T-SDHCAL

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for the T-SDHCAL groups
IP2I, SJTU, CIEMAT, VUB, Yonsei

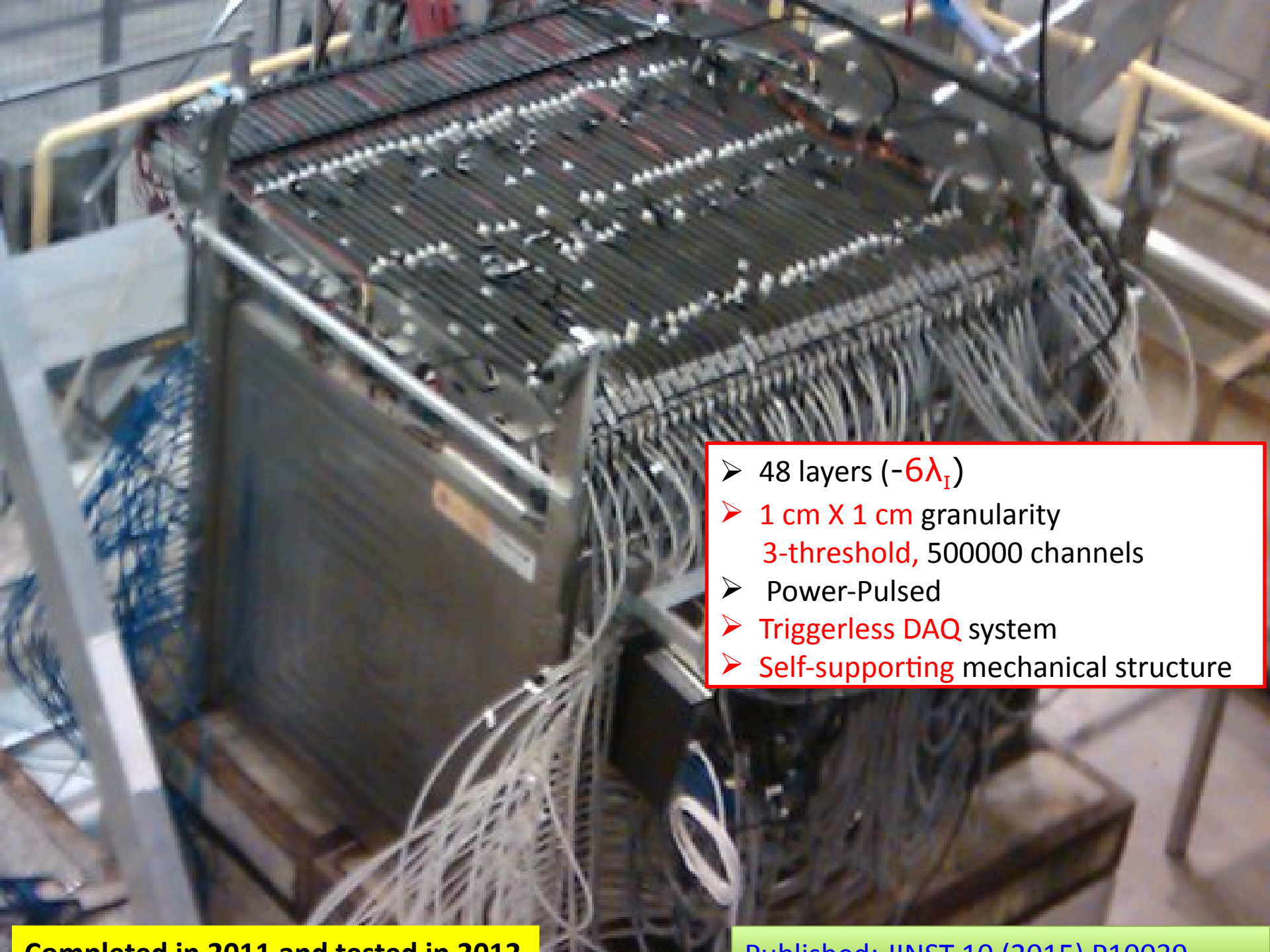
Outline

SDHCAL

- ✓ Short description
- ✓ Summary of the most important results
- ✓ Further improvements on energy reconstruction

T-SDHCAL

- ✓ Why timing is useful?
- ✓ How to achieve it
- ✓ Future developments

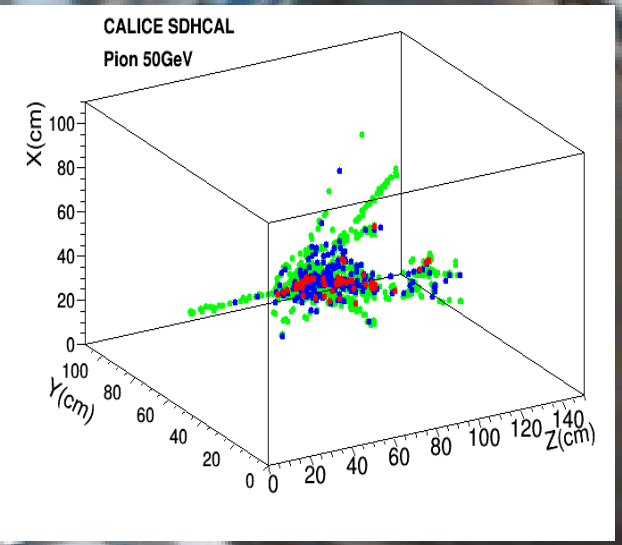


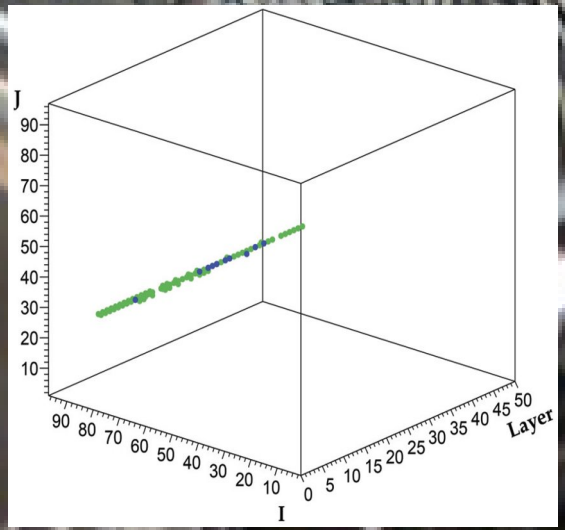
- 48 layers (~$6\lambda_I$)
- 1 cm X 1 cm granularity
  3-threshold, 500000 channels
- Power-Pulsed
- Triggerless DAQ system
- Self-supporting mechanical structure

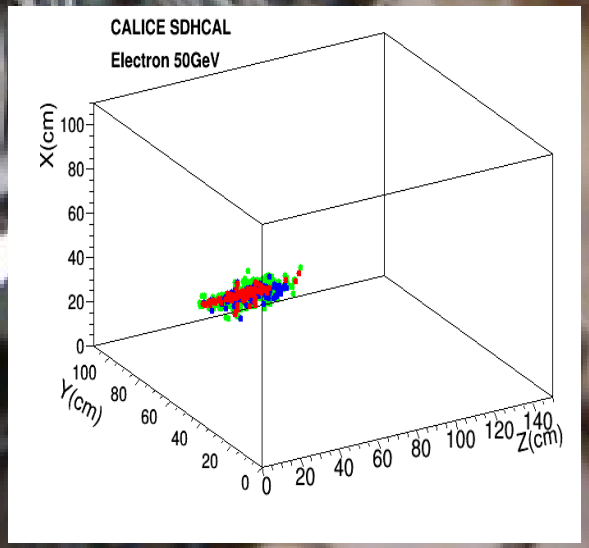
Completed in 2011 and tested in 2012

Published: JINST 10 (2015) P10039

SDHCAL prototype was exposed to beam particles at CERN PS, SPS in 2012, 2015, 2017 and 2018





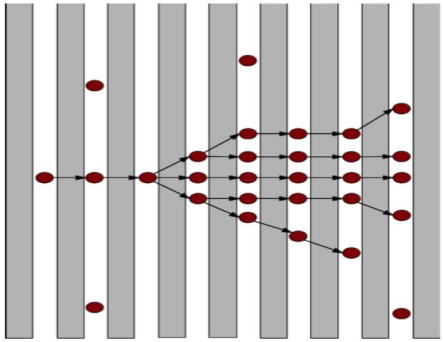


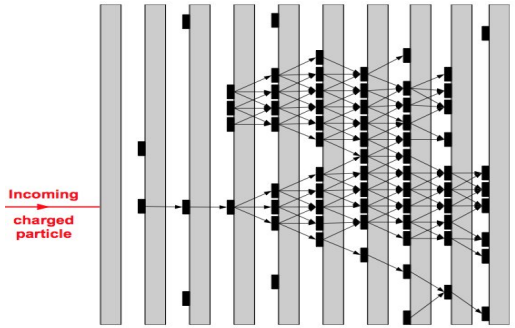
SDHCAL high granularity is important for PFA

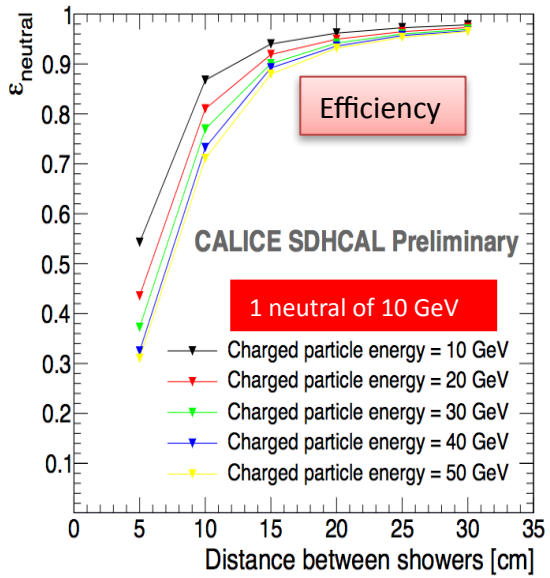
It helps to optimize the connection of hits belonging to the same shower by using first the topology and then the energy information

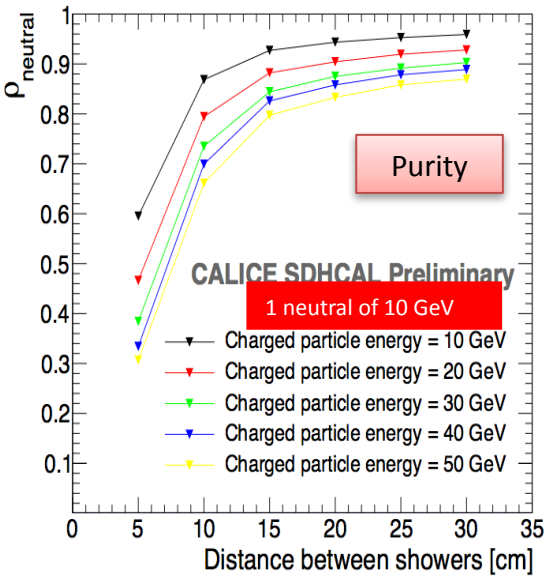
April algorithms:

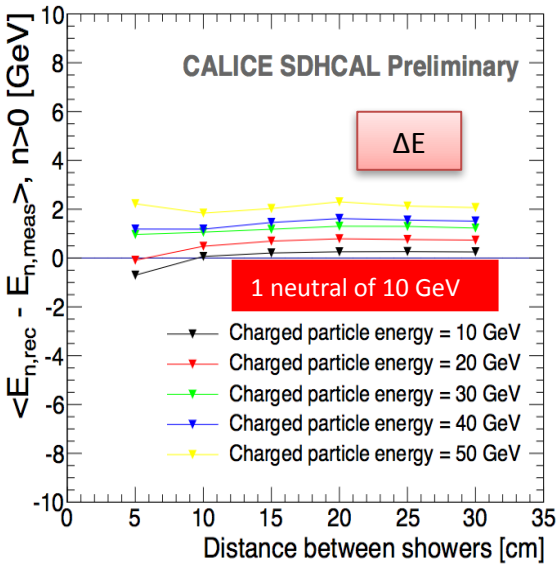
It connect hits and then their clusters using distance and orientation information then correct using tracker information (momentum)











CALICE note CAN054

Energy reconstruction

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

N_1 = Nb. of pads with first threshold <signal < second threshold

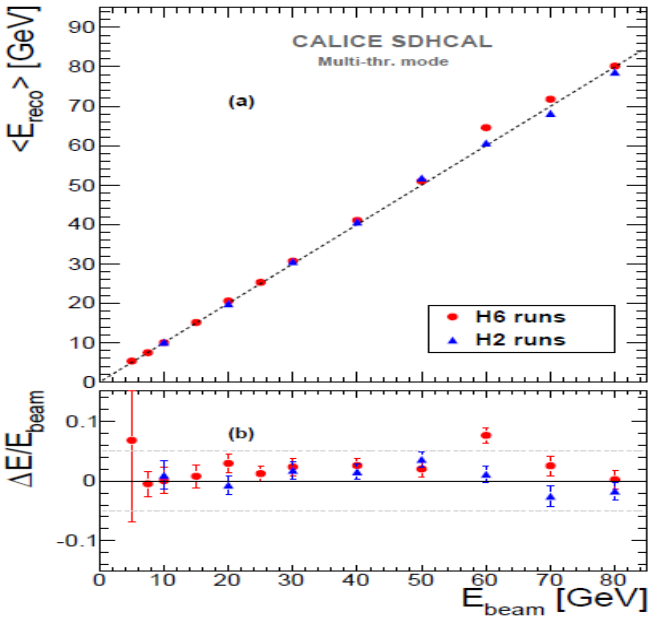
N_2 = Nb. of pads with second threshold <signal < third threshold

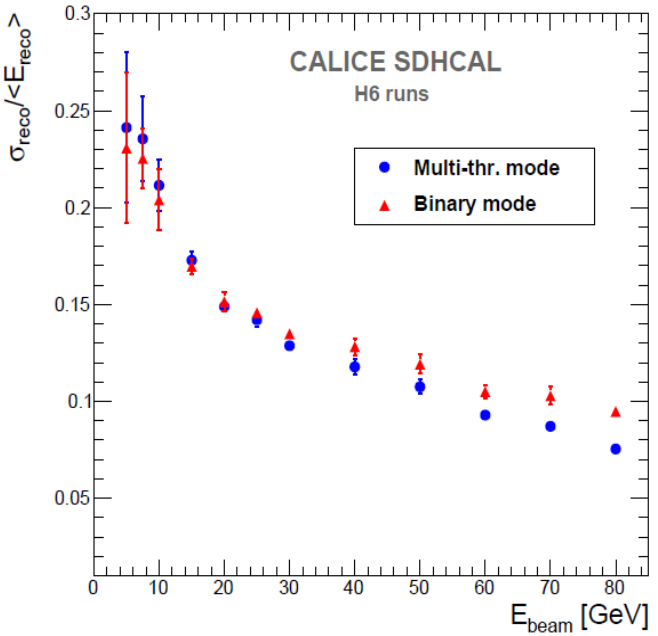
N_3 = Nb. of pads with signal> third threshold

α , β , γ are **quadratic functions** of $N_{tot} = N_1 + N_2 + N_3$

They are computed by minimizing : $\chi^2 = (E_{beam}-E_{rec})^2/E_{beam}$

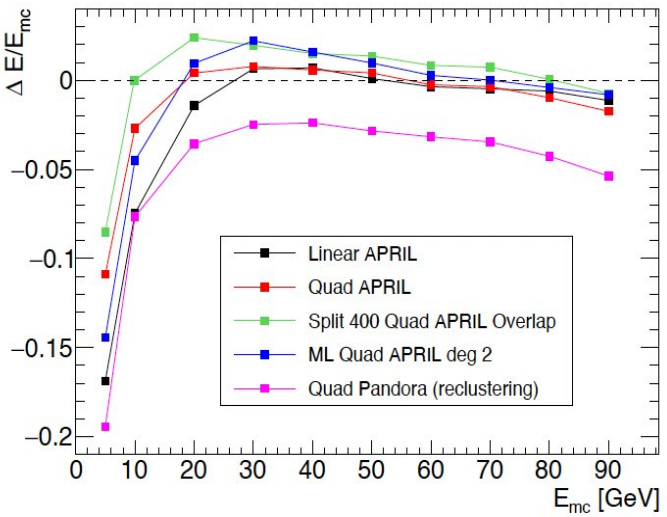
Only a few energy points with small amount of data were used for this minimisation

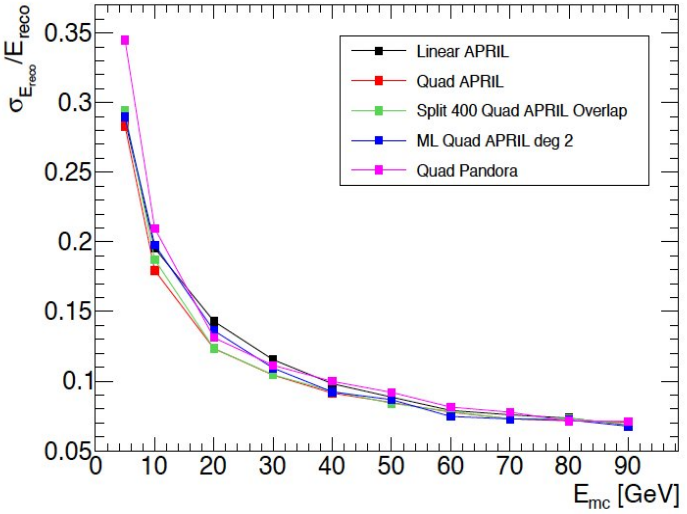




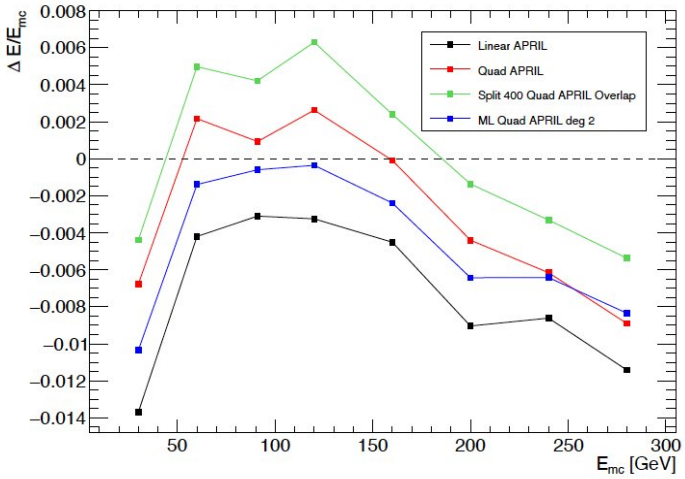
JINST 11 (2016) P04001

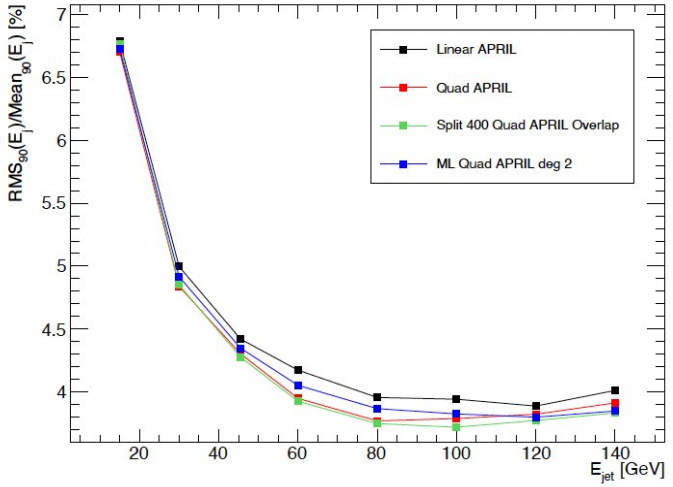
Improvements are obtained by using two sets of parameters for low and high “energy” regions





K^0_L@SDHCAL



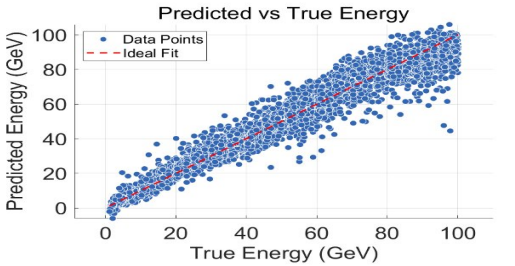


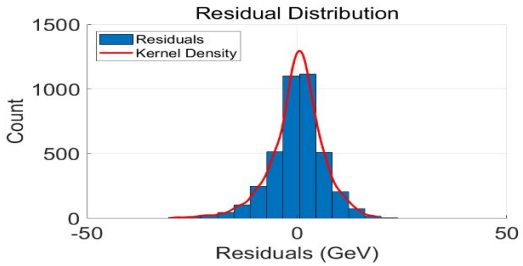
Jets with SDHCAL

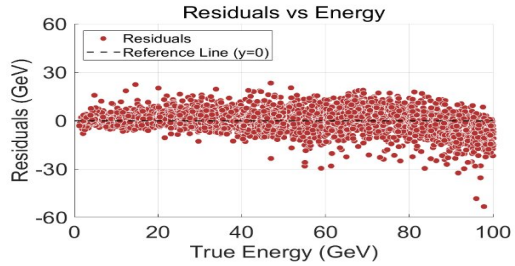
T. Pasquier

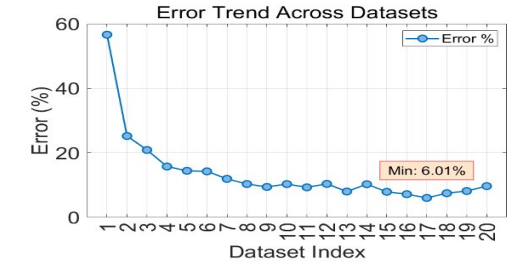
Using GNN to reconstruct the energy is also useful and in particular if you know the nature of the particle : proton, pion…

Pions

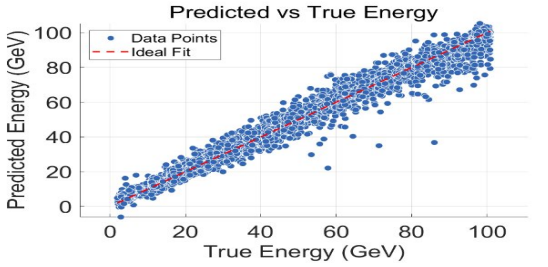


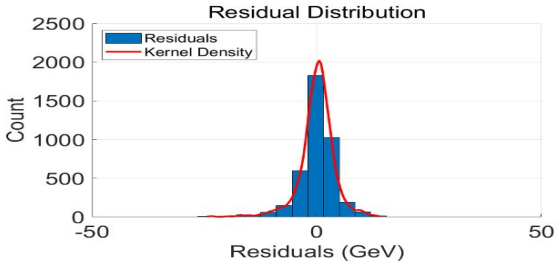


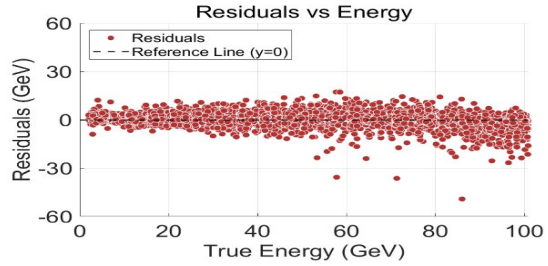


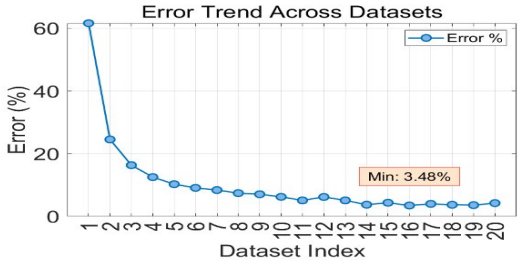


Protons





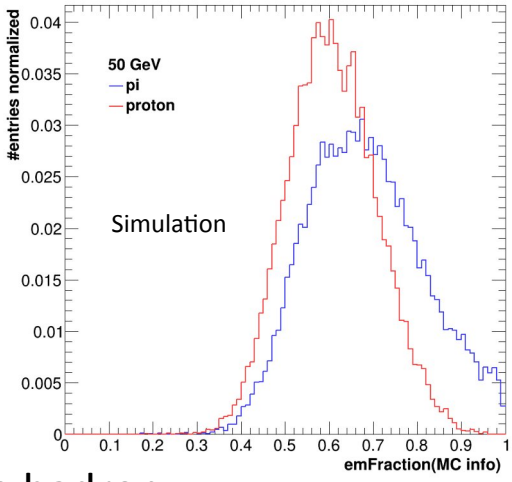




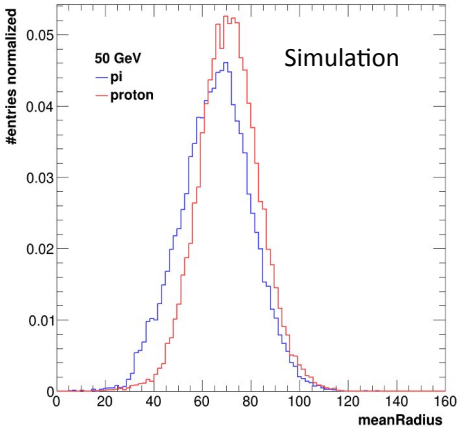
Y. Tan

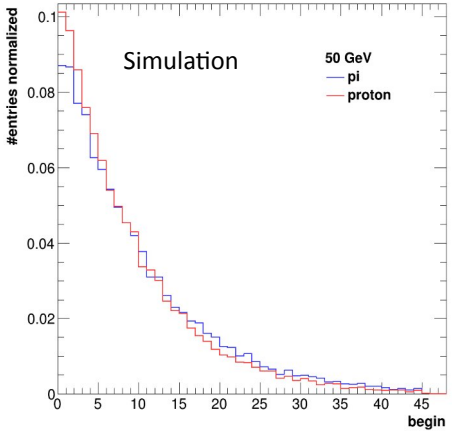
Proton-Pion separation

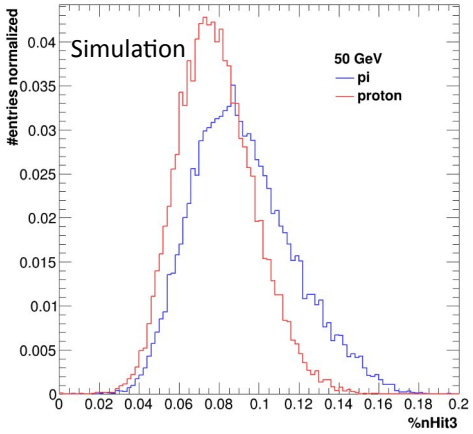
The energy reconstruction method was applied to hadron events.
No distinction was made between pions and protons or others.
Hadronic showers of pions and protons are not identical.

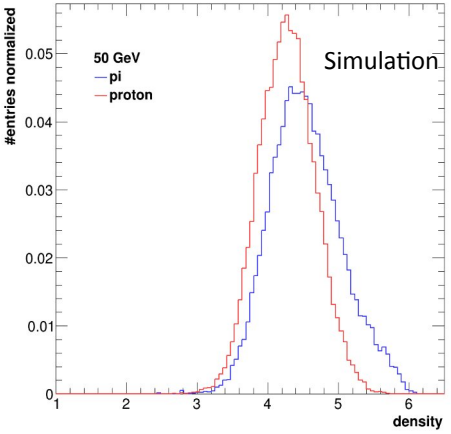


Better construction can be made if one can identify the nature f the hadron.







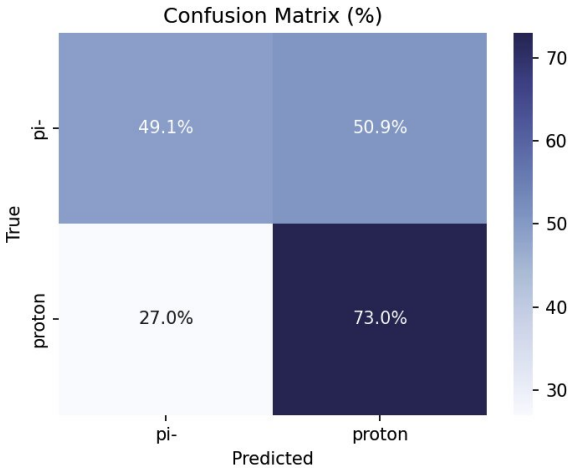


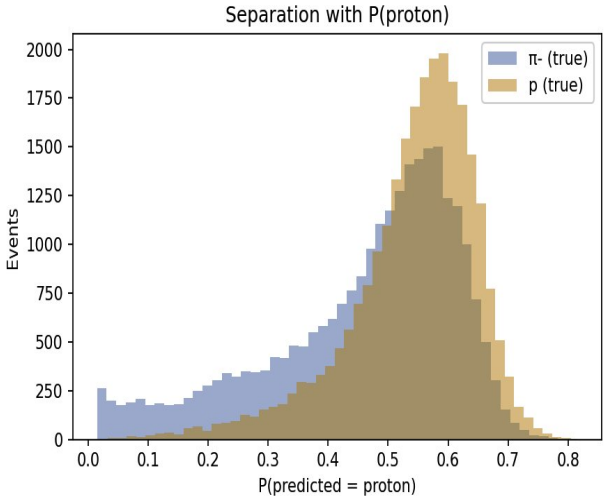
Proton-Pion separation

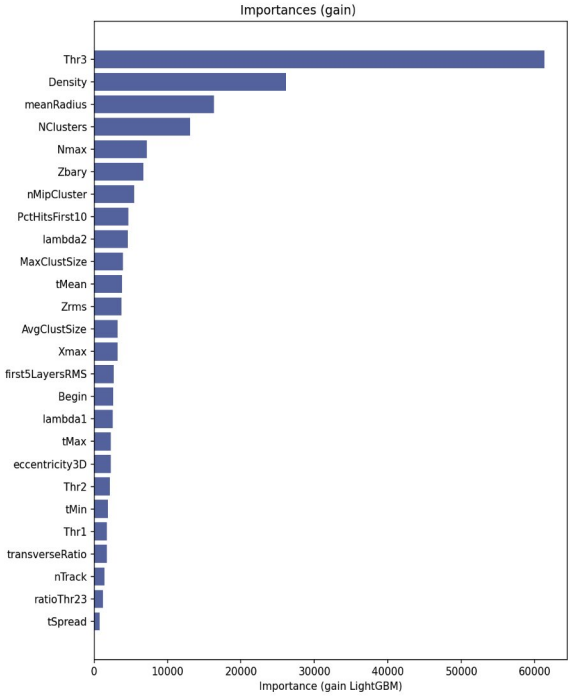
Classifier: Boosted Decision Tree (LightGBM)

Training set: **200k** events/species (π^-, p), uniform **1–130 GeV**

- 80%(**Training set**) for training
- 20%(**Training set**) for validation







M. Idir

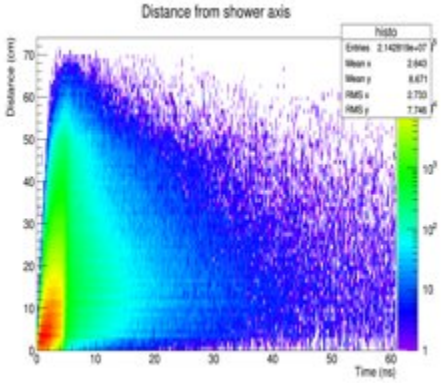
Next step is to use GNN to identify separate proton from pions and then use the same technique to estimate the energy

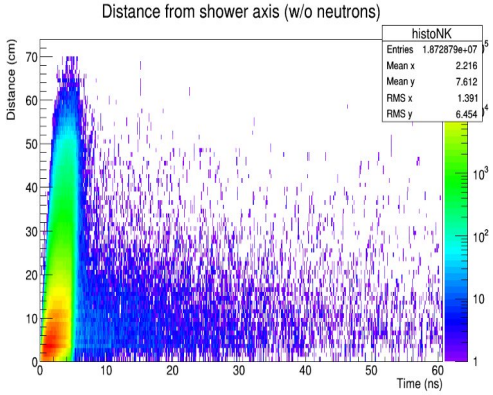
SDHCAL → T-SDHCAL

Circular Collider requirements:

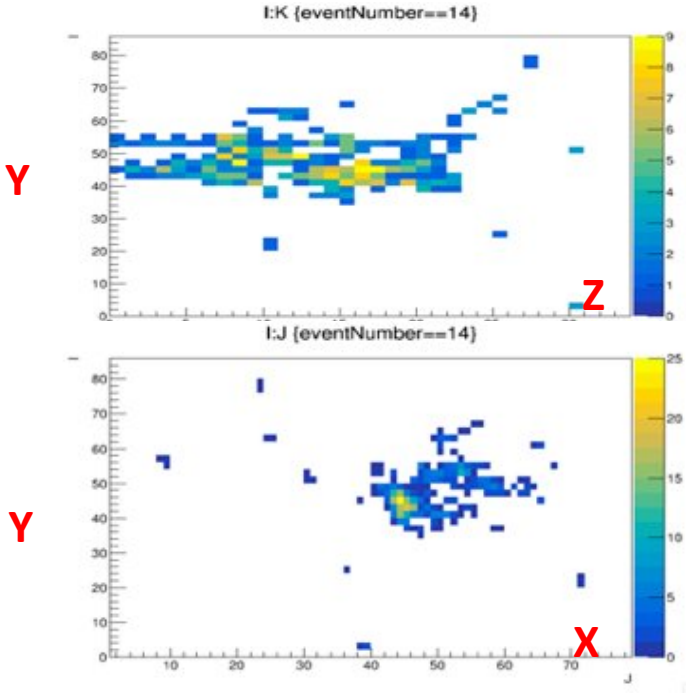
- Continuous readout
- Active cooling
- High rate capabilities

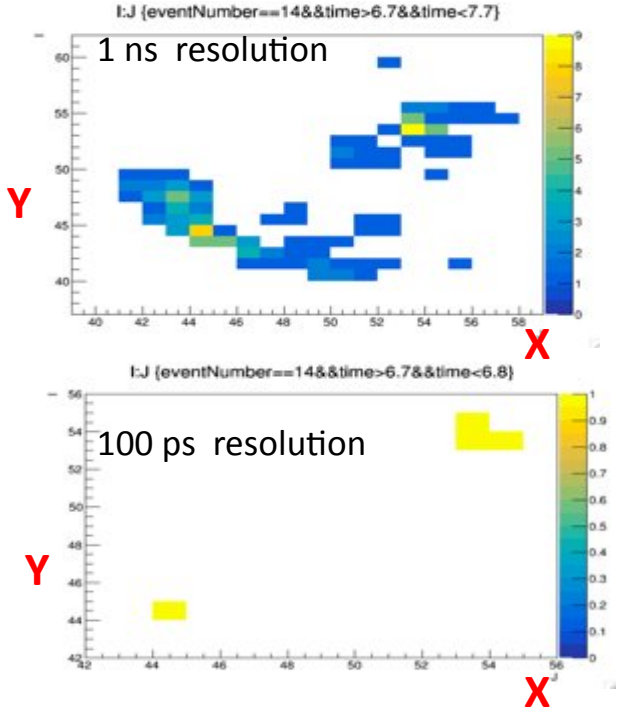
Timing is an important factor to identify delayed neutrons → **better reconstruct their energy**



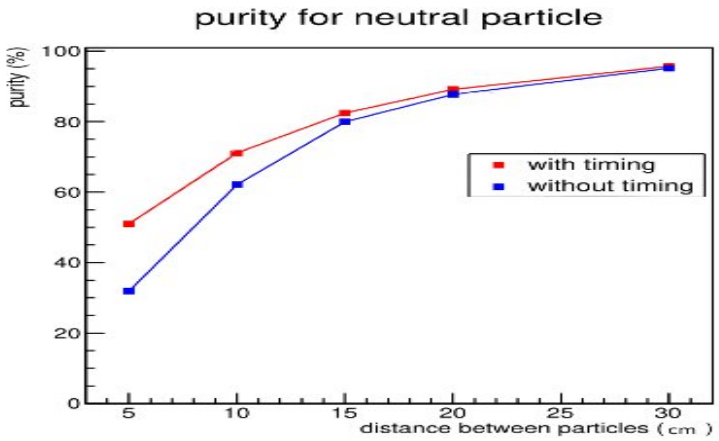


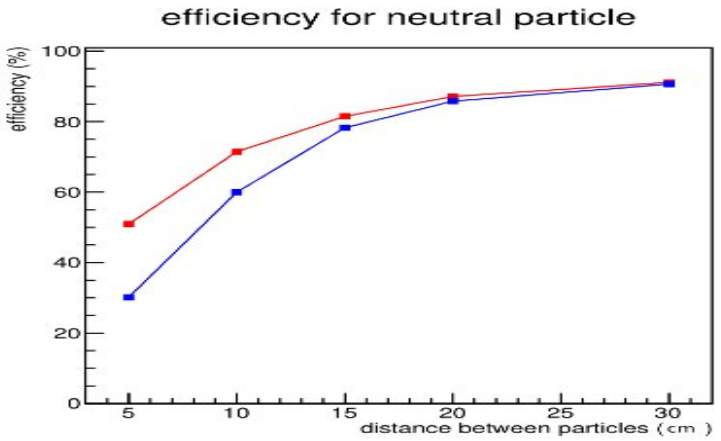
Timing can help to separate close-by showers and reduce the confusion for a better **PFA** application. Example: pi-(20 GeV), K-(10 GeV) separated by 15 cm.

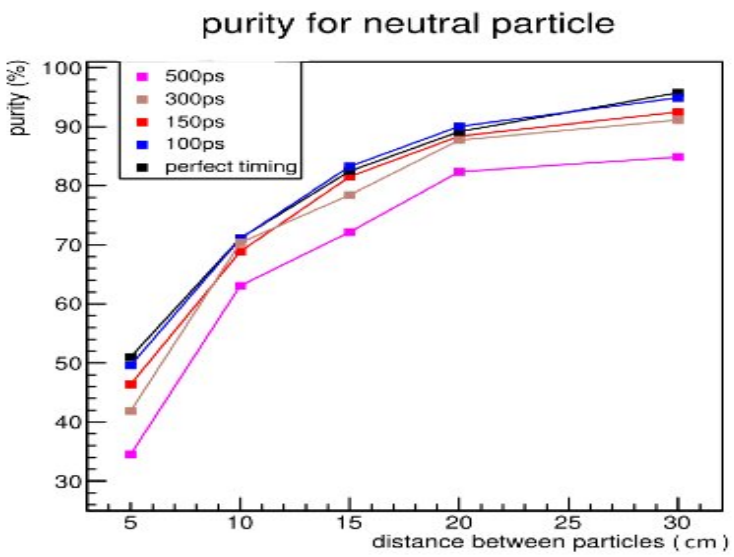


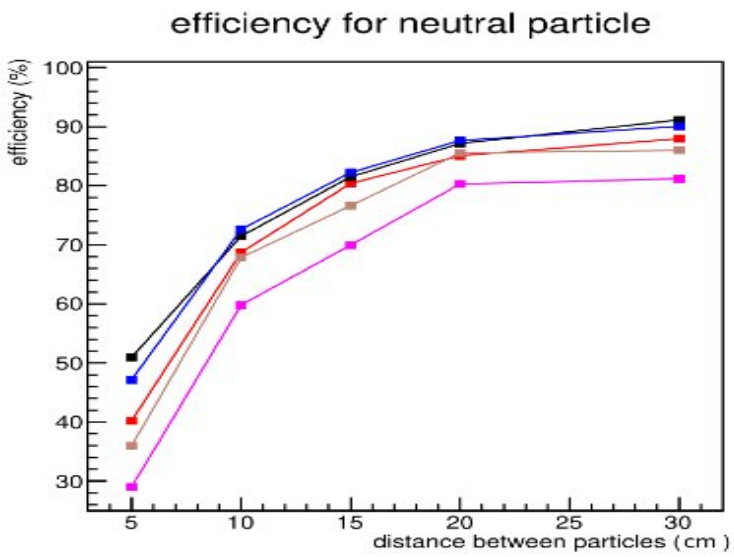


Including time information to separate hadronic showers (10 GeV neutral particle from 30 GeV charged particle) using techniques similar to ARBOR's ones.

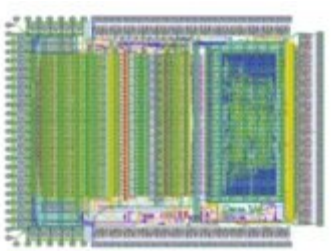








How to achieve an excellent time resolution:

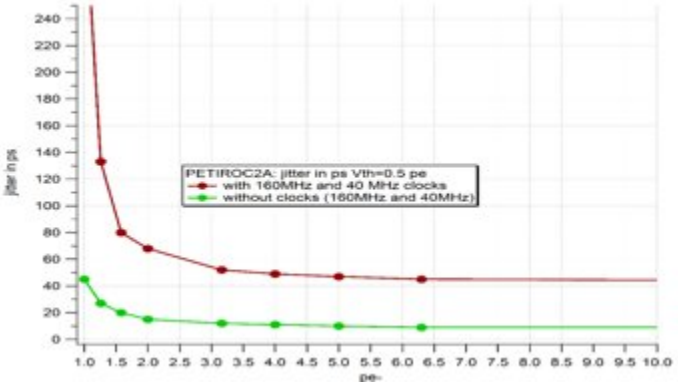


An **ASIC** with a fast preamplifier, precise discriminator and excellent TDC is needed

→**PETIROC** 32-channel, high bandwidth preamp (GBWP> 10 GHz), <3 mW/ch, dual time and charge measurement (Q>50 fC)

jitter < 20 ps rms @ Q>0.3 pC

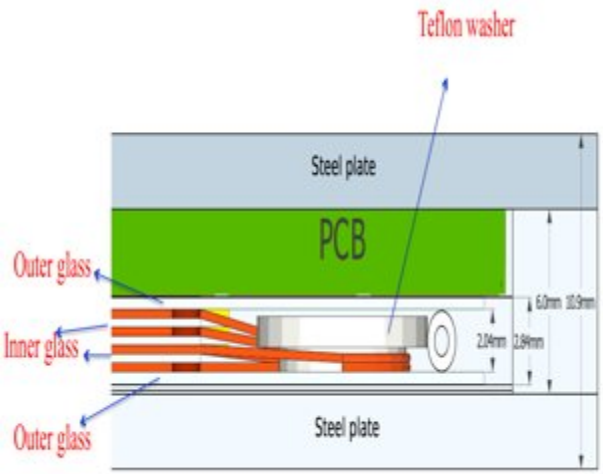
→ Go to **CALOROC** after

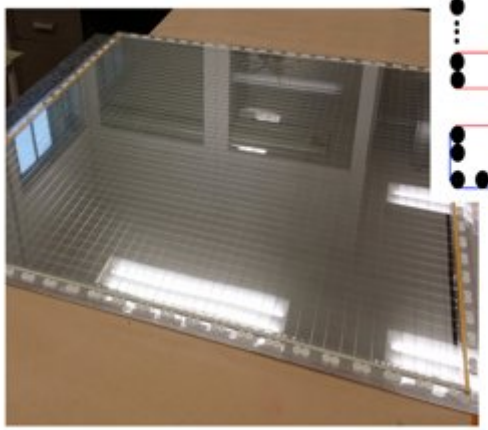


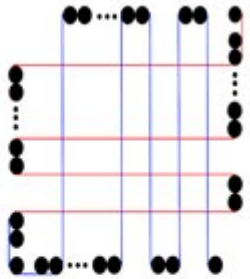
A fast-time **DETECTOR**

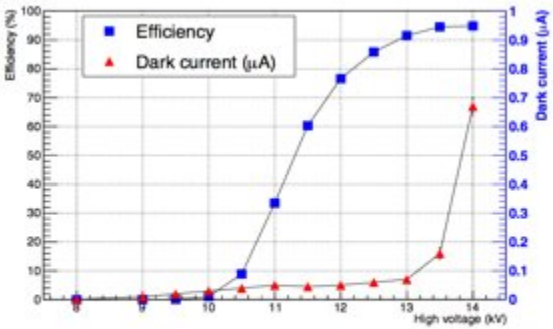
→ **Multigap** RPC is an excellent candidate.

4-5 gaps of 250 µm each can provide 100 ps time resolution





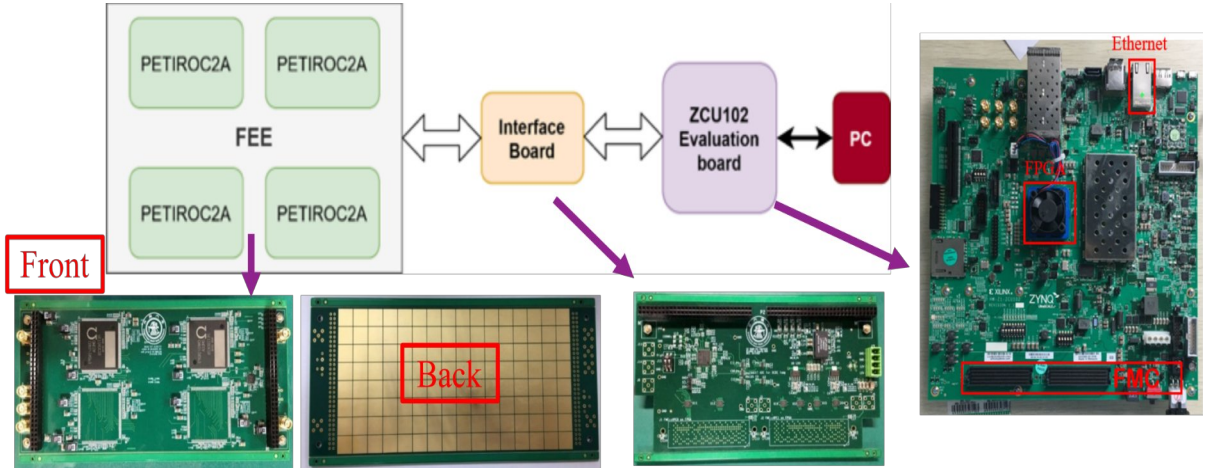




Threshold sets at 114 fC

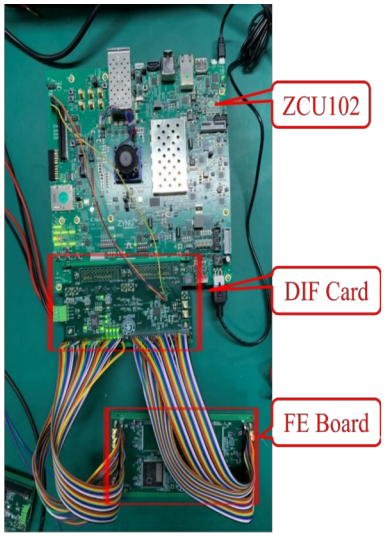
First step towards transforming SDHCAL into T-SDHCAL

W. Wu

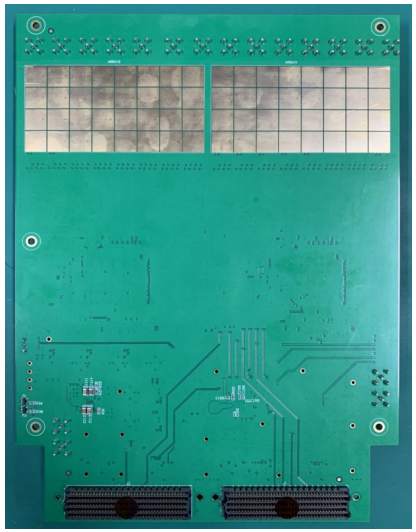


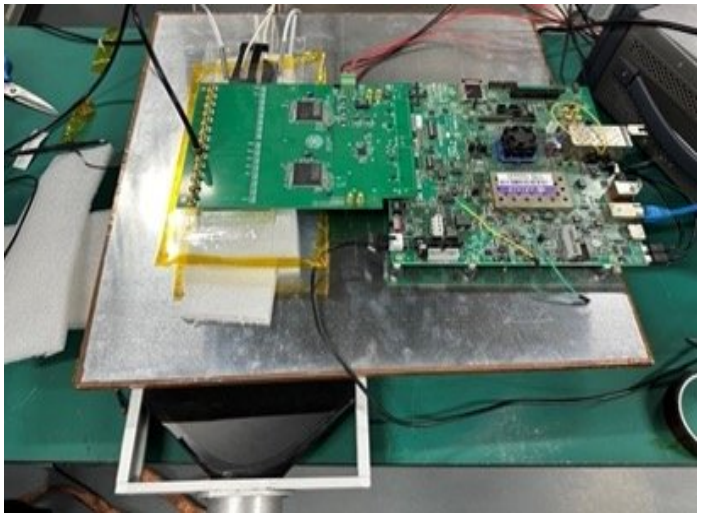
- Front-End Electronics for MRPC readout with high timing resolution
- The system includes a front-end board (FEB), a detector interface card (DIF) and a data acquisition system(DAQ) based on ZCU102.

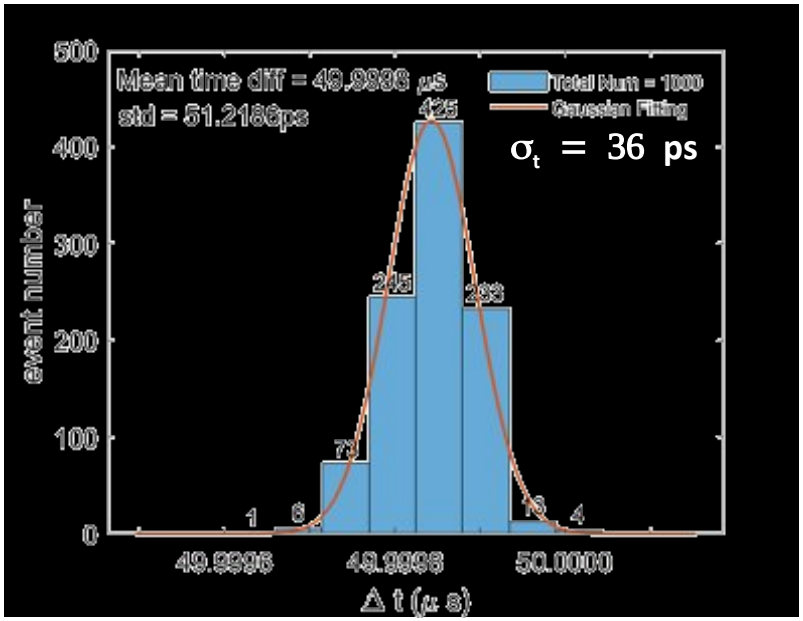
Test System and Setup

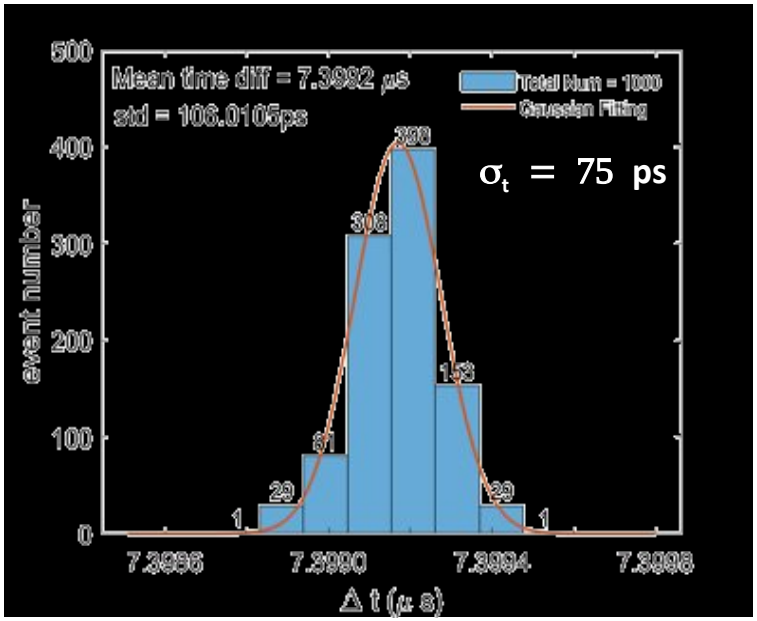


Some noise was observed because of external power lines but fixed with a new iteration







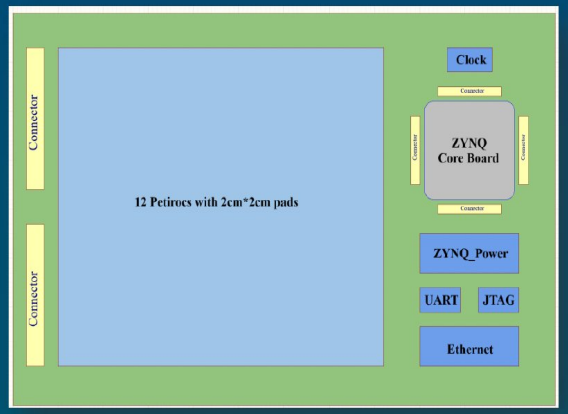


Electronics only

New larger FEB Development

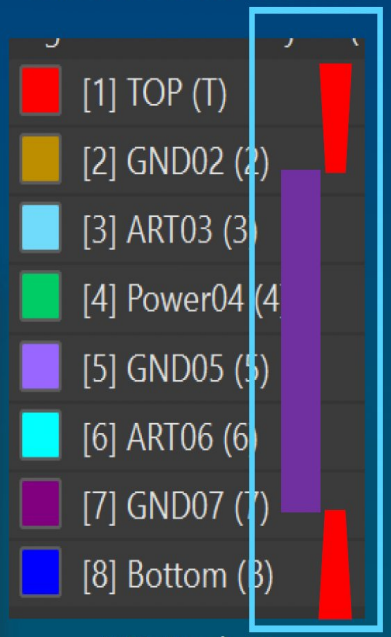
SJTUPA
上海交通大学物理与天文学院

- 1st-version of large FEB-A prototype has been designed and manufactured.
  - Size: 32cm x 50 cm
  - Cell size: 2cm x 2cm
  - Buried and laser vias
  - FPGA on board
  - Low-profile FCC connector

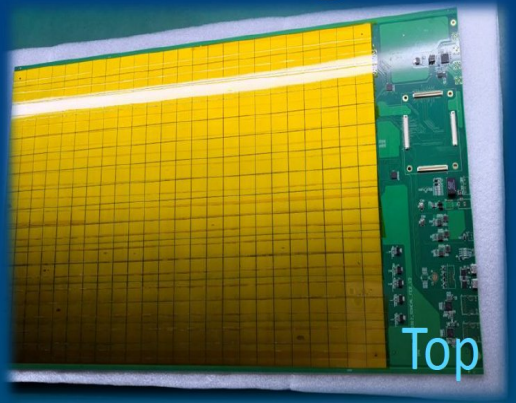


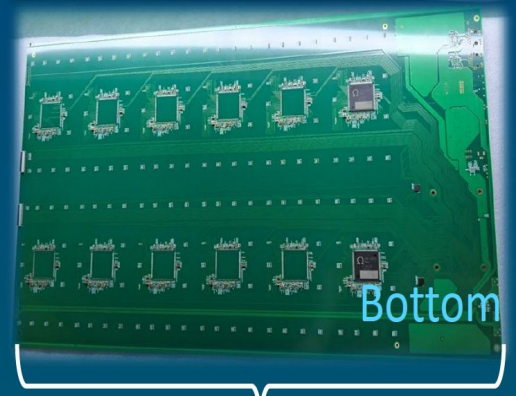
Functional block diagram

Blind and buried vias



PCB Stack-up





0.6 m

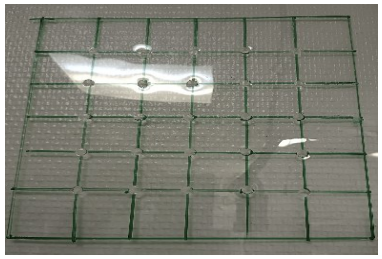
Test will be carried out soon

New and easy way of construction MRPC

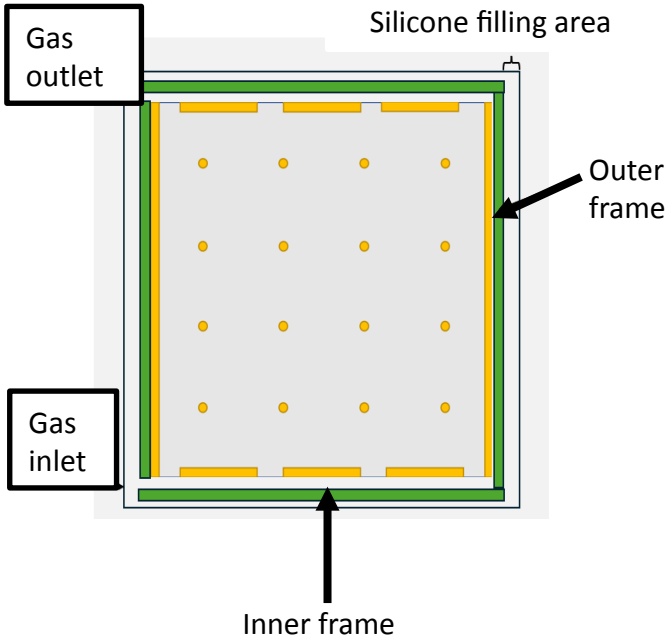
Using mylar foil and double-face tape to produce spacers of the required height

Protection paper to be taken off

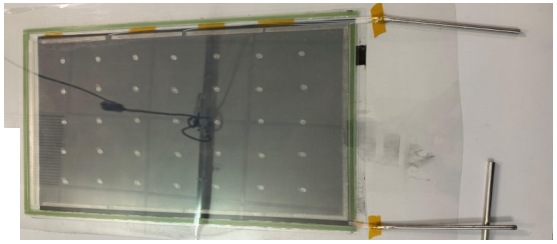
Grid for spacer positioning



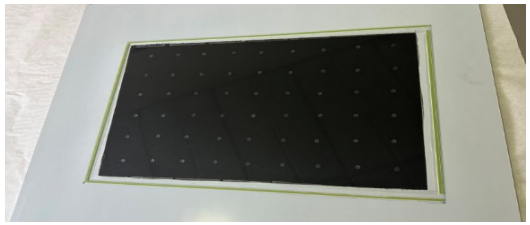
Glass thickness: 280 µm
Gas gap: 220 µm



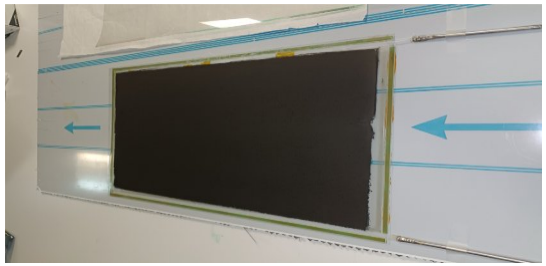
Several gaps put one over the the other



Anode (last plate with coating)

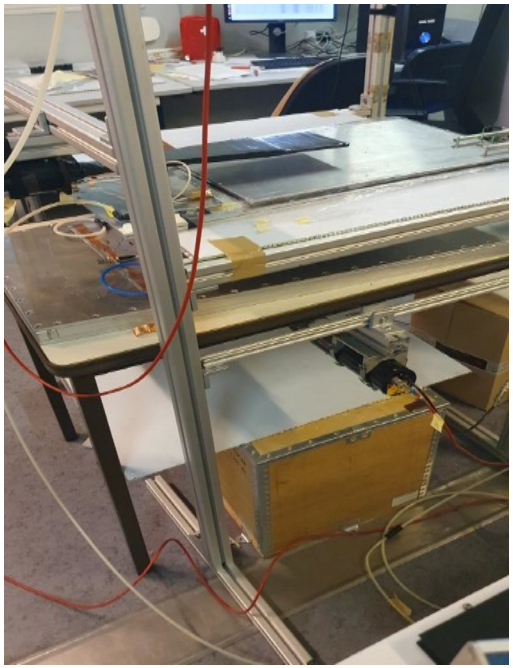


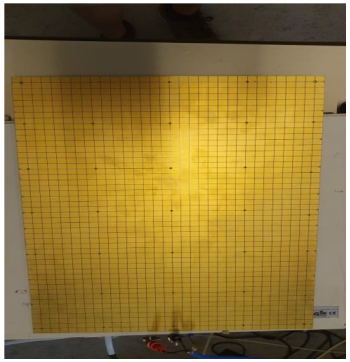
4-gap RPC

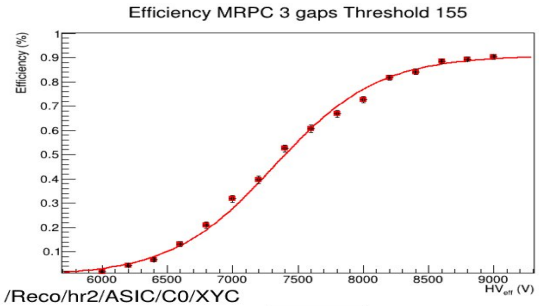


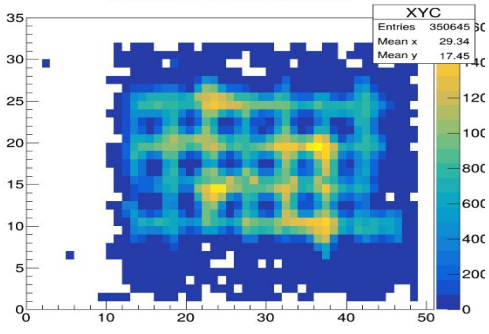
MRPC of 3, 4 and 5 gaps of 50 cm X 33 cm were built using home made spacers of 220 µm height and glass plates of 330 µm

→Homogeneity studied thanks to 1 cm x 1 cm pickup pads with HR ASICs from SDHCAL electronics. 3 cm pitch leads to better homogeneity and lower noise than 5 cm pitch.

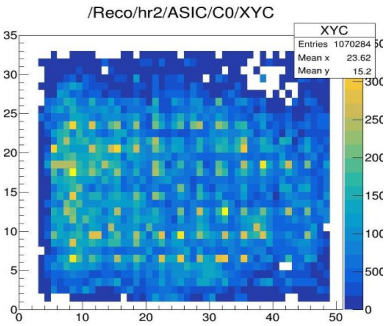






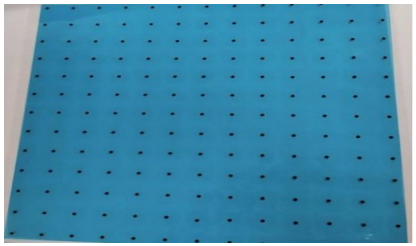


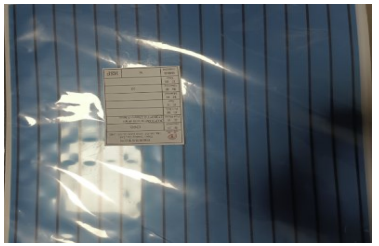
5 cm pitch



3 cm pitch

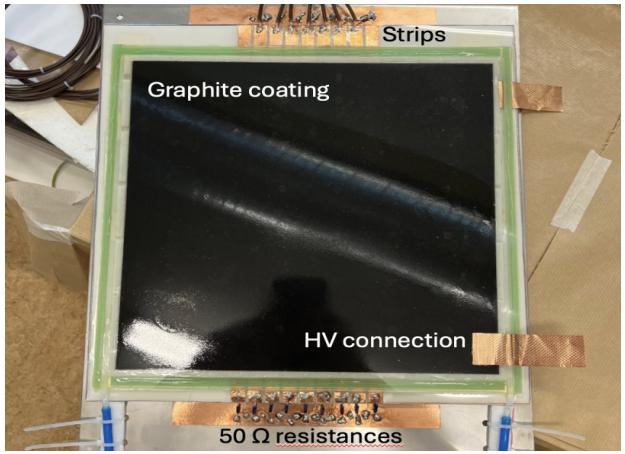
Next step is to use a customized version of the spacers produced by a a company in Taiwan at our request

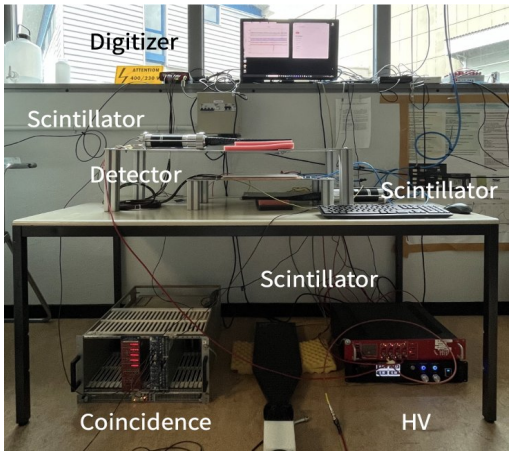


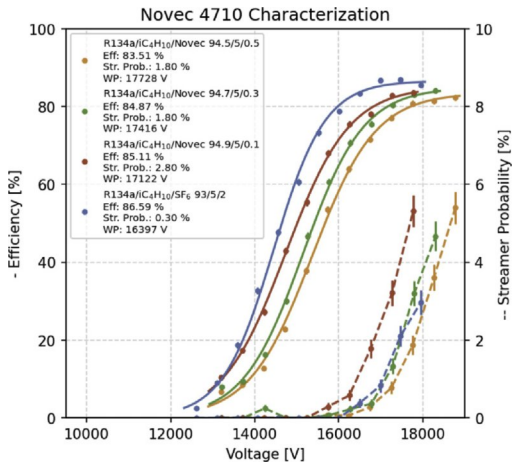


Towards eco-friendly gases

M. Verzeroli (CERN-IP2I) , have produced a few MRPC using the same method at CERN and is testing them with CAEN Desktop Digitizer v1730 to assess their timing performance in an independent way using standard gas mixture and new eco-friendly gases



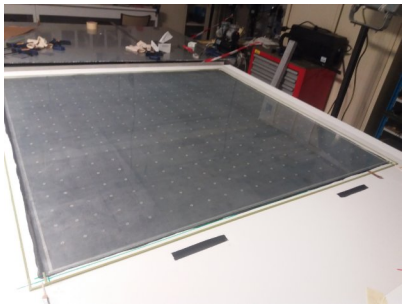




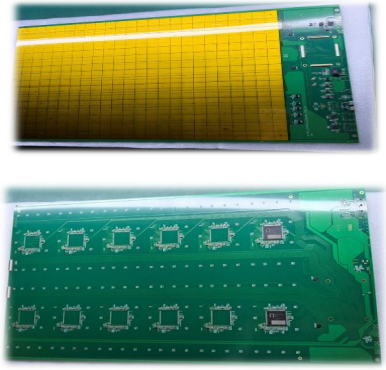
M. Verzeroli et al, NIMA 1078 (2025) 170591

Plans in the near future

Large MRPC

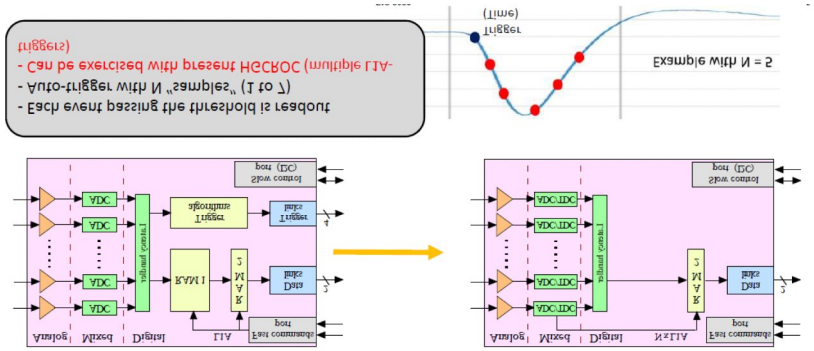


Large ASU

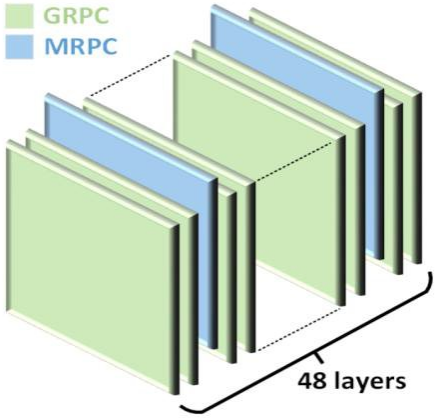


New ASIC

Caloroc D? 64ch in 65 nm TSCM
and a TDC providing 12 ps time resolution



We intend to use the present SDHCAL to test the new system in the context of a hadronic shower
→ Very useful for hadronic shower models in Geant4



We also need

- New cassette design
- Cooling system embedded in the cassette
- DAQ system capable of communicating with both SDHCAL and T-SDHCAL electronics

Some of these could be common to others and collaboration is welcome

Summary

- SDHCAL concept with its high granularity provides an excellent tool not only to apply PFA by separating nearby showers but also to measure their energy.

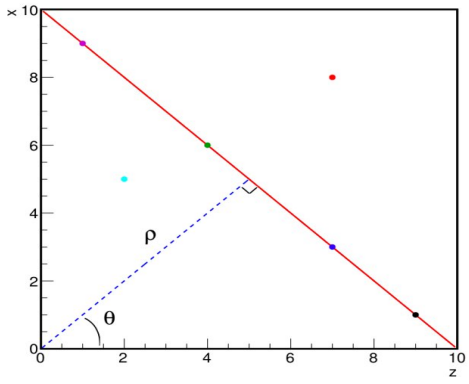
- Different techniques were used to measure hadronic shower energy excellent linearity and very good resolution are obtained

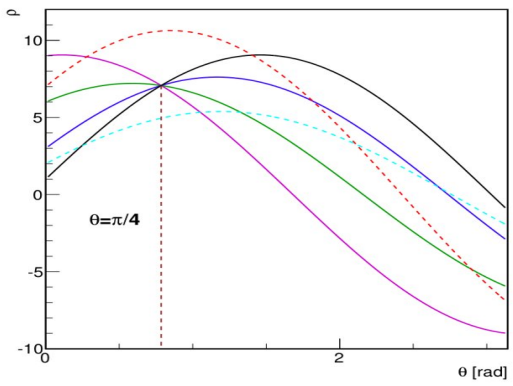
- The exploitation of the hadronic shower shape thanks to the high granularity is an excellent asset to identify particles and then better measure their energy.

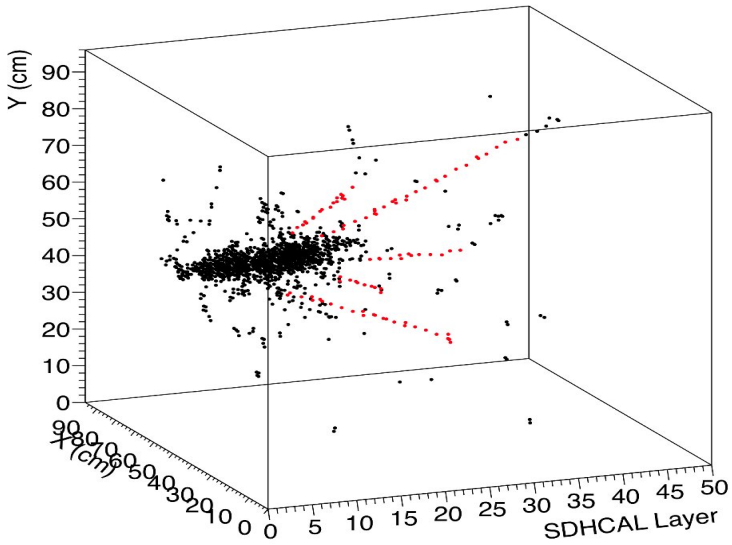
- In the future SDHCAL will exploit precise time information using MRPC. The time information will improve on energy reconstruction by separating delayed neutrons contribution and better estimating it.

SDHCAL High-granularity impact

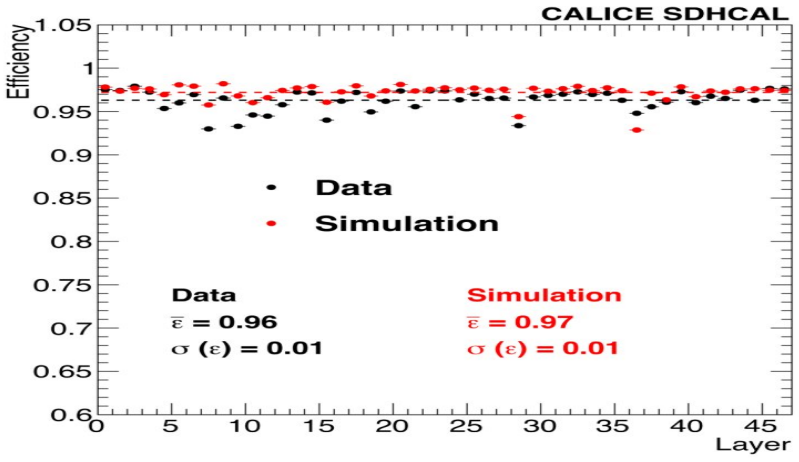
Hough Transform is an example to extract tracks within hadronic showers and to use them to **control the calorimeter in situ**

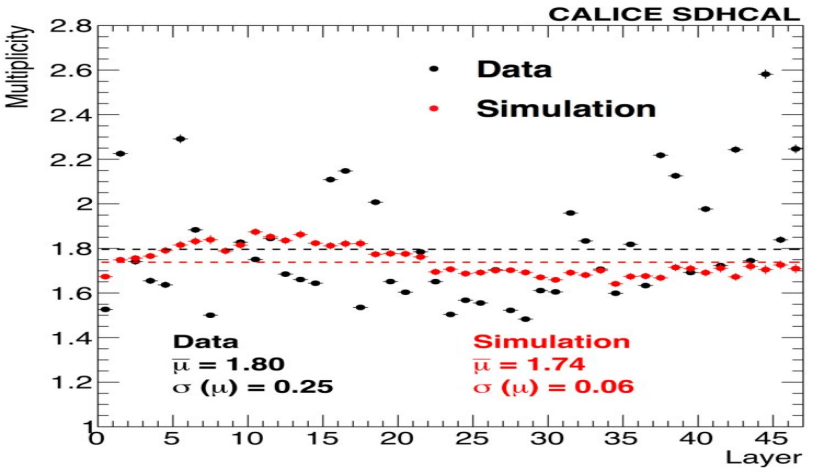






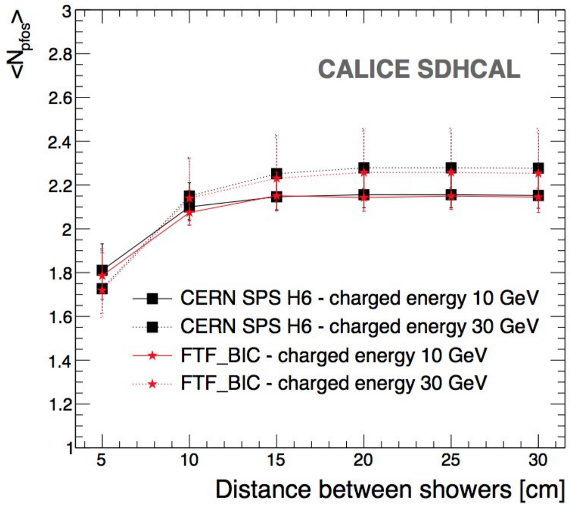
$\rho_{xz} = z \sin(\theta) + x \cos(\theta)$

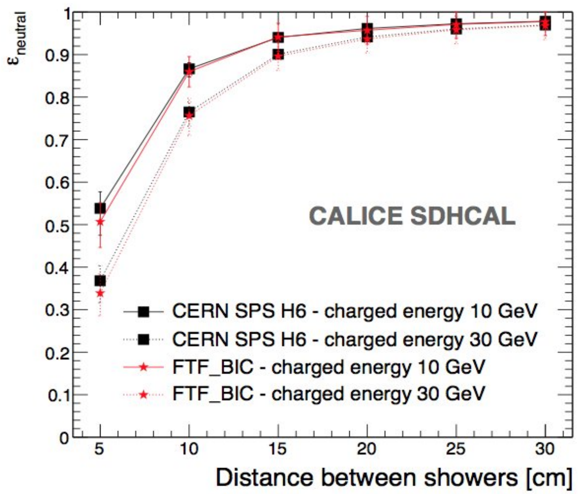


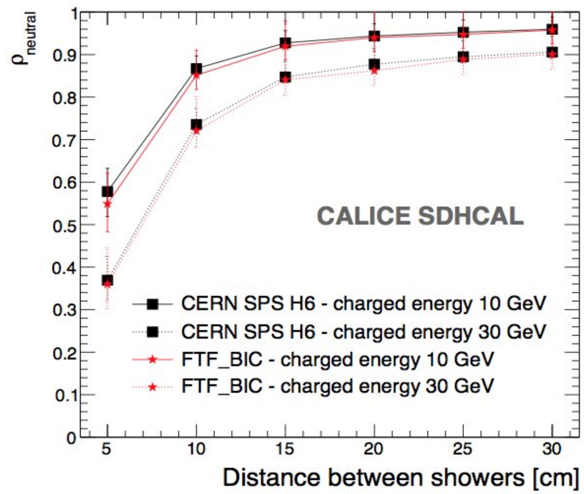


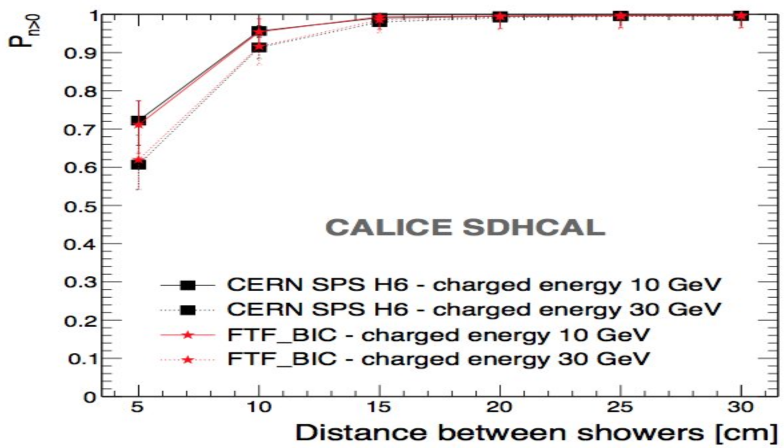
Excellent agreement with efficiency/multiplicity results obtained with cosmic and beam-muons. Excellent agreement data/MC

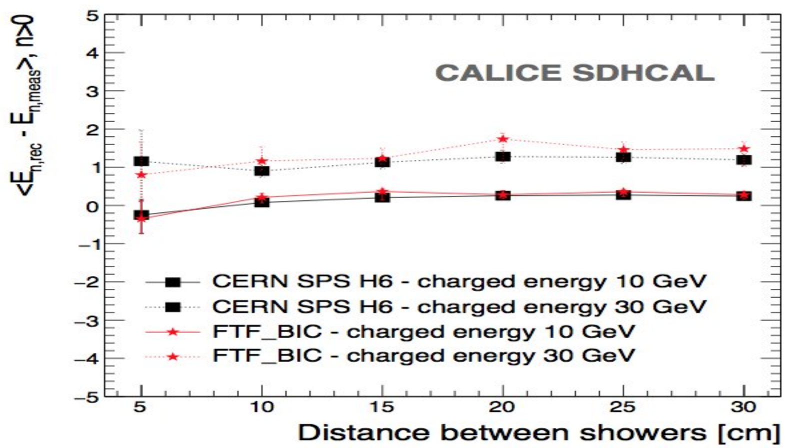
Two hadronic shower separation
10 GeV neutral and 10 (30 GeV) charged pion.



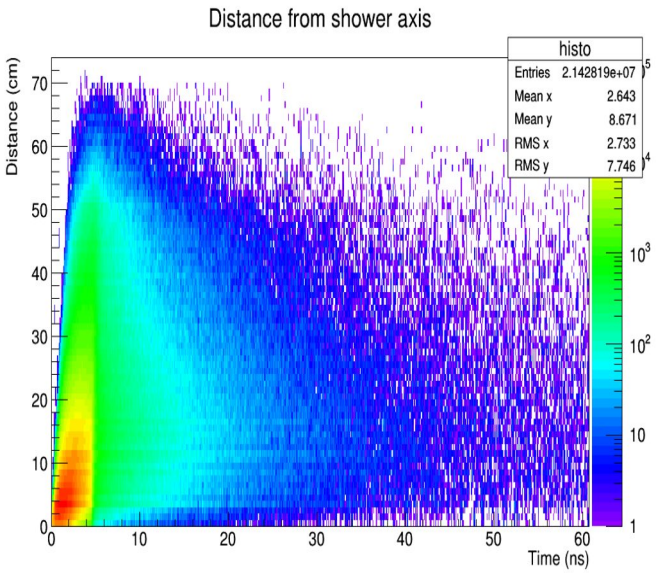


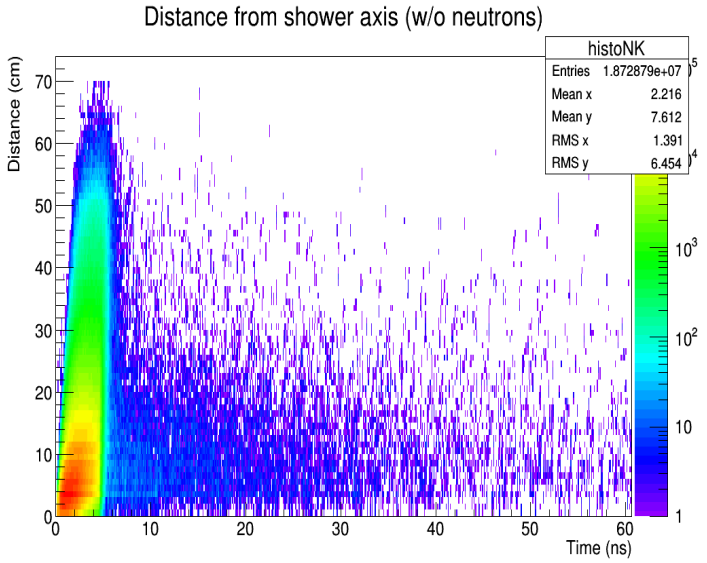






Timing could be an important factor to identify delayed neutrons and **better reconstruct their energy**





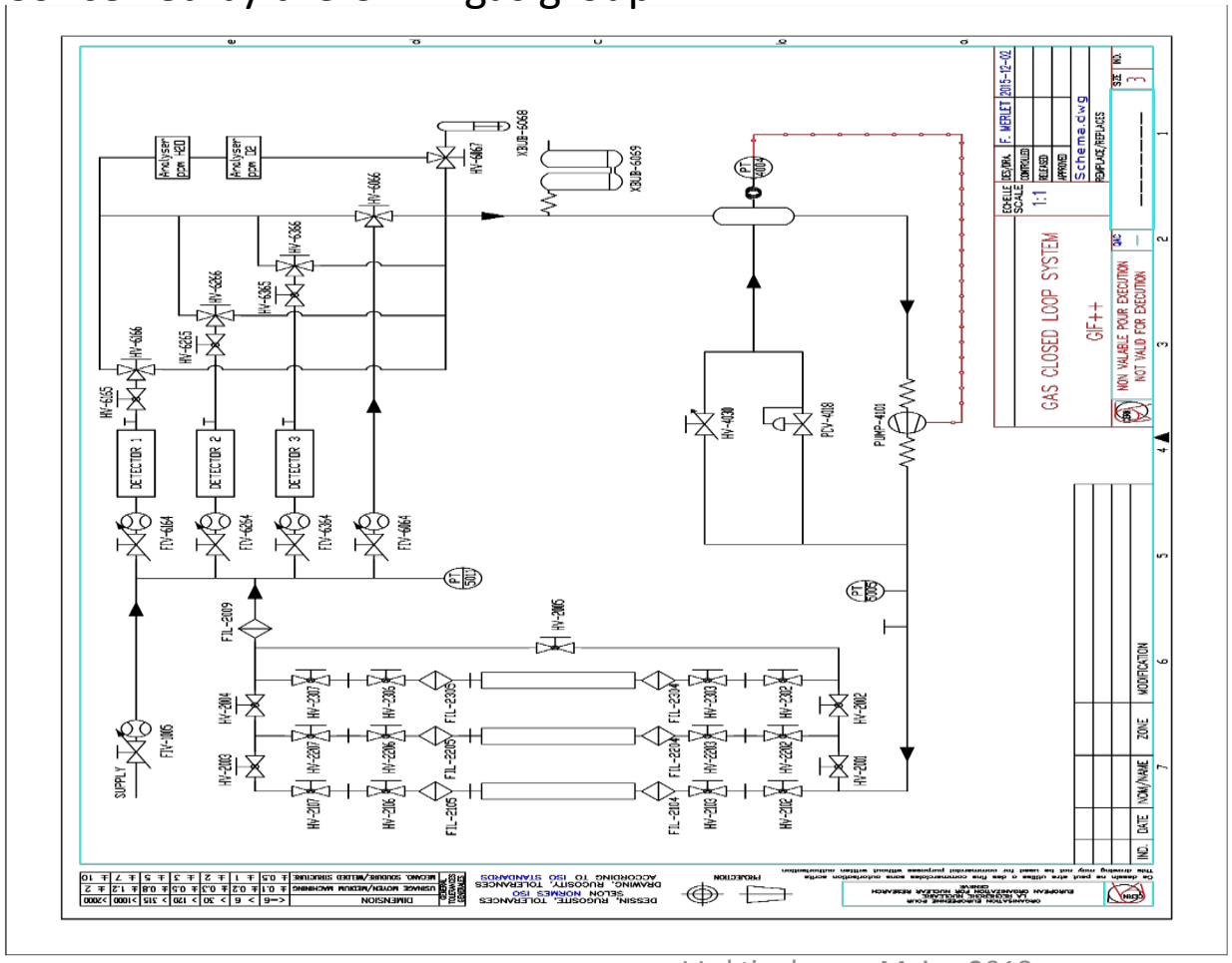
Gas system

Gas recycling is necessary to reduce cost :

-Goal: reduce the gas consumption to reduce the cost.

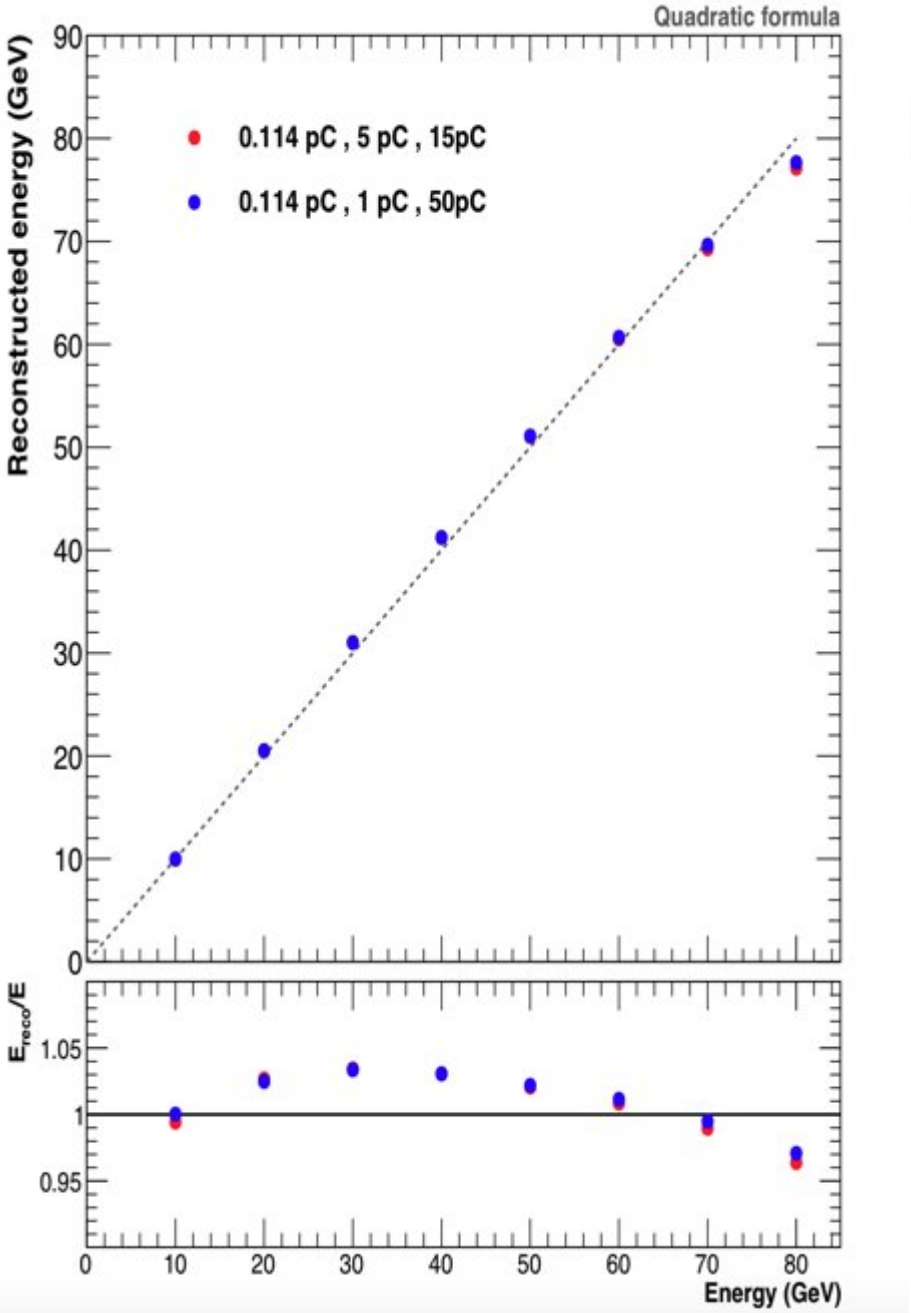
-Gas renewal of 5-10% rather than 100%

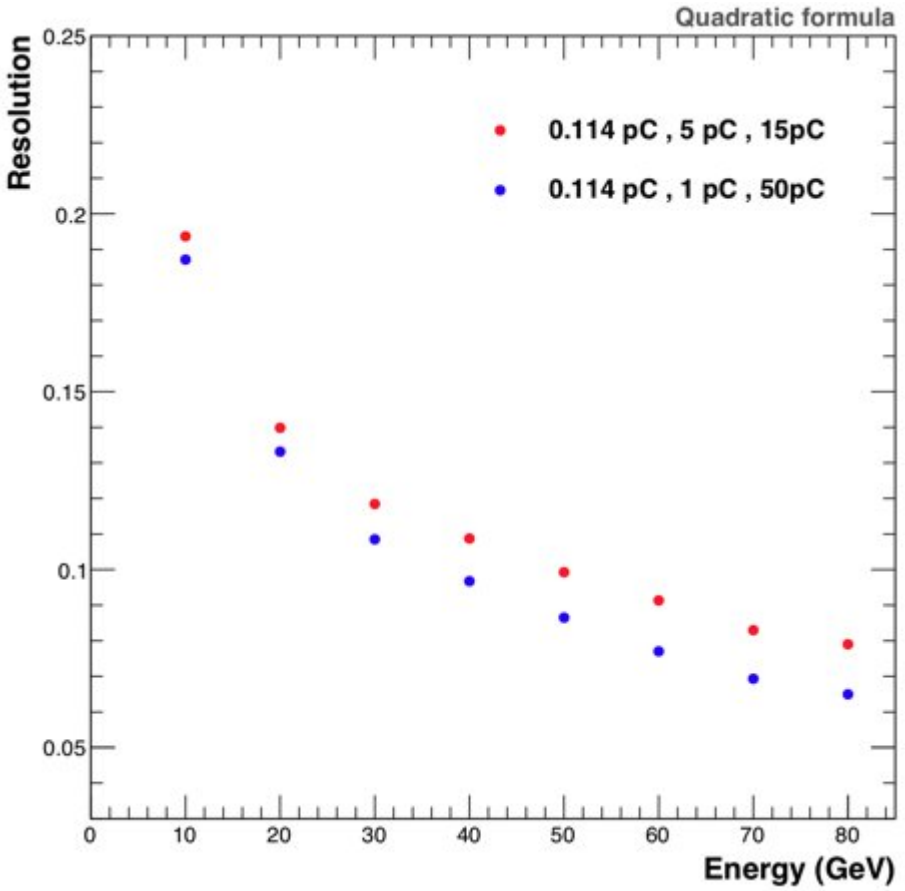
-Conceived by the CERN gas group



SDHCAL Simulation

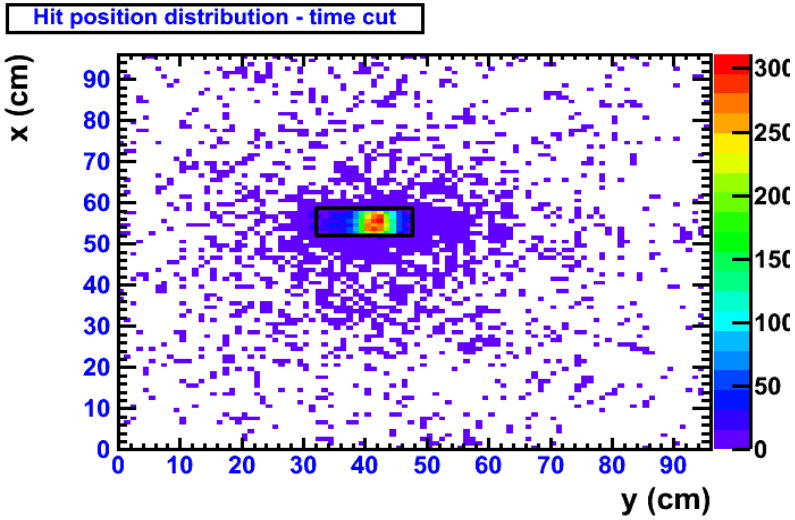
IP2I

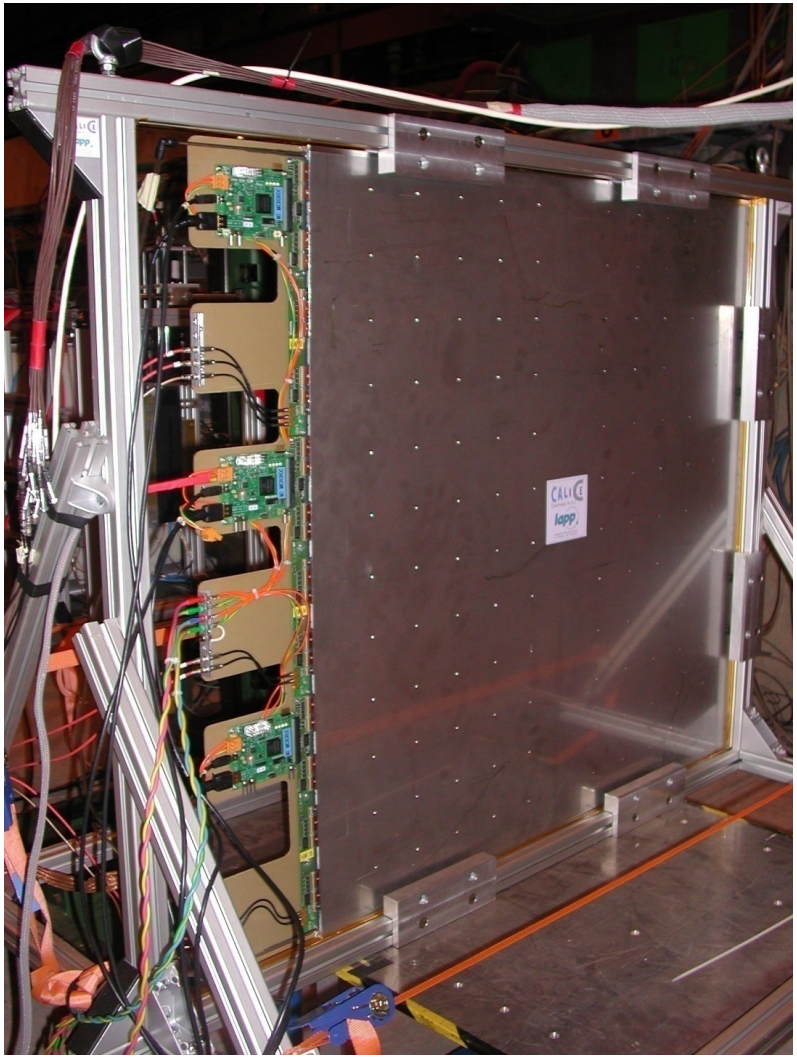




Up to 20% improvment is expected

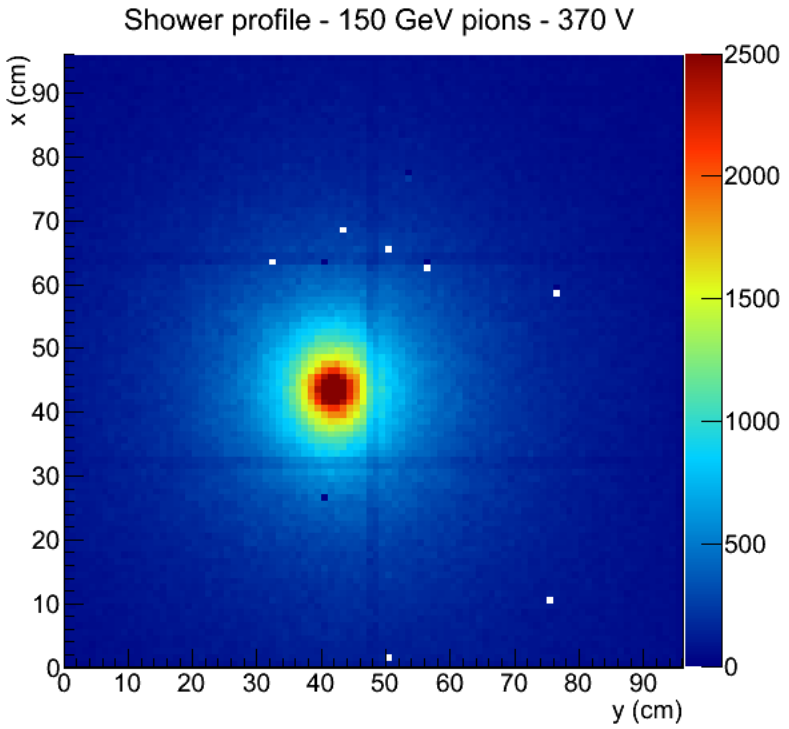
4 units of SDHCAL-MM
1m x 1m each were produced, tested in a muon beam





CNRS-LAPP

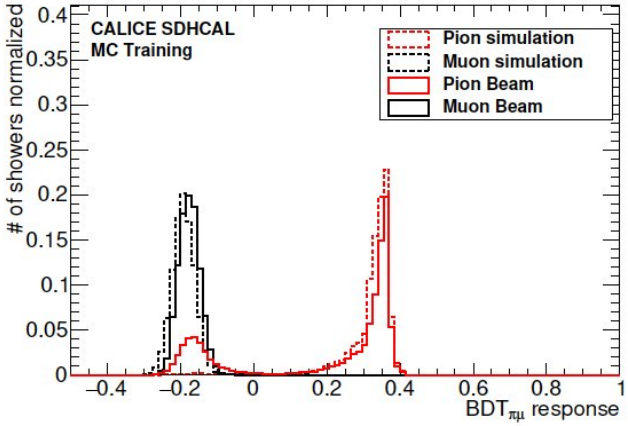
The 4 units of SDHCAL-MM were then inserted in the SDHCAL-RPC prototype replacing the RPC units #10, 20, 35 and 50

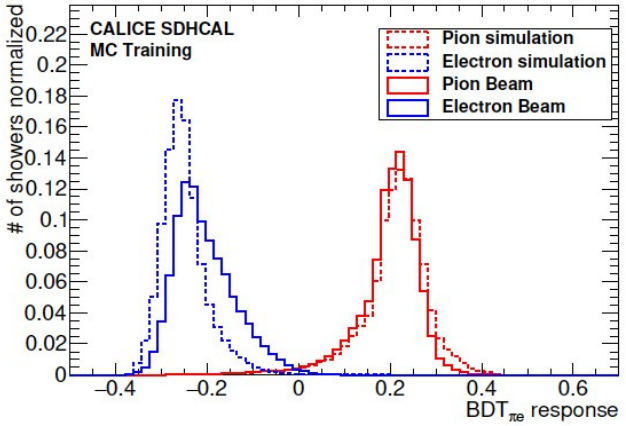


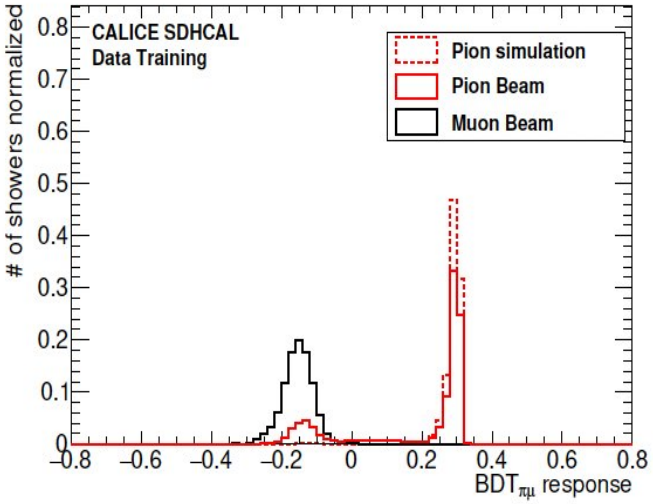
Additional development with Resistive Micromegas has started to render the SDHCAL-Micromegas more robust against discharges that may happen in the core of the shower.

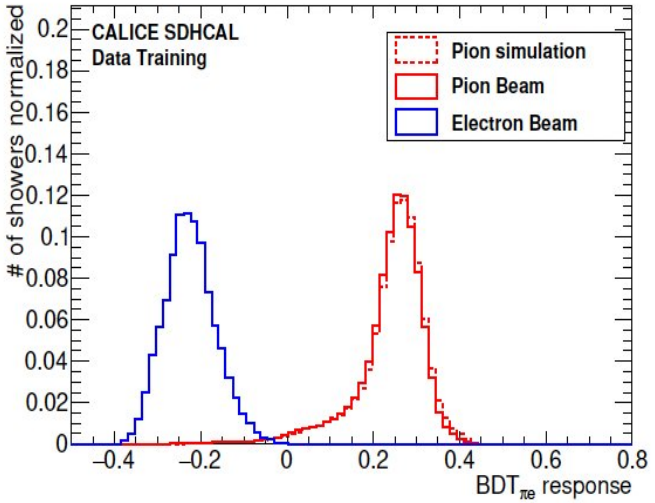
Similar activities with Thick GEM replacing MM were also initiated.

JINST 15 (2020) P10009







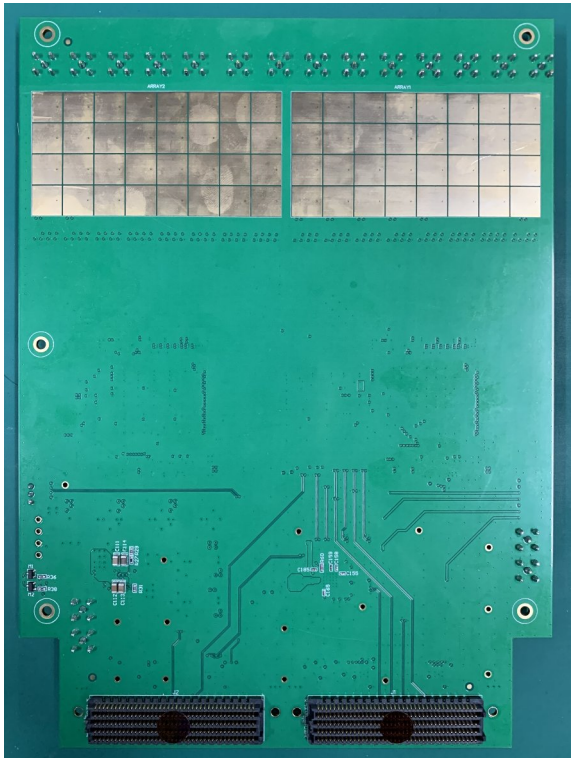


Electron and muon rejection > 99%

New version of PETIROC front-end board

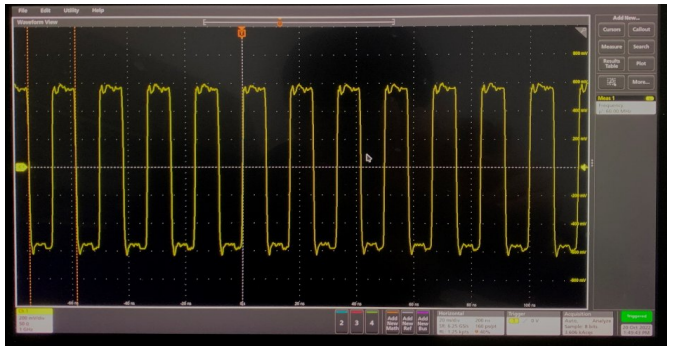
SJTU

Yongqi Tan



1. Improving power rail design
2. Better isolation between sensitive analog signals and digital signals

Its power rails have been tested and verified.



Si5345 – used to generate clocks for Petiroc

Time resolution of about 40 ps measured

Output clocks have been successfully tested

SDHCAL prototype construction

- ✓ 10500 64-ch ASIC were tested and calibrated using a dedicated (ASICs layout : 93%).
- ✓ 310 PCBs were produced, cabled and tested. They were assembled by sets of six to make 1m^2 ASUs
- ✓ 170 DIF, 20 DCC were built and tested.
- ✓ 50 detectors were built and assembled with their electronics into cassettes.
- ✓ Self-supporting mechanical structure.
- ✓DAQ system using both USB and HTML protocol was developed and used.
- ✓ Full assembly took place at CERN.