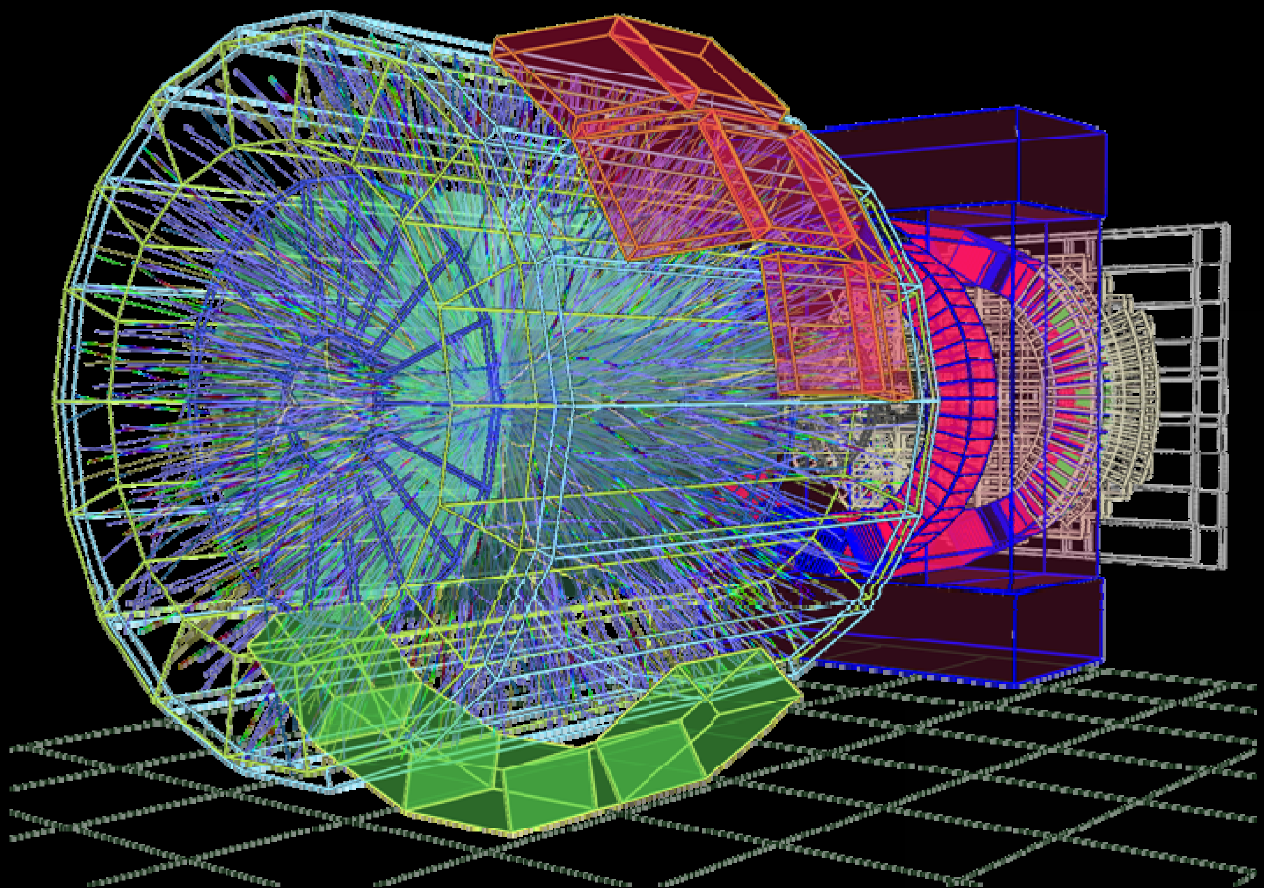
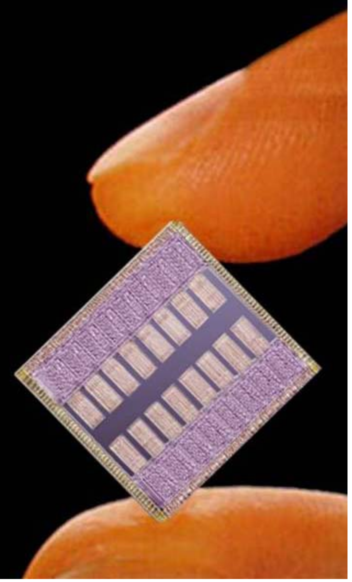
The Alice Time Projection Chamber …

… a Technological Challange in the LHC Heavy Ion Physics

Luciano Musa (CERN)



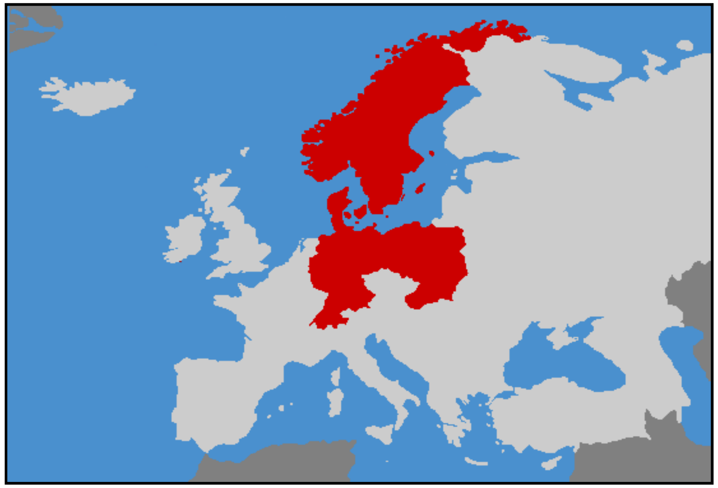


Outline

- General condition at LHC for heavy ion collisions
- The TPC in the ALICE Detector
- Challenges at high particle density
- TPC Main Components
  - Field Cage
  - Readout Chambers
  - Electronics
- Commissioning the full TPC
- Summary and Outlook

Luciano Musa – CERN

The ALICE TPC Collaboration



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Darmstadt TU
GSI Darmstadt
Heidelberg PI
Lund
Bratislava
Copenhagen
Frankfurt
Heidelberg KIP
Krakow

General Conditions at LHC for Heavy-Ion Collisions

ALICE, a general purpose Experiment

- measures hadrons, leptons and photons at mid-rapidity
- Pb – Pb: 5.5 TeV CM-energy (NN)
- pp, pA, A-A

« The biggest step in energy of the history of heavy-ion collisions »
G. Rolland

Luminosity (max)

- Pb + Pb: $1.0 \cdot 10^{27}$ [cm^{-2} s^{-1}]
  - 8 kHz interaction rate
  - event (central) rate 100 – 200 Hz
- p + p: $5.0 \cdot 10^{30}$ [cm^{-2} s^{-1}]
  - 200 kHz interaction rate
  - event rate > 1 kHz

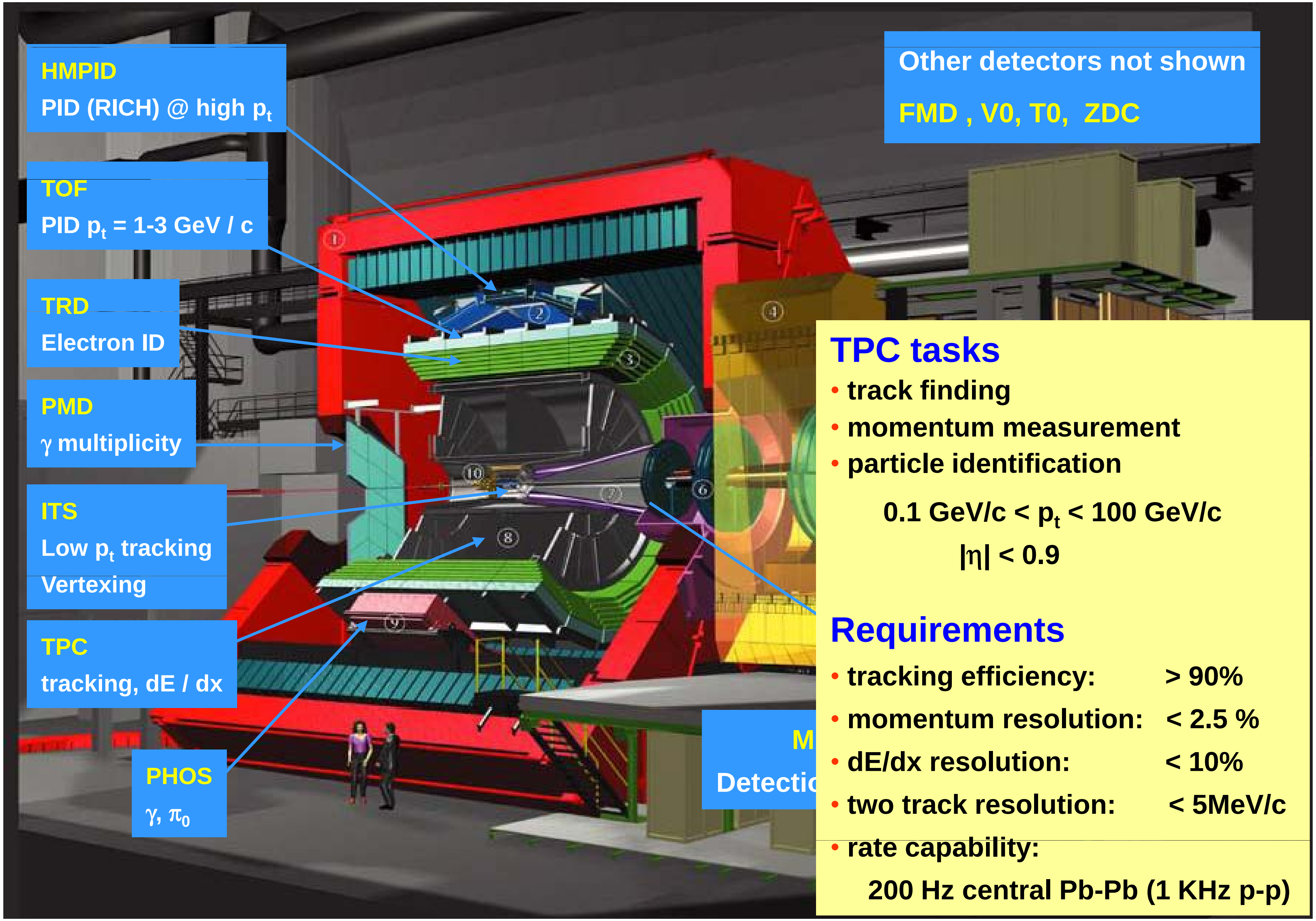
Rapidity density predictions

- dN_{ch} / dy = 2000 – 6000 (model dependent)
- What can we learn from RHIC?
- The first LHC event will give an answer

→ $dN/dy \approx 3500$ at $\eta = 0$
"educated" extrapolation
(saturation model, Eskola *et al.*)

ALICE Detector designed for $dN_{ch} / dy = 8000$

The ALICE Detector



TPC tasks

- track finding
- momentum measurement
- particle identification

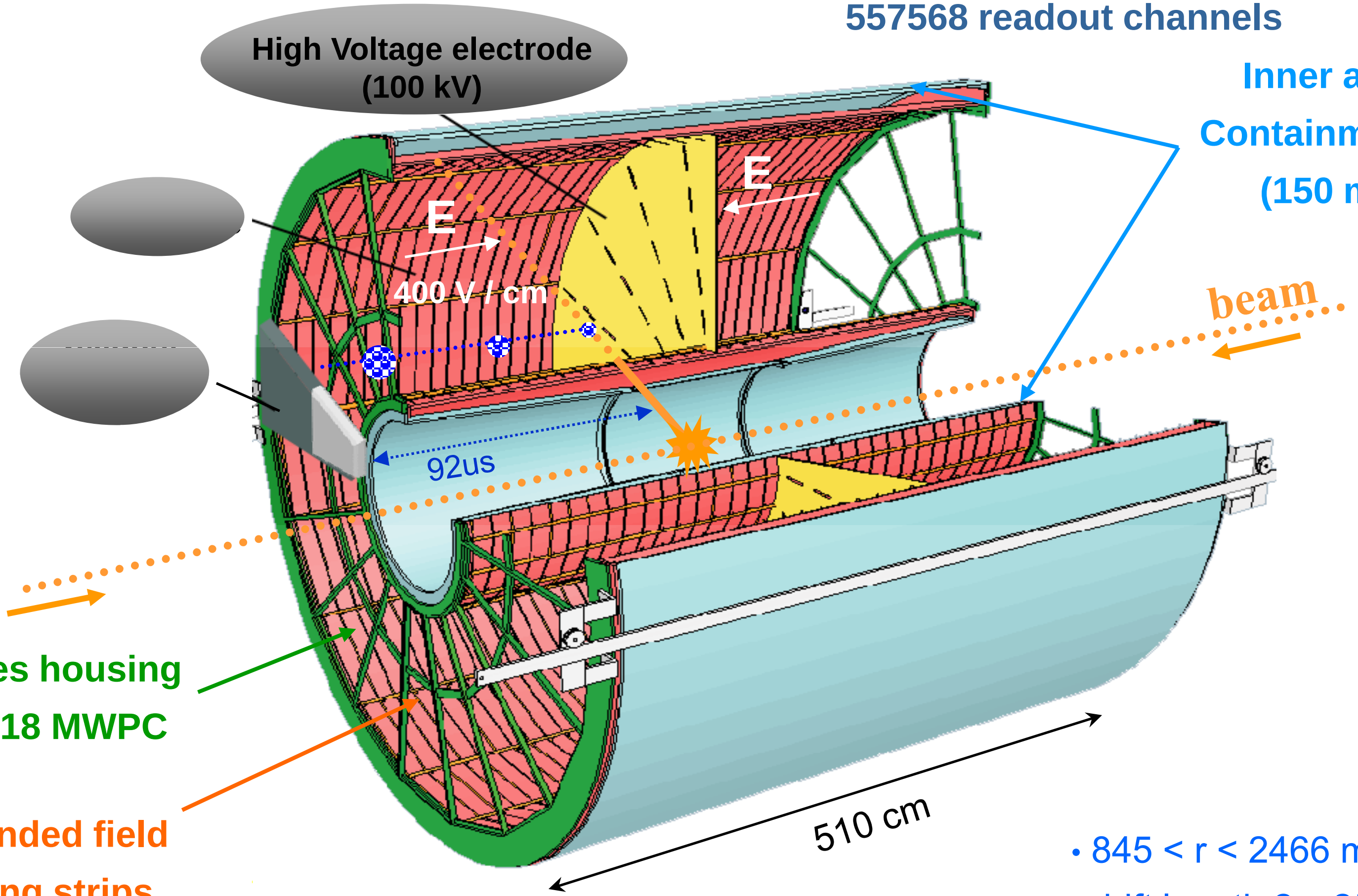
$0.1 \text{ GeV/c} < p_t < 100 \text{ GeV/c}$

$|\eta| < 0.9$

Requirements

- tracking efficiency: > 90%
- momentum resolution: < 2.5 %
- dE/dx resolution: < 10%
- two track resolution: < 5MeV/c
- rate capability:
  200 Hz central Pb-Pb (1 KHz p-p)

TPC Overview

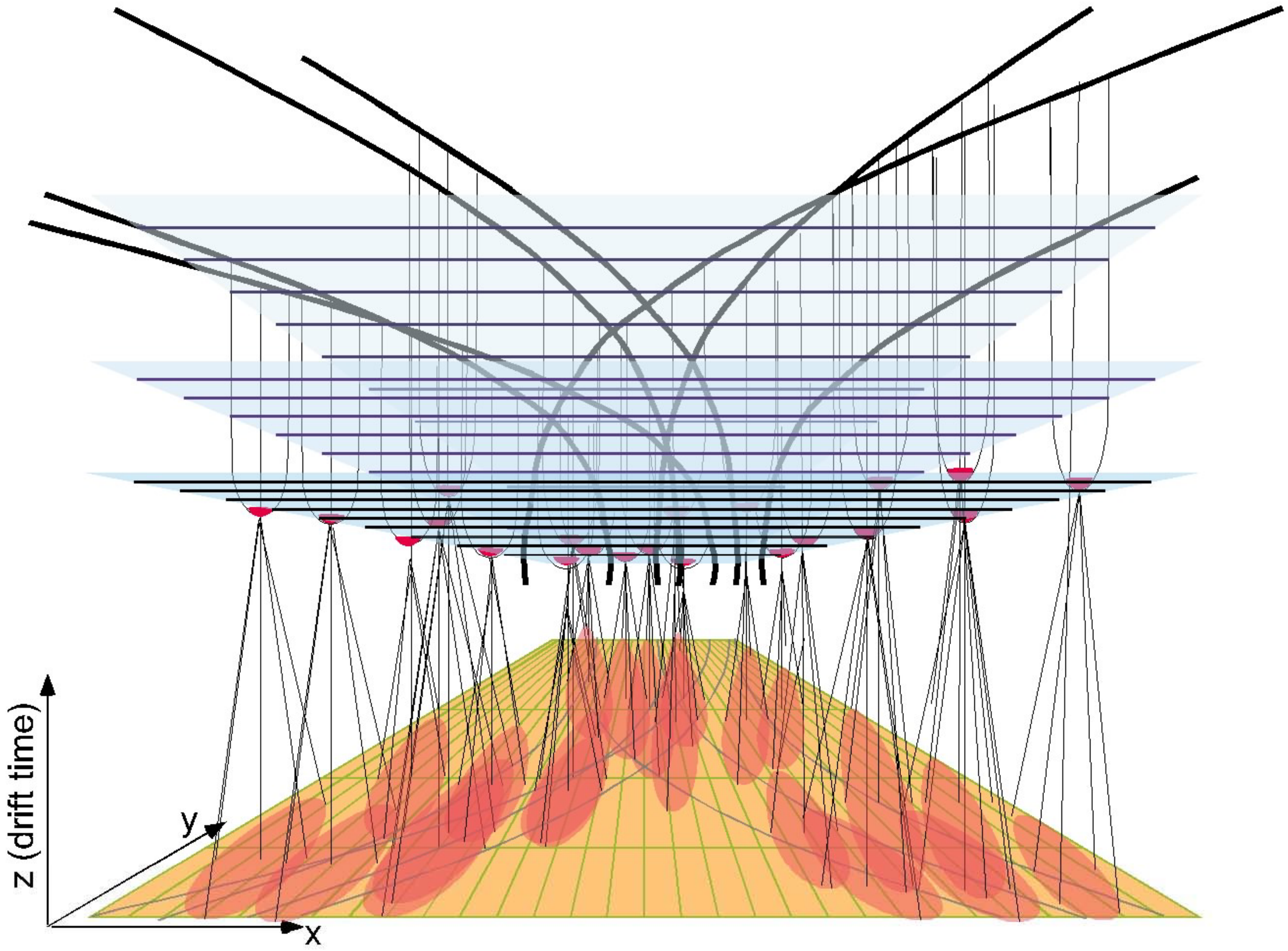


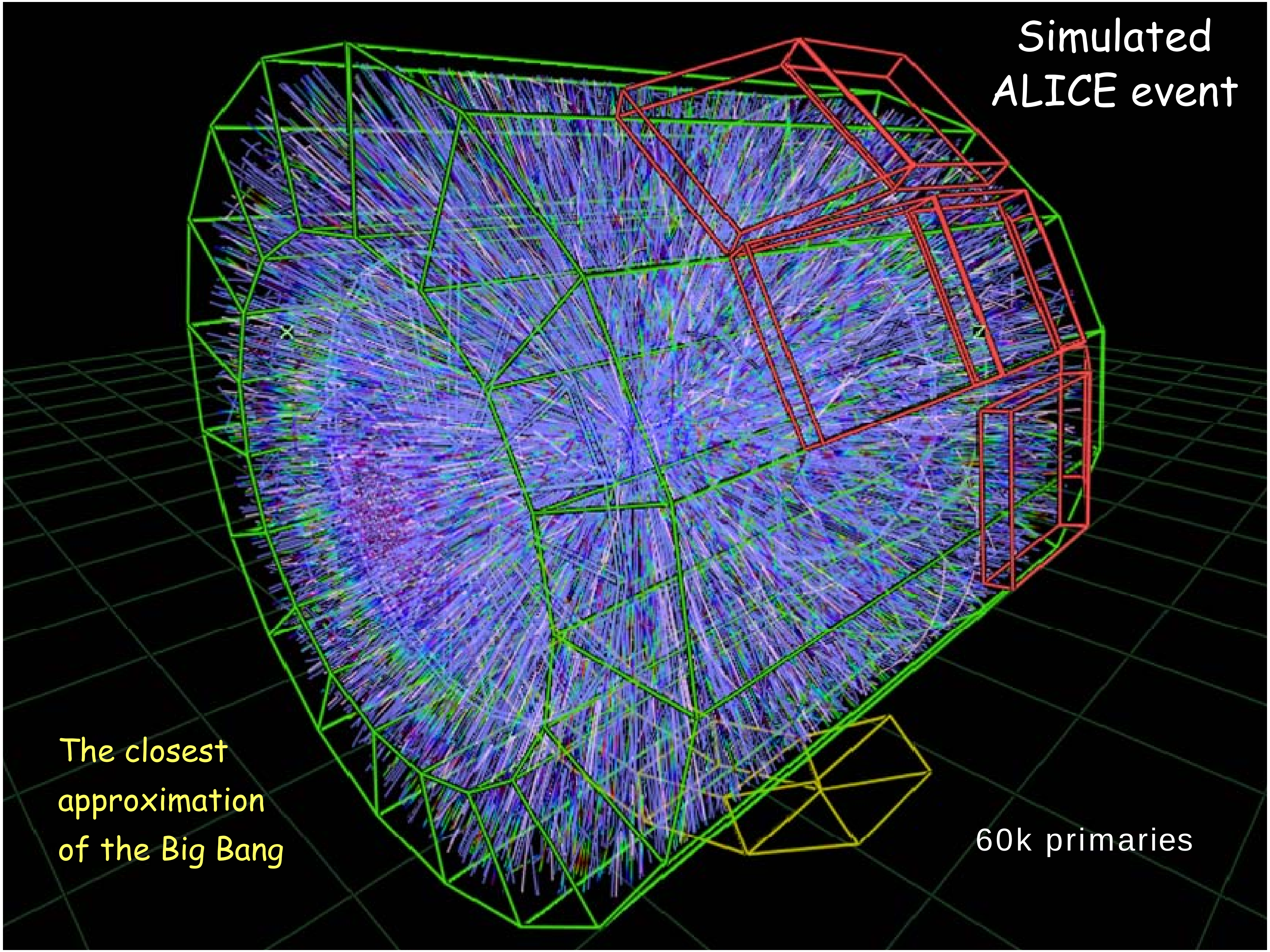
- 845 < r < 2466 mm
- drift length 2 x 2500 mm
- drift gas Ne, CO_2, N_2 (90/10/5)
- gas volume 95 m^3
- 557568 readout pads

ALICE TPC CHALLENGES

up to 2×10^4 charged particles in TPC

TPC WORKING PRINCIPLE




Simulated
ALICE event
The closest
approximation
of the Big Bang
60k primaries

Challenges at high particle multiplicities

Can a TPC be safely operated at this high particle multiplicities and high luminosity ?

- stability of readout chambers and field cage at high load
- ageing problems

Can we measure with enough accuracy
(tracking efficiency, p & dE/dx resolution) ?

- Cluster pile-up

  High granularity ⇨ High data volume

  Low diffusion gas (CO_2) ⇨ low drift velocity ⇨ high drift field (100KV)

- Space charge problems (drift field distortions)

  Low Z gas (Ne) ⇨ little primary ionization ⇨ high gas gain (2×10^4)

- Drift vel. depends sensitively on temp., HV, gas composition
- Gas gain depends sensitively on mixture

Challenges at high particle multiplicities

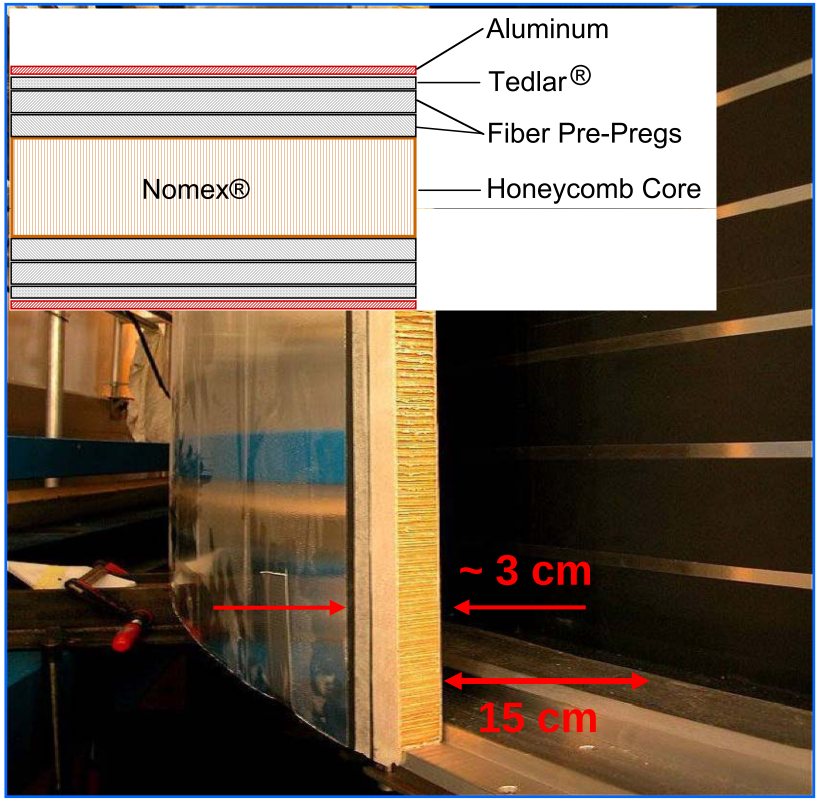
Can we handle the detector data throughput?

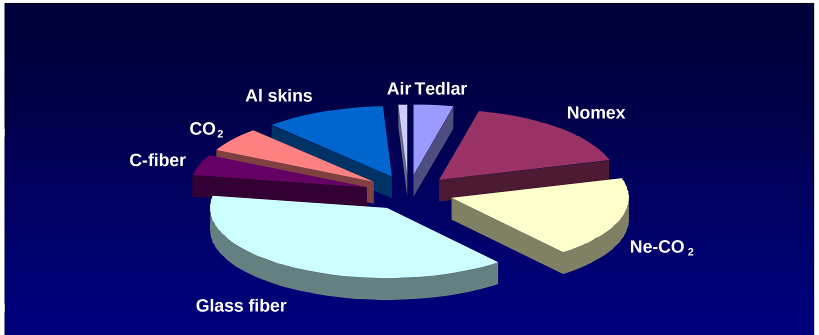
- 557 568 (pads) x 1000 (time bins)
- 712 Mbytes / event
- Pb – Pb (@200 Hz) ➔ 142 Gbyte / sec
- p-p (@1KHz) ➔ 710 GByte / sec

⇨ data compression in FEE

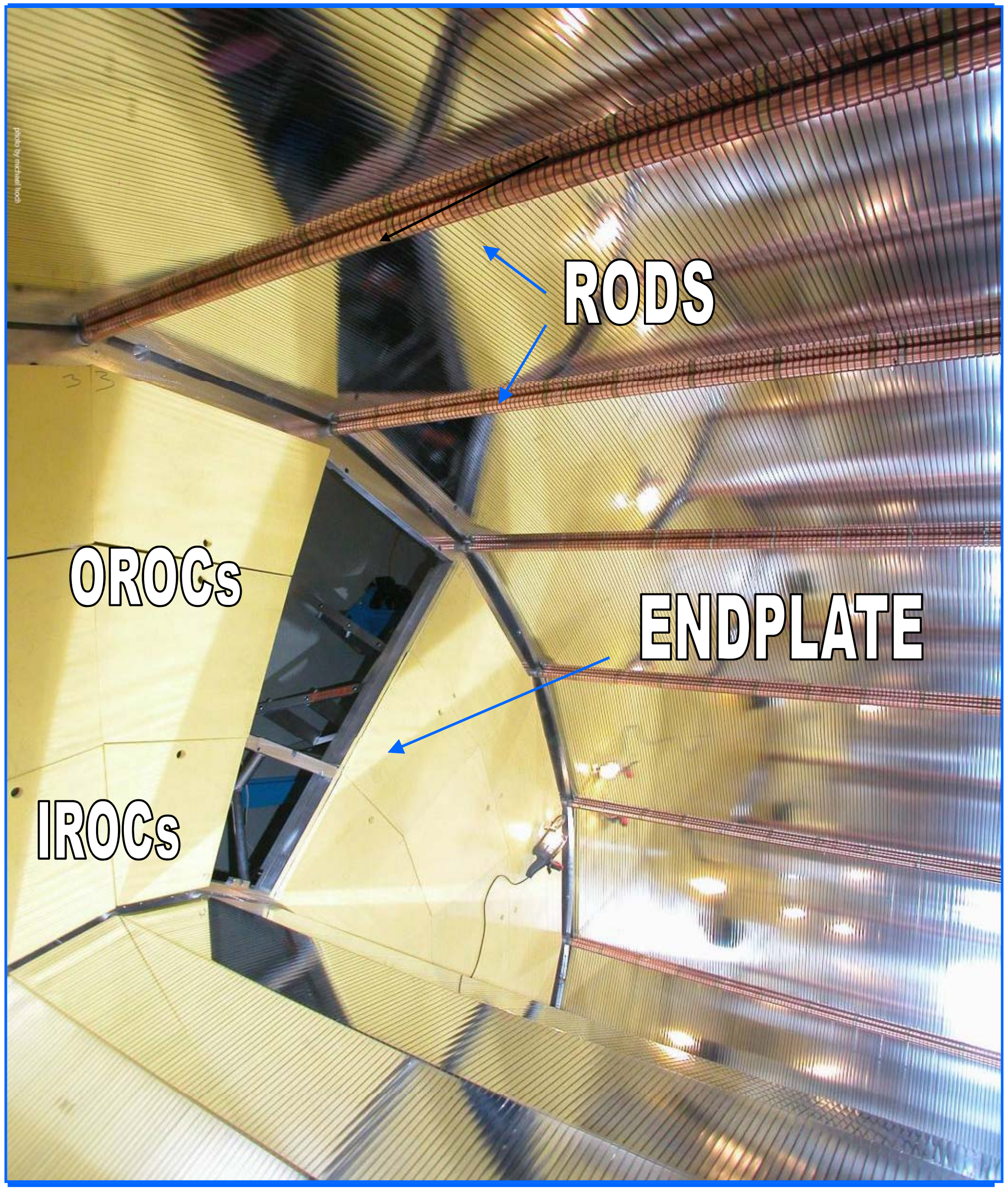
⇨ accurate signal preprocessing in FEE

Low mass Field Cage





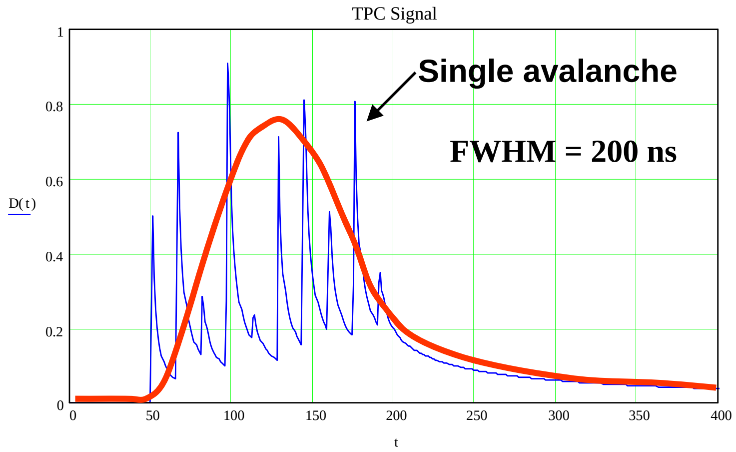
Total x/x_0 ~ 3% radiation length at η = 0



- **Z (time direction): higher sampling rate**

  limitations:
  - signal/noise gets critical
  - temporal signal is diffusion limited

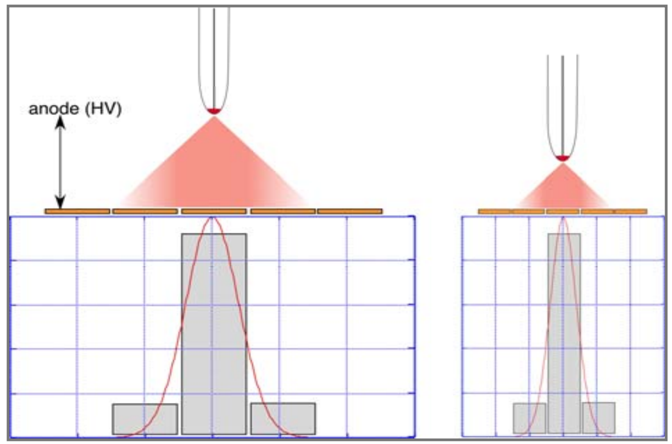
  $\Rightarrow$ **oversampling**



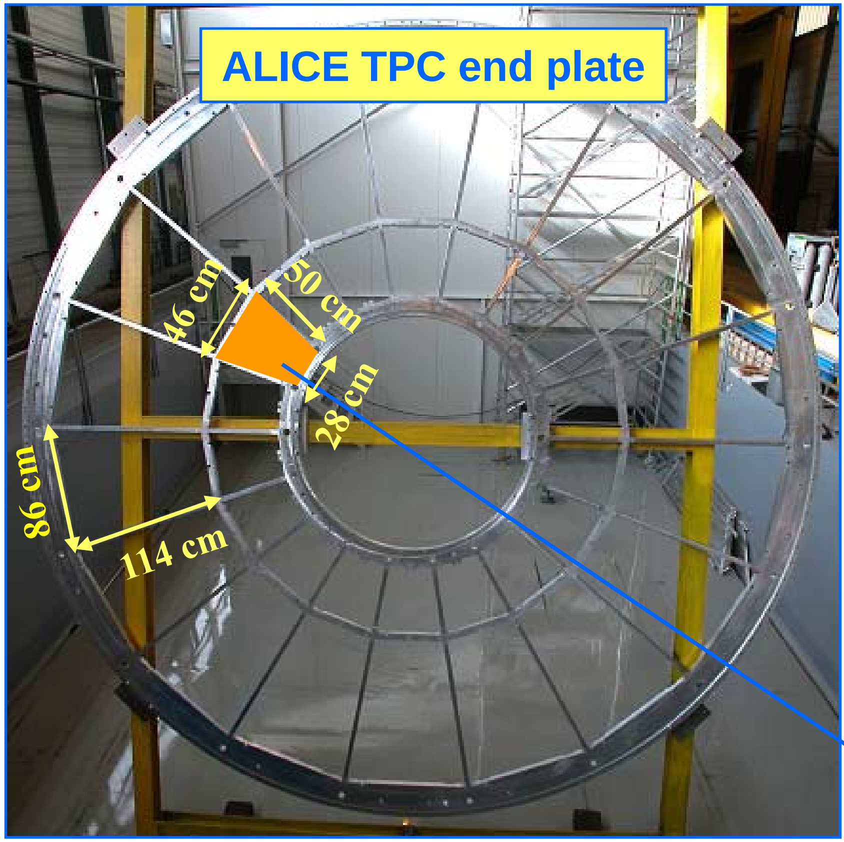
- **R-ϕ (pad direction): smaller pads**

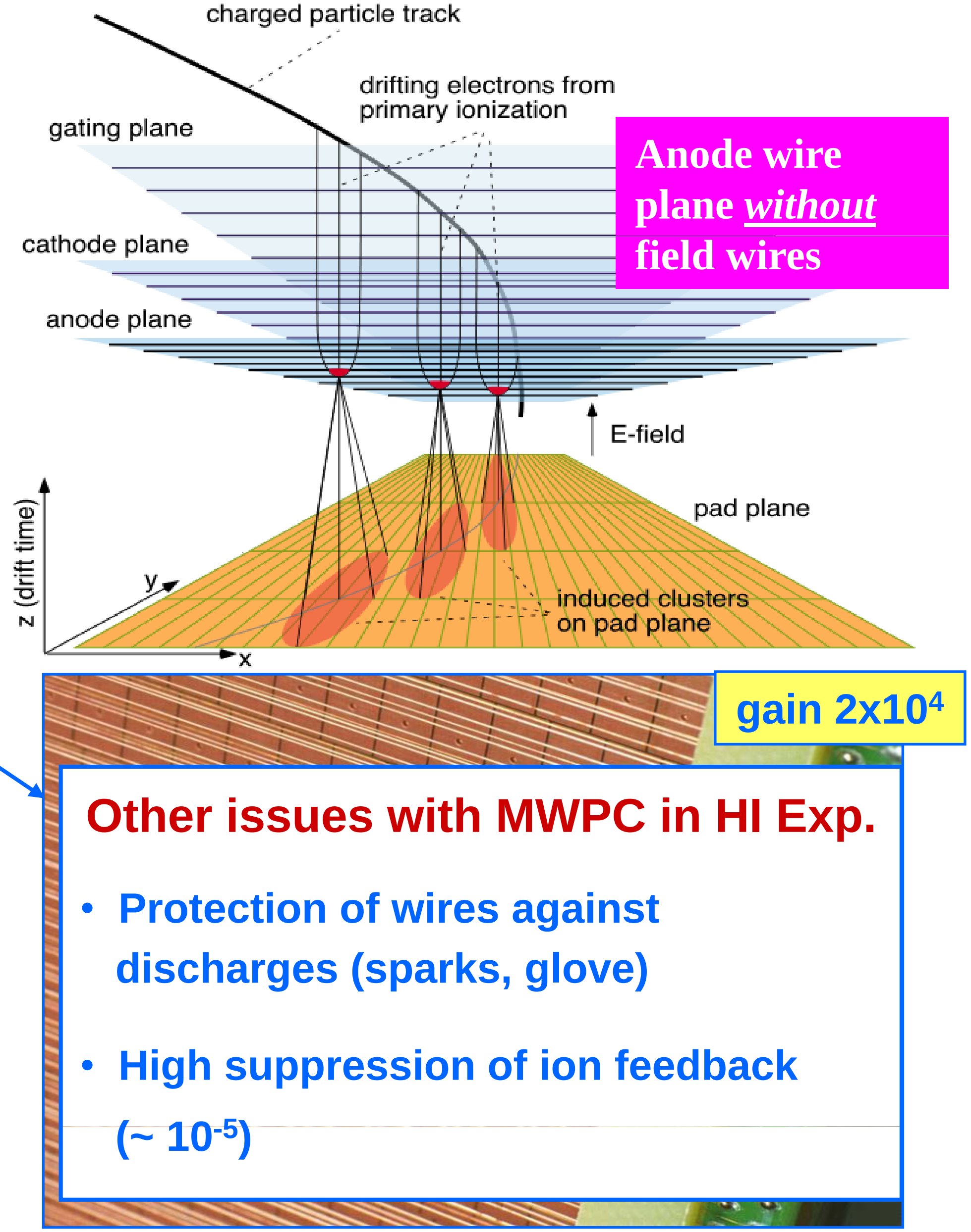
  limitations:
  - # of channels (cost!)
  - HV-GND gets critical
  - PRF is diffusion limited

  $\Rightarrow$ **oversampling**



- **Conclusion**
  - **choose the time/pad area which yields still reasonable signal (S/N > 20)**
  - **for a given pad area optimize aspect ratio**
  - **minimize diffusion: "cold gas", use high drift field**





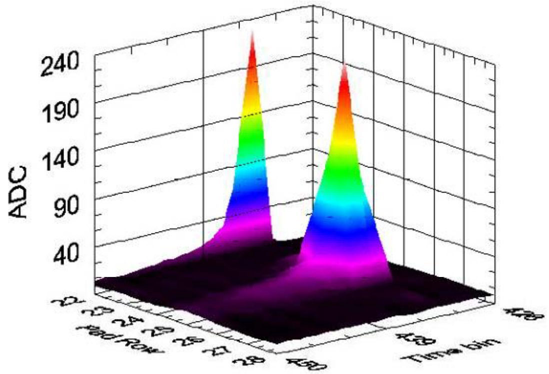
Anode wire plane *without* field wires

Other issues with MWPC in HI Exp.

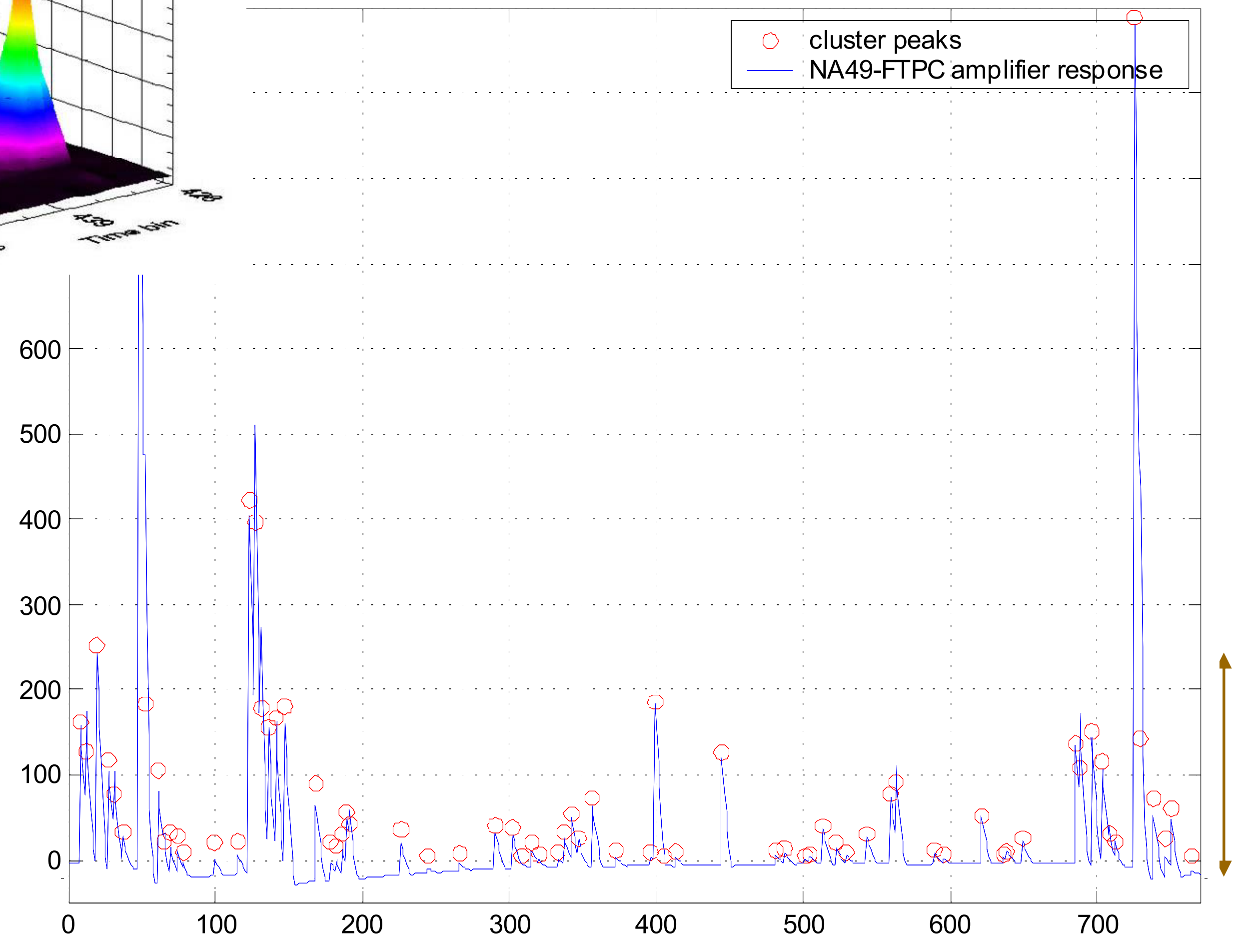
- **Protection of wires against discharges (sparks, glove)**
- **High suppression of ion feedback ($\sim 10^{-5}$)**

- In total 557,568 pads
- 63 rows with 4 x 7.5 mm^2 (inner radius)
- 64 rows with 6 x 10 mm^2
- 32 rows with 6 x 15 mm^2 (outer radius)

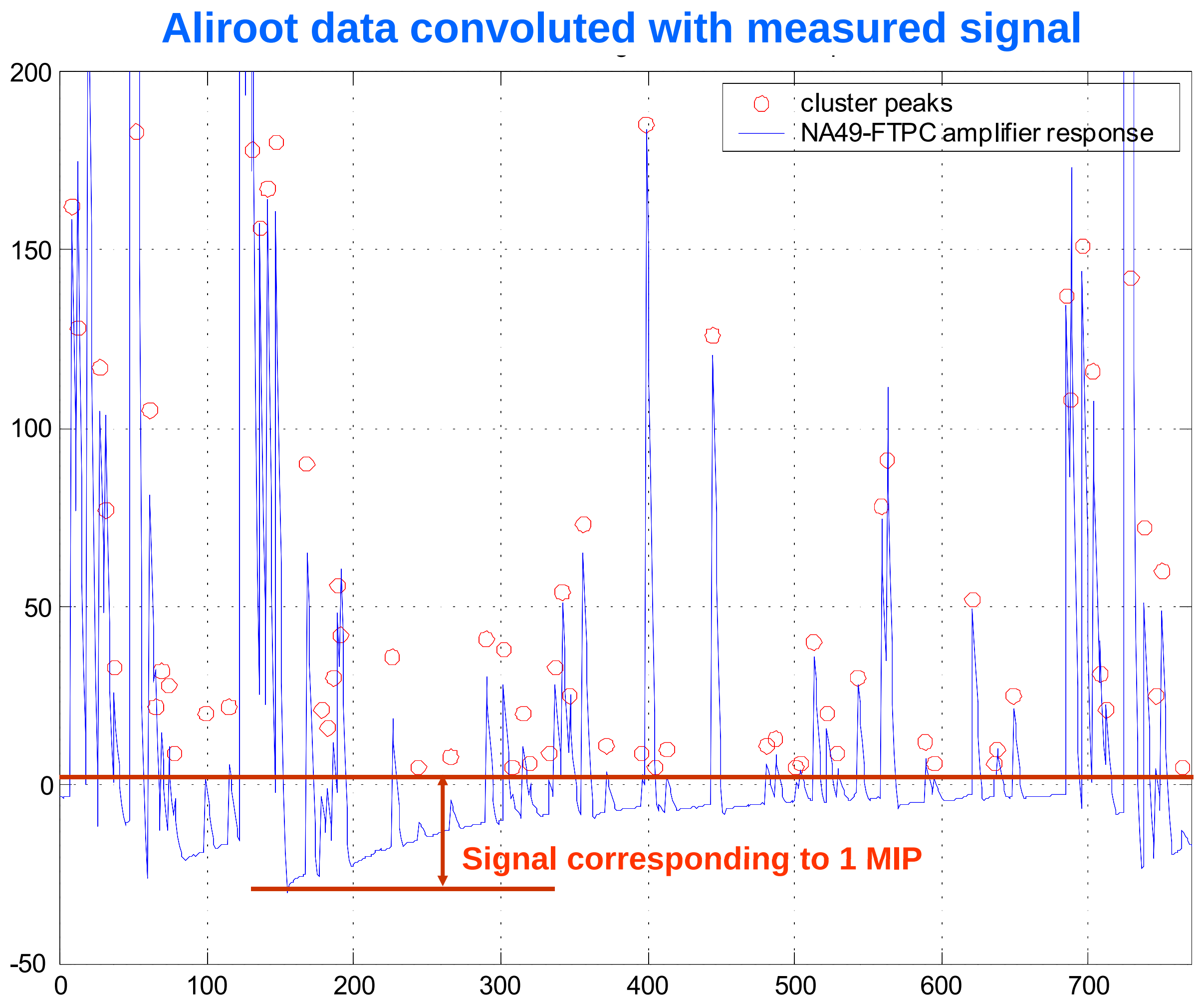
Ionization from ^{83}Kr Decay
Measured with ALICE TPC prototype)



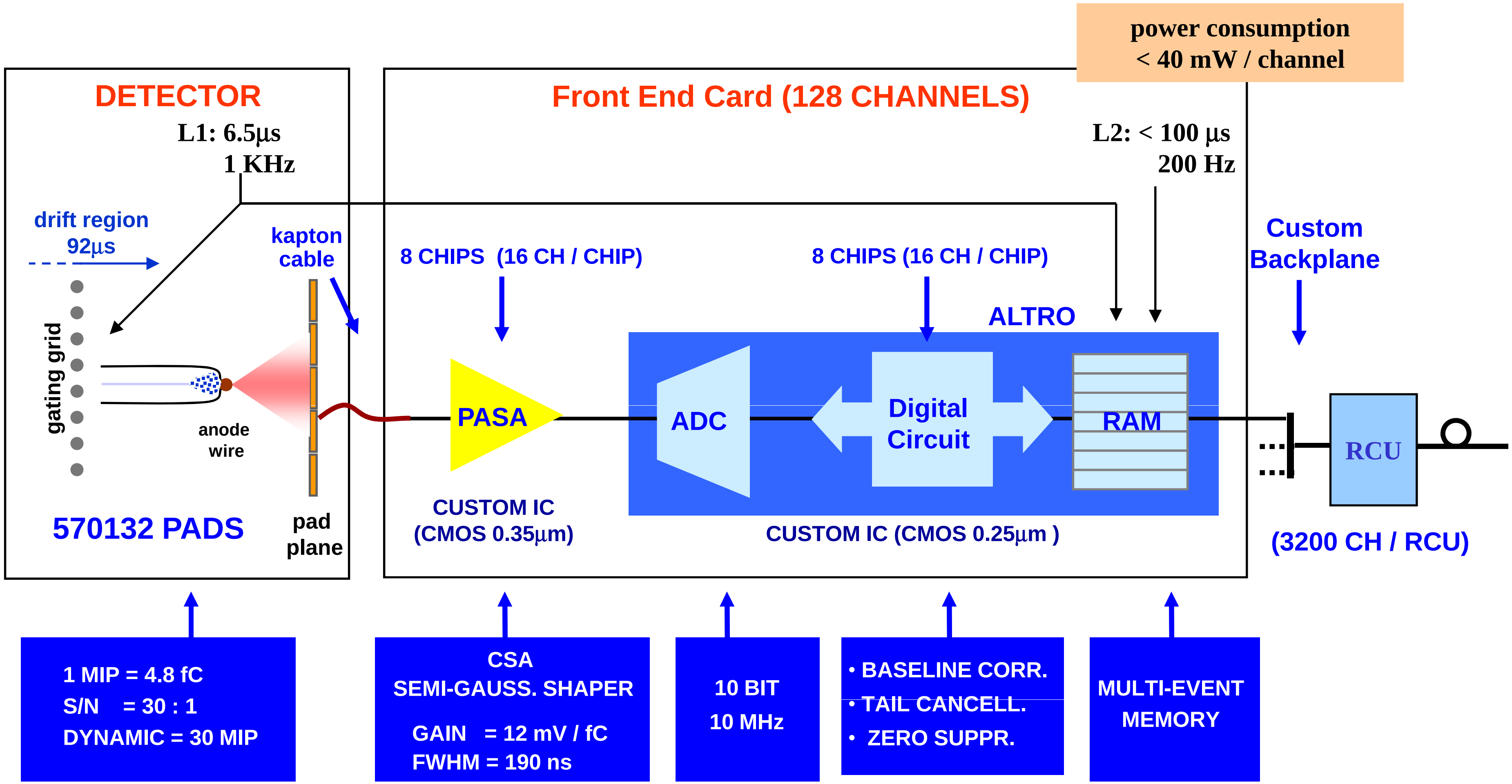
oot data convoluted with measured signal



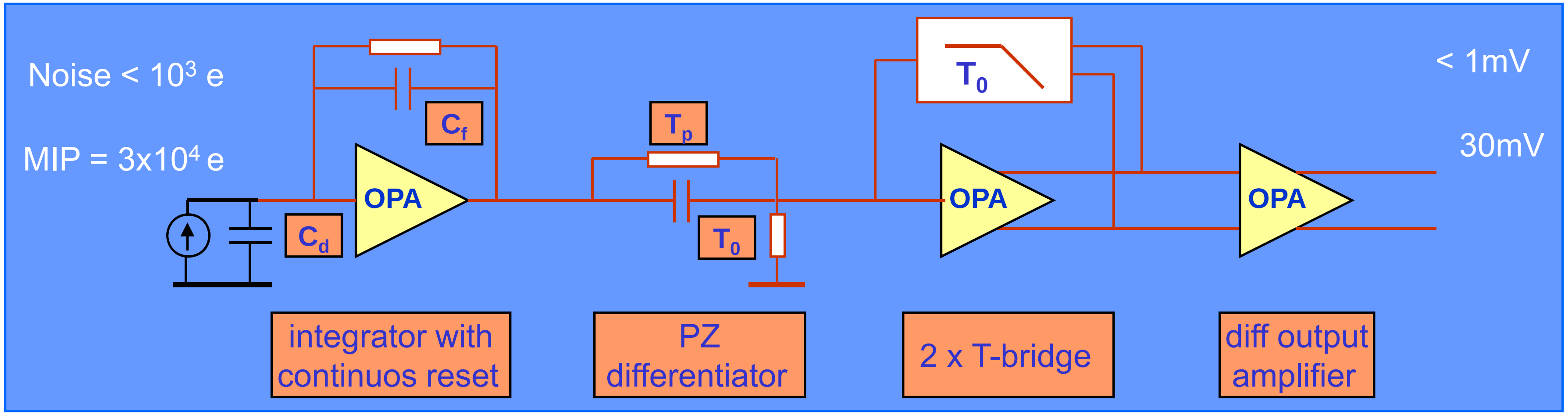
The Ion-Tail Problem

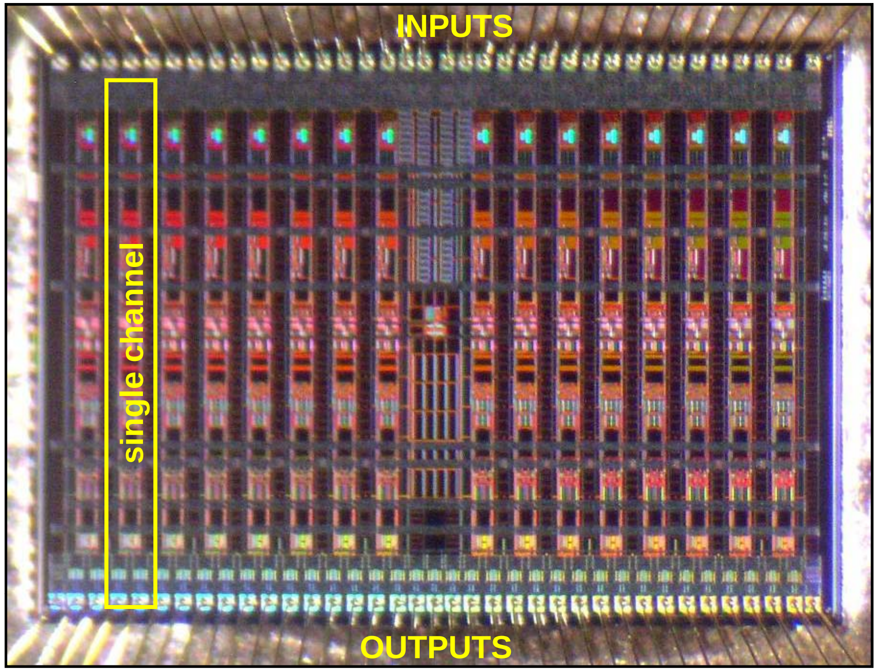


TPC FEE OVERVIEW



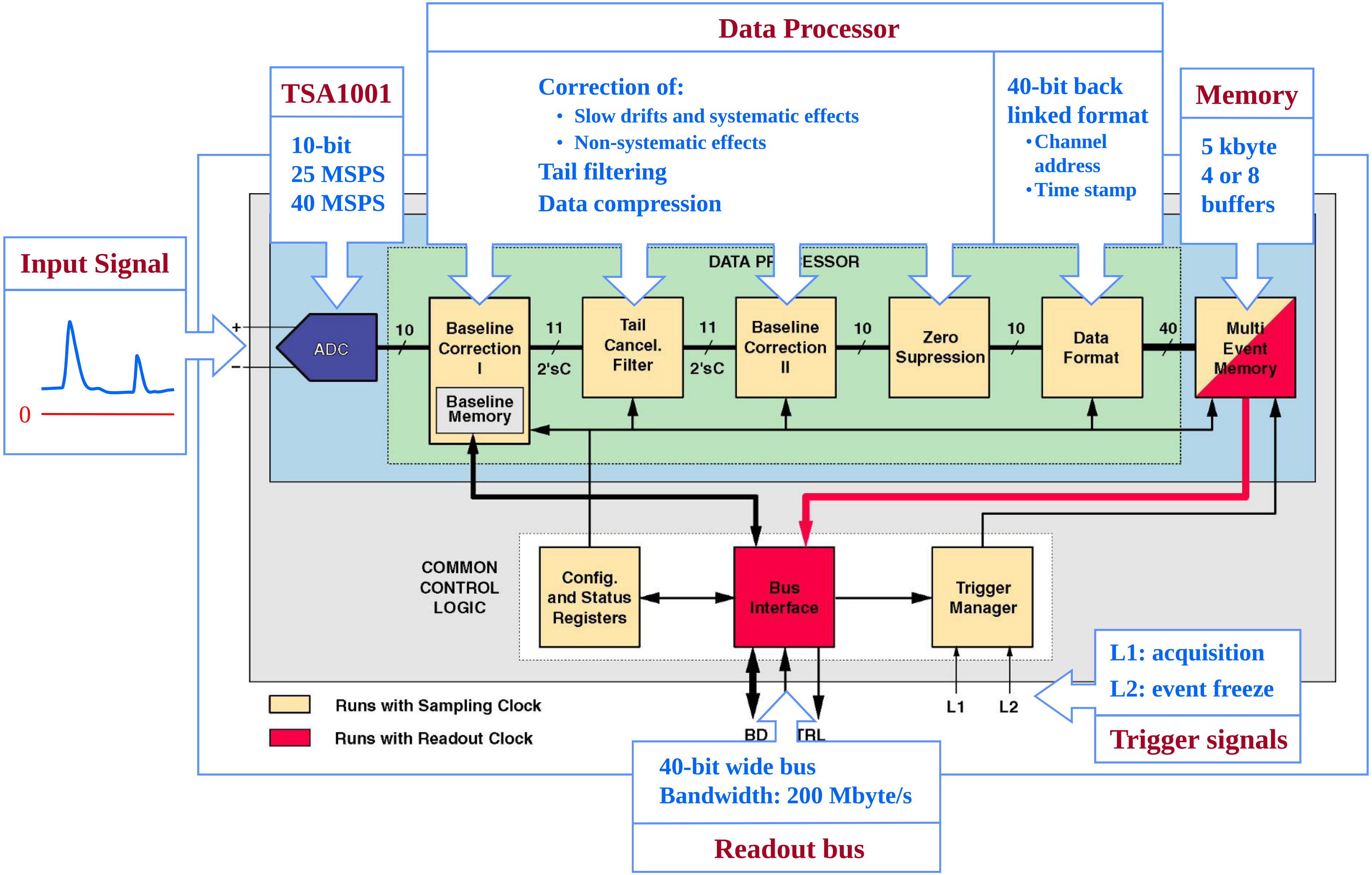
Pre-Amplifier Shaping Amplifier (PASA)



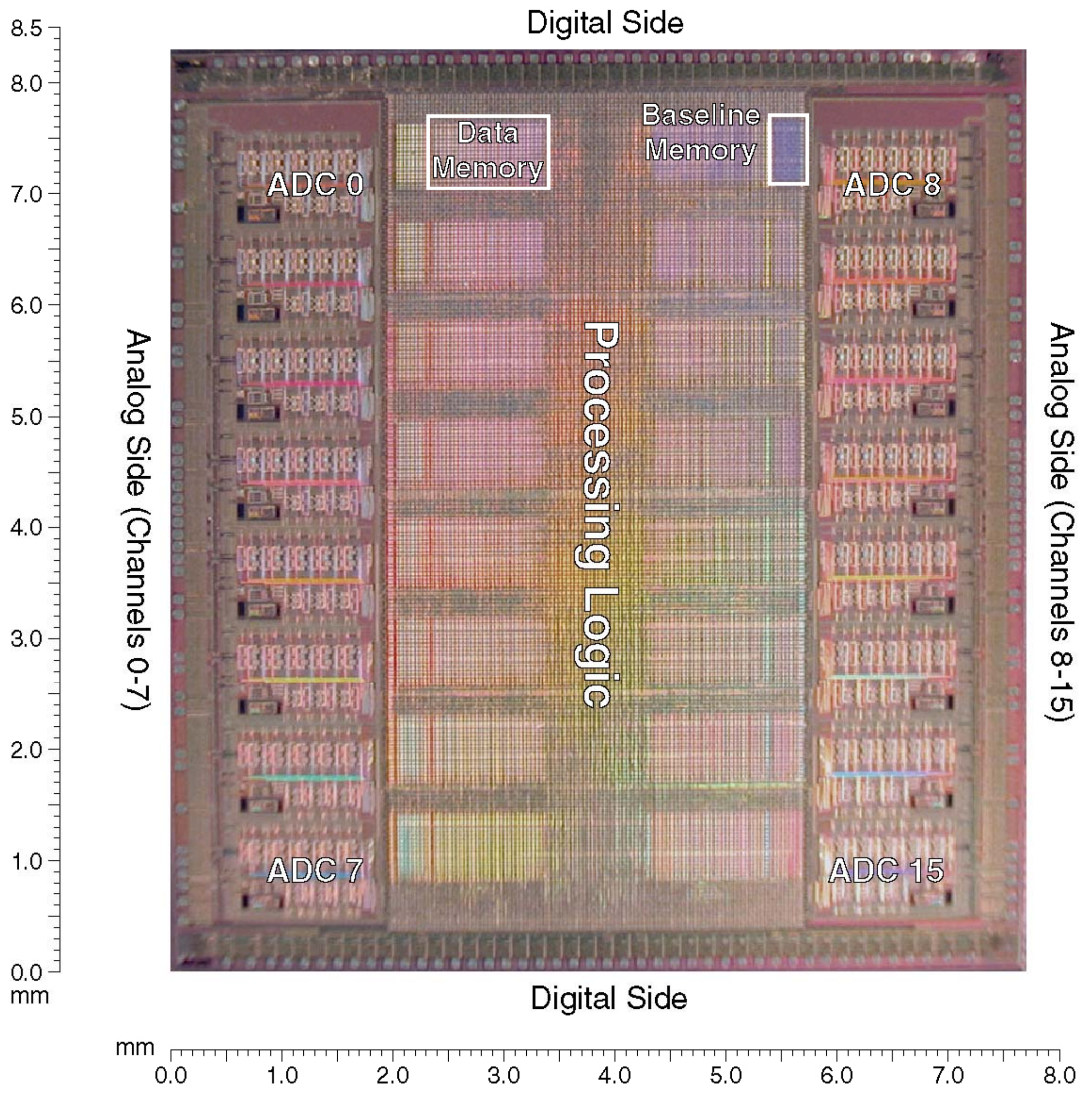


Production Engineering Data		
Process	**AMS CMOS 0.35 μm**	
Area	**18 mm²**	
Yield	**95%**	
Parameter	Requirement	Production
Noise	**< 1000e**	**560e (12pF)**
Conversion gain	**12mV / fC**	**12mV / fC**
Shaping time	**190ns**	**188ns**
Non linearity	**< 1%**	**0.2%**
Crosstalk	**<0.3%**	**< 0.1%**
Power	**< 20mW**	**11mW / ch**

ALTRO Block Diagram



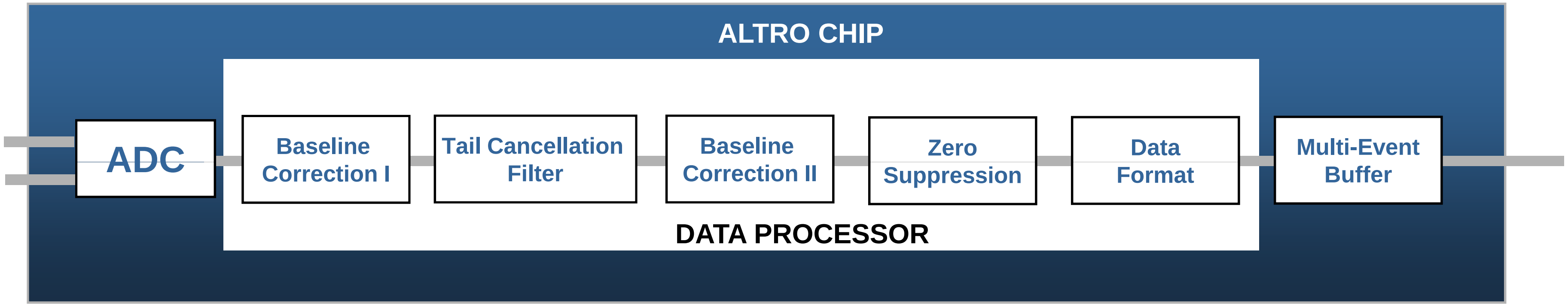
ALTRO layout and production data

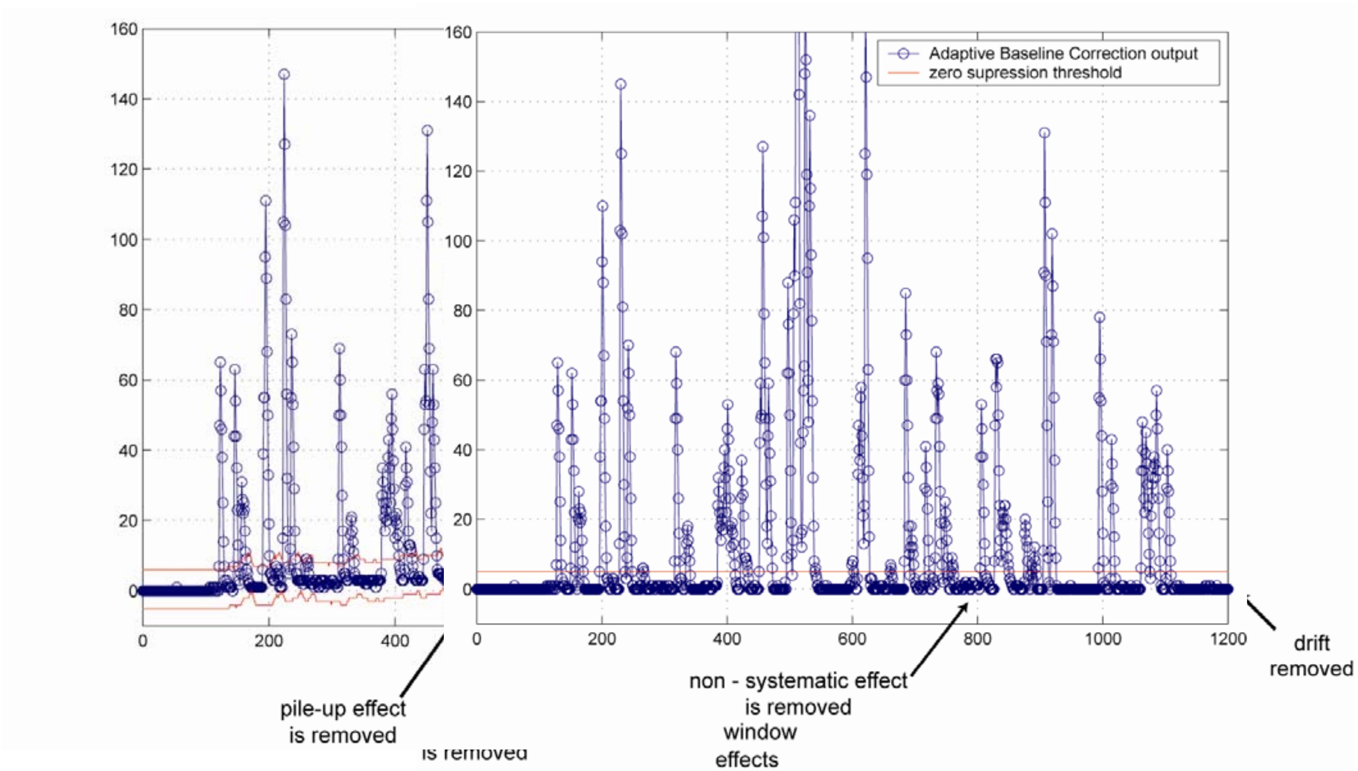


Process	**HCMOS-7 (0.25 µm)**
Area	**64 mm²**
Dimensions	**7.70 × 8.35 mm²**
Transistors	**6 milions**
Embedded memory	**800 kbit**
Supply voltage	**2.5 V**
Power	**16mW / channel**
Package	**TQFP-176**

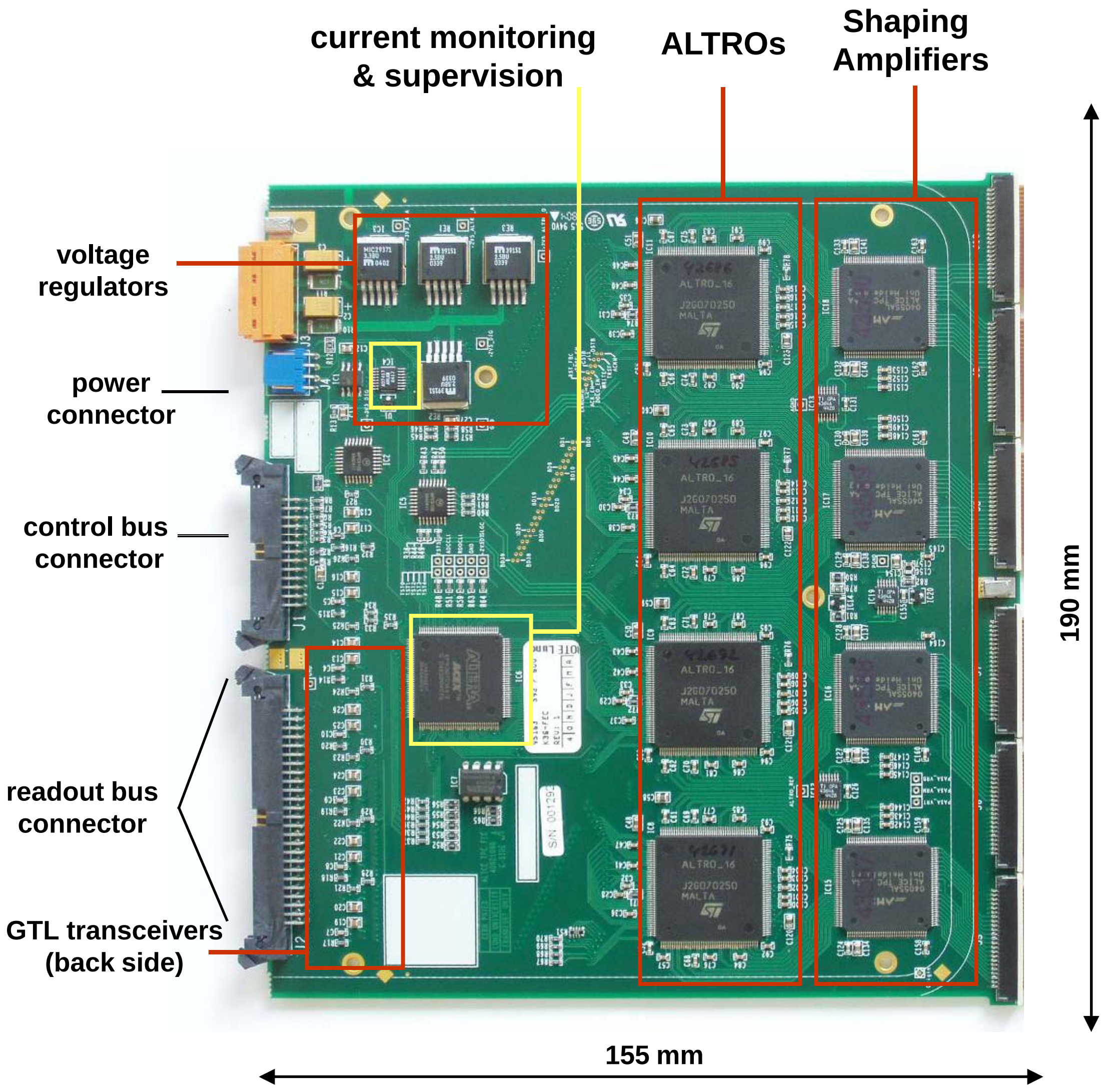
ER (12 wafers)	**Apr '02**
Mass prod. (125 wafers)	**Dec '02**
Yield	**84%**

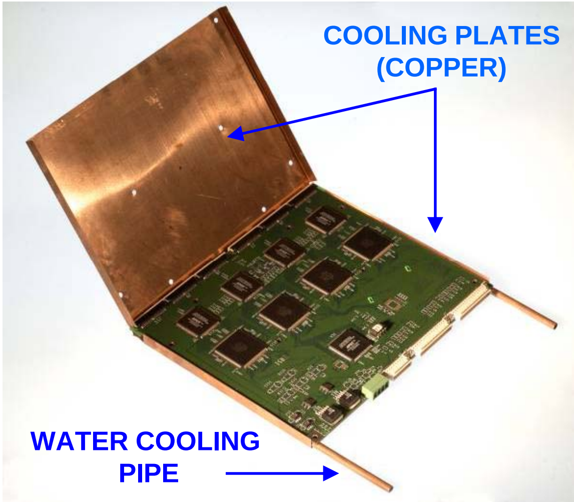
ALICE TPC ReadOut chip (ALTRO)

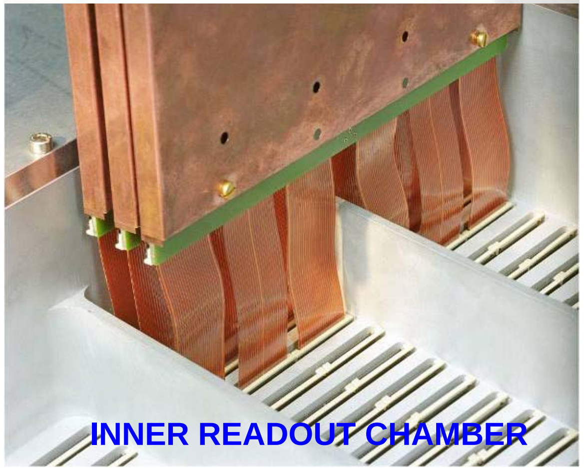




Front End Card: Layout, Cooling and Mounting

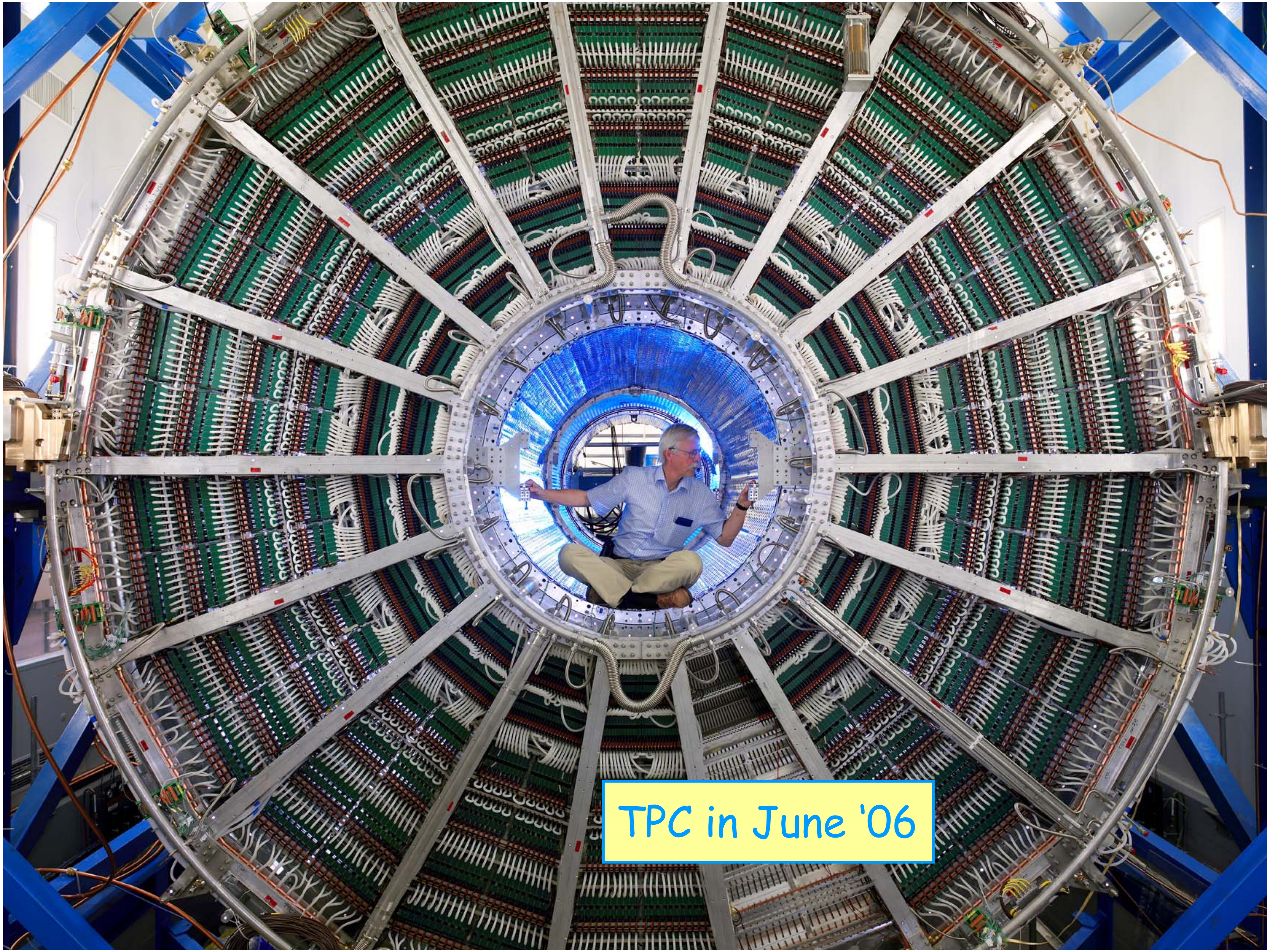




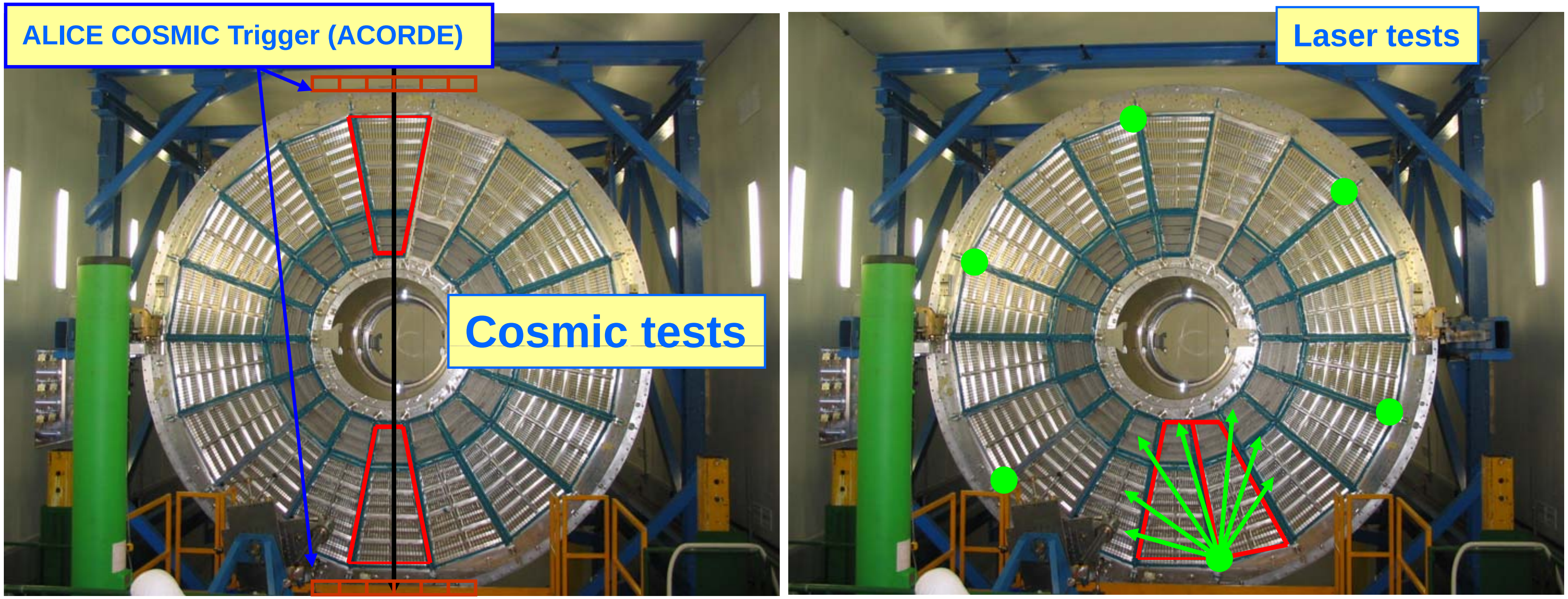


Installation of last Readout Chamber (Summer '05)

Installation of Front End Electronics (Feb-May '06)


TPC in June '06

Commissioning the TPC



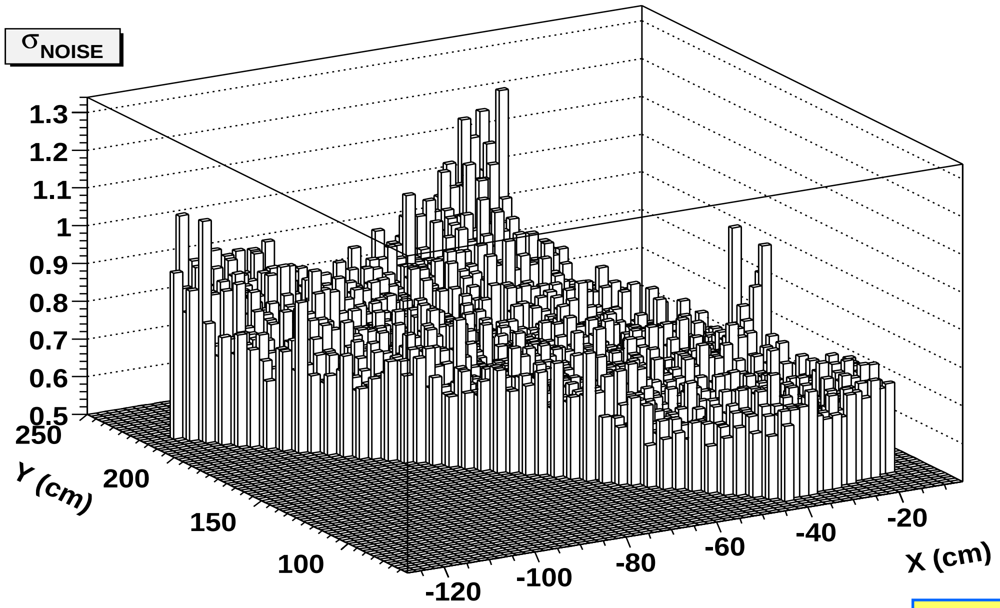
Only two sectors can be instrumented at a time with

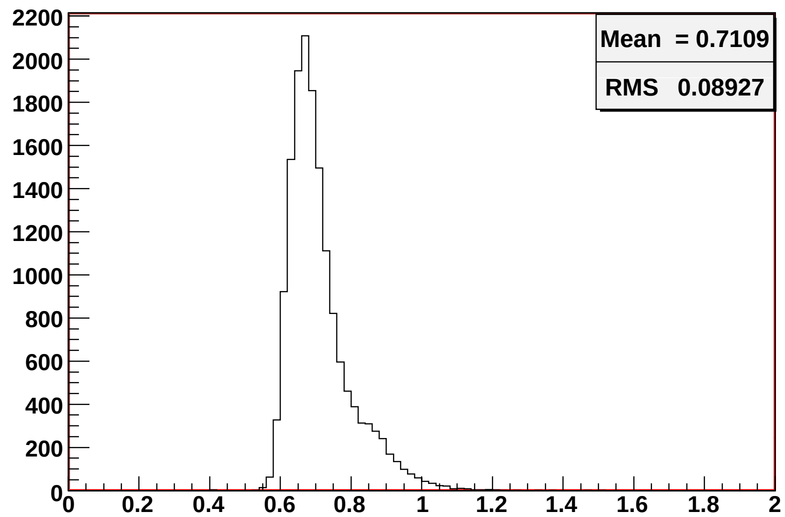
- Low Voltage Power Supplies
- Cooling

Commissioning objectives

Each pair of sectors continuously operated over 48 hours

- Test functionality of all components
- gas stability, noise, signal tails, gain homogeneity, space resolution, etc.

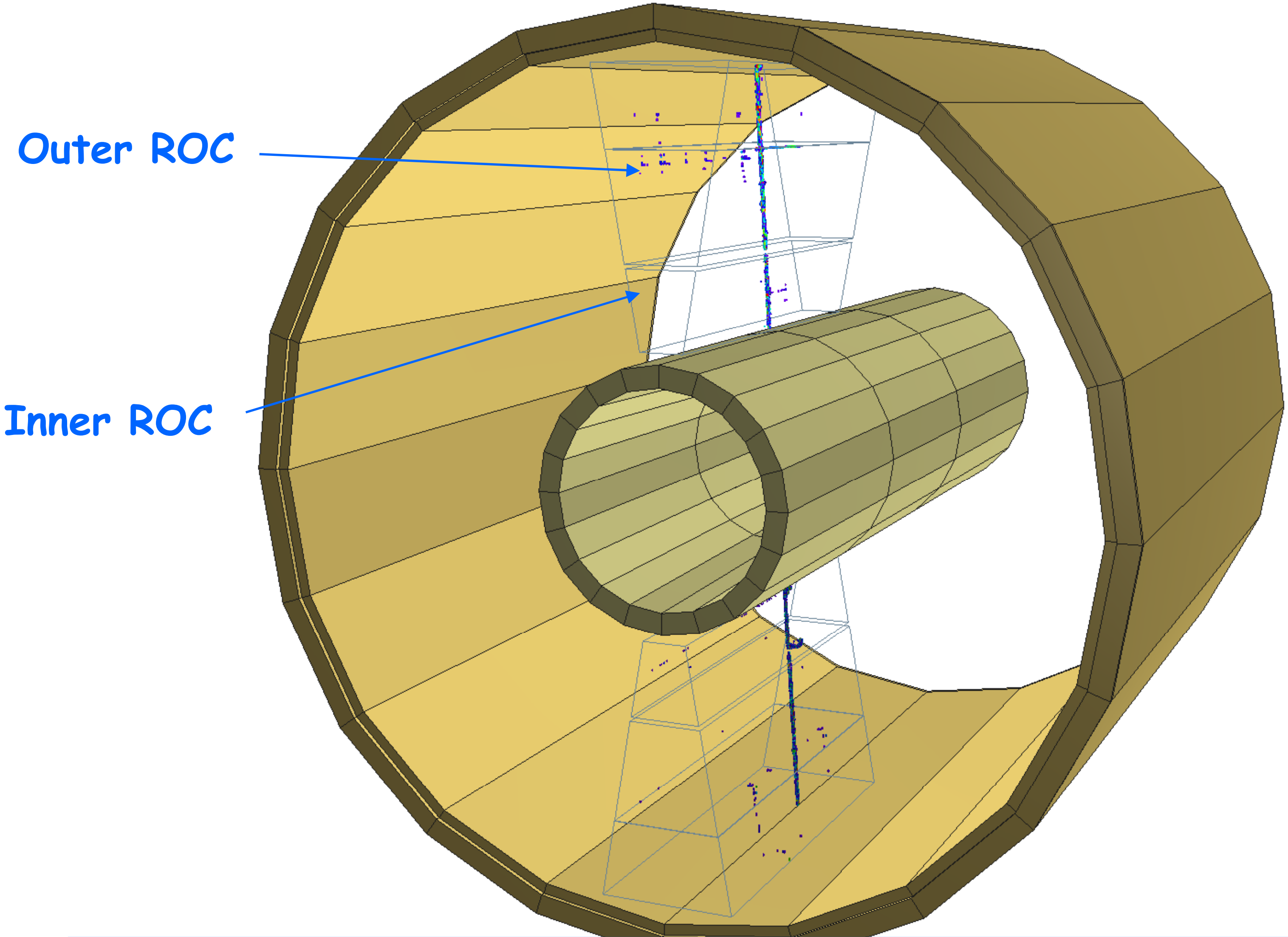




$\sqrt{(PASA_{noise}^2 + ADC_{noise}^2)} = 0.70$ ADC counts

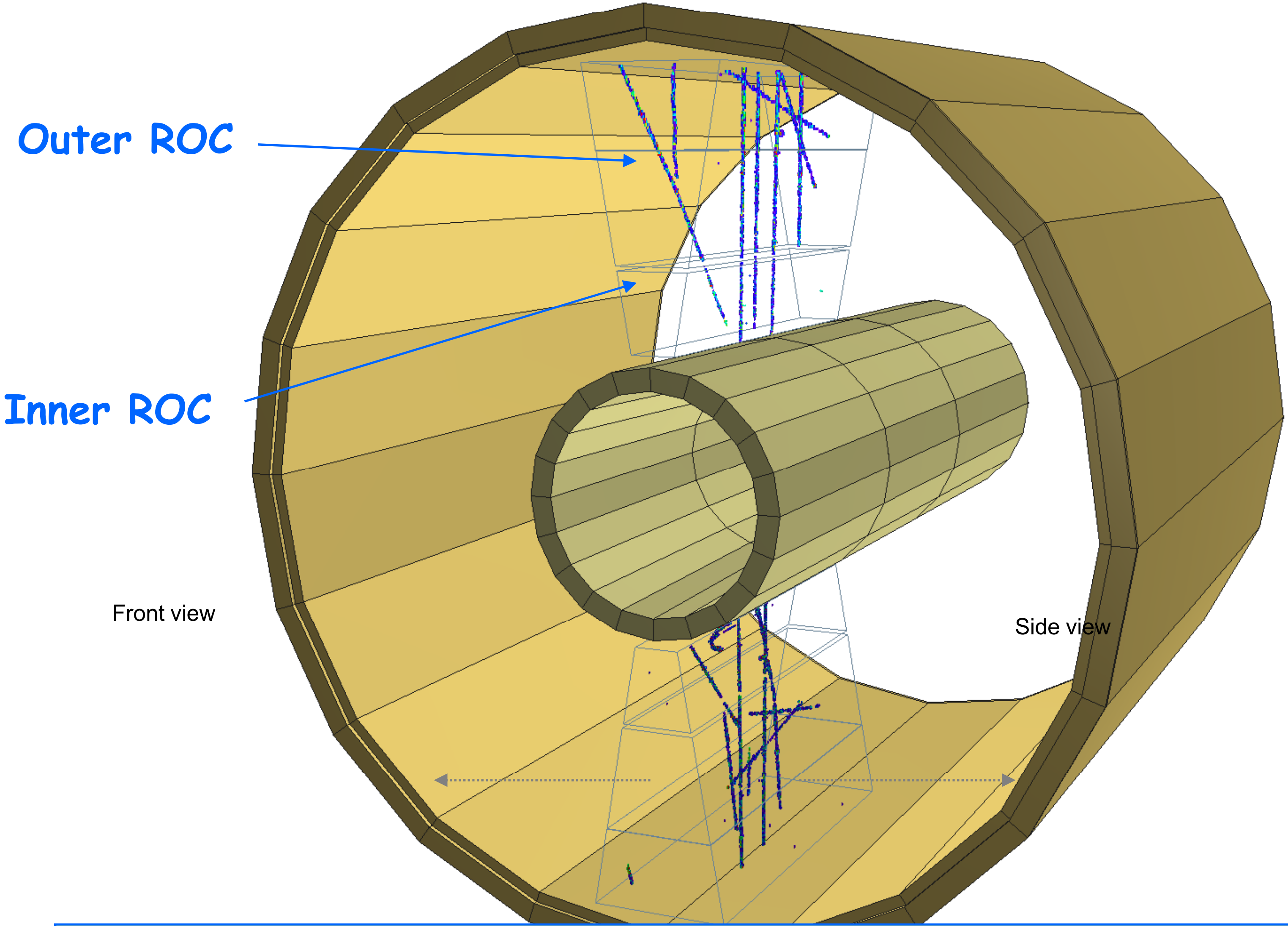
r.m.s. of the pedestals (s_{NOISE}) is below 1 ADC count

as required in the Technical Design Report



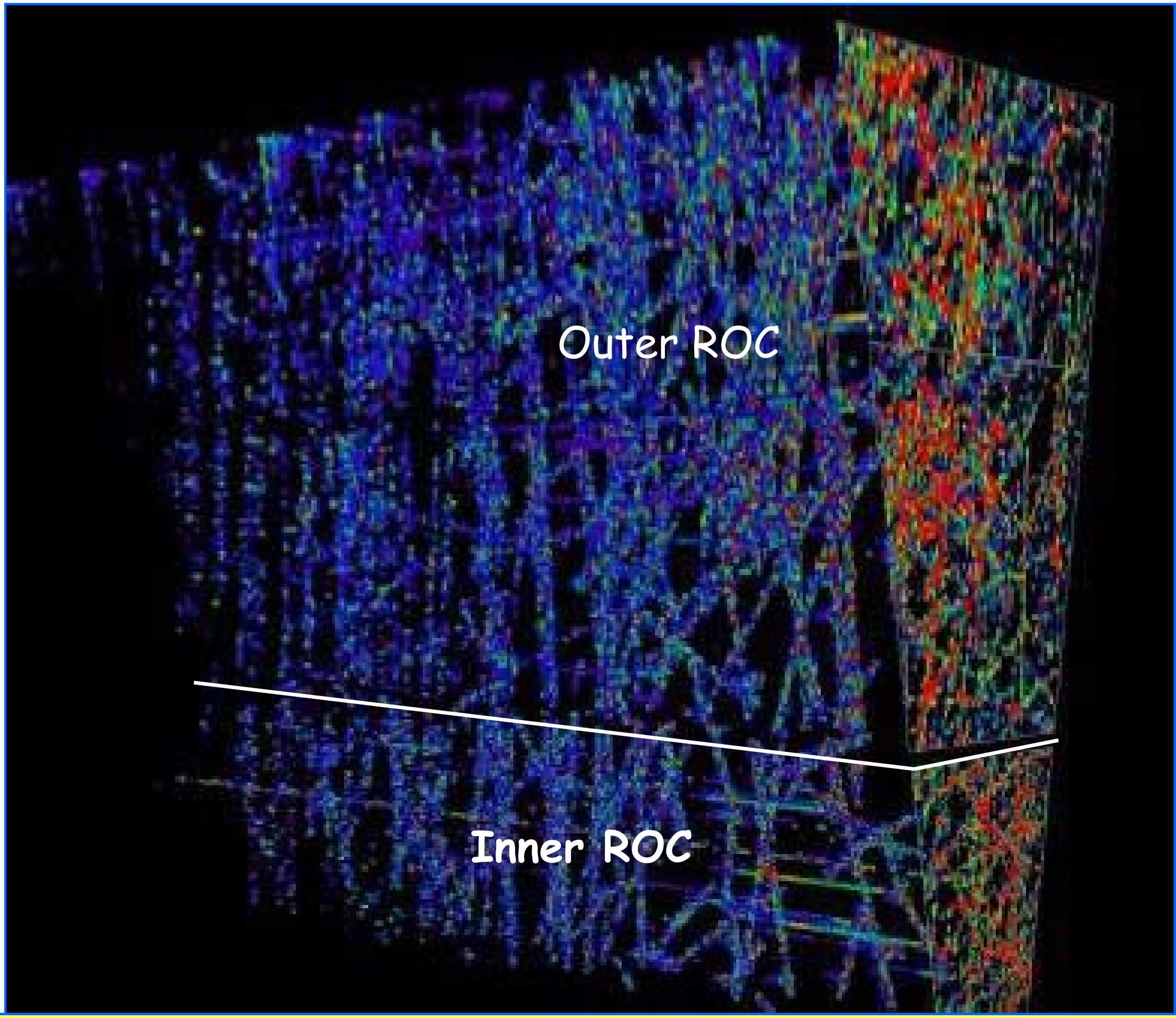
3-dimensional view of a cosmic muon track traversing 2 sectors

First cosmic rays events



3-dimensional view of a shower induced by cosmic rays

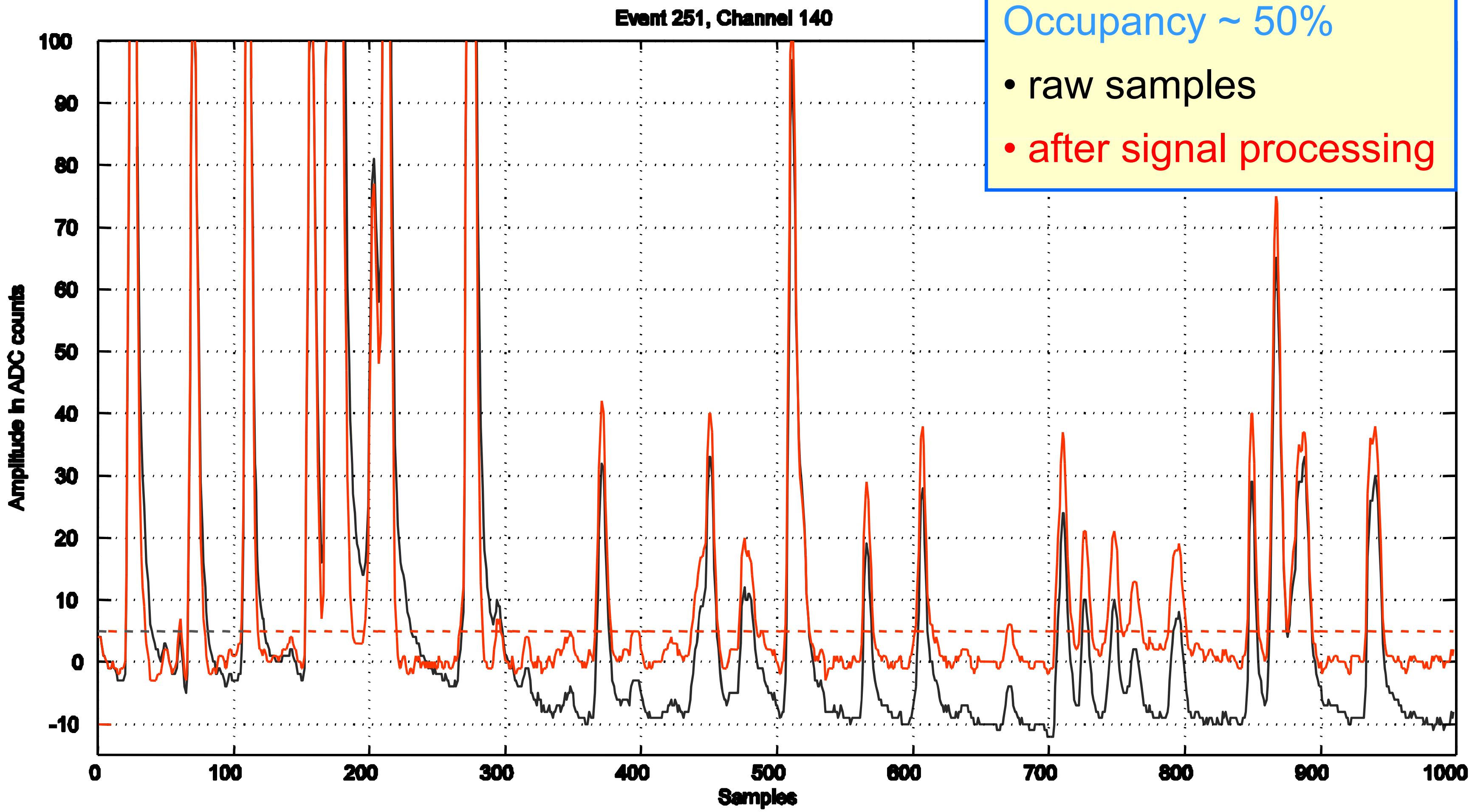
First cosmic rays events



High occupancy shower induced by cosmic rays

ALTRO Signal Processing

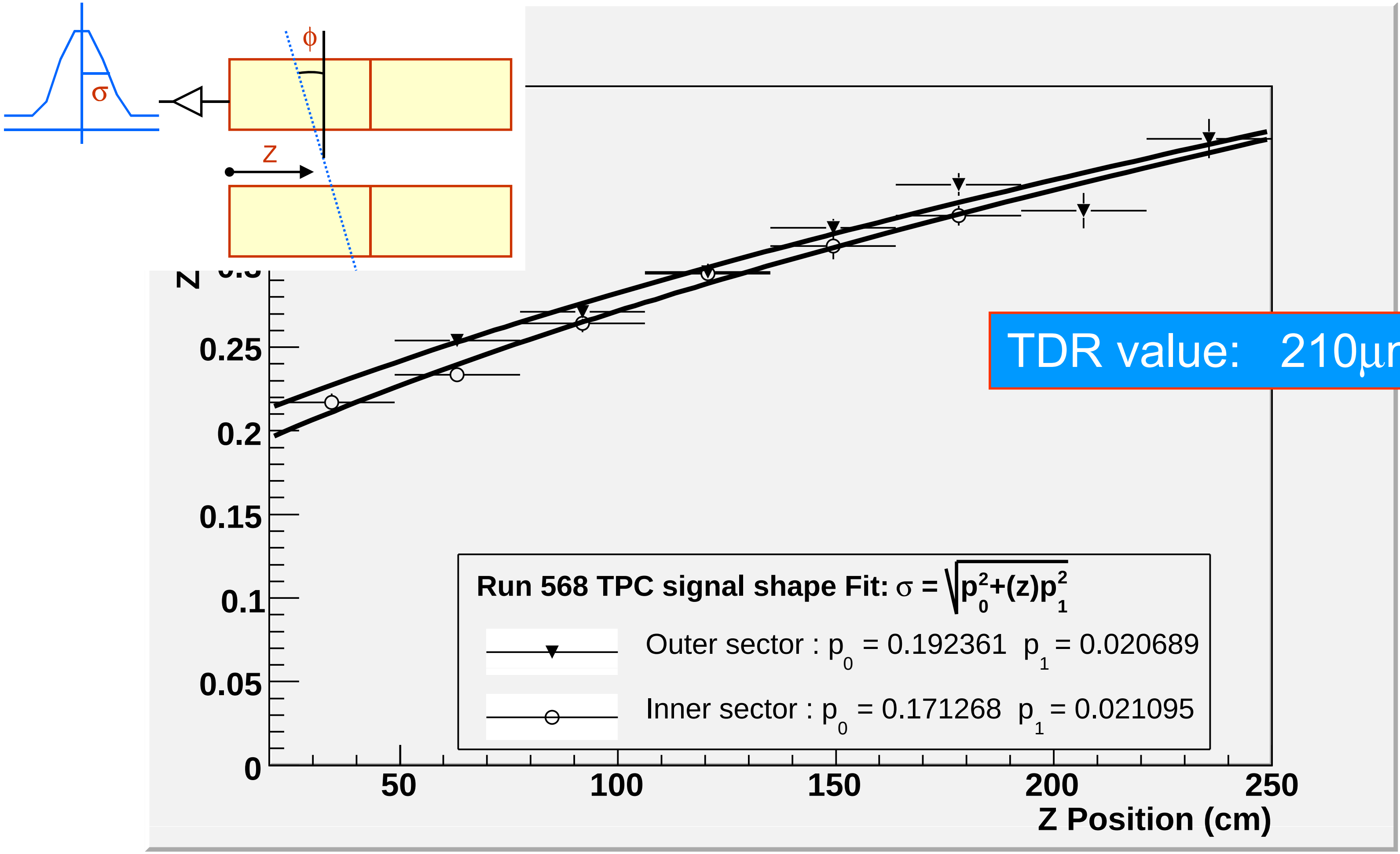
High Multiplicity cosmic rays



Occupancy ~ 50%

- raw samples
- after signal processing

cluster width - diffusion coefficient (1/2)

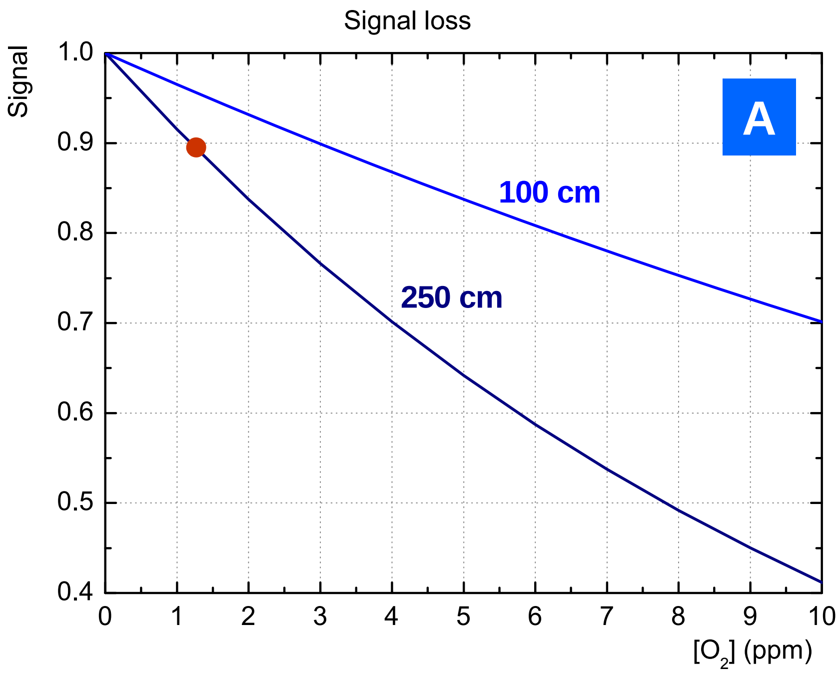


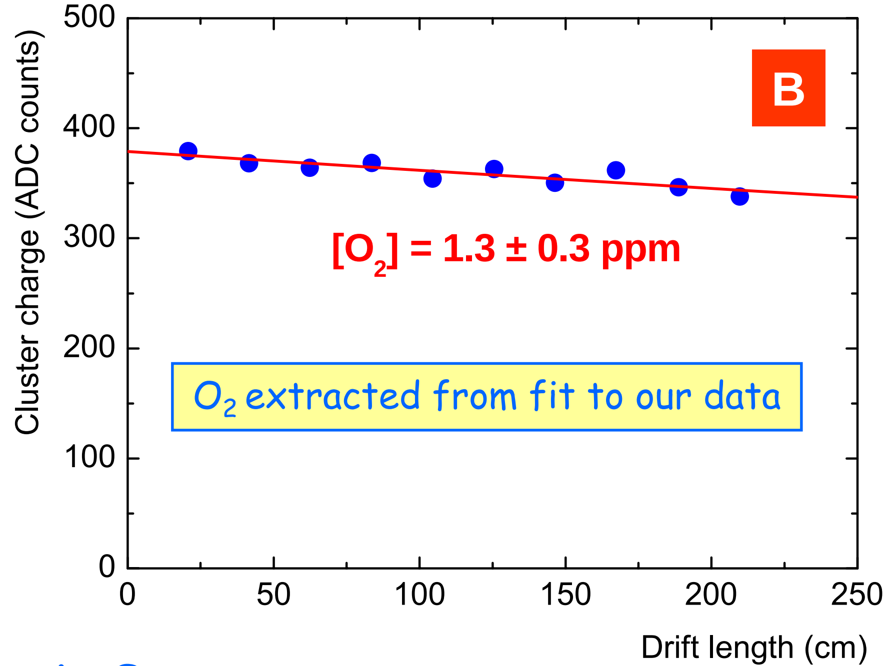
TDR value: 210µm / √cm

width (σ of a gaussian fit) of the charge signal in the longitudinal coordinate Z (drift direction) as function of Z

(cut on inclination angle tan(ϕ) <0.05)

Signal attenuation – electron attachment





A Signal loss due to electron attachmnet in O_2

- At very low O_2 content, signal loss is 3.5% / m / ppm

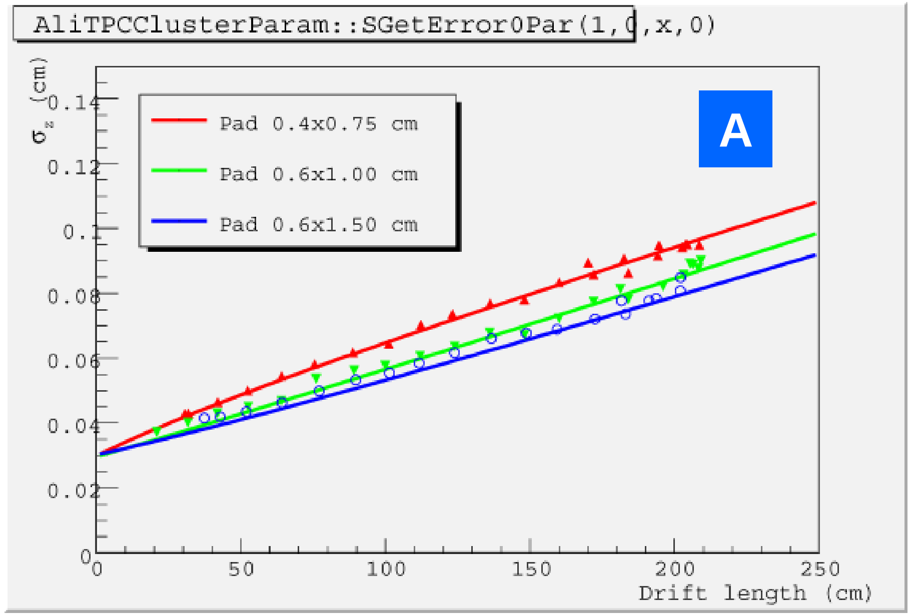
B Q total (total charge in the cluster) as function of z position (drift length)

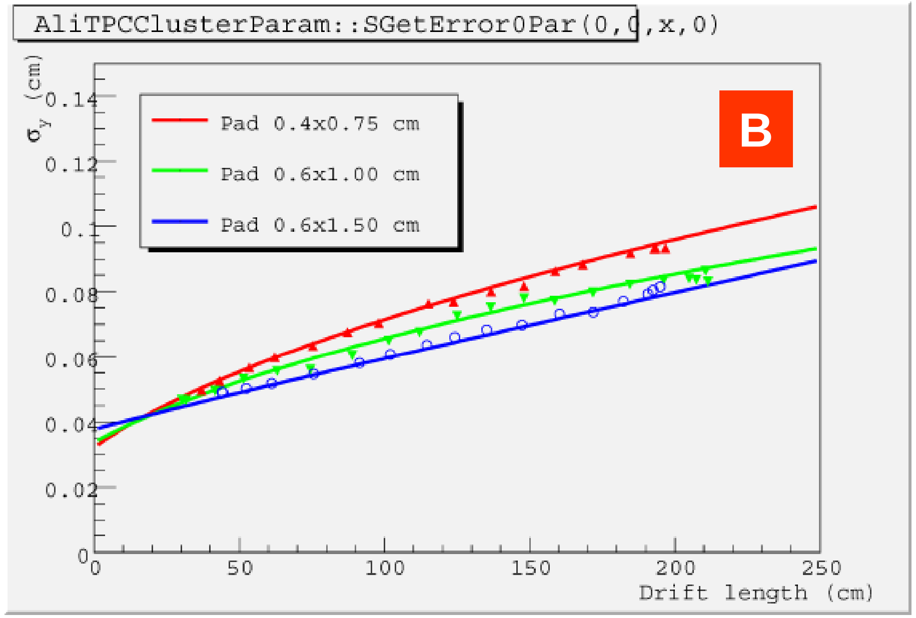
- relative decrease over the full TPC length: ~10%
- decrease due to electron capture and tail losses (diffusion)
- 1-2 ppm of O_2 measured with oxygen analyser

TDR specs
$[O_2]$ < 5ppm

Measurements @ 1/3 of nominal flow
Expected even better performance at full flow

Position resolution





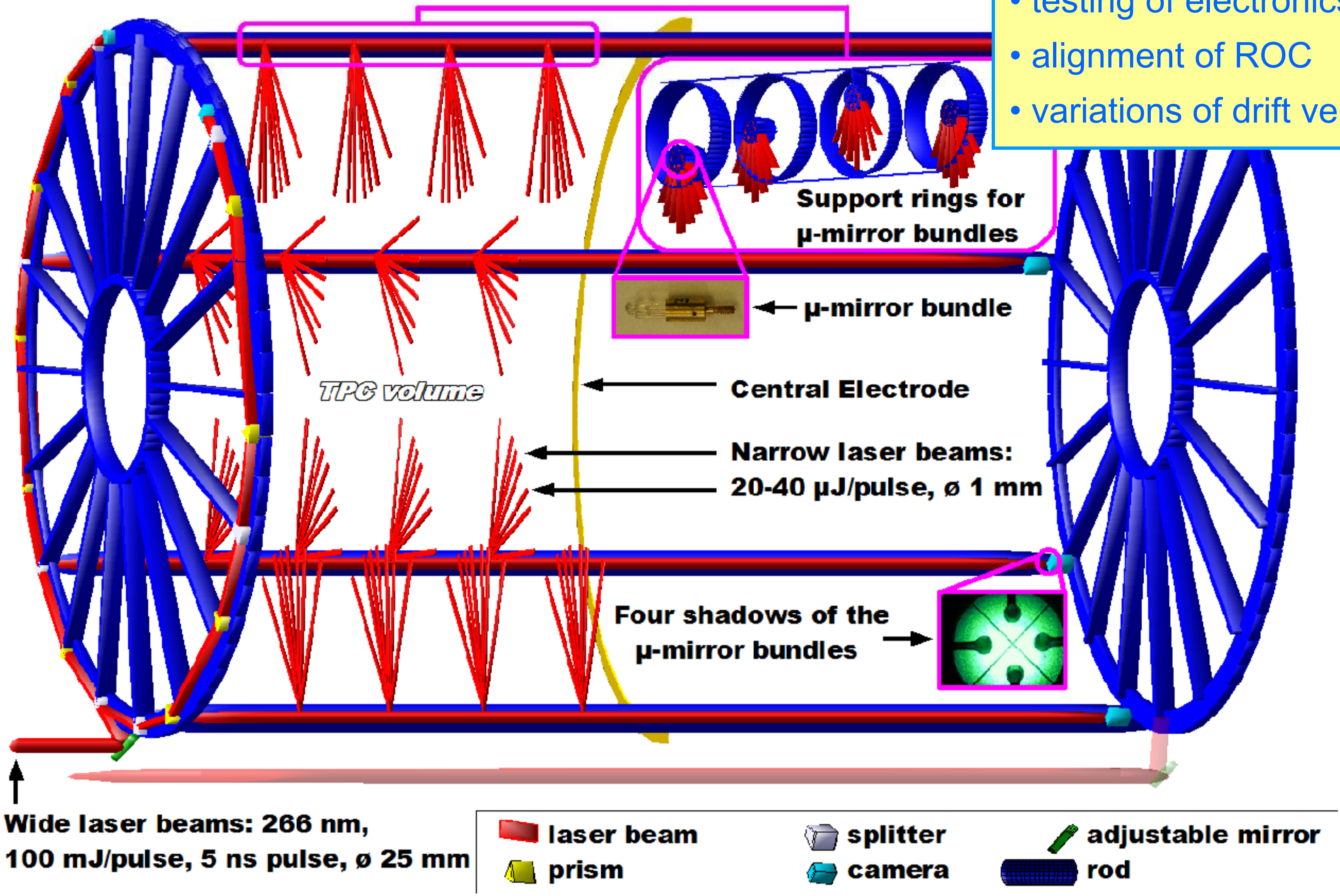
A space point resolution in Y direction as function of z position (cut on inclination angle tan(ϕ) <0.05)

B space point resolution in Y direction as function of z position (cut on inclination angle tan(ϕ) <0.05)

Laser system for the TPC

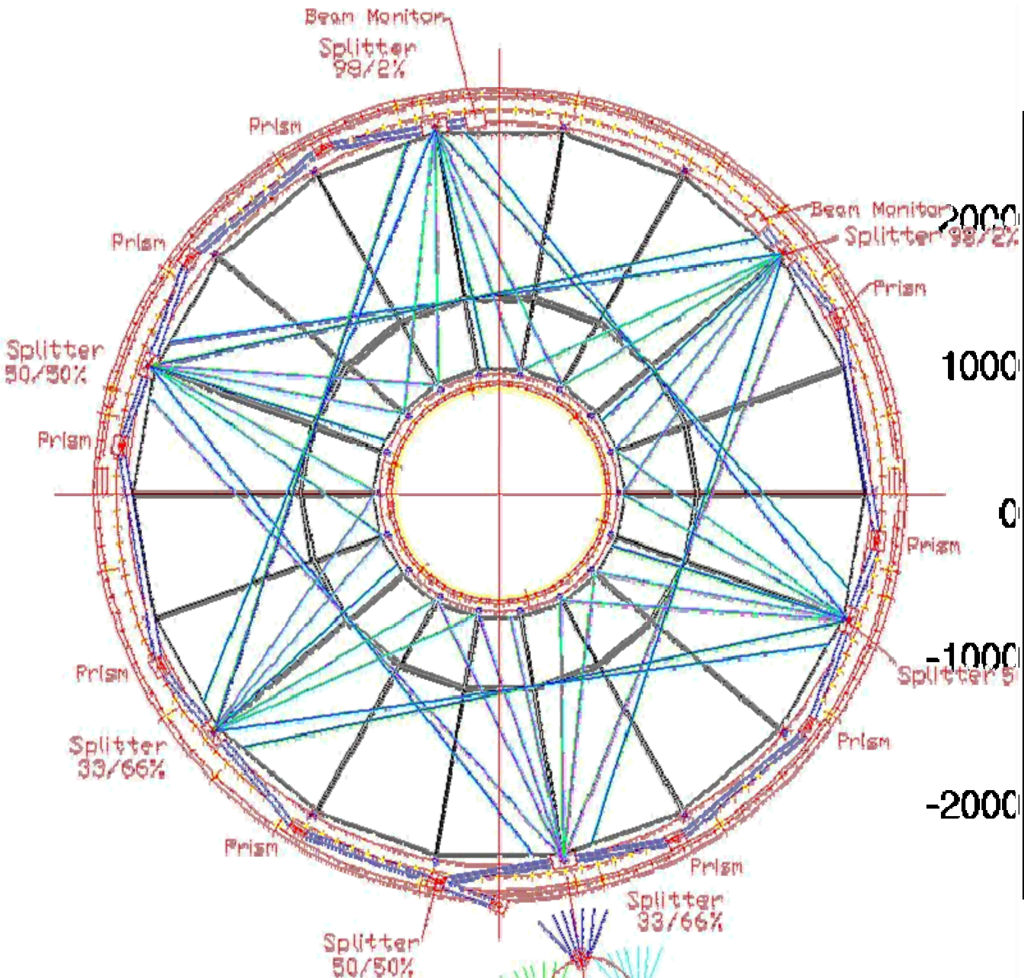
Test and Calibration

- testing of electronics
- alignment of ROC
- variations of drift velocity

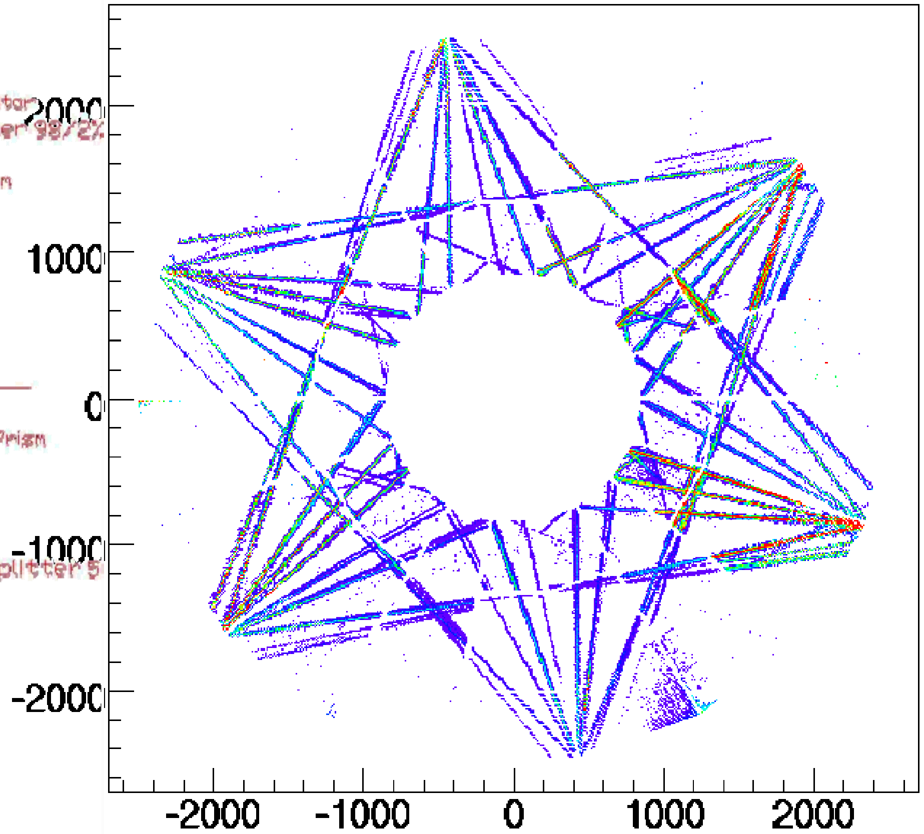


Laser tracks in the TPC

Design

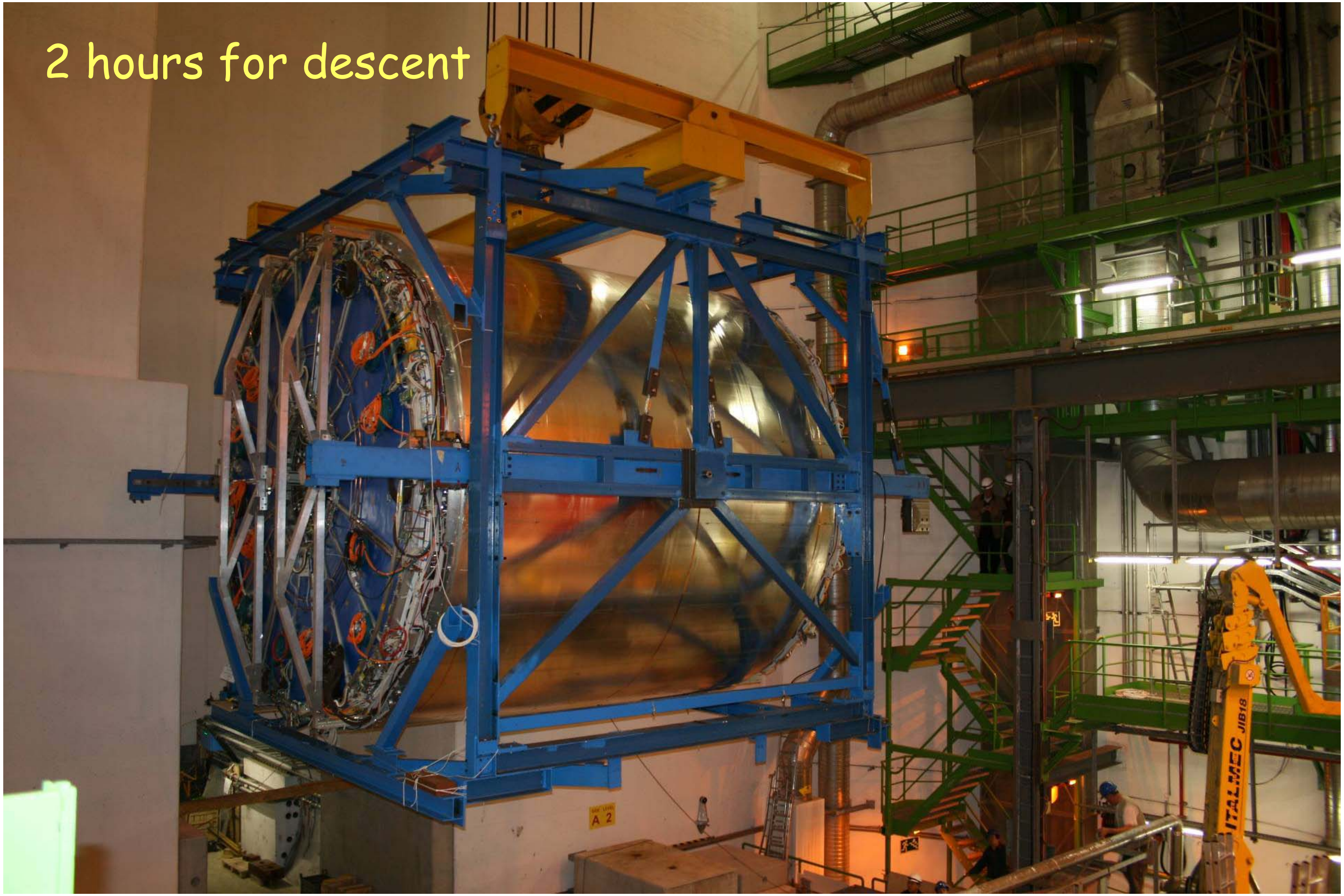


Measured

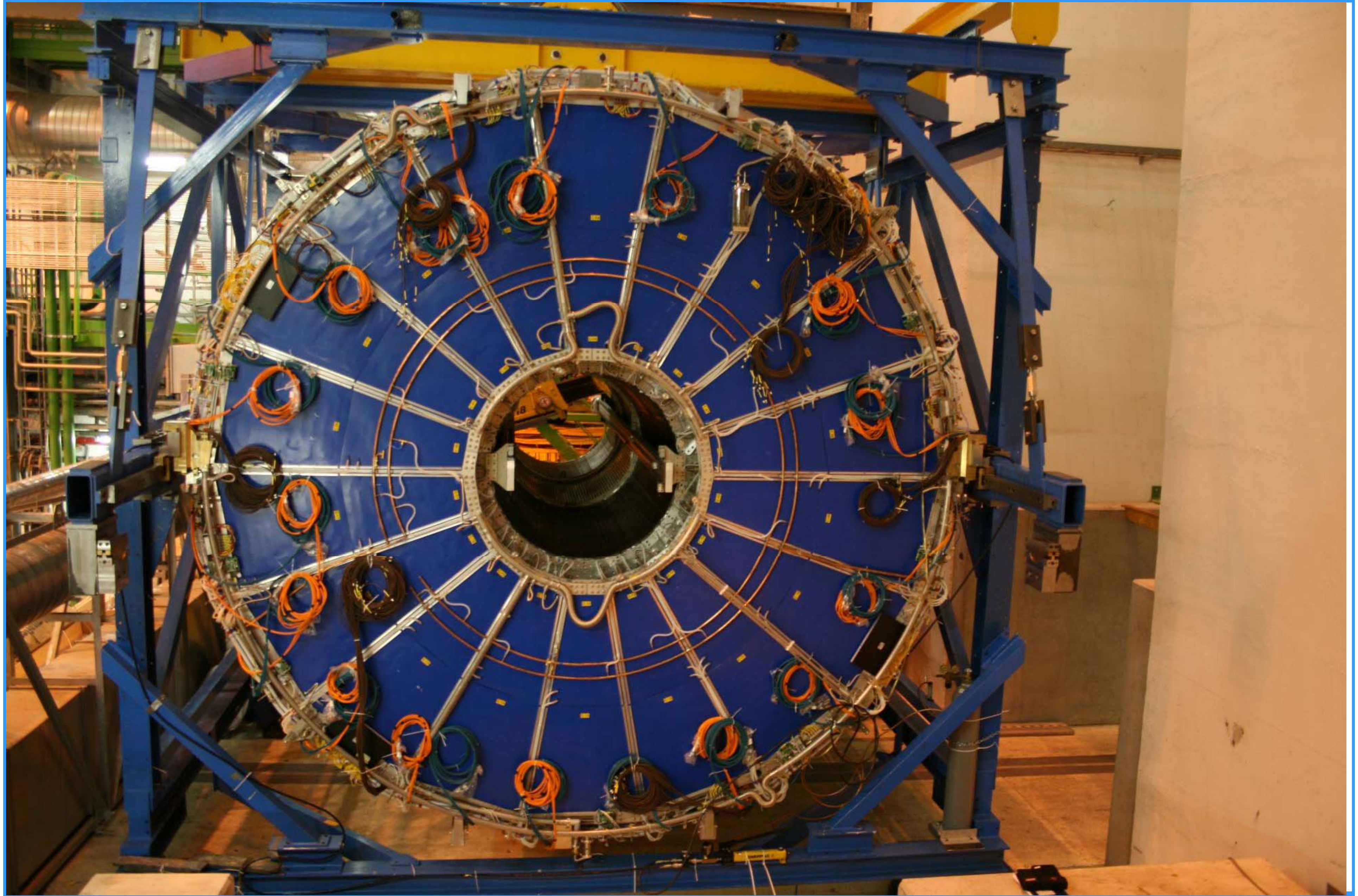


Drift velocity = 2.73 cm/µs ➔ agreement with drift monitor detector (Goofie)

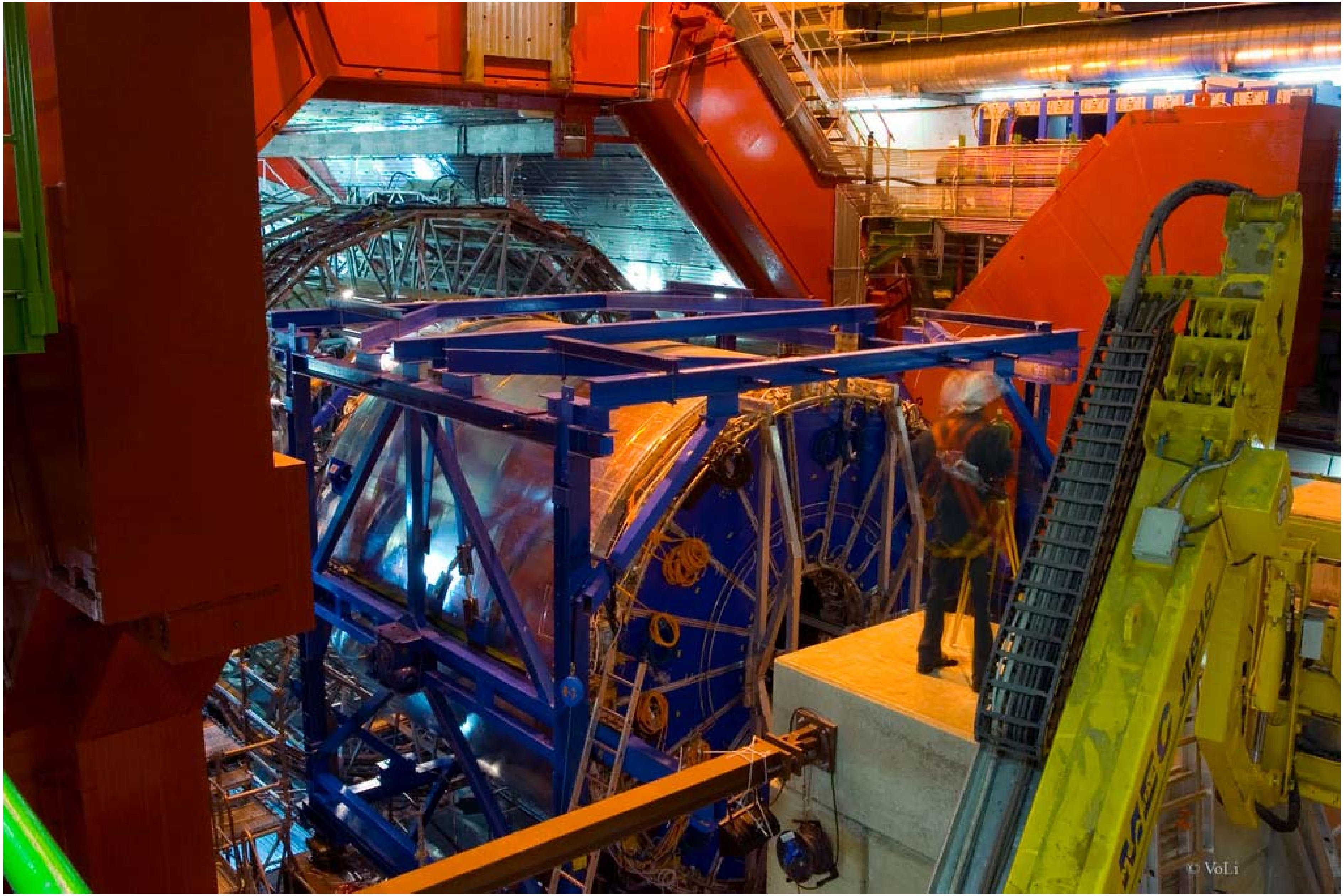
Descend to the cavern (Jan '07)



TPC in the cavern floor



Ready to go inside the spaceframe (Jan '07)



Inside the Space-frame (May '07)

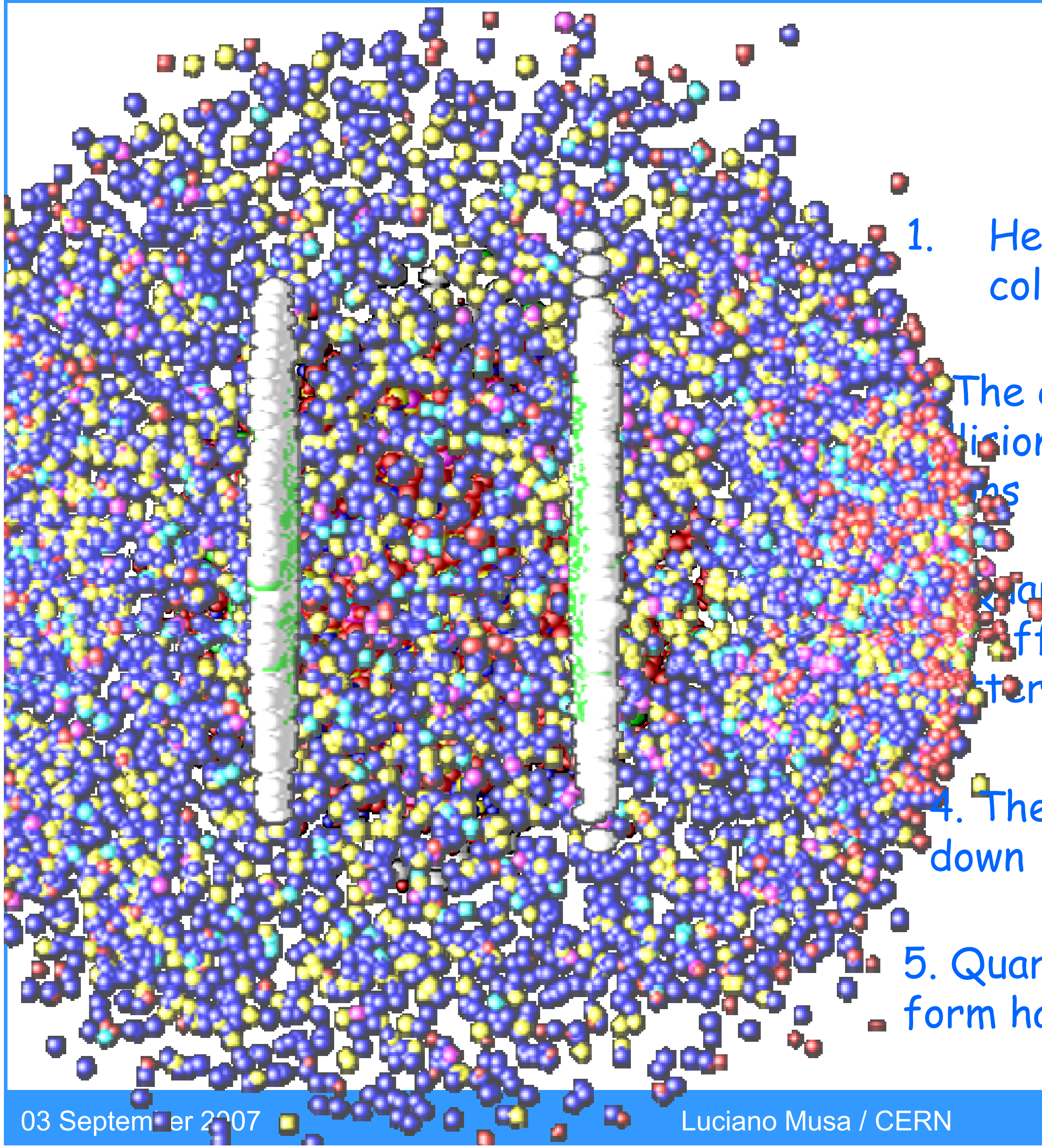
Summary

- The largest TPC ever built will be at the hart of the ALICE Experiment to study the ultra-relativistic collision of heavy ions
- High optimization of all components and some innovative aspects
- Commissioning, two sectors at a time, with cosmic and laser tracks since June '06
- Preliminary results show many features achieve the expected performance:
    - Gas pressure: excellent stability!
    - Noise < 1000 e
    - Signal well separated from noise ("S/N" > 30 for MIP)
    - Space point resolution ~ 1mm after 2.5m of drift

- Jan – Mar '07: installation underground in the ALICE Detector
- Nov – '07: start commissioning of full TPC in its final position in ALICE

Back-up Slides

LHC: The closest approximation of the Big Bang



Mini Bangs

1. Head-on ultra-relativistic collision of two heavy ions

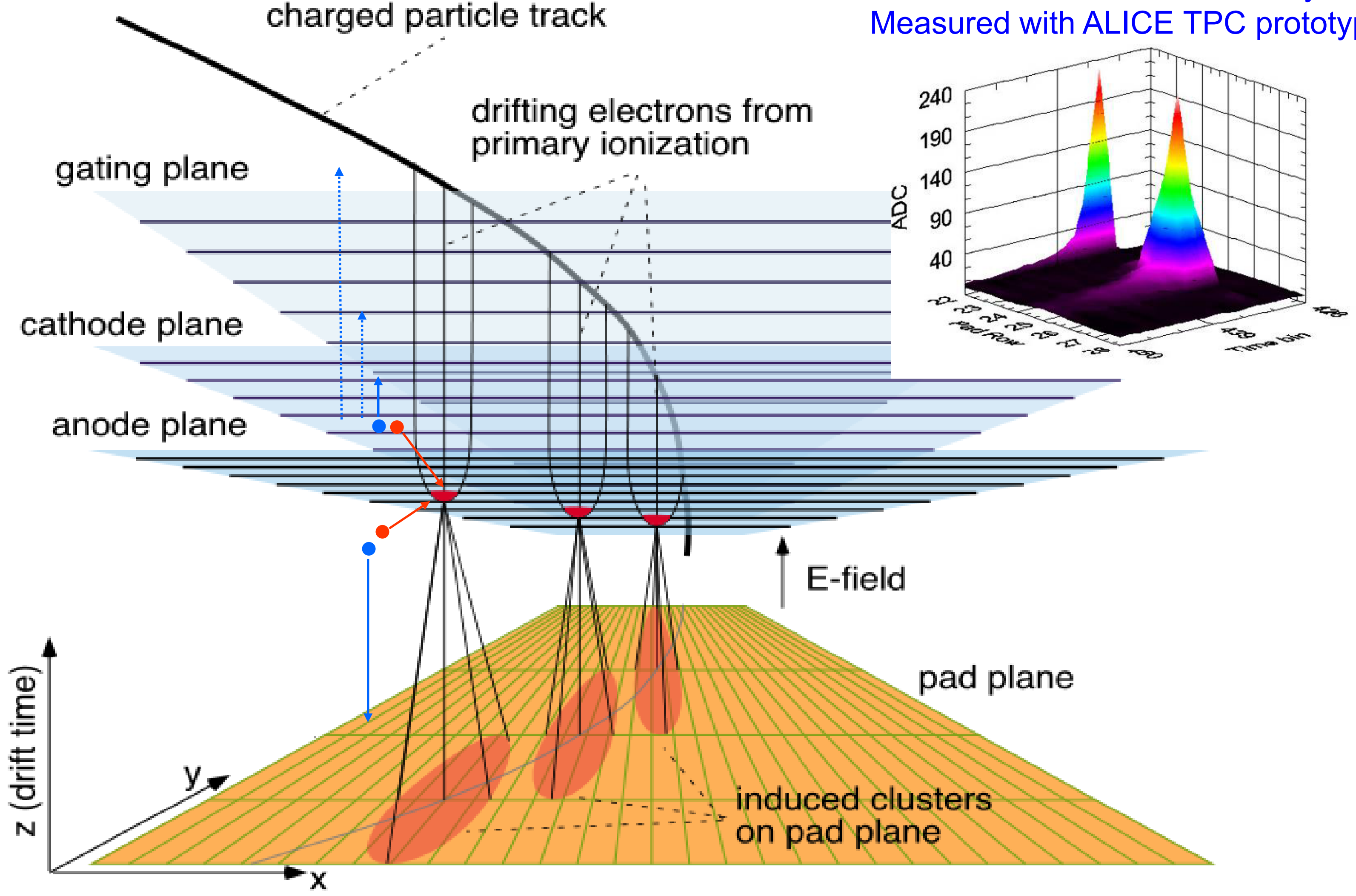
The energy made available in the ...ision generates many quarks and ...ns

...arks and gluons interact under ...ffect of strong interaction: ...ter tends towards equilibrium

4. The system expands and cools-down

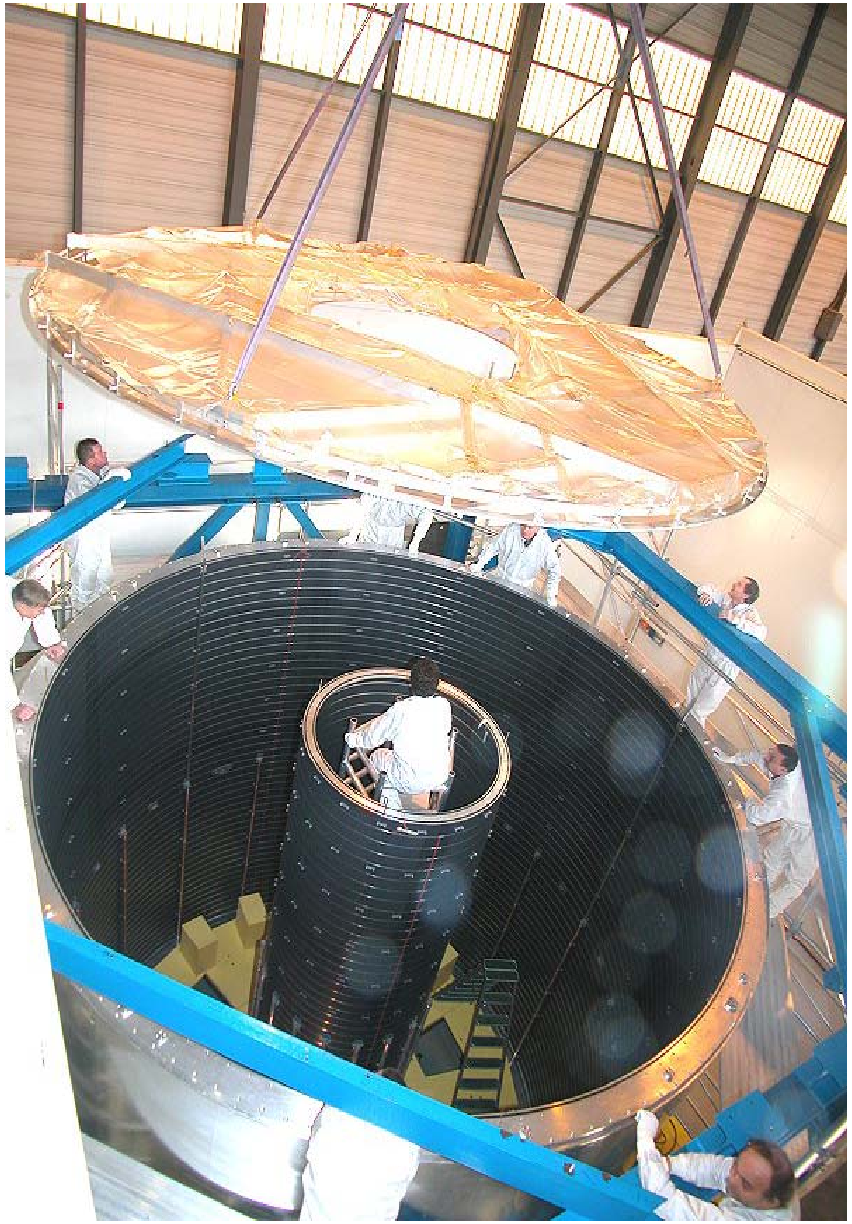
5. Quarks and gluons link together to form hadrons

TPC WORKING PRINCIPLE

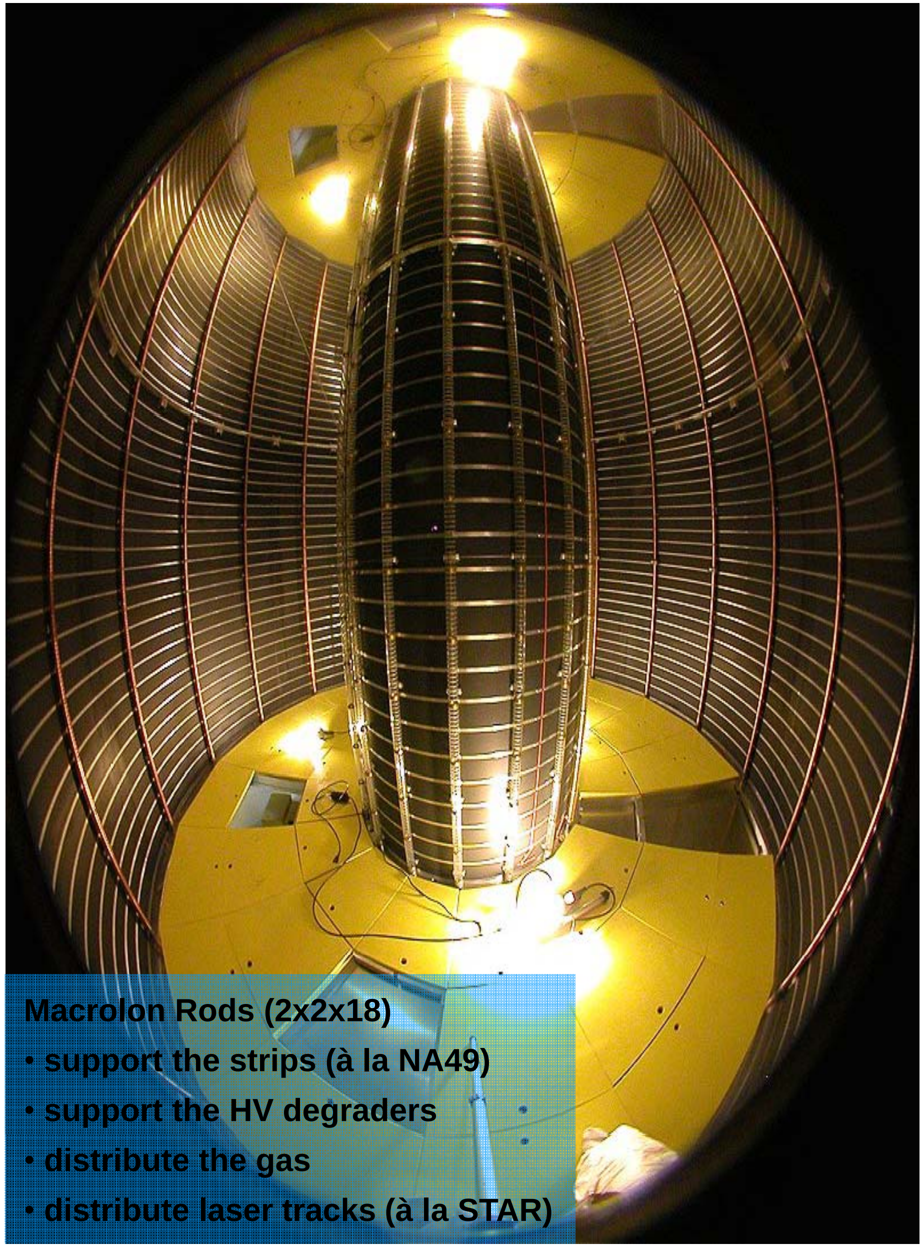


Ionization from ^{83}Kr Decay
Measured with ALICE TPC prototype)

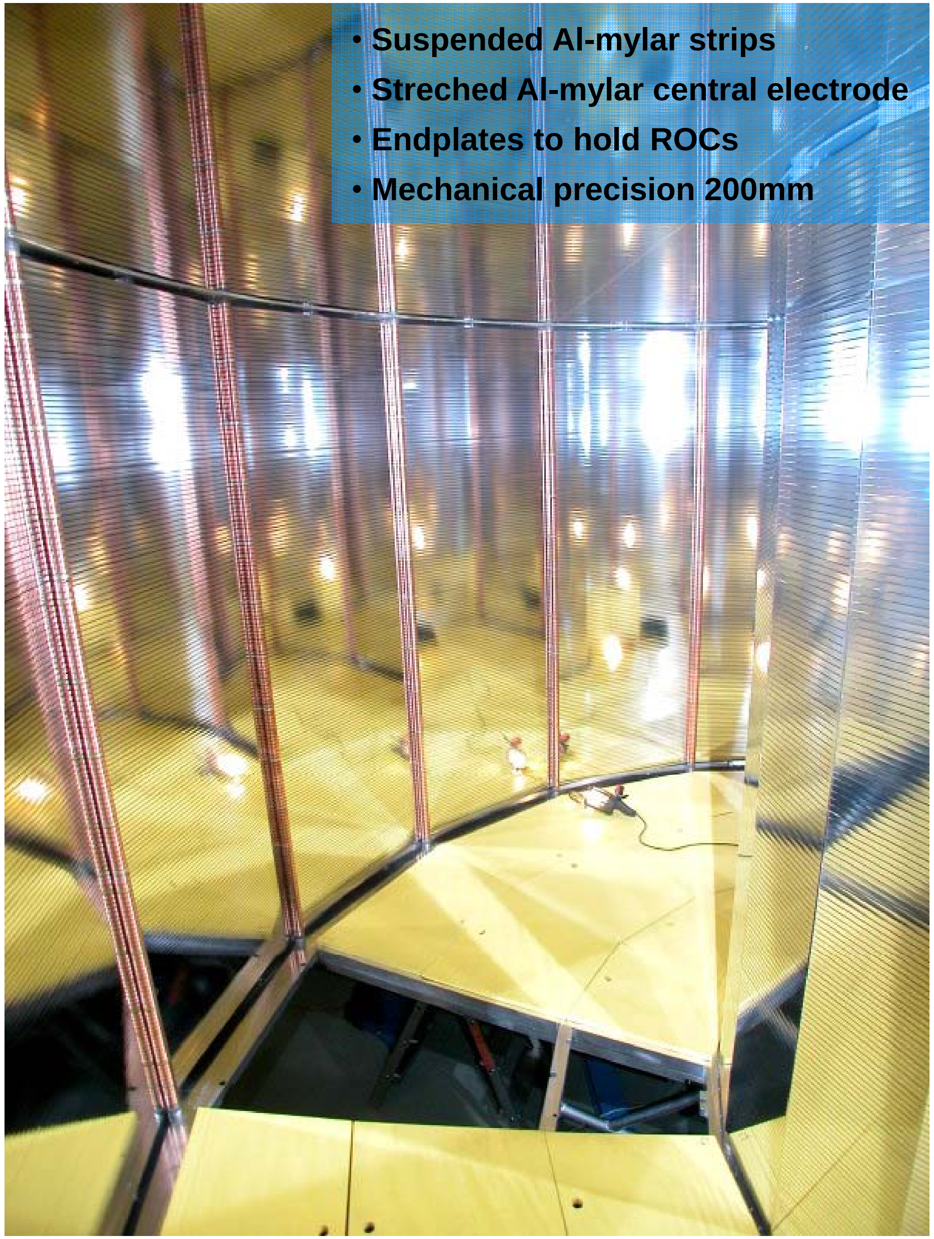
Field Cage - Construction



Field Cage - Construction



Macrolon Rods (2x2x18)
- support the strips (à la NA49)
- support the HV degraders
- distribute the gas
- distribute laser tracks (à la STAR)

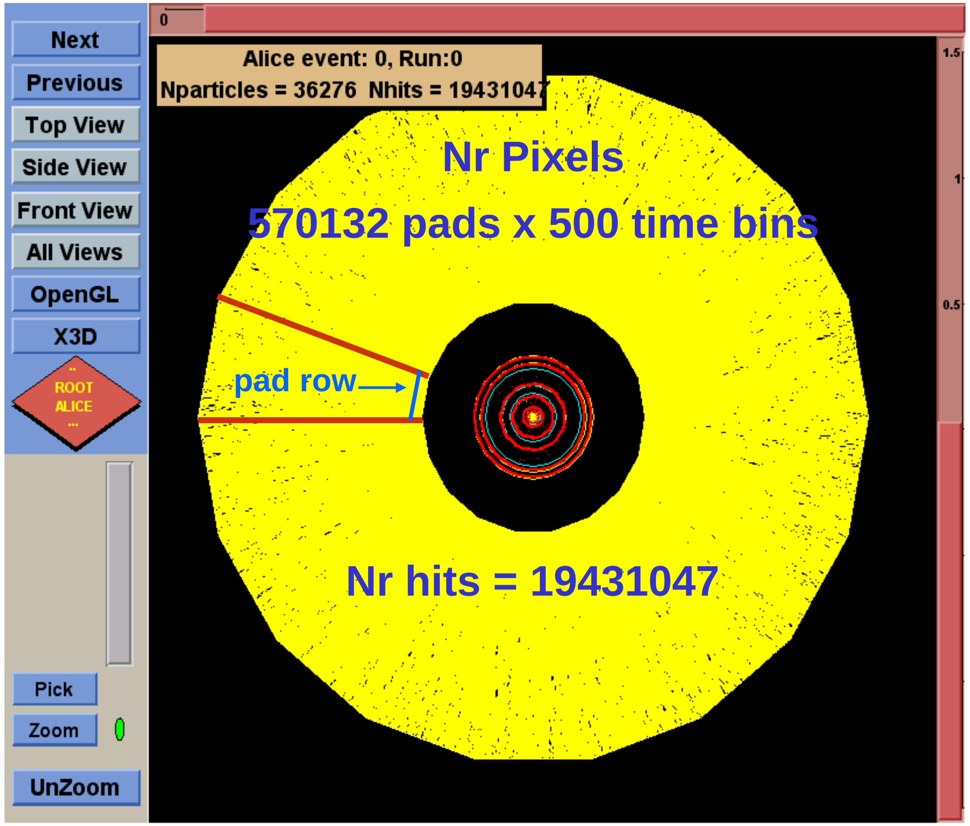


- Suspended Al-mylar strips
- Streched Al-mylar central electrode
- Endplates to hold ROCs
- Mechanical precision 200mm

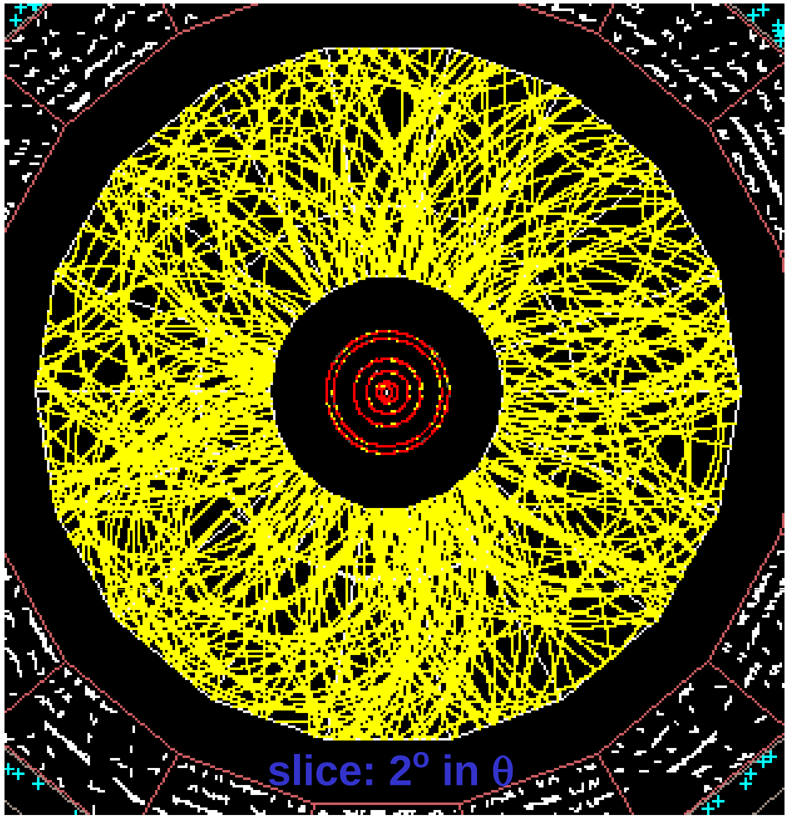
The ALICE Event Display

Projection of the drift volume into the pad plane

$dN_{ch} / dy = 8000$ ➡ 2×10^4 charged particles



Projection of a slice (2° in θ)



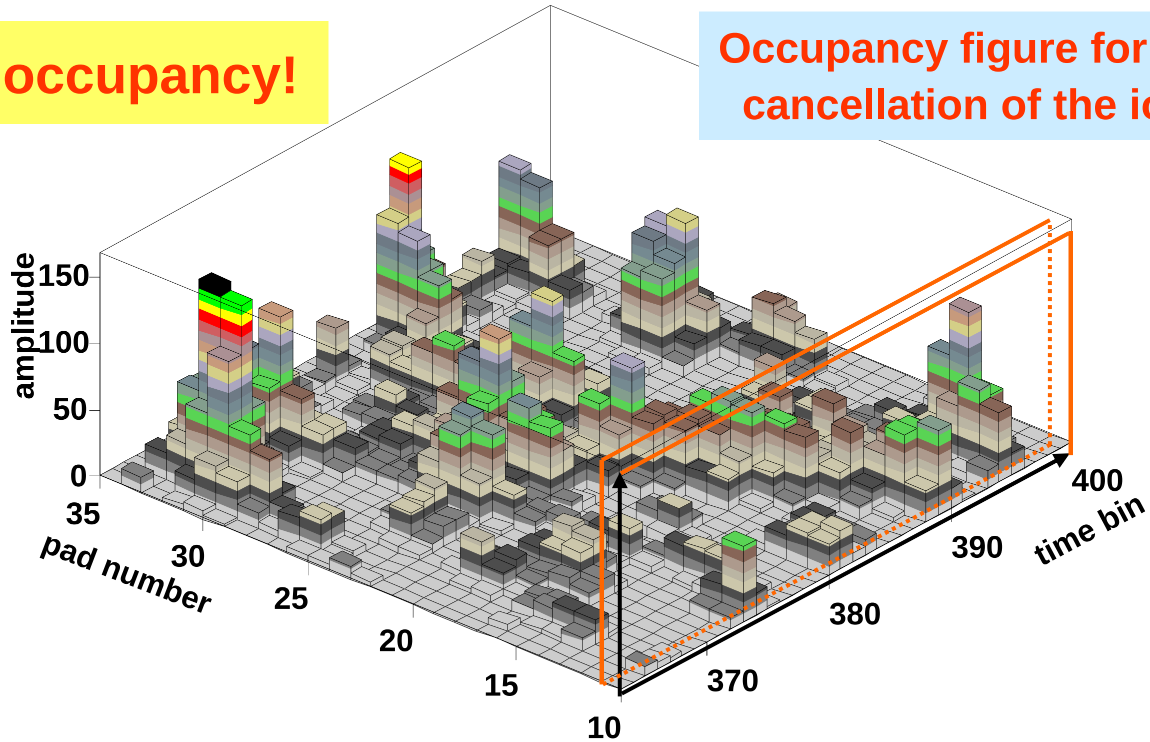
TPC OCCUPANCY(*) IN THE PAD-TIME SPACE

- INNERMOST PAD ROW: 50%
- OUTERMOST PAD ROW: 17%
- AVERAGE OCCUPANCY: 25%

(*)Occupancy = N_{ABOVE} / N_{ALL}

40% occupancy!

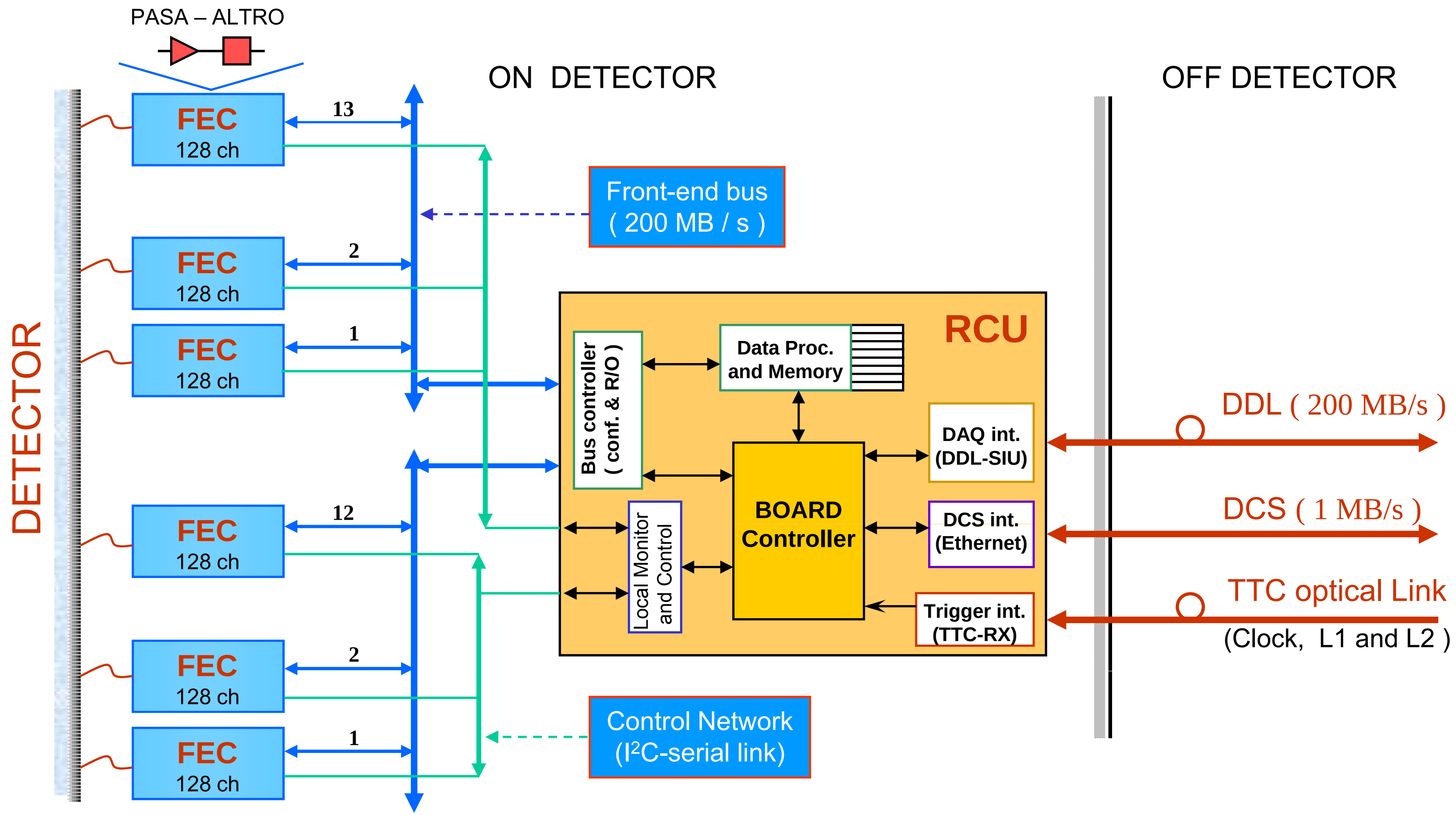
Occupancy figure for an ideal cancellation of the ion tail!



CLUSTER AT THE INNERMOST PAD ROW OF THE TPC

Architecture and Main Components

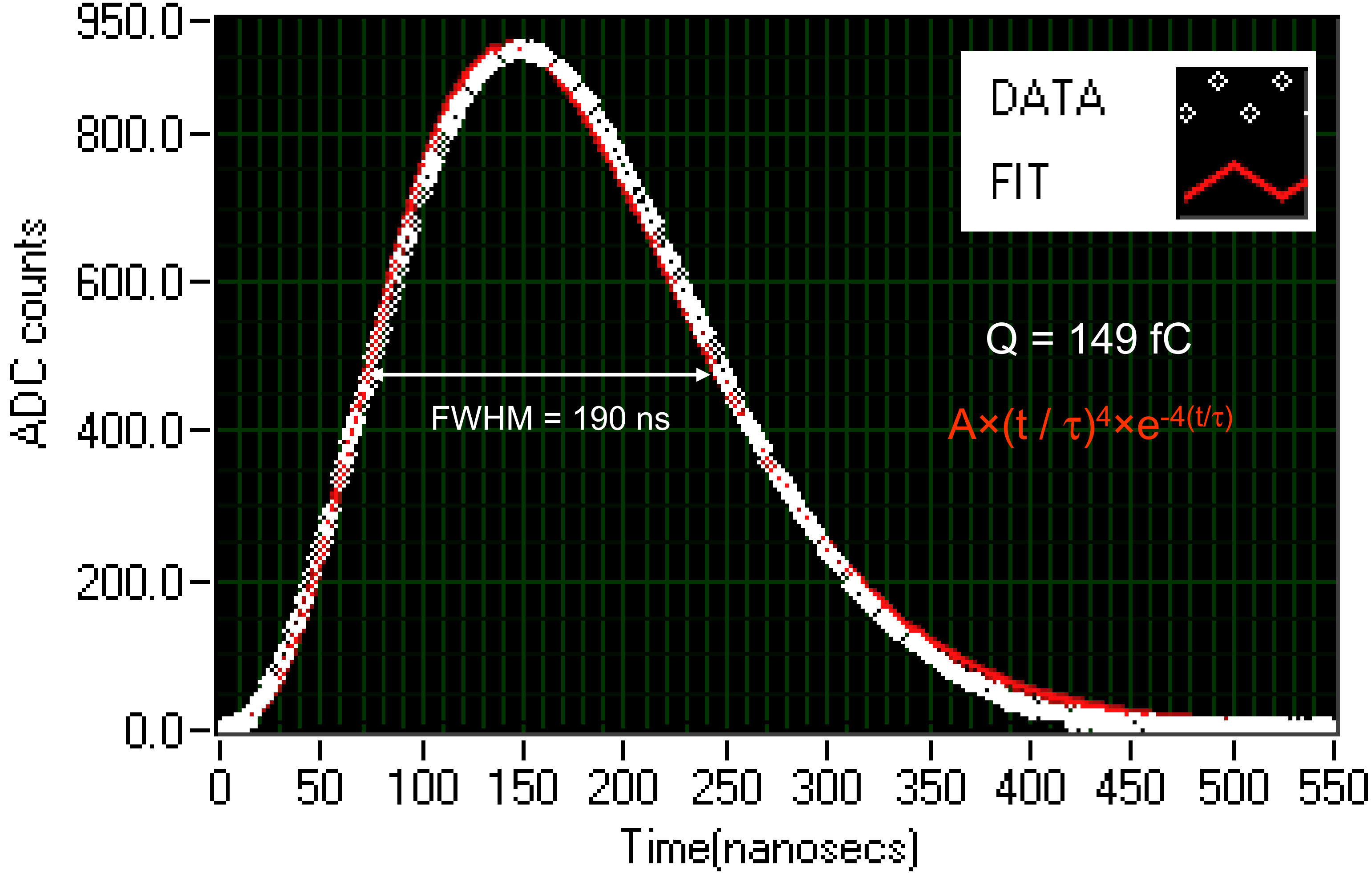
Each of the 36 TPC Sectors is served by 6 Readout Partitions

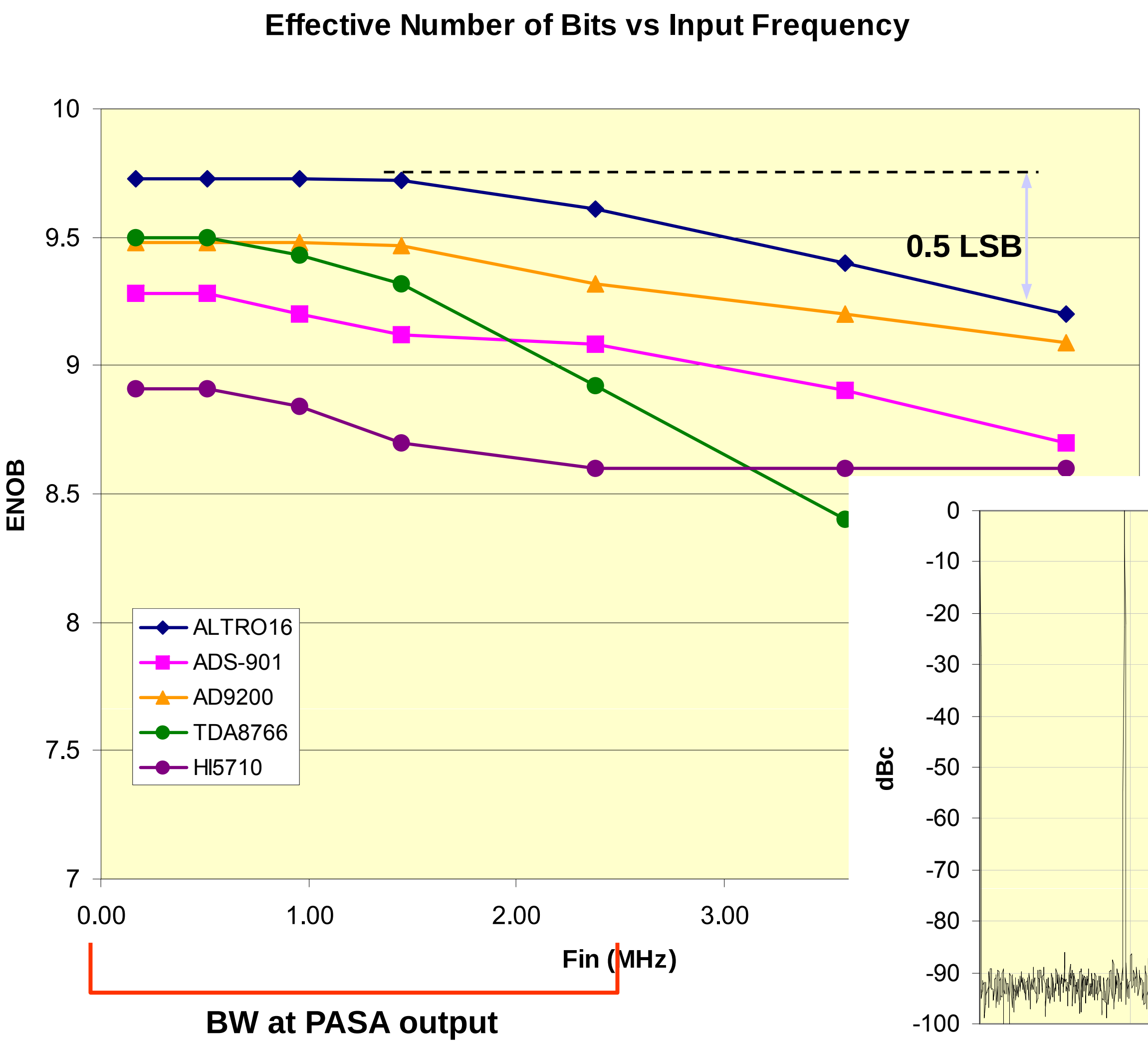


Overall: 4356 Front End Card 216 Readout Partitions

Pre-Amplifier Shaping Amplifier (PASA)

Impulse Response Function

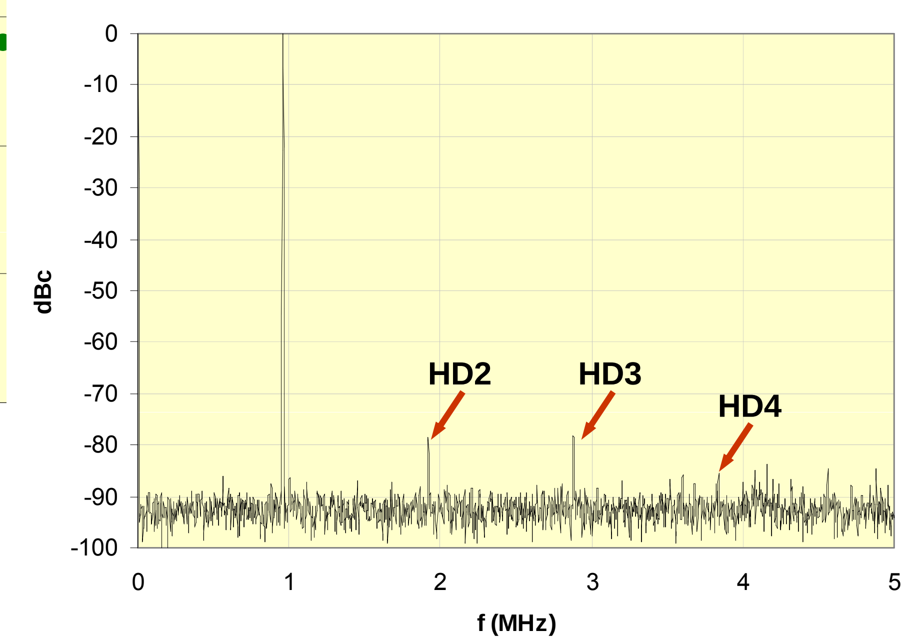




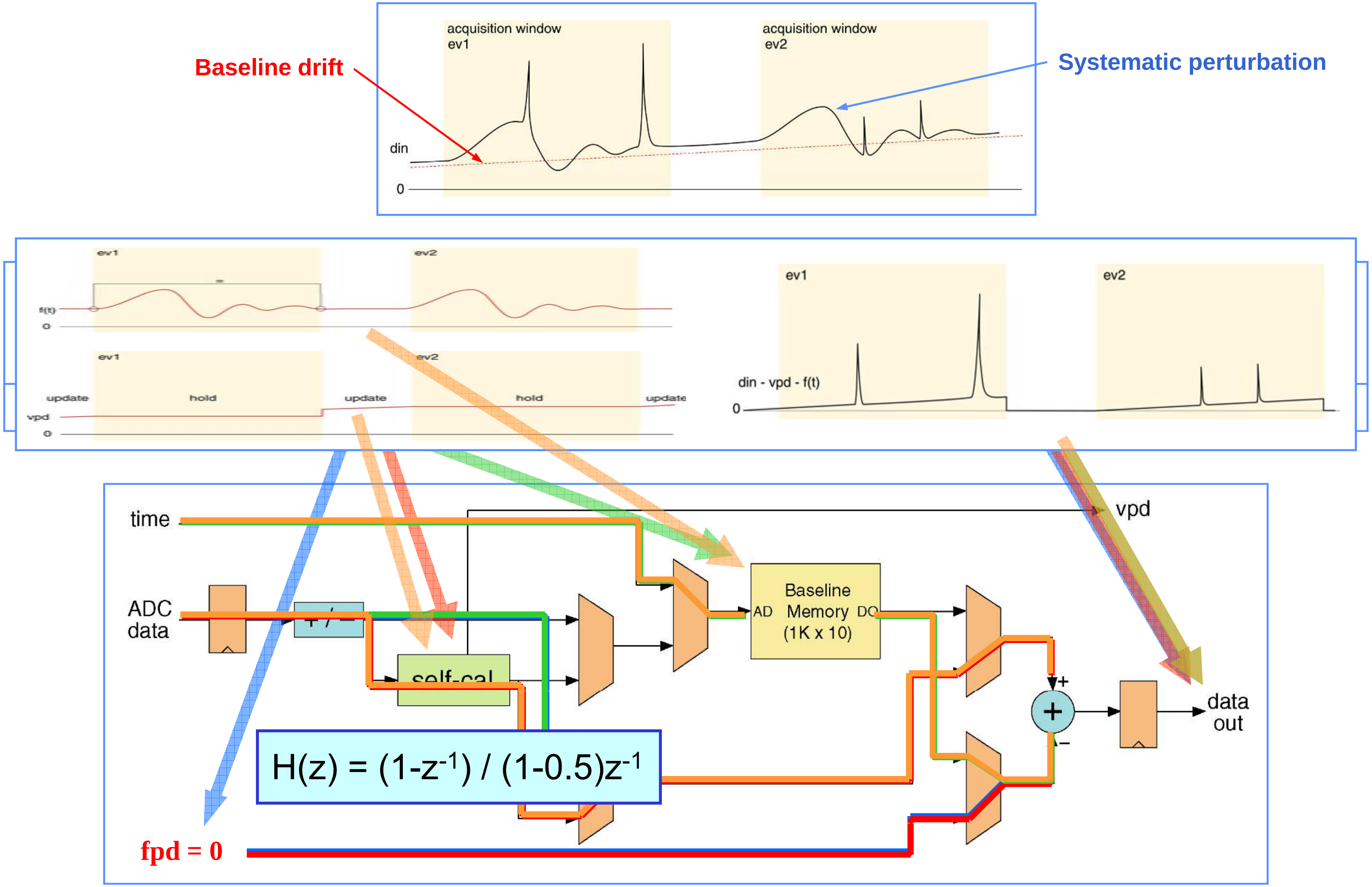
Quartz Jitter:

25ps r.m.s.

Amplitude Uncertainty:



Baseline Correction I

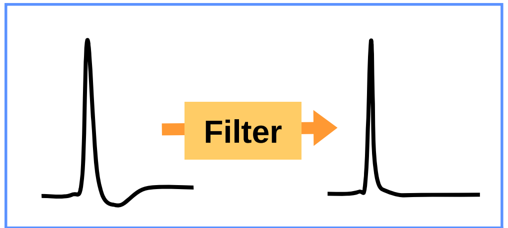


$$H(z) = (1-z^{-1}) / (1-0.5)z^{-1}$$

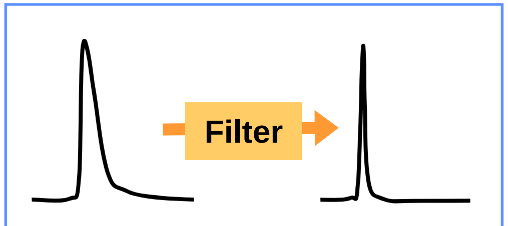
fpd = 0

Tail Cancellation Filter

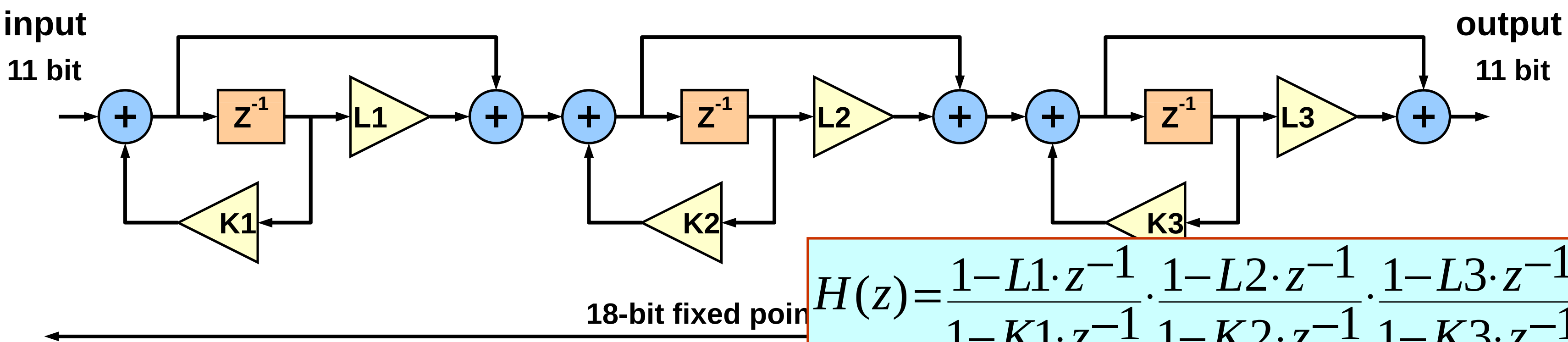
- **Functions**
  - signal (ion) tail suppression
  - pulse narrowing ⇒ improves cluster separation
  - gain equalization
- **Architecture**
  - 3[rd] order IIR filter
  - 18-bit fixed point 2’sC arithmetic
  - single channel configuration ⇒ 6 coefficients / channel



compensates undershoot



Narrows the pulse

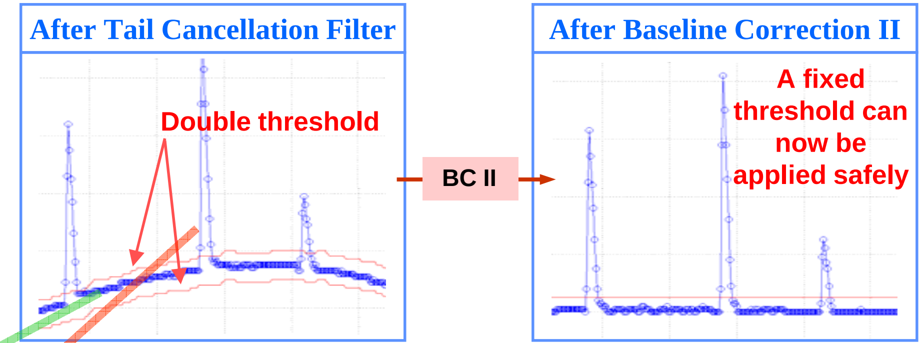


$$H(z)=\frac{1-L1\cdot z^{-1}}{1-K1\cdot z^{-1}}\cdot\frac{1-L2\cdot z^{-1}}{1-K2\cdot z^{-1}}\cdot\frac{1-L3\cdot z^{-1}}{1-K3\cdot z^{-1}}$$

Baseline Correction 2

Characteristics:

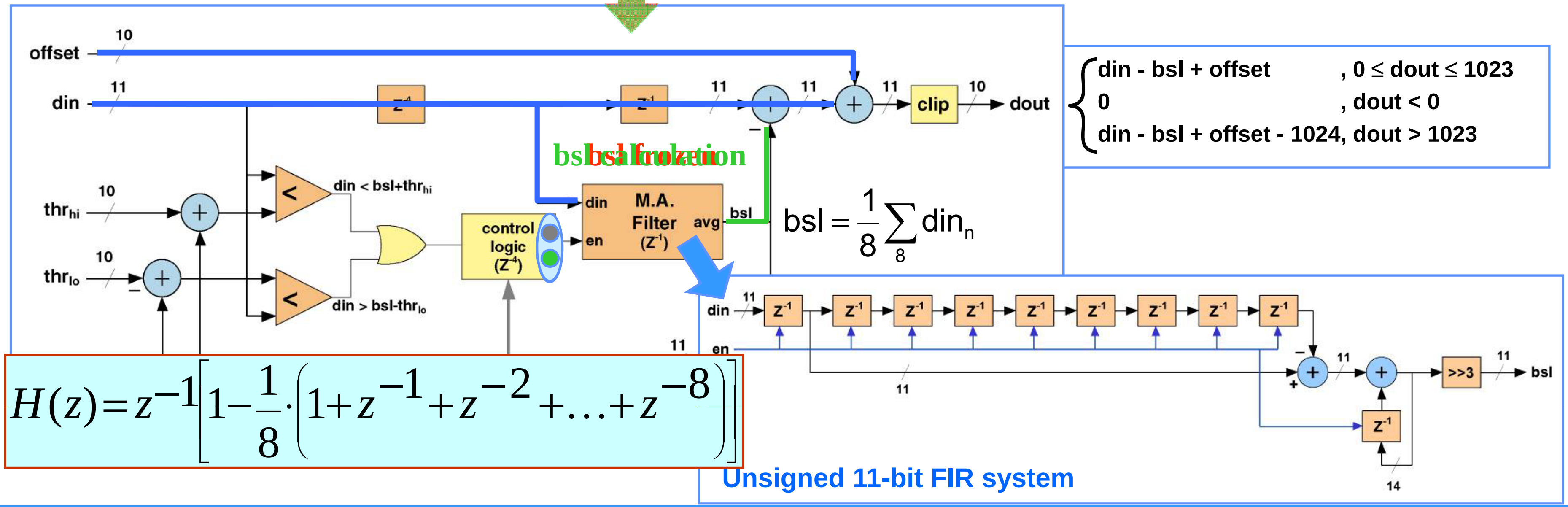
- Corrects non-systematic perturbations during the processing time
- Moving Average Filter (MAF)
- Double threshold scheme (acceptance window)



Operation

1. Slow variations of the signal ⇒ Baseline updated

2. Fast variations of the signal ⇒ Baseline value frozen

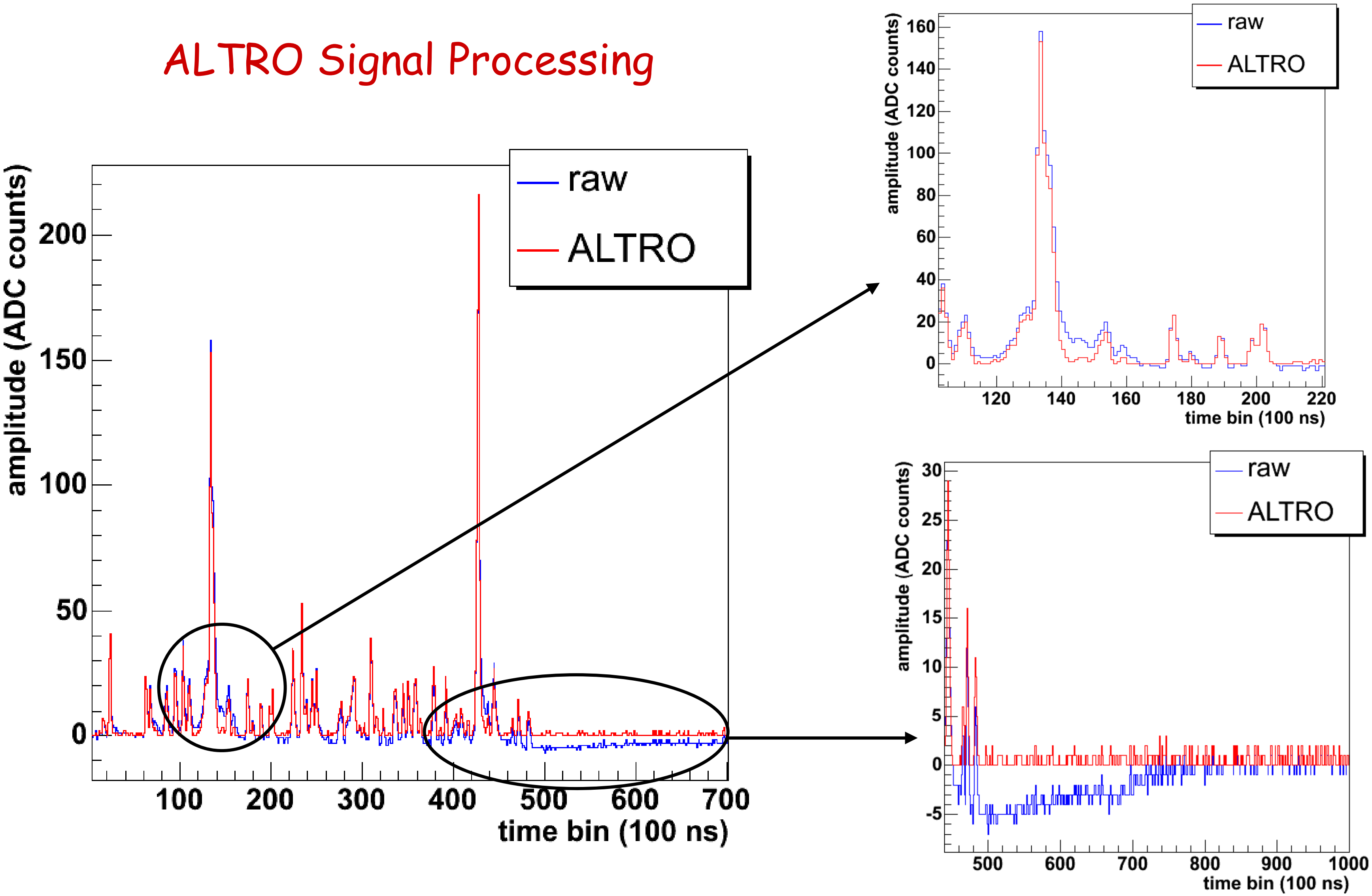


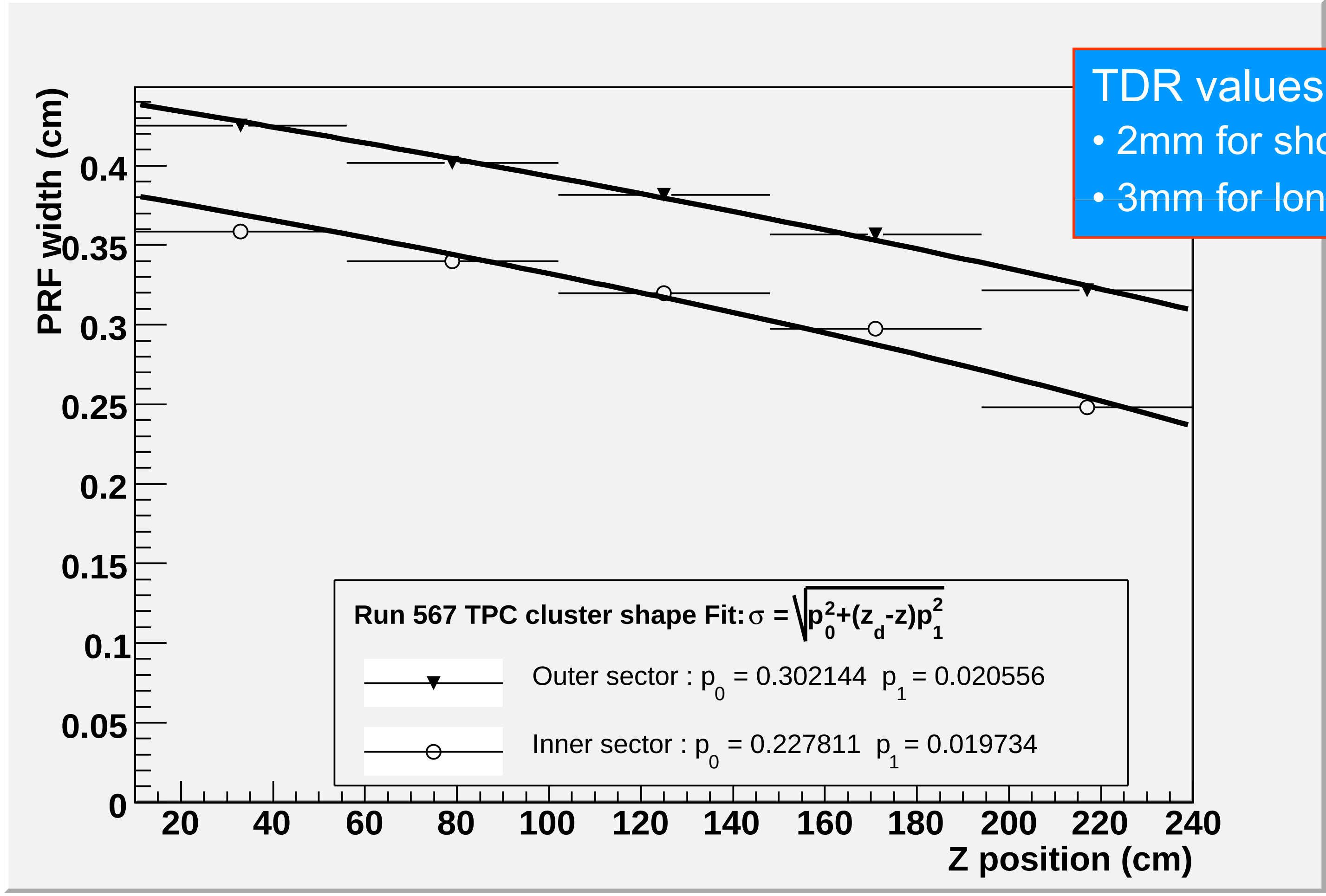
$$dout = \begin{cases} din - bsl + offset & , 0 \leq dout \leq 1023 \\ 0 & , dout < 0 \\ din - bsl + offset - 1024 & , dout > 1023 \end{cases}$$

$$bsl = \frac{1}{8}\sum_{8} din_n$$

$$H(z) = z^{-1}\left[1 - \frac{1}{8}\cdot\left(1 + z^{-1} + z^{-2} + \ldots + z^{-8}\right)\right]$$

ALTRO Signal Processing





TDR values

- 2mm for short pads
- 3mm for long pads

width (σ of a gaussian fit) of the charge signal in r-ϕ direction (pad row) as function of Z

(cut on inclination angle tan(ϕ) <0.05)

Laser tracks in the TPC