The NTU Activities in CMS HGCAL Project

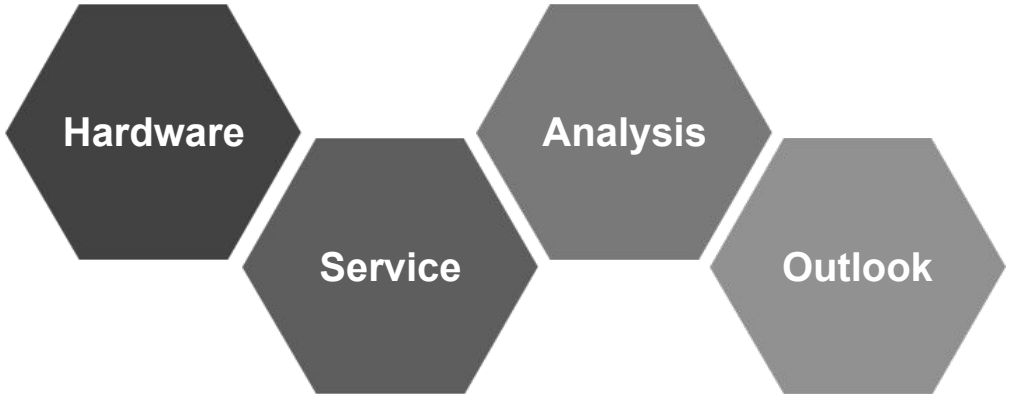
TIDC Annual Meeting

Yu-Wei Kao and You-Ying Li for the NTU-CMS Group

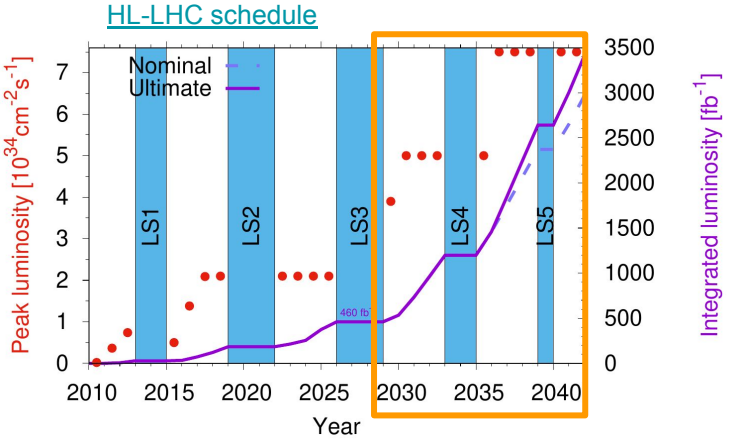
January 05, 2026

Agenda

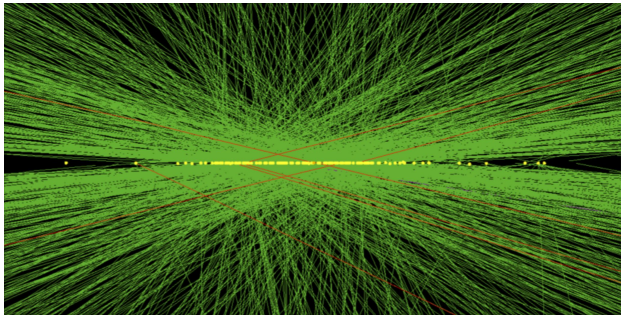
- Status of NTU Module Assembly Center (MAC)
- Participation in HGCAL Cassette Workshop
- Development of HGCAL DQM Service
- Participation in 2025 Test Beam Campaign
- Summary



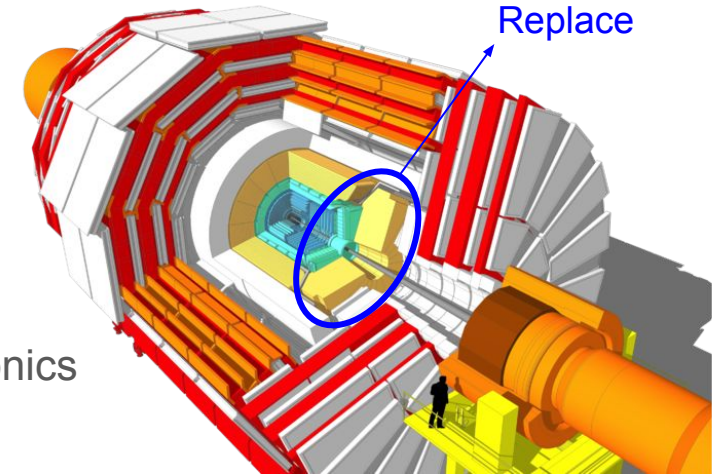
HL-LHC Challenges and CMS Calorimeter



CMS simulation of 140 p-p collisions



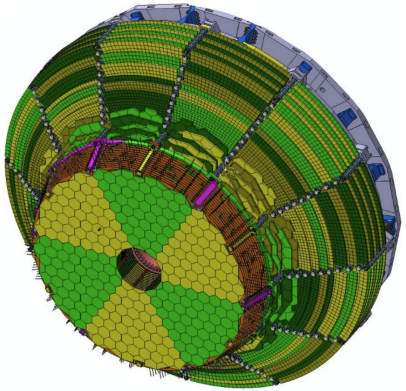
- Expect to reach **3000 fb^{-1}** during **phase-2 operation**
  - High radiation dose, high pile-ups, etc.
- Current CMS calorimeters
  - Reach the original design of 500 fb^{-1}
  - Need high radiation tolerance of sensors and electronics

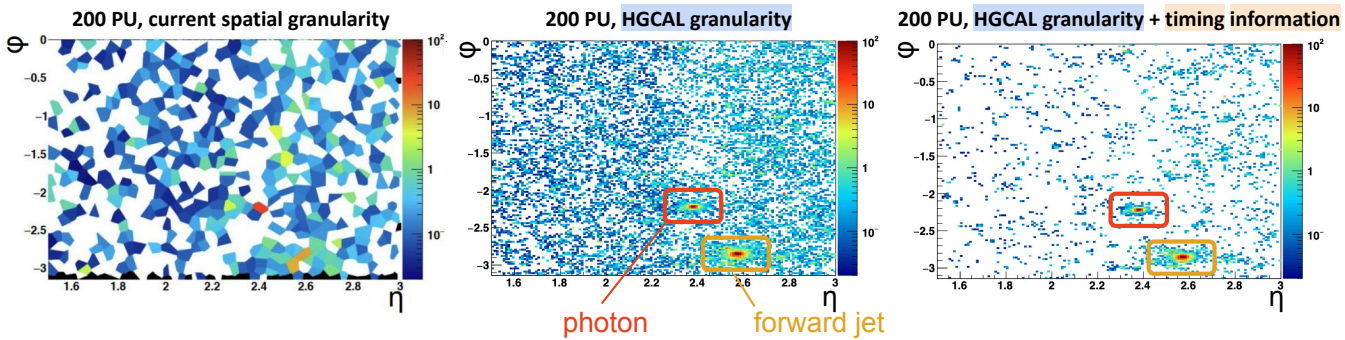


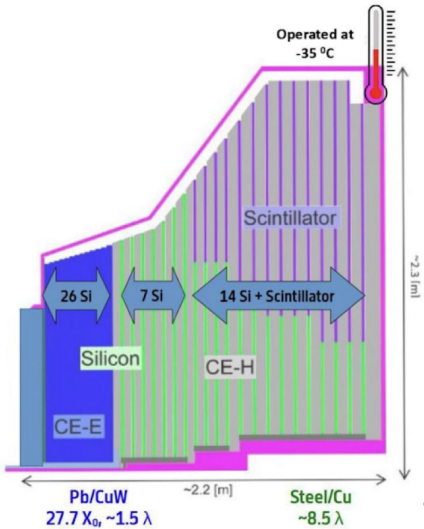
High Granularity Calorimeter (HGCAL)

CMS-TDR-019

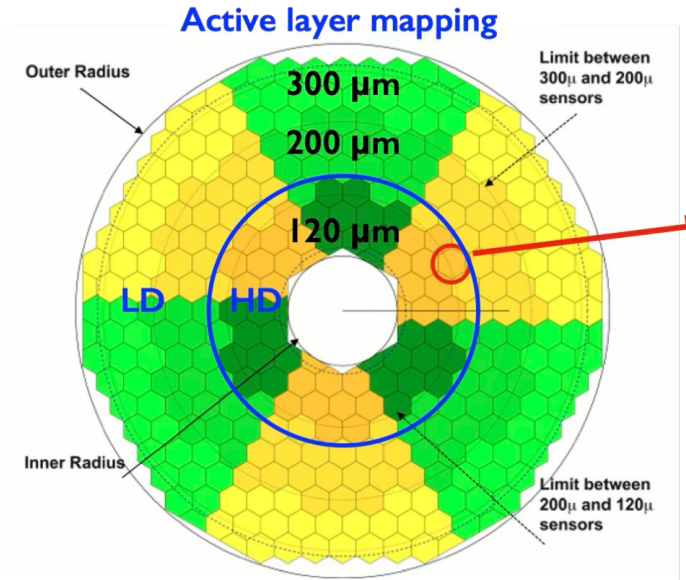
- A novel particle-flow calorimeter
  - Replacing the ECAL and HCAL in endcap regions, 1.5 < |η| < 3.0
  - 5D information (energy, position and time) for particle showers
  - Unprecedented transverse and longitudinal readout segmentation
- Physics opportunity example: Vector Boson Fusion H→γγ
  - VBF processes are very sensitive to BSM effects (e.g. VBF→HH)
  - Jets from the production mode at high-η

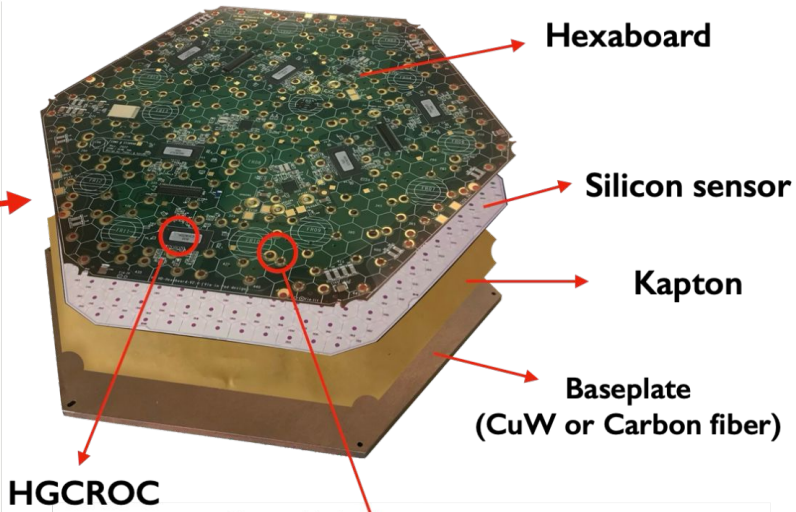


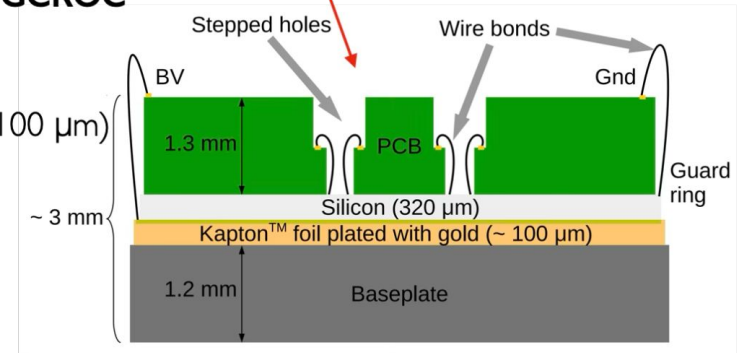




Silicon Modules







Requirement

- ☑ Small offset between HB/Sensor/Baseplate (< 100 μm)
- ☑ High radiation tolerance (> 1.5 MGy)
- ☑ 850 HV available for bias
- ☑ Low noise for each readout channel
- ☑ Temperature change tolerance (-40~20°C)

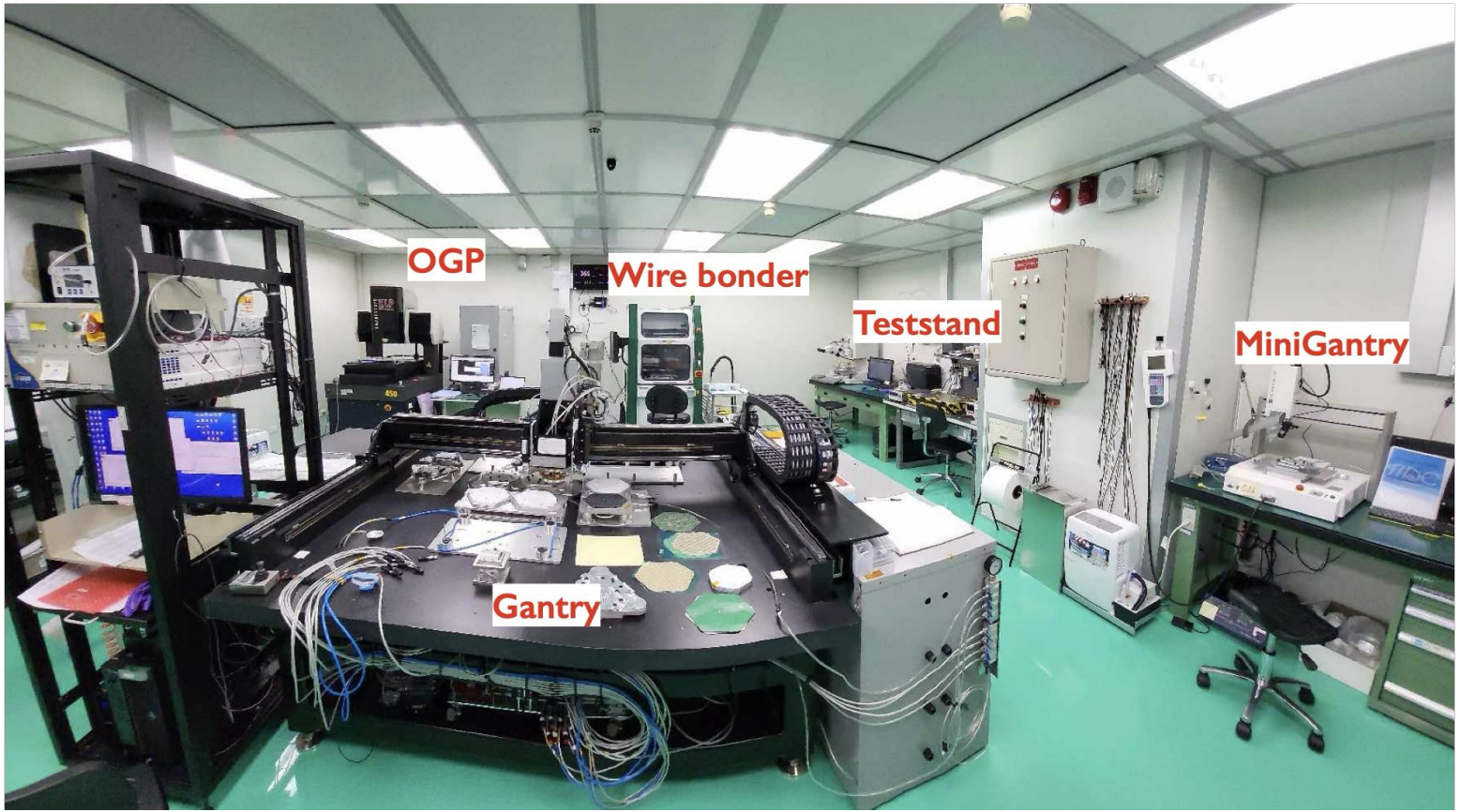
NTU Module Assembly Center

NTU Module Assembly Center (MAC)

- The HGCAL MAC in Taiwan was established in 2018.
- One of the six HGCAL MACs worldwide:

  Taiwan NTU, IHEP China, TIFR India, UCSB US, TTU US, CMU US
- Hosts main module assembly and shipping; coordinates with Ploteck for hexaboard fabrication.
- Targets the production of around 5000 silicon modules over the next two years.

Clean Room of NTU MAC



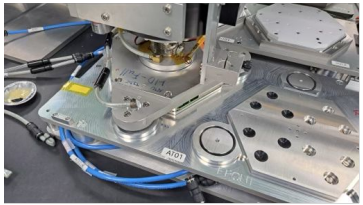
From Materials to Modules

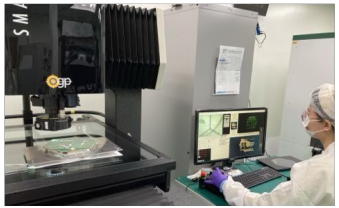
More details: [You-Ying, TIDC Annual Meeting 2024]

Material

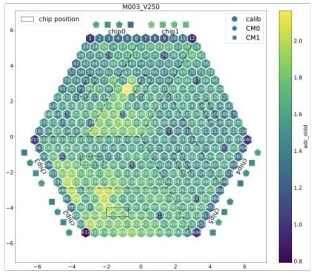
8 modules per day

Assembly





OGP QC

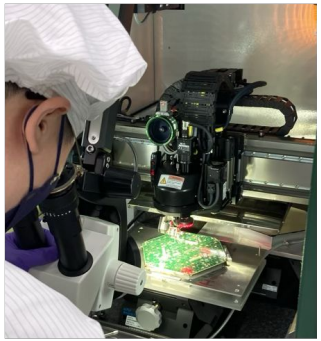


Electronic test

Thermal cycle

6 modules per run

Wire bonding



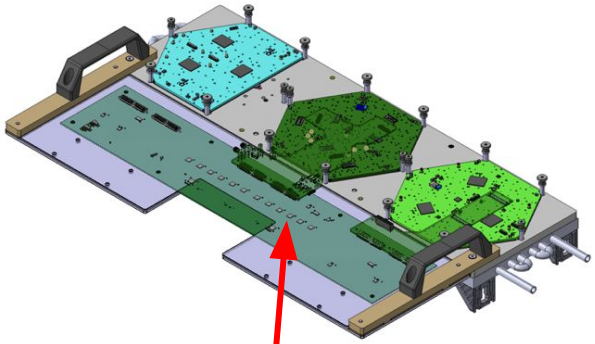
Encapsulation

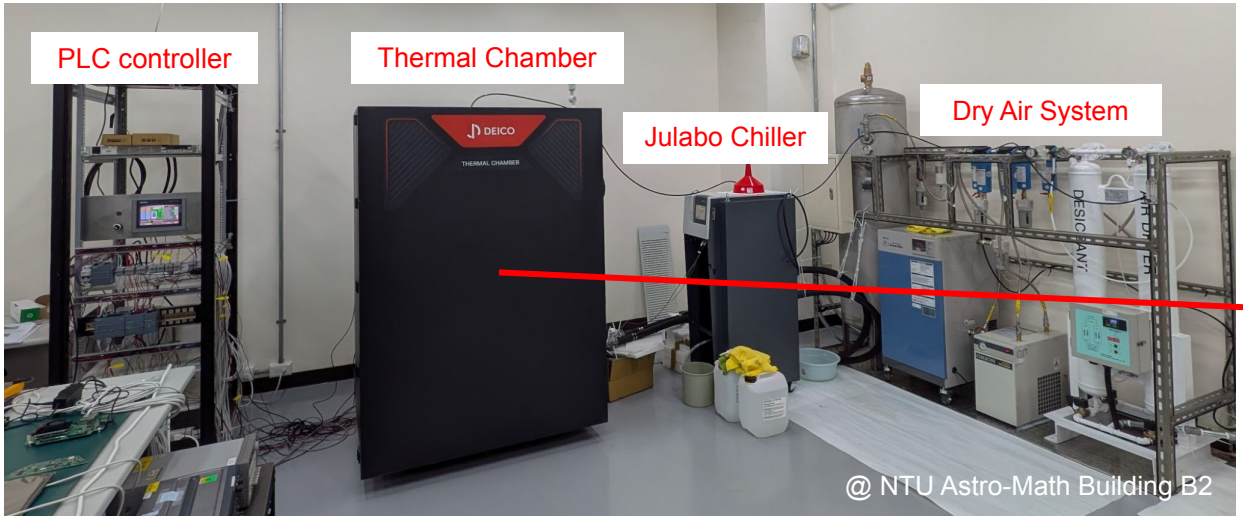
Module

Multi-Module Test System (MMTS)

- MMTS provides thermal cycle test and DAQ test for the modules at the same time.
- Large test capacity of at most 24 modules per time.
- Replace our current thermal cycle test with the limit capacity of 6 modules and without DAQ but only IV scan

Module mounted on the cooling plate

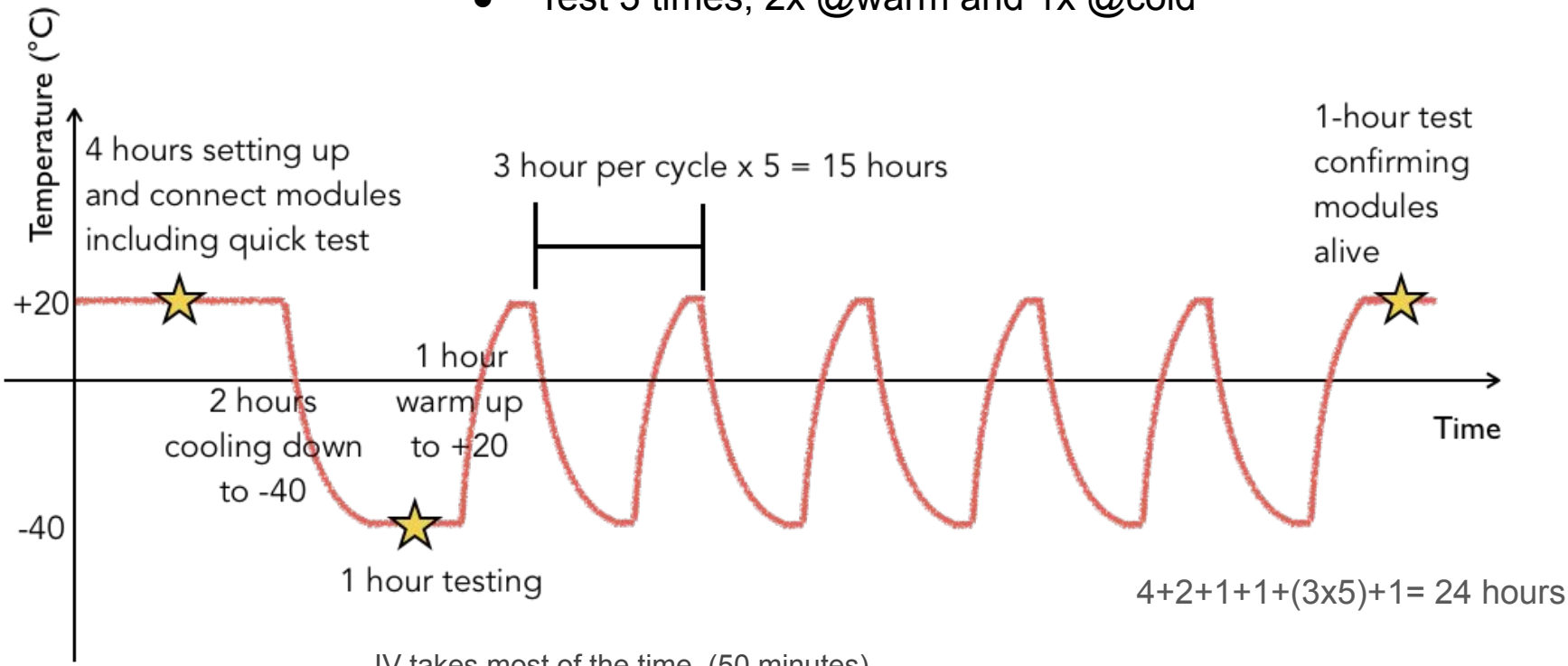




Thermal Cycle

- Reach -40°C 6 times.
- Test 3 times, 2x @warm and 1x @cold

Material from Rong-Shyang Lu



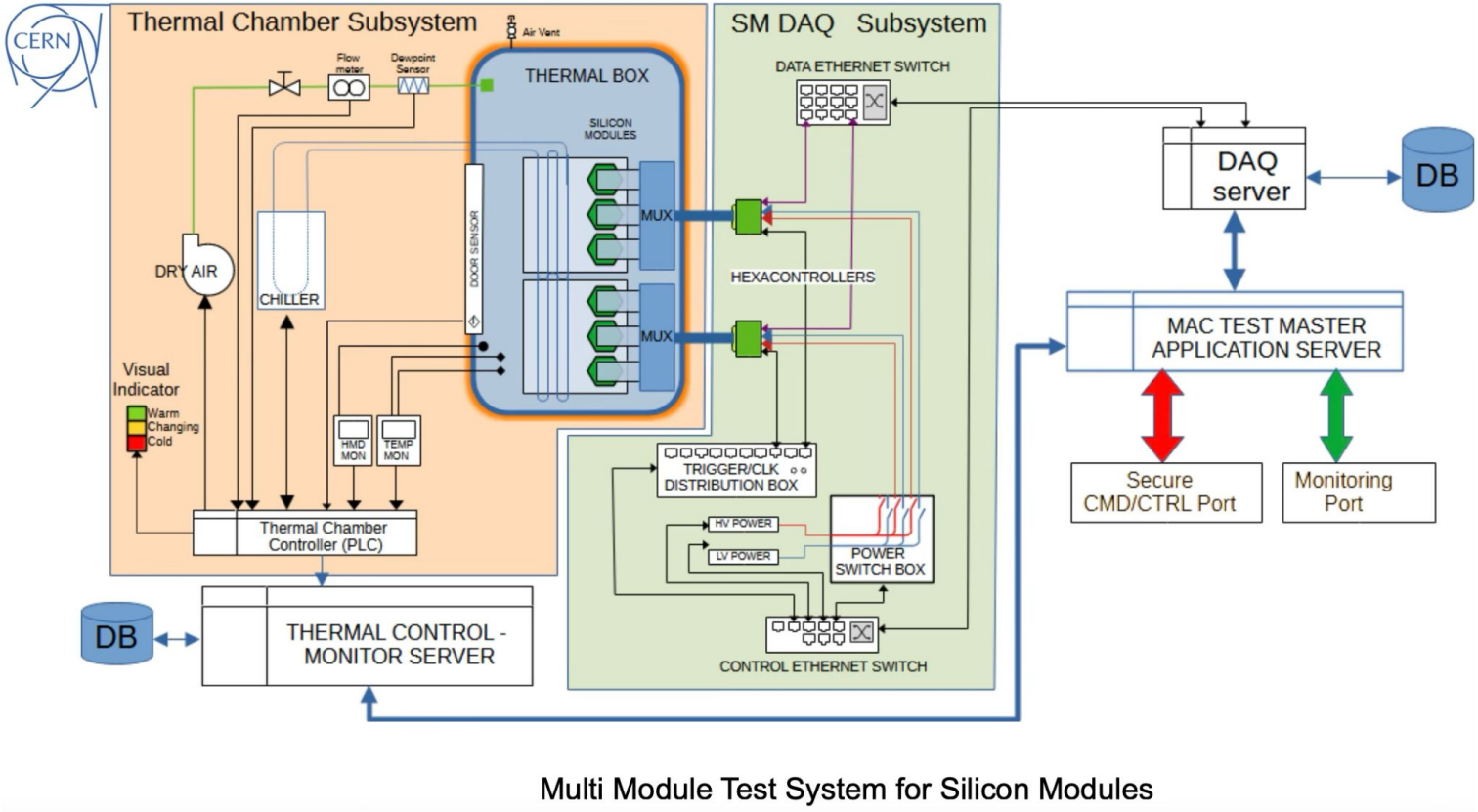
- IV takes most of the time. (50 minutes)
- Pedestal/noise (1 minute)
- Optional: Charge injection at cold (4 channels per chip / ~2 minutes)

Thermal Cycle – Pilot Run (Jan. 05, 2026)

Courtesy from Xing-Fu Su

- Temperature reaches −10°C; dew point down to −40°C
- Next steps: target −40°C and communitcate with DAQ subsystem

A Full Schematic View of MMTS



Multi Module Test System for Silicon Modules

Status of Module Production in Taiwan MAC

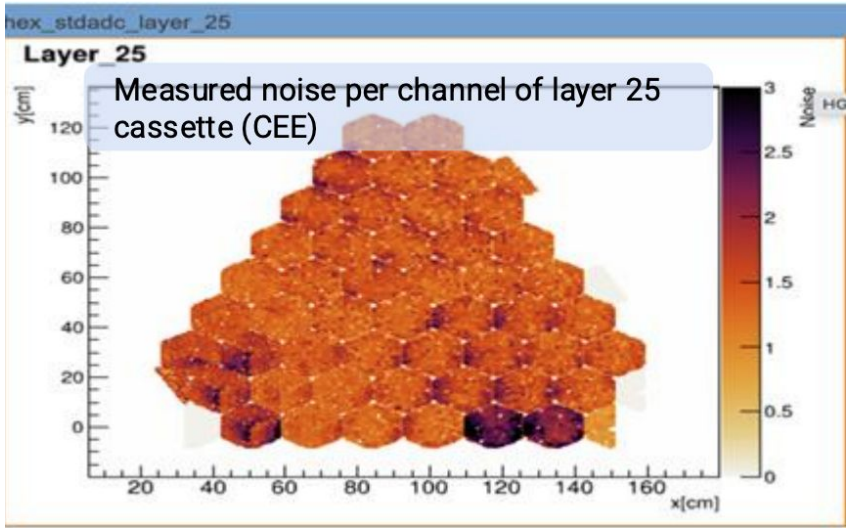
- Taiwan MAC have migrated to production stage.
- The production capacity for the same type of modules currently reaches stable 8 modules per 1 day (9 am – 5 pm).
- Construct the MMTS
- We continue to optimize the production process to head towards 12 modules per day and finally 16 modules per day.

Targeted yields of each silicon module type for NTU MAC

	High Density					Low Density					
	Full (120)	Full (200)	Bottom (120)	Left (120)	Right (120)	Five (300)	Top (300)	Bottom (300)	Left (300)	Right (300)	Total
NTU	750	1032	312	156	156	612	240	492	264	204	4218

From Modules to Cassette

- Cassette assembly has started (2025–2027)
- Preseries cassette at CERN CMS experiment site (point 5)
- Runs analysed and available on data quality monitoring (DQM) service

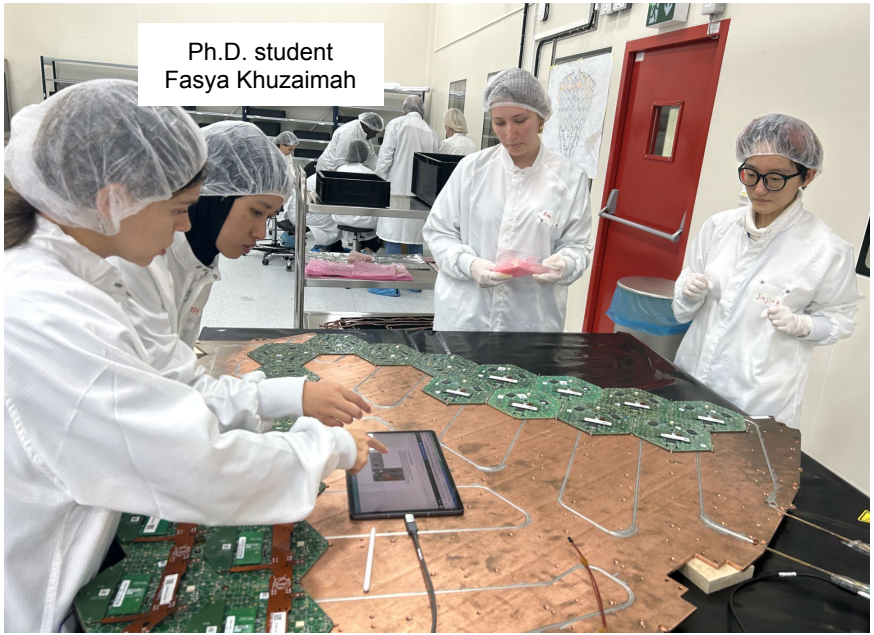


November 2025 HGCAL Cassette Workshop

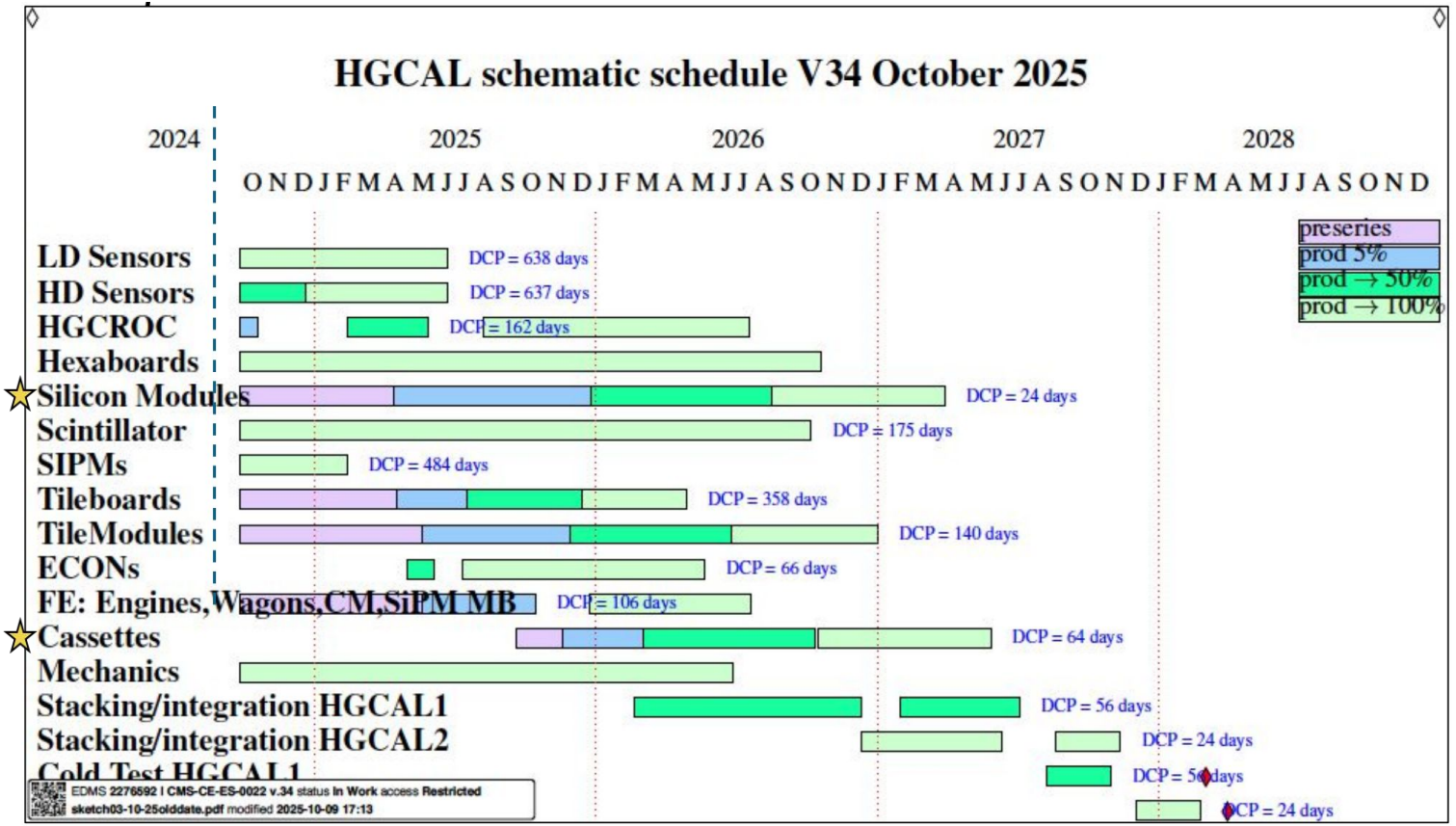
Two sessions of 3 hours for each participant

- Session-1: Get familiar with the components and the tools
- Session-2: Cassette Assembly and test: learn to assemble

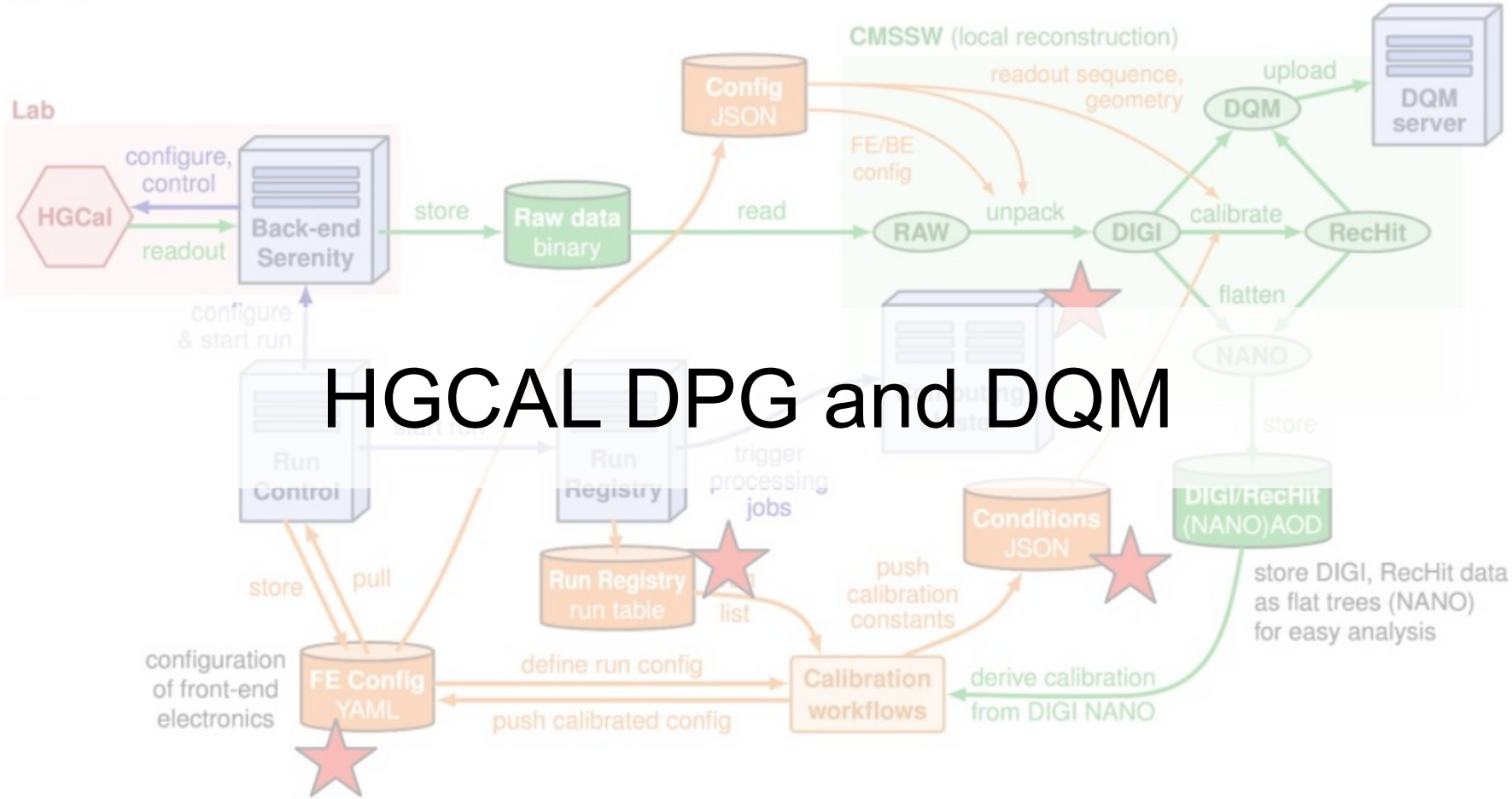
NTU postdocs actively involve in testing cassette, developing database, and training manpower.



Schematic Schedule



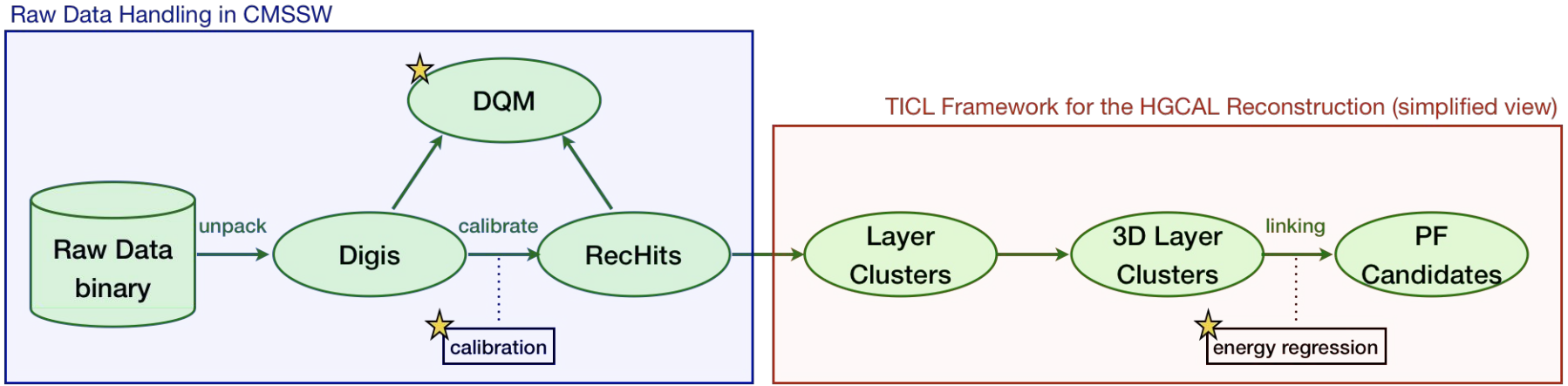
HGCAL DPG and DQM



Involvement HGCAL Detector Performance Group

Participation in recent years

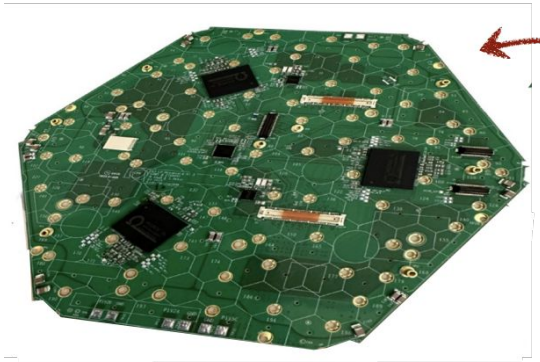
- Raw data handling group (2022–Now)
- Participation in Patatrack Hackathon events (2023–2025)
- Test beam & cassette workshop (2025)



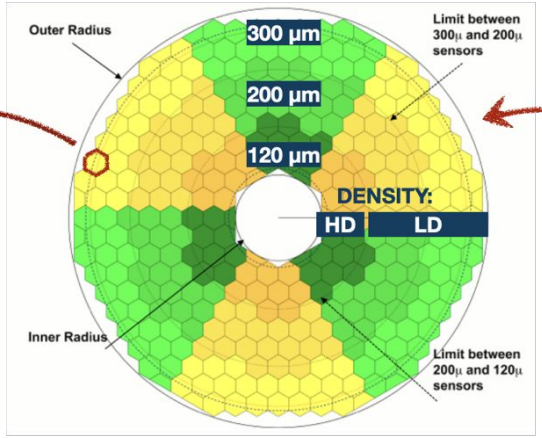
DQM Development for HGCAL (1/3)

Chanllenge

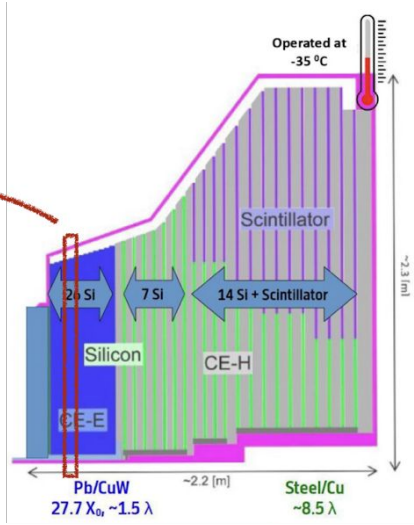
- HGCAL geometry is non-standard (hexagonal modules/cells)
- Traditional histograms don’t match detector layout
- Need intuitive visualization for DQM



Silicon Module



Layer



Endcap

DQM Development for HGCAL (2/3)

Solution

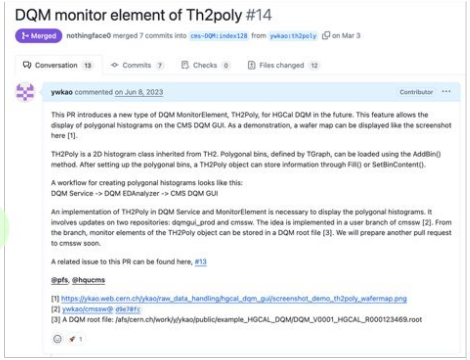
- Developed flow for polygonal histograms (TH2Poly)
- Created PRs in CMSSW and DQM GUI
- Integrated into CMS DQM service

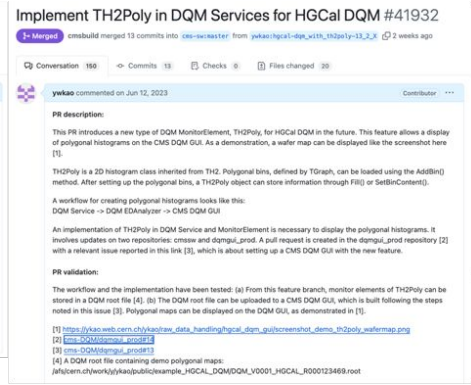
Polygonal Cells (python script) → Wafer Maps (DQM EDAnalyzer) → Display (CMS DQM GUI)

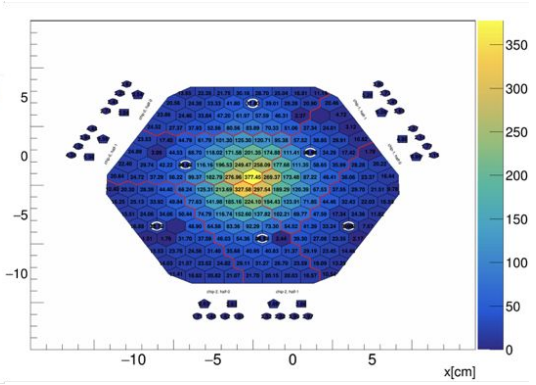
GitHub: HexHist | PR-CMSSW #41932 | PR-CMS-DQM #14

"It will be great if we can display the wafer map on DQM GUI."

"Okay, let me try."







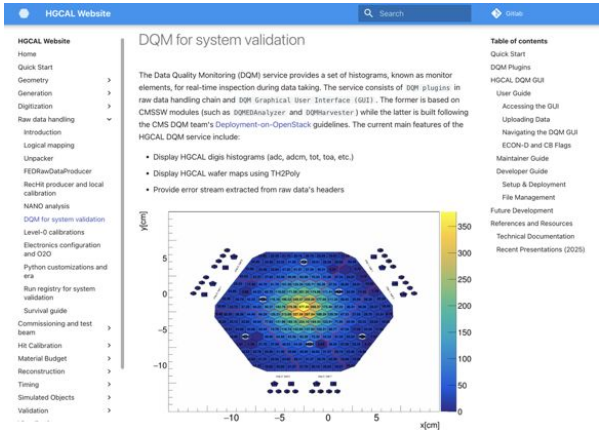
June, 2023
ROOT CTOR issue

Mar, 2023 — June, 2023 PR created — Aug/Sep, 2023 HGCAL test beam — Jan, 2024 Remind the issue — April, 2024 Follow-up — August, 2024 Patch TH2Poly — Sep-Oct, 2024 ROOT supports — Nov, 2024 Address DQM unit test — Mar 2025 PR merged

DQM Development for HGCAL (3/3)

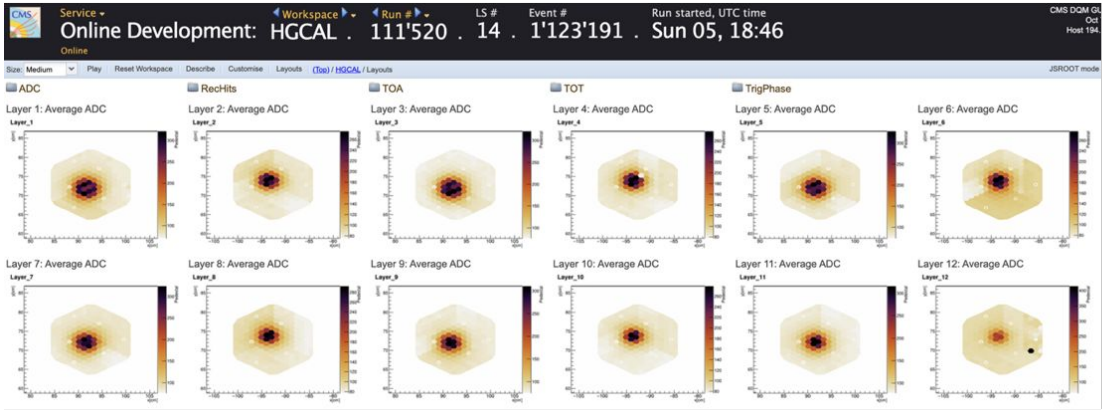
Impact

- Real-time monitoring for system validation (2023–Now)
- Used by HGCAL community for lab tests (2024–Now)
- Provided documentation for newcomers

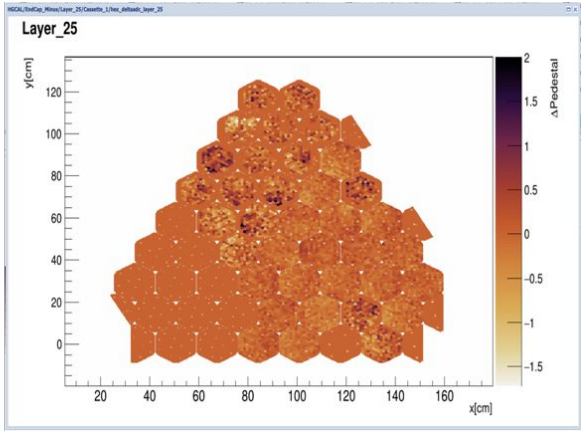


https://hgcaldocs.web.cern.ch/RawDataHandling/dqm_sysval

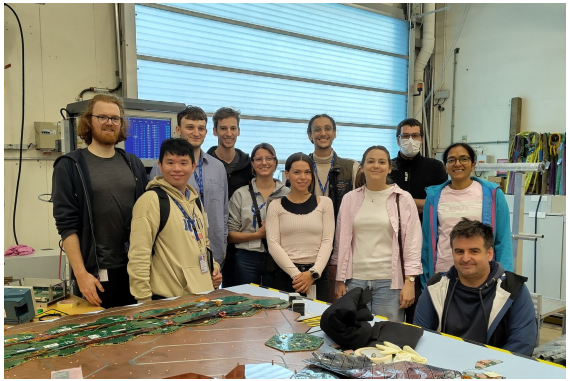
2025 test beam @ CERN SPS



Cassette test @ CMS P5



2025 DQM Development



18th Patatrack hackathon (19–23 May)

- Structured DQM plots in HGCAL hierarchy
- Factorized DQM flow into two-prong streams (fast and slow)
- Implemented an error reporting mechanism

Raw data hackathon (15–19 Sep)

- Integrated monitoring of trigger primitive generator (TPG) data (hgcal-dpg/comm/MR#167)
- Enabled display of event information on the DQM GUI
- Supported student on developing TPG monitor elements in DQM

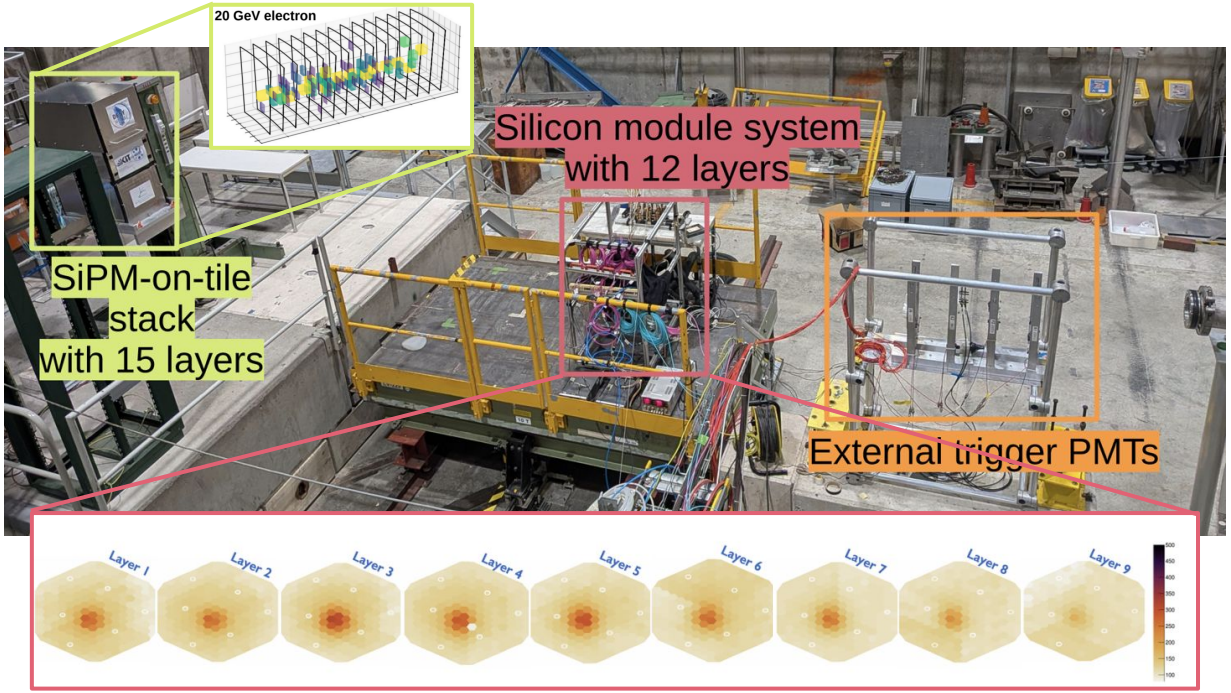
HGCAL test beam (24 Sep—08 Oct)

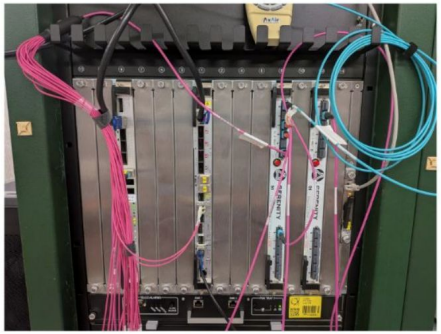
- On-site support at CERN SPS H2 beam line area
- Added user-friendly features: logical paths, color scheme, noise markers (MR#183), etc.
- Presented “DQM in CMSSW and TB2025 experience” in HGCAL workshop at DESY (indico)
- Developed data certification based on DQM data (MR#194)

2025 Test Beam Event

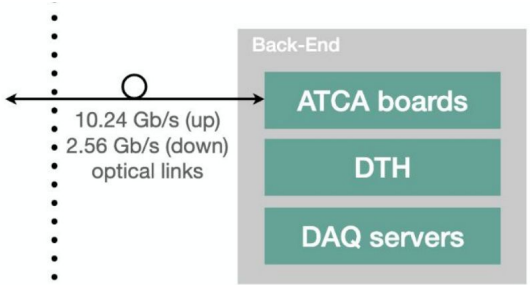
October 2025 HGCAL Beam Test Event

- First large scale tests with the final back-end electronics boards
- NTU students took shifts during the event





Serenity S ATCA-based board

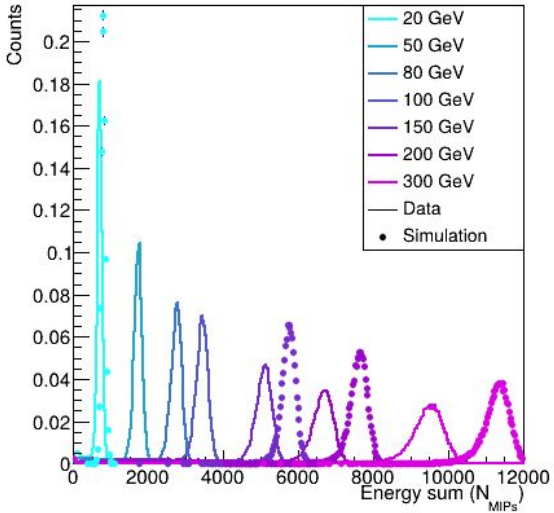


2025 Test Beam Analysis - EM Shower Energy

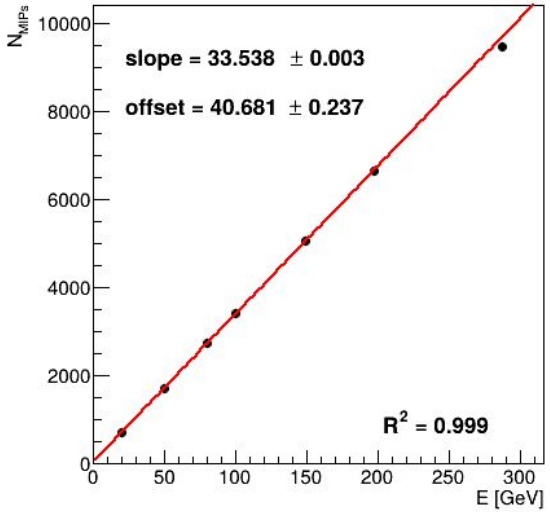
Master student
Shao-Chun Hung

- Electron beam with energy in [20, 300] GeV
- Preliminary result shows non-zero offset and a constant term of 0.028
- Plan to check calibrations and fit quality of MIP distributions

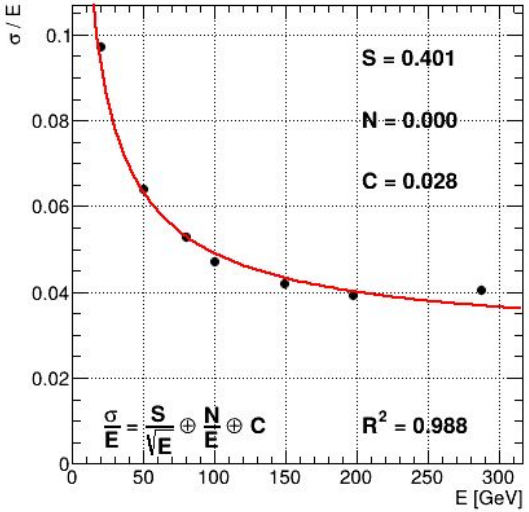
Energy sum in MIPs



Energy linearity



Energy resolution

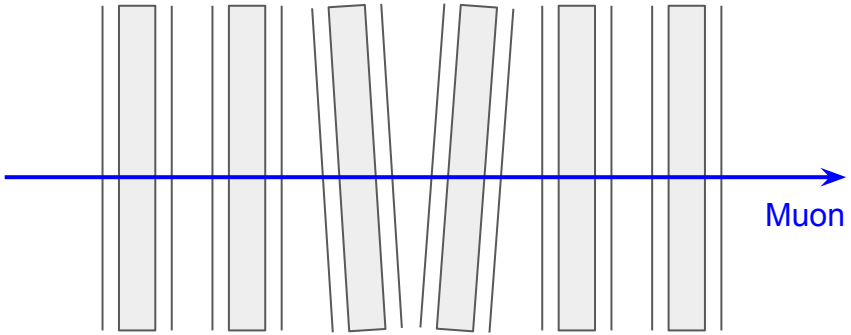


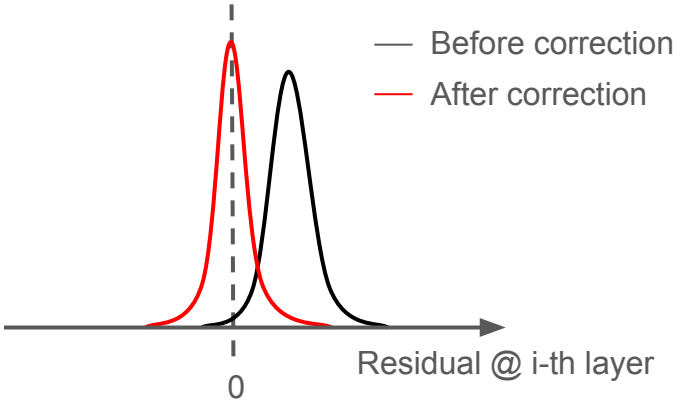
2025 Test Beam Analysis - Alignment Exercise

Undergraduate student
Hung-Wei Liu

- Analyze muon data with baseline selection
- Propose to assume most probable cause is relative tilting of layers
- Use angle measured between first and last layer and interpolate in the intermediate

$$\text{Residual} = \frac{(\text{Observed hit position} - \text{Expected from interpolation})}{\text{interpolated coordinate}}$$





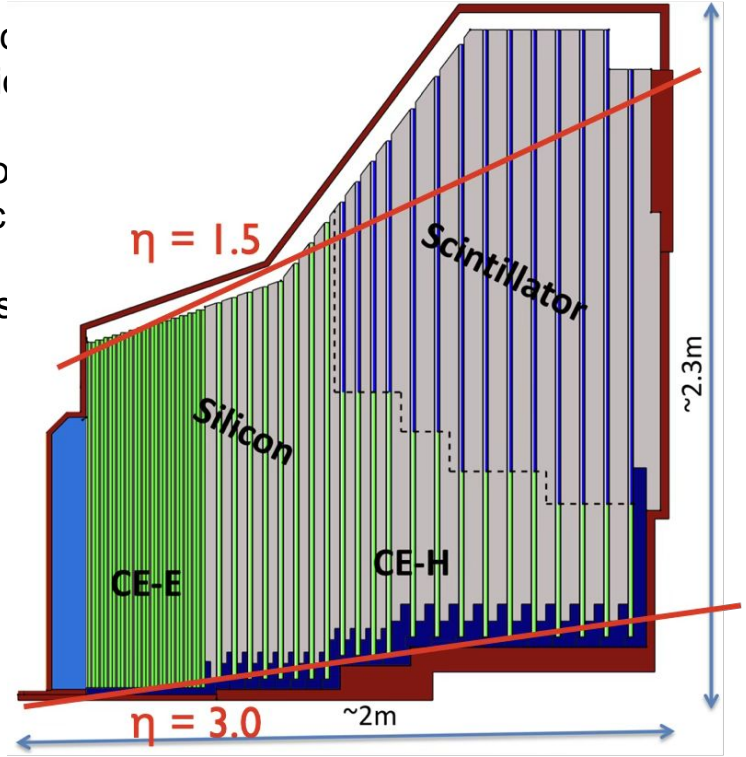
Summary

- 2025 is a year of production ramp up.
- NTU MAC is dedicated to producing silicon modules and commissioning the MMTS to enhance production capacity.
- NTU is actively involved in cassette production, HGCAL DQM service development, and test beam campaigns.
- Looking ahead, 2026 will be the year of mass production.

Thank You for Your Attention!

HGCAL Composition

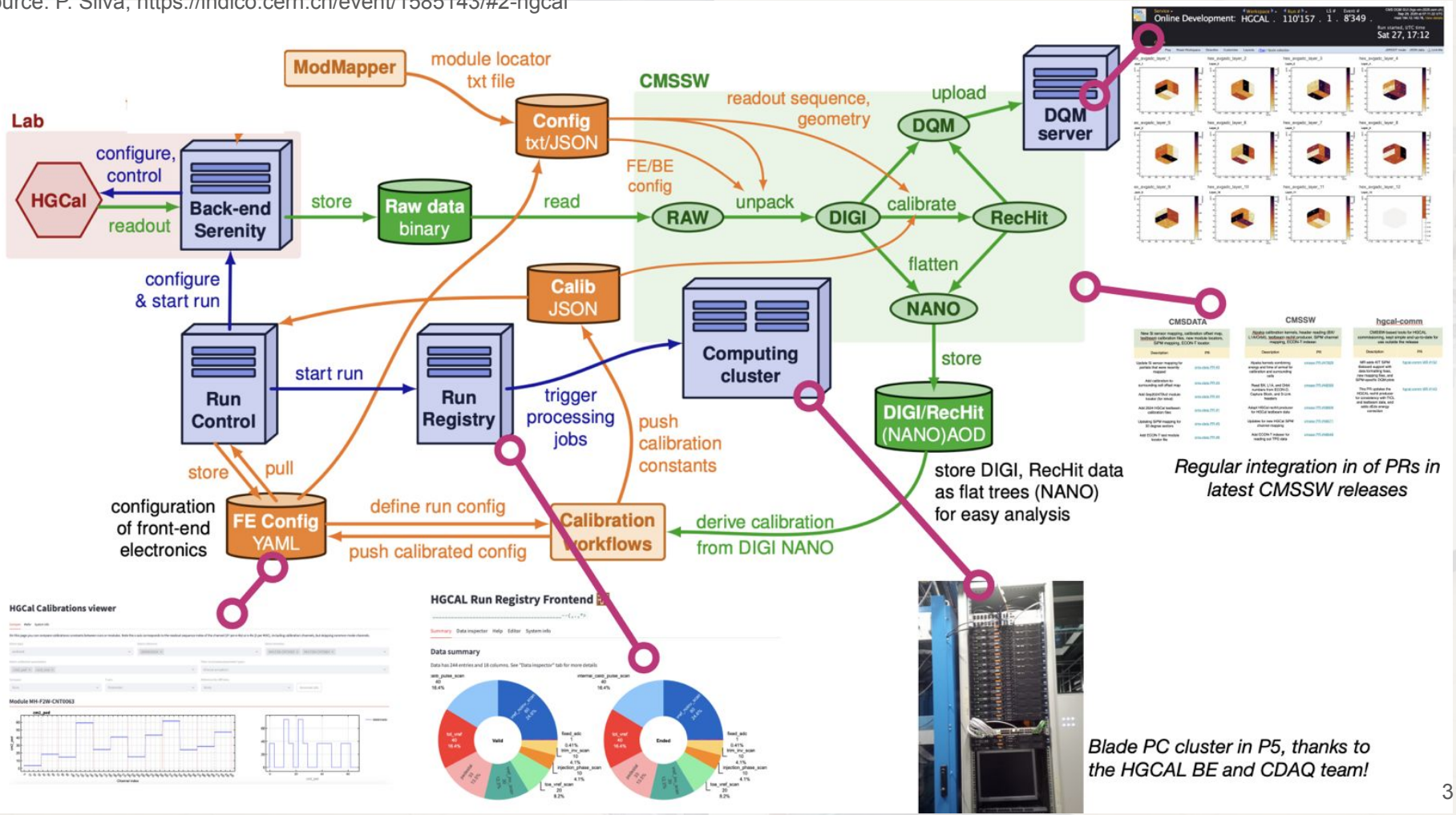
- The HGCAL detector is CMS Phase II upgrade in the endc calorimeter, replacing the ECAL and HCAL in endcap regi
- A sampling detector with three parts:
  - CE-E : 26 layers of silicon modules with Cu/Pb abso
  - CE-H : 21 layers of silicon modules with Cu and thic absorbers.
  - Scintillator : SiPM to tiles with Cu and thick steel abs



Key parameter:

- Cover 1.5 < |η| < 3.0
- Full system maintained at -30 °C
- 6 M channels with 27 K silicon modules
- Silicon cells of size of 0.5 (HD) and 1.1 (LD) cm2

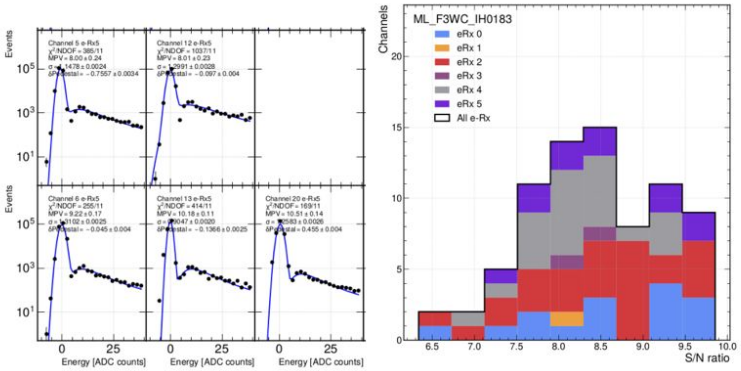
Source: P. Silva, https://indico.cern.ch/event/1585143/#2-hgcal



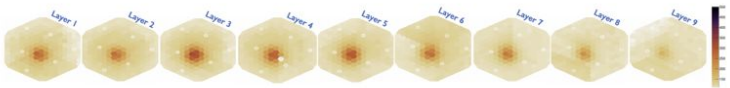
Source: Arnaud Steen, CMS HGCAL P2UG

Operation of Silicon system with beam

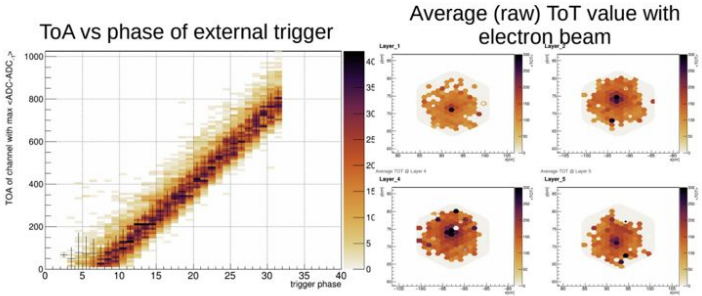
- Muon data for MIP calibration and S/N measurement
  - Compatible with results from previous beam test results!



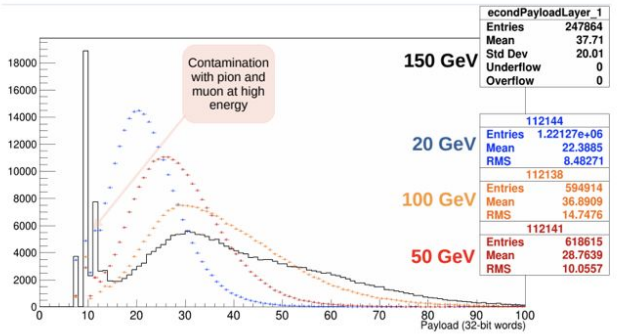
- Electromagnetic longitudinal profile (from 100GeV electron run)



- Plenty of TDC data in run with electron beam

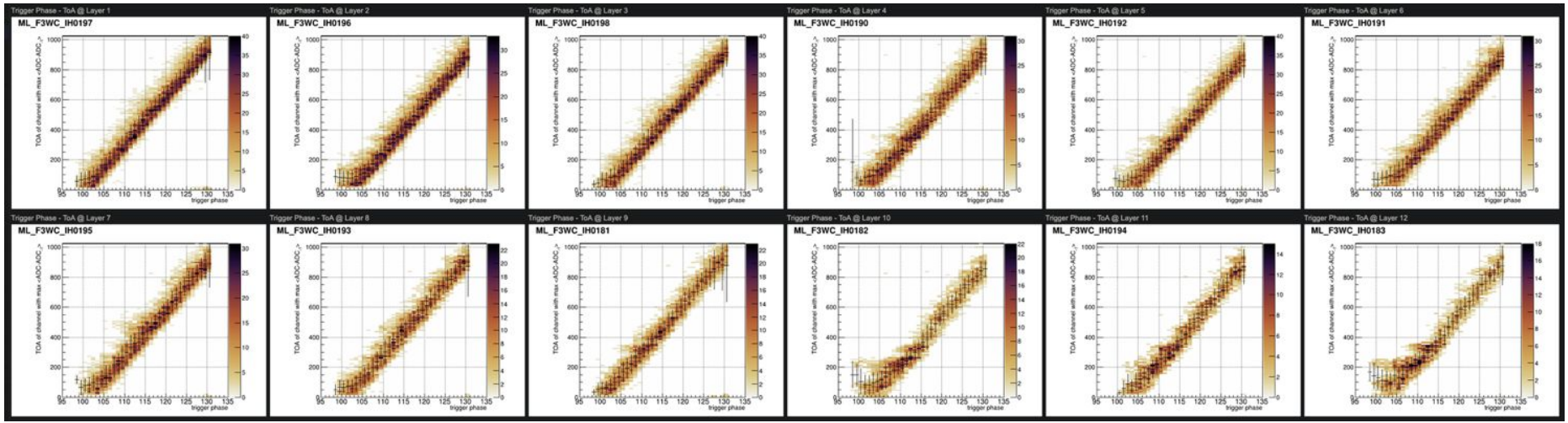


- ECON-D payload size with zero suppression



DQM Service in TB2025

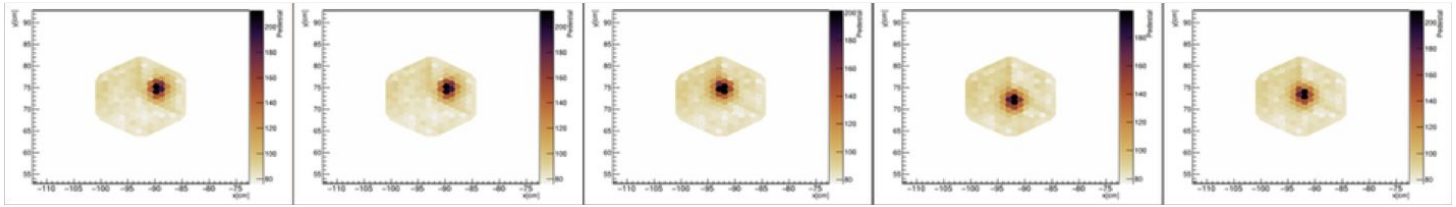
- Logical arrangement in DQM GUI allows to monitor all 12 modules simultaneously
- Example: Distribution of TOA vs. external trigger phase after calibration runs



DQM Service in TB2025

Example 1:
Beam alignment record

Layer 2: Average ADC



Example 2:
Observable across
various beam energies

RecHit Multiplicity