Vertex Detector Mechanics

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Introduction

- Designs must:
  - Satisfy radiation length requirements
    - Goal is ~ 0.1% of a radiation length per layer
  - Ensure that sensor geometry is known and provide good stability of sensor positions
    - Goal is a vertex resolution < 5 μm in each coordinate
  - Allow reliable assembly
  - Ensure that connections for services and readout are made in a low-mass way and preserve sensor geometry
  - Take into account cooling requirements and sensor operating temperature.
- During the past year, open video/telephone conferencing meetings have been held with participation from LCFI (United Kingdom), the Fermilab / University of Washington group, Japan, Germany, and other facilities to investigate vertex detector mechanical issues.
- Ultimately, we want the best possible design for the vertex detector.
- We have also investigated integration of vertex detector mechanics with forward calorimetry (FCAL group).

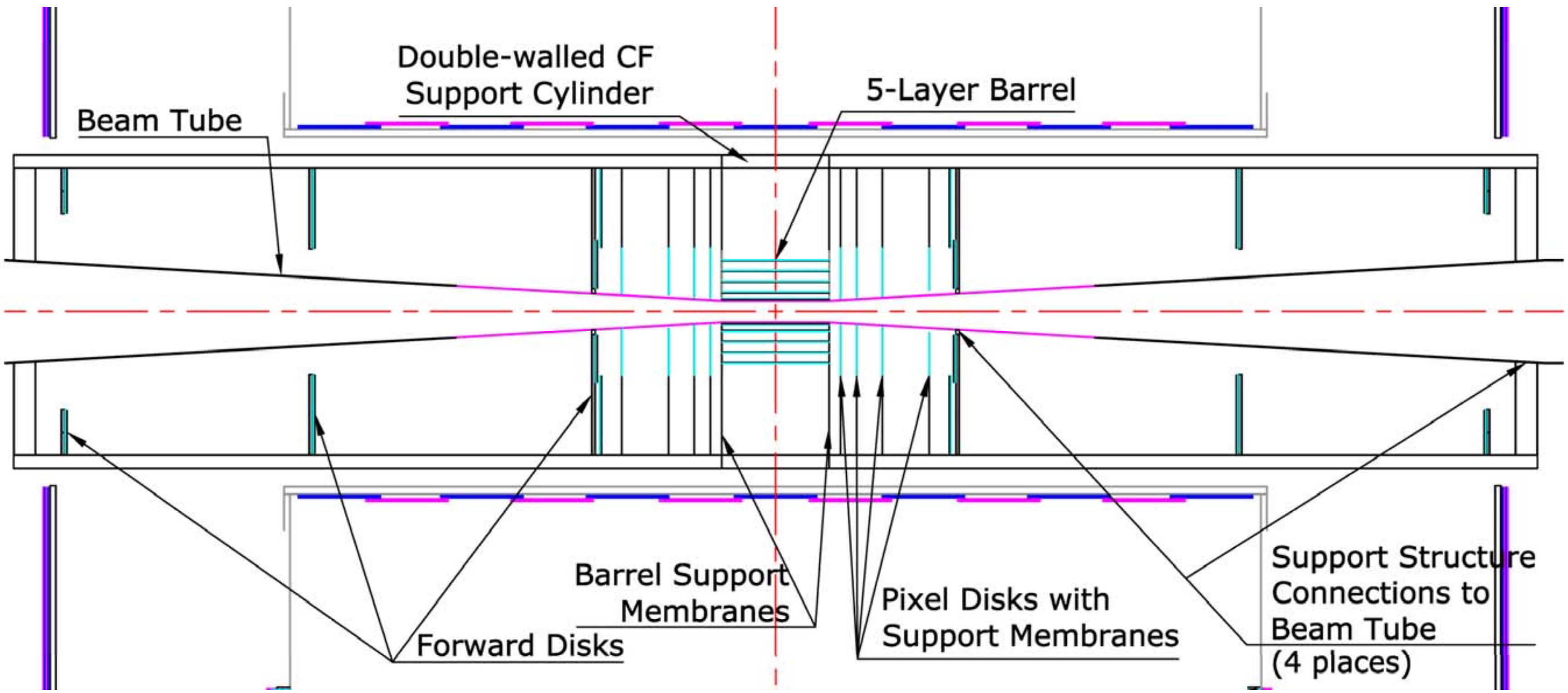
How Do You Design and Build a Low-Mass Detector?

- Silicon represents ~0.1% X0 for each 100 microns of thickness

  → Need thin sensors with low-mass readout
  - 20 µm to 75 µm sensors are under consideration
    - 50 µm to 75 µm matches single-sided support with a very low mass support structure
    - 20 µm matches a silicon – foam ladder structure
    - 50 µm matches a silicon – foam – silicon ladder structure
- Gravitational deflection, thermal distortions, deflection from mounting forces, and deflection from cabling are important
  - Gravitational deflections and thermal distortions depend on geometry and material selection
    - That has led us to structures whose stiffness derives from quasi-cylindrical geometry or, alternatively, to double-sided ladders.
    - Material properties must be correctly understood.
  - Precision, disconnectible mounts which don't transmit uncontrolled moments and forces are difficult.
    - That has led us to consider structures which are glued together.
  - Distortions from cables (as well as radiation length considerations) have led us to seek thin cables.
    - That has led to the initiation of studies of serial power.
- It should not be necessary to say that high-precision handling and assembly tooling will be needed.

SiD Vertex Detector Baseline Design

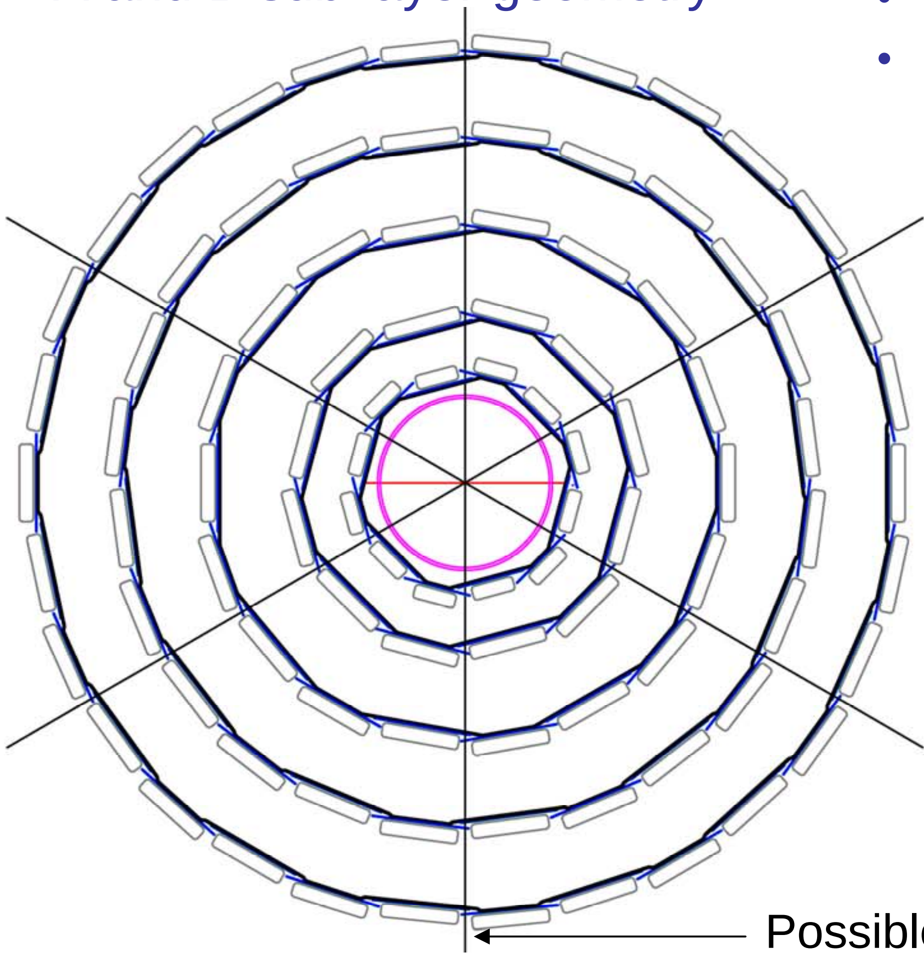
- The baseline design assumes a central, 5-layer barrel of length ~ 125 mm, four pixel disks at each end of the barrel, and three additional disks per end which extend coverage of the outer tracker.
- All elements are supported indirectly from the beam tube via double-walled, carbon fiber laminate half-cylinders with longitudinal ribs.



End View of the Original SiD Baseline Design

- Basis for prototyping
- 2 types of sensors
- A and B sub-layer geometry

- 6-fold symmetry
- To reduce mass, barrel layers are glued to form a unit.
- Up to 15 sensors per unit
- Small variations in parameters with time



Sensors:
IR_A = 14, 22, 35, 47.6, 60 mm
IR_B = 15.15, 23.13, 35.89, 48.41, 60.77 mm
Active widths: 9.1, 13.3 mm
Cut widths: 9.6, 13.8 mm
Beam pipe IR: 12 mm
Beam pipe OR: 12.4 mm
March 3, 2006

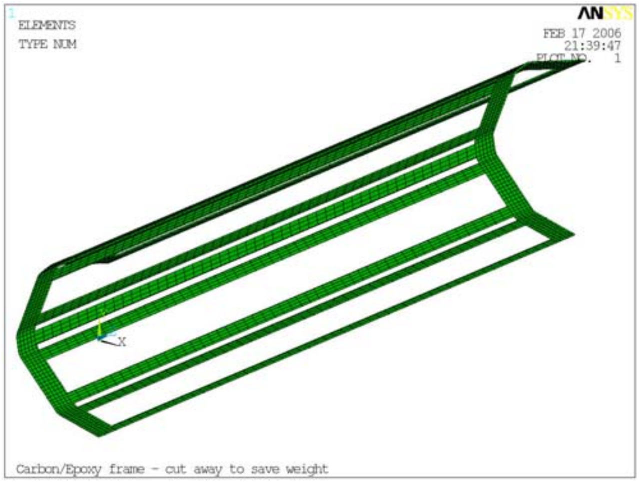
Oblong boxes are openings in end rings and end membranes for cables, optical fibers, and air flow.

Splitting into two halves allows assembly about the beam pipe.

Possible clam-shell split line

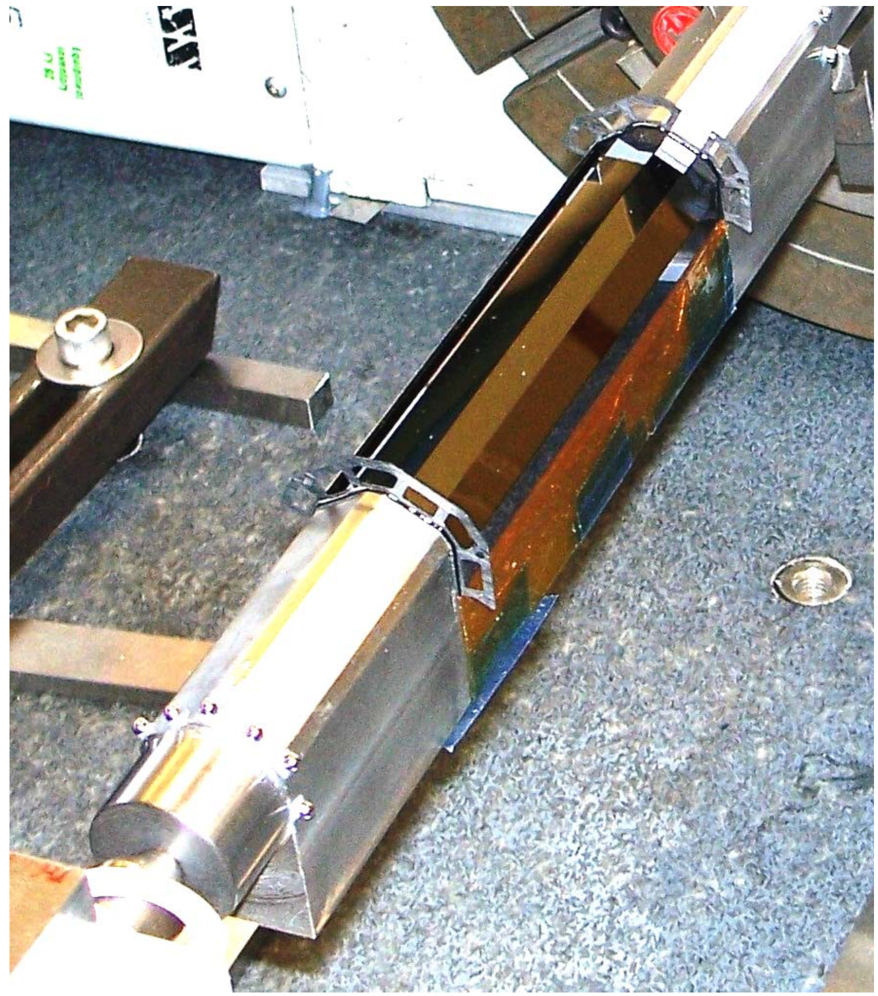
Layer 1 Prototypes

Mesh for Layer 1 finite element analysis (courtesy of the University of Washington)



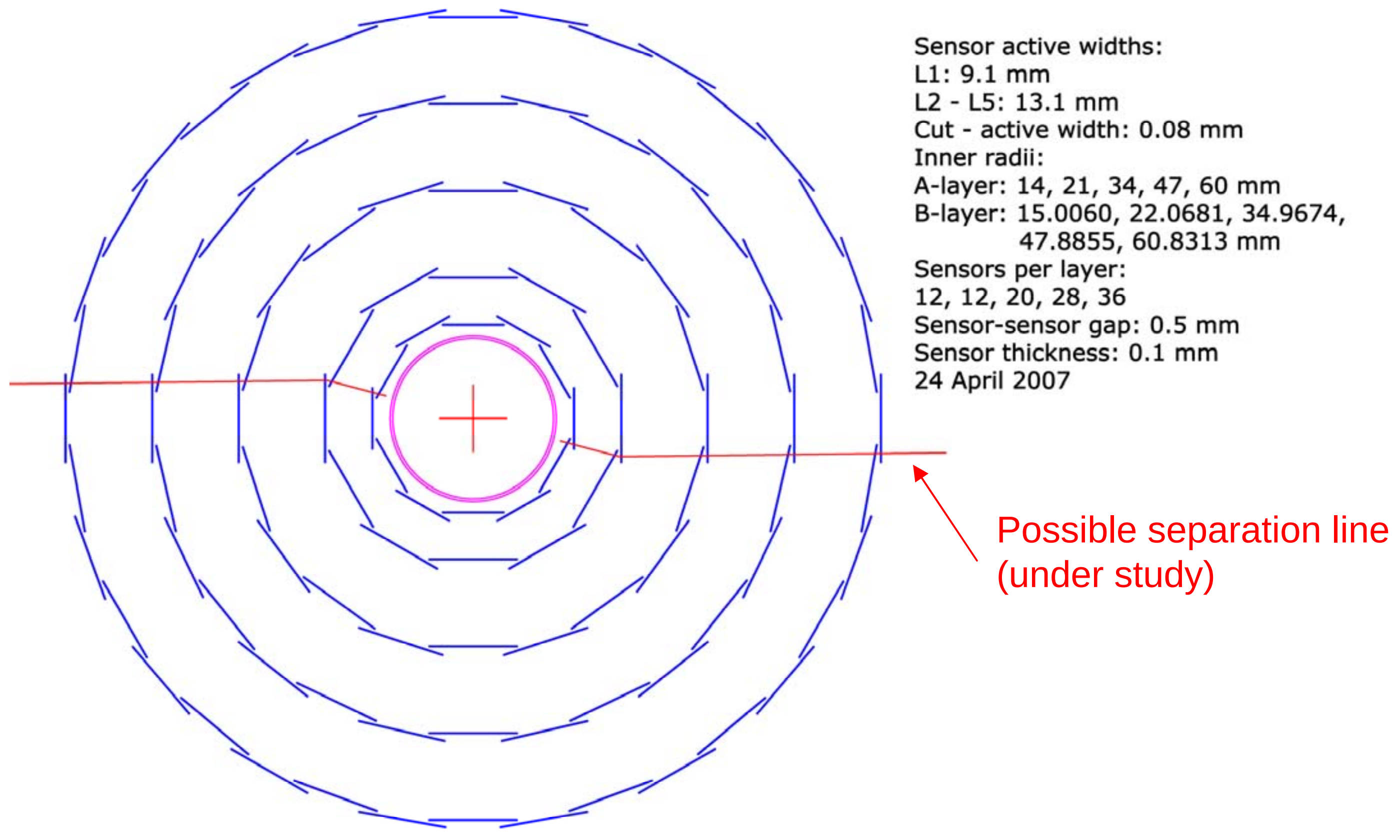
Layer 1 support structure with G-10, rather than carbon fiber, end rings

All CF structure populated with 75 µm thick silicon (CF cylinder and mandrel by UW, CF end rings and addition of silicon by Fermilab)



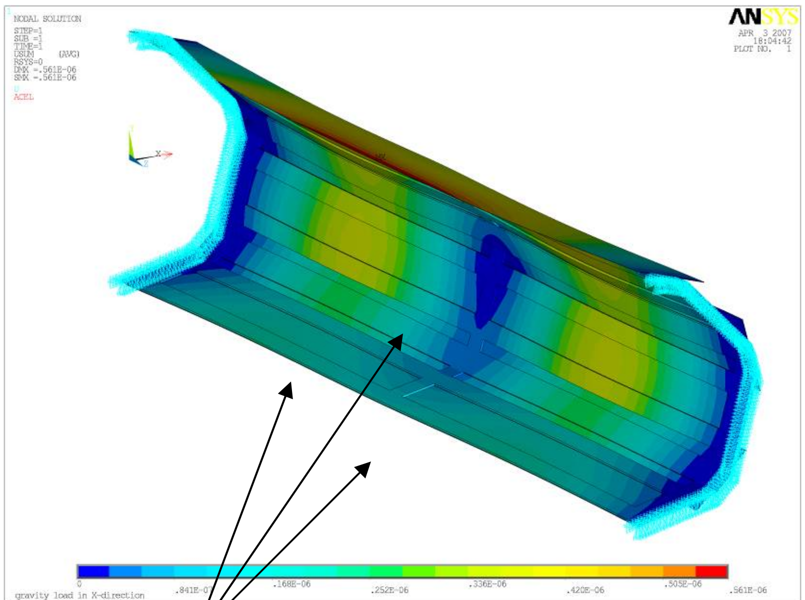
SiD Design Studies and Issues

- New barrel end-view geometry developed last spring
- Sensor counts were increased in L3, L4, L5 to obtain multiples of 4 and fully identical barrel halves (not fully identical originally).

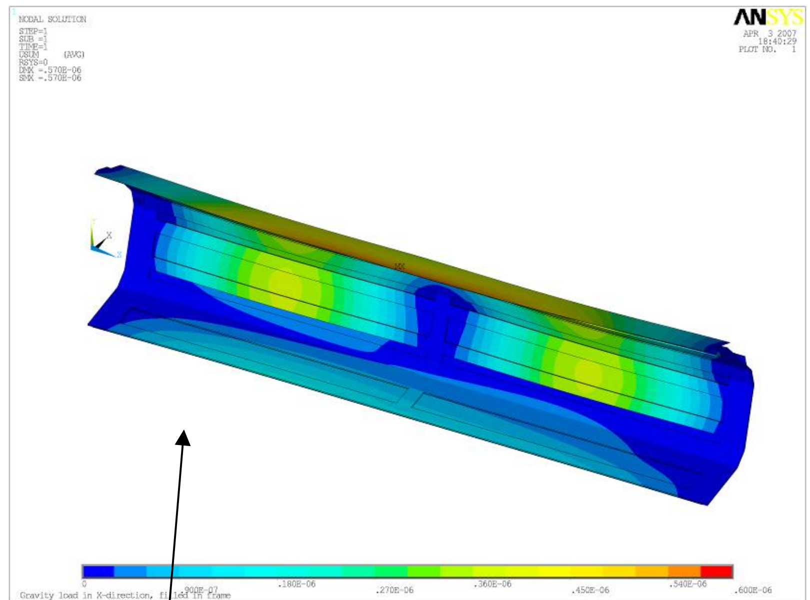


UW FEA Studies, Silicon on CF Structure

- This work has the aim of understanding how to optimize the geometry of the carbon fiber/epoxy composite frame to minimize deflection due to gravity and temperature changes.
- This model uses a 4-layer (0,90,90,0 degree) lay-up. The gravitational deflections of two slightly different structures are:



Open slots to reduce material

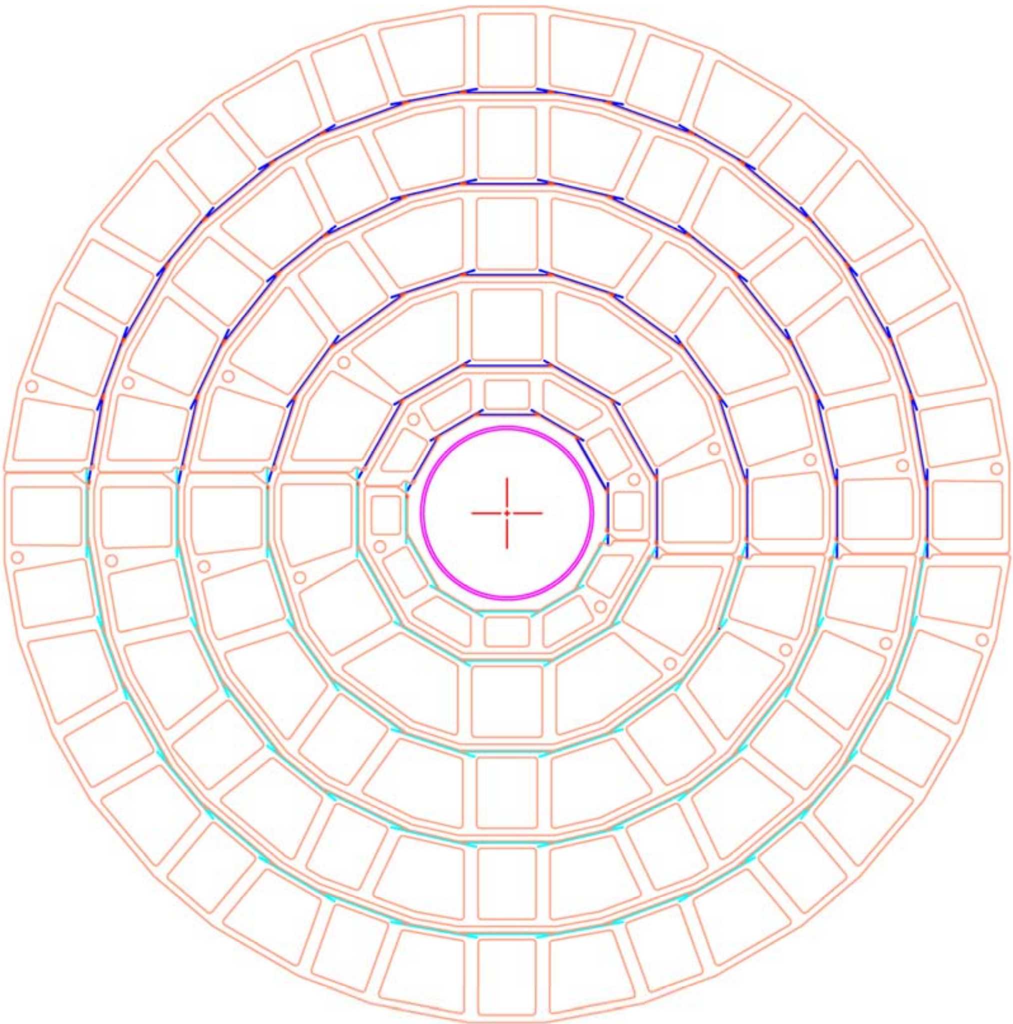


One slot closed to reduce thermal deflection

- The maximum deflection vector is about 0.6 µm in each case.
- Work continues of models with 3-layer CF structures and different CF geometry with the aim of optimizing the mass of the CF and the thermal deflections.
- **Thermal distortions are a serious issue for sensors below ~ 10ºC.**

“All-Silicon” Layout

- Proposed to mitigate CTE issues
- Sensors glued to one another along edges and supported from ends
- 75 µm silicon thickness assumed
- Could be modified for thicker or thinner sensors



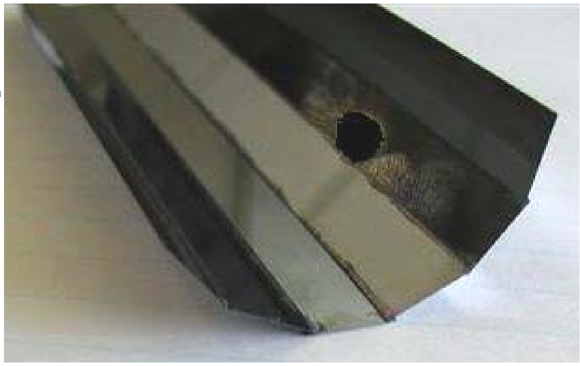
Sensor active widths:
L1: 8.6 mm
L2 - L5: 12.5 mm
Cut - active width: 0.08 mm
Inner radii:
A-layer: 14, 21, 34, 47, 60 mm
B-layer: 14.4593, 21.4965, 34.4510, 47.3944, 60.3546 mm
Sensors per layer:
12, 12, 20, 28, 36
Sensor-sensor gap: 0.1 mm
Sensor thickness: 0.075 mm
7 June 2007, 14 August 2007

- End rings dominate what you see.
- It should be straight-forward to ensure end ring out-of-round stiffness is large compared to that of sensors.
- End ring material has been assumed to be CF in initial modeling.

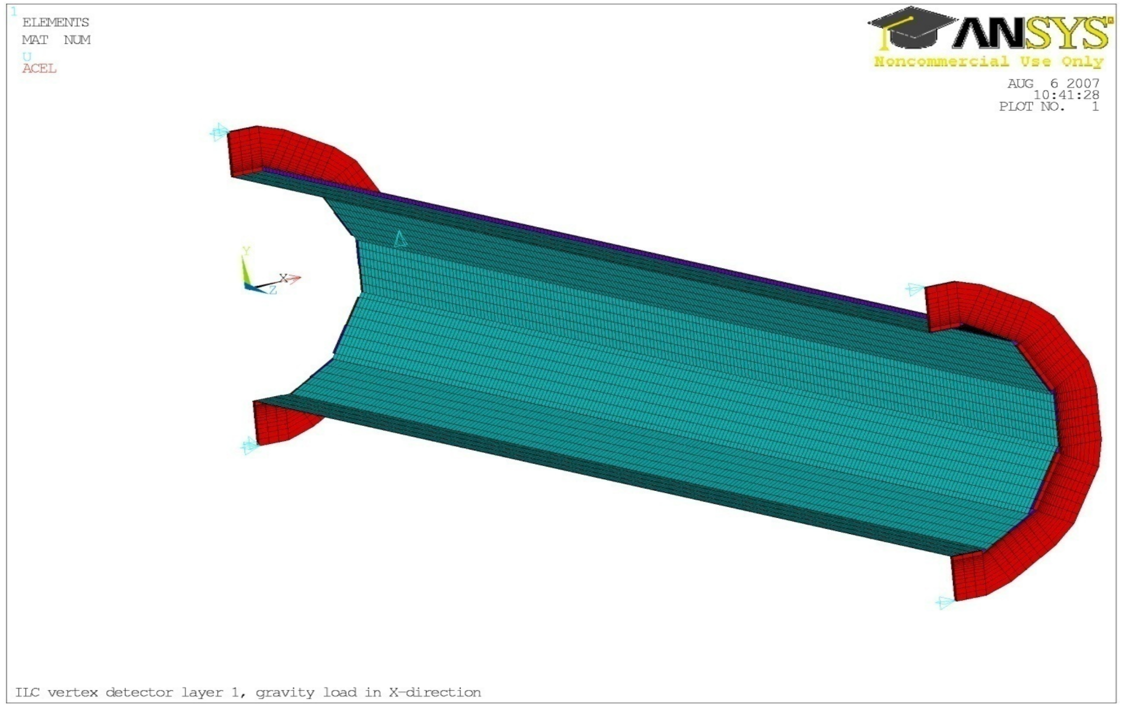
UW FEA of an All Silicon Structure

- This version of the vertex detector uses only the silicon sensors in "cylindrical" portions of the structure.
  - They are connected along their long edges by thin beads of epoxy.
  - Thin, flat carbon fiber/epoxy end membranes included in the model.
  - These membranes will be refined as a more detailed design is developed.
- Model is parametric and can generate models for all 5 layers of this detector.
  - Only a 180 degree segment is modeled. It is assumed here that the detector will be built as two such segments to permit assembly onto the beam pipe and that these will not be connected.
- The gravity sag is calculated and displayed as deflection in the gravity (X) direction.
- Maximum displacements in the X, Y and Z directions are calculated for a 10 C delta T.
  - Note that the Z deflection is composed mainly of the simple change in length of the detector.

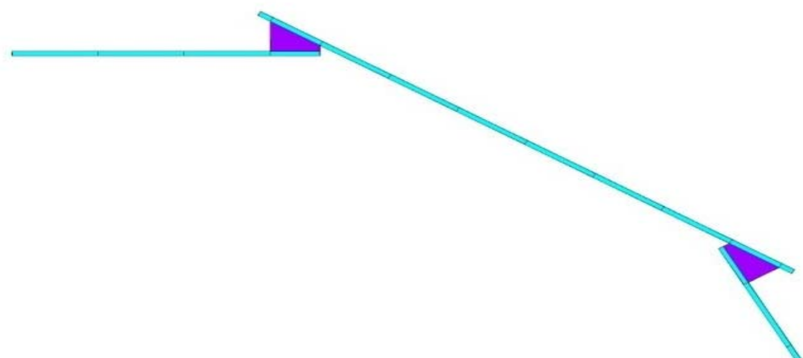
Layer 1 mechanical prototype (Kurt Krempetz)



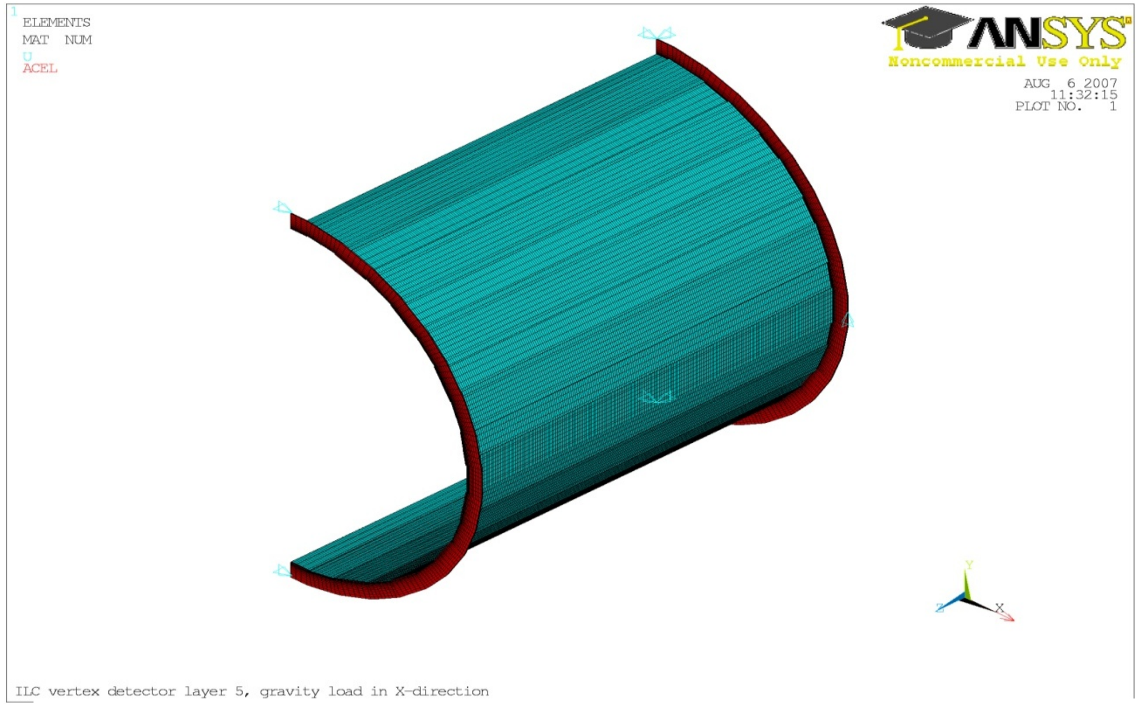
Model of layer 1



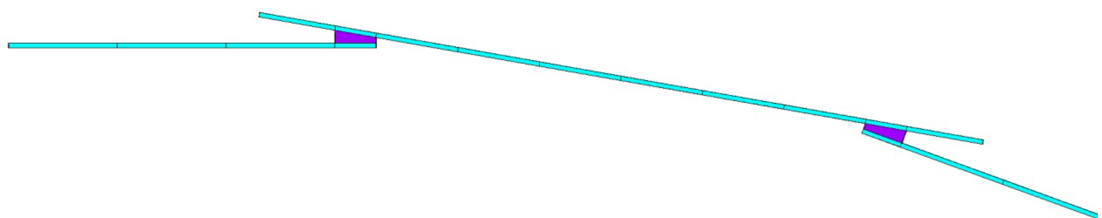
Detail of model of layer 1 showing the 0.7 mm wide epoxy joints.



Model of layer 5.



Detail of model of layer 5 showing the 1.0 mm wide epoxy joints.



Initial FEA results for ILC vertex detector - all silicon structure (**8/6/2007 C H Daly)**

Layer no.	Gravity sag µm	Thermal displacement X-direction µm (10 C delta T)	Thermal displacement Y-direction µm (10 C delta T)	Thermal displacement Z-direction µm (10 C delta T)
1	0.145	0.86	1.84	5.34
2	0.1	1.01	2.97	5.61
3	0.266	1.62	3.99	5.82
4	0.642	2.64	5.67	6.22
5	1.4	4.4	8.1	6.6

In a collaborative effort to develop an all-silicon design, LCFI institutions carried out similar FEA.

Comparison of Initial FEA Results – all silicon layer 5

Model boundary condition – simulating full model effect

	Gravity load only	Thermal displacement X	Thermal displacement Y	Thermal displacement Z
Case A	1.1 micron	4.0 microns	4.6 microns	3.95 micron
Case B	1.9 microns	4.6 microns	9.4 microns	4 microns
Colin's results *	1.4 microns	4.4 microns	8.1 microns	6.6 microns

Case A – runs using isotropic carbon fibre material properties;
Case B – model using orthotropic carbon fibre material properties compatible with those used by Colin;
Boundary condition used in Colin's model may be different from those used in Cases A & B – confirmation needed.

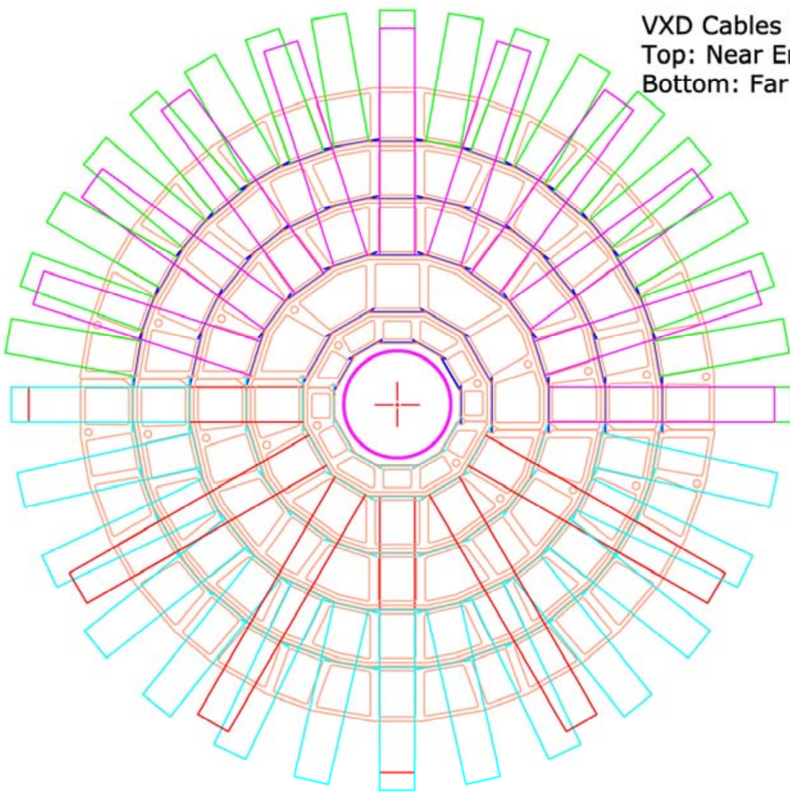
X direction – out-of-plane horizontal
Y direction – out-of-plane vertical;
Z direction -- axial

LCFI mechanical – S. Yang Oxford university

It's quite helpful to see how results depend on material properties and reassuring to see similar results for a given set of properties.

Cables

- Cables still require substantial effort with regard to sensor requirements, the possibility of serial power, and paths to limit material within the tracking acceptance.
- **An “all silicon” layout with one cable per “ladder” and series power within each ladder is shown.**
- Layer 1 cables, which may run along beam pipe, are not shown.
- Layer 2 & 4 cables at one end, 3 & 5 at the other



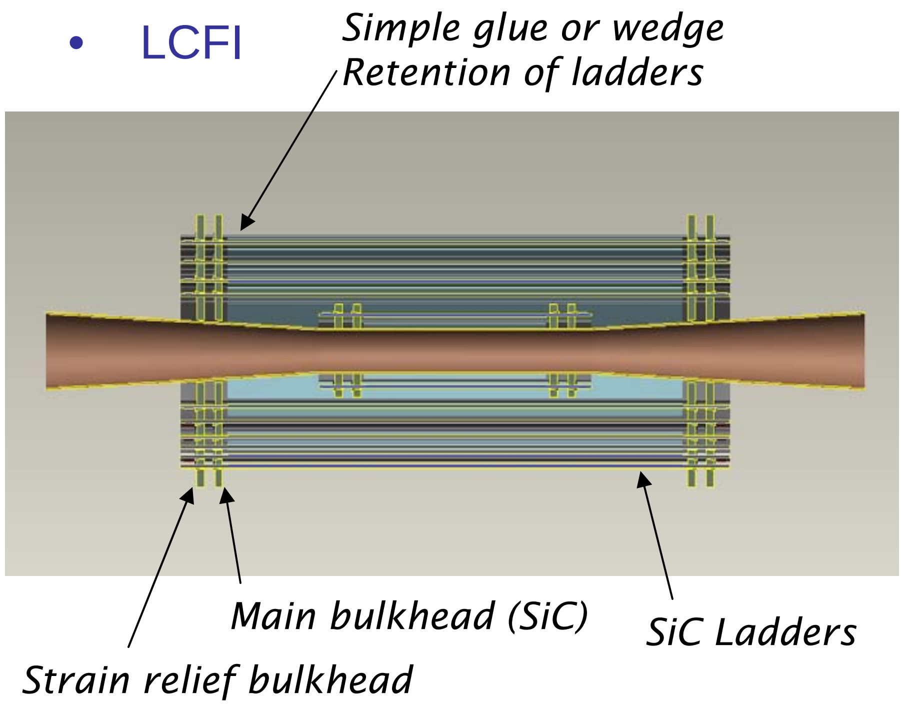
Two cable thicknesses in many places.

Power Delivery

- Power cycling and series power affect designs in different ways.
- Power cycling will be crucial to allow dry gas cooling with most present sensor and readout technologies.
  - A factor ~80 reduction of average power with respect to peak power has been assumed.
- Connecting sensors so that they are powered in series:
  - Limits power dissipated by cables and / or reduces material represented by cables.
  - We have just begun investigating the benefits of series power in reducing moments imposed on sensors by cabling.
    - Trade-off between power dissipated by cable and cable stiffness
- Initial estimates of heat removal capability apply to the sum of power dissipated by sensors, cables, and readout within the volume of interest.

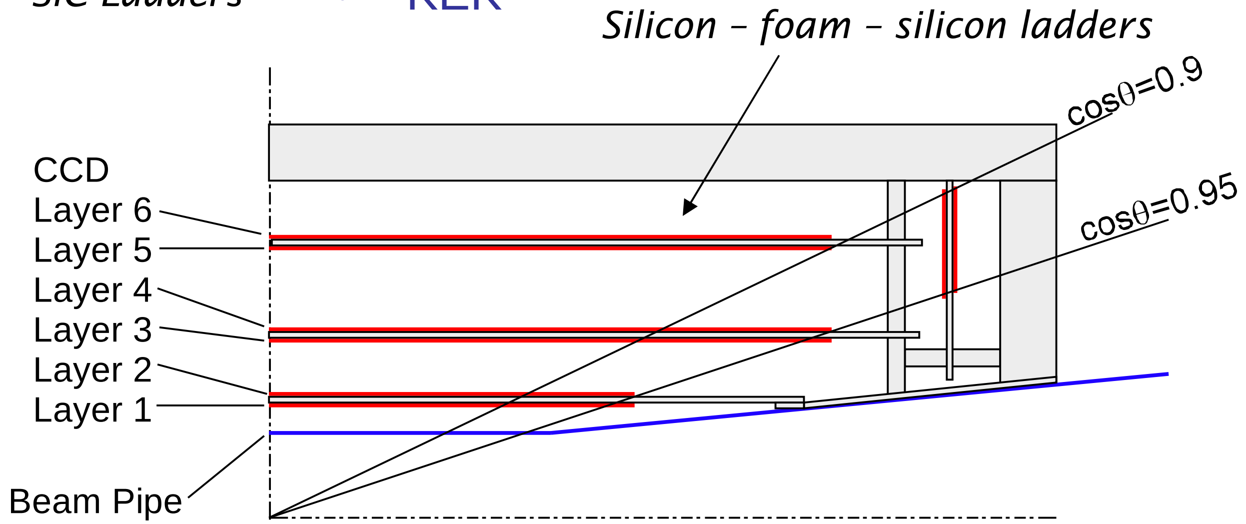
Other Approaches

- LCFI



- Both approaches include interesting ladder features, which could be applicable to the shorter ladders assumed in the SiD design.

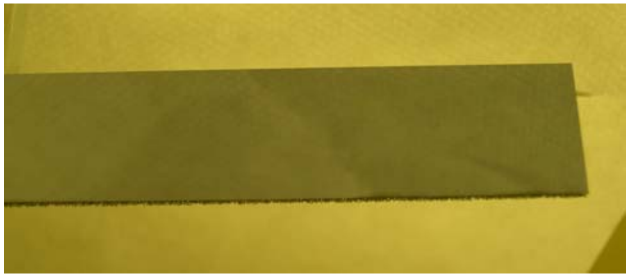
- KEK

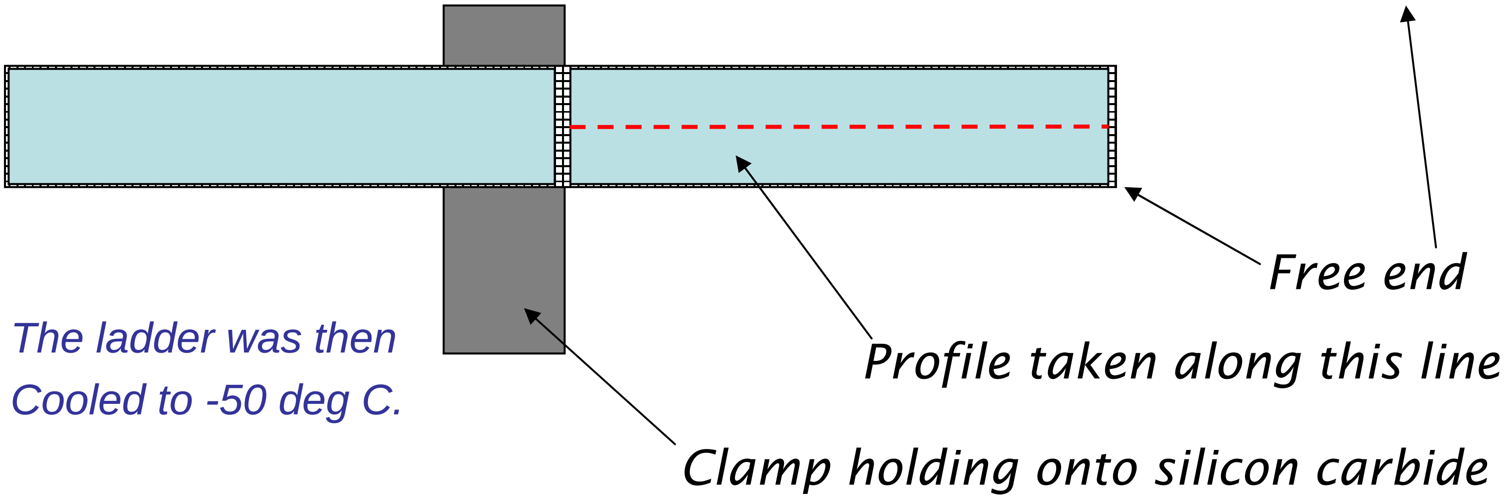


Other Options: Silicon on SiC Foam (LCFI)

Early studies

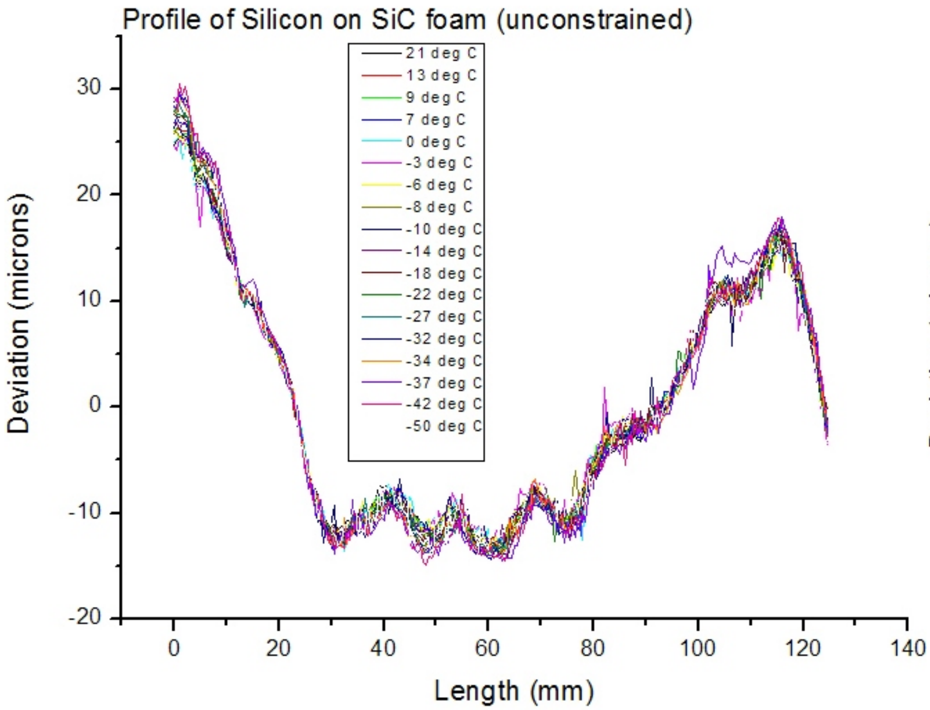
- *LCFI have investigated silicon on foam for several years.*
- *Recently (2007), Erik Johnson has made some good 2D studies with simply supported SiC foam-thin silicon structures*
- *Reduces thermal distortions*
- *A SiC Ladder was made and supported in the middle with one end totally free (no mounting frame)*

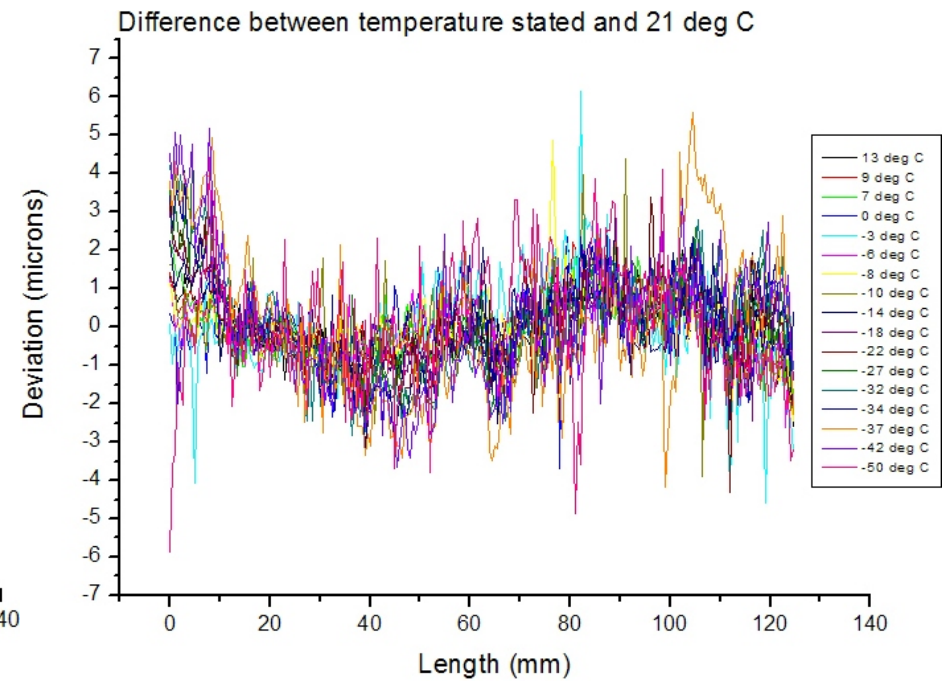




- *The ladder was then*
- *Cooled to -50 deg C.*

2D results show negligible thermal distortion





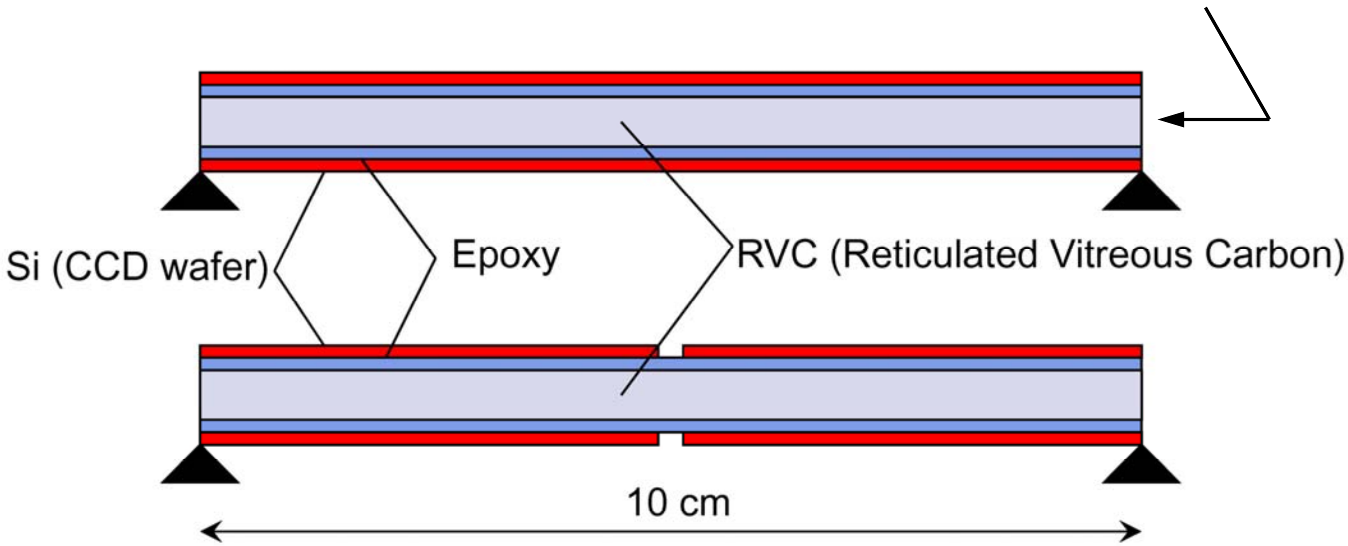
- *Results show good stability with respect to temperature change.*
- *Need to ensure that the method to hold the ladders in place does not cause deflections.*
- *6% to 8% SiC foam obtained from ERG so far*
  - *~ 3% foam needed, but hard to obtain*

FEA of Ladders

Deflection:

0.54 µm for 100 mm length

~8.6 µm for 200 mm length



Deformation by self-weight is calculated by FEA program COMSOL

Symmetric structure reduces thermal distortions

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Material budget allows 50 µm silicon, which may simplify handling during fabrication.

FEA of Ladders

- Parameters (assumption)

	Density (g/cm^3)	X0 (g/cm^2)	E (GPa)
Si	2.33	21.8	110
Epoxy	1.15	40.9	3
RVC	0.05	42.7	0.031

- Geometry

	Thickness	Weight	Radiation length
Si	50 µm	0.01165 g/cm^2	0.0534%X_0
Epoxy	50 µm	0.00573 g/cm^2	0.014%X_0
RVC	2 mm	0.0084 g/cm^2	0.0234%X_0
Epoxy	50 µm	0.00573 g/cm^2	0.014%X_0
Si	50 µm	0.01165 g/cm^2	0.0534%X_0
Sum		**0.04316 g/cm^2**	**0.1582%X_0**

0.08%X_0/layer

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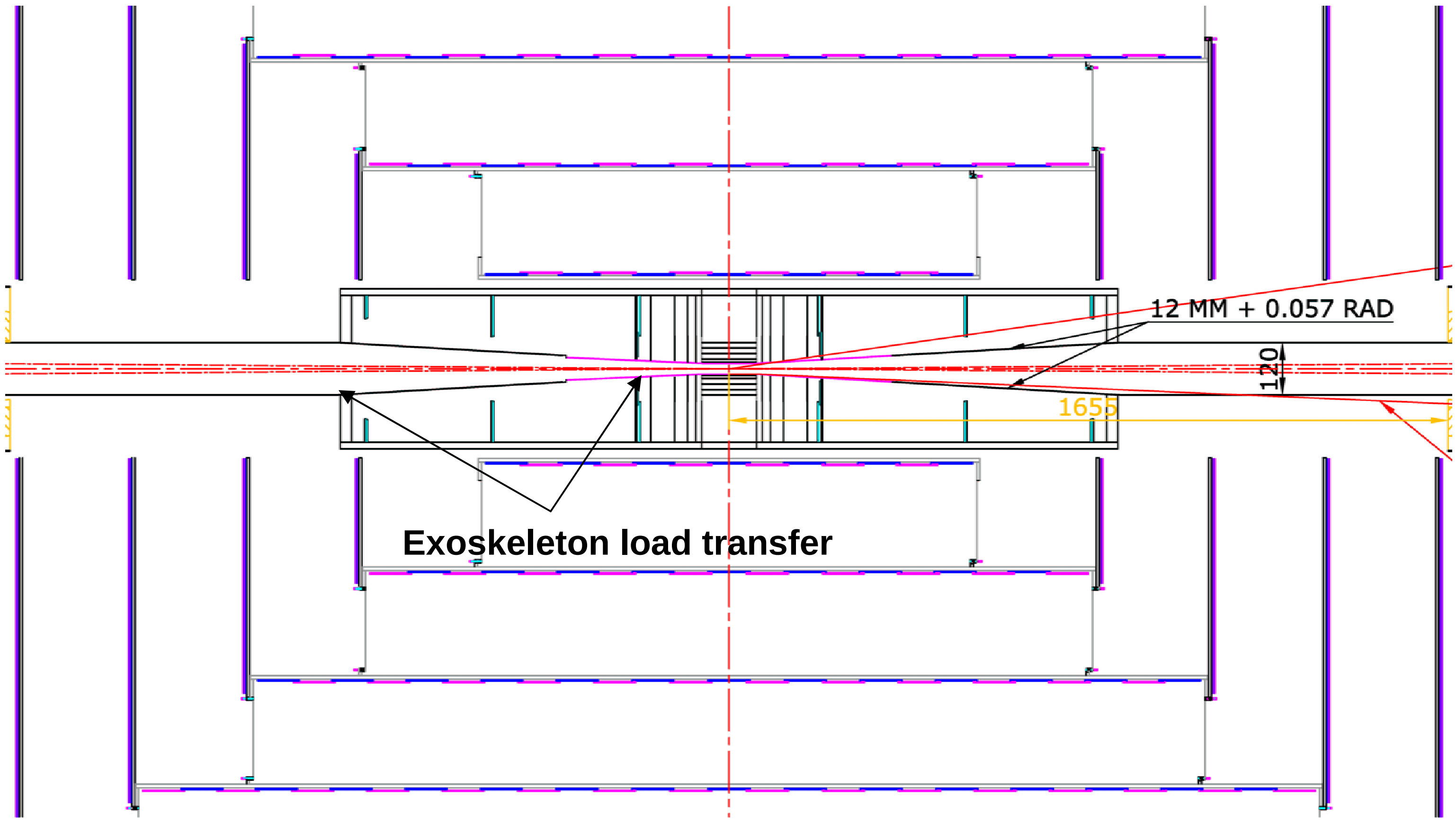
Thickness allows initial determination of track vector

SiD Vertex Detector & Beam Pipe Support

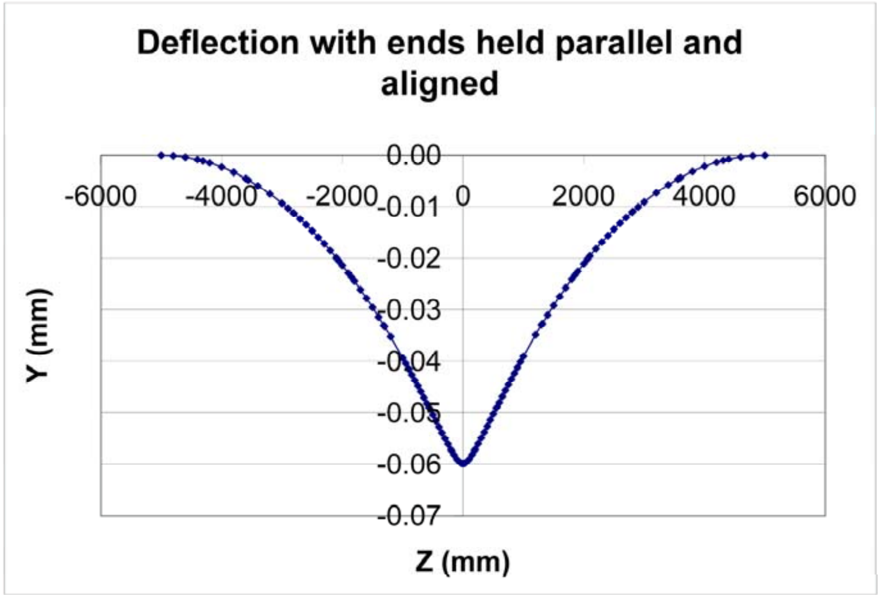
- The CF laminate exoskeleton not only supports the vertex detector from the beam pipe, it also holds the small radius, beryllium portion of the beam pipe straight.
- Both the beam pipe and the exoskeleton bend in the process.



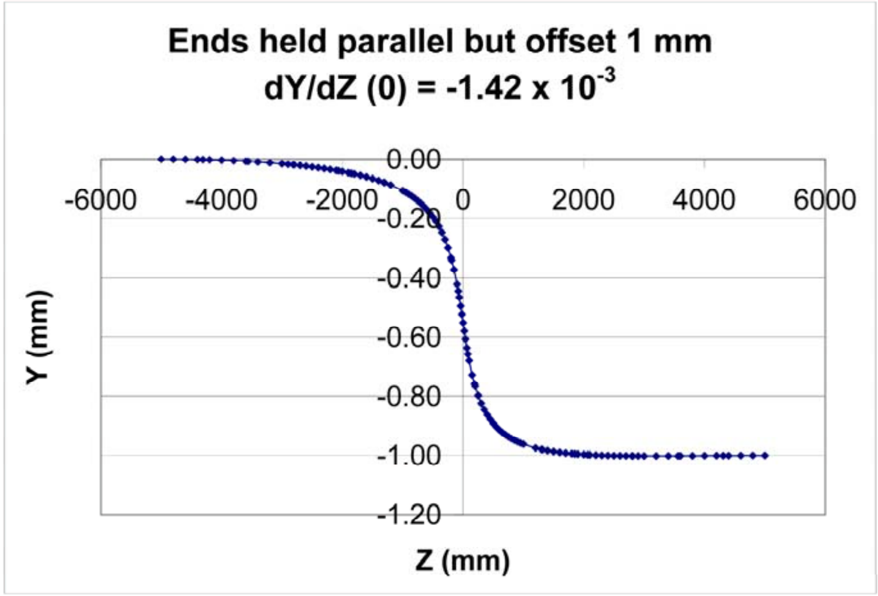
Beam Pipe Deflections

- For these calculations, an all-beryllium beam pipe was assumed.
  - Wall thickness of 0.25 mm was assumed in the central, straight portion.
- The radius of conical portions was assumed to increase with dR/dZ = 17/351.
  - Wall thickness in the conical portions was chosen to correspond to collapse at slightly over 2 Bar external pressure.
- An inner detector mass of 500 g was assumed to be simply supported from the beam pipe at Z = ± 900 mm.

Inner detector weight contributes ~ 0.008 mm.

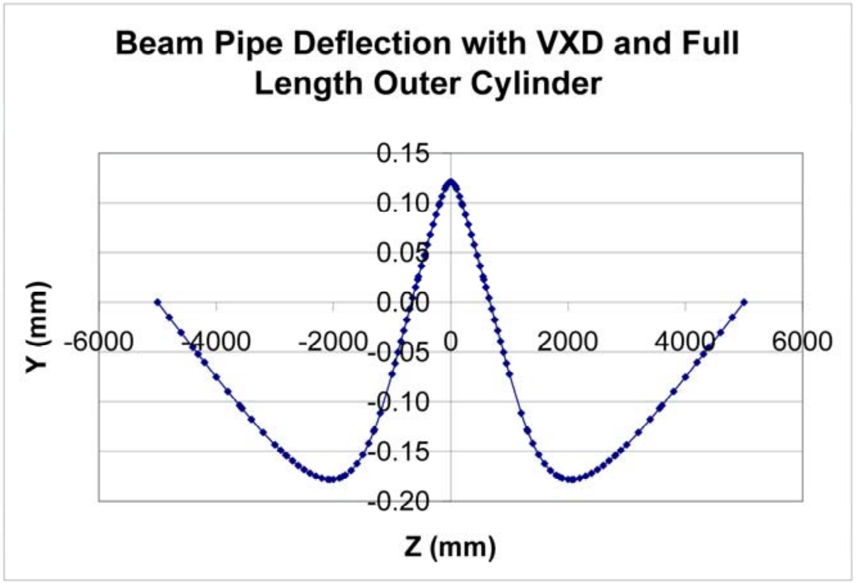


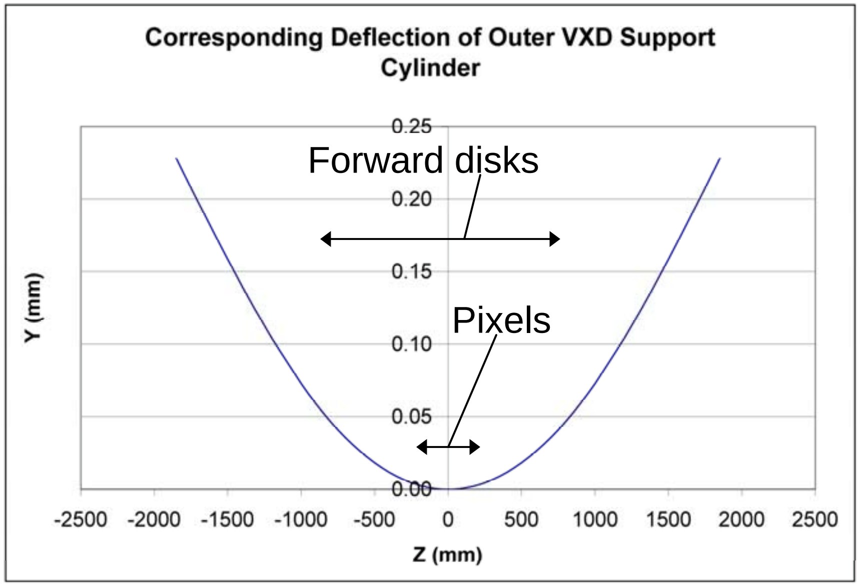
Maximum stress ~ 20 MPa



Beam Pipe Deflections

- A basic assumption has been that the beam pipe would be guided, not just simply supported, at its ends.
- If one assumes that the beam pipe would be simply supported (more realistic), then the outer support cylinder for the vertex detector could be extended to ±1.85 m.
- Connect to beam pipe at ±1.85 m and ±0.90 m (not optimized).

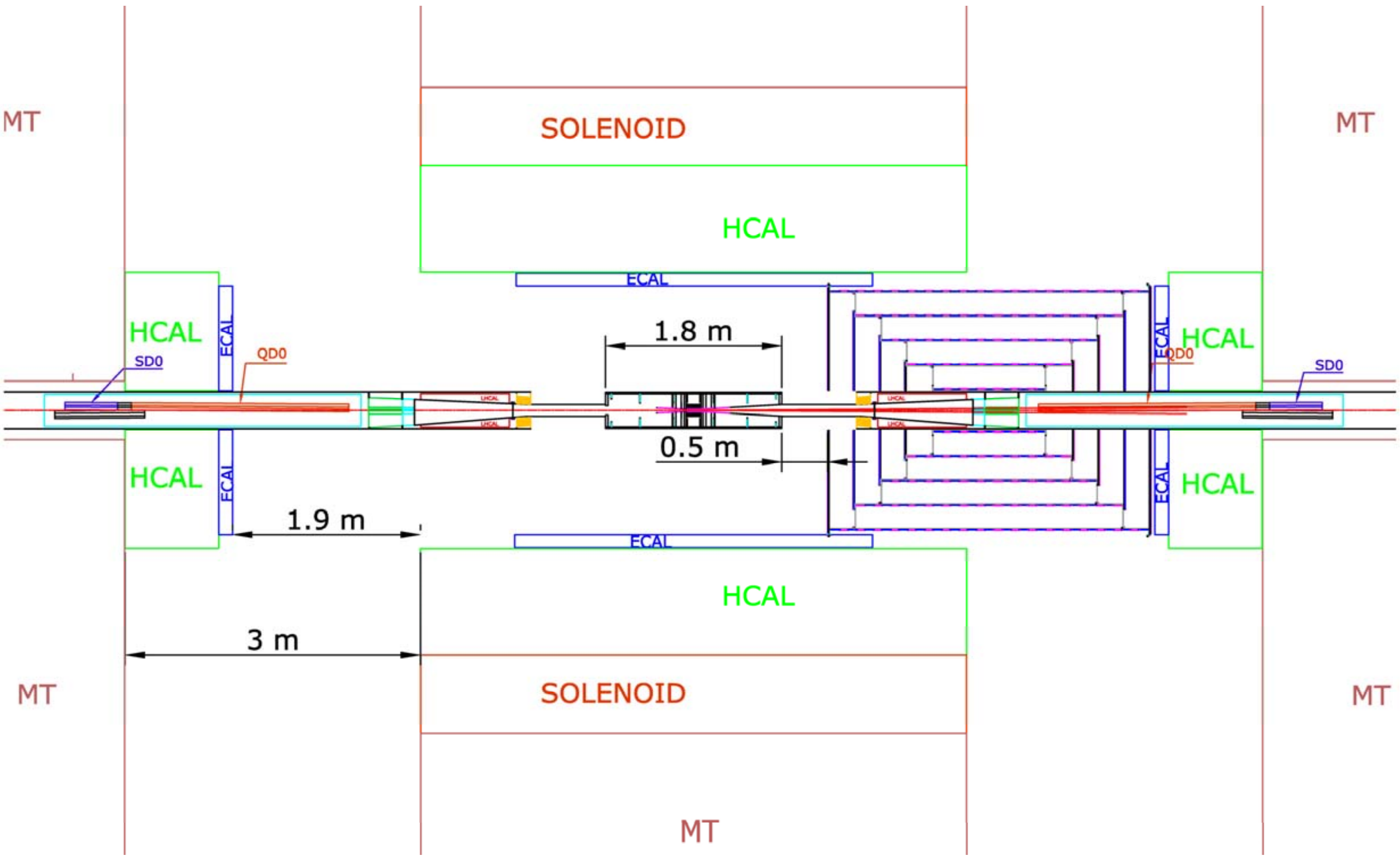




- Calculations remain to be completed with a beam pipe which is partially of denser material, such as stainless steel.

Servicing Vertex Detector & Tracker (SiD)

- Detector open 3 m for off-beamline servicing
- Vertex detector can be removed / replaced.



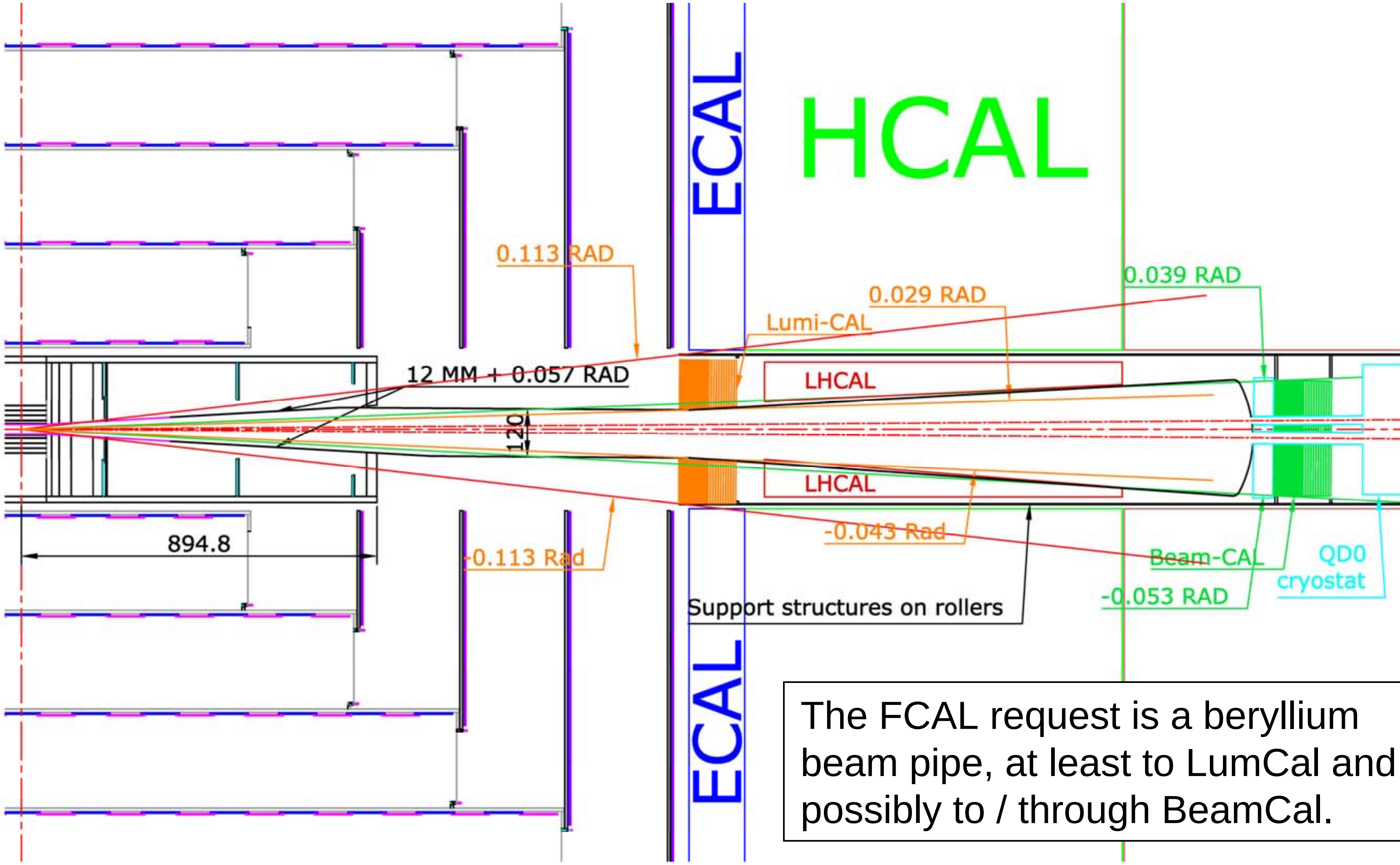
SiD Forward Region

- Very useful discussions at SLAC during IRENG07
- The general layout of forward calorimetry follows parameters provided by Bill Morse and concepts suggested by Tom Markiewicz.

LumiCal inner edge	≈36mrad about outgoing
LumiCal outer edge	≈113mrad about 0mrad
LumiCal fiducial	≈46-86mrad about outgoing
BeamCal outer edge	≈46mrad about outgoing
LumiCal	$30X_0$ Si-W
BeamCal	$30X_0$ rad-hard Si,diamond....

SiD Beam Pipe

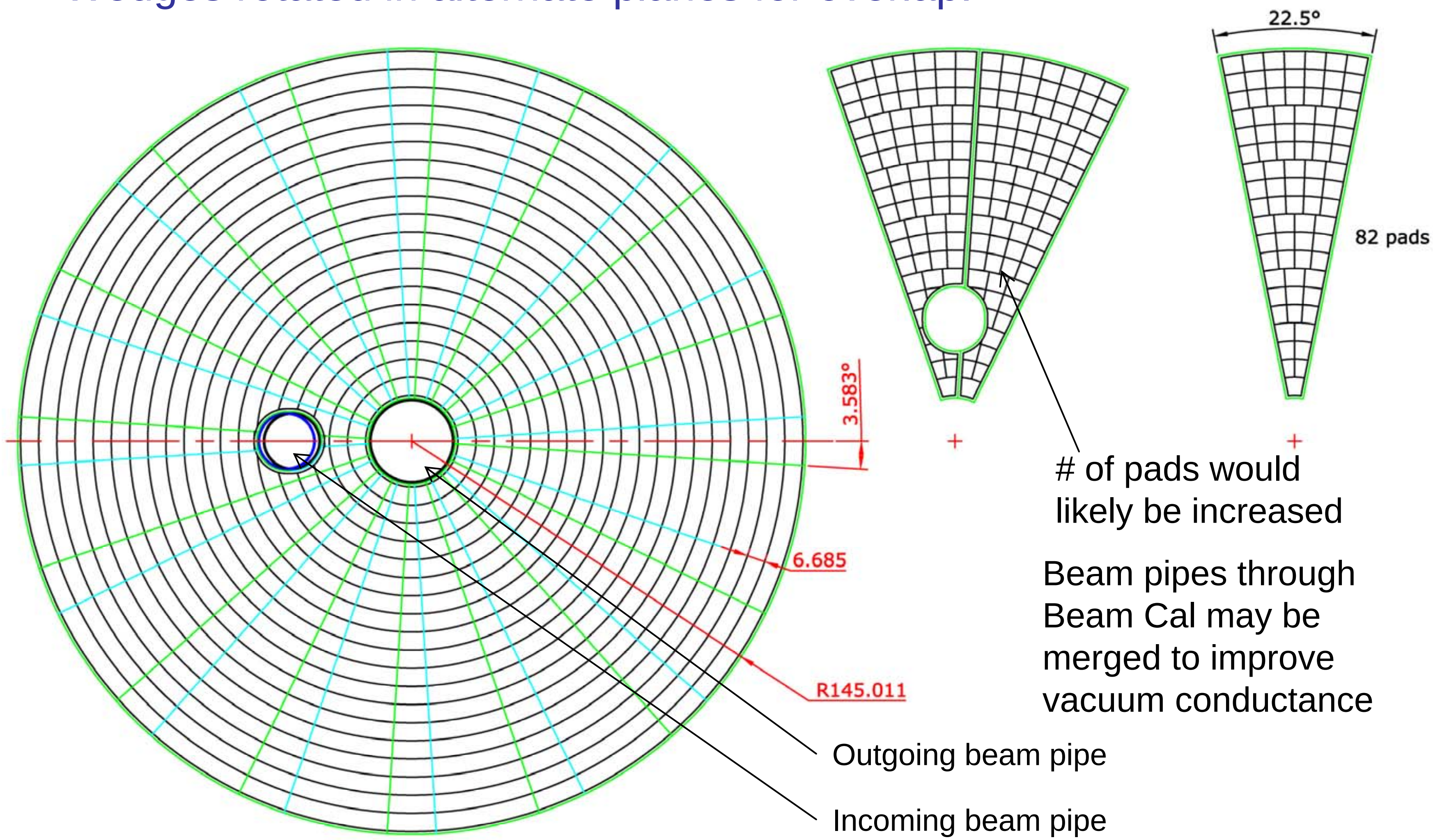
- The beam pipe shape in the forward region is shown below.



The FCAL request is a beryllium beam pipe, at least to LumCal and possibly to / through BeamCal.

Preliminary BeamCal Sensor Layout

- Assumes 6” silicon sensor technology.
- Wedges rotated in alternate planes for overlap.



Short-term Tasks (Under development)

		Description	FTE (MM)
Material properties	1	Spreadsheet and hand calculations to understand the ideal epoxy thickness between silicon and CF	0.5
	2	Determination and testing of suitable, alternative adhesives, such as silicone or cyanoacrylate	0.25
	3	Spreadsheet calculations of CF laminate properties: mechanical, thermal conductivity, CTE, CME	0.25
	4	Test set-ups to measure thermal conductivity, CTE, and CME	1
	5	Test setup to measure thermal bowing	1
	6	Investigation of RVC and SiC foams	2
Fixtures	7	Epoxy application fixture	1
	8	Fixtures for all-silicon barrel	
		Glue application	1
		Silicon handling	1
		Layer assembly	1
		Barrel assembly	1
	9	Rotary table tooling	1
	10	Spinner	?
	11	Reverse bump bonder	?
Measurement R&D	12	Non-contact measurements of Z	0.75
	13	Laser interferometer	2
	14	Large CMM	1
	15	Low temperature measurements	0.5
	16	Low humidity measurements	0.5
Supplies	17	Wirebonding: purchase and testing of 18 micron aluminum wire	0.5
	18	Inventory of CF	Done
	19	Inventory of epoxy	0.25
	20	Inventory of silver epoxy	0.05
	21	Inventory of kapton and similar insulating materials	0.05
	22	Inventory of mandrels	Done
Prototyping	23	All-silicon Layer 1	1.25
	24	All-silicon Layer 5	1.25
	25	CF-silicon Layer 1	1.25
	26	CF-silicon Layer 5	1.25
	27	End rings	1
	28	Outer support half-cylinders	2
		Mandrels	0.25
	29	Connections to beam pipe	0.25
	30	Cable paths	0.5
	31	Outer tracker modules and module mounts	2
	32	Prototype cables	1
	33	Prototype optical fibers and connections	?
Drawings	34	Drawings for all items under prototyping	?
Beam pipe	35	Beam pipe drawings	?
	36	Beam pipe collapse and bending calculations	?

Short-term Tasks (Under development)

- Given present resources, this task list will need to be trimmed.
- We will also need to understand priorities between documenting the existing design, completing missing studies on that design, and further R&D.
- The budget and shifting priorities are obvious constraints.