Prague's Contribution to the ATLAS Inner Tracker Upgrade

CZ+SK HEP Workshop 2026

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ATLAS ITk

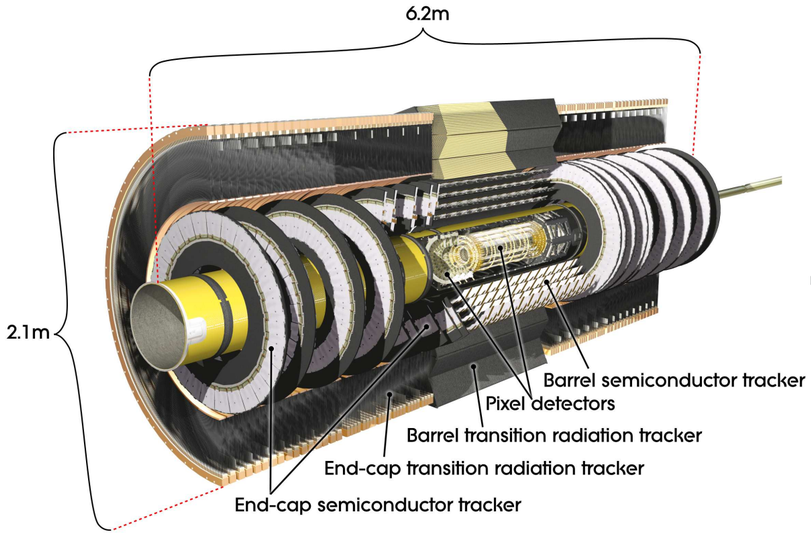
Faculty of Mathematics and Physics
Charles University

The HL-LHC Upgrade

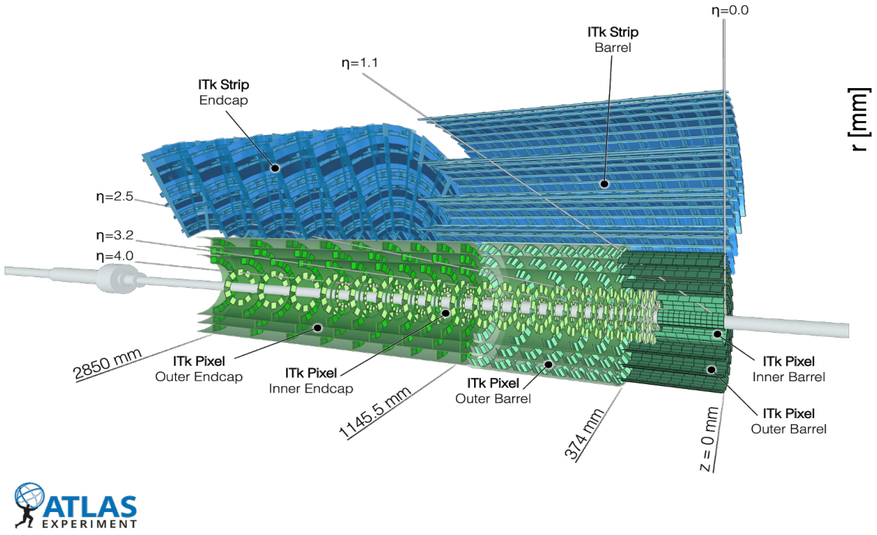
- The LHC is going through a major upgrade: the HL-LHC project
  - The work is done during Long Shutdown 3, which started this July
  - Increase of nominal instantaneous luminosity to $\mathcal{L} = 5 \times 10^{34} \mathrm{cm}^{-2} \mathrm{s}^{-1}$
  - The maximum luminosity is going to be $\mathcal{L} = 7.5 \times 10^{34} \mathrm{cm}^{-2} \mathrm{s}^{-1}$
  - New average number of proton-proton collisions per bunch crossing: $\langle \mu \rangle = 140$
  - Potentially can reach a maximum of $\langle \mu \rangle = 200$
- Along the LHC, the detectors also need to be upgraded, including ATLAS
  - The HL-LHC parameters challenge the operation conditions of the detectors

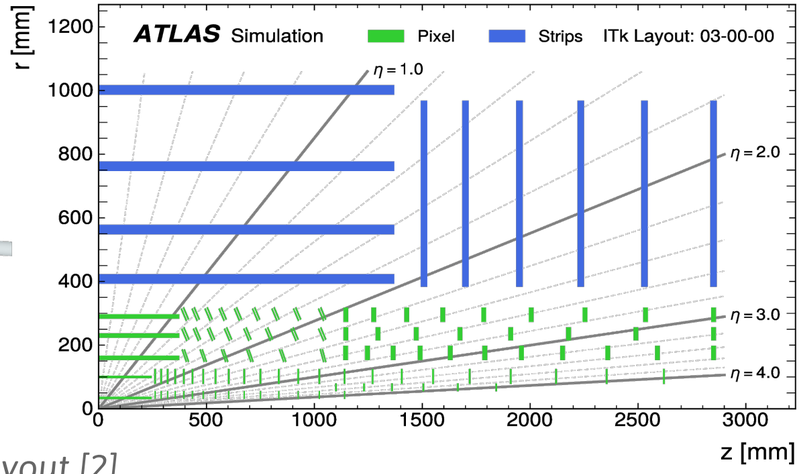
The ATLAS Upgrade and ITk

- The luminosities and the pile-up of HL-LHC present a significant challenge to the ATLAS detector
- As part of the upgrade, the Inner Detector (current ATLAS tracker) will be replaced by Inner Tracker (ITk)
- ITk is going to be fully made from silicon modules, as opposed to ID, which also contains gas sub-detector
- The aim of ITk is to maintain comparable (or slightly improved) resolution of track parameters in the new environment



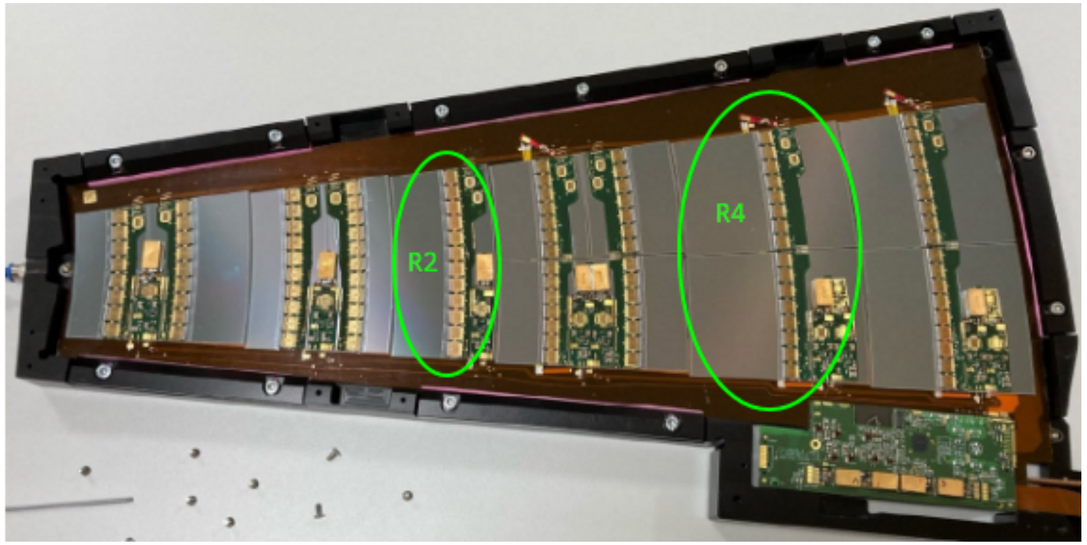
The layout of ID [1]





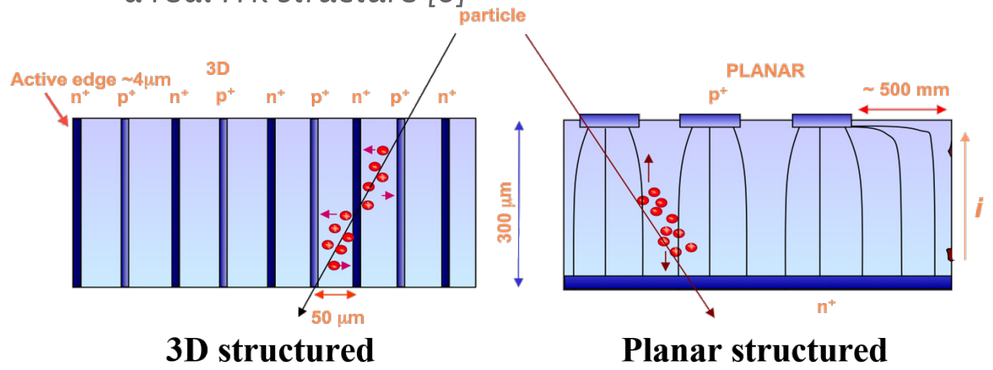
The ITk layout [2]

The ITk module



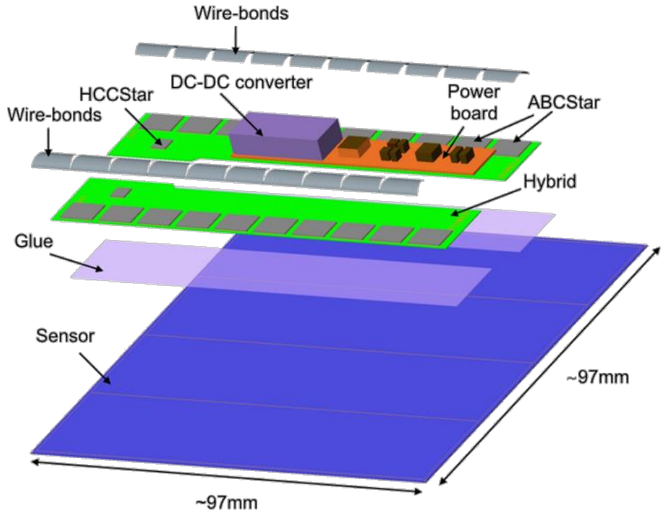
- ITk will feature 3D and planar pixel sensors
- Planar modules will use n-in-p doping
- Pixel sizes:
  - Barrel: 25 μm × 100 μm
  - Endcap: 50 μm × 50 μm
- Six types of endcap strip modules: R0 - R5
  - The pitch sizes vary depending on the type, from 69 μm to 84 μm
- IPNP is working on production of R2 and R4 endcap strip modules

Comparison of a 3D and a planar sensor. Not a real ITk structure [6]

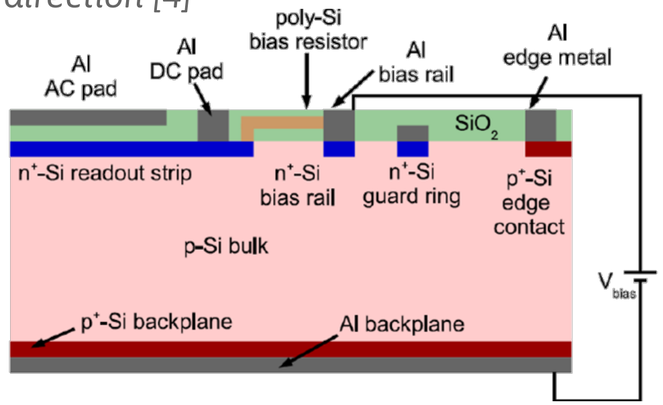


The ITk module structure

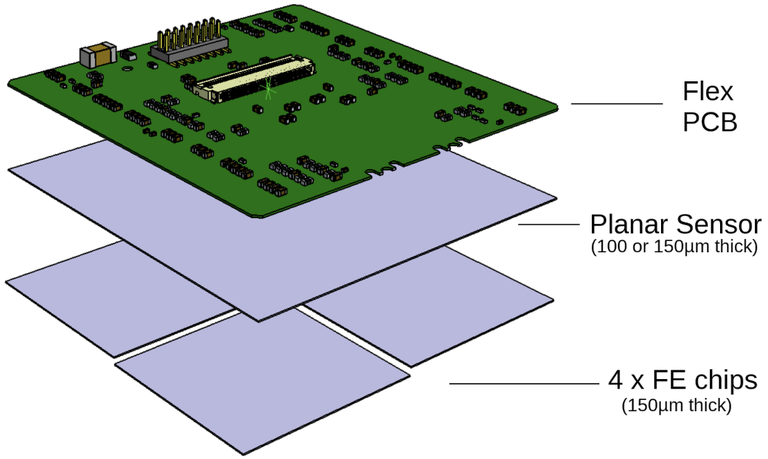
Exploded view of a short-strip barrel module with all relevant components [3]



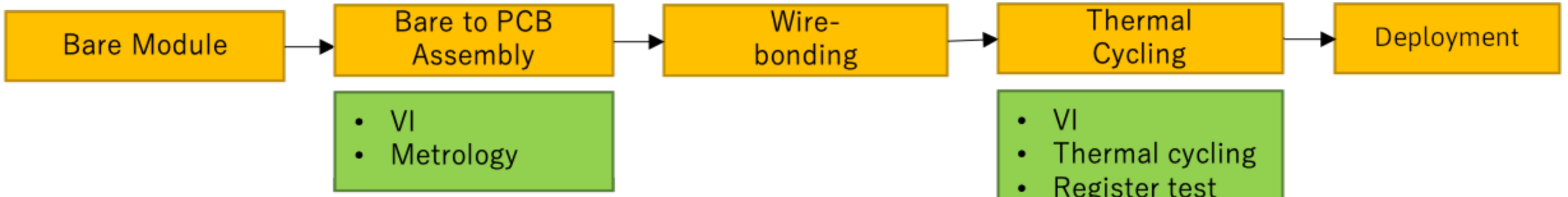
Schematic cross-section along the strip direction [4]



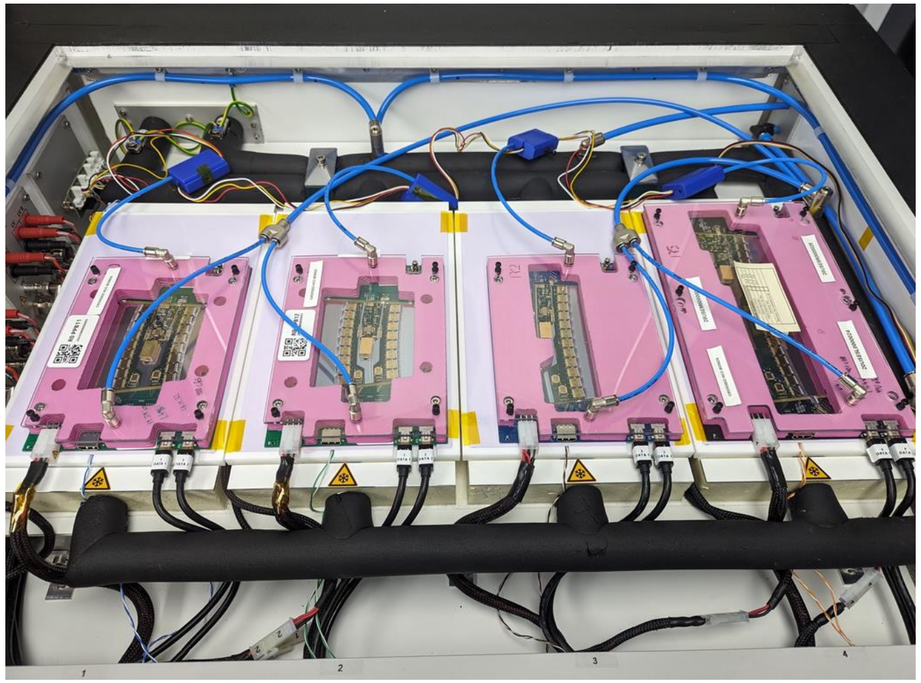
Component stack of pixel module [5]



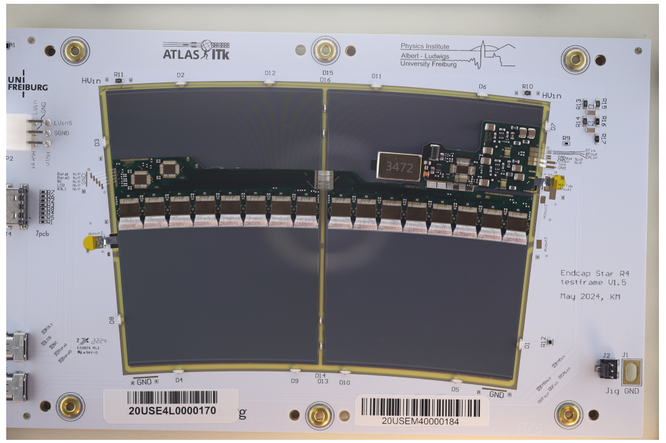
The lifecycle of ITk module at IPNP



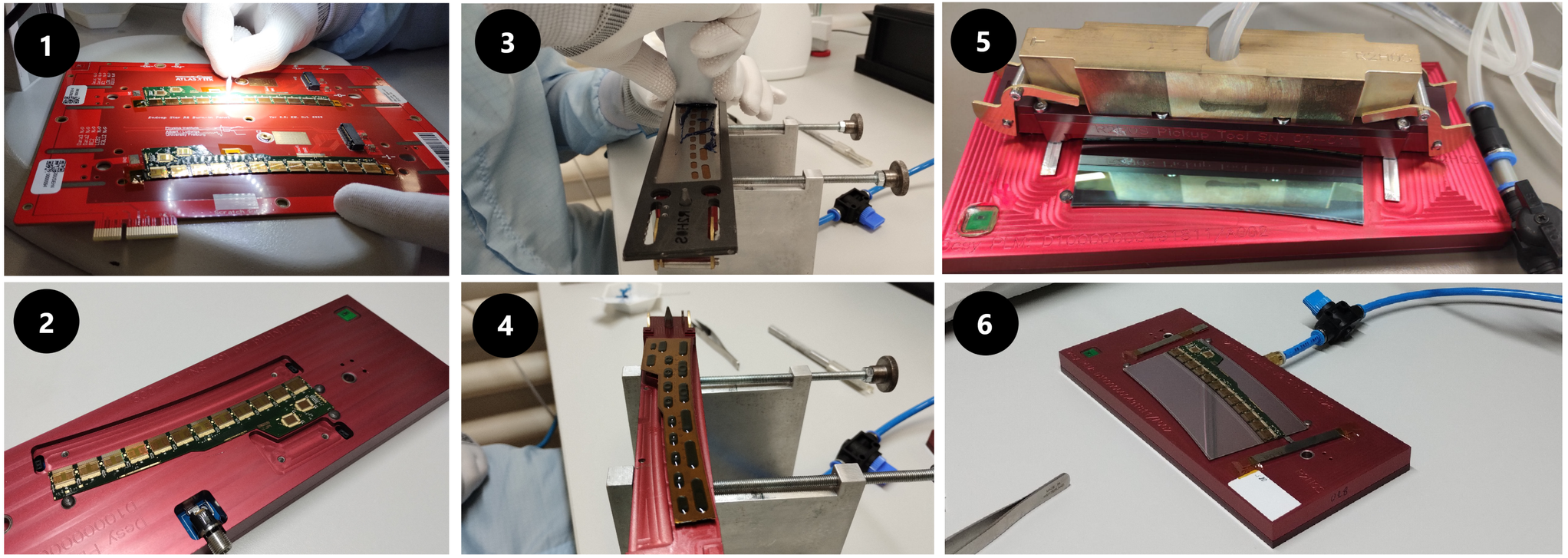
Variouse end-cap strip modules in a coldbox



R4 strip module on a testframe



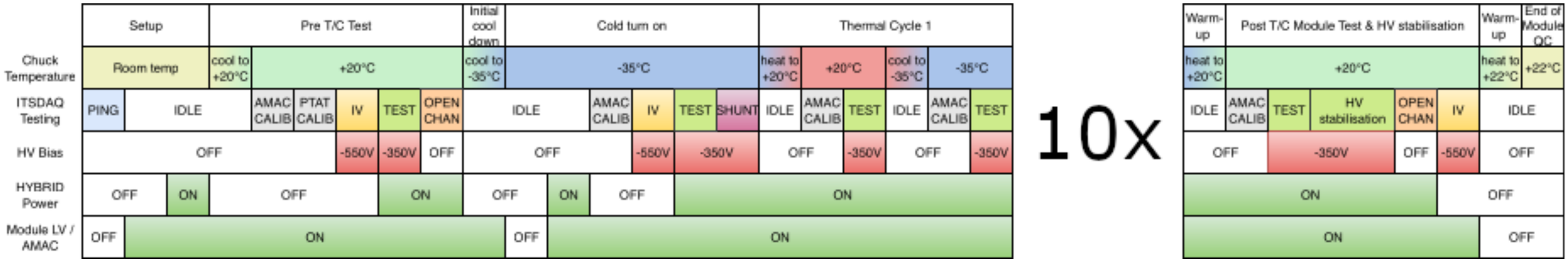
The gluing process [7]



1. The component is released from a carrier board
2. The hybrid is aligned on an alignment tool
3. Glue is applied to the underside of the hybrid through a stencil
4. Photo of the glue pattern
5. The hybrid is put on a sensor and weighted down
6. Photo of the hybrid glued on the sensor.

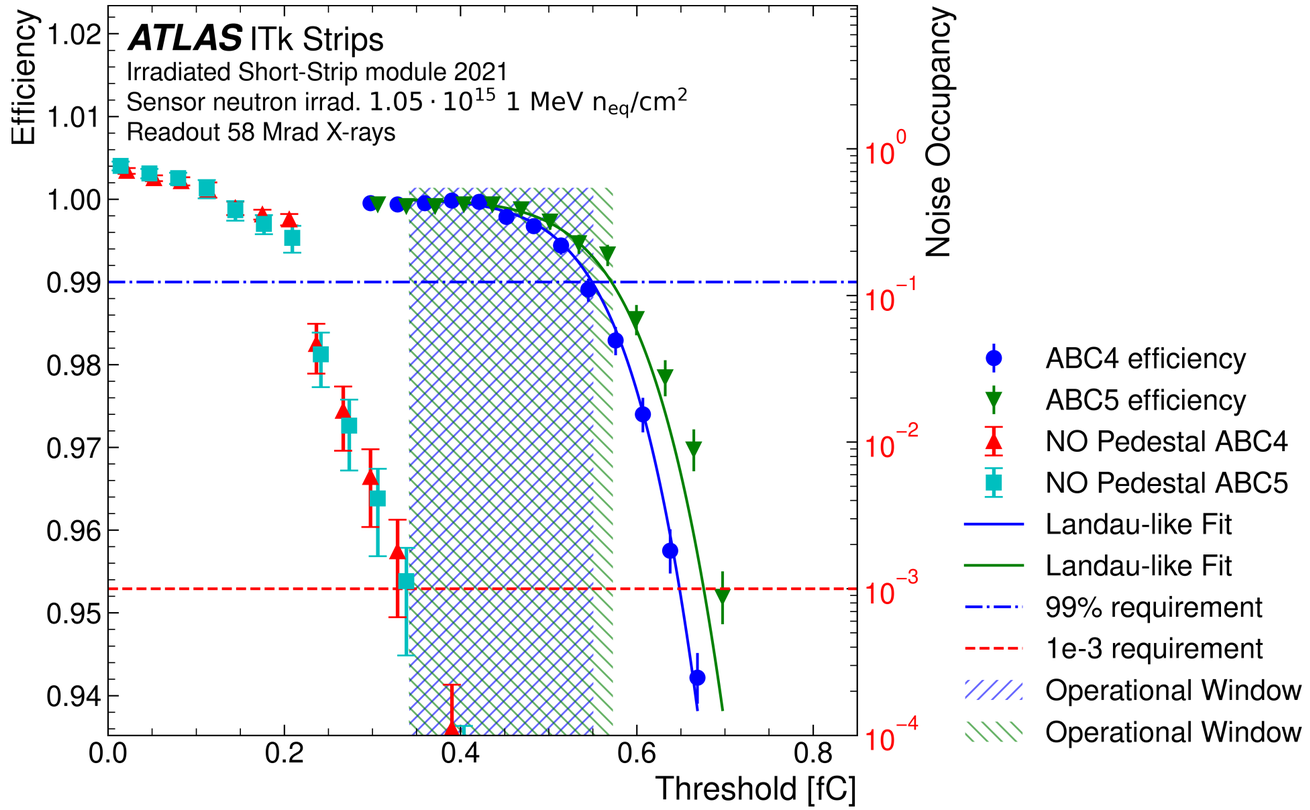
The thermal testing

- Glued modules go through extensive testing to ensure they work correctly and that they can survive the environment of the detector (except the radiation)
- The modules are subjected to ten cycles of tests at 20 °C and -35 °C



Testbeam

- Few modules go through further testing at beam facilities at CERN and DESY
- These modules are put into a beam of protons (CERN) or electrons (DESY)
- The modules are operated in a similar manner to the normal operation inside the finished detector
- These tests are performed to measure various characteristics like the operational window of the modules and spatial resolution
- Modules are surrounded by a telescope, which is a series of independent tracking and other detectors
    - They serve as a reference against which the module is tested
- These tests are done for unirradiated modules and for modules irradiated to end-of-life fluences



References

[1] The ATLAS Collaboration, Journal of Instrumentation, 3, S08 003, URL https://doi.org/10.1088/1748-0221/3/08/S08003, 2008.

[2] The ATLAS Collaboration, Expected tracking performance of the atlas innertracker at the high-luminosity lhc, Journal of Instrumentation, 20, P02 018, URLhttps://doi.org/10.1088/1748-0221/20/02/P02018, 2025.

[3] Technical Design Report for the ATLAS Inner Tracker Strip Detector, Tech. rep., CERN, Geneva, URL https://cds.cern.ch/record/225775, 2017.

[4] Klein et al., Initial tests of large formatsensors for the atlas itk strip tracker, Nuclear Instruments and Methods in Physics ResearchSection A: Accelerators, Spectrometers, Detectors and Associated Equipment, 986, 164 677,URL https://www.sciencedirect.com/science/article/pii/S0168900220310743, 2021.

[5] Vannoli, L., ATLAS ITk Pixel Detector - Overview, URLhttps://cds.cern.ch/record/2857574, 2023.

[6] Technical Design Report for the ATLAS Inner Tracker Pixel Detector, Tech. rep., CERN,Geneva, URL https://cds.cern.ch/record/2285585, 2017a.

[7] Sýkora, M., Detector and Physics Performance of the ATLAS Inner Tracker, URLhttps://dspace.cuni.cz/handle/20.500.11956/207507, 2026.

[8] ITk Collaboration, Test beam performance of ITk-Strip ABCStar Module,https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/ITK-2021-003/, accessed:10. 6. 2026

Backup

The lifecycle of ITk module - details

The journey begins...

The life of a module starts in Japan, where the sensors are manufactured, and in various other countries in Europe and North America, where power boards and hybrids are manufactured. These parts are then shipped to Prague. However, before the sensors end up in our lab, they are first tested by M. Mikestivova's team at the FZU. They check if the sensors were properly manufactured and if they are of the desired quality.

The first tests

Once we receive all the components, we need to make sure all of them survived the shipping. We visually check for mechanical damage and perform basic electrical checks. We check if the leakage current of the sensors is still within the limit. We make sure that the powerboards can deliver the appropriate voltages and currents. For example, the hybrids are checked to see if the intrinsic noise of the chips is not too high. Every failed component is reported and sent back to the manufacturer for rework if possible.

Gluing

The actual assembly of modules is not done in Prague. We send the components to an external company that glues the modules. They also perform the necessary wire bonding. The gluing process itself is not easy and takes several hours (including the curing time). High precision of alignment, glue mass and module high is required. The modules are glued by hand, and the necessary precision is accomplished by using custom made tools. Once the glue is cured, the height and position of the glued components are checked on a metrology station.

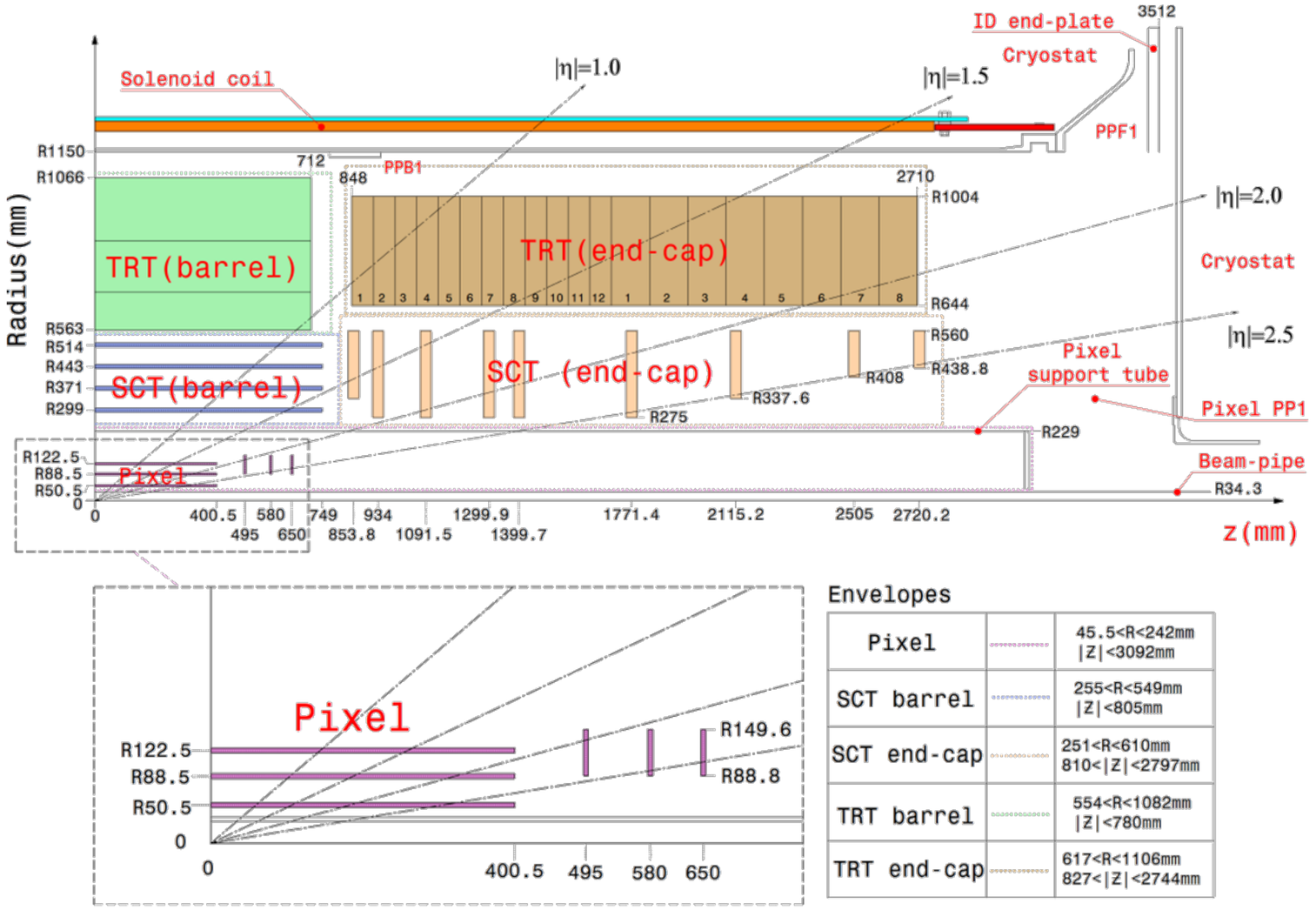
The final testing

The assembled module is brought back into our clean room. We again make sure that the new modules survived shipping. If the modules pass these preliminary checks, they are loaded into insulated light-proof boxes where they are stress tested. Inside the boxes, ten cycles of cooling to -35 °C and heating back up to 20 °C are performed. During each cycle, the modules are electronically measured. This includes IV curve measurement, noise measurement, response curve, etc.

To ATLAS and beyond

After they pass all the tests, the modules finished in Prague are send to IFIC in Valencia, where they are mounted on support structures called petals. One petal holds six modules (R0 - R5). Petals also need to be tested to make sure the modules work together, and thermocycling is done. Finished petals are sent to DESY in Germany and NIKHEF in the Netherlands, where they will be mounted to support structures. After two years of module production, everything is send to CERN and loaded into the detector.

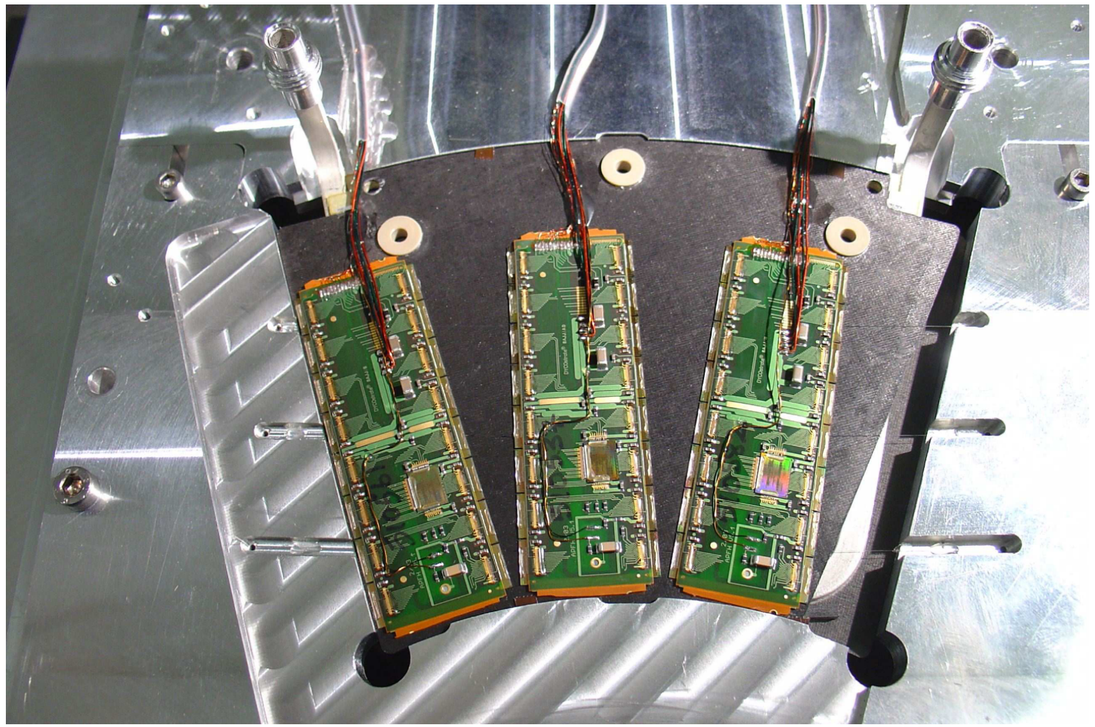
The whole ID layout

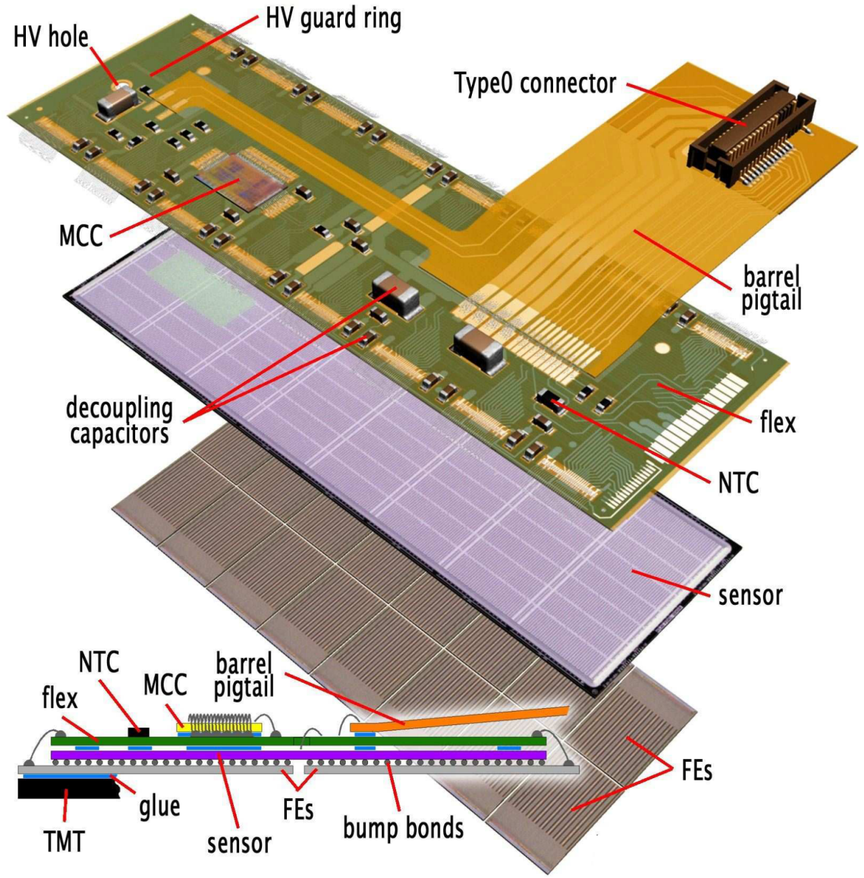


Envelopes

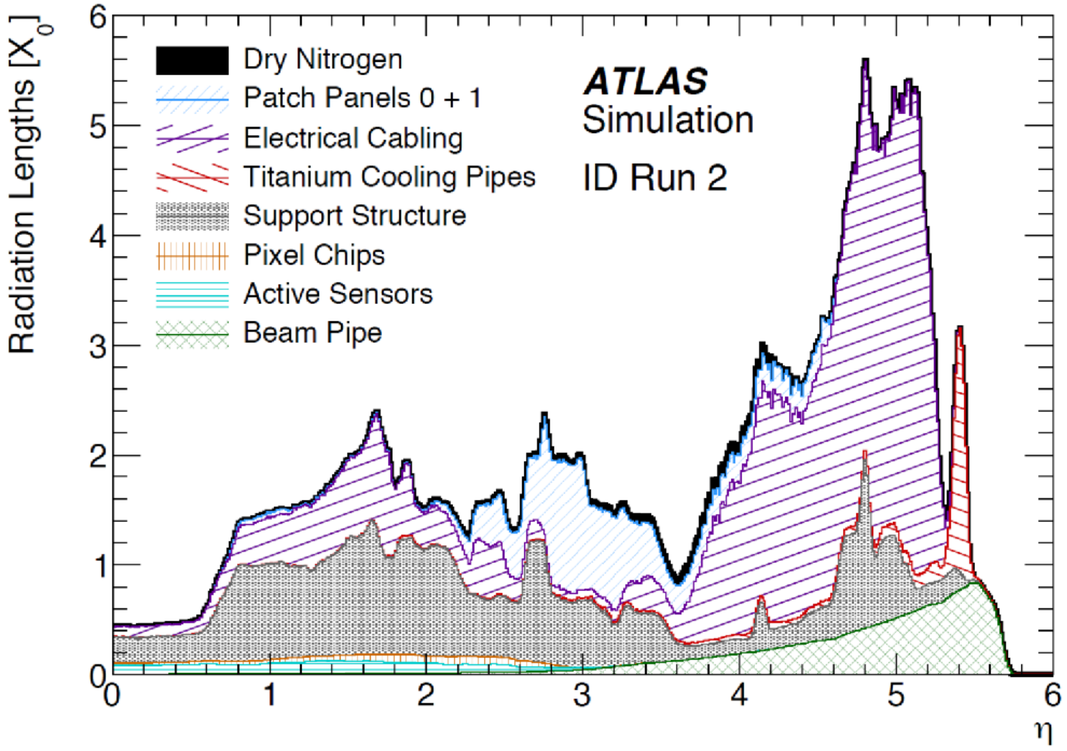
Pixel		45.5<R<242mm |Z|<3092mm
SCT barrel		255<R<549mm |Z|<805mm
SCT end-cap		251<R<610mm 810<|Z|<2797mm
TRT barrel		554<R<1082mm |Z|<780mm
TRT end-cap		617<R<1106mm 827<|Z|<2744mm

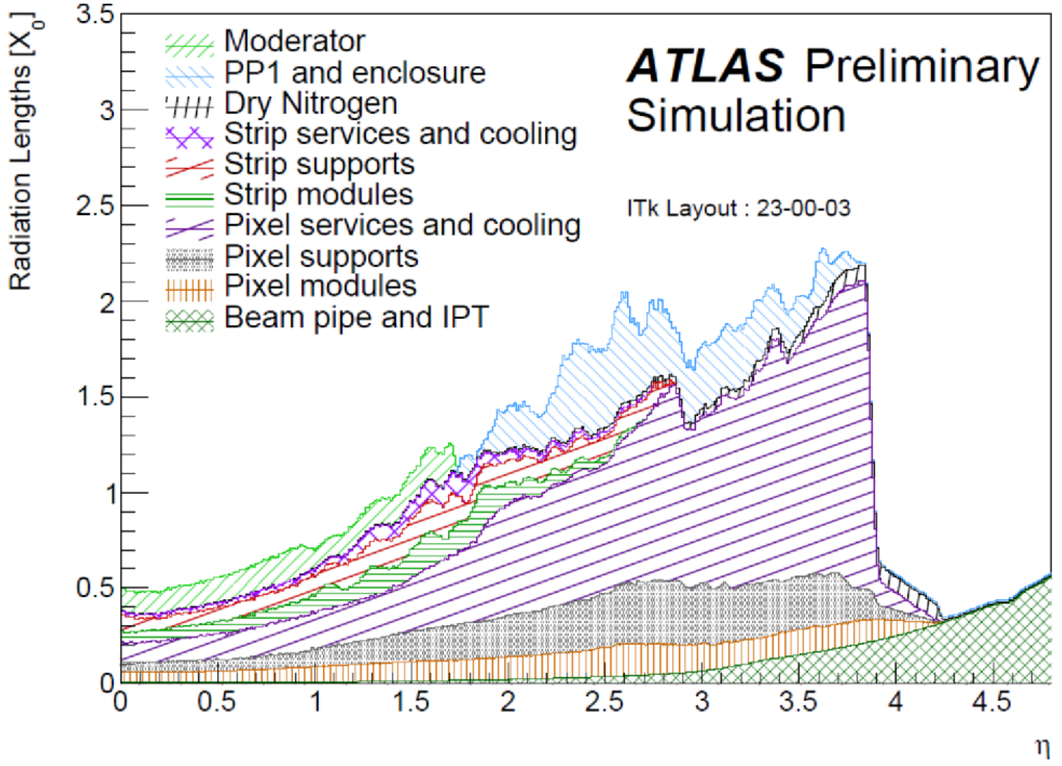
Pixel modules



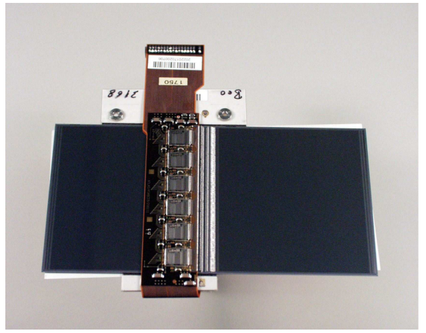


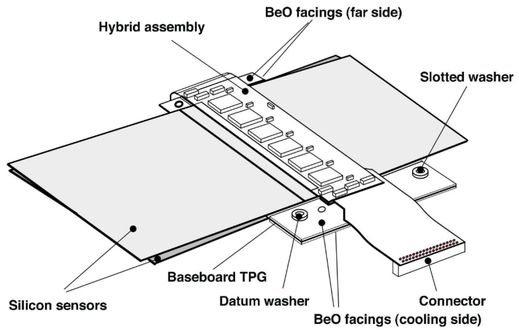
ITk material budget

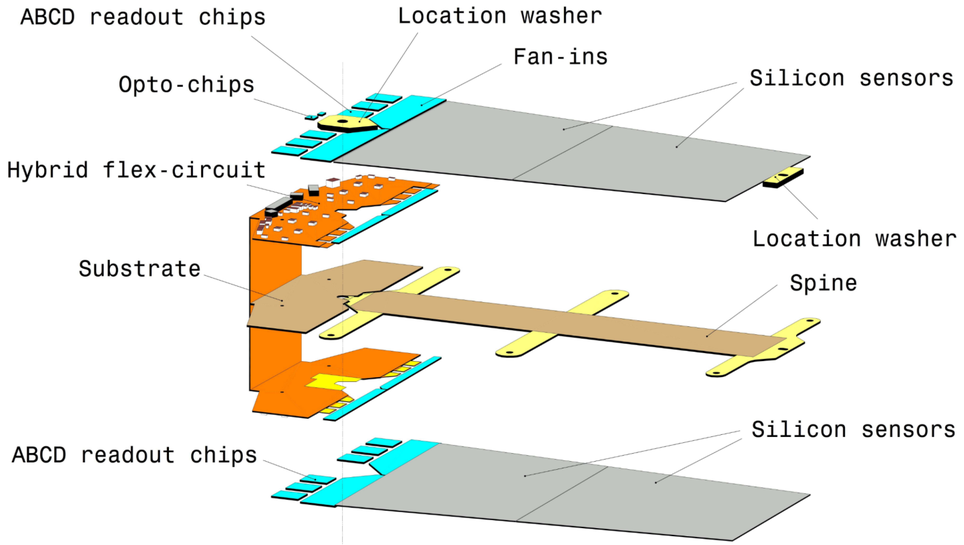


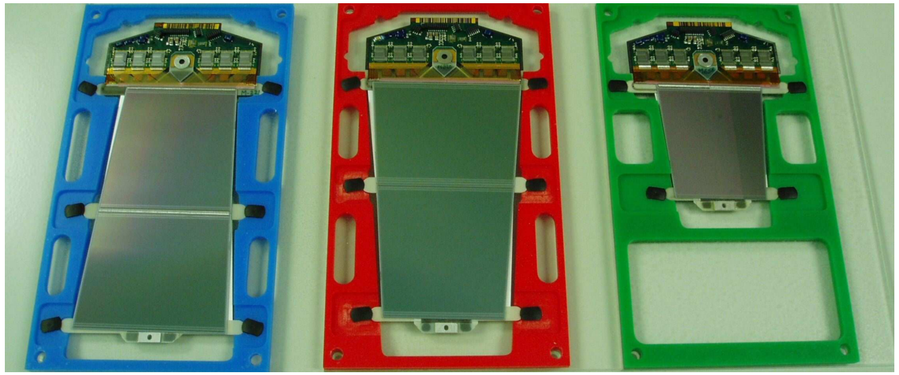


SCT modules

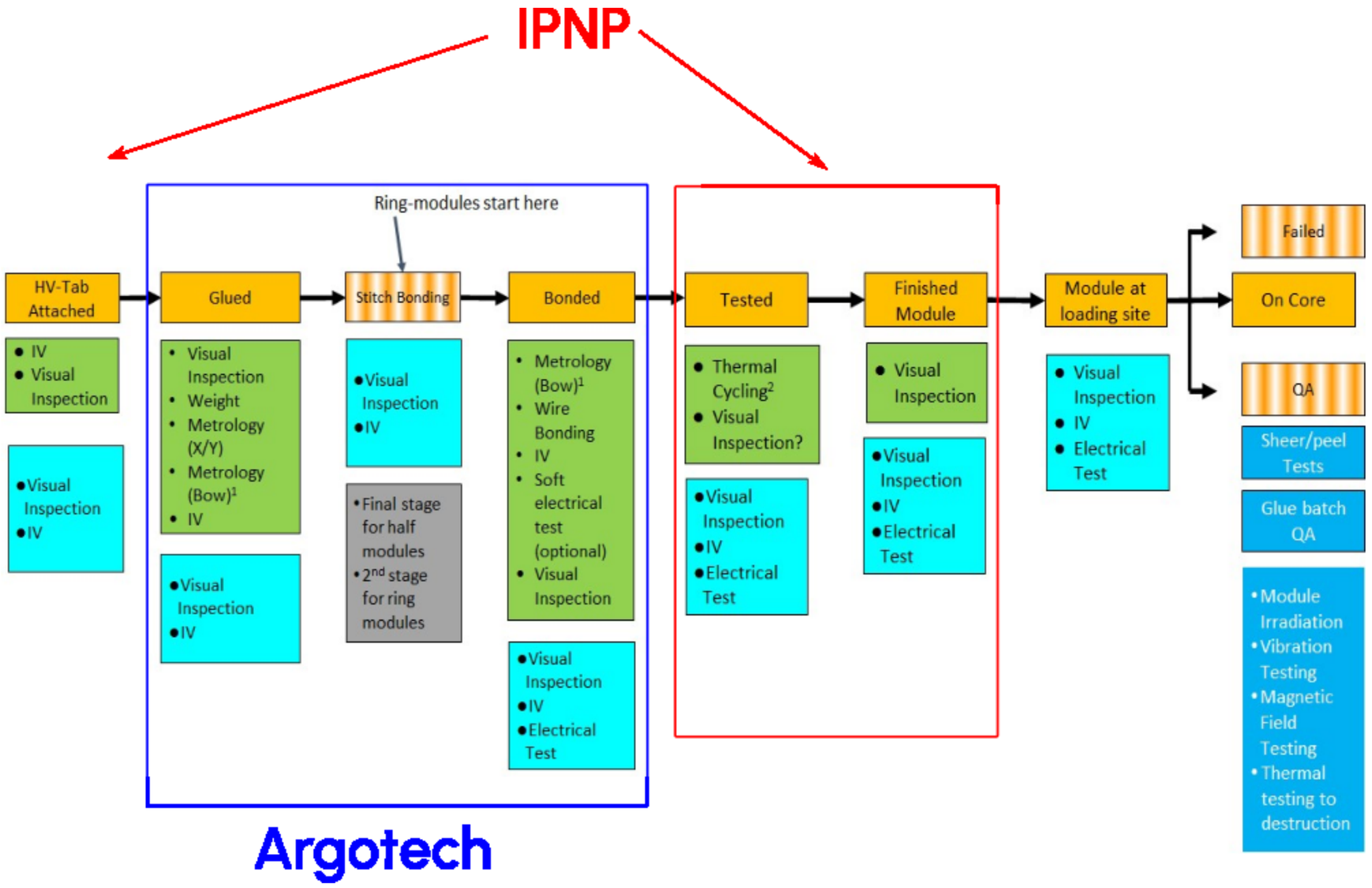



Hybrid assembly
BeO facings (far side)
Slotted washer
Baseboard TPG
Datum washer
Connector
Silicon sensors
BeO facings (cooling side)


ABCD readout chips
Location washer
Fan-ins
Opto-chips
Silicon sensors
Hybrid flex-circuit
Location washer
Substrate
Spine
Silicon sensors
ABCD readout chips



Full workflow



Full TC

- Glued modules go through extensive testing to ensure they work correctly and that they can survive the environment of the detector (except the radiation)
- The modules are subjected to ten cycles of tests at 20 °C and -35 °C
- The following tests are performed during one cycle:
  - **IV characterisation** up to –550 V
  - **Pedestal trim** smooths out varying offsets of the readout amplifiers
  - **Strobe delay** synchronises the timing of the chip readout with the system clock
  - **Response curve** measures the response of the chips to different charges
  - **Trim** injects 1 fC charge into the chips and calibrates the threshold (found in the previous test) such that each strip would have the same response to the charge
  - **Open channel search** looks for any chip channels that are not bonded to the sensor
  - **Noise occupancy** is determined by reading out empty (no charge) channels for a certain amount of time while varying the threshold