DRD1 plans on gaseous detectors
for
calorimeters

I. Laktineh

Outline

- DRD1
- Current activities for calorimeters
- Future projects

DRD1 Scientific Organization (proposal)

Working Groups

WG1: Technologies, limitations, and challenges → WG2, WG4

Includes detector physics aspects

(**P. Colas**, F. Resnati, P. Wintz, I. Deppner, M. Tytgat, L. Moleri)

- MPGDs
- RPCs, MRPCs
- Large Volume Detectors (drift chambers, TPCs)
- Wires: straw tubes, TGCs, CSCs
- New amplifying structures

WG2: Applications → WG1

full alignment with the ECFA detector R&D roadmap and Work Packages funding model

(F. Garcia, **P. Gasik**, F. Grancagnolo, D. Gonzalez Diaz, G. Aielli, G. Pugliese; A. Colaleo, M. Titov for the ECFA part)

- Muon systems
- Inner and central tracking with particle identification capability
- Calorimetry → DRD6
- Photon detection → DRD4
- Time of Flight systems
- TPCs for rare event searches →DRD2
- Fundamental research applications beyond HEP
- Medical and industrial applications

WG3: Gas and material studies → WG7

Interdisciplinary working group

(**B. Mandelli**, G. Morello, F. Renga, K. Dehmelt, S. Roth, D, Piccolo, A. Pastore, B. A. Gonzalez)

Gas
- Gas Properties (e.g. cross-section, chemical characterization, measurements)
- Eco-gases studies
- Light emission in gas

Systems
- Gas recuperation and recirculation systems
- Gas systems
- Sealed detectors and systems

Materials
- Resistive electrodes
- Solid converters
- Photocathodes (novel, aging, protection)
- Novel materials (e.g. nanomaterials)
- Material properties for detector and infrastructures
- Light (low material budget) materials
- Precise mechanics

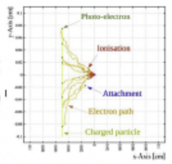
Long-term operation
- Ageing
- Outgassing
- Radiation hardness

WG4: Detector physics, simulations, and software tools

(M. Abbrescia, M. Borysova, P. Fonte, O. Sahin, **P. Verwilligen**, R. Veenhof,)

- Detector Physics
  simulation & modeling of physics processes that happen inside detectors:
  - basics: primary ionization; electron & ion drift; avalanches; signal induction
  - advanced: avalanche to streamer; discharges; rate-capability; clustering of ions …
- Detector Performance
  modeling and simulation of detection efficiency, spatial resolution, time resolution, track reconstruction, two-track separation, …

  - stand-alone (e.g. Garfield++)
  - integrated in big experiment (e.g. GEANT4 & custom C++ digitizers)
- Software development and maintenance
  people working on SW integrated in their experiments – private code
  Stand-alone or re-usable code available to everyone (e.g. Garfield++)
- Gas Properties Databases (e.g. cross-sections)
  Measurements - Extraction of cross-sections from data
  Upload in DB – Implementation in SW Tools (e.g. Magboltz)
- Detector design
  Specific software used for detector design …
  of course we need this but … commercial … no R&D in our community



WG5: Electronics for gaseous detectors → DRD7

(H. Muller, **J. Kaminski,** M. Gouzevitch, R. Cardarelli)

- Analog/Digital Electronics
- Discrete Readout Front End Electronics and ASICs (strips/pixels)
- Charge/Photon readout
- FE input protection & spark quenching
- Waveforms and Digitizer
- Cluster Counting
- Signal Processing
- Specific needs: Timing, High rate, Low noise, Wide Dynamic Range,...)
- Grounding and shielding
- Calibration
- SoC based sensor readout
- General purpose DAQ, FPGA based readout/trigger and Trigger-less systems
- High Voltage Systems and High Voltage distribution schemes
- LV Powering
- Cooling
- Laboratory instrumentation (High resolution floating ammeters, Monitoring and control systems)

WG6: Detector production

(R. De Oliveira, **F. Jeanneau,** A. Delbart, G. Iaselli, I. Laktineh, G. Charles)

- Common production facilities
- Process industrialization
- Collaboration with industrial partners
- Material database

WG7: Common test facilities → Euro-labs, WG3

Includes development of common detector characterization standards

(**Y. Tsipolitis**, E. Oliveri, R. Guida, G. Iaselli, A. Ferretti)

Detector common test facilities:
- Detector development laboratories
- Test beam
- Irradiation facility
- Laser
- Cosmic ray test bench

Specialized characterization facilities:
- Ageing Study Facility
- Outgassing Study Facility
- Gas studies facility
- Chemistry and material laboratory

Support Facilities (not testing but assembly,..):
- Clean Room(s)
- Detector Mechanical workshop(s)
- Gas system workshop(s)
- Metrology facility

WG8: Training and dissemination → ECFA TF9

(**F. Brunbauer**, M. Iodice, E. Baracchini, B. Liberti, A. Paoloni)

- Topical workshops
- Schools
- Technical trainings
- Knowledge and technology transfer
- Education and outreach
- Supporting and promoting careers

There are two activities within DRD1 that are connected to calorimetry of DRD6 with two proposals

- **T-SDHCAL** based on **MRPC**

IP2I Lyon, CIEMAT; VUB, OMEGA, U Cordoba, Yonsei Cancer Center, GWNU, SJTU, U Tunis El Manar

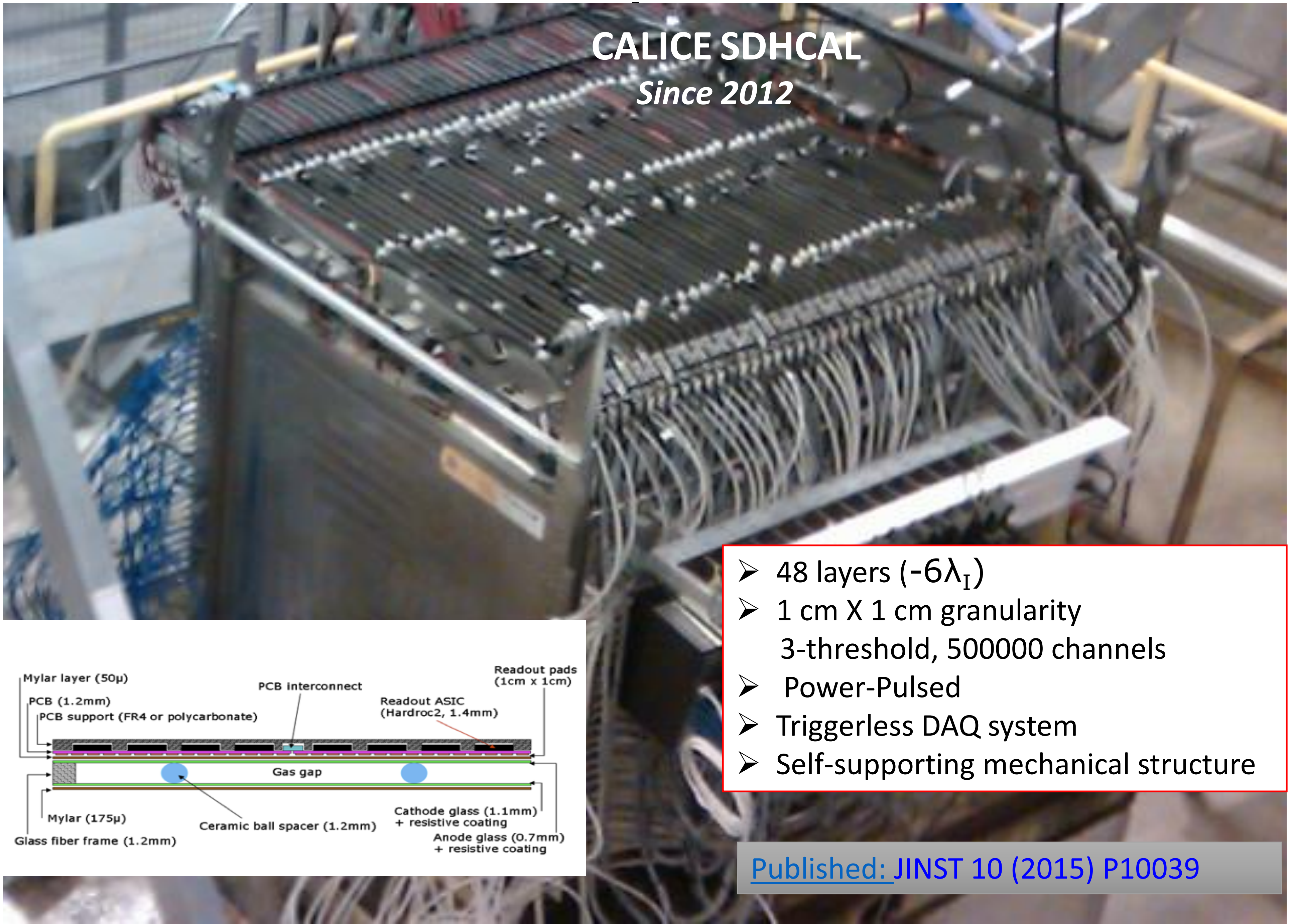
- **SDHCAL** using **MPGD**

INFN & U Bari, Weizman Inst.

The two proposals will use gaseous detectors which development will be important activities of the DRD1

CALICE SDHCAL

Since 2012

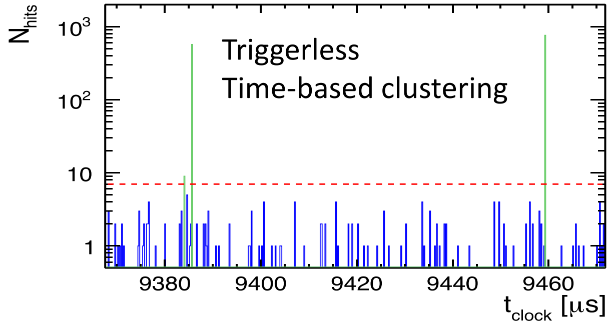


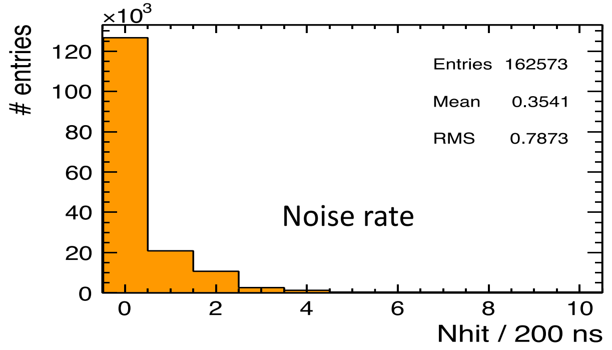
- 48 layers ($\sim 6\lambda_I$)
- 1 cm X 1 cm granularity
  3-threshold, 500000 channels
- Power-Pulsed
- Triggerless DAQ system
- Self-supporting mechanical structure

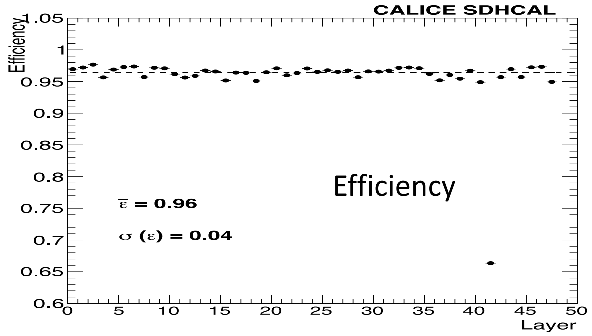
Published: JINST 10 (2015) P10039

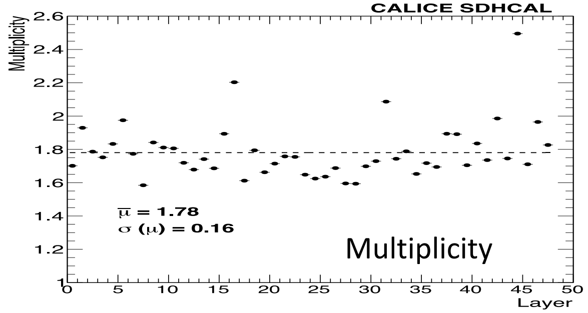
SDHCAL performance

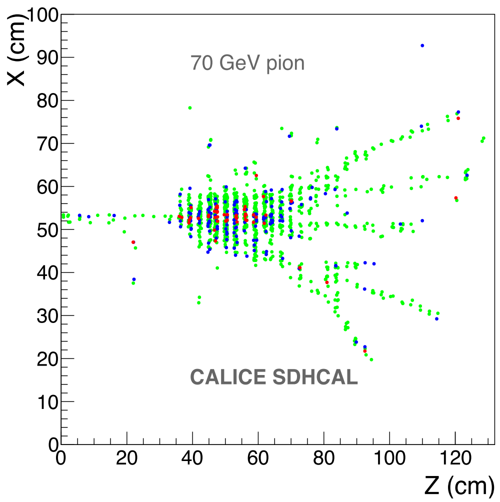
- The SDHCAL prototype was exposed to hadron, muon and electron beams in 2012, 2015 , 2018 and 2022 on PS, H6 and H8 -SPS lines.
- **Power-pulsing** using the SPS spill structure was used to reduce the power consumption.
- **Self-triggering** mode is used but external trigger mode is possible
- The threshold information helps to improve on the energy rec. by better accounting for the number of tracks crossing one pad
- Data were taken in 2012, 2015, 2017, 2018 and 2022 with continuously improved DAQ system.

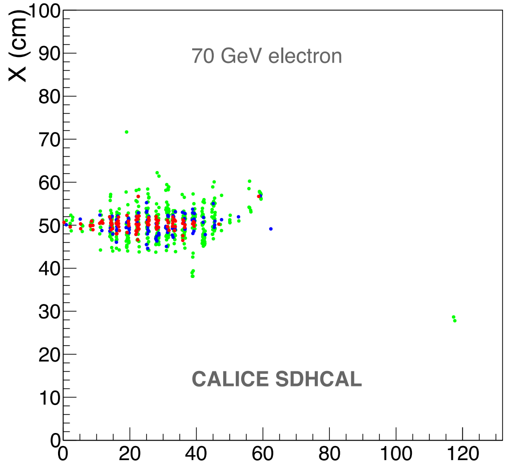












SDHCAL Performance

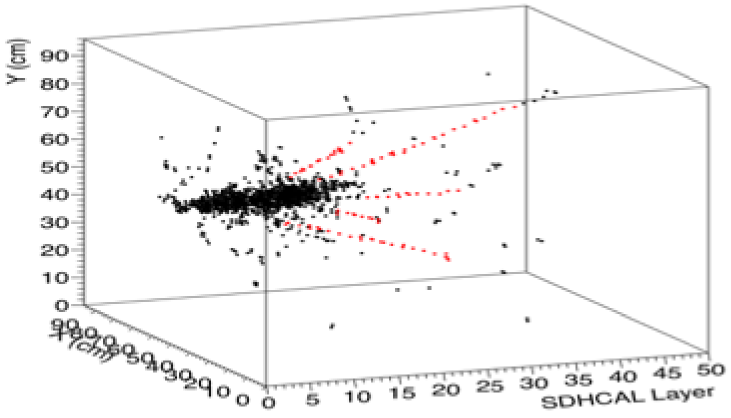
$$E_{rec} = \alpha(N_{tot})\, N_1 + \beta(N_{tot})\, N_2 + \gamma(N_{tot})\, N_3$$

α , β , γ are **quadratic functions** of
They are computed by minimizing :

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

Hough-Transform

Track segments reconstruction using 3D-Hough Transform helps apply different treatment to the hits of these segments.



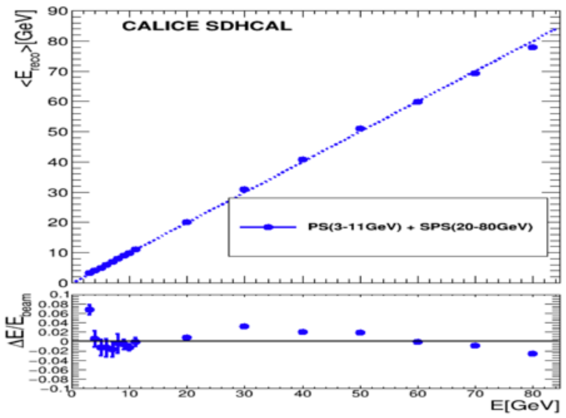
Track segments can also be used as in-situ calibration and monitoring tools

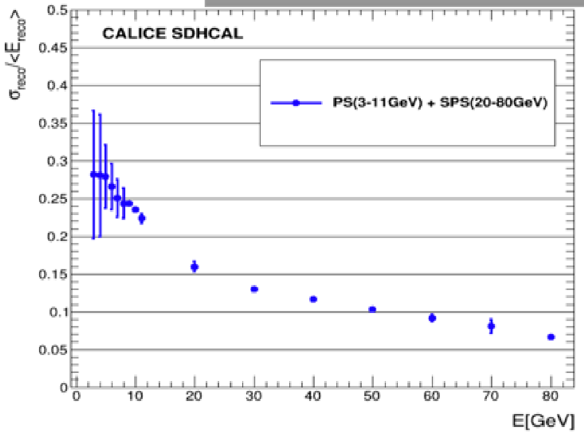
JINST 12 (2017) P05009

Energy reconstruction

JINST 11 (2016) P04001

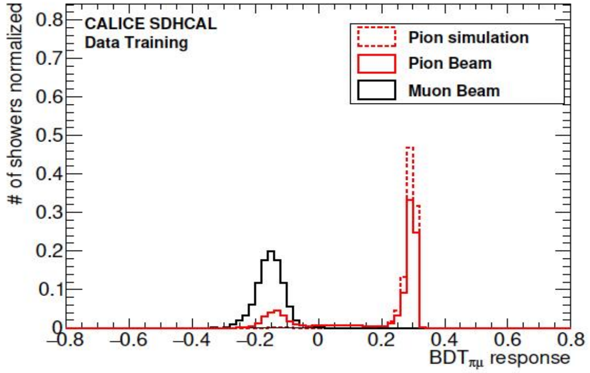
JINST **17** (2022) P07017

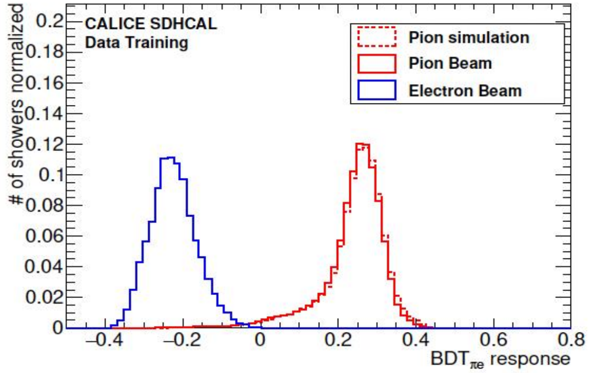




Particle identification

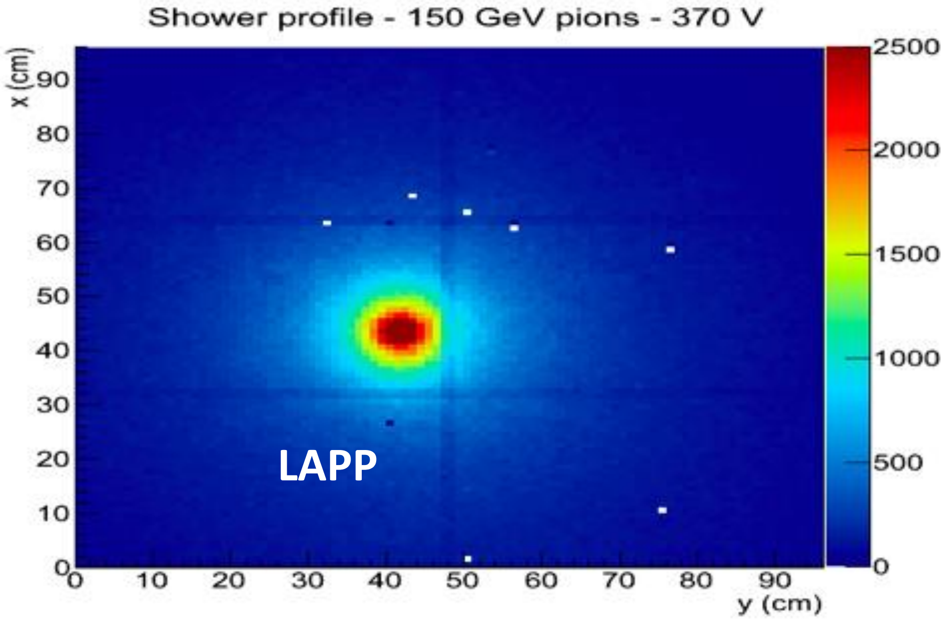
JINST 15 (2020) P10009



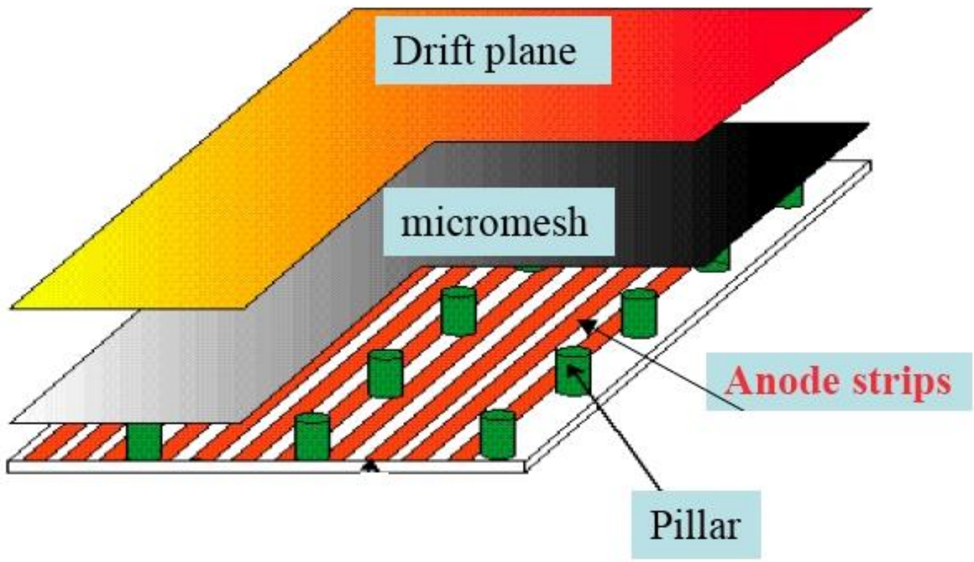


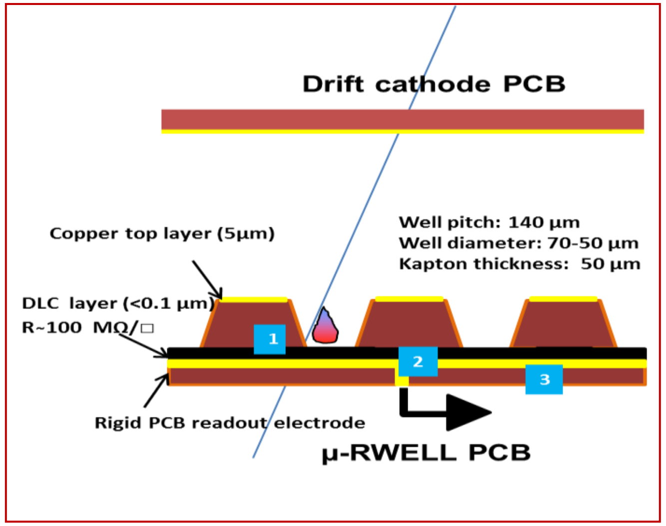
MicroMegas-SDHCAL

4 units of SDHCAL-MM 1m x 1m each were produced, tested in a muon beam. The 4 units of SDHCAL-MM were inserted in the SDHCAL-RPC prototype replacing the RPC units #10, 20, 35 and 50. Results were successfully confirmed by simulation



MPGD-(S)DHCAL


Drift plane
micromesh
Anode strips
Pillar


Drift cathode PCB
Copper top layer (5µm)
Well pitch: 140 µm
Well diameter: 70-50 µm
Kapton thickness: 50 µm
DLC layer (<0.1 µm)
R~100 MΩ/□
1
2
3
Rigid PCB readout electrode
µ-RWELL PCB

MPGD SDHCAL

- HCAL for Experiment with Particle Flow design
  - Semi-digital with high granularity ($1cm^2$ pad) very promising (CALICE)
  - MPGD detectors as alternative gaseous detector
    - Advantages: non-flammable and non-greenhouse gas; reduced values of HV; high-rate
  - Resistive MPGDs are protected against discharges
  - Apply latest Resistive MPGD technology for HCAL + keep options open for new MPGDs
  - Research project within RD-51 Collaboration (co-funded)
    - Resistive Micromegas (experience INFN Rome & INFN Napoli)
    - Resistive uRWELL (experience INFN Frascati)
    - Resistive Plate WELL (experience Weizmann Institute of Science)
    - FastTiming MPGD (experience INFN Bari)
- Can be applied for any HCAL @ Future Collider Facility
  - Both for e^+e^-, *pp* or $\mu\mu$ colliders
  - Key benefit: intrinsic radhard (gaseous) and high-rate capable (MPGD)
- HCAL R&D is expensive => *small size prototype*
  - Prototype 6-8 readout layers; 2 nuclear interaction lengths depth; OK for 2-6 GeV p,$\pi^{\pm}$
  - Study timing properties of MPGDs (expect ~1ns) → FATIC electronics
  - In future allow specific fast timing layers based on MPGD technology

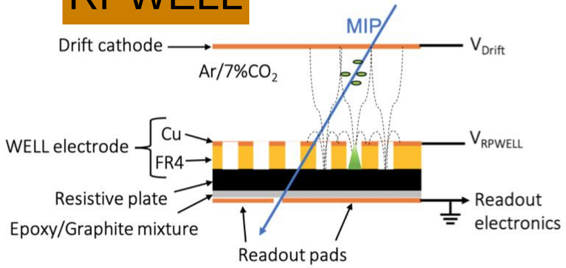
MPGD SDHCAL

Bressler, S., et al. "Novel Resistive-Plate WELL sampling element for (S)DHCAL." NIMA 958 (2020): 162861.

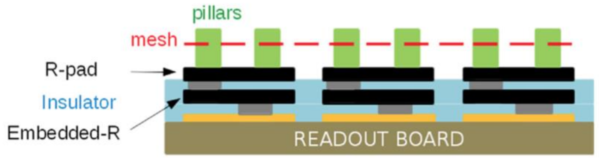
Project supported by the RD51 common project (WIS-Aveiro-Coimbra & LAPP-Demokritos)

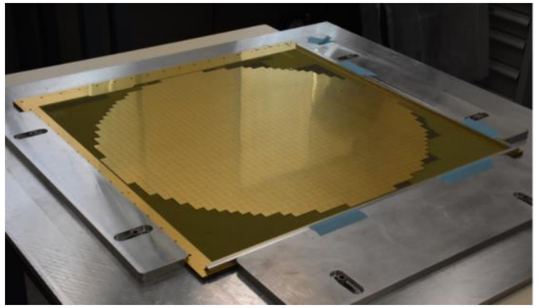
- MM and RPWELL technologies
- 5 prototypes
- 50cm x 50cm area
- ASU anode with integrated MICROROC ASIC chips
- Combined test in CERN PS in 2018

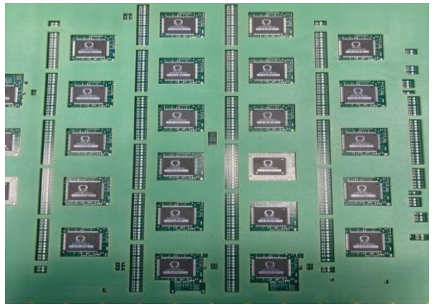
RPWELL

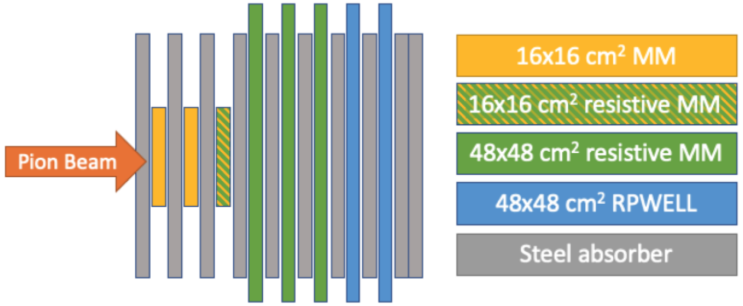


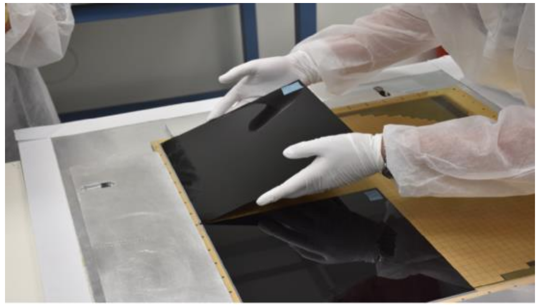
Resistive MM

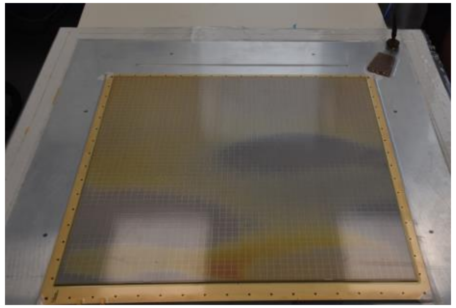








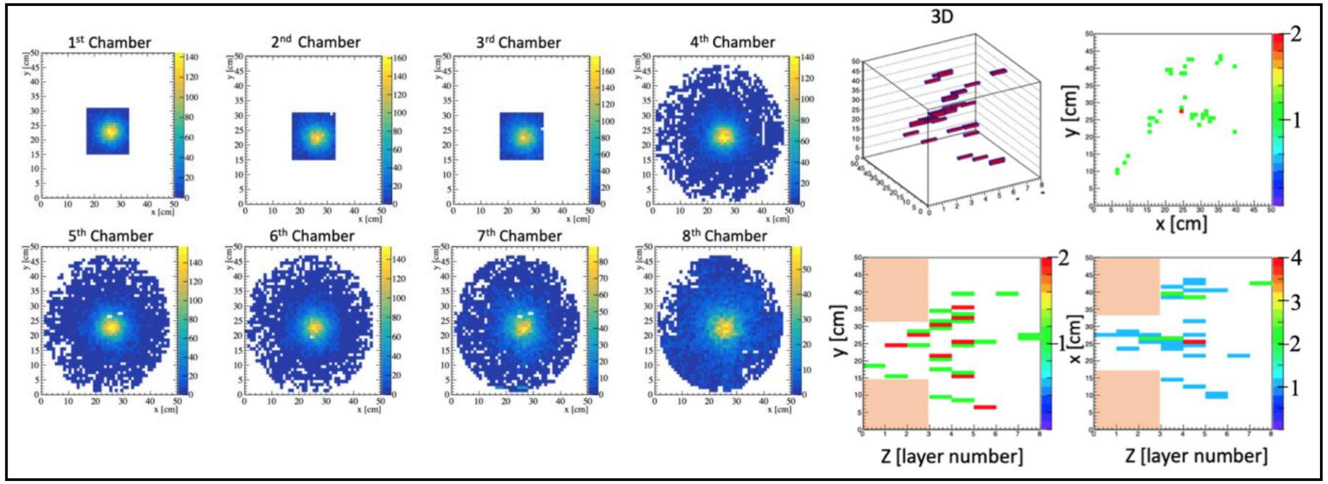




MPGD SDHCAL

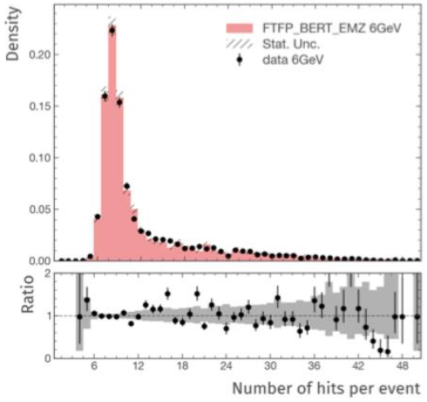
Shaked-Renous, Dan, et al. "Test-beam and simulation studies towards RPWELL-based DHCAL." *JINST* 17.12 (2022): P12008.

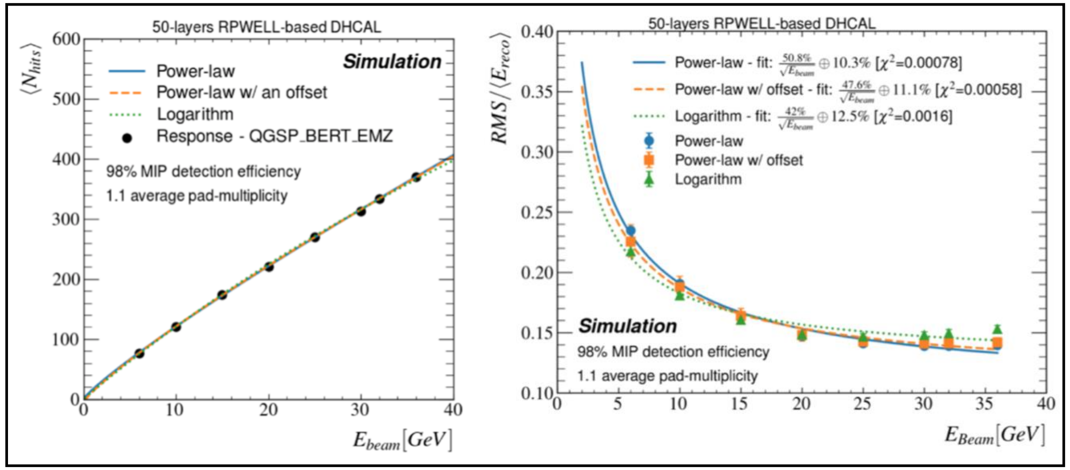
Project supported by the RD51 common project (WIS-Aveiro-Coimbra & LAPP-Demokritos)



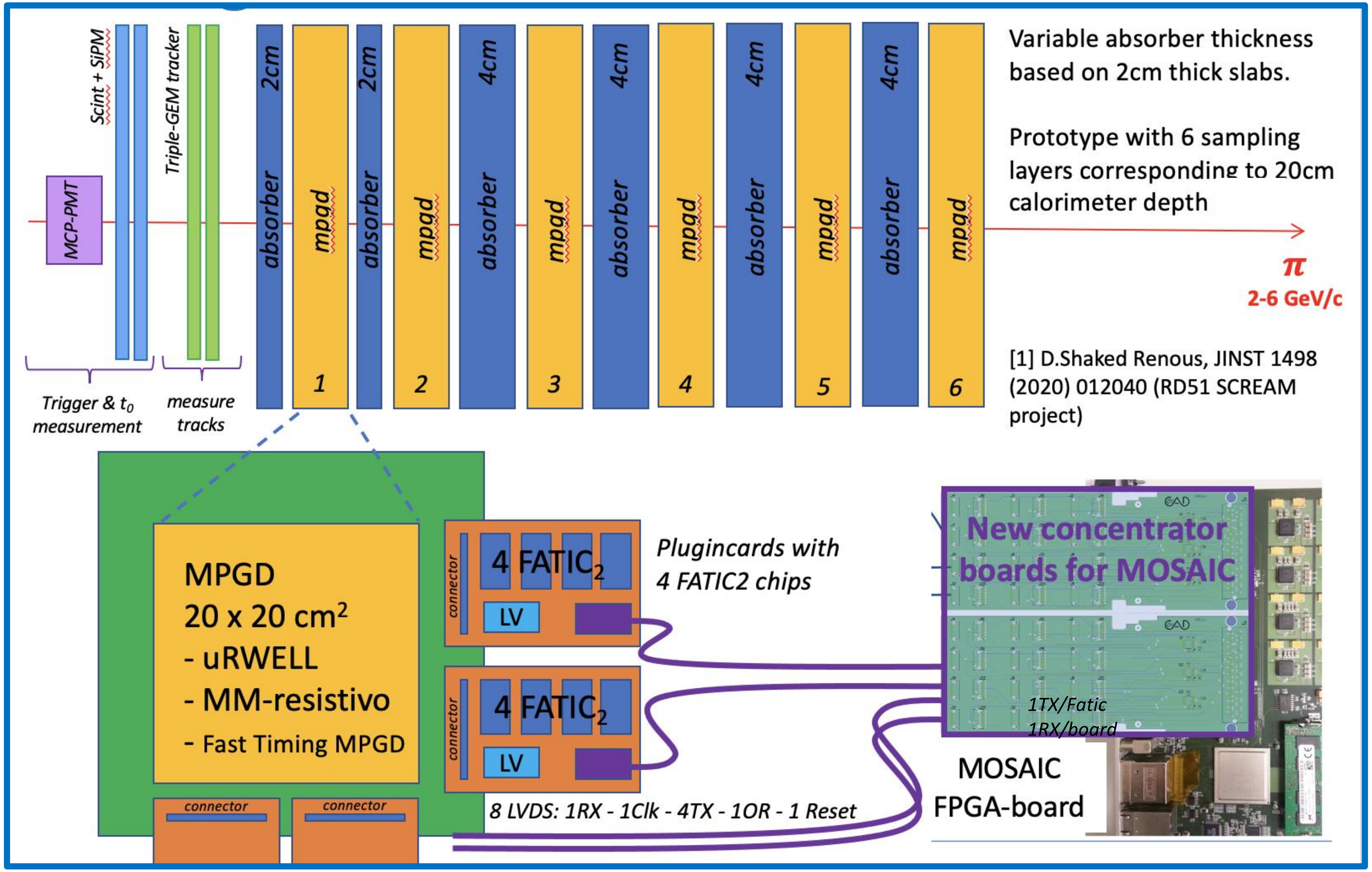
Combined test in CERN PS in 2018

- Measurement with 2-6 GeV pions
- Data validation by Geant4 simulation
- MC simulation of a 50 layers prototype





MPGD SDHCAL

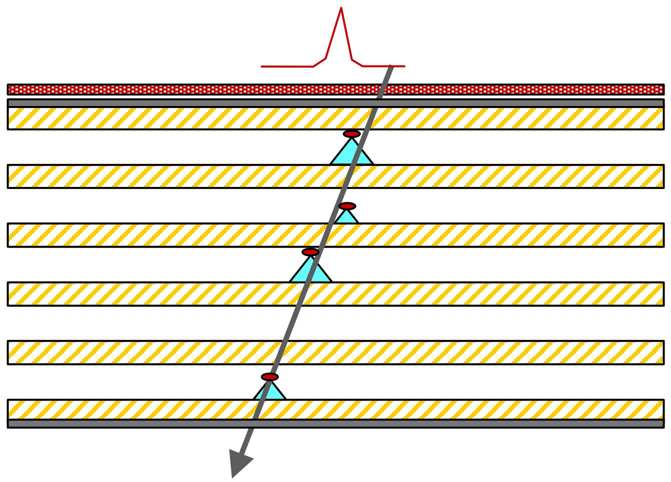


RD-51 Common Project:
INFN Bari, Frascati, Napoli, Rome
Weizmann Institute of Science

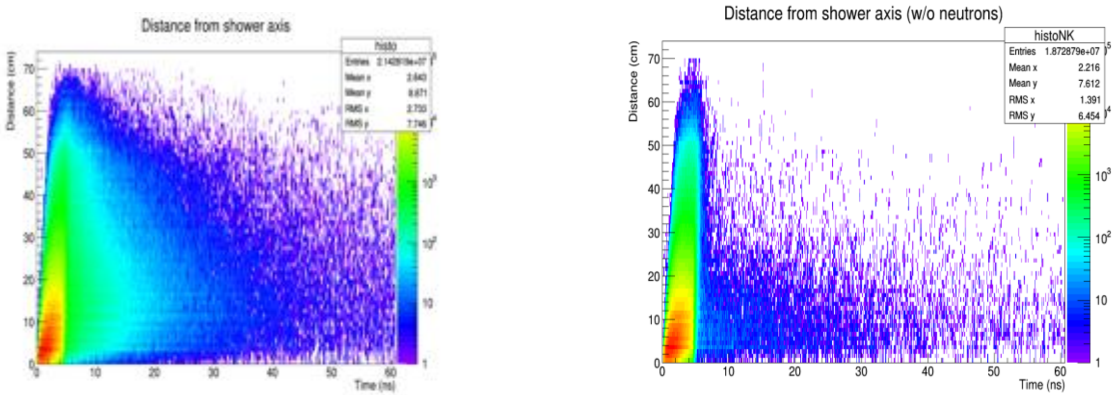
Timeline 2022-2024
- Design Spring ‘22
- Production Summer ‘22
- Test detectors Fall-Winter ‘22
- Testbeam (TB) (μ) July ‘23
- TB (2-6 GeV p,$\pi^{\pm}$) Aug ’23
- Next Step: new Design Fall ‘23

FATIC electronics & concentrators
- 7ns rise-time; 300ps jitter @ 1fC
- 2nd version FATIC - Asic tested (single asic) with good results
- Unexpected noise on 4-asic board required for testbeam
- => 2023 test with APV & SRS
- => 2024 test with FATIC

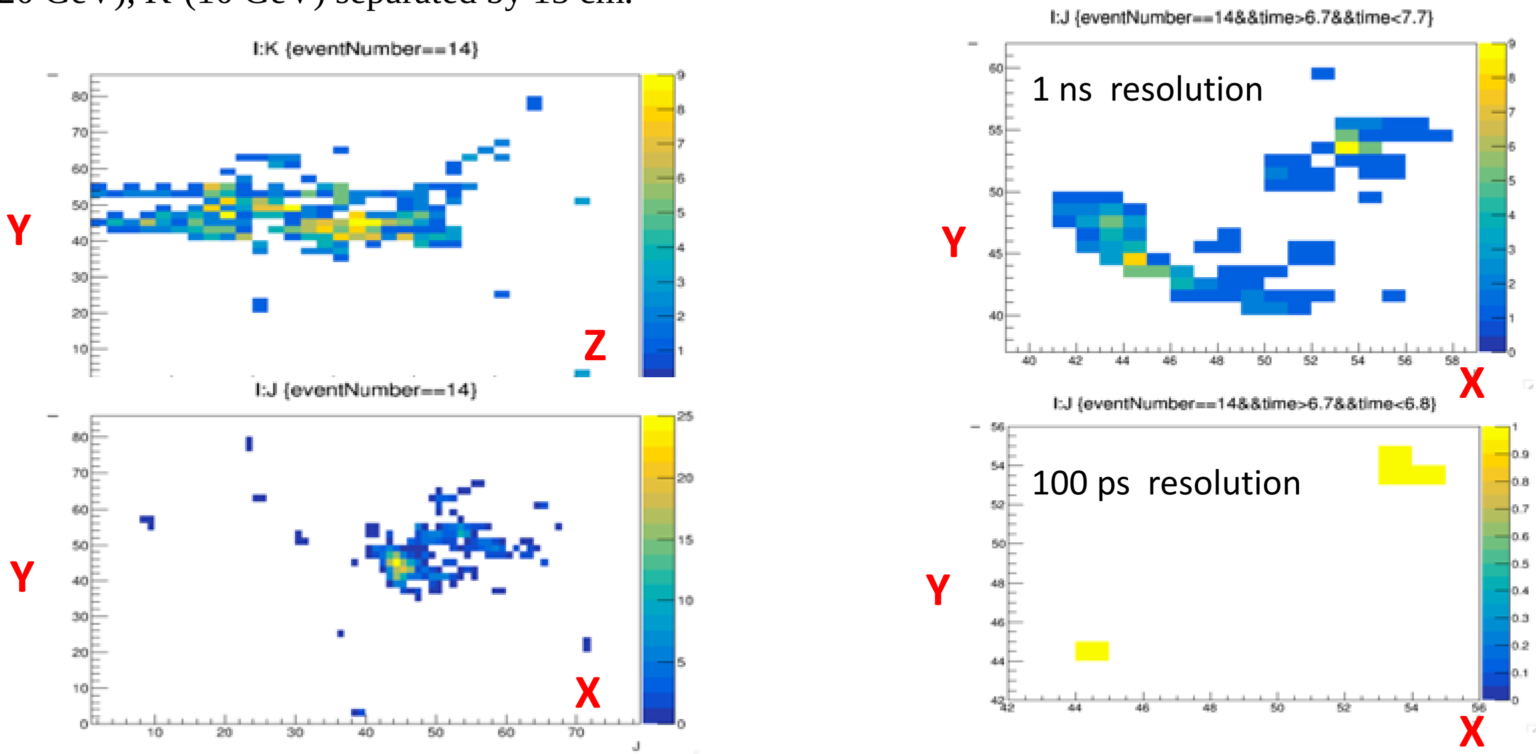
T-SDHCAL



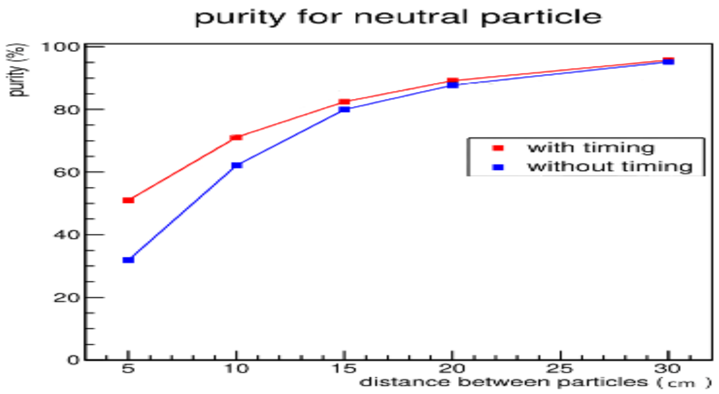
Timing is an important factor to identify delayed neutrons and **better reconstruct their energy**

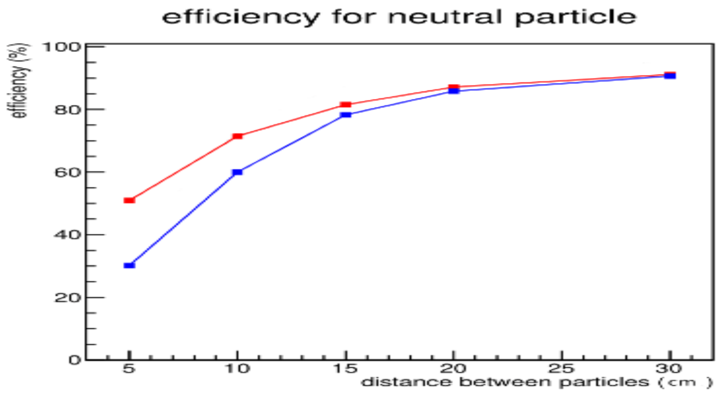


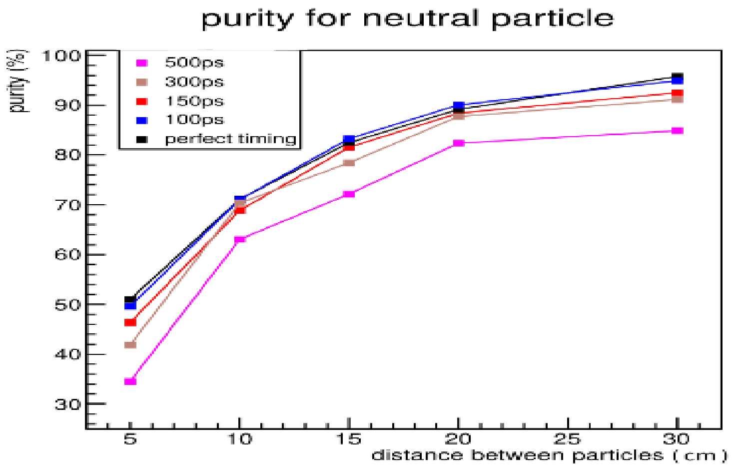
Timing can help to separate close-by showers and reduce the confusion for a better **PFA** application. Example: pi-(20 GeV), K-(10 GeV) separated by 15 cm.

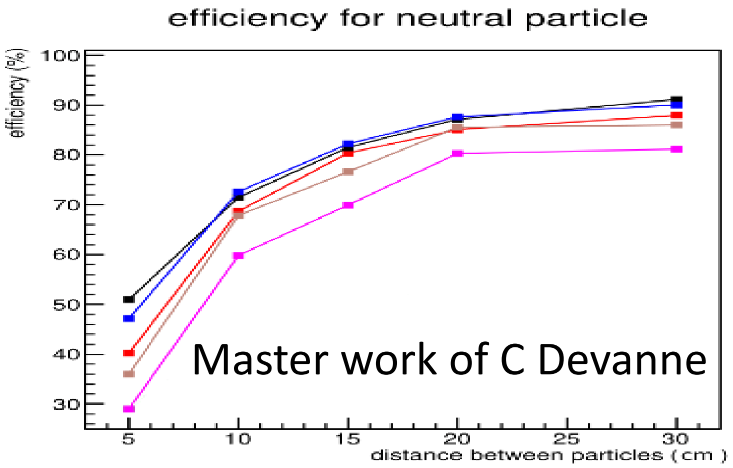


Including time information in the simulation to separate hadronic showers (10 GeV neutral particle from 30 GeV charged particle) using techniques similar to ARBOR's ones.







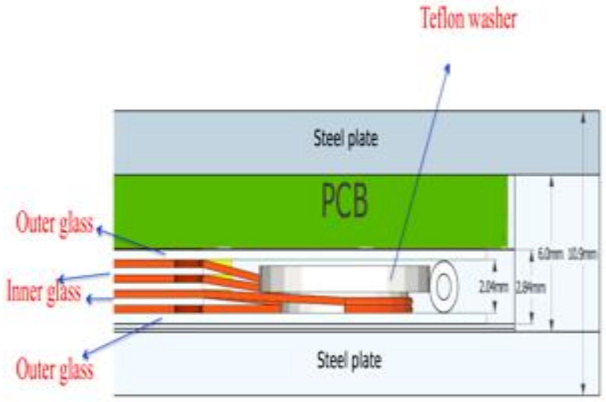


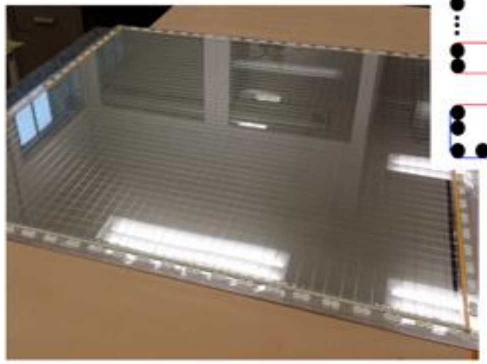
Master work of C Devanne

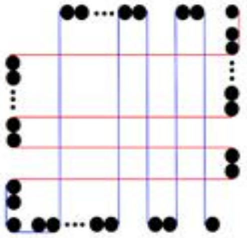
DETECTOR

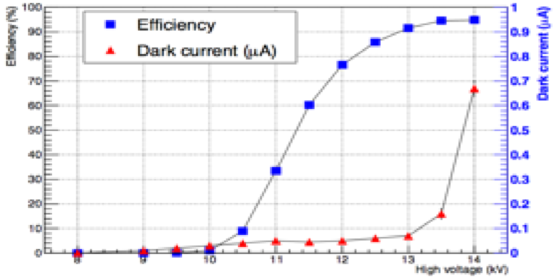
MultiGAP RPC is an excellent candidate.
5-gap of 200 µm each separating glass plates of 250 µm thick can provide a time resolution of around 100 ps

The standard method to build MRPC is based on using fishing line



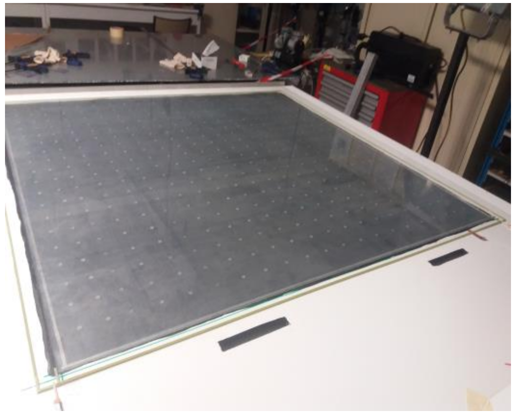






Threshold sets at 114 fC

New and easy way of construction MRPC. Preliminary results show an efficiency > 93% with 5 gaps

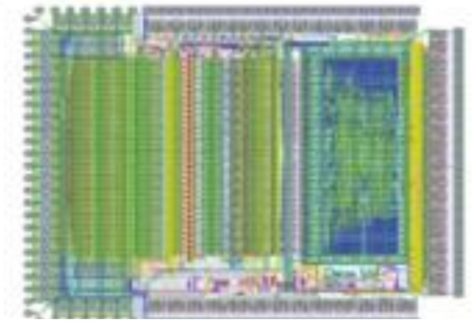


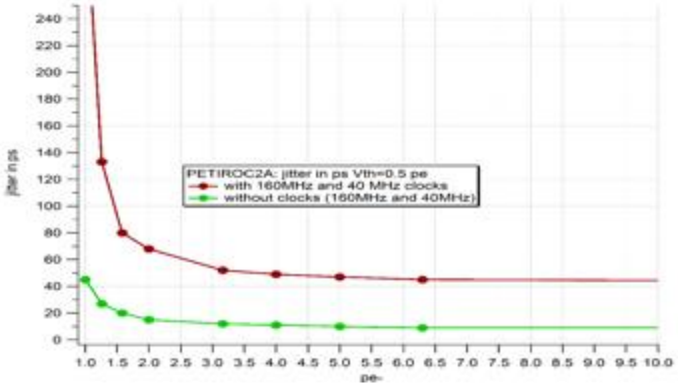
Electronics readout

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

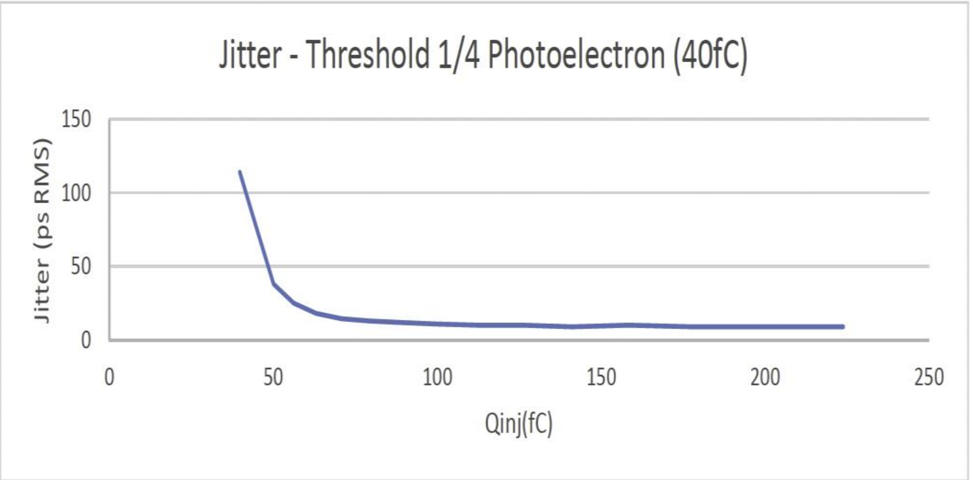
→**PETIROC** 32-channel, high bandwidth preamp (GBWP> 10 GHz), <3 mW/ch, dual time and charge measurement (Q>50 fC)
jitter < 20 ps rms @ Q>0.3 pC

Internal TDC of 50 ps time resolution.



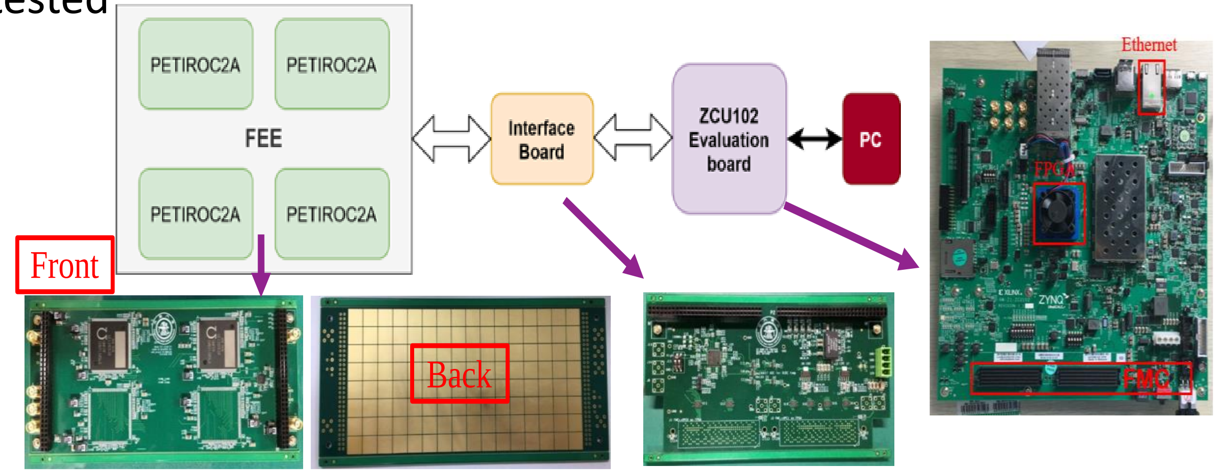


Another ASIC in TSMC 130 nm developed by OMEGA&WEEROC called **LIROC** with a time **jitter < 10 ps** is to be used in the future but it needs to be equipped with an internal TDC before.



Small ASU

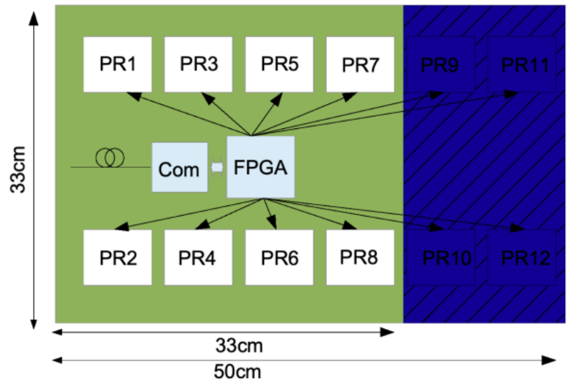
A board with 4 petiroc, 128 pads as well as the whole DAQ system was developed and being tested

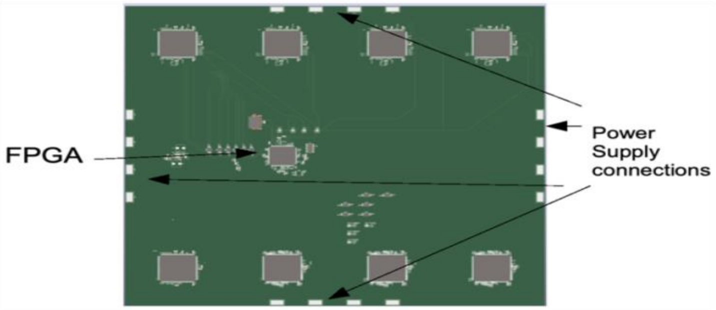


- Front-End Electronics for MRPC readout with high timing resolution
- The system includes a front-end board (FEB), a detector interface card (DIF) and a data acquisition system(DAQ) based on ZCU102.

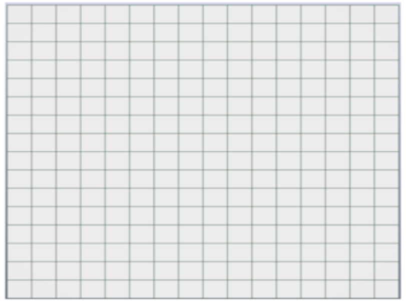
Large ASU

- Board with 8 (could be extended to 12) Petircoc2B ASICs
- Pads 2cm x 2cm, 256 channels
- Local FPGA (Xilinx Spartan-6 TQFP) embedded on board





Top view



Bttom view

High-Rate capability

(M)RPC are low-rate capability detectors due to the resistive nature of the electrodes. The capability could be significantly increased by developing low resistivity materials.

Dopped glass (by Tsinghua group) could be a solution
PVdF and **PEEK** are very stable and chemically inert thermoplastic

-New kind of PVdF developed with the help of PolyOne company, doped with CNT → bulk resistivity of $10^{11\text{-}12}$ Ω.cm
-New charged PEEK developed with the help of Krefine company. doped with Black Carbon→ bulk resistivity of $10^{8\text{-}9}$ Ω.cm was achieved.

A few small detectors were made using doped PVdF plates of 2-3 mm thickness.
An excellent efficiency is obtained with cosmic but

Plates made with charged PEEK were produced
Some homogeneity due to extrusion need to be fixed before to have a final material.

New friendly gases

The CERN gas group has identified friendly gases to replace TFE and SF6 for (M)RPC

TFE→ HFO1234ze (
SF6→ Nova4710 (not good for Bakelite but ok for GRPC and MRPC)

Techniques of recycling the gas mixture is being constantly improved (>90%)
Techniques to recover the different exhaust gases (distillation…etc) are being developed and promising results have been obtained.

Conclusion

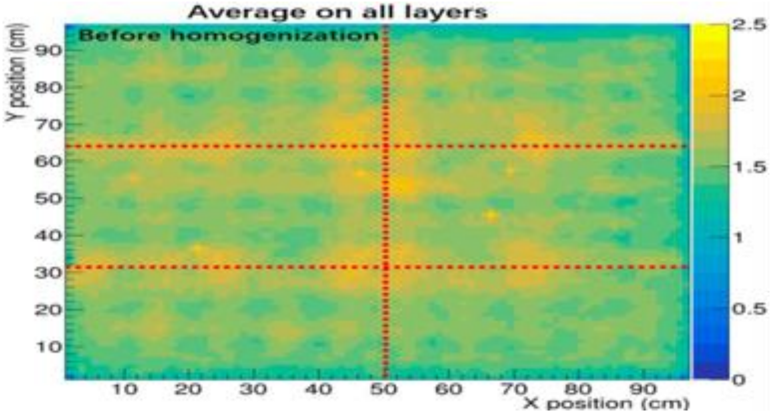
- Several gaseous detectors will be developed to be used as active area in calorimeters
- Efficiency, timing and high rate capabilities are important features to be investigated.
- Synergy between several groups involved in both DRD1 and DRD6 will be a precious tool for the success of the proposed projects

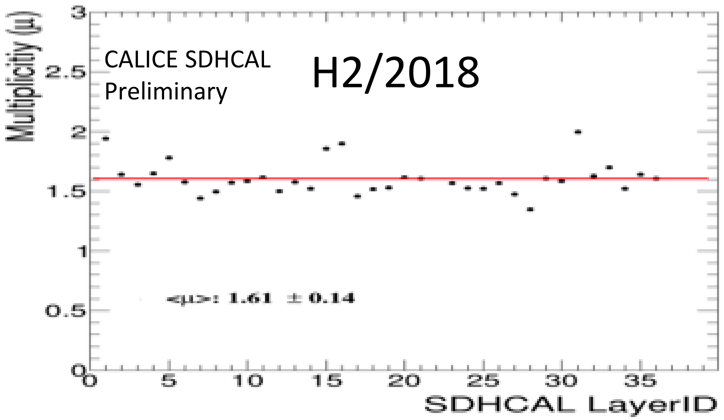
Many thanks for Luca Moleri and Piet Verwilligen for their contributions to this talk

Further improvements on the energy reconstruction

Detector homogeneity

The homogeneity of the detector response is important to achieve better energy reconstruction





A new calibration method based on varying the thresholds rather than the electronic gain was found to be powerful. Muon runs with different thresholds Thr1: 0.1-0.42 pC, Thr2: 0.4-5, Thr3:4.7-24) and efficiency and multiplicity were measured for each value. The values of the three thresholds of each ASIC were fixed to obtain same multiplicity (first threshold) and the same efficiency for thr2 and thr3.

$$\varepsilon(t;\bar{q},\delta,\epsilon_0) = \varepsilon_0 \cdot \left(1 - \int_0^t P(q;\bar{q},\delta)dq\right)$$
$$P(q;\bar{q},\delta) = \frac{1}{\Gamma\left(\frac{\bar{q}}{\delta}\right)\delta^{\frac{\bar{q}}{\delta}}} q^{\frac{\bar{q}}{\delta}-1} e^{-\frac{q}{\delta}}$$

$$\mu(t;f,p,c) = f \cdot t^p + c$$

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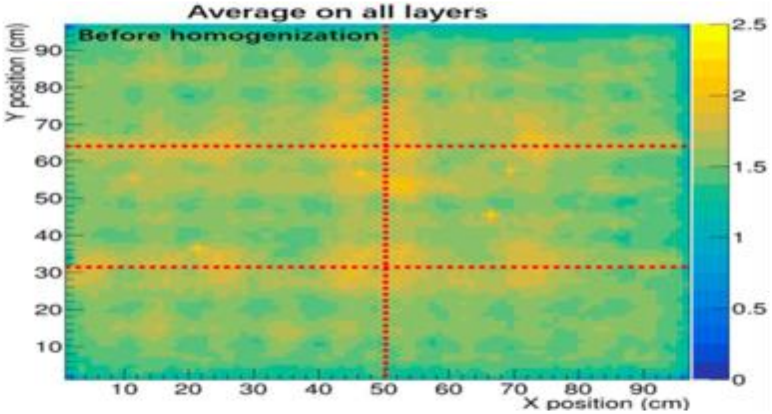

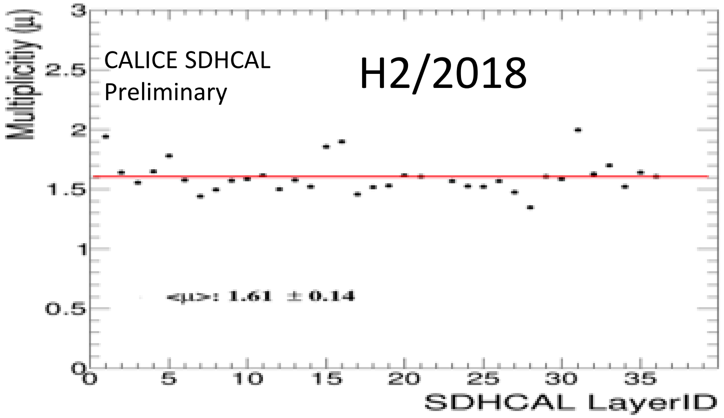

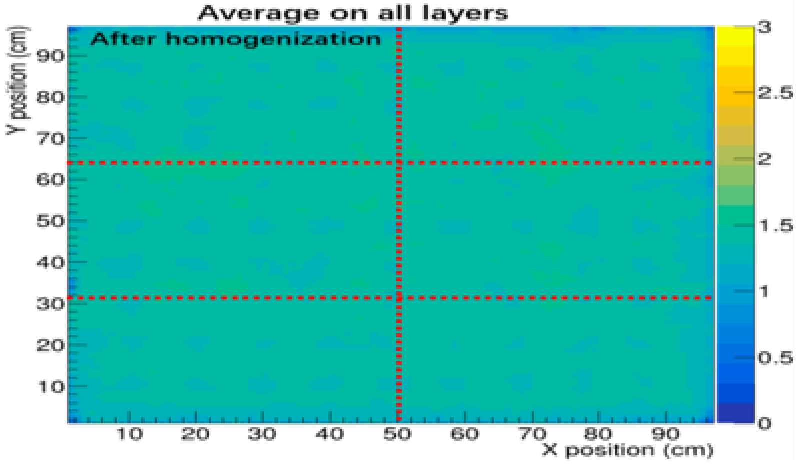

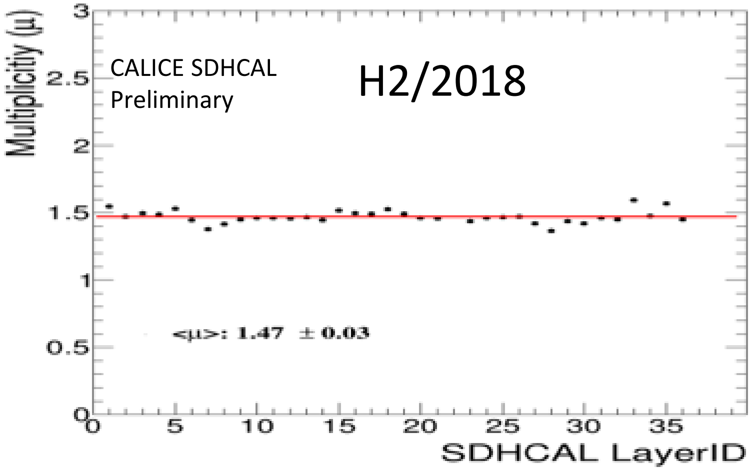

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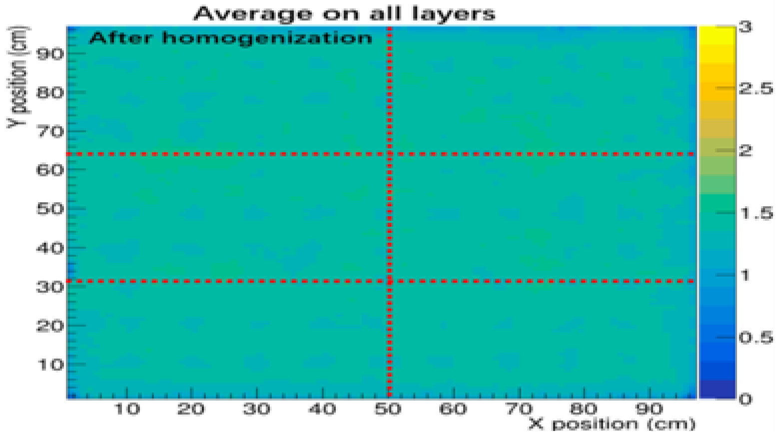
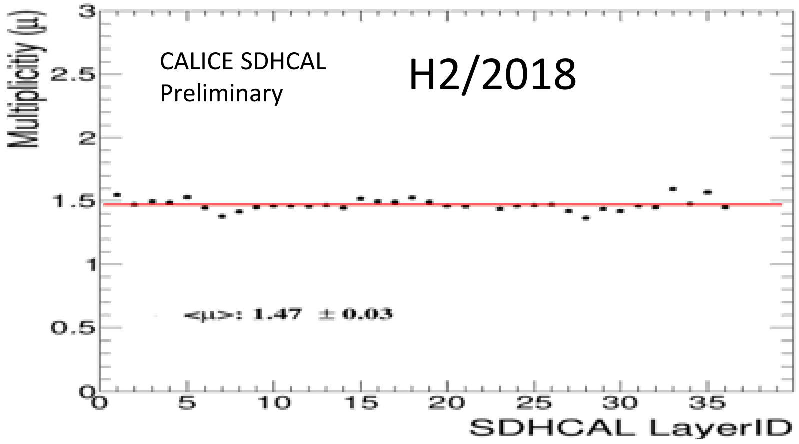
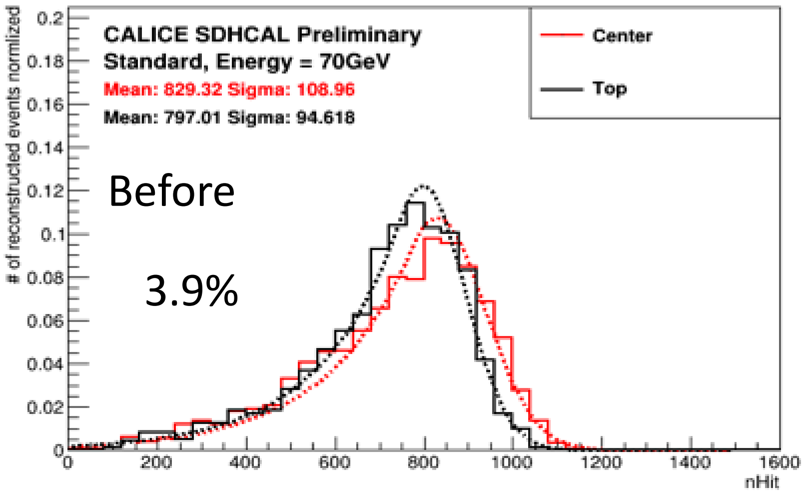
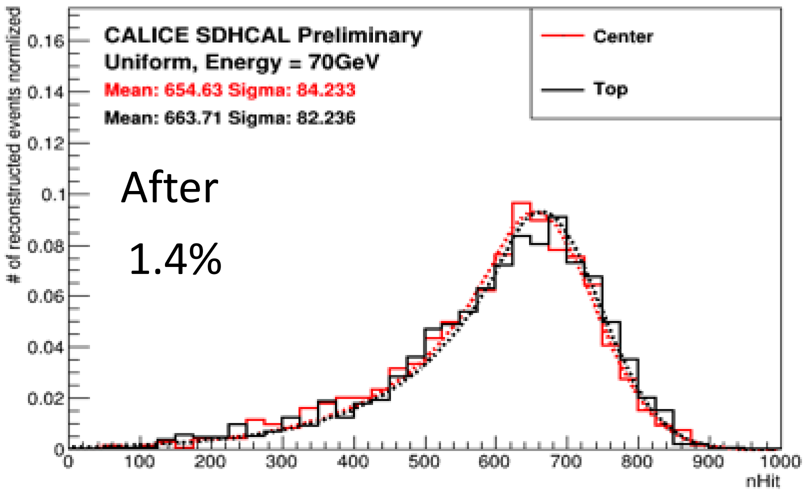








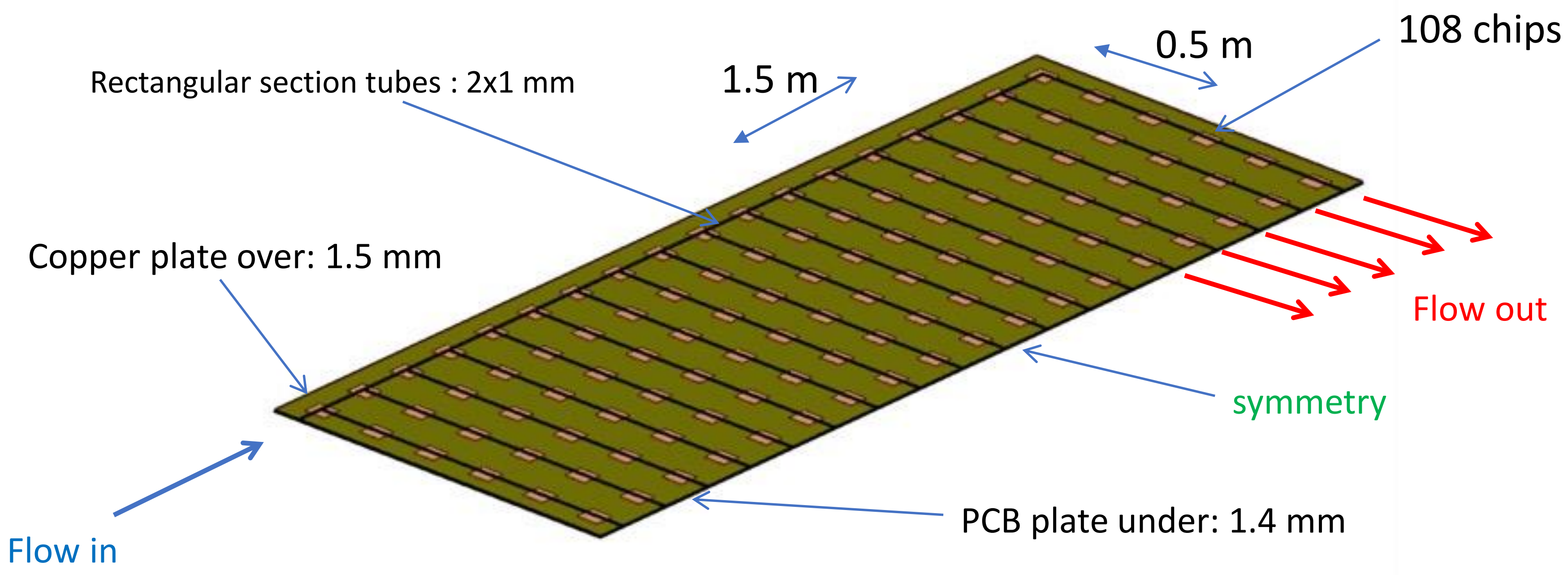
G. Garillot PhD thesis

Large SDHCAL module

SDHCAL power consumption and cooling

The duty cycles of CEPC/FCCee are different from that of ILC and no power pulsing is possible.
The power consumption is therefore increased by a factor of 100-200 with respect to ILC and active cooling is needed.
Lyon and Shanghai groups worked on a simple cooling system for SDHCAL based on using water circulating into copper pipes

0.8 mW/chips with power pulsing → 80 mW/chips without power pulsing



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