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The phase II ATLAS Pixel: The Inner Tracker (ITk)

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Summary. — The ATLAS experiment is expected to enter the high-luminosity programme of the LHC (HL-LHC) with a thoroughly upgraded detector. This includes an all-silicon tracking system Inner Tracker (ITk) that will completely replace the current Inner Detector. The innermost part of the ITk will consist of a five-layer pixel detector in the barrel region complemented by two end-caps characterized by annular supports leading to an extended track-reconstruction coverage. Different sensor technologies (planar, 3D and CMOS) are being investigated for instrumenting the detector, which will need to cope with the high occupancy and radiation level that are expected in the HL-LHC environment. For the same reason a new front-end chip is being developed within the RD53 Collaboration. High data rates, expected in particular in the innermost layers, require the development of new technologies allowing high bandwidth transmission and handling.

1. – HL-LHC

With the upgrade to HL-LHC, the ATLAS detector will need significant improvements to be able to exploit and sustain its extremely high integrated luminosity $L \sim 4000\,\text{fb}^{-1}$ and its high number of interactions per bunch crossing: $\mu \sim 200$. The project for the Inner Tracker [1, 2] consists of three main critical aspects necessary to meet the detector and physics requirements:

- new geometry to widen the detector acceptance, reduce the material budget and increase the number of track points;
- new sensors to improve granularity and efficiency and to better cope with the increased occupancy and radiation damage;
- new acquisition system, from front-end to read-out, to improve radiation hardness, bandwidth, scalability and reduce power consumption.

In this paper we focus on the aspects concerning the Pixel Inner Tracker [2].

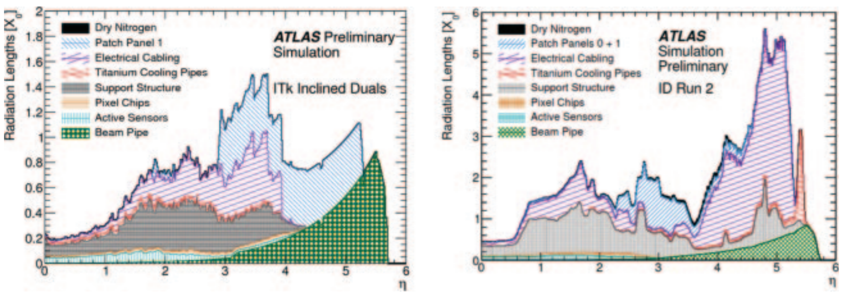

Fig. 1. – The material budget of the *Inclined Duals* layout of the ITk Pixel Detector compared with the current ATLAS material budget as a function of the particle pseudo-rapidity [2].

2. – Layout and structure

The Pixel ITk for the HL-LHC will feature an innovative design from the barrel to the end-cap region. In the barrel region it will have 5 layers (instead of 4) to improve vertex determination and will feature a new layout in the forward region where modules are inclined by 56 deg and 75 deg instead of laying flat. This reduces significantly the material budget while increasing the number of track points of forward tracks. In the end-cap region the modules are no longer disposed on a fixed amount of disks, but are instead attached to concentric shells that allow a more strategic placement of the modules to maintain a constant number of hits with varying pseudo-rapidity η. In addition to the new layout, the support, cooling and services design was modified to support the new structure while further reducing the material budget with respect to the Run II Inner Detector. The barrel, in particular, uses a *longeron* system sporting a light-weight composite system with CO_2 cooling and inclined plates with high thermal conductivity in the inclined region. The material budget, compared to its Inner Detector [3] counterpart, is shown in fig. 1.

3. – Sensors: Planar and 3D

The bulk of the sensors used in ITk is based on the tried and tested concept of the hybrid sensors: a passive sensor chip is coupled with a front-end chip through a technique called *bump-bonding*, allowing to use the best silicon design for both the FE chip and the sensor chip. The sensor chip will consist of two variants:

- The planar pixel sensors consist of a classic diode array, with $p+$ electrodes on one side of the module and an $n+$ common layer on the other side, with a pitch of $50 \times 50\,\mu$m, with the option of using $25 \times 100\,\mu$m instead.

- The 3D sensors have parallel cylindrical p and n electrodes that pass through all or most of all the silicon chip, providing shorter drift distance, a lower number of trapped charge carriers, lower capacity and thus much better radiation resistance; a good signal-to-noise ratio can be maintained up to a fluence $\Phi \sim 1.4\times10^{16}\, n_e q/\mathrm{cm}^2$.

The higher cost (due to the custom process) makes the 3D sensors unsuitable for usage over the whole detector area, so they will be restricted to the innermost layer, where the radiation is expected to be $\Phi \sim 1.3 \times 10^{16}\, n_e q/\mathrm{cm}^2$.

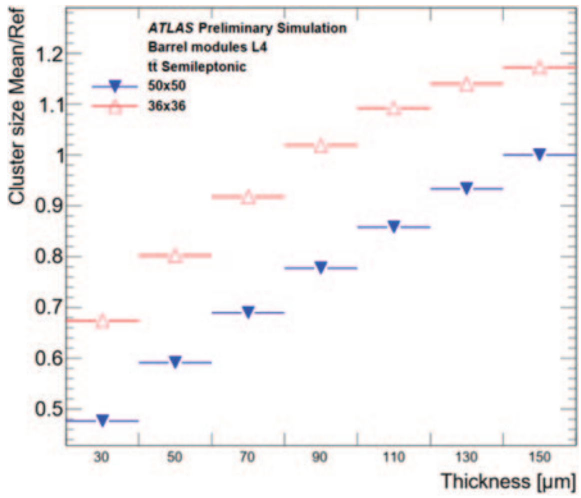

Fig. 2. – Performance studies for CMOS detectors in layer 4: relative cluster size variation as a function of the depleted region size for the reference pixel size $50 \times 50\,\mu\text{m}^2$ (blue) and the $36 \times 36\,\mu\text{m}^2$ (red) already realised in small fill-factor designs, the reference point is a fully depleted $150\,\mu$m thick sensor foreseen for the baseline layout [2].

A new sensor pitch and the prohibitive conditions of HL-LHC require a new front-end chip. The RD53 Collaboration between ATLAS and CMS was put together with this aim. Designed in 65 nm CMOS technology, the chip has a $50 \times 50\,\mu$m pitch and will be bump-bonded to both planar and 3D sensors, an operation that gets more difficult and expensive with every pitch shrink.

4. – Sensors: CMOS

The option of using CMOS monolithic sensors or capacitive-coupled hybrid sensors is currently under evaluation. This sensor type uses standard CMOS processes to include part or all of the front-end logic functions onto the chip, shielded from the sensor currents by a highly doped deep well. The advantages of these methods stem from the removal of the *bump-bonding* process and, possibly, of the entire front-end, creating significant savings when used in large areas and creating the option of using different pixel sizes and depletion thickness, as shown in fig. 2. Adequate radiation hardness of these solutions is still to be fully demonstrated, though.

5. – Conclusions

The ITk is an ambitious project, crucial to the performance of the ATLAS detector for HL-LHC. New solutions have been developed to reach the goal of further improving the current detector in every aspect, even at the HL-LHC conditions. The ITk Italia group, consisting of 7 institutes, has been heavily involved in the sensor research and development and is going to assemble and test one of the end-cap segments of the detector.

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