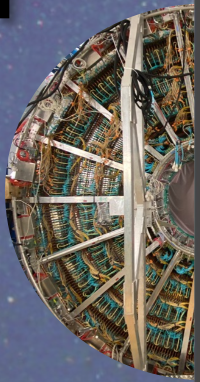
Commissioning of the continuous readout TPC in the ALICE experiment



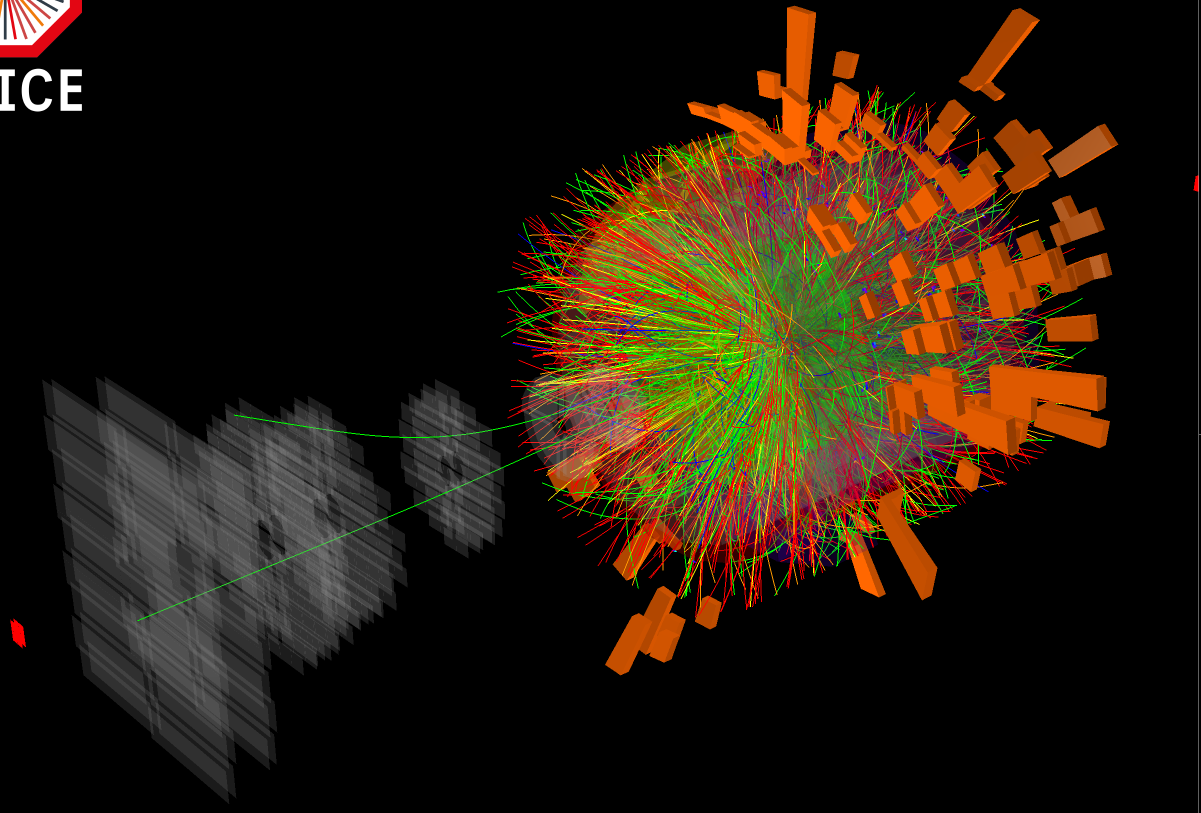
C. Lippmann
for the ALICE collaboration

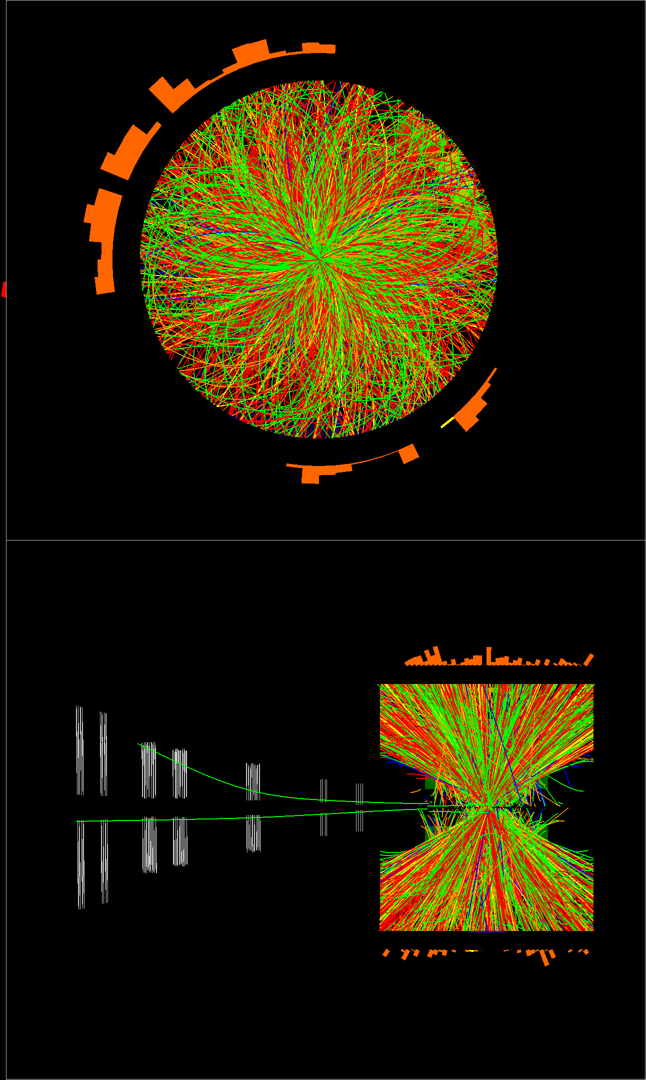
Frontier Detectors for Frontier Physics

15th Pisa meeting on advanced detectors

La Biodola • Isola d'Elba • Italy
22 - 28 May, 2022

The past: Example heavy-ion collision. One triggered event

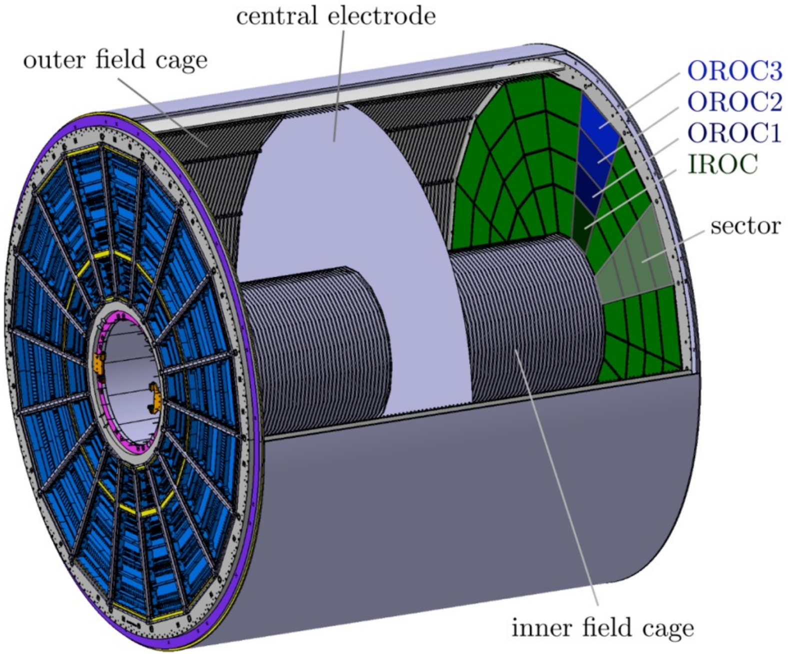




Run:280235
Timestamp:2017-10-12 20:57:22(UTC)
Colliding system:Xe-Xe
Energy: 5.44 TeV

Introduction (1)

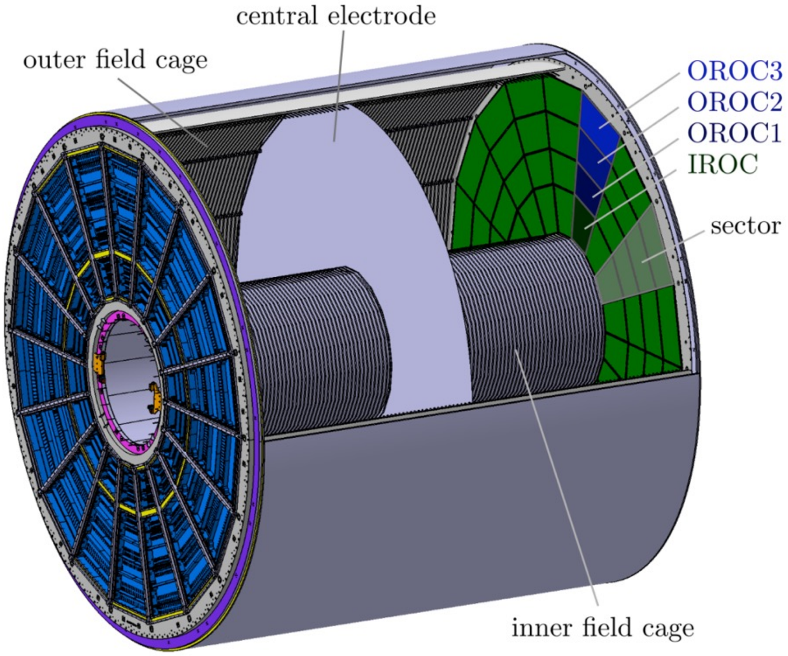
- ALICE is the dedicated heavy-ion experiment at the CERN Large Hadron Collider (LHC)
  - Pb–Pb, p–Pb (and pp) collisions
- Large tracking and PID device in the central barrel: TPC
  - Cylindrical drift volume, 5 m long, 5 m diameter
  - Two sides, split by central drift electrode
  - 18 sectors with readout chambers per side
  - ~100 us electron drift time for max. drift distance



[ALICE TPC Collaboration – JINST 16 – 2021]

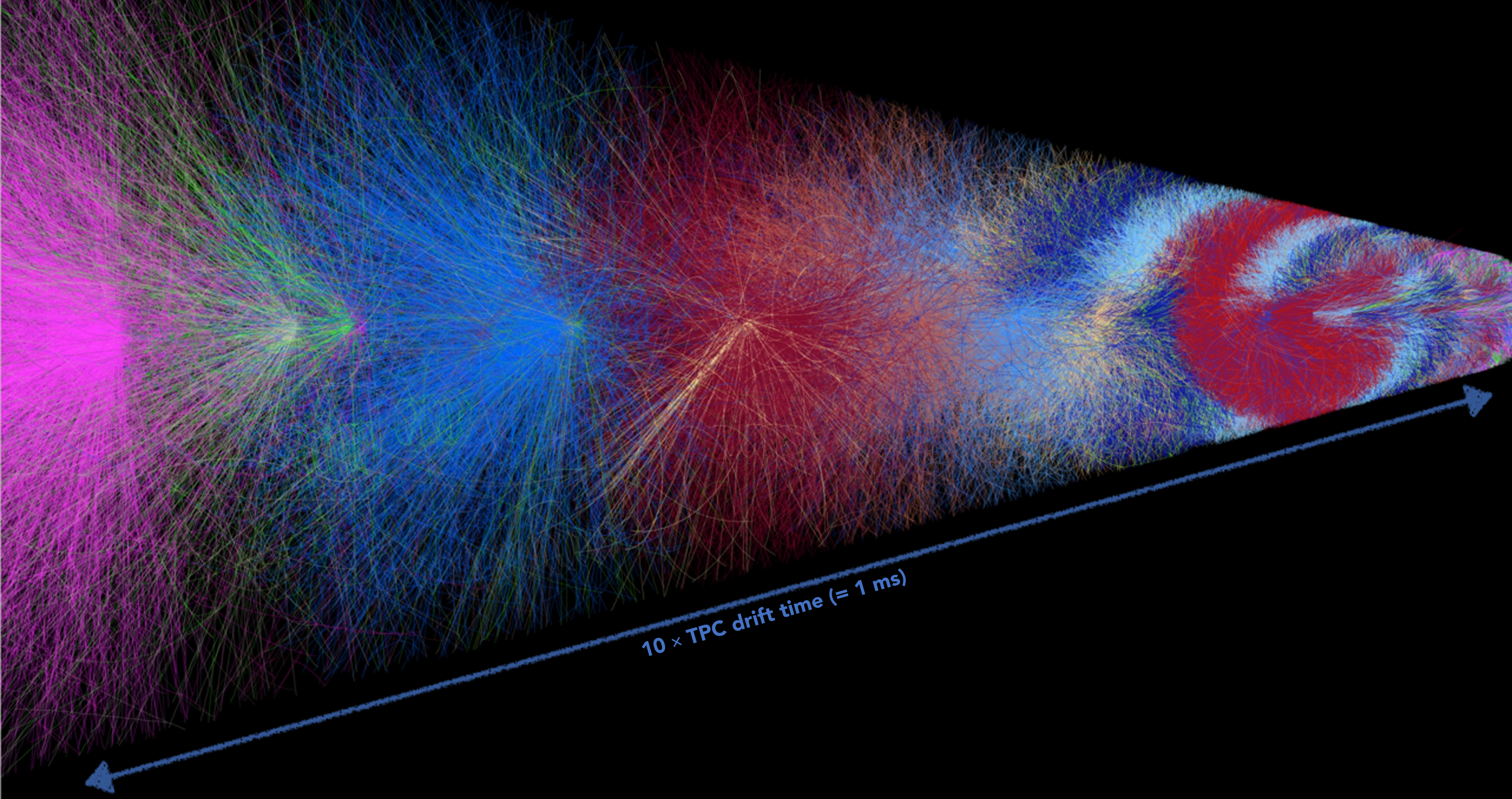
Introduction (2)

- ALICE is the dedicated heavy-ion experiment at the CERN Large Hadron Collider (LHC)
  - Pb–Pb, p–Pb (and pp) collisions
- Large tracking and PID device in the central barrel: TPC
  - Cylindrical drift volume, 5 m long, 5 m diameter
  - Two sides, split by central drift electrode
  - 18 sectors with readout chambers per side
  - ~100 us electron drift time for max. drift distance
- The past: MWPC readout until 2018
  - < 2 kHz event readout rate with Pb–Pb collisions
- The future: Continuous readout
  - New requirement: Min. bias readout at increased Pb—Pb collision rate (50 kHz)
  - No dead time allowed, no triggering, no gating
    ➔ need to minimise ion backflow

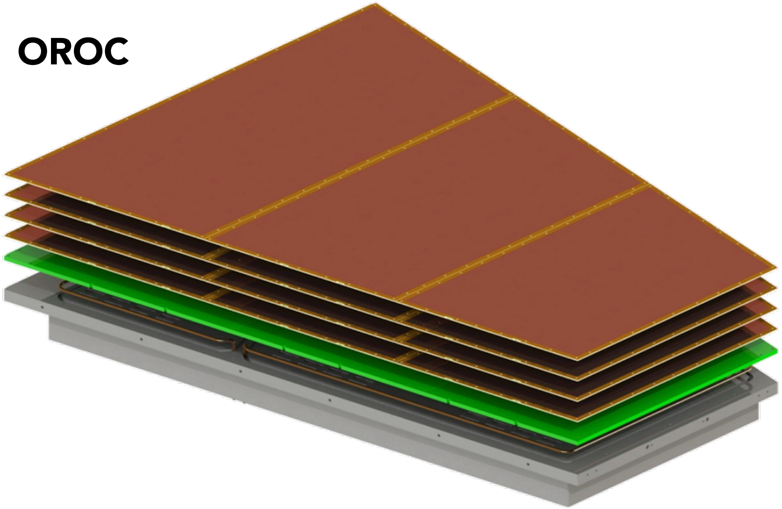


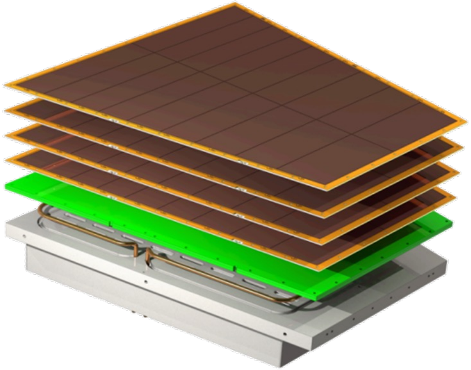
[ALICE TPC Collaboration – JINST 16 – 2021]

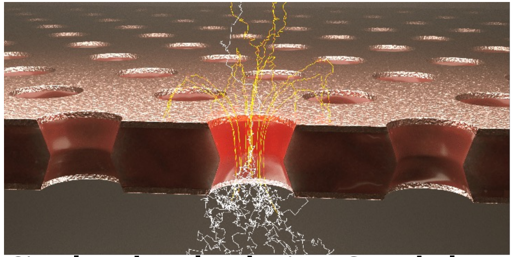
The future: Continuous stream of overlapping heavy-ion collisions (simulation)



Readout chambers



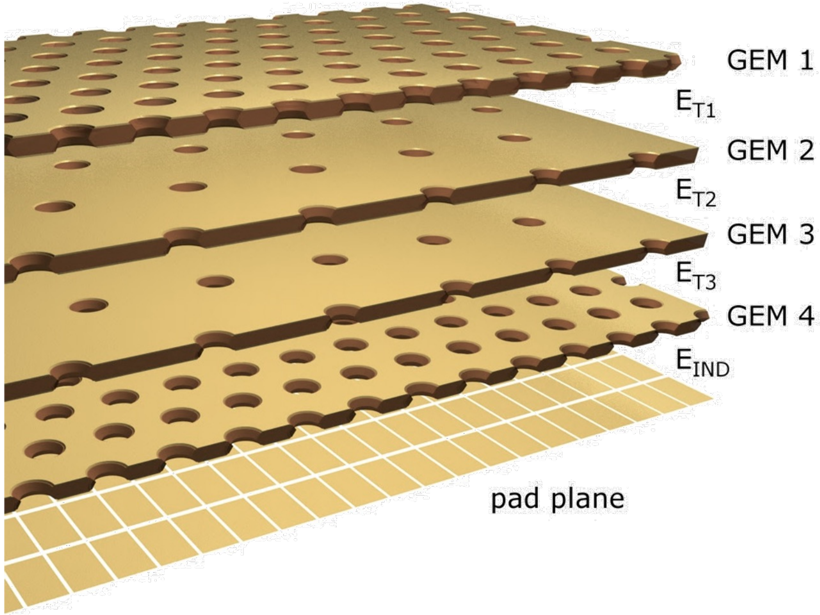




Simulated avalanche in a GEM hole

- GEM = Gas Electron Multiplier
- Stacks of 4 GEM foils
- 3 stacks for the large Outer ReadOut Chambers (OROC)
- 1 stack for the smaller Inner ReadOut Chambers (IROC)

4-GEM stacks (1)



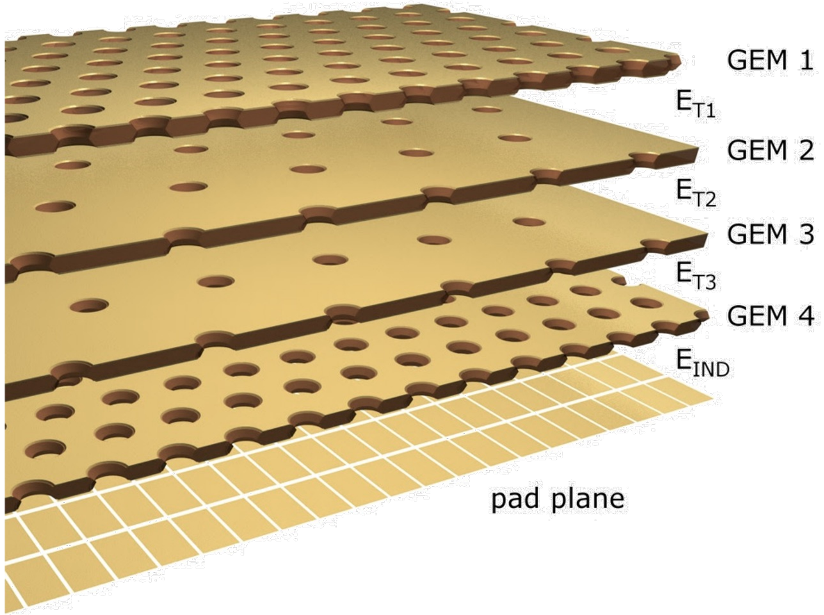
Schematic view of pad plane and 4-GEM stack

GEMs 1 and 4: Standard large-area single-mask GEM foils

GEMs 2 and 3: Large-pitch GEM foils

Highly optimized HV settings (see backup slides)

4-GEM stacks (2)



Schematic view of pad plane and 4-GEM stack
GEMs 1 and 4: Standard large-area single-mask GEM foils
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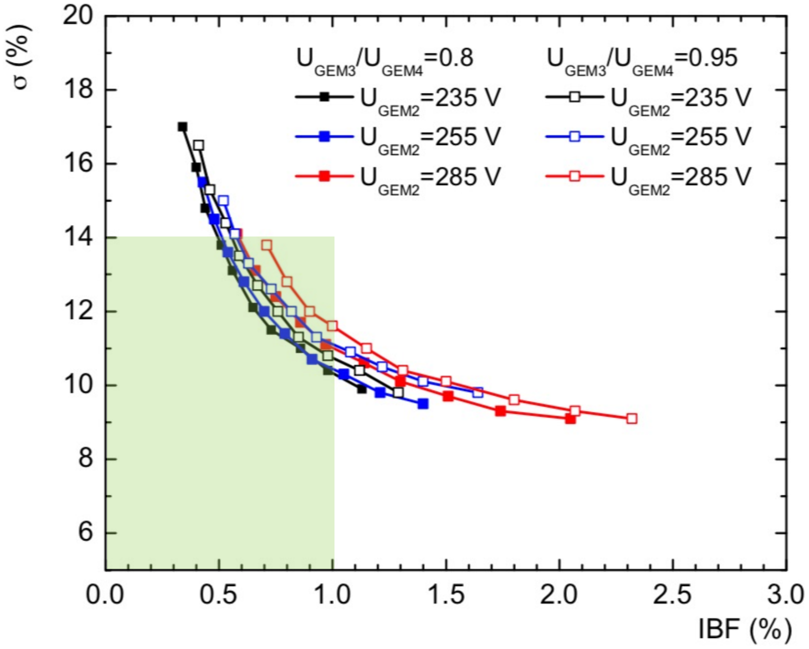
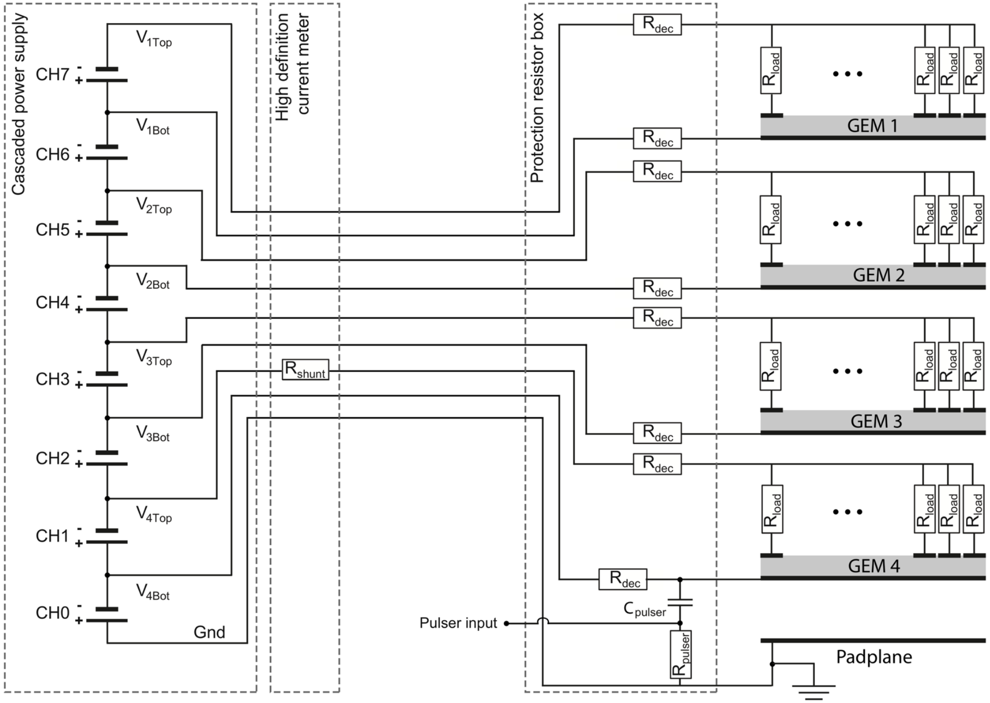
Highly optimized HV settings (see backup slides)



Performance with optimised HV configuration
IBF = Ion BackFlow
σ = energy resolution for ^{55}Fe

HV system

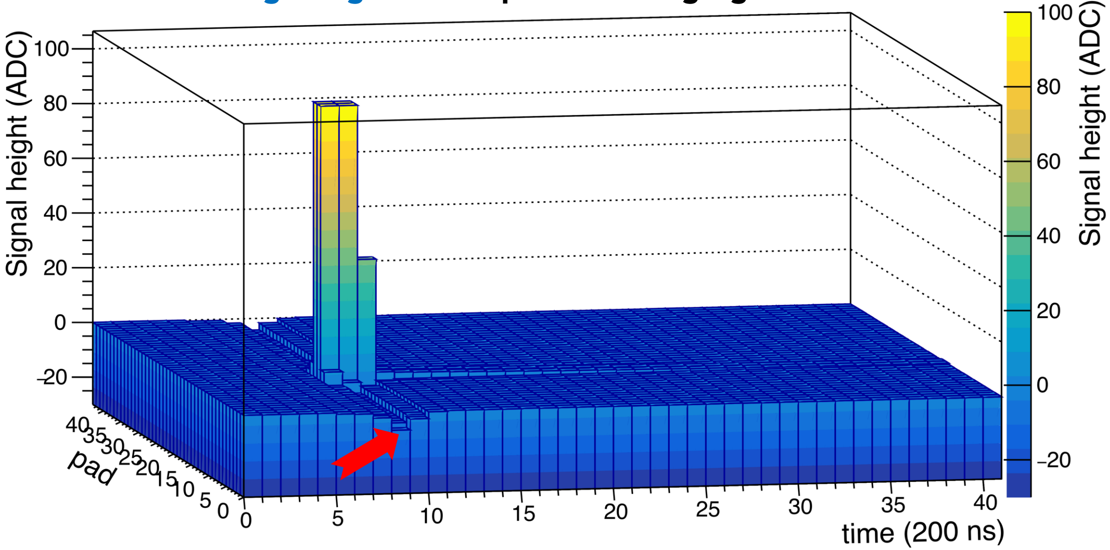
CAEN A1515

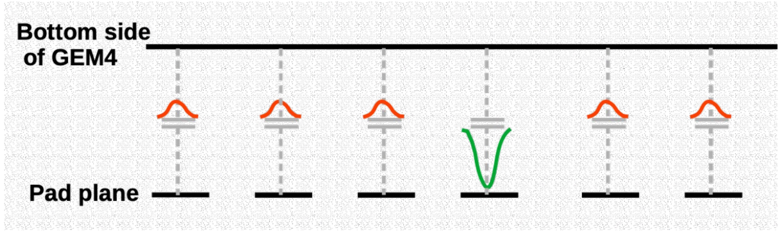


- Cascaded power supply units from CAEN
  - Also good alternative from ISEG available
- Designed for the operation of quadruple-GEM systems
- Shunt resistor in GEM 4 top line for high-definition current measurements (for space charge distortion calibration)
- Pulser input via capacitor in GEM 4 bottom line

Common mode (CM) effect

Zoom to averaged signal on 40 pads including signals from laser track

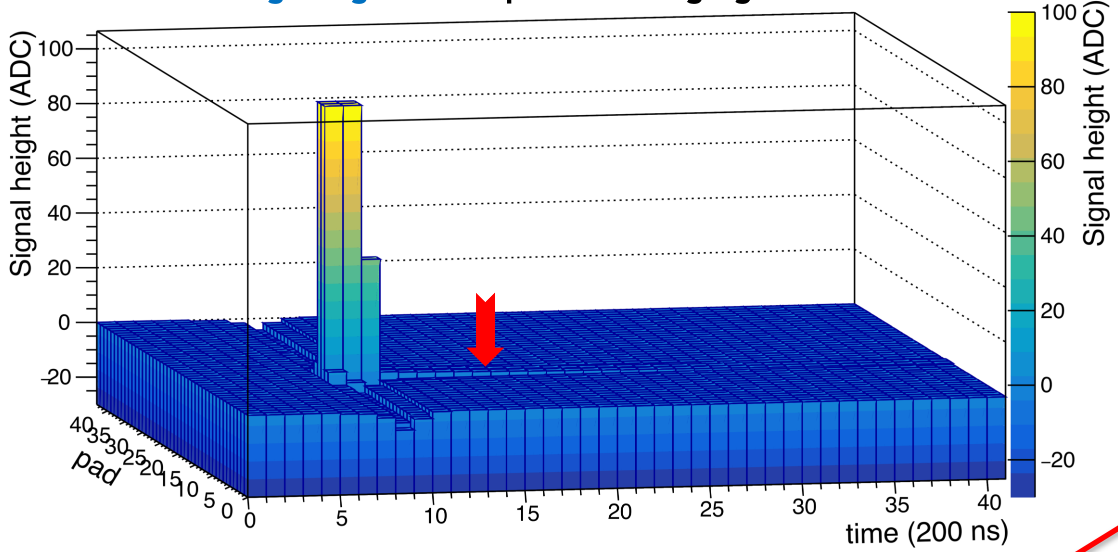


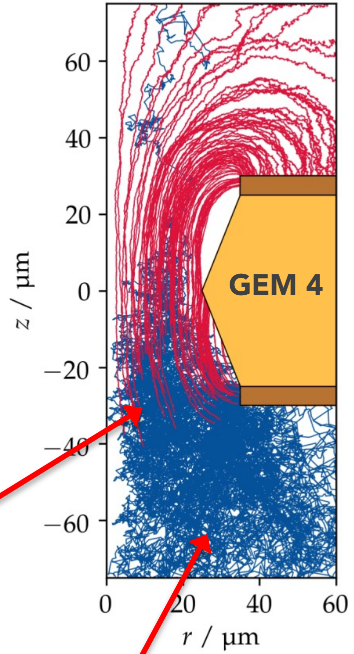


- Capacitors in HV distribution often used to reduce CM effect
- But such capacitors would lead to potential problems with discharges
- At high occupancy the CM signals from many tracks will superimpose and lead to a baseline shift
- This baseline shift is measured in the readout system (CRU FPGA) and removed online

Ion tail!

Zoom to averaged signal on 40 pads including signals from laser track



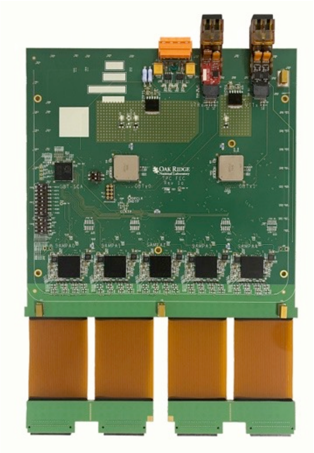


- **An ion tail is visible. Two contributions:**
  - **Exponential contribution from ions created just below GEM 4**
  - **Linear component from ions produced in induction gap (particular to our HV settings)**
- **Online ion tail correction also in CRU FPGA**

TPC readout electronics

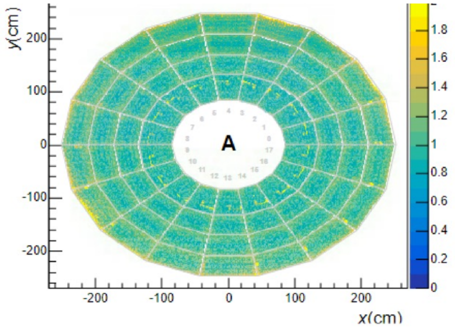
- **SAMPA ASIC**
  - 130 nm TSMC CMOS
  - 32 channels with preamplifier, shaper, 10 bit ADC and digital filters
  - Continuous or triggered readout

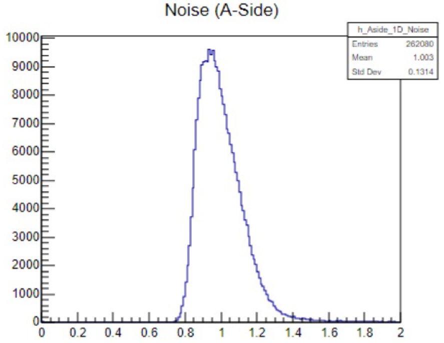
- **Front-End Cards (FECs)**
  - 5 SAMPA chips per FEC (3276 FECs in total)
  - Continuous sampling at 5 MHz
  - All ADC values read out: 3.3 TB/s total
  - Readout link: CERN GBT / Versatile link system



- **FPGA-based readout cards receive the data through 6552 optical links**

Noise on one side of TPC

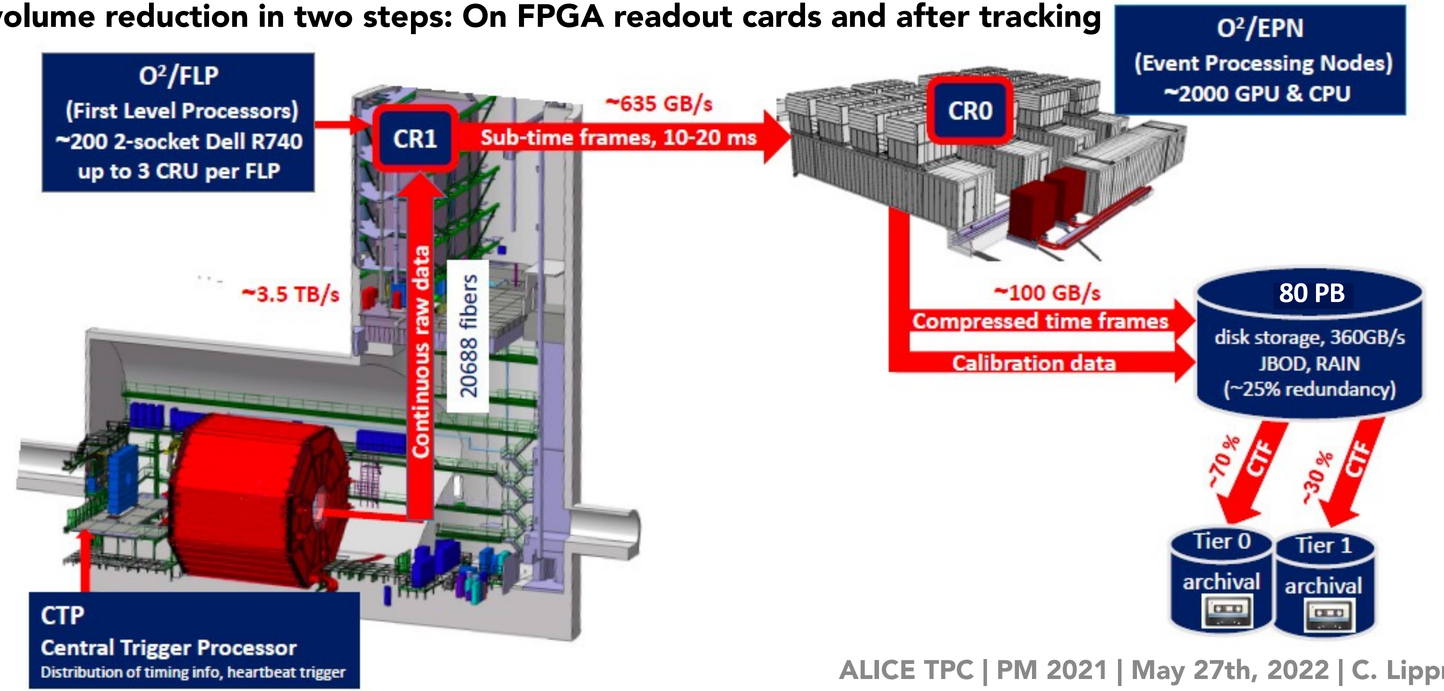




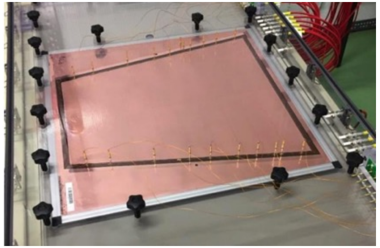
Excellent mean noise: 670 e^- @18 pF

Readout system: O^2

- O^2 = Online × offline (the new ALICE data processing cluster)
- 3.5 TB/s continuous raw data flow (all ALICE detectors)
- Continuous data flow is chopped into (sub-)time frames on the FLPs
- Data volume reduction in two steps: On FPGA readout cards and after tracking

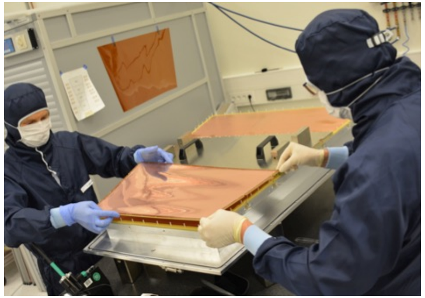


TPC upgrade timeline



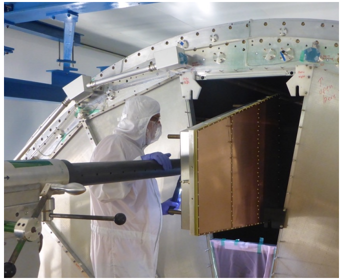
Start GEM production

Aug 2016



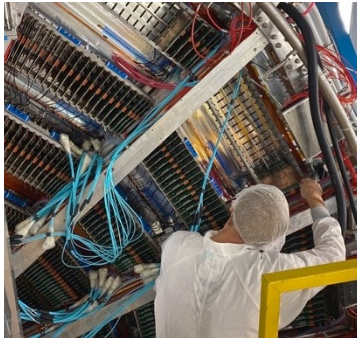
Start GEM ROC production

March 2017



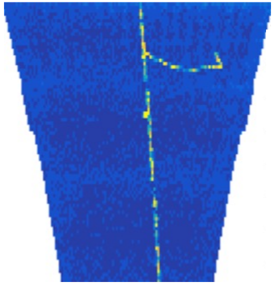
Start GEM ROC installation

May 2019



Start installation FEE and services

Sep 2019

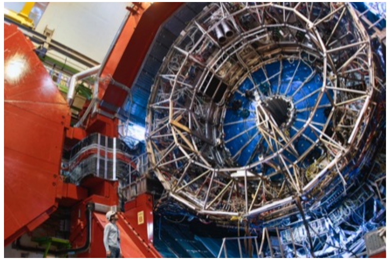


Start pre-commissioning

Nov 2019

Transportation to LHC P2

Aug 2020

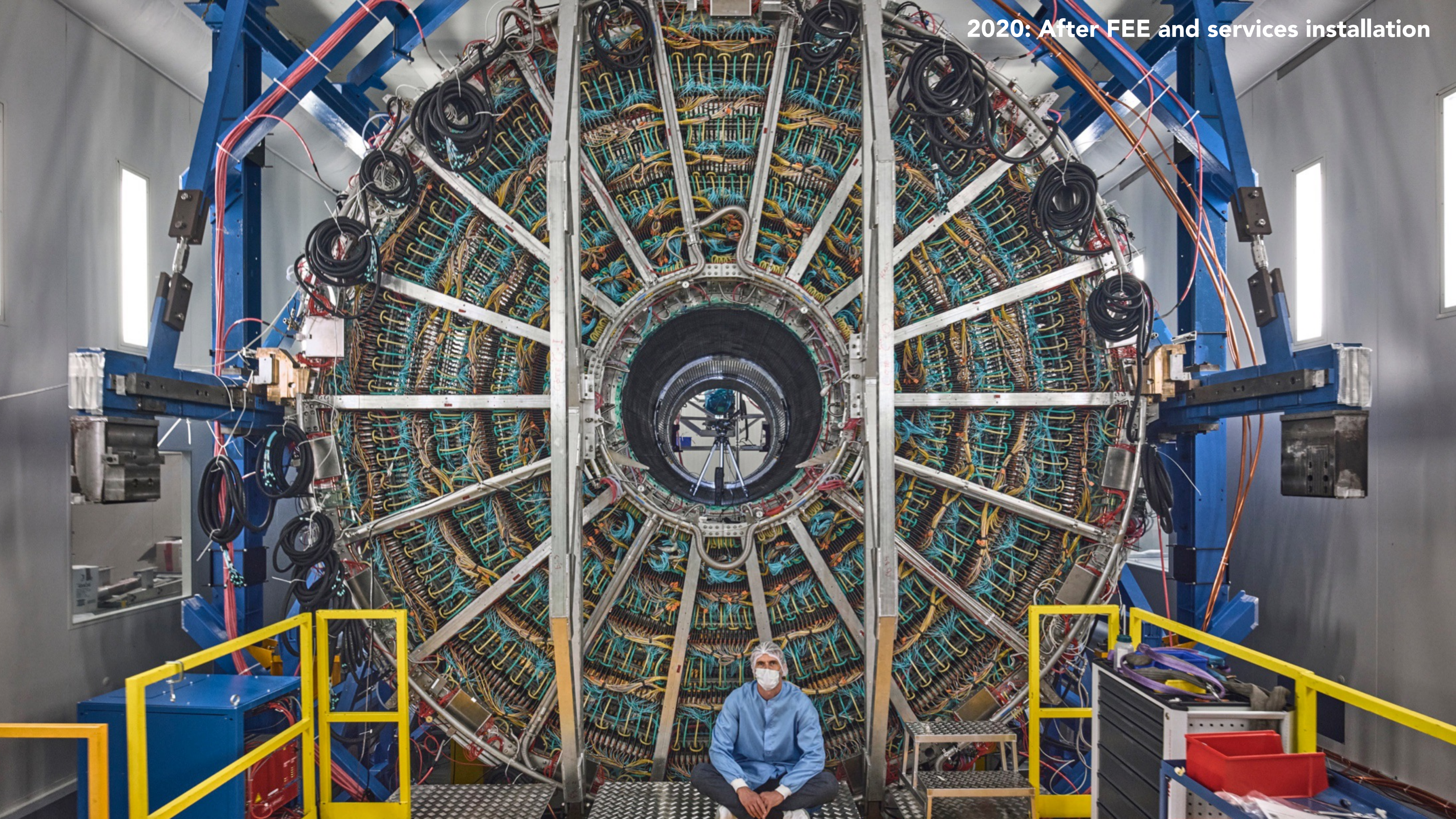


Start connection and commissioning

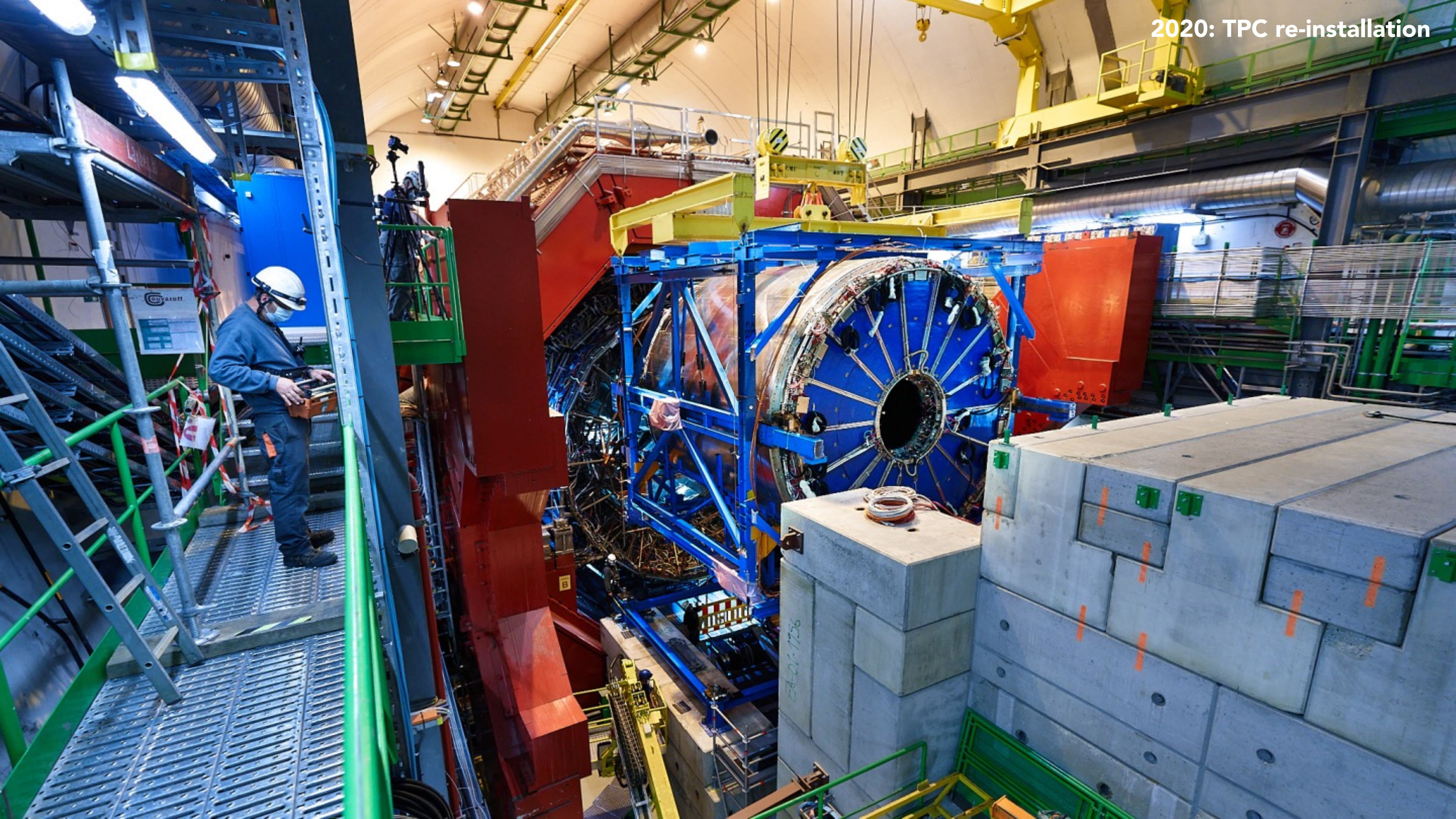
Dec 2020


2019: OROC installation

2019: GEM stacks mirrored on aluminised central drift electrode before installation of last IROC

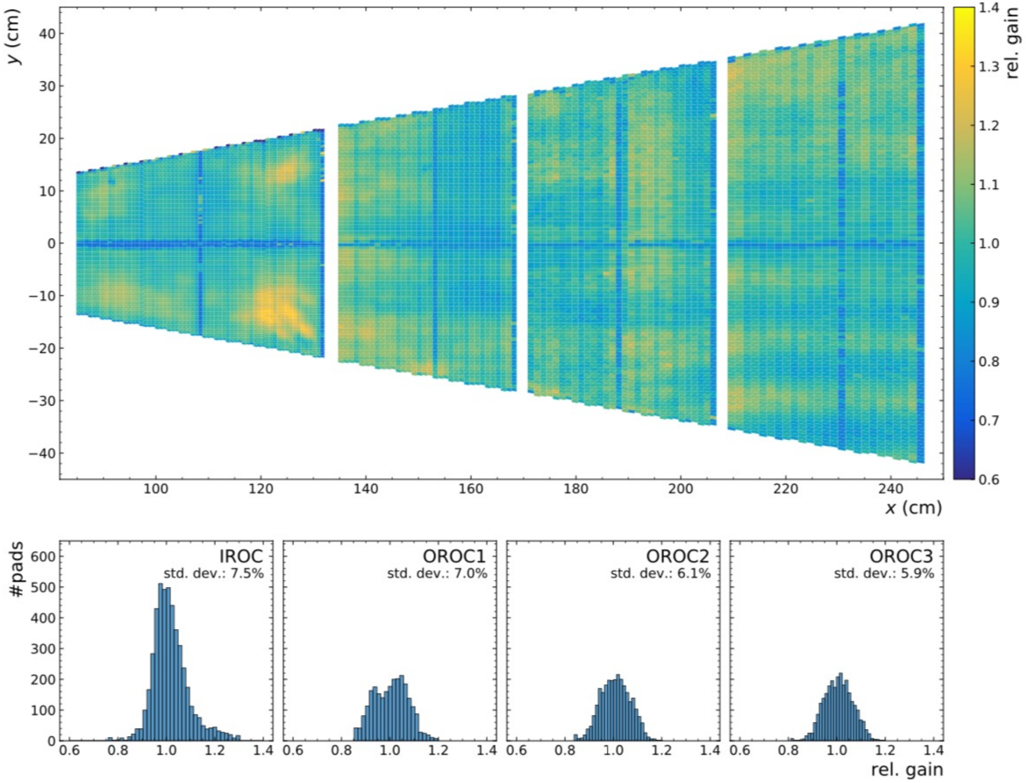

2020: After FEE and services installation

2020: TPC re-installation



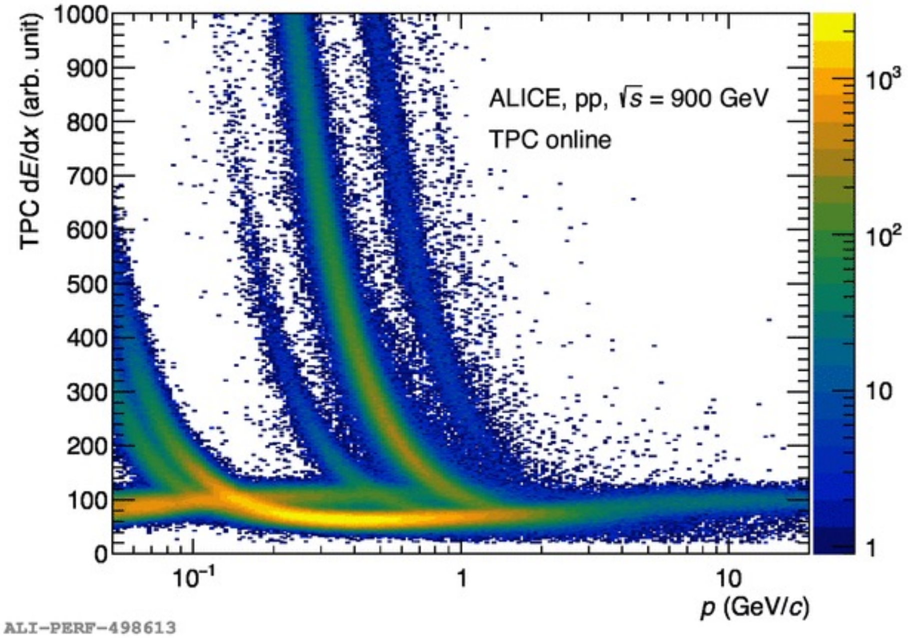
Gain calibration

- **Krypton gain calibration**
  - Well known technique for TPCs
  - ^{83}Rb (half life 86 days) decays into ^{83m}Kr
  - Radioactive ^{83m}Kr isotopes decay in TPC volume
  - Spectrum for each GEM stack or for each pad
- **Stack-by-stack HV adjustment**
- **Spectrum for each pad ➔ gain calibration (using main peak of spectrum)**
- **Some remarkable structures**
  - **foil sagging,**
  - **wrinkles,**
  - **GEM hole size distribution**



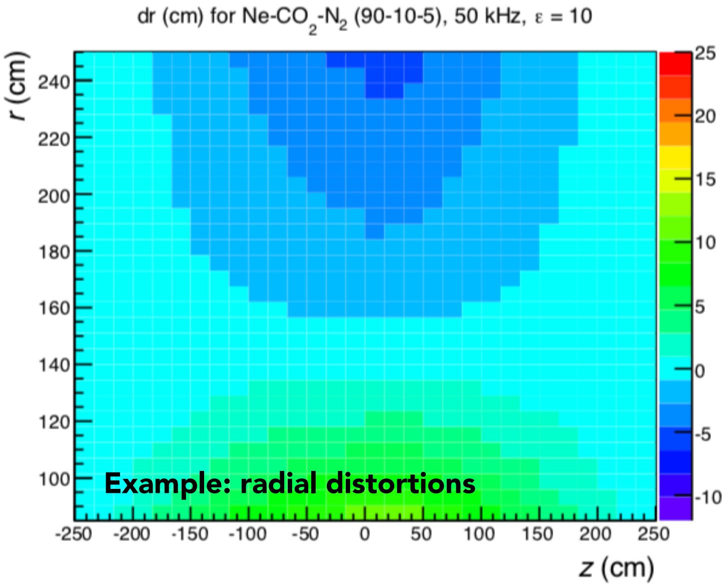
LHC "pilot beams"

- **First pp collisions delivered by LHC in Oct 2021**
- **Commissioning of online data processing including tracking**
- **Plot shows online quality assurance plot from tracking**



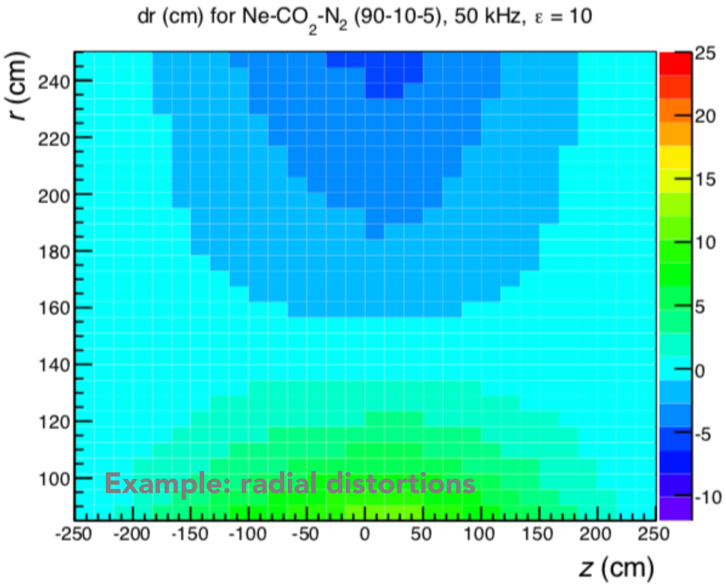
Distortions (1)

- With remaining ion back flow still **considerable space charge distortions** up to few cm

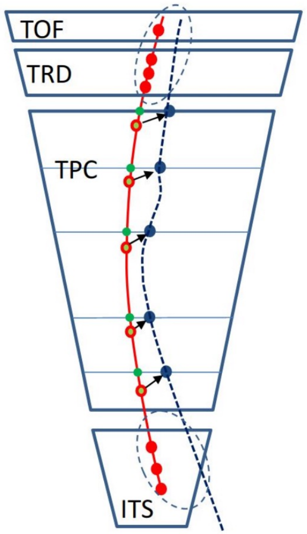


Distortions (2)

- With remaining ion back flow still considerable space charge distortions up to few cm

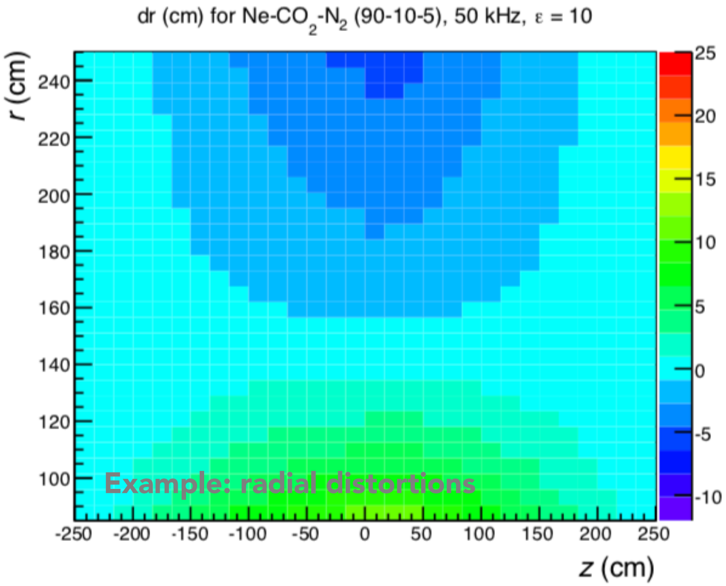


- **Correction using track interpolation (experience from Runs 1 and 2)**
- **Calculate average distortion map which is slowly changing with collision rate**



Distortions (3)

- With remaining ion back flow still considerable space charge distortions up to few cm



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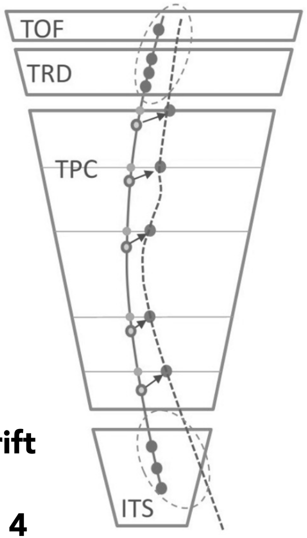
- Calculate average distortion map which is slowly changing with collision rate



- **In addition, fluctuations around the average distortions are important to reach intrinsic TPC resolution**
- **Fluctuations can be extracted by**
  - **integrating the ADC values over the ion drift time (Integrated Digital Currents) or by**
  - **measuring the analog currents at the GEM 4 top electrodes of all GEM stacks**

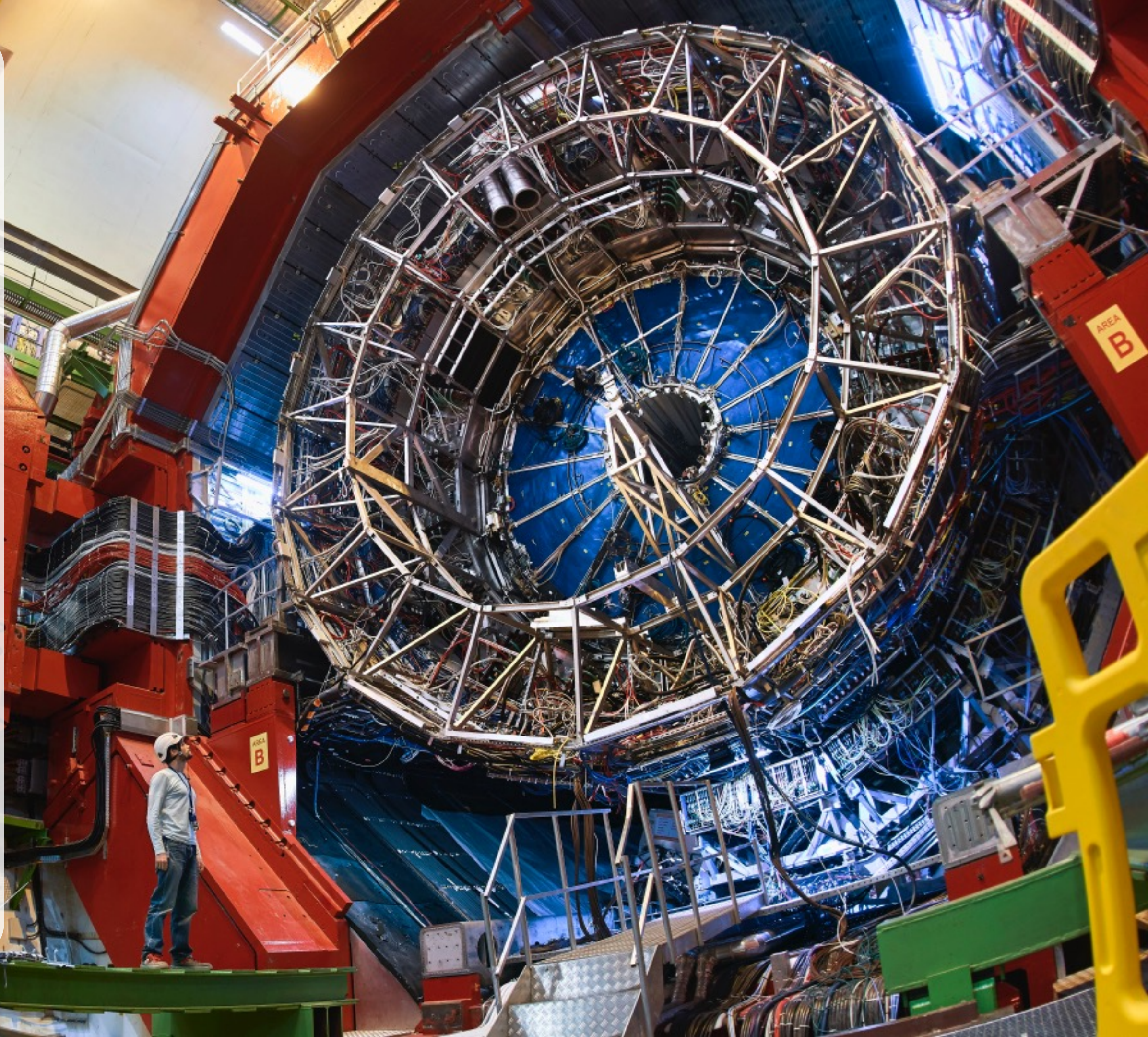
- **These calibrations are the next big challenge!**

Summary

- The upgraded TPC has been re-installed into the ALICE setup
- Data taking with colliding beams about to start
- Next challenge: TPC calibration

Upgrade paper: The upgrade of the ALICE TPC with GEMs and continuous readout (link)

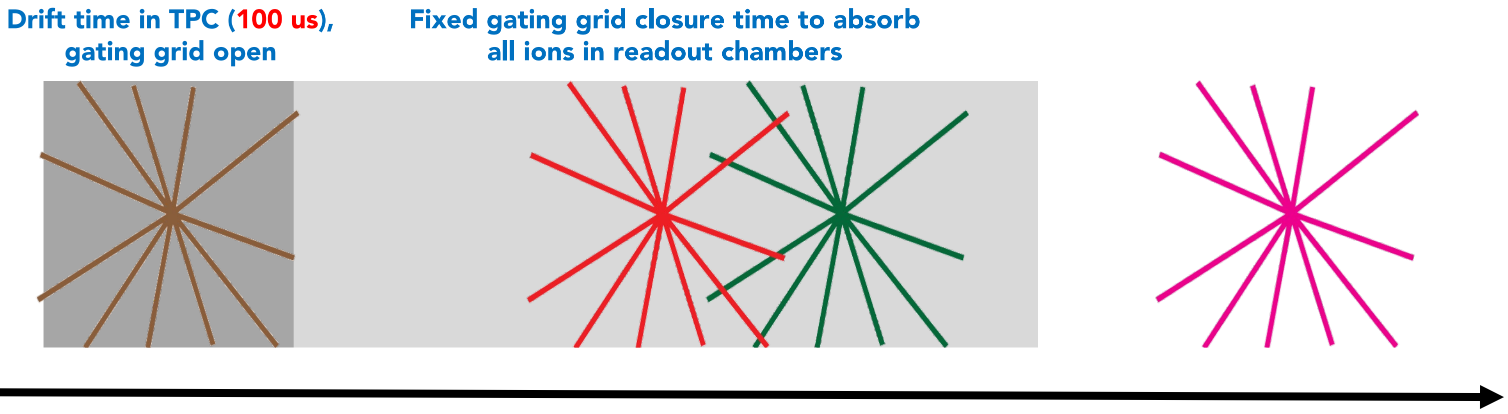
Thank you for your attention!



The past: Triggered TPC operation

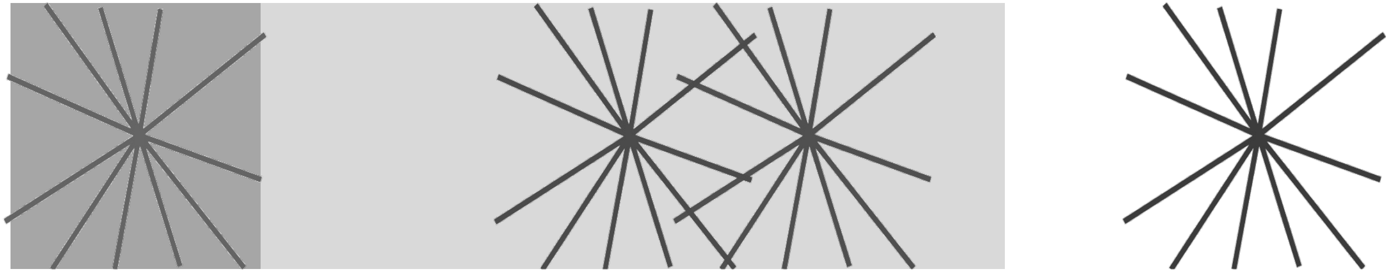
TPC operation in LHC Runs 1 and 2 (2009 – 2018)

Typical Pb–Pb coll. rate: few kHz



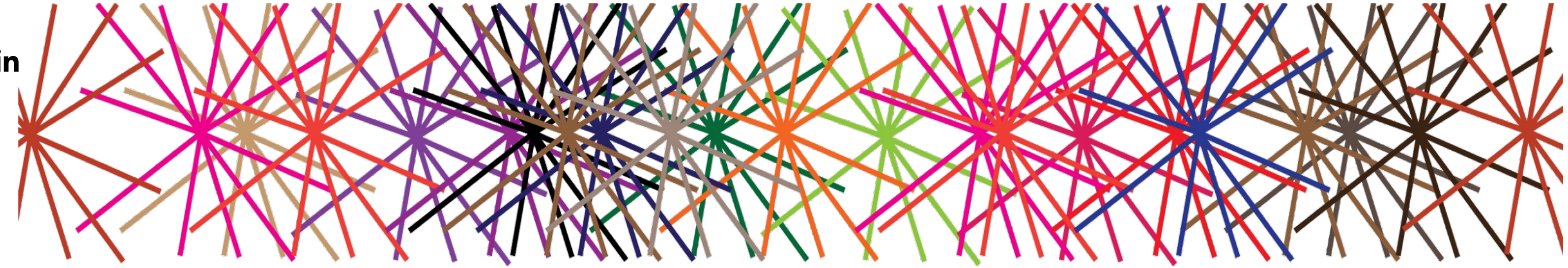
The future: Continuous operation

TPC operation in
LHC Runs 1 and 2
(2009 – 2018)
Typical Pb–Pb coll. rate: few kHz



time →

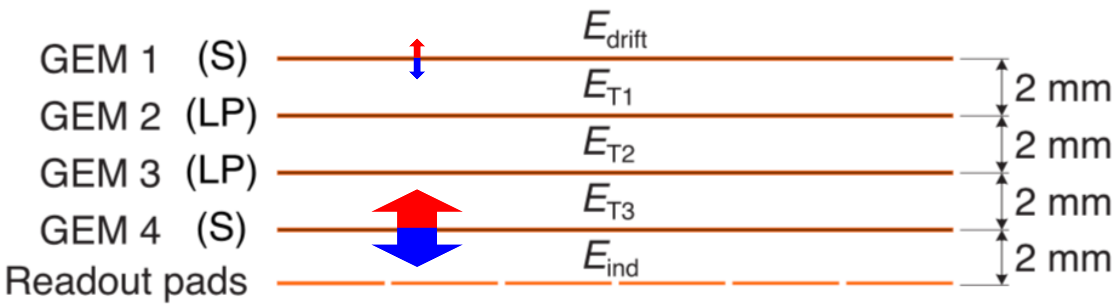
TPC operation in
LHC Run 3
(from 2022)
50 kHz Pb–Pb coll. rate



IBF suppression (1)

3 effects effectively suppress the backflow of ions into the drift region:

1. low gain in GEM 1, highest gain in GEM 4



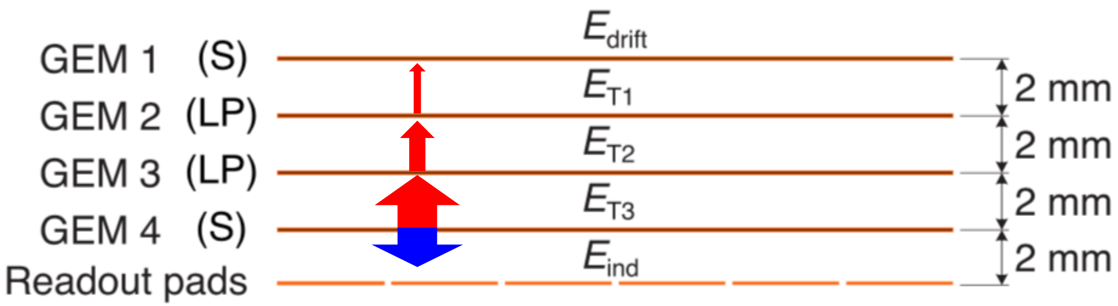
Baseline HV settings

$\Delta V_{GEM\,1}$	=	270 V
$\Delta V_{GEM\,2}$	=	230 V
$\Delta V_{GEM\,3}$	=	320 V
$\Delta V_{GEM\,4}$	=	320 V
E_{drift}	=	$400\ V\,cm^{-1}$
E_{T1}	=	$3500\ V\,cm^{-1}$
E_{T2}	=	$3500\ V\,cm^{-1}$
E_{T3}	=	$100\ V\,cm^{-1}$
E_{ind}	=	$3500\ V\,cm^{-1}$

IBF suppression (2)

3 effects effectively suppress the backflow of ions into the drift region:

1. **low gain in GEM 1, highest gain in GEM 4**
2. **two layers of large pitch (LP) foils (GEM 2 and GEM 3) block ions from GEM 4**



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E_{T3}	=	$100\,\mathrm{V\,cm^{-1}}$
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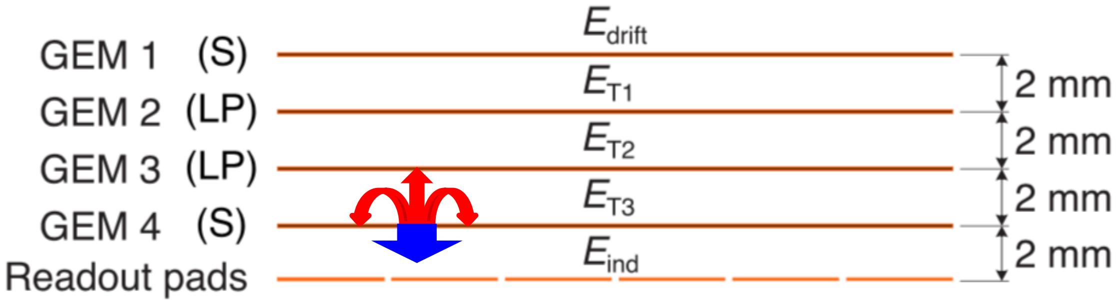
IBF suppression (3)

3 effects effectively suppress the backflow of ions into the drift region:

1. low gain in GEM 1, highest gain in GEM 4
2. two layers of large pitch (LP) foils (GEM 2 and GEM 3) block ions from GEM 4
3. very low transfer field E_{T3} between GEM 3 and GEM 4



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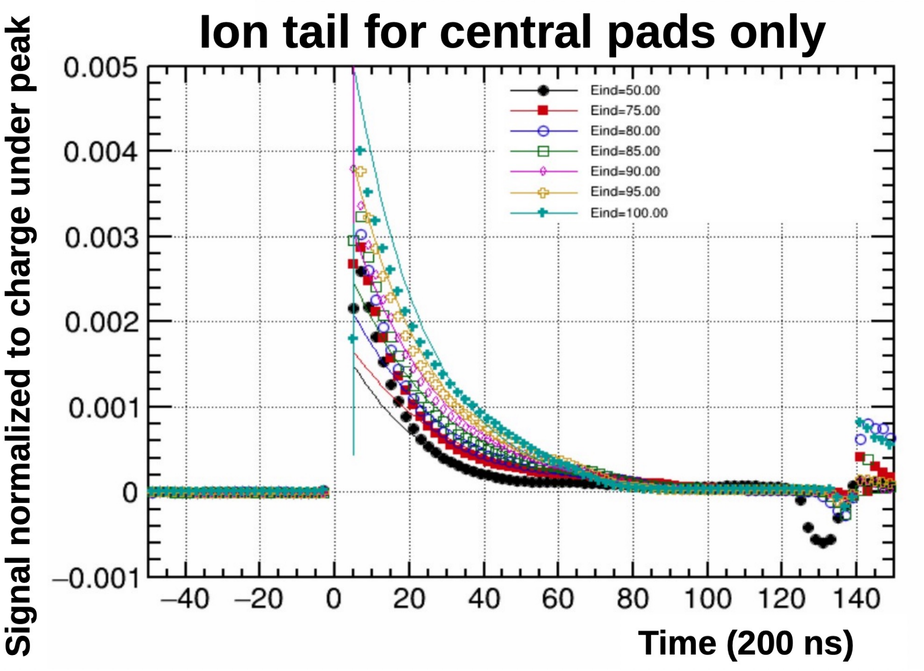
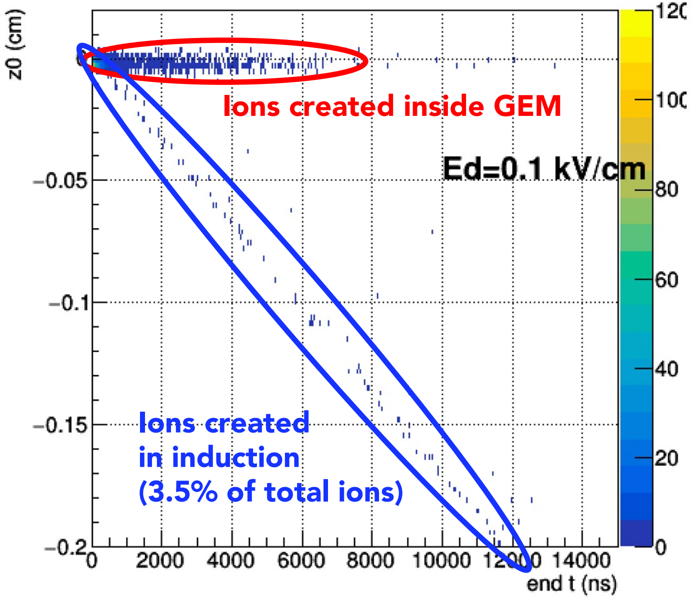
E_{ind}	=	$3500\,V\,cm^{-1}$

Ion tail studies



Measurement: Ion tail at different induction fields



Simulation: Ion production points vs. end-of-drift time (absorption of ions at GEM4 top)