Upgrade of the CMS hadron outer calorimeter with SiPM's

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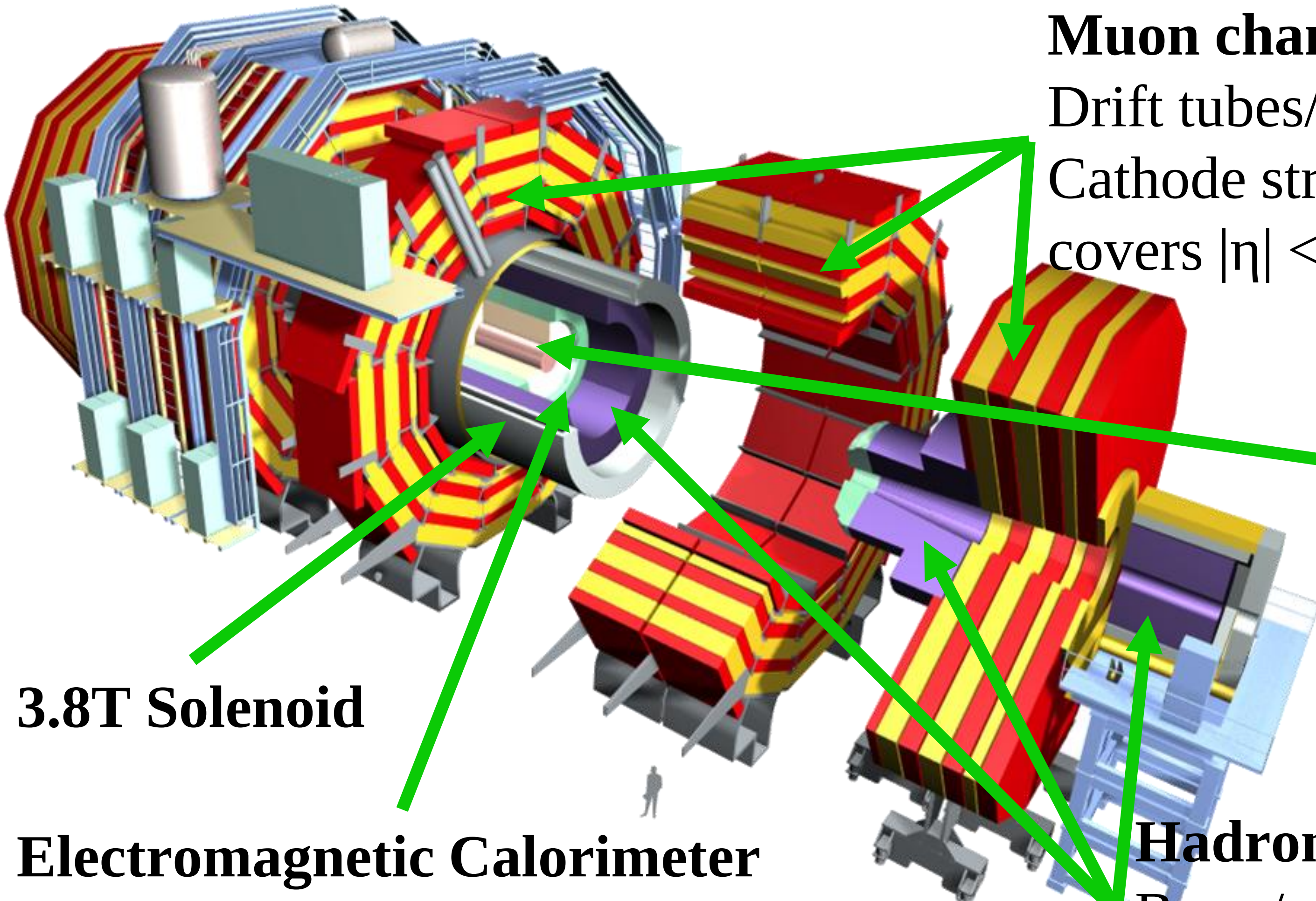
Fermilab

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 $|\eta| < 2.4$

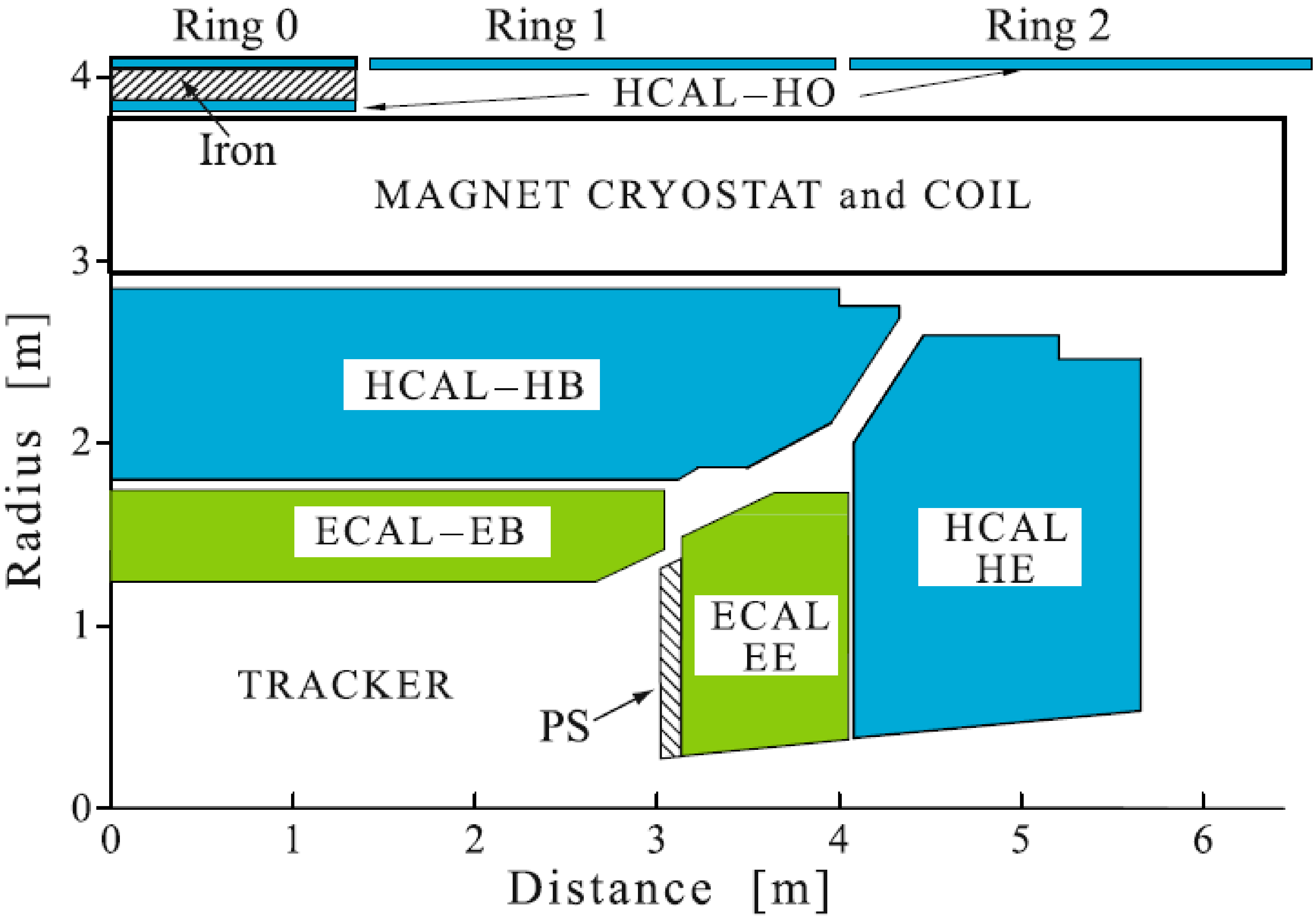
Inner tracker
Silicon pixels
Silicon strips

3.8T Solenoid

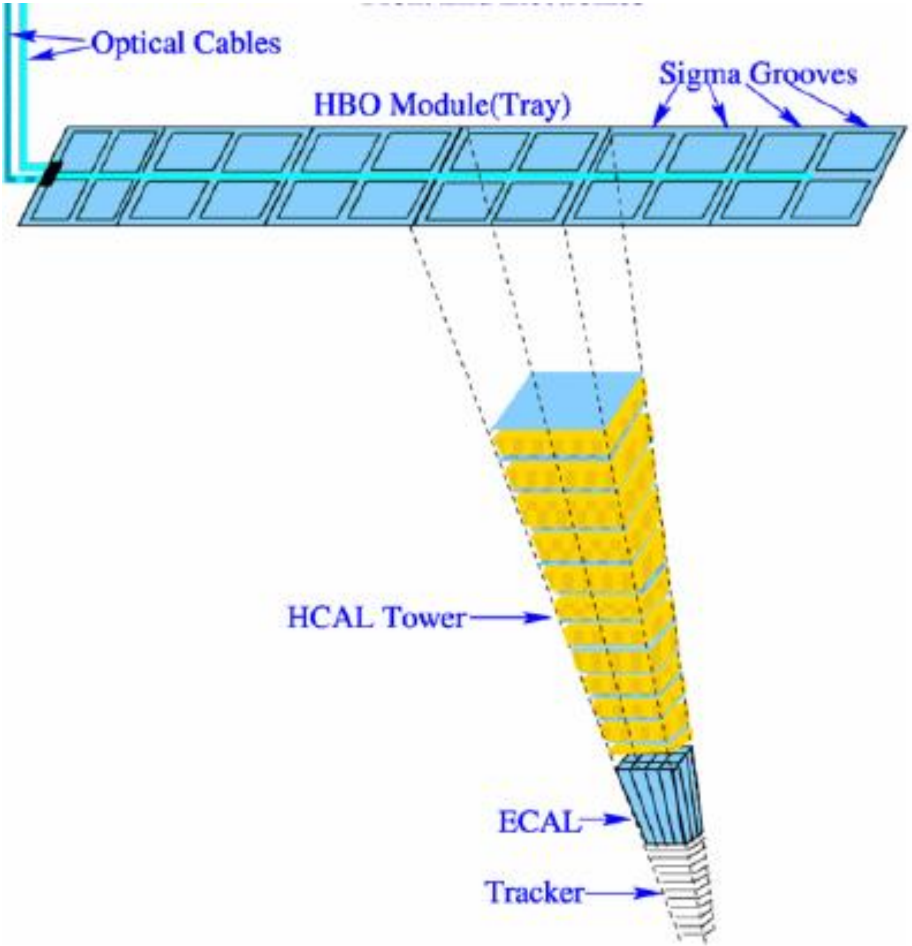
Electromagnetic Calorimeter
76k $PbWO_4$ crystals

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

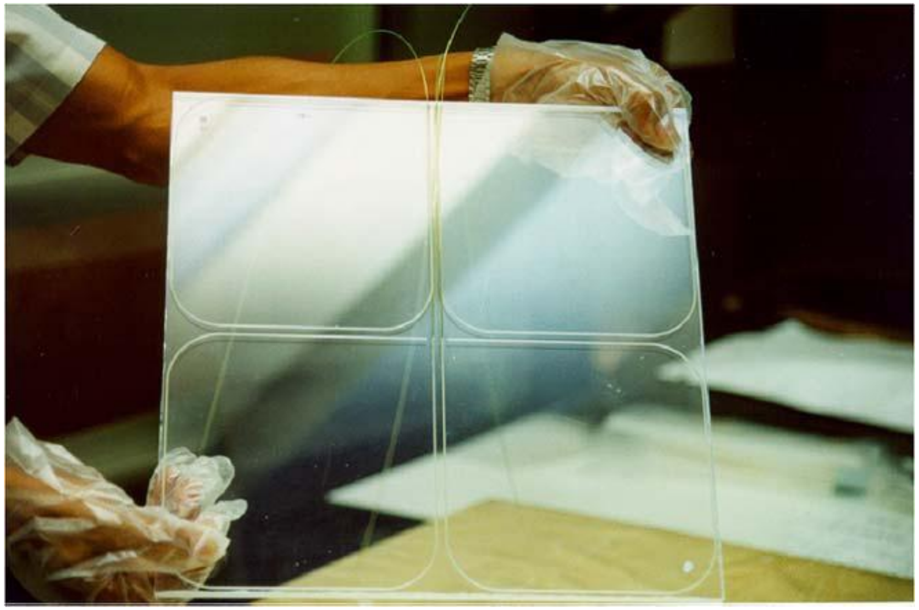
CMS calorimeters



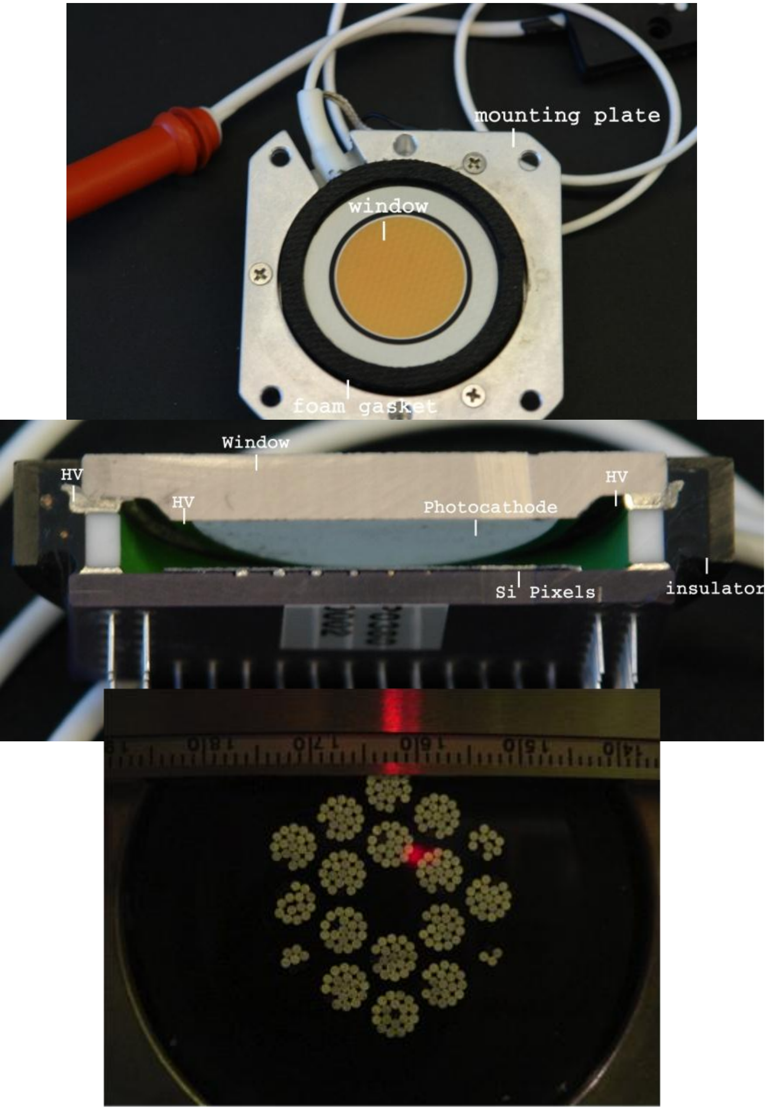
The hadron outer calorimeter (HO)



- "Tail catcher" for the barrel calorimeter.
  - correct missing E_T and jets particularly in Ring 0.
  - Could be used to identify muons as well.



HO front-end readout

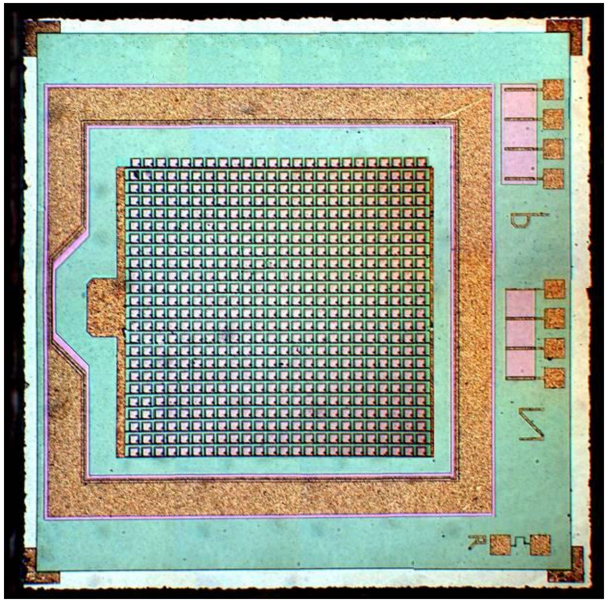


- The fibers from a single projective tower of scintillator are routed using an optical decoder (ODU) and then illuminate a pixel of an HPD.
- The HPD signal is amplified and digitized using a charge-integrating ADC ASIC.
- Data is transmitted off the detector via optical fiber.

Proposed upgrade

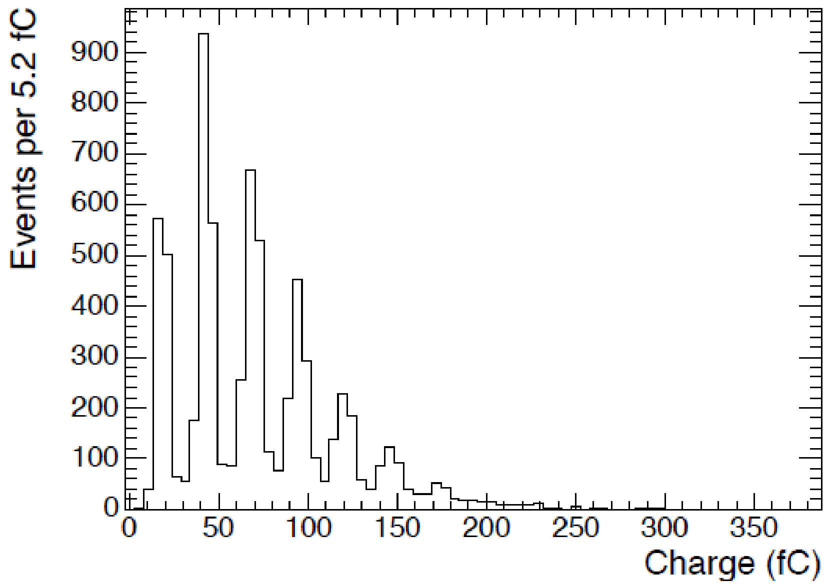
- While the HPD works well in high magnetic field barrel, it is too sensitive for consistent, reliable operation in the less well determined fields of the return yoke.
- This lead to an effort to develop a “drop-in” replacement based on SiPM sensors.

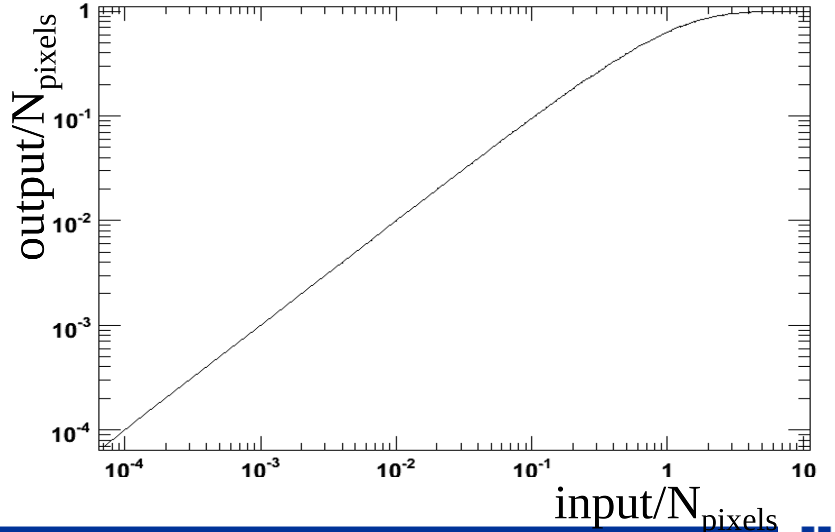
- SiPM advantages
  - insensitive to magnetic fields
  - better signal to noise
  - eliminate 8kV HV supplies and maintenance



A SiPM sensor

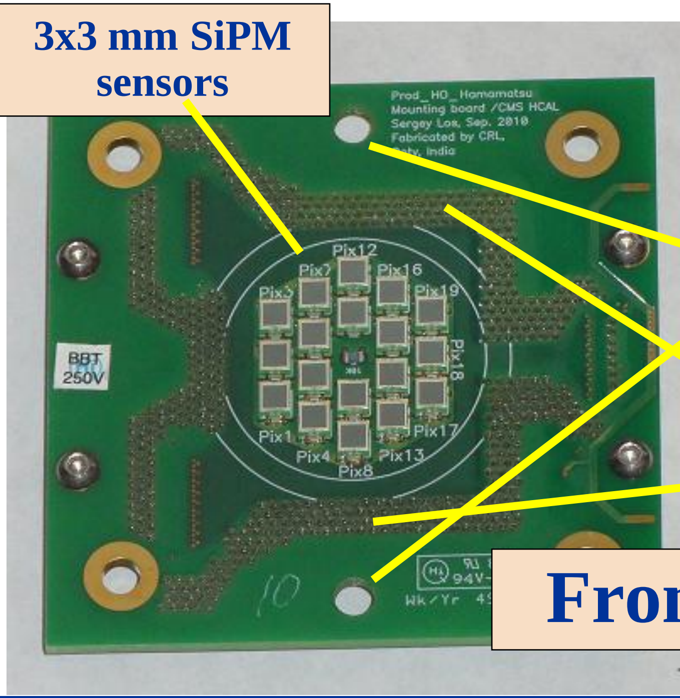
- A SiPM consists of an array of tiny APD pixels, operating in Geiger mode with common readout.
- The pixels “count” photons.
  - signal $\propto \Sigma$ cells fired
- The sensor saturates as more photons hit more pixels.
- A hit pixel takes some time to recover to full sensitivity.
- Additionally
 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

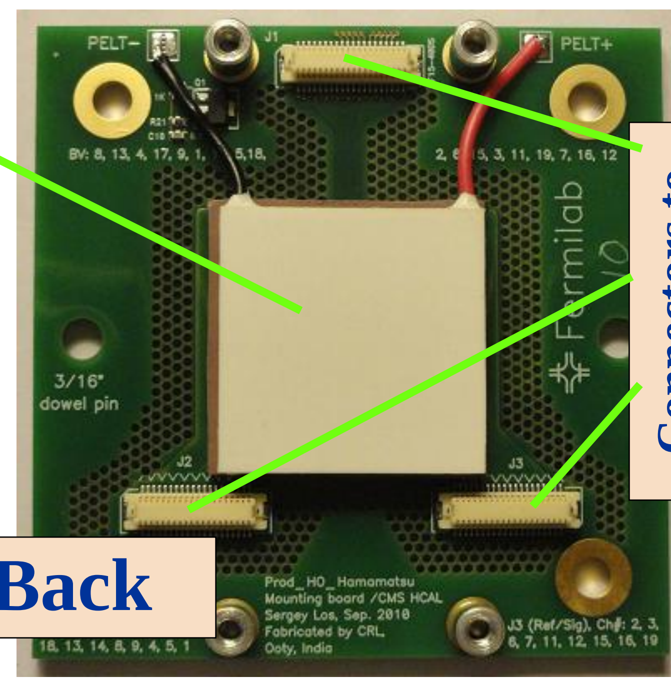




“Drop-in” replacement

- 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.

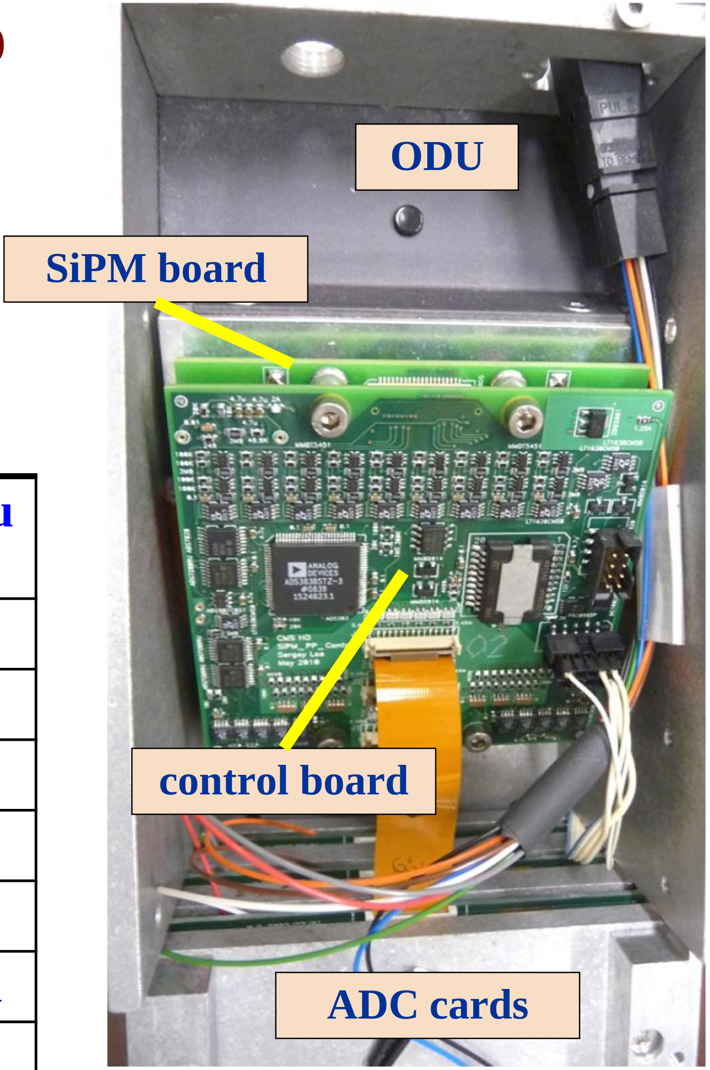




Control board

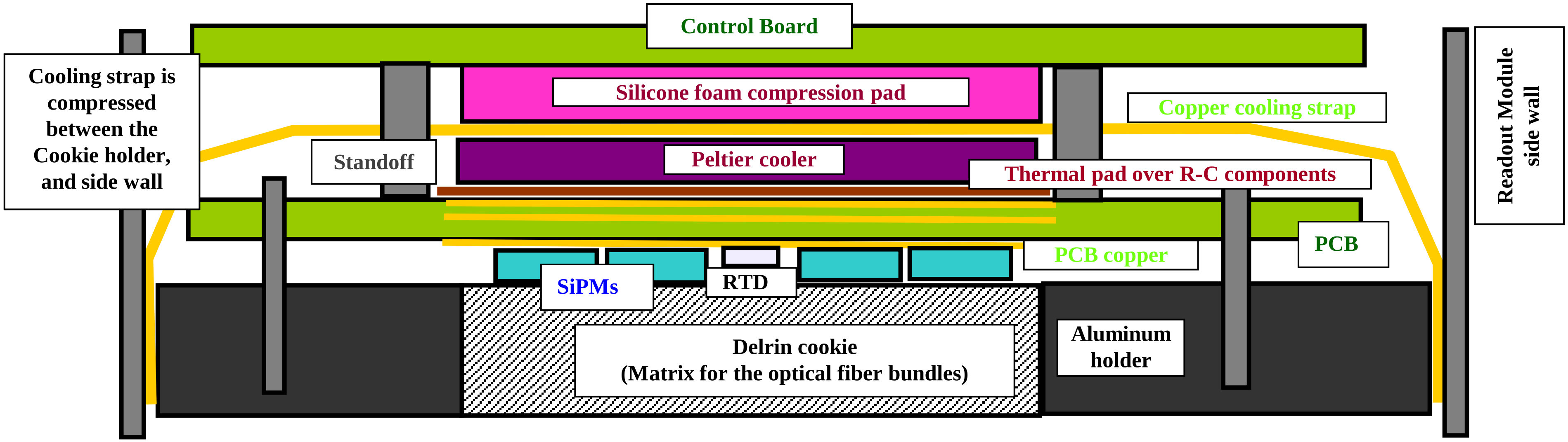
- Provides individual bias voltage to each sensor.
- Measurement of leakage current.
- Signal attenuation and shaping
- Peltier temperature controls.

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

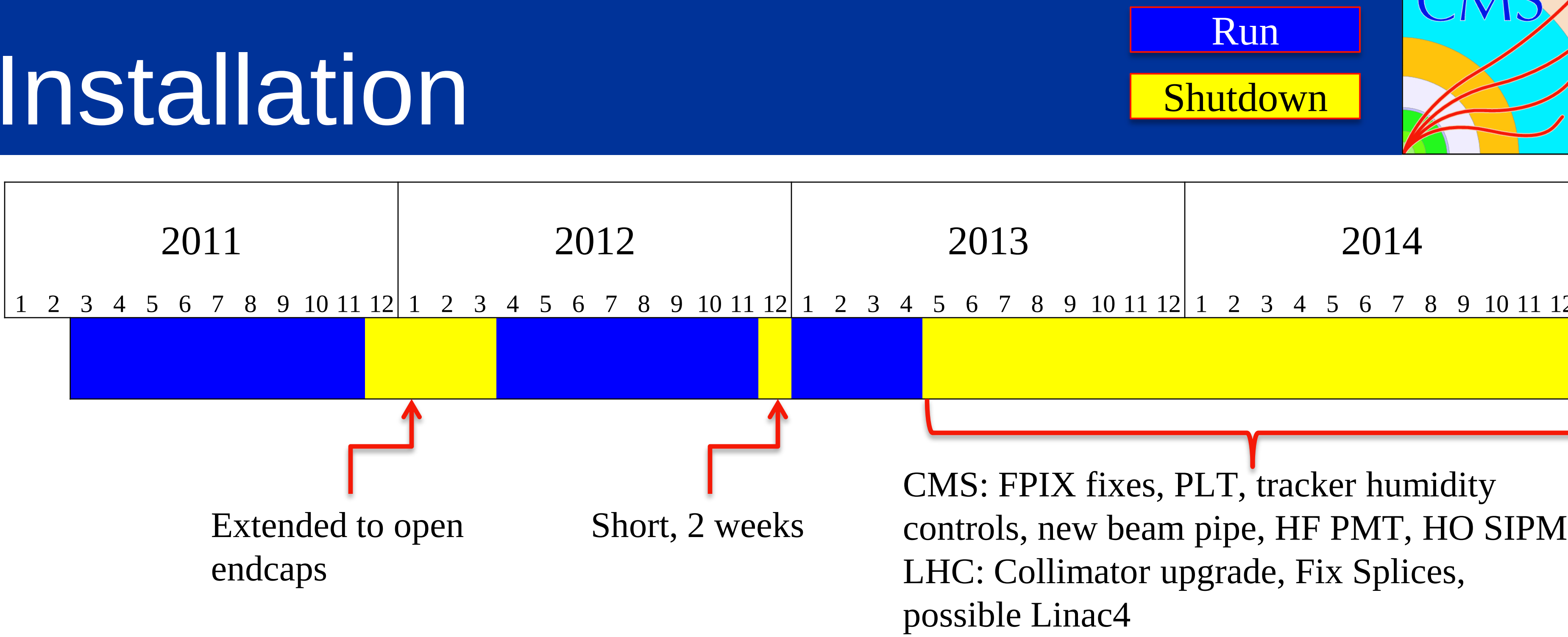


Putting it together

- 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 I^2C.



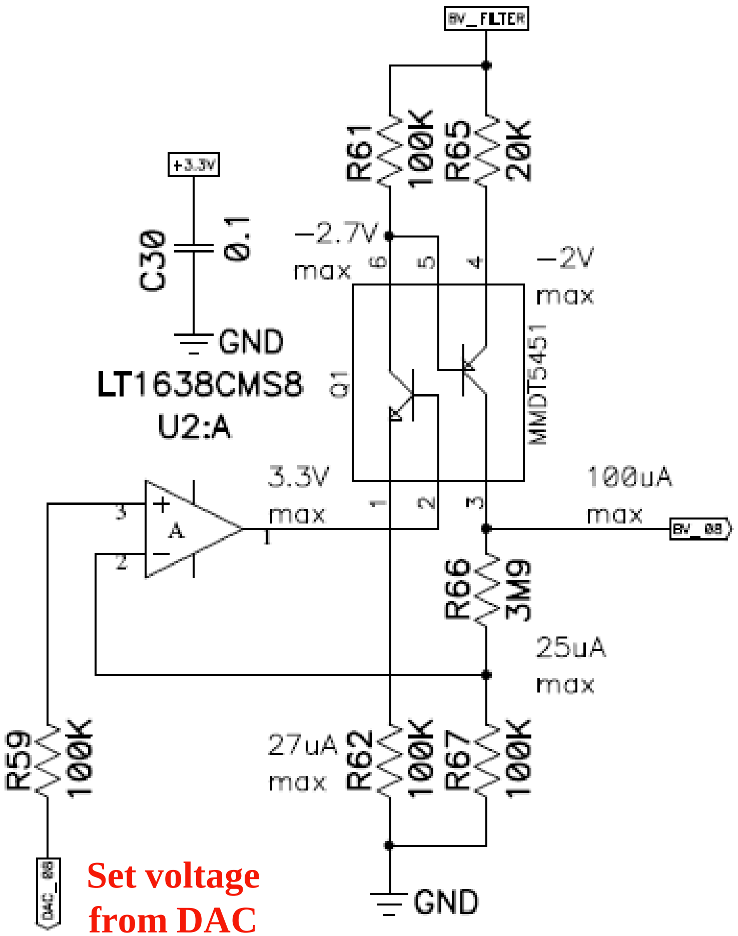
Installation



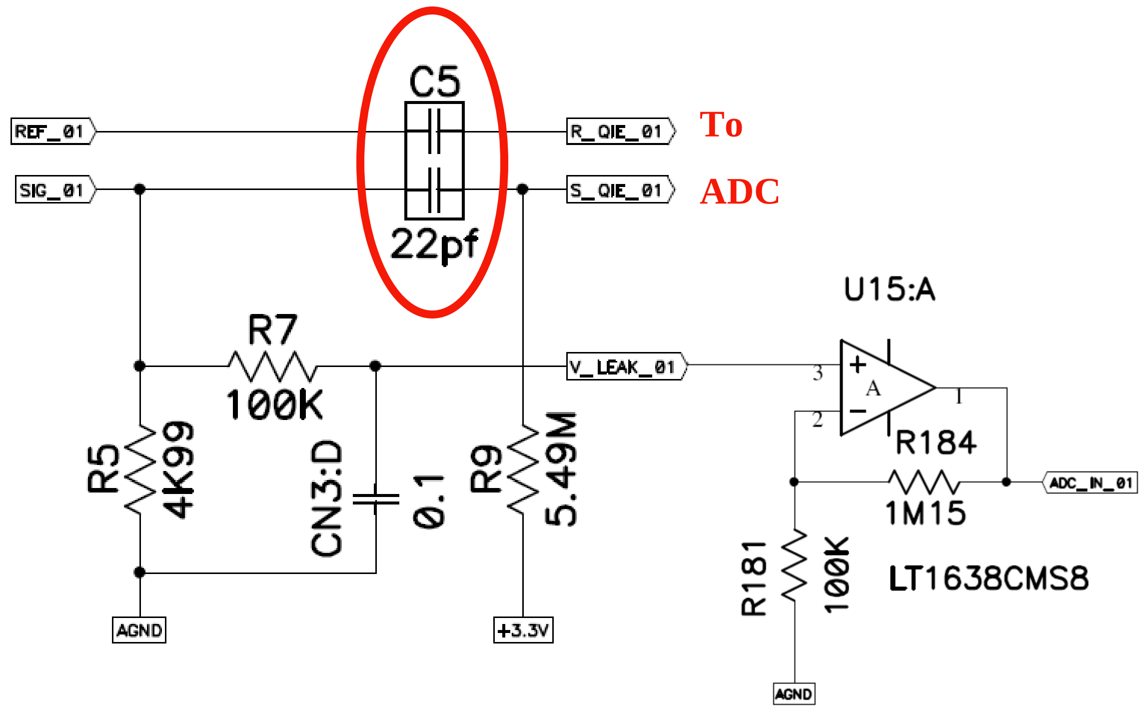
- CMS made an initial installation during the spring of 2009, replacing ~10% of the HO HPD's.
- This initial trial has been successful, and CMS is preparing to replace all of the HO HPD's during the next long LHC shutdown, foreseen in 2013.

Controlling it all

Bias voltage circuit

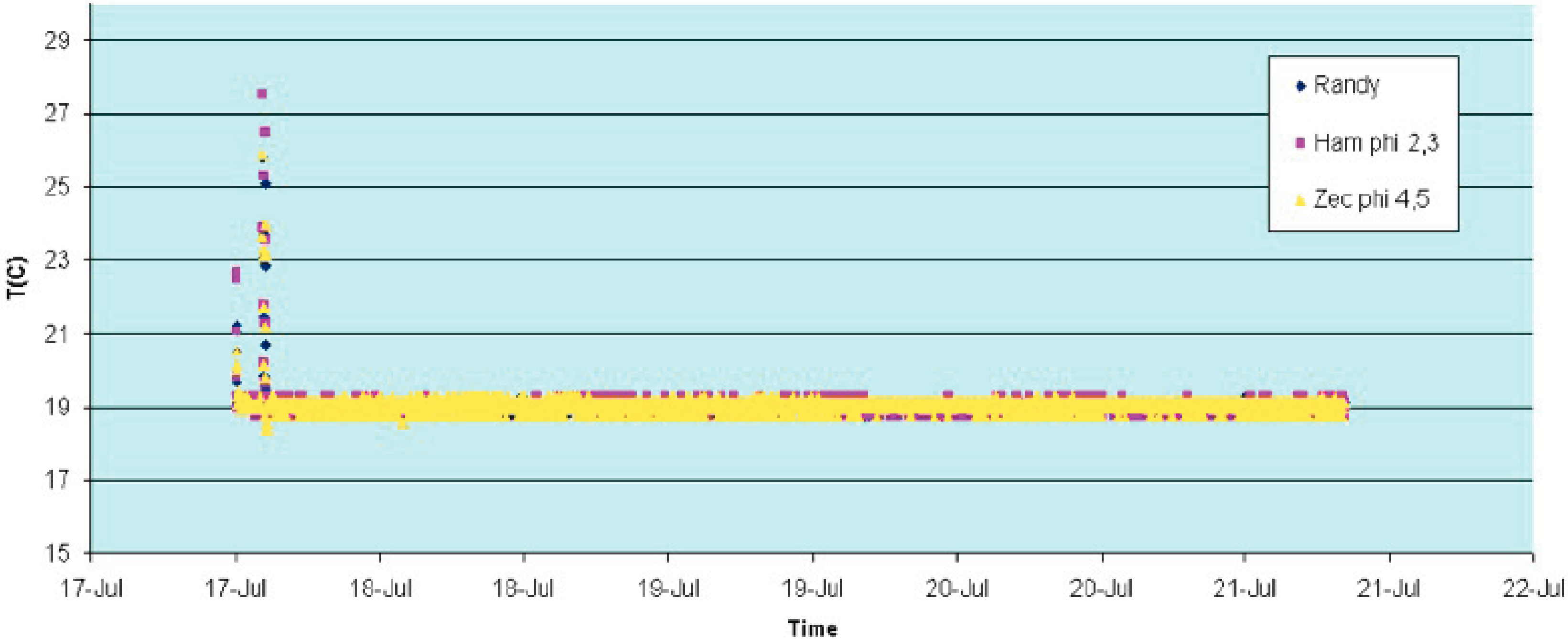


Capacitive coupling and leakage current monitoring



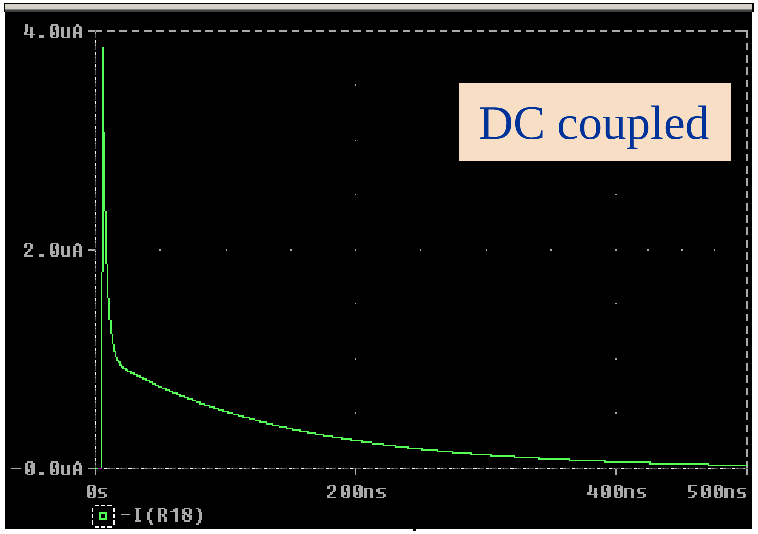
Temperature control

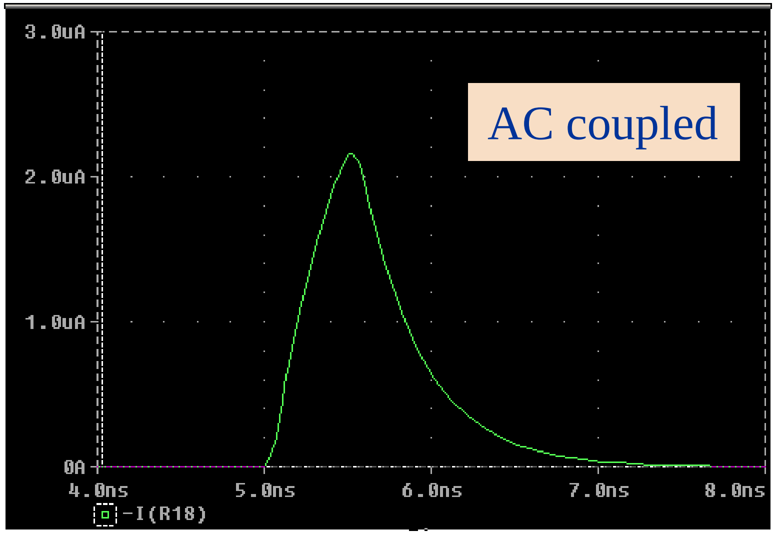
- Control voltage on Peltier element and read back temperature.
  - Under-temperature limit at 16° C.
  - Feed-back possible to maintain a set temperature.



Capacitive coupling

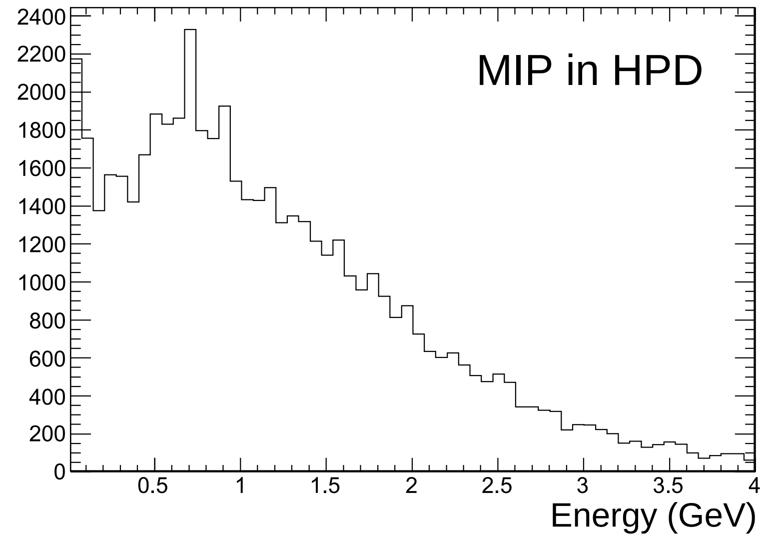
- Because the ADC was specified for the HPD with an order of magnitude less gain, signals from the SiPM are coupled to the ADC via a 22 pF capacitor, reducing the gain by a factor of 16.
- Also decouples the large SiPM capacitance from the low input impedance of the ADC.

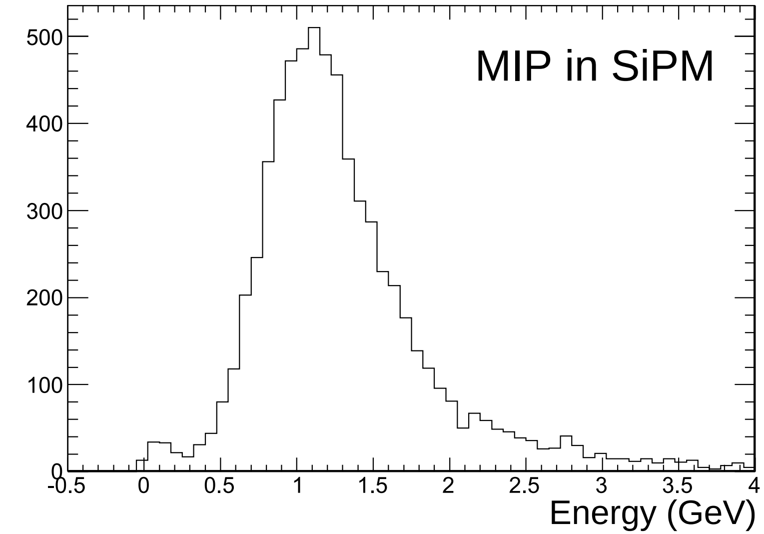




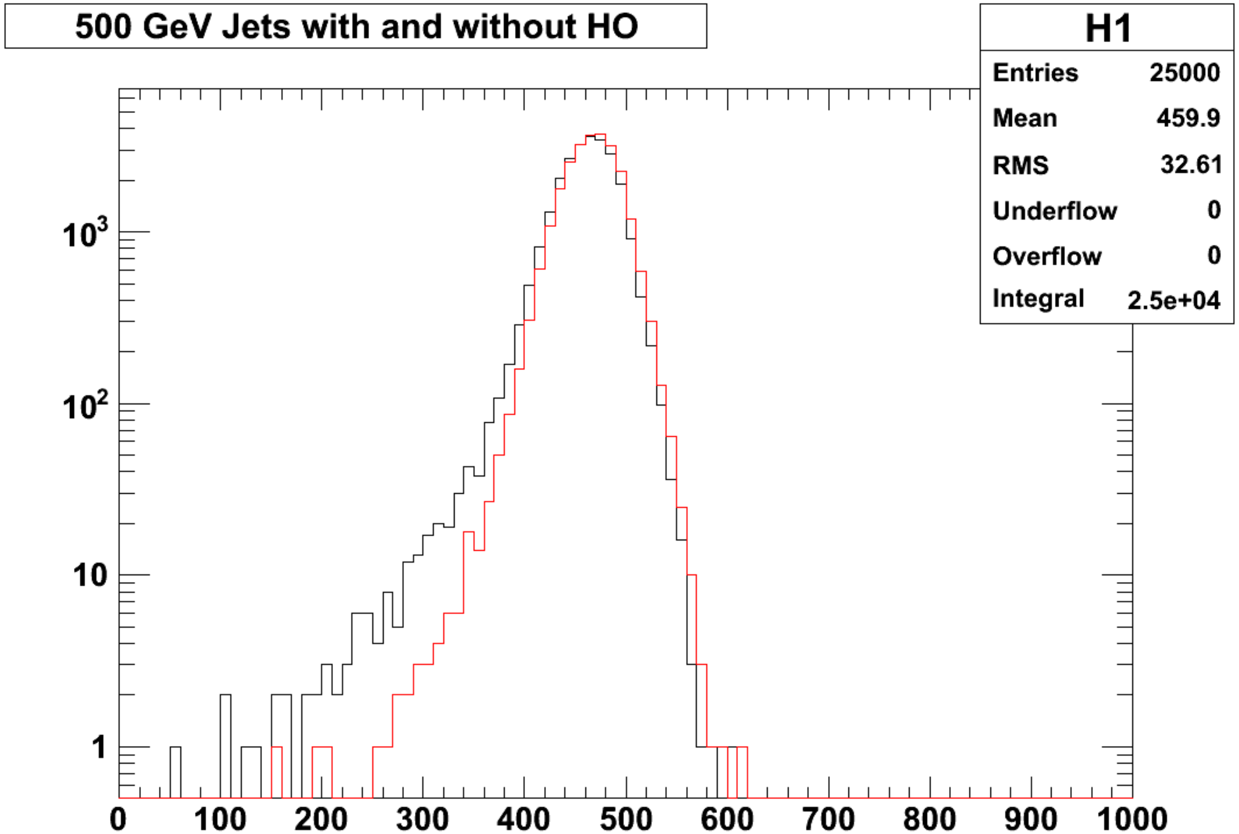
Performance

- 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.





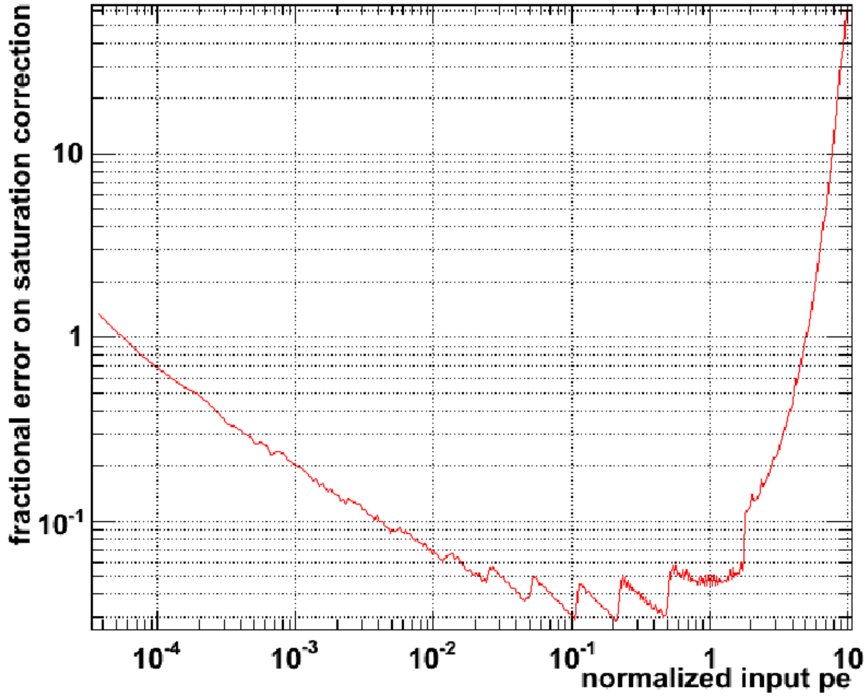
Hadronic performance



- 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.