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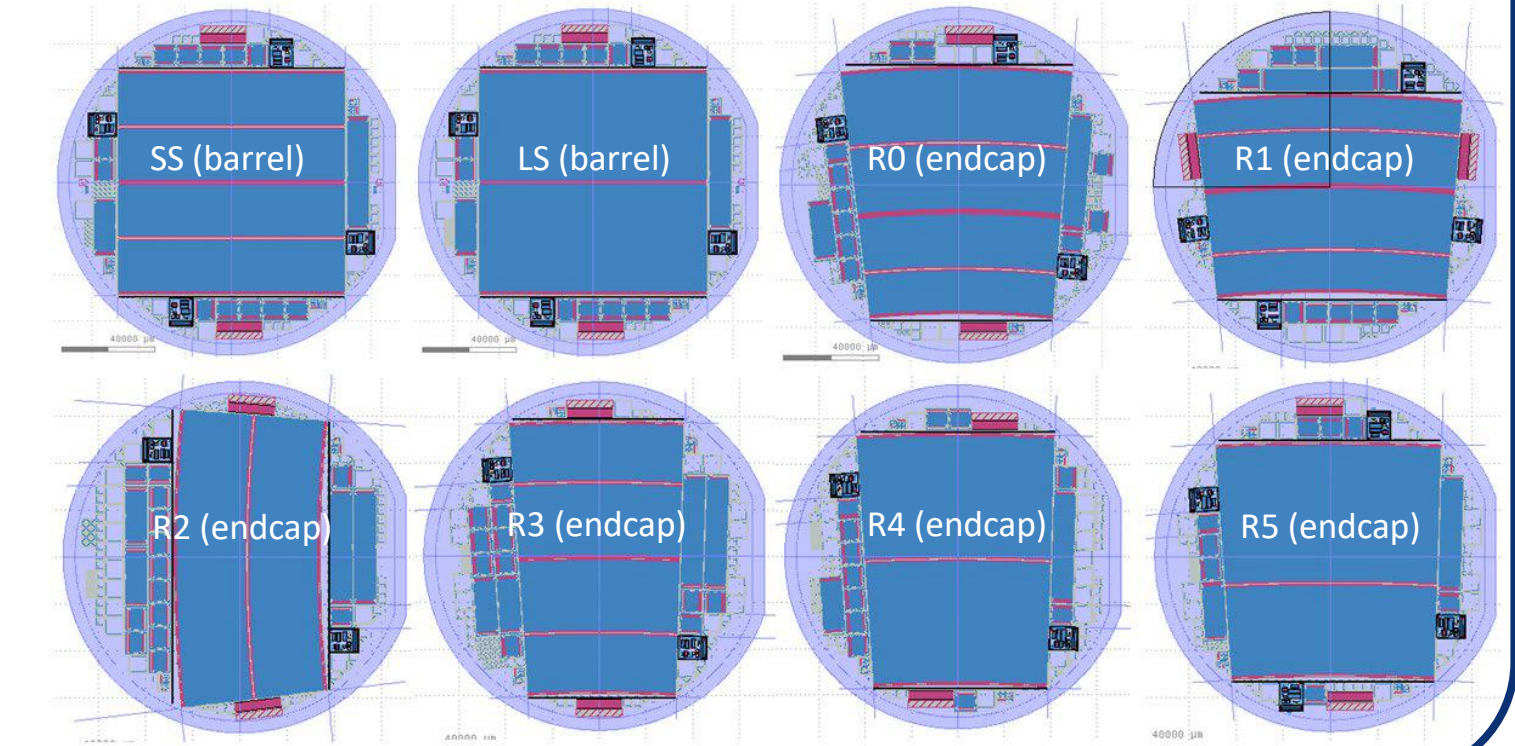
Introduction

The ATLAS experiment will replace its existing Inner Detector with the new all-silicon Inner Tracker (ITk) to cope with the operating conditions of the forthcoming high-luminosity phase of the LHC (HL-LHC). The outer regions of the ITk will be instrumented with ~18000 ATLAS18 strip sensors fabricated by Hamamatsu Photonics K.K. (HPK). With the launch of full-scale production of 20800 sensors in 2021 (including anticipated losses during assembly), the ITk strip sensor community has undertaken quality control (QC) testing of these sensors to ensure compliance with mechanical and electrical specifications agreed with HPK. The testing is conducted at seven QC sites on each of the monthly deliveries of ~500 sensors.

ITk strip sensors

HPK produces silicon strip sensors in 8 geometries:

- 2 for barrel (LS, SS), 6 for endcap (R0-R5)
- 320 μm thick n⁺-in-p silicon
- Strip pitch 75.5 μm for barrel, 70-80 μm for endcap
- Each wafer contains 1 main sensor + assorted test structures[†]

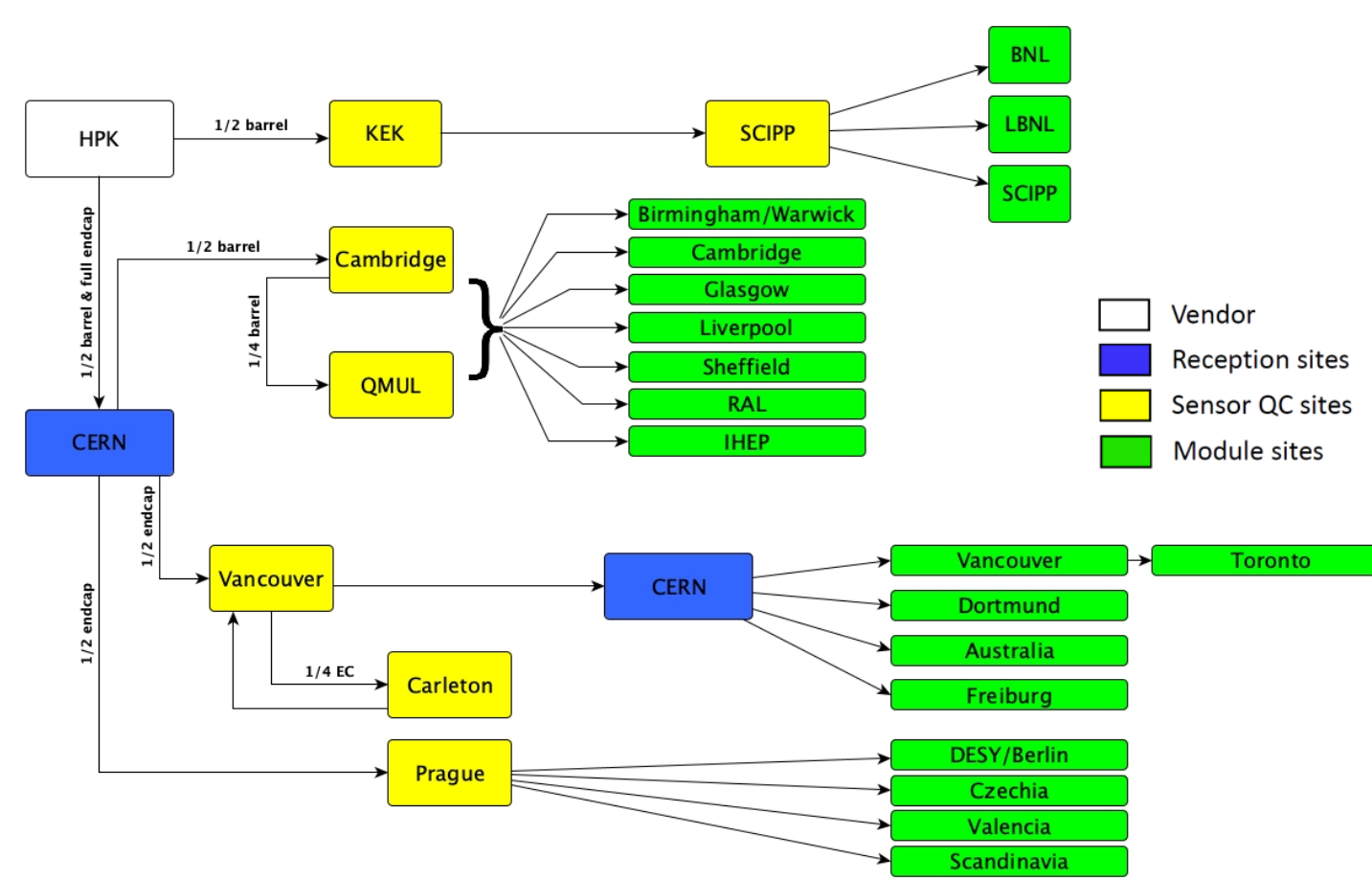


[†]Test structures are used for quality assurance (QA) tests to identify defects in manufacturing process; see talk by E. Bach "Analysis of the Quality Assurance Results from the Initial Part of Production of the ATLAS18 ITk Strip Sensors"

Sensor quality control (QC) programme

Seven ATLAS sites conduct quality control (QC) tests on each main sensor to identify and discard defective products.

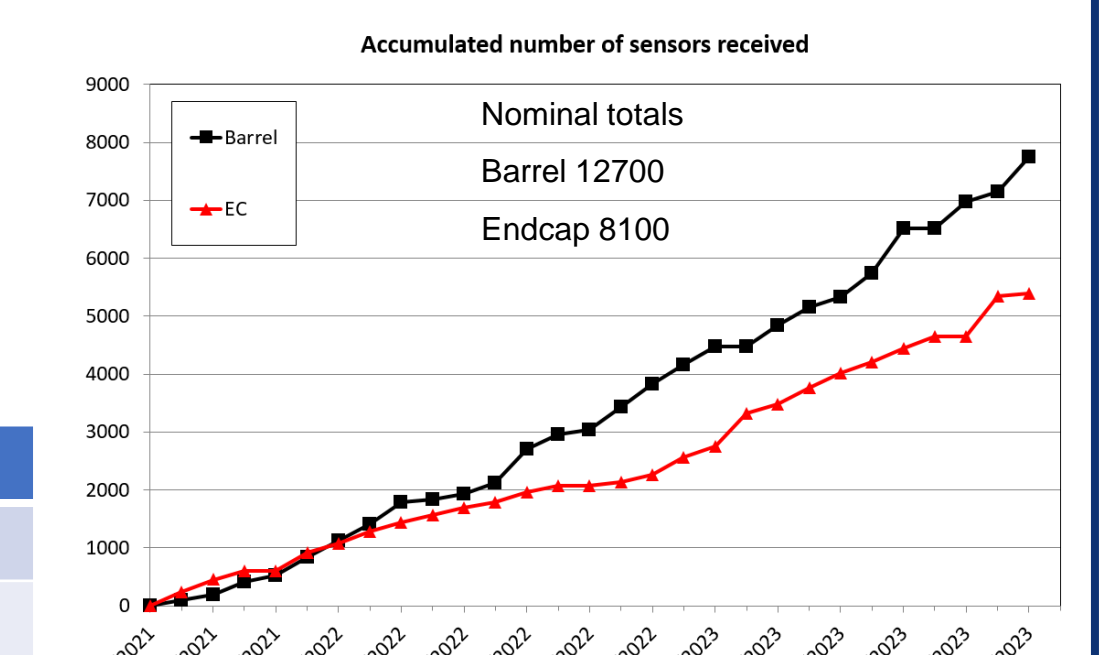
- Each site generally focusses on sensors of particular geometries (barrel or endcap).
- Flexibility to test other flavours when load sharing required.



Production progress

Deliveries of production sensors commenced August 2021; to last for ~3.5 years.

- Received 13136 sensors (63% of total production).
- HPK now fabricating sensors at full production rate.
- Slow ramp-up in barrel production.
- Early production issues were fixed.

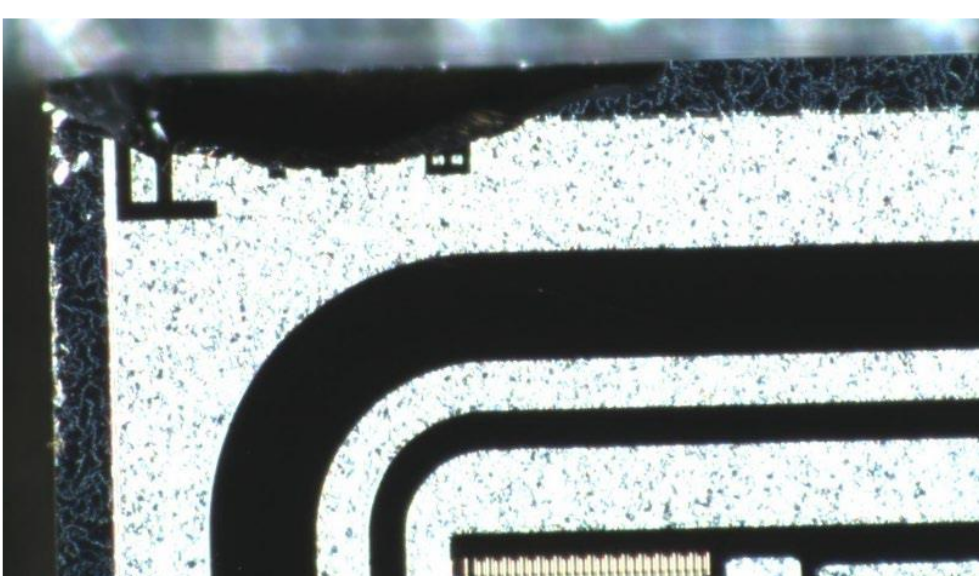


Sensor type	Total	LS	SS	R0	R1	R2	R3	R4	R5
Nominal quantity	20800	8300	4400	900	900	1800	1800	1800	1800
Delivered	13136	6895	847	624	576	614	1190	1246	1144
% delivered	63%	83%	19%	69%	64%	68%	66%	69%	64%

QC tests on every sensor

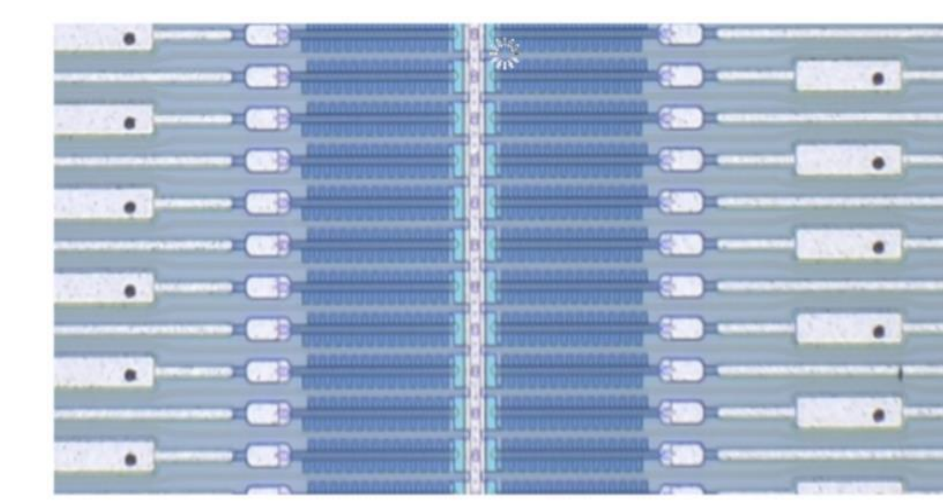
Visual inspection:

- Look for chips, scratches, etc.



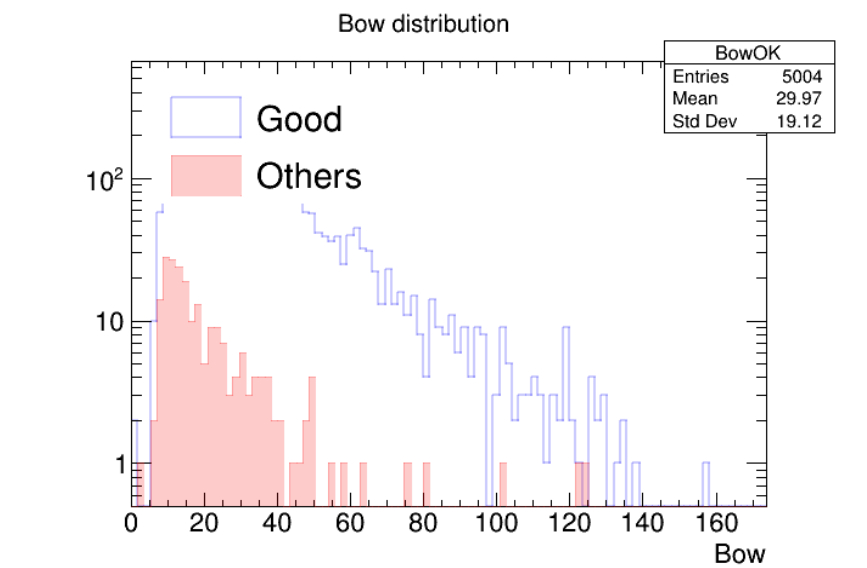
Visual image capture:

- 2 x 2 μm^2 resolution scan of sensor; for warranty purposes



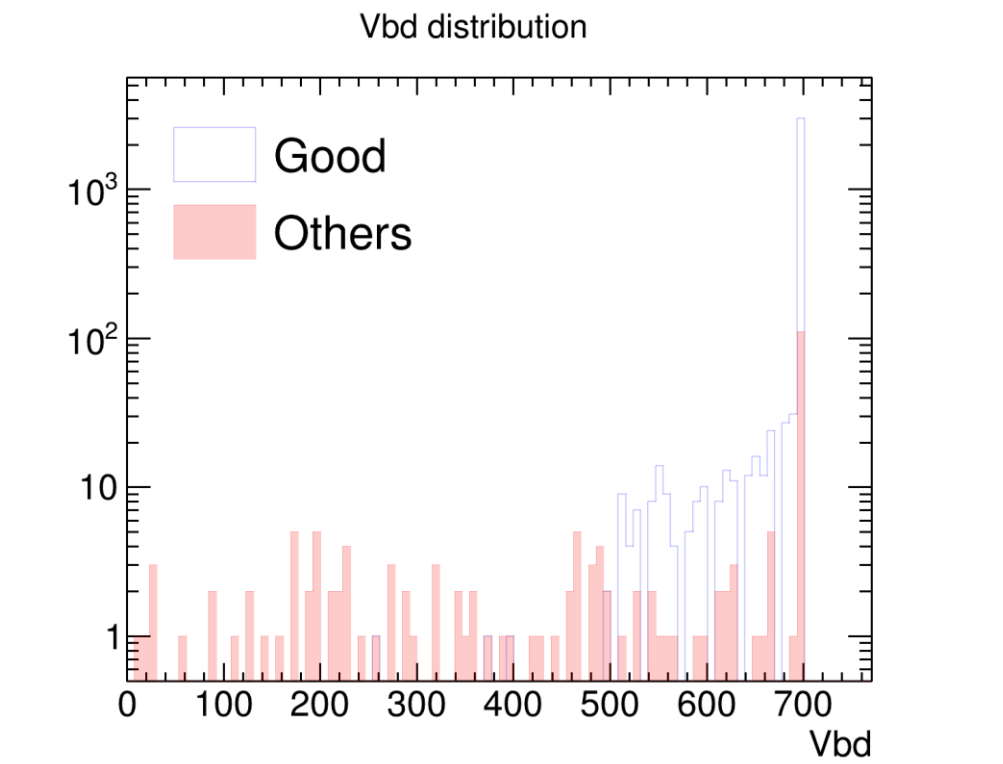
Metrology:

- Sensor bow < 200 μm ; flatness for module assembly + loading on local support



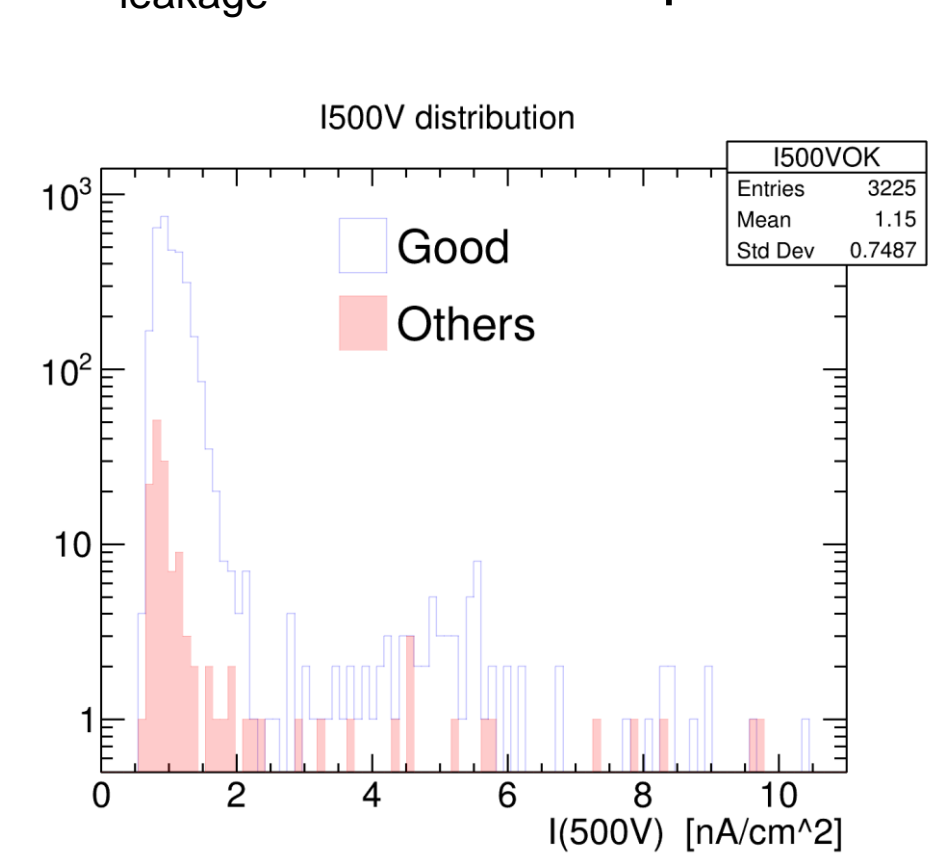
Sensor IV:

- $V_{\text{breakdown}} > 500\text{V}$; no breakdown at maximum operating voltage



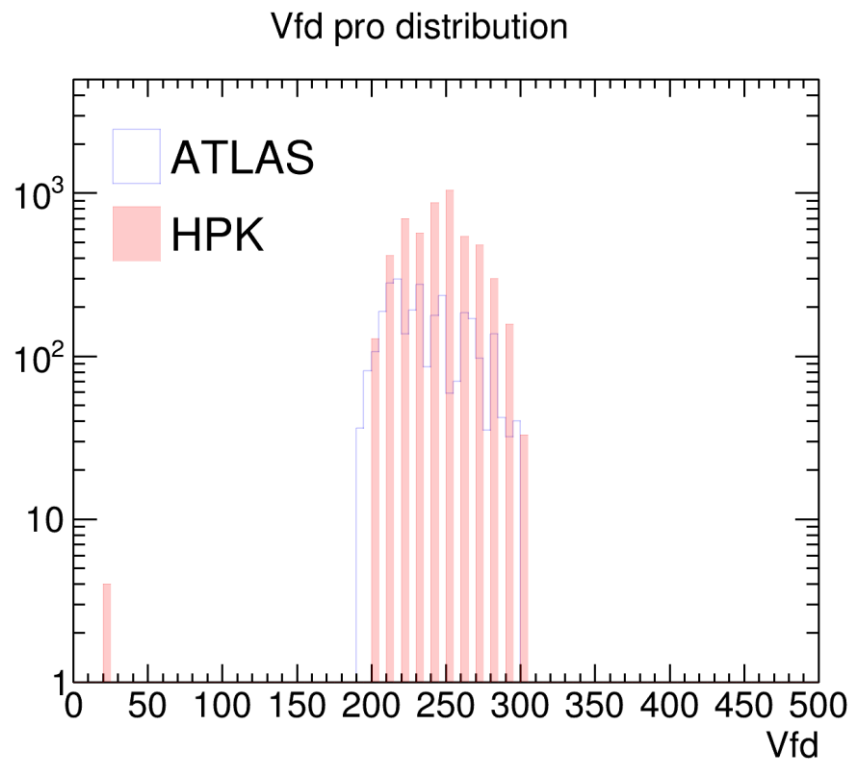
Sensor CV:

- $I_{\text{leakage}} @500\text{V} < 0.1\mu\text{A}/\text{cm}^2$



Sensor Vd:

- $V_{\text{depletion}} < 350\text{V}$; full depletion at max operating voltage



Recovery treatments

In early production, a relatively large number of sensors were failing their initial QC tests.

- High static charge (hundreds of Volts) observed on sensors and protective sheets at QC sites.

After discussion with HPK, a number of recovery treatments have been applied:

- De-ionization by ion blower, UV-A or UV-C irradiation, "bakeout" in oven
- After treatments, 72% of sensors have recovered from initial QC fails.
- HPK also enacted new packaging procedures and material \rightarrow static charge levels are now < 50V.

For more details, see talk by E. Staats "Identification and Recovery of ATLAS18 Strip Sensors with High Surface Static Charge"

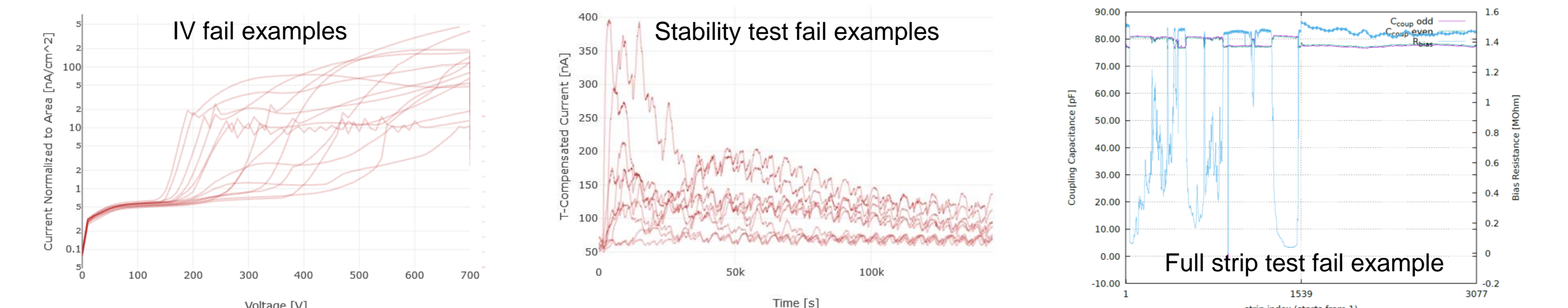
Sensor approvals

Once all QC and QA tests completed on a monthly delivery, an approval report for the delivery is written and submitted to HPK.

Individual sensor rejected if it fails any QC test.

- IV is most commonly failed test; due to being performed on every sensor.
- Full strip test most likely to fail; only performed on a sampling of sensors.
- Inspection and stability test also result in substantial number of fails.
 - Sensors with questionable IV behaviour are targeted for stability test \rightarrow artificially higher failure rate than full population.
- No rejections attributed to metrology, thickness or CV (correlated to IV fail).

Test type	Inspection	IV	Stability	Strip test
Tested	8035	7623	3108	1207
Failed	94	119	51	82
% failed	1.17%	1.56%	1.64%	6.79%



Full batch of sensors can be rejected if QA results found to be out of specification.

- Often found in conjunction with large fraction of sensors rejected by QC.
- 330 production batches have been QC tested (306 QA tested); 6 rejected.

Nearly 11000 strip sensors (53%) have been accepted for use in ATLAS ITk detector.

- Almost 50% of total for each endcap sensor geometry.
- In barrel, 78% of LS and 9.5% of SS (1st delivery in August 2023).
- 2.1% rejection rate of individual sensors; 3.7% total rate with batch rejections included.
 - These rejected sensors are to be replaced with new sensors later.

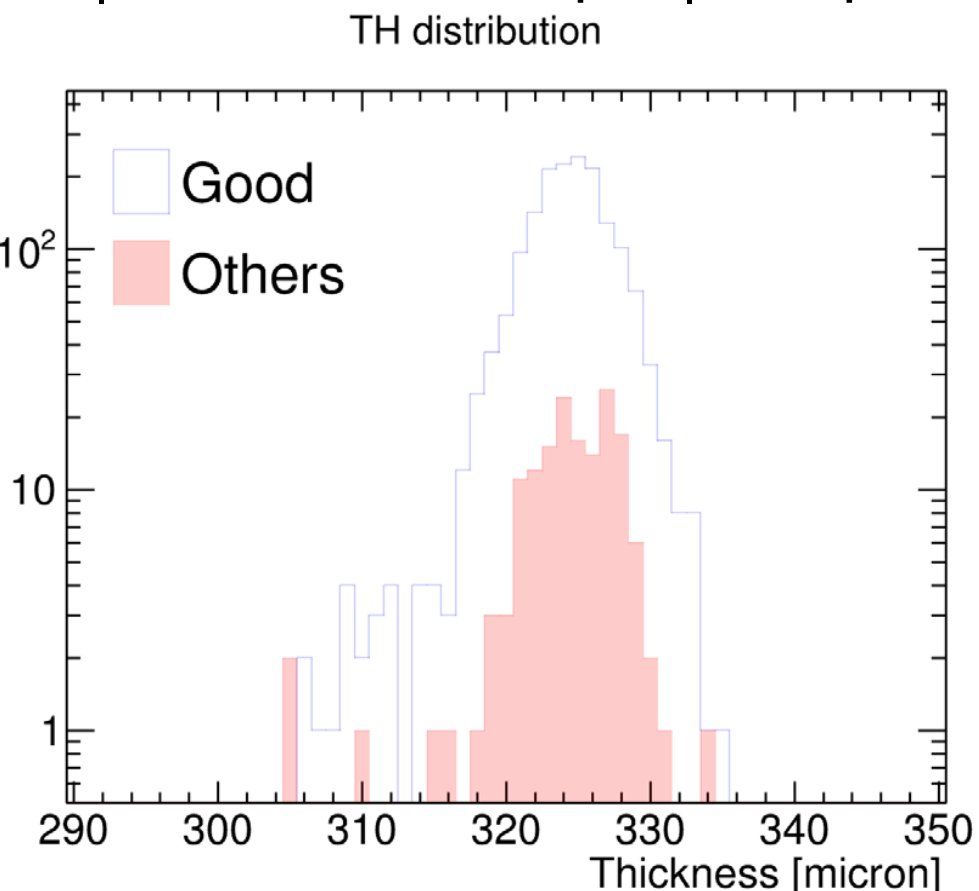
Sensor type	Total	LS	SS	R0	R1	R2	R3	R4	R5
Final quantity	20800	8300	4400	900	900	900	1800	1800	1800
QC tested	11388	6519	420	545	488	524	938	1062	892
Accepted	10965	6444	416	438 [†]	477	440 [†]	881 [†]	998 [†]	871
% of tested rejected	3.7%	1.2%	0.95%	20%	2.3%	16%	6.1%	6.0%	2.4%
% of final accepted	53%	78%	9.5%	49%	53%	49%	49%	55%	48%

[†]Includes batch rejections after considering QA results

QC tests on batch subset

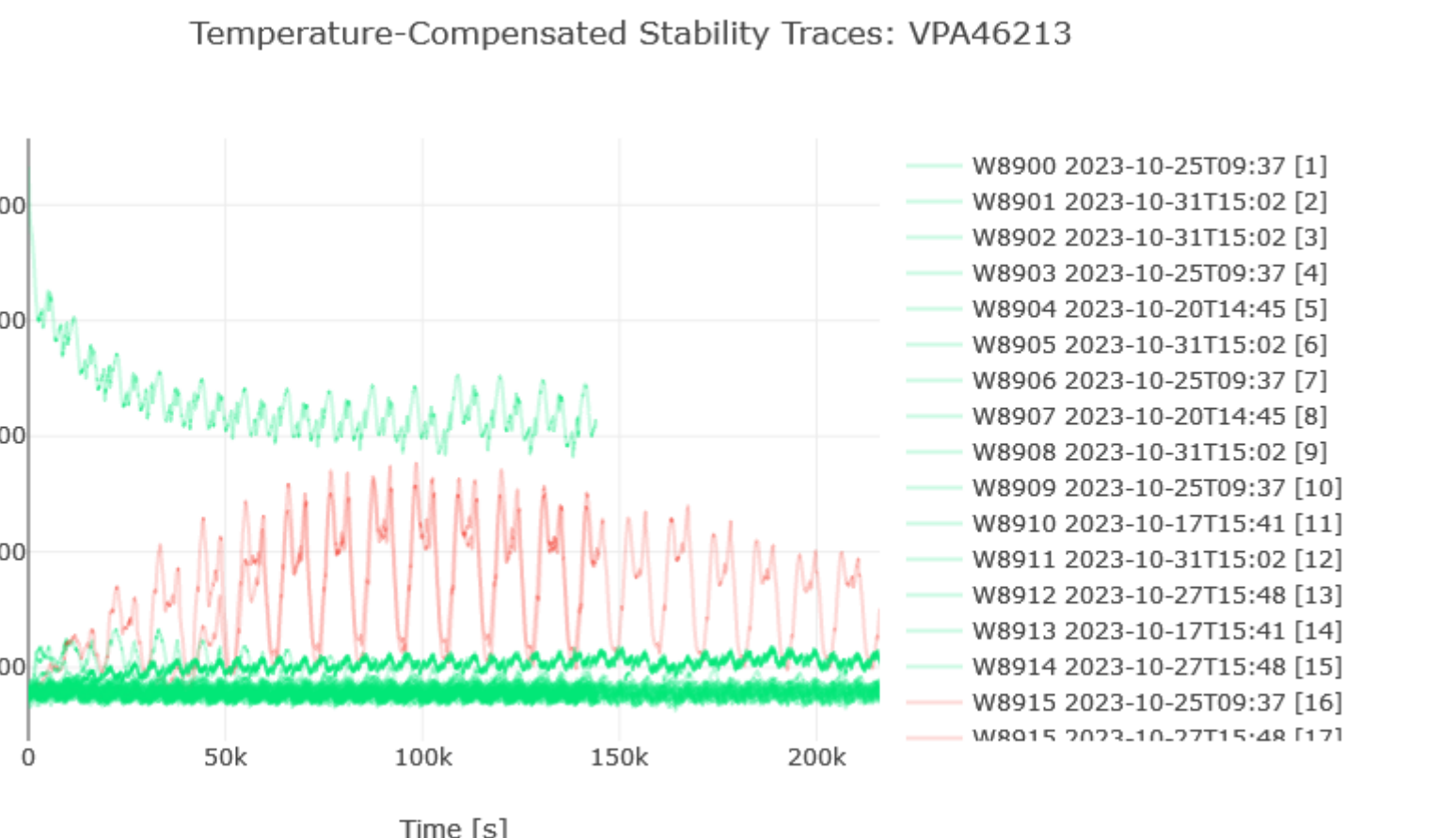
Mechanical thickness

- $|\text{thickness} - 320\mu\text{m}| < 15\mu\text{m}$



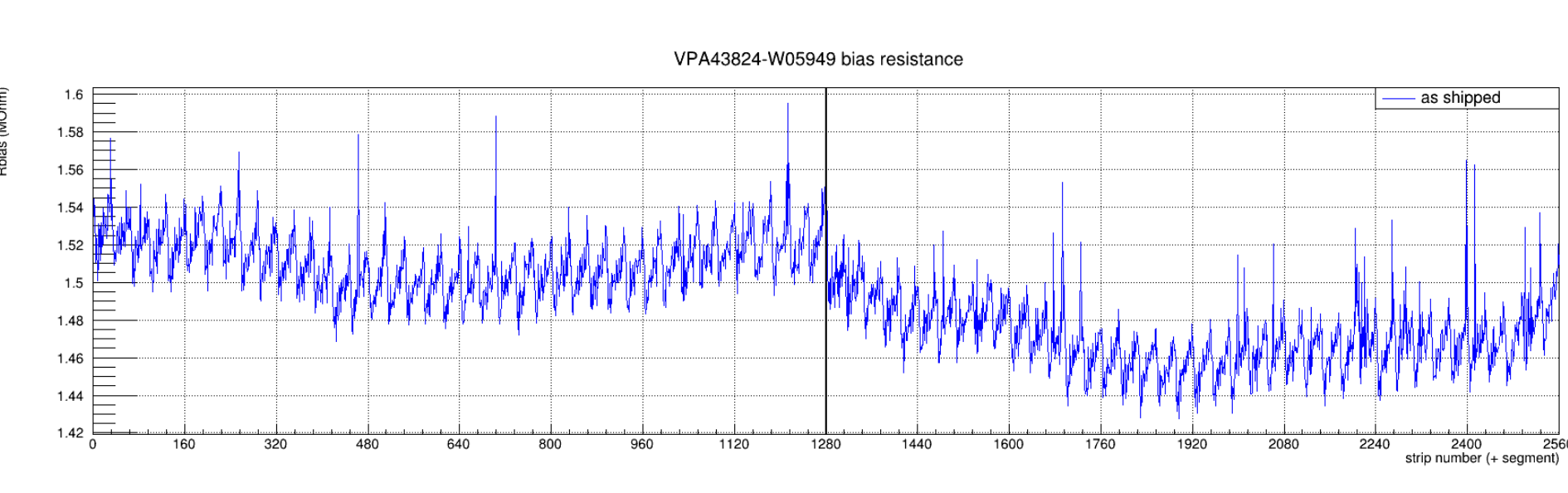
Long-term leakage current stability (10%-20%):

- $\Delta I < 15\%$ for 24h+



Full strip test (2%-5%)

- Per strip: $I_{\text{strip}} < 200\text{nA}$, $1\text{M}\Omega < R_{\text{bias}} < 2\text{M}\Omega$, $C_{\text{coupling}} > 20\text{pF}/\text{cm}$
- < 1% failed strips/segment
- ≤ 8 consecutive failed strips



Conclusions

Since August 2021, Hamamatsu Photonics K.K. (HPK) has been fabricating strip sensors for the ATLAS Inner Tracker (ITk) detector. Through collaborative discussions with ATLAS, HPK has overcome challenges in early stages of production to deliver 63% of the production order. Recovery treatments applied by ATLAS QC sites have reduced the sensor rejection rate to 3.7%. Nearly 11000 strip sensors, representing 53% of the required total, have been accepted for use in the ITk detector.

Acknowledgements

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