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Cooling and noise performance of the ATLAS ITk strip system tests

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ABSTRACT

The current tracking system of the ATLAS detector will be replaced by the new Inner Tracker (ITk) to cope with the challenging conditions expected at the High Luminosity Large Hadron Collider. This new tracking system will be an all-silicon detector consisting of silicon pixel sensors in the inner most layers and silicon micro-strips sensors in the outer layers. A central barrel section surrounds the interaction point and two end-cap sections cover the forward regions. This contribution focuses on the results of the system tests for the ITk strips detector in which several close-to-final detector components are evaluated before production. The barrel system tests structure at CERN consists of up to eight staves, while for the end-caps a structure at DESY is loaded with up to twelve petals. Staves (petals) consist of core structures loaded with square (trapezoid) shaped sensors of various lengths and strip pitches, and include readout and power electronics mounted on top of the sensors. Objects are mechanically held in place in a support structure and connected to the electrical, optical and cooling services as true as possible to the final system. With these setups, it is possible to validate the detector design, including the verification of the detector data acquisition, powering and cooling. This article gives an overview of the system tests and summarizes their current status by showing a selection of test results.

1. The strip detector of the ATLAS Inner Tracker

During the high luminosity phase of the Large Hadron Collider (HL-LHC), experiments will face new and unprecedented conditions in terms of radiation levels and occupancy in their detectors. For the ATLAS detector, the current tracker system will be replaced by an all-silicon tracker, the Inner Tracker (ITk), which consists of a pixel detector closest to the interaction point surrounded by a micro-strip detector [1]. The strip system is further segmented into a central barrel region, consisting of four cylindrical layers with sensor modules parallel to the beam axis, and two end-cap regions in the forward directions, made out of six disks with a perpendicular module orientation. The building blocks of the strip detector are the so-called *staves* for the barrel and *petals* for the end-caps. Local support structures, called *cores*, are made of carbon–fiber based materials, have a cooling pipe for dual-phase CO_2 cooling embedded and offer a bus tape for electrical connections on the surfaces. The sensitive units called *modules* are glued on top of these and consist of a stack-up of an n-in-p silicon microstrip sensor with a hybrid printed circuit board with front-end electronics and a powerboard with a direct-to-direct current converter stage, connected by wire bonds. For the barrel, modules have a rectangular shape with either four rows of $\sim 2.5\,\mathrm{cm}$ short strips (SS) for the inner or two rows of $\sim 5\,\mathrm{cm}$ long strips (LS) for the outer layers. In the end-caps, trapezoid-shaped modules are used with six different flavors called, from the inner to the outer radii, R0 to R5, using radial strips and an already embedded stereo angle. As the gateway to the off-detector systems, the *End-of-Substructure* board (EoS) provides power and control and transmits the detector data via optical fibers.

2. Overview of ITk strips system tests

For the development and validation of the full ITk detector design, the ATLAS Collaboration is pursuing system tests, which serve as a realistic testbed for testing and evaluating the performance of several close-to-final detector components.

The setup for the barrel detector system tests is hosted at CERN. It consists of a custom-made support structure with mechanical holders in the form of locking brackets allowing for insertion of up to eight staves and enclosed by thermal insulation and a Faraday cage. In its current state, it is populated with four fully loaded staves from the pre-production series: three short strip and one long strip staves with

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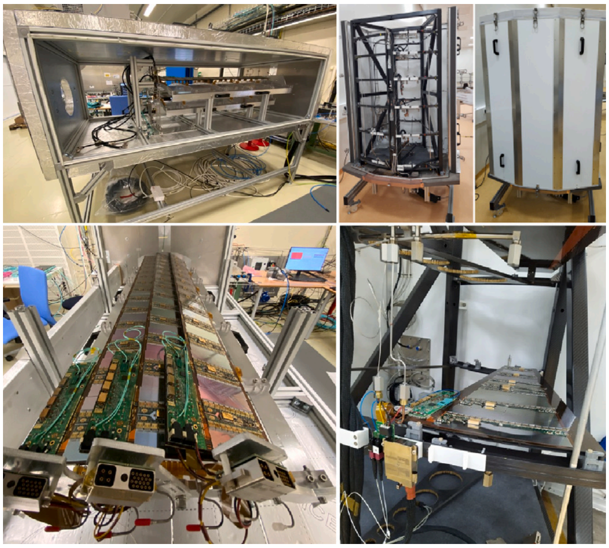

Fig. 1. Overview of the barrel setup at CERN populated with four staves (left) and the corresponding end-cap setup at DESY with one petal (right).

pre-production chipsets. The system tests setup for the end-cap detector is hosted at DESY. A sector of the end-cap global structure is replicated using carbon–fiber structural elements. This setup, including cooling lines and electrical services, offers mechanical locking points for up to twelve petals, and is enclosed in a custom-made thermal box. In its current state, the structure is populated with one fully loaded petal using pre-production parts. Fig. 1 shows overview pictures of both setups.

For cooling of staves and petals in the system tests, dual-phase CO_2 cooling is used. At CERN, the cooling plant can reach temperatures down to −25° C, whereas the used CO_2 cooling plant at DESY offers sufficient cooling power to deliver −35° C. For powering, the foreseen ITk detector powering chain is used. Low and high voltage power supplies are connected via a set of patch panels and transfer cables on the outside to the individual objects inside the system test boxes. For optical readout, fibers are running within a fiber harness from the staves/petals and a patch panel to the DAQ system.

3. Selection of test results

With the system tests, various characterization measurements can be performed to demonstrate the overall feasibility of the full system design of the ITk strip detector. As such, all aspects from the detector performance of individual staves and petals to the performance of the services to power up, read out and cool down the detector are under evaluation, from which two examples are discussed below.

For the barrel, Fig. 2 shows the results of a cooling test of all four staves at a temperature set point of −25°C. The temperatures are measured using negative temperature coefficient (NTC) thermistors on the EoS board as function of time while powering up, as well as the NTC temperatures measured on each of the fourteen modules of one stave-side after fully powering the front-end electronics. Although the LS stave draws just half the power compared to the SS stave, it can be observed that both staves reach similar temperatures. This is by design as the flow distribution in the capillary system is tuned to deliver roughly half the flow to the LS stave compared to the SS stave. Overall, this result matches the expectation from simulations in the detector design phase, such that the expected cooling performance for the ITk strips system can be reached.

For the end-caps, Fig. 3 shows the measured input noise as an electrical calibration test for the outermost R4 and R5 modules on the

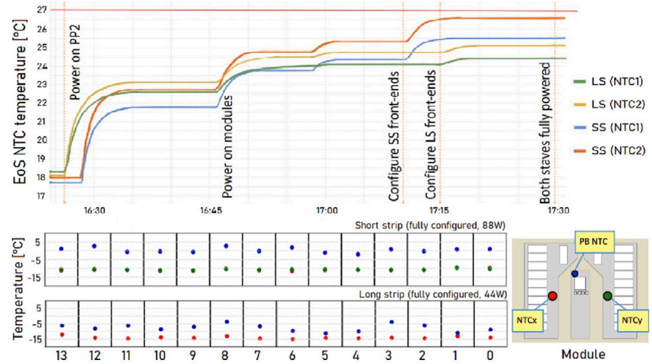

Fig. 2. CO_2 cooling profiles of long-strip (LS) and short-strip (SS) staves at the cold setpoint of −25°C. On the top, the measured temperatures using NTC thermistors on the EoS board are shown. The bottom shows NTC values for individual modules along the stave and located according to the sketch.

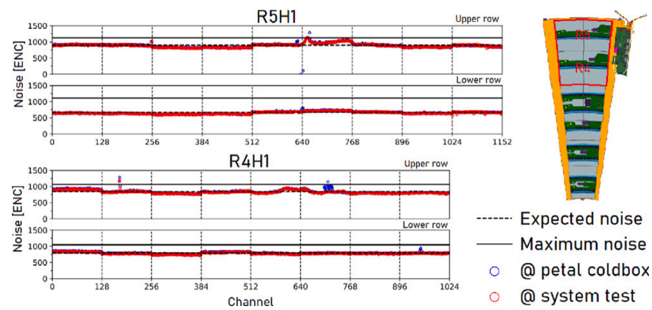

Fig. 3. Comparison of the input noise distributions for parts of the front R4 and R5 modules of a petal at the cold set point of −35° C before (blue) and after (red) insertion in system tests structure using the full detector powering chain.

petal front side at a temperature set point of −35° C in the system test structure. This measurement is compared to the noise measured when the petal was tested in a stand-alone coldbox. It shows that the petal is fully functional after the petal insertion process and no additional noise occurs due to the different powering services in each setup.

4. Summary

Both system tests at CERN and DESY for the ITk Strips detector are fully operational and the developed setups are online, with all needed infrastructure in terms of services, cooling and DAQ available. Performance measurements are being conducted and their results are needed to reach full production readiness of the detector.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

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