Status of the R&D activities for the upgrade of the ALICE TPC

Alexander Deisting for the ALICE TPC Collaboration

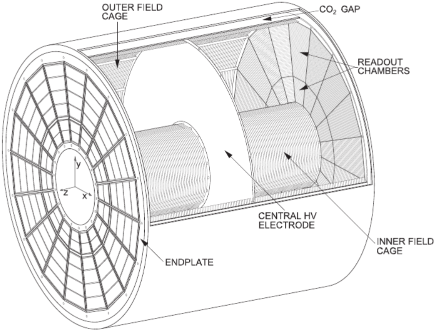
GSI Helmholtzzentrum für Schwerionenforschung GmbH

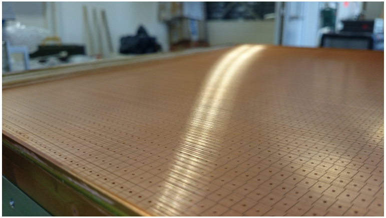
13$^{\mathrm{th}}$ of October, 2015

The ALICE TPC

The ALICE TPC

- 90 m^3 gas volume read out by 18 inner and 18 outer readout chambers per side
- Readout chambers utilising MWPC with pad readout
- To prevent ions from moving into the drift volume a gating grid is used
- Maximal readout rate with gating grid $\sim$ 3.3 kHz





Upgrade of the ALICE TPC

LHC Run 3

- Increased rate of $\mathrm{Pb}-\mathrm{Pb}$ collisions of up to 50 kHz ($\rightarrow$ 20 µs)
- On average 5 events piled up inside the TPC

$\Rightarrow$ **New readout chambers which allow continuous readout are needed**

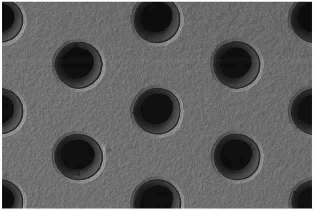
Requirements on the new chambers:

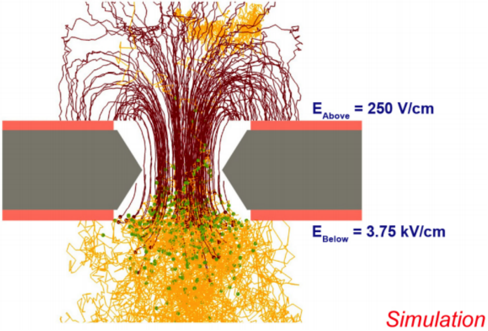
- Preserve the momentum and $\mathrm{d}E/\mathrm{d}x$ resolution of the old chambers ($\frac{\sigma_{\mathrm{E}}}{E_{55_{\mathrm{Fe}}}} \leq 12\%$)
- Provide an **I**on **B**ack **F**low of less than 1% in order to keep the space charges in the TPC at a tolerable level
- Stable operation at the LHC Run 3 conditions

New GEM-based readout chambers

Gas Electron Multiplier foils

- 50 µm polyimide foil with a 5 µm copper layer on each side
- Holes with (typically) 140 µm pitch and 80 µm (50 µm) outer (inner) diameter
- In stacks: Offer high gain and good stability at reasonable voltages

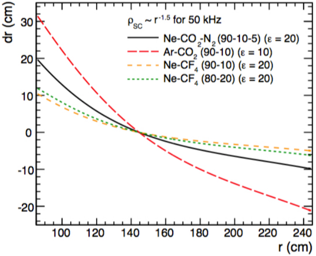


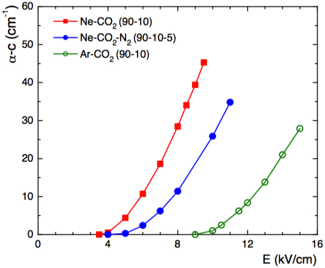


Outline

- R&D with small prototypes
  - Optimisation of IBF and Energy resolution
  - Charging-up studies of quadruple GEM stacks
  - Discharge studies
- Stability tests with a large prototype at CERN SPS
- $\mathrm{d}E/\mathrm{d}x$ studies with a large prototype at CERN PS
- Studies of electromagnetic sagging utilising large foils
- Conclusions

Gas choice





- High ion drift velocity $\Rightarrow$ **Ne**
- Admixtures of $\mathrm{CO_2}$ as well as $\mathrm{CF_4}$ perform similar in terms of r and $r\phi$ distortions
- The TPC (and the gas system) is not validated for $\mathrm{CF_4}$ $\Rightarrow$ **Ne-CO$_2$** (90-10)
- Gas amplification in $\mathrm{Ne{-}CO_2}$ starts around $4\,\mathrm{kV\,cm^{-1}}$ $\Rightarrow$ **Ne-CO$_2$-N$_2$** (90-10-5)

IBF and Energy resolution

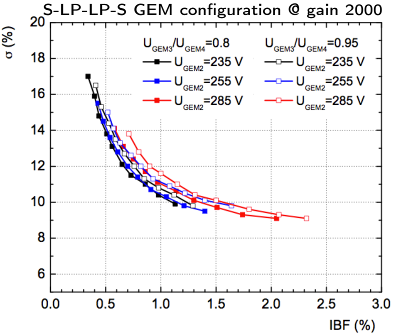
⇒ Quadruple GEM stacks

- Extensive R&D done with small prototypes ($10\,\text{cm} \times 10\,\text{cm}$ GEMs) at several institutes
- Different GEM geometries in different combinations tested

Measurements

- Energy resolution: $^{55}\mathrm{Fe}$
- IBF: X-Ray guns

- Optimisation of energy resolution and IBF are competing effects

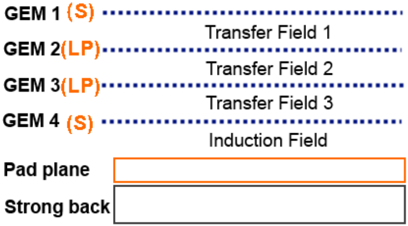


See "*Upgrade of the ALICE Time Projection Chamber*", CERN-LHCC-2013-020

Baseline settings for the ALICE TPC upgrade

Baseline settings

The baseline solution employs standard-pitch (S, 140 µm) and large-pitch (LP, 280 µm) GEMs, rotated 90° relative to each other



- Current solution provides an IBF of 0.6 %-0.7 % as well as an energy resolution of 11 %-12 %

Optimised voltage settings

ΔV_{GEM1}	ΔV_{GEM2}	ΔV_{GEM3}	ΔV_{GEM4}	E_{T1}	E_{T2}	E_{T3}	E_{Ind}
270 V	250 V	270 V	340 V	$\frac{4\,\mathrm{kV}}{\mathrm{cm}}$	$\frac{2\,\mathrm{kV}}{\mathrm{cm}}$	$\frac{0.1\,\mathrm{kV}}{\mathrm{cm}}$	$\frac{4\,\mathrm{kV}}{\mathrm{cm}}$

Drift field: $400\,\mathrm{V\,cm^{-1}}$

Charging-up studies with a quadruple GEM stack

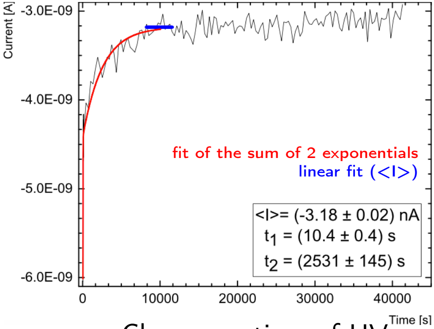
Question:

How long would it take to move from a "safe" set of voltage settings to a setting where the detector is operational? "*Studies on charge-up effects and gain stability for the ALICE TPC upgrade with GEMs*", Ba. thesis by Y.Vetter, Uni HD

Procedure

- Irradiate the detector with a source
- Measure the current on the pad plane while and after the ramping
- Fit the sum of two exponentials to the obtained data

$$I(\mathrm{t}) = I_0 - A_1 e^{-\frac{\mathrm{t}-t_0}{\tau_1}} - A_2 e^{-\frac{\mathrm{t}-t_0}{\tau_2}}$$



- τ_1 – Charge-up time of HV elements
- τ_2 – Charge-up time of the polyimide foil

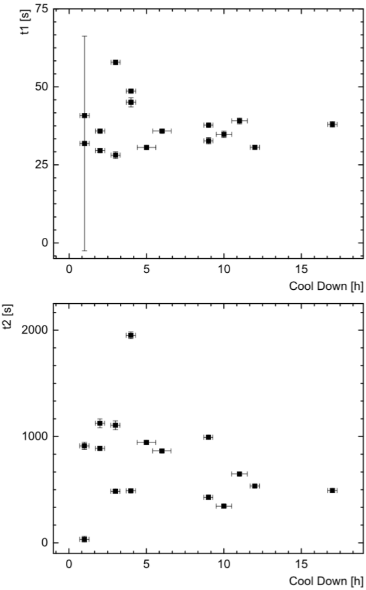
Results of the charging-up studies

- AVD is used to supply HV to the foils
- "Safe":= 75% of the "ready" settings
- Measurements done with 300 ppm H_2O (100 ppm planned for the upgraded ALICE TPC)
- Cool-down time := time during which the detector was in "safe" settings

- $\tau_1 \sim 35\,s$
- $\tau_2 \sim 12\,min$

→ Both, τ_1 and τ_2 do not depend on time the detector was turned off

⇒ **The stabilisation of the gain takes long enough to follow it with the online calibration**



Discharge studies

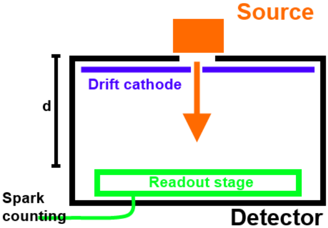
Rate considerations (LHC Run 3):

- Pb-Pb collisions $< \mathrm{d}N/\mathrm{d}|\eta| >= 1000$ (TPC acceptance)
- Yearly heavy ion run @ 50 kHz:

$\Rightarrow 1000 \times 50\,\mathrm{k} \times 10^6 = 5 \times 10^{13}$

- 144 GEM stacks and a factor of 2 to account for background:

$\Rightarrow 7 \times 10^{11}$ particles/stack/HI – run



Sources and rates

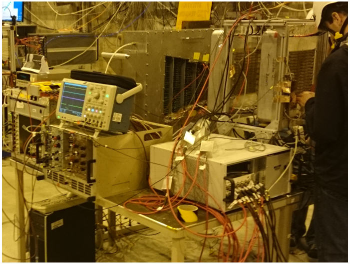
- $^{241}\mathrm{Am} \sim 11\,\mathrm{kHz}$
- $\alpha_{\mathrm{mixed}} \sim 600\,\mathrm{Hz}$
- $^{90}\mathrm{Sr} \sim 60\,\mathrm{kHz}$

gain	2000	3000	5000
α_{Am}	$< 1.5 \times 10^{-10}$	7.1×10^{-10}	
α_{mixed}	$< 3.1 \times 10^{-9}$		$(1.8 \pm 1.1) \times 10^{-8}$
β			$< 3 \times 10^{-12}$

Discharge studies @ CERN SPS (Dec. 2014) – 1/2

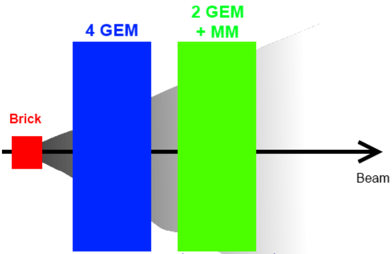
→ The rates of the sources lead to too long measurement times

→ A large prototype should be tested and irradiated over its full surface



Setup at CERN SPS

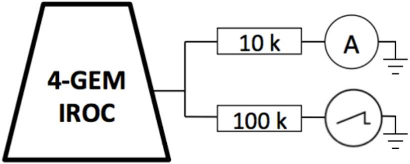
- $\sim 2 \times 10^6\ \pi/\text{spill}$ (150 GeV)
- Produce particle showers with an Fe brick → $\sim 1.8 \times 10^8\ \pi/\text{spill}$
- Line up test detectors with their readout plane facing the beam

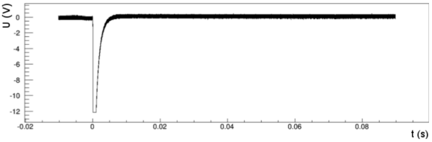


Discharge studies @ CERN SPS (Dec. 2014) – 2/2

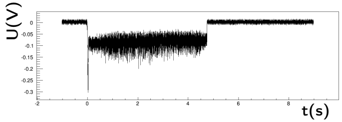
Readout

- Current readout on the pad plane (rate measurement)
- Read out the induced voltage signal on the pad plane (discharges)





SPS-Spill



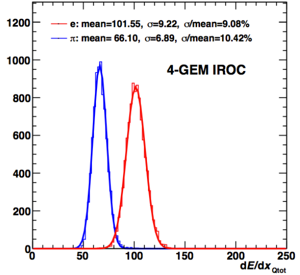
Results

- 3 discharges seen $\Rightarrow (6 \pm 4) \times 10^{-12}$ discharges/incoming hadron
- 5 discharges per HI-run and GEM stack expected for the ALICE TPC in Run 3 See "*Addendum to the Upgrade TDR of the ALICE TPC*", CERN-LHCC-2015-002

$\mathrm{d}E/\mathrm{d}x$ Measurement

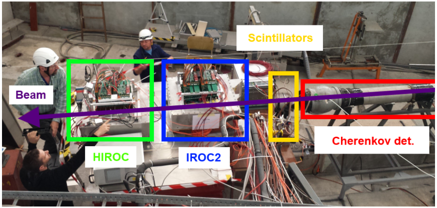
Was extensively treated in the talk by A. Mathis on Monday:

Study of the dE/dx resolution of a GEM Readout Chamber prototype for the upgrade of the ALICE TPC



In brief:

- Tested an **I**nner **R**ead**O**ut **C**hamber at CERN PS with an electron and π-beam (1 GeV)
- Discriminated e from π with a Cherenkov detector
- Checked the separation in $\frac{\mathrm{d}E}{\mathrm{d}x}$ with the IROC

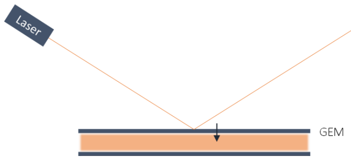


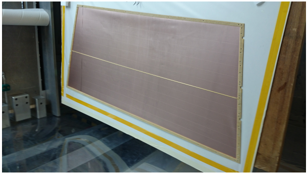
$\Rightarrow$ **$\mathrm{d}E/\mathrm{d}x$ separation power is compatible with that of the existing TPC**

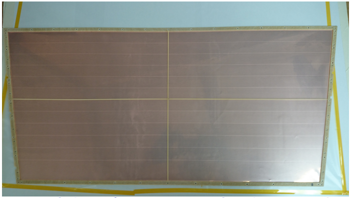
Foil sagging

The foils of the GEM stack with the largest foil dimensions were framed without spacer grid ⇒ Measure the sag due to electrostatic attraction of the foils *(Reminder: Gaps of* 2 mm*)*

Measurement:







- Foils touch without spacer grid
- One grid piece is enough to prevent the foils from touching
- No visible sagging with a cross was observed

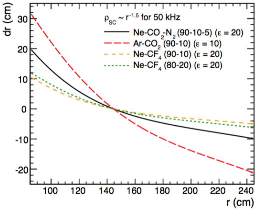
Conclusion

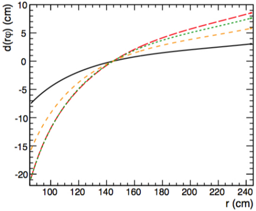
- The ALICE TPC has to be upgraded in order to cope with the high rates at LHC Run 3
- Readout chambers equipped with quadruple GEM stacks were found to fulfill the requirements. It has been shown that they provide:
  - $0.6\,\% \leq \text{IBF} \leq 0.7\,\%$
  - Energy resolution of $11\,\%$-$12\,\%$ at the $^{55}\mathrm{Fe}$ photopeak
  - Discharge probability of $\Rightarrow (6 \pm 4) \times 10^{-12}$ discharges/incoming charged hadron
  - Electron/π separation in $\mathrm{d}E/\mathrm{d}x$ compatible with the separation power of the existing TPC
- Studies of 4GEM stacks showed that the charge-up is slow enough to follow it with online calibration
- A suitable spacer grid is needed to prevent the large foils of the future readout chambers from sagging due to electrostatic attraction

Backup

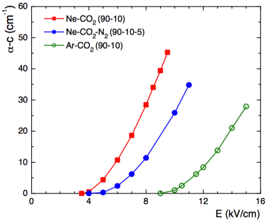
Gas choice

Distortions



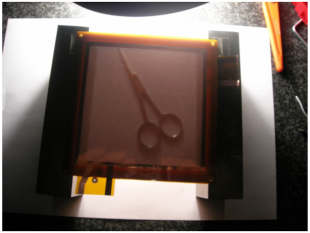


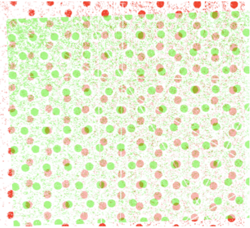
Distortions at $z = 0$, $\epsilon :=$ number of ions drifting back into the drift volume per primary electron



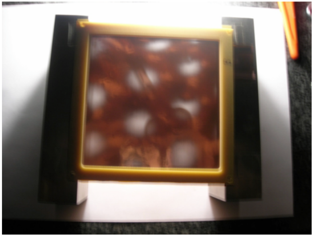
Effective Townsend coefficients as function of the electric field.

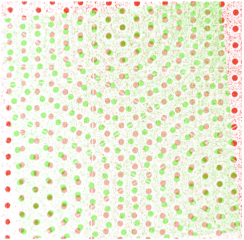
Relative GEM orientation





One foil rotated by 90° relative to the other foil

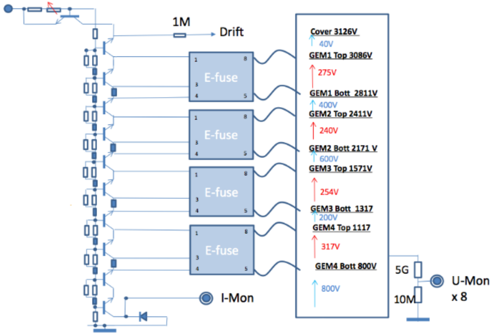




No rotation of the two foils

First experience with the Active Voltage Divider – 1/3

In collaboration with H. Müller and RD51 a AVD was tested as an alternative to the baseline solution which foresees cascaded power supplies for the GEM stacks of the upgraded TPC



See "*Studies on charge-up effects and gain stability for the ALICE TPC upgrade with GEMs*", Bachelor thesis by Y.Vetter, Uni Heidelberg

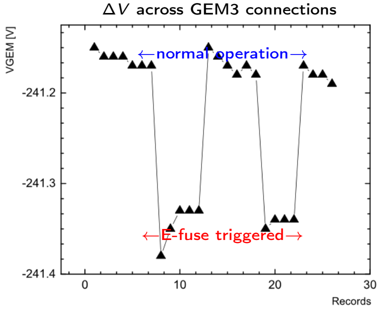
AVD

- Distributes voltages from a single channel power supply to all the HV channels of a quadruple GEM stack
- Due to the transistors in the resistor chain the load dependence of the HV supply is reduced
- E-fuses protect GEMS in case of discharge across the GEM

First experience with the **A**ctive **V**oltage **D**ivider – 2/3

Triggering the E-fuse on the GEM2 connections:

- As the current through a GEM rises above 40 µA, the resistance of the E-fuse rises from 50 kΩ to 6.5 MΩ → triggering the fuse results in reducing the voltage across GEM2
  - If the current across the GEM2 connectors goes down again, the E-fuse resistance falls eventually back to 50 kΩ
  - The plot shows the influence of this operation on the voltage across GEM3



First experience with the **A**ctive **V**oltage **D**ivider – 3/3

Temperature effects

- PCB dissipates about 4 W of heat
- After 40 min the PCB reaches its equilibrium temperature of 40 $^\circ$
- With an additional 4 Ω heating resistor, the time to reach the equilibrium state could be significantly reduced
- In an ALICE-like environment cooling has to be applied to the board