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ATLAS ITk Strip Detector for High-Luminosity LHC

Stefania Stucci, on behalf of the ATLAS Collaboration*
Brookhaven National Laboratory
E-mail: stefania.stucci@cern.ch

The ATLAS experiment is currently preparing for an upgrade of the inner tracking detector for High-Luminosity LHC operation, scheduled to start in 2026. The radiation damage at the maximum integrated luminosity of 4000 fb^{-1} implies integrated hadron fluencies over $2x10^{16}$ n_{eq}/cm^2 that require replacement of the existing Inner Detector. An all-silicon Inner Tracker (ITk) is proposed with a pixel detector surrounded by a strip detector. The current prototyping phase, targeting an ITk Strip Detector consisting of a four-layer central barrel and forward regions composed of six disks at each end, is described in the ATLAS Inner Tracker Strip Detector Technical Design Report (TDR). With the approval of the TDR by the CERN Research Board, the pre-production readiness phase has started at the institutes involved. In this contribution we present the design of the ITk Strip Detector, the current status of R&D on various detector components and preparations for production.

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*Speaker.

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1. Introduction

The High Luminosity LHC (HL-LHC) will begin its operation in 2026 and will provide an instantaneous luminosity of $5-7.5 \times 10^{34}$ cm^{-2} s^{-1} corresponding to approximately 200 inelastic proton-proton interactions per bunch crossing, with an accumulated integrated luminosity for proton-proton collisions up to 4000 fb^{-1} over the full run. The HL-LHC will thus present an extremely challenging environment to the ATLAS experiment, well beyond that for which it was designed. In order to at least maintain the performance of the present tracker, the ATLAS detector subsystems must be upgraded to cope with the significant increase in detector occupancies and the harsh radiation environment of the HL-LHC. The ATLAS Collaboration has described its plans and goals for the corresponding upgrade of the detector in the Letter of Intent [1] and Scoping Document [2]. At the core of the ATLAS detector upgrade for the HL-LHC is a new all-silicon sub-detector for tracking charged particles, the Inner Tracker (ITk).

2. The ITk Strip Detector Outline

In the central region of the ITk, the sensors are arranged in cylinders around the beam axis, with five pixel layers followed by four strip layers of paired stereo modules. The forward regions will be covered by six strip disks and a number of pixel rings as shown in Fig. 1. The strip system covers $\pm$2.7 units of pseudorapidity. The strip barrel extends from -1400 mm to +1400 mm along the z-axis while the End-Cap (EC) disks are located between 1512 mm and 3000 mm on each side of the detector. The mechanical building blocks of the barrel layers and EC disks are staves and petals, respectively. These units consist of a low mass central stave/petal local support that provides the mechanical rigidity, support for the modules and host the common electrical, optical and cooling services. The mechanical and cooling performance of the local support is determined by employing high stiffness, high thermal conductivity carbon-fiber for the face-sheets and the sandwich geometry, which gives high rigidity and allows the cooling structures to be buried within the core such that heat generated by the modules is removed directly. Electrical power, TTC (Timing, Trigger and Control) data, DCS (Detector Control System) data transfer services are carried out by a copper/kapton co-cured bus tape mounted on both side structures. The electrical services needed to power and control modules are connected to the off-stave services via the End-of-Substructure (EoS) card and distributed to each module along electrical connections on the surfaces of the local support core. The EoS includes a low power GigaBit Tranceiver (lpGBTx [4]) performing the serialization/deserialization required for data being transmitted and received on the bus tape, and a Versatile link (VTRx+ [5]) fibre optics driver for high speed optical transmission and reception between the EoS and the off-detector electronics. The four barrel layers consist of 392 staves while each EC disk is populated with 32 petals leading to a total number of 382 petals. Each barrel stave is populated with 28 modules (14 on each stave side) while each individual petal has nine modules on each side with six different sensor geometries, corresponding to six rings around the beam axis in different rϕ planes, to cover the wedge shape petal surface. The two inner layers of the barrel are equipped with short strips of 24.1 mm length to increase granularity at small radius while the two outer layers have longer strips of 48.2 mm length. The strip lengths in the EC are optimized to keep the strip occupancy below 1%, resulting in a range of values between 19 mm (in the closest

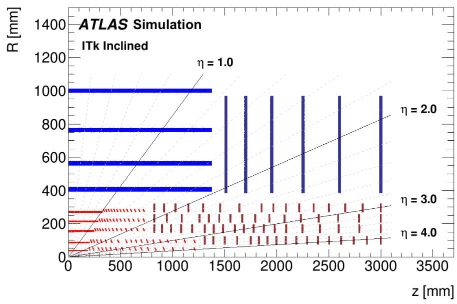


Figure 1: Schematic layout of the ITk for the HL-LHC phase of ATLAS. Here only one quadrant and only active detector elements are shown [3].

region to the beam axis) to 60.1 mm (in the outermost region). In the barrel, the strips are rotated by 26 mrad on each side of a layer with respect to the beam axis to allow a total stereo angle of 52 mrad. In the EC a 40 mrad stereo angle is achieved by rotating the strips by 20 mrad with respect to the radial orientation in each disk. The basic unit of the ITk Strip Detector is the silicon-strip module. A module consists of one sensor and one or two low-mass PCBs, called hybrids, hosting the read-out ASICs (HCCstar and ABCstar), and one power board (see Fig. 2). Hybrids host between seven and 12 ABCStar ASICs and one or two HCCStar ASICs which receive the signals from the ABCStar, build packets and move them on in the read-out chain. The HCCStar receives also the TTC from the EoS and distributes it to the ABCStar via the TCC bus on the bus tape. These read-out ASICs are glued to the hybrids with UV curing glue and the hybrids are glued directly to silicon sensor with a two-component epoxy. Connections between ASICs, silicon sensors and electronics will be made through ultra-sonic wire bonding. The baseline powering scheme adopted is DC-to-DC conversion with on-detector radiation hard buck DC-to-DC converters (bPOL12V), lowering the voltages to those required by the on-detector electronics. The converter is hosted in the power board together with auxiliary on-detector electronics. The topology of the board can be segmented into four groups: the already discussed low-voltage DC-to-DC power block, a High Voltage (HV) bias filtering circuit, a HV multiplexer and a block containing the Autonomous Monitor and Control Chip (AMAC) for monitoring powering and environmental conditions. Based on the measured conditions, the AMAC will control both the HV (via the HV multiplexer) and the Low Voltage (LV) power of each module independently.

3. Thermo-Mechanical Prototypes

One of the crucial aspects of the detector development is the prediction of the temperature distributions across the sensor, the front-end ASICs and the local support structures. Detailed dimensional thermal Finite Element Analysis (FEA) models have been developed addressing major concerns during normal operation such as thermal runaway, sensor leakage current increase under high fluence conditions and cooling requirements. These evaluations need to be verified by comparison with "thermo-mechanical" structures. Three prototypes have been built for this purpose as well as to allow the evaluation of the assembly process. Pictures of two of the prototypes are shown in Fig. 3.

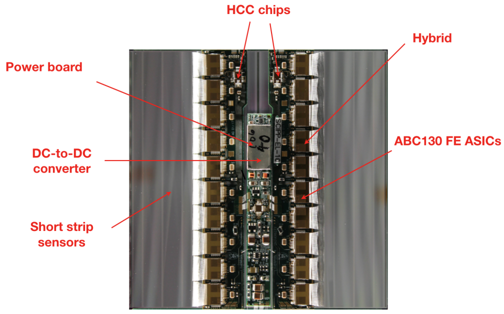
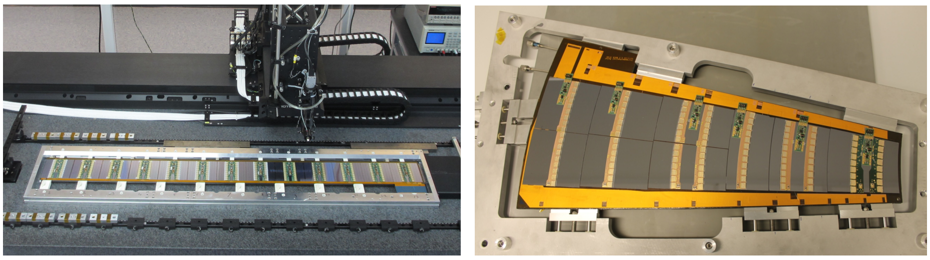


Figure 2: Fully assembled short-strip barrel module with the prototypes ASICs ABC130 and HCC130.



(a) (b)

Figure 3: Photo of the thermo-mechanical stave (a) and petal (b) prototypes.

4. Conclusions

Meeting the requirements imposed by the HL-LHC operational conditions presents a unique challenge for the design of the ITk Strip detector. Stave and petal prototypes have been built and are undergoing various tests, including metrology, mechanical bending and infrared imaging. Preliminary comparisons between the test results and the FEA models show a good agreement albeit investigations for minor differences are still ongoing. In the last few months, two electrical stave prototypes have been built as well.

References

[1] ATLAS Collaboration, *Letter of Intent for the Phase-II Upgrade of the ATLAS Experiment*, CERN-LHCC-2012-022.

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[5] The CMS Collaboration, *The versatile link, a common project for super-LHC*, JINST 4, P12003 (2009).