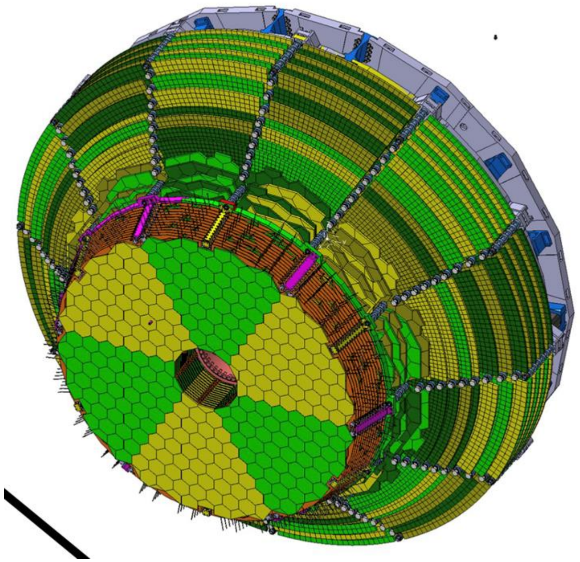

CMS HGCAL
cosmic test stand

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On behalf of SMC Collaboration

1) ANSL, Yerevan
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The CMS HGCAL: Key Features I

Radiation Tolerance:

The CMS HGCAL uses silicon sensors for the electromagnetic section of the calorimeter, as well as for those parts of the hadronic section that are exposed to the highest radiation levels.

Plastic scintillator tiles with direct (on-tile) SiPM readout are used for those sections of the hadronic calorimeter that will be exposed to less than ~$5\text{x}10^{13}$n/cm^2 after 3'000fb^{-1}.

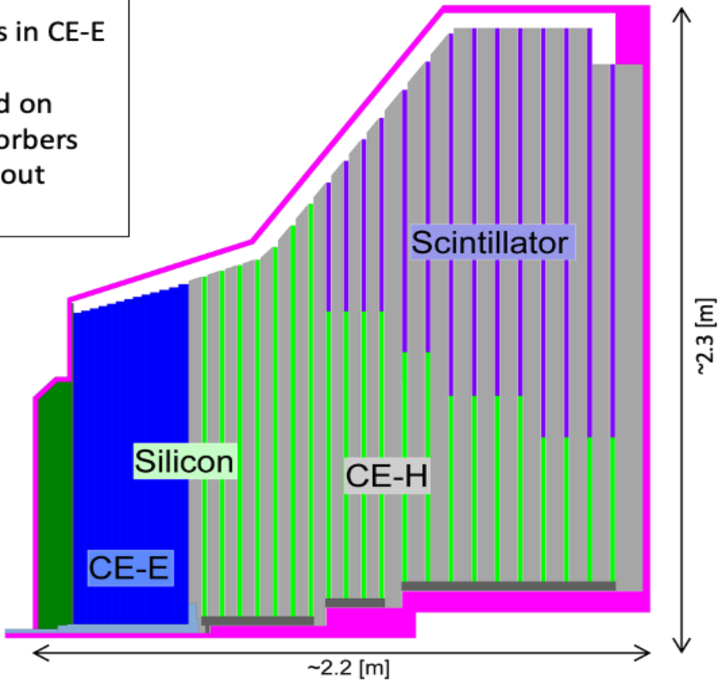
Both Si sensors and readout SiPMs require to operate at -35 deg. to reduce radiation induced electronic noise

Active Elements:

- Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
- "Cassettes": multiple modules mounted on cooling plates with electronics and absorbers
- Scintillating tiles with on-tile SiPM readout in low-radiation regions of CE-H

Key Parameters:

Coverage: $1.5 < |\eta| < 3.0$
~215 tonnes per endcap
Full system maintained at -35°C
~620m^2 Si sensors in ~30000 modules
~6M Si channels, 0.5 or 1cm^2 cell size
~400m^2 of scintillators in ~4000 boards
~240k scint. channels, 4-30cm^2 cell size
Power at end of HL-LHC:
~125 kW per endcap



Electromagnetic calorimeter (**CE-E**): **Si**, Cu & CuW & Pb absorbers, 26 layers, 25 X_0 & ~1.3λ
Hadronic calorimeter (**CE-H**): **Si** & **scintillator**, steel absorbers, 21 layers, ~8.5λ

The CMS HGCAL: Key Features II

High Granularity:

The longitudinal segmentation is driven by Energy Resolution requirements

The need to track effects of radiation damage and maintain ability to calibrate with MIPs dictates small read-out cell transverse size

The CMS HGCAL employs ~600m2 of silicon sensors with ~6M readout channels, and close to 370m^2 of plastic scintillator with about 240'000 readout channels.

Active Elements:

- Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
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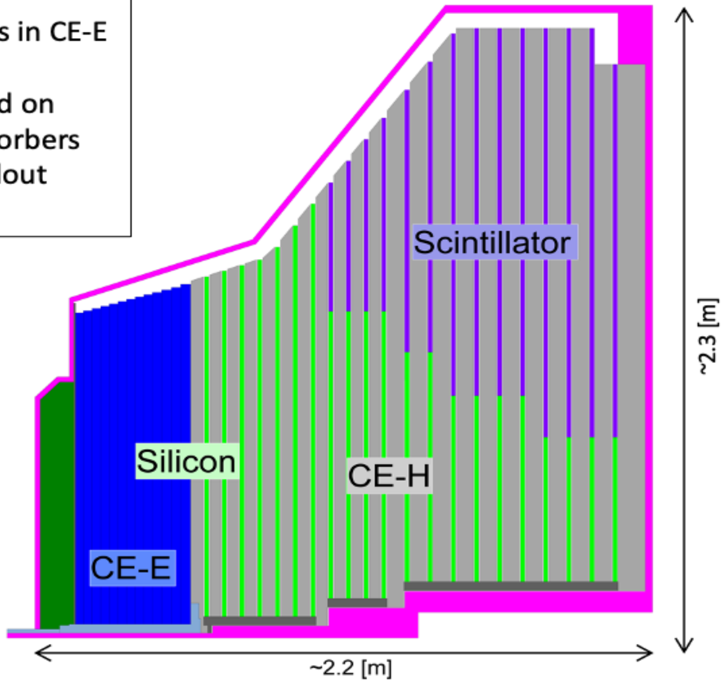

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The CMS HGCAL: Key Features III

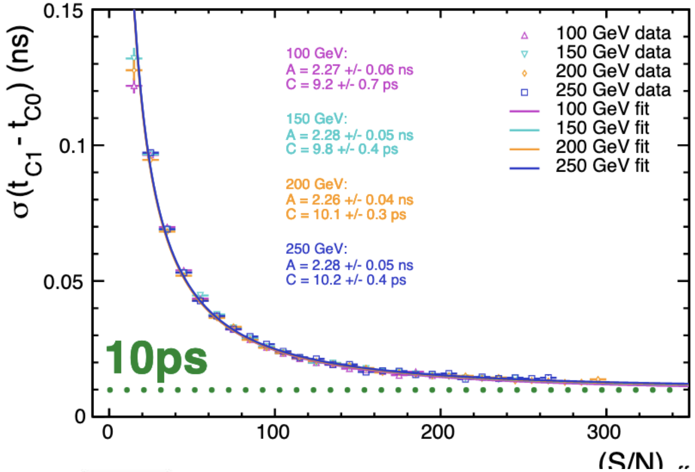
High Granularity and Precision Timing:

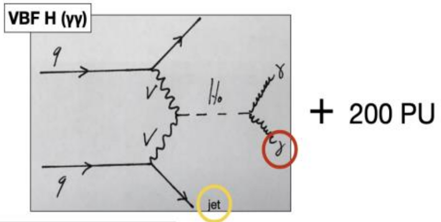
In addition to each cell providing an energy measurement, individual silicon sensor pads with more than a few MIPs equivalent enrgy deposit will also provide precise timing information, down to ~20ps

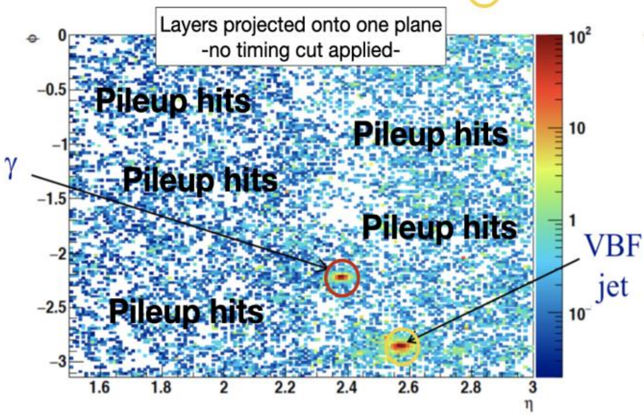
⇒ **HGCAL will be the first large scale 5D calorimetric imaging detector**

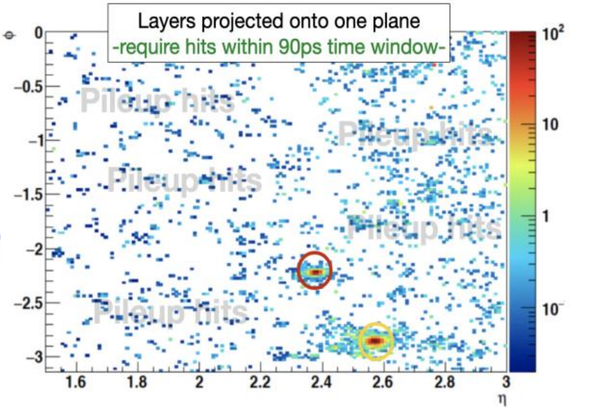
High granularity and precise timing will allow to resolve individual showers, characterise jet (sub-)structure, and mitigate effect of the 140~200 pile-up collisision within single bunchcrossing

Si sensor timing vs S/N 2016 beam tests
[JINST13 (2018) P10023]







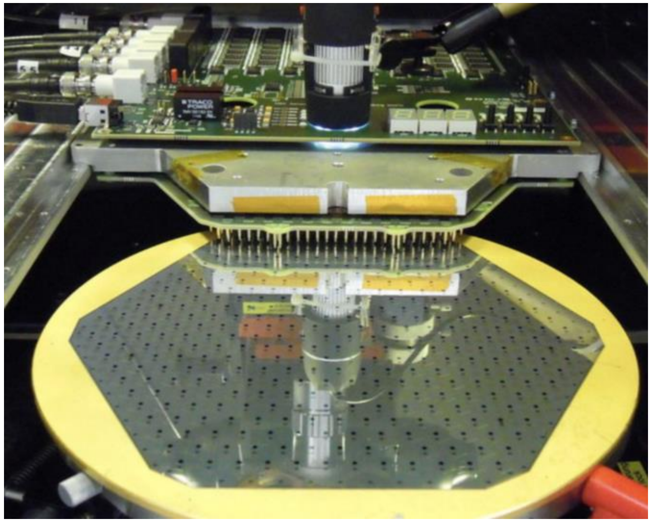


The Silicon Sensors of the CMS HGCAL

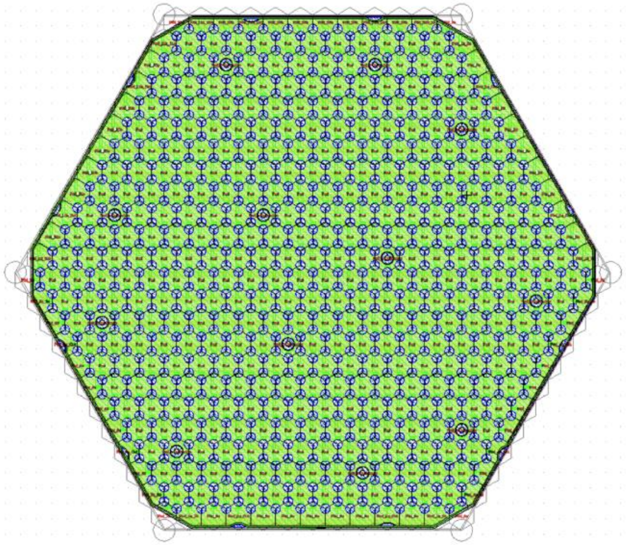
The silicon sensors are of hexagonal shape, the largest tile-able polygon, which allows the most efficient use of the sensor wafer: **in combination with the use of 8” wafers this minimizes the number of modules** to be assembled and integrated into the system, **reducing it by well over a factor two** compared to the more usual square sensors produced on 6” wafer sensors.

There are three different sensor thickness: 300um, 200um and 120um to optimize performance as function of radiation, which varies from $5x10^{13}n/cm^2$ at the Silicon-Scintillator interface up to close to $1x10^{16}n/cm^2$ towards the inner radius of the CEE.

There are two different pad sizes: ~1cm² for the 300um and (most of) the 200um sensors (LD), and ~0.5cm² for the 120um sensors (HD), in order to limit the pad capacitance and leakage current, so as **to ensure sufficient S/N for MIP calibration** over the full HL-LHC operation of the HGCAL.



LD 192 x 1.18cm^2 sensor cells*

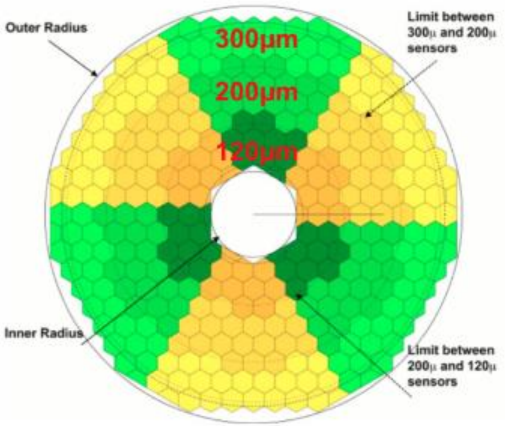


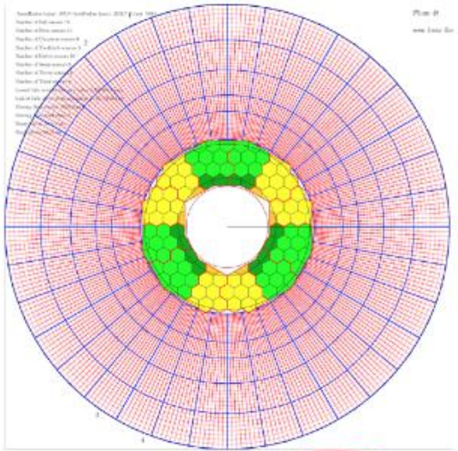
HD 432 x 0.52cm^2 sensor cells*

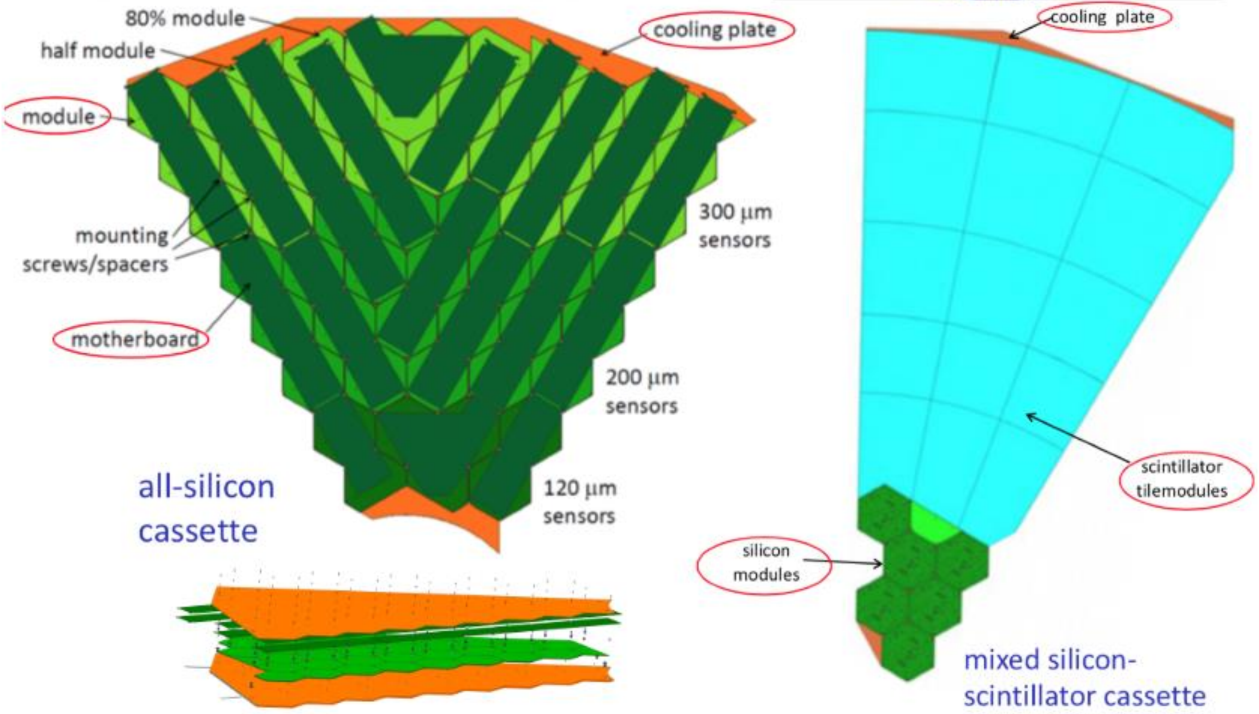
The CMS HGCAL cassettes

Each layer is constructed using 60 or 30 deg cassettes:

- ⇒ Silicon and scintillator modules assembled into cassettes
- ⇒ Supported and cooled by copper cooling plate
- ⇒ Data from modules collected by motherboards
- ⇒ Cassettes house all services and DC2DC converters
- ⇒ Cold testing of the cassettes with cosmic muons is the main task of the HGCAL test stand



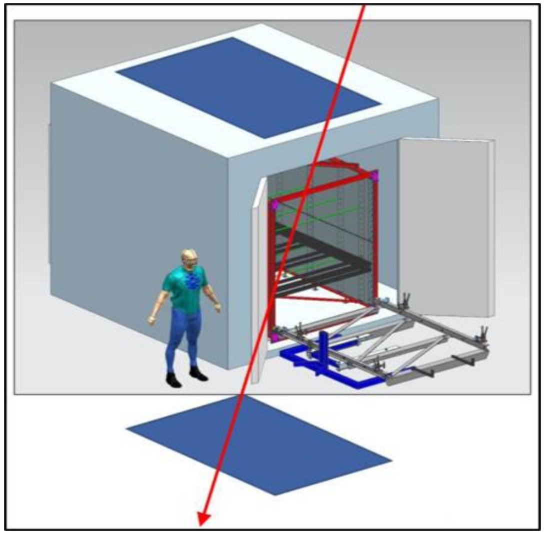


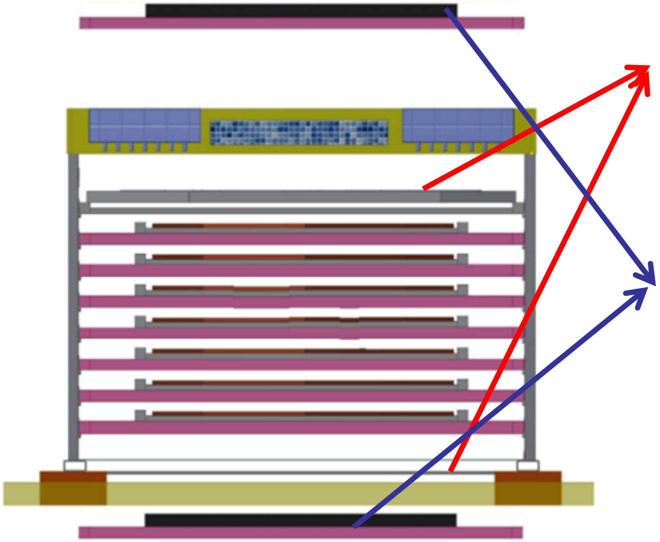


all-silicon cassette

mixed silicon-scintillator cassette

HGCal cassettes test stand in cold room with cosmic rays



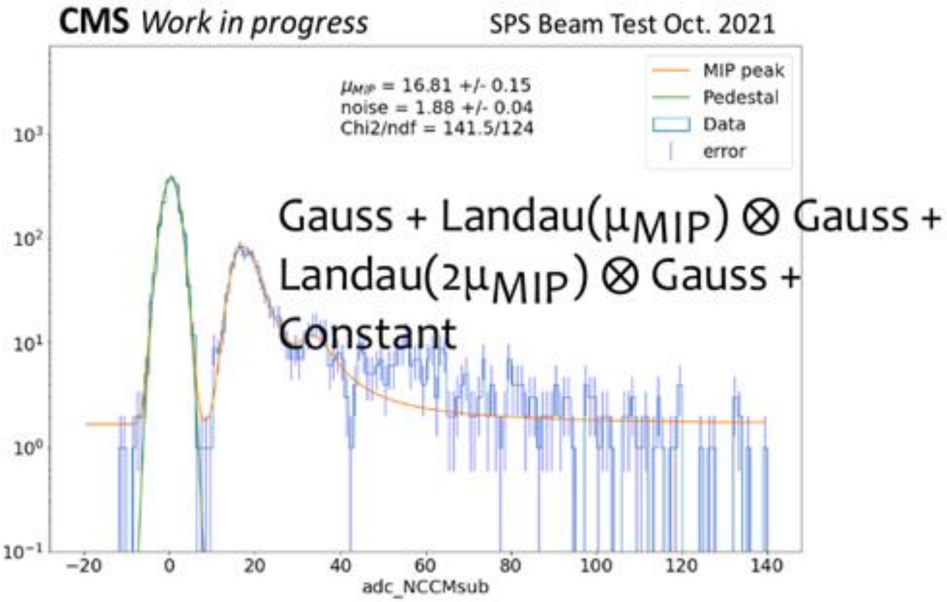


Trigger option 1 (inside cold room). More efficient with smaller triger plane size

Trigger option 2 (outside cold room). Requires large trigger planes, less efficient. But WLS fibers are sensitive to freezing cycles.

Geliang Liu, CMS Upgrade Days 6-8 Feb 2023*, CERN, Geneva*

- Cold Room with trigger planes and CE-E cassette stacks (up to 10 cassettes at a time). CE-H cassettes can be tested if needed as well
- Necessary statistics from 1000 to 1500 events for each cell to be reached in 2 weeks. Two Cold Rooms are required to match time lines.
- The energy calibration should provide intercalibration precision of 3%.
- Initial S/N requirement for MIP for different active thickness is from 11 to 4.5 (from 300 µm to 120 µm). N and S correspond to the standard deviation of the noise amplitude (pedestal σ) and MPV for MIP signal (S) measured by an individual cell .
- Setup characterization/optimization with dedicated MC using realistic cosmic muons spectra (energy-angle) .

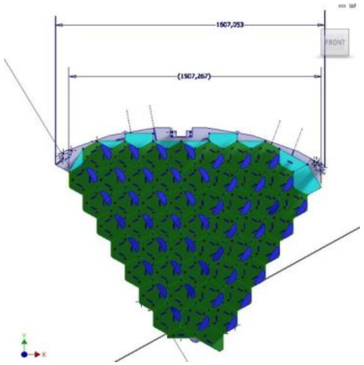


Gauss + Landau(μ_{MIP}) ⊗ Gauss + Landau($2\mu_{MIP}$) ⊗ Gauss + Constant

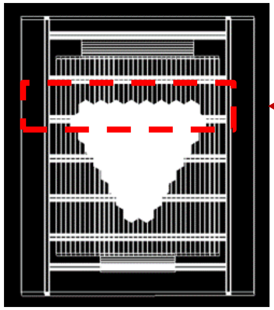
Simulation of the HGCAL cassettes test stand with cosmic muons in Cold room

- Scintillator Trigger Planes optimization
- Performance estimations, detector evaluation algorithms tests

Cassete in MC model (right)



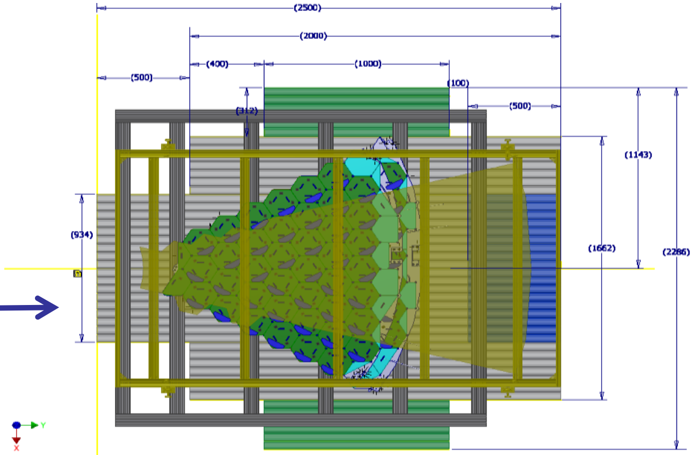
Most wide area less statistics



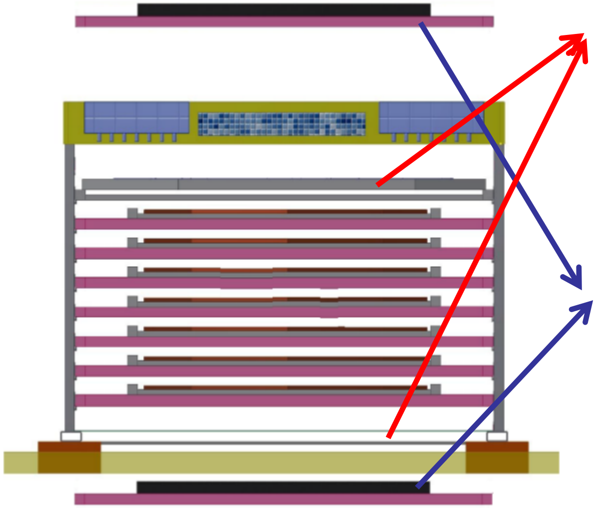
Trigger planes geometry

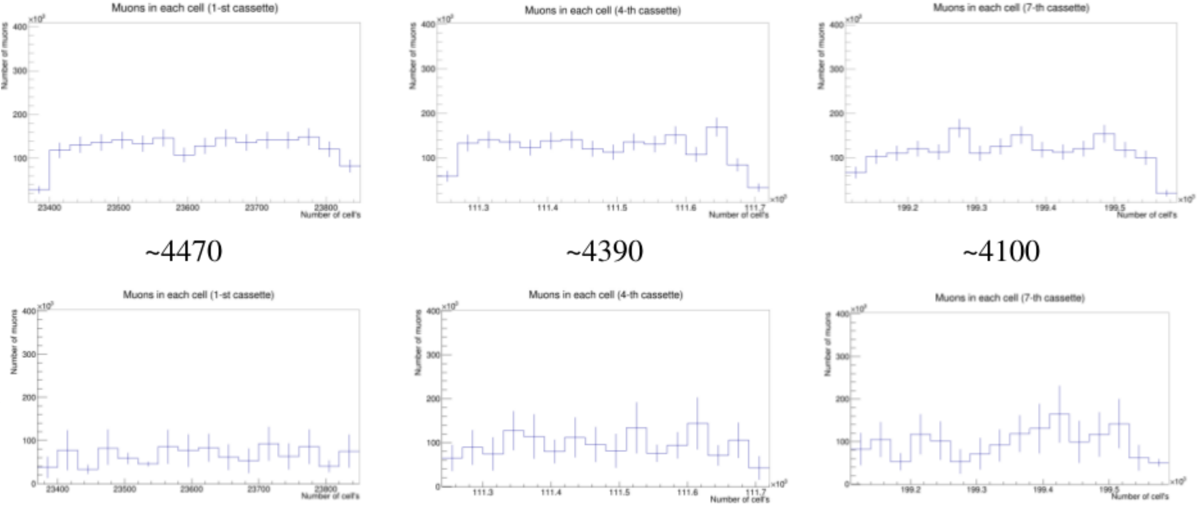
Inside option

Outside option



Cold room trigger planes position options





~1800 muons/cell in 2 weeks for outside option

Trigger planes design

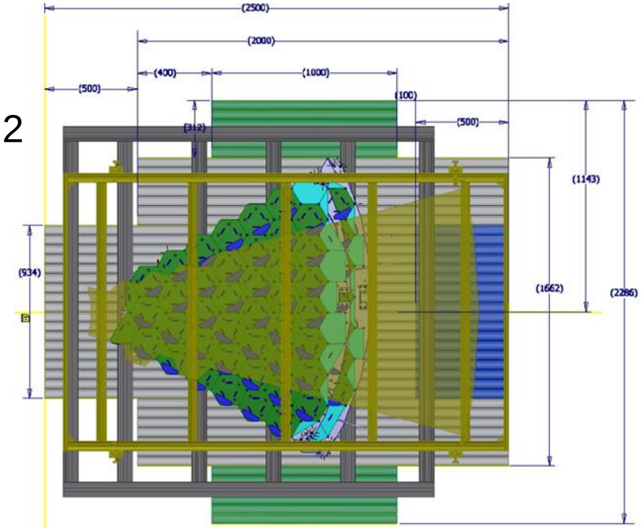
The collection of light is provided using 4 shifters of 2 in one hole.

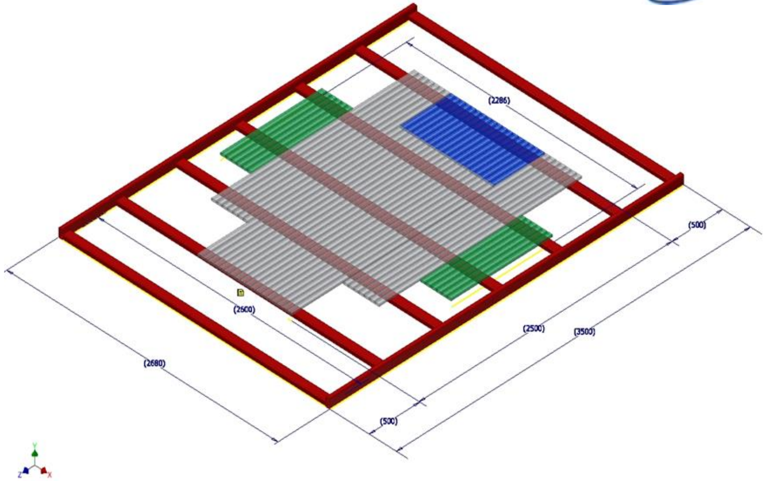
Each side of WLS are grouped into one bunch and coupled to PMT.

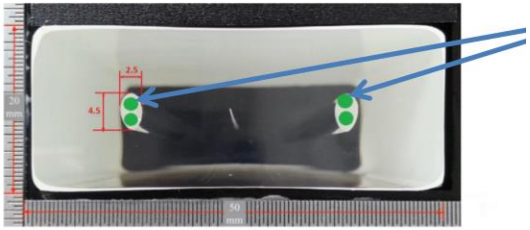
The symmetrical design allows the use of shifters of the same length for all bars (about 4.5-5 m)

The light is collected from two sides on two 1" PMTs.

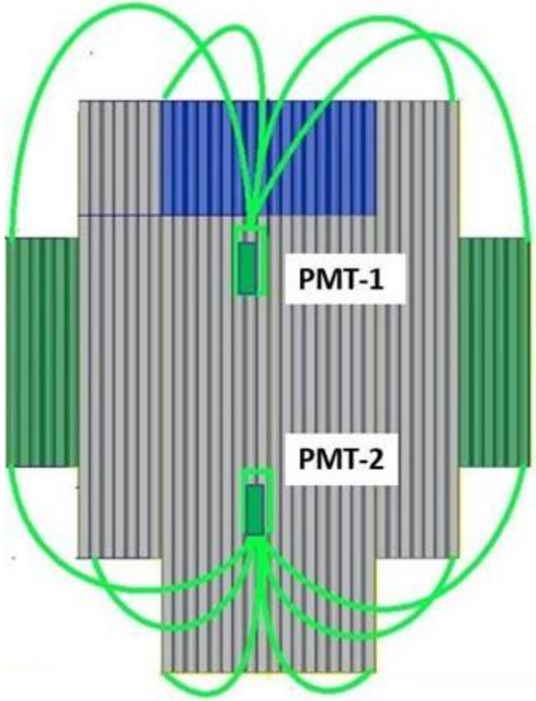
Typical size of scintillator bar is 2x5x200 cm







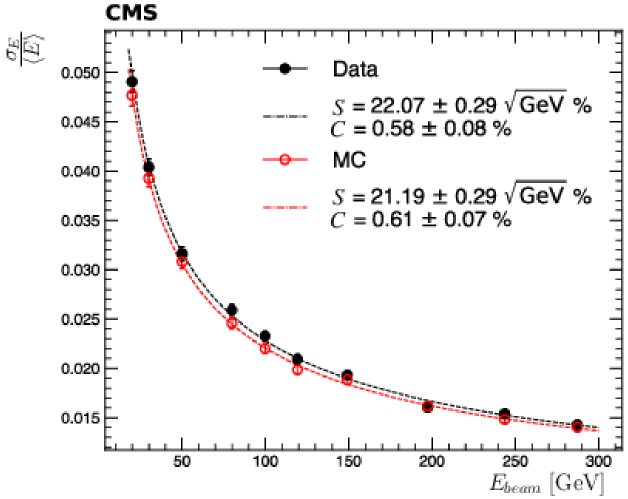
WLS fibers



Recent testbeam results of the CMS HGCAL

Testbeam results for positron beam
(arXiv:2111.06855)

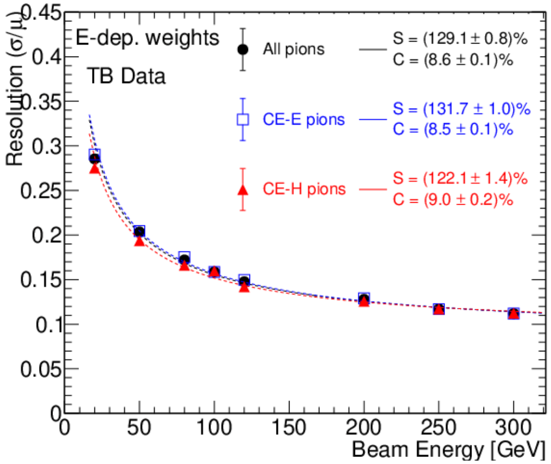
Stochastic term is 22%
Constant term of 0.6%
Linearity within 3%
Good agreement between data and simulation, also for angular resolution



Energy resolution for positron beam

Testbeam results for pion beam
(arXiv:2211.04740)

Stochastic term is 129%
Constant term of 9%
Good agreement between data and simulation, also for linearity



Energy resolution for pion beam

Summary and Outlook

- HGCAL will be the first large scale calorimeter with Si and SiPM-on-tile technologies providing unprecedented granularity and time resolution.
- Beam tests confirm expected performance
- Timeline:
  - mass-production to start in 2023 (sensors, scintillator tiles, electronics)
  - module assembly to start beginning of 2024
  - cassette assembly to start beginning of 2025 <- start of cold room testing
  - cassette assembly finished late summer 2026
  - first endcap ready for lowering March 2027
  - second endcap ready for lowering July 2027