Common mode and ion tail analysis of the GEM upgrade of the ALICE TPC

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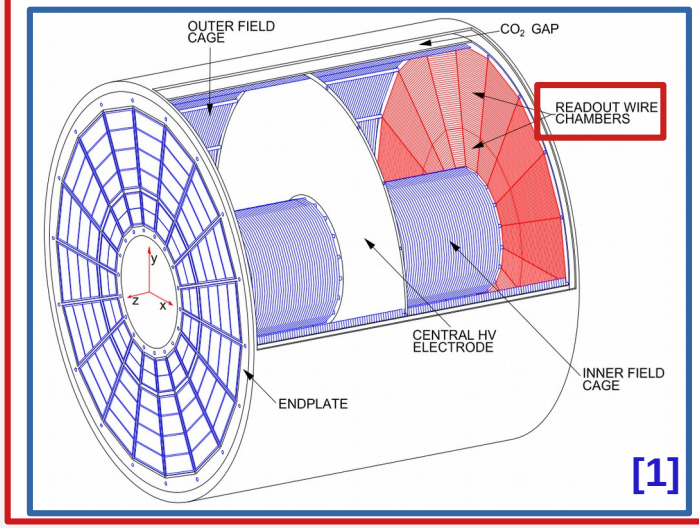
Outline of presentation

- **Introduction**
  - The GEM upgrade of the ALICE TPC
  - Common mode and ion tail in GEMs
  - The ALICE TPC laser system
- **Common-mode analysis**
  - Results
  - ROOT interactive framework demonstration
- **Ion-tail analysis**
  - Induction field scan results
  - Two ion type contributions investigation

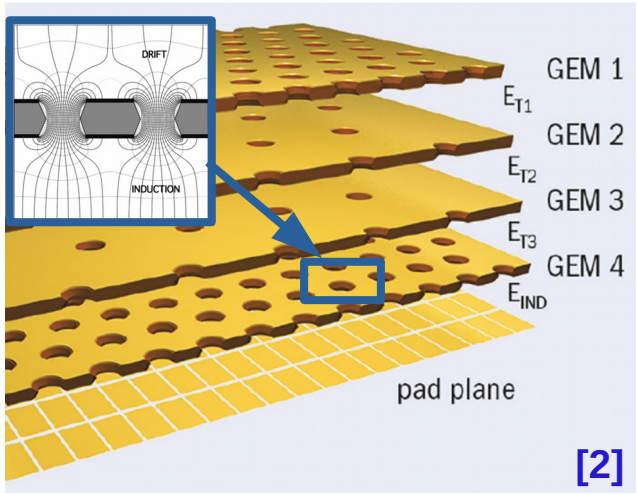
The GEM upgrade of the ALICE TPC

The MWPC-based readout system of the ALICE TPC was upgraded to a GEM-based for Run 3

ALICE TPC (Time Projection Chamber)

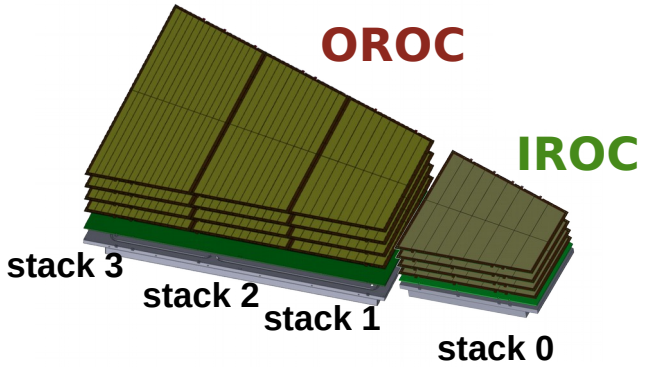


ALICE TPC GEMs (Gas Electron Multipliers)



ALICE TPC ROCs (Readout Chambers)

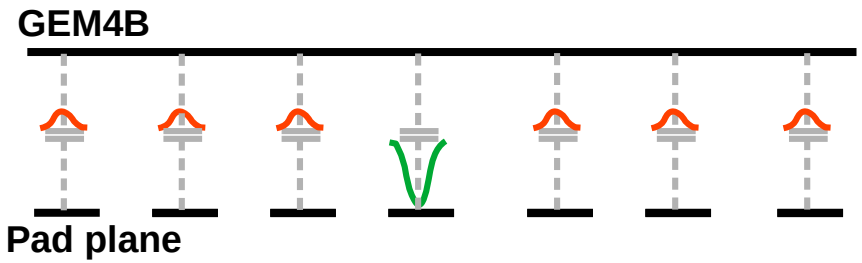
- A sector consists of an **IROC**, **OROC**
- An OROC consists of 3 stacks



- **Before operation in the cavern, the TPC was pre-commissioned in the cleanroom**
- **Collected laser data to study the common mode and ion tail**

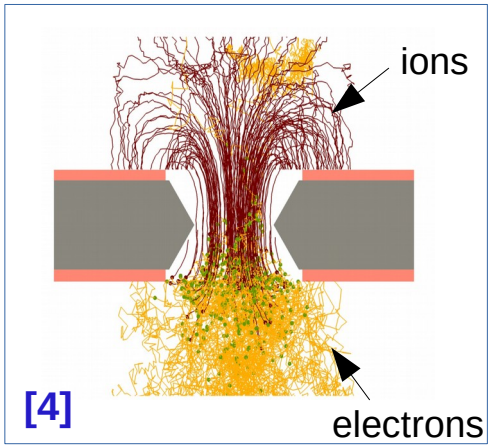
Common mode and ion tail in GEMs

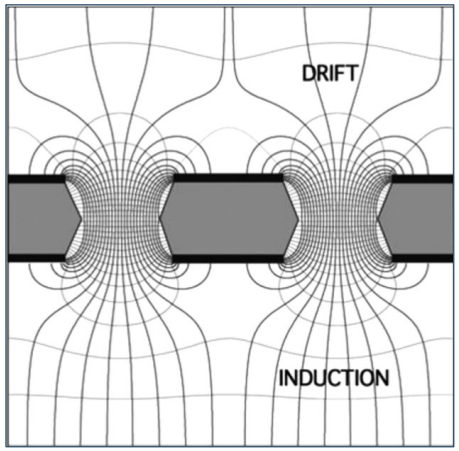
Common mode



- Result of **capacitive coupling** between the GEM foils and the pad plane
- When a **“real” signal** (due to motion of electrons) is detected on a single pad, a **“capacitive” signal** of opposite polarity is **simultaneously** created on all pads of the same stack.

Ion tail

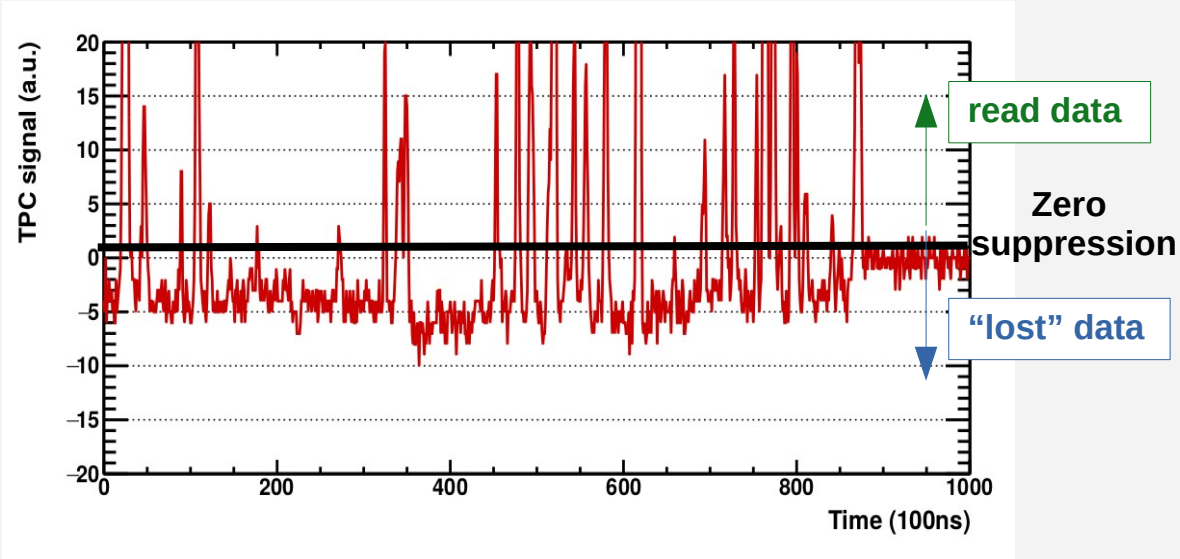




- Ions created in ionization processes contribute to the measured signal

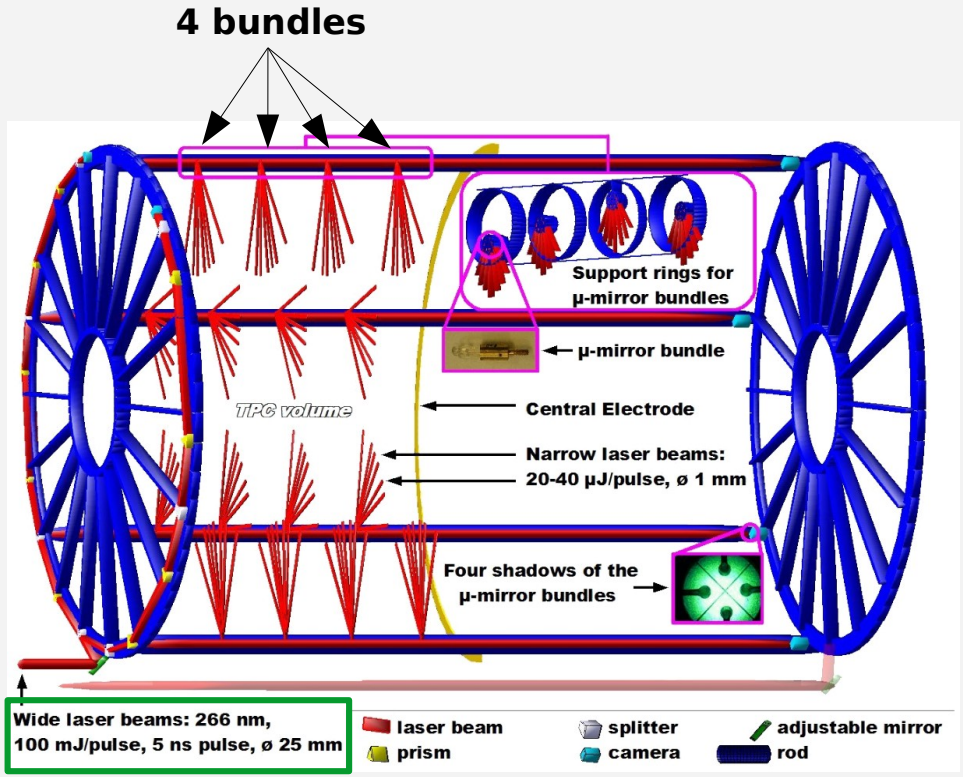
Importance of common mode and ion tail corrections

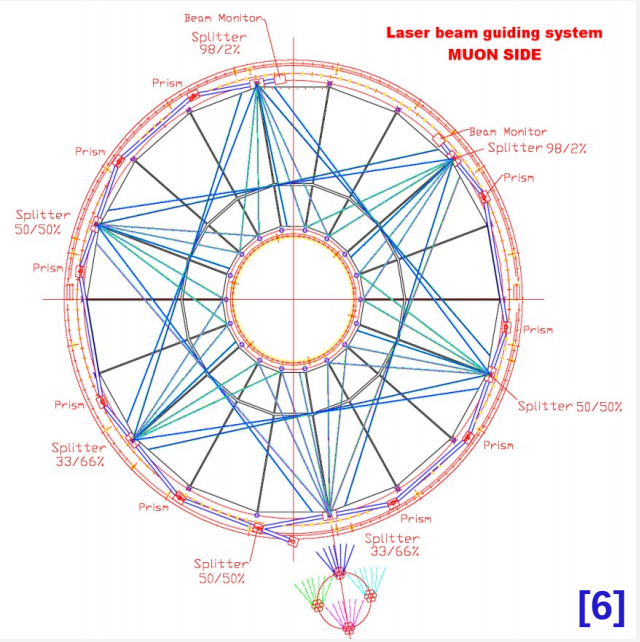
Simulation of a pad signal for a central Pb-Pb event
where only the common-mode effect is implemented **[5]**



- The two effects result in significant cluster loss, as well as deterioration of the d*E*/d*x* and cluster position resolution
- **Goal: understand the effects in the GEM ALICE TPC and determine algorithms for online correction before zero suppression is applied**

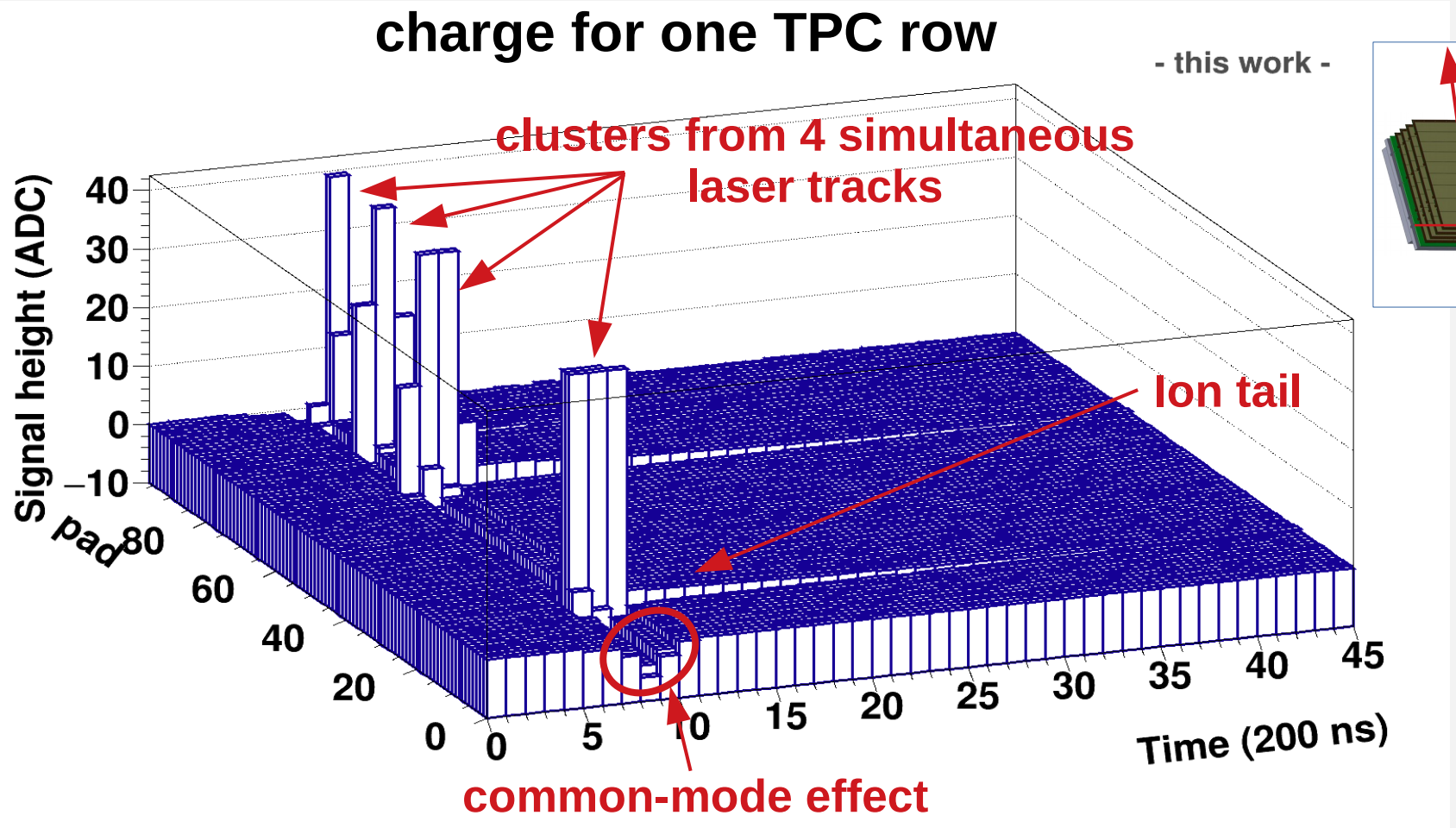
The ALICE TPC laser system





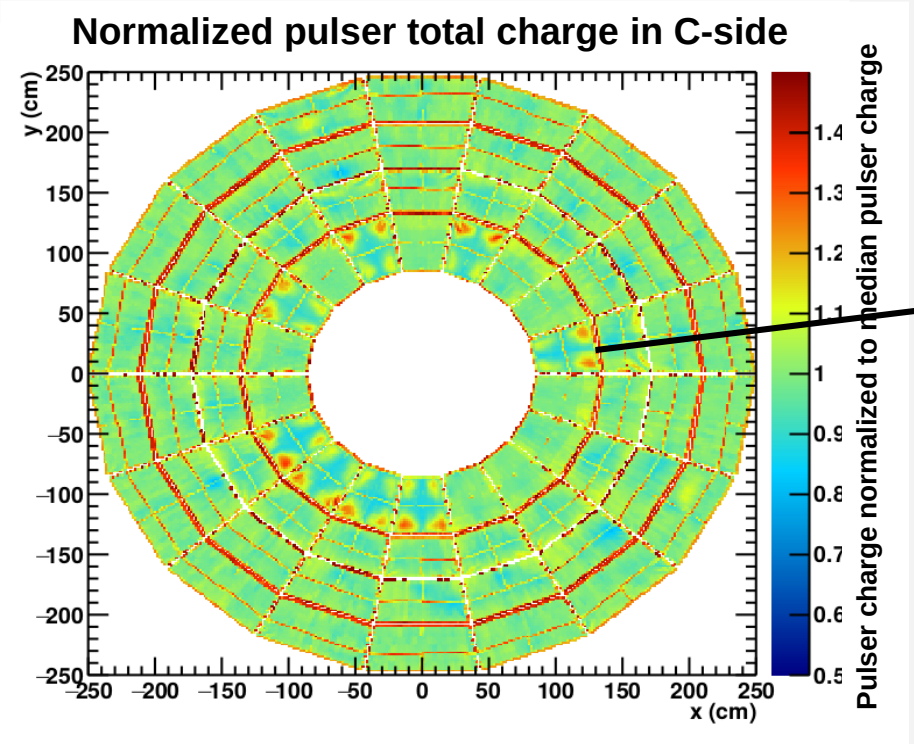
- 336 simultaneous beams
- Used to monitor the gas properties in terms of electron drift velocity and gain
- Ideal tool to study the signal shapes for the common mode and ion tail
- Data-taking campaign during November 2019 – July 2020

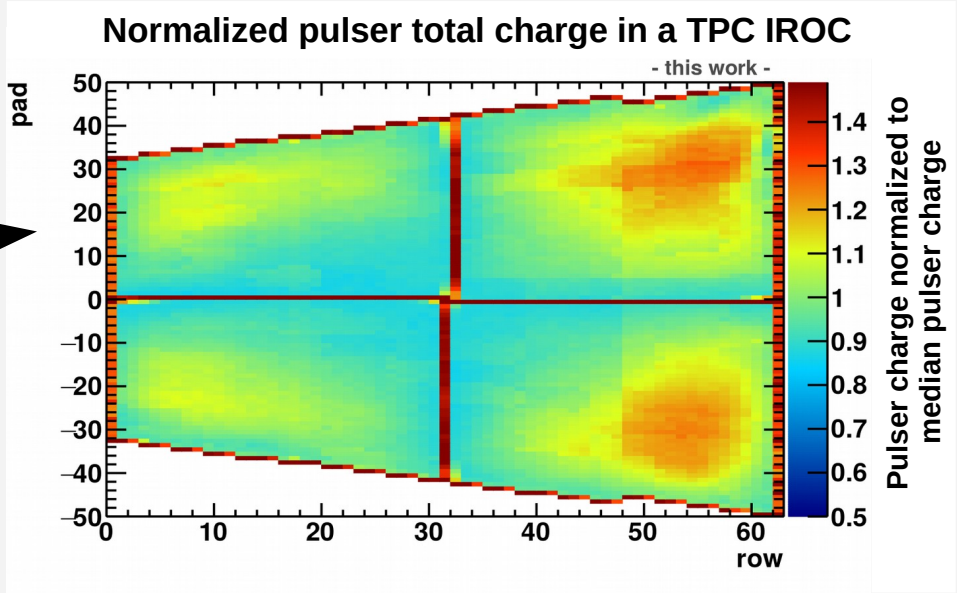
Common mode and ion tail in the GEM ALICE TPC



Correlation of pulser data to common mode/ion tail

- Injection of pulse on GEM4B induces a signal on the pad plane by capacitive coupling
- Ideally the pulser charge measured on the pad plane should scale with stack dimensions





GEM4B to pad plane distance variations affect the induction field/capacitance which in turn affects the ion tail/common mode effect

→ **Use pulser maps in common mode and ion tail correction algorithms**

Common-mode analysis

Common-mode analysis – strategy

(1) Understand the physics:

- Perform the machine learning Random Forest algorithm on

$$\text{Common-mode fraction (CF)} = \frac{\text{pad common-mode charge}}{\text{average laser charge in stack}}$$

Possible dependencies:

- **Normalized pulser charge (→ pad-by-pad capacitance variations)**
- **Stack area (→ capacitance)**
- Average positive charge in stack
- Number of signal pads

} **Account for missing charge**

- Bundle (diffusion)
- Accuracy in pedestal calculation
- Beam (cluster shape)
- ….

(2) Construct FPGA-based online correction algorithms

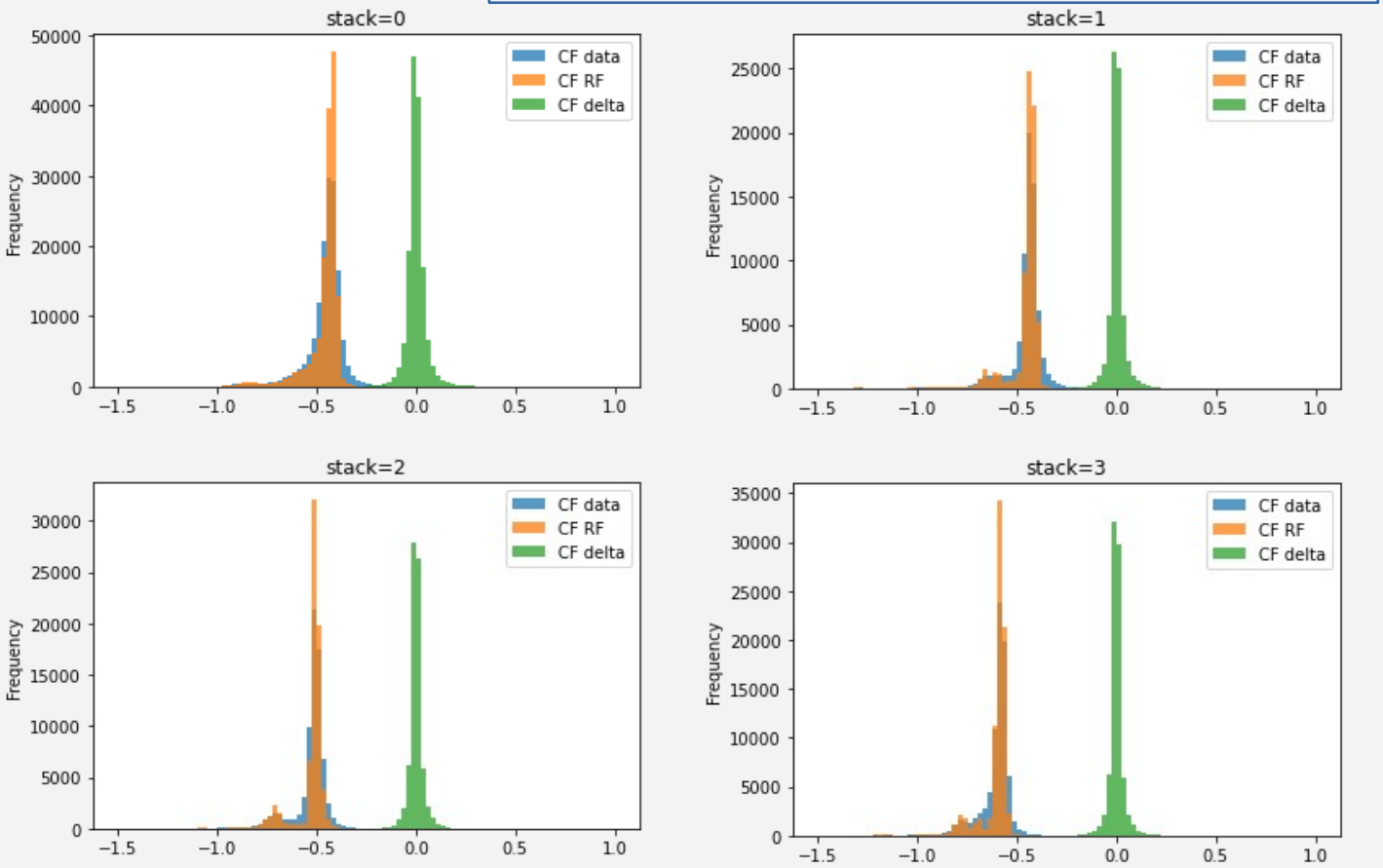
Simple linear models with parameters available at the online stage

Random Forest output

$$\text{Common-mode fraction (CF)} = \frac{\text{pad common-mode charge}}{\text{average laser charge in stack}}$$

Relative importance of the parameters

Normalized pulser charge	61.2%
Stack (area)	33.3%
Accuracy in pedestal	1.9%
Number of signal pads	1.5%
Average positive signal	1.1%
Bundle	0.9%



- CF scales with stack area
- Strong dependence of CF on the pulser charge → next slide

stack	0	1	2	3
Area (mm^2)	171154	174853	231284	294836

Random Forest output

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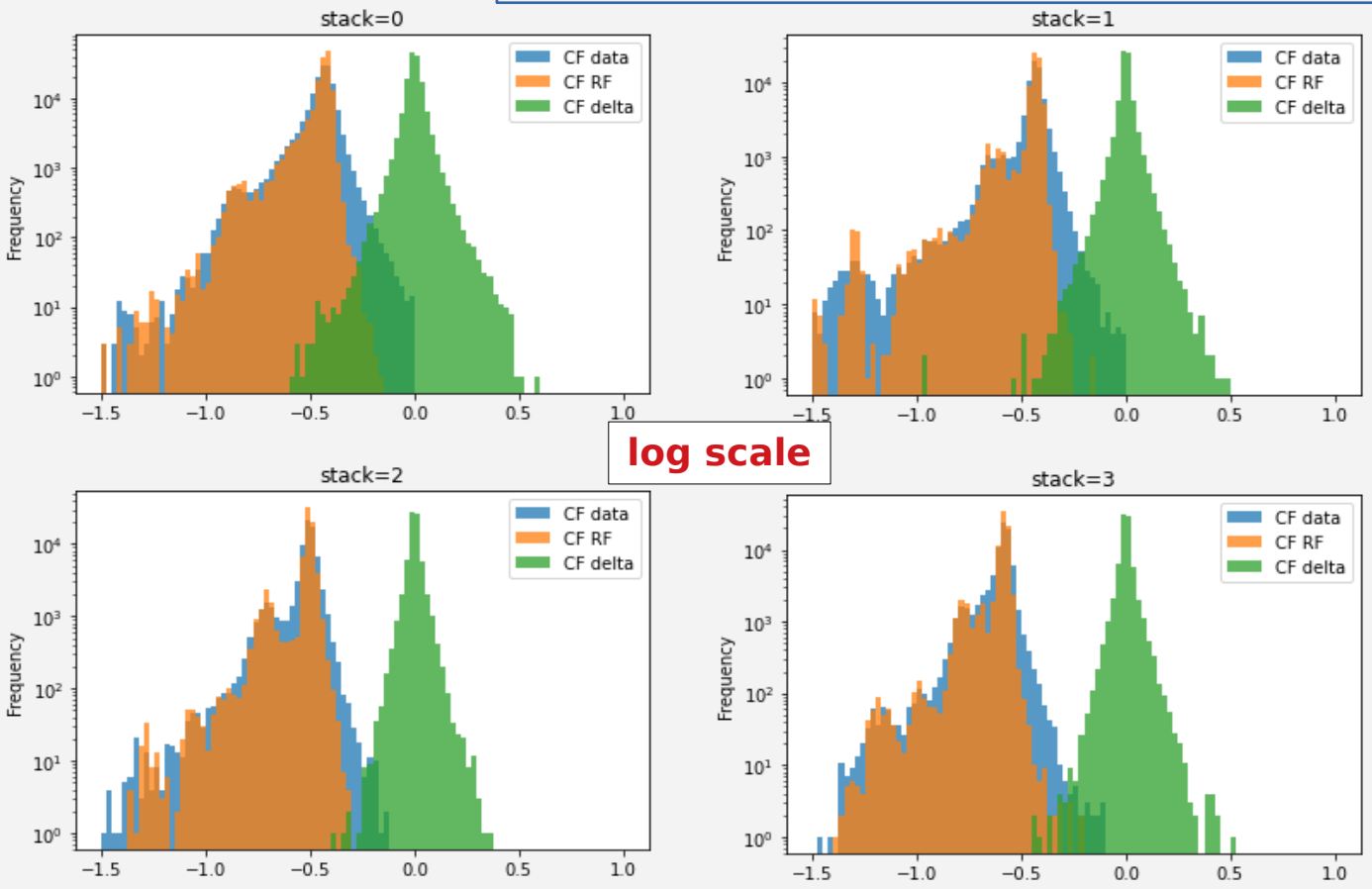
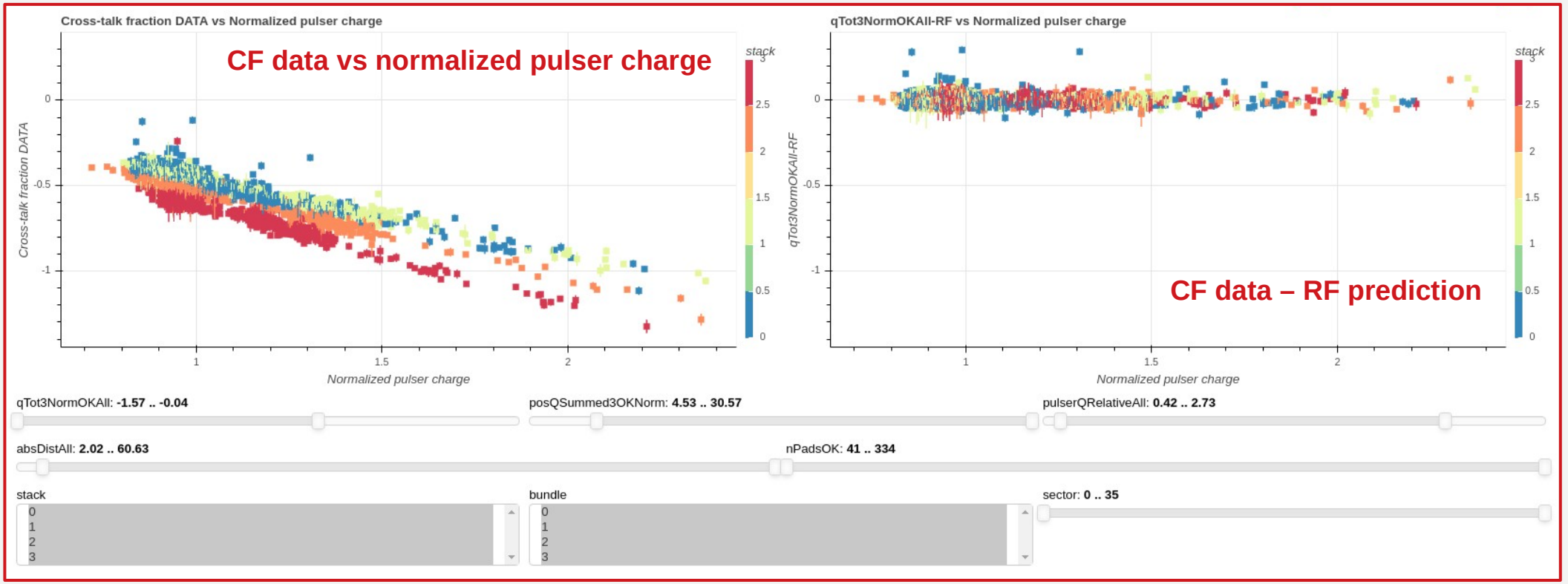


- CF scales with stack area
- Strong dependence of CF on the pulser charge → next slide
- Small differences in data-RF
- Origin of outliers understood via ROOT interactive

ROOT Interactive visualization for common mode effect



[Video demonstration of ROOT interactive for common mode effect]
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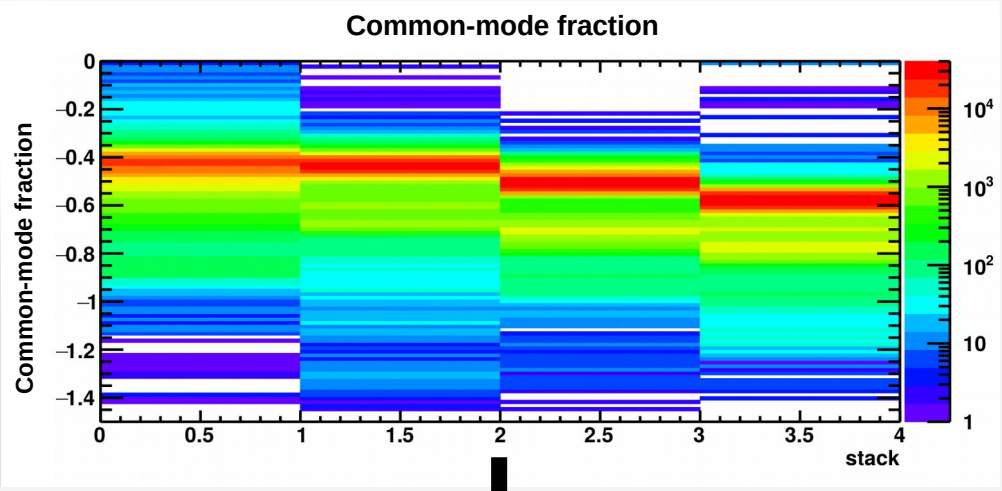
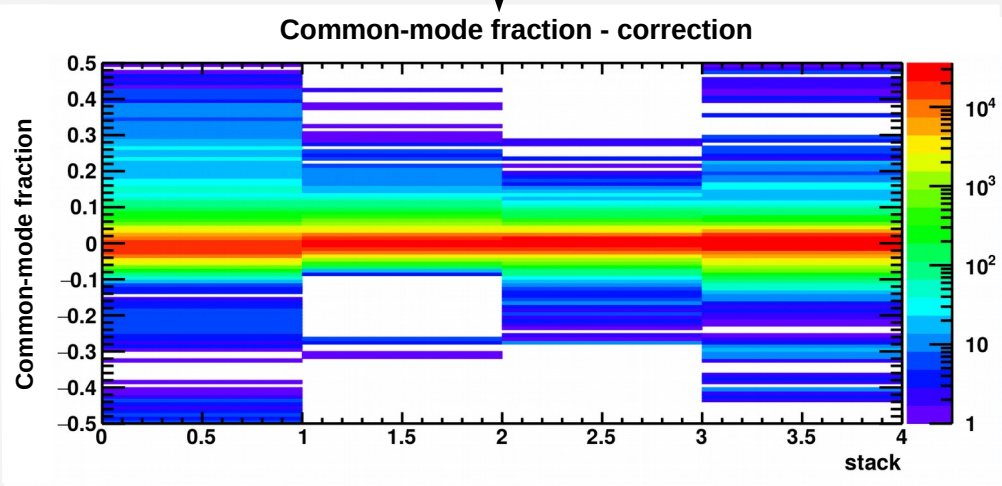
- Interactive tool to understand the effect and locate the origin of outliers
- Strong (linear) dependence of CF on the normalized pulser charge
- Slope increases with increasing stack index (→ area)

Linear models

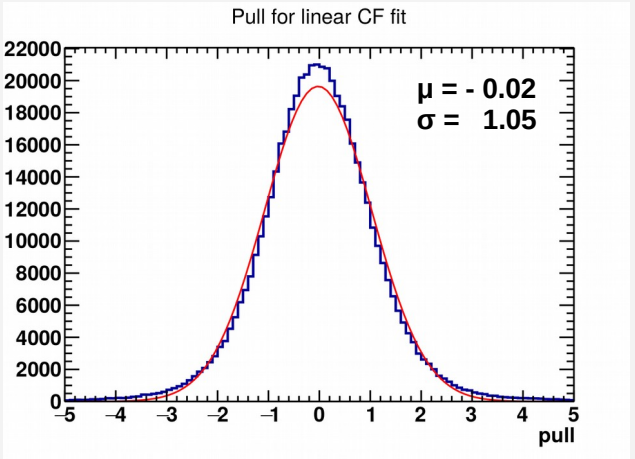




Perform **linear** fits for online correction with parameters available at the online stage:

- Normalized pulser charge
- Stack area
- Average laser signal in stack
- Number of signal pads

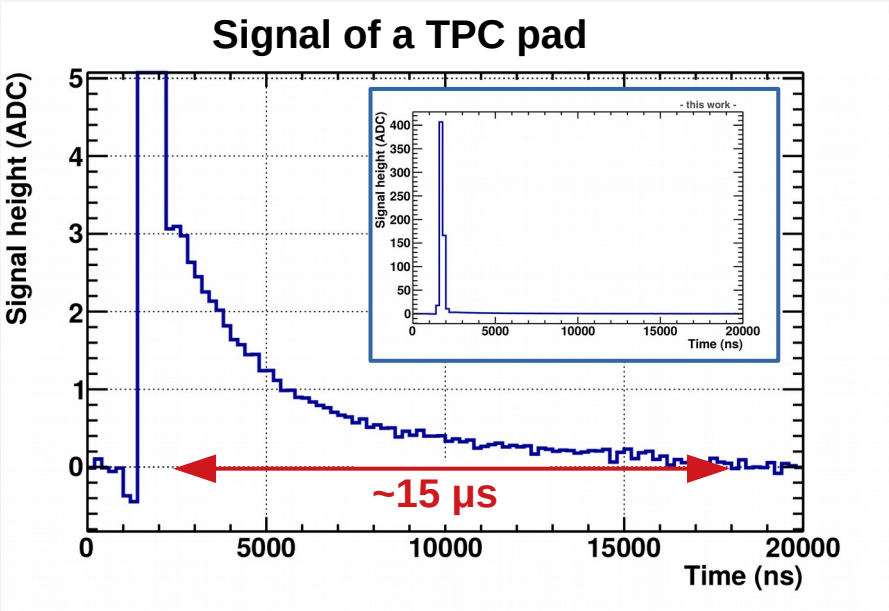
$$\text{pull} = \frac{(\text{CF data}) - (\text{CF fit})}{\text{error due to noise}}$$

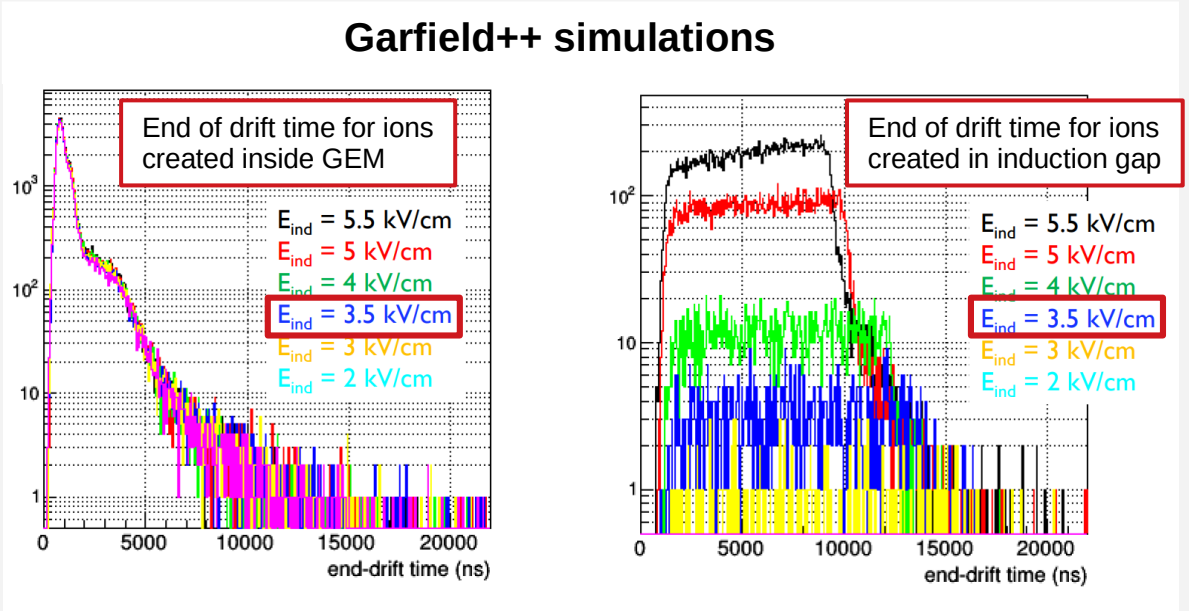


Ion-tail analysis

Ion tail effect and demonstration via the laser data

- Long tail after signal due to ions drifting away from the pad plane





- **(tail max) / (electron signal) ~ 0.5%**
- **(tail integral) / (electron signal) ~ 9.0%**
- **MWPC-based TPC in Run 1&2 ~ 50 %**

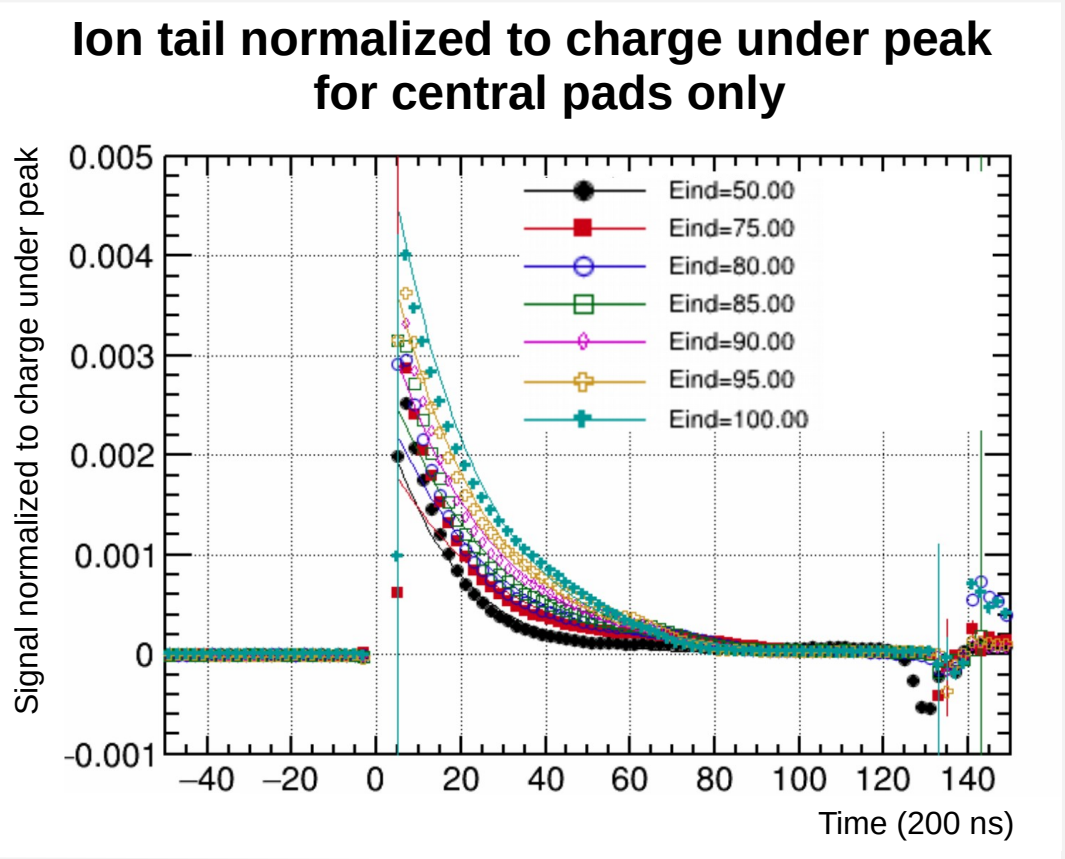
Two types of ions contributing to the tail:

- Created inside GEM4 (fast component)
- Created in the induction gap (slow component)

Investigation of the tail properties by varying the induction field value (E_{ind}) from 50% to 100% (nominal value of 3.5 kV/cm) in steps of 5%.

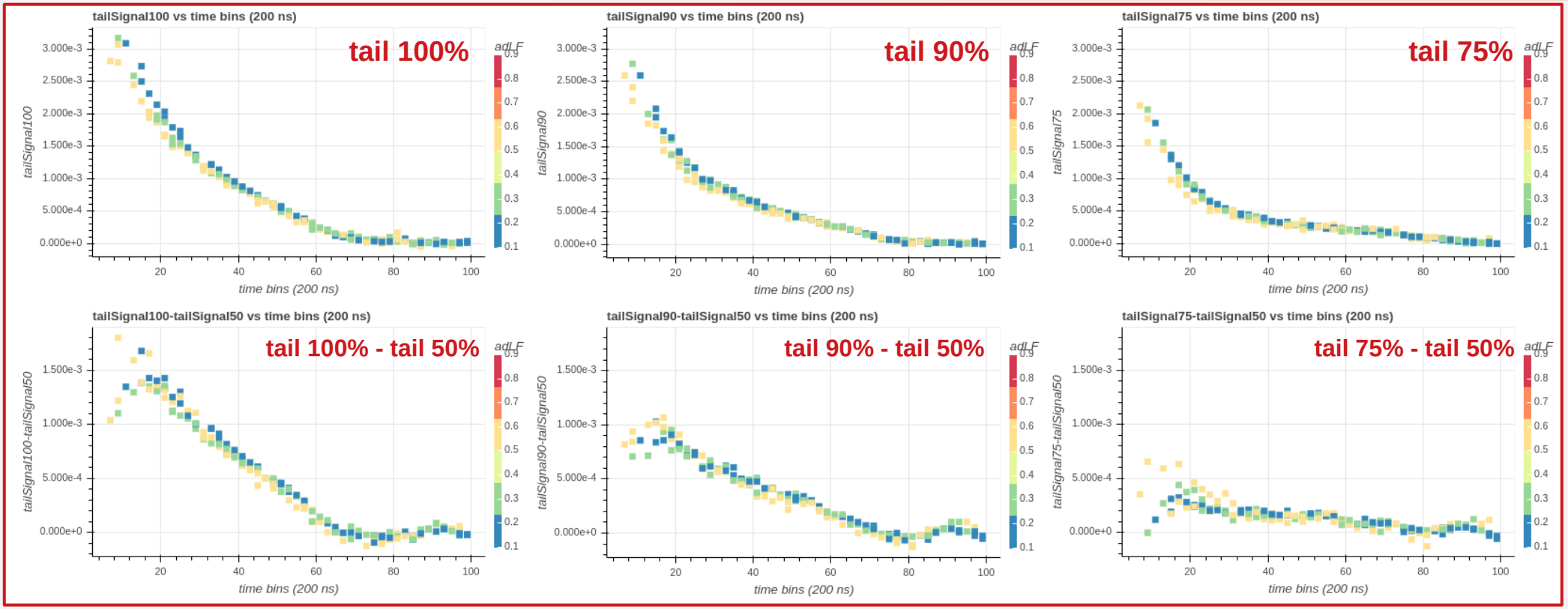
Results of induction field scan

- The tail properties change with changing Eind
  - The tail duration is smaller for E_{ind} = 100%
  - The tail integral is the largest for E_{ind} = 100%
- Differential analysis via ML ongoing. Parameters:
  - Distance of the pad from the COG of cluster
  - Track inclination (→ cluster shape)
  - Bundle (→ diffusion)
  - Pulser charge (→ effective field variations)
  - …



Nominal setting (100%): 3.5 kV/cm

Ion-type contributions with ROOT interactive



- At E_{ind}=50% only contributions from ions produced in the GEM expected

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- Estimate contribution from ions produced in the induction gap at each E_{ind} setting via the difference from the 50% tail
- A triangular shape is observed – as expected for uniformly produced ions in the induction gap
  - Correction needed to account for the ion drift velocity variations – assuming linear dependence

Summary of analysis & outlook

- The **common-mode effect** in the GEM-based ALICE TPC was studied using the laser calibration system
  - Dependencies understood using machine learning
  - Simple linear models are suitable to correct for the effect online

- An **ion tail** has been observed
  - Its dependence on the induction field indicates two contributions which we can disentangle via machine learning:
    - Ions created in the amplification region at the last GEM
    - Ions created in the induction gap

Thank you for your attention
Questions?

References

[1] ALICE TPC Collaboration. “The ALICE TPC, a large 3-dimensional tracking device with fast readout for ultra-high multiplicity events”. In: Nucl. Instr. Meth. A 622 (2010), p. 316.

[2] F. Sauli. The gas electron multiplier (GEM): Operating principles and applications. Nuclear Instruments and Methods in Physics Research A 805 (2016) 2–2424

[3] ALICE TPC Collaboration, Technical Design Report for the Upgrade of the ALICE Time Projection Chamber, CERN-LHCC-2013-020

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[5] M. Arslandok, PhD thesis, Event-by-Event Identified Particle Ratio Fluctuations in Pb–Pb Collisions with ALICE

[6] G. Renault, B. S. Nielsen, J. Westergaard and J. J. GaardhOJe, The laser of the ALICE time projection chamber, 2007