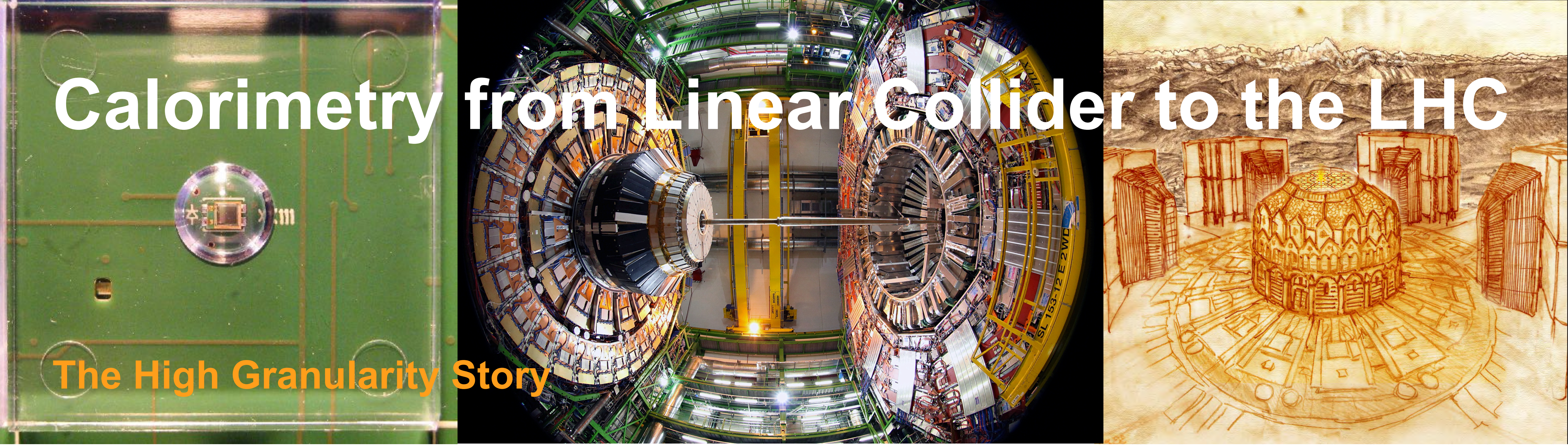


Calorimetry from Linear Collider to the LHC

The High Granularity Story

CLIC Workshop 2018

CERN, January 24, 2018

Felix Sefkow
DESY

Outline

This Talk.

High granularity for LC and LHC

- Particle Flow and pile-up

CALICE - technologies and validation

- State of the art and on-going work

The HGCAL upgrade of the CMS endcap calorimeter

- New challenges

Outlook

With a personal bias to SiPM-on-tile technology

Detector Requirements for LC and LHC

Accelerator environment.

Compared to LHC, LC radiation tolerance and bandwidth requirements are benign

Precision requirements are more demanding for LC:

- 2x for jet energies, 10x for track momenta, 5-10x for material budgets, 2x for strip and pixel dimensions

At LC, bunch train structure allows power cycled operation (~1%)

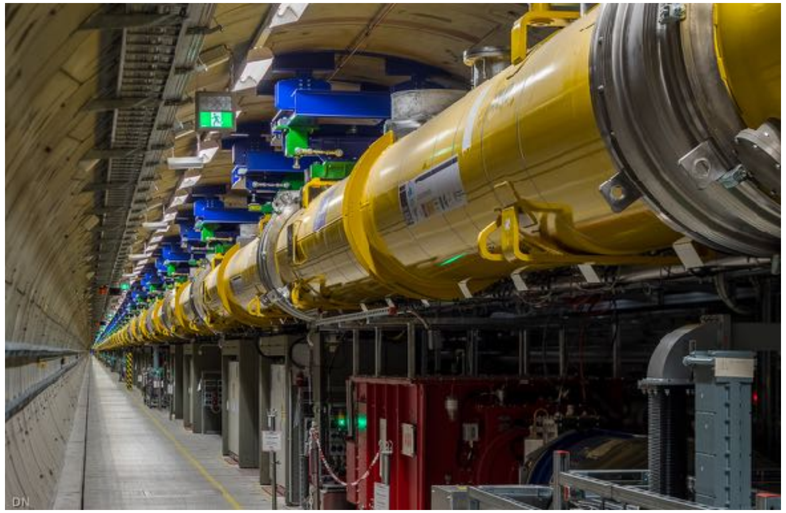
- simplifies powering and cooling: thinner trackers, denser calorimeters

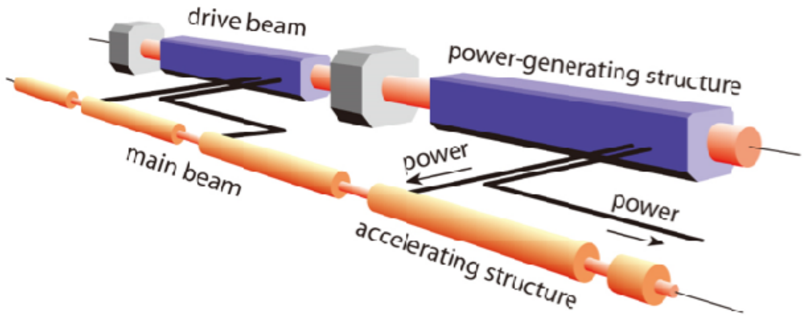
Backgrounds from beamstrahlung and hadronic 2-photon interactions

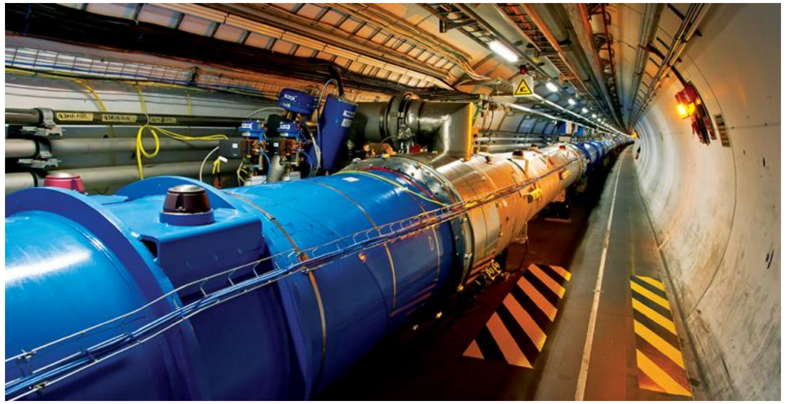
- more relevant for CLIC, higher E and smaller beam spot ($5x1nm^2$)
- somewhat higher emphasis on fine granularity and precise timing

Shifted focus and unwanted long time span led to development of new detector concepts up to TDR readiness level

- Imaging calorimeters
- Other examples: MAPS / ALICE ITS, ….







From LC…

Particle Flow Paradigm

Tackle the jet energy challenge.

In e+e- physics every event counts - exclusive reconstruction possible

- Heavy objects - multi-jet final states

W / Z mass splitting dictates required jet energy resolution of 3-4%

- Cannot be archived with classical calorimeters (e.g. ZEUS: 6%)

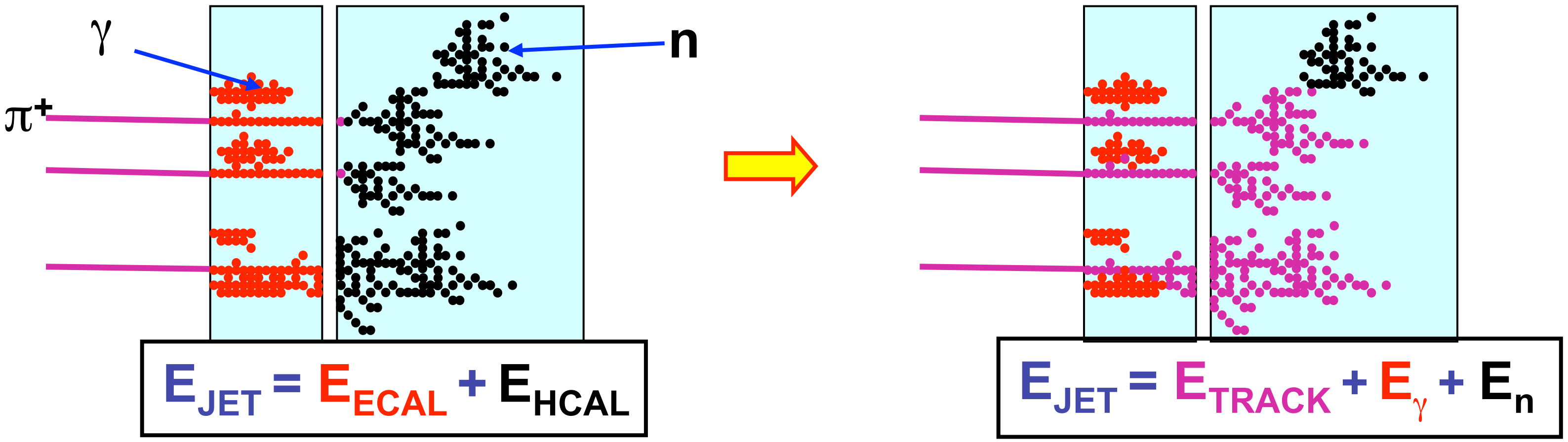
Reconstruct each particle individually and use optimal detector

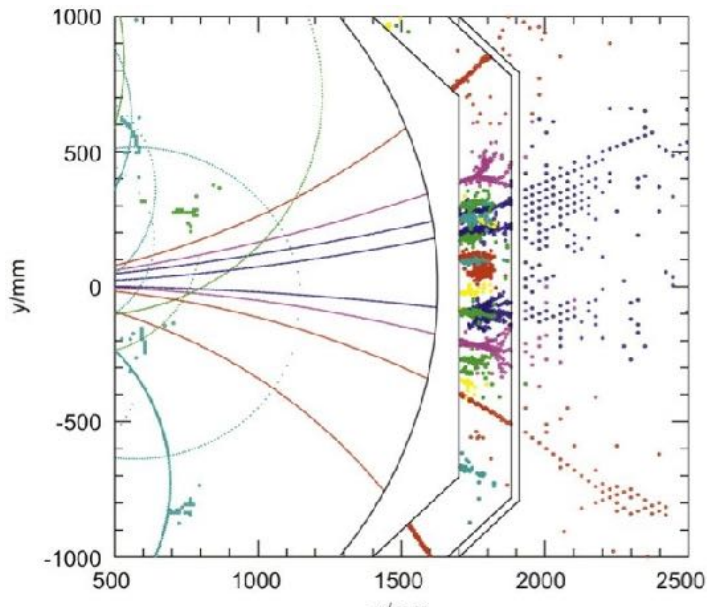
- 60% charged, 20% photons, 10% neutral hadrons

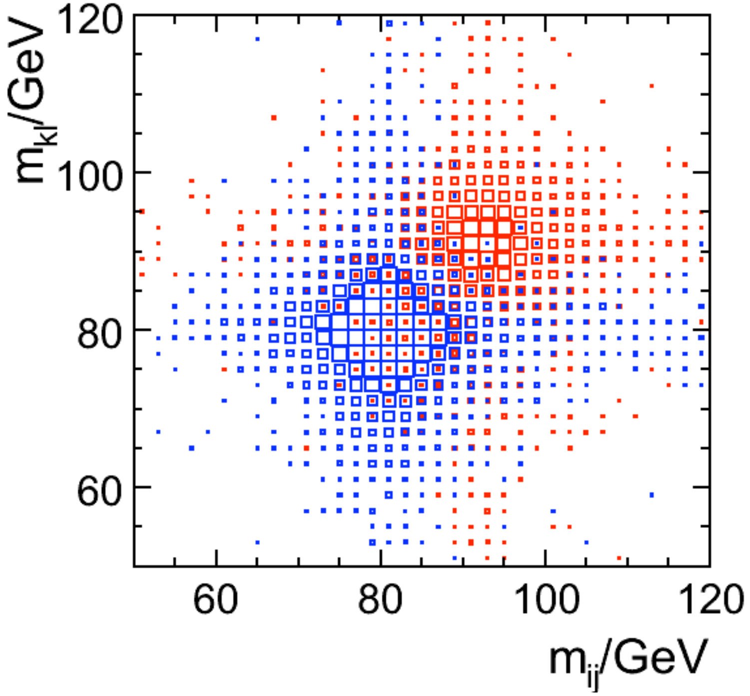
Requires fine 3D segmentation of and sophisticated software

- ECAL few 10 mm², HCAL 1-10 cm² - millions of channels

Today all linear collider detector concepts follow particle flow concept







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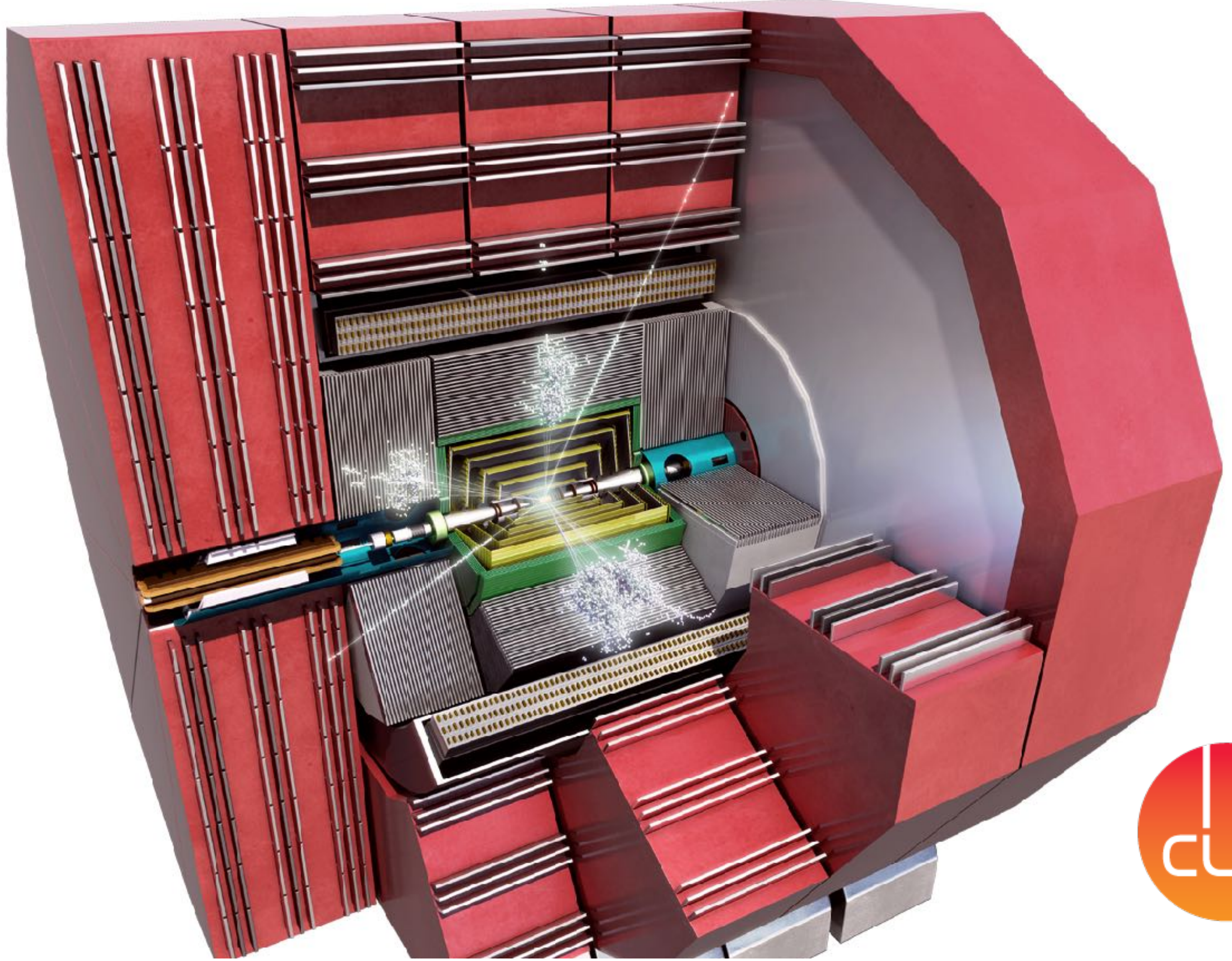
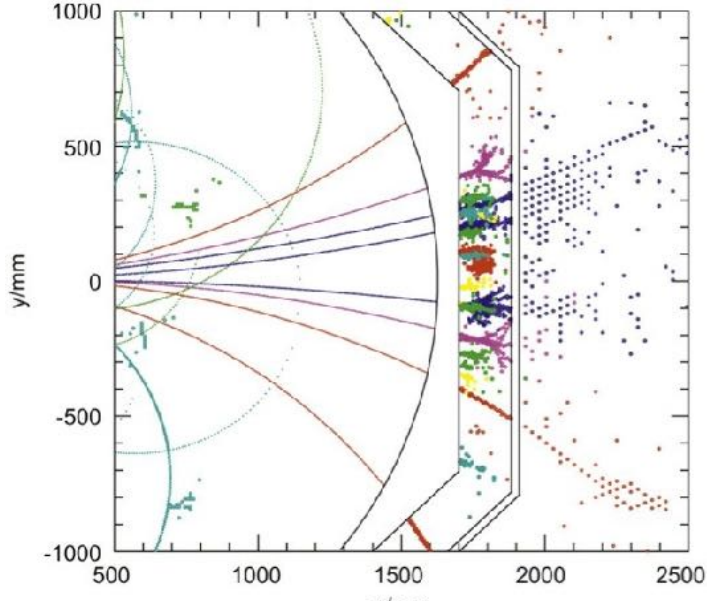
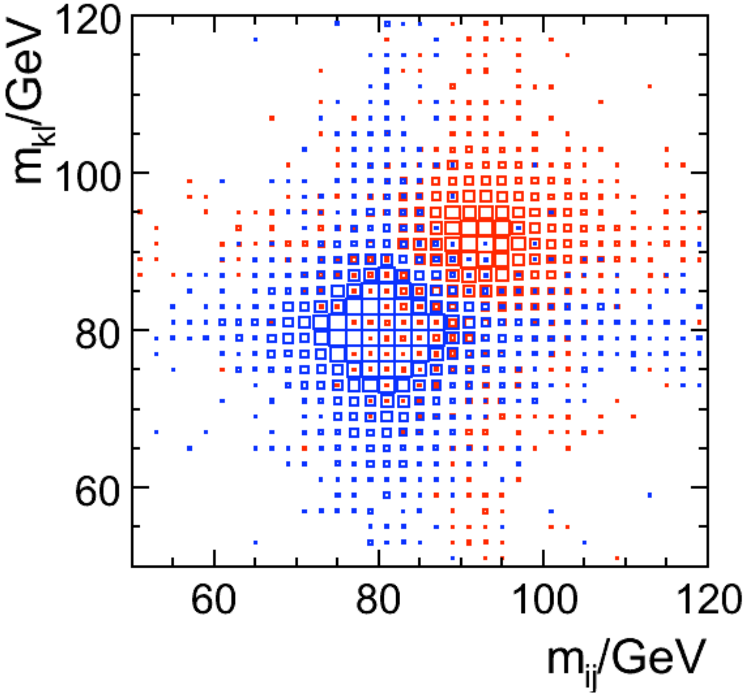






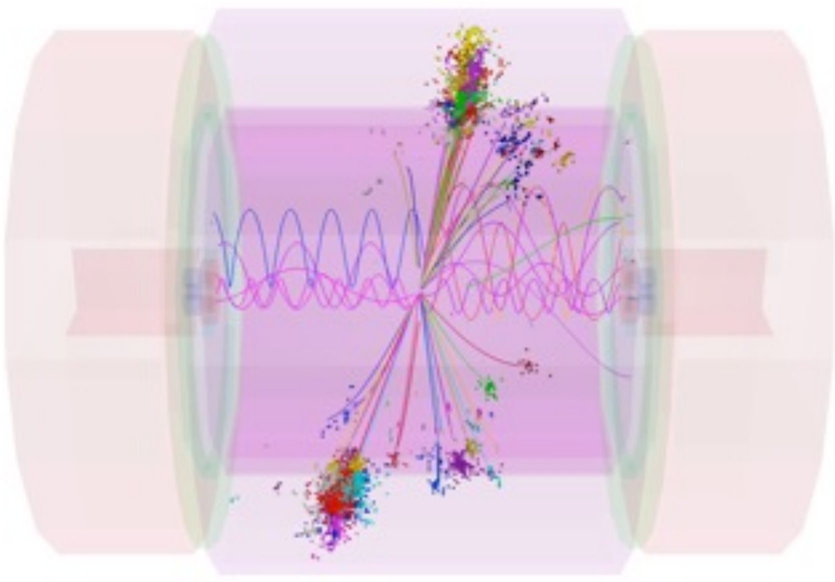
High Granularity and Pile-up

Particle flow with harsher backgrounds.

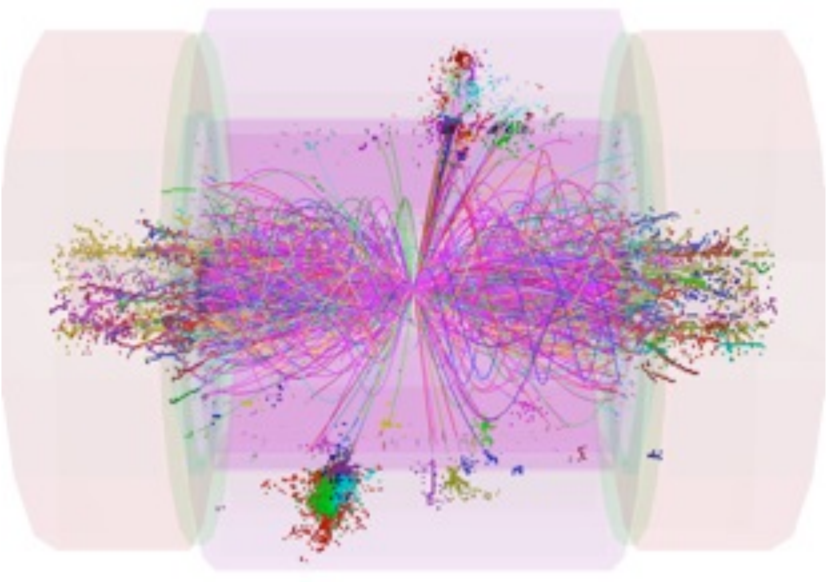
Studied intensively for CLIC: backgrounds from γγ → hadrons and short BX 0.5 ns

- Overlay γγ events from 60 BX, take sub-detector specific integration times, multi-hit capability and time-stamping accuracy into account
- Apply combination of topological, pt and timing cuts on cluster level (sub-ns accuracy)

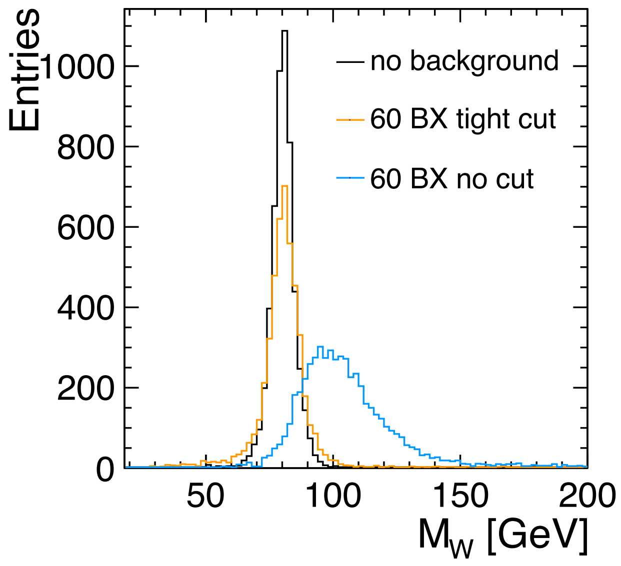
High granularity essential for pile-up rejection capabilities



Z @ 1 TeV



+ 1.4 TeV BG (reconstructed particles)



E_W = 500 GeV

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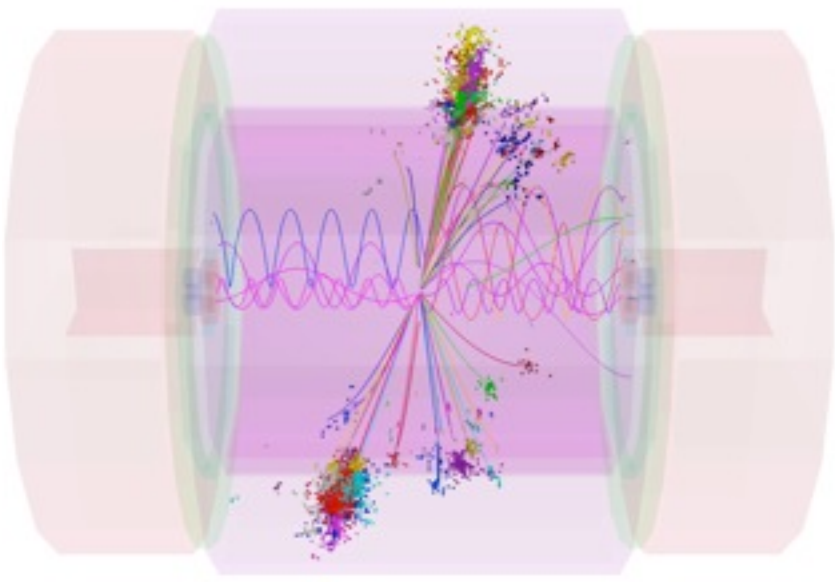

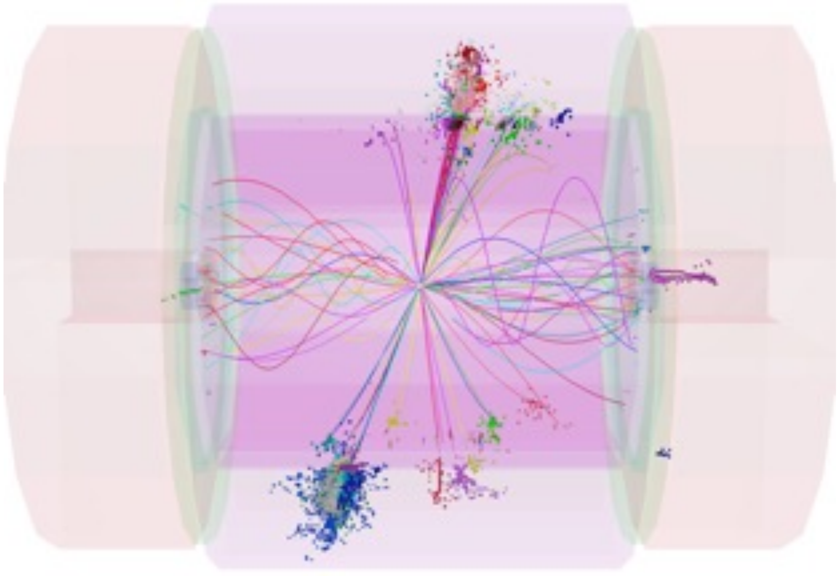

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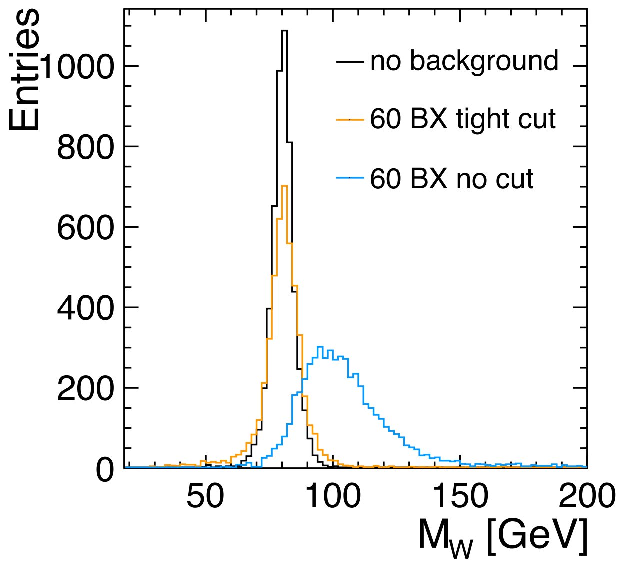


E_W = 500 GeV

Technologies for Highly Granular Calorimeters

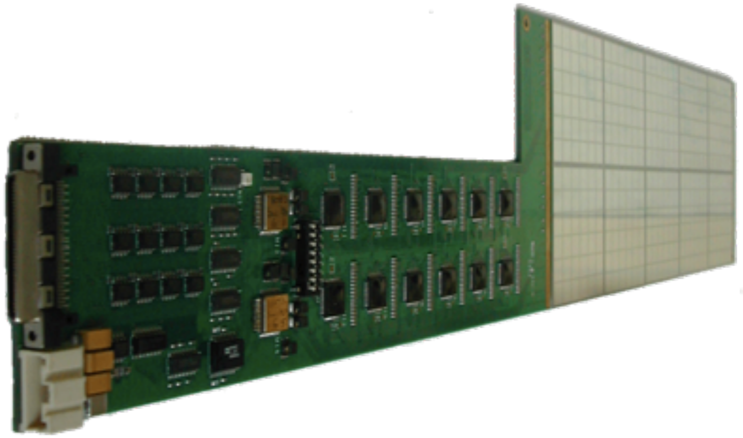
Because we can.

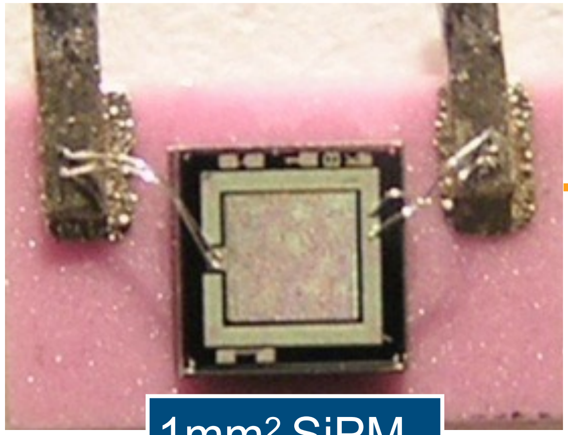
Large area silicon arrays

- silicon calorimetry grows out of the domain of small plug devices

New segmented gas amplification structures (RPC, GEM, µMs)

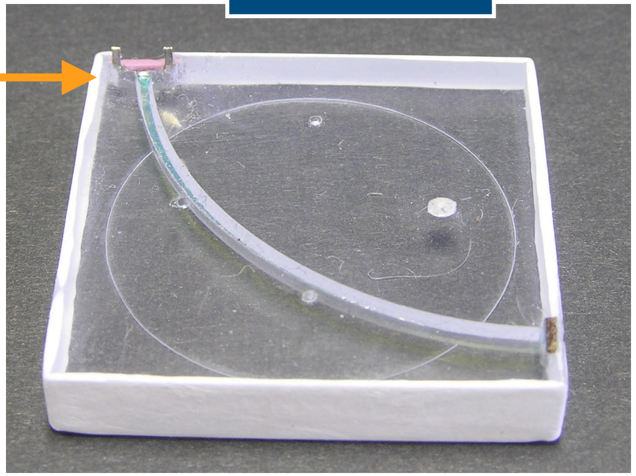
Silicon photomultipliers on scintillator tiles or strips





1mm² SiPM

2004



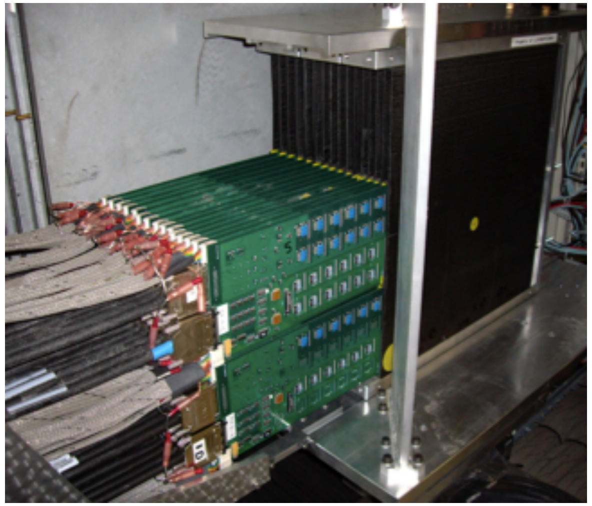
3x3cm² tile

small, B-insensitive, cheap, robust

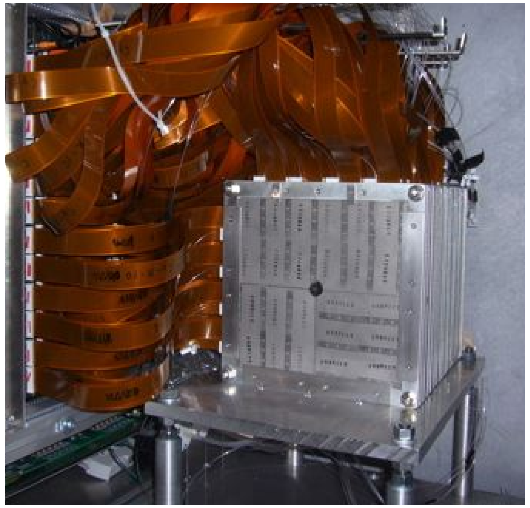
CALICE Test Beam Experiments

Large prototypes, complex systems.

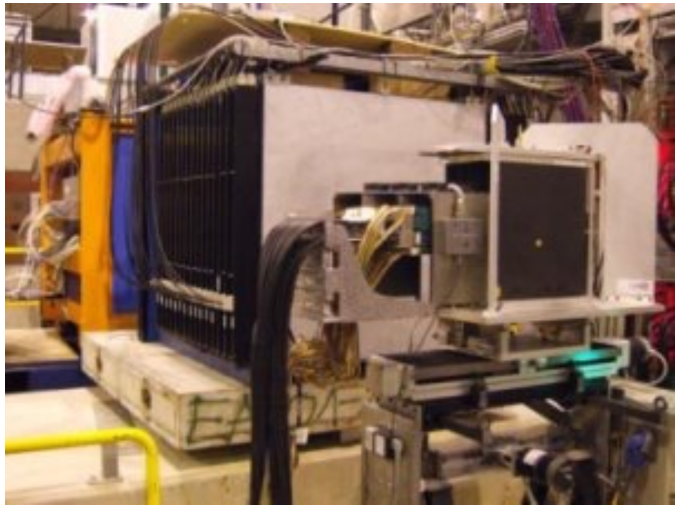
SiW ECAL



ScintW ECAL

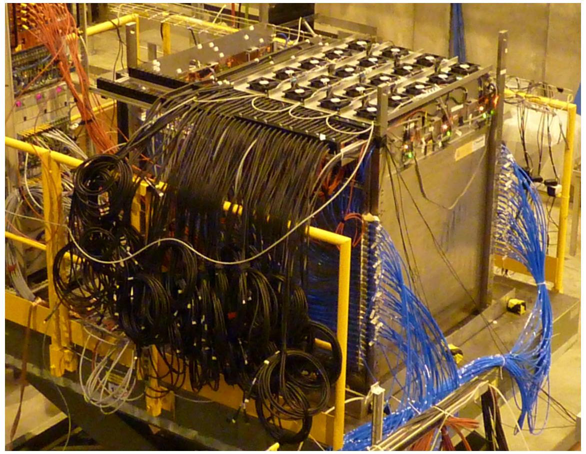


Scint AHCAL, Fe & W



RPC DHCAL, Fe & W

RPC SDHCAL, Fe



plus tests with small numbers of layers:

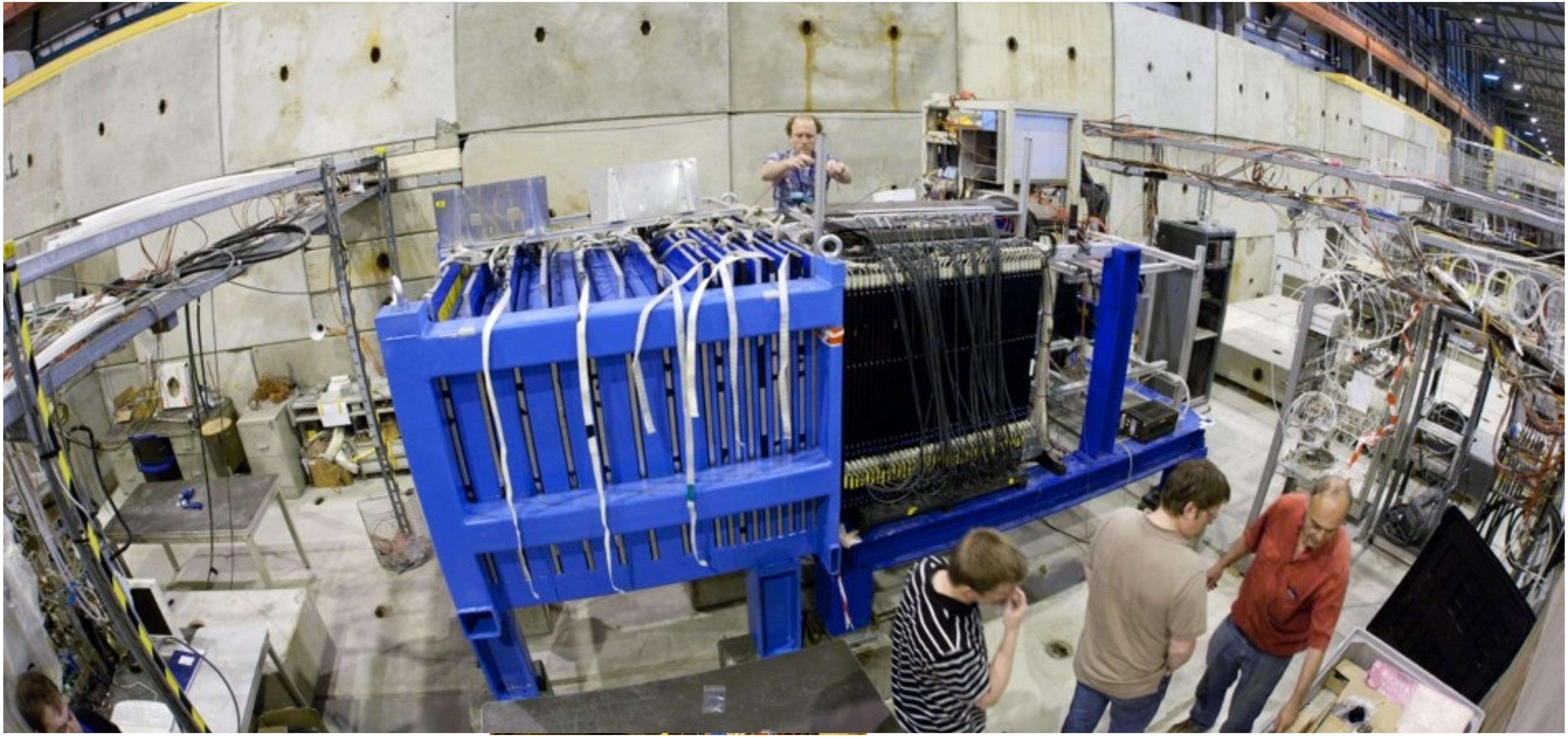
- ECAL, AHCAL with integrated electronics

- Micromegas and GEMs

CALICE

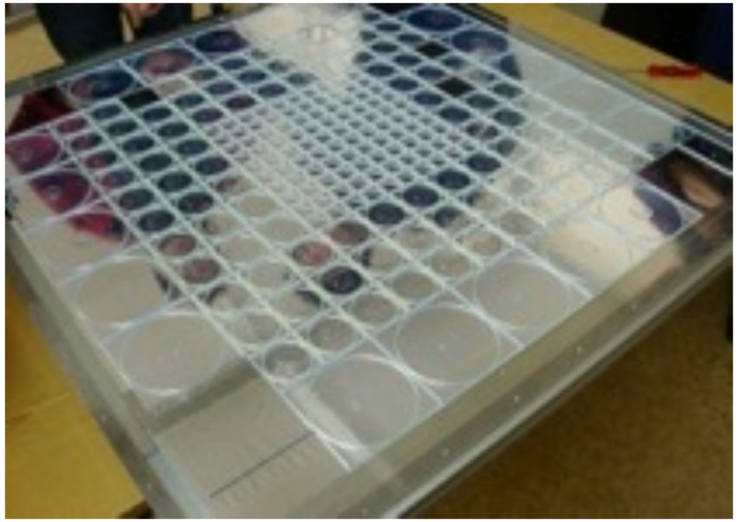
CALICE Test Beam Experiments

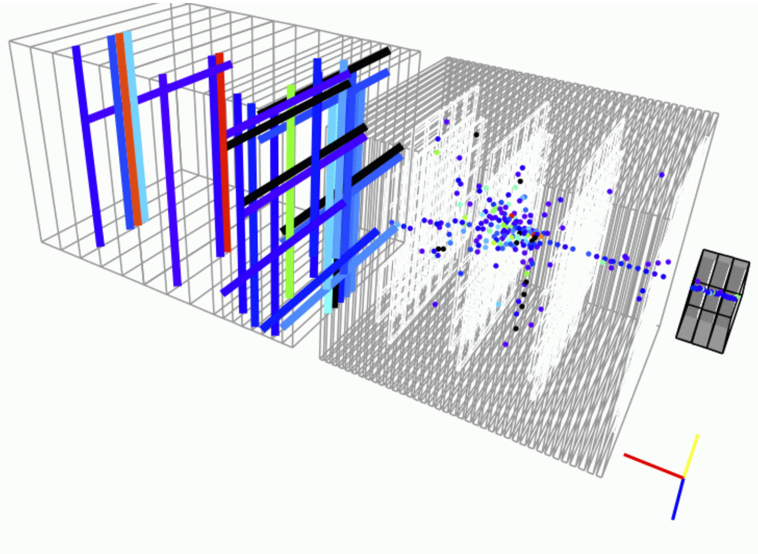
Large prototypes, complex systems.

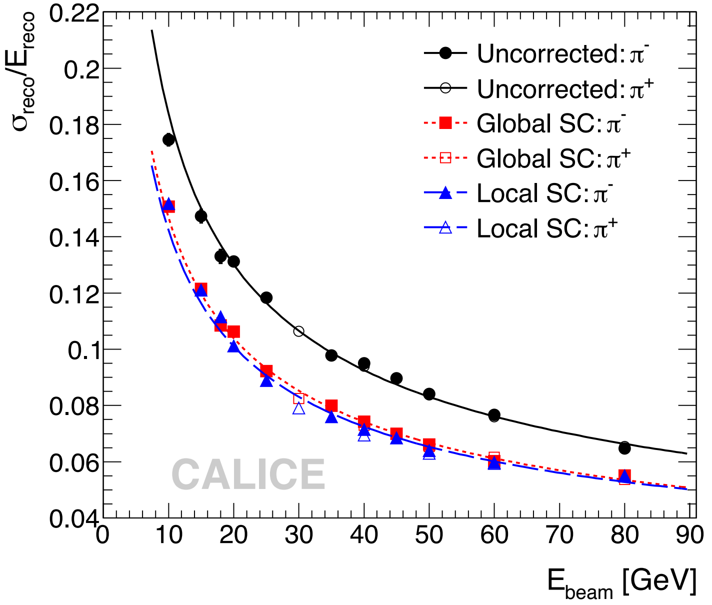


Proof-of-Principle

Validation of performances, simulations and algorithms.







- 38 layers, 7608 channels - first large-scale application of SiPMs
  - 6 years of data taking at DESY, CERN, Fermilab
- 12 journal papers (from SiPM-on-tile phototype alone)
  - resolution for electrons and hadrons, shower shapes and shower separation, different particle types and absorber materials,…
- All CALICE results
  - https://twiki.cern.ch/twiki/bin/view/CALICE/CalicePapers

$\sigma/E = 45.1\%/\sqrt{E} \oplus 1.7\% \oplus 0.18/E$

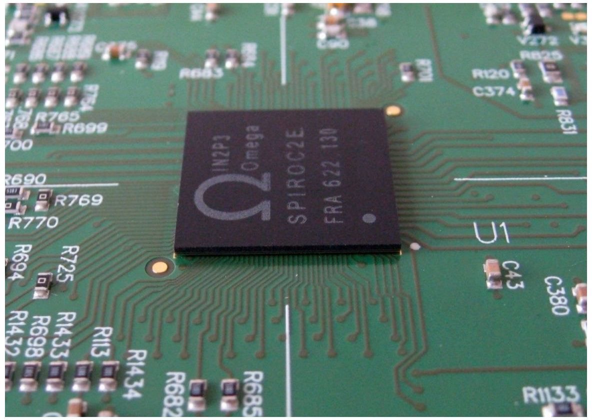
software compensation
now implemented in Particle Flow

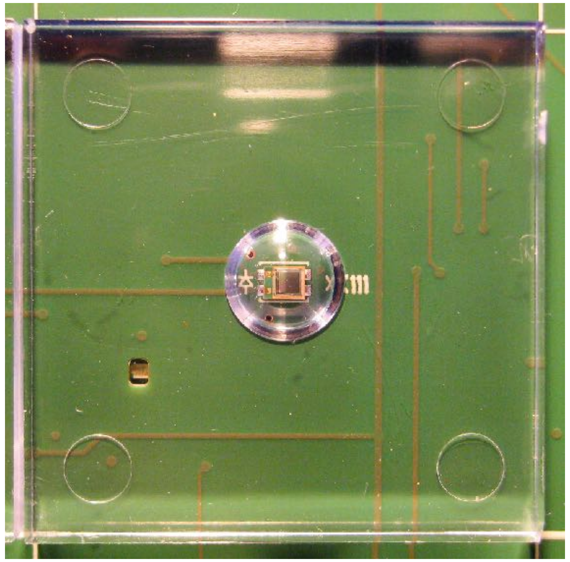
Eur. Phys. J. C77 (2017) 698

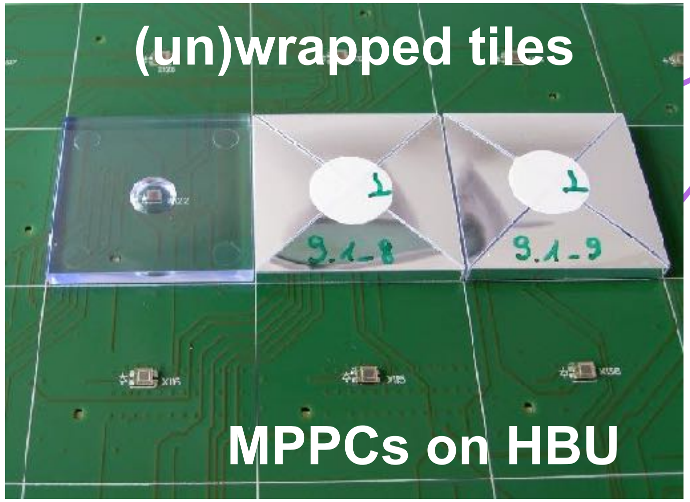
Rev.Mod.Phys. 88 (2016) 015003

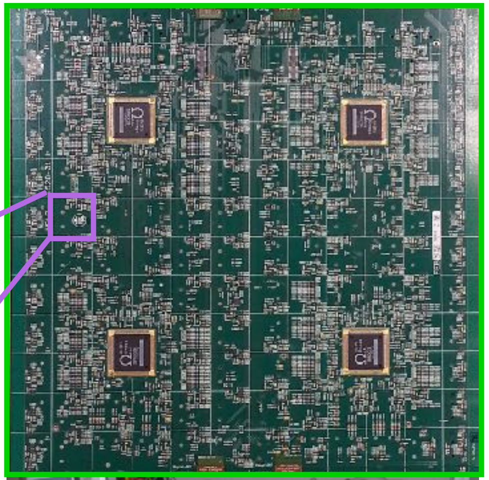
The Next Step: Scalability

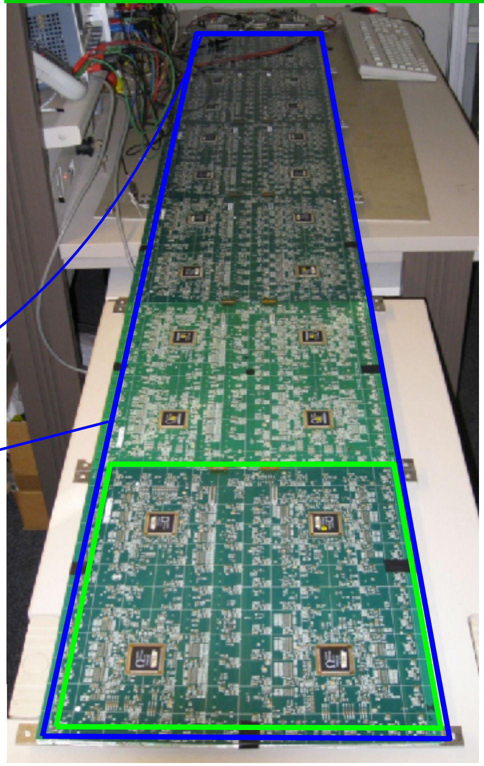
Technological prototypes.

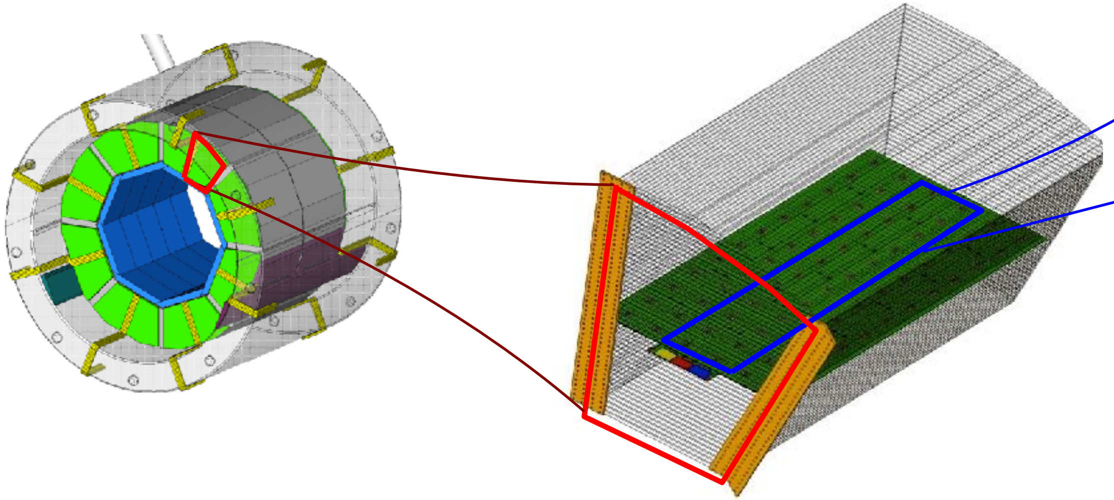








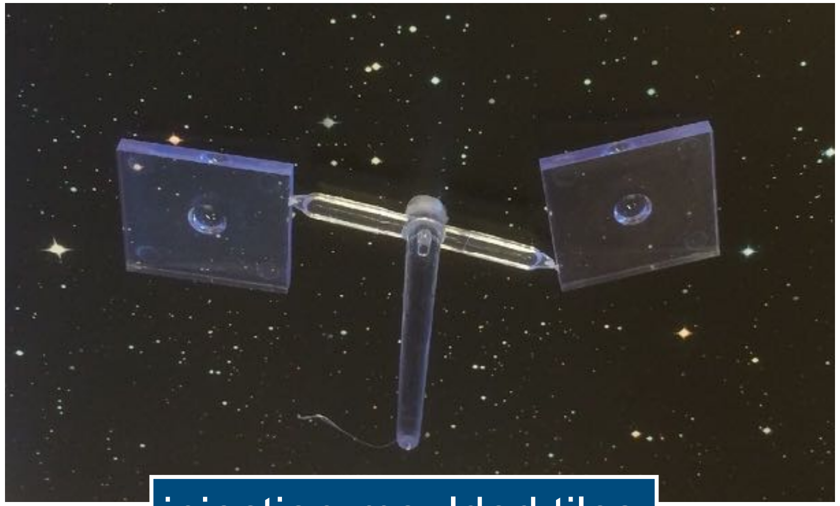




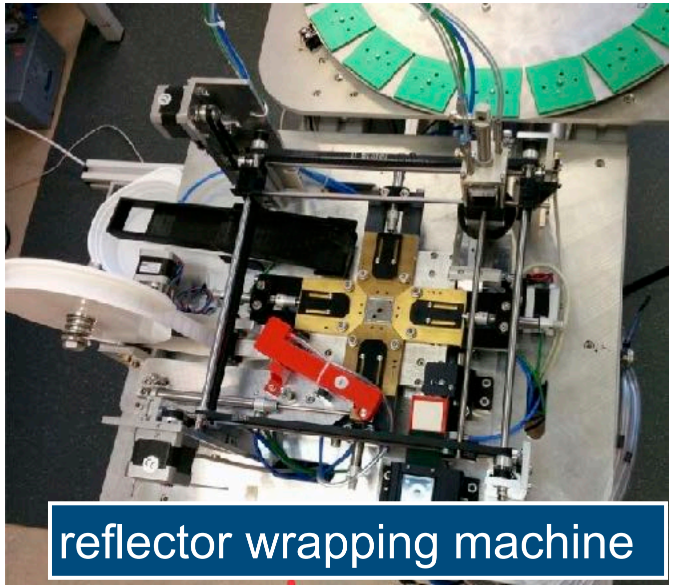
- 1000’s of channels per m^2
- 1000’s of m^2
- must embed electronics and go digital as early as possible
- Integrate SiPMs in read-out board, too

Automated Production and Quality Assurance

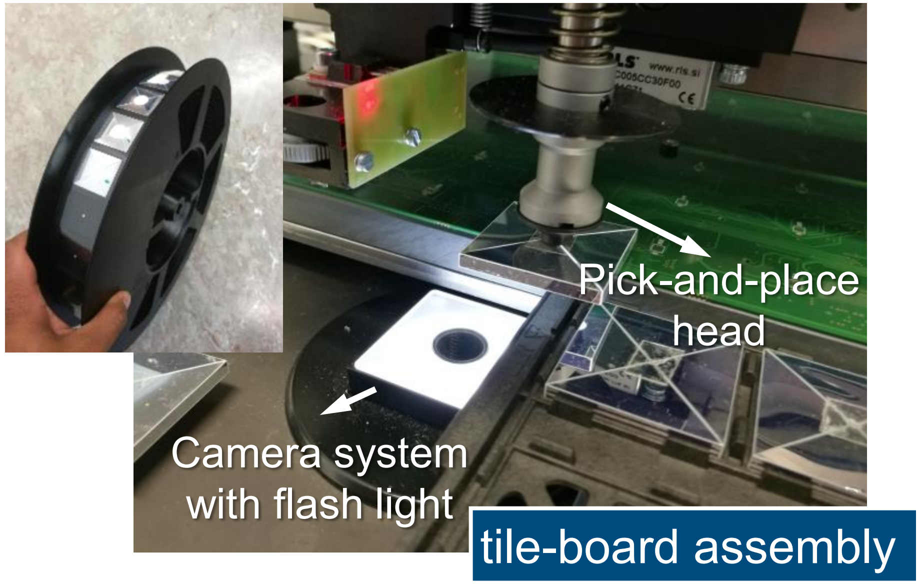
Establishing the concept.



injection-moulded tiles



reflector wrapping machine



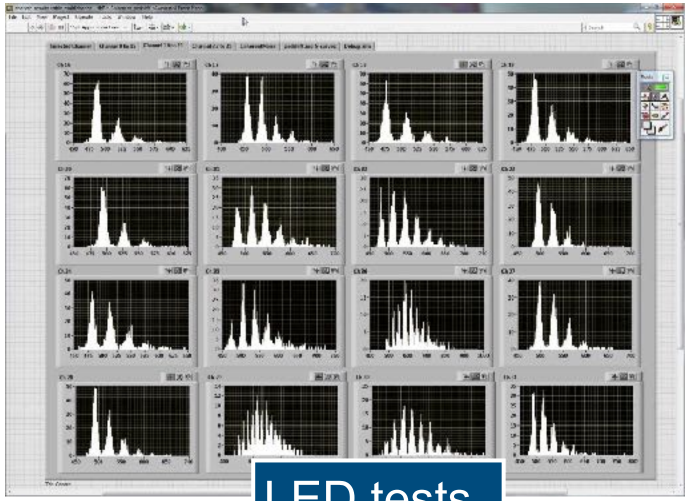
tile-board assembly

In addition test infrastructures:

- Multi-channel SiPM tests
- Automated ASIC tests
- PCB tests using LEDs
- Coscmic tests after tile assembly

AIDA2020

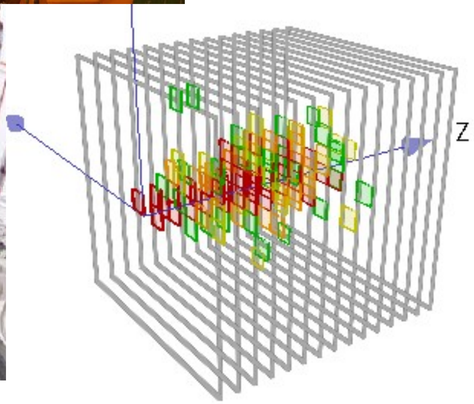
read-out boards

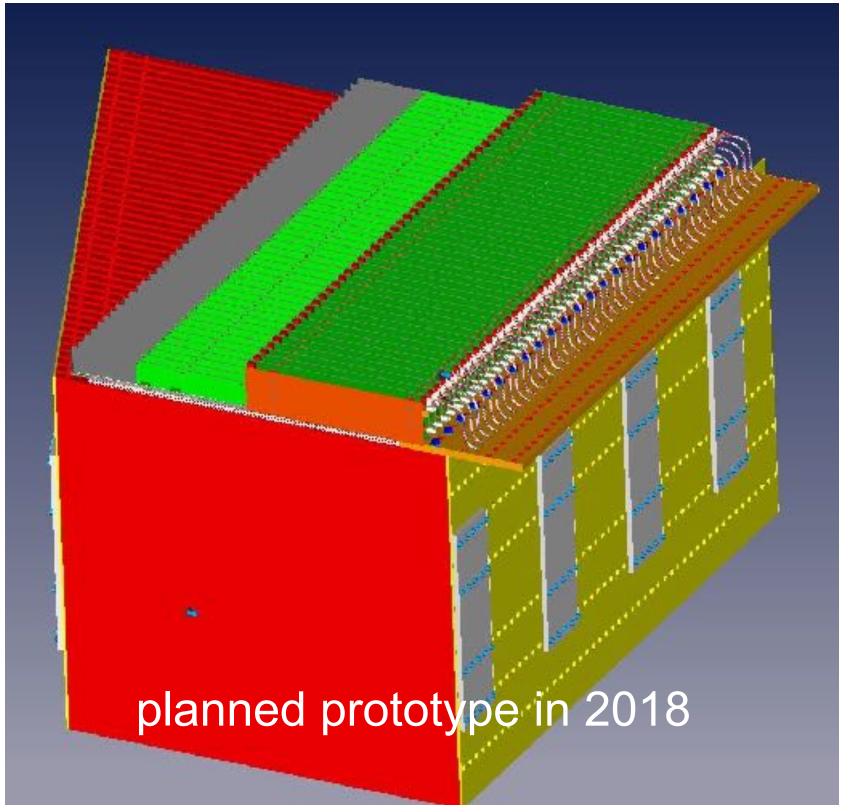


LED tests

New Prototypes

`New beam tests





Small stacks tested with electrons

- B field compatibility
- Active temperature compensation

Big HCAL prototype under construction for beam in May + June

- 40 layers, 160 boards, 640 ASICs, 23’000 SiPMs
- Running at full speed - readiness review in April

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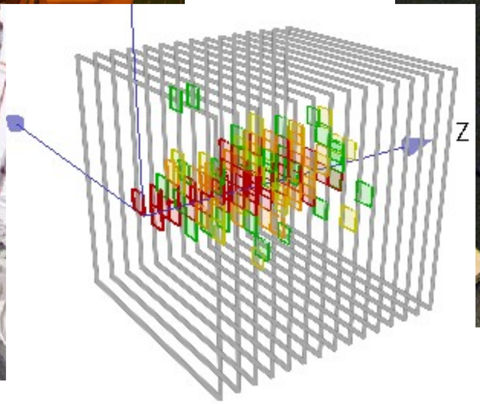

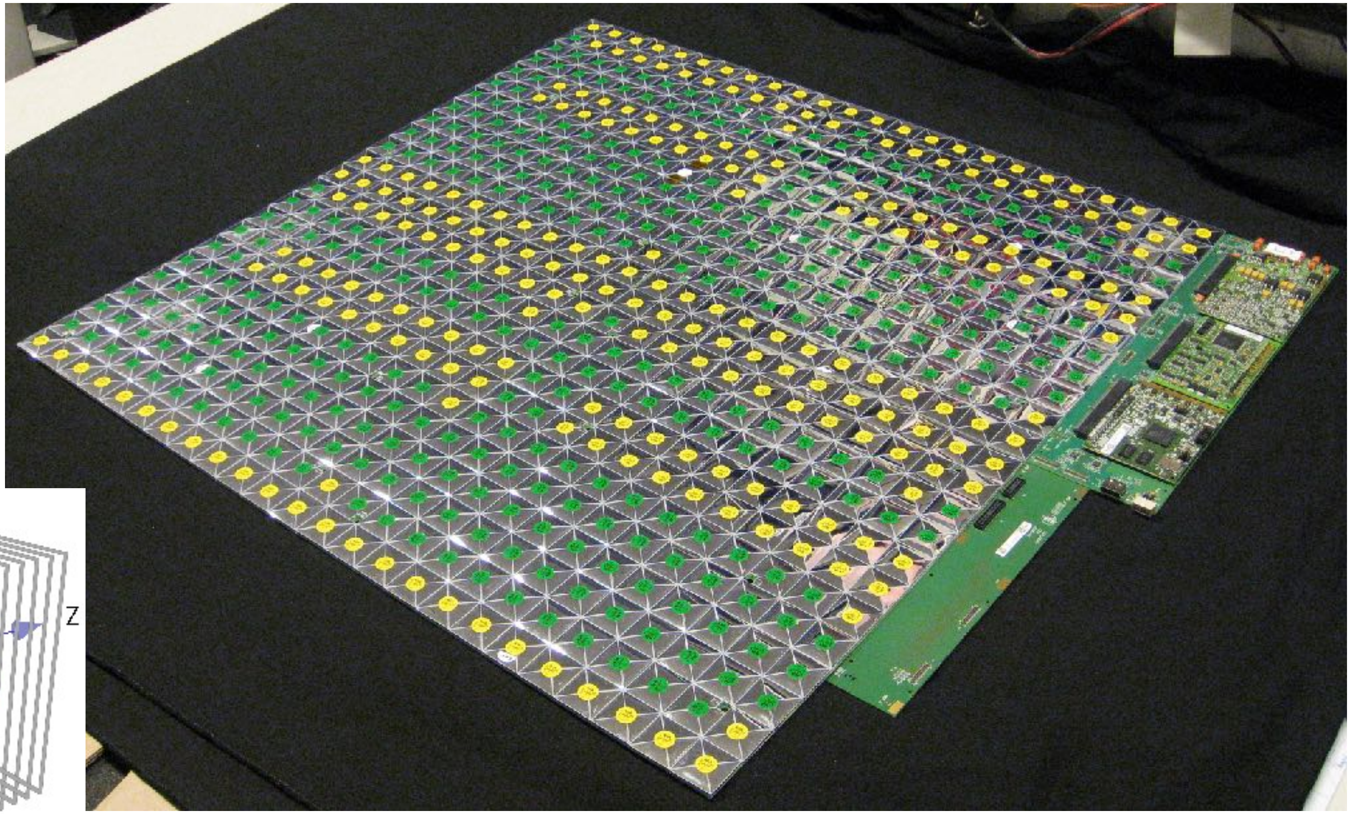

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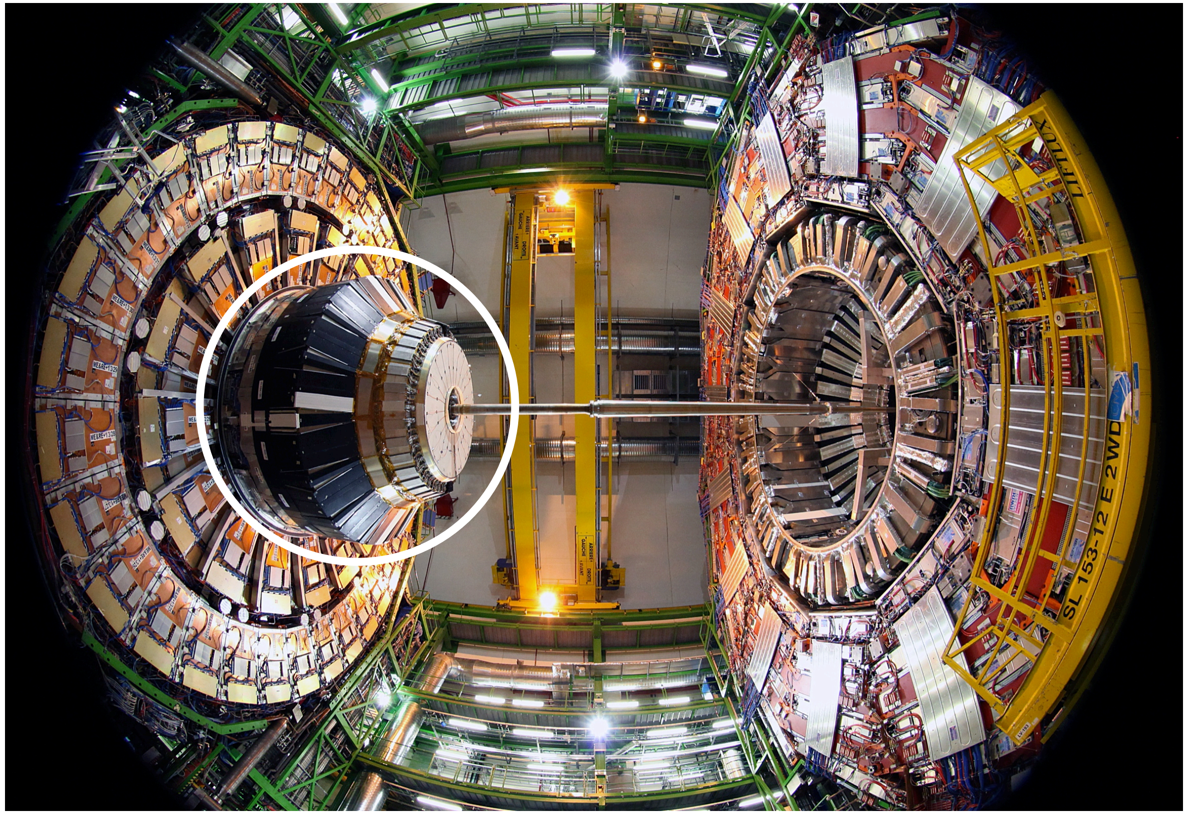
… to LHC

HGCAL motivation and timeline

High Granularity Endcap Calorimeter for CMS.

HL-LHC: 300 -> 3000 fb-1 to start end of 2026

- Emphasis moves to vector boson fusion initiated processes
- Narrow and merged jets, isolated objects
- Pile-up: 200 collisions per BX, keep thresholds
- Existing end-cap will be degraded at end of Run 2 (2023)



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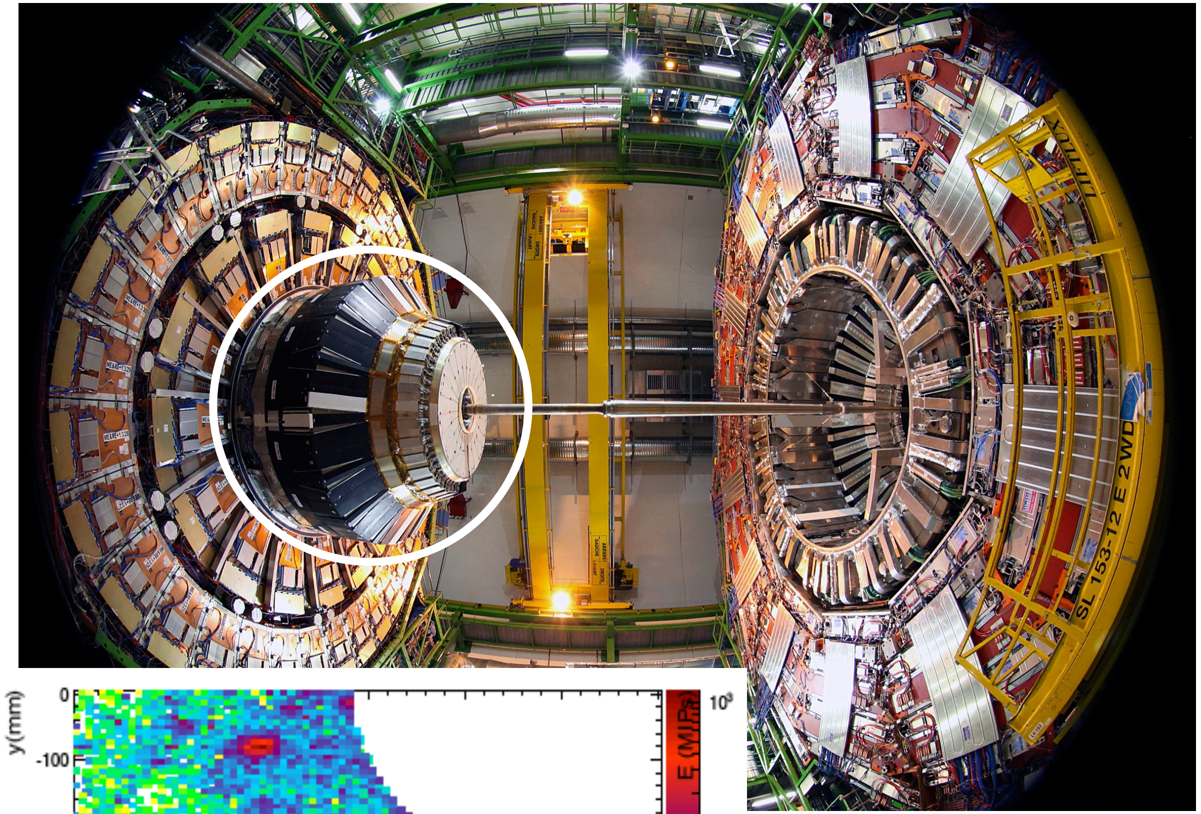

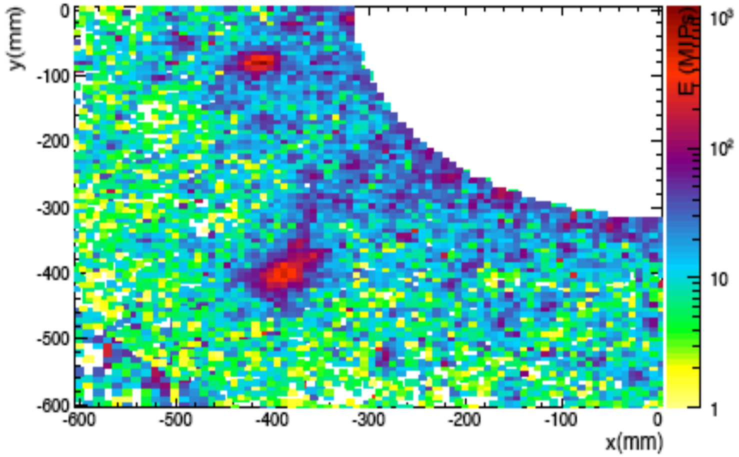

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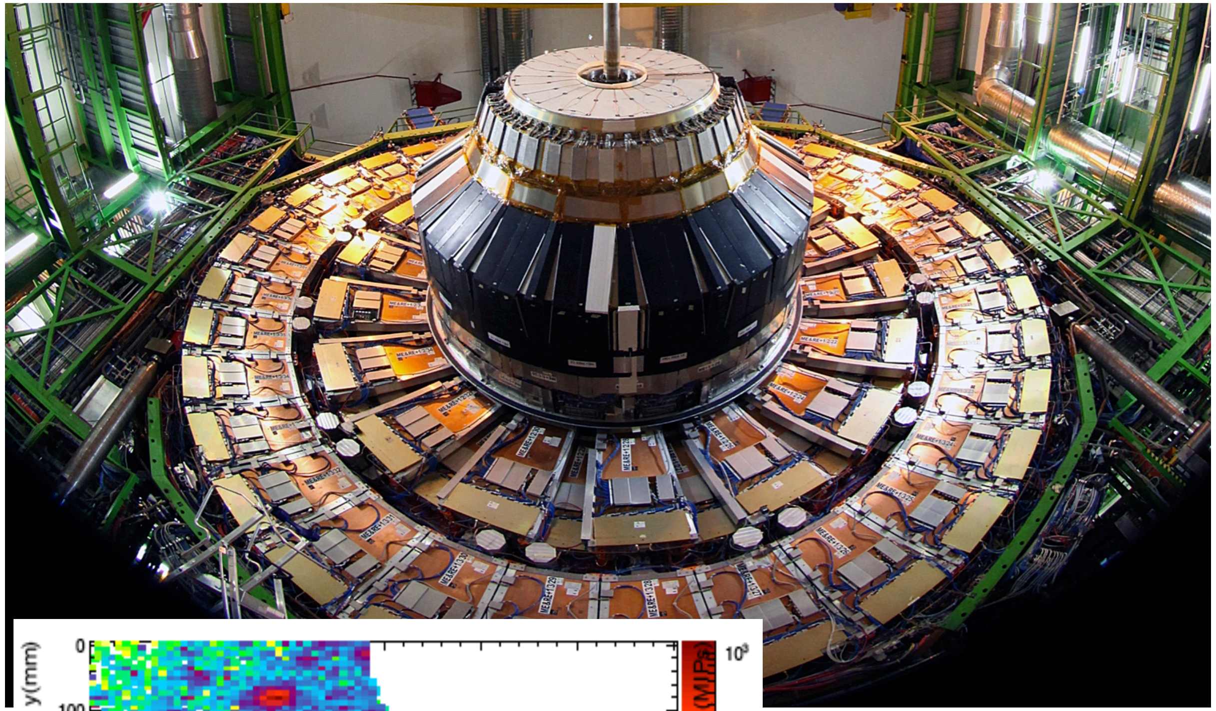

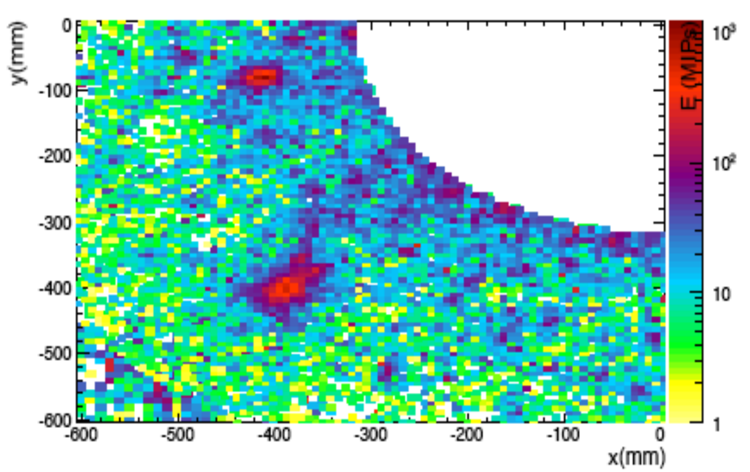

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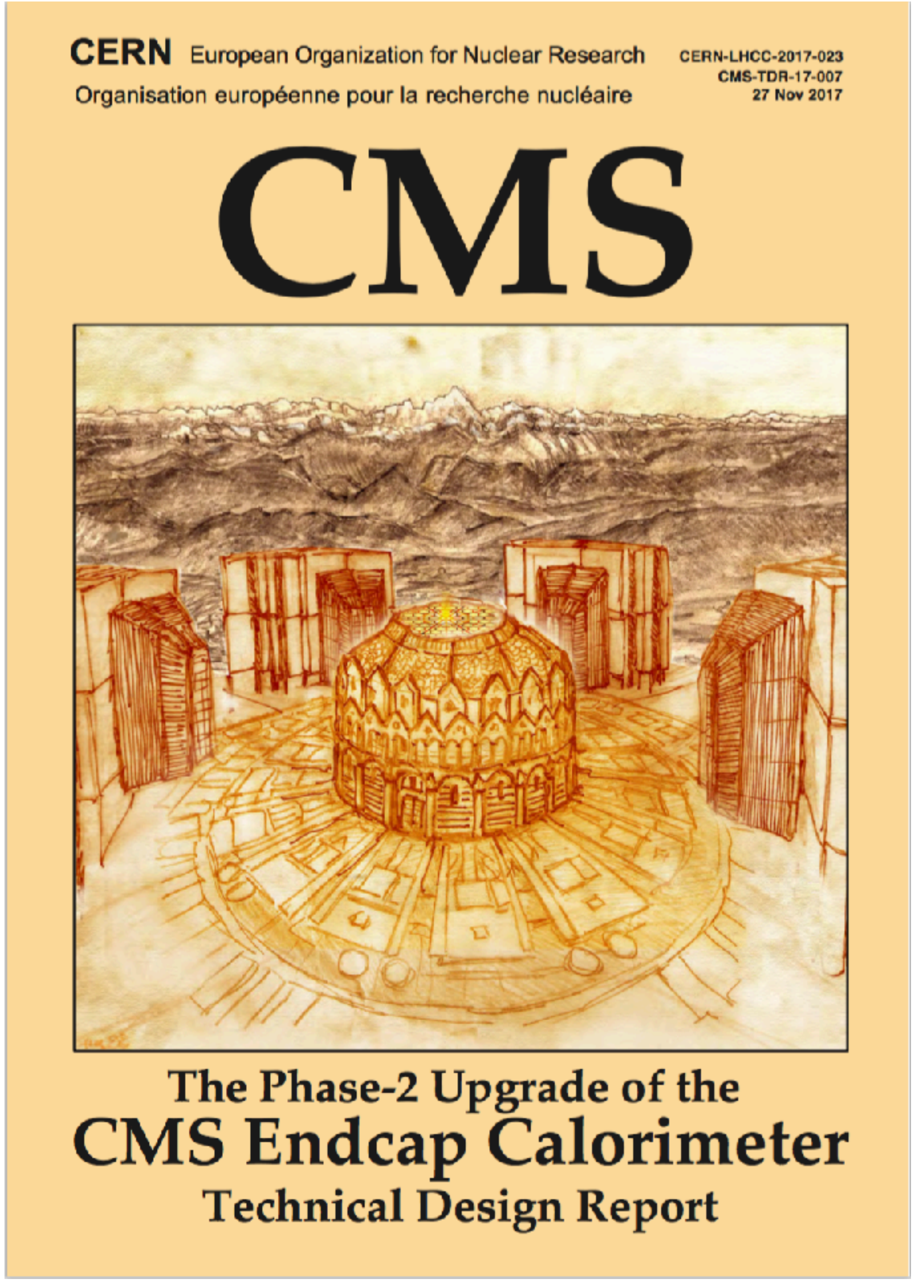
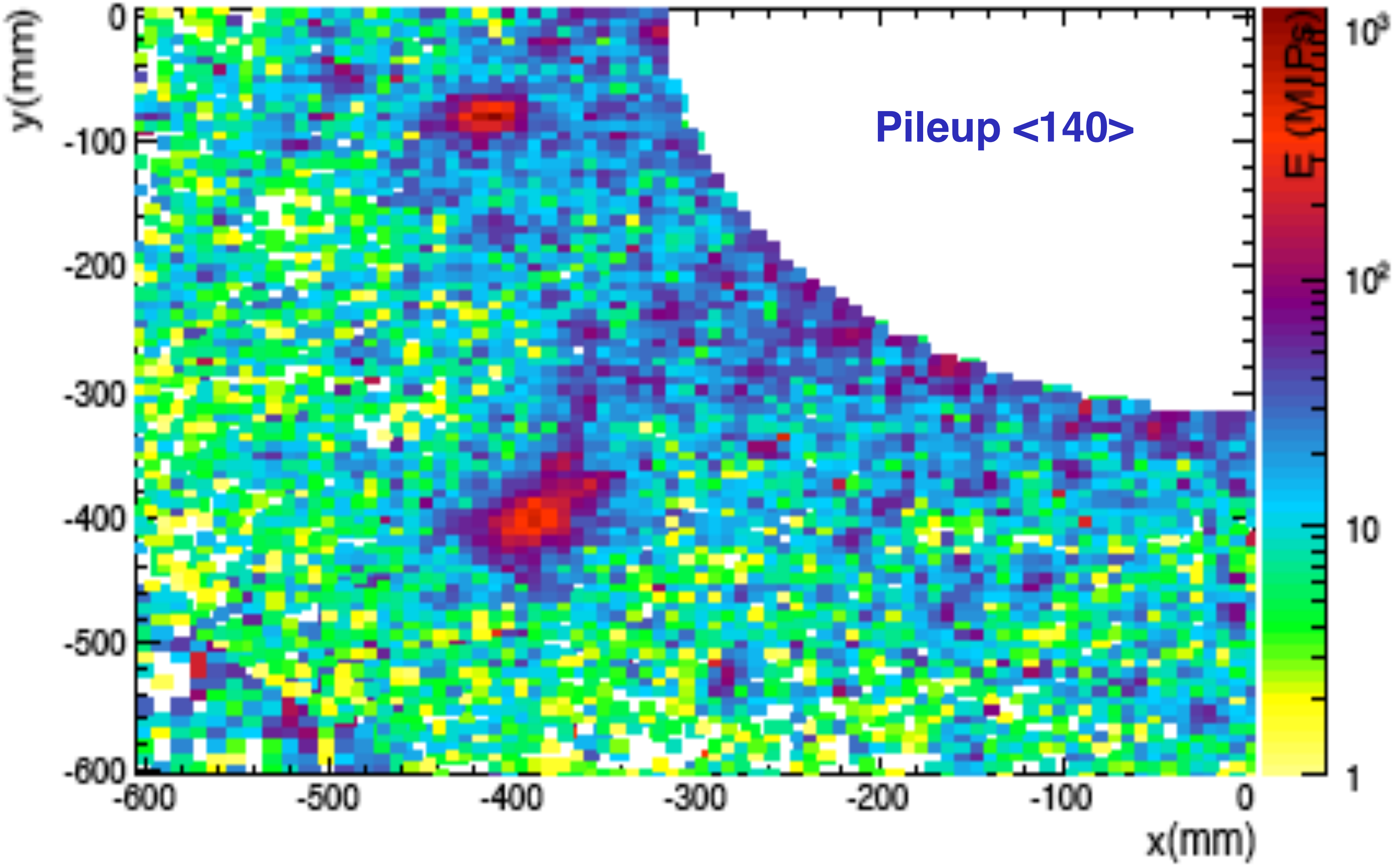


The Power of High Granularity at the LHC

VBH jets + H →γγ: 720 GeV jet, 175 GeV photon



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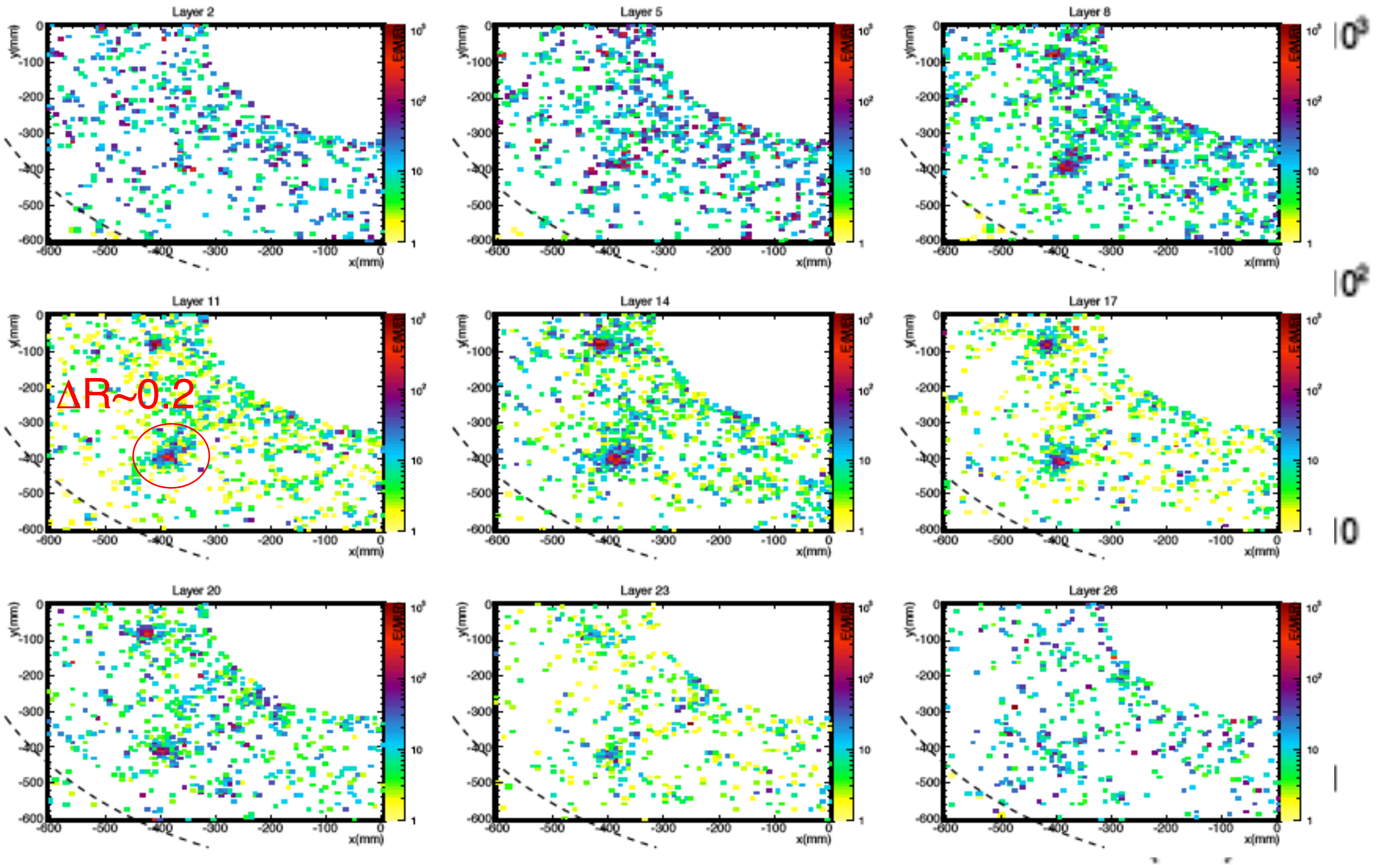

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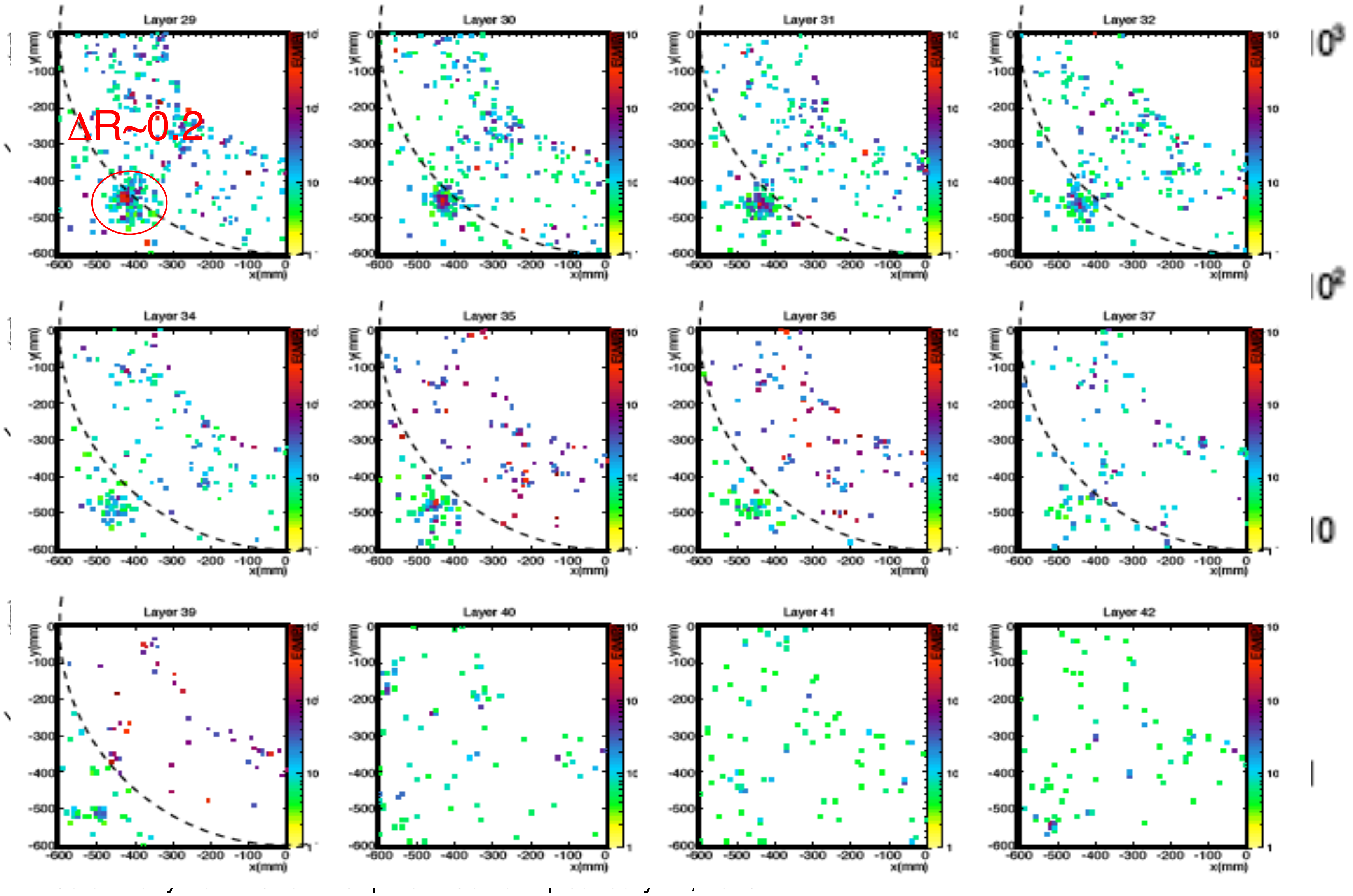
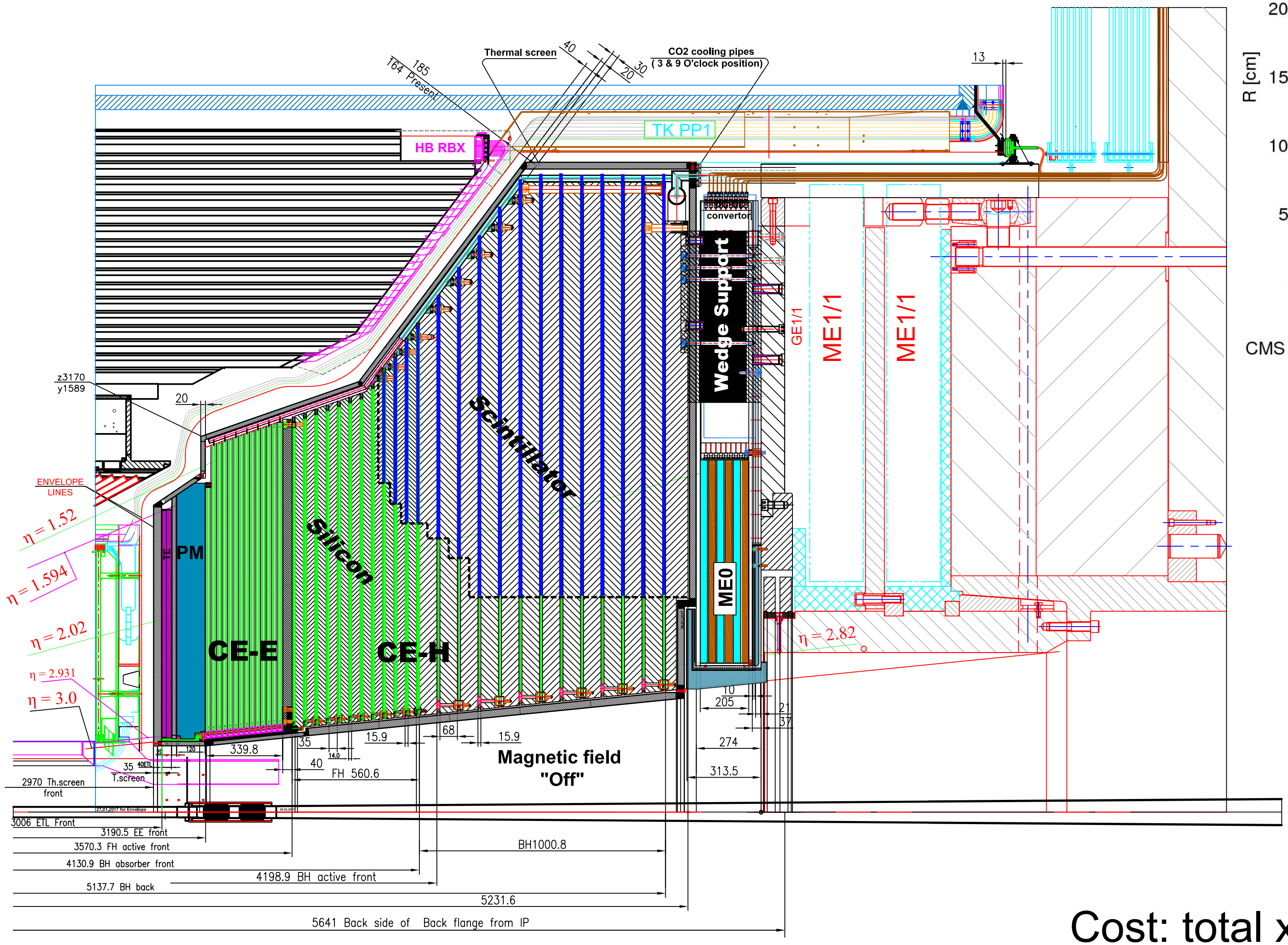
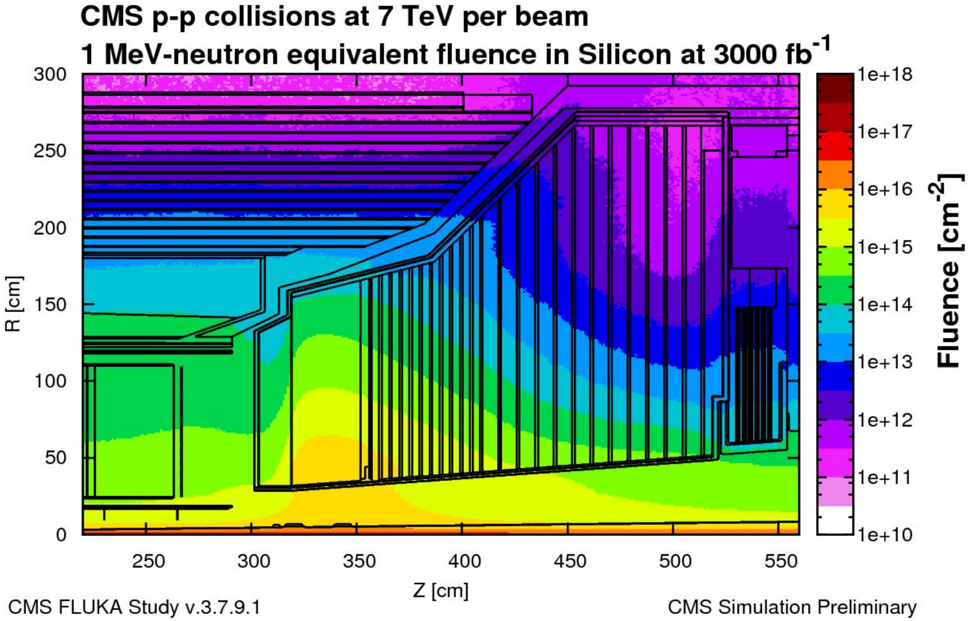


HGCAL layout and key numbers

Driven by radiation levels



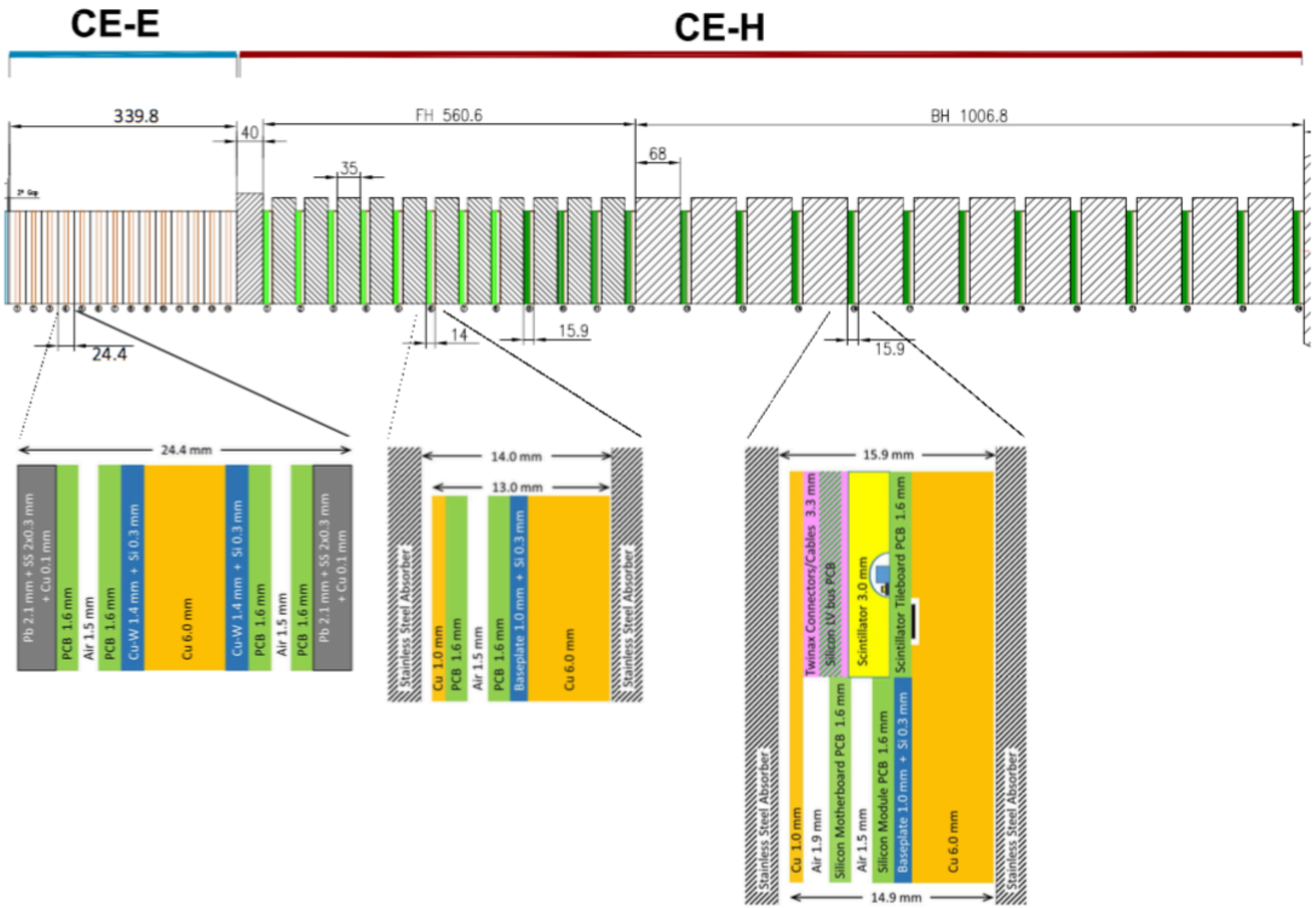


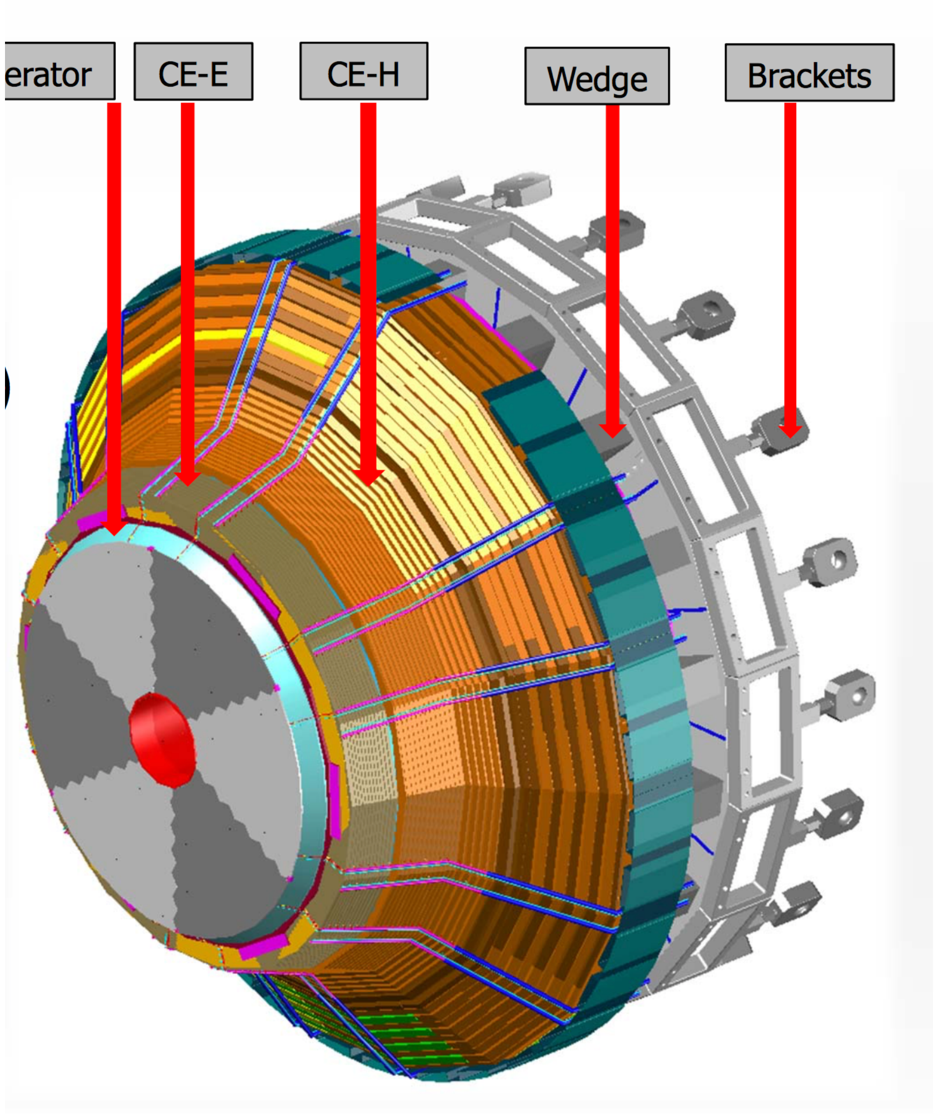
	CE-E	CE-H	
	Si	Si	Scintillator
Area (m^2)	368	215	487
Channels (k)	3916	1939	389
Si modules (Tileboards)	16 008	8868	(3960)
Partial modules	1008	1452	–
Weight (t)	23	205	
Si-only planes	28	8	
Mixed (Si+Scint) planes		16	

Cost: total xM, Scintillator-SiPM Tile Modules yMCHF

Longitudinal structure

28 silicon, 8 silicon and 16 mixed silicon scintillator layers.

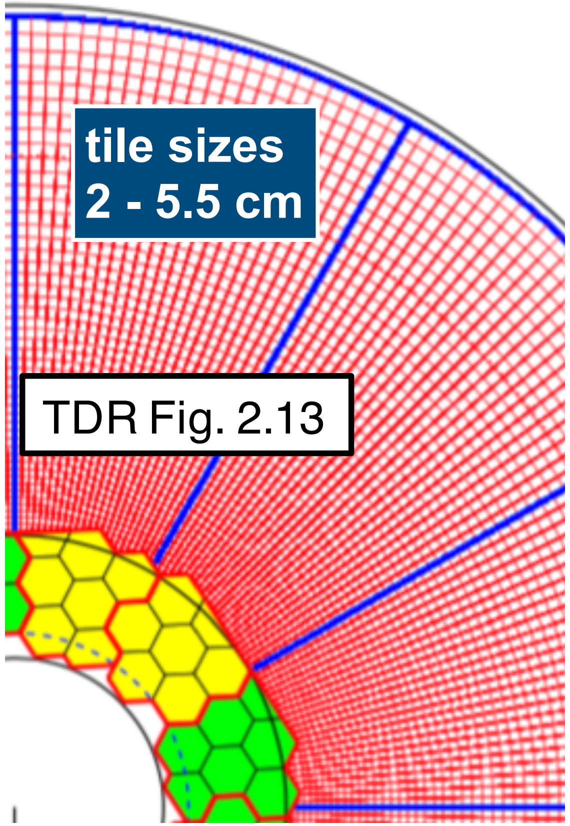


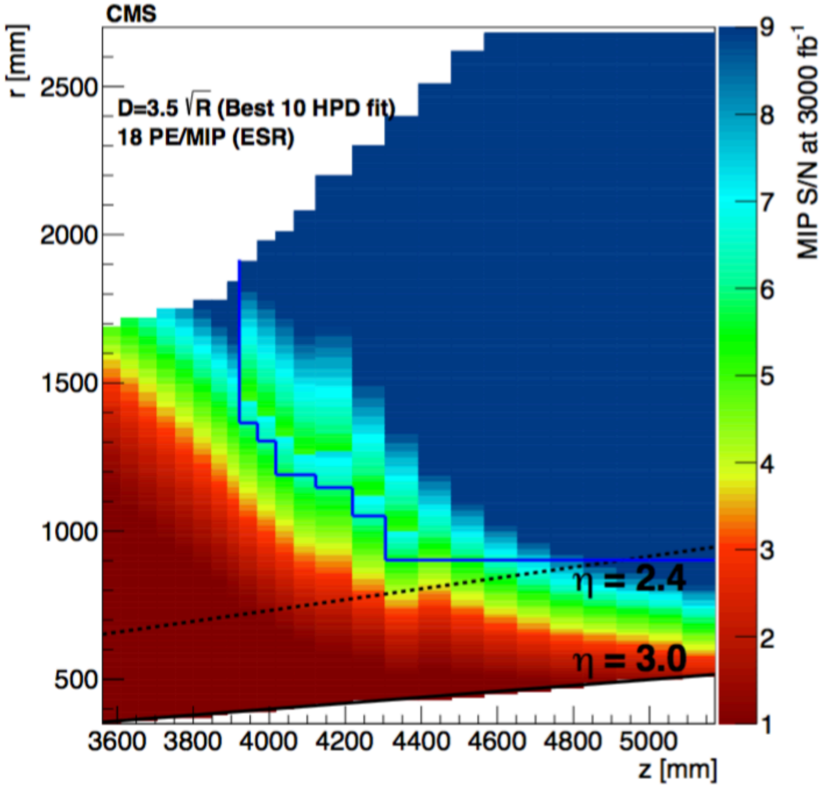


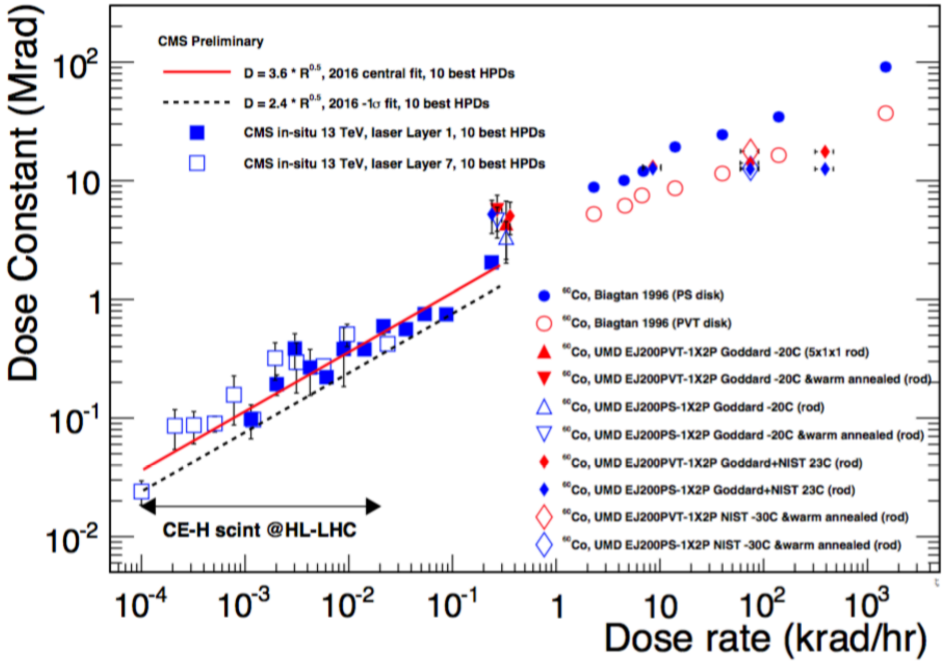
SiPM-on-Tile segmentation

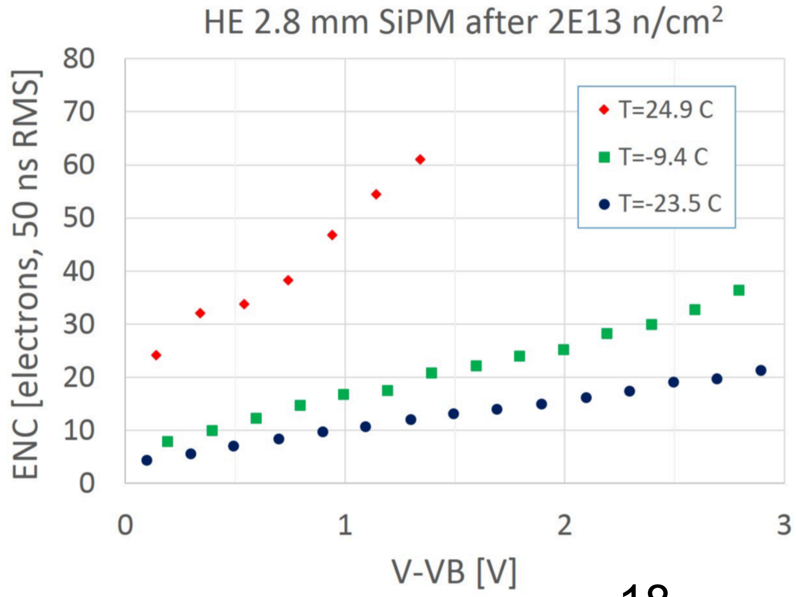
Match radiation levels and trigger geometry

- Higher **dose** (<200 kRad) - smaller tile area - more signal
- Higher **fluency** (<5e14 n/cm²) - larger SiPM area - more S/N







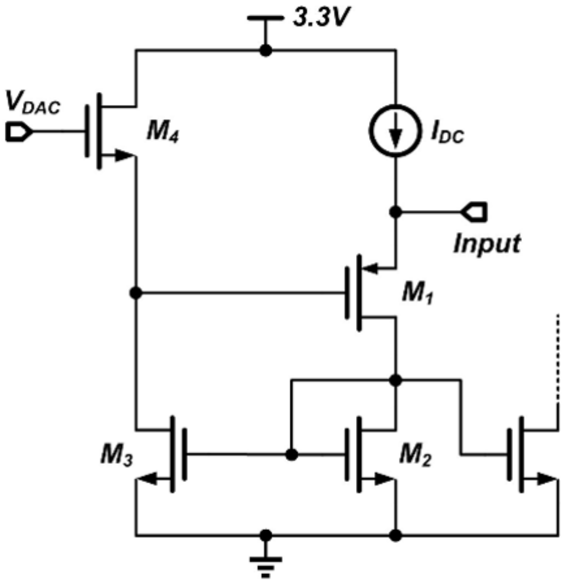


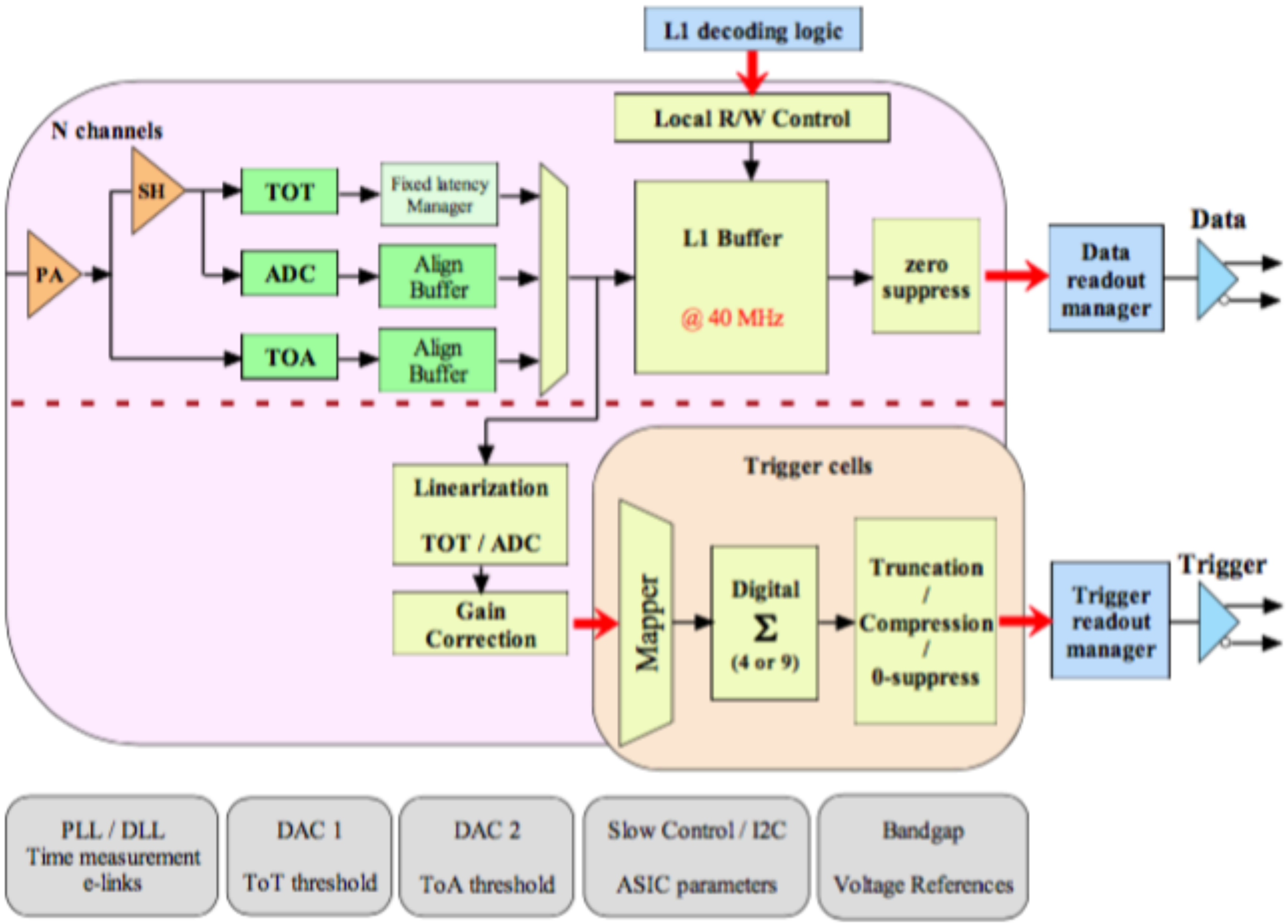
Read-out electronics

Front-end based on CALICE developments

HGCROC based on SKIROC and SPIROC

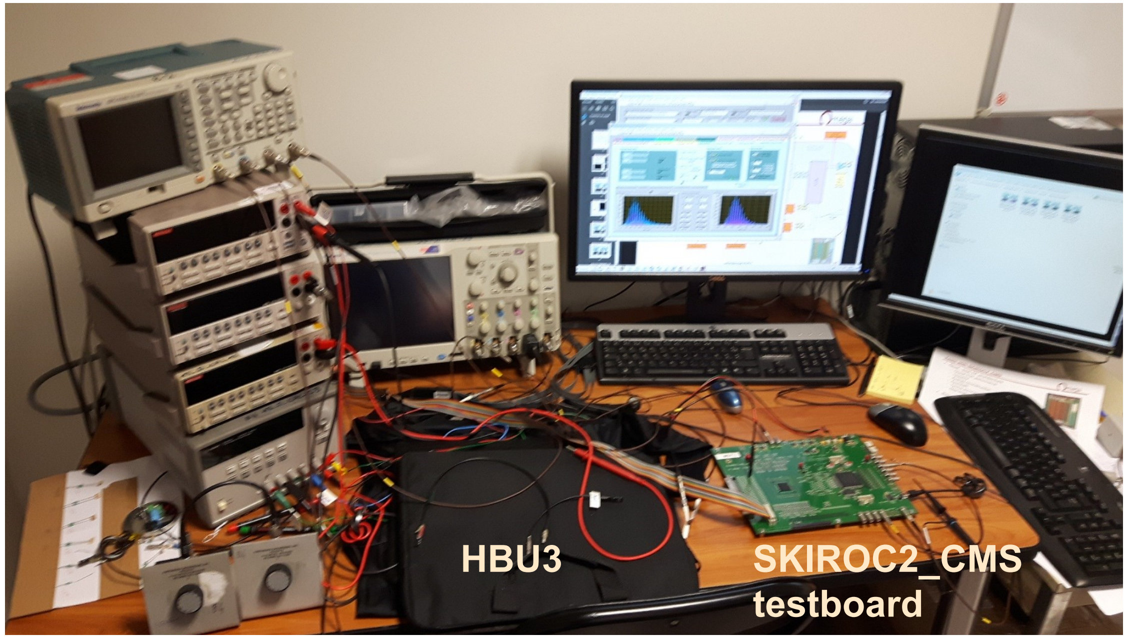
- 1 GB/s data, 1GB/s trigger output
- ADC, TDC, ToA and ToT
- ToT not compatible with AC coupling
- Analoge input stage using current conveyor a la KLauS (Heidelberg)

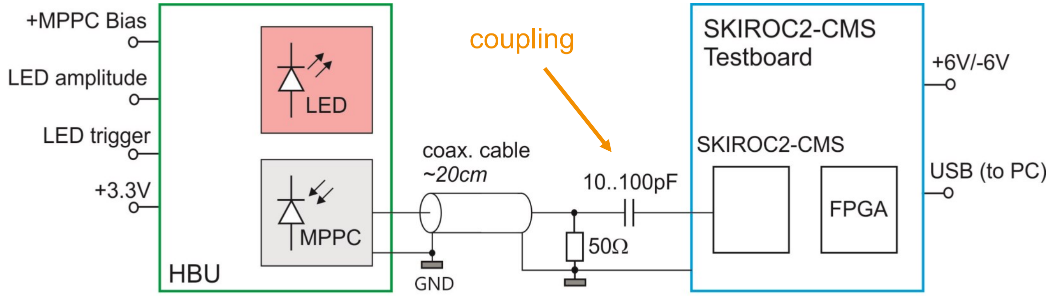




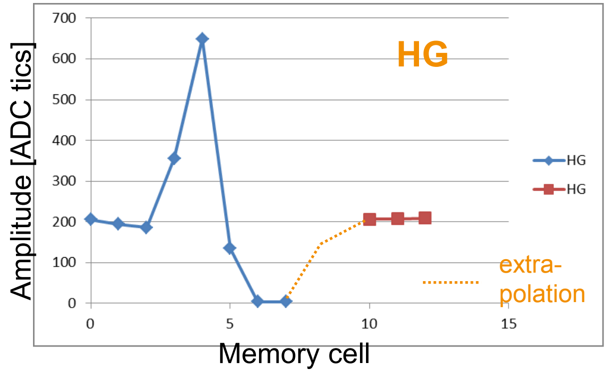
First steps

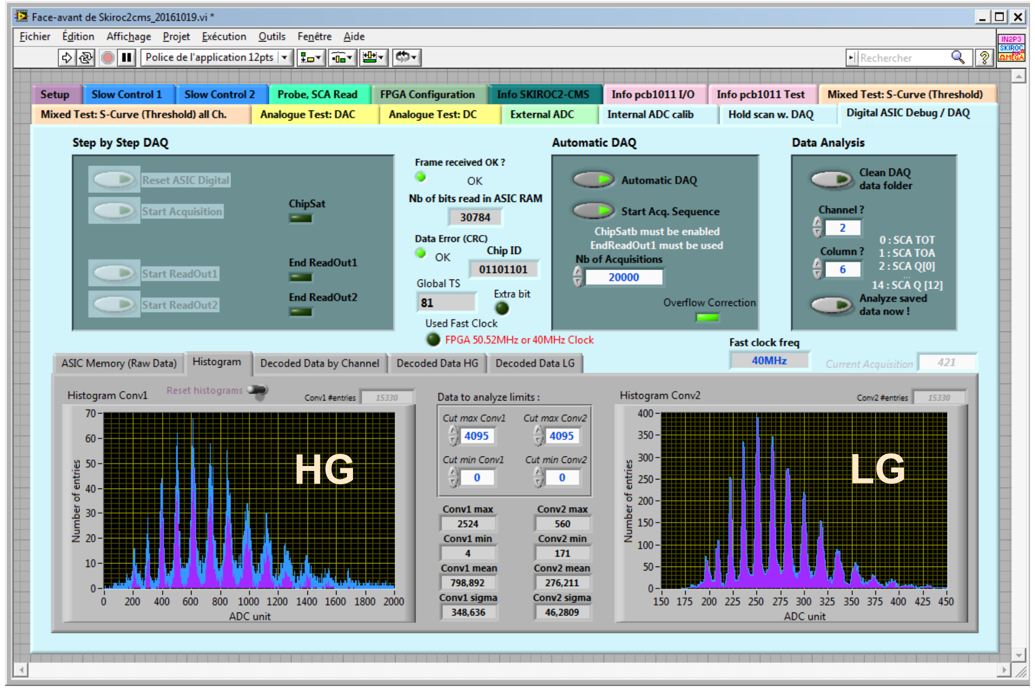
Test SiPM read-out with CMS-style ASIC





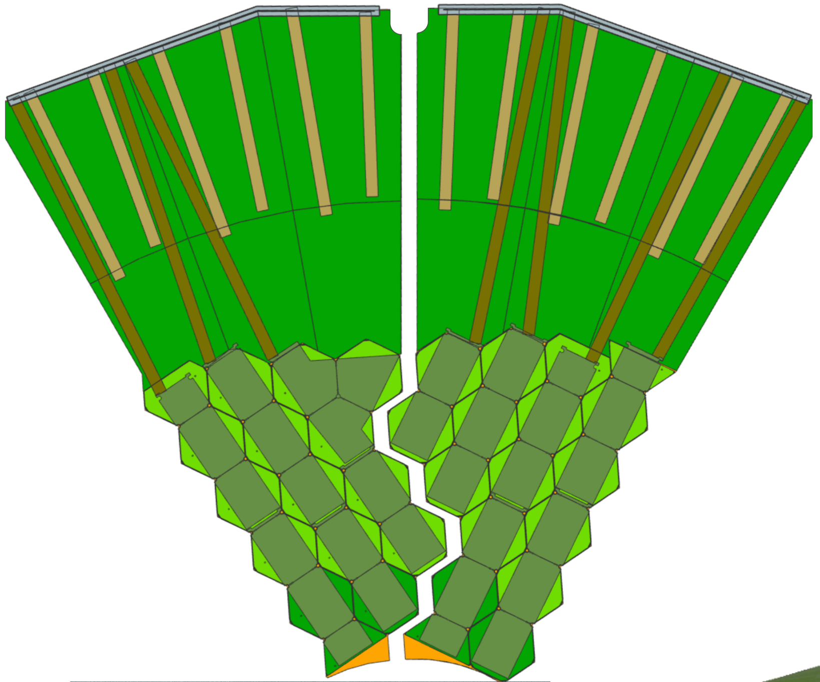
M.Reinecke (DESY), S. Callier (OMEGA)

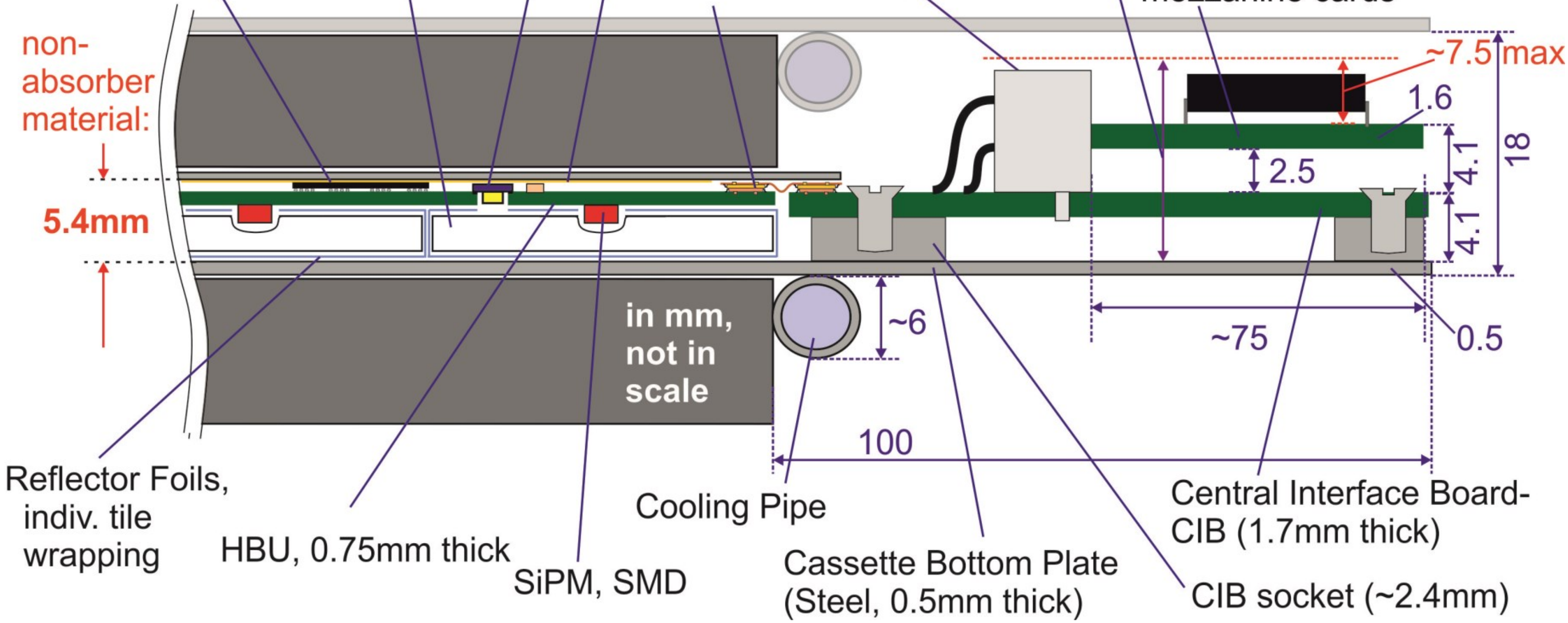


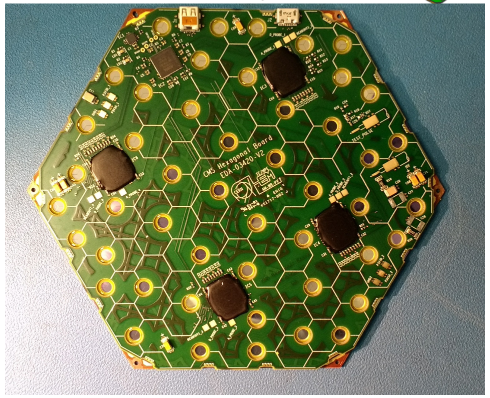


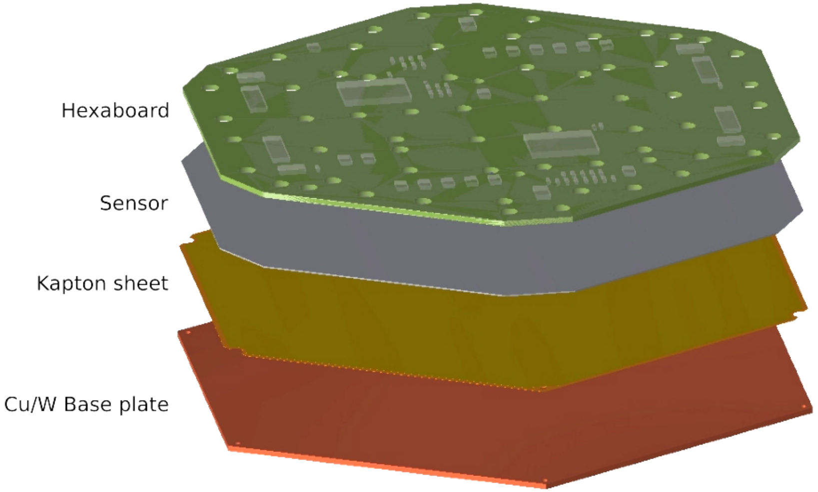
HGCAL active layers

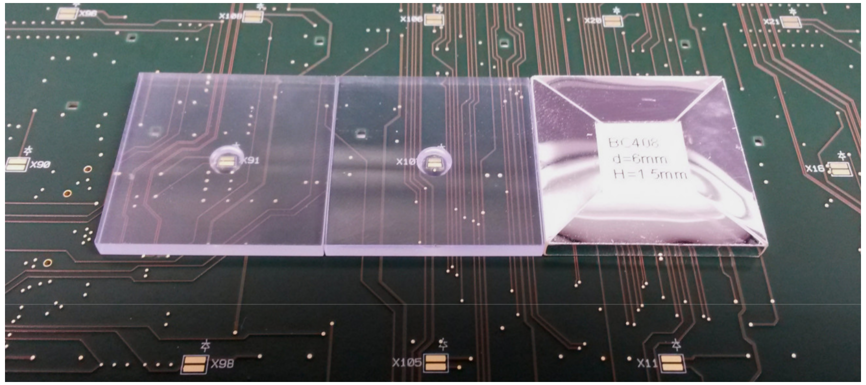
Mixed cassettes







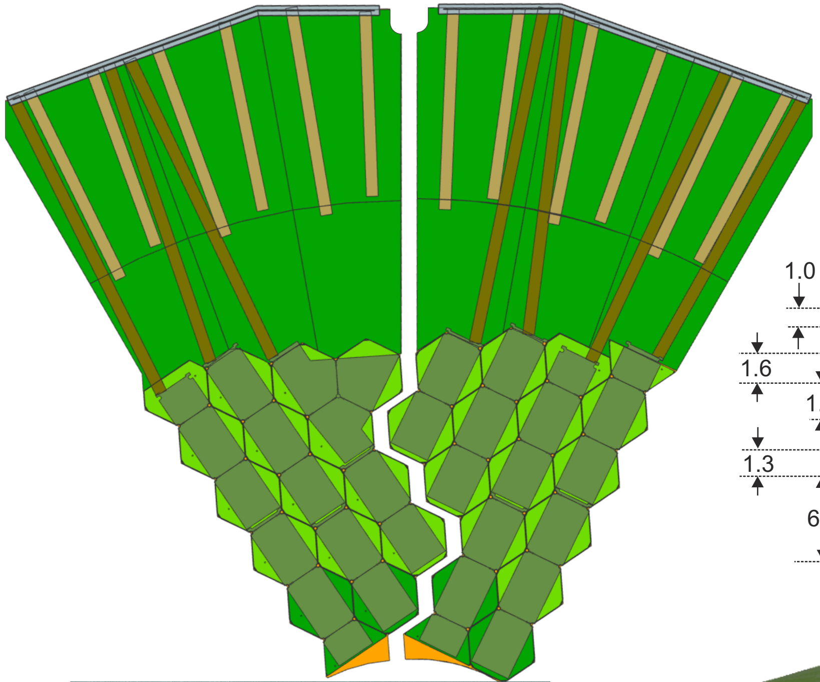


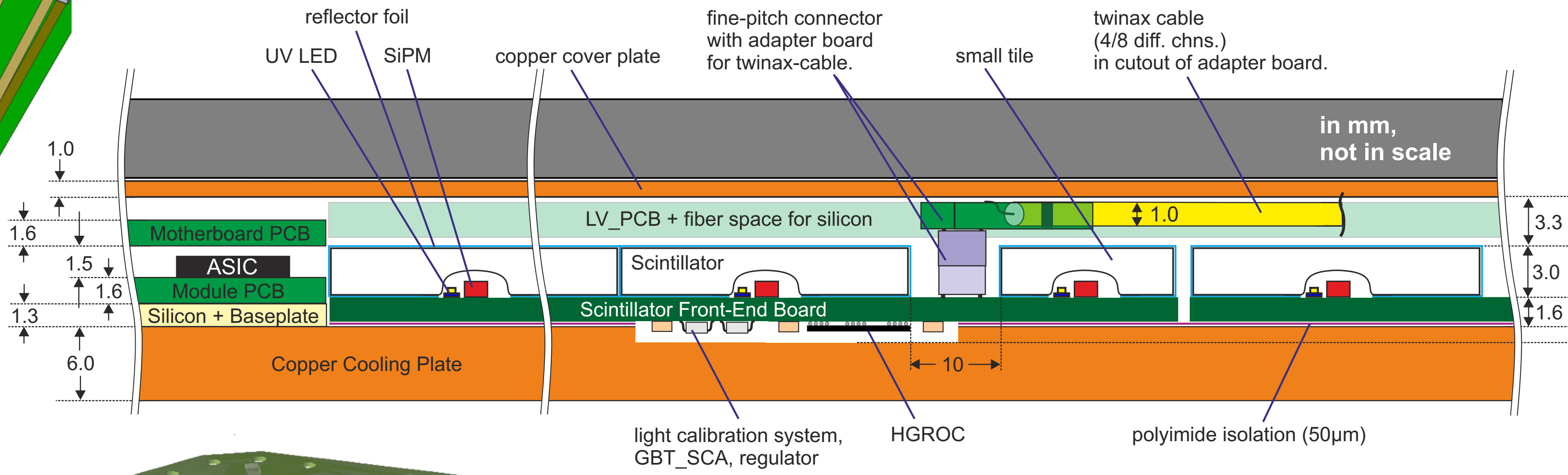


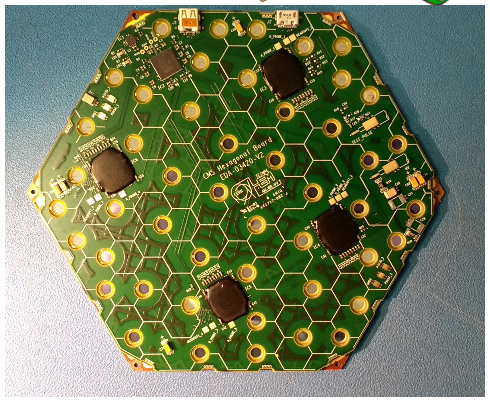
tile sizes 2 cm - 5.5 cm

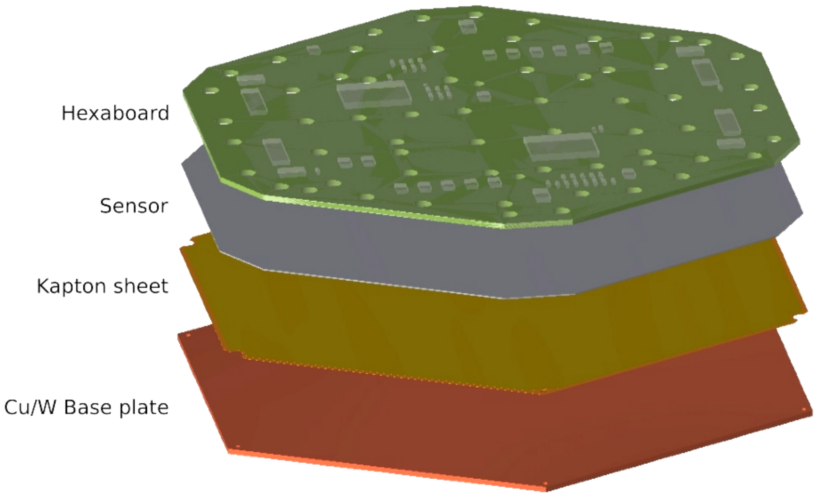
HGCAL active layers

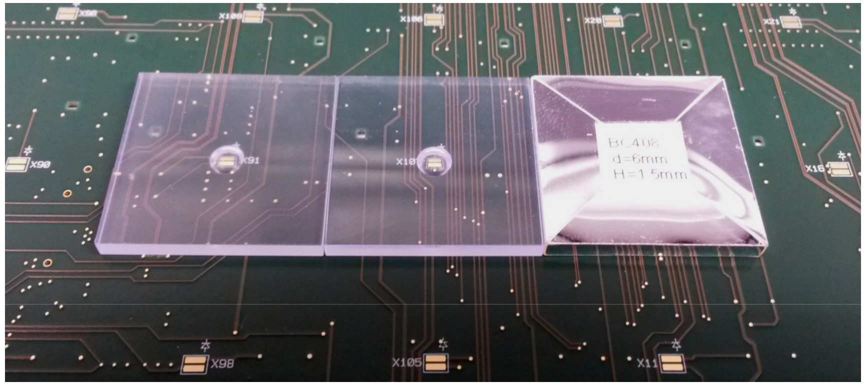
Mixed cassettes







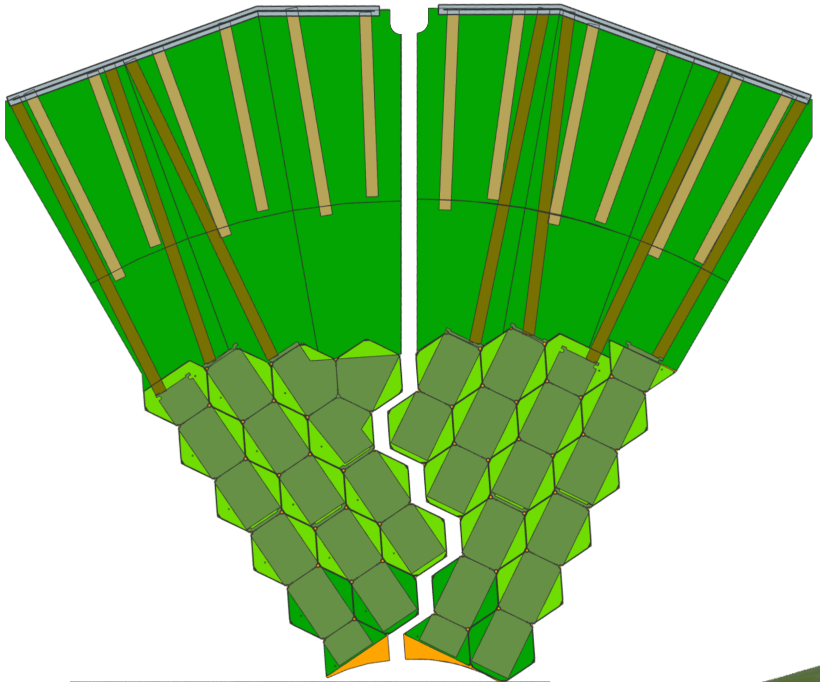


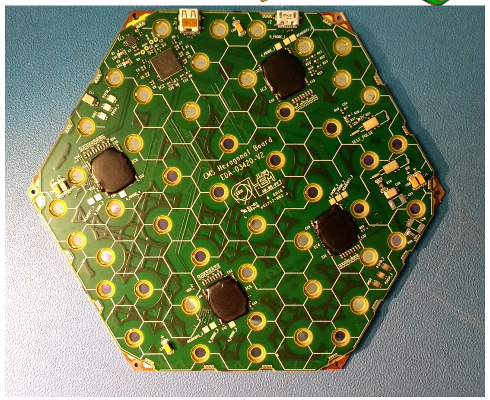


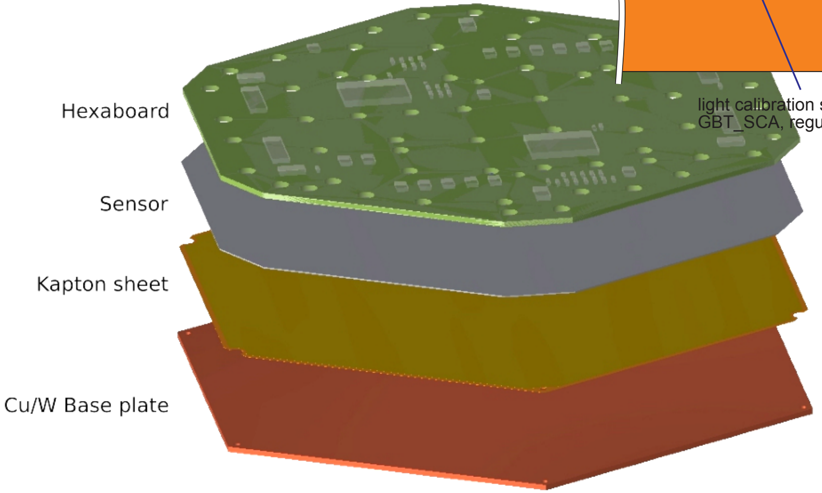
tile sizes 2 cm - 5.5 cm

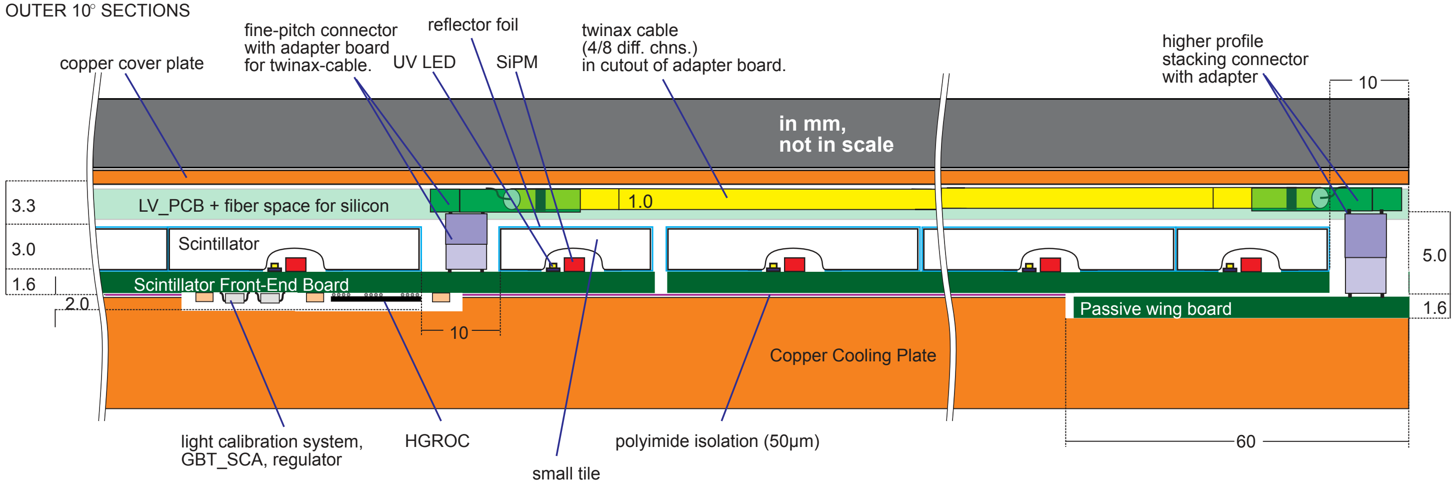
HGCAL active layers

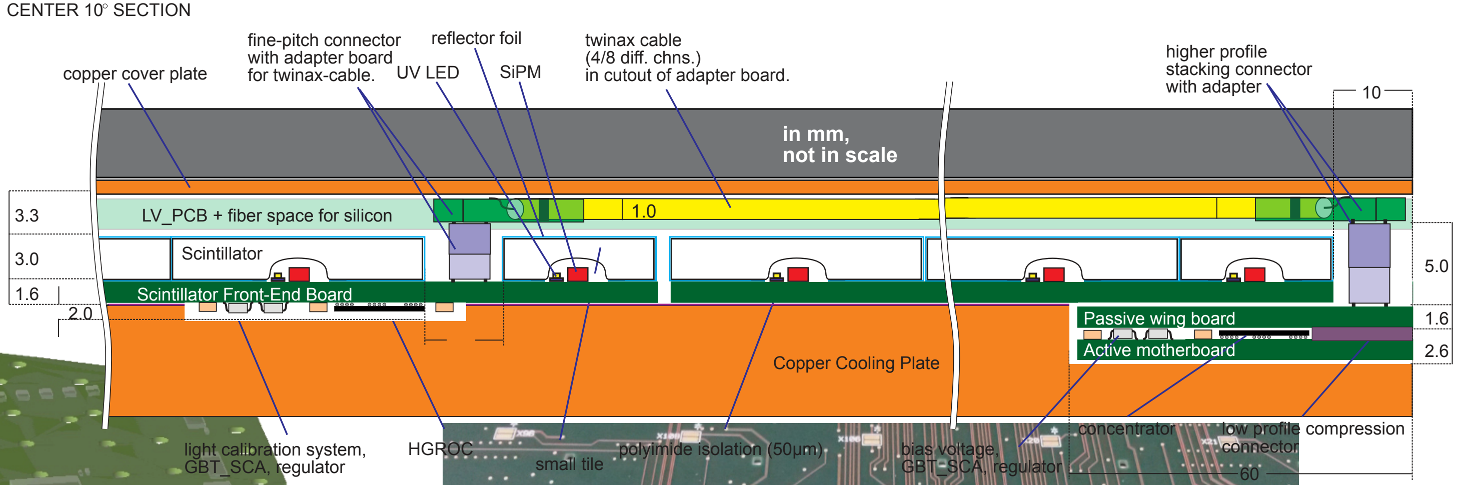
Mixed cassettes

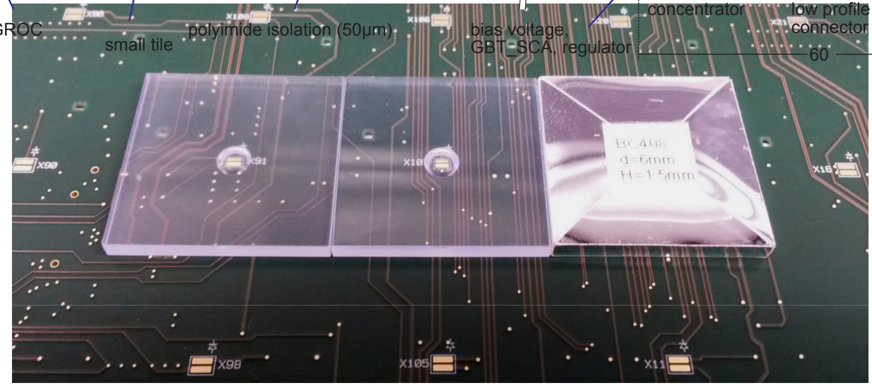












tile sizes 2 cm - 5.5 cm

HGCAL tile-modules

The DESY part.

Tile-boards = HBUs

- only 6 different types (assuming we can cut them)

Tile-modules = tile-boards + scintillator

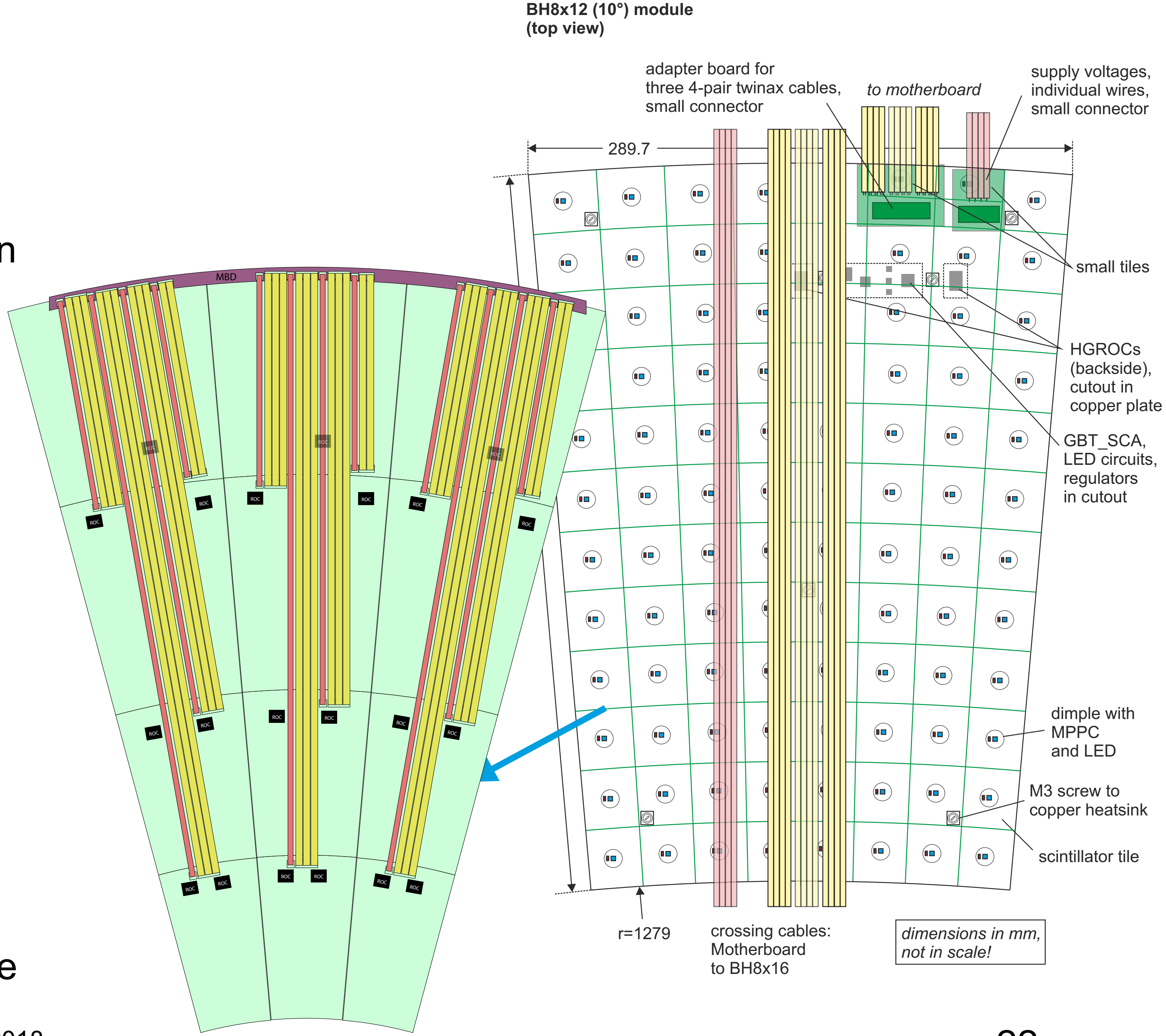
- individual tiles for larger sizes
- mega-tiles for smaller sizes

New technical challenges

- high-speed data transfer
  - 2x 1GB/s / ASIC
- Cooling of SiPMs through PCB
- Thermo-mechanical issues +- 40 ^{o}C
- Rad-hard components

Basic R&D:

- scintillator and SiPM radiation tolerance

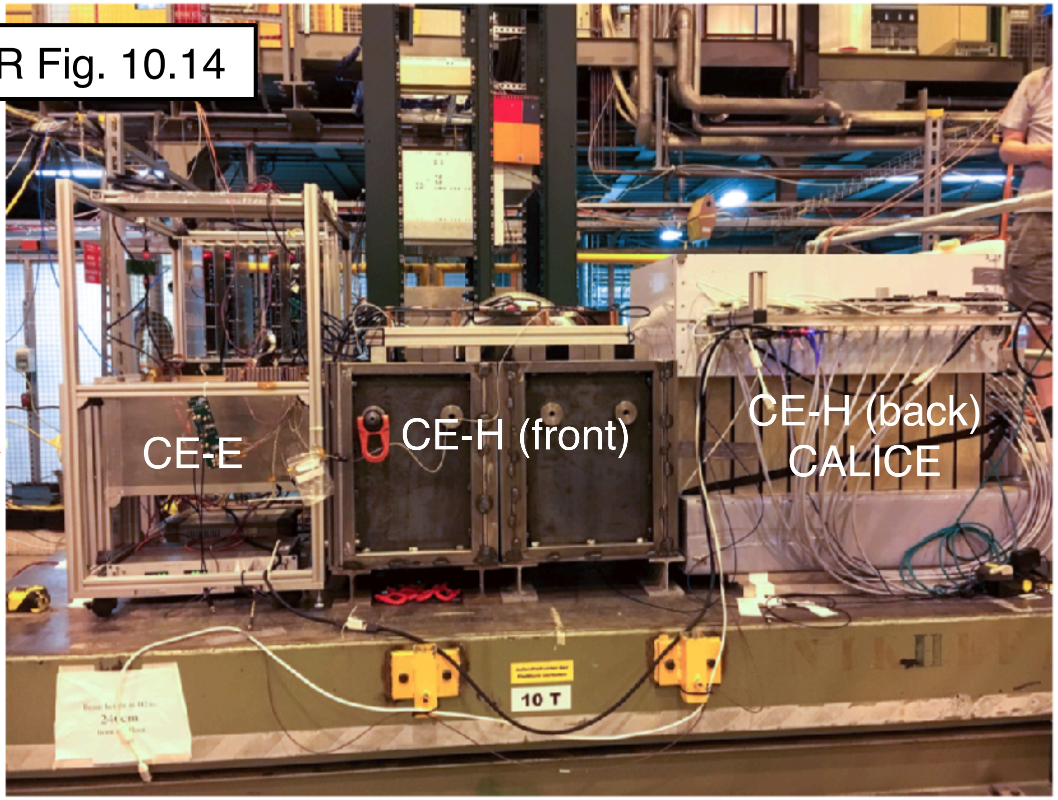


CALICE CMS Common Test Beam

AHCAL prototype as Backing Hadron calorimeter

TDR Fig. 10.14

e, π, μ
beam



- Common DAQ: EUDAQ

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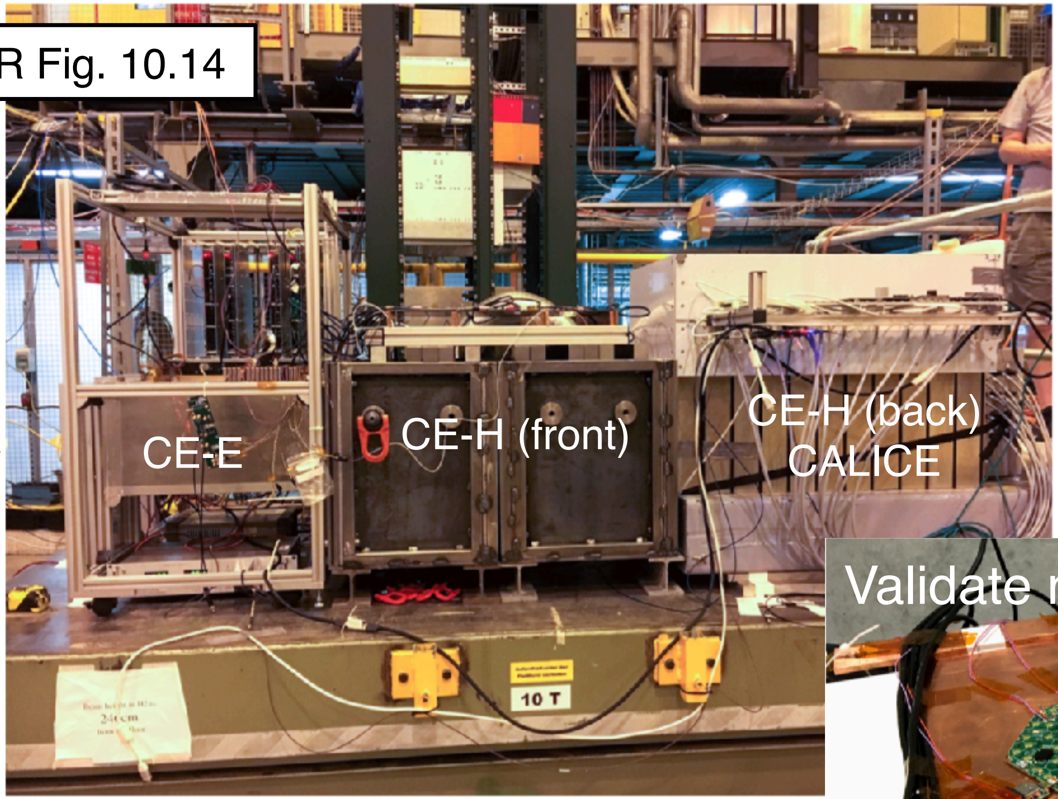
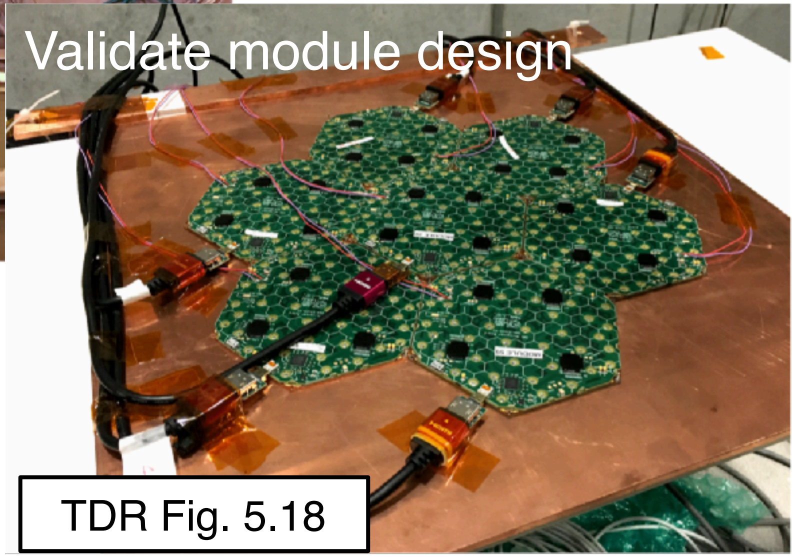
CALICE CMS Common Test Beam

AHCAL prototype as Backing Hadron calorimeter

TDR Fig. 10.14

e, π, μ
beam





TDR Fig. 5.18

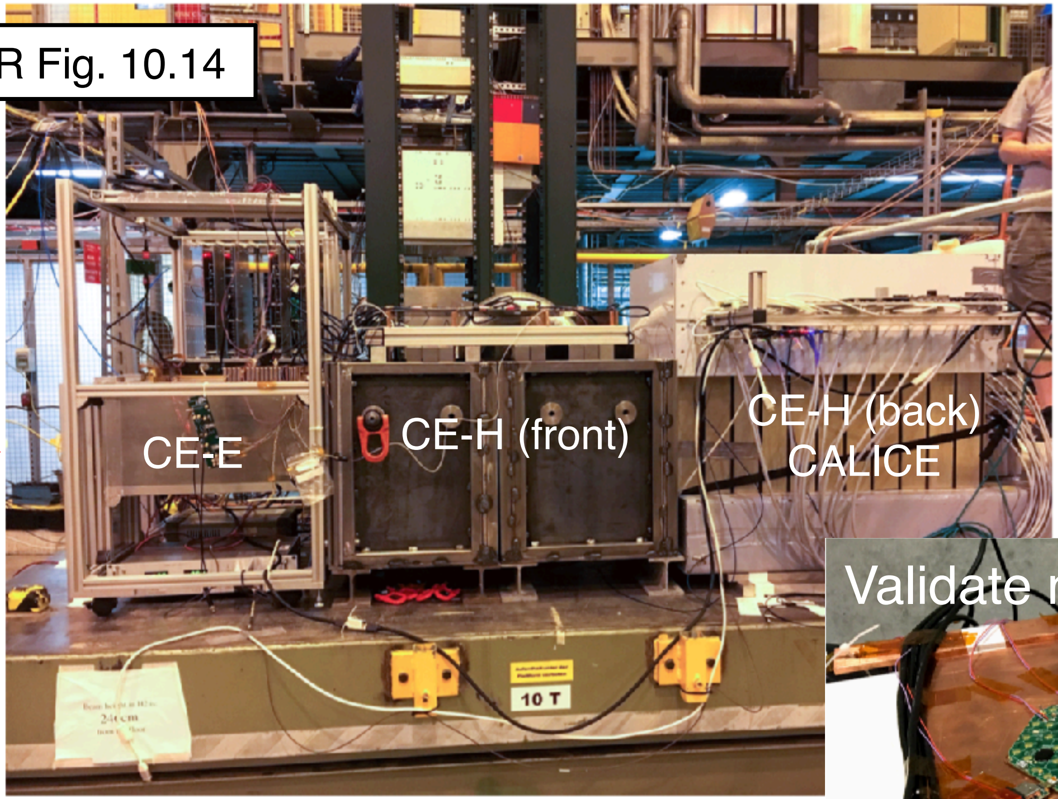
- Common DAQ: EUDAQ

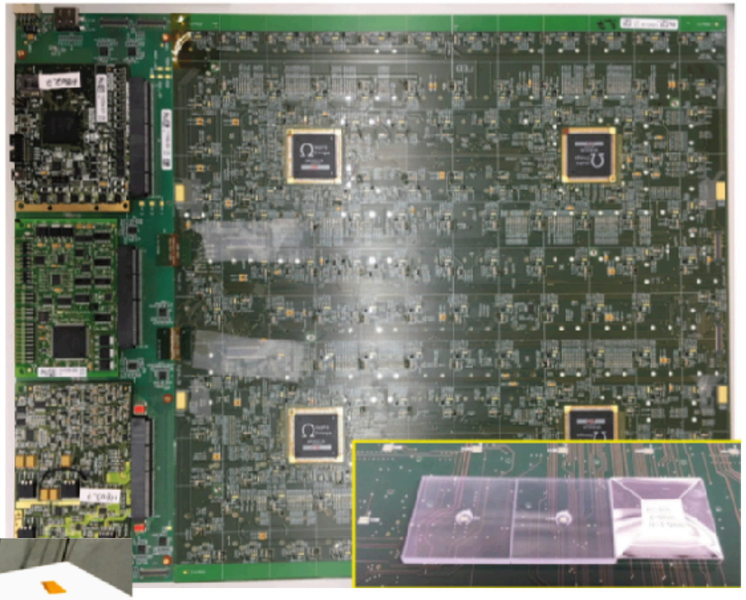
CALICE CMS Common Test Beam

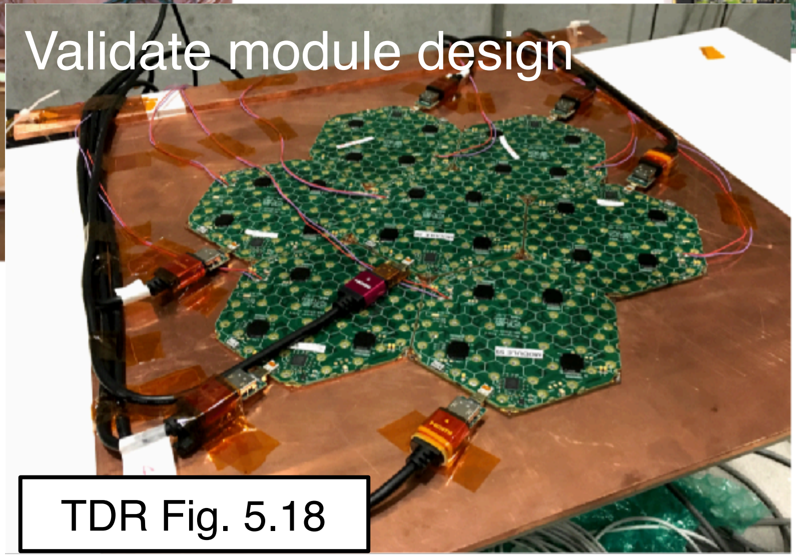
AHCAL prototype as Backing Hadron calorimeter

TDR Fig. 10.14

e, π, μ
beam







TDR Fig. 5.18

- Common DAQ: EUDAQ

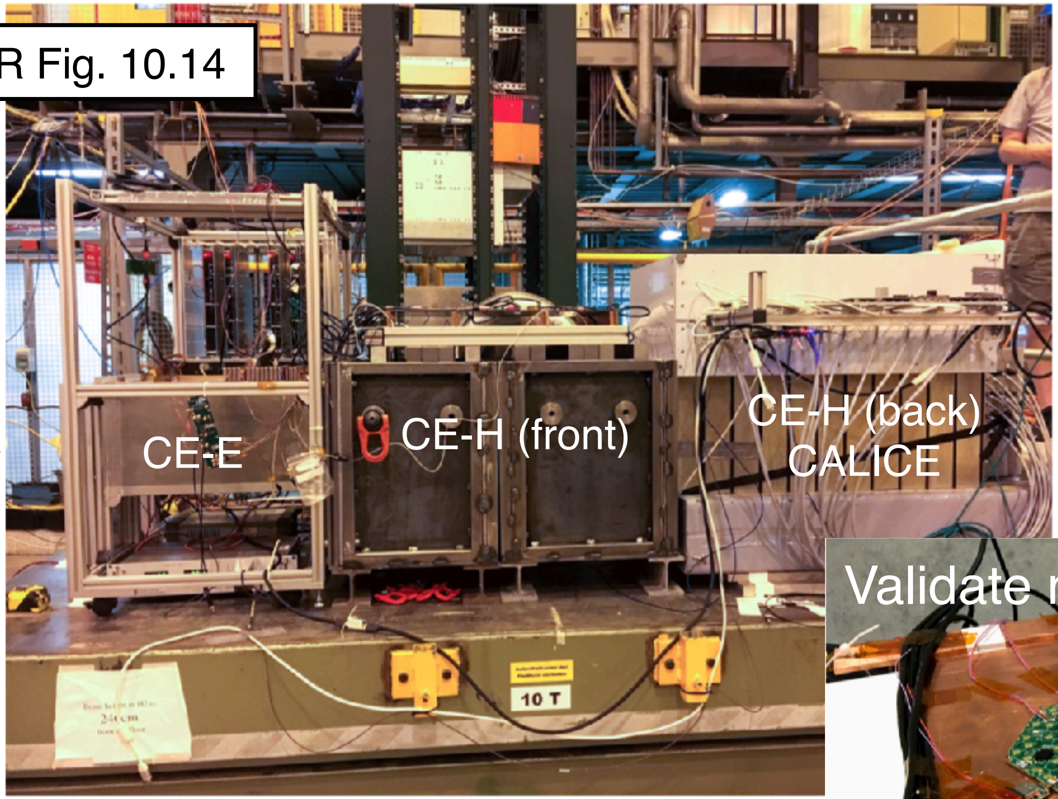
AIDA2020

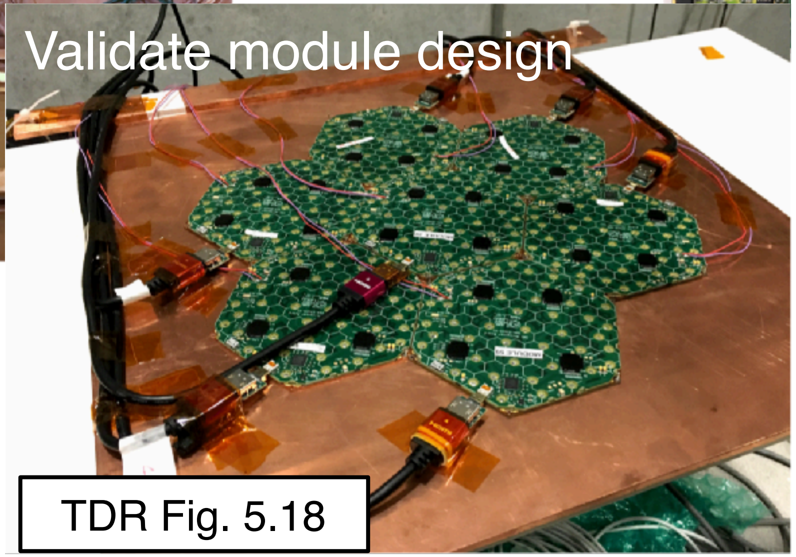
CALICE CMS Common Test Beam

AHCAL prototype as Backing Hadron calorimeter

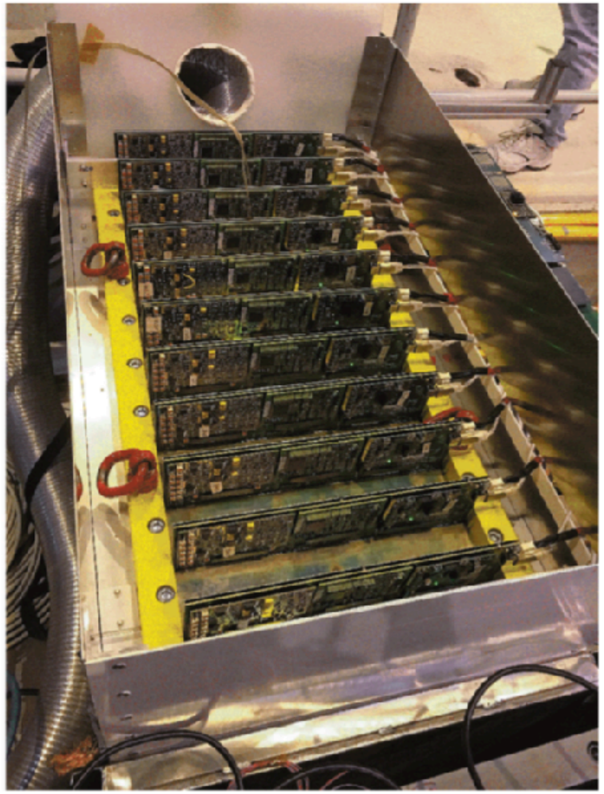
TDR Fig. 10.14

e, π, μ
beam





TDR Fig. 5.18



TDR Fig. 10.12

- Common DAQ: EUDAQ

AIDA 2020

Summary

No conclusion.

CALICE SiPM-on-tile HCAL design largely adopted for HL-LHC upgrade of CMS endcap calorimeter.

- 20 x CALICE, 1/20 x CLICdet - and many new challenges

Exciting to connect LC and LHC expertise.

Breathtaking to progress to TDR, EDR, construction.

Rewarding for both sides - absolutely.