Status and future of the ALICE TPC, a high-resolution detector for the highest particle multiplicities

Christian Lippmann
for the ALICE TPC collaboration

DPG spring meeting, Dresden, 04–08 Mar 2013

Outline

- Heavy-ion collisions at the LHC
- The ALICE experiment at the LHC
- What is a Time Projection Chamber?
- Description of the ALICE TPC
- Data taking
- Calibration: gain, drift velocity and distortions
- Tracking and PID performance
- Outlook: Continuous readout upgrade
- Summary

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Heavy-ion collisions at the LHC (1)

- A comprehensive heavy-ion programme at the Large Hadron Collider (LHC)
  - 1 month of beam time devoted to heavy-ion physics each year
  - colliding the largest available nuclei (Pb) at the highest possible energy
- ALICE is the dedicated heavy-ion detector at the LHC

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	pp LHC design	pp ALICE 2012	Pb–Pb (design)	Pb–Pb (Nov 2011)
Centre of mass energy	14 TeV	8 TeV	5.5 ATeV x 208 = 1144 TeV total	2.76 ATeV x 208 = 574 TeV total
Luminosity	10^{34} Hz/cm^2	<10^{31} Hz/cm^2	10^{27} Hz/cm^2	4×10^{26} Hz/cm^2
Bunches per beam	2808	1374	592	358
Bunch spacing	25 ns	50 ns	100 ns	200 ns
β^*	0.5 m	3 m	0.5 m	1 m
Min. bias trigger frequency	10^9 Hz	<10^8 Hz	8000 Hz	3200 Hz
$dN_{ch}/d\eta$	unknown	6	~2300 (expected)	1600

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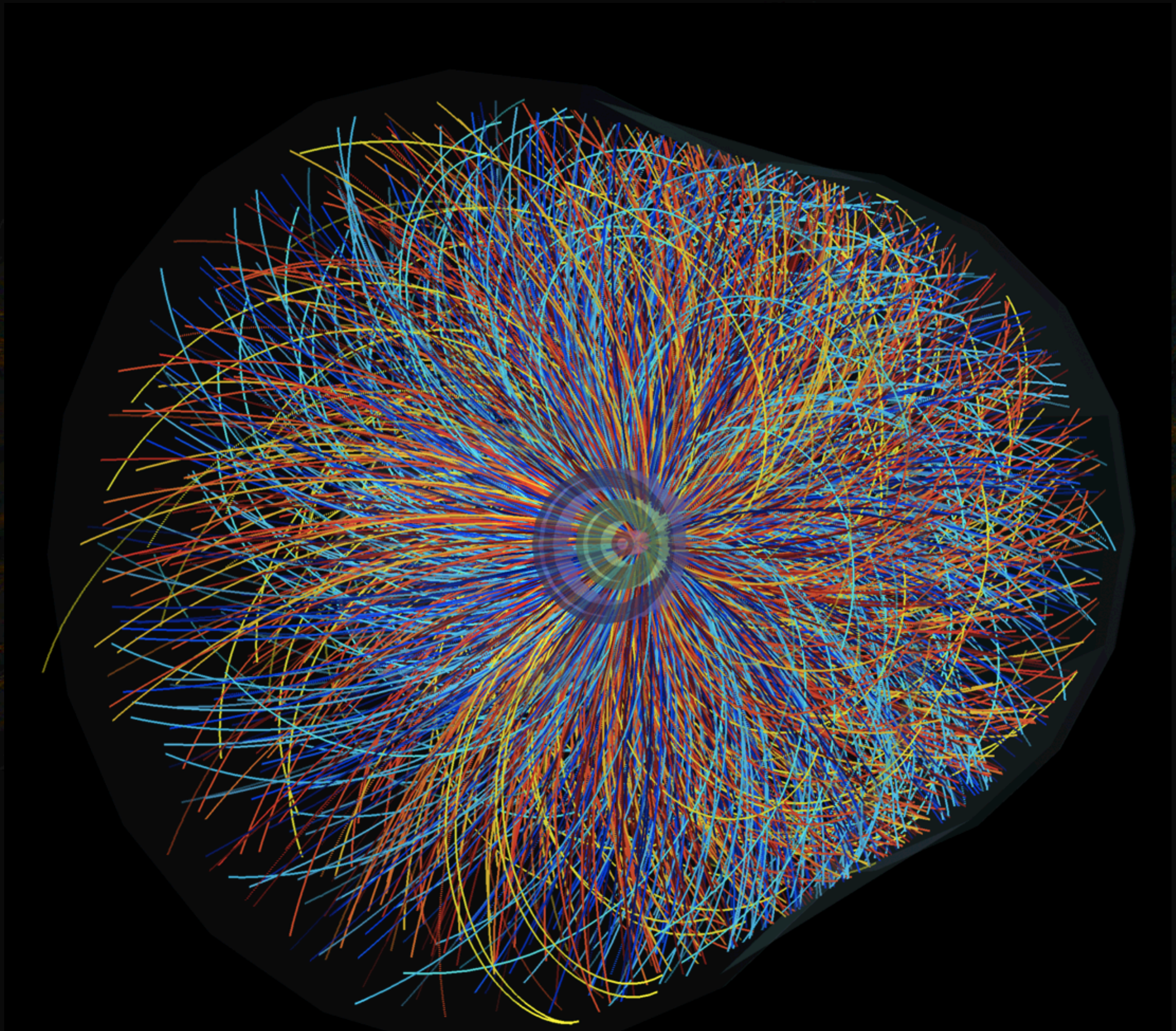
A typical Pb–Pb event



Tracks reconstructed in the ALICE TPC

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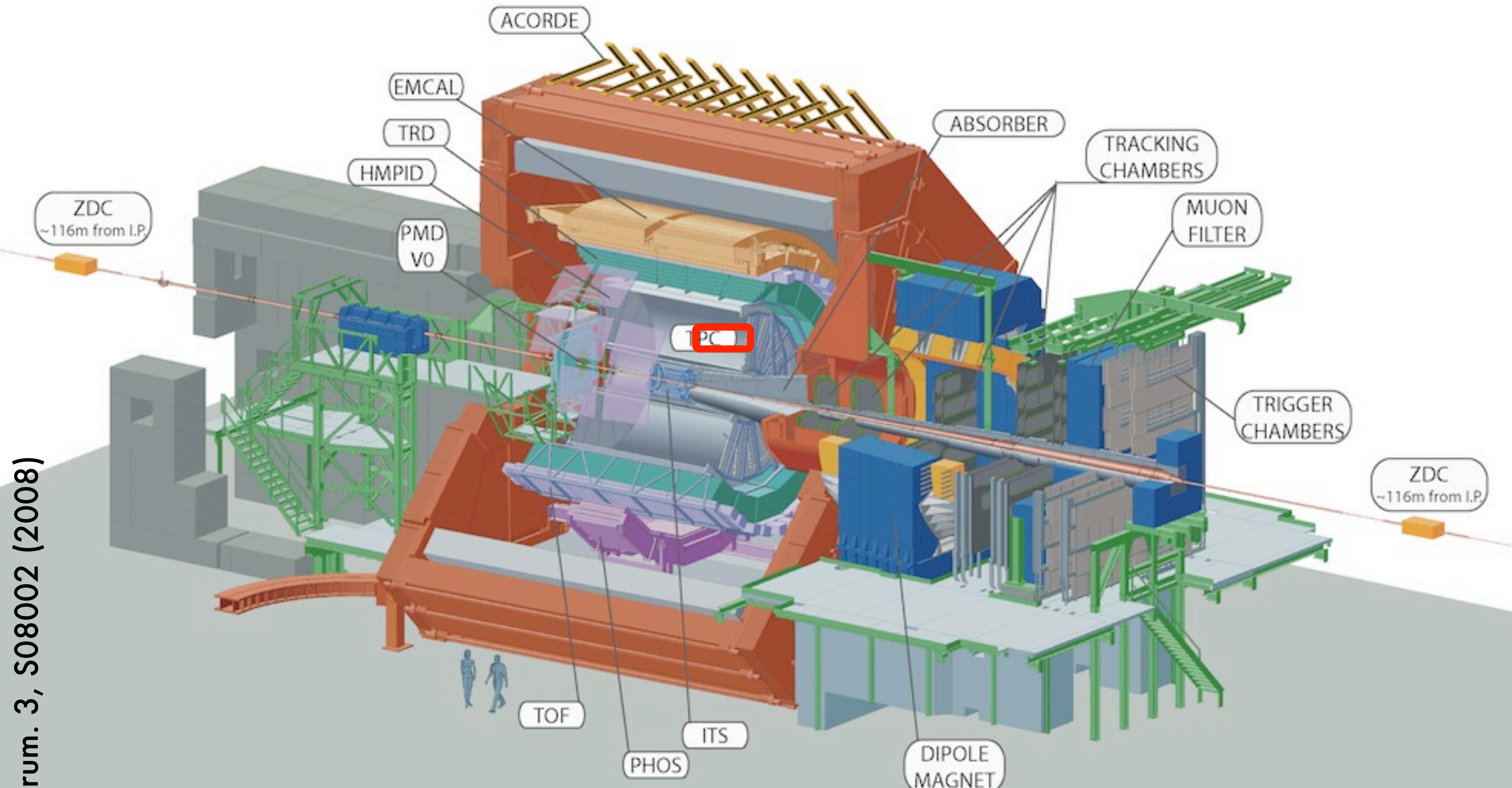
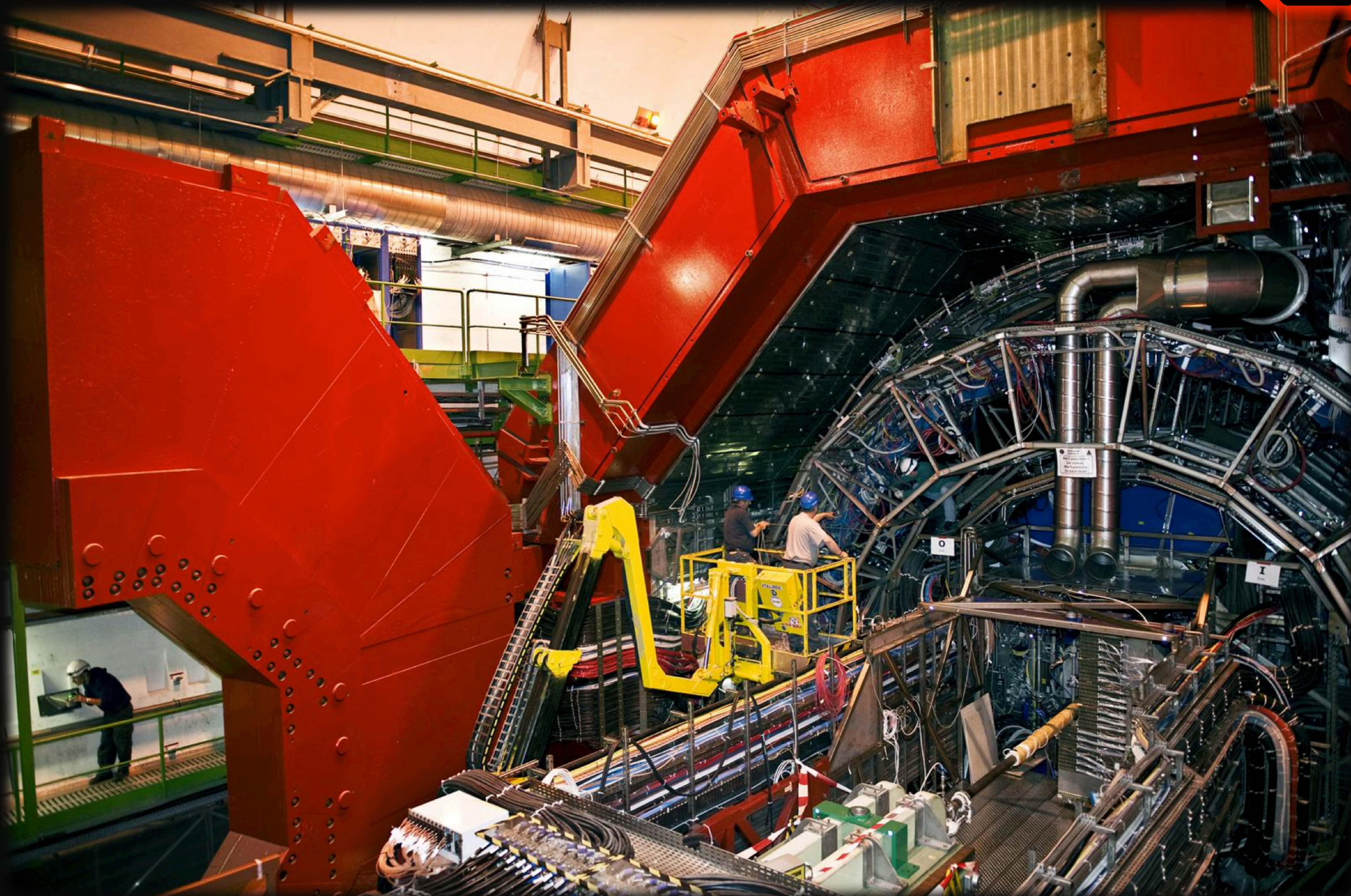
Size: 16 x 26 meters
Weight: 10,000 tons

ALICE setup (1)



J. Instrum. 3, S08002 (2008)

ALICE setup (2)



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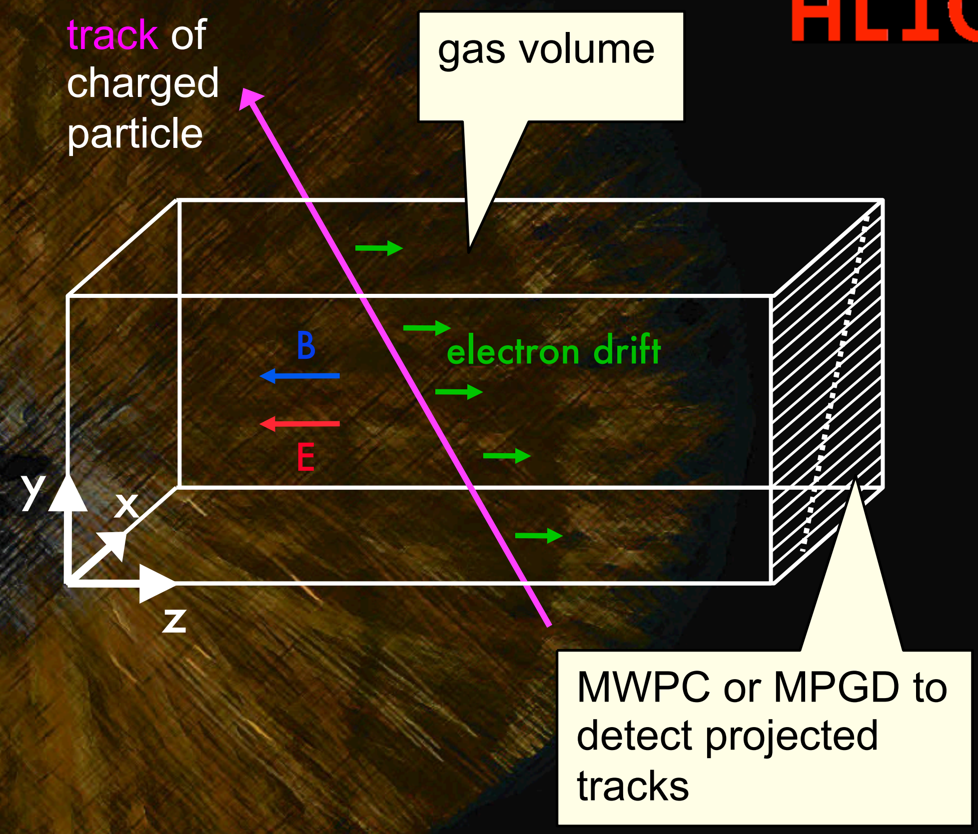
What is a TPC?

1) A charged particle ionises the gas inside a field cage with homogeneous E and B fields.
2) The electrons drift towards the readout elements (up to few m).
3) The projected track is registered on readout chambers (wire chambers, GEMs, ...).



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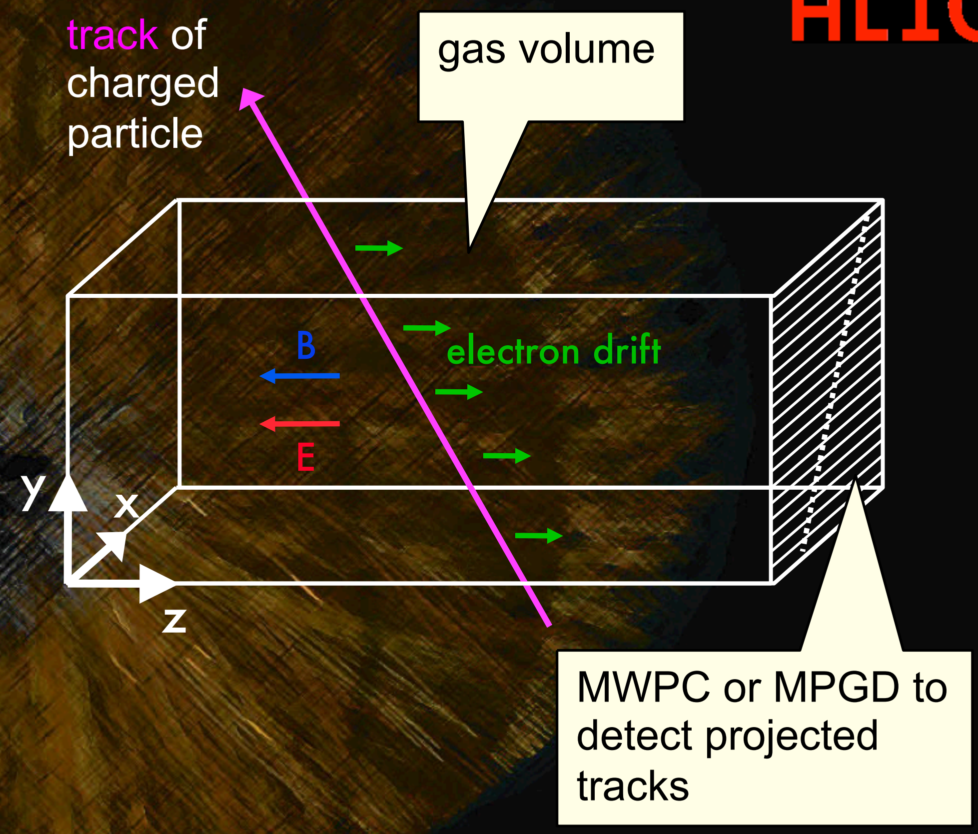
4) The third coordinate is reconstructed from the drift time.



$$\vec{u} = \frac{\mu|\vec{E}|}{(1+\omega^2\tau^2)} \left[\hat{E} + \omega\tau \left(\hat{E} \times \hat{B}\right) + \omega^2\tau^2 \left(\hat{E}\cdot\hat{B}\right)\hat{B} \right]$$

Langevin equation for the drift velocity vector with E and B fields

Why use a TPC?

- A TPC is the perfect detector for HI collisions ...
  - almost the whole volume is active
  - minimal radiation length (field cage, gas)
  - easy pattern recognition (continuos tracks)
  - PID information from ionization measurements
  - transverse spread of the drifting electron clouds due to diffusion may be minimized by choosing a gas mixture with $\omega\tau>1$ together with parallel B and E fields

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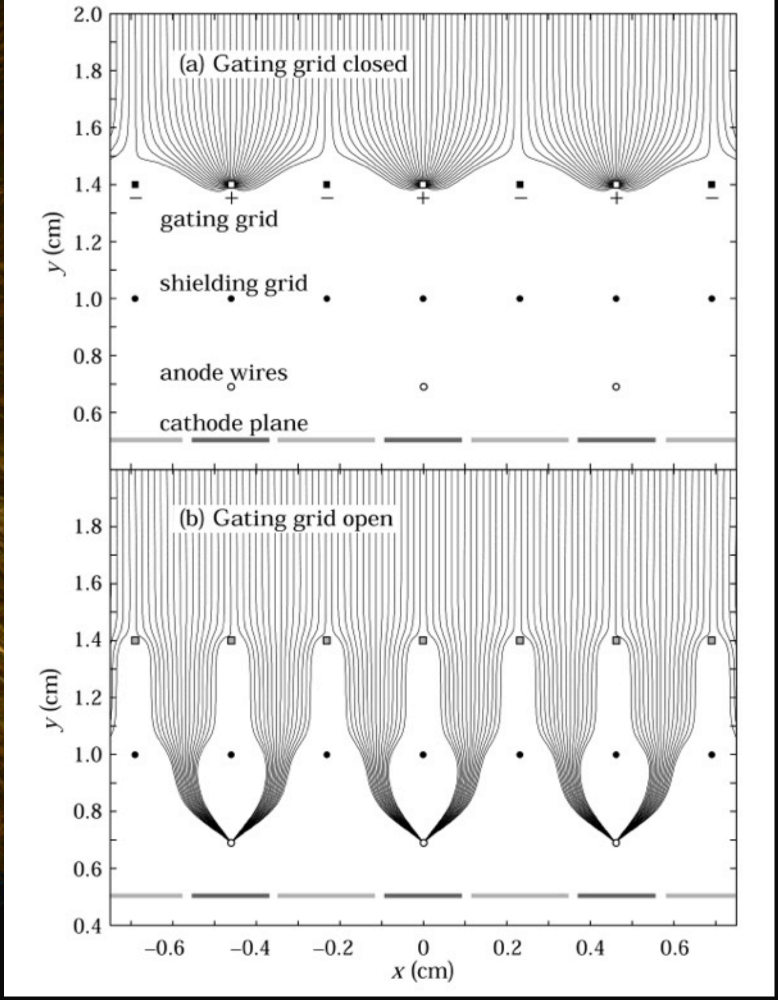
  - transverse spread of the drifting electron clouds due to diffusion may be minimized by choosing a gas mixture with $\omega\tau>1$ to-gether with parallel B and E fields
- ... but there are also limitations:
  - Gating needed to limit space charge in drift region ⇒ low trigger rates
  - Demanding calibration



Principle of gating in TPCs

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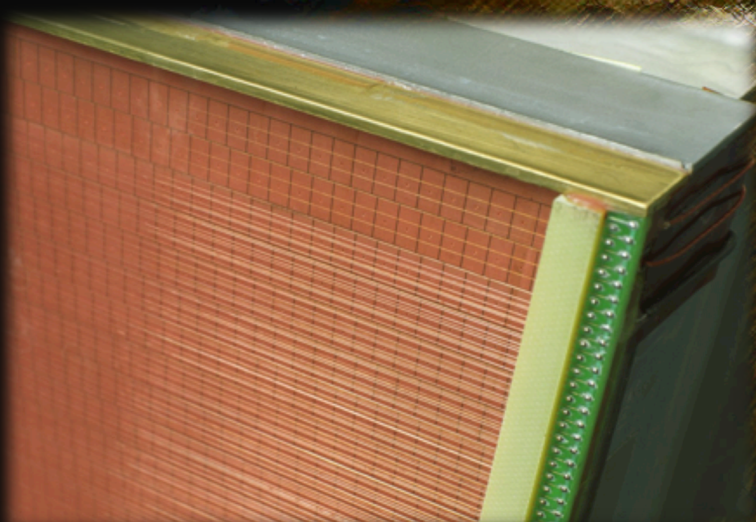
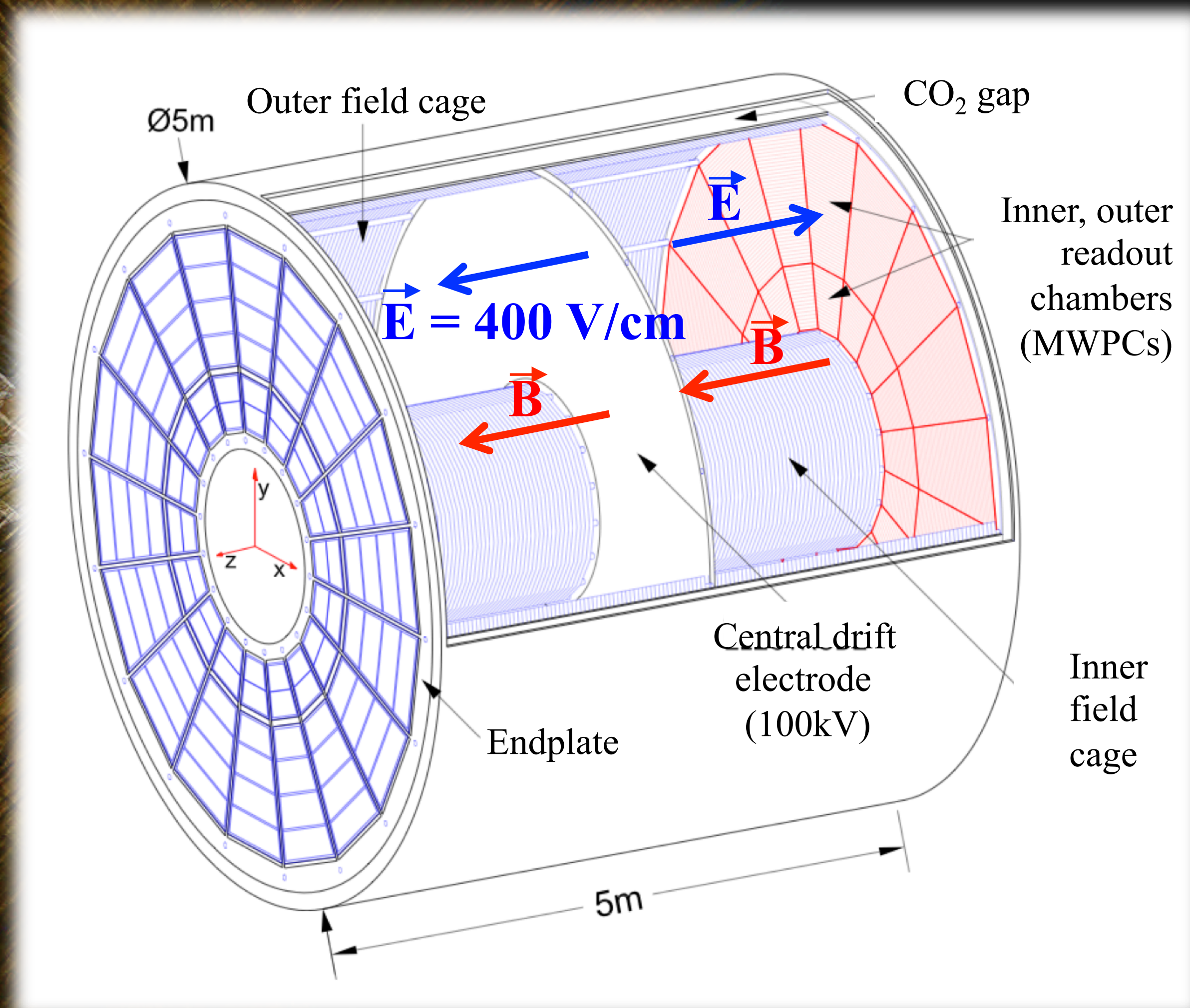
ALICE TPC field cage and MWPCs

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


Detail of one readout chamber

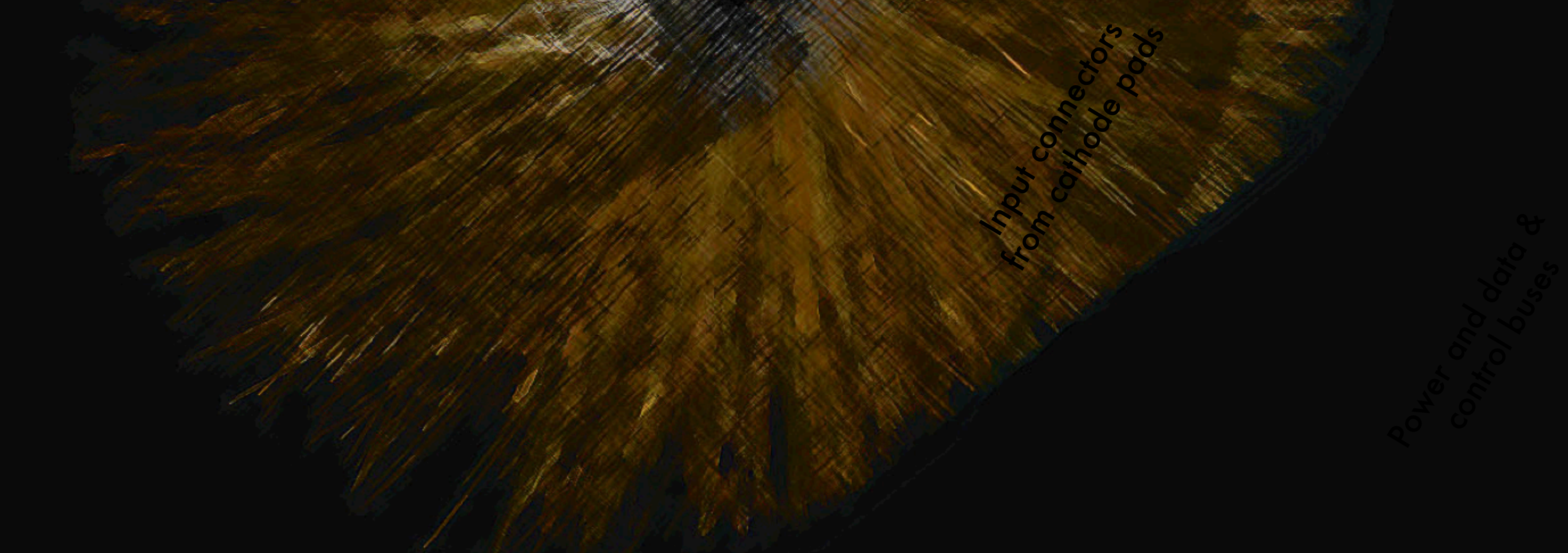


Low mass, high precision field cage

[Nucl.Instrum.Meth. A622 (2010) 316-367]

Gas and Front End Electronics (1)

- Gas mixture: Ne, CO_2 (90-10) with a bit of N_2
  - Low diffusion ("cold gas")
  - $\omega\tau$=0.32
  - low Z (low radiation length, 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
- ~100 ppm H_2O added for stability



[Nucl.Instrum.Meth. A622 (2010) 316-367]

Gas and Front End Electronics (2)

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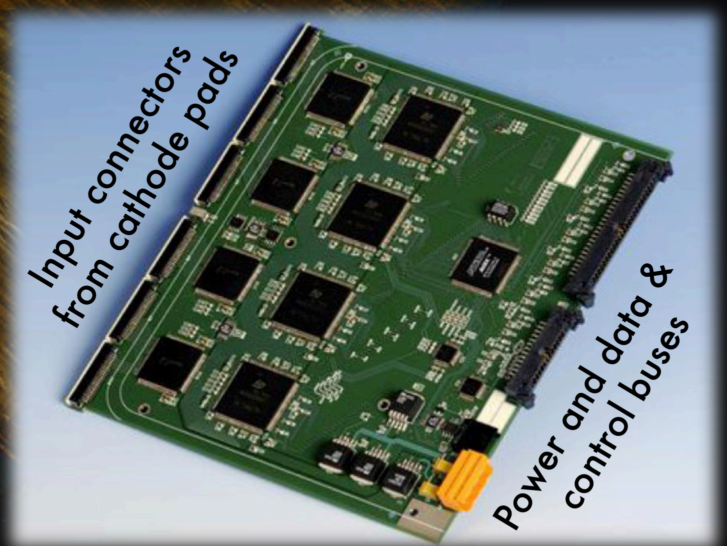
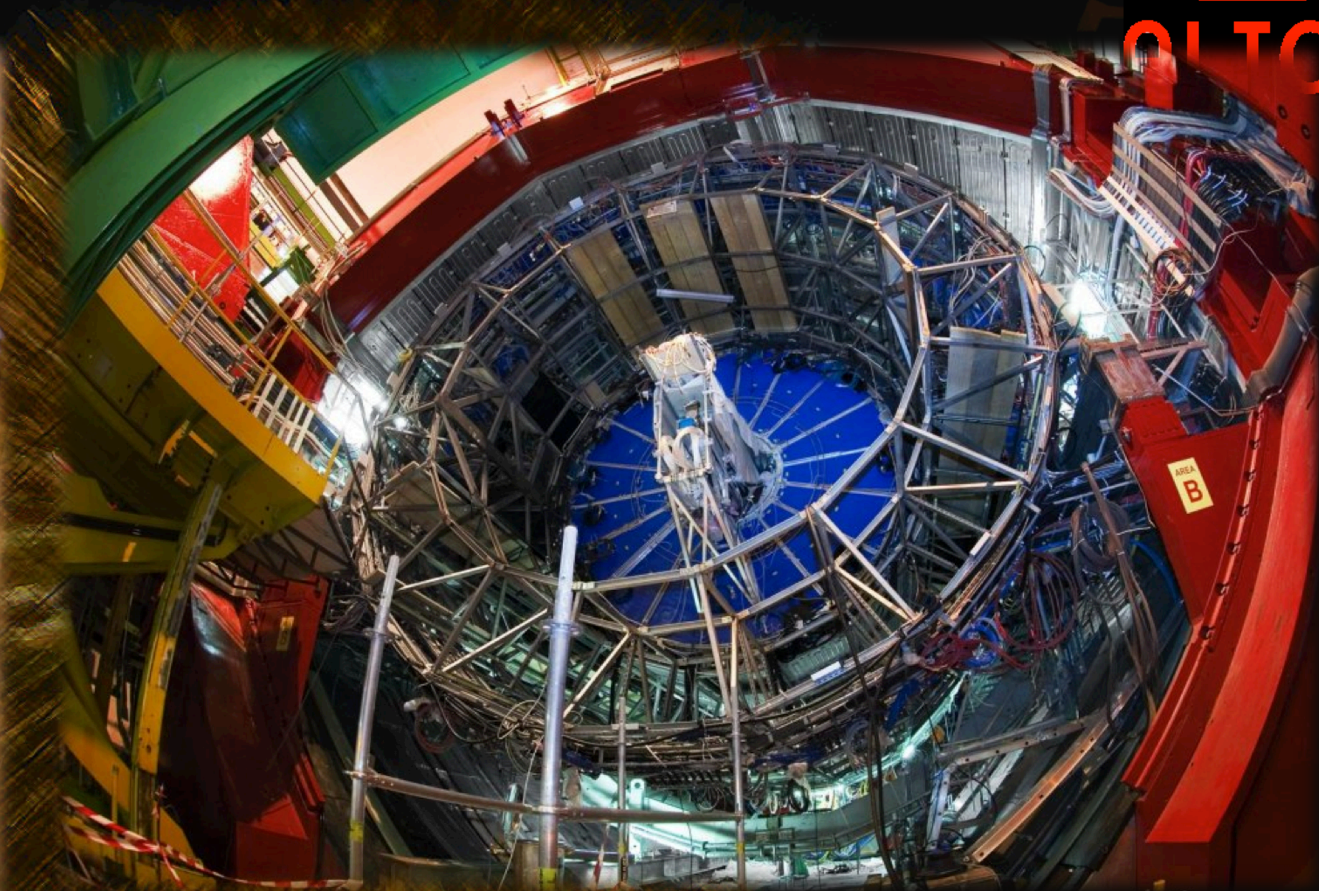
- Maximum electron drift time (250 cm drift) : ~92 μs
- Field cage, MWPCs and gas system very leak tight: ~1 ppm O_2
- ~100 ppm H_2O added for stability
- 557 568 read out pads and FEE channels
- 1000 time bins ⇒ 557 million voxels
- PreAmplifier ShAper (PASA)
  - 12 mV/fC, 190 ns FWHM
- ALTRO digital chip
- 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)

[Nucl.Instrum.Meth. A622 (2010) 316-367]

The past and the present



- Field Cage assembly: 2002 – 2004
- MWPC installation: 2005
- Electronics installation: 2006
- Installation into ALICE L3 magnet: 2007
- Commissioning & calibration: 2007 – 2009
- Data taking: 2009 – 2013

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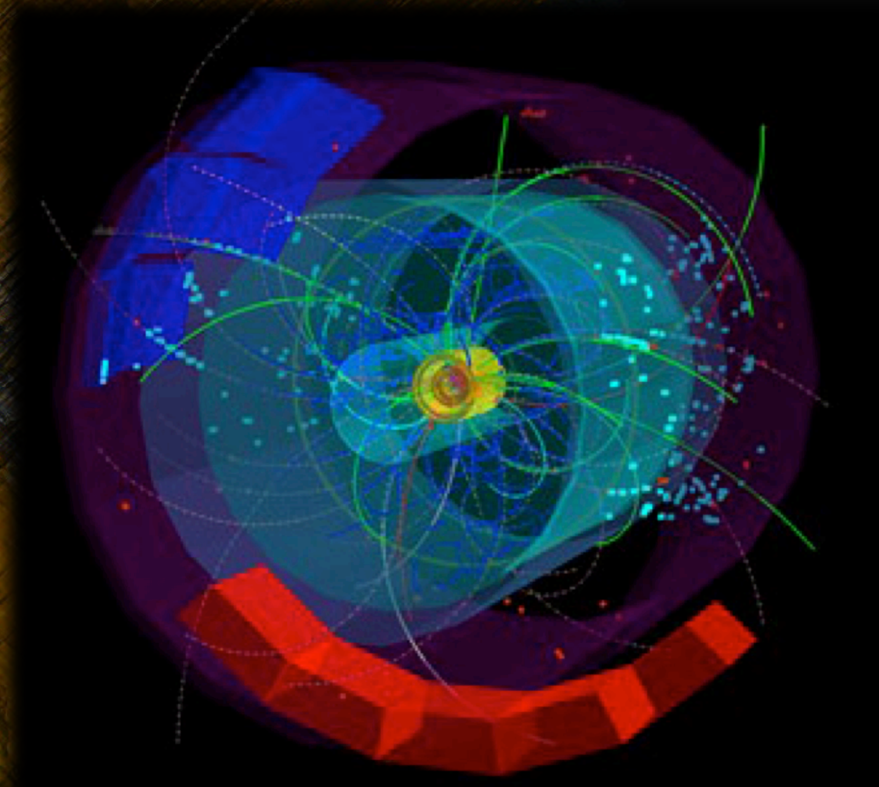
Luminosities and readout rates (1)

- 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
  - ≤400 kHz with high beam background in 2012

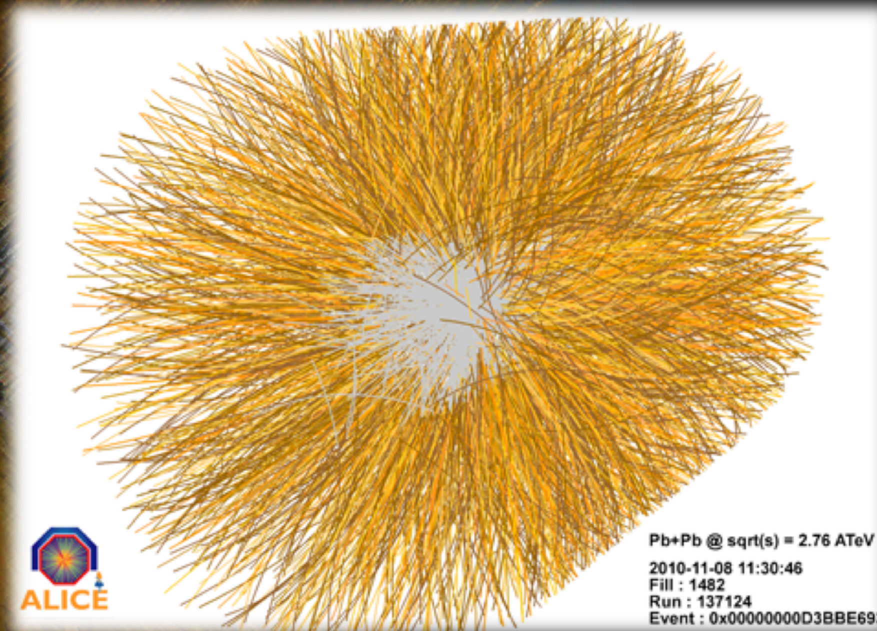
- Maximum TPC readout rates:
  - 1 kHz for pp



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

Luminosities and readout rates (2)

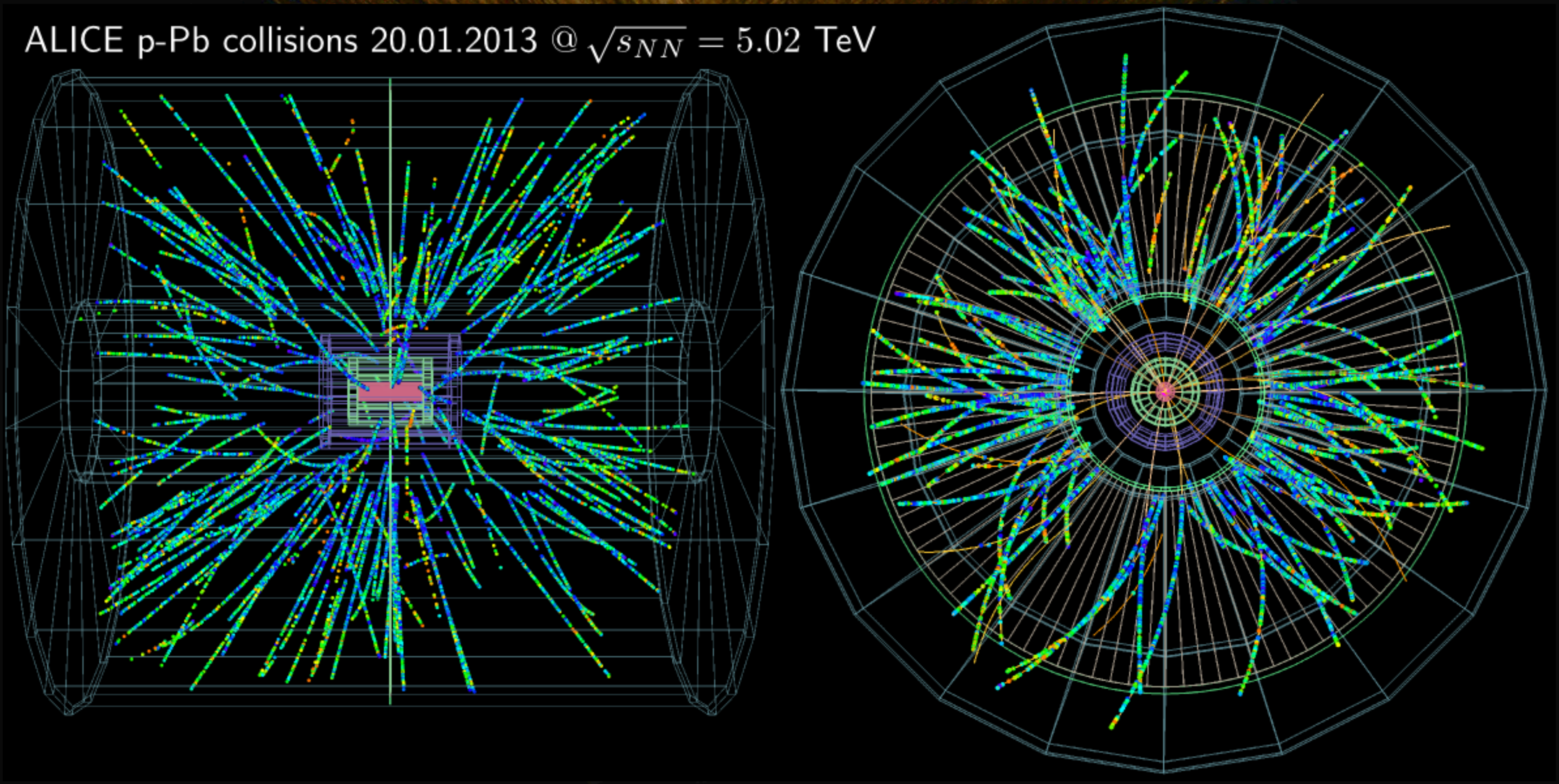
- pp interaction rates in ALICE:
  - ~10 kHz for large cross section observables, almost no event pile up in TPC
  - ≤200 kHz for rare processes, acceptable event pile up
  - ≤400 kHz with high beam background in 2012 pp running
- Pb–Pb interaction rates:
  - ≤10 kHz Pb–Pb collisions
- Maximum TPC readout 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

2013 Highlight: pA run

- Luminosity up to 10^{29} Hz/cm^2 (≤200kHz interaction rate)



General data taking experience (1)

- In general very good experience with operating the detector
  - High accuracy tracking and PID even for highest multiplicity events
  - No space charge effects visible
  - No ageing effects observed
    - none expected, $152 \mu b^{-1}$ Pb–Pb collisions integrated so far

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- In general very good experience operating the detector:
  - High accuracy tracking and PID even for highest multiplicity events
  - No space charge effects visible
  - No ageing effects observed
    - none expected, $152\mu b^{-1}$ Pb–Pb collisions integrated so far
- Few problems:
  - Some baseline fluctuations (ion tails) not yet be removed using online processing (ALTRO moving average filter)
    - Use offline correction instead, see also HK 68.1
  - Some damage to electronics due to discharges
    - Removal of HV capacitors in 2011/12
  - Some HV trips (automatic HV ramp down in case of overcurrent)
    - reconsider (or optimize) gas mixture

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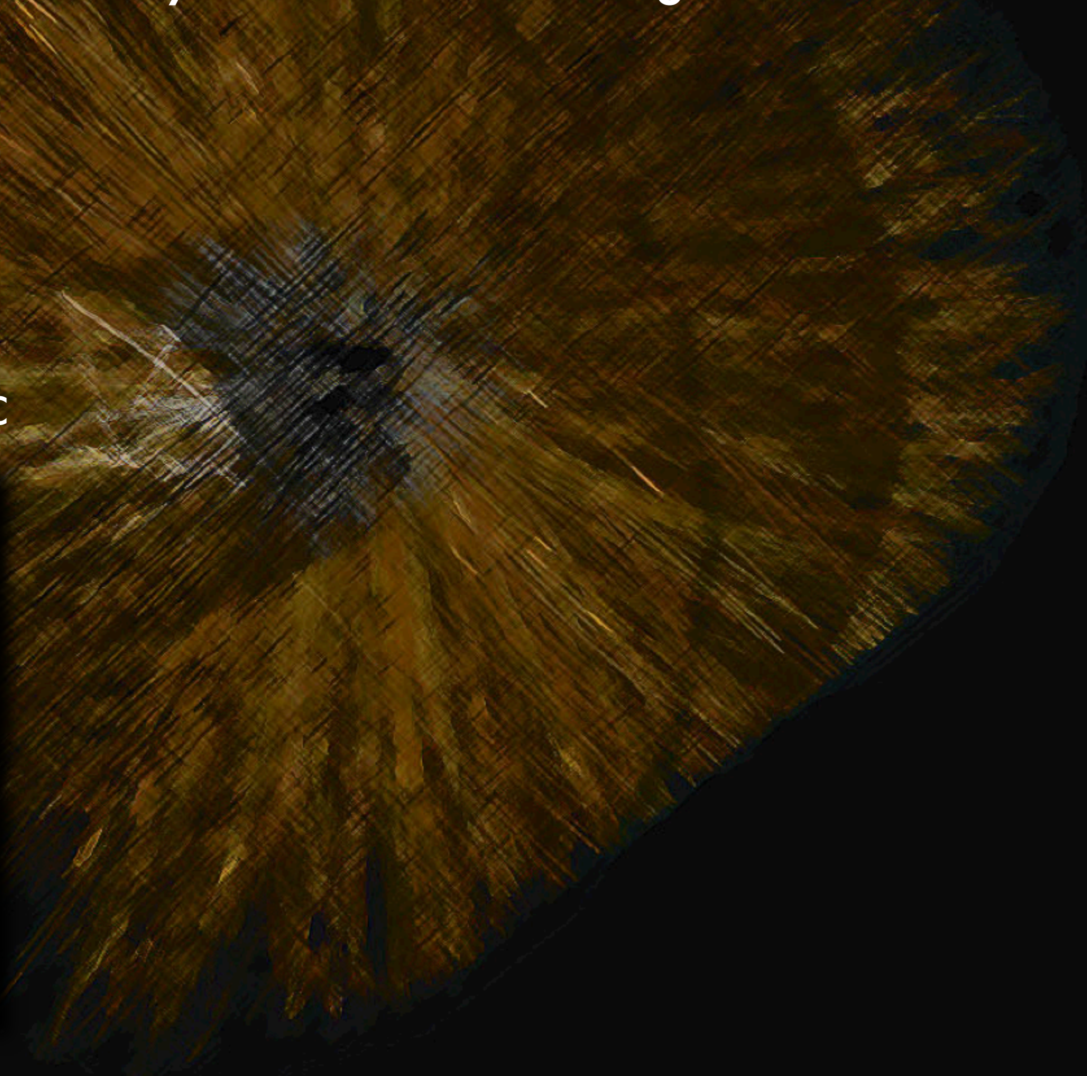
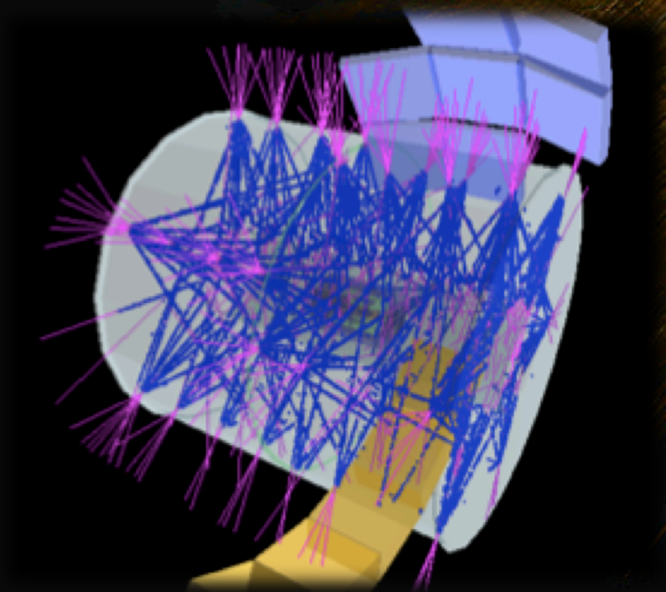
Calibration overview (1)

- The main TPC calibration procedures are
  1. laser data: drift velocity calibration and alignment



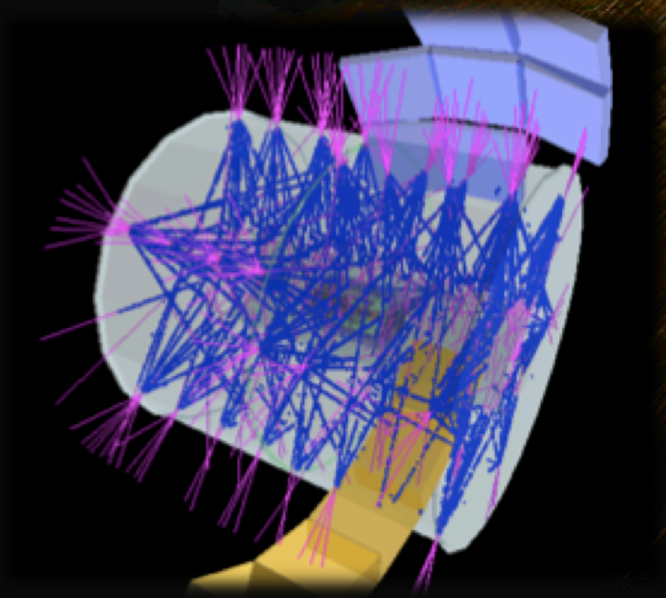
A reconstructed laser event in the TPC



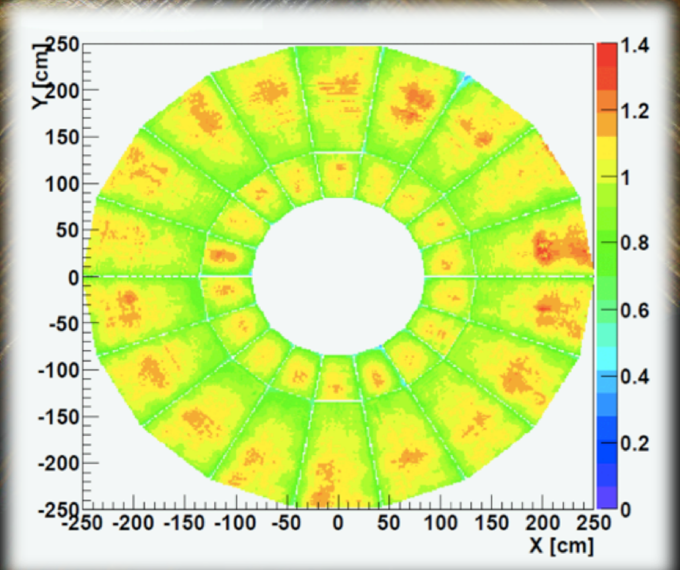
Calibration overview (2)

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

A reconstructed laser event in the TPC



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



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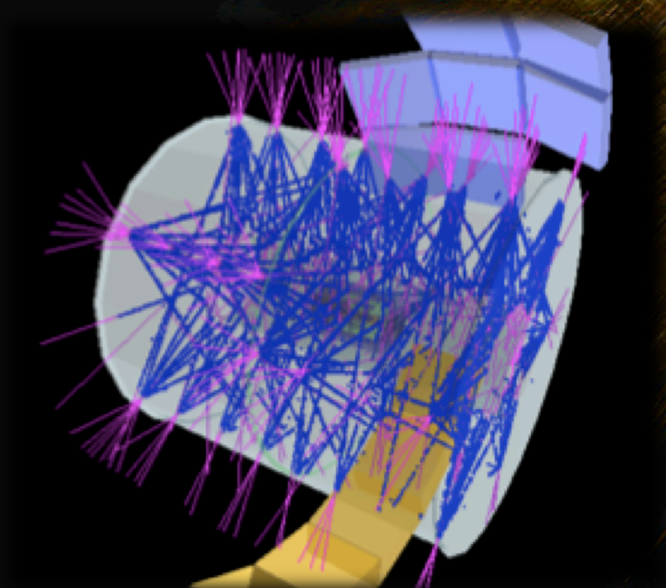
  3. cosmics and Physics (collisions) tracks: alignment and gain calibration

A reconstructed laser event in the TPC



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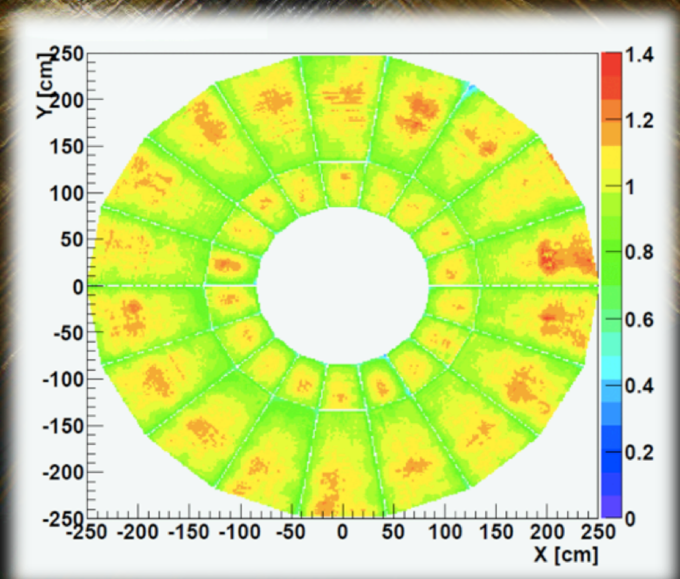
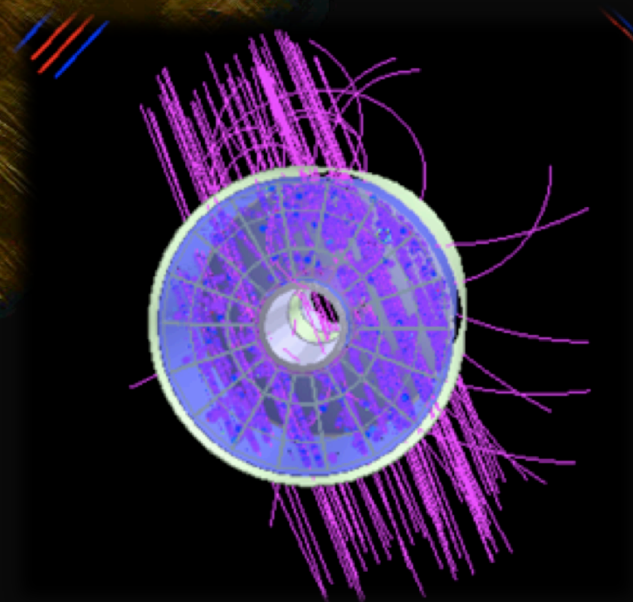
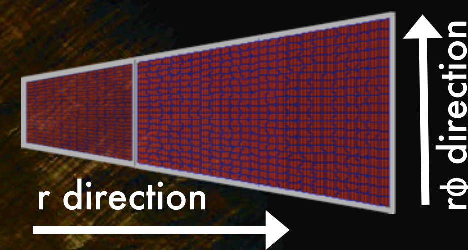


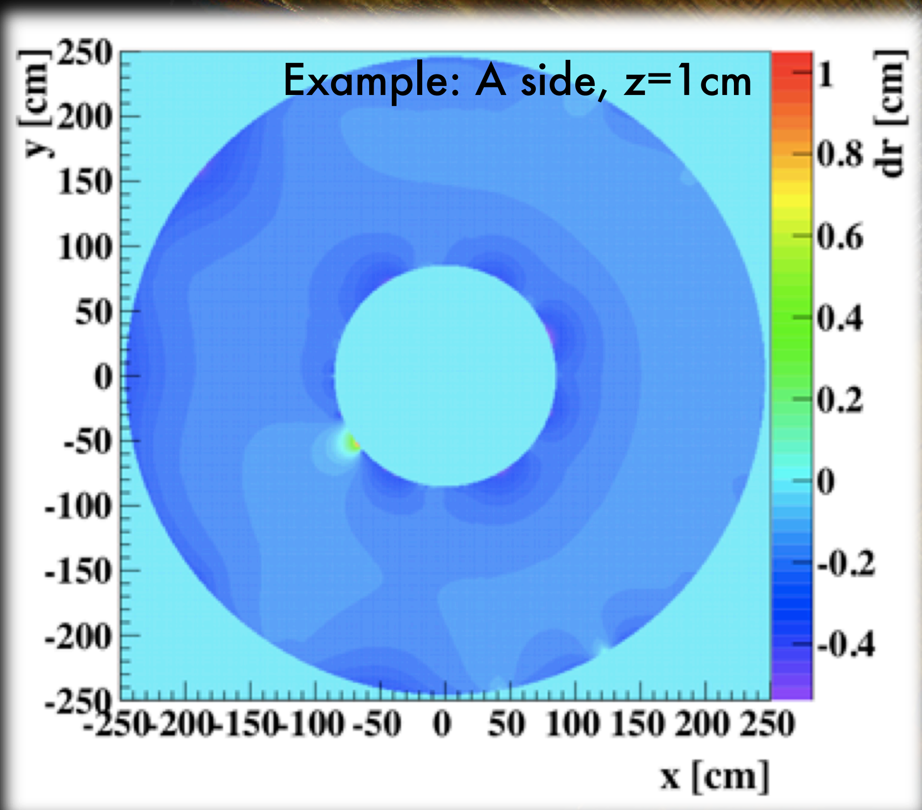
A cosmic muon shower, triggered by ACORDE

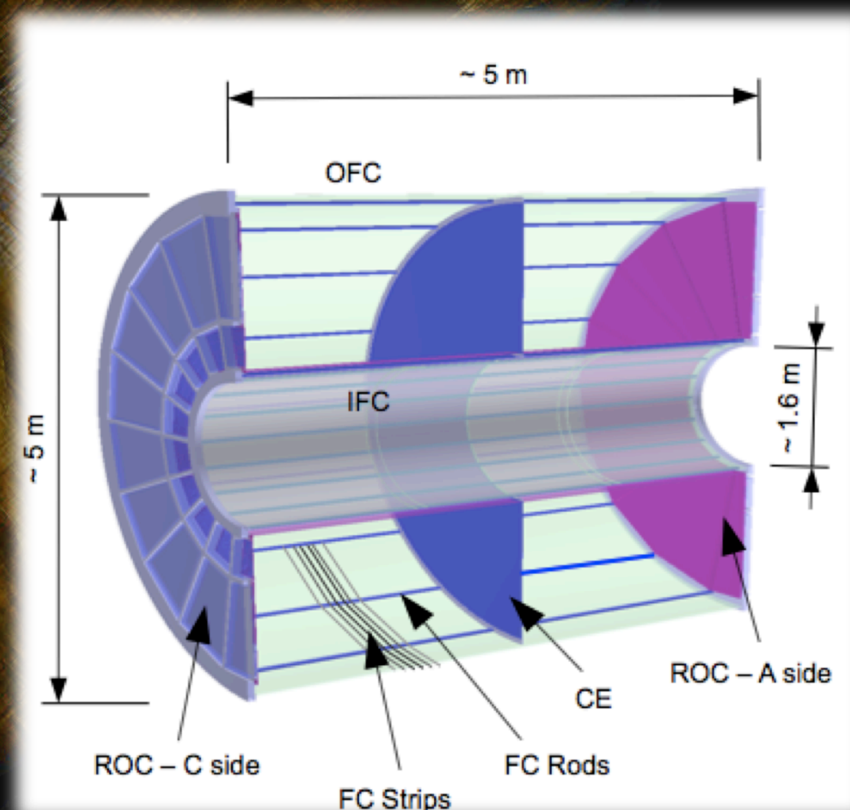


Example 1: Field cage imperfections

- Drifting electrons are deflected from ideal drift path
- Imperfections in the field cage
- Maximum (very local): δr = 10 mm (shown here); $\delta r\phi$ = 0.8 mm

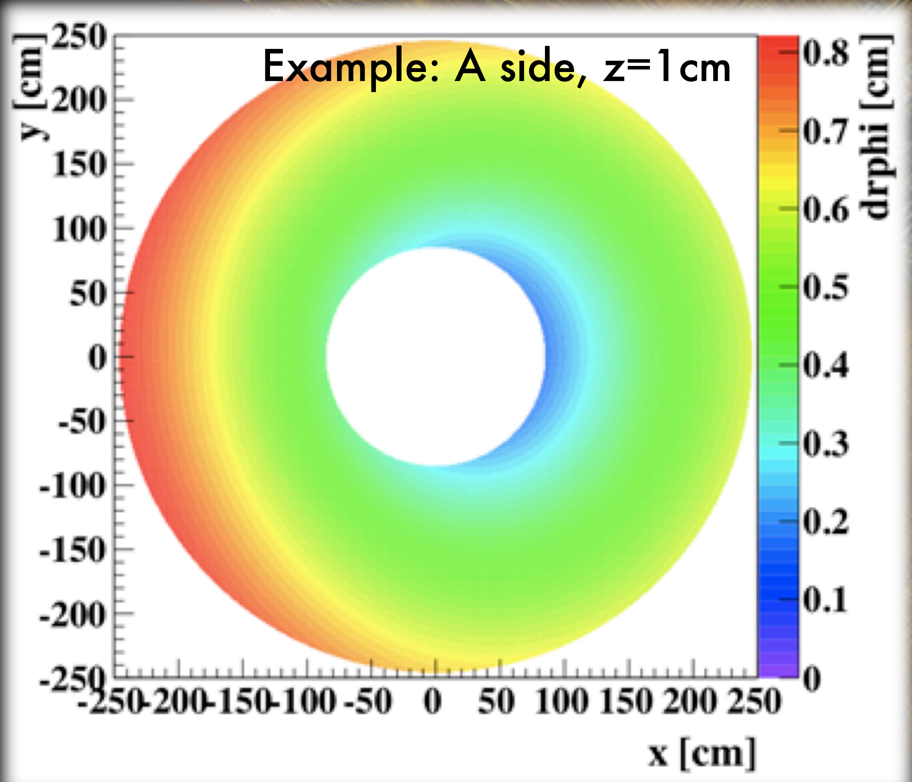


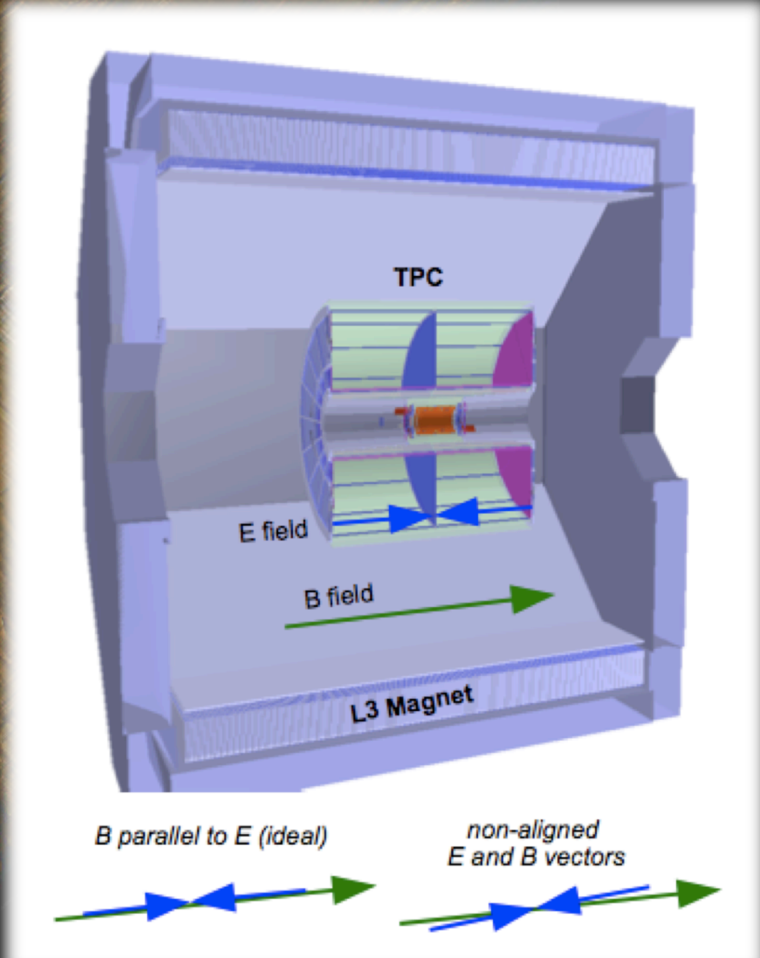




Example 2: Non-ideal B field

- Drifting electrons are deflected from ideal drift path
- B field shape (homogeneity) and alignment with E field
- Maximum: δr = 4 mm;
  $\delta r\phi$ = 8 mm (shown here)





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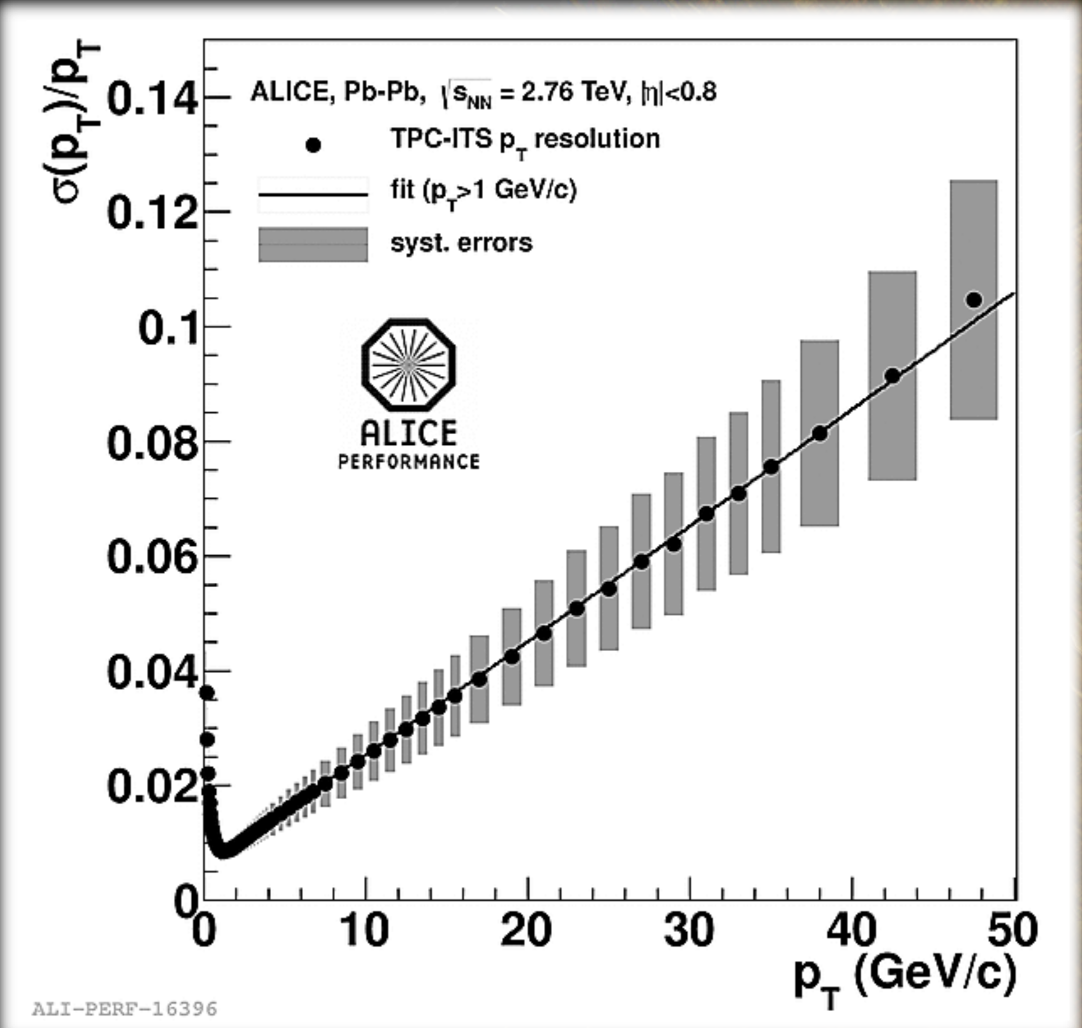
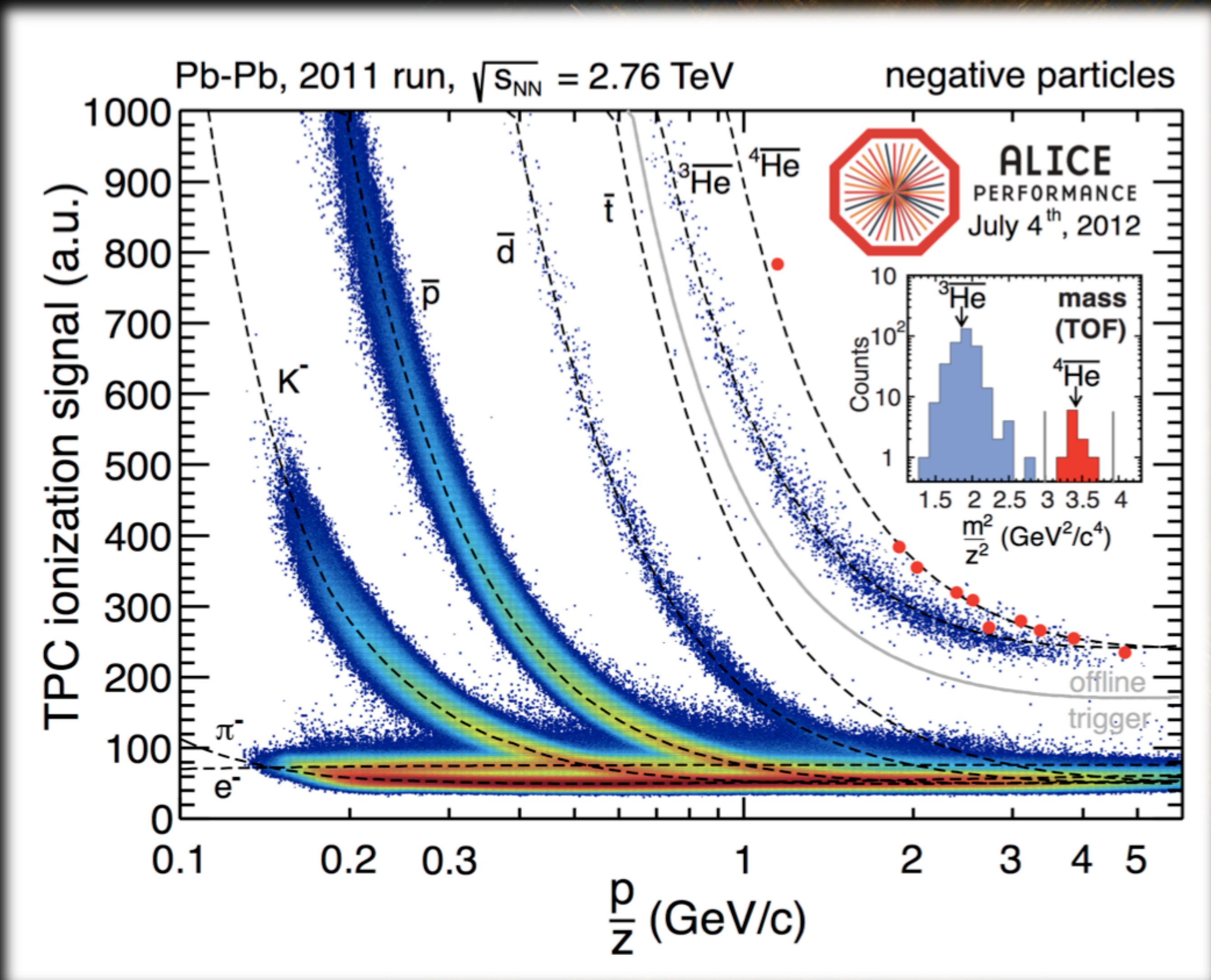
Transverse momentum resolution



Transverse momentum resolution with TPC and silicon Inner Tracking System (ITS). Status of the calibration which corresponds to the recent physics results.

- Expected: $\sigma(p_T)/p_T$ = 5% [ALICE PPR II, 2006 J. Phys. G: Nucl. Part. Phys. 32 1295]
- Current official number: $\sigma(p_T)/p_T$ = 20% at 100GeV/c
- For next round of pyhsics results: $\sigma(p_T)/p_T < 10\%$ at 100 GeV/c
- Ultimately, including also the TRD, the resolution can reach even 3% at 100 GeV/c
- Note: Performance epends not only on TPC

PID with the TPC



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

- Measured Resolution with maximum number of samples: $\sigma_{dE/dx} \approx 5\%$
- Expected: 5.5% [ALICE PPR II, 2006 J. Phys. G: Nucl. Part. Phys. 32 1295]
- Resolution for the highest multiplicity HI events: $\sigma_{dE/dx} \approx 6\%$
- Expected: 7%

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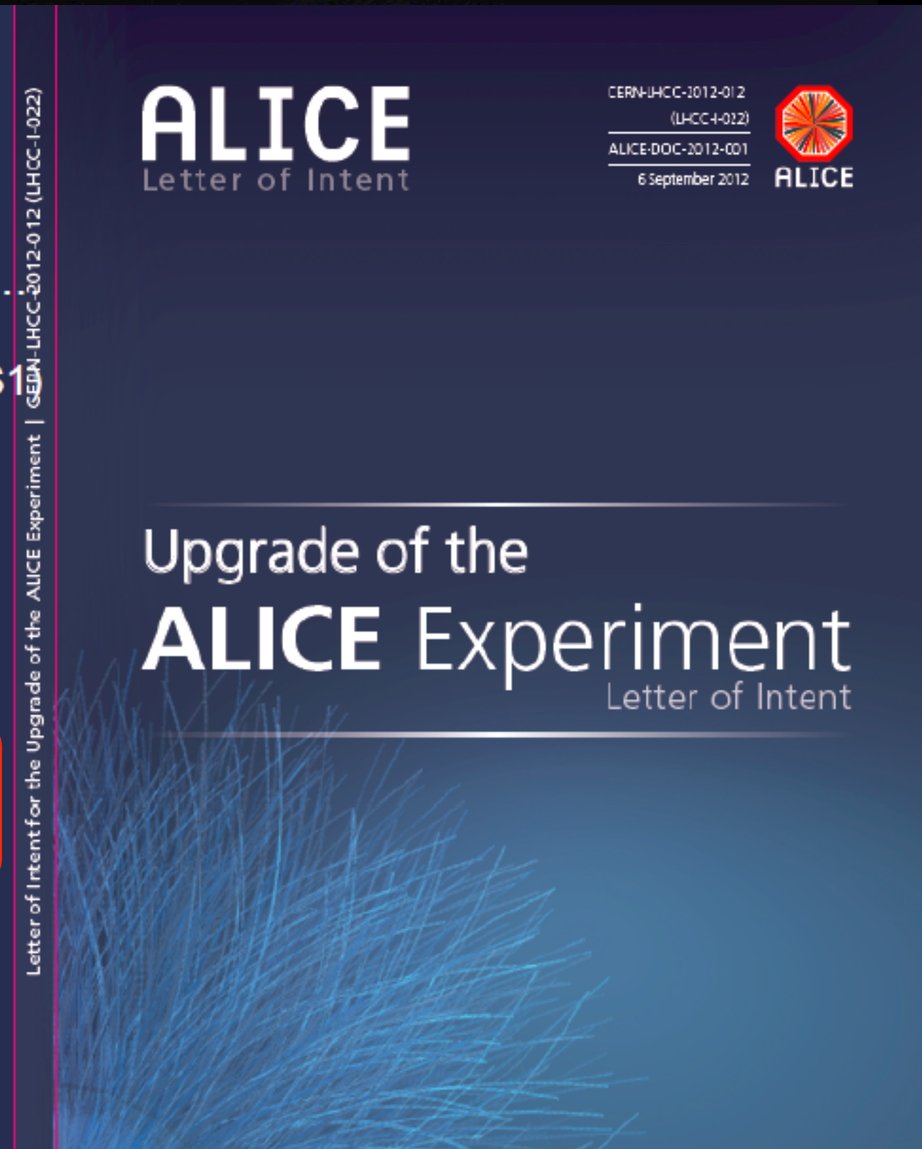
The future

- 2013: **pPb and Pbp**
  initial state effects, shadowing...
- 2013-14: LHC Long Shutdown 1 (LS1)
- 2015-17: **FULL ENERGY !!**
  pp @ 7 TeV,
  PbPb @ √sNN = 5.5 TeV
- 2018: LHC Long Shutdown 2
- ≥ 2019: **HIGH LUMINOSITY**
  50 kHz PbPb collisions

ALICE UPGRADES
- New vertex detectors
- Faster readout, high level triggers...
- TPC with continuous readout ...

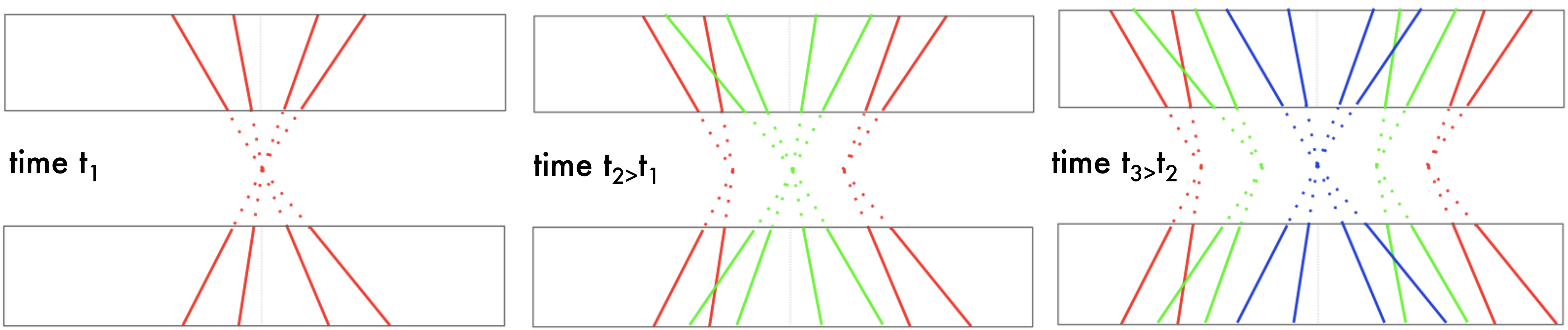


ALICE upgrade Letter of Intent: Endorsed by LHCC

Continuous readout upgrade

- Goal: Operate TPC at high luminosity
  - Luminosity for lead collisions: 6×10^{27} Hz/cm^2
  - Up to 50–100kHz interaction rate
  - Up to 5—10 events overlapping (shown below)
  - Inspect all minimum bias events

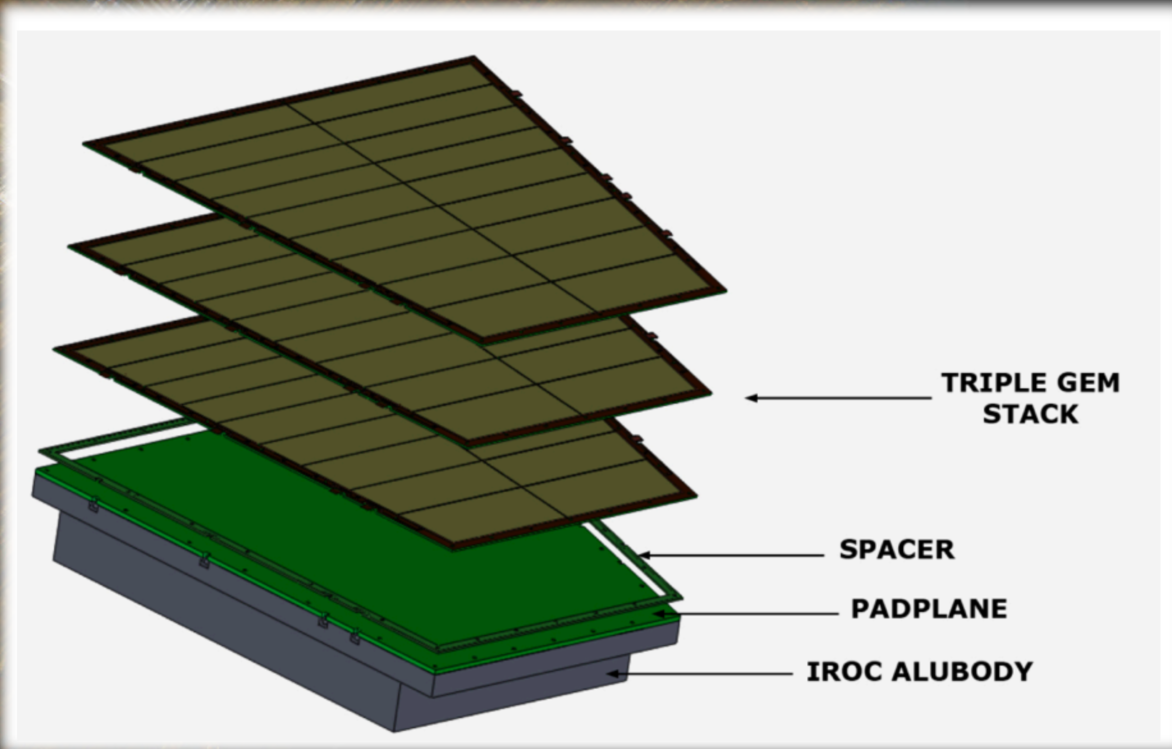
⇒ No gating
⇒ Continuous readout (no triggers)



Example of a time sequence with 3 events overlapping in the drift volume of the TPC

Upgrade plan

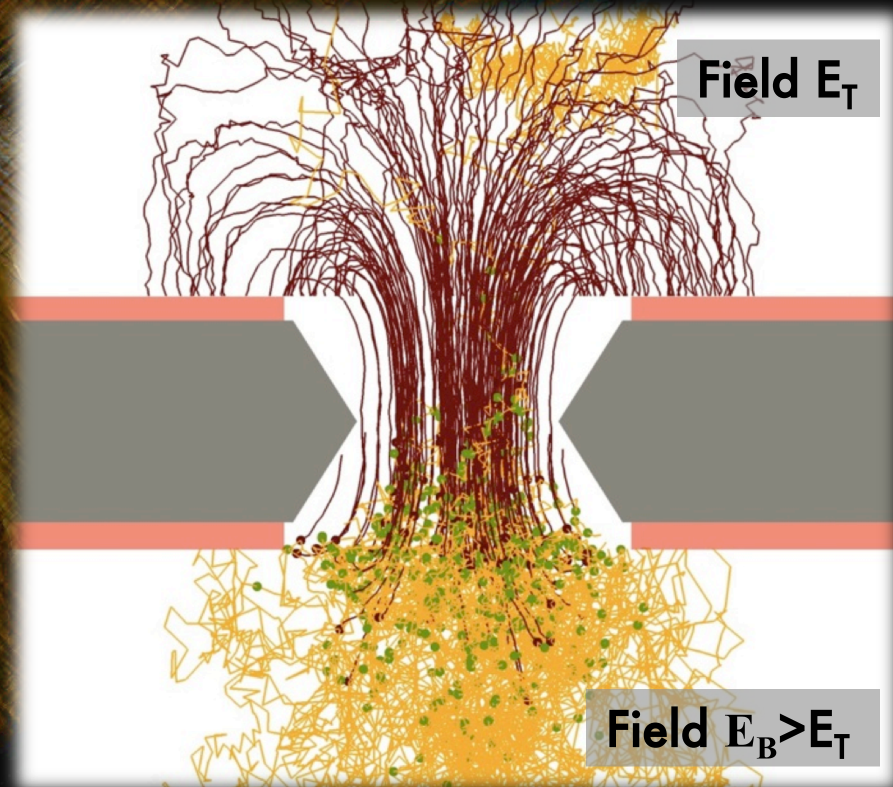
1. Keep existing field cage, gas mixture, laser and services
2. Replace wire planes by GEMs (⇒ See next presentation (HK 80.2)
3. New readout electronics, data acquisition (DAQ) and high-level trigger (HLT)
    - Continuous readout
    - online event reconstruction and calibration



Ion backflow suppression (1)

- Challenge: Minimize space charge in drift region!
- Low ion density in drift region requires
  - low primary ionization n_{ion}
  - low gain G_{eff}
  - low ion backflow IB

$$n_{tot} = n_{ion} \times IB \times G_{eff}$$
$$\varepsilon = IB \times G_{eff} - 1$$



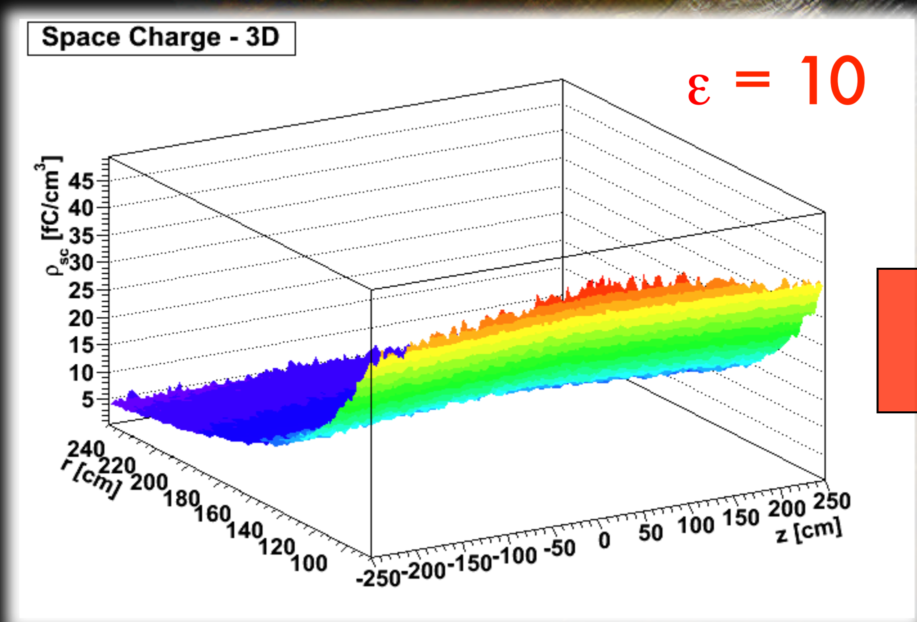
Ion backflow suppression (2)

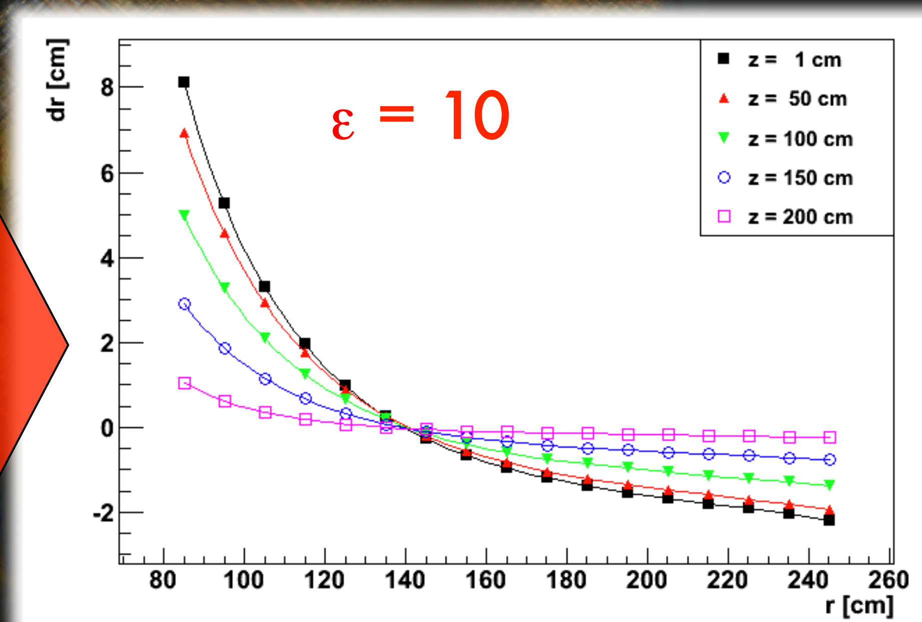
- Challenge: Minimize space charge in drift region!
- Goal: IB = 0.5%, ε = 10 at G_{eff} = 2000

⇒ **Resulting distortions ($\mathcal{O}$(cm)) can be corrected**

$$n_{tot} = n_{ion} \times IB \times G_{eff}$$
$$\varepsilon = IB \times G_{eff} - 1$$

- Current issue under study: Optimisation of IB
  - Measurements and simulations
  - Direction of studies: Different gas mixtures, 4-GEM configuration





Summary

- The ALICE TPC is a large 3-dimensional tracking device for ultra-high multiplicity events
- It has been operated successfully with pp, Pb−Pb and p-Pb collisions at the LHC
- The TPC offers powerful particle identification and tracking in high multiplicity events
- The LHCC has recently endorsed the Letter Of Intent for the upgrade of the ALICE central barrel
- The upgraded TPC will be operated in a continuous mode with GEMs as readout detectors
- Current issue under study: Ion backflow optimization and readout electronics

ALICE TPC collaboration

Koll 5: ALICE TPC-Kollaboration

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