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The Compact Muon Solenoid Experiment

CMS Performance Note

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The CMS Outer HCAL SiPM Upgrade

CMS collaboration

Abstract

The CMS Outer Hadron Calorimeter (HO) is the first large scale hadron collider detector to use SiPMs. By late January 2014 the installation of 1656 of 2376 channels was completed. The HO readout system provides for active temperature stabilisation of the SiPMs to less than 0.1°C using Peltier coolers, temperature measurement, and software feedback. Each channel has independently controlled bias voltage with a resolution of 25mV. Each SiPM is read out by 40MHz QIE ADCs. We report on the system design, schedule and progress. The next phase for the detector is commissioning during 2014 before the 2015 LHC run. We report on the status of commissioning and plans for operation. We discuss the calibration strategy with local cosmic ray runs using the HO's self trigger ability.

The CMS Outer HCAL SiPM Upgrade

the CMS collaboration

April 15, 2014

Talk items:

- Presentation of the CMS Hadronic Outer (HO) Calorimeter.
- Commissioning steps and calibration possibilities of freshly installed front-end readout electronics – SiPMs.
- Installation verification and first approach calibration of HO with cosmic muons using HO self-triggered local runs.

HO Front End Readout – Upgrade

HO used HPDs to detect the scintillation light as all HCAL, but they are not optimal for the HO conditions:

- Problems with running in fringe field of the CMS magnet
- Low gain and photo detection efficiency
- Ageing

Because of these problems CMS has decided to replace the HPD sensors with Silicon Photo Multiplier (SiPM) sensors.

Figure : Hybrid Photo Diode (HPD)

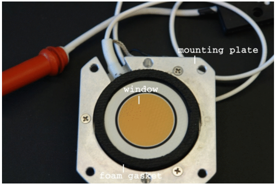
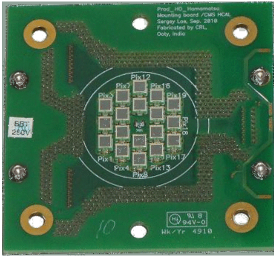
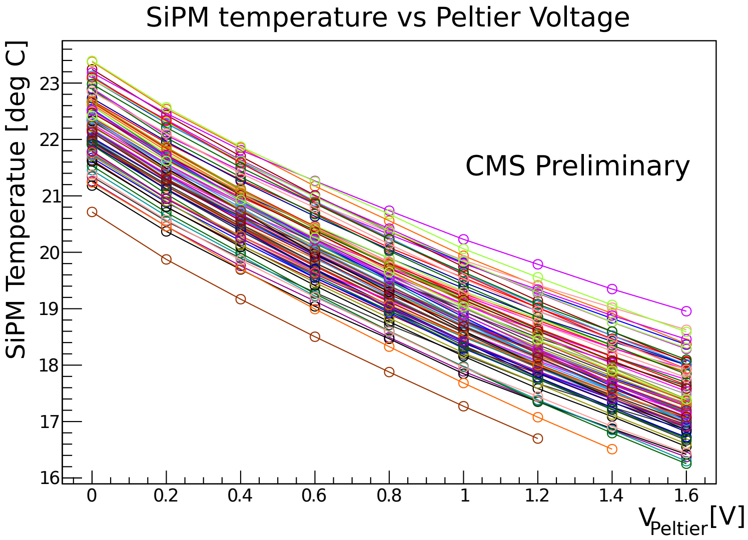


Figure : SiPM mounting board



Peltier Voltage optimisation:



Peltier Voltage optimisation:

- The SiPM temperature is controlled by a Peltier element
- Peltier voltage ranges from 0 to 2.3V
- Working point is selected at 0.3V to lower power consumption, rather than same temperature for all SiPMs.
- All SiPMS operate at own temperature

HO Layout

- HO is located in all 5 barrel wheels of CMS and is split in **30** $i\eta$ **sections** along the Z-axis (beam-pipe).
- In the transverse plane HO consists of 12 sectors à 6 trays and is split thereby in **72** $i\phi$ **sections**.
- Each $i\eta - i\phi$ tile is read-out by a separate channels making 2160 physical channels.
- In addition, some readout modules [RM] have several "dark" channels for noise measurements and calibration.

$\Rightarrow$ **Each of the 2376 channels has to be tested.**

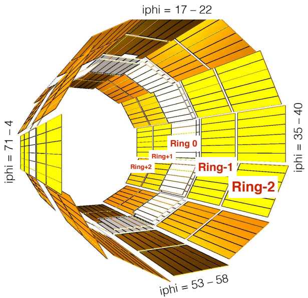
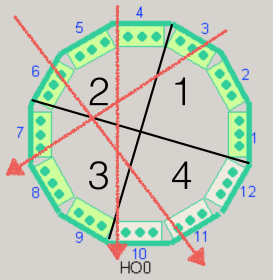


Figure : Layout of all the HO trays in the overall CMS detector

Cosmic muons with HO

Cosmics analysis motivation:

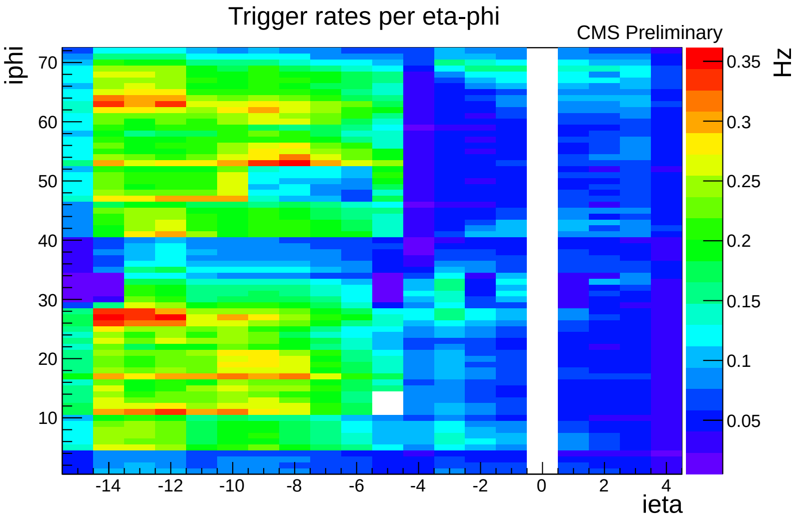
- Validation: verify the correct cabeling in eta-phi map
- Calibration: extract MIP values for all channels



Trigger setup – HO only!

- Each wheel is divided in 4 quadrants
- Trigger threshold 40 fC per 1 TS
- Coincidence between any top sector (1,2) with any bottom sector (3,4)
- 1 TimeSlice (25 ns) delay for top sectors

Trigger rates map



Trigger rates map

- Plot shows trigger rate for each individual channel
- CMS not in closed position: big gap between YB0 and YB-1,2
- Higher rate observed in horizontal tiles (iphi = 15-25, 55-65) in the wheels under shaft (YB-1,2)
- Rate spikes mainly due to scintillator tile size, which varies.
  - ieta [-15,-11] corresponds to YB-2
  - ieta [-10,-5] corresponds to YB-1
  - White spot at ieta -5 corresponds to magnet chimney (no HO scintillator tiles)
  - ieta [-4,-1],[+1,+4] corresponds to YB0
  - ieta = 0 is not a physical gap, but doens't exist in electronics
  - ieta [+5,+15] was not instrumented at data taking

SiPM Noise

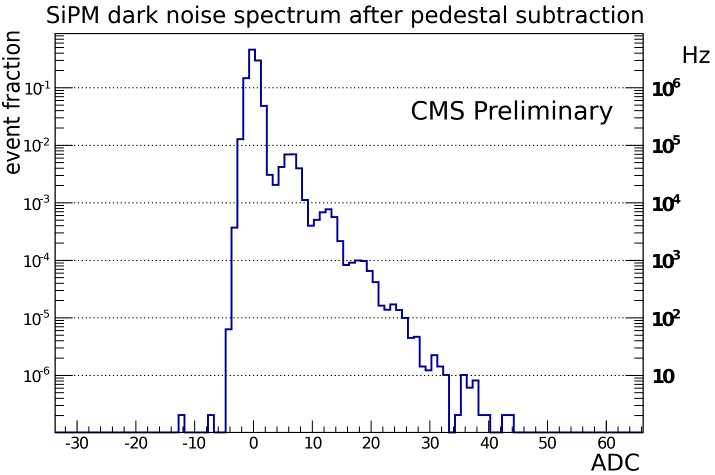


Figure : SiPM noise rates

SiPM Noise

- Signal is summed up for 4 time slices (100ns) and measured in ADC counts.
- First peak corresponds to pedestal
- Following peaks are single photo electron (SPE) peaks corresponding to single pixels fired
- Plot can be used to estimate the random coincidence rate:

$$f = p^2 \frac{N-1}{100ns}$$

where p is the probability for the channel to fire at the given threshold and N the number of channels.

MIP extraction

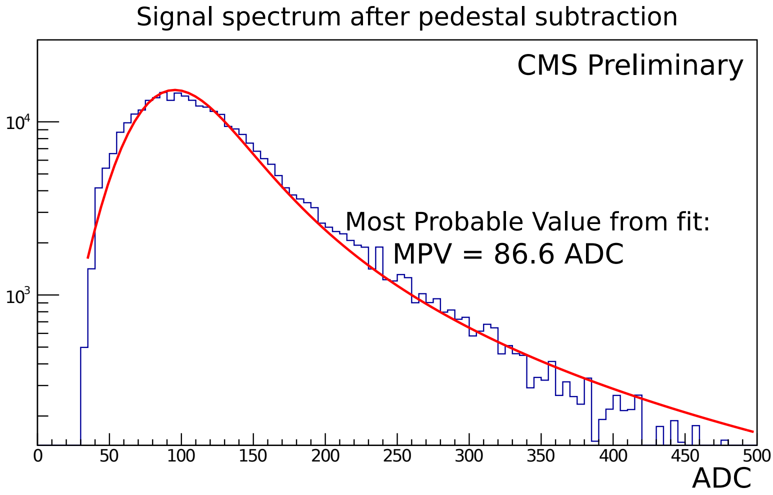


Figure : Single channel signal spectrum with coincidence trigger

MIP extraction

- Signal is summed up for 4 time slices (100ns) and measured in ADC counts.
- Data taken with coincidence trigger
- Muon MIP value is the Most Probable Value (MPV) of a Landau-Gauss convoluted fit of the signal distribution.
- In case of noise contamination the noise tail is also fitted (with an exponent)

MPV map

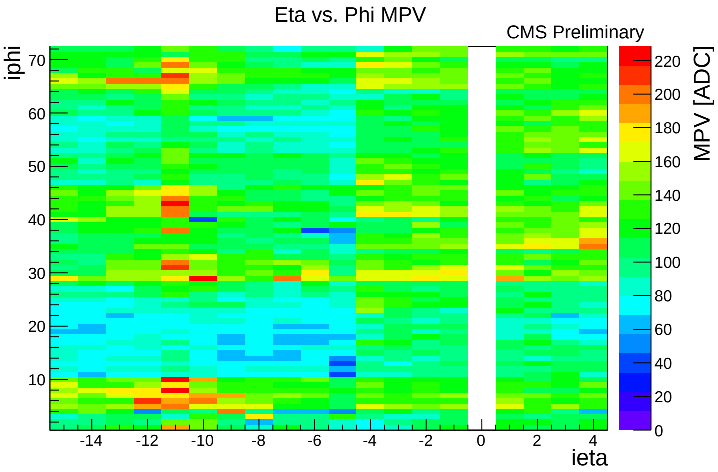


Figure : MPV value of each channel

MPV map

- MPV value of signal fit for each channel plotted
- MPV values won't be uniform because of several factors:
  - YB-1,2/YB0 have 1/2 scintillator layer/s
  - Scintillator tiles have different sizes $\rightarrow$ light collection efficiency varies
  - Fibres connecting SiPMs and tiles vary in length. Readout is located in gap between YB-1/2 and on +/- sides of YB0. ieta = -11 is the nearest to the YB-2 readout and has the shortest fibres in whole HO.
  - iphi variation because of sector alignment and cosmic ray muon track path-length (track vs. tile angle):
    lowest MPVs measured at top and bottom tiles

Muon track angle correction

Problem

- Muon signal gets altered because of different track lengths in tile.
- MIP distribution gets shifted.
- Signal has to be corrected by the cosine of the muon track incidence angle.

Solution

- Each event the muon track is build for the two tiles with highest signal.
- Cos(track,tile) is computed and the signal values of the two tiles are corrected.

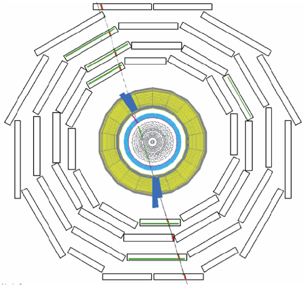


Figure : Muon track through CMS

Muon track angle correction

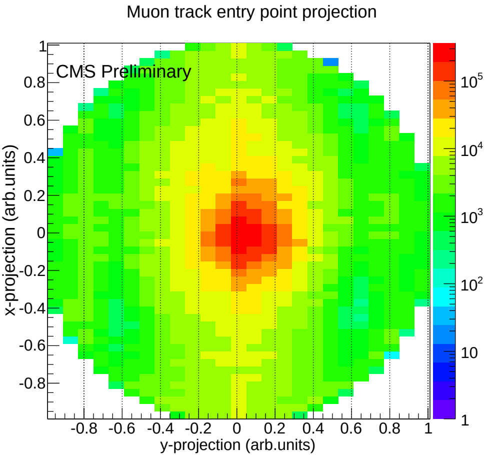
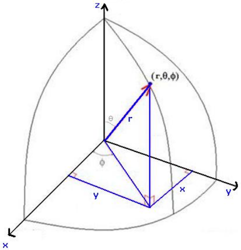


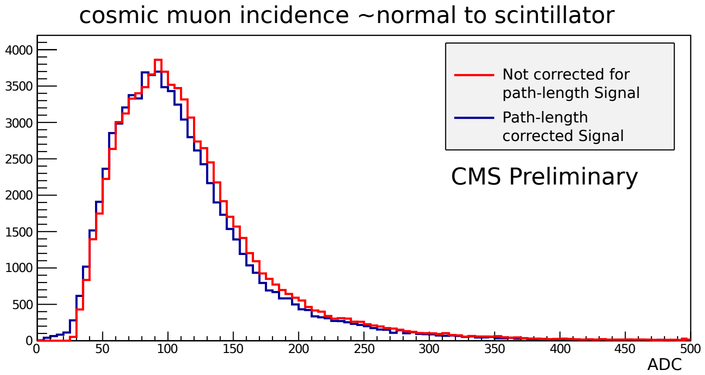
Figure : HO muon entry point distribution is shifted because of shaft.

Muon track angle (path length) correction



- Muon track is constructed from HO hits only
- x and y are coordinates of the muon track vector projection on the horizontal plane
- x,y $= 0$ corresponds to a vertical muon
- Shift in y is due to shaft (flux from $\mathrm{y} > 0$ increased)
- $|\mathrm{y}| < 0.4$ marks HO wheels acceptance (barrel, no endcaps)

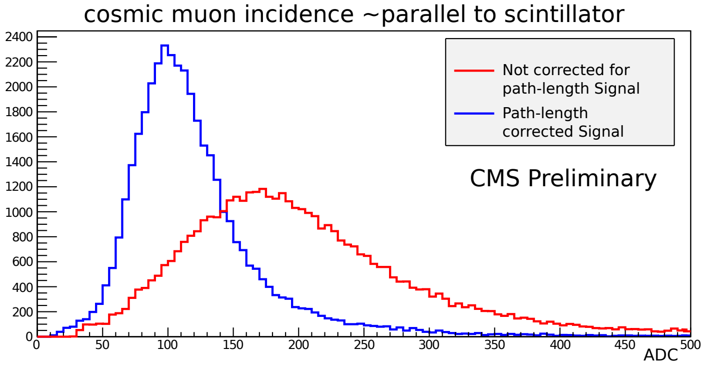
Muon track angle correction



Muon track angle correction

- Raw/uncorrected and path-length corrected MIP distributions in a horizontal tile almost identical.
- Muons traverse tile at around 90 deg in the horizontal tiles.

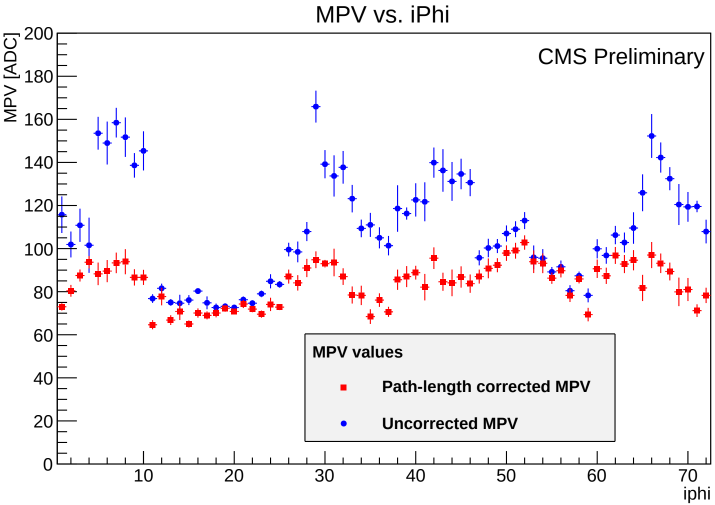
Muon track angle correction



Muon track angle correction

- Raw/uncorrected and path-length corrected MIP distributions in a vertical tile show de-smearing and shift of MPV value with respect to horizontal tile signal.
- Shift is removed after applying path-length corrections.

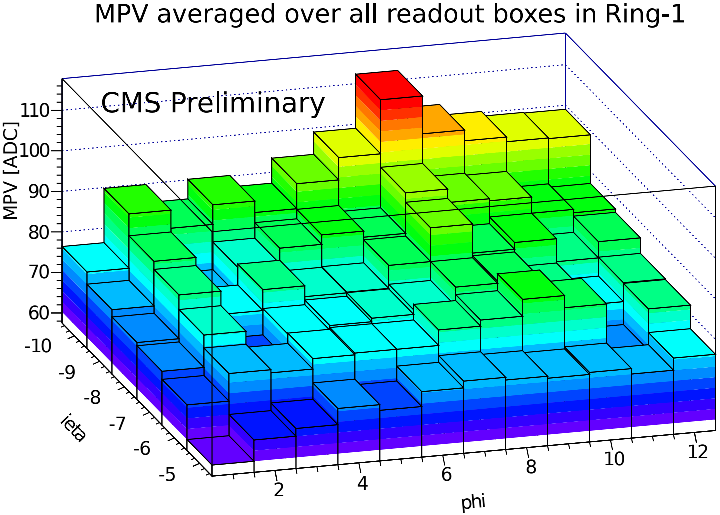
Uncorrected/path-length corrected MPV vs phi in YB-1,2



Uncorrected/path-length corrected MPV vs phi in YB-1,2

- In uncorrected MPV distribution a substructure is seen: groups of 6 iphi tiles. These are different sectors, which are aligned differently.
- Minima around top and bottom (horizontal) tiles.
- Almost no un/corrected MPV difference in these tiles.
- MPV values are more uniform after path-length correction.
- The remaining phi variation is due to different length of fibres, which connect the SiPMs to the scintillating tiles.

Fibre light attenuation



Fibre light attenuation

- From the cabling point all sectors within a wheel are the same, so an averaged MPV can be calculated for a single sector.
- Each Readout Box is connected to 12 iphi sectors in YB-1,2.
- One can clearly see the location of the readout modules and the decrease to the sides.
  - Decrease in ieta is due to the fibre length inside the scintillator
  - Decrease in phi is due to the fibre length outside (farther away from SiPM)