Queen Mary University of London

UKRI Science and Technology Facilities Council | Particle Physics

# Curved and flexible radiation detectors


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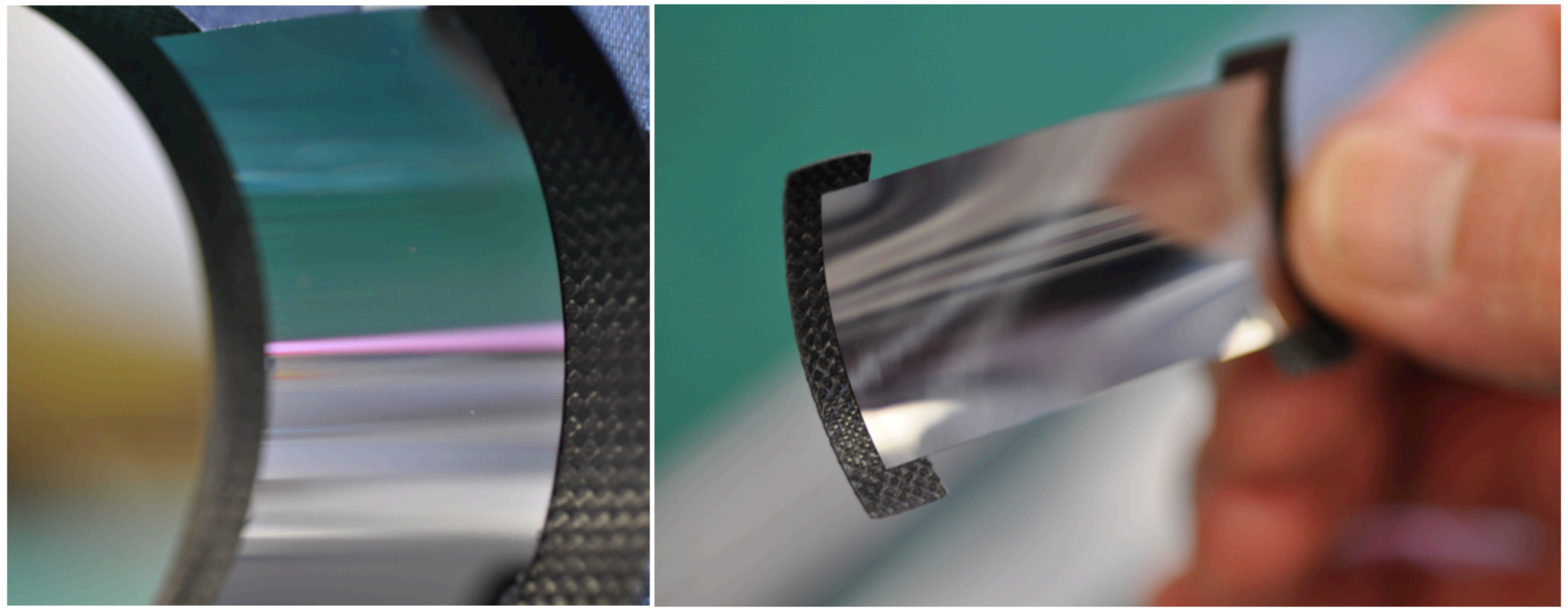
# Overview

- Silicon:
  - Early concept prototyping
  - Other example applications
  - Large scale module construction
  - Test results:
- Organic Semiconductors
  - See Theo for details of device performance
- A COTS readout solution
- Future work

# 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)

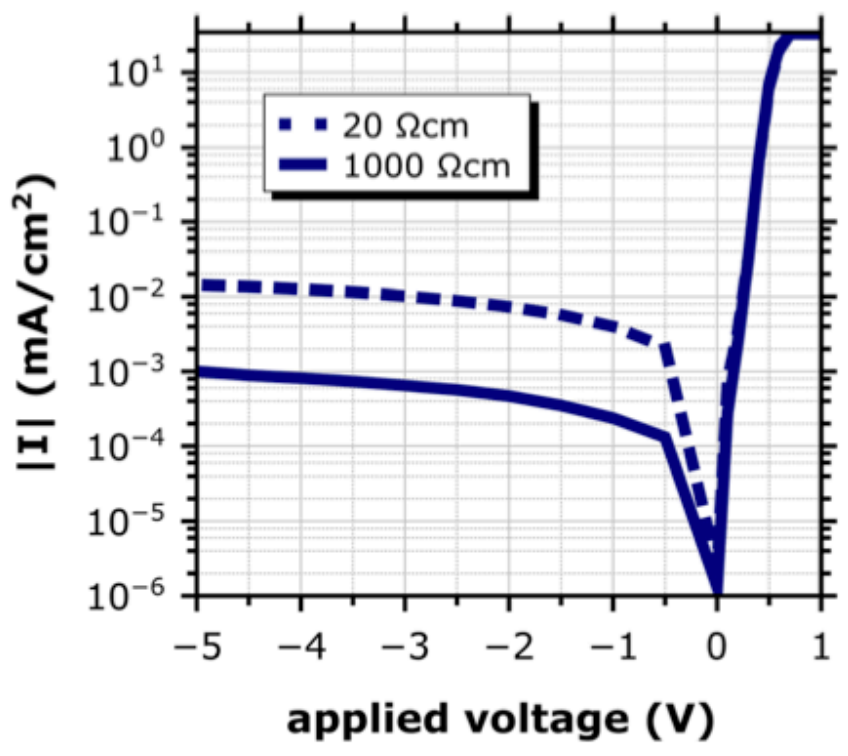
Use laser coordinate measuring machine to map chip surface

# Other example applications

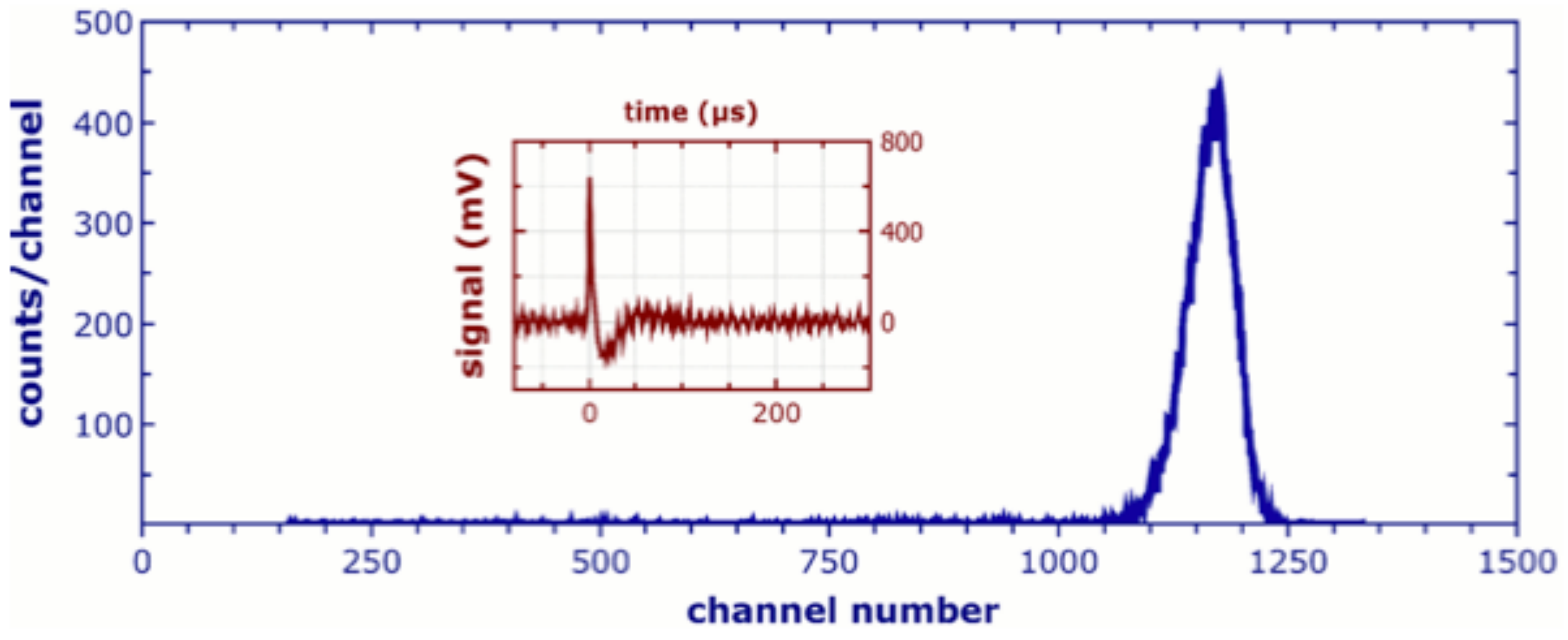
- Commercial and HEP project applications have pursued curved (cylindrical and spherical) sensor technology; demonstrating the feasibility to make functional devices

**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

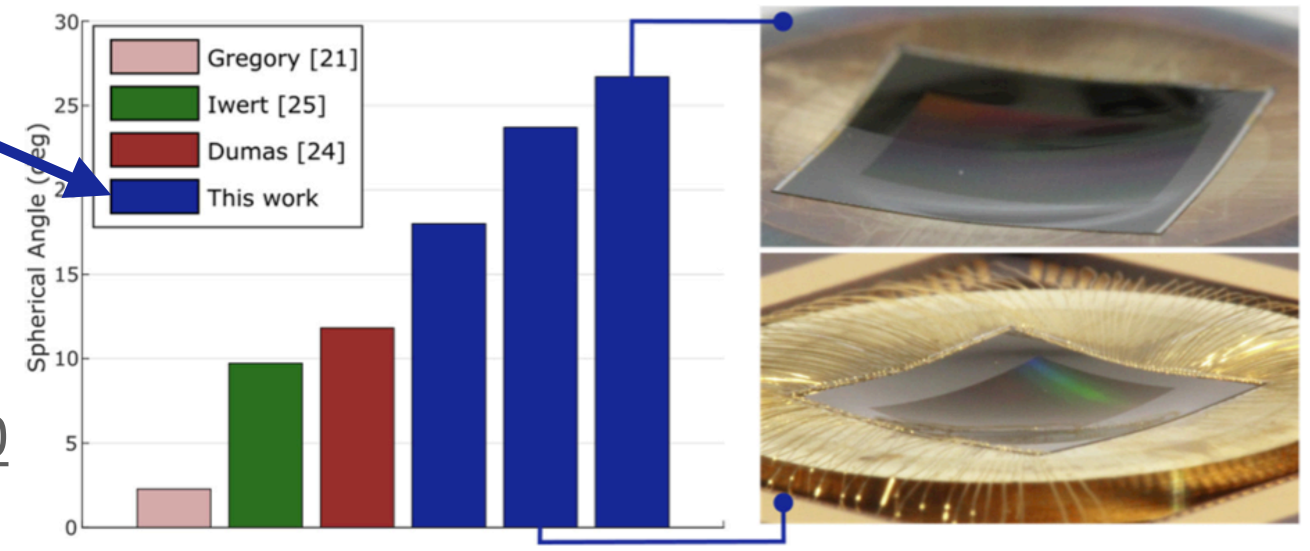
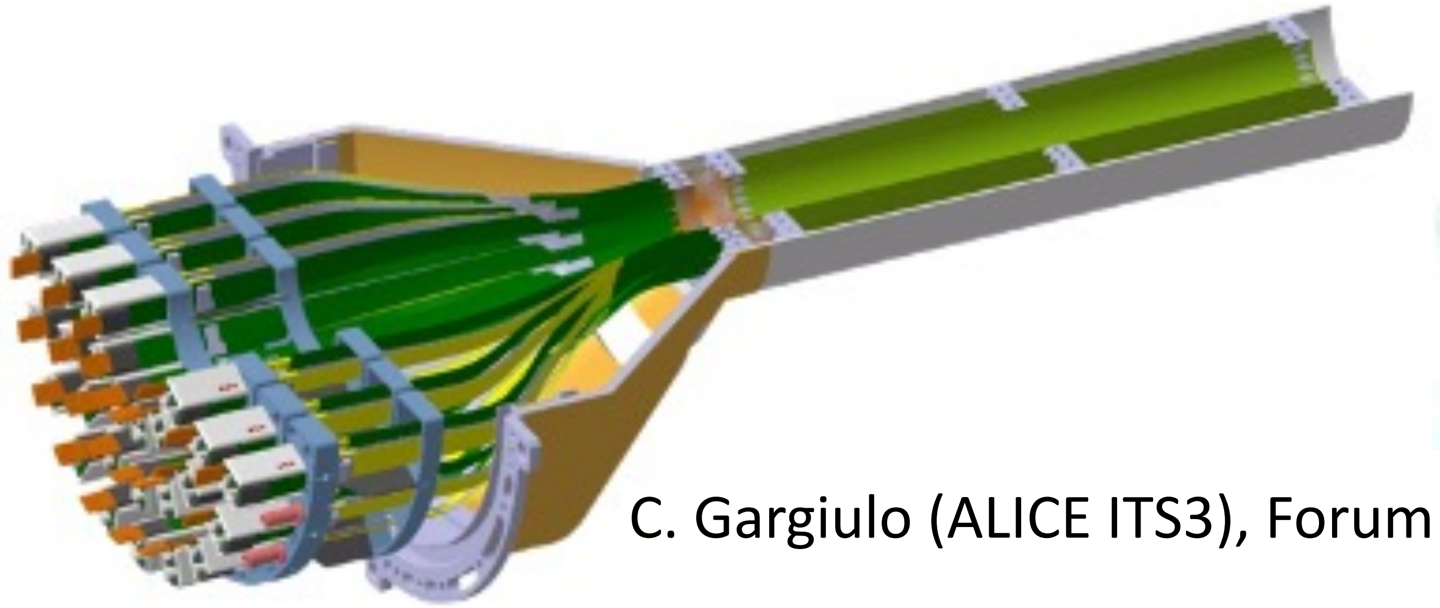



Fig. 5. Comparative graph of curvature achieved in working sensors between this work and the significant work from the literature. A wirebonded sensor used for one camera in this study is shown in the lower right, having a spherical curvature of 23.7°. The working sensor in the upper right has a curvature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

**ALICE ITS3 project**

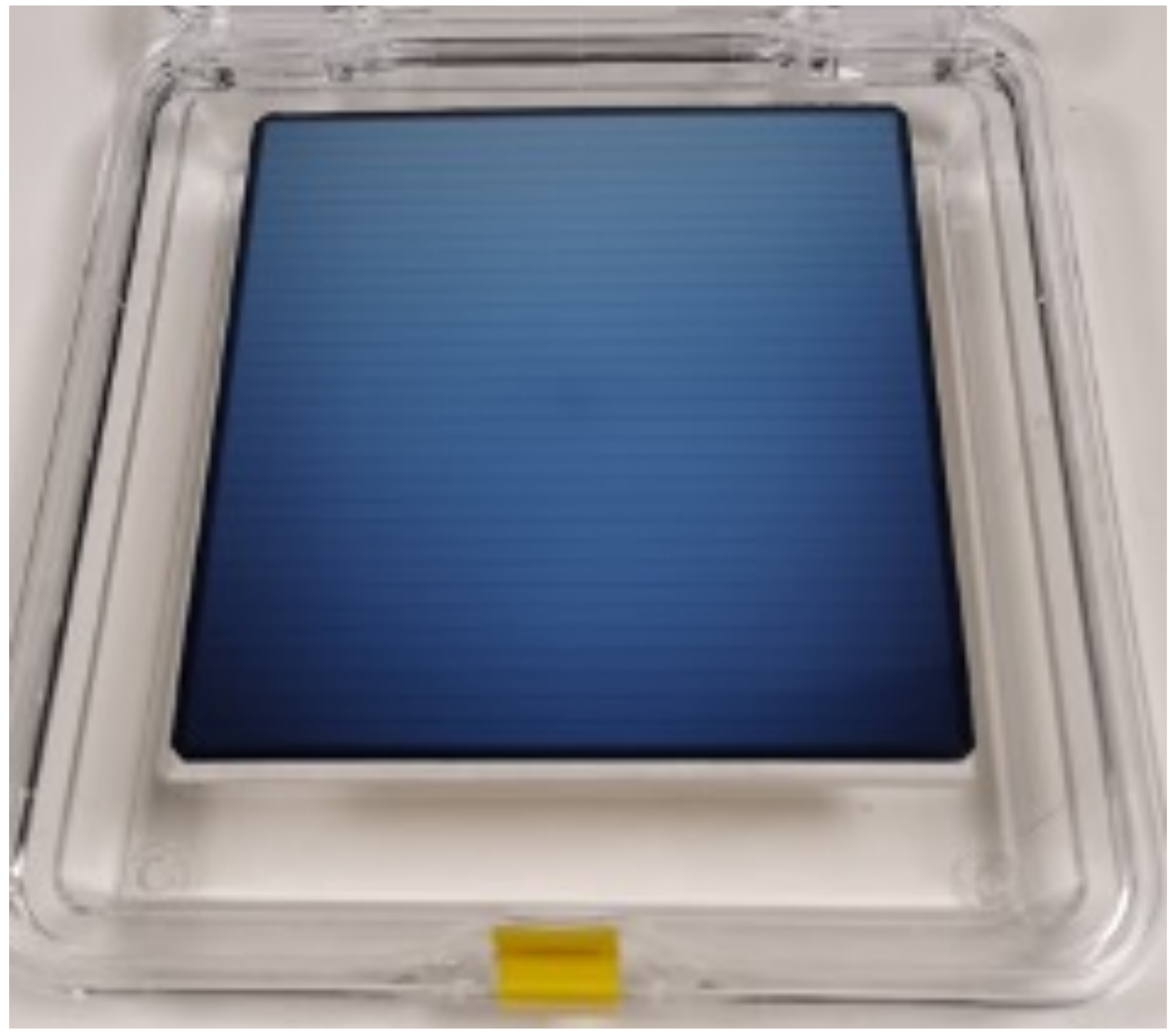


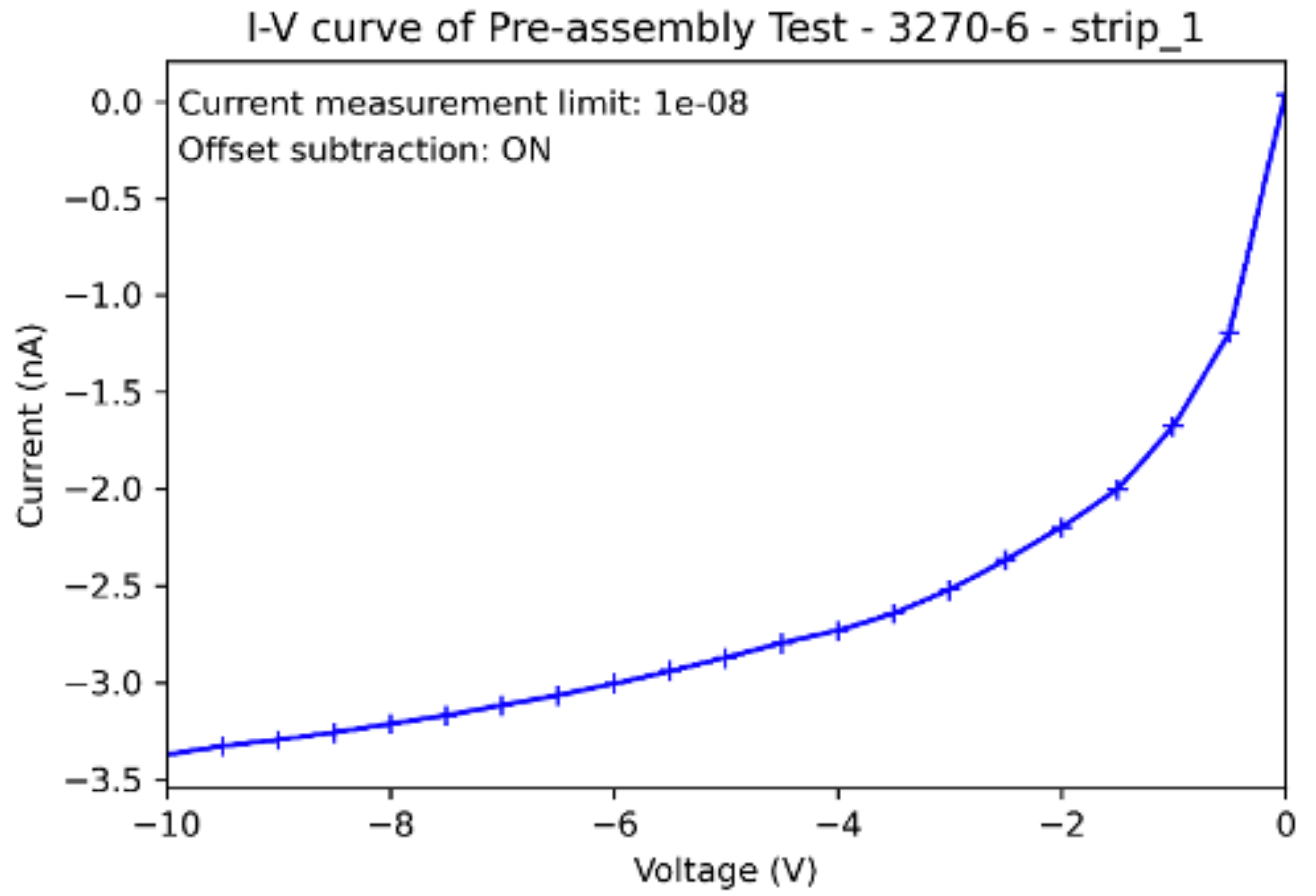
C. Gargiulo (ALICE ITS3), Forum on Tracking Detector Mechanics 2021

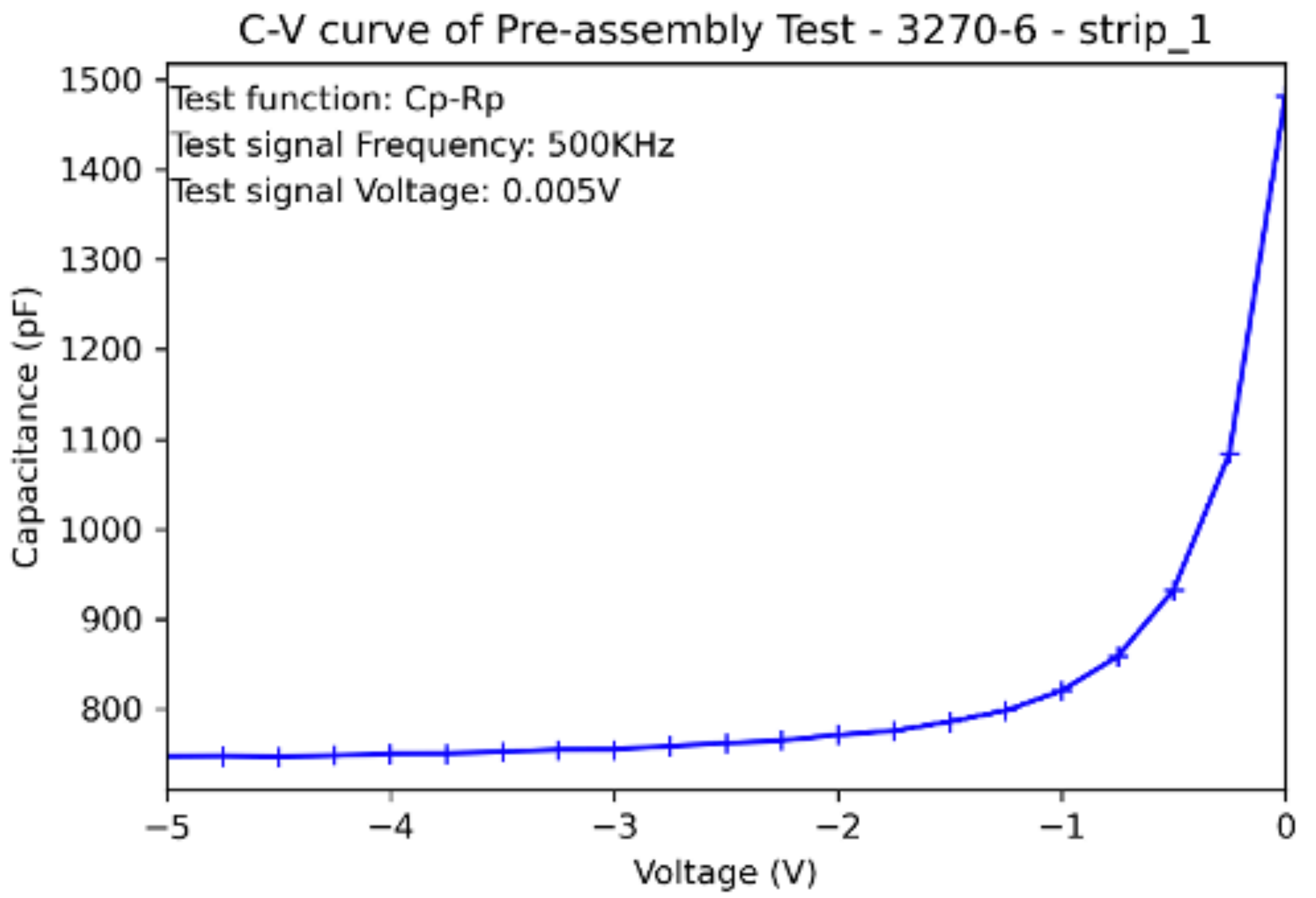
# Large scale module construction

- 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 |



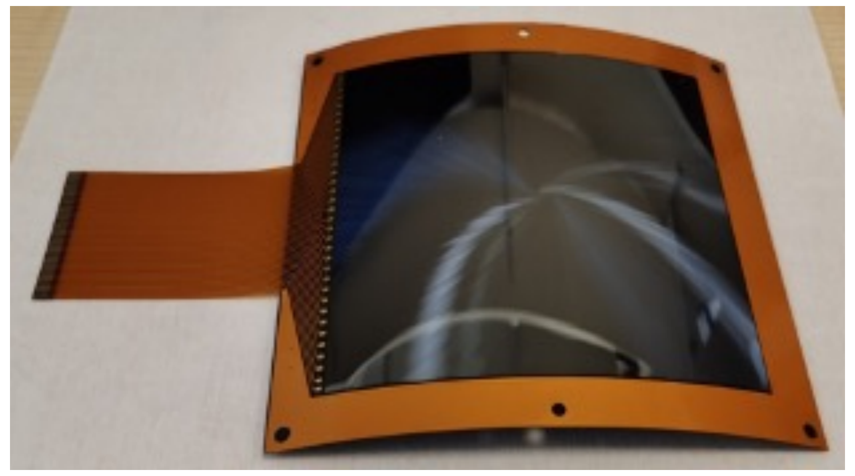


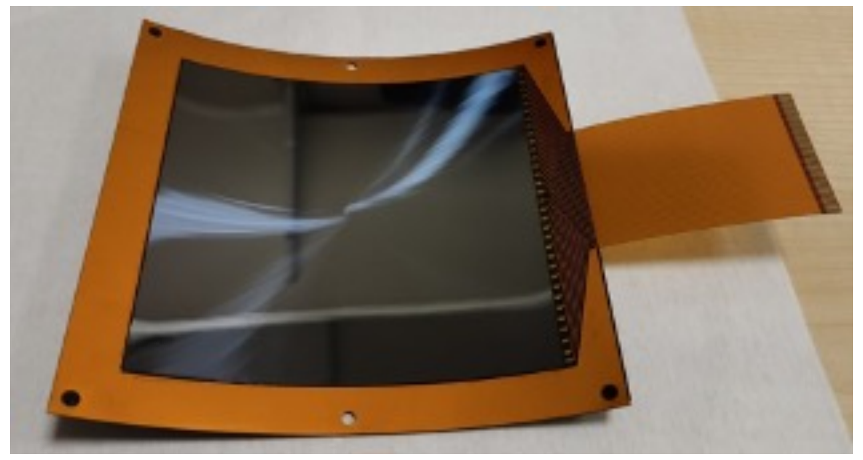
# Large scale module construction

- 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

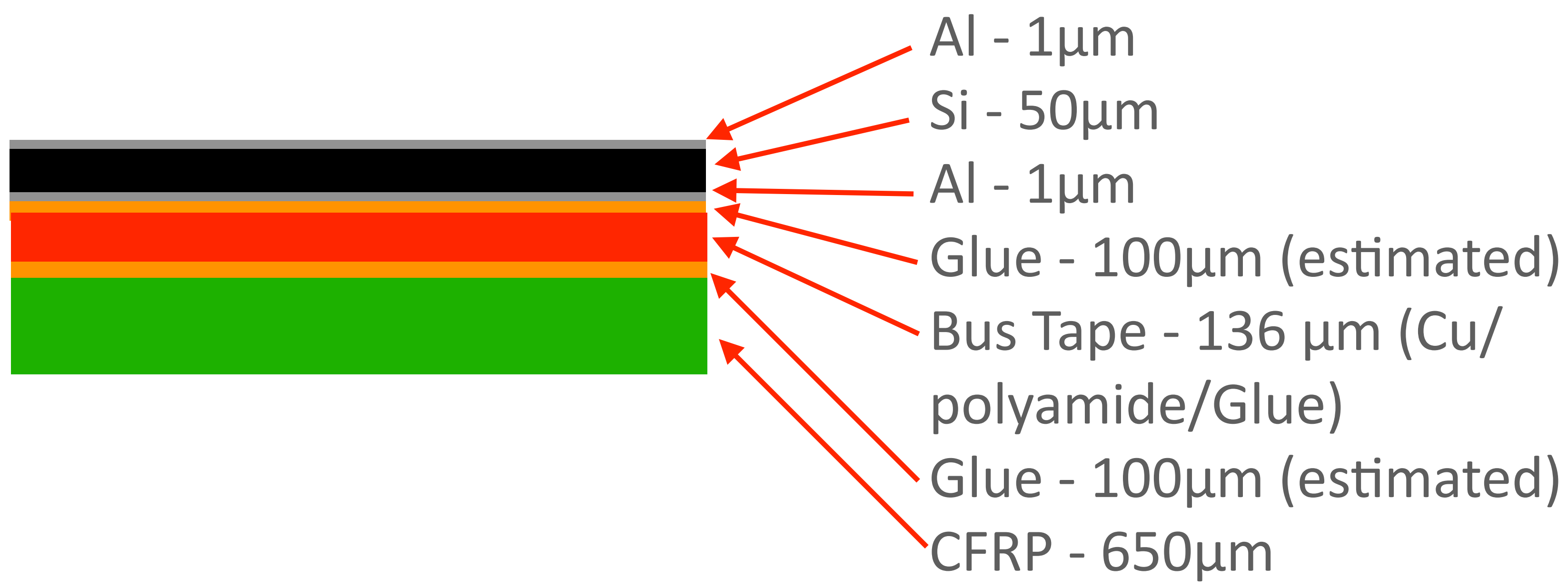


Convex, R=150mm

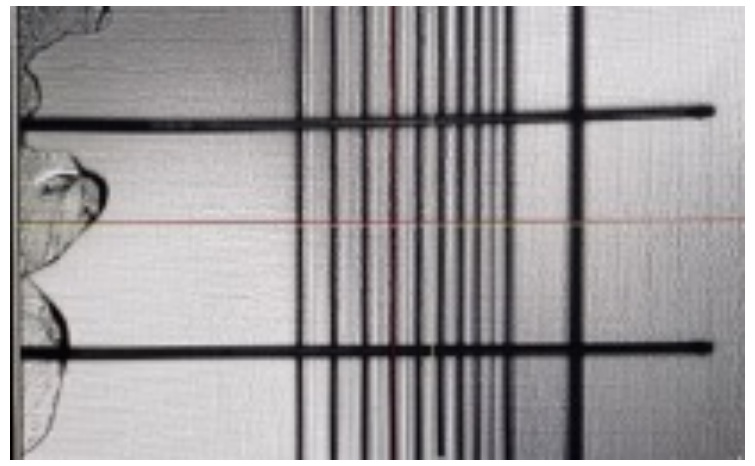


Concave, R=150mm

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

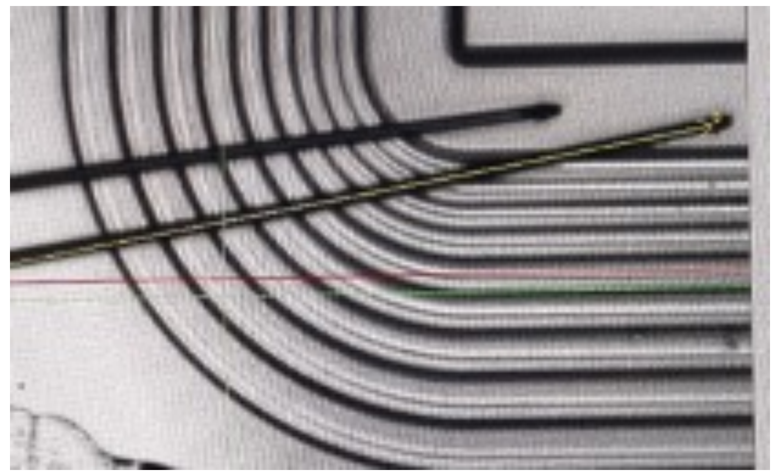



- Wirebonding is a little more tricky than with a flat module:



Bonding to a strip

Overview

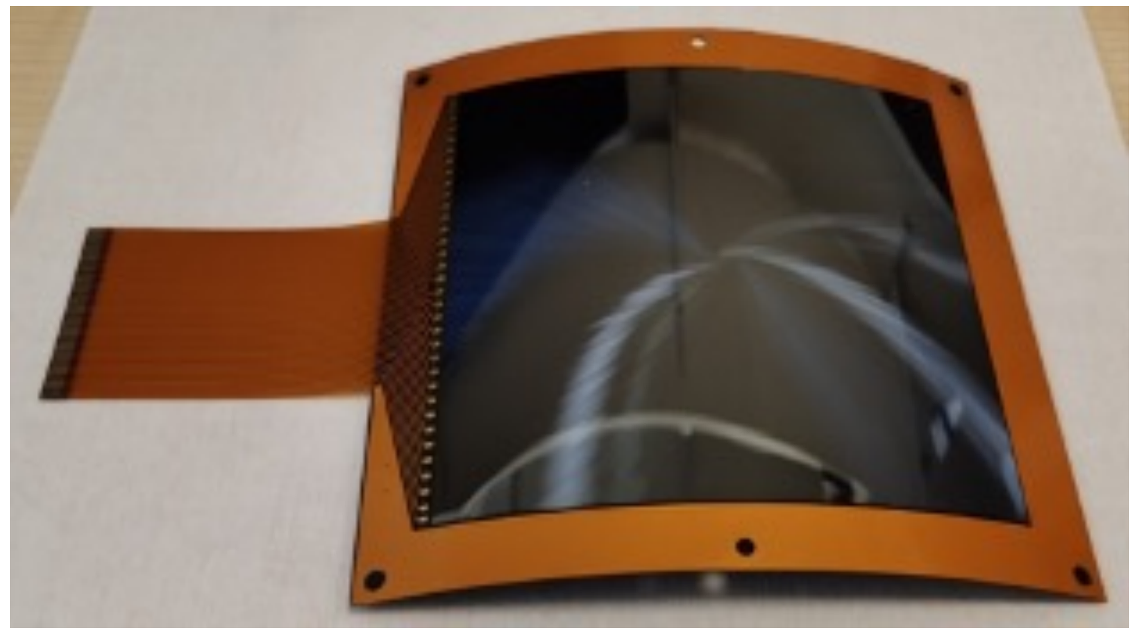


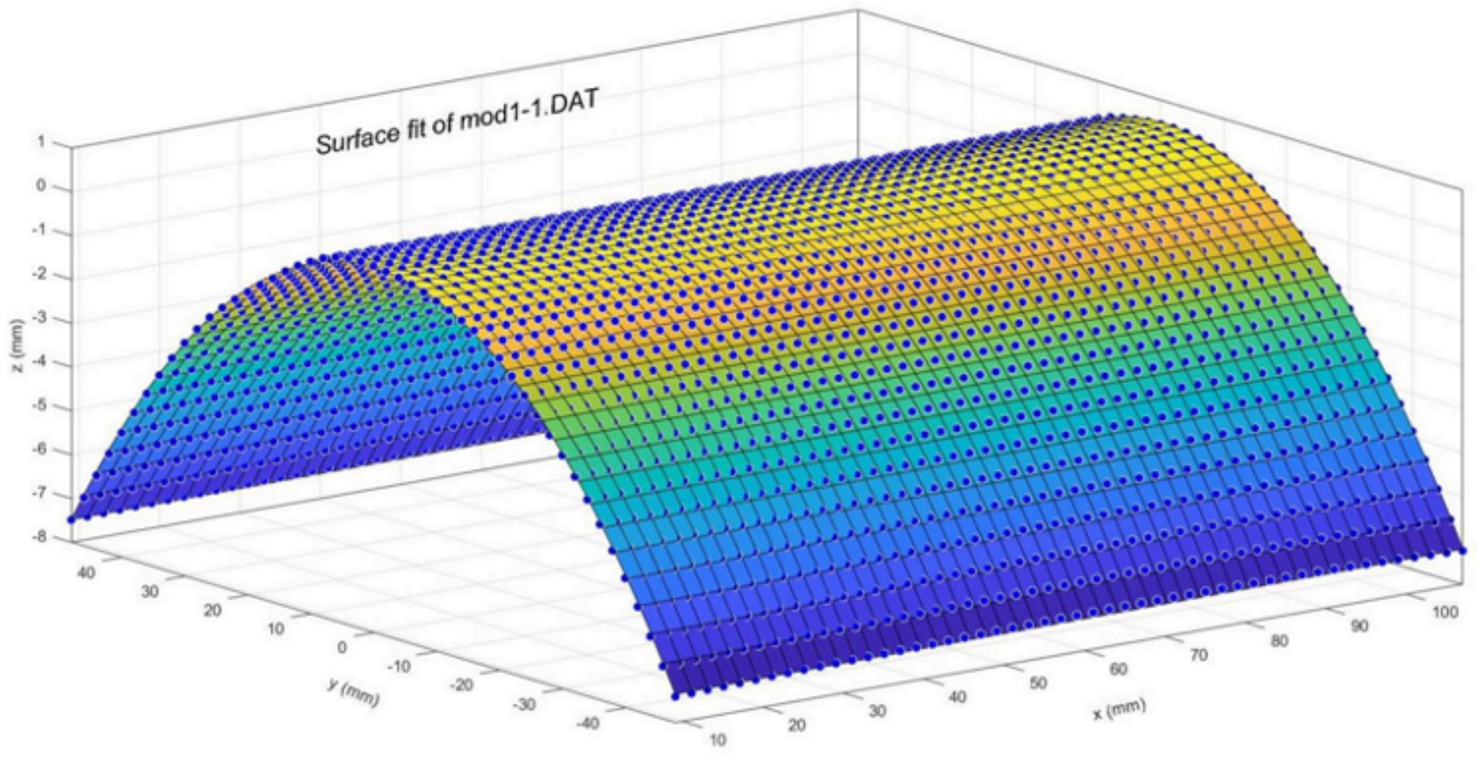
Guard Ring

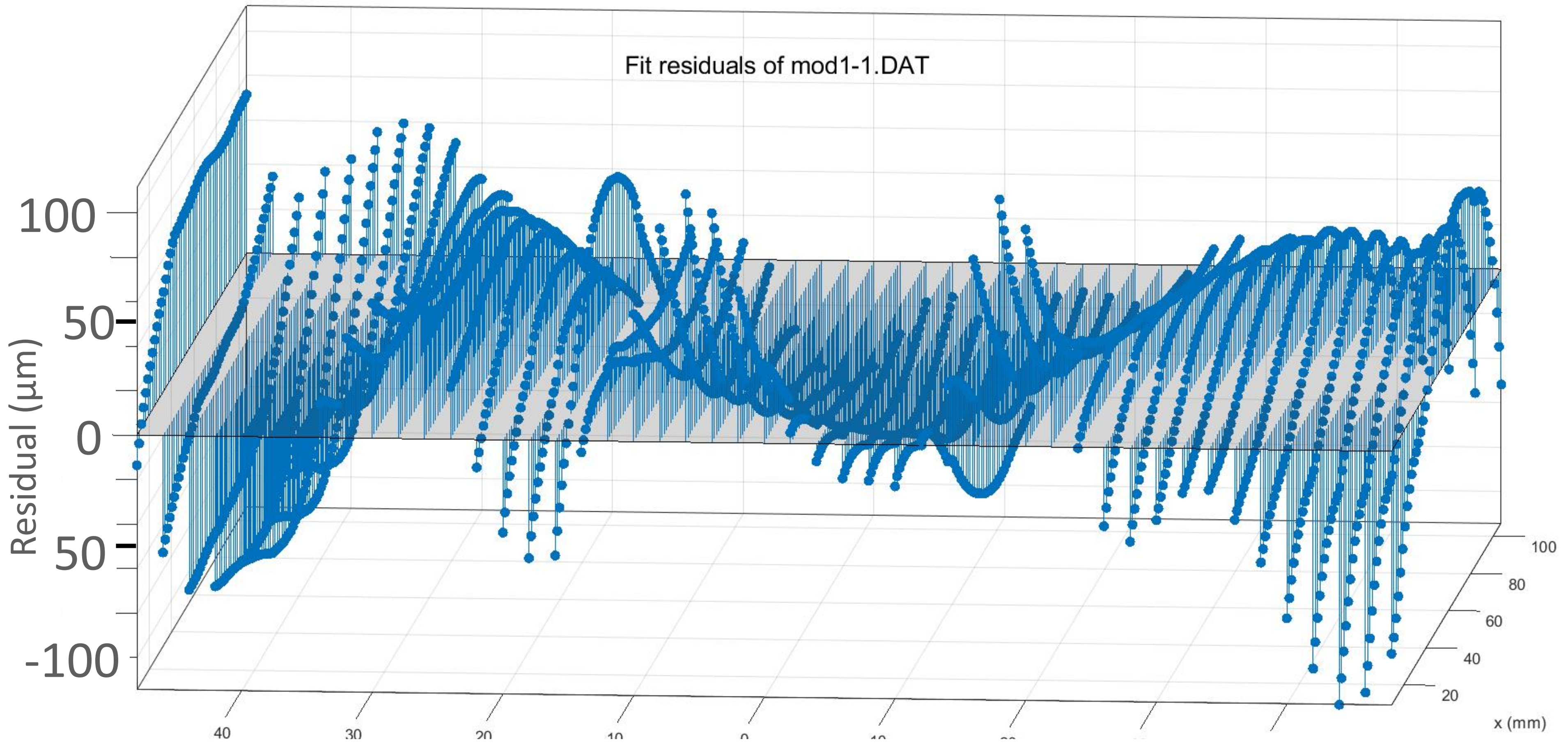
# Test results: surface shape

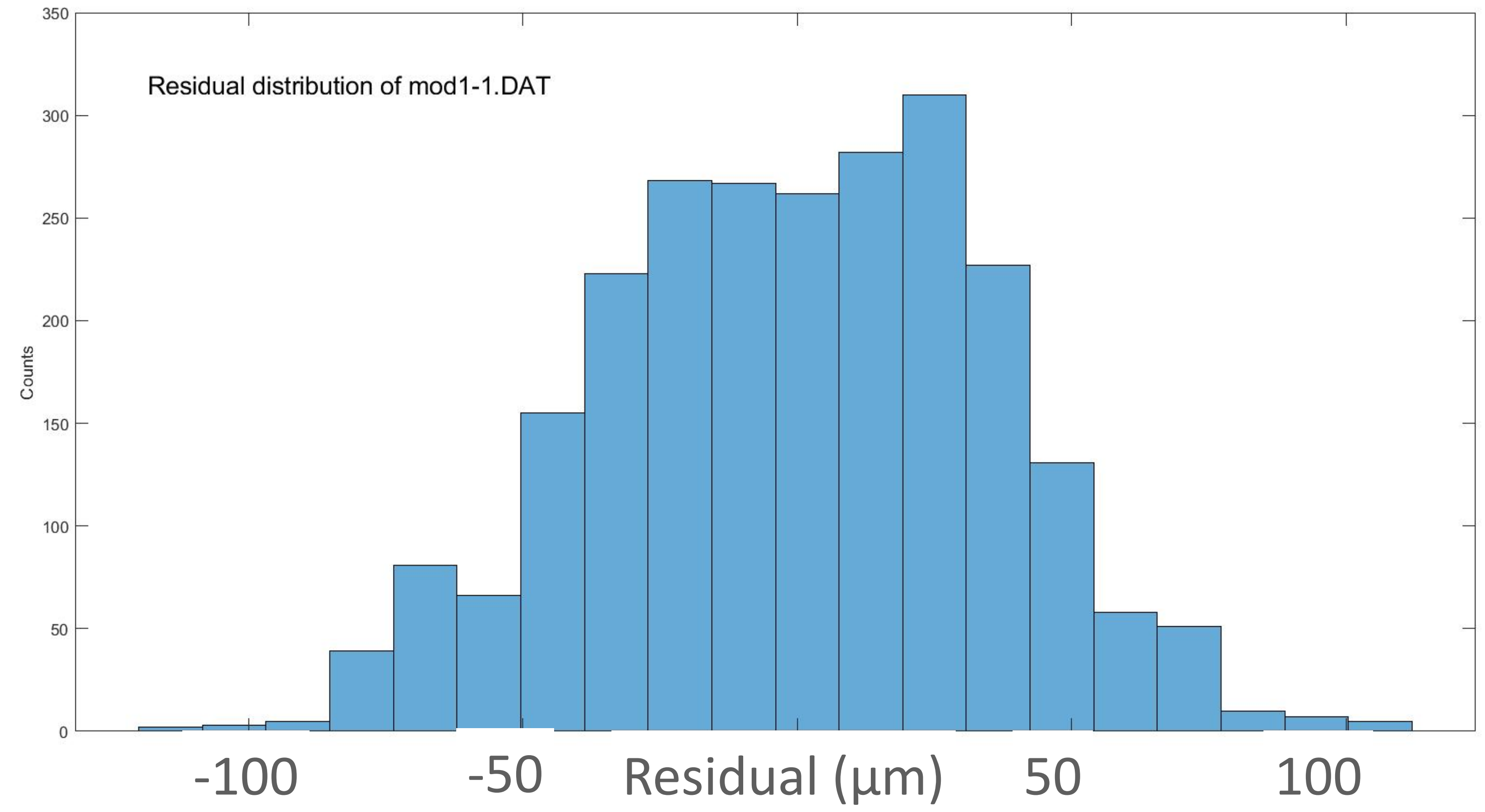
- Use a smartscope laser-scan of the surface to measure the form

- Matlab fits the surface to a given model (add twist)





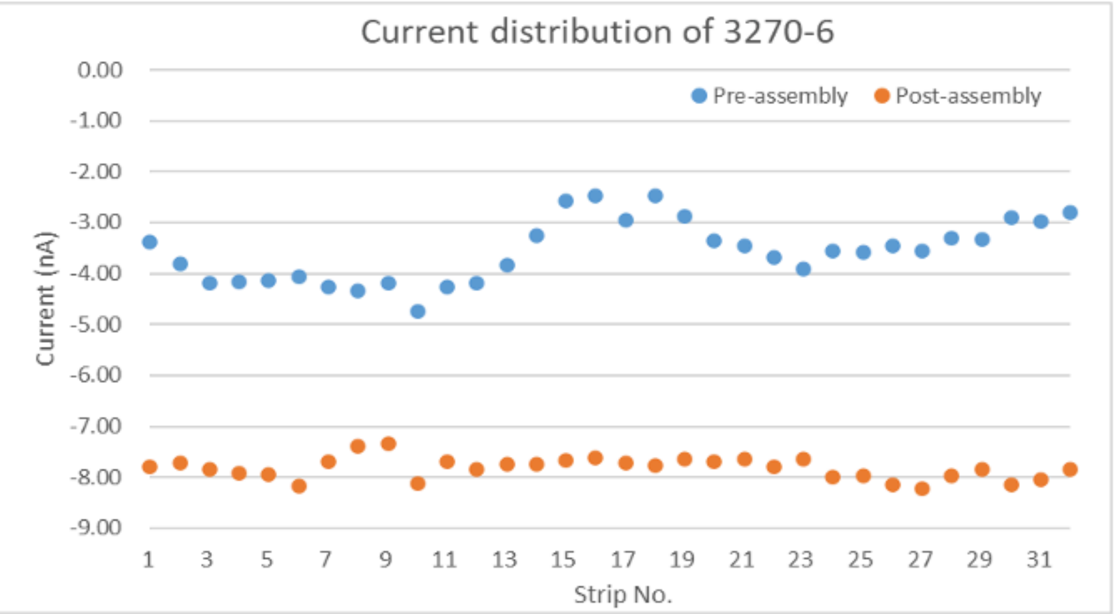



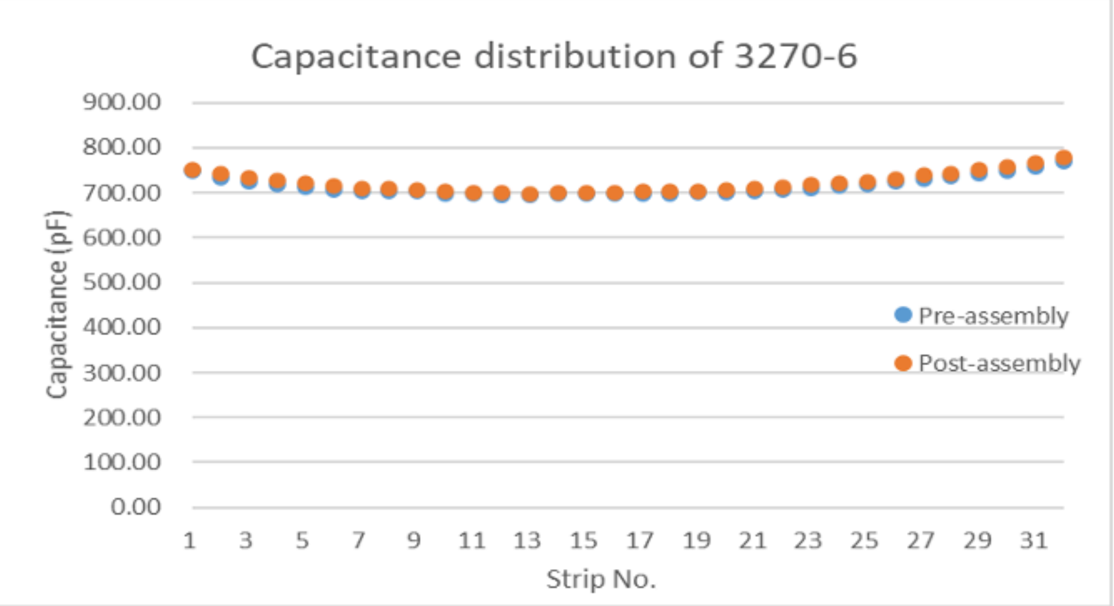

- Residuals vary across the module but remain acceptable
  - Slight improvement if we allow for a twist term (*)
- Room for improvement with tooling and assembly procedure

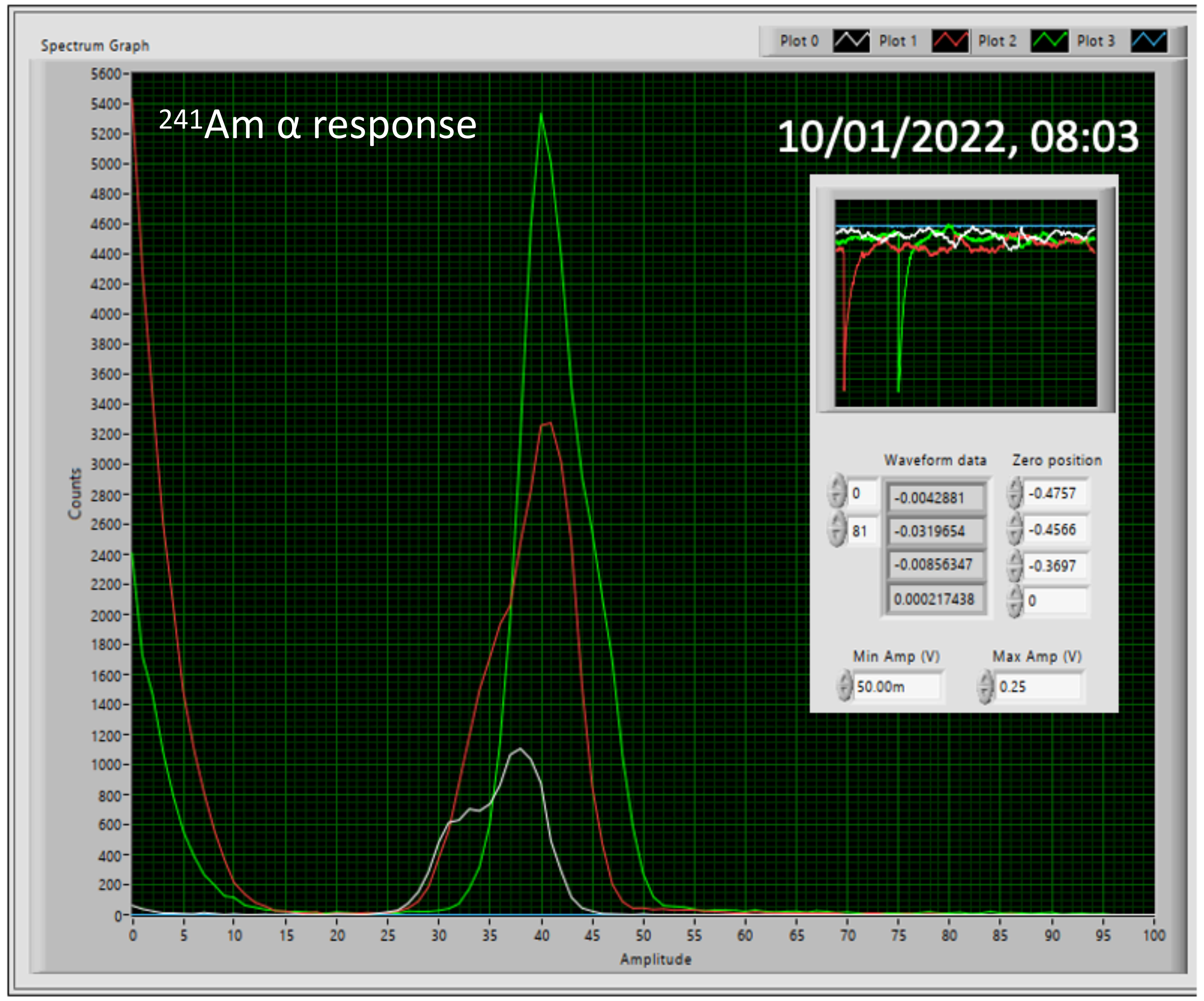
(*) See backup - based on CMS alignment model

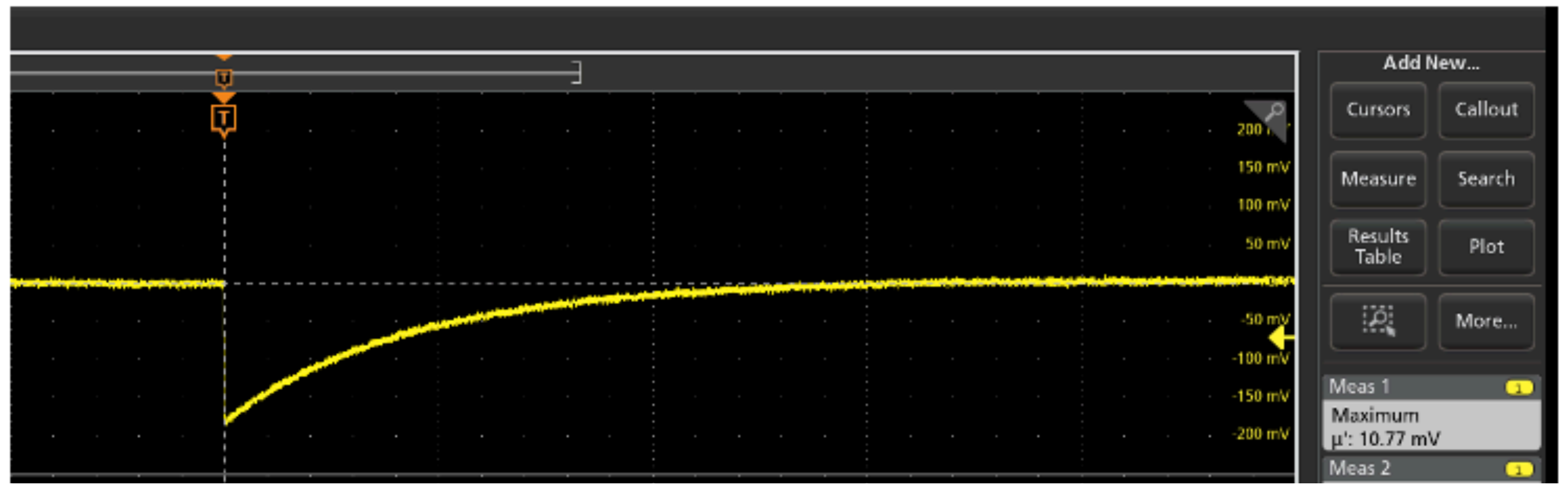
# Test results: electrical performance

- 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)
- Can improve further with shaping amp



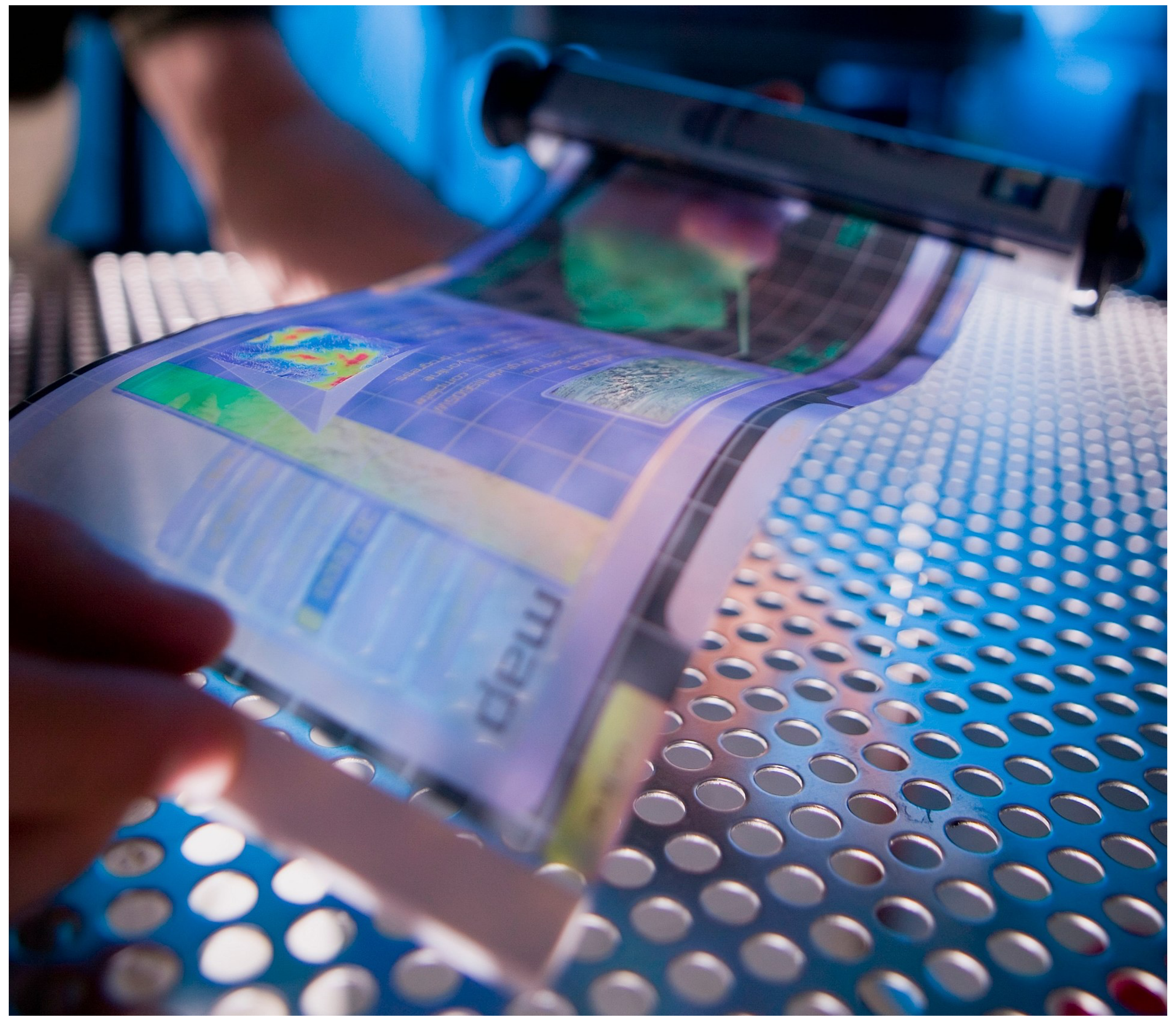



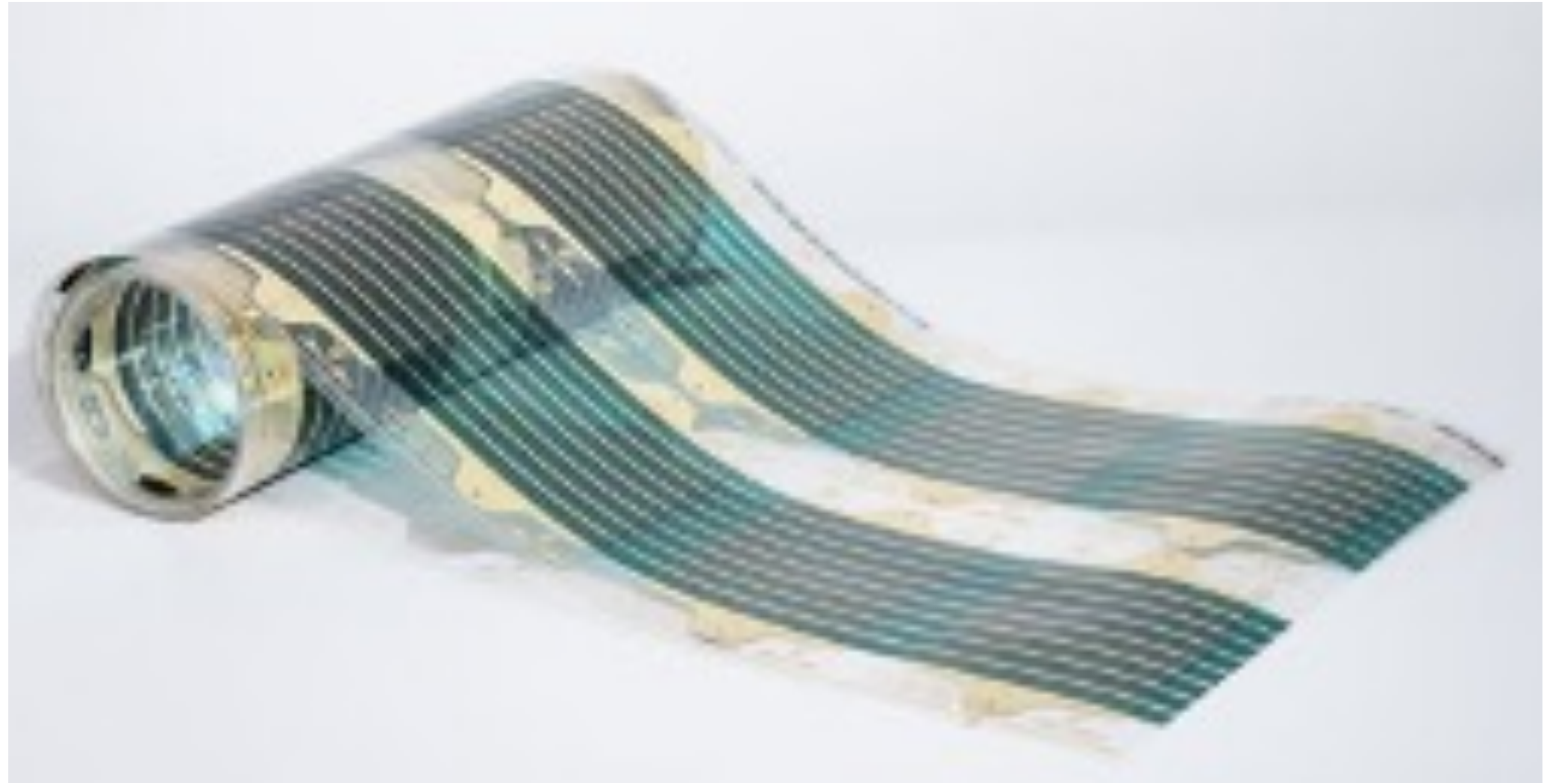
# Organic Semiconductors

- Cheap:
  - Few k per m2 for industrial organic semiconductors
  - More expensive for research materials

- Scalable:
  - Mainstream consumer electronics: smart devices, TVs etc.

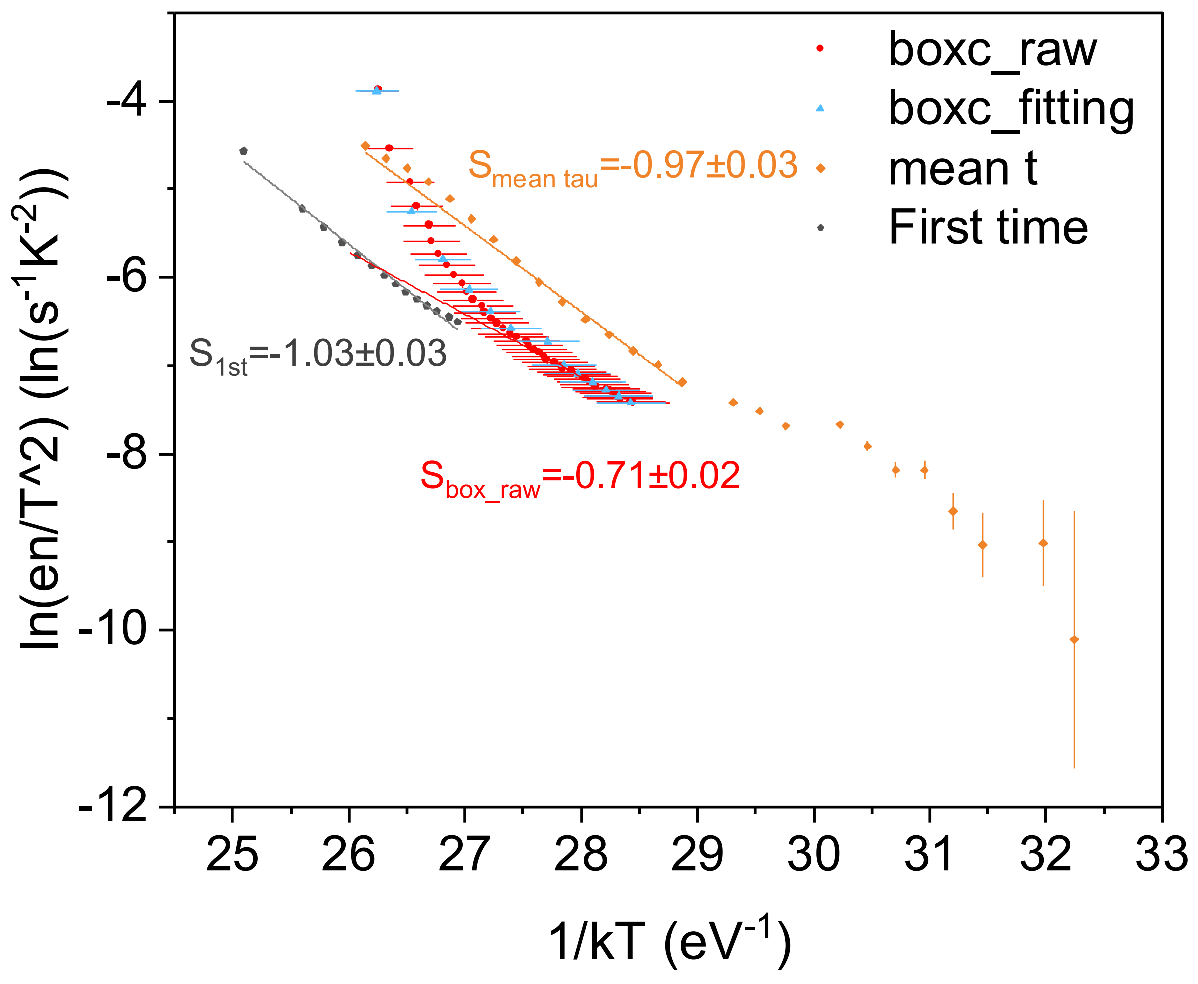
- Flexible:
  - Make on a flexible substrate to get a sensor that conforms



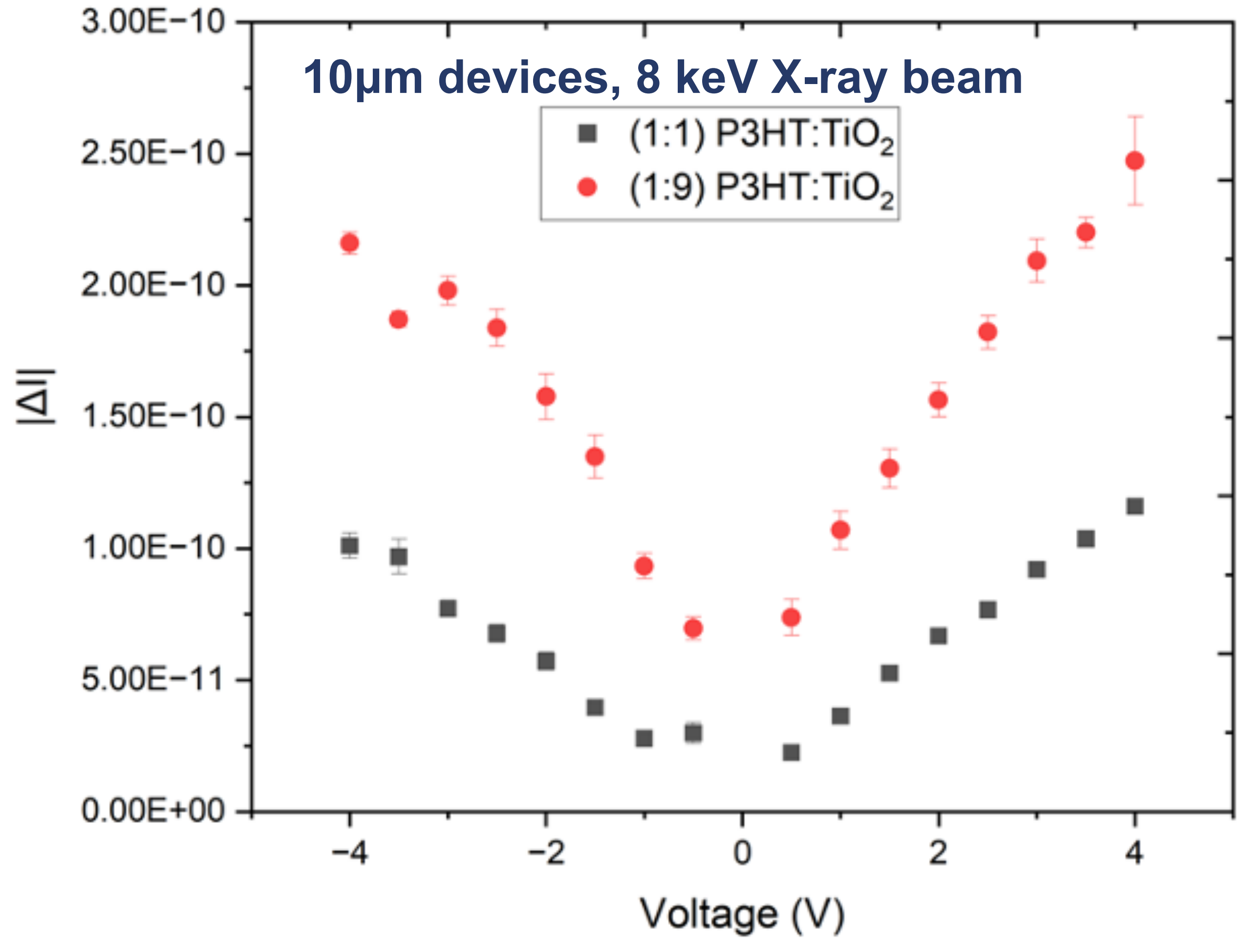


# Organic Semiconductor Radiation Detectors

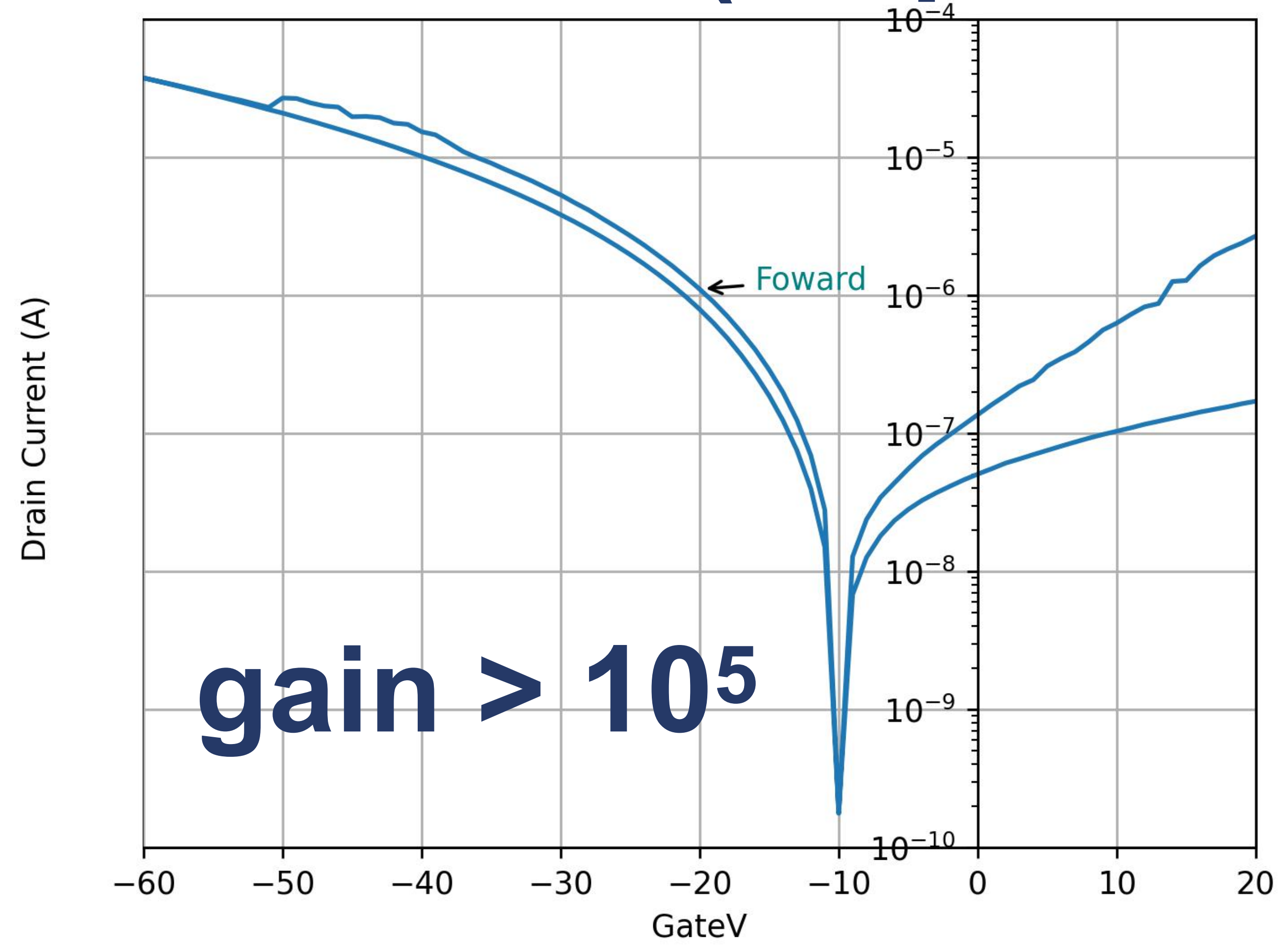
## Studying trap states




## X-ray detectors

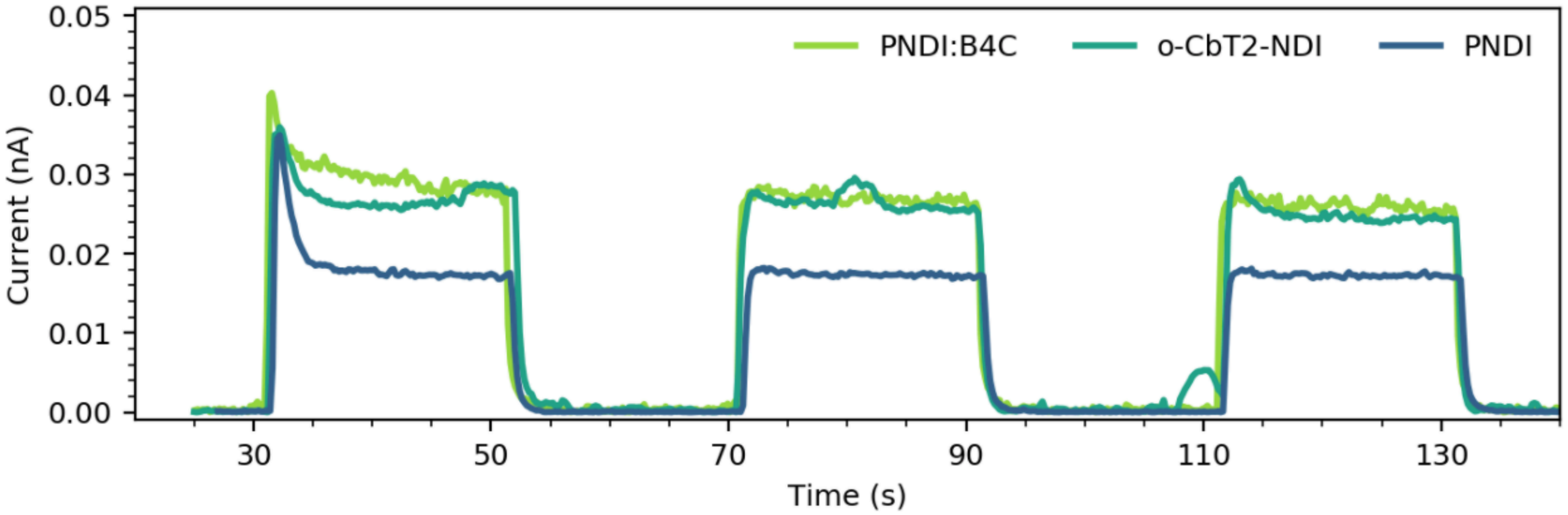



## Transistors (amplifiers)



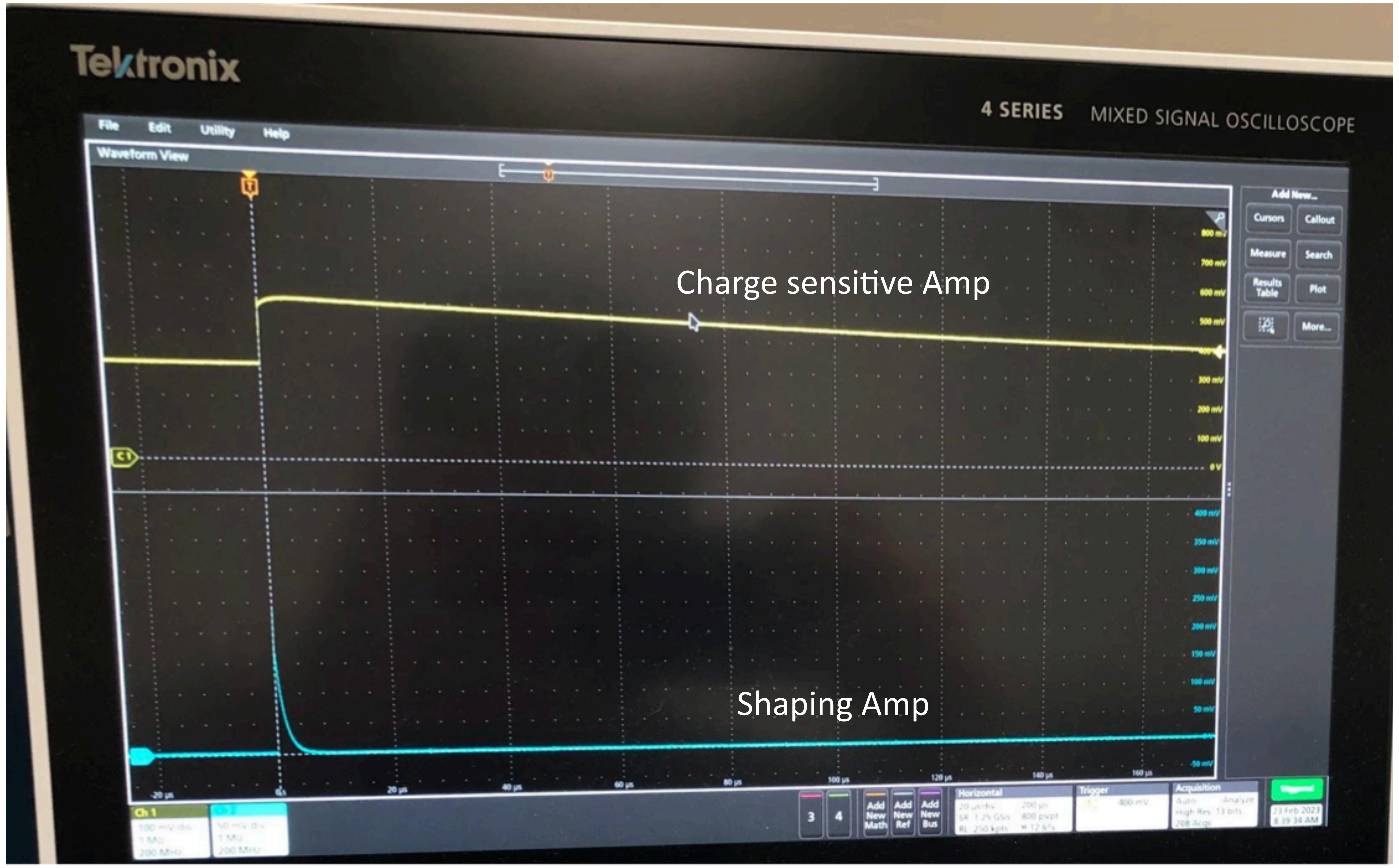

## Field tests @ National labs

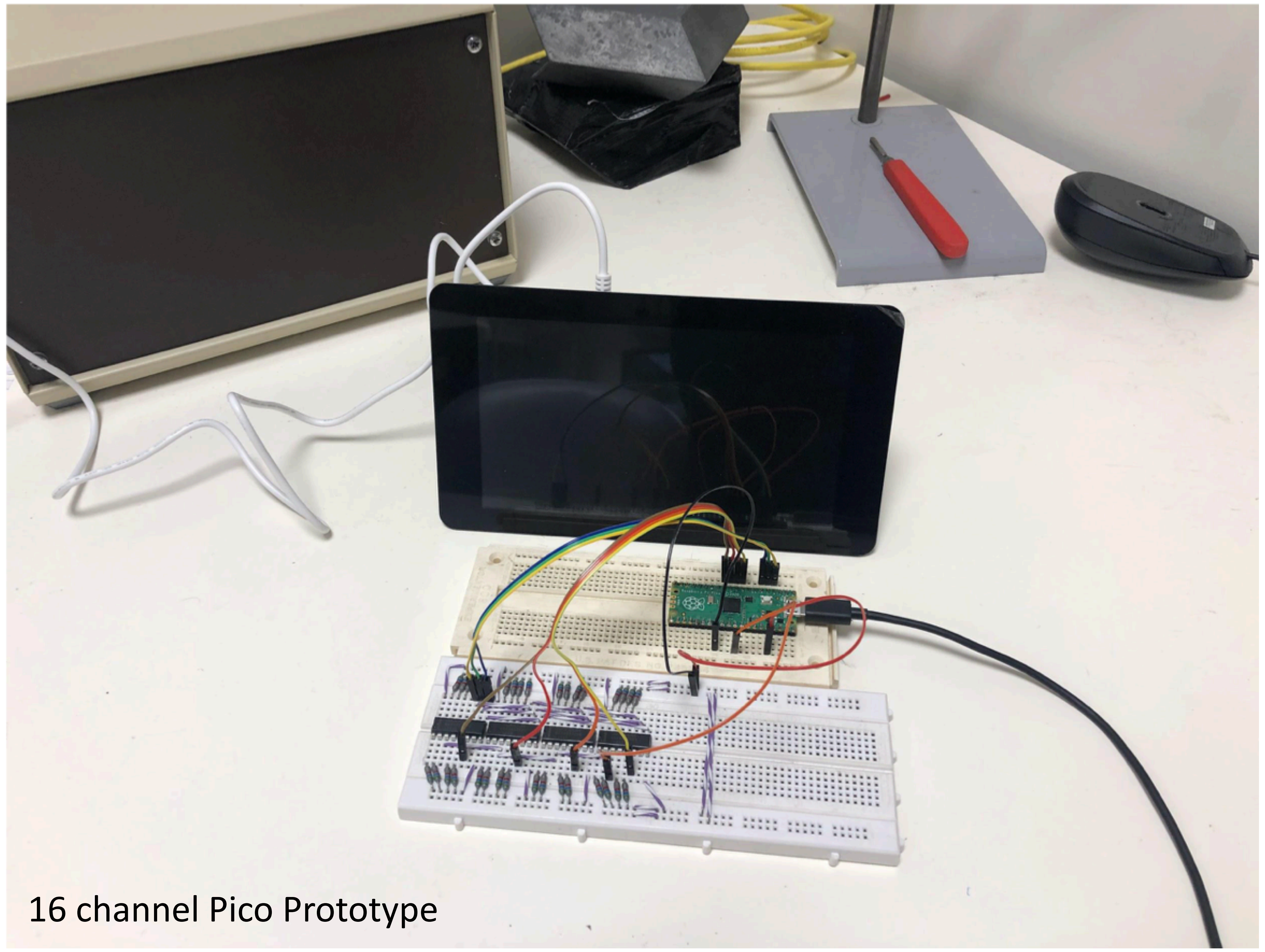
## Diodes for α and n detection



# A COTS readout solution

- Want a cheap scalable data acquisition system to be able to demonstrate proof of concepts



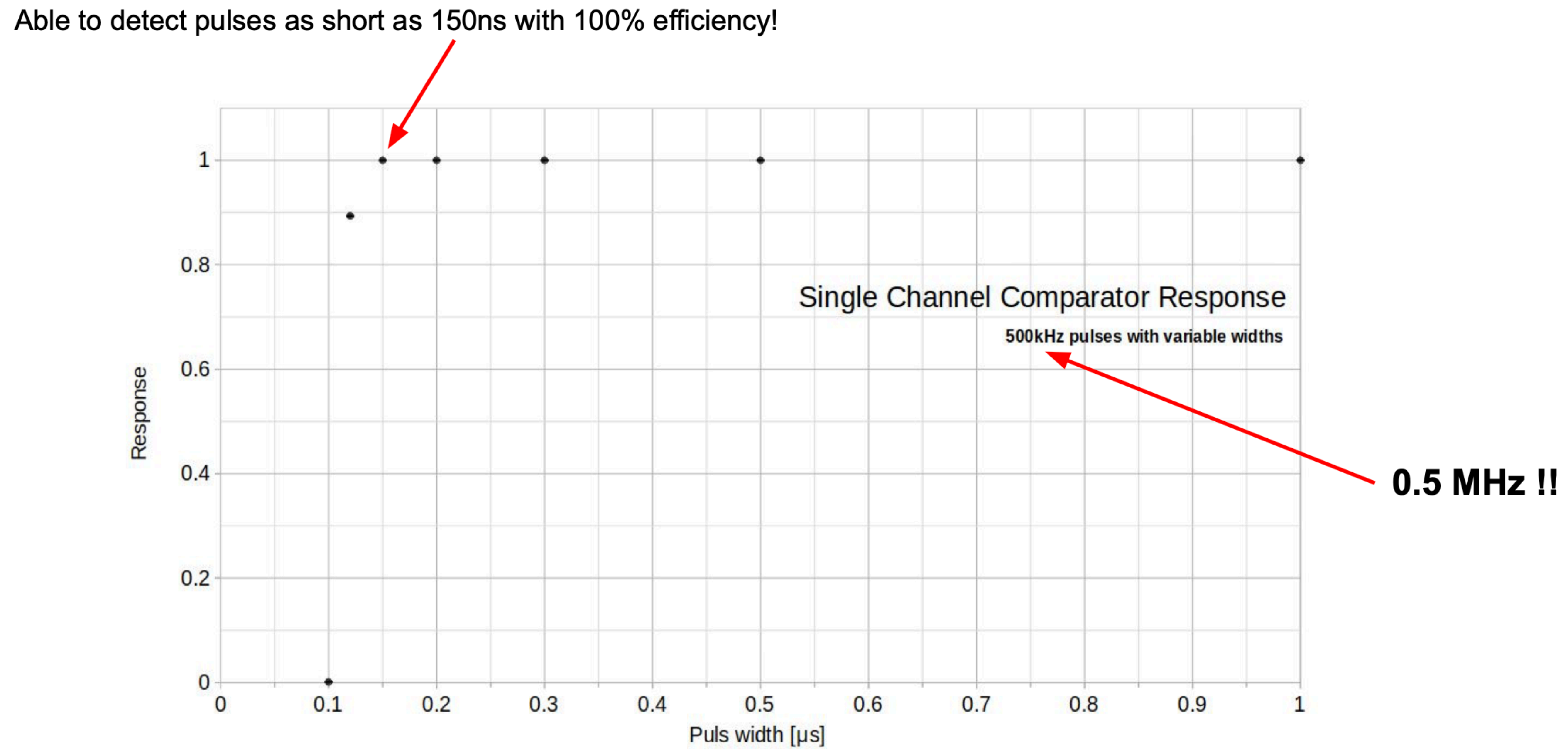



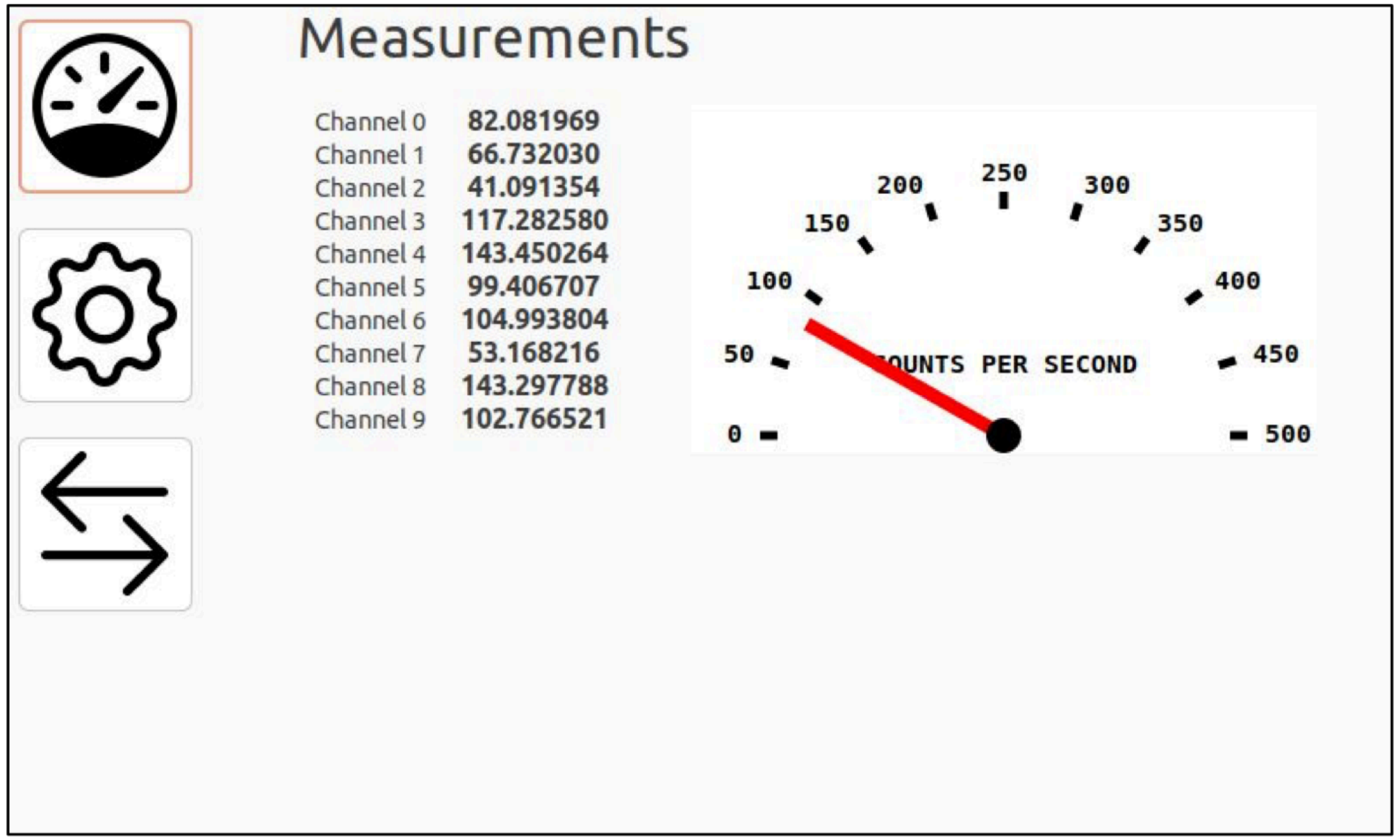
16 channel Pico Prototype

# A COTS readout solution

- Able to efficiently monitor radiation with a 150ns clock and a rate of up to 0.5 MHz
- GUI developed for simple interpretation of the count rate being read out

Response for comparator+Pico set-up



# Future work

- Finalising a proposal with Micron Semiconductor Ltd. NNL, Dounreay, ARC and other commercial partners on the curved thin silicon work:
  - Includes robotic deployment using the technology Kaspar talked about
- Have just been awarded an NDA studentship to work on developing a flexible organic semiconductor radiation detector to test with decommissioning applications.  Here we are working with NNL, Sellafield and Dounreay.
- Evaluating the prototype DAQ system and will test with silicon, diamond and organic systems to be able to bridge sensor R&D to proof of concept demonstrator
  - We know what we want for research and will develop tools in that direction
  - BUT - feedback from industry partners will be invaluable to ensure we develop something usable for the real world

# 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
- Developing COTS DAQ based on a Rasberry Pi + Pico system
- Starting to look into applications for pipe inspection

# QMUL's Detector Development Group

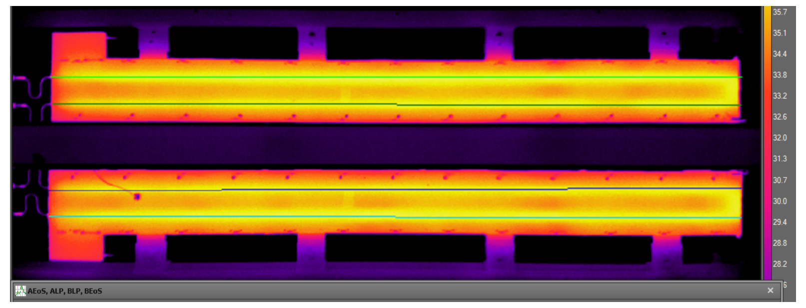
Fully equipped ISO 7 certified clean room

A multidisciplinary team of experts working on

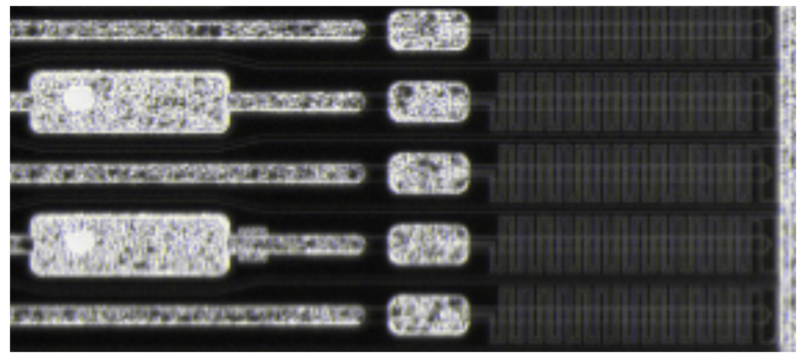
- Novel radiation sensing technologies
- Instrument design and construction
- Radiation damage simulation

for particle physics and industrial application

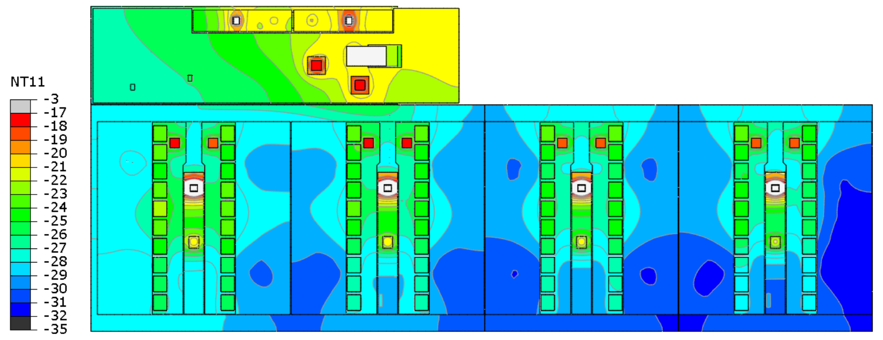
| Technologies | Simulation |
|---|---|
| Diamond | ABAQUS |
| Silicon | DL_POLY |
| Organics | FLUKA |
| Graphene | GEANT4 |
| Perovskite | MCNP6 |
| Scintillator | Zeemax |



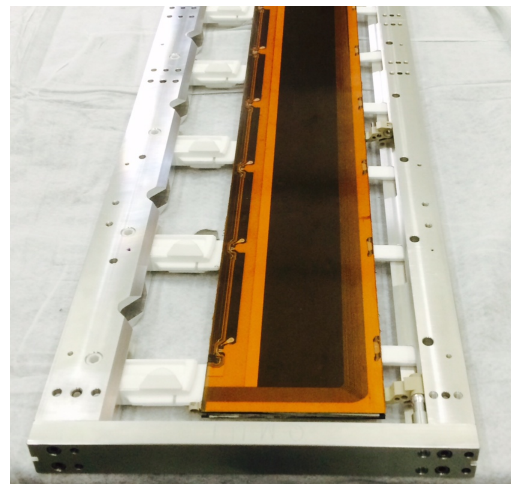
Infra-red thermal imaging system



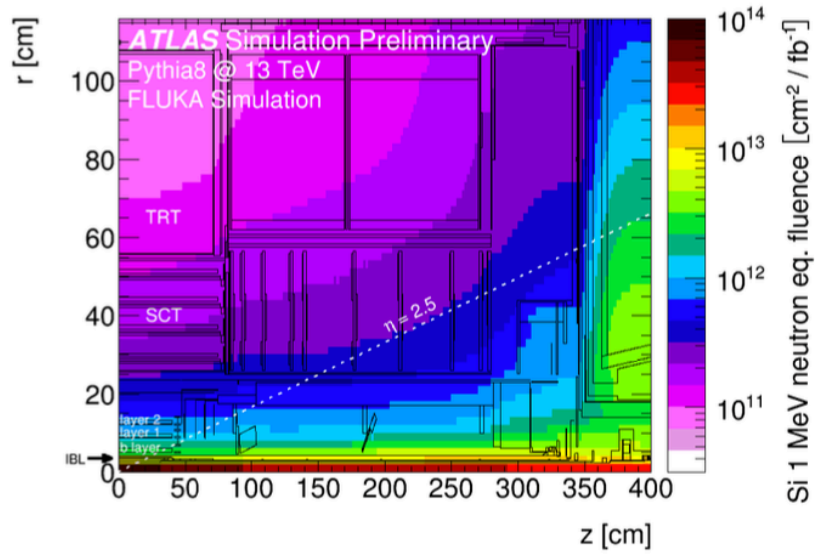
Silicon strip sensors for LHC



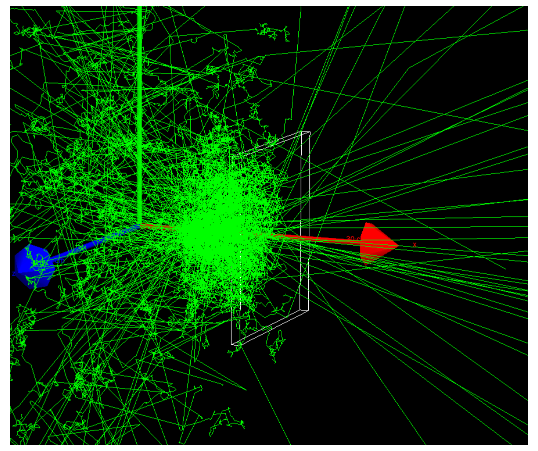
Heat transfer simulation for detector system cooling design



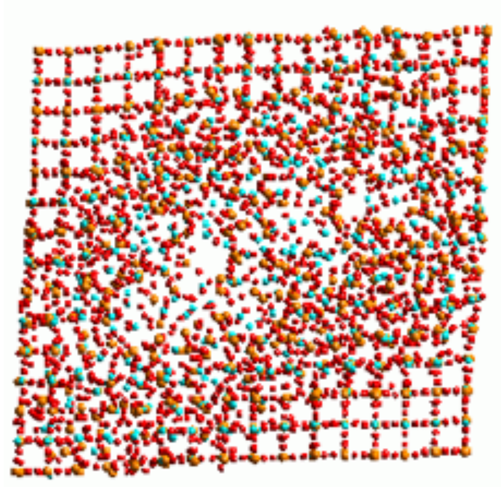
Module assembly engineering




FLUKA radiation environment simulations



Geant4 sensor interaction simulations



DL_Poly material damage simulation