The ATLAS ITk Strip Module Pre-Production

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Introduction

For the High-Luminosity phase of the Large Hadron Collider (HL-LHC), the current ATLAS Inner Detector will be replaced by an all-silicon new Inner Tracker (ITk), featuring a strip detector surrounding an inner pixel detector. A total of 19,000 barrel and endcap type modules are required to complete the strip detector.

Each module is built from a silicon strip sensor and between one and three flexes containing readout electronics, through a series of precision assembly and quality control steps. Assembly tools and quality control procedures are standardized across the project to ensure consistent results.

To prepare for the module production phase, 5% of the module production volume was assembled during the pre-production phase to test the entire assembly and quality control (QC) chain. This contribution presents an overview of the results from the ATLAS ITk strip tracker pre-production phase and highlights selected issues discovered during the process.

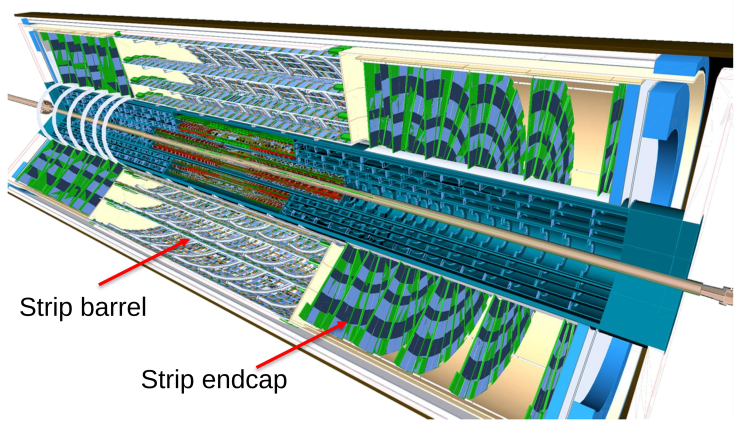


Fig: Visualisation of the ITk [1].

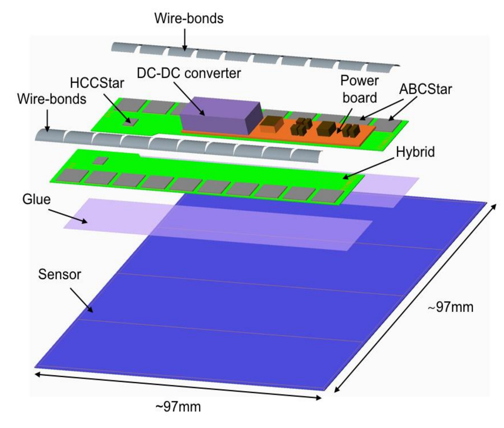


Fig: Exploded view of a short-strip barrel module with all relevant components [1].

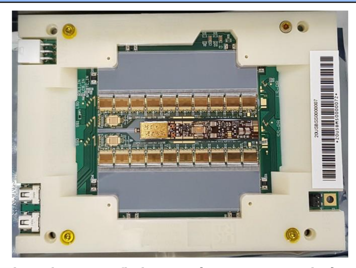


Fig: (one of) barrel type modules

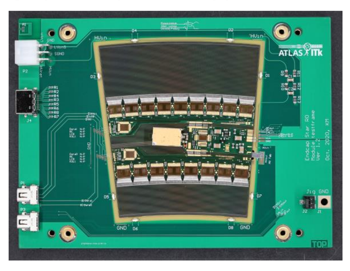


Fig: (one of) endcap type modules

Site Qualification

1. An internal reviewing process based on a set of agreed-upon procedures.
2. Nearly 30 module assembly institutes worldwide. Each site is allowed to start production when reaching production readiness, i.e:
   - completion of pre-production
   - full site qualification and production readiness check
3. Site qualification is motivated by:
   - the need to streamline and to standardize QC procedures and thresholds for comparability and cross check
   - limited number of components available during pre-production
     → to ensure that all parts being built follow procedures
     → to ensure sufficient number of parts available to develop procedures
     → to ensure possibility of partial site qualification

QC Programmes

1. Motivated from past experience of large assemblies:
   - Bonding issues/bonding reliability (e.g. SCT)
   - Sensor bow (as seen in ATLAS07 prototype sensors)
   - Concerns from other activities that involves modules (e.g. clearance within local support/global structures)
   - Other requirements (no hybrids overhanging the sensor edge, proper glue coverage for support and good thermal contact)

External parts QC
Ensure third party manufactured parts are fit for purpose

In-situ / post-assembly QC
Ensure correctness of assembly and suitable for next step

Performance QC
Ensure parts performance is within specification and fit for purpose within ATLAS detector.

Reception QC
Ensure parts are not damaged during shipping.

Module In-situ / Post-assembly QC

1. **Module metrology**: measure hybrid and powerboard position, glue height, height of powerboard components
   → different machines and procedures are validated by cross-checks and module exchanges between institutes

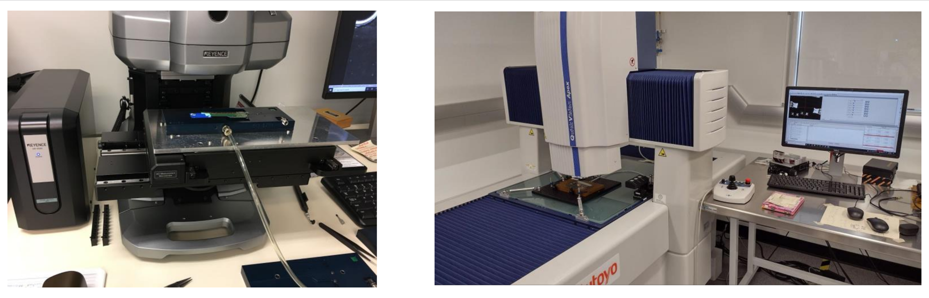


Fig: Metrology is performed using specialized optical (*z*-focusing, edge finding, pattern recognition) or laser ranging measurement system (e.g Keyence, CMM)

2. **Module glue weight**: weigh parts before and after gluing and calculate glue weight from the difference
   → data showed glue dispensing is well under control, may be descoped as it requires risky handling

Table: Module metrology specifications.

Dimension	Specification	
	Old	New
X alignment of hybrid and powerboard, Δx	±100 μm	±250 μm
Y alignment of hybrid and powerboard, Δy	±300 μm	±250 μm
Average glue heights under ASIC and powerboard, h	120 ± 40 μm	70 to 170 μm: Pass 40 to 70 μm: Pass with Problems <40 μm or > 170 μm :Failure
Shield box height	< 5710 μm over sensor surface	

Metrology feedback and further studies led to relaxation of assembly tolerances allow for higher throughput/yields.

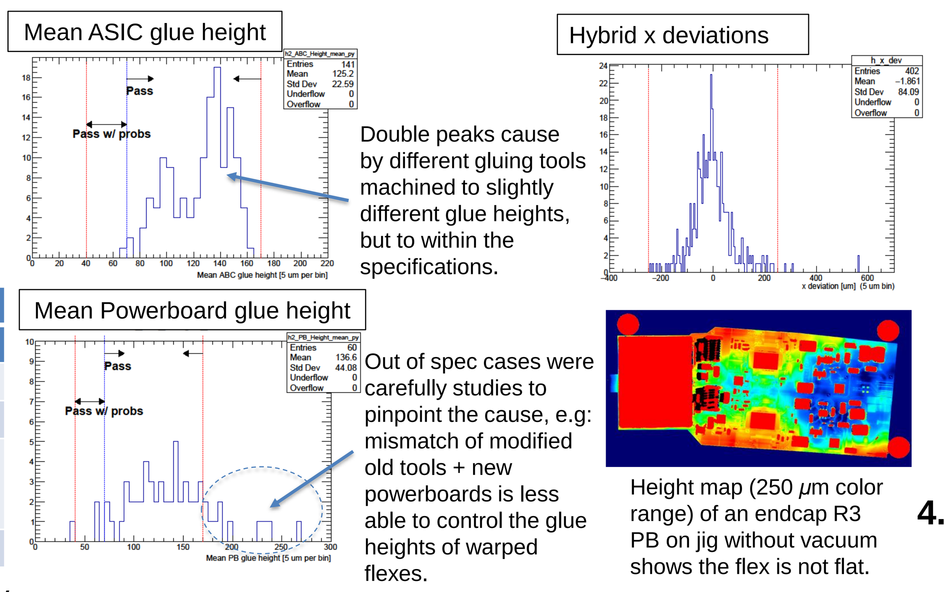
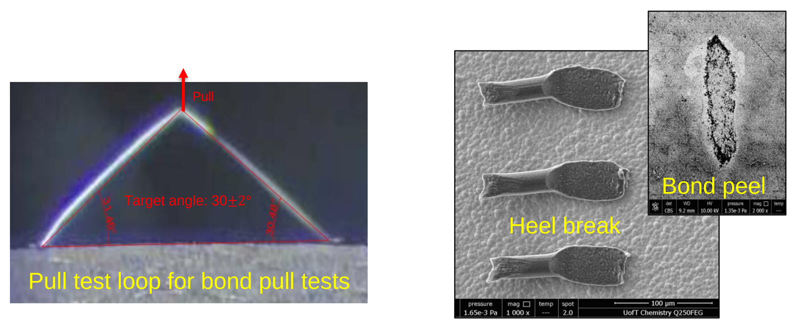


Fig: Example of endcap module metrology results

3. **Module wire bonding**:
   → **periodic wire bond pull test** to ensure optimal bond weld quality to various bonding surfaces, cross check between different building sites.
   → record repaired and missing bonds for quantification of "bad channels" and identification of any systematic issues.



Wirebonding requirements:
- $\geq$ 100 wires per sample
- $\geq$ 8g mean pull strength with <10% peel offs
- $\sigma \leq$ 1.5g
- $\geq$ 5g for single wire pull strength

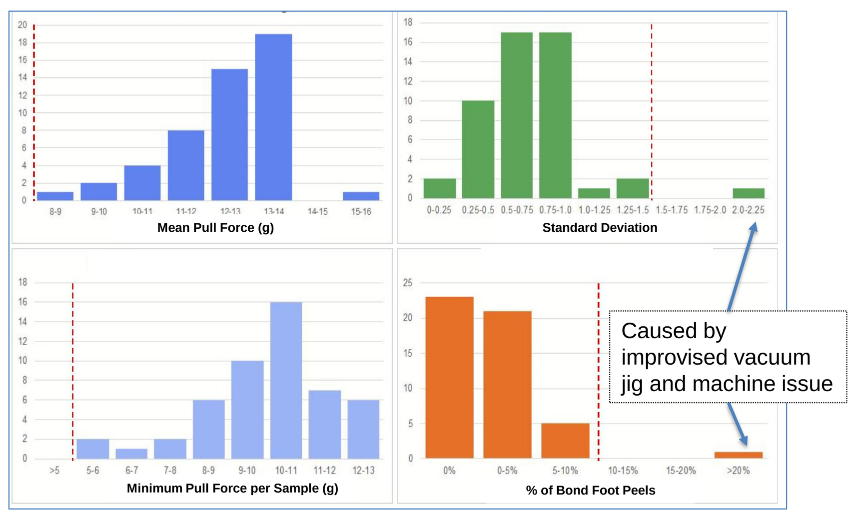


Fig: Pull test results with half moons sensor sample. 50 samples from 15 sites (barrel and endcap) [2].

4. **Visual Inspection**: after each assembly step to ensure objects were not damaged or no obvious issues occurred (e.g. glue seepage onto bond pads)

Performance QC

1. Electrical tests is performed in light-tight enclosure fed with dry air.
   - in a single module test setup at room temperature as quick confirmation and for finding bad channels
   - in a multi-module thermal cycling box as a stress test.
2. Test evaluates the threshold, gain, input noise, output noise and noise occupancy of each strip/ channels.
3. A module fails if:
   - ≥1 bad chips
   - >2% channels fail a set of channel requirements
   - streak of >8 consecutive bad channels
4. Causes of failure (trapped charge, component defect, ASIC tuning, aggressive classifier cuts) were identified and mitigated in subsequence module building.
5. IV test: measure sensor current as function of voltage multiple times to evaluate sensor performance, e.g:
   - as part of sensor reception
   - before and after HV tabbing
   - after every sensor or module shipment
   - during module thermal cycling
6. Thermal cycling:
   - 10 cycles from -35ºC to 20ºC (was 40ºC)
   - full test sequence (as above) at each temperature point
   - evaluate if there is any degradation in module performance over a full set of cycles

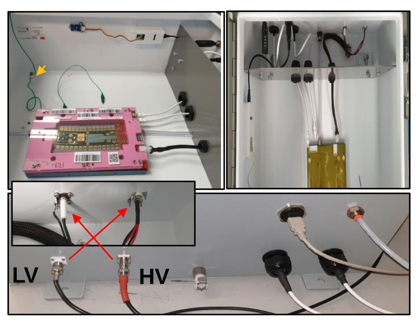


Fig: Example of an single module test box.


Fig: Four endcap modules in thermal cycling box.

Module type	#pass/total	%pass
Barrel SS	74/86	86.0
Barrel LS	74/79	93.4
Endcap R0	3/4	75.0
Endcap R1	3/6	50.0
Endcap R2	2/2	100
Endcap R3 half module	23/26	88.5
Endcap R4 half module	18/20	90.0
Endcap R5 half module	11/16	68.8

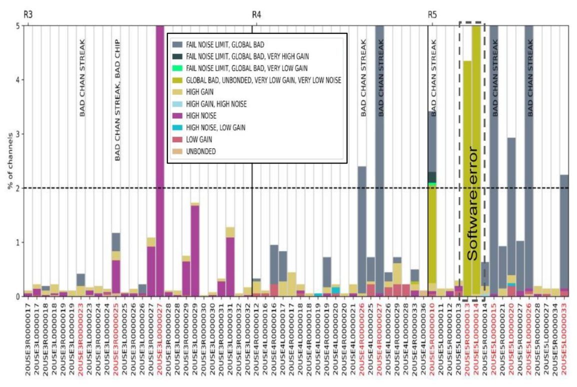


Fig: Example of endcap module electrical test result and failure types [2].

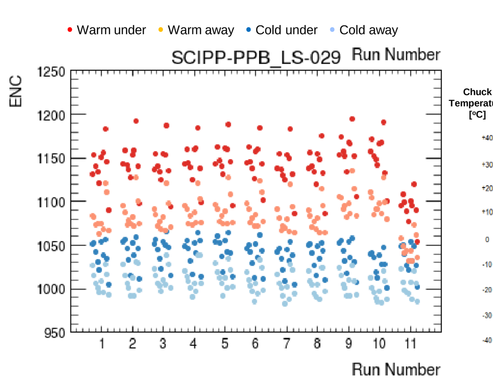


Fig: Module noise over full thermal cycles [2]

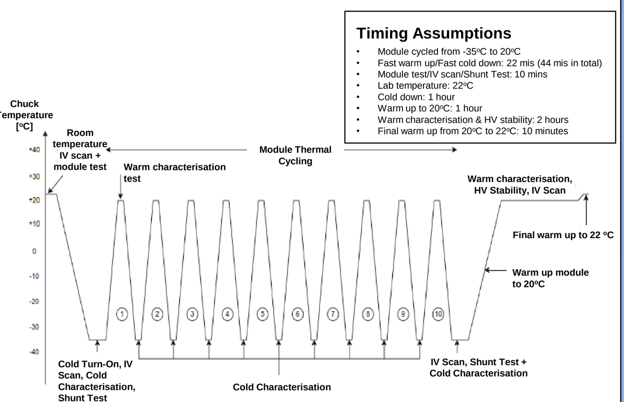


Fig: Thermal cycle sequence

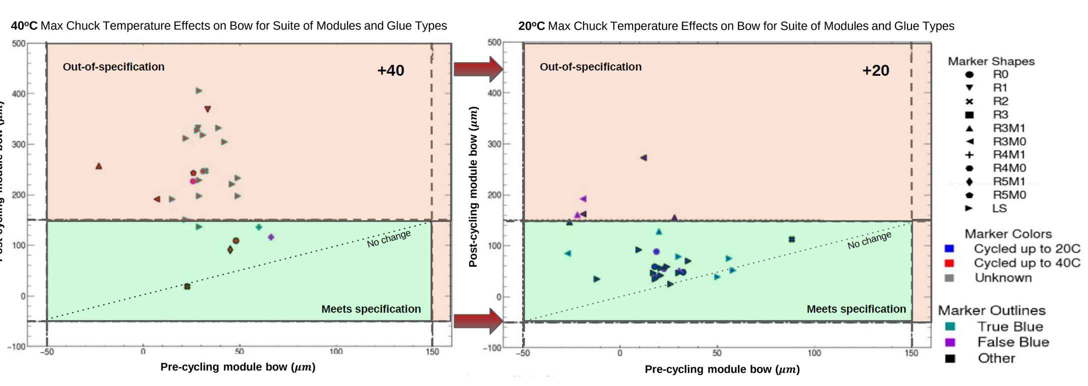


Fig: The maximum temperature during cycling is limited to 20°C, which has been confirmed to reduce stress on modules and reduce the module bow measured after cycling. [2]

Database

1. It is aims to record the entirety of ITk production.
   - trace component relations even for large assembly components, e.g.: when an ASIC is glued onto a hybrid, the ASIC becomes a child of the hybrid
   - to track components, components are associated to an institute where it is built, so does its current location:
     → physical shipment must be accompanied by a database shipment record
     → such component tracking is especially necessary for export controlled items.
   - to reflect their QC status/stage
   - every test result and its properties are also recorded in the database, useful for further studies
2. Stored information can be retrieved and generate yield report, check inventory, track module throughput and overall project status and etc.

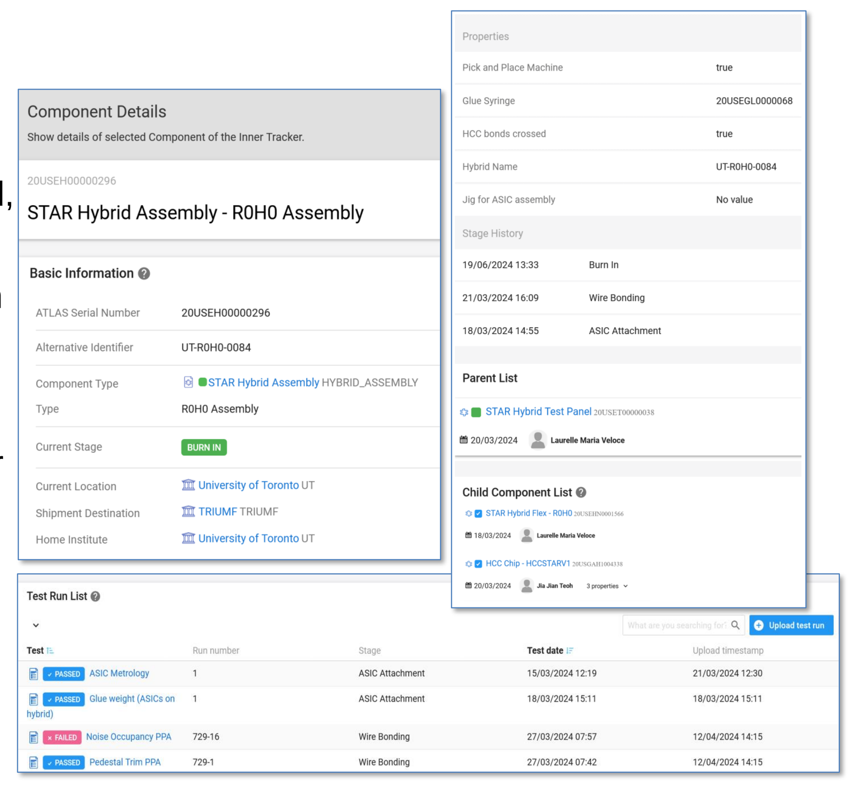


Fig: Example of component record in the database.

Summary

1. Pre-production was largely successful:
   - site qualification far advanced (mostly >90% qualified)
   - lots of modules were built with overall acceptable yield
   - database structures were set up, tools and interfaces were developed
   - QC was performed:
     → results were collected and fed back to improve techniques and tooling
     → targets re-evaluated to more reasonable thresholds
   - QC has found known problems in assembly and uncovered others, for e.g:
     → tooling mismatch
     → powerboard noise
2. Several challenges remain that require extensive investigation and combined effort at many sites. Several mitigation strategies were thoroughly studied and potential solution has been identified. Such challenges include:
   - cold noise– clusters of noisy channels for modules tested at cold temperatures (-35ºC)
   - early module HV breakdowns and sensor cracking

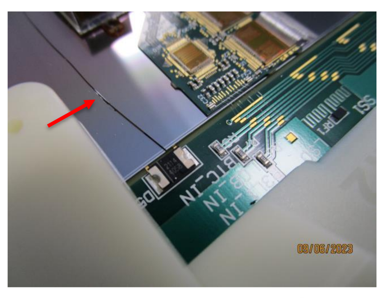


Fig: Sensor cracked after thermal cycling [2].

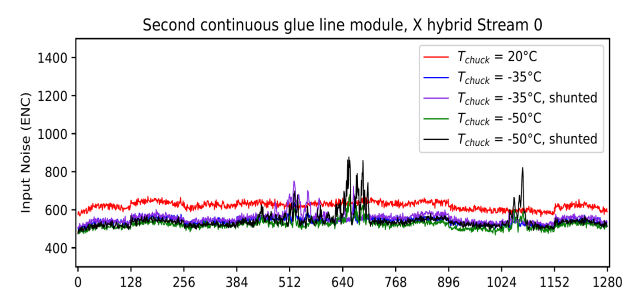
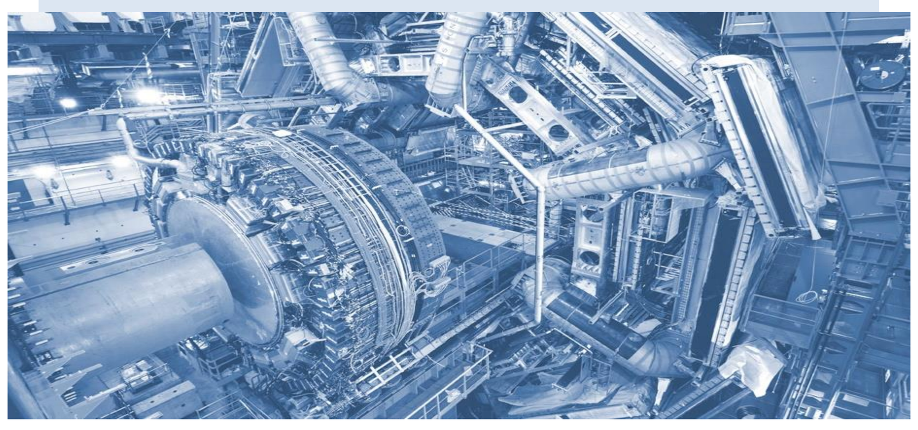
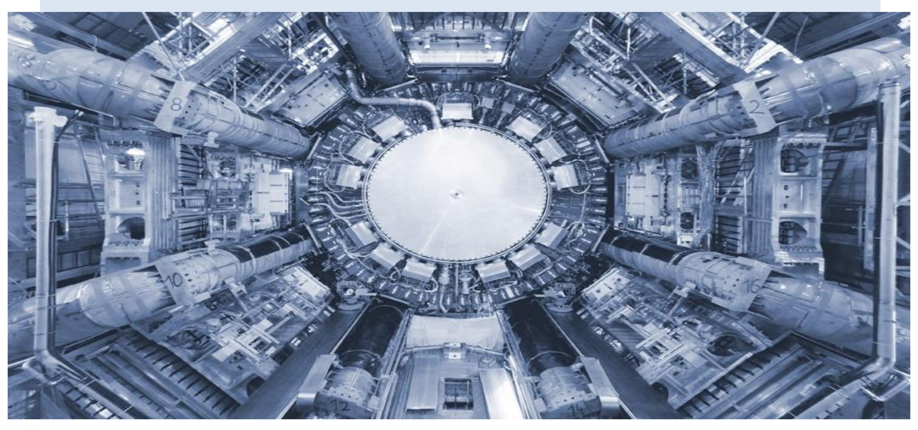


Fig: Cold noise manifested when a module was tested cold [2].





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

[2] Contributions from Ewan Hill[1], Luise Poley[2], Jacob Johnson[3], Karol Krizka[3], Kirsten Affolder[4], Tony Affolder[4], Sten Åstrand[5] et.al for ITk Strip Module Production Readiness Review.
[1]University of Toronto, [2]Simon Fraser University, [3]University of Birmingham, [4]University of California Santa Cruz, [5]Lund University.