Zero Mass Detector Project

Seth Zenz, 7 September 2022

Future UK Silicon Vertex & Tracker R&D Workshop

Zero Mass team: Adrian Bevan[1], Ian Dawson[1], Jens Dopke[2], Jag Mistry[1], Sam Moss[1,2], SZ[1], Zhidong Zhang[1]

[1] Queen Mary University of London, UK

[2] RAL PPD, UK

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

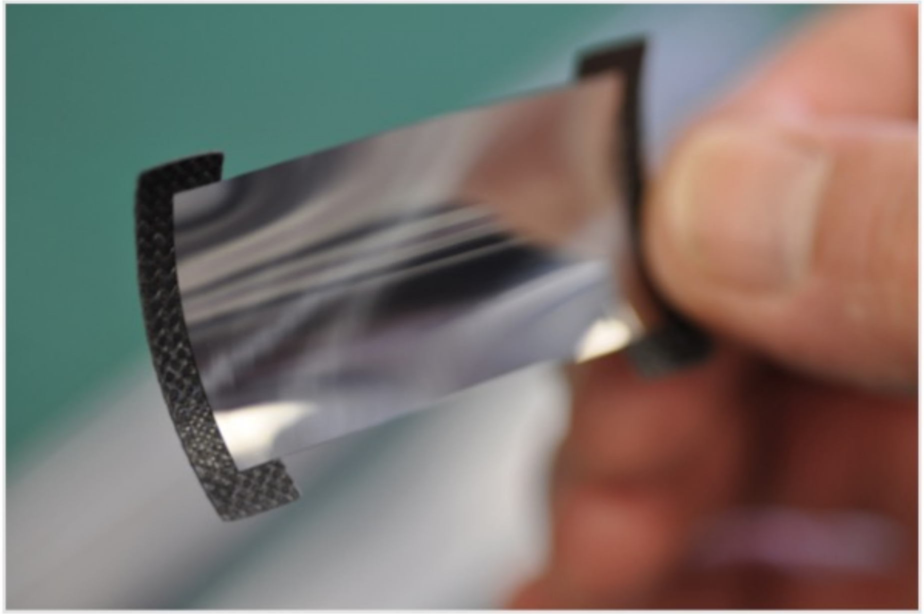
Rationale

- Tracker mass degrades performance

- We want to:
  - Minimise support material
  - Minimise sensor material
  - Maintain electrical properties and measurement capability
  - Maintain consistent and well-described position

Early Concept Prototyping

- Ultrathin silicon has long been known to be flexible
- 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
- **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.
  - Radius down to 13mm
  - 50 µm samples easier to handle than 25 µm
- Rigid supports on two sides sufficient for a self-supporting silicon structure, but this talk focuses on results with 4-sided supports



Curved silicon with a 2.5 cm radius of curvature on a carbon-fibre support, demonstrating the feasibility of making low-mass, rigid FCC-ee detector systems. Credit: Queen Mary University of London.

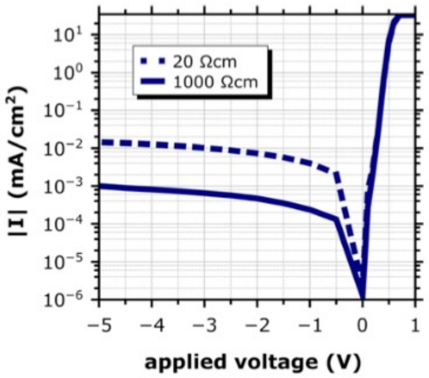
https://cerncourier.com/a/spotlight-on-fcc-physics/

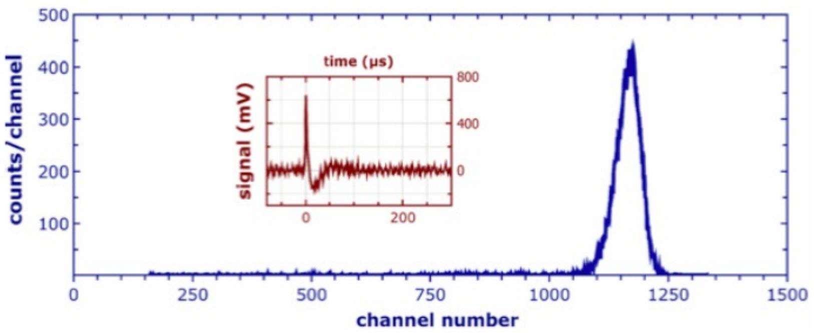
Other example applications

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

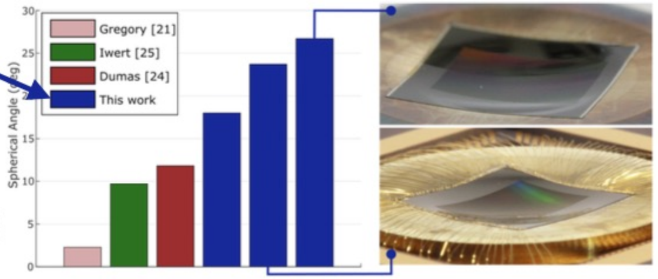
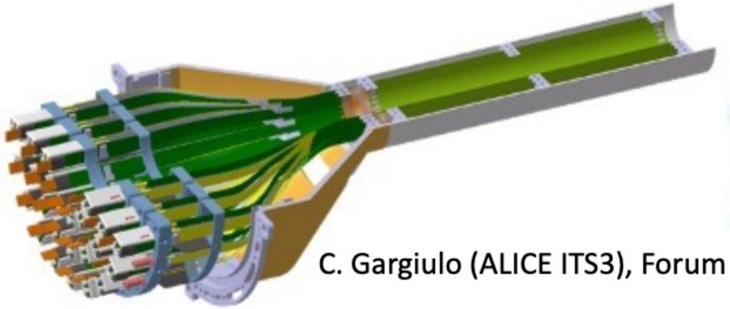
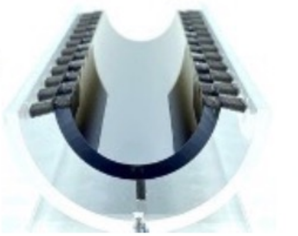


Fig. 5. Comparative graph of curvature achieved in working sensors between this work and the significant work from the literature. A wirebonded sensor used for one camera in this study is shown in the lower right, having a spherical curvature of 23.7°. The working sensor in the upper right has a curvature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

ALICE ITS3 project



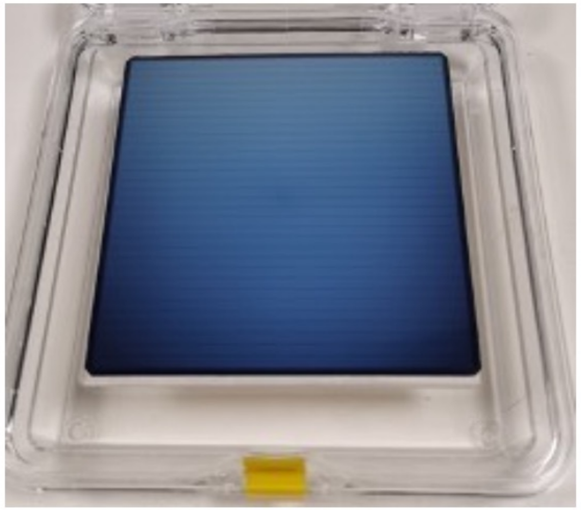


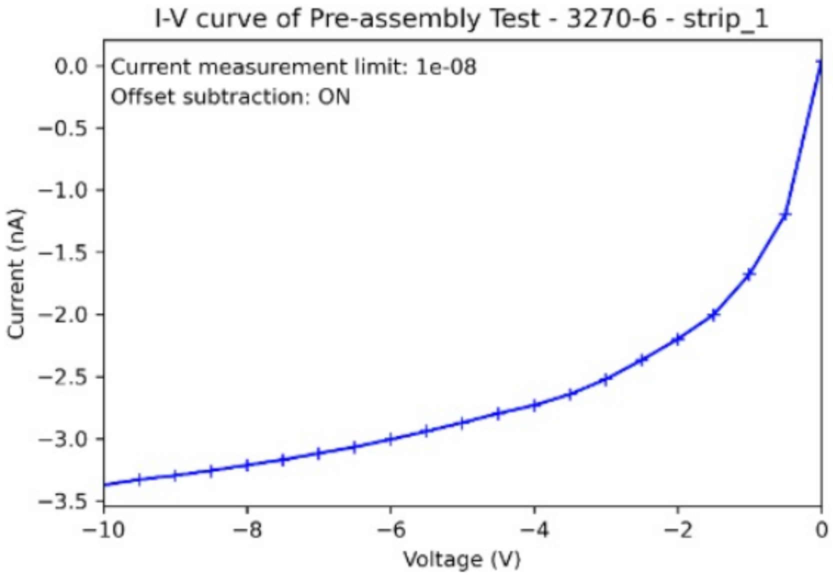
C. Gargiulo (ALICE ITS3), Forum on Tracking Detector Mechanics 2021

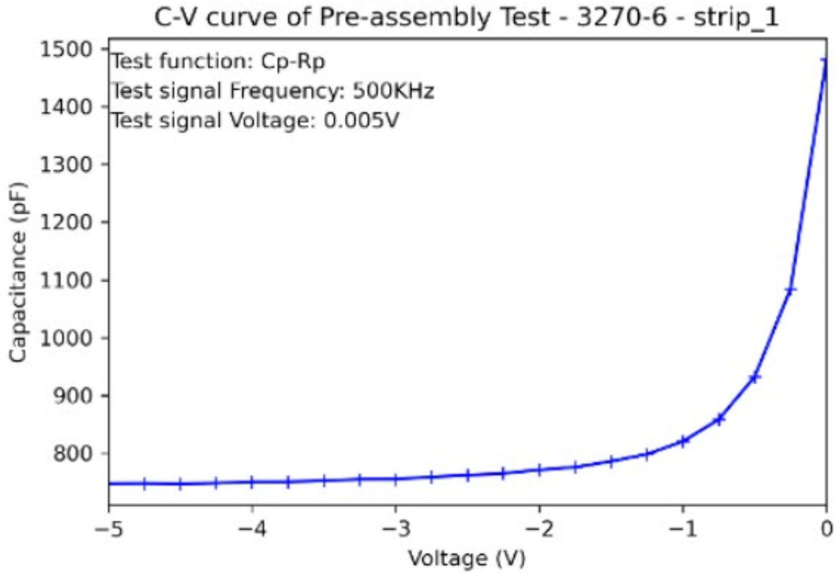
Large Module Construction

- 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



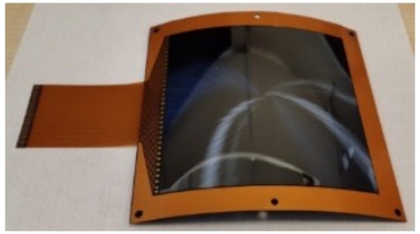




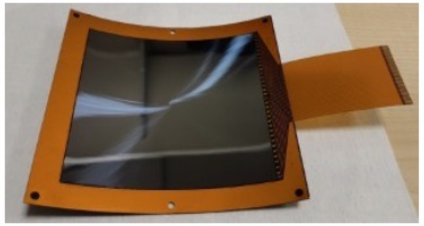
Large Module Construction

- 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



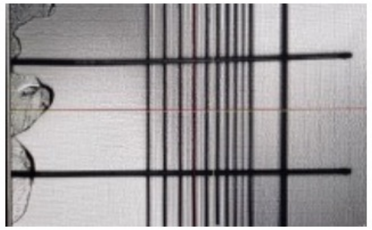
Convex, R=150mm



Concave, R=150mm

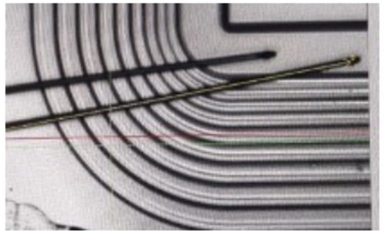
- Module layup for each of these variations is the same:

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



Bonding to a strip

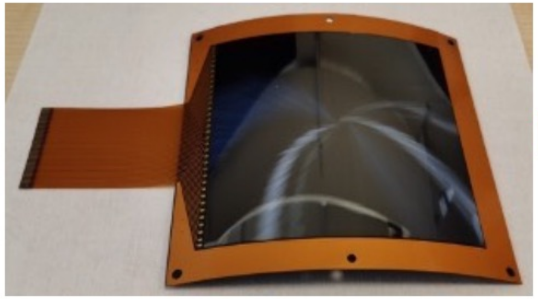
Overview

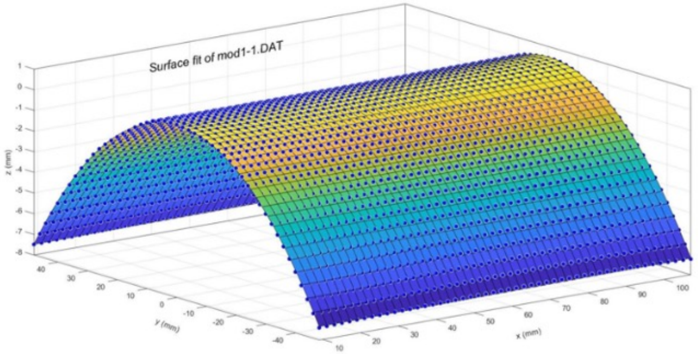


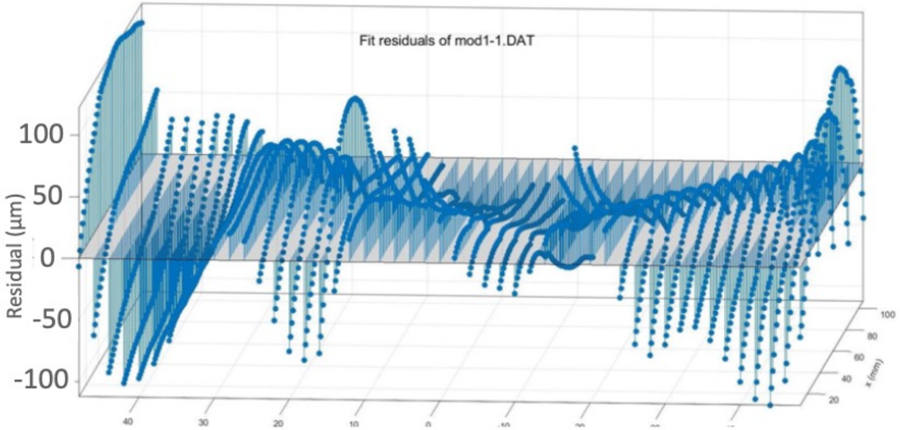
Guard Ring

Test Results: Surface Shape

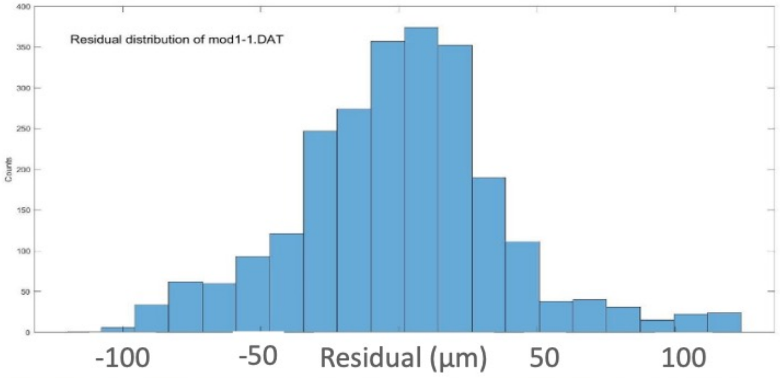
- Use a smartscope laser-scan of the surface to measure the form
- Matlab fits the surface to a given model (cylinder shown)







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



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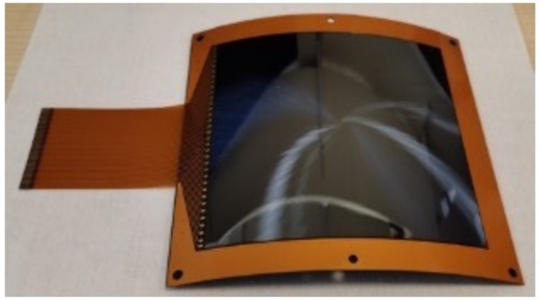
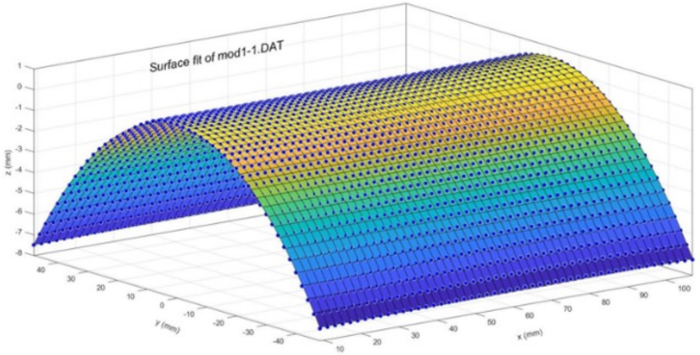
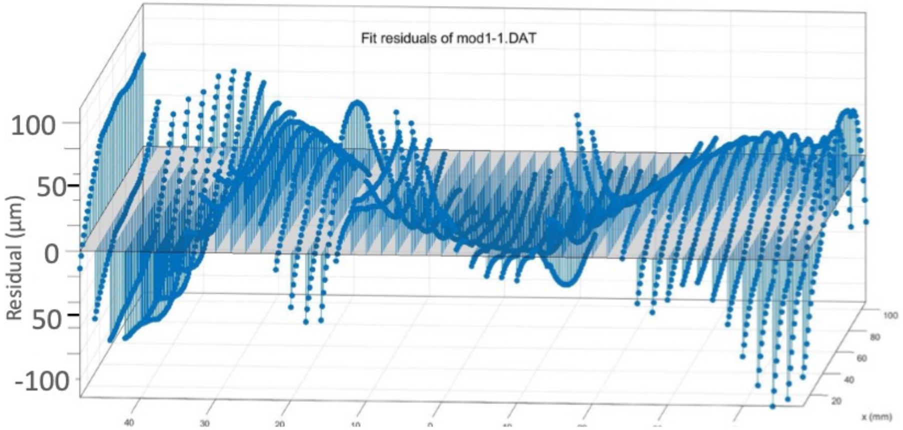
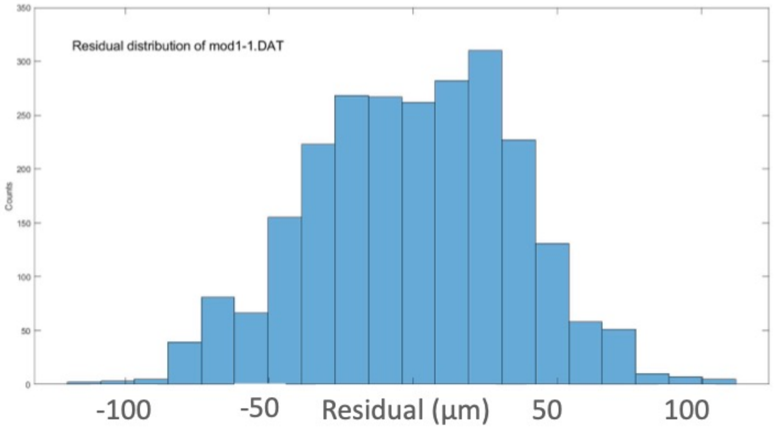








- Residuals vary across the module but remain acceptable
  - Slight improvement if we allow for a twist term (*)
- Room for improvement with tooling and assembly procedure

(*) See backup

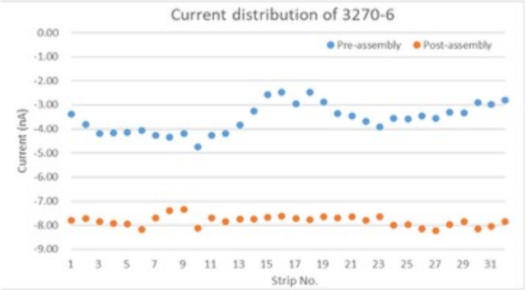
Test Results: Electrical Performance

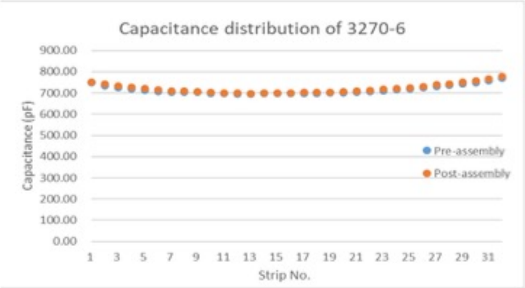
- Post assembly there is an increase in leakage current of 4-5 nA in sensors, but no notable change in the capacitance

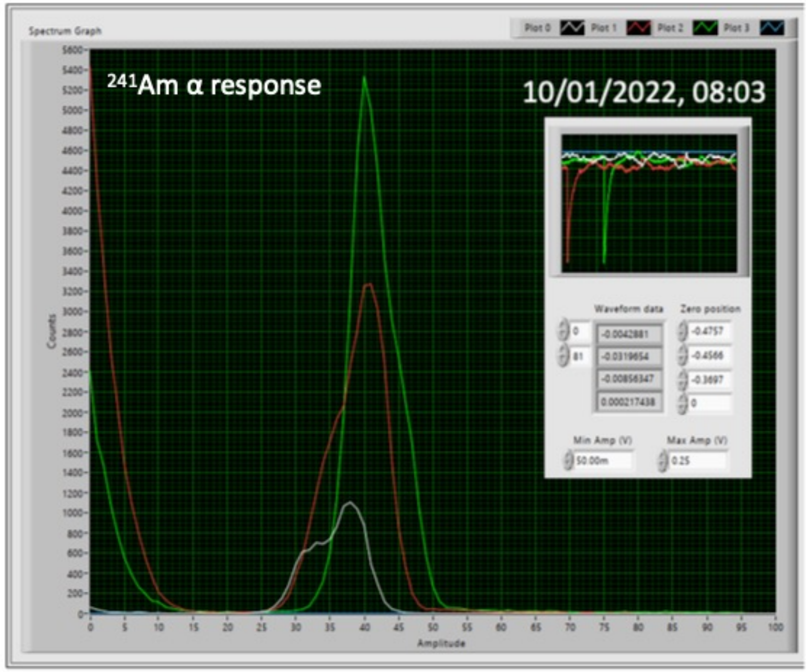
- Use a Cremat amp coupled with either a CRIO NI DAQ or a Tektronix MSO scope for testing

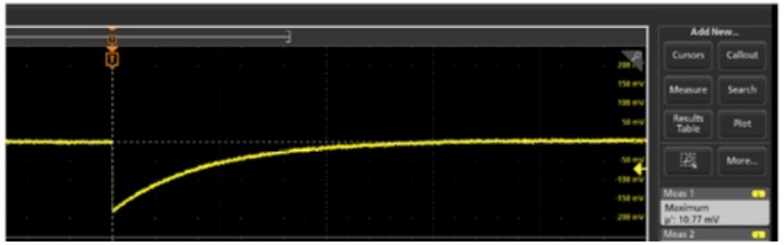
- Clear signals observed

- 3 neighbouring strips shown:
  - Closest to source (Green)
  - Adjacent (Red/White)



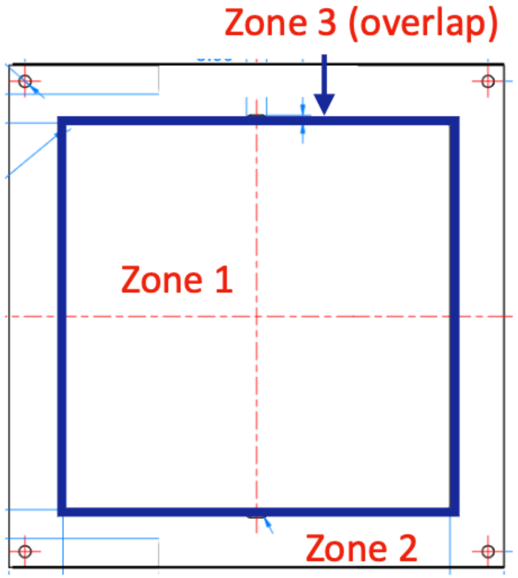


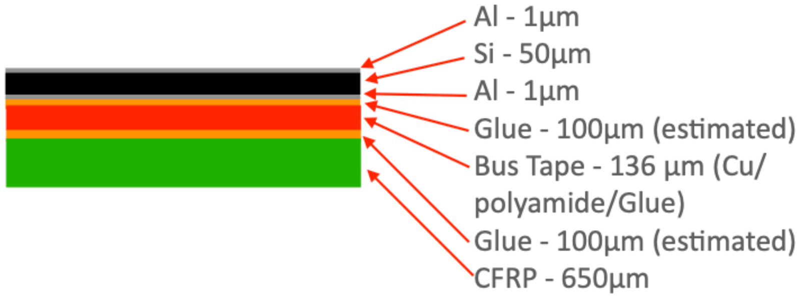




Test Results: X/X_0

- 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	0.281

- Dominated by CFRP and Cu contributions
- Clear improvements possible to drive down to 0.17% by modifying bus tape and support
- Could be advantageous for passively cooled trackers

Future Directions

- Current Project
  - Compare to flat module (ongoing)
  - Tooling for precision construction
- Future work with TTT10
  - More systematic measurements and comparisons
  - Irradiation
  - Thermal simulation: how far can we get with passive cooling?
  - Get a really good handle on impact of thinning and curvature with a well-characterized module!
- Move from strip sensors to CMOS

Conclusions

- Constructed curved modules up to 10cm x 10cm
- Leakage current increase observed for curved module, but acceptable level for particle detection
- Tested using ^{241}Am α particles in the lab
- More to explore and improve, but we think this is a promising approach to consider for a future low mass tracker system
- Looking forward to building collaborations that take advantage of this technology and the practical experience we are building with it!

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

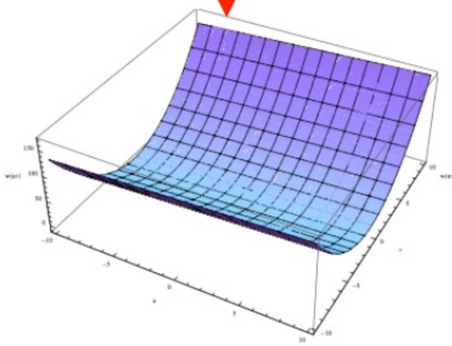
(x, y) is in sensor plane coordinate system, (u, v) is 3-space coordinate system of the instrument

N is order of expansion

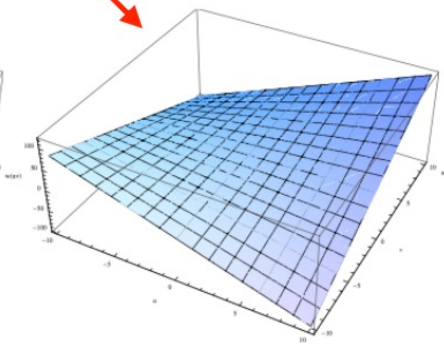
$$w(u,v) = \sum_{i=0}^{N}\sum_{j=0}^{i} c_{ij} L_j(u) L_{i-j}(u)$$

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

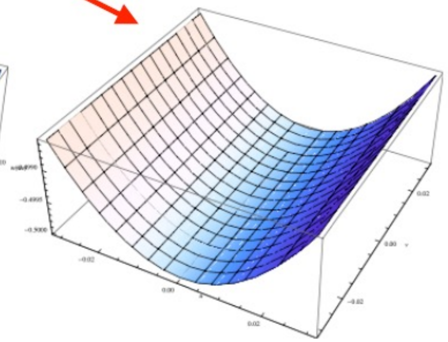
Planar orientation



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.