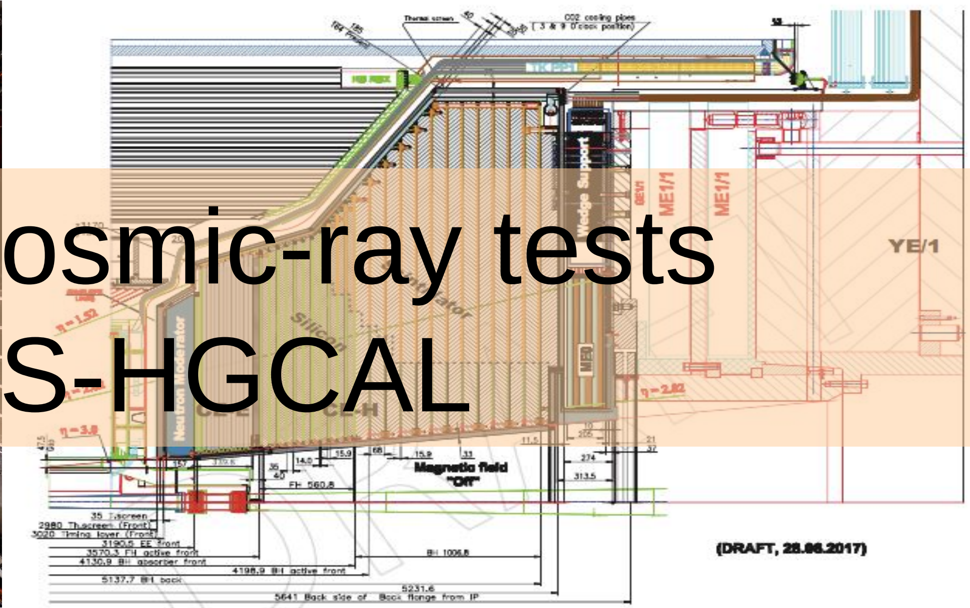
Institute of High Energy Physics
Chinese Academy of Sciences
Beijing

Beam and cosmic-ray tests for CMS-HGCAL



Feng Wang

On behalf of IHEP HGCAL group

28/06/2018

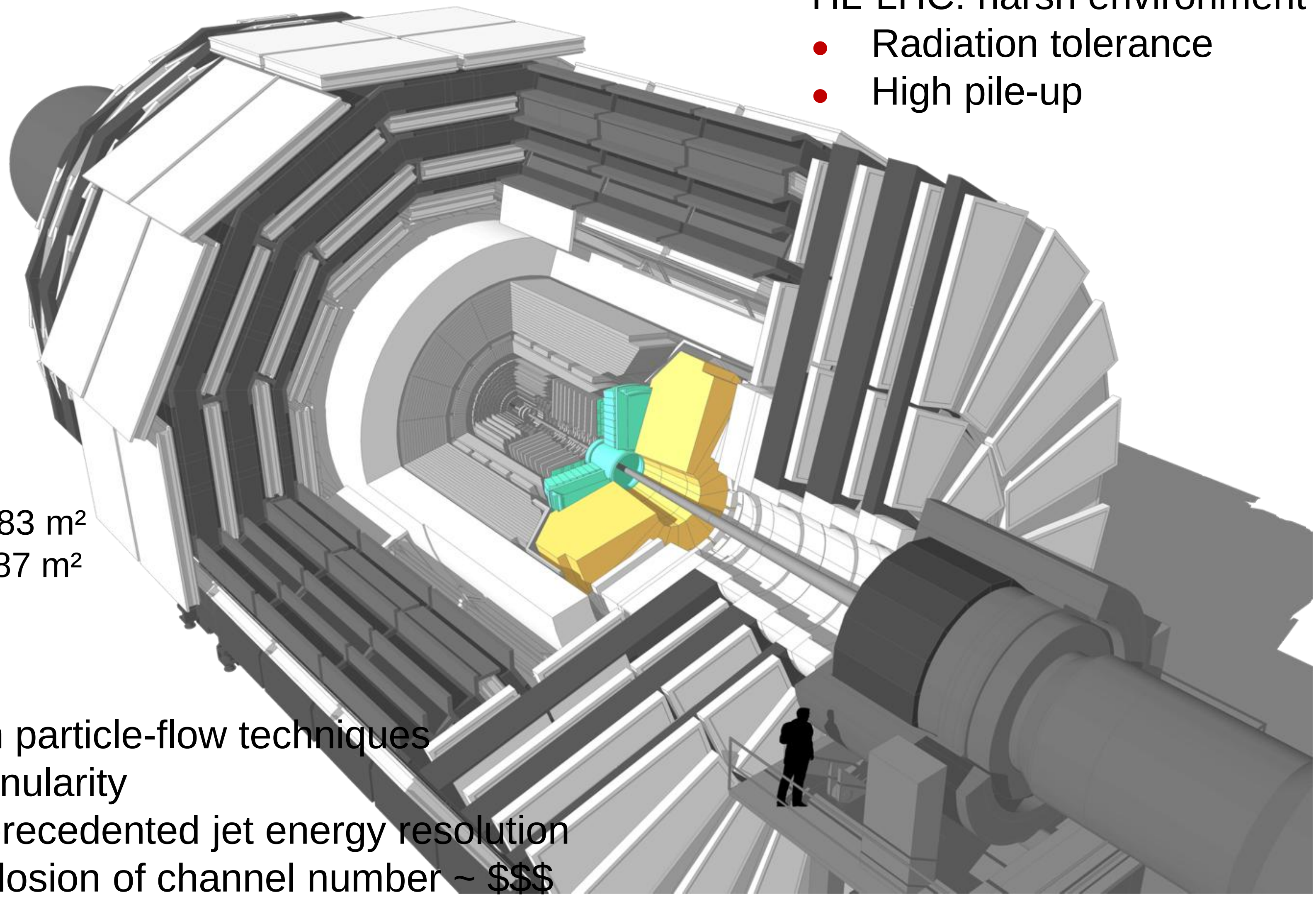
Yong Liu as a new member

Outline

- Introduction of CMS HGCAL
- Test beam
  1. HGCAL modules in test beam
  2. HGCAL cosmic ray in IHEP
- Summary and plans
  1. Work plan for beam test at IHEP

CMS will replace its endcap calorimeters for High-Luminosity LHC:
the High-Granularity Calorimeter (HGCAL)

HL-LHC: harsh environment
- Radiation tolerance
- High pile-up

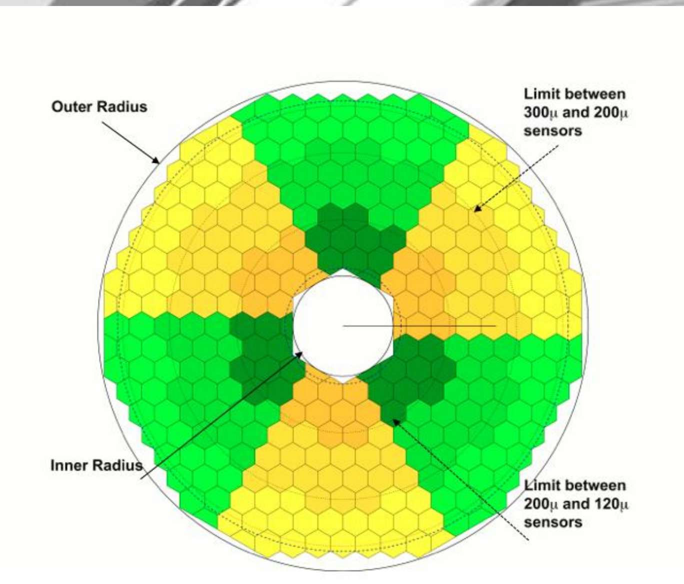


Si-sensors: 583 m²
Scintillator: 487 m²

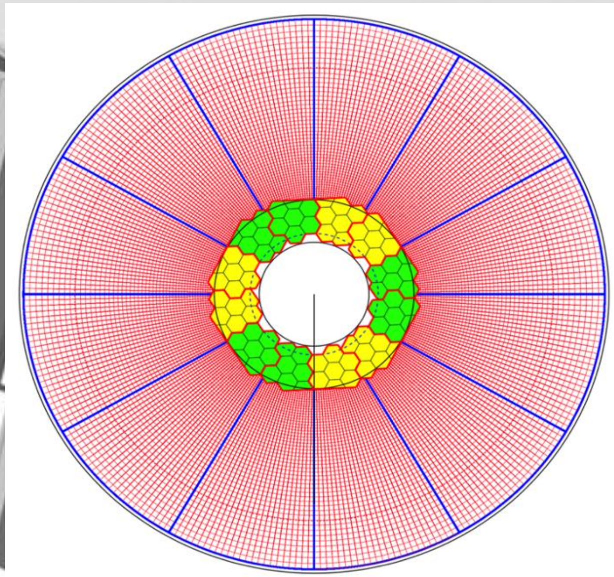
Benefit from particle-flow techniques
- High granularity
  - Unprecedented jet energy resolution
  - Explosion of channel number ~ $$$

Totally ~6M channels (silicon+SiPM) in HGCAL: ~67M CHF

The CMS HGCAL



CE-E 9th layer



CE-H 22nd layer

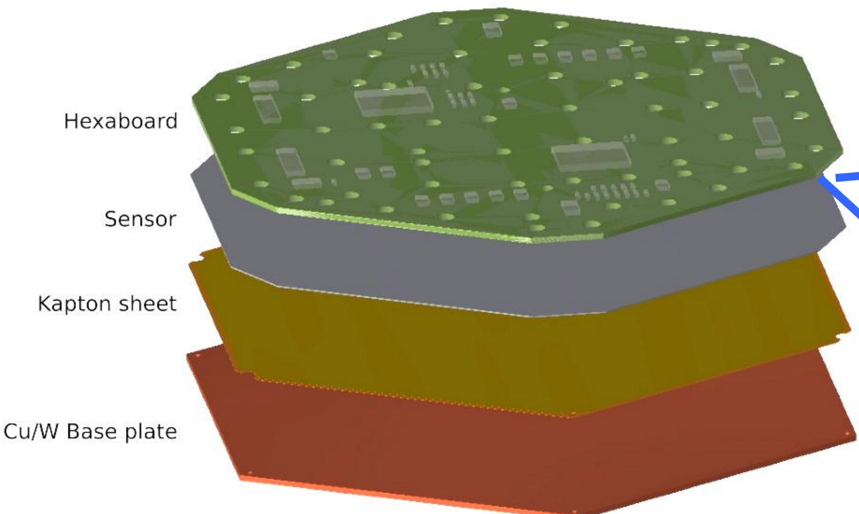
Si-only layer
- **Sensor thickness (120-300 μm) optimized for radiation hardness**

Mixed Si-scintillator layer
- **Boundary optimized vs radiation hardness**

The whole HGCAL will be operated at $-30^{o}C$

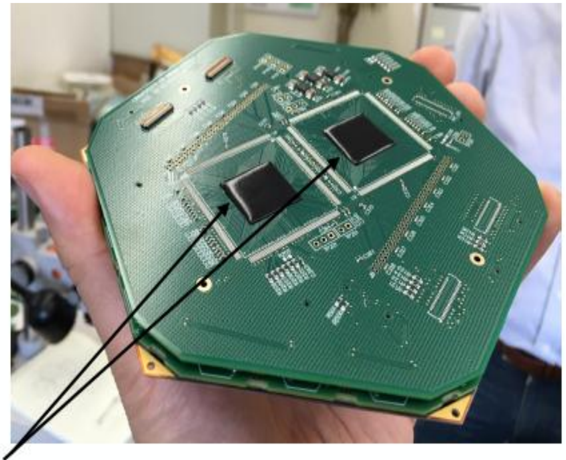
Silicon Detector Module Design of HGCAL

Assembly Center: IHEP-Beijing, BARC-Mumbai, Taiwan, USA (CMU, TTU, UCSB)

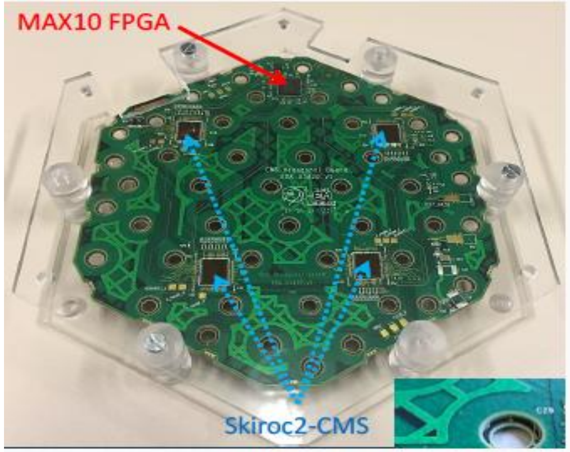


2016 TB

2017 TB



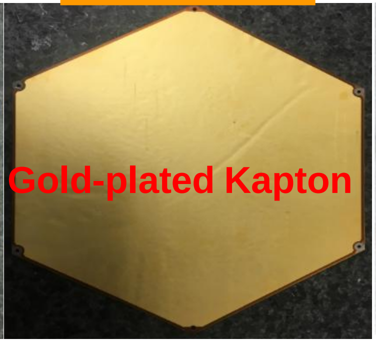
SKIROC 2 ASIC developed by OMEGA group designed for ILC. Not the final front-end chip for CMS.



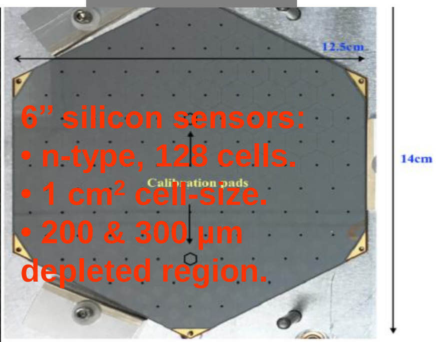
Skiroc2-CMS ASIC,
- Developed for CALICE and adjusted for CMS requirements.

Baseplate

Kapton®



Sensor

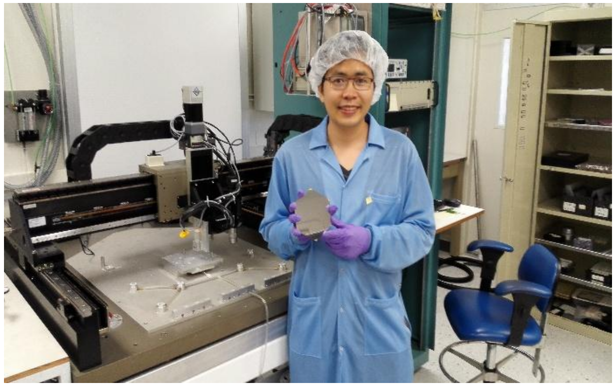


- Module assembled by gluing a stack of **baseplate**, **Kapton®**, **Si sensor** and **PCB** (with FE)

Test beam from 2016 to 2017

Date	Location	No. of module	PCB type	ASIC type	Database	IHEP
2016	FNAL	16 Si modules	"2 layers" PCB	SKIROC 2 ASIC	e beam (4-32 GeV)	✔
2016	CERN	8 Si modules	Single layer PCB (V1)	SKIROC 2 ASIC	e beam (20-250 GeV) π beam (125 GeV)	✔
8-15May 2017	CERN	1 Si module	Single layer PCB (V1)	SKIROC 2CMS ASIC	e beam (20-250 GeV)	✔
12-19 July 2017	CERN	10 Si modules	Single layer PCB (1 V1 & 9 V2)	SKIROC 2CMS ASIC	e beam (80 GeV) π beam (300 GeV)	✔
29 Sep-2 Oct 2017	CERN	17 Si modules	Single layer PCB (1 V1 & 16 V2)	SKIROC 2CMS ASIC	e beam (20-90 GeV) hadrons beam (100-350 GeV)	✔
19-23 October 2017	CERN	20 Si modules	Single layer PCB (1 V1, 16 V2 & 3 V3)	SKIROC 2CMS ASIC	e beam (20-80 GeV) hadrons beam (50-120 GeV)	✔
2017 From July to October	CALICE-AHCAL joined the combined beam test with CMS-HGCAL 12 active layers Each layer: 144 scintillator tiles (30×30×3 mm^3), Readout by SiPM					✔

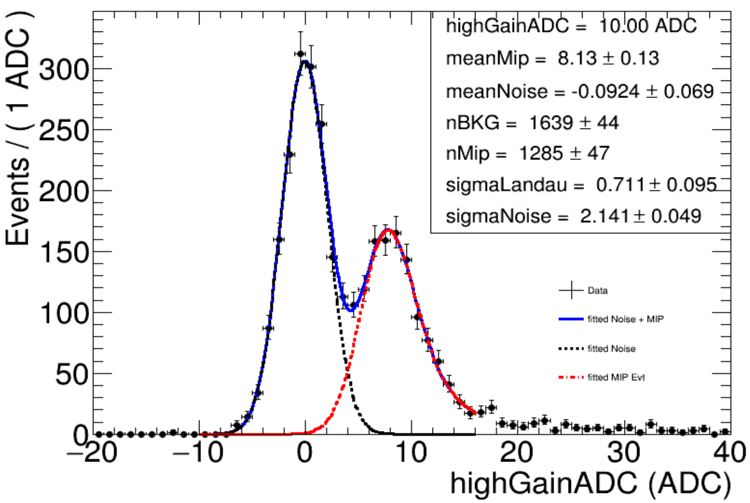
Test beam @ FNAL in 2016

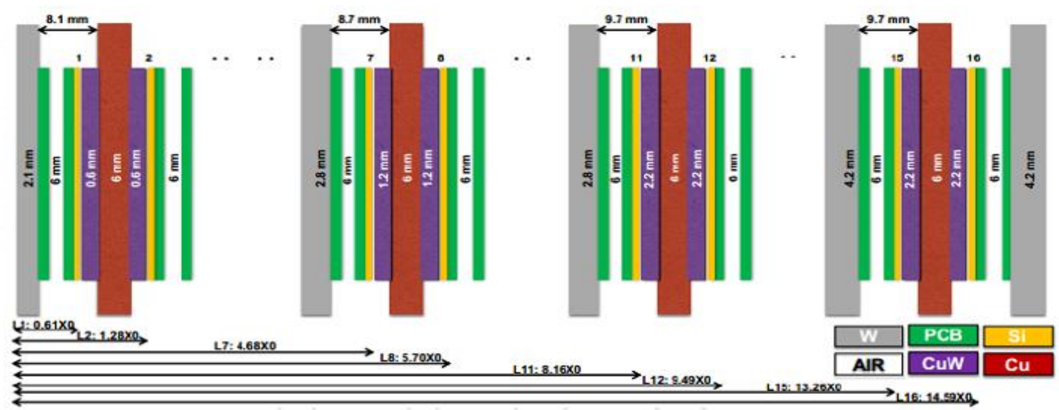


- 16 Si modules, 15 X_0
- e beam (4-32 GeV)
- π beam (120 GeV) for calibration

- Huaqiao ZHANG participated the HGCAL module assembly at UCSB in Mar. 2016
- Participated the first HGC beam test @ FNAL

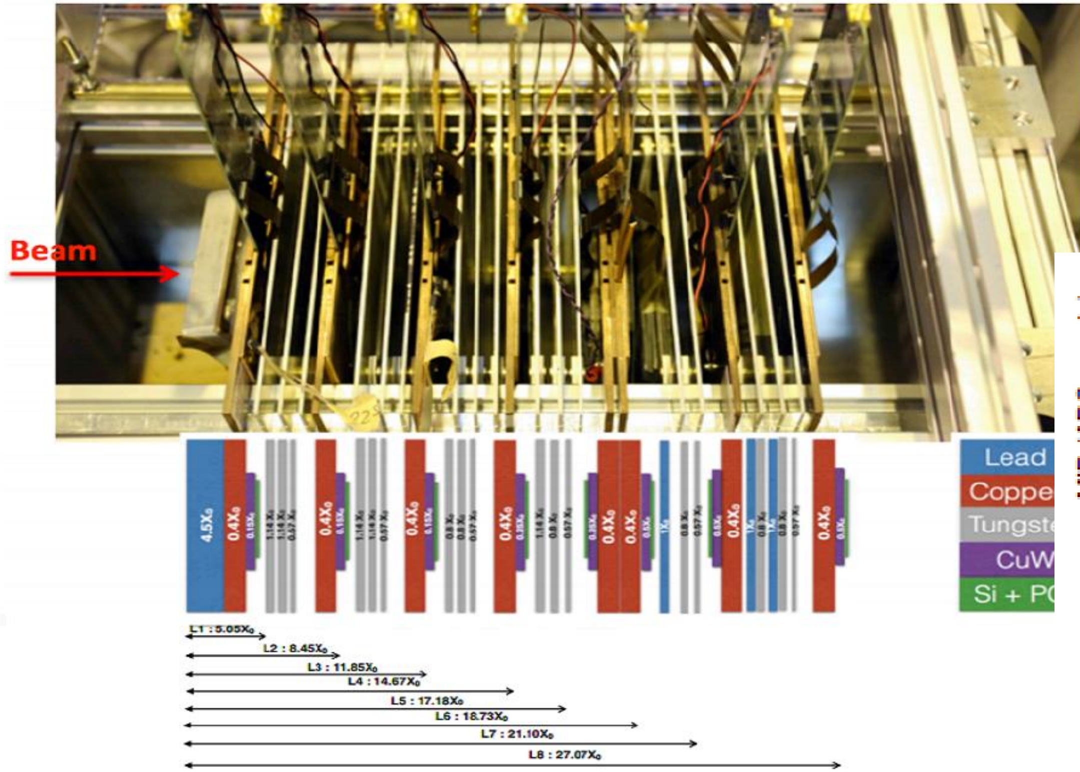
Beam



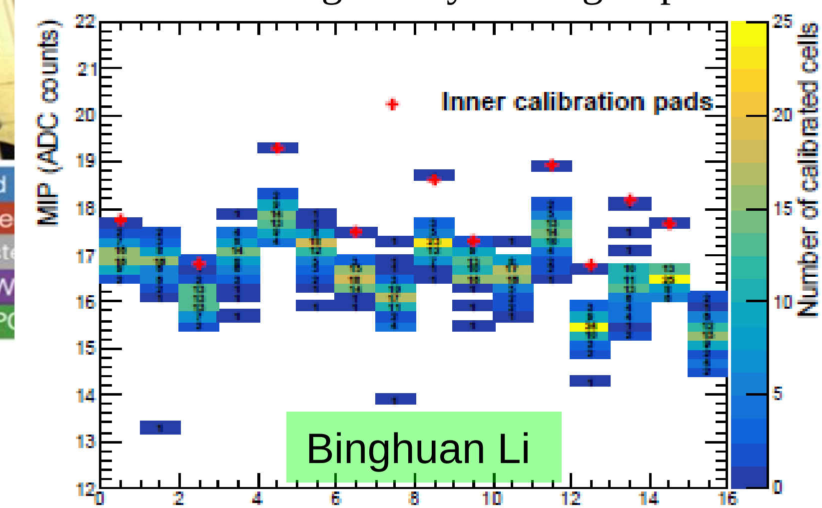


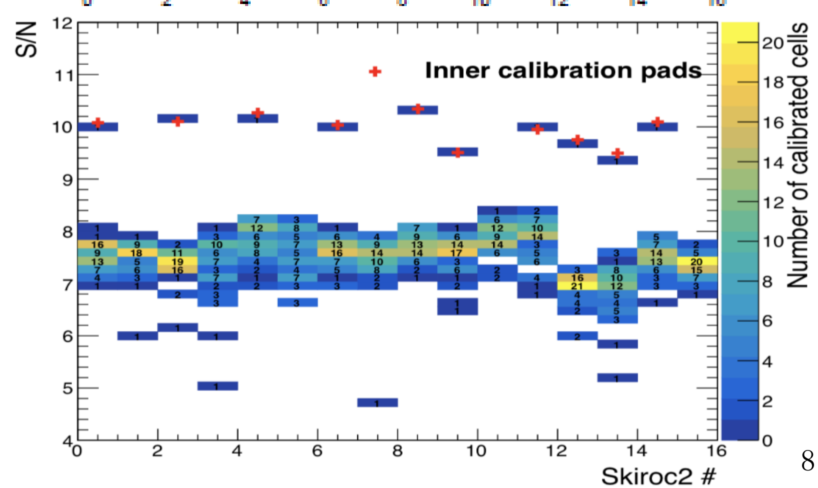
The first MIP signal fit of a HGCAL module by Huaqiao Zhang

Test beam @ CERN in 2016



- Binghuan LI, Francesco and Feng Wang participated the test beam @ CERN
- Experimental beam MIP signals were investigated by IHEP group





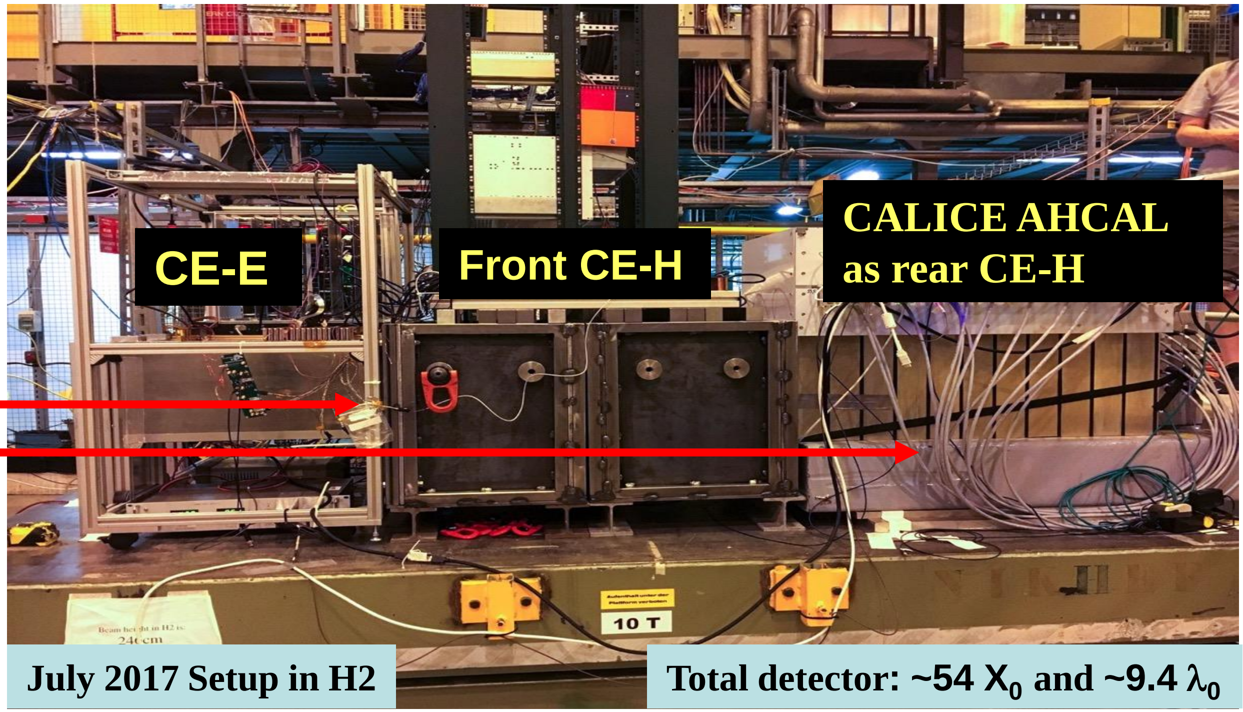
- ❖ 8 Si modules; 2 setups: 5-27 X_0 and 6-15 X_0
- ❖ e beam (20-250 GeV)
- ❖ π beam (125 GeV), " (120 GeV) for calibration

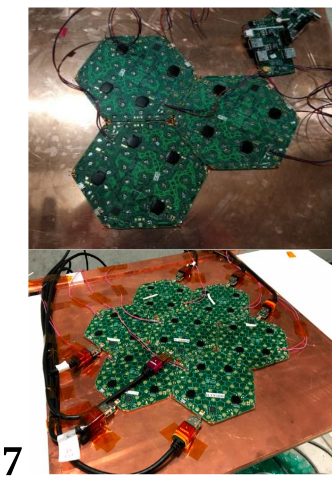
Test beam setup @ CERN in 2017

- CE-E part: Hanging file structure with **lead** absorber.
- CE-H (Si) part: Hanging file structure with **iron** absorber.
- Data taking together with CALICE-AHCAL prototype as CE-H part (scintillator+SiPM)

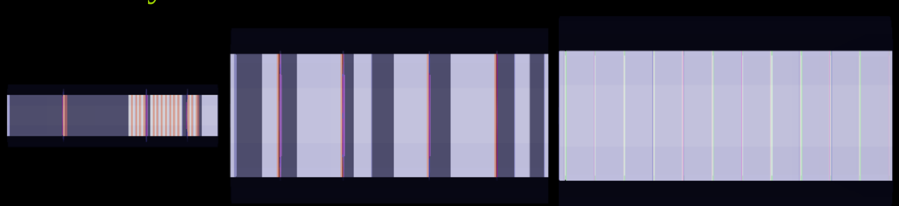
e

π/p





Geometry in Simulation for 2017 Beam test



CE-E (Si + Pb) **CE-H(Si +Fe)** **CE-H(Scint.+ SiPM)**

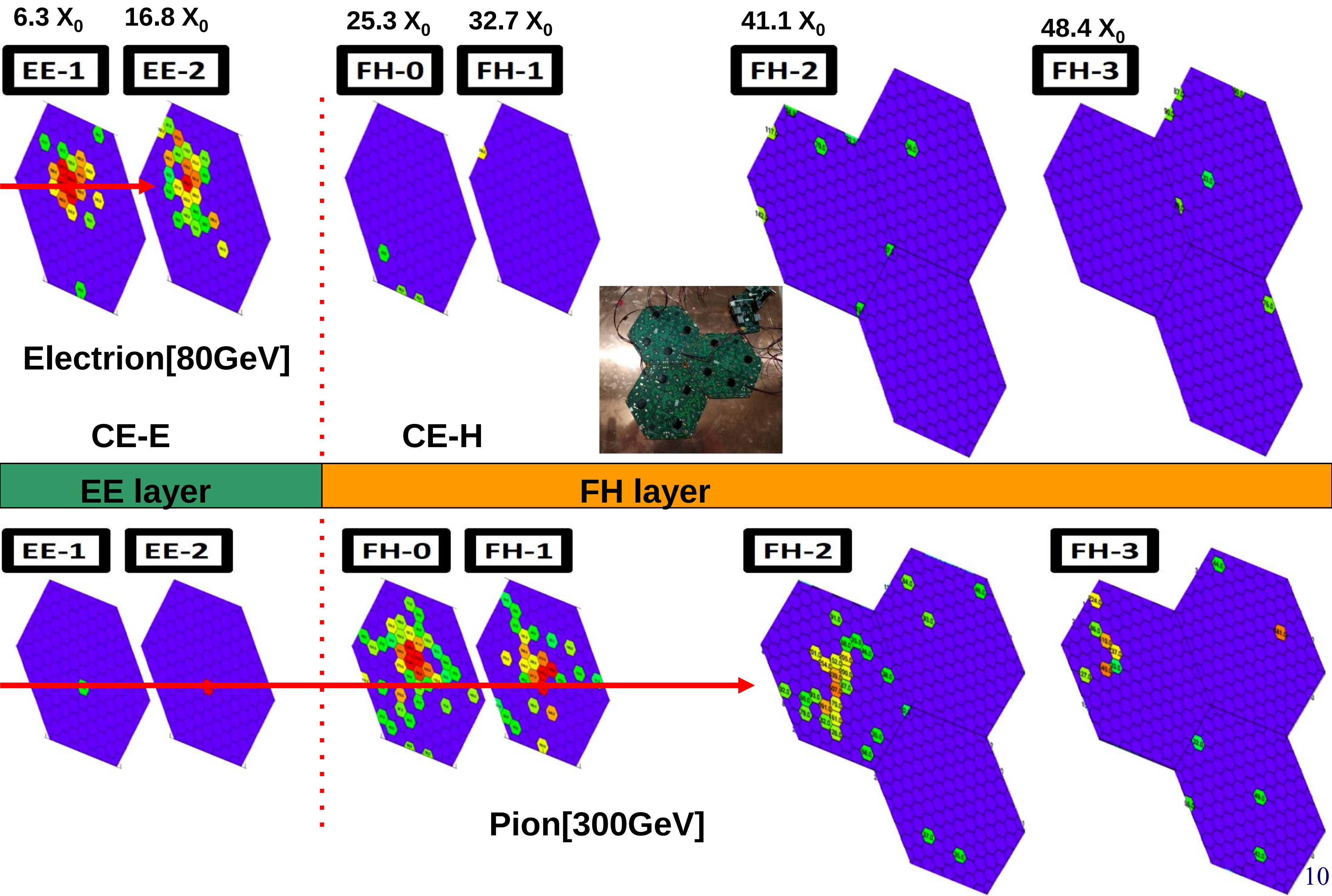
Test 20 modules @ CERN in 2017

-- 5 in CE-E

-- 15 in CE-H: 5 layers (1 module per layer) + 1 layer (3 modules)+ 1 layer (7 modules)

-- Binghuan Li and Francesco participated the CERN beam test

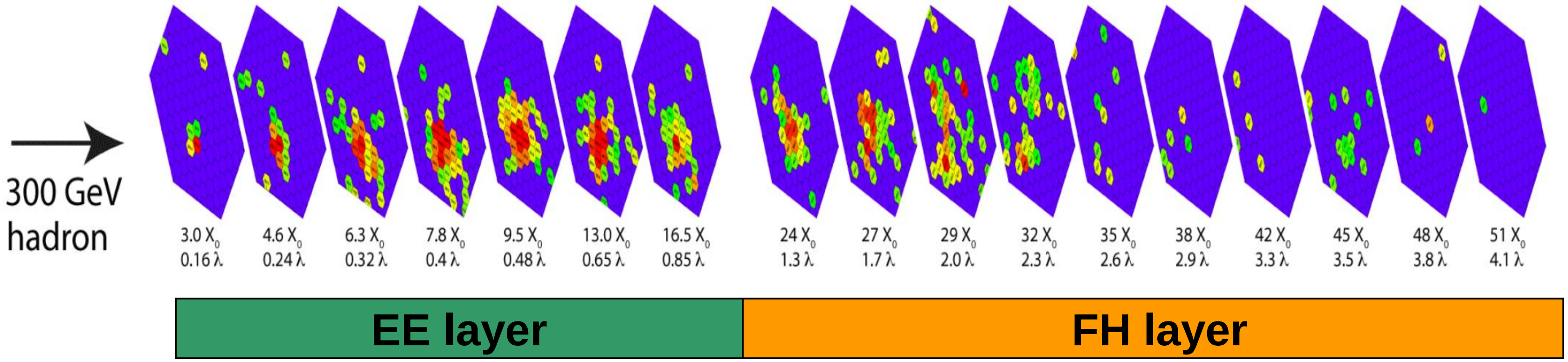
Event display for electrons and pions



More data taking in Fall 2017

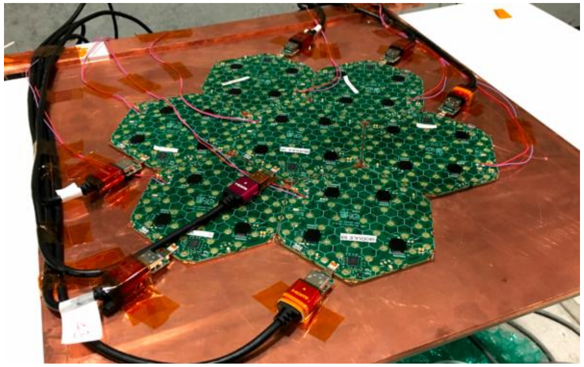
Several configurations were explored with more module assembled （up to 20 modules finally）

- **29/09 - 02/10 in H2：** 17 modules: **7 layers in EE, 10 layers in FH.**

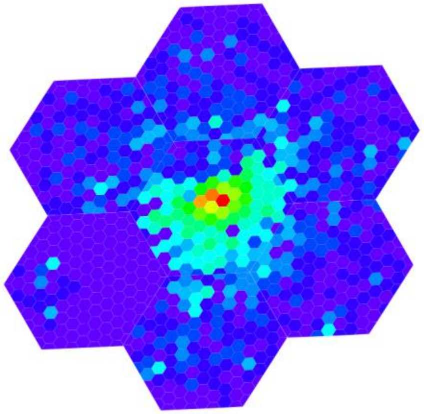


- **19/10 - 23/10 in H6a：** 20 modules: **5 layers in EE, 7 layers in FH.**

  - Increased the statistics with respect to the July beam test
  - Test the DAQ with the daisy-chain structure shown right.

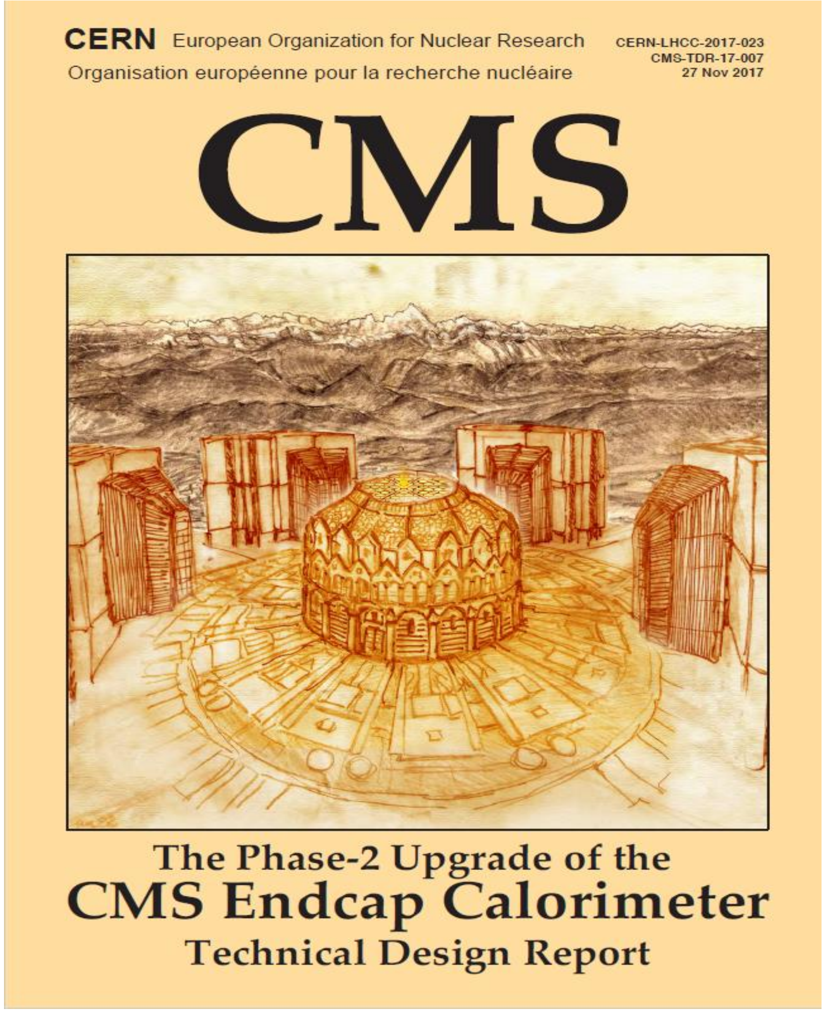


FH: - 1x 7 module layer
- 1x 3 module layer
- 5x 1 module layers



TB October 2017, H6
120 GeV hadron

HGCAL: contributions from IHEP



- TDR: https://twiki.cern.ch/twiki/pub/CMS/EC-TDR/TDR-17-007-paper-v1.pdf
- Paper of HGCAL module beam test submitted to Journal of Instrumentation

Test beam in 2018

- **More beam tests in 2018:**

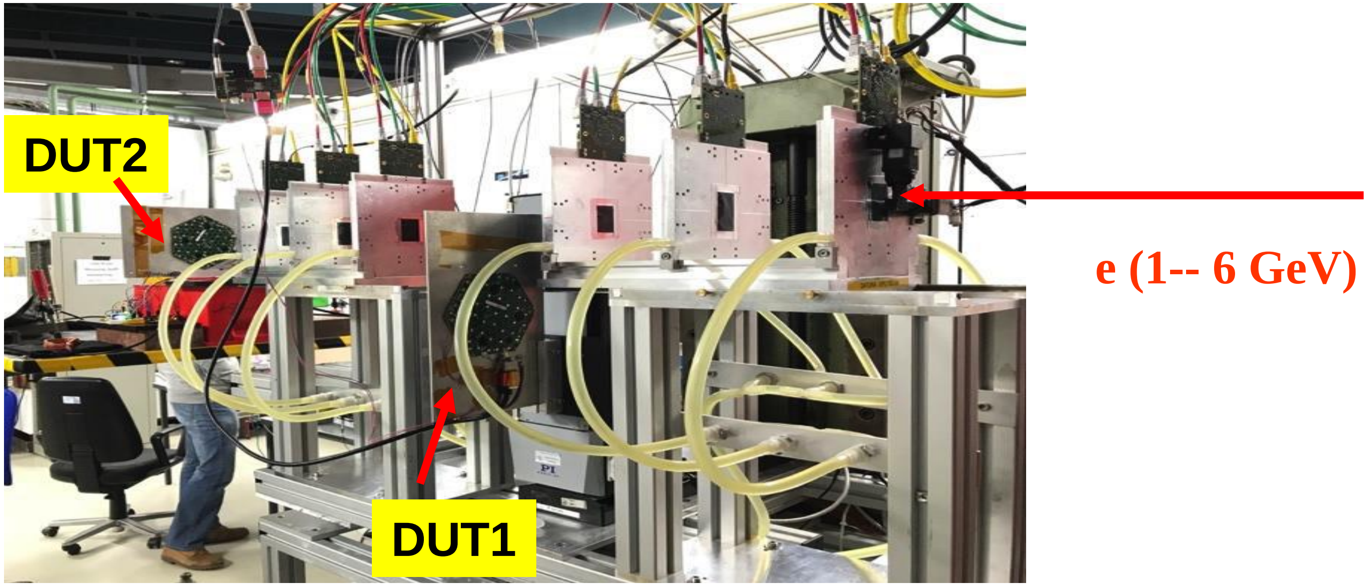
  -**10 days @ DESY** in March: low-energy showers, performance studies at different positions (Huaqiao Zhang participated the test beam)

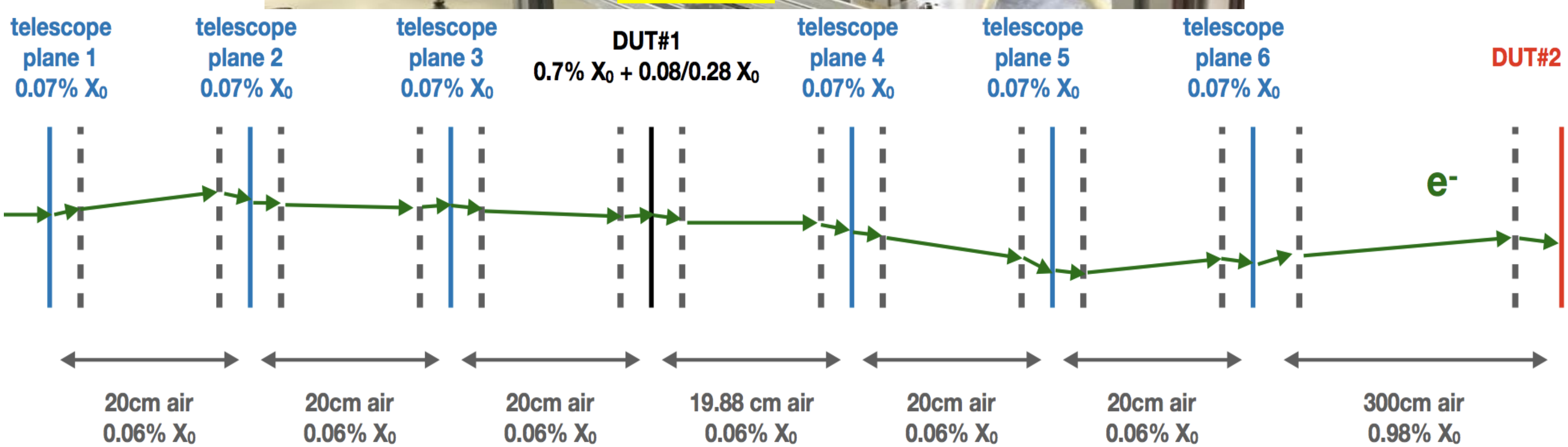
  -**10 days @ CERN** in June: 28-layer electromagnetic section (Huaqiao Zhang and Hongbo Liao participated the test beam)

- Another test with extended prototypes foreseen at CERN:

  14 days @ CERN in October: 28-layer EM + 12-layer hadronic section + CALICE-AHCAL

Test beam @ DESY in March 2018

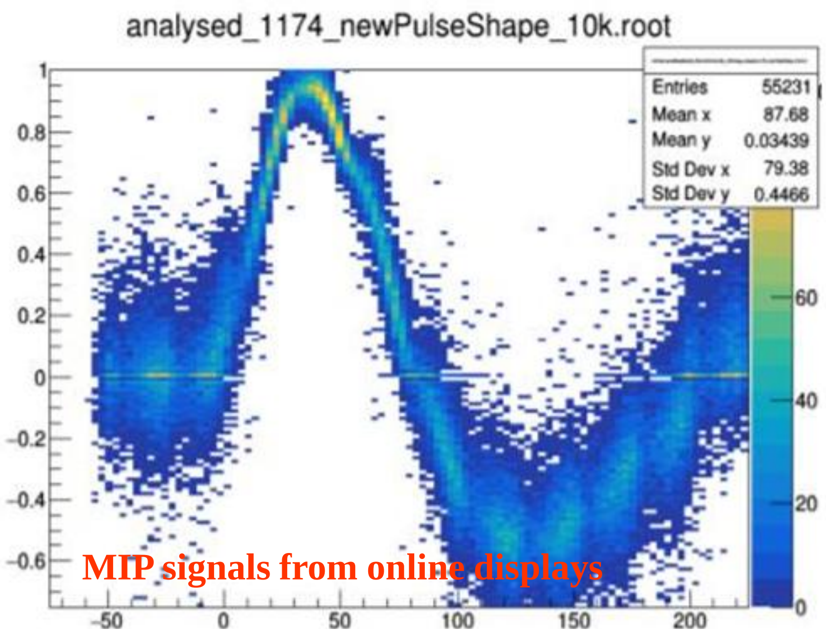


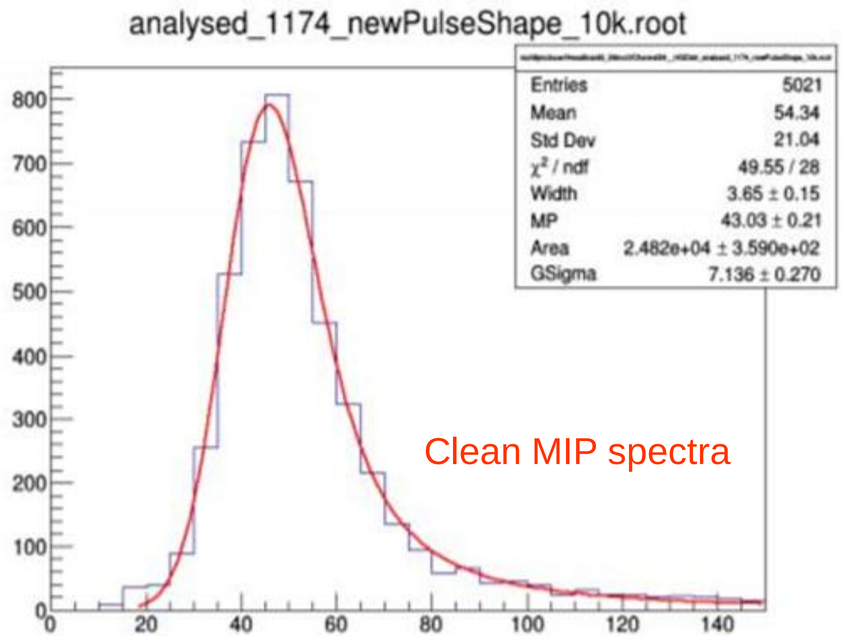


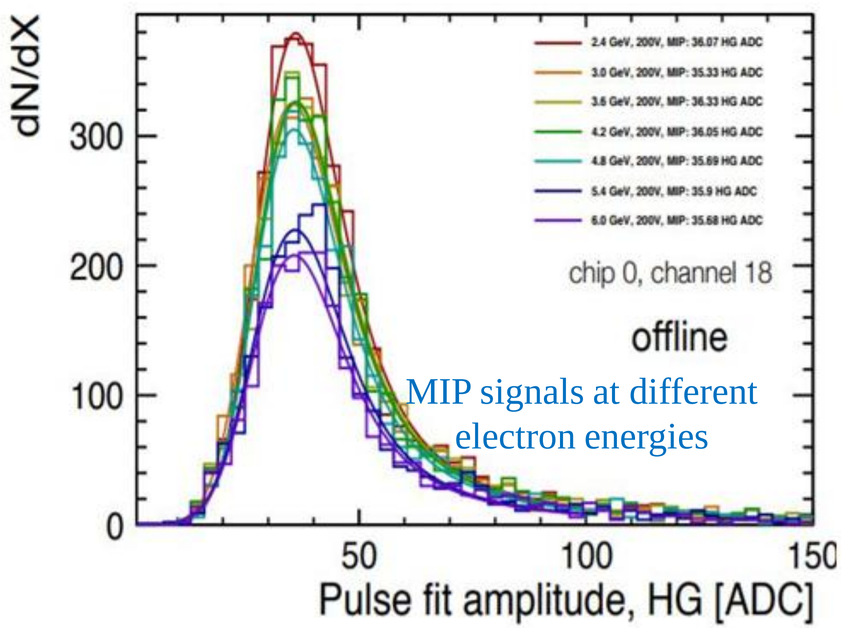
not to scale ;-)

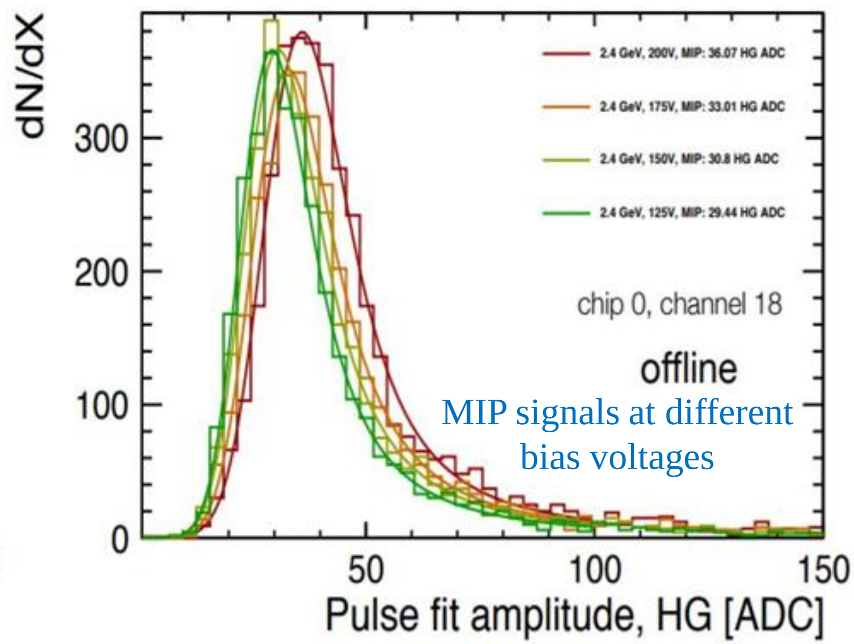
- **MIP calibration (DUT1)**
- **Energy response uniformity (DUT2)**

MIP signal @ DESY in 2018



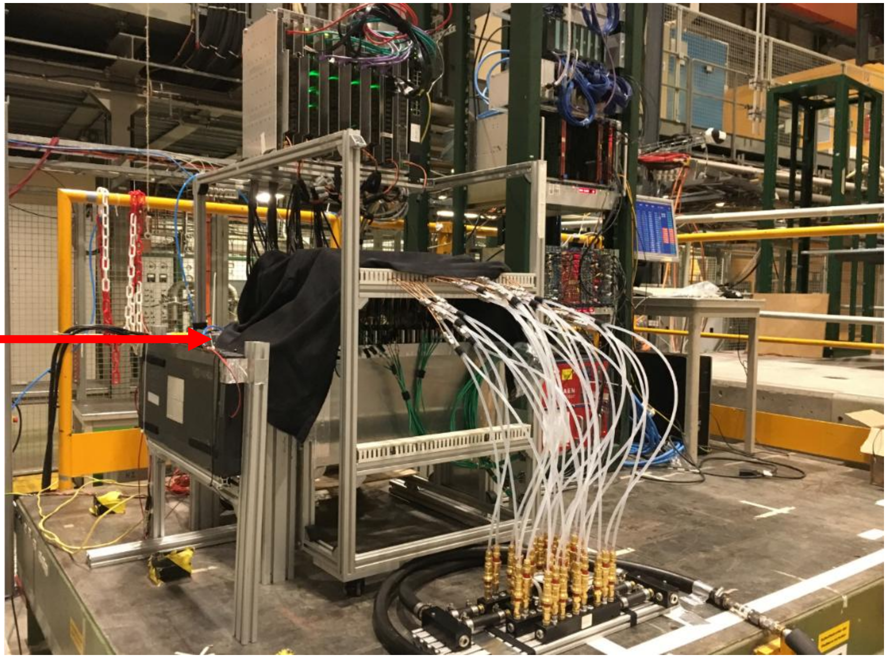




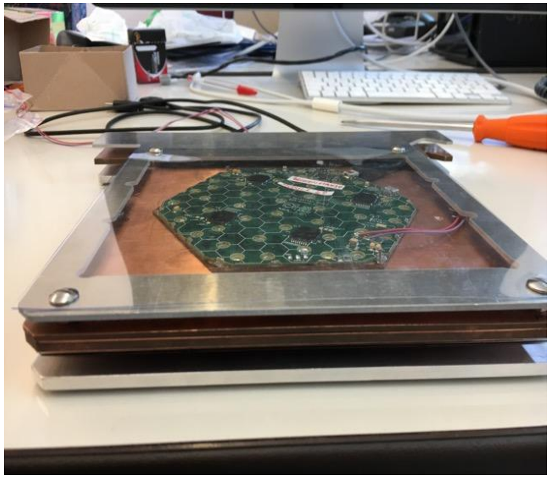


Test beam @ CERN in June 2018

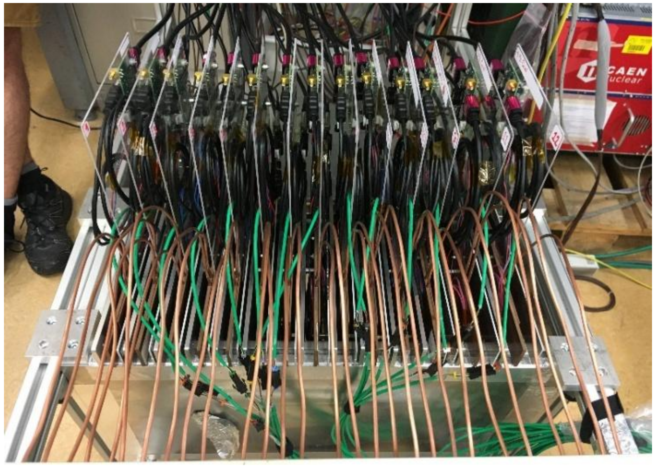
e (100GeV)



- Module assembly @UCSB (Feng Wang, Huaqiao Zhang)
- Module testing setup, data taking @CERN (Huaqiao Zhang, Hongbo Liao)



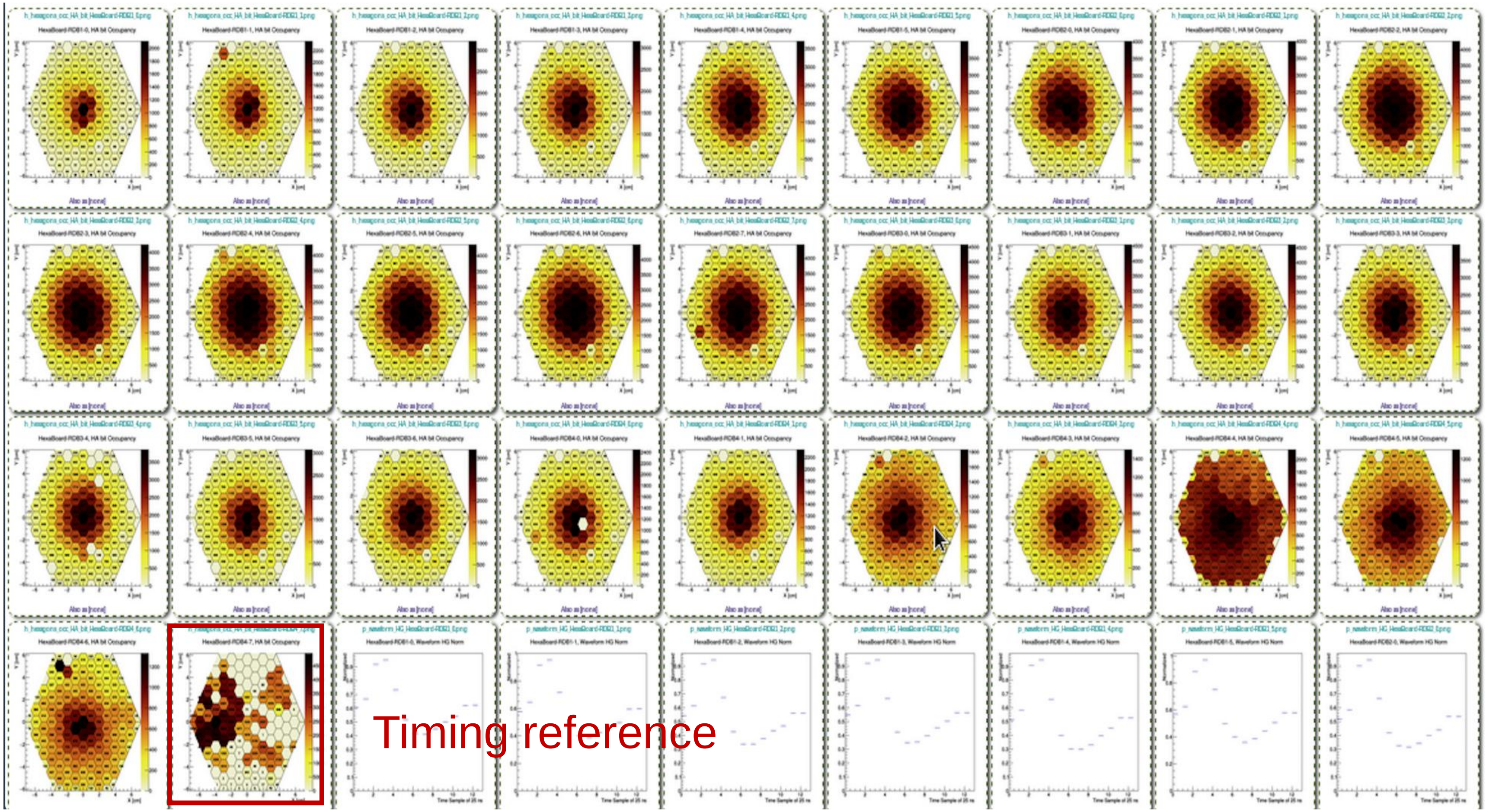
Double-sided "cassette"



28 modules in 14 "cassettes"

Water cooling

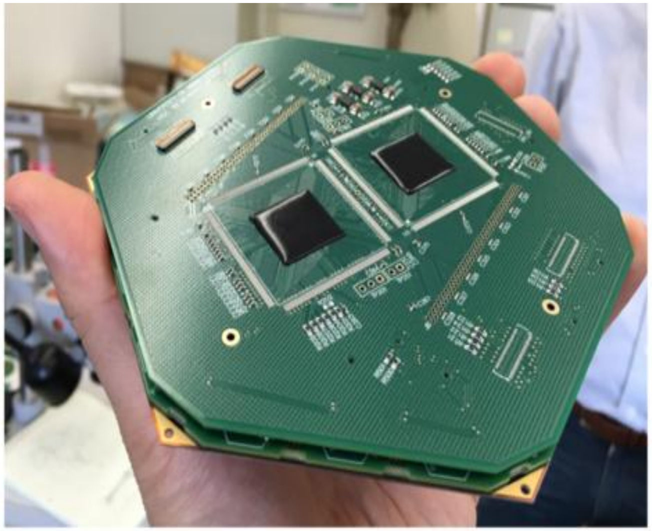
Shower shape at CERN in June 2018



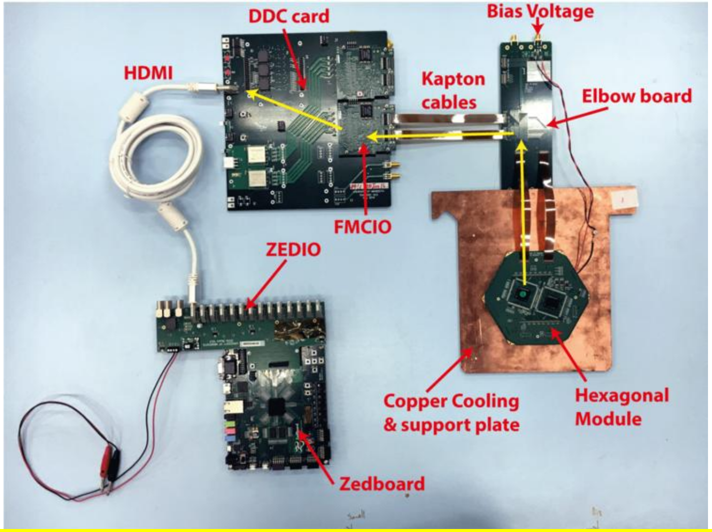
- 100GeV electrons: occupancy plots for all 28 layers;
- The last 3 layers are noisy;
- 29th module is a bare hexaboard as a timing reference

Plan: testing with cosmic rays

- ➢ 2019-2020: no beams at CERN
- ➢ But beams available at DESY, FNAL, IHEP;
- ➢ External signal sources: IR Laser / **cosmic rays**
  - ✓ To study long-term stability, uniformity, noise, temperature dependency, etc.
  - ✓ Training peoples

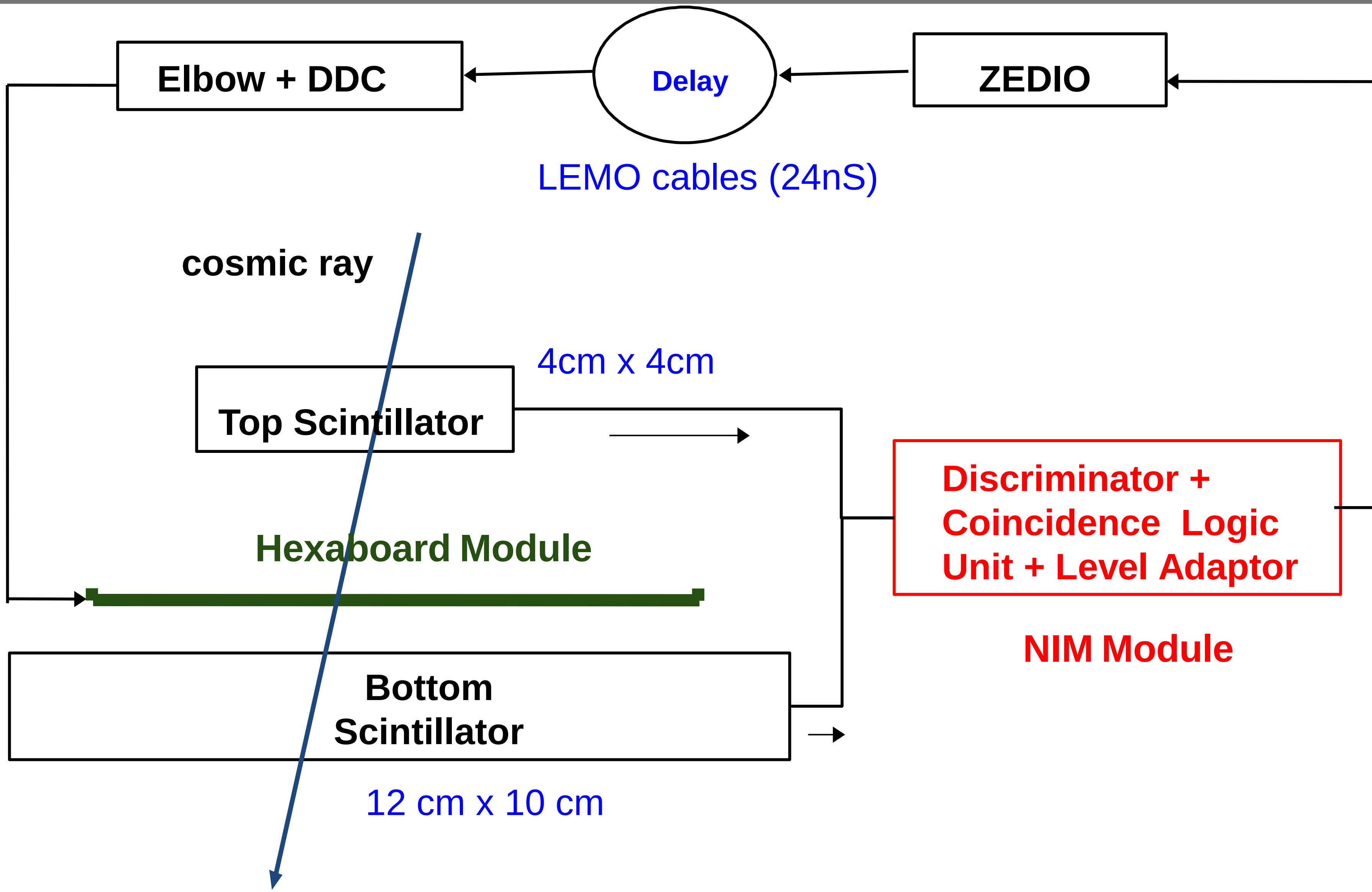


HGCAL module of 2016 version



The DAQ hardware components

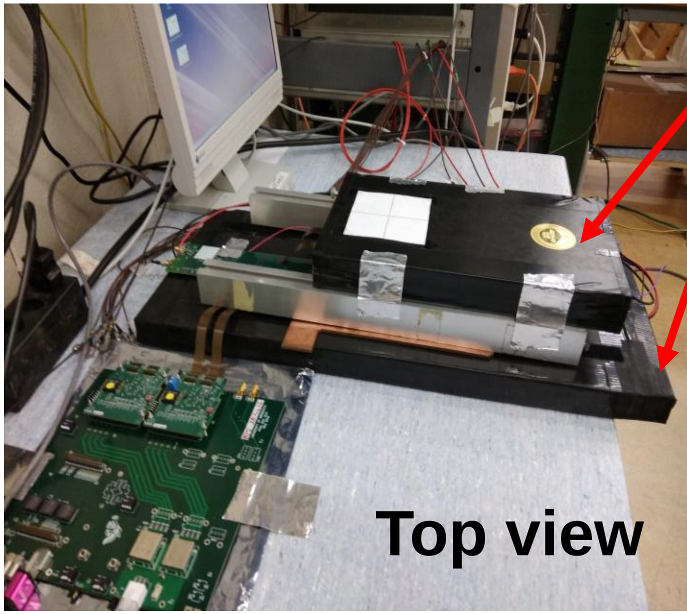
Cosmic-ray setup: schematics



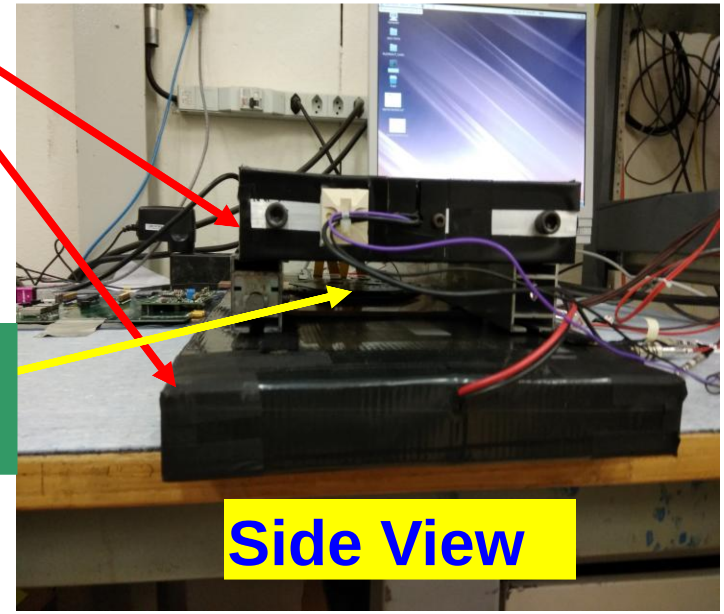
Cosmic-ray Setup built at CERN

Hongbo Liao

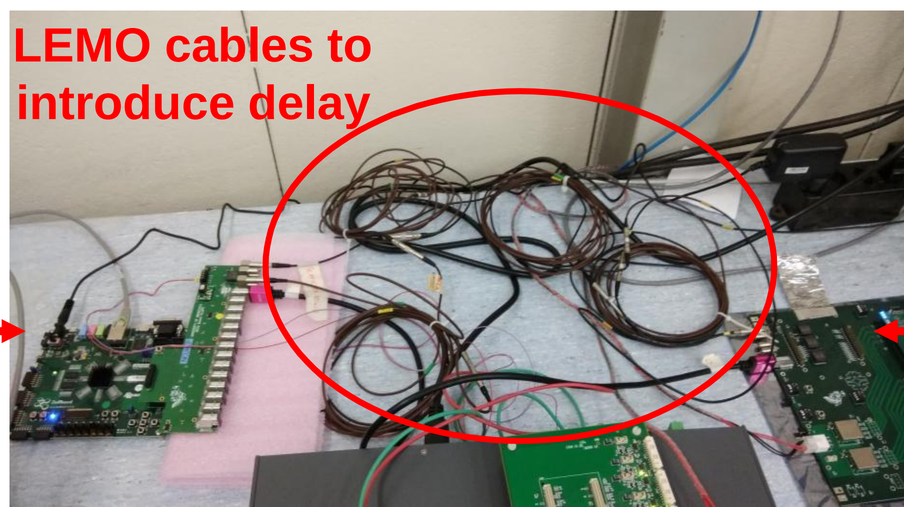
Scintillators



HGCAL Module



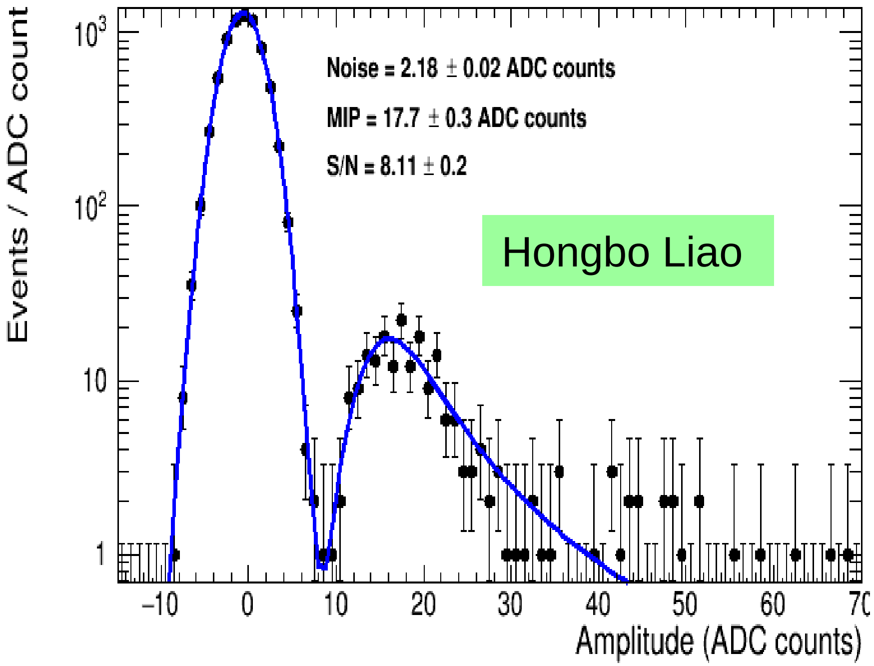
ZEDIO



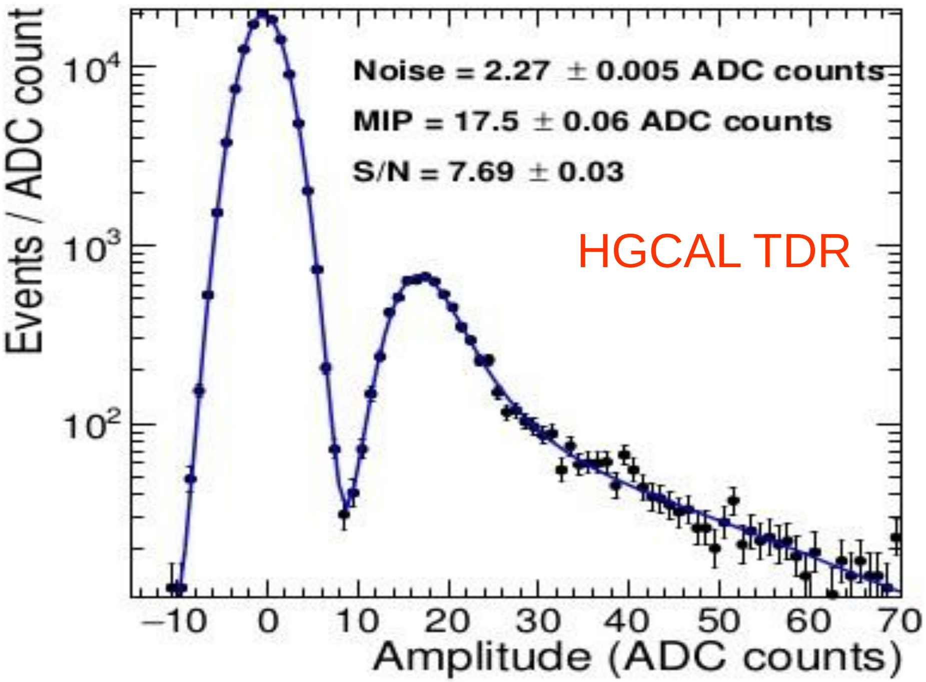
DDC Board

MIP signal in cosmic ray

MIP signal in cosmic ray @ CERN



MIP signal in silicon cell with TB 2016



MIP signals seen from cosmics:

• We successfully built a cosmic testing system at CERN for 2016 HGCAL module • S/N is consistent with TB 2016

• Cosmic testing system (hardware & software) is working well

Summary and next to do

- HGCAL: beam test campaigns

  1. Extensive beam tests (at CERN, FNAL and DESY) since 2016 to validate the HGCAL design

  2. IHEP group fully participated all HGCAL beam tests till now; independently analyzed the beam test data.

- Cosmic-ray tests

  1. A cosmic-ray testing system is built and works well.

  2. This testing system will be sent to IHEP with one Si-module (2016 version) within this year.

- Plans

  1. Will join the CERN beam tests within 2018

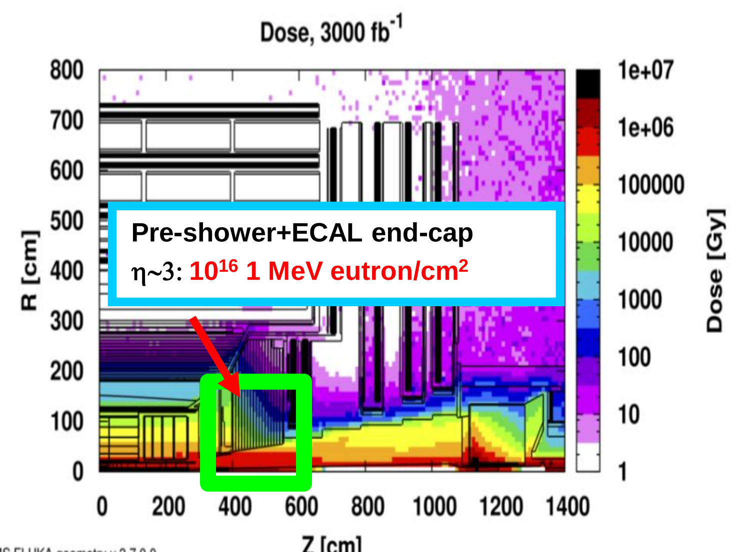
  2. Prepare a beam test at IHEP: in late 2018 or early 2019 (if everything goes smoothly)

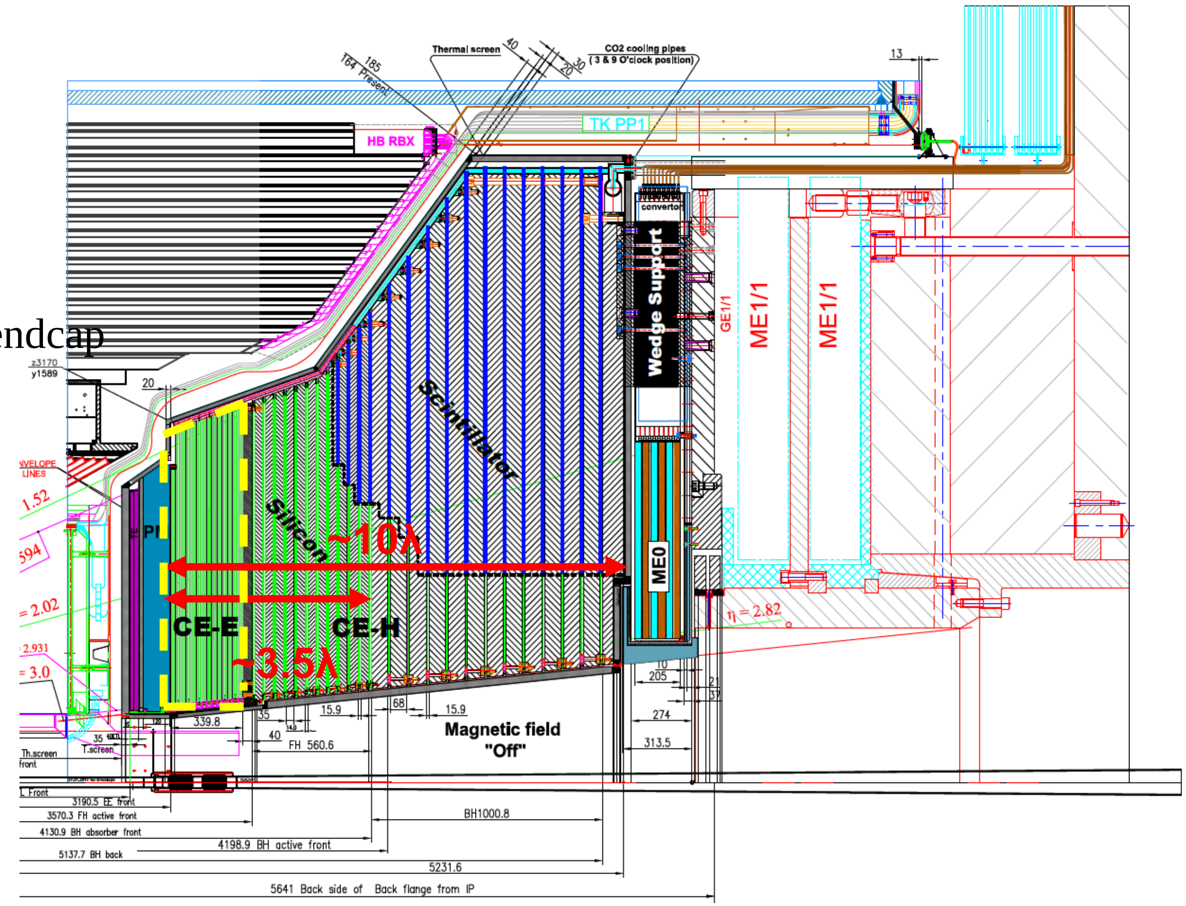
Back up

The CMS HGCAL

Key Parameters:

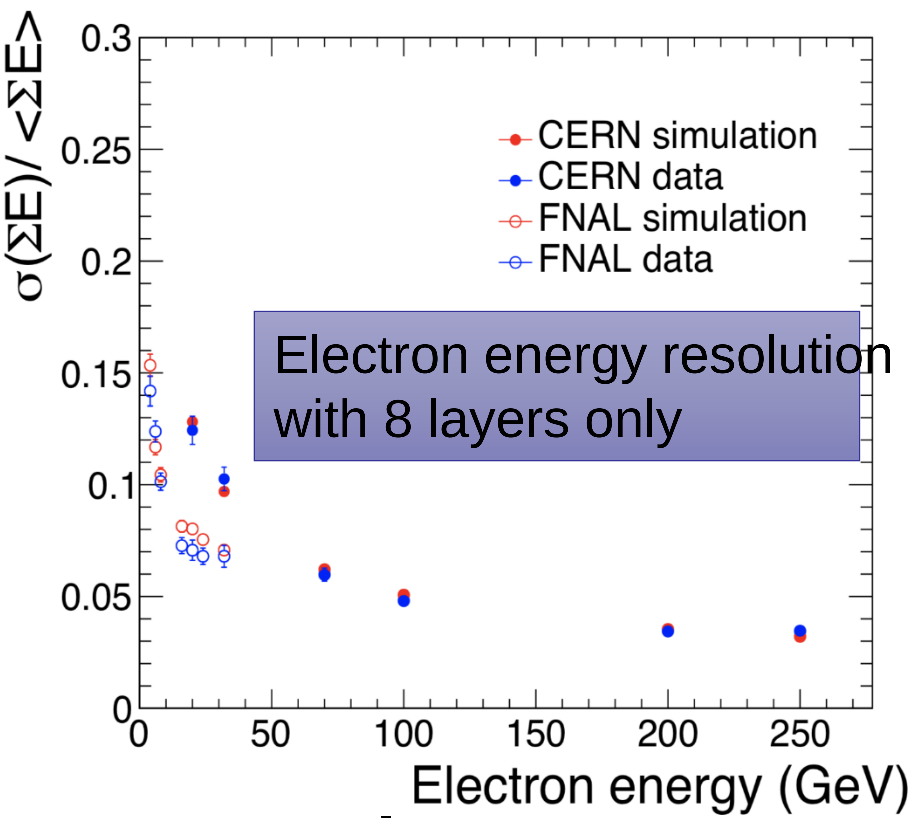
- HGCAL covers 1.5 < η< 3.0
- Full system maintained at -30°C
- ~600m² of silicon sensors
- ~500m² of scintillators
- 6M Si channels, 0.5 or 1 cm² cell size
- ~27000 Si modules (CE-E:16008)
- Power at end of HL-LHC: ~60 kW per endcap

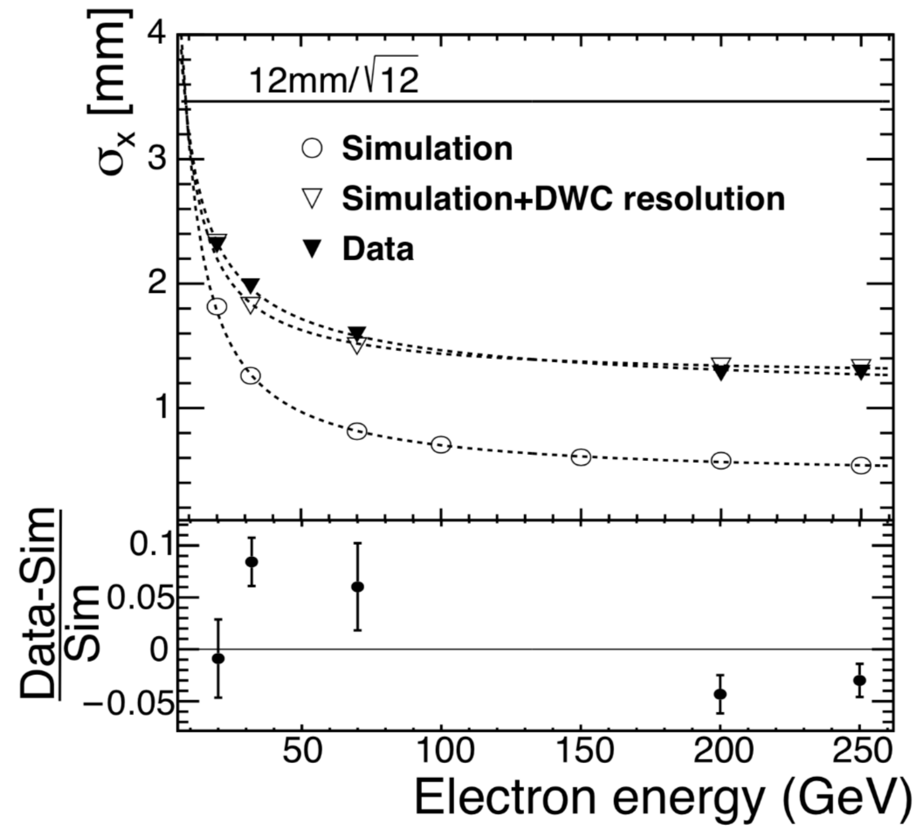




Endcap Electromagnetic calorimeter (EE): Si, Cu & CuW & Pb absorbers, 28 layers, 25 X_0 & ~1.3 λ_0
Front Hadronic calorimeter (FH): Si & scintillator, steel absorbers, 12 layers, ~3.5 λ_0
Backing Hadronic calorimeter (BH): Si & scintillator, steel absorbers, 12 layers, ~5 λ_0

Electron energy & position resolution



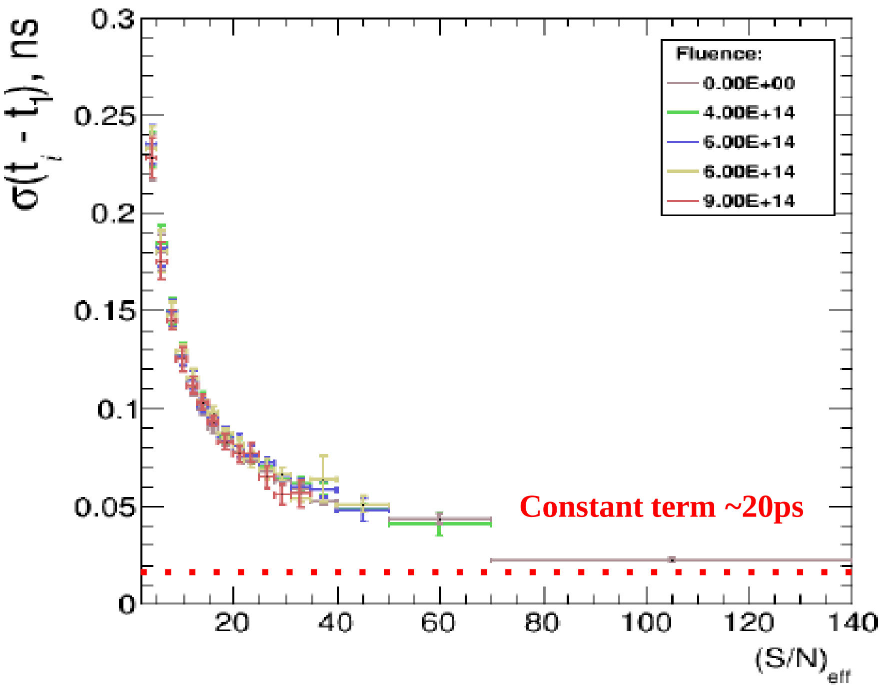


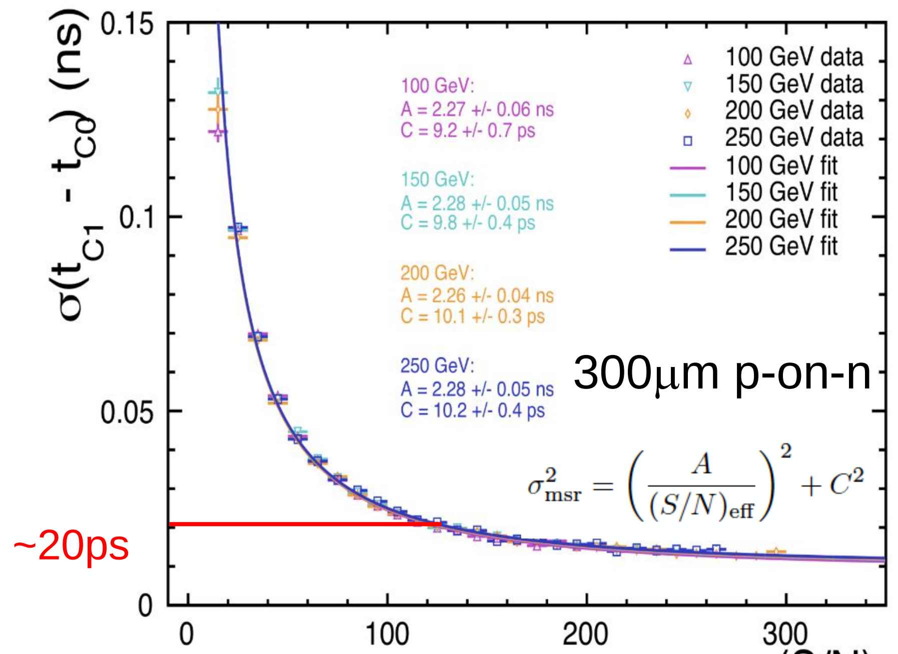
- Energy resolution:
  -- Distributions from electrons match those predicted by simulation (to within 5%)
  -- Beam tests in 2016 & 2017 with few layers validated basic design

HGCAL TDR

- Position resolution:
  -- The DWC contribution to the uncertainty is quite large
  -- The agreement between data and simulated showers is very good with DWC uncertainty
  -- The intrinsic spatial precision at this depth is around 0.6mm for high-energy electrons

Time resolution





$$\sigma^2_{\text{msr}} = \left(\frac{A}{(S/N)_{\text{eff}}}\right)^2 + C^2$$

$$(S/N)_{eff} = \frac{(S/N)_{\text{ref}}(S/N)_{\text{dut}}}{\sqrt{(S/N)^2_{\text{ref}} + (S/N)^2_{\text{dut}}}}$$

HGCAL TDR

- Time resolution:

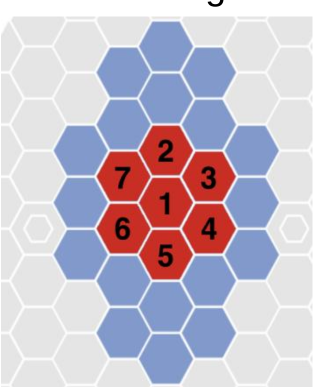
  -- The intrinsic timing resolution does not significantly depend on the fluence at a given S/N ratio

  -- Tests with larger energy range at CERN (100-250 GeV)

  -- It is better than 20 ps for S/N > 100

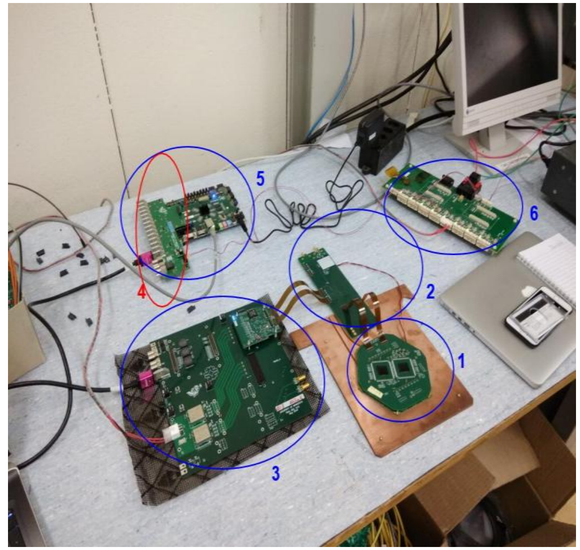
  -- The n-on-p diodes showed very similar performance

25 fast timing cells



系统搭建

B27 @ CERN

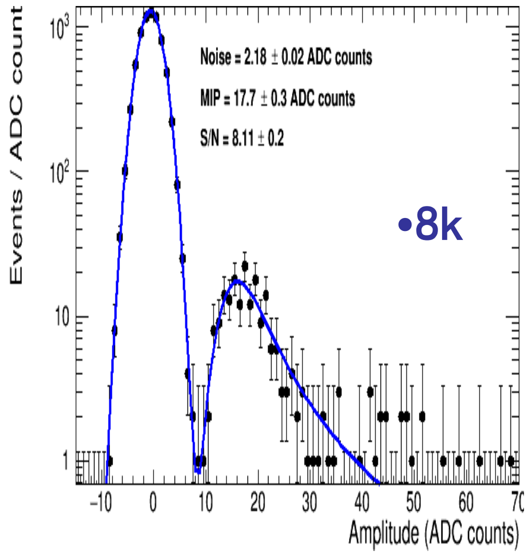


1. Module
2. Elbow board
3. DDC board
4. ZEDIO board
5. ZedBoard
6. 电源
7. 高压低压
8. LEMO cable
9. 闪烁体
10. 光电倍增管

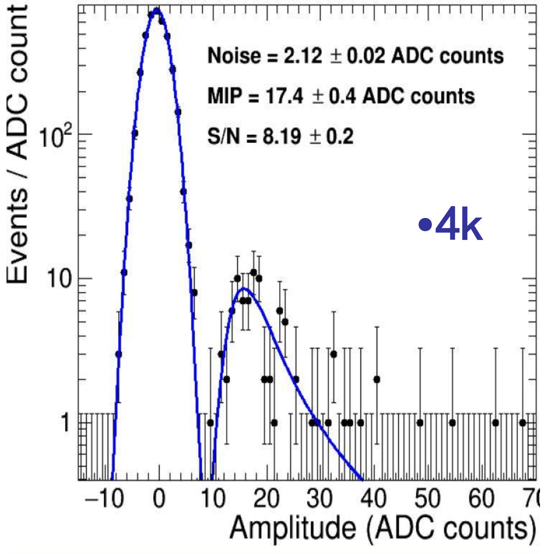
- 从CERN邮寄到高能所
- 在高能所准备

系统运行

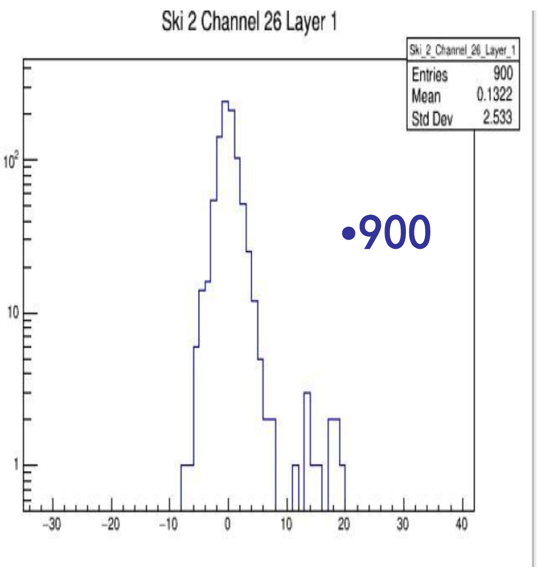
•第一套系统



•第二套系统



•个人电脑取数



- ✓ 俩套系统均搭建成功，工作正常；
- ✓ 操作，运行，分析等软件都已经测试；
- ✓ 主要材料正在安排由CERN邮寄到高能所；
- ✓ 六月底到七月初能在高能所搭建自己的系统。