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The upgrade of the ALICE Inner Tracking System at the CERN LHC

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Summary. — In 2021, for the third run of the CERN Large Hadron Collider (LHC), Pb–Pb collisions will be performed at a centre-of-mass energy per nucleon of $\sqrt{s_{\rm NN}} = 5.5$ TeV, with an integrated luminosity of 6×10^{27} cm^{-2}s^{-1} and at an unprecedented interaction rate of 50 kHz. To fulfil the requirements of its physics program for Run 3 the ALICE experiment at LHC is preparing a major upgrade during the Long Shutdown 2 of LHC in 2019-2020. One of the key elements of the program, is the construction of a new ultra-light and high-resolution Inner Tracking System (ITS) to enhance the determination of the distance of closest approach to the primary vertex, the tracking efficiency at low transverse momenta, and the read-out rate capabilities, with respect to what can be achieved with the current detector. The ITS will consist of seven cylindrical and concentric layers equipped with silicon Monolithic Active Pixel Sensors (MAPS) with a pixel size of the order of 30×30 μm^2 built with the TowerJazz 0.18 μm CMOS Imaging process. The ITS upgrade collaboration has finished the R&D of the detector components and has started the production phase.

1. – Physics motivation

The ALICE Collaboration at the CERN Large Hadron Collider (LHC) is building a major upgrade of the experimental apparatus to be installed during the Long Shutdown 2 of LHC in 2019-2020. The upgrade will enhance the physics capabilities of ALICE for the measurements of rare probes on a wide range of transverse momenta in pp, p-Pb and Pb-Pb collisions. The physics goal consists in reaching high-precision measurements of the Quark-Gluon Plasma (QGP) state, studying quarkonia down to very low transverse momenta ($p_{\rm T}$), vector mesons and low-mass dileptons, as well as light nuclei and hypernuclei.

The upgrade of the ALICE Inner Tracking System (ITS) plays a key-role for the enhancement of the physics capabilities relaying on the determination of the distance of closest approach to the primary vertex, the tracking efficiency at low transverse momenta (< 1 GeV/c), and the read-out rate [1] [2].

One example of the physics performance the new setup can achieve is related to the study of the B meson. With the present setup it cannot be accessed but, with the upgraded apparatus it will be possible to reconstruct the following decay channels: B $\rightarrow$ D^0 + X (down to $p_T \approx 0$ GeV/c), $B^{\pm} \rightarrow J/\psi(\rightarrow ee) + K^{\pm}$ (down to $p_T \approx 1$ GeV/c) and, $B^+ \rightarrow \bar{D}^0 + \pi^+$ (down to p_T = 2–3 GeV/c) [1].

2. – Limitations of the present ITS

At present, the three main limitations of the current ITS setup are [1]:

- the readout rate of the Silicon Drift Detectors (SDD) installed on the two middle layers is limited to about 1 kHz, independent on the detector occupancy, with dead time close to 100% (the same limit is in the shadow of the dead time introduced by the Time Projection Chamber (TPC)). This restricts ALICE to use only a small fraction of the full Pb–Pb collision rate of 8 kHz that currently LHC is providing.
- The material budget, which is about 1.1% of the radiation length (X_0) for the innermost layers. At present it is the lowest among the current LHC experiments, but a further reduction is needed to improve the tracking performances of the future ITS especially for the innermost layers;
- the spatial resolution for the determination of the secondary vertices. The resolution is limited to about 110–120 μm at $p_T \approx 500$ MeV/c (low p_T). This is a strong limitation given the path lengths of 123 μm and 60 μm of the D^0 meson and of the Λ_c baryon, respectively.
- The impossibility to access the present detector for the maintenance and repair interventions during the yearly shutdowns of LHC. This represents a limitation for reaching high data quality.

3. – The upgraded ALICE ITS

To fullfil the requiments of the Run 3 physics program of LHC, the upgraded ITS will be equipped with seven cylindrical and concentric layers of silicon Monolithic Active Pixel Sensors (MAPS) called ALPIDE covering a total active area of about 10 m^2 and a pseudo-rapidity acceptance of $|\eta| < 1.22$. The layers are divided into three Inner Layers (IL), two Middle Layers (ML) and two Outer Layers (OL) as shown in Fig. 1. The four outermost layers constitute the Outer Barrel (OB) while the three innermost layers form the Inner Barrel (IB). The main features of the upgraded ITS compared to the ones of the present detector are summarised in Table I [1].

The sensor, produced by TowerJazz with its 0.18 μm CMOS imaging process, features a pixel size of $\sim$27$\times$29 μm^2. The main characteristics of ALPIDE are (1) a n-well diode about 100 times smaller than the pixel size, leading to a small capacitance of few fF; (2) a fast data driven encoder [5] with an integration time of $\sim$2 μs; (3) a n-well of p-MOS transistors shielded by a deep p-well allowing a full CMOS circuitry within the active volume [3] [4]; (4) a pixel analogue signal amplified and digitized at a pixel level leading to a low power consumption < 40 mW/cm^2 and, (5) the possibility to apply a moderate reverse bias voltage to the substrate between -6 V and 0 V. The detection efficiency and the fake-hit rate (per event per pixel) of irradiated and non-irradiated ALPIDE chips were measured in various beam tests demonstrating a sufficient operational margin even after 10$\times$ lifetime Non-Ionizing Energy Loss (NIEL) dose [1].

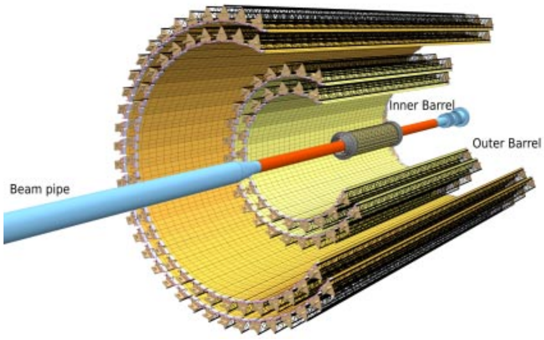

Fig. 1. – Schematic layout of the upgraded ITS

The ALPIDE chips are arranged in Hybrid Integrated Circuits (HIC) featuring 14 (9) ALPIDE chips for the OB (IB). A Flexible Printed Circuit (FPC) wire-bonded to the chips into a HIC is used for clock, control and data transmission towards and from the outside electronics [1]. Their production is shared among six different laboratories around the world.

The HICs are then glued on a cold plate for chip cooling. For the IB, the cold plate is attached to a ultra-light space-frame forming the IB-Stave with a total length of about 30 cm. For the OB, 7(4) HICs are glued on a OL(ML) cold plate with 10–20 μm precision to build an OL(ML)-Half Stave (HS) with a total length of $\sim$150(80) cm. Two HSs are then aligned on a carbon-fiber support structure (space frame) with $\sim$100 μm precision for the assembly of the final Stave. The Stave features also two power buses and two bias buses (one per HS) for chip powering and chip reverse bias voltage supply, respectively. The IB-Stave are completely produced at CERN while the OB-Stave production is shared among five different laboratories around the world. A schematic view of the Staves for the upgraded ITS is given in Fig. 2.

Figure 3 shows an example of the typical eletrical tests performed on the OB-Stave, measuring the discriminating thresholds and the electronic noise of each sensor. The

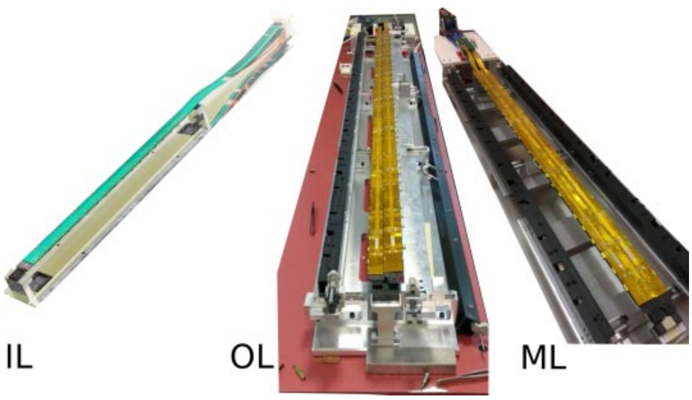

Fig. 2. – View (not to scale) of an Inner Layer Stave (left), Outer Layer Stave (middle) and Middle Layer Stave (right) for the upgraded ALICE ITS.

Table I. – *Main technological features of updraded ITS compared to the present ITS.*

	Present ITS	Upgraded ITS
Readout rate	up to 1 kHz	> 100 kHz (Pb-Pb) > 400 kHz (pp)
Material budget	1.1 % X_0	0.3 % X_0 (Inner Barrel) $\sim$1 % X_0 (Outer Barrel)
Pixel size	50×425 μm^2	$\mathcal{O}$ (30×30 μm^2)
Resolution (p_T = 500 MeV/c)	$\sim$240 μm (z) $\sim$120 μm ($r\varphi$)	$\sim$50 μm (z) $\sim$40 μm ($r\varphi$)

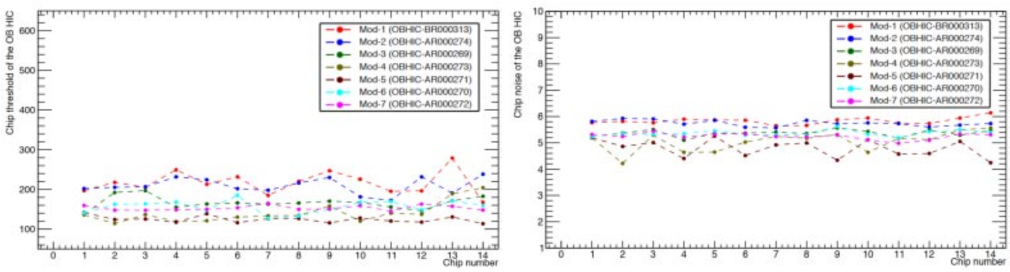

Fig. 3. – Discriminating threshold and electronic noise (expressed in electrons) of one of the produced OL-HS. The results are shown for all the chips of the seven HICs composing the HS.

results are related to one of the produced OL-HS, in fact the threshold and noise for seven HICs are shown for each chip. A good stability of the parameters among the different chips and HICs composing the HS is measured. At present the first three Inner Half-Layers have been assembled at CERN. For what concerns the production of the Staves for the four outermost layers, their production will end in May 2019, within the schedule.

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