Performance of ALICE silicon tracking detectors

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

Dedicated heavy ion experiment at the LHC

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

Barrel Tracking features

- 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, calorimetry and topological PID

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Central Barrel

2π tracking & PID

Δη ≈ ± 1

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

Collaboration:
> 1200 Members
> 132 Institutes
> 36 countries
The ITS tasks in ALICE

• Improve primary vertex reconstruction, momentum and angle resolution of tracks from outer detectors
• Secondary vertex reconstruction (c, b decays) with high resolution \( \rightarrow \) Good track impact parameter resolution < 60 \( \mu m \) (\( r\phi \)) for \( p_T > 1 \) GeV/c in Pb-Pb
• 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 pp and Pb-Pb

Detector features

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

3 different technologies

• 2 layers of Silicon Pixel Detector (SPD)
• 2 layers of Silicon Drift Detector (SDD)
• 2 layers of Silicon double-sided microStrip Detector (SSD)
The ITS parameters

<table>
<thead>
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<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 (%XXd)</th>
<th>Power dissipation (W)</th>
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Accurate description of the material in MC

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ALICE data taking: 2008 – 2012

Cosmic (2008)
100 K events in the ITS using the pixel L0 dedicated trigger

\[ \sqrt{s} = 900 \text{ GeV} \] (300 K + 8 M events MB)
\[ \sqrt{s} = 2.36 \text{ TeV} \] (40 K events MB)
\[ \sqrt{s} = 2.76 \text{ TeV} \] (70 M events MB)
\[ \sqrt{s} = 7 \text{ TeV} \] (800 M events MB in 2010)
\[ \sqrt{s} = 7 \text{ TeV} \] (550 M events MB in 2011)
\[ \sqrt{s} = 8 \text{ TeV} \] (ongoing)

Pb – Pb collision (2010-2011)
\[ \sqrt{s} = 2.76 \text{ TeV/nucleon} \]
(\( \approx 30 \text{ M events MB in 2010} \))
(\( \approx 46 \text{ M events MB in 2011} \))
Alignment procedure

Data sets
- 100k cosmic tracks collected in 2008 with dedicated pixel L0 trigger
- pp data with (~115M tracks) /without magnetic field (~40M tracks)
  ▶ Significant improvement in statistics and detector coverage

General strategy
- Validation of survey measurements
- Start with layers easier to calibrate: SPD and SSD
- Include SDD at the last step of the procedure
  ▶ Longer calibration needed (interplay between alignment, drift velocity and time-zero calibration)
- Align the whole ITS wrt TPC

Two independent track-based alignment methods
- global: Millepede (default method)
- local: iterative method based on residuals minimization

For details in the procedure: “Alignment of the ALICE Inner Tracking System with cosmic-ray tracks”, JINST 5, P03003”
ITS alignment with cosmic rays 2009: SPD and SSD

Target: minimize the residual misalignment to optimize the resolution

SPD \rightarrow \text{hierarchical approach}

- Spatial resolution = 14 \, \mu m
- Residual misalignment = 7 \, \mu m

D_{xy} \rightarrow \text{distance between 2 half tracks in the xy plane at } y=0

\sigma_{d_{XY}|y=0} = 2\sigma_{d_0}

SPD

Good alignment with survey for SSD spatial resolution = 21 \, \mu m

Residual misalignment for modules on ladders = 5 \, \mu m (negligible)

Millepede with cosmics used mostly to align the whole SPD barrel w.r.t. SSD

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ITS alignment with collisions 2010: SPD and SSD

“extra” clusters distance = point-to-track distance in acceptance overlaps

Alignment with mixed B>0, B<0 and B=0 collision data + B<0 cosmic data, using the curvature measured by the TPC and keeping the SSD points fixed

Extra cluster distance still compatible with a residual misalignment of about $\sigma_{\text{mis}} \sim 8 \, \mu m$

SSD

- re-validation of survey with “extra” clusters in SSD using pp collisions (full SSD barrel)
- estimated residual misalignment confirmed to be compatible with the survey precision on the whole detector ($\sim 5 \, \mu m$)

"Extra cluster" residual distribution: SPD1

MC (8 $\mu$m misal)
Data 7 TeV
SDD calibration and alignment (1)

- In SDD, local $x$ determined from drift time:
  \[ x_{\text{loc}} = (t - t_0) \times V_{\text{drift}} \]

- Drift region divided into 2 halves

- Drift field generated by a voltage divider implanted on the surface

- Auxiliary external divider connected every ~20 cathodes

- Two calibration parameters: $t_0$ and $V_{\text{drift}}$

- $t_0$ initial values estimated either from the minimum drift time or from track to point residuals in the two drift regions

- $V_{\text{drift}}$ online estimation by means of MOS charge injectors integrated on the detector surface. Stability within 1‰ mandatory to guarantee desired resolution of $\sim 30$ µm

- $V_{\text{drift}}$ offline accurate estimation using the track to point residuals thus recovering the information for the modules with malfuctioning injectors
V\(_{\text{drift}}\) monitored at every LHC fill with dedicated calibration runs

- Stability \(\sim 1\%\) to get nominal resolution \(\sim 30\ \mu\text{m}\)

Corrections on \(V_{\text{drift}}\) needed for:
- Modules with malfunction injectors (\(\sim 30\%\))
- Systematic effects in the estimation of the drift speed with injectors

After correction for non uniformity of the drift speed and fine tuning of \(t_0\) and \(V_{\text{drift}}\):

- track to point residuals \(\sim 30\ \mu\text{m}\) (transverse plane along the drift coordinate) at high \(p_T\)
- nominal resolution for SDD (resolution along the anodes \(\sim 35\ \mu\text{m}\))
Tracking strategy and performance

“Global”

- Seeds in outer part of TPC @ lowest track density
- Inward tracking from the outer to the inner TPC wall
- Matching the outer SSD layer and tracking in the ITS
- Outward tracking from ITS to outer detectors → PID ok
- Inward refitting to ITS → Track parameters OK

“ITS stand-alone”

- ITS+TPC left-over space points can be used for stand-alone ITS tracking
- 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 $\pi$)

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Vertex reconstruction

- The procedure needs only SPD local reconstruction, i.e. SPD points
- A more accurate vertex estimate is done after tracking
- Method based on matching points on the 2 SPD layers → tracklets

✓ $\Delta\phi$ cuts and constraints on the Distance of Closest Approach to the beam axis are used for tracklet definition
✓ Cuts applied in an iterative way → Independence of possible beam displacements
✓ Vertex → the best common origin of the found tracklets
✓ High efficiency: the sole Z coordinate of the vertex can be done with a single tracklet
Method to evaluate resolution on the vertex position:

- The track sample is randomly divided into two sub-samples
- A primary vertex is reconstructed for each 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 (orange box)
Pile-up detection

- The SPD can be used to tag pile-up interactions occurring in a time window of 100 ns (4 bunch crossings).
- The vertexers are used to find not only one vertex, but the tracklets which are not pointing to the “main” vertex are used to see if there are other points originating particles.

Distribution of the distance along $z$ between main and pileup vertices reconstructed with the SPD.

The peak at $\Delta z = 0$ is due to tails of the main vertex (and secondaries) reconstructed as a second vertex (false positives).
Measuring centrality and multiplicity

• New tracklets are built using the vertex and the SPD points
  ❖ Tracklet: pair of clusters (inner/outer layer) aligned with the reconstructed primary vertex within fiducial windows in $\theta$ and $\phi$

• measure charged $dN/d\eta$ in p-p and Pb-Pb collisions

“Charged particle multiplicity density at midrapidity in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV”. PRL105, 252301(2010)
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: better than 75 µm for $p_T > 1$ GeV/c.

The material budget mainly affects the performance at low $p_T$ (multiple scattering).

The point resolution of each layer drives the asymptotic performance (at high $p_T$).

ITS standalone enables the tracking for very low momentum particles (80-100 MeV/c pions).
Impact parameter in Pb-Pb, global and ITS standalone

- Good agreement data-MC (~10%)
- Very nice agreement 2010-2011 data

- The ITS standalone tracker is used for very low momentum tracks ($p_T < 100$ MeV/c)
- Impact parameter resolution of the SA tracks similar to the global tracks
- Dependence of the resolution at low $p_T$ on the particle species
  → multiple scattering effect

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Impact parameter in pp, global and ITS standalone

**Graph 1:**
- Impact parameter vs. $p_t$ [GeV/c]
- Data (LHC10c period)
- MC, residual misal.

**Graph 2:**
- Impact parameter vs. $p_t$ [GeV/c]
- Data, pions
- Data, kaons
- Data, protons
- MC, pions
- MC, kaons
- MC, protons

**Graph 3:**
- Impact parameter vs. $p_t$ [GeV/c]
- ITS standalone
- Data (LHC10b period)
- MC

**Graph 4:**
- Impact parameter vs. $p_t$ [GeV/c]
- ITS standalone
- Data, Pions
- Data, Kaons
- Data, Protons
- MC, Pions
- MC, Kaons
- MC, Protons

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Secondary vertex reconstruction

✓ Very good impact parameter resolution allows reconstruction of secondary vertices

✓ Detect open-charm mesons

$[D^+(c\tau \sim 312 \, \mu m), D_0(c\tau \sim 123 \, \mu m), D^*, D_s(c\tau \sim 150 \, \mu m)]$

\[3<p_T<36 \, \text{GeV/c}\]

$D^+ \rightarrow K^- \pi^+ \pi^+$

Pb-Pb, $\sqrt{s_{NN}}=2.76 \, \text{TeV}$

Centrality: 0-7.5%, 15.8M evts

$\mu = 1.869 \pm 0.001$, $\sigma = 0.013 \pm 0.001$

$S/B (3\sigma) = 0.0881$

$D^0 \rightarrow K^+ \pi^+$

$\mu = 1.864 \pm 0.001$, $\sigma = 0.010 \pm 0.002$

$S (3\sigma) = 12803 \pm 432$

$S/B (3\sigma) = 0.087$

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ITS Performance: Particle Identification

The \( \frac{dE}{dx} \) measurement:
- Analogue read-out of four deposited charge measurements in SDD & SSD
- \( \frac{dE}{dx} \) measurement for low momentum, highly ionizing particles, down to the lowest momentum at which tracks can still be reconstructed. The ITS is a stand-alone low-\( p_T \) particle spectrometer
- Up to 4 sample per track, combined via truncated mean → achieved resolution of about 12%

The PID performance:
- PID combined with stand-alone tracking allows one to identify charged particles below 100 MeV/c
- \( p-K \) separation up to 1 GeV/c; \( K-\pi \) separation up to 450 MeV/c
Identified particle spectra

• Combined results of different PID techniques
  ➢ High $p_T$: TOF
  ➢ Intermediate $p_T$: TPC
  ➢ Low $p_T$ (down to 100 MeV/c for pions): ITS standalone tracks

Low $p_T$ reach is very important for reducing the extrapolation of the yield down to $p_T = 0$ (extrapolation = 10% for p)
Summary

- ALICE ITS performance is in excellent agreement with the requirements.
- The achieved alignment is in agreement with the expected residual misalignment.
- Track and vertex reconstruction is in good agreement with Monte Carlo simulations.
- The achieved impact parameter resolution allows one to reconstruct the charmed decay secondary vertices.
- Standalone capability allows to track and identify charged particles with momenta down to 100 MeV/c.

Now it’s time to Upgrade.....
ITS Upgrade: why?

- Extend ALICE capability to study heavy quarks as probes of the QGP in heavy-ion collisions
  - Study the quark mass dependence of the energy loss
    - Measure the Nuclear Modification factor $R_{AA}$ vs $p_T$, down to low $p_T$, of D and B mesons
  - Study the thermalization process of heavy quarks in the hot and dense medium formed by heavy ion collisions
    - Measure the baryon over meson ratio ($\Lambda_c / D$ or $\Lambda_b / B$)
    - Investigate collective phenomena for heavy flavours by measuring azimuthal anisotropies of D mesons at low $p_T$
  - Comprehensive measurement of low-mass dileptons
    - Yield of low mass $e^+e^-$ (virtual $\gamma$)
    - Spectral function of $\rho$-meson - $e^+e^-$ effective mass spectrum down to 200 MeV

- Exploit the LHC luminosity increase improving the readout capabilities, now limited to $\approx 1$ kHz

All the details on the ITS Upgrade in the R. Santoro presentation on Thursday afternoon
Thanks for your attention
Backup slides
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 %
2 layers of pixels grouped in 2 half barrels mounted face to face around the beam pipe

- Total surface: $\sim 0.24 \text{m}^2$
- Power consumption $\sim 1.4 \text{kW}$
- Evaporative cooling $\text{C}_4\text{F}_{10}$
- Operating at room temperature
- Fast two-dimensional readout (256µs)
- High efficiency (> 99%)
- L0 trigger capability
- Material budget per layer $\sim 1\% X_0$
SDD - Silicon Drift Detector

<table>
<thead>
<tr>
<th>Layer</th>
<th>Radius (cm)</th>
<th># Ladders</th>
<th>Mod./ladder</th>
<th># modules</th>
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<tr>
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<td>23.9</td>
<td>22</td>
<td>8</td>
<td>176</td>
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Cooling (H₂O) tubes

Cables to power supplies and DAQ

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

SDD Barrel

Central Cathode at -HV

Voltage divider

Anodes

70.2 mm

HV supply

LV supply

Commands

Trigger

Data
SSD - Silicon Strip Detector

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

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

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<tr>
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<td>43.0</td>
<td>38</td>
<td>25</td>
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- carbon fibre support
- module pitch: 39.1 mm
- Al on polyimide laddercables
Centrality

Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV

Data

Glauber fit

$N_{\text{BD}} \times (f N_{\text{part}} + (1-f) N_{\text{coll}})$

$\text{f} = 0.806$, $\mu = 29.003$, $\alpha = 1.202$

VZERO Amplitude (a.u.)

-3.7 $< \eta <$ -1.7

V0A

V0C

2.8 $< \eta <$ 5.1

Pixel 1

Pixel 2

Drift 1

Drift 2

Strip 1

Strip 2

centrality percentile resolution

ALICE Performance

13/05/2011