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CMS CR -2013/226

The Compact Muon Solenoid Experiment

Conference Report

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

16 August 2013

The CMS Hadron Forward Calorimeter Upgrade during Phase I

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Abstract

The CMS Hadron Forward Calorimeter will be upgraded during phase 1. The upgrade will include the replacement of the current PMTs with the 4-anode ones and the readout electronics. Currently, stray muons hitting the PMT windows produce Cherenkov light causing erroneous signals. These signals are detrimental to the triggering and physic results, since such signals mimic very high energy events. The new 4-anode PMTs are selected because of their thin windows to reduce the Cherenkov light production. Additional anodes also provide information to eliminate such signals. These new PMTs have been tested extensively to understand their characteristics and to develop the algorithms to eliminate the unwanted signals. Eventually, the current read out will be replaced with two-channel readout electronics for each PMT. The overall expected improvement on the physics results will also be discussed.

Presented at *ICATPP Villa Olmo 14th ICATPP Conference on Astroparticle, Particle, Space Physics and Detectors for Physics Applications*

The CMS Hadron Forward Calorimeter Upgrade During Phase I

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The CMS Hadron Forward Calorimeter is being upgraded during phase 1. The upgrade includes the replacement of the current PMTs with the 4-anode ones and the readout electronics. Stray muons hitting the PMT windows produce Cherenkov light causing erroneous signals. These signals are detrimental to the triggering and physic results, since such signals mimic very high energy events. The new 4-anode PMTs are selected because of their thin windows to reduce the Cherenkov light production. Additional anodes also provide information to eliminate such signals. These new PMTs have been tested extensively to understand their characteristics and to develop the algorithms to eliminate the unwanted signals. Eventually, the current read out will be replaced with two-channel readout electronics for each PMT. The overall expected improvement on the physics results will also be discussed.

Keywords: Calorimetry, LHC, CMS, Forward Calorimetry, PMT, Multi-anode PMT, Cherenkov radiation

The CMS-HF Calorimeter was designed[1] to detect particles scattered in the very forward region, $3 < \eta < 5$. The two cylindrical units are located at each end of the CMS detector. Placing a calorimeter at such a forward position optimizes the detection of forward jets. It would be easier to observe or discover some interesting processes that are believed to produce forward jets, such as those processes involving heavy Higgs-like and SUSY particles. These forward calorimeters also improve the determination of the missing transverse energy.

The HF calorimeter is a sampling calorimeter with plastic clad quartz fibers embedded into iron absorber. Each unit has an active radius of 1.4 m. Both calorimeters are 1.65 m long and composed of 18 slices of 20-degree sections. Long (1.65 m - depth1) and short fibers (1.43 m - depth2) in the calorimeter sample the energy in electromagnetic and hadronic showers, respectively. Cherenkov radiation produced in each fiber goes into the PMT.

Original PMTs installed in the HF detectors were single anode PMT with a 2-to-6 mm thick window. At the start of the LHC run, anomalously large signals[2] were observed. These signals were produced by the Cherenkov radiation caused by the fast muons traversing the PMT windows. Fast muons are thought to pass through the calorimeter and reach the position where the PMTs are installed. Initially such window hits were expected to produce signals either in the long fibers or in the short fibers, but not in both. Also the signals come earlier since the muons directly hitting the PMT windows arrive before the Cherenkov light coming through the fibers. However, these could be used afterwards to eliminate the unwanted signals and the existence of such anomalous signals can affect the trigger, lowering the efficiency of data taking. As the luminosity increases and with the possibility of running at a 25 ns time structure, even these methods start to fail due to high occupancy and it was imperative to find a faster hardware solution to the problem.

A 4-anode PMT with a thinner window and a higher quantum efficiency (Hamamatsu R7600U-200-M4) is chosen[3] to replace the existing PMTs in the HF Calorimeter. Thinner windows will greatly reduce the Cherenkov radiation produced by the stray muons. With the help of a new read out system utilizing multiple anodes, Cherenkov signals can be further eliminated by using the correlations between different anodes. The light coming through the fibers illuminate all four anodes but the window hits only one anode.

The 4-anode PMTs were tested extensively under the test beams at CERN and Fermilab.[4] In these tests the new 4-anode PMTs and the existing PMTs in the HF were placed in the same setup to compare their performances in various situations. When the 150 GeV/c muon beam hit the PMT windows directly, Cherenkov radiation generated in the window produces signals in the PMTs. Comparison of these signals shows significant reduction in the pulse heights measured in the 4-anode PMTs due to thinner glass window compared to the existing ones (Figure 1 - left).

Performance of the 4-anode PMTs in the HF calorimeter was also tested by placing a fiber bundle behind a 5-cm steel absorber and attaching the fiber bundle to the PMTs. 80 GeV/c electron beam was the primary source of particles in this calorimeter setup and the resulting signals show a significant enhancement in the pulse heights for the 4-anode PMTs due to their higher quantum efficiencies (Figure 1 - right).

Prior to the 2011 LHC collision data taking period, several PMTs in

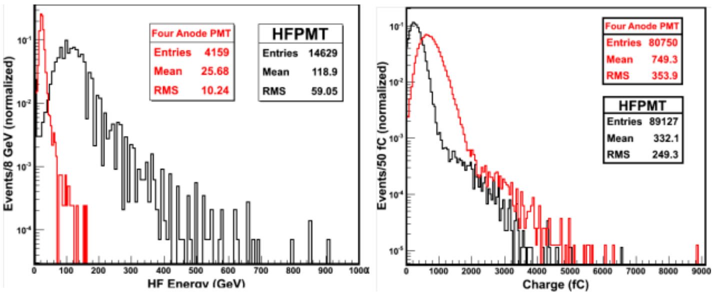

Fig. 1. (left) The 4-anode PMT displays (red) a lower rate and a reduced signal response for the window hits compared to the single anode ones (black). (right) Response to the Cherenkov light generated in the fibers. The 4-anode PMTs (red) have a higher response due to their better quantum efficiency than the older single anode PMTs (black).

the HF+ were replaced by the new 4-anode ones to test them under the LHC running conditions. The results were similar to the test beam measurements. A significant drop was seen in the noise[5] (mostly due to window hits) in the new 4-anode PMTs (Figure 2). Six of these eight 4-anode PMTs (Figure 3-top left) were read out as a single anode PMT (four channels ganged together) to measure the noise and one was read out as two-channel to test cleanup algorithms.

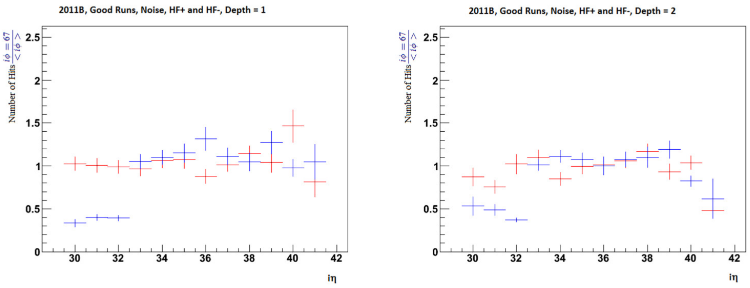

Fig. 2. The noise rate measured for the PMTs with the collision data. The 4-anode PMTs placed in the lowest η towers of the HF+ (blue data points) show a significantly lower noise rate compared to the single anode PMTs. HF- measurements were also added into the plots for comparison (red points).

During the LS1 period, all the PMTs in the HF are being replaced with the 4-anode ones. PMT upgrade will have been completed by the end of 2013 and then the burn-in and the required calibrations will have been

Fig. 3. A picture of the modified robox for the slice test during 2011 and 2012 runs (top left); robox modified for the 4-anode PMTs (top right); 4-anode PMTs installed in their baseboards (bottom left); old single anode PMTs removed from the detector (bottom right).

done by mid-2014 to be ready for the higher energy LHC beam in 2015. Installation of the new PMTs will utilize the existing robox structure as much as possible. Since the 4-anode PMTs have different pin configuration and smaller sizes, new baseboards have been designed and produced.[6] New baseboards and the accompanying adapter boards are designed in a flexible way so that single, double or quadruple anode readouts will be possible simply by replacing the front-end cards. Cables between the robox and the electronics system are also redesigned to select between these options. Plans for upgrading the readout electronics, especially for utilizing the multi-anode capability of these PMTs are underway. QIE chips in the front-end cards will be upgraded to provide dual channel readout and fast TDC signals. New front-end cards that will include the upgraded QIE chips will be ready for the early 2016 and be installed during the technical shutdown after the 2015 run. Initially, the new PMTs will use the existing front-end cards and read out as single anode PMTs by combining all four anodes together. To accommodate these additional channels more data fibers will be installed. The existing VME based back-end system will be replaced with a microTCA based system to improve the noise rejection, granularity, resolution and the trigger signal of the HF.

The HF calorimeter with these upgrades will be even more important to processes, such as, vector boson fusion production of higgs, SUSY, etc., that require better forward jet detection and higher missing E_T (MET) resolution. These measurements and the contribution to the L1 trigger will be more accurate with less background due to better noise elimination foreseen in the new PMT and the readout system.[7]

The upgrade of the HF calorimeter in Phase 1 is planned mostly towards eliminating the anomalous signals observed in the calorimeter. These signals are caused by muons hitting the PMT windows directly. Cherenkov radiation due to these muons produces large signals and results in false discovery-type signals. 4-anode PMTs with much thinner windows will both significantly reduce such window events and provide additional information to eliminate them. Electronics system will be upgraded to take advantage of the additional channels and to accommodate the new PMTs with the existing roboxes. After the upgrades, improved MET and jet determination will help the discovery and/or measurement of the physics processes.

Acknowledgements

Valuable comments and helpful suggestions of B. Bilki, Y.Onel, and T. Yetkin are greatly appreciated. This work was partially supported by Bogazici University Scientific and Technological Research Fund (#6653).

References

1. “Design, Performance and Calibration of the CMS Forward Calorimeter Wedges,” CMS HCAL Collaboration, Eur. Phys. J. C **53** (2008) 139-166.
2. “A Study of Anomalous Events in CMS-HF PMTs,” A. Halu, E. Gülmez, M. Deliomeroglu, the Proceedings of the International Conference on High Energy Physics In Memoriam Engin Arik and Her Colleagues, Oct. 27-31, 2008, Istanbul, Turkey, Balkan Physics Lett., **17,** 17021, 138-141(2009).
3. “CMS Technical Design Report for the Phase 1 Upgrade of the Hadron Calorimeter” CMS HCAL Collaboration, CMS-TDR-010, CERN, Geneva, 2012.
4. “Study of Various Photomultiplier Tubes with Muon Beams And Cherenkov Light Produced in Electron Showers,” CMS HCAL Collaboration, J. of Inst., JINST 5 P06002 (2010) and “Study of Various Photomultiplier Tubes for Window Events: Upgrade R&D for CMS Hadron Forward Calorimeters,” B. Bilki, J. Phys. Conf. Ser. 293 012011, (2011)
5. “Comparison of the Multi-Anode PMTs with the Old HF PMTs by Studying the Collision Data,” Y. Oz, MS. Thesis, Bogazici University, Istanbul, Turkey (2013) and CMS Thesis, CMS TS-2013/019 (2013)
6. “Tests of CMS hadron forward calorimeter upgrade readout box prototype,” CMS HCAL Collaboration, J. of Inst., **7** P10015 (2012)
7. “CMS Hadron Forward Calorimeter Phase I Upgrade Status,” Y. Onel, CHEF2013: Calorimetry for High Energy Frontier, 22-25 April 2013, Paris, France (2010)