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The new Inner Tracking System of the ALICE experiment

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Abstract

The ALICE experiment will undergo a major upgrade during the next LHC Long Shutdown scheduled in 2019-20 that will enable a detailed study of the properties of the QGP, exploiting the increased Pb-Pb luminosity expected during Run 3 and Run 4.

The replacement of the existing Inner Tracking System with a completely new ultra-light, high-resolution detector is one of the cornerstones within this upgrade program. The main motivation of the ITS upgrade is to provide ALICE with an improved tracking capability and impact parameter resolution at very low transverse momentum, as well as to enable a substantial increase of the readout rate.

The new ITS will consist of seven layers of innovative Monolithic Active Pixel Sensors with the innermost layer sitting at only 23 mm from the interaction point. This talk will focus on the design and the physics performance of the new ITS, as well as the technology choices adopted. The status of the project and the results from the prototypes characterization will also be presented.

Keywords: ALICE, MAPS, Inner Tracking System, ITS, silicon tracker

1. Introduction

The ALICE Collaboration [1] at the CERN Large Hadron Collider (LHC) is preparing a major upgrade of its apparatus to be implemented during the Long Shutdown 2 (LS2), in the years 2019-2020.

This will greatly enhance the physics potential of the experiment with the aim of making high precision measurements of rare and/or untriggerable probes, including charm and beauty hadrons, over a wide transverse momentum range in pp, p-Pb and Pb-Pb collisions at the maximum LHC energy. A detailed description of the ALICE upgrade plans can be found in the Letter of Intent [2].

A cornerstone of the upgrade is the replacement of the present Inner Tracking System (ITS) [1], based on two layers of hybrid pixel, two layers of silicon drift and two layers of silicon strips sensors, with a completely new detector, fully based on Monolithic Active Pixel Sensor (MAPS) technology.
In the following sections, the plans and status of the new ITS are presented.

2. Inner Tracking System

The present ITS fully meets the initial design requirements, however the measurements foreseen in 2020 and beyond require significant improvement both in tracking performance (efficiency at p_{T} as low

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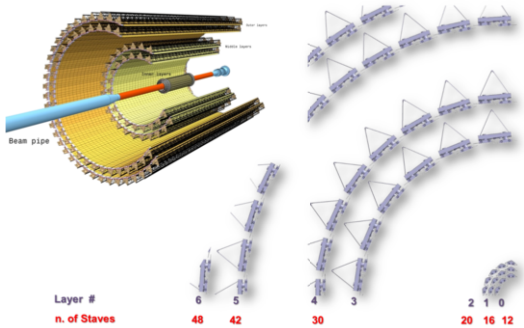
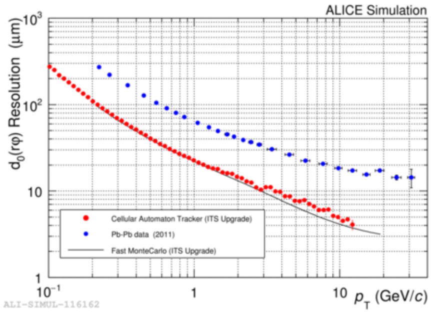
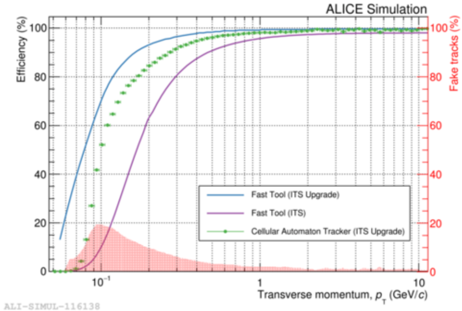


Fig. 1: Schematic view of the new ALICE ITS. The three innermost layers are referred to as Inner Barrel (IB), while the four outer layers are referred to as Outer Barrel (OB). The IB and the OB are mechanically independent. The carbon fiber structures supporting the chips, shown on the right, are referred to as staves. The staves of the IB are 270 mm long while the OB ones 840 and 1475 mm. The detector covers the -1.2 < η < 1.2 range. Cooling pipes are integrated in the stave structure.
The material thickness is as low as 0.3% X_0 (per layer, IB) and 1% X_0 (per layer, OB).



(a) Impact parameter resolution vs. p_T



(b) Efficiency vs. p_T

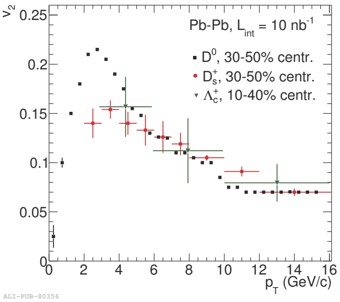
Fig. 2: On the left the impact parameter resolution (in the rφ plane) vs. p_T: the upper (blue) points the performance of the present ITS for Pb-Pb data, the lower (red) points simulated performance using CA, continuos line using the Fast tool. In the right panel the reconstruction efficiency vs. p_T, from right to left the present ITS, new ITS with CA, new ITS with Fast Tool.

as 100 MeV/c, secondary vertex resolution) as well as readout capability, in order to exploit the planned increase in luminosity for Pb-Pb collisions. Therefore the present ITS will be replaced, during LS2, with a new, ultra-light, detector based on an innovative MAPS chip, with a total active surface area of about 10 m^2. A schematic view of the new ITS is shown in figure 1, while in [3] and [7] the reader can find more details.

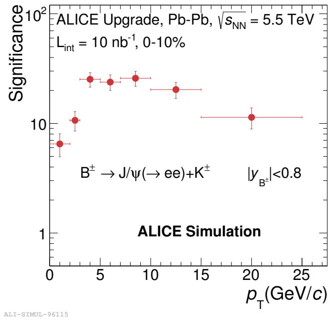
The layout of the new ITS has been optimized using a dedicated MonteCarlo program, refered as Fast Tool, while developing an algorithm for the reconstruction based on the Cellular Automaton (CA) technique, already in use for the TPC online reconstruction [8]. Online reconstruction will be mandatory in Run 3, due to the expected data throughput (40 GB/s ITS only, 1.1 TB/s in total). Strong data compression will be achieved recording reconstructed instead of raw data.
A new beam pipe, made of Beryllium, with reduced diameter and thickness, will replace the present one, allowing for moving the first detection plane as close to the IP as 23 mm (present: 39 mm).
Figure 2 shows the comparison between the performance of the present and new detectors.

Physics performance studies were carried out for heavy flavors, low mass dielectrons and hypernuclei as benchmarked and validated with full Monte Carlo simulations. The detailed physics reach with the new ITS can be found in [3].

The improved performances, together with the increase in statistics (a factor 100 is expected for minimum bias in Pb-Pb), will provide access to observables not yet measurable, with the present detector, in Pb-Pb collisions, such as v_2 of Λ_c as shown in figure 3a. Note also the very low p_T reach for D^0. Measurement of B mesons via decay channels involving J/Ψ or D^0 mesons will become possible, as shown in figure 3b for the J/Ψ case. Measurement of the yield of Λ_b will also be accessible for $p_T > 7$ GeV/c.



(a) v_2 of D mesons and Λ_c baryon.



(b) Significance for charged B mesons.

Fig. 3: Example of measurements with the upgraded ALICE apparatus. Both examples are for $L_{int} = 10$ nb^{-1}, $\sqrt{s_{NN}} = 5.5$ TeV.

3. The pixel sensor: ALPIDE

ALPIDE (ALice PIxel DEtector) is the MAPS chip developed in the 180 nm CMOS TowerJazz process [4] for the new ITS. Details can be found in [5] and [6], in the following its main features are recalled.

It is implemented on silicon wafers (p-type) with a high resistivity (> 1 kΩ/cm) p-type epitaxial layer, 25 μm thick. It measures 15 mm x 30 mm and contains half a million pixels organized in 1024 columns and 512 rows. Distinctive features are an extremely low power consumption, less than 40 mW/cm^2; very low, less than 10^{-10} pixel/event fake-hit rate; detection efficiency larger than 99% and spatial resolution of 5 μm over a large operational range. A moderate, negative ($-6V < V_{BB} < 0V$) reverse bias can be applied to improve charge-collection efficiency and operational range. A high speed (up to 1.2 Gbit/s) serial link is used to connect the sensor to the R/O electronics, about 5 m from the IP.
ALPIDE is the only active electronics component present in the sensitive volume of the experiment.
The R&D phase was completed at the end of 2016, when the mass production was launched.
Figures 4 and 5 show measurements from the validation campaign obtained with a 6 GeV/c π^- beam at the CERN PS. Some of the chips shown in the plots were irradiated for total ionizing dose (TID) and neutron fluence (NIEL) up to 500 kRad and 1.7×10^{13} (1 MeV n_{eq}/cm^2), i.e. more than the expected dose after 10 years of operation in ALICE.

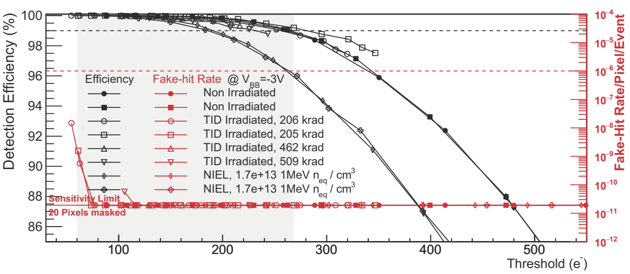


Fig. 4: The left axis shows the detection efficiency vs. threshold for several ALPIDE chips, irradiated and non-irradiated. On the right axis, the fake-hit rate is reported. Dotted lines represent the design requirements: detection efficiency larger than 99%, fake-hit rate lower than 10^{-6} pixel/event. The 20 noisiest pixels, out of 5×10^5, were masked. Results are shown for -3V reverse bias.

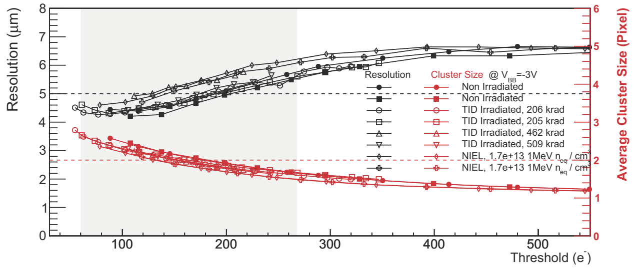


Fig. 5: The left axis shows the resolution vs. threshold for several ALPIDE chips, irradiated and non-irradiated. The right axis shows the cluster size. Results are shown for -3V reverse bias.

4. Summary and outlook

The planned major upgrade of its apparatus, together with the foreseen increase of the luminosity delivered by LHC after 2020, will allow the ALICE Collaboration to extend the physics reach to new observables and substantially improve the precision for current ones.

A cornerstone of the upgrade program is the new ITS, optimized for tracking and vertexing at low p_{T} while preserving the excellent performance of the present one at high p_{T}.

The new ITS is based on the ALPIDE sensor, a MAPS pixel chip fabricated using the 180 nm CMOS Imaging TowerJazz process and it will consist of more than 24000 sensors for a total active area of about 10 m^2.

The start of ALPIDE sensor mass production in December 2016, marked the end of the R&D phase, begun in 2011, to fully characterize the prototypes. The production of all detector elements, including auxiliary systems, will enter full swing in 2017 and will be completed by the end of 2018. After commissioning in the assembly hall, the detector will be installed in the experiment during the second half of 2020.

5. Acknowledgements

The ITS project acknowledges the support received from several test beam facilities during the R&D phase: BTF (Frascati, Italy), PS & SPS (CERN), DESY TB (Hamburg, Germany), PAL (Pohang, Korea), SLRI (Nakhon Ratchasima, Thailand). In particular the availability of beam at BTF and DESY TB, along with the precious help from local staff, during the Long Shutdown 1 of the CERN accelerator complex, has been instrumental to the development of the ALPIDE sensor and to keep the project on schedule.

The final ALPIDE chip as well as several prototype versions have been tested for TID and NIEL hardness at the following irradiation facilities: BASE LBL (Berkeley,US), HIF UC (Louvain-la-Neuve, Belgium), NPI (Prague, Cech Republic), TRIGA Mark II reactor (Ljubljana, Slovenia).

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