The new Inner Tracking System for the ALICE Upgrade

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Goals of the ALICE Upgrade

Physics motivations for the Upgrade → High precision measurements of rare probes over broad $p_T$ range

- Heavy flavour dynamics and hadronization at low $p_T$
- Charmonium down to zero $p_T$
- Thermal dileptons, photons, vector mesons
- High-precision measurement of light and hyper-nuclei

Main upgrade requirements

- Continuous read-out rate in excess of > 50 kHz to fully exploit the LHC Pb-Pb and pp interaction rate during Run3 and Run4
- Improved tracking performance down to very low $p_T$

Upgrade strategy

- New silicon trackers: ITS (mid-rapidity), MFT (forward rapidity)*
- New TPC read-out chambers (GEMs) and electronics**
- New Fast Interaction Trigger (FIT)
- Fast read-out of other detectors (TOF, TRD, Muon arm, ZDC,...)
- New Online plus Offline system (O2 project)

* see Adam's talk @ 10:30
** see Andrea's talk @ 11:45
**ITS upgrade - Requirements and design**

**ITS upgrade requirements:**

- **➢ Improve impact parameter resolution**
  - Reduce distance from IP to first layer \(\rightarrow\) new beam pipe
  - Reduce material budget
  - Reduce pixel size
- **➢ Improve tracking efficiency and \(p_T\) resolution at low \(p_T\)**
  - Increase granularity \(\rightarrow\) from 6 to 7 layers, all pixels
- **➢ Increase read-out capabilities**

<table>
<thead>
<tr>
<th></th>
<th>ITS Run1/Run2</th>
<th>ITS upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of layers</strong></td>
<td>6 (pixel, drift, (\mu)strip)</td>
<td>7 (MAPS*)</td>
</tr>
<tr>
<td><strong>Rapidity range</strong></td>
<td>(</td>
<td>\eta</td>
</tr>
<tr>
<td><strong>Material budget per layer</strong></td>
<td>1.14% (SPD)</td>
<td>0.35% (IL)</td>
</tr>
<tr>
<td><strong>Distance to interaction point</strong></td>
<td>39 mm</td>
<td>22 mm</td>
</tr>
<tr>
<td><strong>Pixel size</strong></td>
<td>50 x 425 (\mu)m(^2)</td>
<td>29 x 27 (\mu)m(^2)</td>
</tr>
<tr>
<td><strong>Spatial resolution (r(\phi) x z)</strong></td>
<td>12 (\mu)m x 100 (\mu)m**</td>
<td>5 (\mu)m x 5 (\mu)m</td>
</tr>
<tr>
<td><strong>Max. readout speed Pb-Pb</strong></td>
<td>1 kHz</td>
<td>100 kHz</td>
</tr>
</tbody>
</table>

**•** SPD

**• Monolithic Active Pixel Sensors**
ITS upgrade - Layout and components

7-layer barrel geometry based on MAPS
- Inner Barrel (IB) : 3 layers
- Outer Barrel (OB) : 4 layers
- $r$ coverage: (min) 22 - (max) 394 mm
- $\eta$ coverage: (min) 1.3 - (max) 2.5
- Layers are azimuthally segmented in staves, which are mechanically and electrically independent.

12.5 G-pixel camera (~10 m$^2$)

Layer #

1. n. of Staves

48 42 30 24 20 16 12

Outer Layers (OL)

Middle Layers (ML)

Inner Layers (IL)

Inner Barrel (IB)

Outer Barrel (OB)

ALICE PIXEL DETECTOR
7-layer barrel geometry based on MAPS

- Inner Barrel (IB) : 3 layers
- Outer Barrel (OB) : 4 layers
- $r$ coverage: (min) 22 - (max) 394 mm
- $\eta$ coverage: (min) 1.3 - (max) 2.5
- Layers are azimuthally segmented in staves, which are mechanically and electrically independent.

Inner Barrel:
- 48 staves
- 9 ALPIDE chips on 1 row per stave
- Chip thickness: 50 $\mu$m
- Stave length: 290 mm
- Distance from IP: (min) 22 - (max) 42 mm

Inner Barrel Stave

Hybrid Integrated Circuit (HIC)
ITS upgrade - Layout and components (Outer Barrel)

7-layer barrel geometry based on MAPS

- Inner Barrel (IB) : 3 layers
- Outer Barrel (OB) : 4 layers
- \( r \) coverage: (min) 22 - (max) 394 mm
- \( \eta \) coverage: (min) 1.3 - (max) 2.5
- Layers are azimuthally segmented in staves, which are mechanically and electrically independent.

Outer Barrel:
- 54 staves in ML + 90 staves in OL
- ML: 112 ALPIDE chips on 4 rows per stave
- OL: 196 ALPIDE chips on 4 rows per stave
- Chip thickness: 100 \( \mu \)m
- Stave length: 843 - 1473 mm
- Distance from IP: (min) 194 - (max) 394 mm

Outer Barrel Stave

Hybrid Integrated Circuit (HIC)

- Power bus
- FPC
- ALPIDE chips
- Cold plate
- Half-Stave
- Space frame

Tilted staves with overlap

12.5 G-pixel camera (~10 m²)

Layer # n. of Staves

<table>
<thead>
<tr>
<th>Layer</th>
<th>Staves</th>
</tr>
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<tbody>
<tr>
<td>IB</td>
<td>3</td>
</tr>
<tr>
<td>OB</td>
<td>4</td>
</tr>
<tr>
<td>ML</td>
<td>3 + 4</td>
</tr>
<tr>
<td>OL</td>
<td>3 + 4</td>
</tr>
</tbody>
</table>

Outer Barrel HIC

FPC SIDE

SENSOR SIDE

Yasser Corrales Morales

EPS.HEP 2019, Ghent, Belgium
ITS upgrade - Component production status

**ALPIDE Chips:**
- Institutes:
  - 50 um CERN
  - 100 um Yonsei, Pusan
- Total # chips tested: ~70000
- Total # of wafers: ~1700
- Total yield: 63.7%
- Series test ended in mid 2018

**Outer Barrel HICs:**
- HIC Institutes:
  - Bari (IT), Liverpool (UK), Pusan (KR), Strasbourg (FR), Wuhan (CH), Trieste (IT)
  - ~2500 HICs assembled with a yield of 85%

**Inner Barrel HICs and Staves:**
- Institutes: CERN
- ~140 staves assembled with a yield of 73%
  - Enough for 2 fully working copies of IB
- ~140 staves assembled with a yield of 73%

**Outer Barrel Staves:**
- Stave Institutes:
  - Berkeley (US), Daresbury (UK), Frascati (IT), Nikhef (NL), Torino (IT)
  - Yield above 95%
  - OL stave production almost completed (by July 2019)
  - ML stave production will end by September 2019

**Outer Barrel stave metrology results**

- Residual in X at 95% percentile, ML+OL final metrology
- Residual in Y at 95% percentile, ML+OL final metrology
- Mean residual in Z (to nominal), ML+OL final metrology

Production completed!  
Production completed!  
Production on schedule
**ITS upgrade - Component production status**

**Readout electronics:**
- Institutes: Austin (US), Bergen (NO), CERN, Nikhef (NL), Padova (IT)
- 192 FPGA based RUs, operating in a mild radiation environment (<10 krad, $10^{12} \text{ MeV}/\text{n}_{eq}$)
- Board production completed. Functional test ongoing

**Power System**
- Institute: Berkeley (US)
- CAEN powering modules available and in use in commissioning setup
- Power board production completed. Functional test ongoing (until July 2019)

**Support structures**
- Institutes: Berkeley (US), CERN, Padova (IT), St. Petersburg (RU)
- Component production completed
- Insertion dry test performed
Fully equipped clean-room at CERN (Bld. 167) for layer assembly and commissioning
→ Same backend system that will be used in the experiment (Cooling plant, Power and Read-out racks, Trigger and DAQ system)
Layer assembly proceeds with the availability of staves (Outer Barrel)
DCS and DAQ systems: development of full functionalities ongoing
Commissioning before installation
continuous operation 24/7
data taking with cosmic rays and calibration scans
Fully automatised data quality control flow under preparation
Inner Barrel

➢ All staves and mechanical supports available
➢ IB-HL-0: able to read out all staves
➢ Final powering and read-out chain
➢ IB-HL-1: fully connected to electronics and under test
➢ IB-HL-2: connection under preparation
➢ Remaining HLs will follow with the availability of RUs
➢ Commissioning ongoing of IB-HL-0

Threshold Tuning for IB-HL-0

before tuning

<table>
<thead>
<tr>
<th>0</th>
<th>12.8</th>
<th>17.2</th>
<th>15.8</th>
<th>15.8</th>
<th>11.5</th>
<th>9.7</th>
<th>17.5</th>
<th>18.0</th>
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<tbody>
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<td>15.4</td>
<td>15.7</td>
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<td>20.6</td>
<td>14.3</td>
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<td>18.6</td>
<td>18.0</td>
<td>16.8</td>
<td>14.0</td>
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<tr>
<td>25.3</td>
<td>23.0</td>
<td>23.9</td>
<td>23.3</td>
<td>24.4</td>
<td>26.2</td>
<td>20.7</td>
<td>27.9</td>
<td>21.4</td>
</tr>
</tbody>
</table>

 histórico: 0
Threshold tuning after tuning

➢ All staves and mechanical supports available
➢ IB-HL-0: able to read out all staves
➢ Final powering and read-out chain
➢ IB-HL-1: fully connected to electronics and under test
➢ IB-HL-2: connection under preparation
➢ Remaining HLs will follow with the availability of RUs
➢ Commissioning ongoing of IB-HL-0

Threshold Tuning for IB-HL-0
ITS upgrade - Assembly and commissioning

Outer Barrel

➢ All Staves assembled on following half-layers
  • OB-HL-3 → Integration ongoing
  • OB-HL-4 → Completed
  • OB-HL-5 → Completed!
  • OB-HL-6 → Completed!

➢ Cabling ongoing on OB-HL-6
  • Next HL to be included in the commissioning
Cosmic-1
• Taken into account the overlaps, we have a (small) cross-section for cosmics with 3 track-points within half-layer 0
• This is one event from a 50kHz fake hit rate run
• … 1 out of 2 million events (~40s life time)

Inner Barrel Layer commissioning
• Taking into account the overlaps, there is a (small) cross-section for cosmic tracks with 3 track-points within half-layer
• This is one event from a 50kHz (dark hit rate) run
• … 1 out of 2 million events (~40s life time)

Cosmic tracks reconstructed in single layers

Detector component production almost completed ➔
- Two IB 100% ➔ completed!
- OB ~ 85% ➔ End by September 2019
- RU boards, Power boards and Service barrel structure ➔ completed!

Stave integration progressing
- Commissioning on surface started in May 2019 ➔ until May 2020
- Preparation of P2 services for detector installation on schedule ➔ 6 months of commissioning after installation in ALICE

➢ First reconstructed cosmic ray track in the IB-HL-0
➢ Thanks to the overlap between adjacent staves
➢ Three aligned pixel clusters observed in staves 6, 7 and 8 as shown in the figures
ITS upgrade - Backup slides
» Similar assembly procedure for stave in IL, ML and OL
» Extensive characterisation and quality checks in many assembly steps