Available on CMS information server

CMS CR-2008/047

The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

21 July 2008

CMS HCAL Installation and Commissioning

Kerem Cankoçak, Yasar Onel

Department of Physics and Astronomy, The University of Iowa, Iowa City, IA 52242, USA

Pawel de Barbaro, Dima Vishnevskiy

Department of Physics and Astronomy, University of Rochester, Rochester, NY 14627, USA

Abstract

The installation and commissioning of the Hadron Calorimeter system of the CMS detector is described and the performance of the various monitoring systems, the progress in the calibration work and the current plans for the HCAL calorimeter are summarized.

Presented at *XIII International Conference on Calorimetry in High Energy Physics,26 - 30 May 2008,Pavia,Italy*

1 Introduction

The CMS hadron calorimeter system consists of a brass/scintillator sampling hadron calorimeter (HCAL) with coverage up to $|\eta| \leq 3.0$, followed by the iron/quartz-fiber Hadron Forward (HF) calorimeter with coverage $3.0 \leq |\eta| \leq 5.0$, comprising 9528 readout channels in total [1].

The Barrel Hadron calorimeter (HB) is 9 meters long, one meter thick and 6 meters in the outer diameter, consisting of two half barrels of 18 identical 20^o wedges in ϕ, each made of flat brass alloy absorber plates with wavelength shifting fiber (WLS) readout, parallel to the z-axis in CMS coordinate frame. The two End Caps (HE) covering the geometrical region $1.305 < |\eta| < 3.0$, are also made of brass and scintillator, with a diameter of 0.8 to 6.0 m. and a thickness of 1.8 meters. HB and HE are inside the 4-tesla solenoid coil and have a $\Delta\eta \times \Delta\phi = 0.087 \times 0.087$ segmentation, except near $|\eta| = 3.0$, where the size of the segmentation is doubled. The two forward calorimeters (HF) are made of quarts fibers embedded in iron. Cherenkov light generated in the fibers is transmitted to the photo tubes (PMT). The central shower containment in the region $|\eta| < 1.26$ is improved with an array of scintillators located outside the magnet in the outer barrel hadronic calorimeter (HO). The inclusion of the HO layers extends the total depth of the calorimeter system to a minimum of $11\lambda_I$ for $|\eta| < 1.26$. The optical signal from the HCAL towers, except HF, is detected with hybrid photo diodes (HPD) mounted at the ends of the barrel.

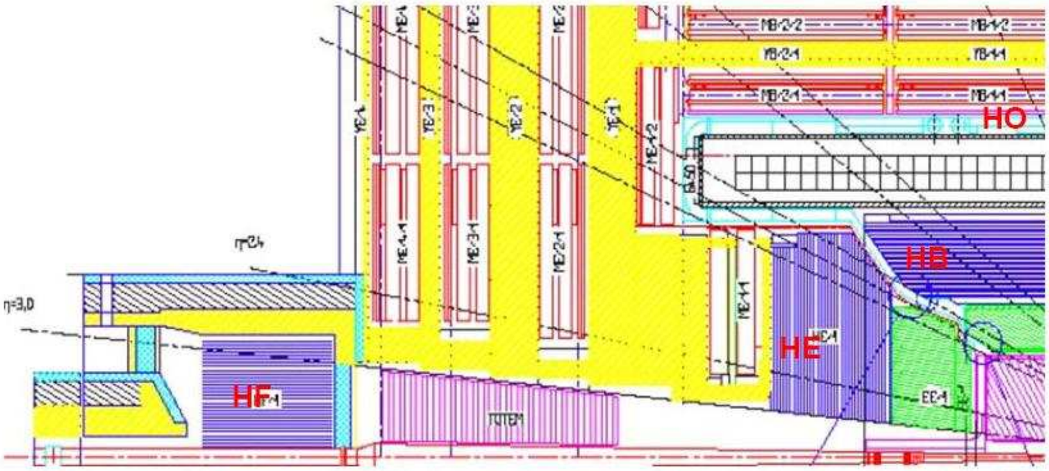

Figure 1: HCAL view in $r - z$ plane

1.1 HCAL Readout and data path

The optical signals from the subsystems are converted to the electrical signals using multichannel HPD's and PMT's. The analogue signal is converted to a digital signal by the charge-integrating ADC (QIE), which consists of four capacitors running one after another in 25ns time slices. The digital outputs of three QIE channels are combined together to create a 32-bit data word which is then transferred via the Gigabit Optical Link (GOL) at a rate of 40 MHz and transmitted to the counting house. In the counting house USC55, the data is received by the HCAL Trigger Readout (HTR) board, containing the Level-1 pipeline. The trigger primitives are sent to the Regional Calorimeter trigger (RCT) via Serial Link Board mezzanine cards [1].

2 HCAL Commissioning strategy

2.1 In the surface assembly hall (SX5)

Before lowering the CMS detector into the detector cavern, all sub-detector elements were commissioned using test beams and cosmic rays. Energy calibration of HCAL was done using test beam data and radioactive source measurements. The absolute energy scale of HCAL was established by measuring HCAL response to 50 GeV pions with data recorded in the H2 test beam in 2006 [2]. The relative (tower-to-tower) calibration of HCAL was performed using radioactive sources as part of commissioning the HCAL Barrel wedges in the CMS surface hall (SX5) in 2005 and 2006. Following the Magnet Test and Cosmic Challenge (MTCC) in summer 2006, all 15 heavy elements of the CMS detector have been lowered into the CMS cavern (Fig 2).

2.2 In the underground cavern (UX5)

The commissioning work in the underground cavern includes collecting data using using sub-detector DAQ systems (local runs) and central CMS DAQ and trigger systems (global runs). The global runs deploy larger and larger parts of detectors, as they are built and commissioned detector and then are included into simulations and data analysis. The main steps of the commissioning in the underground cavern are :

- commissioning using local runs (pedestals, LED);
- synchronization of various sub-detector systems (Muon, Calorimetry, Tracker);
- global commissioning runs (using cosmic ray triggers);
- preparing for 24 hours/7 days operation.

Figure 2: CMS cavern during the period 2006-2008

2.3 HCAL activities 2006-2008

Main HCAL activities between the period 2006-2008 were:

- 2005/2006: Installation and commissioning of hardware and readout electronics on the surface (SX5 assembly hall), initial testing of the HCAL readout with LED and Laser systems, relative calibration of all HCAL towers using radioactive source system and participation in MTCC data taking.
- 2007: Lowering of detector elements into underground hall, installation of readout and service cables between detector cavern and underground service cavern, establishing power up sequence, timing and calibration procedures.
- 2008: Full integration of HCAL with CMS system, monitoring of HCAL hardware (pedestals, LED), participation in CMS global runs.

2.4 Milestones for CMS commissioning

The main milestones for CMS in 2008 are:

- May-June, 2008 : Global runs with all CMS wheels/disks without Tracker, without the magnetic field
- July-August 2008 : Global runs with all CMS wheels/disks including Tracker, without the magnetic field
- late Summer 2008: Cosmic run at 3.8 Tesla, CRAFT (CMS closed and Field-on)

2.5 Commissioning with local runs

Data was taken for entire HB,HE,HO and HF subdetectors. Readout of all HCAL channels have been tested and verified that they have good optical connections. In particular, we monitored the stability of the pedestals and pedestal widths. LED runs were used to make sure that all the channels are functioning properly and to check the gain stability of HPDs and PMTs.

3 Global Runs

The basic goal of global runs is to allow the transition of CMS from a set of commissioned subsystems (HCAL, Muon, ECAL, Tracker) into a fully integrated detector (Fig. 3).

Muons traversing the HCAL Barrel tower are expected to deposit 1 to 2 GeV of energy, while the typical noise in HCAL (single channel, summed over 10 bunch crossings) is approximately 230 MeV. The first sample of cosmic ray muons in HCAL Barrel was recorded in September 2005 [3]. In September and October 2007 during global runs, HCAL collected the first cosmic ray muons in the underground cavern (Fig.4). In December 2007, over 0.5 million of cosmic ray muons events were recorded. This was the first global run which included. all 36 HCAL Barrel wedges in the readout. Finally, during the Cosmic Runs at Zero Tesla (CRUZET) in May, June and July 2008, a sample of over 40 million cosmic ray triggers has allowed us to apply stringent quality cuts on muons traversing HCAL.

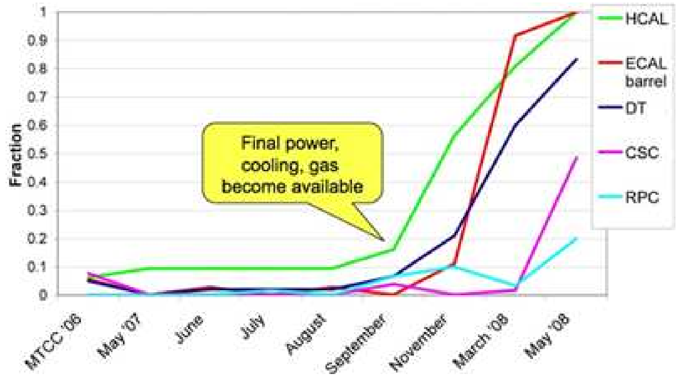

Figure 3: Fraction of Live Front Ends in CMS Global Runs

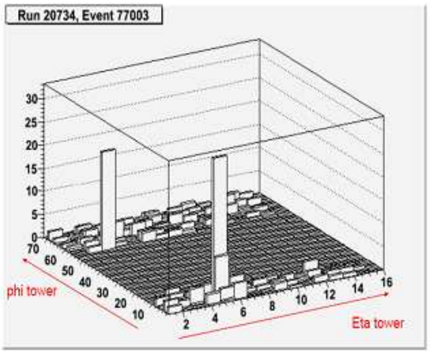

Figure 4: HCAL Barrel $\eta - \phi$ energy scatter plot in a Cosmic ray event triggered by muon track in Drift Tube (DT) during September 2007 Global Run.

3.1 Overview of Cosmic Run at Zero Tesla, May 5-14 2008, (CRUZET-1)

HCAL has collected over 23M good quality events with cosmic ray triggers. All Front End Devices were read out, including HCAL Barrel (HB) , Endcap(HE), Outer (HO) and Forward (HF). This is factor of 50 larger data set with respect to previous data sets (Sept 2007-March 2008).

For each Level-1 trigger (L1A) , HCAL readout acquires precision digi information from charge integrators (QIE cards) for ten 25 nanoseconds long time-slices or LHC bunch crossings (bx). It is crucial to verify that the signal from the cosmic ray muon which generates the trigger is registered well within HCAL readout window. In order to verify the synchronization of HCAL readout with respect to trigger, we looked at the timing of HCAL events selected by requiring that the sum of the signal in a single HCAL tower is above the noise threshold. Timing of the HCAL signal is determined on an event by event basis for each HCAL Barrel readout channel, requiring the ten time-slice (bunch crossing) signal sum to be at least 1 GeV above pedestal. Precision QIE digi information from four time-slices around the time slice with maximum signal is used to obtain energy weighted time average for each channel above energy threshold:

$$t_\mu = \frac{\sum_{i=E_{max-1}}^{i=E_{max+1}} \Big(E_i(ADC) - ped\Big) * i}{\sum_{i=E_{max-1}}^{i=E_{max+1}} \Big(E_i(ADC) - ped\Big)} \qquad (1)$$

Fig. 5 shows the timing of the HCAL signals which are well timed in with respect to DT and RPC triggers, using data from the run 43434. Nevertheless, additional work is required for precise synchronization of triggers.

3.2 Muon DT and ECAL vs HCAL correlations

Using the cut on HCAL events mentioned above, we observed a good correlation between η and ϕ of DT tracks from cosmic ray muons and the position of corresponding signals in Hadron Barrel, and Outer, calorimeter towers.

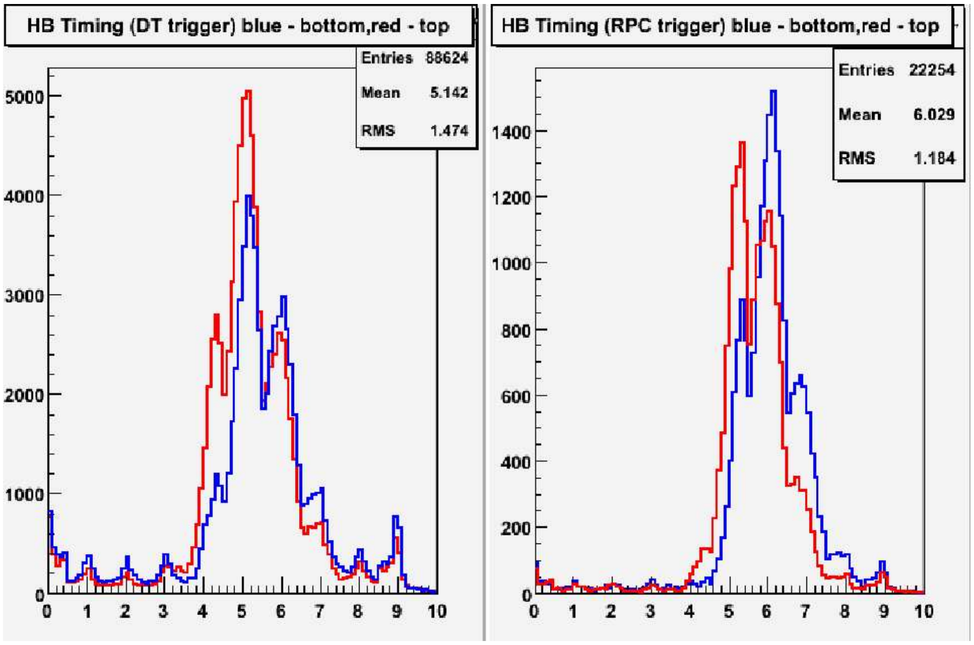

Figure 5: Timing of HB signal with respect to DT and RPC triggers from the Cruzet1 run 43434. Blue lines from HB-Bottom towers and red lines from HB-Top towers.

Fig. 6 show the correlation between the position of the DT track in ϕ and η, extrapolated into the center of HCAL Barrel towers. Similar correlations are obtained as well between ECAL and HCAL ϕ and η towers (Fig. 7). In these plots, the events were selected by requiring that track impact parameter in xy plane is less then 40 cm.

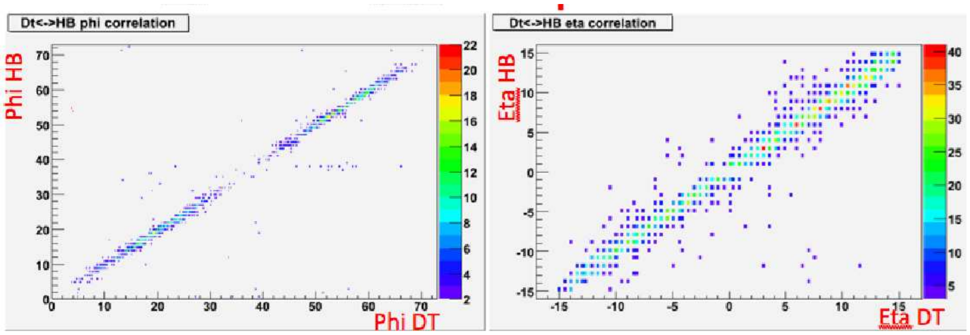

Figure 6: Correlations between DT track η and ϕ positions vs HCAL η (left) and ϕ (right) towers, during CRUZET-1

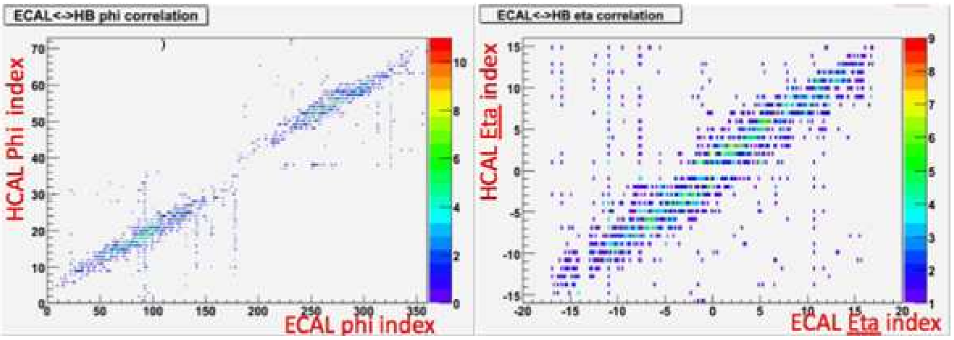

Figure 7: Correlations between ECAL η and ϕ positions vs HCAL η (left) and ϕ (right) towers, during CRUZET-1

3.3 Selecting cosmic ray muons using Muon chamber (DT) tracks

To obtain an unbiased measurement of muon energy deposited in HCAL, we used DT tracks extrapolated into HCAL volume, to determine the block of HCAL $\eta - \phi$ towers crossed by a muon track (Fig 8). Cosmic ray muons which cross the detector with a large distance from the CMS interaction point, will traverse and deposit energy in multiple HCAL towers. For such events, one would need to sum up large number of towers, both in η (large impact parameter in z plane) and ϕ (large impact parameter in x-y plane) in order to fully contain muon energy deposit cluster. We require that muon track crosses only single HCAL 5 degree ϕ section. This requirement is imposed by checking position of the track at the inner and outer radius of HCAL. $\eta - \phi$ occupancy of the selected muons in HCAL are shown in Fig. 9.

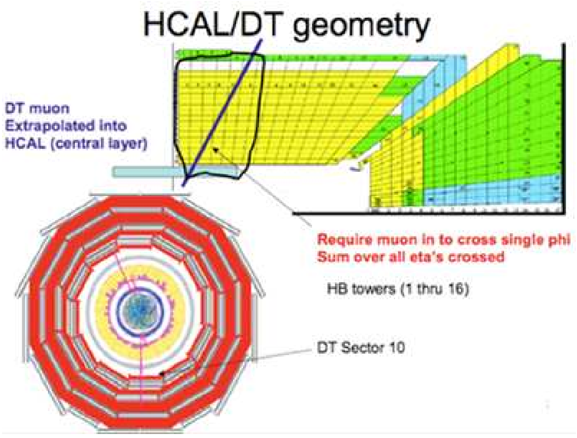

Figure 8: Diagram of the CMS detector showing the topology of muons selected from the DT tracks.

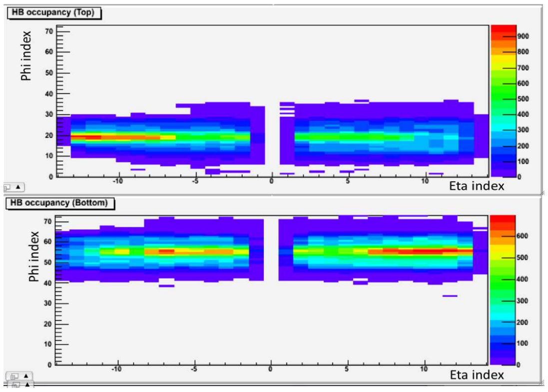

Figure 9: HB towers $\eta - \phi$ occupancy of selected muons from DT tracks. The muons enter HCAL though the top, negative half-barrel region and exit through the bottom, positive half-barrel region.

3.4 HB calibration validation using Cosmic muons

The source calibration was used to establish energy calibration from test beam wedges to the wedges assembled into Hadron Barrel calorimeter. The absolute energy scale and relative (tower-to-tower) calibration coefficients can be tested by comparing test beam and radioactive source results with the response of HCAL to cosmic ray muons [**?**].

Fig. 10 shows muon energy deposition in HCAL Barrel using Cruzet1 data set. The energy of muon is defined as:

$$E_{\mu}^{3\phi} = \sum_{\phi_0 - 1}^{\phi_0 + 1} \sum_{\eta_{min} - 1}^{\eta_{max} + 1} E(\phi_0, \eta)[GeV] * Cos(\theta) \tag{2}$$

Here, $E_{\mu}^{3\phi}$ is the HCAL energy summed over 3 ϕ towers and is obtained using HCAL Barrel $\eta - \phi$ tower clusters. The energy sum is performed over a range of towers crossed by DT track in η direction and expressed in GeV, after calibration coefficients have been applied. Three 5 degree ϕ sections in HB are included in the energy sum, one indicated by DT track (ϕ_0) and the two neighboring ones. All energies are corrected to correspond to normal incidence in the y-z plane.

The ratio of HCAL gains obtained from source calibration to uncalibrated response of HCAL to muons has of 4 to 5 percent RMS value. Energy deposited by cosmic ray muons in HCAL is consistent with measurements done in the test beam 2006 using 50 GeV/c pions [2]. One hour of running with cosmic ray triggers at 250 Hz rate yields approximately 1 million muon candidate events. Analysis of Cruzet1 data shows that using a 20 million sample of cosmic ray muon triggers, which can be collected in less than one day of running, one can validate HCAL calibration with precision better than 5 percent (Fig. 11). The accuracy of the validation process can be further increased by improving muon selection cuts.

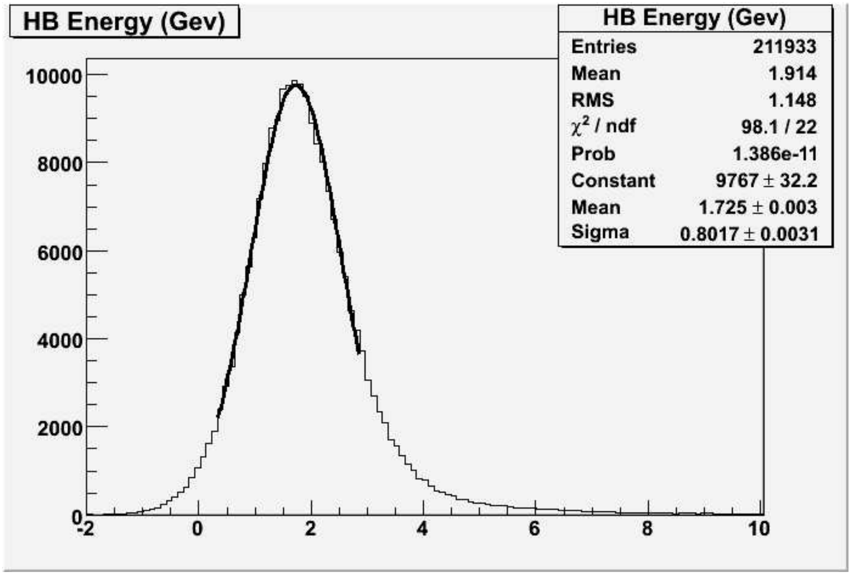

Figure 10: Muon energy deposition combined for the HCAL Barrel (HB).

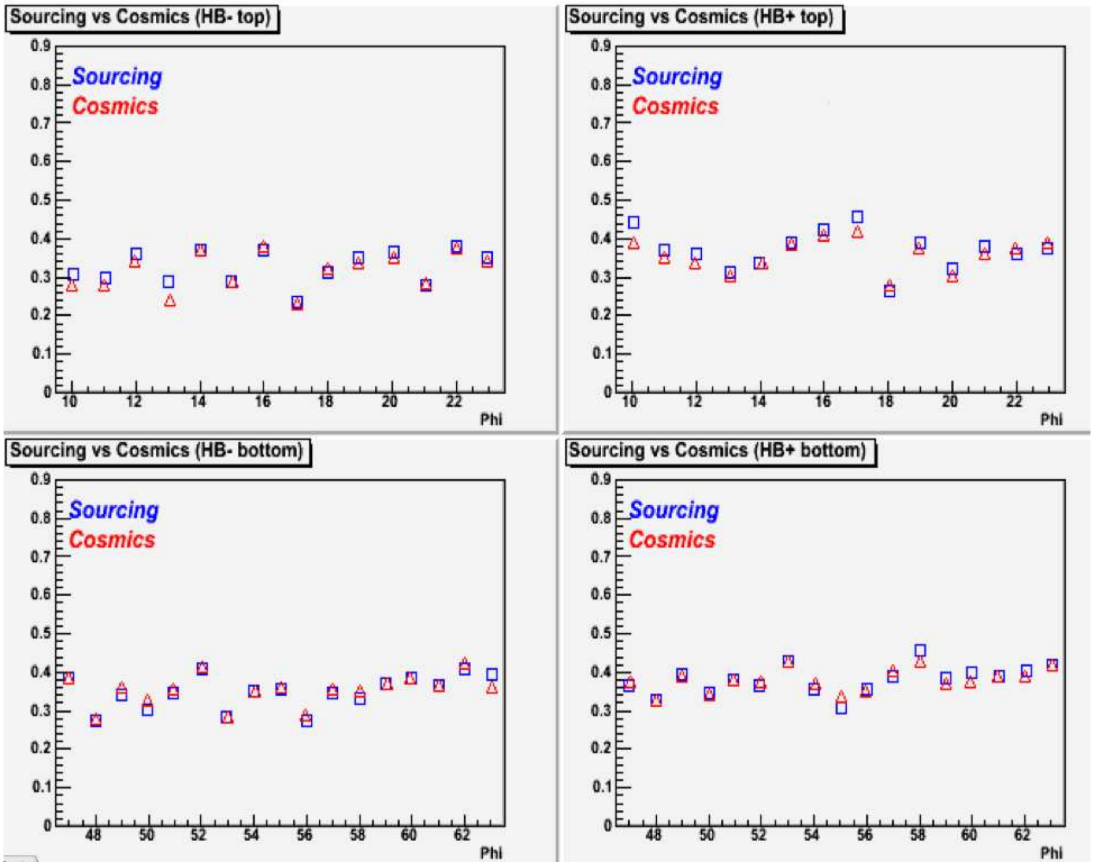

Figure 11: HCAL tower gains obtained from radioactive source calibration (blue squares) compared with the energy response of cosmic ray muons (red triangles).

4 Conclusions

- CMS Hadronic Calorimeter (HCAL) is fully installed and commissioned using local and Global runs,
- HCAL is timed in with respect to DT,RPC, CSC and ECAL during Global runs;
- DT/HCAL and ECAL/HCAL $\phi - \eta$ correlations are good;
- Relative timing of various triggers will be further adjusted;

References

[1] CMS Physics TDR, Volume I: CERN-LHCC-2006-001, 2 February 2006

[2] Design, performance and calibration of the CMS forward calorimeter wedges, G. Bayatian et al., Eur.Phys.J.C53:139-166,2008..

[3] The CMS Magnet Test and Cosmic Challenge (MTCC Phase I and II), CERN/LHCC 2007-011/G-129, 7 March 2007