The status of Semi-Digital Hadronic calorimeter

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On behalf of the CALICE SDHCAL groups

IHEP, Beijing, Nov 19, 2019

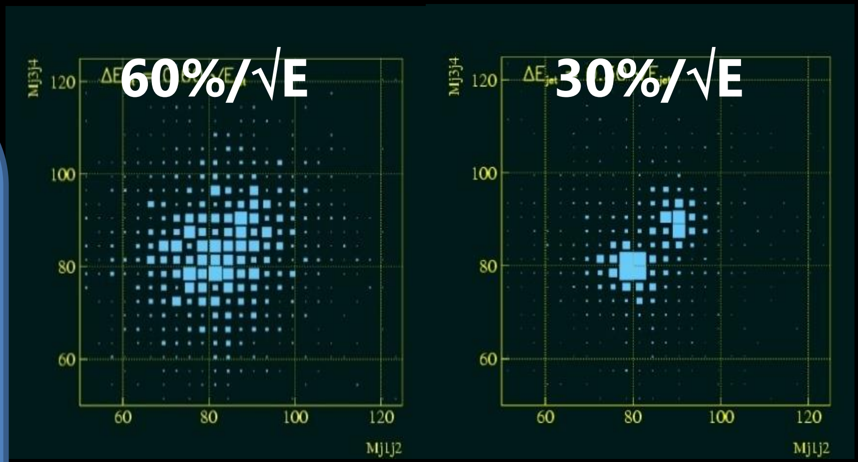
Outline

- Semi-Digital Hadronic calorimeter (SDHCAL) concept
- SDHCAL ongoing activities
- New module0 progress
  - Detectors
  - Readout electronics
  - Gas recycling
- Future activities
- Conclusions

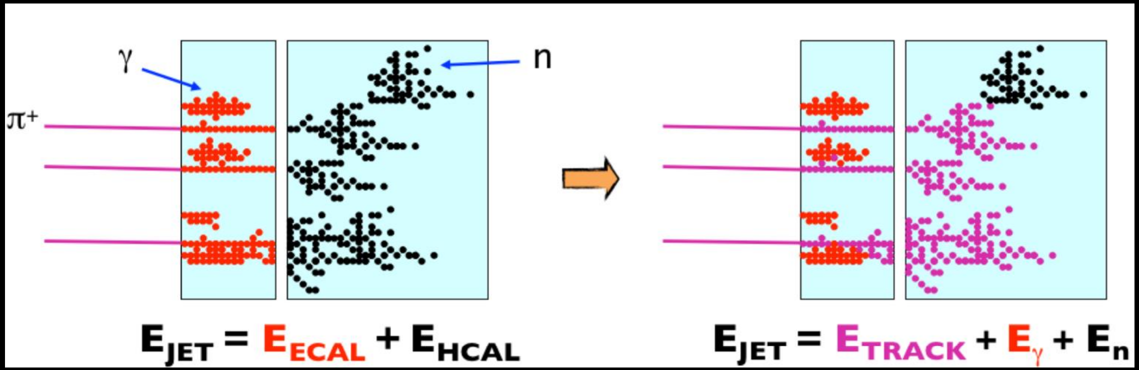
Particle Flow Algorithm (PFA) oriented Calorimeter

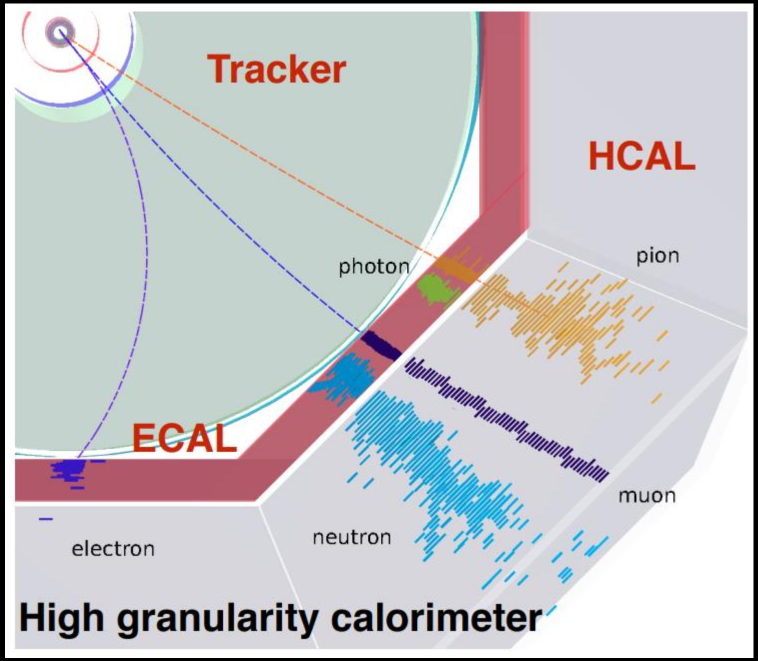
Particle Flow Algorithm : an algorithm that tries to reconstruct individual final state particle from the information recorded in detector.

- It can lead to measure jet energy accurately, and consequently improve the energy reconstruction and event identification
- High granularity needed



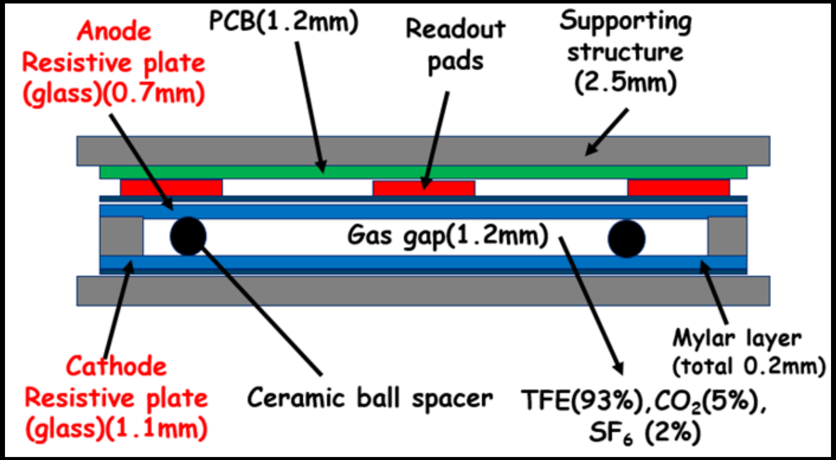
Simulation of W, Z reconstructed masses in hadronic mode.





SDHCAL prototype — Main features

Detector: GRPC (glass resistive plate chamber, 1 X 1 m^2) operating in avalanche mode



1×1 cm^2 pads.

Semi-Digital readout, 2bits — 3 thresholds

→ Counts how many and which pads have a signal larger than one of three thresholds

Advantages of Resistive Plate Chambers:

- High efficiency
- Good Homogeneity
- Well contained avalanches
- Not expensive, robust, …

→ **Energy resolution**

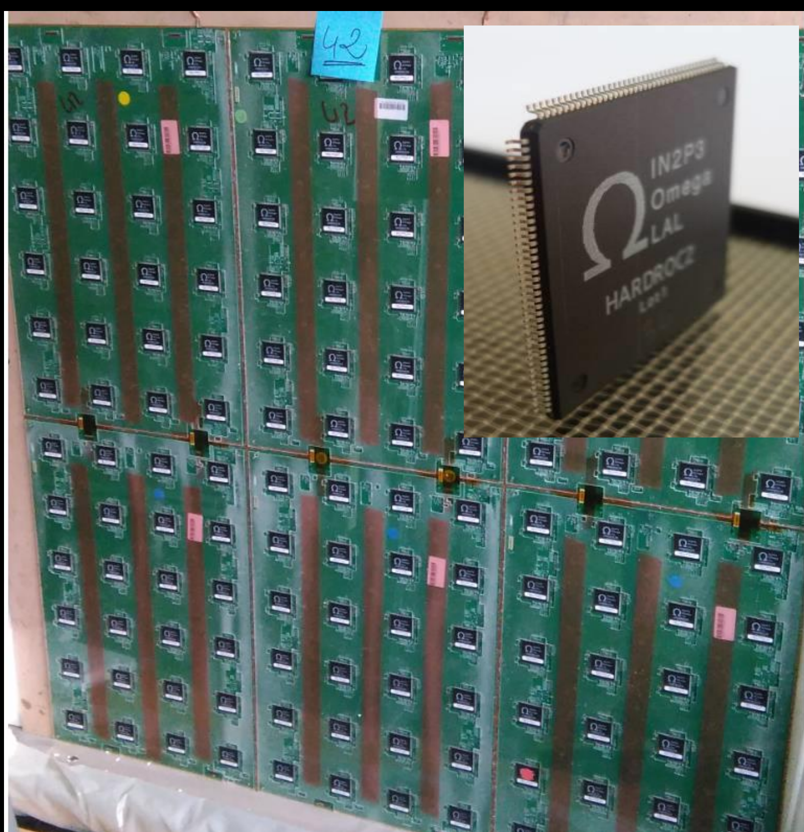
SDHCAL prototype — Main features

Embedded electronics:

PCB separated from the GRPC by a mylar layer (50 µm)

→**Bottom** : 1 × 1 cm² pads, one layer 9216 pads.

→**Top**:144 **HARDROC** (**HA**dronic **R**pc **D**etector **R**ead**O**ut **C**hip)



Absorber:

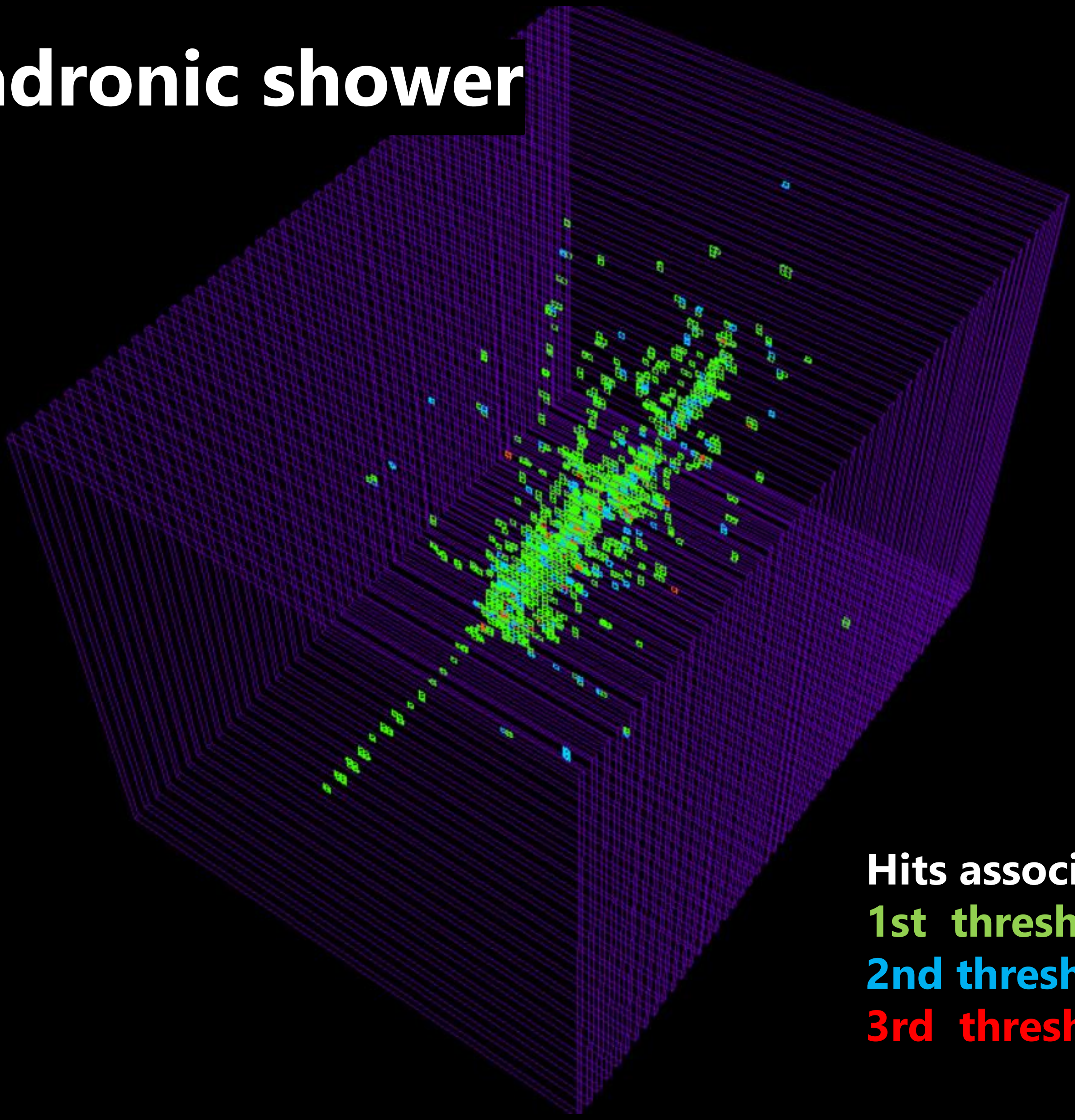
Stainless steel (20mm)

Surface planarity < 1mm

Thickness tolerance 50 µm


SDHCAL
Since 2011
1 cm x 1 cm pads, 48 layers, power-pulsed,
mechanical self-supporting structure
TB: 2012,2015, 2016, 2017 and 2018 with ECAL

Hadronic shower



Hits associated to:
1st threshold (110 fC)
2nd threshold (5pC)
3rd threshold (15pC)

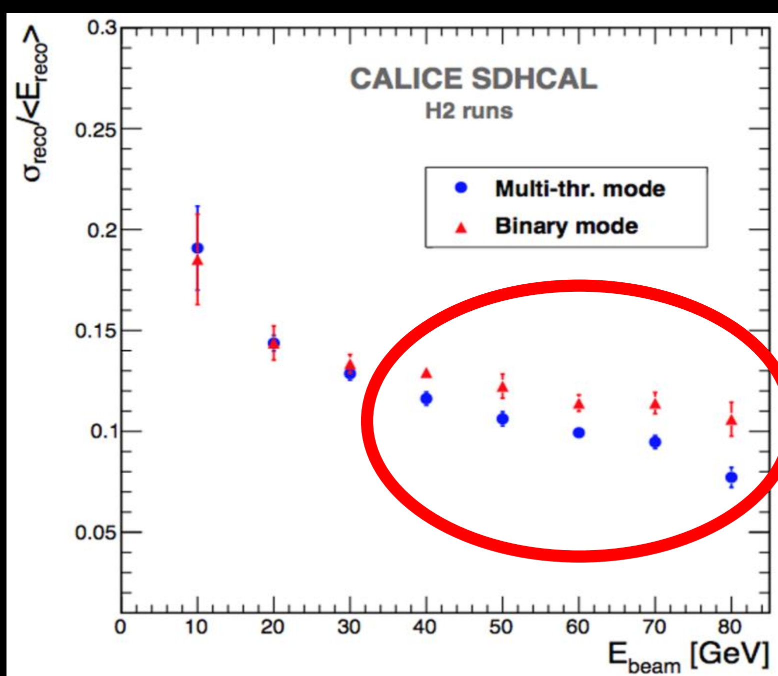
SDHCAL prototype — Performance

$$E_{reco} = \alpha N_1 + \beta N_2 + \gamma N_3$$

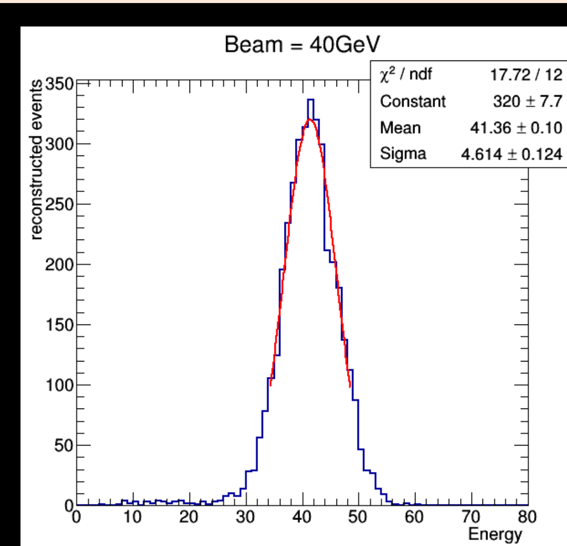
→ N_1 = Nb. of hits with 1st threshold < signal < 2nd threshold
→ N_2 = Nb. of hits with 2st threshold < signal < 3nd threshold
→ N_3 = Nb. of hits with signal > 3rd threshold
→ $N_{tot} = N_1 + N_2 + N_3$

α, β, γ are parameterized as quadratic functions of N_{tot}
→ They can be computed by minimizing a χ^2

$$\chi^2 = \sum_{i=1}^{N} \frac{(E^i_{beam} - E^i_{reco})^2}{\sigma_i^2} \qquad \sigma_i = \sqrt{E^i_{beam}}$$



SDHCAL with 3-threshold results in better energy resolution than binary mode for E_{beam} > 30 GeV



New energy reconstruction

New Energy estimation using density

- Quadratic:

$$E_{quad} = \sum_i \alpha_i N_t \quad i \in \{1,2,3\}$$

$$\alpha_i = \alpha_{i0} + \alpha_{i1} N_T + \alpha_{i2} N_T^2$$

- Linear formula using density:

$$E_{dens} = \sum_i \sum_d \alpha_{id} N_{id}$$

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

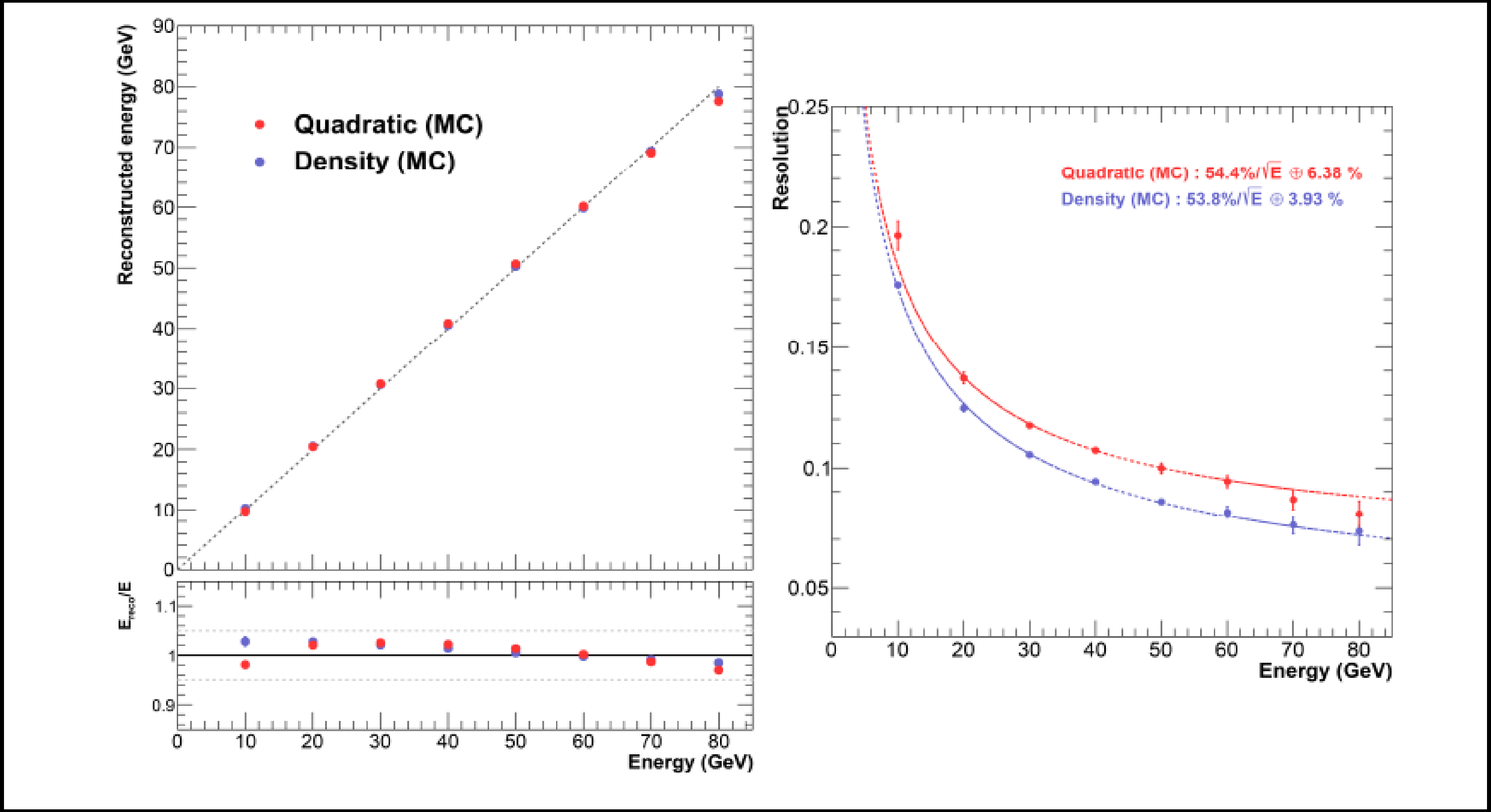
					4				
				6	7	6	4		
	3	4	6	7	9	7		4	3
		4		6	7	5		3	
					5				
	1				2				

- **The density of each hit is the number of hits in the surrounding 3x3 cells (including itself)**
- **It can vary from 1 (lone hit) to 9 (completely surrounded)**

- **For these 3 formulas, the α parameters are found using a chi2 minimisation :**

$$\chi^2 = \sum_{i=1}^{N} \frac{(E_{beam}^i - E_{reco}^i)^2}{\sigma_i^2} \qquad \sigma_i = \sqrt{E_{beam}^i}$$

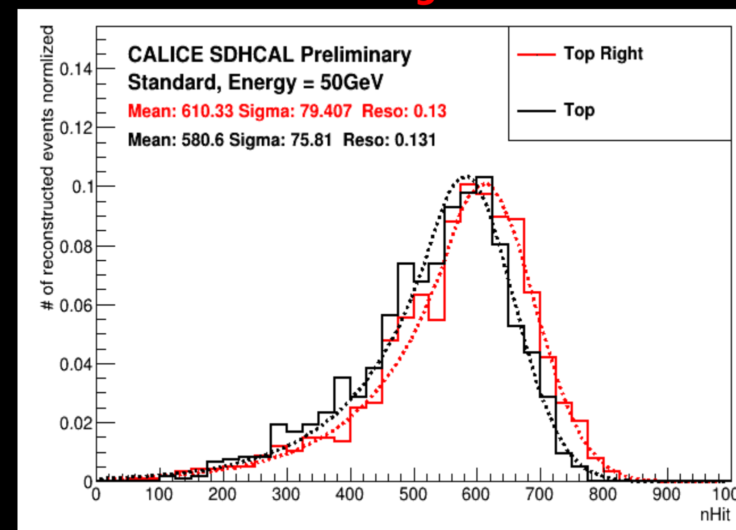
New energy reconstruction

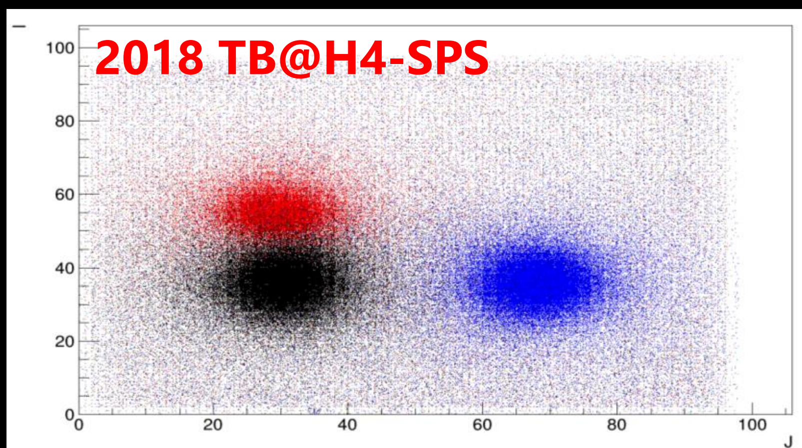


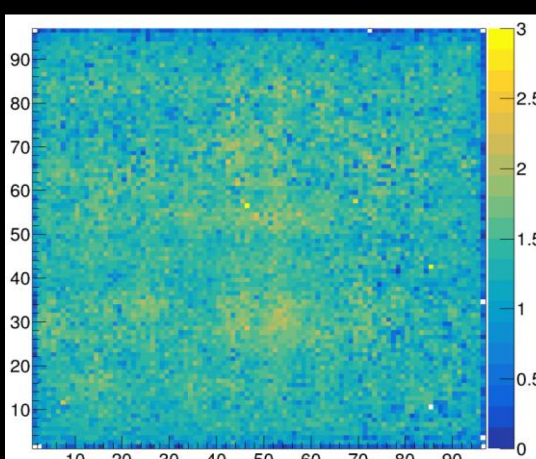
Homogenization of the SDHCAL response

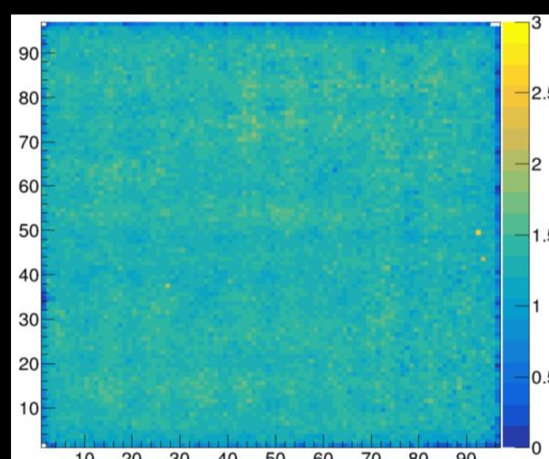
→Use the muons threshold scan to study both efficiency and multiplicity.
→Use the average multiplicity and that of the second and the third threshold efficiency as a reference and then for each ASIC change the thresholds to obtain the average values.

Before homogenization



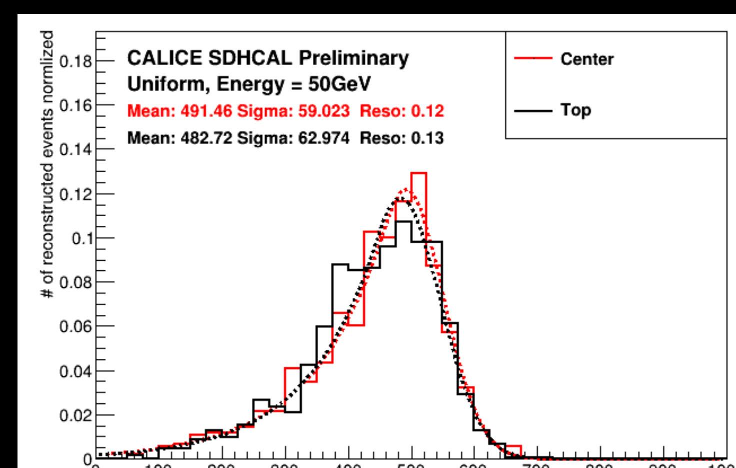






Before homogenization

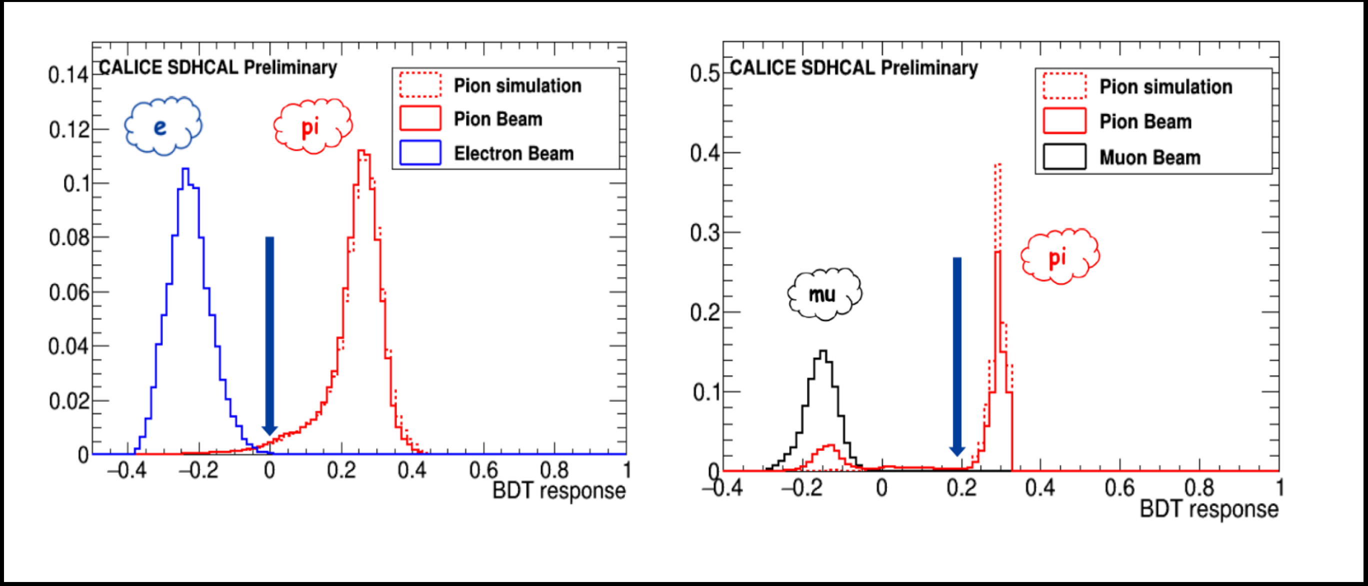
After homogenization



After homogenization

SDHCAL: Particle identification

➔ **BDT helps to improve the hadron/e/mu PID, purify TB samples.**
➔ **Keep 99% of pion efficiency and to reject >99% of e/mu.**



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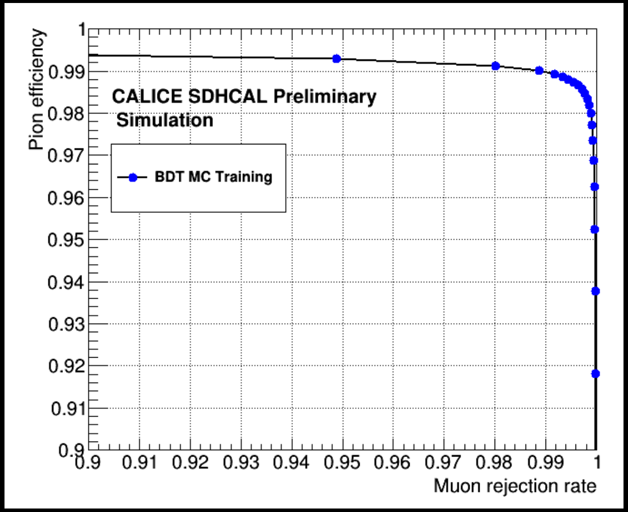
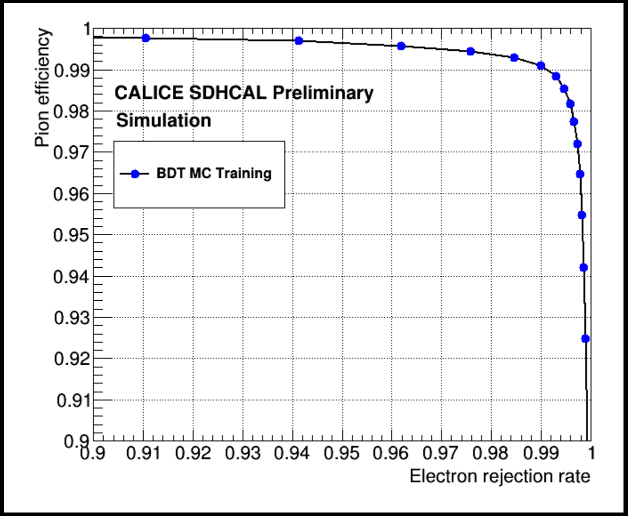
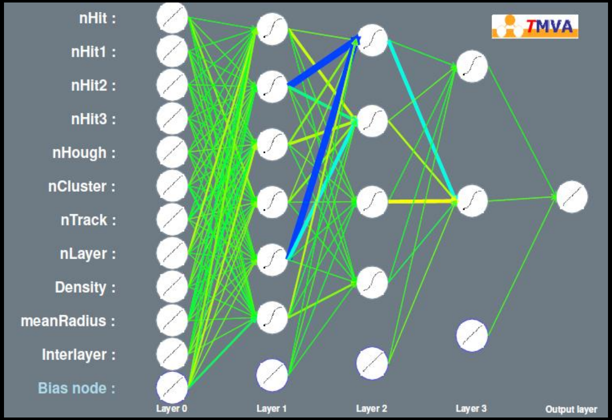
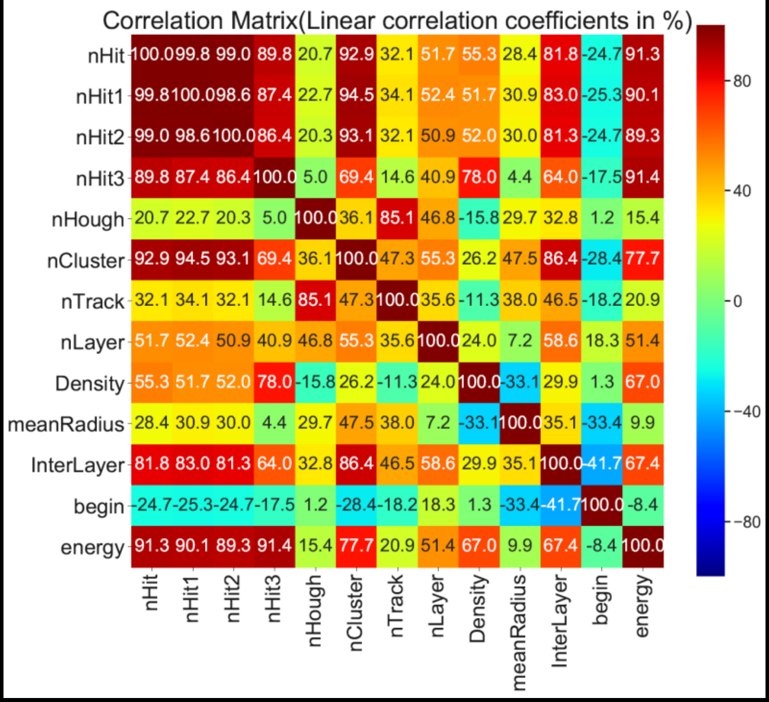


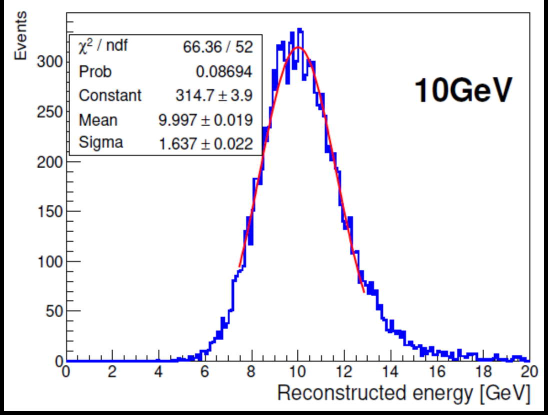


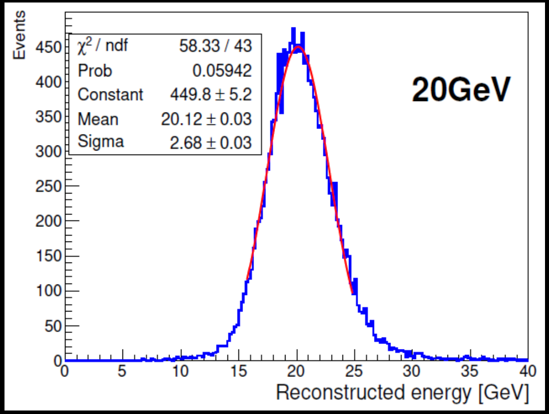
SDHCAL: Energy Reconstruction (MVA)

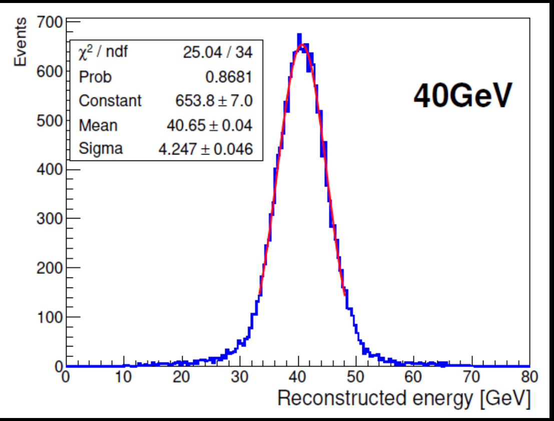


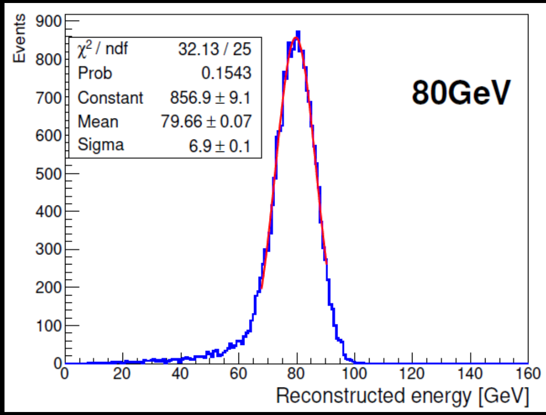
Besides 4 Nhits variables, 8 new variables are built to describe hadronic showers, and to improve the energy reconstruction performance.







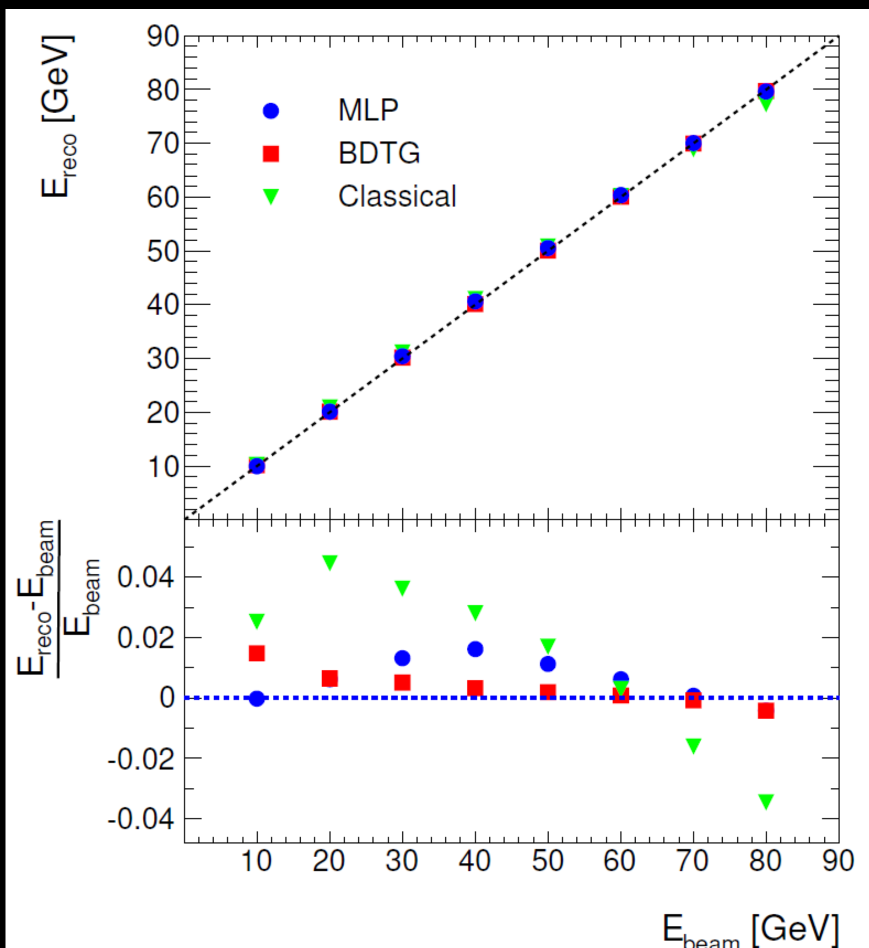


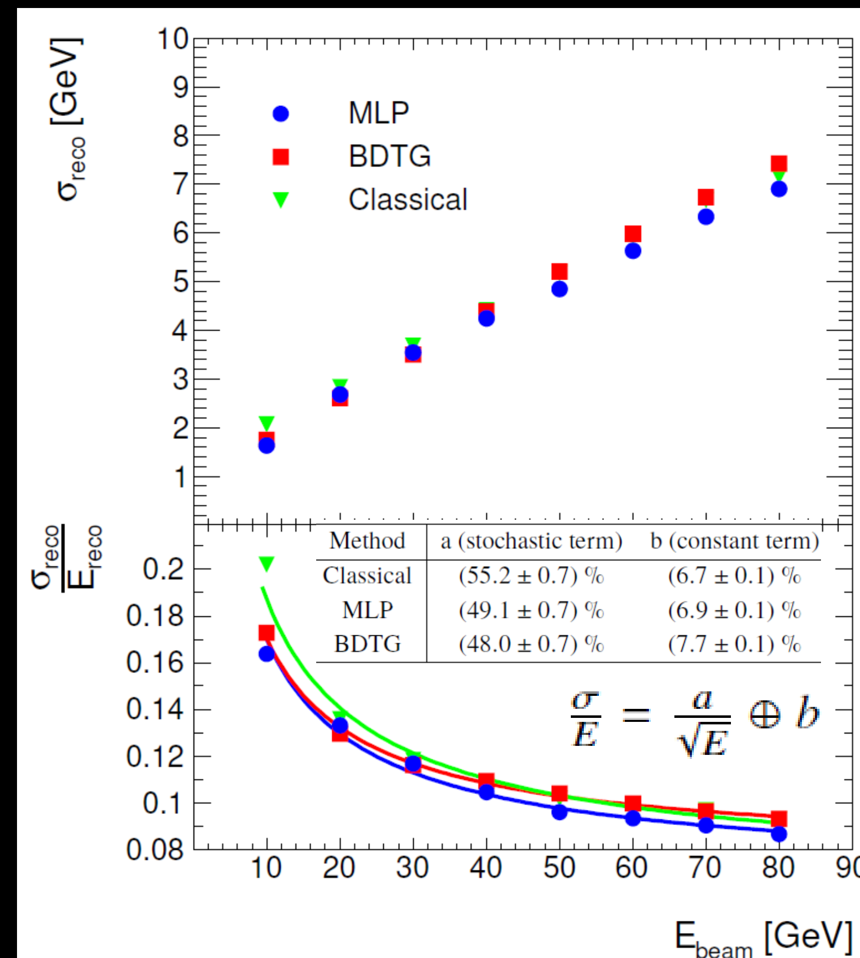


SDHCAL: Energy Reconstruction (MVA)

Energy linearity improves from 3-4% to 1-2% level using MVA

Energy resolution improves about 5-15% using MVA





JINST 14, P10034 (2019)

First common test with the technological SiW ECAL prototype

Common DAQ: same start acquisition (using the spill start)

Combined test: SDHCAL + SiW ECAL

SiW ECAL

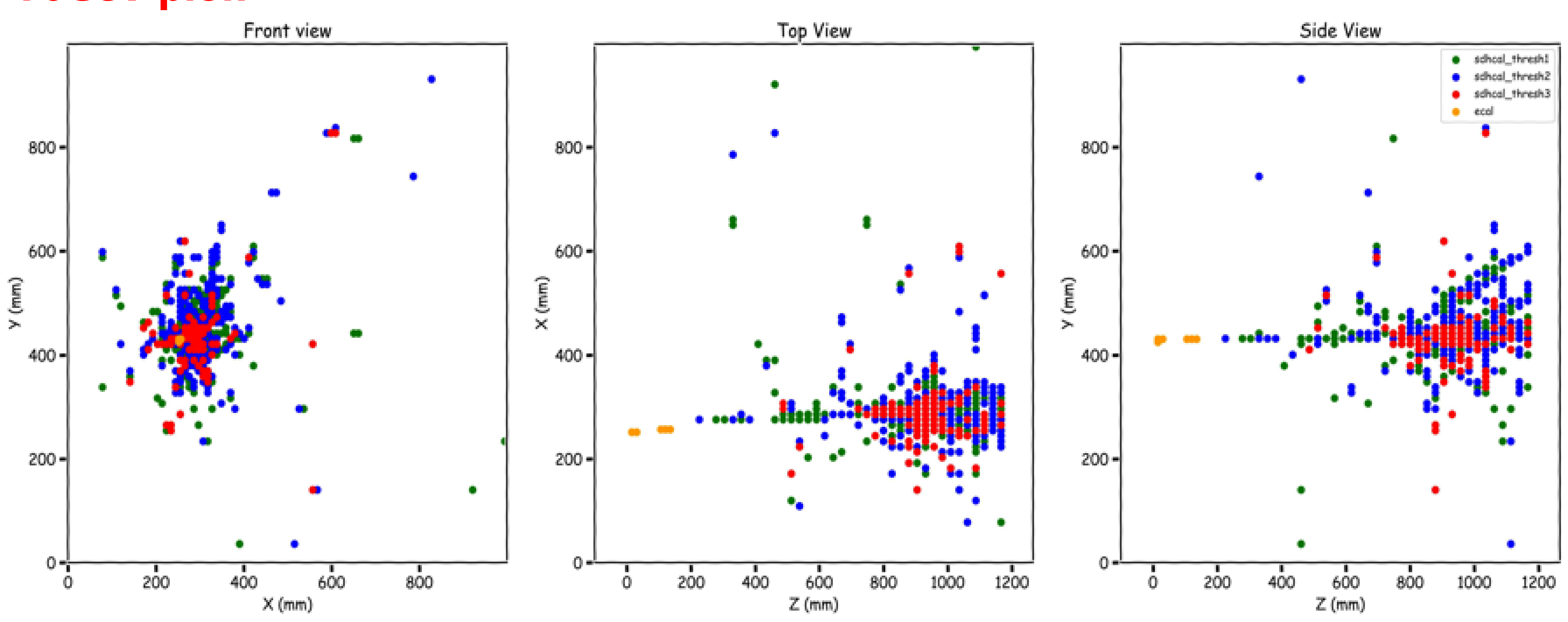
→ 9 working layers (several layers malfunctioning)

→ Placed in front of SDHCAL

SDHCAL

→37 GRPC layers present in prototype

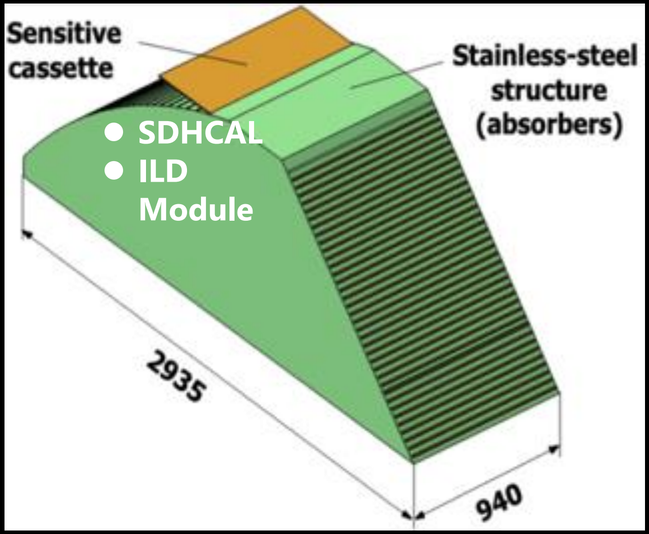
70GeV pion



SDHCAL R&D for ILD

- 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..

- GRPC
- Glass Resistive Plate Chambers

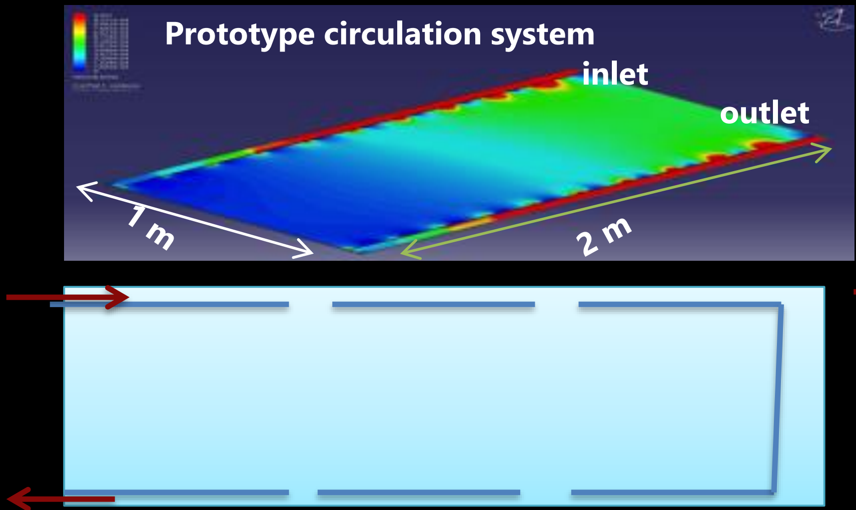


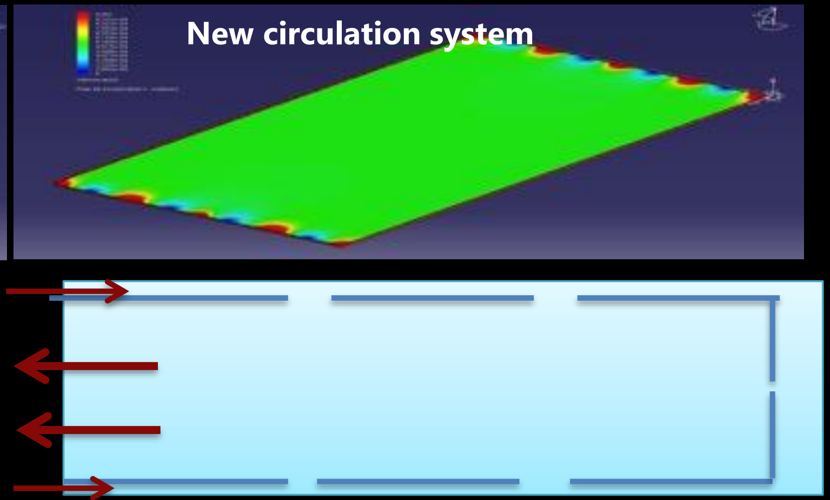
- Goal: to build new prototype with few but large GRPC with the new components
- → ILD Module0

SDHCAL Module0 progress: Detectors

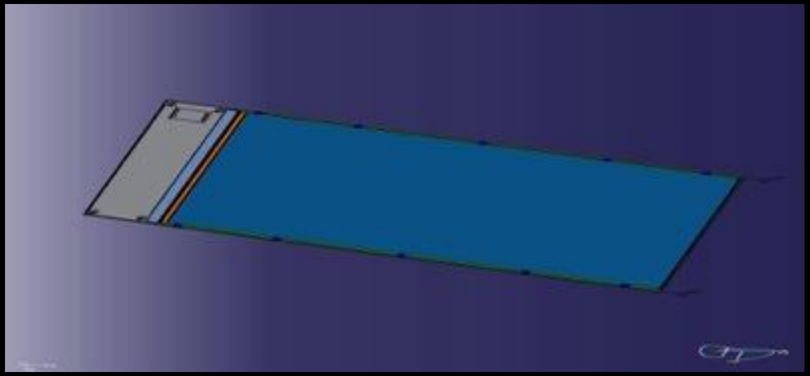
Construction and operation of large GRPC necessitate some improvement with respect to the present scenario.

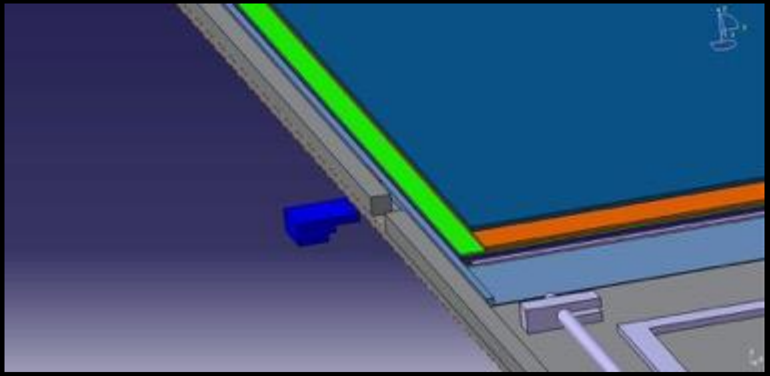
Gas distribution : new scheme is proposed





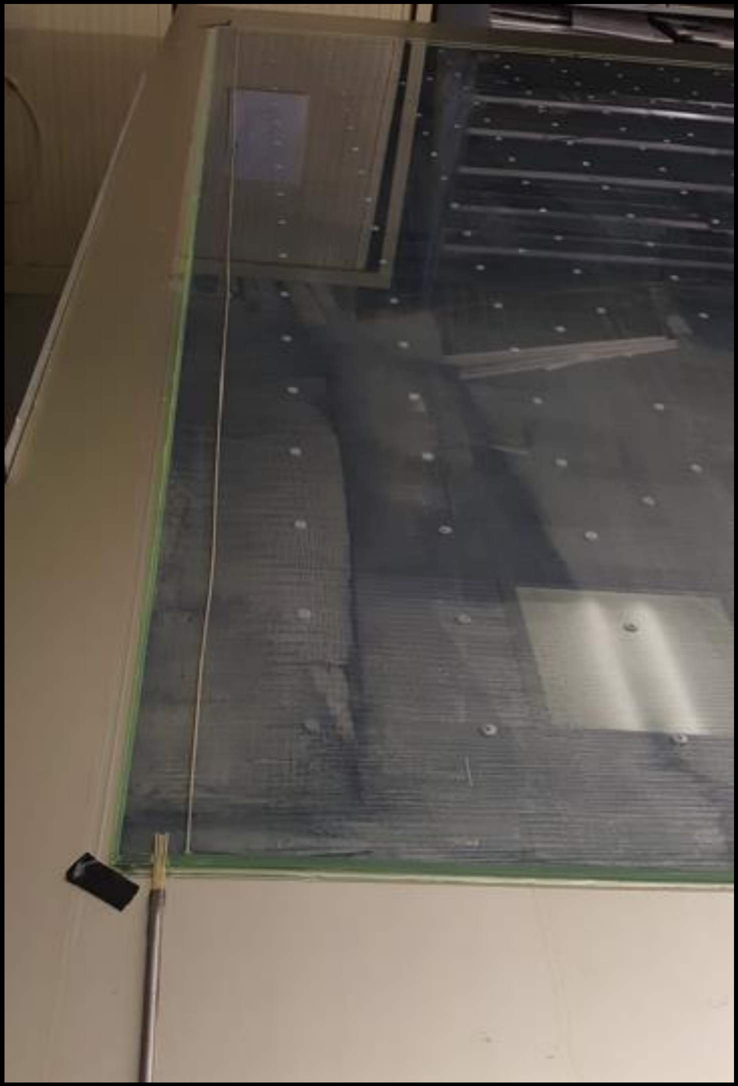
Cassette conception to ensure good contact between the detector and electronics is to be improved





SDHCAL Module0 progress: Detectors

First 2x1 m^2 RPC chamber was successfully built with a new gas circulation system



SDHCAL Module0 progress: New electronics

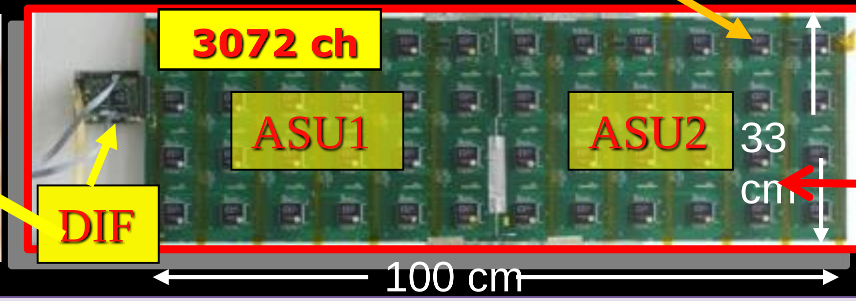
Electronics readout for the 1m³ prototype

HADROC chip (ASIC)

1m² board ➔ 6 ASUs hosting 24 ASICs

USB

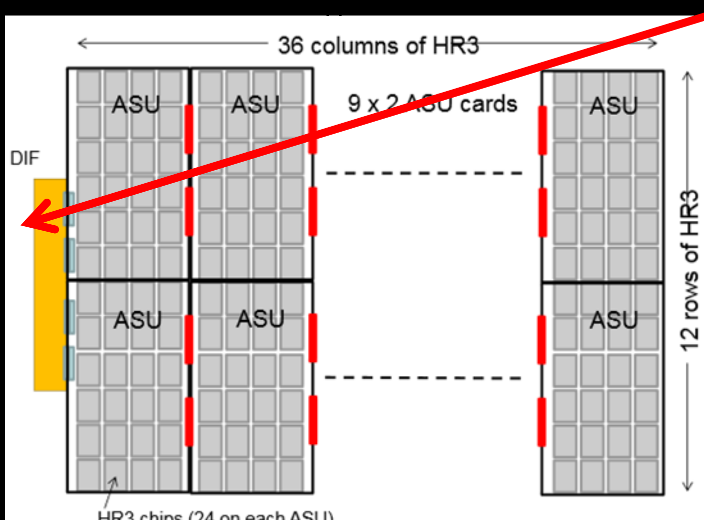
HDMI



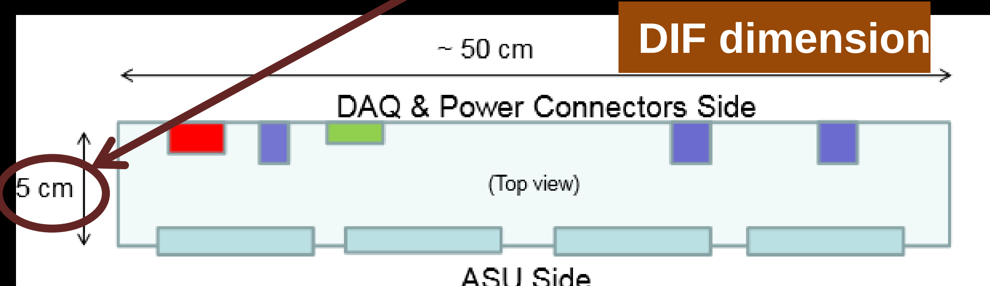
1 DIF (detector InterFace) for 2 ASU (Active Sensor Unit.- PCB+ASICs)
➔ 3 DIFs for ONE 1m2 GRPC detector

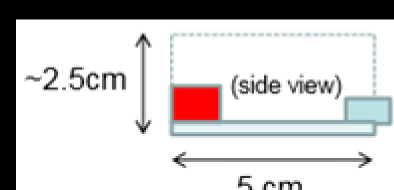
Electronics readout for the final detector

Only 1 DIF per GRPC (any size) with small dimensions to fit in the **small** space available at the **ILD detector**



DIF dimension





SDHCAL Module0 progress: New electronics

New electronics: ASIC

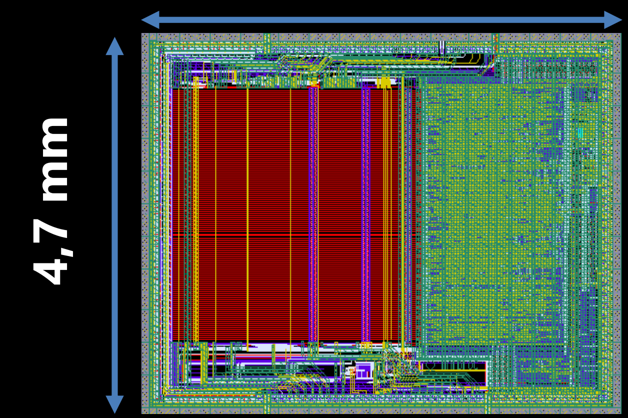
HARDROCR3 main features:

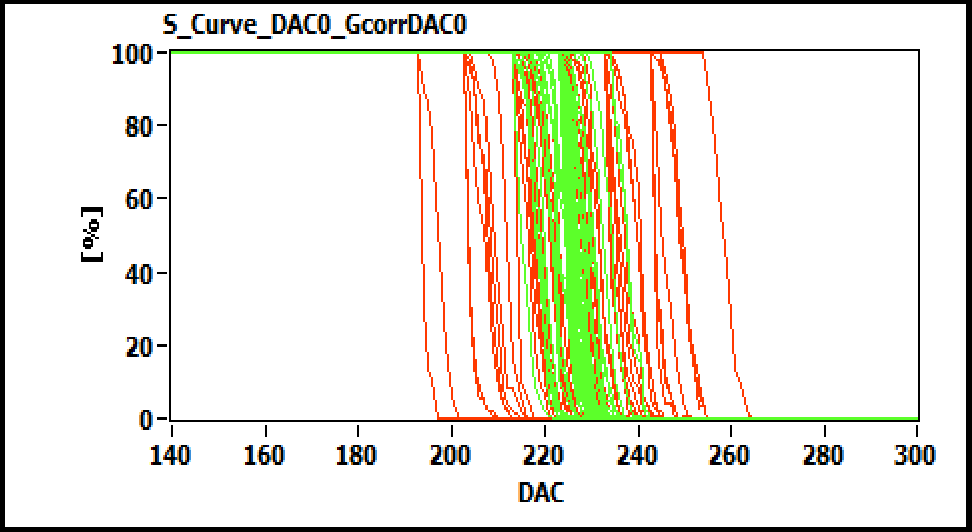
- Independent channels
- Zero suppress
- Extended dynamic range (up to 50 pC)
- I2C link with triple voting for slow control parameters
- packaging in QFP208, die size ~30 mm^2
- Consumption increase (internal PLL, I2C)

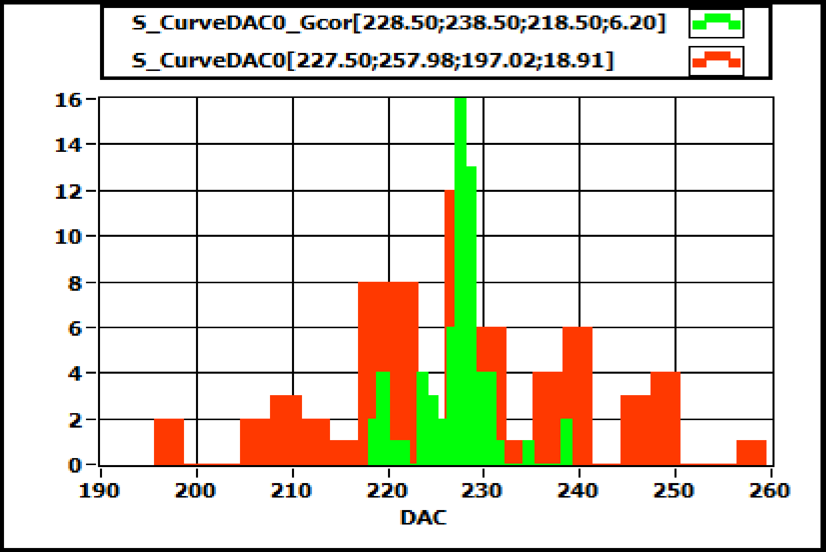
H3B TESTED : 786, Yield : 83.3 %

OMEGA

6,3 mm





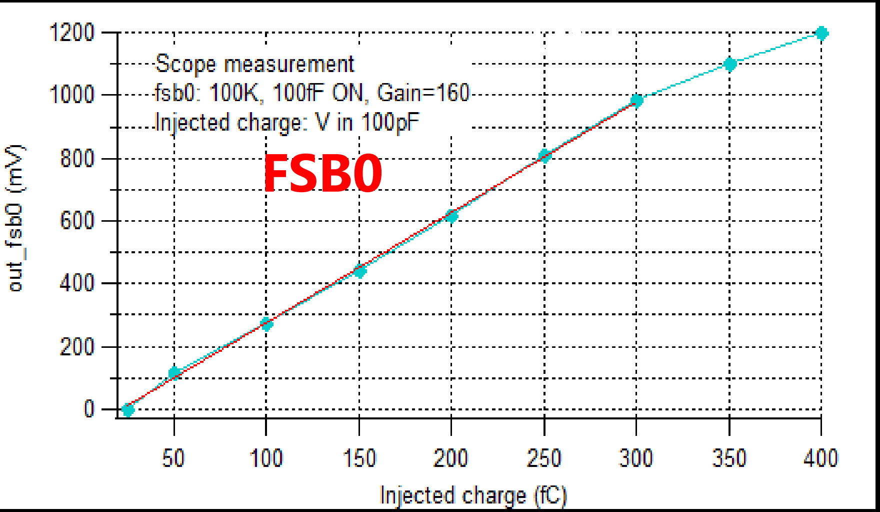


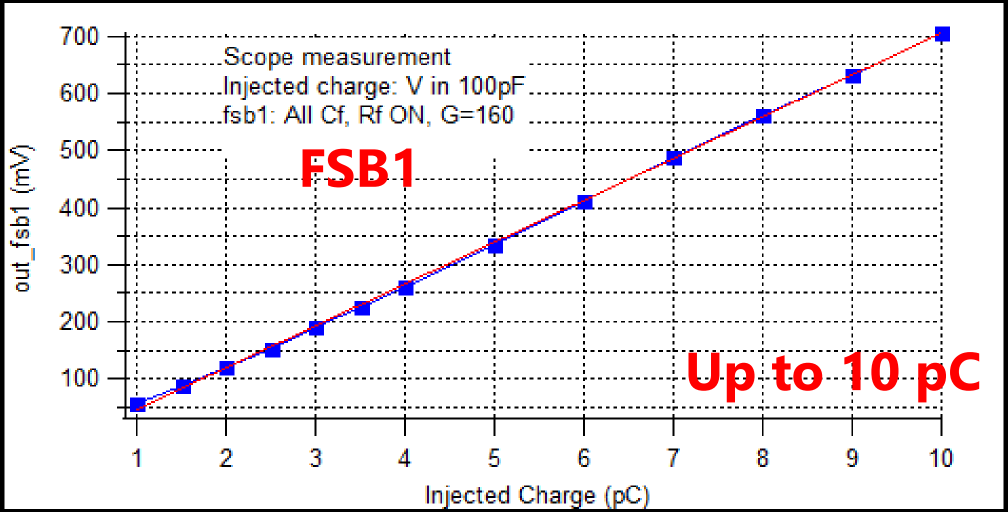
SDHCAL Module0 progress: New electronics

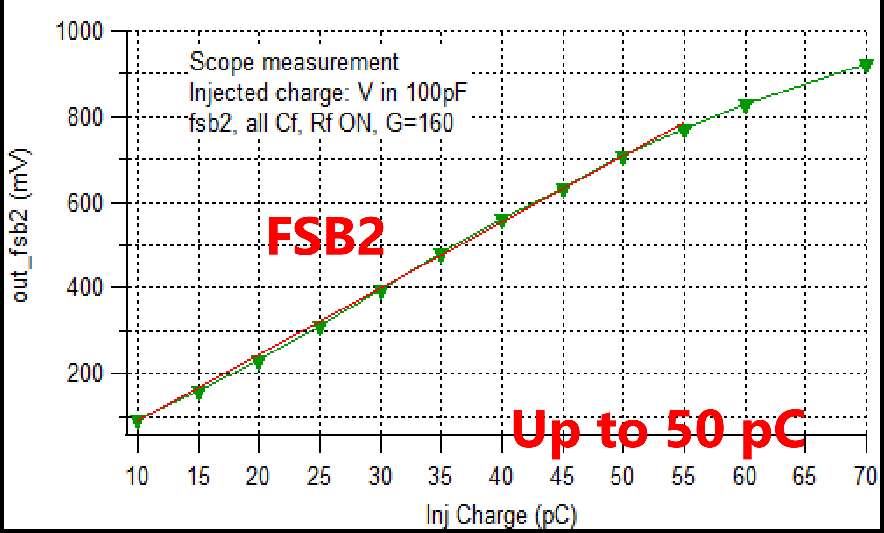
HARDROC3: Analog linearity

OMEGA

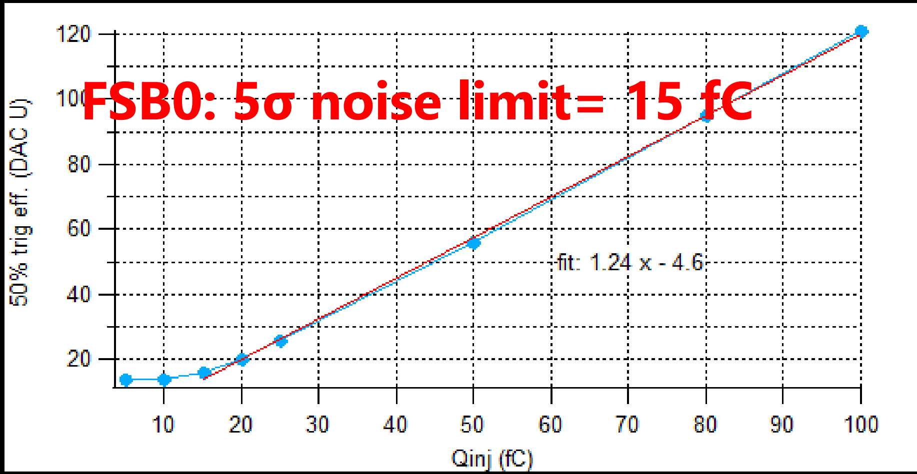
Fast shaper outputs (mV) vs Qinj







50% trig. Eff. (DAC units) vs Qinj (fC)



Dynamic range: 15fC - 50 pC

SDHCAL Module0 progress: New electronics

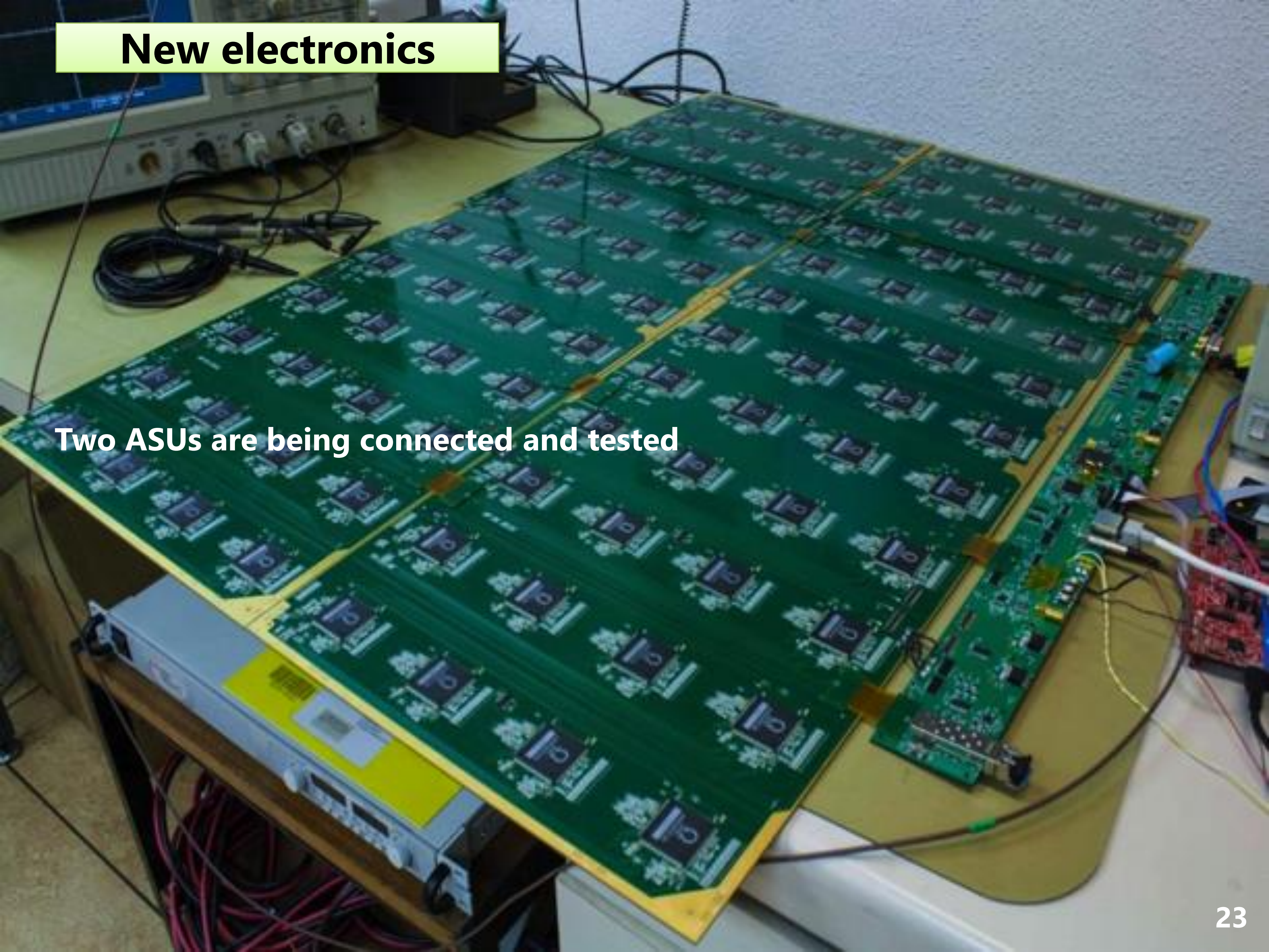
ASU (Active Sensor Unit)

An important challenge is to build a PCB up to 1m length with good planarity to have a homogeneous contact of pads with RPCs in order to guarantee an uniform response along all the detector.

A company was found and ***1x0.33 m2 with 13 layer ASUs*** have been built.

The ASU-ASU (= ASU-DIF) connections also produced

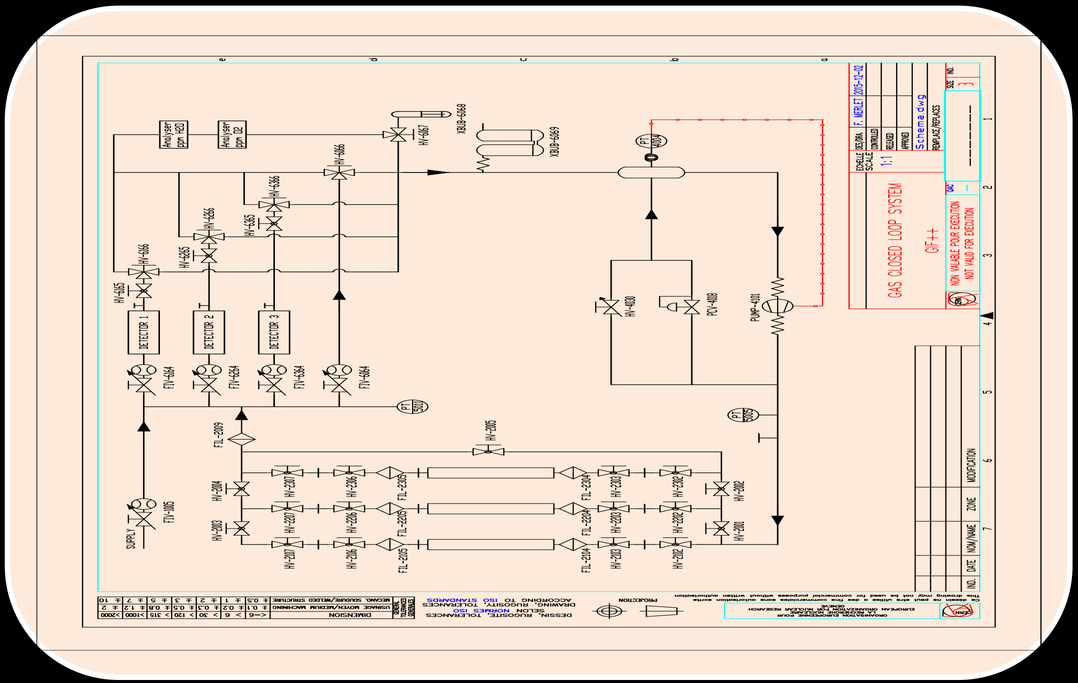
New electronics



Two ASUs are being connected and tested

SDHCAL Module0 progress: Gas system

Gas recycling is necessary to reduce cost :
-Goal: reduce the gas consumption to reduce the cost.
-Gas renewal of 5-10% rather than 100%
-Conceived by the CERN gas group and successfully used.



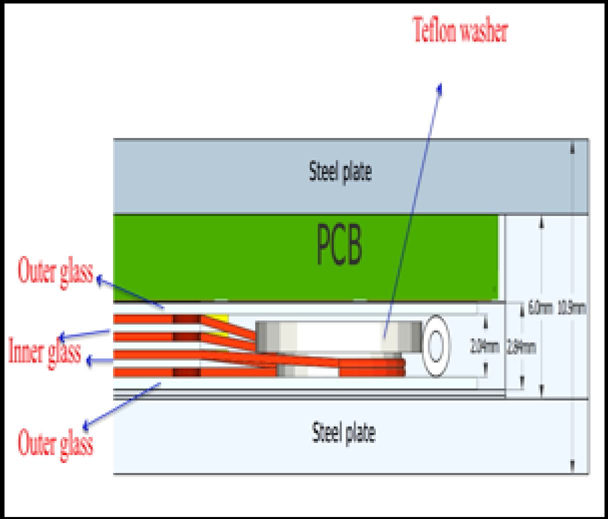
We will start using HFO1234ze soon (GPW=3)
We have also now a remotely a gas controller

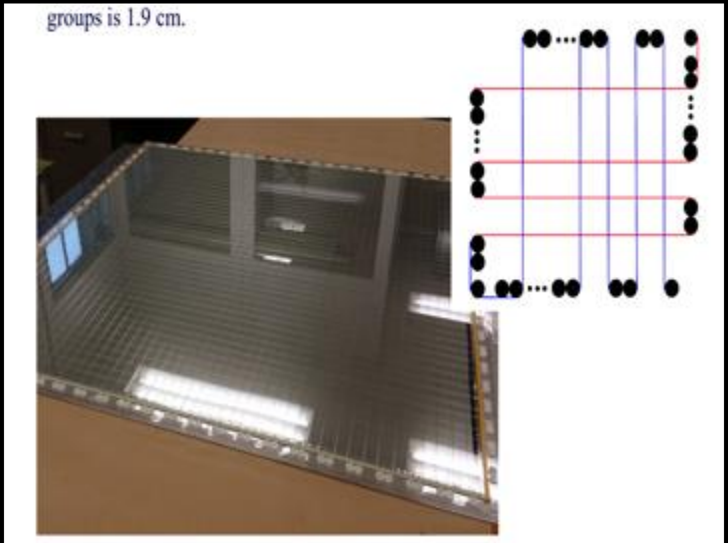
Future activities: Timing

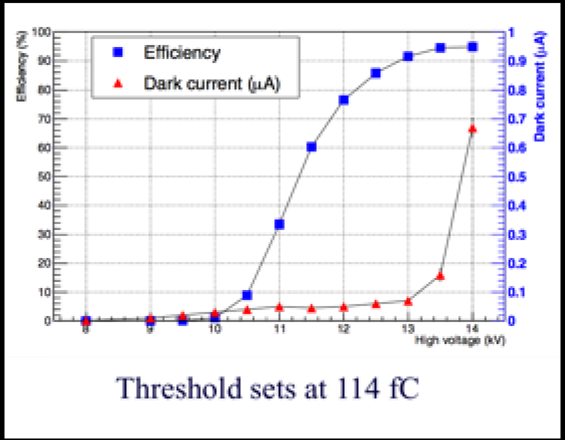
2020-2022

Timing : the new dimension

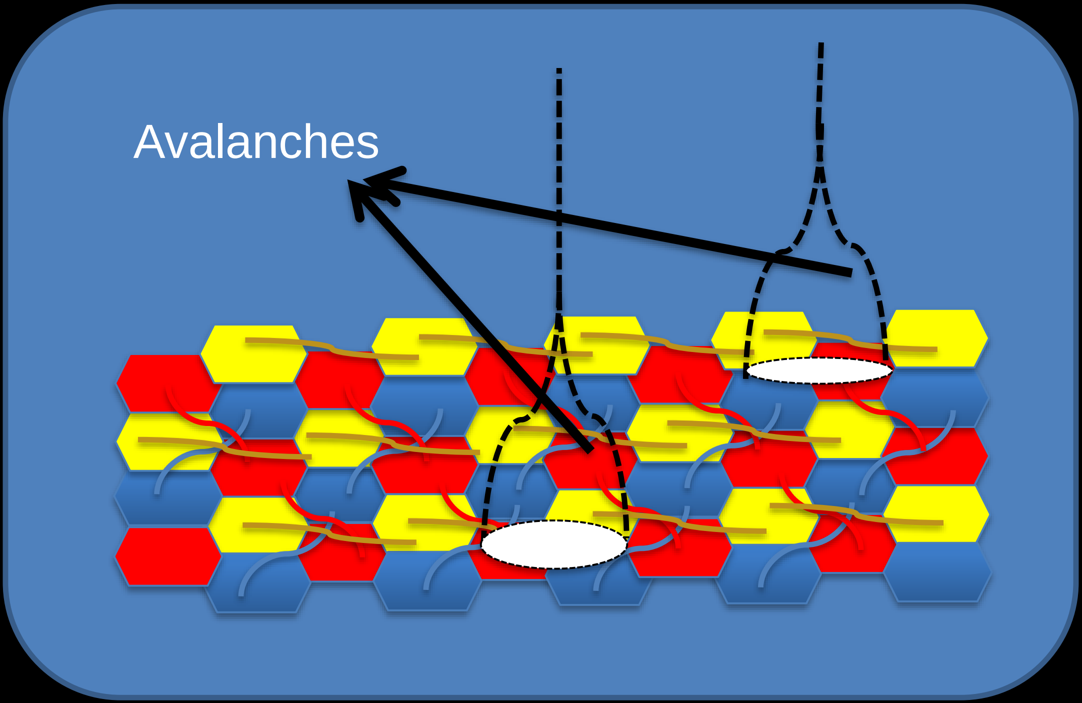
- Build large MRPC (fast timing detectors)
- Develop fine timing readout (PETIROC or equivalent ASIC) of 10-100 ps
- Develop appropriate TDC (for time measurement and ToT)
- Conceive ASUs with pads of 1x1 cm^2
- Develop a new DAQ system with the time information.
- Build a small prototype





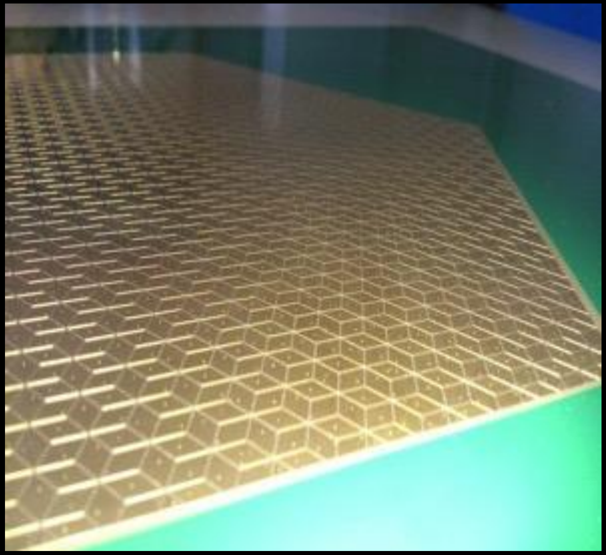


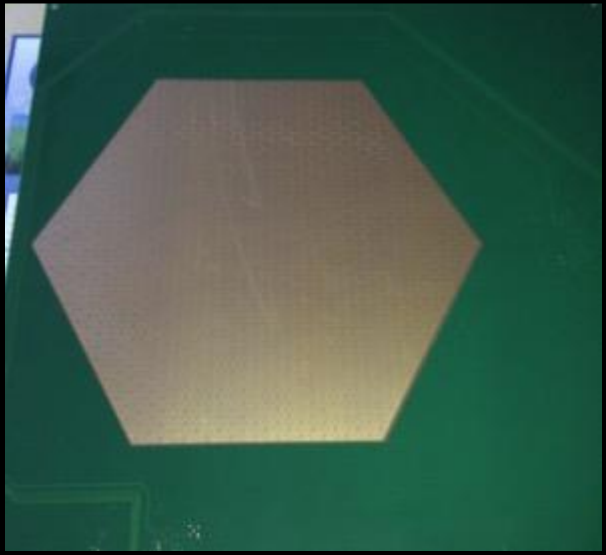
Future activities: New readout scheme

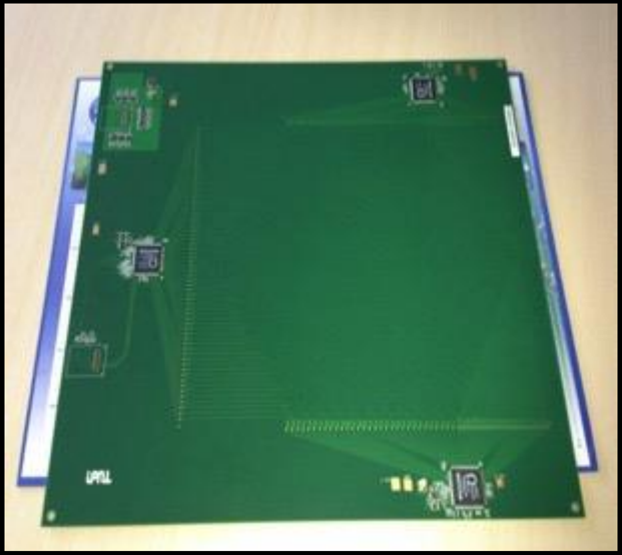


The principle is simple: the charge is shared among several pads/pixels The pads/pixels are inter-connected in a smart way so one can identify the position of the impinging particle by identifying the fired strips and thus find the hit as the crossing points.

In addition there is no ambiguity as far as the number of particles crossing the particles is not very high thanks to the use of at least 3 directions strips.
Patented:
(PCT/EP2018/053561-FR3062926: I.Laktineh)

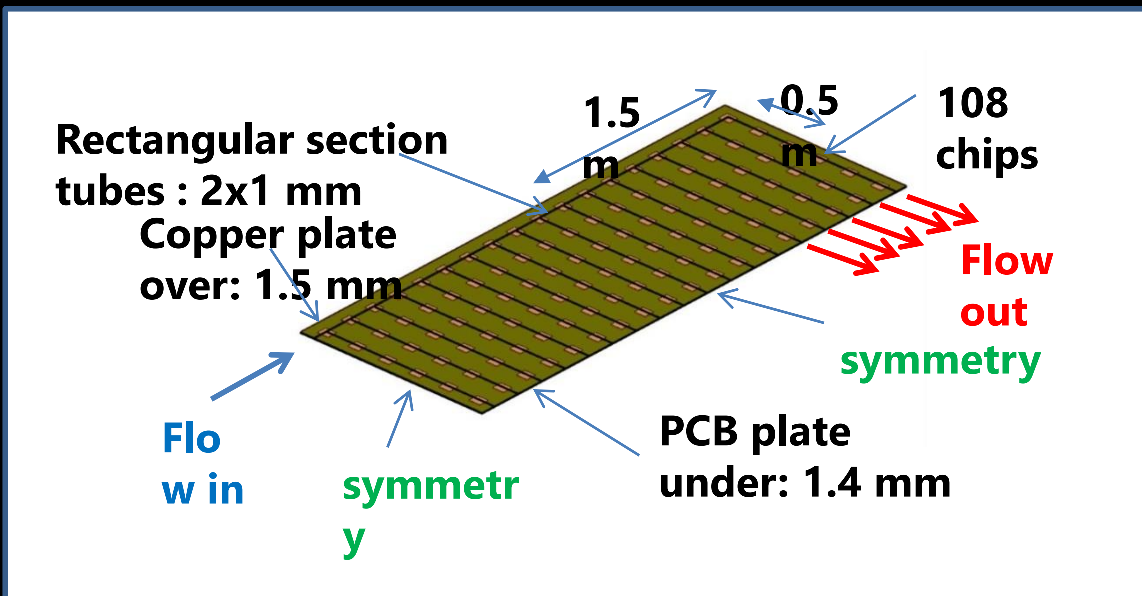




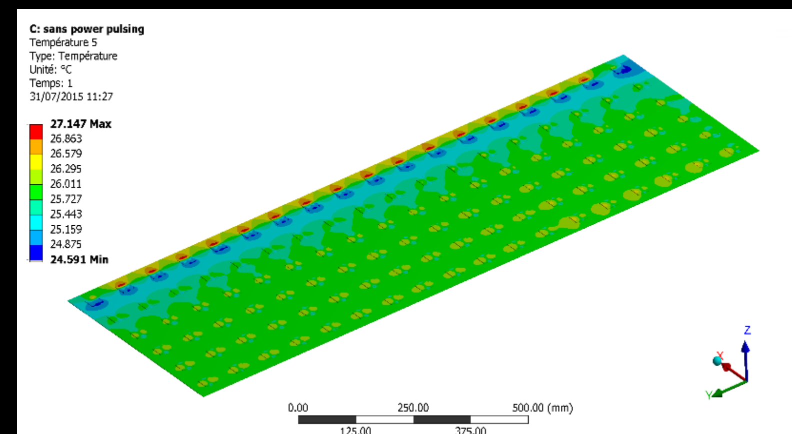


Future activities: Active cooling

Cooling may become necessary if it is operating at continuous mode (CEPC)



27.147 (max) – 24.591 (min) = 2.556 °C



- A water-based cooling system inside copper tubes in contact with the ASICs to absorb excess heat.
- Temperature distribution in an active layer of the SDHCAL.

Water cooling : $h = 1000\ W/m^2/k$
Thermal load : 90 mW/chip

- To simulate temperature distribution in an active layer
- To simulate temperature distribution for 1m*1m*1m (40 layers) SDHCAL
- optimize tube size and geometry
- optimize water flow rate and cooling capacity

Summary

- Technological protoype running successfully since 2012
- Many results validate the potential of the concept
- Large prototype with the new generation of readout electronics is on the rails
- We have several ideas for the future....

Thanks for your attention !