A continuous-readout TPC for the ALICE upgrade

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on behalf of the ALICE collaboration
ALICE experiment (1)

- The dedicated heavy-ion experiment at CERN LHC
ALICE experiment (2)

- Excellent performance in Run1 (2009 - 2013) and Run2 (2015-now)
- Time Projection Chamber (TPC) is main device for tracking and PID in central barrel

![ALICE performance](image)

- ALICE performance
- $pp, \sqrt{s} = 13$ TeV
- $B = 0.2$ T
Motivation: Focus on high-precision measurements of rare probes at low $p_T$

- Low signal-to-background ratio prevents selection with hardware trigger
- Need to record large sample of events

Strategy: Read out all Pb–Pb interactions at maximum interaction rate of 50 kHz

- Factor 50 improvement with respect to now


ALICE Upgrade Letter Of Intent: https://cds.cern.ch/record/1475243
Addendum to the TDR: https://cds.cern.ch/record/1984329
ALICE upgrade strategy (2)

- High-rate capability → Increased statistics
- Example: Low-mass di-leptons after background subtraction

Simulation: Current data rate (2.5e7 events)

Simulation: Upgrade scenario (2.5e9 events)
ALICE TPC overview

- Diameter: 5 m, length: 5 m
- Gas: Ne–CO$\textsubscript{2}$–N$\textsubscript{2}$, Ar–CO$\textsubscript{2}$ in 2015 and 2016
- Max. drift time: $\sim$100 $\mu$s
- 18 sectors on each side
- Inner and outer read out chambers: IROC, OROC

**Current detector** (RUN1, RUN2):
- 72 MWPCs
- $\sim$550 000 cathode pads
- Wire gating grid (GG) to block Ion BackFlow (IBF)
- Rate limitation: few kHz
Run 1 and 2: Gated operation

- Drift time in TPC, gating grid open
- Fixed gating grid closure time, no event readout

- Typical trigger rate in Pb–Pb: ~500 Hz
- Triggered operation with gating grid (GG)
- Ion backflow (IBF) suppression with gating grid: 10\(^{-5}\)
- Electron drift time: 100 μs + fixed closure time of the GG: 200 μs (400 μs for Ar mixture)
  - Intrinsic limitation of the readout rate to few kHz
Run3: Continuous operation

- 50 kHz Pb–Pb collisions with the goal to inspect them all!
- Average event spacing: ~20μs → average pileup: 5 events
- Triggered operation does not make sense
- Minimize IBF without the use of a gating grid

⇒ Continuous read-out with GEMs (Gas Electron Multiplier)
New Readout chambers

OROC

IROC

Continuous read-out with GEMs (Gas Electron Multiplier)
GEM stack configuration (1)

**Quadruple** GEM stack in S-LP-LP-S configuration

- Combination of **Standard** (S) and **Large Pitch** (LP) GEM foils
- Highly optimized HV configuration
- Result of intensive R&D
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Requirements for GEM readout system:

- Nominal gain = 2000 in Ne-CO$_2$-N$_2$ (90-10-5)
- IBF < 1 % ($\varepsilon = 20$)
- Energy resolution: $\sigma_E/E < 12\%$ for $^{55}$Fe
- Stable operation under LHC RUN3 conditions

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R&D highlights (1)

- IBF and energy resolution have to be optimized in parallel

![Graph showing the relationship between IBF and energy resolution](image-url)
Conservative operational limits: IBF < 1 %, local energy resolution < 12 % for $^{55}\text{Fe}$
R&D highlights (3)

Extended operational range: IBF < 2 %, energy resolution < 14 %
Multi-stage quality assurance (QA) using traffic light system (Bad / HV ok / Good)

1. Basic QA at CERN
   - Reject malfunctioning foils as early as possible
   - Fast feedback to the producer
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   - Gain uniformity prediction

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3. Further QA steps at the framing and assembly sites
   - Continuous quality monitoring after each production step
Final ROC characterization:

- Gas tightness (< 0.5 ml/h)
- Gain curve
- Gain uniformity (<20 %)
- IBF uniformity (IBF < 1 %, uniformity < 20%)
- Full X-ray irradiation for more than 6h (10 nA/cm² pad-plane current)

First production ROCs meet requirements
First production OROC meets requirements
ROC characterization (3)

✓ First production IROC meets requirements

Systematic measurement effect: Apparent lower gain in region close to edges and GEM spacer frame
Readout strategy

- Read all ADC values (no compression)
- Radiation hard data and control link: CERN GBT system
- Online data correction (baseline fluctuations, common mode effect) and cluster finding in CRU (FPGA based readout card)

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On the Front-End Card (FEC): New FE ASIC **SAMPA** (130 nm TSMC CMOS):

- Positive or negative input
- Programmable conversion gains and peaking times
- Readout modes: triggered or continuous
- Digital Signal Processing (can be bypassed)
Readout electronics (2)

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  - Programmable conversion gains and peaking times
  - Readout modes: triggered or continuous
  - Digital Signal Processing (can be bypassed)

SAMPA requirements:
- Signal-to-noise ratio: 20:1 for IROC and 30:1 for OROC
- System noise (ENC): 670 e
- Conversion gain: 20 mV/fC
- Shaper peaking time: 160 ns
- Preamplifier saturation limit: > 10 nA
- ADC: 10 bit (ENOB>9.2), 5 MSPS
System integration

- Front End Card prototypes (Rev 0a) on a GEM read-out chamber
System noise

Noise r.m.s.
Noise sigma

Position of 55Fe source

Required noise performance

Noise (LSB)

FEC channel number

1 LSB ≈ 670 e (ENC)
Performance in beam test

- Successful beam test at CERN PS in May 2017
- Example: Particle identification performance at 2 GeV/c

![Histogram of pions and electrons with statistical uncertainties and separation](image)

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Summary and outlook

- **Major upgrade** of the ALICE experiment for installation in 2019/20
- **Continuous TPC readout** to inspect 50 kHz Pb–Pb collisions
- New TPC readout chambers based on **quadruple GEM stacks**
- Required **performance** (ion backflow, energy resolution, stability) achieved
- Extensive QA on produced **GEM foils**
- **ROC assembly** started
- **New electronics** for continuous readout
- **Successful system tests**
TPC team at the T10 beam line at CERN PS in May 2017
MORE
Approval of the Technical Design Report (TDR)  

Readout chambers:
- Engineering Design Review (EDR)  
- Readout Final Design Review  
  ✓ Final design approved  
- Production Readiness Review (PRR)  
  ✓ Start of mass production  

Front End Electronics:
- Rev 0 schematic review  
- Rev 0 layout review  
- Rev 1 schematic review  
- Rev 1 layout review  
- EDR  
- PRR  

Installation:
- Start of readout chamber installation  
- Start of FEE installation  

Milestones

June 2015
November 2015
June 2016
March 2017
May 2016
July 2016
March 2017
April 2017
October 2017
August 2018
April 2019
August 2019
ROC assembly flow

GEM Frame Ledges → OROC Alubody (Europe) → Padplanes (Europe) → GEM Production (CERN) → IROC Alubody (UT Austin) → GEM Frame Ledges

GEM QA (CERN)

OROC body assembly (U Heidelberg) → GEM framing (TU Munich) → OROC assembly + tests (HPD Bucharest)

OROC body assembly (U Frankfurt) → GEM framing (U Bonn) → OROC assembly + tests (GSI)

Advanced QA (Helsinki) → Advanced QA (Budapest)

IROC body assembly (U Tennessee) → IROC assembly + tests (U Yale)

Final Test/Storage Integration (CERN)

Legend:
- external supplier
- WP1: GEM foils
- WP2: IROC (USA)
- WP3: OROC (Europe)
FEE assembly flow

- **SAMPA ASICs** (Brasil, Norway)
- **GBT components** (CERN)
- **FEC schematics** (ORNL)
- **SAMPA Testing** (Lund, Brasil)

**FEC Revision 0** (ORNL)
- **Testing** (U Houston)
- **Testing** (ORNL, UT-K)

**FEC Revision 1** (ORNL)
- **Testing** (U Houston)
- **Testing** (ORNL, UT-K)

**FEC Production** (ORNL)
- **QA** (U Houston)
- **QA** (ORNL, UT-K)
- **Installation on TPC**

- **Control software** (NIAS, Frankfurt)
- **Firmware** (Frankfurt, Heidelberg, NIAS)
- **CRU boards** (Budapest / Kolkata)
- **Test system** (Heidelberg, Frankfurt, GSI)
- **Installation in CR1**

- **External supplier**
- **Common ALICE projects** (SAMPA and CRU)
- **WP5: FEE**
- **WP6: Readout system**
- **WP7: Installation and commissioning**

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