ALICE TPC

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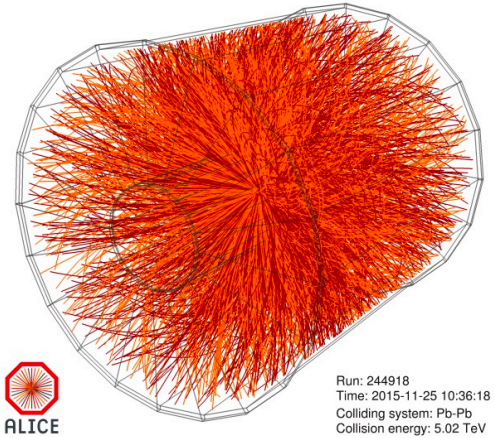
on behalf the ALICE Collaboration

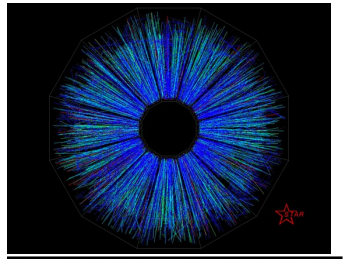
(GSI/FAIR, Darmstadt)

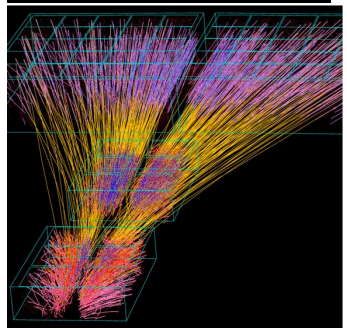
TPC - a versatile tracking detector

TPC – an (almost) ideal tracking detector

- Almost the whole volume is active
- Minimal radiation length (field cage, gas)
- 3D spatial information about hits
- Easy pattern recognition (continuous tracks)
- High particle densities
- Good momentum, time and spatial resolution
- Particle identification via measurement of $\langle dE/dx \rangle$
- Operating under high magnetic fields

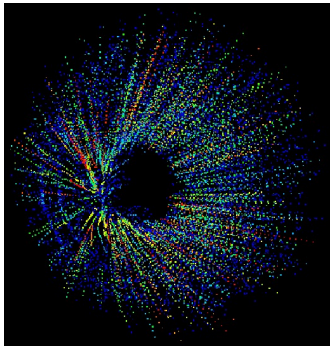


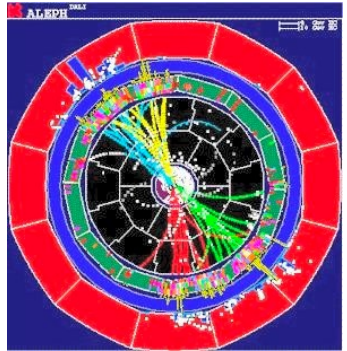




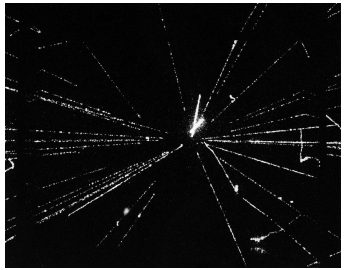
Wide range of applications

- Colliders and fixed-target: pp, e^+e^-, HIC
- Low energy nuclear physics, neutrino physics
- BSM physics: DM, $\beta\beta 0\nu$, ….



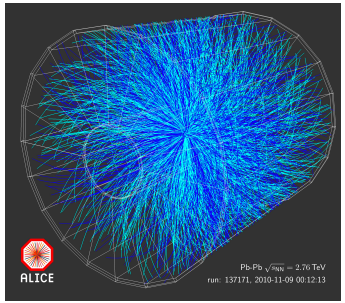


“Theory of evolution”



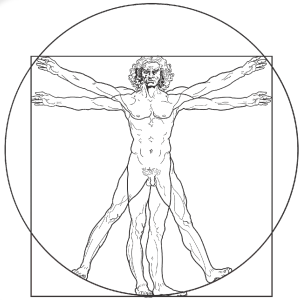
1970s - …

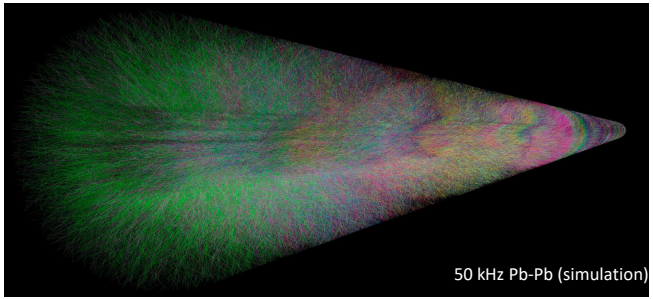
- Streamer chambers
- Photos on chemical film
- 3D information by stereo angles
- Trigger rate ~1 – 10 Hz



1990s - …

- „Classical“ MWPC TPCs (e.g. NA49, CERES, STAR, ALICE)
- ~1000 subsequent electronical images per event
- 3D information from relation to drift time
- 4-momentum vectors of all charged particles
- Trigger rate ~ 100 – 1000 Hz
- Live time ~1 – 10%



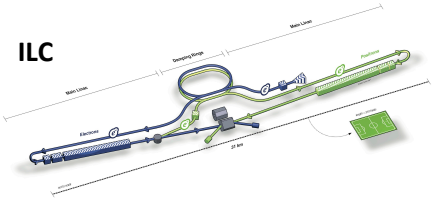


2020s - …

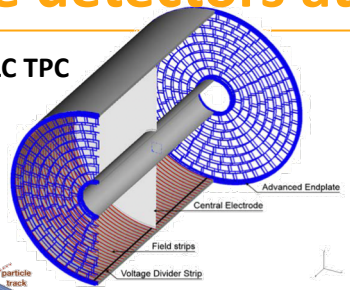
- Continuous operation in video mode
- Live time 100%
- Event rate 10 – 100 kHz
- ALICE TPC, sPHENIX TPC, future e^+e^- collider TPCs?

Future large volume detectors at future ee/eh machines

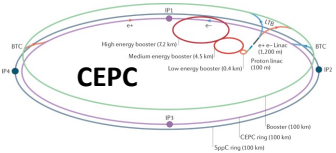
ILC



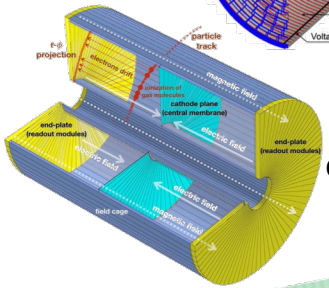
ILC TPC



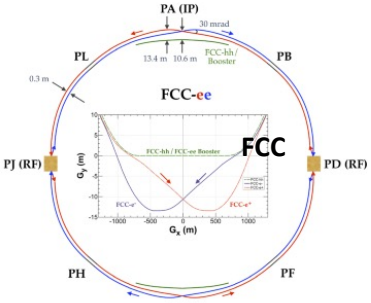
CEPC



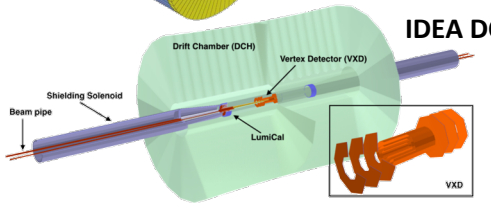
CEPC TPC



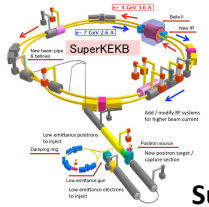
FCC



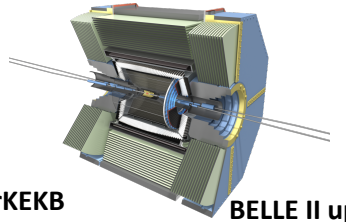
IDEA DC



- High and ultra-high luminosities
- High-rates of physics events
- “Continuous” or “pulsed” beams

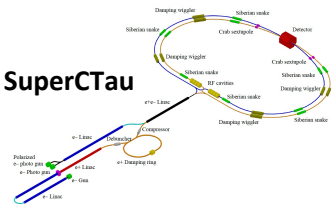


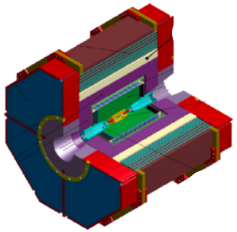
SuperKEKB



BELLE II upgrade

SuperCTau

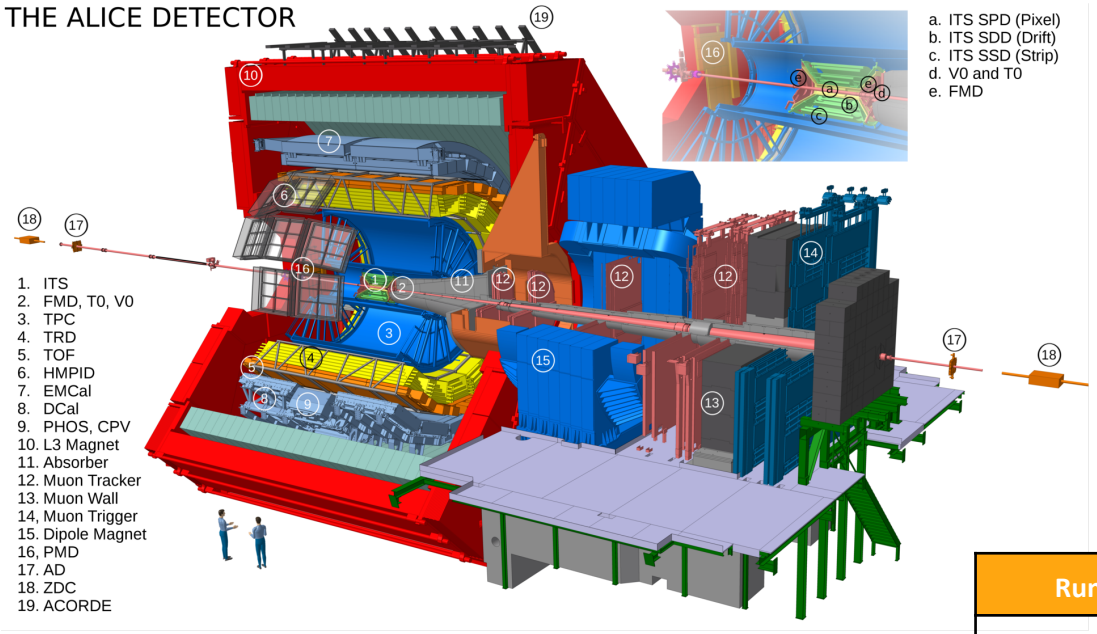




SCTD TPC+DC

ALICE TPC UPGRADE

ALICE in Run 1 and Run 2



ALICE detector

- Central Barrel: $-0.9 < \eta < 0.9$
- Muon spectrometer: $-4.0 < \eta < -2.5$
- Forward detectors: trigger, centrality

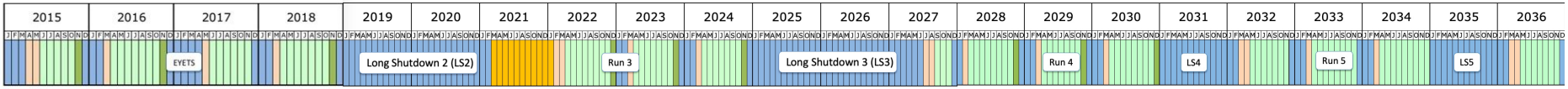
Operation in Run 1 and Run 2

- Tracking and PID in large kinematic range
- High resolution vertex reconstruction

Run 1 (2009 – 2013)
Pb-Pb @ $\sqrt{s_{NN}}$ = 2.76 TeV
p-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV
pp @ $\sqrt{s}$ = 0.9, 2.76, 7, 8 TeV

Run 2 (2015 – 2018)
Pb-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV Xe-Xe @ $\sqrt{s_{NN}}$ = 5.44 TeV
p-Pb @ $\sqrt{s_{NN}}$ = 5.02, 8.16 TeV
pp @ $\sqrt{s}$ = 5, 13 TeV

ALICE in Run 3 and Run 4



ALICE strategy for Run 3 and Run 4:

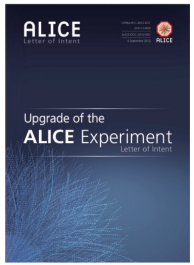
- Increase minimum bias sample x50-100 wrt. Run 2, collect $\mathcal{L}_{\text{Pb-Pb}} = 13\ \text{nb}^{-1}$
- Write all Pb-Pb interactions at 50 kHz; current readout rate $\mathcal{O}(1\ \text{kHz})$
- No dedicated trigger
- Experiment upgrades (LS2)

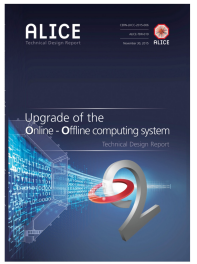
Improve tracking efficiency and resolution at low p_{T}

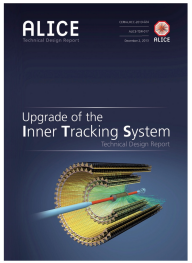
- Increase tracking granularity
- Reduce material thickness
- Minimize the distance to the interaction point

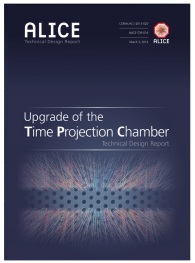
Preserve particle identification (PID)

- Consolidate and speed up main ALICE PID detectors

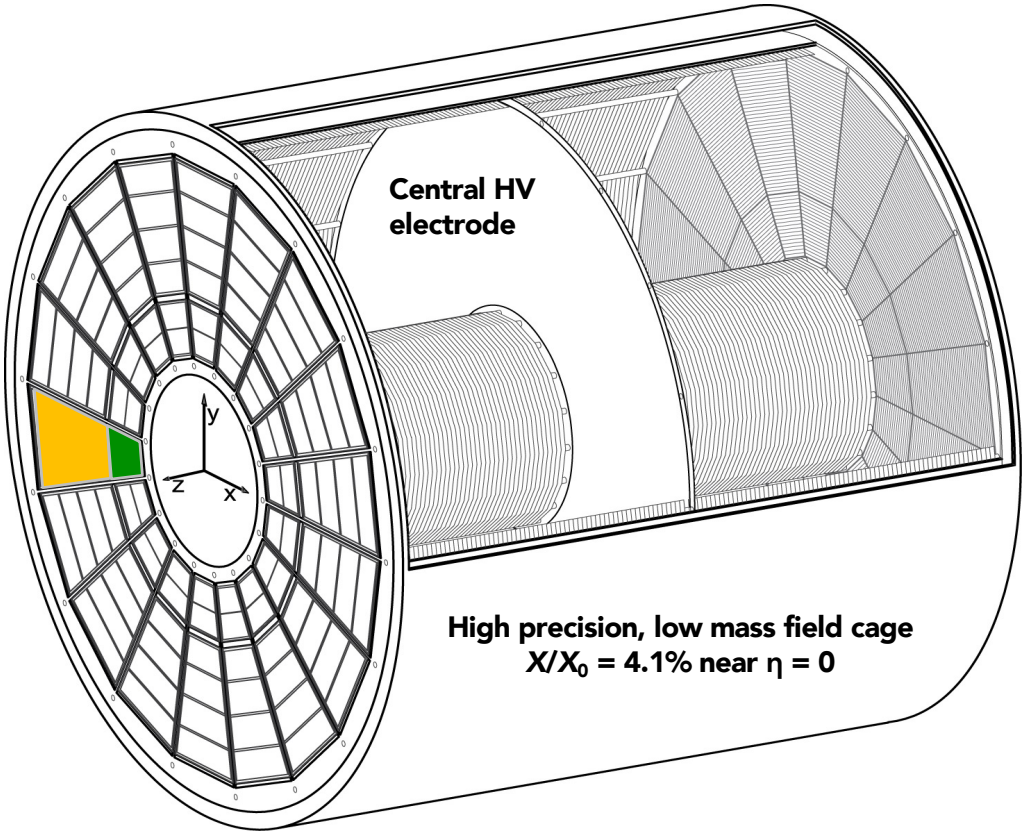








ALICE TPC

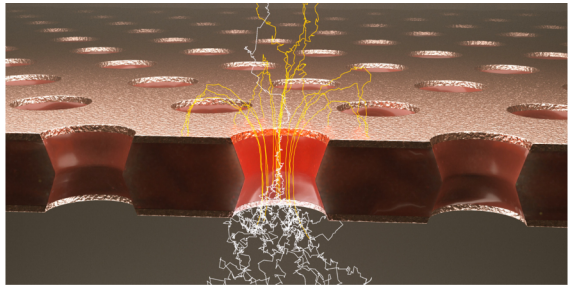


- Diameter: 5 m, length: 5 m
- Gas: Ne-CO_2-N_2, Ar-CO_2
- Max. drift time: ~100 µs
- 18 sectors on each side
- Inner and outer readout chambers: IROC, OROC

- TPC in Run 1 and Run 2:
  - 72 MWPCs
  - ~550 000 readout pads
  - Wire gating grid (GG) to minimize ion backflow (IBF)
  - Rate limitation: few kHz

Operate TPC at 50 kHz
⟶ no gating grid and continuous readout

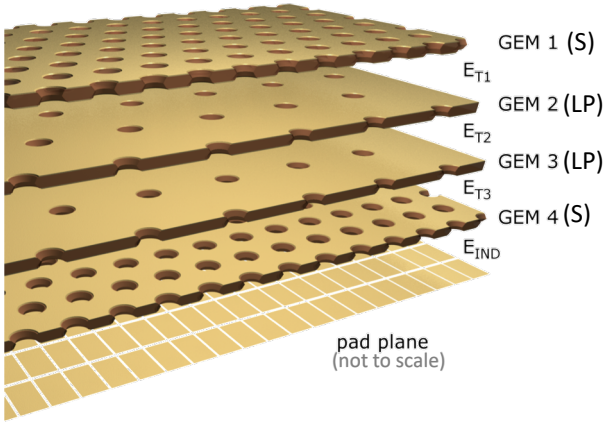
Continuous readout with GEMs



Gas Electron Multiplier (GEM)

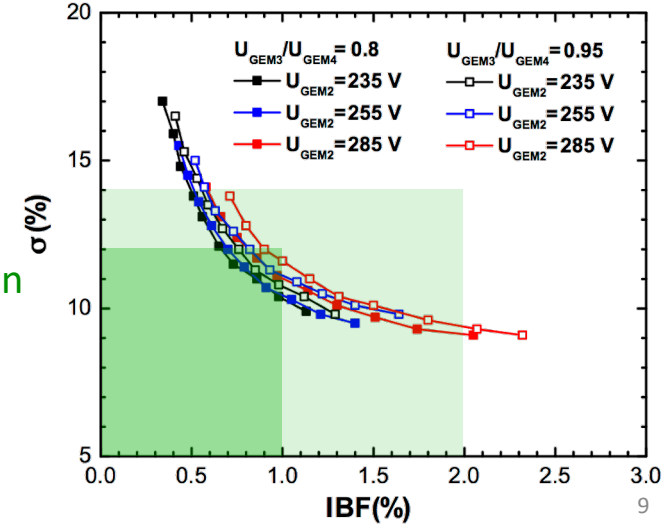
TPC upgrade requirements:

- Nominal gain = 2000 in Ne-CO_2-N_2 (90-10-5)
- Ion backflow (IBF) < 1% (ε = 20)
- Energy resolution: σ_E/E < 12% for ^{55}Fe
- Stable operation under LHC Run 3 conditions



Solution: 4-GEM stack

- Combination of standard (S) and large pitch (LP) GEM foils
- Highly optimized HV configuration
- Result of intensive R&D



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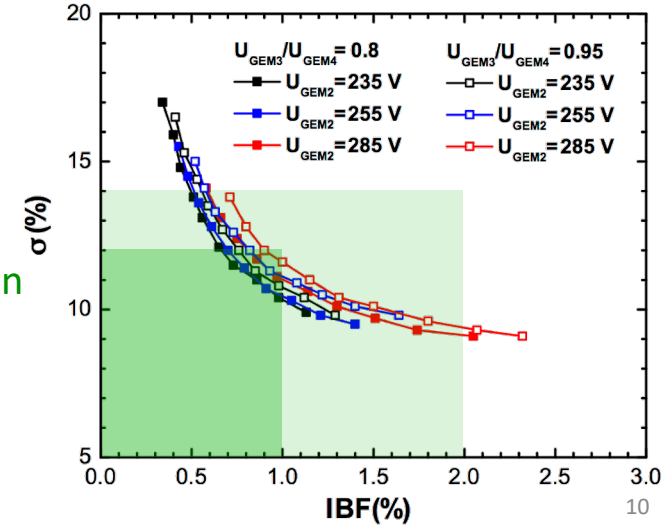
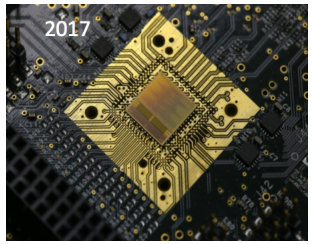
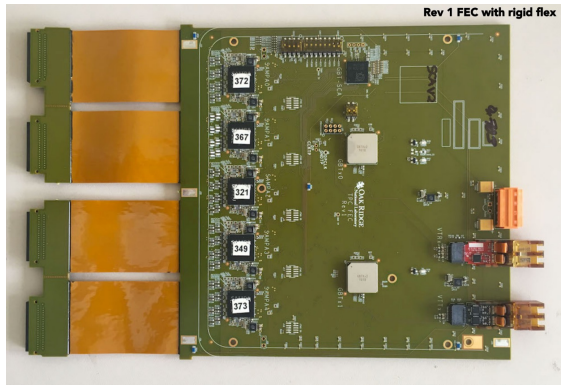


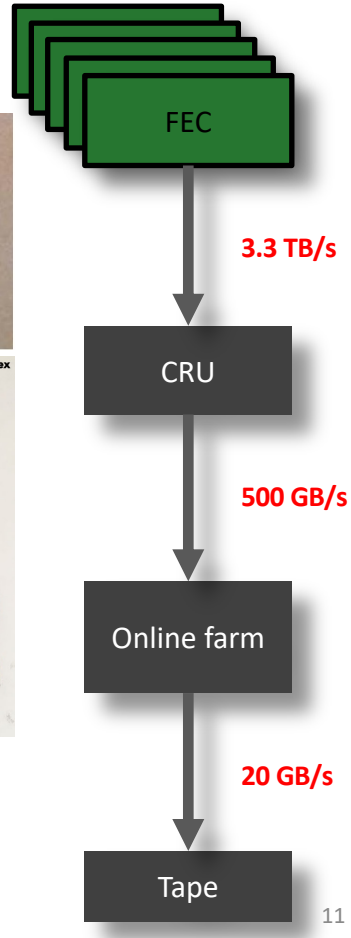
TPC readout electronics

- Newly developed Front-End **SAMPA** ASIC (TPC and MUON chambers)
  - 130 nm TSMC CMOS
  - **32 channels (positive or negative input)**
  - PASA preamplifier + 10-bit ADC
  - Programmable conversion gain and peaking times
  - DSP, Memory, High speed e-links
  - **Readout mode: continuous or triggered**
  - **Excellent noise figure of 670 e^-**
  - **Power consumption performance: 8.3 mW/channel**



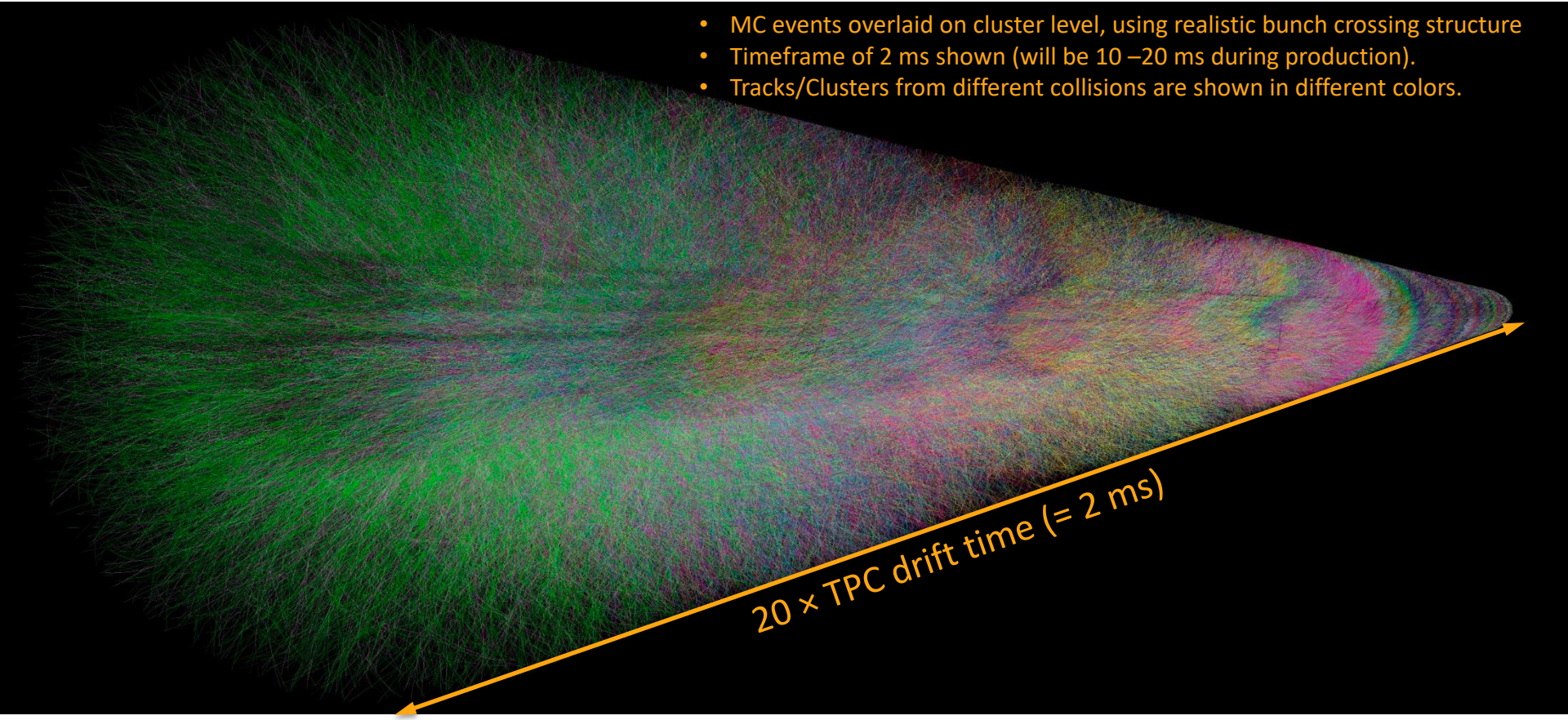


- Front-End Cards (FEC)
  - 5 SAMPA chips per FEC (3276 FECs in total)
  - **System continuously digitizes signals at 5 MHz**
  - **All ADC values are read out - 3.28 TB/s**
  - FECs send digitized data over fiber optic links to ALICE Common Readout Units (CRU)



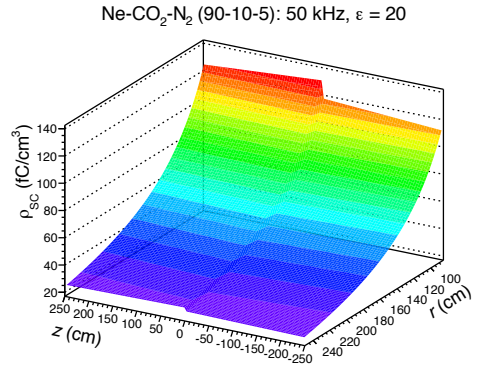
50 kHz Pb-Pb collisions

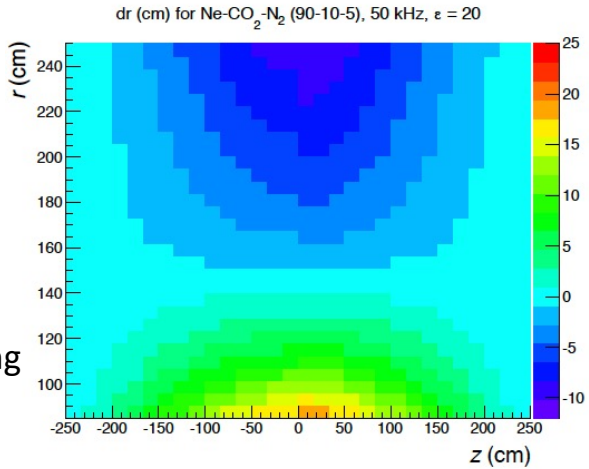
- MC events overlaid on cluster level, using realistic bunch crossing structure
- Timeframe of 2 ms shown (will be 10 –20 ms during production).
- Tracks/Clusters from different collisions are shown in different colors.



Expected performance

- Ions from 8000 events pile up in the drift volume at 50 kHz Pb-Pb
  - 1% of IBF at G_{eff} = 2000 (ε = 20)
  - distortions up to dr ≈ 20 cm and drϕ ≈ 8 cm (at small r and z)
  - well below 10 cm for the largest part of drift volume
  - Corrections to $\mathcal{O}(10^{-3})$ are required for final calibration
    to the level of intrinsic resolution, $\sigma_{r\phi} \approx 200$ µm
    (space charge maps + external detectors (ITS, TRD))
  - 2-stage calibration and reconstruction scheme
  - Measured ROCs IBF uniformity (0.56 ± 0.14)% - large margin for fine-tuning

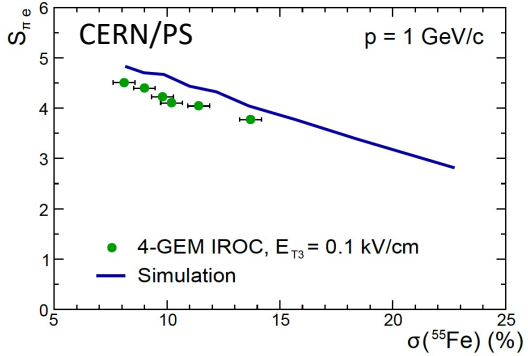




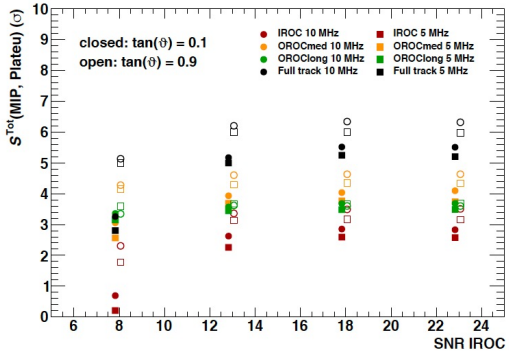
ALICE, CERN-LHCC-2013-020, 2013
ALICE, CERN-LHCC-2015-002, 2015

Expected performance (PID, momentum)

ALICE TPC, NIM A 903 (2018) 215

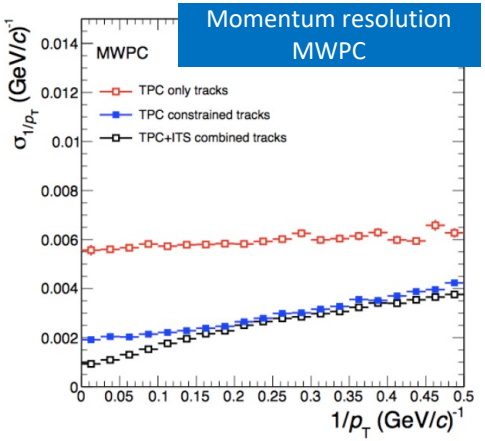


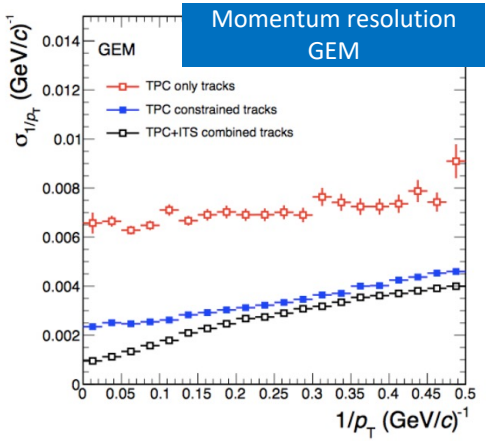
ALICE TPC, JINST 16 (2021) P03022



- New TPC readout chambers (GEM):
  - PID performance via d*E*/d*x* preserved
  - Confirmed with several test beams at CERN/PS
  - Energy resolution compatible with MWPC TPC (~5.5% in pp and ~7% in Pb-Pb)
  - Slight deterioration of separation power for 5 MHz sampling

ALICE, CERN-LHCC-2013-020, 2013

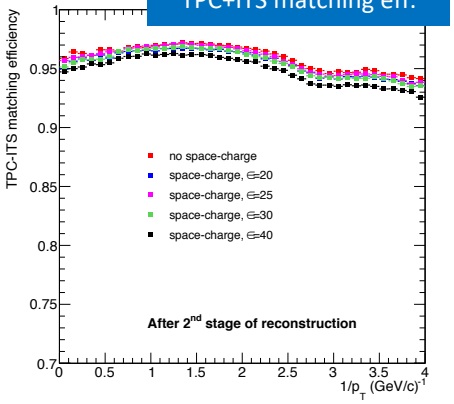




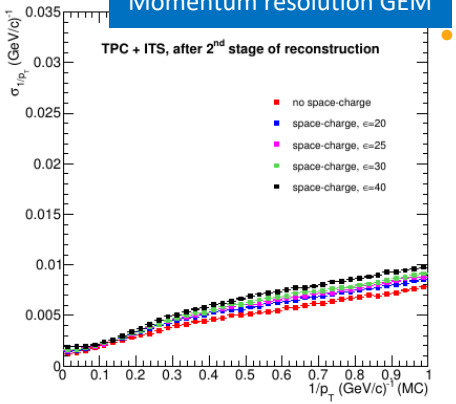
- Preserve momentum resolution for TPC + ITS tracks
- $\sigma_{pT}/p_T \lesssim 1\%$ at 1 GeV/*c*, $\sigma_{pT}/p_T \lesssim 3.5\%$ at 50 GeV/*c*

Expected performance - limits

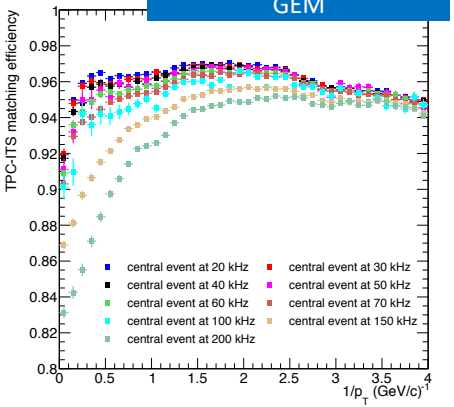
TPC+ITS matching eff.



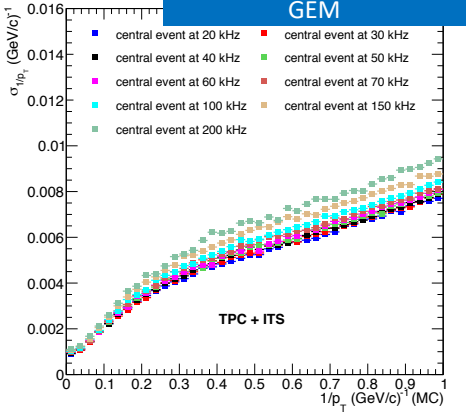
Momentum resolution GEM



Matching efficiency GEM



Momentum resolution GEM



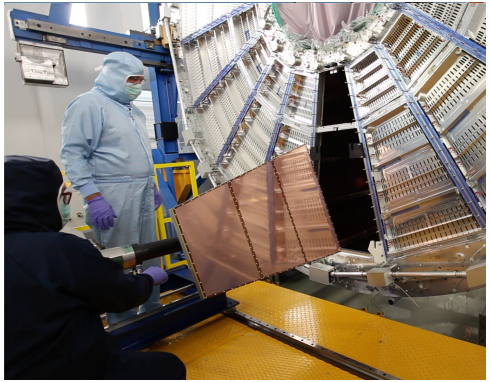
- New TPC Readout Chambers (GEM):
  - Calibration procedure tested up to IBF = 2% (ε = 40)
  - tracking efficiency not compromised
  - slight decrease in p_t resolution at low momenta does not compromise physics program
  - Track matching efficiency and $1/p_T$ resolution stable for interaction rates **up to** 100 kHz

ALICE, CERN-LHCC-2015-002, 2015

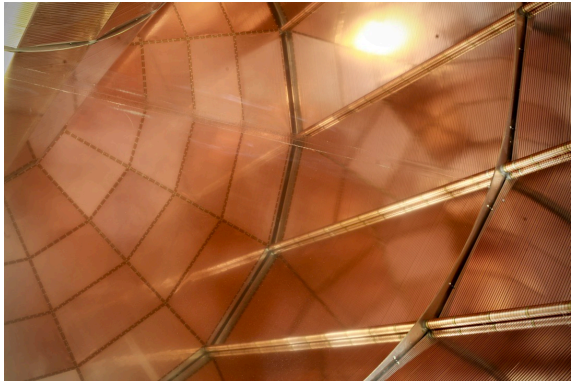
INSTALLATION & COMMISSIONING

TPC upgrade

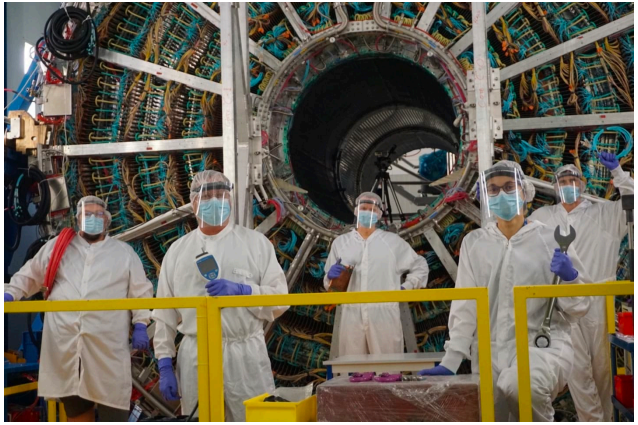
- The ALICE TPC was extracted and upgraded in the cleanroom in 2019
- All chambers and FECs are installed
- Pre-commissioning completed
- TPC is back in the ALICE cavern



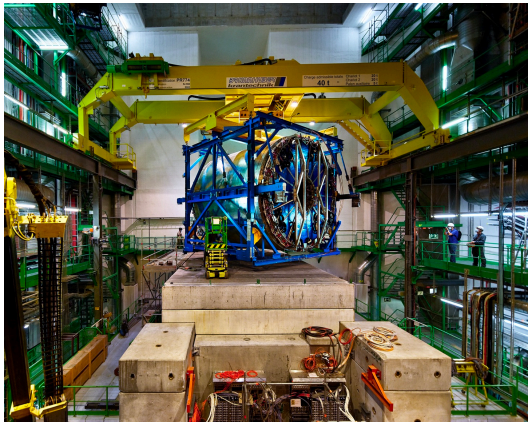
ROC installation



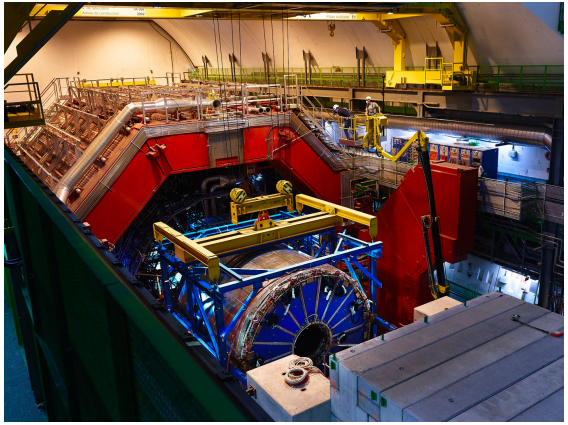
GEM chambers reflection



Upgraded TPC



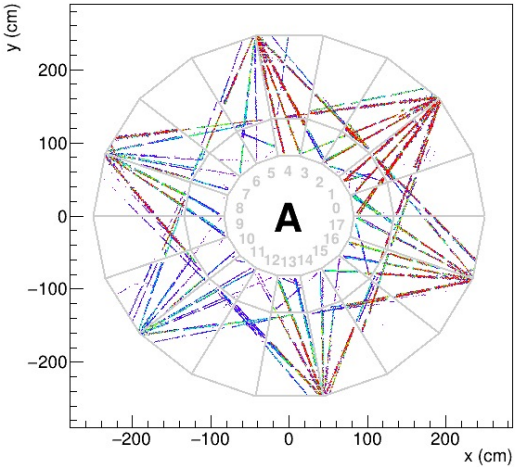
TPC lowering



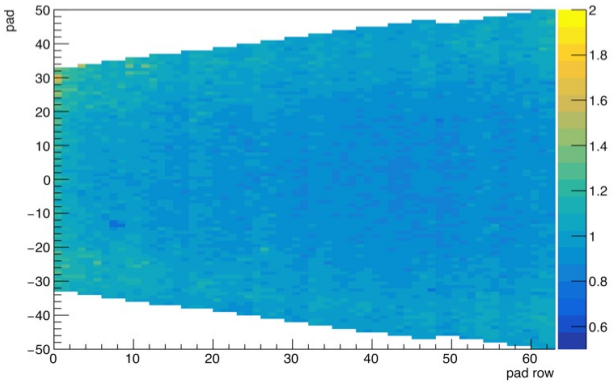
TPC positioning

TPC pre-commissioning on the surface

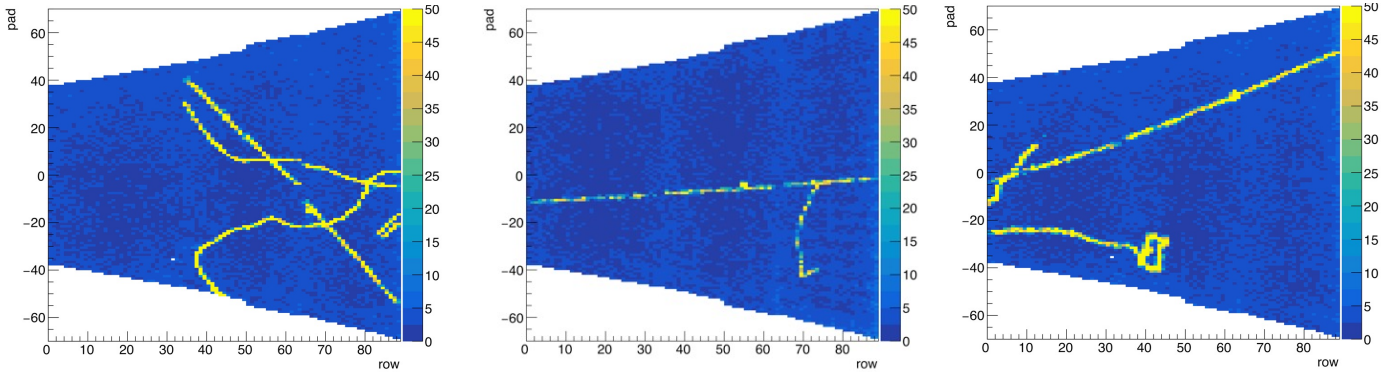
- Pre-commissioning on the surface
- 2 sectors tested at a time:
  - Pulser and noise
  - Laser and cosmic runs
  - X-ray irradiation



Laser tracks in the TPC



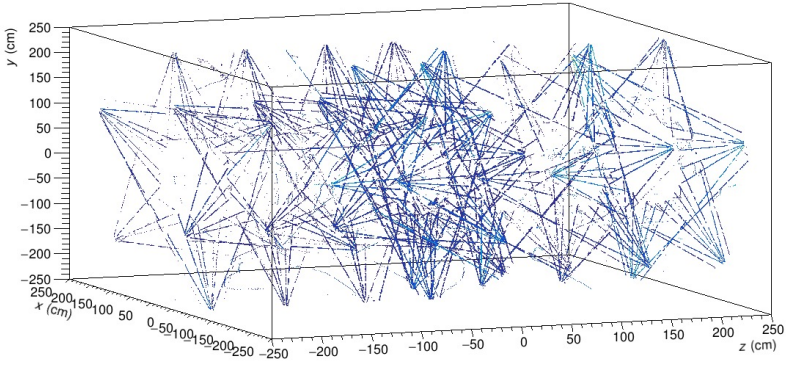
Excellent noise figure of 1 ADC



Cosmic tracks examples

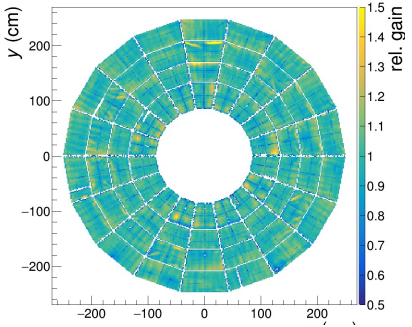
TPC commissioning in ALICE

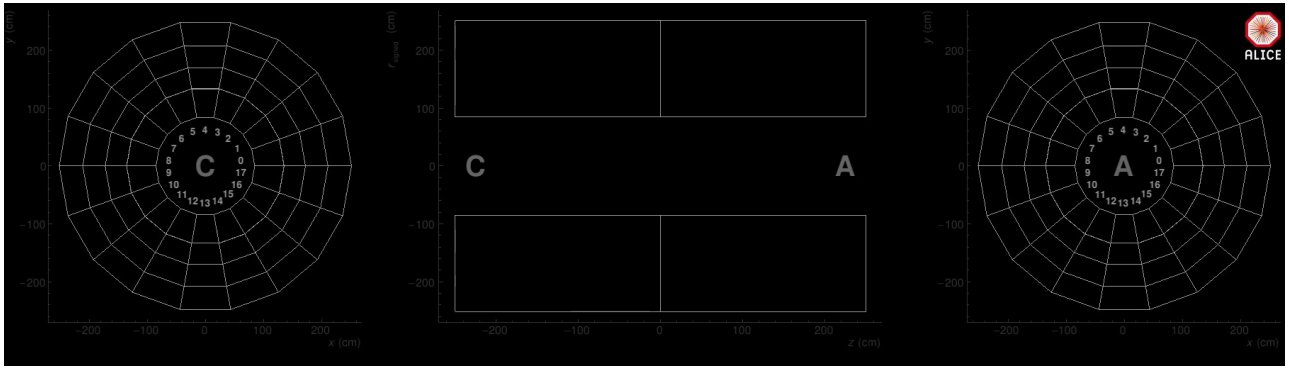
- Laser runs
- Pulser runs
- Cosmic runs
- X-ray runs
- Readout commissioning
- Gain equalization,
  pad-by-pad calibration with ^{83}Kr source



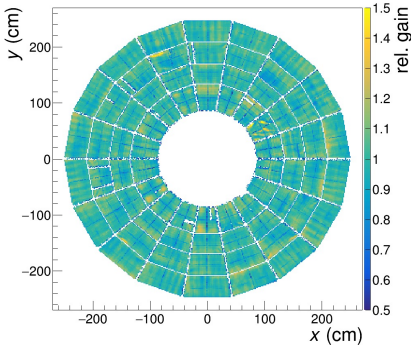
Laser tracks in full TPC volume

Gain maps



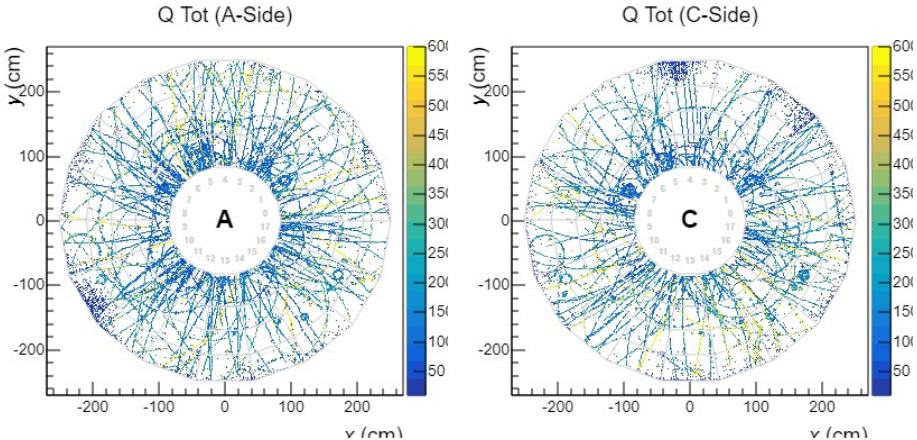


Cosmic run with continuous readout

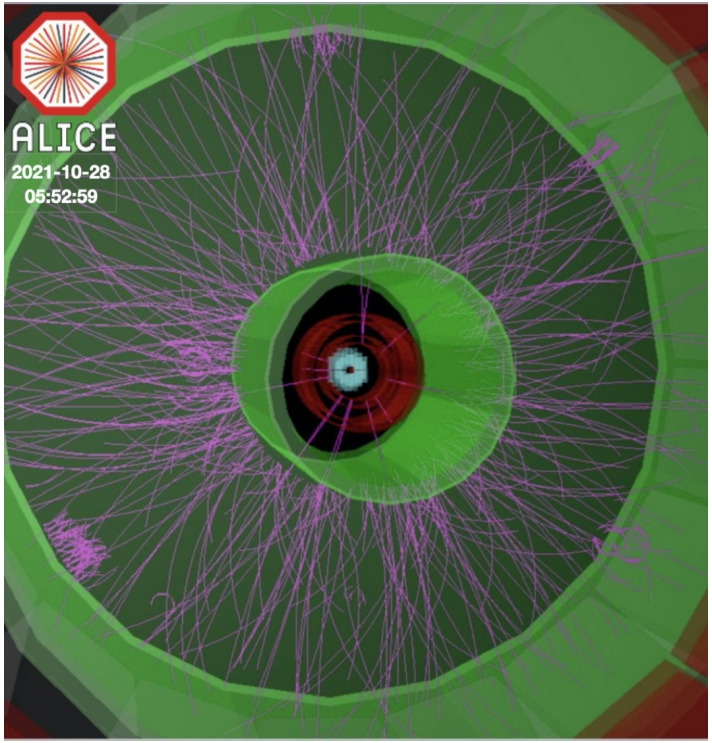


First beams on 27.10.2021!

- First Stable Beams declared since almost 3y
- pp collisions at $\sqrt{s}$ = 900 GeV, 2 colliding bunches
- First tracks recorded with the upgraded TPC
- Performance with basic calibration as expected, further optimization ongoing → stay tuned!



QA plot – first tracks with the upgraded ALICE TPC



ALICE event display

First beams on 27.10.2021!

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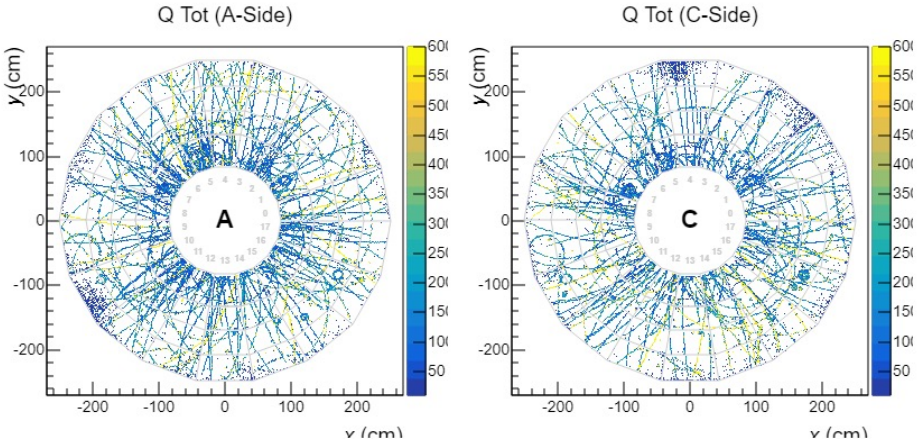
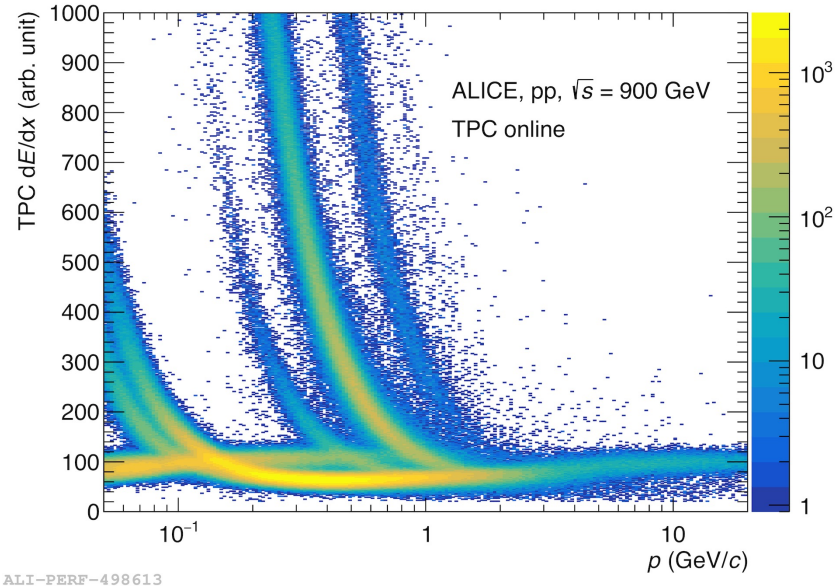


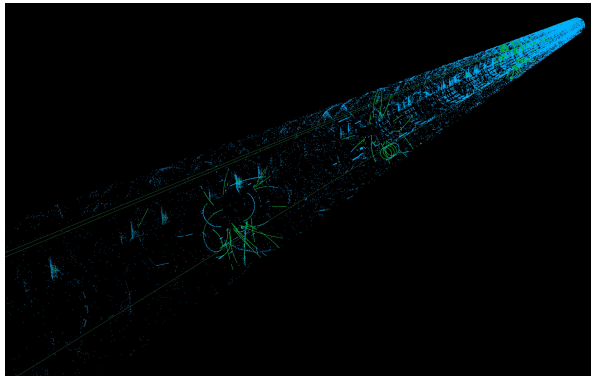
QA plot – first tracks with the upgraded ALICE TPC

Online plot from QC during pilot run with 900 GeV collisions



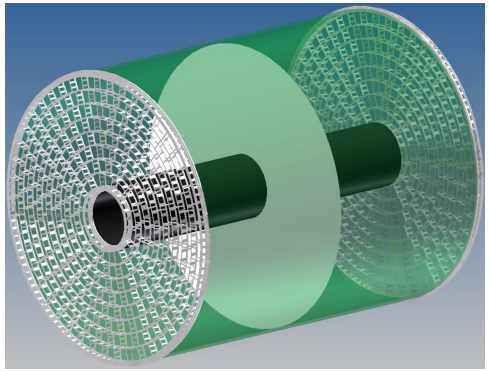
Summary

- ALICE TPC was upgraded with GEMs and continuous readout (JINST 16 (2021) P03022)
- Quadruple GEM readout for low ion backflow operation
- Extensive (pre-)commissioning campaigns concluded with first pp collisions recorded!
- Getting ready for a fruitful Run 3 and Run 4



TPC time frame visualization of real data from pilot beam

- We are not at our limits, still going bigger, faster, more precise…many challenges ahead!
- TPC can be considered as a perfect tracker for many applications, including e^+e^- machines!



CEPC/ILC/FCC TPC concept