The Time Projection Chamber for the ALICE Experiment

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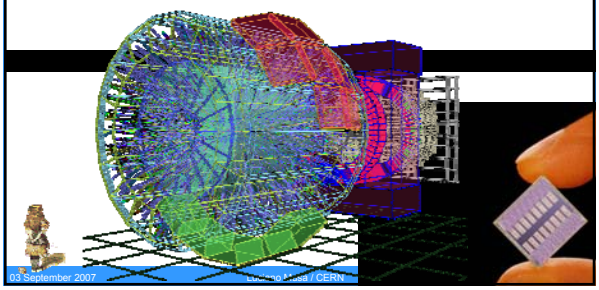
… a Technological Challange in the LHC Heavy Ion Physics

Luciano Musa (CERN)



The ALICE Time Projection Chamber

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

Bergen, CERN, 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

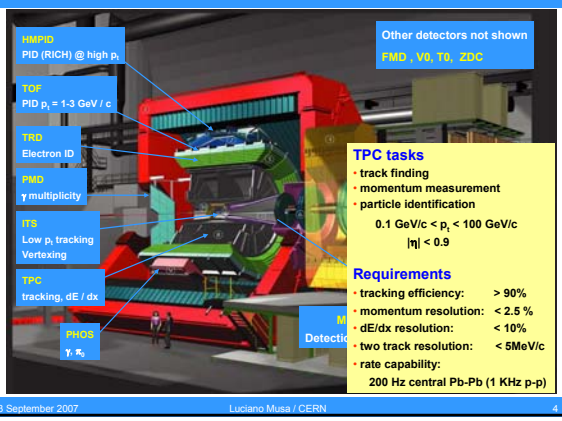
Rapidity density predictions

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

dN/dy ≈ 3500 at η= 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

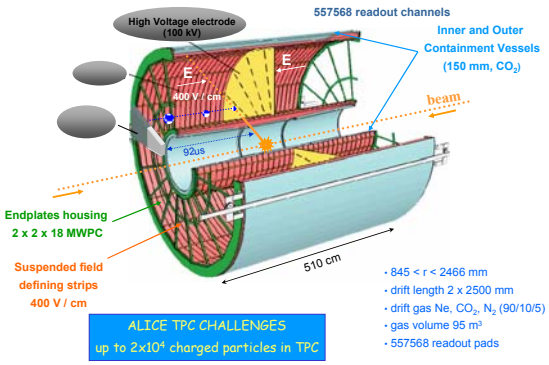
0.1 GeV/c < p_t < 100 GeV/c
|η| < 0.9

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

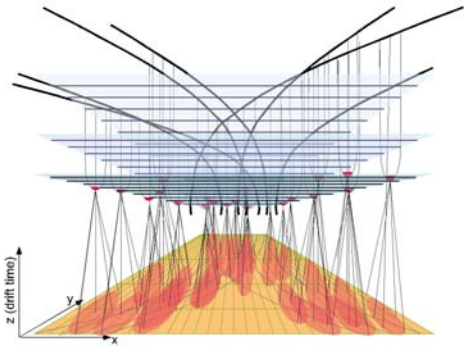


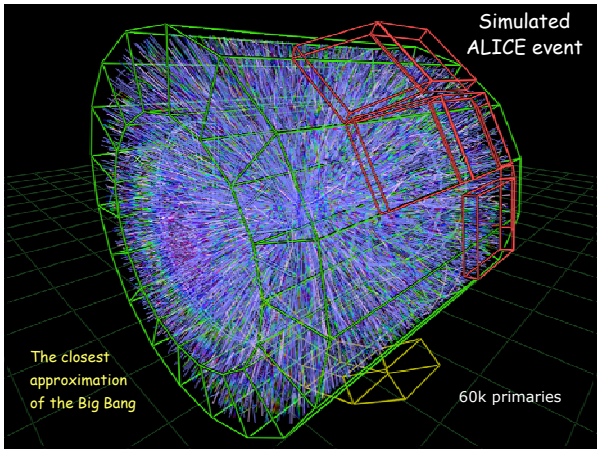
ALICE TPC CHALLENGES
up to 2x10^4 charged particles in TPC

- 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

Challenges at high particle multiplicities

TPC WORKING PRINCIPLE





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 ($2x10^4$)
- Drift vel. depends sensitively on temp., HV, gas composition
- Gas gain depends sensitively on mixture

Challenges at high particle multiplicities

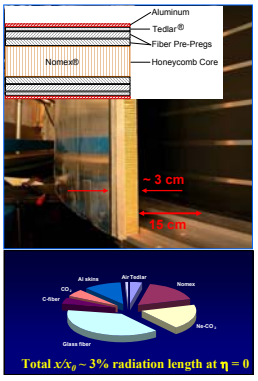
Can we handle the detector data throughput?

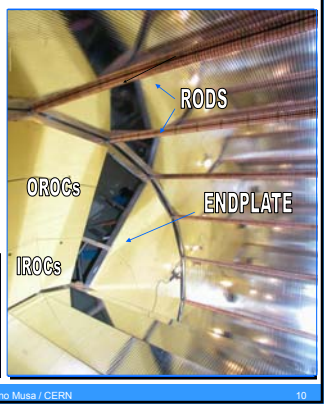
- 557 568 (pads) x 1000 (time bins)
- 712 Mbytes / event
- Pb - Pb (@200 Hz) ➔ 142 Gbyte / sec
- p-p (@1KHz) ➔ 710 GByte / sec

⇨ data compression in FEE

⇨ accurate signal preprocessing in FEE

Low mass Field Cage

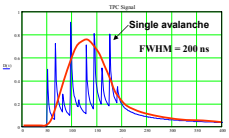




Readout Chambers - Design Considerations

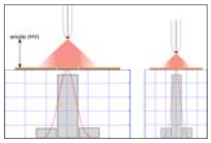
- **Z (time direction): higher sampling rate**
  limitations:
  - signal/noise gets critical
  - temporal signal is diffusion limited

  ⇒ **oversampling**



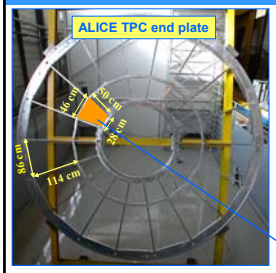
- **R-ϕ (pad direction): smaller pads**
  limitations:
  - # of channels (cost!)
  - HV-GND gets critical
  - PRF is diffusion limited

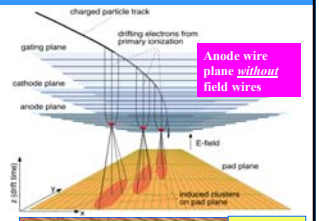
  ⇒ **oversampling**



- **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

Readout Chambers





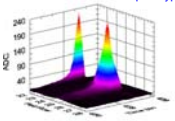
- In total 557,568 pads
- 63 rows with 4 x 7.5 mm² (inner radius)
- 64 rows with 6 x 10 mm²
- 32 rows with 6 x 15 mm² (outer radius)

Other issues with MWPC in HI Exp.

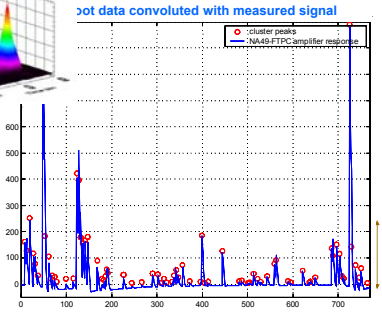
- **Protection of wires against discharges (sparks, glove)**
- **High suppression of ion feedback (~ 10^{-5})**

The Ion-Tail Problem

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

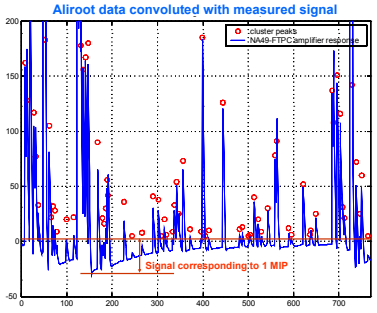


oot data convoluted with measured signal

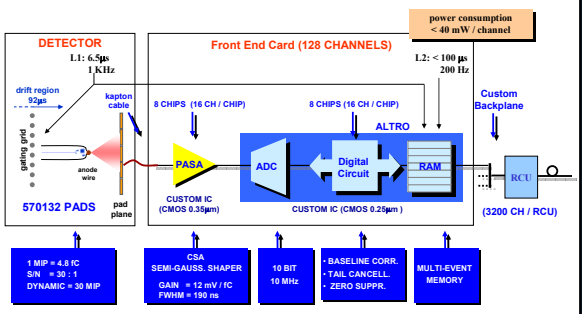


The Ion-Tail Problem

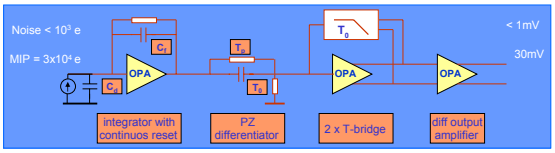
Aliroot data convoluted with measured signal

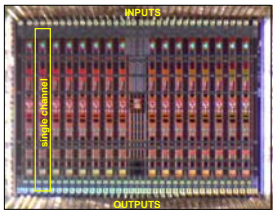


TPC FEE OVERVIEW



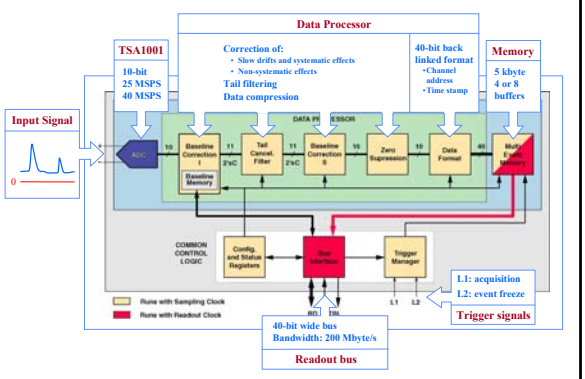
Pre-Amplifier Shaping Amplifier (PASA)



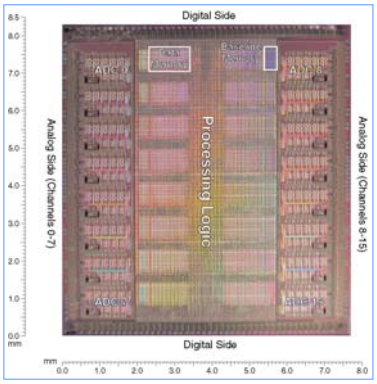


Production Engineering Data		
Process	AMS CMOS 0.35 µm	
Area	18 mm²	
Yield	95%	
Parameter	**Requirement**	**Production**
Noise	< 1000e	560e (12pF)
Conversion gain	12mV / fC	12mV / fC
Shaping time	190ns	188ns
Non linearity	< 1%	0.2%
Crosstalk	<0.3%	< 0.1%
Power	< 20mW	11mW / ch

ALTRO Block Diagram



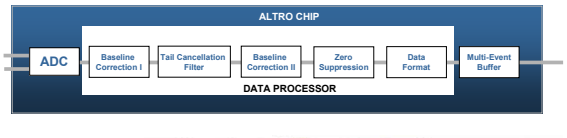
ALTRO layout and production data

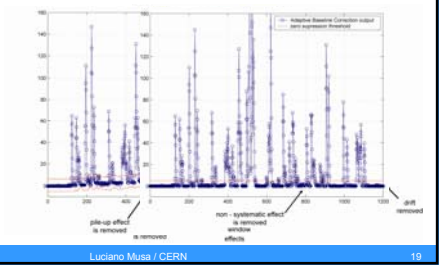


Process	HCMOS-7 (0.25 µm)
Area	64 mm²
Dimensions	7.70 × 8.35 mm²
Transistors	6 milions
Embedded memory	800 kbit
Supply voltage	2.5 V
Power	16mW / channel
Package	TQFP-176

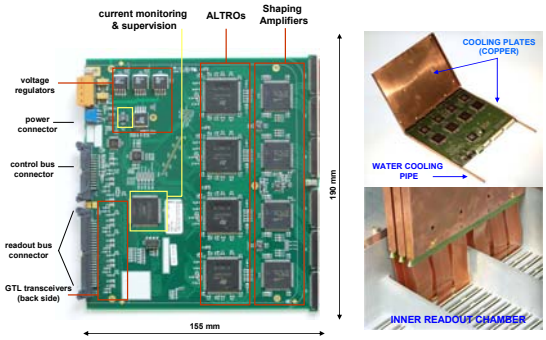
ER (12 wafers)	Apr '02
Mass prod. (125 wafers)	Dec '02
Yield	84%

ALICE TPC ReadOut chip (ALTRO)



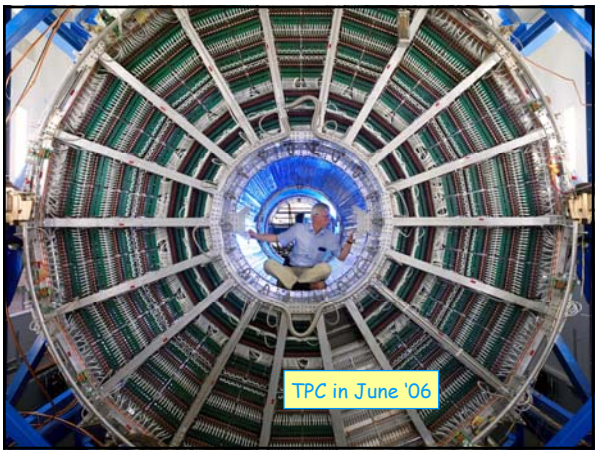


Front End Card: Layout, Cooling and Mounting

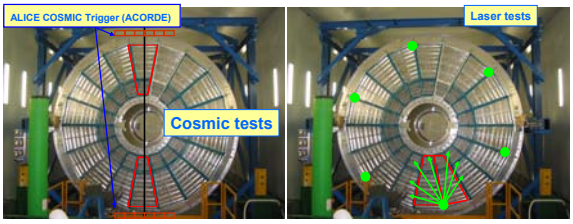


Installation of last Readout Chamber (Summer '05)

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



Commissioning the TPC



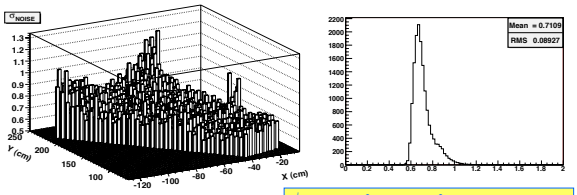
Only two sectors can be instrumented at a time with
- Low Voltage Power Supplies
- Cooling

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.

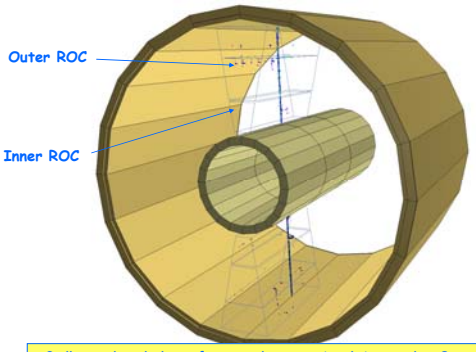
TPC pre-commissioning (2006); some results – Noise measurements



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

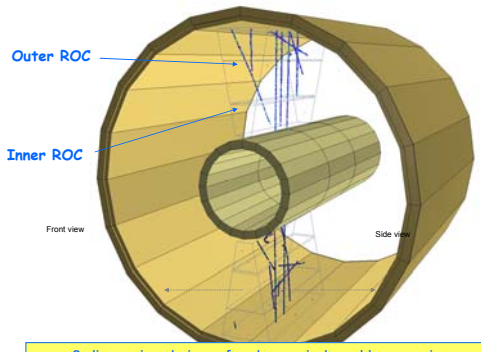
r.m.s. of the pedestals (s_{NOISE}) is below 1 ADC count
as required in the Technical Design Report

First cosmic rays events



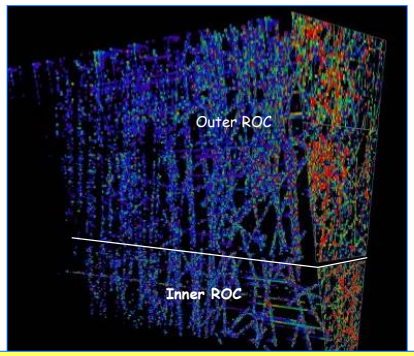
3-dimensional view of a cosmic muon track traversing 2 sectors

First cosmic rays events



3-dimensional view of a shower induced by cosmic rays

First cosmic rays events

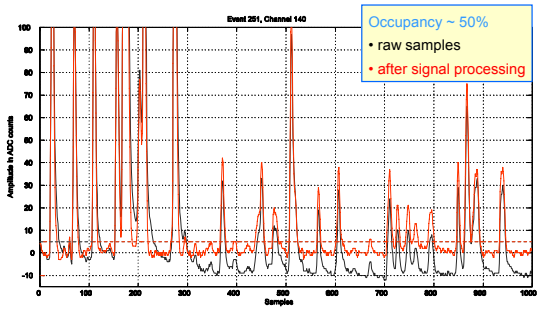


High occupancy shower induced by cosmic rays

Tail cancellation and baseline restoration

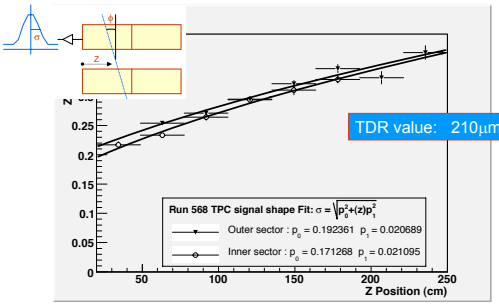
ALTRO Signal Processing

High Multiplicity cosmic rays



Occupancy ~ 50%
- raw samples
- after signal processing

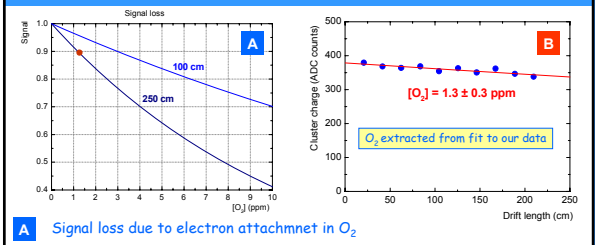
cluster width – diffusion coefficient (1/2)



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

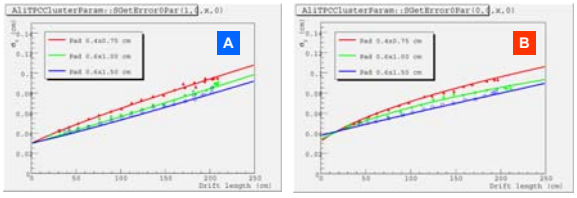
B Q total (total charge in the cluster) as function of z position (drift length)

- 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 $[O_2] < 5$ppm

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

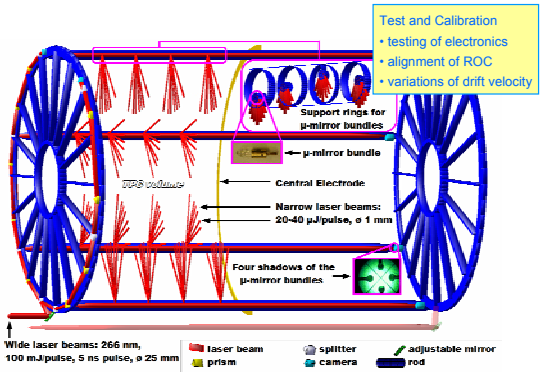
Position resolution



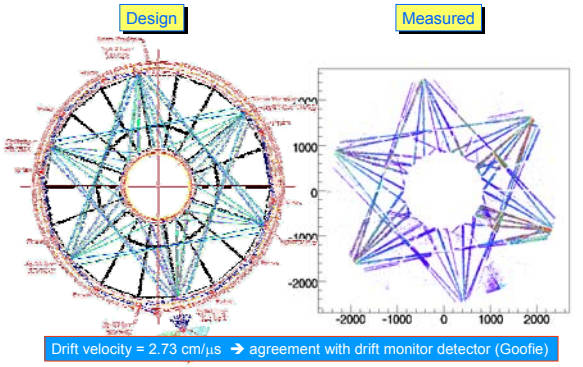
A space point resolution in Y direction as function of z position (cut on inclination angle tan(ϕ) <0.05)

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



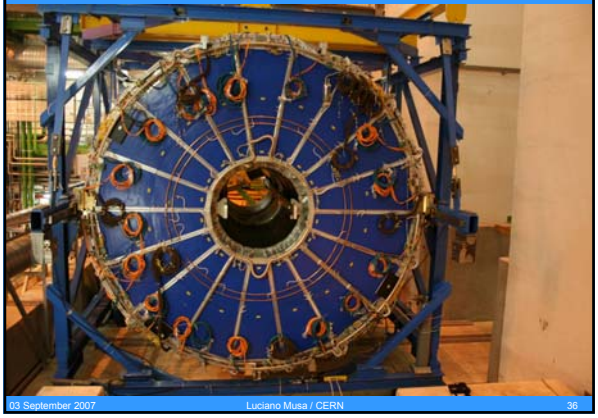
Laser tracks in the TPC



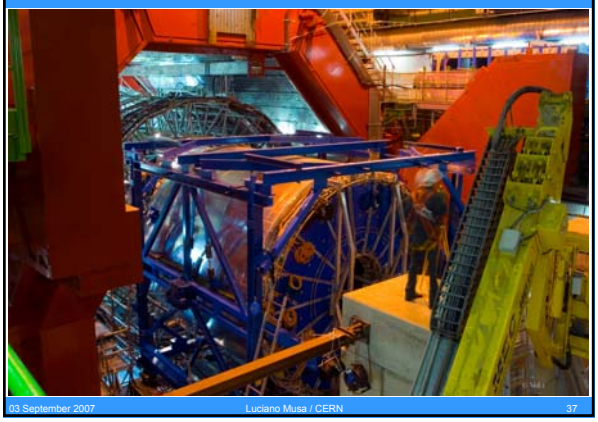
Drift velocity = 2.73 cm/μs → agreement with drift monitor detector (Goofie)

Descend to the cavern (Jan '07)

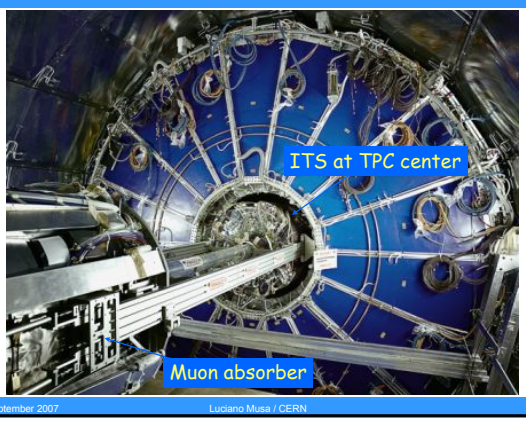
TPC in the cavern floor



Ready to go inside the spaceframe (Jan '07)



Inside the Space-frame (May '07)

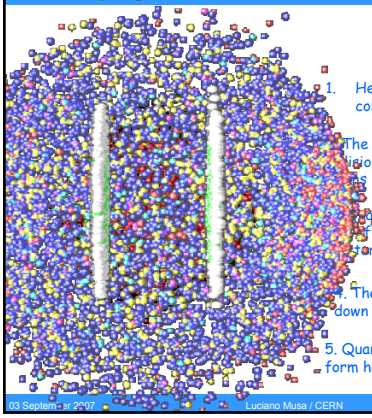


Summary

- 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

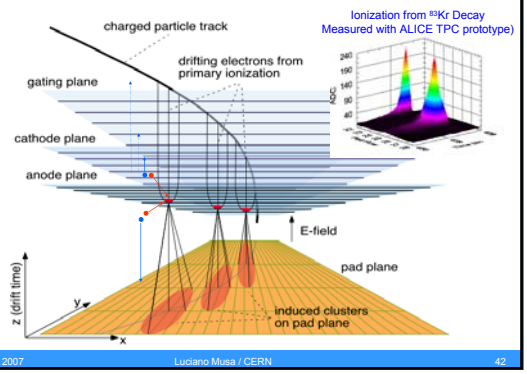


Mini Bangs

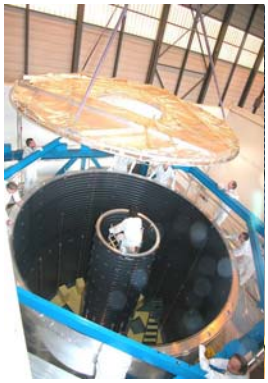
1. Head-on ultra-relativistic collision of two heavy ions
2. The energy made available in the ision generates many quarks and
3. rks and gluons interact under ffect of strong interaction: or tends towards equilibrium
4. The system expands and cools-down
5. Quarks and gluons link together to form hadrons

How to Measure in a High Track Density ?

TPC WORKING PRINCIPLE



Field Cage - Construction



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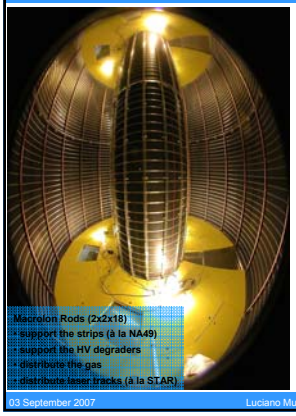
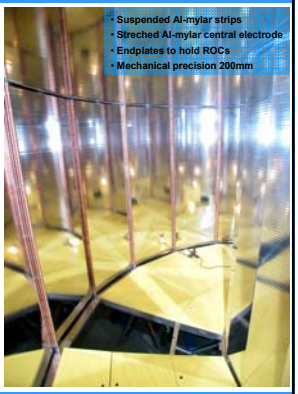


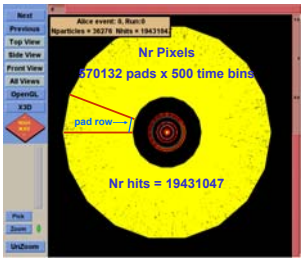


How to Measure in a High Track Density?

The ALICE Event Display

Projection of the drift volume into the pad plane dN_{ch} / dy = 8000 ➡ 2x10⁴ charged particles

Projection of a slice (2° in θ)



How to Measure in a High Track Density?

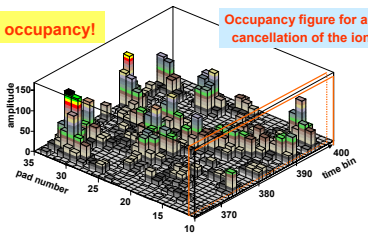
TPC OCCUPANCY(*) IN THE PAD-TIME SPACE

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

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

40% occupancy!

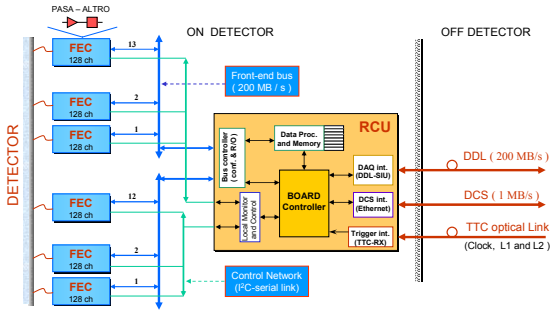
Occupancy figure for an ideal cancellation of the ion tail!



CLUSTER AT THE INNERMOST PAD ROW OF THE TPC

Architecture and Main Components

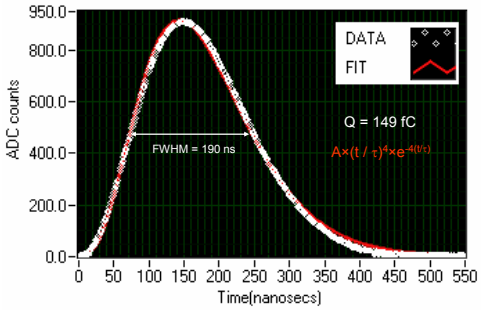
Each of the 36 TPC Sectors is served by 6 Readout Partitions



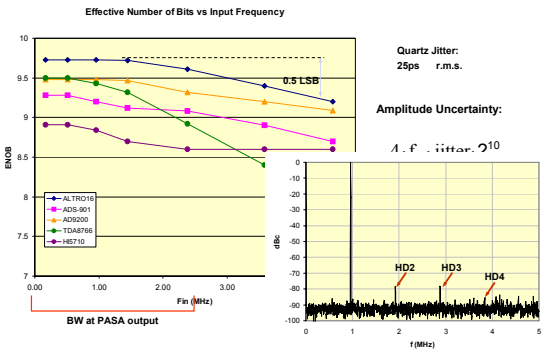
Overall: 4356 Front End Card 216 Readout Partitions

Pre-Amplifier Shaping Amplifier (PASA)

Impulse Response Function



ALTRO PERFORMANCE

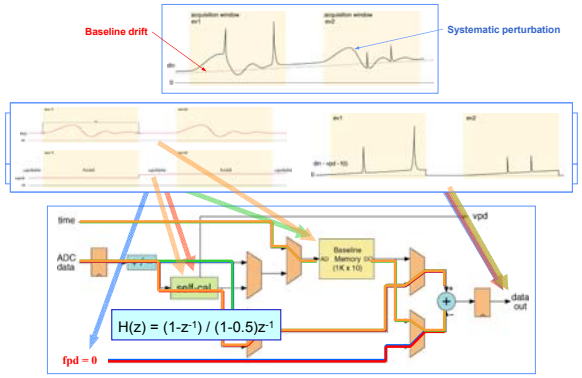


Quartz Jitter:
25ps r.m.s.

Amplitude Uncertainty:

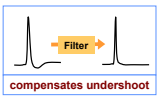
$A \cdot f_{in} \cdot jitter \cdot 2^{10}$

Baseline Correction I

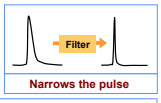


Tail Cancellation Filter

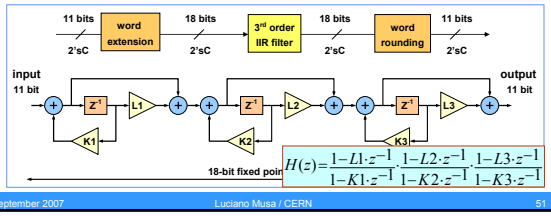
- **Functions**
  - signal (ion) tail suppression
  - pulse narrowing ⇒ improves cluster separation
  - gain equalization
- **Architecture**
  - 3rd order IIR filter
  - 18-bit fixed point 2'sC arithmetic
  - single channel configuration ⇒ 6 coefficients / channel



compensates undershoot



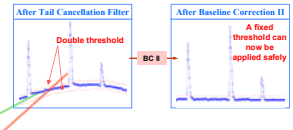
Narrows the pulse



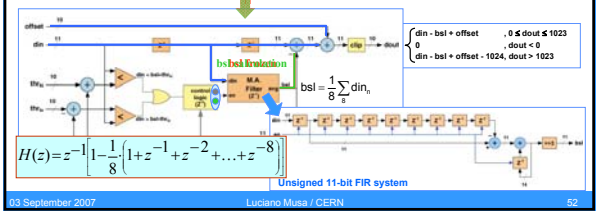
$$H(z)=\frac{1-L1\cdot z^{-1}}{1-K1\cdot z^{-1}}\cdot\frac{1-L2\cdot z^{-1}}{1-K2\cdot z^{-1}}\cdot\frac{1-L3\cdot z^{-1}}{1-K3\cdot z^{-1}}$$

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

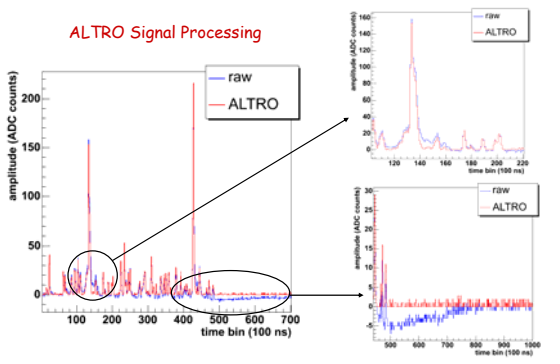


$$bsl=\frac{1}{8}\sum_{8}din_i$$

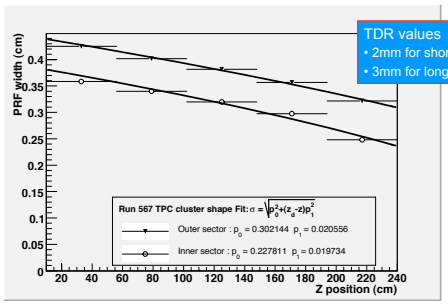
$$H(z)=z^{-1}\left[1-\frac{1}{8}\left(1+z^{-1}+z^{-2}+\ldots+z^{-8}\right)\right]$$

Unsigned 11-bit FIR system

Tail cancellation and baseline restoration



cluster width – diffusion coefficient (2/2)

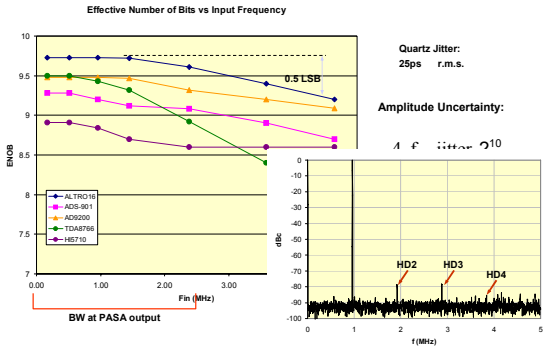


TDR values
- 2mm for short pads
- 3mm for long pads

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)

ALTRO PERFORMANCE



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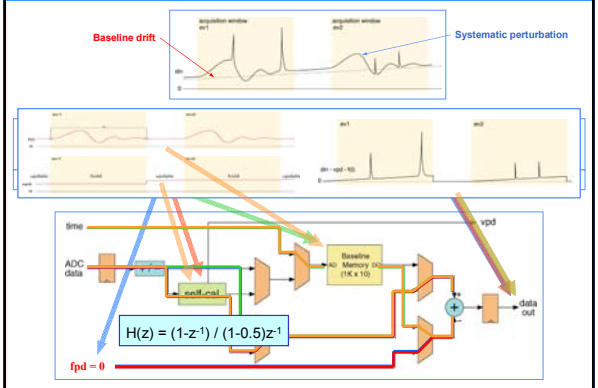

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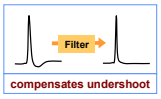

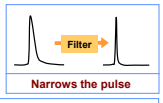

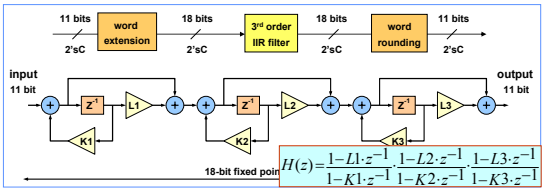

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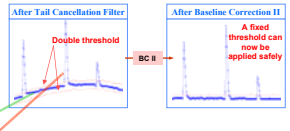

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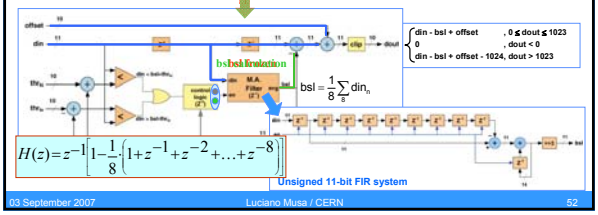
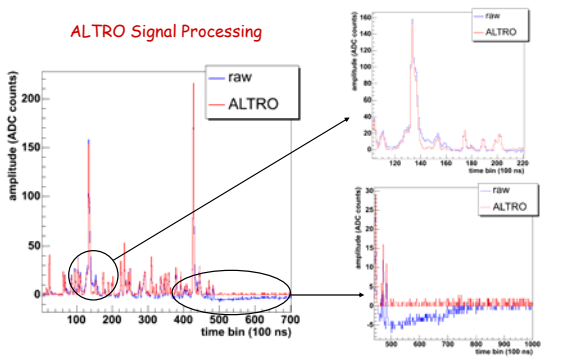


Tail cancellation and baseline restoration



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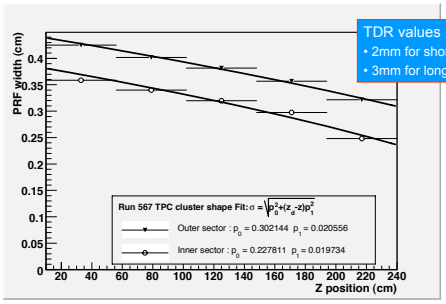

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Laser tracks in the TPC