Progress of CMS China group on Phase II upgrade

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IHEP, Beijing

On behalf of CMS-China group

The 11th China LHC Physics meeting(CLHCP2025)

CMS Upgrade on track

Tasks of China Group

L1-Trigger
https://cds.cern.ch/record/2714892
- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting

DAQ & High-Level Trigger
https://cds.cern.ch/record/2759072
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

Tracker
https://cds.cern.ch/record/2272264
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

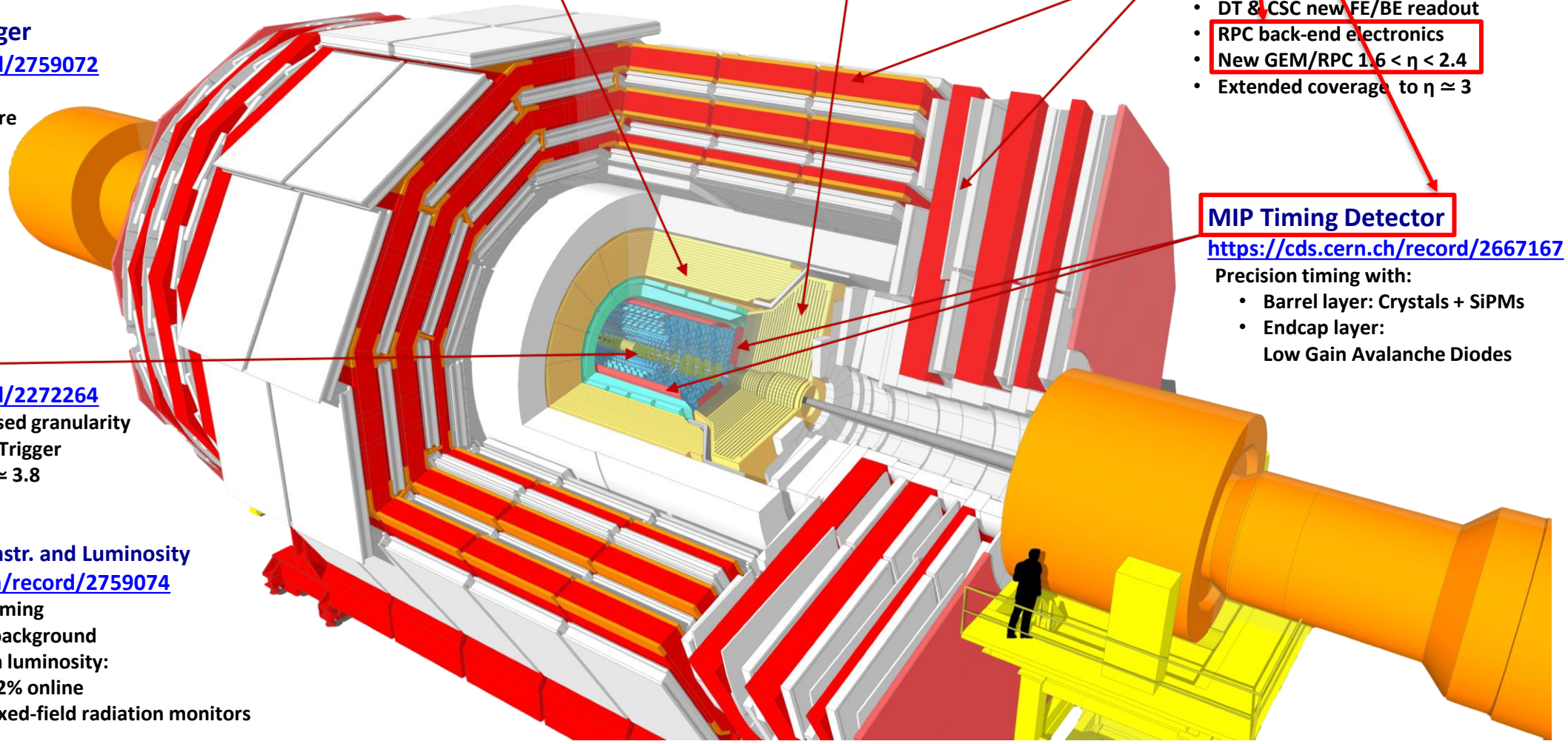
Beam Radiation Instr. and Luminosity
http://cds.cern.ch/record/2759074
- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity:
  1% offline, 2% online
- Neutron and mixed-field radiation monitors

Barrel Calorimeters
https://cds.cern.ch/record/2283187
- ECAL single crystal granularity at L1 trigger with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards

Calorimeter Endcap AKA HGCAL
https://cds.cern.ch/record/2293646
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

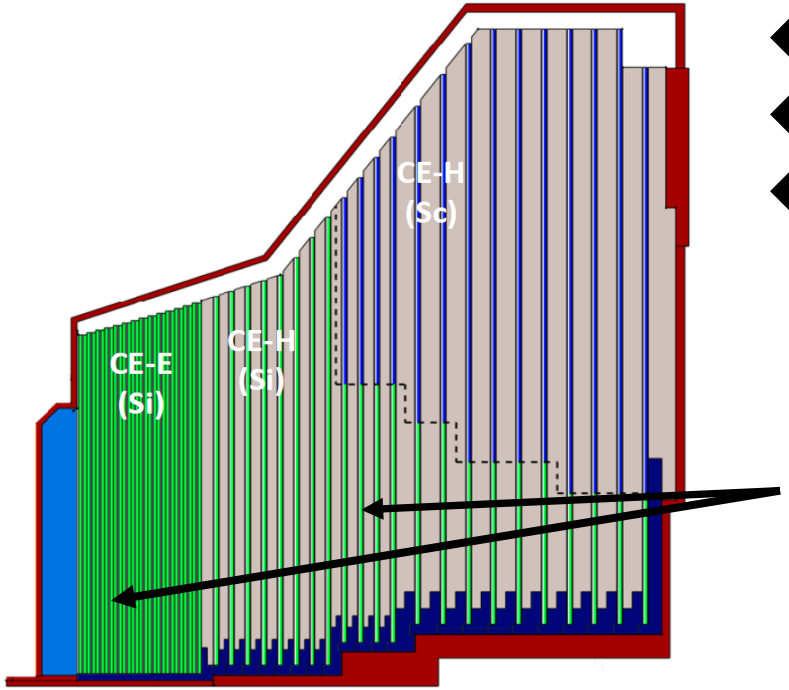
Muon systems
https://cds.cern.ch/record/2283189
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$

MIP Timing Detector
https://cds.cern.ch/record/2667167
Precision timing with:
- Barrel layer: Crystals + SiPMs
- Endcap layer:
  Low Gain Avalanche Diodes

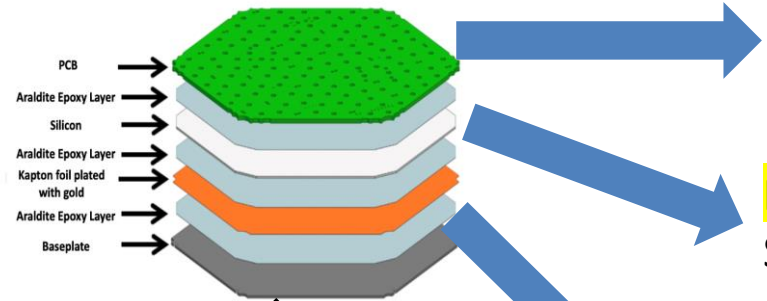


I. CMS Calorimeter Endcap progress

HGCal tasks in China

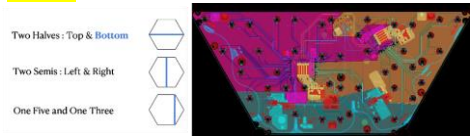


- China is one of founder that proposed HGCal in 2014
- Host one of the Module assembly center at IHEP (total 6)
- Collaboration between Chinese and outside China

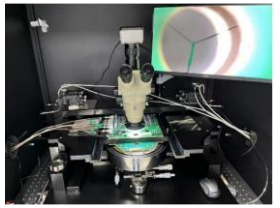


~26000 Si Module (620m² Si sensor)

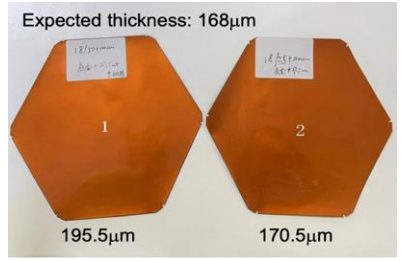
ZJU: Partial PCB design



IHEP Silicon SQC site



IHEP CuW Baseplate R&D



Core tasks of China: produce ~20% Si module

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

Not include Taiwan

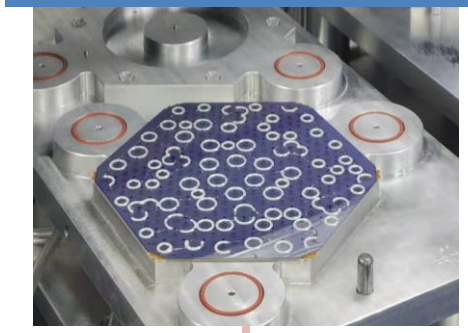
~0.5 m²/day production speed is needed: challenge for the project

HGCal Silicon module Assembly methodology

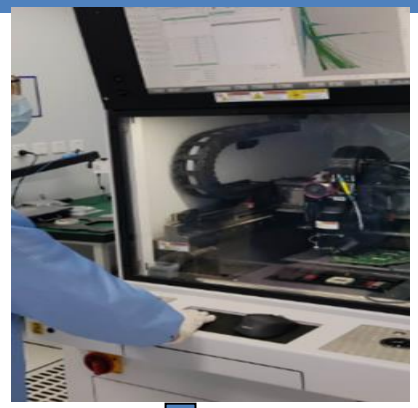
Workflow and process

Quality check of components
- **Hexaboard**
- **Silicon Sensor**
- **Baseplates**

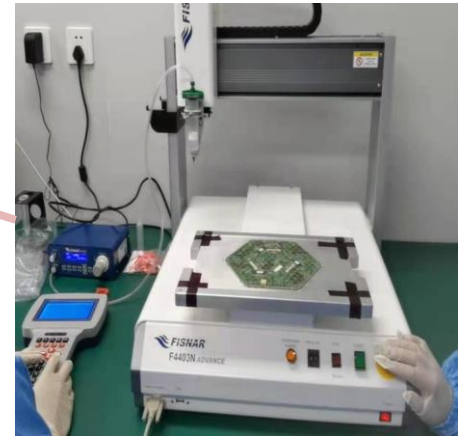
High precision assembly with gantry



High Speed wire bonding

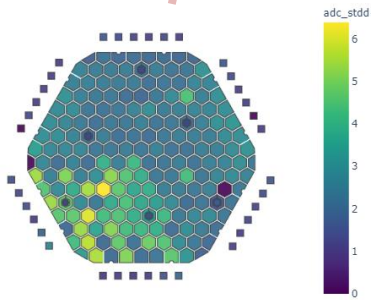


QA/QC Data Base



Auto encapsulation

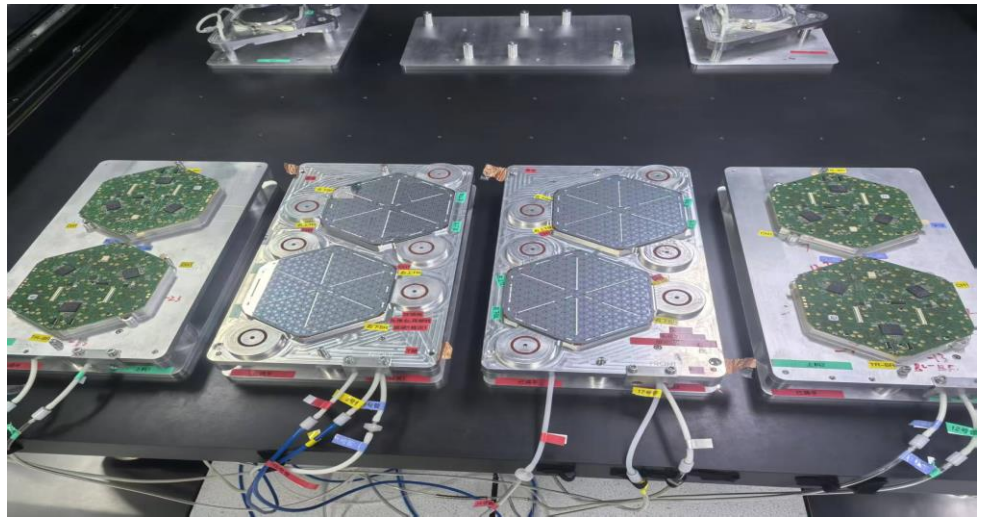
Package, shipping and receiving
- **Taxes**
- **export/import license**



Elec. testing with thermal cycling

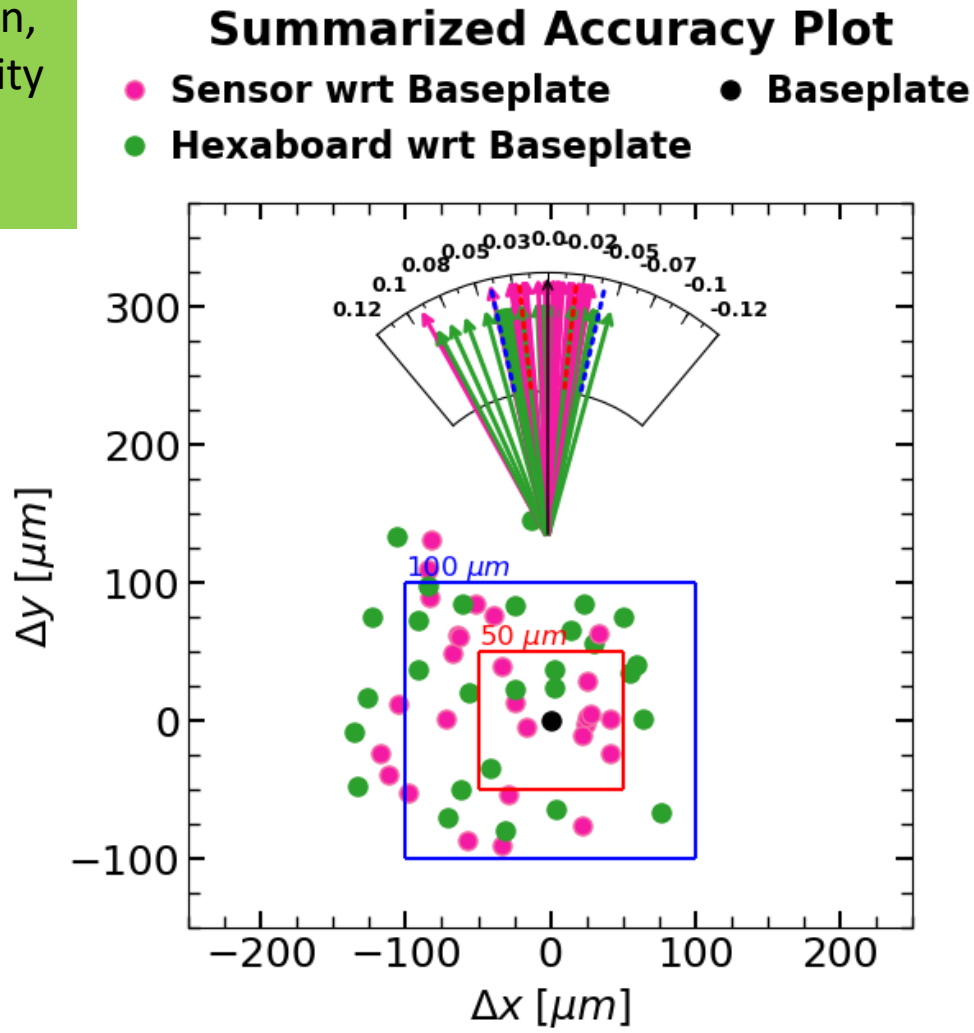
Highly automated + high accuracy silicon module assembly process

Silicon Module production ramping up



Paralization, Calibration, automation, high quality control etc to improve the production speed

4 modules/day for 7 days

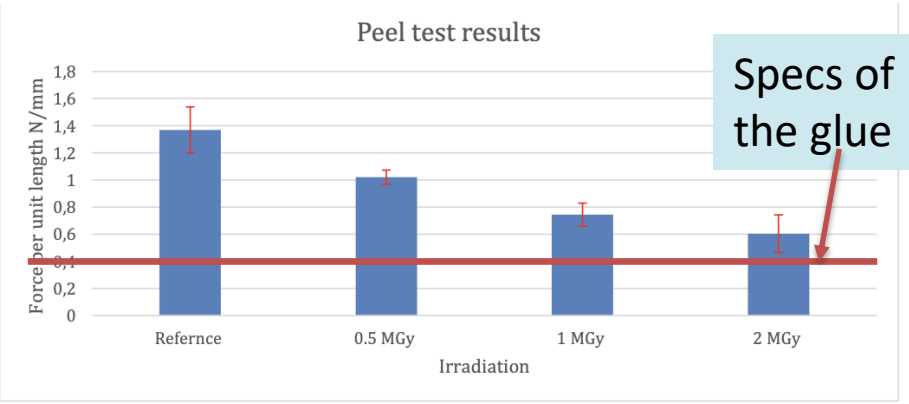


- The module production ramping up at IHEP.
  - ❑ 1 module/day: done
  - ❑ 2 modules/day: done
  - ❑ 4 modules/day: done
  - ❑ 8 modules/day: planed in Nov. 2025
  - ❑ 16 modules/day: expected by 1st or 2nd quarter of 2026
- Limited by components availability (hexaboards)

Stable ramping up

CuW baseplate production (1)

- R&D on CuW baseplate at IHEP since 2022
  - Several batches produced and tested
  - IHEP baseplate use industry hot-press method for the lamination(IHEP design)
  - Radiation hard material identified

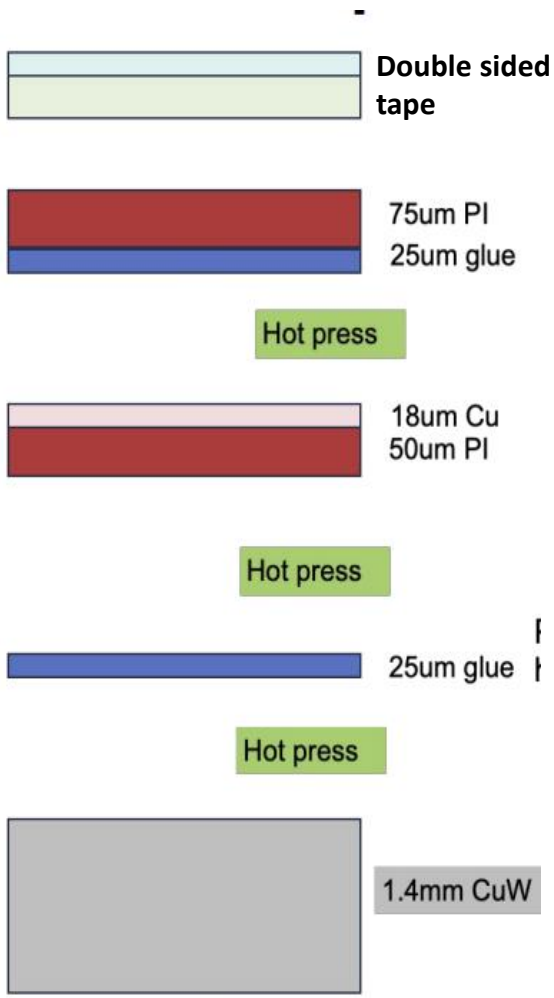


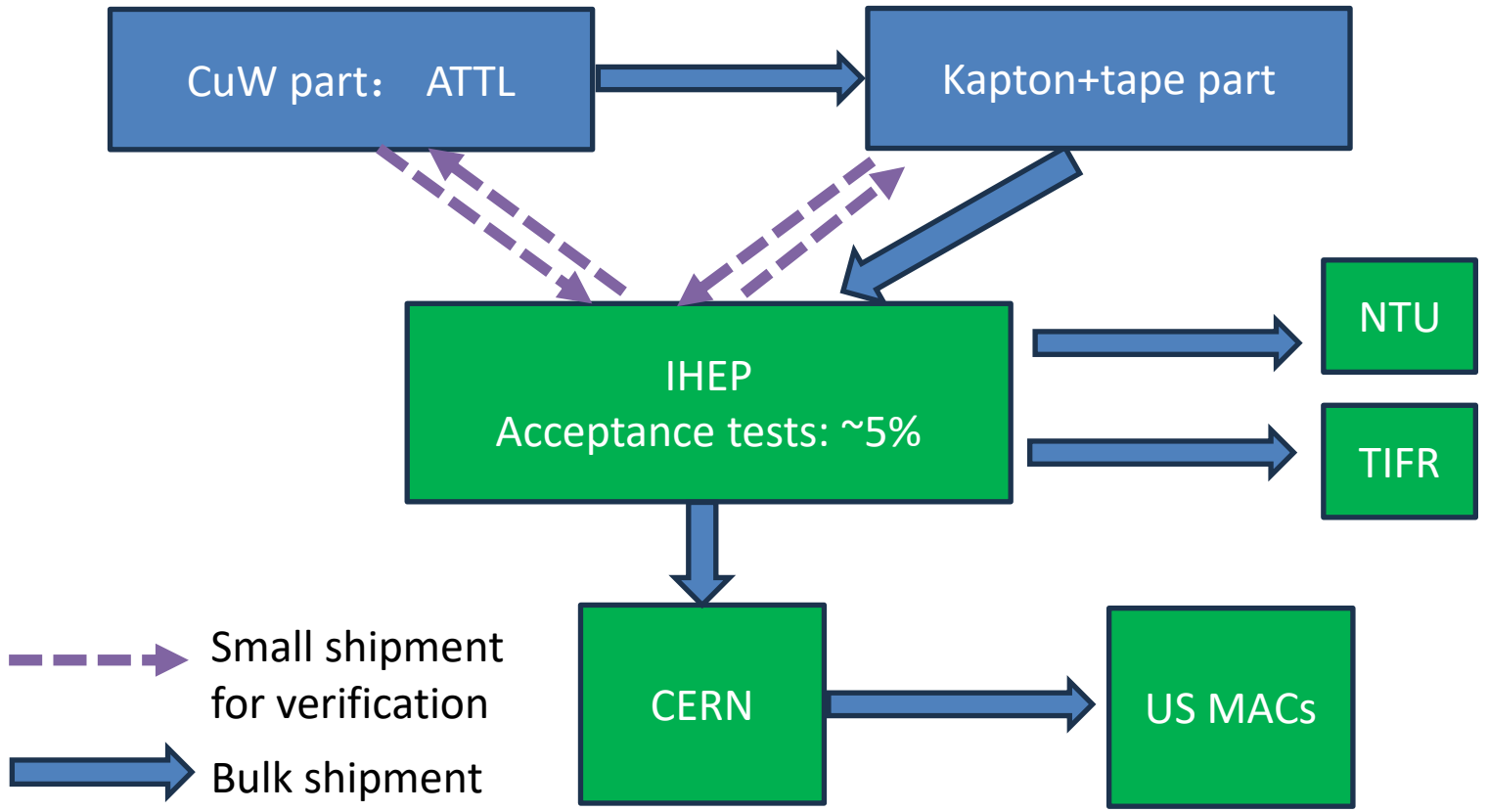
- K-contract between IHEP-CERN signed in Nov-2024
  - ~12k full size CuW baseplated will be procurement via IHEP, with CERN and IHEP contribute 50% each, Covers ~90% of CuW production
  - Procurements/bid process and final adjustment on design since then
- First batch of 1200 CuW baseplate ready in July-Aug. 2025
  - Very good quality confirmed (Grade A for All CuW part, and 95% yield after lamination)
  - Full production foreseen by end of 2026

CuW baseplate dominated by IHEP

CuW baseplates Production (2)

IHEP design



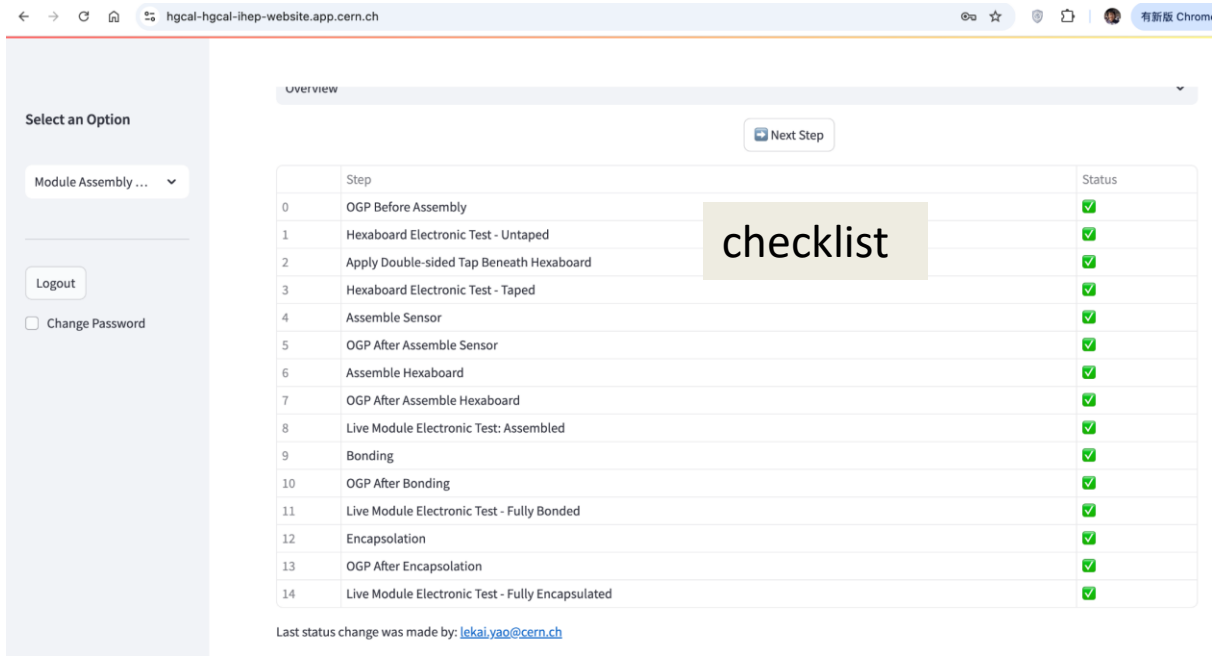


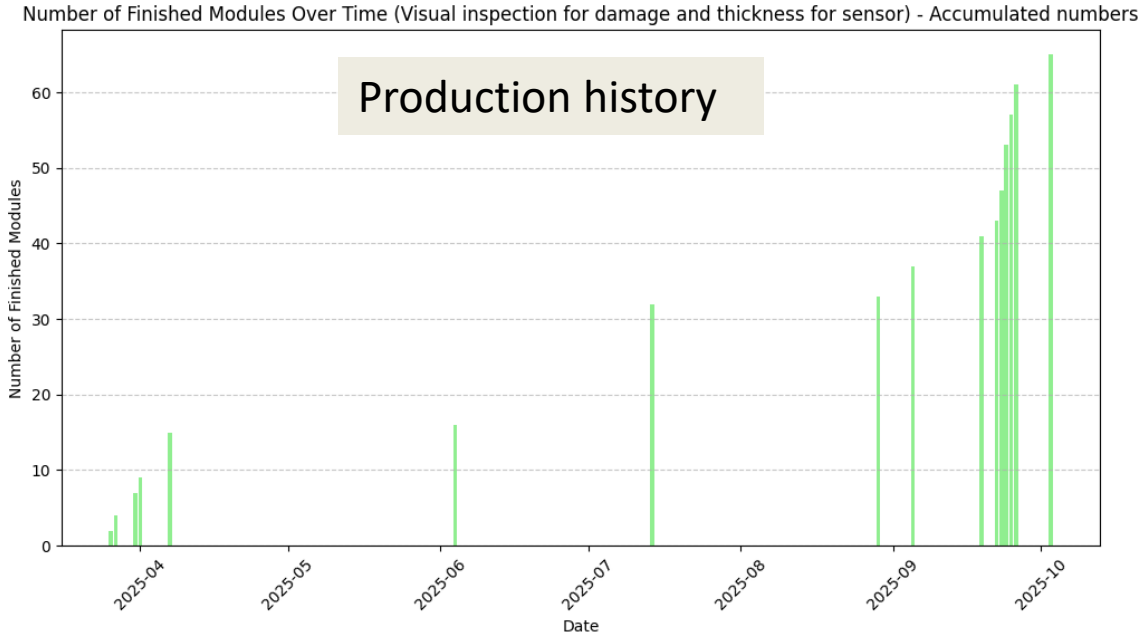
◆If no tariff issues, IHEP can send CuW directly to MACs
- For US MACs, send via CERN (preparing paperwork of CERN→US)

Work flow management webpage developed

- ~12 FTE needed for full speed silicon module production, to reach the 16 modules/day production rates
- Automate Checklist and notification to ensure smooth coordination
- Management via production webpage developed by IHEP/FDU, and shared to other MACs for efficiently usage

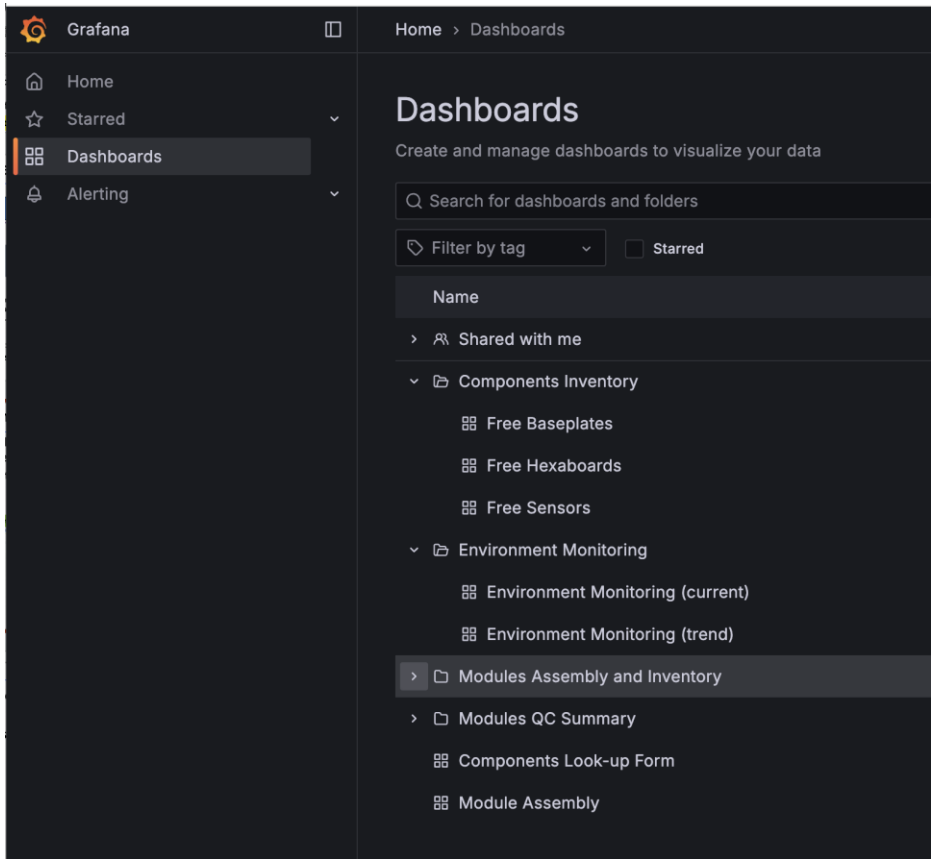
https://hgcal-hgcal-ihep-website.app.cern.ch/





Production Database integration

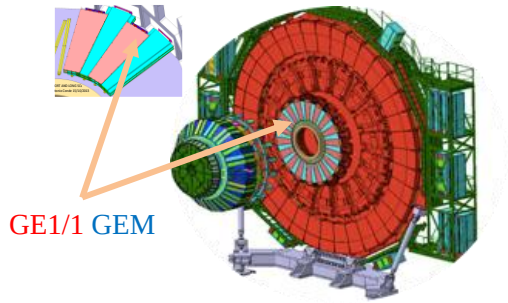
- SQL database for local (postgres) and central (CMSR)
- Deployed Grafana based local database monitoring
- Long term and high statistics silicon module quality study ongoing

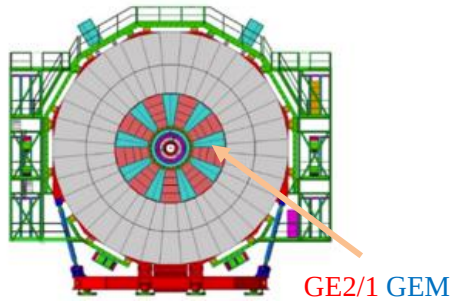


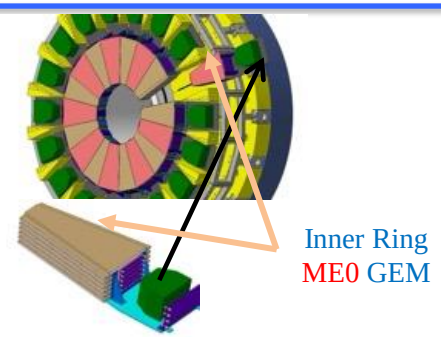
II. CMS Muon progress

CMS GEM upgrade: CMS-China tasks

CMS GEM System Phase-II upgrade:

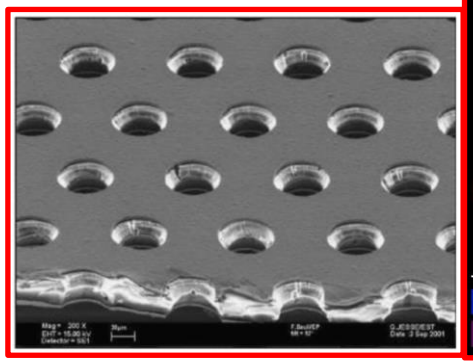


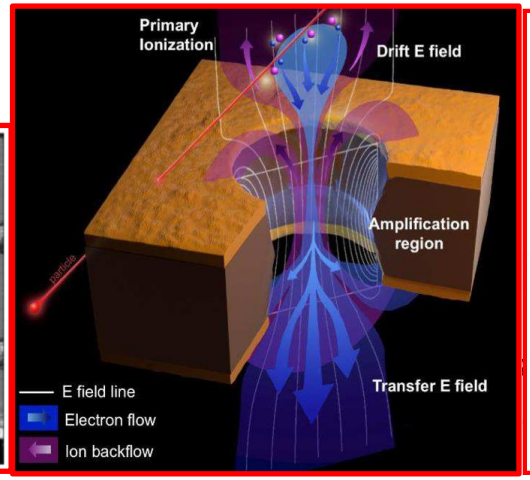


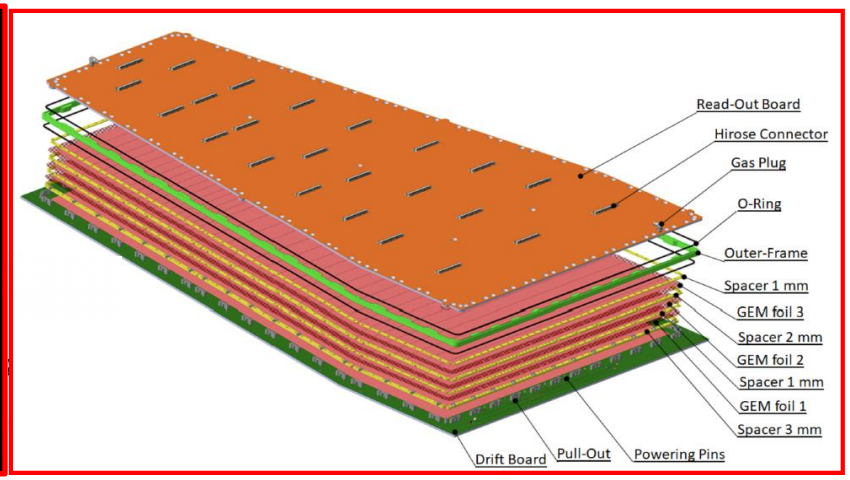


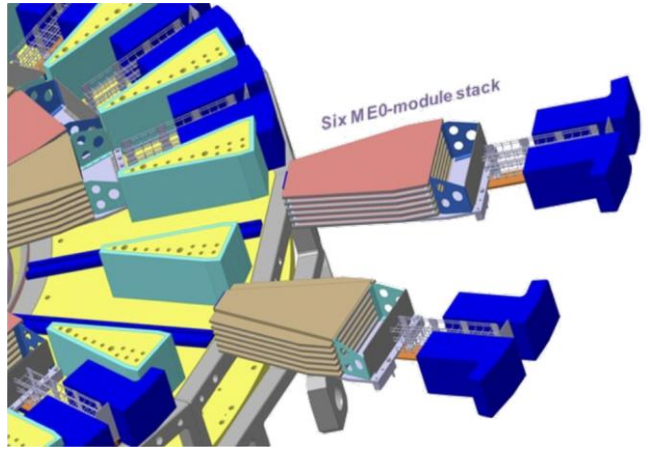
		GE1/1	GE2/1	ME0
Numbers*		288（=2×36×4）	288（=2×18×8）	216（=2×18×6）
plan	prototyping	2013-2017	2014-2022	2014-2023
	batch **production**	2017-2019	2022-2028	2024-2026
	Install&commission	2018-2020	2028-(?)	2027-2029
CMS-China **Contributions**		Production and test of all electronic boards(GEB) Participate assembly, test and commissioning at CERN	Design, production and test of all electronic boards(GEB) Assembly and QC of ~1/8 GEM detectors at PKU，Participate assembly, test and commissioning at CERN Production of FR4 frames, mechanical structures, etc	Design, production and test of all electronic boards(GEB)， Assembly and QC of ~1/5 GEM detectors at PKU， Participate assembly, test and commissioning at CERN Production of FR4 frames, mechanical structures, etc

CMS GEM upgrade: GEM module assembly









GEM module production timeline

- **Vendors**
  - Manufacturing of the detector components
  - Shipment to CERN
- **Central Site (at CERN)**
  - Material inspection (QC1/QC2)
  - Pre-assembly work
  - Preparation of assembly kits
  - Shipment to/back from production sites
- **Production Sites**
  - Module assembly
  - QC2-QC5 tests
  - Data Base updates

1st	2nd	3rd	4th & 5th	6th
Jul-Sep 2024 ✓	Oct-Dec 2024 ✓	Feb-May 2025 ✓	Oct-Nov 2025	2026

CERN
- QC 1: material inspection
- QC 2: GEM foils test (fast + long)

Production sites (e.g. PKU)
- QC 2: GEM foils test (fast)
- Assembly preparation + Assembly
- QC 3: gas leak test
- QC 4: HV test
- QC 5: gas gain calibration (gain + uniformity)

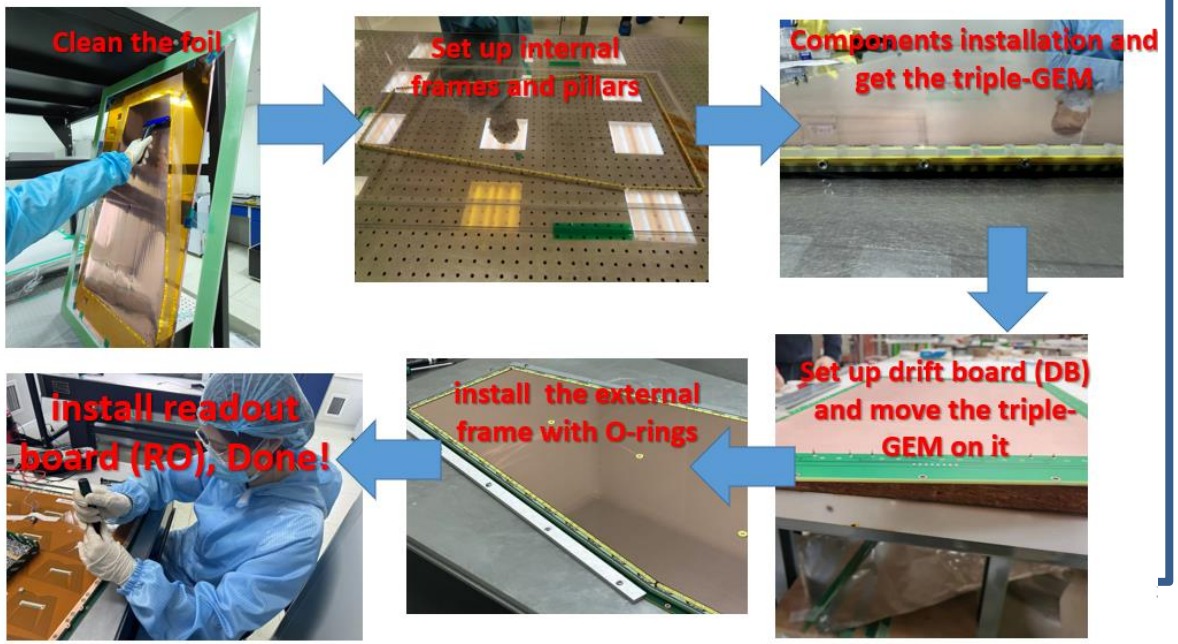
CERN
- QC 6: HV stability test
- QC 7: electronics connectivity test
- QC 8: cosmic ray test

CMS GEM upgrade: GEM module assembly

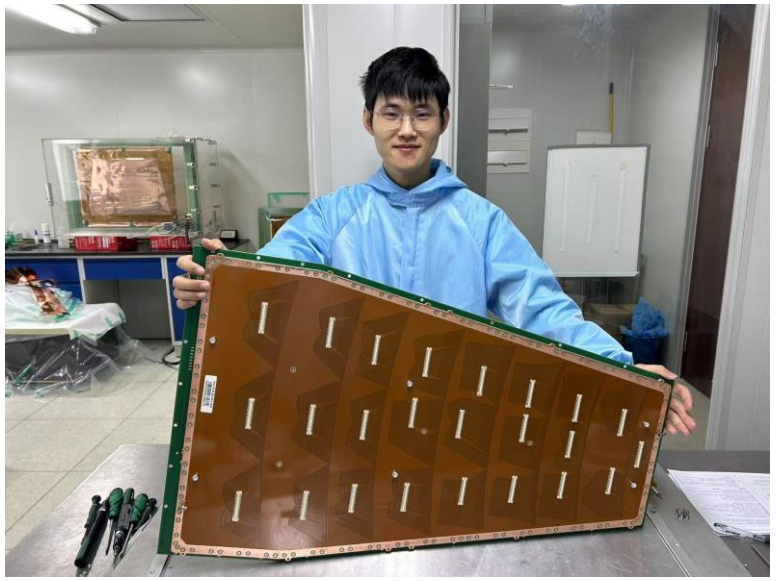
◆ **Second batch of 10 ME0 GEM assembly and test at PKU (Mar.-May. 2025)**

GEM Production Laboratory

GEM Assembly Process



1st ME0 module (2nd batch) assembled at PKU (Apr. 2025)

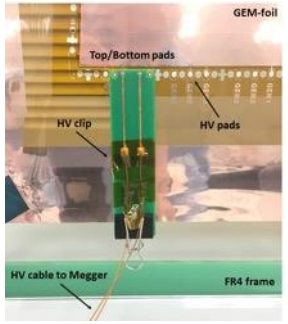


- Totally ~220 ME0 GEM modules will be produced
- PKU site is expected to produce 1/5 of them. 20 produced by now

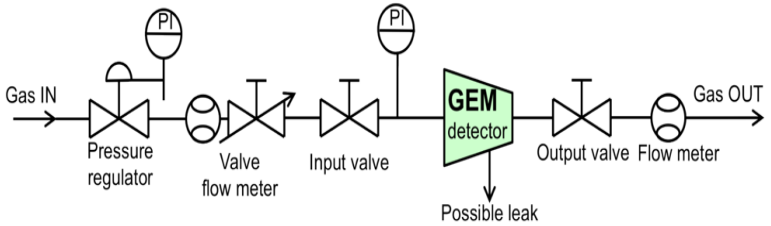
CMS GEM upgrade: GEM module QC test

- **All 10 GEM were tested, trouble-shot, and shipped to CERN in May 2025**

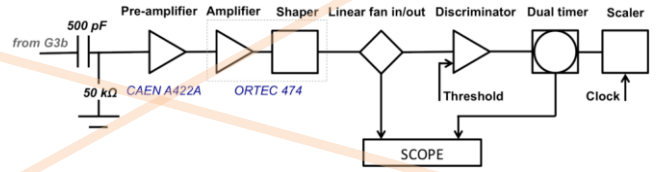
QC2:
GEM foil impedance



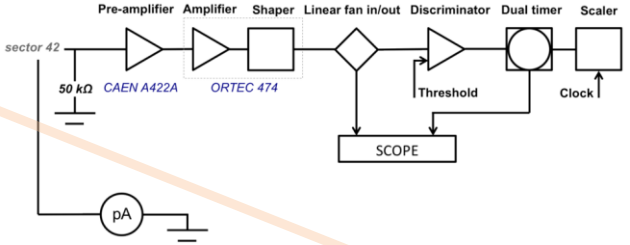
QC3:
gas leakage

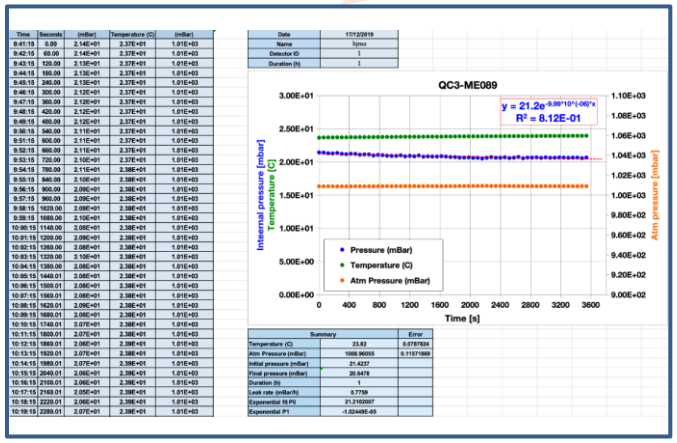


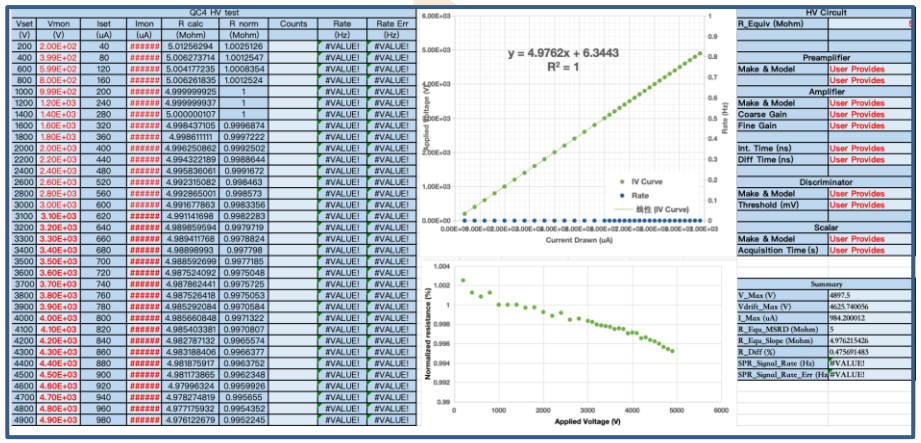
QC4:
V-I performance

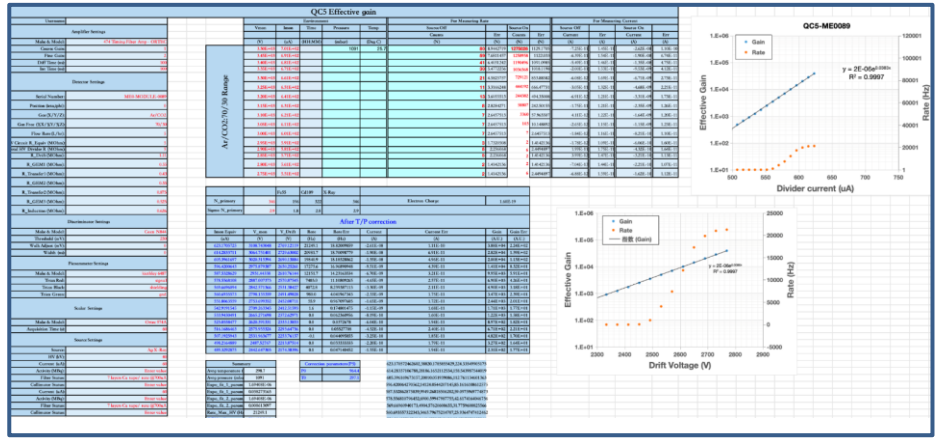


QC5:
effective gas gain







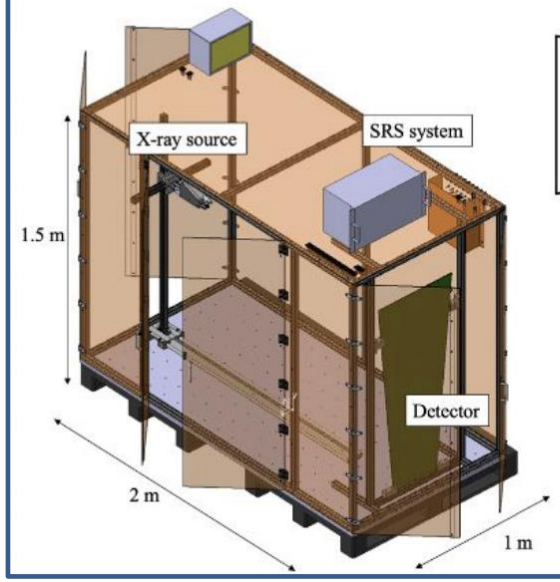


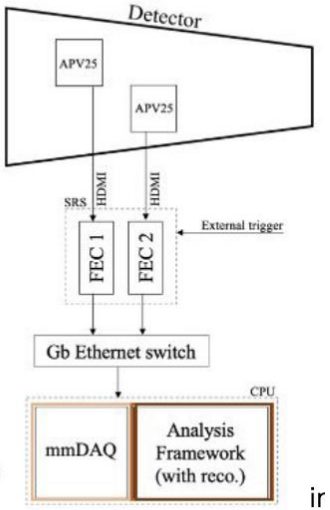
CMS GEM upgrade: GEM module production

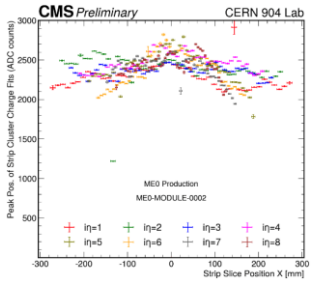
- The assembly and test of the second batch of 10 ME0 GEM modules at PKU is completed, shipped to CERN at May 2025.
- Due to ROB (read-out boards) quality problem, ROB of all modules (from all production sites) were replaced at CERN, along with other treatments.
- Next batch of 10 ME0 GEM production at PKU is scheduled in Nov. 2025, preparation is under way.

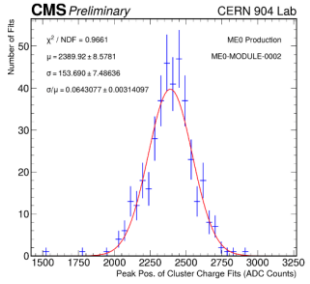
Further tests at CERN: Gain Uniformity Measurement, Stack and cosmic-ray test

Gain Uniformity Measurement

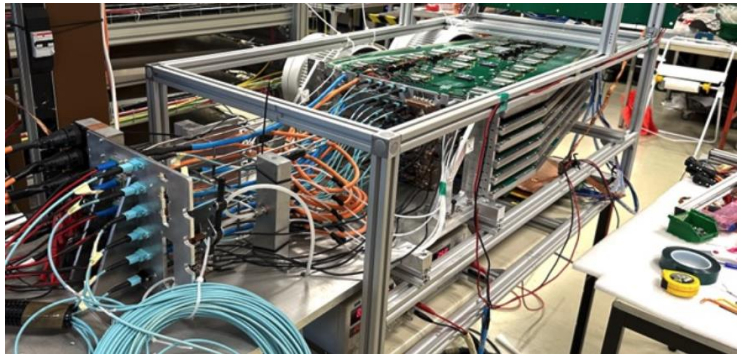


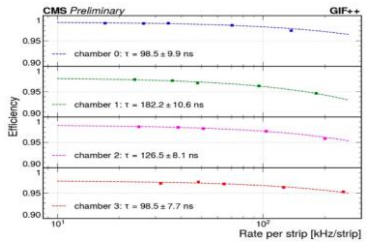


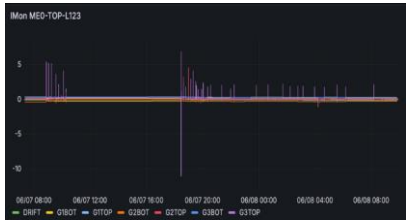


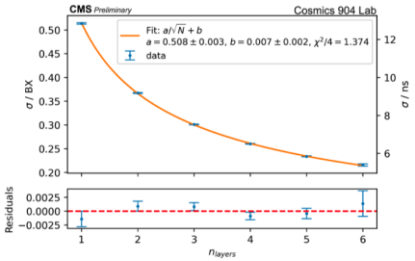


Stack and cosmic-ray test

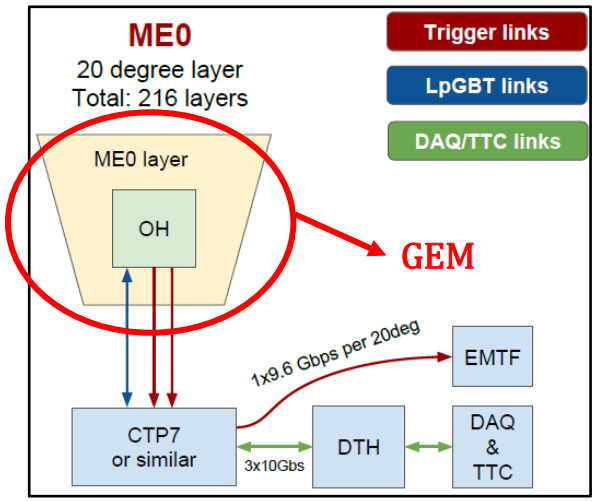




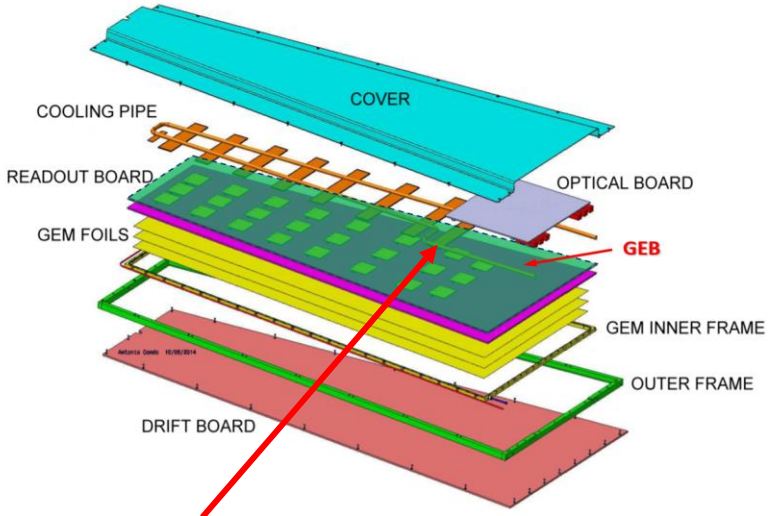




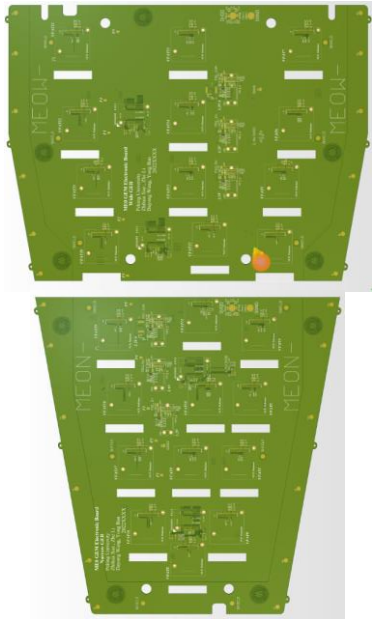
CMS GEM upgrade: ME0 GEB Status



DAQ system of CMS-GEM



GEB: front-end electronics board of upgraded CMS-GEM (GE1/1, GE2/1, ME0)



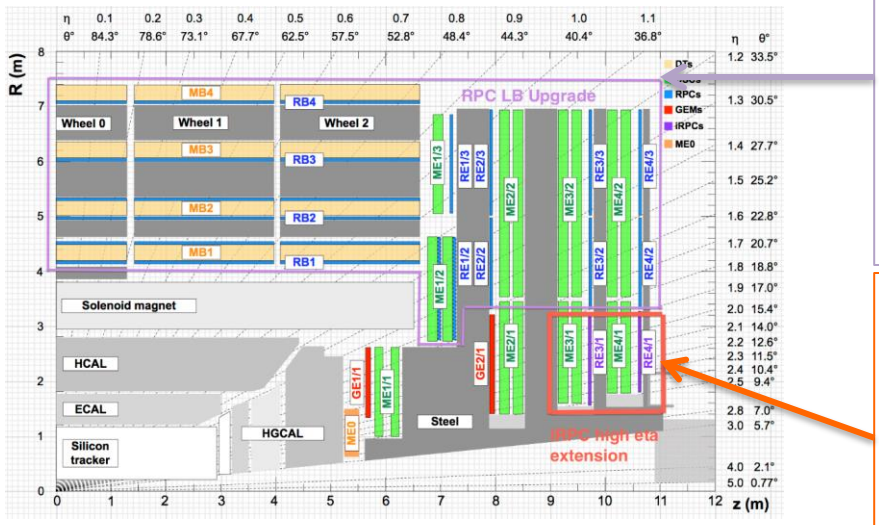
- **Function of GEB :**

  Carrier of front-end and back-end electronics system; front-end signal transmission carrier; provide direct shielding for GEM detectors

- **Tasks of CMS China group:**
  - Production and test of GE1/1 GEB
  - Design、production and test of ME0 and GE2/1 GEB
  - Development of automatic tester

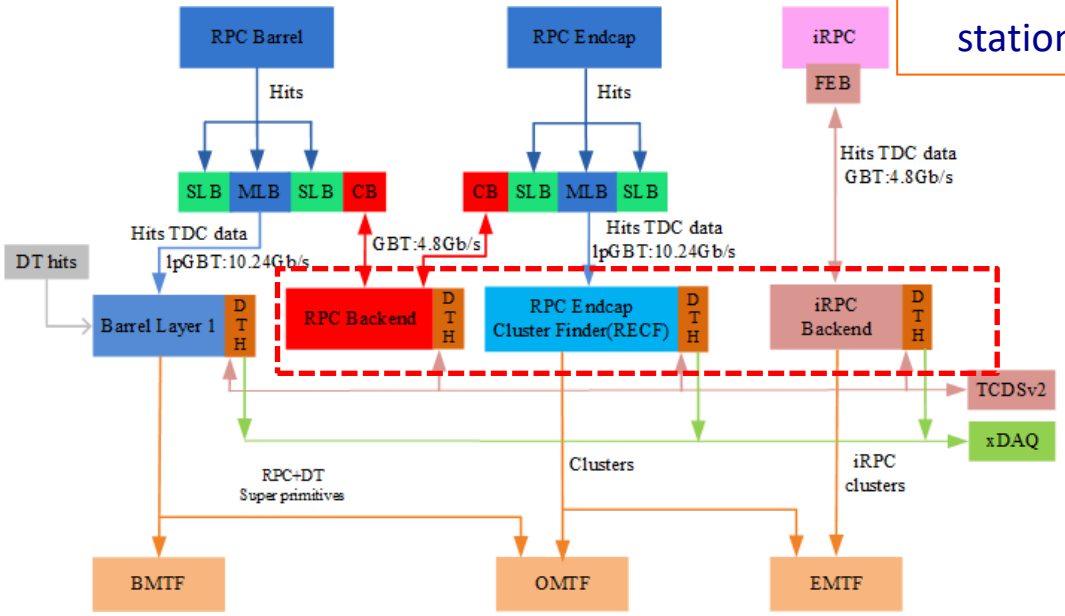
- **Milestone of ME0 GEBs production and test:**
  - 1st batch of 15 sets of ME0 GEBs produced on Jan. 2023, completed test at CERN in Apr. 2024
  - 240 sets of the remaining GEBs production completed in Feb. 2024, 2nd batch of 95 sets of GEBs tested in China and shipped to CERN in April 2024
  - 3rd batch of 145 sets of GEBs tested at China completed in Nov. 2024, shipped to CERN ~end of Nov. 2024
- **Acceptance test at CERN:** make sure no damage in shipment.
  - ➢ By Oct. 2025, half of ME0 GEBs has been tested by PKU group with acceptance criteria, all qualified.

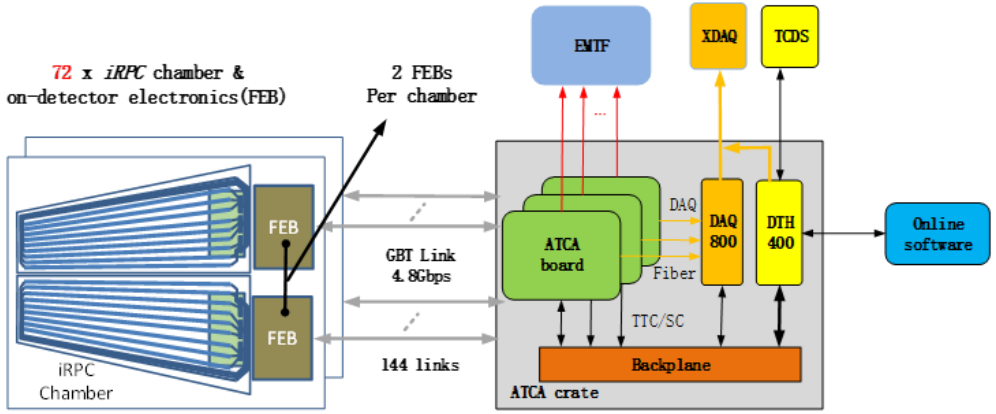
Phase-II RPC BE/TRG tasks in China

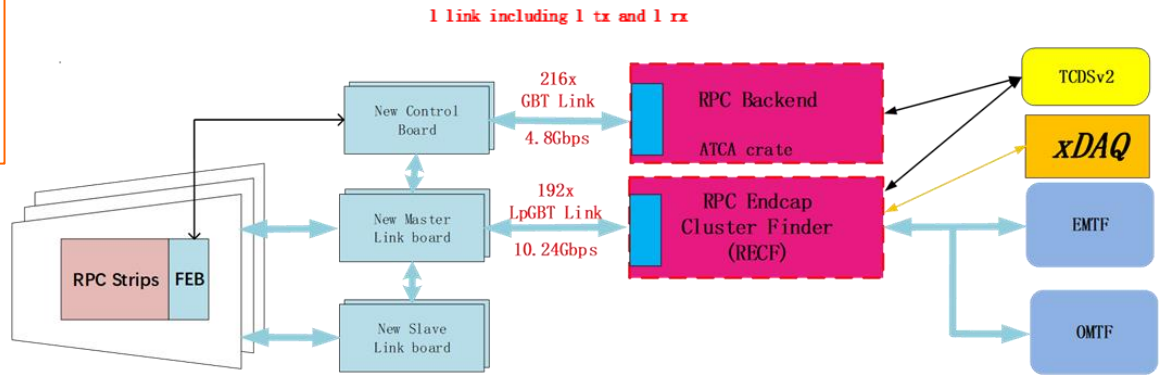


Upgrade of Link System to improve timing resolution for existing RPC (**|η| < 1.9**)

Extend the RPC coverage up to |h| = 2.4 to increase redundancy in high eta region in stations 3 and 4







- iRPC backend system
  - 1 ATCA Crate
  - 1 DTH400
  - 1 DAQ800
  - 8 ATCA serenity boards

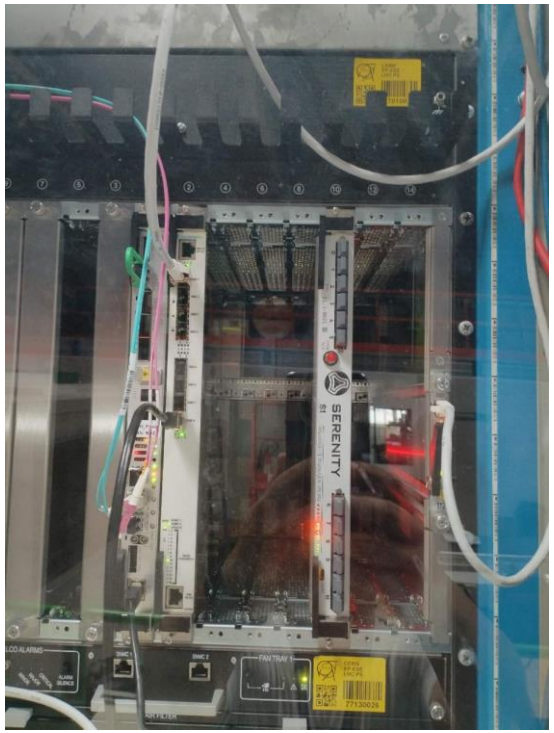
- RPC Backend
  - 1 ATCA Crate
  - 1 DTH400
  - 4 Serenity ATCA boards

- RECF
  - 1 ATCA Crate
  - 1 DTH400
  - 1 DAQ800
  - 8 Serenity ATCA boards

RPC Endcap BE/TRG development platform

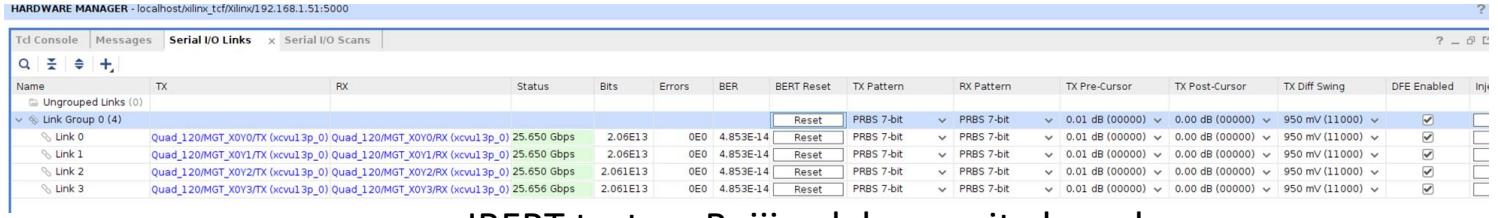
- Two pilot ATCA-Serenity boards arrived recently.
- Two serenity development platforms setup
  - one in 904 electronic integration area shared L1T ATCA crate
  - The other one in Beijing lab
  - Firmware work can be developed in parallel in two locations

- It starts the ATCA firmware work.
  - Serenity server start works.
  - Power supply and debug port(XVC) works well
  - Small ibert project successfully running on Serenity board



ATCA serenity platform in 904

ATCA serenity platform in Beijing TRG Lab



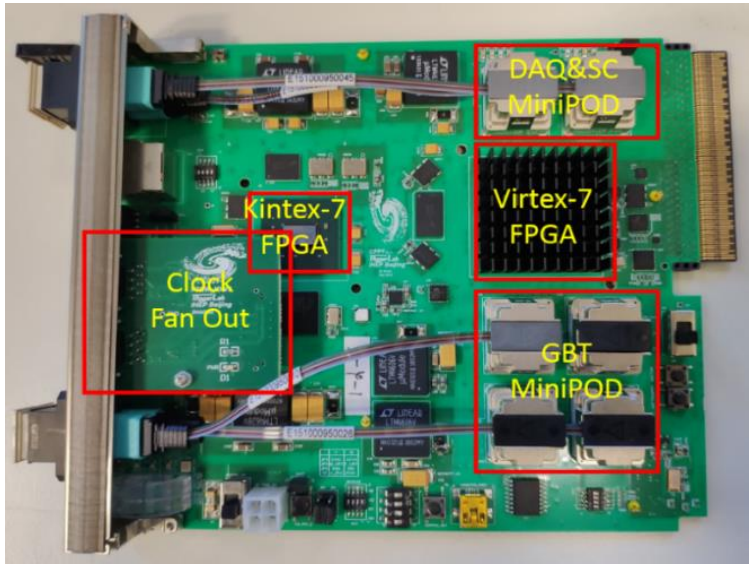
IBERT test on Beijing lab serenity board

iRPC BE/RECF study platform

- Currently, firmware development on MicroTCA BE(Virtex-7) and VCU118 is in progress in parallel.
- The main difference between ATCA is the FPGA platform; Firmware can be transferred to the ATCA FPGA.

- Virtex-7 Platform:
  - BE board designed by IHEP trigger group
  - Virtex-7 FPGA： Core FPGA(GBT Communication with Feb + data processing);

- Virtex Ultrascale Plus platform
  - VCU118 evaluation board with VCU9P with 2 QSFP+ port
  - VCU118 for GBT/lpGBT-FPGA link test
  - iRPC BE firmware start to move to VCU118 platform to debug firmware move to Virtex Ultrascale Plus



MTCA BE board

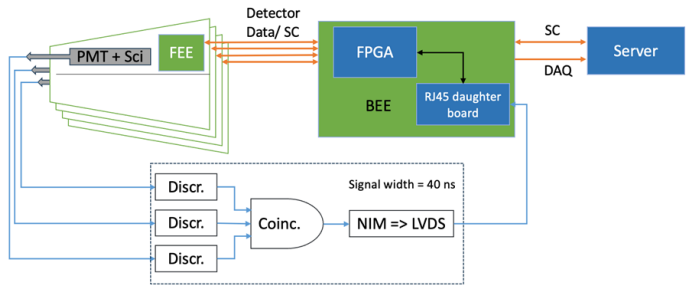
VCU118 evaluation board with VCU9P

Achieved test with Cosmic and beam

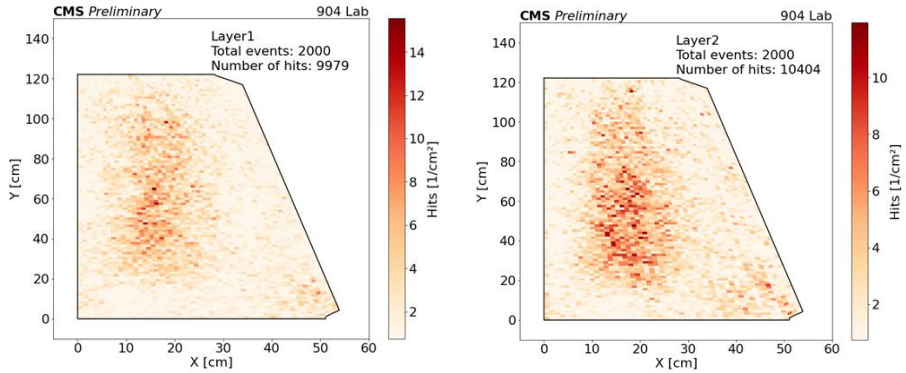
- Based on MircoTCA BE Demo, RPC BE/TRG finished FEB timing alignment, calibration, timing reference and cluster finding algorithm development.
- iRPC BE joint test with iRPC chamber and FEB for cosmic test and beam test.
- With cosmic data and beam data, Check-Sort-Push data sending and DAQ readout window studied.

- **New progress this year**
  - iRPC BE firmware for 4 FEBs finished
  - Cosmic data taking has been done successfully, and hit plots has been obtained.

- Full function of the 4-channel firmware verified, it will be used for QC3, iRPC chambers verification in P5 before LS3.

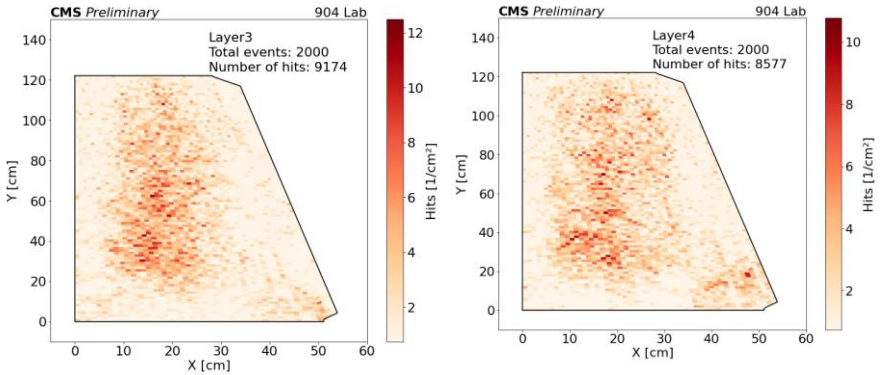


Four channels firmware verification setup



Chamber 226

Chamber 228



Chamber 227

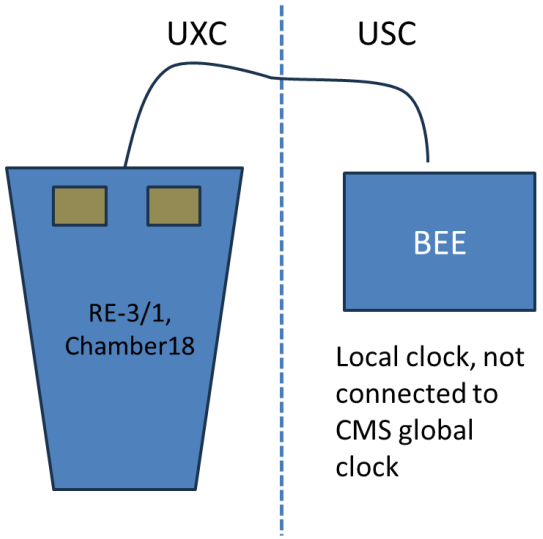
Chamber 236

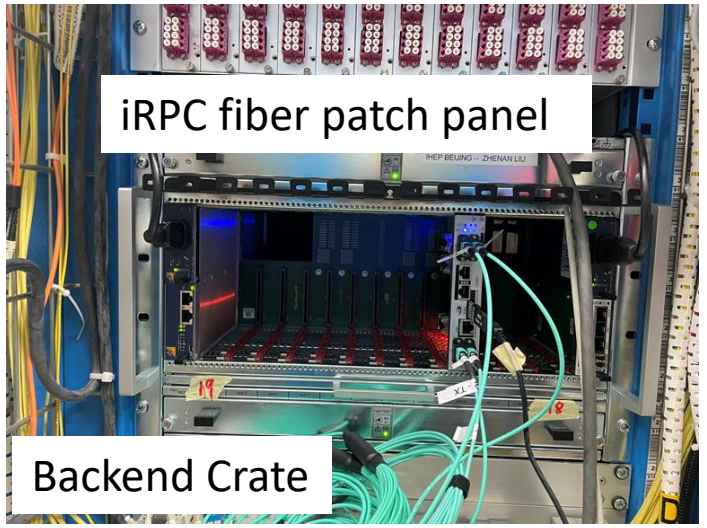
P5 BE Demonstrator integration status and plan

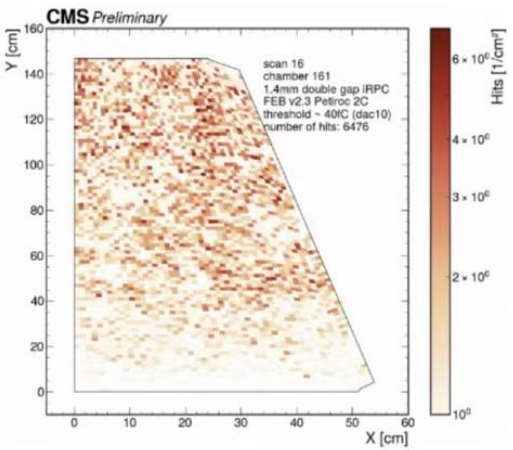
- P5 iRPC MicroTCA BE integration before LS3
  - One is for the iRPC chambers verification after installation
  - iRPC BE will connect one link to EMTF, which will help validate the iRPC cluster finding algorithm.

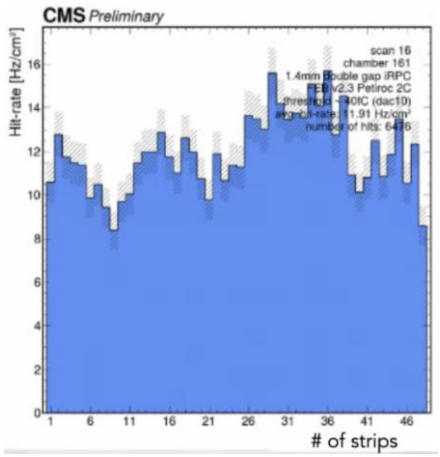
- Achievement part:
  - P5 iRPC BE Demo System integrated in 2024
  - iRPC BE Data taking successfully with self-trigger/Random trigger,

- Next step:
  1. iRPC BE link to EMTF
  2. Take chamber data with the global clock and global trigger.





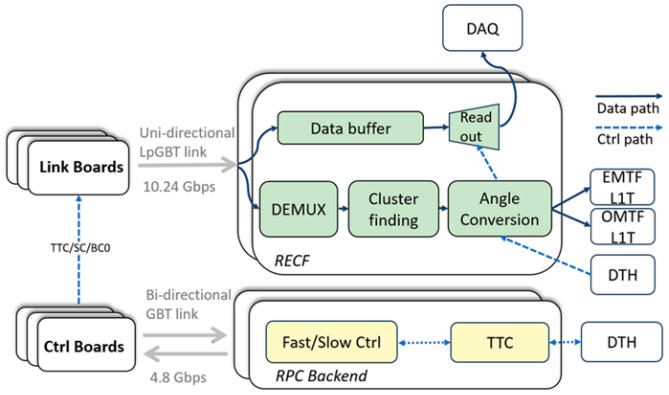




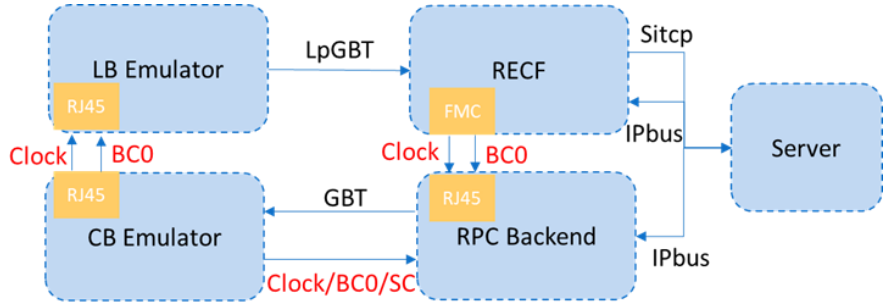
Full RE-3/1 fully commissioned with B field OFF. Disk not grounded. Higher level of Background radiation due to FIN.

RECF/RPC Backend emulator system setup

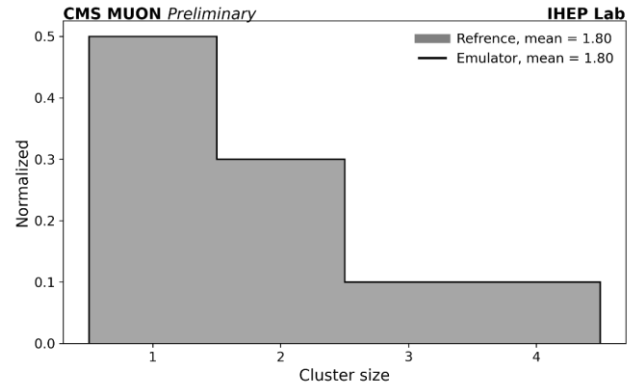
- Preliminary emulator system were set up at the Beijing lab for RECF/RPC BE function study.
  - VCU118 platform(VCU9P) used for RECF
  - MirocTCA board with Virtex-7 FPGA used for RPC backend, Link Board emulator and Control Board Emulator



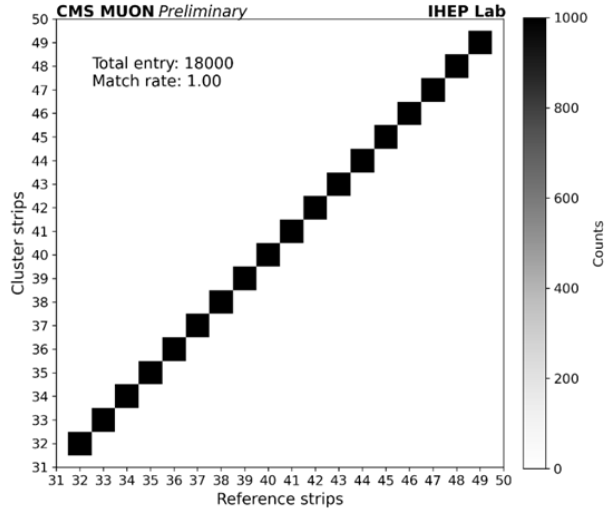
RECF/RPC BE system structure



RECF/RPC BE emulator system structure



Cluster Size Comparison: Reference vs. Emulator



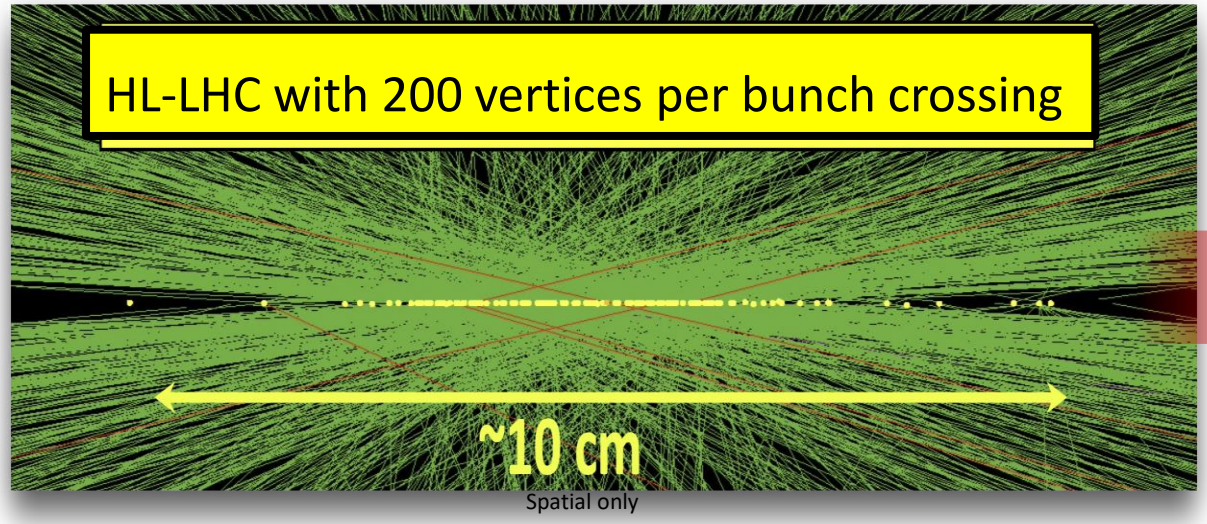
Cluster Strips Comparison: Reference vs. Emulator

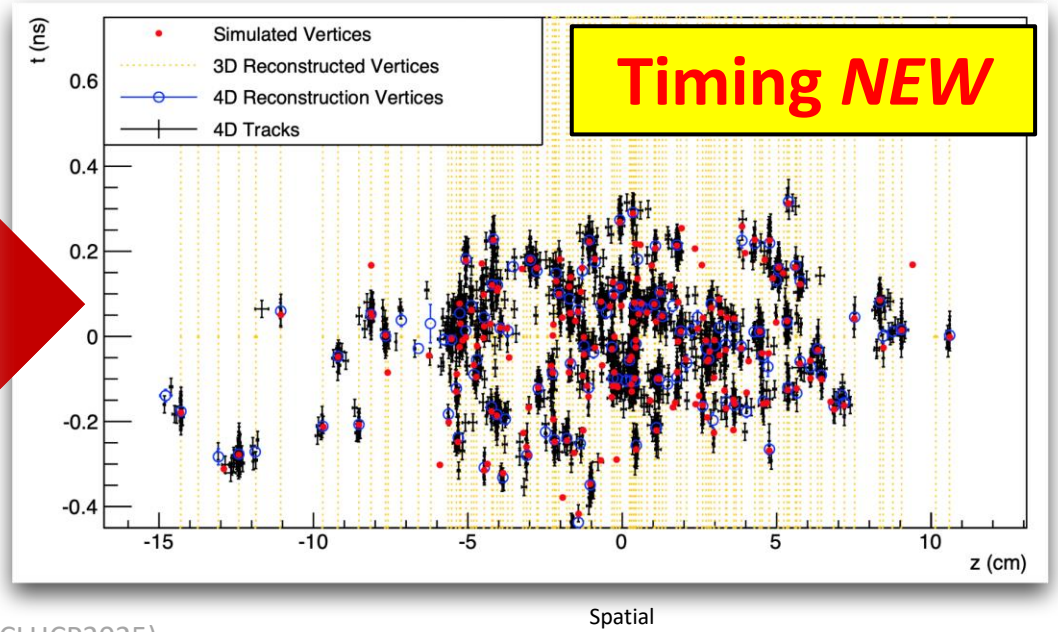
III. CMS MTD progress

CMS-MTD-BTL introduction

- Participants: PKU, THU, BUAA
- MTD BTL is a novel timing detector dedicated in CMS barrel region aiming at mitigating the high pileup issue at HL-LHC

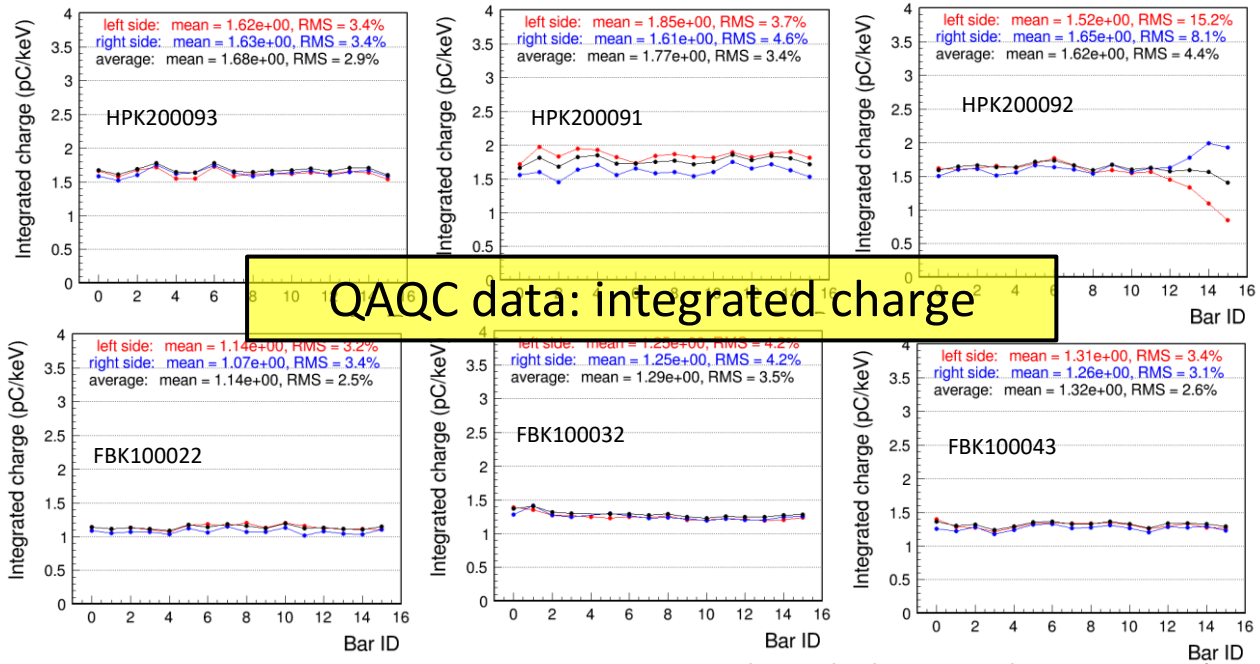
	CMS-MTD	ALICE-TOF	STAR-TOF	BESIII
Time resolution (ps)	30	56	80	68





Sensor module design and assembly techniques

- Sensor module design (LYSO+SiPM) were completed
  - Reached 30 ps at Vov=3V with the optimization majorly in SiPM



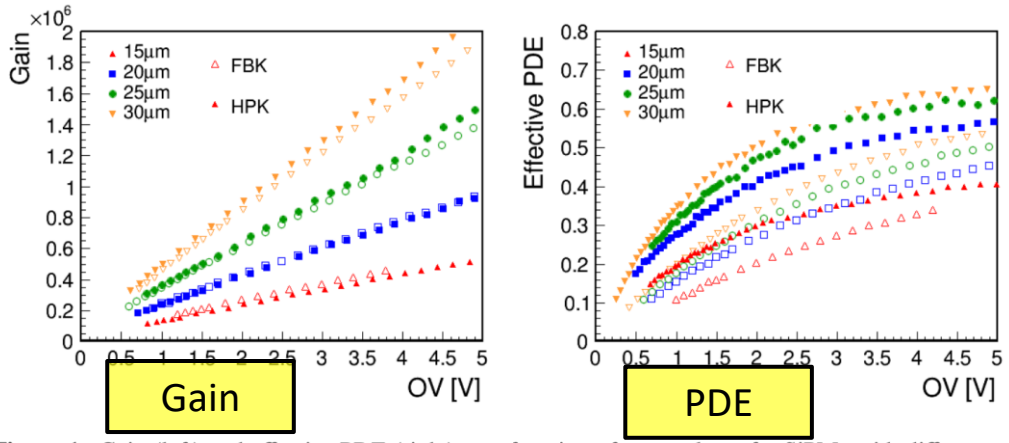


Figure 1. Gain (left) and effective PDE (right) as a function of over-voltage for SiPMs with different cell size and from different manufacturers. The effective PDE corresponds to the measured $PDE(\lambda)$ convoluted with the emission spectrum of LYSO:Ce crystals, which peaks around 420 nm.

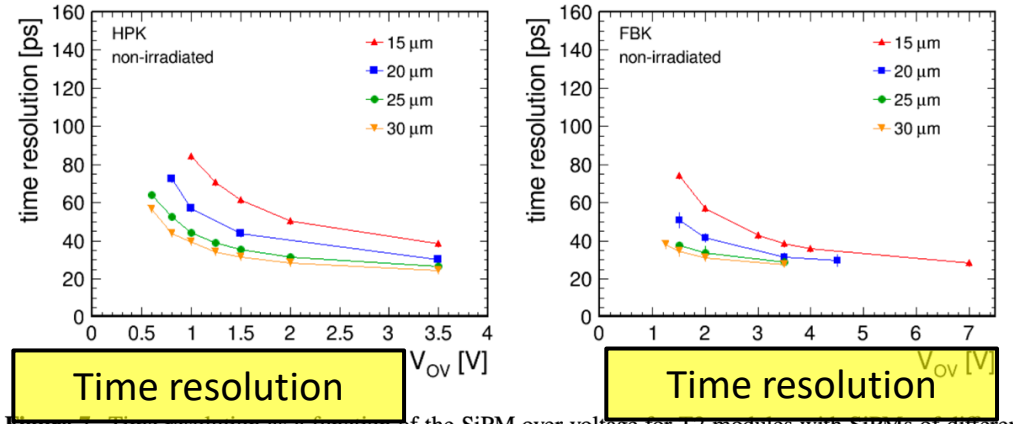
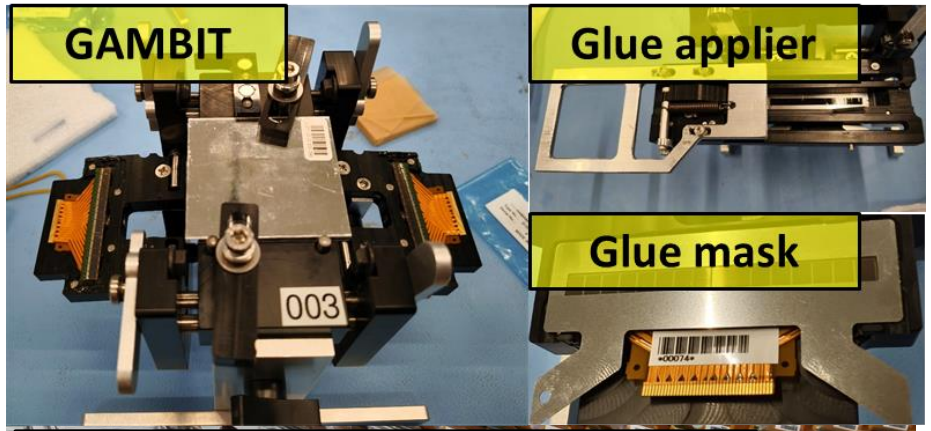


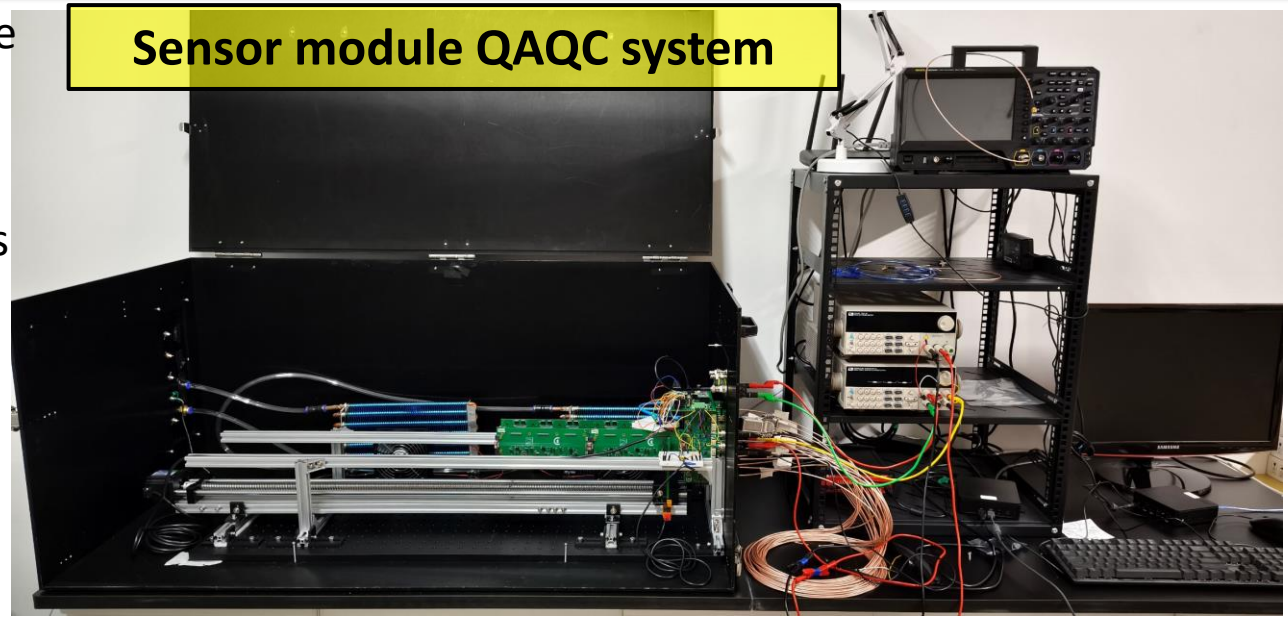
Figure 7. Time resolution as a function of the SiPM over-voltage for T2 modules with SiPMs of different cell-size. Left: modules with SiPMs from HPK. Right: modules with SiPMs from FBK.

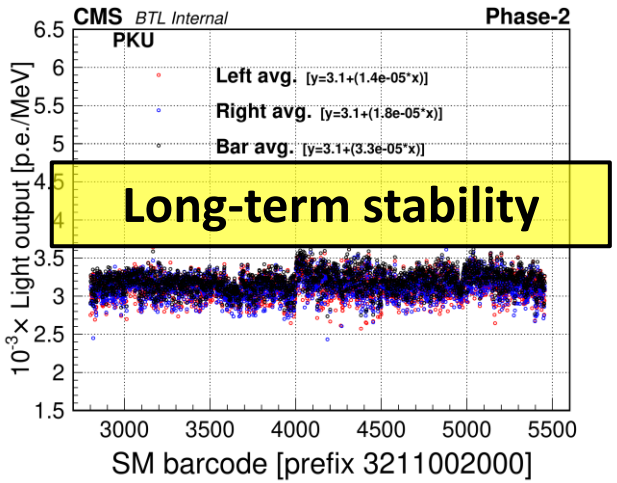
Sensor module assembly tool and QAQC setup

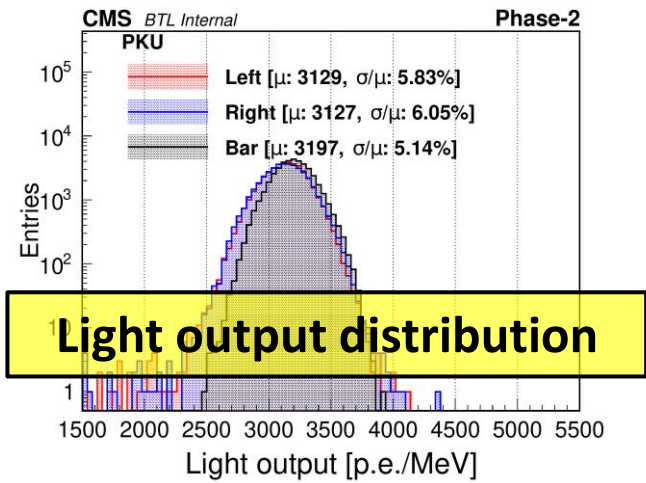
◆Assembly techniques and tools were developed and now are used for everyday production smoothly

◆QAQC setup of sensor modules were established and functioned well to measure the light output of sensor modules



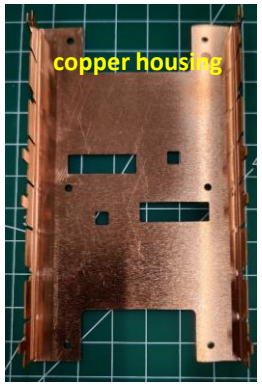


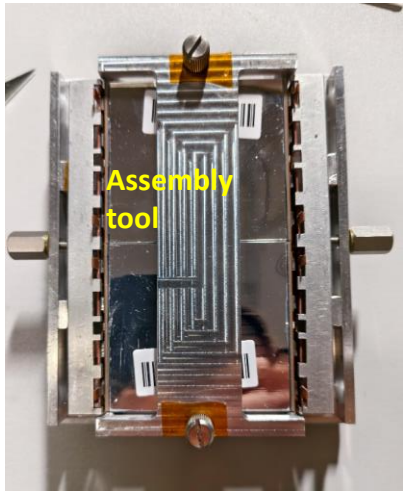


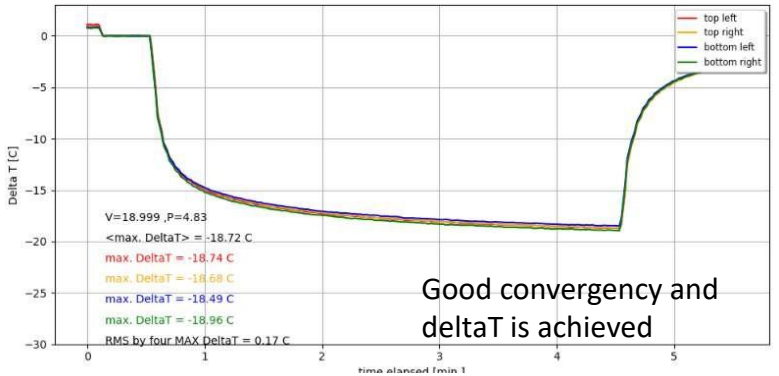


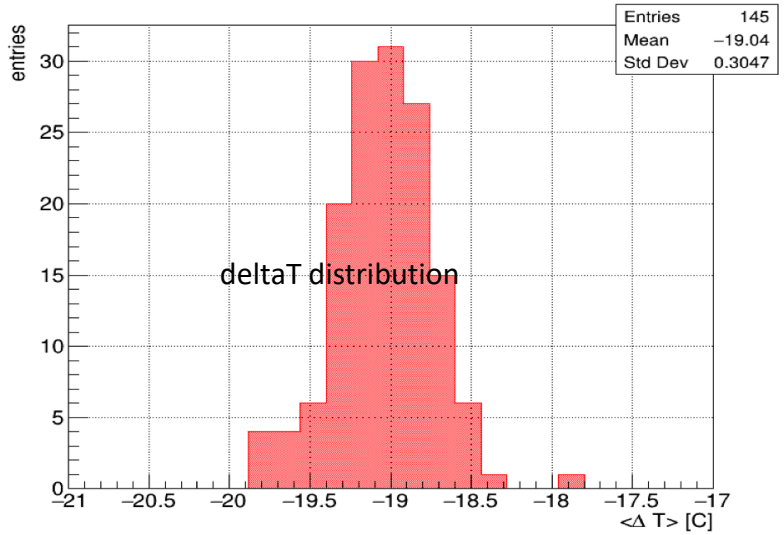
Detector module design, assembly & QAQC

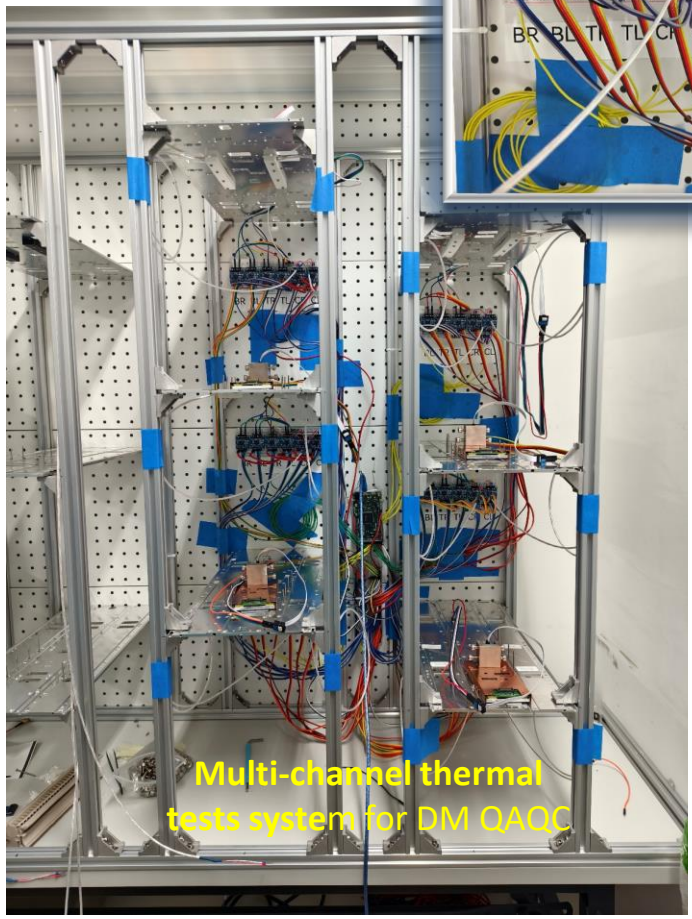
- Detector module is made of two sensor modules and one front-end board hosted in a copper housing
- The thermal contact is verified in the detector module QAQC system
- First realization of multi-channel QAQC system in PKU







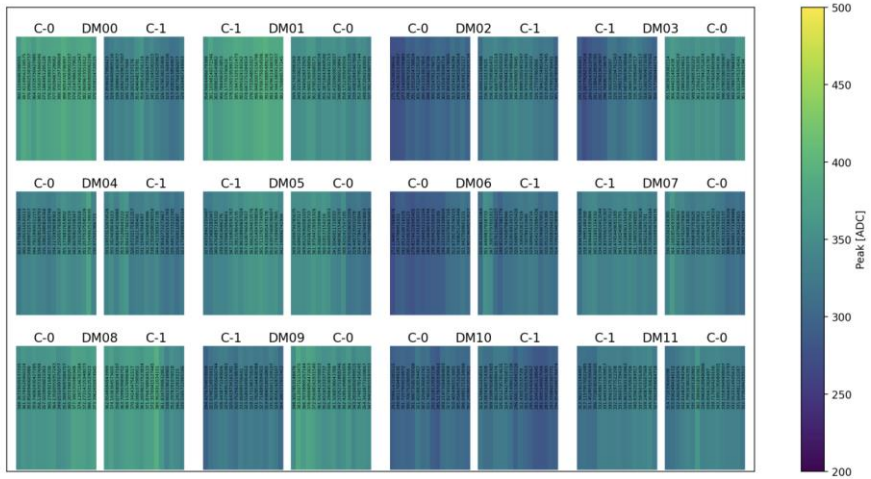


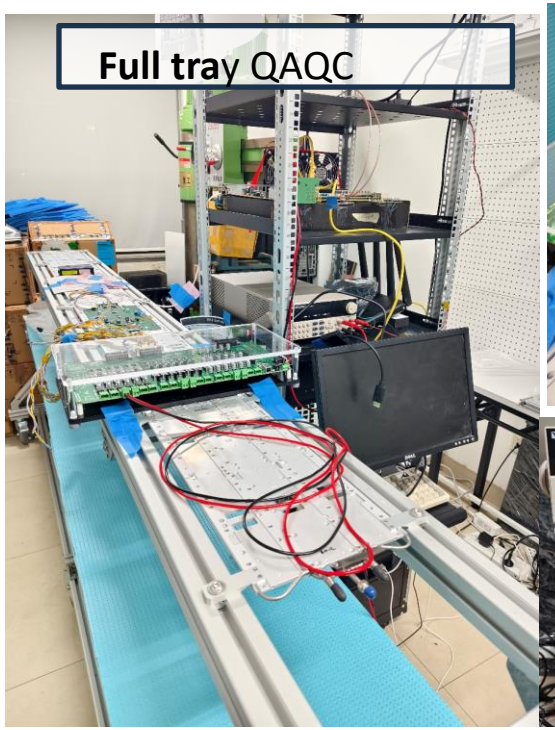


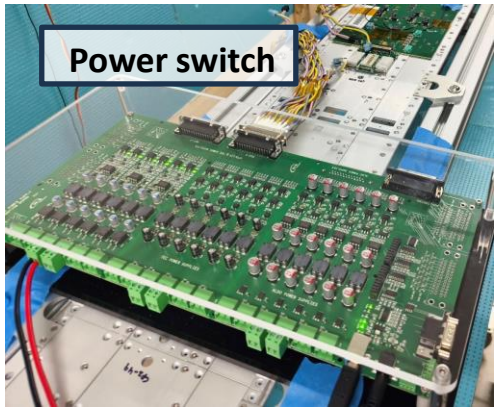
Tray build

- Started building full BTL trays over the summer
- Built the first PKU tray in May 2025
- Full QAQC system with Serenity back-ends for trays are ready and functioned well
  - Connections, test pulses, LYSO data-taking, IV scan all passed

Tray58 RU1 data-taking tests

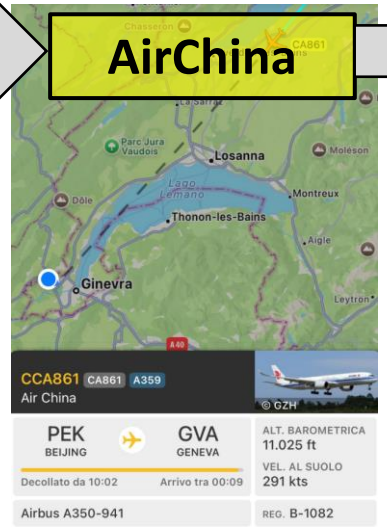


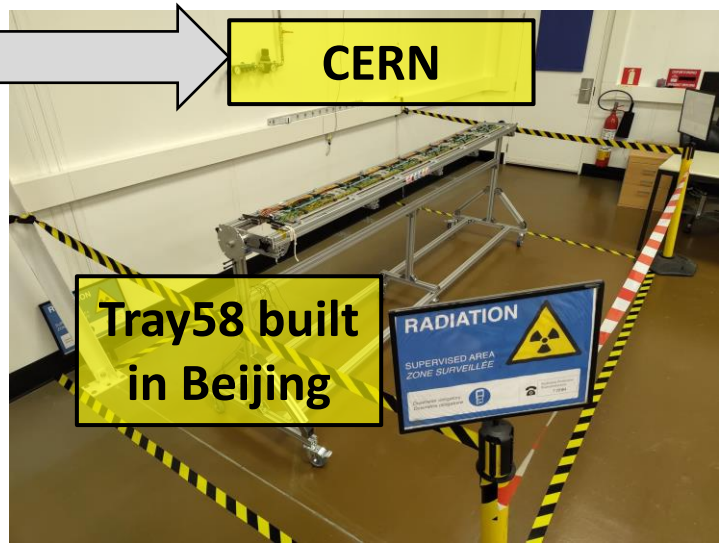




Beam tests @ CERN

- First oversea tray was shipped from Beijing to CERN
- Beam tests were performed in autumn and data analyses are undergoing

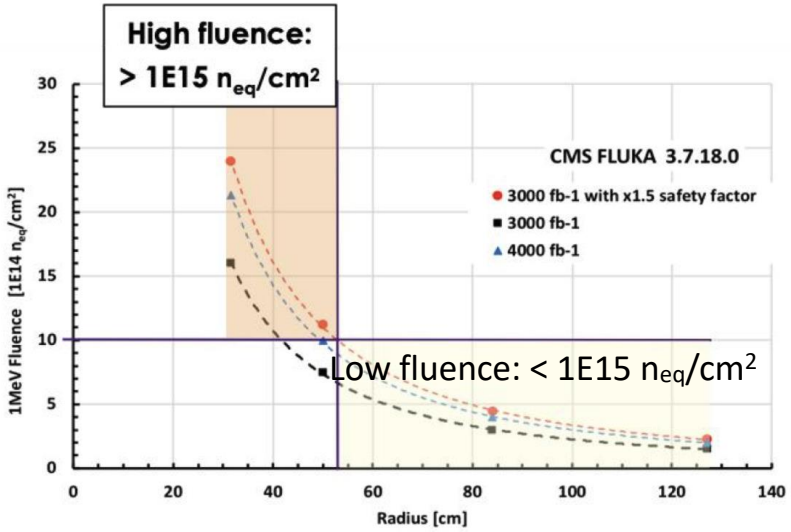




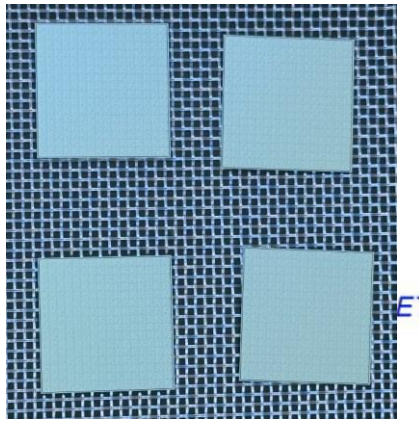
Overview of MTD ETL Detector

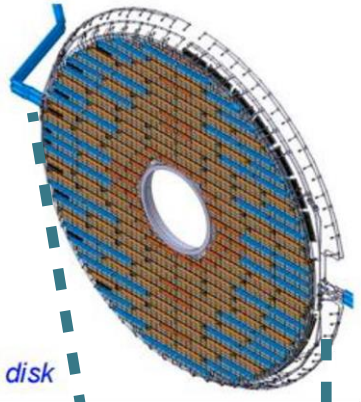
- Technical Design Report plan: 2 disks on each side, several staging options being considered
  - Pseudorapidity coverage 1.6 < |η| < 3.0
  - Radius 31.5 cm < R < 120 cm
  - Radiation hard requirement: total neutron fluence
  - 8.6 million channels in total in ETL

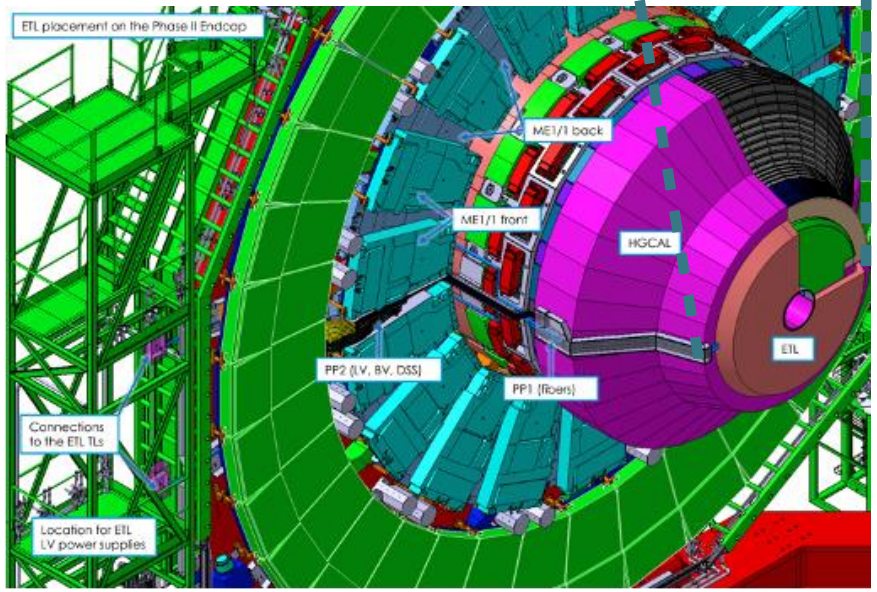
Developing characterization system is essential for LGAD R&D and quality control



HPK full-size LGADs of 16 × 16 arrays



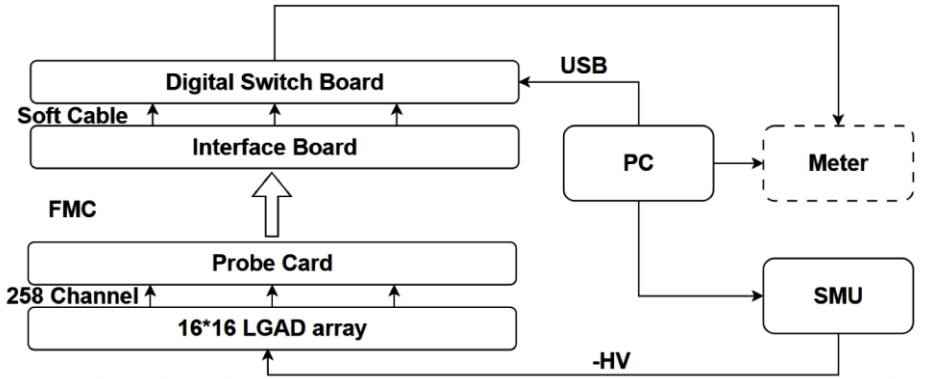


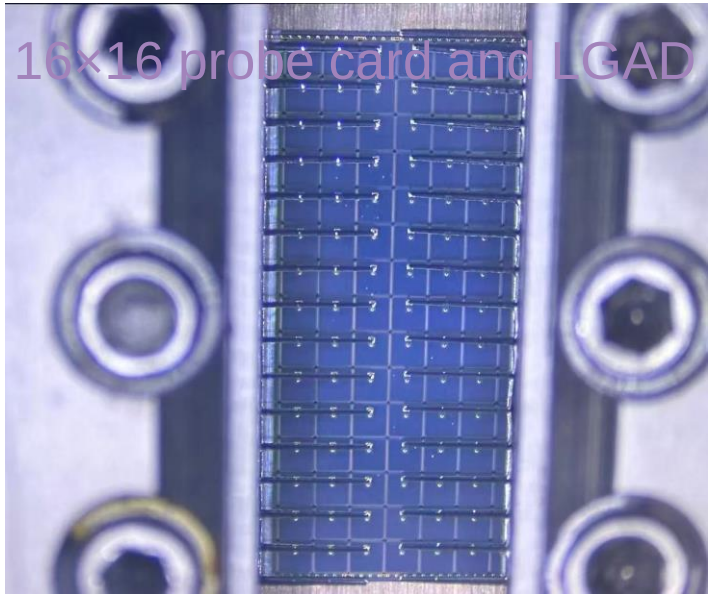


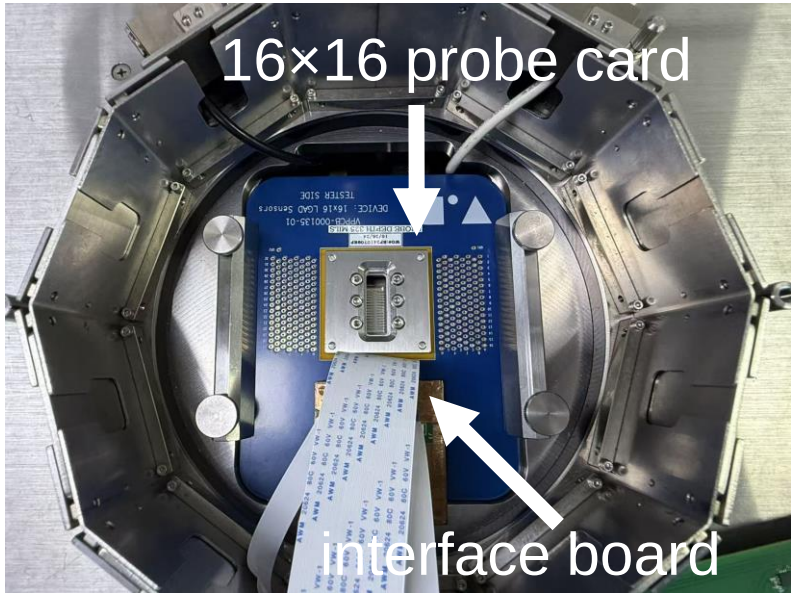
- Current status: final stage of R&D and prototyping, transition to production

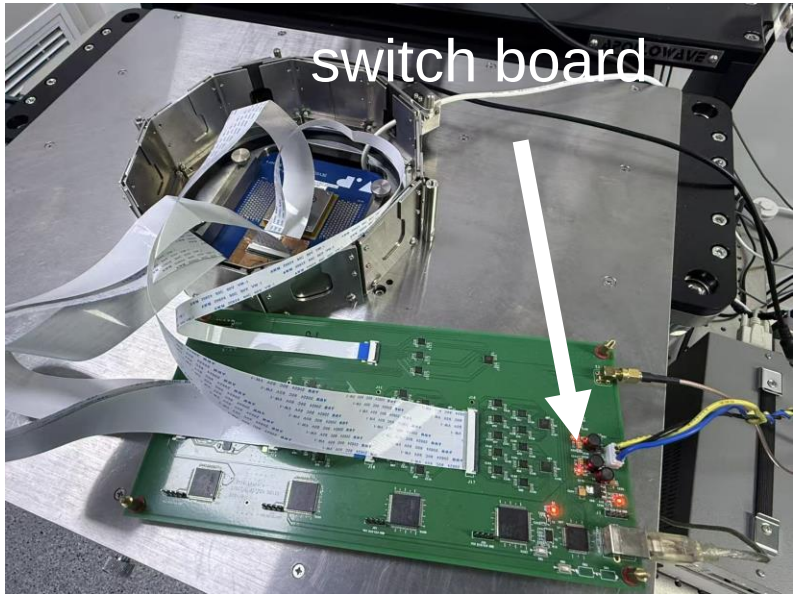
16 × 16 LGAD IV and CV characterization

- The pad under test selected by a dedicated digital switch board designed and made at USTC, other pads and the guard ring grounded.
  - More precise measurement than commercial automatic probe station
- Some interests to use this setup in multiple testing sites during LGAD QC



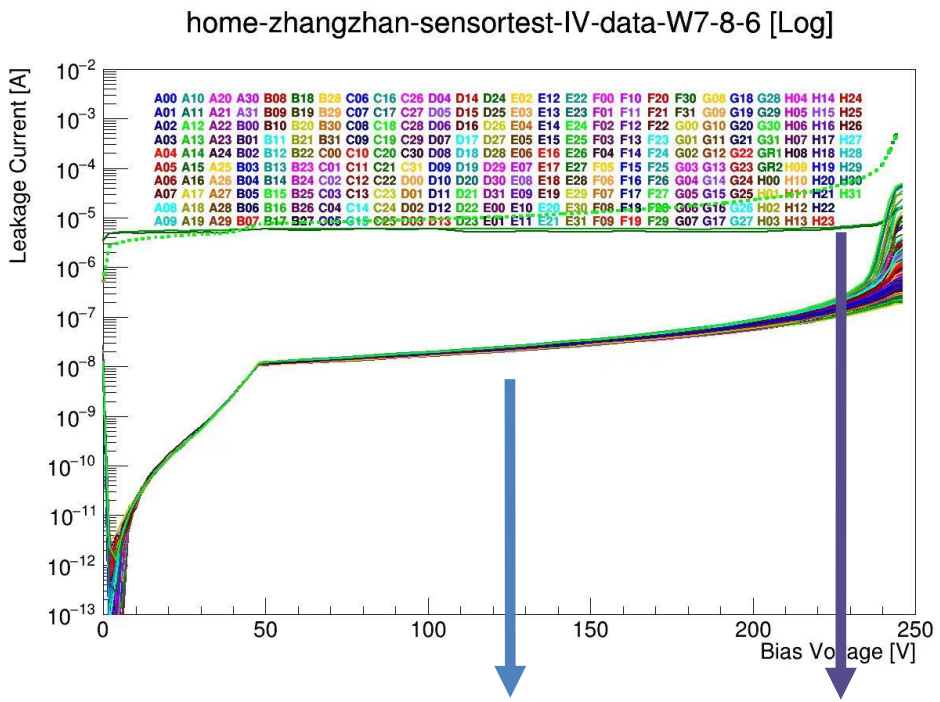




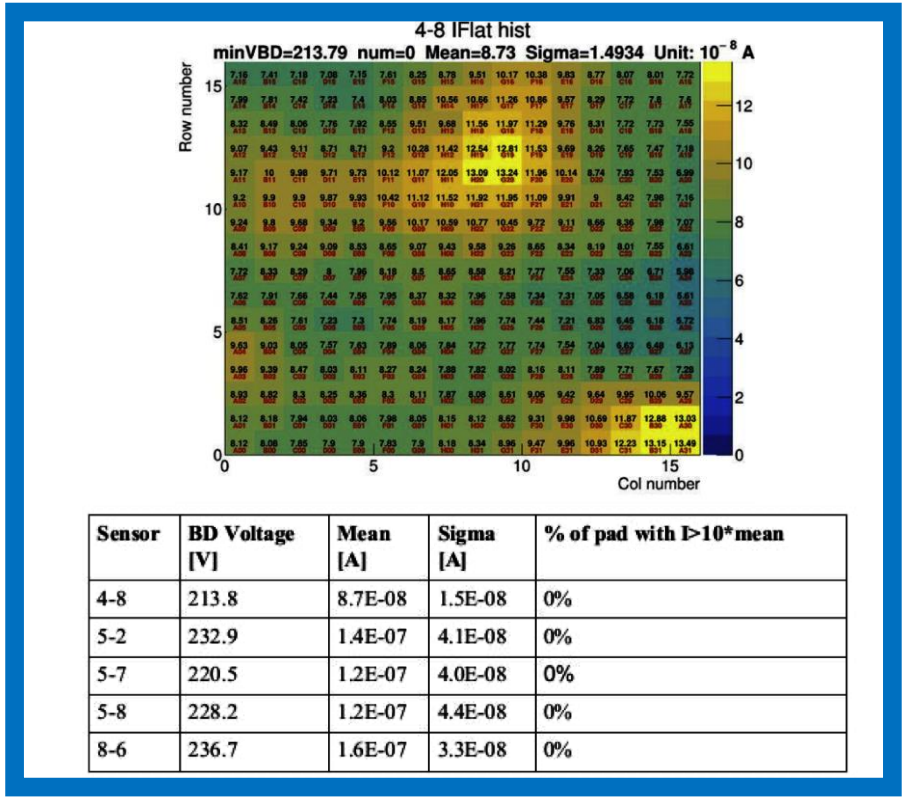


16 × 16 LGAD IV and CV characterization

- Good quality full-size sensor single-pad IV measurement and leakage current map measured at USTC



USTC lab: each of 256 pads + guard ring

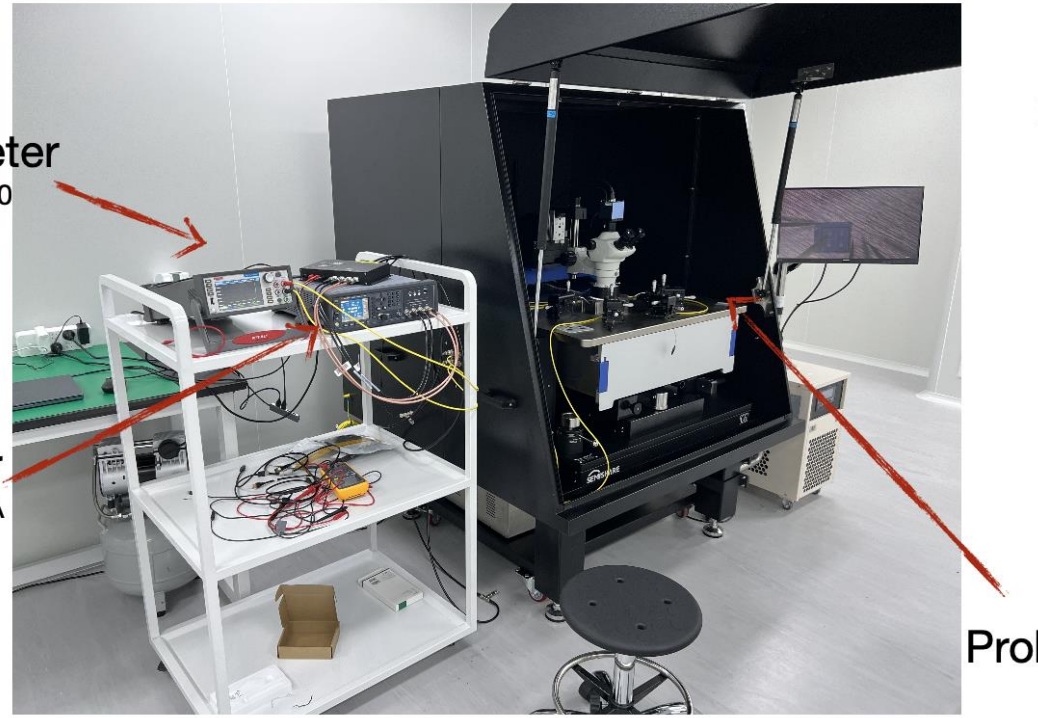


Sensor	BD Voltage [V]	Mean [A]	Sigma [A]	% of pad with I>10*mean
4-8	213.8	8.7E-08	1.5E-08	0%
5-2	232.9	1.4E-07	4.1E-08	0%
5-7	220.5	1.2E-07	4.0E-08	0%
5-8	228.2	1.2E-07	4.4E-08	0%
8-6	236.7	1.6E-07	3.3E-08	0%

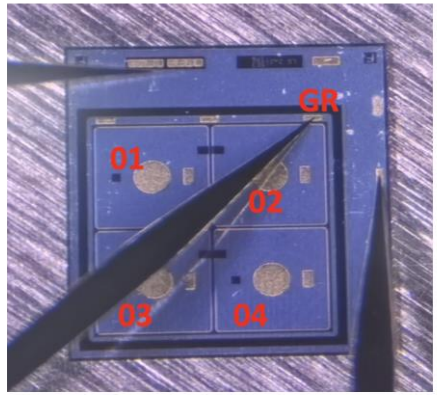
pad leakage current map of a full-size sensor contributed to FBK-LFoundry sensors Procurement Readiness Review in 2025

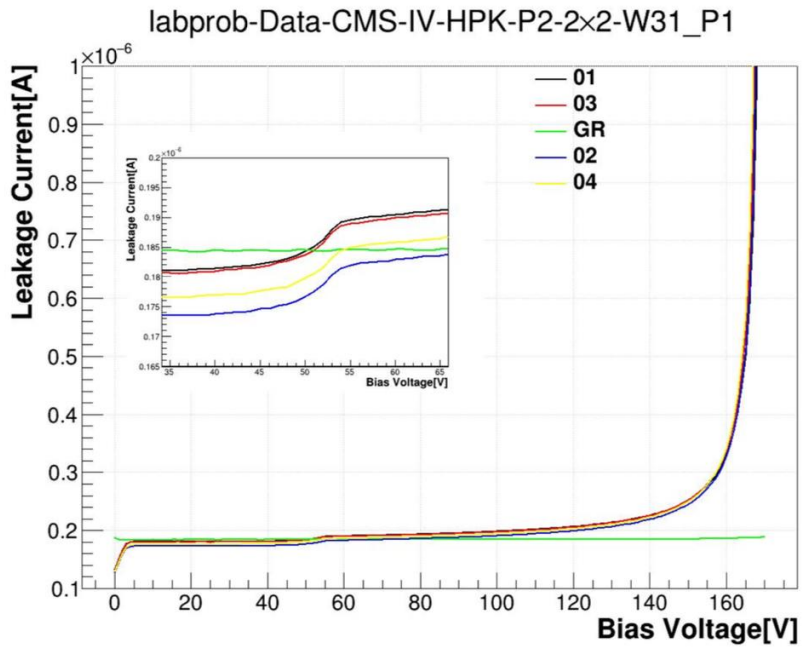
2 × 2 LGAD IV and CV characterization

- South China Normal University: LGAD IV and CV charactorization for 2x2 LGADs, 16x16 LGAD test system to be integrated;



2×2 FBK LGAD芯片

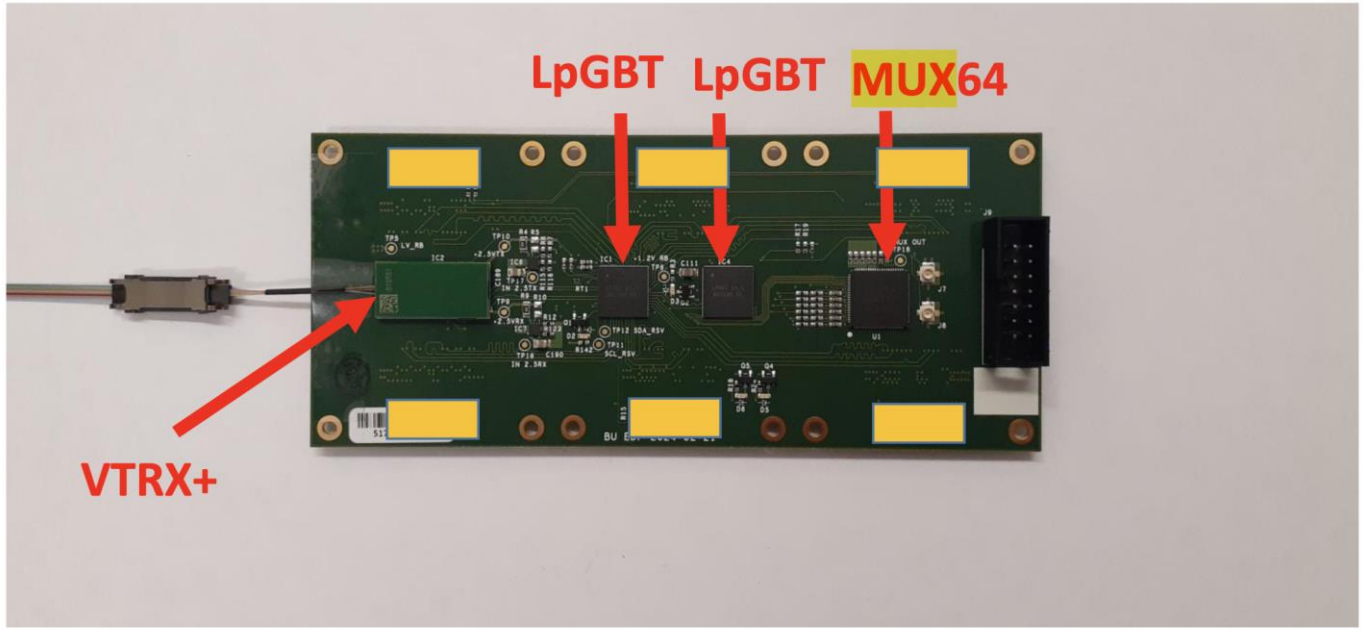




MTD-ETL MUX64 chip procurement

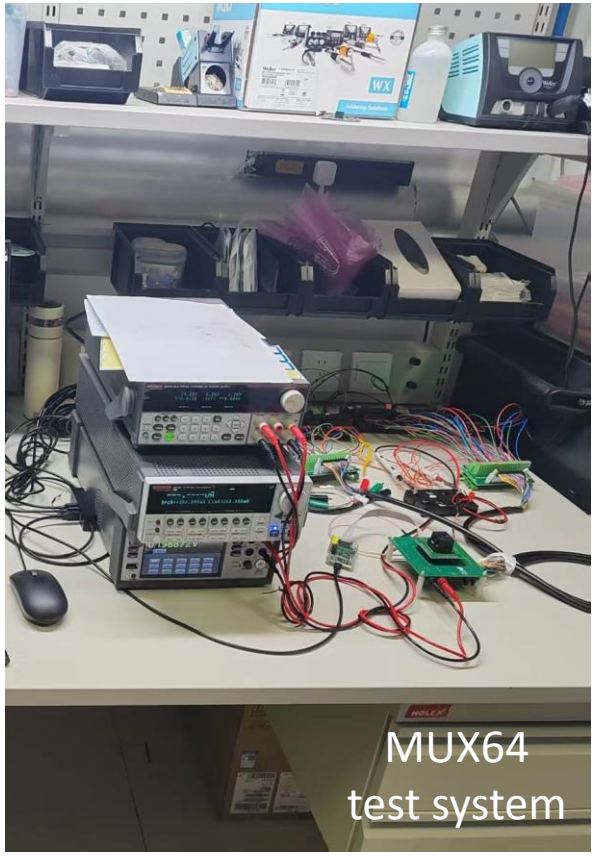
◆ South China Normal University: procurement of MUX64 chip for ETL readout board

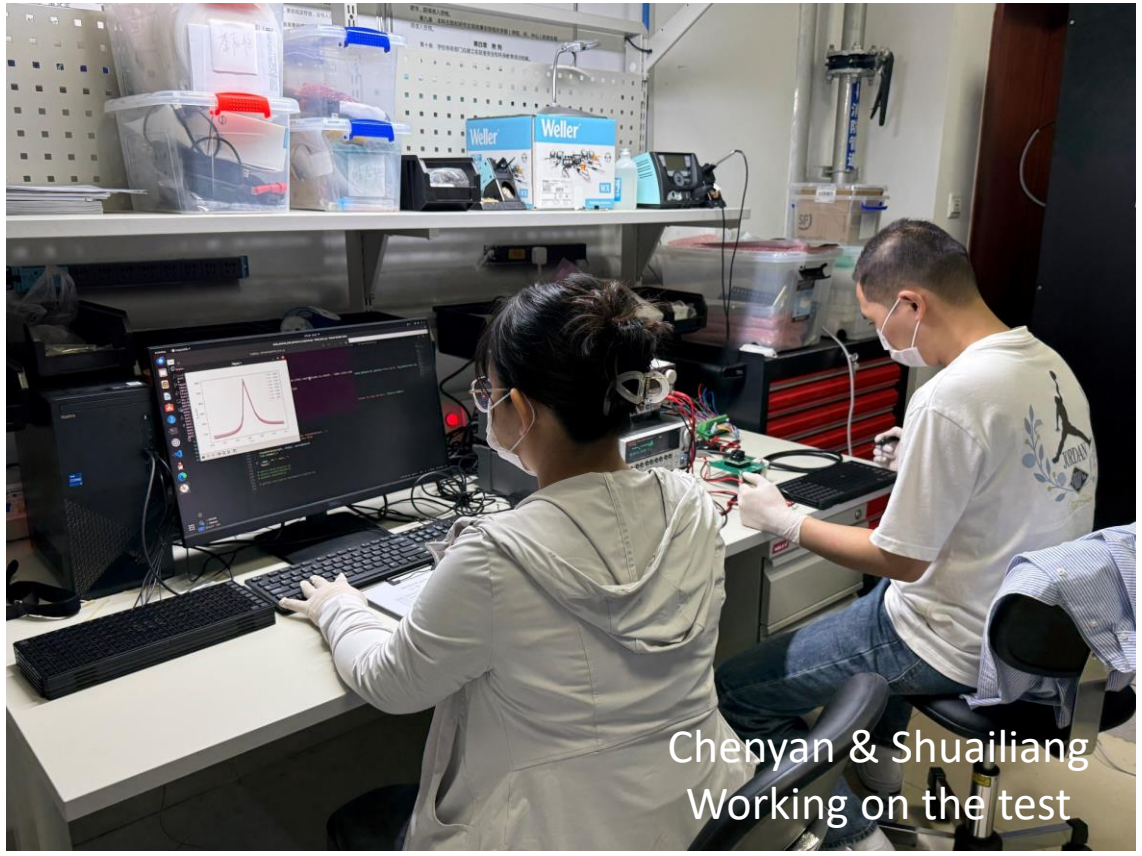
ETL readout board (picture provided by ETL group)



MUX64 chip

MTD-ETL MUX64 chip testing


MUX64
test system


Chenyan & Shuailiang
Working on the test

MUX64 chip for the ETL monitoring system
In cooperation with Rice University to test ~2,000 chips at SDU
Finished ~1200, good rate > 94%

Summary （1）

◆ **HGCAL:**

- IHEP HGCAL group developed highly automated and high accuracy silicon module assembly process .
- Hgcal module production speed ramping up to 4 modules/day now.
- CuW baseplate dominated by IHEP, and First batch of 1200 CuW baseplate ready in July-Aug. 2025.

◆ **Muon(GEM/RPC BE&TRG)**

- Second batch of 10 ME0 GEM assembly and test at PKU (Mar.-May. 2025)
- All 10 GEM were tested, trouble-shot, and shipped to CERN in May 2025
- By Oct. 2025, half of ME0 GEBs has been tested by PKU group with acceptance criteria, all qualified.

- Two pilot ATCA-Serenity boards arrived recently for RPC BE/TRG.
- Full function of the 4-channel firmware verified, it will be used for QC3, iRPC chambers verification in P5 before LS3.
- RECF and RPC Backend emulator system setup based on VCU118(VCU9P) platform was done successfully.

Summary（2）

◆**MTD(BTL/ETL)**

- Sensor module design (LYSO+SiPM) were completed. Assembly techniques and tools were developed for mass production.
- QAQC setup of sensor modules were established and functioned well to measure the light output of sensor modules.
- First PKU Tray finished in May and beam test were performed in autumn 2025.

- USTC designed a dedicated digital switch board for full-size LGADs test. It gives more precise measurement than commercial automatic probe station.
- Good quality full-size sensor single-pad IV measurement and leakage current map measured at USTC.
- SCNU purchased of MUX64 chip for ETL readout board and arrived.

In one word, CMS China group made great progress on each respective tasks.
All upgrade works are pushed forward steadily in accordance with CMS overall plan.

Thanks!