ITk Strip Module Design and Performance

On behalf of the ATLAS ITk Strip Community

Martin Sýkora[1]

[1]Faculty of Mathematics and Physics, Charles University, Prague (Czech Republic)

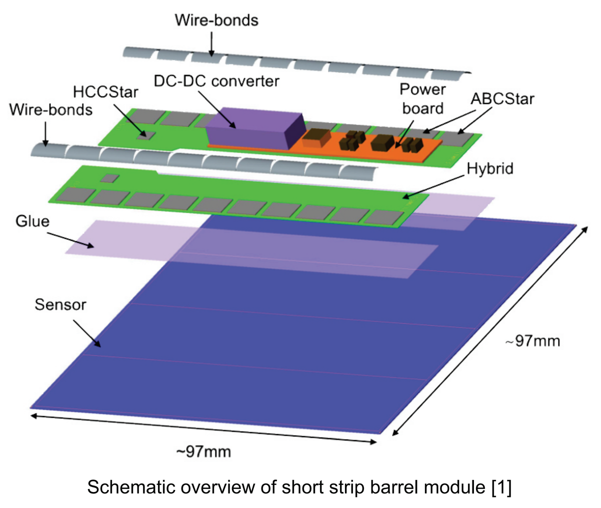
FACULTY OF MATHEMATICS AND PHYSICS Charles University

27th International Workshop on Vertex Detectors (VERTEX 2018), 21st - 26th October 2018, MGM Beach Resorts, Chennai, India

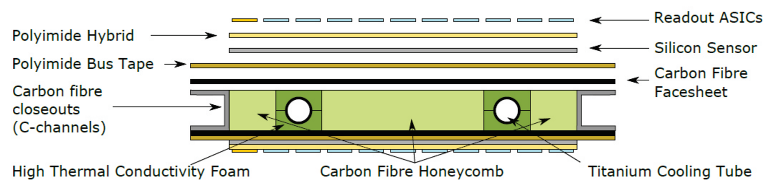
Design of the ITk Strip Modules

The ITk strip module as a basic component of local support substructures, including all 6 end-cap (R0 - R5) and 2 barrel design modifications, consists of 300 μm thick n^+-in-p silicon sensor, where one or two kapton PCBs, called hybrids, are glued. They are hosting various number of ABCStar readout chips and one HCCStar control chip developed on the basis of previous prototypes. The module DC-DC powering is ensured by power board providing power to the FE of ASICs, sensor HV biasing and other on-detector electronics.

The sensor pitch determining its resolution varies between 69 - 84 μm. Sensor bulk will be depleted by nominal voltage of 500 V including possibility to increase the value up to 700 V to improve its performance after radiation damage at the end of life. The lowest required limit of signal-to-noise ratio for the ITk strip modules is 10:1 to reach detection efficiency greater than 99% and channel noise occupancy below 10^{-3}, but estimations show almost twice as high performance.



Schematic overview of short strip barrel module [1]



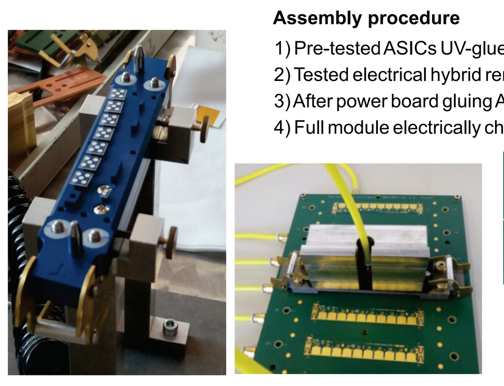
Design of stave core [1]

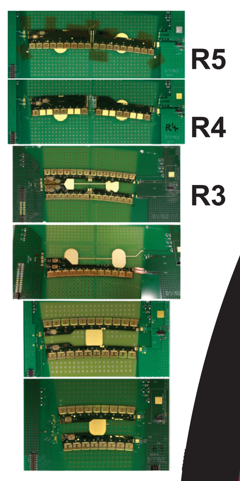
Additional stave core description

- sensor stereo angle 52 mrad (barrel) and 40 mrad (implemented directly in end-cap sensor design)
- bus tape - power and data flow from/to EoS
- CO_2 cooling down to -40°C

Assembly procedure

1) Pre-tested ASICs UV-glued using pick-up tool onto hybrid and wire-bonded
2) Tested electrical hybrid removed from hybrid panel and glued onto sensor
3) After power board gluing ASICs wire-bonded to strips by four row procedure
4) Full module electrically characterized by QC testing processes





Module Type	Fluence 10^{14} n_{eq} cm^{-2}	Charge ke^- (500 V)	Charge ke^- (700V)	Noise e^-	S/N 500 V	S/N 700 V
SS	9.7	12.8	15.2	665	19.2	22.9
LS	5.1	16.2	18.4	810	20.0	22.7
R0	15.9	10.2	12.8	685	14.8	18.6
R1	13.0	11.2	13.7	678	16.5	20.3
R2	11.3	12.0	14.4	697	17.2	20.7
R3	10.3	12.4	14.9	689	18.1	21.6
R4	8.8	13.3	15.7	862	15.4	18.2
R5	7.8	13.9	16.3	909	15.3	18.0

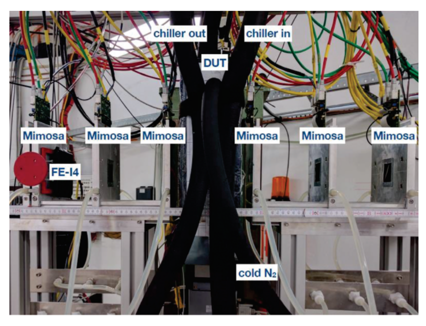
Estimation of crucial module parameters at the end of life [1]

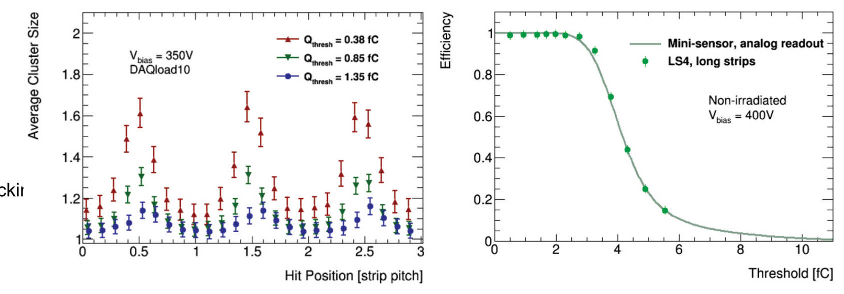
Testing Methods and Results

To check that the ITk strip modules meet the requirements they are being tested by both external and internal charge injections into ASICs' channels. The internal calibration circuit provides injection of charge with exact value preset in the complex strip software called ITSDAQ. The external charge injection via strips is performed ideally at the DESY-II and CERN SPS test beam facilities or using beta source and laser in several collaborating institutes.

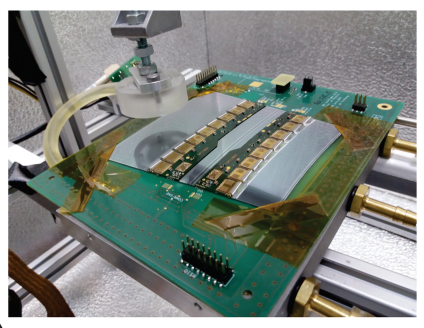
All these testing methods require electrical readout based on ITSDAQ scans over threshold at the FE discriminators since the modules use binary readout. The most critical extracted quantities are noise, gain, collected charge, hit efficiency and noise occupancy.

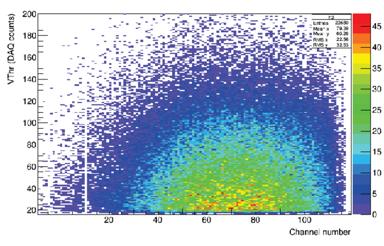
- Test Beam
  - approx 2 - 3x per year, particle beam (120 GeV pions or 4 GeV electrons)
  - Mimosa pixel sensors for tracking (pitch 18.4 μm, resolution 2 μm)
  - FEI4 for track tagging, scintillator triggering, beam profile of 1 x 1 cm^2
- Beta Source Test
  - available, cluster and depletion studies, natural injected charge, no tracking
  - ^{90}Sr electron source, external triggering (scintillator)
- Laser Test
  - available, interstrip studies, good spatial resolution, adjustable intensity, trackii
  - no natural injected charge, red/infra-red laser, fine 3D translation stages

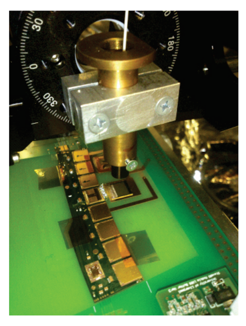


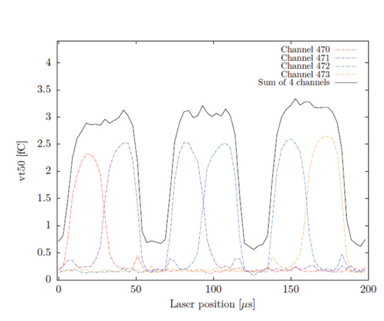


Test beam setup, DAQload cluster analysis and comparison with analogue beta source test [1]




Beta source testing (R0) and 3D hit map of DAQload

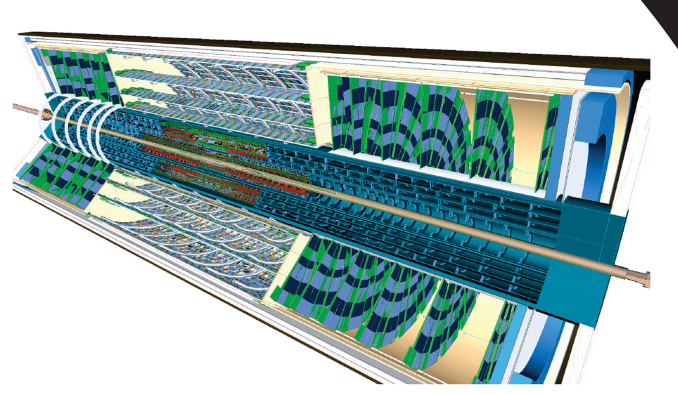



Laser testing and interstrip scan of ITk strip miniature DAQload

What are the ITk Strip Modules?

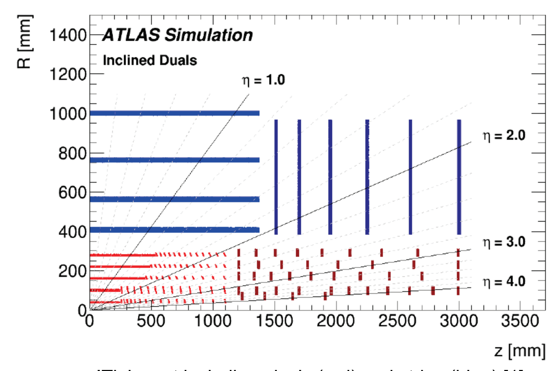
The Inner Tracker (ITk), all-silicon vertexing and tracking device, is being developed in the framework of Phase-II Upgrade project as a successor to the Inner Detector (ID) currently used in the complex detection system ATLAS at the LHC at CERN. The ITk consists of the Pixel Detector close to the beam line and the large area Strip Detector at the outer radii.

During the 30-month shutdown scheduled between years 2024 - 2026 the HL-LHC will be put into operation at the peak luminosity of 7.5 × 10^{34} $cm^{-2}s^{-1}$ corresponding to approximately 200 inelastic proton-proton interactions per beam crossing. This places high demands on future detection modules, which will be exposed in the strip region to fluences equivalent to 1.2 × 10^{15} n_{eq}/cm^2, ten times higher than in current SCT.


Arrangement of the future ITk detector [1]

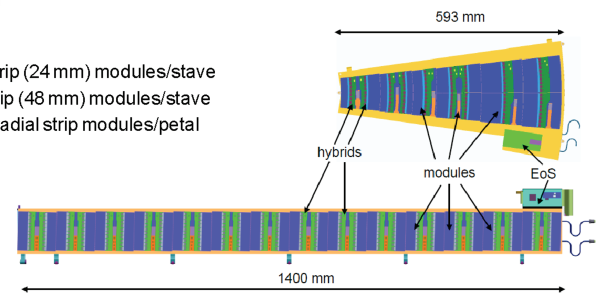
Both barrel and end-cap layers will be populated with identical substructures called staves and petals bringing together groups of modules. They will provide local support for the modules, mechanical rigidity and common electrical, optical and cooling services.

The strip detection system covers ± 2.5 units of pseudorapidity and occupies an area of 165 m^2. Nearly 18,000 strip modules are loaded on both sides of staves and petals, respectively, with a stereo angle implementation to determine the z-position of the strip clusters.



ITk layout including pixels (red) and strips (blue) [1]

- 2 inner barrel layers of staves → 2 × 14 short strip (24 mm) modules/stave
- 2 outer barrel layers of staves → 2 × 14 long strip (48 mm) modules/stave
- 12 end-cap disks → 32 petals/disk → 2 × 9 radial strip modules/petal



Overview of supporting substructures: End-cap (upper), barrel (lower) [1]

Data Acquisition

Just the strip section of the ITk detector requires reading out from nearly 60 million channels. This huge amount of data is being processed by individual ATLAS Binary Chip's (ABCStar) FE electronics, where previously generated signal from sensor is amplified, shaped and finally discriminated to get binary output. The L0/L1 trigger rate reaches 1 MHz/400kHz. Other wire bonds are needed for powering and DAQ during electrical readout tests.

Binary data for each hybrid are transmitted through the Hybrid Control Chip (HCC) at 640 Mbit/s to the End of Structure (EoS) of stave/petal via copper bus tape. The tape provides Timing, Trigger and Control (TTC) input data transmitting to ASICs, output data coming from their channels and power distribution of LV and HV to the power boards.

The final EoS data processing and optical conversion is performed by universal components of Phase-II electronics such as low power Gigabit Transceiver (lpGBTx) chips and Versatile Tranceiver (VTRx+) providing multimode optical I/O fibres. Moreover, the global and local interlock and common monitoring system as parts of the Detector Control System (DCS) generates additional data information.

The EoS serves as an interface between the on- and off-detector electronics that is represented by the FELIX board. This board is able to convert specific optical signals from detector to standard communication protocols.

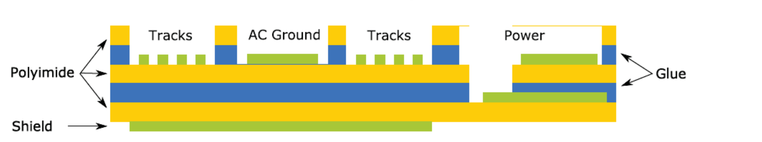
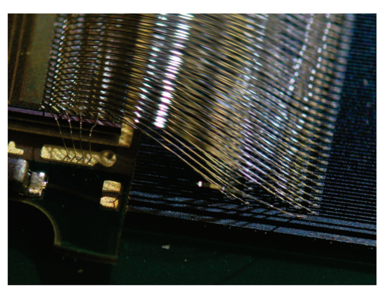
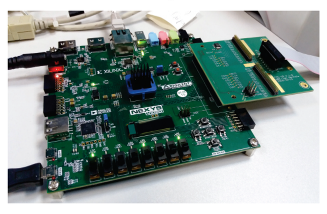
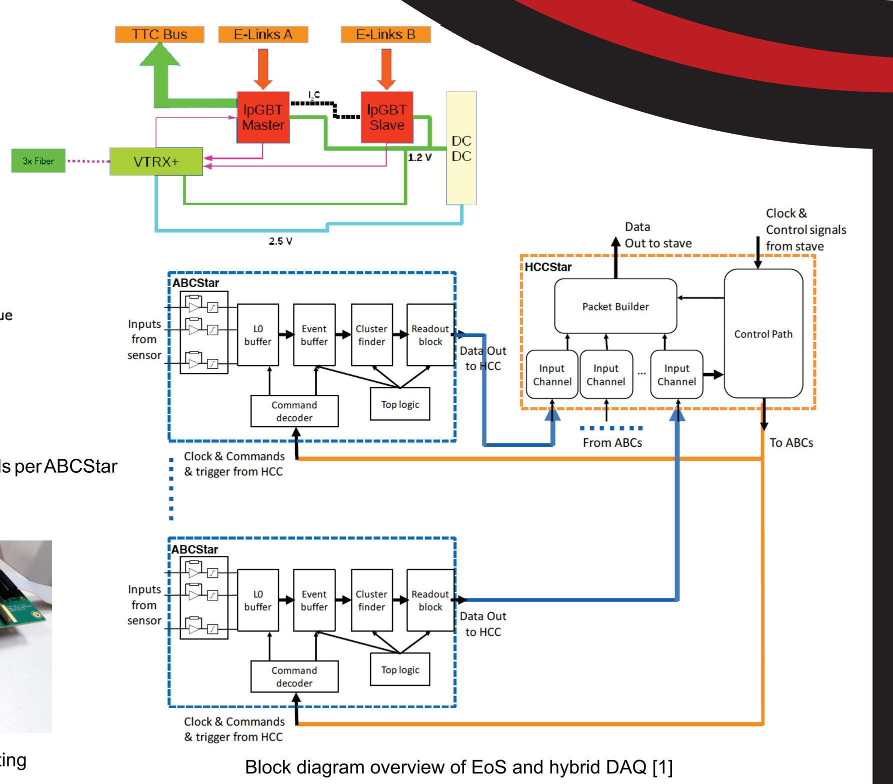


Illustration of the bus-tape [1]

- 256 strip-to-channel wire-bonds per ABCStar
- 2 streams per hybrid
- 4-row wire-bonding procedure


Strip pads wirebonded to readout chip


DAQ board for module testing



Block diagram overview of EoS and hybrid DAQ [1]

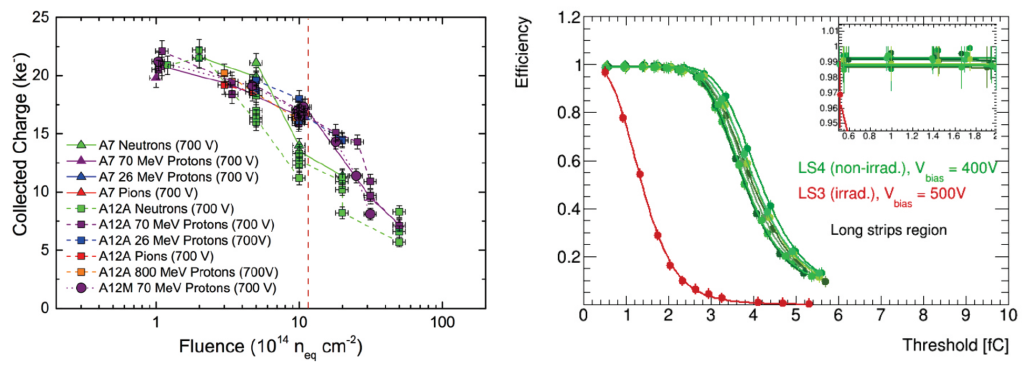
Irradiation and Database

The ITk strip project uses six different irradiation facilities providing neutrons and protons at different energies, or beams of pions or electrons. Studies of irradiated sensors and modules show impact of radiation damage on the collected charge, especially at the end of their expected lifetime. While its value for the non-irradiated modules is around 4 fC and the sensor is fully depleted at 350 V, the signal from the irradiated ones is in the range of 2.2 - 3.1 fC for the region of highest irradiation and different module types at the depletion voltage of 700 V.

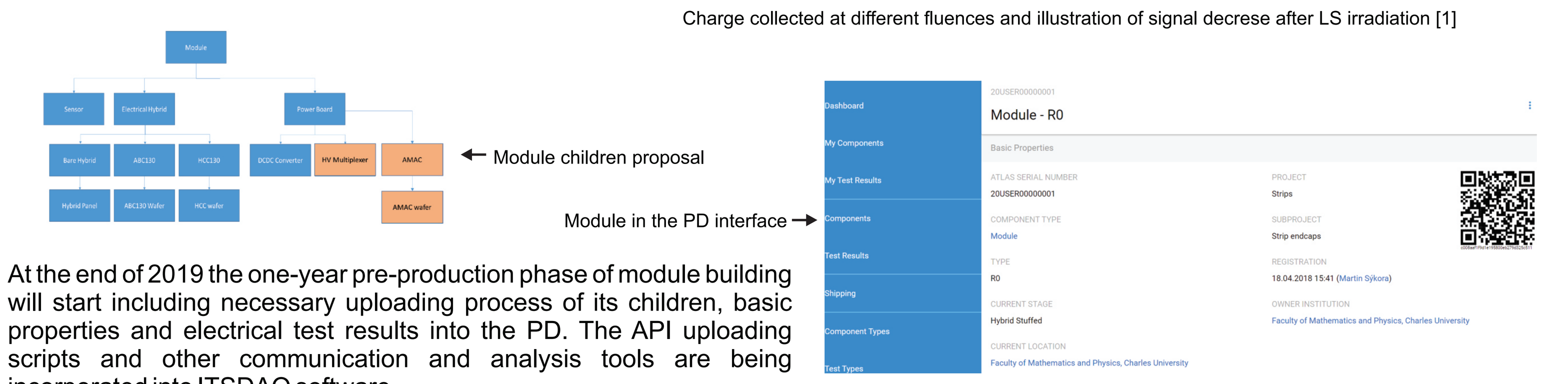
The hybrids, ASICs and sensor surface suffers during irradiation procedure from ionizing radiation, sensor bulk is then affected by point and cluster defects caused by non-ionizing energy loss. It was shown that the largest changes under irradiation reaches sensor inter-strip resistance, but it still stays significantly above the 15 MΩ specification.

For the testing purposes 3 irradiation campaigns were organized during last year at CERN IRRAD proton facility, where predominantly miniature testing substructures were irradiated including the full-sized R0 module that was cooled down after accepting its lifetime dose of 10^{15} n_{eq}/cm^2 for the test beam studies.

Monitoring of all individual components of the production process will be caried out by the ITk Production Database (PD) common for strips, pixels and ITk mechanics/electronics. The PD will serve as a storage for assemblies, shipments and test results of almost 10^7 numbered items and provide detail information leading to better understanding of future defects.

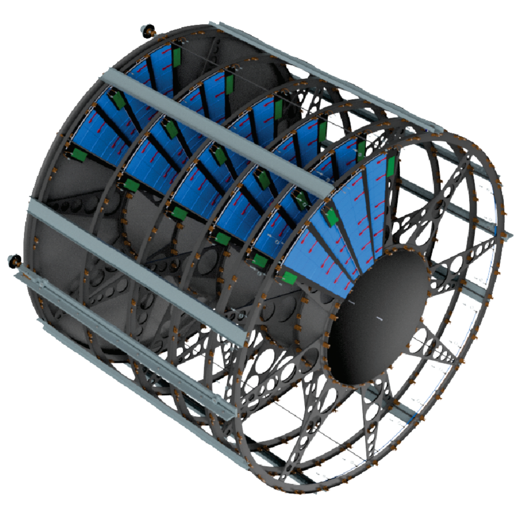


Charge collected at different fluences and illustration of signal decrease after LS irradiation [1]



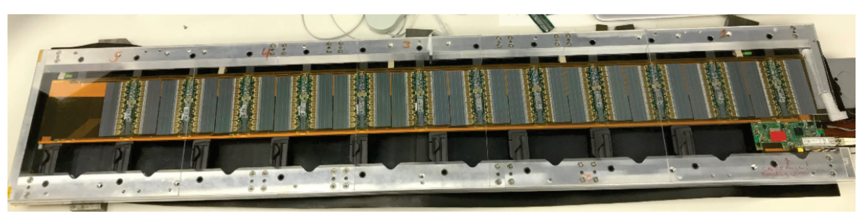
At the end of 2019 the one-year pre-production phase of module building will start including necessary uploading process of its children, basic properties and electrical test results into the PD. The API uploading scripts and other communication and analysis tools are being incorporated into ITSDAQ software.

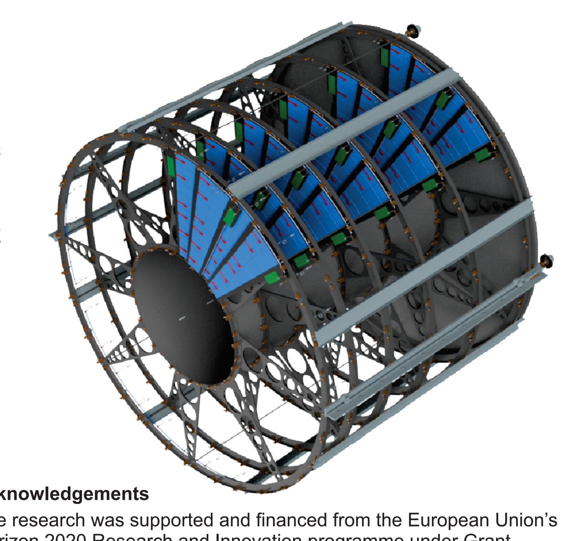
Conclusions



The exciting ATLAS ITk Upgrade project brings many technical and logistical challenges arising from the outlined requirements and distributed production model. The strip detection system is designed to reasonably fill outer radii of the current Inner Detector volume. Since the end of 2019, the ramping-up pre-production phase will start followed by the production phase at the beginning of 2021. All procedures and gradual steps aim to lower and insert the assembled ITk detection complex instead of at that time already decommissioned Inner Detector in 2025.

The ITk strip modules provide 8 different designs mounted on complex substructures (barrel staves and end-cap petals) playing also the role of interface between the on- and off-detector electronics. The active strip detection system will be supplemented by the global mechanical support. The intensive LS, SS, R0 and miniature module testing of the both non-irradiated and irradiated samples is ongoing at the institutions involved. The production will require specific Quality Control (QC) testing procedures such as visual inspection, metrology and multiple electrical characterization of hybrids or modules. One of the key points is the Production Database, which will serve as a production data storage for all components and their QC test results. In the next few months modules and hybrids hosting the final production ABCStar chips will be available for irradiation and beam testing. The production of the remaining end-cap sensor types will start and new test beam and irradiation facilities will be chosen in view of CERN shutdown.





References

[1] The ATLAS Collaboration, "Technical Design Report for the ATLAS Inner Tracker Strip Detector", CERN-LHCC-2017-005, ATLAS-TDR-025

Acknowledgements

The research was supported and financed from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168; and the Ministry of Education, Youth and Sports of the Czech Republic coming from the project LM2015058-Research infrastructure for experiments at CERN.