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

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

Inner tracker
Silicon pixels
Silicon strips

3.8T Solenoid

Electromagnetic Calorimeter
76k PbWO$_4$ crystals

Hadronic Calorimeter
Brass/scintillator/wls fiber
Iron/quartz fiber
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 $\propto \Sigma$ 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.

<table>
<thead>
<tr>
<th>Control Board Parameter</th>
<th>Hamamatsu 3x3 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum DAC set BV</td>
<td>100 V</td>
</tr>
<tr>
<td>BV resolution</td>
<td>25 mV</td>
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<tr>
<td>BV current limit (per diode)</td>
<td>100 uA</td>
</tr>
<tr>
<td>Maximum measurable leakage current</td>
<td>40 uA</td>
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<tr>
<td>Leakage current resolution</td>
<td>10 nA</td>
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<tr>
<td>Diode grounding resistor</td>
<td>4.99 kOhm</td>
</tr>
<tr>
<td>Temperature resolution</td>
<td>0.018 C</td>
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</tbody>
</table>
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

• **CMS made an initial installation during the spring of 2009, replacing ~10% of the HO HPD’s.**

• **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.**
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 ~12 p.e./MIP => full dynamic range of 200 MIPS.
  - Ring 0 has ~20 p.e./MIP.
- This assumes no saturation of course.

- We have tested correcting saturation effects and believe we could do it to ~5000 p.e.
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.