Queen Mary University of London

UKRI Science and Technology Facilities Council | Particle Physics

5th FCC PHYSICS WORKSHOP
LIVERPOOL
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In-person meeting for the first limited number of registering attendees
www.cern.ch/FCCPhysics2022

Large area curved silicon modules for future trackers

Adrian Bevan, Feb 2021

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FUTURE CIRCULAR COLLIDER

Overview

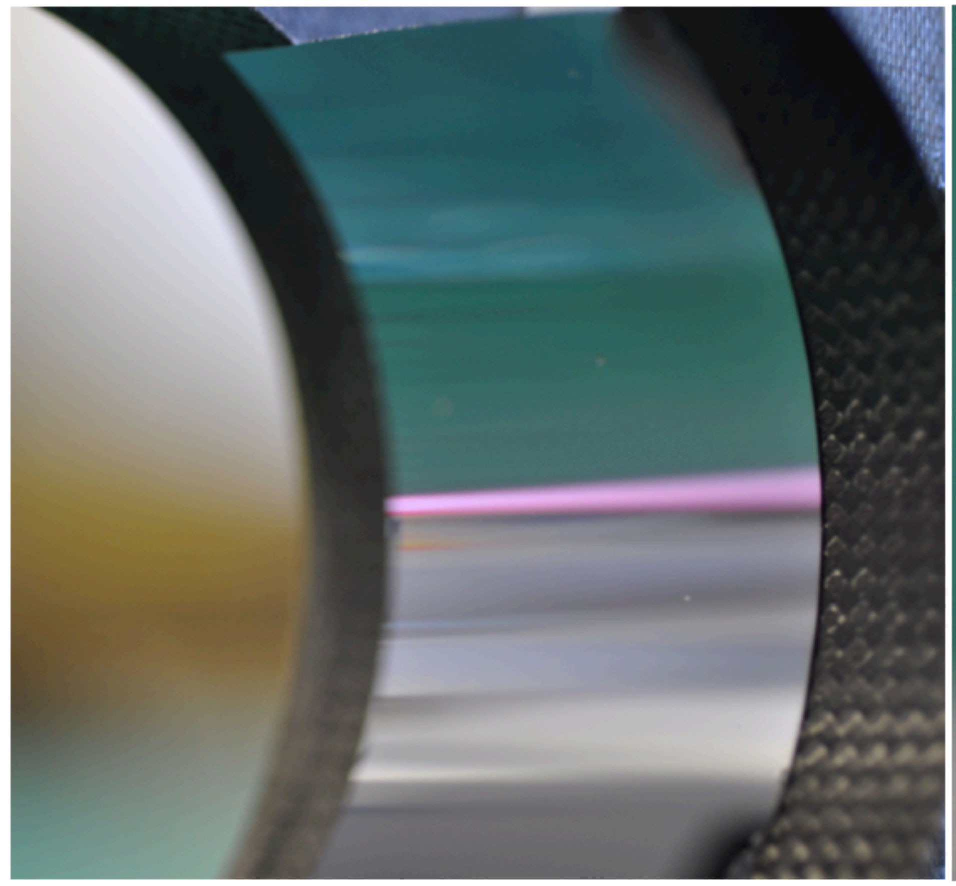
- Rationale
- Early concept prototyping
- Other example applications
- Large scale module construction
- Test results:
  - Surface shape
  - Electrical performance
  - X/X_0
- Future directions
- Summary

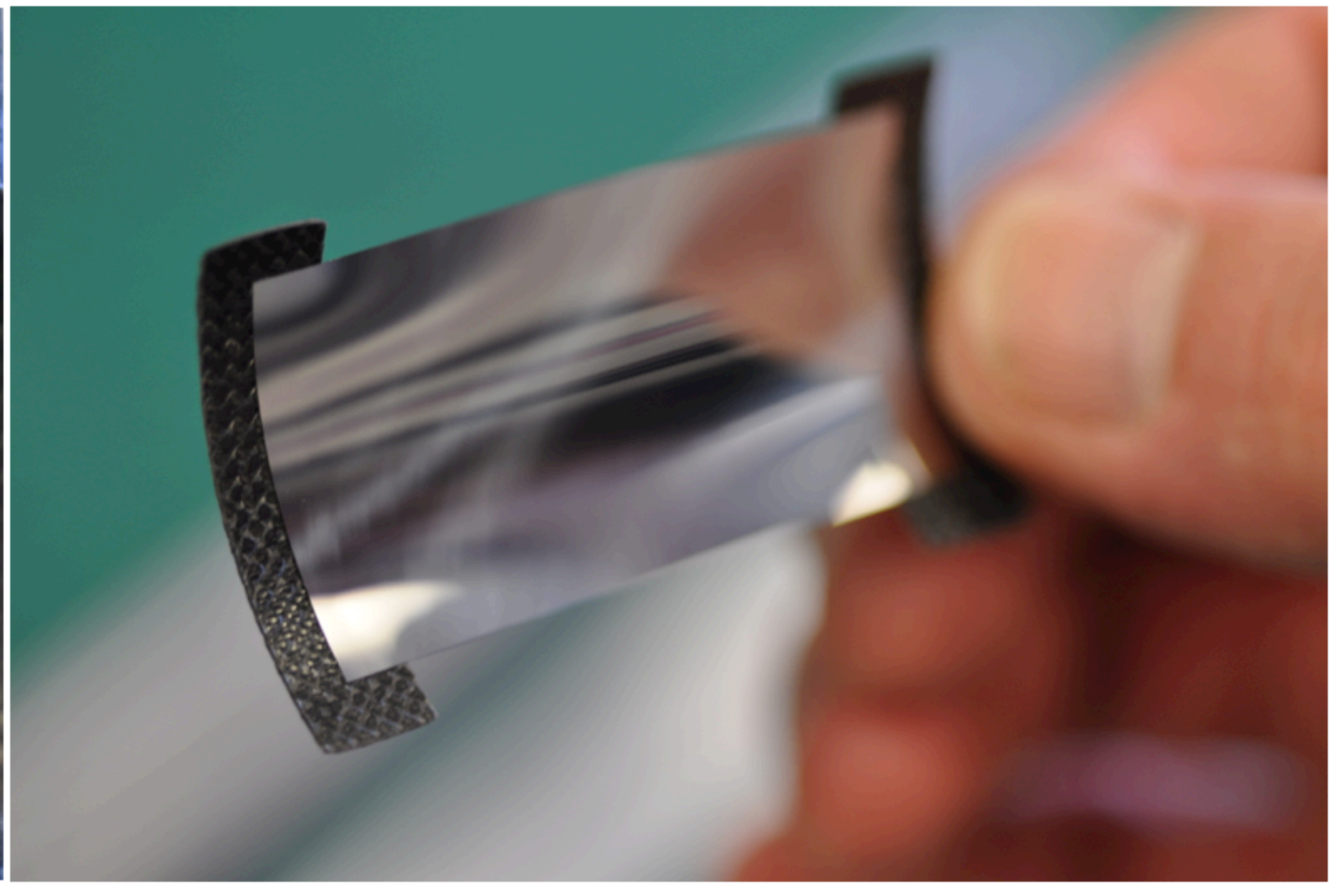
Rationale

- Tracker mass degrades performance
- Want to:
  - Minimise support material
  - Minimise sensor material
  - Retain measurement capability and structural integrity
  - Understand the shape of modules produced
- Extension to staves is a logical next step

Early concept prototyping

- Ultrathin silicon has been known to be flexible for a long time
- Thin film theory predicts dislocations lock in on the surface, making strong stable structures
- Don't need to provide full frame to support a curved sensor





- Radius of curvature shown: 25mm
- Able to bend silicon to radii of 13mm
- Repeatable
- Larger radii are easier
- 50µm are much easier to handle than 25µm samples

June 2012: the STFC funded Arachnid project [CMOS MAPS] made curved silicon mechanical tokens and studied the shape. Tokens remain intact today; consistent with expectations.

Rigid supports on two sides sufficient for a self-supporting silicon structure

This talk: focus on 4-sided frame; but can go a step further and use the silicon as part of the structural support for smaller systems (e.g. vertex detectors)

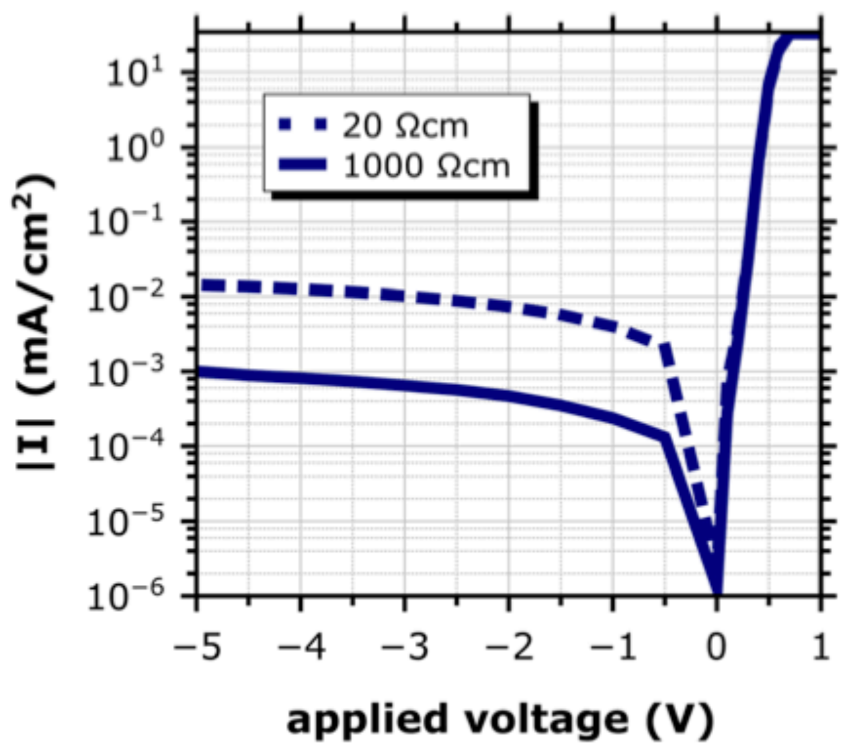
Use laser coordinate measuring machine to map chip surface

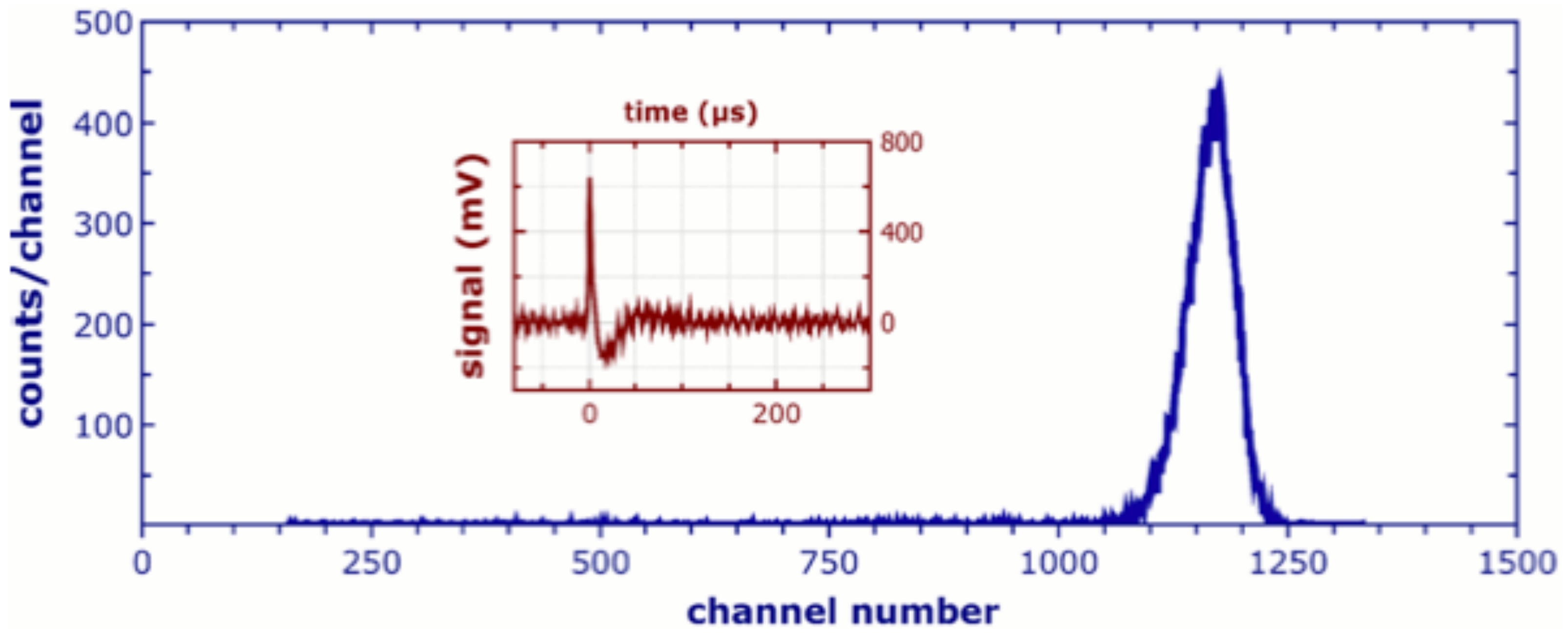
Other example applications

- Commercial and HEP project applications have pursued curved (cylindrical and spherical) sensor technology; demonstrating the feasibility to make functional devices

Flexible silicon-based alpha-particle detector

C. S. Schuster et al., Appl. Phys. Lett. 111, 073505 (2017);
https://doi.org/10.1063/1.4999322





Imaging sensors: Curve One, CEA Leti, Sony produce these

Sensor plane matching the Petzal surface results in simpler optics (cheaper cameras)

e.g. Brian Guenter et al.

https://doi.org/10.1364/OE.25.013010

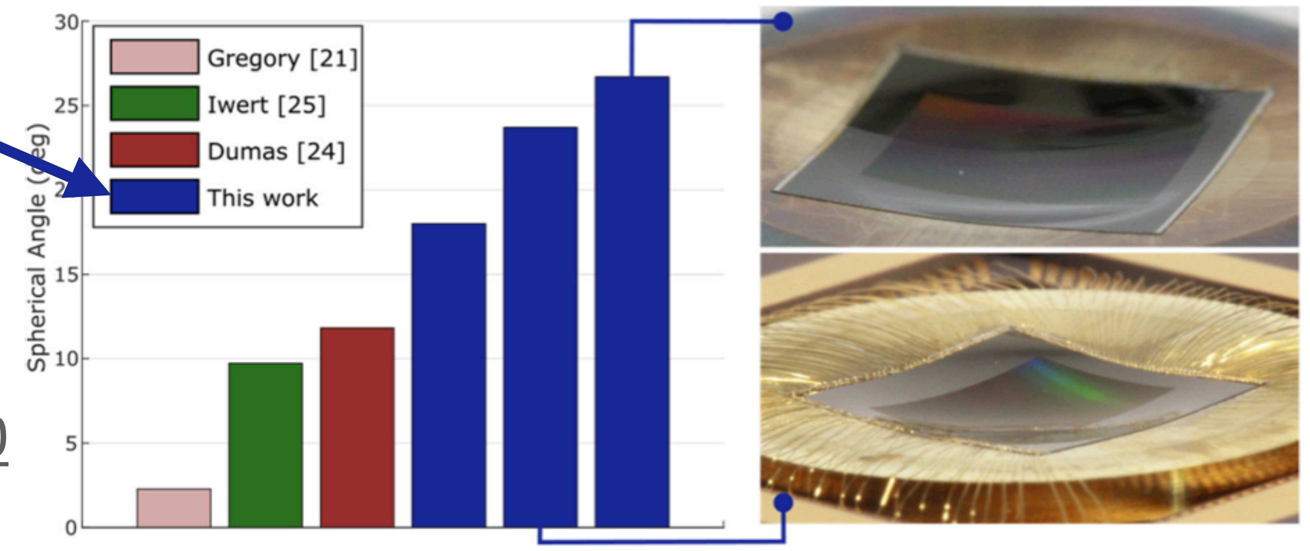
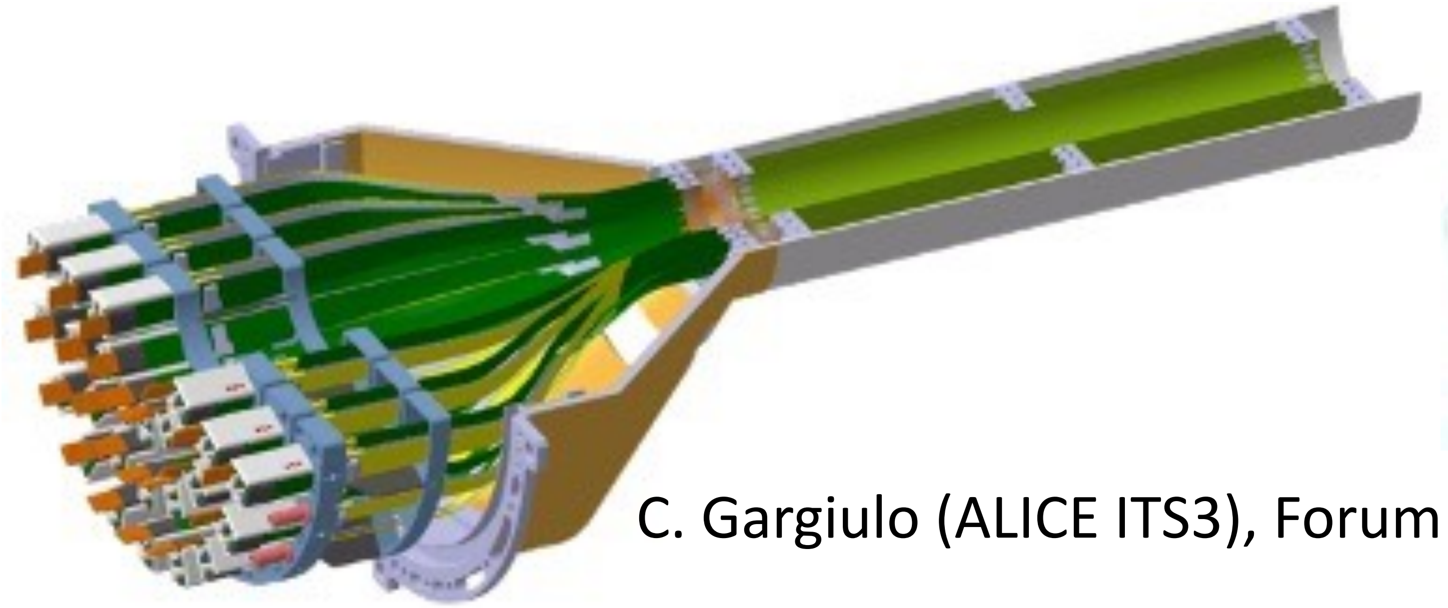
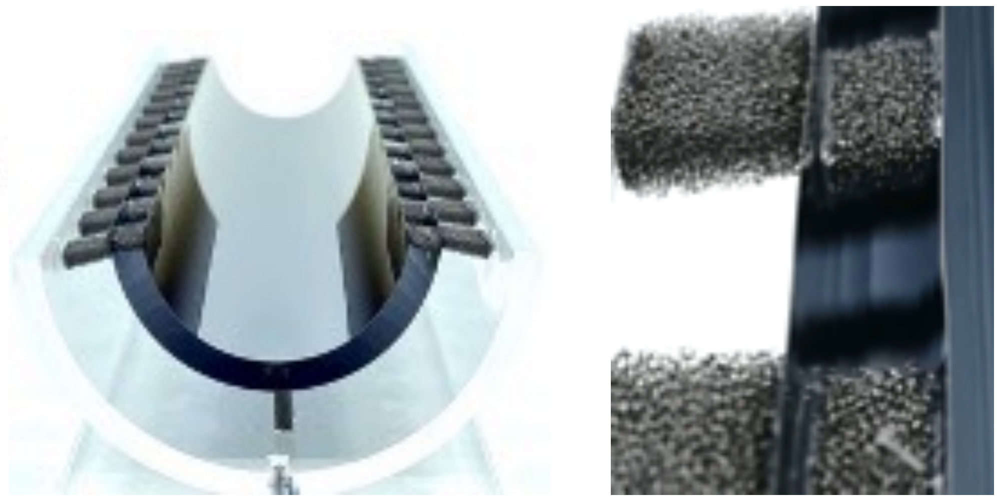


Fig. 5. Comparative graph of curvature achieved in working sensors between this work and the significant work from the literature. A wirebonded sensor used for one camera in this study is shown in the lower right, having a spherical curvature of 23.7°. The working sensor in the upper right has a curvature of 26.7° but could not be used for this study as it does not match the lens.

ALICE ITS3 project



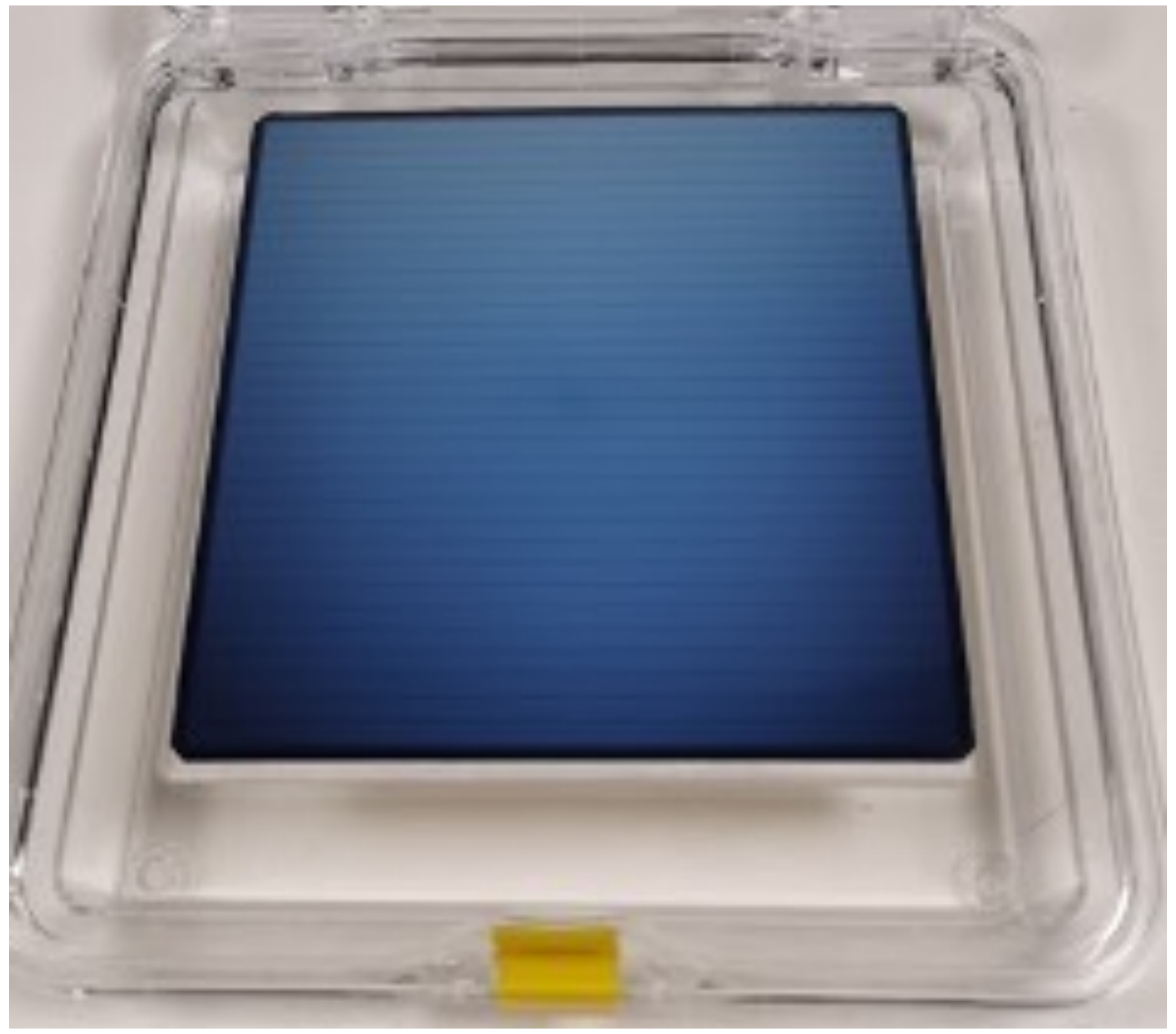


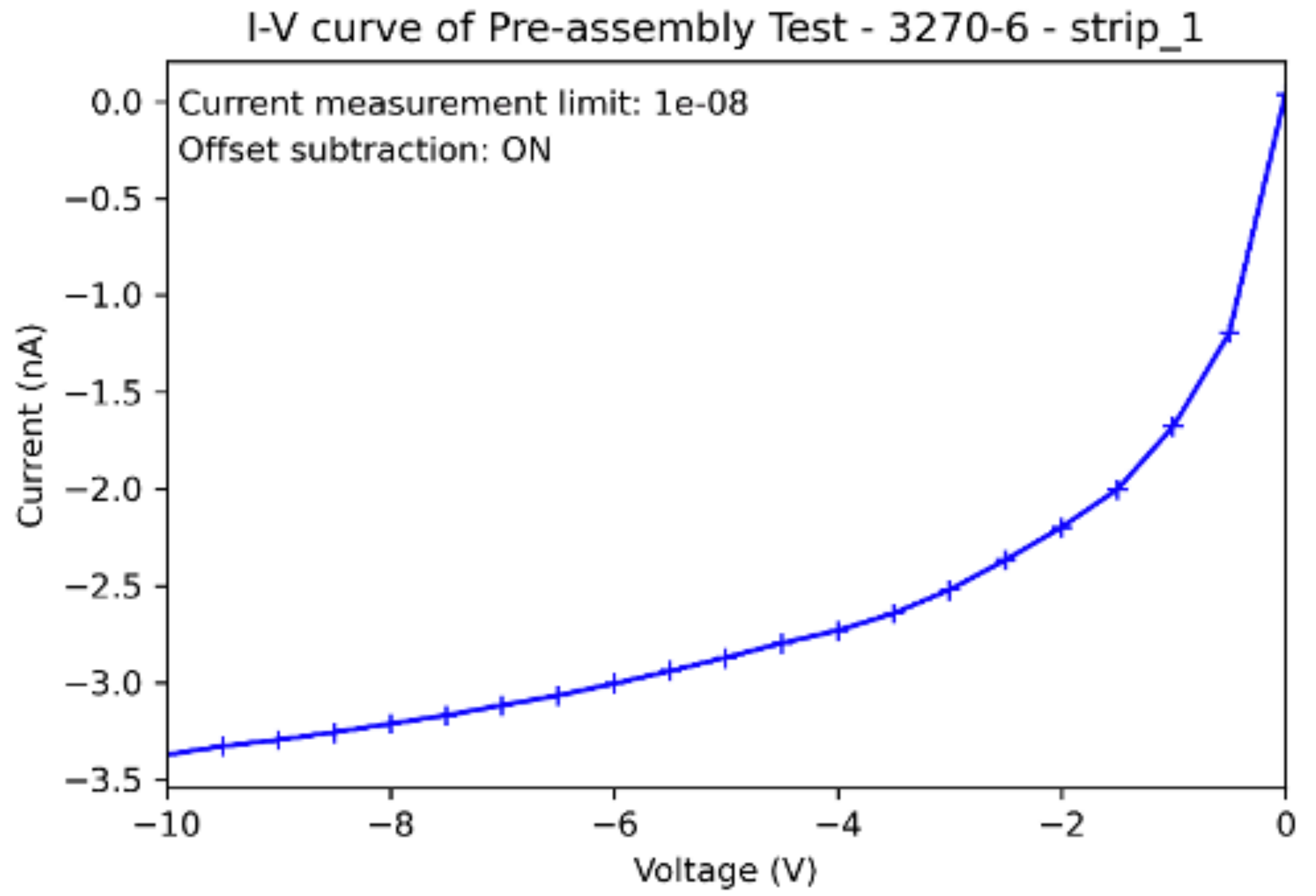
C. Gargiulo (ALICE ITS3), Forum on Tracking Detector Mechanics 2021

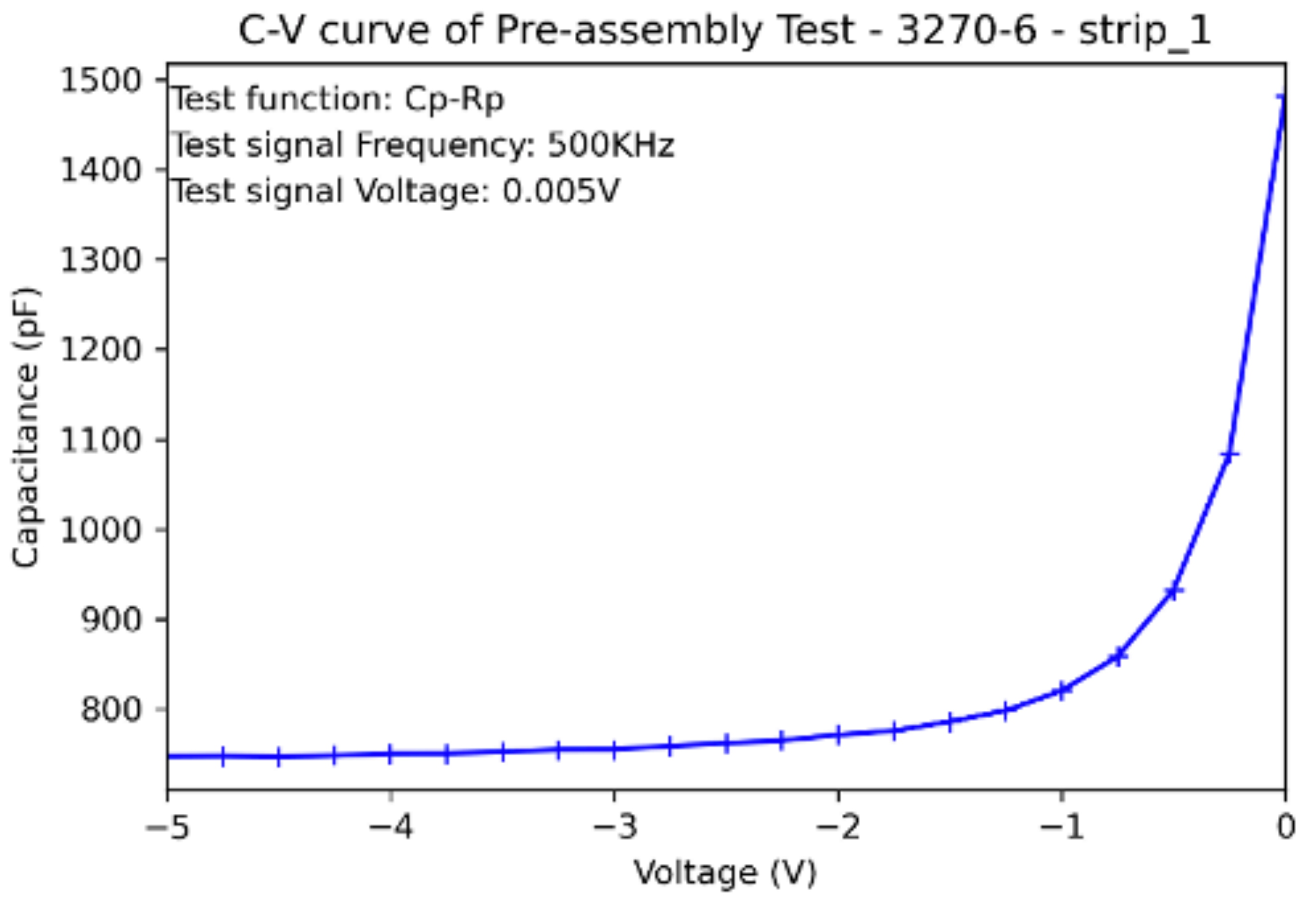
Large scale module construction

- Focus on DC coupled TTT10 from Micron Semiconductor
- Sensors nominally 50µm, with range of 30-50 µm

Specification	TTT10
Thickness	50µm
Active Area	100mm×100mm
No. of Strips	32
Strip Pitch	3mm
Wafer Type	N-Type
Wafer Resistivity	5K ohm·cm
Metalizing	300nm Al
Wafer Technology	Float Zone
Orientation	[100]
Junction Depth	0.5µm
Strip Leakage Current	10nA Max



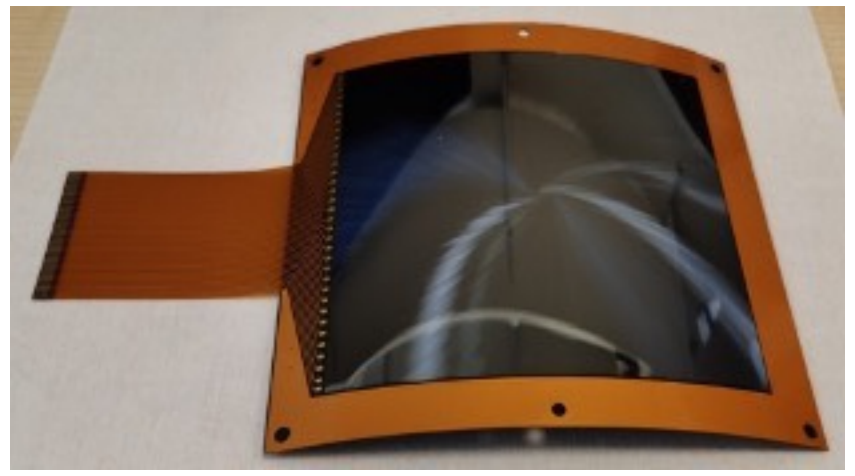




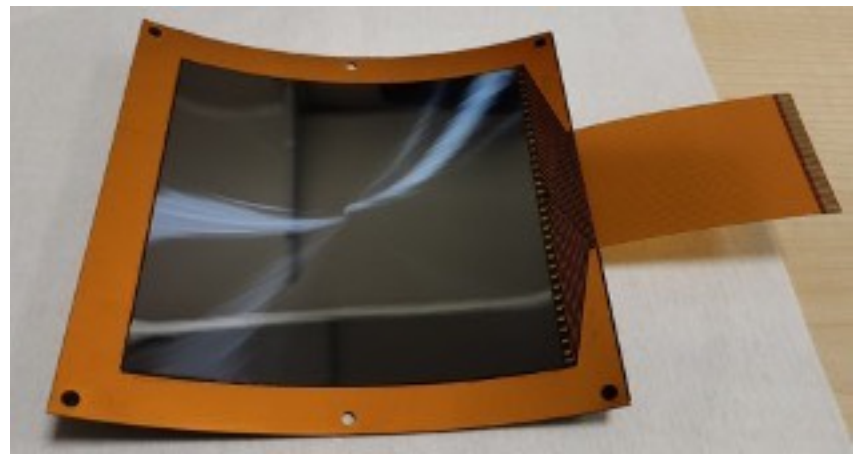
Large scale module construction

- Focus on flat and R=150mm modules to demonstrate the concept
- Tokens made with R down to 13mm, so plenty of scope for changing the radius either way

Flat



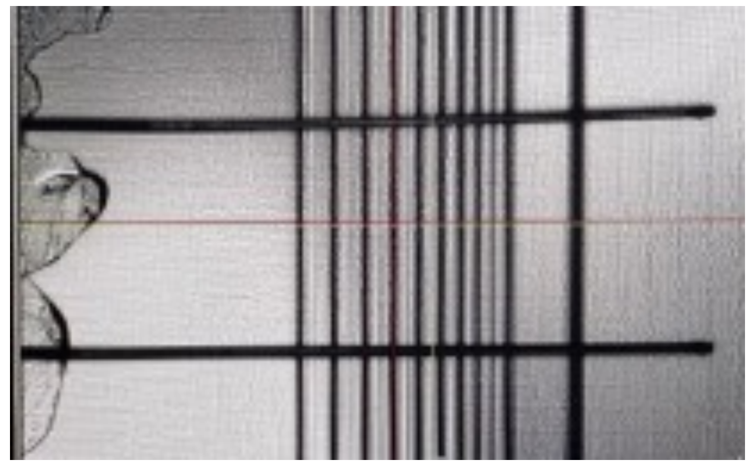
Convex, R=150mm



Concave, R=150mm

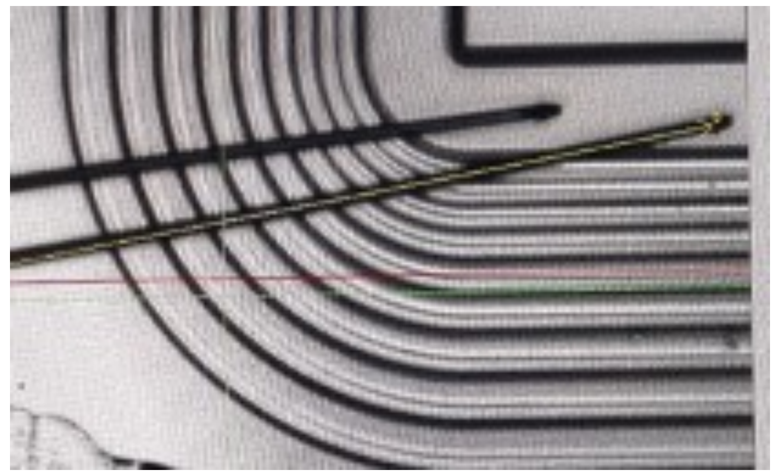
- Module layup for each of these variations is the same:

- Wirebonding is a little more tricky than with a flat module:



Bonding to a strip

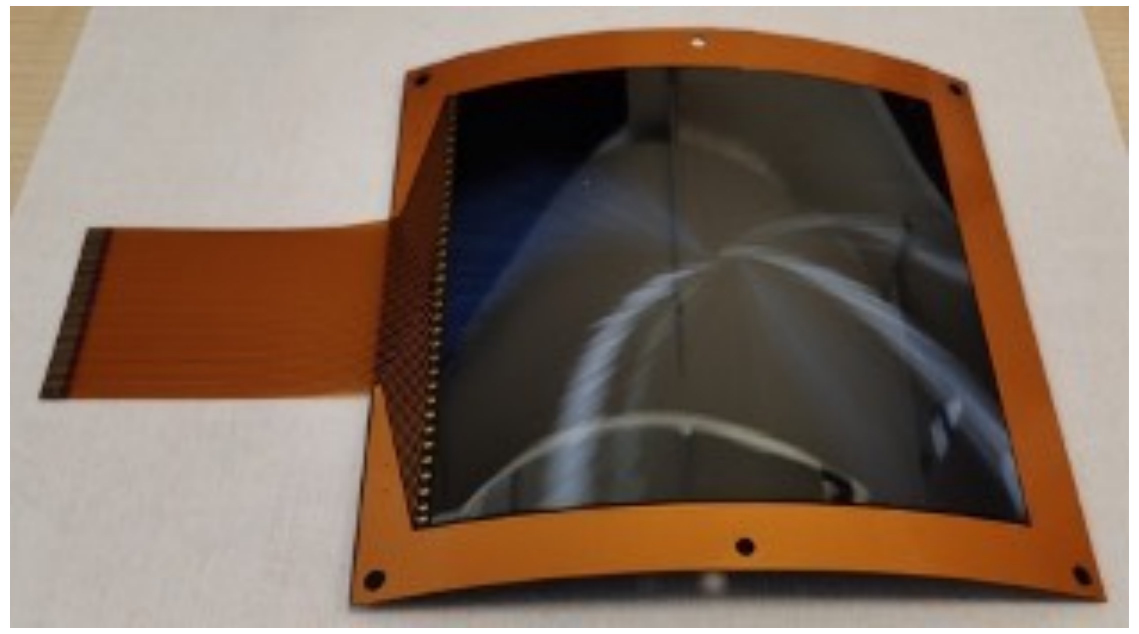
Overview

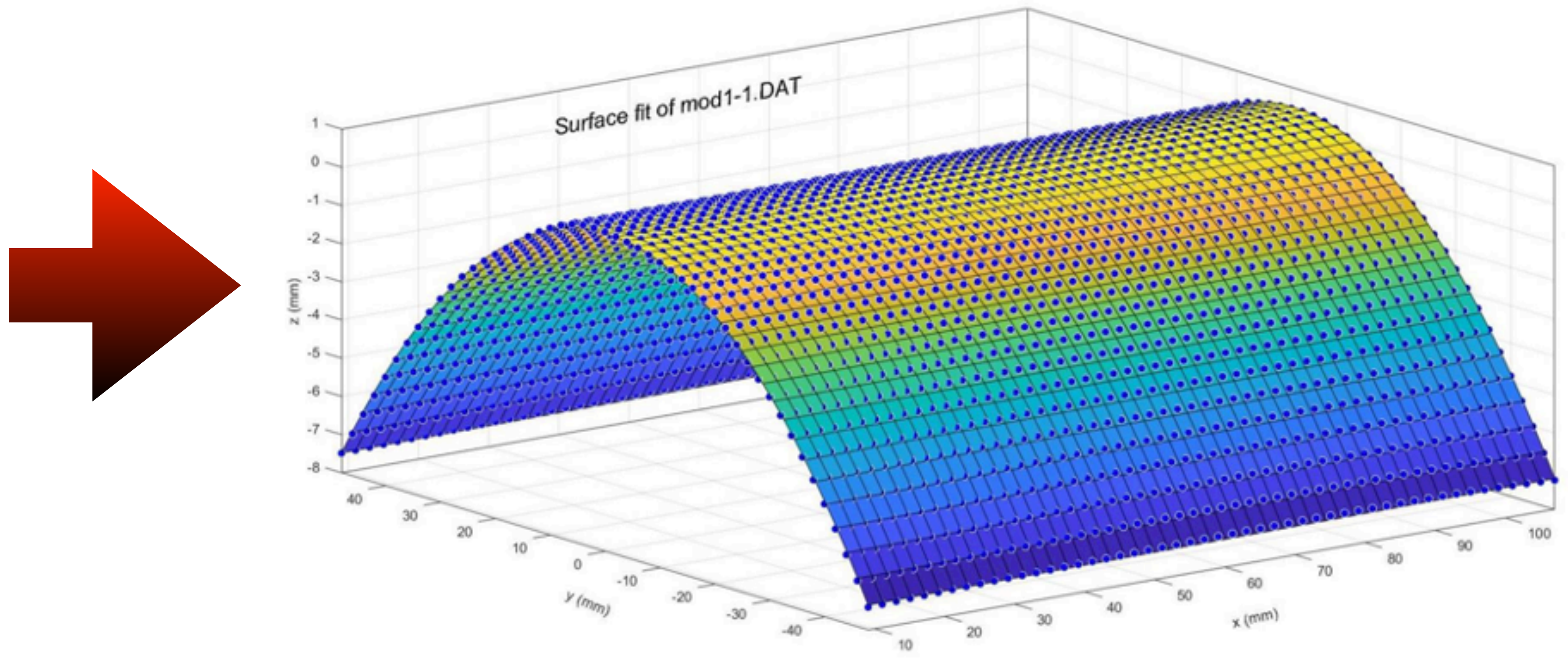


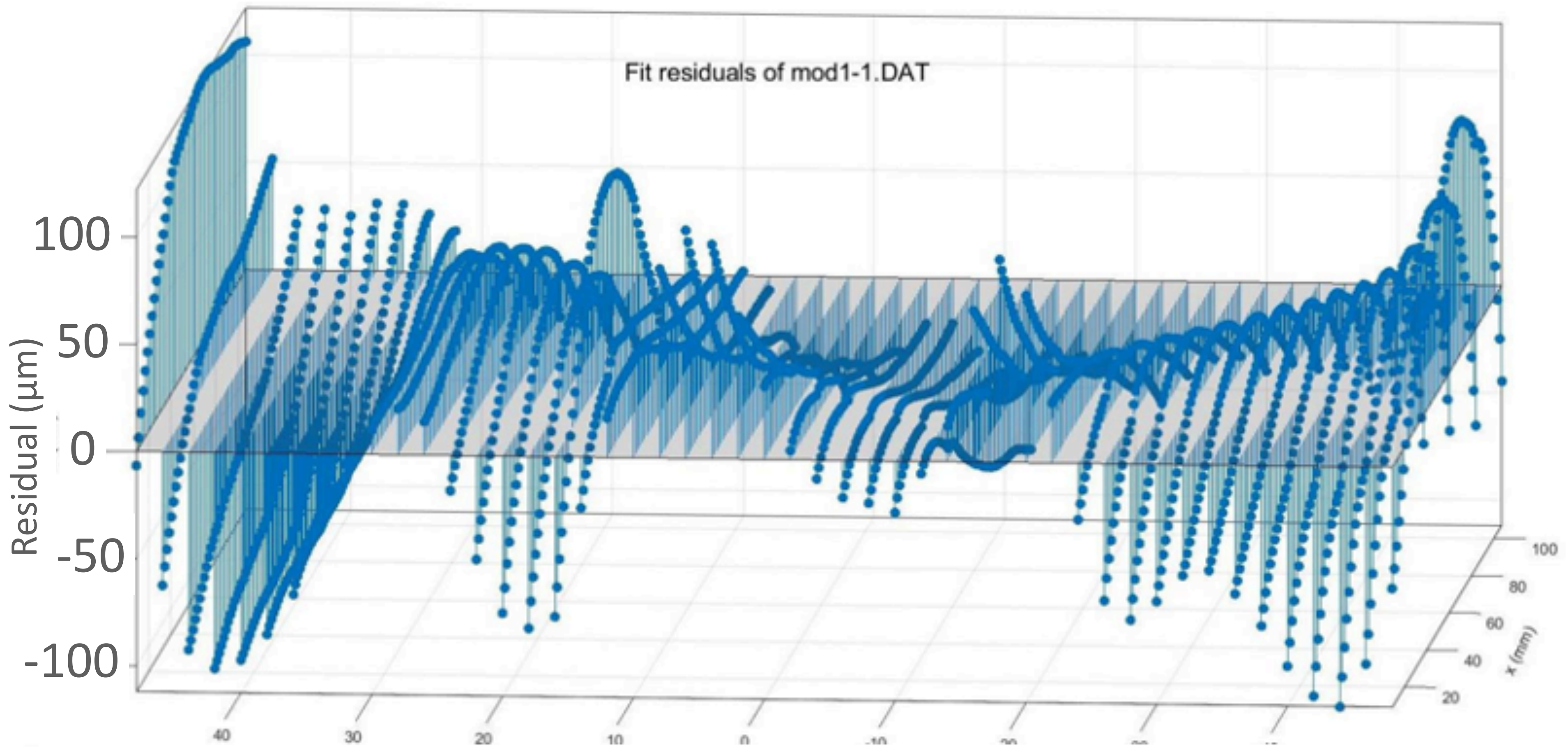
Guard Ring

Test results: surface shape

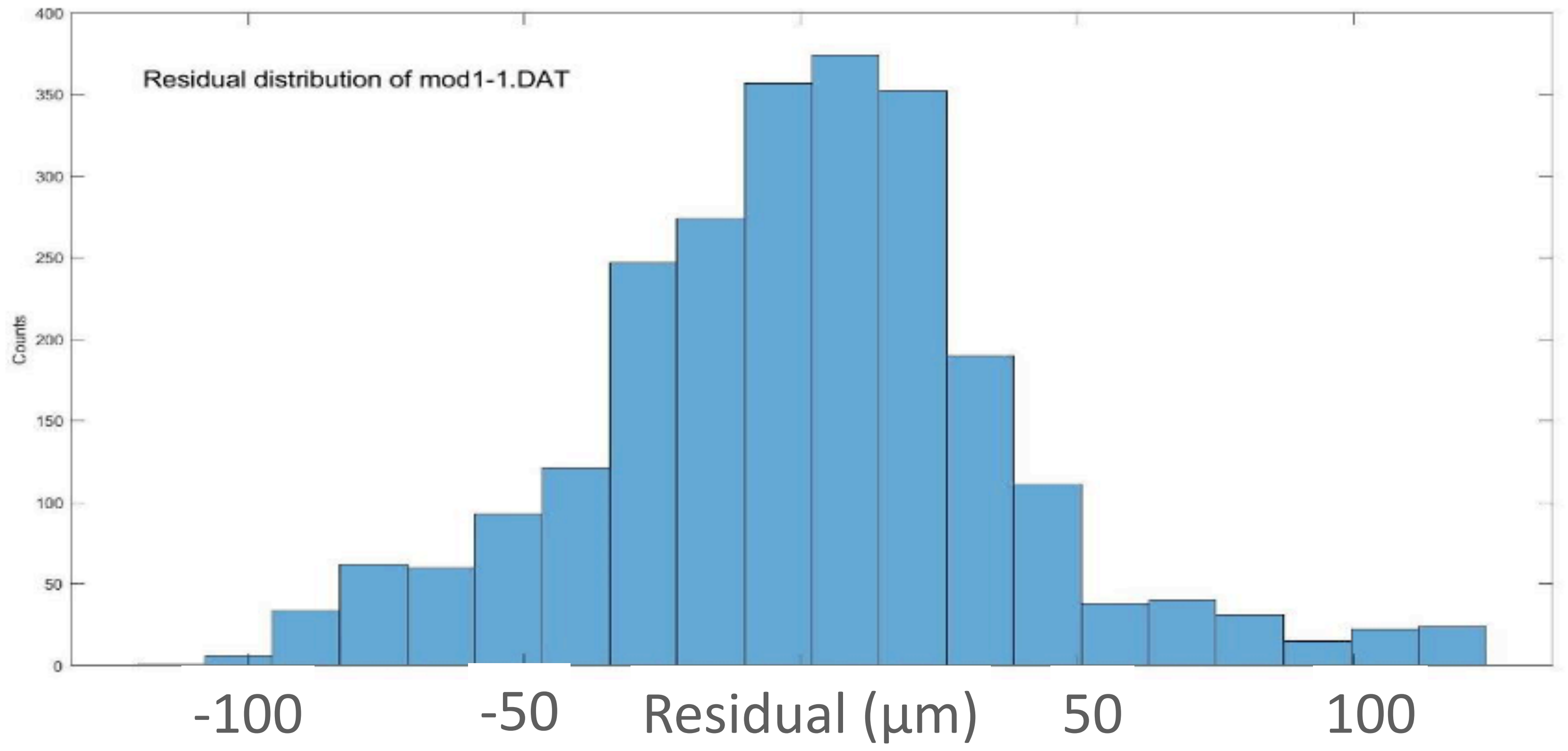
- Use a smartscope laser-scan of the surface to measure the form
- Matlab fits the surface to a given model (cylinder shown)







- Residuals vary across the module but remain acceptable
- Room for improvement with tooling and assembly procedure



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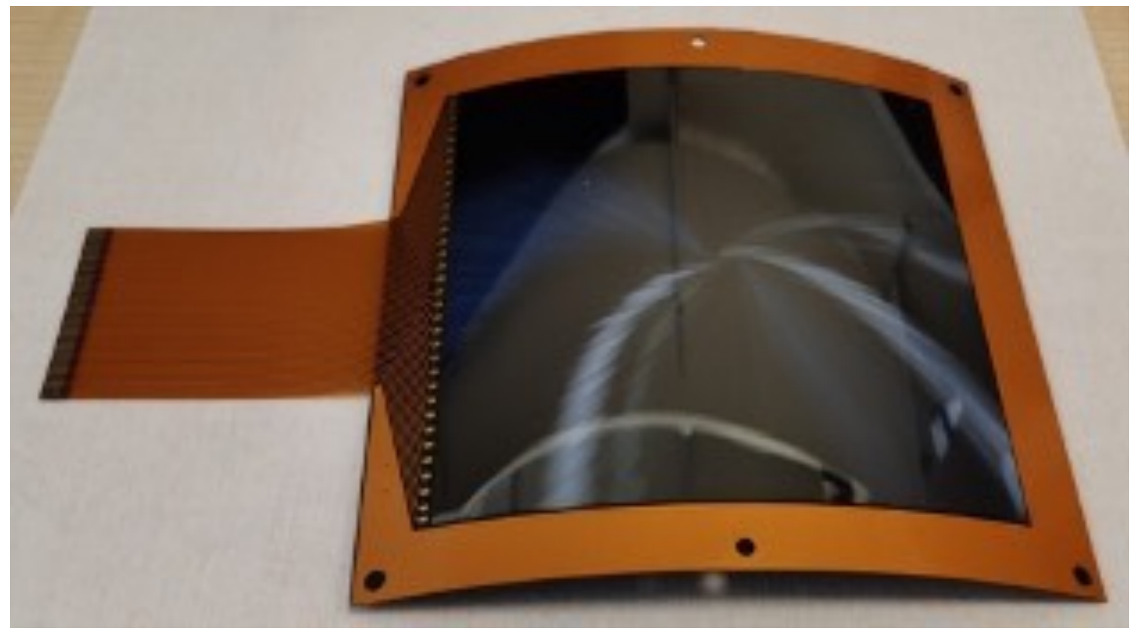
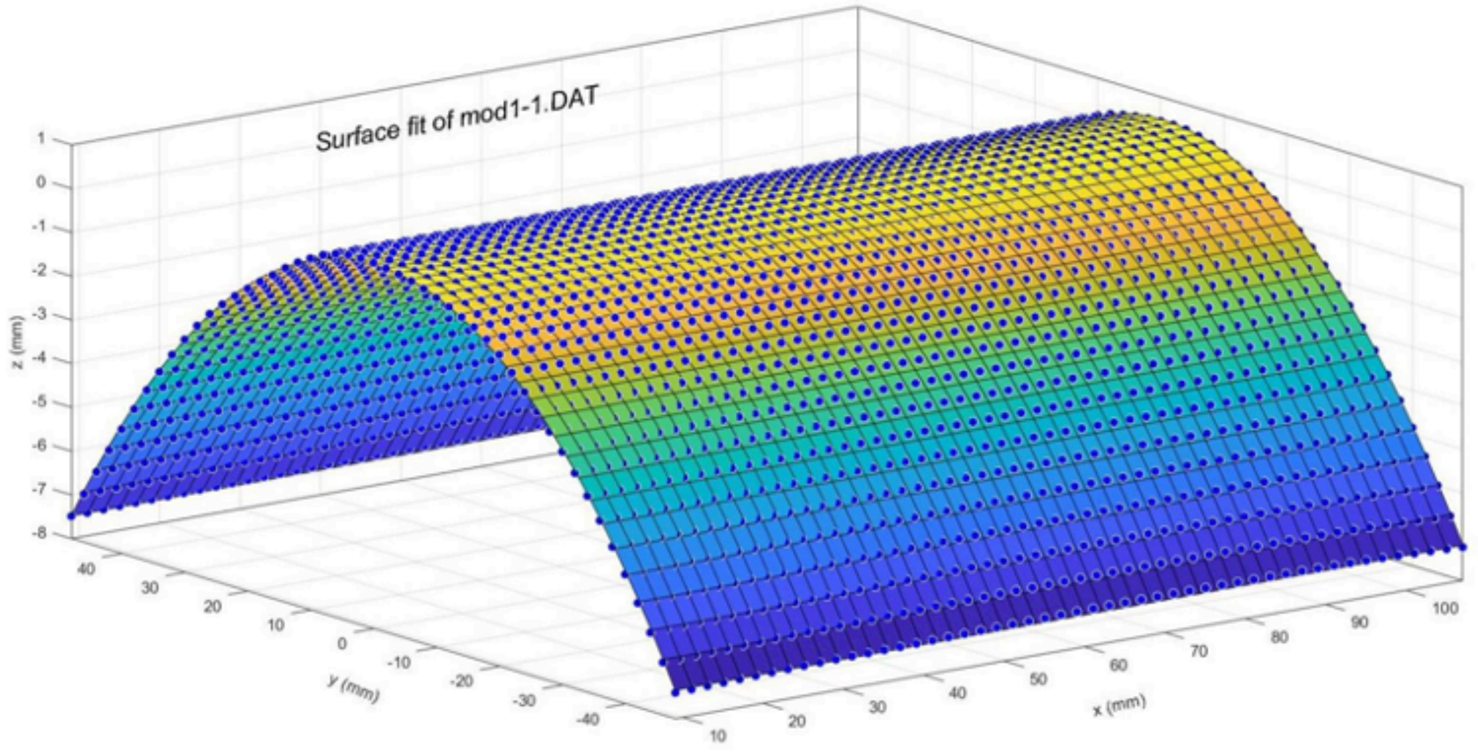
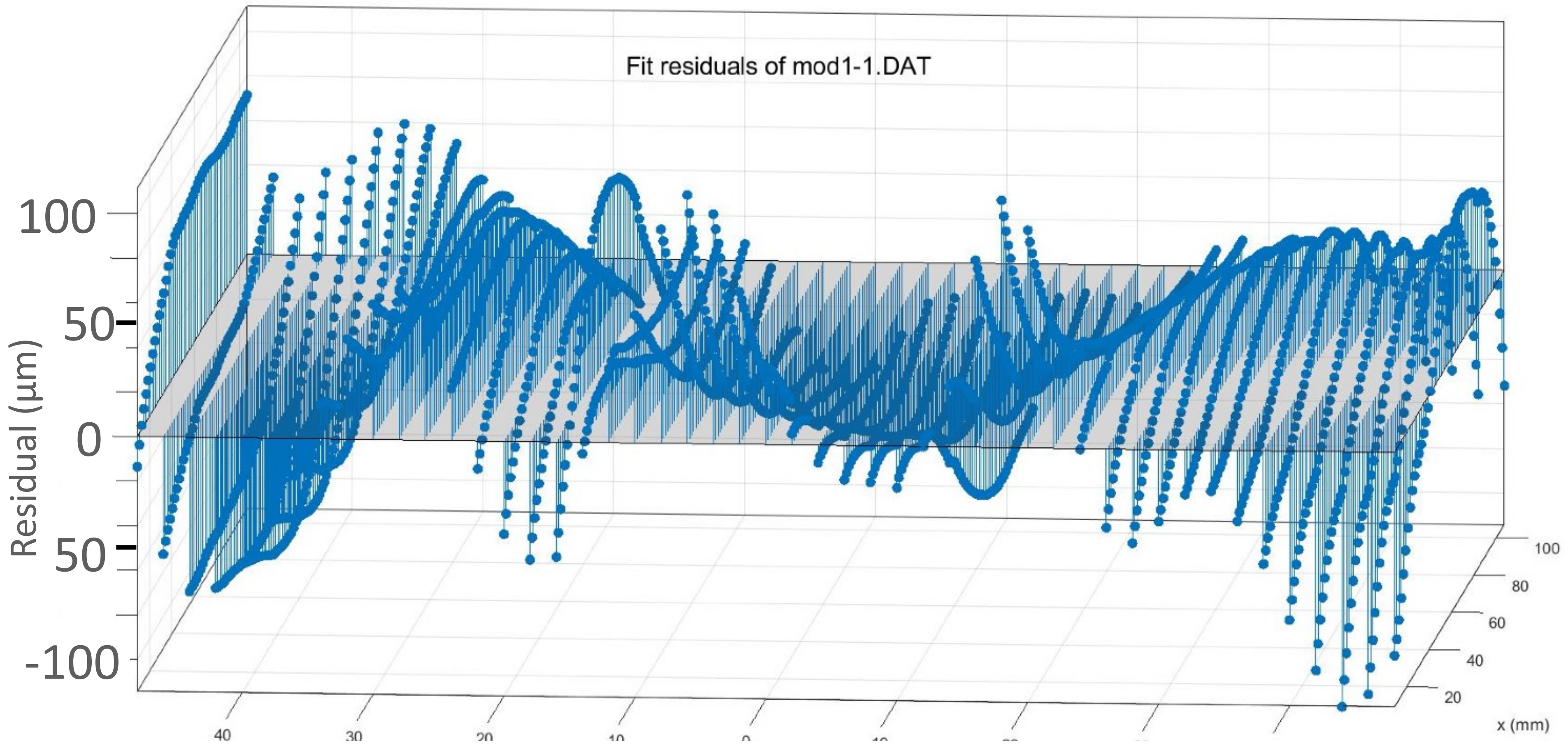
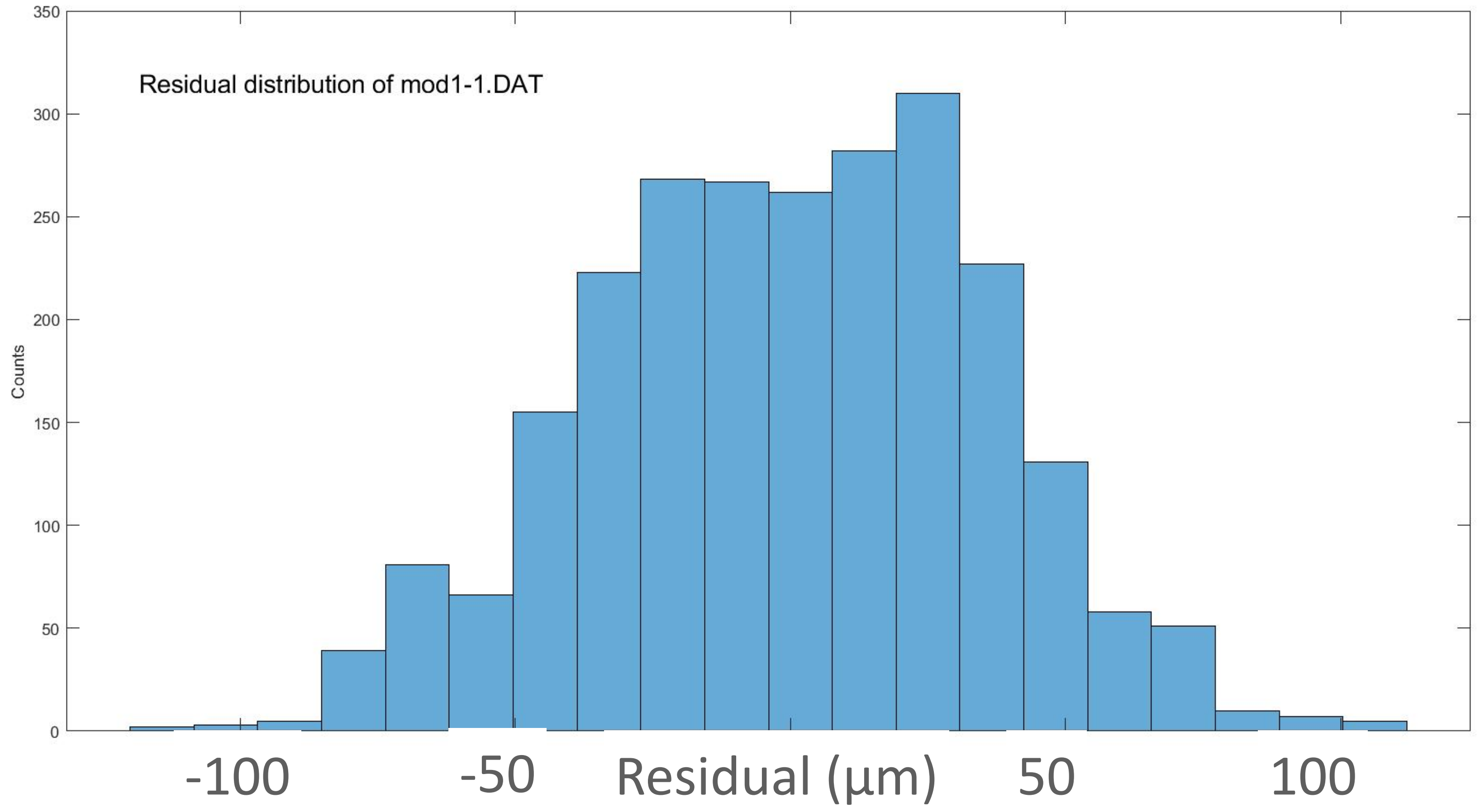






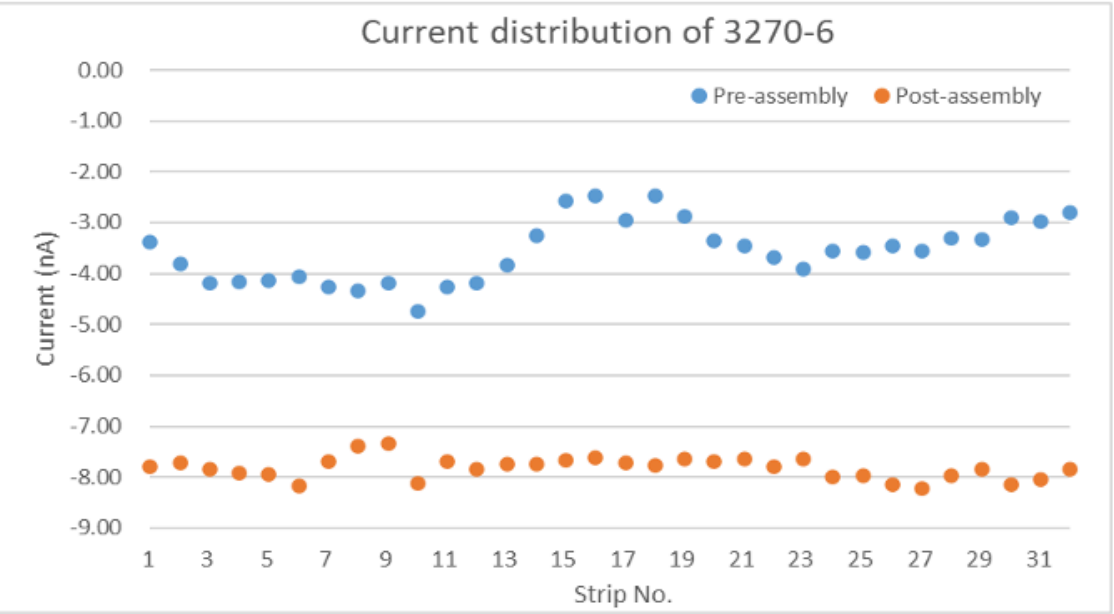


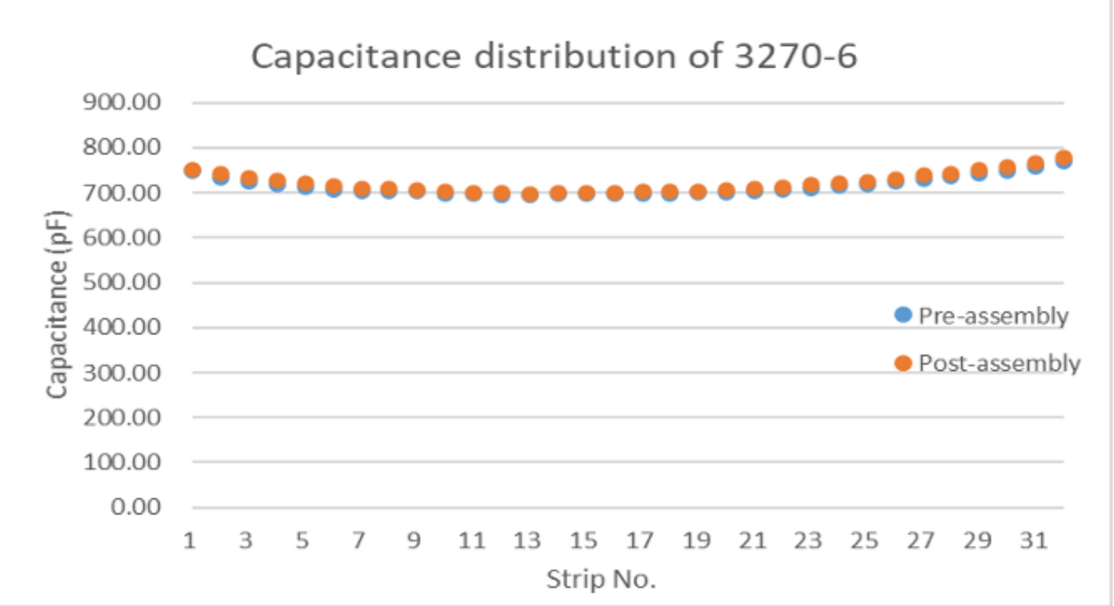
- Residuals vary across the module but remain acceptable
  - Slight improvement if we allow for a twist term (*)
- Room for improvement with tooling and assembly procedure

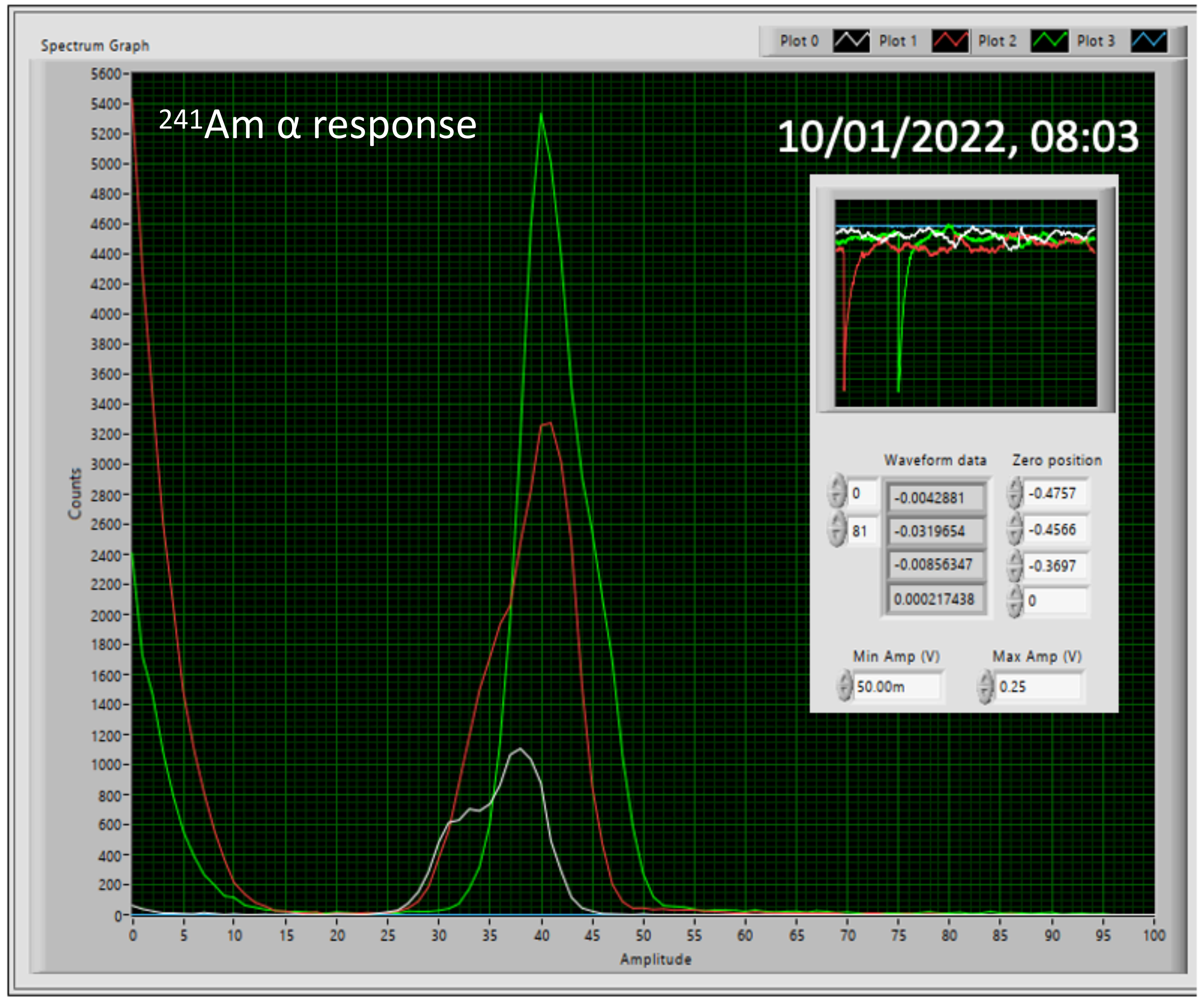
(*) See backup

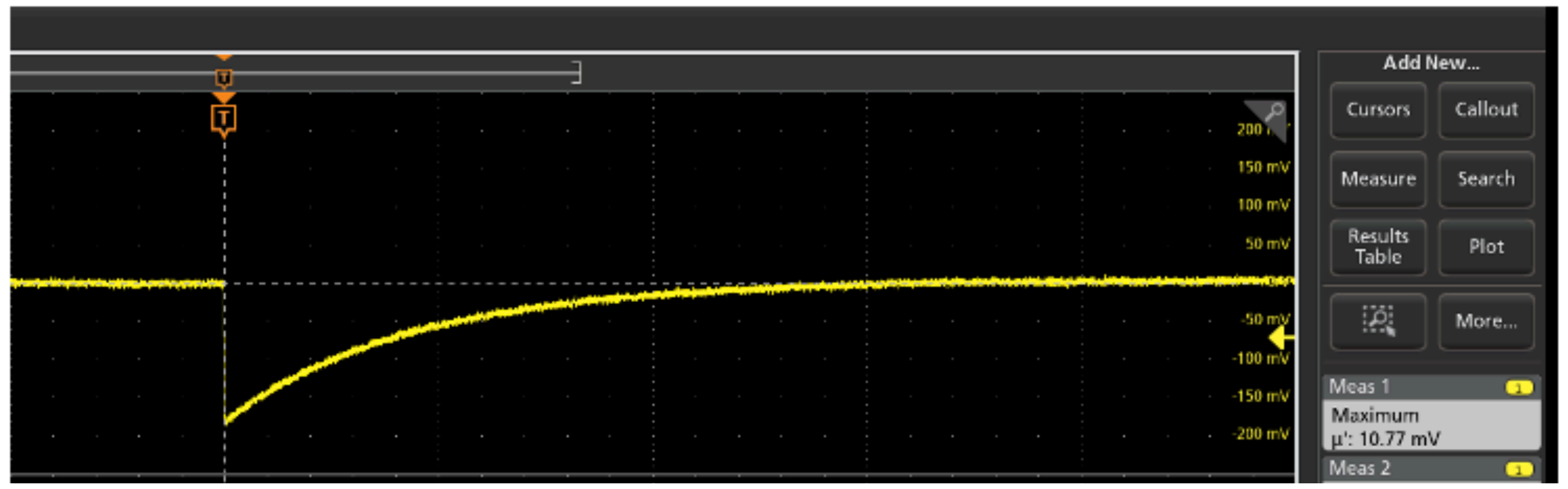
Test results: electrical performance

- Post assembly there is an increase in leakage current of 4-5 nA in sensors, but no notable change in the capacitance
- Use a Cremat amp coupled with either a CRIO NI DAQ or a Tektronix MSO scope for testing
- Clear signals observed
- 3 neighbouring strips shown:
  - Closest to source (Green)
  - Adjacent (Red/White)



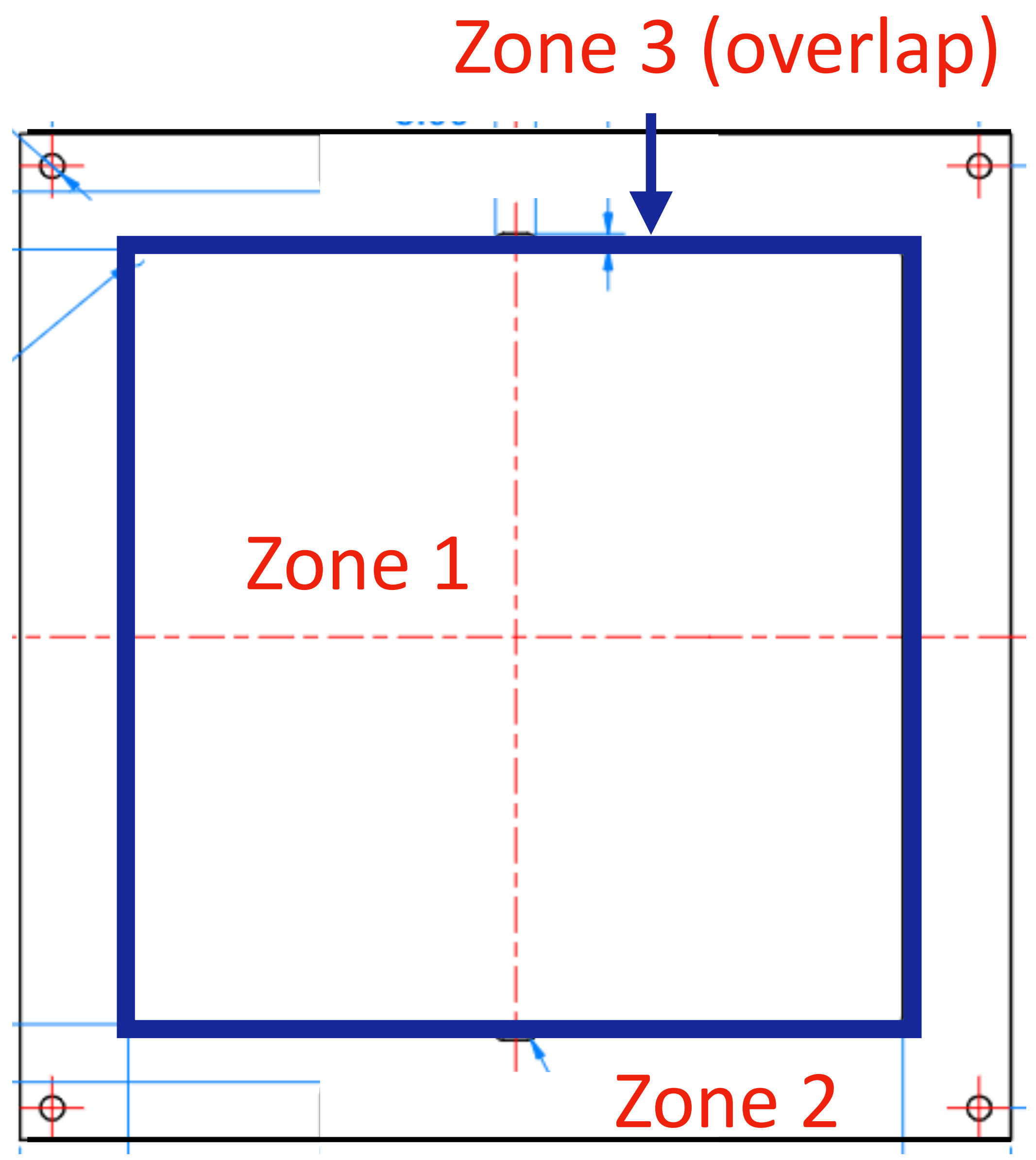


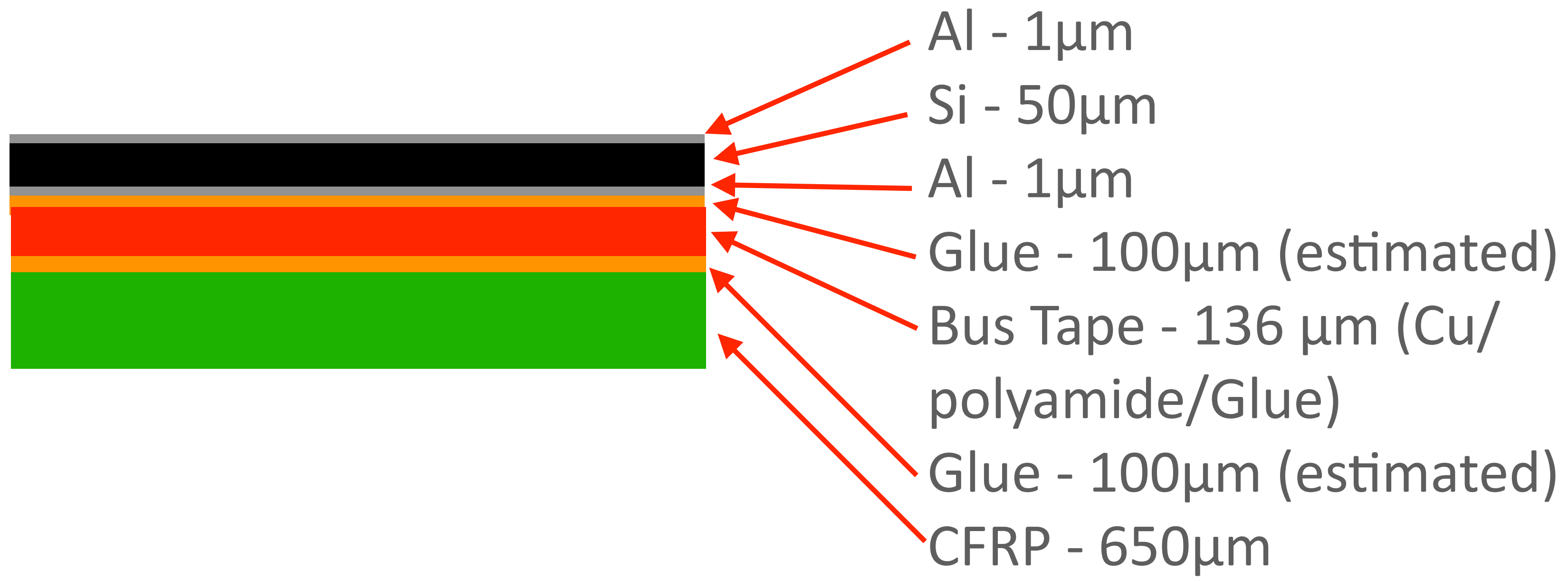




Test results: X/X_0

- Break the module down into 3 zones to calculate X/X_0





- Current design provides

Zone	X/X_0 (%)
1	0.054
2	0.619
3	0.703
Average	0.276

- Dominated by CFRP and Cu contributions
- Clear improvements possible to drive down to 0.16% by modifying bus tape and support
- Could be advantageous for passively cooled trackers

Future directions

- Compare with flat module performance (work in progress)

- Increase precision of assembly - tooling for precision construction being finalised

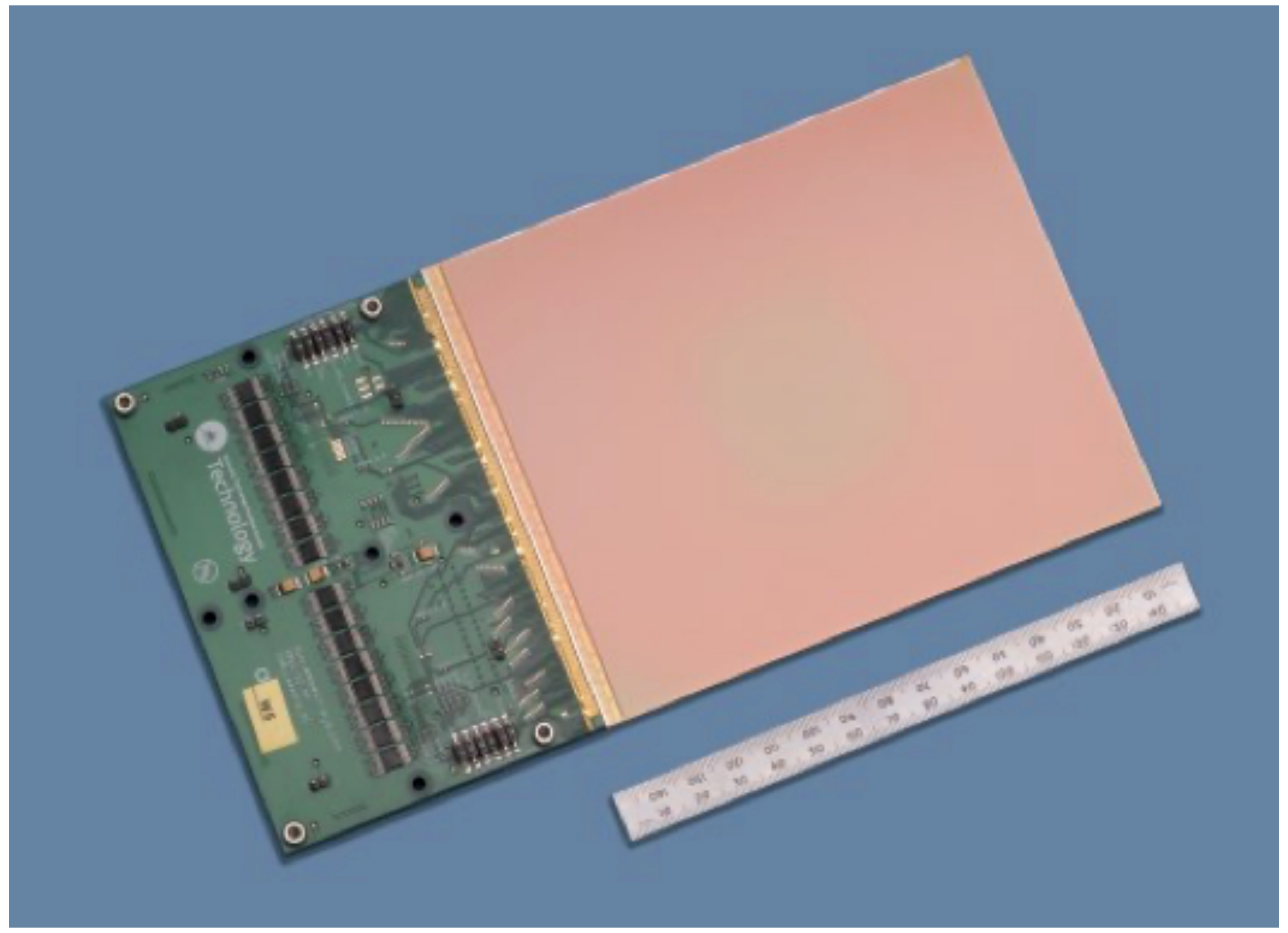
- Move on from strip sensors to CMOS
  - LASSENA chip:

    180nm CMOS sensor

    Large area stitched CMOS technology

    120mm x 145mm chip size

    Great candidate to demonstrate detector concept application to CMOS



Parameter	Unit	Value
Effective Pixel pitch (X)	um	50
Effective Pixel pitch (Y)	um	50
Effective No. of pixels	Millions	6.72
Effective pixel format (X)	pixels	2,400
Effective pixel format (Y)	pixels	2,786
Frame rate	fps	34
Noise	e- rms	70.0
Conversion Gain	uV/e-	9.8
Linear Full Well Capacity	e-	112,000
Maximum Full Well Capacity	e-	144,000
Dynamic Range (linear)	dB	64.1
Dynamic Range (linear)	bit	10.6
Dynamic Range (maximum)	dB	66.3
Dynamic Range (maximum)	bit	11.0
Wavelength	nm	540
Quantum Efficiency	%	50.1

I. Sedgewick et al., proceedings of the 2013 International Image Sensor Workshop, Snowbird, Utah, USA, June 2013, 297-300

Summary

- Demonstrated the curved modules can be constructed up to 10 x 10cm
- Leakage current increase observed for curved module, but acceptable level for particle detection
- Tested using ^{241}Am α particles in the lab
- Still a lot of work to do to explore concept and plenty of scope for improvement - but we think this is a promising approach to consider for a future low mass tracker system
- If you have an application that could benefit from this concept, very happy to talk about collaborating & would like to continue to develop our concept for the FCC

QMUL's Detector Development Group

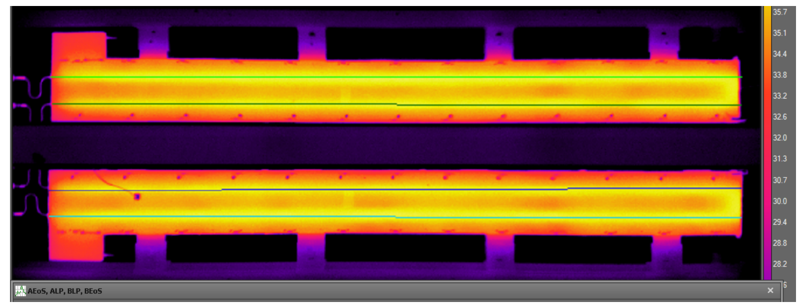
Fully equipped ISO 7 certified clean room

A multidisciplinary team of experts working on

- Novel radiation sensing technologies
- Instrument design and construction
- Radiation damage simulation

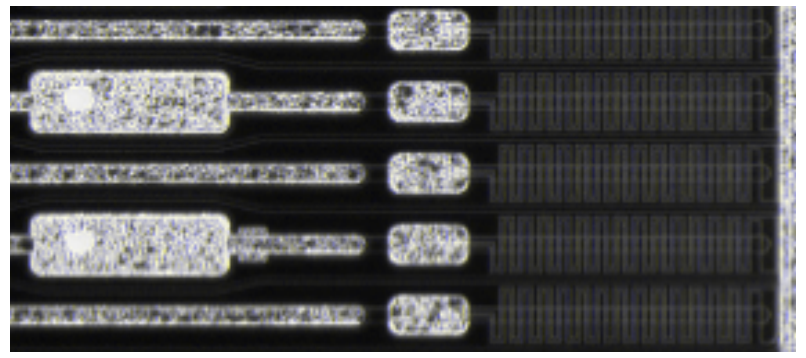
Technologies
Diamond
Silicon
Organics
Graphene
Perovskite
Scintillator

Simulation
ABAQUS
DL_POLY
FLUKA
GEANT4
MCNP6
Zeemax

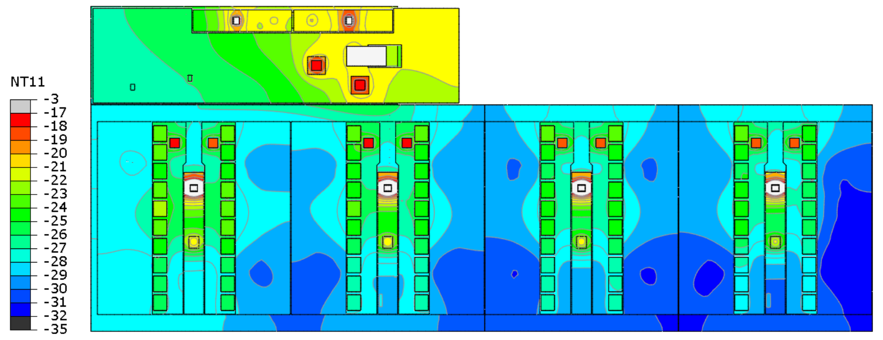


Infra-red thermal imaging system

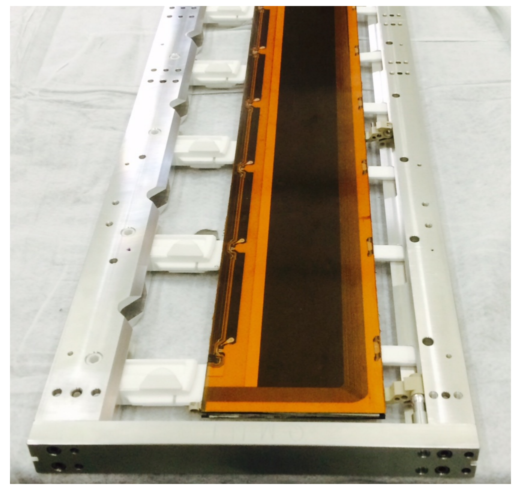
for particle physics and industrial application



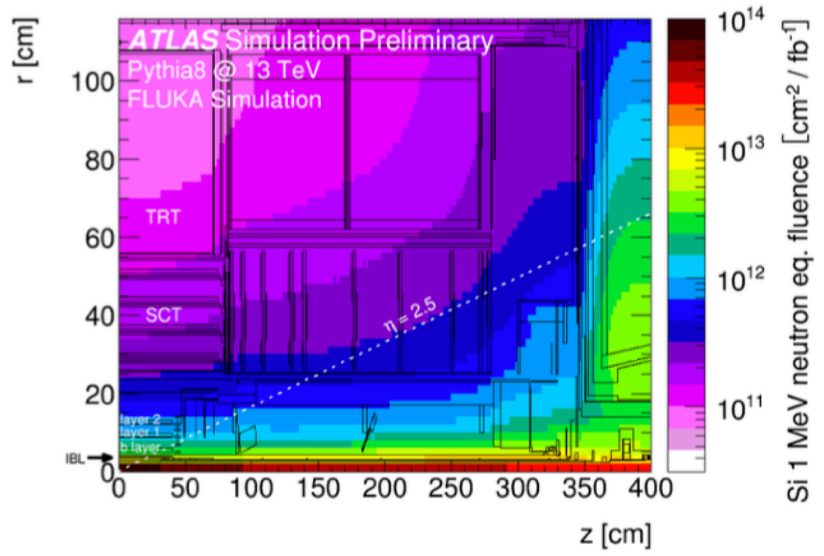
Silicon strip sensors for LHC



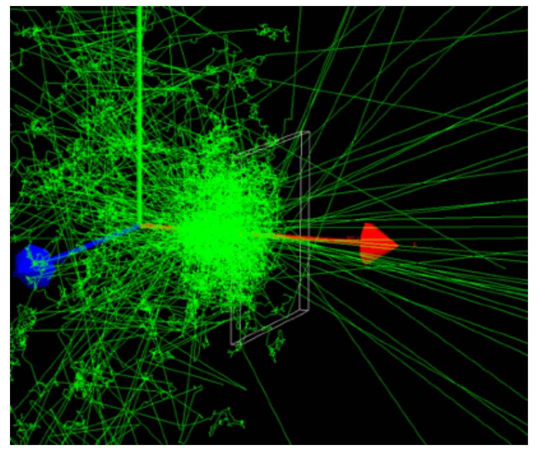
Heat transfer simulation for detector system cooling design



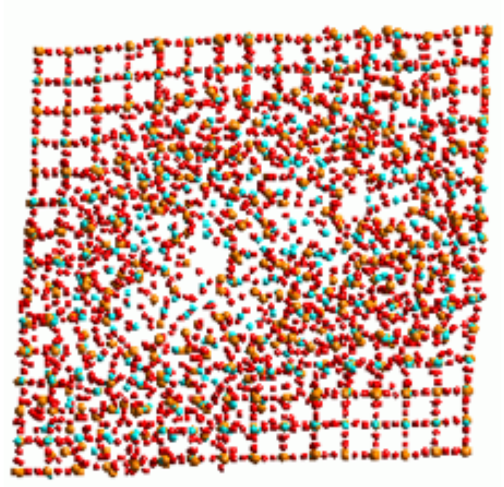
Module assembly engineering



FLUKA radiation environment simulations



Geant4 sensor interaction simulations



DL_Poly material damage simulation

Backup

- Fitting the module surface; in addition to using a cylinder based model, also explore the use of Legendre polynomials following the CMS alignment method [1]:

c_{ij} are coefficients describing orientation and shape of the silicon

$L_{i,j}$ are Legendre polynomials

w(u, v) is surface model

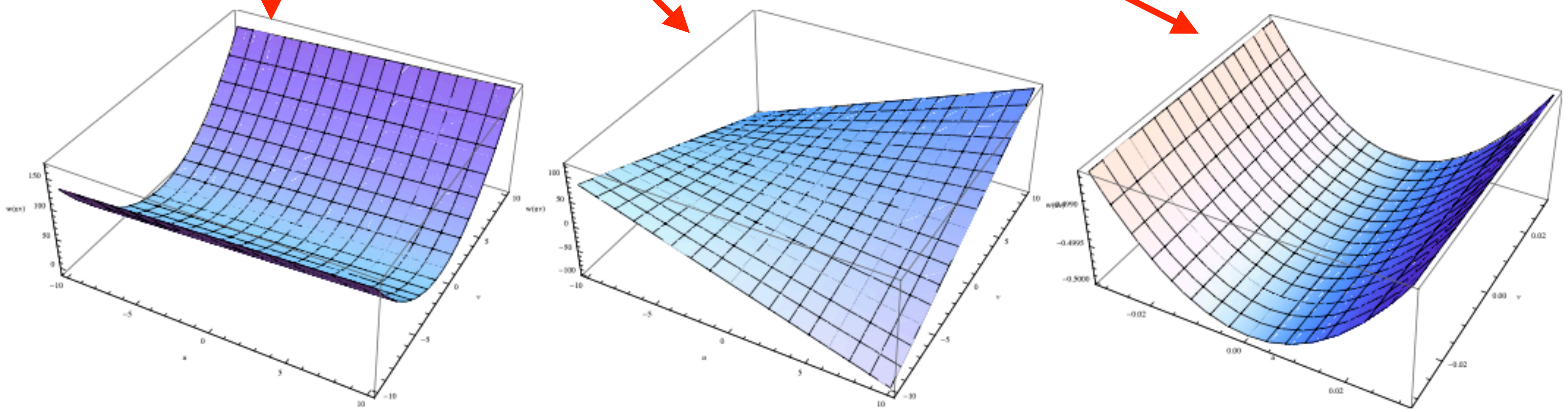
(x, y) is in sensor plane coordinate system, (u, v) is 3-space coordinate system of the instrument

N is order of expansion

$$w(u,v) = \sum_{i=0}^{N} \sum_{j=0}^{i} c_{ij} L_j(u) L_{i-j}(u)$$

$$w(u,v) = c_{00} + c_{10}v + c_{11}u + c_{20}\frac{3v^2-1}{2} + c_{21}uv + c_{22}\frac{3u^2-1}{2}$$

Planar orientation



Cylinder along axis v

twist

Cylinder along axis u

[1] F. Meier C. Kleinwort. Alignment of the CMS Silicon Tracker – and how to improve detectors in the future. Nucl.Instrum.Meth., A650:240–244, 2011.