Gain Calibration of the Upgraded ALICE TPC

Philip Hauer

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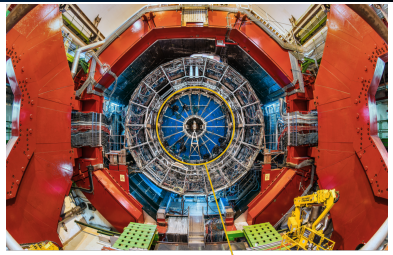
FSP ALICE
Erforschung von
Universum und Materie

UNIVERSITÄT BONN

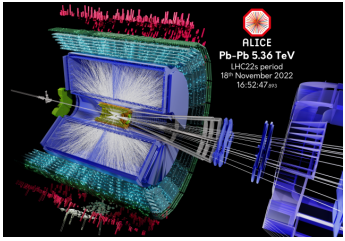
Introduction – ALICE

- A Large Ion Collider Experiment (ALICE)
- One of the four large experiments at Large Hadron Collider (LHC) at CERN
  - Dedicated to heavy-ion physics
    - Usually Pb-Pb
  - Huge multiplicities
    - Up to 20 000 tracks per collision
  - Reconstruct all tracks
  - Identify all particles
- Time Projection Chamber (TPC)
  - Gaseous detector
  - Main tracking and PID device



TPC

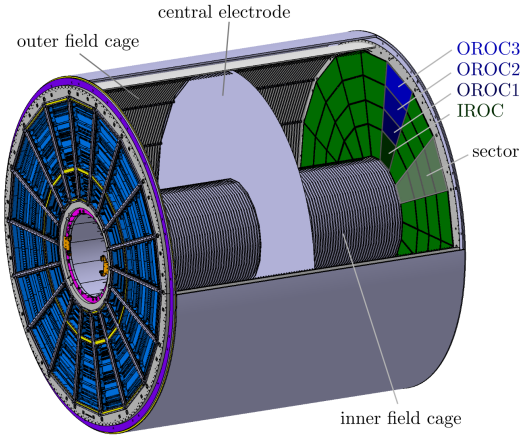
[ALICE figure repository]



[ALICE figure repository]

Introduction – TPC

- Cylindrical TPC
  - 5 m outer diameter
  - 5 m long
  - Filled with Ne-CO_2-N_2 (90-10-5)
- Upgrade: Replaced MWPC-based amplification stage by GEMs
  - 50 kHz Pb-Pb interaction rate
- 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



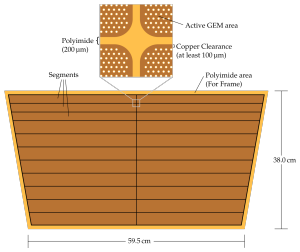
[ALICE TPC Collaboration – JINST 16 – 2021]

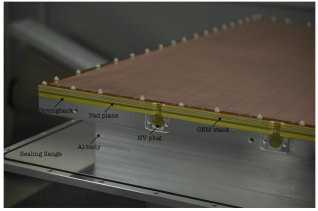
Introduction – GEMs in the ALICE TPC

- For ALICE TPC: Large-area GEM foils are used
  - Divided into several high-voltage segments
  - Stability cross to prevent sagging
- Ion backflow suppressed to $< 1\,\%$
  - Important to minimise space-charge distortions
- $\sigma_E/E < 14\,\%$ at ^{55}Fe
  - Important for particle identification
- 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

$\Rightarrow$ Continuous operation possible

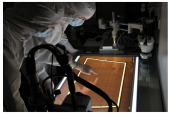
GEM for OROC2:





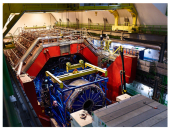
[ALICE TPC Collaboration – JINST 16 – 2021]

Introduction – Timeline of the Upgrade



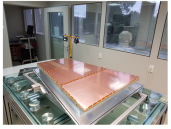
GEM Production

Aug 2016



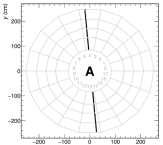
TPC to Cleanroom

Mar 2017



ROC Production

Mar 2019

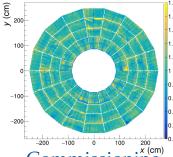


Pre-Commissioning

May 2019

ROC Exchange

Nov 2019

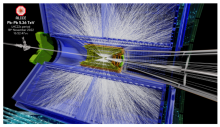


Commissioning

Aug 2020

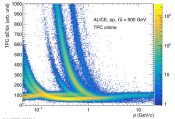
TPC Movement to LHC P2

Dec 2020



Lead-Lead Beams

Oct 2021



Pilot Beams (First pp Collisions)

Nov 2022

Time

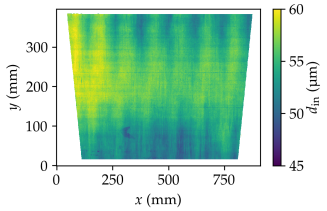
Calibration of the ALICE TPC

- 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
  - $^{83\mathrm{m}}\mathrm{Kr}$

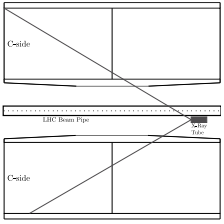
Hole sizes of a GEM foil:



GEM sagging:

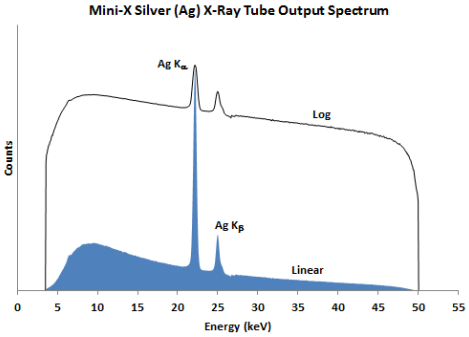
Commissioning – X-Ray Irradiation

- 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



Commissioning – X-Ray Irradiation

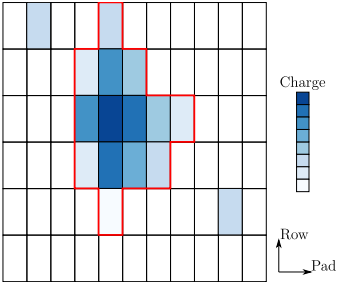
X-ray spectrum:



[Amptek]

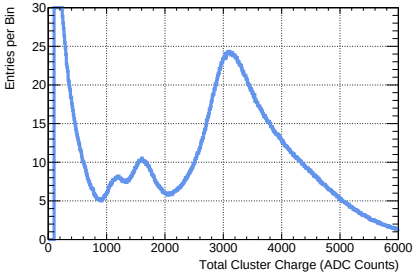
- Characteristic Ag-lines on top of bremsstrahlung background

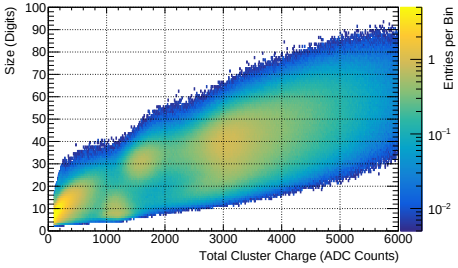
Expectation: No tracks but charge "blobs"



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

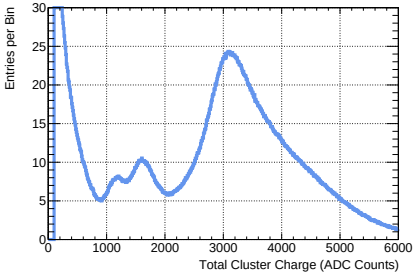
Commissioning – X-Ray Irradiation

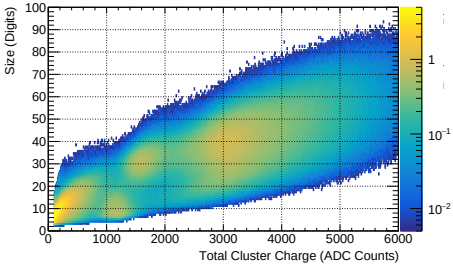




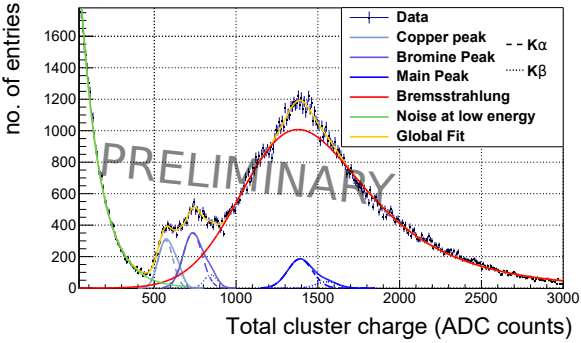
- Four prominent regions:
  - Main peak at $\approx$ 3000 ADC
  $\Rightarrow$ K_α and K_β from Ag X-ray tube
  - Fluorescence peak at $\approx$ 1100 ADC
  $\Rightarrow$ Origin: Copper (GEMs)
  - Fluorescence peak at $\approx$ 1600 ADC
  $\Rightarrow$ Origin: Bromine (vessel material)
  - Exponential at low energies
  $\Rightarrow$ Compton effect
  $\Rightarrow$ Low energetic X-ray lines
  (energy too high for noise and cosmics)

Commissioning – X-Ray Irradiation





Geant4-based simulation:

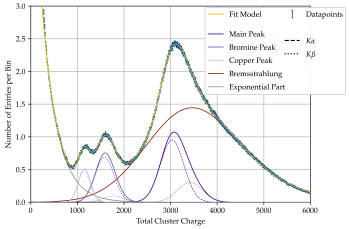


- Exponential at low energies

⇒ Compton effect

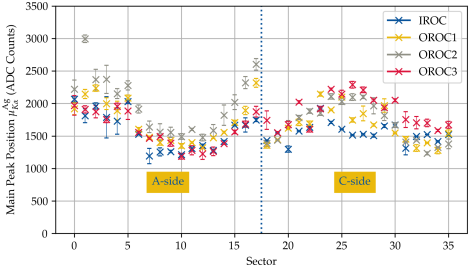
⇒ Low energetic X-ray lines
(energy too high for noise and cosmics)

X-Ray – Coarse Gain Equalisation

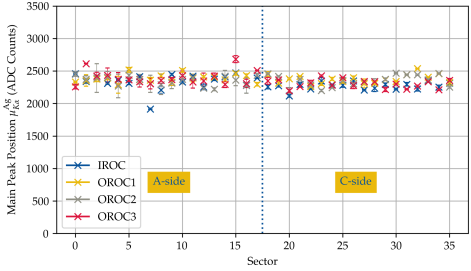


- Developed fit model
- Main peak used for coarse gain equalisation
  - Spectrum for each stack
  - Stack-by-stack gain variations
  - Was used for tuning HV settings
    - Uniform potential on GEM1T

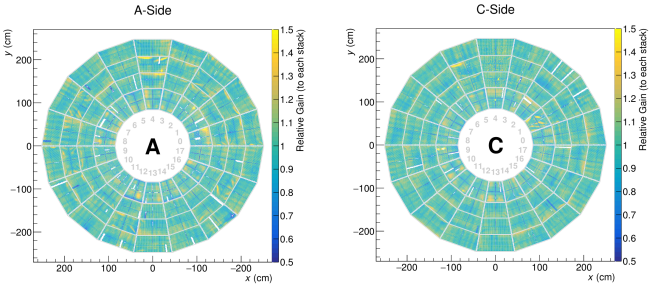
Before:

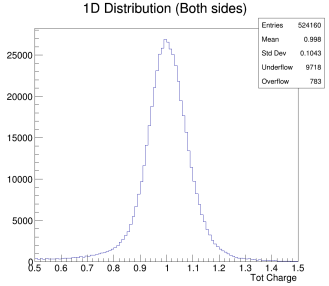


After:



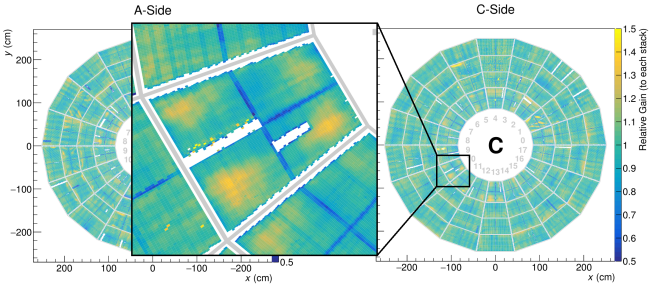
X-Ray – Pad-by-Pad Gain Map

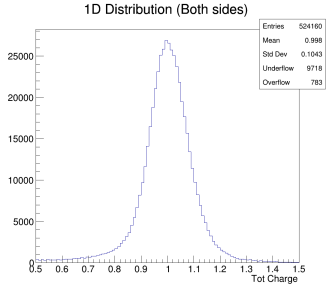




- Spectrum for each pad
  - 524160 pads
- Software-wise correction
- Remarkable structures

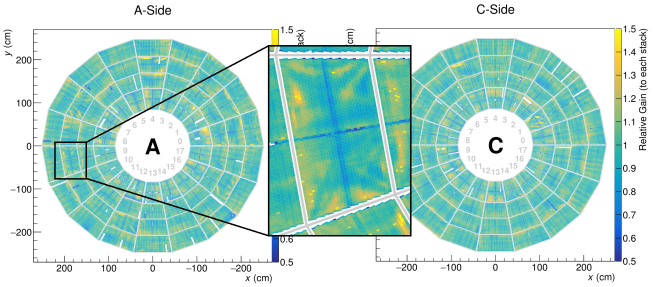
X-Ray – Pad-by-Pad Gain Map

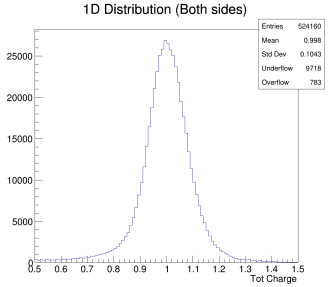




- Spectrum for each pad
  - 524160 pads
- Software-wise correction
- Remarkable structures
  - Sagging

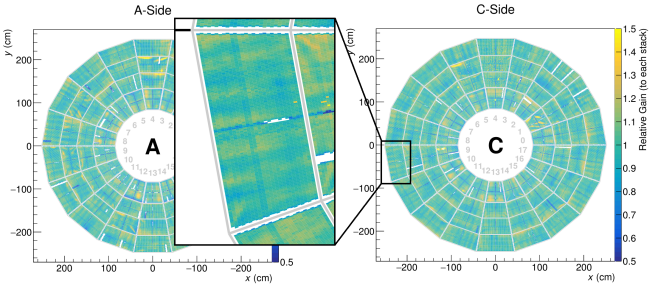
X-Ray – Pad-by-Pad Gain Map

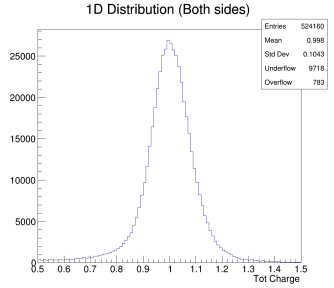




- Spectrum for each pad
  - 524160 pads
- Software-wise correction
- Remarkable structures
  - Sagging
  - Wrinkles

X-Ray – Pad-by-Pad Gain Map

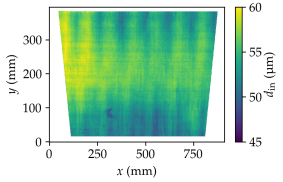




- Spectrum for each pad
  - 524160 pads
- Software-wise correction

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

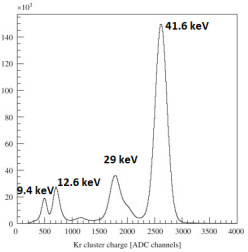
GEM2 OROC3 in C09:



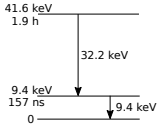
- Common method to calibrate TPCs
  - Well known spectrum
  - Was already done in previous runs
- ^{83}Rb decays to $^{83\mathrm{m}}$Kr
  - Rb has a rather long half-life (86 days)
  - Normally implanted into polyimide foil
- Two energy levels
  - 32.2 keV transition internal conversion (releases a shell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

Krypton spectrum:

[Alme et al. – NIMA 622 – 2010]

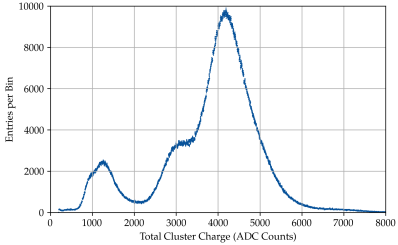


Krypton decay scheme:

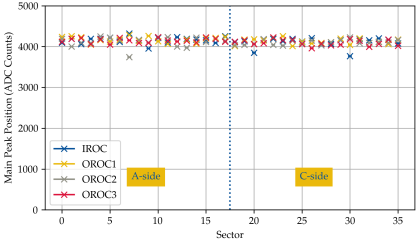


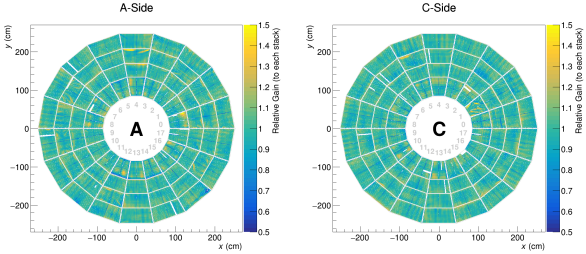
Krypton – Static Gain Calibration

Raw Krypton spectrum:



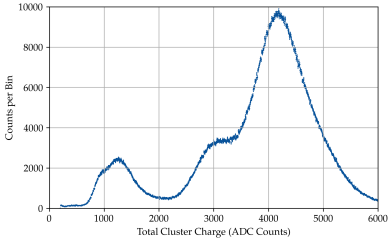
- Main peak used for:
  - Coarse gain equalisation
  - Pad-by-pad gain map
- Similar results to X-ray measurements



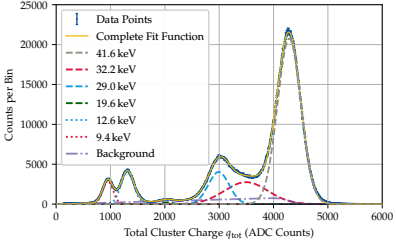


Static Gain Calibration – Application

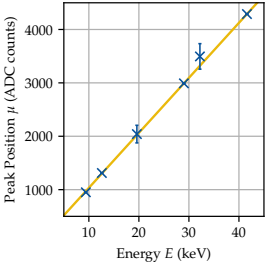
Raw Krypton spectrum:

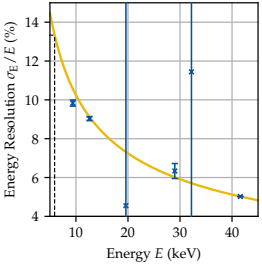


Corrected Krypton spectrum:



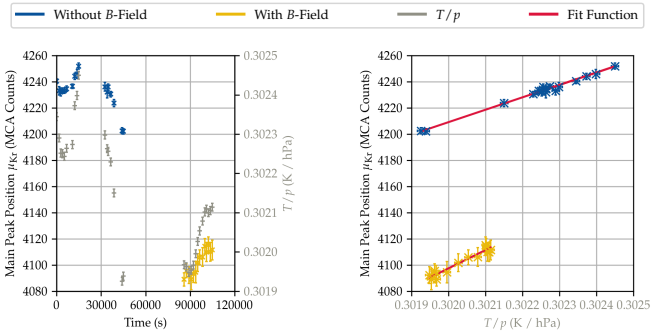
- Apply pad-by-pad gain map to data
- Energy resolution (main peak) improves significantly
  - Raw spectrum: $\sigma_E/E = 11.2\,\%$
  - Corrected spectrum: $\sigma_E/E = 5.0\,\%$
- σ_E/E at ^{55}Fe $= 13.3\,\%$
  - Requirement: σ_E/E at ^{55}Fe $< 14\,\%$





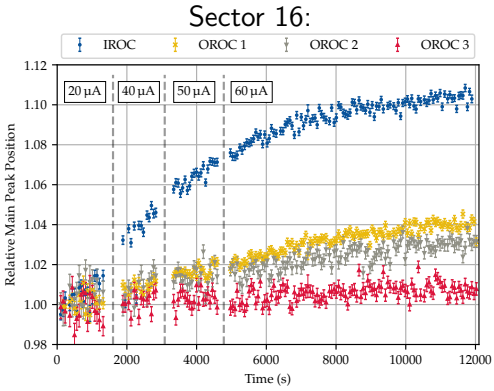
Calibration – Temperature and Pressure

- Temperature T
  - Sensor in TPC
- Pressure p
  - Sensor in cavern
- Gain depends on T/p
- 32 measurements
  - Time span $\approx 30\,\mathrm{h}$
  - With $^{83\mathrm{m}}\mathrm{Kr}$
- With and without B-field
- Correlation of T/p with main peak position
- Different behaviour with vs. without B-field
  - Origin not clear (yet)



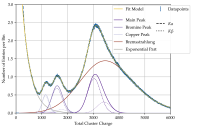
Calibration – Charging-Up of GEM Foils

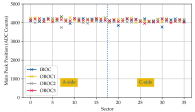
- 2 month break in pre-commissioning due to COVID
  - TPC was not operated
- Afterwards: X-ray irradiation
- IROC: Clear exponential behaviour
  - Charging-up
- Longer time-constant in other GEM stacks
  - X-ray tube in middle of TPC
  - Smaller rate in outer GEM stacks

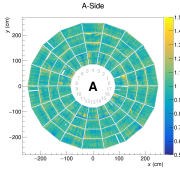


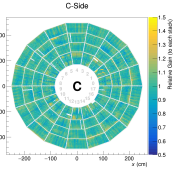
Summary and Outlook

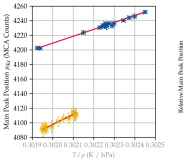
- Upgrade of the ALICE TPC
  - Replaced old amplification stage by GEMs
  - Fully operational with continuous readout
  - “Movies instead of pictures”
- Calibration of
  - Static gain variations
    - Coarse gain calibration
    - Pad-by-pad gain map
  - Dynamic gain variations
    - Temperature and pressure
    - Charging-up
- Pb-Pb data taking campaign next year
- Until then: Further calibrations
  - E.g. removed skirt electrode

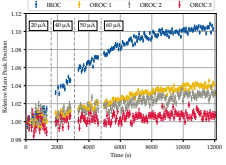








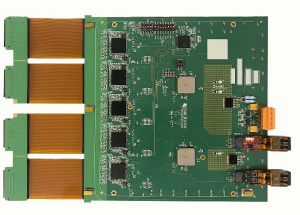




Thanks for your attention!

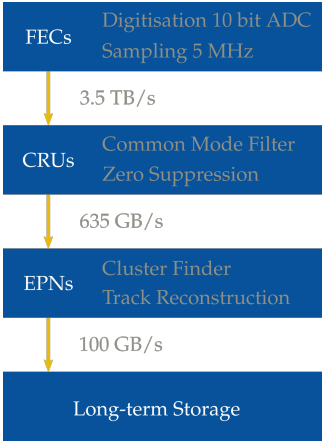
Backup

FECs and Data Processing



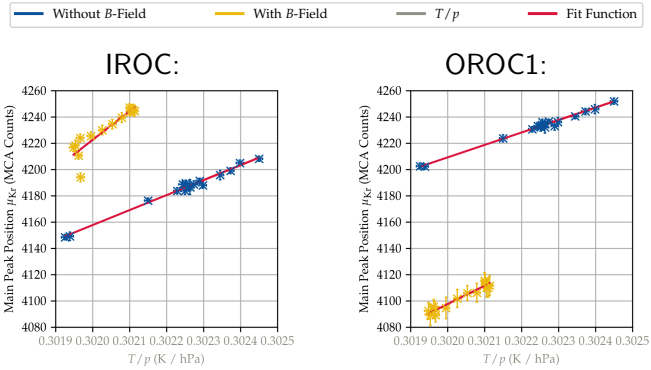
- New FECs designed and installed
  - New ASIC: SAMPA
  - Preamplifier, shaper and 10 bit ADC
  - Continuous sampling with 5 MHz
- In total 524160 readout channels (pads)
  - 3276 FECs needed
  - 3.3 TB/s

$\Rightarrow$ Compress data online



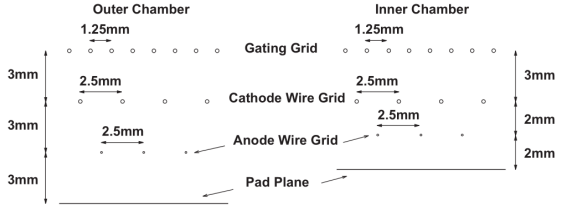
With vs. Without B-field

- Shift of main peak position
  - With vs. without B-field
- Shift upwards in IROC
- Shift downwards in OROC (not only OROC1)
- Origin not clear
  - Idea: Threshold effects due to noise cuts
  - Under investigation

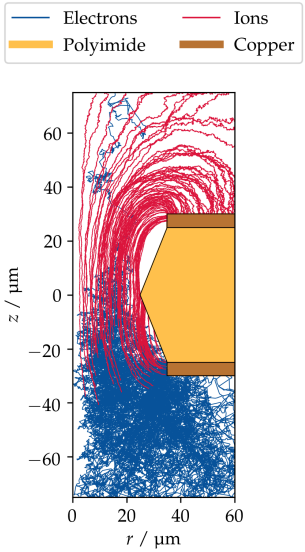


MWPCs vs. GEMs

[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 $\approx 3\,\mathrm{kHz}$



Why Ne-CO2-N2?

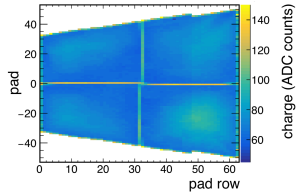
[ALICE TPC Collaboration – JINST 16 – 2021]

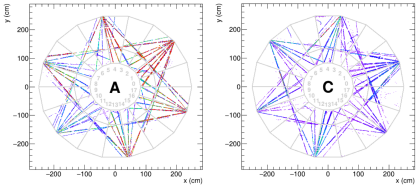
Gas	Eff. ionization energy W_i (eV)	Number of electrons per MIP N_p (primary) (e cm^{-1})	N_t (total) (e cm^{-1})	Drift velocity v_d (cm µs^{-1})	Diffusion coeff. D_L (µm/$\sqrt{\text{cm}}$)	D_T (µm/$\sqrt{\text{cm}}$)	$\omega\tau$
Ne-CO_2-N_2 (90-10-5)	37.3	14.0	36.1	2.58	221	209	0.32
Ne-CO_2 (90-10)	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

Installation Status – Pulser and Laser

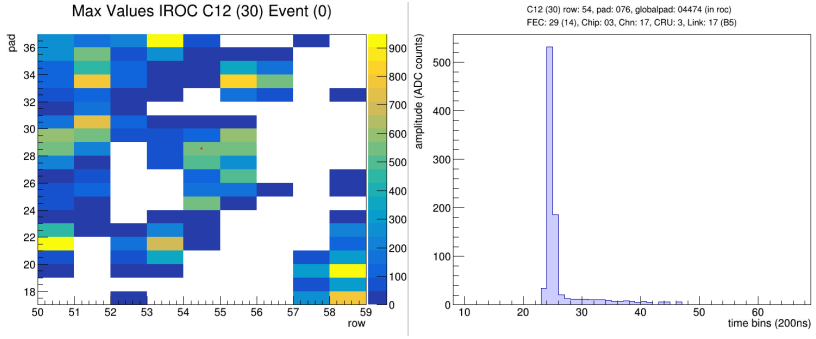
- Upgraded calibration pulser system is installed
- Voltage pulse injected on GEM4 bottom
  - Signal induced on all pads (capacitive coupling)
  - Used to study timing and shaping for each channel
- Laser system is re-installed
- Artificial tracks created inside TPC
- In addition: Signal from central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





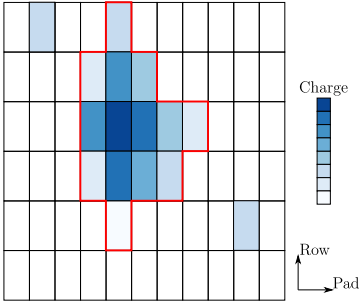
[ALICE TPC Collaboration – JINST 16 – 2021]

Ion Tail

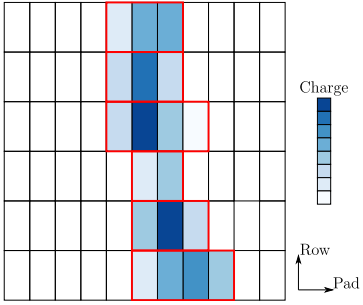


- Long tail: Probably due to backdrifting ions
- Created between GEM4 and pads
- To be investigated

3D box cluster finder:

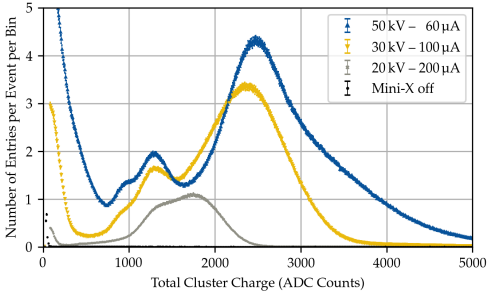


"Normal" cluster finder:

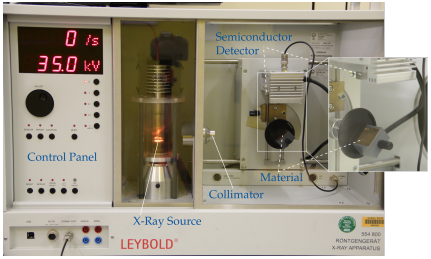


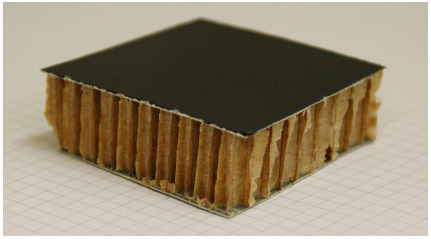
Main Peak Identification

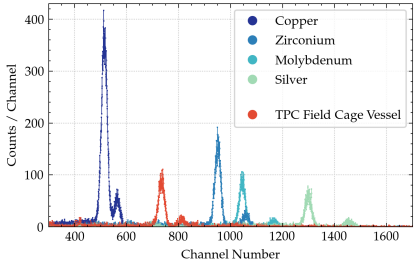
- Reduced Mini-X voltage
- Peak vanished at 20 kV
- Clear indication that characteristic lines are responsible
  - $E_{K\alpha}^{\mathrm{Ag}} = 22\,\mathrm{keV}$
  - $E_{K\beta}^{\mathrm{Ag}} = 25\,\mathrm{keV}$

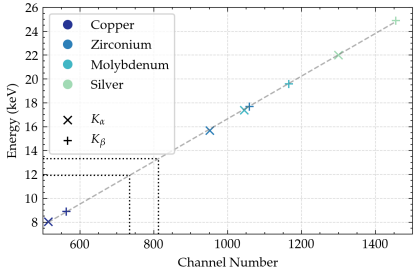


Bromine Peak Identification



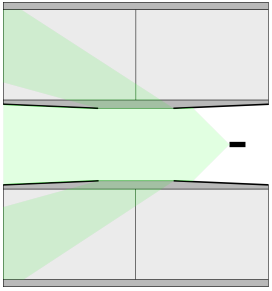


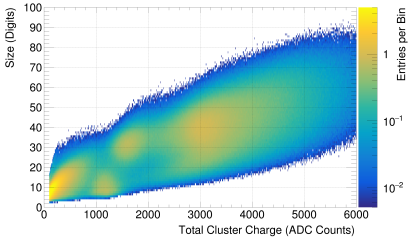


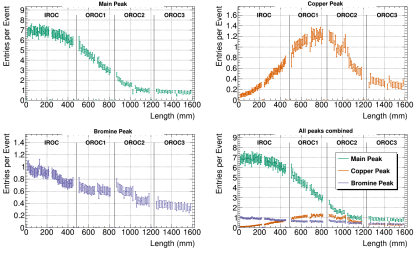


Copper Peak Identification

- Is only visible on irradiated side
- Radial distribution fits to irradiated GEM area
- Small sizes due to small diffusion

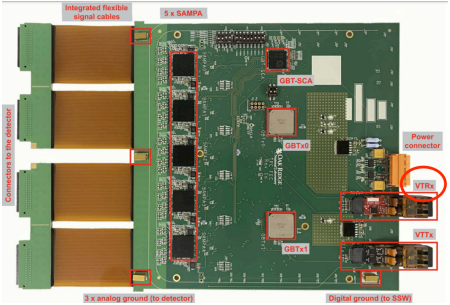






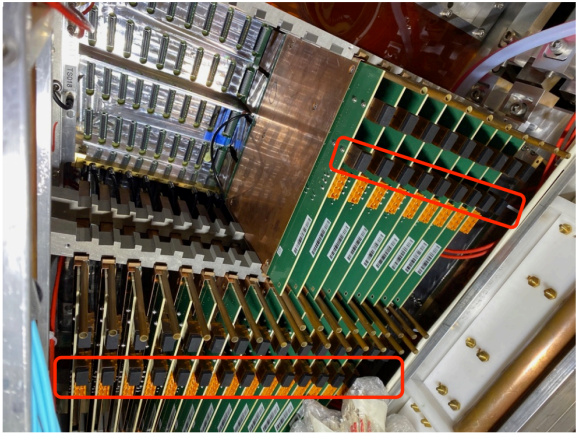
Installation Status – VTRx Failures

[ALICE TPC Collaboration – JINST 16 – 2021]



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

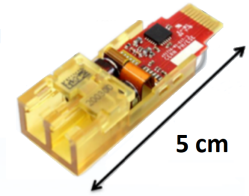
[Christian Lippmann – Personal Comm.]

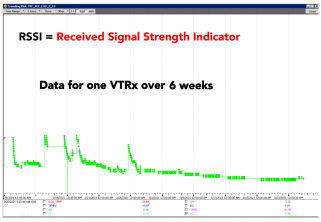


- FECs in an IROC

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.]

Installation Status – VTRx Failures

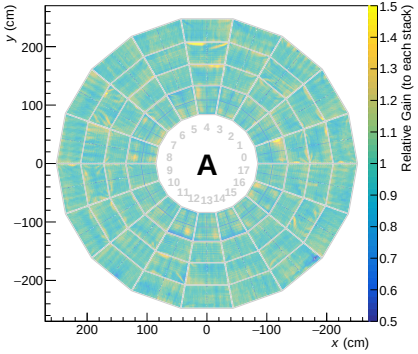
- Reason: Epoxy not cured well during production
- If it gets warm ⇒ Outgassing
- Fibre connection becomes less transparent
- RSSI decreases

- 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.]

Full Gain Map

A-Side



C-Side