The Upgraded ALICE TPC
VCI 2022

Philip Hauer
on behalf of the ALICE Collaboration

22nd February 2022

ALICE

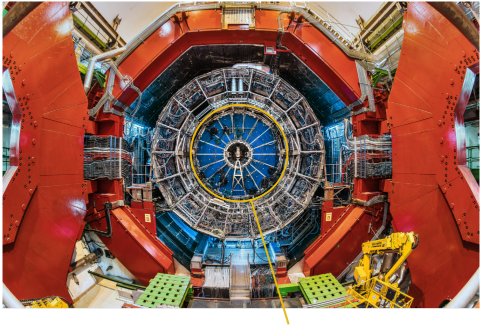
UNIVERSITÄT BONN

AG Ketzer

Outline

- Introduction
- Installation status
- Commissioning
- X-ray data taking
- Krypton data taking

Picture of the ALICE detector:

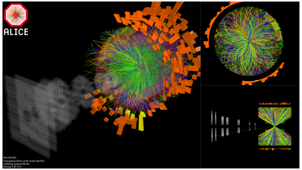


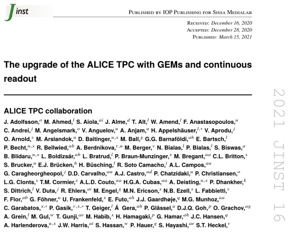
Introduction

- A Large Ion Collider Experiment (ALICE)
  - Dedicated to heavy-ion physics
  - Huge multiplicities (up to 20 000 tracks per collision)
  - Reconstruct all tracks
  - ⇝ Many talks on this conference
- Time Projection Chamber (TPC)
  - Gaseous detector
  - Main tracking and PID device
- During LHC's Run 1 and Run 2: MWPC-based readout
  - Long dead time due to gating grid
  - Or: No gating grid but large space charge distortions
  - ⇒ Not suitable for the Pb-Pb interaction rate of 50 kHz foreseen in Run 3
- Upgrade with Gas Electron Multipliers (GEM)

[F. Sauli – NIM A – 1997]

Event Display:

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The upgrade of the ALICE TPC with GEMs and continuous readout

ALICE TPC collaboration

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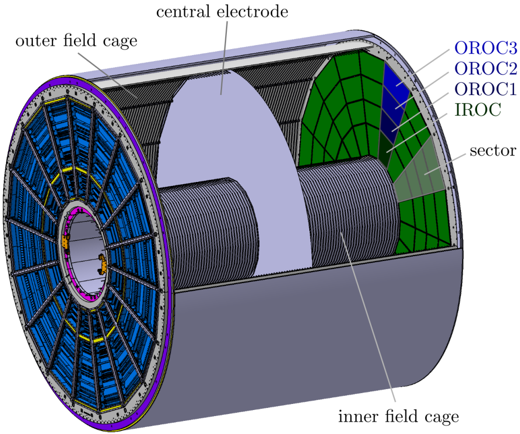
2021 JINST 16

[ALICE TPC Collaboration – JINST 16 – 2021]

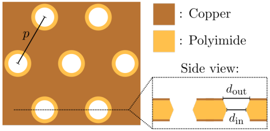
- Cylindrical TPC
  - 5 m outer diameter
  - 5 m long
  - Filled with Ne-CO_2-N_2 (90-10-5)
- Charged particles ionise atoms
- Electrons drift towards amplification stage
- Read out of induced signals on 2D pad plane
- A- and C-side split by central electrode
- In total 36 sectors, subdivided in IROC, OROC1-3



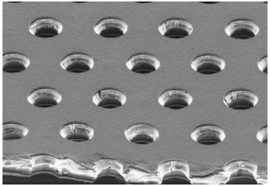
[ALICE TPC Collaboration – JINST 16 – 2021]

- Amplification stage: GEM foils
- Copper-polyimide-copper sandwich
- Perforated with many holes in photolithographic process
- Standard GEM:
  - Pitch $p = 140\,\mu m$
  - Outer diameter $d_{out} = 70\,\mu m$
  - Inner diameter $d_{in} = 50\,\mu m$
- If suitable voltage applied between copper electrodes: gas amplification

Standard pitch GEM:



Picture with electron microscope:

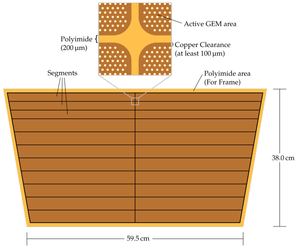


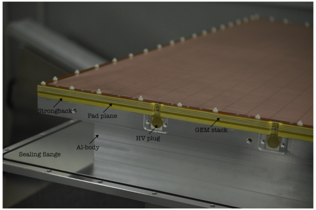
[Altunbas et al. – NIMA 490 – 2002]

- For ALICE TPC: Large-area GEM foils are used
  - Divided into several high-voltage segments
  - Stability cross to prevent sagging
- R&D investigation
  - First GEM TPC: FOPI [B. Ketzer et al. – NIMA 869 – 2017]
  - TDR for ALICE TPC [ALICE TPC Coll. – CERN-LHCC-2013-020]
  - Stack of four foils: S – LP – LP – S
  - Effective gain ≈ 2000
- Ion backflow suppressed to $< 1\,\%$
  - Important to minimise space-charge distortions
  - Can be corrected for

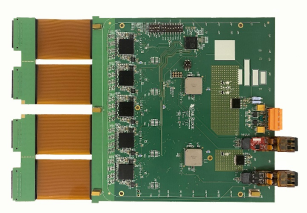
⇒ Continuous operation possible

GEM for OROC2:





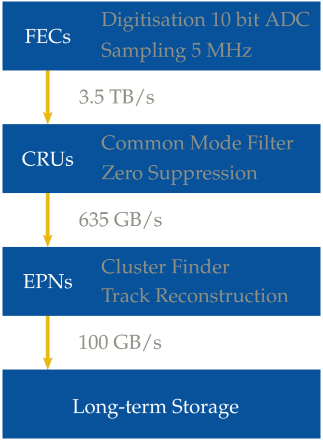
[ALICE TPC Collaboration – JINST 16 – 2021]



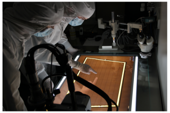
- New FECs designed and installed
  - New ASIC: SAMPA
  - Preamplifier, shaper and 10 bit ADC
  - Continuous sampling with 5 MHz
- In total 524160 readout channels (pads)
  - 3276 FECs needed
  - 3.3 TB/s

⇒ Compress data online

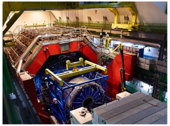
⇝ Presentation by David Rohr



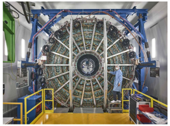
Introduction – Timeline of the Upgrade



GEM Production

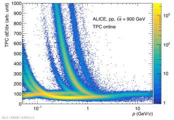


TPC to Cleanroom



Installation FEE
and Services

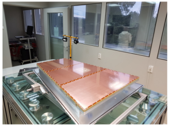
TPC Movement
to LHC P2



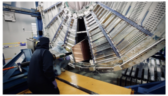
Pilot Beams
(First pp Collisions)

Aug 2016 | Mar 2017 | Mar 2019 | May 2019 | Sep 2019 | Nov 2019 | Aug 2020 | Dec 2020 | Oct 2021 | Time

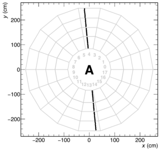
ROC Production



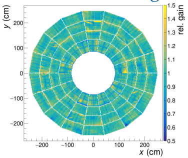
ROC Exchange



Pre-Commissioning

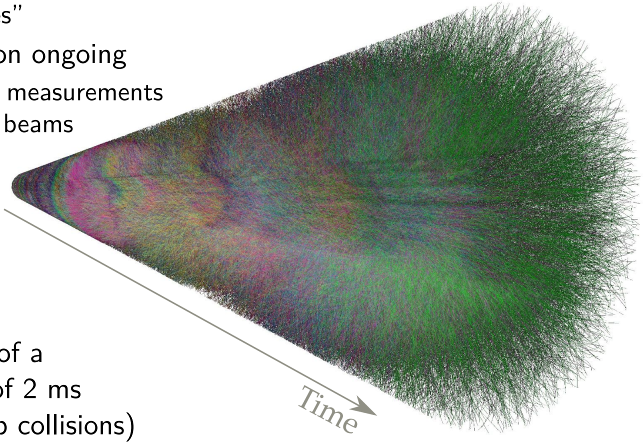


Commissioning



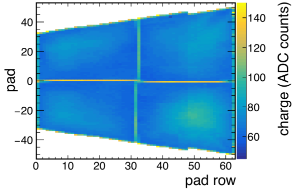
Installation Status – General

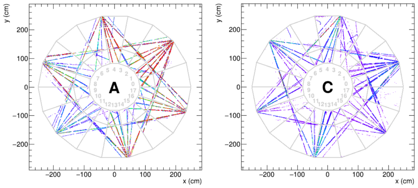
- TPC is operating successfully
  - This includes continuous readout (no trigger) with no dead time
  - "Movies instead of pictures"
- Commissioning and calibration ongoing
  - Examples from calibration measurements
  - First results from pp pilot beams



Simulation of a
timeframe of 2 ms
(with Pb-Pb collisions)

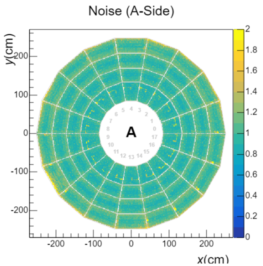
- Upgraded calibration pulser system is installed
- Voltage pulse injected on GEM4 bottom
  - Signal induced on all pads (capacitive coupling)
  - Used to study timing and shaping for each channel
- Laser system is re-installed
- Artificial tracks created inside TPC
- In addition: Signal from central electrode
  - Used to measure drift velocity of electrons

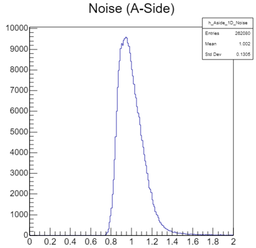




[ALICE TPC Collaboration – JINST 16 – 2021]

Commissioning – Noise Studies





- Pedestals: Offset of the baseline
- Noise: RMS of baseline fluctuations
- Average noise ≈ 1 ADC count
- Matches with design value of 670e (ENC)
- Only a few regions show higher noise
  - Dots in OROC and L-shape in IROC
  - Reason: Cables of temperature sensors
- Online zero suppression
  - Threshold based on noise of each channel

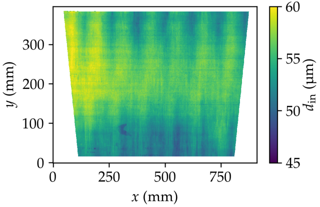
- Measured charge $\propto$ deposited energy $(\mathrm{d}E/\mathrm{d}x)$

$\Rightarrow$ Constant gain required

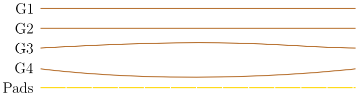
- But: Gain variations expected
  - Electronic gain in FECs
  - Mechanical imperfections
  - Hole size variations
  - Sagging of foils
  - Charging-up of GEMs
  - Temperature and pressure variations

- Calibration required!
  - X-Ray tube
  - ^{83m}Kr

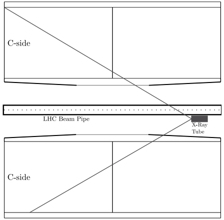
Hole sizes of a GEM foil:



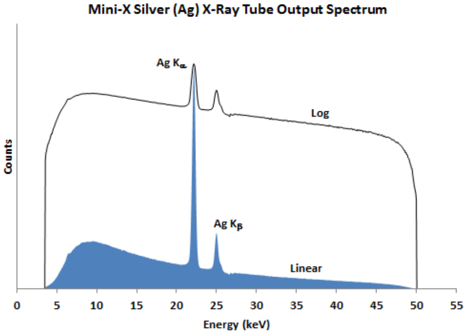
GEM sagging:



- Already during pre-commissioning: Measurements with X-ray tube
  - Only with two sectors simultaneously
- Data very useful
  - to adjust high voltage settings
  - to investigate stability at high loads
  - to calibrate TPC
- Before installation of ITS: Another measurement campaign with full TPC



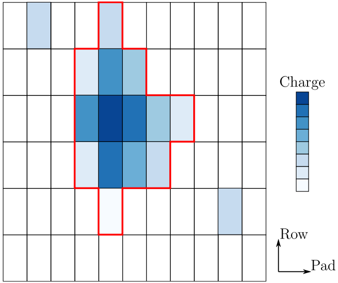
X-ray spectrum:



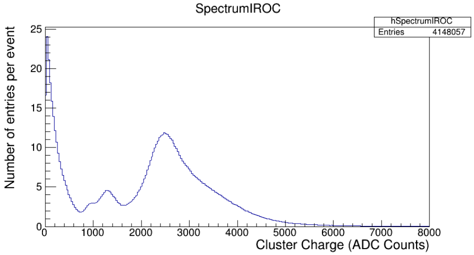
[Amptek]

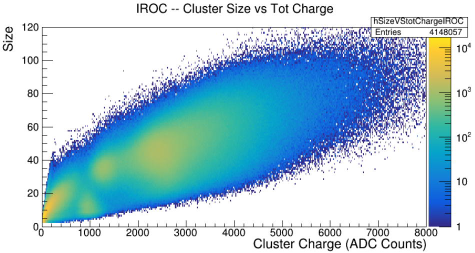
- Characteristic Ag-lines on top of bremsstrahlung background

Expectation: No tracks but charge "blobs"



- Implemented a dedicated 3D cluster finder
- Analyse the measured data





- Four prominent regions:
  - Main peak at ≈ 2500 ADC Ch.

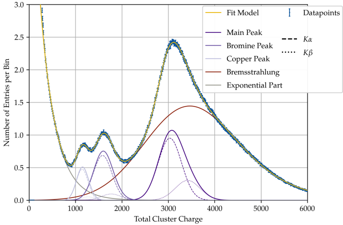
    ⇒ K_α and K_β from Ag X-ray tube
  - Fluorescence peak at ≈ 1000 ADC Ch.

    ⇒ Origin: Copper (GEMs)
  - Fluorescence peak at ≈ 1300 ADC Ch.

    ⇒ Origin: Bromine (vessel material)
  - Exponential at low energies

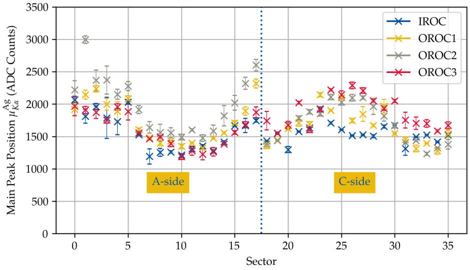
    ⇒ Compton effect

    ⇒ Low energetic X-ray lines (energy too high for noise and cosmics)

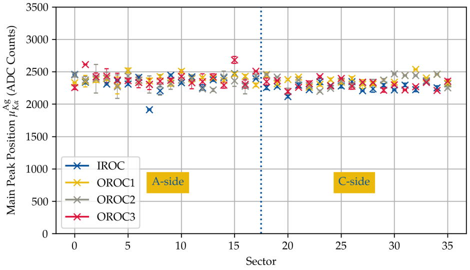


- Developed fit model
- Main peak used for coarse gain equalisation
  - Spectrum for each stack
  - Stack-by-stack gain variations
  - Was used for tuning HV settings
    - Uniform potential on GEM1T

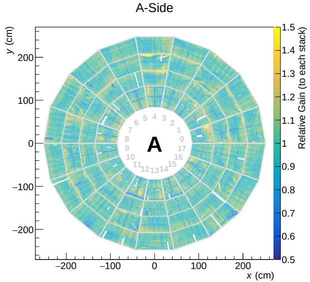
Before:

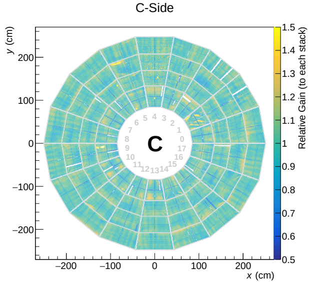


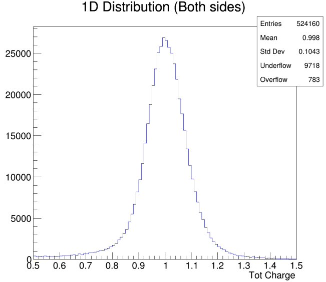
After:



X-Ray – Pad-by-Pad Gain Map



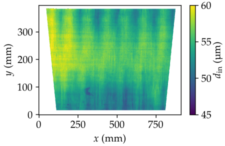




- Spectrum for each pad
- Is corrected for software-wise

- Remarkable structures
  - Sagging
  - Wrinkles
  - Hole-size distribution

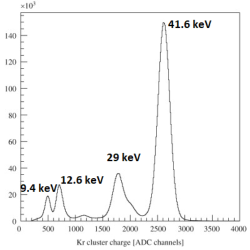
GEM2 OROC3 in C09:



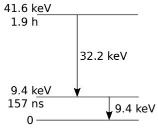
- Common method to calibrate TPCs
  - Well known spectrum
  - Was already done in previous runs
- ^{83}Rb decays to $^{83\mathrm{m}}$Kr
  - Rb has a rather long half-life (86 days)
  - Normally implanted into polyimide foil
- Two energy levels
  - 32.2 keV transition internal conversion (releases a shell electron)
  - 9.4 keV transition is internal conversion (95 %)

Krypton spectrum:

[Alme et al. – NIMA 622 – 2010]

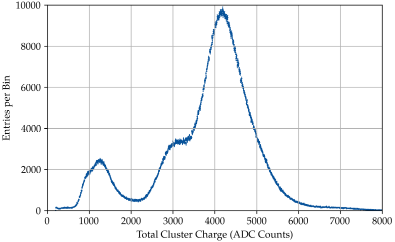


Krypton decay scheme:

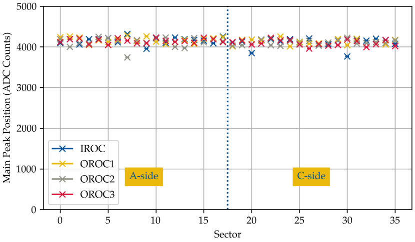


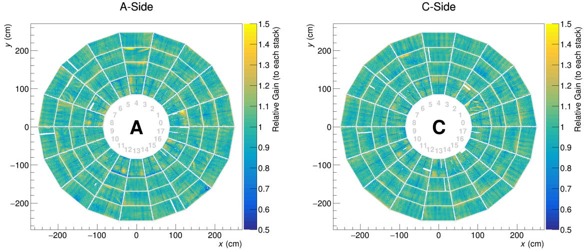
Krypton – Gain Calibration

Raw Krypton spectrum:



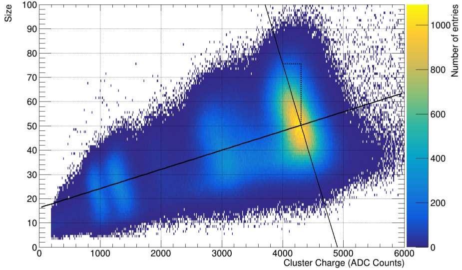
- Main peak used for:
  - Coarse gain equalisation
  - Pad-by-pad gain map
- Similar results to X-ray measurements



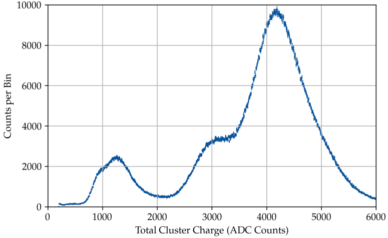


Krypton – Gain Calibration

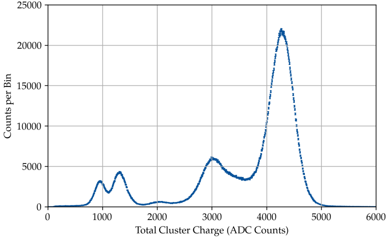
- Apply pad-by-pad gain map to data
- Example: Krypton spectrum
- Correct for electron attachment
- Energy resolution improves significantly
  - Raw spectrum: $\sigma_{\mathrm{E}}/E = 11.2\,\%$
  - Corrected spectrum: $\sigma_{\mathrm{E}}/E = 5.0\,\%$



Raw Krypton spectrum:

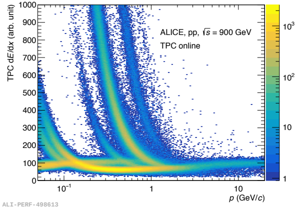


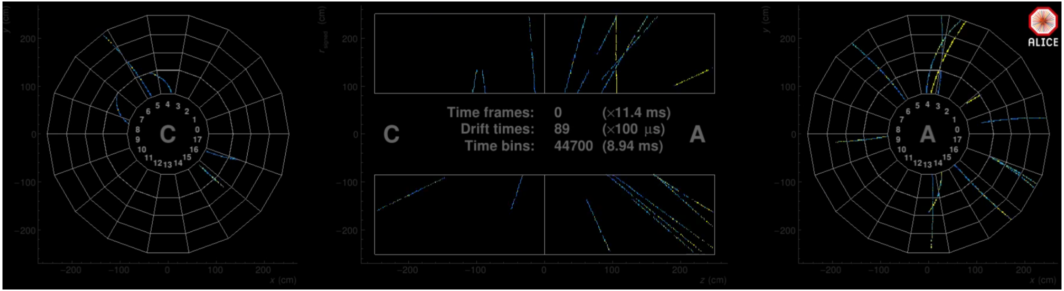
Corrected Krypton spectrum:



- October 2021: LHC pilot beams
  - pp collisions
  - $\sqrt{s} = 900$ GeV
- ALICE TPC with magnetic field (0.2 T)
  - $\mathrm{d}E/\mathrm{d}x$ vs. p plot
  - "Live event display"

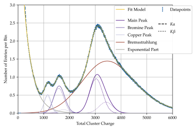
From online quality control:

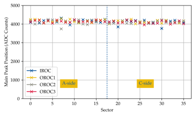


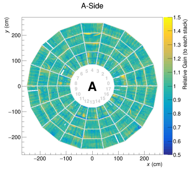


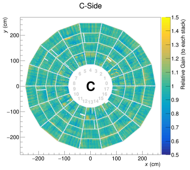
Summary and Outlook

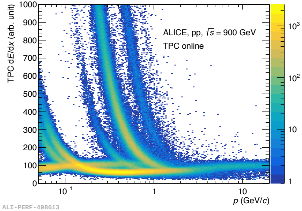
- The ALICE TPC is fully operational with continuous readout
- Pulser and laser are working as expected
- X-ray and Krypton data taking were successful
  - Coarse gain equalisation
  - Pad-by-pad gain calibration
- Measurements during pilot beams
  - First $\mathrm{d}E/\mathrm{d}x$ plot
- Commissioning and calibration ongoing
- Start of pp physics running in June 2022
- Lead beams expected for November 2022









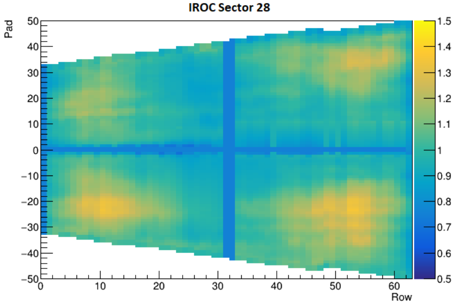


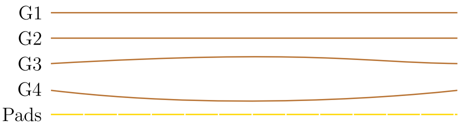
Thanks for Your Attention

Thanks for your attention!

Backup

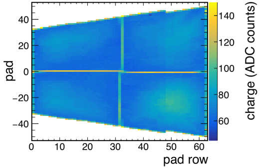
Ion Tail





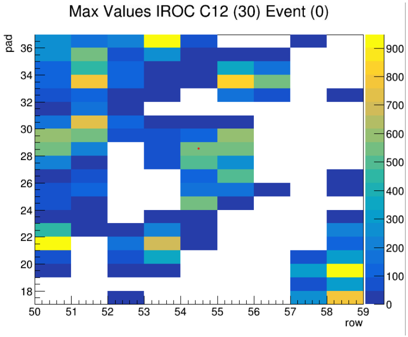
- Some areas have a significantly higher gain
  - Occurs mainly in the edges
  - An "ion-tail" can be observed in these regions
- Possible reason: Sagging of GEM foils
  - One or more foils bend towards neighbouring electrode
  - Strong electric fields in between them
  - Gas amplification occurs

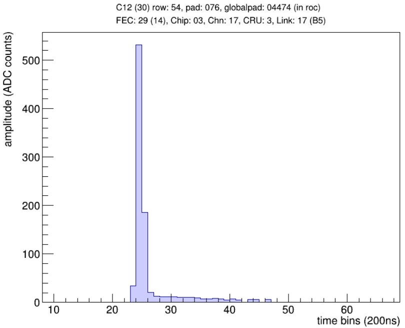
From Pulser:



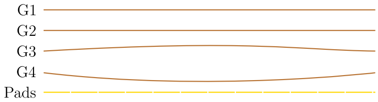
[ALICE TPC Collaboration – JINST 16 – 2021]

Ion Tail





- Long tail: Probably due to backdrifting ions
- Created between GEM4 and pads
- To be investigated



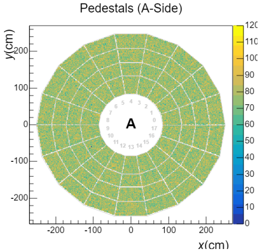
Why Ne-CO2-N2?

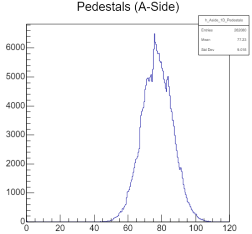
[ALICE TPC Collaboration – JINST 16 – 2021]

Gas	Eff. ionization energy W_i (eV)	Number of electrons per MIP N_p (primary) ($e\,cm^{-1}$)	N_t (total) ($e\,cm^{-1}$)	Drift velocity v_d ($cm\,\mu s^{-1}$)	Diffusion coeff. D_L ($\mu m/\sqrt{cm}$)	D_T ($\mu m/\sqrt{cm}$)	$\omega\tau$
Ne-CO_2-N_2 (90-10-5)	37.3	14.0	36.1	2.58	221	209	0.32
Ne-CO_2 (90-10)	38.1	13.3	36.8	2.73	231	208	0.34
Ar-CO_2 (90-10)	28.8	26.4	74.8	3.31	262	221	0.43
Ne-CF_4 (80-20)	37.3	20.5	54.1	8.41	131	111	1.84

- High ion mobility $\Rightarrow$ Ions quickly get removed from system
- No ageing effects expected
- N_2: Less primary discharges

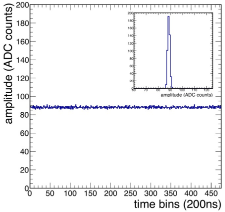
Commissioning – Pedestals and Noise



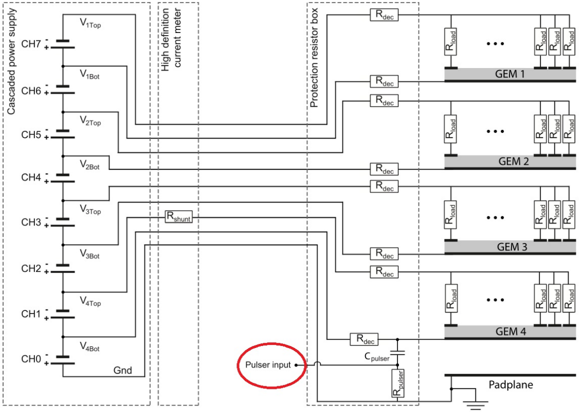


- Pedestals: Offset of the baseline
- Noise: RMS of baseline fluctuations
- Pedestals almost perfectly homogeneous
- Online pedestal subtraction

Baseline of a single pad:

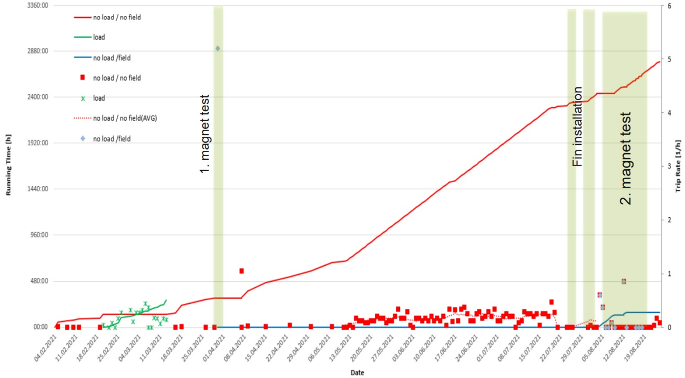


[ALICE TPC Collaboration – JINST 16 – 2021]



[ALICE TPC Collaboration – JINST 16 – 2021]

- Cascaded power supply
- High rate current monitor
- Trip: Current exceeds
  - 6 μA in GEM1 - GEM3
  - 10 μA in GEM4

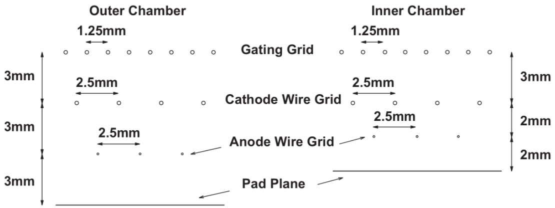


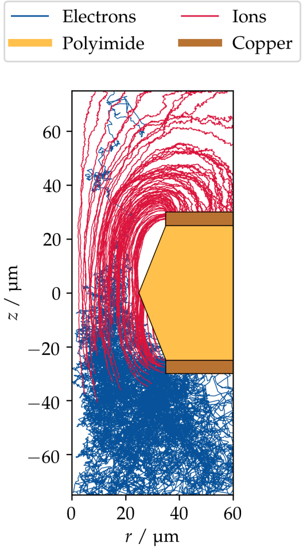
[Robert Münzer – Personal Communication]

Average trips per hour:

- No load (≈ 2000 h)
  - 0.08/h
- X-ray (≈ 284 h)
  - 0.25/h
- Magnet:
  - Increased trip rate during magnet ramping
  - Adapted HV settings
  - Under investigation
- 5/3024 ($< 0.2\,\%$) shorted segments

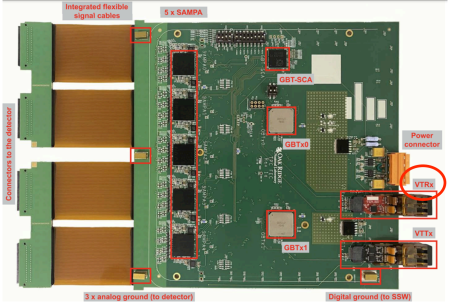
[Alme et al. – NIMA 622 – 2010]





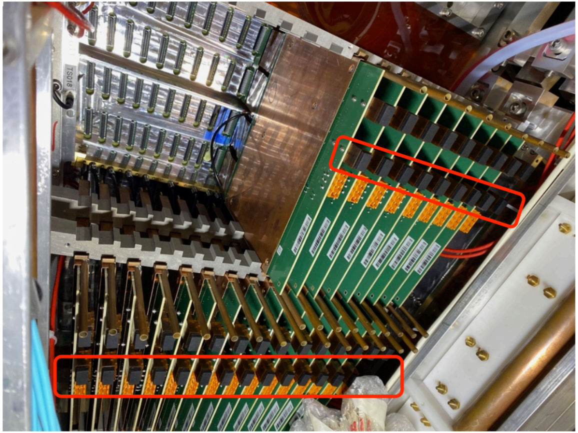
- Ions are captured by gating grid
- Electrons can not pass
- Has to be opened and closed
- Max. interaction rate $\approx 3\,\text{kHz}$

[ALICE TPC Collaboration – JINST 16 – 2021]



- Front-end card (FEC)
- In total: 3276 FECs for whole TPC
- 1 VTRx per FEC

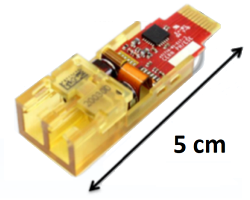
[Christian Lippmann – Personal Comm.]

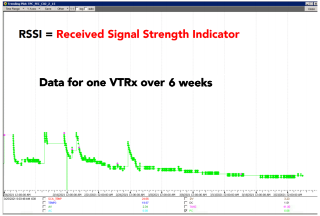


- FECs in an IROC

Installation Status – VTRx Failures

- Communication problems with FECs
- Problematic component: VTRx optoelectric transceiver
- Received signal strength indicator (RSSI) decreases with time
  - First seen by CMS HCAL (operational since 2018)
  - Confirmed by ALICE ITS (operational since 2020)
- Affects approximately 50 % of all modules
- Becomes problematic (link failures) in up to 20 % of installed modules

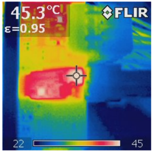


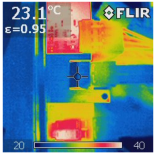


[Christian Lippmann – Personal Comm.]

- Reason: Epoxy not cured well during production
- If it gets warm ⇒ Outgassing
- Fibre connection becomes less transparent
- RSSI decreases

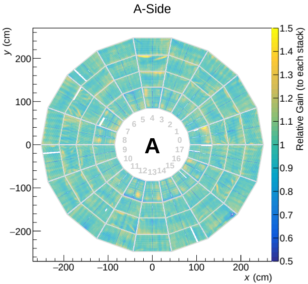
- How to overcome this issue?
  - Post-curing not feasible (typical: 120 °C for 2 h)
  - Regularly cleaning impossible
- Add cooling fins to system
  - Installation possible without unmounting FECs
  - All FECs equipped with fins
  - Stable operation afterwards

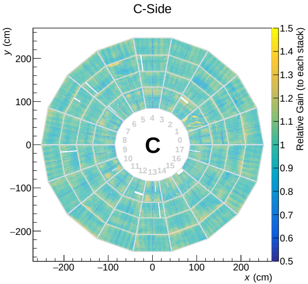


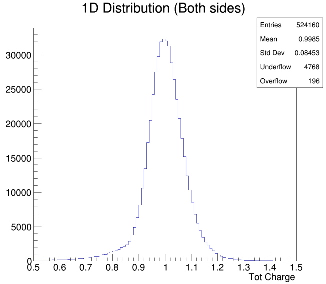


[Christian Lippmann – Personal Comm.]

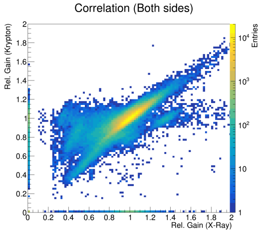
Krypton – Pad-by-Pad Gain Map



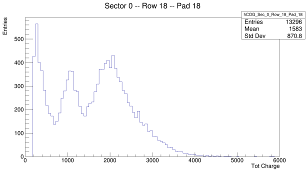




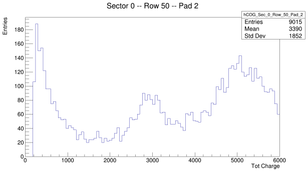
- Known structures
  - Sagging
  - Wrinkles
  - Hole size distribution
- Compare to pad-by-pad gain map from X-ray
  - Correlation looks very good
  - Outliers can be explained



“Normal” spectrum:



Spectrum with high gain:



Spectrum below cross: