Motivation for HGCAL upgrade

High luminosity Large Hadron Collider (HL-LHC) run is expected to start around 2027. HL-LHC will integrate 10 times more luminosity than the LHC over 10 years of operation.

- The HL-LHC run will allow to collect more statistics for Higgs and other Standard Model (SM) precision measurements and Beyond Standard Model (BSM) physics searches.
- It will pose various challenges for the CMS detector:
  - High Pile up condition: $\sim 140 - 200$
  - Very high radiation dose in the forward region of the detector
  - $p$-on-$n$ type Si
    - Each chip can connect up to 64 channels
    - Different gain stages to provide large dynamic range
    - High Gain (HG), Low Gain (LG)
    - Low Gain to Time (LG-toT)
  - 4 chips per module
  - 200 or 300 cell area $\sim 1.1\, \text{cm}^2$
  - System maintained at $240\, \text{kscintillator channels}$
  - Fluence up to $10^5 \, \text{m}^2\, \text{sr}^{-1} \, \text{GeV}^{-1}$
  - 0.5 cm readout chips
  - Wire bonds between Si cells & PCB

Summary

- First large-scale beam test with ~100 modules.
- Overall 85% channels of CE-E and CE-H-Si were calibrated using muon beam data.
- Physics performance results show good agreement between data and simulation.
- Multiple publications are expected for submissions in the upcoming months based on beam test data.

Acknowledgement

I would like to thank CMS HGCAL beam test analysis group and my PhD advisor Dr. Seema Sharma for valuable discussions and inputs.

High Granularity Calorimeter

Electromagnetic Calorimeter (ECAL)

- To cope with the harsh environment without losing physics performance in the HL-LHC run, endcap calorimeters of CMS will be replaced by High Granularity Calorimeter (HGCAL).
- Requirement:
  - Radiation Tolerant
  - Dense enough for shower containment
  - Fine longitudinal and lateral granularity

Features:
- Sampling Calorimeter with 50 sampling layers.
- 1.5 $< |\eta| < 3.0$ coverage
- 64 Si channels with 0.5 cm$^2$ or 1.1 cm$^2$ cell size
- 240k scintillator channels, 4-30 cm cell size
- System maintained at $38\, ^\circ\, \text{C}$

Active elements:
- Hexagonal modules based on Si sensors in electromagnetic compartment (CE-E) and high radiation regions of hadronic compartment (CE-H) of endcap calorimeter (CE).

Calibration

- Pedestal/Noise estimated and subtracted from each cell on event-by-event basis.
- Equalize response for different cells with minimum-ionizing particles $\sim 200$ GeV muon beam
- Integrate calibration (HG-LG & LG-ToT) to ensure linear response over a large dynamic range.
- Signal to noise ratio is $\sim 7$ for 300 $\mu$m Si cells.

Physics Performance

Electromagnetic shower:
- See Matteo’s “Electromagnetic performance analyses of HGCAL prototypes” paper for detailed results of EM shower in HGCAL TB setup.

Hadronic Showers:
- Setup was exposed to 20 to 300 GeV charged pions.
- Results presented here are without AHCAL.

Silicon sensor module

- High Granularity Calorimeter
- Electromagnetic Calorimeter (ECAL)
- Hadronic Calorimeter (HCAL)

 Beam Test at H2 SPS beamline

CE-E:
- Silicon sensors
  - 28 sampling layers, 1 module per layer
  - Pb/Cu/CuW absorber
  - $26\, \text{X}_0 \sim 1.4\, \text{X}_0$
  - $\sim 3.5$ channels

CE-H:
- Silicon sensors
- 39 sampling layers
- Stainless steel absorber
- $\sim 4.3\, \text{X}_0$
- $\sim 22$ channels

CE-H-Si:
- Silicon sensors
- 12 sampling layers
- Upto 7 modules
- In daisy formation
- Stainless steel absorber
- $\sim 3.4\, \text{X}_0$
- $\sim 8.4$ channels

Energy
- $E$ with energy ranging from 20 GeV to 300 GeV and 200 GeV $\mu$ beam was used.

PCB
- Anodic $\mu$m Epoxy layer
- Gold plated Kapton™ lid
- Epoxy layer
- Copper/CuW Backplates

Si sensor prototype module
- 128 silicon cells
  - $p$-in-$n$ type Si
  - 200 or 300 $\mu$m active thickness
  - cell area $\sim 1.1\, \text{cm}^2$

References

2. J. Borg et al, Skiroc - Skiroc2-CMS an ASIC for testing CMS HGCAL, 2017 JINST 12 C02019