Front-End Electronics
for
Gaseous Calorimeters

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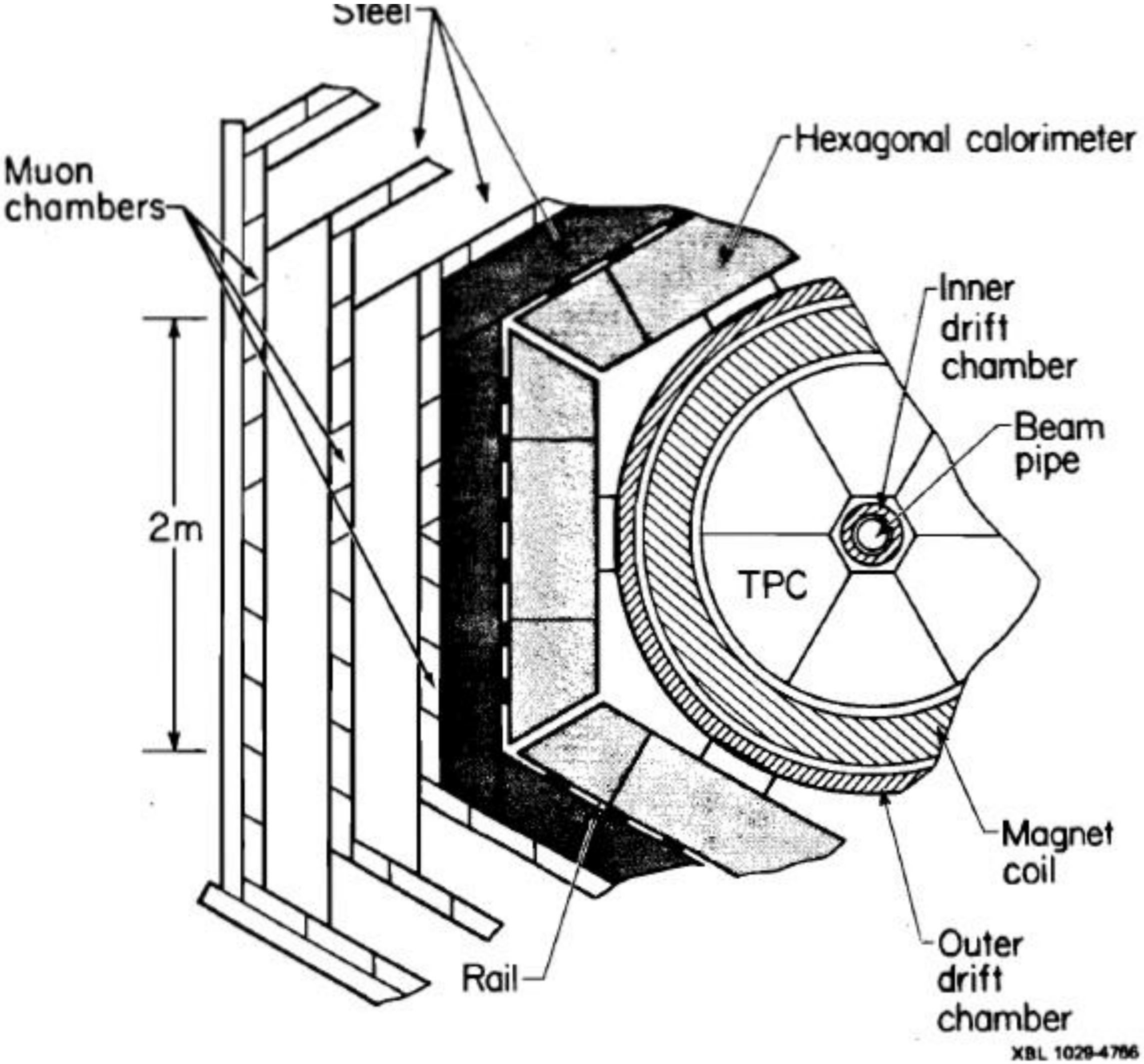
A bit of History

The use of gaseous detectors as sensitive media in calorimeters is not a new idea. Calorimeters based on gaseous detectors using proportional, saturated avalanche and streamer modes were developed since the seventies of the last century.

In some cases digital readout (counting the number of tracks the shower) and in others analogue readout were used.

Example : PEP4 Electromagnetic Calorimeter Gaseous (argon-Ethyl-bromide) Geiger cells+ Lead

Resolutions obtained with gaseous calorimeters were shown to be equivalent to those obtained with scintillators calorimeters.



PEP4 experiment scheme

WHY GAS SAMPLING CALORIMETRY

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Until a few years ago gas sampling calorimeters were seldom used in high energy experiments where track multiplicities were low and energy resolutions obtained from scintillator sampling were substantially better than gas sampling. Gas sampling calorimeters have gained in popularity during the last few years because of needs for fine segmentation, especially in colliding beam experiments at super high energies in order to provide a detector with good pattern recognition capability and e, γ, π and μ identification within dense tracks. This can be achieved with wire chambers by providing sufficiently small pads, strips which are grouped longitudinally in two or three sections, especially using a conductive plastic drift tube structure.

The gap in energy resolution between scintillator and gas sampling calorimeters has become less significant with recent advances in gas sampling. The papers contributed to the proceedings of this workshop are about some of the recent advances in this method.

A gas calorimeter has dual functions: measures energy flow through the layers and provides excellent track position resolution. A shower centroid position accuracy of 1 mm is obtainable from 1.2 cm wide cathode strips.[1] The same accuracy was obtained from 3 cm x 5 cm cathode pads using conductive plastic structures.[2] Gabathuler et al.[3] has shown that 2-5 cm separation is sufficient to resolve two showers depending upon their energy ratio.

Ease of pulse height calibration, insensitivity to magnetic fields and ease of signal transmission add to the attractiveness of these devices. Our experience with extruded drift tube counters is that gain uniformity along anode wires and within a large number of tubes is within ±2%. This makes monitoring gas gains easy by using a radioactive source (e.g., 5.9 keV line of Fe^{55} or 22 keV line of Cd^{109}).

Sufficiently large signals obtainable in the saturated avalanche mode or self quenching streamer mode eliminate needs for a preamplifier, simplifies electronics construction and calibration, and reduces cost.

As will be seen in the following papers, small departure from linearity shows up above 40 GeV with the electromagnetic, and above 75 GeV with the hadronic calorimeters running in the saturated avalanche mode. The departure is due to space charge saturation that is independent of the gas mixture. It can be improved by using small size tubes and/or by lowering the gas gain at the expense of σ/E which is a very slow function of gas gain. Experiments show that small local space charge saturation starts above 30 pC of charge with 12 mm x 12 mm size tube for around a 10mm wire segment (see the contributed paper on prevention of breakdowns and rates).

There has been concern about the lifetime of these devices. Some answers can be found in the contributed paper.

References:

(1) M. Atac et al., IEEE Trans. on Nucl. Sci. NS-28, No. 1 (1981) 500.

(2) Y. Hayashide et al., IEEE Trans. on Nucl. Sci., Vol. NS-30 No. 1 (1983) 112.

(3) E. Gabathuler et al., Nucl. Instr. and Methods 154 (1978) 47.

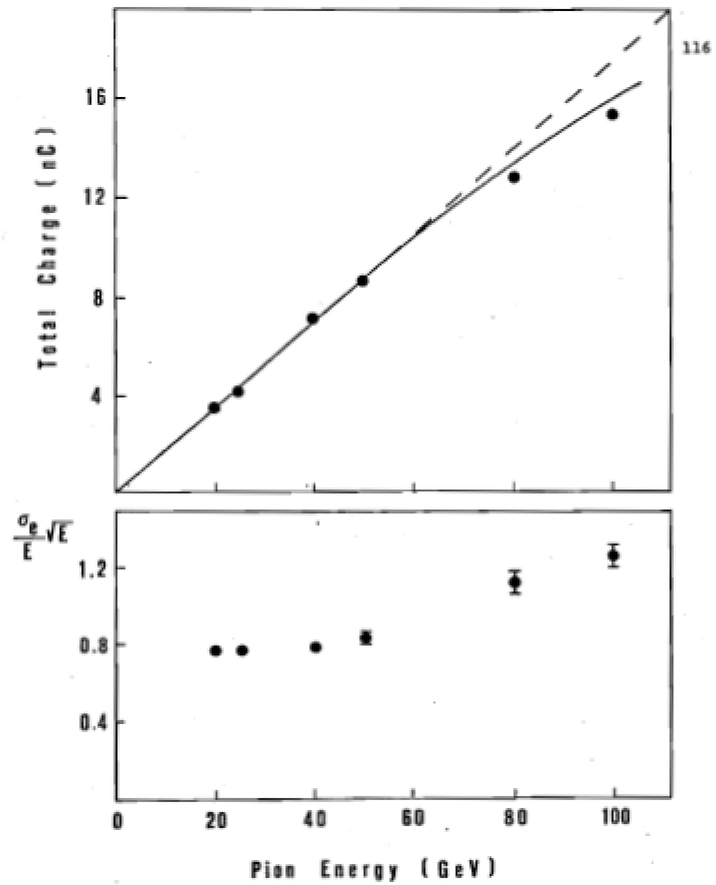


Fig. 7

Linearity of gaseous calorimeter

Some examples of gaseous calorimeters

:

The four LEP experiments at CERN (ALEPH, DELPHI, L3, OPAL)
had their hadronic calorimeters or part of it made with gaseous detectors:

ALEPH : Iron + Streamer tubes

85%/√E

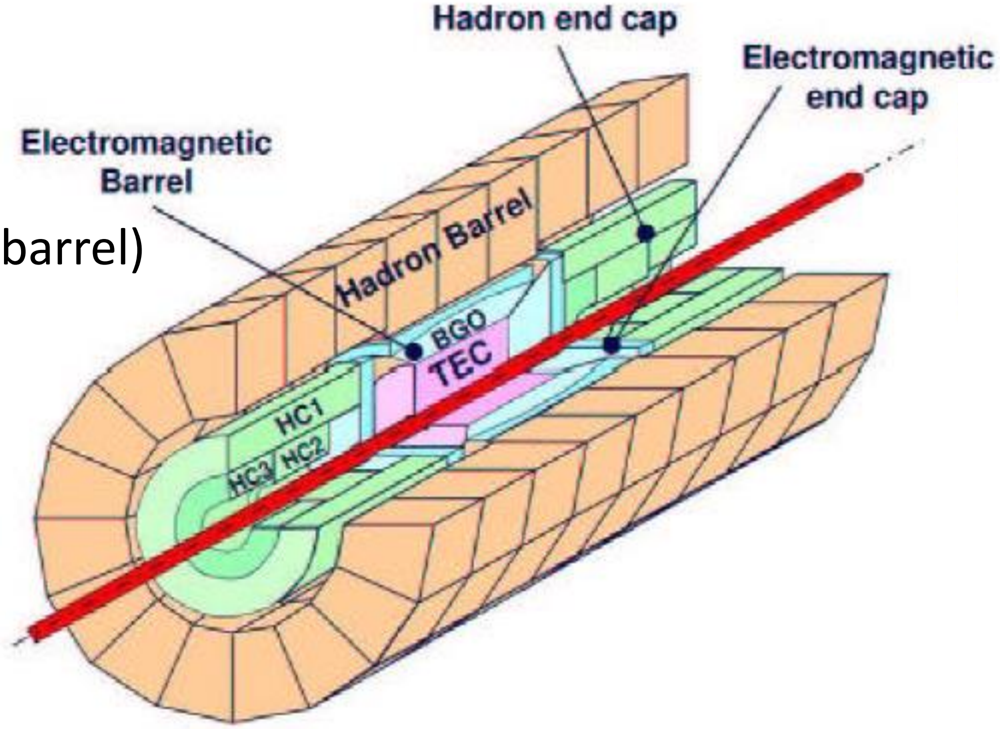
DELPHI :Iron + Streamer tubes (only barrel)

21%+112%/ √ E

L3 : Uranium +Wire chambers

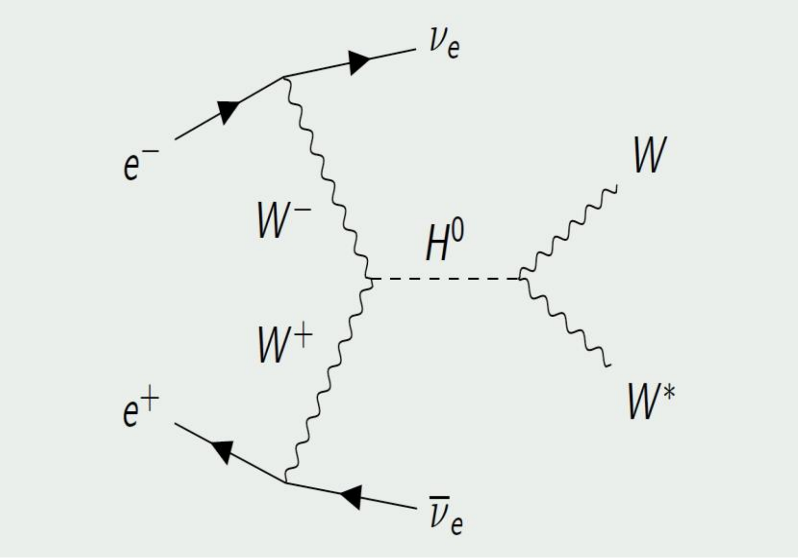
OPAL : Iron + Streamer tubes

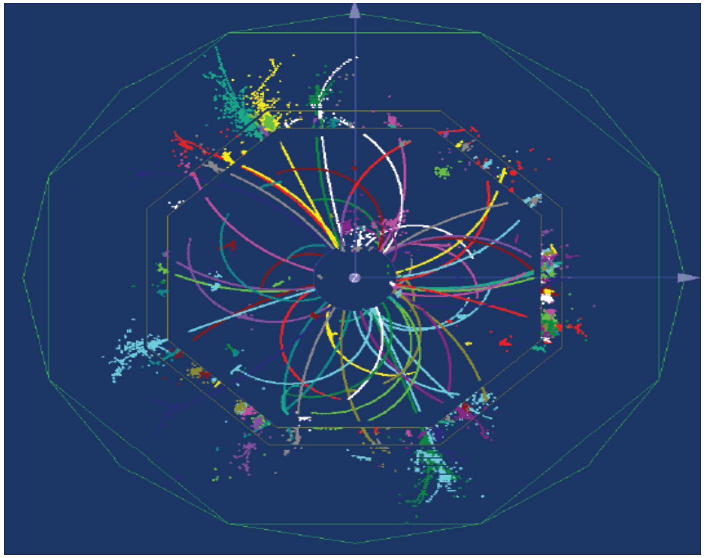
120%/√E



Why Gaseous calorimeters again?

For future colliders, jet energy resolution will be a determinant factor of understanding physics beyond the Standard Model.

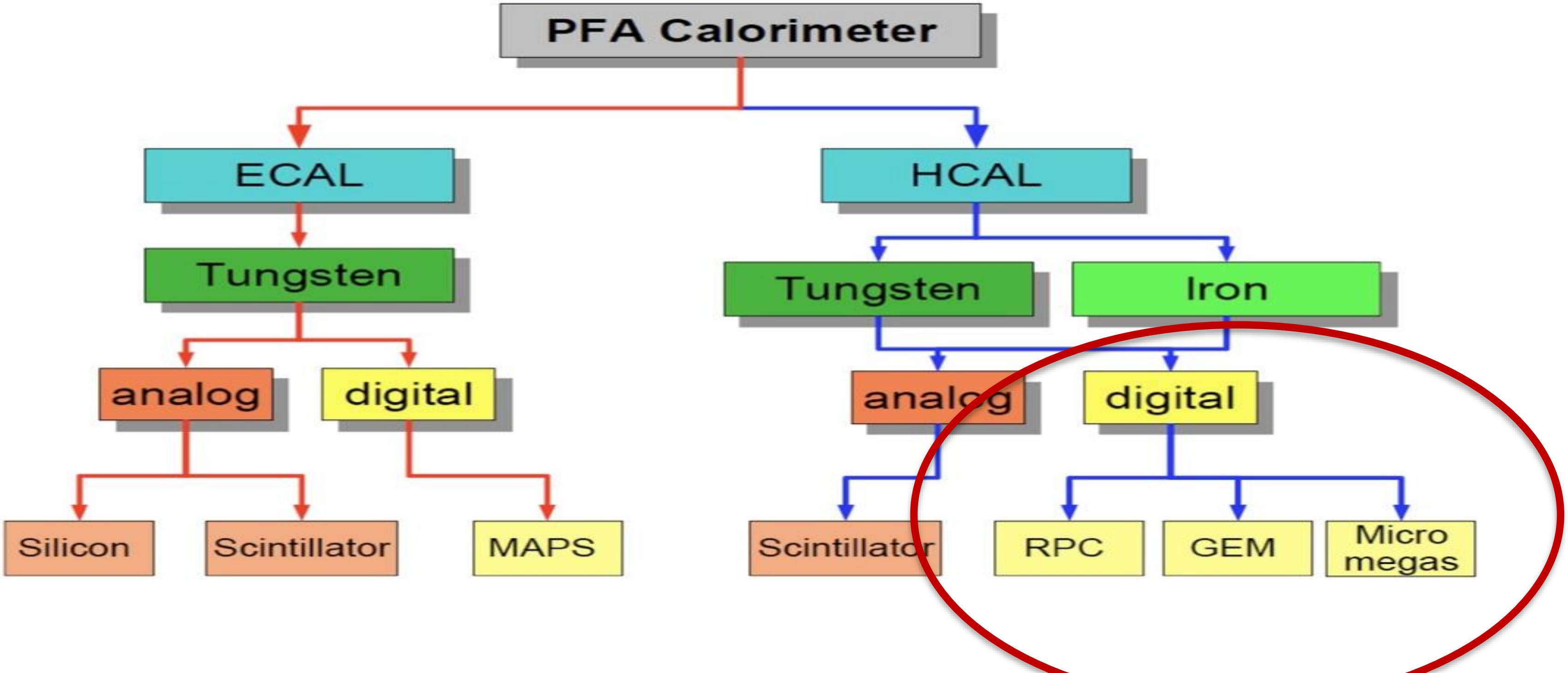




PFA is a promising solution to reduce the confusion term → high granularity Calorimeters
Gaseous detector are a suitable tool:

- Efficiency
- Spatial precision
- Large area at low cost

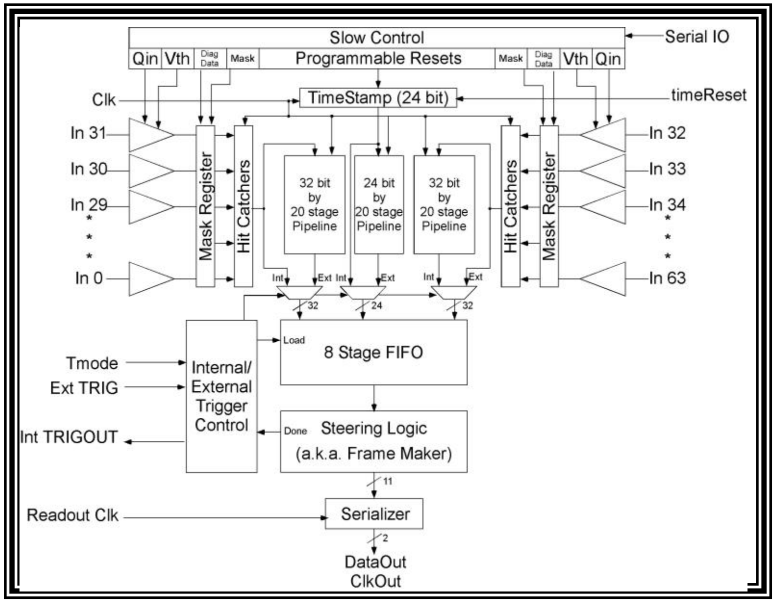
CALICE Collaboration develops high granularity EM and Hadronic calorimeters of different kinds including gas-based ones



Two kinds of electronics were developed for the gaseous hadronic calorimeters:

-Binary readout: DCAL, KPIX
-Multi-threshold: HARDROC, MICROROC
-Timing-based readout: Petiroc

Binary readout **DCAL ASIC**



- 64-channel
- amplifier/shaper/discriminator
- ***Single programmable threshold***
  - 1 bit dynamic range
  - DAC has 8-bit range
  - Common threshold per ASIC
- ***2 gain ranges***
  - High gain for GEMs (20 fC - ~200 fC signals)
  - Low gain for RPCs (100 fC - ~10 pC signals)
- ***Timestamp***
  - A clock of 100 nSec (24 bit counter)
- ***Data from FE consists of hit pattern in ASIC + timestamp***
  - 24 bit timestamp + 64 hit bits = 88 bits (+ address, error bits, etc.)

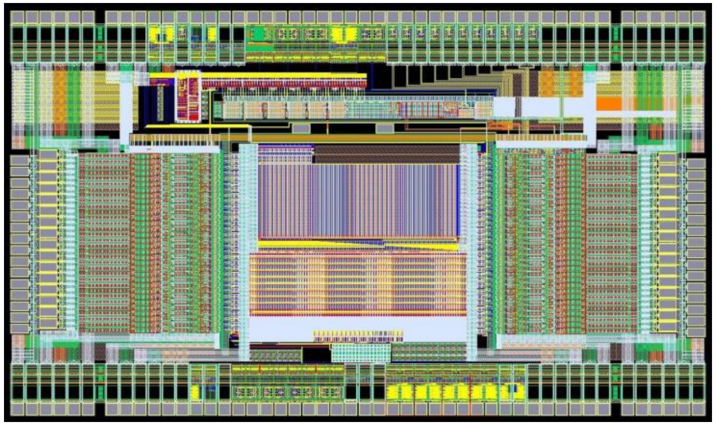
- ***Self Triggering*** → Noise, Cosmic rays
  but also capability for External Triggering → (beam events)

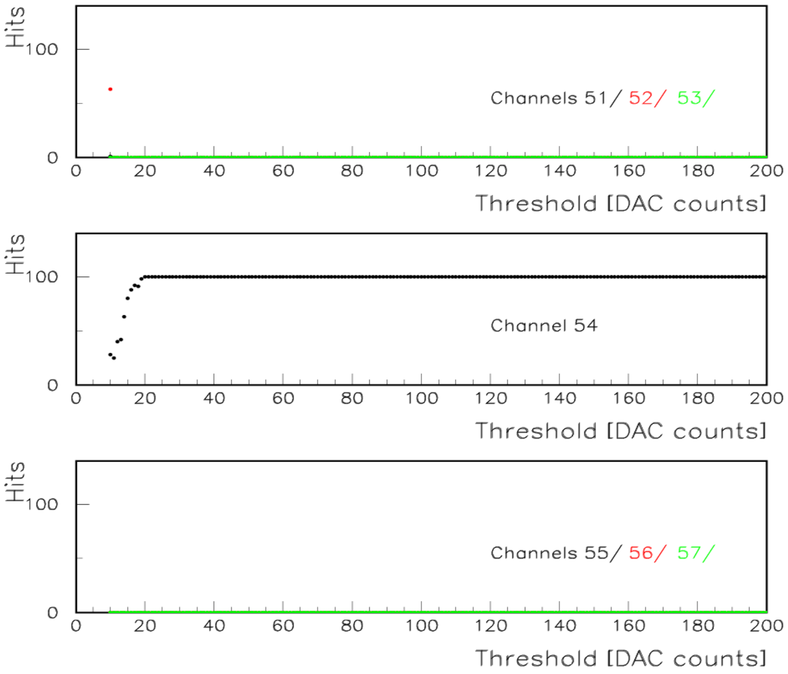
- **Deadtimeless readout**

DCAL ASIC

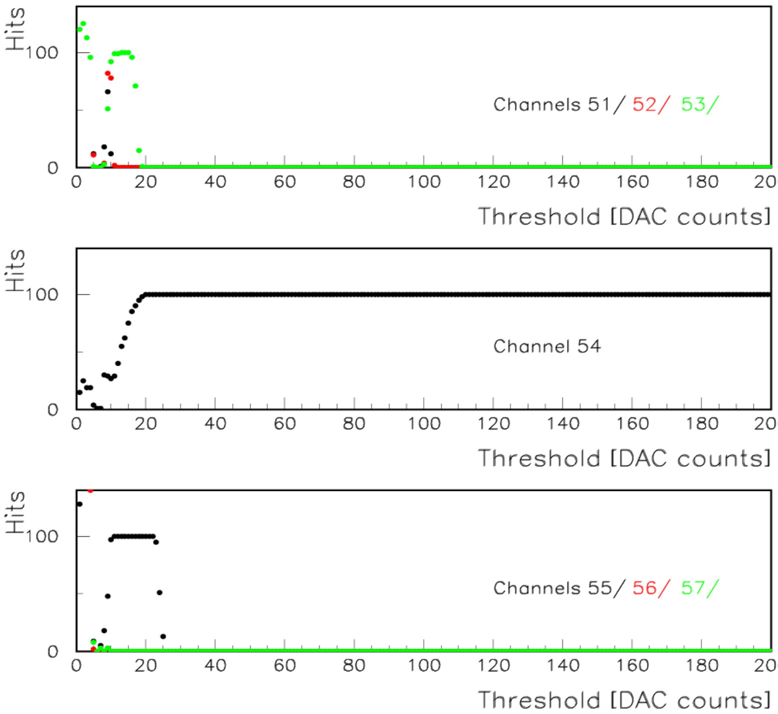
Developed by Fermilab&ANL for the DHCAL concept

Fabricated in TSMC 0.25 μm CMOS
Die ~4 mm x 6 mm, 160-pin TQFP package





DCAL2.1 - Qinj = 5.0 pC



DCAL2.1 - Qinj = 10.0 pC

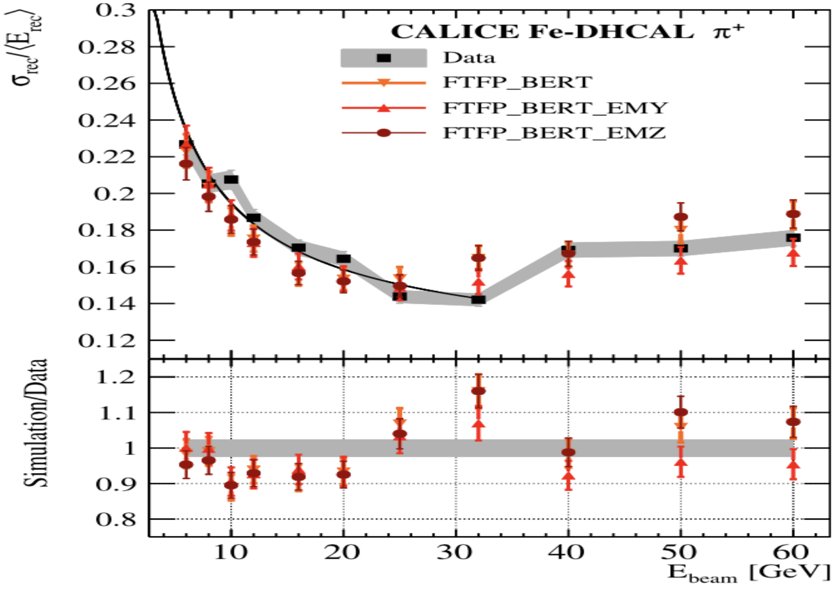
CALICE DHCAL prototype

-54 units, Each made of 3 RPCs

-RPC size : 33 cm x 100 cm.

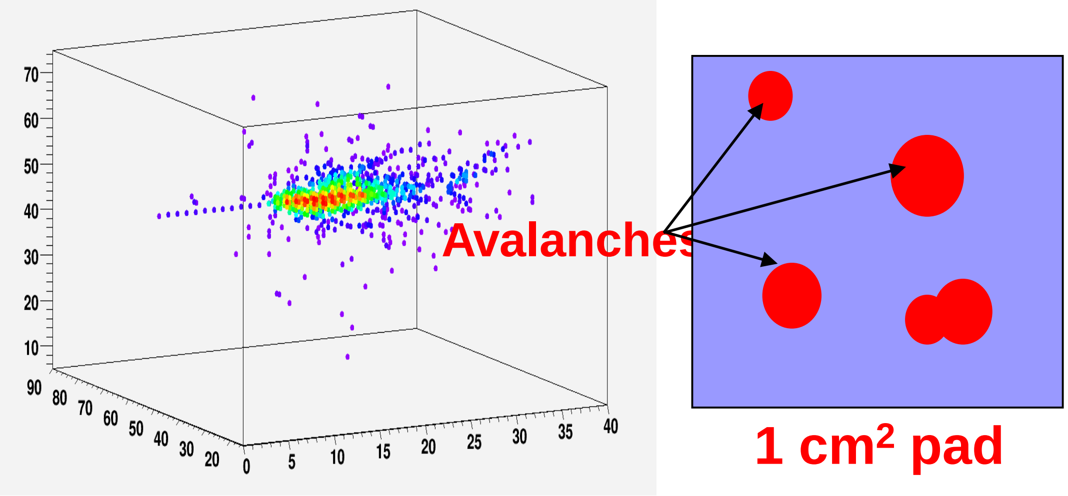
-Embedded readout electronics

-96 DCAL/Unit



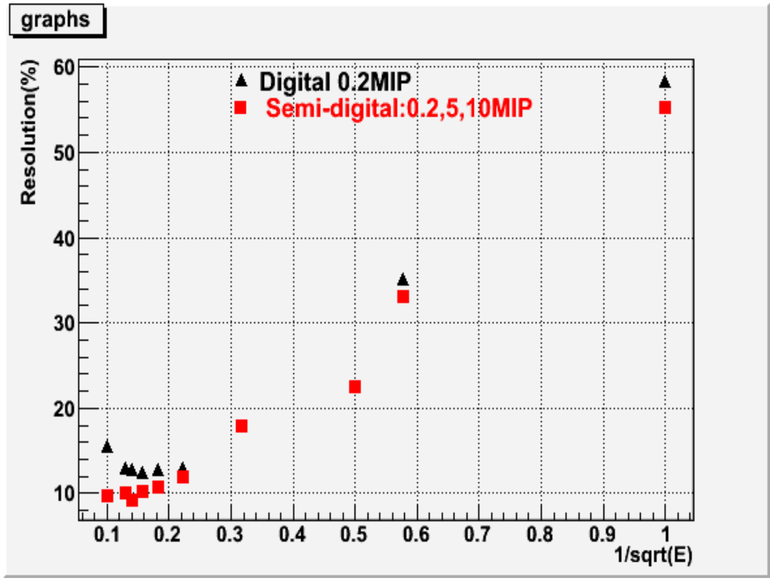
Multi-threshold readout **HARDROC2 ASIC**

A simple binary readout leads to a good energy resolution However, at high energy the Shower core is very dense and saturation shows up



2-bit readout allows to account for one, few and too many particles crossing one cell

It therefore improves on energy resolution at energies> 30 GeV

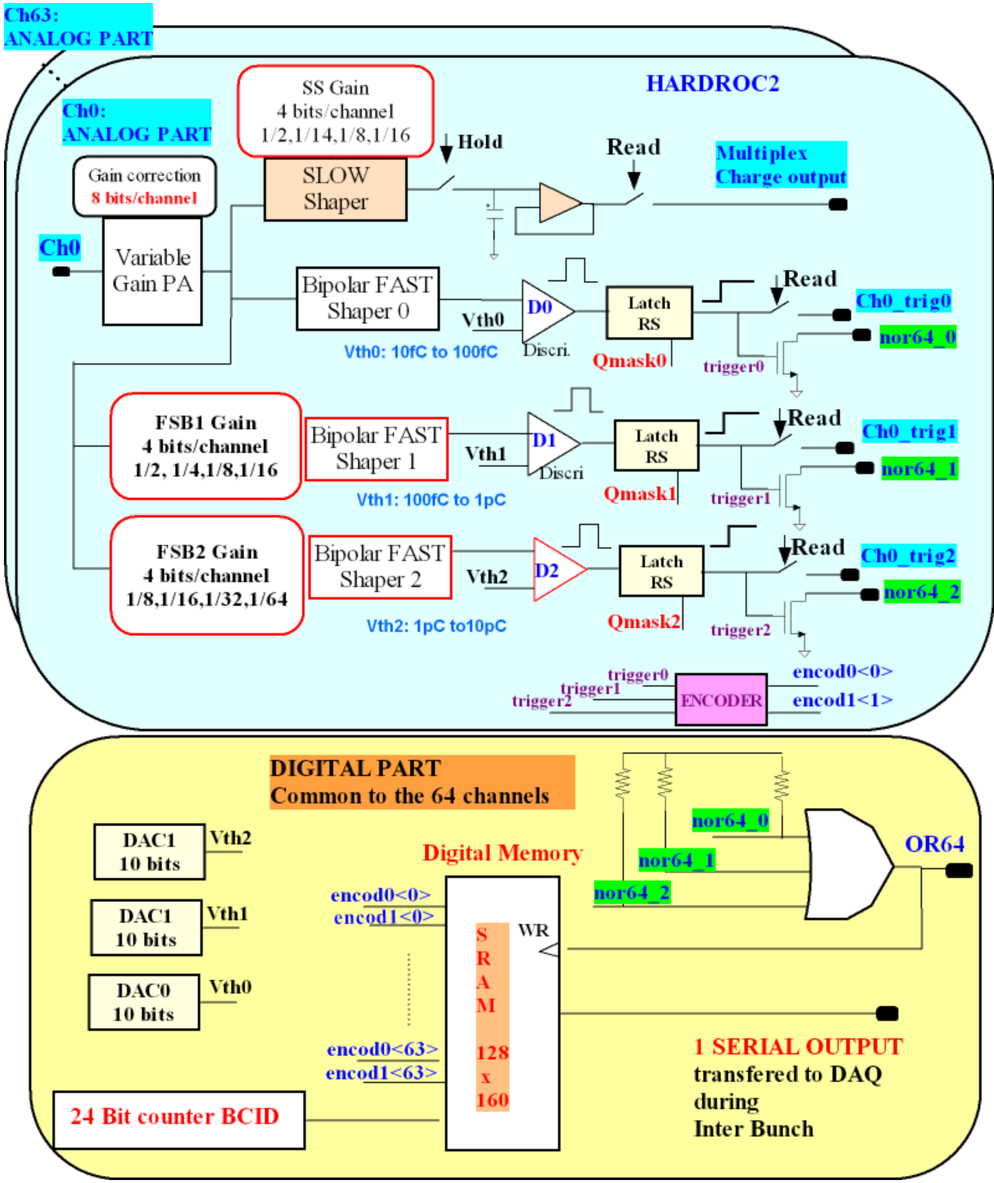


HARDROC2 ASIC

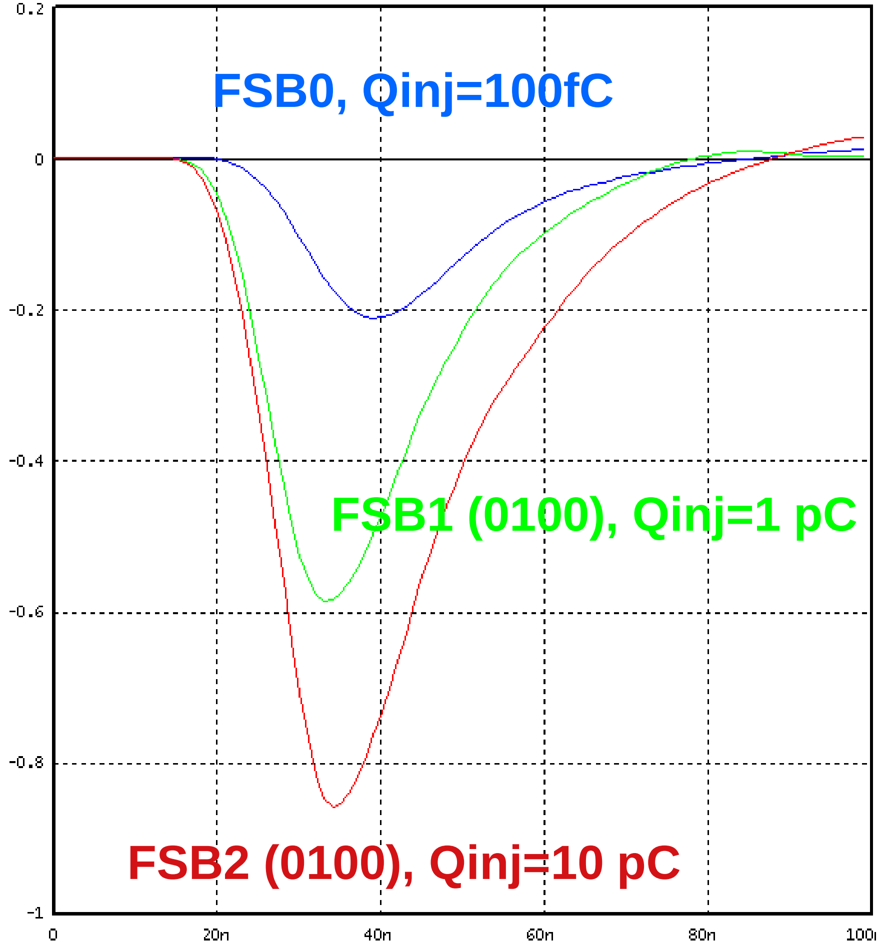
Developed by OMEGA&IP2I for the SDHCAL-RPC concept

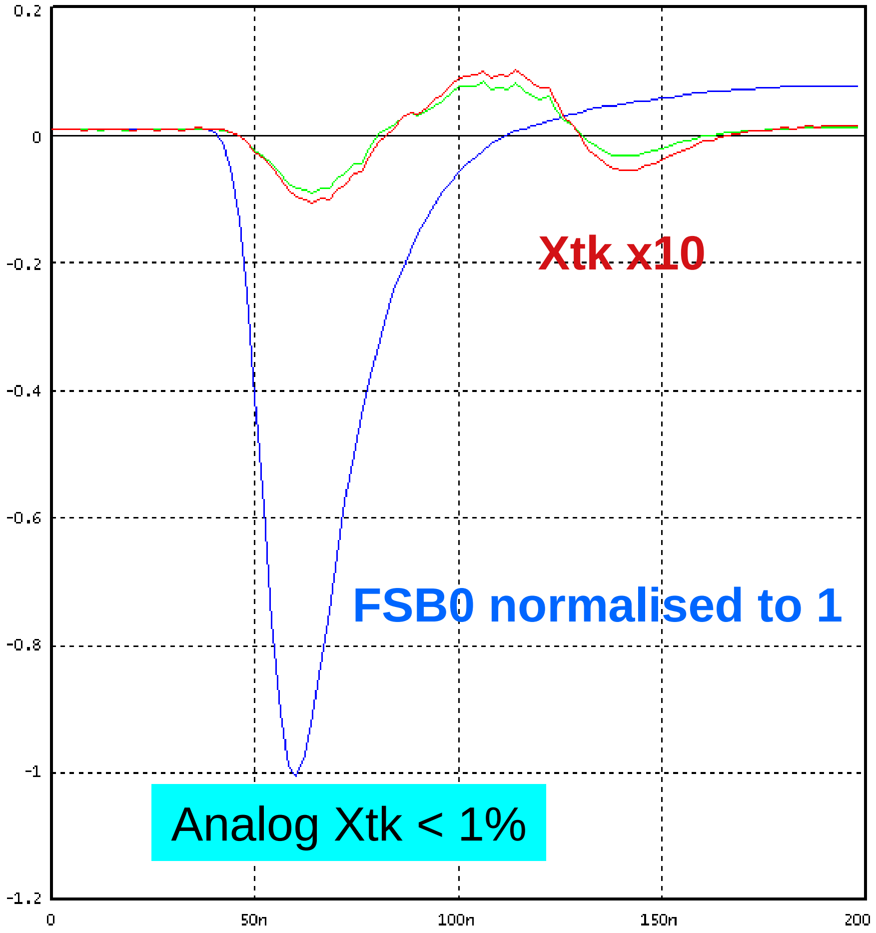
64-Channel

- **Dynamic range**
  - ☐ Gain correct.: **8 bits**
    G=0 to 255 (analog G=0 to 2)
  - ☐ **3 shapers, different Rf,Cf and gains**:
    - Fsb1, G= ½,**1/4**,1/8,1/16
    - Fsb2, G= 1/8,**1/16**,1/32,1/64
  - ☐ **3 thresholds** (=> 3 DACs):
    - 100fC, 1pC, 10pC (GRPC)
- 128 memory depth
- Mask
- **872 SC registers**, default config
- **Power pulsing:**
  - ☐ Bandgap +ref Voltages + master I: power pulsed
  - ☐ POD module (power budget)



Waveforms and Xtk



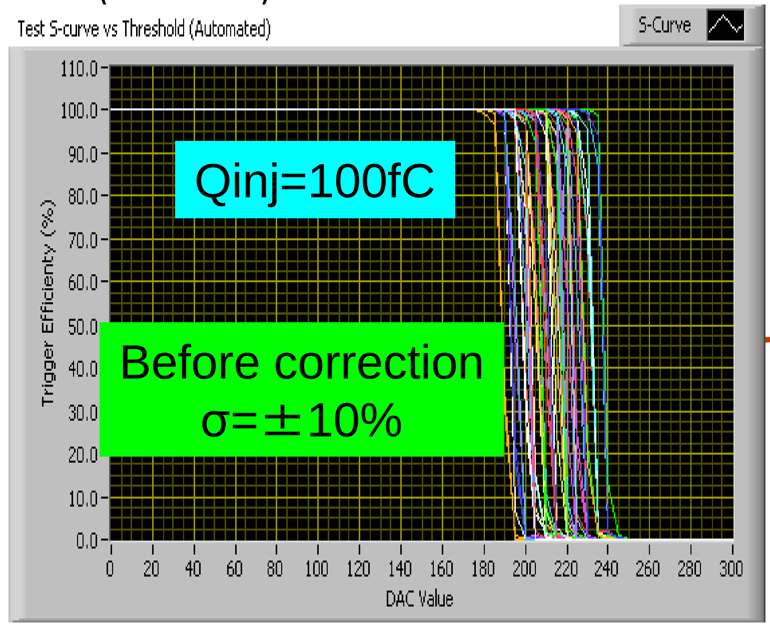


Analog Xtk < 1%

Testboard wo any decoupling cap.

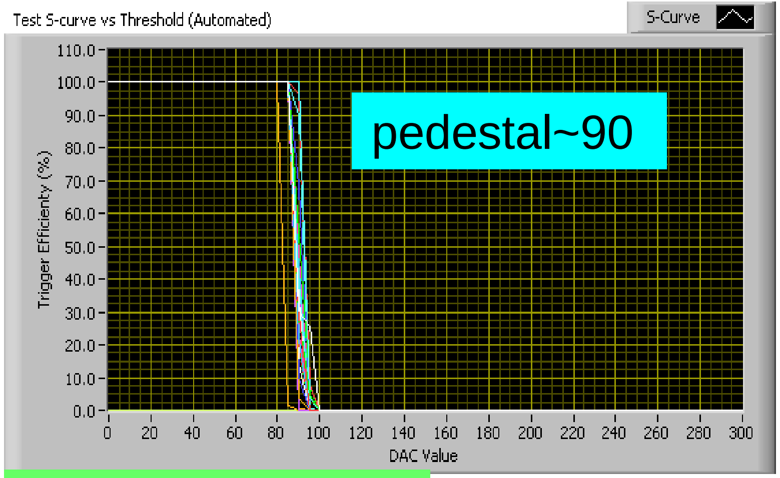
Trigger efficiency measurements

- Scurves performed on FSB0 by varying the DAC value (Threshold)



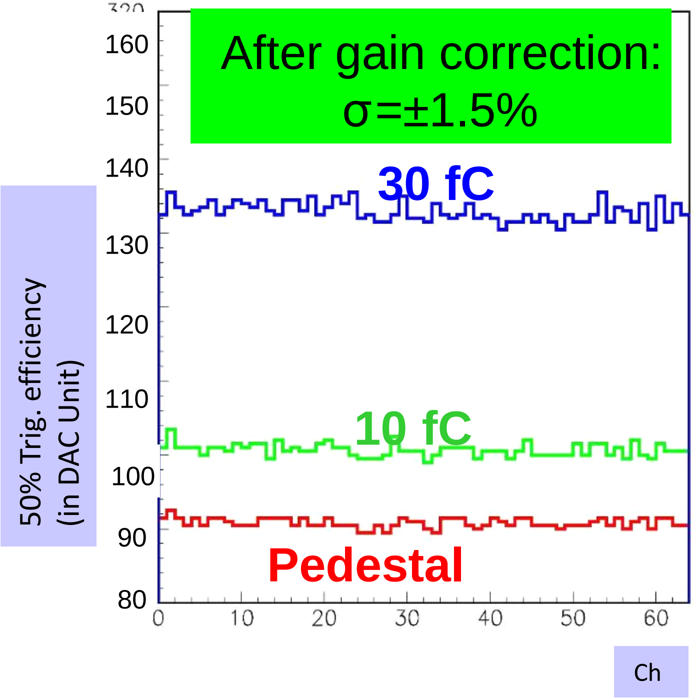
Qinj=100fC

Before correction
σ=±10%



pedestal~90

FSB0, 100K, 100fF, G=144

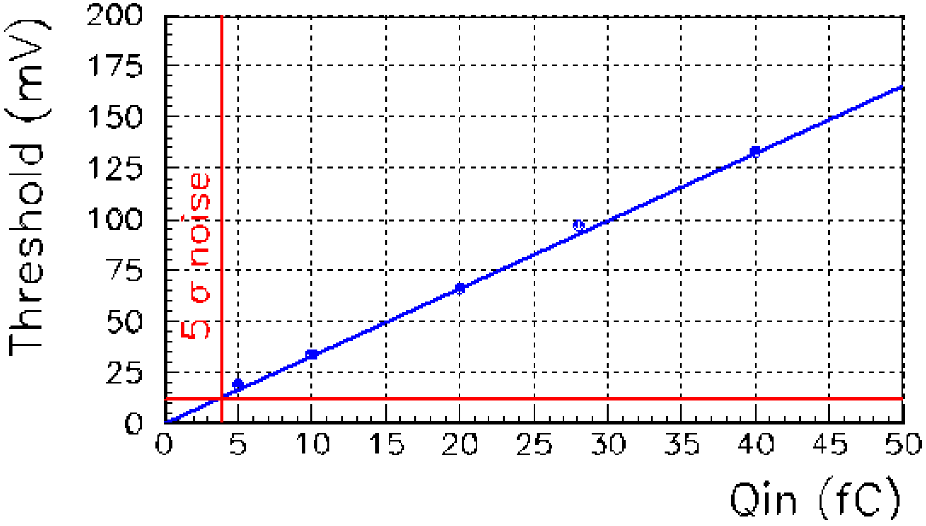


After gain correction:
σ=±1.5%

30 fC

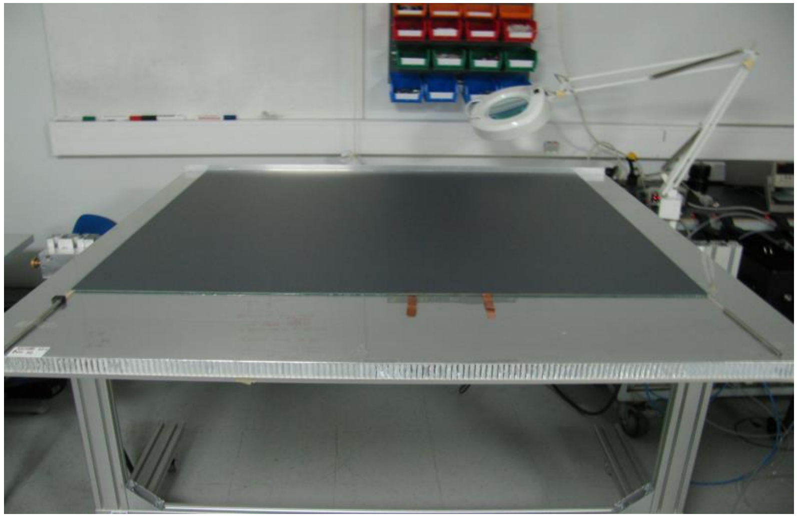
10 fC

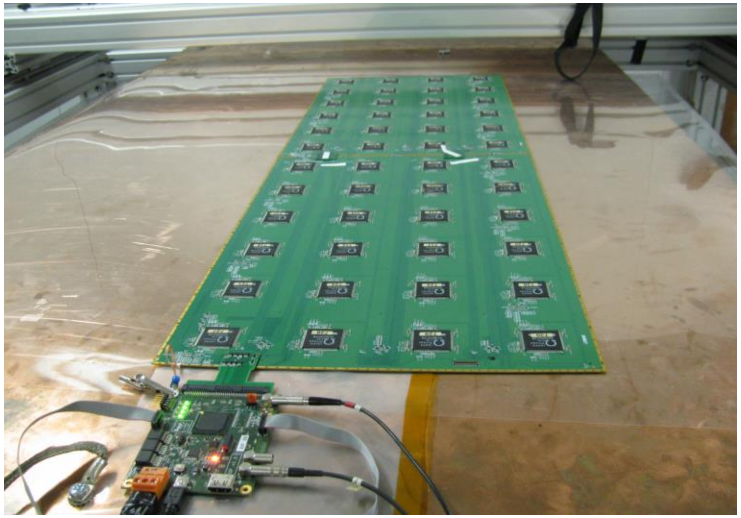
Pedestal

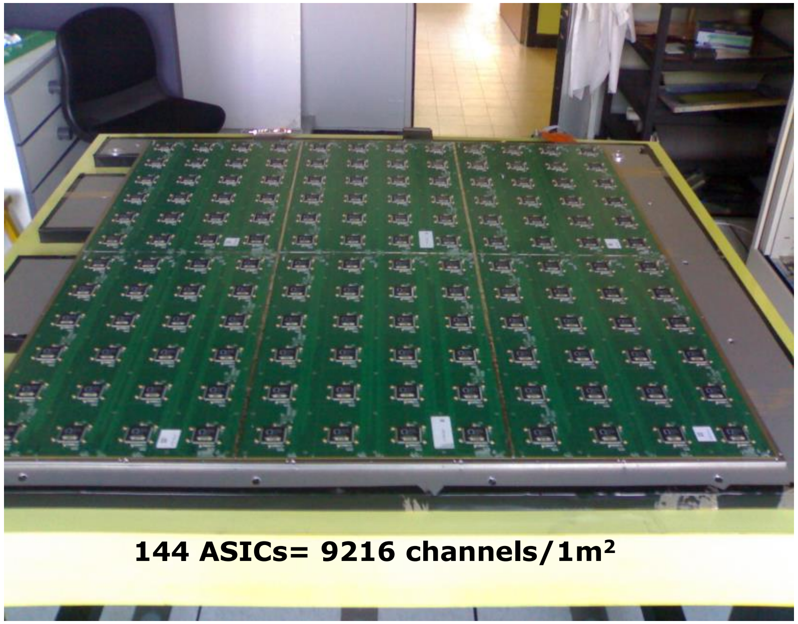


CALICE SDHCAL prototype

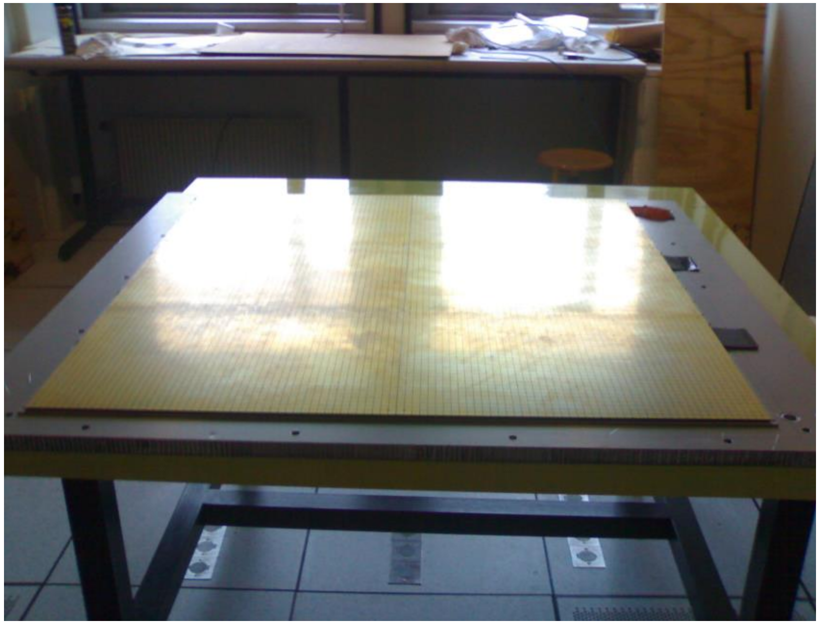
50 layers of 1 m X 1m GRPC with their embedded electronics





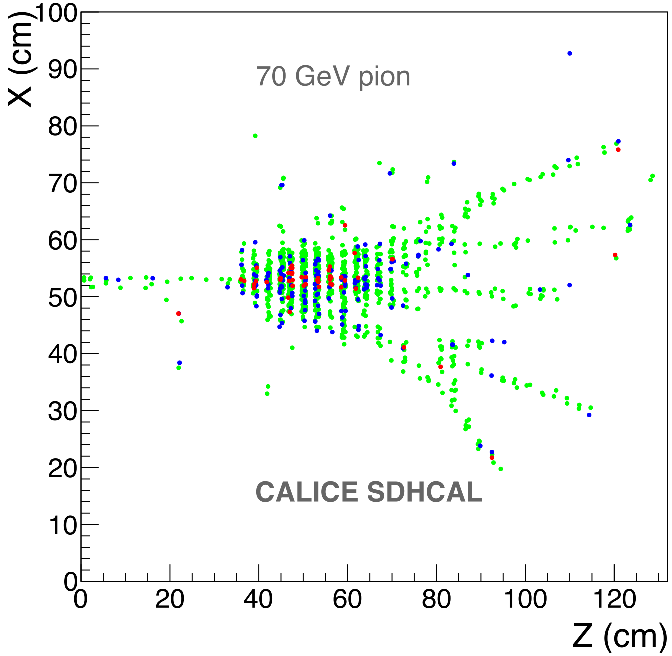


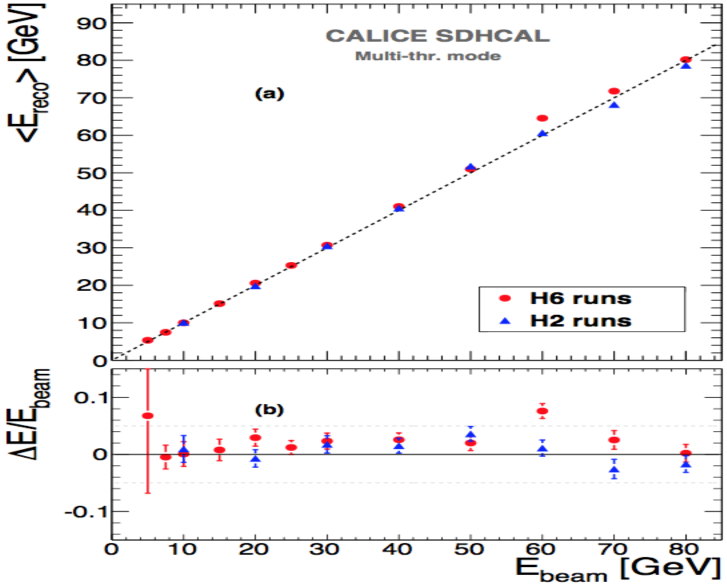
144 ASICs= 9216 channels/1m²



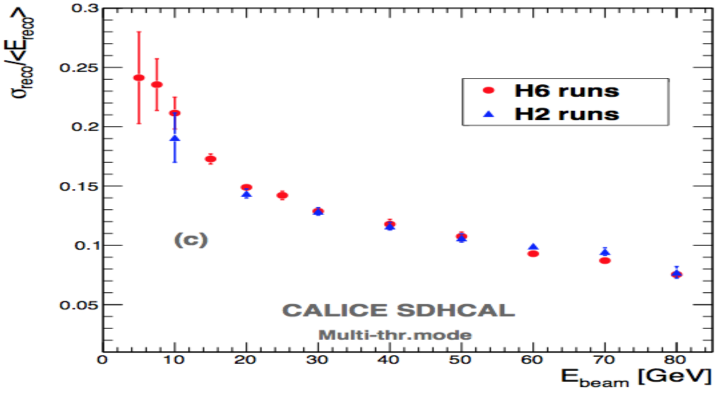
CALICE SDHCAL prototype

Self-supporting absorber





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

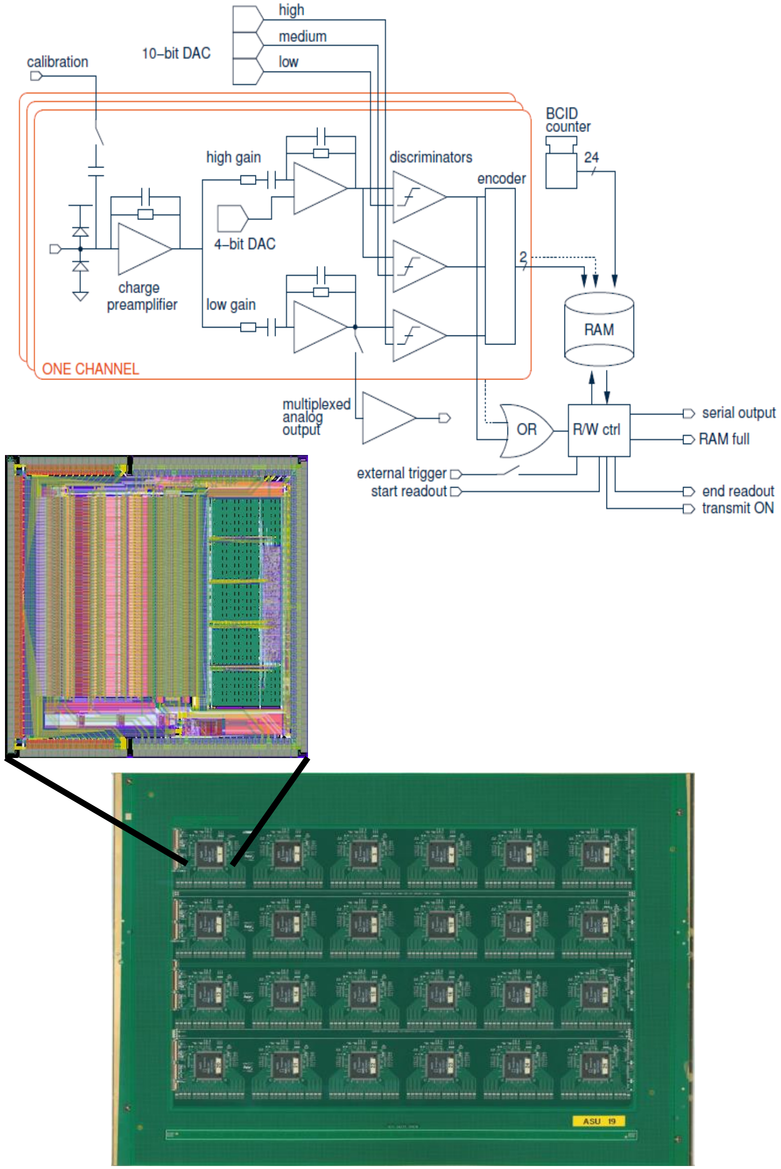


Multi-threshold readout **MICROROC ASIC**

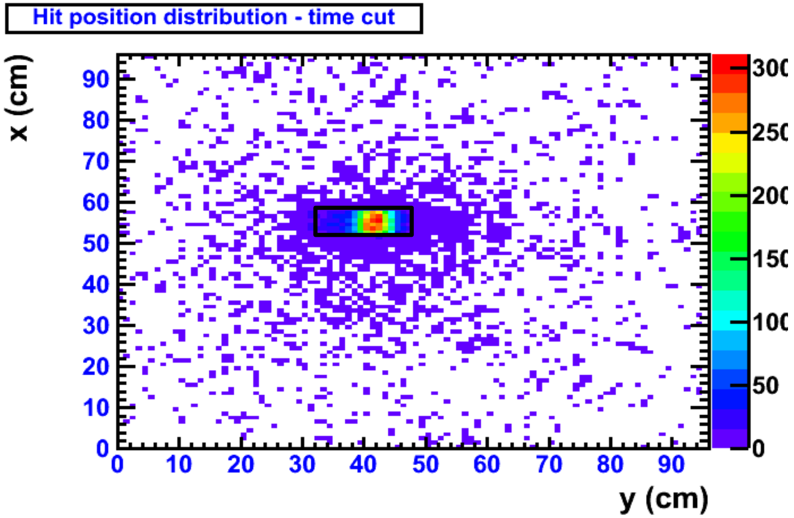
Developed by OMEGA&LAPP for the SDHCAL-MM concept

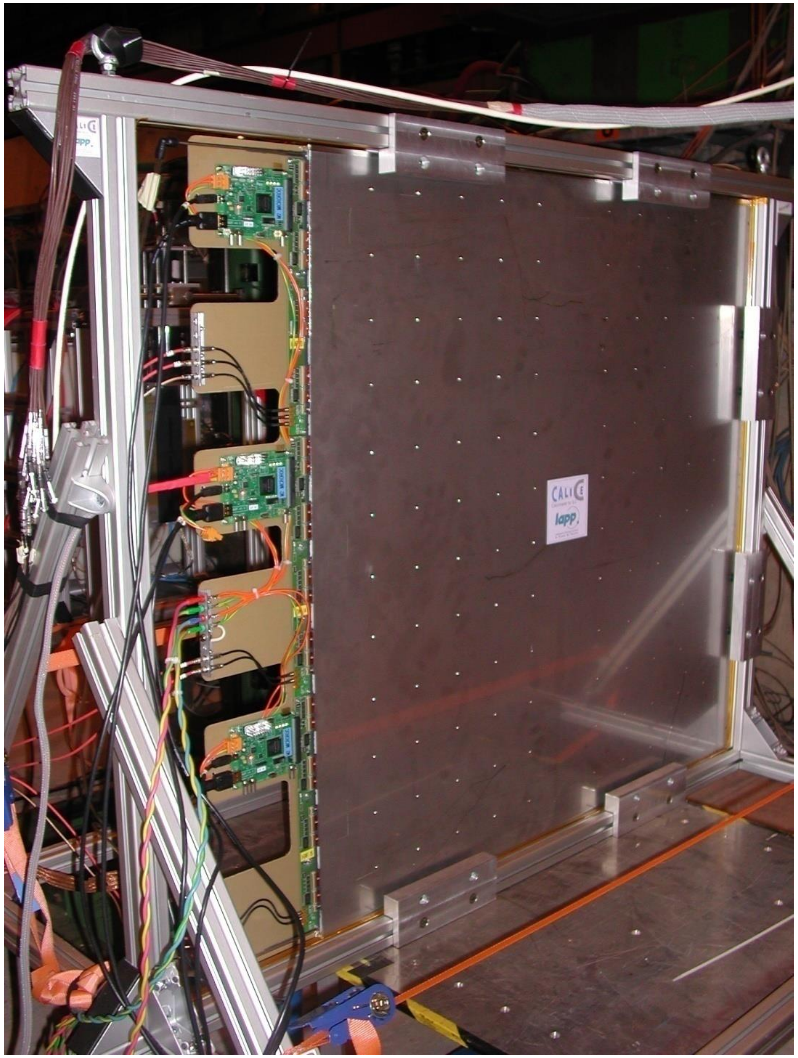
MICROROC is obtained from HARDROC2 to accommodate the characteristics of large size Micromegas detectors:

- Same digital part : pin-to-pin compatibility
- Current preamp replaced by charge preamp
- Individual threshold adjustment
- Additional spark protections inside silicon
- Fast shaper (~20ns) replaced by 2 tunable shapers (30-200 ns)
- 8 bit preamp gain corrections replaced by 4-bits pedestal corrections

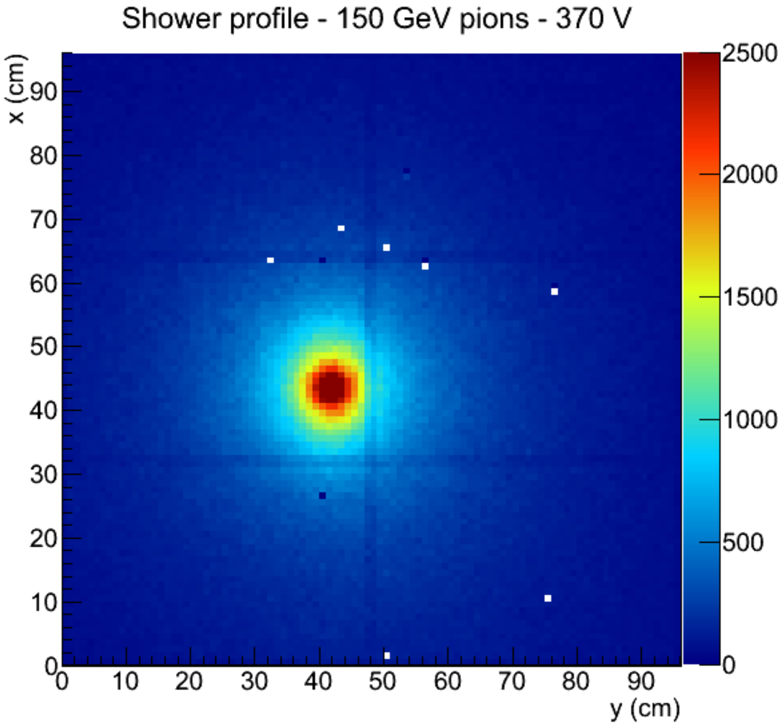


4 units of SDHCAL-MM
1m x 1m each were produced, tested in a muon beam





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

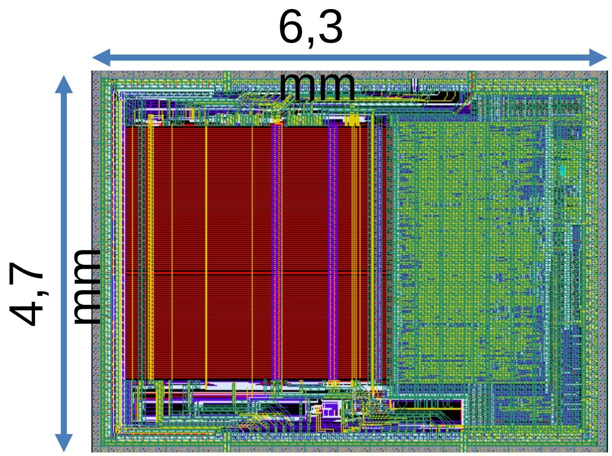


Additional development with Resistive Micromegas has started to render the SDHCAL-Micromegas more robust against discharges that may happen in the core of the shower.

Similar activities with Thick GEM replacing MM were also initiated.

Ongoing activities

HARDROC3

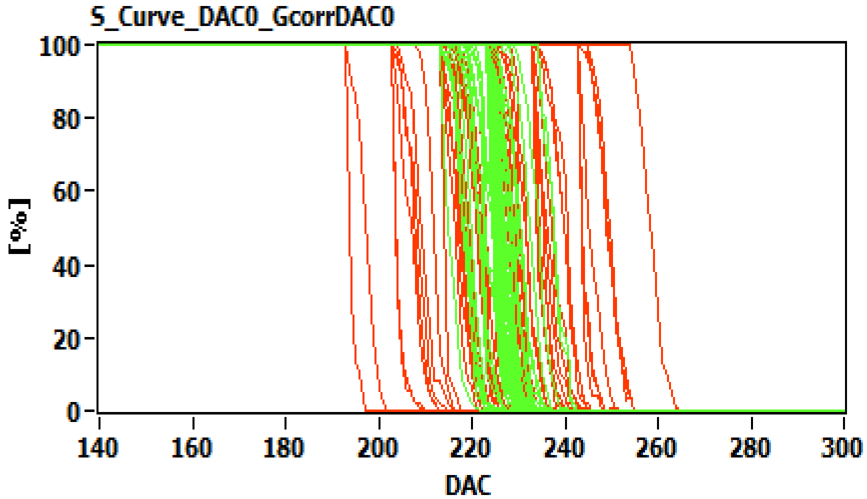


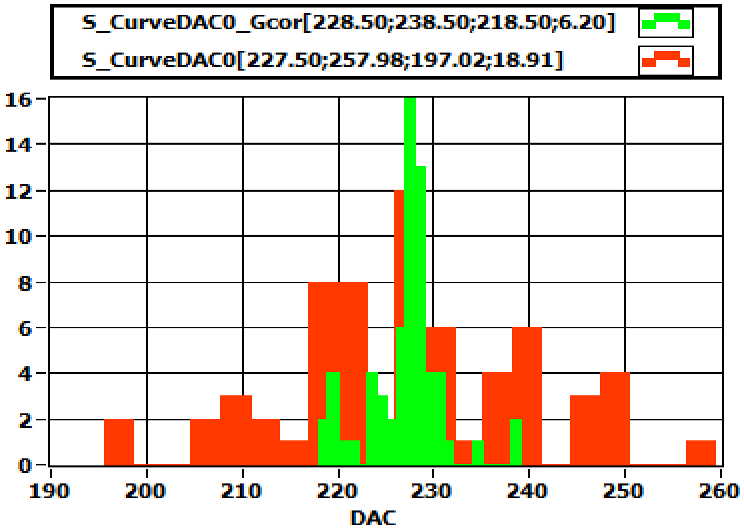
This is the third generation of HARDROC ASIC

HARDROCR3 main features:

- Independent channels
- Zero suppress
- Extended dynamic range (up to 50 pC) to improve on energy construction
- I2C link with triple voting for slow control parameters
- packaging in QFP208, die size ~30 mm^2
- Consumption iis ncreased with respect to HR2 (internal PLL, I2C)

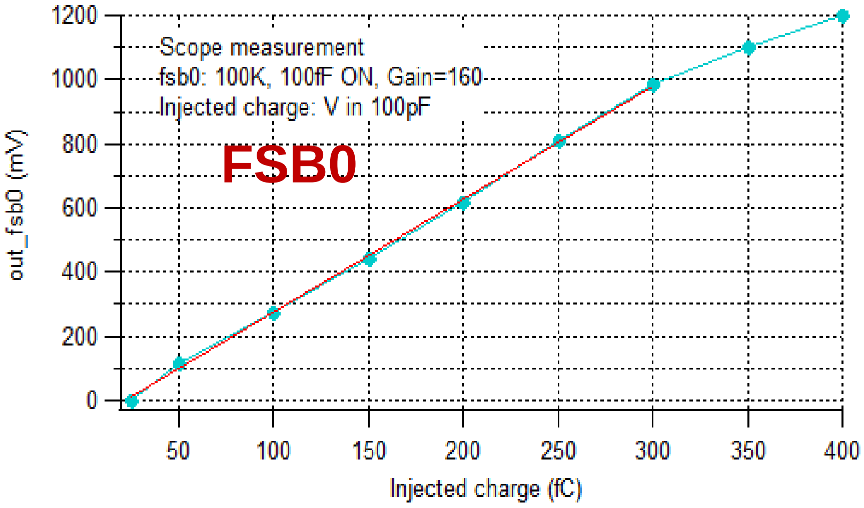
H3B TESTED : 786, Yield : 83.3 %

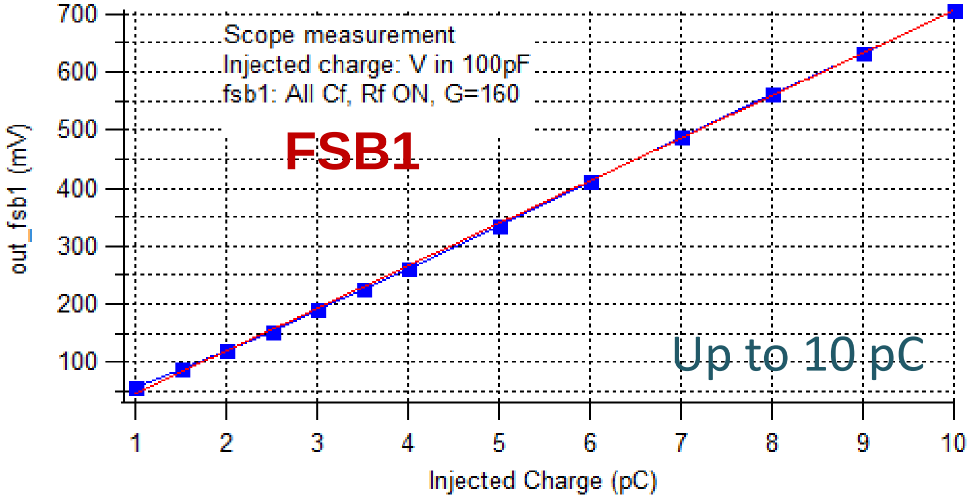


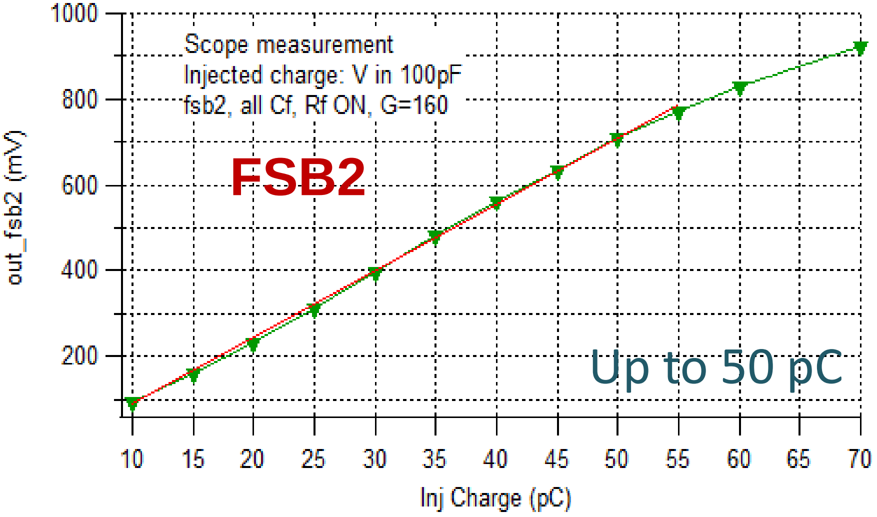


HARDROC3: Analog linearity

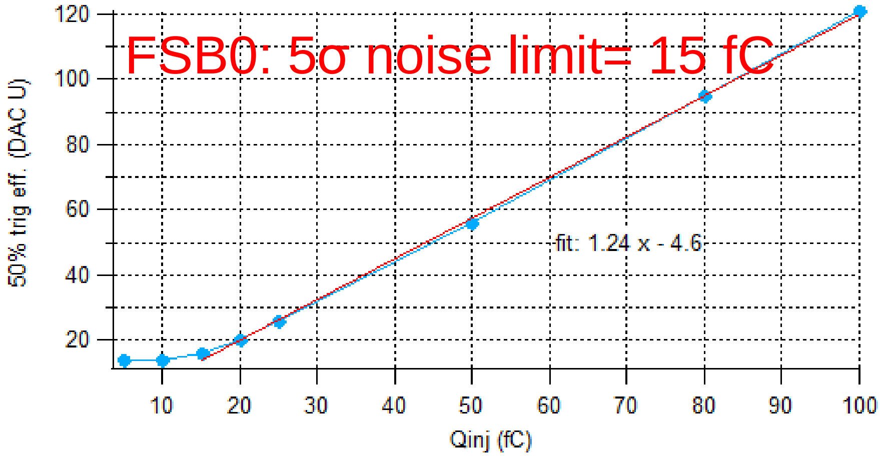
Fast shaper outputs (mV) vs Qinj (fC)







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

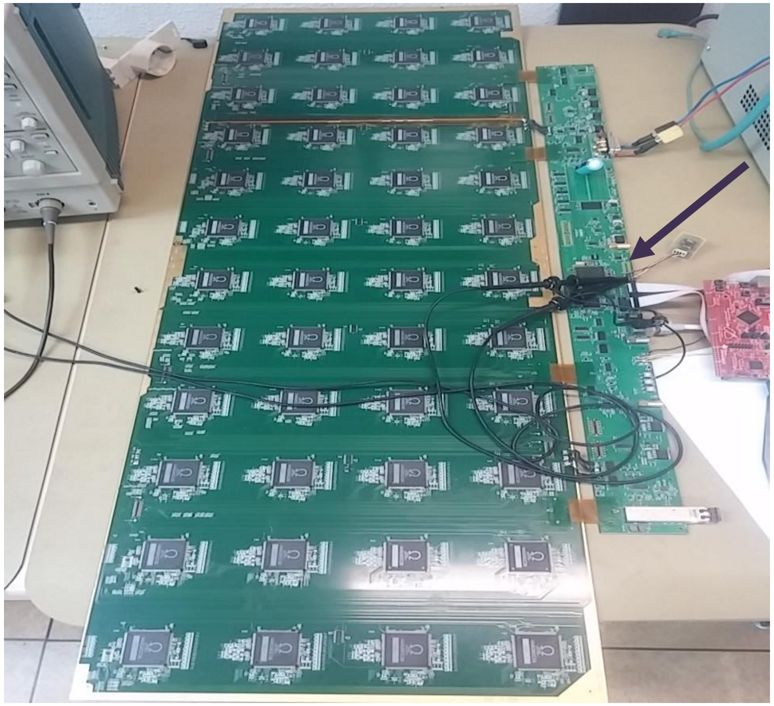


Dynamic range: 15fC - 50 pC

A word on ASUs (Active Sensor Unit)

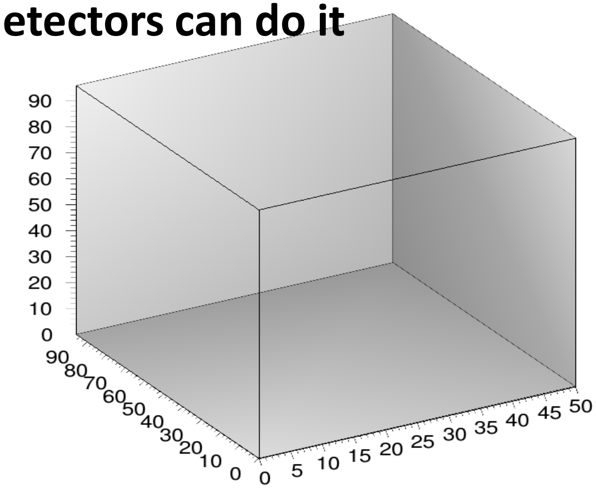
One important challenge is to build a PCB up to 1m length with good planarity to have a homogeneous contact of pads with RPCs in order to guarantee a uniform response along all the detector.

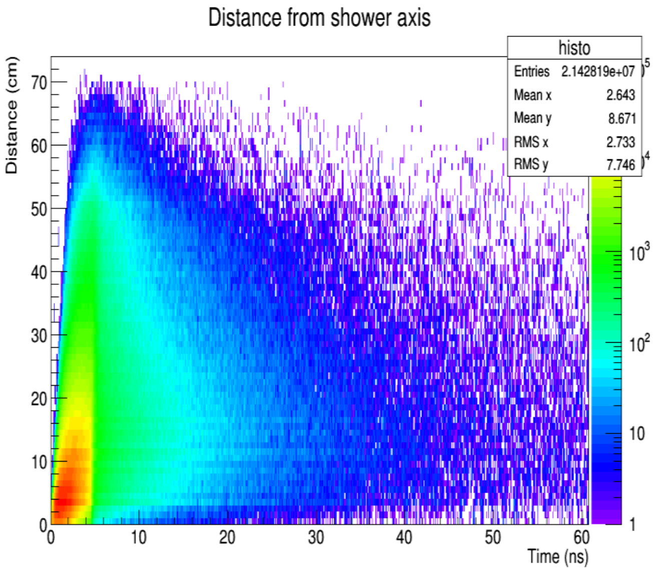
1x0.33 m2 ASUs have been built.

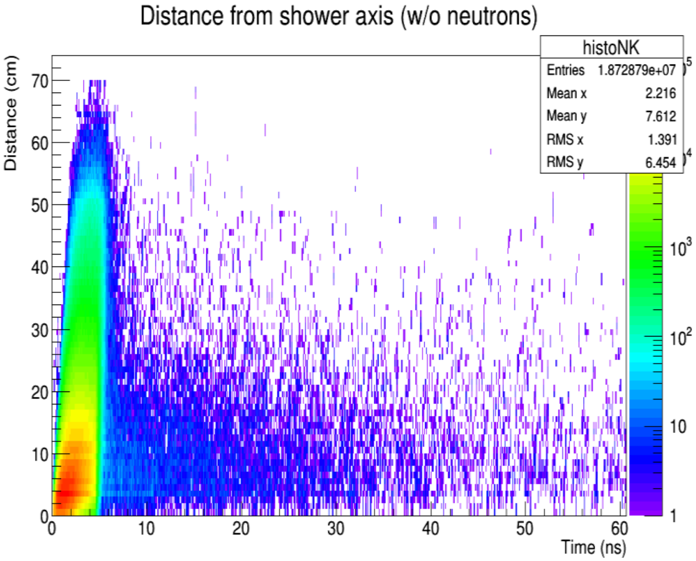


5D calorimeter concept

Timing could be an important factor to identify delayed neutrons and to **better reconstruct their energy** → **Gaseous detectors can do it**

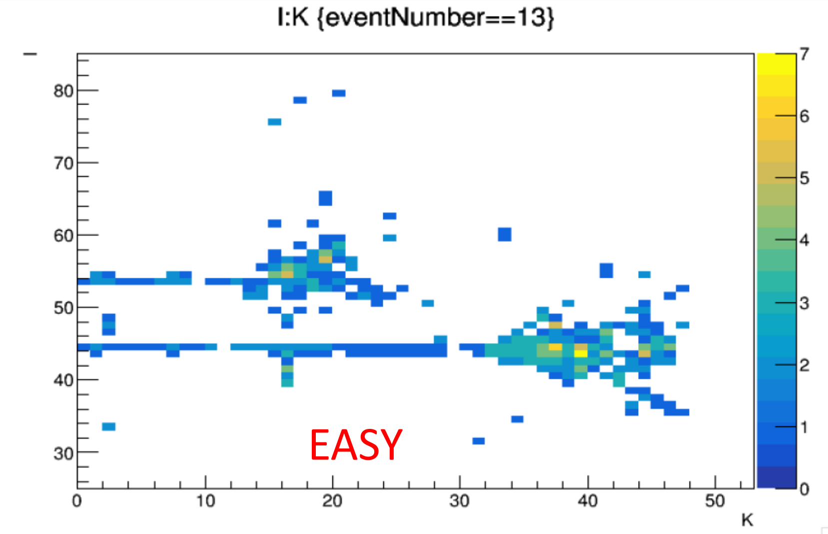






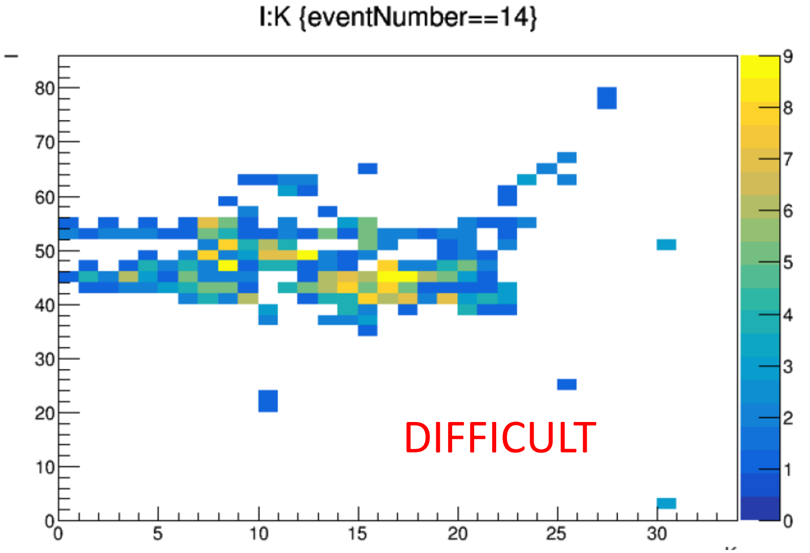
Timing

Time information 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.



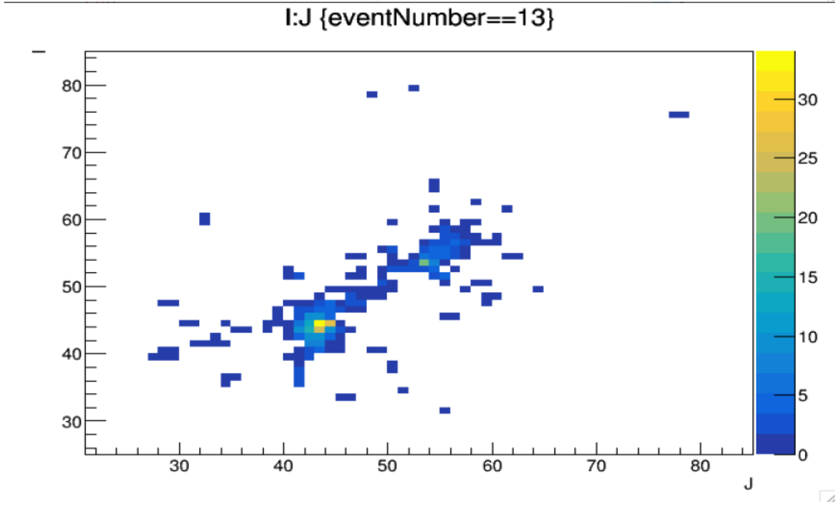
I:K {eventNumber==13}

EASY

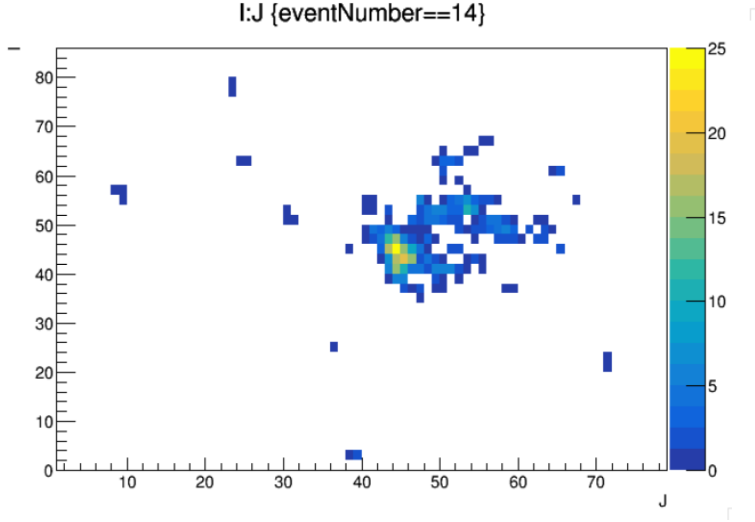


I:K {eventNumber==14}

DIFFICULT

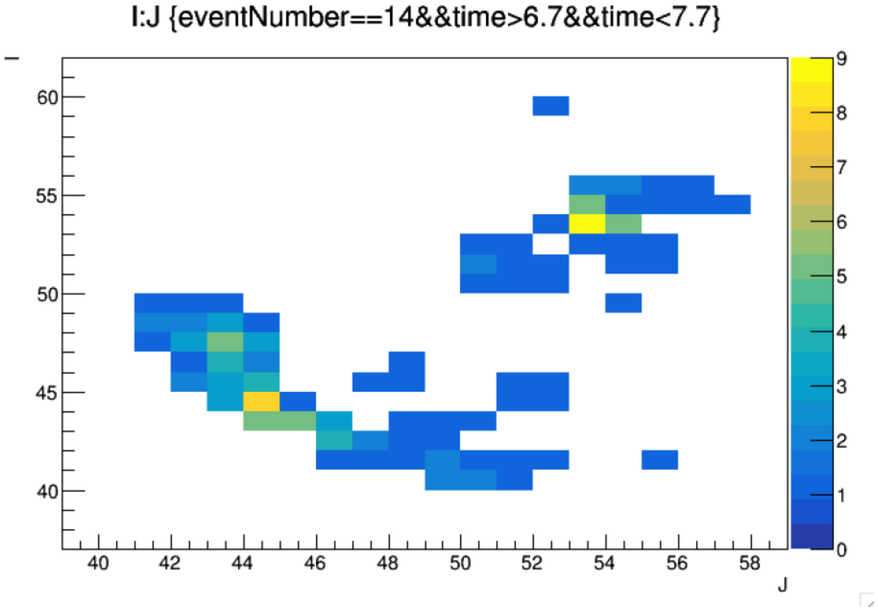


I:J {eventNumber==13}

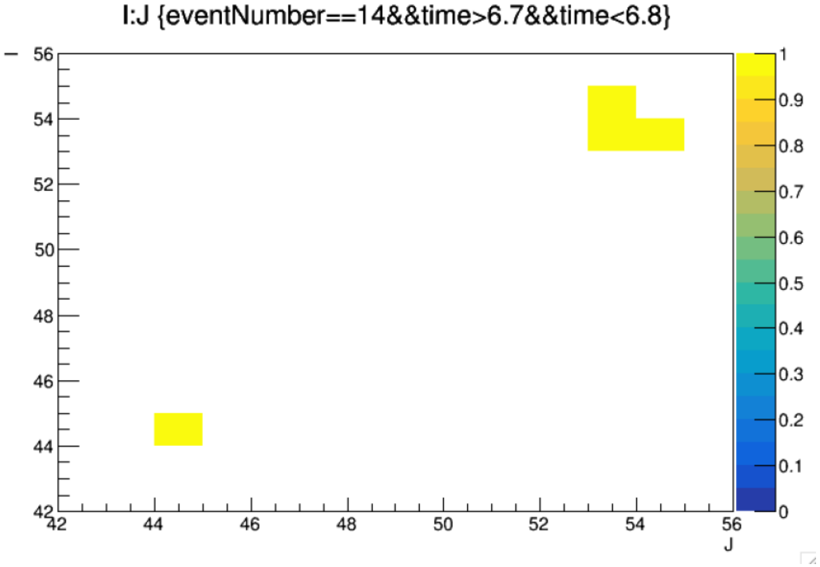


I:J {eventNumber==14}

If we have 1 ns resolution


I:J {eventNumber==14&&time>6.7&&time<7.7}

If we have 100 ps resolution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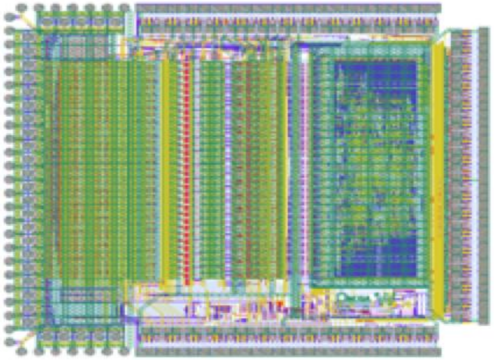
Timing ASIC: PETIROC



Developed by OMEGA&WEEROC

How to achieve an excellent time resolution:

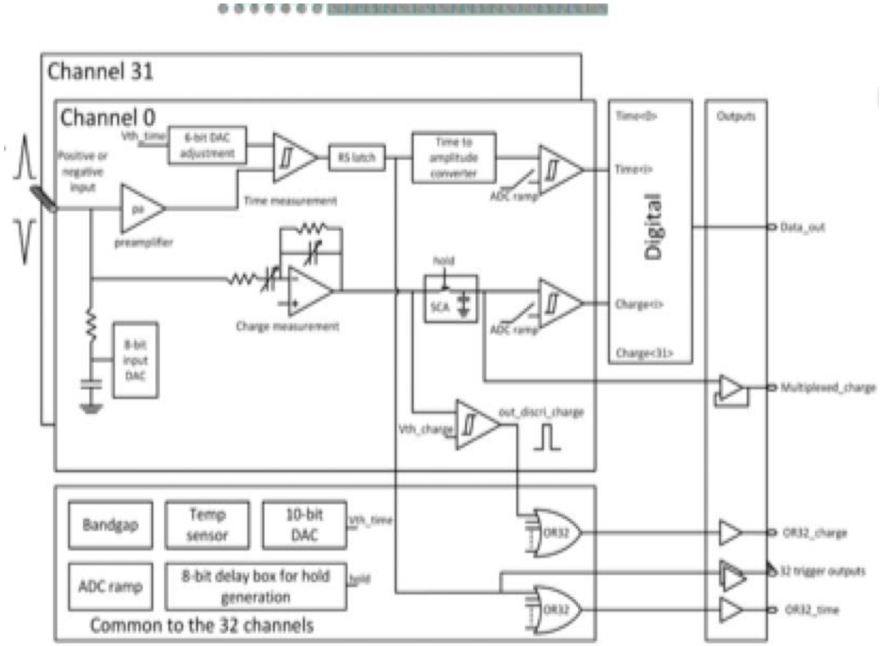
☐ Adequate detector **MRPC**

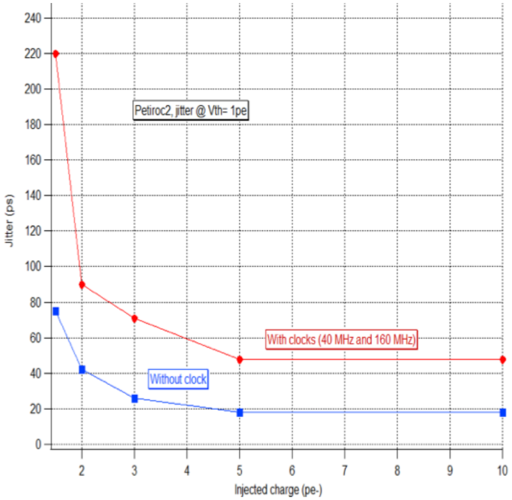
☐ An ASIC with a fast preamplifier, precise discriminator and excellent TDC

→**PETIROC2, 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

→ TDC either internal (100 ps) or
external using either an FPGA or a chip (< 10 ps)
(delay-line, Vernier,..etc)

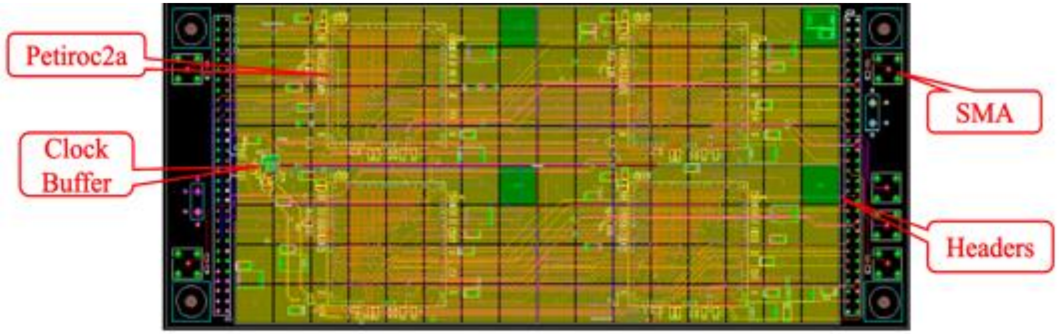


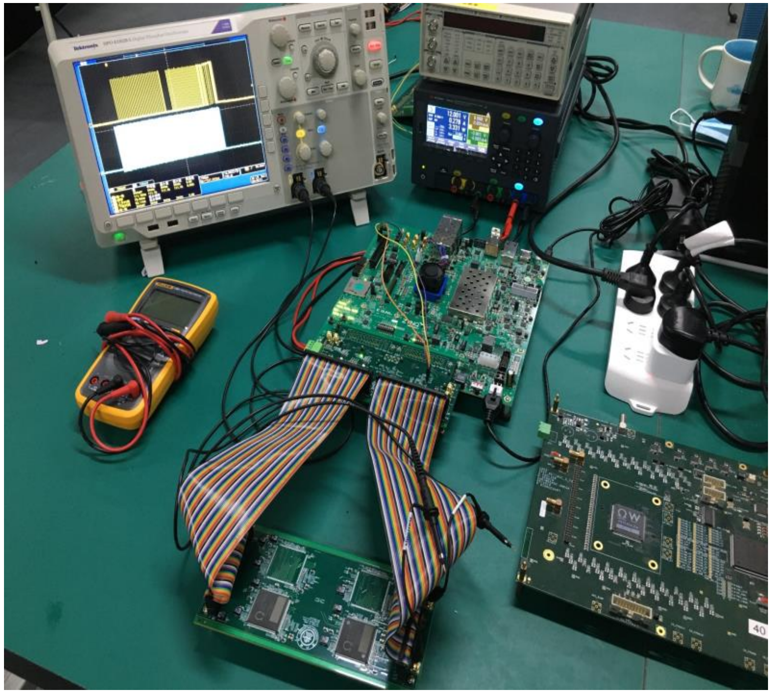


PETIROC

To check the possibility of reaching 100 ps time resolution, a new electronics development in collaboration between IP2I, OMEGA and SJTU groups have been initiated. This is a common ILC-CEPC R&D. We are exploiting the expertise we have been accumulating from the CMS iRPC update project where PETIROC to readout 2-gap RPC is used.

The collaboration is being extended and will be supported by AIDAnova.





Conclusion

- Gaseous detectors are excellent candidates for EM and HCAL
- They offer excellent granularity and quite very good energy performance
- Many successful readout electronics have been developed but some should be updated in finer technologies (130, 65 nm)
- Excellent results are obtained and will be certainly improved in he coming years with hopefully more efforts to use MPGD such Thick GEM and Resistive Micromegas to be dedicated to build new prototypes