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# Silicon Photomultipliers for the CMS Hadron Calorimeter

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We present a plan for upgrading the CMS HCAL photodetectors with Silicon Photomultipliers (SIPM).

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## 1. Introduction

The CMS Hadron Calorimeter [1] is comprised of four distinct subdetectors: the Barrel (HB), the Endcap (HE), the Outer Barrel (HO), and the Forward (HF). The HB, HE, and HO subdetectors are scintillator sampling calorimeters with embedded wavelength shifting fibers (WLS) in scintillator tiles. The fibers from the sampling layers are ganged together to form towers whose light is detected by photo-sensors. The ganging is done in a unit called the Optical Decoding Unit (ODU) just before the photodetectors. The photo-sensors that are currently used are hybrid photodiodes (HPDs). Recently performance issues for HPDs exposed to mis-aligned magnetic fields have been detected. The HPD generates unexpected noise pulses. Additionally in recent years the SIPM has become a practical choice for photodetector. It has numerous advantages over the HPD (operating voltage 80 volts rather than 8KV; Gain of $5*10^4$ to $1*10^6$ rather than 1000 to 2000; insensitivity to applied magnetic fields; very compact size.) These features allow us to contemplate an improved HCAL that would have all HPDs replaced with SIPMs.

## 2. The Immediate Upgrade

We plan on two rounds of upgrades: an "immediate" upgrade that would take place in the next one-two years; and a longer term upgrade that would take place in about 4 years.

The immediate upgrade is to replace the HO HPDs with SIPMs [2]. To do this we have developed "drop-in" packages that would simply replace the existing HPDs. The HPD is a 19 pixel device (the central pixel) is unused in HCAL) with the pixels arranged in a hexagonal grid. Figure 1 shows an array of SIPMs arranged in the same grid pattern as the HPD pixels.

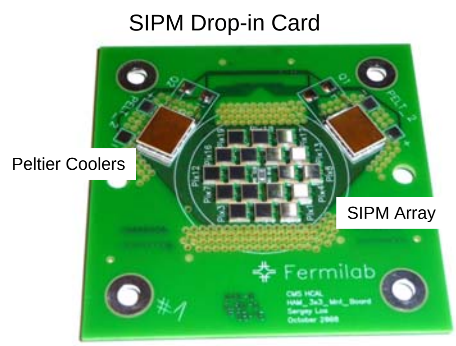


Figure 1. The SIMP "drop-in" card for the HO HPD replacement project.

The SIPM drop-in card has 18 3X3mm SIPMs that match the geometry of the HPD. The card also contains 2 Peltier coolers that are used to regulate the local temperature. In the center of the SIPM array we placed a RTD for temperature readout. The temperature measured is used in an software feedback loop that calculates and sends corrections to the drive voltage of the Peltier coolers. We have found that we can stabilize the temperature of the SIPMs to better than 0.2 $^{o}$C. One problem with SIPMs is the large temperature variation (from 4% to 8% $^{o}$C). Our temperature stabilization scheme eliminates this concern.

The SIPMs operate at bias voltages of 40-80 volts (depending on the type of SIPM). We generate the bias voltages locally, measure the leakage currents, and shape the signal for input into the flash ADC (QIE) [3]. These functions are done on an additional card stacked onto the SIPM Card.

We have installed 144 of the SIPMs into CMS HO in April and have operated them since. We installed 36 Zecotek 3X3mm SIPMs, each with 15K pixels/mm$^2$ and 108 Hamamatsu 3X3mm SPIMs with 400 pixels/ mm$^2$. As expected they have much better signal to noise than the HPDs they replace. Figure 3 shows the muon energy loss tail in the HO as measured by the SIPMs from a CMS full magnetic field test. As a comparison, Figure 4 shows the performance for HPDs to muons at a test beam.

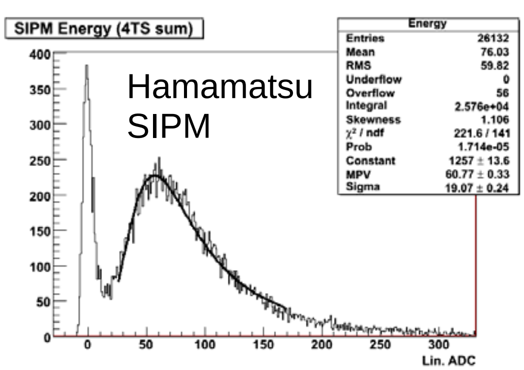


Figure 2. Muon response in a single tower of CMS HO from an SIPM.

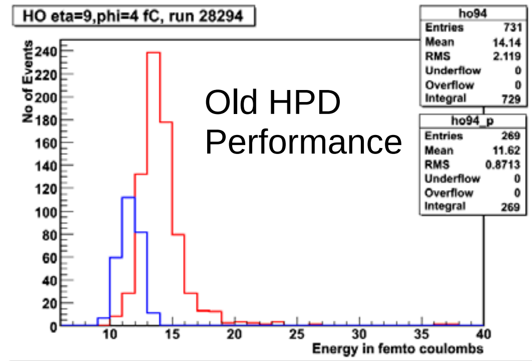


Figure 3. Testbeam response to muons for a HO tower read out by HPD. Blue is pedestal, red is signal. We see poor separation.

We plan on replacement of a large fraction (1000) of the HO channels with SIPMs at the end of the upcoming LHC run. This run will end approximately November 2010 after which we will begin the upgrade.

## 3. Longer Term Upgrade

We are developing plans for replacement of the central HCAL (HB and HE) HPDs with SIPMs. We will take advantage of the SIPM's very small size compared to the HPD to redefine the longitudinal depth segmentation of the HB and HE calorimeters. Instead of a single depth, we will develop a system with 4 depths. Physics motivations are discussed in reference [4]. This upgrade is expected to be installed around 2014 and to last through the end of the complete LHC and SLHC programs.

In the upgrade the ODU will be replaced with an EDU (Electrical Decoder Unit). In the EDU optical fibers are no longer ganged together to create calorimeter readout segments. Rather each fiber from the calorimeter tiles is read into a separate SIPM. (Approximately 100K total). Calorimeter readout segments are formed by electrically ganging the analog signals from the appropriate SIPMs together. Figure 4 shows details of the EDU concept.

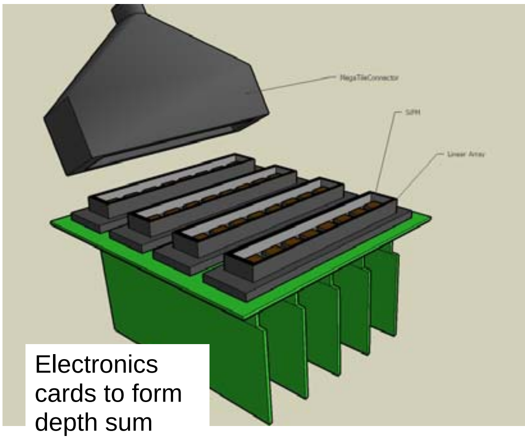


Figure 4. The EDU concept. Optical cables from the calorimeter tiles plug into arrays of SIPMs. Electrical summing of the analog signals is performed on daughter cards.

Figure 5 shows a candidate of the SIPM strip (18 individual SIPMs in a package that exactly mates to the existing HCAL optical cables.)

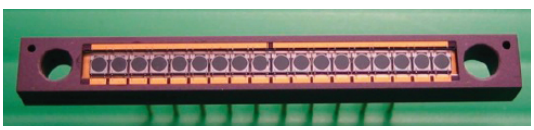

Figure 5 SIPM Array from Zecotek.

One of the most severe requirements for the HCAL upgrade is the radiation hardness issue. The SLHC will ultimately achieve instantaneous luminosities of $1\times10^{35}cm^{-2}s^{-1}$. The lifetime dose of high energy neutrons at the SIPM locations could approach 1E13 $n/cm^2$ and the SIPM needs to remain operational. We have begun a series of radiation tests of SIPMs from various vendors to measure their performance after irradiation [5]. In one test we exposed the SIPMs to 212 MeV protons and measured response to an LED pulse. We found that the relative response decreased after irradiation. Figure 5 shows a summary of performance for different vendors. We see that Zecotek SIPMs (labeled MAPD on this plot) suffers about a factor of 2 loss in pulse height after 1E13 $n/cm^2$.

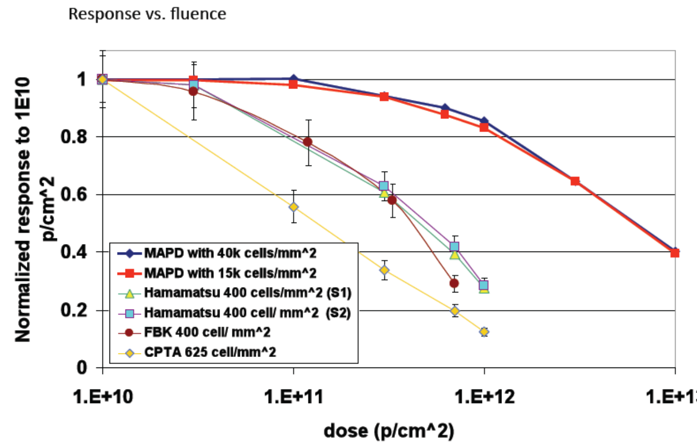


Figure 5. Relative response to LED pulse vs exposure to 212 MeV protons for various SIPMs.

## 4. Summary

We have an active program of upgrading the CMS HCAL with newly available SIPMs. We have already installed 144 SIPMs into HO and are currently operating them. They show promising results. We are developing a plan to replace the HB and HE HPDs with SIPMs to achieve lower noise performance and add depth segmentation.

## References

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