Performance of the ALICE Time Projection Chamber

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for the ALICE TPC collaboration

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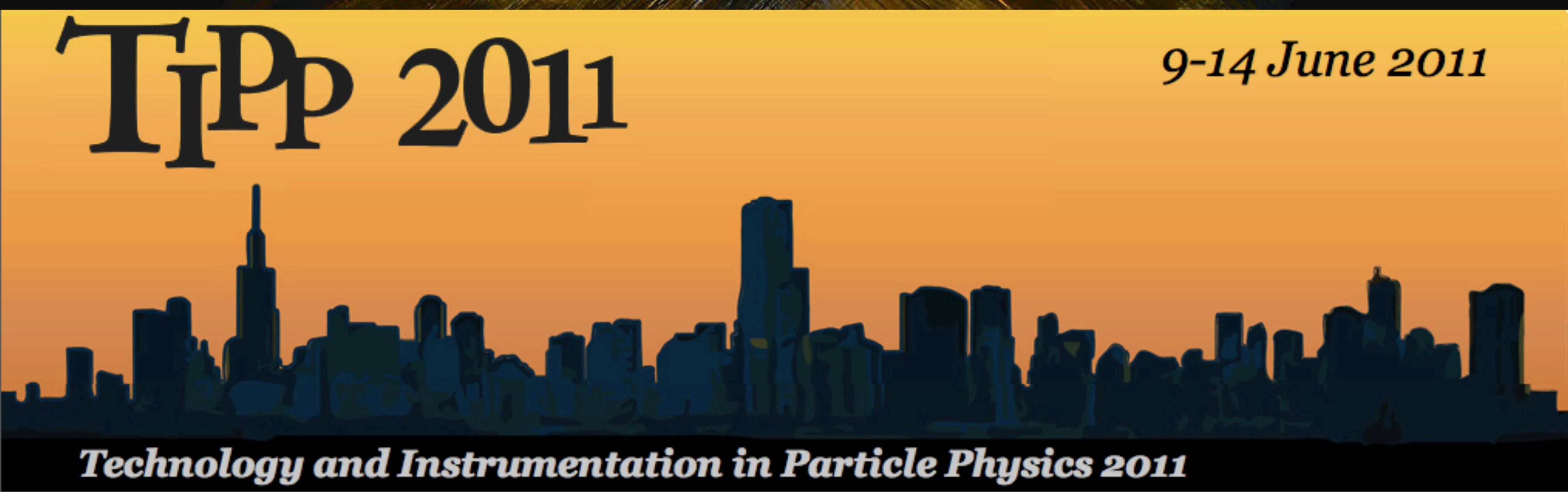
Technology and Instrumentation in Particle Physics 2011

Outline

- Heavy ion collisions at the LHC
- The ALICE experiment at the LHC
- A general slide on TPCs for Heavy Ion collisions
- Description of the ALICE TPC
- Calibration: gain, drift velocity and distortions
- Tracking performance
- PID performance
- Summary



HI collisions at the LHC (1)

- A comprehensive heavy-ion (HI) programme at the LHC
  - 1 month of beam time devoted to HI physics each year
  - colliding the largest available nuclei (Pb) at the highest possible energy (5.5 ATeV, currently 2.76 ATeV)
- ALICE is the dedicated HI detector at the LHC

HI collisions at the LHC (2)

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	pp (design)	pp (June 2011)	Pb–Pb (design)	Pb–Pb (Nov 2010)
Centre of mass energy	14 TeV	7 TeV	5.5 ATeV x 208 = 1144 TeV total	2.76 ATeV x 208 = 574 TeV total
Luminosity	10^{34} Hz/cm^2	10^{33} Hz/cm^2	10^{27} Hz/cm^2	3×10^{25} Hz/cm^2
Bunches per beam	2808	1092	592	137
Bunch spacing	25 ns	50 ns	100 ns	500 ns
β^*	0.5 m	1.5 m	0.5 m	3.5 m
Min. bias trigger frequency	10^9 Hz	10^8 Hz	8×10^3 Hz	2×10^2 Hz
$dN_{ch}/d\eta$	unknown	6	unknown	1600

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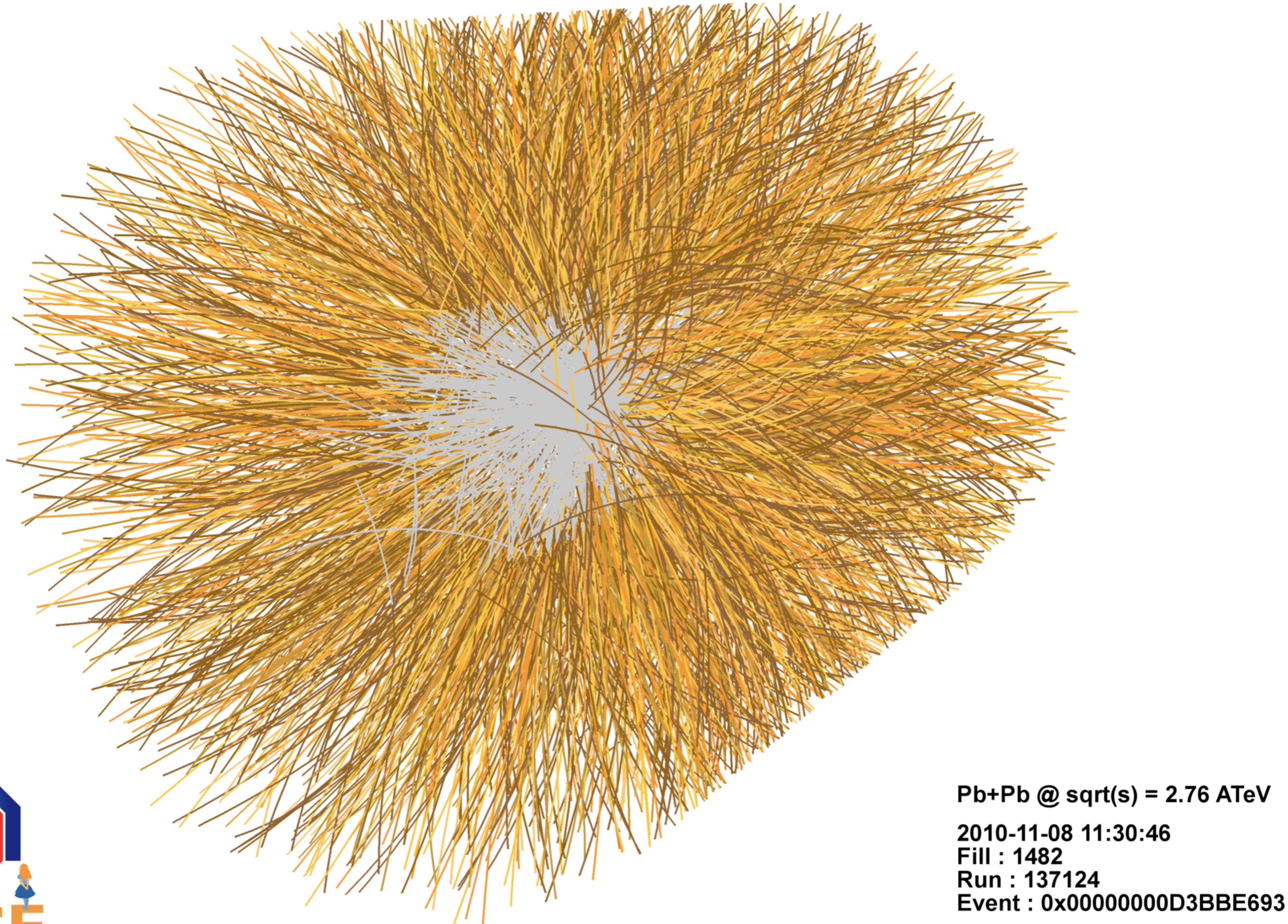
A Pb–Pb event in the ALICE TPC

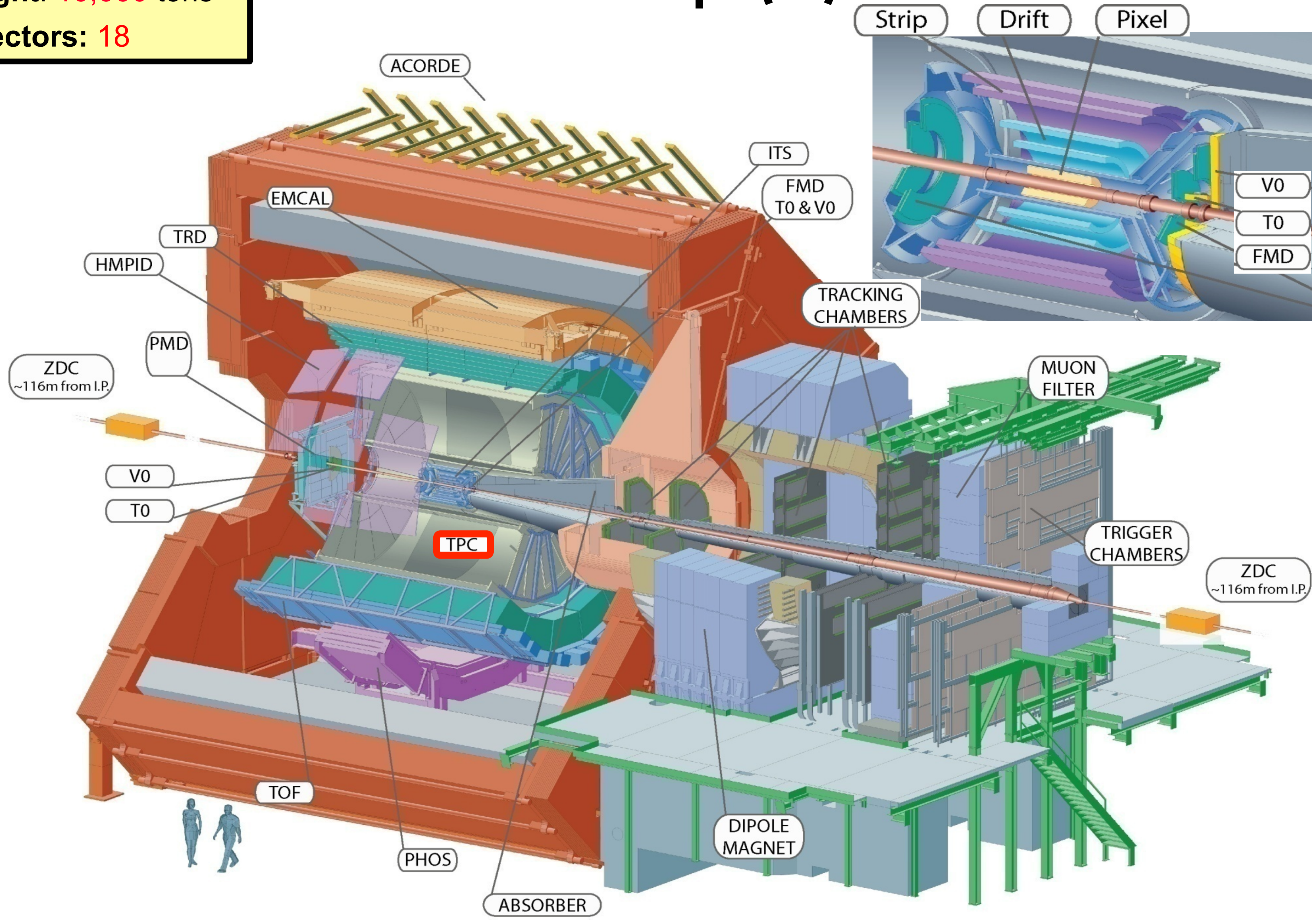


ALICE

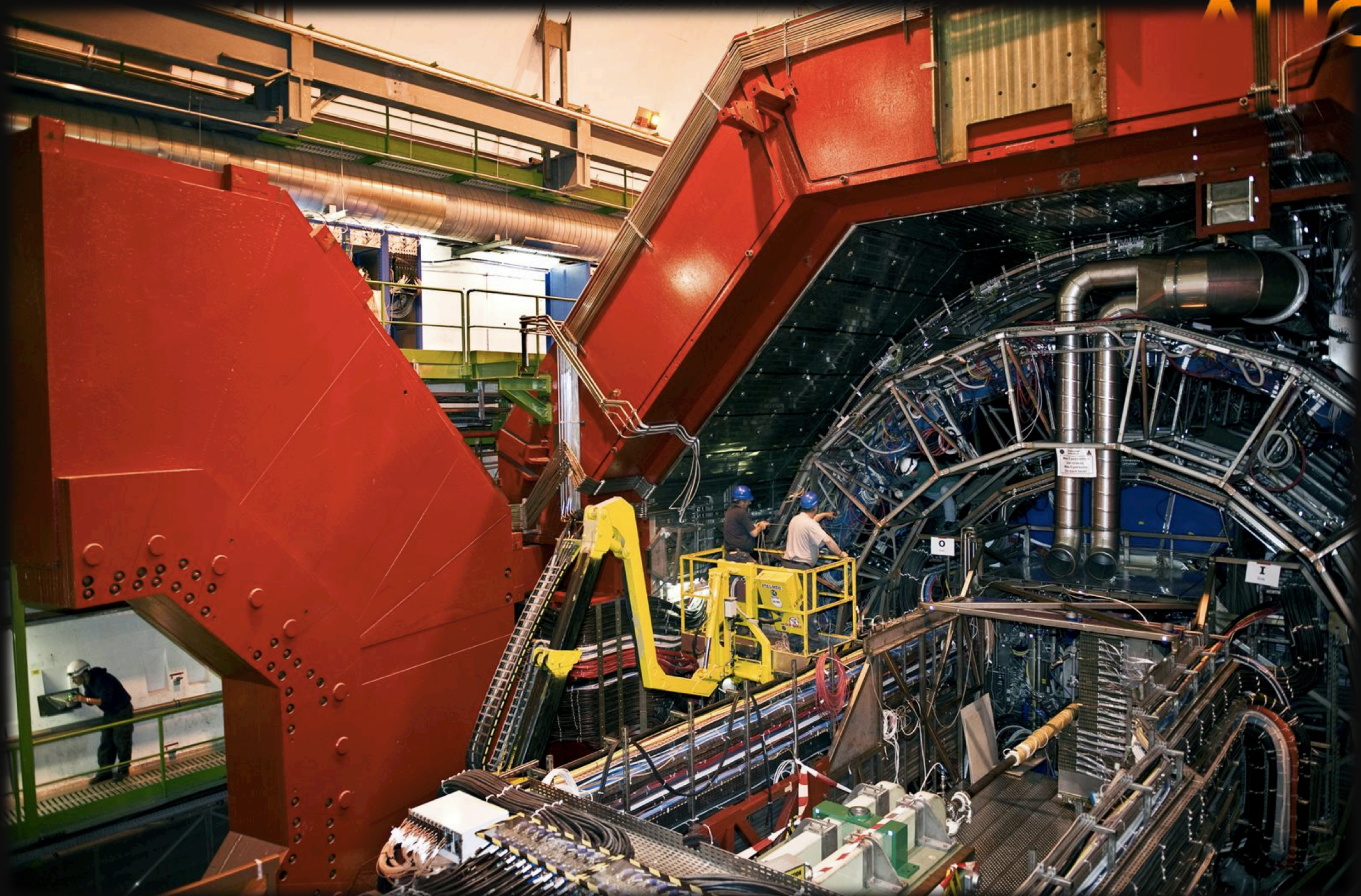
Size: 16 x 26 meters
Weight: 10,000 tons
Detectors: 18

ALICE setup (1)

The ALICE experimanet: J. Instrum. 3, S08002 (2008)



ALICE setup (2)



The ALICE experimanet: J. Instrum. 3, S08002 (2008)

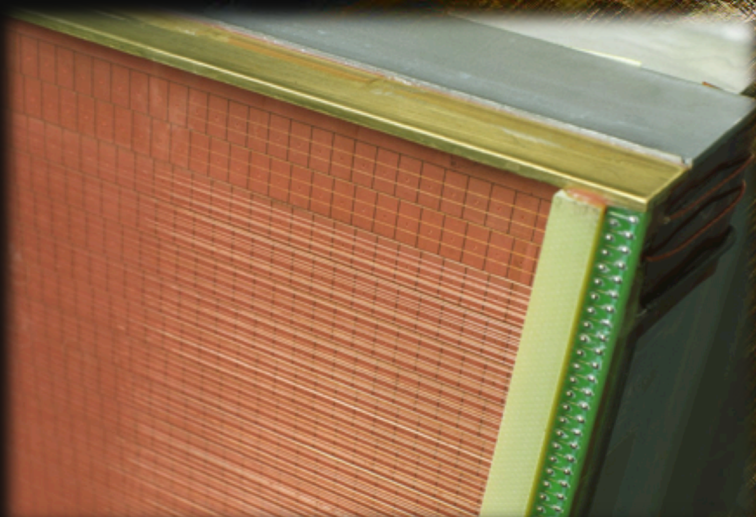
A general slide on TPCs

- A TPC is the perfect detector for HI collisions
  - the whole volume is active
  - minimal scattering due to minimal radiation length (field cage, gas)
  - easy pattern recognition (continuos tracks)
  - PID information from ionization measurements (very powerful especially in the low energy region where energy loss $\propto 1/\beta^2$; $p \leq 1 GeV/c$)
  - transversal diffusion of the drifting electrons may be minimized by choosing a gas mixture with $\omega\tau>1$ and a configuration with B and E fields parallel
- … but …
  - relatively slow (at least as compared to most LHC detectors): Maximum readout speed is dominated by electron drift time (and event sizes)

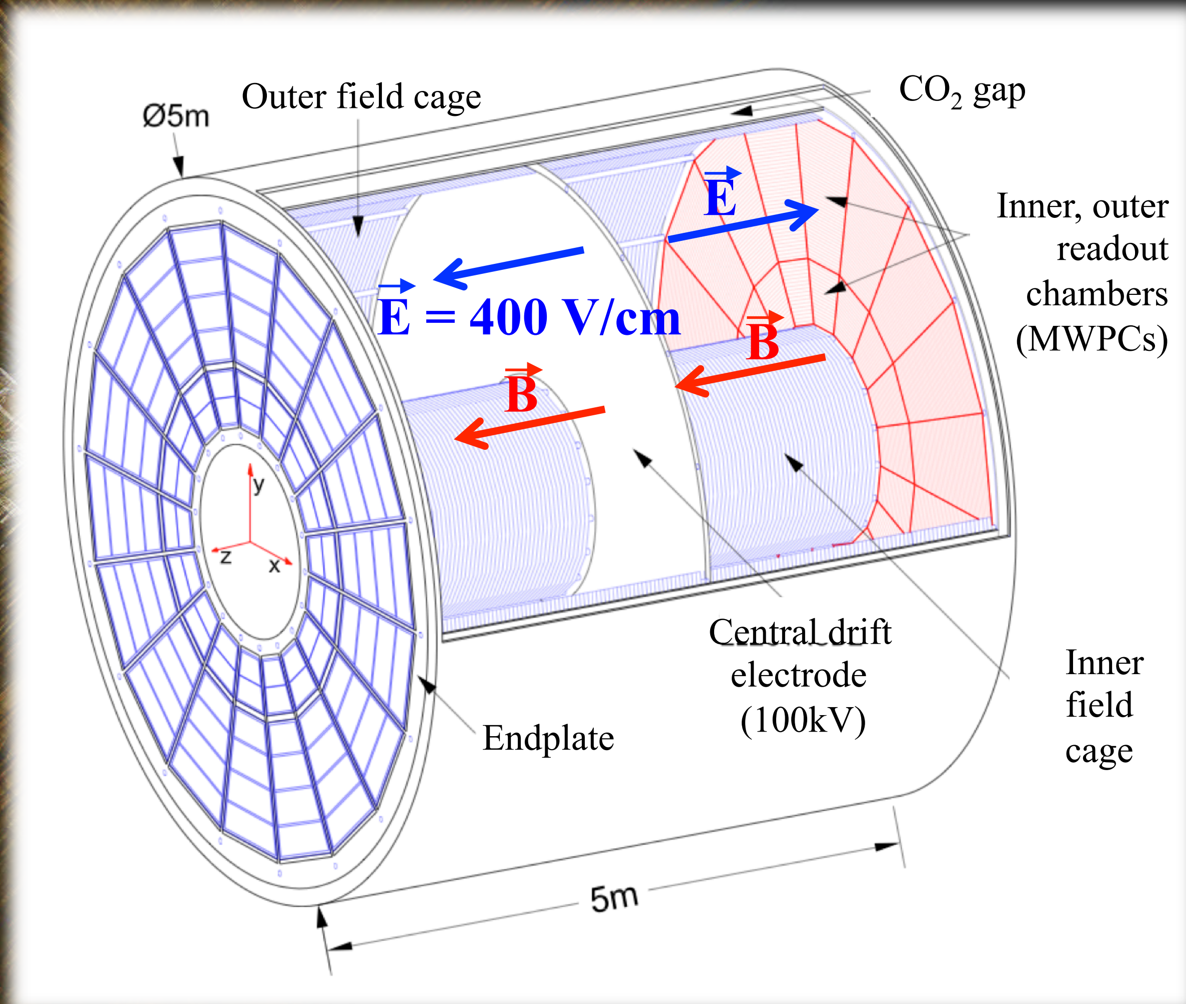
ALICE TPC field cage and MWPCs

arXiv:1001.1950v1 [physics.ins-det]

- Gas volume ~92 m^3
- Material budget 3% X_0 at $\eta=0$
- 72 (=18×2×2) Readout chambers: MWPCs with cathode pad readout

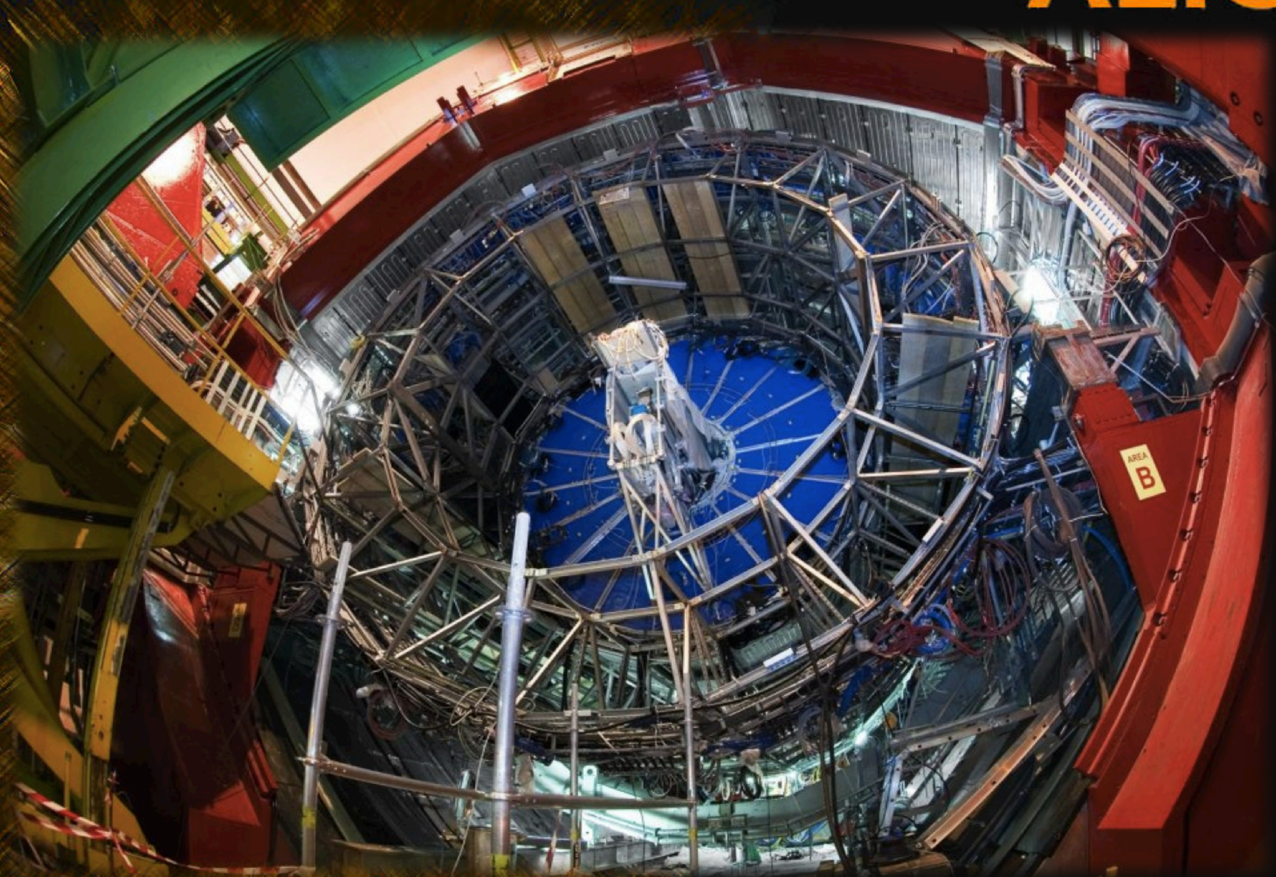


Detail of one readout chamber



Low mass, high precision field cage

Installation and commissioning



- Field Cage assembly: 2002 – 2004
- MWPC installation: 2005
- Electronics installation: 2006
- Installation into ALICE L3 magnet: 2007
- Commissioning & calibration: 2007 – 2009
- Calibration and data taking: 2009 – now

Gas and Front End Electronics (1)

arXiv:1001.1950v1 [physics.ins-det]

- Gas mixture: Ne, CO_2 (90-10)
  - Low diffusion ("cold gas"); $\omega\tau$=0.32; low Z (low multiple scattering, low primary ionization)
- Maximum electron drift time (250 cm drift) : ~92 μs
- Field cage, MWPCs and gas system very leak tight: ~1 ppm O_2
- ~200 ppm H_2O added for stability

Gas and Front End Electronics (2)

arXiv:1001.1950v1 [physics.ins-det]

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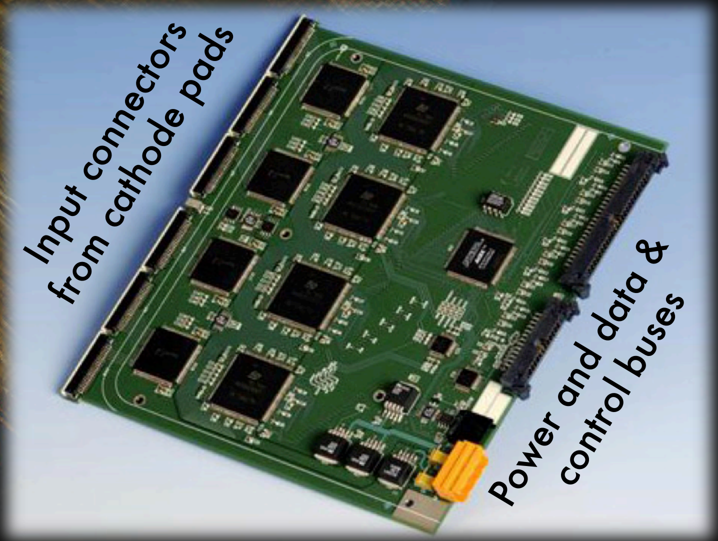
- Maximum electron drift time (250 cm drift) : ~92 μs
- Field cage, MWPCs and gas system very leak tight: ~1 ppm O_2
- ~200 ppm H_2O added for stability
- 557 568 read out pads and FEE channels
- 1000 time bins ⇒ 557 million voxels
- PreAmplifier ShAper (PASA)
  - 12 mV/fC, 190 ns FWHM
- ALTRO digital chip
  - see next slide
- 0.7 ADC mean noise (700 e^-) on detector (Requirement: 1000 e^-)

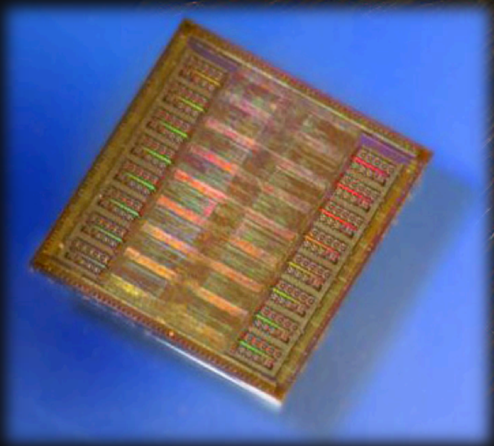


A TPC Front End Card holds 8 PASA and 8 ALTRO chips (4 each on each side)

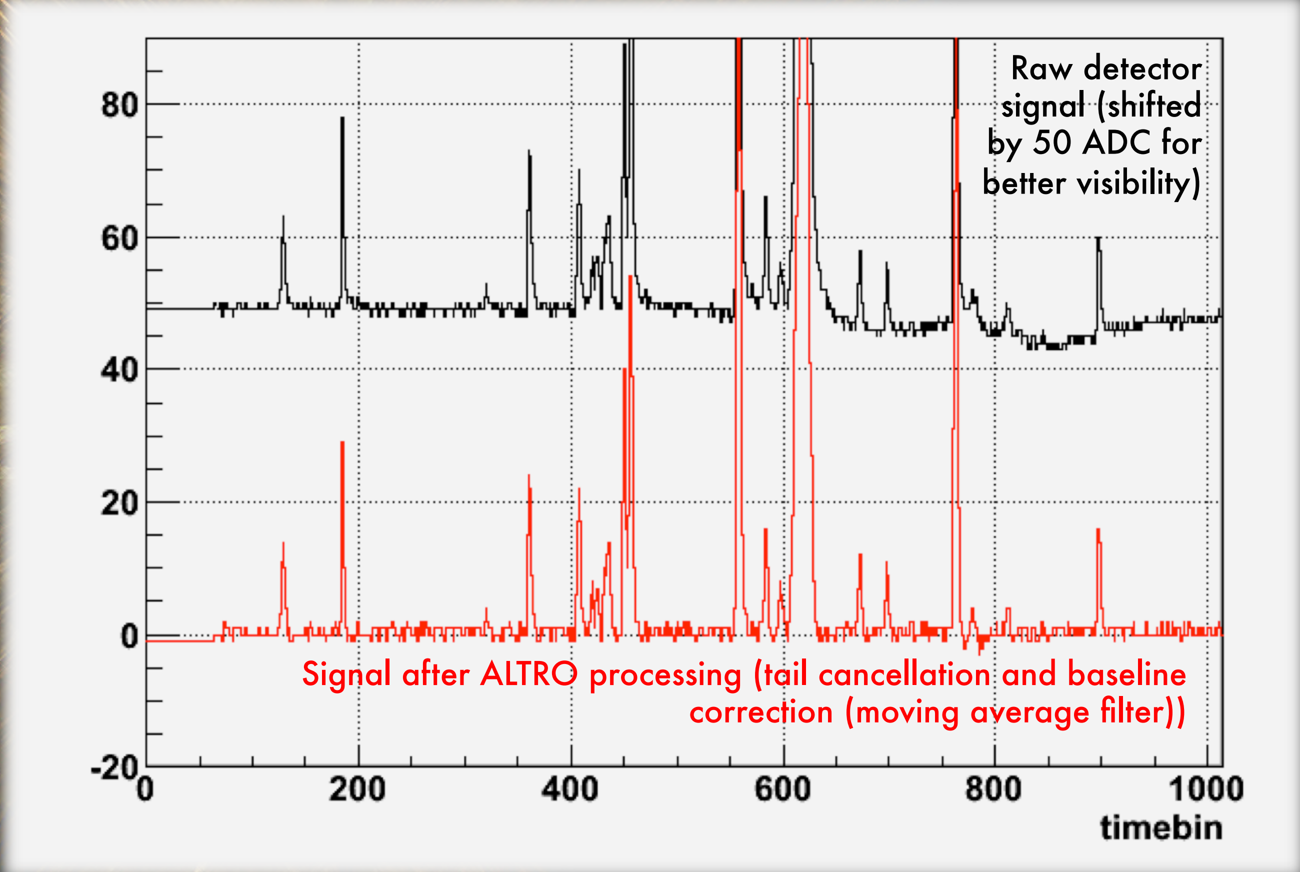
ALICE TPC ReadOut (ALTRO) chip

arXiv:1001.1950v1 [physics.ins-det]

- 10 bit ADC
- 10 Mhz sampling
- 2 baseline restoration circuits
- tail cancellation
- zero suppression with glitch filter
- multi event buffer



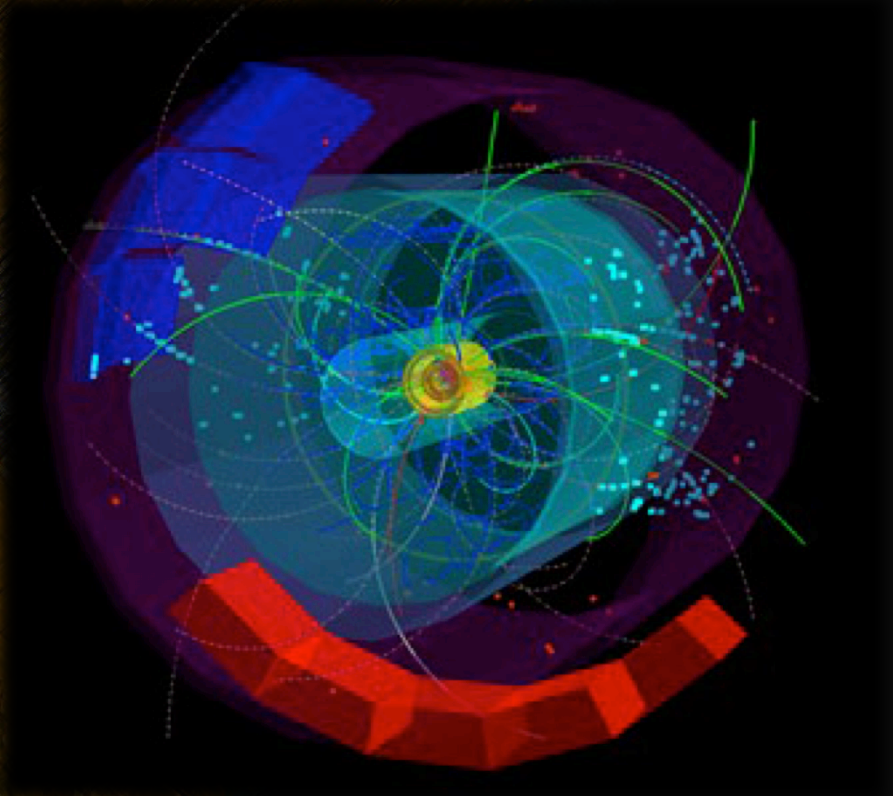
16 channel ALTRO chip



Pileup of ion tails results in systematic baseline shifts. Plot shows simulation of the ALTRO filter performance on real data from Pb–Pb collisions.

Luminosities and read out rates (1)

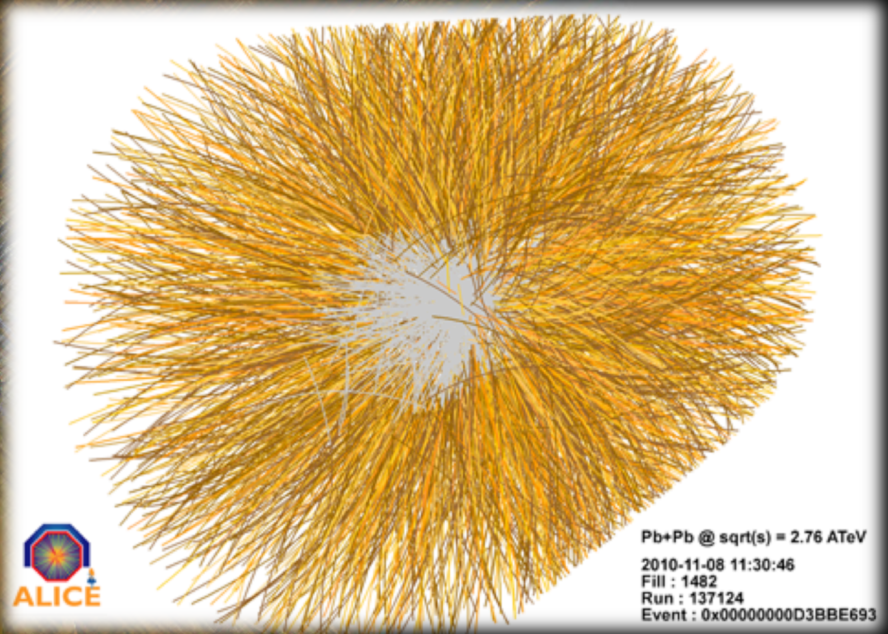
- pp interaction rates in ALICE:
  - ~10 kHz for large cross section observables, almost no event pile up in TPC
  - ≤200 kHz for rare processes, acceptable event pile up
- Maximum TPC readout rates:
  - 1 kHz for pp



A pp collision at 7 TeV: reconstructed tracks in TPC, ITS and other subdetectors

Luminosities and read out rates (2)

- pp interaction rates in ALICE:
  - ~10 kHz for large cross section observables, almost no event pile up in TPC
  - ≤200 kHz for rare processes, acceptable event pile up
- Pb–Pb interaction rates:
  - ≤10 kHz Pb–Pb collisions
- Maximum TPC readout rates:
  - 1 kHz for pp
  - 200 Hz for Pb–Pb (central)

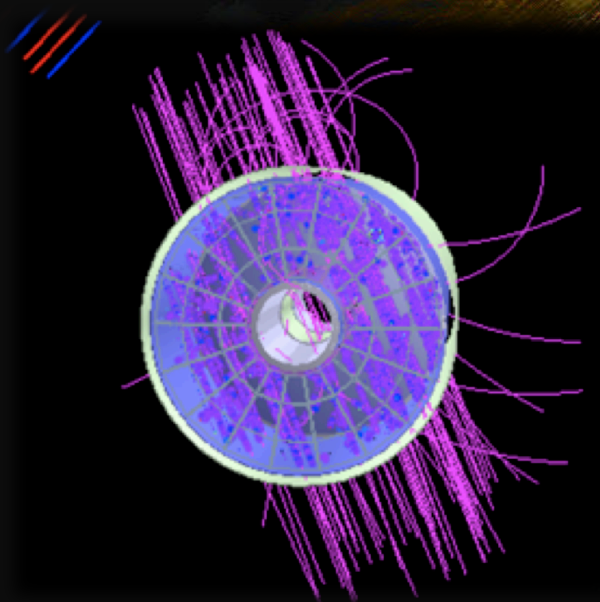


A central Pb–Pb collision at 2.76 ATeV: reconstructed tracks in the TPC

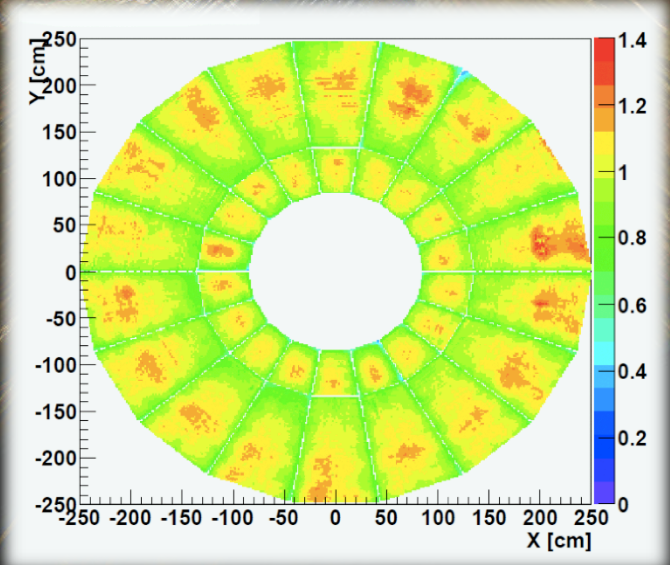
Calibration overview

- The main TPC calibration procedures are
  1. gain calibration using short-lived radioactive gas (^{83}Kr)
     - produces electron spectrum in the right energy range
     - result: gain determination to within 1%
  2. laser data: drift velocity calibration and alignment
  3. cosmics and Physics (collisions) tracks: alignment and gain calibration

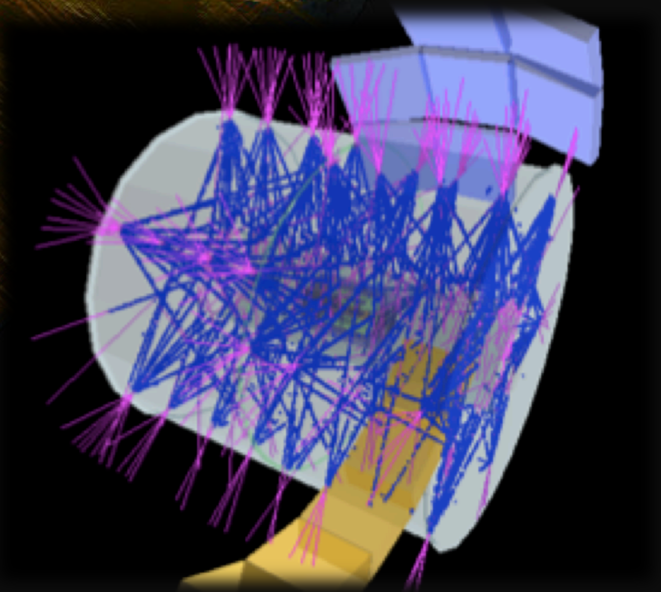
A cosmic muon shower, triggered by ACORDE



Pad-wise gain correction map from Kr calibration (C side shown)

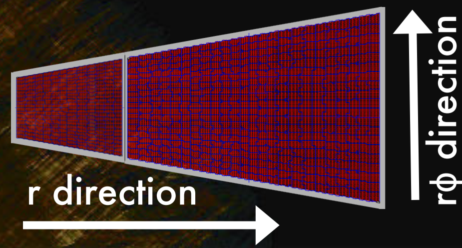


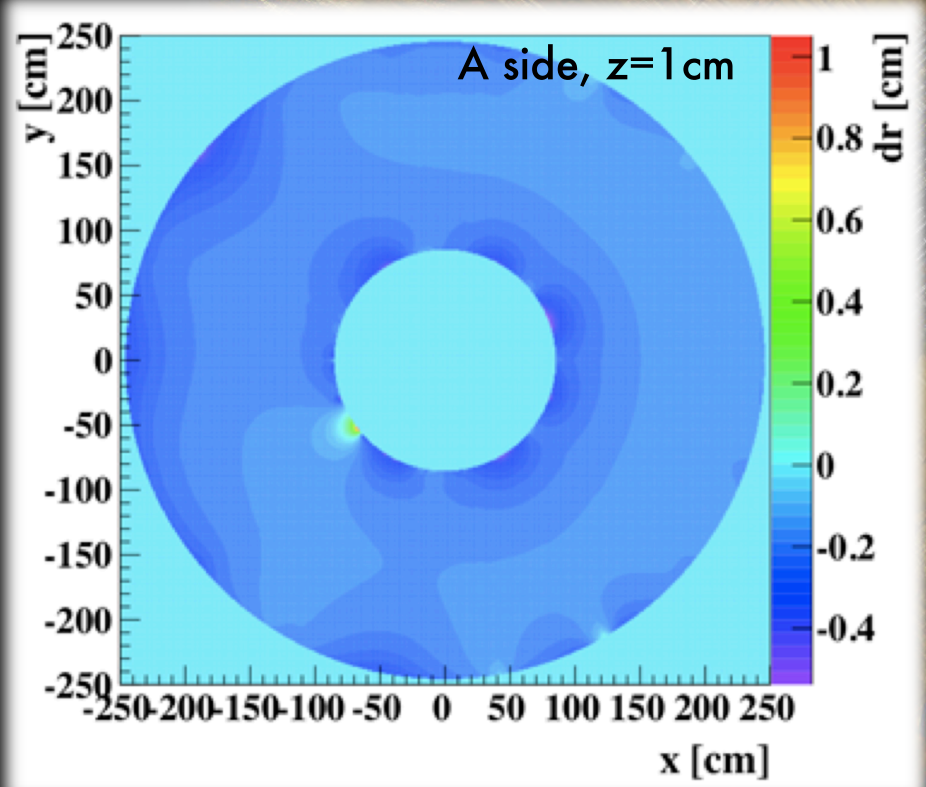
A reconstructed laser event in the TPC

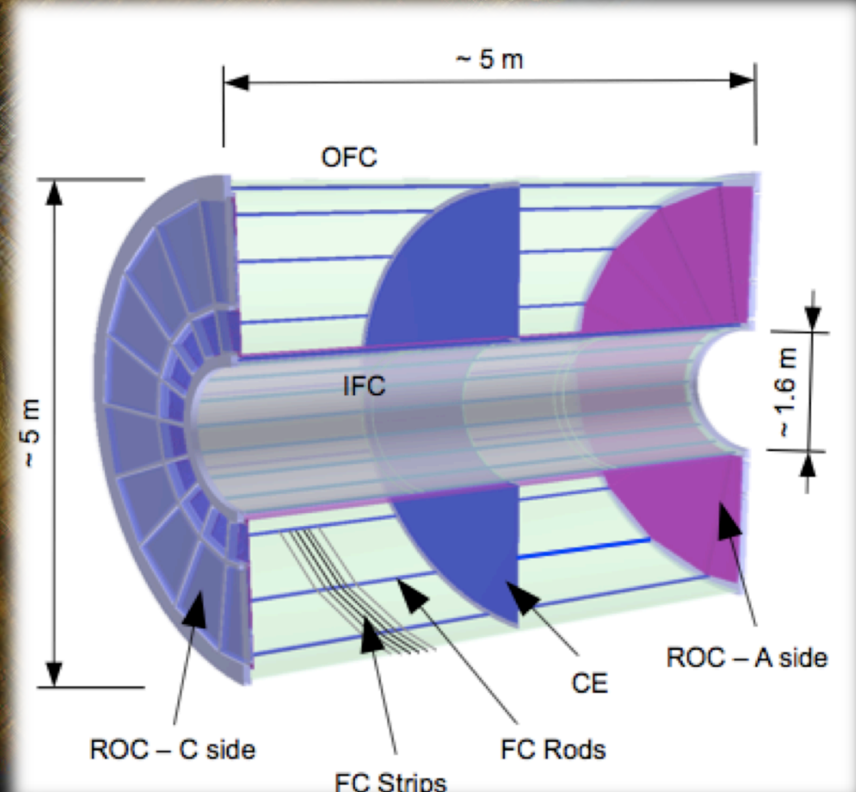


Distortions due to field cage imperfections (1)

- Drifting electrons are deflected by distortions
- Imperfections in the field cage
- Maximum (very local): δr = 10 mm (shown here); δrϕ = 0.8 mm







Distortions due to field cage imperfections (2)

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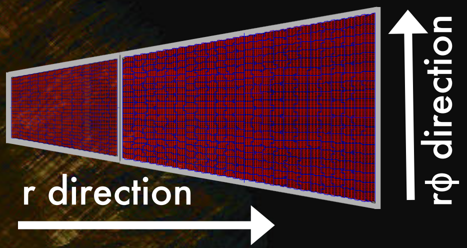
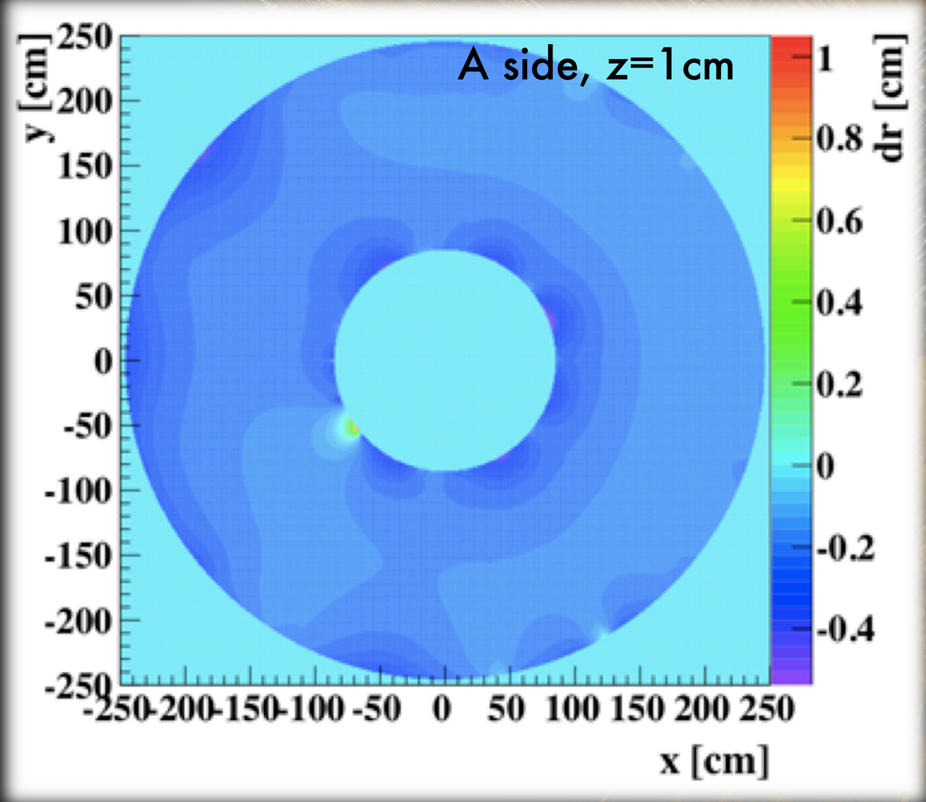
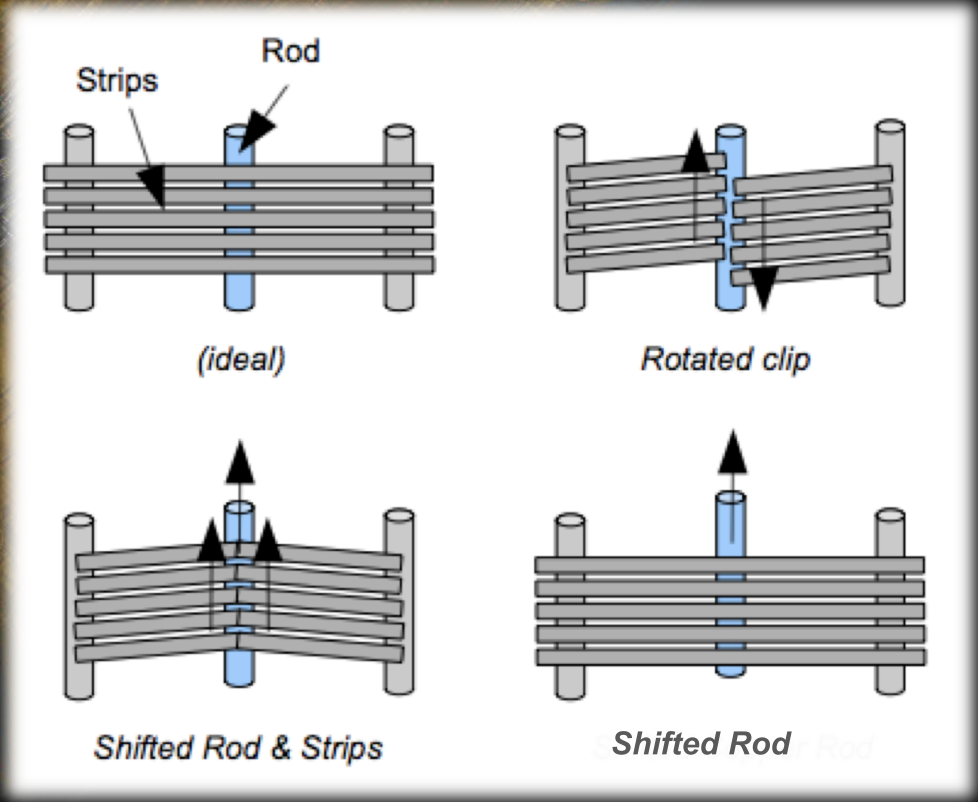
- Imperfections in the field cage
- Maximum (very local): δr = 10 mm (shown here); $\delta r\phi$ = 0.8 mm

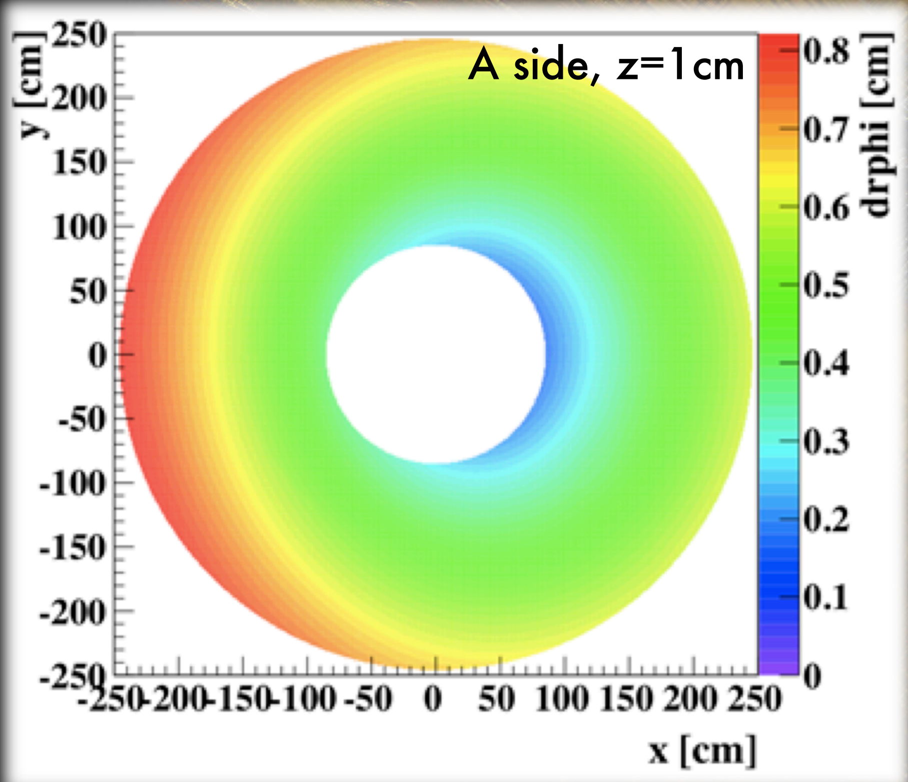


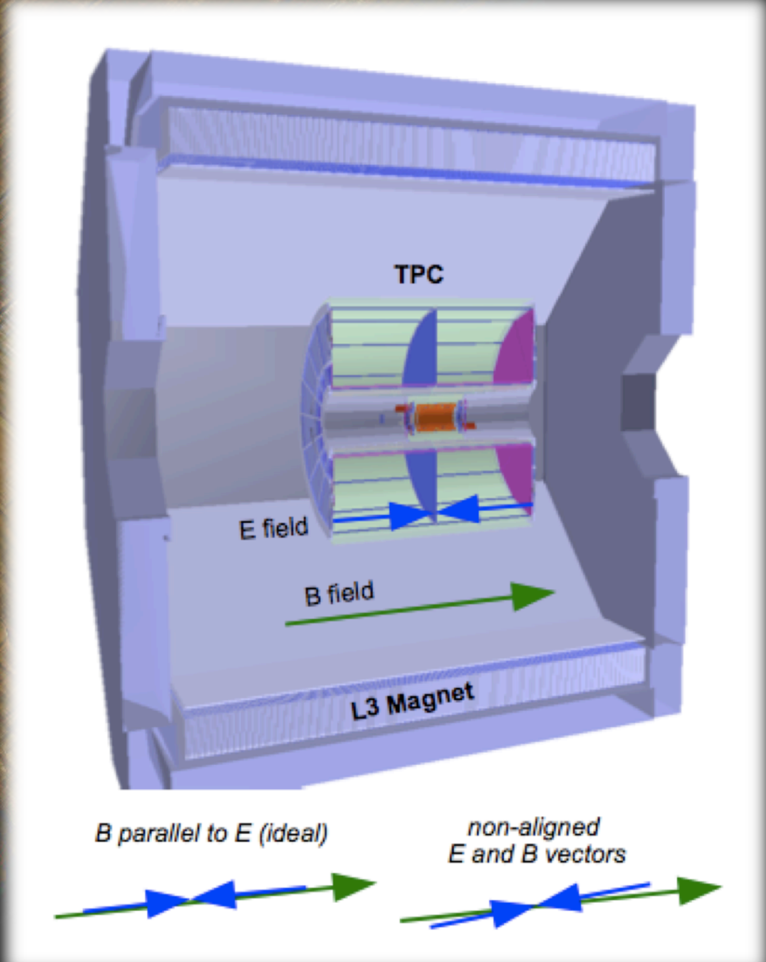




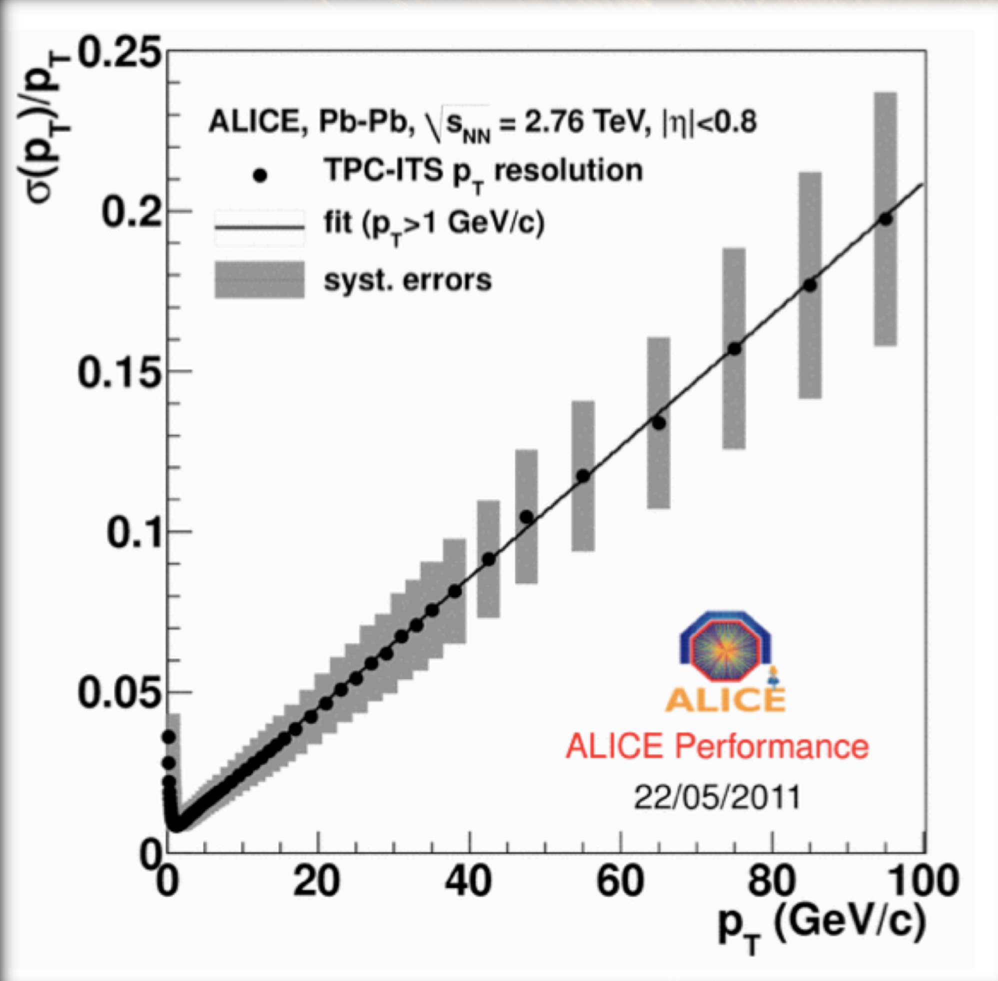
Distortions due to non-ideal B field

- Drifting electrons are deflected from ideal drift path by distortions
- B field shape (homogeneity) and alignment with E field
- Maximum: δr = 4 mm;
  δrϕ = 8 mm (shown here)





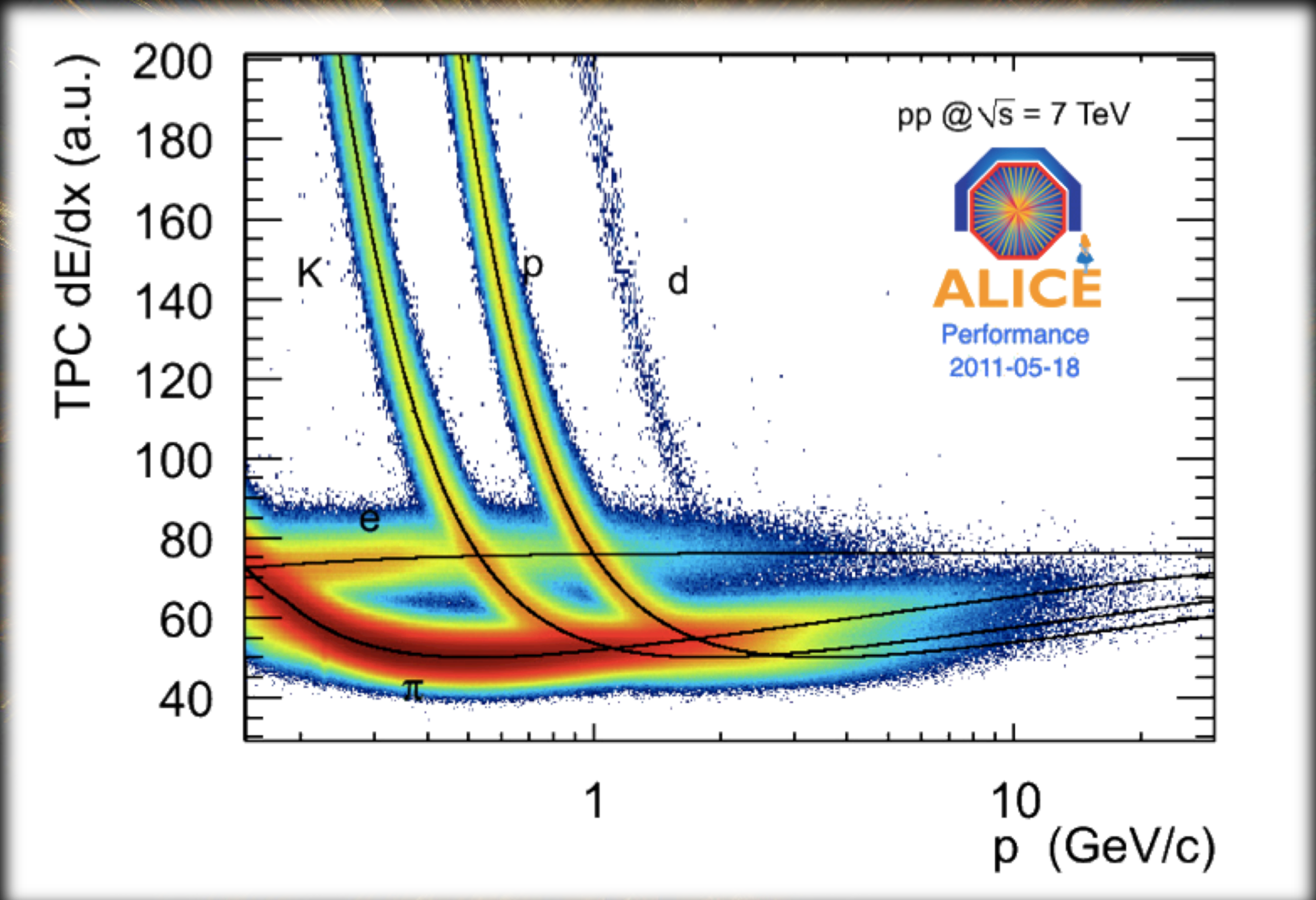
Transverse momentum resolution



- Combined tracking (TPC & ITS):
  - $\sigma(p_T)/p_T$ = 20% at 100 GeV/c
- Expected from simulations:
  - $\sigma(p_T)/p_T$ = 5% at 100 GeV/c (3.5% for ITS & TPC & TRD)

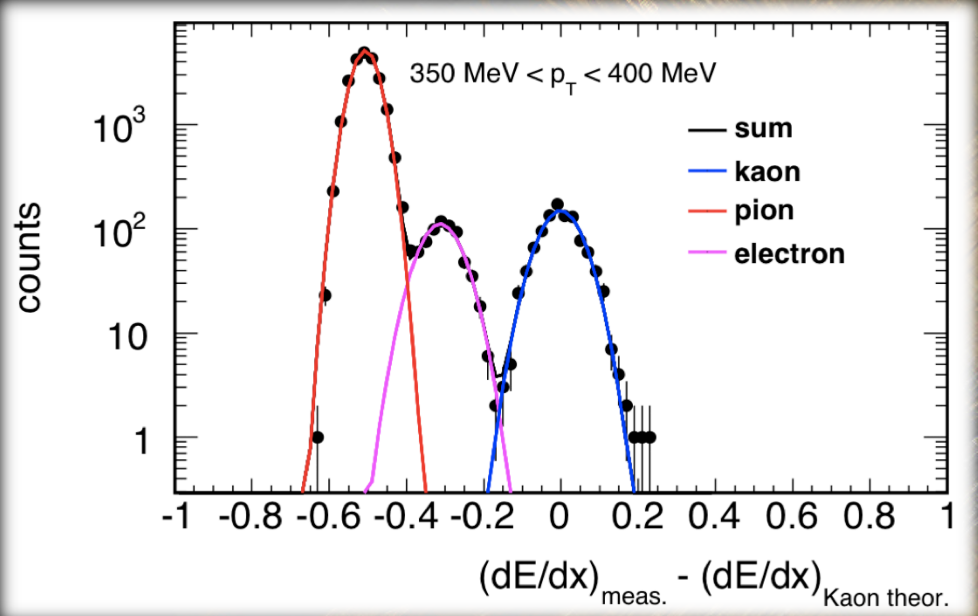
  [ALICE PPR II, J. Phys. G 32 (2006) 1295]
- The expected performance (TPC&ITS) is within reach for 2011
  - corrections for energy loss
  - more precise alignment

PID

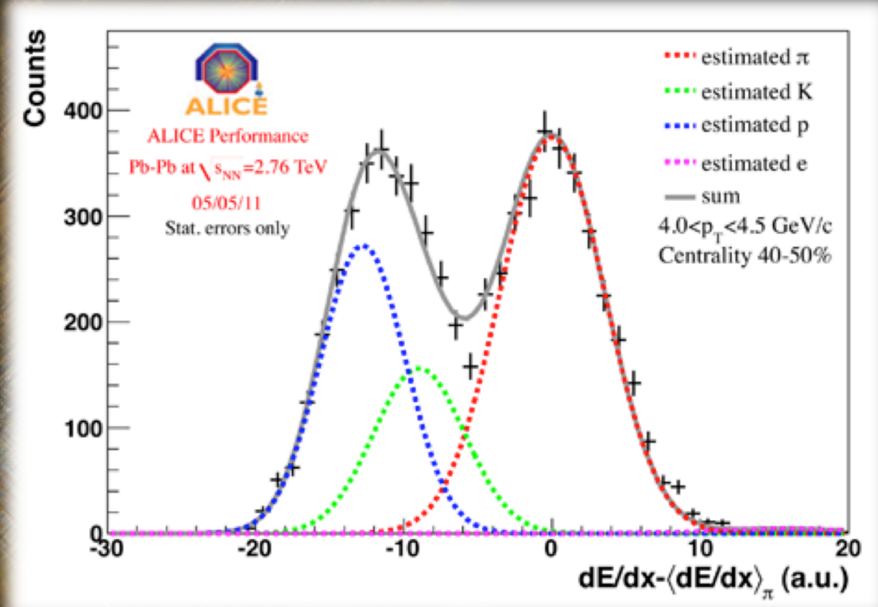


10 bit ADC: Dynamic range up to 26×MIP

PID performance



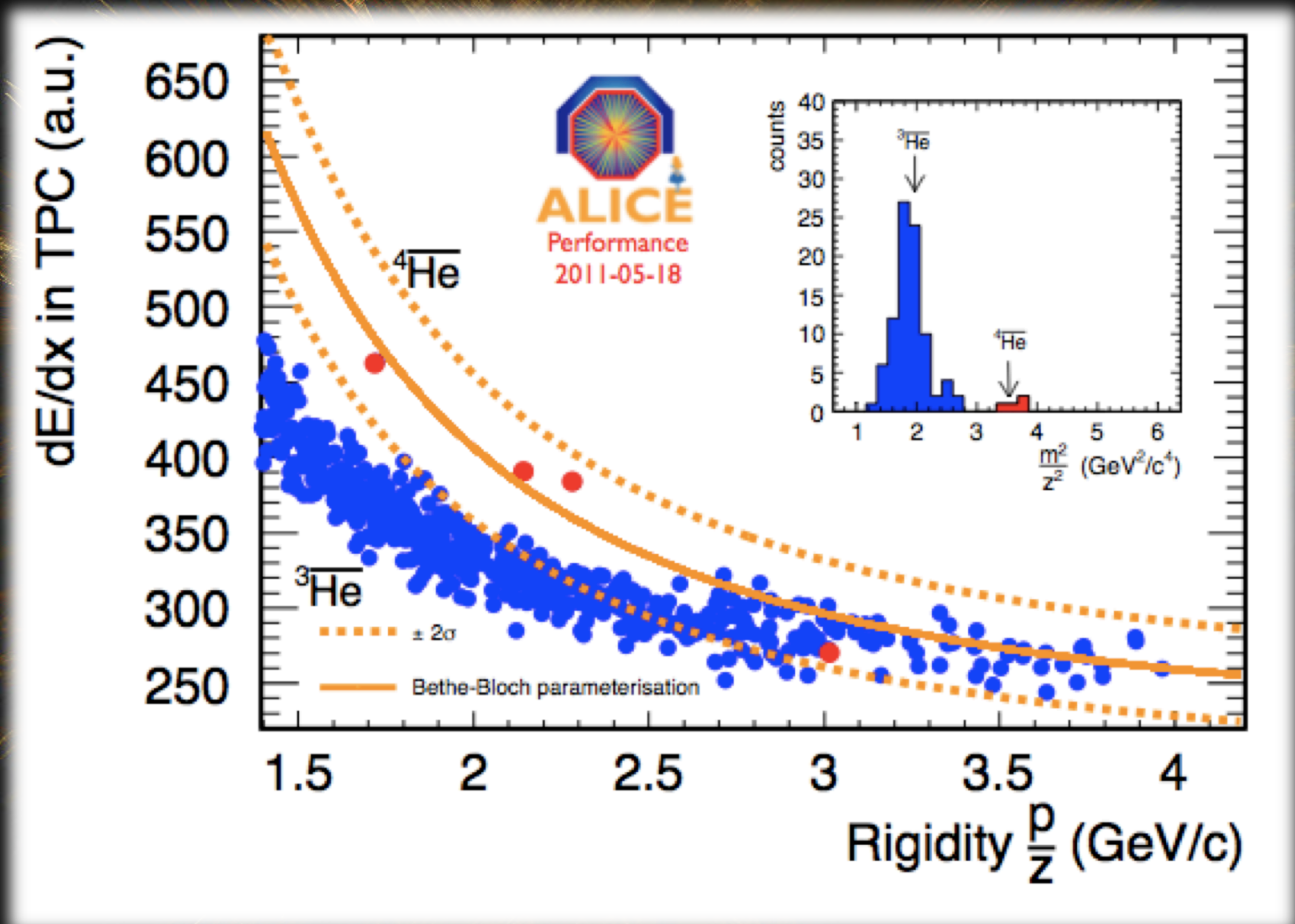
dE/dx distributions with fits for a momentum slice in the <u>1/β^2 region</u> (log scale!). pp collisions at 900 GeV. Published in arXiv:1101.4110 [hep-ex]



dE/dx distributions with fits for a momentum slice in the <u>relativistic rise</u> (linear scale!). HI collisions at 2.76 AGeV

- Measured Resolution with maximum number of samples: $\sigma_{dE/dx} \approx 5\%$ (requirement: 5.5% [ALICE PPR II, J. Phys. G 32 (2006) 1295])
- Resolution for the highest multiplicity HI events: $\sigma_{dE/dx} \approx 6\%$
- PID in the relativistic rise possible using statistical methods

Anti-alpha observation

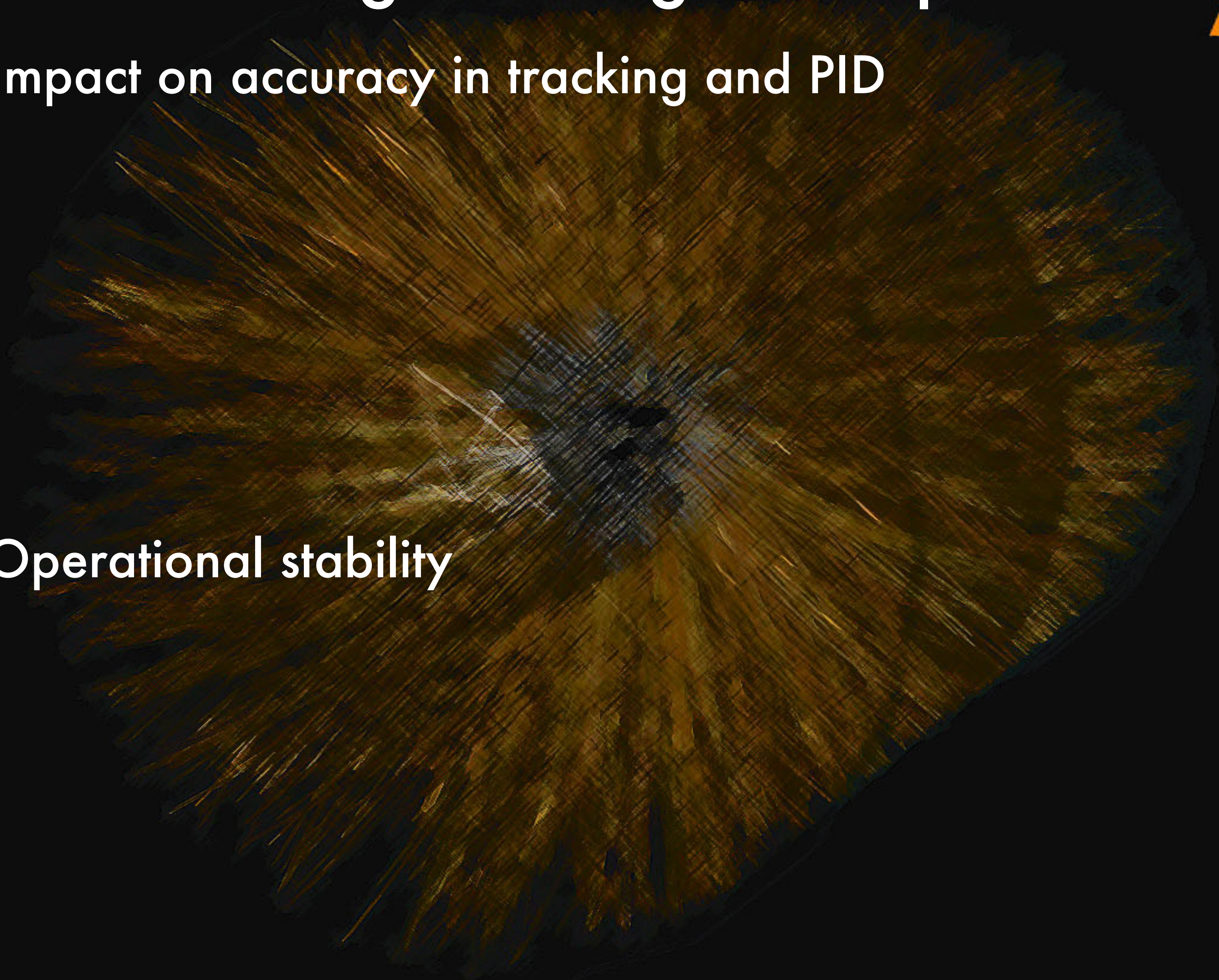


4 anti-alpha candidates from Pb-Pb collisions (PID using TPC and TOF)

Summary (1): Challenges at high multiplicities

1. Impact on accuracy in tracking and PID

2. Operational stability



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1. Impact on accuracy in tracking and PID
   - overlapping tracks (custer pile up)

     ⇒ minimized by high granularity (small pads) and low diffusion gas mixture
   - distortions due to space charge
   - baseline fluctuations (ion tails)
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   - operational stability

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   - operational stability ⇒ Some HV trips and also some damage to FEE happening as luminosities increase.

Summary (2)

- The ALICE TPC is a large 3-dimensional tracking device for ultra-high multiplicity events
- It has been operated successfully with pp and Pb–Pb collisions at the LHC
- A physical model of all possible distortions allows their correction and permits the best possible calibration
- The TPC offers powerful PID with an energy resolution of 5%
- A transverse momentum resolution of 20% at 100 GeV/c can probably be pushed to close to 5%

- See also poster 41: *"Trigger induced mechanical resonance of gating wires in the multi-wire proportional chambers of the ALICE TPC"*

ALICE TPC collaboration

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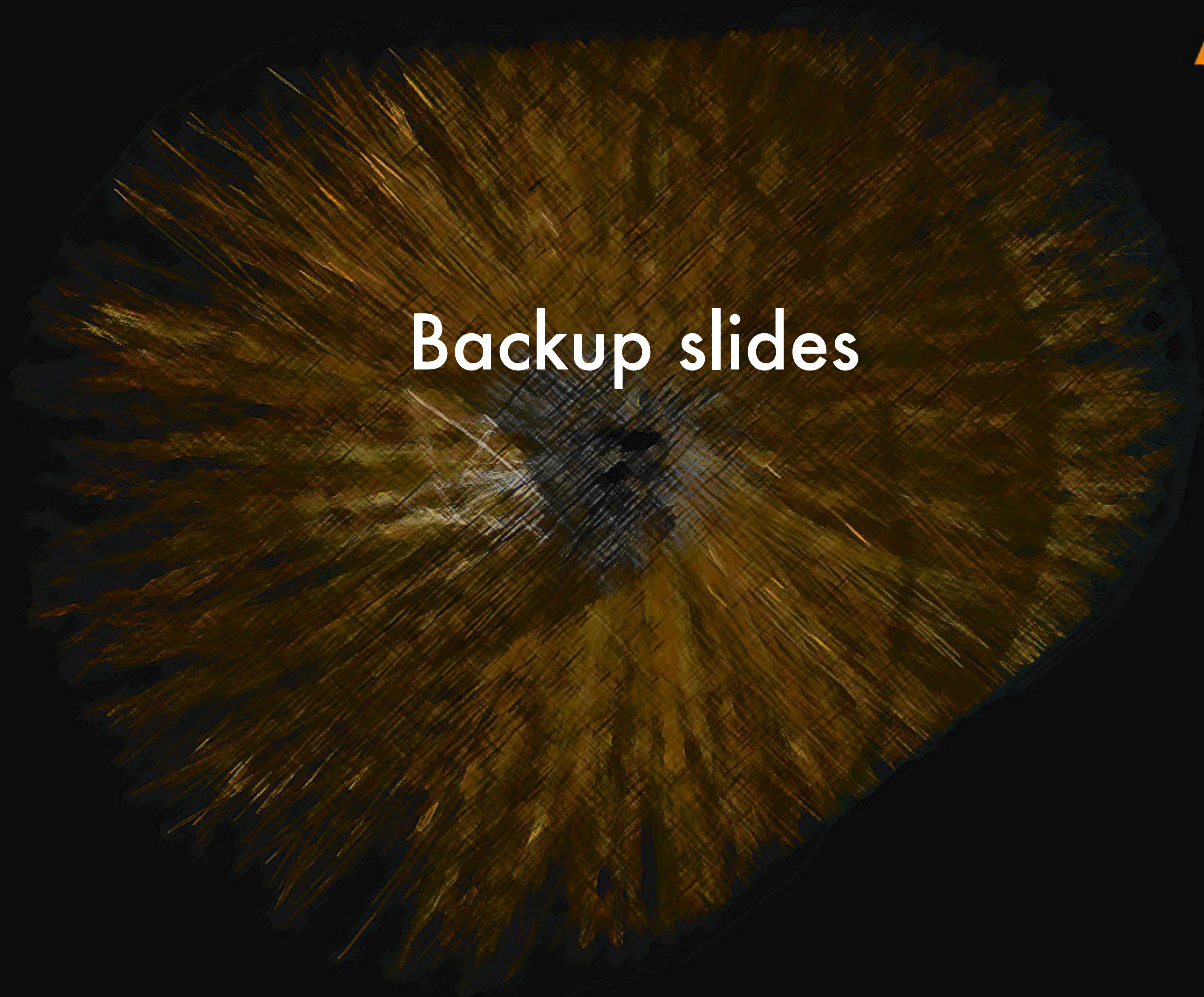
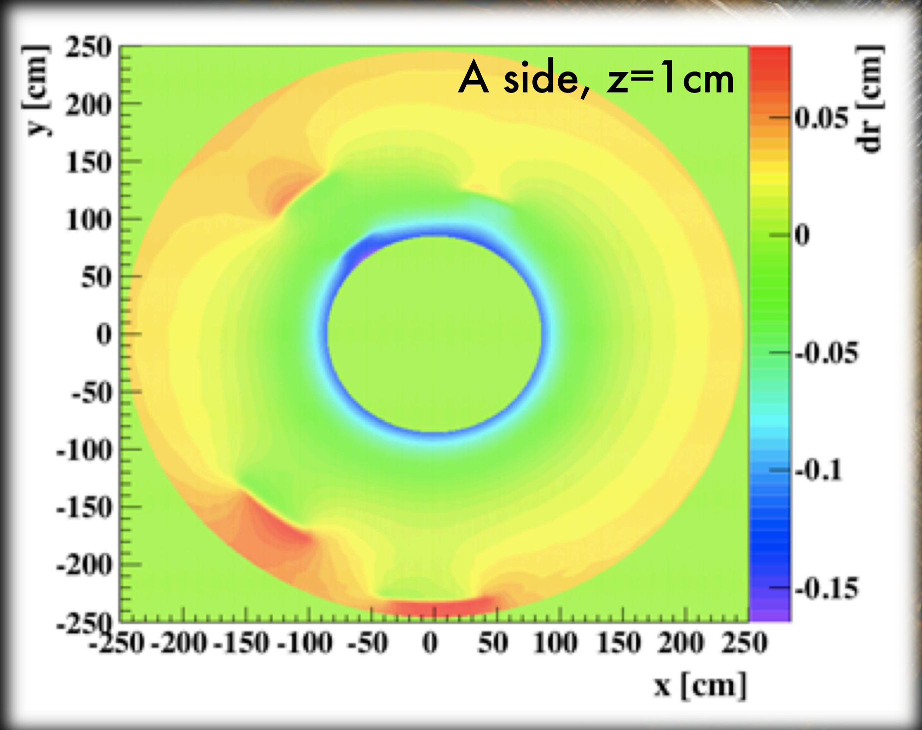
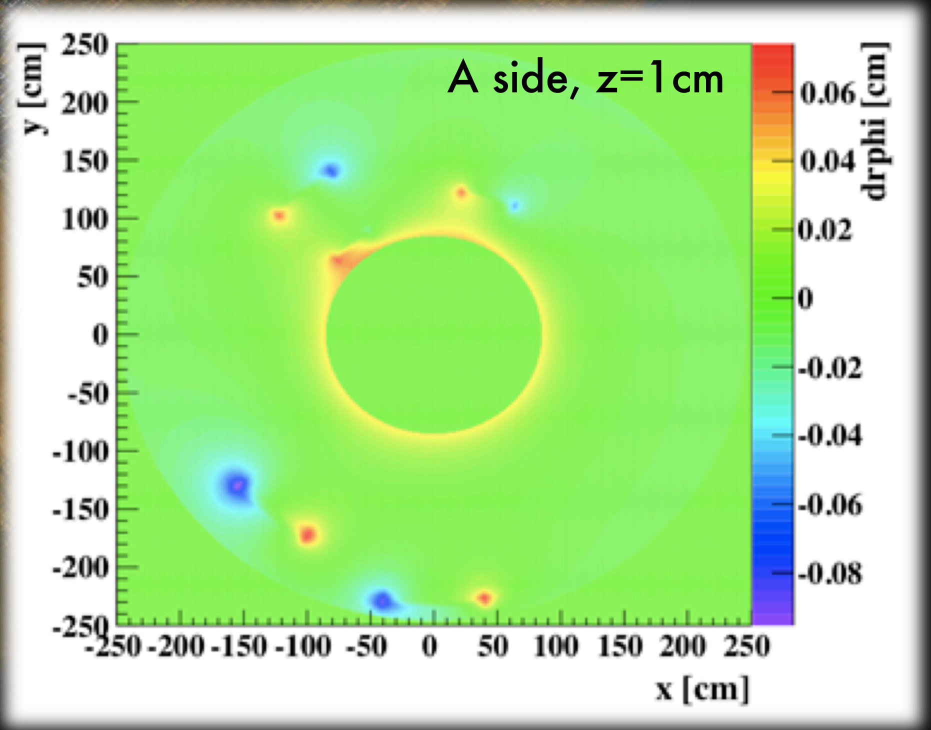
Backup slides



Space charge distortions

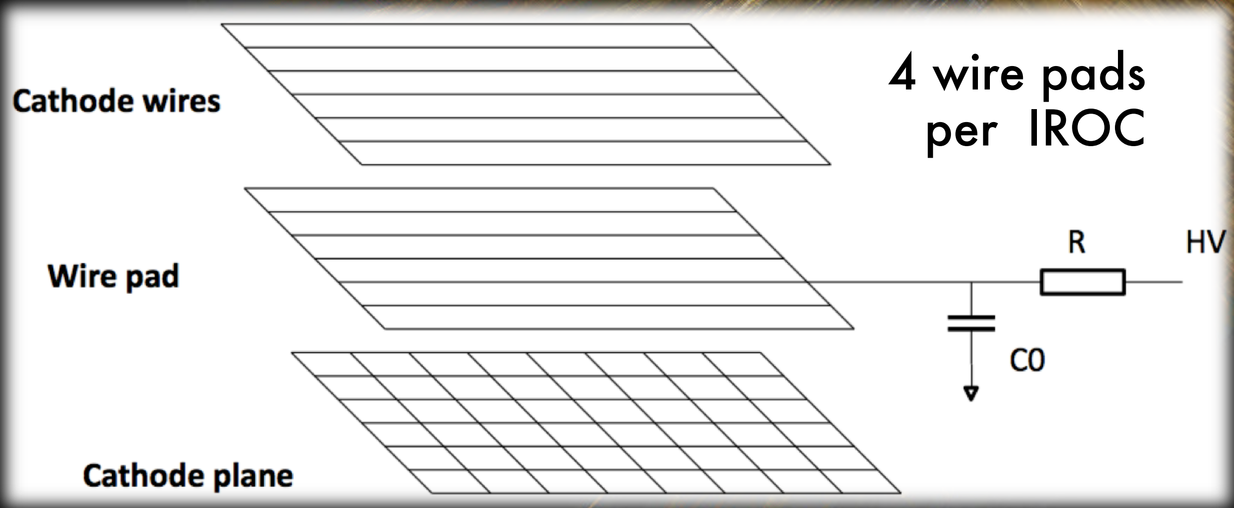
- Drifting electrons are deflected due to space charge
  - So far invisible in pp and Pb–Pb collisions
  - Some effect expected at maximum Pb–Pb luminosity
- Maximum expected distortions: δr = 5mm (left plot); $\delta r\phi$ = 0.8mm (right plot)
  - Space charge is in general radially symmetric
  - read out chamber imperfections (ion leakage) on top



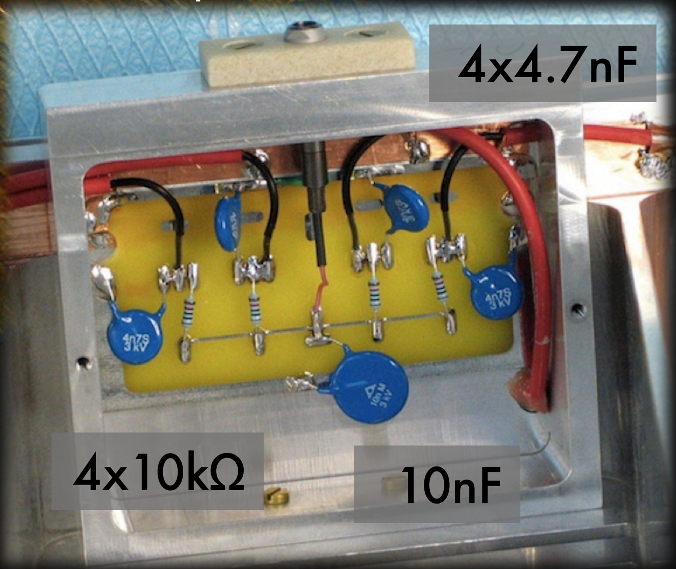


Improving the operational stability

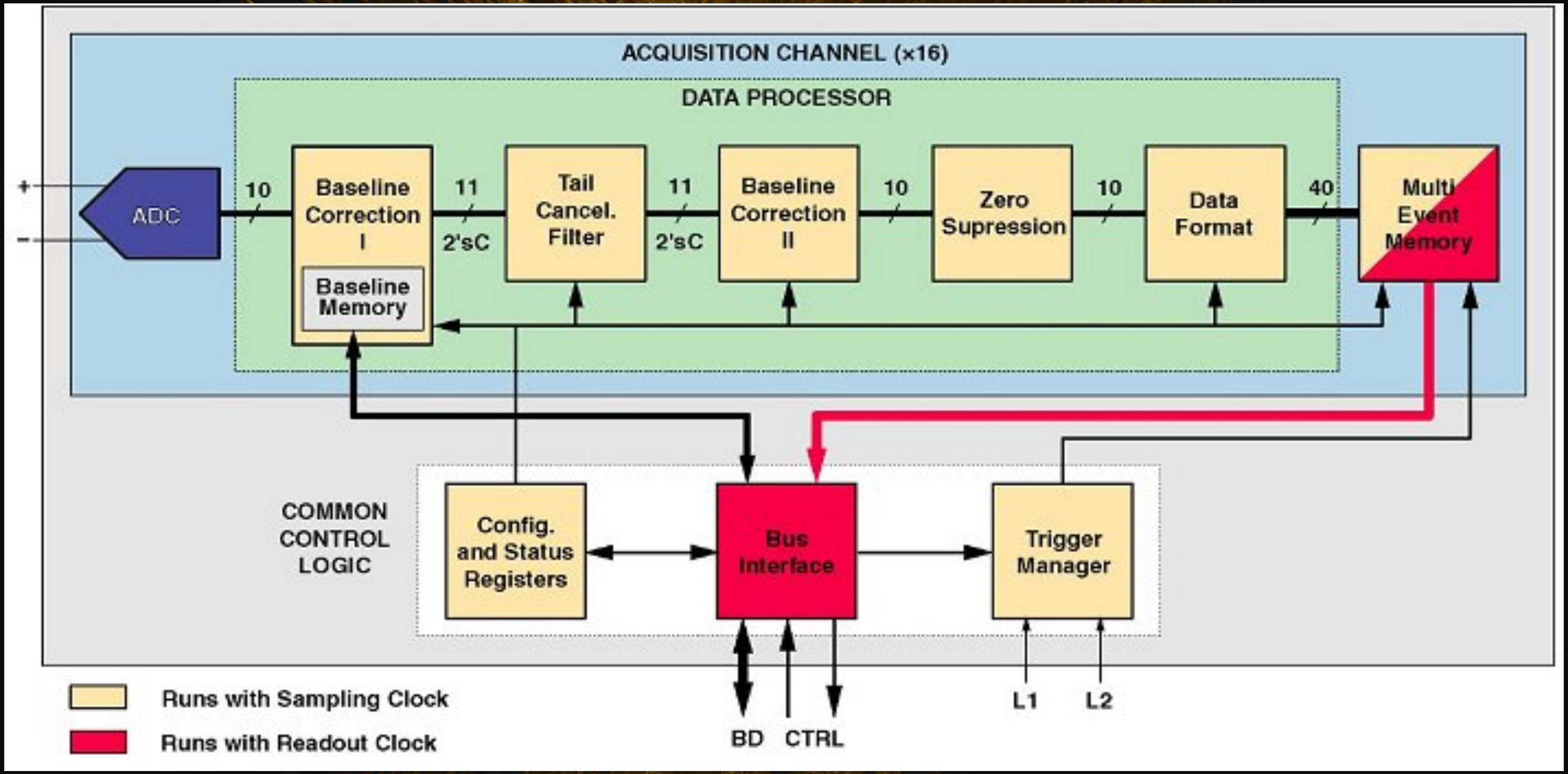
1. Reduce stored energy by reducing capacitor size in HV distribution
2. Add additional input protection to FEE by installing modified cables connecting FEE to padplane
3. Until then the gain in the concerned MWPCs will be reduced to avoid damage. The impact on the performance is small



Input from HV PS

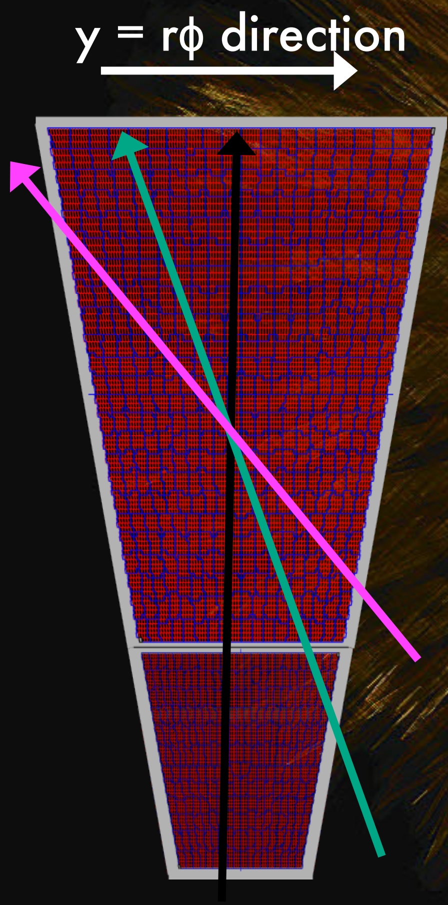


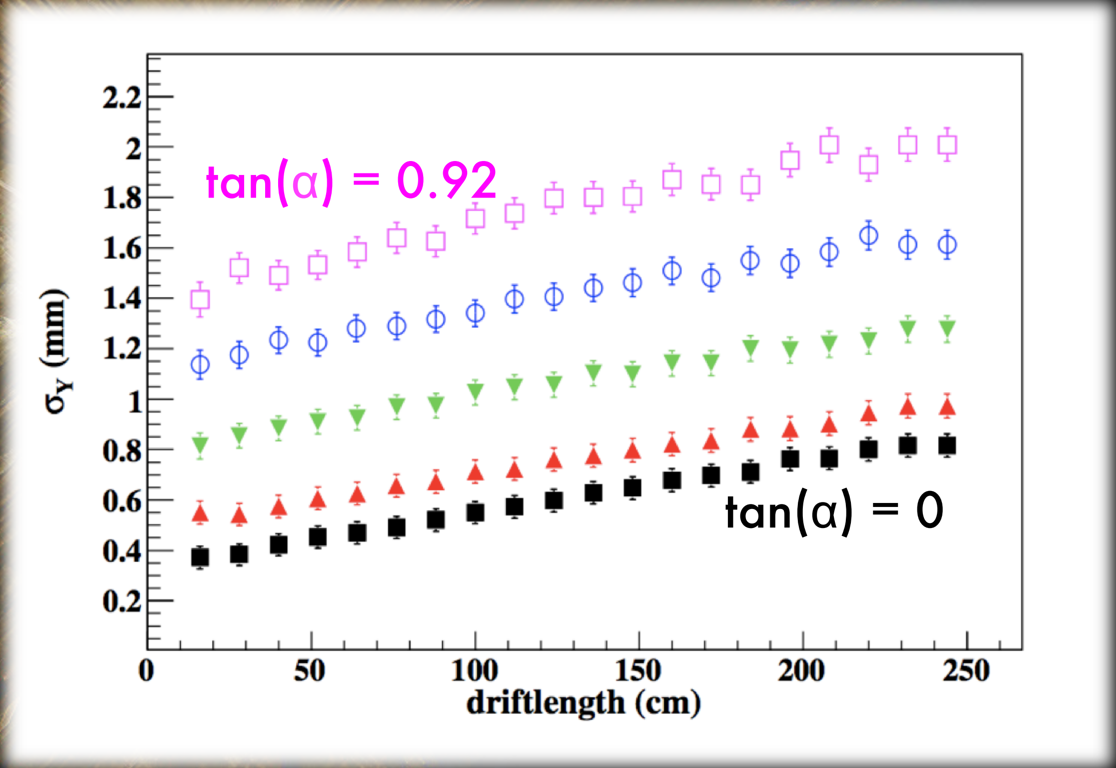
ALTRO processing chain



Space point resolution

- Depends on drift length (diffusion) and pad inclination angle (shown here)

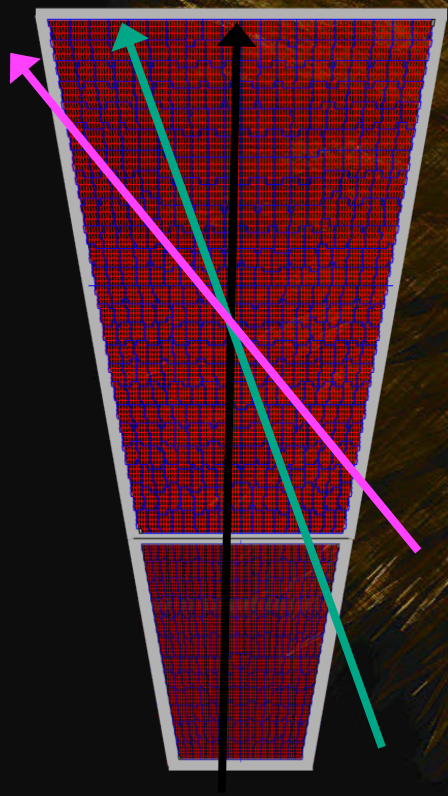


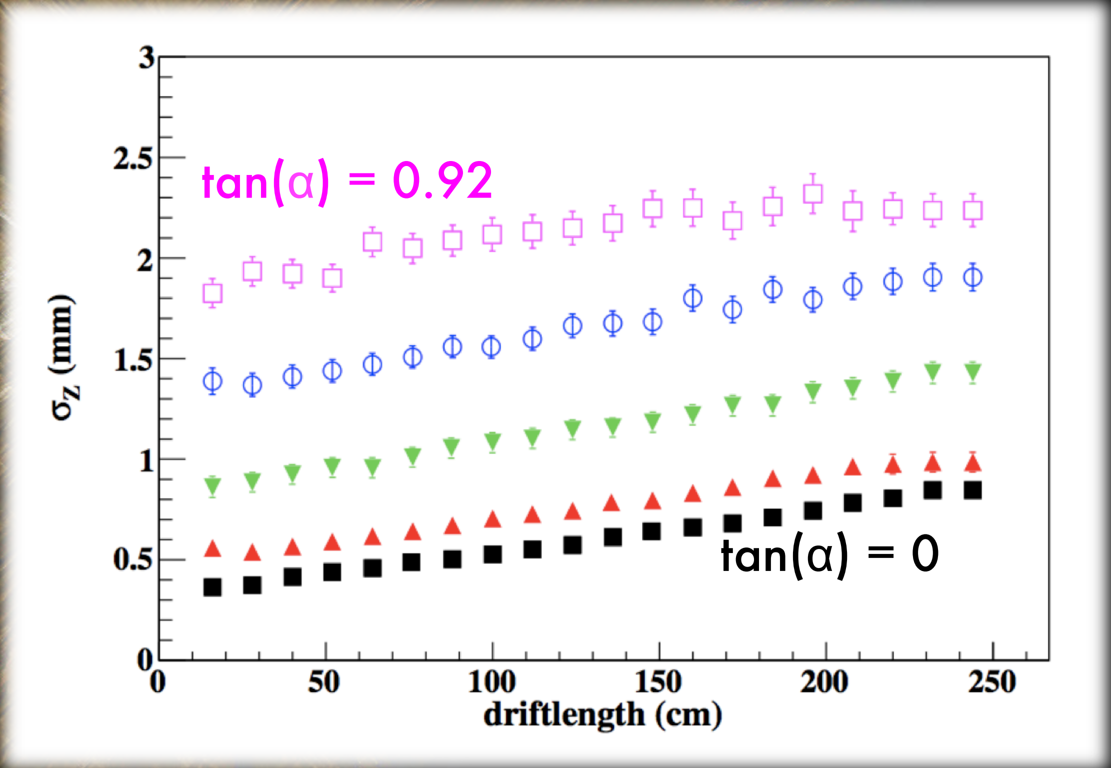


Space-point resolution in rϕ: 300–500 μm for high–p_T tracks

Space point resolution (more)

- Depends on drift length (diffusion) and pad inclination angle (shown here)



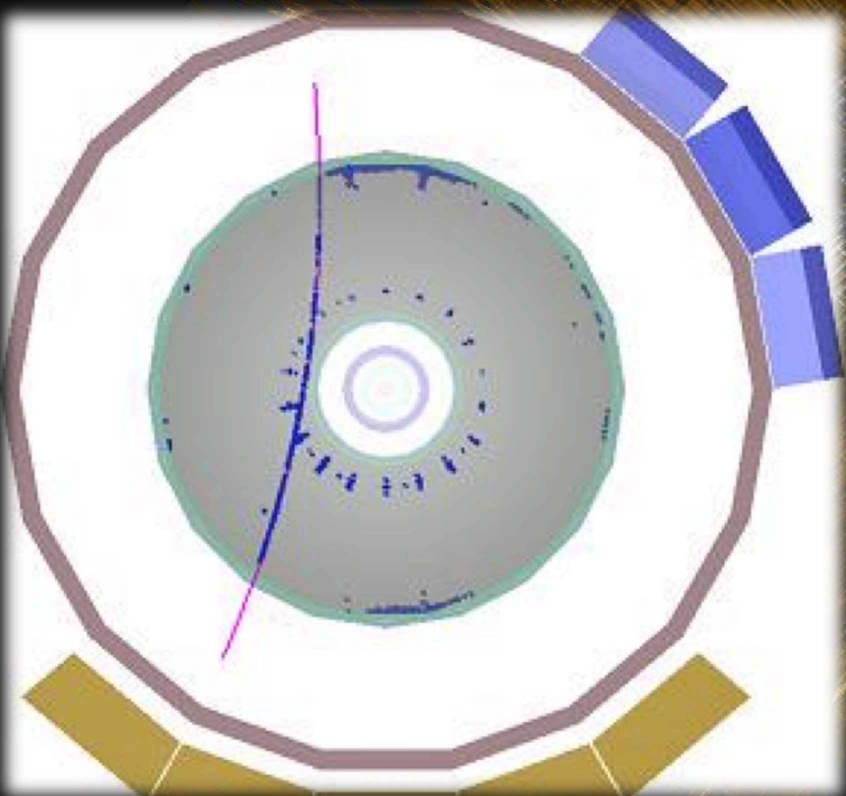


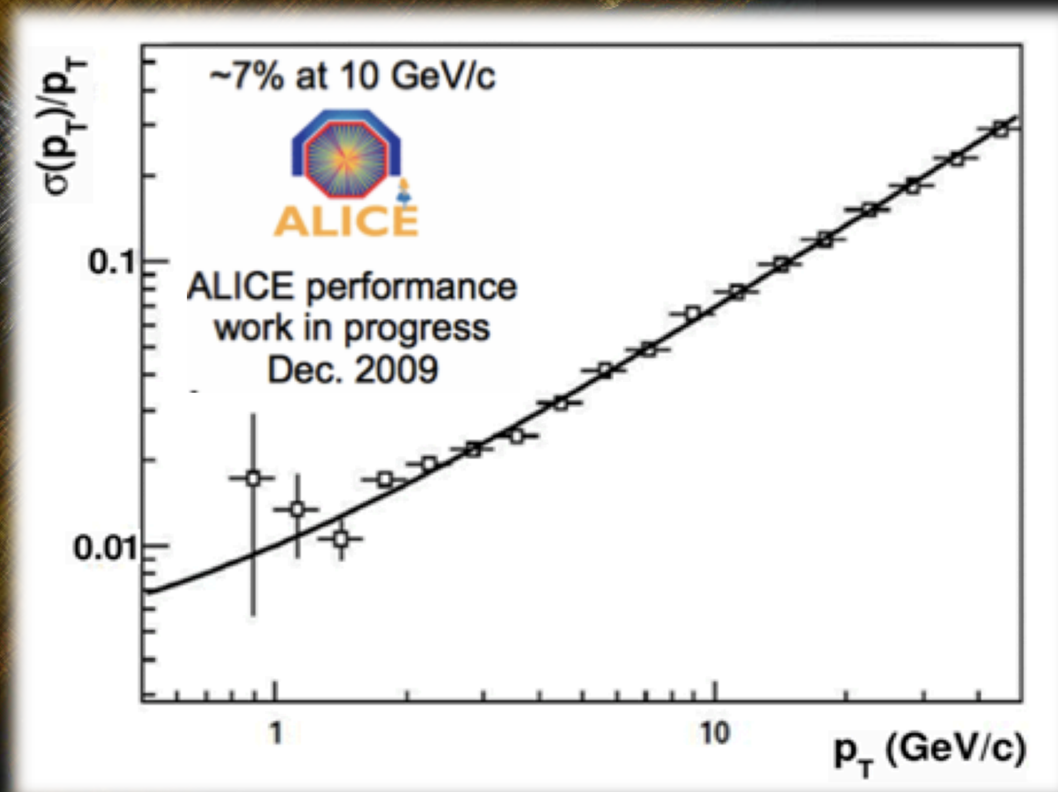
Space-point resolution in z (drift) direction

Standalone momentum resolution

Measured with comic tracks in 2009 by comparing the two track segments in the upper and lower half of the TPC

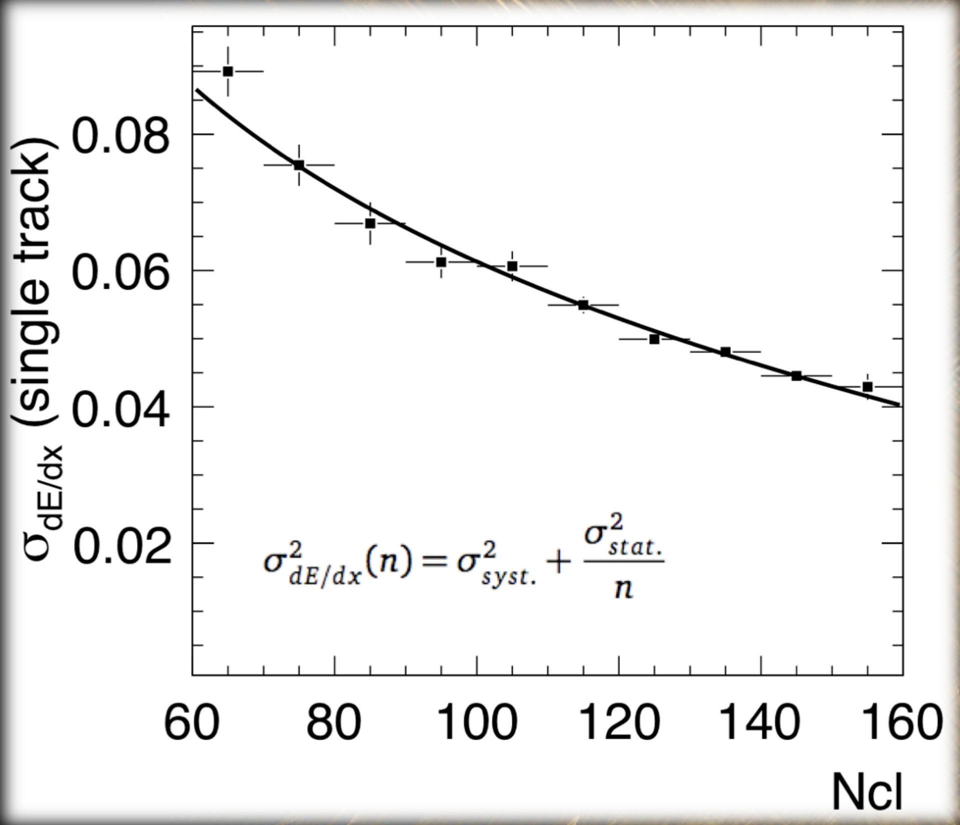
Design value: $\sigma\,(p_T)\,/\,p_T = 4.5\%$ at 10 GeV/c

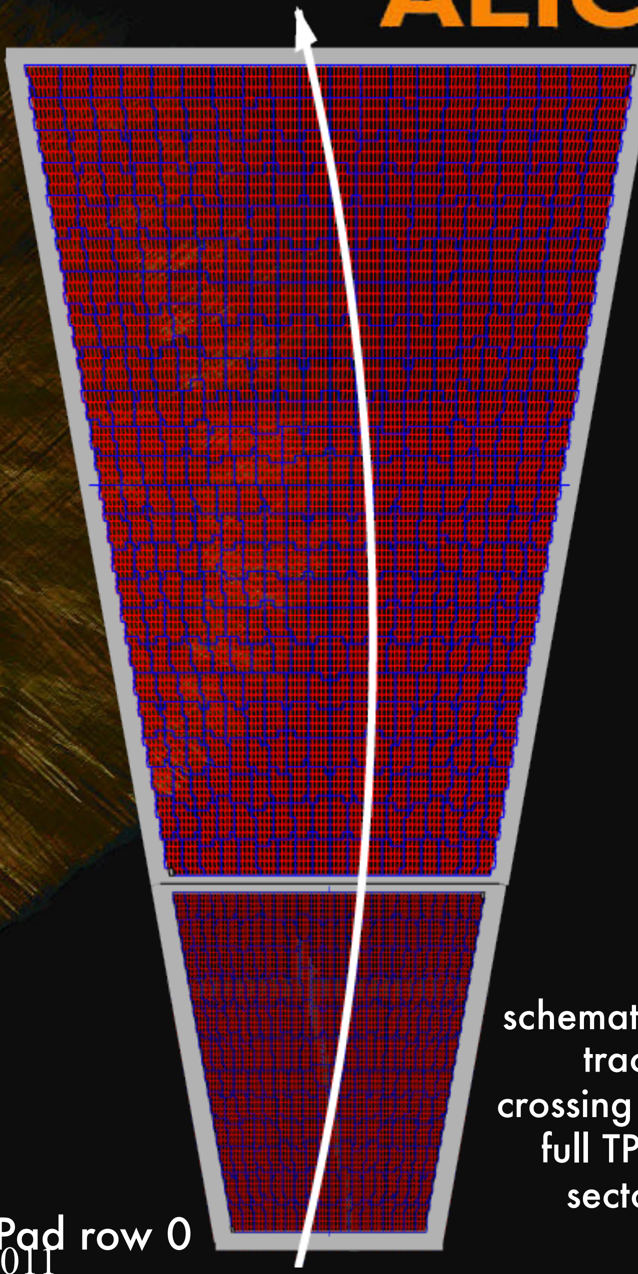




PID performance (2)

Energy resolution from cosmics, 2009





- Dependence of the resolution on the number of clusters along the track