs (pedestal, laser, and self-triggered) are taken during local activities of HCAL. During the collisions, however, local time is limited. Therefore, monitoring and calibration events are also collected in orbits where no proton bunches exist (also known as abort gap). The gain stability of the HCAL is monitored by using LED runs. The local and abort gap monitoring data are processed by quality control jobs to produce histograms and tables for overall HCAL status. In case of problems, HCAL operations experts intervene and correct the behavior. During the commissioning and operation of HCAL, the development of the tools continued, and an expert team was formed to help operation of HCAL.

3. Performance studies with cosmic ray muons

Data taken with cosmic ray muons played crucial role in commissioning of CMS detectors. All sub-detectors were included and commissioned to act as a combined, unified system throughout cosmic ray muon tests\cite{3}. As shown in Figure 1, left, by the end of commissioning phase all sub-detectors were successfully included in global runs. HCAL was one of the few sub-detectors whose commissioning completed earlier than others. Another very important goal was to collect more than 300 million events for performance studies. As shown in Figure 1, right, in about 25 days this goal was achieved and performance studies from these data resulted in much better understood detector.

HCAL group had specific goals for the cosmic ray muon runs. Among them was to participate to global runs with all components, measure the impact of magnetic field on HCAL response, measure the muon energy in a wide muon momentum range to confirm the absolute energy scale,
confirm initial calibrations and if possible improve them, and measure the electronics noise rates and effect of magnetic field on the rate.

The active material in HB and HE are plastic scintillators and about 10% increase in response is expected with the magnetic field[4–8]. Of 10%, 5-8% is due the intrinsic brightening of the scintillator[8], 1-2% is due to the increased path length of charged particles inside scintillator and 2% is due to the cross-talk between hybrid photo-diode (HPD) pixels due to small misalignments[9]. On average 9.5% increase in HB and 8.4% increase in HE was observed[9]. One of the benefits of cosmic rays and having a working tracker system was the ability to validate absolute energy scale of HCAL. Muons with momentum in the range of ∼100-200 GeV/c were used in the analysis[9]. Independent checks were also done for data and MC agreement, and it was shown that they agreed each other reasonably (Figure 2, bottom). The muon energy loss in calorimeter was measured in beam tests by using 150 GeV/c muons and found as 2.80±0.03 GeV in HB[10]. By using cosmic ray muons in the range of 135 and 170 GeV/c the energy deposition was found to be 2.85±0.02 GeV/c (Figure 2, top) [9].

The calibration constants in HCAL were determined by using particle beams of known momentum in beam tests and by using radioactive source measurements. For the barrel and endcap calorimeters absolute energy scale was set using the response to 50 GeV/c charged pions of the parts of the detector exposed to the beam[9]. Since these parts correspond to small fraction of readout segments (in φ), φ to φ variations in the response are expected, and they are mostly due to HPD gain differences. The variations were partially corrected by using cosmic ray muons as well[9]. The splash events taken in 2008 were used to adjust timing in η, where we expect variations due to cable length and readout box positioning. Since the position of the collimator is known, the timing was able to be calculated and converted into time measured from interaction point to particular HCAL cell[11]. At first, delay settings for barrel came from test beam measurements, whereas the delay settings for other sections were set to zero. Figure 3, left, shows the difference of predicted and measured times for different parts of the detector and for different readout depths. Measured time matches to predicted within 1 ns for barrel section. After calculating the delays by using splash events the synchronization in η is achieved within 2 ns as shown in Figure 3, right[11]. The splash events were also used to find corrections for calibration constants.
These corrections were used to smooth the response in $\phi$ for barrel, endcap, and outer parts.

Since December 2009, LHC is colliding protons in the center of experiments. The collisions started with first in 900 GeV and 2.36 TeV center of mass energies. The CMS experiment has been collecting data with very high efficiency to enable first physics studies. The reconstructed objects which uses HCAL and their comparison with Monte Carlo reflect the understanding and performance of HCAL. For example, jet and $E_T$ can be reconstructed by using calorimeter readout towers for which understanding of shower shapes and energy scale is very important. Figure 4 shows number of jet constituents (i.e., calorimeter towers) and $E_T$ resolution for 900 GeV collision data[12, 13]. Although there is a long way for more precise measurements, the Monte Carlo description of first data is remarkable.

Studies during beam tests and cosmic ray muons helped to understand and categorize noise sources in HCAL [14]. In HCAL there are two major sources for noise: the noise from HPDs and photo-multiplier tubes, the former is used for barrel, endcap, and outer calorimeter, the
latter is used for forward calorimeter. Both noise classes are studied and rates were measured during cosmic runs and collisions. Overlap rate of HPD noise with physics event is less than $10^{-5}$[14]. For the PMT hit events, the rates are around $6 \times 10^{-3}$ per event[14]. There are filtering algorithms developed both at trigger and analysis level to reject noisy events. Further improvements on the noise and R&D studies with new photo-devices for the upgrade is ongoing.

4. Conclusion

7 TeV collisions at LHC in March 2010 has marked the beginning of new era in particle physics. Experiments will exploit the first collision data in the coming months to re-confirm Standard Model to demonstrate that the detectors are well understood. HCAL, as being the device for energy measurements of strongly interacting particles, will play very crucial role for new physics discovery program in CMS. In the last couple of years CMS detectors commissioned fully and collected millions of cosmic ray muons. With this period we learnt how to operate HCAL as a part of the CMS experiment. As of this conference, LHC was delivering beams with $10^{10}$ protons per bunch, and CMS experiment collected more than 1 nb$^{-1}$ of data with these bunches. During this period, the efficiency of HCAL, i.e. participation percentage, was more than 99%, and HCAL had more than 99% live channels. Consequently, HCAL is operational and the experience gained during the commissioning is paying well, as HCAL participates jet and $E_T$ measurements with very high efficiency.

References

[1] Chatrchyan S et al. (CMS Collaboration) 2008 JINST 3 S08004
[2] Bayatian G L et al. (CMS Collaboration) 2007 J. Phys. G 34
[3] Chatrchyan S et al. (CMS Collaboration) 2010 JINST 5 T03001
[4] Bertolucci S et al. 1987 Nucl. Instrum. Methods Phys. Res., Sect. A 254 561 – 562
[5] Cumalat J P et al. 1990 Nucl. Instrum. Methods Phys. Res., Sect. A 293 606 – 614
[6] Blaker D et al. 1992 Nucl. Instrum. Methods Phys. Res., Sect. A 311 505 – 511
[7] J M et al. 1992 Nucl. Instrum. Methods Phys. Res., Sect. A 312 451 – 456
[8] Bertoldi M et al. 1997 Nucl. Instrum. Methods Phys. Res., Sect. A 386 301 – 306
[9] Chatrchyan S et al. (CMS Collaboration) 2010 JINST 5 T03012
[10] Abdullin S et al. (USCMS Collaboration) 2009 Eur. J. Phys. C 60(3) 359–373
[11] Chatrchyan S et al. (CMS Collaboration) 2010 JINST 5 T03013
[12] URL http://cdsweb.cern.ch/record/1248210/files/JME-10-001-pas.pdf
[13] URL http://cdsweb.cern.ch/record/1247385/files/JME-10-002-pas.pdf
[14] Chatrchyan S et al. (CMS Collaboration) 2010 JINST 5 T03014