PROCEEDINGS OF SCIENCE

The ATLAS ITk Strip Detector for the Phase-II LHC Upgrade

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The inner detector of the present ATLAS experiment has been designed and developed to function in the environment of the present Large Hadron Collider (LHC). During the future High-Luminosity phase of the LHC (HL-LHC), the particle densities and radiation levels will exceed current levels by a factor of ten. The inner detector has been redesigned and will be rebuilt completely. The new ATLAS Inner Tracker (ITk) consists of several layers of silicon particle detectors. The innermost layers will be composed of silicon pixel sensors, and the outer layers will consist of silicon microstrip sensors. The production of the ITk is underway. This manuscript focuses on the strip region of the ITk, describing the system, the final design choices, and the production status of the different activities.

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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 $\mathscr{L} = 7.5\ 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, 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 $2{\times}10^{16}$ 1 $\mathrm{MeVn_{eq}cm^{-2}}$ fluence and 10 MGy Total Ionising Dose.

Current ATLAS Inner Detector (ID) [1] would not be able to cope with the expected data rates and radiation levels so a new Inner Tracker (ITk), designed to operate at the HL-LHC, will replace the current ATLAS ID. ITk [2] will be an all-silicon detector system comprising of a pixel detector and a strip detector (Figure 1).

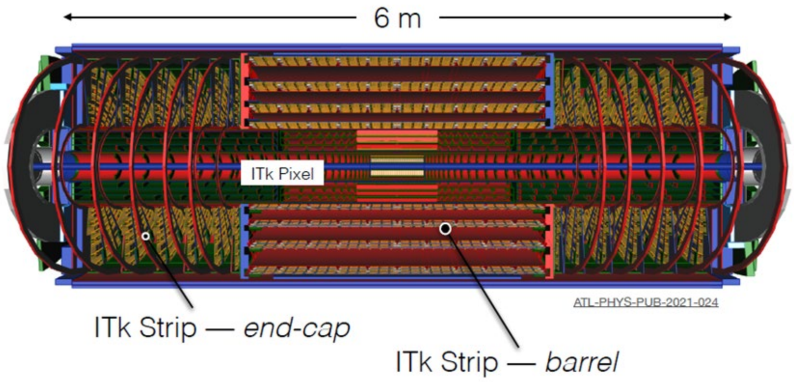


Figure 1: New ATLAS ITk.

The HL-LHC conditions require ITk to have higher radiation tolerance, more coverage at low angles, better spatial resolution in order to deal with the higher interactions per event, which means more readout channels, better power management and higher trigger rate.

The pixel detector will consist of five central layers and an array of 30 rings with varying radii in the forward regions. The strip system, surrounding the pixel detector, is made of a barrel with four layers and two endcaps containing 6 discs each.

2. The ITk Strips Detector

The strip detector is surrounding the pixel detector and it consists of a barrel and two end-caps. The barrel consists of four concentric layers, each of the two end-caps has 6 disks. Table 1 summarises the higher requirements of the ITk Strips in comparison with the present strips part of the Inner Detector.

Table 1: Strips comparison between Inner Detector and ITk.

Inner Detector SCT (Strips)	**ITk Strips**
4,088 sensors	17,888 sensors
61 m^2 of silicon	165 m^2 of silicon
Strip length: 12.8 cm	Strip length: 1.4 – 6 cm
6 million strips	60 million strips
Dose: up to 3.8 Mrad	Dose: up to 50 Mrad

2.1 ITk Strips Barrel

The four barrel concentric layers have a length of ~2.8m and are centered with the ATLAS interaction point. Each barrel layer consists of several sub-structures called staves (Figure 2), each one has a length of ~1.4m. The staves have 14 sensor modules at each side. In total, the Strips barrel has 392 staves with 10,976 modules.

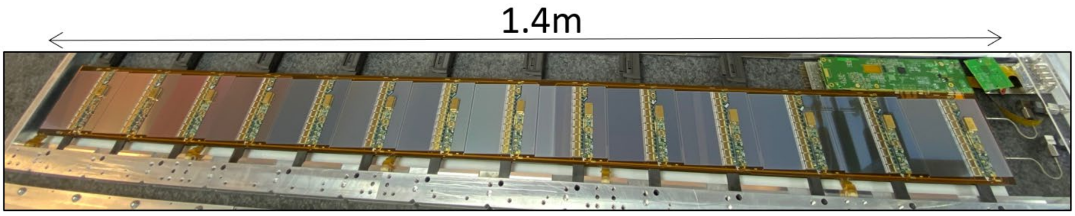


Figure 2: LS Barrel stave

Each sensor module [3] has a silicon microstrip sensor (10x10cm) [4] with two types of electronics board glued on top of the sensor: the amplifying, buffering, control and readout circuit with a developed ASICs and a separate power circuit, also with an ASIC and a DCDC converter (Figure 3a).

Each sensor has rows of 1280 strips with a pitch of 75.5µm. As the granularity requirements are stricter close to the interaction point, the two innermost barrel layers have modules with four rows of strips, each strip has a length of 24.1mm. These modules are called Short Strips (SS). For the two outermost layers the same sensor dimension is used with only two rows of strip, each strip has a length of 48.3mm (Figure 3b).

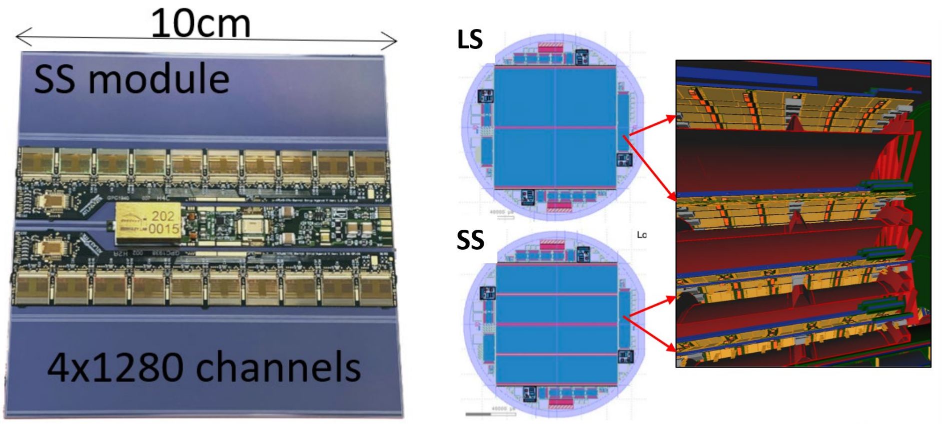


Figure 3: a) SS barrel module; b) LS staves and SS staves.

2.2 ITk Strips Endcaps

Each of the two endcaps has 6 disks and each disk has 32 sub-structures that in the endcap are called petals due to their trapezoidal shape (Figure 4a). The two endcaps have 384 petals and 4,608 modules [5].

The petal requires 6 different sensor geometries, that lead to 6 different module types (R0 to R5), see Figure 4b. The strip pitches vary from 70µm to 80µm. The strip lengths vary from 1.4cm in R0 modules to 6cm in R5.

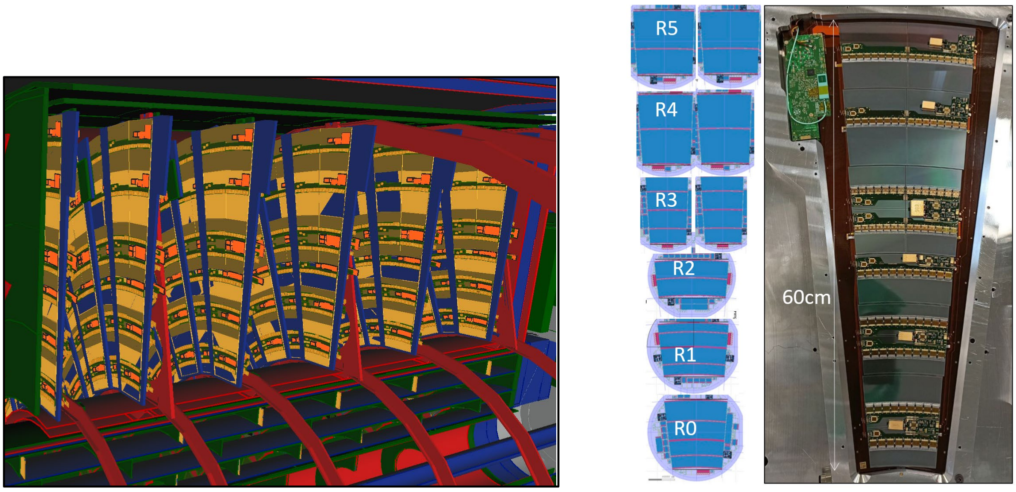


Figure 4:a) Each encap has petals in 6 disks; b) Sensors in a petal.

2.3 Stave and petal design and power scheme

An important effort has been made to integrate all these sensors in a simple lightweight sub-structure (stave or petal). They are low mass sub-structures made of carbon fibre honeycomb with carbon fibre facings. They also provide the necessary cooling with embedded small Titanium pipes surrounded of a high temperature conductive foam (Figure 5).

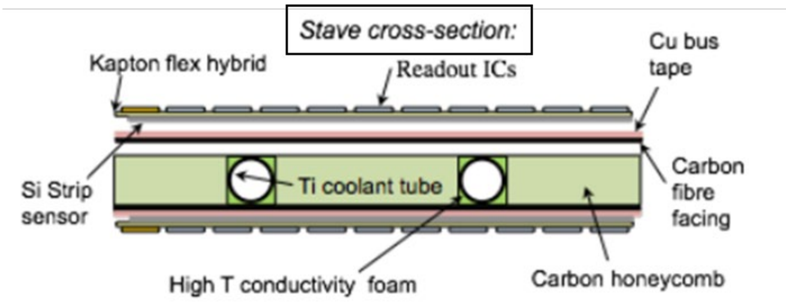


Figure 5: Stave cross-section.

Services have been minimized to reduce the non-sensitive material. One single electrical power cable is used per sub-structure for both sides. It has one single Low Voltage (LV) line to power all electronics on one side of the stave (14 modules) or petal (6 modules). A DCDC scheme is used to reduce the voltage drop along the power chain. Also, the High Voltage (HV) is shared for several sensors, with bigger share for the outer barrels and endcaps.

Services have gone through a long custom design for ITk Strips. The connectors have a minimized volume (with up to 48 contacts) with metallized plastic hoods and a locking handle to avoid the use of any tool. In order to minimize the mass. inside the ITk volume, cables use Aluminum as wire conductor and a light cable shield (metallized Kevlar).

3. ITk Strips schedule requirements

The full ATLAS ITk needs to be installed in the cavern at the beginning of 2028. One year before, ITk Strips needs to be ready in order to be integrated in the surface laboratory with the pixels. The activity of inserting staves and petals in the barrel layers and endcap disks will take more than 2 years, thus, this activity needs to start in 2024. The module production to build staves and petals was about to start at the end of 2023, at the time of this conference.

All activities of the project are either in pre-production or production. They are reviewed twice a year by the ATLAS management and by the LHC Committee.

4. ITk Strips project status

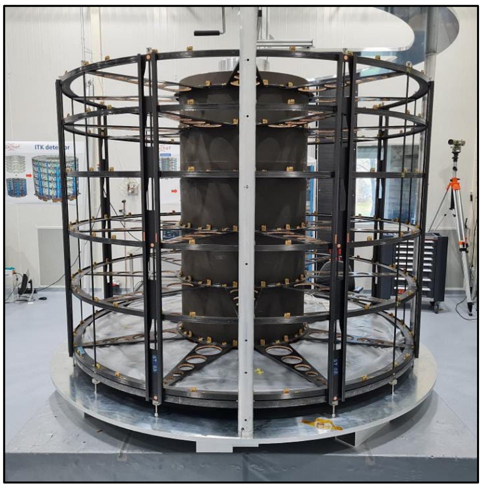
Sensor production started in 2021 and at the time of the conference 54% of the sensors were already received. Barrel LS and endcap sensors were given priority as the barrel SS will be needed later in the project. The delivery is going as planned and with a low rejection rate.

The custom ASICS are manufactured at Global Foundry using 130nm technology. Special care has been taken to achieve the radiation hardness: simulations, triplication of logic to improve SEE (Single Event Effect) protection and validation in several test beams. Pre-irradiation is performed to avoid an initial high current consumption. The manufacturing is close to be completed with most of the ASICs going through pre-irradiation before being distributed.

At the time of the conference the module construction was halted due to a noise effect that was noticed during the pre-production. This excess noise only appears at very low temperatures, so it is referred as *Cold Noise*. After more than one year of investigation, it is accepted that the source of the noise is mechanical vibrations in the power board. The mechanism by which this vibration couples back into the front-end remains to be fully understood. The barrel LS can use a different glue to prevent this effect, and the endcap modules do not show this behavior as they have a different circuit material and layout. However, a solution for the SS modules is still needed as it has higher current in the power board that reflects in higher vibrations and higher noise.

The stave and petal sub-structure is about to finish pre-production. A thin flexible circuit (bus-tape) is glued on the carbon facings. The petal bus-tapes [6] are already in production, whereas the barrel ones are about to start the production after some technical issues. For module mounting on the sub-structure, precision tooling and cameras on XYZ stages have been developed.

Global structures are in production. The first endcap has been finished (Figure 6a), the second is in production. The four barrel layers are in production, the outer one (L3) is being finished and being dressed with stave clamps (Figure 6b).



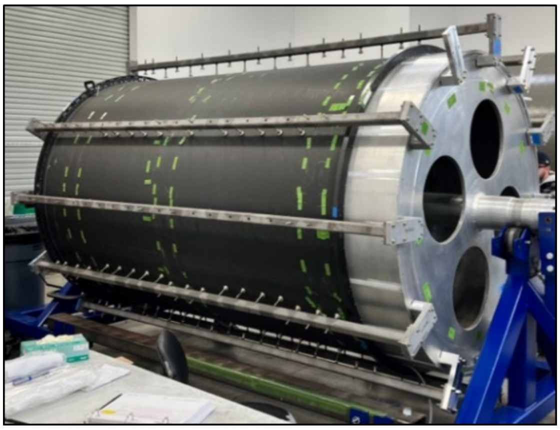


Figure 6: a) First endcap structure; b) Outer barrel layer (L3).

5. Conclusions

Building a tracker detector for operation at the high luminosity LHC is challenging and needs special attention to radiation hardness, high granularity and low mass. The ITk Strips detector is progressing through production and integration will come soon. It is not and easy path, and new issues appear, like the Cold Noise.

The project requires an important effort of coordination among the 57 institutions in 14 countries. In addition to the mentioned activities, coordination efforts have been taken into account as a production database, logistics and project scheduling.

The ITk strips collaboration is starting with enthusiasm the production of modules, staves and petals, a task that will take the next 3 years.

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