Module development for the ATLAS ITk Pixel Detector

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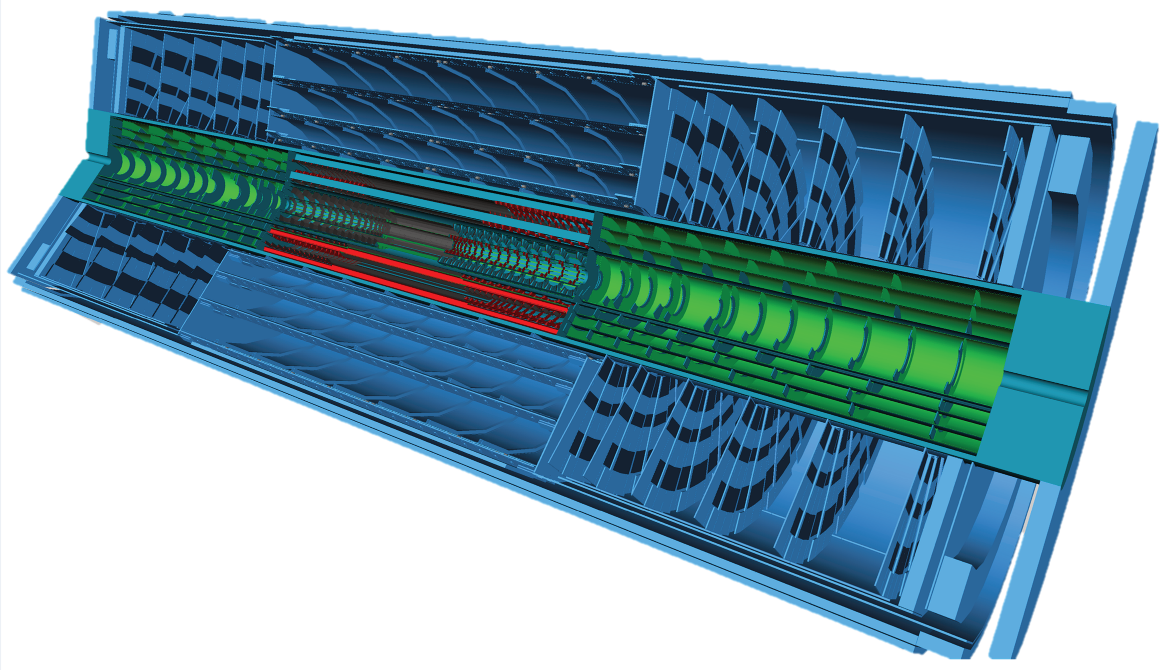
On behalf of the ATLAS ITk Collaboration

Introduction

The ATLAS experiment will upgrade its tracking detector during the Phase-II LHC shutdown to take advantage of the increased luminosity of the HL-LHC, with data-taking expected to start by 2029.

The upgraded tracker will consist of a barrel of concentric layers (5 pixel + 4 strip) with several endcap rings and will likely cover an extended eta[1] range. It is foreseen to cover up to |eta|<4.0. Following substantial developments in the area of silicon hybrid module technologies to optimise their assembly and integration, pre-production of modules has now begun.



Proposed layout for the ITK detector[2], 1 m in radius and 6 m in length. The silicon sensors shown as red/blue/green cells are secured onto detector-long carbon support structures.

This has been made possible following the validation of numerous production, assembly, integration tests and wider infrastructure necessary in preparation for commissioning the ITk[3]. As these tools and procedures have matured, the focus of further developments has been directed towards the parallelisation of module production in order to manage the target throughput spread across multiple sites globally. Tests with the production ITkPixV2 front-end are now ongoing.

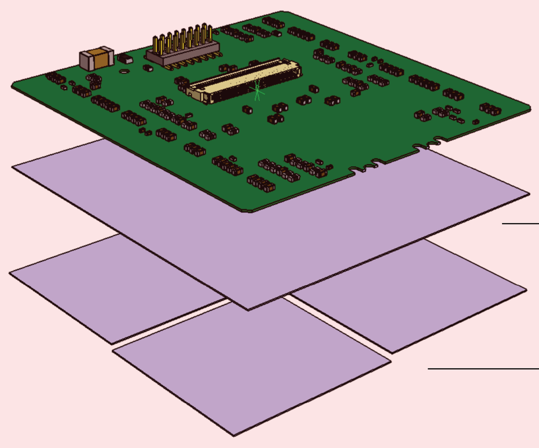
Assembly chain – Towards Production

A module consists of a silicon sensor bump-bonded to a front-end (FE) chip (forming a bare module) glued to a flexible PCB that relays the data and power connections to dedicated pigtail cables.

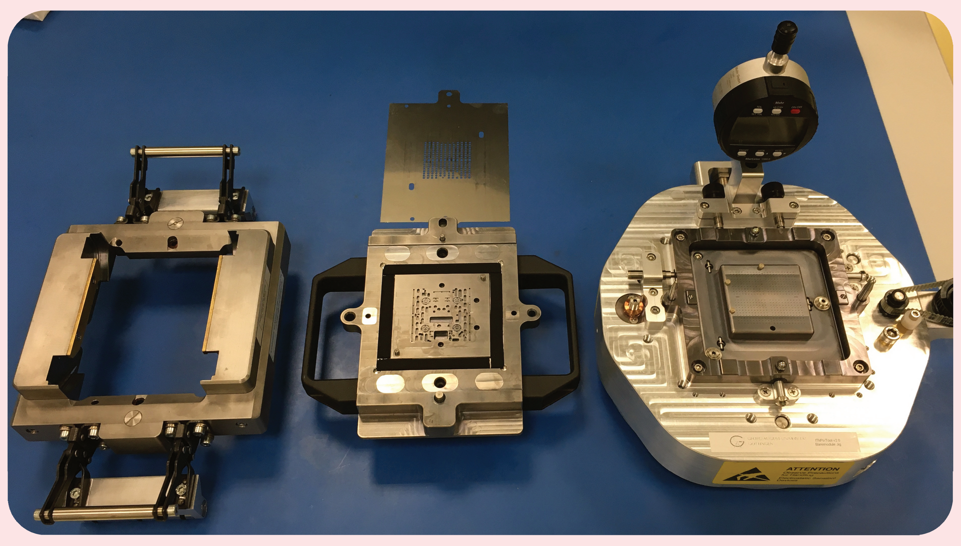
The module assembly process comprises of several key stages including:

- **Visual Inspection, Metrology, Flex Attach, Parylene Coating & Mechanical Wire-bond Protection Assembly.**

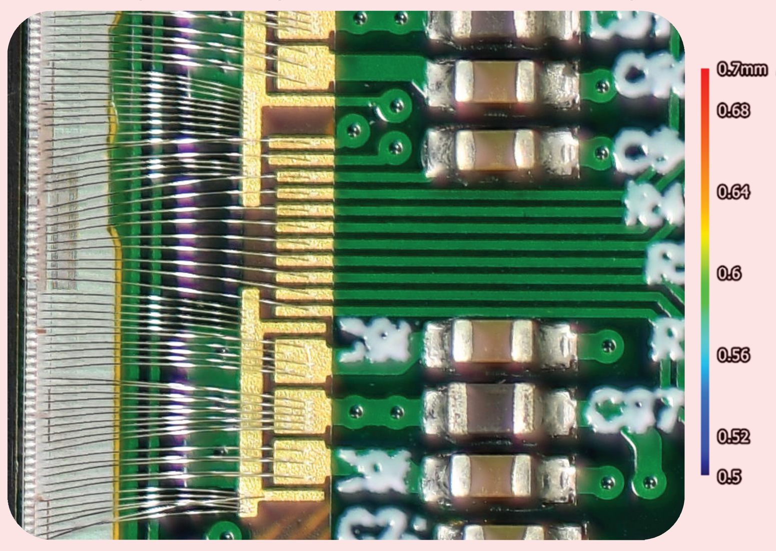
Quad Module



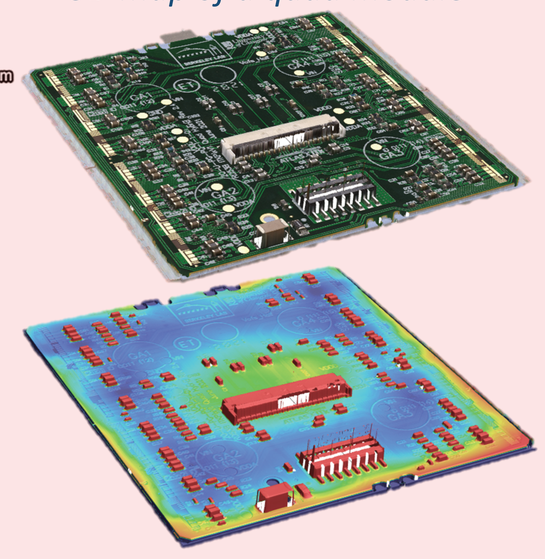
Tooling accounts for bare component thickness variations



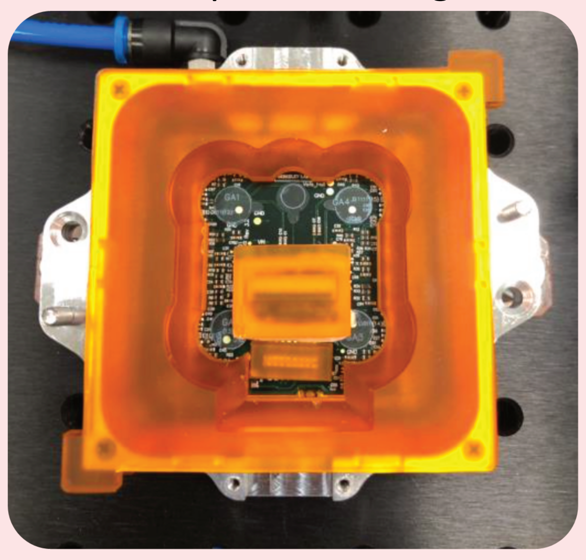
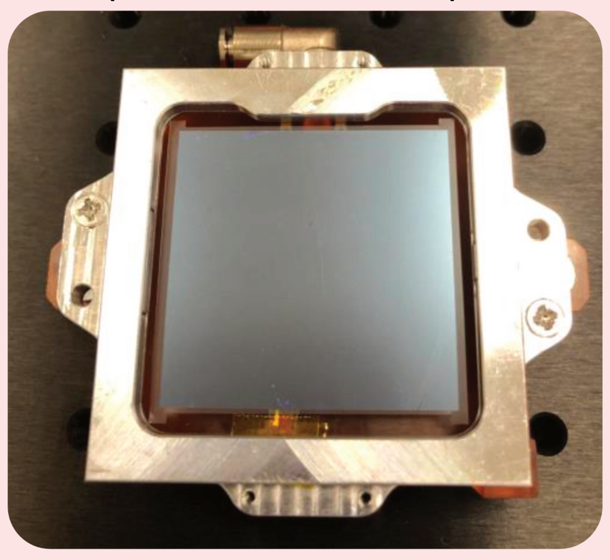
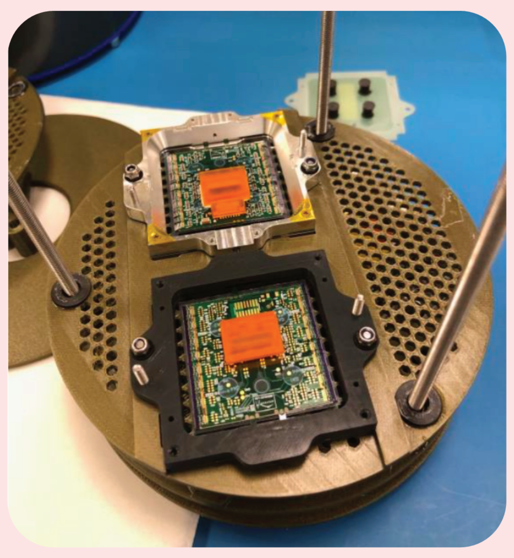
Inspection of wire-bonded assembly



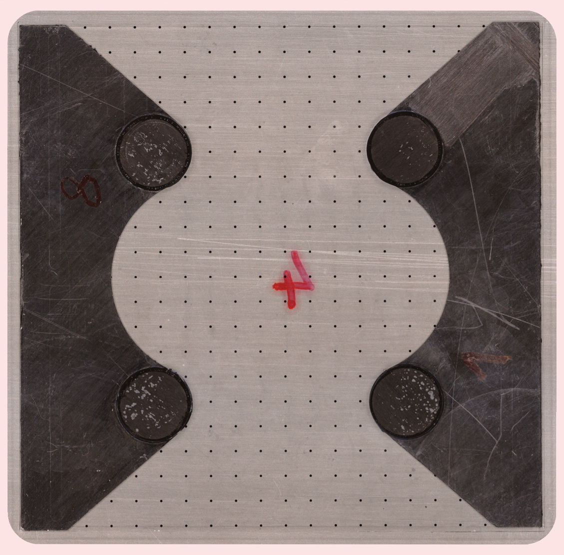
3D map of a quad module



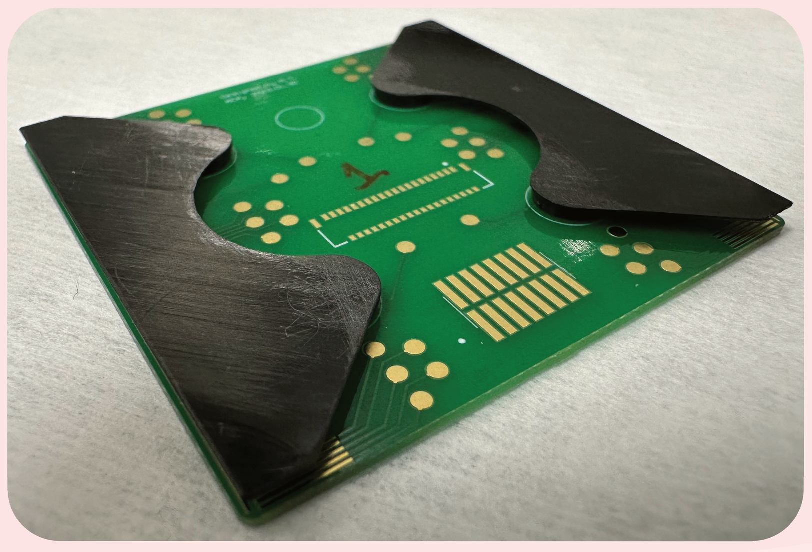
- A 7.5 µm thick parylene coating is applied, requiring masking of connectors and FE back side surfaces as well as development of large & secure shipment batches for production.

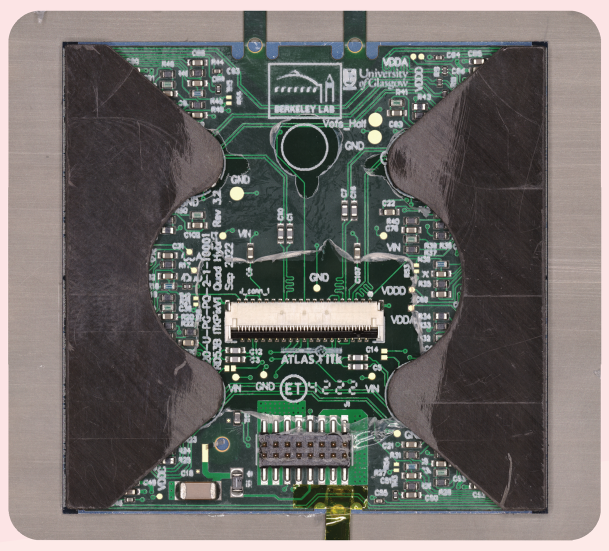

- The final assembly stage involves the addition of a carbon-fiber mechanical protection element required for the Outer Barrel modules' wire-bond protection. To prevent these components from remaining electrically floating, a silver-based glue is applied along with Araldite for mechanical adhesion.



Assembly on glass tile showing glue spread

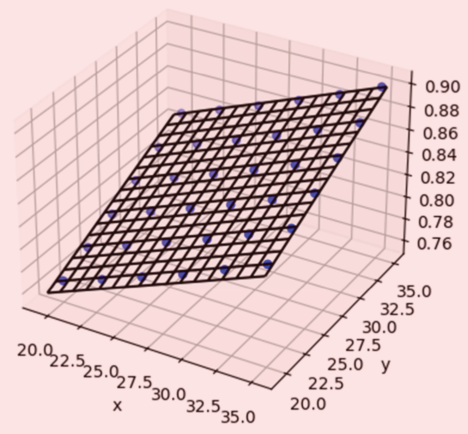


Assembly on test PCB to validate electrical connectivity

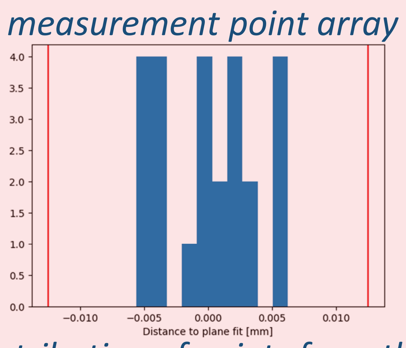


Assembly on parylene coated & wire-bonded dummy module

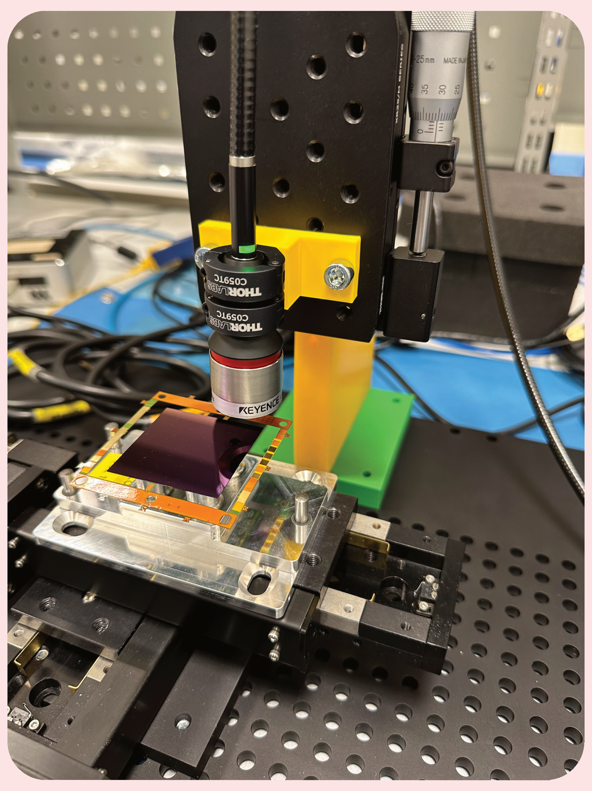
- Following full completion of all production stages, the module's back side metrology must be assessed to ensure it is still within specification. This is achieved through the use of a custom confocal measurement system.



Least square fit plane of a 25 measurement point array



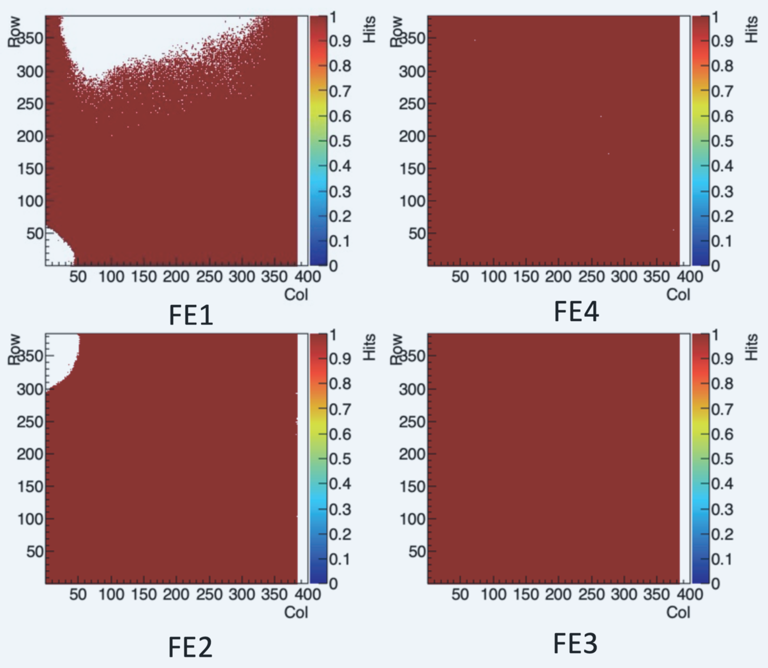
Distribution of points from the fitted plane, within the 25µm specification



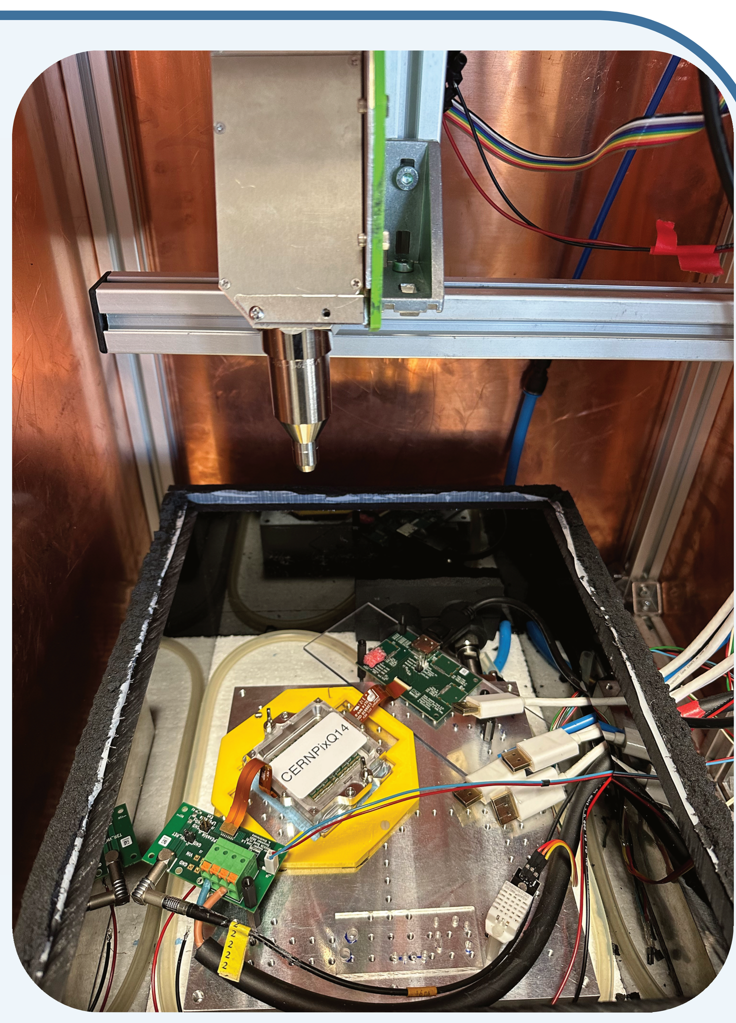
Automated confocal back side metrology system

Testing chain & parallelisation

- Beyond the suite of electrical QC tests developed for pre-production & production, several dedicated studies have been performed to assess the quality of flip-chip bumps from different vendors. This has enabled optimisations in the flip-chipping process leading to greater bare module yields upon reception.

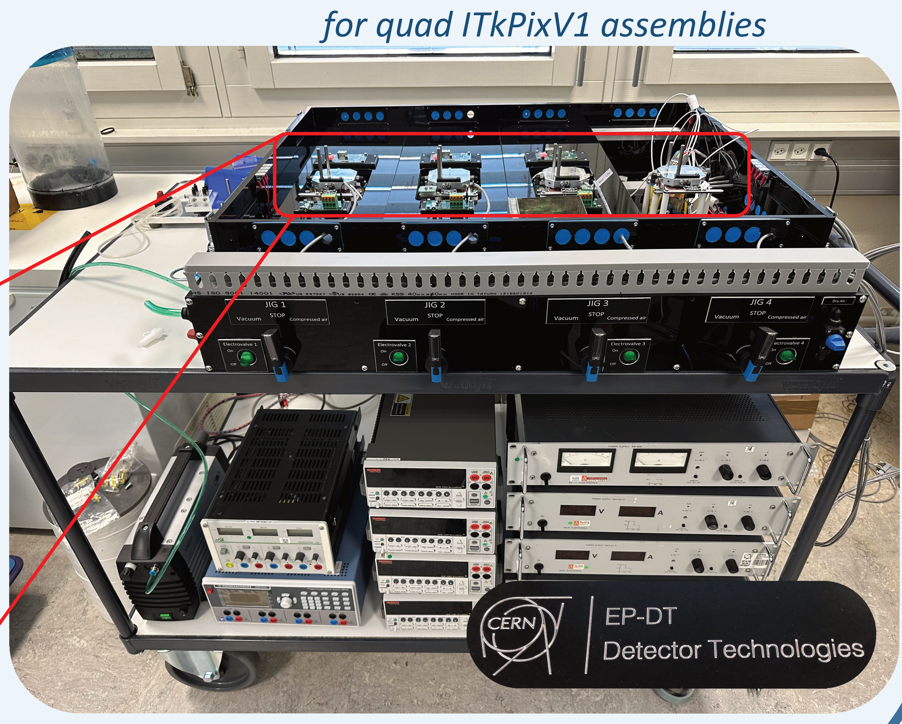
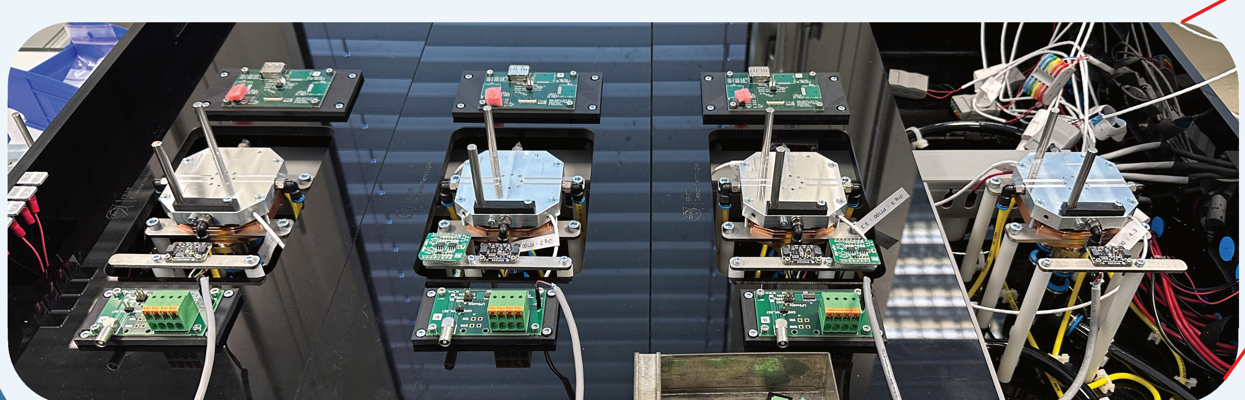


Such tests are made possible through the use of an illumination source, typically commercial X-ray tubes.



Electrical testing & X-ray illumination setup for quad ITkPixV1 assemblies

- An emphasis towards parallelisation has led to the development of multiple flexible setups intended to be operated by a single DAQ station in order to qualify modules at various stages along the production chain. These include modules that have been loaded onto aluminium graphite and pyrolithic graphite structures known as cells, necessary for their eventual integration onto the final mechanical supports that make up the detector.

Quad parallelised testing setup designed to accommodate modules before & after being loaded onto cells.

Bibliography

[1]Eta: pseudo-rapidity = $-\ln\left(\tan\frac{\theta}{2}\right)$, where θ is the angle between a particle and the beam axis.
[2]Technical Design Report ATLAS Inner Tracker Pixel Detector, CERN, ATLAS Collaboration, 2017
[3]RD53 collaboration rd53.web.cern.ch

HSTD13
13th "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors

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