Design and manufacture of the supports for the ATLAS barrel strip staves

Eric Andersen[1], Todd Claybaugh[1], Charles Evans[2], Liam Cooper[2], Georg Viehhauser[3], Stephanie Qing Yang[3]

[1] *Lawrence Berkeley National Laboratory, USA*
[2] *Rutherford Appleton Laboratory , UK*
[3] *Physics Department, University of Oxford, UK*

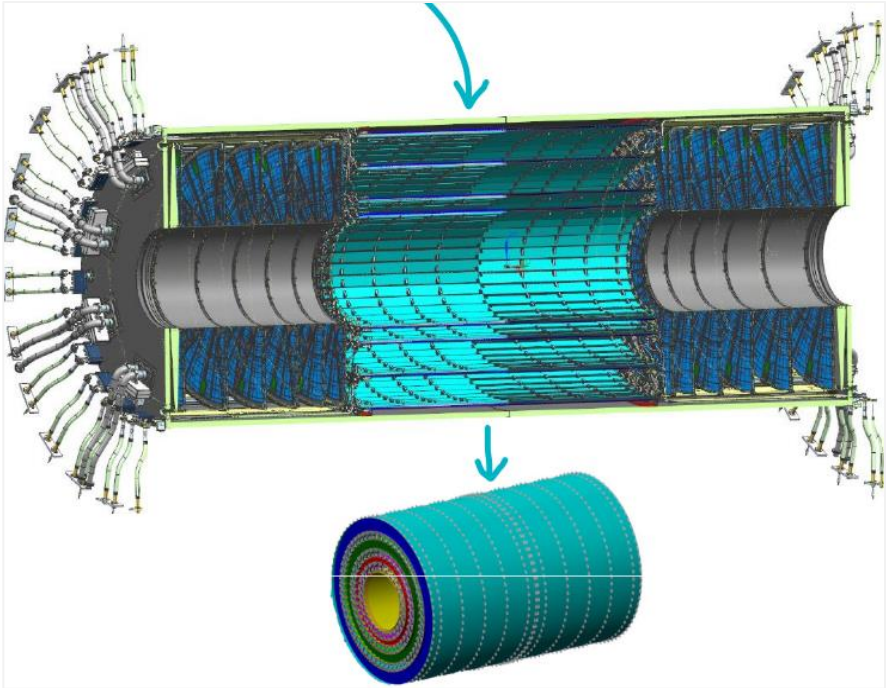
Outline

- Introduction
- Stave design
- Stave support
- Locking points assembly
- Cylinder dressing
- QA/QC tests
  - LPs production parts
  - LPs assembly
  - Cylinder dressing
- Summary

Introduction

ATLAS upgrade ITK strip system:

Cylindrical geometry made of four concentric layers

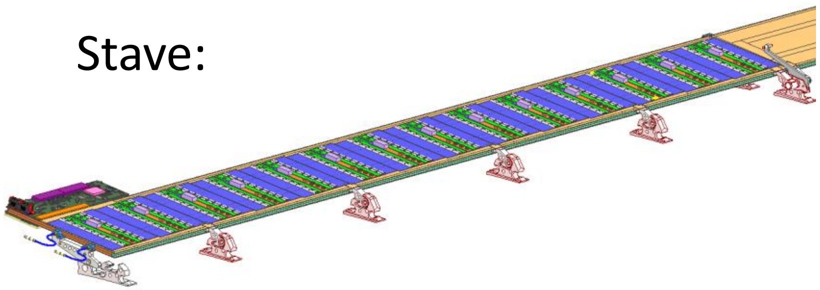


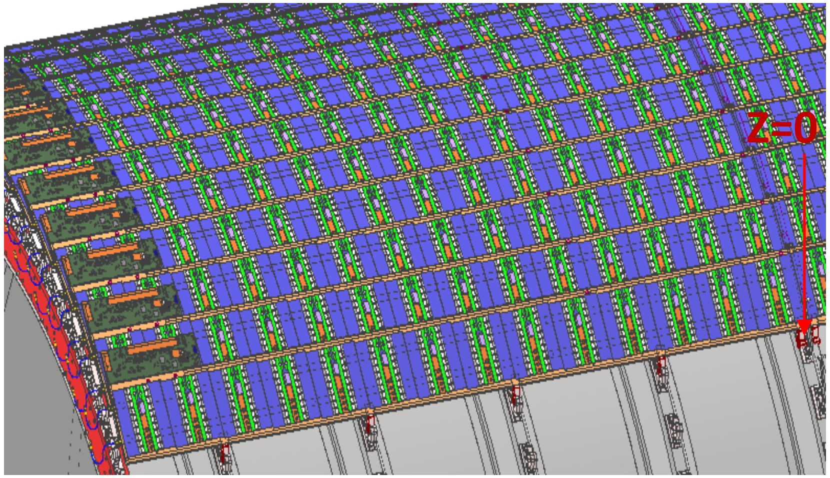
Picture credit: https://cds.cern.ch/record/2857573/files/ATL-ITK-SLIDE-2023-122.pdf

- ITk strip system consists of a barrel section and two endcaps
- Contained in a carbon fiber outer cylinder (OC)
  - See backup slide28 for OC pictures.
- Strip sections will be built separately, and inserted into the OC at CERN
  - Finally the pixel system will be inserted
- All this is done on the surface, and the whole of the ITk is then lowered in one piece and inserted into ATLAS
- Barrel strip section consists of four concentric cylindrical layers
  - Radii@ 1000 mm (L3), 762 mm (L2), 562 mm (L1) and 399mm (L0).
  - Length: 2.8 m

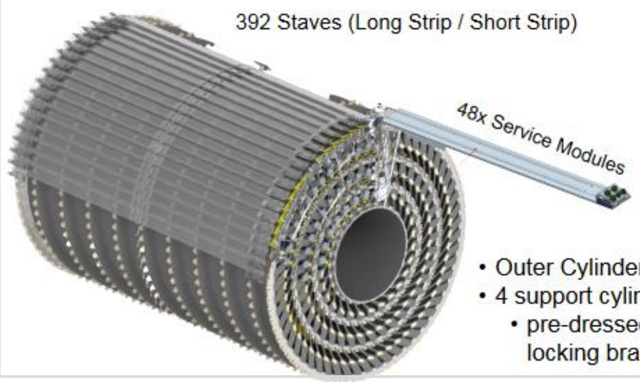
Barrel strip system

Stave:





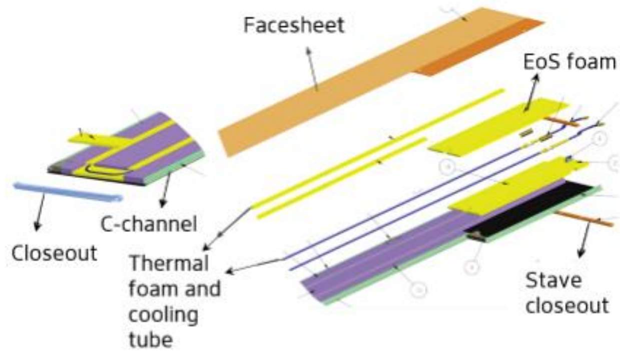
- Change from current ATLAS SCT: introduce intermediate support layer: staves
  - Plan was that this would give fully functional units that could be tested aggressively early on in the project
- Another early design decision:
  - Build complete barrel support structure and insert staves from the ends



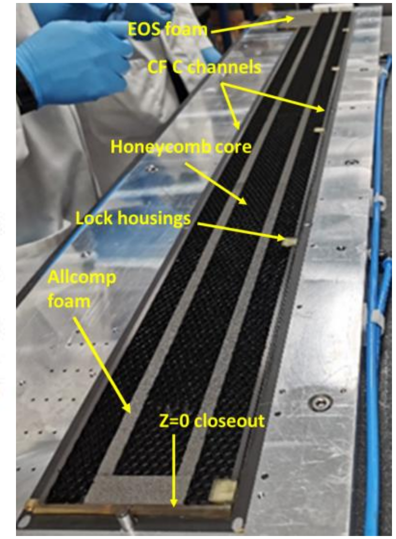
Picture credit: https://cds.cern.ch/record/2885955/files/ATL-ITK-SLIDE-2023-671.pdf

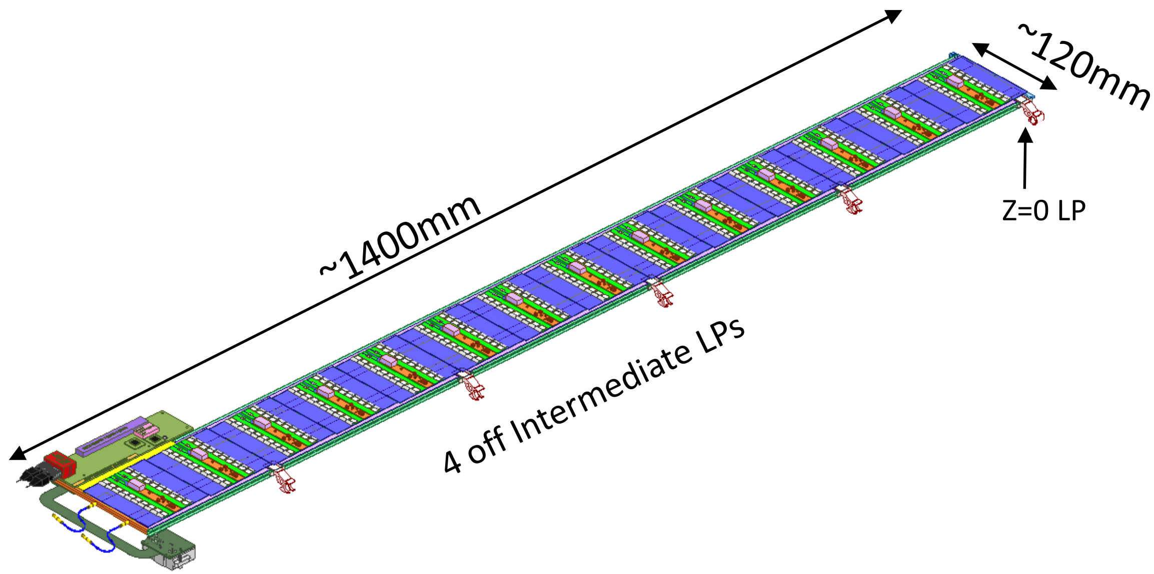
Stave design -1

- The stave is the local support in the ATLAS phase II upgrade barrel strip system
  - carbon fibre/honeycomb sandwich
  - Ti cooling loop embedded in K9 foam
- Silicon strip modules are glued to both sides of the stave
  - 14 modules per side and 28 per stave
  - End of Stave card with overall DAQ electronics.



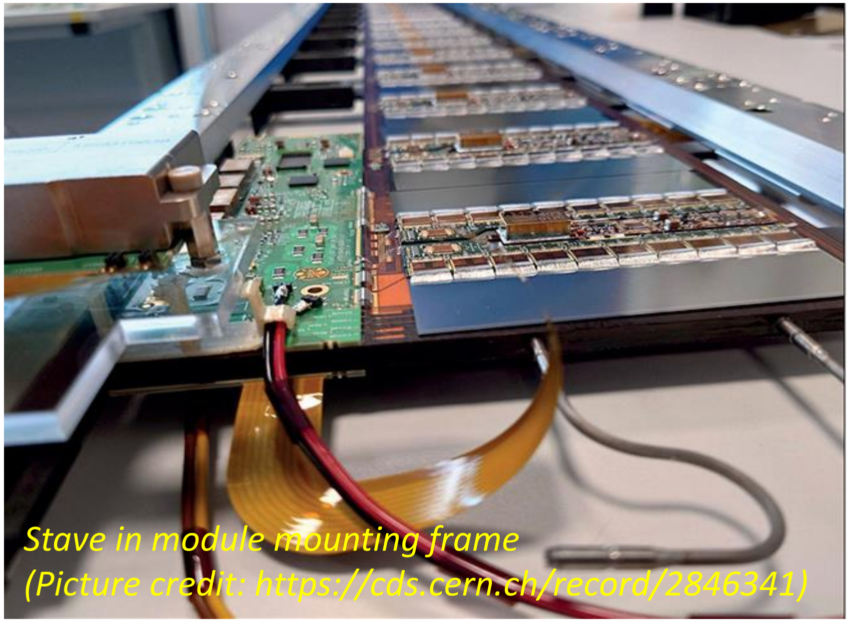
Stave core assembly process detail, see page27.





Stave design -2

- The bus tape co cured with 3 layers of uni-directional carbon fiber (0/90/0, K13C2U) to make the face sheets.
  - This bus connects modules to the end-of-stave card (EoS), which contains multiplexers and the stave connector to the external services.
  - All connections to the tape are done by wire-bonding.



Stave in module mounting frame
(Picture credit: https://cds.cern.ch/record/2846341)

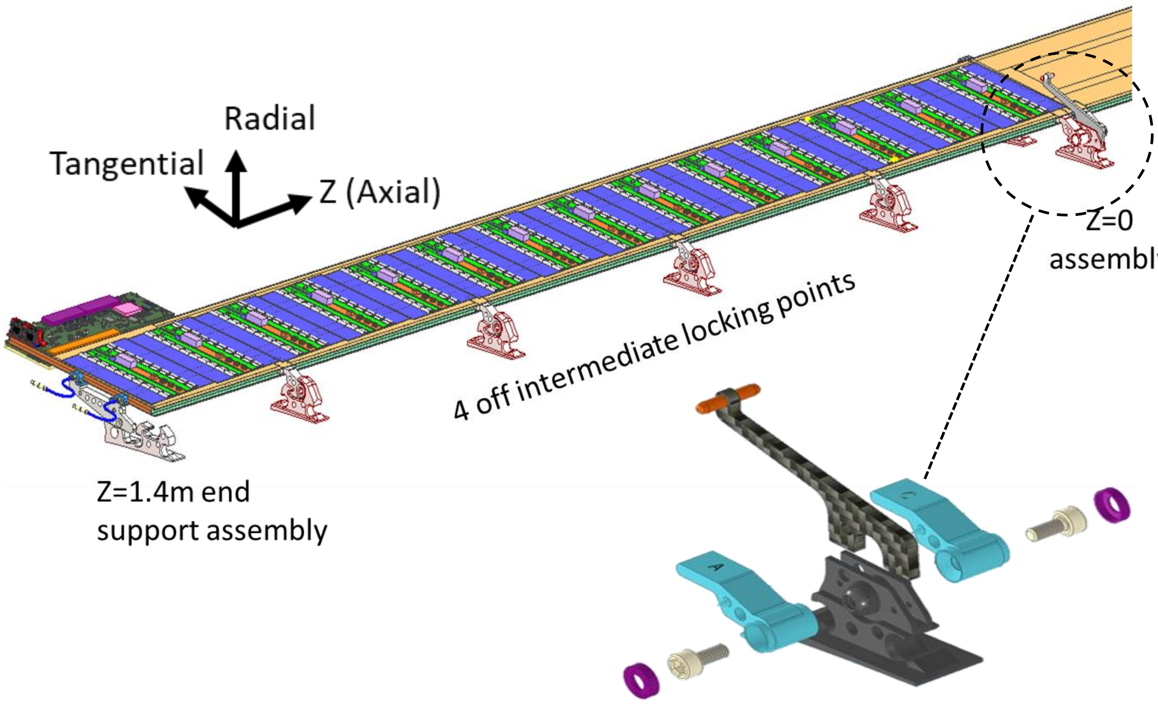
Stave support concept

Goals:

- End insertion
- All tooling is completely removed after insertion
- Use a tiled layout with minimum tiling angle to minimize material
- Achieve physical locking of the stave in the final configuration
- Allow for differential thermal expansion between staves and carbon fibre support cylinders

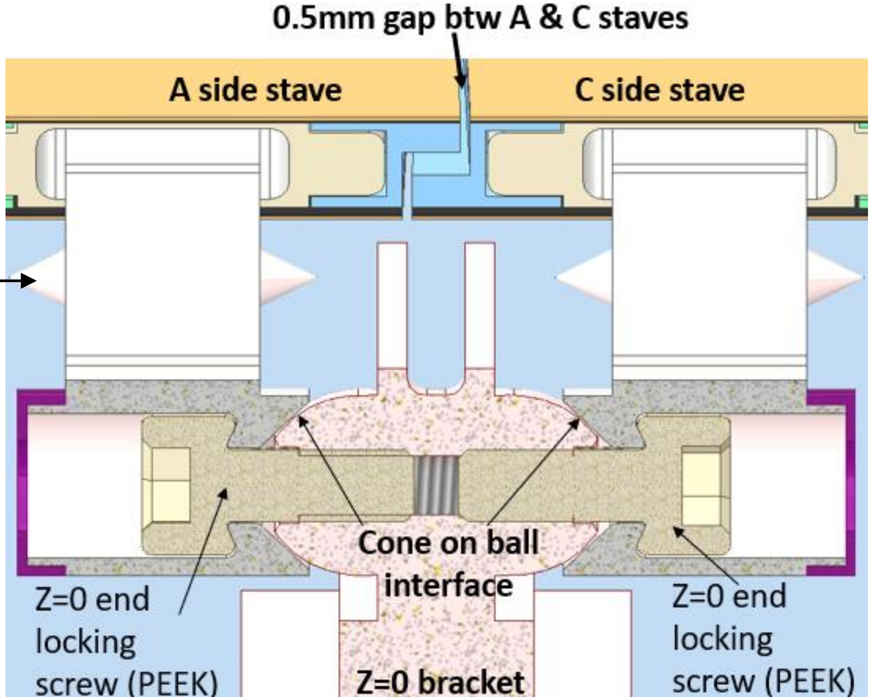
Design:

- Single edge mounting design
  Stave is supported only along one edge, except at stave ends, which constrain stave angle.

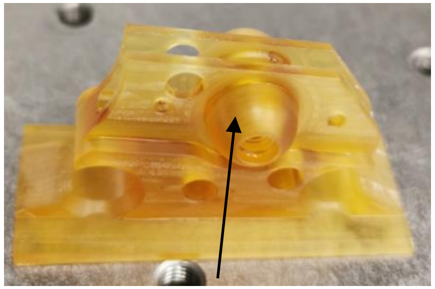


Stave support @ Z=0 end

- Stave is anchored at Z = 0 with a cone-on-ball interface
- Z=0 end locking point assembly



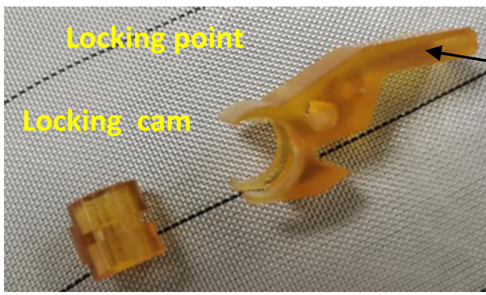
Cone on Z=0 LP



Ball on Z=0 bracket

Stave support – Locking mechanism

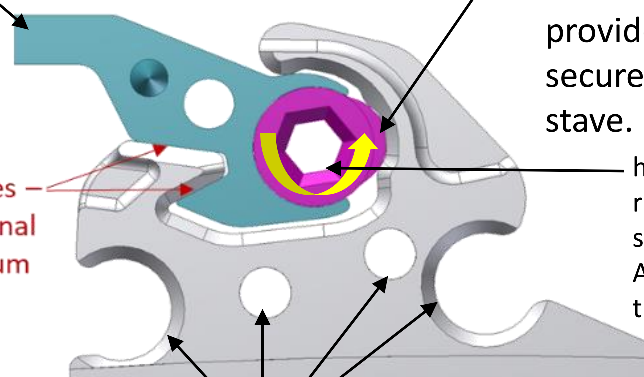
- Intermediate locking brackets provide radial & tangential support to the stave, and also support to the insertion tooling
- Intermediate locking mechanism assembly:



Locking point bonded to the stave core

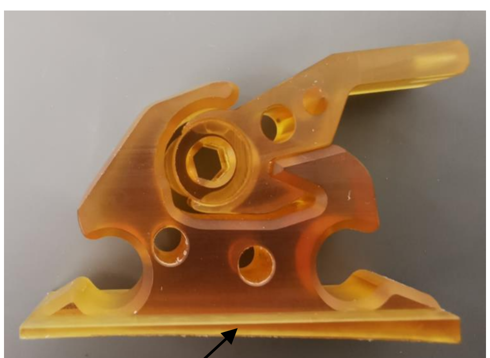
Locking is achieved by a cam that pushes LP into “wedge” of the bracket which provides accurate and secure mounting for the stave.

Reference faces – known positional reference datum



hex inner bore for the rotation, which also acts as a support for the 1.4m long M4 Allen key during the locking of the LP brackets.

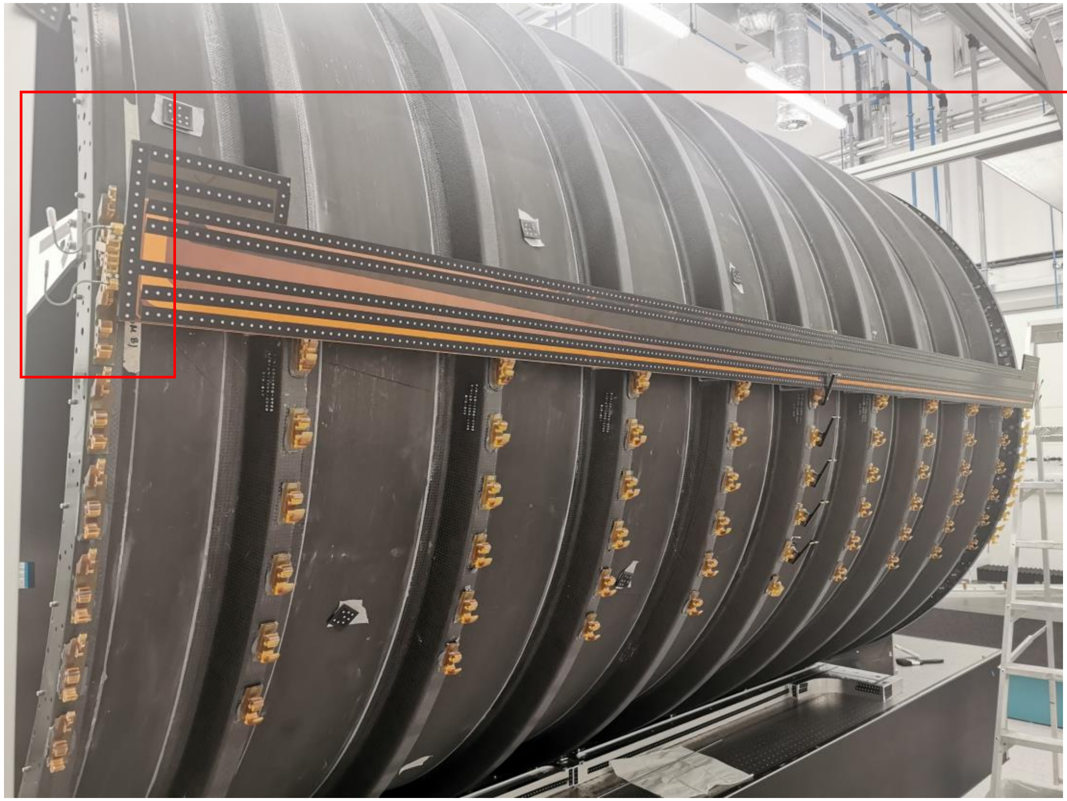
Tooling holes for stave Insertion

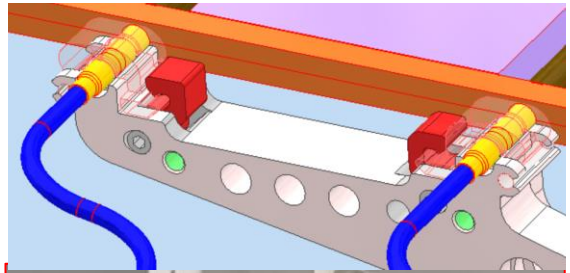


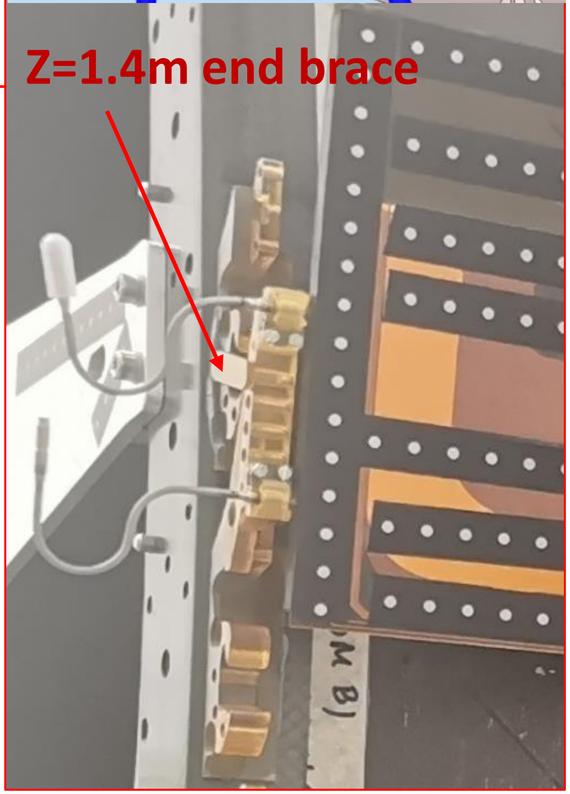
Locking bracket bonded to the support cylinder

Stave support @Z=1.4m

- Z=1.4m end support: Radial support only

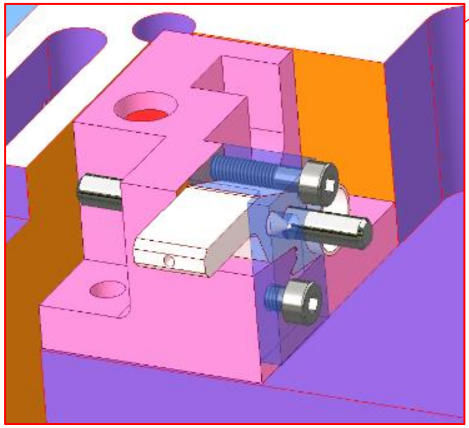




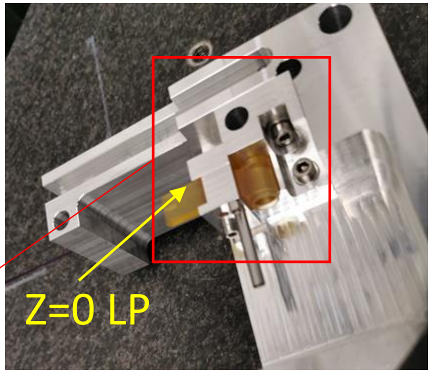


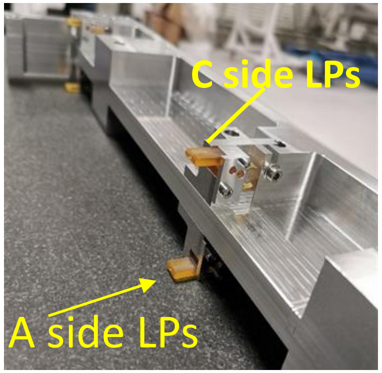
Locking points assembly

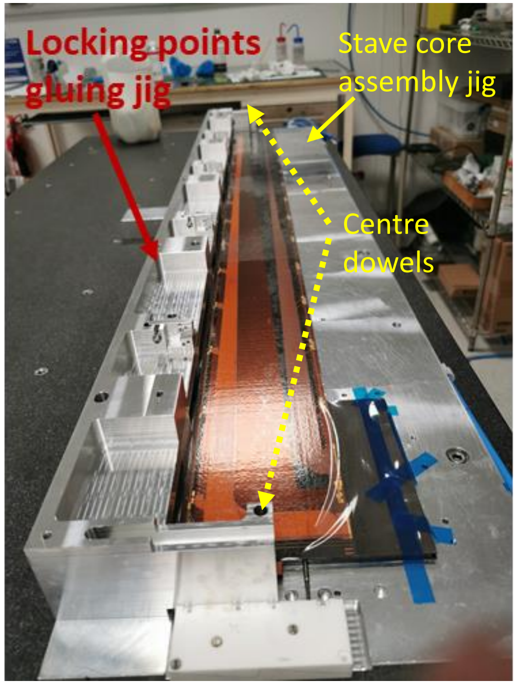
- The LPs collinearity tolerance:
  - +/-0.05mm.
- The LPs assembly jig is a precision tooling used to assemble the locking points to the stave core.

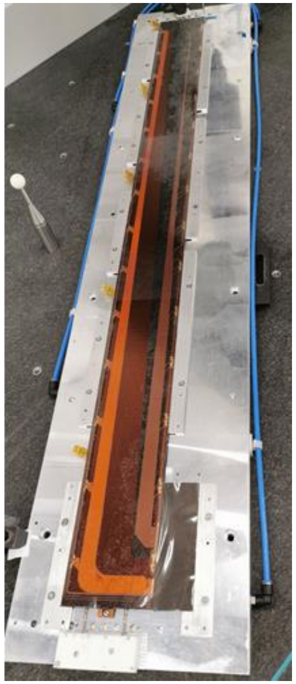


- The stave core assembly fiducials are referenced for the LPs gluing – guarantee the positioning accuracy.



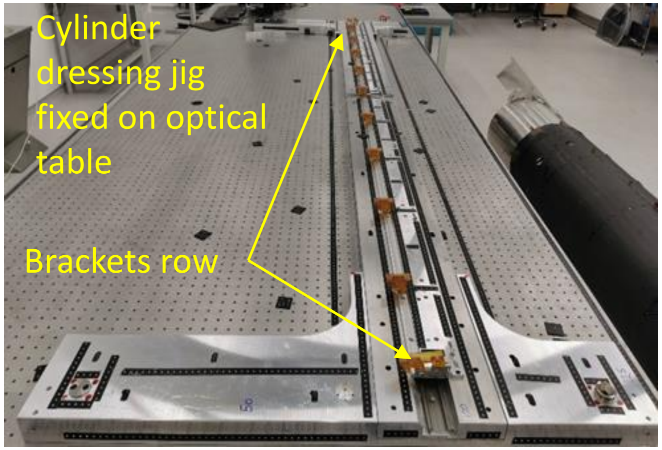






Cylinder dressing

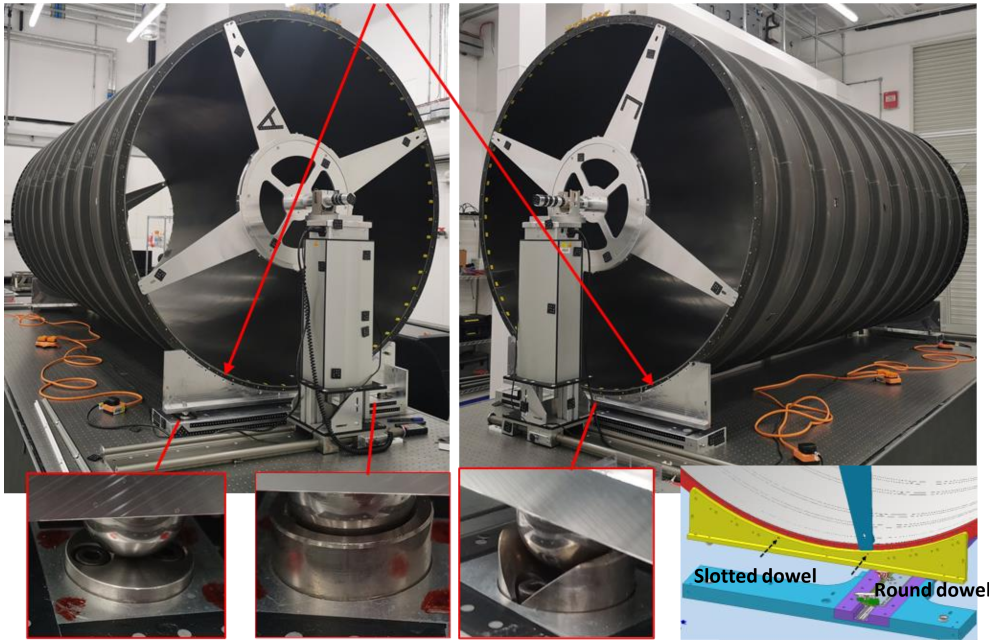
- Cylinder dressing is the bonding of the Locking brackets onto the support cylinders.



- Positioning of tooling with respect to local fiducial holes on cylinder end flanges.
  - Local referencing was chosen to be robust against cylinder dimensional variations

- The local fiducials position a support plate that interfaces to the dressing jig by a 3 point kinematic mounts.

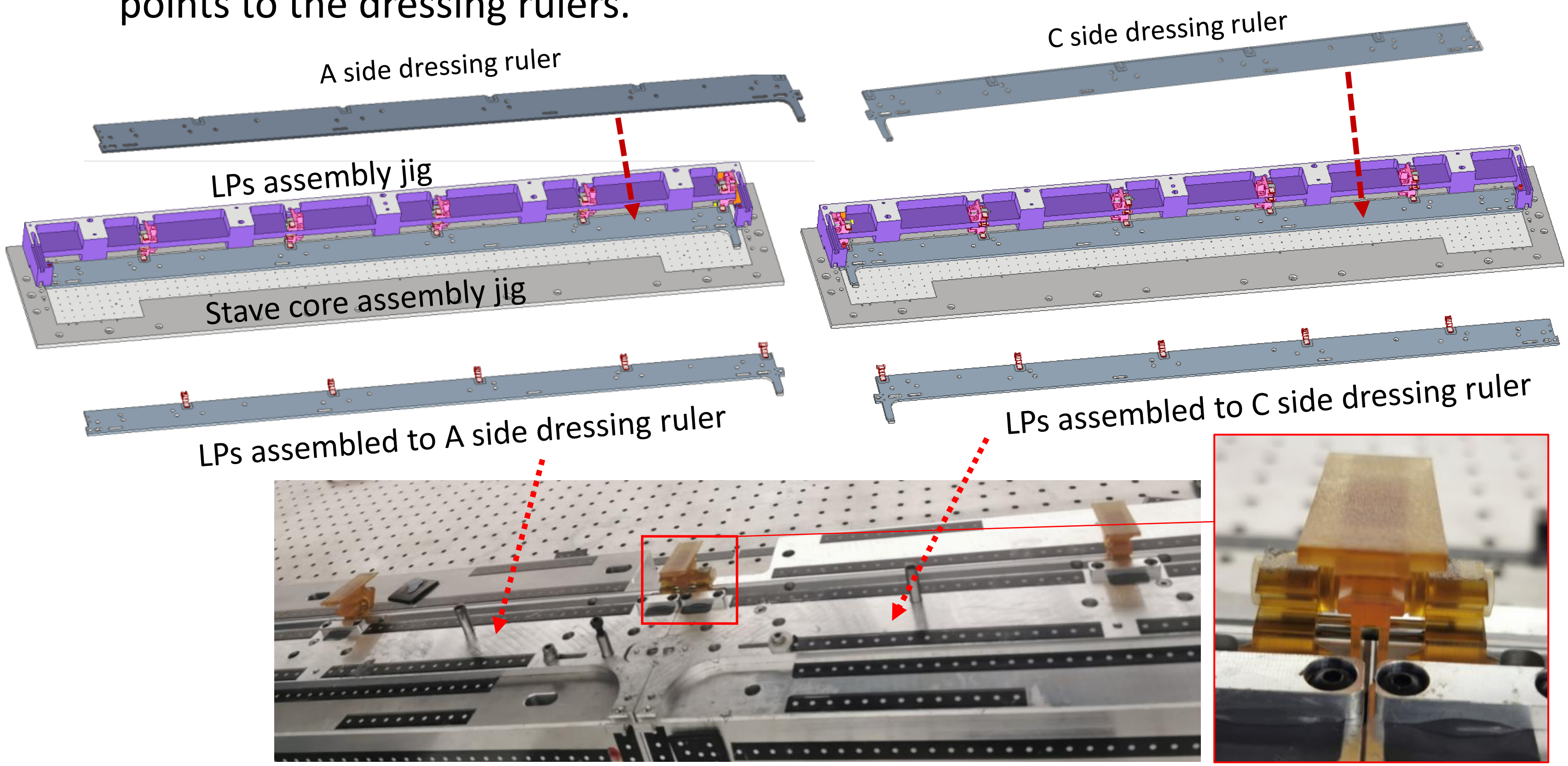
Support plates doweled to the barrel end flange



- Requirements: +/-0.2mm (radially), +/-0.1mm tangentially and +/-0.5mm axially.

Cylinder dressing tooling - 1

- The alignment of the locking brackets is achieved by the single source reference, i.e. the same LPs assembly jig for stave is used for the assembly of the locking points to the dressing rulers.

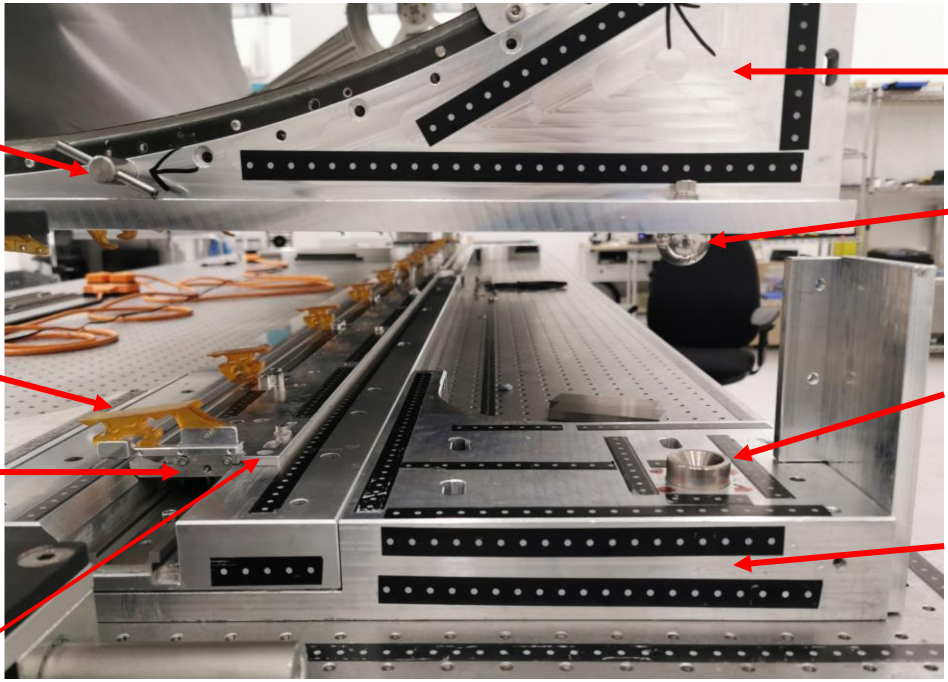


Cylinder dressing tooling - 2

Dowel pin to the flange fiducial

ULTEM brackets

Dressing rulers



A side support plate

Tooling Ball on A side support plate

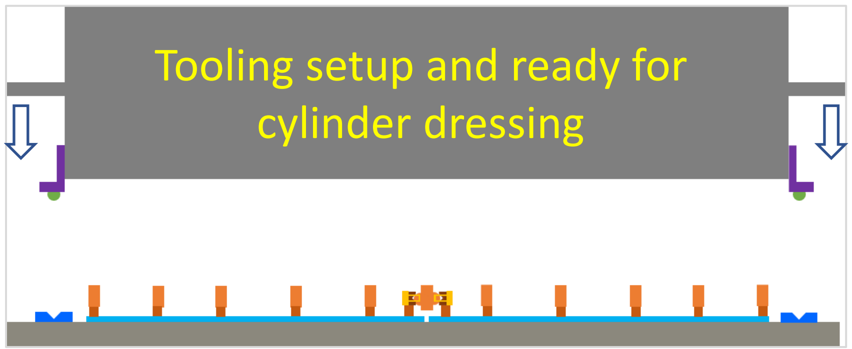
Cone on jig base

The main part of the jig is bolted down to the optical table (known reference).

Dressing rulers are movable parts, i.e. they are fixed to the main jig during gluing and can be slid outwards after the dressing is done.

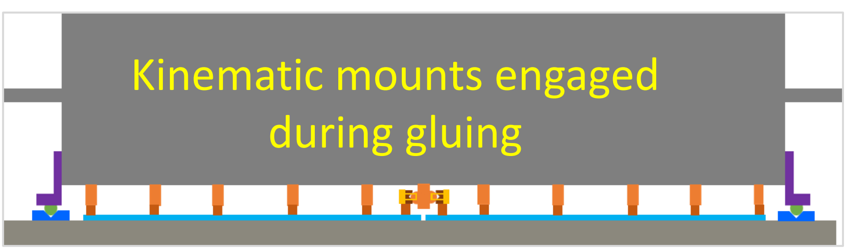
Cylinder dressing Process

Step-1

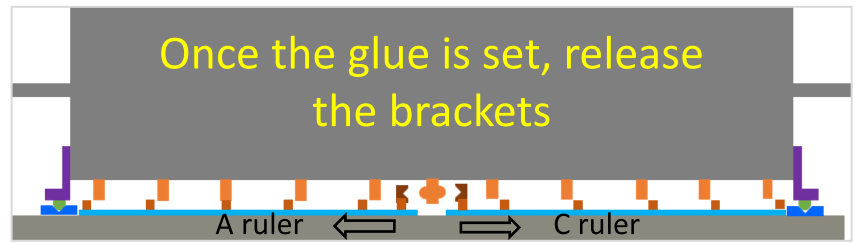


Dressing jig is bolted onto the optical table to guarantee the flatness

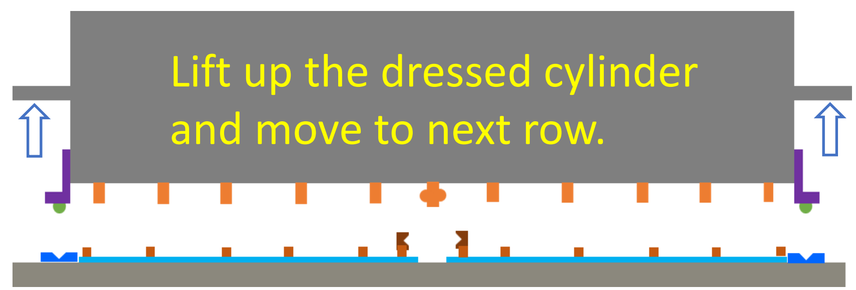
Step-2



Step-3

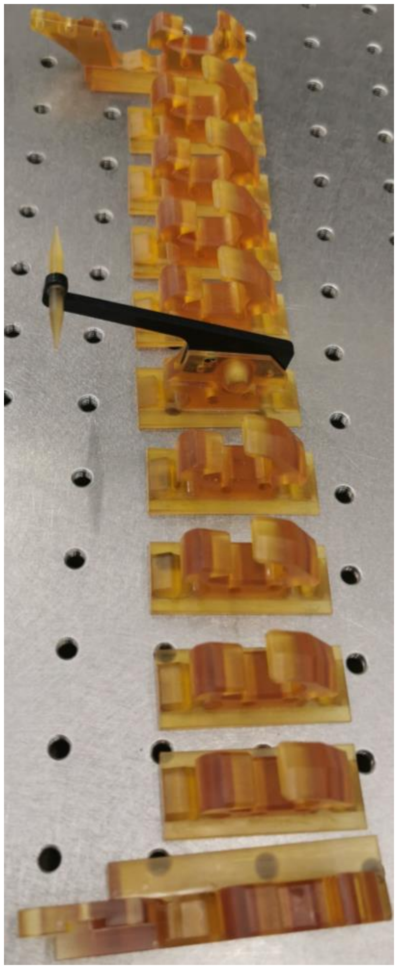


Step-4

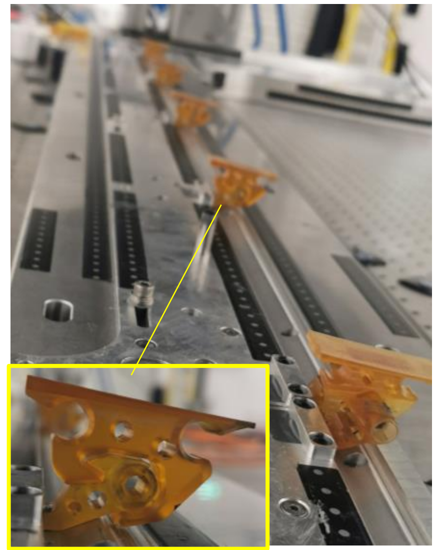


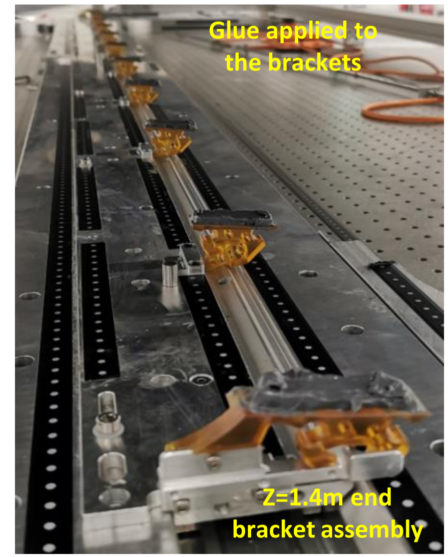
The same process is repeated on every row.

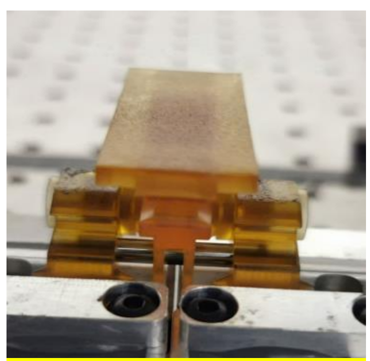
Cylinder dressing assembly in detail



11 ULTEM brackets per row (1 off Z=1.4 A side, 1 off Z=1.4 C side, 1 off Z=0, 8 off intermediate brackets)

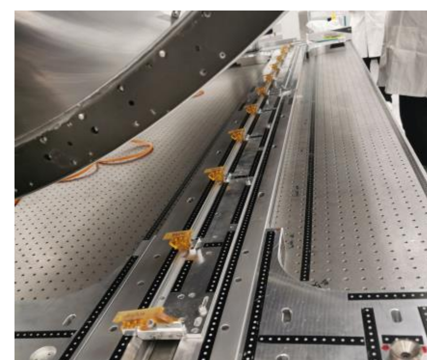






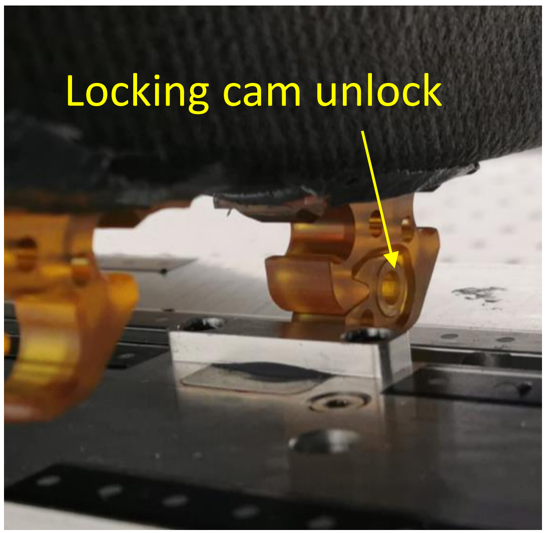
Z=0 bracket assembly

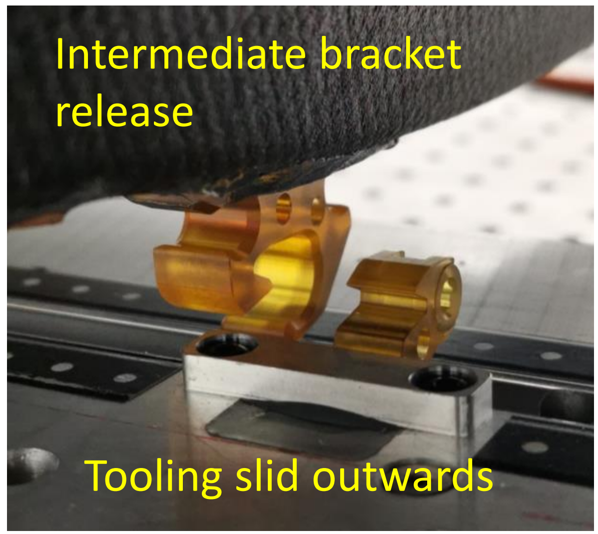
Intermediate bracket assembly

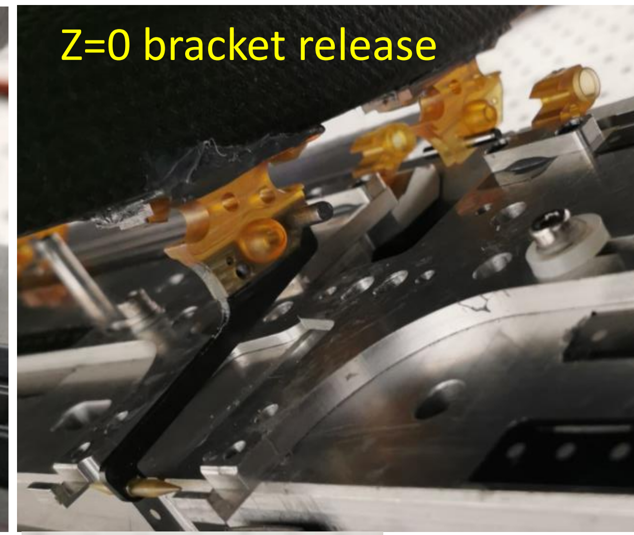


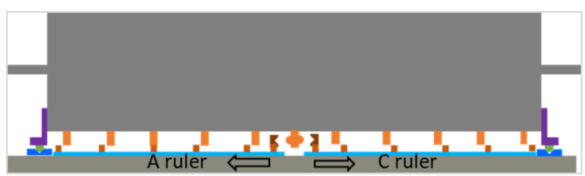
Locking brackets on dressing jig assembly

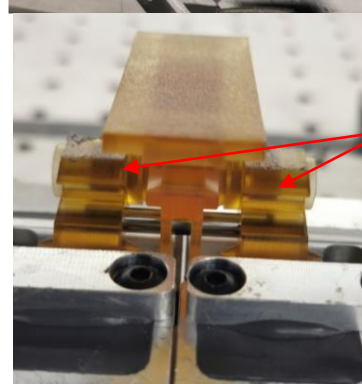
Cylinder dressing brackets release









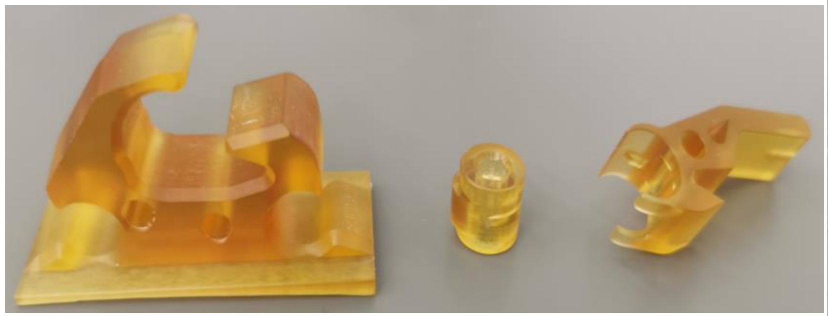


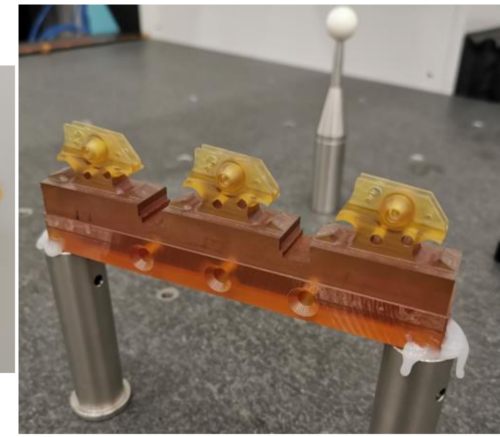
PEEK fixation screws removal

QA/QC tests

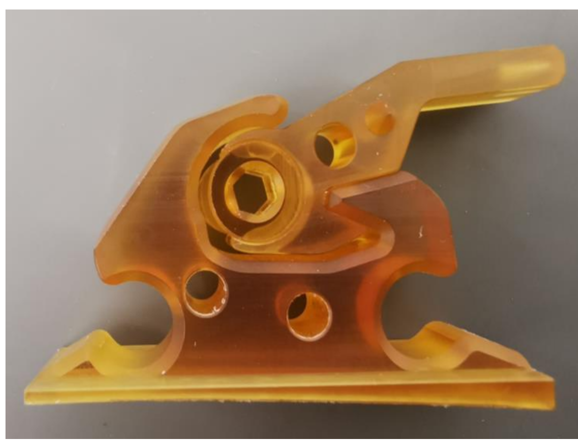
LPs production parts QA/QC

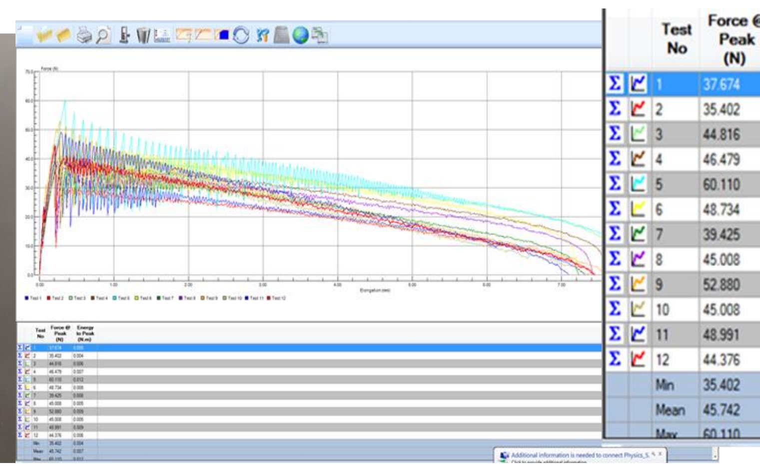
- The validation of CNC programmes and machine setup procedures are done with small batch prototypes CMM.





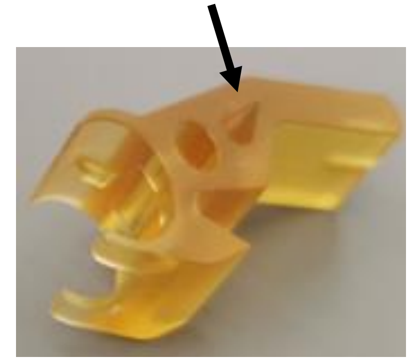
- LPs Pull tests for frictional sliding.
- Tooling also serves as go and no-go gauge before Parts assembled to stave /cylinder





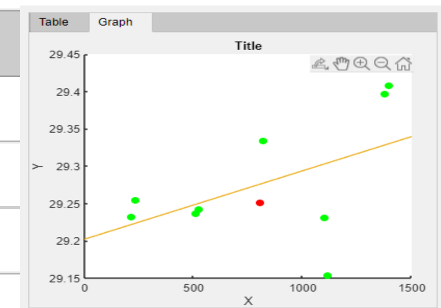
LPs assembly QA/QC

- LPs assembly jig checked with CMM
- LPs collinearity on pre-production staves were measured at RAL using confocal microscope.



UK Core #	Type	LP max deviation (um)
31	A-side PPA	-108.82
36	A-side PPB	92.56
37	C-side PPB	-150.73
38	A-side PPB	53.87
39	C-side PPB	59.61
40	A-side PPB	49.67
41	A-side PPB	-60.37

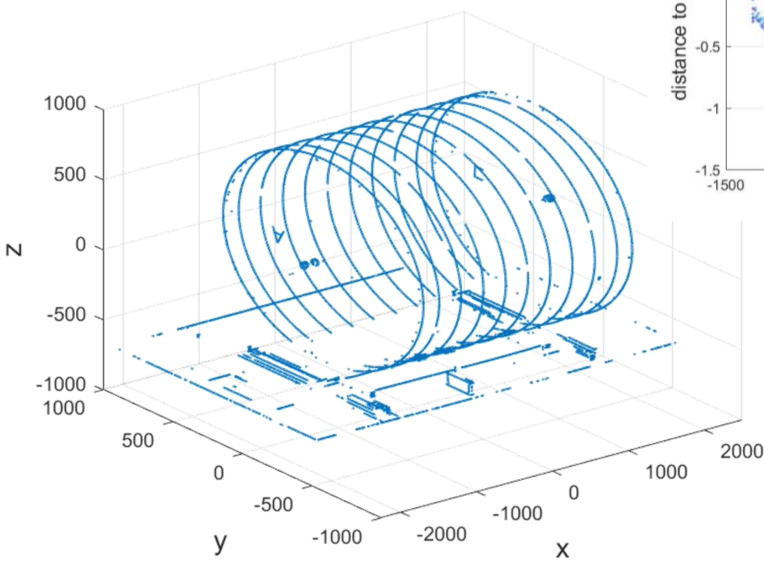
Earlier LPs prototypes



[Credit to Debra Dewhurst @ RAL: https://indico.cern.ch/event/1402464/]

Cylinder dressing QA/QC -VSTAR

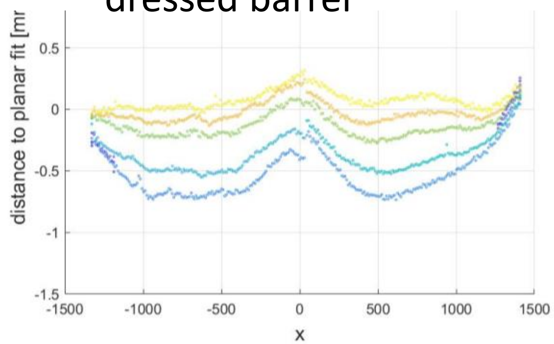
Photogrammetry with targets in barrel flange fiducials and on hat stiffeners. Coordinate system from cylindrical fit to hat stiffener measurements

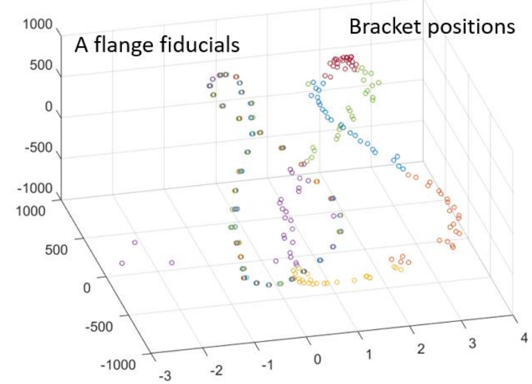


Raw data (includes targets on table)

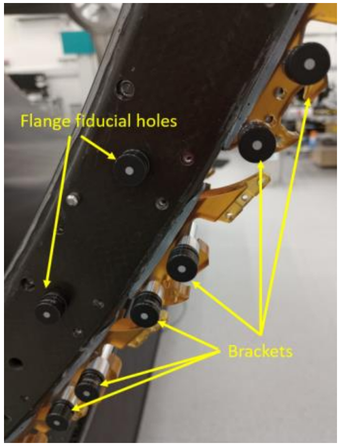
Credit to Georg Viehhauser

Measured Stave profile when mounted on the dressed barrel





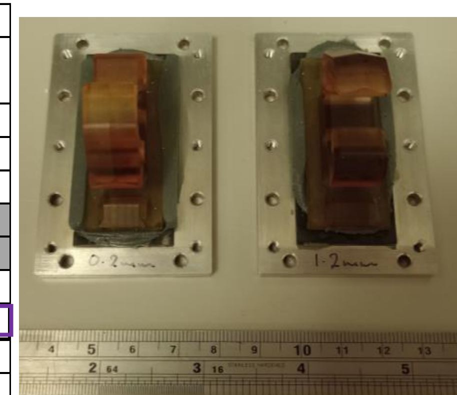
L3 dressing Z positions



Adhesive tests – Justification for the chosen glue

- Test samples (8 types of fast cure structural glue) have been irradiated to 500 kGy.
- Followed by thermal cycles (50 cycles at -30°C/20°C and 50 cycles at -50°C /50°C) and mechanical shear/pull/peel load tests (limited to the load cell of 500N).

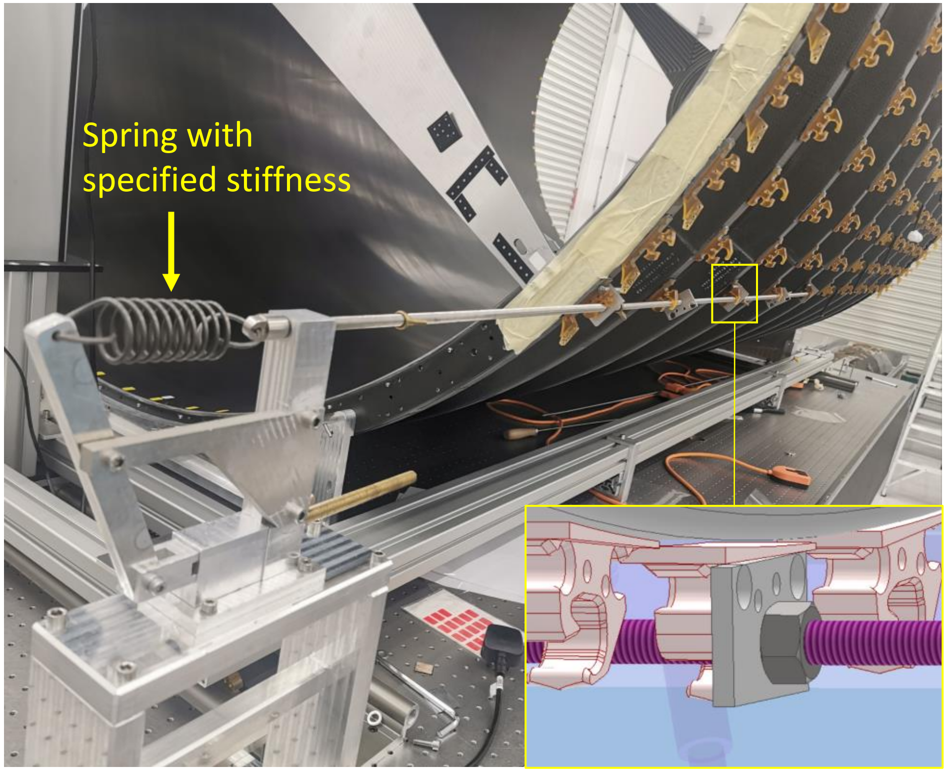
#	*Adhesive Name /type of tests*	samples before irradiated	samples after irradiated		
		mechancial load tests (up load 500N)	Thermal cycles		mechanical load tests
		Pull/peel/shear	50 cycles (-30C~20C)	50 cycles (-50C~50C)	pull/peel/shear
1	LOCTITE EA3430	pass	pass	pass	fail
2	ARALDITE Rapid	pass	pass	pass	fail
3	Intertronics Born2Bond	pass	fail	fail	
4	EasyComposites VM100	fail			
5	Permabond PT326	pass	pass	pass	fail
6	MB EP21TDCF-3NV	pass	pass	pass	pass
7	Gorilla epoxy glue	pass	pass	pass	fail
8	3M Scotch-Weld DP410	pass	pass	pass	fail



- MASTERBOND EP21TDCF-3NV loaded with 2% West System 406 colloidal silica adhesive filler and unloaded samples passed all the tests.
- Destructive test on ULTEM bracket bond to CF hat stiffener samples: the shear load tested to be >>75kg.

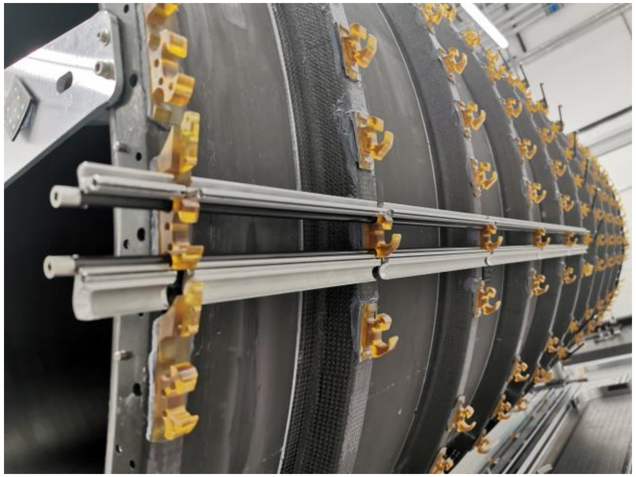
Cylinder dressing QA/QC – bond joint pull testing

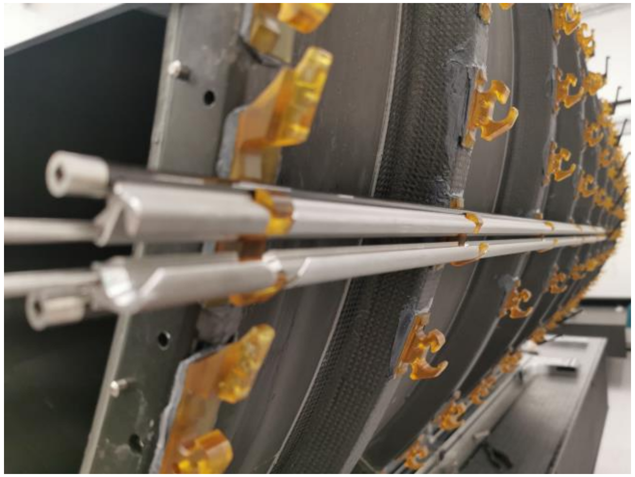
- To test integrity of the bond joint by showing that it can sustain a shear load of up to 200N.
- The test applies to every bonded bracket.



Stave insertion rails

- It provides a guide and continues support to the stave during the stave insertion.
- The rails are removed after the stave is inserted.
- Dry fit to the dressed cylinder as part of QC.





Summary

- Tooling work as expected and reliable.
- Photogrammetry is a very useful tool.
- We have completed cylinder dressing for L3 and L2 barrels, and all survey results are repeatable as expected.
- We are confident that the subsequent barrels will achieve the same precision.

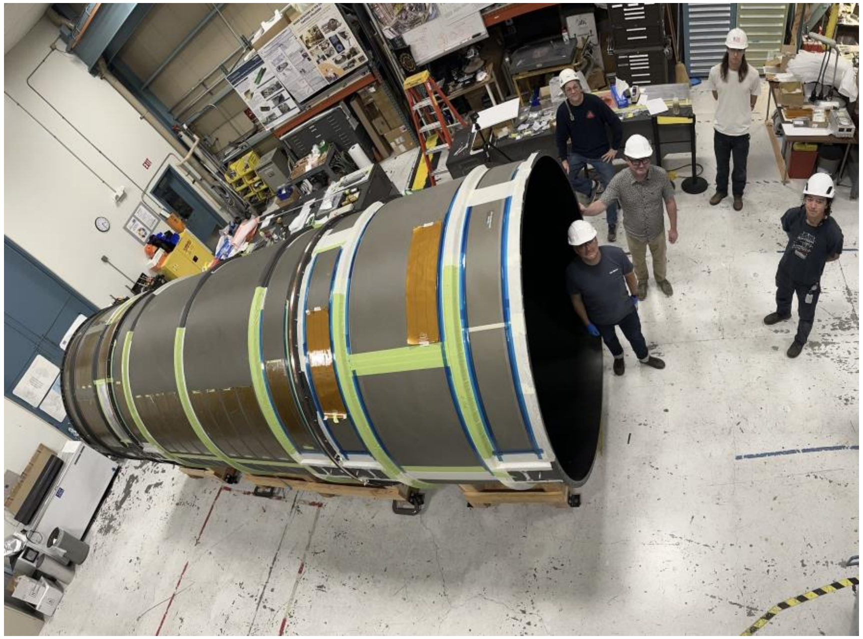
Dressed L2 barrel

Thank you
for your attention

Back up slides

Outer Cylinder at LBNL

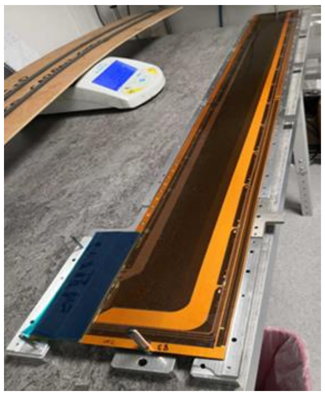
Dry fit of all cylinders



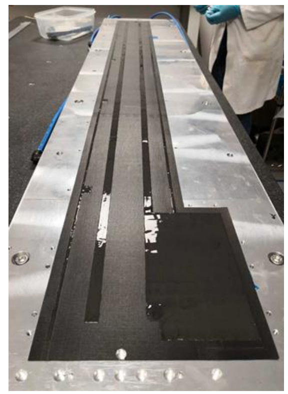
OC with heaters

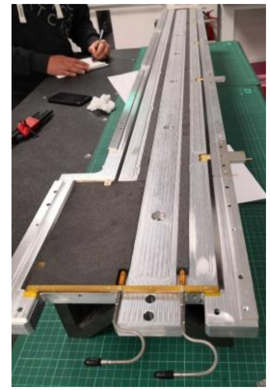
OC pictures from Eric Anderssen

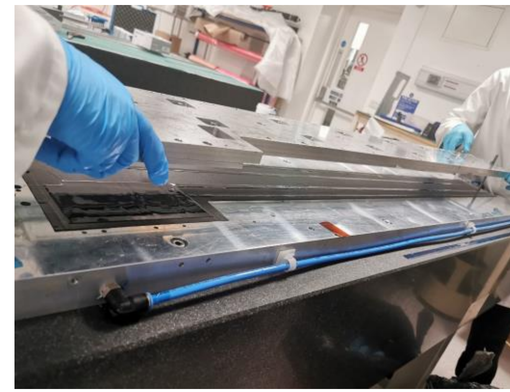
Stave core assembly

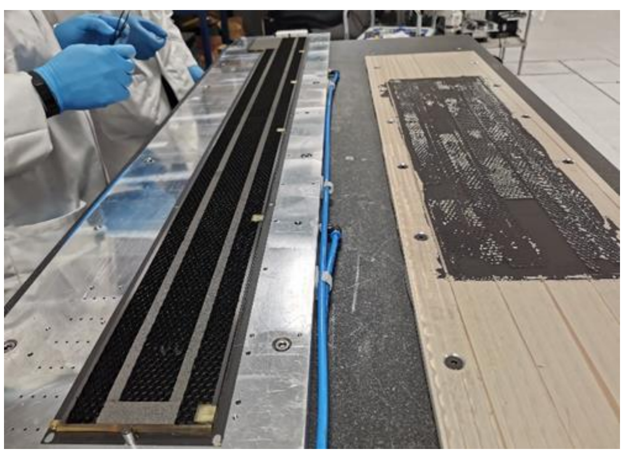

BUS tape and 3 layers of CF co-cured Face sheets

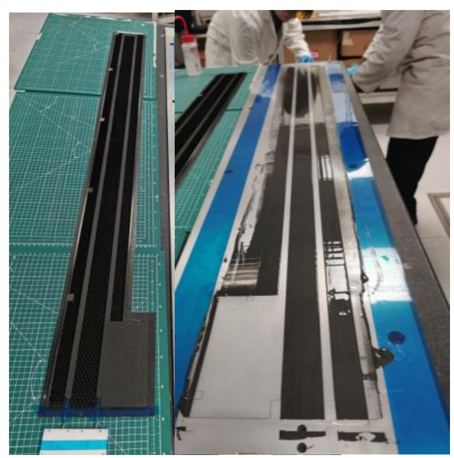

1st facing on vac jig


Glue applied on foam region on the face sheet

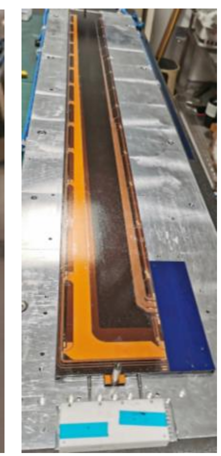

Foam pipe closeouts assembly


The Foam-pipe closeouts assembly onto the face sheet

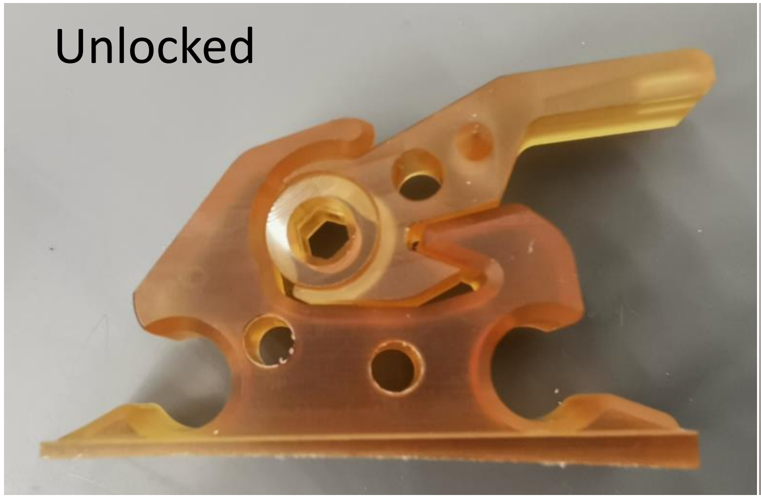

Carbon fibre honeycomb core gluing

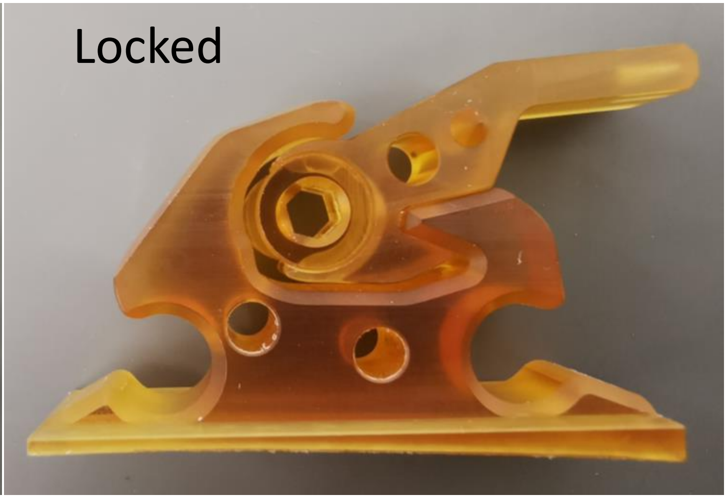

Glue bath for core to 2nd face sheet gluing

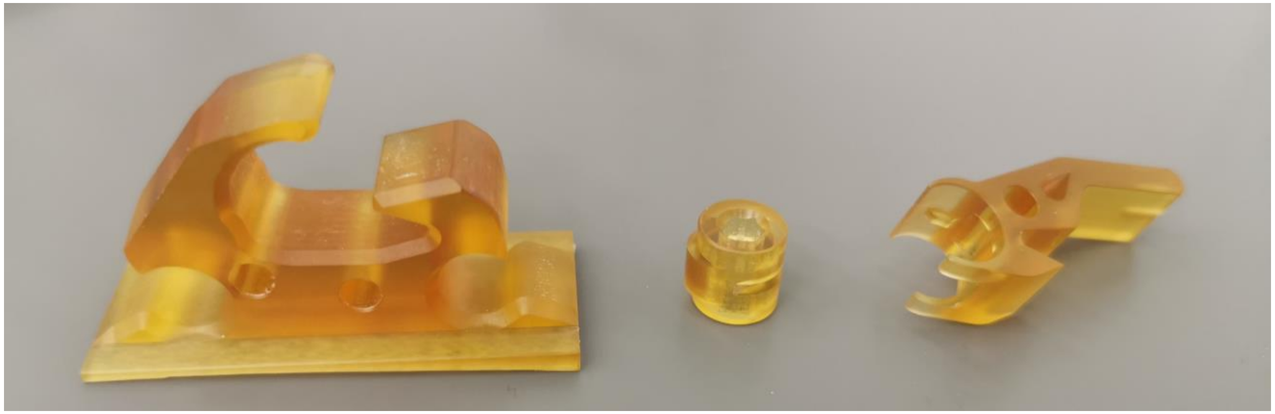

Glue applied on foam region


Completed core with sacrificial edges trimmed except the ends

Locking mechanism parts assembly







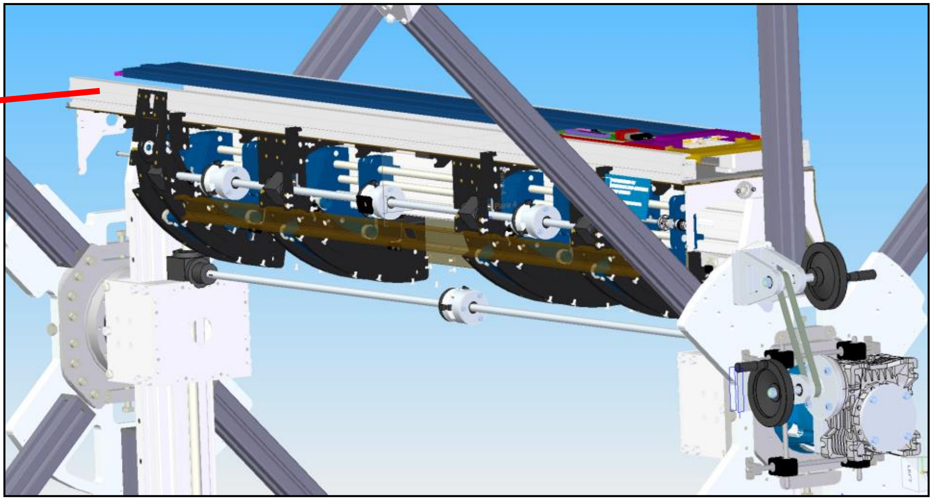
Dressed L3 barrel

L3 dressed barrel: ~Ø2m by ~3m

Prototype staves mounted on L3 for survey

Stave insertion test setup at RAL

Picture credit: Charles Evans @RAL



- Stave insertion test at various positions
- Clearance measurement during insertion
- Insertion force measurement

Stave frame