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The Compact Muon Solenoid Experiment

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CMS Hadron Forward Calorimeter Phase I Upgrade Status

Yasar Onel for the CMS Collaboration

Abstract

The Hadron Forward Calorimeter of CMS completed the Long Shutdown 1 part of the Phase I upgrade. Approximately 1800 photomultiplier tubes were replaced with thinner window, higher quantum efficiency, four-anode photomultiplier tubes. The new photomultiplier tubes will provide better light detection performance, a significantly reduced background and unique handles to recover the signal in the presence of background. The upgrade is also associated with new cabling and channel segmentation options. This report will describe the upgrade and the nature of the essential upgrade elements with supporting test results.

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CMS Hadron Forward Calorimeter Phase I Upgrade Status

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***Abstract*—The Hadron Forward Calorimeter of CMS completed the Long Shutdown 1 part of the Phase I upgrade. Approximately 1800 photomultiplier tubes were replaced with thinner window, higher quantum efficiency, four-anode photomultiplier tubes. The new photomultiplier tubes will provide better light detection performance, a significantly reduced background and unique handles to recover the signal in the presence of background. The upgrade is also associated with new cabling and channel segmentation options. This report will describe the upgrade and the nature of the essential upgrade elements with supporting test results.**

***Index Terms*—LHC, CMS, hadron calorimeter, photomultiplier tube, forward calorimetry, calorimeter upgrades**

I. Introduction

The Compact Muon Solenoid (CMS) [1] is a general-purpose detector designed to run at the highest luminosity provided by the CERN Large Hadron Collider (LHC). Coverage between pseudorapidities (η) of 3 and 5 is provided by the steel/quartz fiber Hadron Forward (HF) calorimeter which is located at 11.2 m from the interaction point. The signal in the HF calorimeter originates from Čerenkov light emitted in the quartz fibers, which is then channeled by the fibers to photomultipliers. The absorber structure is 1.65 m long with 1 mm square grooves. The diameter of the quartz fibers is 0.6 mm and they are placed 5 mm apart in a square grid. The quartz fibers run parallel to the beam line and have two different lengths (1.43 m and 1.65 m), which are inserted into grooves, creating two effective longitudinal samplings. The short fibers start 22 cm inside the absorber, hence are mostly sensitive to hadron interactions. There are 13 towers in η, and the ϕ segmentation of all towers is 10°, except for the highest-η. This leads to 900 towers and 1800 channels in the two HF calorimeter modules [2]. Details of the HF calorimeter design, together with test beam results and calibration methods, can be found in [3].

II. The Need for the Upgrade and the Key Components

The CMS HF calorimeter photomultiplier tubes (PMTs) generate a large, fake signal when the PMT window is traversed by a relativistic charged particle due to Čerenkov light production at the PMT window. The PMTs have circular windows with 2.54 cm diameter and 2 mm thickness at the center that gets thicker towards the rim (Hamamatsu R7525 [4]). This already-known problem was observed in the 2010 and 2011 CMS data to degrade data quality and to constitute a potential to interfere with rare physics events. An upgrade plan was therefore formulated for CMS HF. In this framework, several types of PMTs were tested and the Hamamatsu R7600U-200-M4 PMT with four anodes [4] was selected as the replacement PMT for the upgrade [5]. The upgrade PMT has a square window of size 1.8 cm x 1.8 cm and thickness less than 1 mm indicating a significant reduction in the amount of glass seen by the traversing relativistic particles hence is already promising in terms of background reduction. Furthermore, the new PMT not only reduces the intrinsic level of background, but it also enables tagging of background events and recovering the underlying signal event (if any) by using the multi-anode features. Figure 1 shows R7525 (left) and R7600U-200-M4 (right) PMTs (not to scale).

Fig. 1. Hamamatsu R7525 (left) and R7600U-200-M4 (right) PMTs (not to scale).

The key components of the upgrade include the base board and the adapter board, light guides, light sleeves and cabling inside the readout box, and the Winchester cables from the readout box to front-end electronics. Figure 2 shows a few of the key components.

A readout box (RBX) prototype was built to enable the tests of different readout options for the new four anode PMTs. The new readout boards provide the flexibility to switch between four- channel, two-channel and single-channel readout of the four anode PMTs where the four-channel readout option enables the full multi-anode functionality. Both the internal and external cabling of the RBX were also specific designs and selections, therefore form an integral part of the prototype. The

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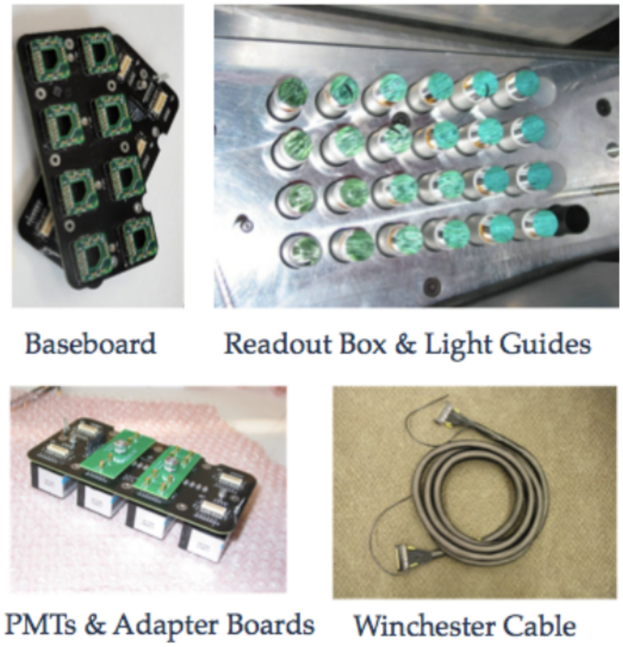

Fig. 2. Pictures of the base board, the readout box with light guides, PMTs and adapter boards, and the Winchester cable as examples of the key components of the upgrade.

prototype RBX was tested in the CERN H2 beam line [6] in Summer - Fall 2011 with electron and muon beams to mimic calorimeter and background responses respectively.

HF front-end and back-end electronics will be upgraded in order to support multi-channel readout of the R7600 PMT. The front-end electronics, named QIE10 (Charge Integrator and Encoder) [7], are radiation tolerant (up to 100 Gy) and include the addition of a TDC circuit. The TDC has a rising edge resolution of 390 to 780 ps (5 or 6 bits). This next generation QIE card has deadtimeless integration and digitization of charge in 25 ns buckets, large dynamic range (3 fC to 330 pC) stored in 17 bits, and has digitization error less than the calorimeter resolution (2-3%). This increased data will require a new pipeline, and the SLHC beam conditions will require a radiation hard solution. The GigaBit Transceiver (GBTx) technology will serialize data from the QIE10 cards and transmit the data to the back-end electronics in the counting room. 288 new GBT data-link fibers will allow for the addition of the TDC bits, including the presence of multiple rising or falling edges. Upgraded HF back-end electronics will replace the current VME based system and will be installed into an industrial-standard microTCA crate. This is the first step of the Phase I electronics upgrade for HF.

III. Upgrade Status

Nearly 1800 upgrade PMTs (R7600s) were tested at the University of Iowa photodetector testing facility. The system involved: 3 dark boxes, a VME and CAMAC data acquisition system, an XY scanner for surface linearity testing, 3 picoammeters, 3 digital oscilloscopes, UV and visible light power meters, UV and Blue LED light sources, 2 nitrogen lasers, DC tungsten light bulbs, optical tables for mounting optical elements in the dark boxes, picosecond LED pulsers and 1 double pulse generator.

Reusing as much existing readout box infrastructure as possible was a major design goal of the project, while still meeting all criteria for proper PMT operation. Another consideration was the flexibility to change the number of channels read out per PMT. This capability became part of the baseboard design. These design considerations were prototyped and tested in CMS in the fall of 2010 during collisions with great success.

A slice-test readout box was designed and prototyped to directly compare HF PMT and R7600 readout in a real collision environment. The slice test mixed 20 R7525s with 8 4-anode R7600 PMTs. This RBX was placed in HF at iPhi 67 and covered towers iEta 29 through iEta 32 in HF+. The R7600 placed at coordinate (iPhi 67, iEta 29) was blacked out so only Čerenkov light generated by MIP interactions would be recorded. Analysis of the collision data was consistent with test beam data, namely the mean energy of the MIP event reduced from 120 GeV to 35 GeV, and the rate was significantly lower.

New shields for the R7600 PMTs had to be manufactured, and the success of the pre-production prototype demonstrated that the design considerations are well understood.

The upgrade readout box was tested at the CERN H2 test beam facility [8]. The operation was very successful, with no abnormal signals and no significant issues. The results show that the performance characteristics are well understood, and the R7600 PMTs have a uniform response under different readout conditions (1, 2, or 4 anode readout). A major success was the negligible response of MIPs with the tagging algorithm. The efficiencies of the algorithms were quantified with 98% for 4-ch readout and 90% for 2-ch readout. The 4-channel readout option has more controlling power on background elimination and is an unprecedented readout segmentation in an operational calorimeter. The results are discussed in detail in [8].

Figure 3 shows the performance comparison of the 2- and 4-channel readout algorithms in tagging muon events.

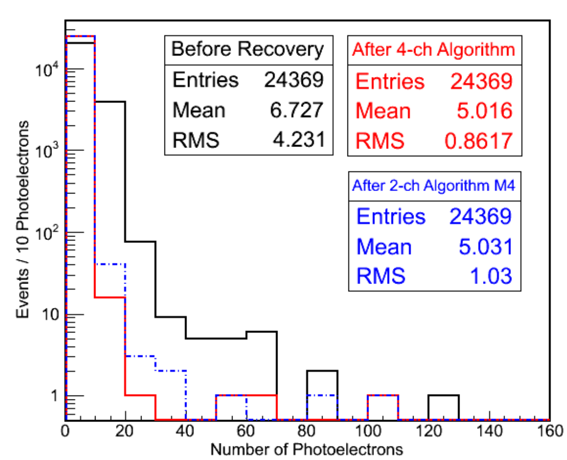

Fig. 3. Response of the PMTs to muons traversing their windows. The fraction of events higher than 30 photoelectrons ($\sim$ 7.5 GeV HF energy) is $\sim 5 \times 10^{-4}$.

IV. Summary

The HF Phase I upgrade is underway with complete readout and electronics components and readout options.

The multi-anode upgrade PMTs do not only reduce the rate of the background as a result of their physical specifications, but also enable the implementation of signal recovery algorithms pertaining to the multi-anode features. The design of the upgrade readout and adapter boards enables simple operation to switch between 1, 2 and 4-channel readout options. The new cabling significantly improves the space issues.

The front- and back-end electronics are developed to enable precision TDC for detailed signal shape information. The electronics is also associated with fast data links and is radiation hard.

All the upgrade components are selected to provide the Hadron Forward calorimeters operations in the upgrade era with the desired performance characteristics. The components are extensively tested and the upgrade concept is validated with several beam tests. Progression of the upgrade is on schedule towards commissioning and operation.

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