Performance of the ALICE Inner Tracking System and studies for the upgrade

Giacomo Contin
Universita’ degli Studi di Trieste & INFN Sezione di Trieste

On behalf of the ITS collaboration in the ALICE experiment at LHC
Summary

• System overview and tasks
• Hardware features
• Physics performance in p-p and Pb-Pb
• Outlook on the ITS upgrade plans
The ALICE experiment

Dedicated heavy ion experiment at LHC

- Study of the behavior of strongly interacting matter under extreme conditions of high energy density and temperature
- Proton-proton collision program
  - Reference data for heavy-ion program
  - Genuine physics (momentum cut-off < 100 MeV/c, excellent PID, efficient minimum bias trigger)

Barrel Tracking requirements

- Pseudo-rapidity coverage $|\eta| < 0.9$
- Robust tracking for heavy ion environment
  - Mainly 3D hits and up to 150 points along the tracks
- Wide transverse momentum range (100 MeV/c – 100 GeV/c)
  - Low material budget (13% $X_0$ for ITS+TPC)
  - Large lever arm to guarantee good tracking resolution at high $p_t$

PID over a wide momentum range

- Combined PID based on several techniques: dE/dx, TOF, transition and Cherenkov radiation
Central Barrel
2 $\pi$ tracking & PID
$\Delta \eta \approx \pm 1$

Detector:
Size: 16 x 26 meters
Weight: 10,000 tons

Collaboration:
> 1000 Members
> 100 Institutes
> 30 countries
The ALICE Inner Tracking System

The ITS tasks in ALICE

- Secondary vertex reconstruction (c, b decays) with high resolution
  - Good track impact parameter resolution < 60 µm (rφ) for p_t > 1 GeV/c in Pb-Pb
- Improve primary vertex reconstruction, momentum and angle resolution of tracks from outer detectors
- Tracking and PID of low p_t particles, also in stand-alone
- Prompt L0 trigger capability <800 ns (Pixel)
- Measurements of charged particle pseudo-rapidity distribution
  - First Physics measurement both in p-p and Pb-Pb

Detector requirements

- Capability to handle high particle density
- Good spatial precision
- High efficiency
- High granularity (≈ few % occupancy)
- Minimize distance of innermost layer from beam axis (mean radius ≈ 3.9 cm)
- Limited material budget
- Analogue information in 4 layers (Drift and Strip) for particle identification in 1/β^2 region via dE/dx
The ITS parameters

<table>
<thead>
<tr>
<th>Layer</th>
<th>Det.</th>
<th>Radius (cm)</th>
<th>Length (cm)</th>
<th>Surface (m²)</th>
<th>Chan.</th>
<th>Spatial precision (mm)</th>
<th>Cell (µm²)</th>
<th>Max occupancy central PbPb (%)</th>
<th>Material Budget (% N/N₀)</th>
<th>Power dissipation (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SPD</td>
<td>3.9</td>
<td>28.2</td>
<td>0.21</td>
<td>9.8M</td>
<td>12</td>
<td>100</td>
<td>2.1</td>
<td>1.14</td>
<td>1.35k</td>
</tr>
<tr>
<td>2</td>
<td>SPD</td>
<td>7.6</td>
<td>28.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.6</td>
<td>1.14</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>SDD</td>
<td>15.0</td>
<td>44.4</td>
<td>1.31</td>
<td>133K</td>
<td>35</td>
<td>25</td>
<td>2.5</td>
<td>1.13</td>
<td>1.06k</td>
</tr>
<tr>
<td>4</td>
<td>SDD</td>
<td>23.9</td>
<td>59.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
<td>1.26</td>
<td>1.75k</td>
</tr>
<tr>
<td>5</td>
<td>SSD</td>
<td>38.0</td>
<td>86.2</td>
<td>5.0</td>
<td>2.6M</td>
<td>20</td>
<td>830</td>
<td>4.0</td>
<td>0.83</td>
<td>850</td>
</tr>
<tr>
<td>6</td>
<td>SSD</td>
<td>43.0</td>
<td>97.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.3</td>
<td>0.86</td>
<td>1.15k</td>
</tr>
</tbody>
</table>

Accurate description of the material in MC
Half-stave

Layer | Radius (cm) | # half-staves | Ladders/half-stave | # ladders
--- | --- | --- | --- | ---
1 | 3.9 | 40 | 2 | 80
2 | 7.6 | 80 | 2 | 160

- Total surface: ~0.24m²
- Power consumption ~1.4kW
- Evaporative cooling C₄F₁₀
- Operating at room temperature
- Fast two-dimensional readout (256µs)
- High efficiency (> 99%)
- L0 trigger capability
- Material budget per layer ~1% X₀

Half-barrel: outer surface

2 layers of pixels grouped in 2 half barrels mounted face to face around the beam pipe
SDD - Silicon Drift Detector

<table>
<thead>
<tr>
<th>Layer</th>
<th>Radius (cm)</th>
<th># ladders</th>
<th>Mod./ladder</th>
<th># modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>15.0</td>
<td>14</td>
<td>6</td>
<td>87</td>
</tr>
<tr>
<td>4</td>
<td>23.9</td>
<td>22</td>
<td>8</td>
<td>176</td>
</tr>
</tbody>
</table>

Front-end electronics (4 pairs of ASICs)
- Amplifier, shaper, 10-bit ADC, 40 MHz sampling
- Four-buffer analog memory

- HV supply
- LV supply
- Commands
- Trigger
- Data

Cooling (H₂O) tubes
Cables to power supplies and DAQ
Carbon fiber support

Central Cathode at -HV
Voltage divider
Anodes

70.2 mm
SSD - Silicon Strip Detector

Hybrid: identical for P- and N-side
Al on polyimide connections
6 front-end chips HAL25
water cooled

<table>
<thead>
<tr>
<th>Layer</th>
<th>Radius (cm)</th>
<th># ladders</th>
<th>Mod./ladder</th>
<th># modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>38.0</td>
<td>34</td>
<td>22</td>
<td>748</td>
</tr>
<tr>
<td>6</td>
<td>43.0</td>
<td>38</td>
<td>25</td>
<td>950</td>
</tr>
</tbody>
</table>

Sensor:
- double sided strip: 768 strips 95 um pitch
- P-side orientation 7.5 mrad
- N-side orientation 27.5 mrad

• carbon fibre support
• module pitch: 39.1 mm
• Al on polyimide laddercables
Tracking strategy and performance

“Global”
1. Seeds in outer part of TPC @lowest track density
2. Inward tracking from the outer to the inner TPC wall
3. Matching the outer SSD layer and tracking in the ITS
4. Outward tracking from ITS to outer detectors → PID ok
5. Inward refitting to ITS → Track parameters OK

“ITS stand-alone”
- Recovers not-used hits in the ITS layers
- Aim: track and identify particles missed by TPC due to $p_t$ cut-off, dead zones between sectors, decays
  - $p_t$ resolution $\approx 6\%$ for a pion in $p_t$ range 200–800 MeV/c
  - $p_t$ acceptance extended down to 80–100 MeV/c (for $\pi$)
Vertex reconstruction

**Vertex from SPD tracklets**

**Procedure:**
- “SPD Vertex” from all possible pairs of 2 aligned hits, in a fiducial window (in $\phi$, $\eta$)
- “SPD tracklet” defined by a pair of hits aligned with the reconstructed vertex

**Used to:**
- Monitor the interaction diamond position quasi-online
- Initiate barrel and muon arm tracking
- Measure charged particle multiplicity
- High efficiency & poorer resolution

**Vertex from reconstructed tracks**

**Procedure:**
- More accurate second reconstruction of interaction vertex from tracks in the barrel

**Used to:**
- Reconstruct secondary vertices
- Estimate the vertex resolution
- Poorer efficiency & high resolution

- Vertex spread distribution in p-p: comparison of the two methods
- The asymptotic limit estimates the size of the luminous region, seen for the vertices reconstructed with tracks.
Vertex resolution estimation in Pb-Pb

Method to evaluate resolution on the vertex position:

- The track sample is randomly divided into two
- A primary vertex is reconstructed for each of the sub-sample
- The resolution is extracted from the $\sigma$ of the distribution of the residual between the two vertices
- The resolution is extrapolated for most central (5%) Pb-Pb collisions
ITS Performance: Impact parameter resolution

- The transverse impact parameter in the bending plane: \( d_0 (r \phi) \) is the reference variable to look for secondary tracks from strange, charm and beauty decay vertices.
- Impact parameter resolution is crucial to reconstruct secondary vertices: below 75 µm for \( p_t > 1 \) GeV/c.
- Good agreement data-MC (~10%).

- The material budget mainly affects the performance at low \( p_t \) (multiple scattering).
- The point resolution of each layer drives the asymptotic performance.
- ITS standalone enables the tracking for very low momentum particles (80-100 MeV/c pions).
Impact parameter in p-p, global and ITS standalone
ITS Performance: Particle Identification

The dE/dx measurement:
• Analogue read-out of four deposited charge measurements in SDD & SSD
• Charge samples corrected for the path length
• Truncated mean method applied to account for the long tails in the Landau distribution

The PID performance:
• PID combined with stand-alone tracking allows to identify charged particles below 100 MeV/c
• p-K separation up to 1 GeV/c
• K-π separation up to 450 MeV/c
• A resolution of about 10-15% is achieved
ITS Upgrade

Physics Motivations and Simulations Studies

The main physics goals for the ITS upgrade:

- improve the charmed baryonic sector studies
- access the exclusive measurement of beauty hadrons

They can be achieved by:

- improving the impact parameter resolution by factor 2-3 to identify short displaced secondary vertices
- implementing a topological trigger functionality
- exploiting PID in the trigger down to lower $p_t$

**Simulations with different ITS parametrizations**

- in $r\phi$ - Current ITS
- in $z$ - Current ITS
- in $r\phi$ - "All New" Conf.
- in $z$ - "All New" Conf.

**Upgrade simulation**

Significance (3$\sigma$) $8.9 \pm 1.1$

S (3$\sigma$) $456 \pm 54$

B (3$\sigma$) $2177 \pm 25$

PbPb $\sqrt{s_{NN}} = 2.76$ TeV, $1.5 \times 10^6$ events 0-20% cent, $0.0 < p_T < 2.0$ GeV/c

Mean = $1.866498 \pm 0.001188$

Sigma = $0.009480 \pm 0.001323$
ITS Upgrade - Technical goals

- Reduce **beam-pipe** radius from 30 mm to ~20 mm
- Add a **Layer 0** at ~20-22 mm radius (now SPD1 at 39 mm)
- Reduce **material budget** in the first layers from 1.1 to 0.5% $X_0$
  - Reducing mass of silicon, power and signals bus, cooling, mechanics
  - Using Monolithic Pixels
- Reduce the **pixel size** to the order of 50 x 50 $\mu m^2$
  (425 x 50 $\mu m^2$ at present)
  - Main improvement in $z$
  - Main impact on medium / high $p_t$ particles
- Reduce the **number of detector technologies**
  - 3 pixel layers followed by 3-4 pixel/strip layers
  - homogeneous output data format/read-out system
- **Trigger capability** (L2 ~ 100us): topological trigger, fast-OR and fast-SUM
Considered detector technologies:

- **Hybrid pixels**
  - 100 µm sensor + 50 µm ASIC
  - 30 µm x 100 µm pixels

- **Monolithic pixels**
  - 50 µm ASIC
  - 20 µm x 20 µm pixels

- **Silicon strips**
  - half-length strips
  - ADC on-chip

Requirements:
- increased spatial resolution
- readout time < 50 µs
- radiation tolerant (2 Mrad, $2 \times 10^{13} \text{n}_{eq}$)
- low power design (250 mW/cm²)
- minimized material budget

New design advantages:
- occupancy ~ 50% $\rightarrow$ lower radii
- better ambiguity resolution
- increased S/N ratio $\rightarrow$ better PID
- digital output and faster read-out

... to be implemented in view of the 2017-2018 LHC shutdown!
Conclusions

• The ALICE Inner Tracking System performance is well in agreement with the design requirements
• Track and vertex reconstruction is in good agreement with Monte Carlo simulations
• The achieved impact parameter resolution allows to reconstruct the charmed decay secondary vertices
• Standalone capability allows to track and identify charged particles with momenta down to 100 MeV/c
• The studies for a possible upgrade to improve the physics performance of the ITS are in an advanced stage
Thanks for your attention
BACKUP SLIDES
SDD calibration

ALICE performance 9/2/2011
SDD module 247 (inner layer)
PbPb @ √s = 2.76 TeV (2010 data)

Drift Time < 1200 ns
Drift Time > 4400 ns

SDD at nominal resolution

Before correction for V_{drift} non-uniformities
After correction

pp @ 7 TeV (LHC10b)

SDD layer 3
SDD layer 4

ALICE Performance
8/4/2011
SSD calibration

Calibration
The measured *intrinsic noise* of the 2.6 million SSD channels is used to:

- assess the detector efficiency
- guarantee the required signal-to-noise ratio
- monitor the SSD stability

Cluster charge distribution measured from collision data with all the SSD modules
- the *gain* can be calibrated at the module level

Gain map tuning: after the calibration, the MPVs are stable within a few %
Centrality