Scintillator Tiles for the High Granularity Calorimeter of the CMS Detector at the HL-LHC

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Outline

Need and Motivation

For High Luminoisty Run, High Granularity Calorimeter (HGCal) will replace Electromagentic and Hadronic Calorimeter (ECAL, HCAL) in endcap.

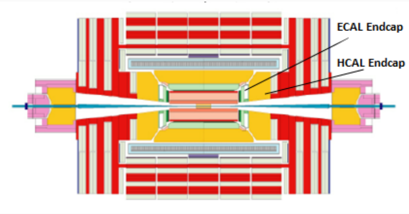

Figure 1: Lonitudinal View of CMS

Under HL-LHC radiation ECAL crystal and HCAL scintillator in forward region will suffer irreparable damage.

Order of reconstructed vertices (i.e. pileup) will be 3-4 times larger than Run2.

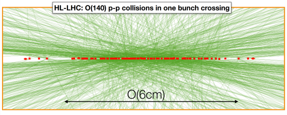

Figure 2: Order of pileup during HL-LHC[1]

HGCAL is designed to have:

- High radiation tolerance.
- Precise timing measurement.
- Fine sampling of showers.
- Observe narrow jets and minimise pileup.

From physics analysis point of view, HGCAL will have improved ability to differentiate jet originating from quark vs gluon.

[1] twiki.cern.ch/twiki/pub/CLIC/TerascaleDW19/CMS_HGCal_TerascaleWS2019_final.pdf

Design and Layout

CE-E (Calorimeter Endcap Electromagnetic)
CE-H (Calorimeter Endcap Hadronic)

- Adaptation of work done by CALICE and designed for HL-LHC.
- Active R&D by institutes/groups from around the world.
- Operating Temparture $-30°C$
- CE-E is all Silicon, made up hexagonal cells is designed for Electromagnetic shower. Absorbers: Lead, Copper-Tungsten, Copper.
- CE-H designed for Hadronic shower has front layers all Silicon and rest are mixed Silicon and Scintillator. Absorbers: Stainless Steel and Copper.

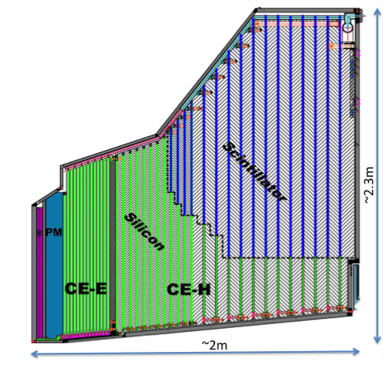

Figure 3: Longitudinal quarter view of HGCAL

Scintillator Layout

Scintillator Tiles (Size and Scale)

- Small size tiles (3mm thick), trapezoidal in shape. (approximately 20 x 20 mm^2 to 60 x 60 mm^2)
- About half a million tiles.
- Need photo sensor for each tile, so that each tile acts as separate channel.

How to get light signal from scintillator to photo sensor?

- Given the scale of number of tiles, guiding light from each tile to traditional photo sensors (Photo Multiplier Tubes) is not feasible.
- Thus, need a small size photo sensor which can be placed next to each scintillator tile.

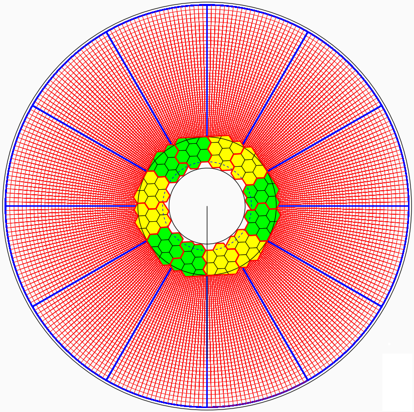

Figure 4: Layout of Silicon Wafers and Scintillator Tiles in Layer 22 of CEH[2]

[2] Figure 2.13, `http://cds.cern.ch/record/2293646`

Photo Sensor - SiPM

Silicon PhotoMultiplier (SiPM)
(Multi Pixel Photon Counter MPPC)

- Small in size (smallest $1mm^2$) with pixel size of 10-50 microns.
- A pixel is basically a APD (avalanche photodiode) with quenching resistor operating in Geiger-mode (i.e. reverse bias).
- All the pixels are connected electrically.

  Which gives,
  - High Gain ($\sim 10^6$) at low operating voltages (30 - 60 V)
- Gain increases linearly as function of Over Voltage ($OV = V_{operating} - V_{breakdown}$)

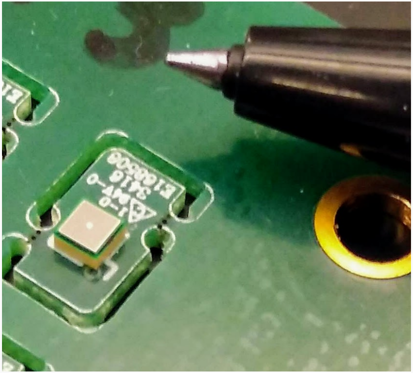

Figure 5: Silicon PhotoMultiplier

Coupling of Scintillator and SiPM

Surface treatment of tiles

- To protect loss of scintillation signal, light produced needs to be trapped and guided to SiPM.
- It is usually done by painting the surfaces with white paint or, wrapping in reflecting foil, etc.

Traditionally, optical fiber is inserted inside scintillator which collects and guide light to SiPM.

- This method is not suitable for large scale assembly.

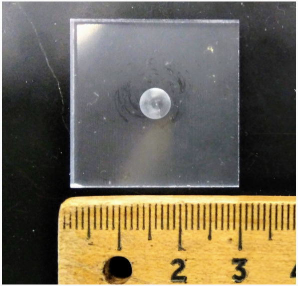

Figure 6: Scintillator Tile with Dimple

Direct Coupling: SiPM-on-Tile

- Concave shaped dimple is made on the tile.
- SiPM is placed directly under the dimple.
- This coupling also gives uniform response.

End of Life Scenario

The signal-to-noise (S/N) ratio of the detector after 3000 fb^{-1}

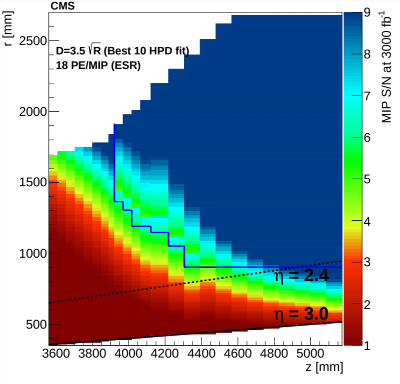

Figure 7: [3]S/N ratio after 3000 fb^{-1}

[3] Figure 2.14, `http://cds.cern.ch/record/2293646`

Tile Wrapping and Assembly

Enhanced Specular Reflector (ESR)

Figure 8: ESR Construction

- ESR is a thin multi-layer polymer, non-metallic film.
- About 65 micron thin.
- Highly reflective ($>$ 98%) over visible spectrum (400-1000nm).
- It is wrapped around scintillator to enhance the light output.

Because of non-adhesive and polymer nature, it makes wrapping a challenging task.

Response of Wrapped SiPM-on-Tile

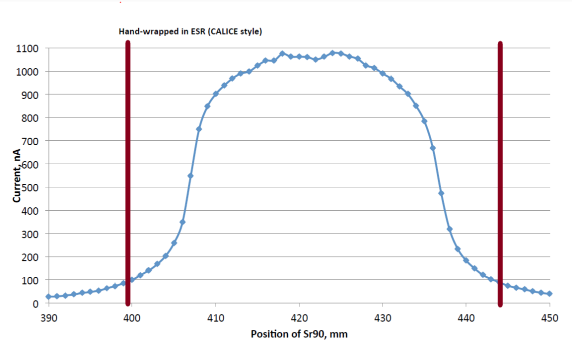

Figure 9: Scan of scintillator tile with Sr90 along the diagonal

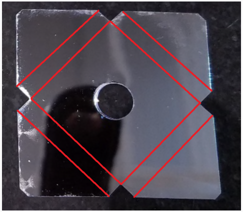

Figure 10: ESR cut out for wrapping (CALICE[4])

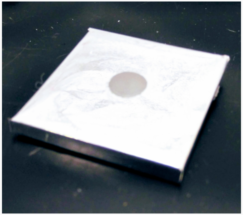

Figure 11: Wrapped scintillator tile

[4] CALICE Collaboration `https://twiki.cern.ch/twiki/bin/view/CALICE`

Response of Wrapped SiPM-on-Tile

- We tried wrapping ESR in different style[5].
- We observed higher response.
- This makes it interesting and important aspect that we are exploring.

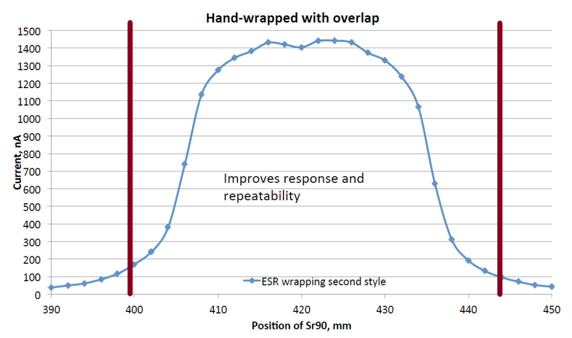

Figure 12: Scan of scintillator tile with Sr90 along the diagonal

[5] Different in terms of ESR cut-out shape

Response of Wrapped SiPM-on-Tile

Response of tiles of different sizes.

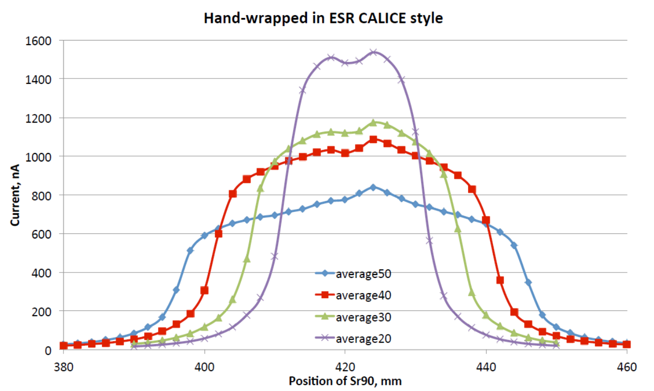

Figure 13: Scan of scintillator tile with Sr90 along the diagonal

Tileboards and Assembly

- Tileboard: basically a PCB with SiPMs and scintillator tiles.
- Size of tileboards: 8 X 8 or 8 X 12 tiles, and their subsets.
- Tiles after wrapping needs to be placed and oriented properly or tileboard.

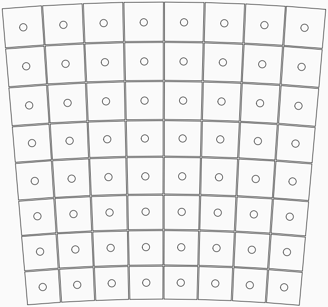

Figure 14: Trapezoidal tiles (Layout of one typical tileboard)

Summary

- HGCAL is a ‘imaging’ Calorimeter with high granularity readout.
- HGCAL will enable us to have superior particle identification and, better pileup rejection in high radiation.
- Significant portion of HGCAL active material will be scintillator, which makes every aspect of R&D interesting from tile fabrication to assembly.

Backup