Upgrade of the CMS hadron outer calorimeter with SiPM’s

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Motivation

• The photo-sensors of the CMS outer hadronic calorimeter (HO) have had problems since their initial cosmic running with the full magnetic field.

• Because of these problems CMS has embarked on an effort to develop a “drop-in” replacement for the HPD sensors with SiPM sensors.

• This will bring the HO up to and exceed design sensitivity.

• This represents the first large scale application of SiPM sensors to accelerator based high energy physics.
The CMS detector

- **Inner tracker**
  - Silicon pixels
  - Silicon strips

- **3.8T Solenoid**

- **Electromagnetic Calorimeter**
  - 76k PbWO$_4$ crystals

- **Muon chambers**
  - Drift tubes/RPC in barrel
  - Cathode strip/RPC in endcaps
  - Covers $|\eta| < 2.4$

- **Hadronic Calorimeter**
  - Brass/scintillator/wls fiber
  - Iron/quartz fiber

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CMS calorimeters
The hadron outer calorimeter (HO)

- “Tail catcher” for the barrel calorimeter.
  - correct missing $E_T$ and jets particularly in Ring 0.
  - Could be used to identify muons as well.
• The fibers from a single projective tower of scintillator are routed using an optical decoder (ODU) and then illuminate a pixel of an HPD.
• The HPD signal is amplified and digitized using a charge-integrating ADC ASIC.
• Data is transmitted off the detector via optical fiber.
Proposed upgrade

- While the HPD works well in high magnetic field barrel, it is too sensitive for consistent, reliable operation in the less well determined fields of the return yoke.

- This lead to an effort to develop a “drop-in” replacement based on SiPM sensors.

- **SiPM advantages**
  - insensitive to magnetic fields
  - better signal to noise
  - eliminate 8kV HV supplies and maintenance
A SiPM sensor

- A SiPM consists of an array of tiny APD pixels, operating in Geiger mode with common readout.
- The pixels “count” photons.
  - signal $\propto \sum$ cells fired
- The sensor saturates as more photons hit more pixels.
- A hit pixel takes some time to recover to full sensitivity.
- Additionally
  - temperature sensitivity
  - radiation hardness
“Drop-in” replacement

- Using Hamamatsu 3mm x 3mm, 50 μm pitch, MPPC, we can mimic the layout of the HPD.
- These are coupled to the existing optical decoders and read out using the same ADC.
Control board

- Provides individual bias voltage to each sensor.
- Measurement of leakage current.
- Signal attenuation and shaping
- Peltier temperature controls.

| Control Board Parameter                          | Hamamatsu 3x3 mm |
|-------------------------------------------------|-------------------|
| Maximum DAC set BV                              | 100 V             |
| BV resolution                                   | 25 mV             |
| BV current limit (per diode)                    | 100 uA            |
| Maximum measurable leakage current              | 40 uA             |
| Leakage current resolution                      | 10 nA             |
| Diode grounding resistor                        | 4.99 kOhm         |
| Temperature resolution                          | 0.018 C           |
Putting it together

• The two board stack is assembled and inserted as a replacement for the HPD.
  ◦ A copper strap carries heat from the Peltier element to the water cooled sidewalls of the enclosure.
  ◦ Bias voltage, Peltier voltage and other settings are controlled via I²C.
### Installation

| Year | Events                                                                 |
|------|------------------------------------------------------------------------|
| 2011 | CMS made an initial installation during the spring of 2009, replacing ~10% of the HO HPD’s. |
| 2012 | This initial trial has been successful, and CMS is preparing to replace all of the HO HPD’s during the next long LHC shutdown, foreseen in 2013. |

#### Timeline

- **2011**: CMS made an initial installation during the spring of 2009, replacing ~10% of the HO HPD’s.
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**Extended to open endcaps**

**Short, 2 weeks**

**CMS**: FPIX fixes, PLT, tracker humidity controls, new beam pipe, HF PMT, HO SIPM

**LHC**: Collimator upgrade, Fix Splices, possible Linac4
Controlling it all

Bias voltage circuit

Capacitive coupling and leakage current monitoring

Set voltage from DAC

To ADC
Temperature control

• Control voltage on Peltier element and read back temperature.
  ◦ Under-temperature limit at 16°C.
  ◦ Feed-back possible to maintain a set temperature.
Capacitive coupling

- Because the ADC was specified for the HPD with an order of magnitude less gain, signals from the SiPM are coupled to the ADC via a 22 pF capacitor, reducing the gain by a factor of 16.
- Also decouples the large SiPM capacitance from the low input impedance of the ADC.
Performance

- Using data from test beams and from our initial trial installation, we can verify operational performance.
  - Muons in collision data and test beams to see the improved signal to noise.
  - Pions in test beams to look at “jet” reconstruction.
  - Also used to tune MC routines to simulate the detector performance.
Hadronic performance

- We can see the improvement in cleaning up the low tails of hadronic jets.
- This is particularly important for ring 0 where the barrel calorimeter is its thinnest.
Dynamic range

- Our arrangement allows us to illuminate roughly 2500 of the 3600 pixels per sensor.
  - Ring 1 is \(\sim 12 \text{ p.e./MIP} \Rightarrow\) full dynamic range of 200 MIPS.
  - Ring 0 has \(\sim 20 \text{ p.e./MIP}.\)
- This assumes no saturation of course.

- We have tested correcting saturation effects and believe we could do it to \(\sim 5000 \text{ p.e.}\).

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Summary

• CMS has developed a replacement photo transducer for its outer hadronic calorimeter based on SiPM sensor technology.

• We have been able to successfully develop a sensor package that can functionally replace the HPD sensors and exceed their performance.

• We have been able to show from test installations, beam and bench tests that the new sensors will exceed the requirements of the HO system.

• The full system is under construction and is scheduled to be installed during the LHC shutdown of 2013.