PROCEEDINGS OF SCIENCE

Commissioning Results of the CMS-HF Online Radiation Damage Monitoring System and Implications for Run III

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The CMS-HF calorimeter uses quartz fibers as active elements to measure the energy of the particles. Since the CMS-HF detector is in a high radiation area, radiation effects decrease the performance of the detector by gradually damaging the active elements. As a consequence, losing transparency in the fibers causes gradual change in the calibration of the detector. Hence, the change in the transparency has to be monitored during the collisions to make corrections in the energy calibration. The online radiation damage monitoring system does this by measuring the ratio of the direct and reflected light pulses in a long fiber in the detector. The existing system was upgraded and commissioned during the last months of the Run II period. In this presentation, the results of the commissioning will be shown and, using these results, the possible ways for the implementation of the system during Run III, especially the implications of the complex behavior of the quartz fibers, will be discussed.

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1. Introduction

Forward going particles (at $3 < \eta < 5$) produced in the LHC pp collisions may produce important discovery type events. Two HF detectors placed at each end of the CMS detector are designed to detect and measure the energies of such particles. Each of the CMS-HF detectors has a cylindrical shape and is 1.65 m long with an active radius of 1.4 m. The CMS-HF calorimeters are sampling calorimeters with plastic-clad quartz fibers as active elements. Two different length fibers are embedded in the iron absorber. The long (1.65 m) fibers are sensitive to both EM and hadronic showers and the short fibers to only hadronic showers. When the particles produced in the showers pass through the fibers, they produce Cherenkov radiation, which is carried by the same fibers to the PMTs attached to them with an air-core light-guide. Four anode PMTs are used in the HF detectors. Each pair of channels are ganged together to form a two-channel readout from a single PMT.

2. The New HF Online RADDAM Monitoring System

The intensity of the Cherenkov light coming through the fibers and shining on the PMTs is used to determine the energy of the particles passing through the fibers. The regular attenuation in the fibers is folded into the overall calibration done at the beginning. However, as the accumulated luminosity increases, the resulting radiation continues to damage the fibers. The fibers used in the CMS-HF detectors are extensively tested under different types of radiation [1, 2]. As the damage increases, the transparency of the fibers decreases causing higher attenuation of the light passing through and underestimating the energy of the corresponding particles. It is imperative to determine the radiation damage as a function of the accumulated luminosity and make corrections in the calibration accordingly.

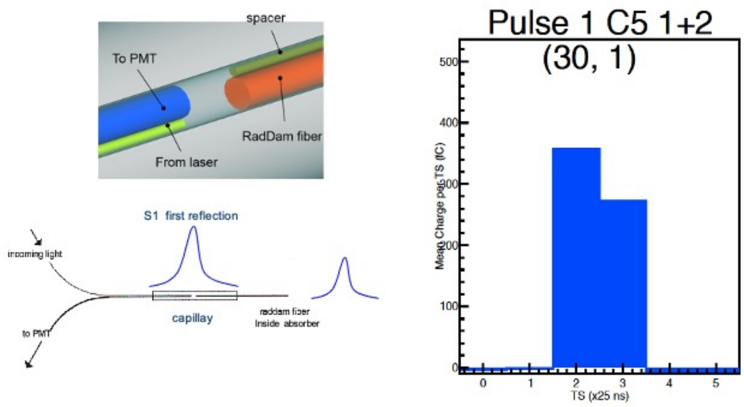

Figure 1: (Top-left) Sketch of the laser-light splitting scheme at the entrance to the raddam fiber. (Bottom-left) Part of the light reflects at the entrance and goes directly to the PMT (S1); the other part of the laser light goes into the raddam fiber and reflected from the other end and then goes to the PMT (S2) [3]. There is about 25 ns time difference between these two signals hitting the PMTs. (Right) An example for both signals in the QIE output; both signals are completely separated and S1 is in time slice 2 and S2 in time slice 3.

The HF Online RADDAM Monitoring System is designed to address this issue. 56 long fibers (similar to the long fibers used in the detector) are placed in seven eta rings of four wedges. The HF

Online RADDAM Monitoring system utilizes two light pulses to measure the loss of transparency in the fiber. A light pulse is split into two parts at the entrance of the long raddam fiber (Fig. 1-bottom-left). Part of the light is immediately reflected into the fiber attached to the PMT (direct pulse) and the other part continues into the raddam fiber. At the other end of the raddam fiber the light pulse (reflected pulse) is reflected back to the starting point to go into the same fiber attached to the PMT (Fig. 1-top-left). The light pulses shine on the same PMT separated in time by about 25 ns. The ratio of the signal produced by the second pulse to the first one is normalized by the same ratio at the beginning of the measurement period. The normalized ratio gives us the relative radiation damage with respect to the starting time.

Initially a 351 nm laser coupled to a wavelength shifting scintillator is used to provide the light pulse. The laser used in this setup was not very stable and had wider pulses producing wider PMT signals, wider than 25 ns. The goal is to place each signal into two adjacent time slices (TS) without any overlap between the PMT signals (Fig. 1-right). Each TS is 25 ns wide. In the new system, the laser with the accompanying optics are replaced with a PIN diode producing 450 nm and 5 ns wide light pulses. PIN diode output is twenty times brighter and much more stable than the old laser [4].

2.1 Commissioning of the new HF Online RADDAM Monitoring System

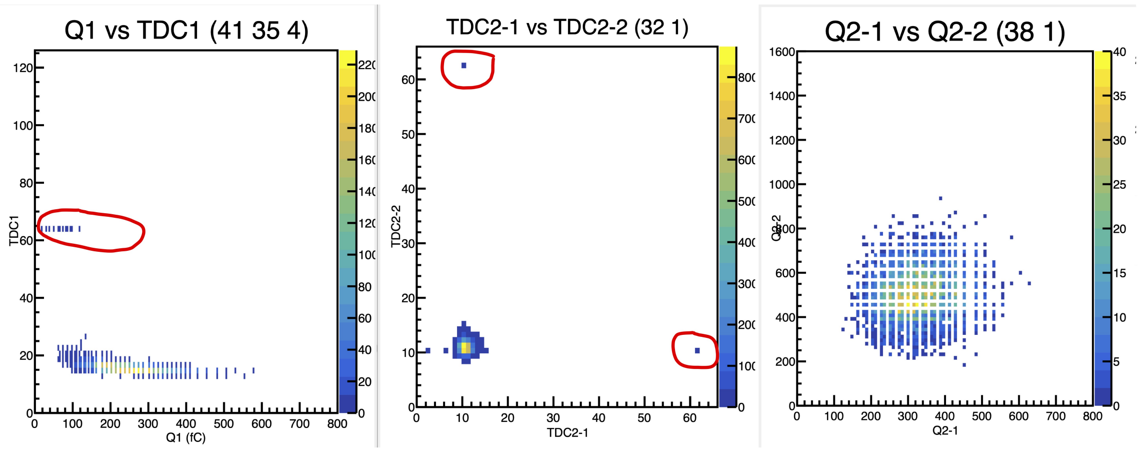

Figure 2: (Left) Cuts placed on the charge and timing signals. Some signals are low or just noise. These signals stay below the TDC threshold and give a time-out value (channel 63). These events are eliminated. (Middle) Two TDC channels should result in similar values. If one of them times out, these events are discarded also. However, if both channels time out these events are accepted. (Right) Charge values for both channels on the same PMT should agree with each other and show a distribution as seen in this 2-D histogram.

The new HF Online RADDAM System is commissioned at the end of the LHC Run II period. August 19, 2018 (day 0) was the starting date for the commissioning and the ratio obtained on this day is used to normalize all the other measurements taken. Then, the signal ratio (S2/S1) was calculated for all the 112 channels total in both detectors [5]. Timing and charge information were obtained through the two channels of the ADC and TDC for each PMT. The cuts placed on the first signal (S1) are for the events with one or two TDC timing out even though the corresponding total charge value for the signal is nonzero (Fig. 2-Left) and both channels are not timing out. Usually, the S1 signal is large enough to be above the TDC threshold and the timeouts are not that many, except in those cases when the splitting produces a much smaller direct pulse. On the other hand, the reflected pulse is usually smaller and sometimes both channels timeout. This is acceptable, since both channels have the same type of signal. However, due to stray muons in the vicinity of the PMTs, sometimes Cherenkov light is produced by a muon right in the PMT, producing a signal only in one of the channels; real signals produce comparable signals in both channels. Those events with one timeout in S2 are also discarded (Fig. 2-Middle). Charge distributions for the reflected signal show a wider distribution with comparable values on both channels (Fig. 2-Right).

3. Results

The signal charge ratios (Q2/Q1) are calculated by using the events surviving the cuts. Statistical uncertainties are very small. As mentioned above, the ratio for "day 0" is used as the reference value to normalize all the later ratios. Systematic uncertainties are estimated by comparing the earlier and later PIN diode delay sets (delay time), varying the TDC cut positions (TDC cuts) and the reference date to any other date (day 0). Combined systematic uncertainties due to delay time, TDC cuts and "day 0" are estimated to be less than half a percent. Since the statistical uncertainties are much smaller than this, the overall uncertainties are still less than 0.5%.

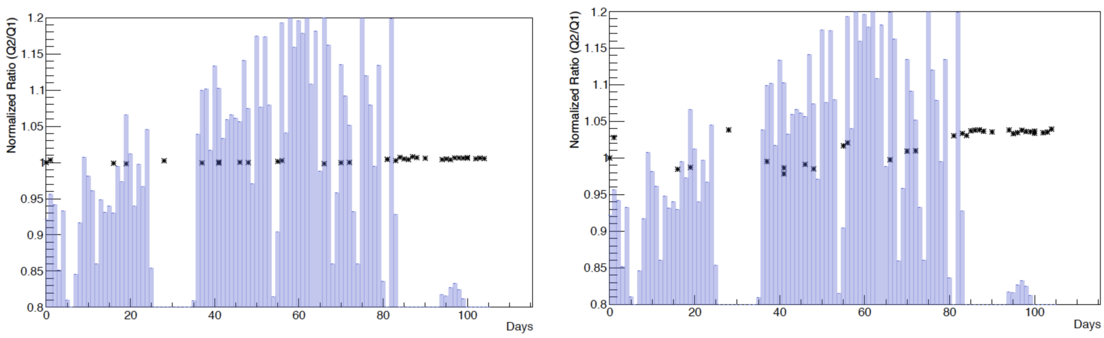

Figure 3: (Left) The normalized ratios for an HF tower (ieta = 30 and iphi = 21). There is not much fluctuation in the values. This tower is one of the furthest from the beam-line. (Right) The normalized ratios for an HF tower (ieta = 41 and iphi = 19). There is a significant amount of fluctuation in the values. This tower is one of the closest to the beam-line. Daily integrated luminosity values (maximum = 850 pb^{-1}) are overlaid in both plots. During the heavy ion collisions (around day 100), the accumulated luminosity is very low, comparable to the no-collision period. When the beam is off, fibers immediately start recovering, hence the rise in the ratios. Error bars seen in the plots are combined statistical and systematical uncertainties as explained in the text.

The radiation damage measured for the lowest η values (furthest away from the beam line) is very low (Fig. 3-Left). The results show very small fluctuations and one can see a flat trend in the results. On the other hand, the results for the highest η values (closest to the the beam line, hence higher radiation levels) display large fluctuations (Fig. 3-Right). For the higher η values, the radiation damage and the recovery are more pronounced. When the beam is off, of course, these fibers have more damage to recover and the recovery can be seen clearly. In fact, the fibers recovering immediately when the beam goes off, complicates the radiation damage measurement. To measure the actual radiation damage, data have to be taken either while the protons are colliding or as soon as the collisions stop. However, during the collisions, we have to take data only for the physics analysis. Hence, the radiation damage data have to be taken as soon as the collisons stop. This was not the case for most of the runs during the commissioning.

3.1 Fiber Recovery and the Future Plans

Quartz fibers used in the HF detectors show a rapid recovery as soon as the radiation falling onto them stops. This behaviour was studied in the test beams with protons [6]. Radiation damage measurements have to be carried out as close to the time the collisions stop as possible to determine the right value for radiation damage in the fibers. Otherwise the fibers will recover to some extent and the measured value will be lower than the actual damage.

The recovery proceeds exponentially; after the radiation stops falling on the fibers, they will recover significantly [2, 6]. During the commissioning runs, data were taken whenever it was convenient and mostly after the collisions stopped. This worked out fine for demonstrating that the system worked and the signals are well separated. However, for actual monitoring of the radiation damage, data have to be taken as soon as the collisions stop.

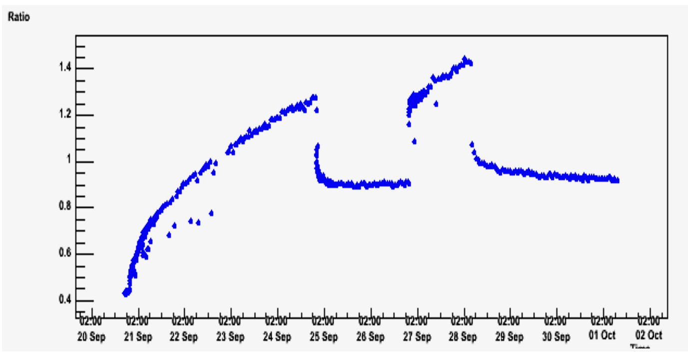

Figure 4: The inverse ratio of S1/S2 during an irradiation of the fibers used in the HF Calorimeters. The test beam measurement that produced this plot was done with protons. As the irradiation increases, the radiation damage also increases. However, when the irradiation stops, fibers recover exponentially but not completely. When the irradiation resumes, the inverse ratio goes back to the last highest value [6].

In the LHC beam structure there is a relatively long period of time when there are no collisions happening; so called "orbit" or "abort" gap. This time period is already being used to monitor the PMT calibrations. To reduce the amount of raddam data taken during this period an optimum PIN diode delay time should be determined and the PIN diode delay should be set to this value. Implementing this scheme is planned for the beginning of the Run III period as soon as the HF Online RADDAM Monitoring system is made sure to be compatible with the updates on the HF systems that are carried out during the LS2 period.

4. Conclusion

The new HF Online RADDAM Monitoring System is commissioned at the end of the Run II. The new system is shown to work as expected; separating the direct and reflected signals clearly in two successive time slices of the DAQ and providing additional timing and charge information to further clean the signals. It is also shown that the radiation damage can be measured reliably as long as the measurements are done very close to the collisions. The fibers close to the beam line show a much higher radiation damage compared to those furthest from the beam line. Consequently, these fibers at high η values display a higher amount of recovery. After reestablishing the operation of the new system and making sure that it is completely compatible with all the LS2 updates on the HF systems, it is planned to take data during the abort gap in between collisions, providing a real time measurement of the radiation damage in the fibers to make corrections and to compare with the estimates done with the collision data.

Acknowledgments

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