dE/dx Resolution Studies of a Pre-Production Readout Chamber for the ALICE GEM TPC

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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 $dE/dx$
- 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: $\sim$100 $\mu$s
- Gated MWPC-based readout in Run 1 and Run 2
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 $\sim 100 \, \mu s$
- Gating grid closure for $\sim 200 \, \mu s$
  - Rate is limited to $\sim 3$ kHz
- 50 kHz interaction rate in Pb-Pb envisaged in Run 3
  - Continuous readout needed
- Alternative solution has to be found to reduce IBF
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 \(\sigma < 12\%\) for \(^{55}\text{Fe}\)
- 4-GEM stack scheme
- \(dE/dx\) resolution of the new readout system has to be verified
  - 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
Test-beam setup

• Test-beam at CERN PS with secondary beam of 1 to 5 GeV/c $\pi^-$ 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$^2$
dE/dx resolution

- dE/dx 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, $\sigma^{(55}\text{Fe}) = 10.8\%$

Separation power $= \frac{2(|\mu dE/dx_e - \mu dE/dx_\pi|)}{\sigma^{dE/dx}_e + \sigma^{dE/dx}_\pi}$
dE/dx resolution

- dE/dx 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
- $\sigma^{(55\text{Fe})}$ and IBF heavily depend on voltage across GEM 1

In general:
- Low $\Delta U_{\text{GEM1}} \rightarrow$ low IBF, high $\sigma^{(55\text{Fe})}$ 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 $Q_{\text{tot}}$
- Charge distribution reproduces measurement very well

- $dE/dx$ 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 m² 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
Summary and conclusion

Test-beam campaign
- First data analysis with new framework $O^2$ successfully finished
- Newly implemented readout scheme works
- $dE/dx$ resolution in pre-production IROC:
  - 11.9 % for pions
  - 10.7 % for electrons
- Separation power of electrons and pions:
  - $\sim 3.6 \sigma$ at 1GeV/$c$
  - Up to $\sim 3 \sigma$ 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
• Correct for local gain variations in GEM and variations in front-end electronics
• Gain distribution well within the specifications ($\sigma = 5.5\%$)
• 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 O²
Overview of TPC Simulation in O²

- 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
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
Overview of TPC Simulation

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