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Development and evaluation of prototypes for the ATLAS ITk pixel detector

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In light of the high-luminosity upgrade of the LHC at the end of this decade, the ATLAS experiment will replace its current inner detector by an all-silicon tracker, the ITk. The ITk will outperform the current tracker not only in terms of granularity and radiation hardness, it will also significantly reduce the material budget. To demonstrate that large scale detectors can be built following the envisioned ITk design, smaller scale prototypes are constructed for each of the ITk sub-systems. Three prototypes are built from silicon pixel modules, mimicking the structures in the innermost ITk layers. They provide the unique opportunity to evaluate aspects like the mechanical integration, the serial powering and cooling of modules, as well as the data acquisition in a realistic environment.

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Towards the end of this decade, the high luminosity upgrade of the Large Hadron Collider, HL-LHC [1], will collide proton beams with five times higher instantaneous luminosity than the design value of the currently operating LHC [2]. This upgrade will allow the experiments at the LHC to collect a collision data set of unprecedented size, but, at the same time, the higher luminosity poses challenges to the detectors themselves. Among those challenges are the increased radiation dosage and the higher number of collisions happening per proton bunch crossing, both of which challenge in particular the tracking detectors.

To ensure a successful operation in HL-LHC conditions, the ATLAS experiment [3] will have its inner detector completely replaced by an all-silicon tracker, the ITk [4]. The ITk will improve over the currently installed tracker by having a higher granularity, being more radiation hard and having an increased coverage in pseudorapidity of $|\eta| \leq 4$. In addition, novel approaches like the deployment of serial powering chains and the usage of CO_2 cooling will significantly lower the material budget of the tracker. In the innermost five layers, the ITk will feature pixel detectors, that are further subdivided into the Inner System (IS), the Outer Barrel (OB) and the Outer End-Caps (OEC). The outermost parts will be built using strip detectors, as depicted in Figure 1.

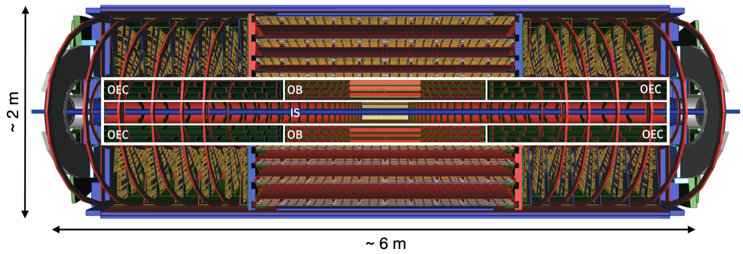

Figure 1: Sketch of the ITk design. The pixel detector is highlighted by the white box and further split into Inner System (IS), Outer Barrel (OB) and Outer End-Cap (OEC). Adopted from [5].

After individual detector modules have been built and operated successfully and before the construction of the actual detector at full size, smaller scale prototypes are important to test the detector system and prove the envisioned detector design. These proceedings present the status of the construction of such prototypes for the ITk pixel detector at the time of the ICHEP 2022 conference.

Each pixel module consists of the actual silicon sensor, which is bump bonded to readout chips (ROCs). For the current prototypes, the RD53A ROC [6] is used, since the final ITkPix ROC was not available in sufficient numbers at the time of the module production. Prototypes are built for each of the subsystems of the pixel detector, as summarized in Figure 2.

The OB prototype is tested at CERN and therefore profits from the already available infrastructure from the construction of the previous trackers. It will be the prototype that is closest to the actual detector. Apart from testing the mechanical integration, the CO_2 cooling and the serial powering of the modules [7], the OB prototype features a WinCC-based system for detector monitoring, controlling and safety, as well as full scale data acquisition chain that is sketched in Figure 3. In the case of the OB region, quad modules with a single sensor and four individual read-out chips (front-ends) are connected via kapton/copper flex to a patch panel, where the electrical signal from the chips is collected and sent with 1.28 Gbps via 3 m long TwinAx cable to the Opto Board. On the

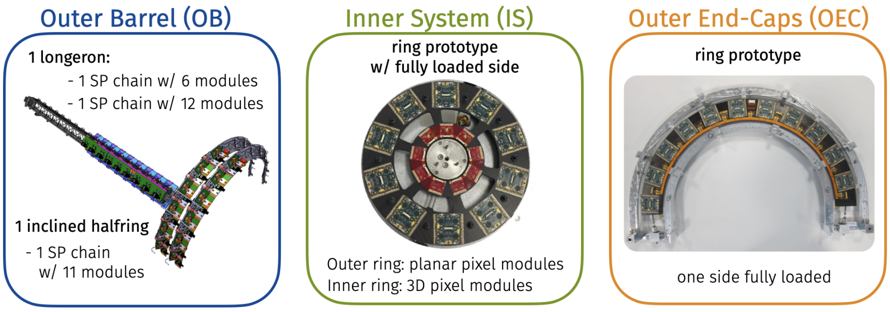

Figure 2: Summary of prototypes for each of the three ITk pixel sub-detectors. Where available a picture of a prototype is shown.

Opto Board the signal is serialized, equalized and converted from an electrical to an optical signal. These operations are performed by three application specific integrated circuits, the lpGBT [8], the GBCR [9] and the VTRX+ [10], respectively. The optical signal is then sent at 10.24 Gbps via a 65 m long fibre trunk to the readout server, which uses the FELIX system [11]. The readout system has been fully commissioned and is successfully used to perform tests ('scans') of the individual pixel modules. Additionally, a second test bench has been built to exercise and develop the data acquisition software independently of the efforts on the prototype construction.

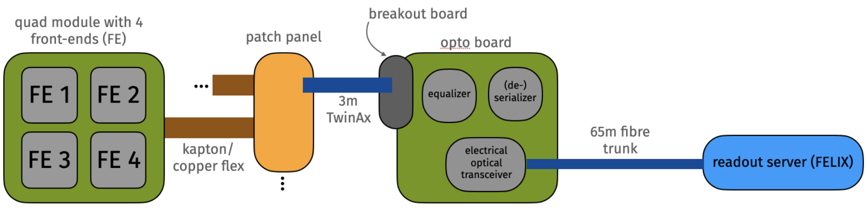

Figure 3: Sketch of the data acquisition chain commissioned for the Outer Barrel prototype.

At the time of writing, individual prototypes have been successfully commissioned and are now being extensively tested. This provides the unique chance to study aspects that are typically developed independently of each other in a joint system and will pave the way towards a new full-scale tracker for the ATLAS experiment.

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