CALICE calorimeters status

I.LAKTINEH

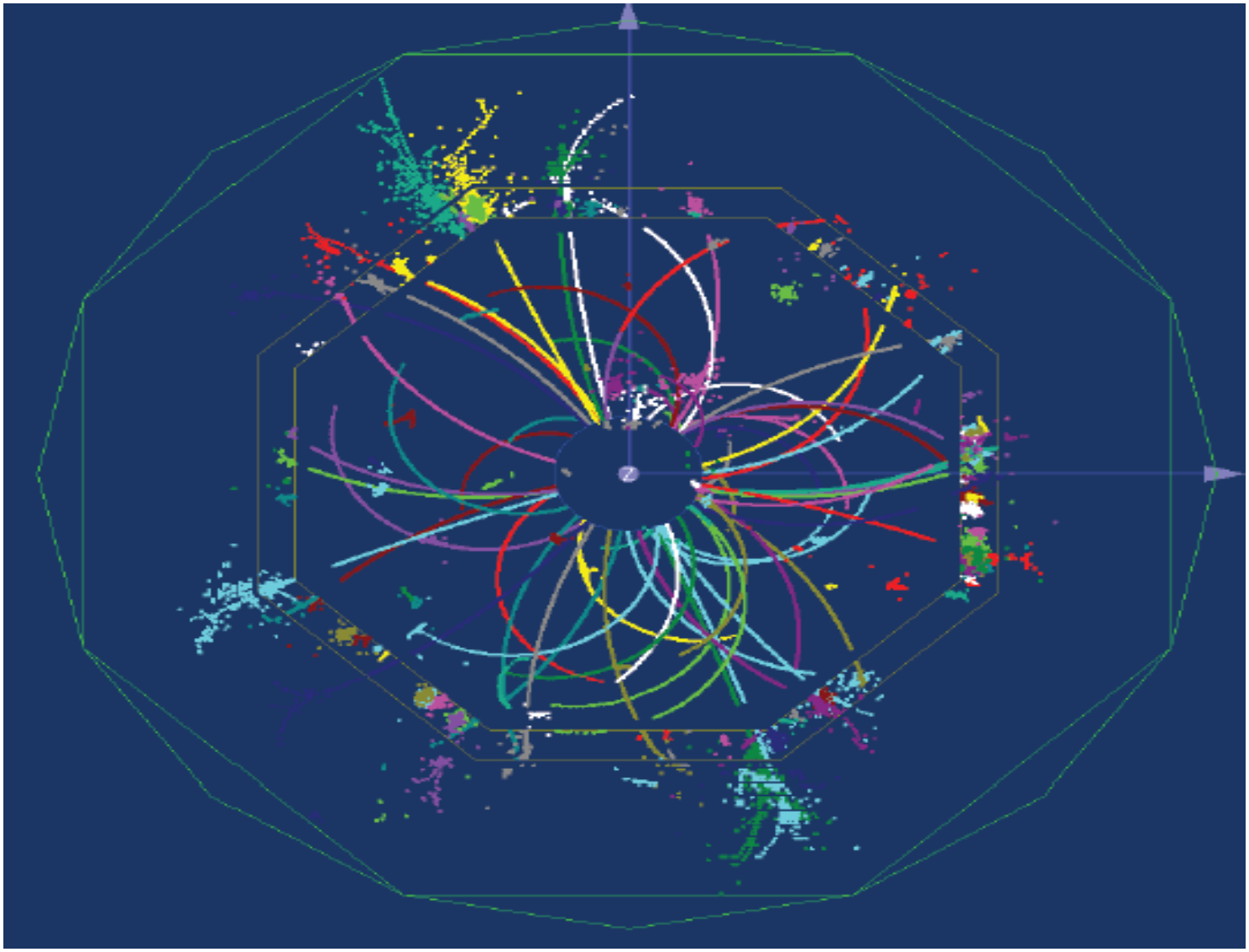
CALICE

CALICE is a collaboration with 59 institutes and 360 people from 4 continents.

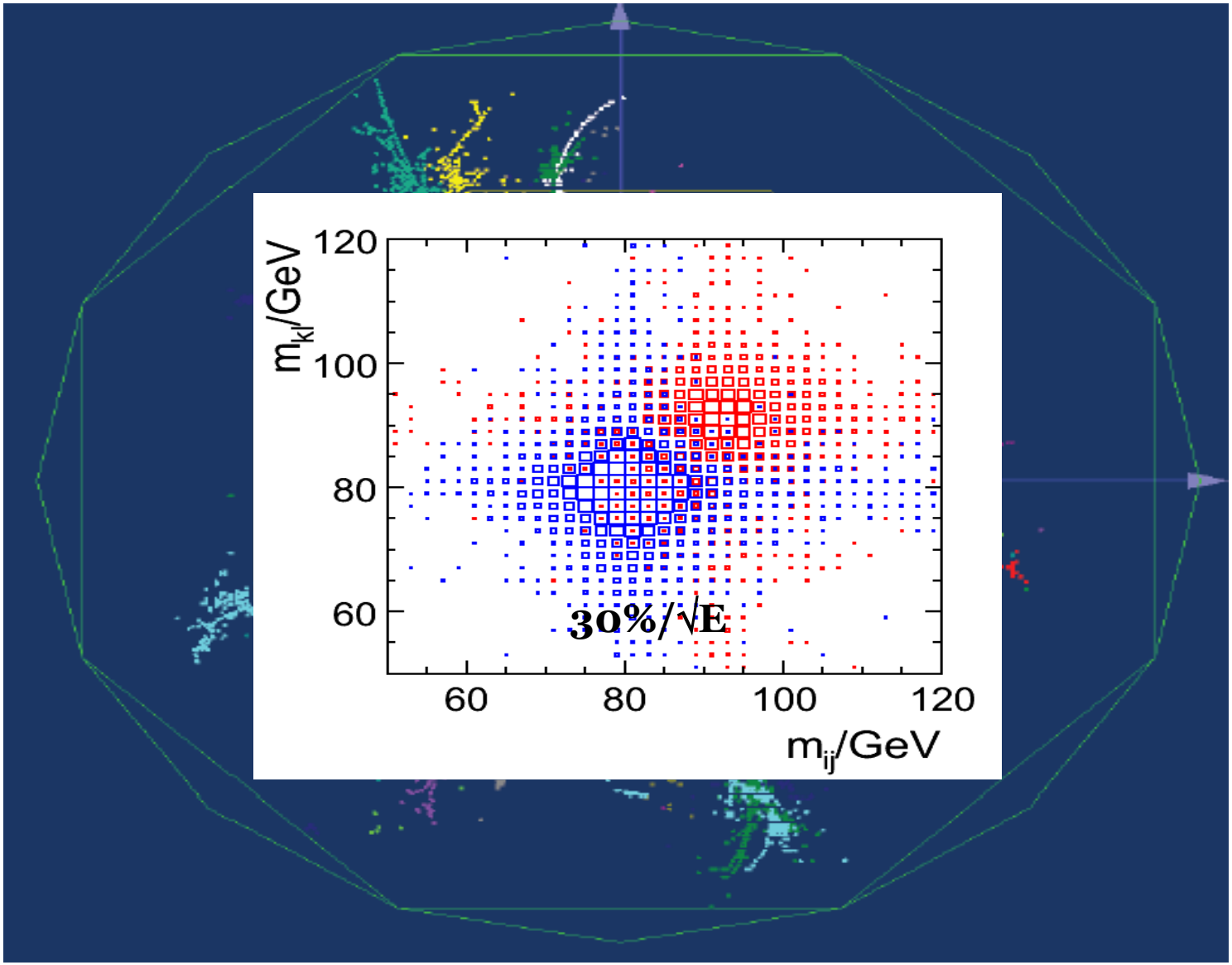
Born in 2005 to provide the needed environment to develop a new generation of calorimeters for the new linear $e^+ e^-$ experiments for which new techniques are proposed: the **P**article **F**low **A**lgorithms (**PFA**)

The PFA techniques try to separate the contribution of each of the produced particles in a collision and then use the right sub-detector for the right energy/momentum measurement. This leads to an optimal **J**et Energy Resolution(**JER**)
and an optimal reconstruction of the event.

A view of a simulated event in a high granularity detector



A view of a simulated event in a high granularity detector



Going granular

For PFA the finer the better but:

ECAL: X_0, ρ_M (length scale &Moliere Radius)

- in W: $X_0 \sim 3.5$ mm, $\rho_M \sim 9$ mm
- in Fe: $X_0 \sim 18$ mm, $\rho_M \sim 17$ mm

W is better in the ECAL to separate close-by photons and also longitudinal EM/had contributions.

HCAL: length scale ~ λ_I, but EM sub-showers impose requirements not too much different than in ECAL.

- in W: $\lambda_I \sim 11$ cm
- in Fe $\lambda_I \sim 17$ cm

However, robust mechanical structure and abundant neutrons production favors Iron.

CALICE technologies

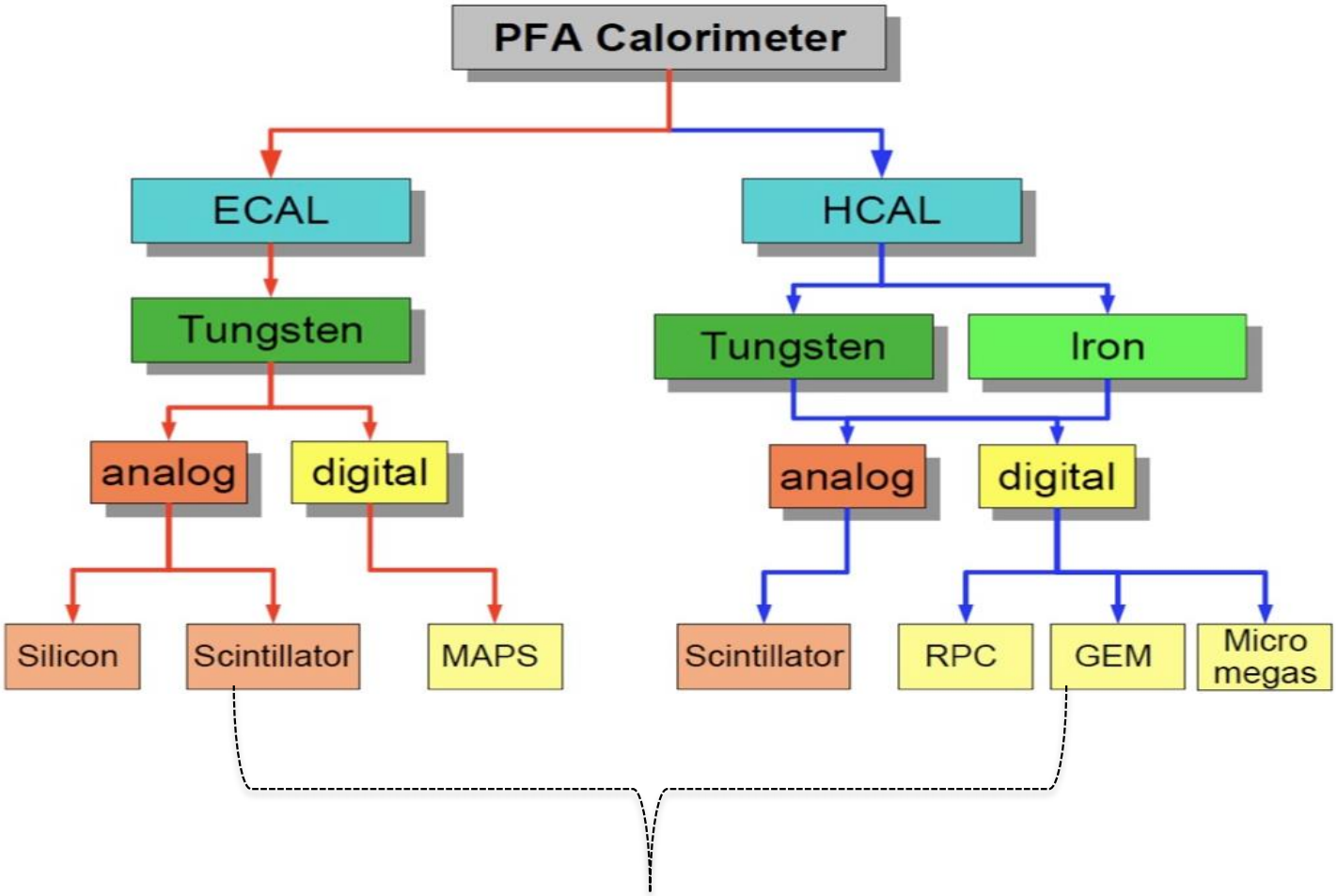
Highly granular calorimeters require enormous number of electronic channels

→ Cost and power consumption issues

PFA calorimeters require full active zones

→ Embedded electronics and integration issues

These challenges are addressed by the CALICE groups for the different proposed technologies. Common issues are addressed in the collaboration



Common readout electronics, common DAQ

Prototypes

Physics

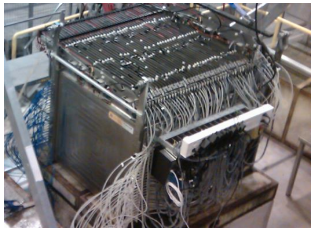
Granularity
Proof of principal

Technological

Power-pulsed
Embedded electronics
compactness

Si-W

DHCAL

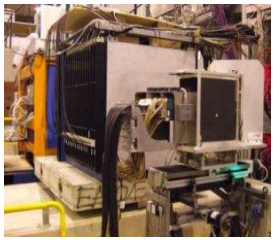


SDHCAL

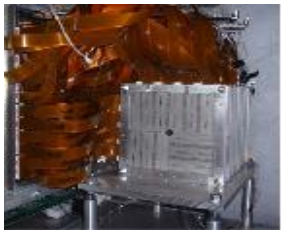
Si-W →

2005 2007 2010 2011 2012 2018

AHCAL



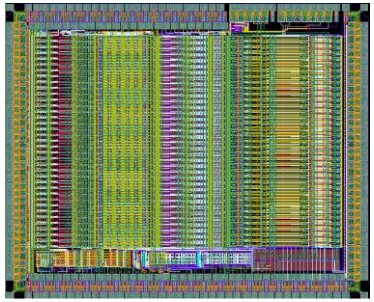
Scint-W



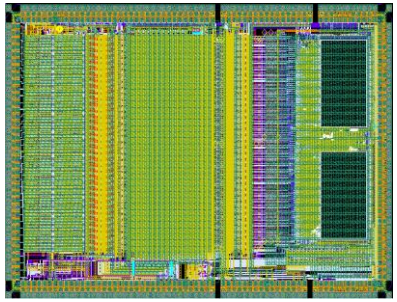
AHCAL

-SDHCAL was operated also by adding 4 Micromegas layers in 2012
-DHCAL and AHCAL were operated with tungsten absorber in 2012
-Devices to measure timing were added to AHCAL, SDHCAL to study shower time evolution
-FOCAL (MAPS technology) was tested in 2016

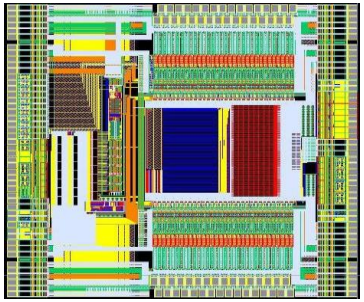
Most of the readout electronics and the DAQ system were developed in common within CALICE: first, second and third ROC generations.



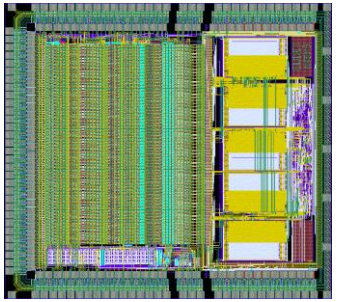
SKIROC
(SiW)



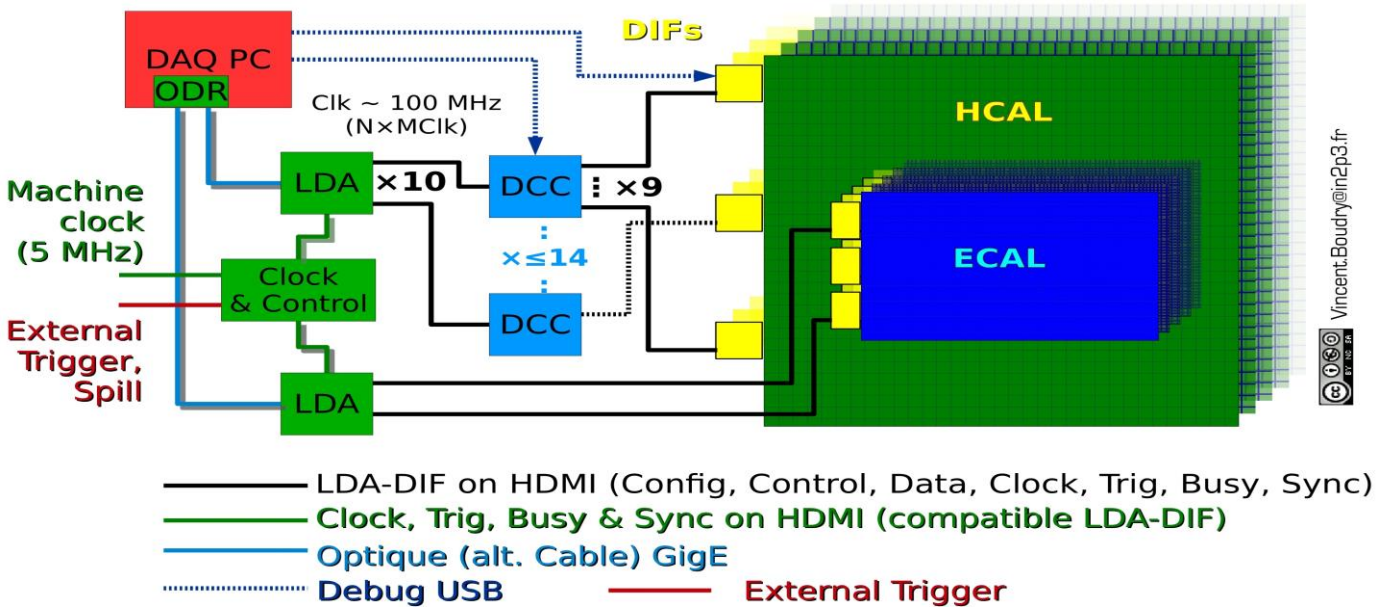
SPIROC
(AHCAL-Scint-W)



DCAL

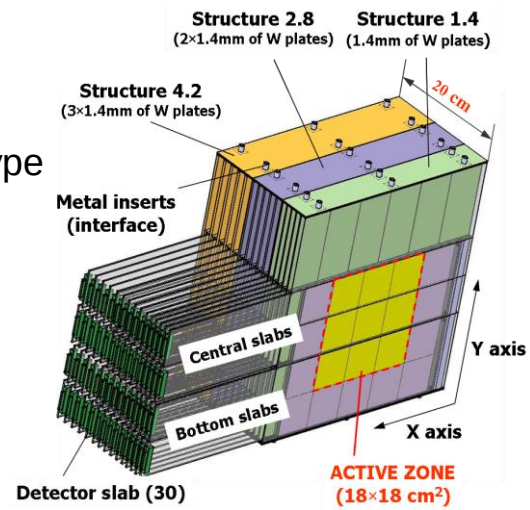


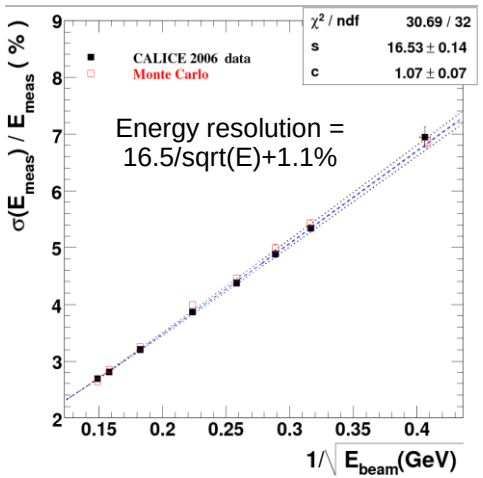
HARDROC



SiW ECAL

30 layer ($24X_0$) silicon-tungsten physics prototype (1x1 cm^2 cell size) with a deported electronics was built and successfully tested.

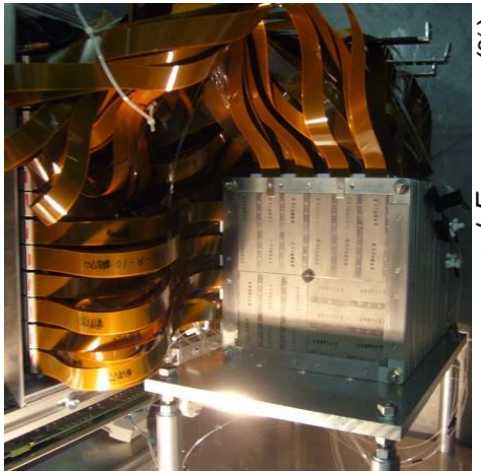


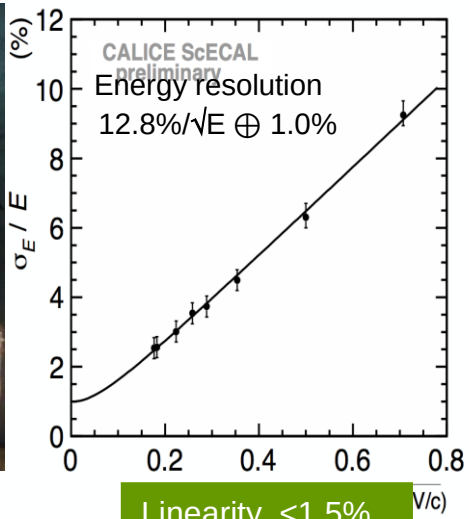


Linearity <1%

Scint-W ECAL

30 layers of tungsten ($24X_0$) interleaved with of 5x45 mm^2 scintillator strip with alternating Direction layers (X&Y) → equivalent of 5x5 mm^2 (SSA) read out by SiPM. A physics prototype with a deported electronics was built and successfully tested



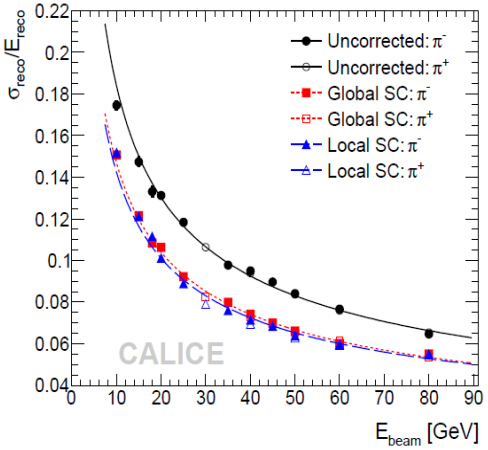


Linearity <1.5%

AHCAL

48 layers of 2 cm stainless steel interleaved with planes made of 3x3 cm^2 tiles, read out directly by SiPM and embedded electronics.

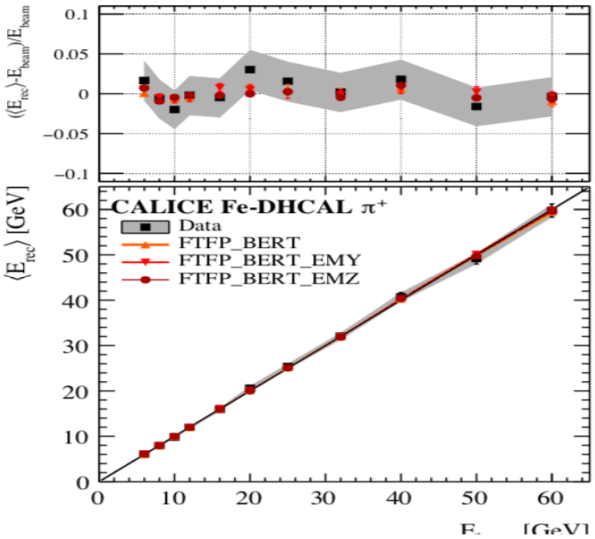
A physical prototype of 38 layers of 1 m^2, totalizing (5.3 λ_I) accompanied by a tail catcher (6 λ_I) with deported electronics was built and Successfully tested.



SC –based energy reconstruction improves on the resolution

DHCAL

A prototype of 50 layers each made of 3 RPC covering 1 m^2 and read out by 1 cm^2 pads With embedded electronics was successfully tested.



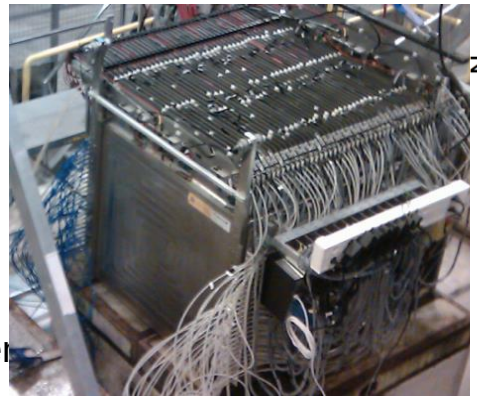
(b) $\langle E_{rec} \rangle$

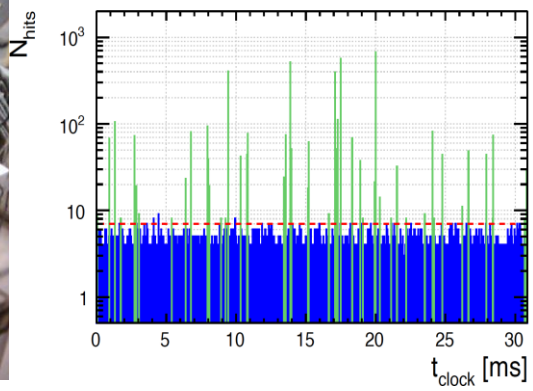
Technological prototypes

SDHCAL technological prototype

First technological prototype (2011->)

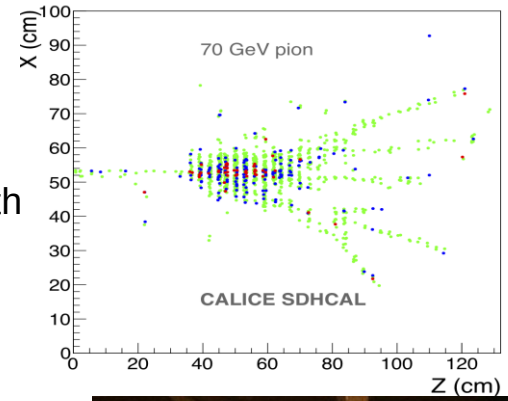
48 layers of 2 cm stainless steel interleaved with planes made of Glass RPC and their embedded readout 2-bit electronics allowing a lateral segmen of 1 cm^2

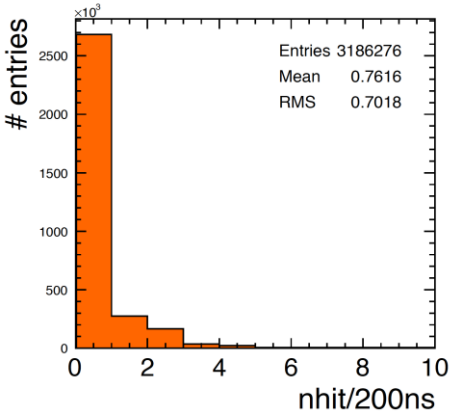




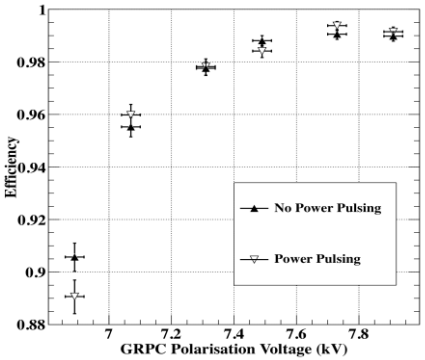
A technological prototype of 48 fulfilling almost all the ILD requirements of compactness and power consumption was built with a self-supporting mechanical structure. It ws successfully tested with

- Triggerless mode
- Power-pulsing mode
- Self-supporting mechanics
- No-dead zone





The GRPC was also successfully tested in a magnetic field of 3 T using the power-pulsing mode

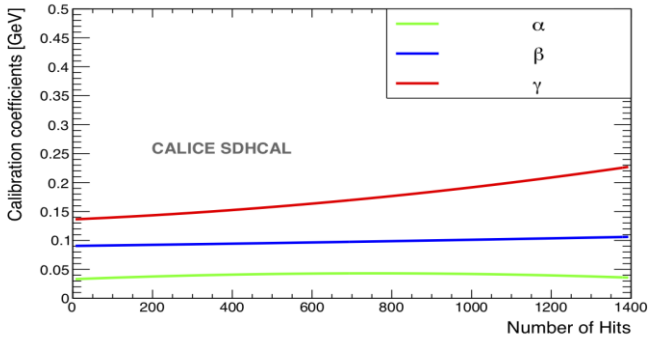


Energy reconstruction

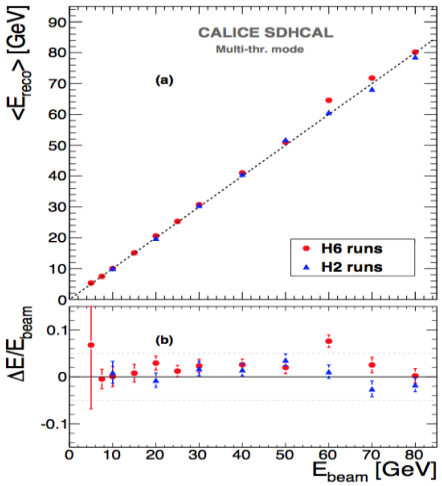
The thresholds weight evolution with the total number of hits obtained by minimizing a χ2:

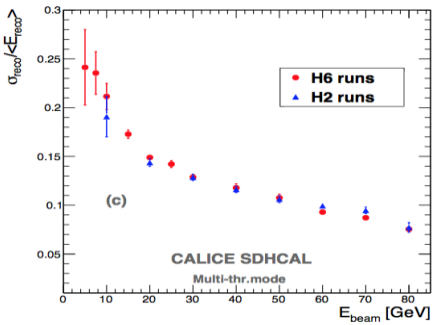
$\chi 2 = (E_{beam}-E_{rec})^2/E_{beam}$

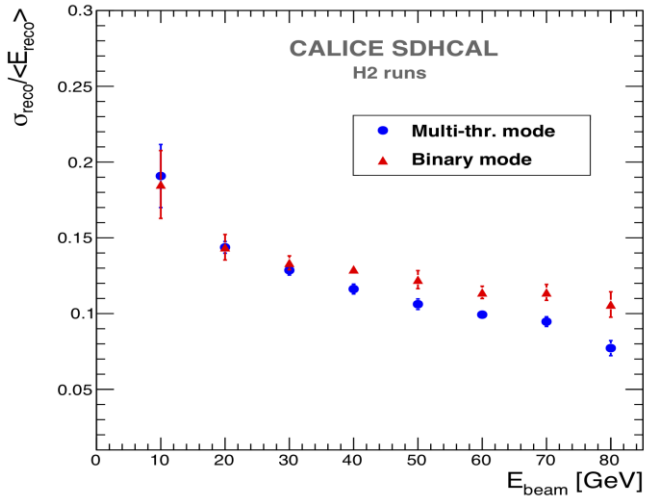
$E_{rec} = \alpha(N_{tot})\, N_1 + \beta(N_{tot})\, N_2 + \gamma(N_{tot})\, N_3$



N_1,N_2 and N_3 : exclusive number of hits associated to first, second and third threshold.
α, β, γ are quadratic functions of the total number of hits (N_{tot})

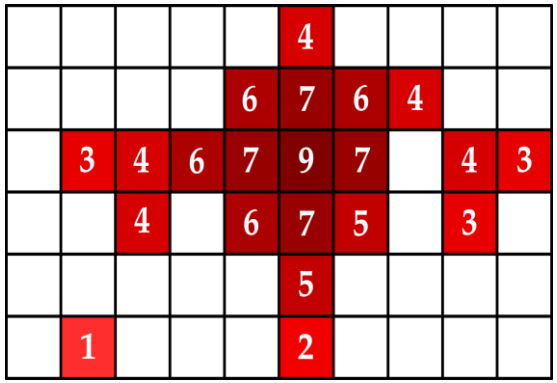






Third threshold hits are related essentially to the EM part. Their weight increases with energy to compensate for the saturation effect.

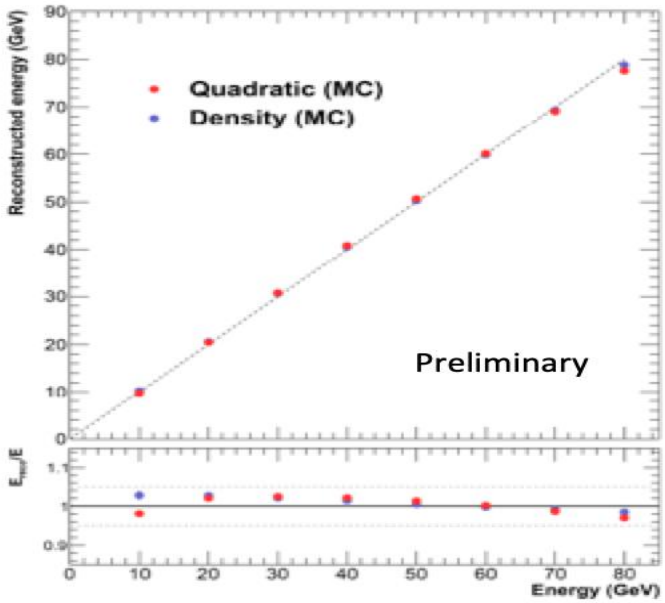
New SDHCAL energy Reconstruction

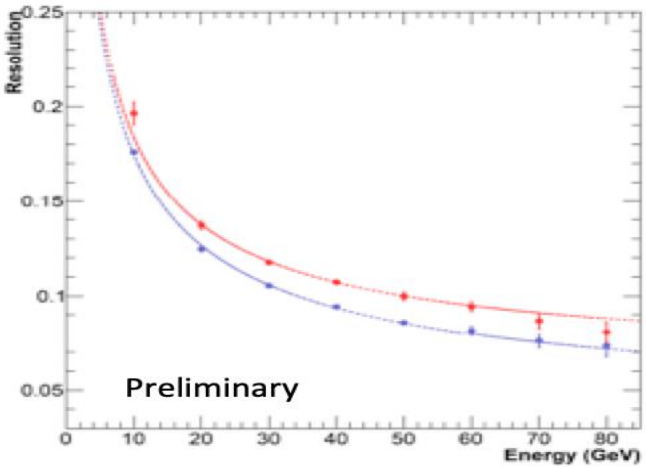


→ In addition to the three thresholds information density information could be very useful

$$E_{dens} = \sum_{i} \sum_{d} \alpha_{id} N_{id}$$

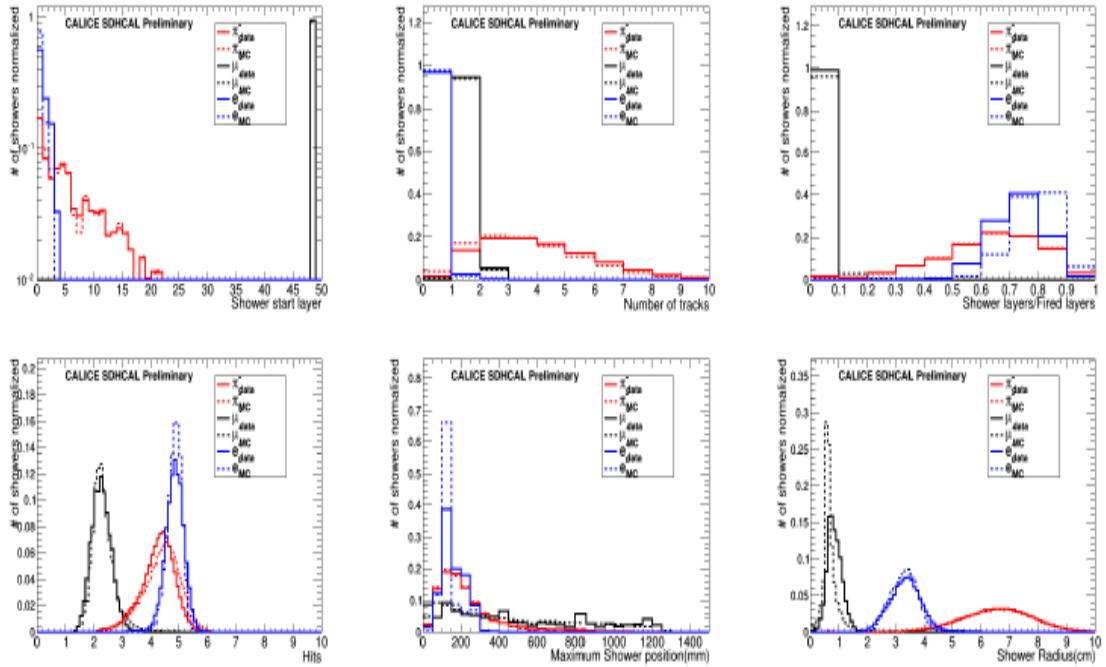
$$i \in \{1,2,3\} \quad d \in \{1 \ldots 9\}$$

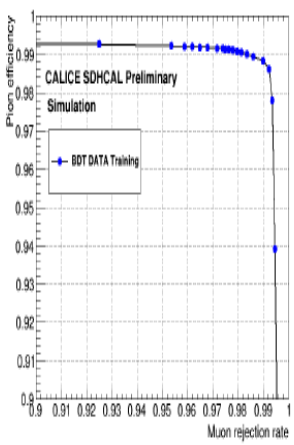


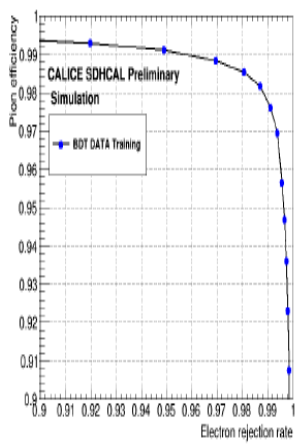


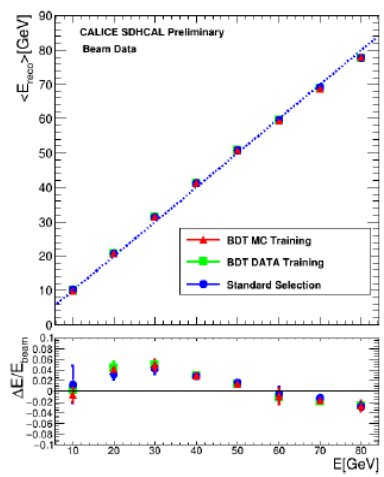
SDHCAL Particle Ident

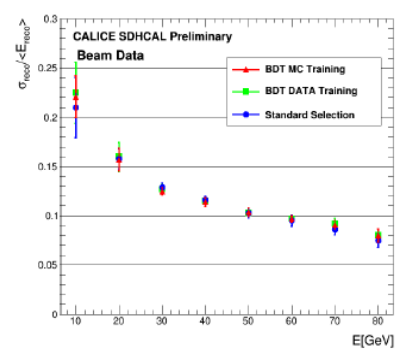
6 variables discriminating the Different species of particles : hadrons, electrons and muons were used to train a BDT on both MC and data and then the BDT was used to keep hadrons (absence of Cernkov detector in front of SDHCAL).











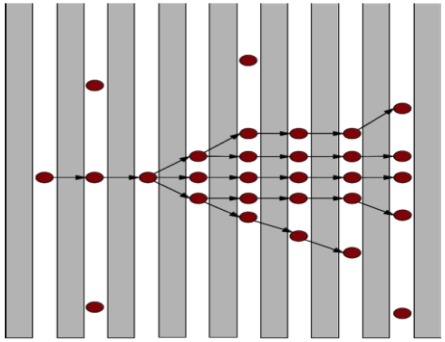
CALICE-CAN-2019-001

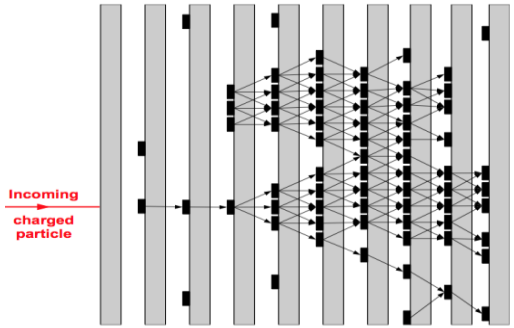
Arbor-Lyon@SDHCAL

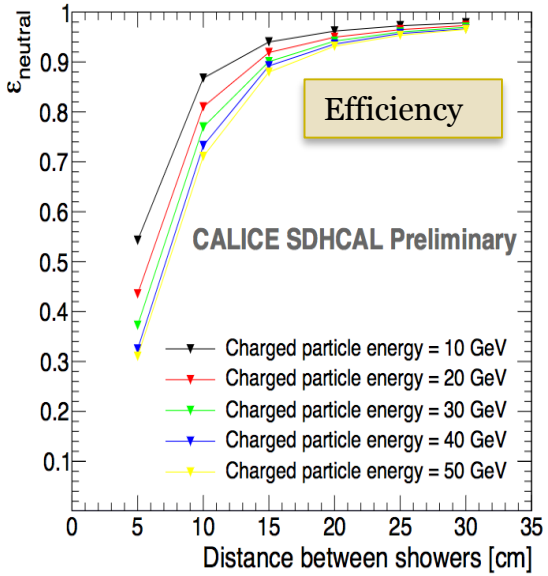
Granularity helps to optimize the connection of hits belonging to the same shower by using first the topology and then the energy information

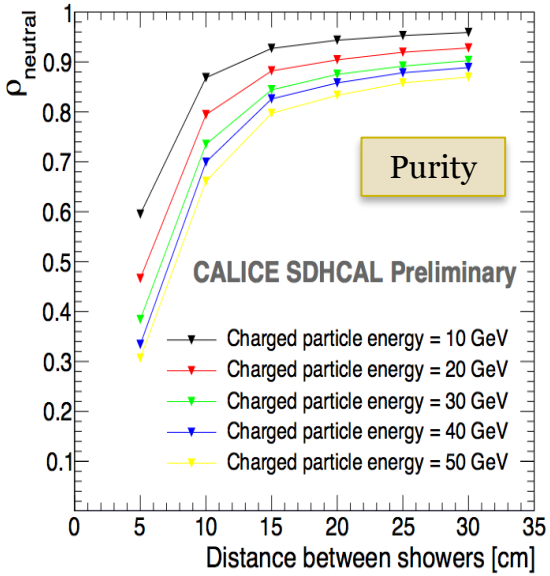
ArborPFA algorithm:

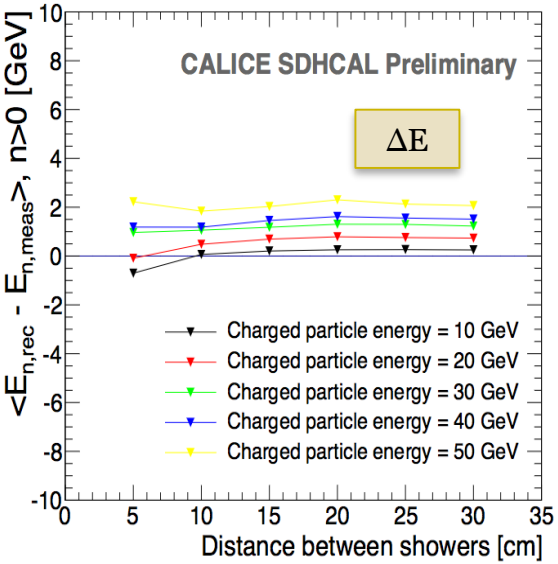
It connect first the hits and then the clusters using distance and orientation information then correct using tracker information





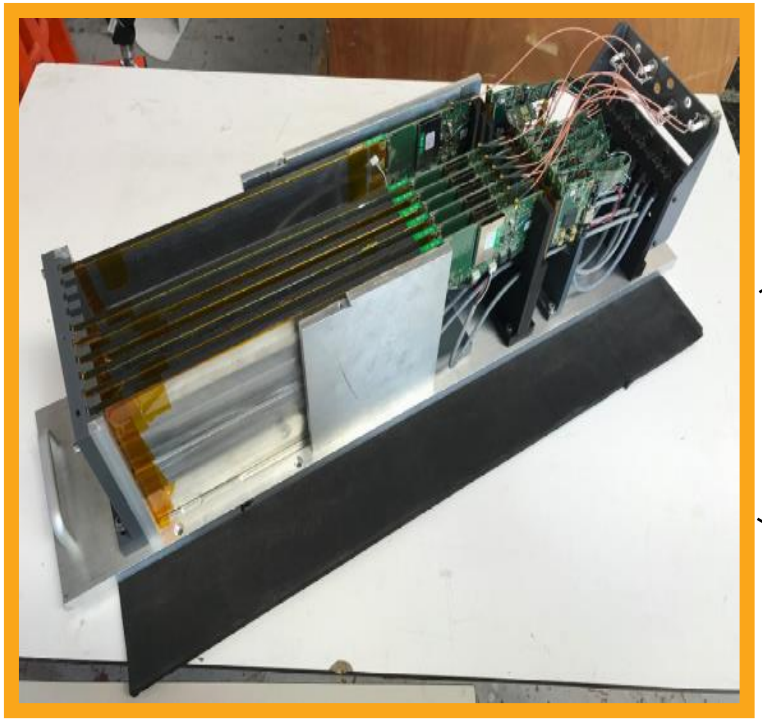


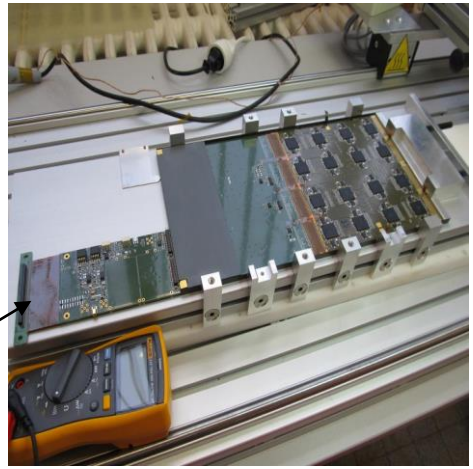




CALICE note CAN054

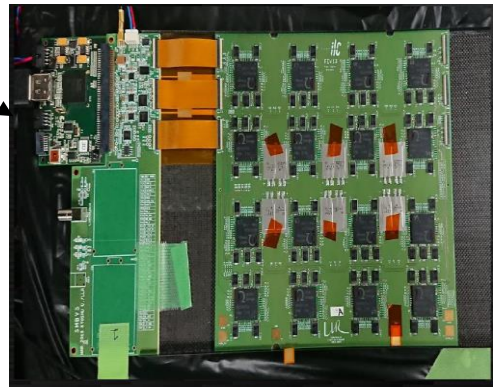
SiW Ecal technological stack for beam tests





PCB FEV12

with long adapter card
Wafer thickness
325 µm



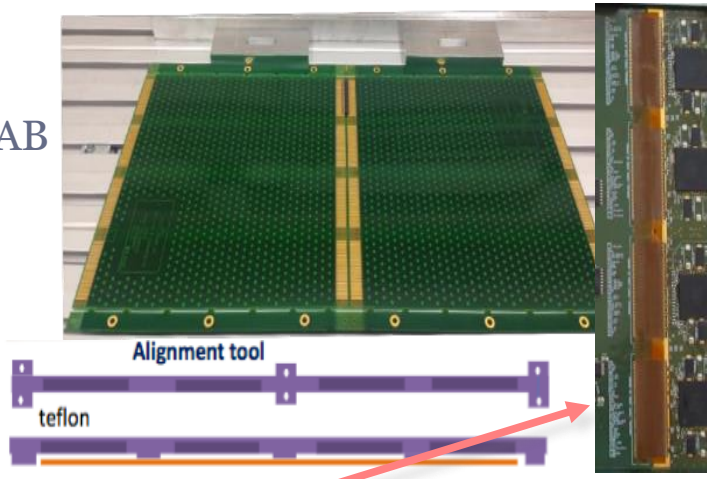
PCB FEV13

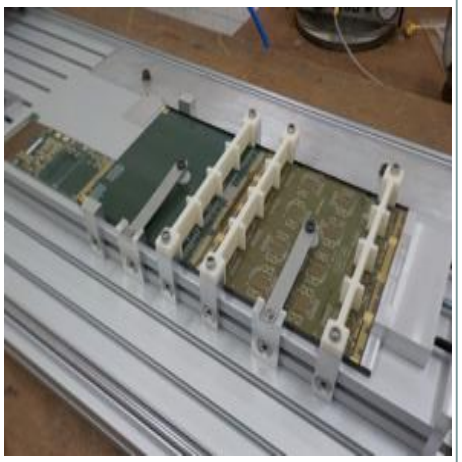
with small adapter card
Wafer thickness
650 µm

- Total ~15 layers constructed
- 1024 channels per layer
- Assembly chains in France and Japan
- Beam tests at DESY and CERN since 2016

Assembly bench for:

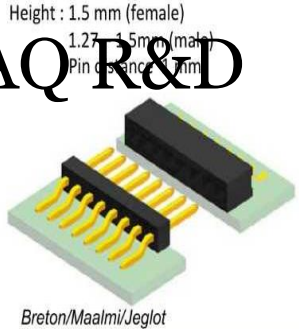
- Fragile Wafer
- Precision of PCB's ~ 50µm
- ⇒ precision of 100µm on SLAB
- Interconnection

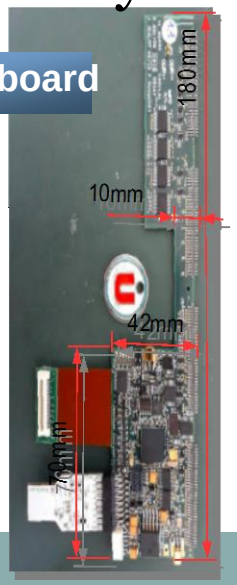


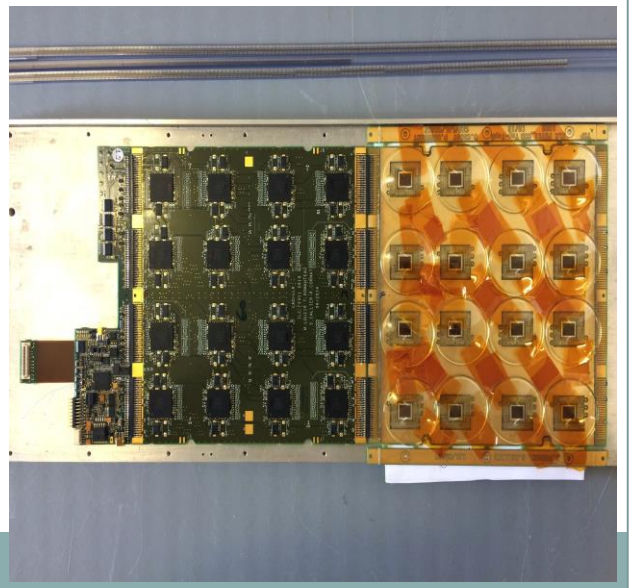


Connections to be handled by industry

- Dedicated Kaptons ✗
- Connectors





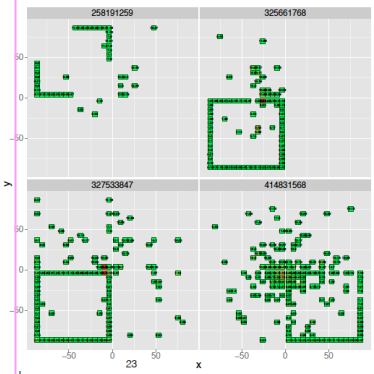


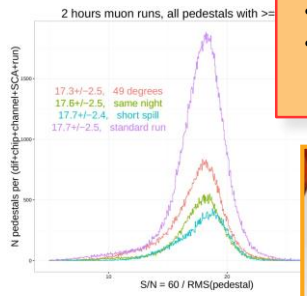
End of Slab and DAQ R&D

Beam-test 2015–2018

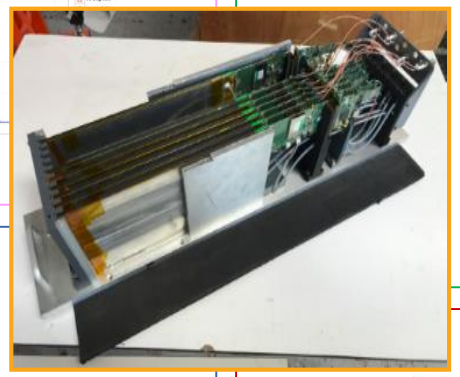
CERN 2015

"Naked FEV11"





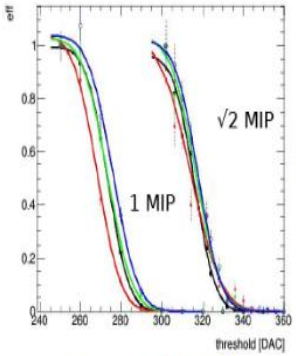
S/N_{ADC} = 16–17
(MIP – ped) / σ_{ped}
Defaults cataract :
- Negative signals
- re-triggers
- ~ high thr.
- sq events / 10

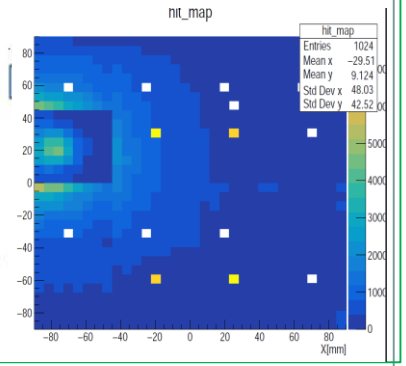


DESY 2018

7 FEV11 + 1 FEV13(650µm)

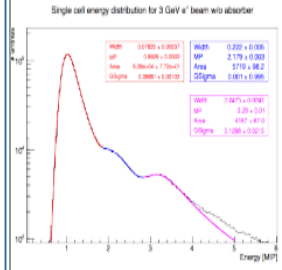
S/N_{Trig} ~ 11.6.±0.7
Trigger → ~1/3 mip (est.)
First comm. of FEV13
S/N_{ADC} ~ 30-40

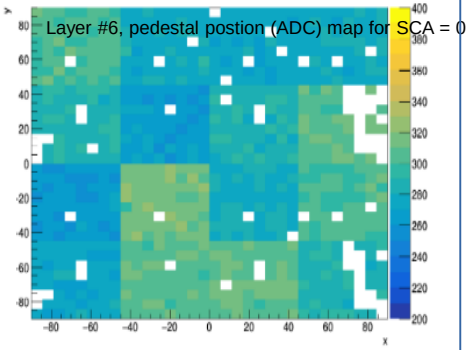


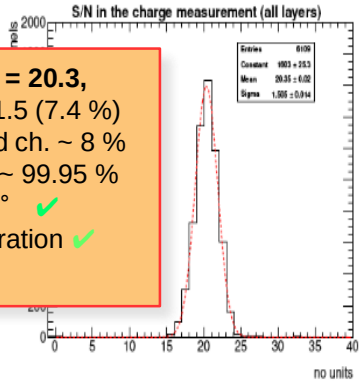


DESY 2017

7 FEV11





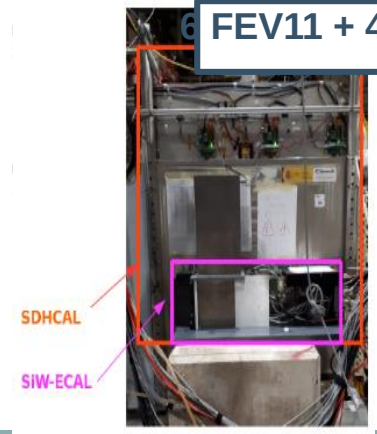


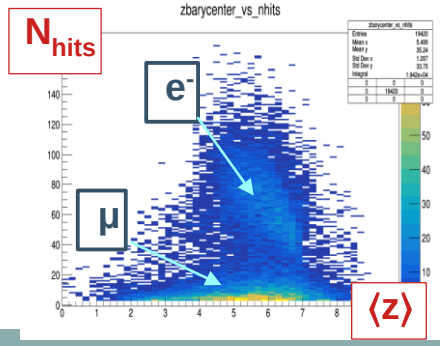
S/N_{ADC} = 20.3,
$\sigma_{S/N}$ = 1.5 (7.4 %)
masked ch. ~ 8 %
Hit eff. ~ 99.95 %
0° , 45° ✔
1T operation ✔

CERN 2018

Masked ch (FEV11) ~ 4 %

FEV11 + 4 FEV13(320 & 650µm) + 24X_0 W



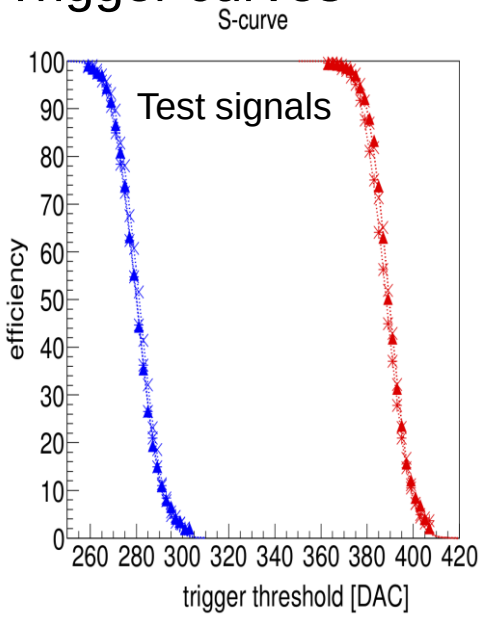


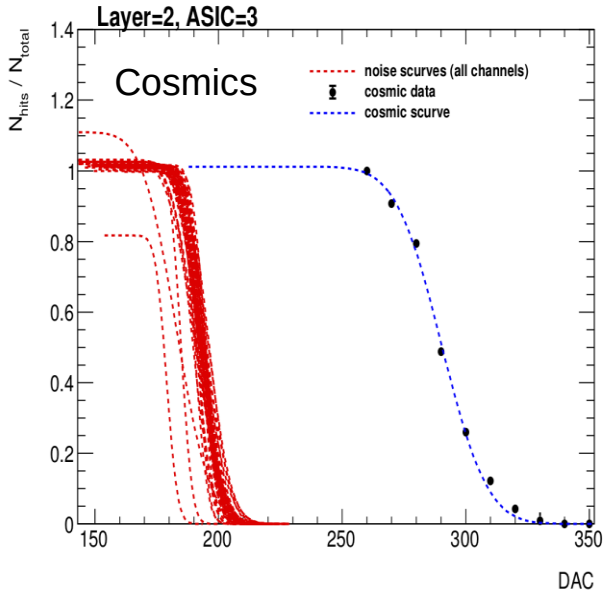
SiW Ecal – Performance at MIP Level I

Objectif: Trigger and readout of small signals, design criterion: S/N ~ 10:1

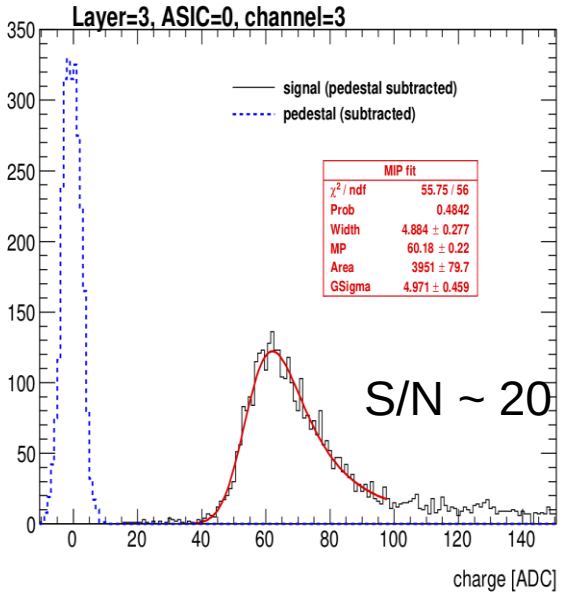
Arxiv:1810.05133

Trigger curves





Charge

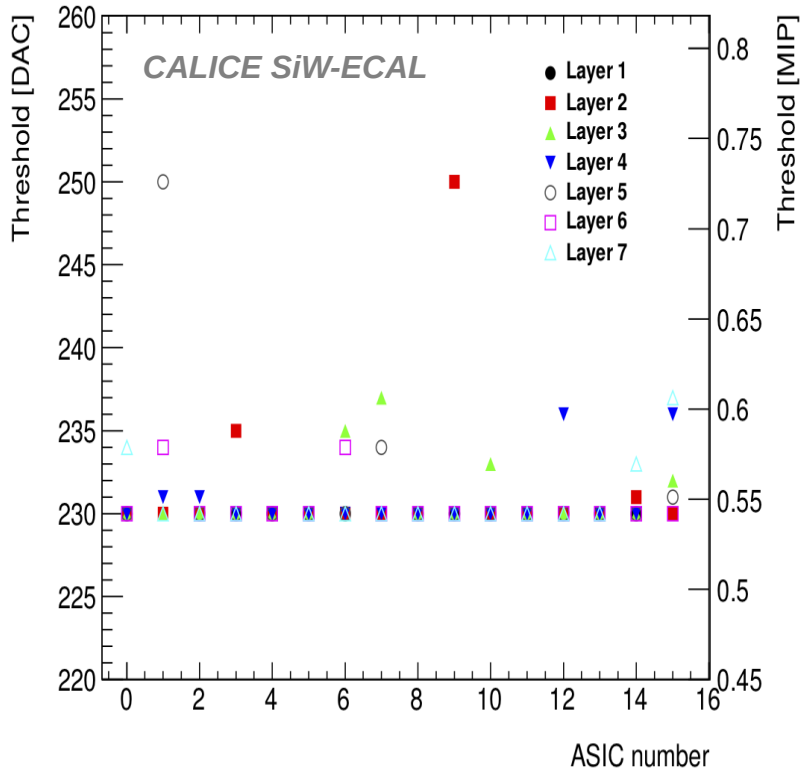


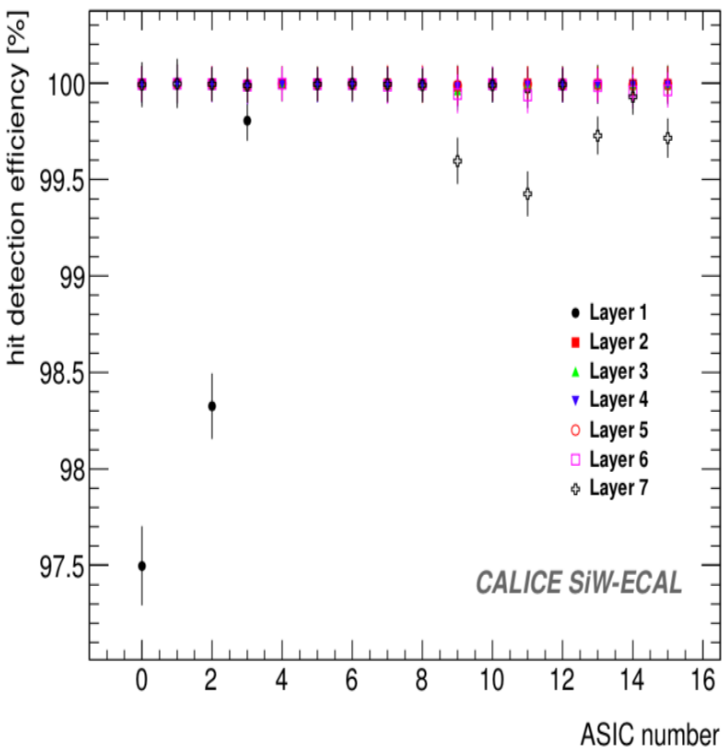
- S/N ratio from relative position and width of threshold curves
- Result here S/N ~12.9±3.4
- Dedicated runs in 2018 TB, Analysis ongoing

Ability to trigger on small signals and to read them out for analysis

SiW Ecal – Performance at MIP Level II

Arxiv:1810.05133





Trigger thresholds uniform at around 1/2 MIP

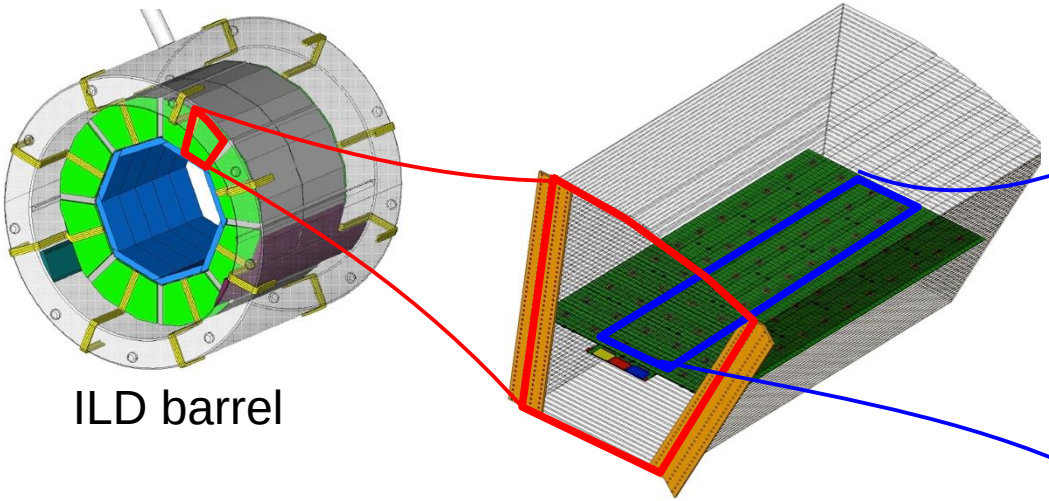
MIP Detection efficiency ~100%

PFA requires:

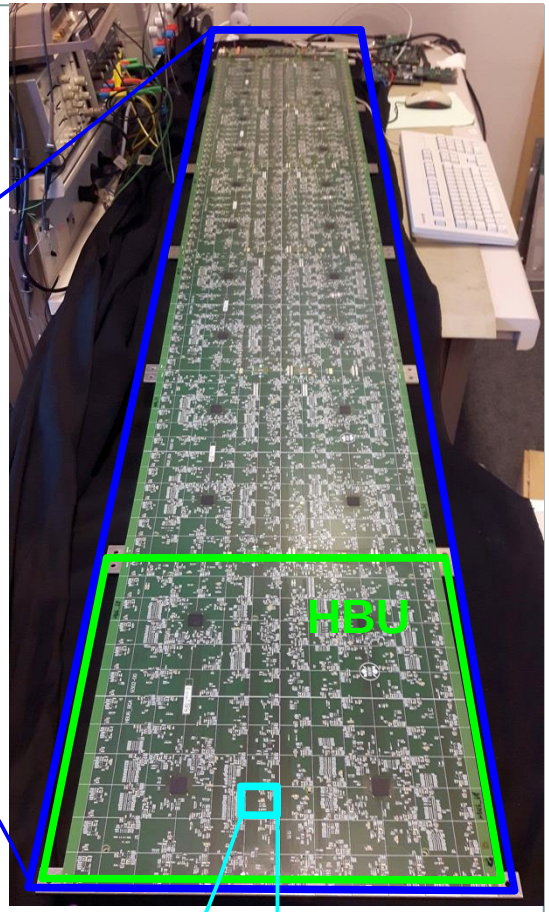
a) Access to small signals -> Low trigger thresholds ✔

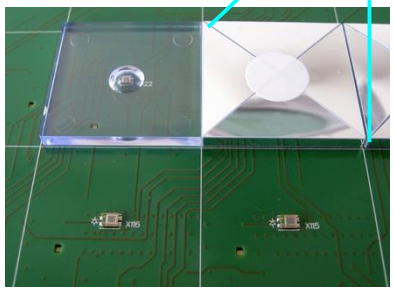
b) Tracking in calorimeters -> High MIP detection efficiency ✔

AHCAL Technolgical Prototype



ILD barrel



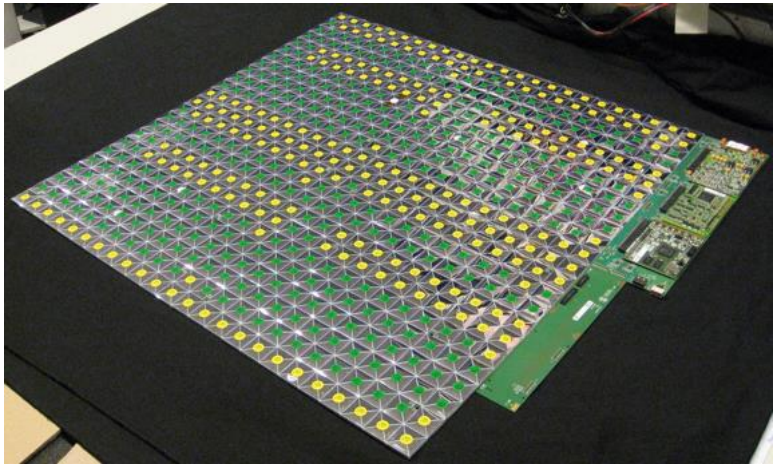


- highly granular scintillator SiPM-on-tile hadron calorimeter, 3*3 cm² scintillator tiles
- fully integrated design
  - front-end electronics, readout
  - voltage supply, LED system for monitoring
  - no cooling within active layers
- scalable to full detector (~8 million channels)
- **H**CAL **B**ase **U**nit: 36*36 cm², 144 tiles, 4 ASICs
  - slabs of 6 HBUs
  - up to 3 slabs per layer

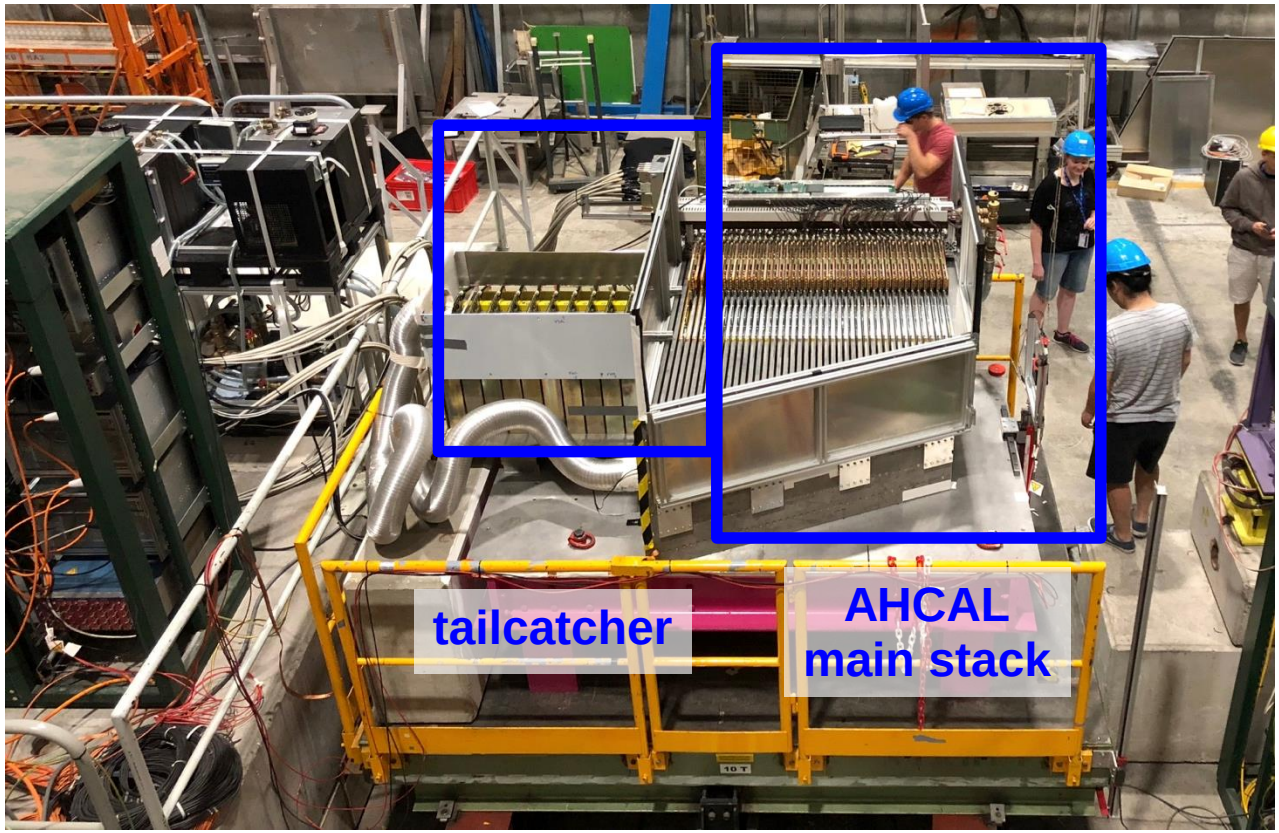
AHCAL Technolgical Prototype

Since 2018

- >38 active layers of 72*72 cm²
- >4 HBUs per module
  - 16 SPIROC 2E readout ASICs, 576 channels of 3*3 cm² tiles
- in total: 608 ASICs, ~22000 channels
- >all modules with surface-mount MPPCs
- S13360-1325PE
  - 2668 pixels (3x physics prototype (PP))
  - operated at 5V overvoltage
    - 50% less temperature sensitivity w.r.t. PP
  - nominal operation voltage within 200mV in a module -> use same voltage
    - Simplified set-up
    - Layer-wise regulation
  - About 3 orders of magnitude less noise
- >steel absorber stack corresponding to ~1% of ILD barrel



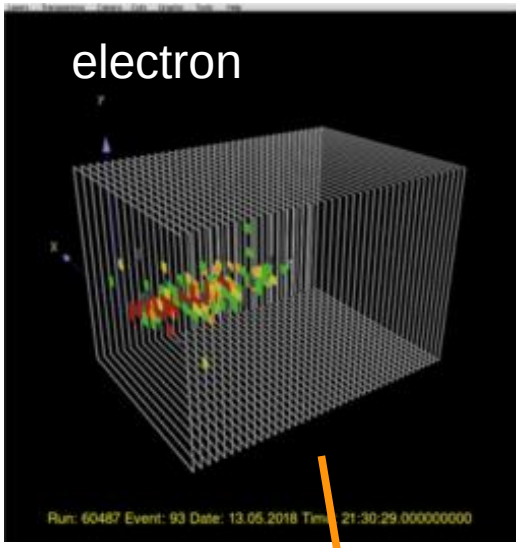
Testbeam Setup 27. June – 4. July 2018 in H2 at SPS

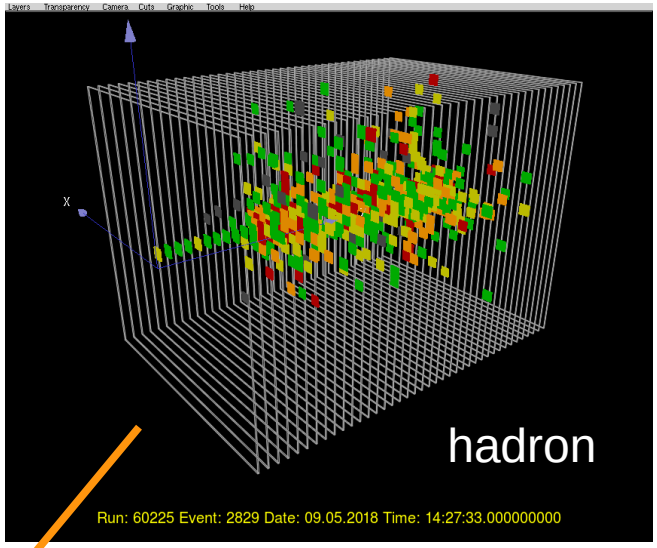


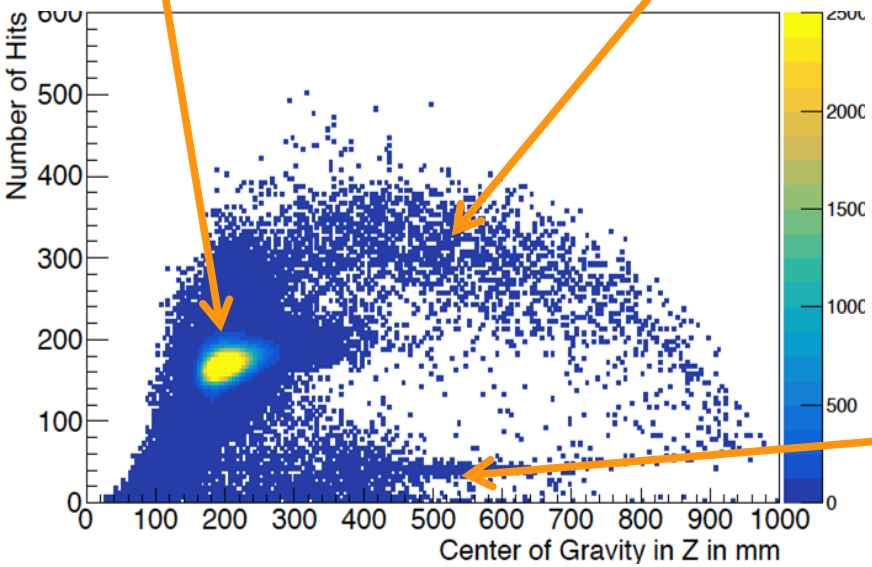
>as in May, plus:

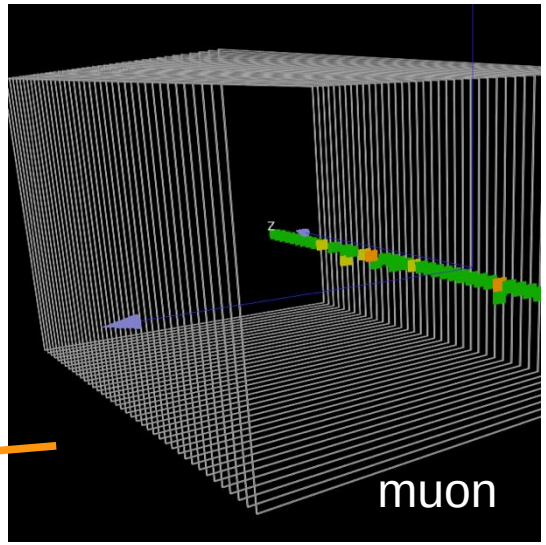
- added one module with 6*6 cm2 tiles (prototype for rear layers)
  - added CMS HGCAL “thick stack” (12 layers of 1 HBU, 7.4 cm steel absorber) as tailcatcher
- added single HBU in front of absorber as “pre-shower” detector

Event Displays and Online Monitoring

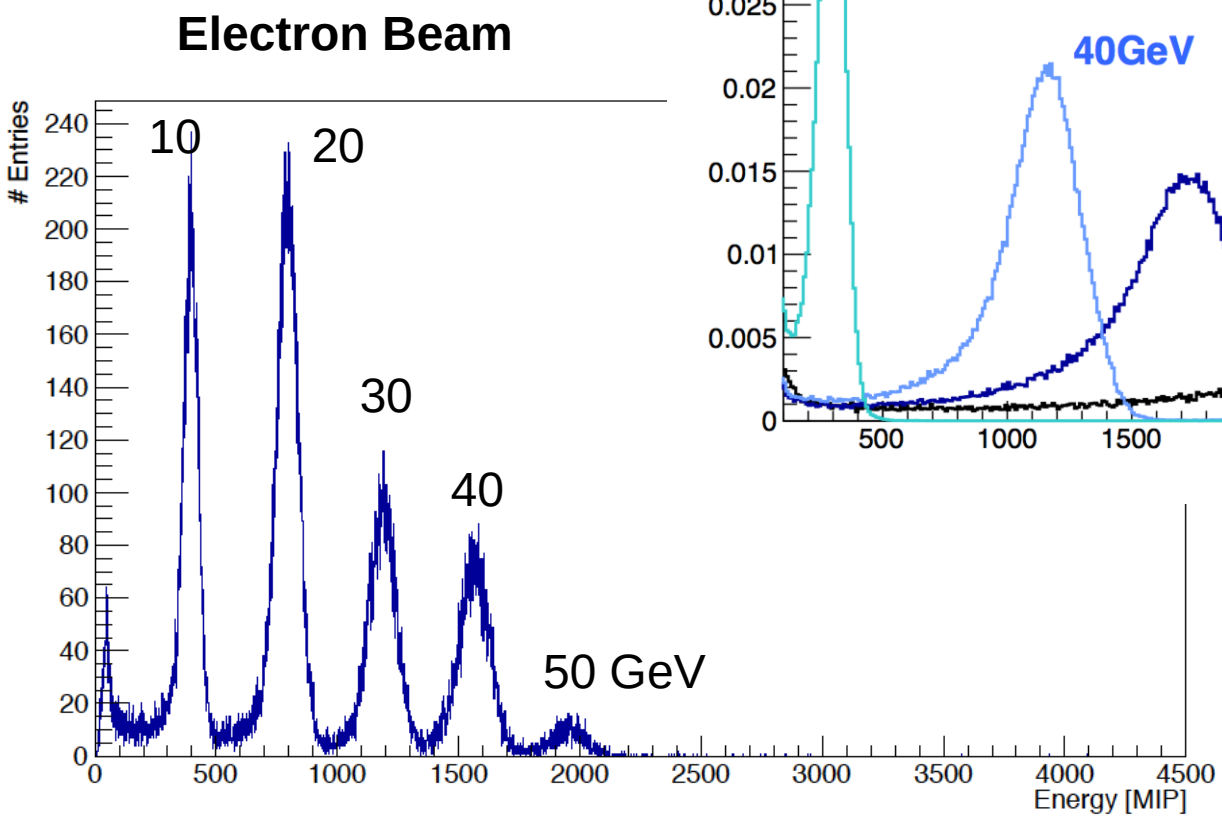


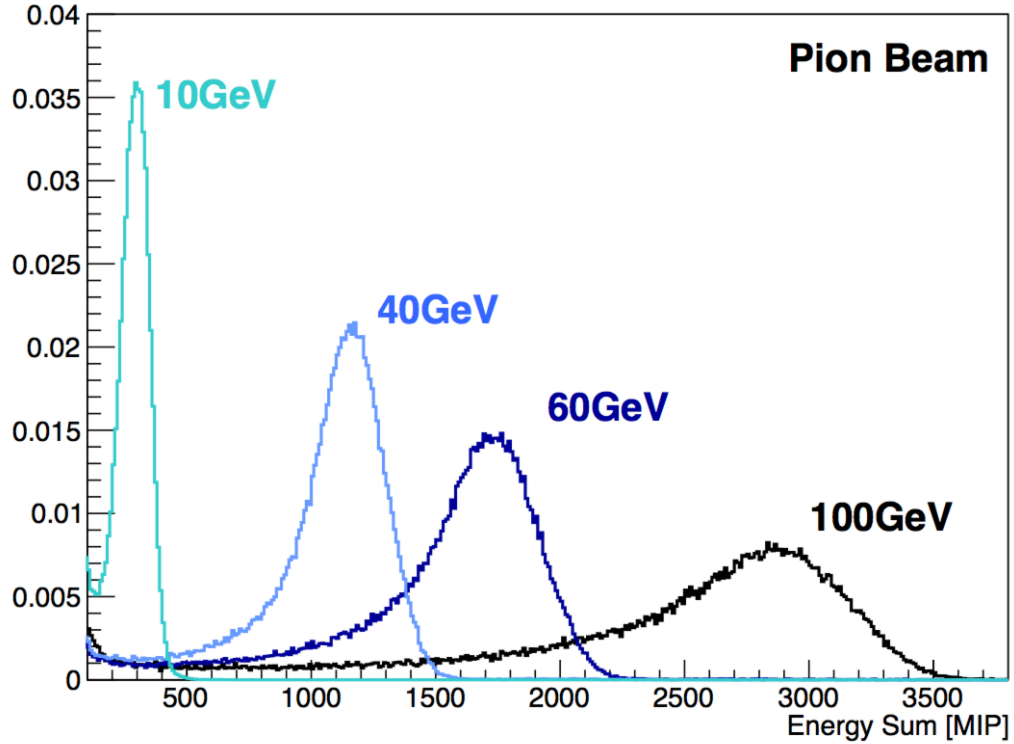




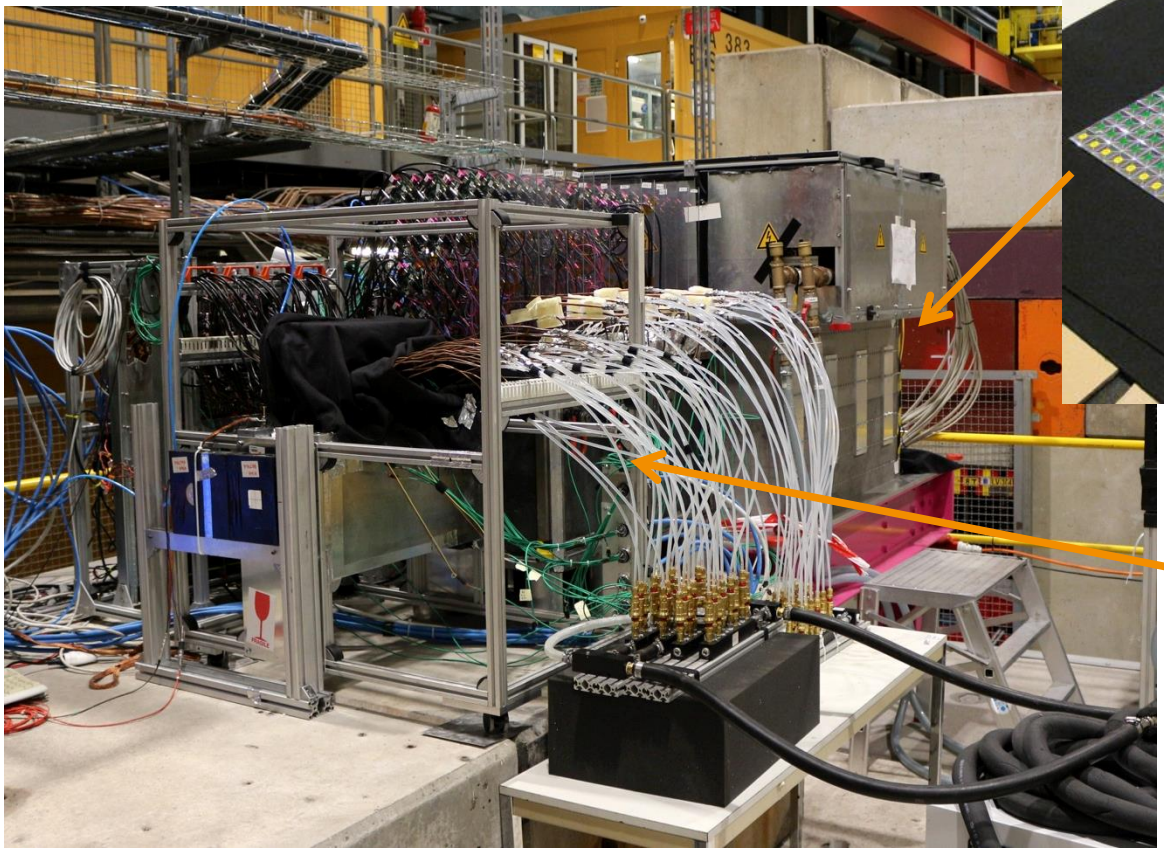


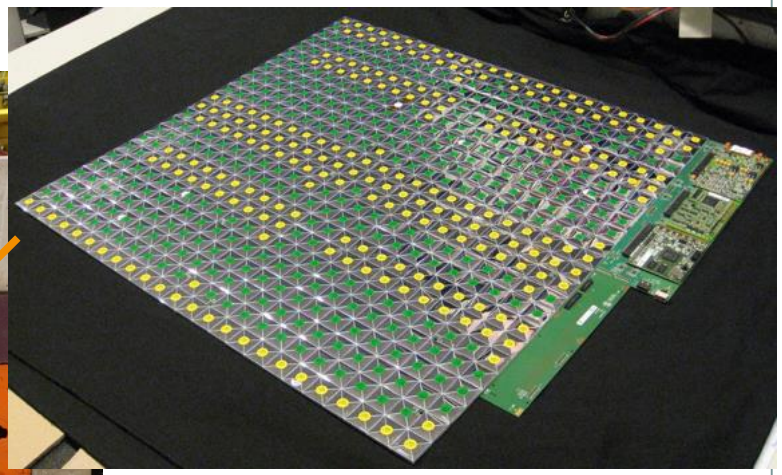
Online Monitoring: Energy Sums

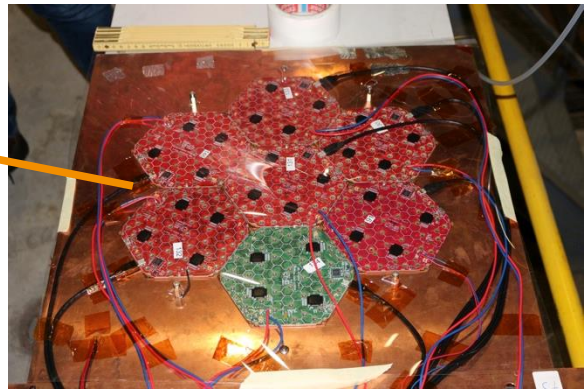




Combined Testbeam: CMS HGCAL + CALICE AHCAL

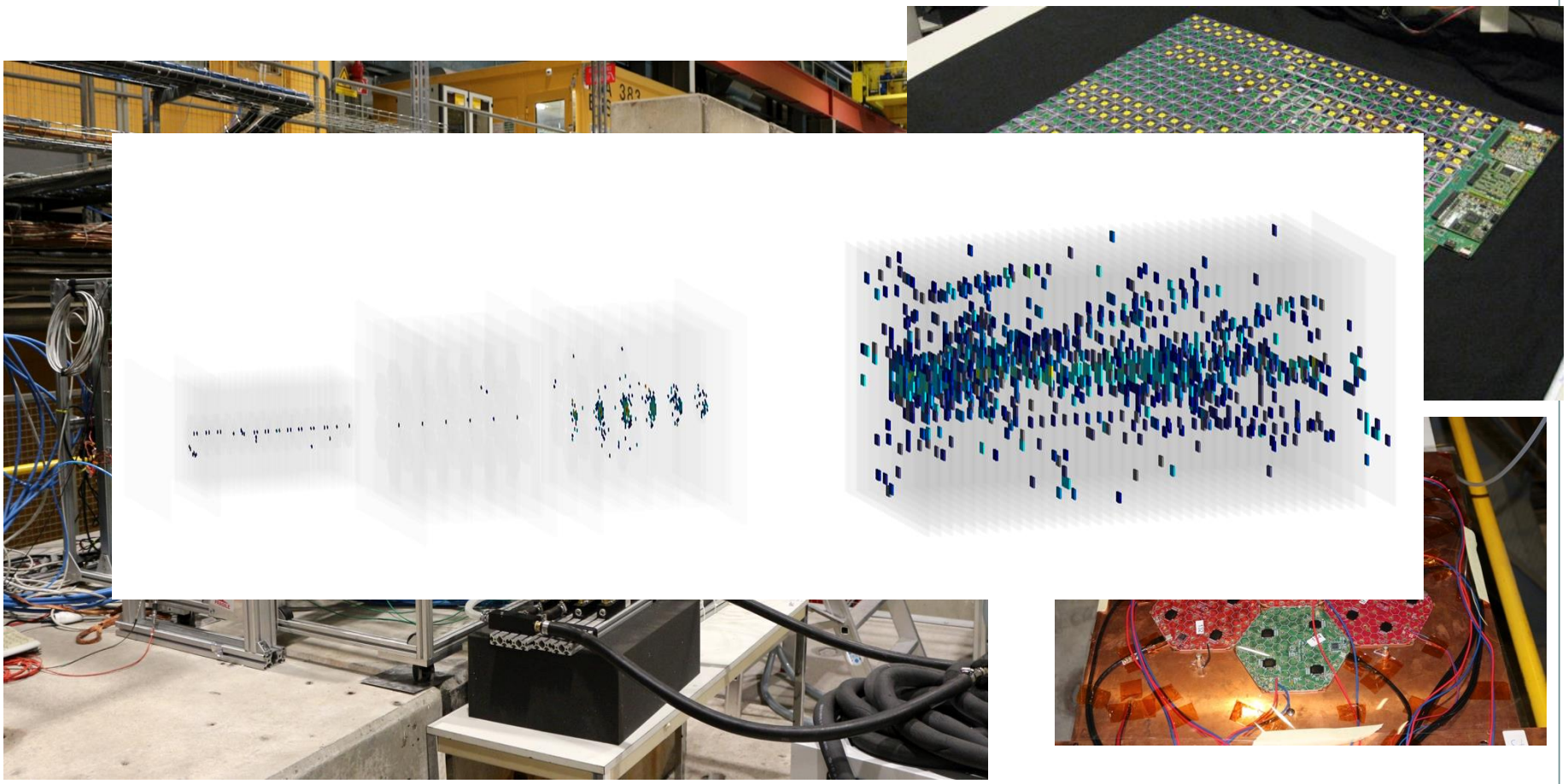






- 2 weeks of combined testbeam at CERN SPS in October 2018
- 28 layers HGCAL EE (silicon/lead), 12 layers HGCAL FH (silicon/steel), 39 layers AHCAL (scintillator/steel); common DAQ: EUDAQ2
- important test of concept, important information for simulation of showers

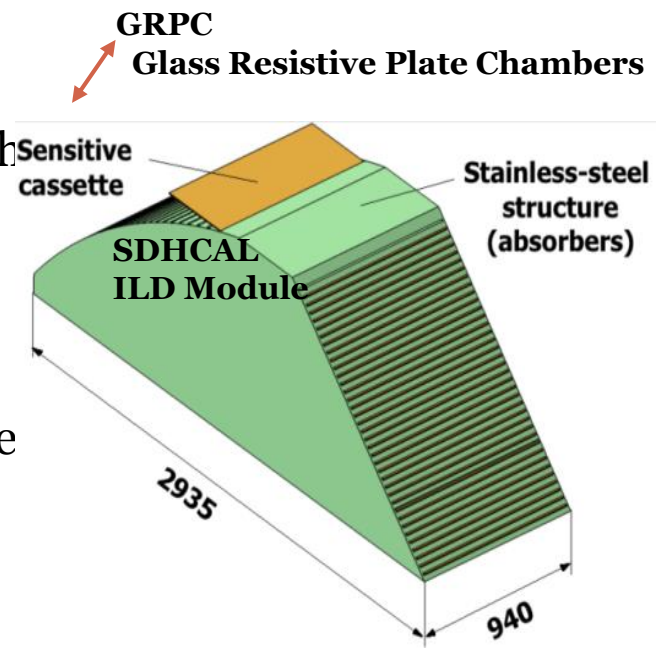
Combined Testbeam: CMS silicon HGCAL CALICE AHCAL



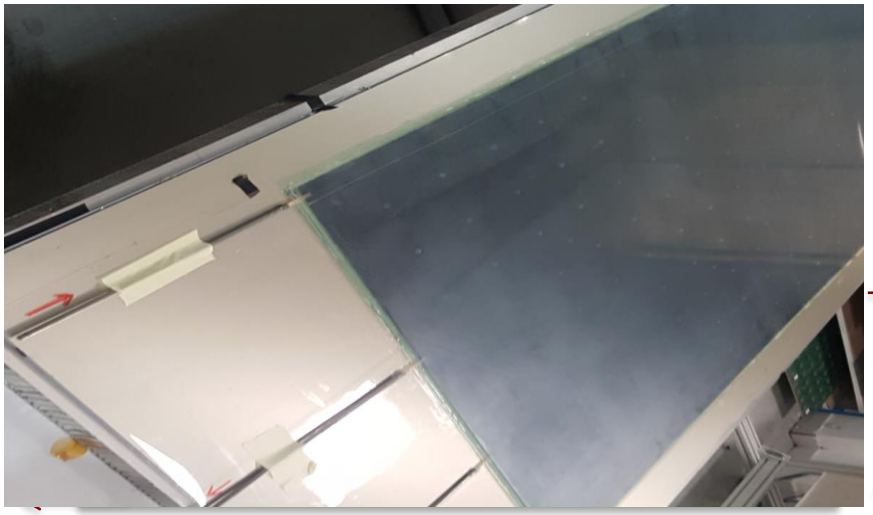
- 2 weeks of combined testbeam at CERN SPS in October 2018
- 28 layers HGCAL EE (silicon/lead), 12 layers HGCAL FH (silicon/steel), 39 layers AHCAL (scintillator/steel)
- important test of concept, important information for simulation of showers

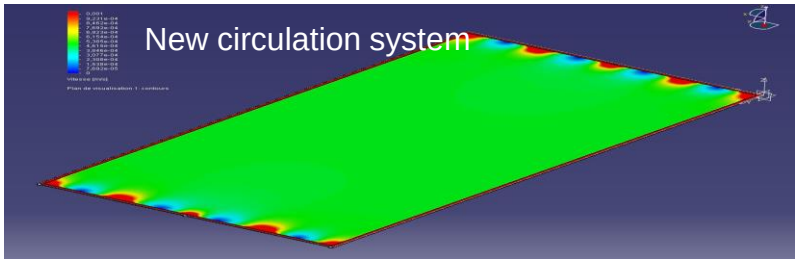
Towards SDHCAL Module0

- Detectors as large as 3m X 1m need to be built
- Electronic readout should be the most robust with minimal intervention during operation.
- DAQ system should be robust and efficient
- Mechanical structure to be similar to the final one
- Envisage new features such timing, etc..



Large detector with new gas distribution scheme





New readout electronics (HARDROC3)

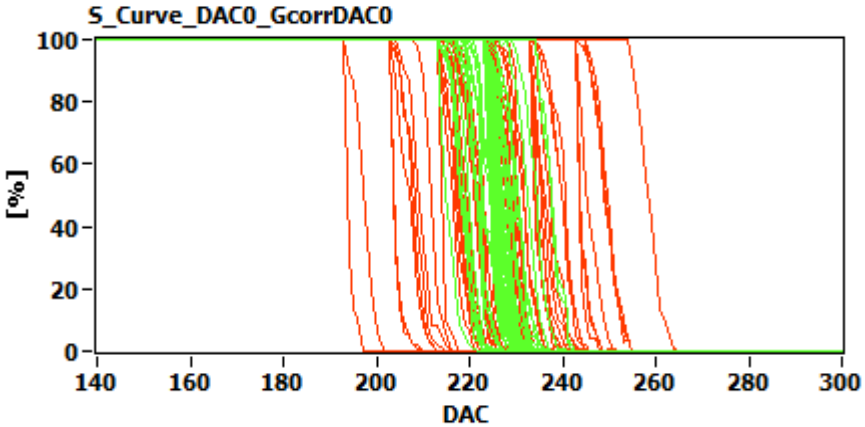
Independent channels

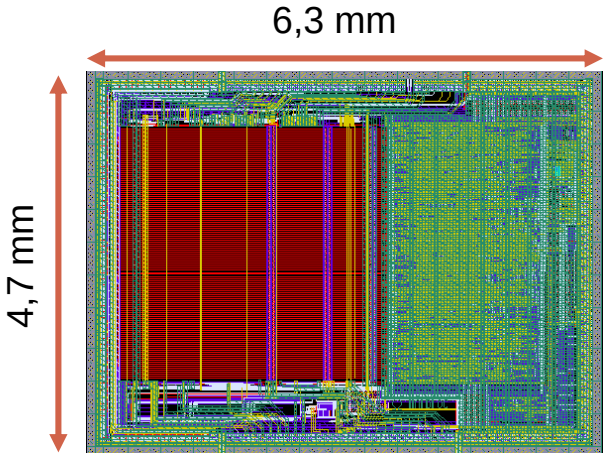
Extended dynamic range (**up to 50 pC**)

packaging in QFP208, die size ~30 mm^2

Zero suppress

I2C link with triple voting for slow control parameters

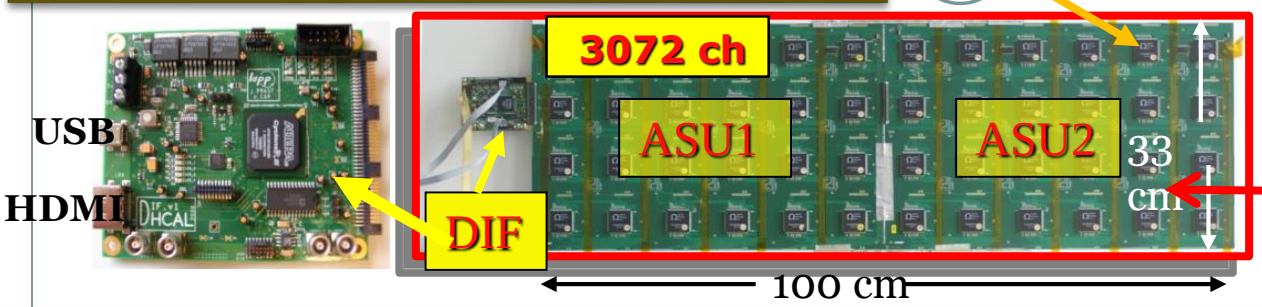




New electronics

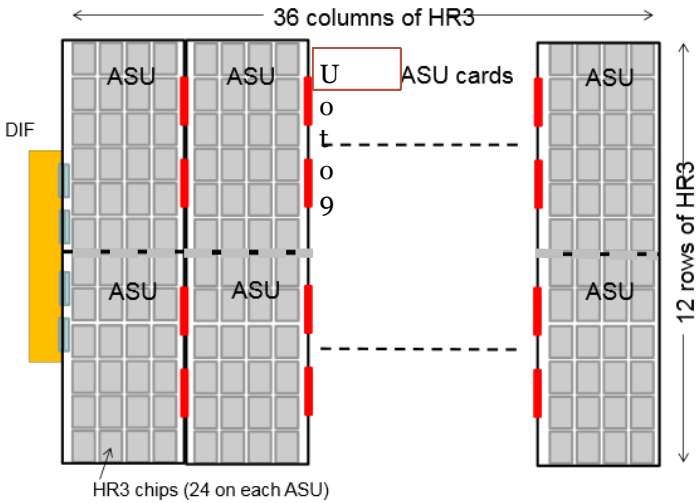
Electronics readout for the 1m³ prototipo

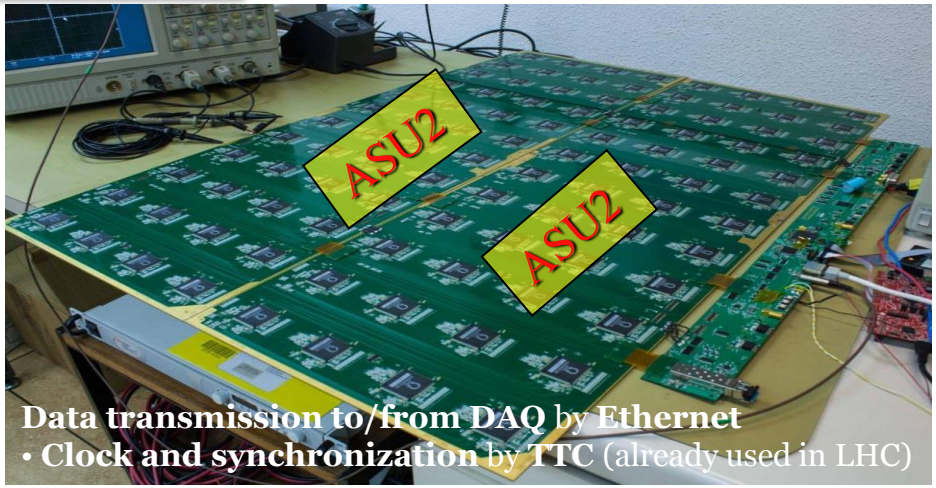
1m² board ➔ 6 ASUs hosting 24 ASICs



1 DIF (detector InterFace) for 2 ASU (Active Sensor Unit.- PCB+ASICs) ➔ **3 DIFs for ONE 1m2**

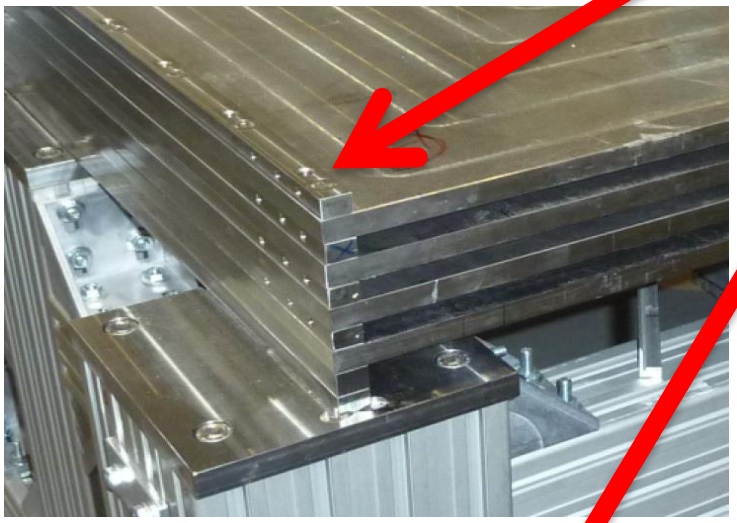
Electronics readout for the final detector

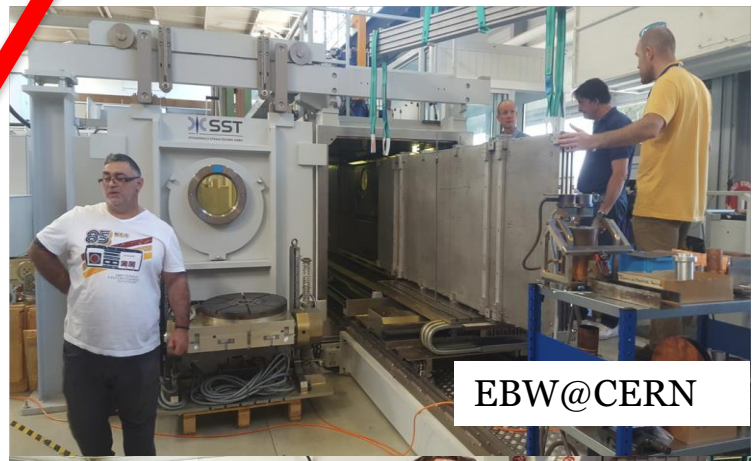




New Mechanical Structure

Goal: To fix the steel plate replace bolts with EWB to reduce the dead zone and the deformation





EBW@CERN

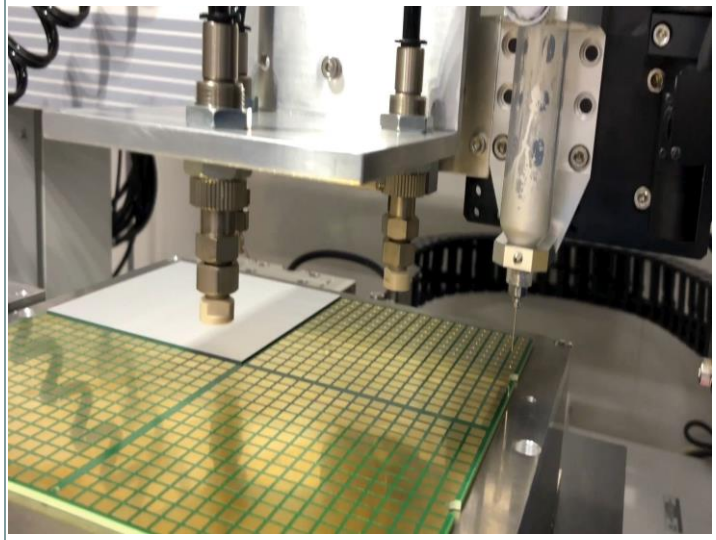
Deformation< 1mm

Conclusion

- A lot of activities within CALICE

- Technological prototypes have been built or being completed.

- A big progress on Scint-W ECAL and MAPS ECAL



^{57}Co response

$S/N_{ADC} \sim 30$