MPGD TPC Electronics

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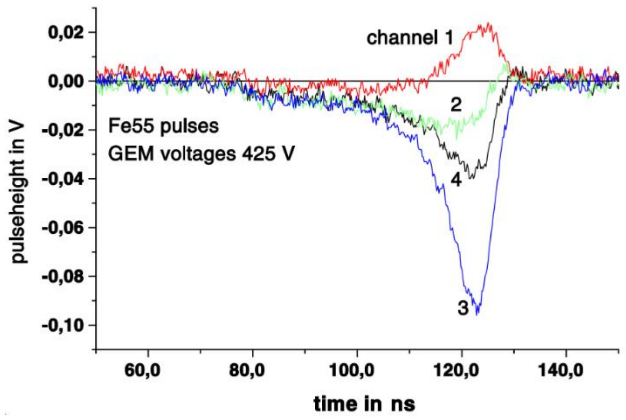
Is it possible to define a range of parameters for a readout chip satisfying the requirements of a majority of applications?

Acknowledgement :
Material from Luciano Musa's lecture at CCAS, Beijing, 2008 and talk from Hans Muller, CERN at European Strategy Detector R&D Roadmap symposium, 2021.

Signal formation in a TPC

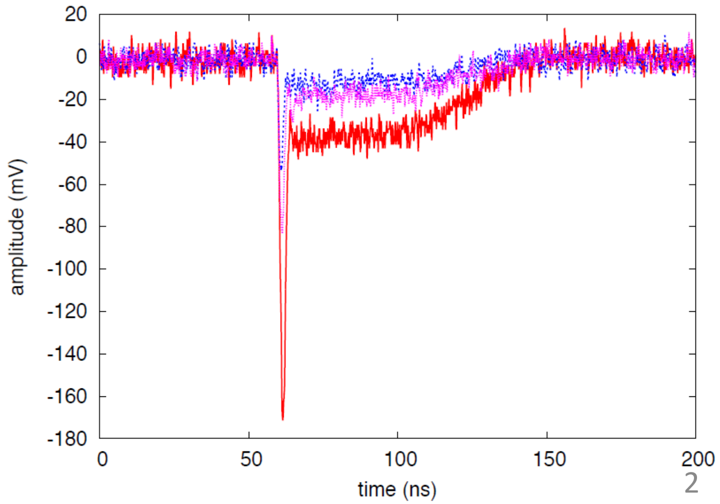
- A single particle (typicall 100s of MeV or TeV) passing though a gas frees electrons, loosing 1 or 2 keV per cm (non-destructive measurement)
- The freed electrons (single or in small clusters) are driven by an electric field over O(m) distances to a detecting endplate, where an avalanche is produced to amplify them and give rise to a signal with 2 components : one from the electrons and the other from the ions.
- Depending on the type of amplification, the base signal shapes differ

Wire chamber : 1/t tails

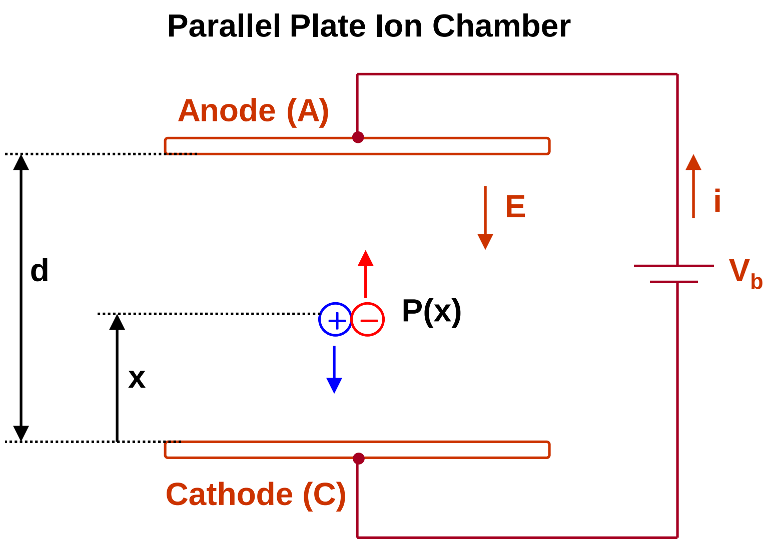


Multi-GEM

Micromegas



Signal induced by a moving charge



$$Q_{A,el} = -q \frac{x}{d}$$

$$Q_{A,ion} = q \frac{x}{d}$$

A constant induced current flows in the external circuit

$$i = \frac{dQ_{A,el}}{dt} = -\frac{q}{d}\frac{dx}{dt}$$

A static charge is not measurable (only way : electrometer)
So particle detectors must use currents induced by moving charges
(possibly integrated through a capacitor to measure charges)
(see Flavio Loddo's lecture)

Signals vary with application

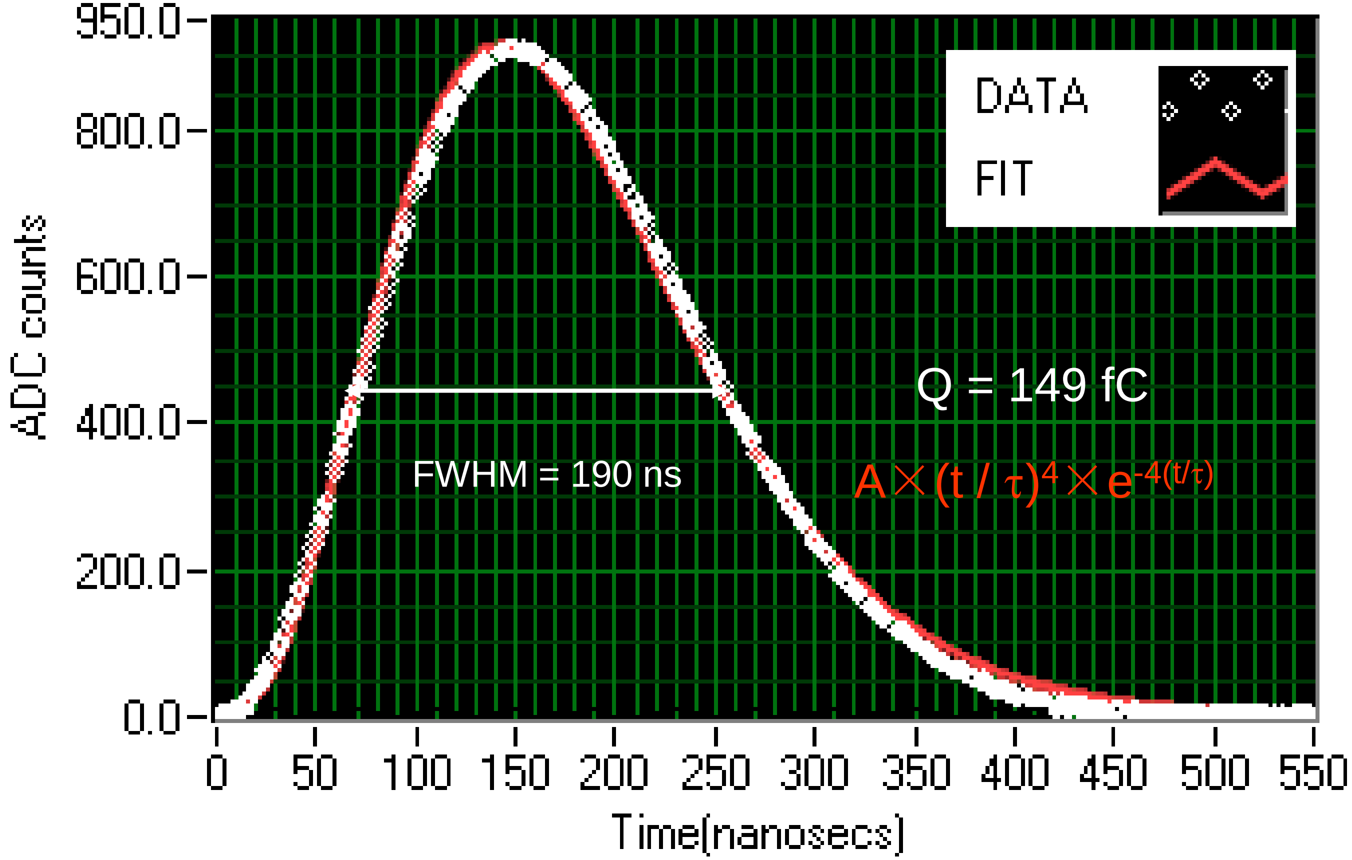
- HEP usually needs to detect MIPs
- In Nuclear Physics slow hadrons and High Z nuclei produce order of several 100s or 1000s times MIPs. Also alpha emitters are usually in the several MeV range.
- In the study of low-energy events (dark matter, action) nuclear recoil energies of few 100 eV are searched for.

Shaping

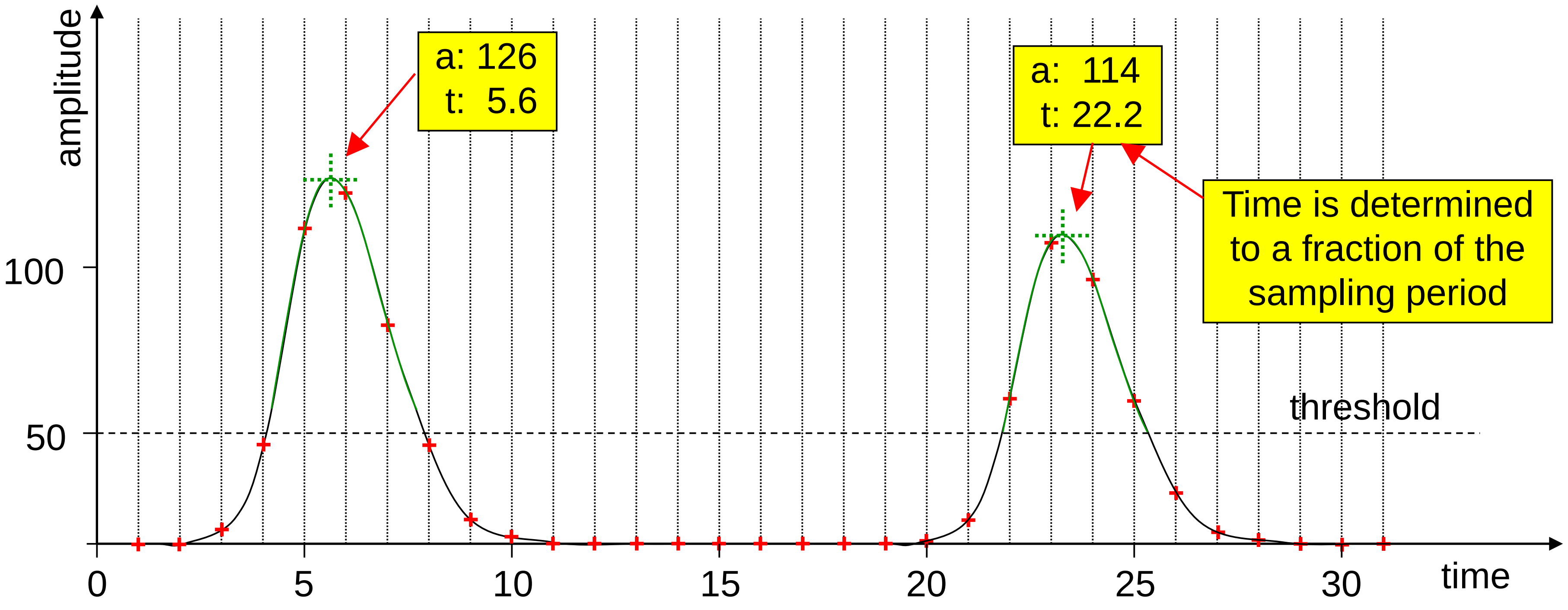
- The natural signal shape is the result of a superposition of 100s of single primary electrons, arriving at different times on a pad, due to diffusion, and then undergoing an avalanche (gains of 1 or a few 1000).
- To relate the pulse height to the total deposited charge, the signal are **shaped**, so that they have all the same duration and shape.
- The signal is usually concentrated in a high frequency region : it can be enhanced and noise suppressed by **filtering** out lower frequencies.

Impulse Response Function

PASA amplifier-shaper



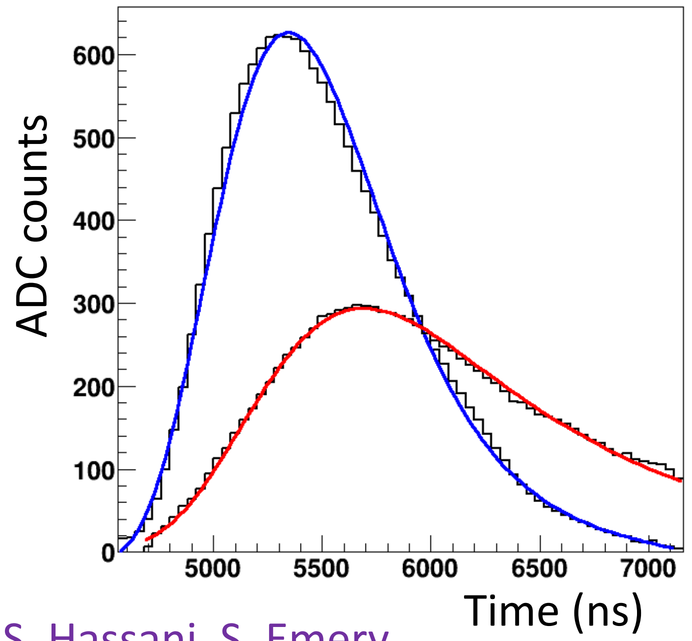
Sampling ADC on each detector channel running at appropriate frequency



Case of a resistive-capacitive anode

- Resistive anodes are used to protect the detector and the electronics by quenching the sparks.
- A resistive anode will deform (delay) the signal while spreading it on neighboring channels.
- The **sampling** capability of a TPC electronics allows the **waveforms** to be recorded and analyzed to improve the position measurement.
- The shaping time must be matched to the duration of the signals. Shaping too short makes you loose the signal. Shaping too large degrades the time measurement.

T2K, AFTER electronics

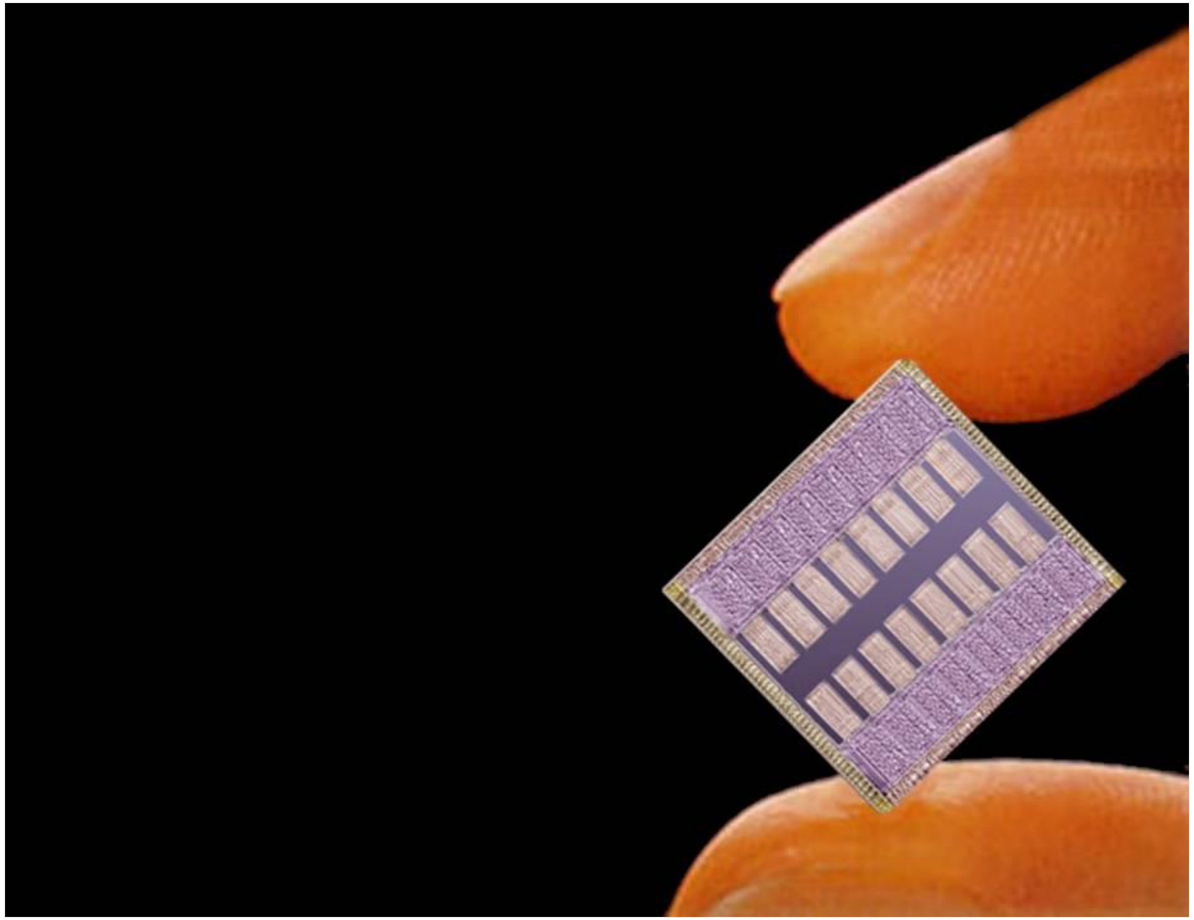


S. Hassani, S. Emery

Brief History : from discrete electronics to chips

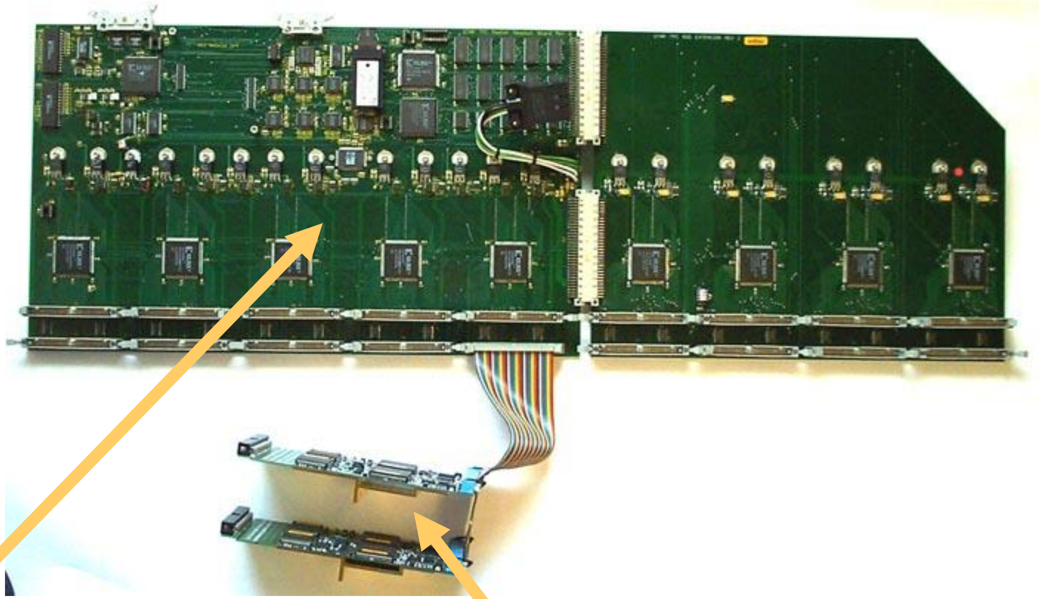
ALEPH and DELPHI TPC's at LEP in the 1980's had a discrete electronics. Preamplifiers were single channel integrated circuits. O(20,000) of these allowed to readout the pads.

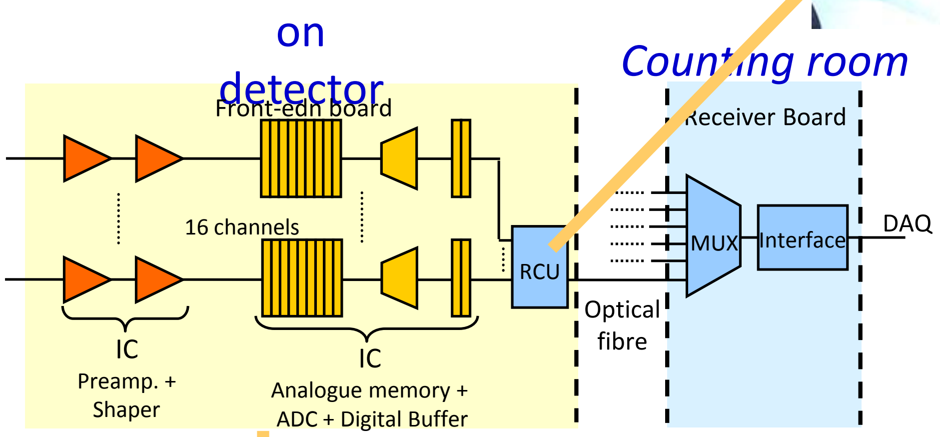
At the end of the 1990's a breakthrough occurred when STAR at RHIC introduced Front-end cards carrying several multi-channel chips.

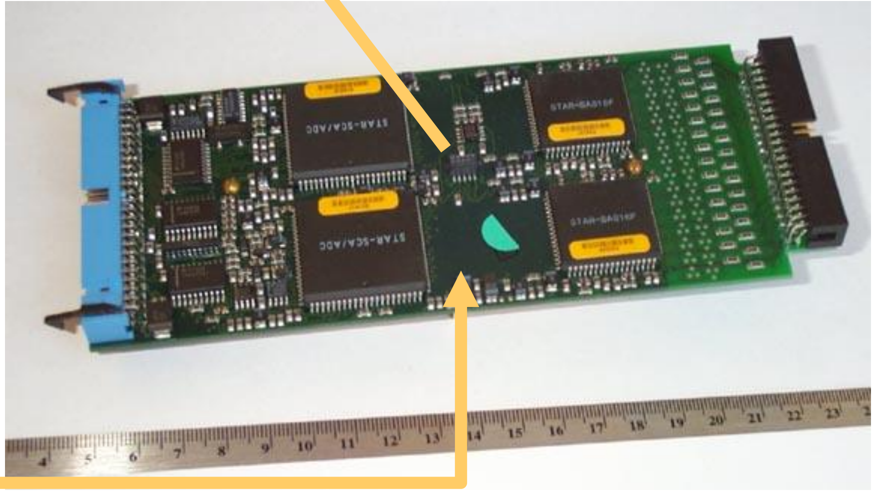


L. Musa, Lecture in CAS TPC school, Beijing, 2008

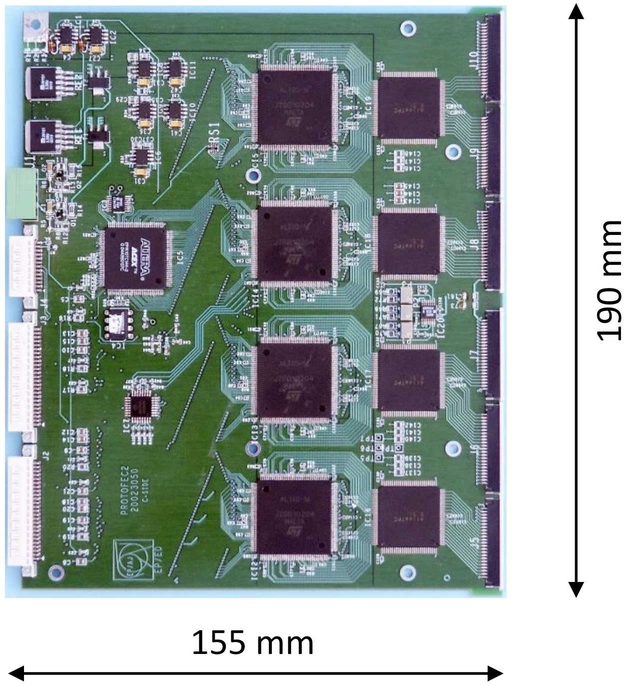
- STAR TPC (RHIC) Front-end cards
  - 47 m3, 136608 channels
  - Negative polarity
  - Front-end unit → 32 channels (17.5 cm x 7.5 cm)
  - Analogue Memory + low sampling rate ADC
  - Similar to the FEE for the TPC of the NA49 Experiment (CERN)

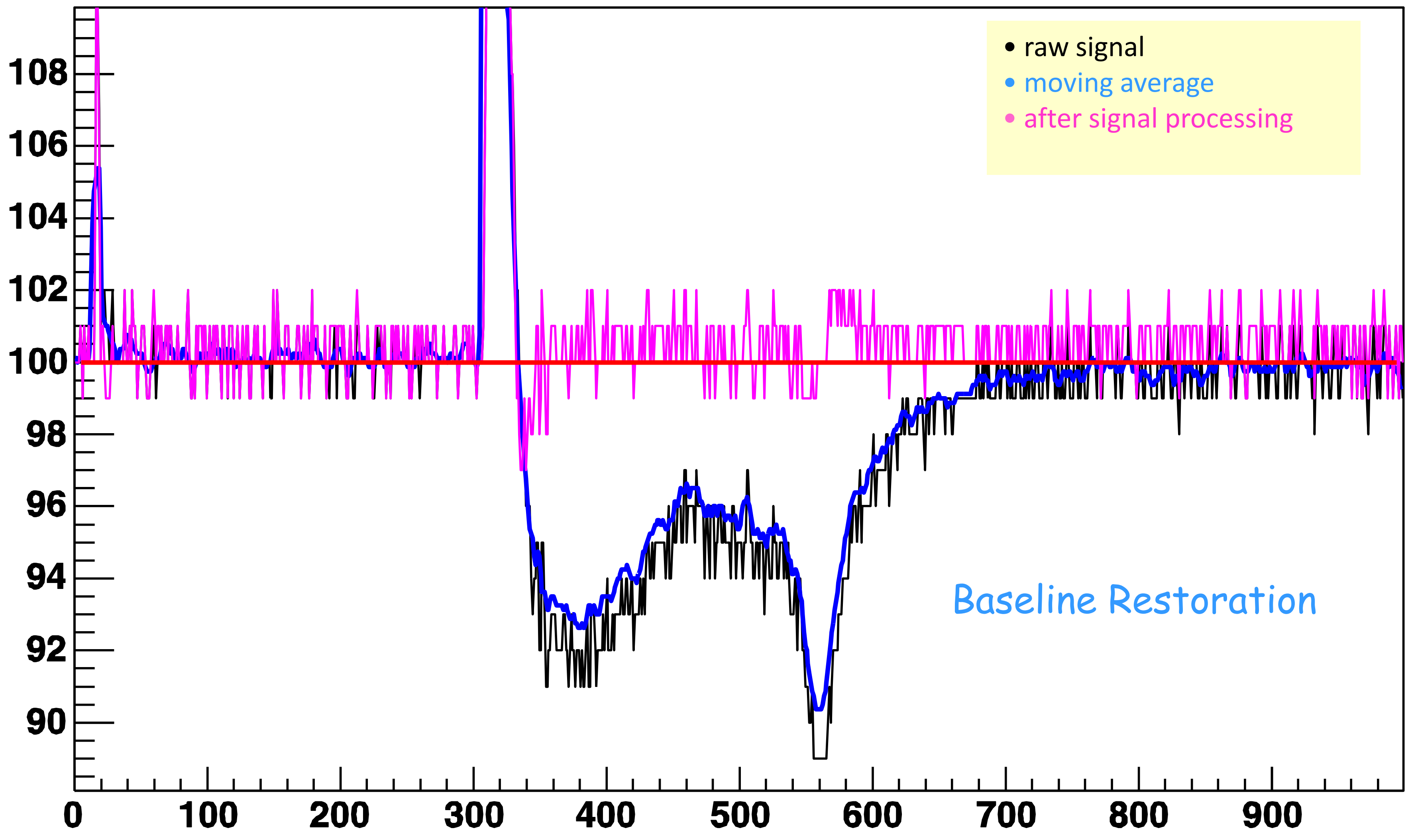




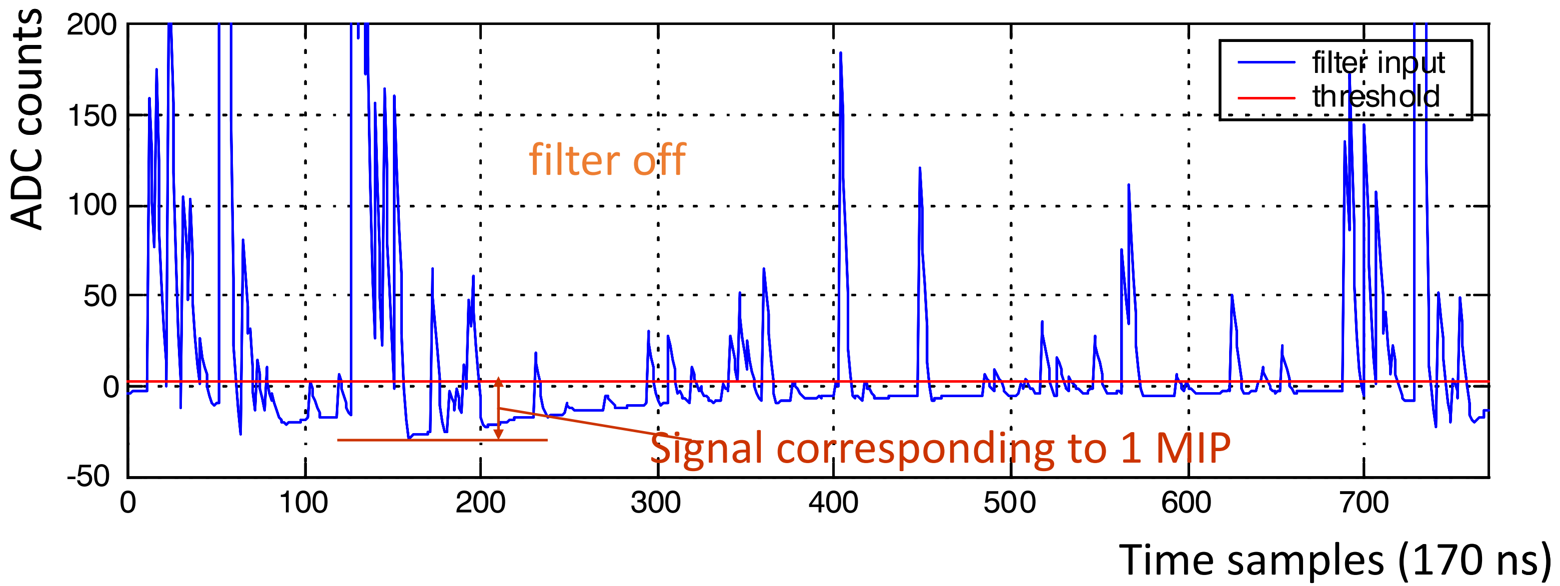


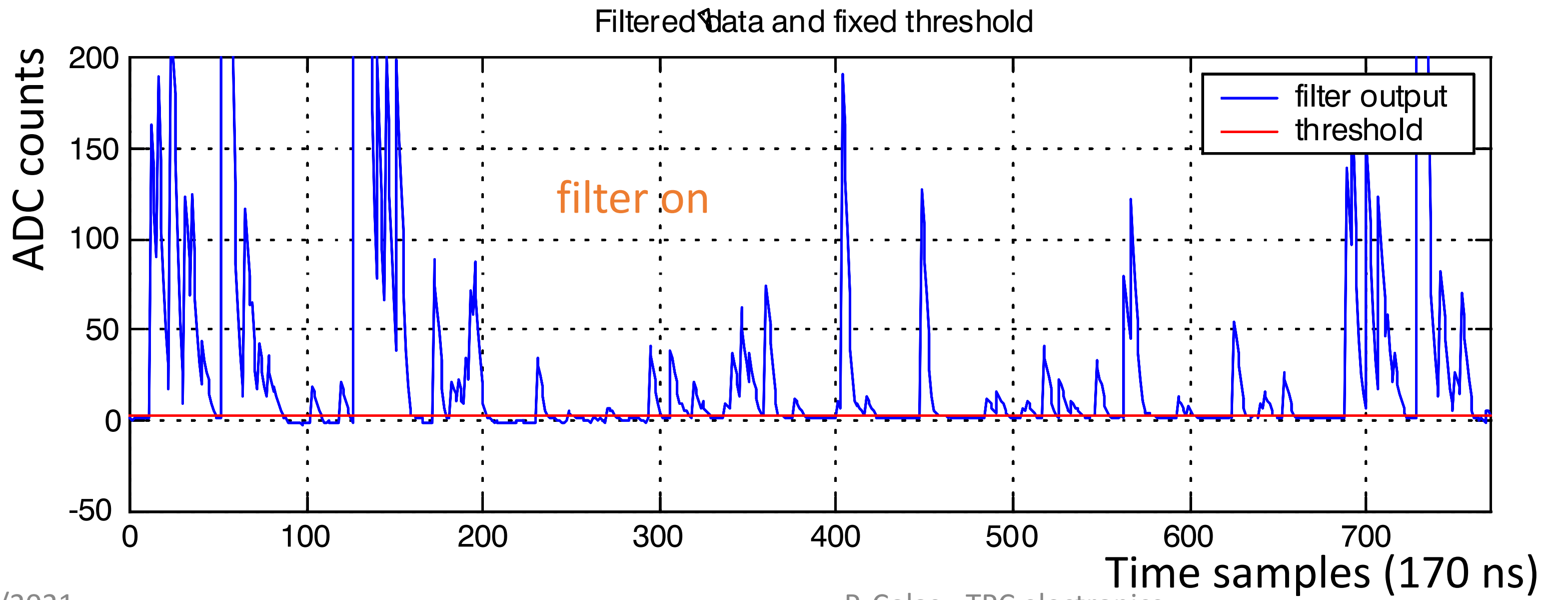
- ALICE TPC (LHC) Front-end cards
  - 50 m3, 557568 channels
  - ALICE TPC Read Out
  - Front-end unit → 128 channels (19.cm x 15.5 cm)
  - Analogue Memory + low sampling rate ADC
  - Evolved in Super-ALTRO in the 2nd decade. Integrated filter



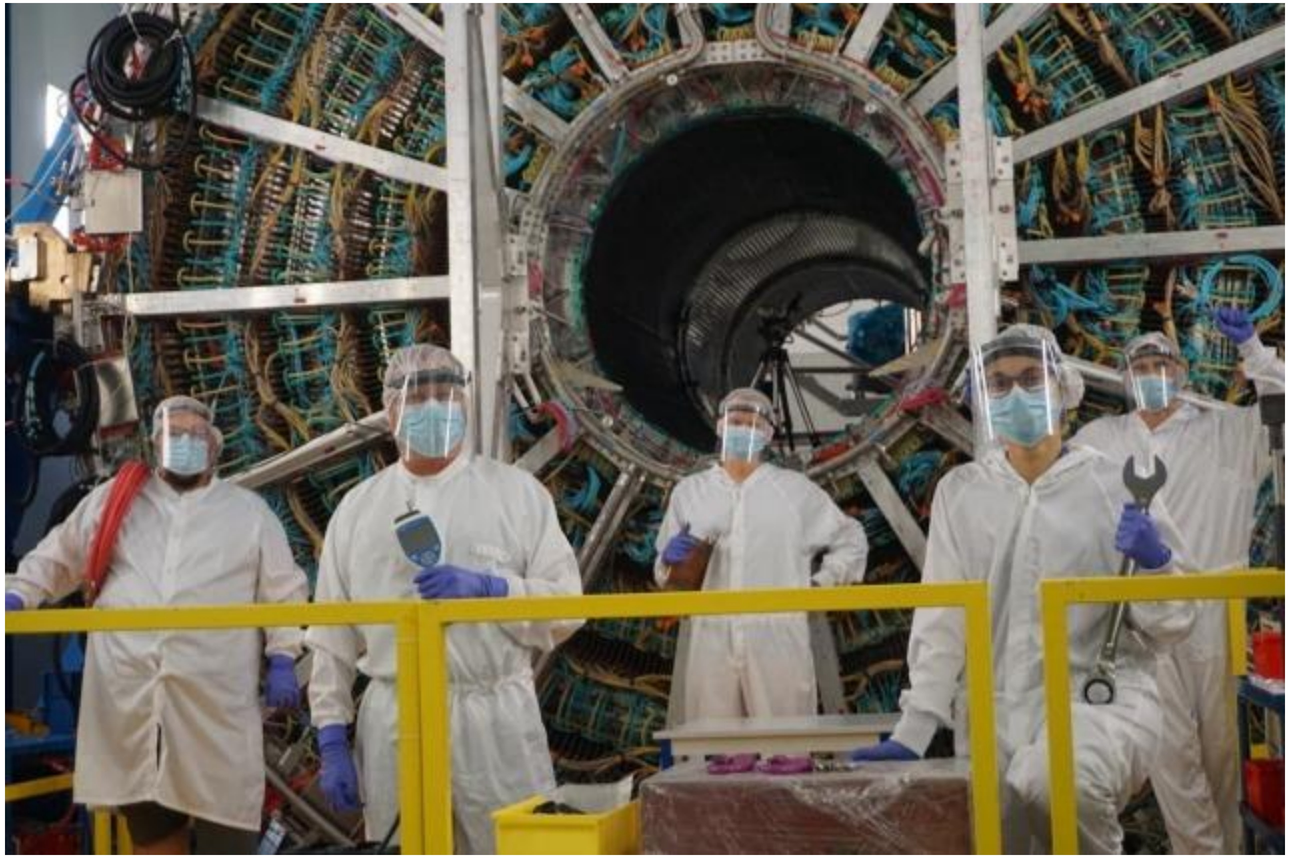

108
106
104
102
100
98
96
94
92
90
0
100
200
300
400
500
600
700
800
900
• raw signal
• moving average
• after signal processing
Baseline Restoration

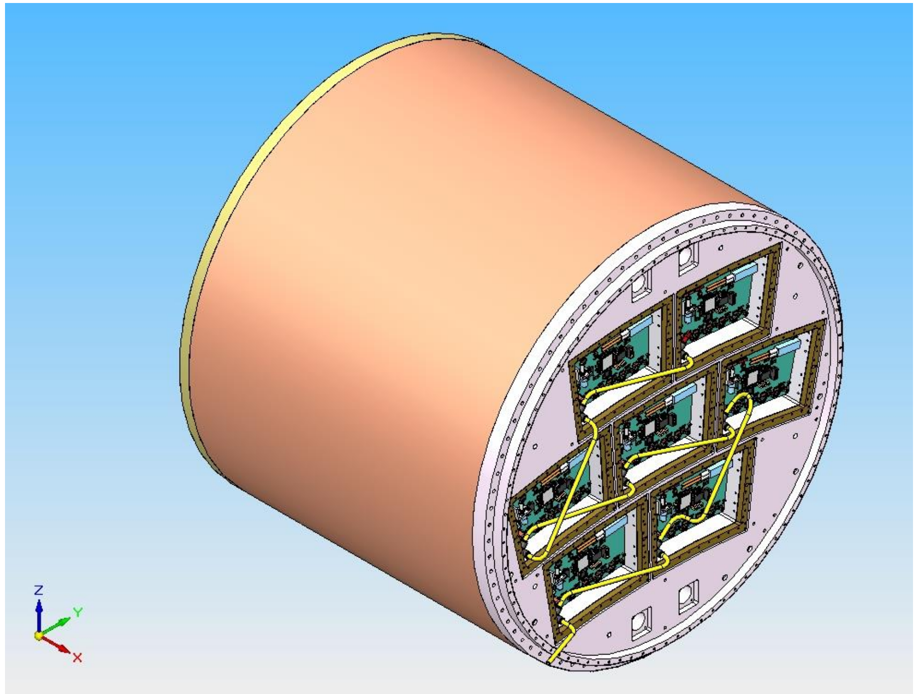
Digital tail cancellation (case of a wire chamber)

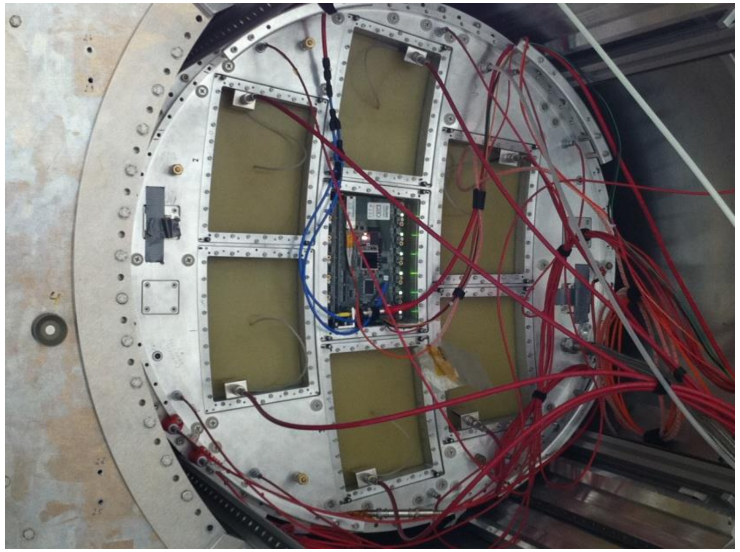




ALICE upgrade with 4-GEMs (May 2020)   524 160 pads







Micromegas TPC for ILC: fully integrated AFTER-based electronics

- New 300 points flat connectors
- New front end: keep naked AFTER chips and remove double diodes (count on resistive foil to protect against sparks)
- New Front End Mezzanine (FEMI)
- New backend ready for up to 12 modules
- New DAQ, 7-module ready and more compact format
- New trigger discriminator and logic (FPGA).

Integrated electronics for 7-module test

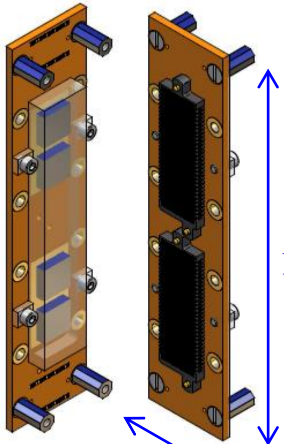
- Remove packaging and protection diodes
- Wire –bond AFTER chips
- Use 2 × 300 pins connector
- Use tiniest resistors (1 mm × 0.5 mm) from O to 10Ω

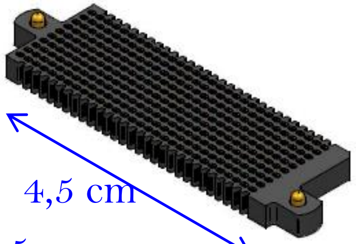
FEC

25 cm

14 cm

3,5 cm





4,5 cm

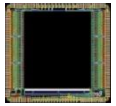
12,5 cm

2,8 cm

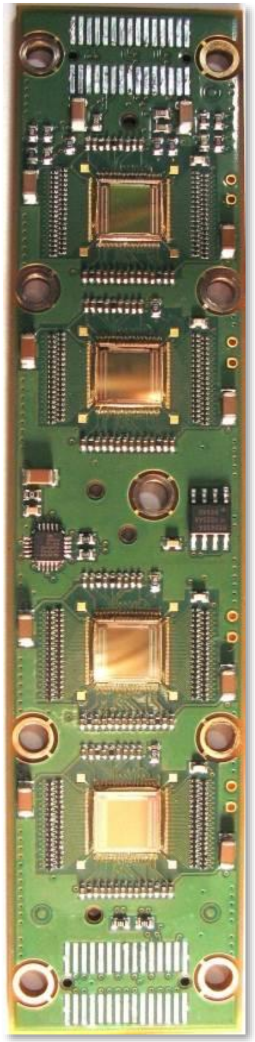
Chip

3,5 cm

0,78 cm

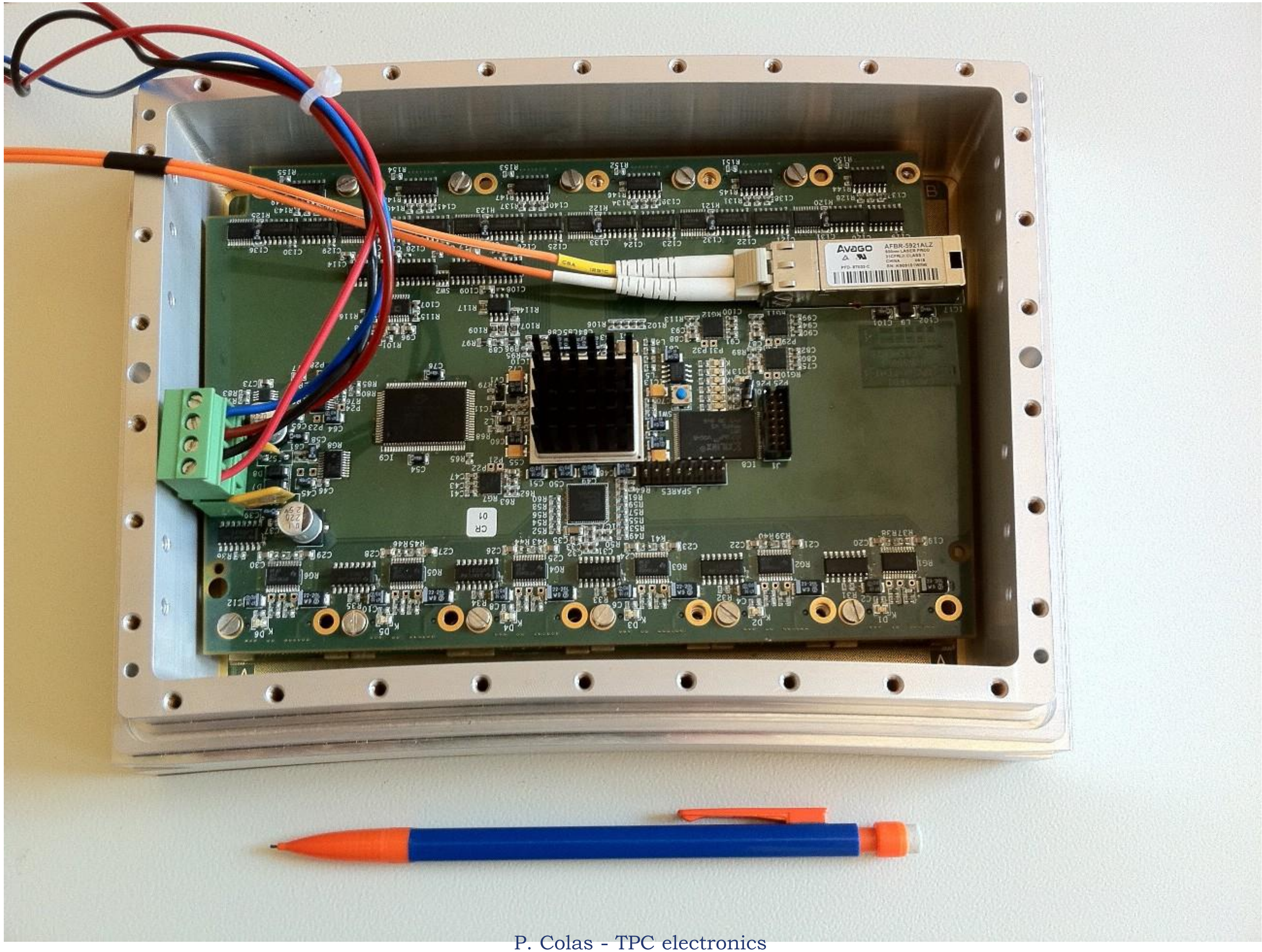


0,74 cm

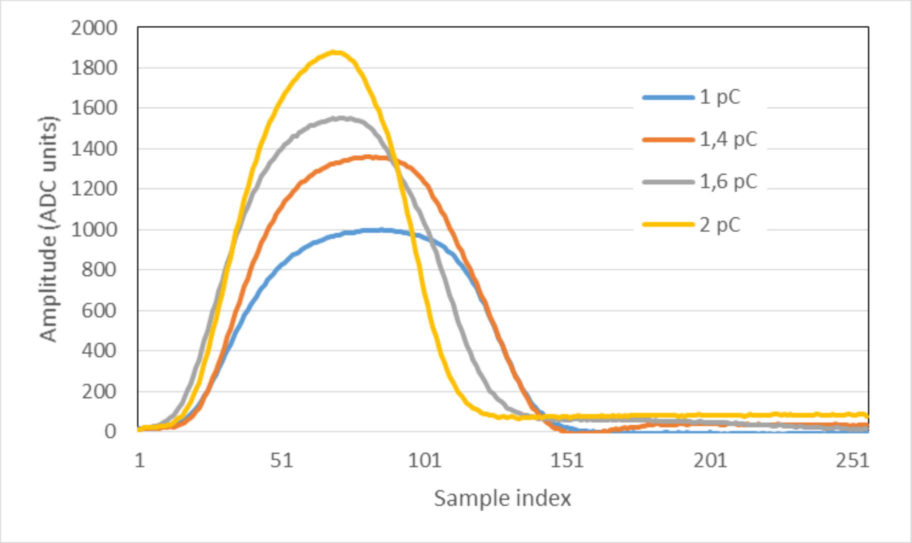


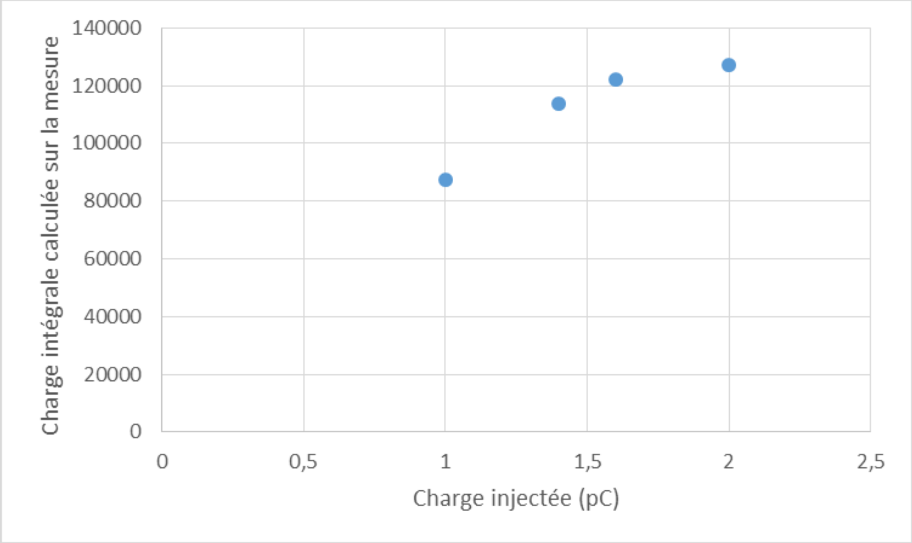
The resistive foil protects against sparks

A fully integrated module : 1728 channels connected with 1 optical fiber, one LC cable and 1 HV cable



Injection of saturating charges (saturation at 1 pC) D. Calvet, 2015





For tracks pointing nearly perpendicular to the detection plane, a very high charge can be integrated. This leads to saturation of the preamp and/or of the ADC.

Evolution of the AFTER family : Add self-triggering capability -> DREAM and AGET

In parallel, evolution of ALTRO : SAMPA for ALICE (see Marco Bregant)

Future evolution : see Damien Neyret's talk

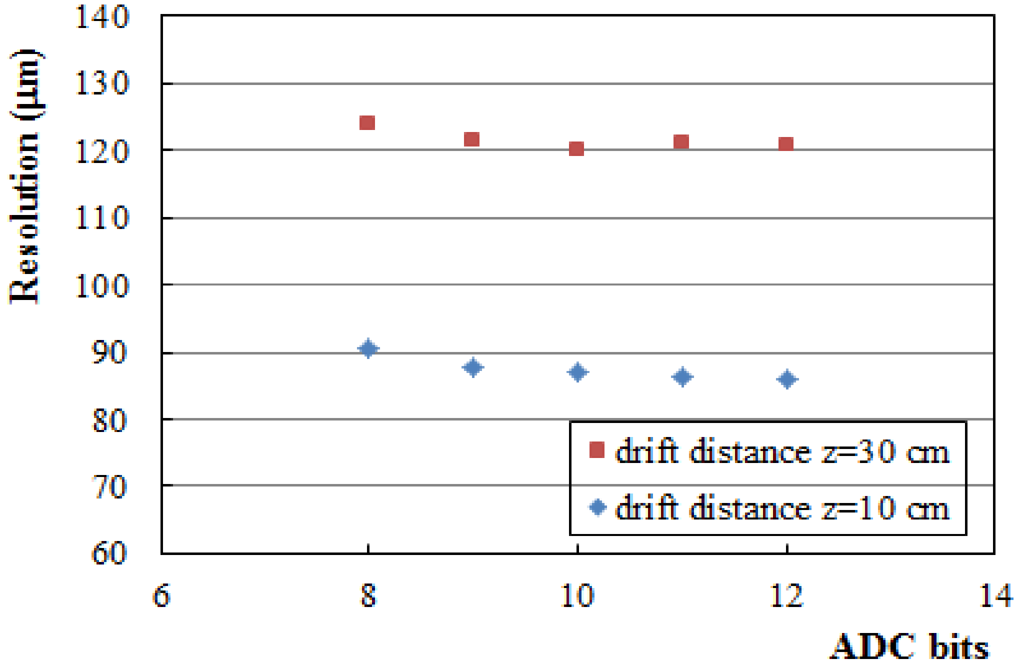
Constraints and limitations

- Real estate, packing factor : the number of channels that you can equip by unit of surface depends on the technology of your ASIC. Today, 1 channel can fit in about 10 mm^2
- Longitudinal diffusion spreads the charge and thus the signal duration. The effect of track angle is of the same order.
- Number of ADC bits (discussed later) constraints dE/dx accuracy and saturation
- Power pulsing and load leveling : when you have bunch train crossing periods with large inter-train periods without interaction (ILC case), you would like to switch off the power on the amplifiers to lower their consumption, or spread power-consumming operations (Analog to Digital conversion for instance) in the inter-train time.
- Saturation effects (case of 90° incidence tracks) examples of HARPO

parameters

- sampling frequency : must be matched to the pulses you want to see. 25 to 40 MHz is well adapted for a typical gas TPC.
- memory depth : must be sufficient to keep all the information. For analog memories (switched capacitor arrays) this is technologically limited to 1000-2000 buckets
- Noise : 500 e- equivalent is achievable. But there is a trade-off with peaking time
- Sensitivity : min signal that can be distinguished from noise.
- number of ADC bits, peaking time, integration time etc… and how to adapt to longitudinal diffusion and to the case of a resistive anode…

How many ADC bits are needed?



The spatial resolution as measured in a Micromegas beam test, as a function of the number of ADC bits used

(12 is the actual number of ADC bits and lower numbers are obtained by rounding up the amplitude to this accuracy).

9 bits largely suffice

For dE/dx (better than 5% accuracy needed) -> **9 to 10 bits required**

Attention should be paid to saturation, but this limitation is already at the amplifier level.

12 bits is an overkill. Costs power.

CONCLUDING REMARKS

- Technology evolution : a new technology is always more performant, and more expensive, but an old technology becomes obsolete. It is always best to use the technology currently up-to-date (130 nm, 65nm) and commonly used in industry.
- Choice between
  - many dedicated ASICs or
  - few versatile ASICs
- Timescale problem : **Test electronics** is always necessary to develop a new detector, but cannot be as performant as the target electronics