Status of CMS Phase-II Upgrade

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On behalf of CMS-China

The 7th China LHC Physics Workshop (CLHCP2021)
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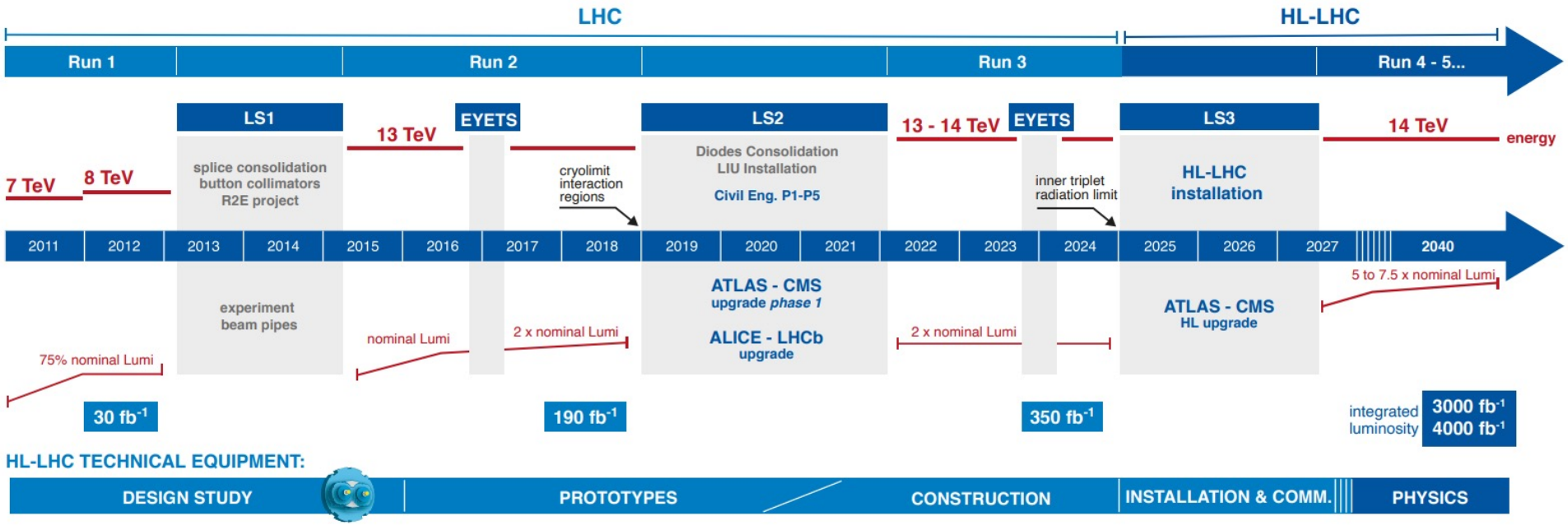
HL-LHC upgrade, challenges and CMS solution



Expected pileup (PU): ~140-200

- Improved granularity wherever possible
- in-time Pile Up mitigation: Precision Timing detectors (30ps)
- Trigger and DAQ: better selectivity, despite high PU.

Radiation damage / accumulated dose in detectors and on-board electronics=> a progressive degradation

=> Maintain performance in harsh conditions:

- Replacement of the Tracker and Endcap Calorimeter systems.
- Electronics overhaul and consolidation of the Barrel Calorimeters and Muon systems

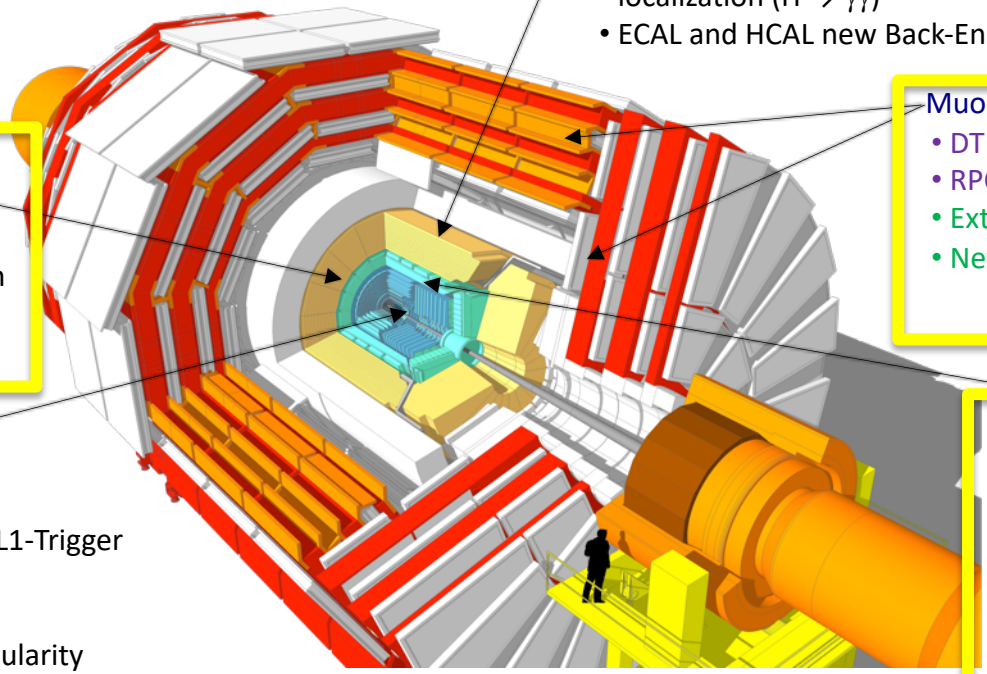
CMS Phase-II upgrades

2019-2026, matching HL-LHC， basis for future physics！

Replacements of existing system/detector
Electronics upgrade/replacement
New detector

L1-Trigger/HLT/DAQ
- Tracks in L1-Trigger at 40 MHz
- PFlow-like selection 750 kHz output
- HLT output 7.5 kHz

Barrel Calorimeters*
- ECAL crystal granularity readout at 40 MHz
- Precision timing for e/γ at 30 GeV, for vertex localization ($H \rightarrow \gamma\gamma$)
- ECAL and HCAL new Back-End boards



Calorimeter Endcap
- 3D showers imaging for pattern recognition
- Precision timing for PU mitigation
- Si, Scint+SiPM in Pb/W-SS

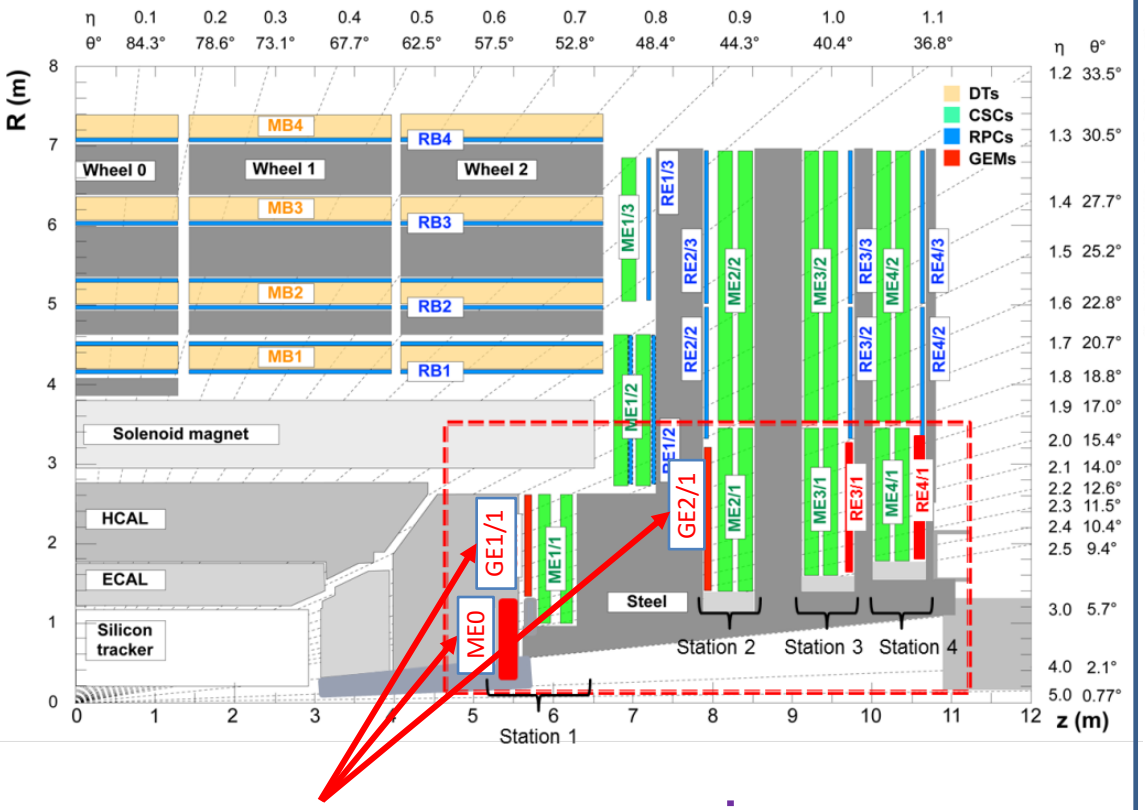
Muon systems
- DT & CSC new FE/BE readout
- RPC back-end electronics
- Extended GEM coverage to $\eta \simeq 3$
- New GEM/RPC $1.6 < \eta < 2.4$

Tracker
- P_T module design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$
- Much reduced material budget
- Si-Strip and Pixels increased granularity

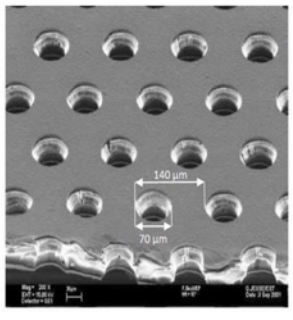
MIP Timing Detector
- Precision timing for PU mitigation
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

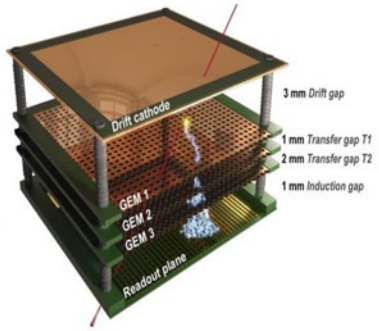
This talk focuses on: Projects with major CMS-China contributions

CMS-GEM Upgrade Project

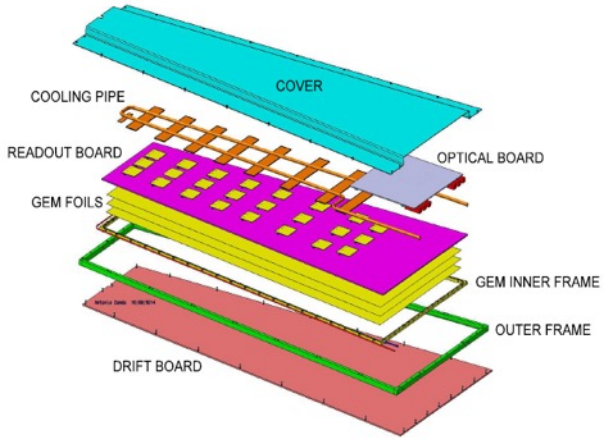


GEM（Gas Electron multipliers）Upgrade（2016-2026）





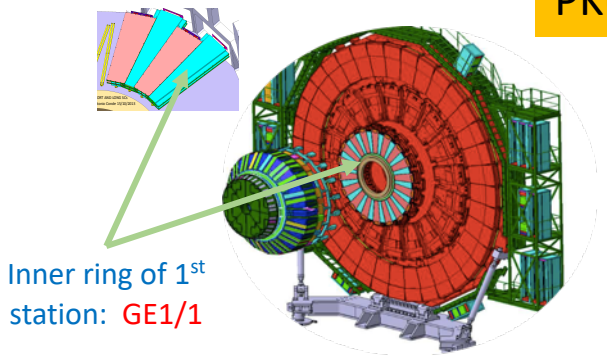
GEM foil，CMS triple-GEM structure and gas multiplication mechanism

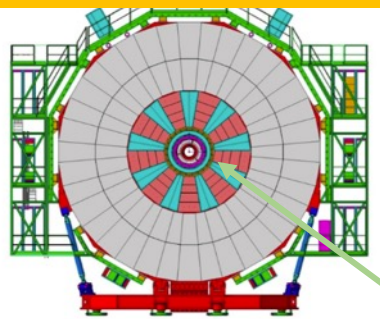


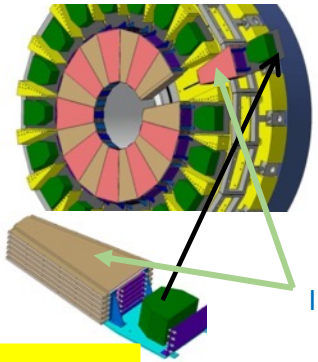
Explode plot of CMS-GEM detector

Tasks by CMS-China in GEM Upgrade

PKU+THU+SYSU+BUAA







GE2/1 demonstrator just installed

Upgrade GEM		GE1/1	GE2/1	ME0
Number of GEMs*		288（=2×36×4）	288（=2×18×8）	216（=2×18×6）
Plan	R&D	2013-2017	2014-2020	2014-2022
	Mass-Production	2017-2019	2020-2022	2022-2024
	Install. & Commi.	2018-2021	2022-2024	2024-2026
Tasks of Chinese Group		Prod. & Test of all GEB in China， GEM Assembly & Test, Install. & Commission at CERN	Design & Prototyping of GEB， Assembly. & Test of ~1/8 GEM in China， Install. & Commission at CERN	Design & Prototyping of GEB， Assembly. & Test of ~1/5 GEM in China， Install. & Commission at CERN

GE1/1 see beams! Monika Mittal's talk

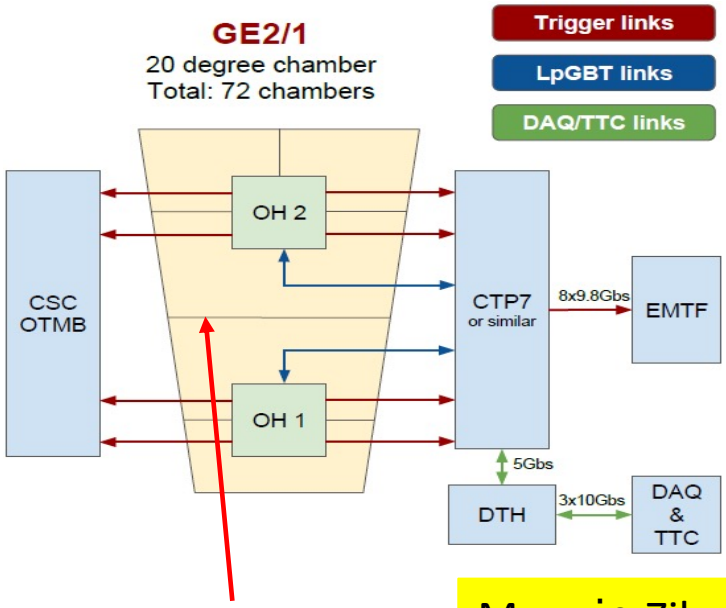
*（Total Num.=Num. of stations × Num. Of module /station × Num. of GEMs /module）

Annual progress

Design and Prototyping of GE2/1 GEB

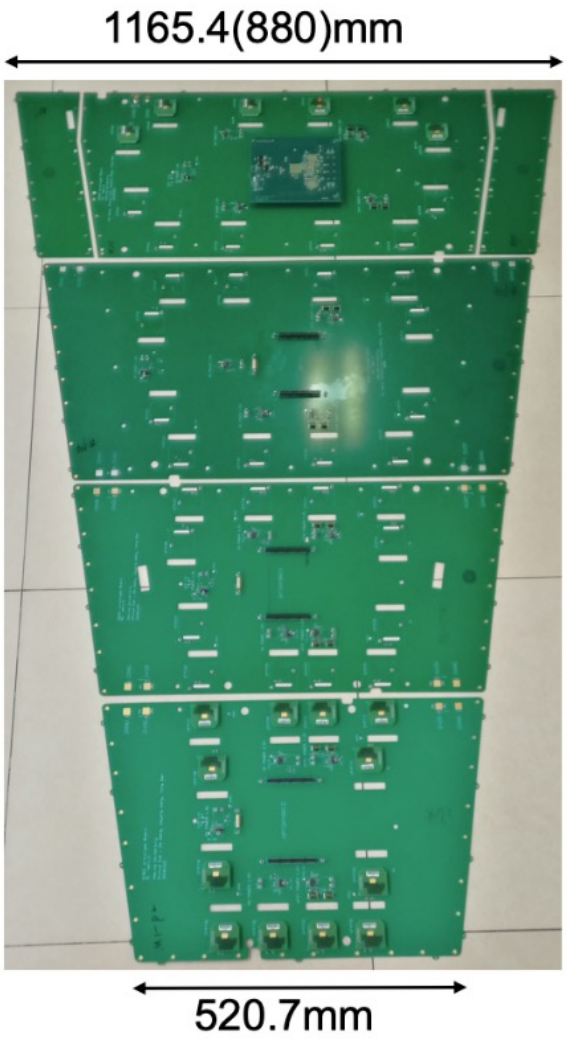
GE2/1 GEB: Design, R&D, Production and Test by Chinese Group (GE2/1 M1-M8 GEB).

During 2020-2021，three versions of 8 types GE2/1 GEB (~20 sets) were designed and produced in Shenzhen Sinofast Ltd. The prototypes were qualified and validated by the test in USA and CERN. Better performance than GE1/1 GEB（designed by ULB）was observed .



GE2/1 Electronics Board (GEB)

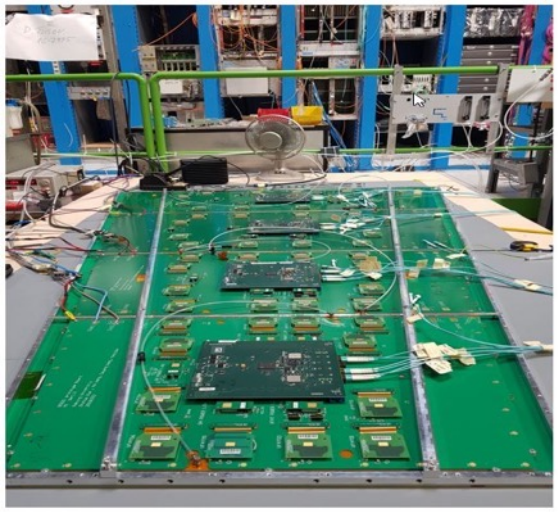
More in Zihan Liang's poster

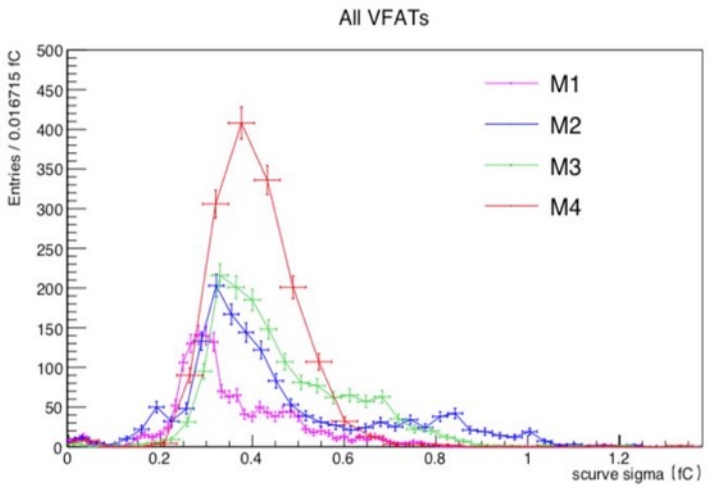


4 types of (M1-M4) GEB 2/1 prototypes

R&D and Mass Production of GE2/1 GEB

- Jan. 20, 2021: GEM GE2/1 ESR Review Meeting was hold at CERN, the presentations on GEB design, test and production plan by PKU group were reviewed and validated. Main comment：Halogen free materials should be used on all PCB and components。
- Jun.-July 2021： first batch of 6 halogen free GE2/1 M1 GEB were produced and shipped to CERN ， shown satisfactory test results。
- Oct. 2021: mass production of GE2/1 M1-M4 GEB (~160 sets) started， expected to be completed and shipped to CERN by early 2022， meanwhile start M5-M8 GEB production (~160 sets).

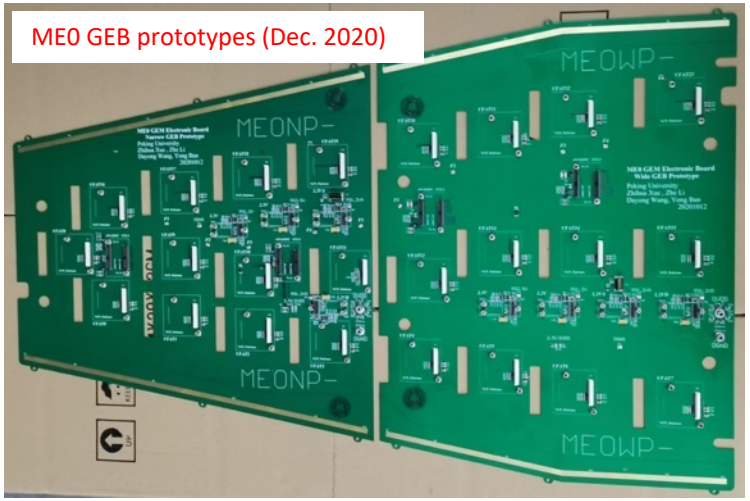


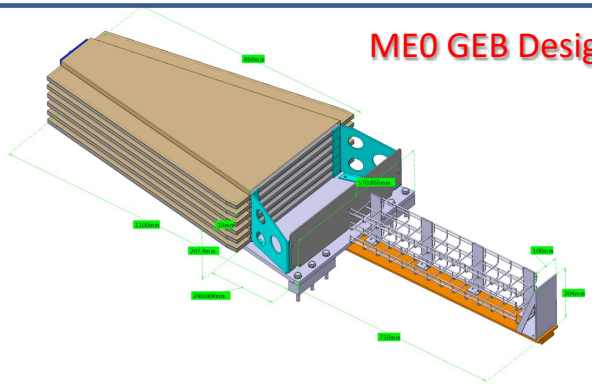


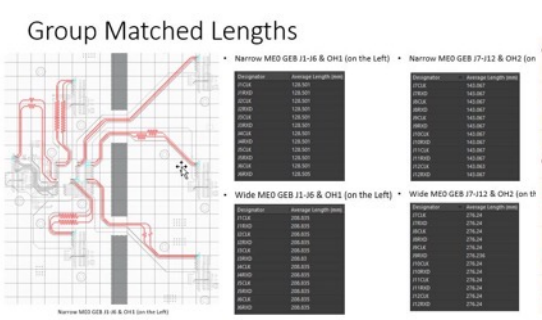
Test platform of GE2/1 M1-M4 GEB, and the result on noise test.

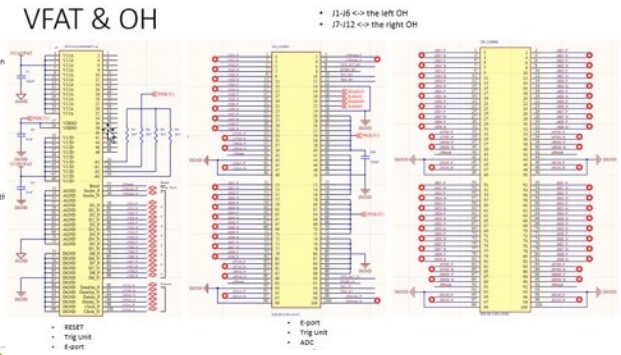
Design and R&D of ME0 GEB

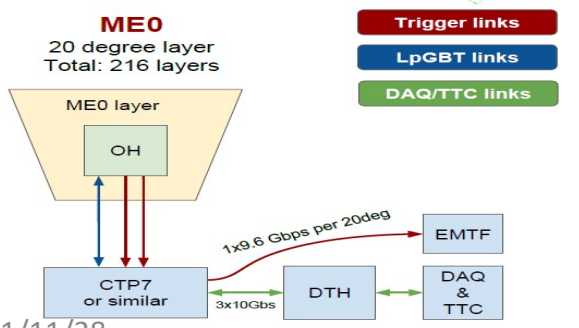
- July 2020: the design of the 1st version of ME0 GEB by PKU group was completed； reviewed and validated by CMS-GEM collaboration；
- Dec. 2020: the 1st prototypes of 7 sets produced (delayed by Covid-19), shipped to CERN&USA in Feb. 2021, shown excellent test results.
- later 2022: mass production is expected to start.

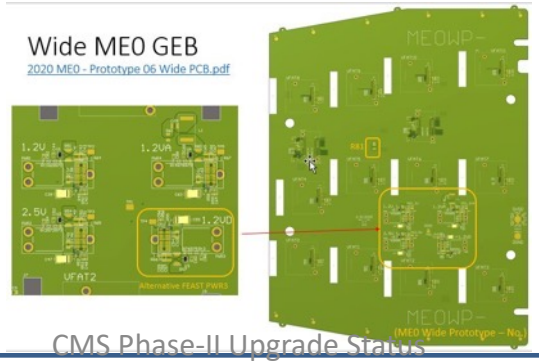


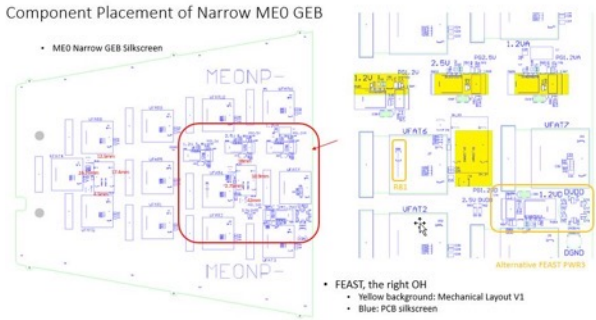












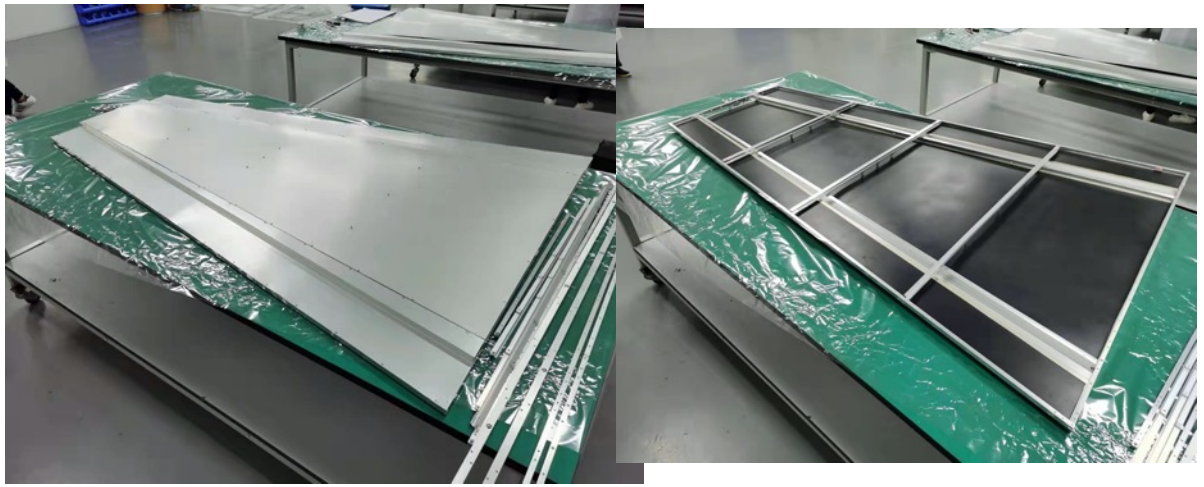
External Frames and SM Structures

GEM External Frame: fabricated with FR4 materials with very high precision (tolerance on thickness < 0.03 mm)

- Start test production in 2019 in China, approved by CMS-GEM review committee in Jun. 2020;
- May 2021: production of all GE2/1 FR4 external frames (320 sets) completed, tested and shipped to CERN

- Screen and supporting structure of GE2/1 Super-Module: 2 types (~1×2m^2) holds 8 GEM chambers (M1-M8), providing mechanical support, insulation, screening
- Apr. 2021: start facility update and test production. Two sets of prototypes produced in Oct. and passed QC.
- ~early 2022: start mass production (~40 sets)

GEM FR4 ext. frames produced



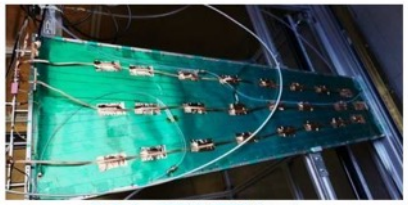
Prototypes of screen and supporting structure of GE2/1 Super-Module

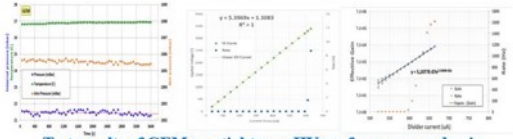
PKU Production Site and activities at CERN

- PKU GEM assembly and QC laboratory ready, with cleanroom and hardware/software platforms
- Mar. 2021: PKU GEM Lab. passed the review of CMS-GEM collaboration, becomes one of the official CMS-GEM production sites.
- Jun.-Sept. 2021: PKU members participated the assembly and test of GE2/1 M1 GEM at CERN,
- ~mid 2022: start production of GE2/1 M5 GEM (~40 chambers) in PKU.

- Completed gas-tightness, HV performance and gain test etc. with full-size GE1/1 GEM, QC procedure setup done.

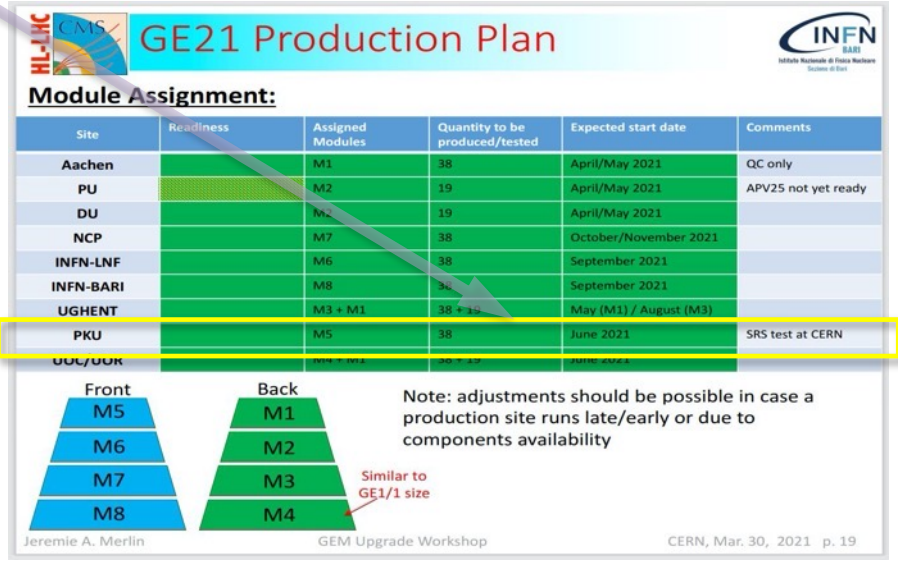

GEM X ray gain test at PKU


Full-size GE1/1 GEM detector


Test results of GEM gas-tightness, HV performance and gain

→ GEM Production site in PKU is ready

Test of Full-size GE1/1 GEM at PKU lab.

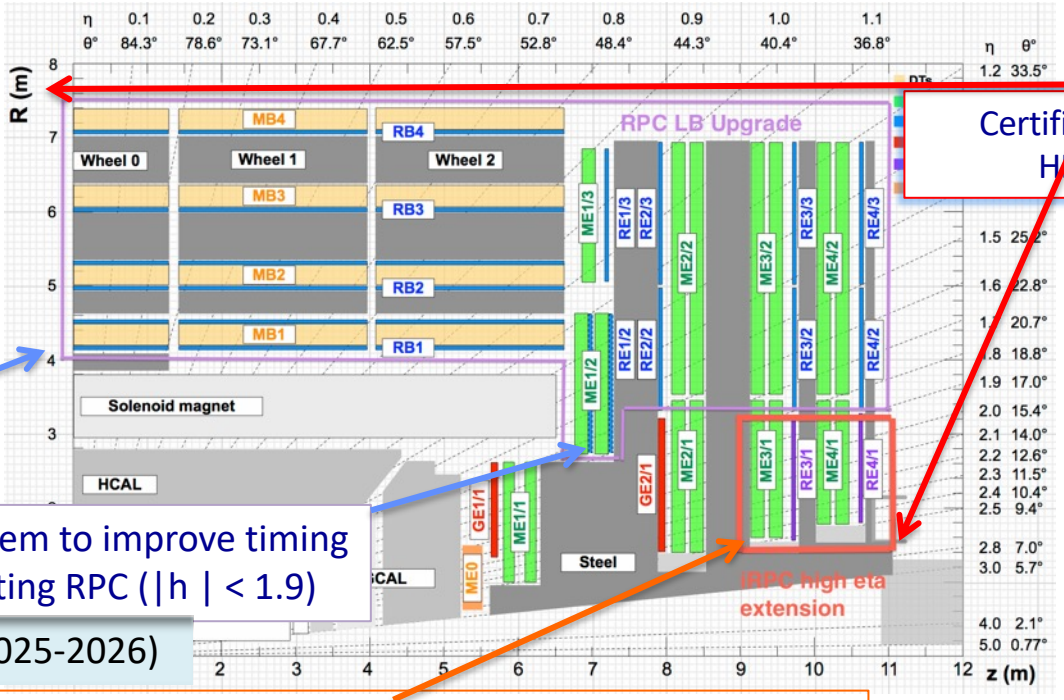


More details in Aera Jung's talk

RPC Upgrade Project

New RE3.1/4.1 (iRPC + FEBs)

New LinkBoard System for present RPC



Certification for HL_LHC

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

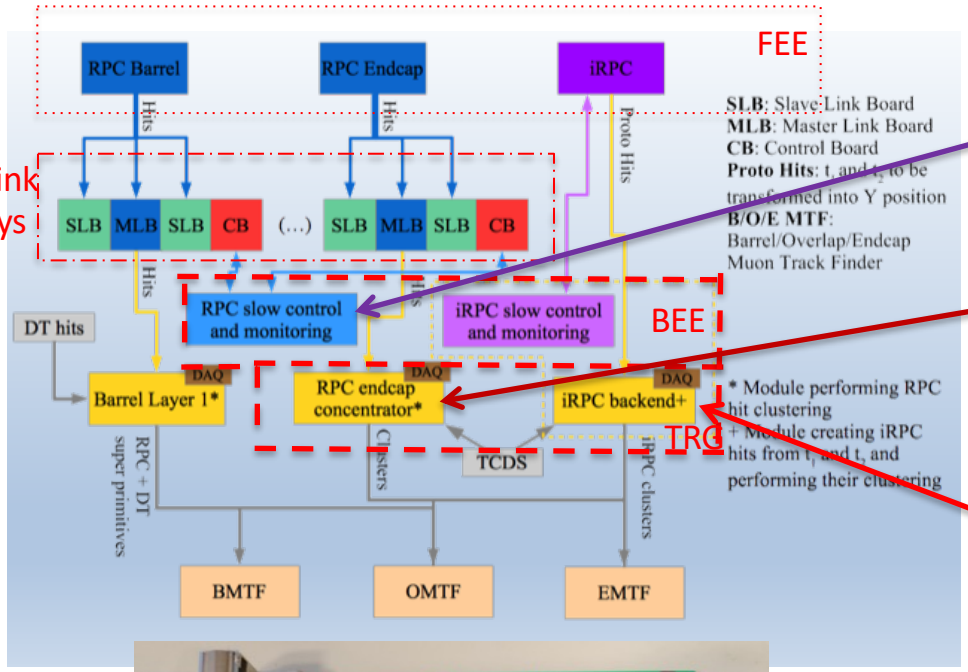
Installation in LS3 (2025-2026)

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

Installation in YETS 2022-23 & YETS 2025-26

RPC/iRPC TRIG/Backend Electronics

IHEP



Exiting RPC Backend(|η| < 1.9),Barrel and End cap

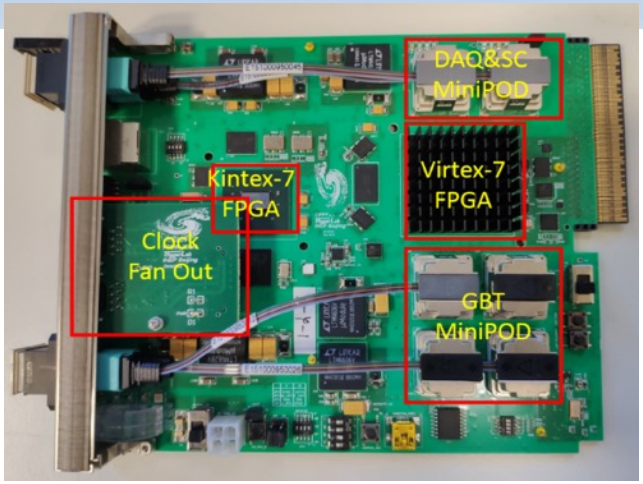
- Communication with LBS/CB
- Monitoring
- Slow Control

RPC Endcap Concentrator/Trigger

- Concentrator
- Trigger primitive(Cluster)
- Readout(DAQ)

iRPC(RE3/1,RE4/1) Backend/Trigger

- Slow Control
- Monitoring
- Fast Control
- Trigger primitive (Cluster)
- Readout(DAQ)



Demonstrator 2021/2022 and Interim 2023/2024 Installation

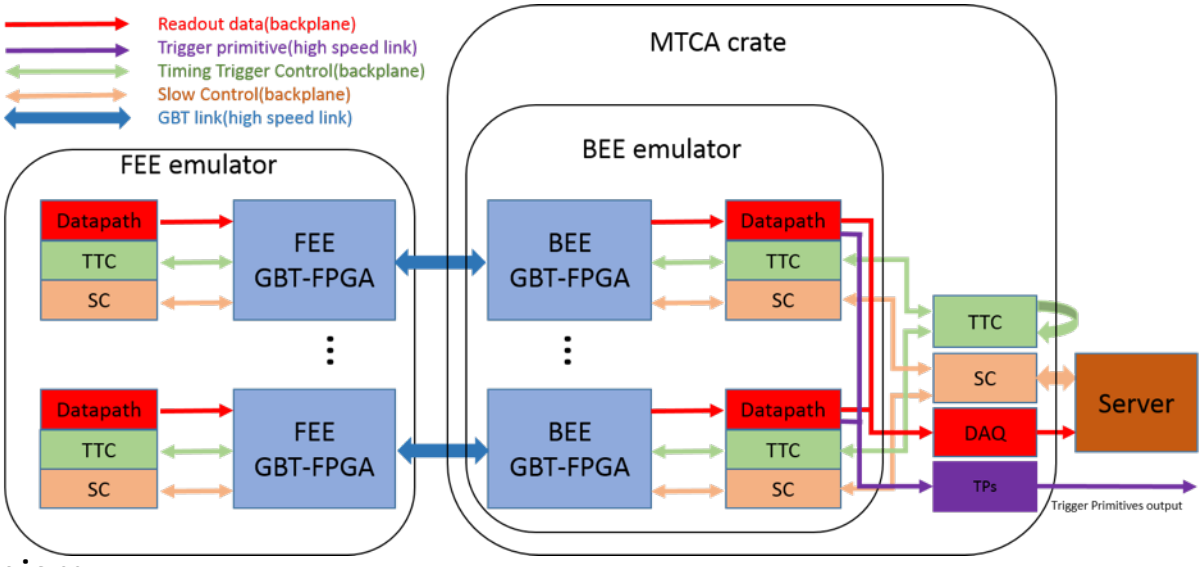
Backend electronic and trigger board by IHEP is key hardware component for backend and trigger

Backend demonstrator: fw and sw

Before joint test with iRPC/FEB, Emulator system were developed and tested to check full functionalities of BE/Trigger.

See SONG Jianing's talk

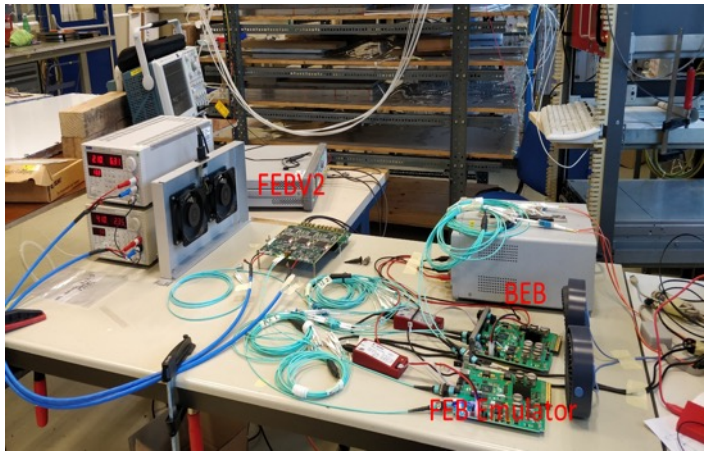
- Fast control/TTC
- Slow Control/SC
- Readout/DAQ
  - Data driven readout
- Trigger Primitives



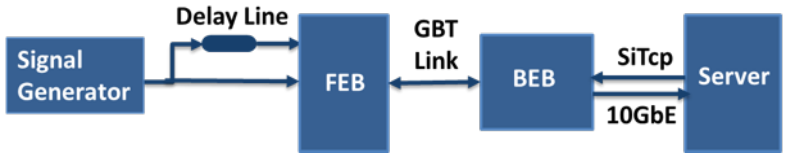
- FE also emulated
  - Check-Sort-Push Mechanism

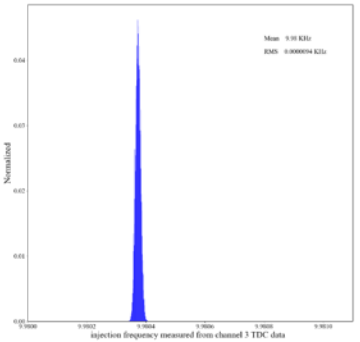
Test working in April/May

iRPC FEE-BE/Trigger Joint test

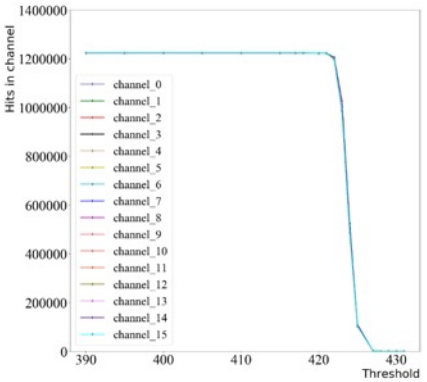


- FEE Emulator ,FEB and BE Joint test system was set up in 904 since July 2021.
- Preliminary results shows that BE/Trigger can configure and readout data correctly from iRPC FEB.





Test signal frequency measurement



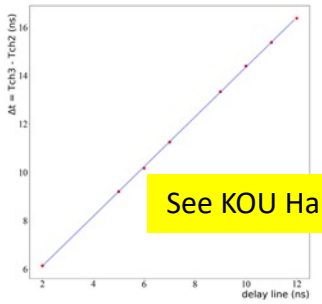
Petiroc threshold scan after calibration

Fan-out output signal

Oscilloscope confirms the delay value

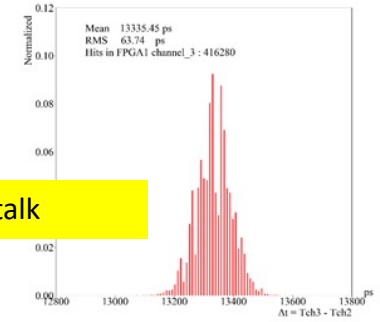
FEB Injection signal

FEB Injection board



Time measurement by adjusting delay line

See KOU Hanjun's talk

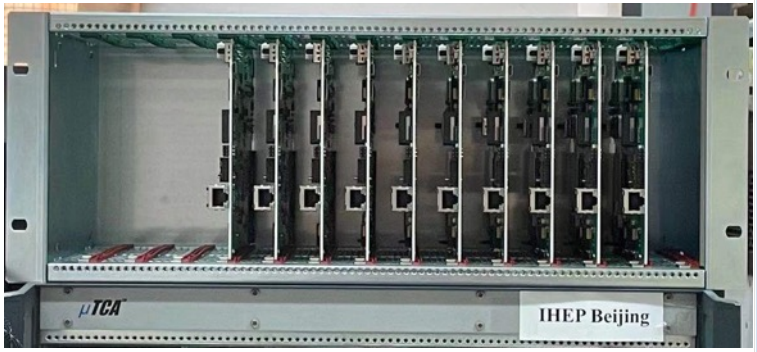


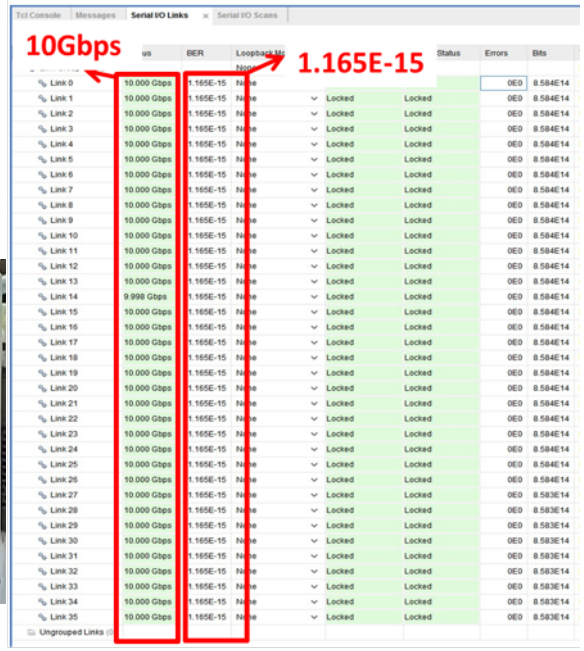
Time resolution of FEB TDC

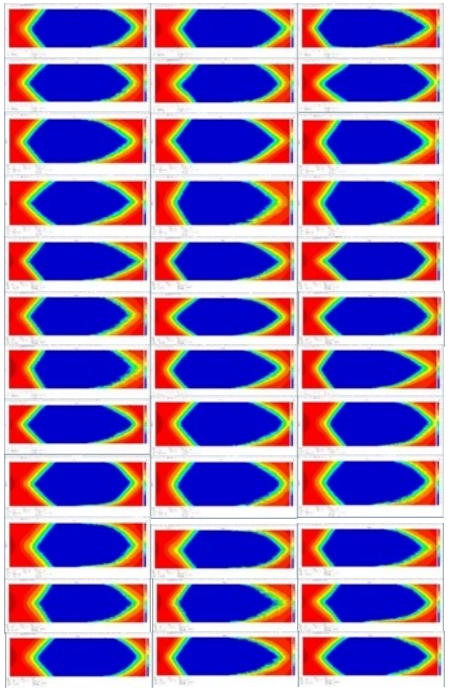
MTCA Mini-Production for installation

See ZHAO Jingzhou's talk

- Finished Mini-Production for 2022/23 Installation done .
- MicroTCA Qualification OK.
- Ready for transportation to CERN .







HGCal Design and Parameters

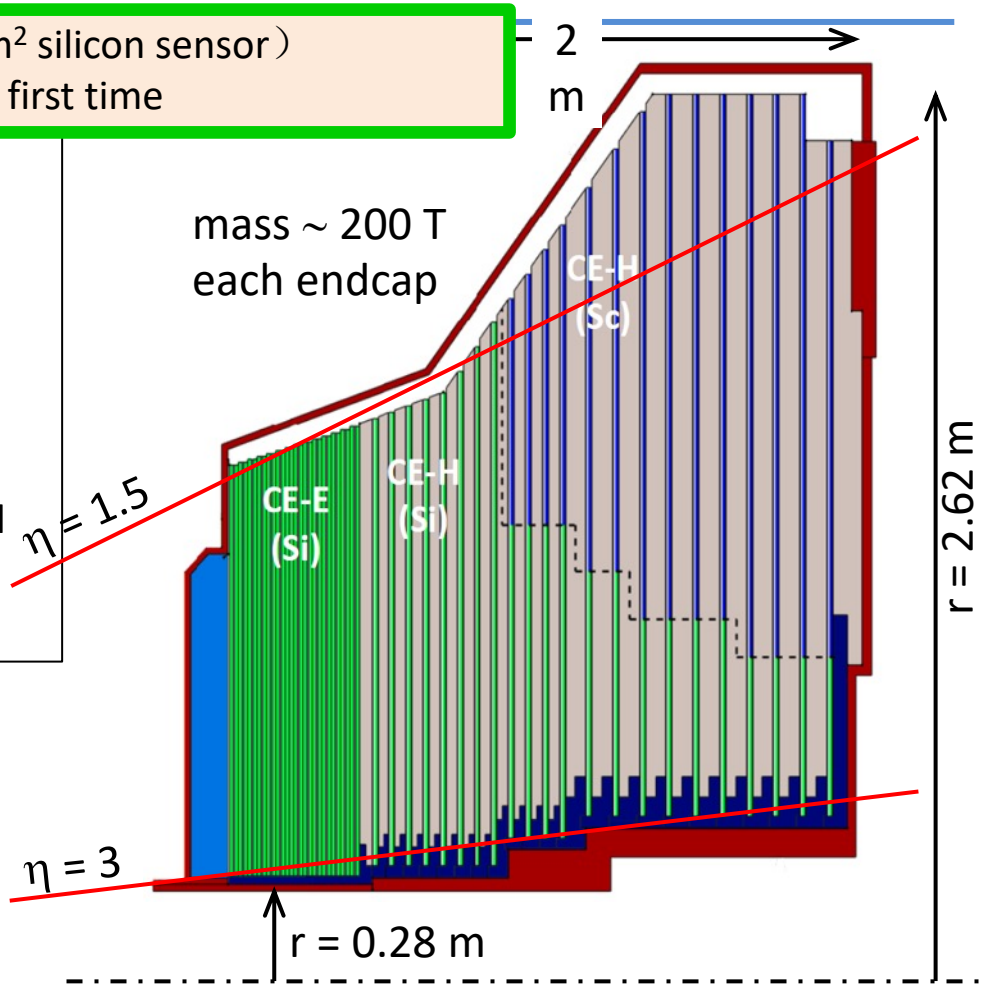
~31k Si Module（640m^2 silicon sensor）
a 5D calorimeter build first time

Key Parameters :

- HGCAL covers 1.5 < η < 3.0
- Full system maintained at -30°C
- ~640 m^2 of silicon sensors
- ~370 m^2 of scintillators
- 6.1M Si channels, 0.5 or 1.1 cm^2 cell size (6M)
  240k scint-tile channels (η–ϕ)
  - Data readout from all layers
  - Trigger readout from alternate layers in CE-E and all in CE-H
- ~31k Si modules (incl. spares)

challenges：

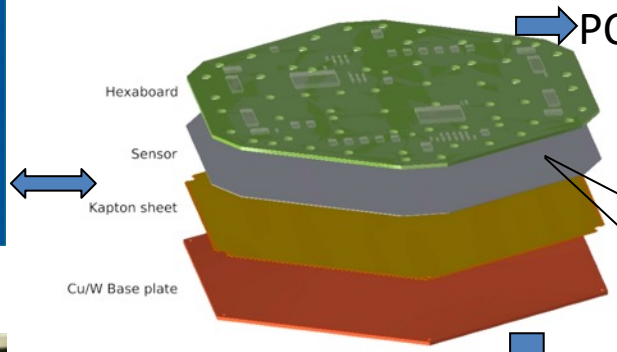
2MGy does
140 pileup
220kW heat load
640m^2 silicon sensor
…



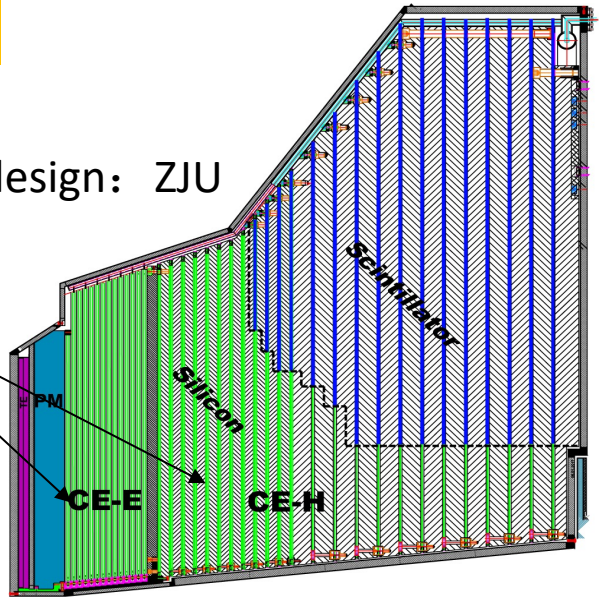
Electromagnetic calorimeter (CE-E): Si, Cu/CuW/Pb absorbers, 28 layers, 25.5 X_0 & ~1.7λ
Hadronic calorimeter (CE-H): Si & scintillator, steel absorbers, 22 layers, ~9.5λ (including CE-E)

Major task for China HGCal: MAC

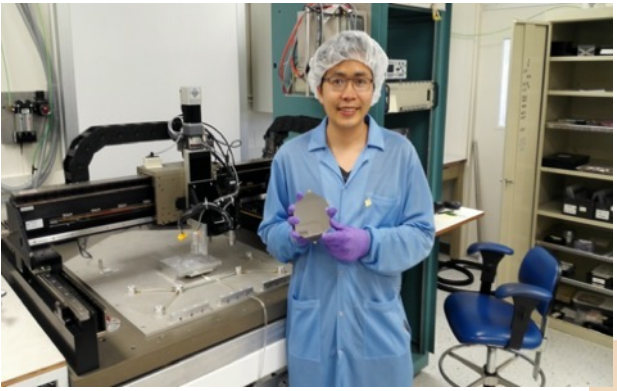
IHEP+ZJU+THU+FDU



PCB design：ZJU



Module Assembly Centers (MAC)：
IHEP，NTU，Indian，UCSB，TTU，CMU
~5200 modules per MAC

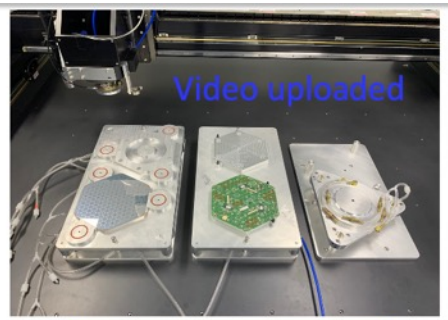


Since first silicon module(6 inch) in 2016, IHEP has close collaboration with UCSB and participate ~20 module assembly

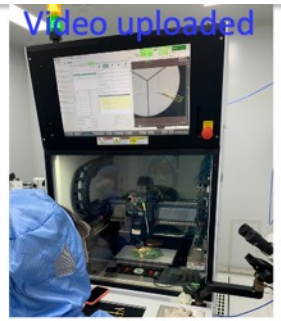
Cost: 69 M CHF
IHEP MAC will produce > 100 m^2 silicon module

Production chain at IHEP MAC set up and qualified

componat tests

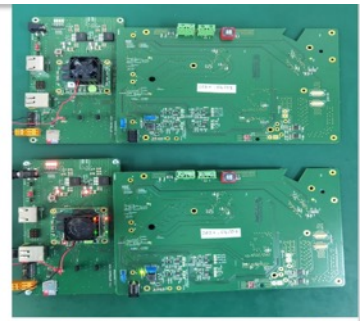


Module assembly

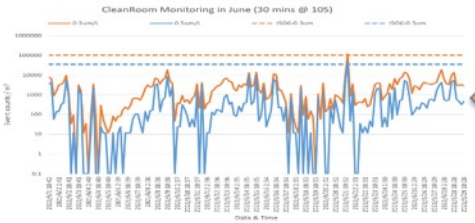


Wire bonding

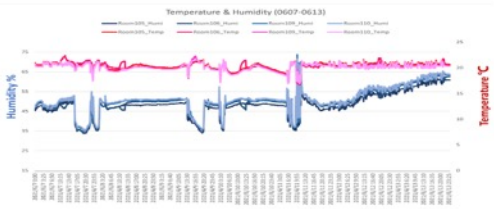
encapsulation



Module testing



Cleanroom status
- Cleanness
- Temperature
- Humility



Ship back to CERN

- Clean room and major equipment are installed, operator trained
- Fixture for gantry, wire bonder, pull tester, encapsulation are fabricated
- Glue parttern for assemly, encapsulation and wire bonding code are tested
- Go through full production chain for the first time on real componats (next slide)

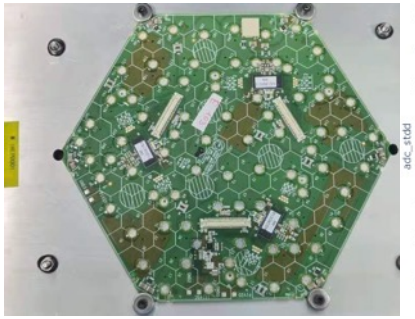
HGC project manager's site qualification report to P2UG

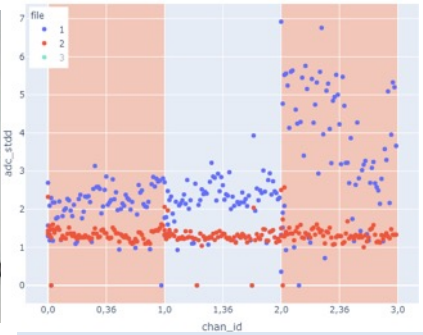
- Silicon module assembly centres: MACs qualified (UCSB, IHEP, and NTU), are close (CMU and TTU), and TIFR now has a green light to order a g
- SiPM market survey closed. Moulded tile prototyping well advanced. Machined cast tile prototypes made and under test, and tileboards development and test advancing well
- SiPM-on-Tile light yield results consolidated from different tests. Inputs collected for the optimization of the overall layout, and calibration procedure being studied for end-of-life with lower S/N
- Tilemodule assembly: automated tile wrapping and tilemodule assembly equipment is working in the TACs
- HGCROCv3 is under test and the analogue results very encouraging, some issues with new digital elements to be understood, and packaging has suffered delays
- ECON-T-P1 submitted. ECON-D design well advance realistic. ECON-T-P2 planned. ECON design and verif depth of the team

Details in Yong Liu's talk

Production of 2 functional 8 inch module

- Successfully build 2 8 inch HGCal silicon module
  - HGC first functional 8″ silicon module
  - Latest HGCROC ASICs
  - Low noise（~2-3ADC）
  - IHEP news report
- Both modules tested by test beam
  - 2021-9 test first module at CERN beam: IHEP module001
  - 2021-10 test second module at CERN beam: IHEP module 002

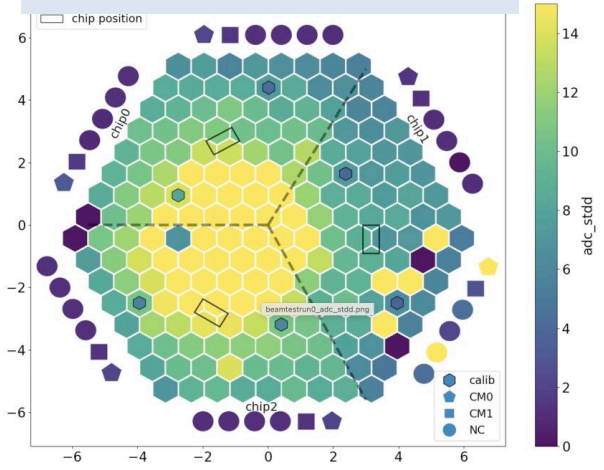




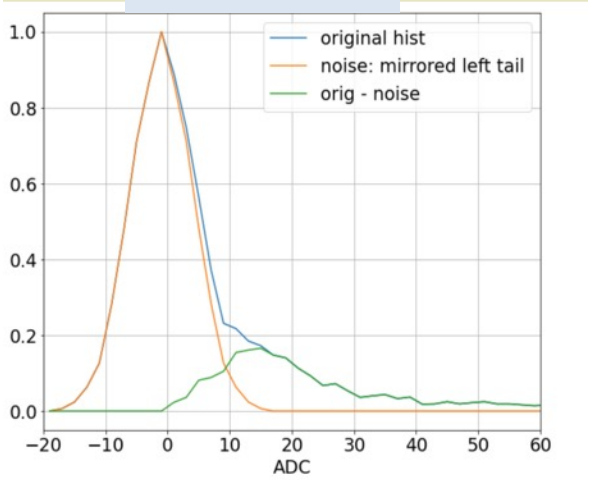
Noise with/w.o. sensor

First time see beam in 8″ silicon module

Beam shower event



MIP signal



Details in Feng Wang ’s talk

FE ASIC/module/beam test at CERN

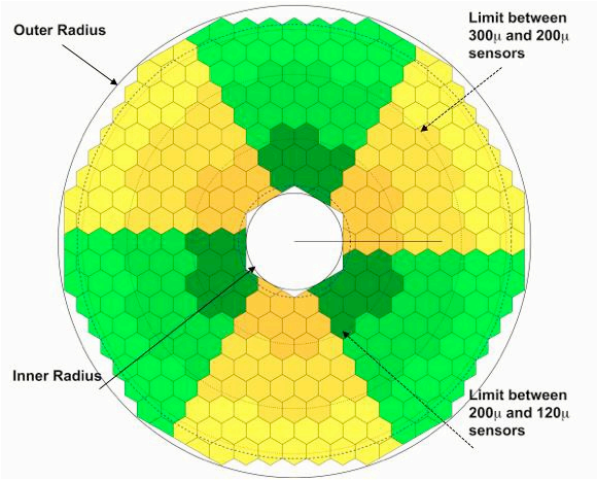
- ~130 HGCROC2 chips tested in April
- ~20 hexaboards received and tested in end of June
  - IHEP produce modules use these hexaboards
- Prepare 2021 Sept. Oct. Beam test, take shifts, and data analysis
- Develop hexaboard tests framework for MACs

IHEP contributions
A. Kapoor
E. Chapon
F. Monti

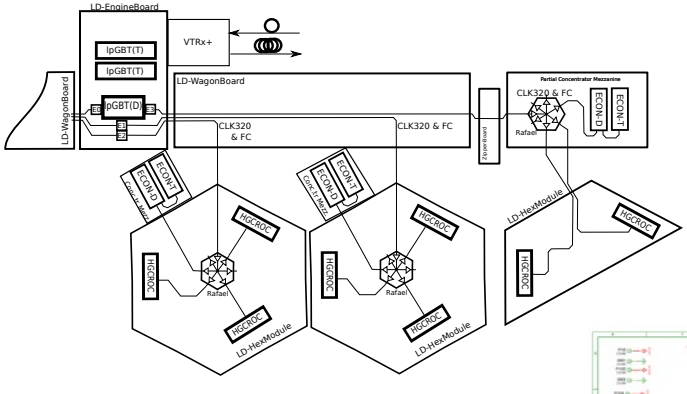
Half-hexaboard design

ZJU

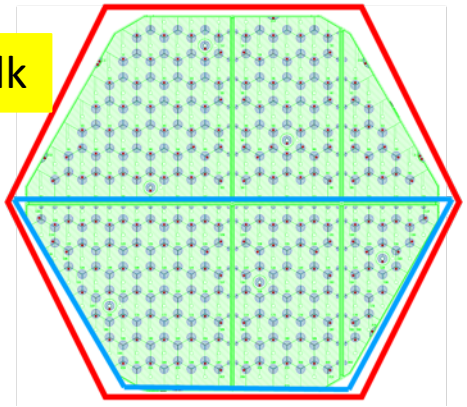
- Complex HGCAL geometry at CMS endcap regions: extra challenges
  - Equipped with both full (hexagonal) modules and partial modules
  - Zhejiang University team: design half modules
    - Schematics done, now working on the layout

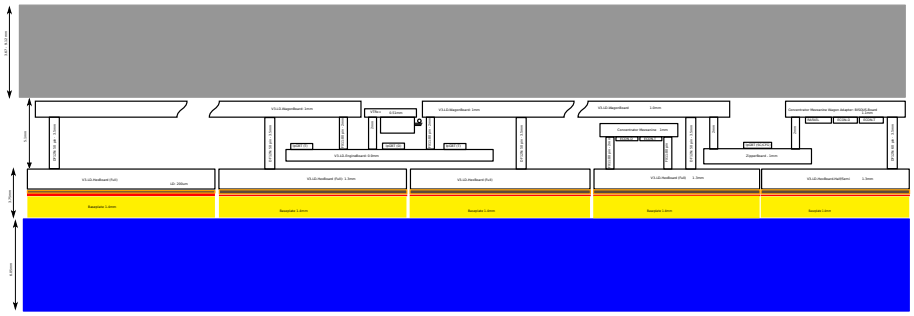


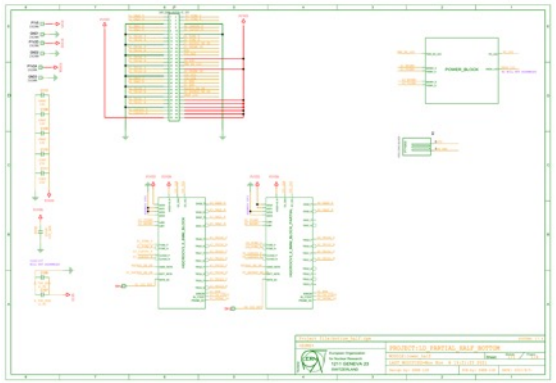
Details in Zhen Lin's talk



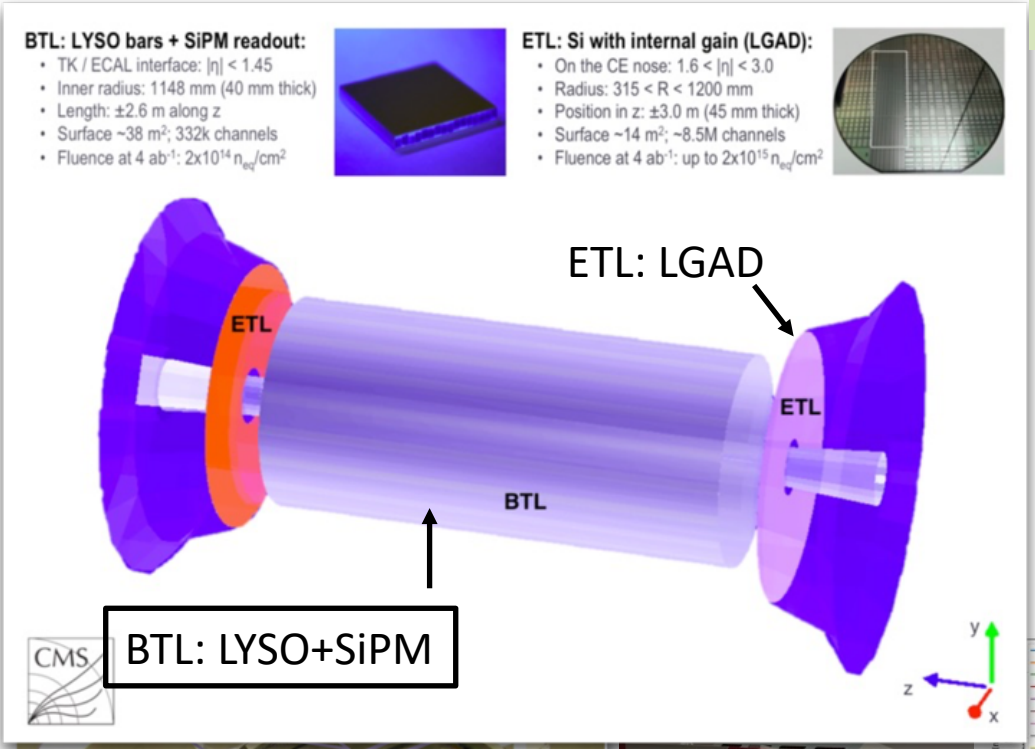
Full module
Half module





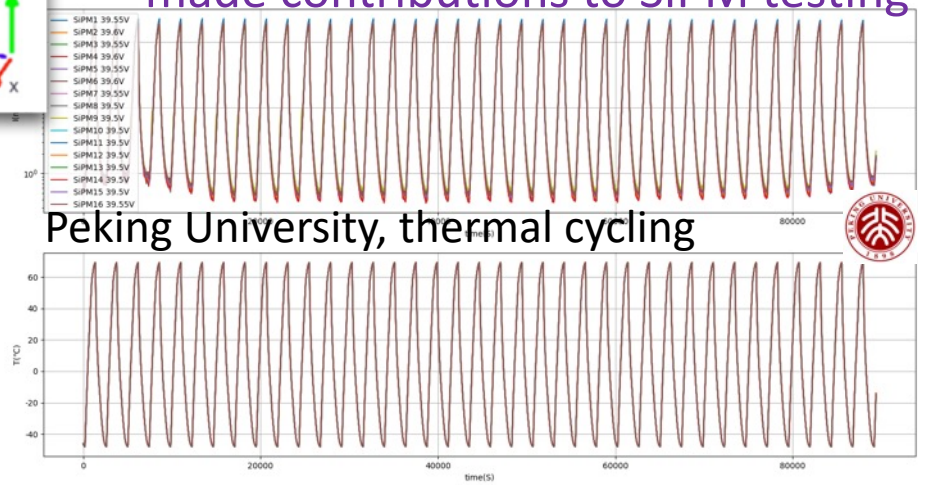


CMS timing detector MTD



CMS-China officially joined MTD in 2021

- PKU, BUAA and THU joined MTD barrel (BTL) studies which uses LYSO+SiPM
- USTC plans to join the MTD endcap (ETL) studies which uses LGAD
- Actively communicated with MTD collaboration, built local labs, set up testing bench, and already made contributions to SiPM testing



More details in Xiaohu Sun's talk

Summary

- CMS Phase-II upgrade projects are fully launched and progress well, with many important contributions from CMS-China
- GEM:
  - GE1/1 fully installed, commisioned and see the first beam;
  - GE2/1 GEB designed and validated by CMS-China and 1/8 chamber production and QC in China to start soon;
  - ME0 under prototyping, with both electronics and chamber
- iPRC electronics and trigger
  - Backend/Trigger development done and verified with emulator system;
  - First step of joint test with iRPC/FEBV2 is successful;
  - Data readout tested with FEE injection system and further test ongoing
- HGCAL
  - Passed IHEP MAC site qualified, silicon module production developed;
  - CMS first 2 8 inch silicon module built at IHEP, validated by CERN test beam;
  - Half-exaboard PCB Designed by ZJU team
- MTD: new contributions from CMS-China, local lab set up