Commissioning of the upgraded ALICE Inner Tracking System (ITS)

Svetlana Kushpil

Nuclear Physics Institute of the CAS
Řež, Czech Republic

on behalf of the ALICE Collaboration
Motivations and goals

- Improved vertex and tracking precision
  - first layer closer to IP, smaller pixels, less material
- Faster readout

Based on MONOLITHIC ACTIVE PIXEL SENSOR (MAPS) ALPIDE

- 10 m² active silicon area (12.5 G-pixels)
- Spatial resolution ~5x5 μm² all layers
- Fake hit rate: < 10⁻⁶ event⁻¹ pixel⁻¹
- Detection efficiency: > 99%

<table>
<thead>
<tr>
<th></th>
<th>ITS 1</th>
<th>ITS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>layers</td>
<td>6</td>
<td>3 Inner Barrel (IB)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 Outer Barrel (OB)</td>
</tr>
<tr>
<td>radius</td>
<td>39mm &lt; r &lt; 440mm</td>
<td>22mm &lt; r &lt; 400mm</td>
</tr>
<tr>
<td>η</td>
<td>-1 ≤ η ≤ 1</td>
<td>-1.3 ≤ η ≤ 1.3</td>
</tr>
<tr>
<td>X/X₀/layer</td>
<td>1.14%</td>
<td>0.35% (IB); 1% (OB)</td>
</tr>
<tr>
<td>rate capability</td>
<td>1kHz</td>
<td>100kHz (PbPb)</td>
</tr>
</tbody>
</table>

“Technical Design Report for the Upgrade of the ALICE Inner Tracking System”
ALPIDE: MONOLITHIC ACTIVE PIXEL SENSOR

Pixel Sensor produced using TowerJazz 180 nm CMOS Imaging Process

- Deep P-well allows in-pixel full CMOS (complex in-pixel circuitry without charge loss)

- Enables low-power read-out

- High granularity, low material budget

- Power: 40 mW/cm²

- Resistivity (>1 kΩ·cm) p-type epitaxial layer (25 μm)

- Possibility of reverse biasing (up to -6 V)

Expected radiation dose*:

- > 2700 krad Total Ionising Dose (TID),

- > 1.7×10¹³ 1MeV nₑq cm⁻² Non-Ionising Energy Loss (NIEL)

( * with safety factor)
ITS2 in numbers

IB: 3 layers
OB: 4 layers

- Pixel sensor chip: ~ 24000 (including spares)
- IB staves: 48
- OB Hybrid Integrated Circuits: 1692
- OB Staves: 90 (Outer Layer), 54 (Middle Layer)
- Readout Units: 192
- Large carbon composite structures: 24

Material budget: ~ 0.35% $X_0$
Readout speed: 1200 Mbps
Radius (mm): 22, 31, 39

Material budget: ~ 1% $X_0$
Readout speed: 400 Mbps
Radius (mm): 194, 247, 353, 405
The Hybrid Integrated Circuit (HIC) modules

**Inner Barrel HIC**
- Nine 50 μm-thick ALPIDE chips
- Aluminum Flexible Printed Circuit (FPC)
- Each chip read out separately
- Clock, control, data, power lines wire-bonded to FPC
- 27 cm length
- Hit density > 9.1 cm⁻²

**Outer Barrel HIC**
- Fourteen 100 μm-thick ALPIDE chips (2 rows)
- Data and control transferred through 1 master chip per row
- Chips wire-bonded to copper FPC
- Power delivered via 6 cross-cables soldered to FPC
- Hit density < 2.8 cm⁻²
Outer Barrel HIC Production

Custom made Module
Assembly Machine (MAM)

Criteria for acceptance:
- < 1% dead pixels
- no low impedance paths
- electrical interfaces (HSlink + DCTRL) functioning with in specifications

HIC production summary
- Total number: 2592
- Detector-grade: 2180
- Global yield: 84%
- Installed in OB: 1698
Outer Barrel Stave Production

Target OB Staves: 90 + 10 (OL), 54 + 6 (ML) (including spares)

Detector-grade staves

End of production: November 2019

ML Staves Total: 64

OL Staves Total: 101

all staves reworked and production is completed
Outer Barrel – (half-) Layer Assembly

Half-Barrel Assembly (a hierarchical Russian doll like assembly)
All half-layers are first tested individually.
Layer and Barrel assembly

All components come to CERN

The staves are **tested** at reception

**validated** after installation or sent to **rework** in case of problems

**Inner Barrel assembly completed: fully functional**

**Outer half-barrel assembly completed**

Maximum acceptable dead area per OB Stave: 1%
ITS upgrade - Component production status

Readout Unit (RU)
- 192 FPGA based RUs, operating in a mild radiation environment ( < 10 krad TID & NIEL of 10^{11} \text{ MeV n_{eq} cm^{-2}})
- Board production completed

Power Boards
- CAEN powering modules available and in use in commissioning
- Services installed by the teams of Bari, Catania, CERN, COMSATS, Daresbury/Liverpool, Strasbourg

Production & Test completed! Everything is installed and cabled!

Power regulation & distribution
- All cables installed in lab on surface
- All Power Boards installed
- Service installation finished
- Final installation will be in ALICE cavern
Commissioning shifts

- Full commissioning of the detector on surface including cosmic muon data taking
- Aim is to obtain the detector performance before installation inside the cavern
- Quality control of the main systems and components
- Commissioning shifts - 24/7
- Tests: threshold & the noise performance, long stability of parameters
- Monitoring: voltages / currents / temperatures
Inner Barrel Commissioning – Threshold Tuning

- Adjustment of front-end parameters to equilibrate the charge thresholds
- Achieving uniform response across the detector, verified on a spare IB half-layer
- Very satisfying threshold stability over time

~28 million pixels (= 3072 x 9216)

- Before tuning
- After tuning

Test data from spare Inner-Barrel Half-layer #0

Very satisfying threshold stability over time
Threshold is a trade-off between:

Detection efficiency:
Threshold < Charge $Q_{\text{MIP}} (~225 \, \text{e}^-)$

Fake-hit rate:
Threshold >> Noise

Extremely quiet detector!

From tests performed on a spare IB layer, running the IB at fake-hit rates below $10^{-10}$/pixel/event seems feasible

Threshold and noise after tuning of an OL Stave (~100M pixels)
We get around 1 cosmic track per minute
We started analyzing “real” data
Goals: study track and cluster parameters, alignment
We get around 3 cosmic tracks per minute
ALICE ITS Upgrade (ITS-2) is based on MAPS technology.

It will improve the ALICE potential performance.

Detector component production, assembly and connection to the services is completed.

Commissioning at the surface is ongoing, will be completed by April 2020.

The detector will be transferred to P2 from May 2020 and installed in ALICE in July 2020.

Installation in ALICE will be followed by commissioning period.

We plan the data taking in 2021.

A further upgrade of the fully-cylindrical ITS Inner Barrel for the LHC Long Shutdown 3 has been proposed and the R&D activities will start in 2020.

2025+ ALICE ITS-3
Innermost layer: at R = 18 mm
Thickness of each layer: 0.05% $X_0$
Back Up
Outline

1. Overview
2. Production of main components
   • Outer Barrel HIC and Stave Production
   • Readout Electronics
   • Power Boards
3. Detector Assembly
4. Commissioning
Detector Construction and Assembly
- Module production: completed!
- Stave production: done
- Electronics production: done!

Assembly and Commissioning
OB Stave Assembly End: done

Installation
6-month Global Commissioning
Outer Barrel Commissioning

Example of threshold scan of one Outer Barrel Stave (~$10^8$ pixels)
Power Supplies for detector and readout electronics

- Completely cabled and tested