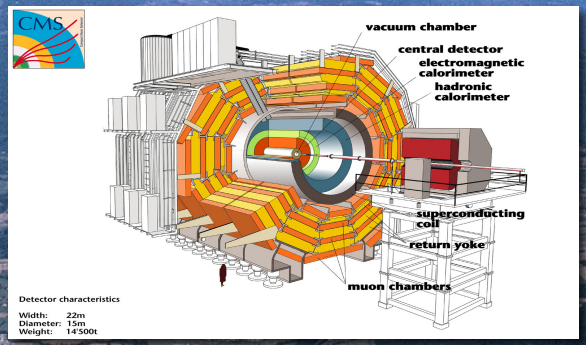
CMS upgrade status

Huaqiao Zhang (IHEP)

LHC and CMS experiment



Geneva lake

•CMS

•LHCb

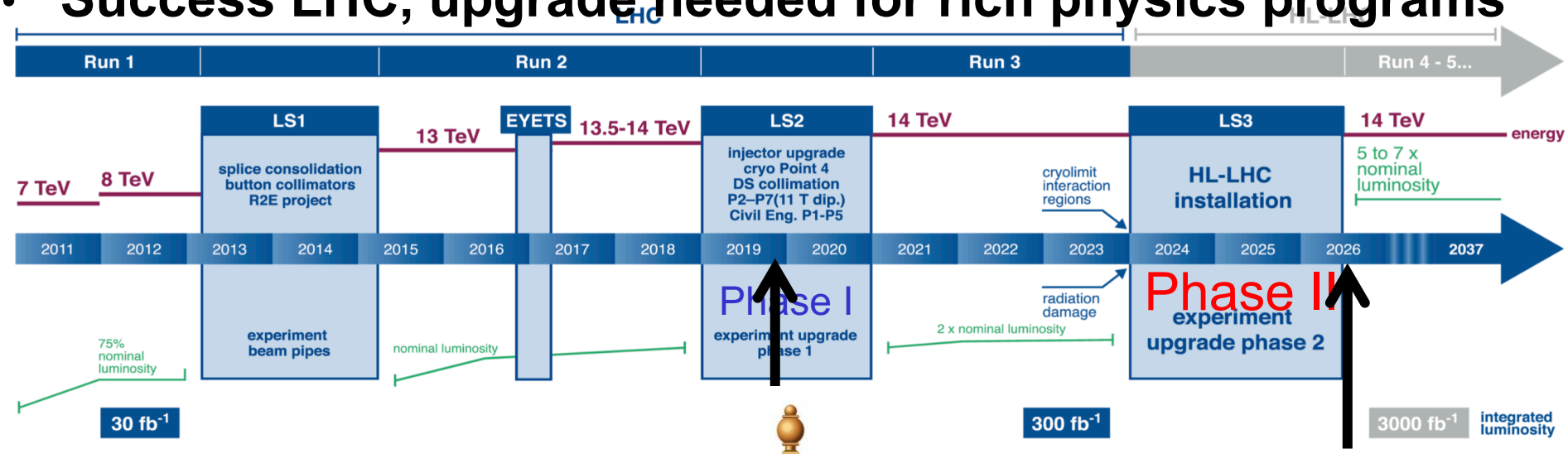
•ALICE

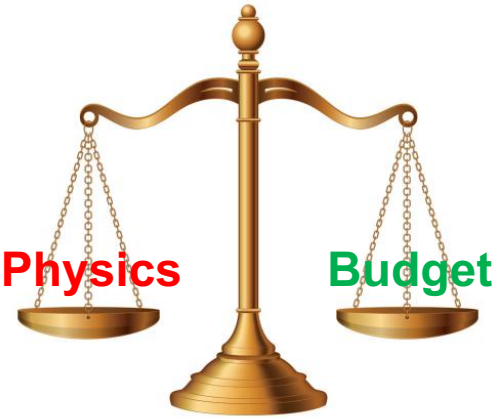
•ATLAS

- 27km, 100m underground, ¼ in Switzerland, ¾ in France
- Designed Ecm 14TeV(14×10^{12}eV) for p-p collisions

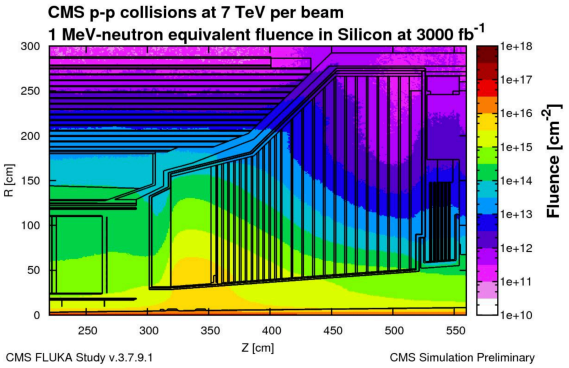
LHC operation Roadmap

- **Success LHC, upgrade needed for rich physics programs**

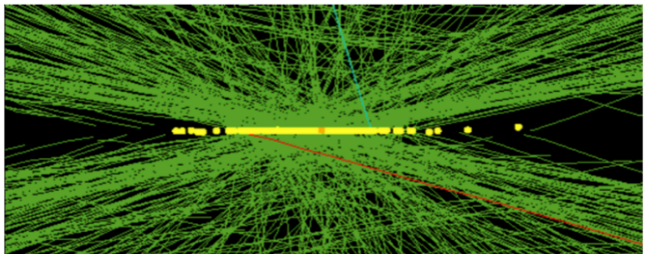




Radiation damage



Pileup challenge



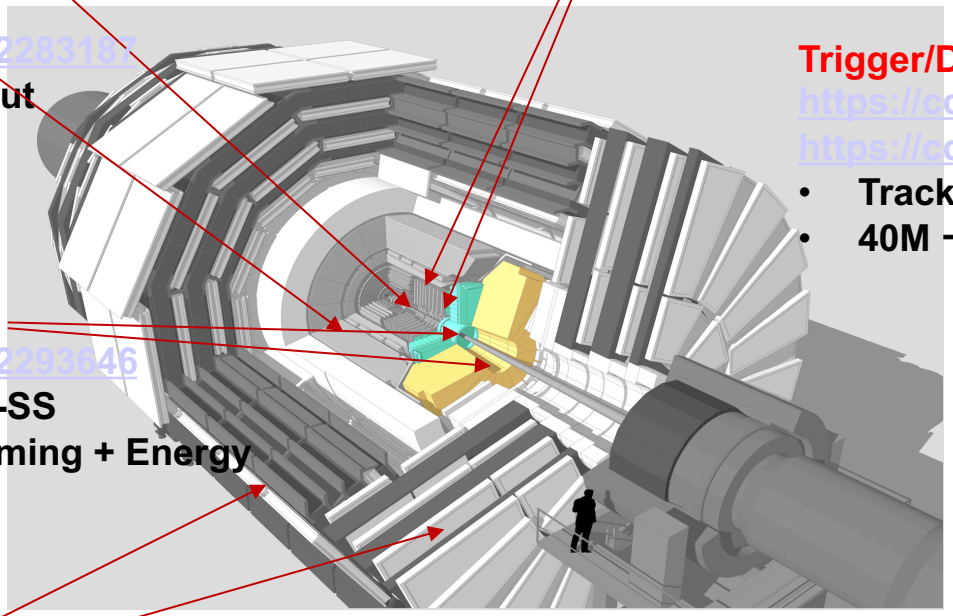
Event rates capability

Overview of CMS phase II upgrade

Tracker: https://cds.cern.ch/record/2272264
- Si-strips and Pixels increased granularity
- Tracking in L1-Trigger
- Coverage extended to |eta|~3.8

MIP Timing detector:
https://cds.cern.ch/record/2296612
- ~30ps timing resolution
- Barrel: Crystals + SiPMs
- Endcap layer: LG Avalanche Diodes

Barrel Calorimeter:
https://cds.cern.ch/record/2283187
- New ECAL/HCAL readout



Trigger/DAQ:
https://cds.cern.ch/record/2283192
https://cds.cern.ch/record/2283193
- Tracks in L1
- 40M → 750k(PF-like) → 7.5k

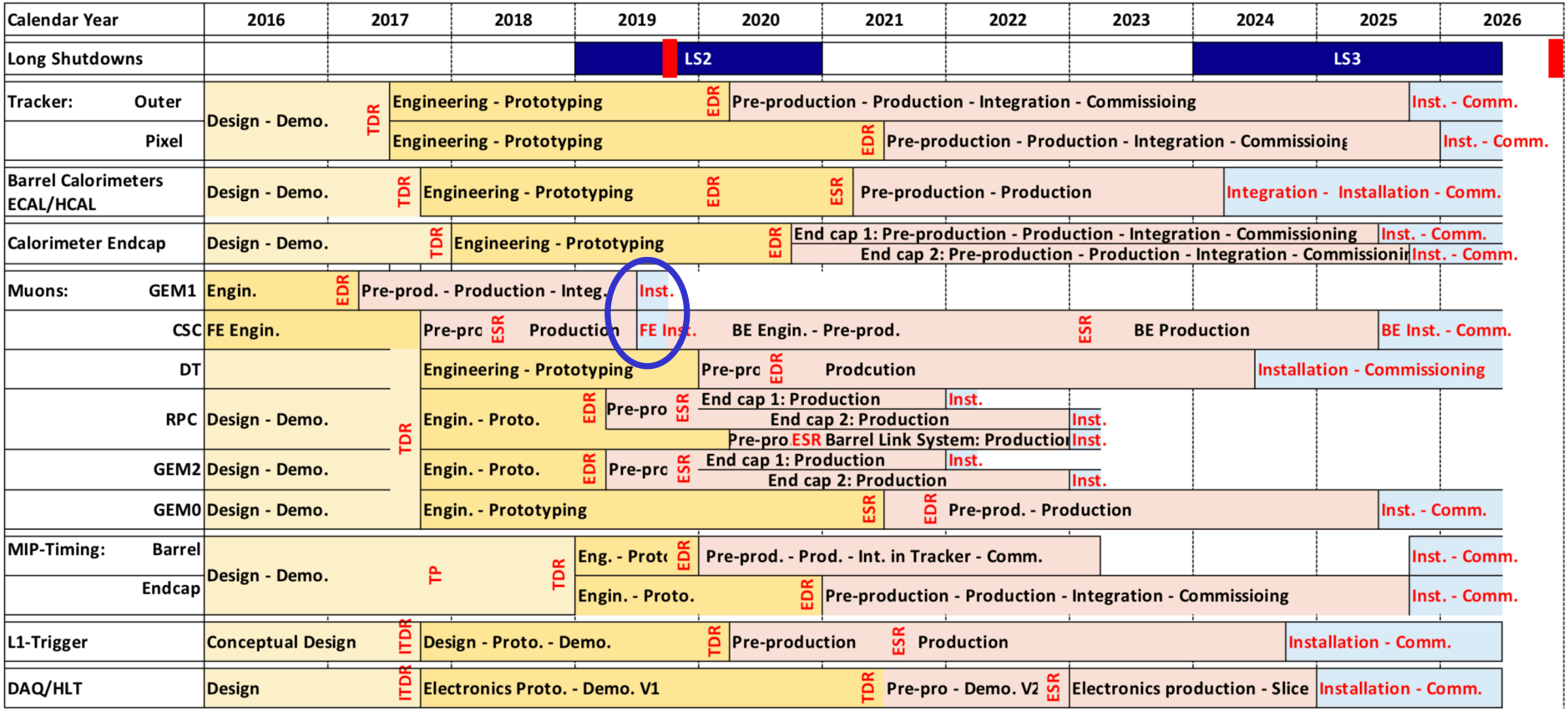
Calorimeter Endcap:
https://cds.cern.ch/record/2293646
- Si, Scint+SiPM in Pb-W-SS
- 3D position + precise timing + Energy

Muon system: https://cds.cern.ch/record/2283189
- New FE/BE readout for DT/CSC
- New GEM/RPC 1.4 <|eta|<2.4
- Coverage extended to |eta|~3

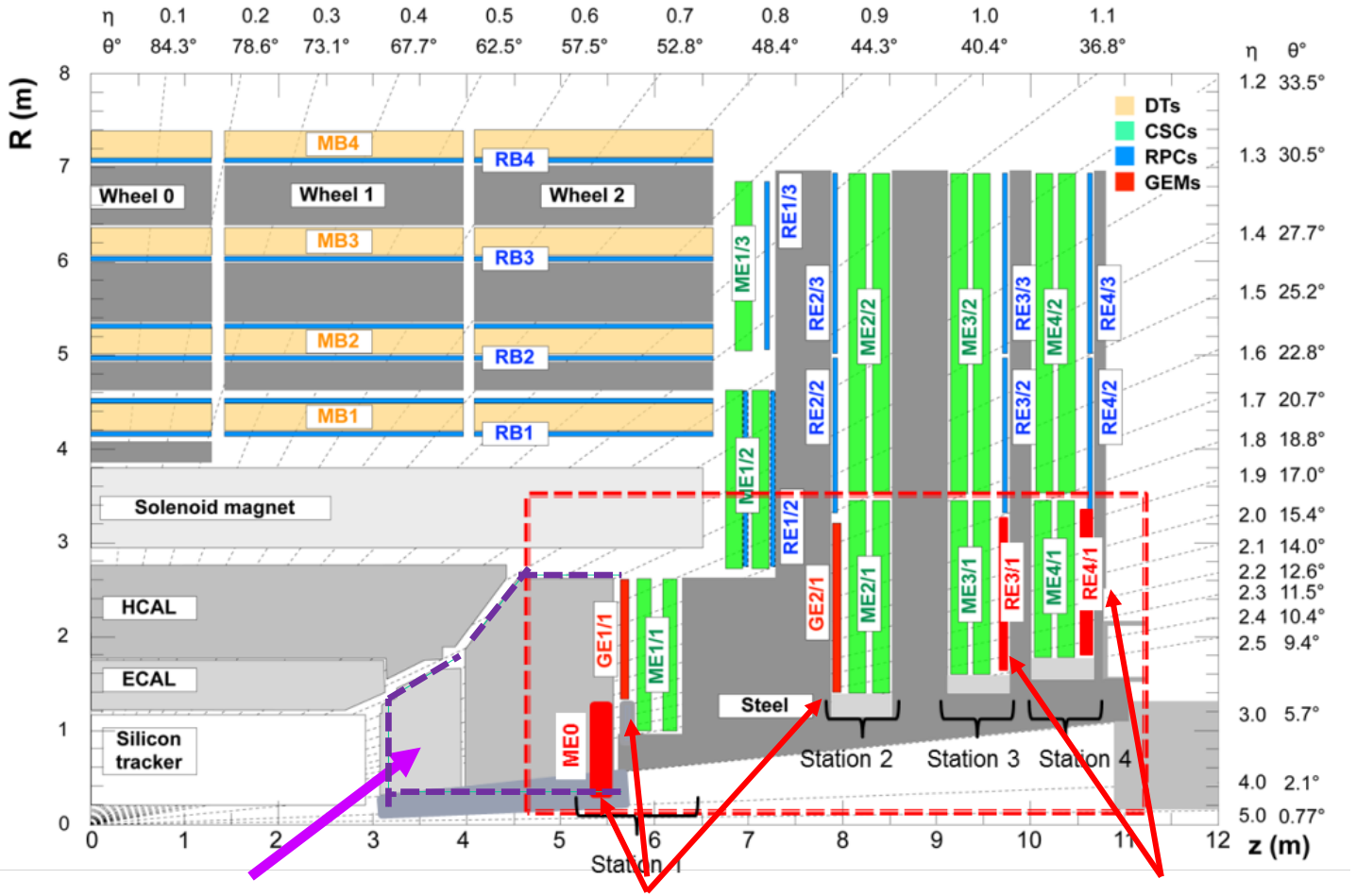
Beam/Luminosity and common Infrastructure
https://cds.cern.ch/record/2020886

Timeline of CMS phase II upgrade

- LS2 (2019-2020):
  - GE1 and CSC FE for inner endcap disk 1-4
  - Beam pipe/magnet infrastructure
- LS3 (2024-2026): All other projects



Chinese in CMS Phase II upgrade



IHEP/THU/ZJU/FDU: HGCal

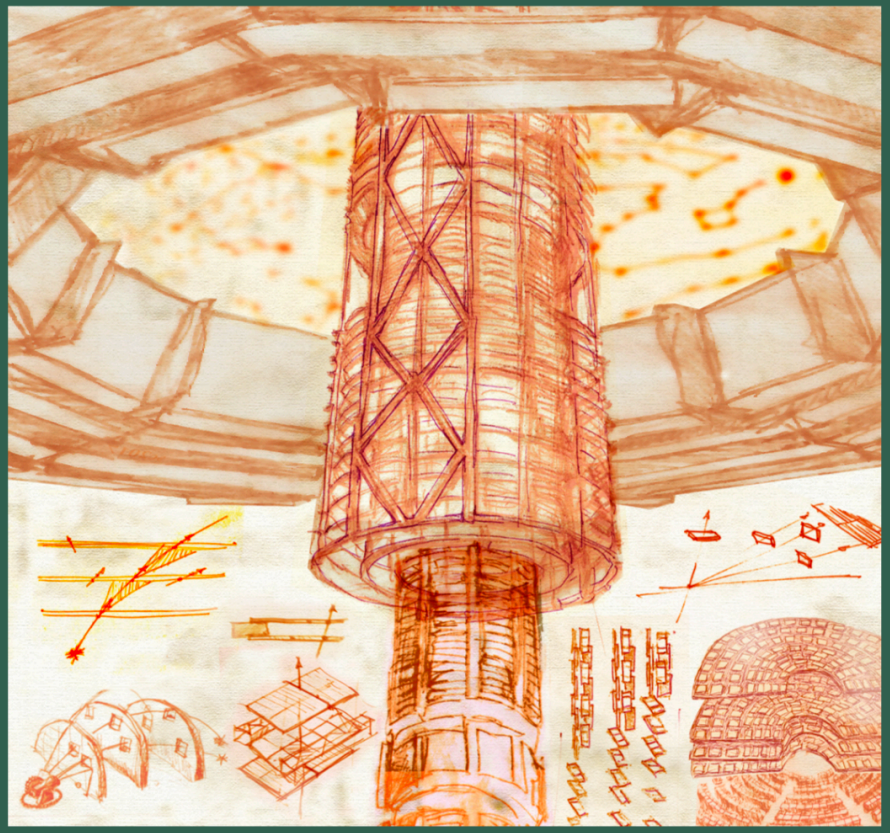
PKU/SYSU/BAAU/THU: GE1/1, GE2/1+ME0

IHEP: muon-Trigger/backend

CERN European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

CERN-LHCC-2017-009
CMS-TDR-17-001
1 July 2017

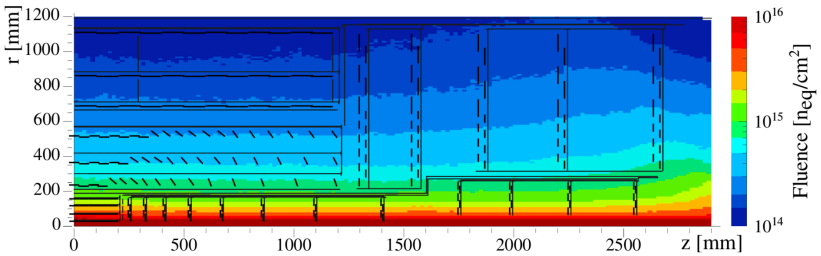
CMS

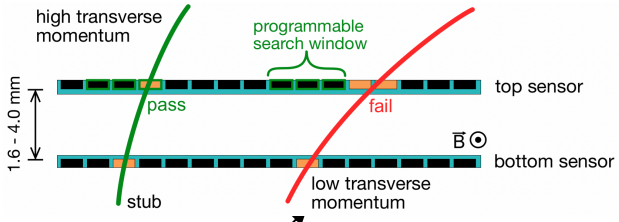


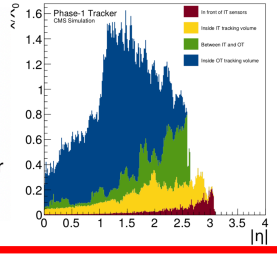
The Phase-2 Upgrade of the CMS Tracker Technical Design Report

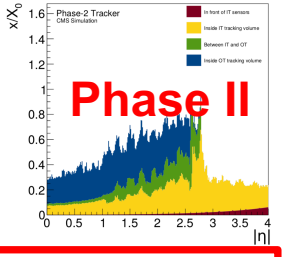
CMS Phase II Tracker design

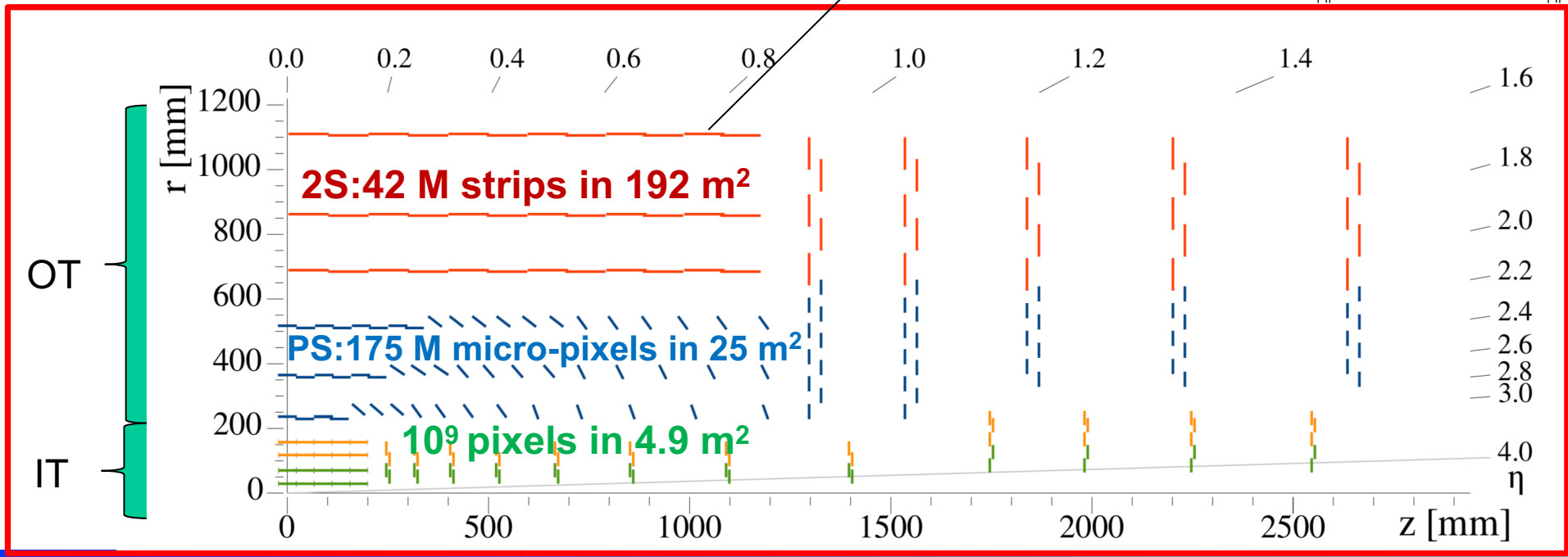
- Radiation: ~2.3*10^{16} MeV neq/cm^2
- 40 MHz input for L1-Trigger
- Increased granularity
  - OT Si-sensors ≃ 200μm thick - 90/100μm pitch - 2.5/5cm strips - 1.5 mm macro-pixels in inner layers
  - IT Si-silicon sensors ≤ 150μm thickness - 50x50 to 25x100μm^2 - large pixels in outer layers?
- Tilted 3 layers of inner OT
- Extend coverage |eta|<3.8
- Reduced material





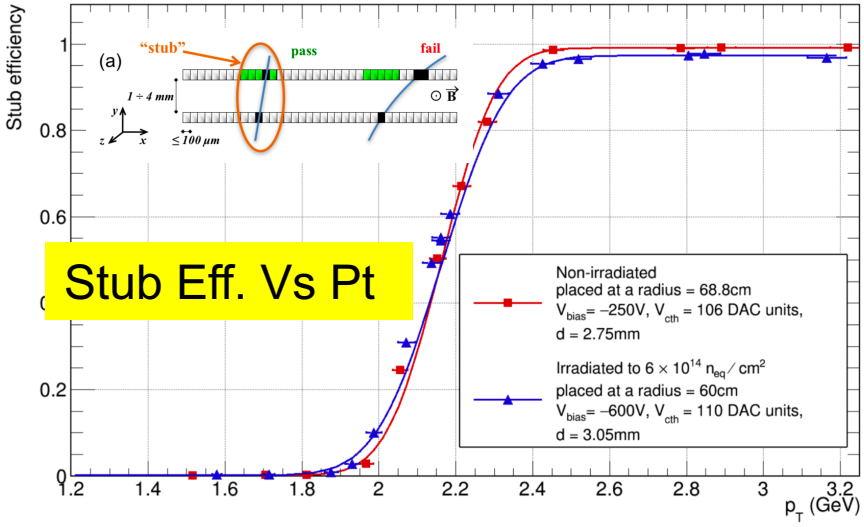


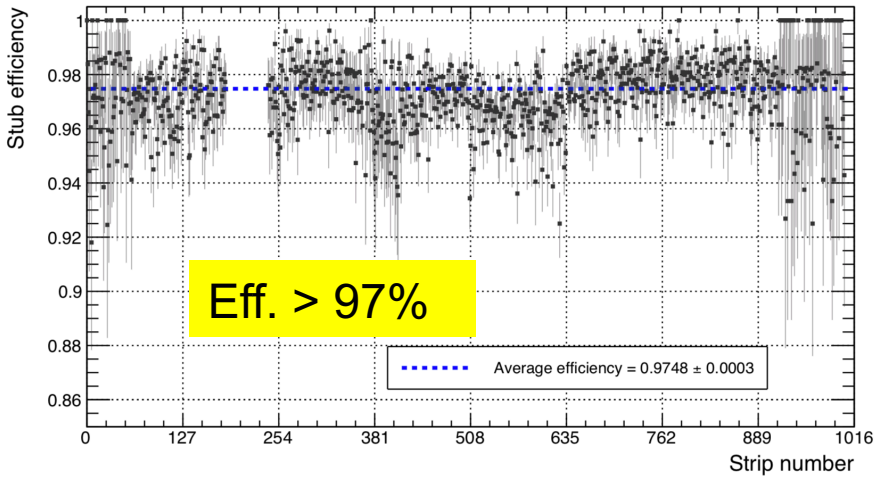


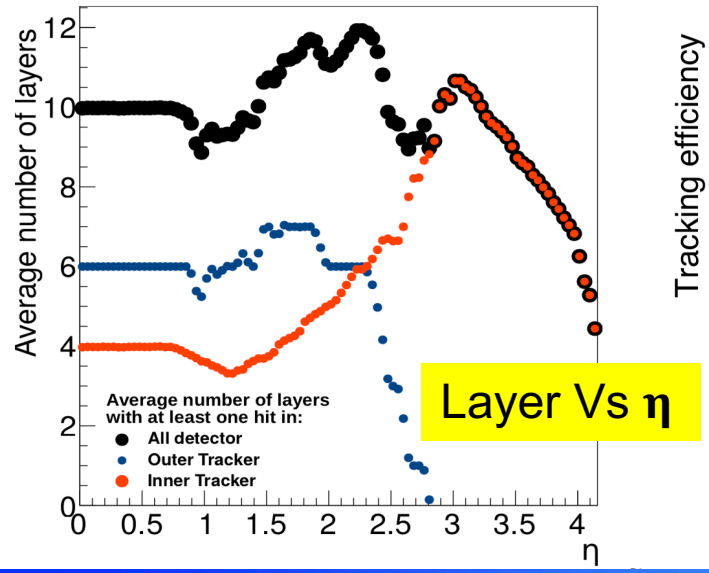


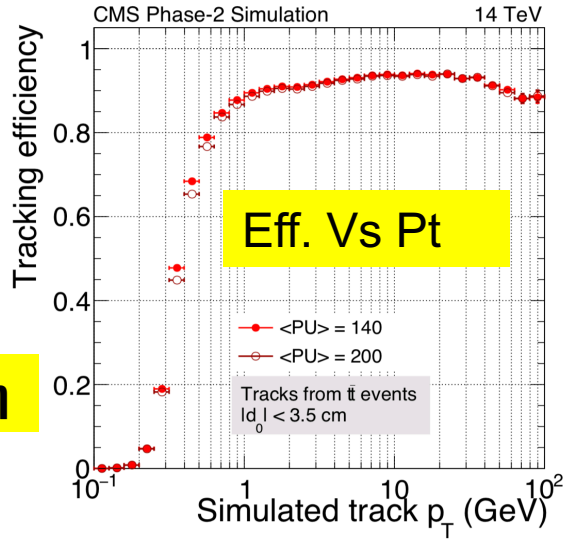
Phase II Tracker performance

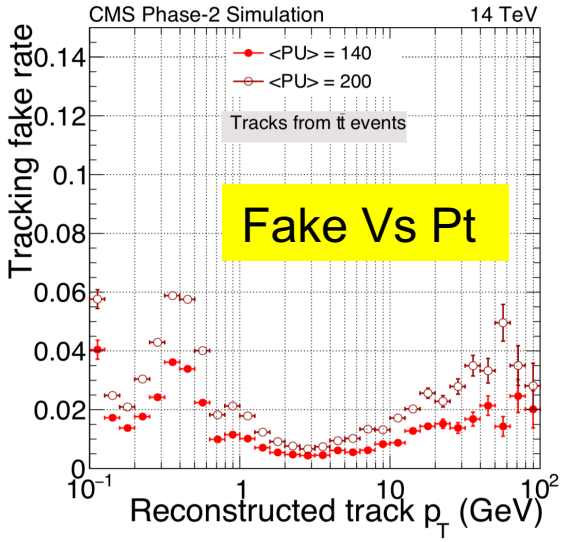
- Tracking efficiency is robust w.r.t. radiation and pileup







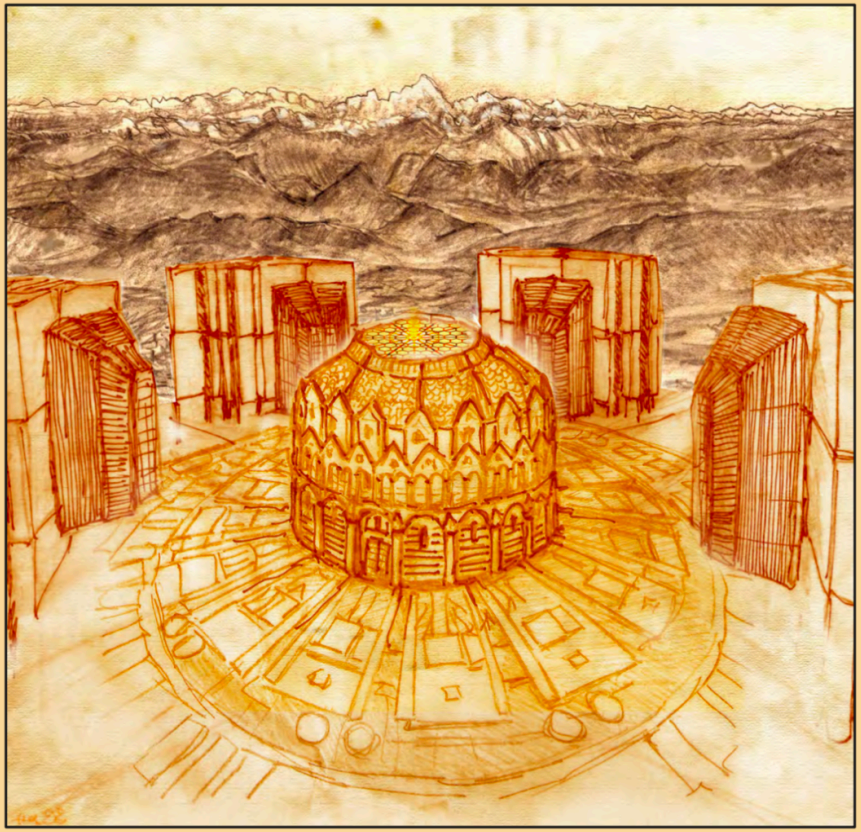




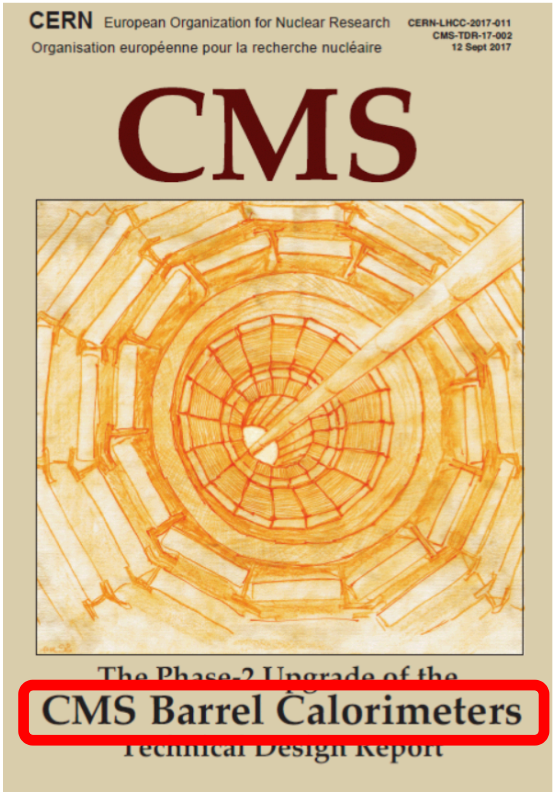
CERN European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

CERN-LHCC-2017-023
CMS-TDR-019
9 Apr 2018

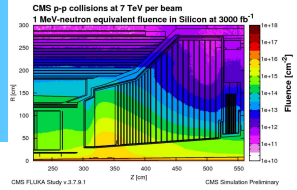
CMS



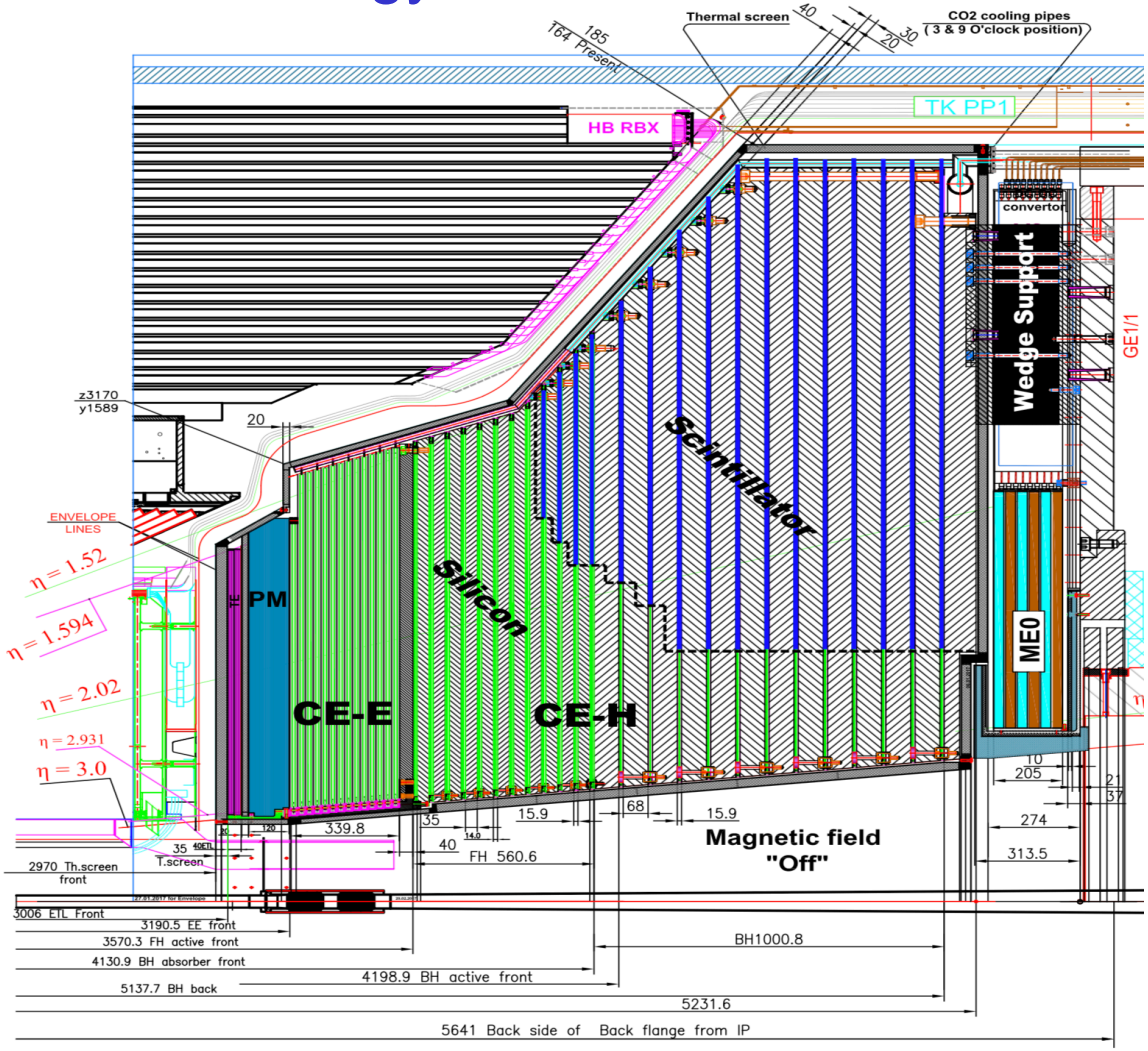
The Phase-2 Upgrade of the
CMS Endcap Calorimeter
Technical Design Report



The Phase II EndCap Calorimeter Overview



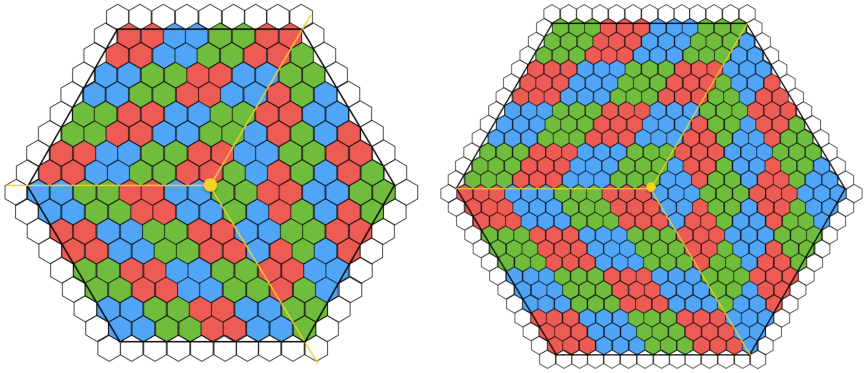
- New Calorimeter: 3D shower + energy + time
  - Ecal + Hcal
- Ecal (CE-E)
  - 28 layers Si + W/Pb/Cu
  - 25 X_0 & ~1.3λ
- Hcal (CE-H)
  - 24 layers Si/Scintillator
  + Stainless Steel
  - ~8.5λ
- Total Silicon:
  - 600 m^2
- Total scintillator
  - 500 m^2
- 6 M Channels



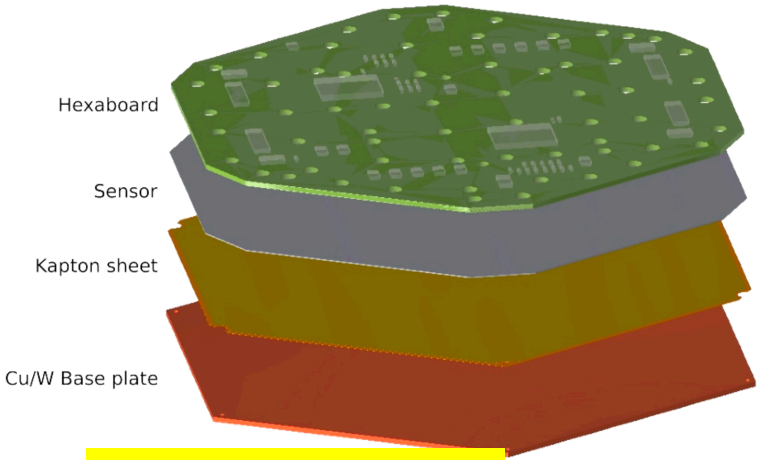
World first(large scale), a dream detector for PF

The HGCal design

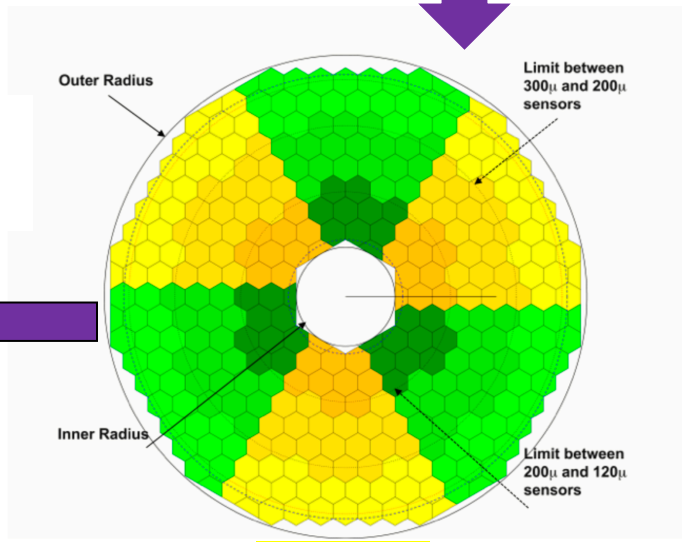
8inch, 1.18cm^2(192) / 0.52cm^2(432)



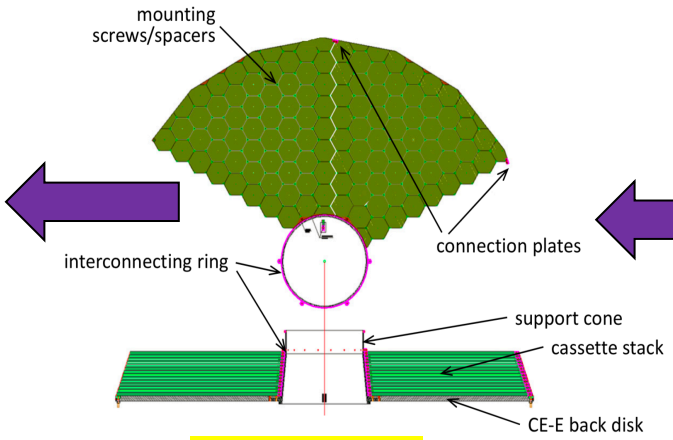
Sensors (Hexagon)



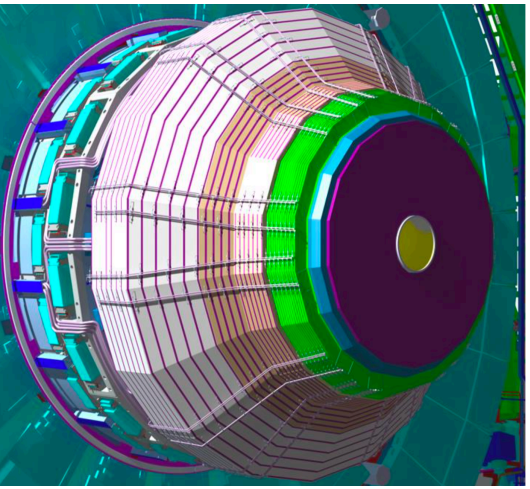
Module Assembly



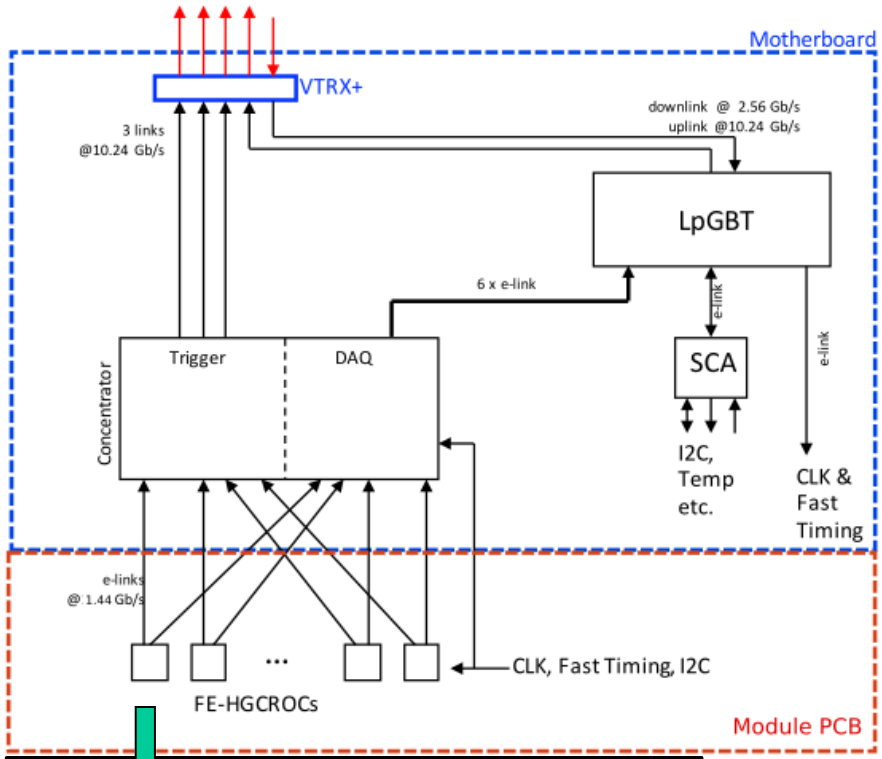
Tiling

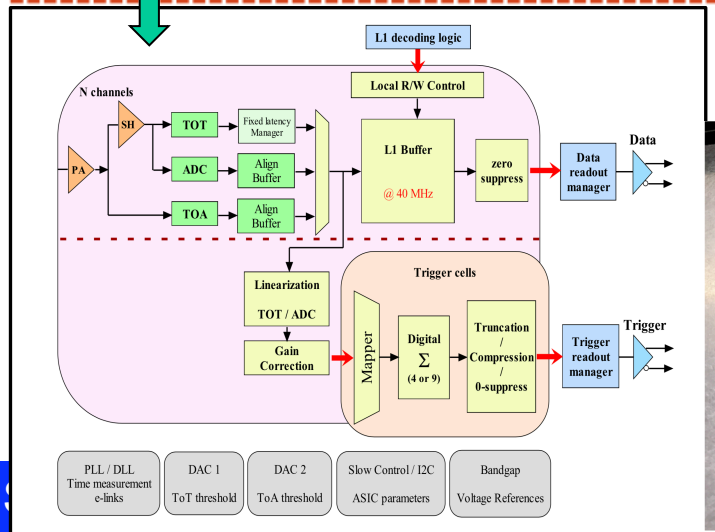


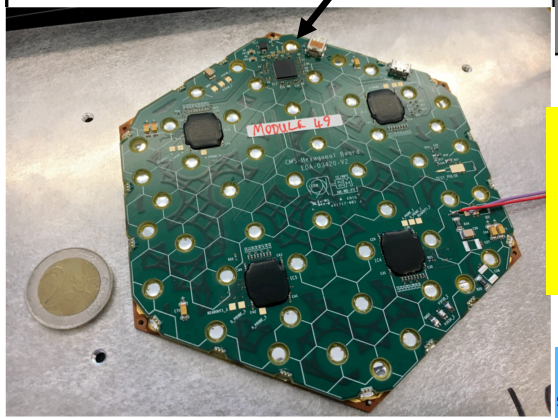
Stacking



HGCal readout

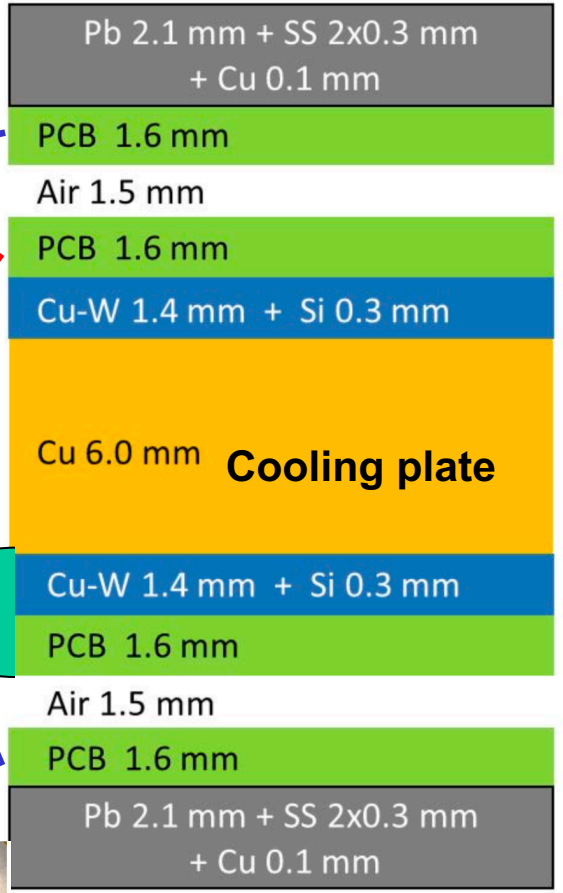






Motherboard

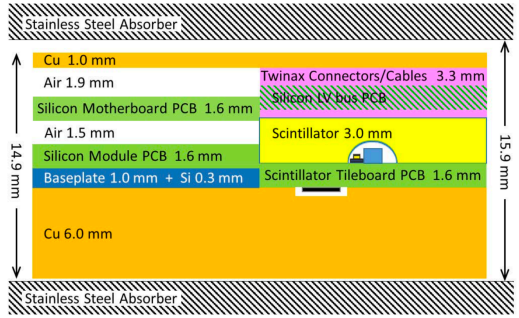
Module PCB

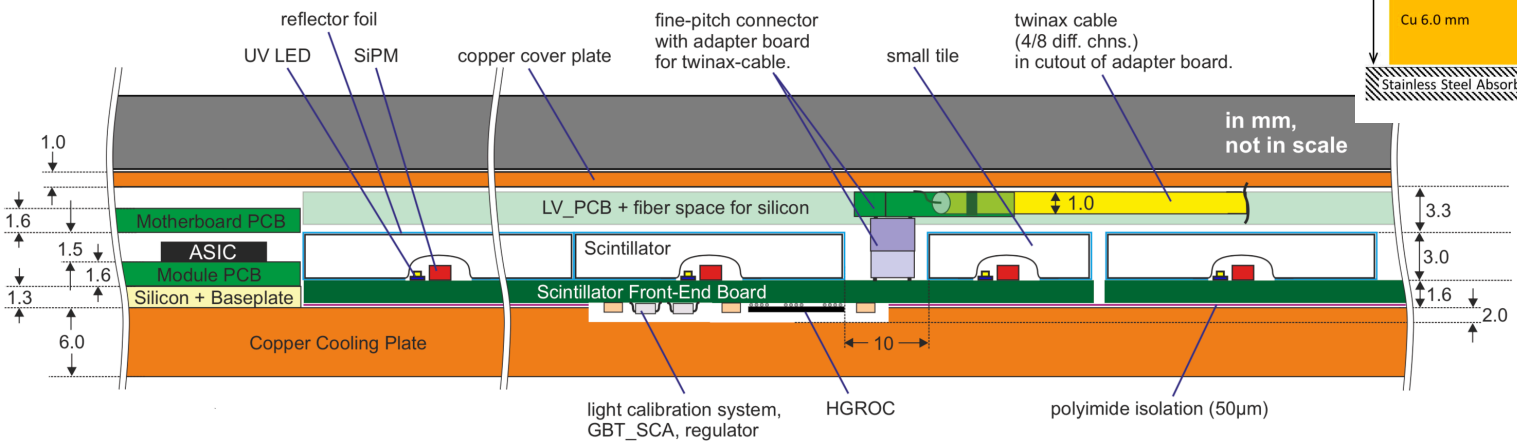


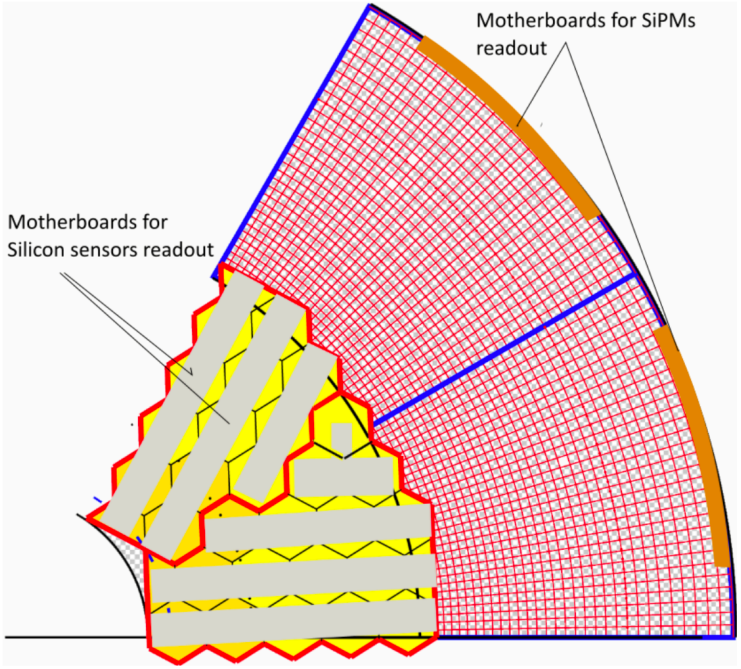
FE developed from SKIROC

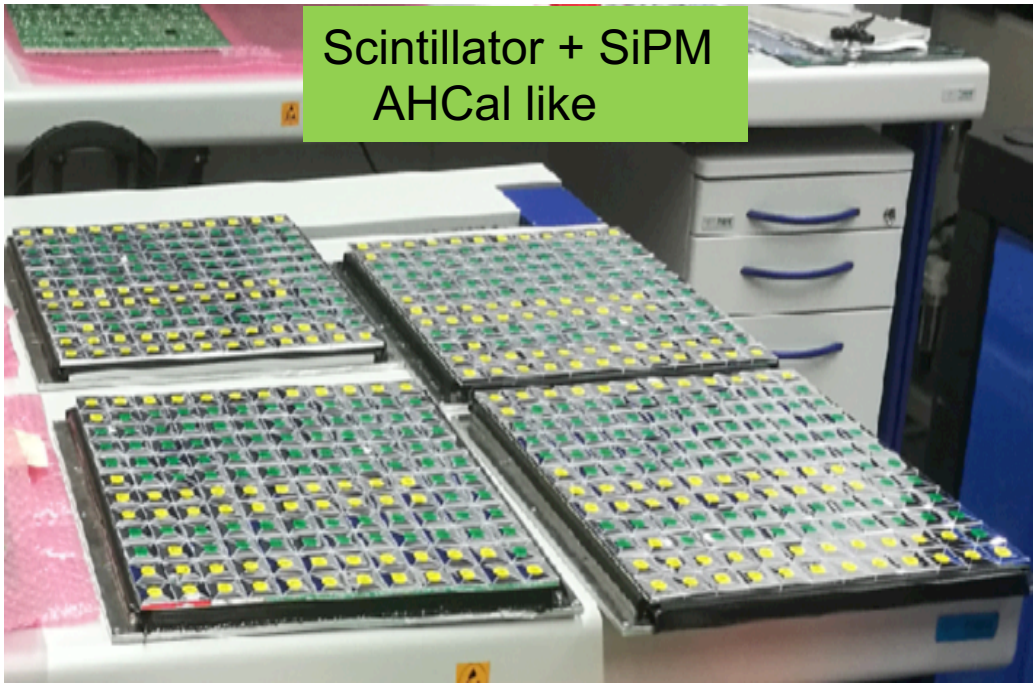
HGCROC V1 is under test

HGCal scintillator hadronic part



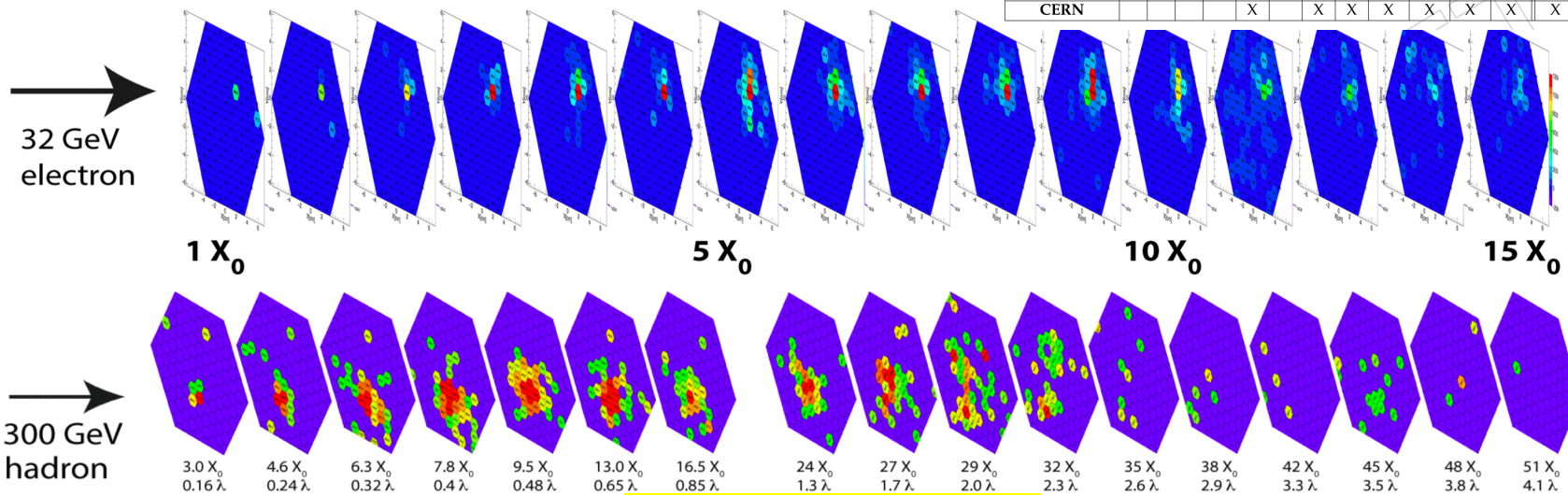




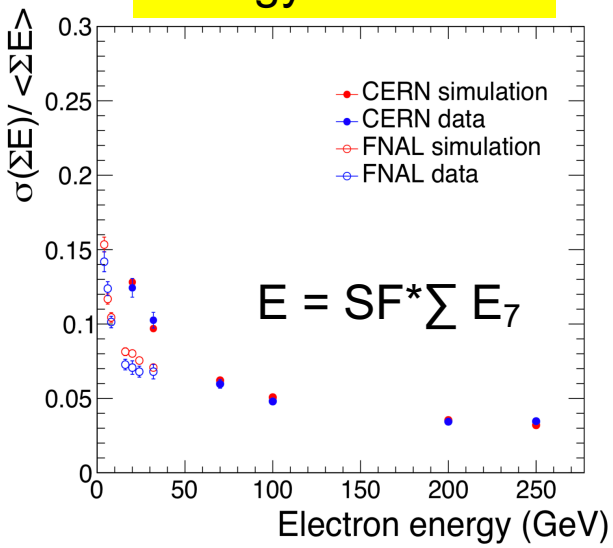


HGCal performance from beam test

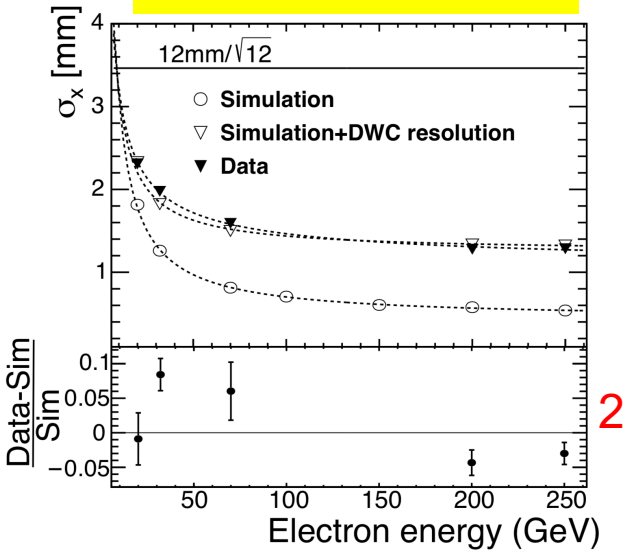
	e^-												π^-	p^+	μ^-
Energy (GeV)	4	6	8	16	20	24	32	70	100	150	200	250	125	120	30-120
FNAL	X	X	X	X	X	X	X							X	
CERN					X		X	X	X	X	X	X	X		X



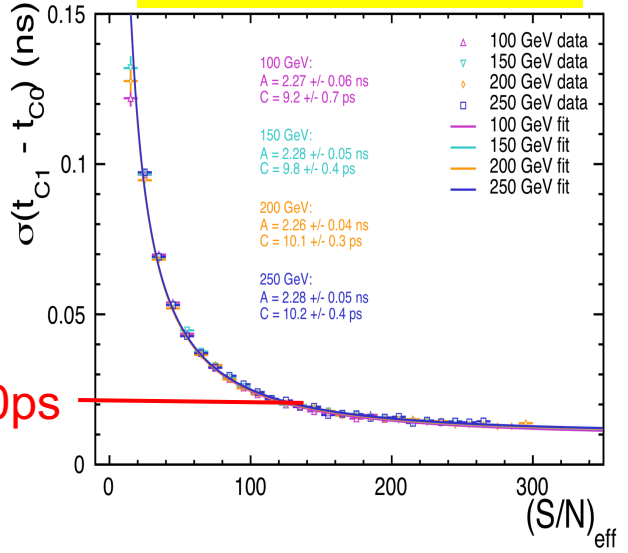
Energy resolution



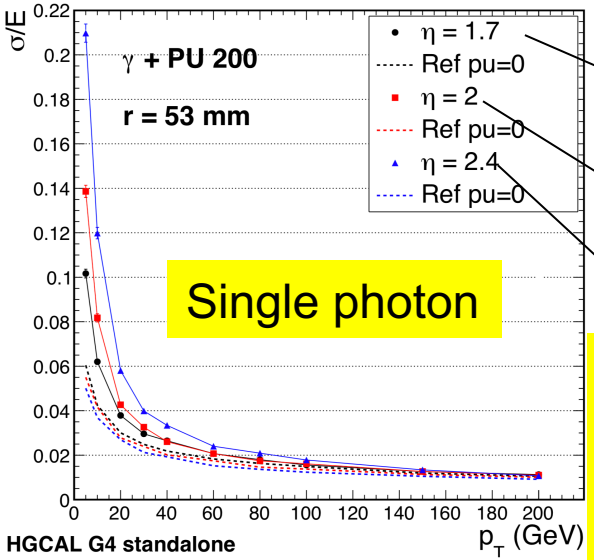
Position resolution



Timing resolution



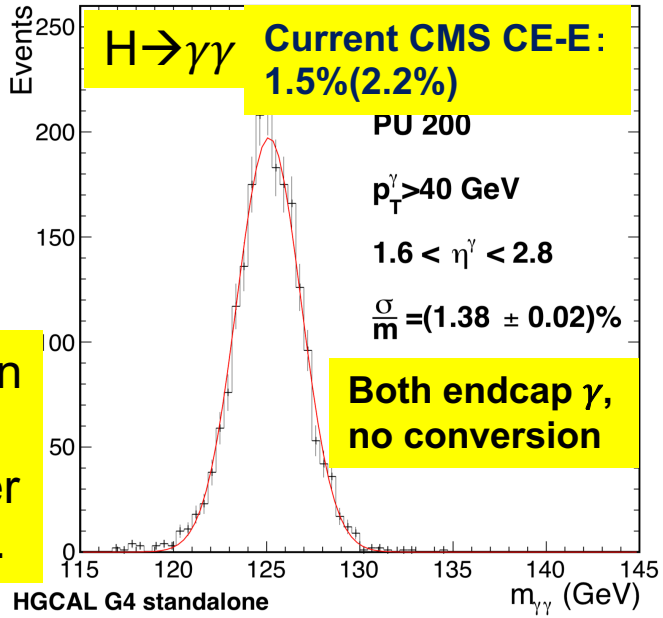
Energy resolution (not-optimal)

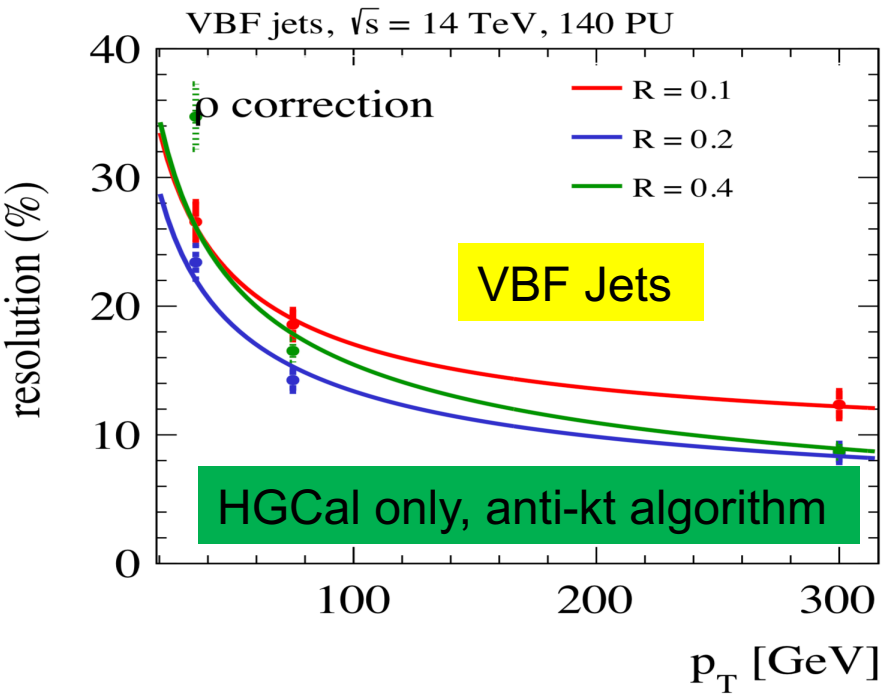


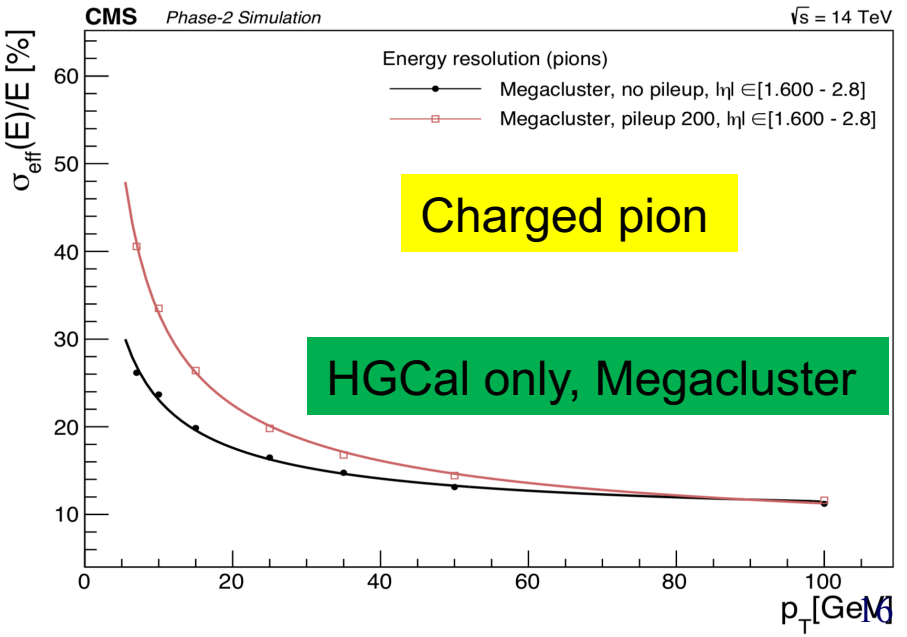
Single photon

Si (um)	stochastic	const
300	23/√E %	0.5%
200	25/√E %	0.5%
100	27/√E %	0.5%

Comparable energy resolution
Lots of potential:
timing, 3D shower, trigger
backpointing, pileup prof.



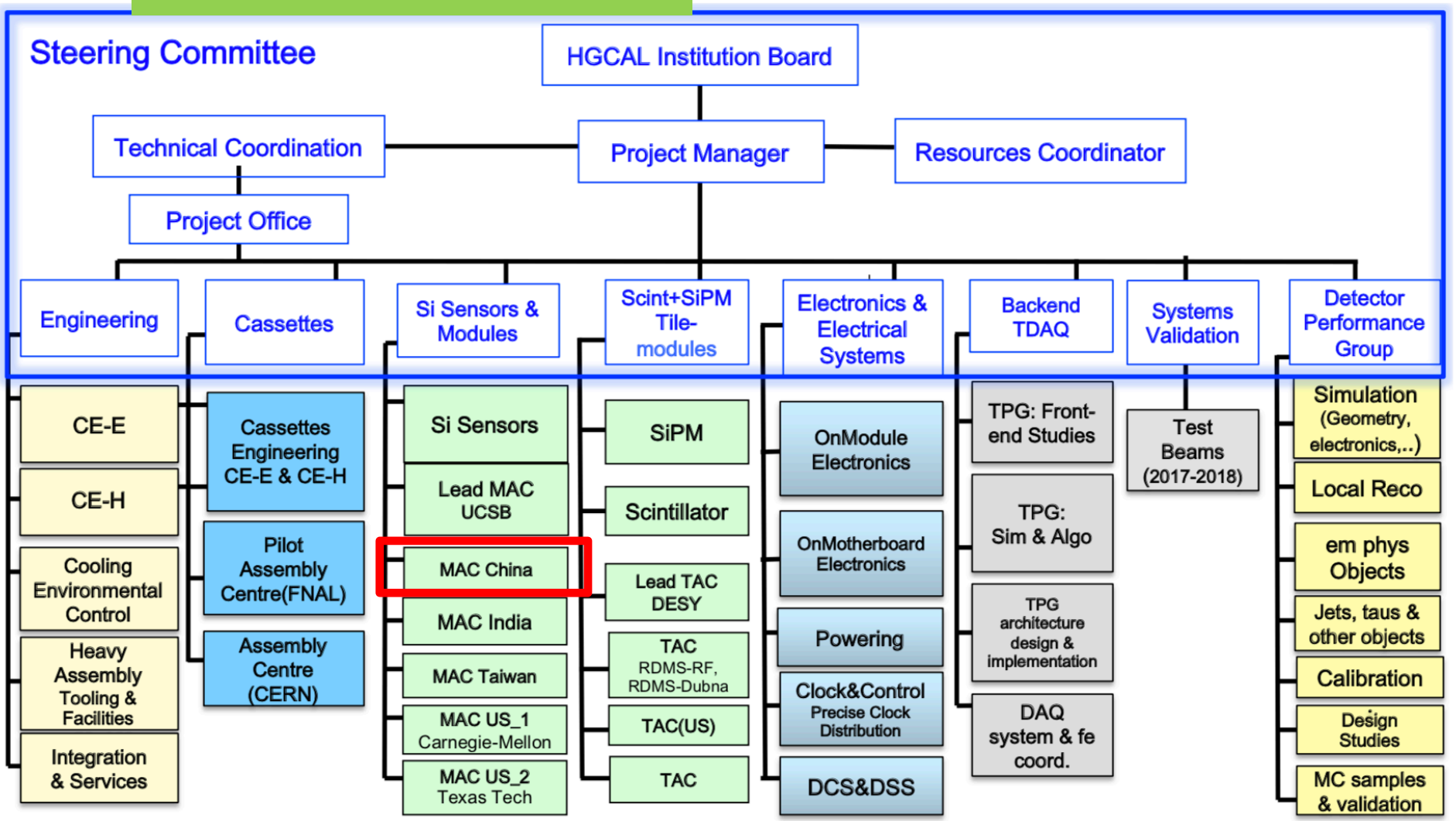




HGCal task of IHEP: Module Assembly Center

- Tasks: MAC Beijing

IHEP+THU+ZJU+FDU



From HGCal TDR: CMS-TDR-019

MoU is in the signature cycle

Preparation of IHEP MAC: facilities

140 m^2 clean room

BJ855 wire bonder

CMS/HGCal management visit IHEP MAC: 2019/09/18

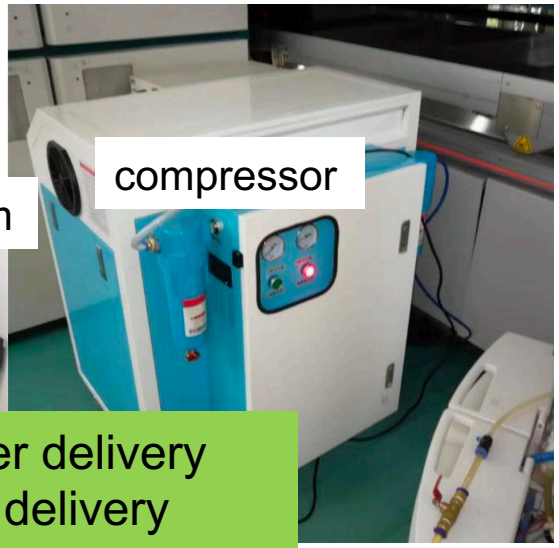
tests equipment

Kethley 2000e multimeter	Arrival
Oscilloscope	Arrival
AFG3100 function generator	Arrival
Keysight E4980AL LCR	Arrival

Glue machine

cabinet

Marble platform



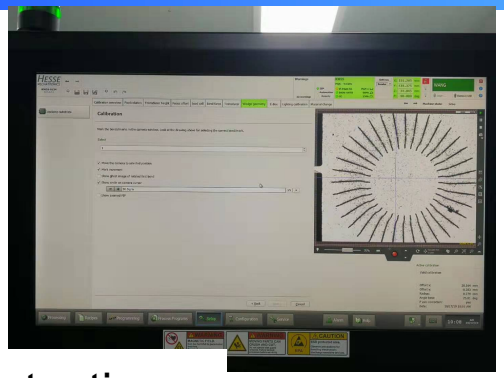
compressor

Gantry: under delivery
OGP: under delivery
Pull tester: purchasing
Mini gantry: purch

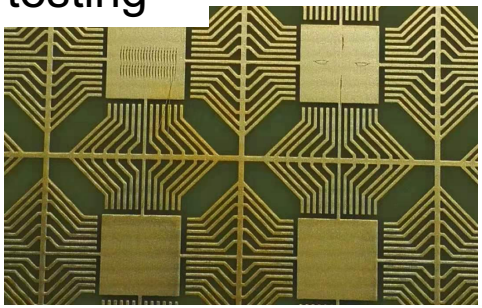
New clean room with new equipment

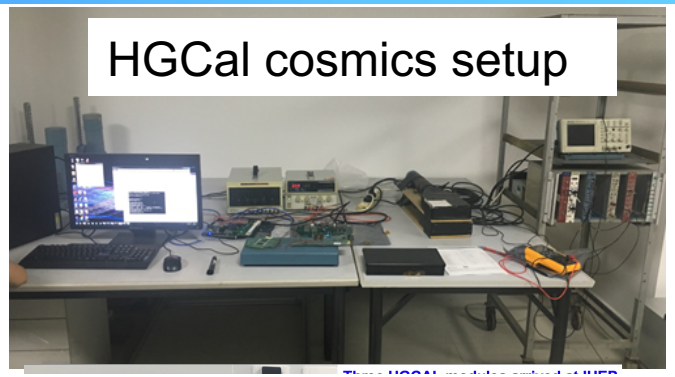
2019: main MAC equipment ready → 2020: training & site qualification → 2021:start mass production

HGCal Activities in China: preparing MAC

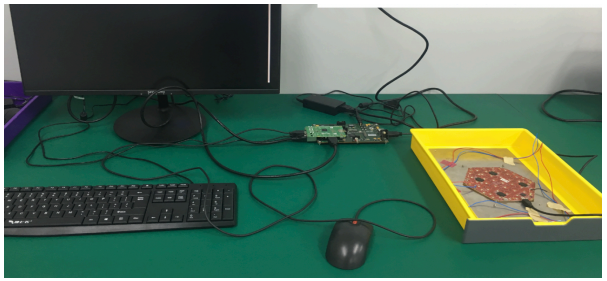


Bonder testing

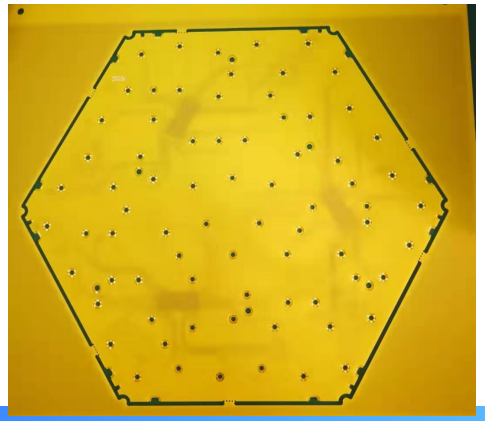


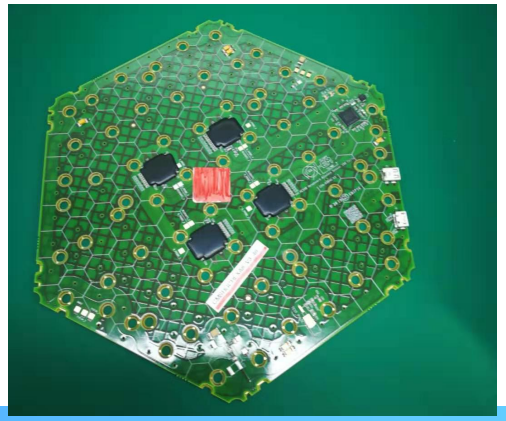


HGCal electronics test stand

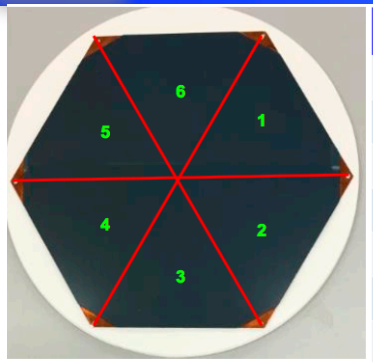


- Switch to 8 inch module studies using dummy sensor/PCB





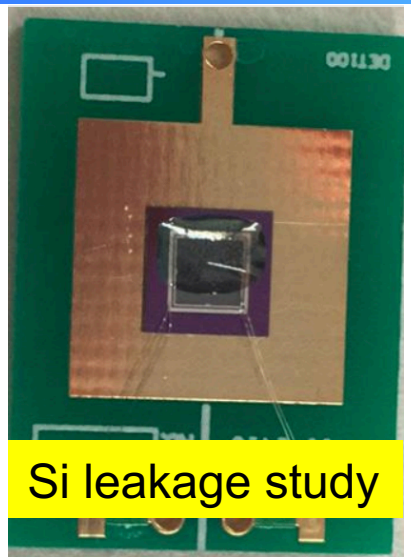
HGC activities in China：HGC Module R&D



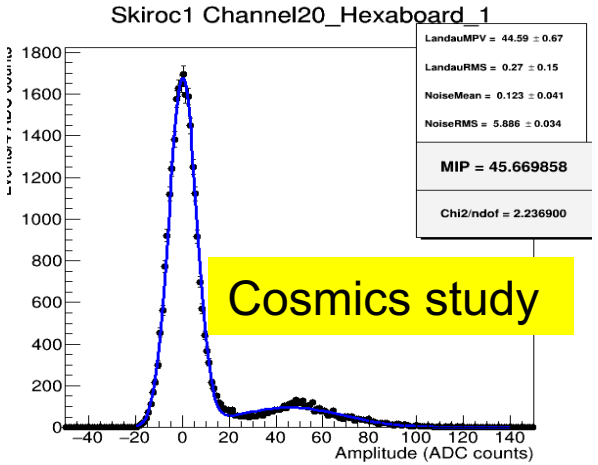
Thickness of glue (mm)	Layer 1	Layer 2
1	0.049±0.003	0.047±0.004
2	0.050±0.003	0.050±0.005
3	0.050±0.004	0.055±0.004
4	0.045±0.005	0.053±0.005
5	0.046±0.003	0.046±0.004
6	0.048±0.004	0.048±0.006

The thickness of glue in the first and second layer both

Glue thickness control study

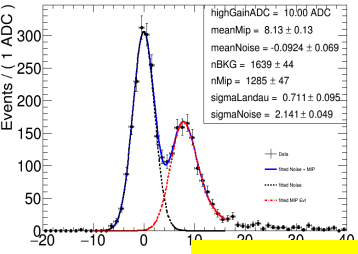


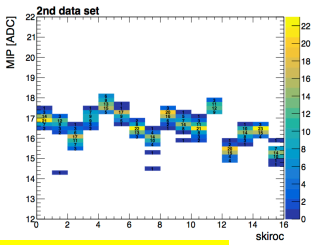
Si leakage study



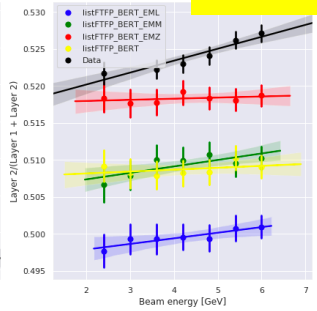
Cosmics study

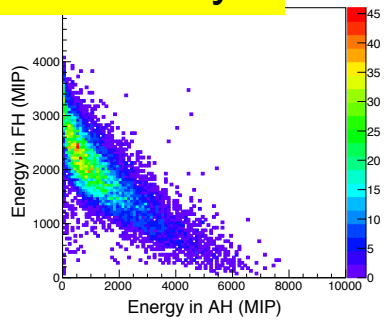
Zhejiang University
Start design partial PCB



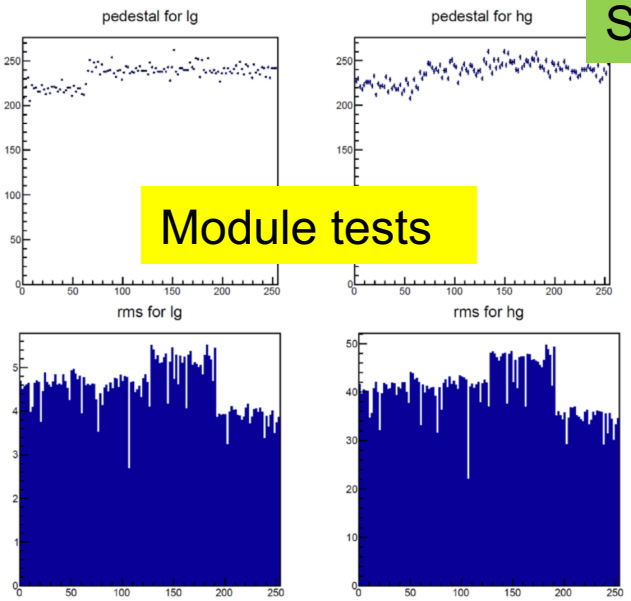


Beam test study





Module tests

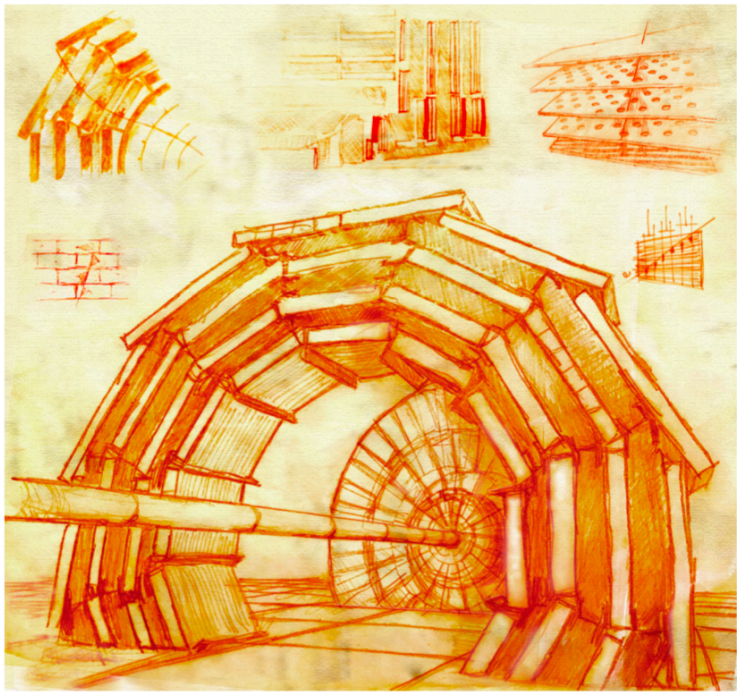


Participate Module production at UCSB

CERN European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

CERN-LHCC-2017-012
CMS-TDR-016
12 September 2017

CMS



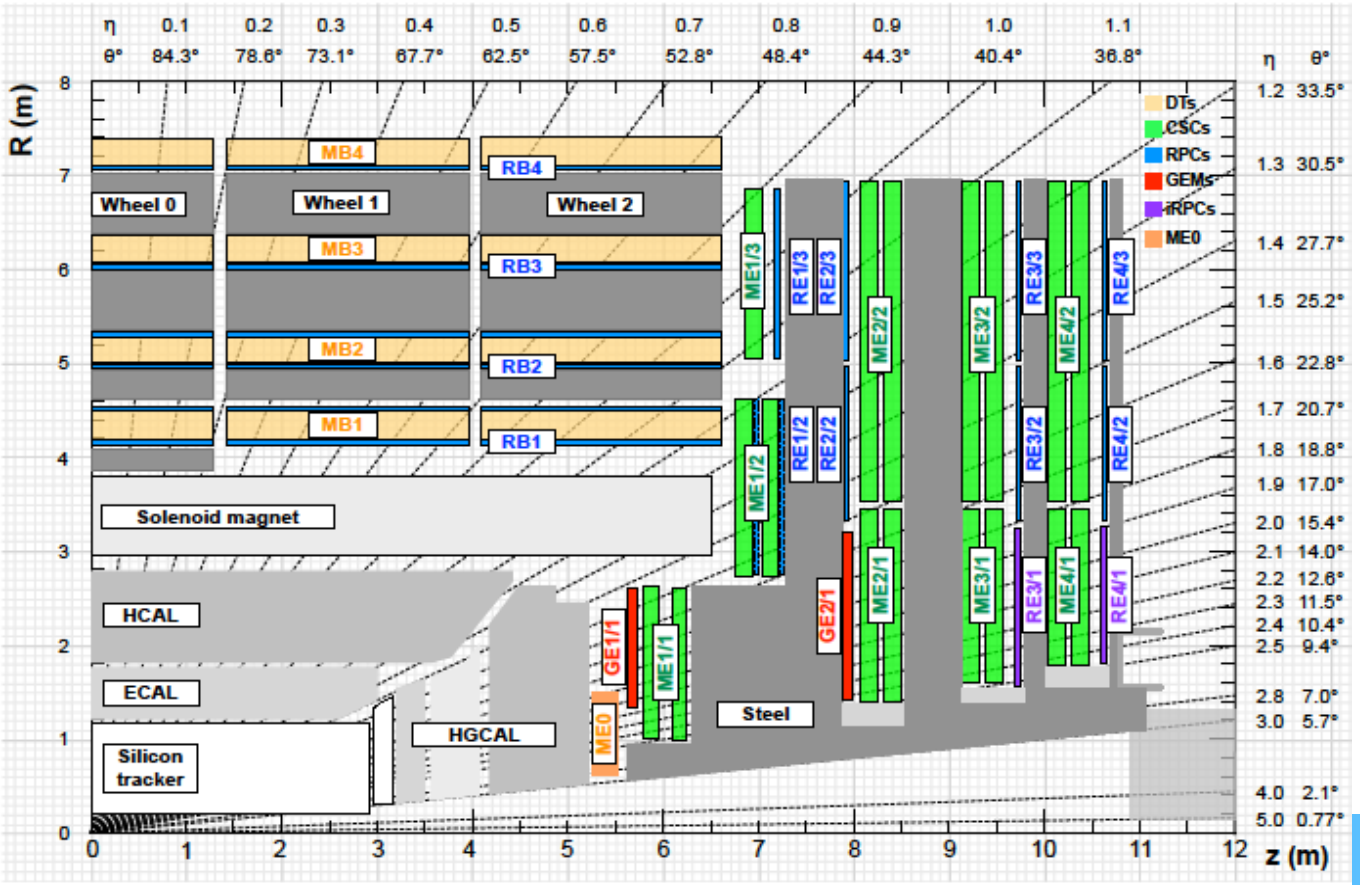
CERN-LHCC-2017-012 / CMS-TDR-016
11/02/2018

The Phase-2 Upgrade of the CMS Muon Detectors

TECHNICAL DESIGN REPORT

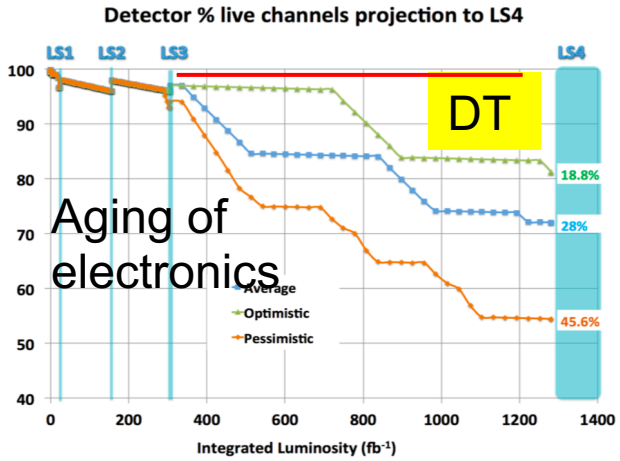
Phase II Muon upgrade overview

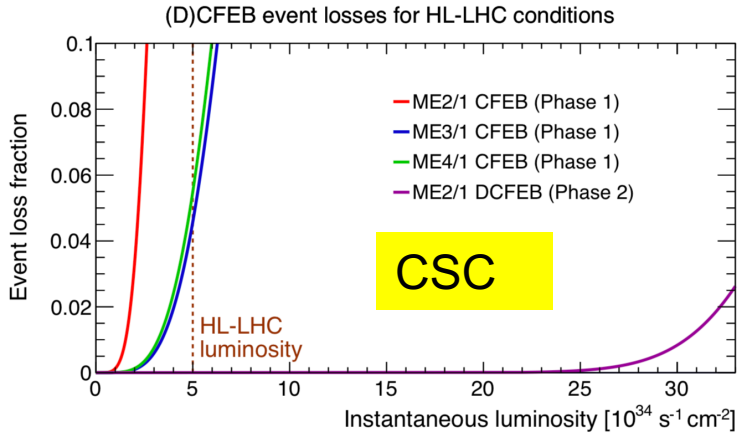
- Drift Tube (barrel): 40 MHz readout with improved z/t -precision
- Resistive plate chamber (barrel): readout with improved t-precision
- Cathode Strip chamber (Endcap): ME234/1 readout with higher bandwidth and latency, replace ME1 with higher radiation hard components
- New stations: GEM1/GEM2; iRPC3/iRPC4, 1.6<|η|<2.4; ME0, 1.15 <|η|<3

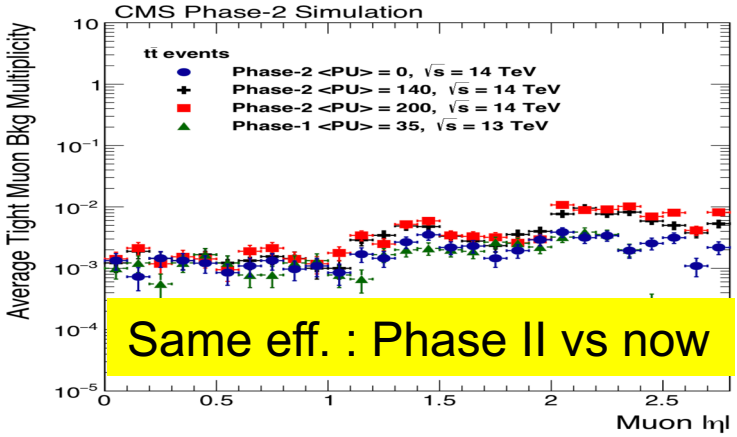


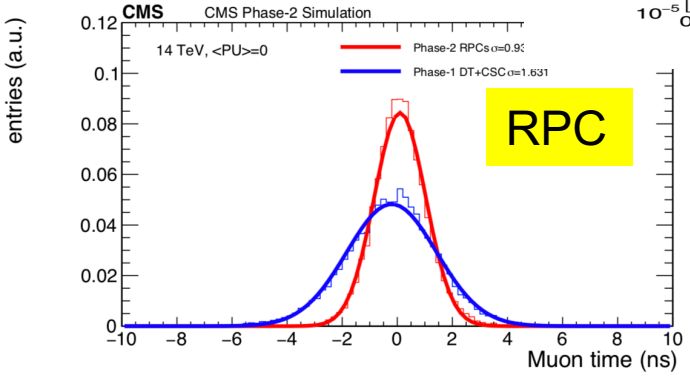
China:
1: GEB design and production
2: one of GEM production site

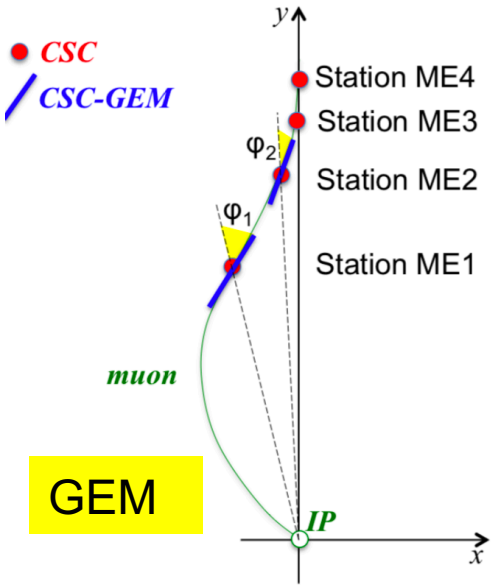
Expect improvement from muon upgrade







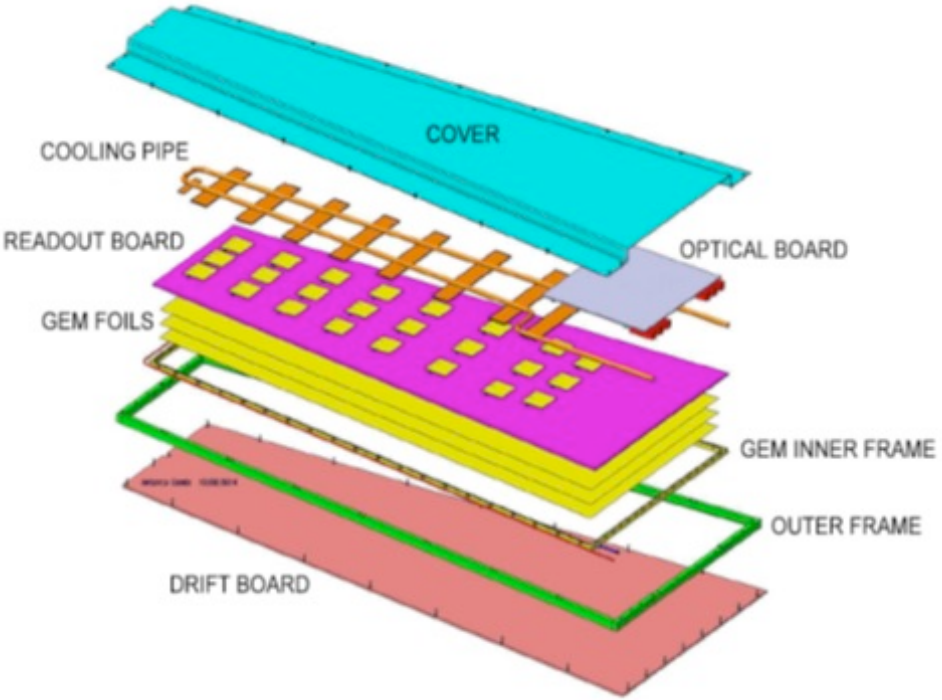




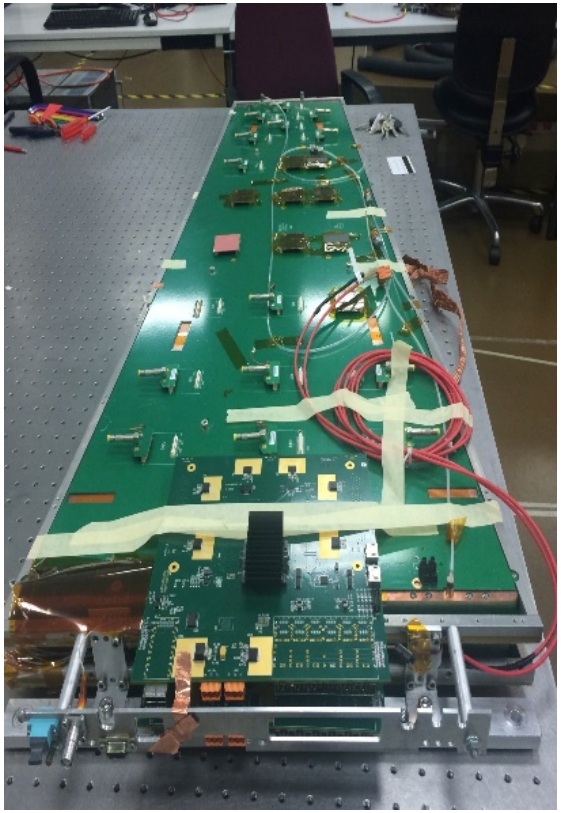
GE1/1 GEB production and test

China provide all GE1/1 GEBs, which are produced in Sinofast Company in Shenzhen, China.

The GEBs were tested by us before transported to CERN.



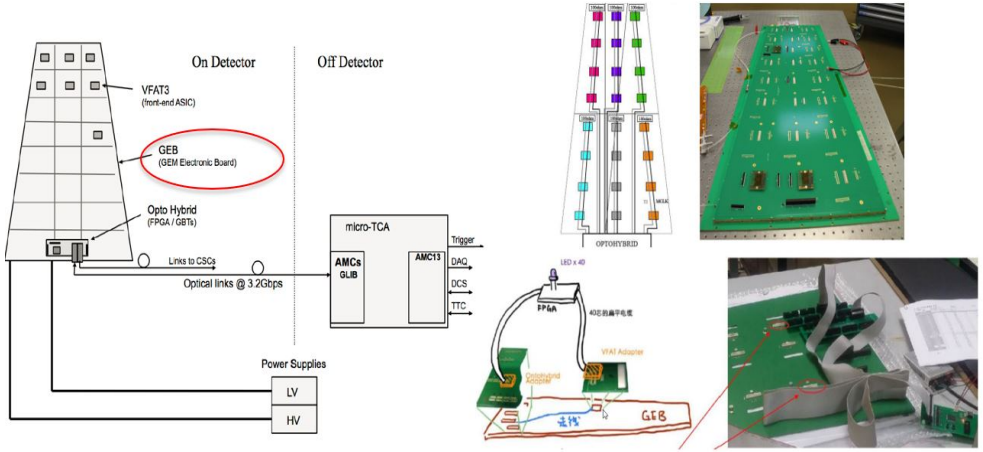
Exploded view of GEM structure



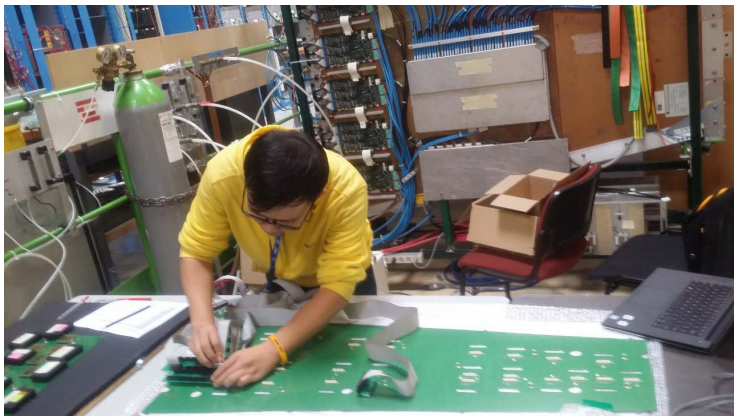
Early version of GEB produced in Sinofast

GE1/1 GEB production and test

- We developed a device with FPGA, LED light etc. for the conductivity test of GEB. Other tests include the torque test of standoff, flatness test etc.
- ~200 sets of GEBs were produced and tested in China. Sun Yetsen U, and Tsinghua U. participated the test at Sinofast.
- The last batch of 50 sets GE1/1 GEB is under production, expected to be completed in couple of weeks.



The conductivity test device developed by PKU

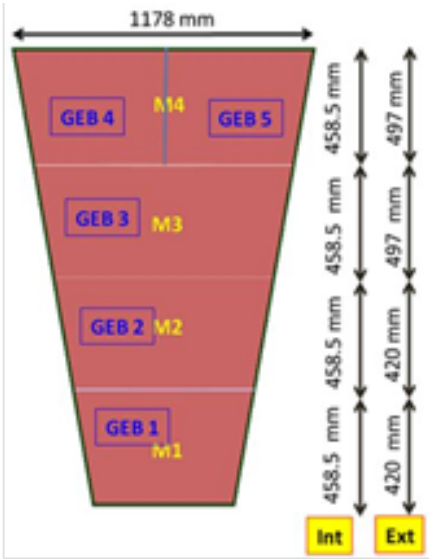


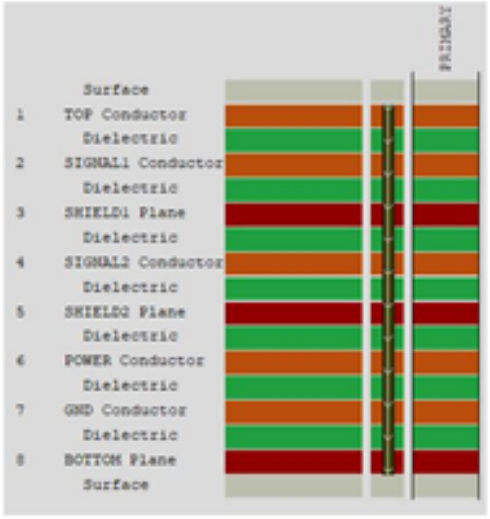
GEB test at CERN

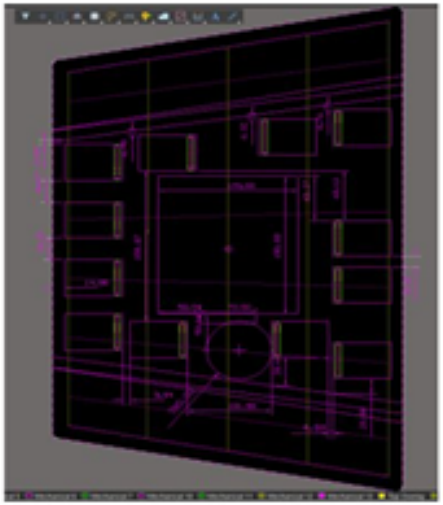
All GE1/1 GEB production in China will be completed by next months

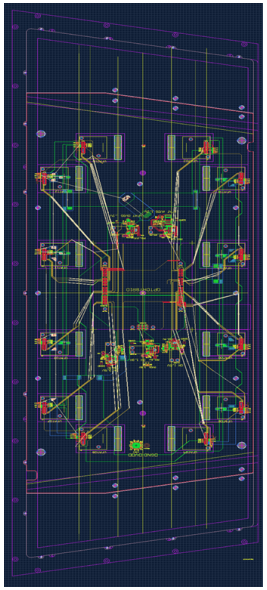
GE2/1 GEB design and prototyping

- Two types of GE2/1 GEM detector (long and short), each divided into 4 sections, totally 8 different GEBs: M1 – M8;
- We completed the design and prototyping of M1 – M5, produced 5-6 GEBs for each types, sent to CERN and Rice U. for test.
- Design of M6-M8 were completed, are being checked by CERN team, prototyping will start next week.



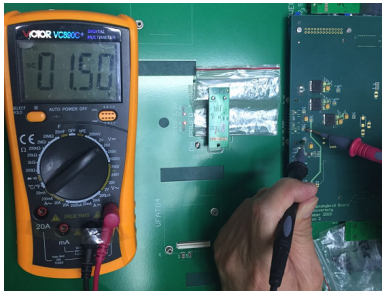


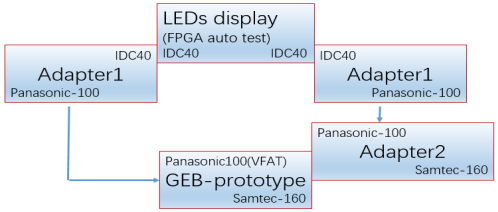




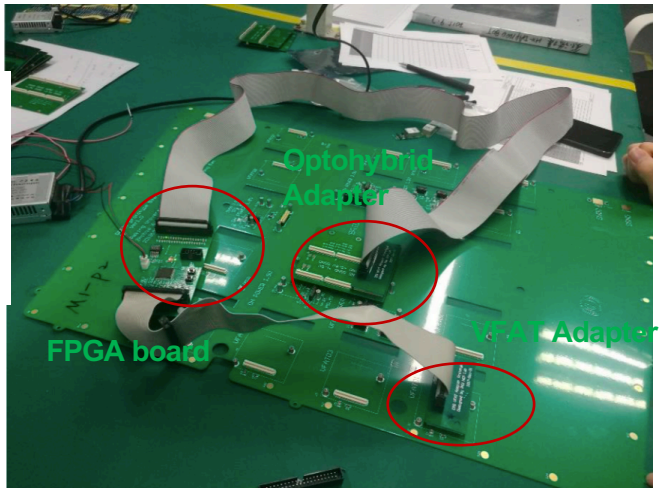
GE2/1 GEB prototype QC test

- Test goal for GE2/1 prototype by PKU is to check the signal Connectivity between VFAT3 hybrid and Optohybrid and make sure the power for each part is delivered correctly.
  - Power test in GEB





connectivity test schematic



GE2/1 GEB M1 connectivity test in Shenzhen

  - Connectivity for VFATs and Optohybrid
  - Standoff alignment and torque test
  - Bending test
- So far, GE2/1 GEB M1-M5 prototypes are all produced in Shenzhen and passed electrical tests by electronic equipment designed by PKU.
- The results of test show the R&D of GE21 GEB prototype is successful by PKU.

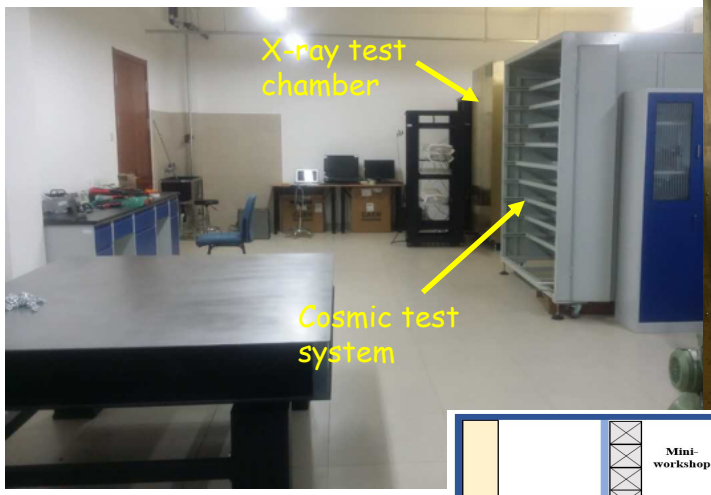
1st version of M1-M8 GE2/1 GEB design completed, M1-M5 prototyping completed, M6-M8 prototype production will start next week

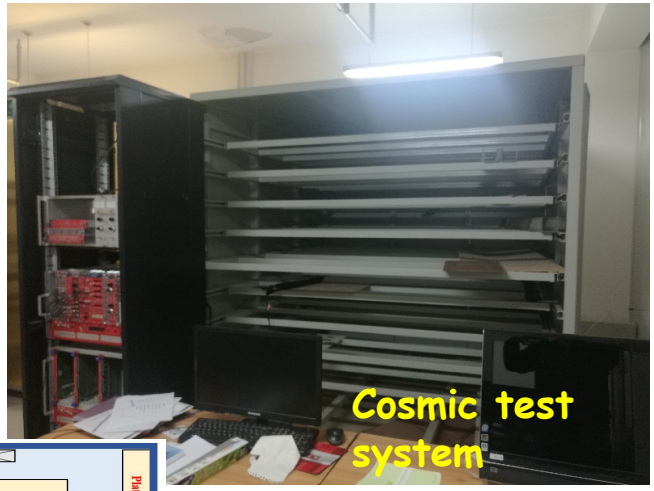
Preparation for GEM production site

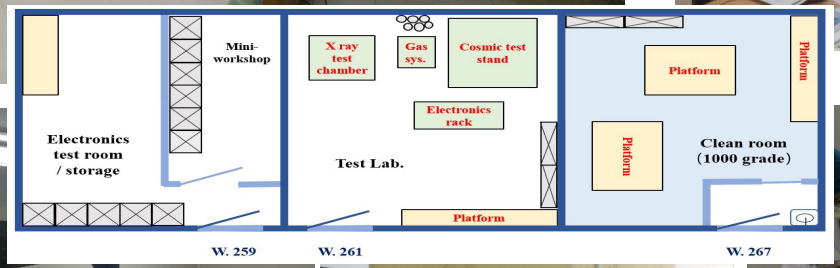
facilities

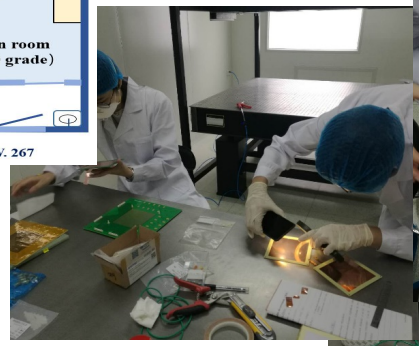
120 m² Lab at PKU

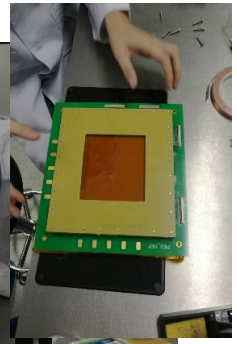
PKU, SYSU, BAAU, THU

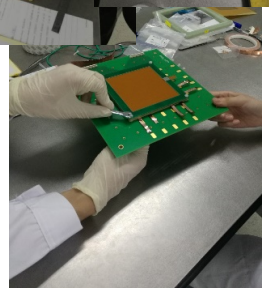










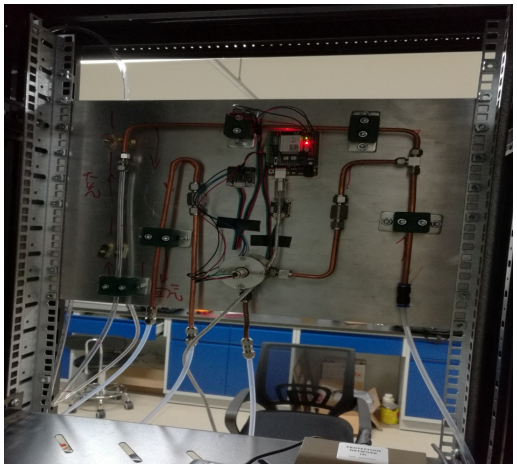


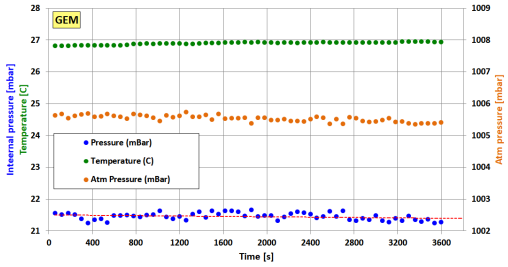
Assembly of 10 × 10 GEM in cleanroom

Preparation for GEM production site

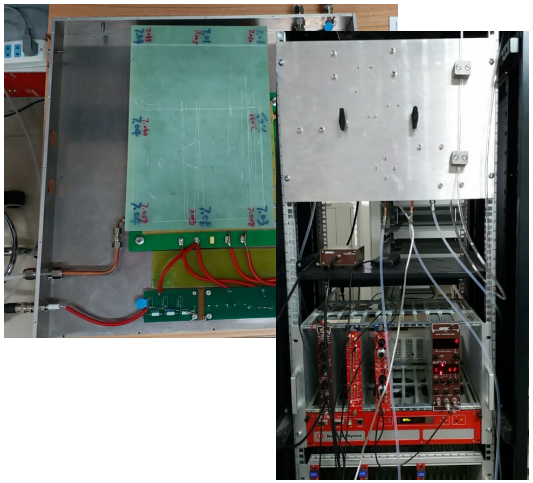
Progress in QC setup

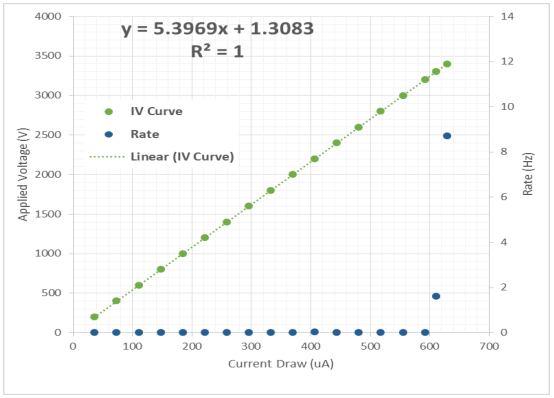
QC3: Gas leak test:



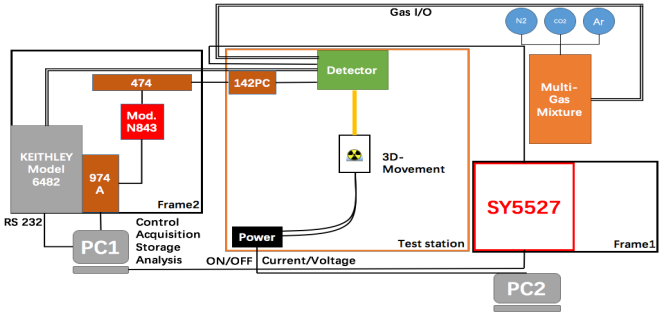


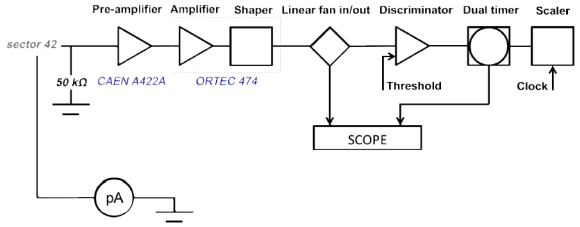
QC4: HV test:





QC5: yield test with X-ray



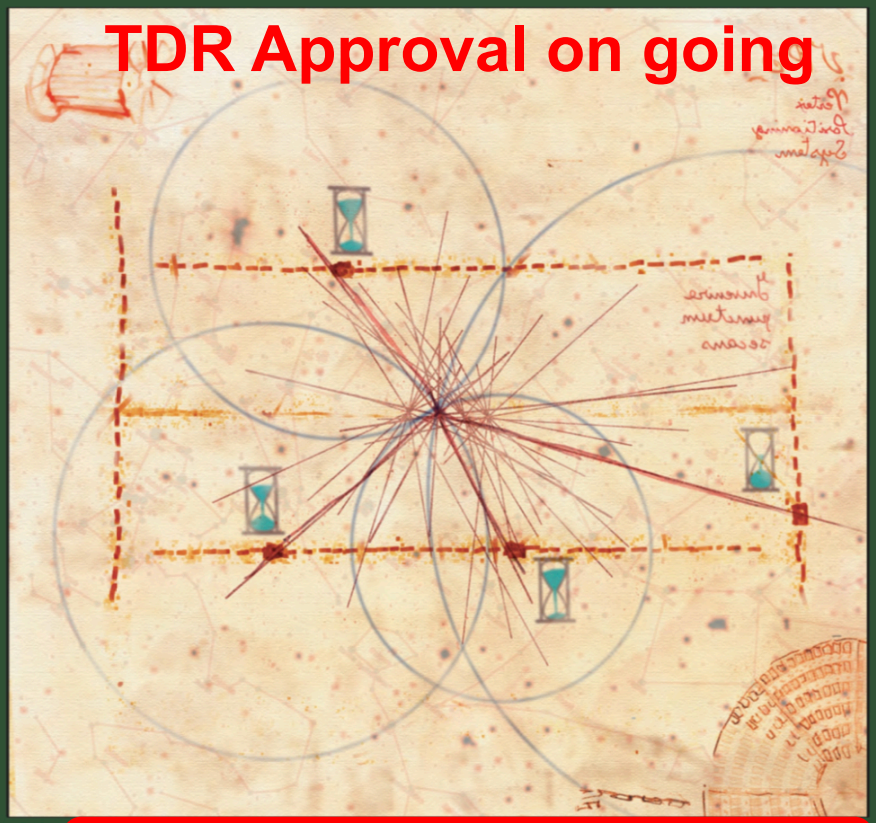


- amplifier settings
  - *Coarse gain* 4, *Fine gain* 4.5,
  - *Integrate* 100*ns* and *Differential* 100*ns*
- the discriminator threshold
  - -100mV

CERN European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire
CERN-LHCC-2019-003
CMS-TDR-020
29 March 2019

CMS

TDR Approval on going



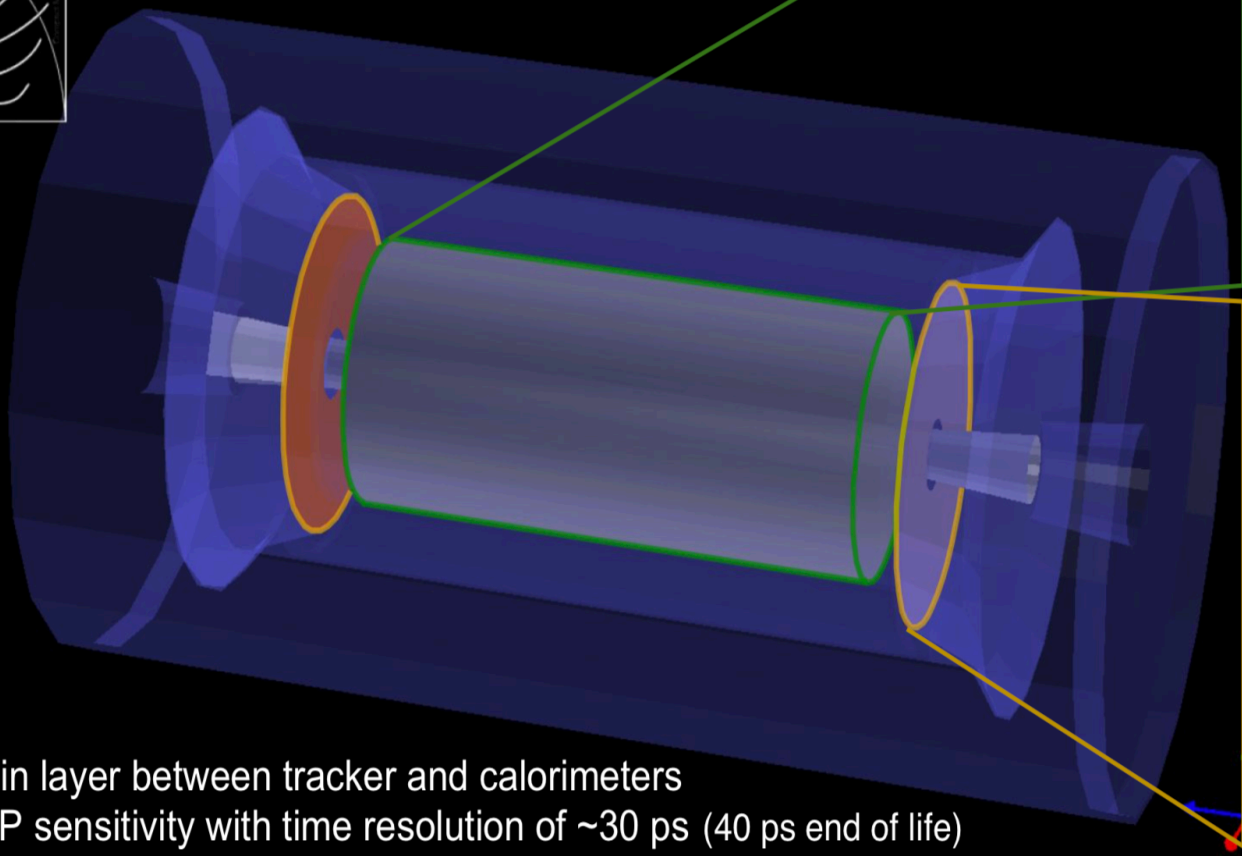
A MIP Timing Detector

for the CMS Phase-2 Upgrade
Technical Design Report

Mip Timing Detector overview

Calorimeter upgrades:

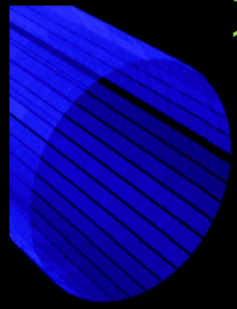
- Precision timing of **showers**
- Provide precision timing on high energy photons in ECAL Barrel
- All photons and high energy hadrons in HGCal Endcap

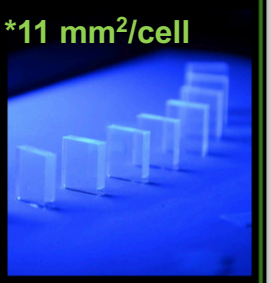


BARREL

TK/ECAL interface ~ 25 mm thick
Surface ~ **40** m^2
Radiation level ~ $2x10^{14}$ n_{eq}/cm^2
Sensors: **LYSO crystals + SiPMs**

11*11 mm^2/cell

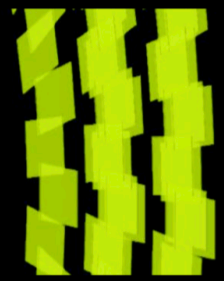


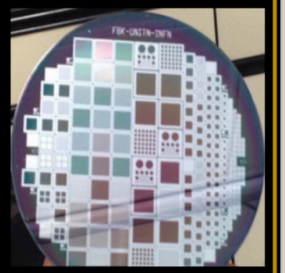


ENDCAPS

On the CE nose ~ 42 mm thick
Surface ~ **12** m^2
Radiation level ~ $2x10^{15}$ n_{eq}/cm^2
Sensors: **Si with internal gain (LGAD)**

1*3 mm^2/cell





- Thin layer between tracker and calorimeters
- MIP sensitivity with time resolution of ~30 ps (40 ps end of life)
- Hermetic coverage for |η|<3

CERN-LHCC-2017-013
CMS-TDR-017
September 12, 2017

The Phase-2 Upgrade of the CMS Level-1 Trigger

Interim Technical Design Report

CMS Collaboration

CERN-LHCC-2017-013 / CMS-TDR-017
01/02/2018

TDR Approval 2020

CERN-LHCC-2017-014
CMS-TDR-018
12 September 2017

The Phase-2 Upgrade of the CMS DAQ

Interim Technical Design Report

CMS Collaboration

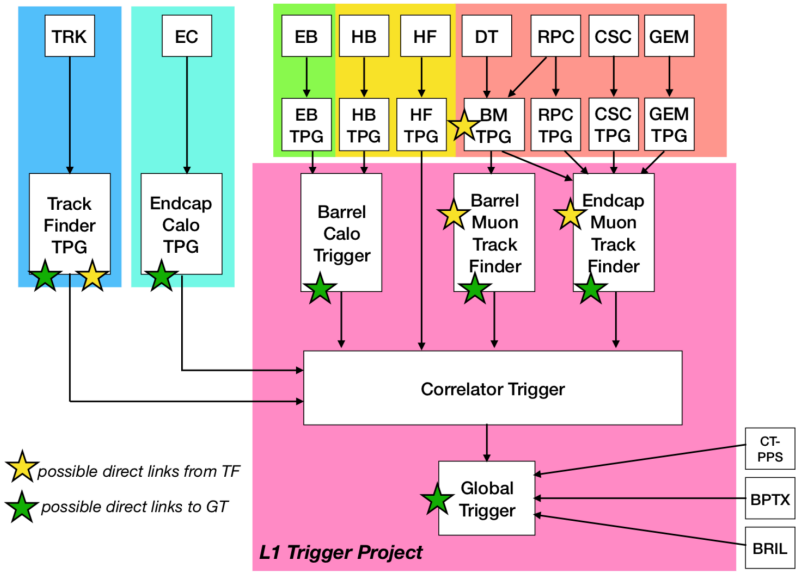
CERN-LHCC-2017-014 / CMS-TDR-018
09/02/2018

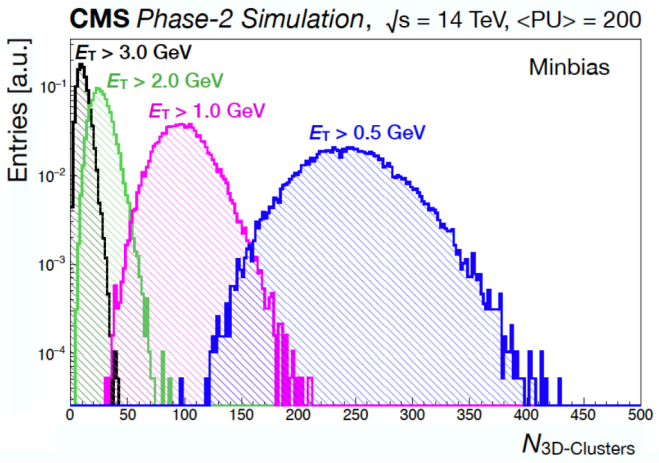
TDR Approval 2021

L1-Trigger

- Increased latency to 12.5μs(from 5μs) and rate up to 750kHz (from current 100kHz)
  - more time (latency) and more bandwidth
  - All detector electronics needs to be updated
- Will use input from the Si outer tracker
  - port Particle Flow algorithms at L1 trigger
- High granularity information from HGCAL but also from ECAL (x25 better granularity)

Notice, we go up in peak luminosity only from 2 to 5 or 7.5 1034 Hz/cm2. So naively one could say we don't need all this. But, because of pileup, the trigger rate is highly non linear with luminosity

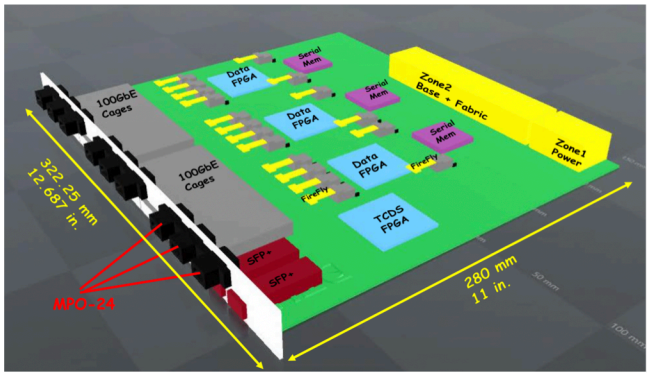


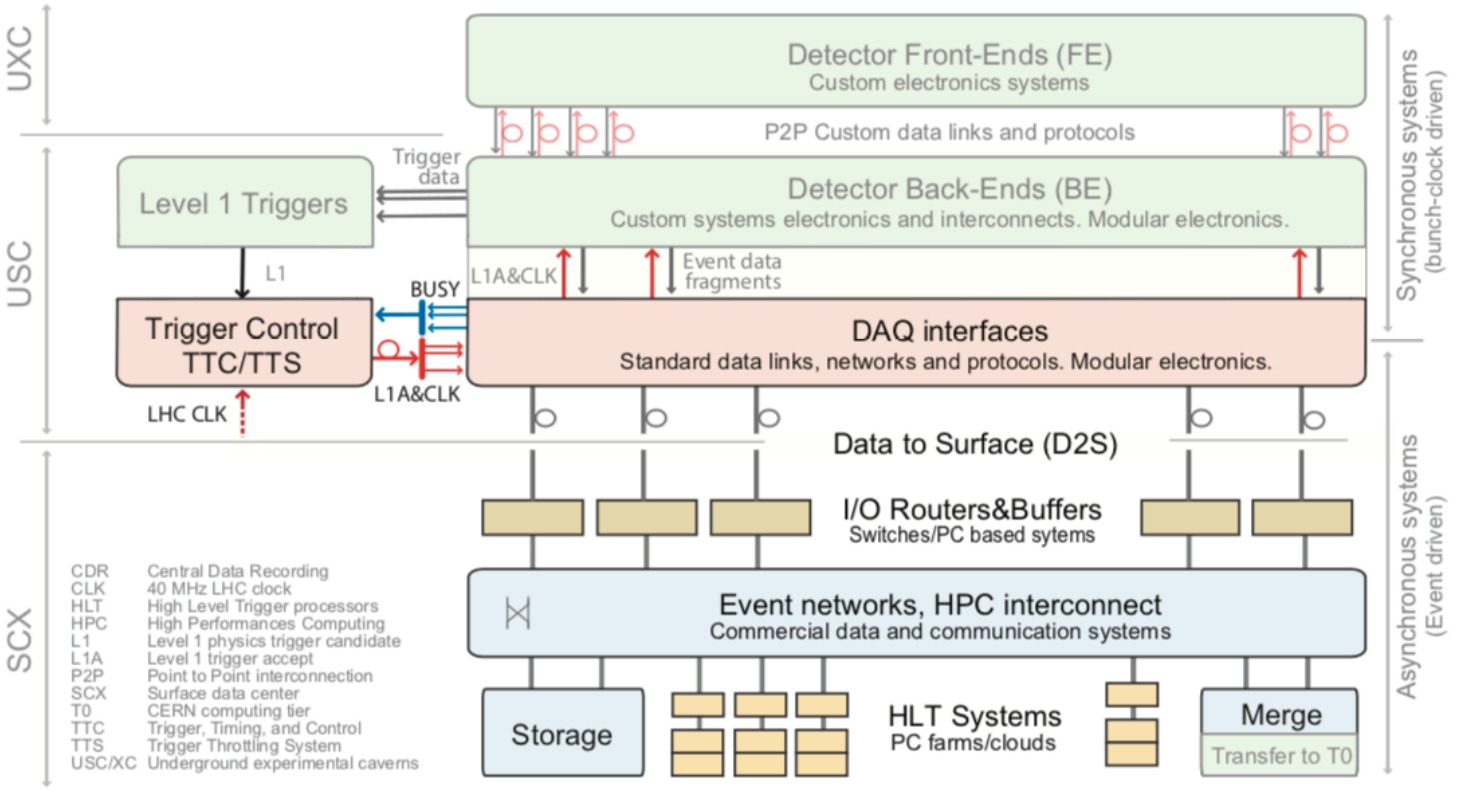


DAQ and HLT

- New TCDS high speed serial distribution of precise clock and multiple triggers data steam
- Systems interface with DTH ATCA boards
- HLT output at 7.5 kHz, 4.5 MHS06 for 500 kHz (140 PU) in LS3 plus 4.7 MHS06for 750 kHz (200 PU) staged to LS4

First ATCA DTH prototype in Q4 2018

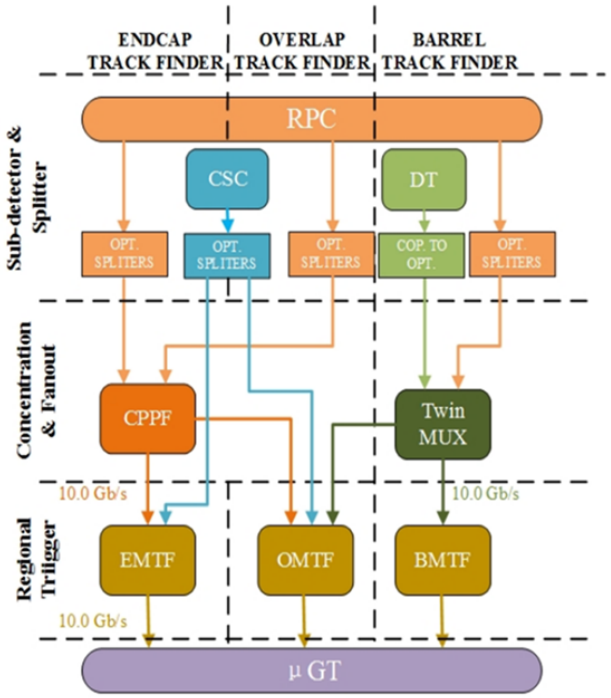




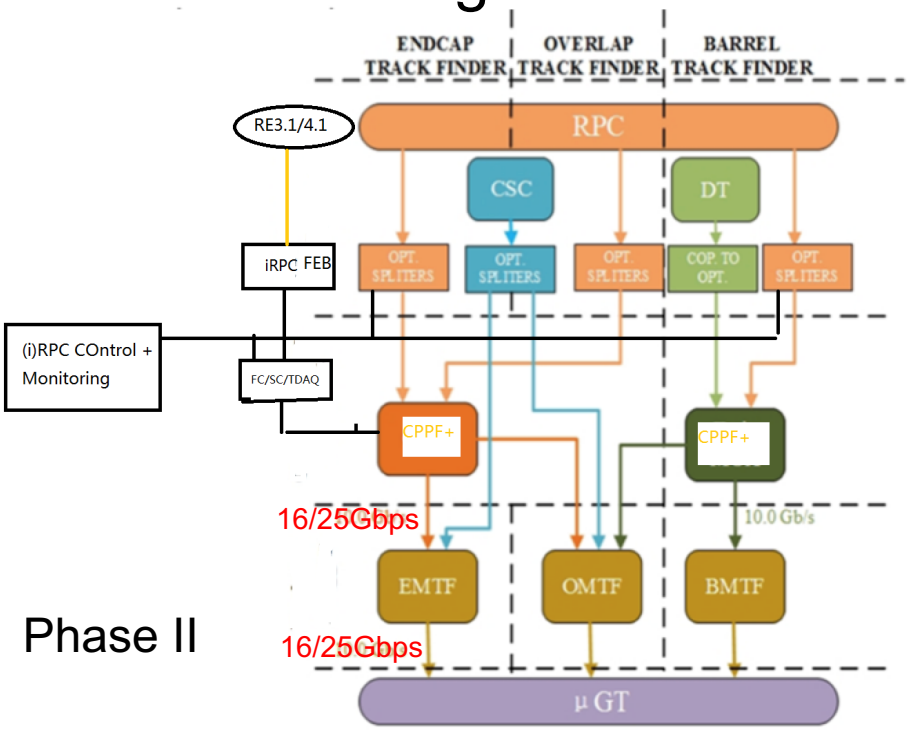
IHEP-Beijing Phase II Tasks

- New requirement
  - uTCA -> ATCA Design
  - 1.6Gbps->4.8/10.24Gbps FEE
  - Trigger 10->16/25Gbps

- New Designs
  - CPPF -> CPPF+ (concentration + TP)
  - iRPC TDAQ
  - RPC Control and Monitering Electronics

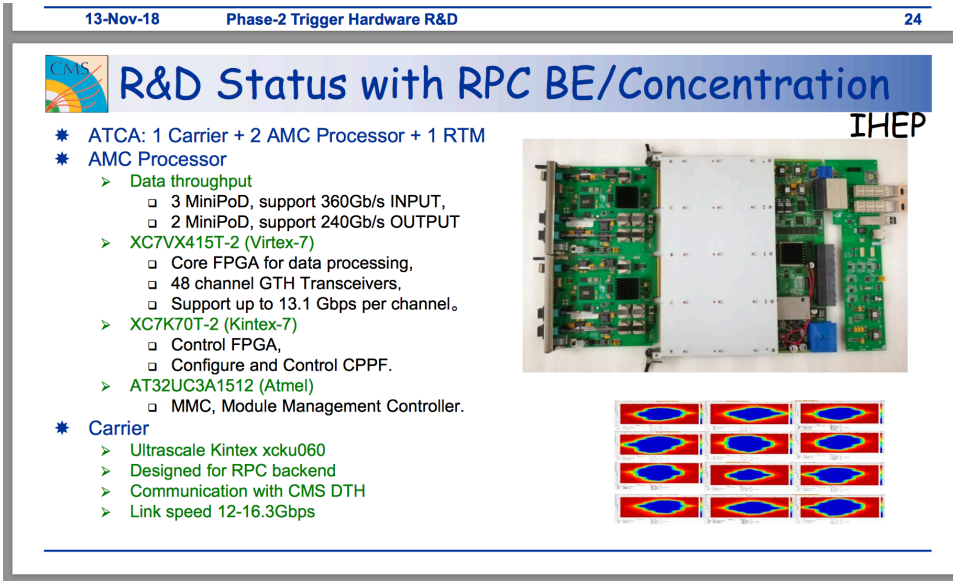


Phase I → Phase II



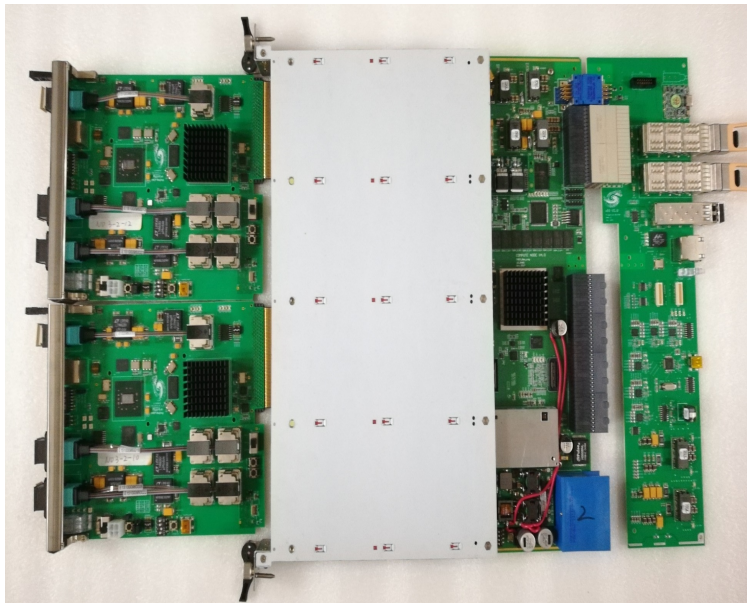
Progress and Status

- uTCA proposal was raised and prototype iRPC electronics for CERN test setup provided.
- ATCA prototype designed/tested at IHEP and reported to CMS Trigger workshops



Status and Progress

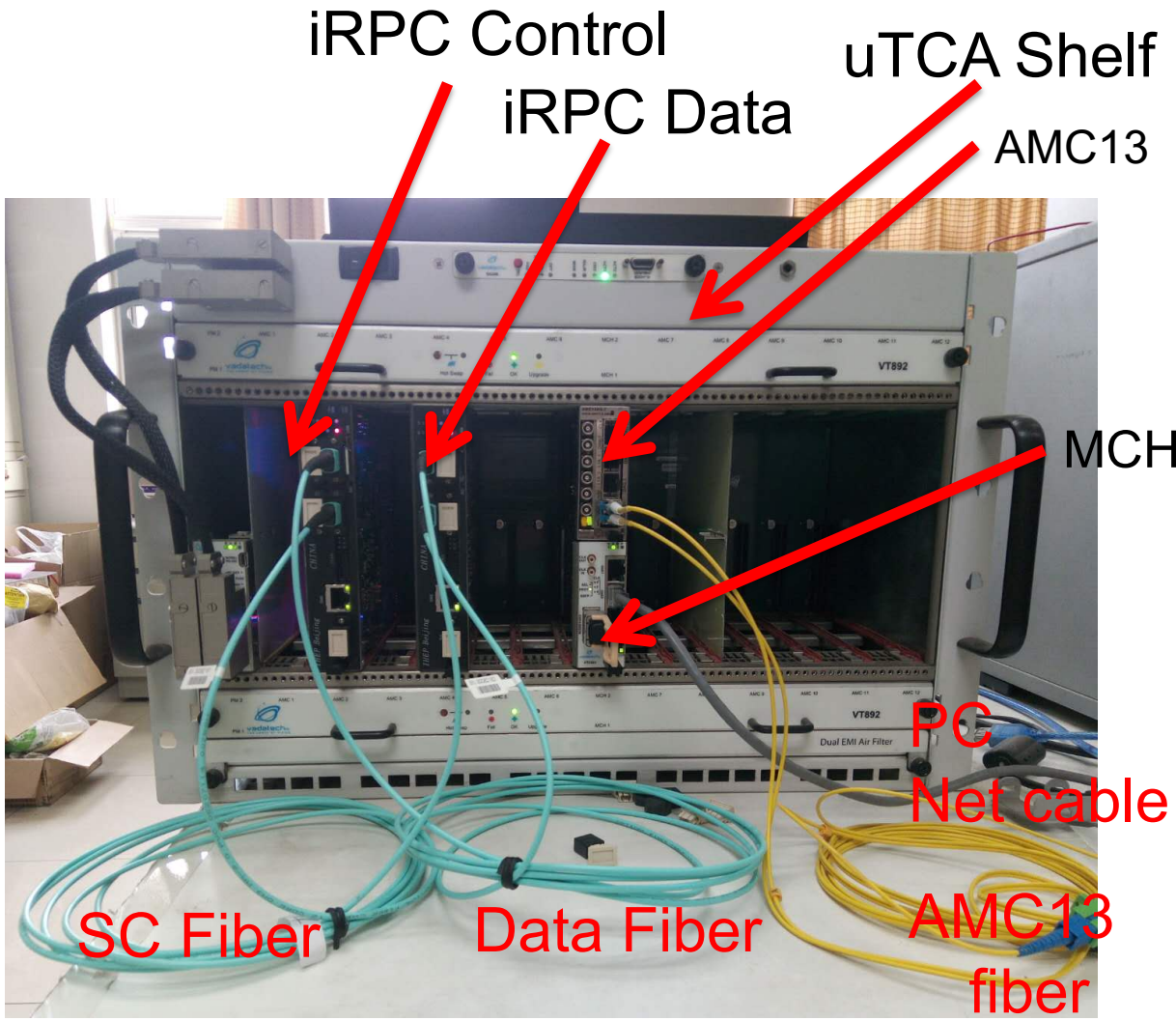
- The RPC Back-End electronics project (requirements, design and cost) was presented to Upgrade, Electronics and DAQ management on 20th February 2019: https://indico.cern.ch/event/800161/.
  - The scope and schedule was approved. For the boards design, it was suggested to re-design the system based on common Serenity platform in order optimize the number of boards and the cost.



Complete iRPC off-detector Electronics

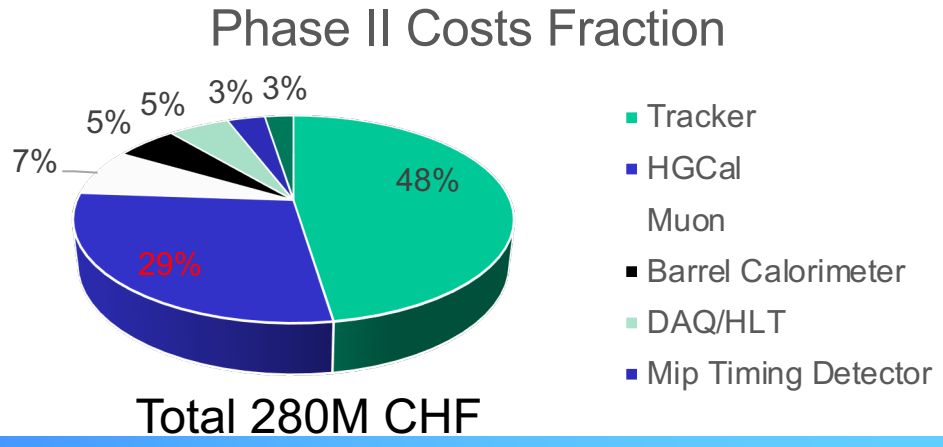
- 5 ixFP cards
  - 4 ixFP cards for slow control
  - 1 ixFP cards for iRPC data
- 1 AMC13
  - TTC
  - DAQ
  - Management
- 1 MCH
  - Slow control
  - Management
- 1 Shelf Manager
- Status

  1. Emulation/Development System working at IHEP
  2. Hardware works fine, GBT/GBT links work fine
  3. Simulation/Emulation under going



Summary

- CMS Phase II upgrades have been approved by LHCC/UCG and CERN RRB
  - L1-Trigger, DAQ/HLT and MIP Timing Detector TDRs is coming
- Production MoU under processing/soon
- Progress being developed
  - Key components such as silicon sensor, gas detectors
  - Electronics such as various FE ASICS, lpGBTs
  - Improvements to detector performance/physics outcome
- Chinese collaborators make key contributions to CMS upgrade
  - HGCal
  - Muon GEM
  - Muon Trigger/DAQ




CMS