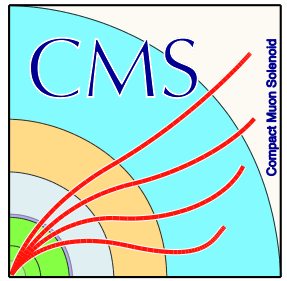
中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

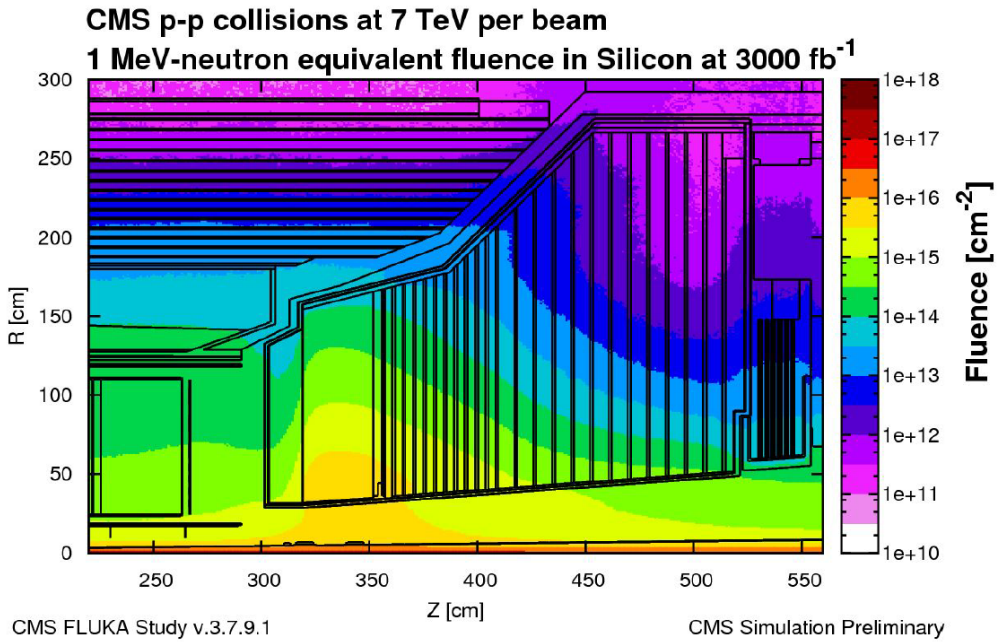
CMS HGCAL Beam Tests

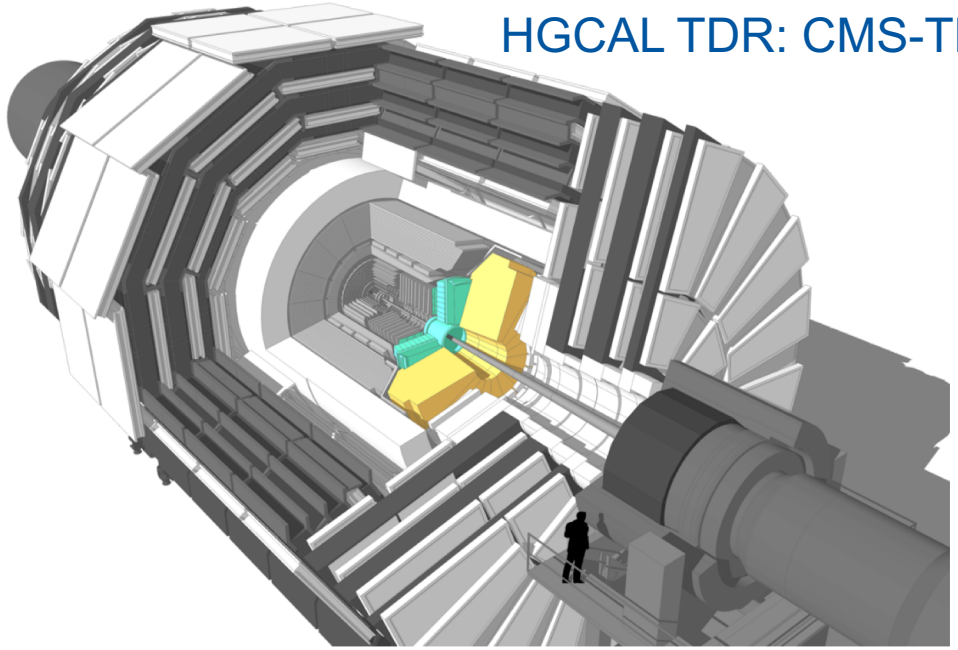
Yong Liu (Institute of High Energy Physics, CAS),
on behalf of the CMS HGCAL Working Group

China LHC Physics Workshop at DLUT, Dalian, Oct. 24-27, 2019



CMS-HGCAL project: overview



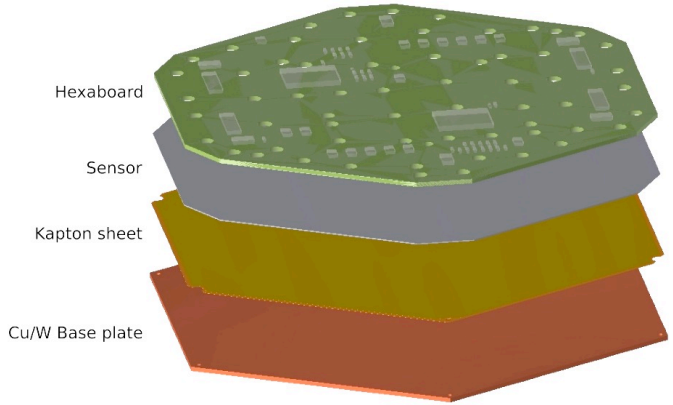


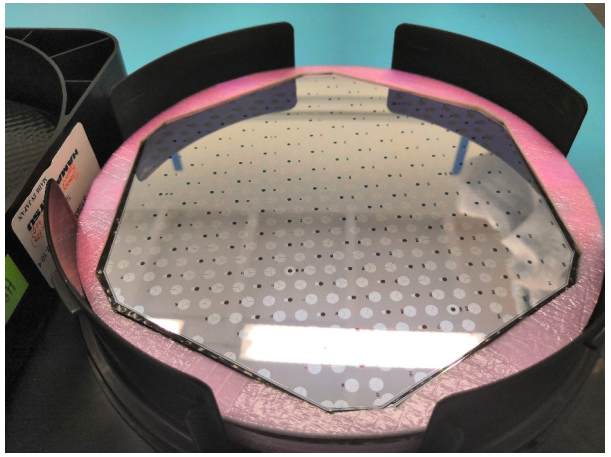
HGCAL TDR: CMS-TDR-019

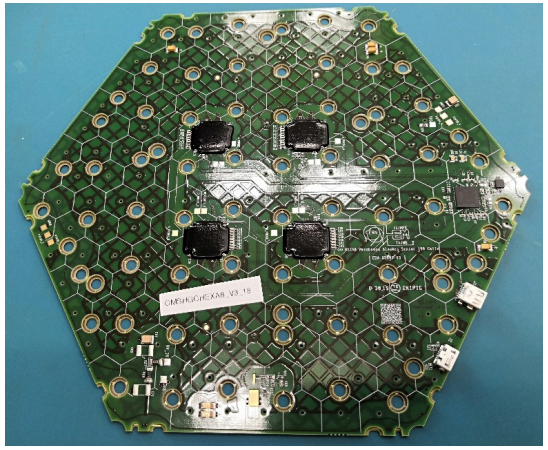
- CMS endcap calorimeters: Phase-2 upgrade
  - Harsh environment at HL-LHC: high pile-up, high radiation level
  - Replace the existing endcap calorimeters
  - Construct a high granularity calorimeter (HGCAL)

CMS-HGCAL: active layers

Silicon sensors

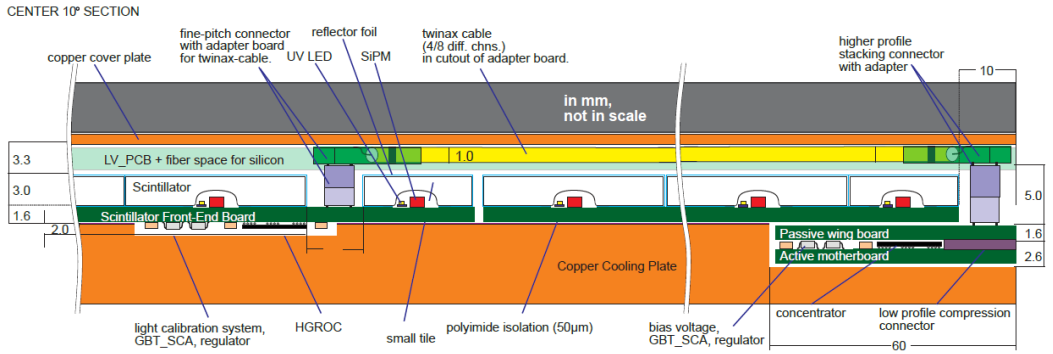


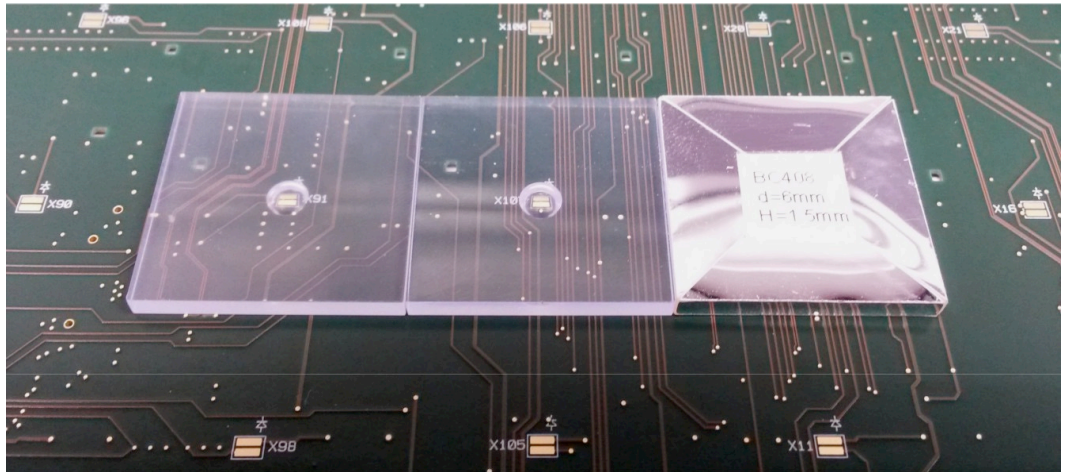




IHEP team focusing on the silicon option

Scintillator + SiPM



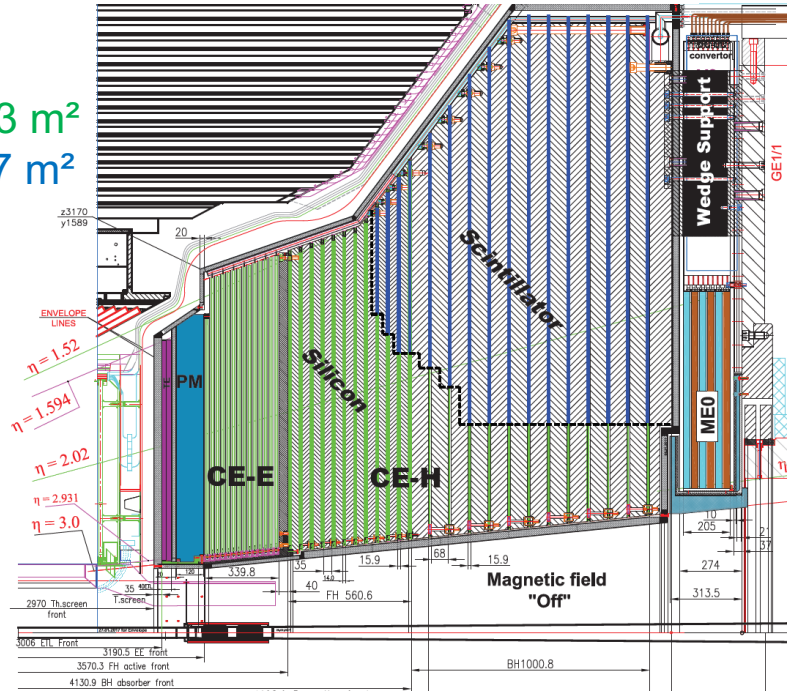


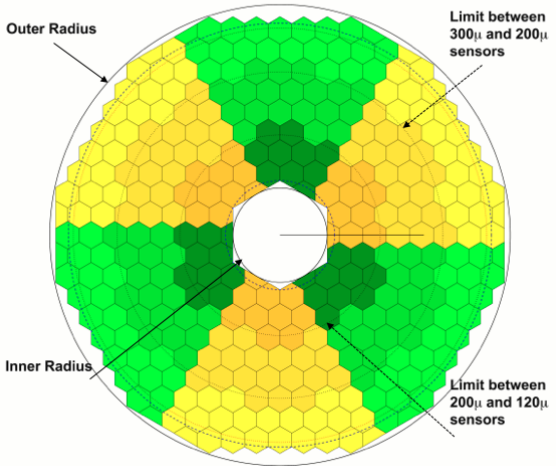
Design (“SiPM-on-Tile”) for CALICE-AHCAL prototype, adopted as the **baseline** for CMS-HGC scintillator part

CMS-HGCAL: active layers

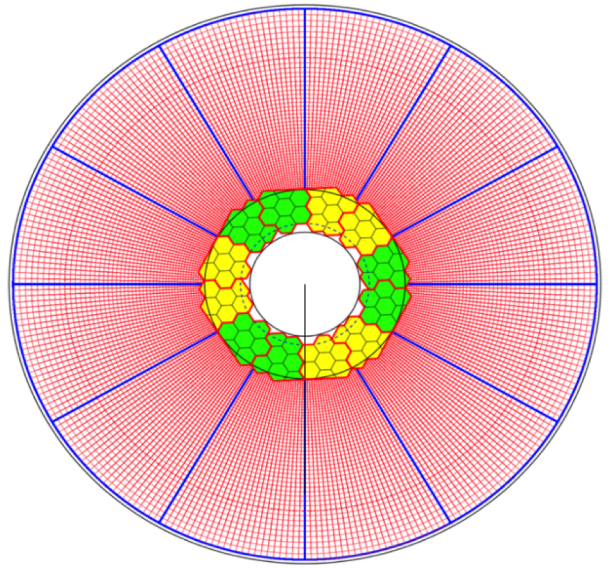
Si-sensors: 583 m²
Scintillator: 487 m²

Longitudinal View





CE-E 9th layer



CE-H 22nd layer

- Silicon-only layers
  - 3 types: 120 μm, 200 μm, 300 μm thick
- Mixed layers: silicon and scintillator-SiPMs
  - Boundary optimized for radiation tolerance

Active thickness (μm)	Cell size (cm^2)	Cell capacitance (pF)	Bulk polarity	Expected range of fluence ($\times 10^{15}$ n$_{eq}$/cm^2)	Number of wafers	Number of partial wafers
300	1.18	45	p / (n)	0.1–0.5	13 164	1284
200	1.18	65	p	0.5–2.5	8712	144
120	0.52	50	p	2–7	3000	324
				Total:	24 876	1752

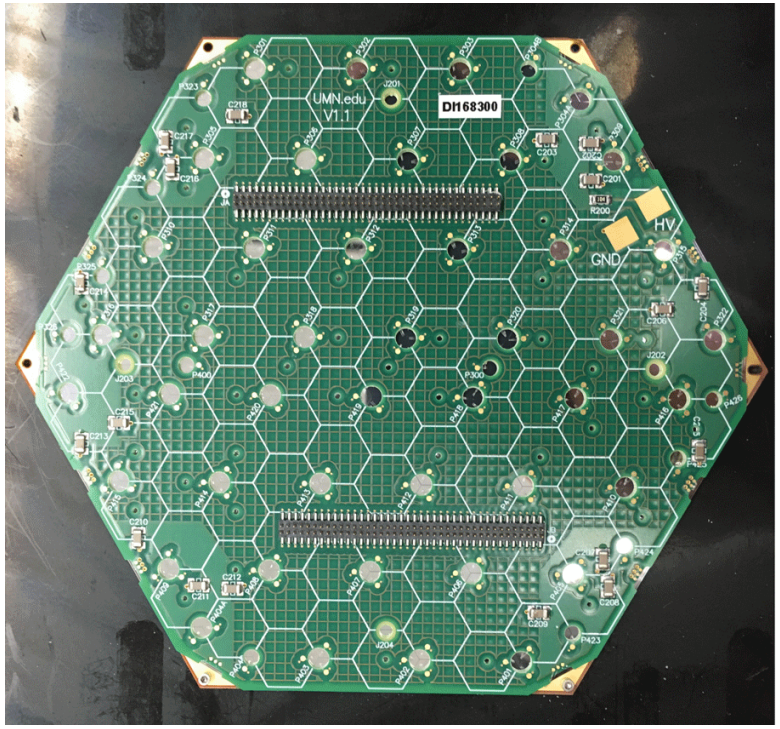
~25k 8-inch modules in total

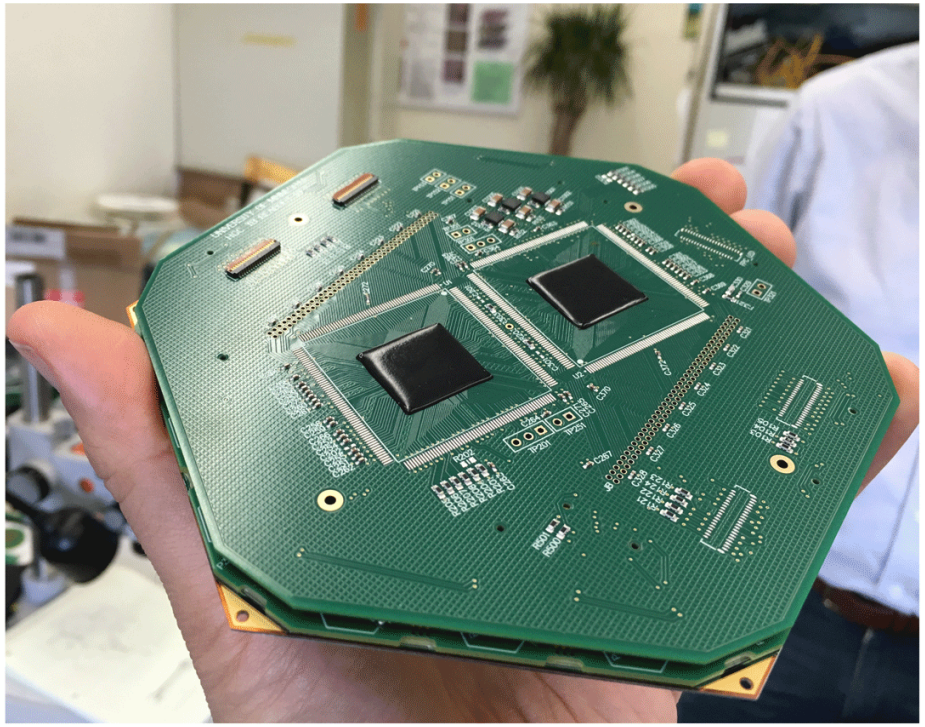
HGCAL beam tests: goals and activities

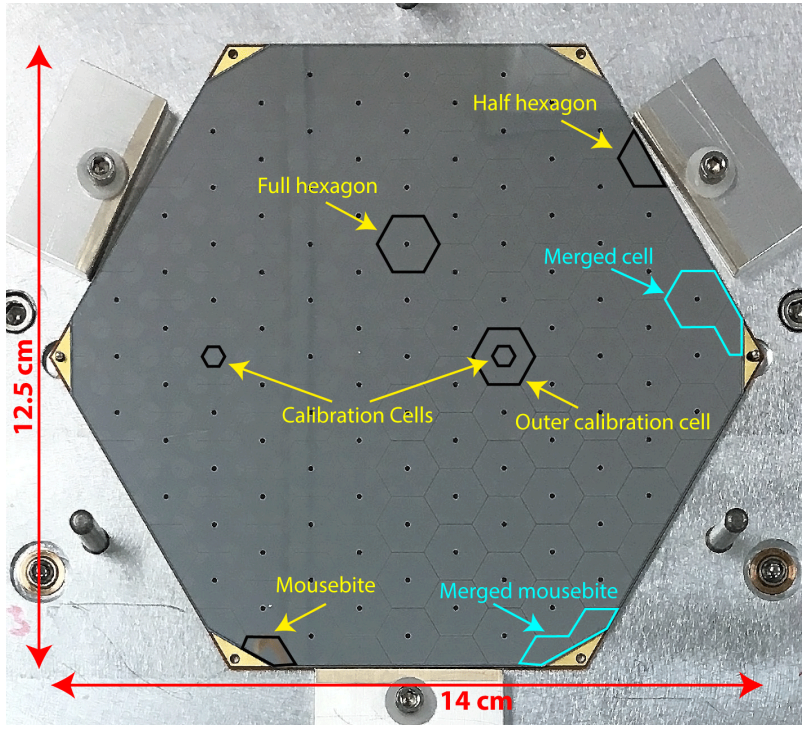
- Goals
  - To validate the HGCAL design and quantify the performance of the silicon-based calorimeter
  - To validate the Monte-Carlo simulation (Geant4)
- 2016 beam tests: results focused in this talk
  - Partially equipped prototypes tested at FNAL and CERN
  - Timing studies with irradiated diodes and modules at CERN
- 2017-2018 beam tests
  - Pilot tests for a few modules (< 20) at CERN and DESY
  - Full-scale prototypes at CERN

IHEP team joined all beam test activities since 2016.

Silicon prototypes in 2016

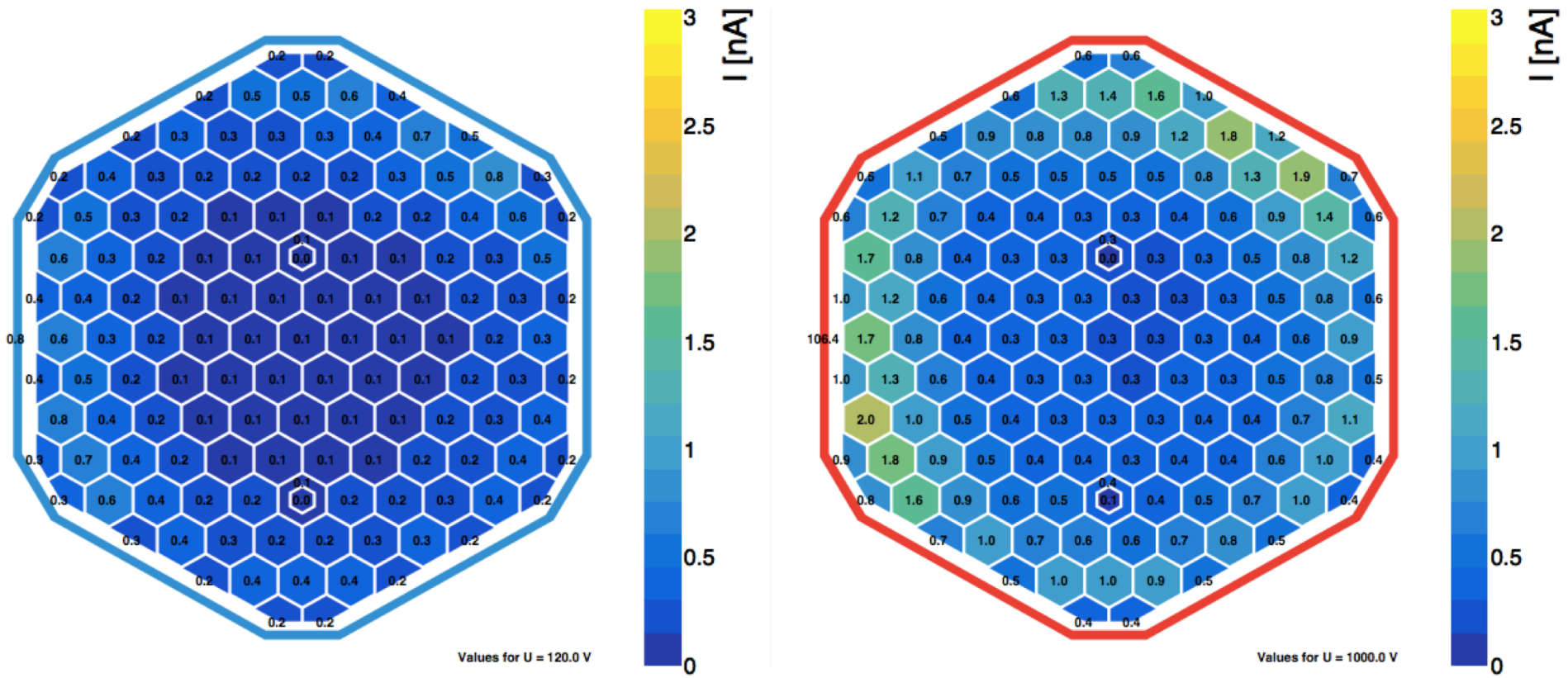






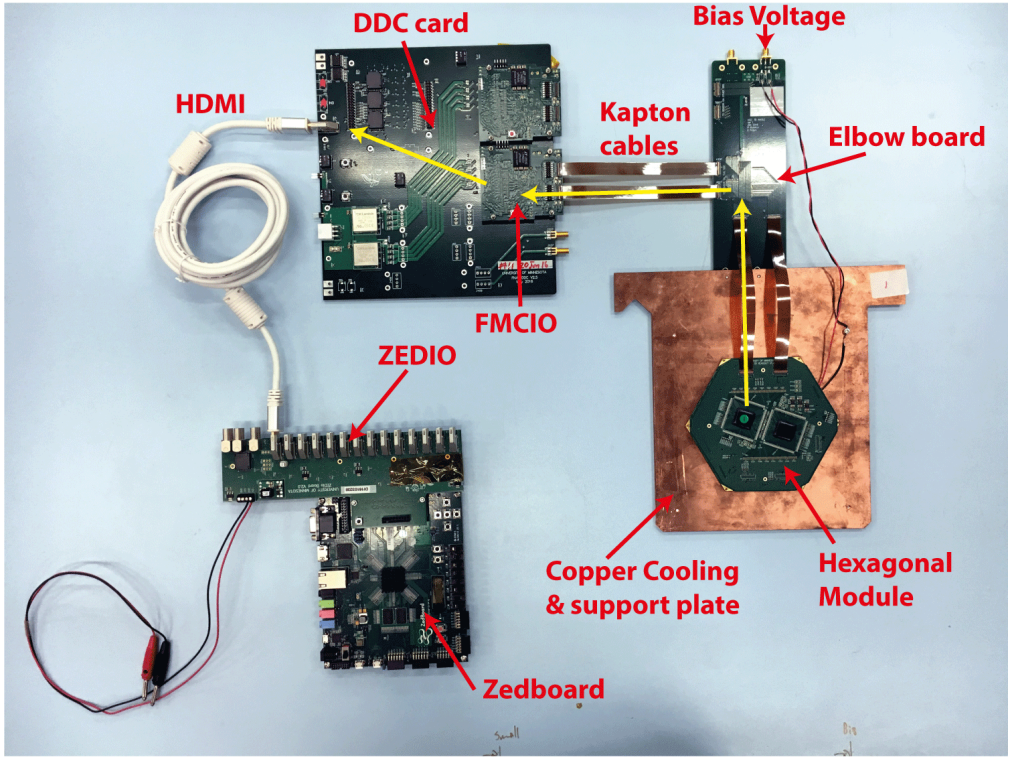
- Prototype modules
  - 6-inch sensor (from HPK)
  - PCB with wire-bonded readout chips (Omega SKIROC2_CMS)
    - 127 channels per module

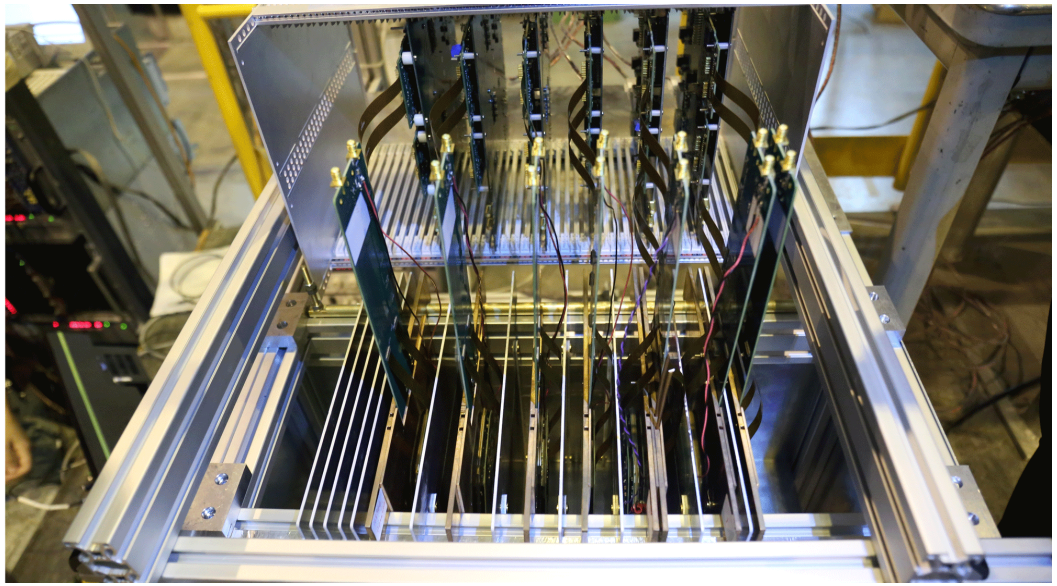
Sensor leakage currents



- Leakage currents
  - Total <120nA per sensor (<0.5nA per cell)
  - Increased by a factor of 3 from 120V to 1000V

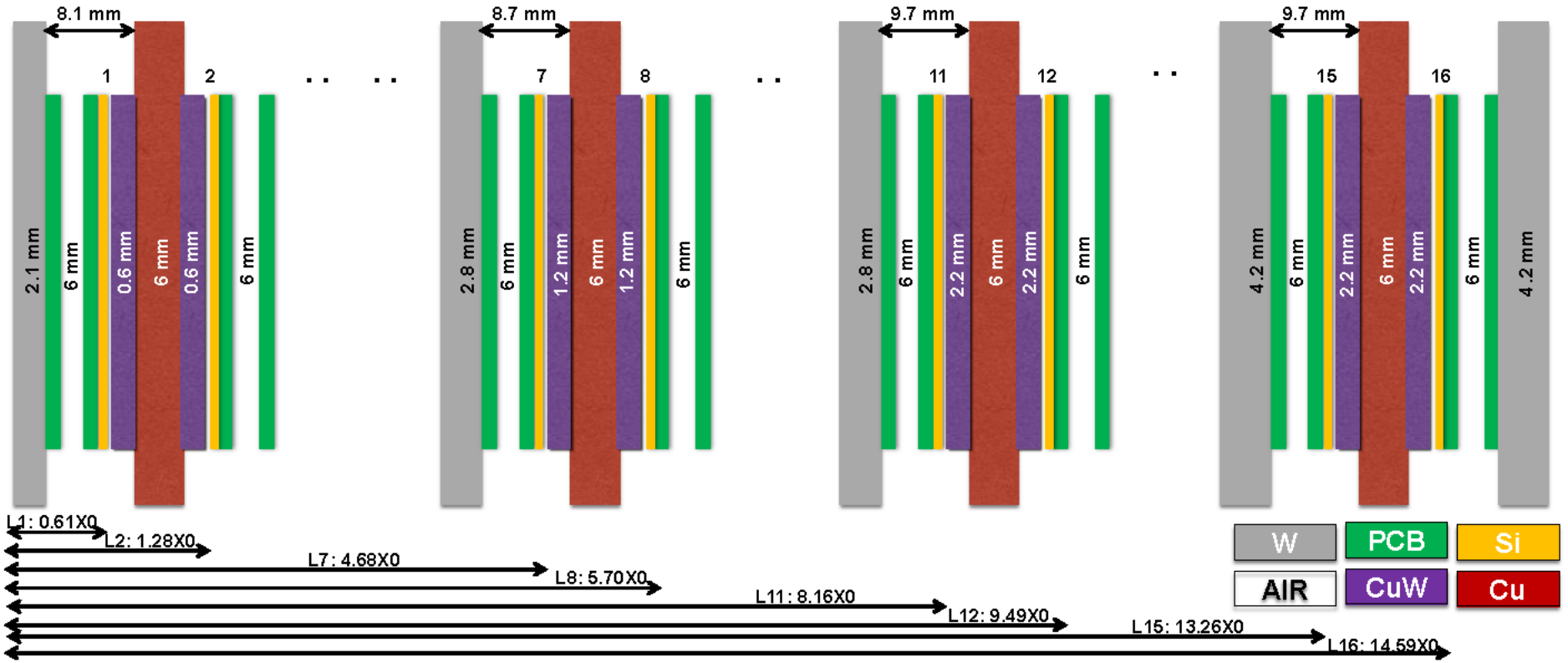
DAQ chain and mechanics





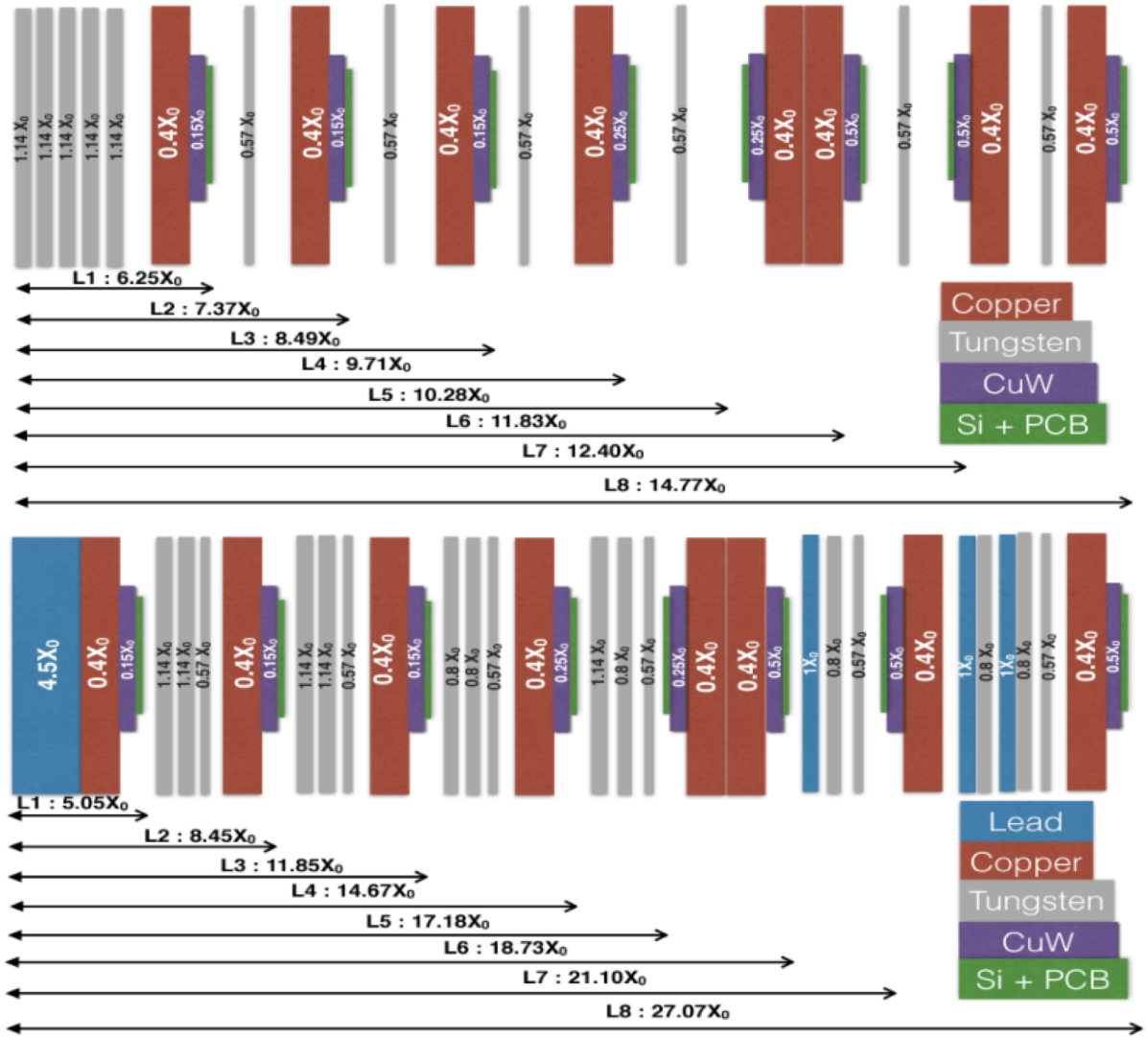
- DAQ based on ZedBoard: capable of handling 28 layers (CE-E)
- Mechanics: “hanging file” design
  - Convenient for insertion of absorber (W) and cooling (Cu) plates

Setup configuration at FNAL in 2016



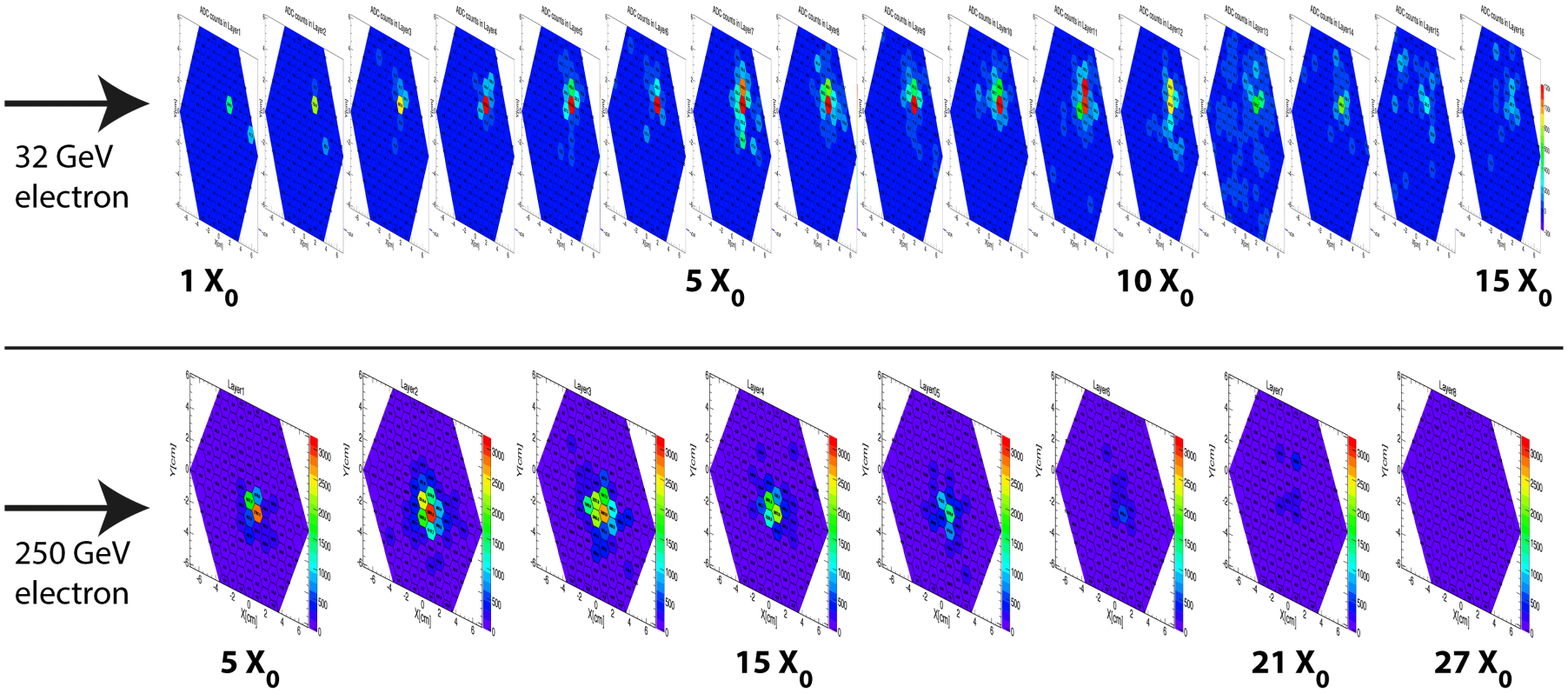
- 16 silicon modules available in total: each as a sensitive layer
- Total thickness (longitudinal) 15X0: up to 32GeV electron beam at FNAL

Setup configuration at CERN in 2016



- Only 8 modules available
- 2 configurations explored
- Setup I (upper)
  - Sensitive layers at 6~15X0
  - Measure the EM shower maximum
- Setup II (bottom)
  - Pb absorber + more W plates
  - 27X0 to contain high-energy electrons

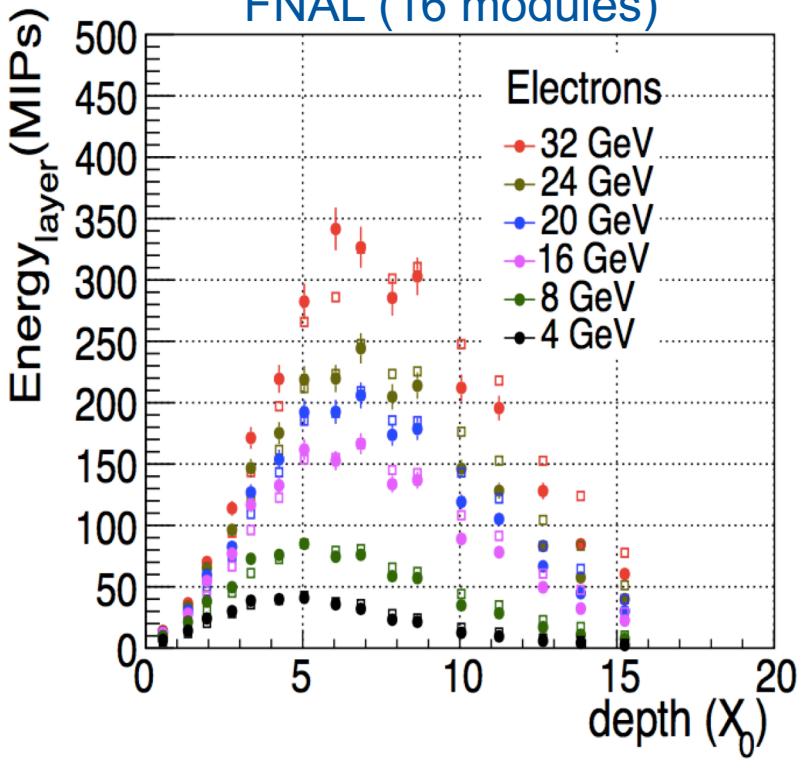
EM showers in HGCAL setups



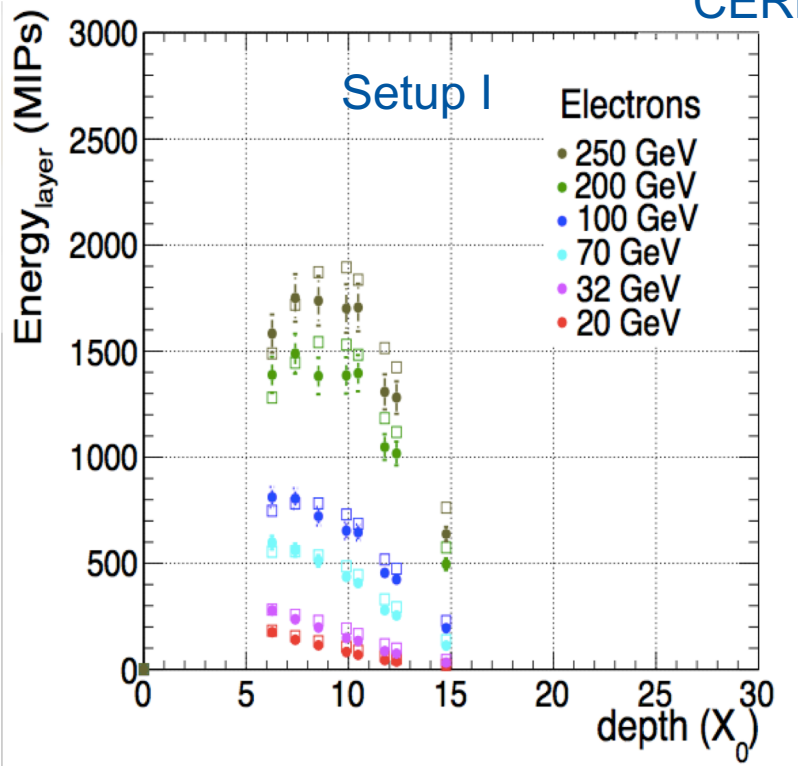
- Finer sampling for 32 GeV electrons at FNAL (16 modules)
- Full containment of 250 GeV electrons at CERN (8 modules)

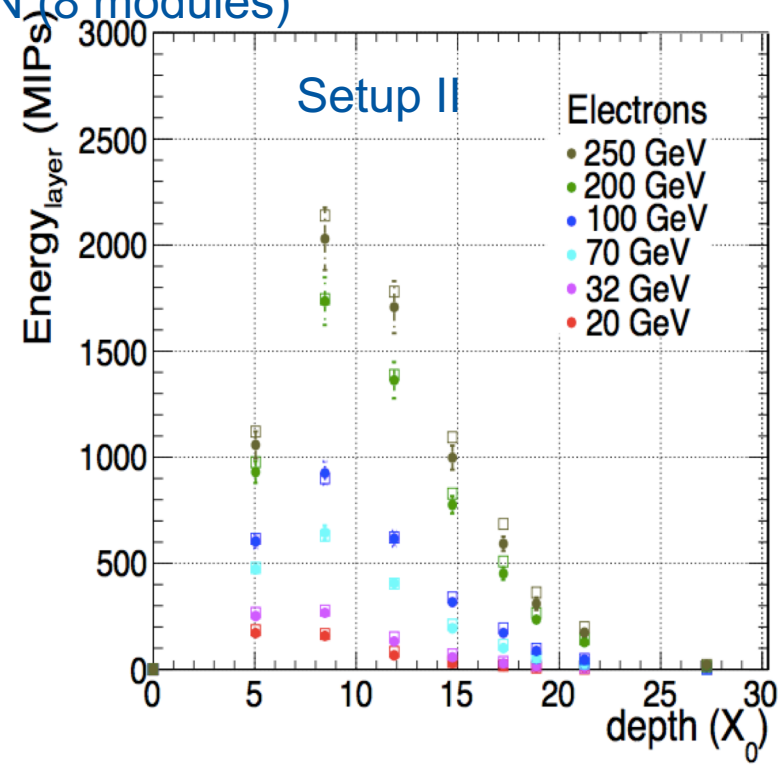
EM shower longitudinal profiles

FNAL (16 modules)



CERN (8 modules)

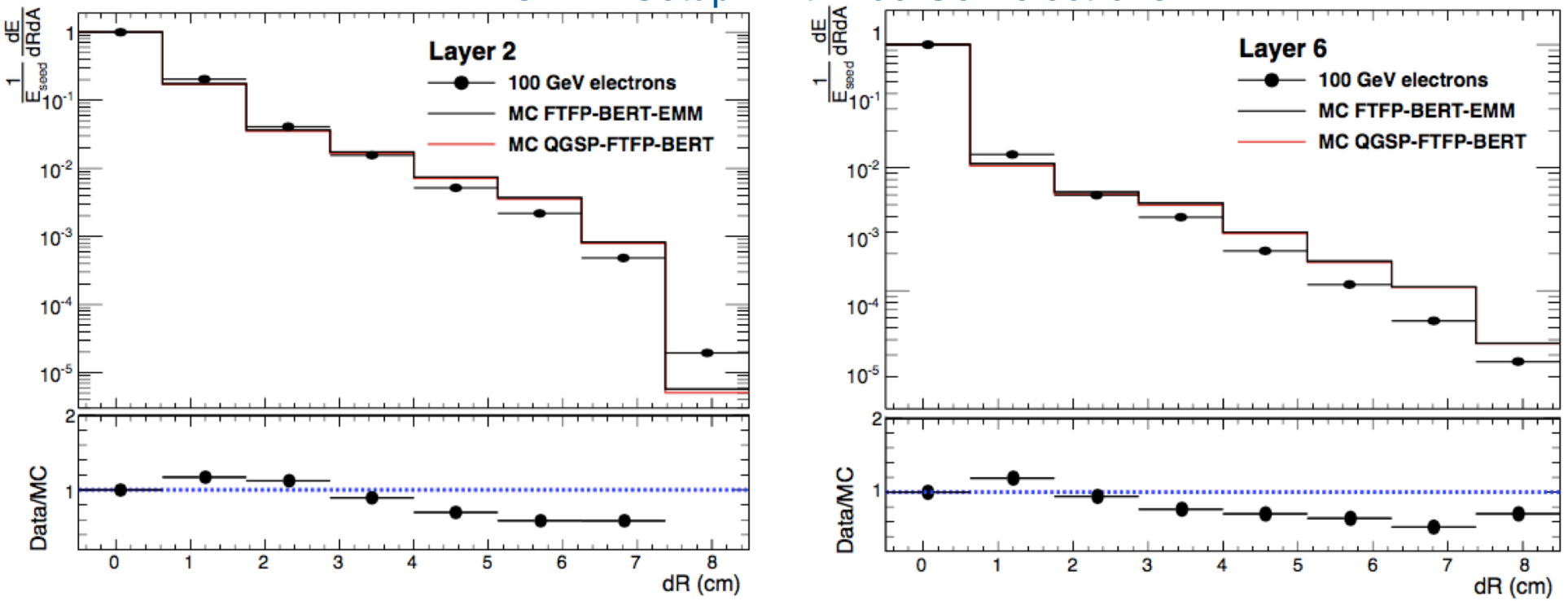




- Energy per layer in the MIP scale
- Agreement at the level <10% between data and simulation

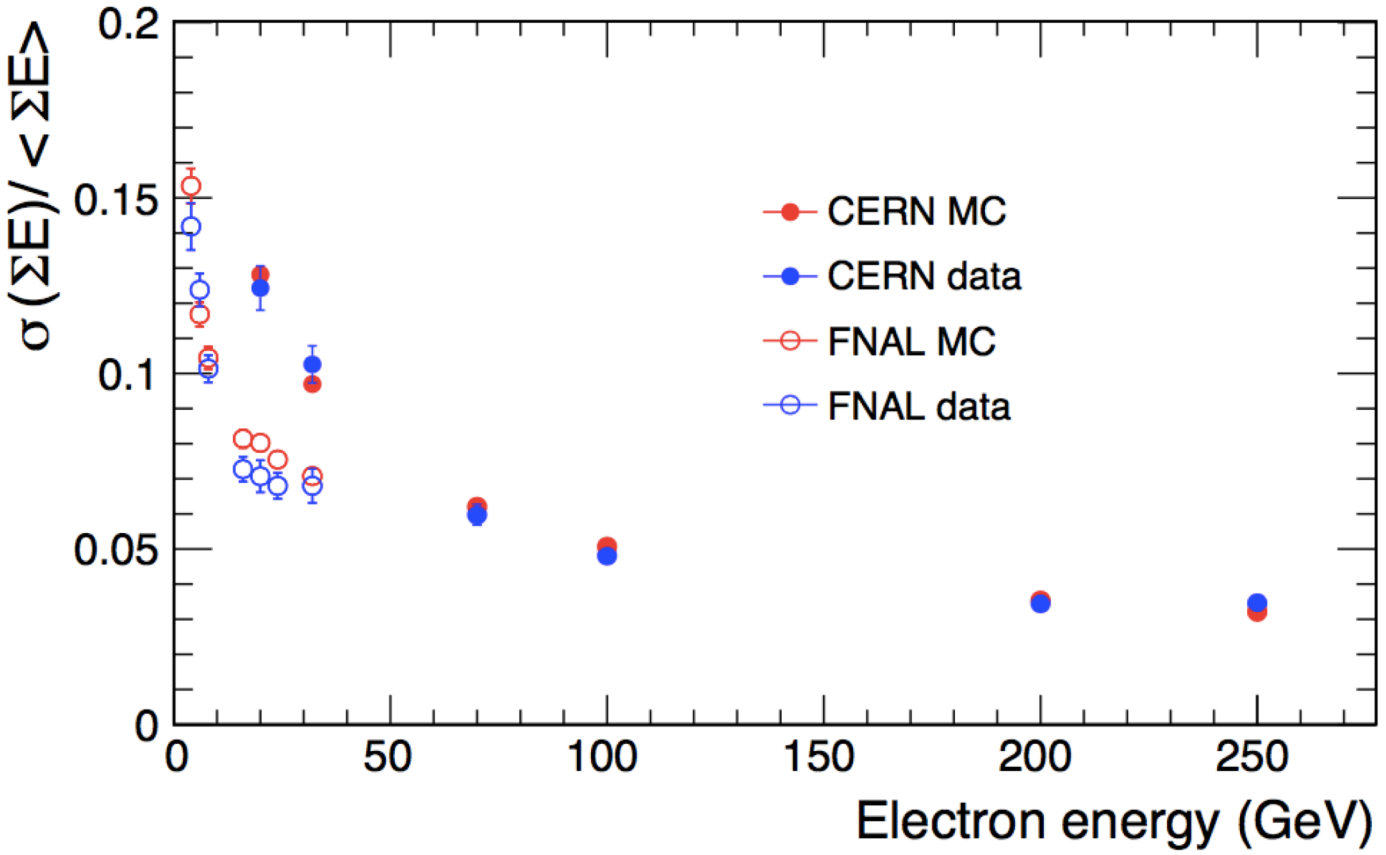
EM shower lateral profiles

CERN Setup I with 100 GeV electrons



- Energy density (energy per sensitive area) vs the radial distance from the shower seed cell
- Good agreement achieved between data and MC

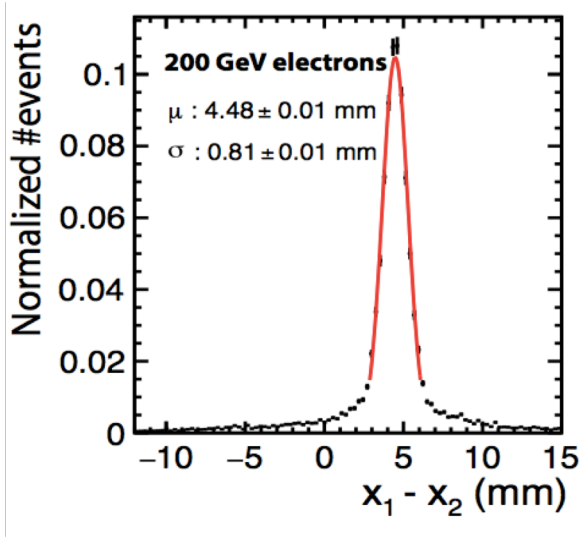
HGCAL prototypes: energy resolution

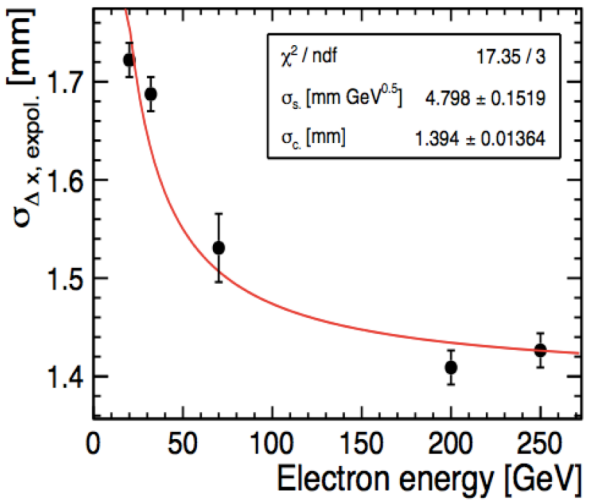


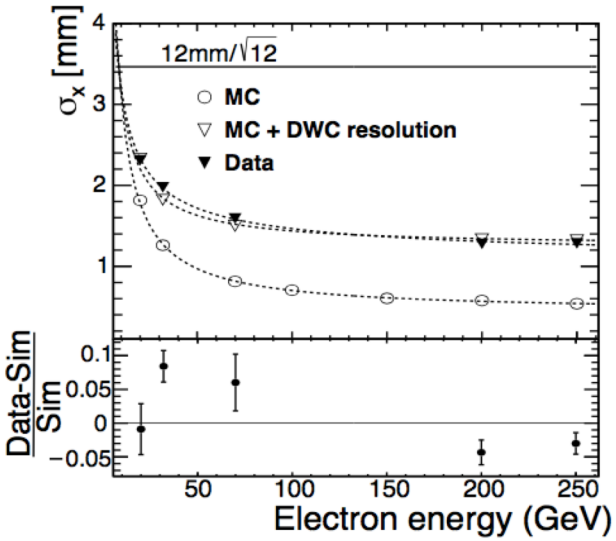
- Focus on the data/MC comparison for the partially instrumented prototypes: good agreement for all energies

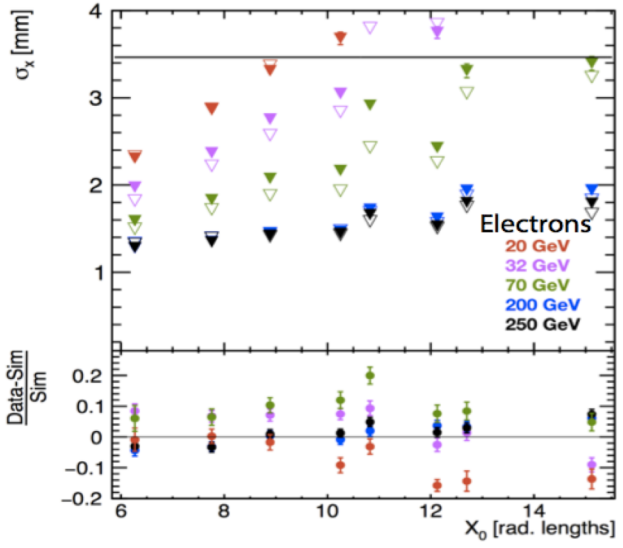
HGCAL prototypes: positioning precision

2 Delay-Wire Chambers at CERN SPS





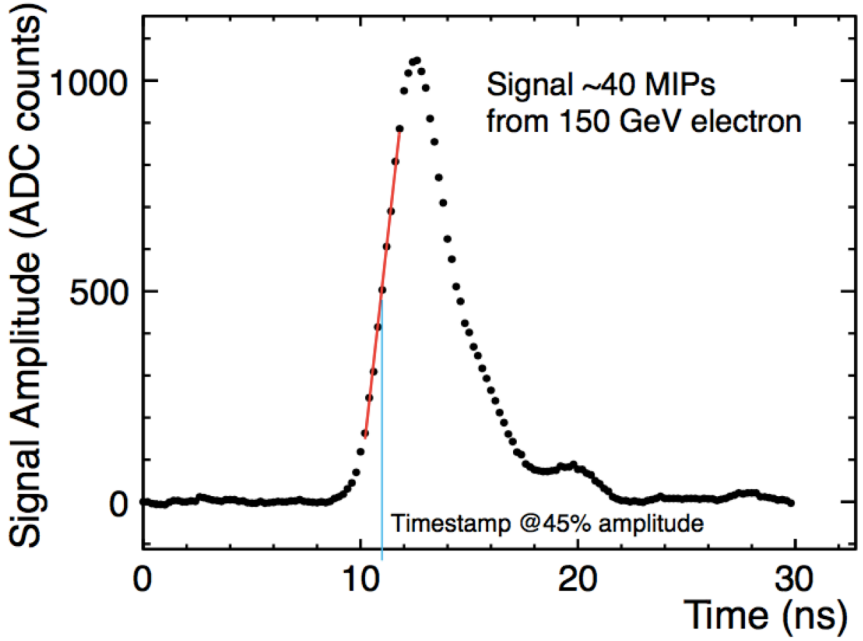




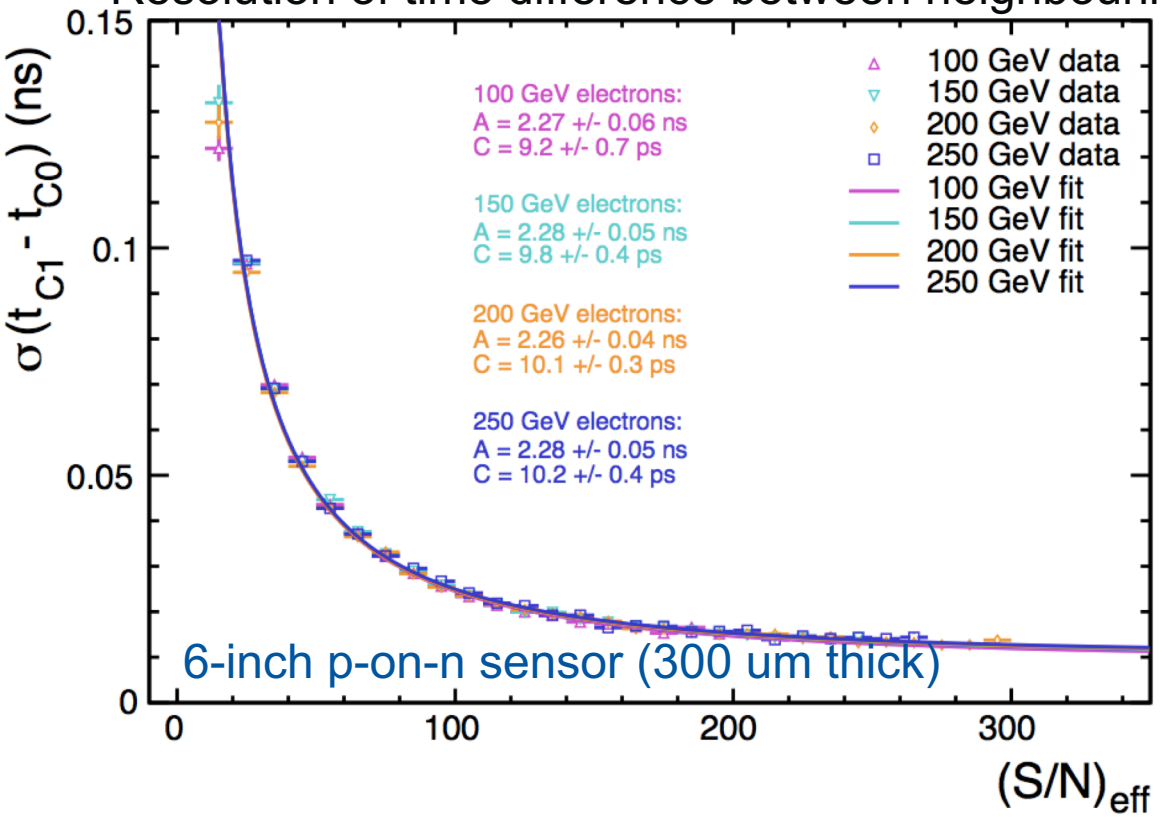
- Intrinsic resolution of HGCAL modules: < 1mm for electrons at around tens of GeV and above
- Fulfill the requirement to match charged tracks with Trackers (Particle-Flow paradigm)

HGCAL module: timing performance

Typical waveform in a cell with 150 GeV electron showers



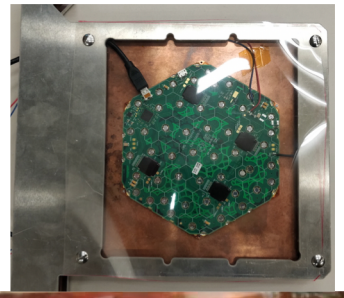
Resolution of time difference between neighbouring cells



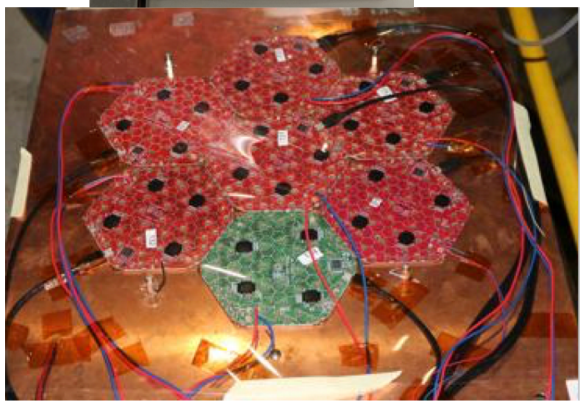
- Timing resolution <20ps achieved for signals with S/N>100

HGCAL fully instrumented prototype

CE-E(Si) layer



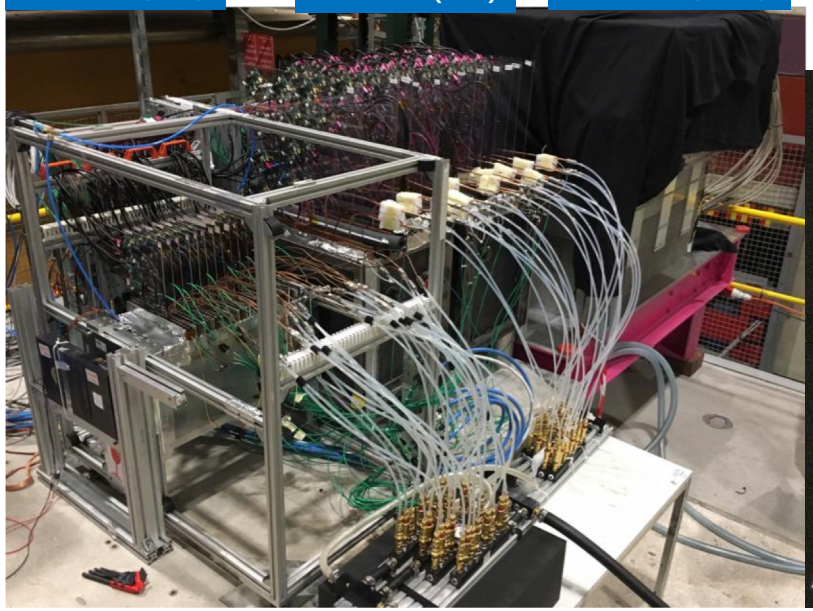
CE-H(Si) layer



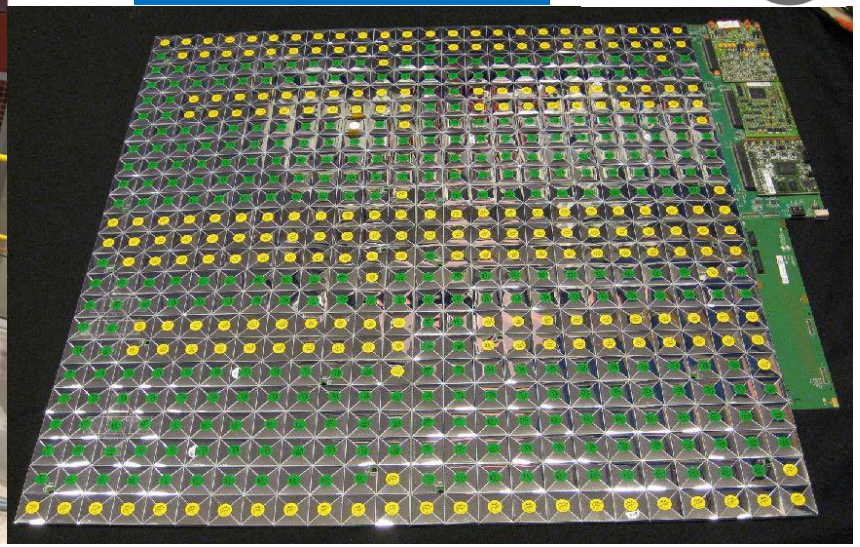
CE-E(Si)

CE-H(Si)

CE-H(Sc)

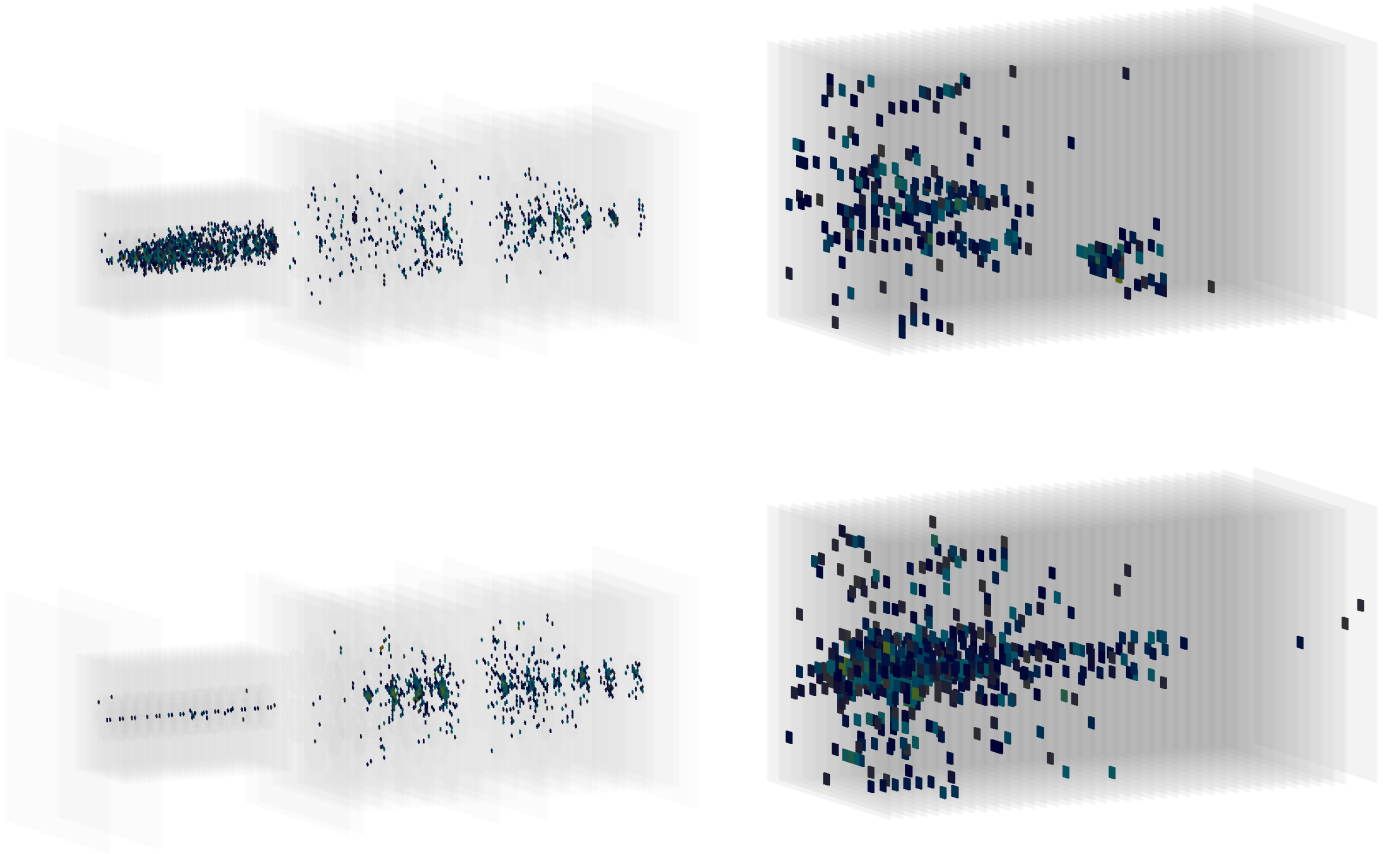


CE-H(Sc) layer



- 94 silicon modules (6”) in the ECAL and front HCAL section (up to 40 layers)
  - ~12k channels
- 156 “SiPM-on-Tile” modules (39 layers) in the HCAL back section
  - CALICE AHCAL technological prototype, ~22k channels
- CERN SPS H2: 2 weeks in Oct. 2018

Event display: 300 GeV pion showers



Ongoing studies on the analysis of EM and hadronic showers in the fully HGCAL prototype

Summary and outlook

- Successful development of HGCAL prototypes
  - Steadily evolving prototypes
- Extensive studies with data from beam tests done/ongoing
  - To validate design, quantify performance
  - To validate shower simulation models thus to improve our understandings of showers (esp. hadronic)
- CMS China groups on HGCAL
  - Ramping up
  - Focus on the silicon sensors/modules (and readout electronics)

15:10 tomorrow (Oct. 25) in the “Detector Upgrade” parallel session:
Progress report on the IHEP local lab for HGCAL sensors/module

Thank you!

Backup: references

- HGCAL Technical Design Report
  - CMS-TDR-019

- The results of HGCAL beam tests in 2016 are published:
  - N. Akchurin *et al* 2018 *JINST* **13** P10023

- "Beam-tests of prototype modules for the CMS High Granularity Calorimeter at CERN"
  - Talk by Arnaud Steen (NTU), PIXEL2018