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Overview of the ATLAS ITk Pixel Detector

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Abstract: In the high-luminosity era of the Large Hadron Collider, the instantaneous luminosity is expected to reach unprecedented values, resulting in up to 200 proton-proton interactions per bunch crossing. To cope with the resulting increase in occupancy, bandwidth and radiation damage, the ATLAS Inner Detector will be replaced by an all-silicon system, the Inner Tracker (ITk), where the innermost part will consist of a pixel detector with about 14 m^2 of active area. Several silicon sensor technologies will be employed in order to deal with the strict requirements in terms of radiation hardness, power dissipation and production yield. Prototype modules assembled with RD53A readout chips are being built to evaluate their production rate, thermal- and electrical performance, before- and after irradiation. In addition, a novel serial powering scheme will be implemented in the ITk pixel detector, which will help to reduce the material budget of the detector inside the active detector volume as well as power dissipation. Multiple system-level tests are being done with serial powering of pixel modules. The latest development of prototype modules, serial powering tests, and procedures of integration of modules and electrical services are presented.

Keywords: Radiation Detection, Detector system, High Energy Physics

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Contents

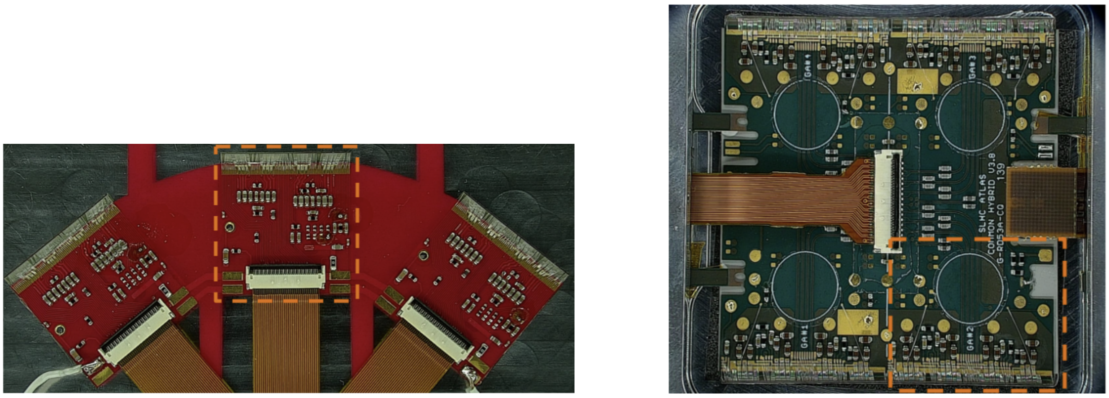
1 Introduction

In 2028 the Large Hadron Collider (LHC) will be upgraded to the High Luminosity LHC (HL-LHC) [1]. The instantaneous luminosity in the ATLAS experiment [2] will reach a value of 7.5×10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$, a 7-fold increase from that today. The average number of proton-proton collisions per 25 ns (pileup) will increase from 50 to 200, and the radiation levels will be 20 times higher for the innermost parts of the pixel detector closest to the interaction point, reaching a non-ionizing radiation fluence of $\phi = 2 \times 10^{16}\ n_{\mathrm{eq}}\mathrm{cm}^{-2}$ during the expected lifetime of the experiment.

The current tracker system in ATLAS is at the end of its life and thus unable to handle these conditions. An all-silicon tracking system called the ATLAS Inner Tracker (ITk) is being developed and is replacing the current Inner Detector (ID) for the HL-LHC upgrade. The ITk will consist of silicon strip [3] and silicon pixel detectors [4] only. Important for all tracking detectors is to have as little material as possible inside the detector volume. In the ITk pixel detector this is solved by employing a serial powering scheme [5]. Realistic system prototypes are being built for all parts of the ITk pixel detector to verify integration schemes and functionality.

2 Modules of the Pixel System

The ITk pixel detector will consist of hybrid planar and 3D silicon pixel detectors where the silicon sensor die is bump-bonded onto the frontend ASIC (FE) developed with the RD53 collaboration [6]. The pixel modules are integrated onto local support either as Quad modules (four frontends bump-bonded onto one large sensor die) or as Triplet modules (three frontends bump-bonded onto three sensor dies), see Figures 1a and 1b.



(a) (b)

Figure 1: **a)** A triplet module attached to flexible PCB. This module consists of three sensors each with one FE chip attached. The orange lines encapsulate one sensor chip and one FE chip. **b)** A quad module. Here, four FE chips are bump-bonded onto one large sensor chip. The orange region shows where one FE chip is attached to the larger sensor chip.

3 Serial powering and services

In order to save on the material budget in the detector, the ITk will implement a novel powering scheme called serial powering (SP). This means that up to 13 modules can be powered in series in one SP-chain. This SP-chain is monitored by a Monitoring On Pixel Services (MOPS) chip that is attached to each SP-chain, and regulates the voltage as well as monitors the temperature on the modules. Figure 2 gives a schematic overview of the service routing inside and outside the detector volume of the ITk. Data transmission is performed by the use of twinax cables from the modules (running at 1.28 Gb/s) and converted into an optical signal by the use of a custom made opto-electric conversion system [7] that performs data-aggregation and electrical-to-optical conversion of the signals, transmitting the signal to read out through fibre optical cables at 10.24 Gb/s.

4 ITk Pixel Detector

The ITk will fill the space of the ID with a radius of 1 m and a length of 6 m. The 5 layers of the innermost part, the pixel system, is subdivided into three regions, the Inner System (IS), Outer Barrel (OB), and Outer Endcaps (OEC), outlined by different colors as shown in Figure 3a.

Parts of the Inner System, the barrel and endcaps of Layer-0 and Ring-0 regions of the pixel system will experience the highest radiation doses, and a study [8] was conducted by the ATLAS collaboration in order to optimize the physics performance and decide what sensor technology to use in the different regions of the pixel system. Following this study, the pixel modules in Layer-0 as well as parts of the endcap rings R0 and R0.5 will have 3D pixel triplet modules. In Layer-1, thin (100 μm active thickness) planar quad modules will be used, and the planar quad modules in layers 2-4 as well as the modules in the Outer Endcaps region will have an active thickness of 150 μm. Additionally, it was found that the tracking performance and resolution could be further enhanced

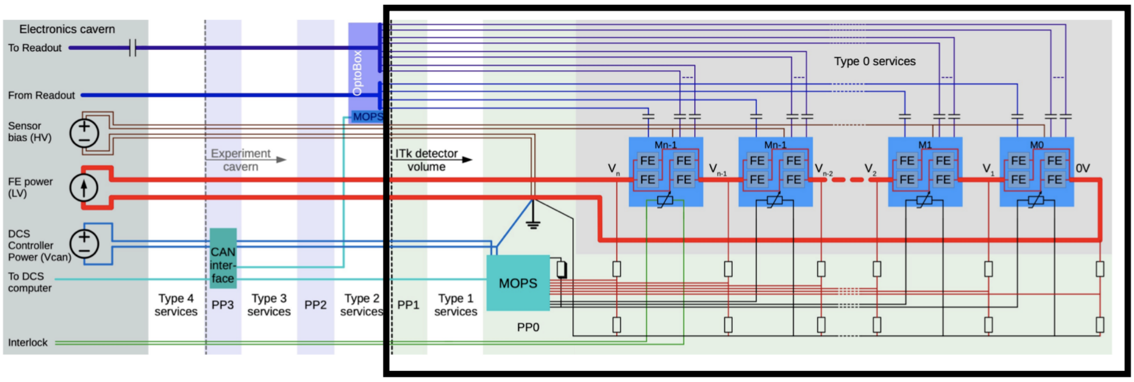
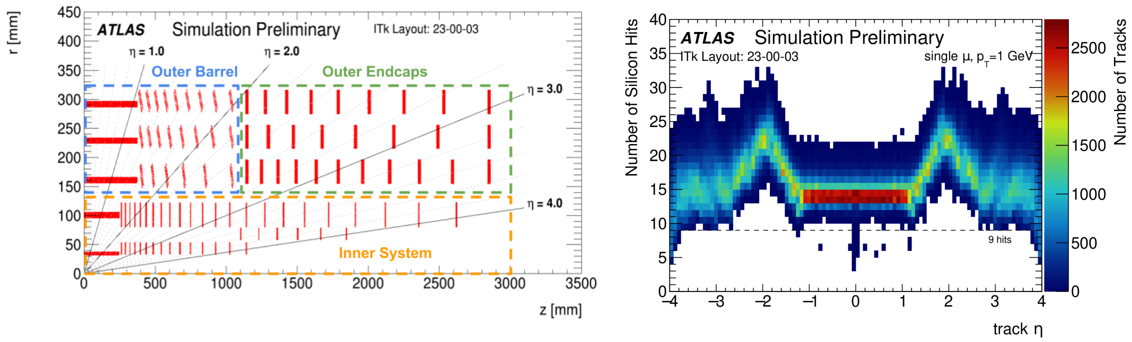


Figure 2: Schematic overview of the services in the ITk, the black rectangle encapsulates what is inside the detector volume. The red lines represent the serial powering chain where a MOPS chip is attached for monitoring. Data is routed using twinax cables out to an opto-electric conversion system (optobox) which is then routed to the read out system.

by using different pixel sizes in the barrel staves and endcap rings of Layer-0. Therefore, the pixel sizes in Layer-0 barrel will be $25 \times 100\ \mu m^2$ and $50 \times 50\ \mu m^2$ in the endcap rings.

A minimum of 9 hits are recorded for the vast majority of charged particle tracks up to a pseudorapidity of $\eta = 4$, as can be seen from Figure 3b.



(a) (b)

Figure 3: **a)** Schematic layout of one quadrant of the ITk pixel system. Red lines represent the layers in the pixel system. Black solid lines show the pseudorapidity, and the pixel detector is designed cover up to $\eta = 4$. **b)** Simulated hits in silicon pixel layers of the ITk. [9]

4.1 Inner System

The Inner System will consist of 2 layers of barrel staves (Layer-0 and Layer-1) as well as three different designs of endcap rings (R0, R0.5 and R1), see Figure 4. The integration (assembly) of the IS is done in quarters, Figure 5a shows one such integrating quarter. Here, services such as power, data transmission and cooling, are run along the outer shell. In Figure 5b the carbon foam local support structure is shown for an endcap ring. A circular connection board that supplies power and transmits data, called a Type-0 service ring, will act as an additional layer between the pixel

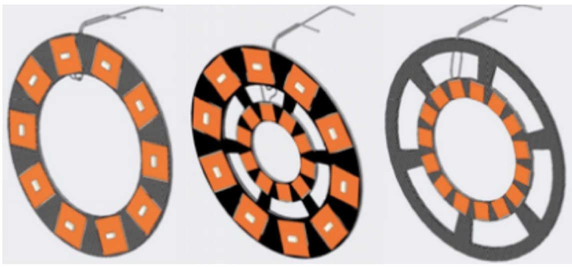
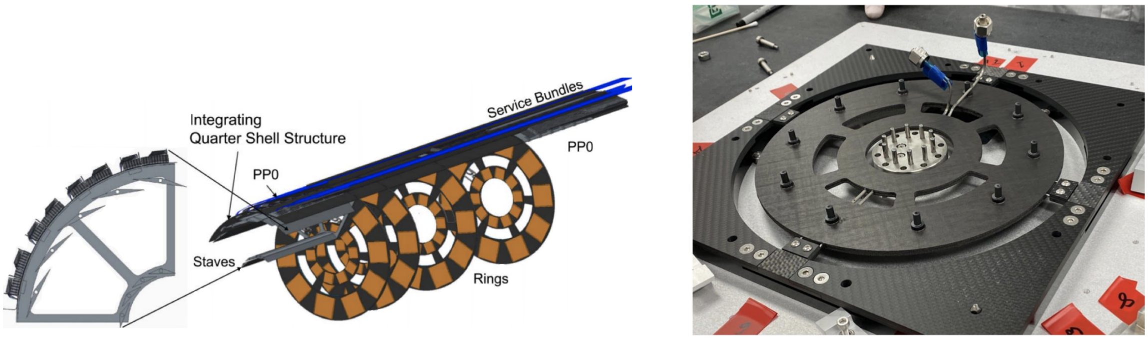


Figure 4: The three different ring designs for the Inner System. From left to right: R1 with only quad modules, R0.5 with quads and triplets and R0 with only triplets.

modules and the patch panels. This Type-0 ring will then be connected to the patch panels, located on the shell of the integrating structure, via pigtail connectors.



(a) (b)

Figure 5: **a)** One integrating quarter with rings and the two layers of barrel staves. Service bundles and patchpanels are located along the Quarter Shell structure. **b)** A carbon local support for a R0.5 prototype.

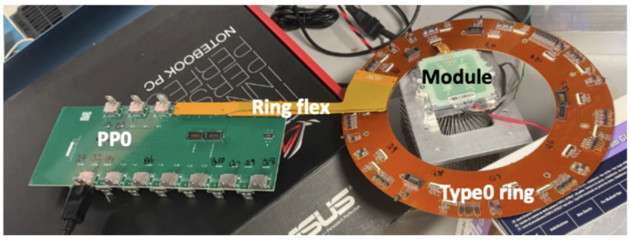
Triplet and Quad modules are mounted onto local support by gluing them directly onto the carbon foam structure as shown in Figure 6a.

A realistic electrical prototype has been built where quads and triplets has been mounted onto a R0 local support, as shown in Figure 6a. Additionally, a test setup for the data acquisition have been built, seen in Figure 6b, where a quad module has been connected to a Type-0 service ring which is read out using a flex connector to a patch panel where the signal is transmitted further into the readout computer.

4.2 Outer Barrel

The Outer Barrel region (OB) of the pixel system is slightly different from the IS. Here, the barrel layers contains additional inclined half rings as well as the flat barrel staves called longerons, see Figure 7. The loading of modules onto local support also requires an extra step where the quad modules are first mounted onto cooling blocks before integration onto longerons or inclined support structures can be performed. A flowchart of the integration scheme is shown in Figure 7.

(a)



(b)

Figure 6: **a)** A loaded R0.5 carbon structure with triplets and quads for electrical testing and verification of loading procedures. **b)** A DAQ prototype for the inner system, where a quad module is read out through a daq chain consisting of a type-0 ring, ring flex and a patch panel (PP0) to verify functionality of the modular design.

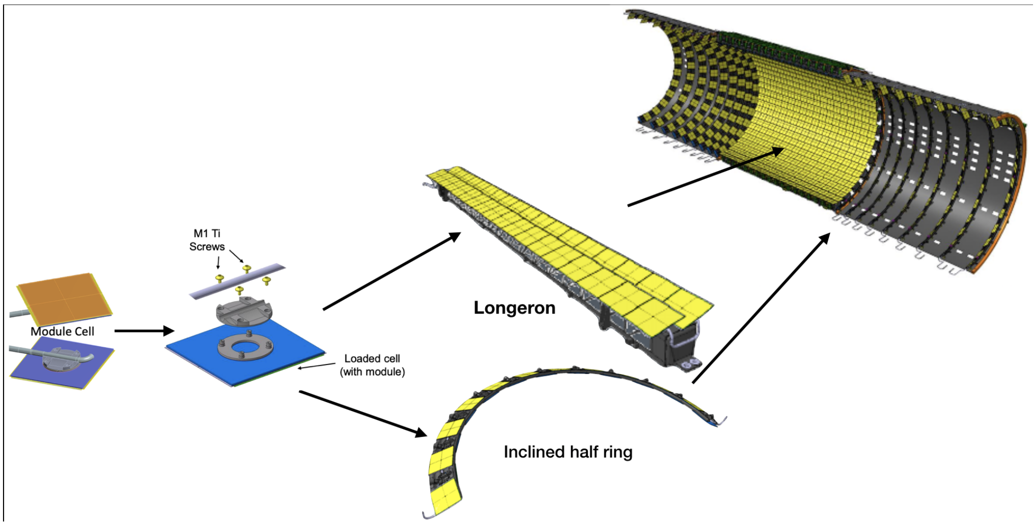


Figure 7: Module cells are loaded onto baseblocks for cooling which are then screwed onto the local support structure of the Outer Barrel, either longerons or inclined rings. The local support structures are then assembled into a half barrel as shown to the right.

For the OB region the patch panels are attached on the back of the longerons and on the edges of the inclined rings and modules can attach via bent pigtail connectors. A prototype of this patch panel is shown in Figure 8. Here, four quad modules are attached to the patch panel in the middle via pigtails and the patch panel transmits the data using a twinax cable.

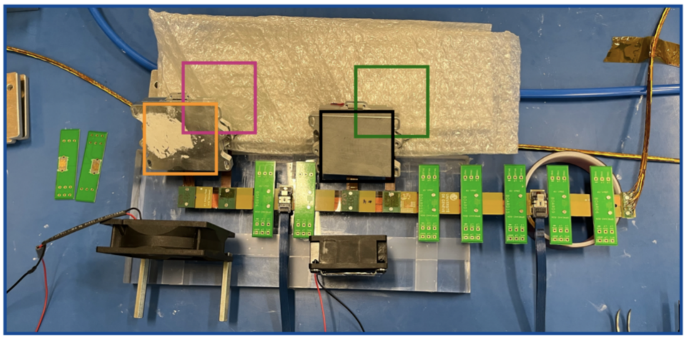
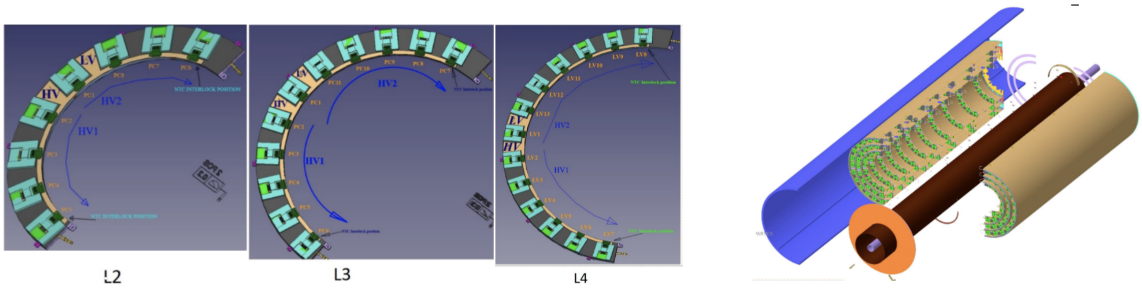


Figure 8: An outer barrel prototype, where four quad modules (inside the colored boxed) are attached to a patch panel. This is read out using a twinax cable.

4.3 Outer Endcaps

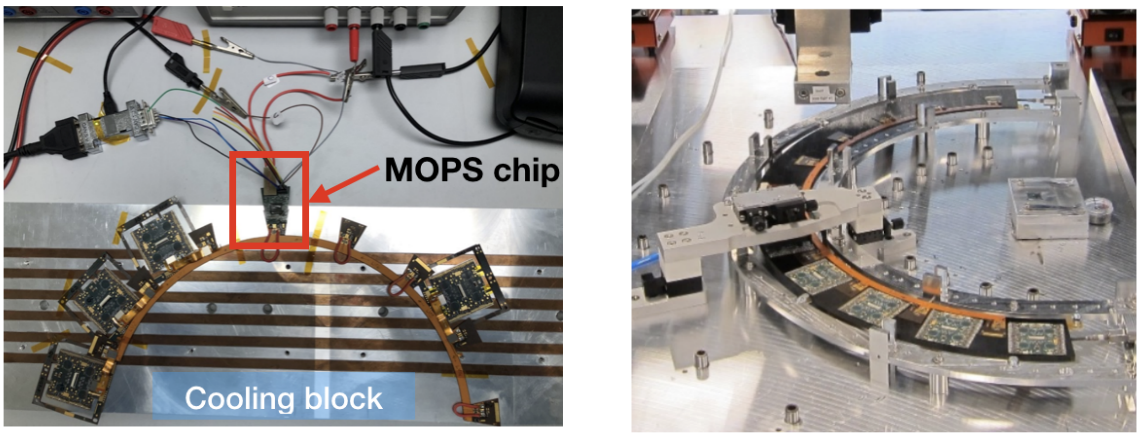
The local support loading procedure for the Outer Endcaps are done in half-rings, shown in Figure 9a, with three different half-ring sizes. These half-rings are then assembled into a half-barrel, shown in Figure 9b, that will be integrated into the ITk pixel system. Similar to the local support in the Inner System, the titanium cooling pipes are integrated into the carbon structures.



(a) (b)

Figure 9: **a)** Three half-ring designs that support 8, 11 and 13 modules respectively. **b)** Exploded view of one side of the Outer Encaps region, illustrating that the full system will be assembeld from two half-barrels.

Each half-ring will have a flex PCB bus tape attached that will supply power, transmit data and have the MOPS chip attached for monitoring, see Figure 10a. Several prototypes of the OEC half rings have been produced for verification of loading procedures as well as system validation, see Figure 10b.



(a) (b)

Figure 10: **a)** Flexible PCB for an OE half-ring with electrical modules attached as well as a MOPS chip. **b)** Loaded half-ring for the OEC region. Also seen is the bustape used for data transmission and powering.

5 Summary

The ongoing work on the pixel system in ATLAS in preparation for the HL-LHC, with new prototypes of support structures, as well as testing data transmission and powering of larger loaded local supports are important to gain a good understanding of this large and complex system. Some parts of the pixel detector are now entering the pre-production phase and further development of system level tests are ongoing.

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