Vertex Detector Mechanics

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Introduction

- The overall approach to mechanical support and cooling has been developed in conjunction with SiD.
- The support structures which have been studied rely heavily on the use of carbon fiber laminate (CF).
  - CF offers a high stiffness * radiation length product.
  - Operation near room temperature (> -10° C) has been assumed during design development.
    - Minimizes thermal distortion effects
  - Operation at lower temperature may be possible, but would require a more carefully engineered design.
- To control the number of radiation lengths, cooling with forced flow of dry gas has been assumed.

Representative Material Properties

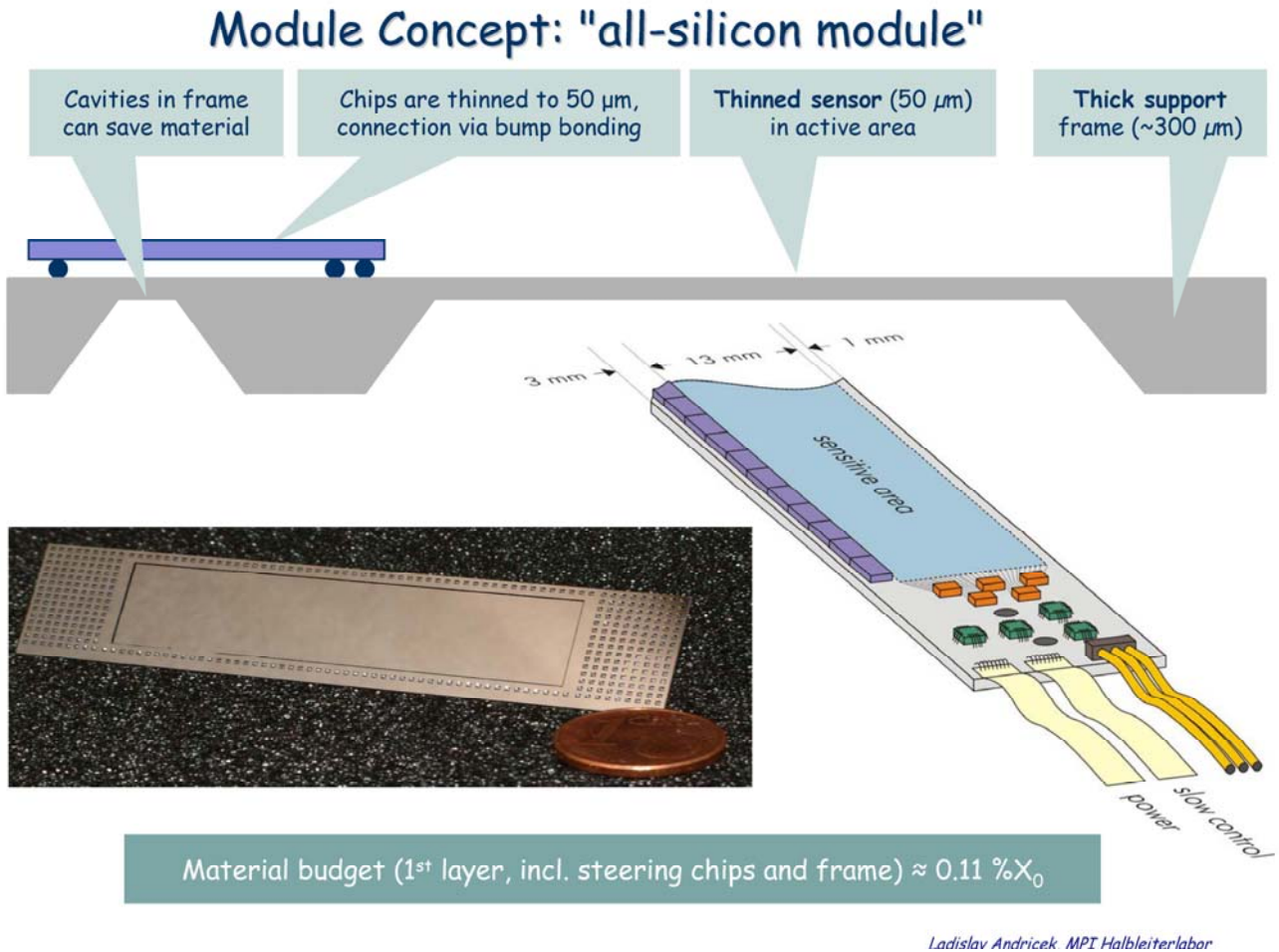
- In general, we are interested in maximizing stiffness and minimizing the number of radiation lengths of a support structure.
- For beam-like deflection of a flat plate of fixed thickness, width, and length, deflection with gravity acting normal to the surface varies linearly with density and inversely with elastic modulus.
- We are also interested in controlling thermal distortions by minimizing differences in CTE.
- The table below suggests the choice of CF with portions removed.
- Behavior of a combined structure is more complicated.

Material	Silicon	Beryllium	CF	¼ CF
Density (g/cm^3)	2.33	1.848	1.56	0.39
Elastic modulus (GPa)	131	290	228	57
Radiation length average (cm)	9.37	35.43	24	96
Relative deflection	1	0.36	0.38	0.38
Relative number of radiation lengths (average)	1	0.26	0.39	0.10
CTE (ppm/^{o}C)	2.6	11.6	-0.6	-0.6

CF modulus and CTE depend on the lay-up

MPI Ladder

- We were asked if we would look at deflections and make a thermal analysis of an MPI ladder. Thermal analysis remains to be done.



MPI Ladder

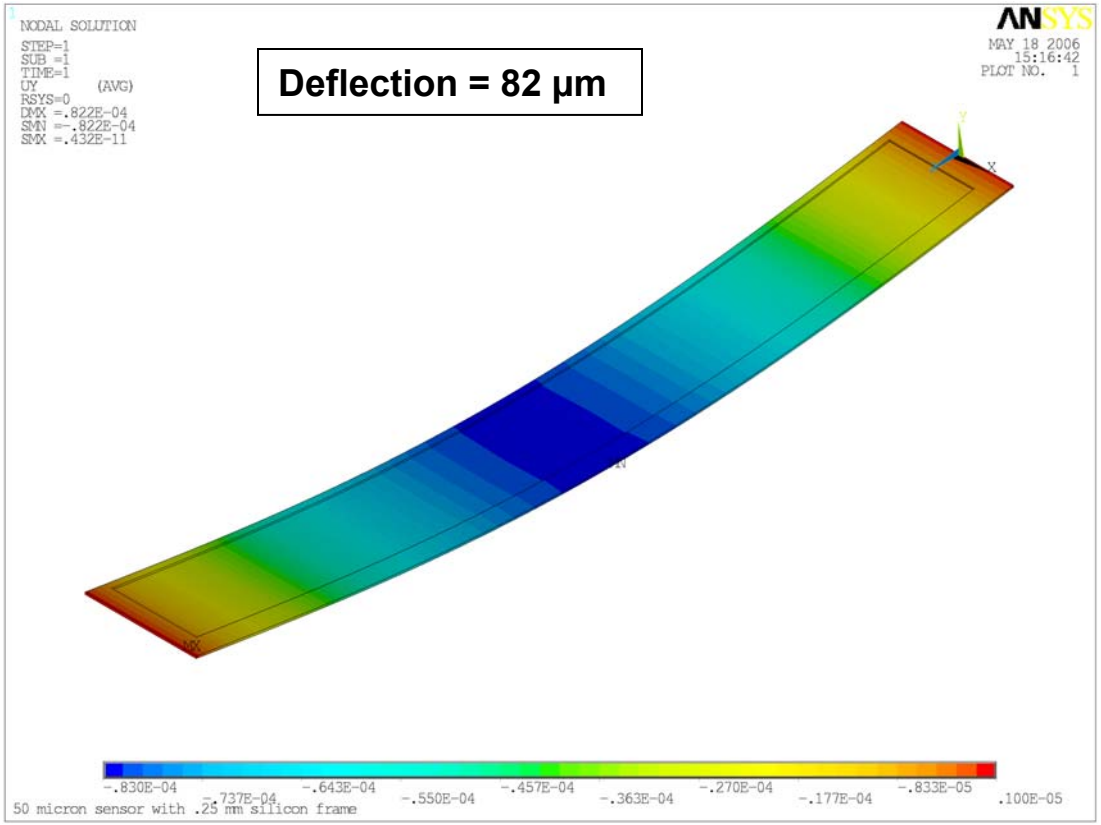
- Ladder was modeled as a window frame 3 mm wide on three edges and 1 mm wide on one long edge plus a thinner portion within frame.
  - Frame thickness = 0.3 mm
  - Thickness within frame = 0.05 mm
  - Overall length = 125 mm

FEA by C. H. Daly

All silicon

Hand calculation gave 77 µm

$E_{silicon}$ was taken to be 110 GPa



MPI Ladder

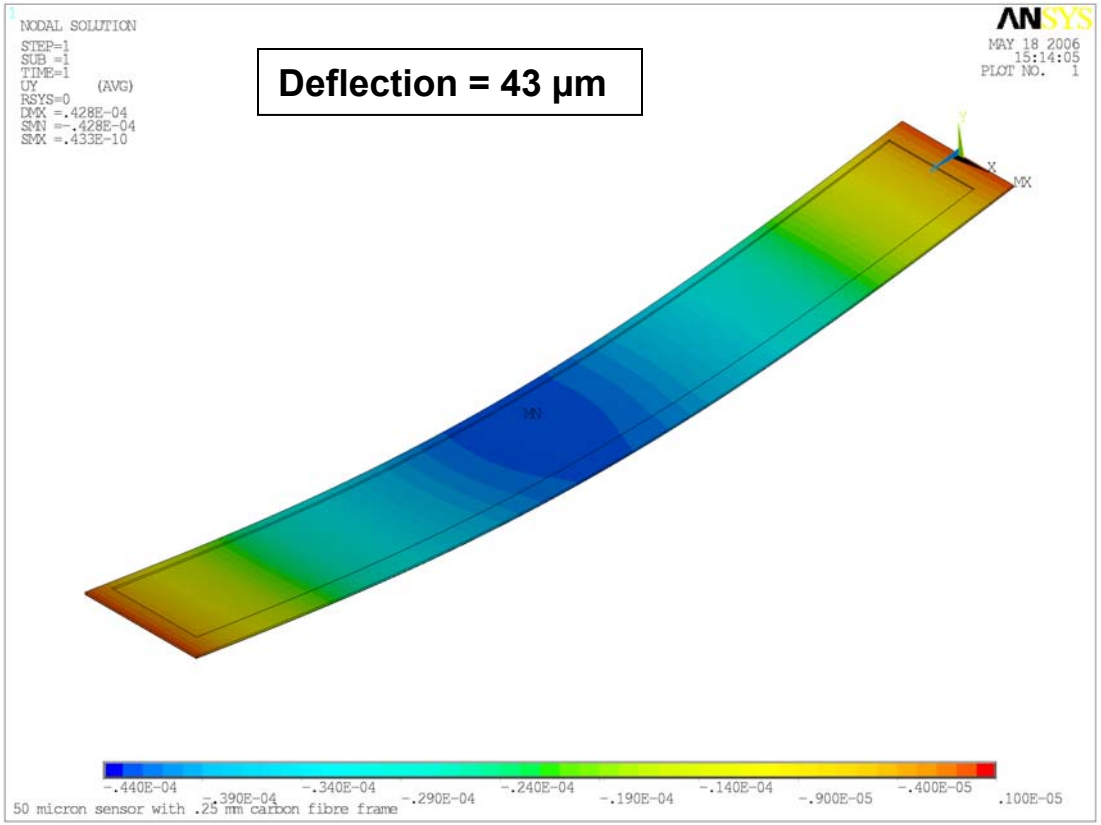
- 0.25 mm of frame thickness was replaced by CF, leaving 0.05 mm silicon thickness over the full extent of the ladder.

FEA by C. H. Daly

Silicon + CF

Hand calculation gave 46 µm

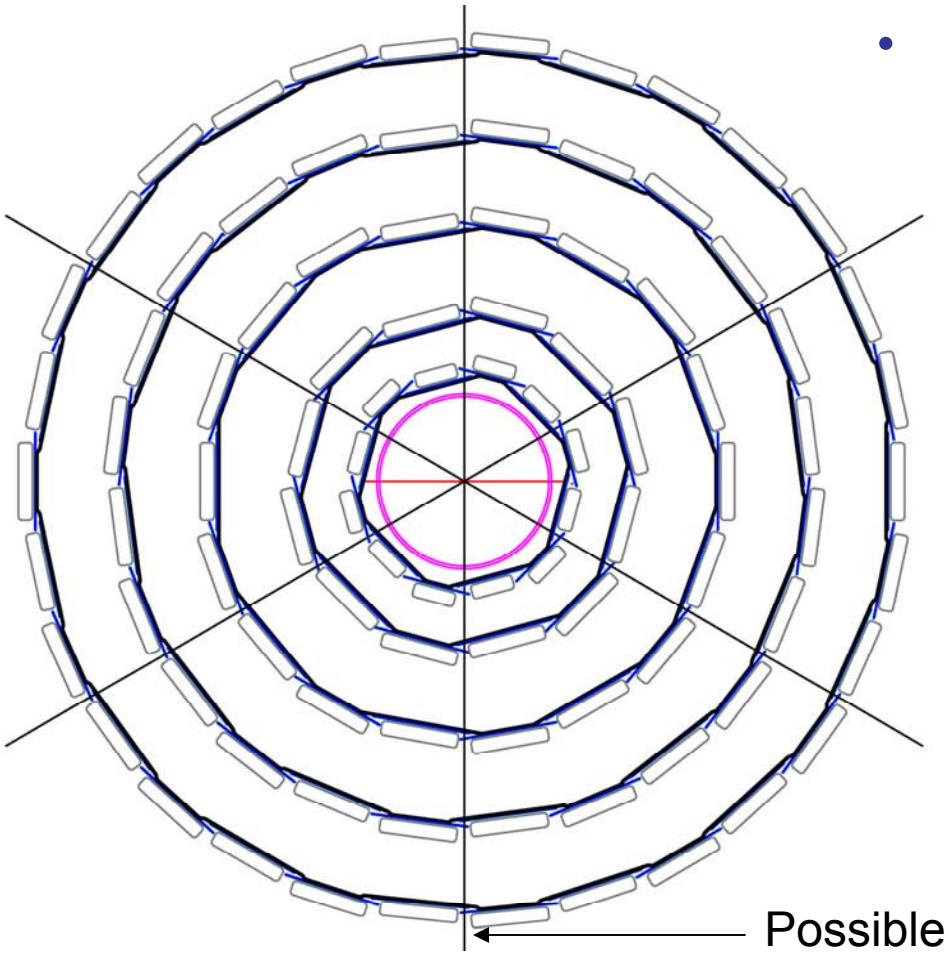
E_{CF} was taken to be 228 GPa



SiD VXD Barrel End View

- 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



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
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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

SiD Sensor Assumptions

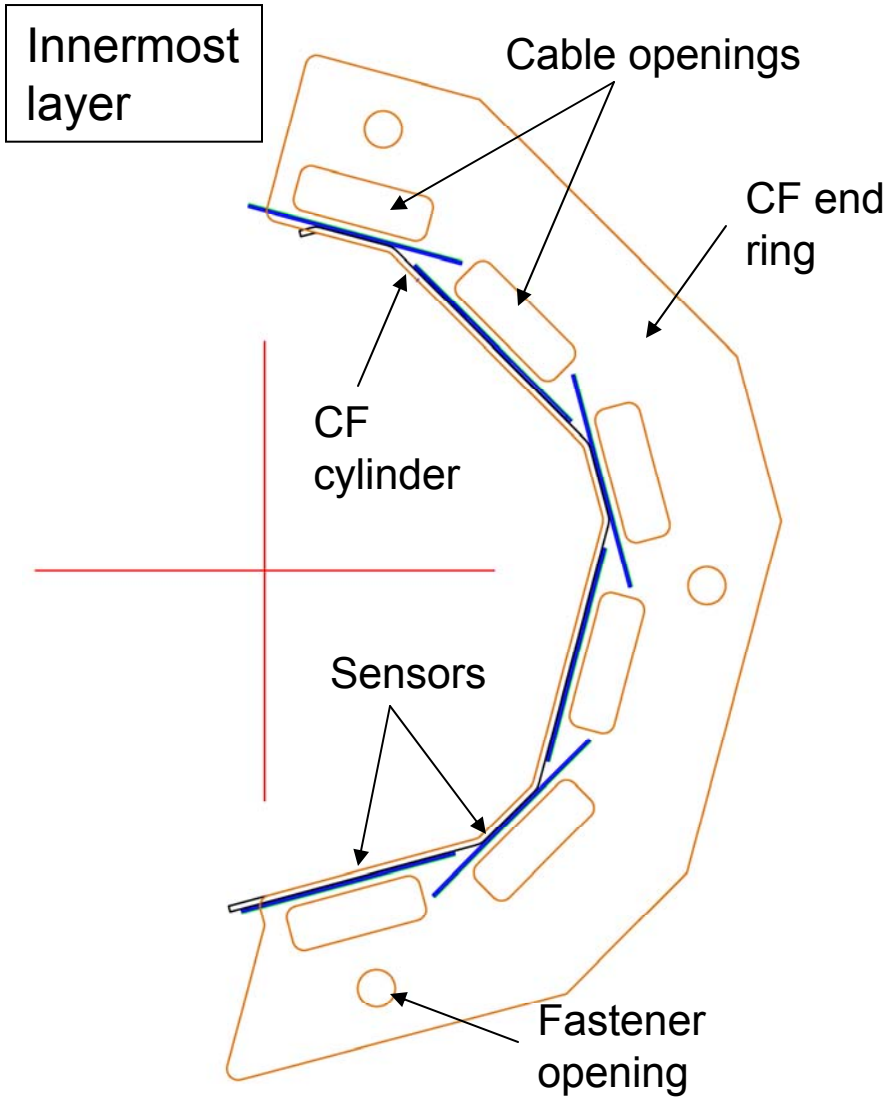
- VXD pixel size = 20 μm x 20 μm x 20 μm (or less) in the central pixel region
  - Provides good resolution and pattern recognition with five layers
  - Forward disks may have a coarser granularity
- Sensors are cooled by forced flow of dry gas.
  - Limits the number of radiation lengths
- To minimize Phi gaps between sensors, we assumed the following.
  - Sensor boundaries about active area are 0.25 mm wide.
  - Sensor thickness, including readout, is 0.15 mm.
  - The gap from the physical edge of one sensor to the surface of the next is 0.5 mm.
    - Of the 0.5 mm, we think 0.25 mm is needed. Portions of sensors could extend into the other 0.25 mm.
- To eliminate the need for barrel sensor-sensor longitudinal overlap, we assumed 125 mm long sensors (6” technology).
- We assumed that sensors are flat as fabricated and do not need to be flattened by support structures.

SiD Sensor Assumptions

- To allow low-mass support with dry air cooling, we assumed a sensor operating temperature > -10° C.
  - Reduces thermal expansion issues with carbon fiber support structures
  - Reduces thermal insulation requirements
- For an initial cooling study, we assumed that average power dissipation of central pixel sensors = 131 μW/mm^2 and that power is uniformly distributed over a sensor.
  - Given present technologies, that implies power is ramped.
  - It allows reasonable sensor temperatures with laminar air flow.
    - Laminar flow minimizes the likelihood of flow-induced vibration.
  - In the forward disks, where pixels may be a factor of 4 larger in area, we assumed 33 μW/mm^2.
- We would expect to modify sensor assumptions to match sensor developments.

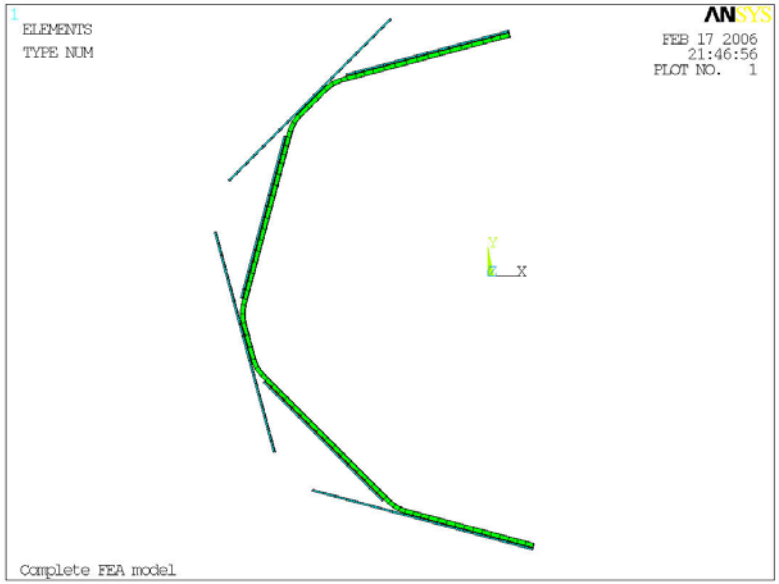
Barrel Layers

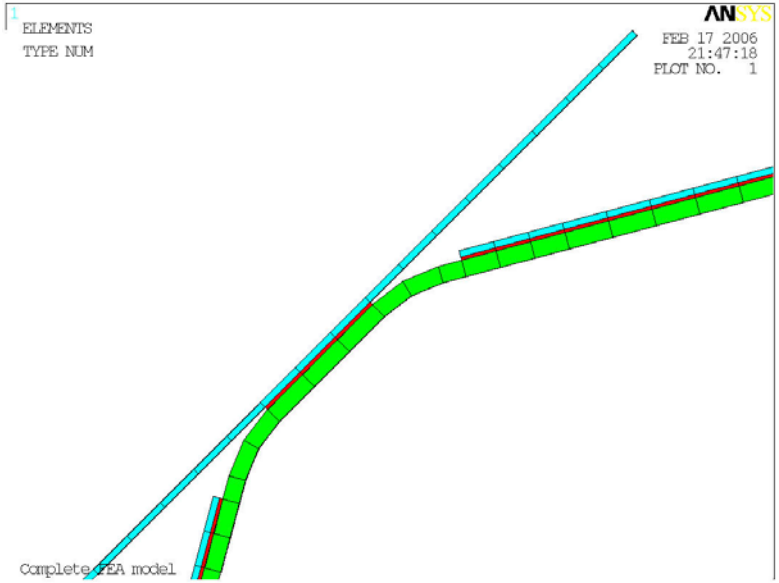
- Sensors are supported from and glued to a carbon fiber (CF) shell.
- Each barrel layer includes a CF end ring, which controls out-of-round distortions.
- Openings provide cable, optical fiber, and dry gas passages.
- Other openings to reduce mass and adjust gas flow would be added.
- End membranes connect one layer to the next to form a half-barrel.
- To control material, the use of fasteners has been limited.
  - Three fasteners per end ring



Finite Element Analysis (FEA)

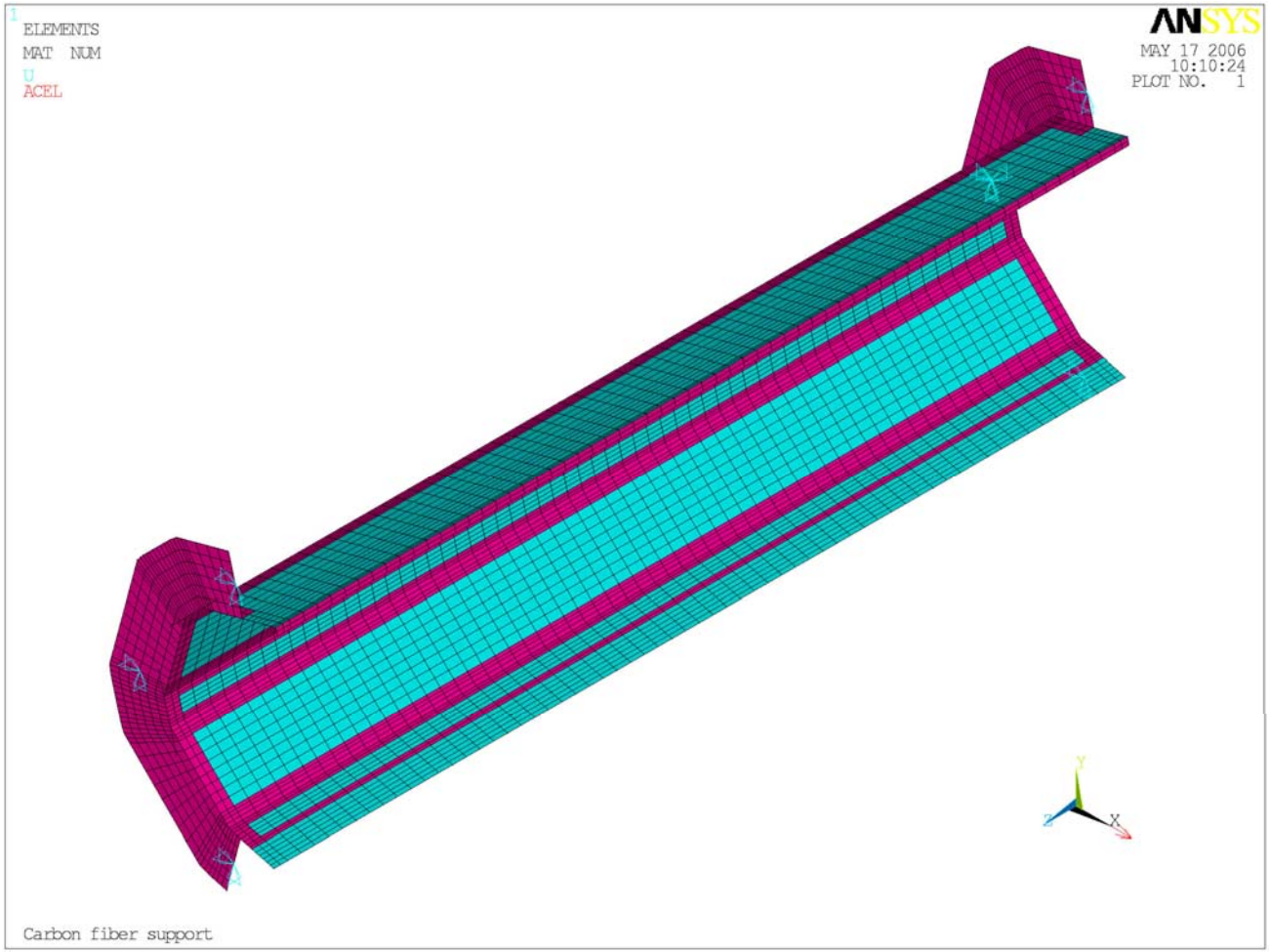
- An initial model was developed by Colin Daly (University of Washington) to represent the barrel 1 carbon fiber (CF) support structure, sensors, and epoxy which holds sensors in place.
- All sensors are on the outer surface of the carbon fiber (CF).
- A & B layers have been placed leaving 0.54 mm from the edge of an A-layer sensor to the surface of a B-layer sensor.
- All barrel 1 sensors are shown 9.6 mm wide (9.1 mm active).
- B-layer sensors overhang CF ~3.3 mm.





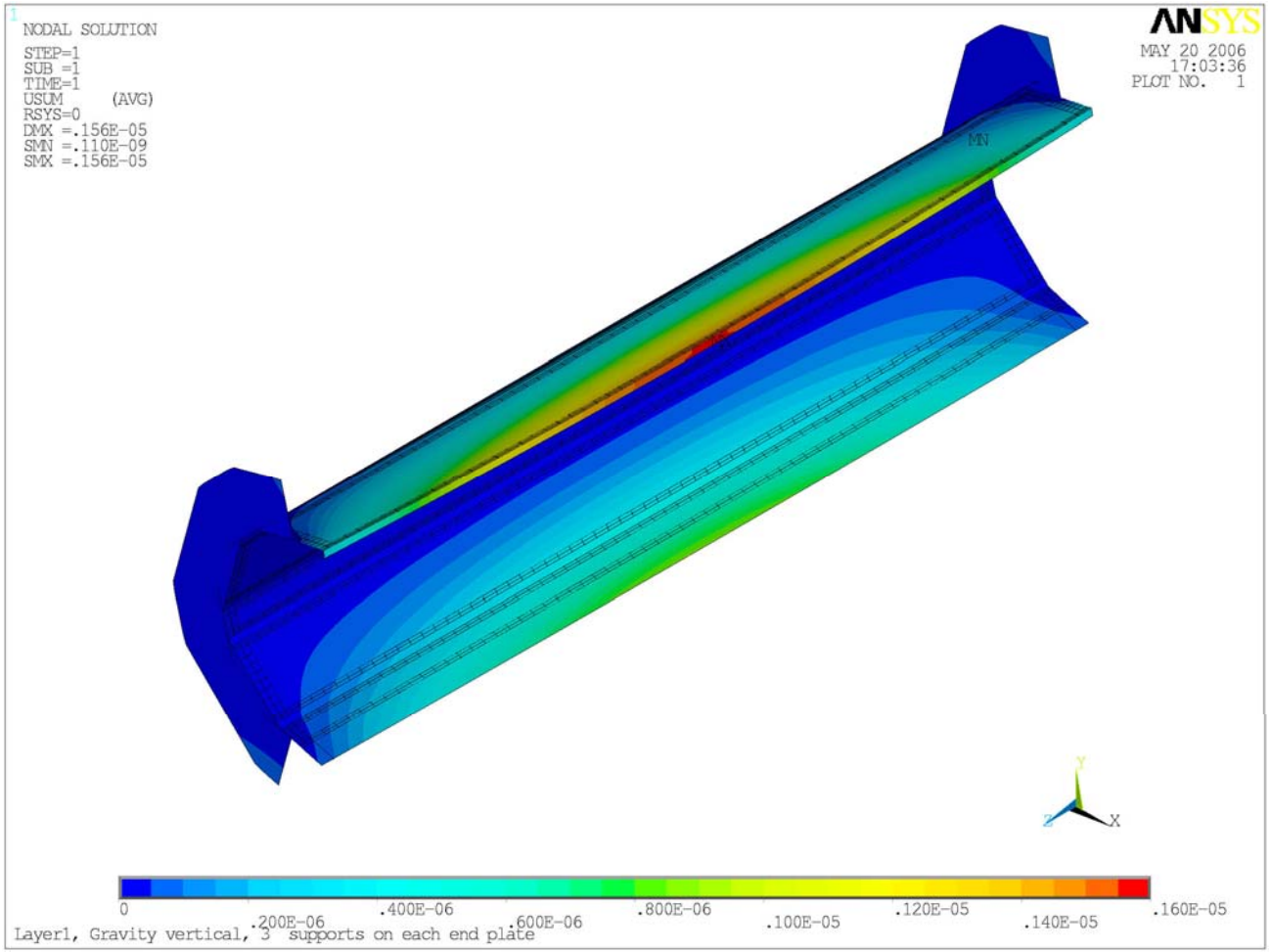
SiD Half Barrel (Innermost Barrel)

- 3 layers of K13C pre-preg (had been 4 layers)
- Composite thickness = 0.195 mm
- 0/90/0 degree lay-up
- CF strut width = 2 mm
- Sensor width for this barrel = 9.6 mm (could change)
- 0.1 mm silicon
- 0.05 mm epoxy
- End rings included



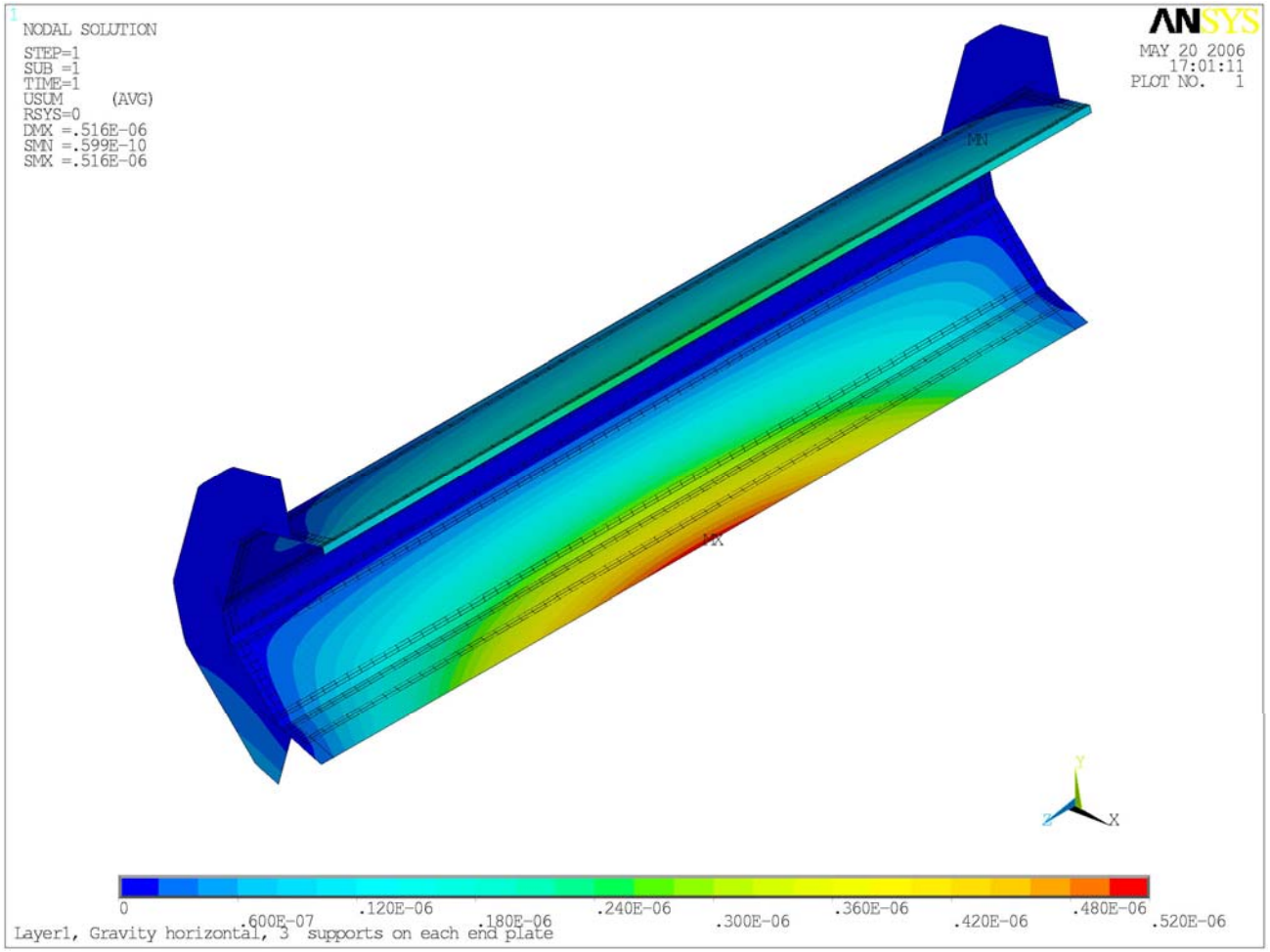
SiD Half Barrel (Innermost Barrel)

- Deflection with gravity acting vertically = 1.6 μm
- Demonstrates the benefits of a support structure with larger transverse dimensions
- Innermost barrel tests beam-like deflections
- Next to outermost barrel will test out-of-round deflections (not done yet)



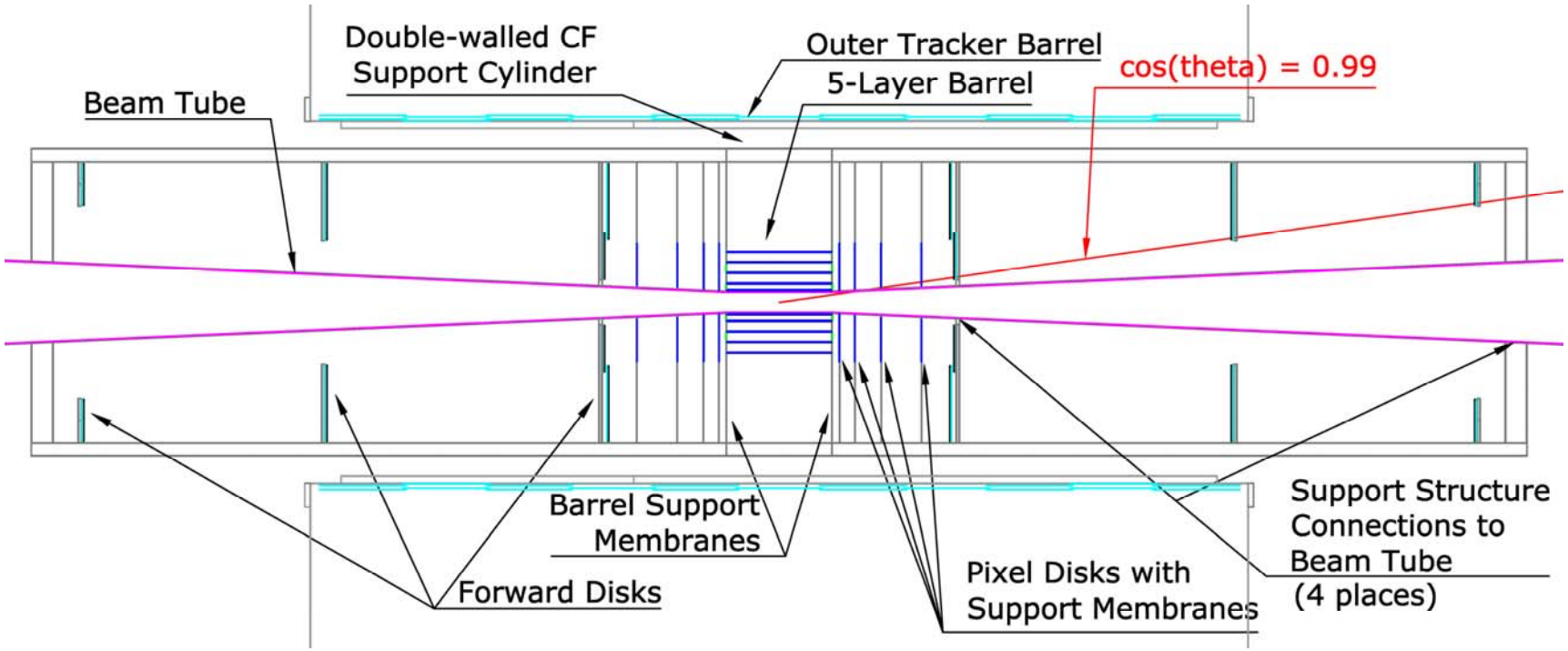
SiD Half Barrel (Innermost Barrel)

- Deflection with gravity acting horizontally = 0.5 μm
- Suggests a split at equator works better
  - A surprise to some of us
- The good results suggest that uncontrolled loading from cables and fibers at the ends may not be so much of a problem.



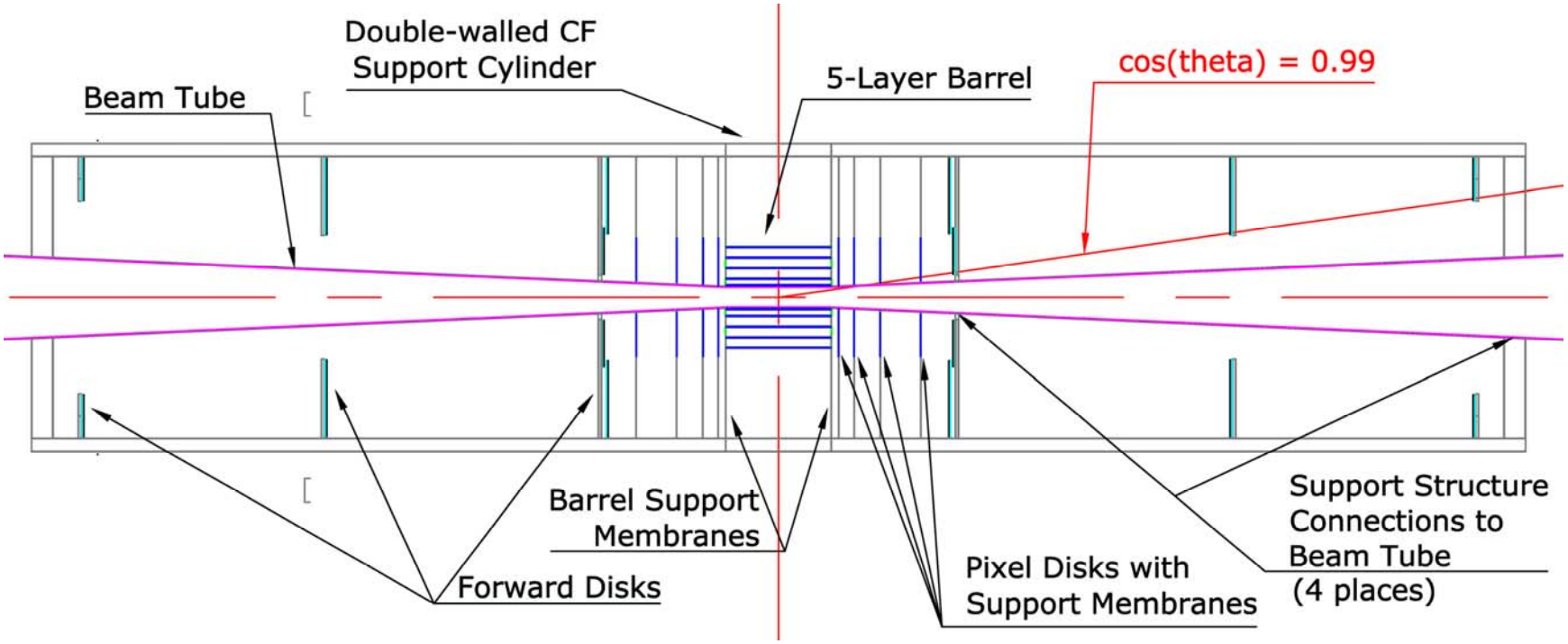
SiD VXD Elevation View

- 5-layer pixel barrel: Z = ±62.5 mm; 14 mm < R < 61 mm
- 4 pixel disks per end: Z = ± 72, ± 92, ± 123, ± 172 mm; R < 71 mm
- 3 forward disks per end: Z = ± 208, ± 542, ± 833 mm; R < 166 mm
  - Could be pixels or pairs of micro-strips
- Coverage extends to cos(theta) = ± 0.99.



SiD VXD Elevation View

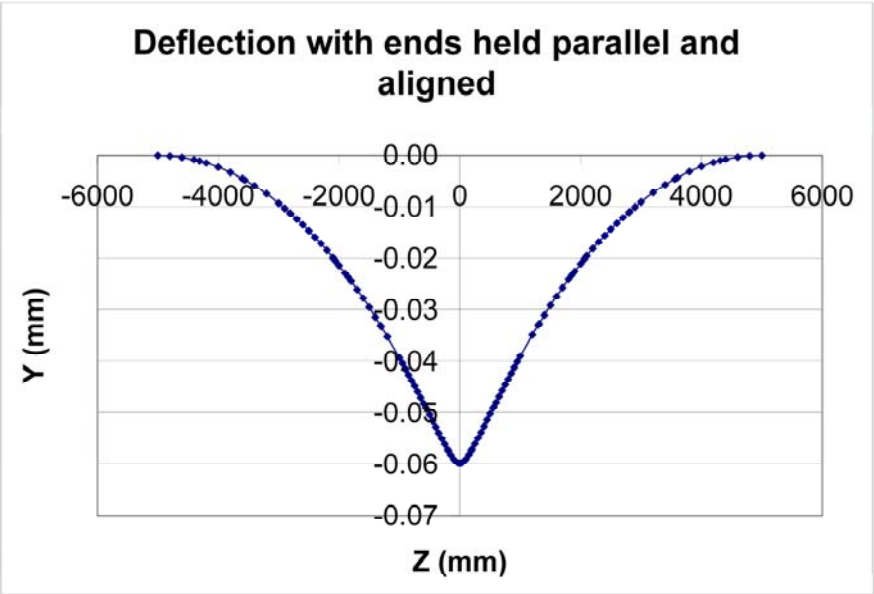
- Outer split cylinders couple to the beam tube at Z = ± 214 and ± 882 mm, are supported by the beam tube, and stiffen it.
- High modulus CF has been assumed for most support structures.
  - Typical thickness, 0.26 mm, assumes 4 layers of pre-preg.
  - In many places, average thickness can be substantially reduced by cutting holes.
- CF membranes support the barrel and disks.



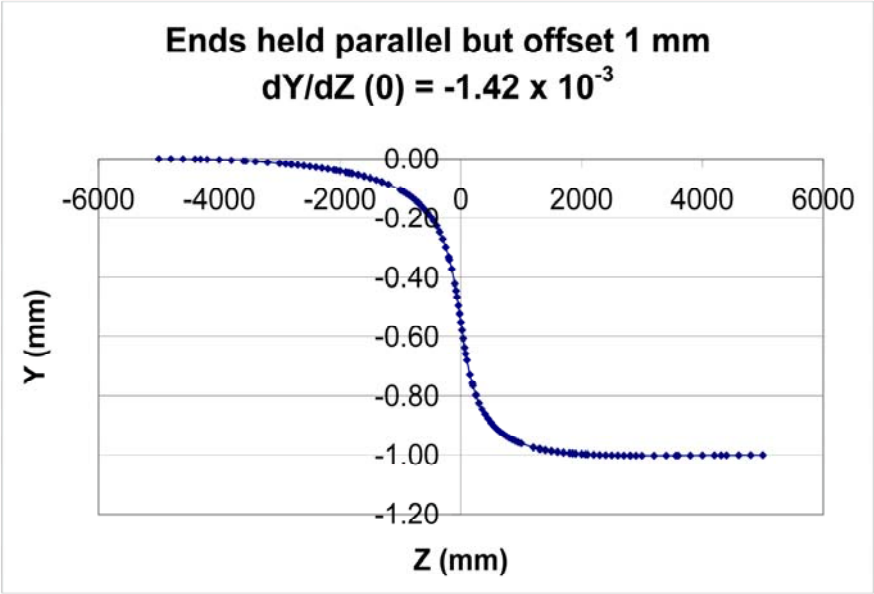
Beam Pipe Deflections

- 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.

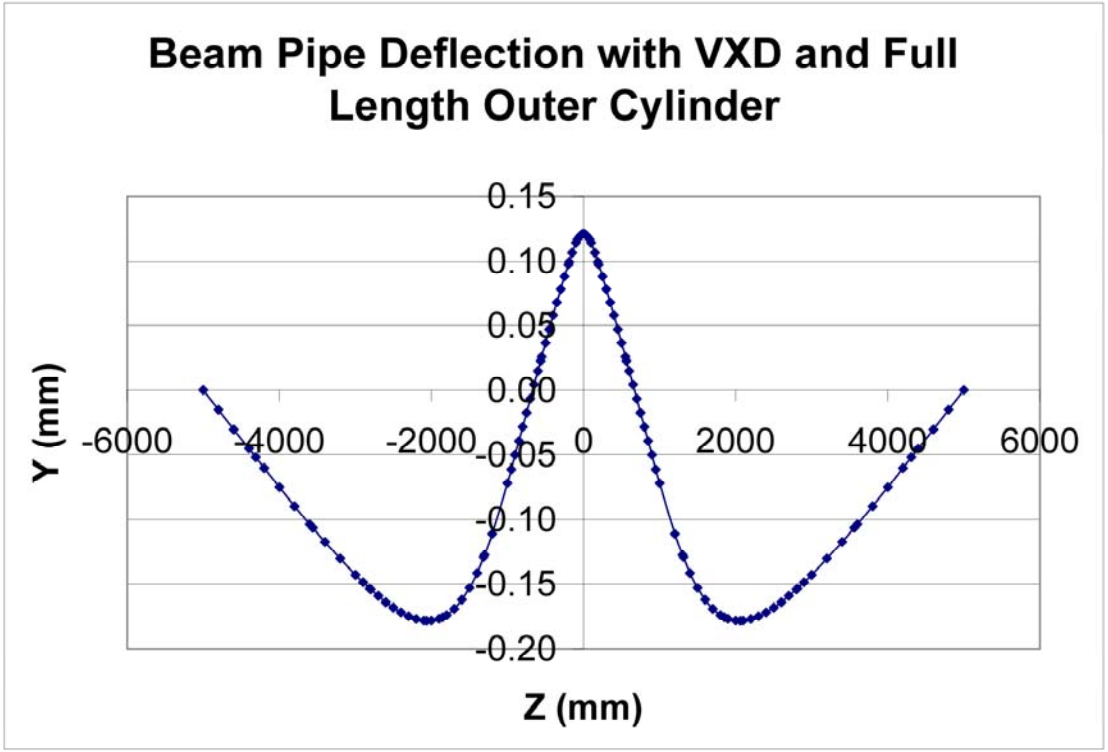


Maximum stress ~ 20 MPa

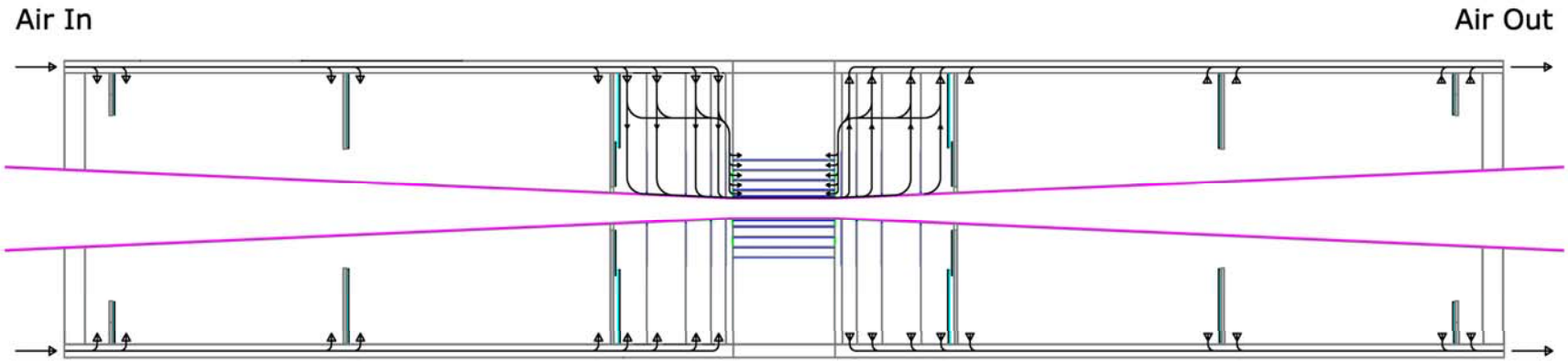


Beam Pipe Deflections

- A basic assumption has been that the beam pipe would be guided, not just simply supported, at its ends.
- If one insists that the beam pipe be simply supported, 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).
  - Deflections of outer cylinder are not taken into account.



VXD Barrel Cooling



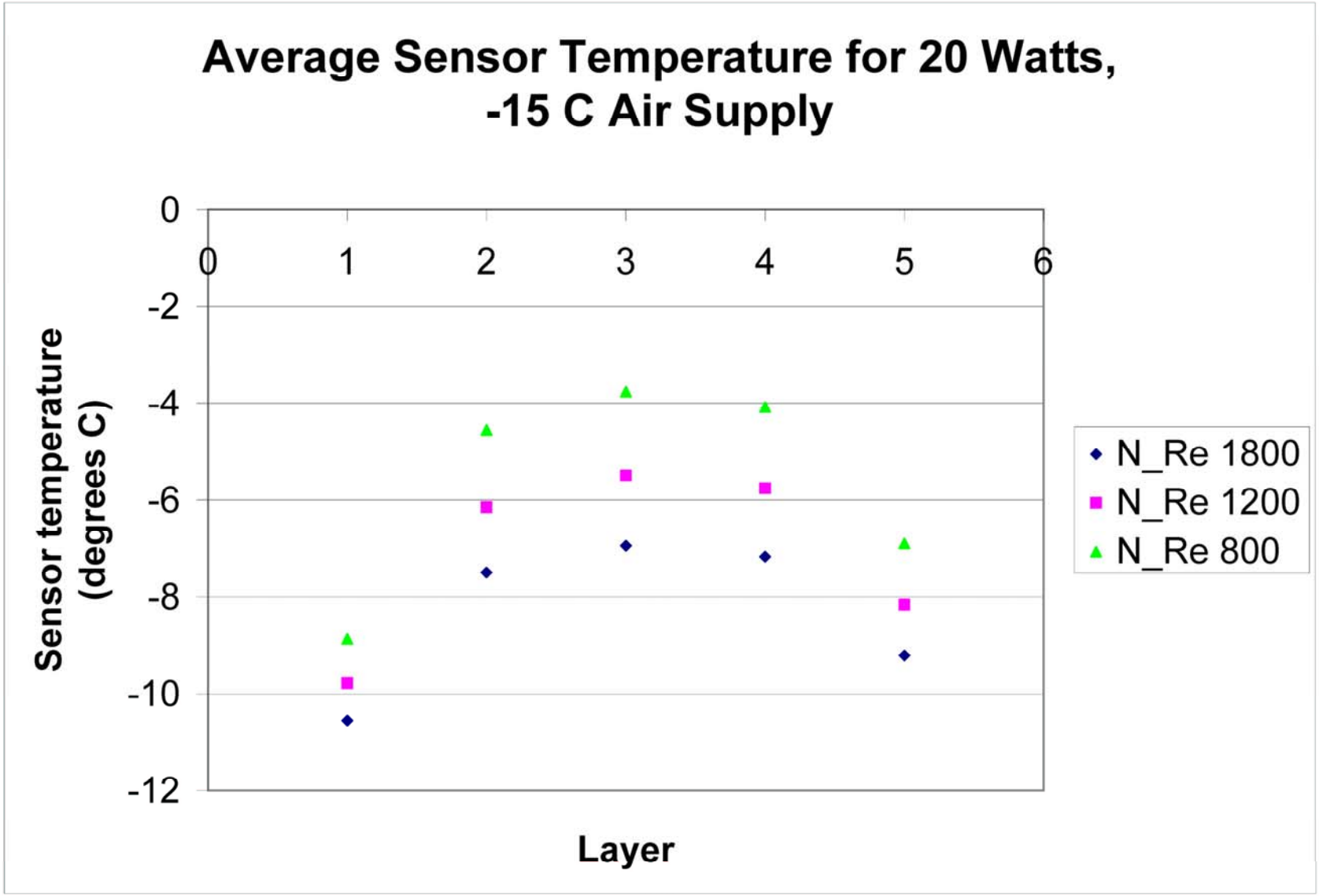
- Dry air was assumed to enter the barrel at a temperature of -15° C.
- We assumed no heat transfer from the beam pipe to the innermost layer, that is, the beam pipe would have thermal intercepts.
- A total power dissipation of 20 watts was assumed for the barrel.
  - Based upon the results, that seems reasonable.

Cooling performance as a function of Reynold's number

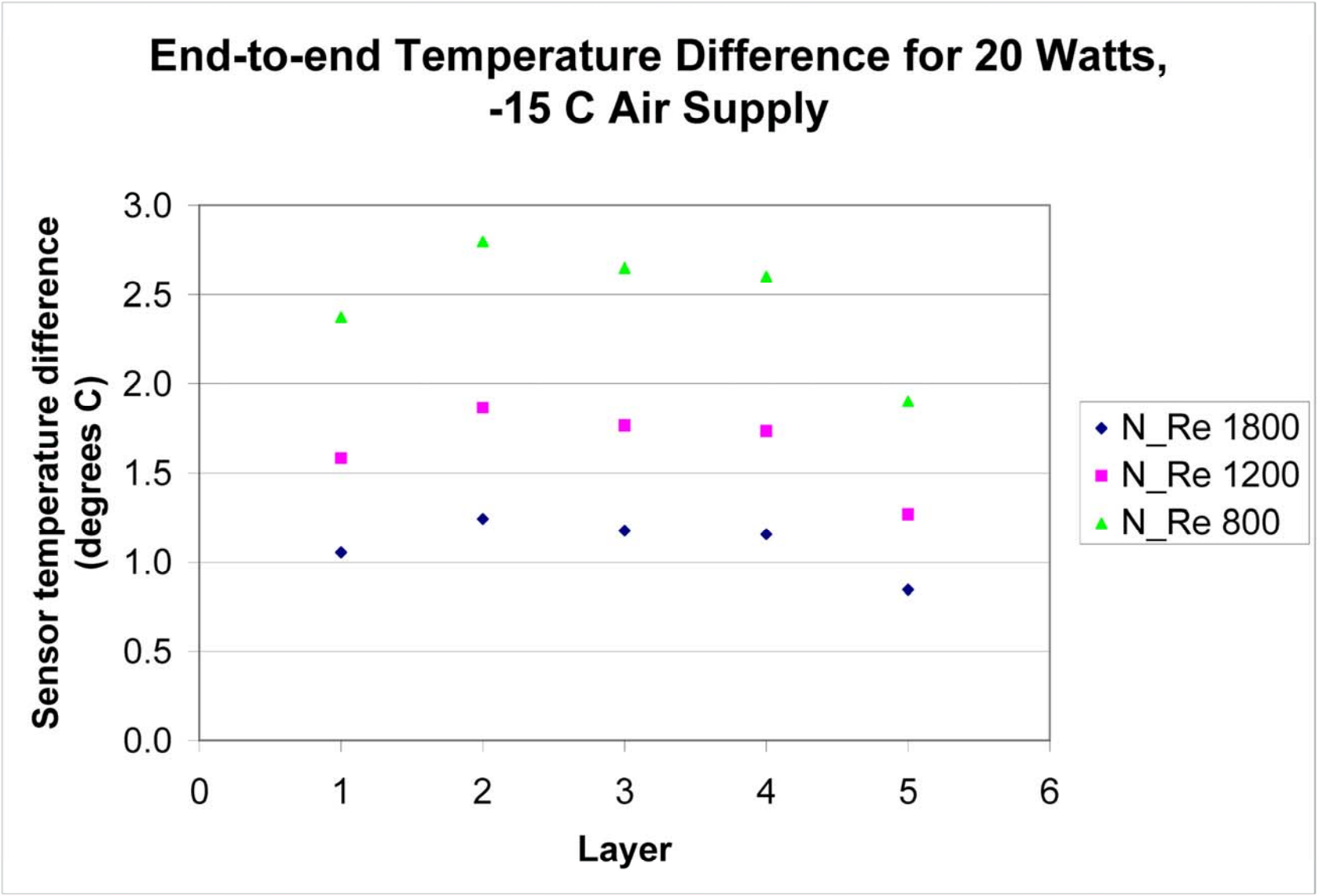
Reynold's number	Total barrel flow (g/s)	Ave. ΔT air (^{o}C)	Max sensor T (^{o}C)
800	9.0	2.21	-2.44
1200	13.5	1.47	-4.61
1800	20.2	0.98	-6.36

- Results as a function of layer are shown on the transparencies which follow.

VXD Barrel Cooling



VXD Barrel Cooling



Disk Cooling and Manifolding

- Sensors of the four disks per end closest to the barrel were assumed to have the same power dissipation per unit area as barrel sensors, 131 $\mu W/mm^2$. For eight disks (both ends) power dissipation would be 17 watts.
- Two options were considered for the three outermost disks per end.
  - Pixels twice the size in each transverse dimension as those of the barrels, so ¼ the power per unit area. Total power dissipation (both ends) = 13 watts.
  - Pairs of silicon micro-strips. Total power dissipation (both ends) = 7 watts.
  - We assumed the larger of the two values, 13 watts.
- To size manifolding to deliver and distribute air, we assumed power dissipation of the barrel and all disks would total 50 watts.
- One obvious possibility is to distribute air via the outer support cylinder. For a 15 mm wall separation, nearly the full circumference is needed to maintain laminar flow. (The Reynold's number in portions seeing full flow = 1900). We assumed air entered support cylinder passages at a temperature of -20° C.

Summary

- A design based largely upon carbon fiber support structures has been developed.
  - That design is intended to be suitable for sensor operation at > -10° C.
- Feasibility of the design depends upon sensor developments.
  - We expect to follow developments and to take them into account.
- An initial FEA model has been developed for barrel sensor structures.
  - Gravitational deflections for 125 mm barrel sensors are small.
  - Deflection of a ladder with simple support at its ends is noticeably larger.
- We have begun to re-examine beam pipe deflections and the outer vertex detector support cylinder.
  - Changes could result.
- An initial study suggests that approximately 20 watts can be removed from the barrel, and 50 watts from the entire vertex detector, by air cooling with laminar flow.
- The number of radiation lengths represented by VXD structures has been reduced considerably (earlier talk at this workshop).