Introduction to CMS HGCal project in China

Huaqiao Zhang

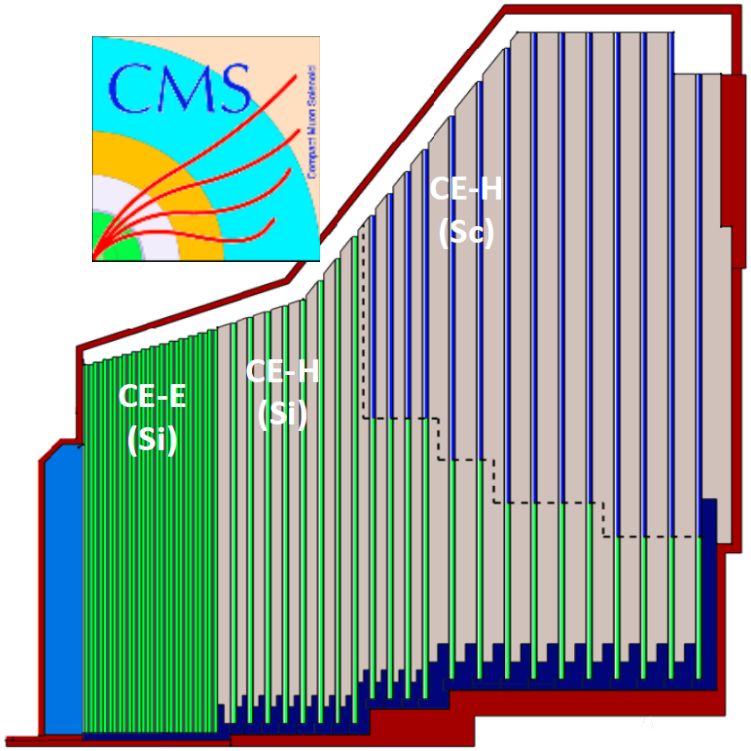
CMS High Granularity calorimeter

France/Prague/Japan/England

Years of R&D,
Application Not yet approved

Similar idea

CMS HGC
Approved to be built 2015-2025



Other future HEP experiments

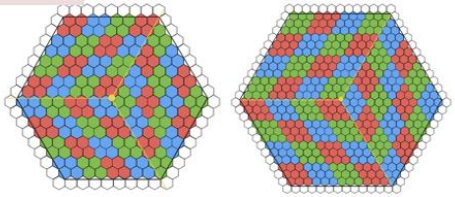
advantage: one readout per cm^3
Excellent energy, position, time res.: 5D Calorimeter

How to build a HGCal

- A collaborative work by 50+ institutions over the world

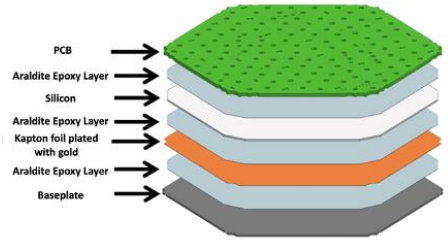
Si Sensor

8inch， 1.18cm² （192） / 0.52cm² （432）



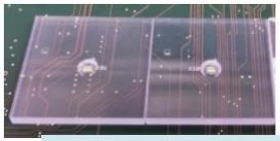
Silicon Module

620m²



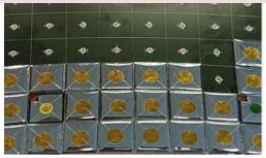
Our tasks

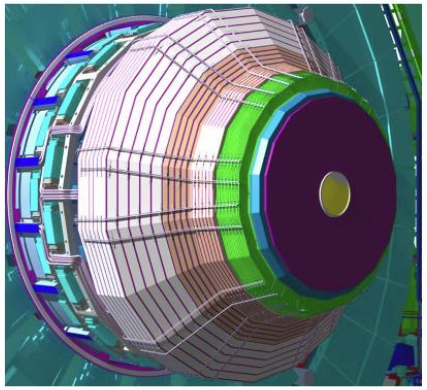
Scintillator

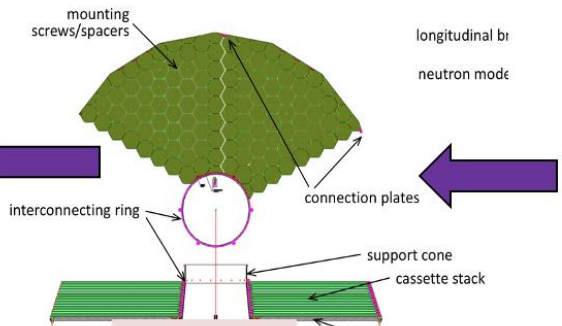


Scintillator tile + SiPMs

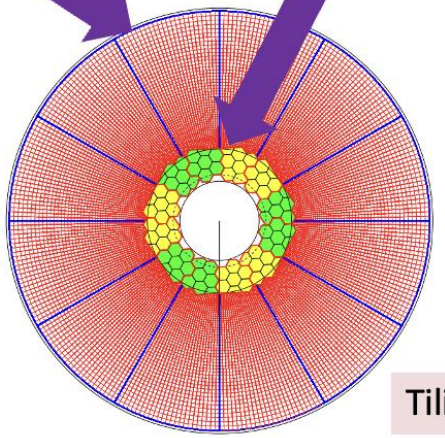
Tile module

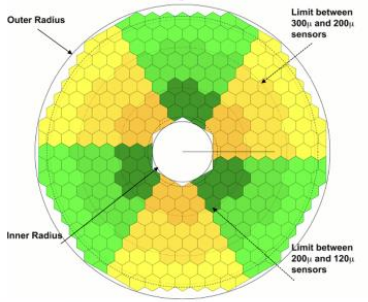






Stacking



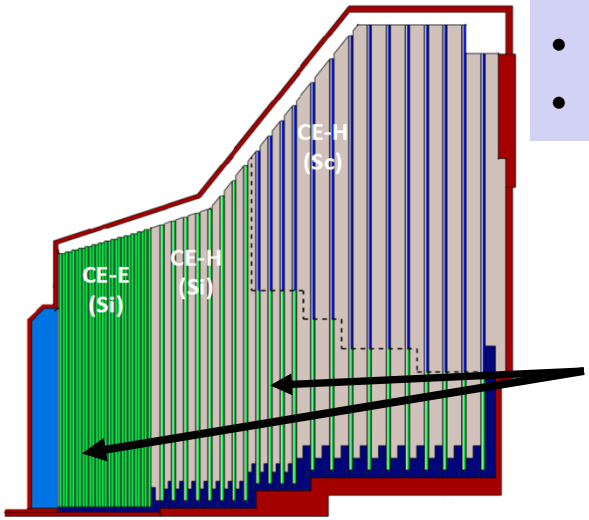


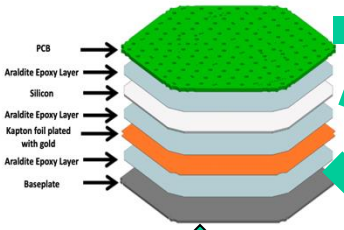
Tiling

Overview The CMS HGCal project in China

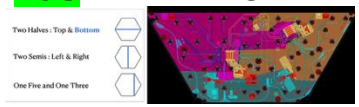
5D: Energy, 3D position, time:
Rad. Hard: 10^{16} n_{eq} MeV /cm^2

- China is one of founder that proposed HGCal in 2014
- Host one of the Module assembly center at IHEP (total 6)
- Collaboration between Chinese and outside China

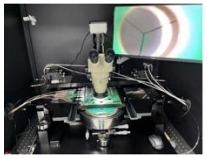




ZJU: Partial PCB design

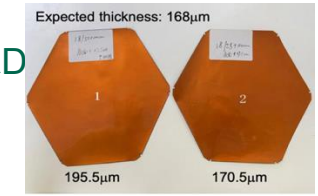


IHEP
Silicon
SQC site



~26000 Si Module
(620m^2 Si sensor)

IHEP CuW
Baseplate R&D



Core tasks of China:
produce ~20% Si module

China:
- **IHEP**
- **FDU**
- **NNU**
- **THU**
- **ZJU**

Not include Taiwan

~0.4 m^2/day production speed is needed: challenge for the project

CMS and HGCal management visiting IHEP @ 2019

Yesterday: assemble 12 modules/day

Core Task

- Module Assembly Center:
  - Produce ~5000 8-inch module, >100m^2
- Silicon Quality Control:
  - Sampling test part of Silicon senor for IHEP MAC
- CuW baseplates:
  - ～90%(area) CuW R&D and Production

- Share other HGCal related tasks at CERN
  - Such as sensor testing, beam tests, installation, commissioning, operation, software dev. etc…

- Core contribution: ～1.118 M CHF, 1.47% of total

Participants

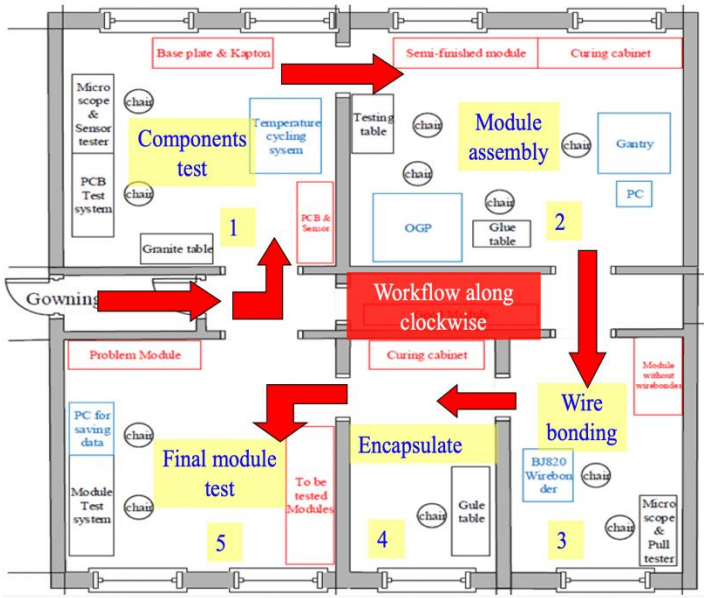
- Participants (Faculties)
  - IHEP：all CMS members + others
    - Huaqiao ZHANG, Yong Liu, Hongbo Liao, Jin Wang, Mingshui Chen, Xuhao Yuan, Shuo Han, Junquan Tao, Feng Wang, Congcong Wang, Wan Xie, Lijun Sun, Xiaoli Dong, Ye Chen, Guoming Chen
  - THU： Zhen Hu（Students + part of hardware）
  - NNU：Kai YI（Students）
  - FDU：Chengpin Shen，Zirui Wang（Students，Software dev.）
  - ZJU：Meng Xiao（PCB design，Student）

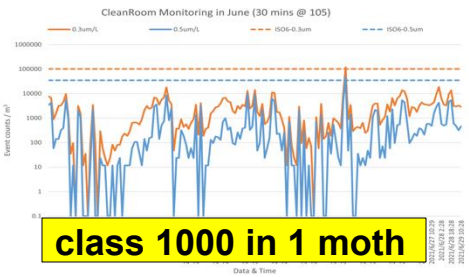
- Students
  - IHEP CMS group students（Module production，CERN HGCal work）
  - Students from THU, NNU, FDU, SXNU, ZJU
  - Few Undergraduates intership

Task 1: CMS HGCal Module assembly center

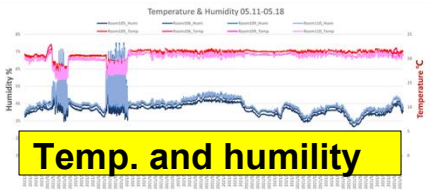
- Hosting a HGCal silicon Module Assemble Center at IHEP
  - Plan prod.: ~5000 modules, >100 m^2 silicon (on average of 6 MACs)

Clean room





class 1000 in 1 moth



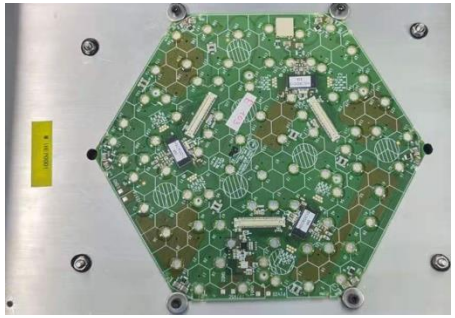
Temp. and humility

HGCal Module Assembly

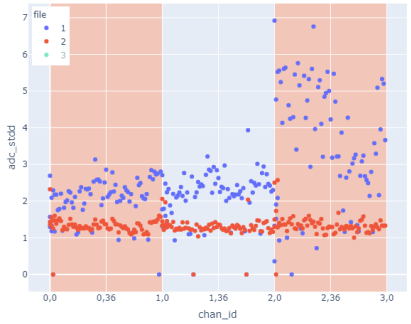
- Components test
- Assembly
- Wire bonding
- Encapsulation
- Module testing
- QA/QC

IHEP module assembly center site qualification

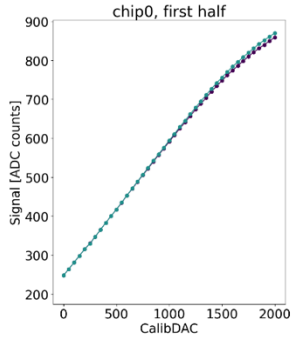
- Site Qualified in 2021
  - One of the very first qualified
  - Produced 2 live modules
  - Verified by beam test at CERN



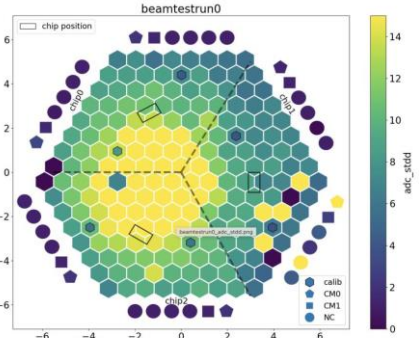
First 8 inch module at IHEP

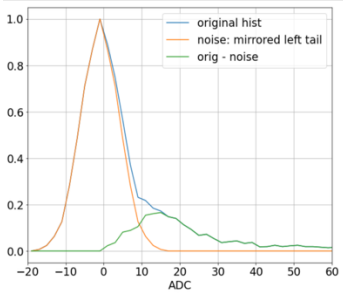


Noise before/aftter assembly



Charge injection





IHEP LD Module with HGCROCv2, 300mm silicon in September 2021 beam test

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
COMPACT MUON SOLENOID COLLABORATION
URL : http://cms.cern

Passed HGCal MAC site qualification

Dr. Karl Gill
CMS HGCAL Project Manager
Principal Applied Physicist
CERN - EP Department
CH - 1211 GENEVA 23
Switzerland
Tel. +41 75 411 4712
E-mail Karl.Aaron.Gill@cern.ch

December 15, 2021

Subject: *Certification of qualification the HGCAL Module Assembly Centre at IHEP, Beijing*

To whom it may concern,

I am writing as Project Manager for the CMS endcap calorimeter upgrade project (HGCAL) to certify that the silicon module assembly center (MAC) at IHEP Beijing, led by Prof. Huaqiao Zhang, has been qualified for the HGCAL project as ready to move into the Pre-Series phase of construction.

HGCAL will replace several of the present CMS sub-detectors: the silicon/lead endcap pre-shower detector, the lead-tungstate crystal electromagnetic endcap calorimeter, and the plastic/brass endcap hadron calorimeter. HGCAL is a novel sampling calorimeter, based on a large-scale deployment of silicon modules (a grand total of approximately 26000 installed, plus 5% spares), positioned between dense layers of absorber. The silicon modules will be complemented with plastic scintillator tiles instrumented by silicon photomultipliers (SiPMs) in regions of the detector where particles arrive with lower intensity.

The qualification of the IHEP Beijing MAC has been completed on time to meet the corresponding project milestone. The MAC is set up in a Class 1000 clean room that is dedicated to this facility and all of the equipment for mass production of silicon modules for HGCAL has been installed in the clean room and commissioned. This equipment includes a gantry machine for automated module assembly, a wire-bonding machine, an optical inspection and coordination measurement machine, and a silicon module test-stand. The IHEP Beijing team has been trained in how to use the MAC equipment, and they have practiced extensively on dummy module components before moving onto using live components.

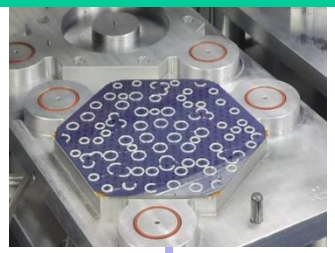
Name	Status	Baseline Date	Execution date	Distance from Critical Path
All Silicon module assembly sites and procedures qualified (HL)	self-delayed	27-May-22	11-Aug-22	649
HGCROC-V3 full silicon module validated (HL)		27-Nov-22	27-Nov-22	165
Silicon Module auxiliary components orders placed (HL)		27-Mar-23	27-Mar-23	240
Sixth silicon module assembly site and procedures qualified		28-Sep-23	28-Sep-23	386
Full silicon module qualified (HL)		7-Dec-23	7-Dec-23	165
Partial silicon's modules qualified (HL)		7-Dec-23	7-Dec-23	339
Full Silicon Modules Pre-Production Start (HL)		7-Dec-23	7-Dec-23	165
All partial silicon modules qualified (HL)		5-Feb-24	5-Feb-24	354
Silicon Modules production 5% complete (HL)		5-May-24	5-May-24	165
Partial silicon module preproduction complete (HL)		18-Aug-24	18-Aug-24	339
Silicon Modules production 50% complete (HL)		23-Feb-25	23-Feb-25	165
Silicon Module production 100% complete (HL)		16-Jan-26	16-Jan-26	165

100 m^2 Silicon module Assembly Lab

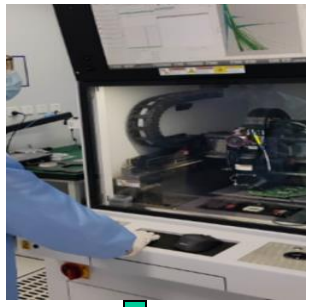
100 m^2 cleanroom, equipment, DB/software/firmware, expertise

Main Components QC
- **Hexaboard**
- **Si Senor（SQC）**
- **CuW baseplate**

High accuracy assembly using gantry

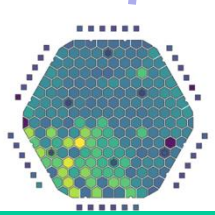


High speed bonding

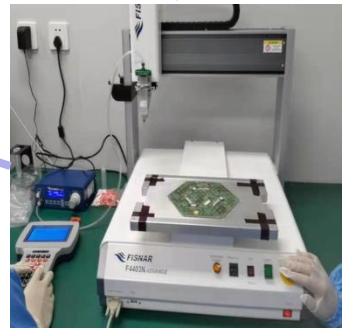


QA/QC DB

Parcking, shipping,
- **Tax**
- **Permits**
  - **embargo**



Automated electronics tests, thermal cycling



Automated encapsulation

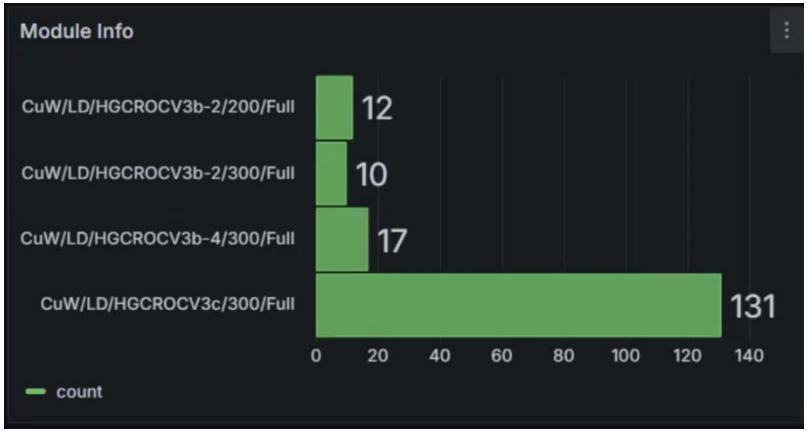
Speed at 16/day

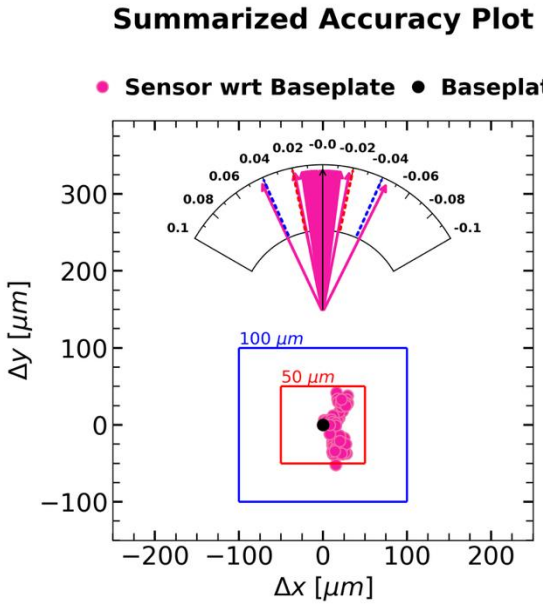
Highly automated + High accuracy Silicon detector assembly system

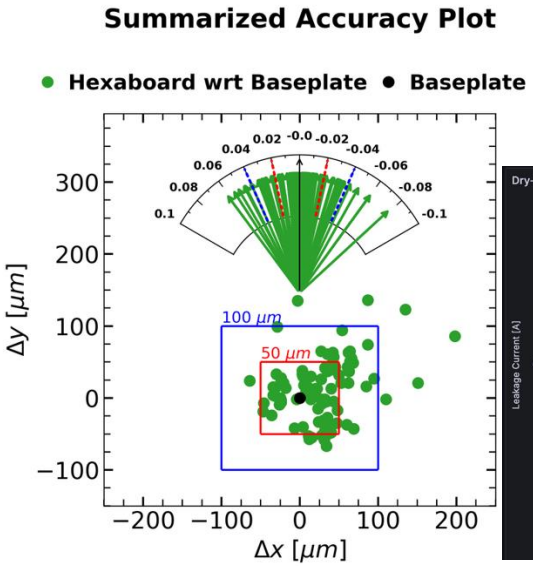
HGCal Silicon module production

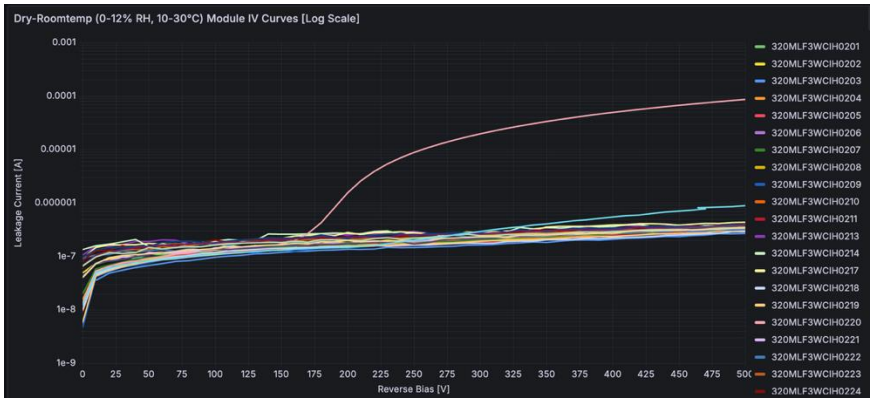
- IHEP: ~3 m^2 silicon module produced with different processes science 2025/1
  - 170 8-inch module done, ~40 left for this year
  - Very good accuracy and module quality (~A)

Nov production: 88 modules @ 11 days





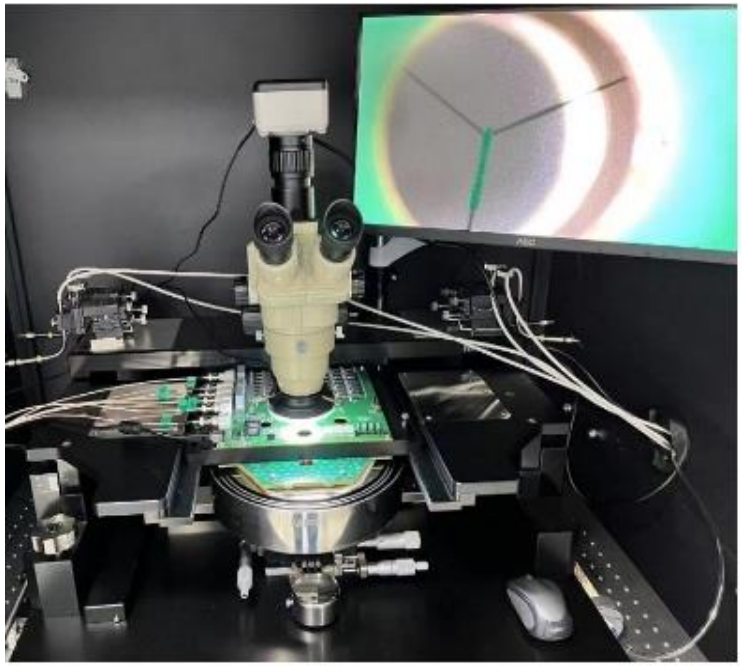


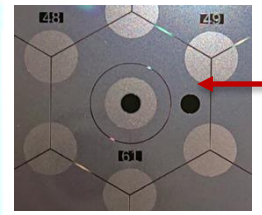


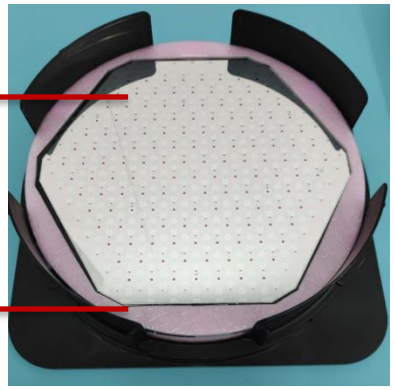
12 modules/day since last Friday

Task 2: Silicon Quality Control site

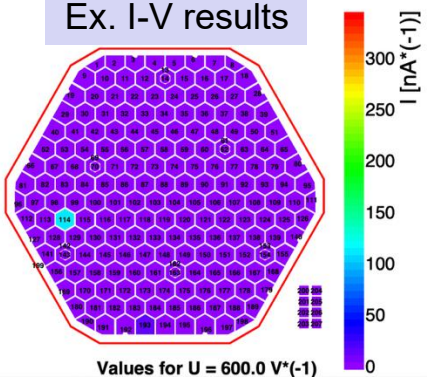
- Motivation: Test Si sensors for IHEP MAC
  - CMS SQC qualification: passed
  - 75 production sensors received. Tests completed
  - Miss-match of sensor production and Module production timeline
  - Try to catch the spare sensor production

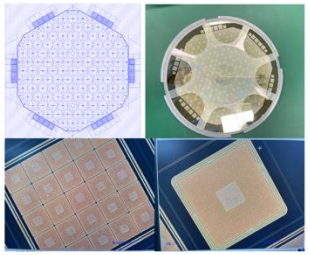


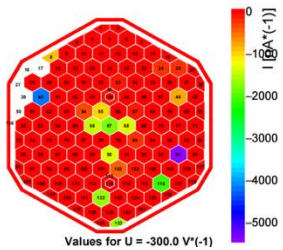




Ex. I-V results





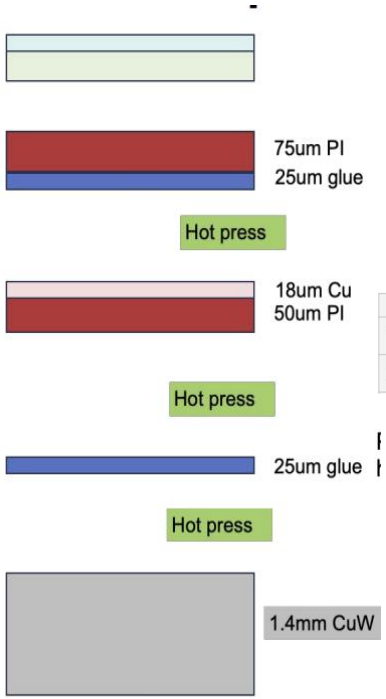


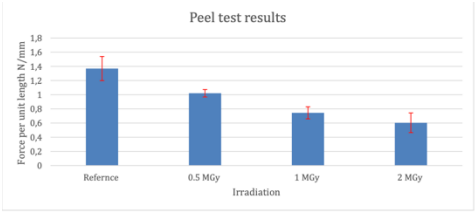
Compatible to test Chinese 6-inch sensor

Ready to ensure quality of more sensors for IHEP MAC

Task 3: CuW production in China

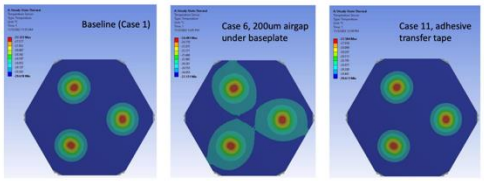
China(R&D + material) vs CERN (material money) = 1:1, order > 10M RMB in China

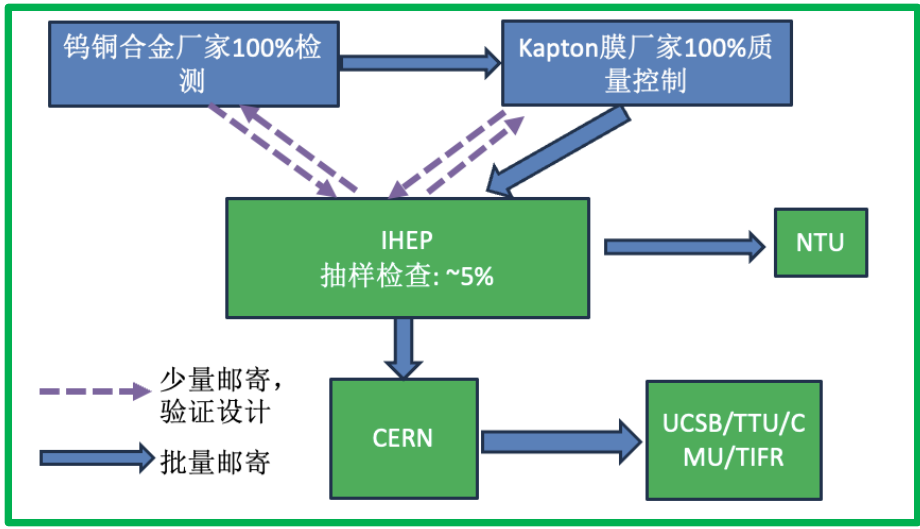




Simulation results:

	CF	Alumina	CuW (1.4 mm)	Titanium	PCB
Si Max Stresses (MPa)	139	94	84	91	115
Module Max. vertical def. (mm)	0.126	0.070	0.018	0.047	0.024





2025/8 pre-production 1200 finished

- 2025/11
  - 2500 CuW (1500LD +1000HD)
- 2026/3
  - 2500 CuW
- 2026/6
  - 2500 CuW
- 2026/9
  - 1300 CuW
- 2026/12
  - 2000 CuW

K-contract signed in 2024, Will produce 12k CuW by ~2026

What is next?

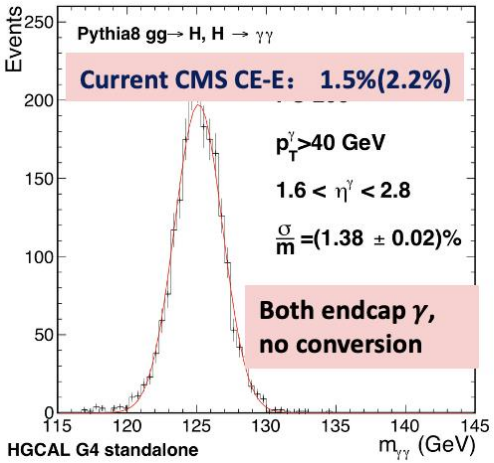
- Mass production of Si Modules for next ~2 years
  - QA/QC
  - Automation
  - Person power/expertise

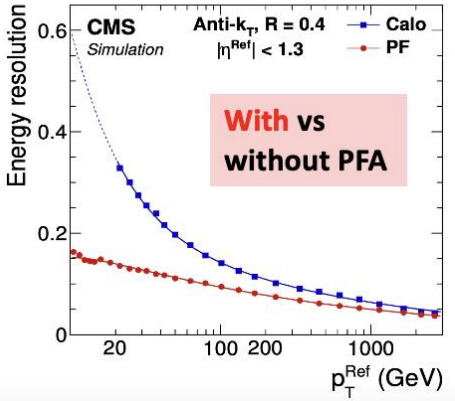
- Open Questions
  - Installation, commissioning, operation, data taking, Calibration, Reconstruction, And Physics？
  - R&D for future collider 5D calorimeter?
    - Experiences from CMS HGCal is crucial


CMS

Examples of principal of improvements

- All physics involves photon, electron, jets, muons will benefit from HGCal at run 4
- Potential is not yet fully explored, reco need dev. from scratch

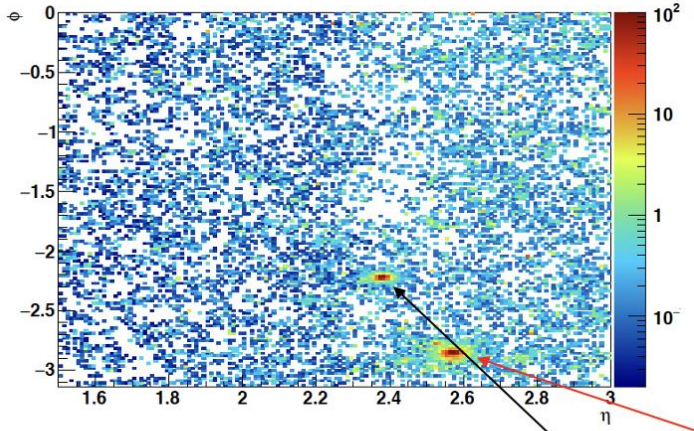




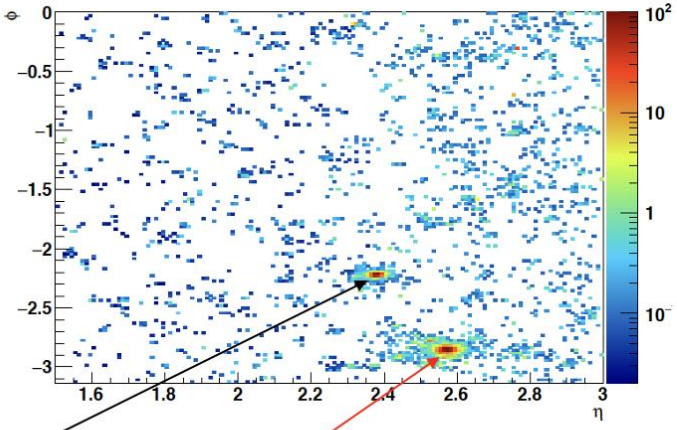
EM resolution improvement
Jet energy resolution improvement
Additional timing information
Pileup mitigation, vertex reconstruction

Expect improve **all physics** using endcap calorimeter, including **Higgs, top, SM BSM, LLP etc.**

Before timing cut



After: Cut Δt < 90ps (3σ at 30ps)

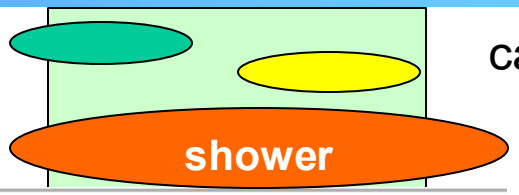


VBF (H→γγ) event with one photon and one VBF jet in the same quadrant

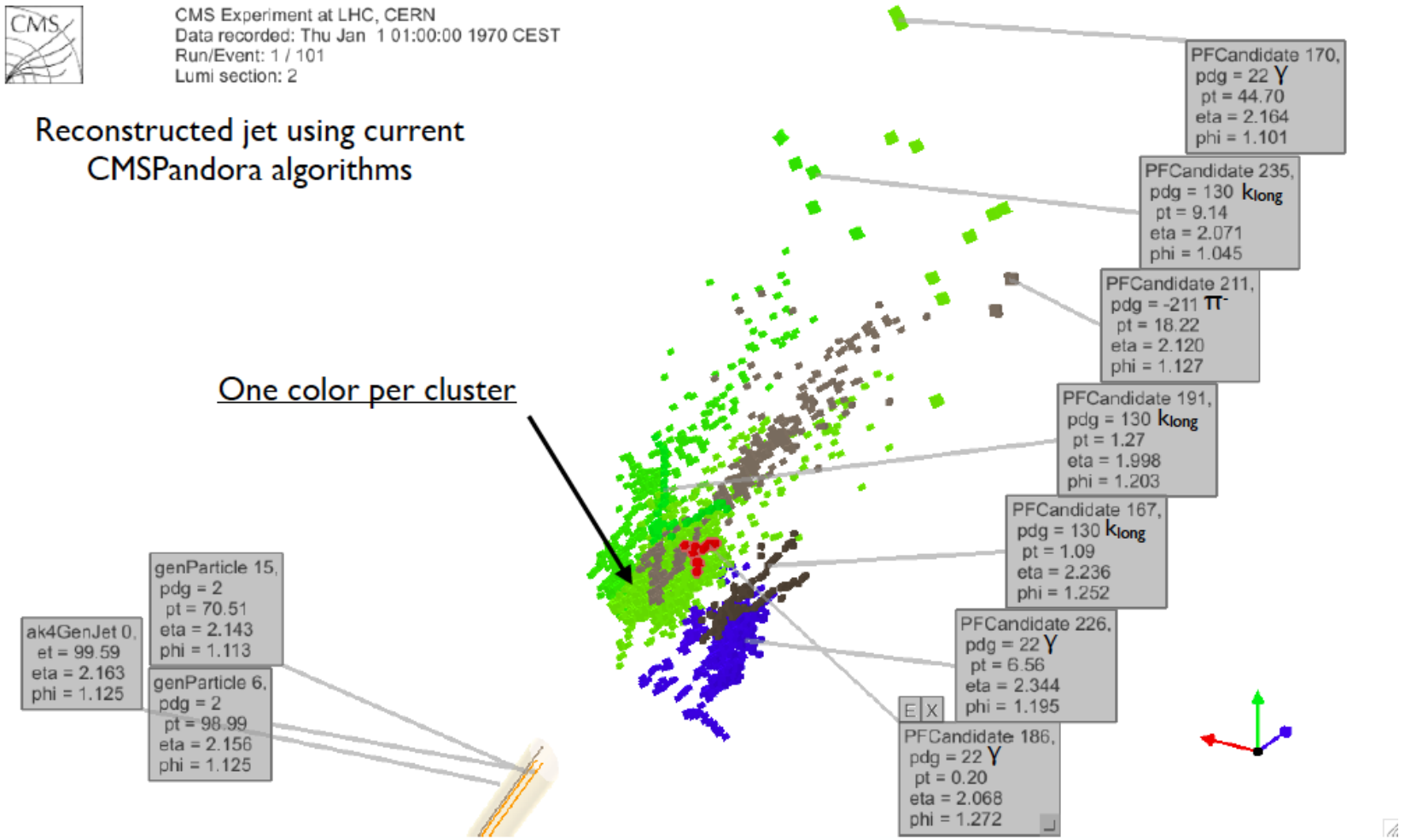
Realized HGCal is the biggest challenge

Advantage of CMS HGCal（1）

- 3D positioning
  - Full shower shape reco.: PID, Energy Calib

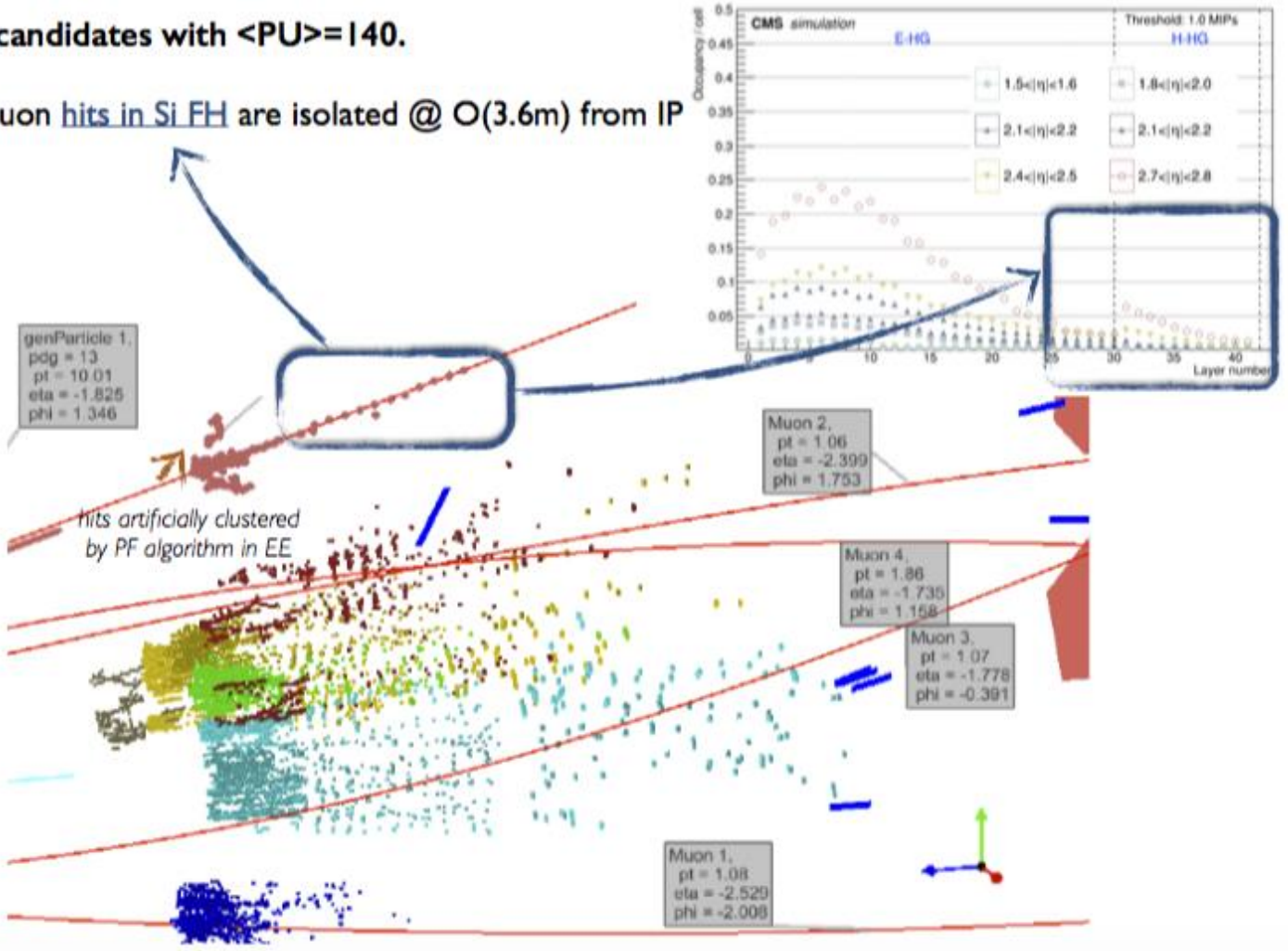


calo



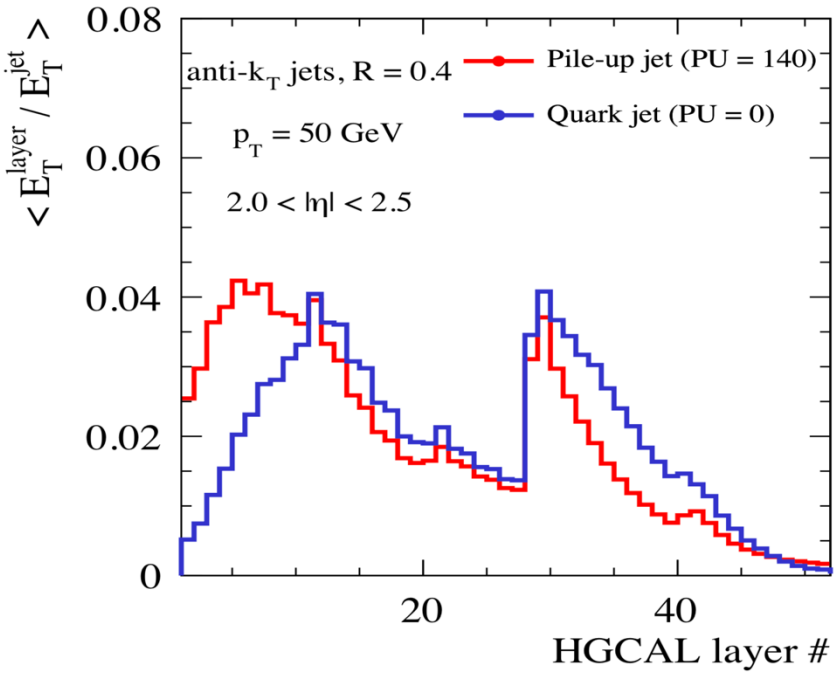
Advantage of CMS HGCal（2）

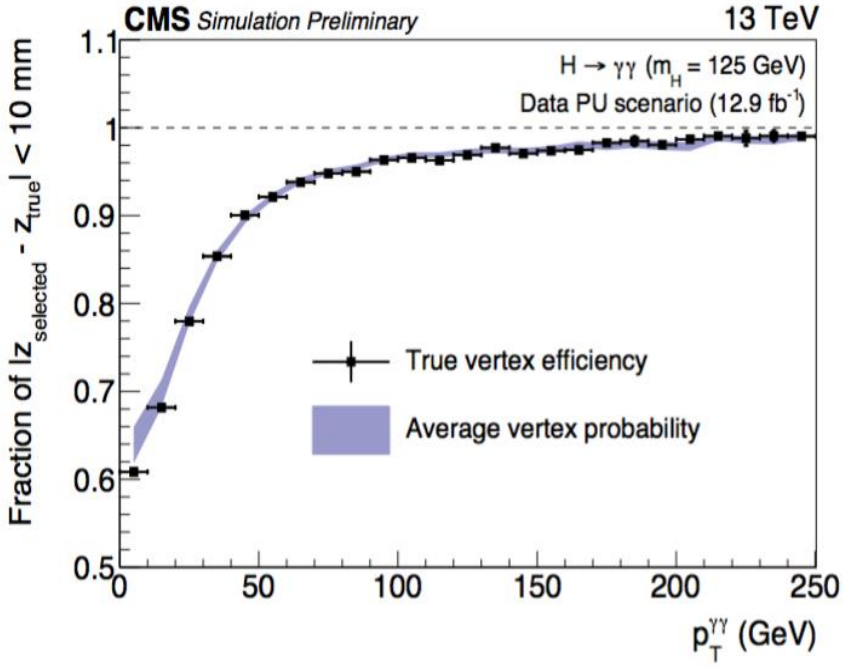
- 3D positioning
  - Full shower shape reco.: muon tag
    - **Muon candidates with <PU>=140.**
    - **True muon hits in Si FH are isolated @ O(3.6m) from IP**



Advantage of CMS HGCal（3）

- 3D positioning
  - Full shower shape reco.: pileup mitigation back pointing etc

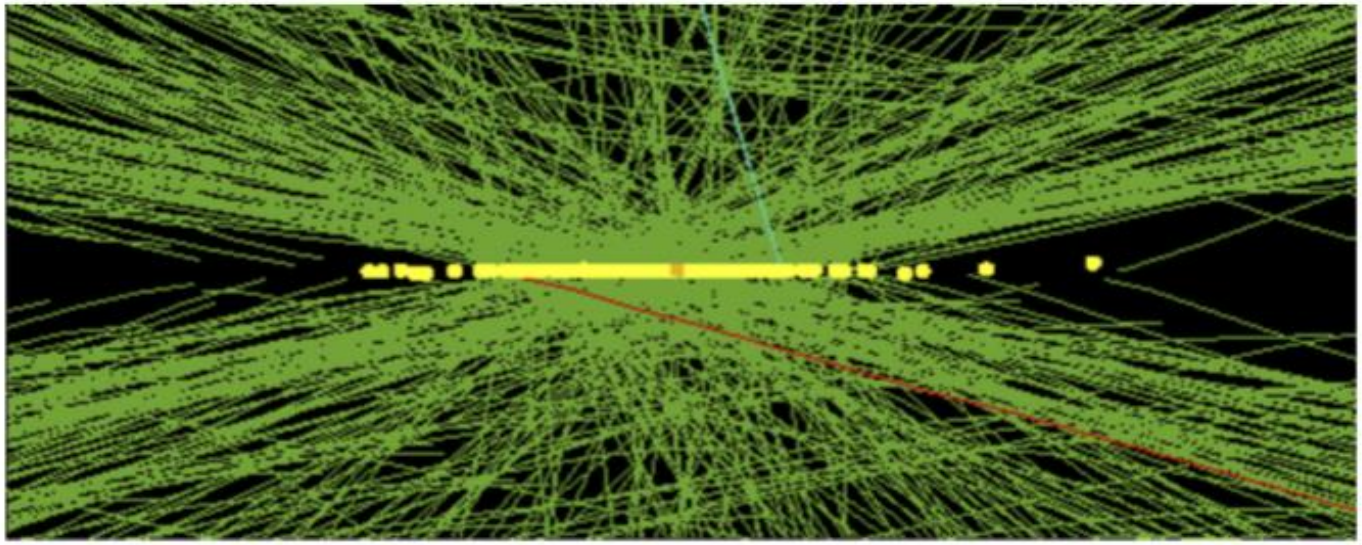




- Pileup Energy prefer deposite in first few layers
- Energy barycenter of each layer pointing back to IP
  - Complementary for IP ID

Advantage of CMS HGCal（4）

- Accurate time information
  - New dimension for calor.



78→200 PU

Figure 1.16: High pileup event with 78 reconstructed vertices taken in 2012

- Particle from different IP has different arrival time w.r.t. ref.:
  - HGC time resolution ~50ps, which light travels ~1.5cm
  - The size of HGC cell is around 1 cm^3
  - For particles from same IP, The difference of arrival time and difference of psudo-rapidility indicates the position of IP