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U.S. DEPARTMENT OF ENERGY

Large moment of inertia structures to reduce mass and improve performance of silicon detectors

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Office of Science
U.S. DEPARTMENT OF ENERGY

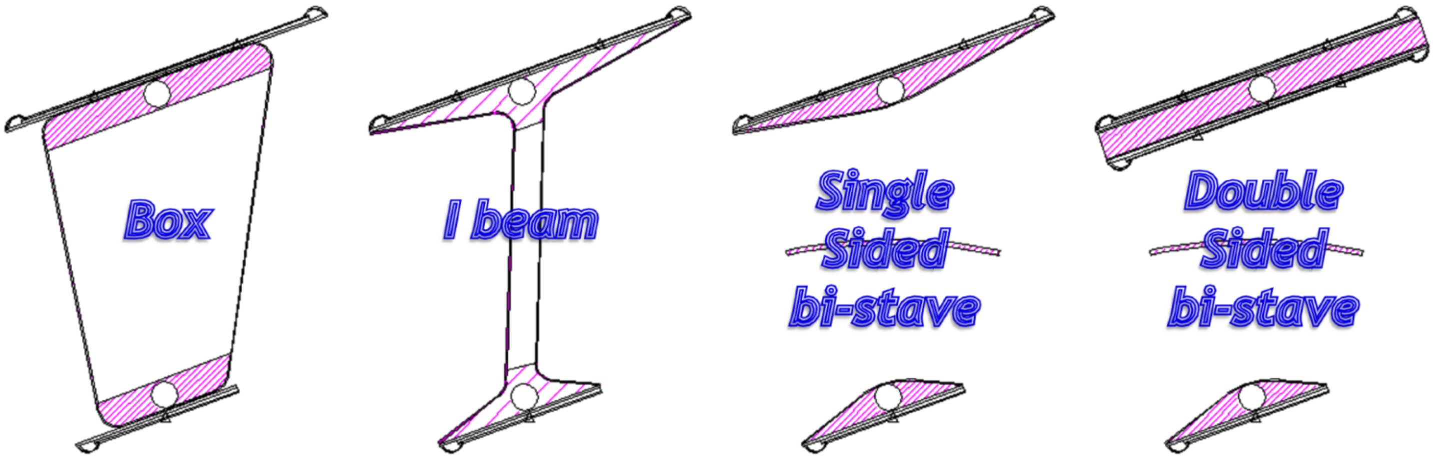
Introduction

- We know that stability has been, and will increasingly be, the most important goal in structural design for silicon detectors
- However, the current detector building block – the « stave » - has been historically very low stiffness
- The obvious solution to this problem is to couple adjacent layers together into high moment of inertia structures
- In fact, these structures can be sufficiently stiff as to allow the total absence of a global support frame

The ATLAS Pixel I-beam

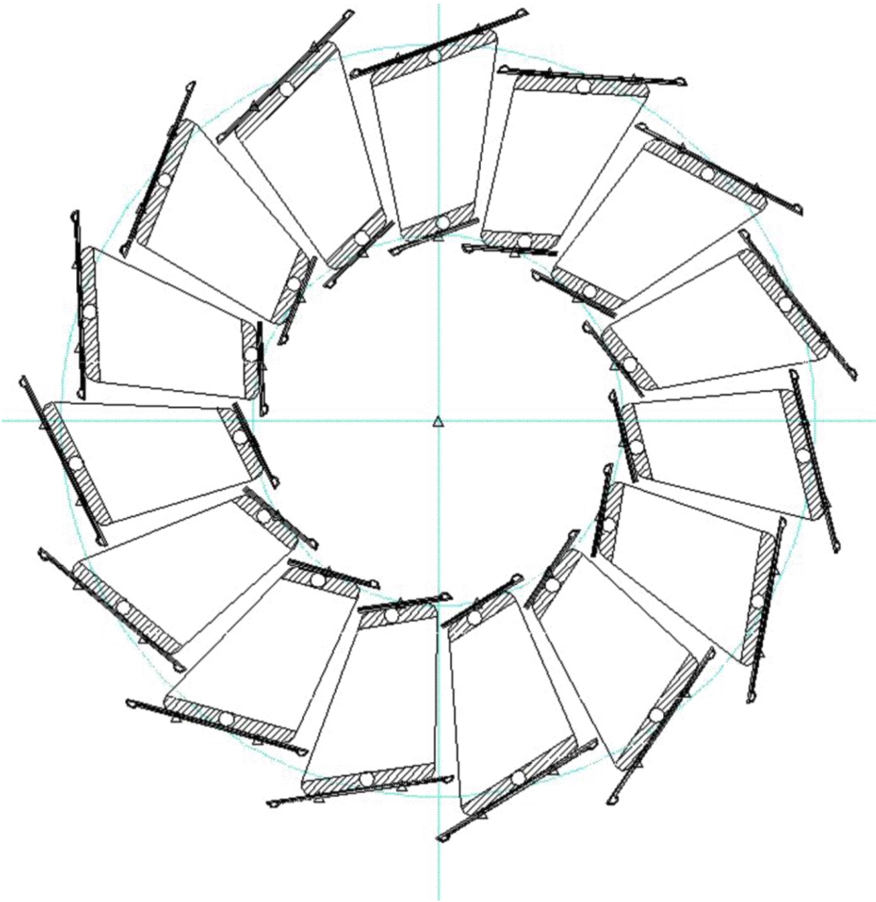
- Most of this work centers around the Pixel I-Beam prototype, but is extendable to many other systems (see Star PXL presentation by H. Weiman)
- The original goal was to create an ultra-simple, ultra-low cost 4 layer replacement for the current pixel detector
- This replacement would consist of little more than
  - the couple-layer staves
  - two endrings
  - rail riders
  - pixel mounts

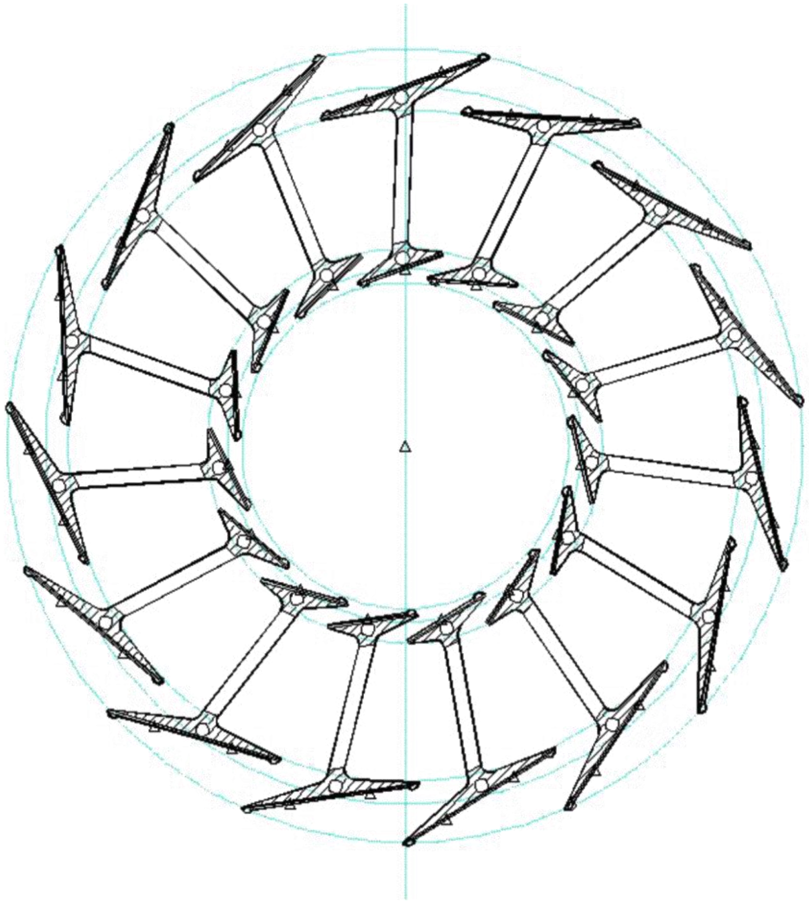
Approaches to coupling adjacent layers



Structure Design	Relative Mass	Relative Stiffness	Stiffness/Mass	Relative Merit
I Beam Design	31.02	6983.85	225.13	152
Box Beam Design	34.51	7712.57	223.51	151
Single Sided bi-stave layout	32.42	6109.06	188.44	128
Double Sided bi-stave layout	45.73	8390.85	183.48	124
Single Double Sided Stave	27.12	40.07	1.48	1

Box vs. I-beam solutions

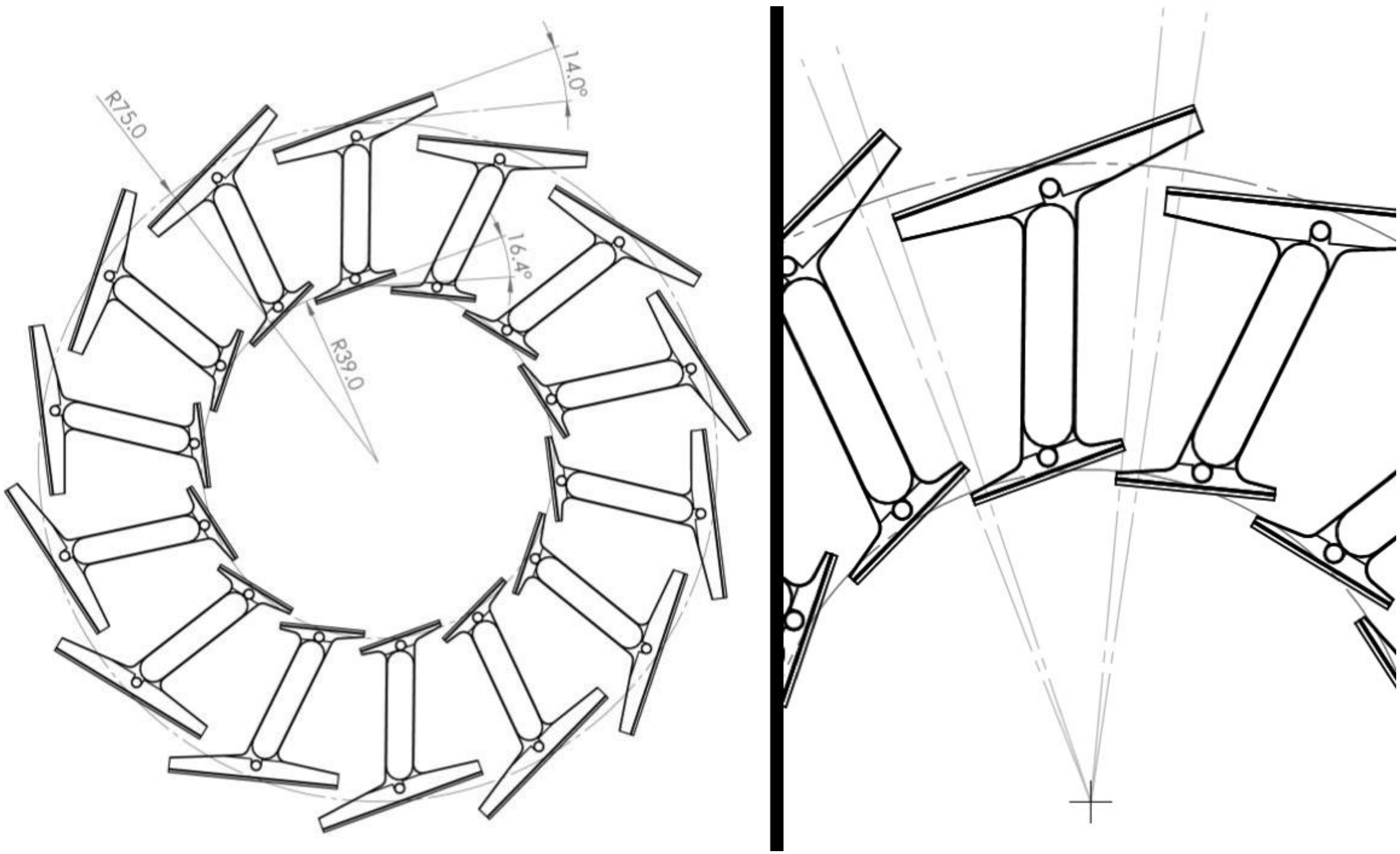




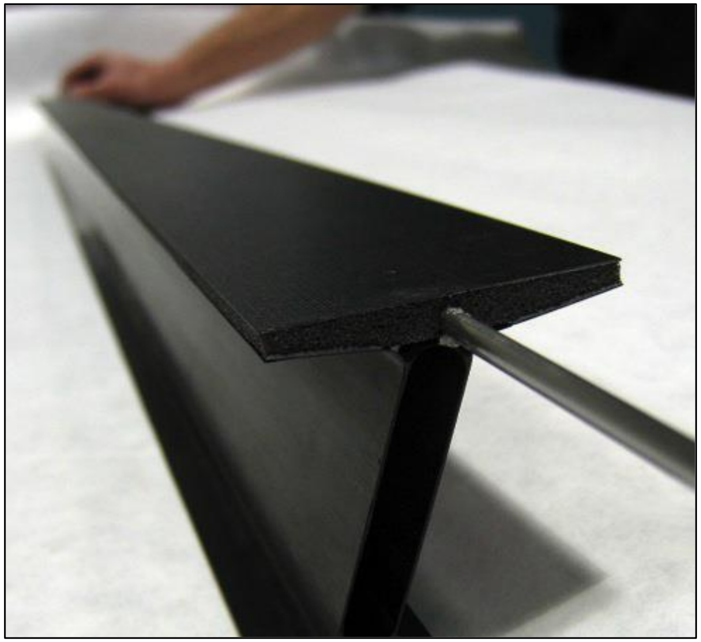
Box vs. I-beam merits

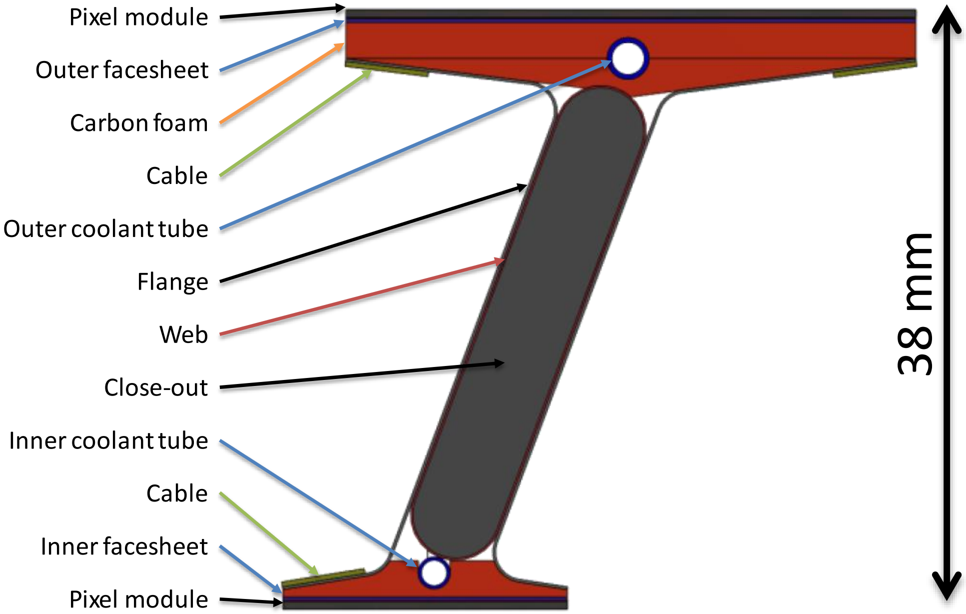
- Or Closed vs. Open section
- Closed section performs slightly better
  - Better torsion resistance
  - Higher transverse moment of inertia
- But, structures are eventually coupled together
  - Torsion and transverse inertia less important
- *AND, open section (the I-beam) offers something like 4-5x more clearance between adjacent structures*

I-beam layout as built (first two layers)

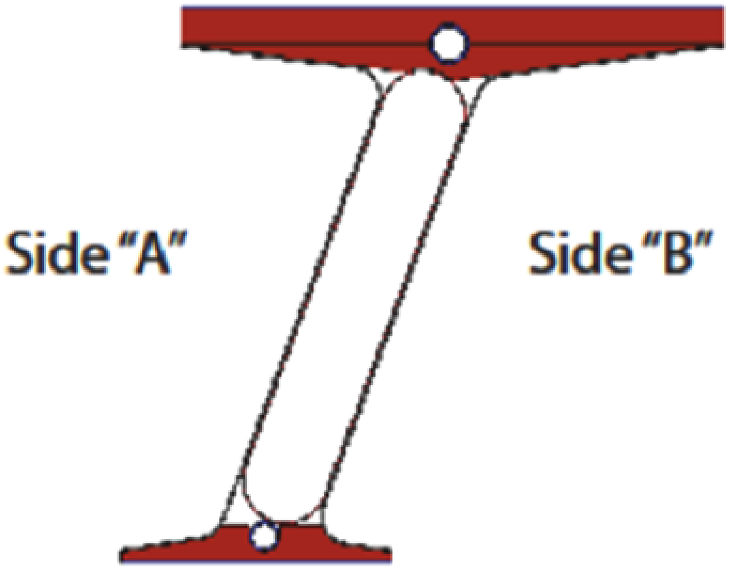


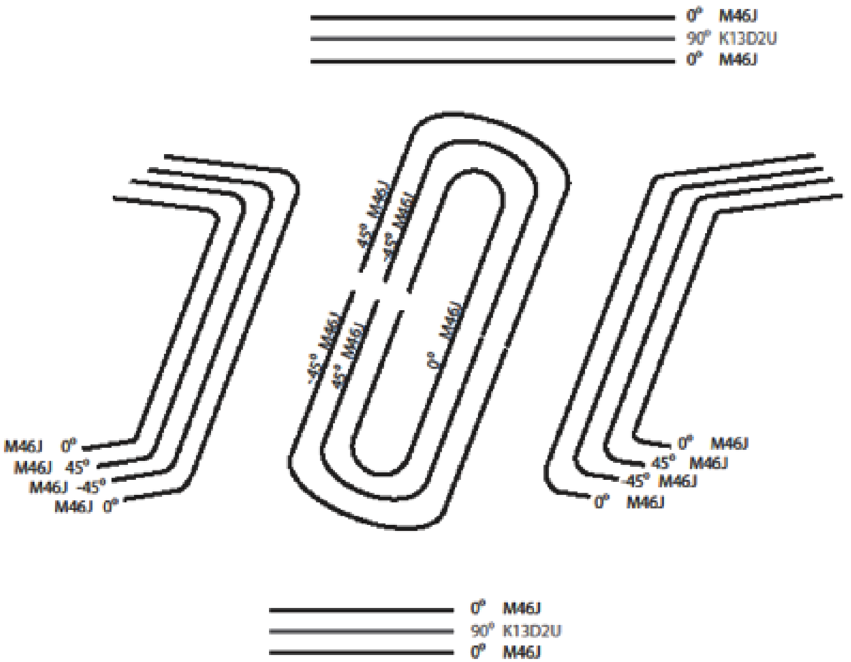
Pixel I-beam Composition



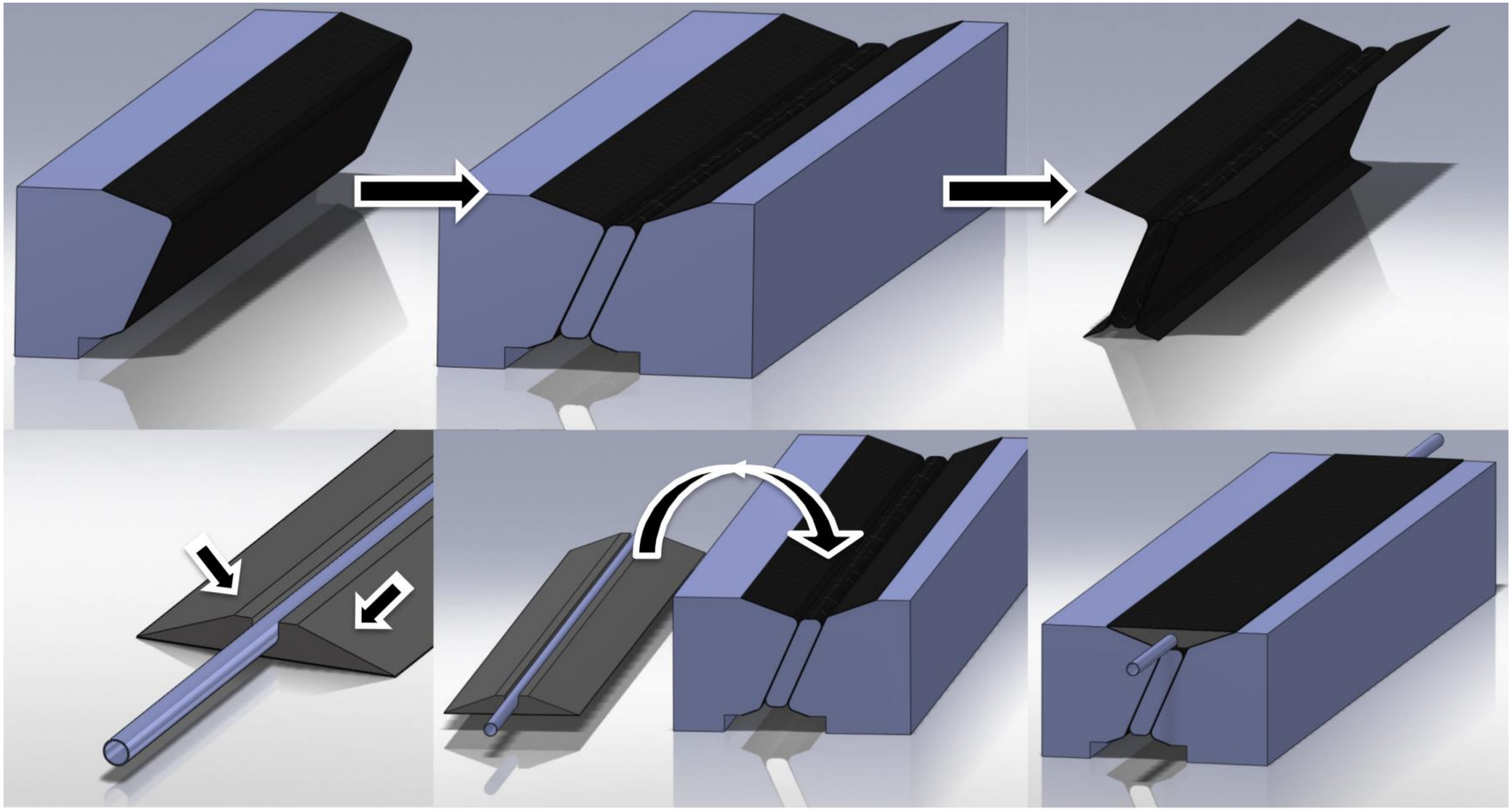


I-beam Laminate

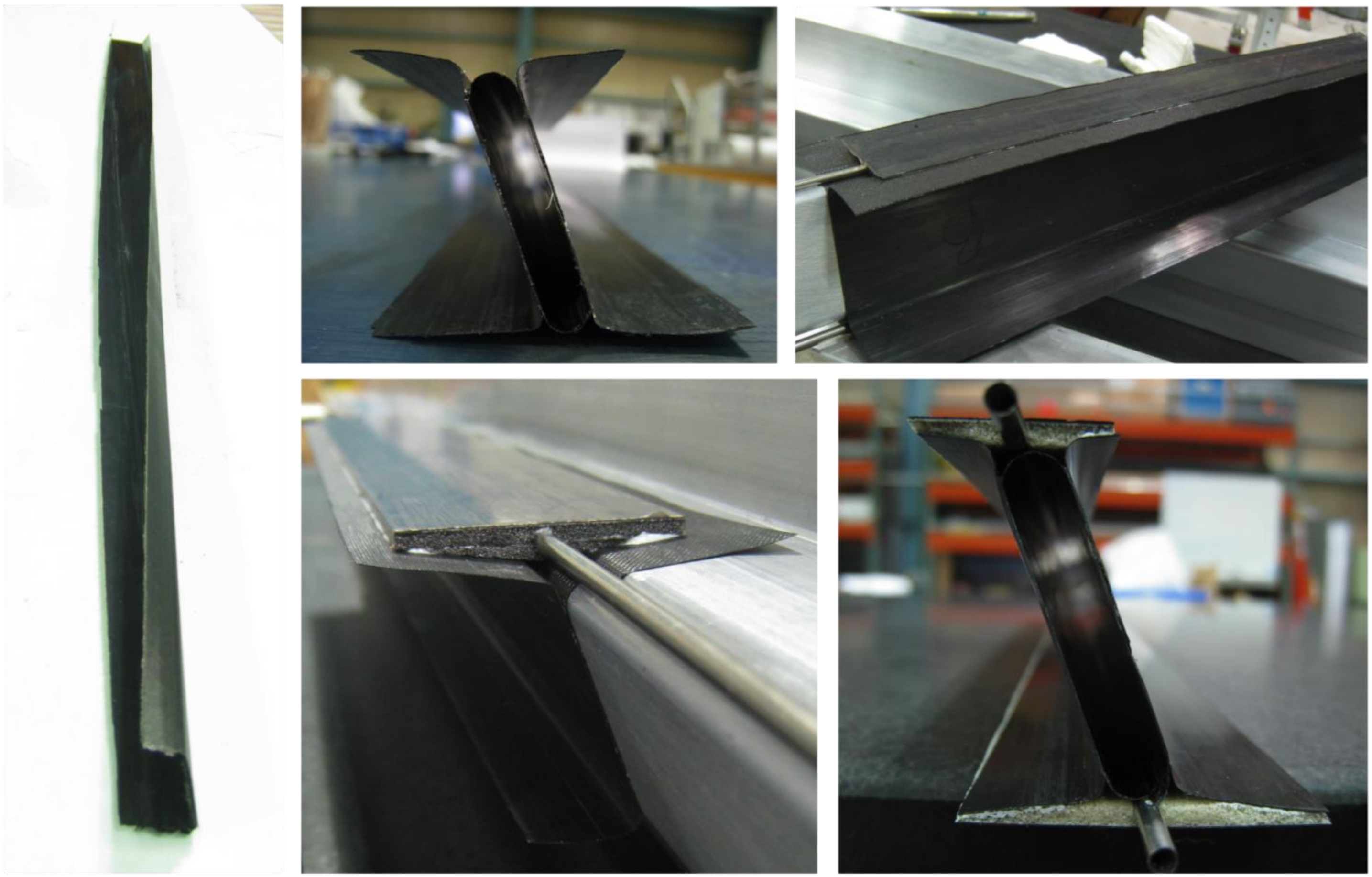




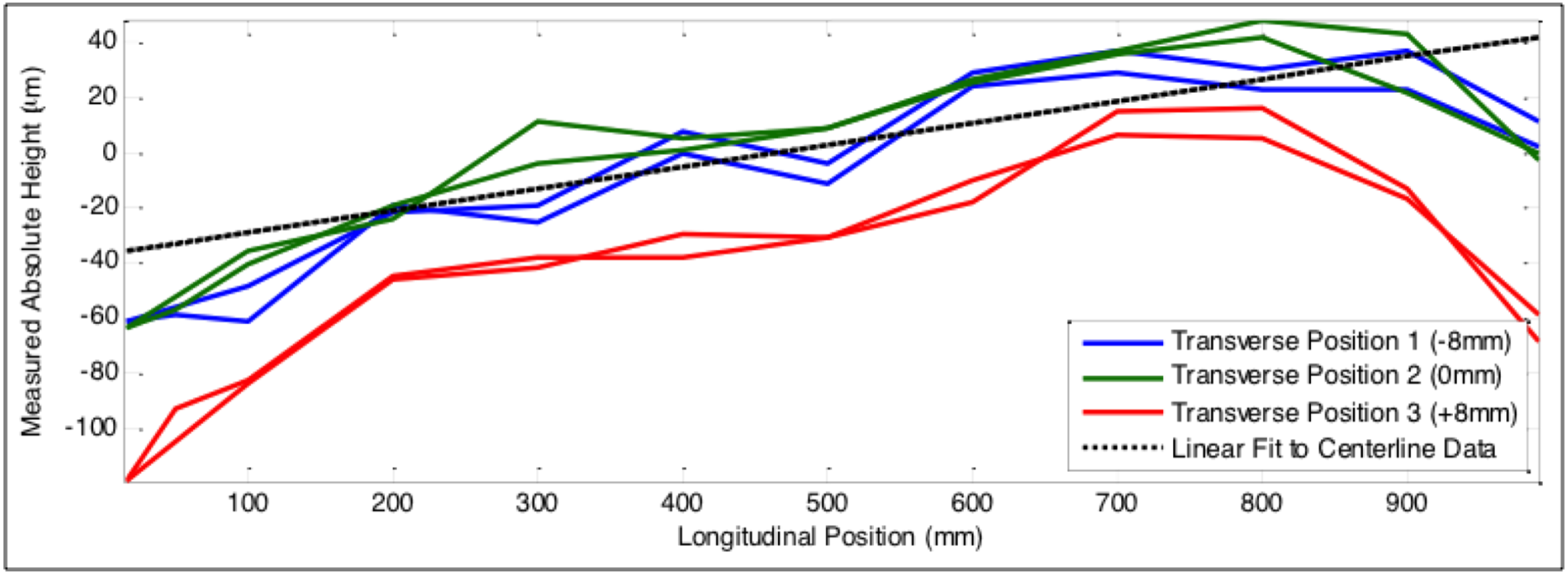
Manufacturing Process



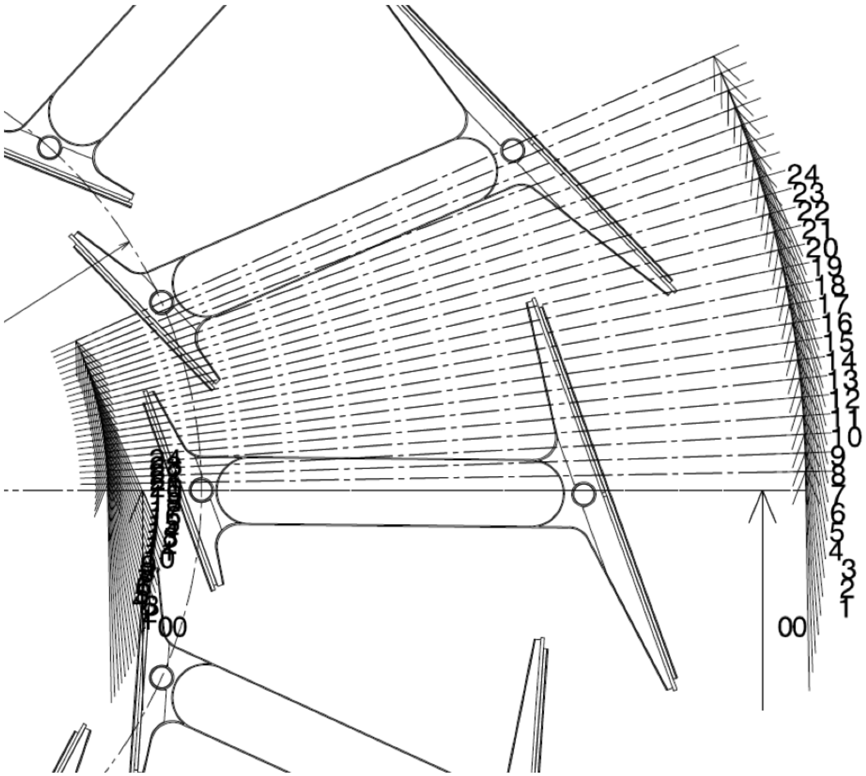
Stages of construction in photos

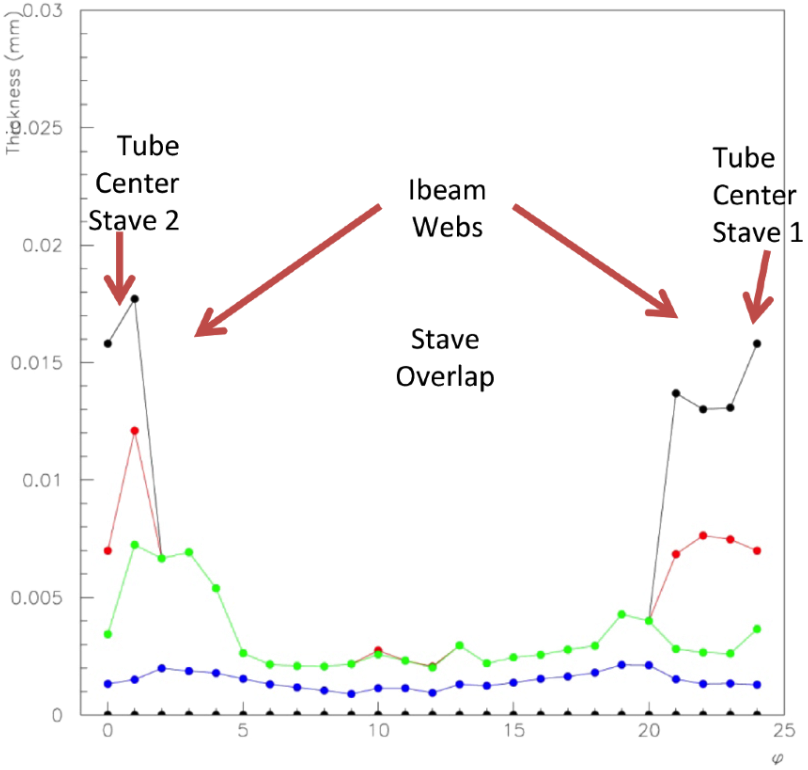


As built flatness on module mounting surface



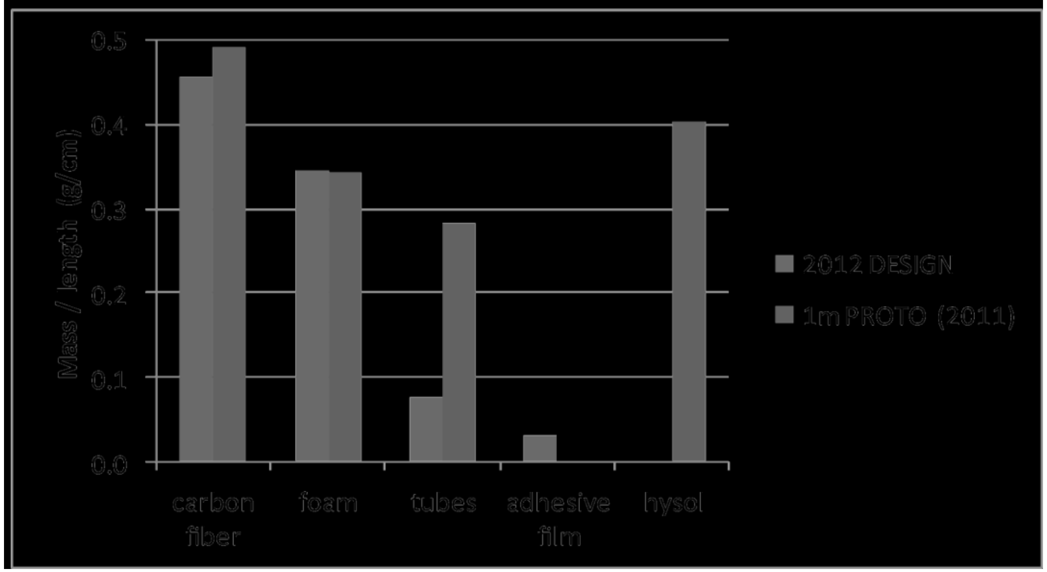
Mass distribution





Overall and projected structural masses

	1m PROTOTYPE	1.4m DESIGN	
	99.6	140	*cm*
	157.69		*g*
		127.62	*g*
	1.583		*g/cm*
	1.524	0.912	*g/cm*
	-3.8%		



Total X0 Calculation

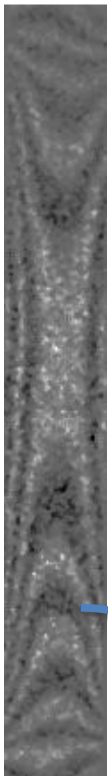
2012 IBEAM DESIGN - COCURING

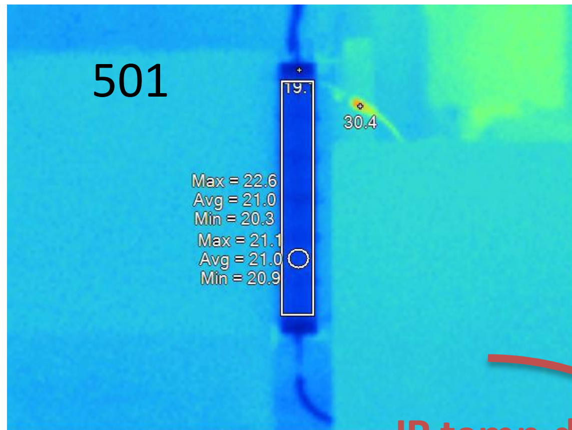
Component	Matl Name	Ref Width	%X	Mass/Length
-	-	cm	-	g/cm
Inner Facesheet	[0K/90K/0K]	1.87	0.049%	0.0396
Outer Facesheet	[0K/90K/0K]	3.75	0.049%	0.0794
Flange A	[0K/+45M/-45M/0K]	2.81	0.096%	0.1162
Flange B	[0K/+45M/-45M/0K]	2.81	0.097%	0.1178
Web	[0K/+45M/-45M]	2.81	0.086%	0.1042
Inner Foam	Allcomp K9 Carbon Foam	1.87	0.072%	0.0579
Outer Foam	Allcomp K9 Carbon Foam	3.75	0.178%	0.2878
Inner Tube	Grade 2 Titanium	1.87	0.126%	0.0381
Outer Tube	Grade 2 Titanium	3.75	0.063%	0.0381
Adhesive, Flange A to Web	EX1515 Cyanate Ester	2.81	0.006%	0.0072
Adhesive, Flange B to Web	EX1515 Cyanate Ester	2.81	0.006%	0.0072
Adhesive, Flange A to Inner Foam	EX1515 Cyanate Ester	1.87	0.003%	0.0024
Adhesive, Flange B to Inner Foam	EX1515 Cyanate Ester	1.87	0.002%	0.0018
Adhesive, Flange A to Outer Foam	EX1515 Cyanate Ester	3.75	0.003%	0.0042
Adhesive, Flange B to Outer Foam	EX1515 Cyanate Ester	3.75	0.002%	0.0038
Adhesive, Inner Tube to Inner Foam	EX1515 Cyanate Ester	1.87	0.003%	0.0023
Adhesive, Outer Tube to Outer Foam	EX1515 Cyanate Ester	3.75	0.001%	0.0023
Adhesive Webbing, Inner Tube to Foam	Carbon veil, 7gsm	1.87	0.001%	0.0005
Adhesive Webbing, Outer Tube to Foam	Carbon veil, 7gsm	3.75	0.000%	0.0005
			Σ(%X_avg)	Σ(M/L)
			0.85%	0.912

predicted total mass (g) @ 1300 mm length --> **118.50**

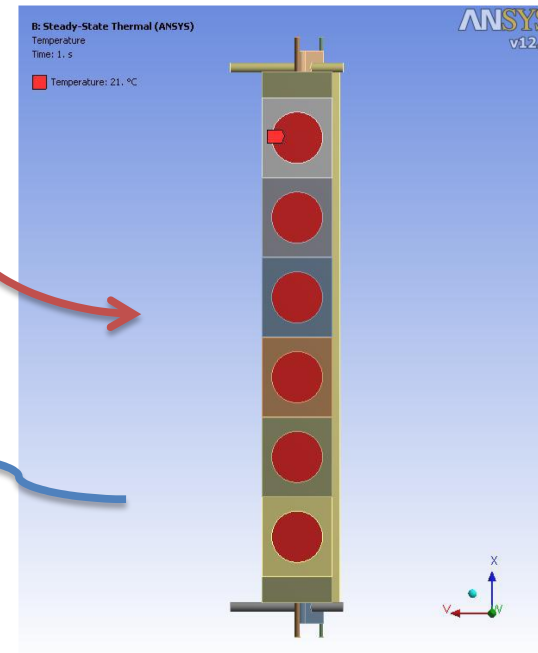
predicted total mass (g) @ 1400 mm length --> **127.62**

Thermal mechanical deflection setup





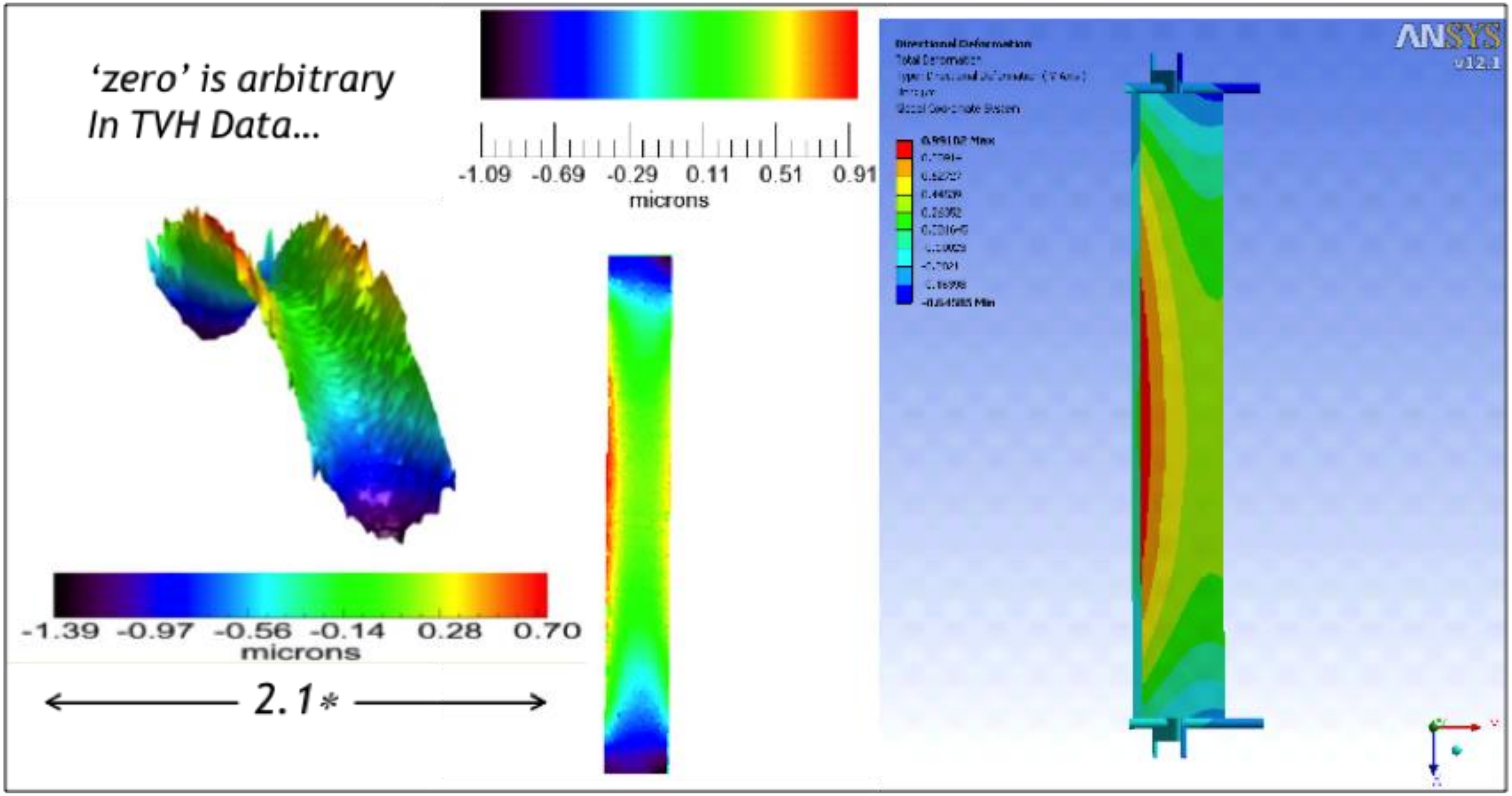
IR temp data
 B.C. for FEA



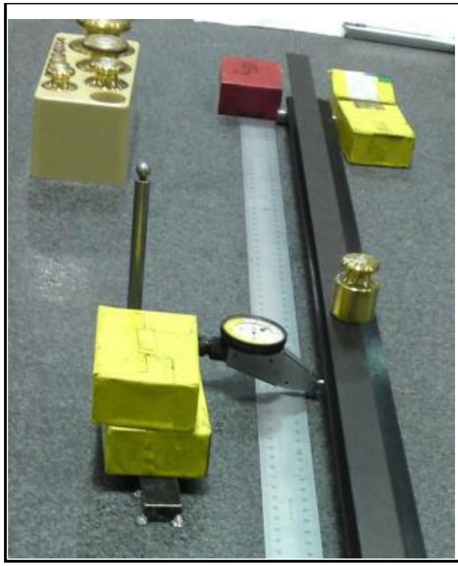
Solve two thermal-stress analyses at the two setpoints and then compare to TVH data

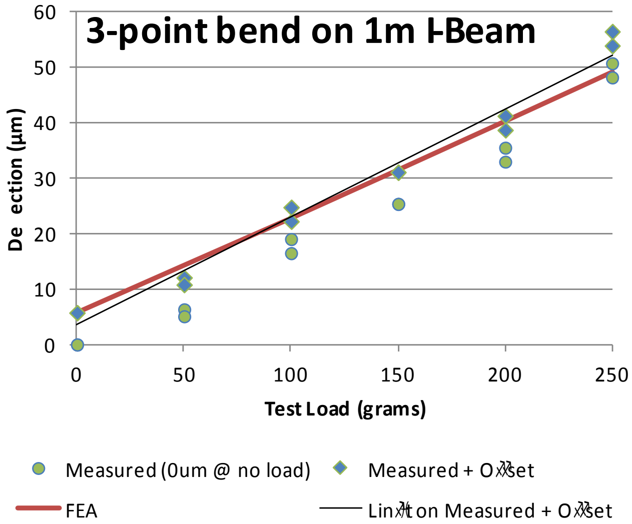
TV holography data
 Di erential de ection between 2 setpoints (2 di erent power inputs to silicon)

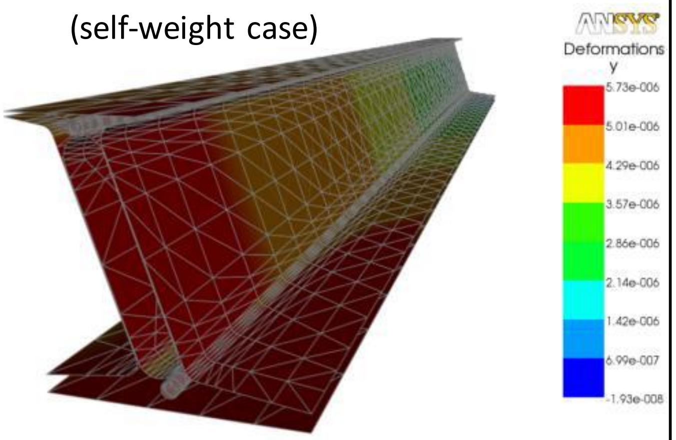
Deflection under thermal load with TVH



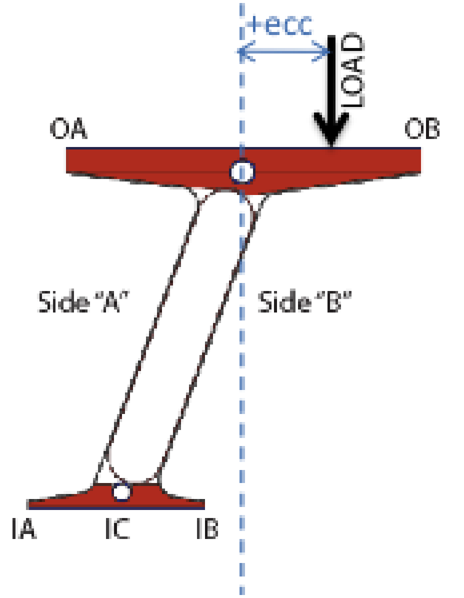
3-point bend test vs. FEA

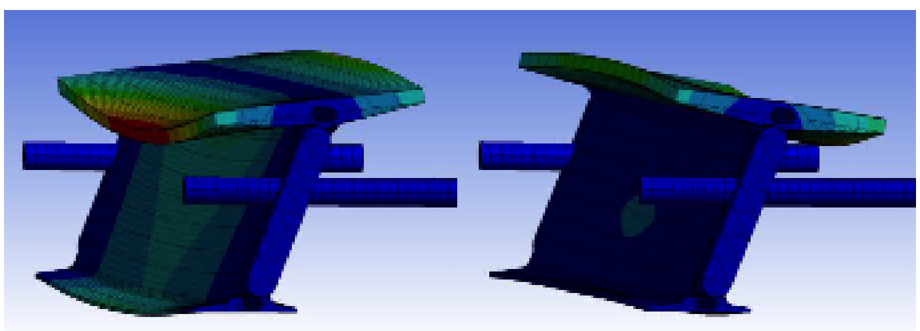


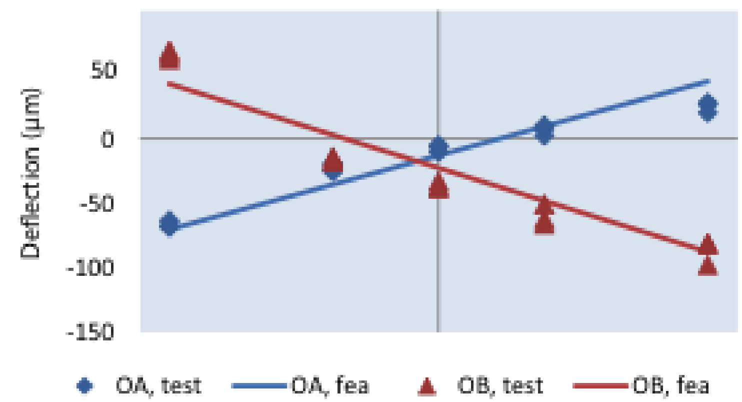


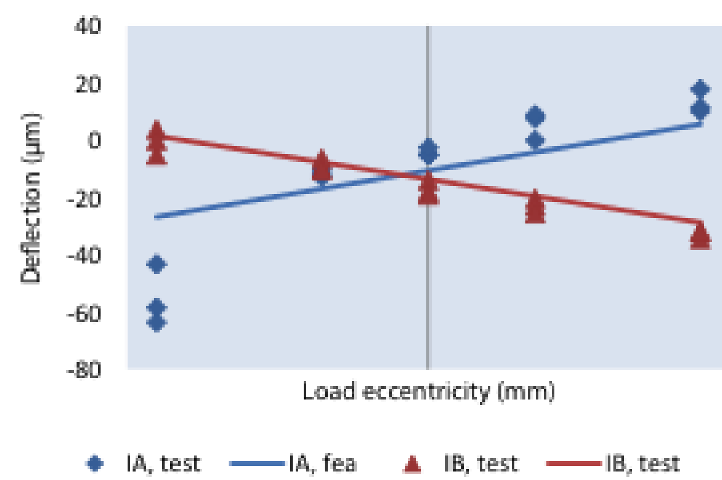


Twist - Eccentric load test vs. FEA

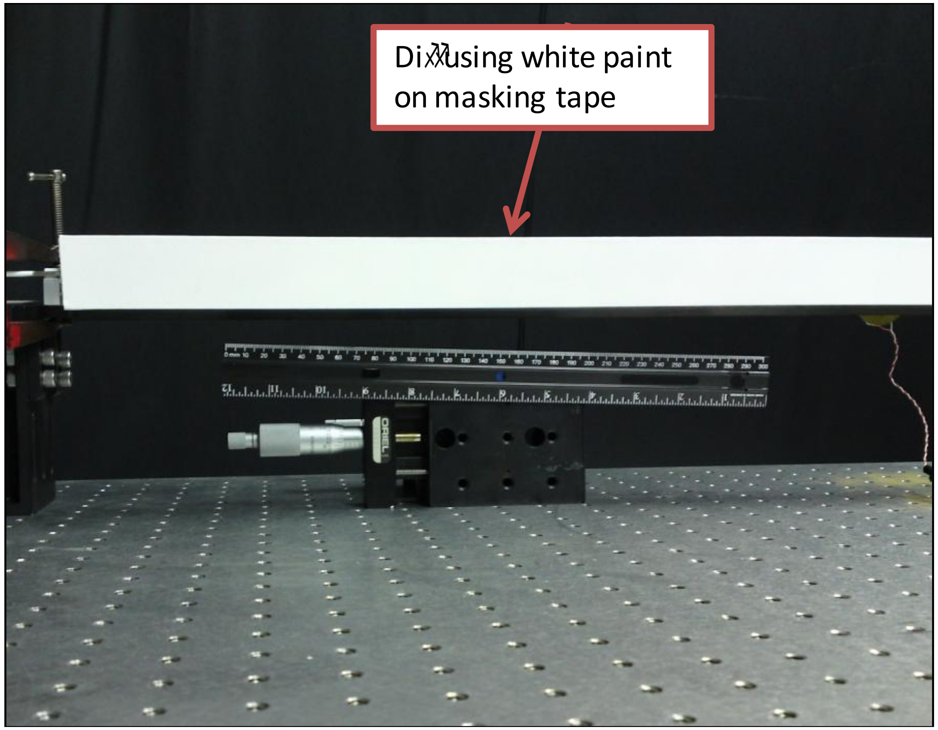


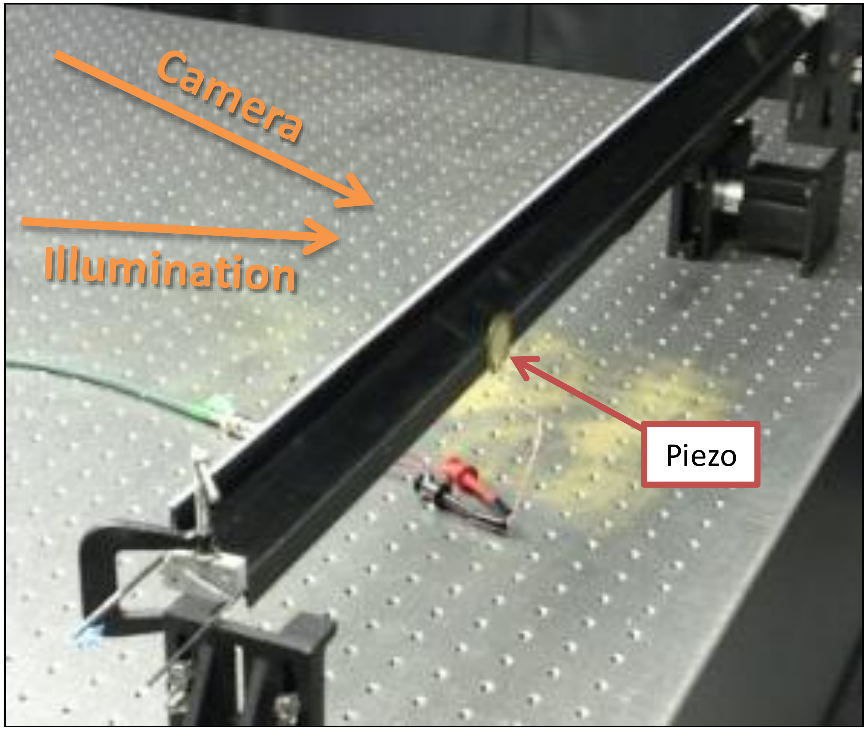




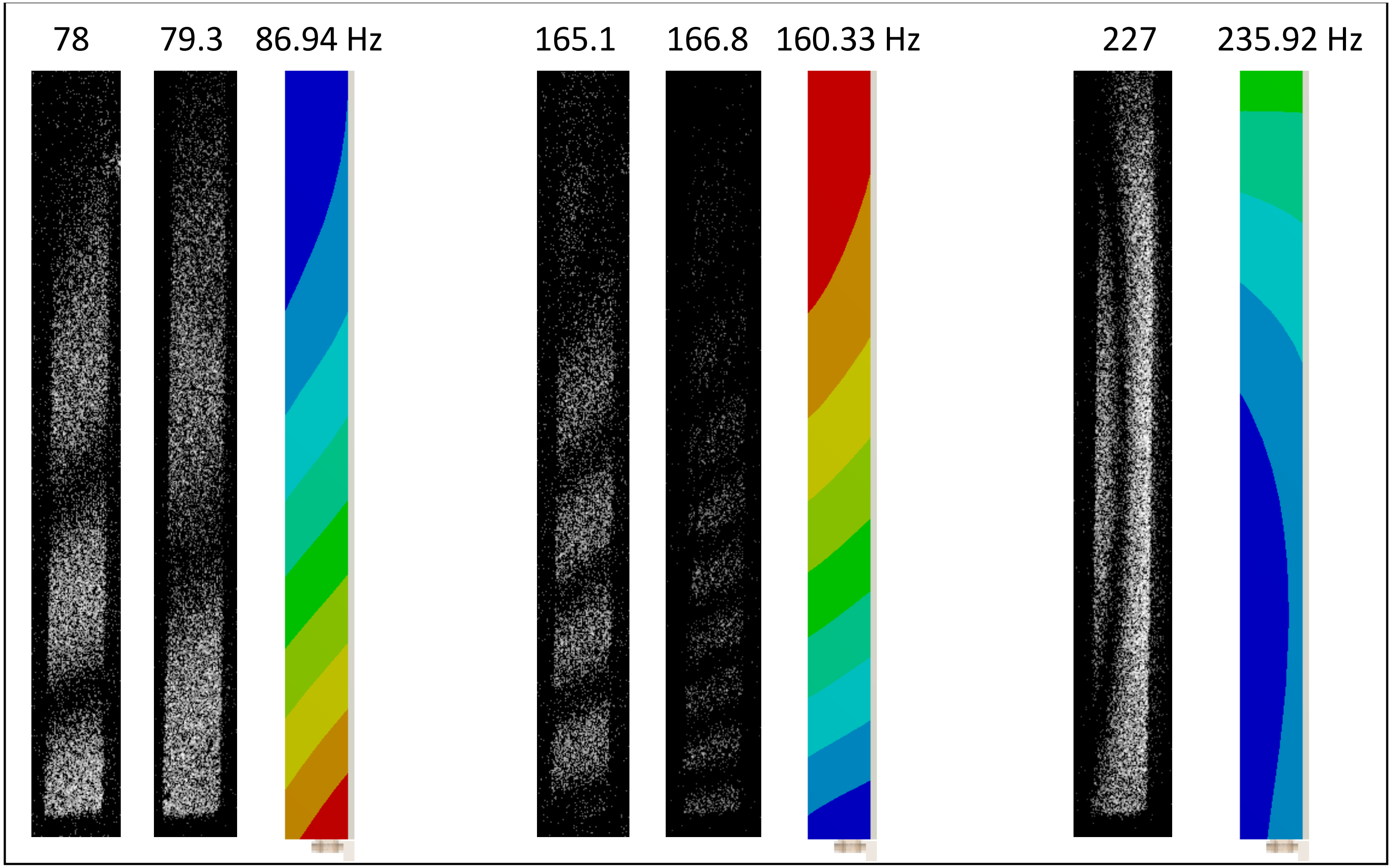


TVH Vibration measurement setup (under piezo excitation)

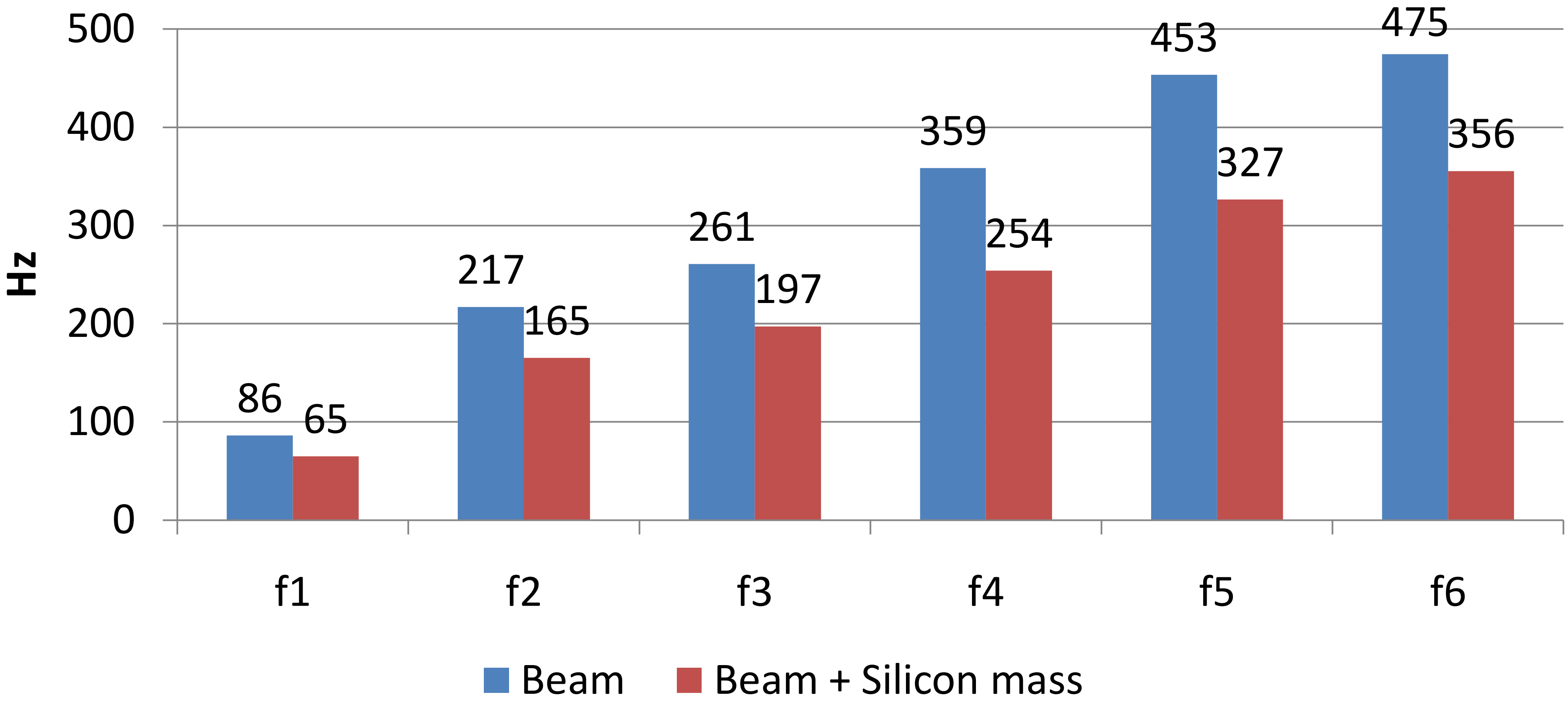




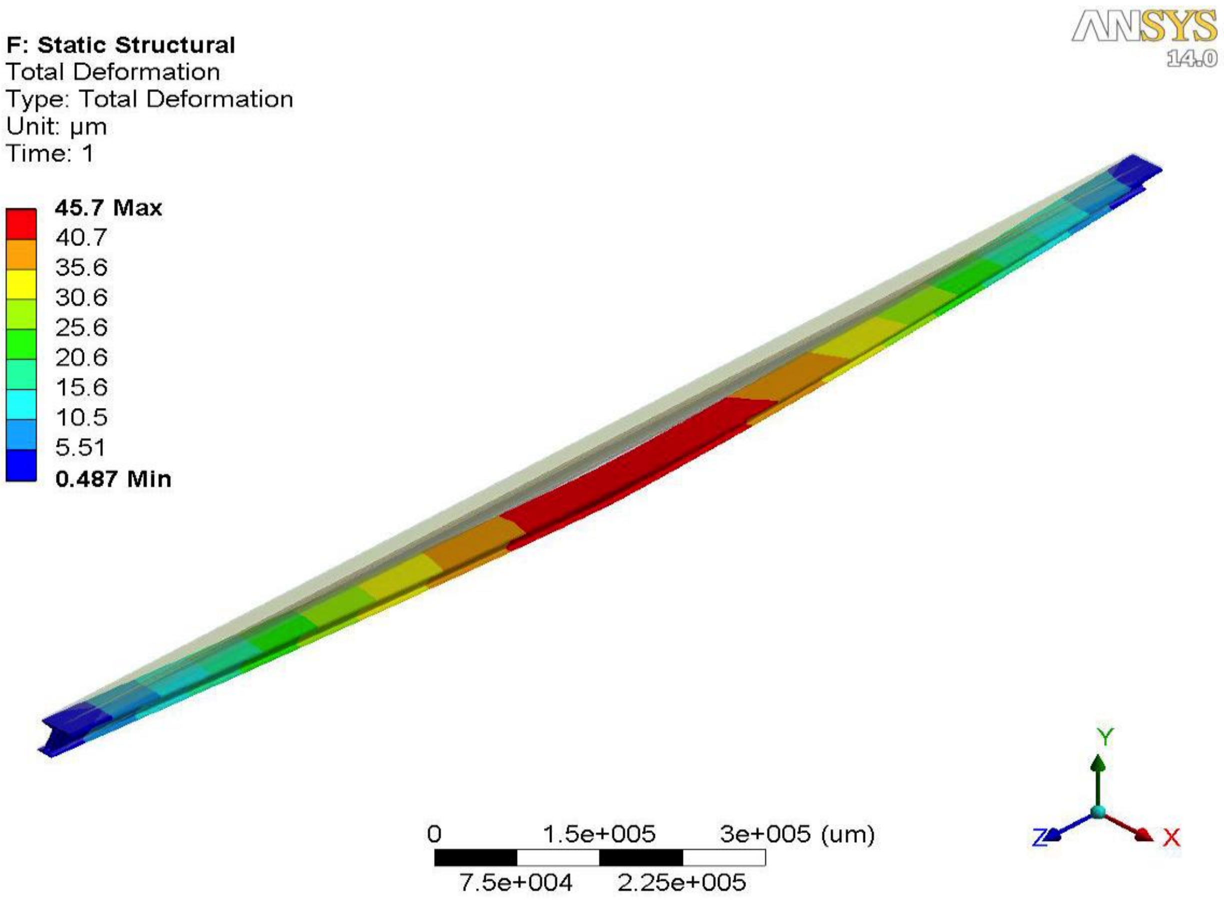
Vibration measured vs. FEA



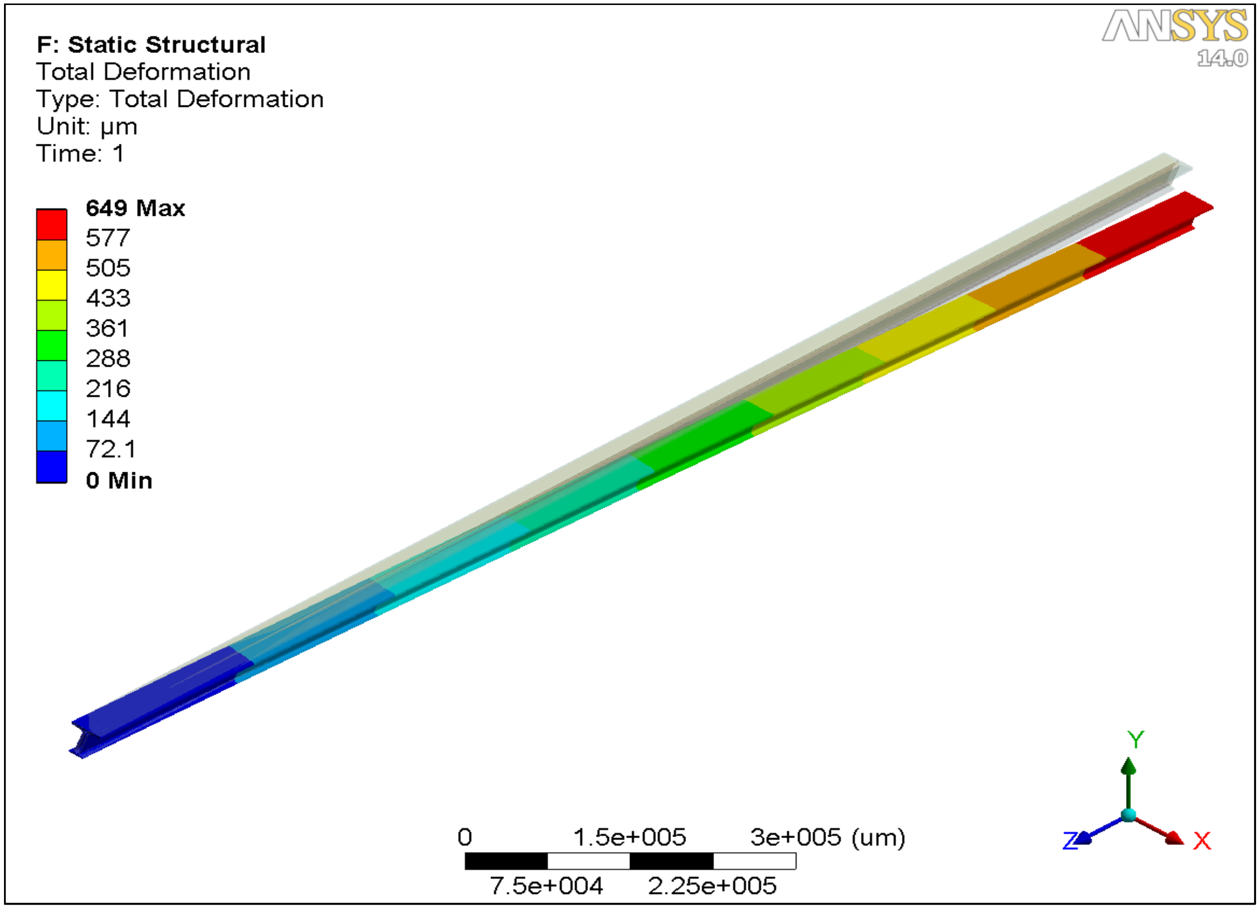
Expected Frequencies with Modules



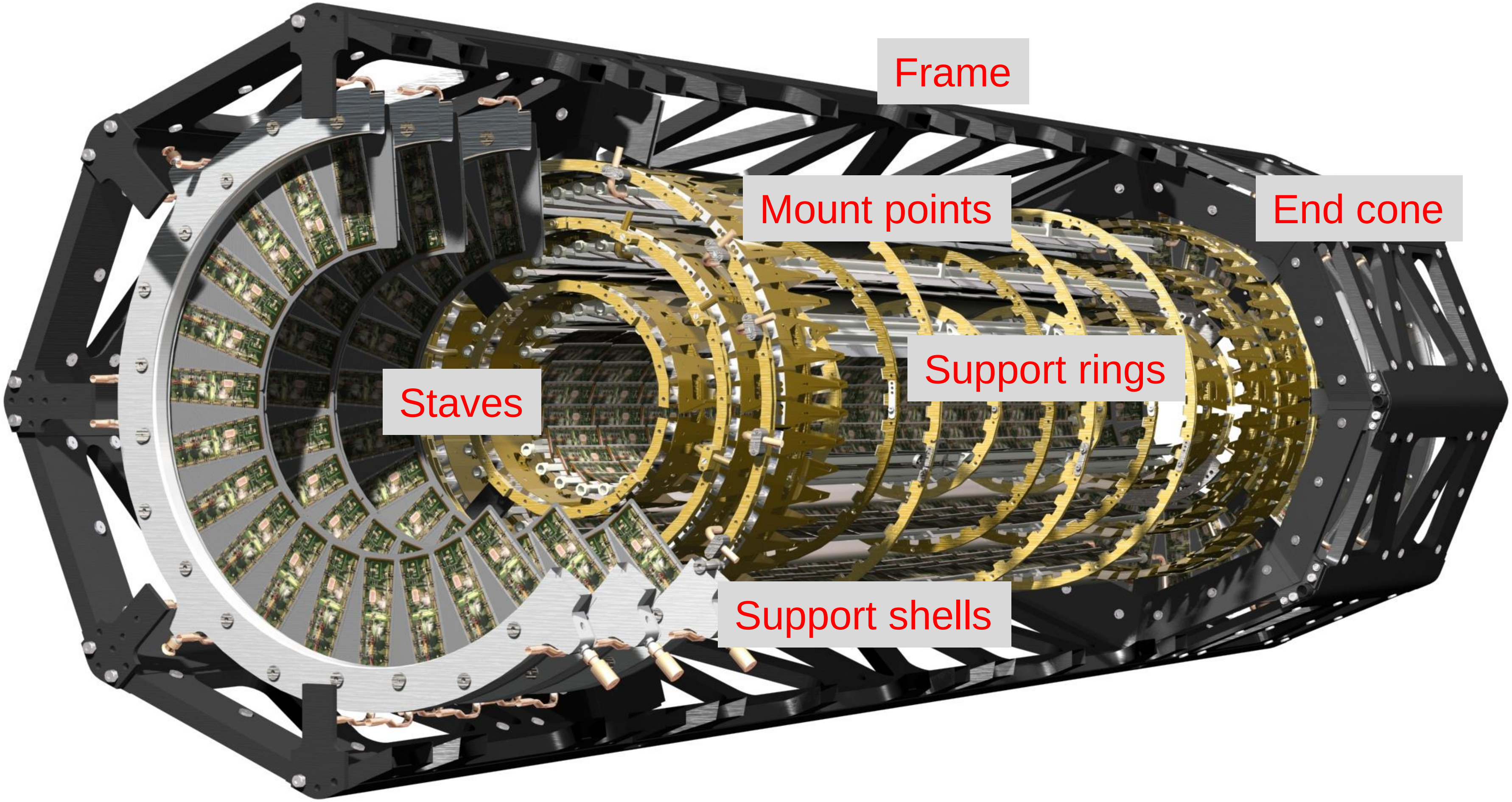
Deflection of 1.4m Ibeam with modules, simple supports



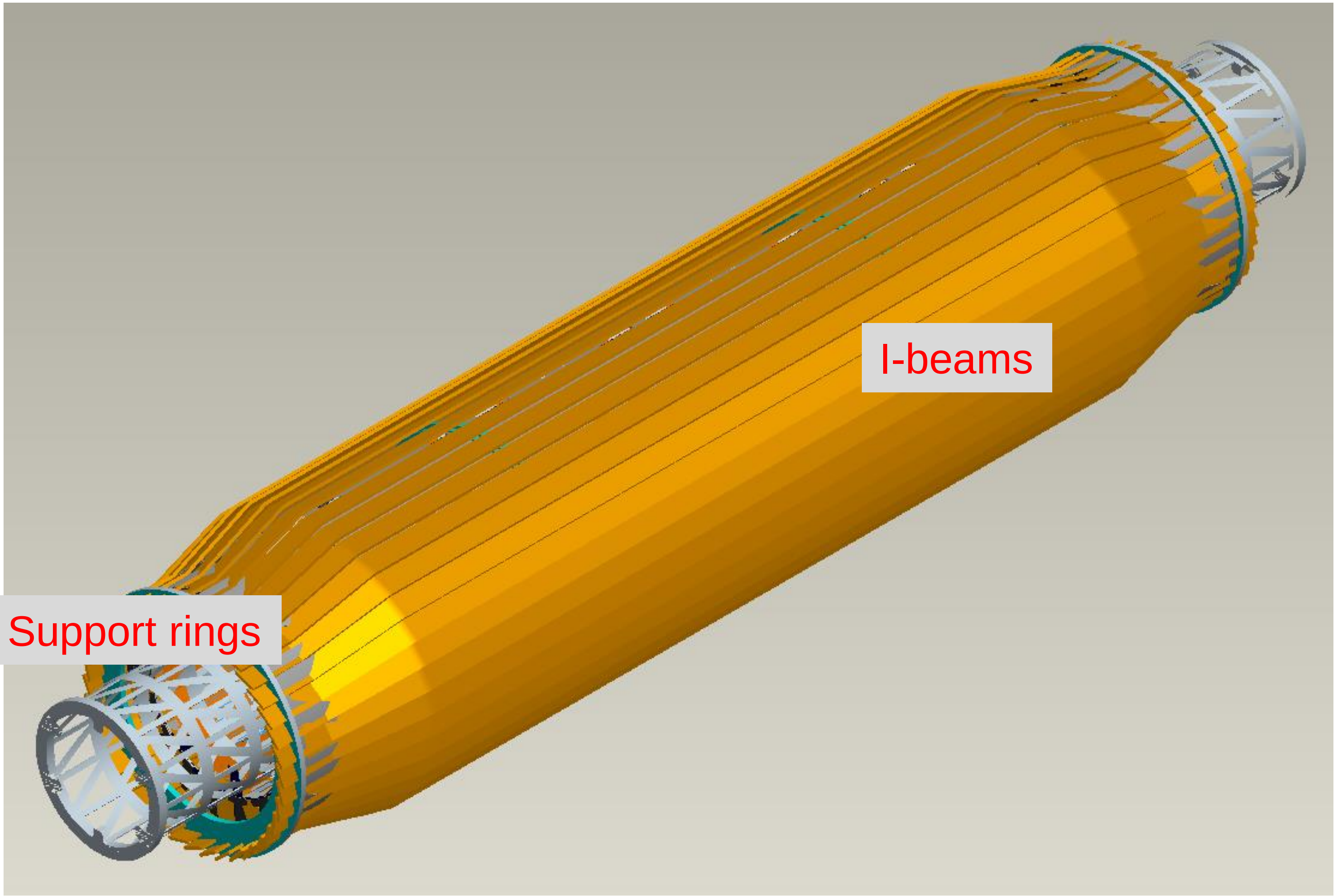
Deflection of 1.4m Ibeam with modules, cantilevered



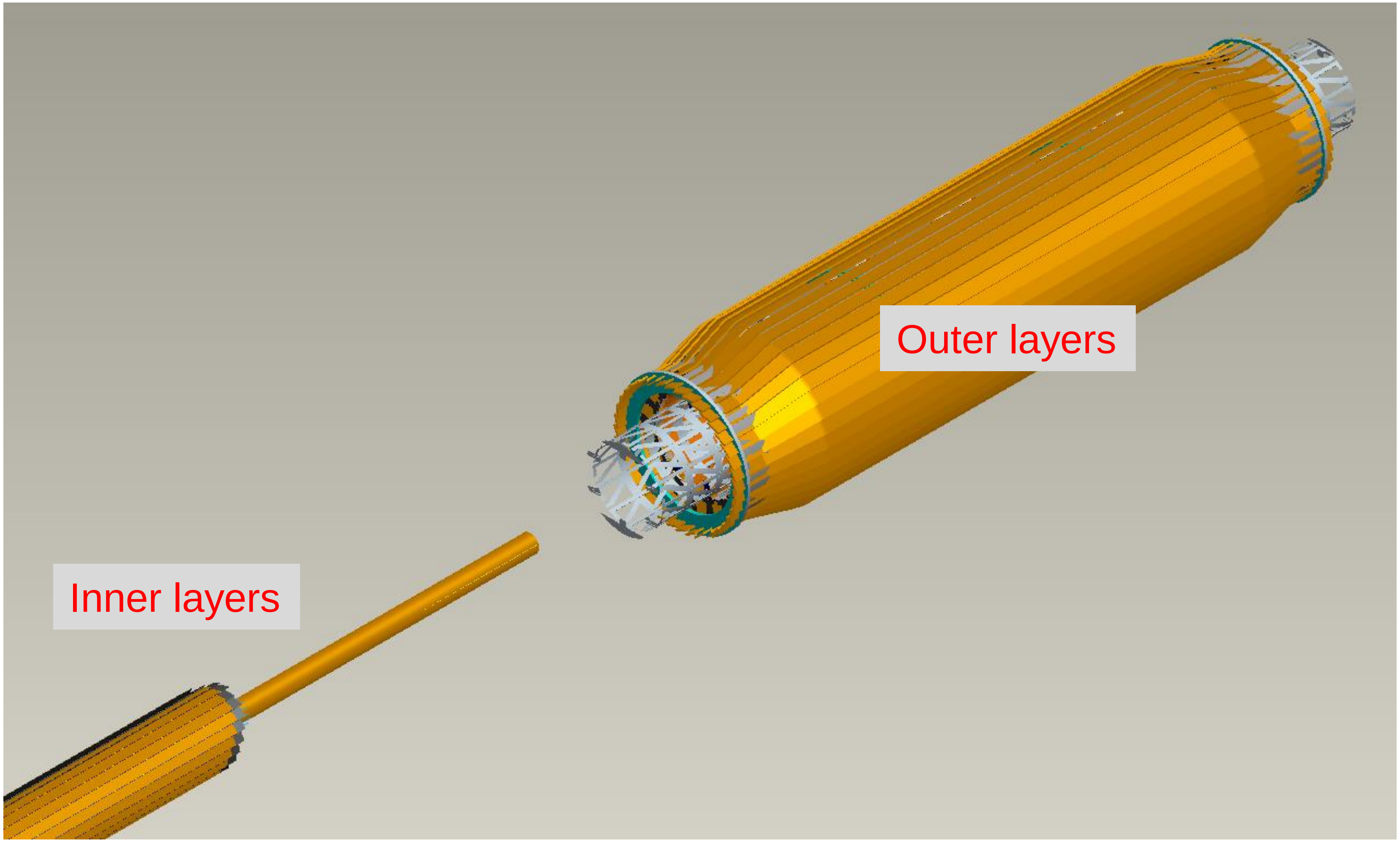
Current Pixel Detector



Coupled Layer Detector



Coupled Layer Detector w/ inner layers



Advantages of the couple layer approach

- Performance
  - Easily achieve more than 50Hz fundamental
  - Lower mass (due to absence of support frame)
- Simplicity
  - Lower part count in structure itself
  - Lower fastener count (or no fastener count)
- Modelability
  - Because there are few joints, bolted connections, etc…
  - FEA models are accurate and easy to make

Potential limitations

- Modularity
  - More modules are tied together into common structures
  - There is a fixed relationship between module sizes and relative radii
    - » Though this is quite « fluid » by playing with overlaps and tilt angles
- Material uniformity
  - Material is concentrated in the web regions
  - Some prevailing logic says that evenly distributed mass is better, *but is this really true?*

Future Plans

- Relauch prototyping campaign
- Improve co-bonding approach
- Develop cable models and prototypes
- Produce bent I-beam for upgrade layout
- Effectively create a partial prototype of full detector assembly