The ALICE TPC: from wires to GEMs

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On behalf of the ALICE collaboration
Outline

- The current ALICE Time Projection Chamber: some borrowed and some self-developed features
- Performance overview
- The upgrade
  - GEM chambers
  - towards RUN3
The ALICE TPC

- The largest TPC
- Probably the last accelerator TPC with wire chambers
- 90 m$^3$ of Ne-CO$_2$(-N$_2$) or Ar-CO$_2$
- 36 Inner and Outer Readout Chambers
- 100 kV at Central Electrode
- Over half a million readout pads
- Operates at interaction rates of a few 100 kHz in pp and few kHz in Pb-Pb

$\sim 5 \times 5 \text{ m}$
Field Cage

- Suspended strips à la NA49 solve problems with charging up and dust collection on the FC walls
- Gas circulated radially through many small holes along supporting rods
- FC walls, light and gas tight, carry their own resistor chain to evacuate the charge produced in the CO$_2$ insulation gaps
- Central electrode made with full Al-mylar to exploit the laser image of it onto the ROCs
Water cooled, removable resistor rods

- Four removable rods with a resistor chain cooled with ultra-pure water and contacts to the strip hooks are shafted into support rods

☞ All dissipated power in the TPC is removed via water cooling; thermal screens cover the detector almost all around
Readout chambers

- Insertion à la ALEPH to minimise acceptance losses
- MWPC equipped with a Gating Grid electrode, à la ALEPH, DELPHI, NA49, STAR, to limit both dose and space charge

☞ The GG opens for 100 µs upon a trigger and stays closed for ≈200 µs before accepting another trigger. Thus, the intrinsic trigger rate limit of these chambers is 3 kHz
Some more original features

- Cover electrodes for chambers
  - matches the drift field and traps escaping ions
- Addition of $N_2$ to the Ne-CO$_2$ gas
  - need constant temperature and composition
  - also add 100 ppm H$_2$O to avoid charging up of insulators
- Full image of central electrode from laser stray light for online drift velocity calibration
  - optics for producing laser tracks copied from STAR
- ALICE TPC ReadOut (ALTRO) chip with digital baseline correction filters
- Readout Control Units (RCU) with FPGAs and SEU correction
- Online data compression (factor $\approx 4$) with High Level Trigger
Performance: $p_T$ resolution

- For 2013 p-Pb data with Ne-CO₂ (90-10):
  - $\sigma_{p_T}/p_T \lesssim 3.5\%$ at 50 GeV/c
  - 10% degradation in Pb-Pb
  - $\sigma_{p_T}/p_T < 1\%$ at 1 GeV/c

- Best performance with combined TPC-ITS tracks

Performance of the ALICE Experiment at the CERN LHC, Int. J. Mod. Phys. A 29 (2014) 1430044
Performance: $dE/dx$

2015 pp data at $B = 0.2$ T, Ar-CO$_2$ (88-12)

- With Ne-CO$_2$:
- $\sigma_{dE/dx} \approx 5.5\%$ in pp
- $\sigma_{dE/dx} \approx 7\%$ in central Pb-Pb
  - deterioration due to overlapping clusters

☞ Single-pad gain calibration with $^{83}$Kr decays in the gas
The TPC upgrade

• Expect, and inspect, 50 kHz Pb-Pb in RUN3 (2021) and RUN4

1. GG limit at 3 kHz
   - continuous readout needed
   - new readout electronics!

2. Space charge near anode wires
   - high rate capability needed

3. Space charge in drift volume
   - solution with IBF < 1 % (Ion Back Flow: fraction of ions drifting back: < 20 at gain 2000)

4. Maintain dE/dx and momentum resolution

ALICE upgrades for RUN3: see related posters and ‘Upgrade of the ALICE ITS’ by P. Riedler
Replace MWPCs with GEMs

- Ion Back Flow in a GEM system was reduced from > 5% (3 GEM) to < 1% (4 GEM)
  - discovered enhanced ion trapping at high rates
- Excellent dE/dx performance maintained, demonstrated also with test beams
- Robust against discharges, with alpha sources and test beams
  - Ne-CO$_2$-N$_2$ (90-10-5)

☞ Use both S (standard) and Large-Pitch foils in a S-LP-LP-S configuration
  ✔ rotated 90° from each other
  ✔ unsegmented side of first GEM faces drift space
Reconstruction and corrections

- Main challenge are space-charge distortions of up to 20 cm
- Real-time map of distortions is used for online track reconstruction
- In a second stage, the required momentum resolution, with combined TPC-ITS tracking, is achieved

Comparison of $1/p_T$ resolution for wires and GEMs

GEM performance at increasing multiplicities.
Expected: blue points
Preproduction

• Full sized prototypes of both chamber types have been produced and operated
  – reuse existing wire chambers

• Full chambers with new pad-planes etc and close-to-final GEM foil being produced now

Single-mask GEM technology allows for production of ~1 m foils
Production and installation

- Start production Q4 2015
  - QA and transport of foils, stacks, chambers
  - readout electronics (SAMPA, FECs, CRUs)
- TPC to surface Q1 2019
  - replace chambers
  - install new electronics
  - precommission
- Commission in cavern
  - through 2020
Summary

• The ALICE TPC employs many features developed for earlier TPCs and incorporates some of its own
• Excellent performance under high rates and/or multiplicities at the LHC
• Chambers and electronics will be replaced during LS2 for 50 kHz Pb-Pb in RUN3+4 by GEM stacks and continuous readout electronics
dE/dx with IROC prototype

dE/dx for $\pi$ and e at gain 2000

Separation power as a function of gain

29.9.2015

QM2015 Kobe - ALICE TPC
Discharge studies with $\alpha$ sources

<table>
<thead>
<tr>
<th>Source</th>
<th>G = 1000</th>
<th>G = 2000</th>
<th>S-LP-LP-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{239}$Pu+$^{241}$Am+$^{244}$Cm</td>
<td></td>
<td>$&lt;3.1 \times 10^{-9}$</td>
<td>IB = 0.63%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>G = 3300</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>$5 \times 10^{-9}$</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(1.8 $\pm$ 1.1) $\times 10^{-8}$</td>
</tr>
<tr>
<td>$^{241}$Am</td>
<td></td>
<td>$&lt;1.1 \times 10^{-8}$</td>
<td></td>
</tr>
<tr>
<td>$E_\alpha = 5.5$ MeV</td>
<td></td>
<td>$&lt;1.5 \times 10^{-10}$</td>
<td></td>
</tr>
<tr>
<td>rate = 11 kHz</td>
<td></td>
<td>$&lt;7.1 \times 10^{-10}$</td>
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</tr>
</tbody>
</table>

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Documents and other talks

- **Mar-2014 TDR**

- **Sep-2014 Taku Gunji, plenary talk in ALICE week**
  [https://indico.cern.ch/event/312789/session/20/contribution/41/material/slides/1.pdf](https://indico.cern.ch/event/312789/session/20/contribution/41/material/slides/1.pdf)

- **Feb-2015 TDR Addendum 1**

- **Mar-2015 Jens Wiechula, plenary talk in ALICE week**
  [https://indico.cern.ch/event/331319/session/13/contribution/21/material/slides/0.pdf](https://indico.cern.ch/event/331319/session/13/contribution/21/material/slides/0.pdf)

- **Mar-2015 Piotr Gasik, talk in Technical Board**
  [https://indico.cern.ch/event/366133/contribution/11/material/slides/0.pdf](https://indico.cern.ch/event/366133/contribution/11/material/slides/0.pdf)

- **Apr-2015 TDR Addendum 2**
Frond-end electronics base on the SAMPA chip

**FEC Version A:**
- 2 GBTx
- 1 VTTx
- 1 VTRx
- 2 data links
- 1 TTS link

**FEC Version B:**
- 1 GBTx
- 1 VTRx
- 1 data link
- 1 TTS link
Calibration and reconstruction flow

- Data compression through Zero Suppression and/or Huffman compressions, clusterisation, and non-relevant data removal