Operational experience with the current tracker in ALICE

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University and INFN - Torino
on behalf of the ALICE Collaboration

The 27th International Workshop on Vertex Detectors
ALICE (A Large Ion Collider Experiment) is a general purpose heavy-ion experiment at the LHC

- Study of **strongly interacting matter**
- Study of the **Quark-Gluon Plasma** properties
The ALICE apparatus

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  - Study of strongly interacting matter
  - Study of the Quark-Gluon Plasma properties

- **Central Barrel**: pseudorapidity $|\eta| < 0.9$
  - **Tracking** in high density collisions:
    - $dN/d\eta \sim 2000$ in central Pb-Pb
  - **PID** (Particle IDentification):
    - $dE/dx$: ITS, TPC
    - Time of flight: TOF
    - Transition radiation: TRD
    - Cherenkov radiation: HMPID
  - **Low $p_T$ reach**: $\sim 0.1$ GeV/c
    - Mild magnetic field $B = 0.5$ T
    - Low material budget: (10% $X_0$ for ITS+TPC)
**The ALICE apparatus**

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The Inner Tracking System

- **Six cylindrical layers** of silicon sensors
  - **Silicon Pixel Detector (SPD):** the two innermost layers
  - **Silicon Drift Detector (SDD):** the two intermediate layers
  - **Silicon Strip Detector (SSD):** the two outermost layers

- The ITS is used for:
  - **primary vertex** reconstruction (resolution better than 100 µm)
  - separation of primary and **secondary vertices**
  - **PID** and **tracking** at low $p_T$
  - **impact parameter** determination
  - **pileup** rejection
  - charged-particle **pseudorapidity distribution** determination
The Inner Tracking System

- Radial dimensions:
  - from 3.9 cm (close to beam pipe) to 43.0 cm (close to TPC inner wall)

- Material Budget (M.B.):
  - ~ 1% $X_0$

<table>
<thead>
<tr>
<th>Layer</th>
<th>Det</th>
<th>Radius (cm)</th>
<th>Length (cm)</th>
<th>Channels</th>
<th>Area (m²)</th>
<th>Resolution (µm)</th>
<th>M.B. (% $X_0$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SPD</td>
<td>3.9</td>
<td>28.2</td>
<td>3.3 M</td>
<td>0.07</td>
<td>12 100</td>
<td>1.14</td>
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<tr>
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<td>28.2</td>
<td>6.5 M</td>
<td>0.14</td>
<td></td>
<td>1.14</td>
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<tr>
<td>3</td>
<td>SDD</td>
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<td>44.4</td>
<td>43 k</td>
<td>0.42</td>
<td>35 25</td>
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<tr>
<td>4</td>
<td>SDD</td>
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<td>59.4</td>
<td>90 k</td>
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<td>1.26</td>
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<td>5</td>
<td>SSD</td>
<td>38.0</td>
<td>86.2</td>
<td>1.1 M</td>
<td>2.20</td>
<td>20 830</td>
<td>0.83</td>
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<tr>
<td>6</td>
<td>SSD</td>
<td>43.0</td>
<td>97.8</td>
<td>1.5 M</td>
<td>2.80</td>
<td></td>
<td>0.86</td>
</tr>
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</table>
Operational experience with the current tracker in ALICE

**Silicon Pixel Detector (SPD)**

- 120 **Half-Stave (HS) modules**, grouped in two Half Barrels
  - each HS contains 2 **ladders**:
    - 1 sensor (200 µm thick) + 5 readout chips (150 µm thick)
    - **Hybrid pixel** sensors with binary output
      - p+n reverse biased (50V)
      - cell size 50 µm (rφ) x 425 µm (z)

- Each half-barrel divided into **10 half sectors**
  - 6 HS: 2 in Layer 1 + 4 in Layer 2

- C$_4$F$_{10}$ evaporative cooling system
Silicon Drift Detector (SDD)

- Two layers of 260 silicon drift modules (300 μm thick)
  - Layer 3: 14 ladders with 6 modules each
  - Layer 4: 22 ladders with 8 modules each
- 512 collection anodes (294 μm pitch)
- Drift HV: 1.8 kV
- Drift velocity: 6.7 μm/ns
- dE/dx measurement for PID
- MOS Injectors to monitor drift velocity
- Leak-tight water cooling
Silicon Strip Detector (SSD)

- 1698 silicon strip modules (300 µm thick)
  - Layer 5: 34 ladders with 22 modules each
  - Layer 6: 38 ladders with 35 modules each
- 768 double-sided strip sensors per module:
  - pitch \( r_\phi \): 95 µm; length: 40 mm; angle: 35 mrad
- \( dE/dx \) measurement for PID
- Leak-tight water cooling system + air dryer system

SSD barrel

SSD modules: silicon sensor + 2 hybrids with six HAL25 chips each
Excellent impact parameter resolution \( (d_0) \):  
- \( \sigma_{d_0} \approx 60 \text{ µm} \) at \( p_T = 1 \text{ GeV/c} \)  
- Secondary vertex reconstruction

![Image of ALICE charged particles](ALICE-charged-particles.png)  
![Image of ALICE Preliminary](ALICE-Preliminary.png)
ITS Physics Performance

- Excellent **track matching** between ITS and TPC
- Good **transverse momentum resolution**:
  \[
  \frac{\sigma_{p_T}}{p_T} = p_T \sigma_{1/p_T}
  \]
  - **ITS stand-alone** algorithm extends the \( p_T \) range down to 80÷100 MeV/c

![Graph showing ITS prolongation efficiency vs. \( p_T \) for ALICE, pp, \( s = 7 \text{ TeV} \)]

**ALICE**
- p-Pb, \( \sqrt{s_{NN}} = 5.02 \text{ TeV}, |\eta|<0.8 \)
  - TPC standalone tracks
  - TPC tracks constrained to vertex
  - TPC+ITS combined tracks
  - TPC+ITS constrained to vertex

\( \sigma_{|p_T|} = \sigma_1/|p_T| \)
Physics Performance

- **PID** for pure stand-alone ITS tracks
  - $dE/dx$ vs momentum
    - $K$-$\pi$ separation in the range $0.1 \div 0.45 \text{ GeV/c}$
    - $K$-$p$ separation in the range $0.1 \div 1 \text{ GeV/c}$
**First Level Trigger**

- **Fast-OR**: at least one hit in a readout chip
- INPUT: 1200 bits every 100 ns from SPD to CTP
- OUTPUT: 10 programmable output based on boolean logic

**Maximum latency** at CTP input: 800 ns
• **Fast-OR** signals (100 ns time window)

• Online beam **background mitigation** with forward rapidity detectors

• Online **Past-future protection**: only events that are alone in the time window (7 bunch crossings)

• **HM selections**:  
  ▸ Hits in Layer 1 ≥ threshold 1  
  ▸ Hits in Layer 2 ≥ threshold 2
- **Low-multiplicity** events: 2 ÷ 4 tracks
- Veto with forward-rapidity detectors
- Fast-OR signal in mid-rapidity region
- **Topological trigger:**
  - **Opening angle** between the two cones
  - **Minimum** and **maximum** number of tracklets
• In some cases the detector acceptance has decreased due to specific problems in the subdetectors

• In Run2 of active modules are found to be stable:
  ▶ some modules excluded due to HV and readout problems

Acceptance (% modules)

<table>
<thead>
<tr>
<th></th>
<th>SPD</th>
<th>SDD</th>
<th>SSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run1</td>
<td>92</td>
<td>87</td>
<td>91</td>
</tr>
<tr>
<td>Run2 (2015-2016)</td>
<td>93</td>
<td>83</td>
<td>91</td>
</tr>
<tr>
<td>Run2 (2017)</td>
<td>93</td>
<td>82</td>
<td>91</td>
</tr>
<tr>
<td>Run2 (2018)</td>
<td>92</td>
<td>81</td>
<td>91</td>
</tr>
</tbody>
</table>
Loss of SPD modules in Run1

- In Run1 SPD suffered some losses due to **cooling problems**
  - The filters were **clogged**: they can only be accessed by removing the TPC!
- The filters were **drilled open**, using a cable
  - From February 2012 (63% active modules) to January 2014 (93% active models)
- Since the end of the drilling-campaign the number of modules in acquisition is stable

Before | After
--- | ---

### Graph:
- Discovery of the problem
- Interventions on the system
- Sub-cooling installation
- Lab commissioning before installation
- First switch on in the cavern
- Restart after LHC forced shutdown
- New flow rate values
- Old flow rate values

<table>
<thead>
<tr>
<th>Sector number</th>
<th>Flow rate [g/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-9</td>
<td></td>
</tr>
<tr>
<td>2.1 g/s</td>
<td>1.8 g/s minimum value for total heat drain</td>
</tr>
<tr>
<td>1.8 g/s</td>
<td>2.1 g/s common setpoint</td>
</tr>
</tbody>
</table>
Loss of SDD modules in Run1

• The SDD suffered many losses during Run1

• During the installation of the detector, one half-ladder of layer 3 had some problem with the electronics
  
  ▪ Since then we could not communicate with these modules

• The beam was dumped close to ALICE and Layer 3 suffered from high radiation
  
  ▪ A lot of MOS injectors were lost
  
  ▪ Since then, HV and LV are off during INJECTION and ADJUSTMENT
SSD - Air dryer System

- For the SSD the **humidity** is an important factor
  - Air dryer system to keep the humidity under control

- In June 2015, a problem with increasing humidity led to **increasing leakage current**
  - can lead to permanent damages
  - Some interventions on the ventilation machine (DESSICA) to keep the conditions under control till the end of 2015

- **New machine** (SAMP) installed in April 2016, with following requirements:
  - **Absolute Humidity** (AH) range: 1 to 1.5 g/kgas
  - **Air quality**: Class 1000 (ISO6) filtering stage at the output of the machine
  - **Fixed Flow**: 350 m$^3$/h (100 m$^3$/h to the SSD)
Detector Control System (DCS)

- Each detector has its own **Detector Control System** (DCS) to control remotely the hardware
  - **New!** Standardisation and completion of high level procedures (related to BEAM SAFE status) for all detectors

- Each detector has specific **security operations**, according to past experience
  - **SPD**
    - Beam injection or adjustment → bias voltage to 2V and sensor not depleted
  - **SDD**
    - Beam injection or adjustment → HV and LV off, but readout electronics ready
      - After the accident with the beam, as precaution
    - **New!** LV crates can be remotely controlled with remote switch
  - **SSD**
    - HV and LV always at their nominal value → keep the conditions stable
Each detector has its own Experiment Control System (ECS) to perform specific operations, e.g. calibration.

Each detector has specific calibration strategy.

- **SPD**
  - Configuration performed only once followed by tuning
  - Noisy-pixel mask updated when a noisy pixel is detected
  - **New!** Pause And Reset (PAR) procedure implemented
    - To reduce the down time in case of failure

- **SDD**
  - Baseline, noise, gain and drift speed measured at the beginning of each physics fill with dedicated calibration runs

- **SSD**
  - Baseline and noise measured at the beginning of each physics fill with dedicated calibration runs
• ALICE runs at reduced
  ▸ the integrated dose of ITS is much lower than the other LHC experiments

<table>
<thead>
<tr>
<th>Detector (inner radius)</th>
<th>TID (krad)</th>
<th>1 MeV neq (cm⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPD (r = 3.9 cm)</td>
<td>17.4</td>
<td>2.9 x 10¹¹</td>
</tr>
<tr>
<td>SDD (r = 15 cm)</td>
<td>1.5</td>
<td>3.6 x 10¹⁰</td>
</tr>
<tr>
<td>SSD (r = 38 cm)</td>
<td>0.34</td>
<td>1.6 x 10¹⁰</td>
</tr>
</tbody>
</table>

No increase in noisy channels and temperature, but increasing leakage current for some SPD Half Staves!
SPD operational performances

- A **slight increase** of the **leakage current** has been observed for some HSs
  - 8/9 belong to Layer 1 (higher dose)
- **Stable** number of **noisy pixels** and **temperature**
SDD operational performance

- The drift speed is stable
  - Measured during the calibration steps with the MOS injectors
  - The drift speed depends on the temperature:
    \[ v_{\text{drift}} \propto T^{-2.4} \]
  - 0.1% resolution on \( v_{\text{drift}} \) to get the spatial resolution of \( \sigma_{r_{\phi}} = 35 \, \mu m \)

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Temperature vs. mod. number - Run 294198

- Side 0
- Side 1

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Drift speed vs. time for 2017 and 2018
SDD operational performance

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- **Noise level** is **low** and **stable**
SSD operational experience

- SSD acceptance **stable**
  - Minor issue related to JTAGs
    - Solved improving cable connections
- Fraction of bad strips:
  - Layer 5:
    - n-side: 10%
    - p-side: 8.7%
  - Layer 6:
    - n-side: 9.2%
    - p-side: 8.2%
SSD – SEU in the FEROM and LV board

- The **Front-End ReadOut Modules** (FEROM) are close to the interaction region
  - exposed to radiation, that can change a bit of information (**Single-Event Upset**)
  - SEU were not expected, due to the presence of a concrete shield
SSD – SEU in the FEROM and LV board

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- 7 SEUs recorded in RUN1 → some measures adopted:
  - Radiation tolerant PROM
  - Firmware upgrade → faster FPGA reload
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- **SEU** statistic in **RUN2**
  - 2015: 8 (ALICE $L_{\text{INT}} = 6.8 \text{ pb}^{-1} (\text{pp}) + 433 \text{ }\mu\text{b}^{-1} (\text{Pb-Pb}))$
  - 2016: 21 (ALICE $L_{\text{INT}} = 13.4 \text{ pb}^{-1} (\text{pp}) + 43.3 \text{ nb}^{-1} (\text{p-Pb}))$
  - 2017: 20 (ALICE $L_{\text{INT}} = 19.2 \text{ pb}^{-1} (\text{pp}))$
  - **2018**: 20 (ALICE $L_{\text{INT}} \sim 25.4 \text{ pb}^{-1} (\text{pp}))
- The ITS was almost always available during the ALICE running time
- ITS caused 10% of the detector-caused End Of Runs (EOR)

<table>
<thead>
<tr>
<th>Availability</th>
<th>SPD</th>
<th>SDD</th>
<th>SSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of 2017 ALICE running time</td>
<td>99.9</td>
<td>99.5</td>
<td>100</td>
</tr>
<tr>
<td>% of 2018 ALICE running time</td>
<td>99.6</td>
<td>99.8</td>
<td>99.8</td>
</tr>
</tbody>
</table>
Summary and Conclusions

- The ALICE Inner Tracking System is currently working smoothly, providing a physics performance in agreement with the design requirements.

- In the current year there were no major issues, just ordinary maintenance of the detector.

- The detector is showing some effects of ageing that do not influence the physics performance.

- During Long Shutdown 2, which will start at the end of this year, the current ITS will be dismissed and completely replaced by a new tracker equipped with 7 monolithic pixel layers:
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