The status of Semi-Digital Hadronic calorimeter

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On behalf of the CEPC SDHCAL groups

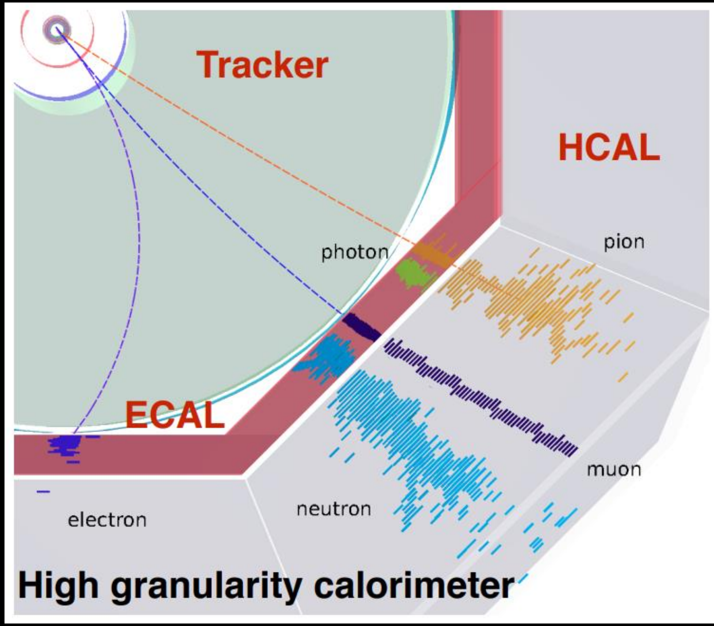
May 6, 2020

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

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E = 3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E = \frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$

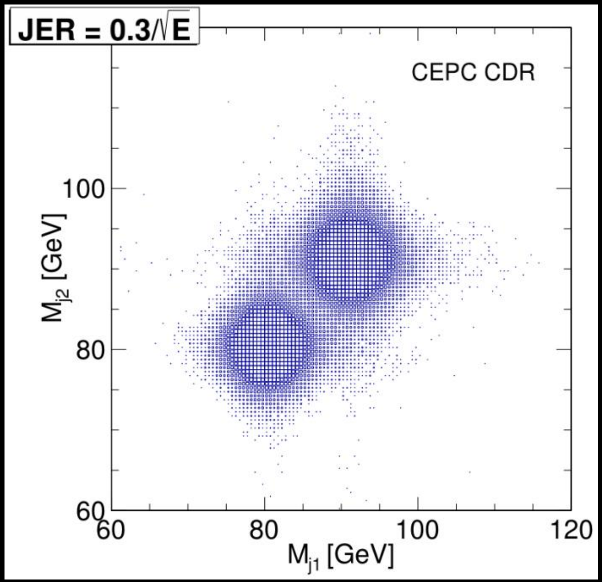


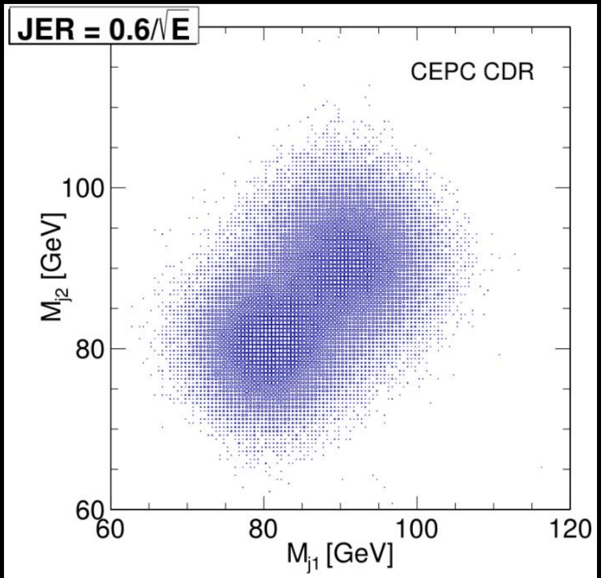
HCAL technology options in CEPC CDR

→SDHCAL with RPC (Baseline)

→SDHCAL with THGEM

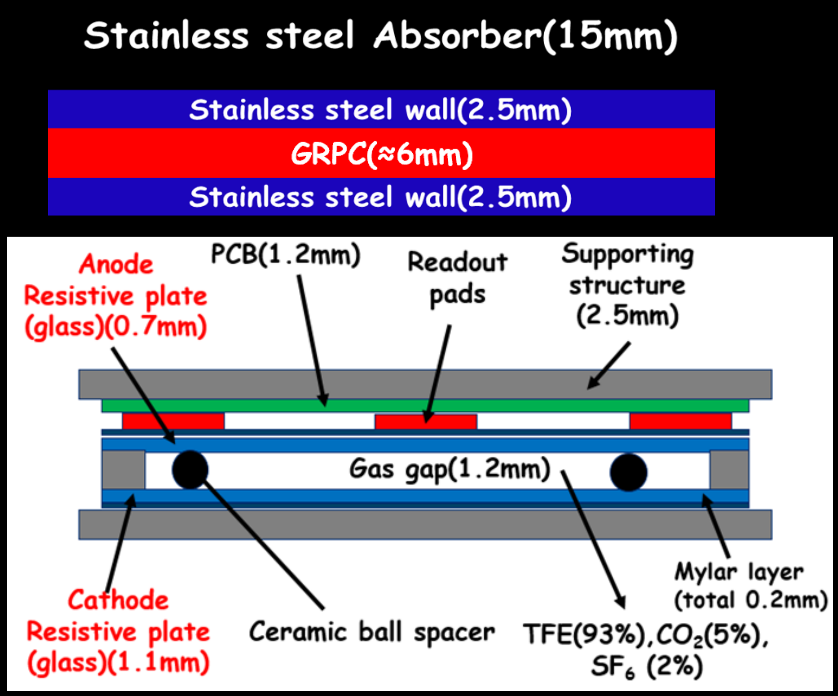
→AHCAL with scintillator + SiPM





SDHCAL prototype — Main features

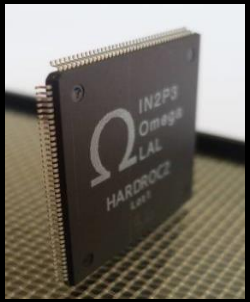
Detector: GRPC (glass resistive plate chamber, 1 X 1 m^2) operating in avalanche mode

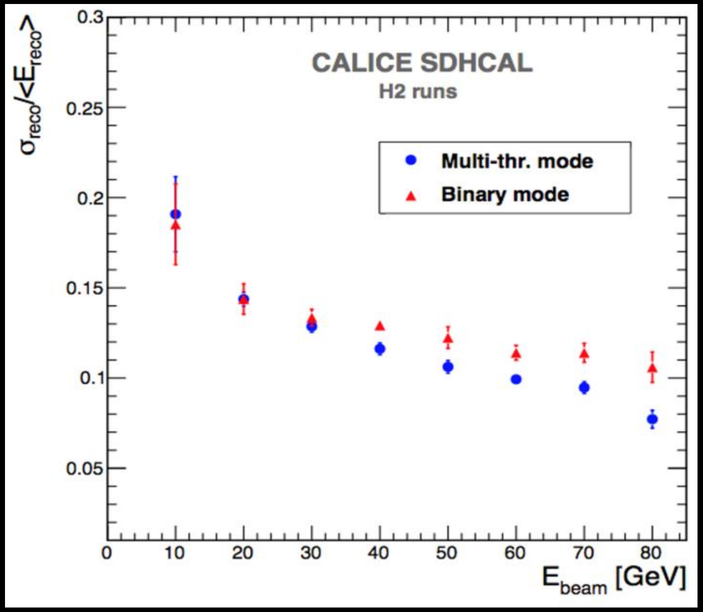


1×1 cm^2 pads.

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, …

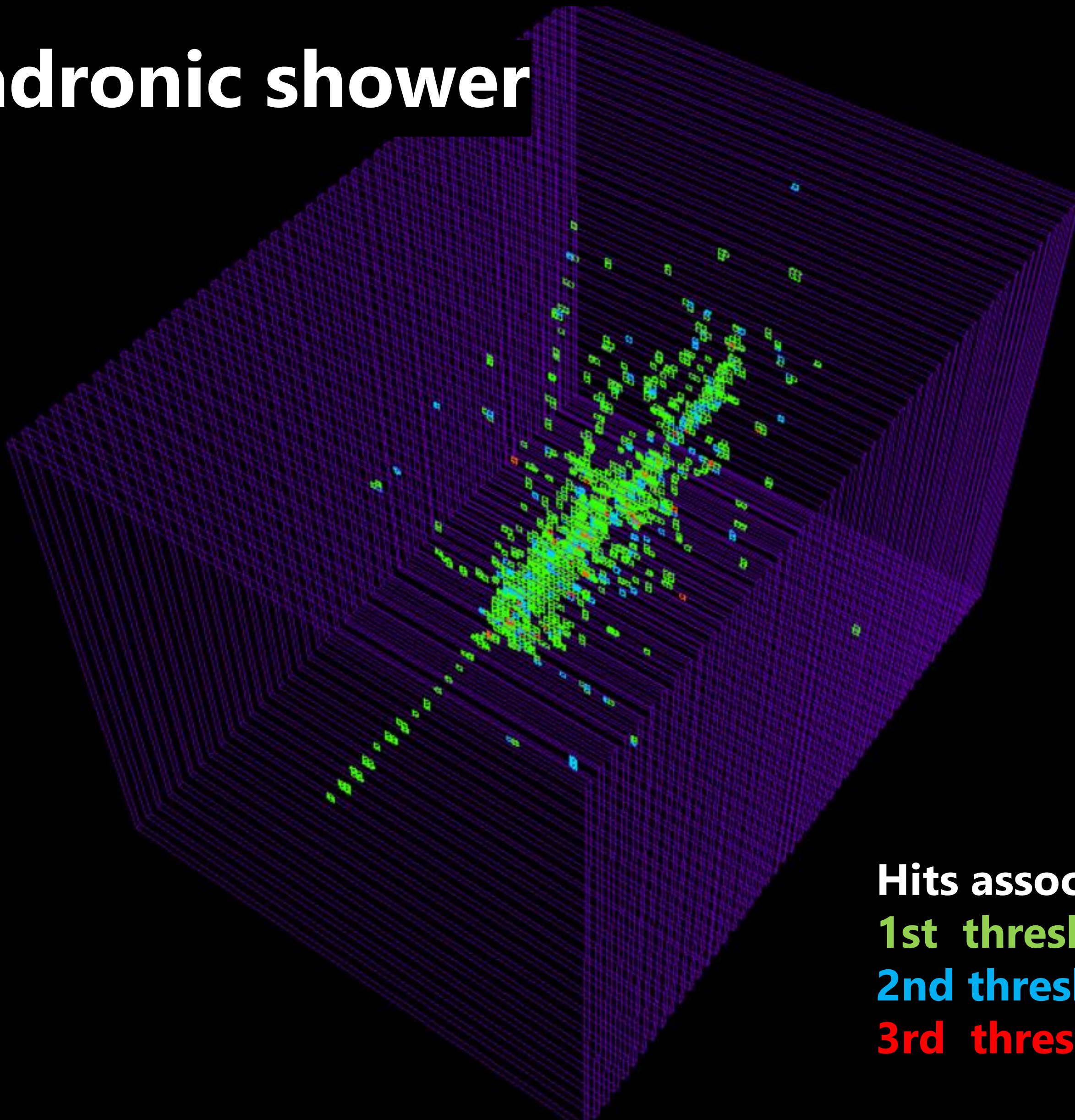
Energy resolution

SDHCAL
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

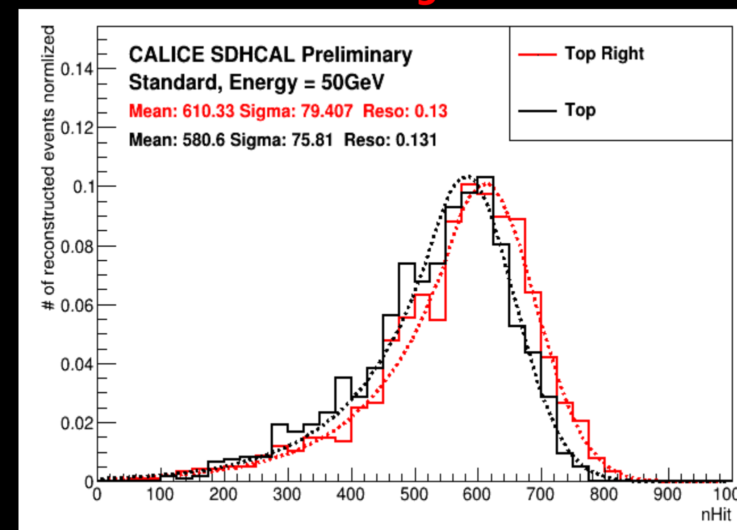


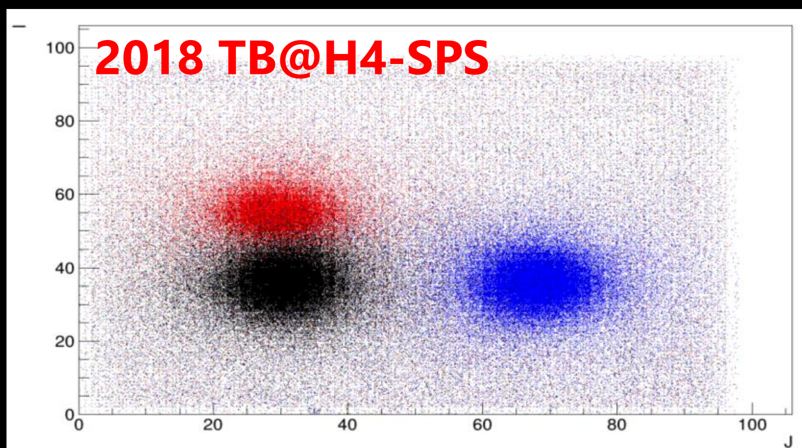
Hits associated to:
1st threshold (110 fC)
2nd threshold (5pC)
3rd threshold (15pC)

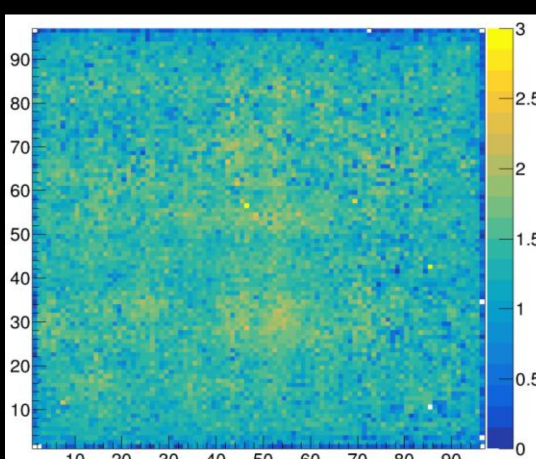
Homogenization of the SDHCAL response

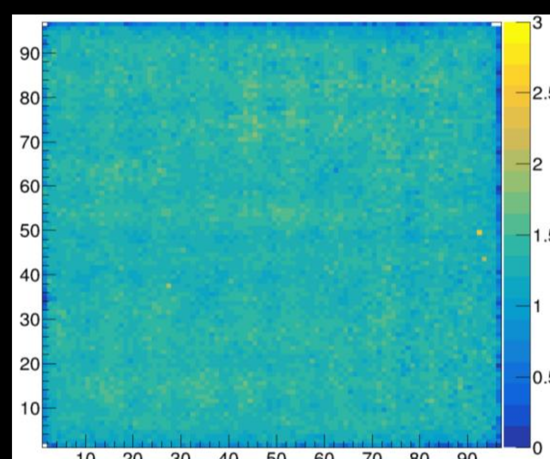
→Use the muons threshold scan to study both efficiency and multiplicity.
→Use the average multiplicity and that of the second and the third threshold efficiency as a reference and then for each ASIC change the thresholds to obtain the average values.

Before homogenization



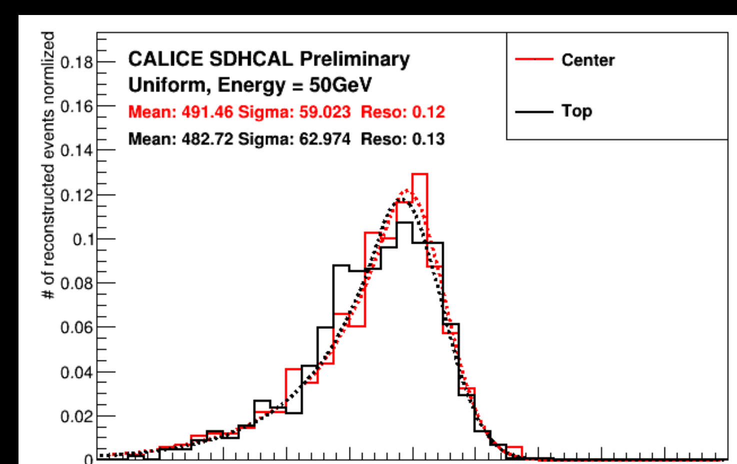






Before homogenization

After homogenization

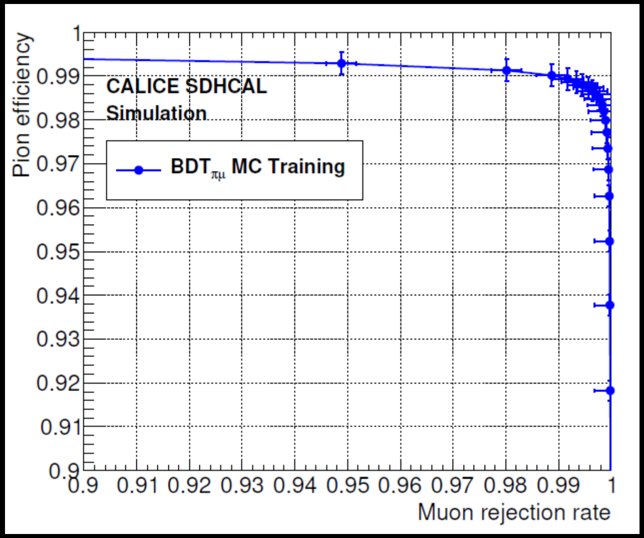


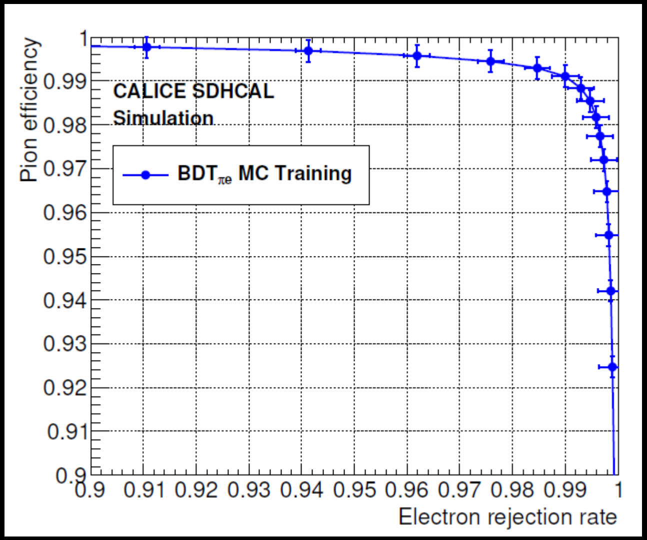
After homogenization

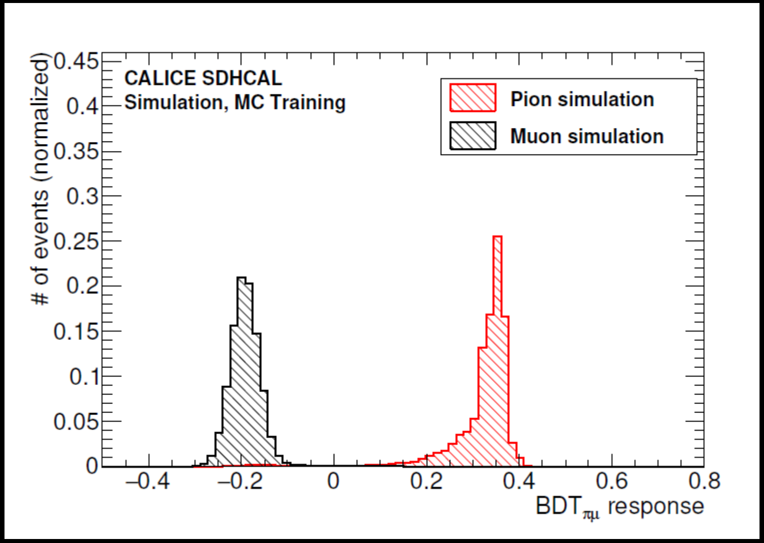
SDHCAL: Particle identification

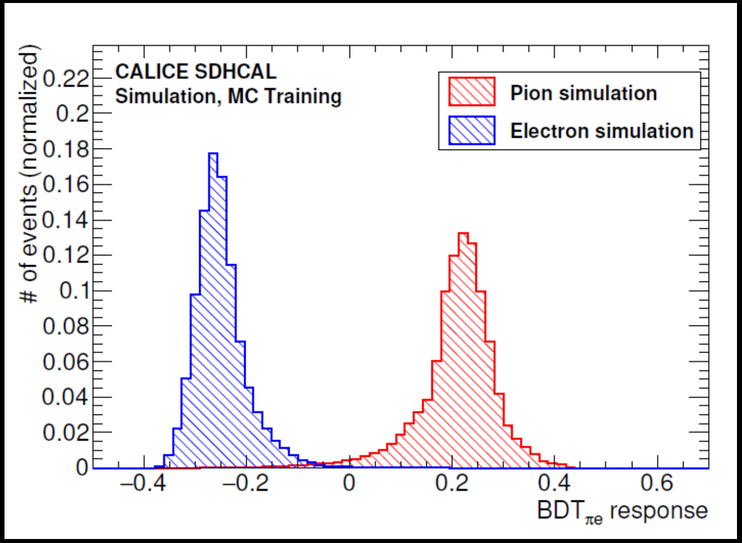
→ BDT helps to improve the hadron/e/mu PID, purify TB samples.
→ Keep 99% of pion efficiency and to reject >99% of e/mu.

arXiv:2004.02972

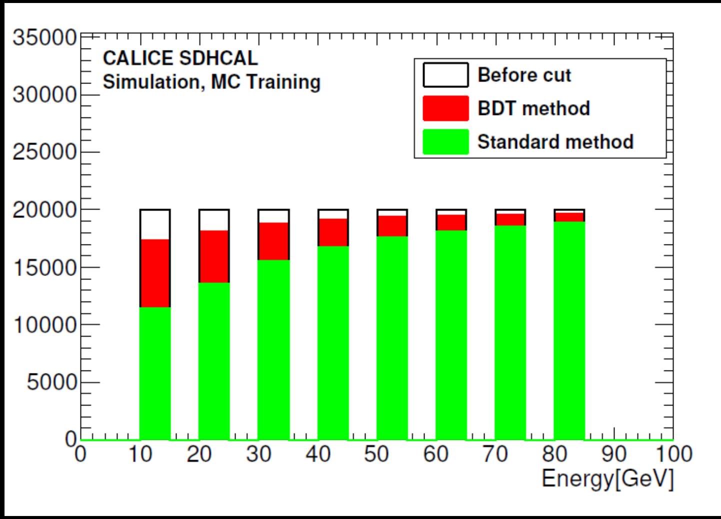


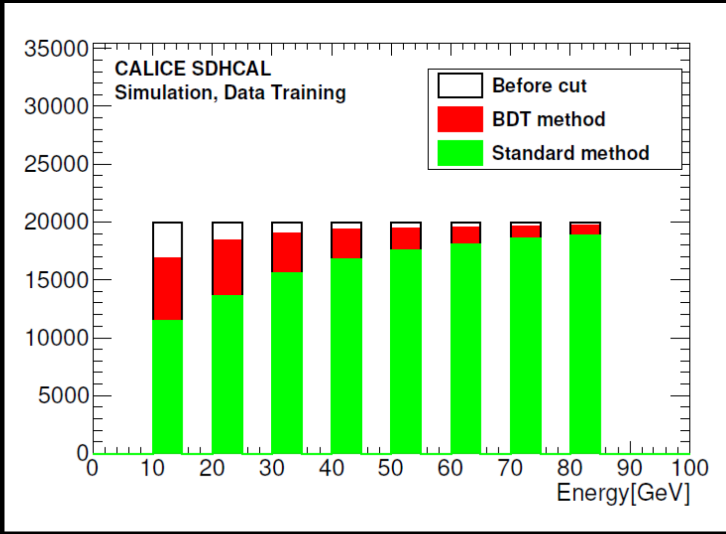


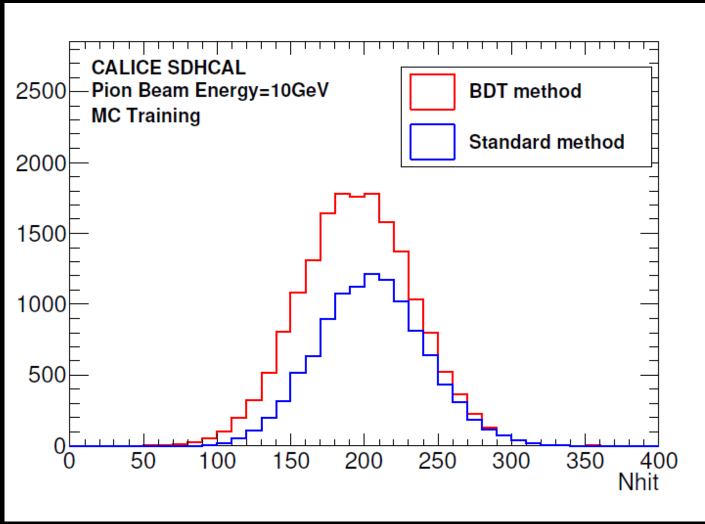


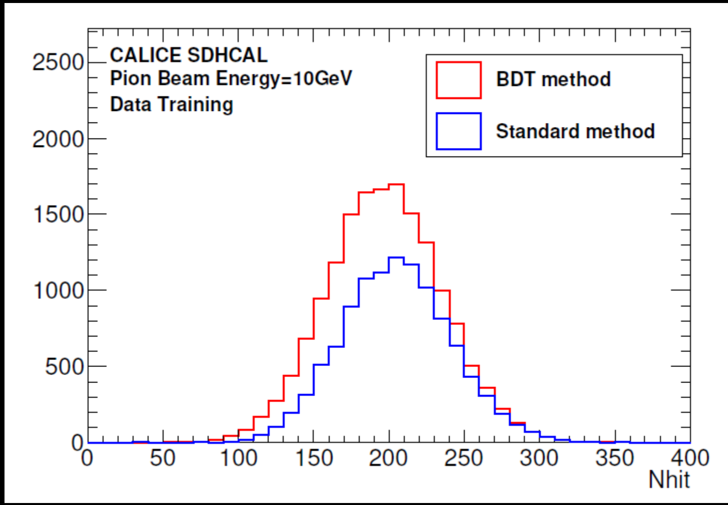


SDHCAL: Particle identification









SDHCAL: Particle identification


First common test with the technological SiW ECAL prototype
SDHCAL
ECAL
Common DAQ: same start acquisition (using the spill start)

Combined test: SDHCAL + SiW ECAL

SiW ECAL

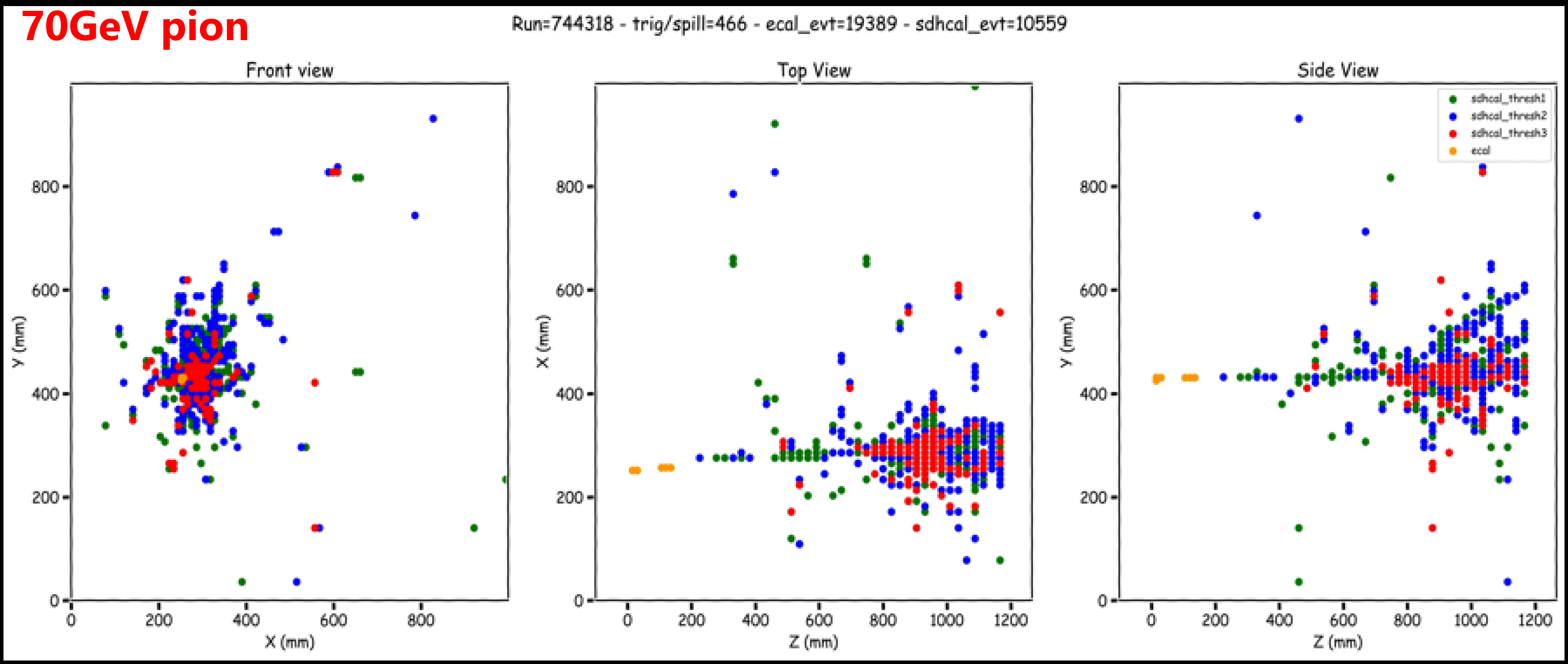
→ 9 working layers (several layers malfunctioning)

→ Placed in front of SDHCAL

SDHCAL

→37 GRPC layers present in prototype

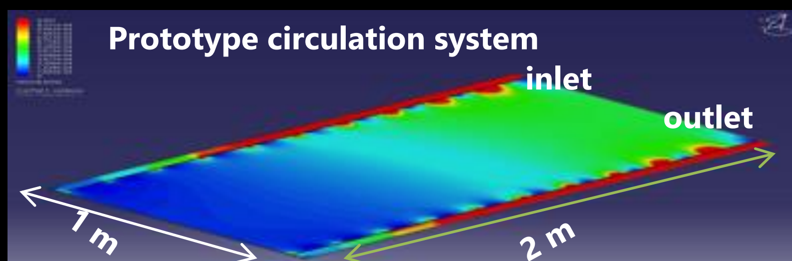
70GeV pion

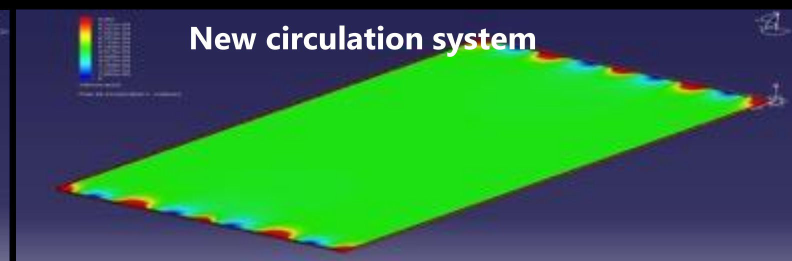


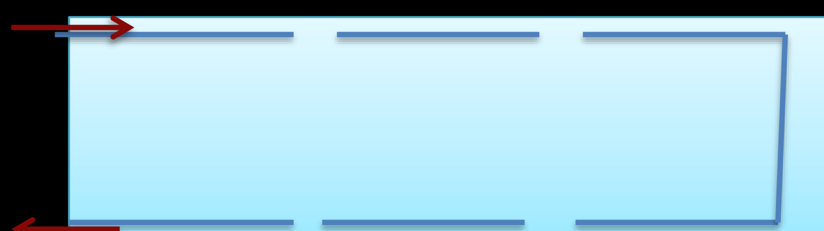
SDHCAL Module0 progress: Detectors

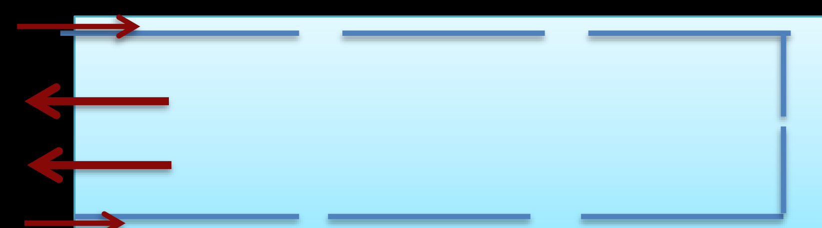
Construction and operation of large GRPC necessitate some improvement with respect to the present scenario.

Gas distribution : new scheme is proposed

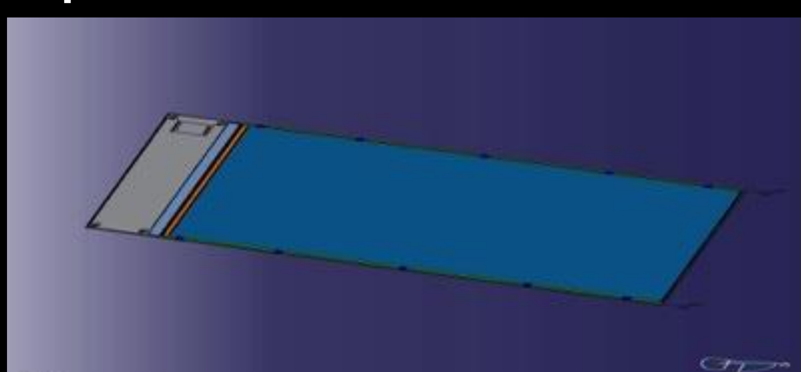


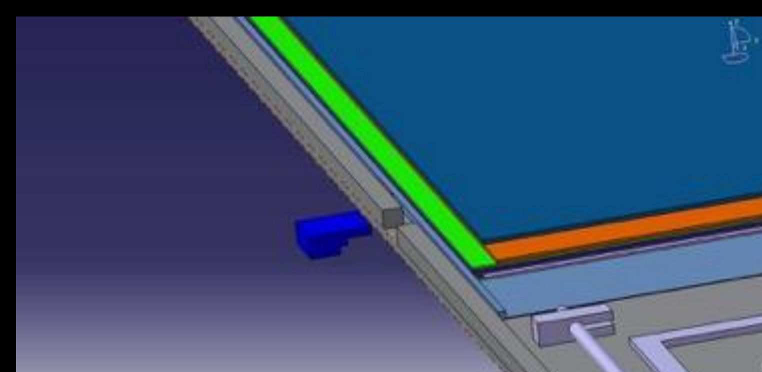






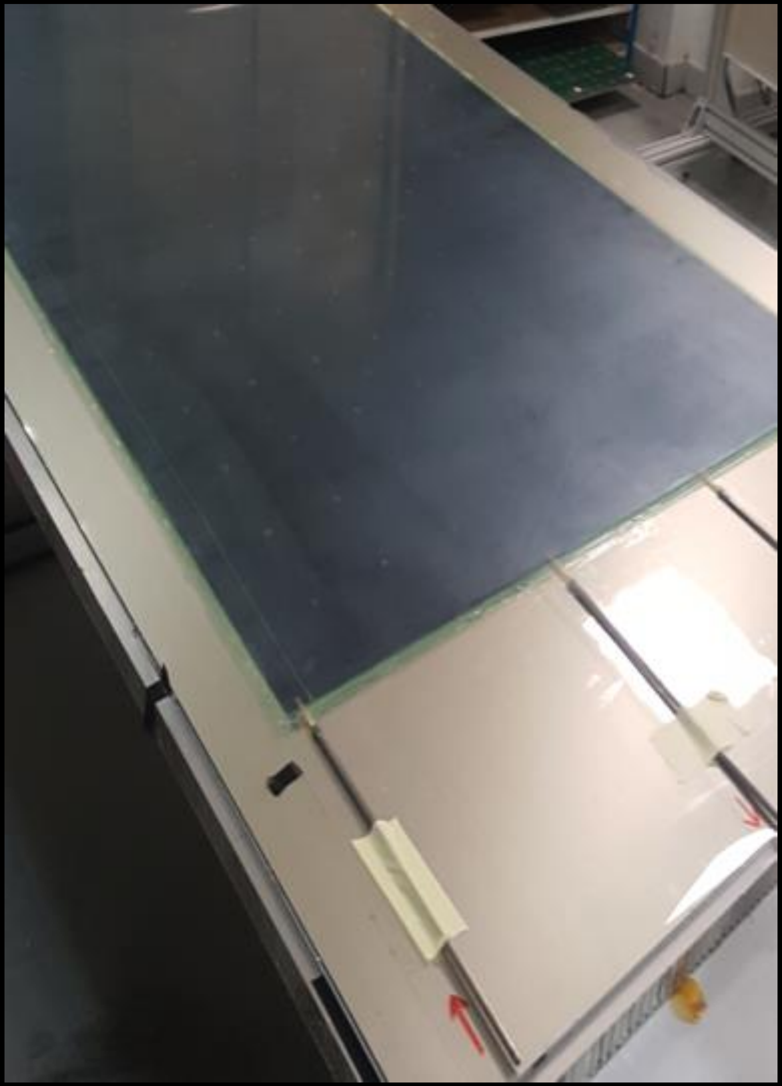
Cassette conception to ensure good contact between the detector and electronics is to be improved

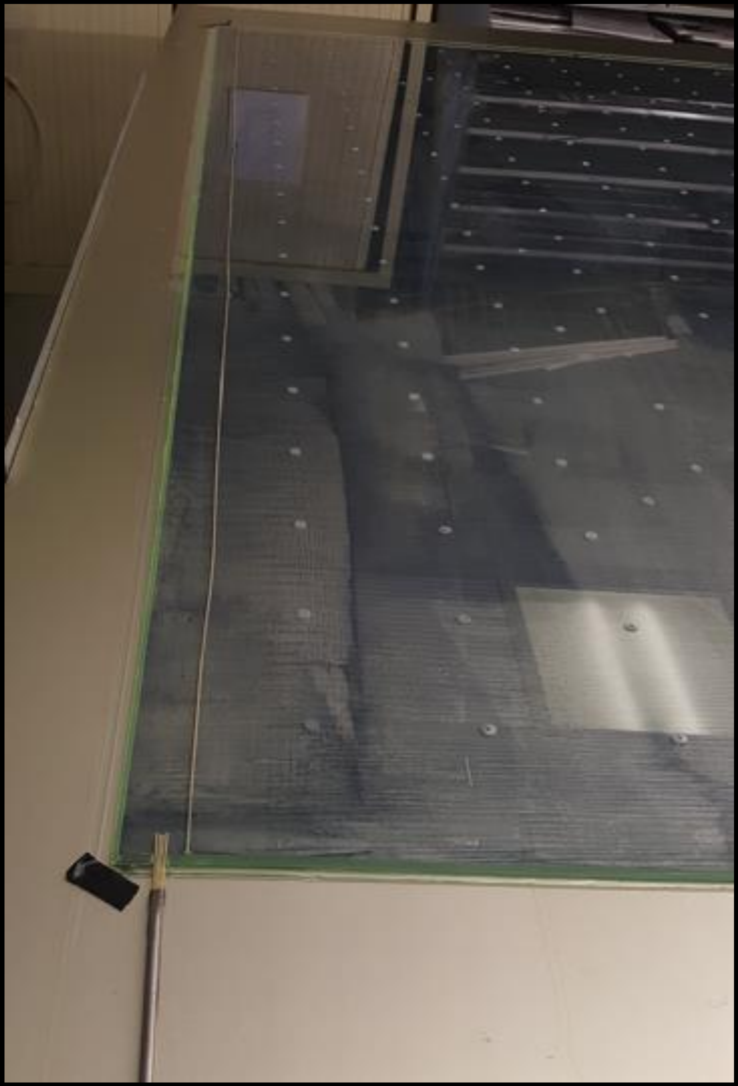




SDHCAL Module0 progress: Detectors

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





SDHCAL Module0 progress: New electronics

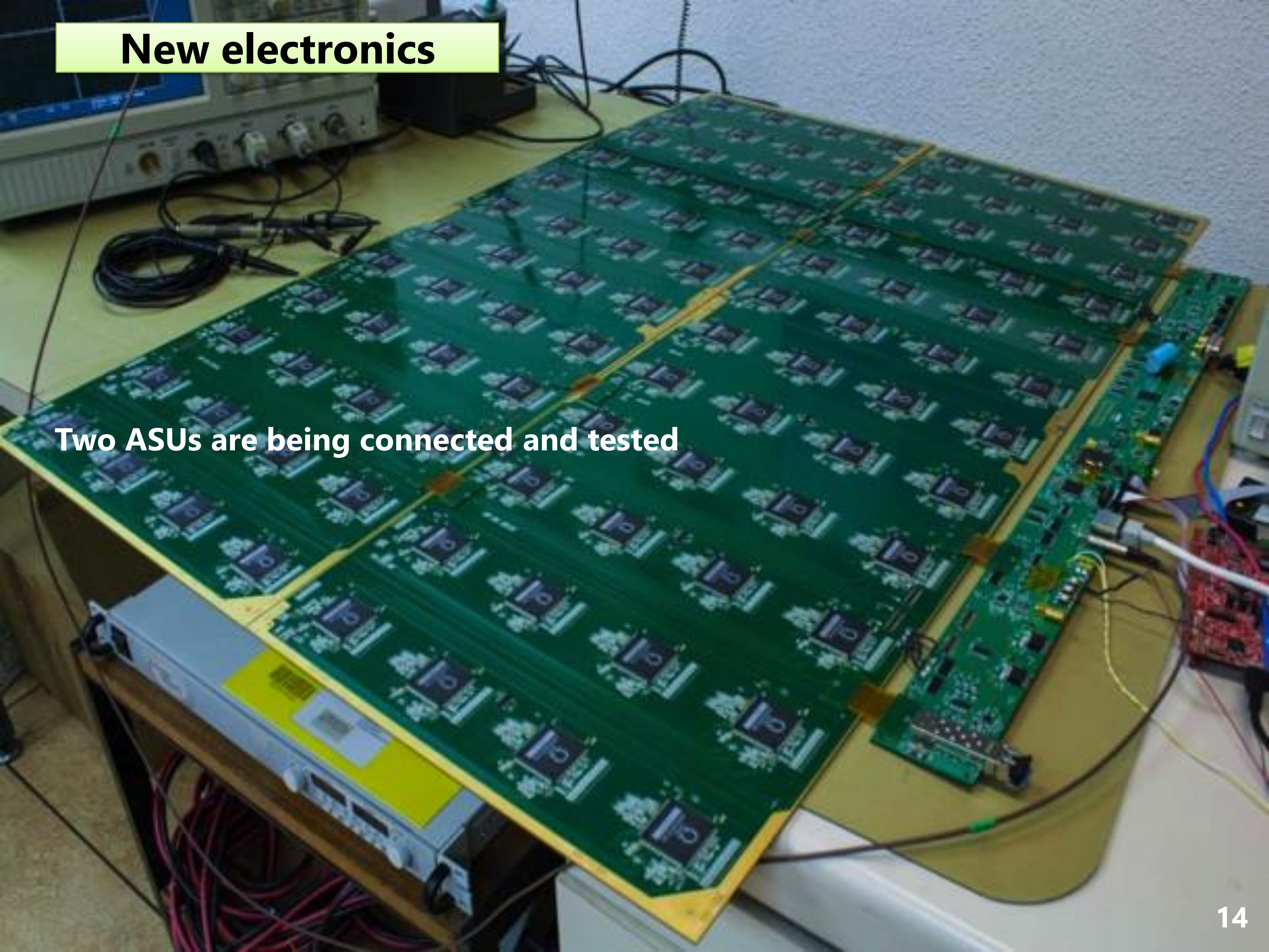
ASU (Active Sensor Unit)

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

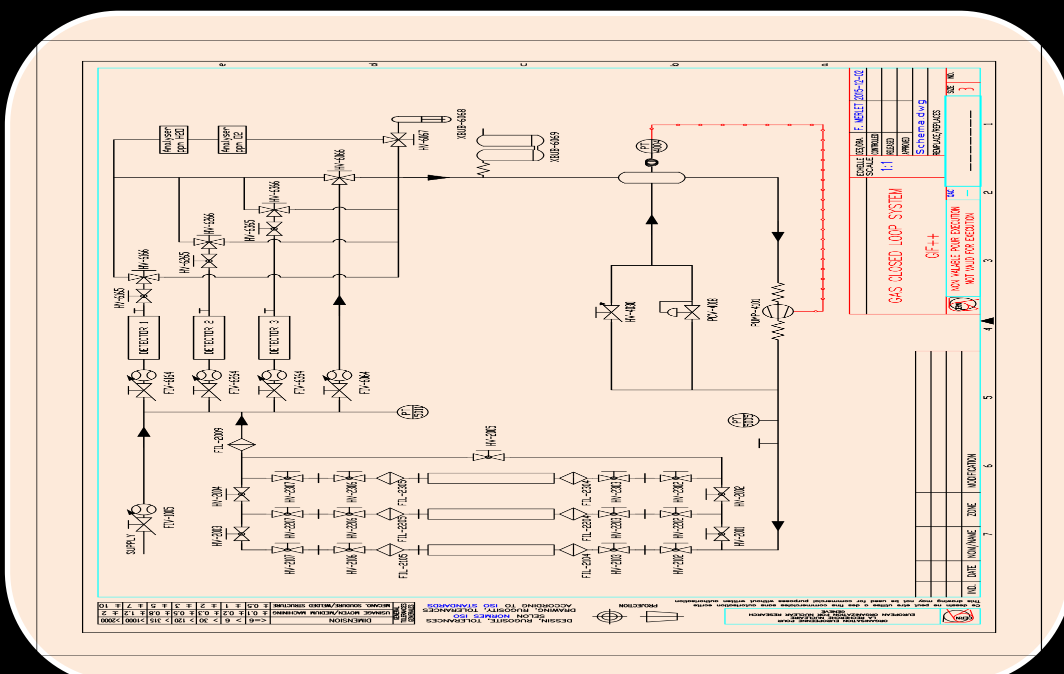
New electronics



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.



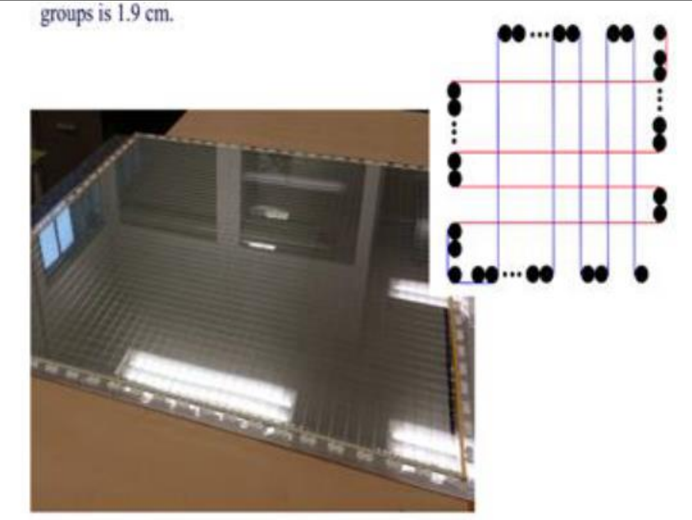
We will start using HFO1234ze soon (GWP=3)
We have also now a remotely a gas controller

Timing Measurement in SDHCAL

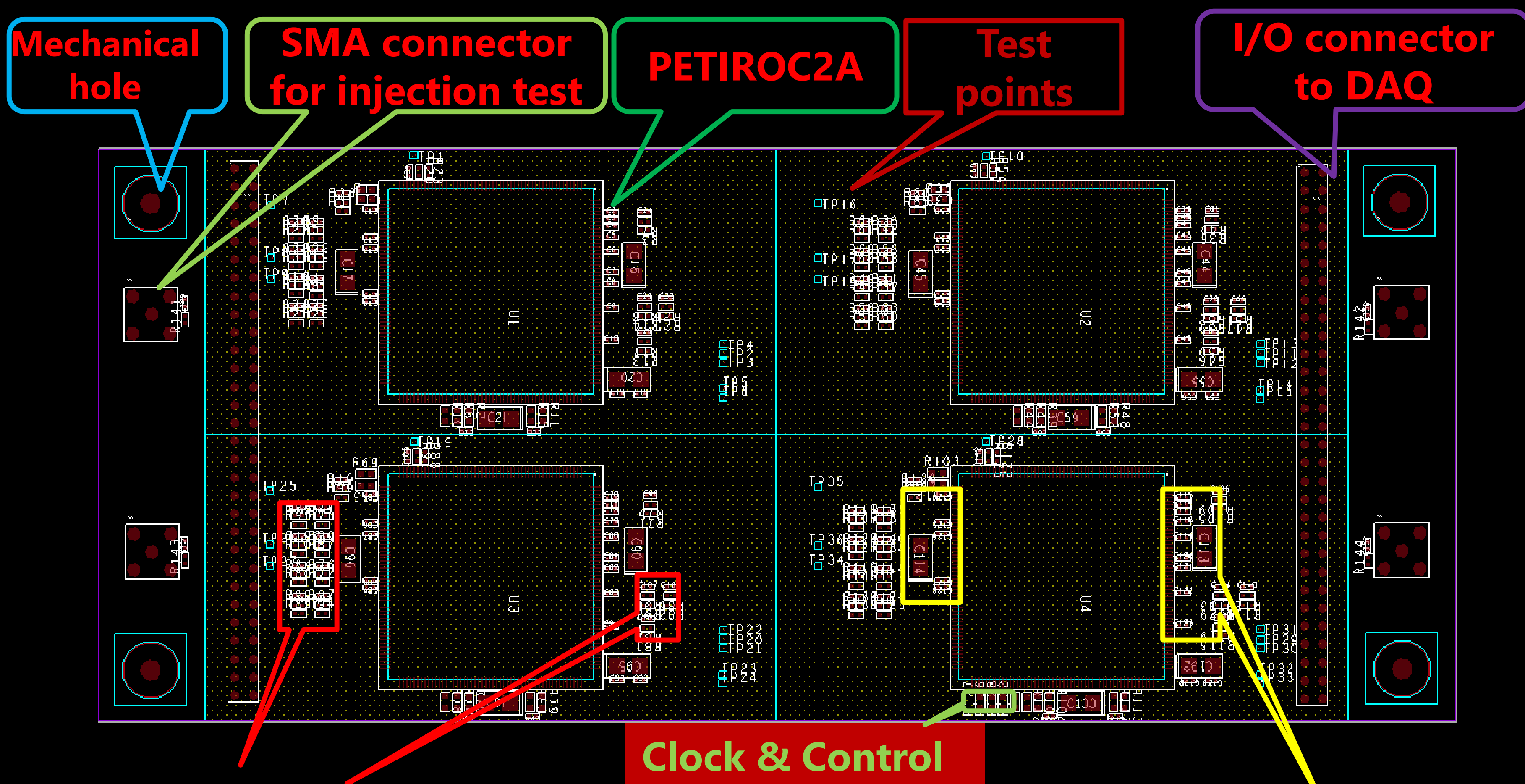
- Purpose: **five dimension Calorimeter**
  - Position, energy and **timing**

- Add **MRPC** layers in the SDHCAL
  - Same size as RPC

- Front-end board for MRPC readout
  - Charge and timing measurement simultaneously
  - **PETIROC2A** from OMEGA group
  - 25 ps timing measurement step
  - **Timing resolution: <10 ps**



Timing Measurement in SDHCAL



four PETIROC2A, I/O connectors, SMAs, capacitors, resistors and test points

Active cooling

- **CEPC is designed to operate at continuous mode with beam crossing rate: 2.8×10^5 Hz. →Power pulsing will not work at CEPC.**

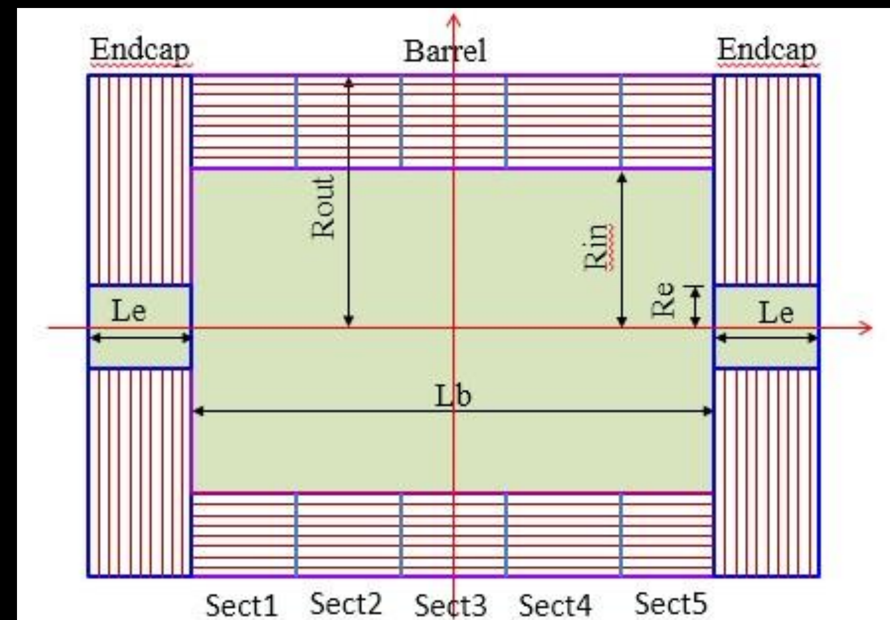
- **SDHCAL option**

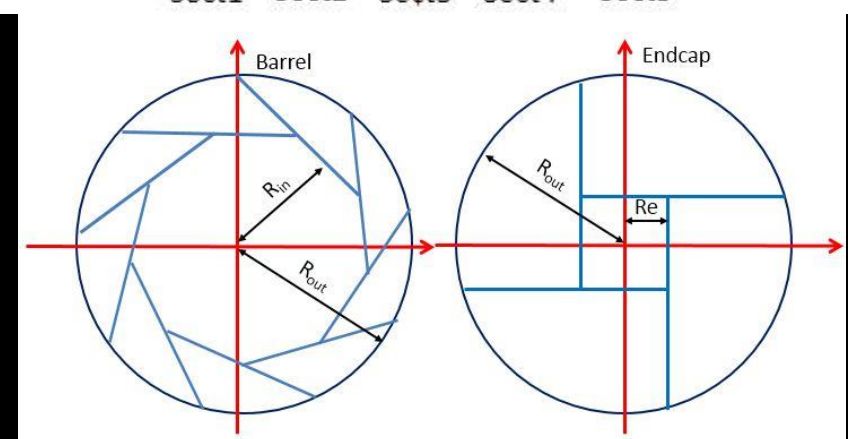
→Inner radius R_{in} = 2300mm
→Outer radius R_{out} = 3340mm
→Inner/Outer of HCAL endcap in Z-axis : 2670mm/3710mm

Area of the active layers :
→40 active layers in barrel and endcaps
→ ~3800m^2 (barrel) + ~2800m^2 (endcaps)

- **Total heat power :**
→ 60M channels (~1mW/channel) → 60kW + readout boards ...

- **Heat affects:**
→Electronics stability, detector unit performance, structure deformation

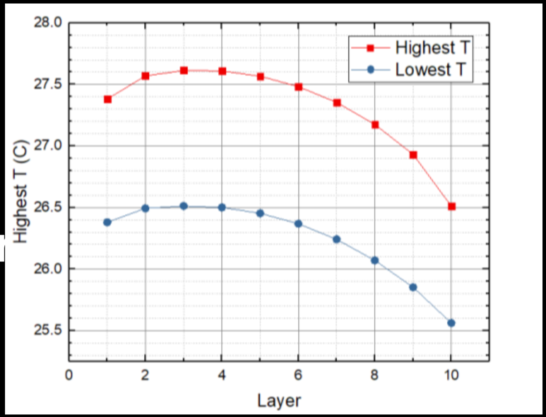




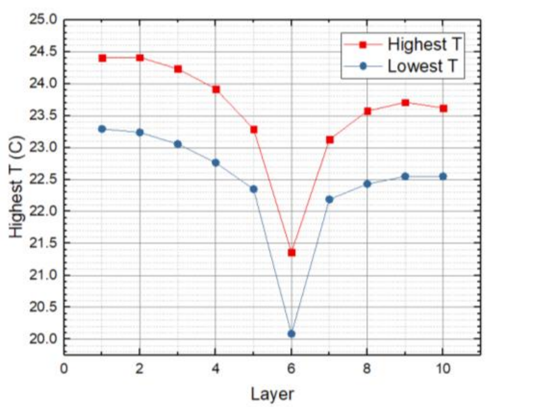
Active cooling

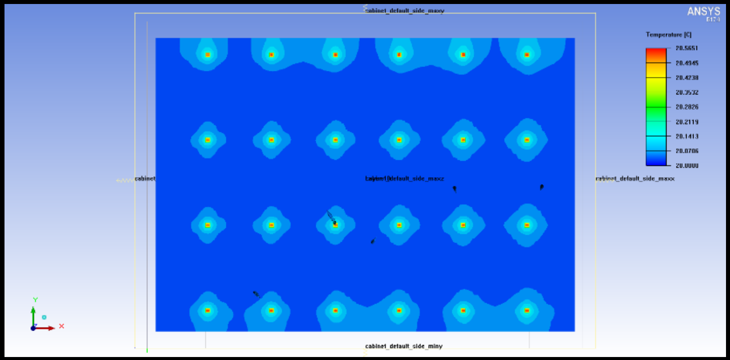
- 10 layers, flow rate: 1m/s
- With cooling at 6th layer:
- With cooling each layer:
  - uniform among layers
  - cooling power: ~1.53W/layer

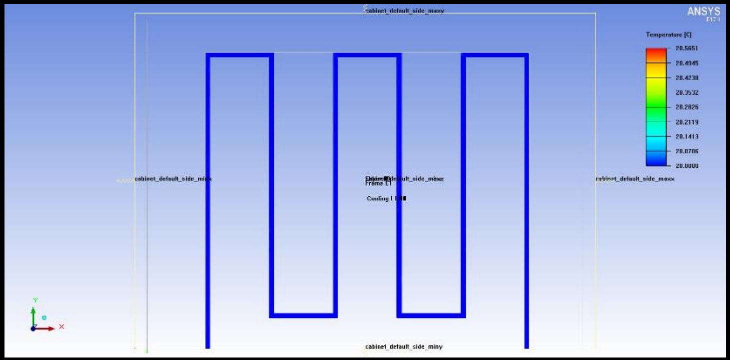
no cooling



cooling at 6th layer

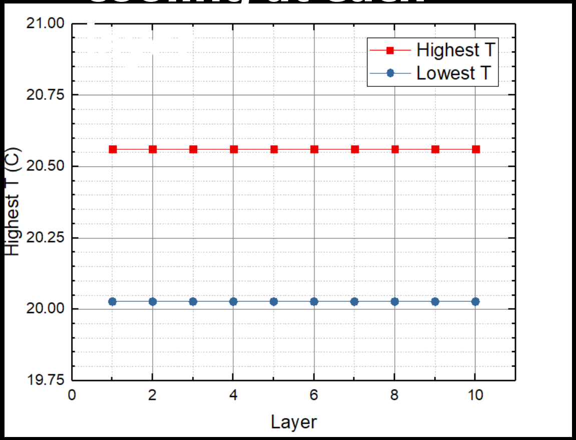


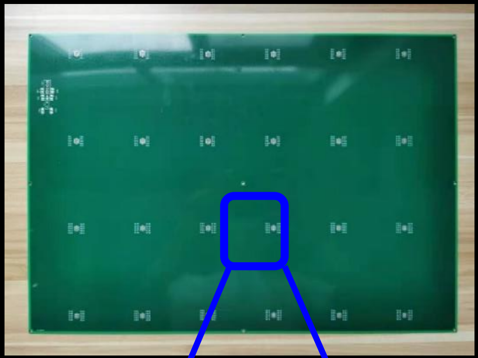




cooling pipes

cooling at each





PCB with resistors to mimic HARDROC ASIC heat source for cooling design and test.

Active cooling-detecting system

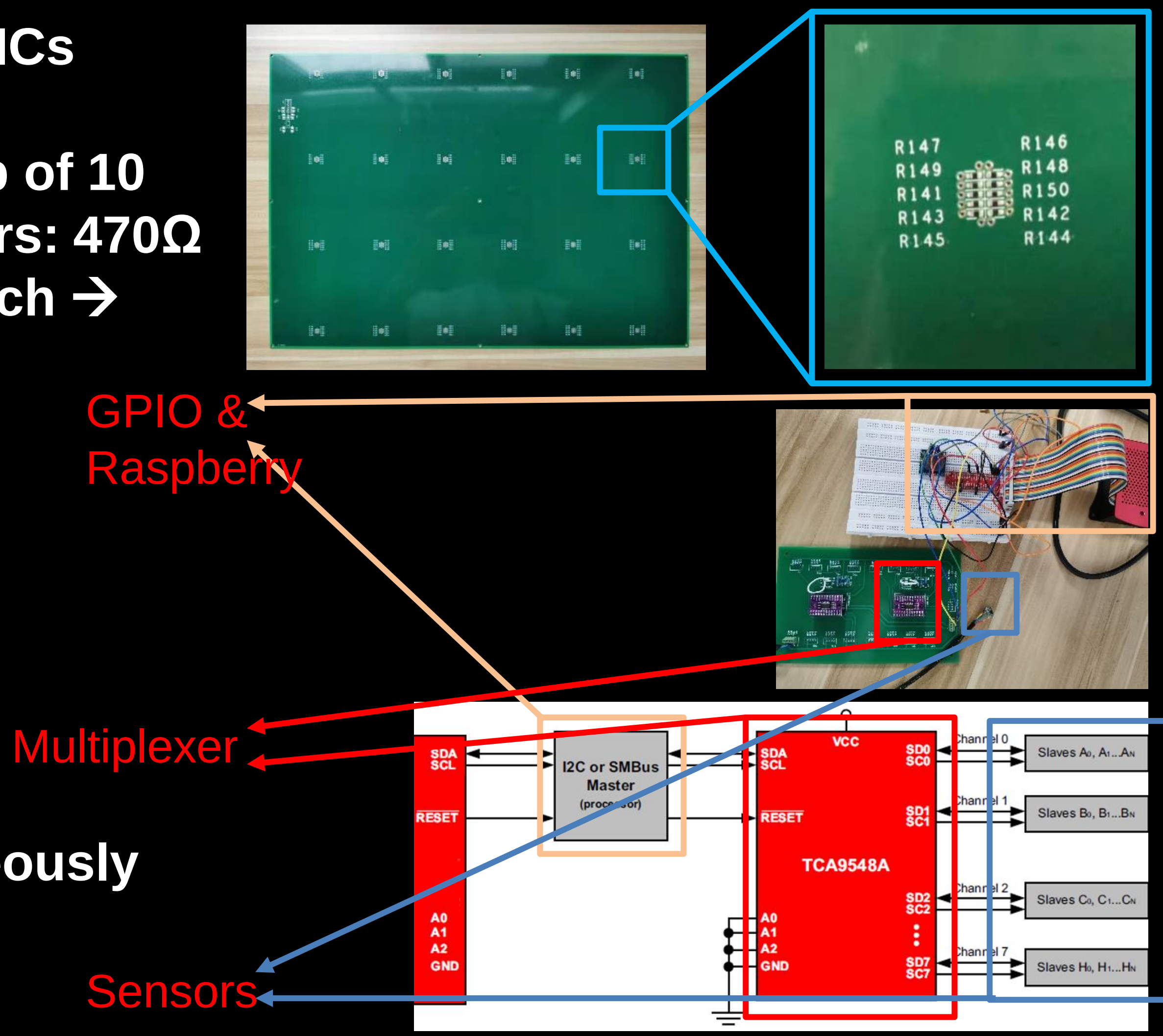
Use resistors substituting for ASICs

- **Resistors: 4*6*10 per PCB**
- **Total resistance of a group of 10 parallel-connected resistors: 470Ω**
- **ASICs in SDHCAL: ~1mW/ch → ~5.5V on resistors**

Sensor: Si70xx, high precision temperature & humidity sensor

- **range: -40~125℃**
- **accuracy: 0.1℃ at most**

8*8 sensors monitored simultaneously with multiplexers based on I^2C



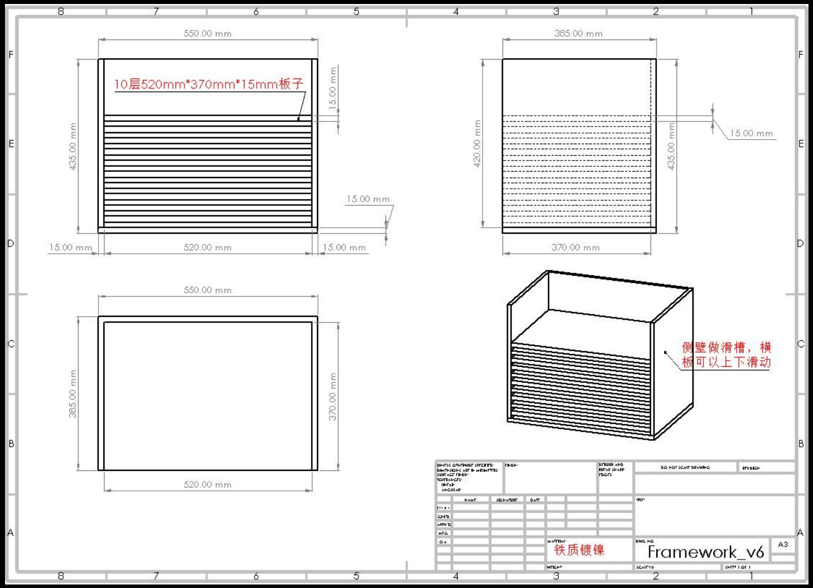
Active cooling

- **Cooling plates: water pipes imbedded in metal plates**
  - **cooling ability: ~kW/m^2**
  - **safety(water is not so good)**

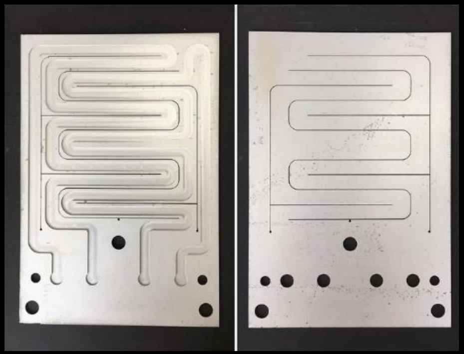
  →Stainless steel
    - **poor heat transmission**
    - **difficult to produce → high cost**
    - **can work as the absorber**
    - **500mm×350mm×15mm**
    - **8000 yuan(~€1000)/piece**

  →Aluminum
    - **good heat transmission**
    - **easy to produce**
    - **4 times the interaction length than steel**
    - **500mm×350mm×10mm**
    - **608 yuan (~€77)/piece for 3000pcs**

Cooling Test Module



Cooling plates



Active cooling-Geant4 simulation

A geant4 simulation for the SDHCAL has been made by the Lyon group. Some changes had to be made to use it for studies on the cooling system for the SDHCAL of CEPC :

Moving from 9.* to 10.* geant4 version allowing to update the simulation (multithreads)

Allowed to change more easily the RPC layers and the absorber structure using json script


```json
{
  "RPCTypes":
  [
    {
      "Name" : "Standard",
      "Layers" :
      [
        {"Name":"FrontCassetteAbsorber" ,"Width": 2.500 ,"Material":"SDHCAL_Steel316L" },
        {"Name":"Mask"                  ,"Width": 1.600 ,"Material":"SDHCAL_epoxy"     },
        {"Name":"PCB"                   ,"Width": 1.200 ,"Material":"SDHCAL_g10"       },
        {"Name":"MylarAnode"            ,"Width": 0.050 ,"Material":"G4_MYLAR"         },
        {"Name":"GraphiteAnode"         ,"Width": 0.050 ,"Material":"G4_GRAPHITE"      },
        {"Name":"ThinGlass"             ,"Width": 0.700 ,"Material":"G4_Pyrex_Glass"   },
        {"Name":"GasGap"                ,"Width": 1.200 ,"Material":"SDHCAL_RPCGaz"    },
        {"Name":"ThickGlass"            ,"Width": 1.100 ,"Material":"G4_Pyrex_Glass"   },
        {"Name":"GraphiteCathode"       ,"Width": 0.050 ,"Material":"G4_GRAPHITE"      },
        {"Name":"MylarCathode"          ,"Width": 0.180 ,"Material":"G4_MYLAR"         },
        {"Name":"BackCassetteAbsorber"  ,"Width": 2.500 ,"Material":"SDHCAL_Steel316L" }
      ]
    }
    ,
```


Code is being reviewed by the Lyon group for merging.

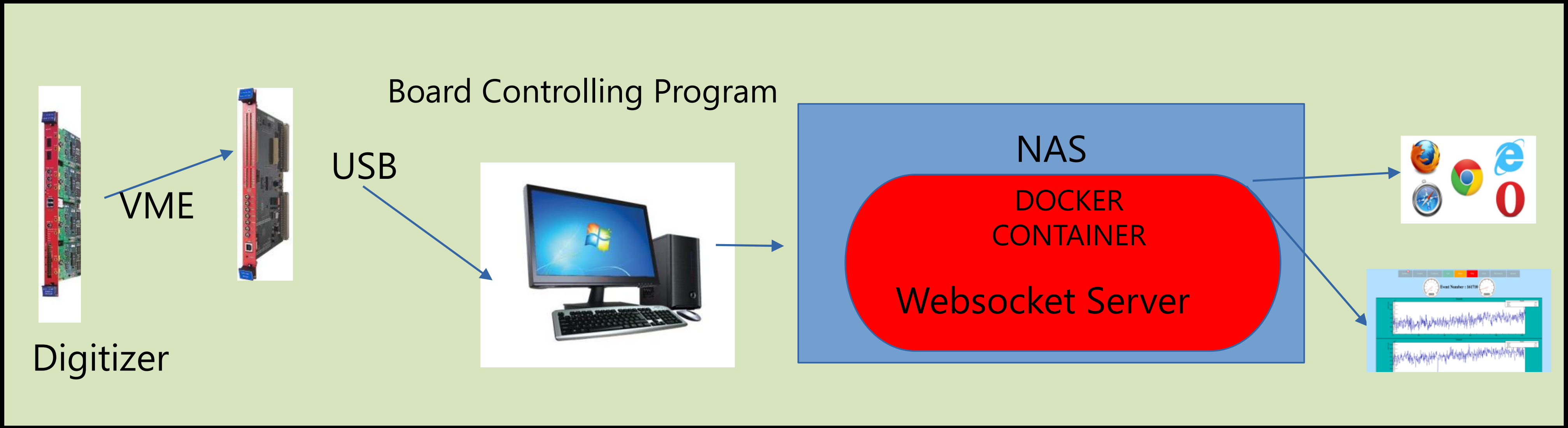
Trying to implement the Absorber options and to install the software needed for the digitization of the hits coming from geant4 for further studies and comparison with the standard SDHCAL design (With VS without Cooling Systems)

RPCLab DAQ

Some months ago a test using websocket for the DAQ system in the lab has been made :
→ waveDump from CAEN for the digitizer.
→Modified to use websockets and be controlled remotely.
→ Online monitored : http://202.120.13.50/test.php
→Able to talk to elog for Run logging.

But has some drawbacks:
→The program was the server and plotter etc : if there is a crash all crash down

Working at new version DAQ
→If some crash the other system continue to work and logger report Errors



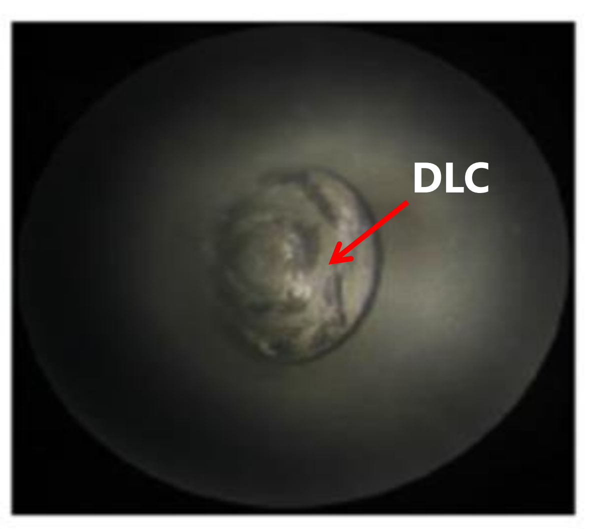
RWELL Detector development

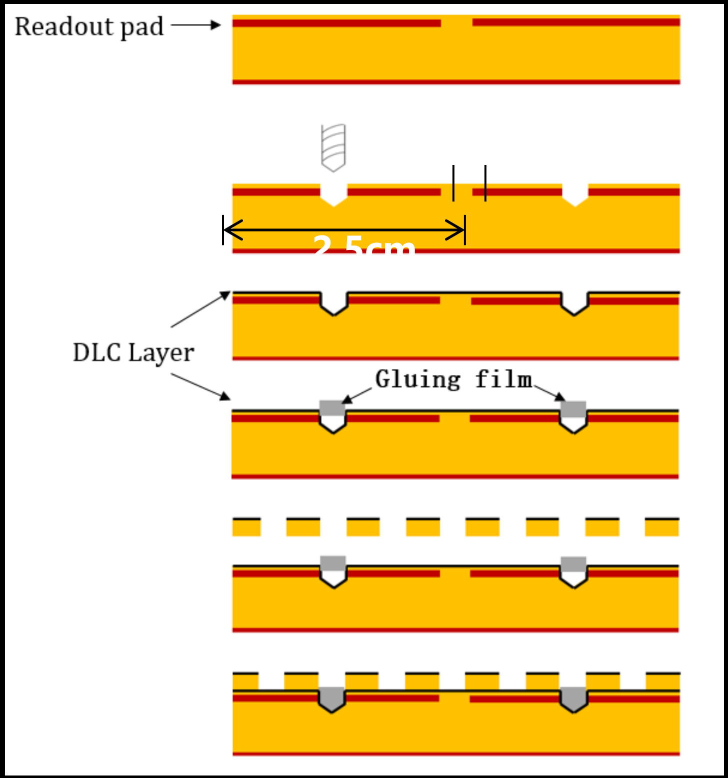
Detector development methods

- Key issues for RWELL:
  1. Resistive layer-DLC(Diamond like carbon)
  2. Bonding method

- Fast grounding method:

  Remove Charge accumulated on the DLC layer





- Thermal bonding technique:

  Gluing the RWELL foil to the readout board by heating the film

RWELL Detector development

DLC deposition procedure

Sample Clamping

Vacuum Pumping

Sample Pre-treating

Deposition

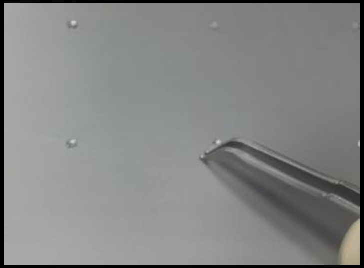
Cooling in Vacuum

Sample taking down

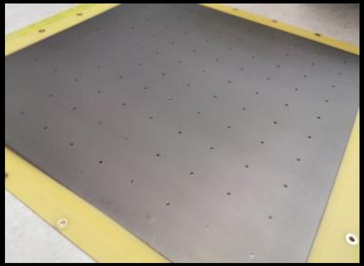
A DLC-coating PCB used as RWELL foil

A DLC-coating Readout Board

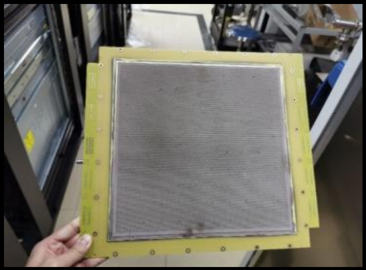
Thermal bonding procedures →



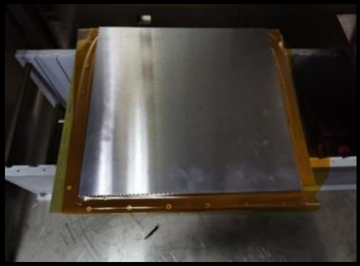
Step 1，Place the gluing film



Step 2，Pre-heating



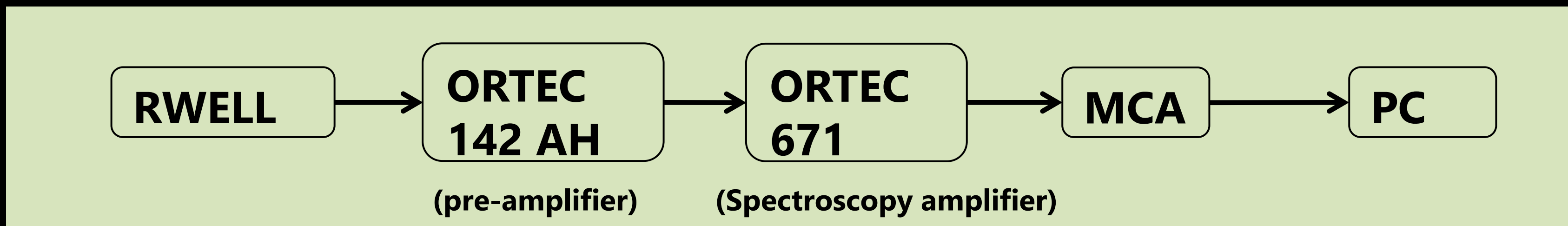
RWELL Detector

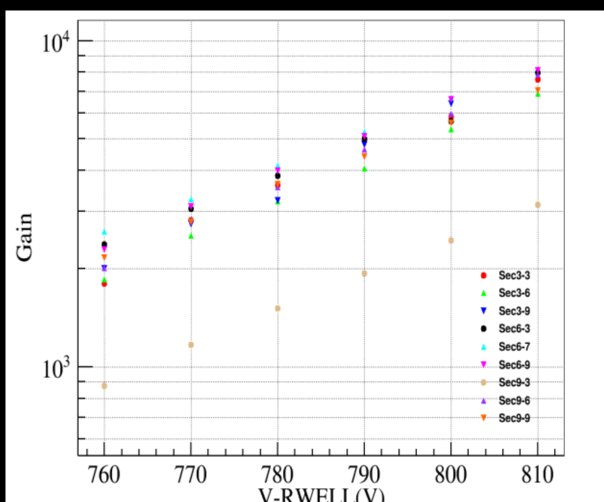


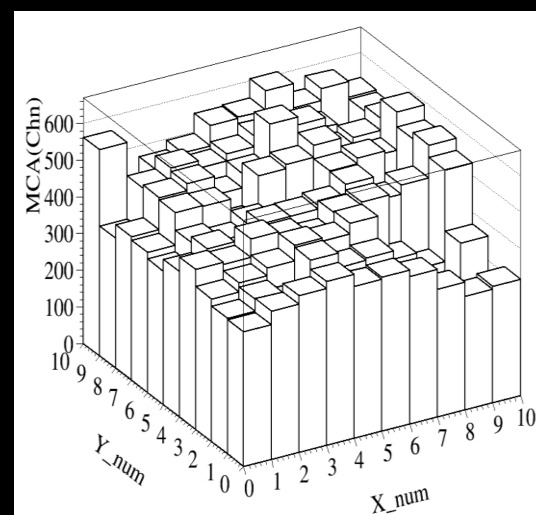
Step 3，Thermal boding

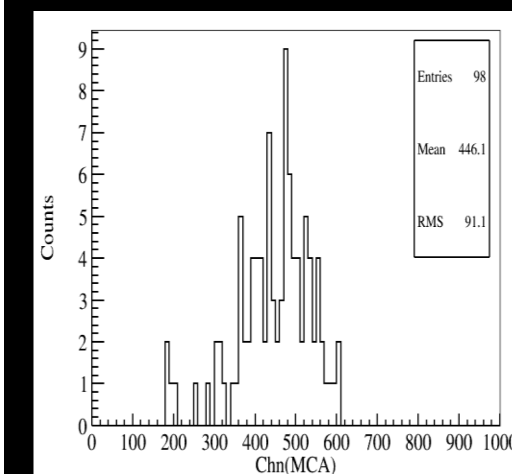
Gain test

- Test setup：









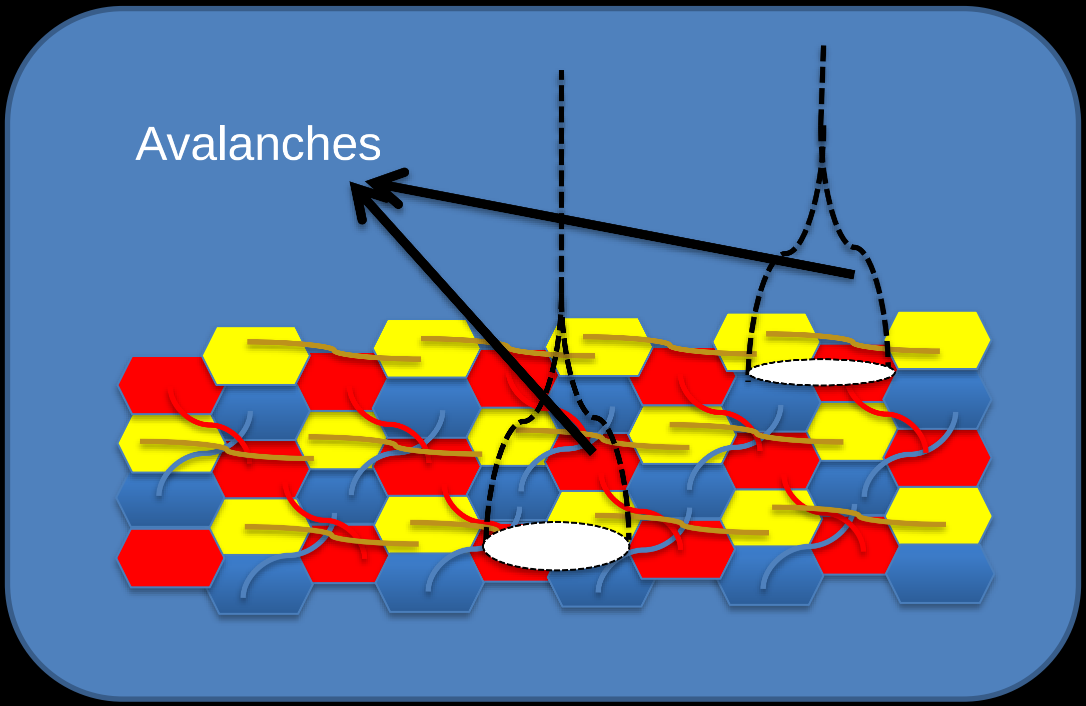
Gain ： ~8000

Gain uniformity :RMS/Mean ～20.4%%

- Gain uniformity is not good. Possible reason:

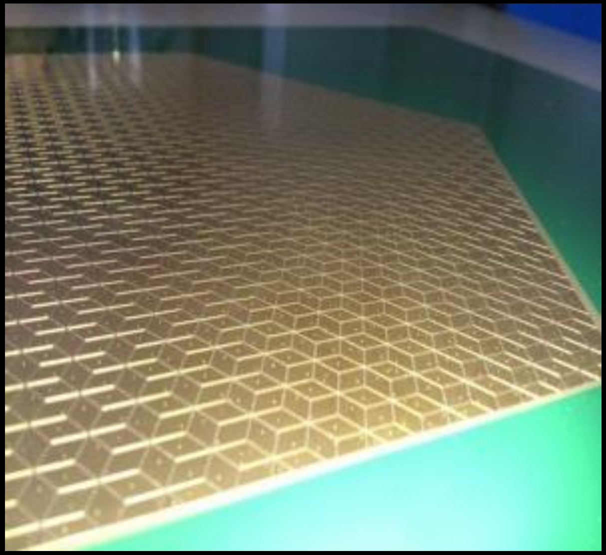
1. Gas flow
2. Uniformity due to the thermal boding procedure

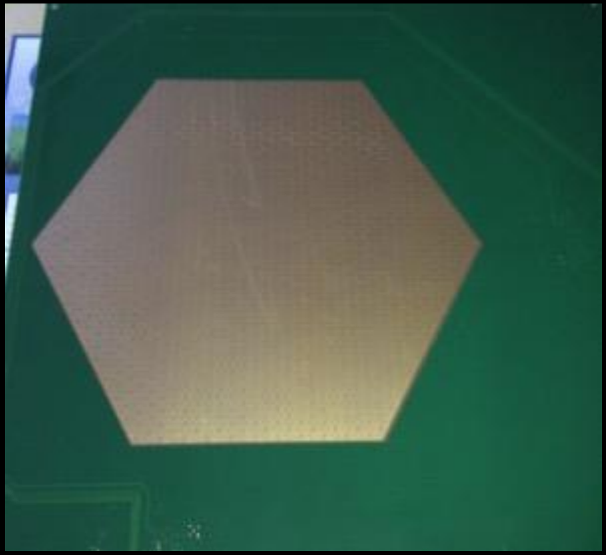
New idea: New readout scheme

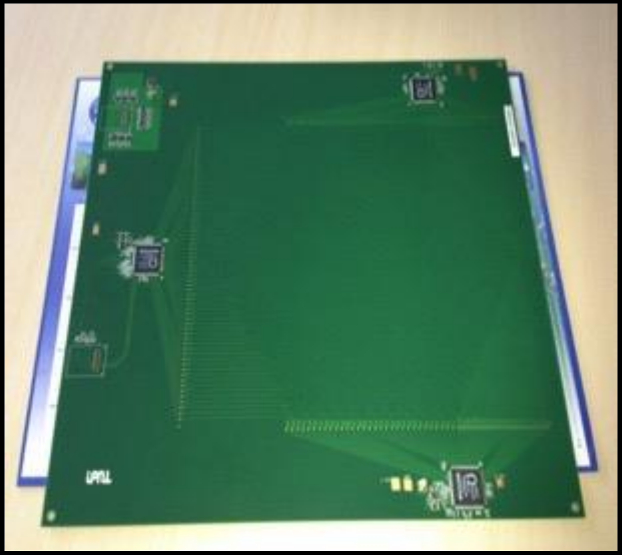


The principle is simple: the charge is shared among several pads/pixels The pads/pixels are inter-connected in a smart way so one can identify the position of the impinging particle by identifying the fired strips and thus find the hit as the crossing points.

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)







Summary

- Technological protoype running successfully since 2012
- Many results validate the performance of the SDHCAL concept
- The design for Front-end board for MRPC readout is ongoing
- The simulation and test module for active cooling is progressing
- The new readout scheme is introduced
- The RWELL detector developed as planed
- Strong collaboration with several international research units

Thanks for your attention !