Temperature Studies of the Scintillating Tileboards for CMS

DESY Summerschool 2021 - 09/08/2021

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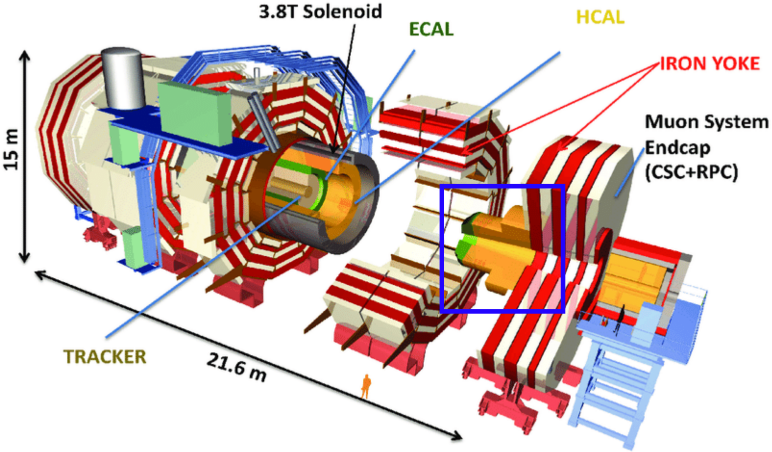
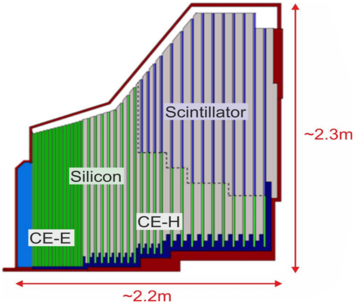
CMS Experiment



- CMS (Compact Muon Solenoid) is a general-purpose detector at the LHC
- Broad research program : discovered Higgs Boson, studying the Standard Model, searching for Dark Matter ...

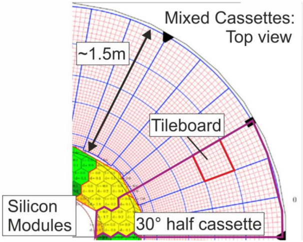
CMS HGCAL

- CMS endcaps will be replaced due to HL-LHC Phase 2 upgrade
- HGCAL aims for improved energy and spatial resolution to overcome expected pile-up
- Two major components: electromagnetic (CE-E) and hadronic calorimeter (CE-H)
- Electromagnetic calorimeter based on silicon detectors
- Hadronic calorimeter based on silicon detectors and 21 layers of scintillating tileboards

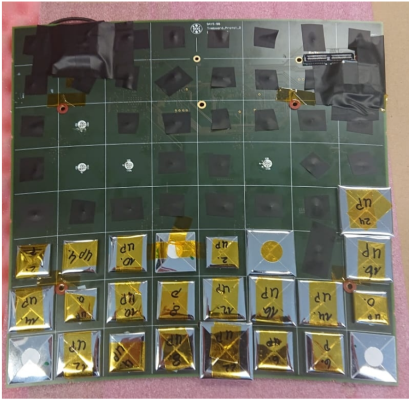


Cross section of the CMS-HGCAL endcap

Scintillating Tileboard



- Tileboards in different geometries ranging from 21×15 to $45 \times 42cm^2$
- Each tileboard itself consists of 64 channels
- Channel consists of scintillating tile glued on Silicon Photomultiplier

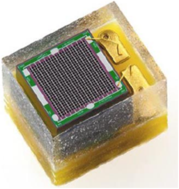


Prototype of the scintillating Tileboard

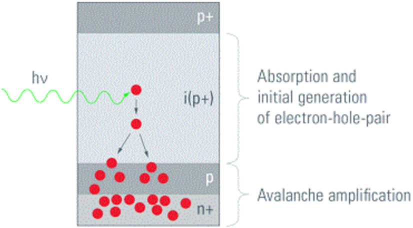
Motivation: Testing tileboards at CMS operation temperature of $-30°C$

Silicon Photo Multipliers (SiPM)

- SiPM consists of a matrix of Single Photon Avalanche Diodes (SPAD)
- SPAD consists of two pn-junctions: one for absorption, one for multiplication
- Photon absorption creates electron-hole pair
- Electrons accelerated towards multiplication region
- Ionization of secondary electrons
  $\rightarrow$ electron avalanche
- Size of avalanche conrolled by overvoltage (OV):
  $OV = V_{bias} - V_{breakdown}$



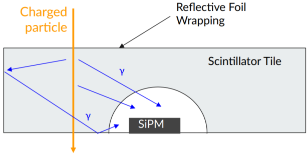
Picture of an SiPM



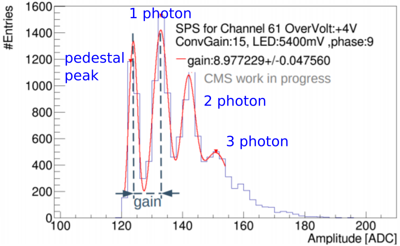
Concept of an SPAD

Single Photon Spectra (SPS)

- Channel consists of wrapped scintillating tile glued on top of SiPM
- Charged particles release photons which are transferred to electric signal by SiPM
- Histogram over integrated pulses called Single Photon Spectrum
- Mean distance between peaks called gain
- SPS can be obtained using built-In LED system

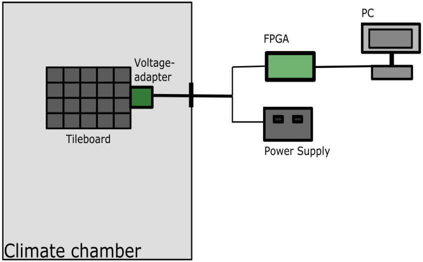


Cross-section of a tile-channel



Example of an SPS

Temperature Setup



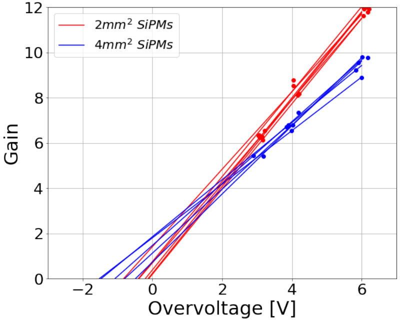
- Tileboard inside the climate chamber connected to FPGA
- Get binary files with voltage and time information from the FPGA
- In order to keep SiPMs voltage constant, a voltage adapter is used

Overvoltage (OV) Measurement

- Took dataset for three OVs: 3 V, 4 V and 6 V
- Linear Fit delivers slope:

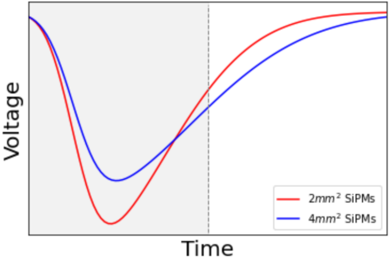
\- For 2 mm^2 SiPMs:
$(\frac{\Delta Gain}{\Delta OV})_{2mm^2} \approx (1.85 \pm 0.07)/V$

\- For 4 mm^2 SiPMs:
$(\frac{\Delta Gain}{\Delta OV})_{4mm^2} \approx (1.34 \pm 0.13)/V$



SiPM Area Influence on Gain

- Possible explanation for the differences in the response:
  - Both SiPM types designed to have the same gain
  - However: SiPM area affects effective SiPM capacitance
    $\rightarrow$ different pulse shape
  - Signal integration time does not cover whole pulse
    $\rightarrow$ Larger SiPM area leads to lower gain



Temperature Dependence of the OV

- Took datasets at temperatures down to $-40\,^\circ C$
- Linear fit delivers slope: $(\frac{\Delta Gain}{\Delta T}) \approx -0.05/^\circ C$
- Determine OV - T gradient: $(\frac{\Delta OV}{\Delta T}) = (\frac{\Delta Gain}{\Delta T})/(\frac{\Delta Gain}{\Delta OV})$

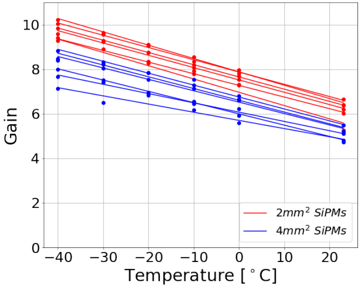
- For 2 mm^2 SiPMs:

  $(\frac{\Delta OV}{\Delta T})_{2mm^2} \approx (33 \pm 2)mV/K$

- For 4 mm^2 SiPMs:

  $(\frac{\Delta OV}{\Delta T})_{4mm^2} \approx (31 \pm 1)mV/K$

$\Rightarrow$ Gradients agree within uncertanties

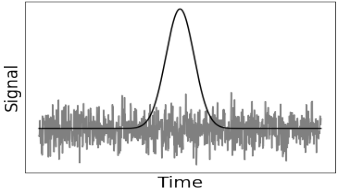


- SiPM data sheet shows slope of $(\Delta OV/\Delta T) \approx 34mV/K$

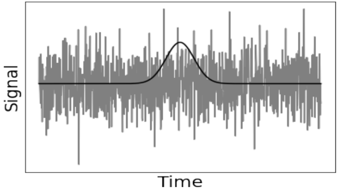
Studies with radiated SiPMs

- Two SiPMs (2 mm^2 and 4 mm^2) were irradiated to $2 \cdot 10^{12} n/cm^2$
- Equivalent to $5 \cdot 10^{13} n/cm^2$ at -30°C (maximum end-of-lifetime dose expected for SiPMs at CE-H)
- Used Tileboard consisting of 2 such SiPMs
- Goal: Study temperature impact on noise-level for radiated SiPMs

Challenges: Noise of radiated SiPMs



Non-radiated SiPMs



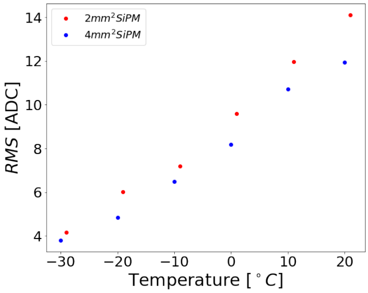
Radiated SiPMs

- Radiated SiPMs have very high noise level (18 to 20 ADC RMS at room temperature)
- For comparison: RMS for non-radiated SiPMs around 1.5 ADC
- But: lower temperature reduces noise level
- Goal: Measure noise level at same OV at different temperature

Temperature Influence on Noise

- Measured RMS of irradiated SiPMs at temperatures down to $-30^{\circ}C$ while maintaining constant OV of 2V
- As expected, noise decreases with lower temperature
- Fit with a model did not converge: $(\frac{RMS}{RMS_0})^2 = (\frac{(T-T_0)}{10K})^a$

$\rightarrow$ Many SiPM parameters are affected by temperature additional to the breakdown voltage (e.g. dark count rates/leakage current)



Summary and Outlook

Summary:

- Tileboard cooled down to temperatures as low as $-40\,^{\circ}C$
- Tileboard responded well to the low temperatures and worked stable
- $(\frac{\Delta OV}{\Delta T})$ coefficient was determined
- Measured noise levels for irradiated SiPMs at low temperatures using a constant OV

Outlook:

- Further investigations needed considering factors influencing OV at different temperatures
- More measurements needed to check additional temperature dependencies on electronics

Thank you!