PROCEEDINGS OF SCIENCE

Towards the construction of the ATLAS ITk Strip Endcap detector for the High-Luminosity LHC

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To sustain the seven-fold increase in instantaneous luminosity of the High-Luminosity phase of the LHC, the ATLAS experiment will replace its current Inner Detector with a new all-silicon tracker detector. The Inner Tracker (ITk) will consist of a silicon pixel detector, surrounded by layers of silicon microstrip sensors. The production phase of the ITk is underway. This document presents an overview of the foreseen steps to build the forward regions of the ITk Strip detector, focusing on the loading of the silicon microstrip sensors on the support structures, and on the preparation for the integration of each structure in the final Endcap frame.

The 32nd International Workshop on Vertex Detectors (VERTEX2023)
16-20 October 2023
Sestri Levante, Genova, Italy

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PoS(VERTEX2023)075

1. Introduction

In 2029, the Large Hadron Collider (LHC) will enter into the High-Luminosity phase (HL-LHC) of its operation. The higher instantaneous luminosity, up to $\mathscr{L} = 7.5 \cdot 10^{34}$ cm^{-2}s^{-1} [1], will pose challenging conditions for the LHC experiments, which will observe up to ~200 interactions per bunch crossing. This will lead to an increase in the data rates and in the radiation levels, reaching up to 2×10^{16} 1 MeV n$_{\mathrm{eq}}$cm^{-2} fluence and 10 MGy Total Ionising Dose. In preparation for the HL-LHC, the ATLAS experiment is carrying out a series of important upgrades to its detectors.

One of the main upgrades of the ATLAS experiment is the replacement of its Inner Detector with a new all-silicon tracking system, the Inner Tracker (ITk) [2, 3]. The ITk will cover up to a pseudorapidity of $\eta = 4$ and will feature higher granularity, improved radiation hardness and readout speed, and low material budget ($< 2.3X_0$) to maintain or exceed the current tracking system performance. A representation of the ITk detector is shown in Figure 1 [3]. The ITk detector will consist of a Pixel detector, surrounded by a silicon microstrip (Strip) detector. It will be operated at temperatures down to −35 °C to minimise radiation damage.

The Strip detector will extend to a radius of 2 m in diameter for a total surface of about 162 m^2. The ITk detector is composed of a central section, the Barrel, closed on both sides by Endcap structures, shown in Figure 1. The ITk Strip detector will consist of about 18000 modules based on 320 μm-thick silicon planar sensors segmented in strips with a pitch of about 75.5 μm [2] and strip lengths ranging from ~ 17 to ~ 56 mm. Modules will be glued on both sides of light-weight carbon fibre support structures with embedded cooling pipes, called *stave cores* in the Barrel section and *petal cores* in the Endcaps.

This document focuses on the assembly and integration of the ITk Strip Endcaps.

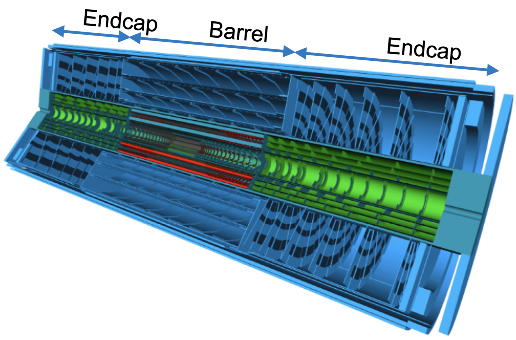

Figure 1: The ITk detector for the ATLAS HL-LHC phase [3].

2. The construction of the ITk Strip Endcap

Each ITk Strip Endcap requires one global support structure, 2304 Endcap modules, 384 End-of-Substructure (EoS) cards and DCDC boards, 192 petal support structures, and dedicated cooling, powering and data transmission services. The global mechanical structure, shown in Figure 2-left, is a 6-disk carbon-fibre structure in which the fully loaded petals will be inserted during integration.

A photo of one of the first fully loaded pre-production petals is shown in Figure 3. Six different module types will be mounted on each side of the petal core. From left to right in the photo, the

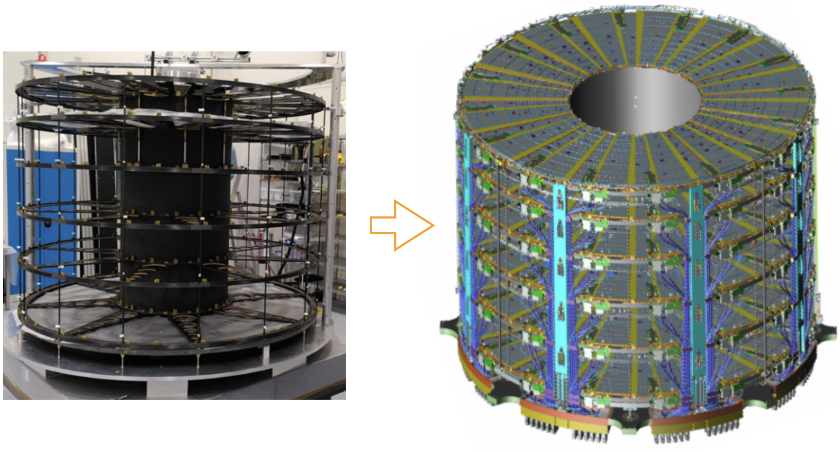

Figure 2: *Left*: the empty global mechanical structure of one of the two Endcaps. Photo courtesy of Marcel Vreeswijk (Nikhef). *Right*: CAD design of the final, fully integrated Endcap.

low-radius ones (R0, R1 and R2) include a single silicon crystal, while the external ones (R3, R4 and R5) are split modules, i.e. composed of two silicon sensors. The modules are read by the EoS cards, which hosts the radiation-hard chips for the aggregation and the optical conversion of the data, and for the power management of each petal side.

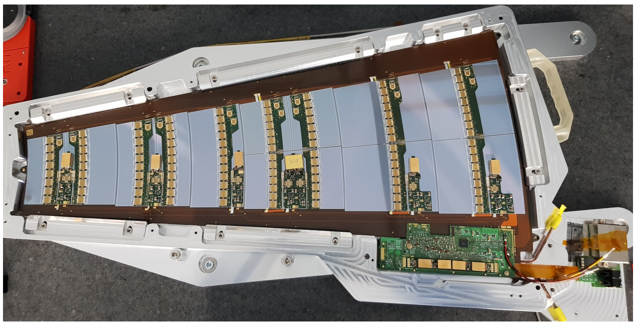

Figure 3: A petal fully loaded with six modules, the EoS card and the DCDC boards, mounted at DESY.

2.1 Module loading

The first step towards integration, once the modules and the petal cores have been produced and have undergone thorough Quality Control (QC) testing, is the module loading. Module loading consists of gluing the module to the petal core, positioning the module such that the photolithographic fiducials of the sensor are within ± 50 μm of their target position on the petal core. In the Endcap loading sites, this operation is done using a gantry, shown in Figure 4-left.

The loading procedure is split into two main steps: the dispensing of the glue on the petal core (Figure 4-A) and the mounting of the module (Figure 4-B). The ATLAS group at the Simon Fraser University (SFU) led the development of the module loading procedure, defining routines to program and automatise the movement of the gantry arm, that the other loading sites (IFIC, DESY and the University of Freiburg) adapted to their specific setups.

The details of the setup and procedure described here refer to the DESY setup. The glue is dispensed using a vacuum-controlled syringe, placed on the side of the gantry arm. As shown in Figure 4-A, the glue is dispensed following a serpentine pattern to maximise its coverage below the module. Afterwards, the gantry head grabs the module by means of a custom-design 3D-printed pick-up tool, sucking it up using vacuum, and positions the module on the petal (Figure 4-B). A survey of the sensor's fiducials is then performed. If it indicates that the module is not placed within specifications, the routine allows for a series of adjustments, re-grabbing the module with the pick-up tool and translating and rotating it for a better positioning. The pick-up tool is then left on the module for two hours, to allow the glue to cure. Once the petal is fully loaded, it is wirebonded and it undergoes electrical and metrology tests.

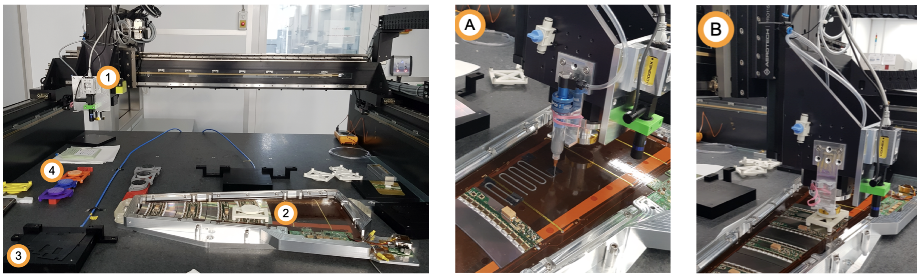

Figure 4: *Left*: Gantry table in the DESY cleanroom. (1) Gantry arm. It can move in the three directions and rotate around the vertical axis, and it is instrumented with a camera and a gantry head connected to a vacuum pipe; (2) A partially loaded petal in its assembly frame; (3) The module jig, where the module is manually positioned before loading; (4) The pick-up tools, coming in four different shapes depending on the module type, are used as an interface between the gantry head and the module. *Centre*: Gluing step, where the glue is dispensed in a serpentine pattern. *Right*: Loading step, in which the module is picked-up by the gantry using the pick-up tool and is placed on the petal.

2.2 Integration

The final step is the integration of the loaded petals in the global mechanical structure and the following tests. This step requires large mechanical tools and dedicated test setups.

First, the cooling pipes of the petals are bent to the final bending geometry, specific for the position of the petal in the disks. The procedure and the tools have been collaboratively defined by the ATLAS groups of Nikhef and DESY, institutes at which the two Endcaps will be integrated.

The very delicate procedure of petal insertion is performed using the *insertion tool*, a manual tool consisting of multiple precision mechanical components that allow for safe handling of the petal and for all the movements required for the final positioning of the petal within the endcap structure: horizontal and vertical translation, rotation, radial movement and tilting. The full integration procedure has been exercised for the first time when the first pre-production petal was successfully inserted inside the Endcap system test setup[1], shown in Figure 5.

Right after the petal is inserted in the Endcap structure, a less-than-a-minute electrical test (called *ping test*) is done to ensure that the insertion has not damaged the modules. It is performed

[1]The Endcap system test setup consists of 1/8 of a full ITk Strip Endcap. Its aim is to demonstrate the full ITk Strip detector system, including final powering, cooling services and readout chain, and all procedures and tools.

briefly establishing connection with all chips on the modules, and measuring the high-voltage return current when the unbiased sensor is exposed to light, to test the modules while avoiding overheating the uncooled petal. The petal cooling pipes are then welded to the cooling manifolds of the Endcap structure. Every 16 petals, corresponding to one cooling manifold, the Endcap is shielded by a thermal enclosure, flushed with dry air and cooled down with a dual-phase, evaporative CO_2 system, the so-called Light Use Cooling Appliance for Surface Zones (LUCASZ) system [4]. Extensive cold testing is then performed on petals of each manifold.

3. Conclusion

This document presents a brief description of the last steps of the production of the ITk Strip Endcap. The detector will be fully assembled by 2027, when it will be installed in the ATLAS experiment in preparation for HL-LHC.

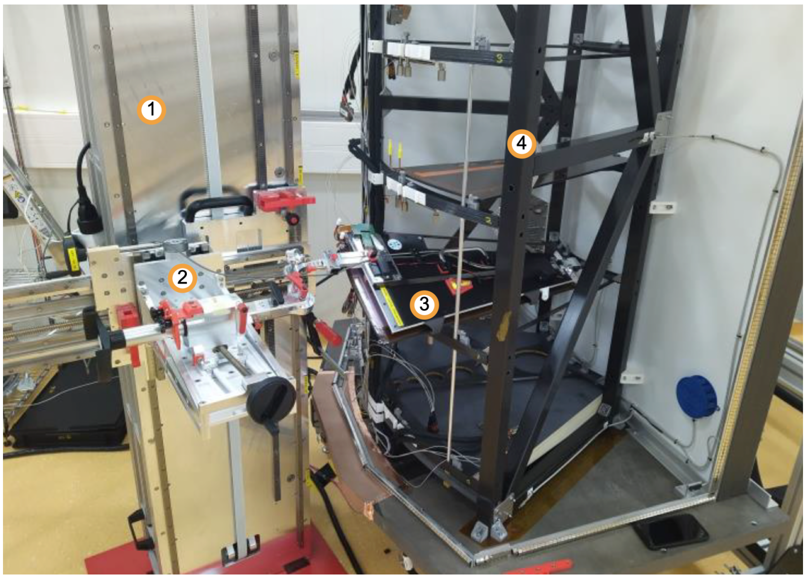

Figure 5: Insertion of the first fully loaded pre-production petal in the Endcap System test setup. (1) Insertion tower; (2) Insertion tool; (3) Insertion hand holding the petal (not visible); (4) Endcap System test structure.

References

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