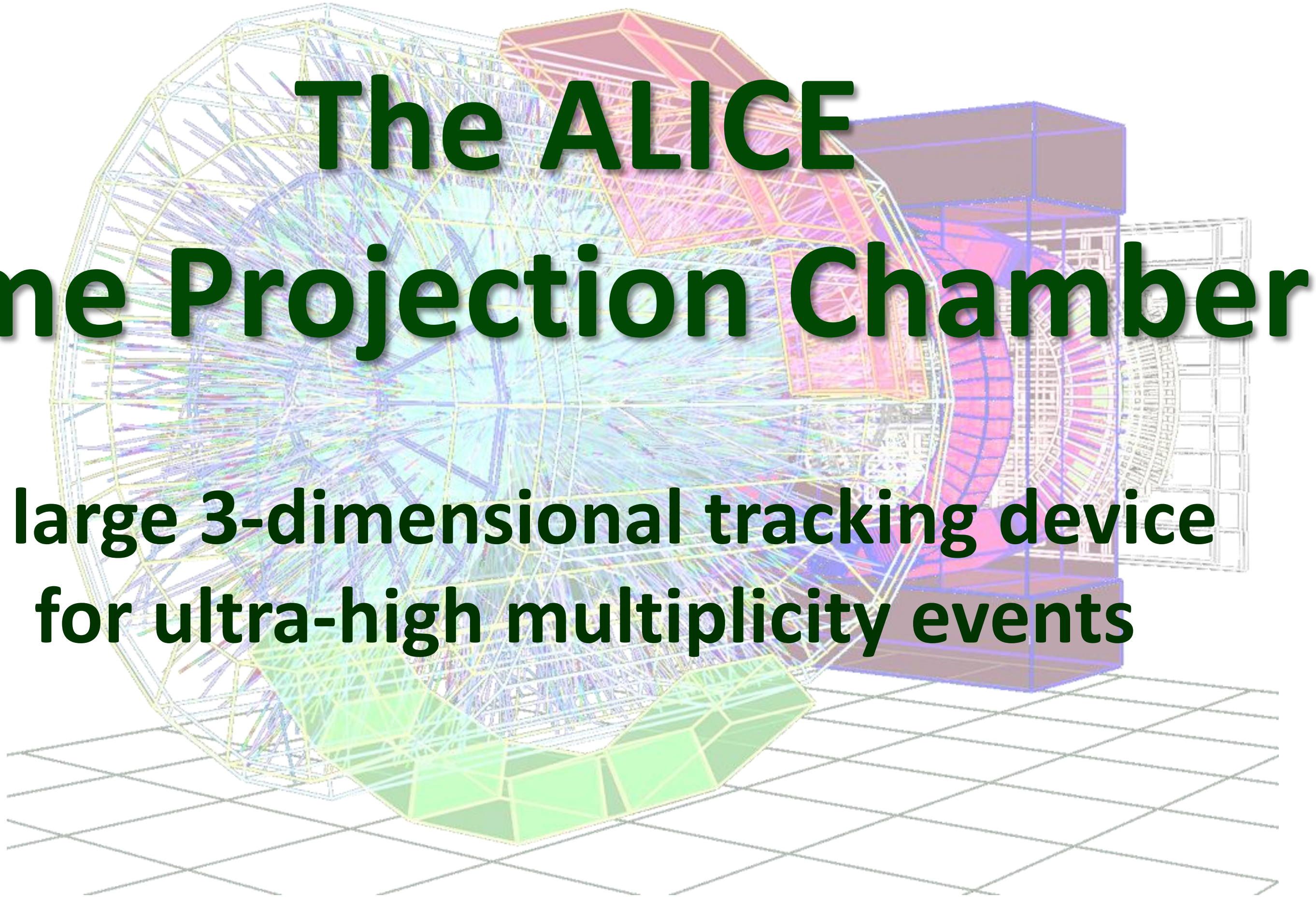


The ALICE Time Projection Chamber

a large 3-dimensional tracking device for ultra-high multiplicity events

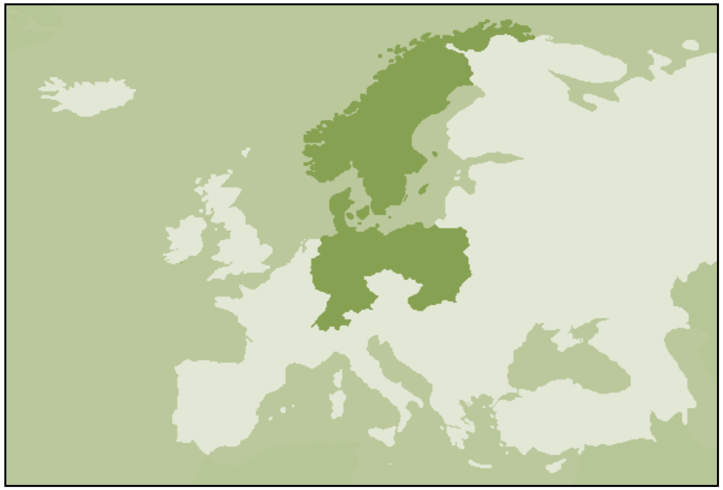
PH Detector Seminar
Stefan Rossegger
on behalf of the ALICE TPC Collaboration
8th of October, 2010

Overview

OUTLINE

- Heavy Ion collision
  - Conditions at LHC
  - Challenges at high flux
- The Alice TPC
  - Main components
  - Operation
- Commissioning & Calibration
- Performance
- Ready for Pb-Pb collisions ?

The ALICE TPC Collaboration



- **Bergen**, Norway, Department of Physics, University of Bergen
- **Bratislava**, Slovakia, Comenius University
- **CERN, European Organization for Nuclear Research**
- **Copenhagen**, Denmark, Niels Bohr Institute
- **Krakow**, Poland, Institute For Nuclear Physics
- **Darmstadt GSI**, Germany
- **Darmstadt TU**, Germany, Technische Universität
- **Frankfurt**, Germany, Institut für Kernphysik
- **Heidelberg KIP**, Germany, Kirchhoff Institut fur Physik
- **Heidelberg PI**, Germany, Physikalisches Institut
- **Lund**, Sweden, Division of High Energy Physics
- **Worms**, Germany, Zentrum fur Techn.transfer und Telekommunik.

General Conditions at LHC for Heavy-Ion Collisions

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

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

Luminosity (max)

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

Rapidity density predictions

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

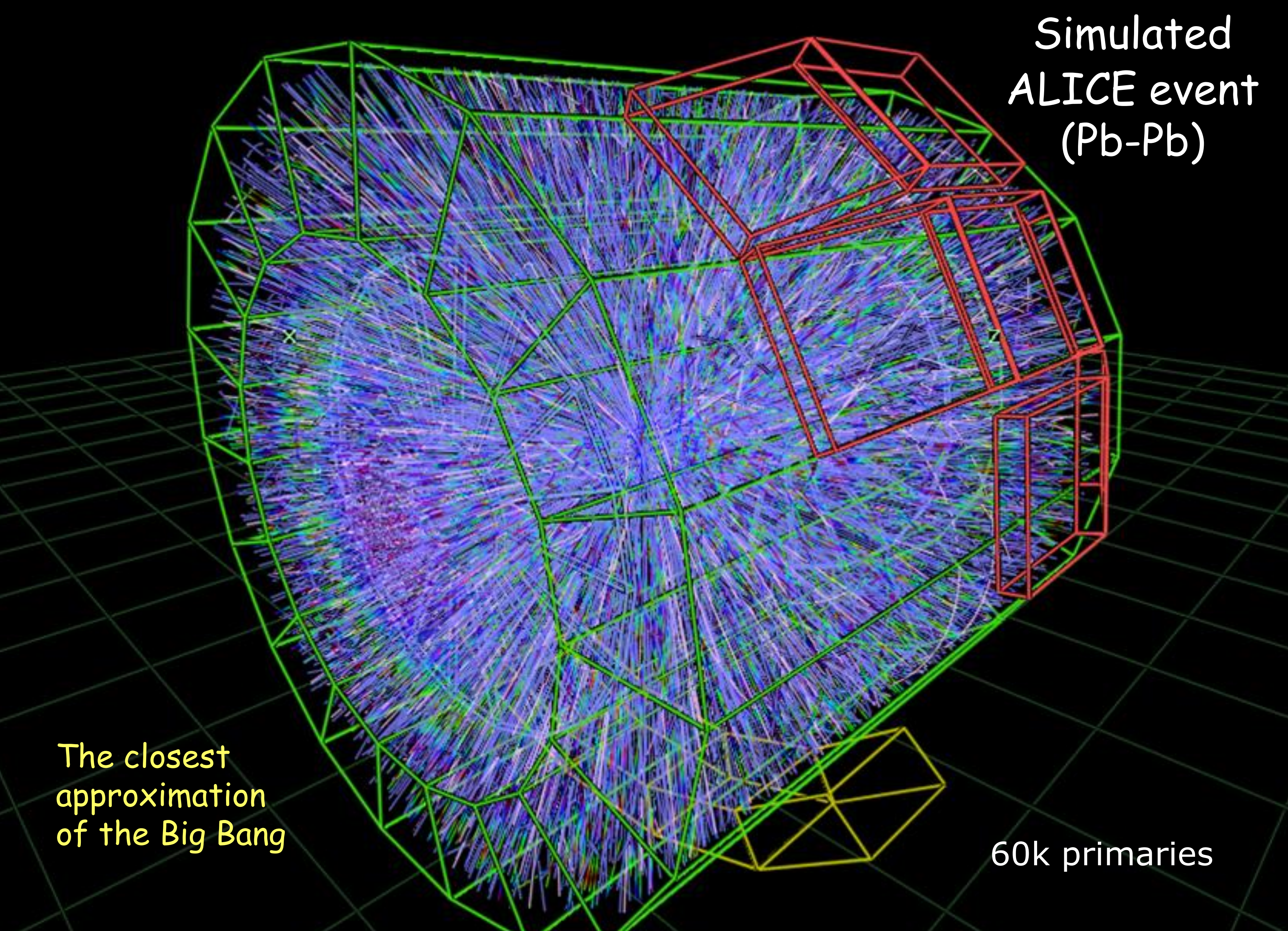
$dN/d\eta \approx 3500$

“educated” extrapolation

(saturation model, Eskola *et al.)*

ALICE Detector designed for $dN_{ch} / d\eta = 8000$

Simulated ALICE event (Pb-Pb)



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 pad 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. and gain depends sensitively on T, P, drift field and gas

  composition ⇨ controlled operation and careful calibration

Challenges at high particle multiplicities

Can we handle the detector data throughput?

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

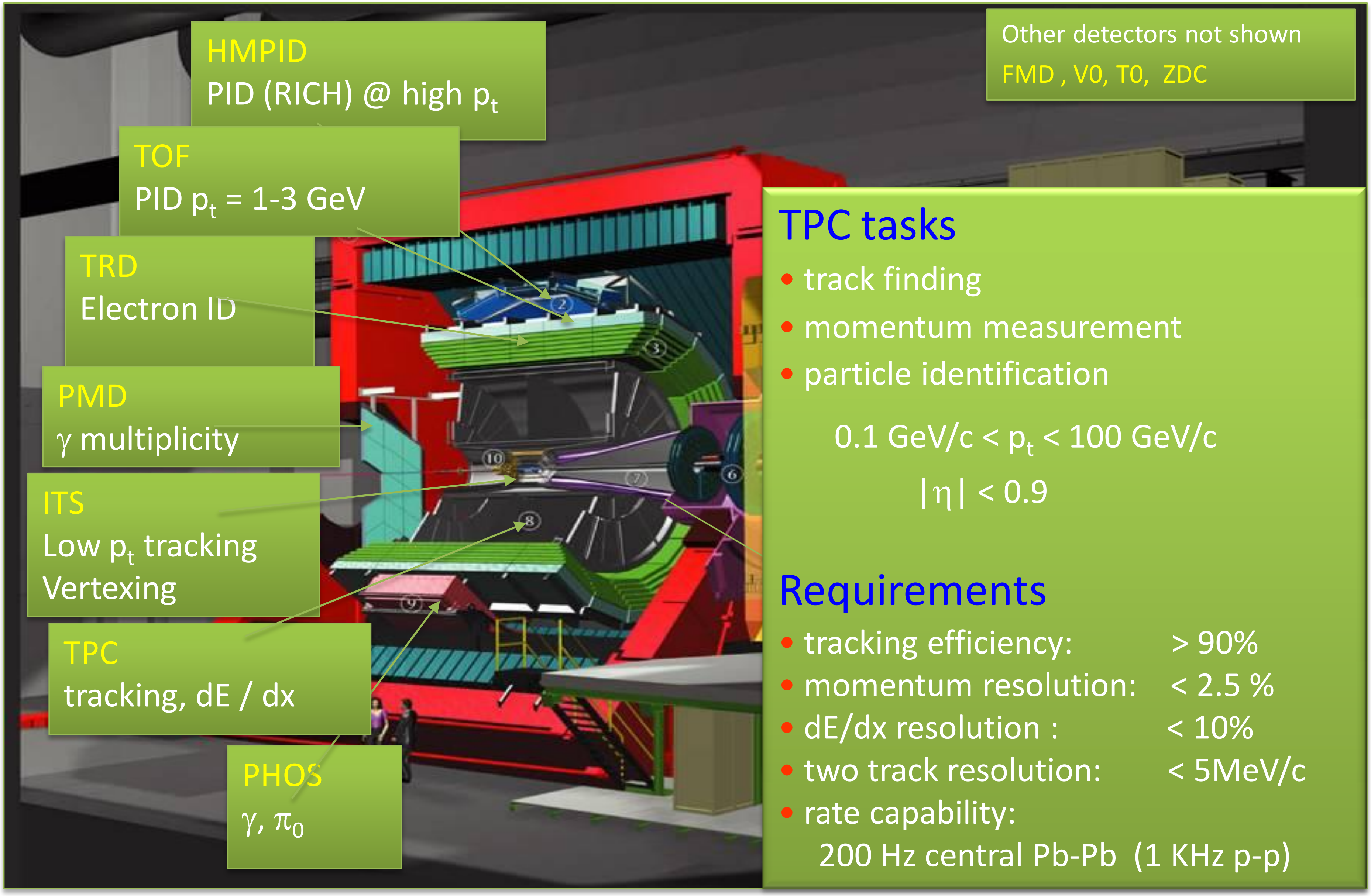
⇨ data compression in FEE (ZS)

⇨ accurate signal preprocessing in FEE (BSC, TCF)

More details on how this challenges were addressed, on the construction as well as on the operation can be found in:

[1] ALICE TPC Collaboration, J. Alme *et al.*, **"The ALICE TPC, a large 3-dimensional tracking device with fast readout for ultra-high multiplicity events"**, Nuclear Instruments and Methods in Physics Research Section A, Volume 622, Issue 1, 1 October 2010, DOI: 10.1016/j.nima.2010.04.042.

The ALICE Detector



HMPID
PID (RICH) @ high p_t

TOF
PID p_t = 1-3 GeV

TRD
Electron ID

PMD
γ multiplicity

ITS
Low p_t tracking
Vertexing

TPC
tracking, dE / dx

PHOS
γ, π_0

Other detectors not shown
FMD , V0, T0, ZDC

TPC tasks

- track finding
- momentum measurement
- particle identification

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

$|\eta| < 0.9$

Requirements

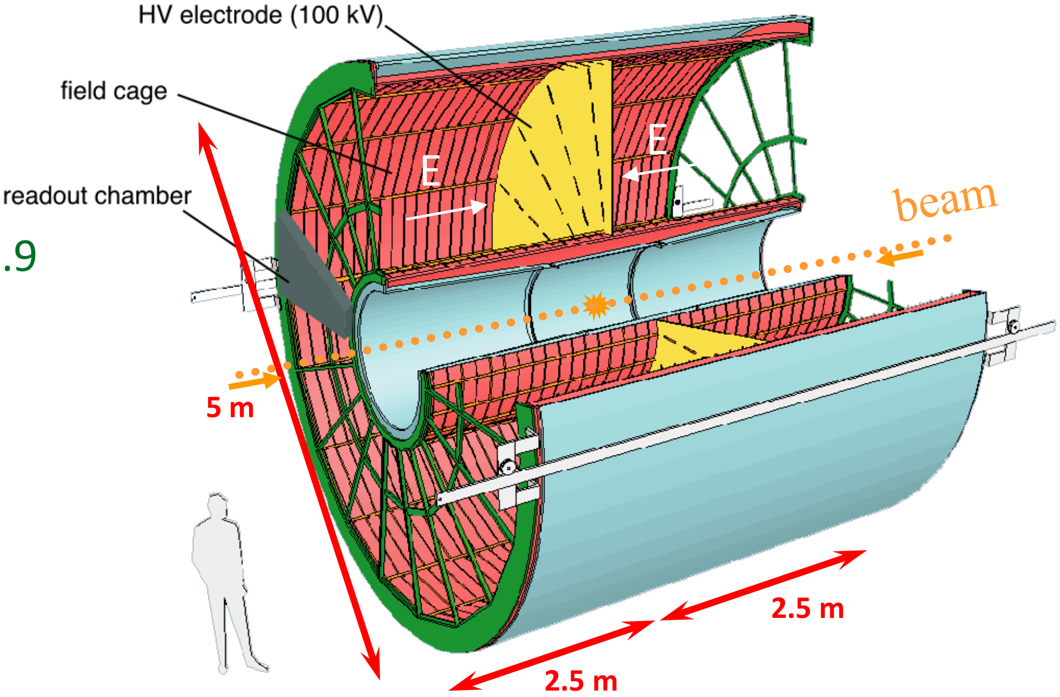
- tracking efficiency: > 90%
- momentum resolution: < 2.5 %
- dE/dx resolution : < 10%
- two track resolution: < 5MeV/c
- rate capability:
  200 Hz central Pb-Pb (1 KHz p-p)

TPC overview

- General features:
  - Diameter × Length : 5 m × 5 m
  - Azimuth angle coverage: 2π
  - Pseudo-rapidity interval: $|\eta|<0.9$
  - Readout chambers: 72
  - Drift field: E = 400 V/cm
  - Nominal drift time: 96 μs
  - Central electrode HV: 100 kV

- Gas:
  - Active volume: 90 m^3
  - Ne-CO_2-N_2: 85.7% - 9.5% - 4.8%
  - Cold gas - low diffusion
  - Non-saturated drift velocity

    ⇒ temperature stability and homogeneity ≤ 0.1 K
  - Gain ~ 10^4



- Data taking rate:
  - ~ 1 kHz for p-p
  - ~ a few 100 Hz for Pb-Pb

ALICE TPC CHALLENGES

up to $2\text{x}10^4$ charged particles in TPC

TPC working principle

Animation by Pawel Debski

The unconventional gas choice: WHY ?

☞ Noble gas chosen to be **Neon**

- Could not be Argon
  - positive ions too slow, much Multiple scattering

☞ Quencher chosen to be **CO_2**

- Quencher could not be a hydrocarbon
  - Flammability, Ageing, Slow proton production
- Quencher cannot be CF4
  - Not well understood at the time of the TDR

☞ Composition at **[90-10]** determined by drift.vel. requirement (vd = 2.8 cm/μs)

☞ Extremely high gain: 2×10^4 (for MWPC read out TPCs)

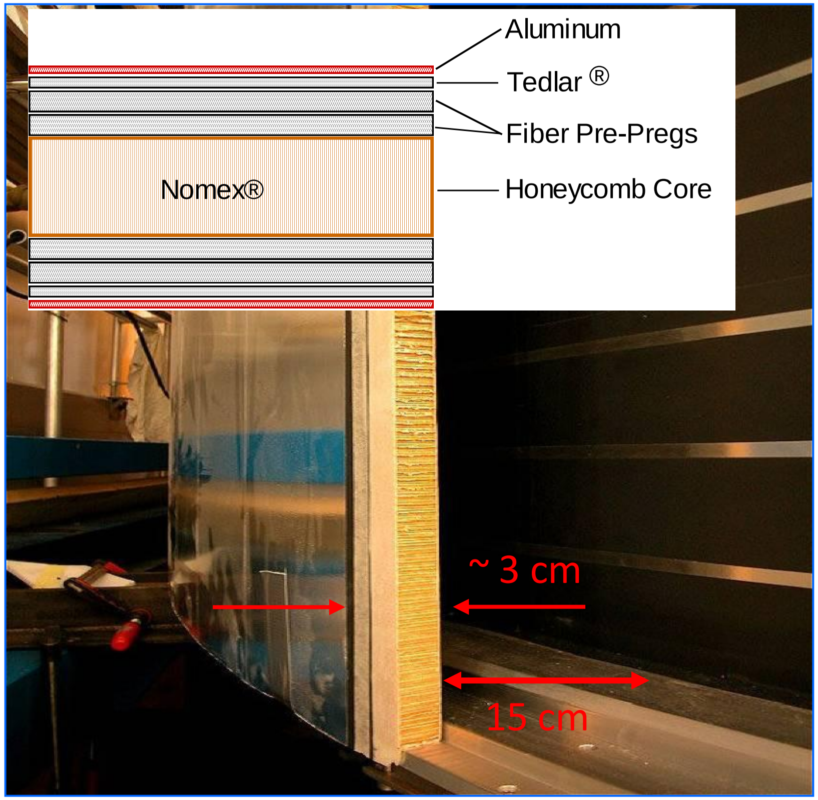
- Due to low primary ionisation + small pads:

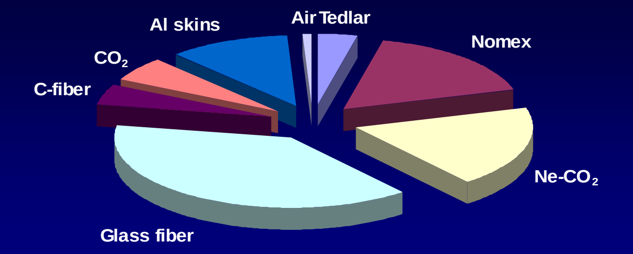
- **Cons:** High sensitivity (gain, v_d) on working conditions (P,T ...)

☞ Overcome **technical challenges** and requirement of **careful calibration**

Stefan Rossegger PH Detector Seminar

Low mass Field Cage





Total $x/x_0 \sim 4$ % radiation length at $\eta = 0$

FIELD CAGE DESIGN OBJECTIVES

Provide high stability and uniformity for:

- drift field (400 V/cm): $E_r / E_z < 10^{-4}$
- gas gain: $> 10^4$
- temperature: $\Delta T < 0.1$ ºC
- drift gas purity: < 5 ppm O_2, < 10 ppm H_2O

Provide high mechanical precision for:

- central electrode: 250 μm
- readout plane: 250 μm

High struct. integrity and low density and low Z

- e-identification (TRD detector)
- minimize multiple scattering

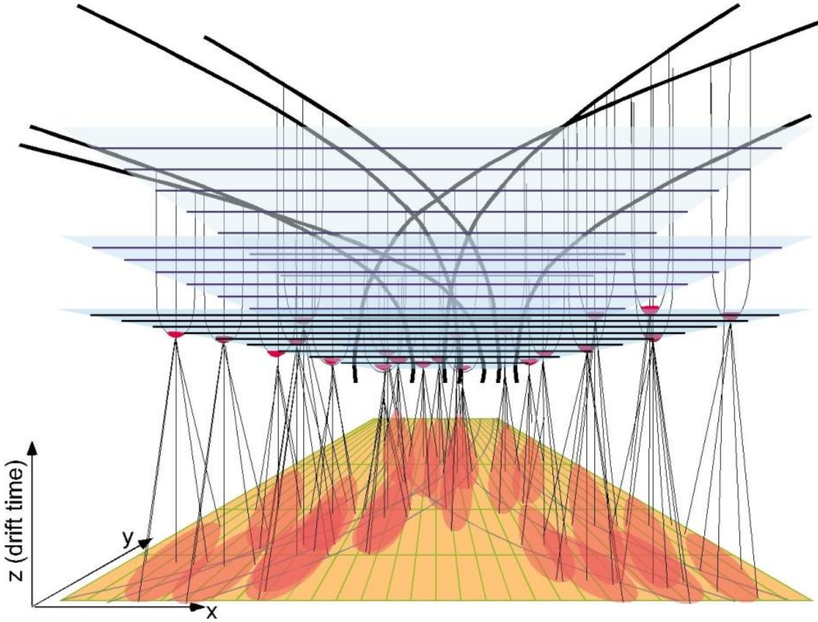
Radiation length X / X0 of FC
1.367 % - inner FC
0.607 % - gas
2.153 % - outer FC

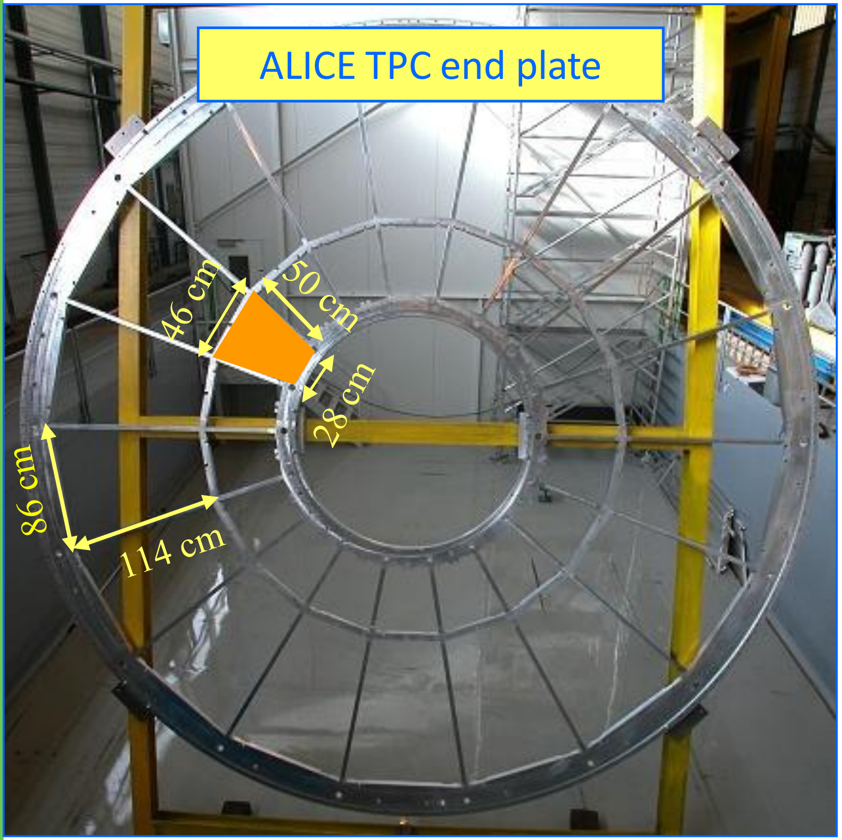
Light composite materials for all four cylinders

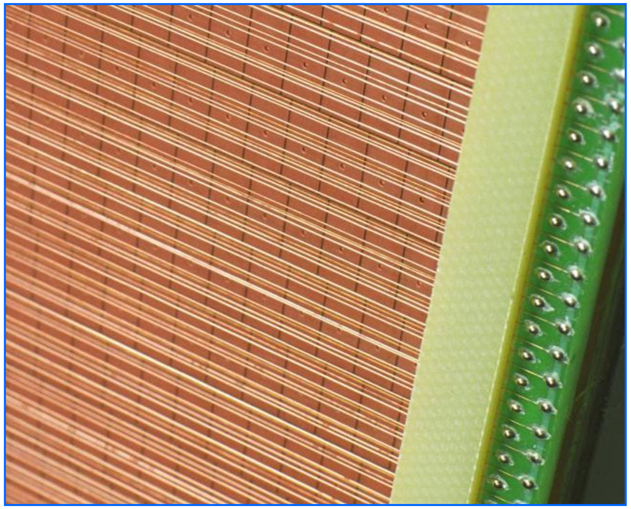
Read-Out Chambers

- 2 sides with 18 sectors
- Sector consists of:
  - Outer chamber (OROC)
  - Inner chamber (IROC)

⇒ 72 readout chambers



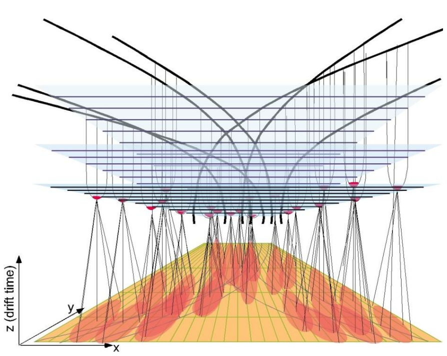


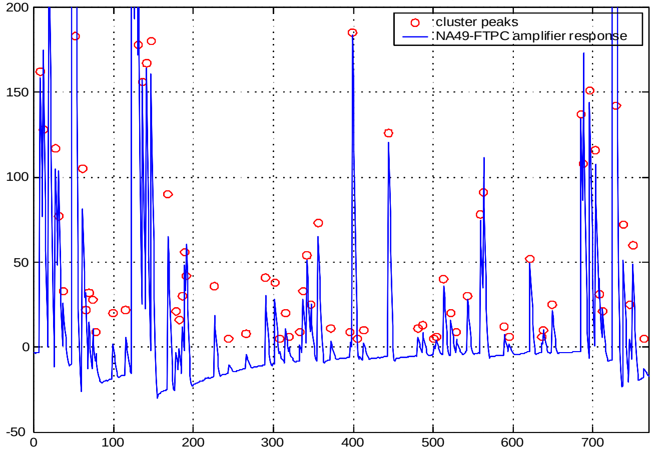


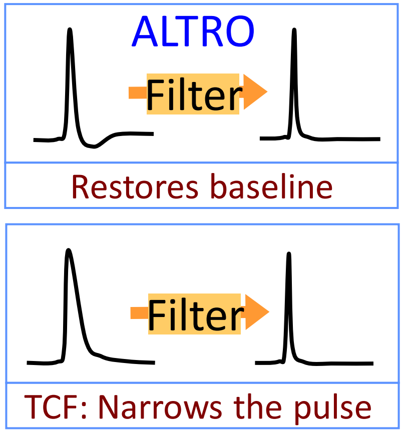
Pad readout

- **Pads (3 types):**
  from 4x7.5mm^2
  to 6x15mm^2
  total: 557 568
- **Samples in time direction:**
  1000 (10MHz)

TPC FEE OVERVIEW



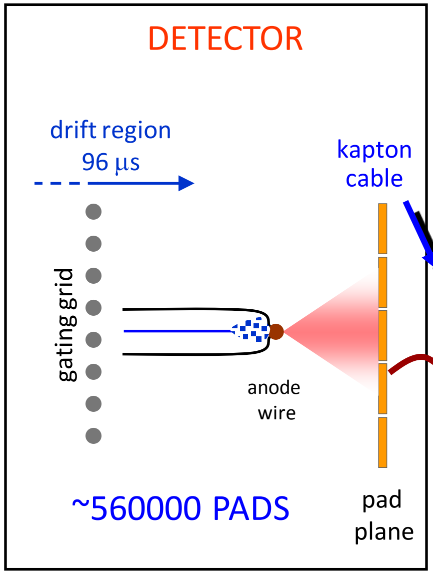




Restores baseline

TCF: Narrows the pulse

DAQ



DETECTOR

drift region
96 µs

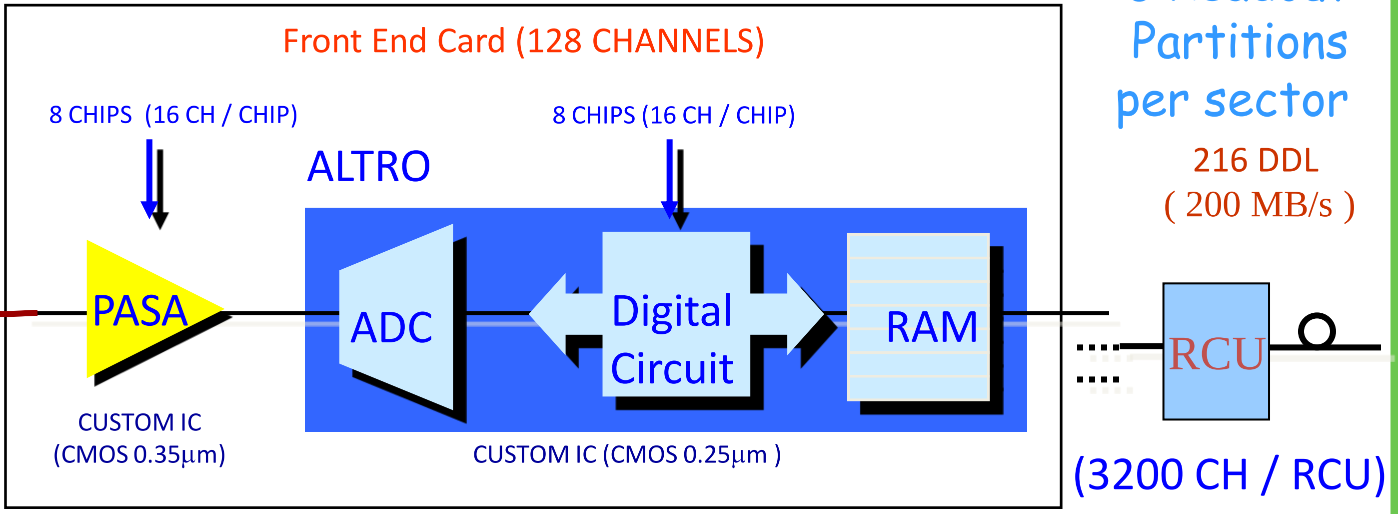
kapton cable

gating grid

anode wire

~560000 PADS

pad plane



Front End Card (128 CHANNELS)

8 CHIPS (16 CH / CHIP)

8 CHIPS (16 CH / CHIP)

ALTRO

CUSTOM IC
(CMOS 0.35µm)

CUSTOM IC (CMOS 0.25µm)

6 Readout Partitions per sector

216 DDL
(200 MB/s)

(3200 CH / RCU)

1 MIP = 4.8 fC
S/N = 30 : 1
DYNAMIC = 30 MIP

CSA
SEMI-GAUSS. SHAPER
GAIN = 12 mV / fC
FWHM = 190 ns

10 BIT
10 MHz

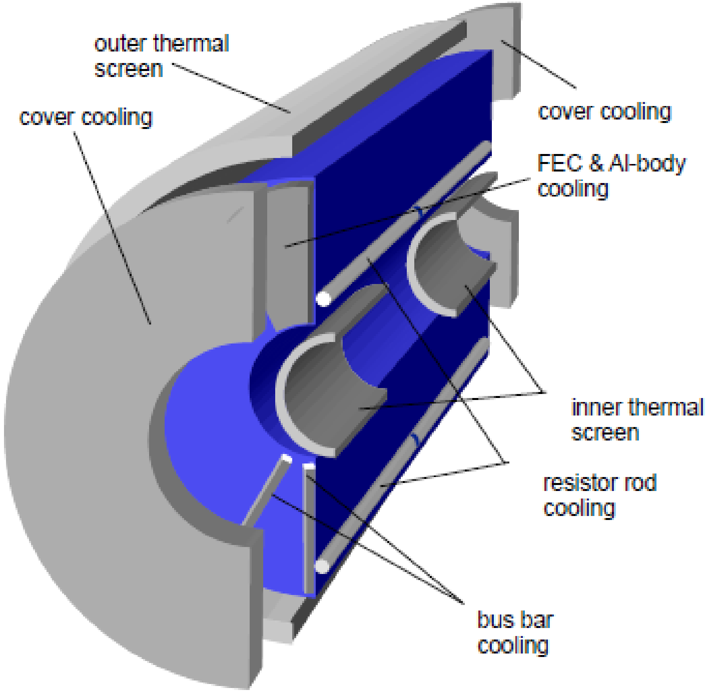
- BASELINE CORR.
- TAIL CANCELL.
- ZERO SUPPR.

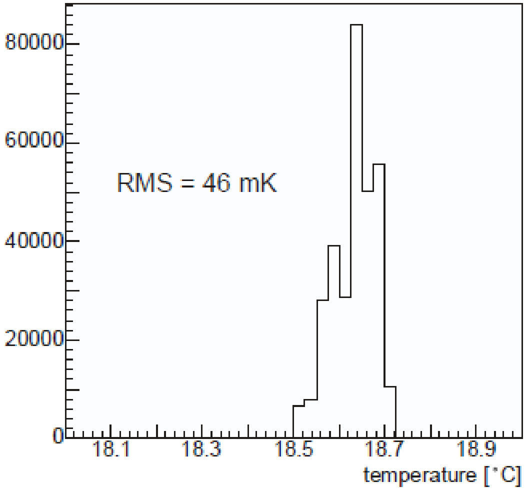
MULTI-EVENT MEMORY

Cooling system

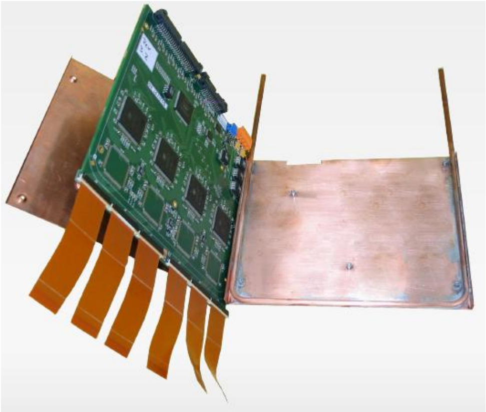
Provide temperature stability

- ~ 500 temperature sensors
- Leakless underpressure system with ~ 60 adjustable cooling circuits
- Thermal screening towards ITS and TRD
- Copper shields of service support wheel
- Cooling of ROC bodies
- Water cooling of FEE in copper envelope (~27 kW)
- Result: Temperature homogenity: σ_T = 0.046 K





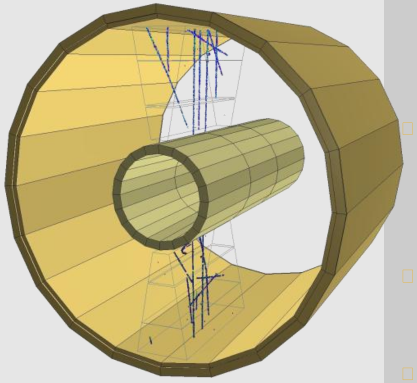
Good agreement with design specifications



FEC with its cooling envelope

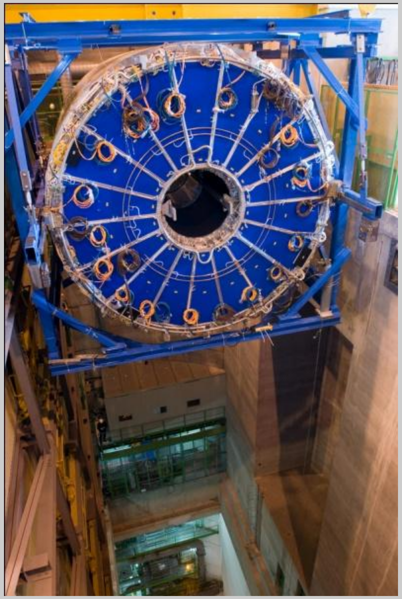
Commissioning - Milestones

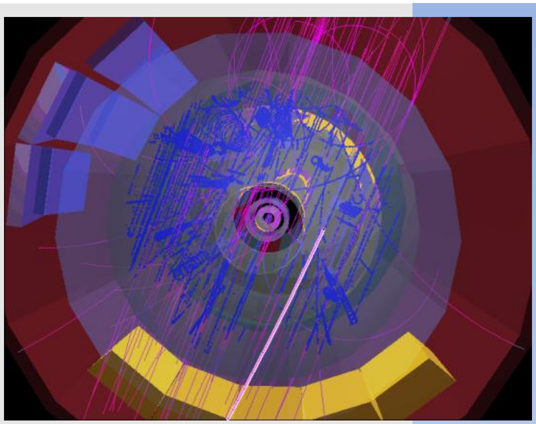
2006 2007 2008 2009 2010



- completely assembled
- first commissioning of sector pairs

- transport to experimental area
- ITS integration
- commissioning of one readout side with final services





- commissioning of complete TPC with final services
- running under final conditions over several months
- extensive calibration runs

- Refinement of the calibration
- Automation of the services
- Preparation for Pb-Pb collisions

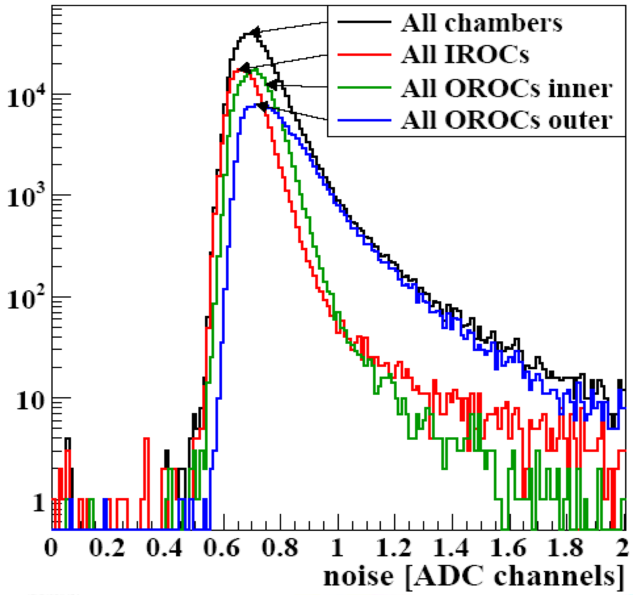
Dec. 2009:
first pp coll. at √s = 0.9 TeV

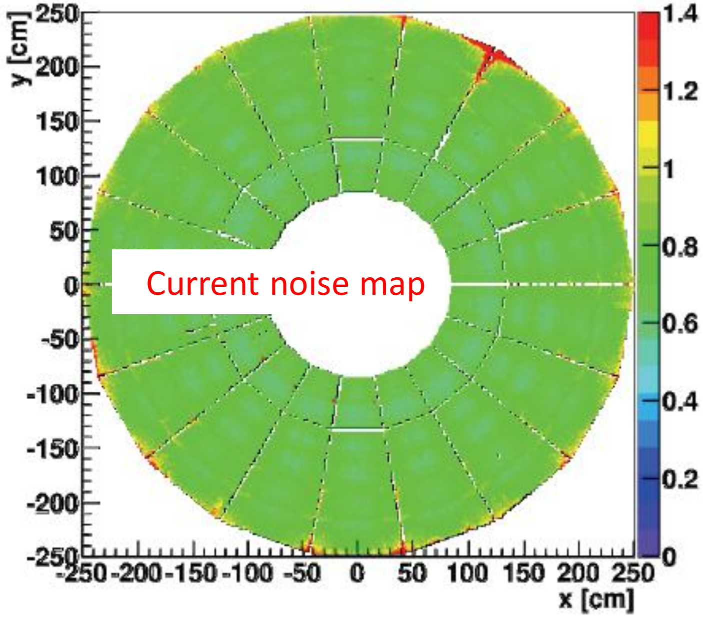
March 2010:
pp collisions at√s = 7 TeV

Nov. 2010:
first Pb-Pb collisions

Noise measurements

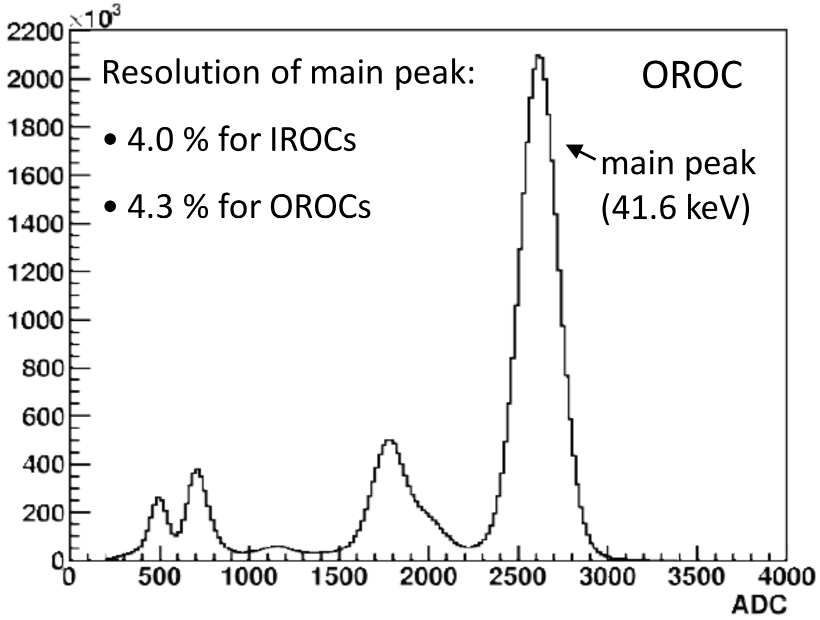
- Mean noise level:
  - 0.7 ADC count (700 e)
  - Designed - 1 ADC count (1000 e)
- Data volume of empty event:
  - ZS event: ~ 30kB
  - non-zero suppressed (ZS): ~ 700MB
- Typical size of the event with data:
  - 0.1 - 1 MB (p - p)
    - 360 kB TPC @ 7 TeV
  - ~ 30 MB (Pb - Pb, dN/dy = 2000 -> expected)





Current noise map

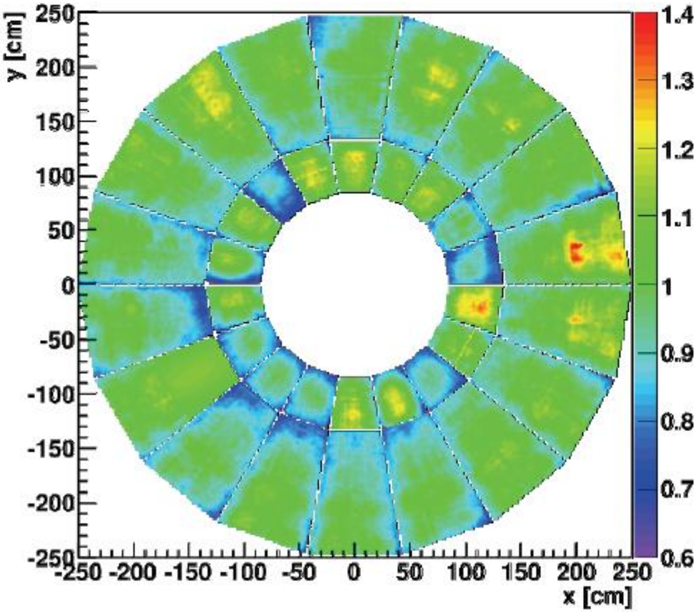
Gain calibration using ^{83}Kr



Resolution of main peak:

- 4.0 % for IROCs
- 4.3 % for OROCs

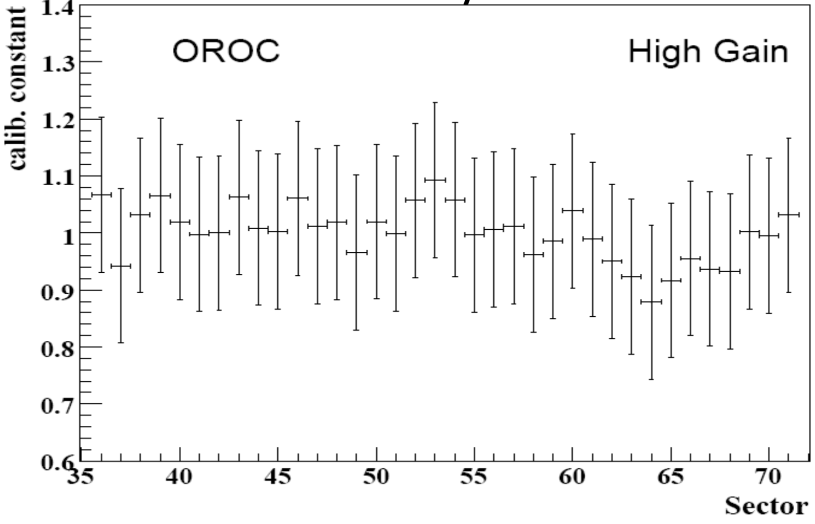
main peak (41.6 keV)



Result: Relative gain variation C-side

Determine gain for each pad

- 3 different HV settings (gains)
- High statistics: several 10^8 Kr events
- Accuracy of peak position: << 1% (design: 1.5%)



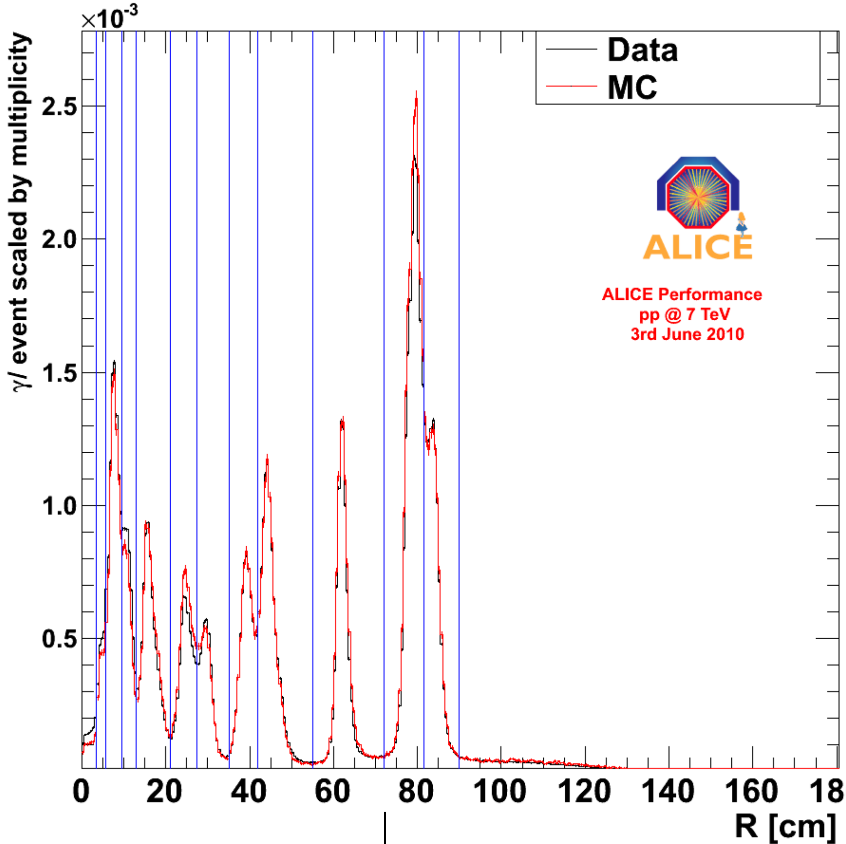
Chamber-by-Chamber

-> recent development:

Equalization on the sector-voltage level

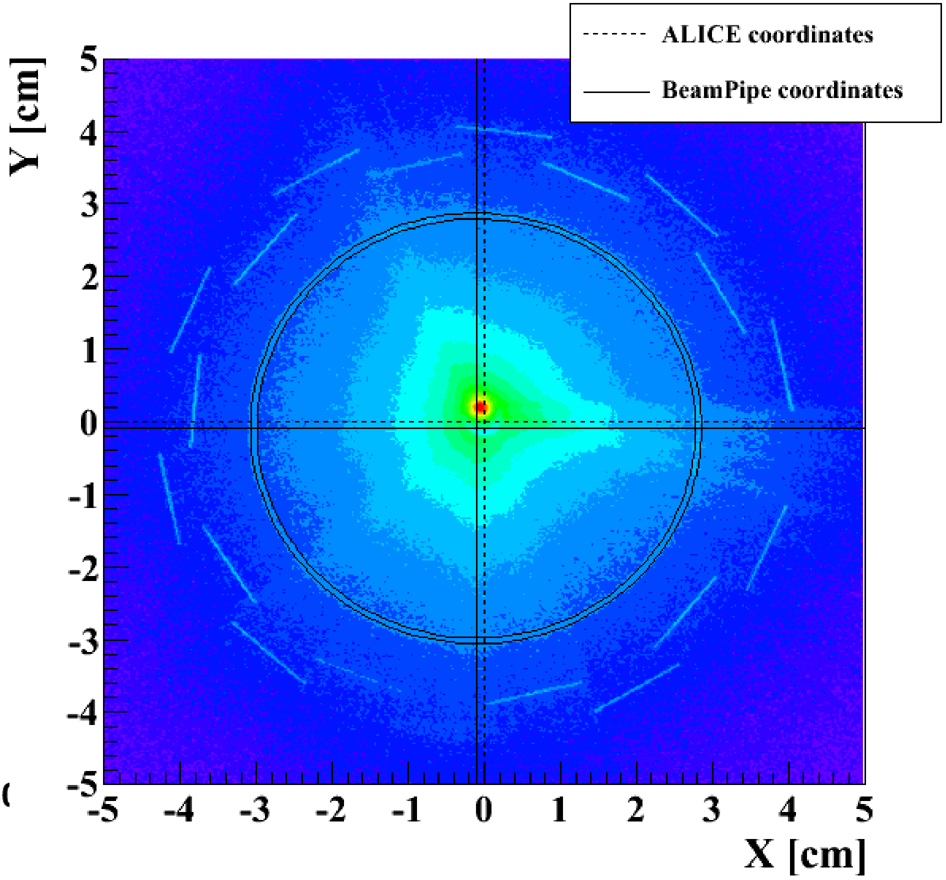
Material budget and Positioning

Radial distribution



TPC begins here

Vertices from hadron interaction

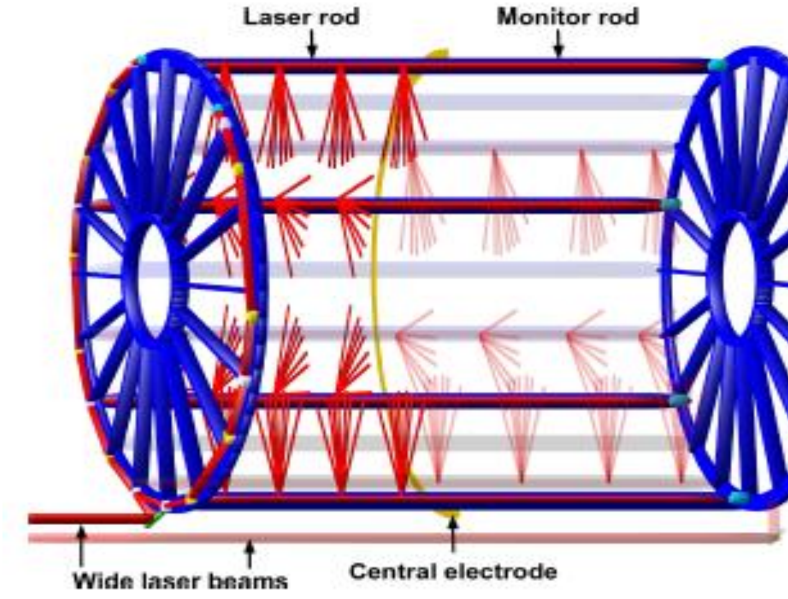


Agreement between MC and DATA: 5 ~ 15 %

Laser system

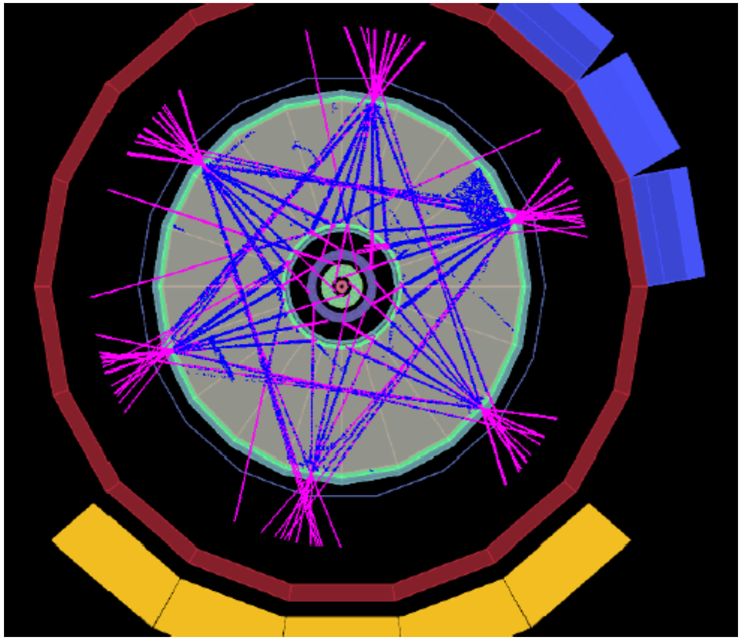
- 336 laser beams
- Used for:
    - E × B effect
    - Drift velocity measurements
    - Partially for alignment

The principle of laser system for the TPC



Laser features:

- λ = 266 nm or E = hν = 4.66 eV
- Energy: 100 mJ/pulse
- Duration of pulse: 5 ns



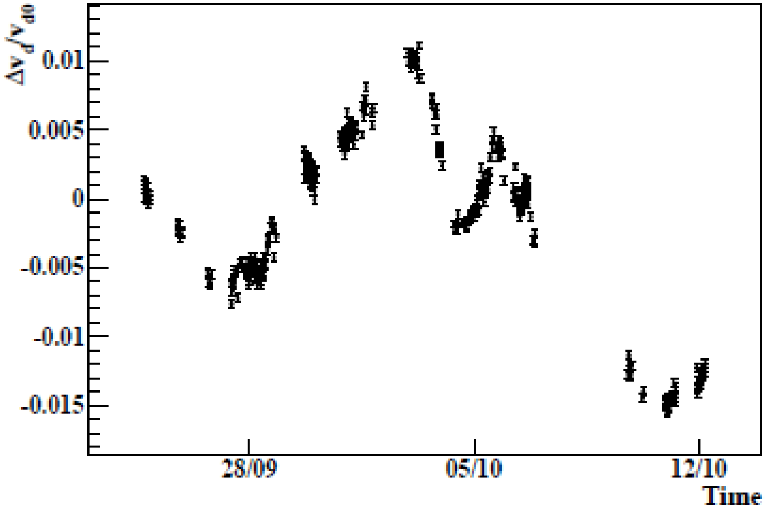
Reconstructed laser tracks

The ionization in the gas volume along the laser path occurs via two photon absorption by organic impurities.

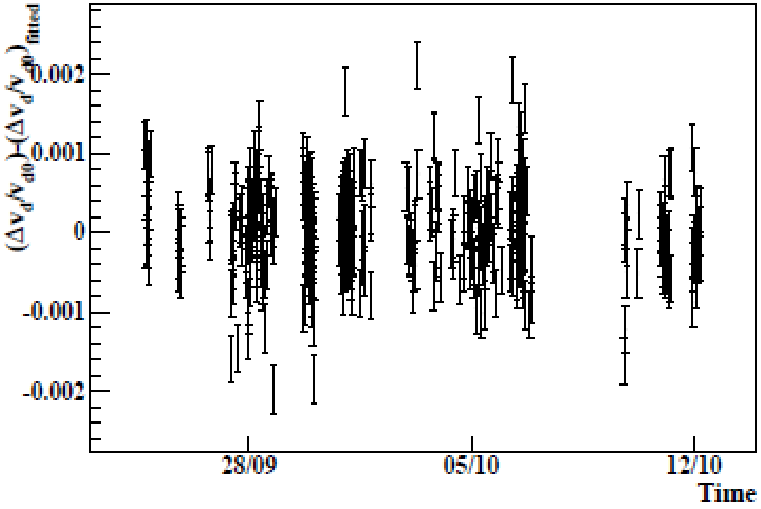
Drift velocity measurements

- $\upsilon_d = \upsilon_d(E, B, \rho(T_{in}, P_{atm}), C_{CO2}, C_{N2})$
- Crucial for track matching with other detectors
- How to obtain drift velocity correction factor:
  - Matching laser tracks and mirror positions
  - Matching TPC and ITS tracks
  - Matching tracks from two halves of TPC
  - Drift velocity monitor
- Required accuracy: $10^{-4} \Rightarrow$ update every 30 min

Drift velocity changes over time

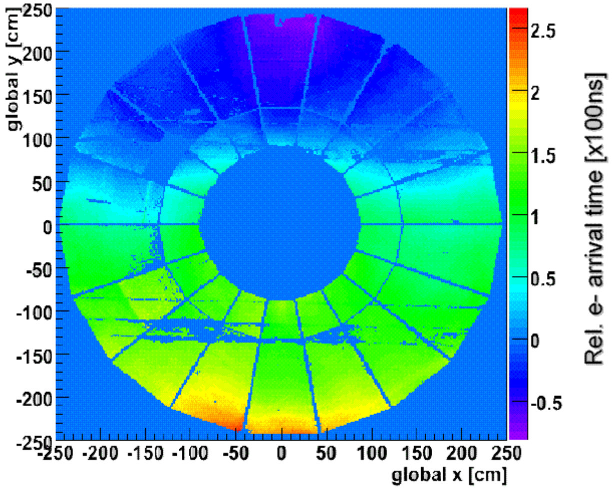


Corrected spectrum



- Photo electrons from central electrode

  monitor top-bottom arrival time offset caused by T and P gradients



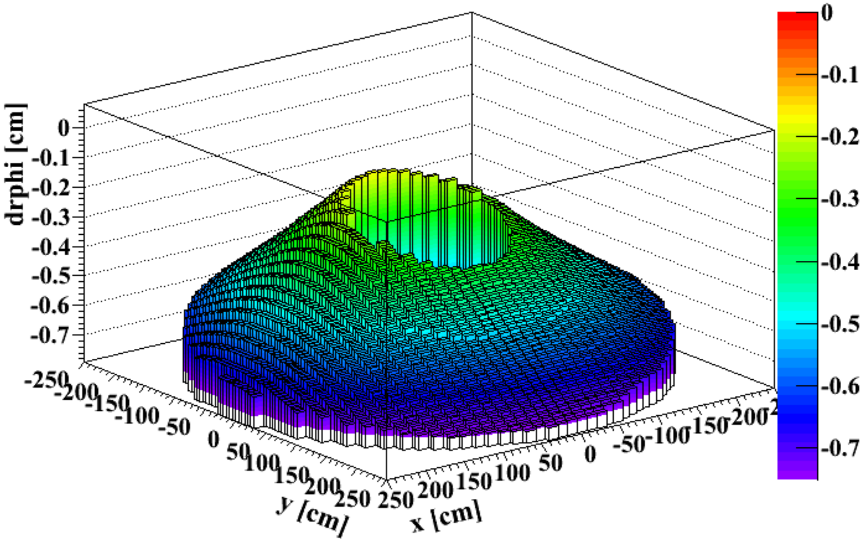
E × B effect

Caused by:

- Imperfect B field (reused L3 magnet)

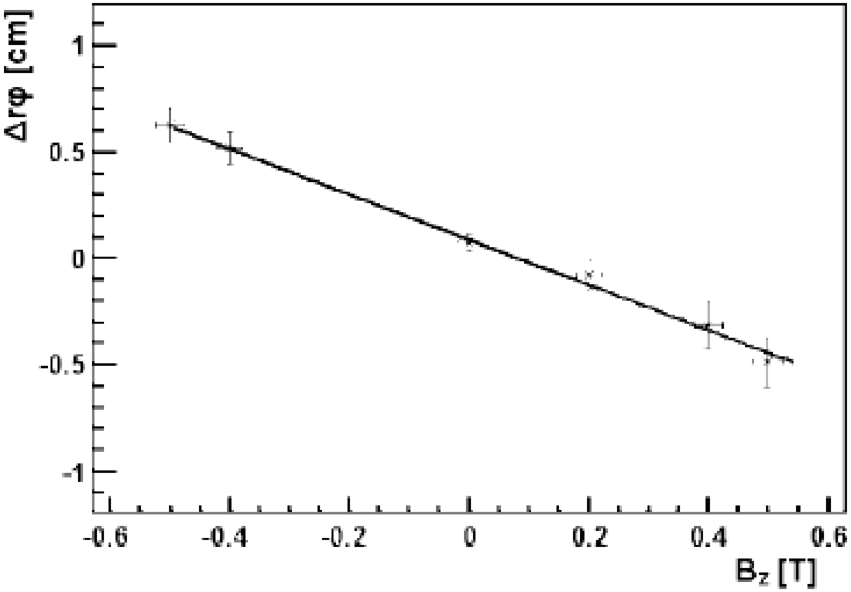
Verification of measured B field maps:

- laser tracks
- Measure $\Delta r\varphi$
- several magnetic field settings



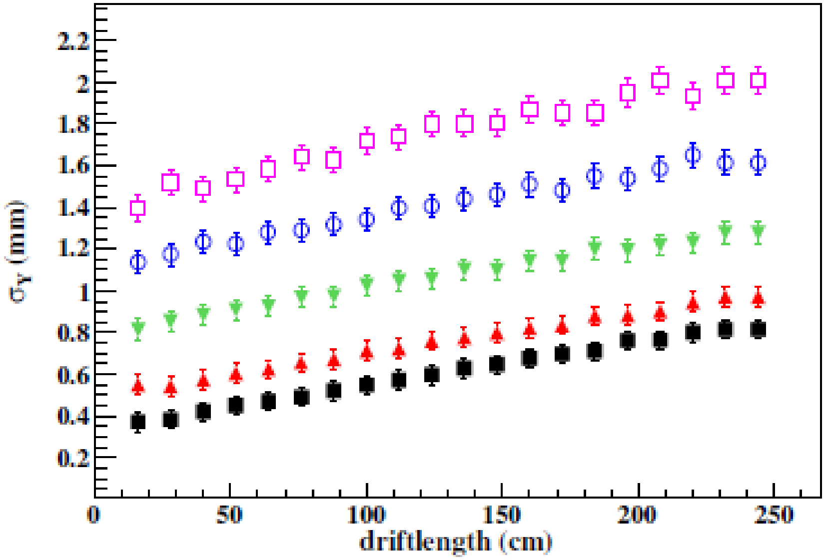
- $\Delta r\varphi$, up to 8 mm

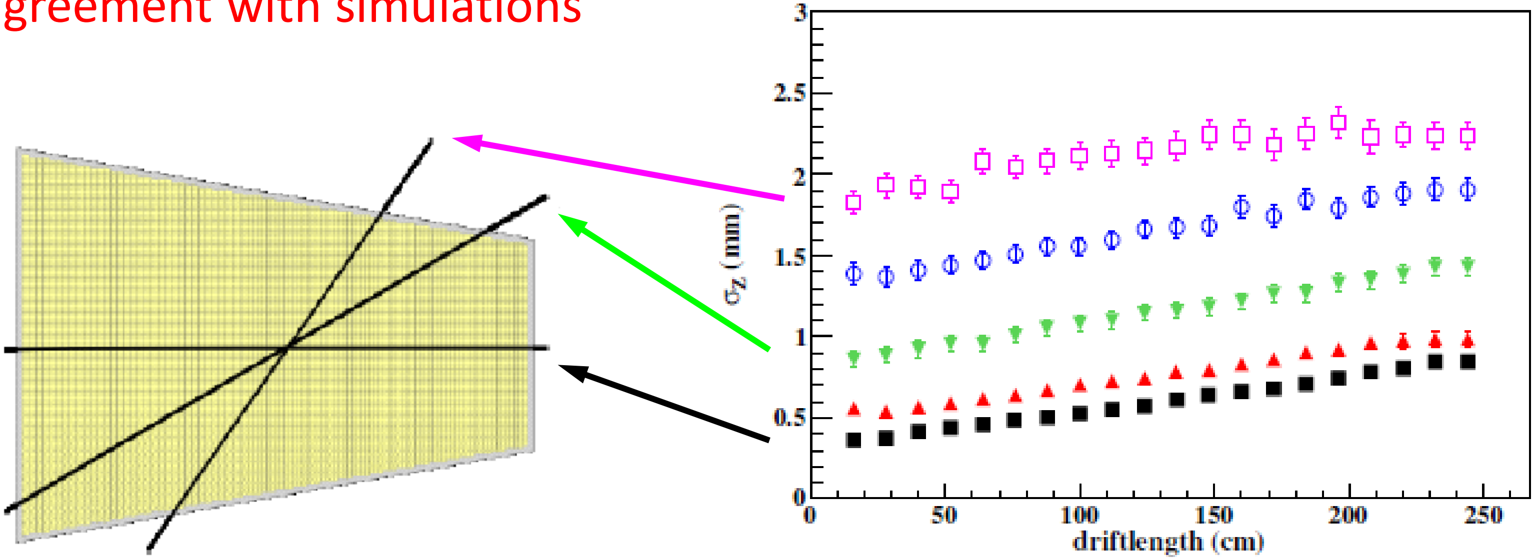
  → for longest drift and nominal field
- Corrected to ~ 0.3 mm
- Ongoing studies regarding the imperfection of the E field



Space point resolution

- Depends on:
  - Drift length
  - Inclination angle
  - Charge deposited on the anode wire
- In rφ direction: $\sigma_Y = 300 - 800\ \mu m$
  - for small inclination angles (high momentum tracks)
- In drift direction: $\sigma_Z = 300 - 800\ \mu m$
- Good agreement with simulations



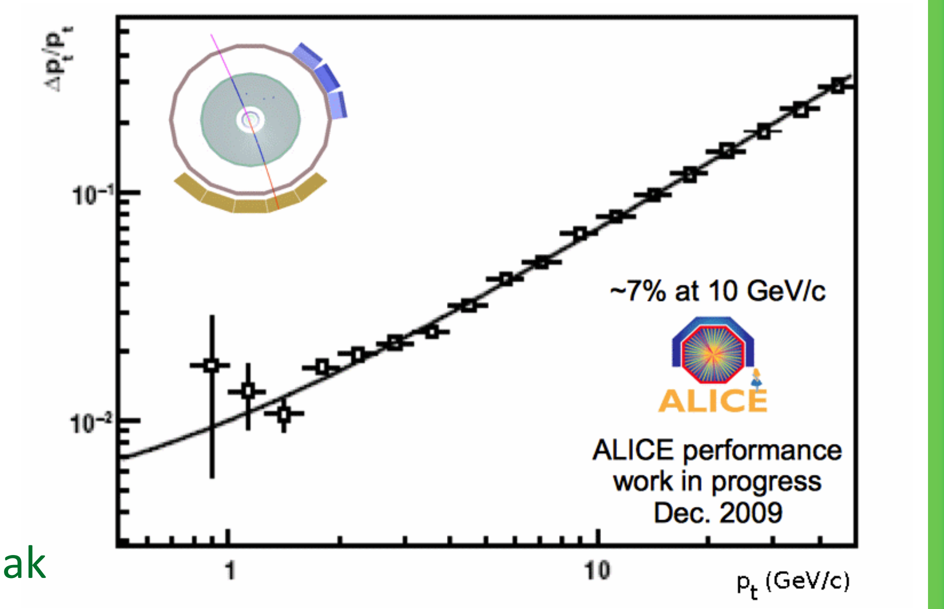


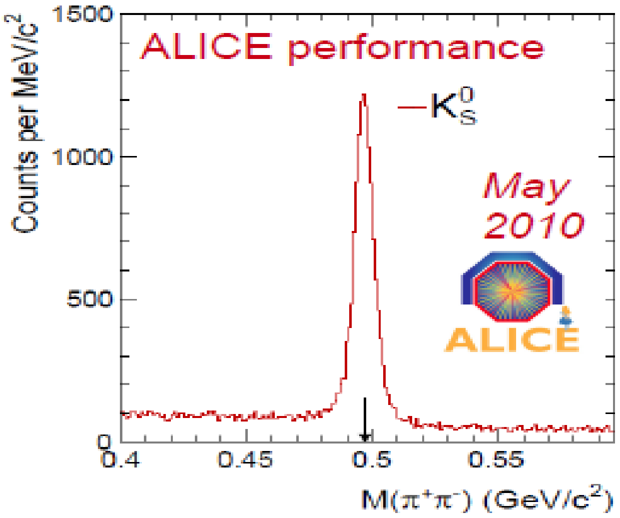
Momentum resolution

- High momentum tracks
  - Cosmic muon tracks treated independently in two halves of TPC
  - Comparison of p_T at vertex gives resolution
  - Statistics: ~ 5×10^6 events
- Low momentum tracks
  - Deduced from the width of K^0_S mass peak
- **Status (end of 2009) :**

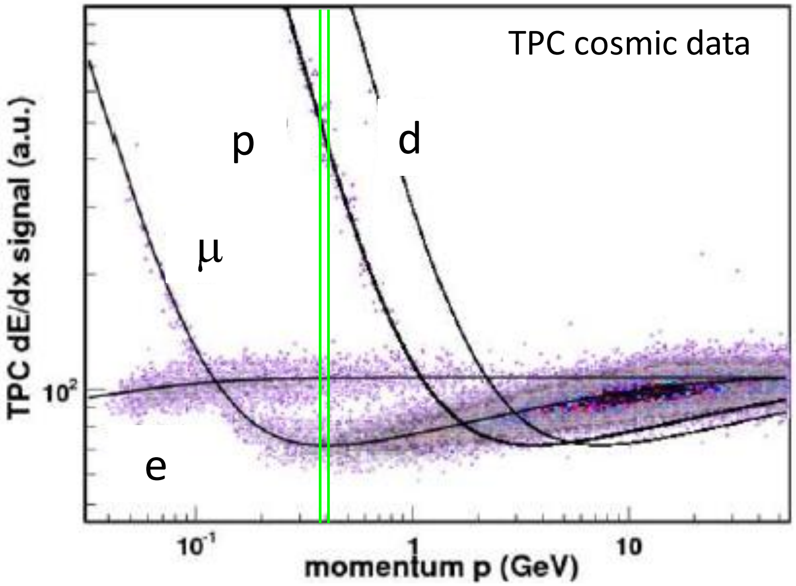
  $(\sigma_{pT}/p_T)^2 = (0.01)^2 + (0.007p_T)^2$
- Achieved: ~ 7 % @ 10 GeV/c

  ~ 1 % below 1 GeV/c
- Ongoing improvements for E field distortions



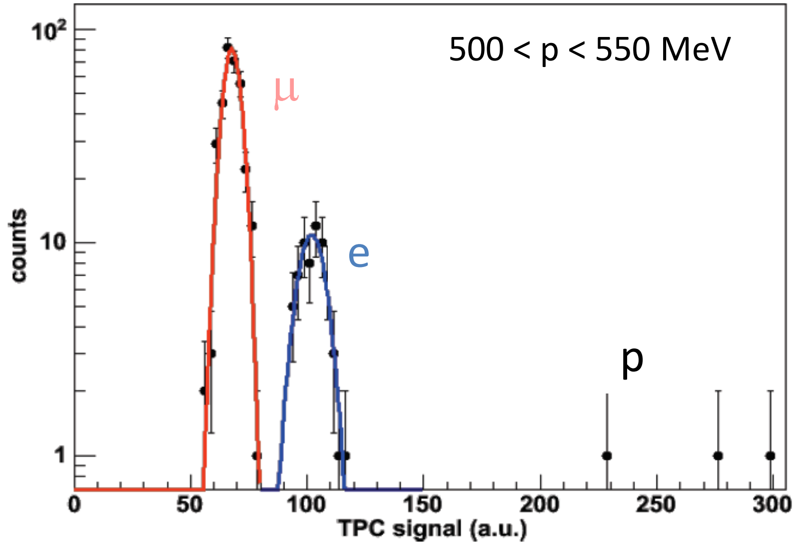


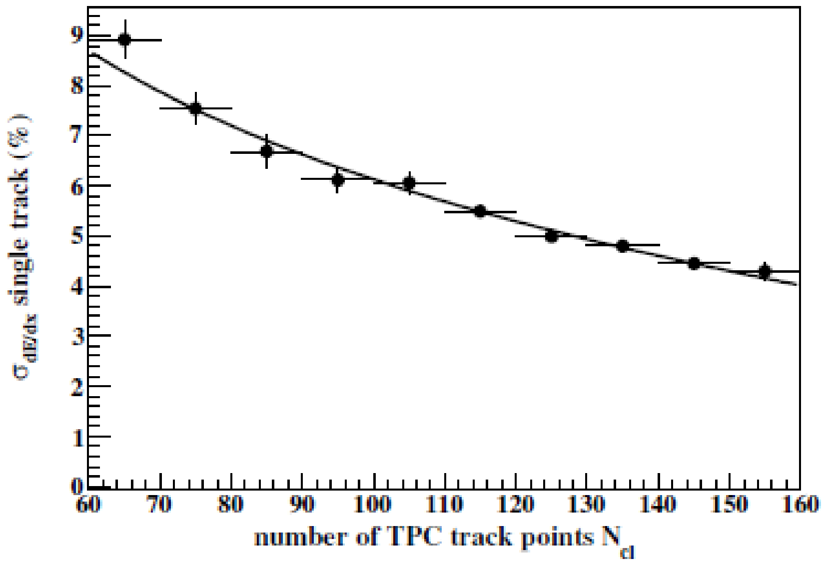
dE/dx resolution - cosmics



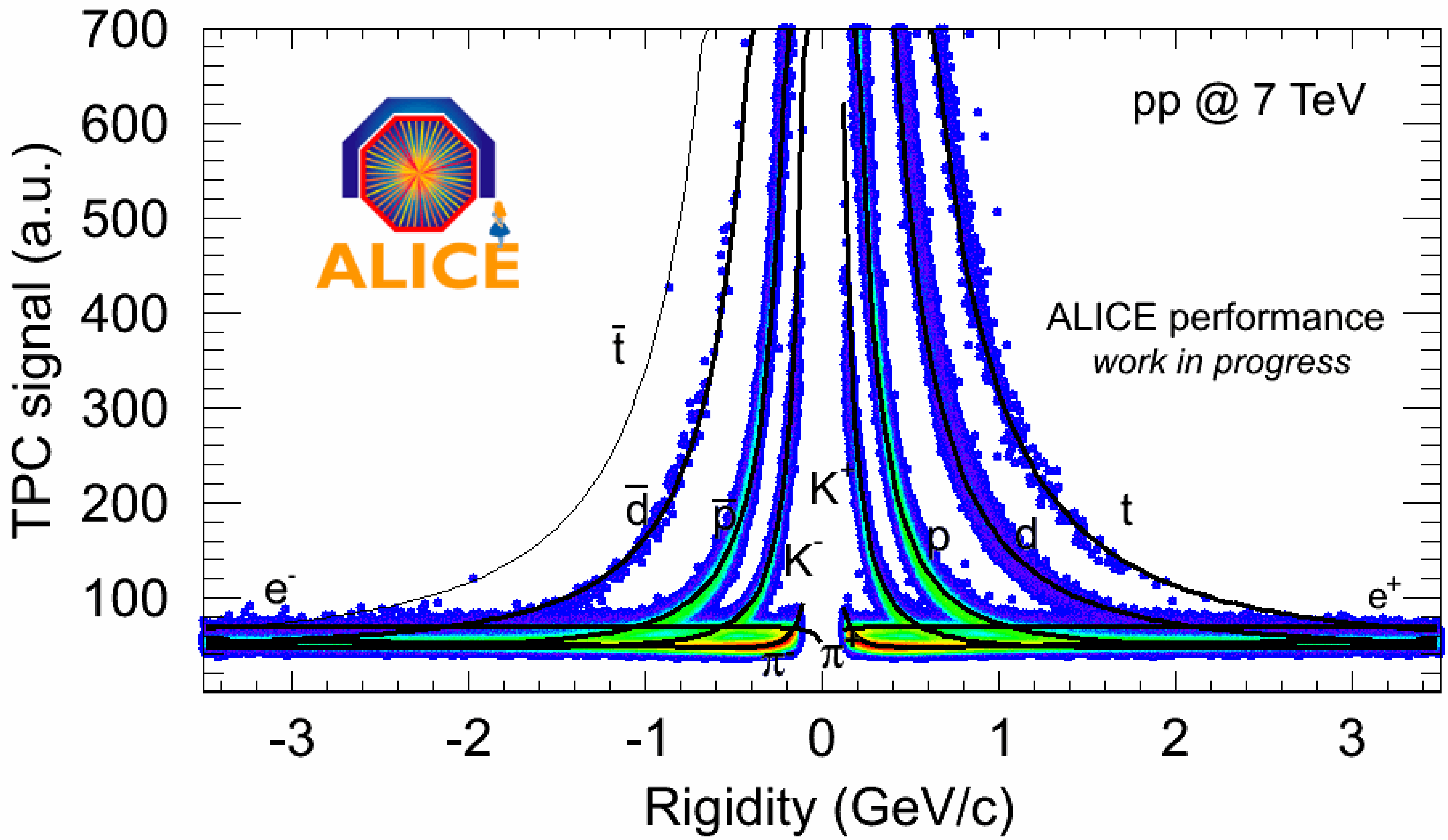
Allows particle identification up to 50 GeV/c

- Statistics: 8.3×10^6 cosmic tracks in 2008
- Design goal: 5.5 %
- Measured: < 5 %





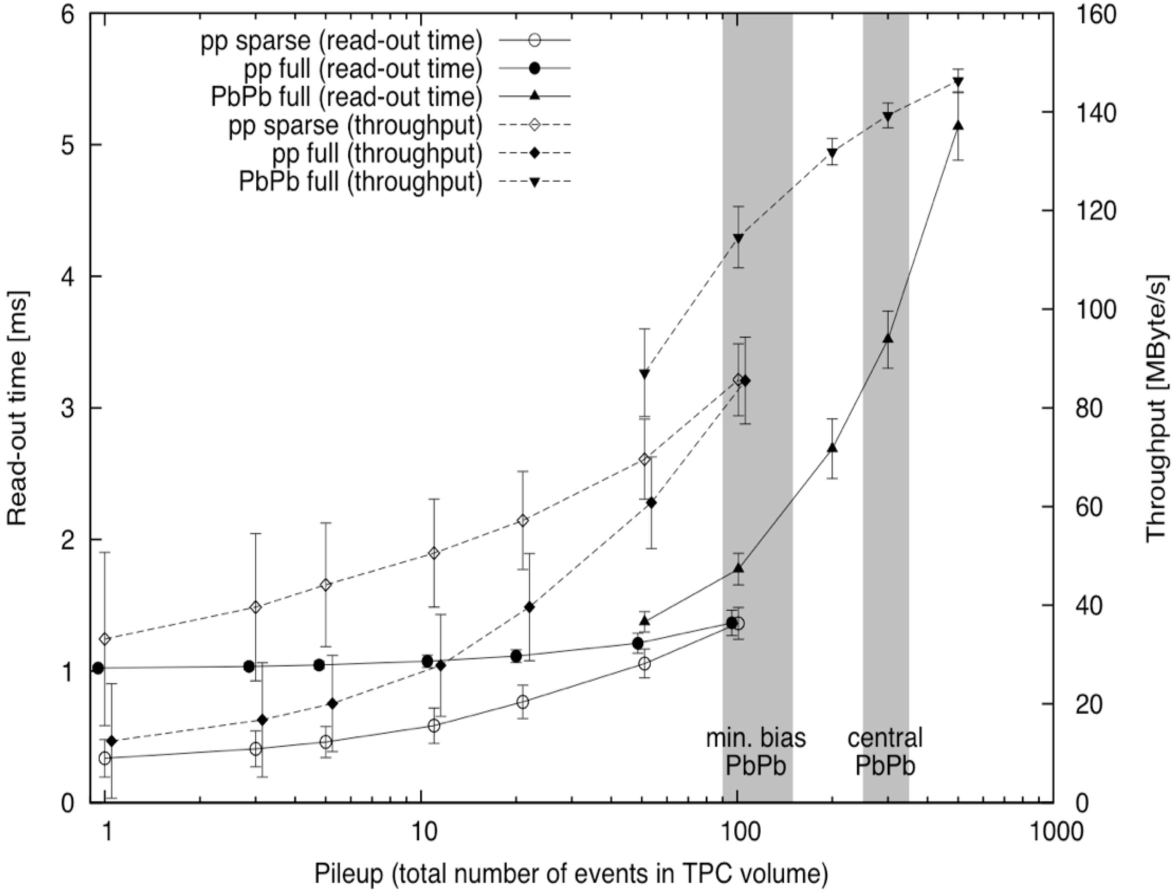
dE/dx spectrum in data



Read out performance

Total number of Read out Channels	**557 568 ch**
6 FECs damaged by HV trips	768 ch
ASIC issues (ALTRO or PASA)	362 ch
Off for noisy location	576 ch
Active Fraction	**99.7 %**

Read-out at slowest partition



1. **central PbPb: 300 Hz**
2. **100 pp pile-up: 700 Hz**

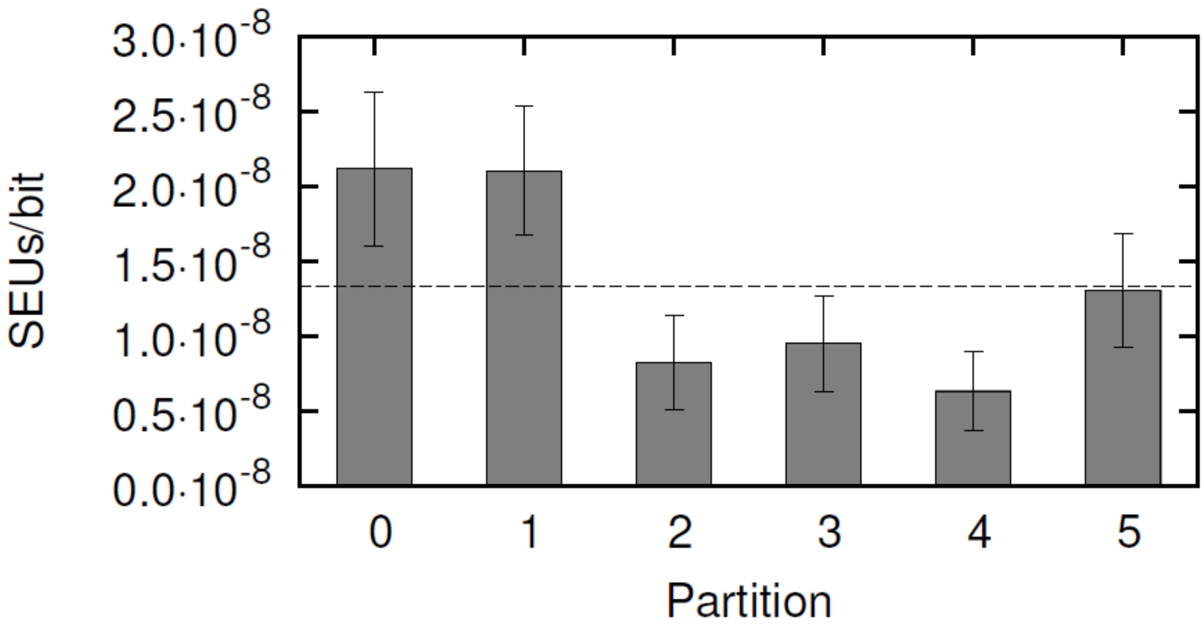
TPC SEU measurement

Strategy:

- Write fixed bit pattern to ALTRO pedestal memory
- Read the pattern at the end of run

Interactions (*)	Bits	SEUs
381 600	5.60×10^9	58
154 500	5.60×10^9	17
OFF	4.90×10^9	0

(*) Time integral of LHC.BRANB.4L2:TOTAL_LUMINOSITY



HV trip of the ROCs

- trips started occurring since 25th May, when LHC started running at higher intensity and/or luminosity, and the TPC was triggered at higher rates (400Hz ➡1kHz).

Total nr. trips	**76 trips**
MTBF*	**3.6 hours**

*MTBF ≡ mean beam time between failure

- 8 FECs have been irreversibly damaged (short circuit at PASA input) as consequence of an HV trip

❑ At present we tend to believe that there might be a “charge cumulative effect” that charges-up some of the insulating parts of the HV elements

COUNTERMEASURES:

1. Increase the content of H_2O in the gas: 50ppm ➡ 200ppm
2. Increase the maximum current limit by a factor 2 (required hardware modification of all PS)
3. Add a protection resistor (~MOhms) and a decoupling capacitor (~10nF) at the output of the power supply (CR4).

Calibration developments in 2010

- 2D and 3D calculations of Field Cage (E field) imperfections
- Extraction of rϕ distortion maps with pp collisions at B=0 field
- Langevin-formalism allows consistent treatment with B = +/- 0.5 T

$$\begin{pmatrix}\delta_{xE}\\ \delta_{yE}\end{pmatrix} = \begin{pmatrix} c_0 & c_1 \\ -c_1 & c_0 \end{pmatrix} \begin{pmatrix} \int \frac{E_x}{E_z}\, dz \\ \int \frac{E_y}{E_z}\, dz \end{pmatrix}$$

$$\begin{pmatrix}\delta_{xB}\\ \delta_{yB}\end{pmatrix} = \begin{pmatrix} c_2 & -c_1 \\ c_1 & c_2 \end{pmatrix} \begin{pmatrix} \int \frac{B_x}{B_z}\, dz \\ \int \frac{B_y}{B_z}\, dz \end{pmatrix}$$

For details, see **“ExB equations”** by **Jim Thomas** (http://rnc.lbl.gov/~jhthomas/public/ALICE/) based on “Blum,Riegler”, “Particle detection in drift chambers” (2009)

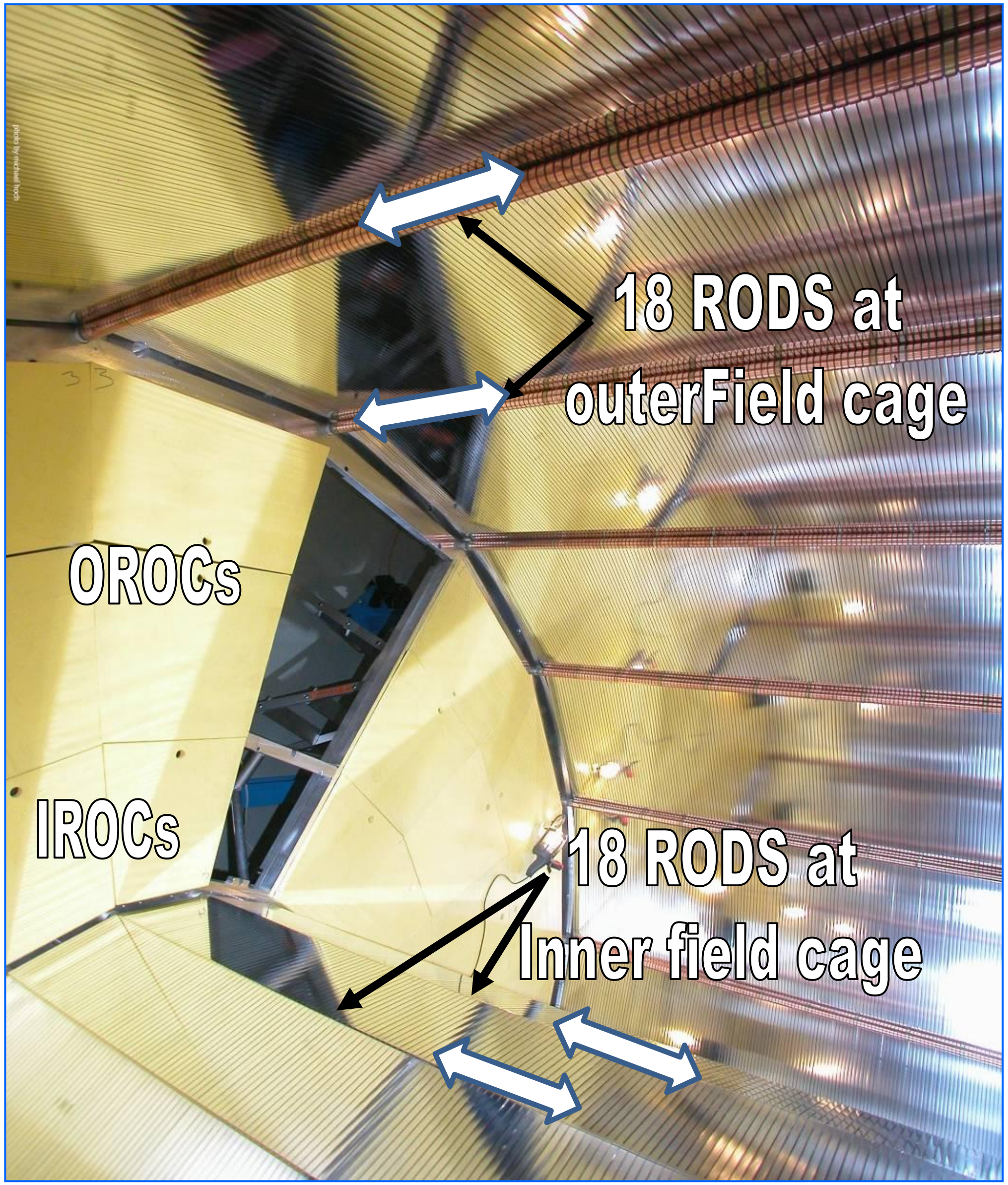
Form is very similar to a rotation matrix, with constants of the motion

$$c_0 = \frac{1}{(1+T_2^2\omega^2\tau^2)}, \quad c_1 = \frac{T_1\omega\tau}{(1+T_1^2\omega^2\tau^2)}, \quad \text{and} \quad c_2 = \frac{T_2^2\omega^2\tau^2}{(1+T_2^2\omega^2\tau^2)}$$

.. two tensor terms (T1 and T2) from the microscopic theory in Blum and Rolandi’s book

$$\omega\tau = -10.0 * Bz\,[kG] * \frac{vd\ [cm/\mu\text{sec}]}{Ez\ [V/cm]}$$

Field cage imperfections



E field inhomogeneities (e.g.):

- 36 Rods at each side are "individually" shifted
- Magnitude: up to 0.8 mm (fantastic for a 5m structure!)
- Resulting non-linear distortions: up to 6 mm (at IFC)

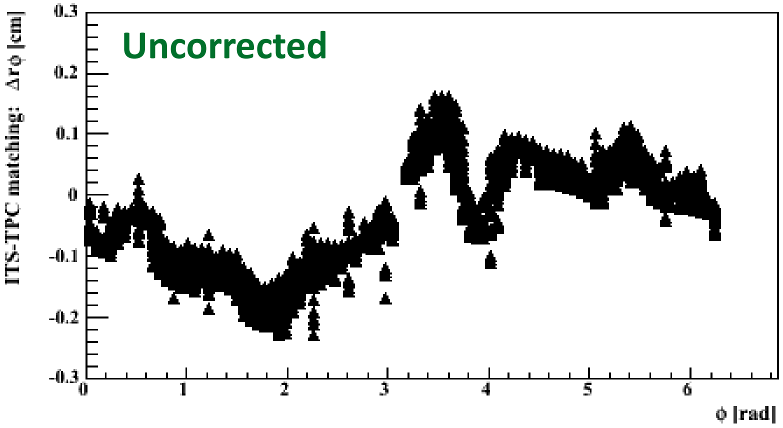
Necessary corrections:

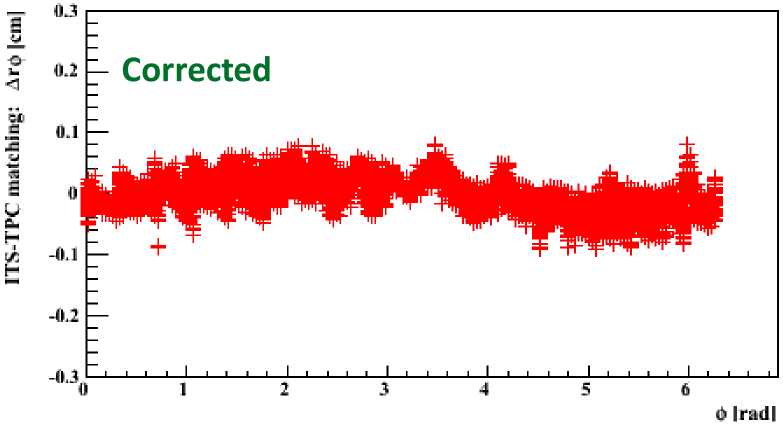
- Non-linear and in 3D
- Important for ITS matching and momentum

Example 1: ROD and Strip shifts

(preliminary result)

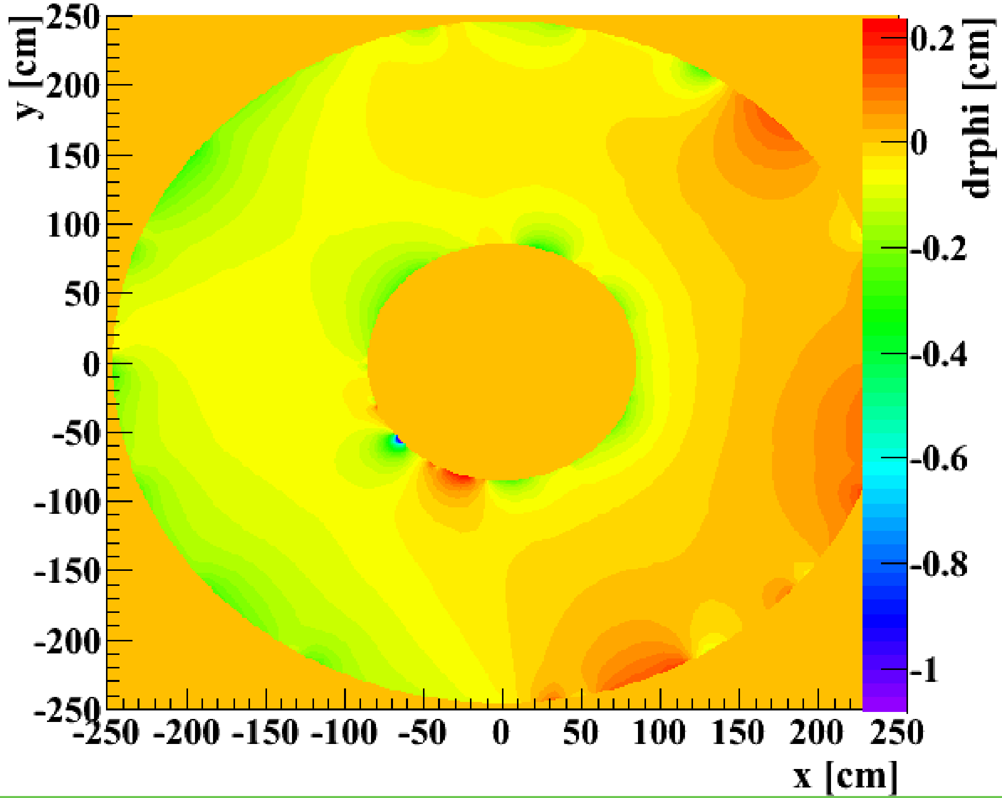
TPC track matching at CE





Example correction map for rϕ:

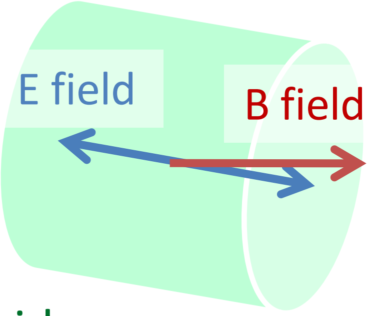
- Highly nonlinear
- Radial and z distortions according to Maxwell equations



Example 2: ExB Twist

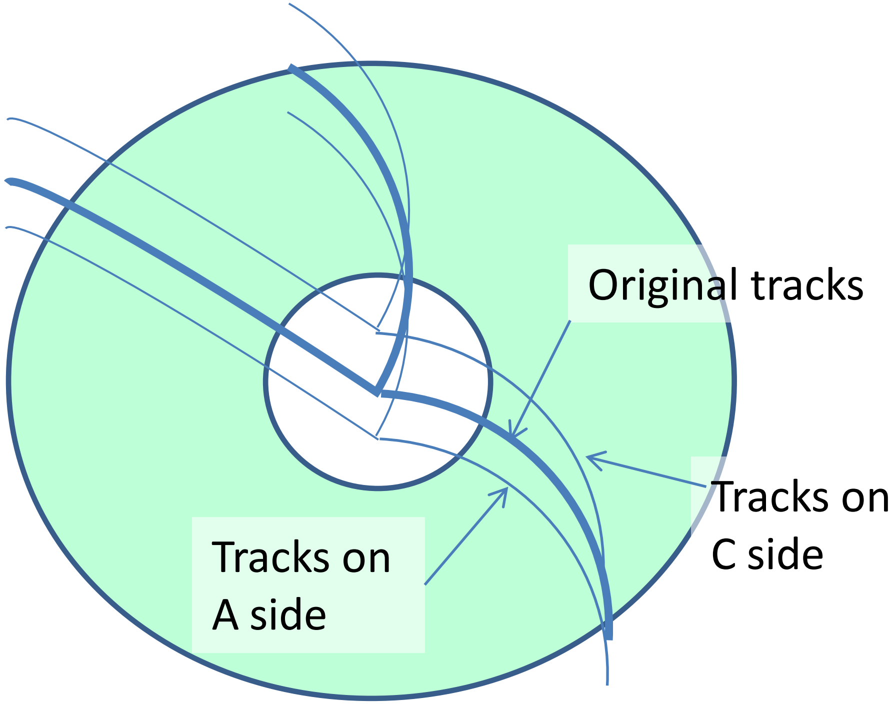
Main components of E and B field vectors not aligned:

- Systematic shifts on both sides of the TPC (opposite direction)



Main observable:

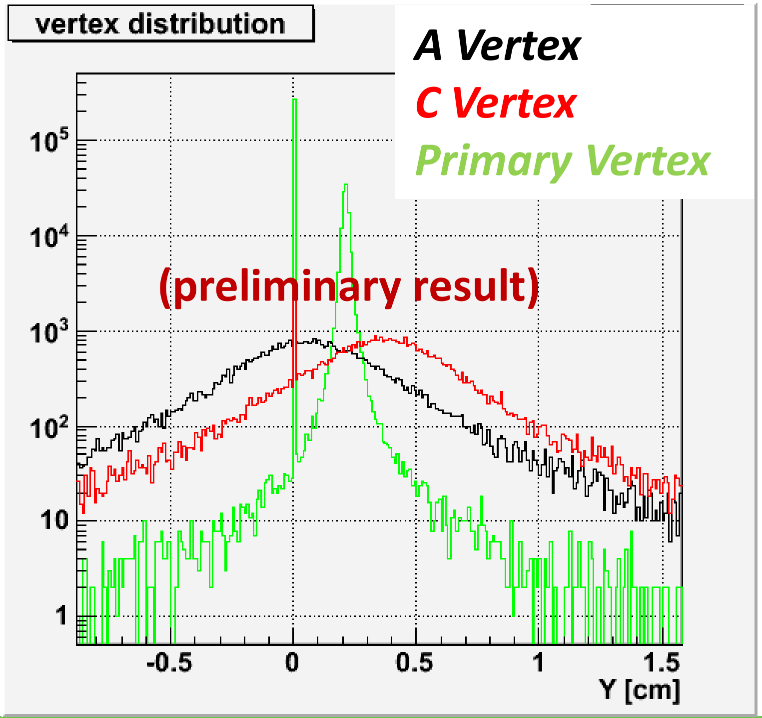
- Reconstructed Vertex is different with A side and C side tracks
- 3 mrad of twist leads to 5 mm vertex offset



Original tracks

Tracks on C side

Tracks on A side



(preliminary result)

READY FOR HEAVY ION?

- Developed corrections are independent of the Run type (pp or Pb-Pb), except for the “Space Charges” …
- Space Charges in the TPC drift volume influence the tracks

SpaceCharge scales with Multiplicity and Interaction rate

Design differences between the STAR and ALICE TPC

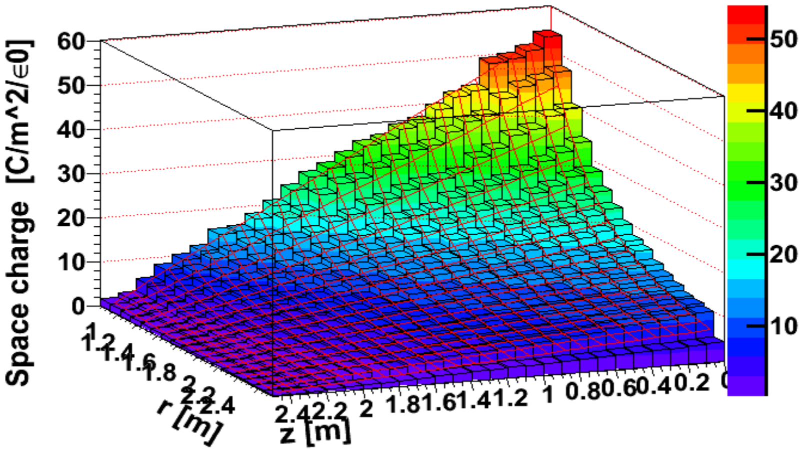
	Star (ArCH$_4$)	Alice (NeCO$_2$N$_2$)	Factor
Acceptance	~1	~1	1
Ion - mobility	1.6 cm^2/Vs	4 cm^2/Vs	
E field	135 V/cm	400 V/cm	
Clearing time	0.96 s	0.156 s	0.16
Energy loss	2.5e-3 MeV/cm	1.4e-3 MeV/cm	0.57
Design scaling factor		**F_{design} =**	**0.0912**

ALICE TPC will see a **factor ~10** less Space Charge thanks to the **gas choice** and the **larger drift field**

Expect. space charge densities in ALICE?

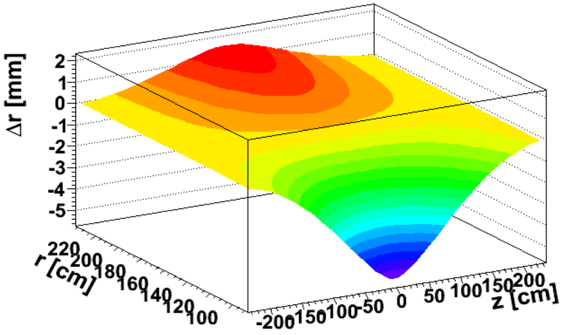
- Dominated by Primary Ionization (according to MC simulation)

Expect. space charge shape:
$\rho(r,z) = (A-B\,z)/r^2$

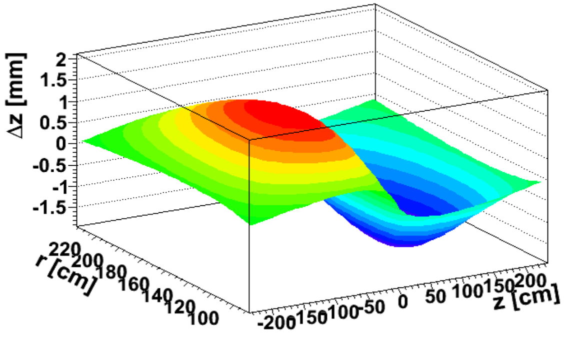


ALICE: MC Simulation settings	
coll.Energy	5.5 TeV
Luminosity	4 10^{26} 1/cm^{2}s
event rate	3200 Hz
Ion clear. time (Ne$^+$)	0.156 s
Mult (central 5%)	~ 2300 dN/dη
Mult (min.bias 80%)	~ 950 dN/dη

Radial distortions



Z - distortions



(due to the sensitive gas)

Note: Shown distortions are for 5 times maximum Pb-Pb Luminosity

Space charge effect at highest LHC rate?

- Maximum **LHC Pb-Pb luminosity:** 10^{27} [1/cm^{2}s]

  → Interaction rate: 7700 Hz
- Charged particle multiplicity (min.bias top 80%, $\sqrt{s}$ = 5.5 TeV, HiJing prediction)

  → $M_{(mb,80)} \sim$ 950 dN/dη

Max. charge density at CE and IFC: ~ 130 C/m^3/e0

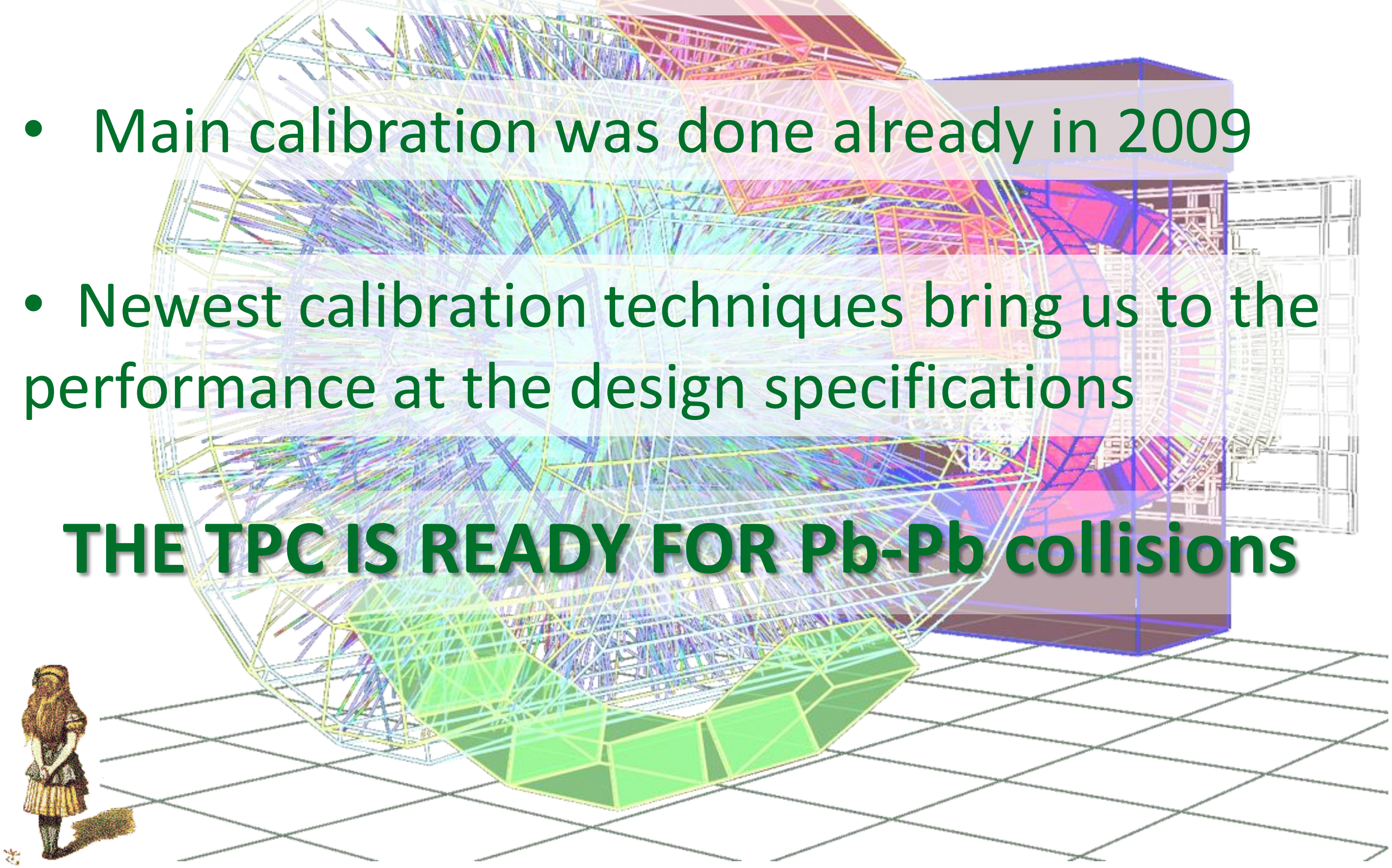
max. Δr ~ 1mm (at IFC&CE)

max. $\Delta r\phi$ ~ 0.35 mm (at IFC&CE)

max. Δz ~ 0.30mm (at z~100cm)

Even at highest rate, the static ExB and other E field distortions are still the dominant effect

CONCLUSION



- ALICE TPC works stably during p-p data taking
- Main calibration was done already in 2009
- Newest calibration techniques bring us to the performance at the design specifications

THE TPC IS READY FOR Pb-Pb collisions

The ALICE TPC collaboration

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11. Zentrum fur Technologietransfer und Telekommunikation (ZTT), Fachhochschule Worms, Worms, Germany.

Backup: HV trip of the ROCs – the facts

What is a "HV trip" of a TPC readout chamber (ROC)?

- The current (from the HV power supply to the ROCs) exceeds a limit (currently 200 μA)
- If limit is exceeded, the power supply ramps-down in about 3s

ROCs HV behaviour - an "historical" perspective

2007 - 2008

- ⦿ Stable operation, but occasional HV trips (due to defective capacitors , all replaced)

2009

- ⦿ after shutdown activities, operation of TPC was resumed end of June
- ⦿ frequent (1 per week) trips occurred (while running TPC with cosmic rays?) in Jul-Aug
- ⦿ adding 50 ppm of H_2O to gas cured the problem
- ⦿ stable operation in Sep - Dec

Backup: HV trip of the ROCs – the facts

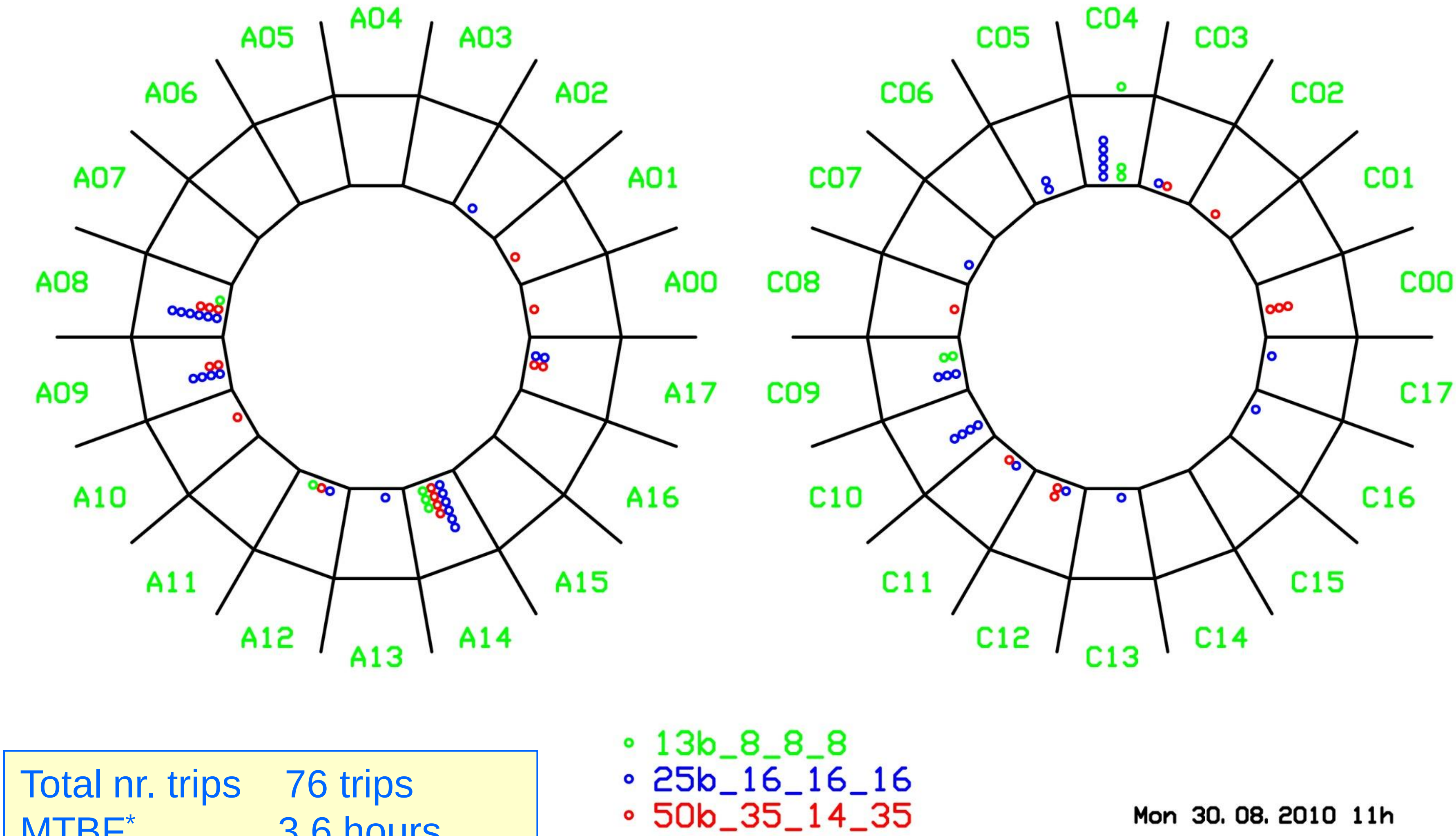
2010

- ⦿ stable in the period mid March – end May
- ⦿ trips started occurring since 25th May when LHC started running at higher intensity and/or luminosity, and the TPC was triggered at higher rates (400Hz ➡1kHz).
- ⦿ ALL HV trips occurred in the presence of colliding beams
  - ⦿ 20% while not triggering (➡ROC's gating grid closed)
  - ⦿ 80% while triggering (➡ ROC's gating grid open)

Note: charge load on the chamber while triggering at e.g. ~1kHz (~10% duty cycle) is at least 25 times larger wrt to when the TPC is not triggered

- ⦿ The fast HV ramp-down (1kV/s) induces a large negative current signal (~nA) at the input of the charge amplifiers, leading to large negative voltages at the input transistor and a large voltage (~kV) across the feedback transistor (lab studies ongoing).
- ⦿ 8 FECs have been irreversibly damaged (short circuit at PASA input) as consequence of an HV trip

Backup: HV trips - how many and where



Total nr. trips 76 trips
MTBF* 3.6 hours

*MTBF ≡ mean beam time between failure

Backup: HV trips – possible causes

What is the root cause of the HV trips? Some hypothesis

- So far we have failed to correlate the HV trips with the signal measured by other ALICE detectors
  - BCMs on the Miniframe: signal integrated over 40ms, too small surface
  - V0: continuous reading of ADC amplitudes is (at present) available only integr. over 2s
  - TPC, FMD and V0: only triggered related data
  - dedicated run with HM trigger (V0 and μTRG) and life time close to 100% did not reveal large multiplicity event that could be correlated with trips (only 1 trip occurred)
  - V0D, which is being instrumented to have a continuous readout, might help in bringing some light into the understanding of these events
- At present we do not exclude any hypothesis concerning the cause of the HV trips, including instantaneous burst of background particles generated close to IP, however:
  - ☐ We tend to exclude the possibility of discharges in the gas
  - ☐ At present we tend to believe that there might be a “charge cumulative effect” that charges-up some of the insulating parts of the HV elements

Backup: HV trips – mitigation measures

1. Increase the content of H_2O in the gas: 50ppm ➡200ppm

2. Increase the maximum current limit by a factor 2 (requires hardware modification of all PS)

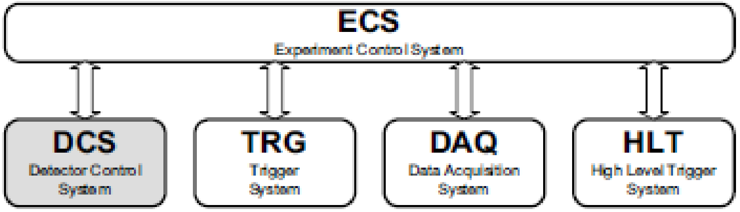
3. Add a protection resistor (~MOhms) and a decoupling capcitor (~10nF) at the output of the power supply (CR4).

The resistor is in series and the capacitor in parallel with respect to the load.
For a current of 100μA the resistor will produce a voltage drop of 100V at the load.
The capacitor has the function of increasing the ramping-down time constant by a factor

Backup: Detector Control System

Ensure a safe and correct operation of TPC

- Integrated into Experiment Control System
- Hardware architecture
  - **Supervisory layer**: user interface (PC) + databases
  - **Control layer**: hub - collect & process information from supervisory and field layers
  - **Field layer**: electronics to control equipment (power supplies, FEE, …)
- TPC is fully controlled by ALICE shifter

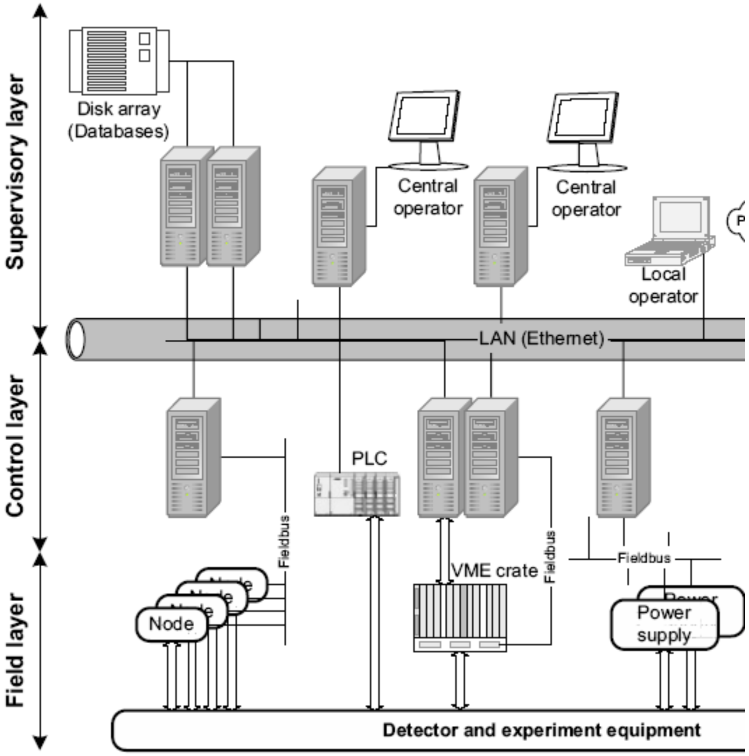

ECS
Experiment Control System

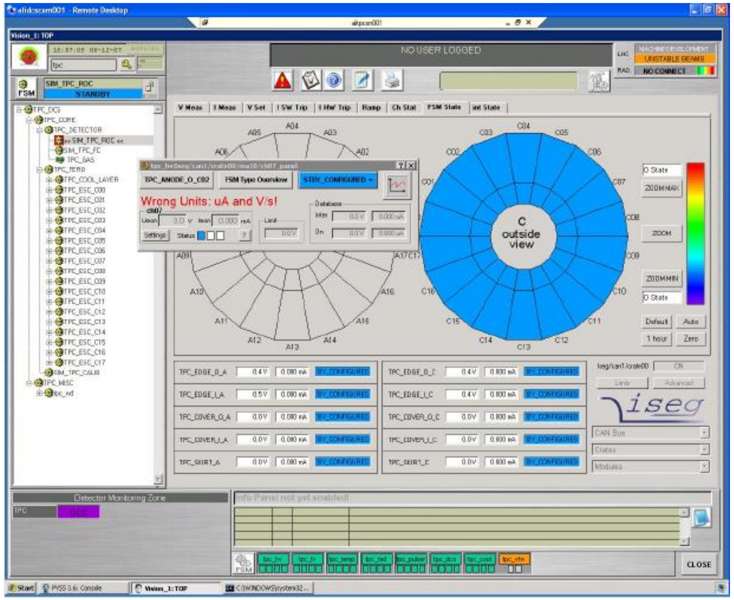
DCS
Detector Control System

TRG
Trigger System

DAQ
Data Acquisition System

HLT
High Level Trigger System




NO USER LOGGED

Wrong Units: uA and V/s!

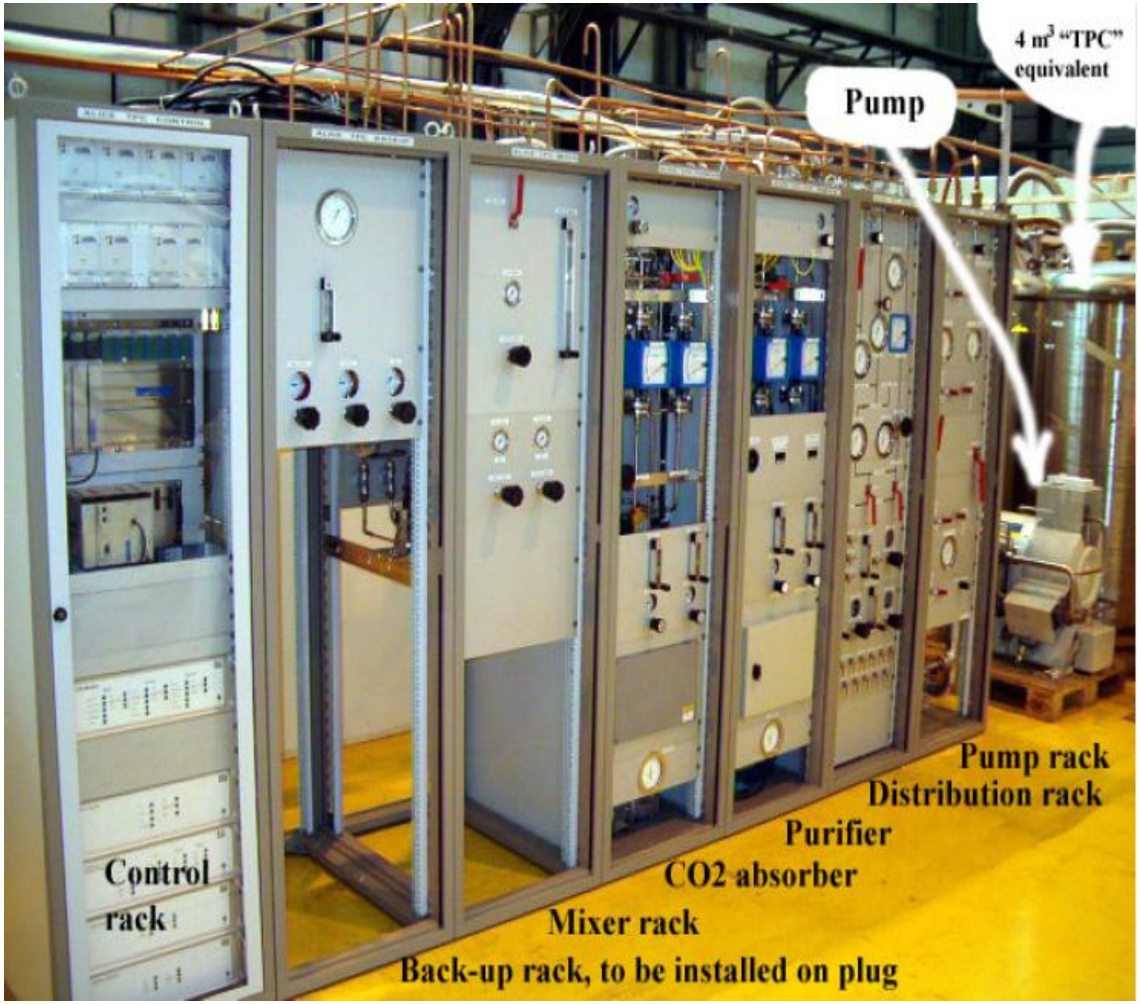
Backup: Recirculating gas system

Precise control of gas mixture

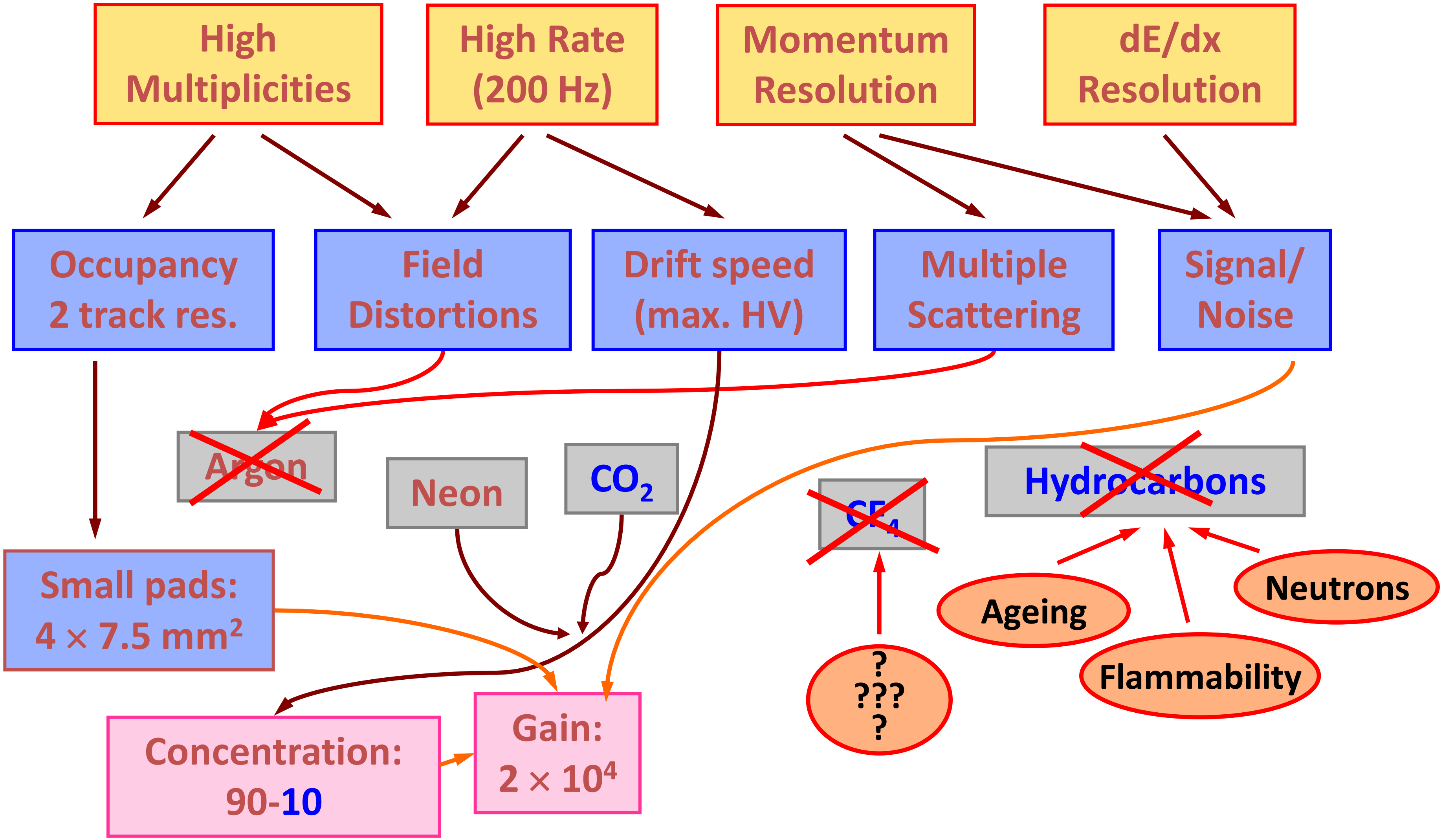
- O_2 and H_2O contamination removed by Cu catalyser
- To minimize signal loss (e^- attachment)
  - Contamination:

    ~ 1 ppm O_2 (design < 5)
- Humidity kept at fixed level (200 ppm)

  → adds conductivity on insulating surfaces
- In operation since 2006



Backup: Challenging requirements for the gas



High Multiplicities

High Rate (200 Hz)

Momentum Resolution

dE/dx Resolution

Occupancy 2 track res.

Field Distortions

Drift speed (max. HV)

Multiple Scattering

Signal/ Noise

~~Argon~~

Neon

CO_2

~~CF_4~~

~~Hydrocarbons~~

Small pads: 4 × 7.5 mm^2

Concentration: 90-10

Gain: 2 × 10^4

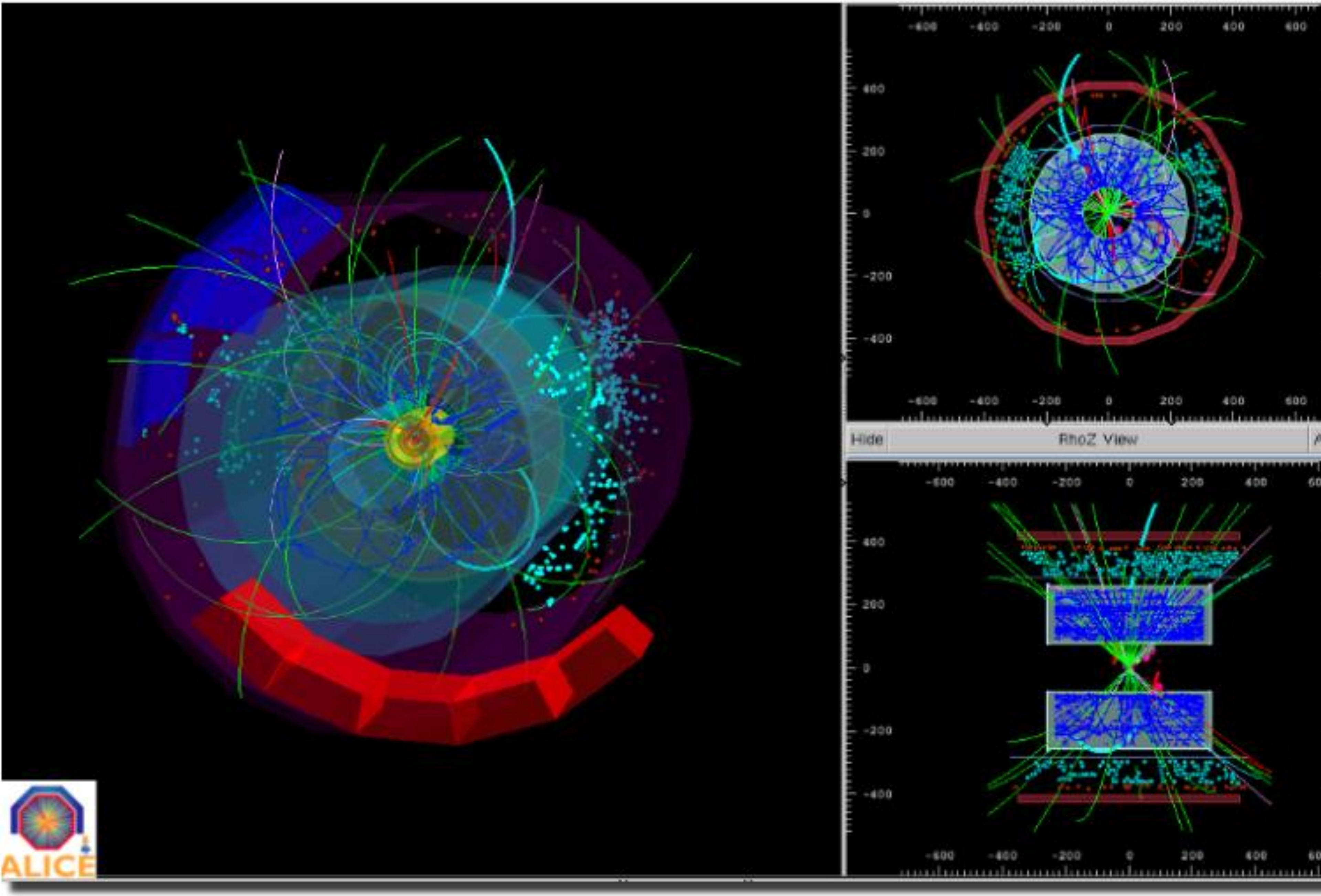
? ??? ?

Ageing

Flammability

Neutrons

Chilo Garabatos: Vienna CI, 2004


-600
-400
-200
0
200
400
600
400
200
0
-200
-400
Hide
RhoZ View
ALICE