The Compact Muon Solenoid Experiment
Conference Report

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The Performance of the CMS Hadron Calorimeter with Cosmic Muons

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Abstract

The CMS Hadron Calorimeter (HCAL) has several subsystems. This talk reports on the progress of three of the sub-systems (barrel, endcap and outer calorimeters) that are sampling calorimeters with the active area made of scintillators with embedded fibers read out by hybrid photomultipliers. These systems are now installed and integrated in the detector and participated in data taking during the four days in September 2008 with single proton beam at 450 GeV impinging on a collimator near CMS. In addition over 300 million cosmic muon data has been taken with and without the CMS magnet on. The HCAL is ready to take data and performs as designed. Results from the cosmic muon data and single beam events will be presented.

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THE PERFORMANCE OF THE CMS HADRON CALORIMETER WITH COSMIC MUONS

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The hadron calorimeter (HCAL) is now installed in the CMS detector and ready to take collision data. The CMS HCAL barrel and end caps are made of scintillator and brass absorber covering the $|\eta|$ range of 0.0 to 3.0. The forward calorimeter, made of quartz fibers and iron absorber, covers the $|\eta|$ range of 3.0 to 5.0. These systems are now installed and integrated in the detector and participated in data taking with over 600 million cosmic muons taken with and without the CMS magnet on. In addition, CMS took data during four days in September 2008, when LHC provided a single proton beam at 450 GeV/c impinging on a collimator near CMS. The HCAL is ready to take collider data and performs as designed.

1. Introduction

The Hadron Calorimeter is a major sub-system of the CMS detector. HCAL will detect jets, single hadrons and μ 's. It is required for the discovery of the Higgs between masses of 100 to 1,000 GeV and for searches of Dark Matter associated with large missing energy. The calorimeter is crucial in measuring missing energy for dark matter searches as well as for many beyond standard physics processes. Figure 1 shows the schematic quarter view of the hadronic system. The Hadron Calorimeter (HCAL) Central Barrel (HB) consists of two half barrels of 18 wedges each made of brass and scintillator. The two End Caps (HE) are also made of brass and scintillators. The η - ϕ segmentation of HB and HE is 0.087×0.087 , except near $\eta = 3.0$. The color code is the depth segmentation where the optical signals of a single tower are added and read by hybrid photodetectors. HB is only 6.5 interaction lengths thick at $\eta=0$ and will not contain completely all the particle showers, so additional scintillators (HO) are placed inside the muon barrel system, outside of the solenoid coil, to measure the HB energy leakage. HF made of iron absorber and quartz fibers are not described in this paper¹. The electromagnetic calorimeter (ECAL) inside of HCAL is made of finely segmented lead tungstate scintillating crystals contributing one interaction length to hadron calorimetry. This combination is highly non-compensating, which poses unique problems in energy measurement and resolution. The performance and resolution of the HCAL – ECAL system in test beams are presented in reference 2.

Figure 1. Quarter slice of CMS Hadronic calorimeter. CMS center is at the right end of the beam line. FEE's are the location of the Front end Electronics.

2. Performance of HCAL with Cosmic μ 's.

CMS has taken cosmic muon data in 2008 in the permanent location about 100m underground with the magnet off (CRUZET -Cosmic Run at Zero Tesla) and on (CRAFT -Cosmic Run At Full Tesla). Cruzet and Craft took about 300 million cosmic μ 's. Figure 2 (left, top) shows the energy loss (dE/dx) in HB of muons

Figure 2. Left: μ energy loss (top) and comparison with MC(bottom) . Right: μ energy spectrum measured by the CMS tracker..

where the relativistic rise of is clearly observed. Left, bottom is comparison of energy loss with MC. Right shows the cosmic muon spectrum. Figure 3 shows the muon energy deposition in the central and end cap calorimeters.

Figure 3. Cosmic μ energy deposition in HB and HE.

Calibration of the calorimeter starts with the test beam² on a few of the calorimeter wedges. The relative calibrations between wedges are measured by a radioactive source. The muon spectrum in each tower was used to refine the calibration constant of each tower as radioactive source measurement accuracies can be more than 10% off. Figure 4 shows the mean values of the muon energy deposition in each HB tower. The energy in each tower is corrected for path length of the muon and reduced by the relativistic rise of ionization loss.

Figure 4. μ energy deposition in the barrel calorimeter after corrections.

The final calibration will be done with particles and jets created in actual collisions at the center of CMS.

3. Performance of HCAL using Beam Collimator Data “Splash Events”

In September 2008, the LHC delivered single pulses of circulating beams at 450 GeV/c protons for four days. CMS observed beam halo events and beam collimator interactions (about 150 m from CMS). These “beam splash” events produced on collimators proved very useful to determine the relative timing of various systems, as well as validating the performance of parts of HCAL. The only particles that survived and penetrated the CMS were μ s. The initial timing of the calorimeter was done by laser pulses into each tower and the accuracy was about 5 ns. With the splash events the timing accuracy was improved to about 1 ns. Even though the scintillator pulse widths (FWHM) is 20 ns and the tail extends to 75 ns, the start of the signal can be determined to 1 ns thereby sorting out events from different LHC cycles (25 ns apart) and reduce background from cosmic rays, electronic noise and beam halo event triggers in Transverse Missing Energy (MET). Figure 5 is a simulation estimate of reduction due to time filter on three different backgrounds in the computation of MET.

Figure 5. Time filter performance on missing transverse energy (MET) for various backgrounds.

4. Electronic Noise

Most high energy experiments have electronic noise and the CMS calorimeter is no exception. In addition there can also be dead or under-performing channels. The three most prominent noise observed during CRAFT are ion feedback in HPDs, HPD noise and data box noise. The source of the data box noise has not been identified yet. These noise pulses have shapes and timing that are very different from the scintillator pulses and these differences have been used to identify and reduce the consequences of the noise that can create fake triggers,

especially in MET. Algorithms have been developed that reduce the fake rate as shown in Figure 6.

Figure 6. MET trigger rate due to electronic noise and reduction in the rate.

5. Conclusion

The CMS HCAL Collaboration has designed, built, installed and commissioned the HCAL system. HCAL has observed cosmic muons during CRAFT and CRUZET runs validating and improving the performance.

Acknowledgments

A detector of this complexity cannot be designed and built without the effort of many people, who have worked very hard during the past decade. We also would like to acknowledge the many funding agencies that have supported this effort including the US DOE, US NSF, Hungarian RMKI-KFKI, and The Scientific and Technical Research council of Turkey, Turkish Atomic Energy Agency, Bogazici University Research Fund and the Russian Ministry of Education and Science and the Russian State Committee for Atomic Energy.

References

1. HF is the topic of another contribution to this conference and will not be presented in this paper.
2. S. Abdullin et al., EPJ C **53**, p. 139-166 (2008); S. Abdullin et al. EPJ C **55**, p. 159–171 (2008); S. Abdullin et al., EPJ C **57**, p.653–663 (2008); S. Abdullin et al., EPJ C **60**, p.359-373 (2009).