d*E*/d*x* Resolution Studies of a Pre-Production Readout Chamber for the ALICE GEM TPC

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E62 Dense and Strange Hadronic Matter

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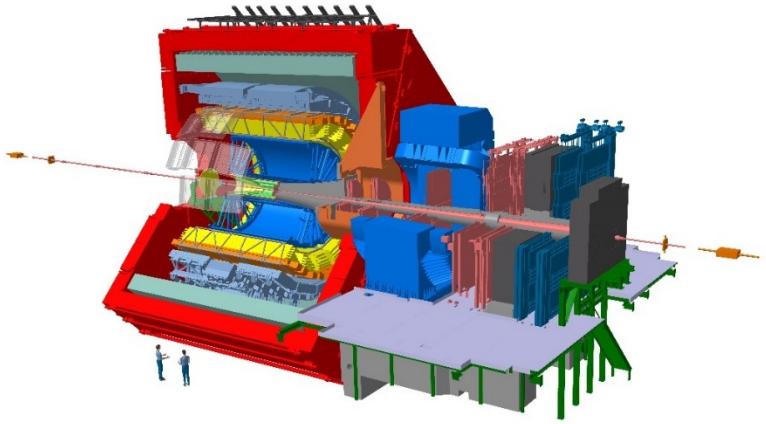
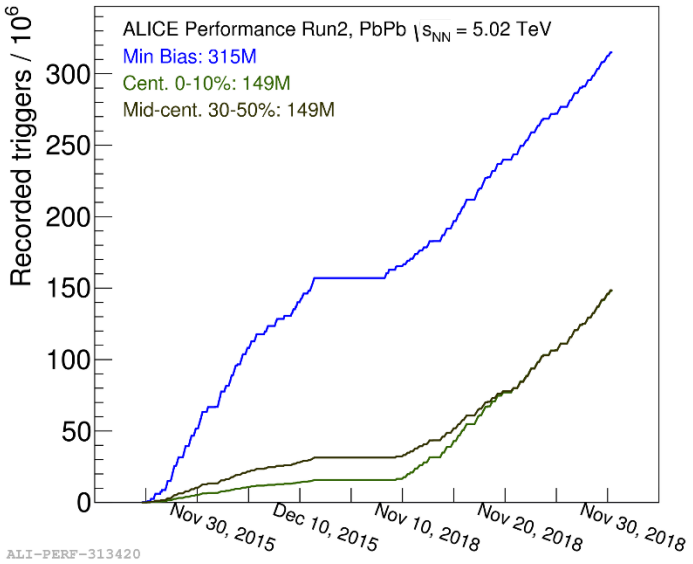
The ALICE Experiment

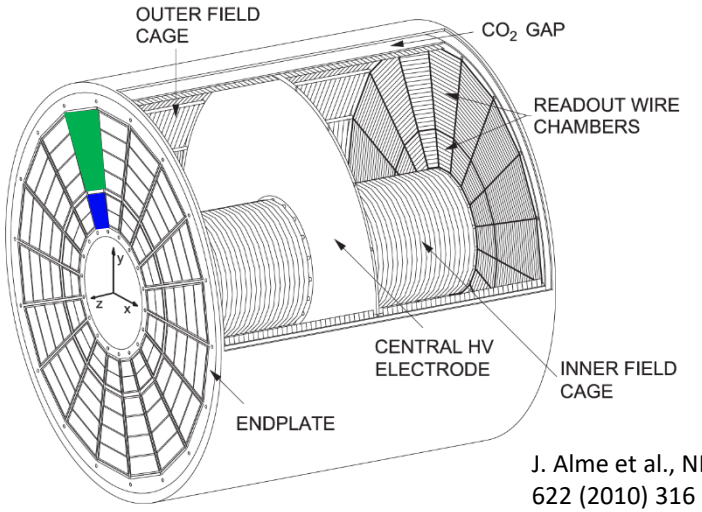
- A Large Ion Collider Experiment
- Specialized heavy-ion experiment at the LHC
- Particle identification and tracking in high multiplicity heavy-ion collisions
- Main goal: characterize the physical properties of the Quark-Gluon Plasma
- Run 2 successfully concluded with a rich data set



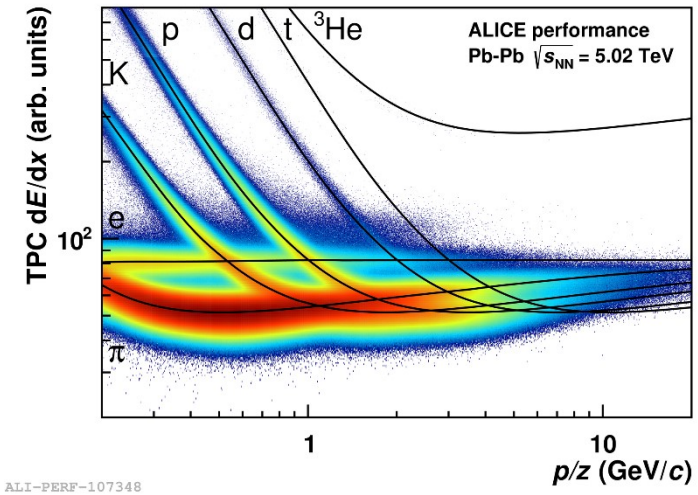


ALICE TPC

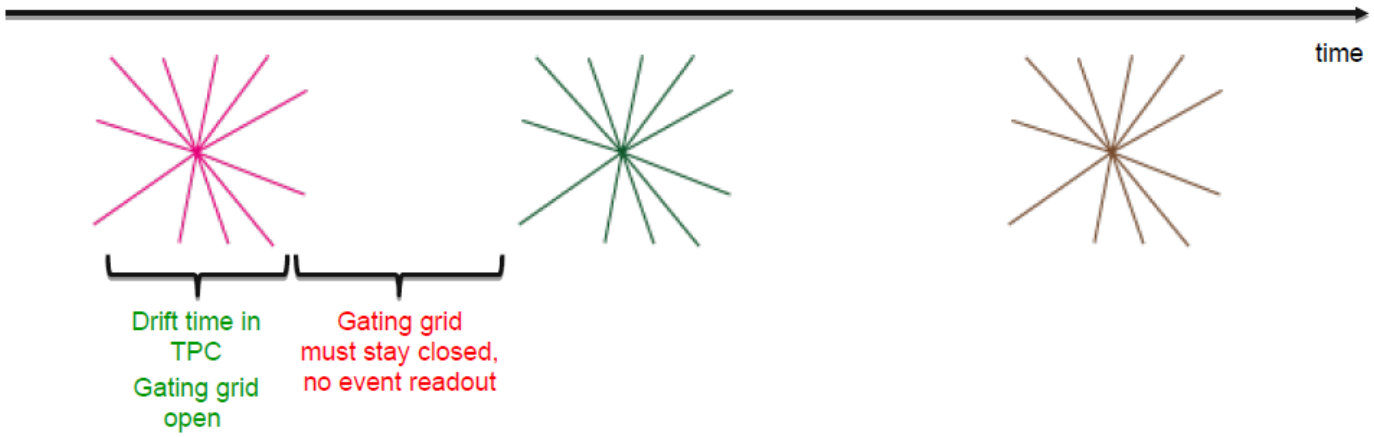
- Time Projection Chamber is main tracking and particle identification device
  - Specific energy loss d*E*/d*x*
- 5 m diameter, 5 m length
- 90 m^3 gas volume
- Largest TPC in the world
- Gas: Ne-CO_2 (90-10), Ar-CO_2(90-10), Ne-CO_2-N_2 (90-10-5)
- Maximum drift time: ~100 µs
- Gated MWPC-based readout in Run 1 and Run 2



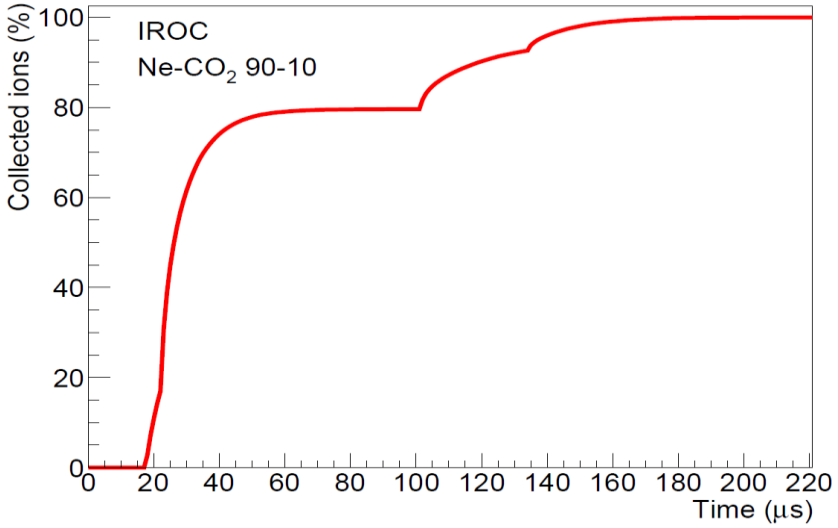
J. Alme et al., NIM A 622 (2010) 316



Operation with gated MWPCs

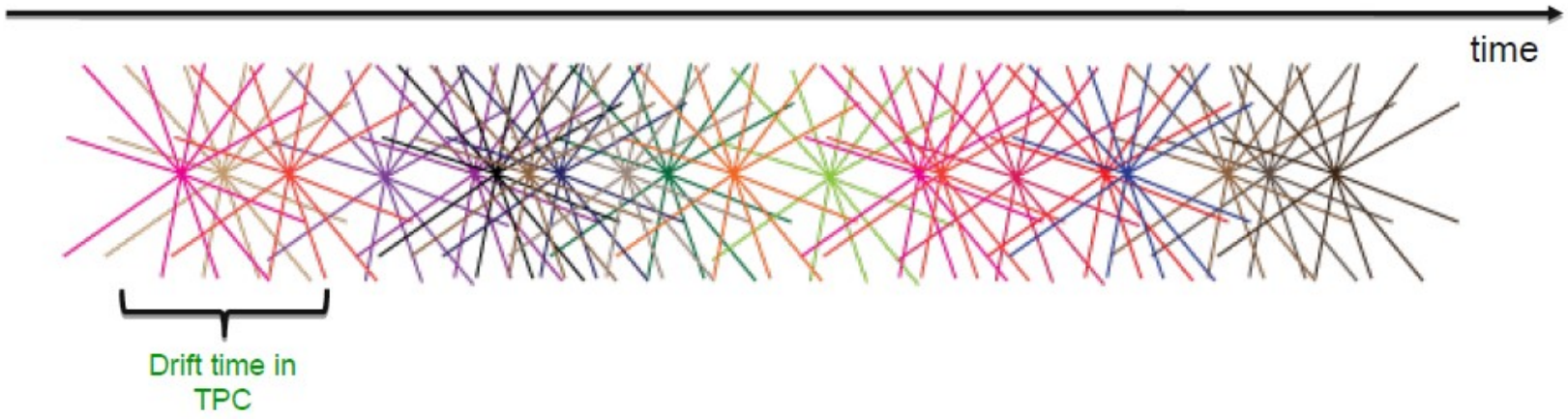


- Gating grid needed to prevent ions from drifting to the active volume
  - Ion back flow (IBF)introduces distortions to drift field, decreases tracking performance
- Electron drift time ~100 µs
- Gating grid closure for ~200 µs
  - ➢ Rate is limited to ~3 kHz
- 50 kHz interaction rate in Pb-Pb envisaged in Run 3
  - ➢ Continuous readout needed
- Alternative solution has to be found to reduce IBF



E. Hellbär

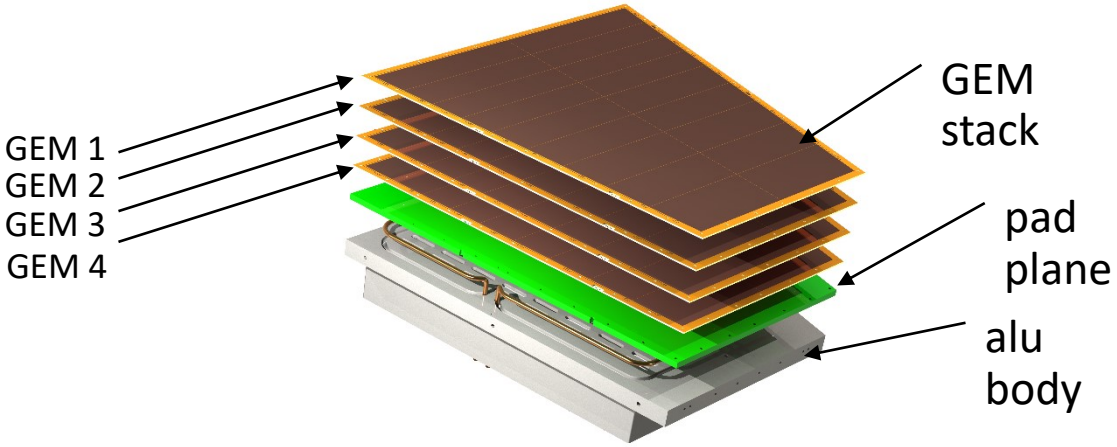
GEM-based continuous readout

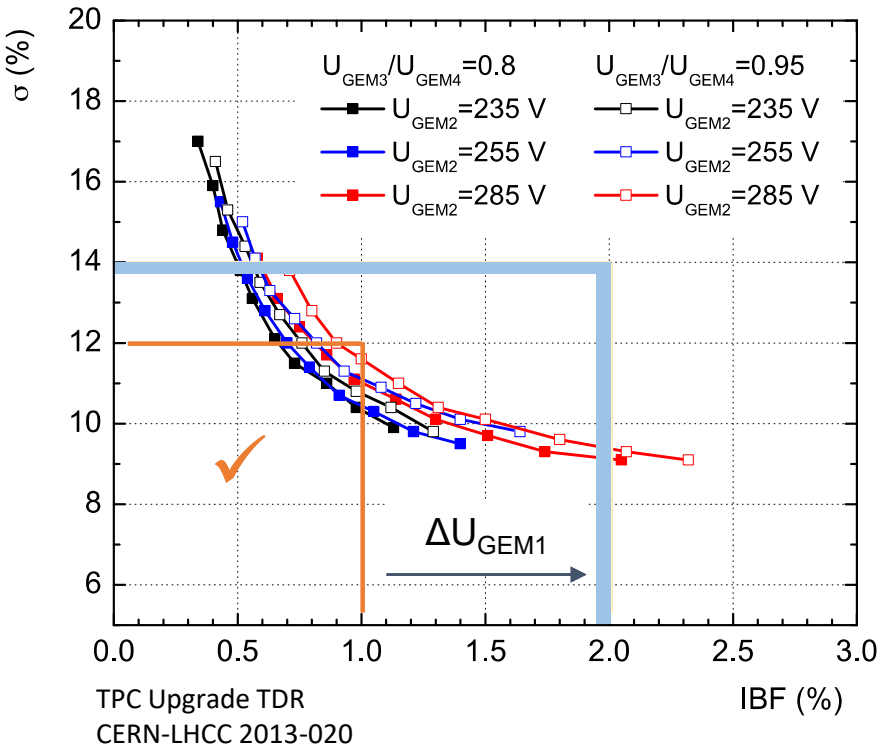


- Electron drift time ~100 µs and 50 kHz interaction rate (20 µs between events)
  - Pileup of 5 events on average
- Abandon gated MWPCs and introduce GEM-based readout
- Intrinsic IBF suppression
  - No gating needed
  - Continuous readout possible

A 4-GEM Inner Readout Chamber

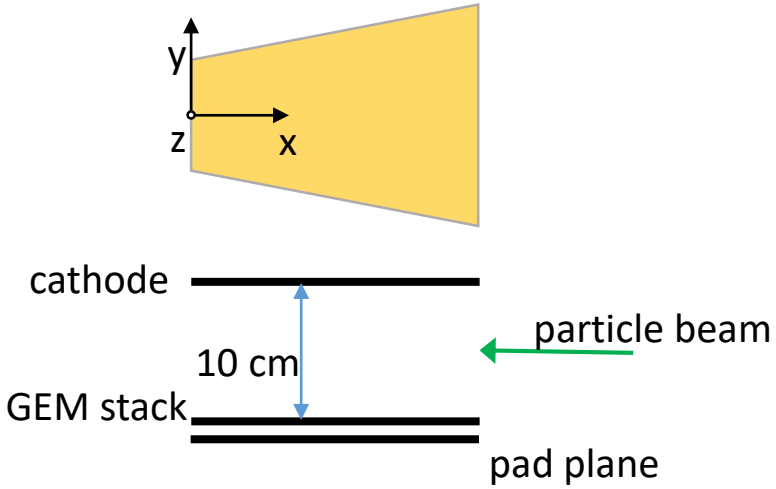
- TPC must maintain tracking and PID capabilities
  - Requirements of *IBF* < 1% and σ < 12% for ^{55}Fe
- 4-GEM stack scheme
- d*E*/d*x* resolution of the new readout system has to be verified
  - Already verified with IROC prototype (M. M. Aggarwal et al., Nucl. Instrum. Meth. A903 (2018) 215–223)
  - With pre-production IROC

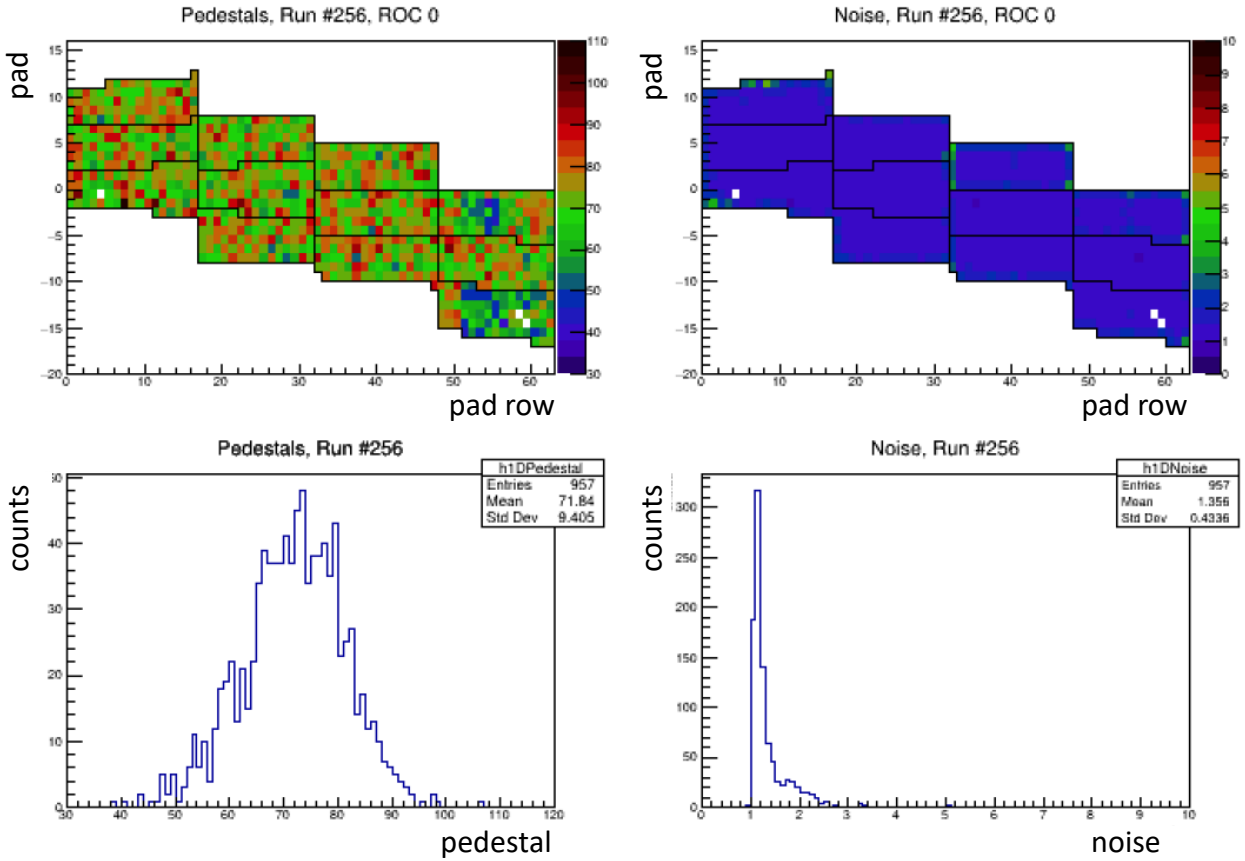




Commissioning

- New Front-End Cards (FEC) with SAMPA ASICs
  - 5 MHz sampling rate
  - Concurrently sample data and transfer data acquired from the detector
  - Handle increased data throughput
  - 6 FECs available at the time of the test beam campaign
- Noise meets requirement of ~1 ADC channel
- ~10 cm drift length in *z*-direction in test box

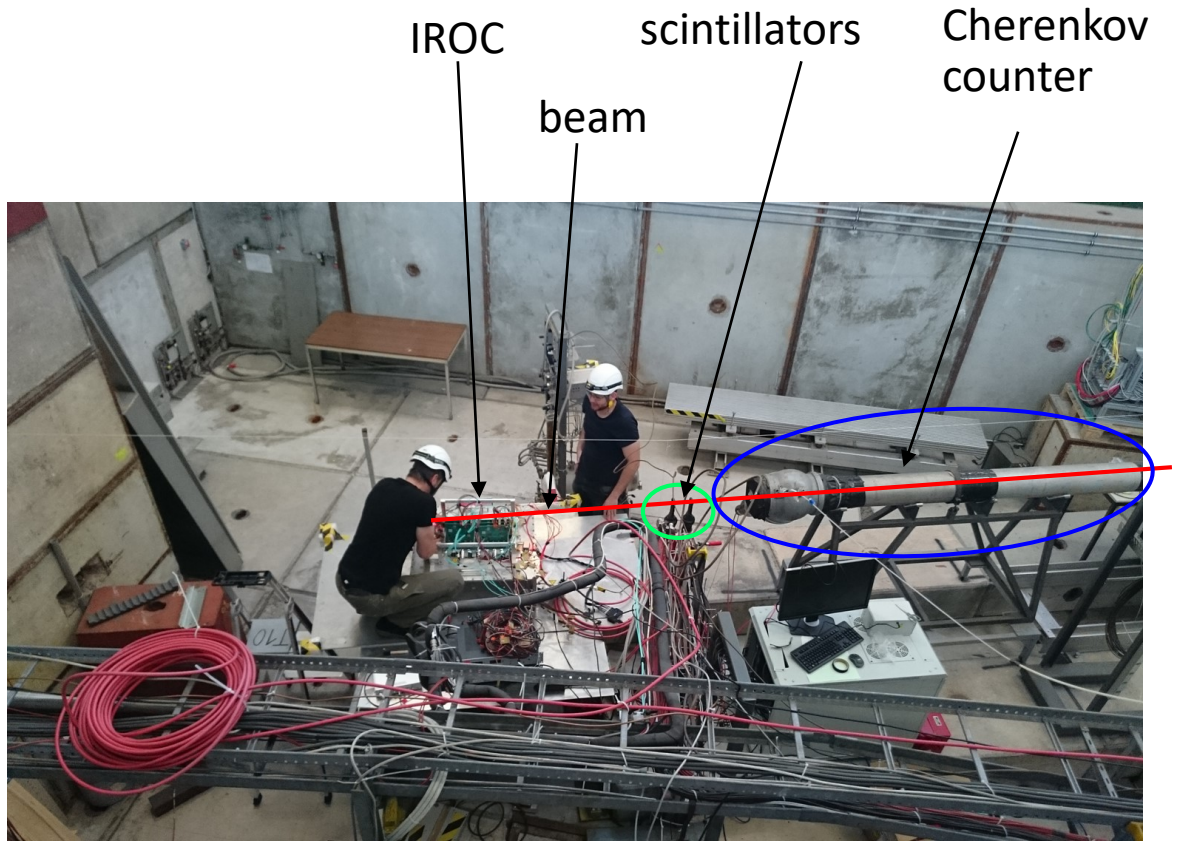




H. Schulte

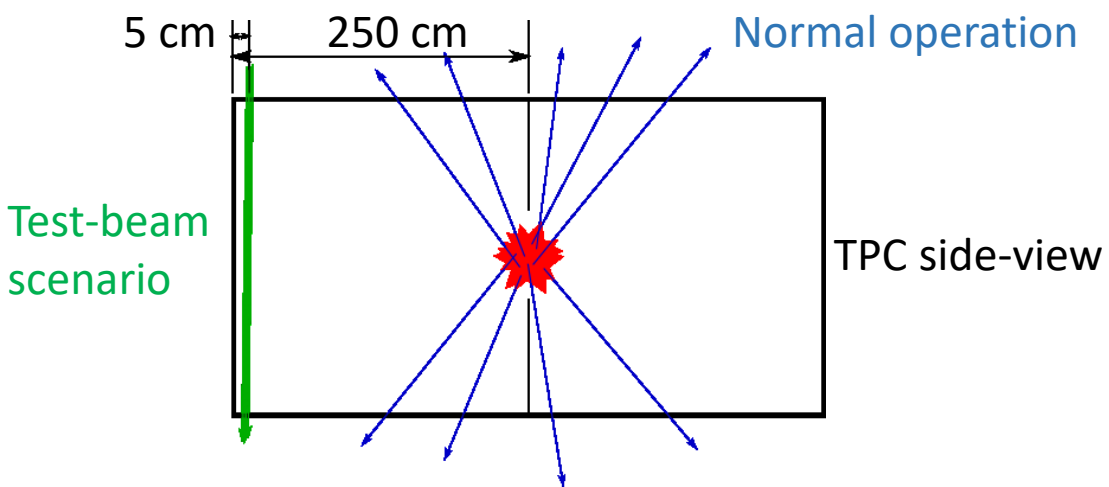
Test-beam setup

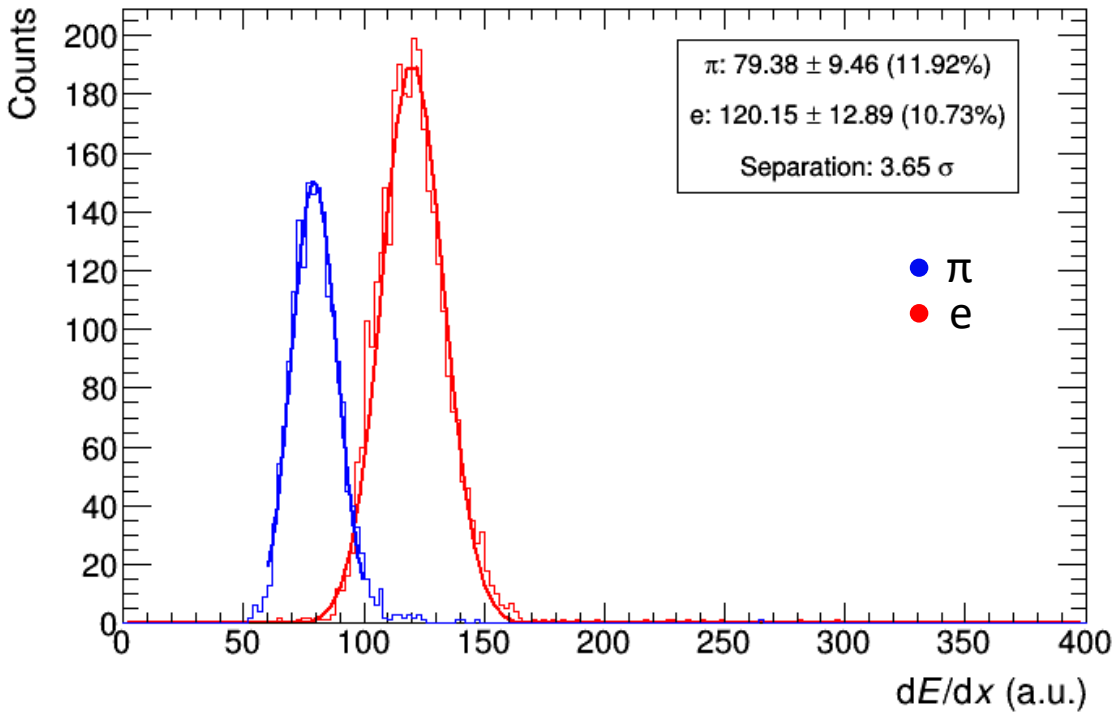
- Test-beam at CERN PS with secondary beam of 1 to 5 GeV/c π^- and e^-
- Cherenkov counter for reference PID
- 11 different HV configurations for GEM amplification stage
  - Different local energy resolution and IBF
- Reconstruction
  - Merge adjacent charges (y- and z-direction) to clusters
  - Linear fit to clusters to obtain tracks
- Analysis conducted with new software framework O^2



d*E*/d*x* resolution

- d*E*/d*x* resolution not representative for TPC performance
  - Short drift length
    - Very small diffusion in *z*-direction
  - Tracks parallel to pad plane
  - Dominated by 5 MHz sampling
- TPC performance in operation not affected by 5 MHz sampling due to diffusion

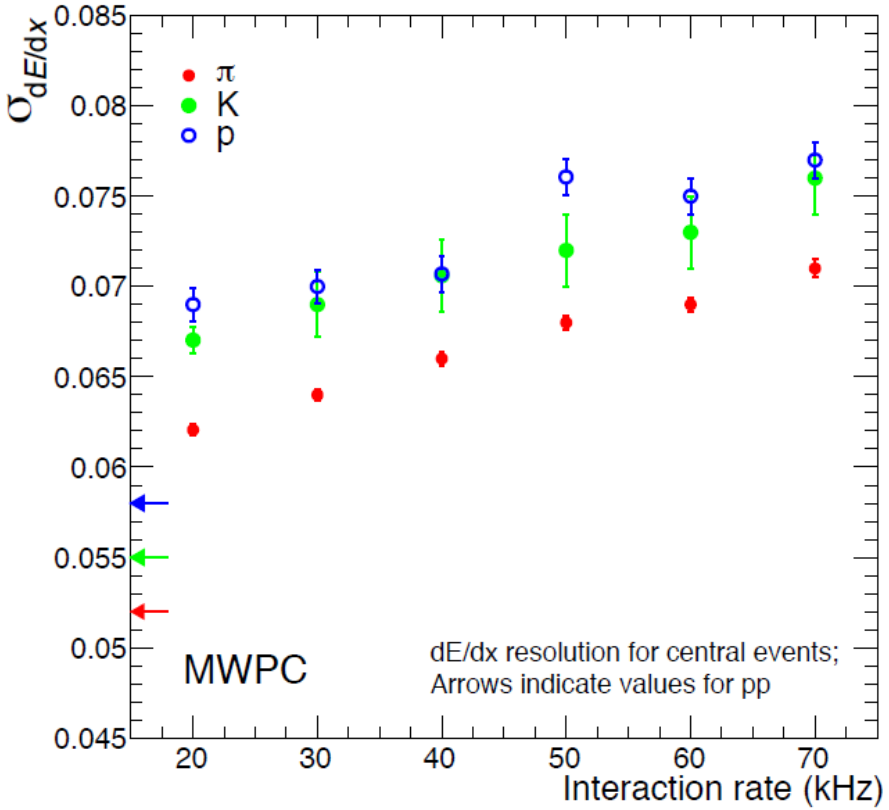


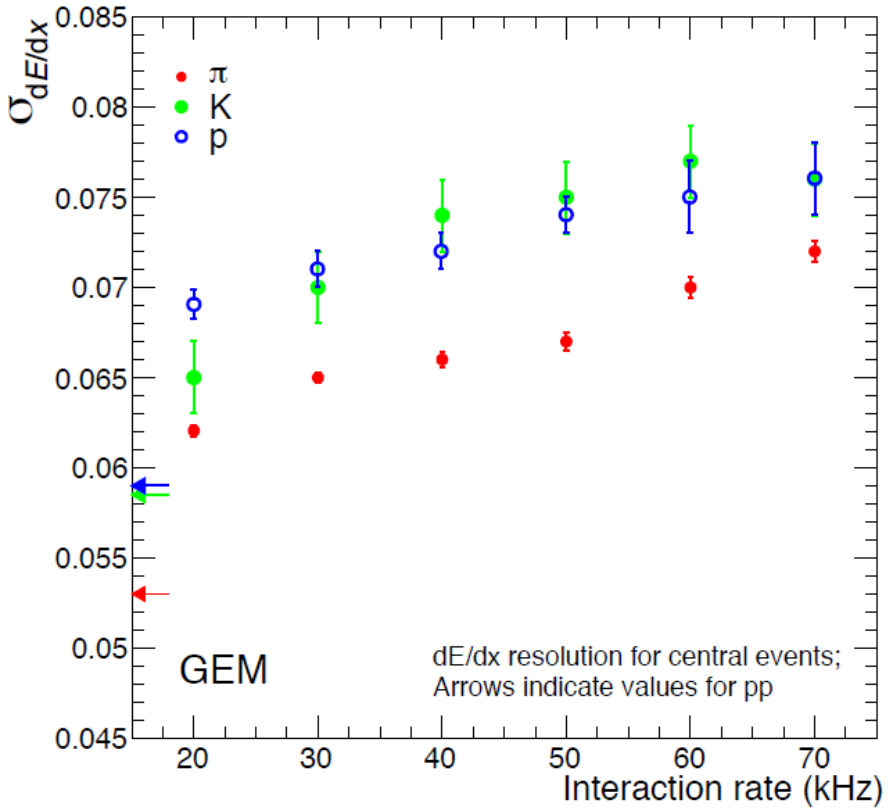


@ 1 GeV/*c* beam momentum, $\sigma(^{55}\mathrm{Fe}) = 10.8\ \%$

$$\text{Separation power} = \frac{2\cdot|\mu_{<\mathrm{d}E/\mathrm{d}x>_e} - \mu_{<\mathrm{d}E/\mathrm{d}x>_\pi}|}{\sigma_{<\mathrm{d}E/\mathrm{d}x>_e} + \sigma_{<\mathrm{d}E/\mathrm{d}x>_\pi}}$$

d*E*/d*x* resolution

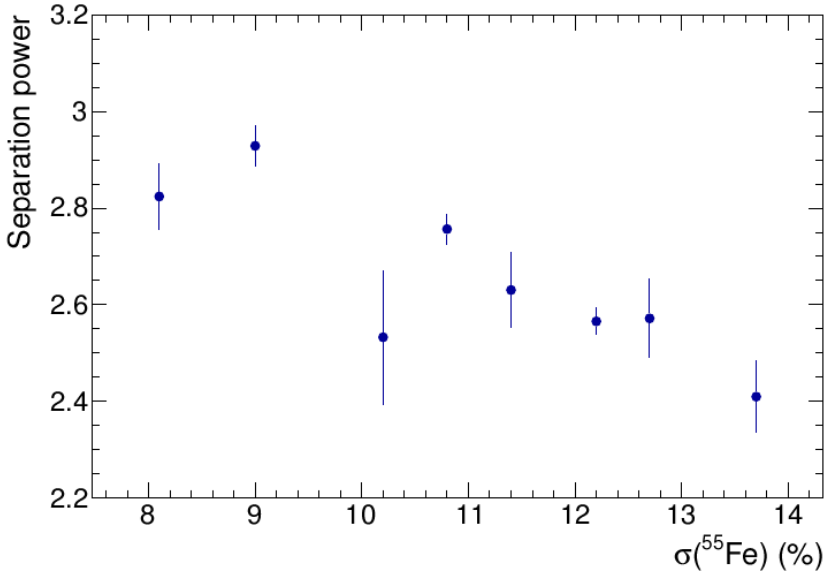


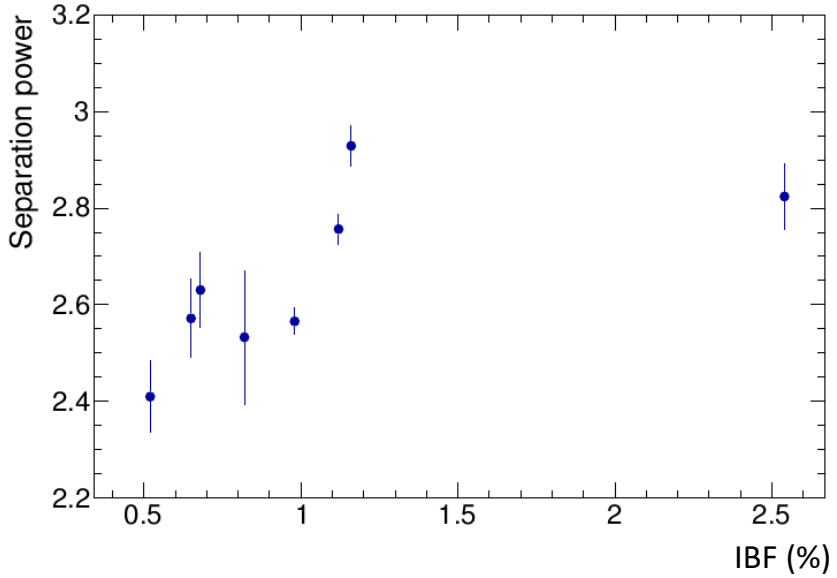


TPC Upgrade TDR
CERN-LHCC 2013-020

- d*E*/d*x* resolution obtained from full scale TPC simulation
- PID performance not compromised by upgrade with GEM-based readout

Separation power





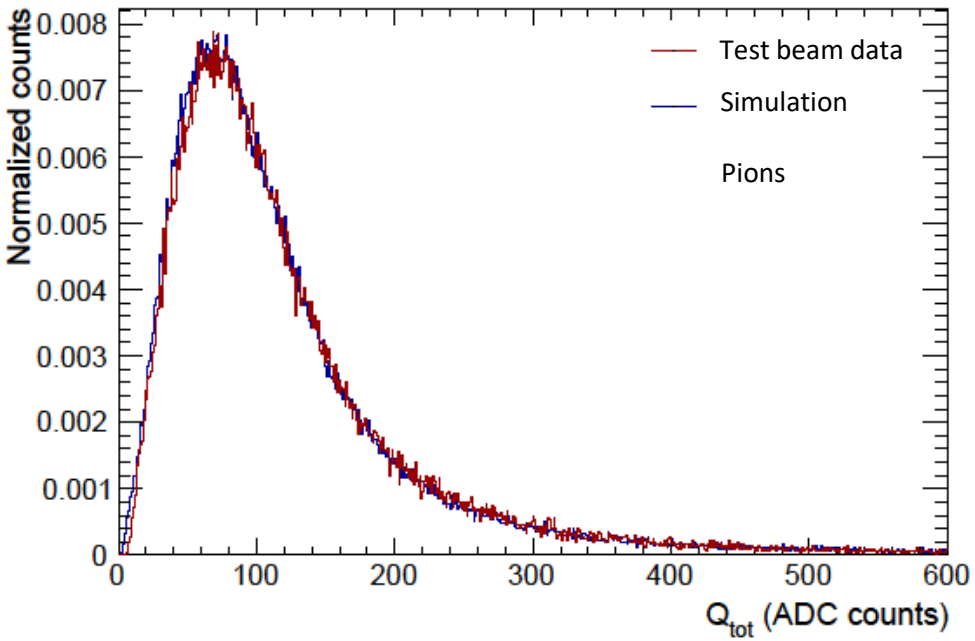
- Separation power at 2 GeV/*c* for different HV settings
- $\sigma(^{55}Fe)$ and IBF heavily depend on voltage accross GEM 1

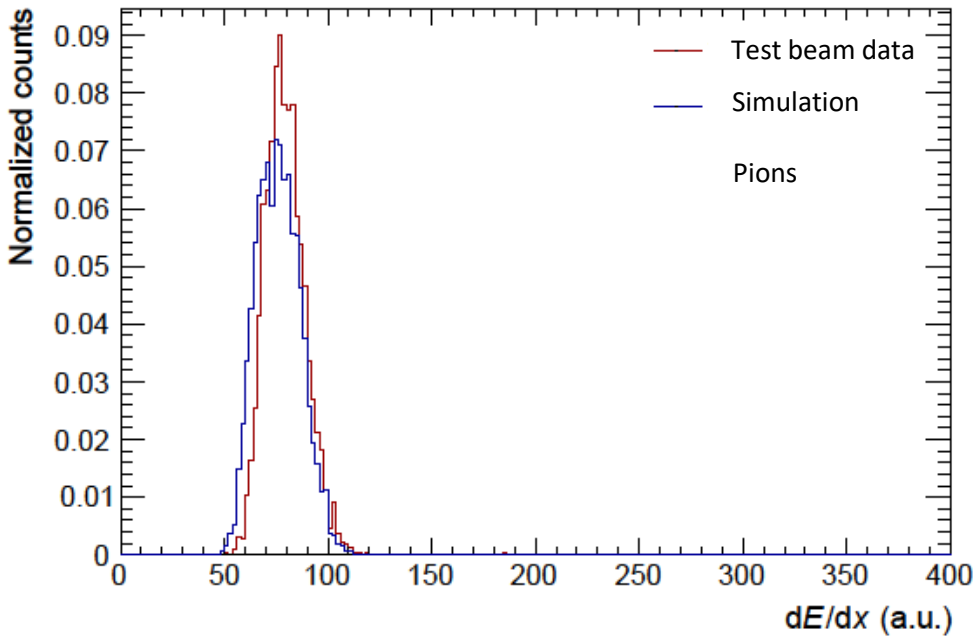
- In general:
  - Low ΔU_{GEM1} → low IBF, high $\sigma(^{55}Fe)$ and vice versa
- PID performance depends on HV setting

Comparison of data and simulation

- Comparison of 2 GeV/*c* pions
- Characteristic observables for signal creation
  - E.g. total cluster charge Q_{tot}
- Charge distribution reproduces measurement very well

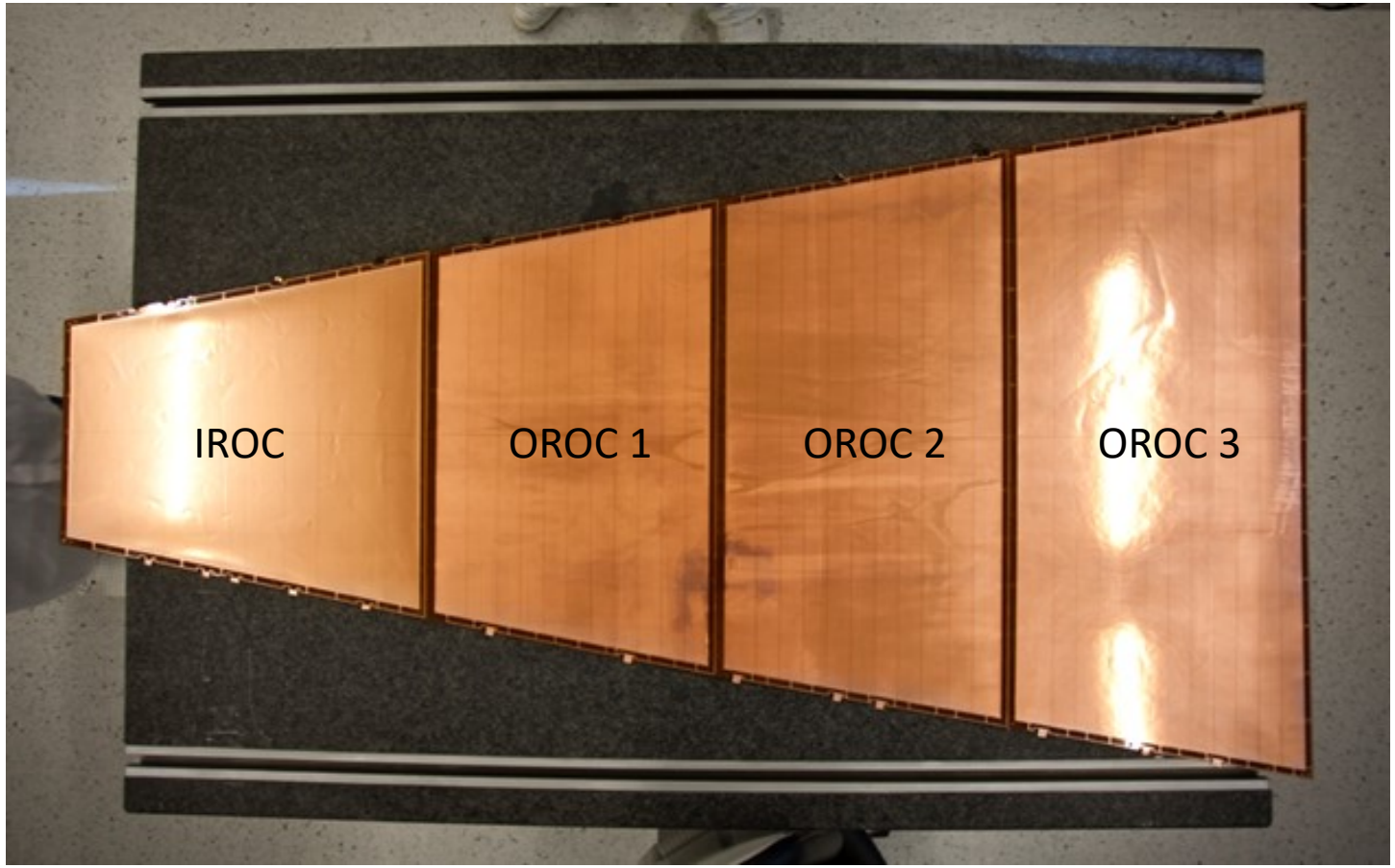
- d*E*/d*x* distribution probes whole simulation
- Work in progress





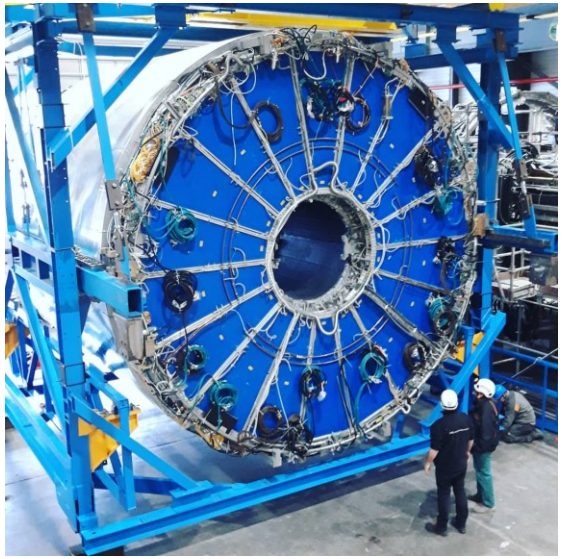
ALICE TPC Upgrade

- 36 inner- and outer readout chambers
- 4 GEM foils in IROC, 12 in OROC
- Overall almost 128 m^2 active GEM area
- Largest active GEM area in any detector



ALICE TPC Upgrade

- TPC back on the surface after more than 10 years
- Replace MWPCs with GEM-based readout chambers
- All required readout chambers produced and commissioned
- Replacement of chambers and front-end electronics currently ongoing and expected to be completed in October 2019



P. Gasik

Summary and conclusion

Test-beam campaign

- First data analysis with new framework O^2 successfully finished
- Newly implemented readout scheme works
- d*E*/d*x* resolution in pre-production IROC:
  - 11.9 % for pions
  - 10.7 % for electrons
- Separation power of electrons and pions:
  - ~3.6 σ at 1GeV/*c*
  - Up to ~3 σ at 2 GeV/*c*

TPC Upgrade

- Readout chambers ready to be mounted
- Replacement of readout chambers and front-end electronics currently ongoing

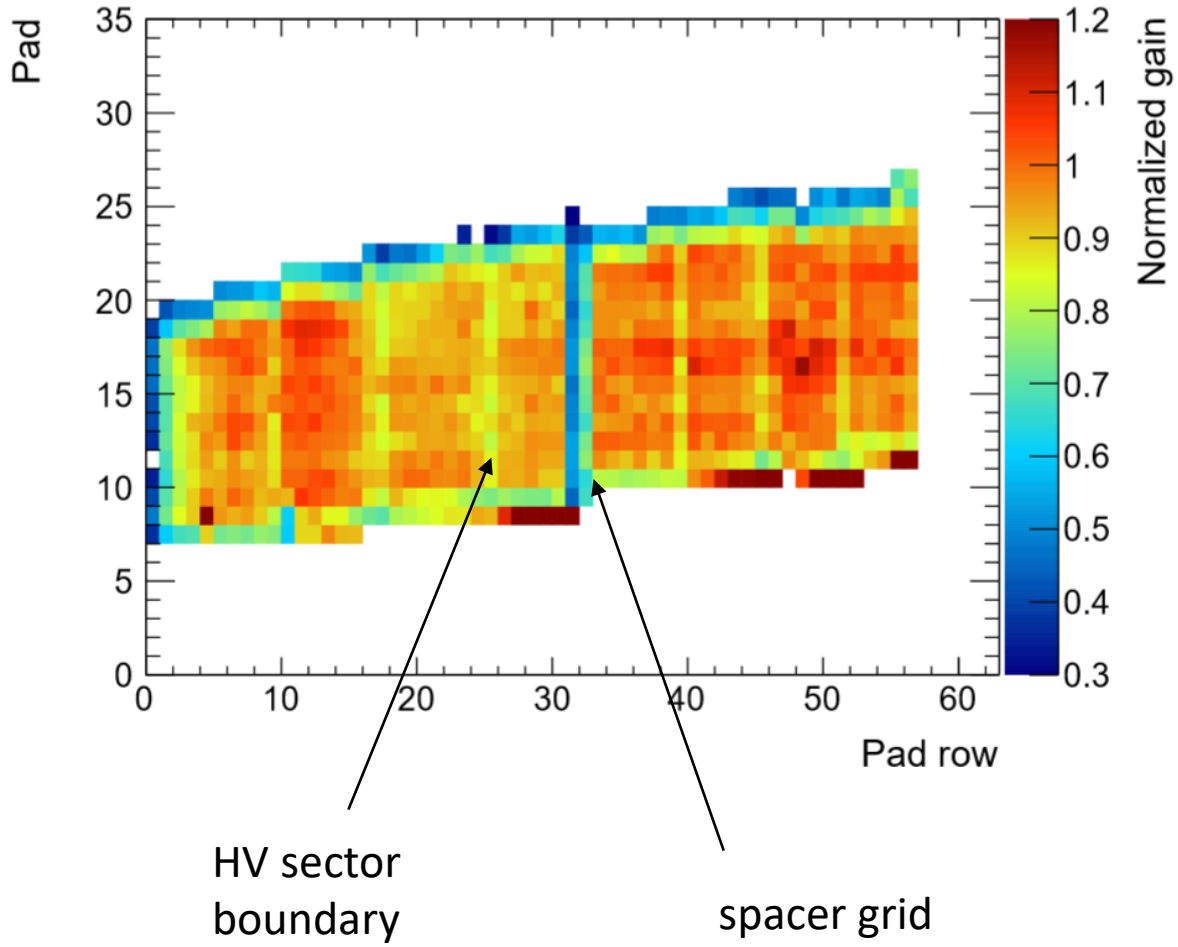
Conclusion: The detector works!

Thank you for your attention!

Backup

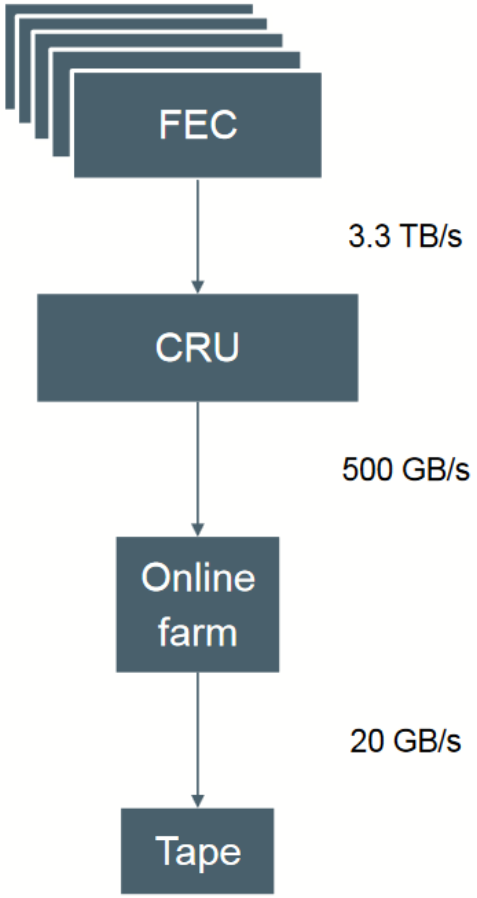
Gain map

- Correct for local gain variations in GEM and variations in front-end electronics
- Gain distribution well within the specifications (σ = 5.5 %)
- Lower gain at edges, spacer grid and HV sector boundary



Readout scheme in Run 3

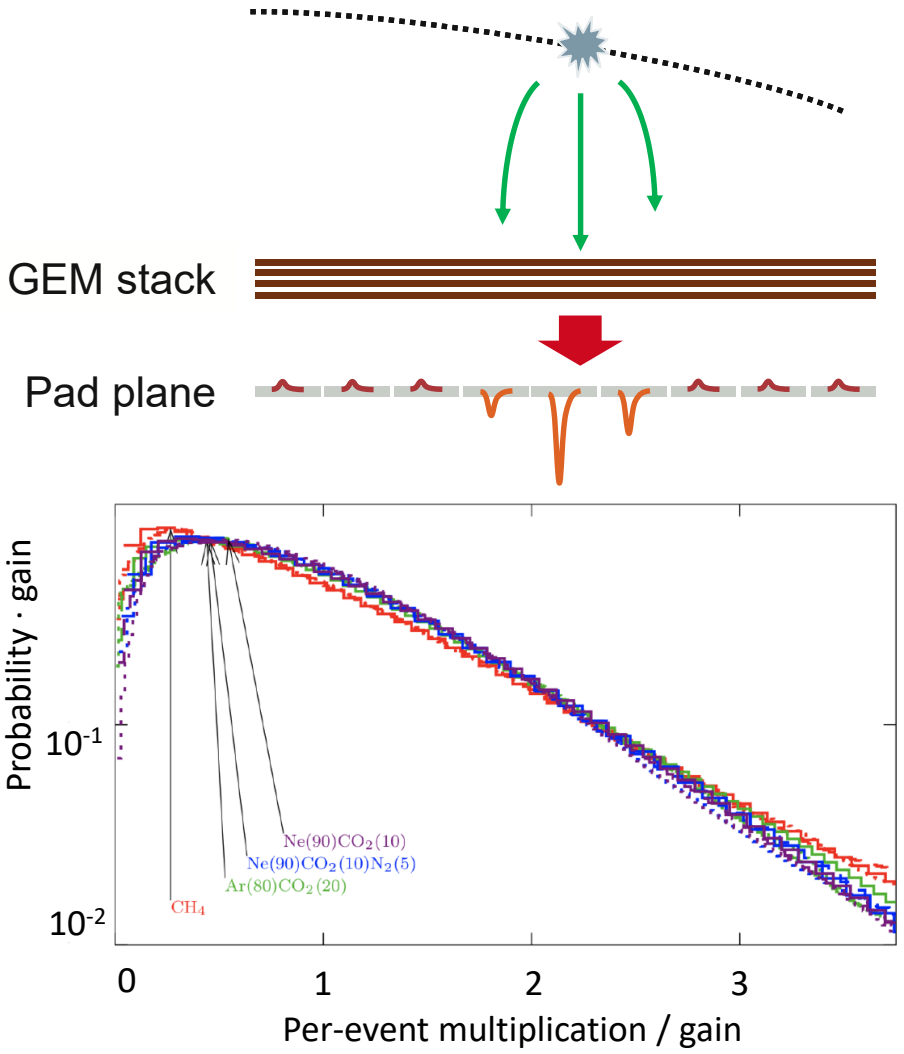
- 3276 FECs - ~550k channels in the TPC
- 360 Common Readout Units in the TPC
  - Common mode and baseline correction
  - Cluster finder
- Online processing
  - Calibration and reconstruction
  - Continuously read out data
  - Compression by online reconstruction
- New computing system with corresponding software framework O^2



Overview of TPC Simulation in O^2

- Simulation needs to properly resemble the detector response
- Large amount of data due to continuous readout and high interaction rates demands for fast simulation
  - Parallelization of tasks, asynchronous event generation, transport and IO (more information in Sandro Wenzel, CHEP 2018)

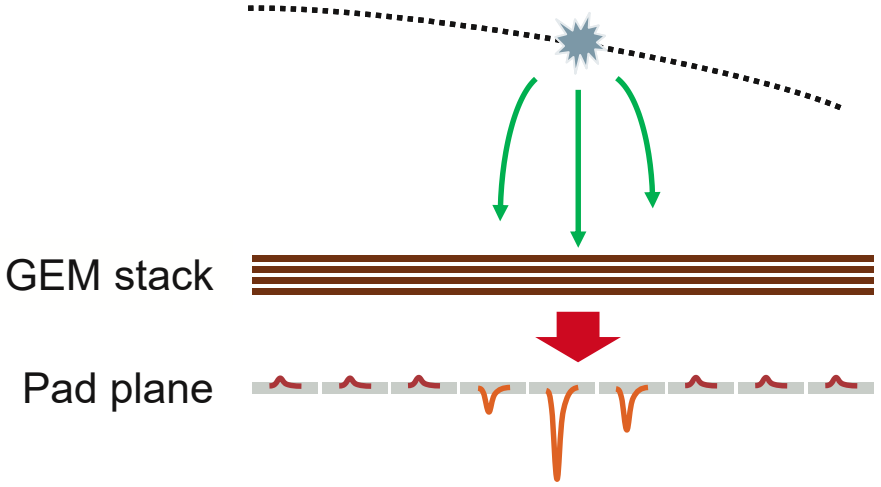
- Total amplification in 4-GEM stack described by 8 binomial distributions (4 times collection- and extraction efficiency) and 4 Polya distributions (amplification in GEM holes)
  - Very resource intensive
  - Instead use a single Polya distribution as an effective description of the GEM amplification

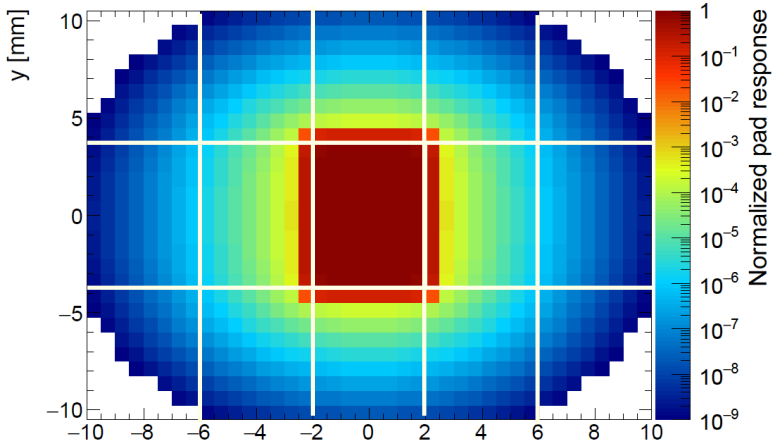


A. László et al., JINST 11 (2016) P10017

Overview TPC Simulation

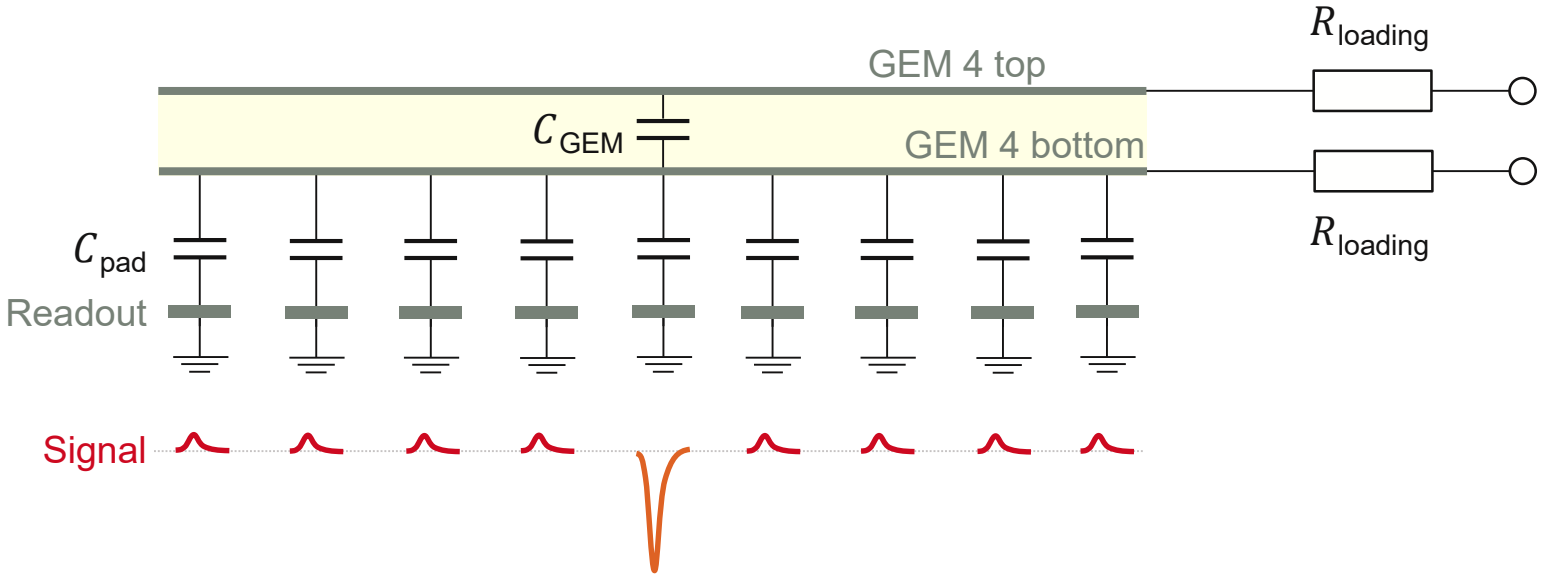
- Description of the signal formation in the detector according to the relevant processes
  - Energy loss of the incident particle
  - Diffusion during up to 250 cm drift
  - Amplification at the GEM stage
  - Signal induction on read-out anode (Pad Response Function)
  - Capacitive coupling of the read-out to the GEM (Common Mode)
  - Time response and signal processing in FECs





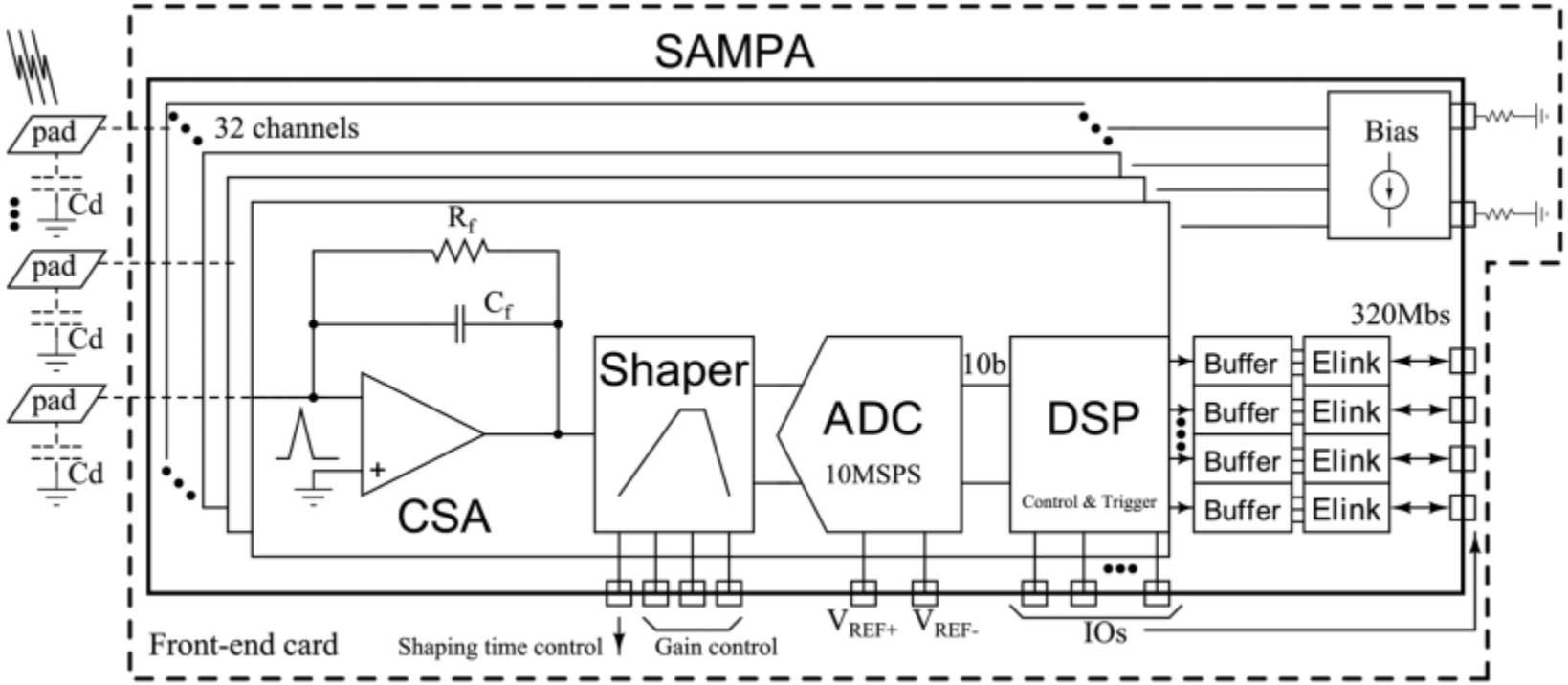
Pad Response IROC

Overview of TPC Simulation



- Signal induction on readout anode
- Capacitive coupling of the readout to the GEM (Common Mode)

SAMPA chip


SAMPA
pad
Cd
pad
Cd
pad
Cd
32 channels
Rf
Cf
CSA
Shaper
ADC
10MSPS
10b
DSP
Control & Trigger
Bias
320Mbs
Buffer
Buffer
Buffer
Buffer
Elink
Elink
Elink
Elink
Front-end card
Shaping time control
Gain control
VREF+
VREF-
IOs

Digitization

Shaping

- Folding the signal of the avalanche with the shaping function
  - Gamma4 function
- Non-linearity of the conversion gain
- Signal is then sampled at 5 MHz

Digitization

- Using the dynamic range of the electronics
- Electronic noise