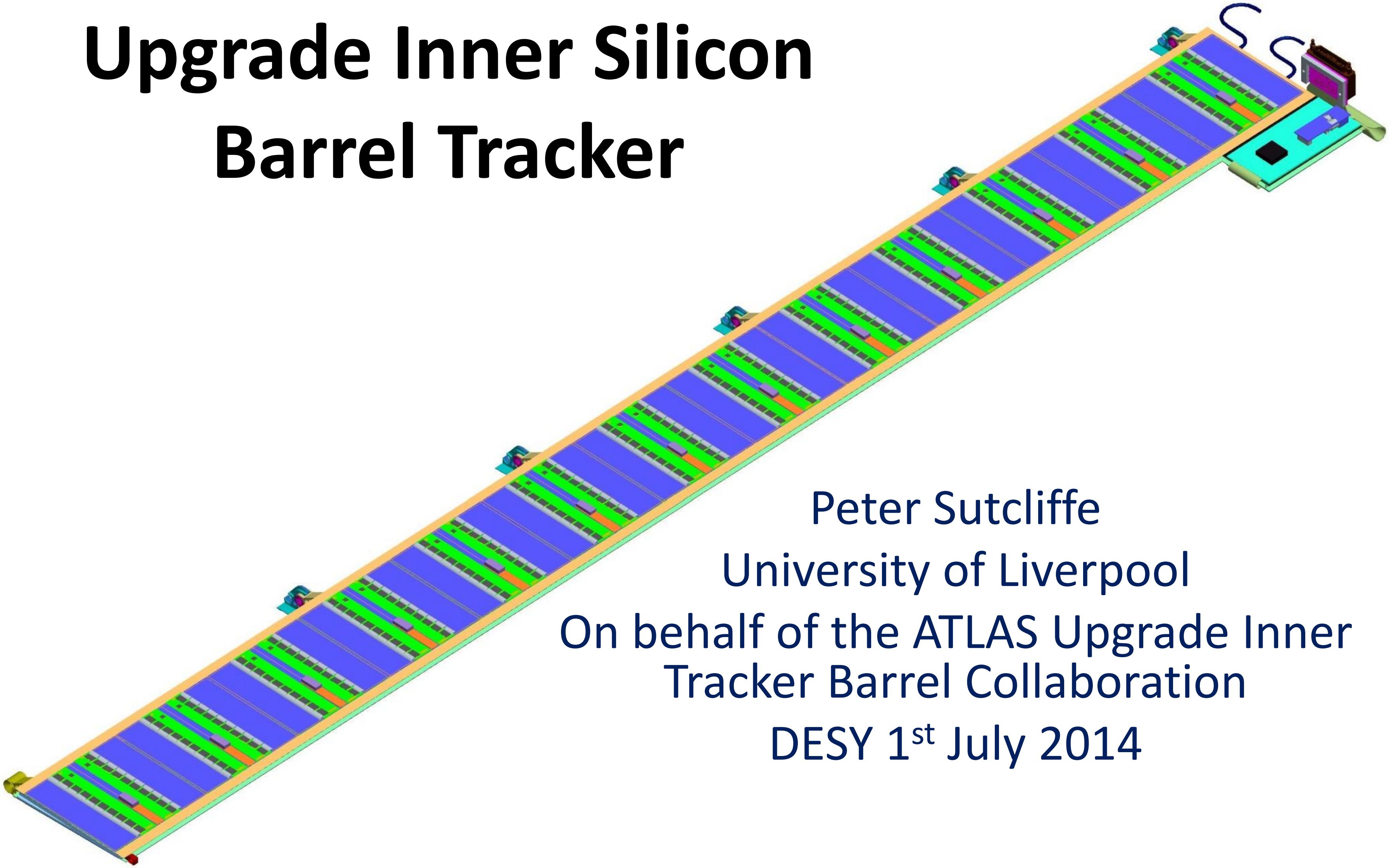
Low Mass Local Supports for the ATLAS Upgrade Inner Silicon Barrel Tracker



Peter Sutcliffe
University of Liverpool
On behalf of the ATLAS Upgrade Inner Tracker Barrel Collaboration

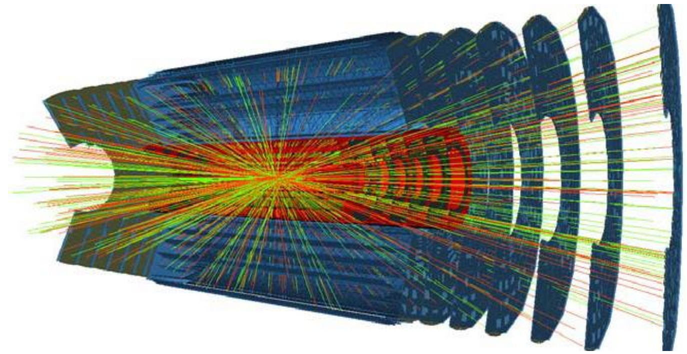
DESY 1st July 2014

Outline of Local Support

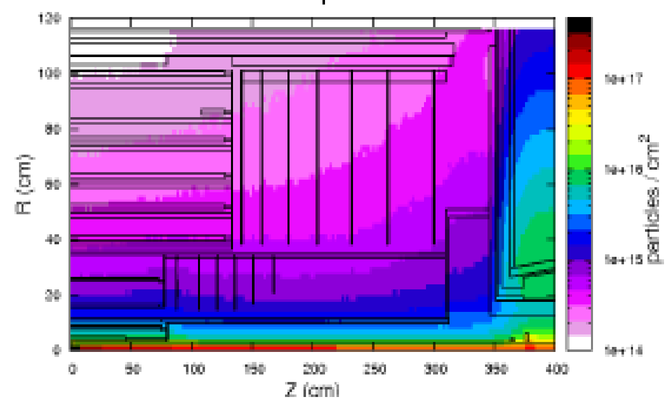
- The local support, or stave is a fully integrated structure.
  - i.e. Stave is a glued assembly, no screws
- The stave is manufactured from low mass, polymeric materials.
- Staves are mounted onto support cylinders using locking points.

ATLAS Phase-2 Upgrade

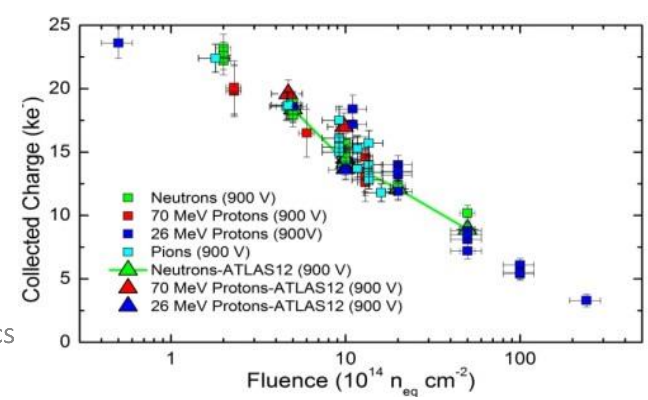
- Post LS3 (2023-2035) LHC enter full HL-LHC operation
  - Typically 200 collisions per bunch crossing at intervals of 25ns.
  - Integrated radiation levels for 3000fb-1 reach $3\times10^{16} n_{eq}/cm^2$
- Replacement required to extend physics output into HL-LHC era
  - Current tracker components will have accumulated radiation damage levels in excess of their original design specifications
  - Current tracker will not cope with new data rates
- Proposed replacement tracker exploits developments in silicon device technology & integrated mechanics



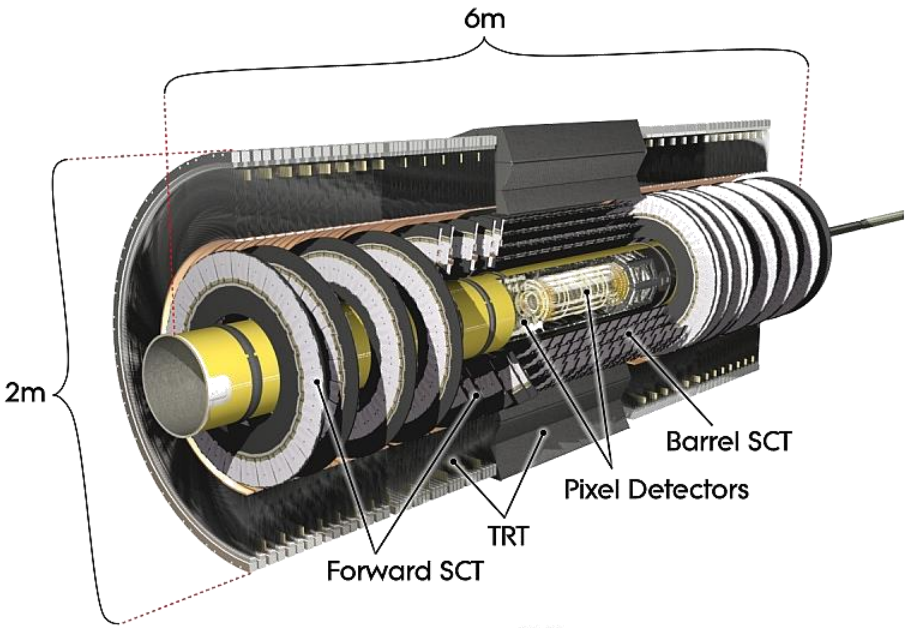
1 MeV neutron equivalent fluence

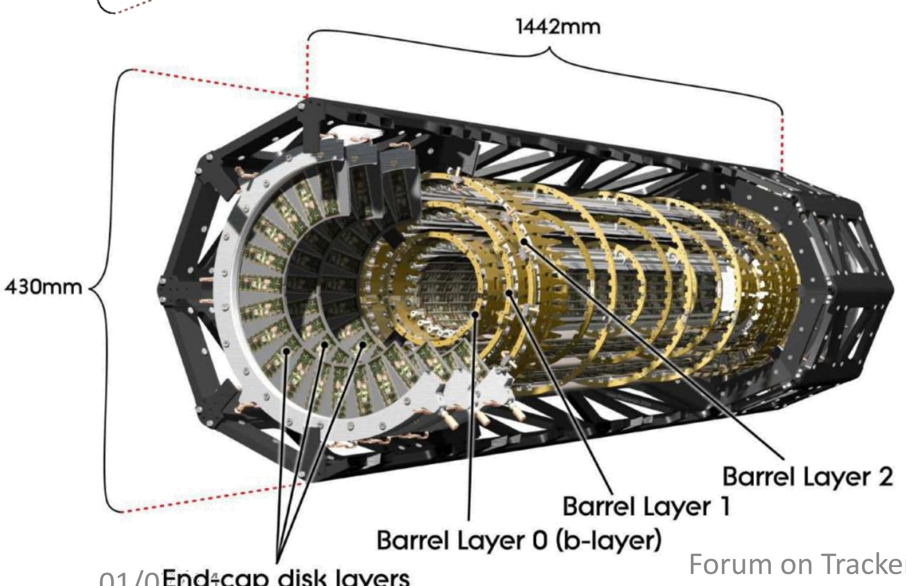


14 TeV collisions; integrated luminosity = 3000fb^{-1}



Current ATLAS Tracking

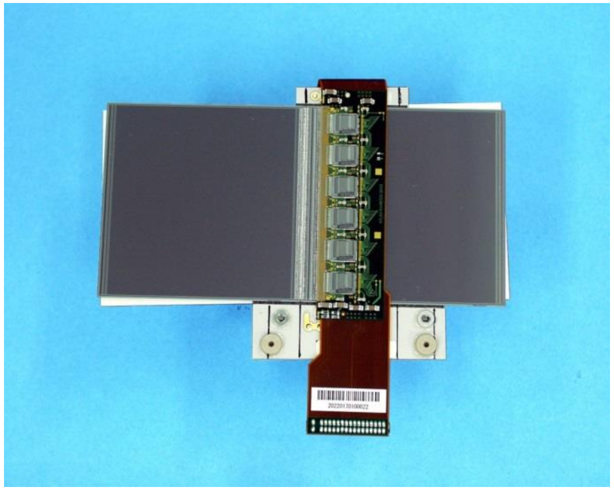




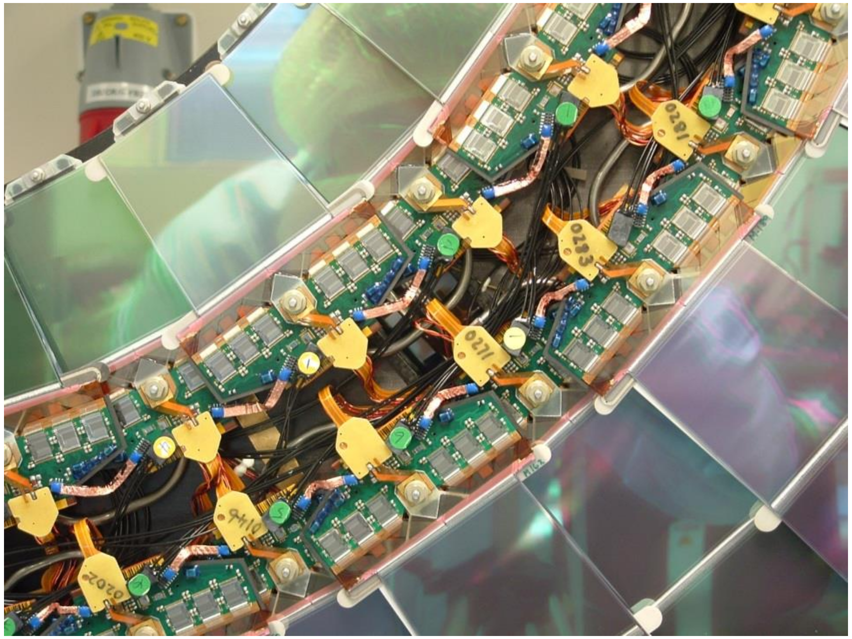
- SCT
  - **$61m^2$** of silicon with 6.2 million readout channels
  - **4088** silicon modules arranged to form 4 Barrels and 18 Disks (9 each end)
  - Barrels : 2112 modules (1 type) giving coverage $|\eta| < 1.1$ to 1.4
  - Endcaps : 1976 modules (4 types) with coverage 1.1 to $1.4 < |\eta| < 2.5$
  - $30cm < R < 52cm$
  - Space point resolution r ~16µm / Z~580µm
- Pixels
  - **1744** Pixel Modules on three barrel layers and 2 x 3 discs covering **$1.7m^2$**
  - 80M readout channels

Module Technologies

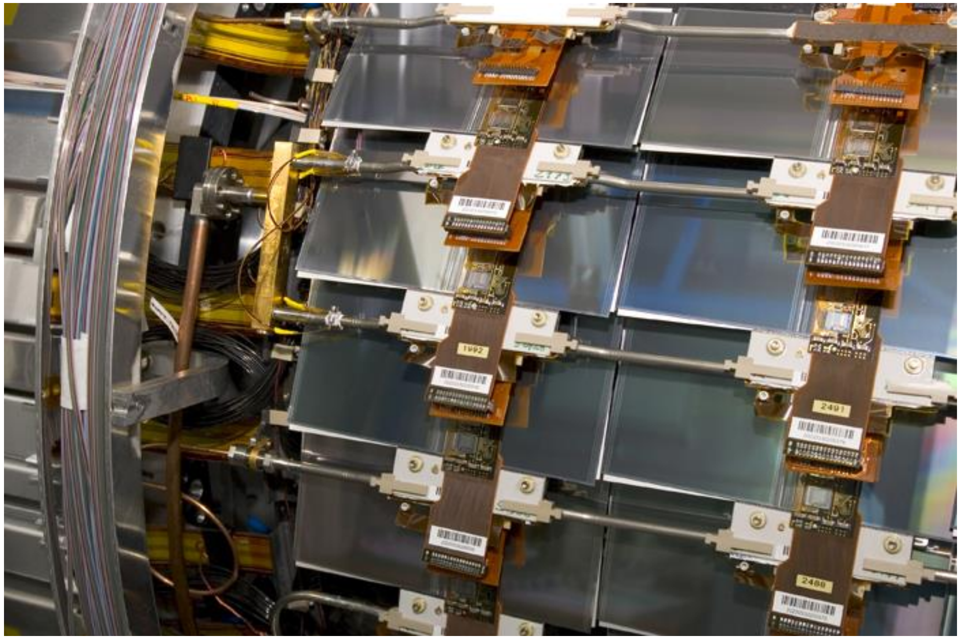
- Current SCT has 4088 independent modules
  - Individually assembled & tested
  - Individually mounted to support structures
  - Individually connected to services



Mechanics & Services of the Existing Tracker
'Classic' Tracker Design

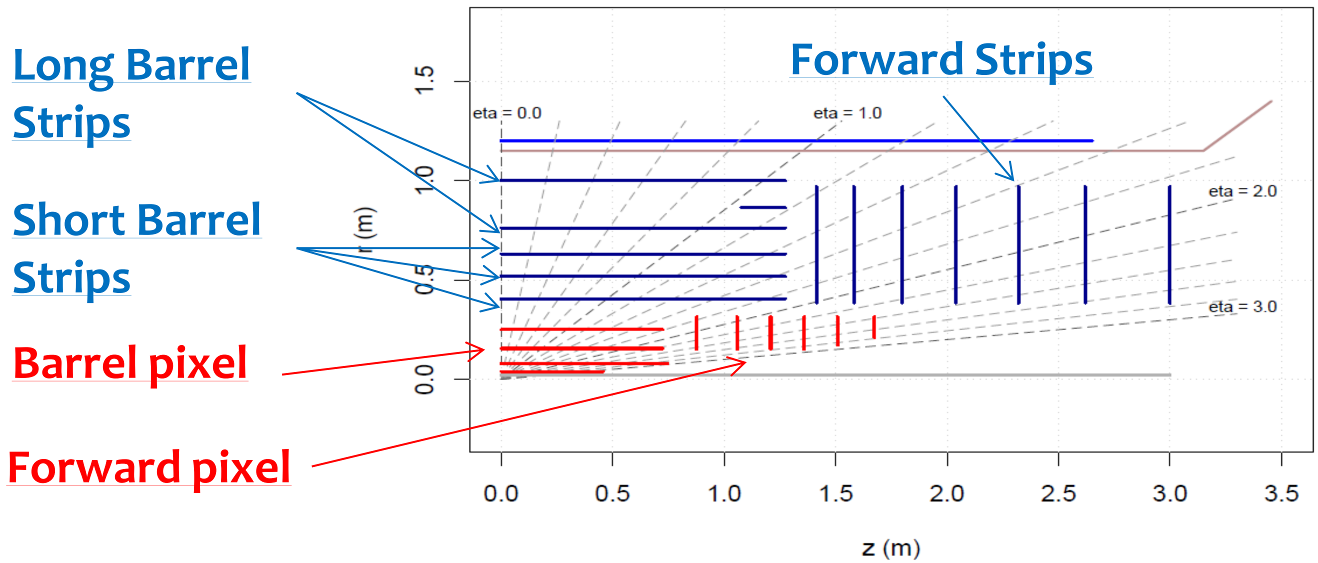


SCT Endcap disk showing outer and inner modules with their services interconnects



SCT Barrel cylinder showing rows of modules with their services interconnects

ATLAS Phase-2 Tracker Upgrade

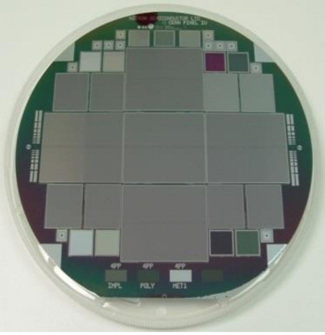


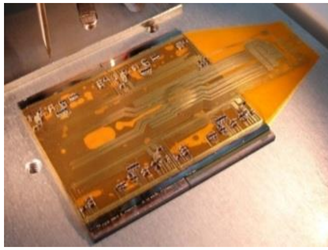
- Baseline layout of the new ATLAS inner tracker aims to have at least 14 hits everywhere for robust tracking

- All silicon Inner Detector
  - 4(pixel) + 5(strip-pairs)
  - Strips: 200m^2 (5 ½ barrel layers + 2x7 disks) (**x3.3**)
  - Pixels: 8 m^2 (**x4.7**)

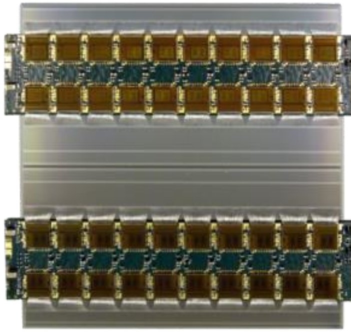
- Exploit "Integration by Design" to fight services complexity

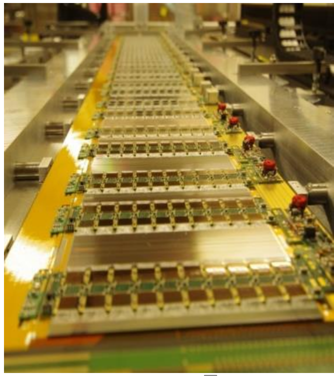
Pixel Sensor Wafer and Module Prototype



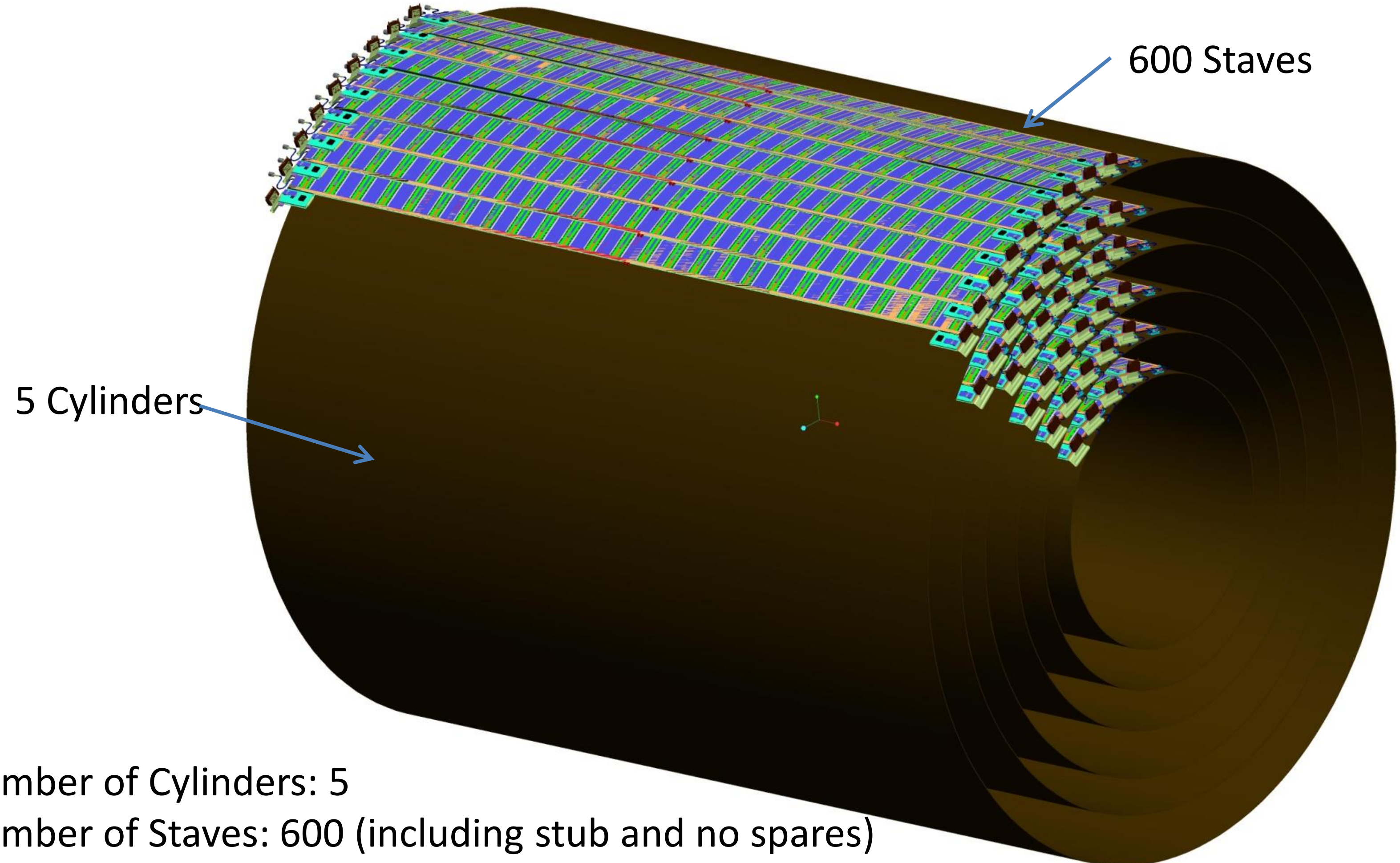


Microstrip Module & Stave Prototype





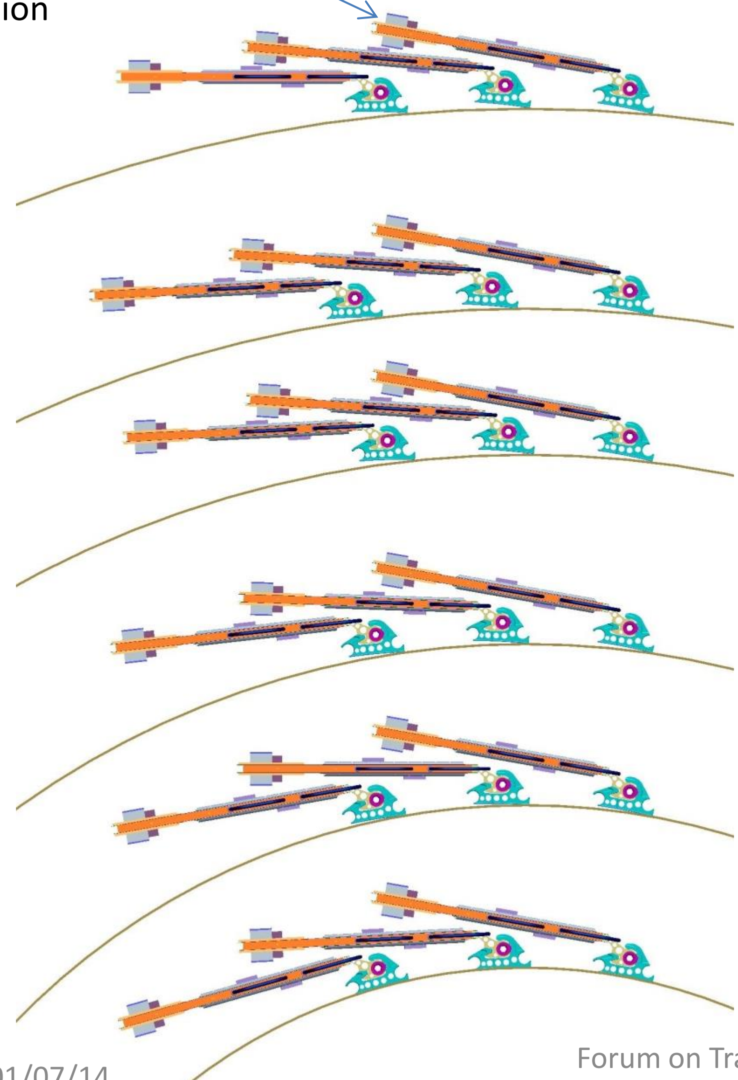
Cylinders and Staves



- Total Number of Cylinders: 5
- Total Number of Staves: 600 (including stub and no spares)
  - currently 8 different stave flavours
- Total Number of Modules: 12784
  - 13 Modules per side of stave = 26 modules per stave
  - 2 Modules per side of stave for a stub

Stave positions on cylinders angle and clearances *

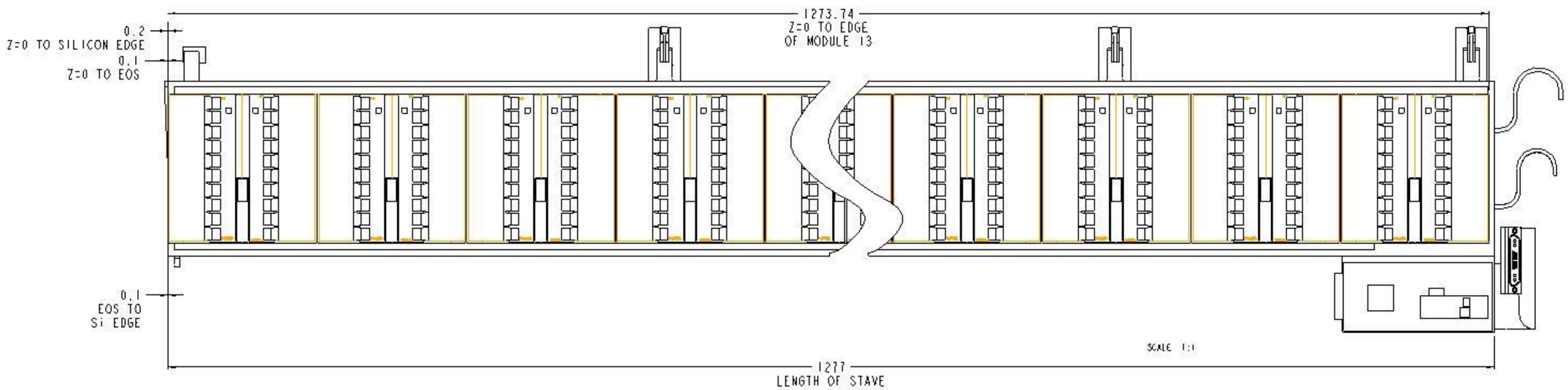
Opto package will change to a slimmer version



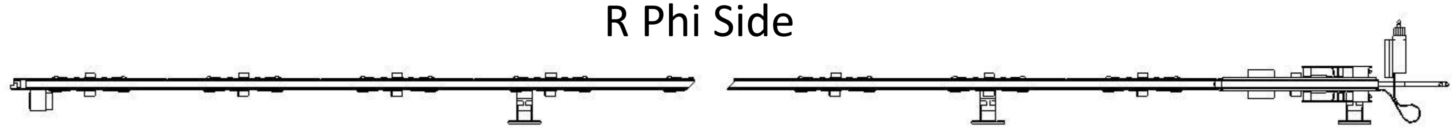
Layer	No of Staves in 360°	Radii to Centre of Stave
0	28	405
1	36	519
2	44	631
3	56	762
4 (Stub)	64	862
5	72	1000

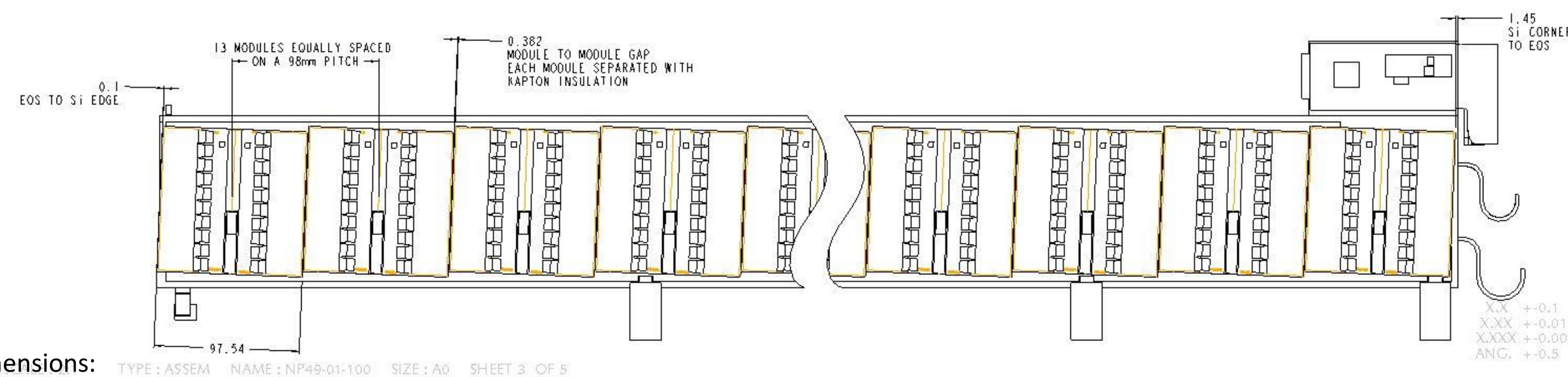
* Minimum clearance between staves to be around 2mm with a 10° tilt angle

Stave Geometry



R Phi Side



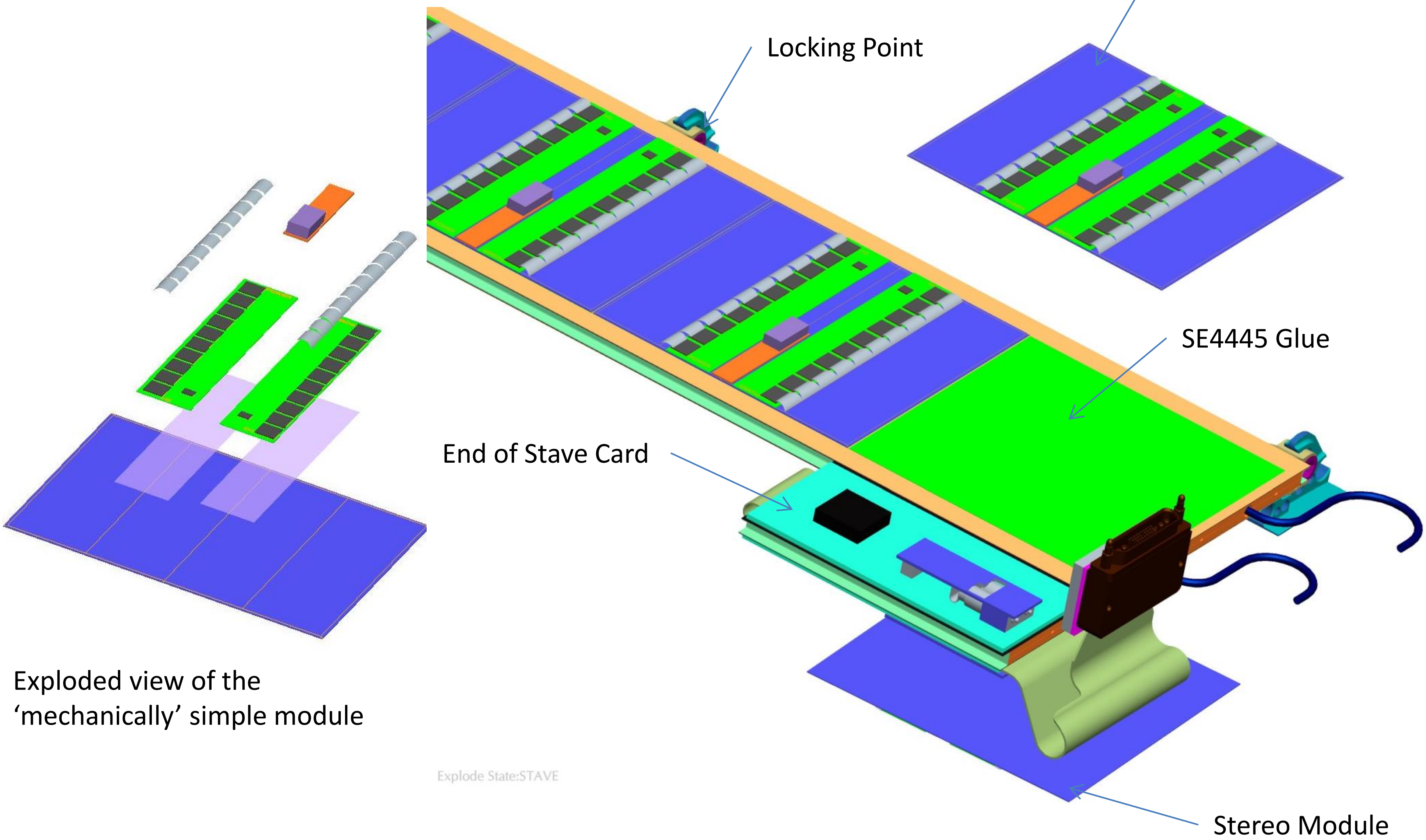


Critical Dimensions:

- Overall Length 1277
- Width 115
- EOS at Z=0 to Silicon Edge 0.1mm
- Module to Module Gap 0.46mm
- Pitch of Modules 98mm

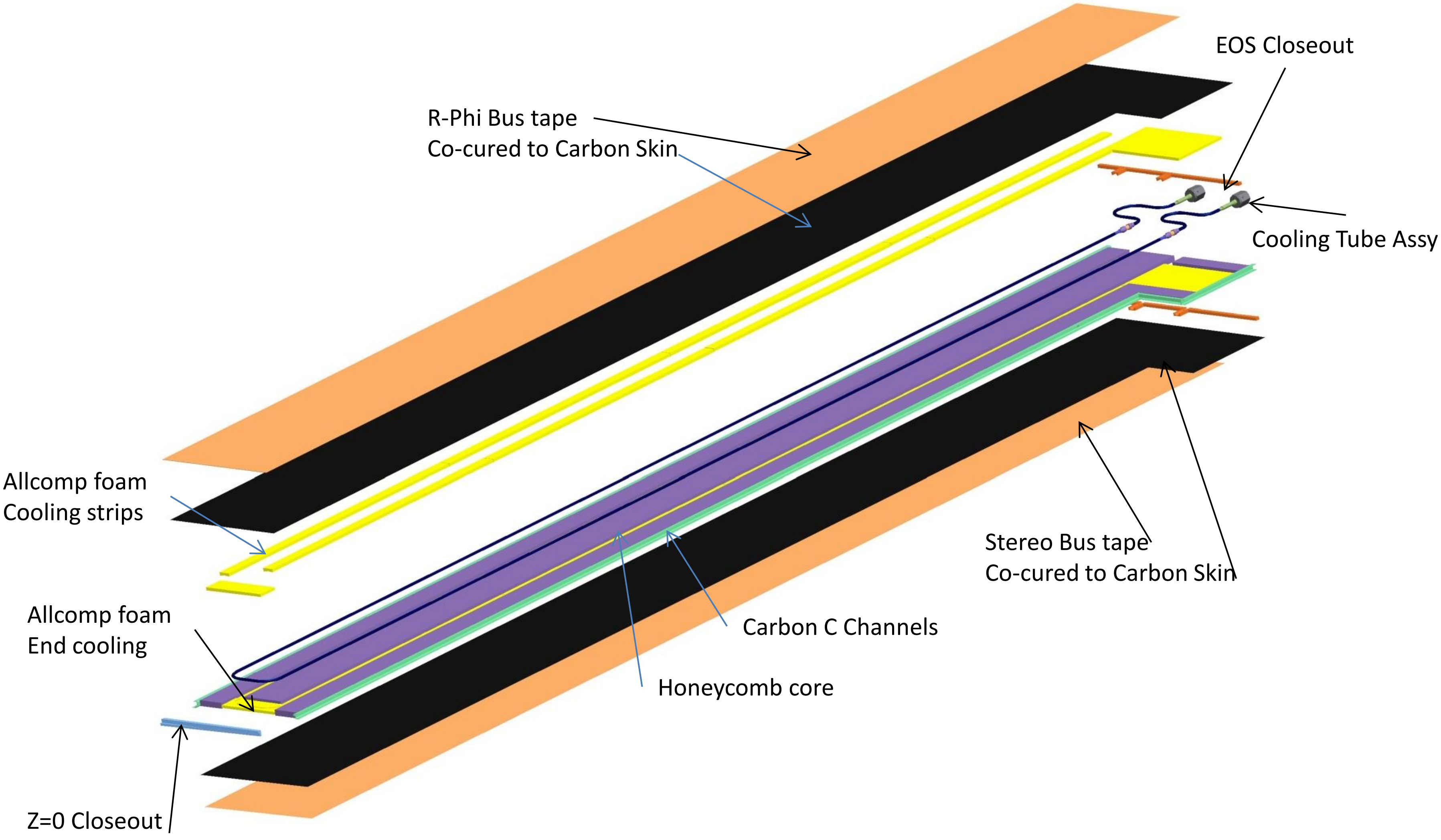
Stereo Side

Modules, End of Stave Cards and Locking Points



Exploded view of the 'mechanically' simple module

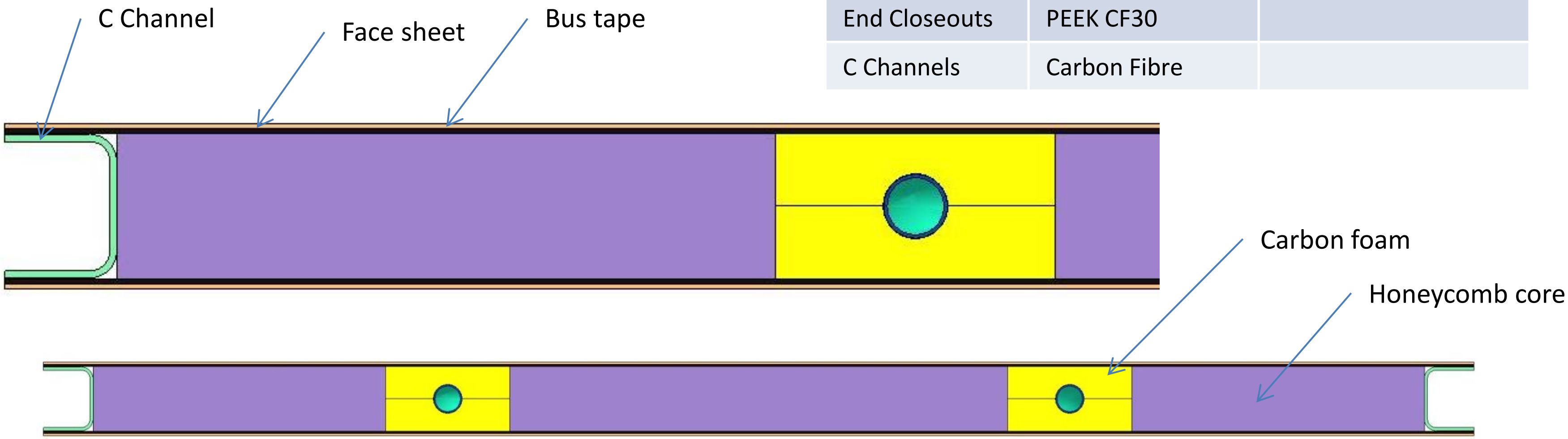
Stave Detail



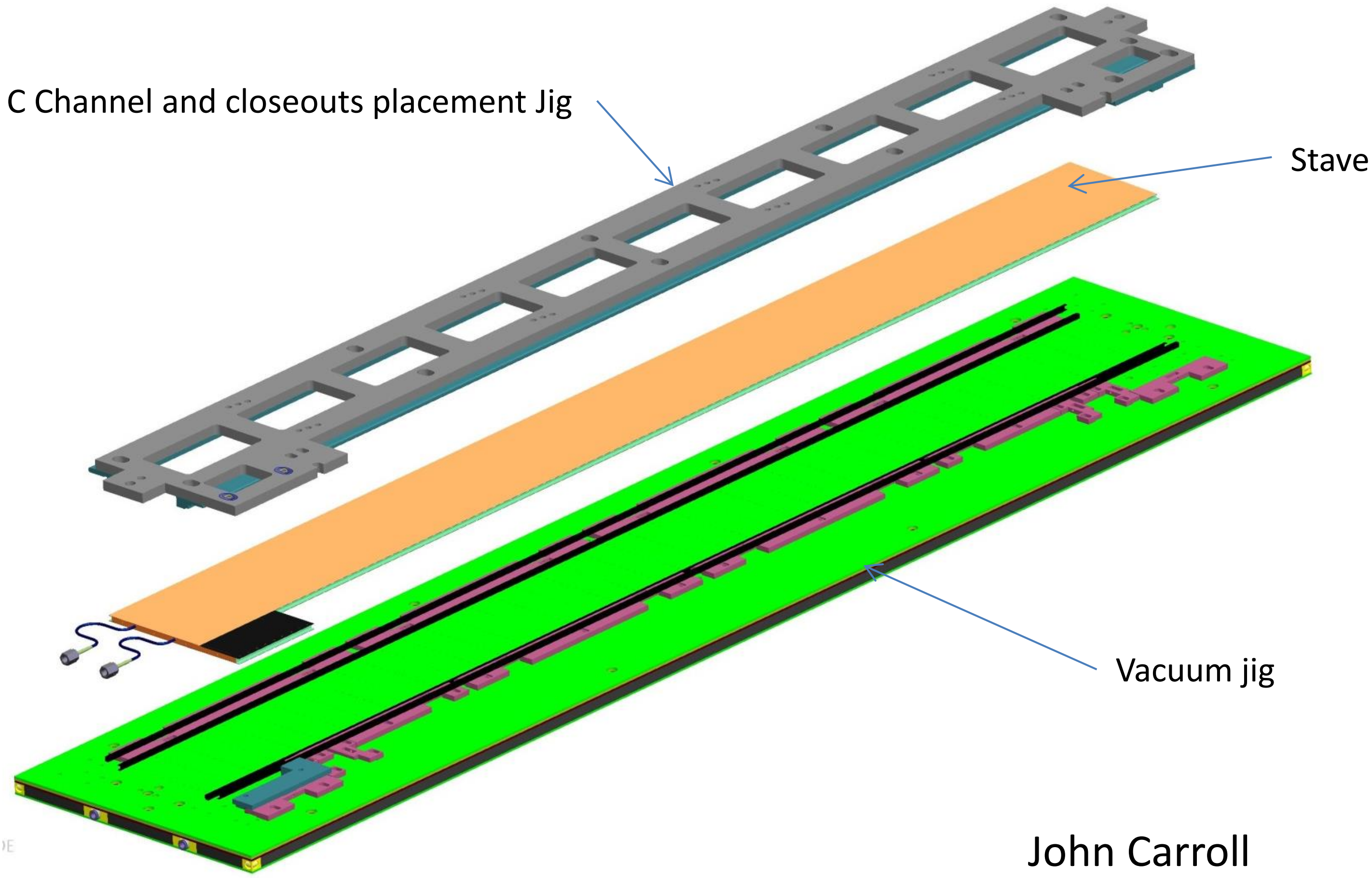
Stave Construction and Materials

- Stave is manufactured from 2 UD Carbon and kapton face sheets with a core manufactured from Ultracor Honeycomb and Allcomp Foam

Component	Material	Remarks
Carbon Face sheet	Tencate K13C2U 45g/m^2 EX1515 Resin	3 layers 90/0/90 total thickness 0.15mm Co-cured onto a kapton bus, thickness 0.2mm
Honeycomb Core	Ultracor Carbon Honeycomb UCF-126-3/8-2.0	Final thickness 5.2mm
Carbon Foam Core	Allcomp K9	Final thickness 5.2mm
Cooling tube	Titanium CP3	2.275 x 0.125 wall
End Closeouts	PEEK CF30	
C Channels	Carbon Fibre	

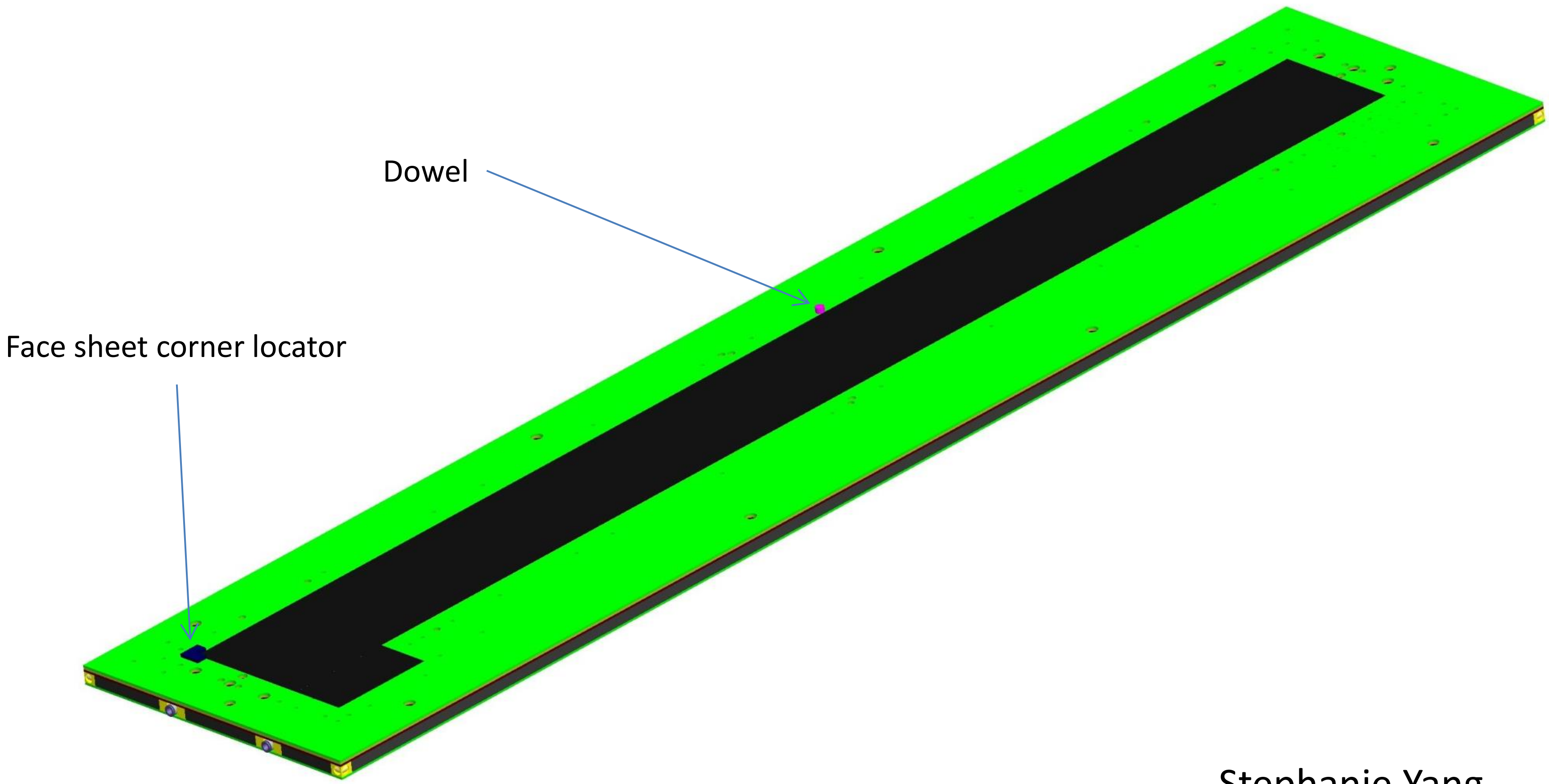


Manufacture of the staves
Stave Assembly tooling



John Carroll
Stephanie Yang

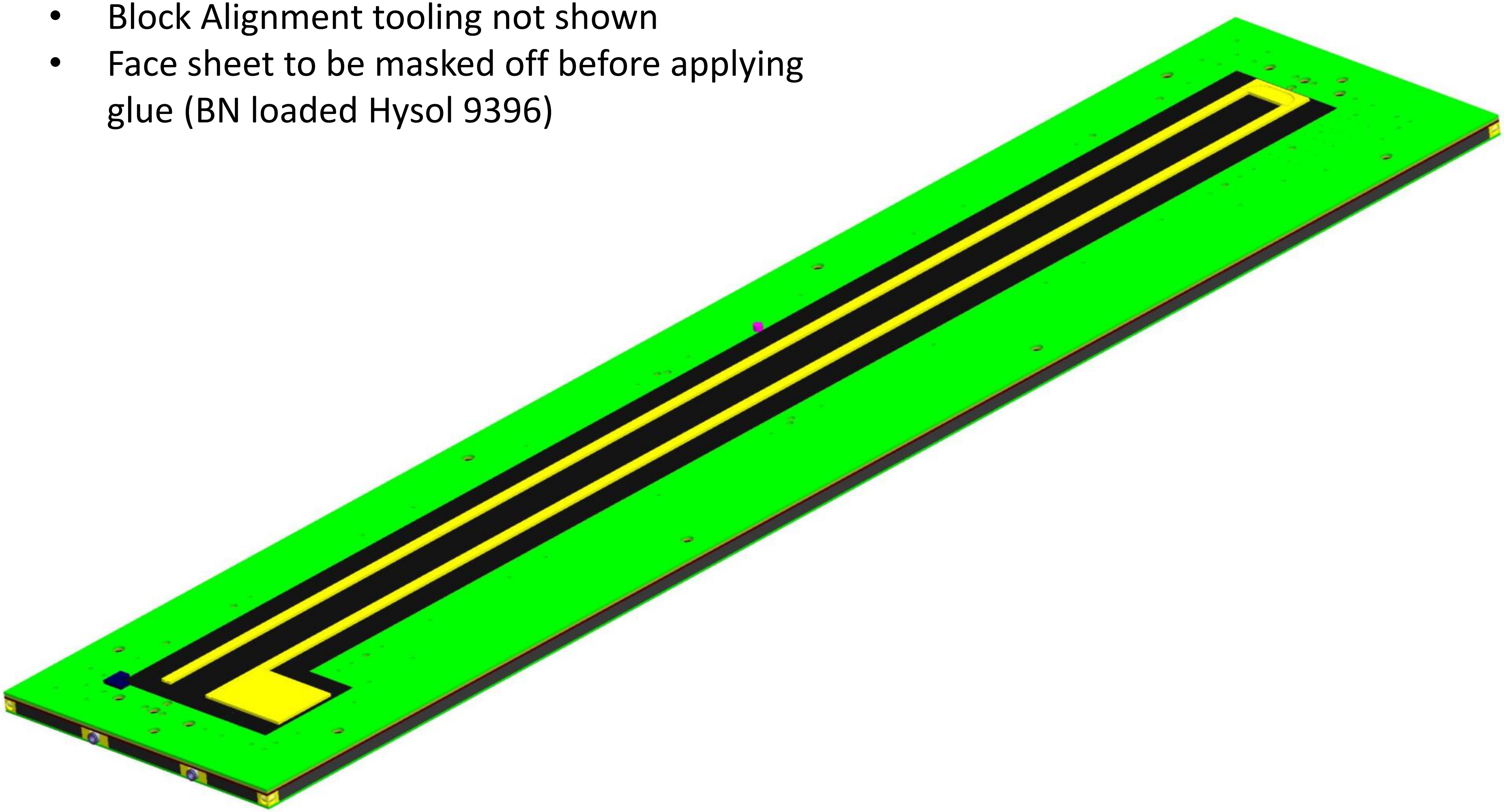
Assembly Sequence- Co-cured face sheet



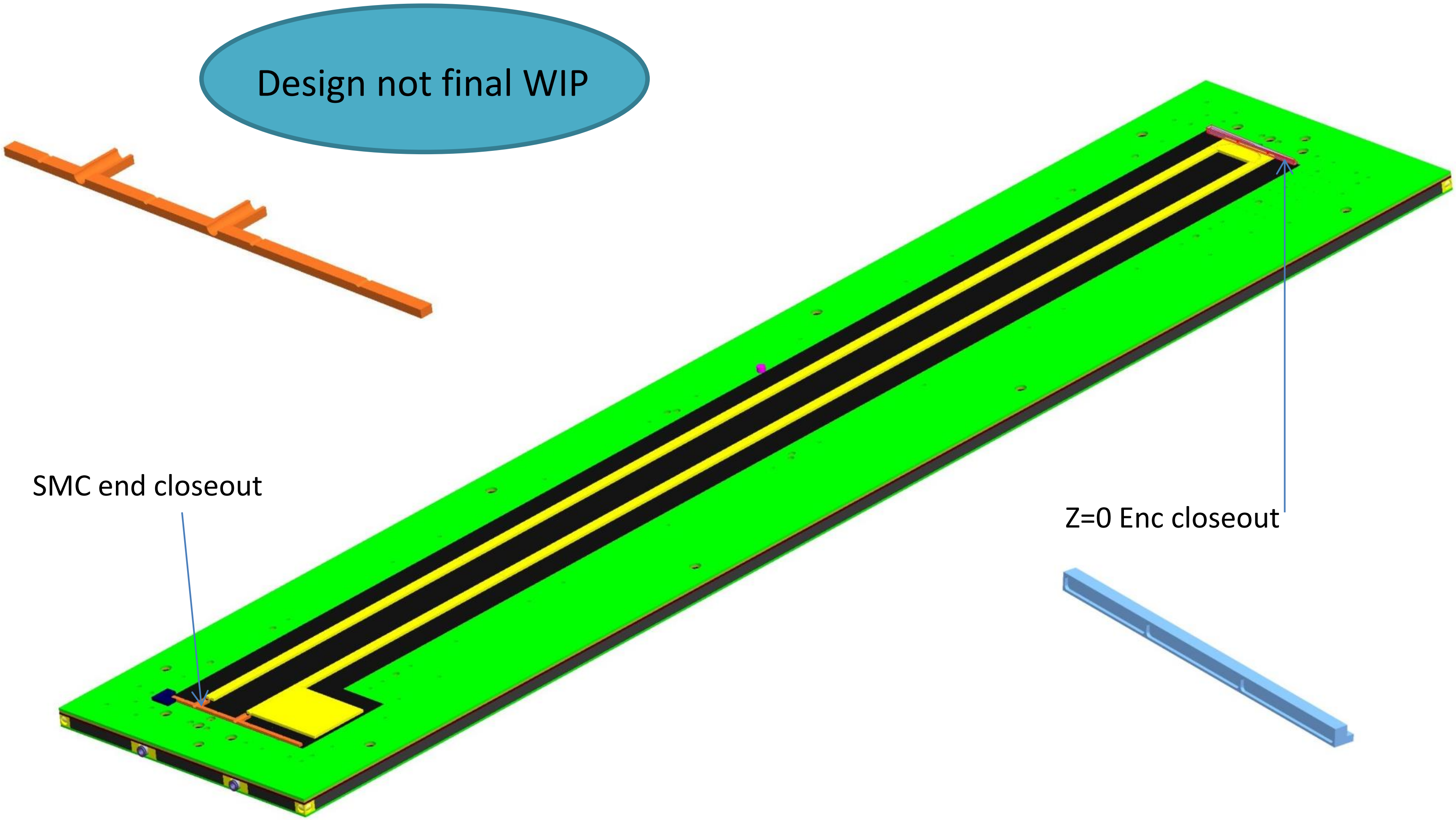
Stephanie Yang

Assembly Sequence- Add lower foam cooling blocks

- Block Alignment tooling not shown
- Face sheet to be masked off before applying glue (BN loaded Hysol 9396)

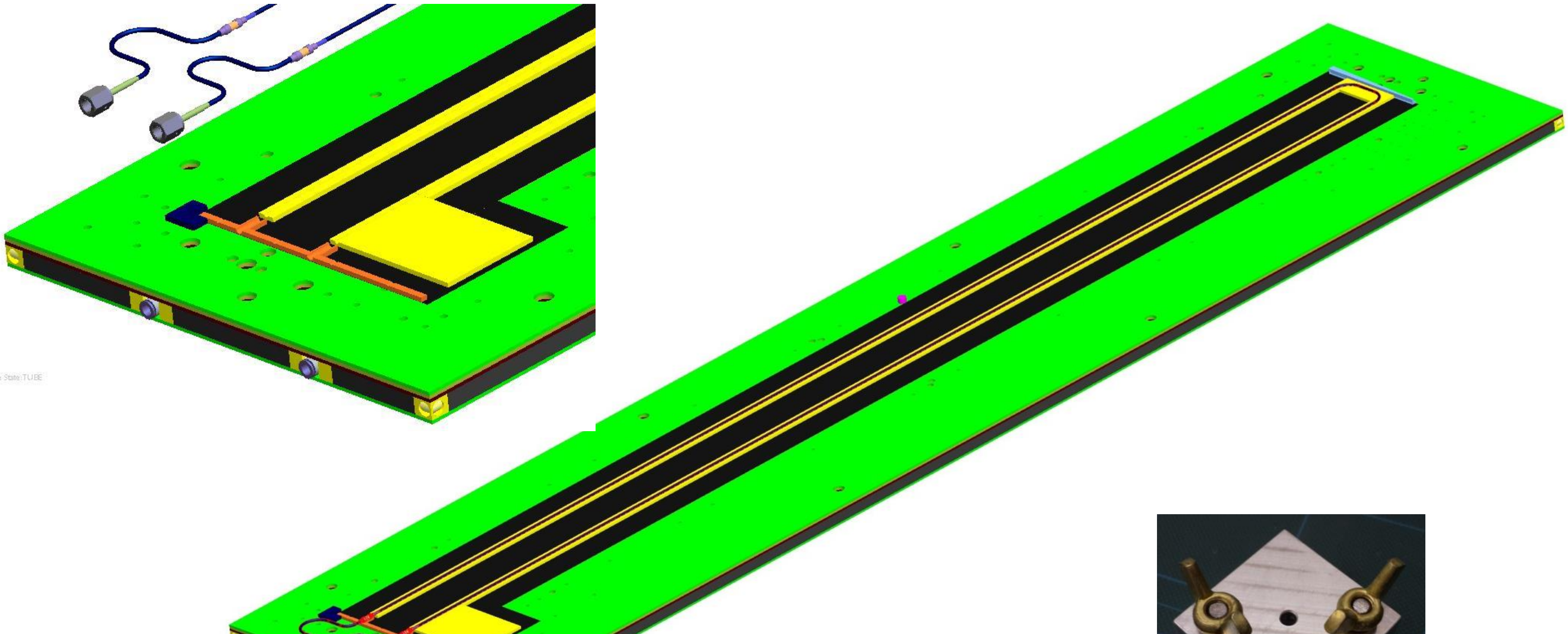


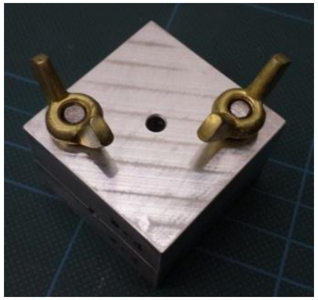
Assembly Sequence- Add Closeouts



Assembly sequence -

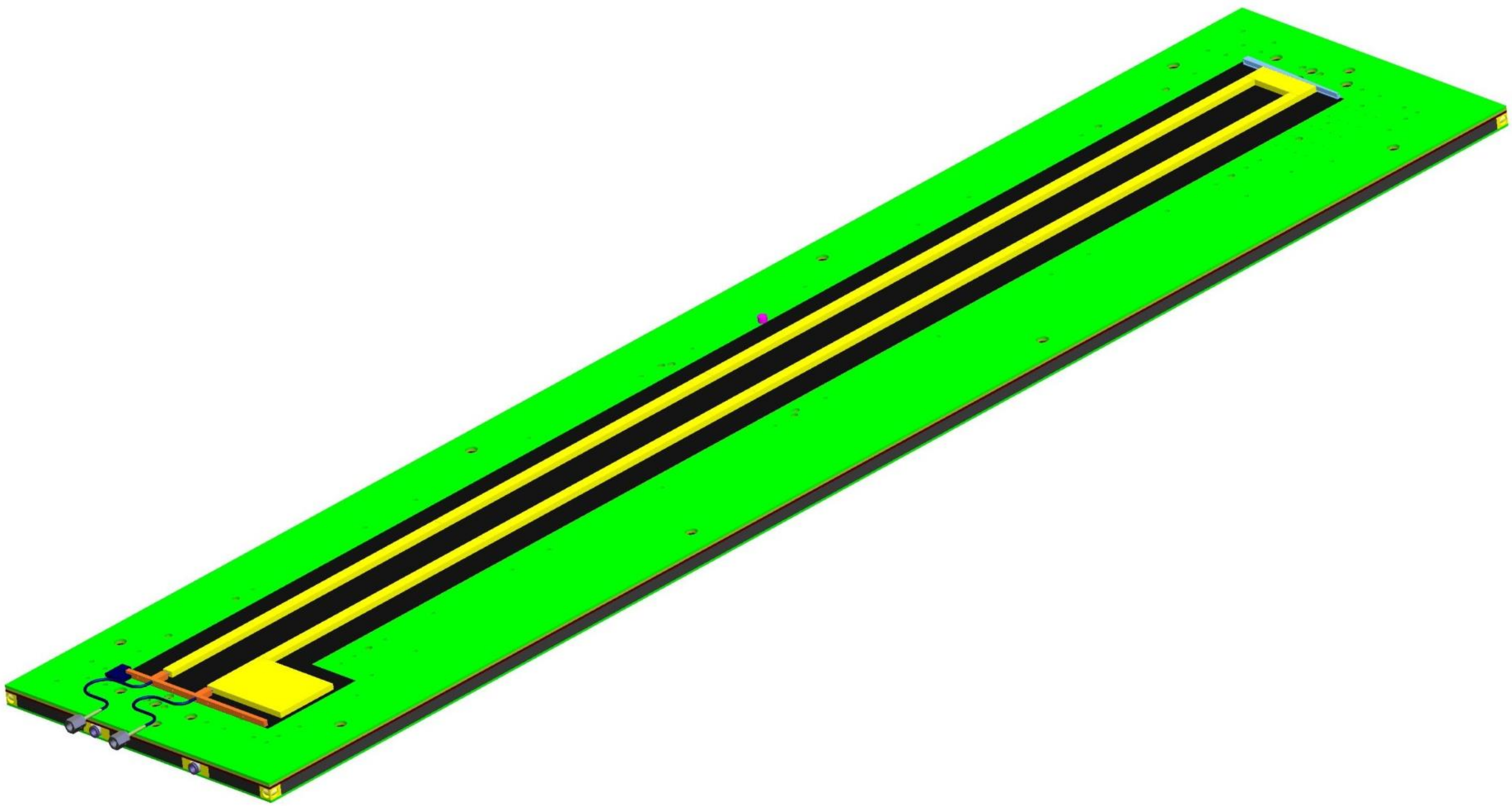
Inserting the cooling tube into the foam grooves



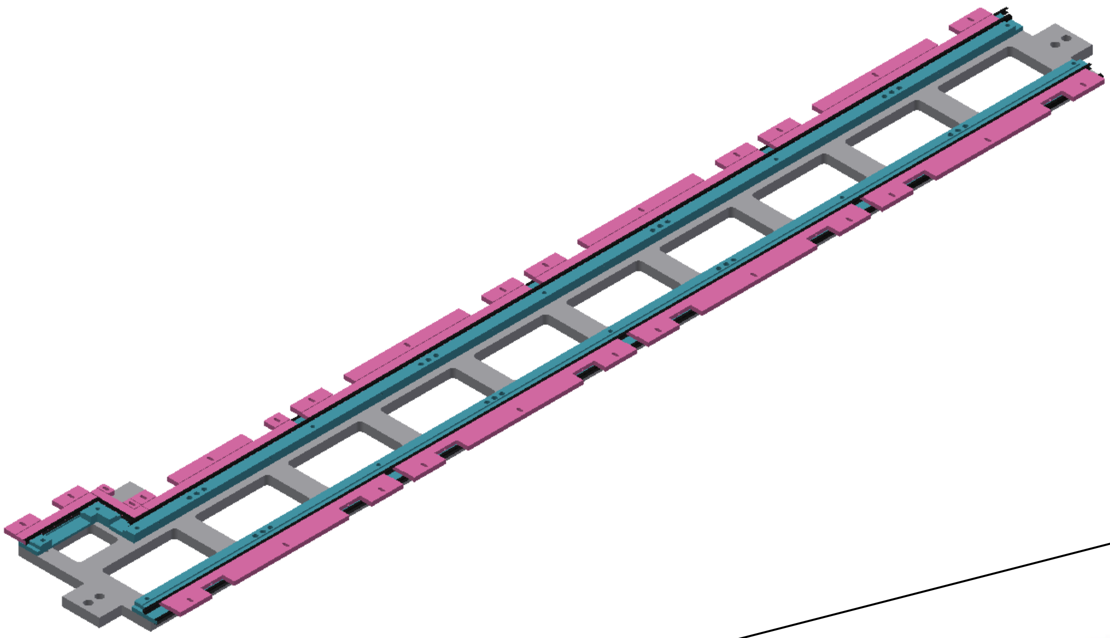


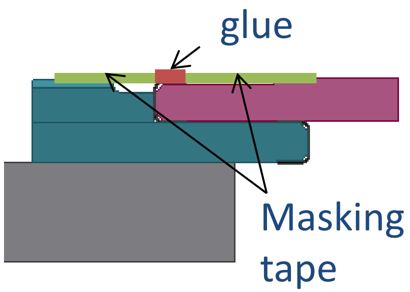
Tube gluing jig

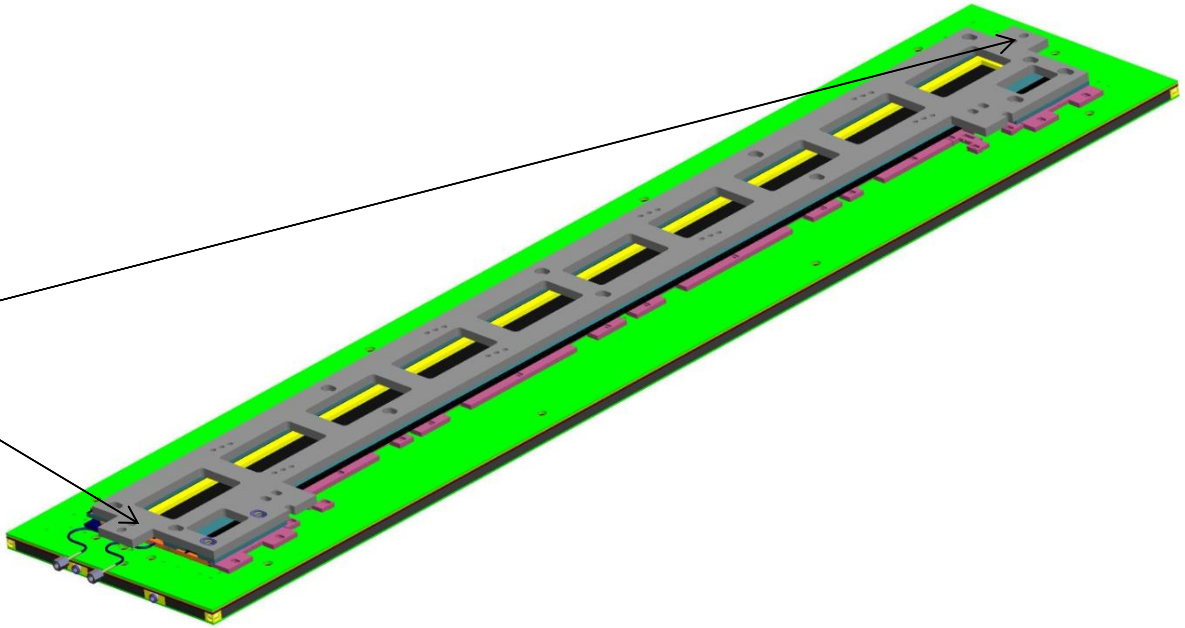
Assembly sequence- Add upper foam cooling blocks



Assembly sequence –
Add 'C' Channels using the 'C' Channel placement jig



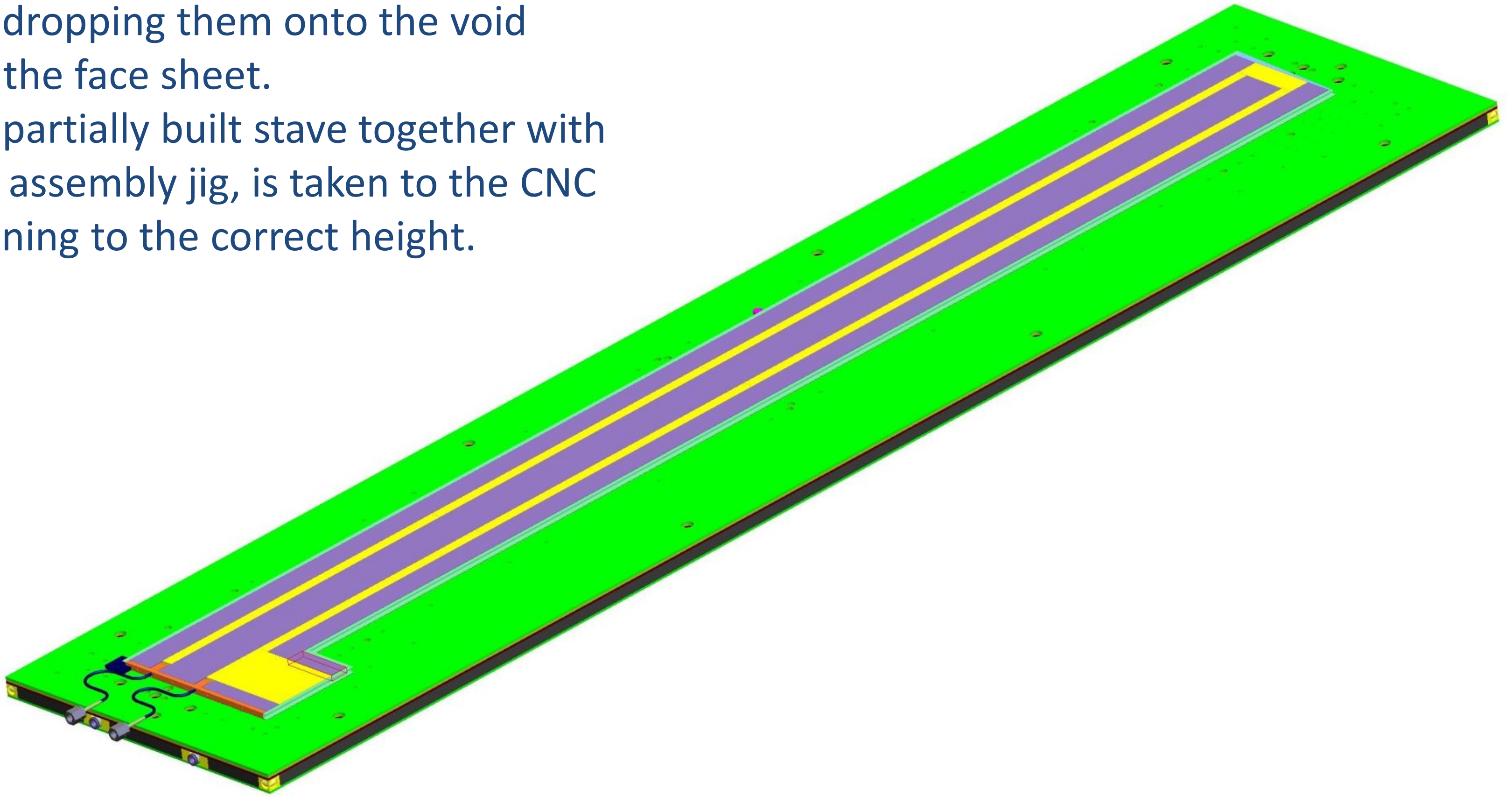




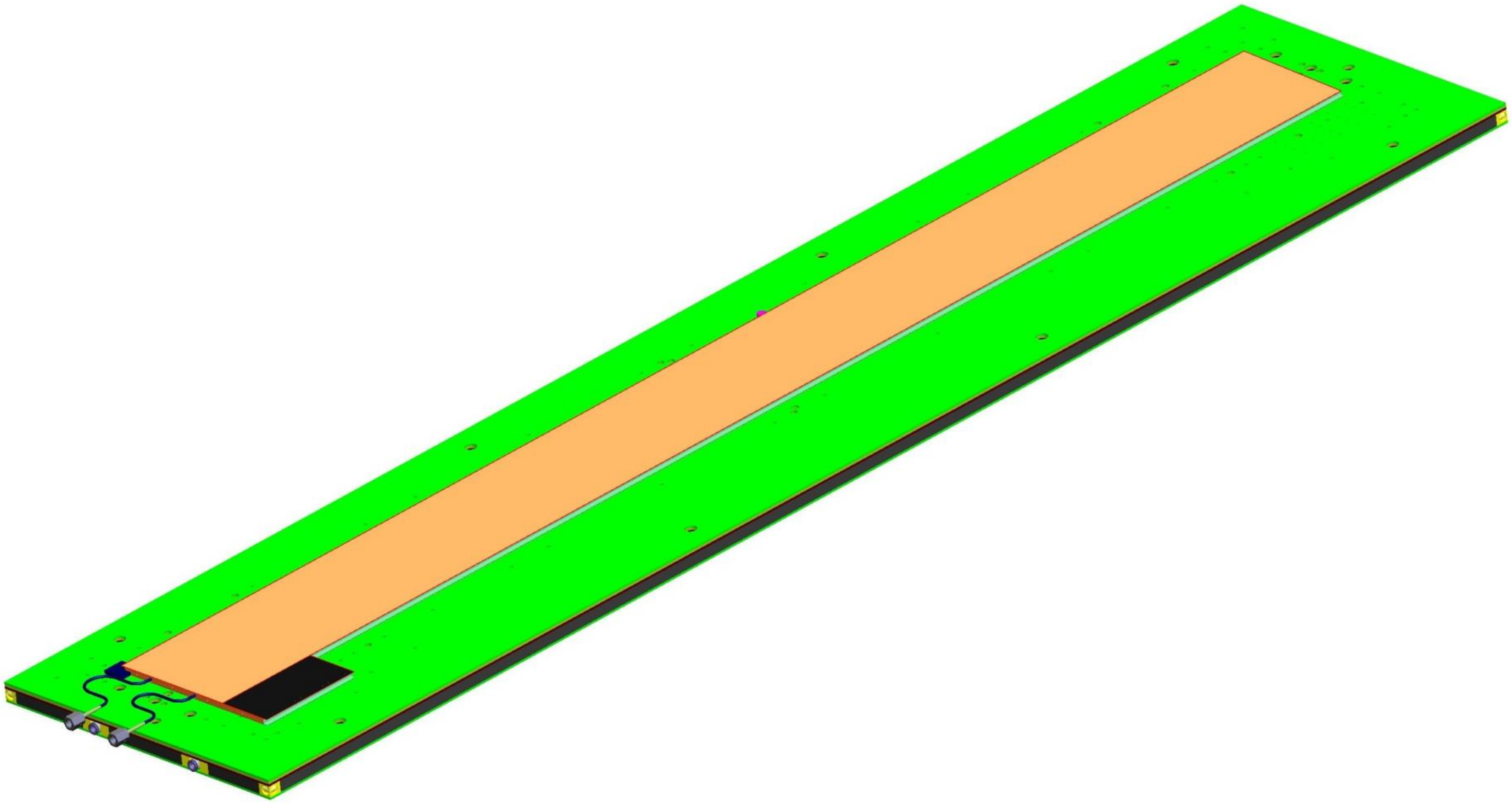
Remove the masking tape and place the assembly unit on to the main jig, reference to the dowels at each end.

Assembly sequence – Adding the Honeycomb

- Next step is Honeycomb gluing process: dipping the honeycomb pieces into the glue bath and dropping them onto the void region of the face sheet.
- Then the partially built stave together with the Stave assembly jig, is taken to the CNC for machining to the correct height.



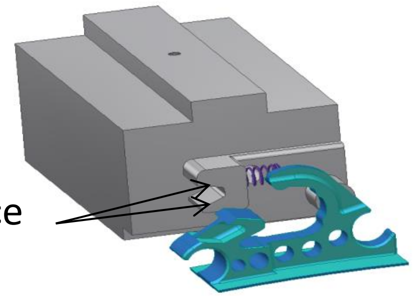
Assembly sequence – Add upper co-cured face sheet



Assembly Sequence –

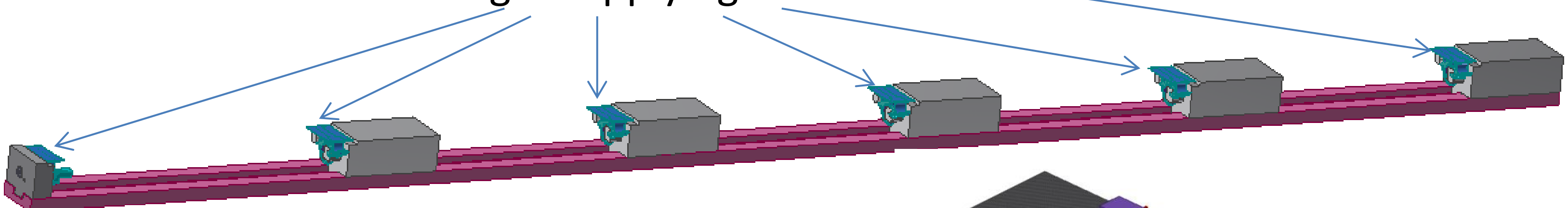
Add the locking points using the locking point gluing ruler

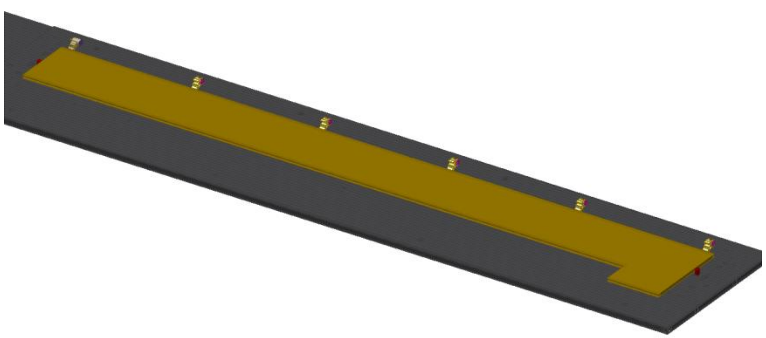
reference faces

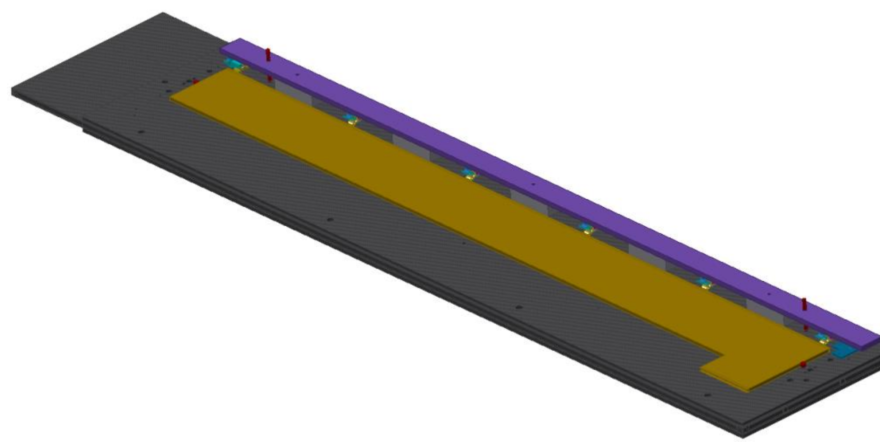


- Insert the locking point into the holding blocks
- Insert the holding blocks into the location ruler
- Glue the locking points into the C channel in the stave

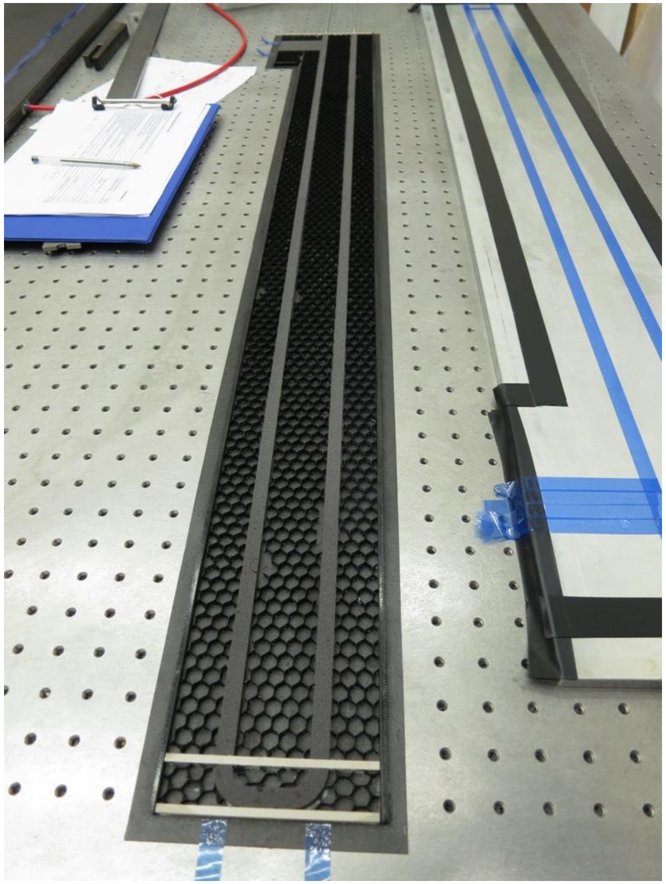
glue applying to this face



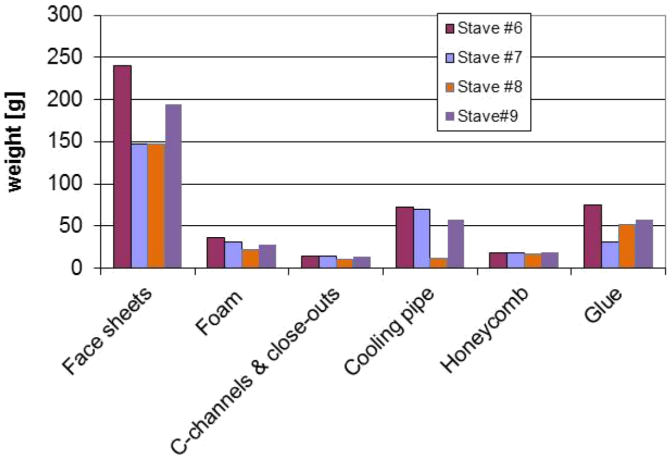


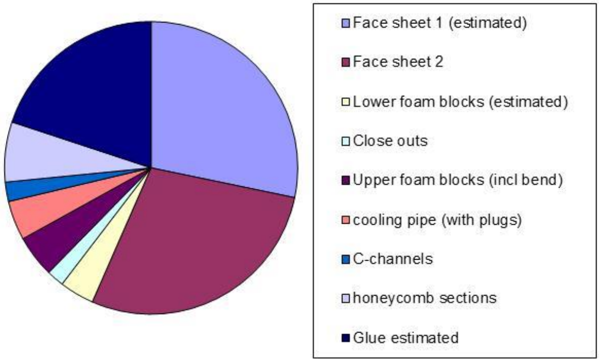


Plank #9 manufacture



- Total weight of stave 330.37g

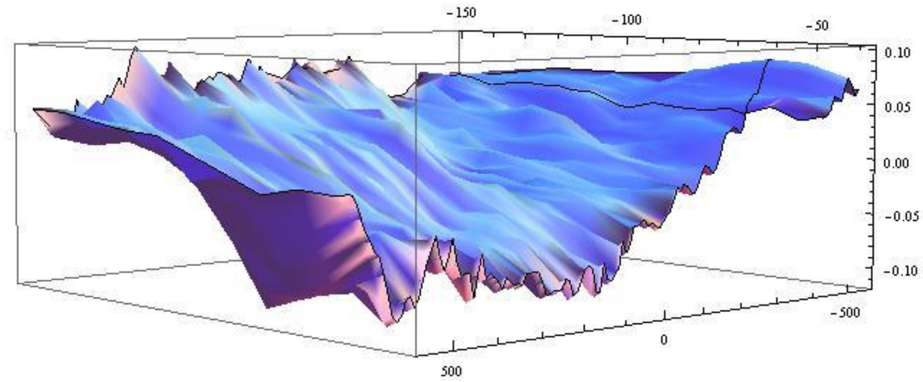




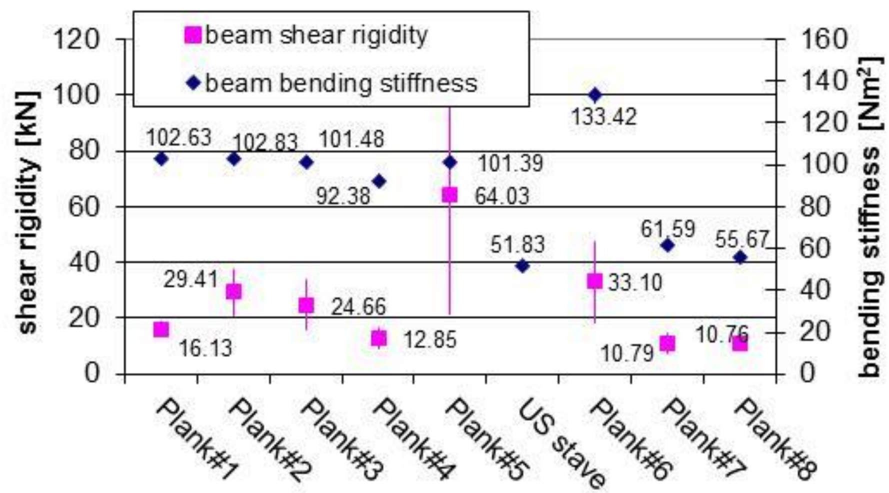
Stephanie Yang
Georg Viehhauser

Plank #9 flatness and stiffness

- Flatness is around 0.20 and a twist has been shown. Not as good as we would like although the overall thickness is very uniform, proving the CNC machining of the core works.

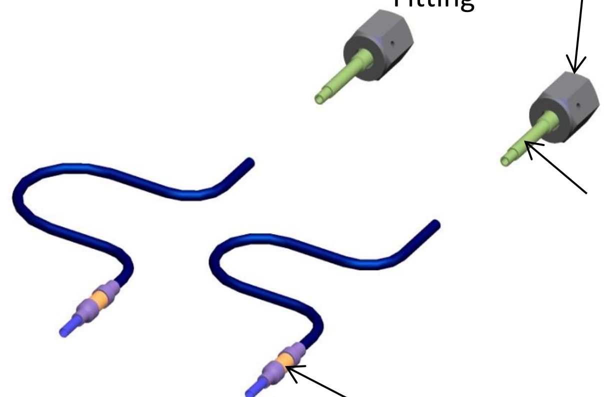


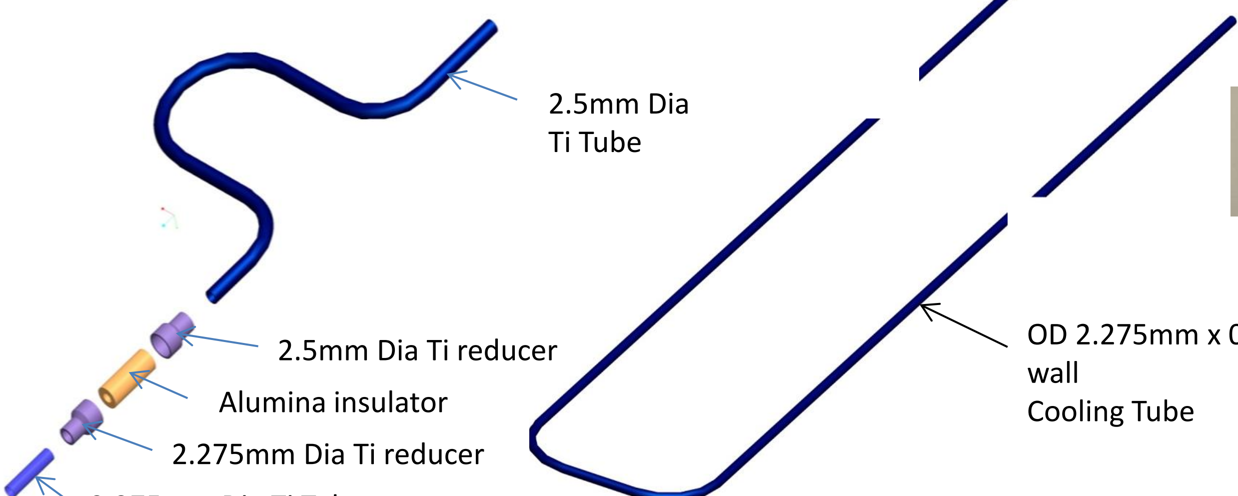
- Bending stiffness of the planks made so far.



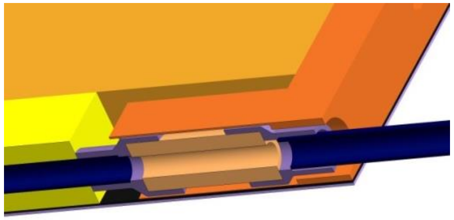
Cooling tube and Electrical Break Assembly

- Assembly vacuum brazed with silver copper eutectic
  - Brazing temperature around 780°C
- Several have been manufactured and look good.
- Alumina insulator is very strong
- Electrical break assembly is welded to the stave and inlet/exit tubes.
- E break assembly is potted into the closeout
- Cooling tube assembly procedure:
  - Manufacture main cooling tube
  - Vac Braze E-Break and U tube assembly
  - Manufacture Ti Glands
  - TIG Weld Above 3 components





Richard French



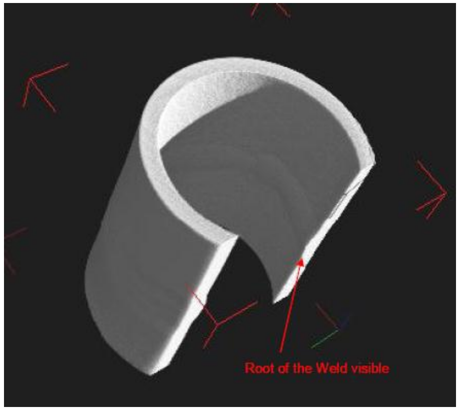
Potted into end closeout

Tube Welding

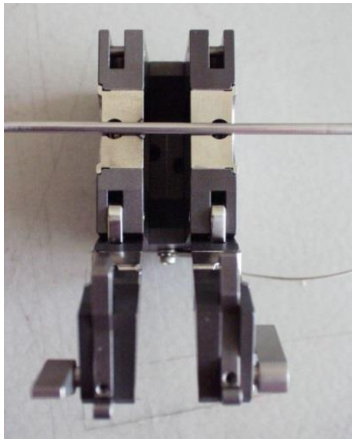
- Material Titanium CP2 Precision drawn round tube, pressure tested to 150 Bar
- Full Metallurgical qualification of TIG welded Ti pipes from MME has been done
- TIG orbital welding:
  - Portable automated equipment, no filler material (autogenous process) or sleeve joint required for welding. Highly repeatable, low cost, low XO when compared with connectors.
- TIG orbital welding limit is around 2.275 OD x 125µm wall
  - Butt welding successful on both 2.275mm and 1/8" tube

Welded Tube

Weld setup

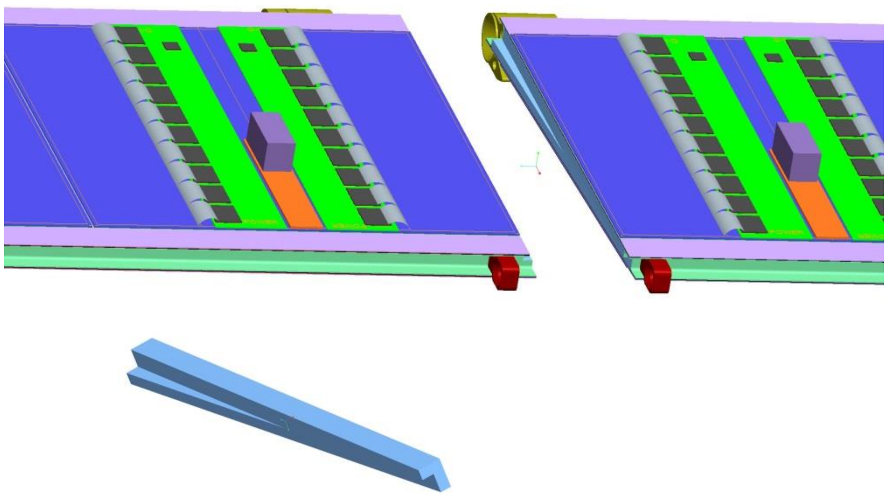


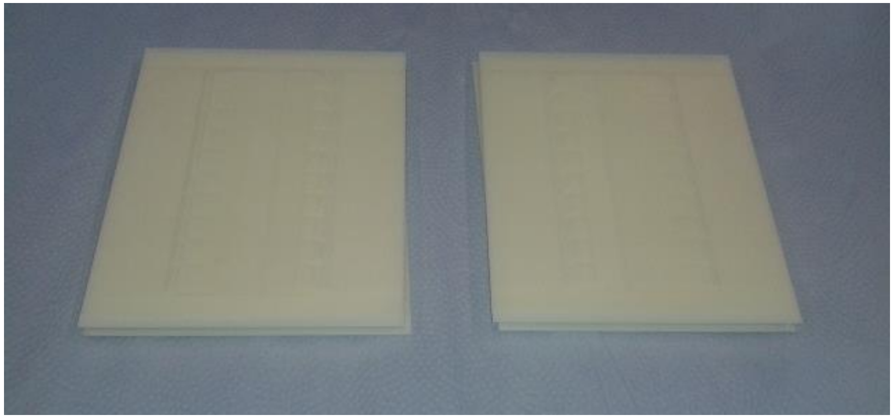
Ct X ray scan



Tube in weld head

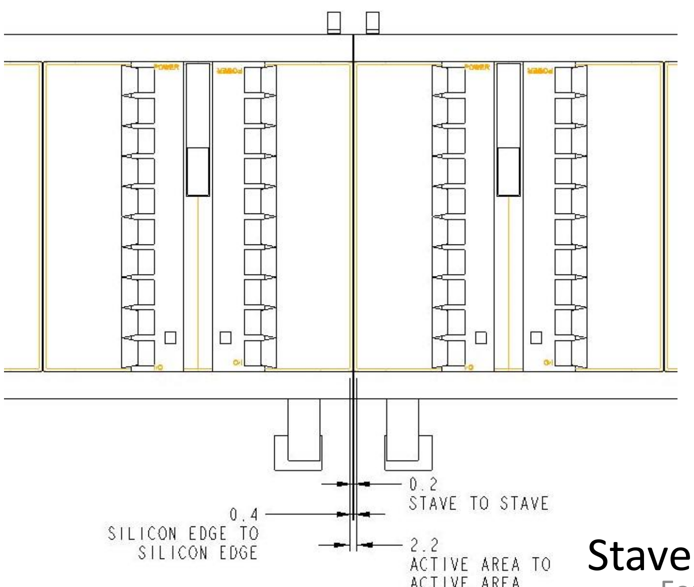
Z=0 End Closeout

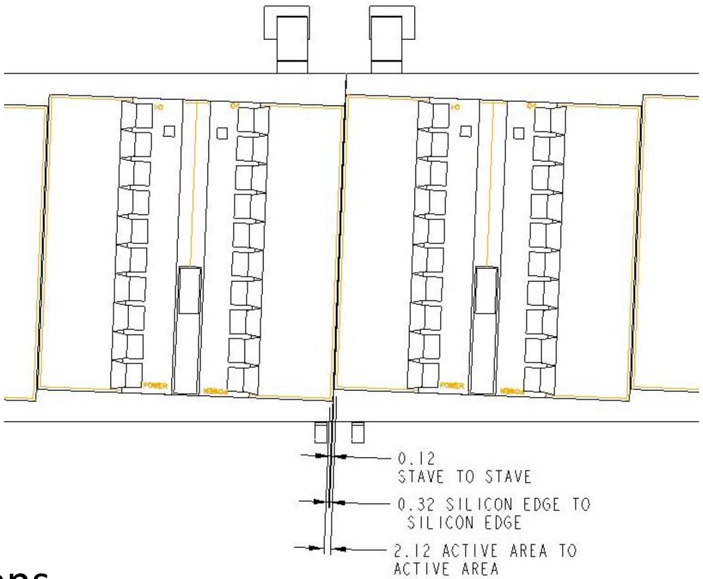




3D Printed Model

Z=0 Closeout manufactured from PEEK

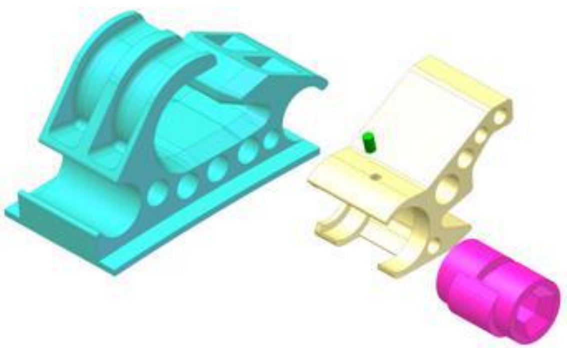


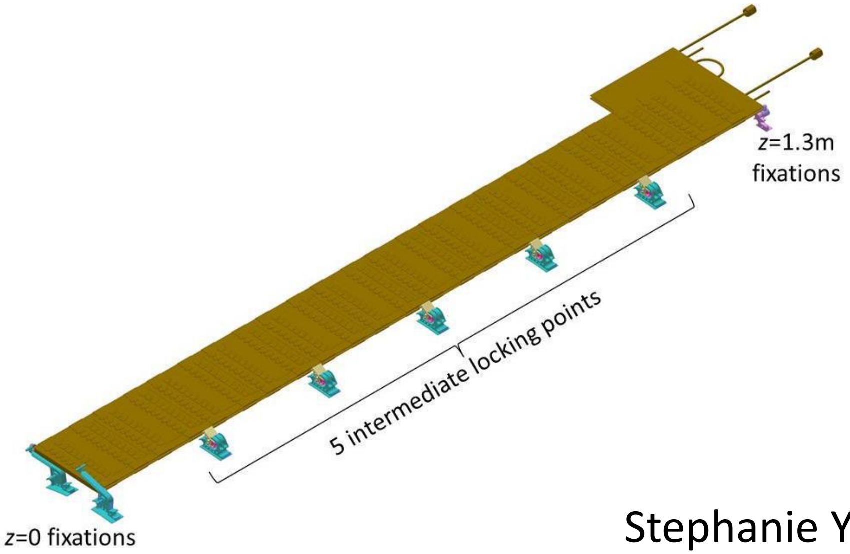


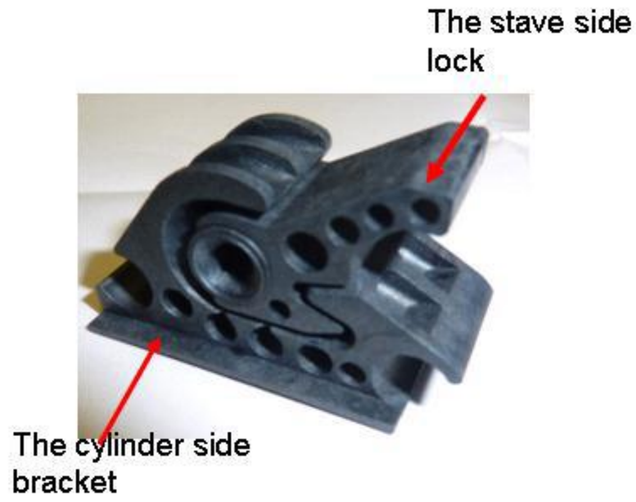
Stave to Stave Dimensions
At Z=0

Stave mounting onto Cylinder

- The stave is mounted onto the cylinder using 5 locking points and 2 location points.
  - The locking points use a cam to lock the stave into position
  - There are 5 locking points on the length of a stave
  - All 5 locking points are fixed sequentially using a long hex key.



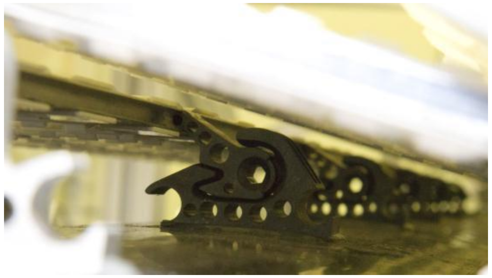


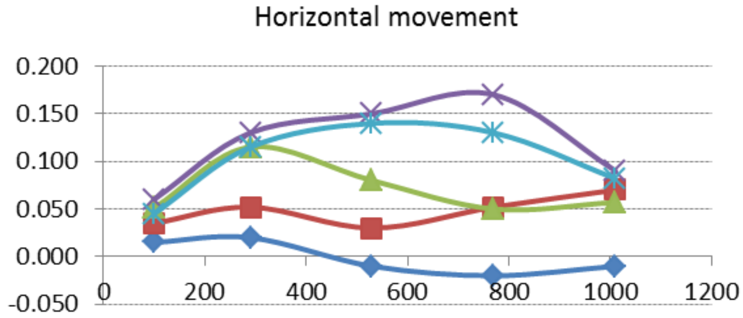


Stephanie Yang

Insertion onto the Cylinder

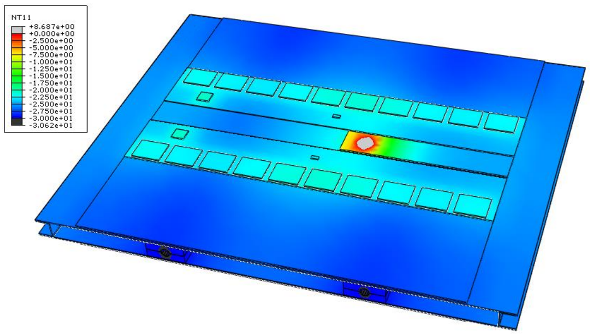
- The picture shows insertion onto a sector prototype
- The locking points are also shown.
- The picture below shows the end brackets and location in Z and R phi
- Insertion trials have demonstrated that the staves are within their designated envelopes.

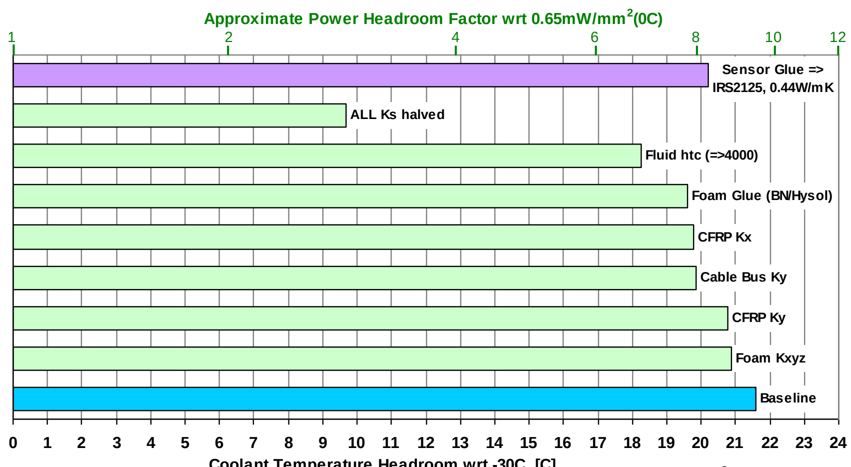




Thermal FEA

- Thermal FEA has been done on all areas of the stave and includes ‘hot spots’ such as the on board DCDC Chip and the Z=0 end of stave region where the cooling tube bends.
- Thermal headroom and Thermal Runaway has been evaluated and the headroom expected at 3000 fm-1 plotted, in terms of sensor power and CO_2 temperature.
  - Headroom takes into account mechanical thermal variations such as material conductivity and glues





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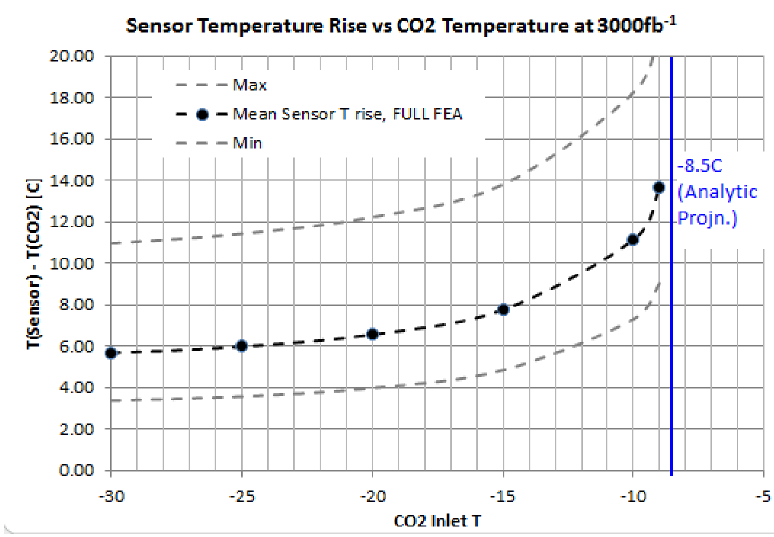

FE Materials Chart

Item	Material	K x / y / z [W/m-K]	thickness [mm]	additional info.	additional info.
Asic	silicon	191 (250K) … 148 (300K)	**0.3**		Table 1 in extended doc.
asic to hybrid	tra-duct-2902	**2.99**	**0.08 (0.1)**	50% area coverage	Poss. alternative: non-conductive glue (thinner)
hybrid	Cu/polyimide	**72 / 0.23[1], 0.54[2] / 72**	**0.2 (0.3)**	New - for 3 layer hybrid (2013-)	[1] outside via region, [2] within 3mm via region. (a poorer approx is 0.36 W/mK over *all* hybrid)
hybrid to sensor	epolite	**0.23**	**0.12 (0.1)**	2mm stay-clear (guard region)	K from Glasgow measurement.
Sensor	silicon	191 (250K) … 148 (300K)	**0.3**		Table 1 in extended doc.
sensor to bus	DC SE4445	**2.0**	**0.2**	(a) 60% glue strips, along Z. R ≡ 0.1mm/1.0W/mK	K[W/mK]: Glasgow ~2 (8Feb11). DaveL: 1.8, mfr's spec:1.26. **Gel! - Seeking alternative**
bus tape	PolyI/Cu/Al	**0.17 / 0.24 / 0.17 (34)**	**0.17**	Shieldless tape. (c) **Estd: awaiting samples**.	Previously: 25um Al shield: Ky (Glasgow, meas) Kxz =34 (Edbg.calc). Cu neglected (~16% area).
bus to facing	**(Hysol)**	**Set high (0.21)**	**(0.1)**	(Hysol)	N/A: Assume co-cure!
Facing	0-90-0 CFRP	**90/1/180 (140/1/280)**	**0.15 (0.21)**	**K13C2U 45gsm** **(K13D2U 100gsm)**	Values for 45gsm/K13C from QMUL(Kab,Kc) Liverpool(thickness, Kx,z calc.). (May 2013).
Facing to Honeycomb	**n/a**	**-**	**-**	**Suppressed in FEA.**	(was Hysol, 0.21 W/mK, 0.1mm)
Honeycomb	**n/a (air)**	**-**	**-**	**Suppressed in FEA**	(CF honeycomb low K / Poor interface to foam).
Facing to Foam	Hysol+BN	**1.33 (1.63)**	**0.1**	R ∝ thickness: no boundary contribution (Glasgow).	~ 1.3W/mK for 35% BN (Glasgow). Joint thickness + integrity uncertain.
Foam	Allcomp	**30 (43/55/43)**	As drawn		**(replaces Pocofoam)**
Foam to Pipe	Hysol+BN	**1.33** (1.63)	**0.1**		See Facing to foam (above).
Cooling Pipe 2mm i/d	Titanium (Grade 2)	**16.4**	0.14	(20-100C, Sandvik data sheet).	Alt: S/Steel 316L, 3.18 o/d, 0.22 wall, K=14, 15.3 at 250, 300K. (Table 2)
Fluid film	CO_2	**htc ~ 8000 W/m^{2}K**		typical at low vapour quality	Varies with vapour quality, mass flow rate etc. (b)

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Modal analysis Model of the structure

4-ply (0/45/-45/90) Barrels w/equivalent mass (+Δρ) (0.248mm)

Representative flange geometries with internal bonded web

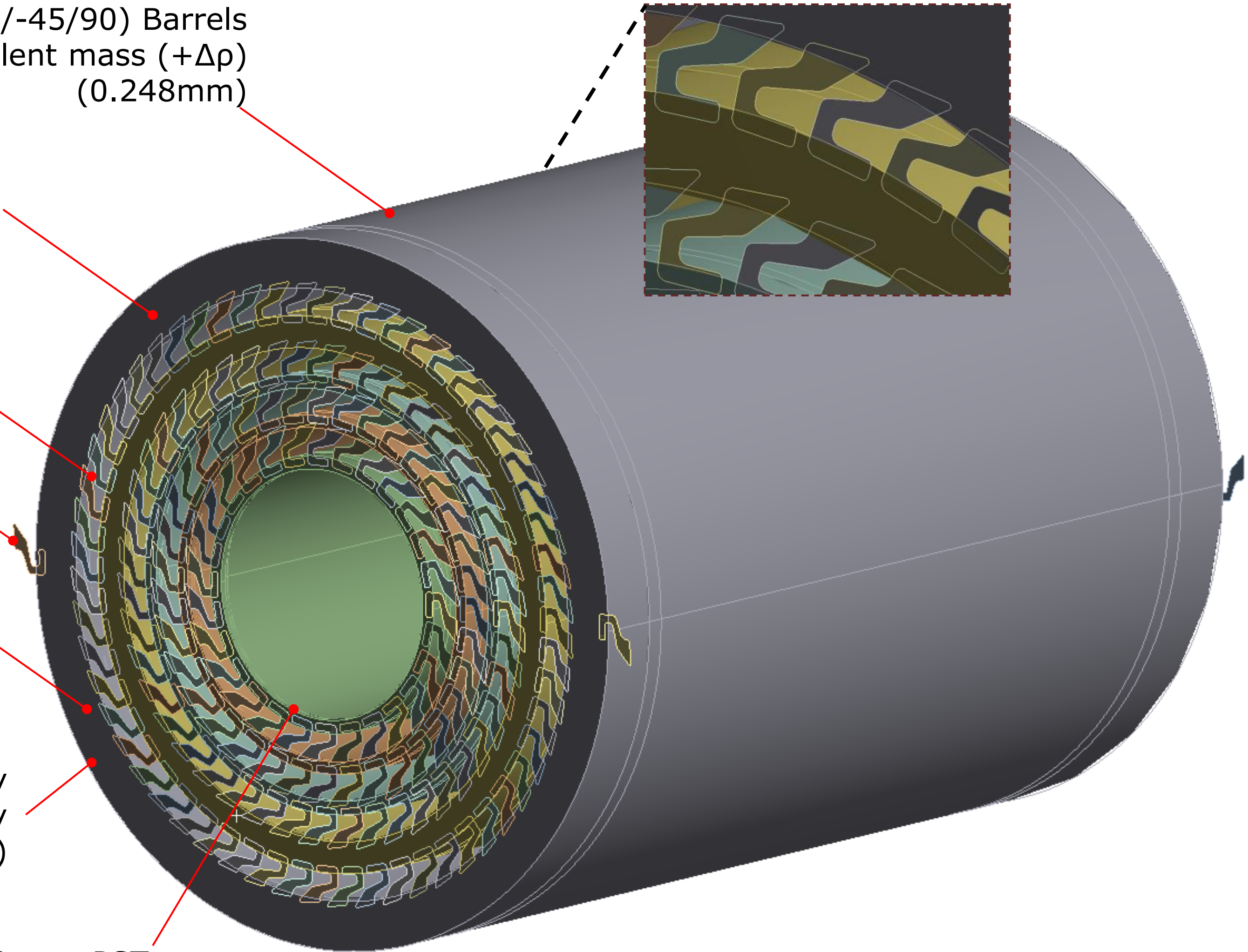
8-ply (0/45/-45/-90 x2) Interlinks w/equivalent mass (+Δρ) (0.496mm)

4 Fixed in 6 dof surfaces, 3 and 9 o'clock positions A & C ends

Bonded interfaces assume zero slip or separation

Staves represented as equally distributed mass in Barrel density (no local support modelled)

No connection at PST assumed



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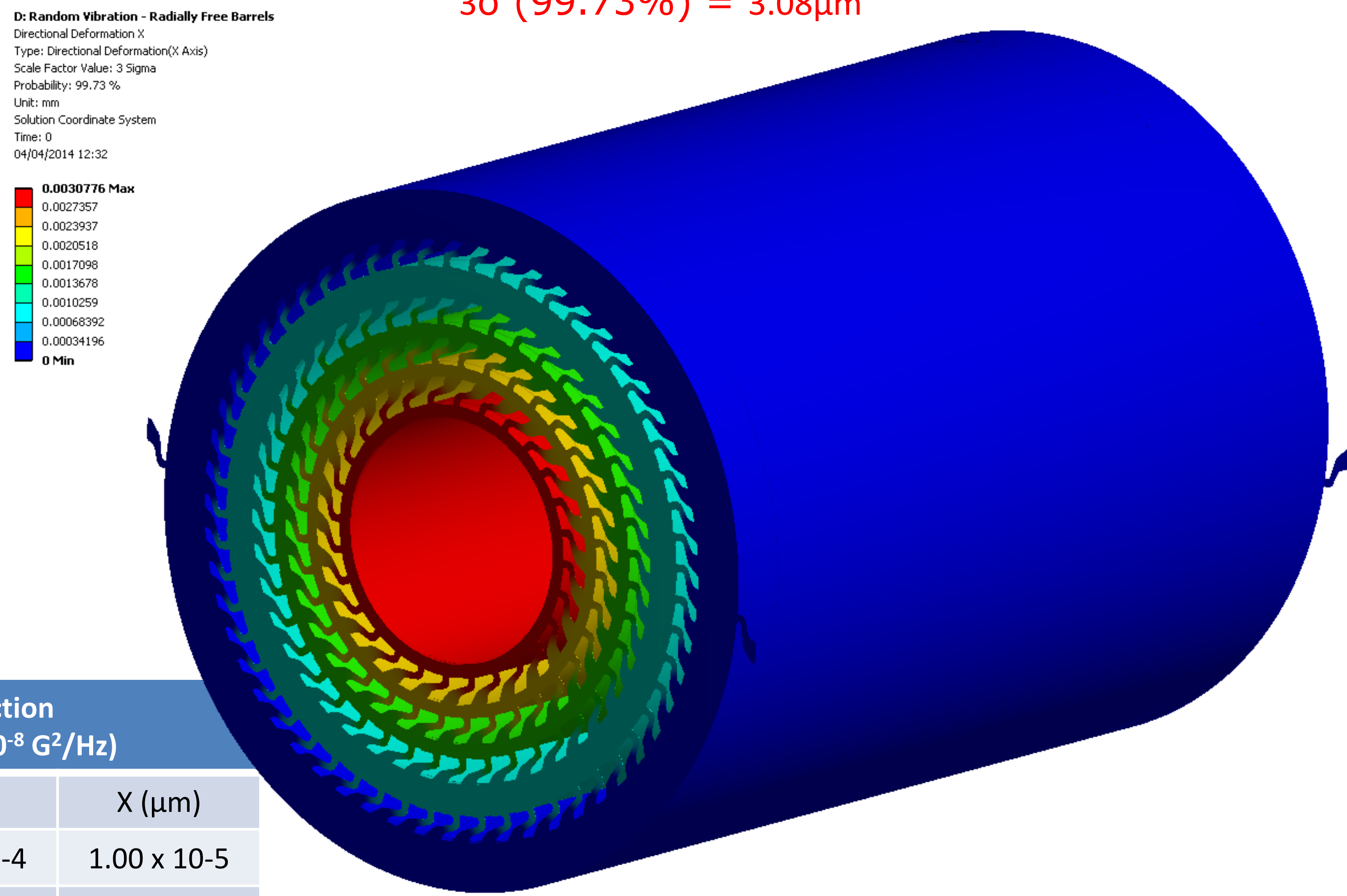
General modal result (WIP)

Random Vibration Results - Deformations

3σ (99.73%) = 3.08μm



ASD Input

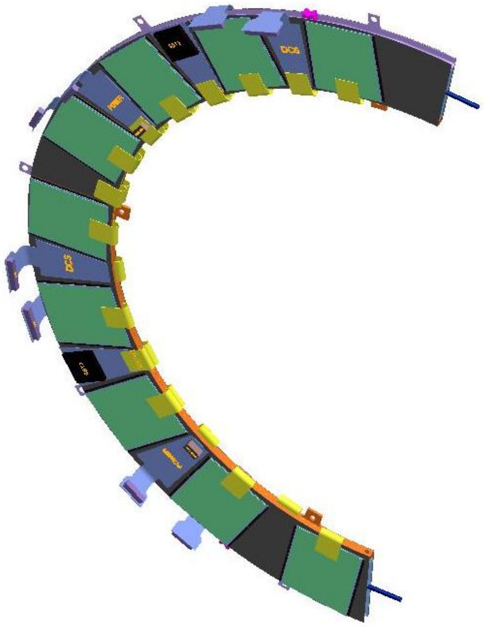
Freq (Hz)	G^2/Hz
1	1×10^{-8}
100	1×10^{-8}
200	1×10^{-8}

Results

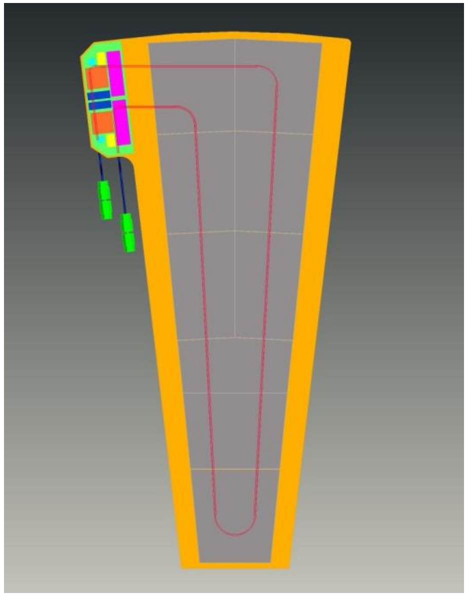
	Input Direction (1→200Hz, 1×10^{-8} G^2/Hz)		
Max. δf	Z (μm)	Y (μm)	X (μm)
UZ	3.08	1.56 x 10-4	1.00 x 10-5
UY	2.09 x 10-2	4.09 x 10-5	1.60 x 10-4
UX	1.29 x 10-2	4.41 x 10-5	1.72 x 10-4

Robert Gabrielczyk

Other local support applications of the integrated low mass structure



Forward pixel half ring



Forward Strip petal
David Santoyo

Summary and Conclusions

- The fully integrated stave reduces potential failure points, such as not having screwed modules and having a fully glued cooling structure, replacing connectors with wire bonds and TIG welded tubes
- Around 10 prototype full size staves and mechanical, thermal and electrical prototypes have been made and have proved to be mechanically and thermally stable.
- Throughout the prototype stages, improvements have been made and major changes such as the change from 250nm chip to 130nm.
- We are now at the stage of producing a 'final' design, which can be transferred to a full scale production of 500 staves of 8 different flavours.