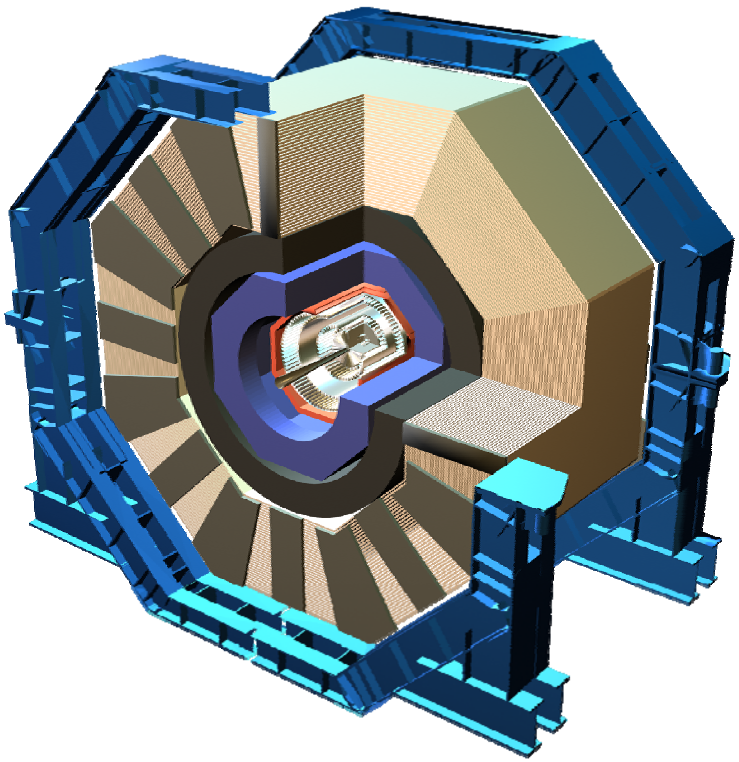
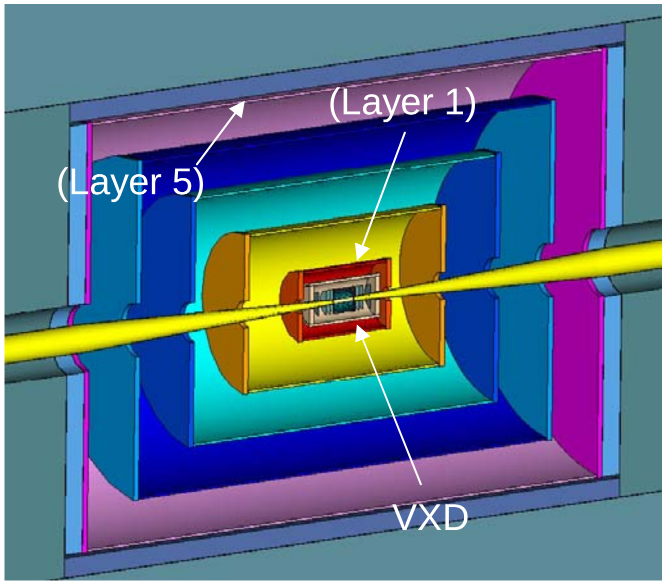
SiD Vertex Detector Mechanical Design



Bill Cooper
Fermilab



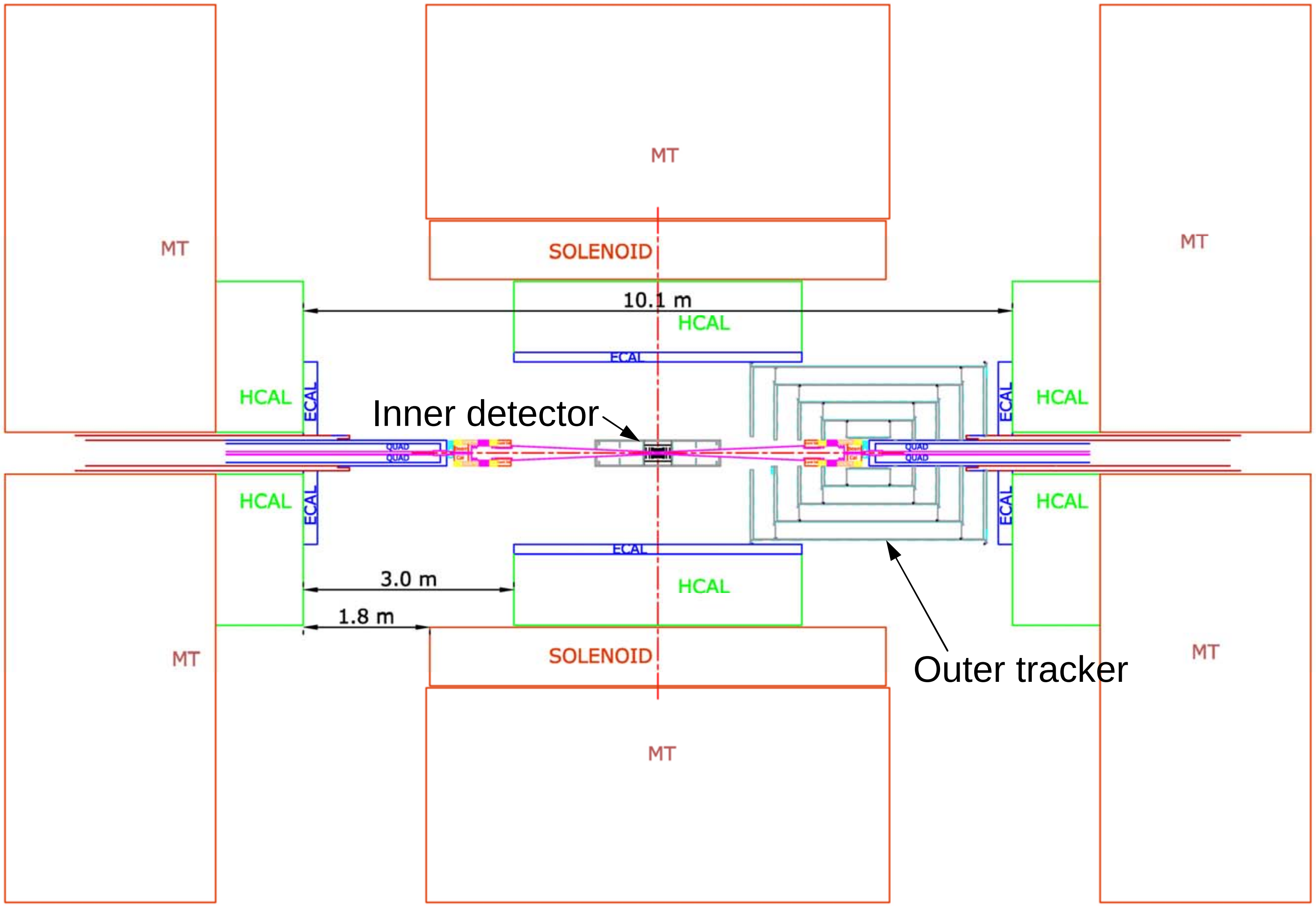
Introduction

- SiD is a closely integrated detector.
  - Designs of the outer tracker and the vertex detector have been developed which include provisions for accessing and servicing the vertex detector.
  - I'll describe those provisions and say a few words about the outer tracker.
- The vertex detector mechanical design is strongly dependent upon sensor technologies.
  - We do not know which sensor technology will be most appropriate when a choice must be made.
  - To make progress, we have developed a design based upon specific assumptions regarding the sensors. Those assumptions will be described.
- Features of the design which was developed will be described.
  - Mechanical support structures
  - Sensor cooling
  - Number of radiation lengths
- Work remains, but we think the design is realistic.

Servicing

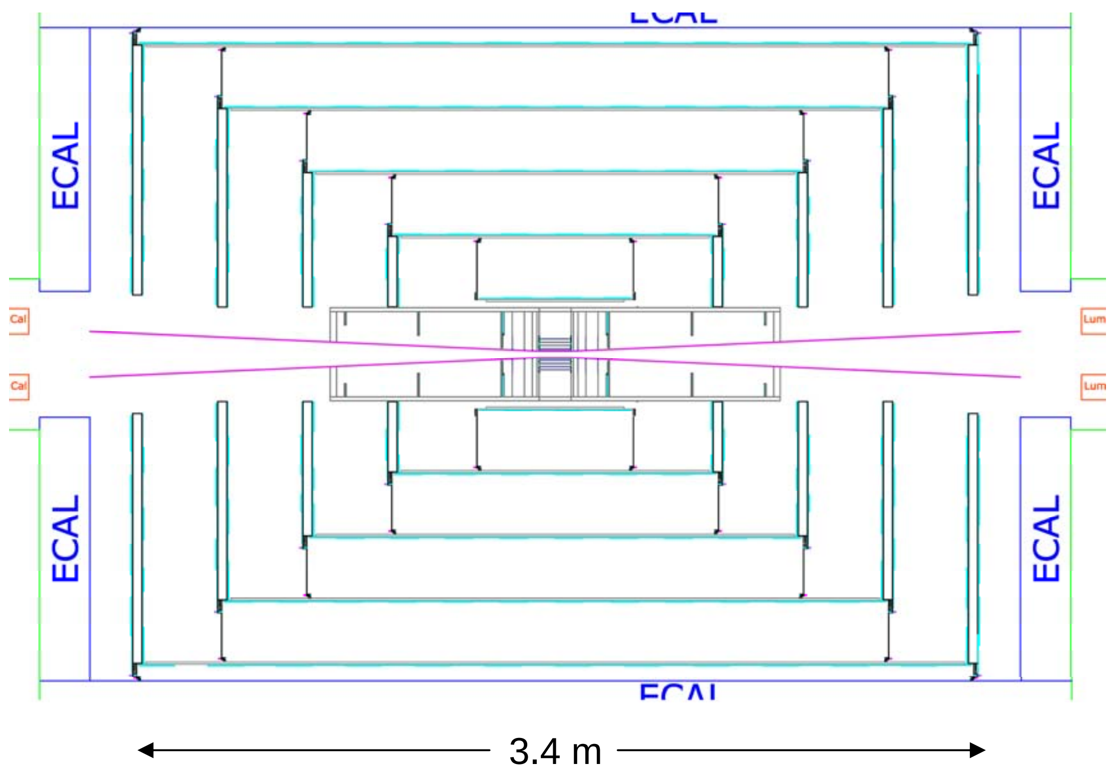
- During servicing, the end-caps are opened.
  - That allows cables and services to be disconnected.
- The silicon outer tracker is moved longitudinally.
  - Portions of the outer silicon tracker can be serviced in that configuration.
- The vertex detector and beam line elements remain fixed.
  - That minimizes disturbances to beam line elements, but does require that appropriate support has been included in their design.
  - The vertex detector is supported from the beam pipe.
  - In that configuration, vertex detector elements can be serviced, or even replaced.
- This approach to servicing sets constraints on the boundary between the outer silicon tracker and vertex detector elements.
  - During servicing, some beam line elements are located within the boundaries of the outer silicon tracker.
  - Adequate clearances must be maintained.
    - Outer tracker to beam line elements
    - Vertex detector elements to outer tracker

Detector Open / Full Access to Inner Detector



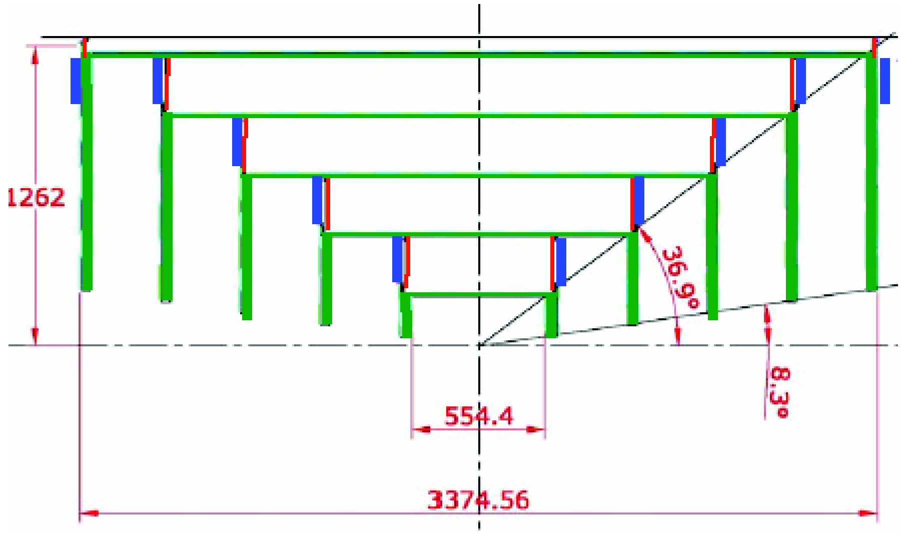
Silicon Tracking Layout

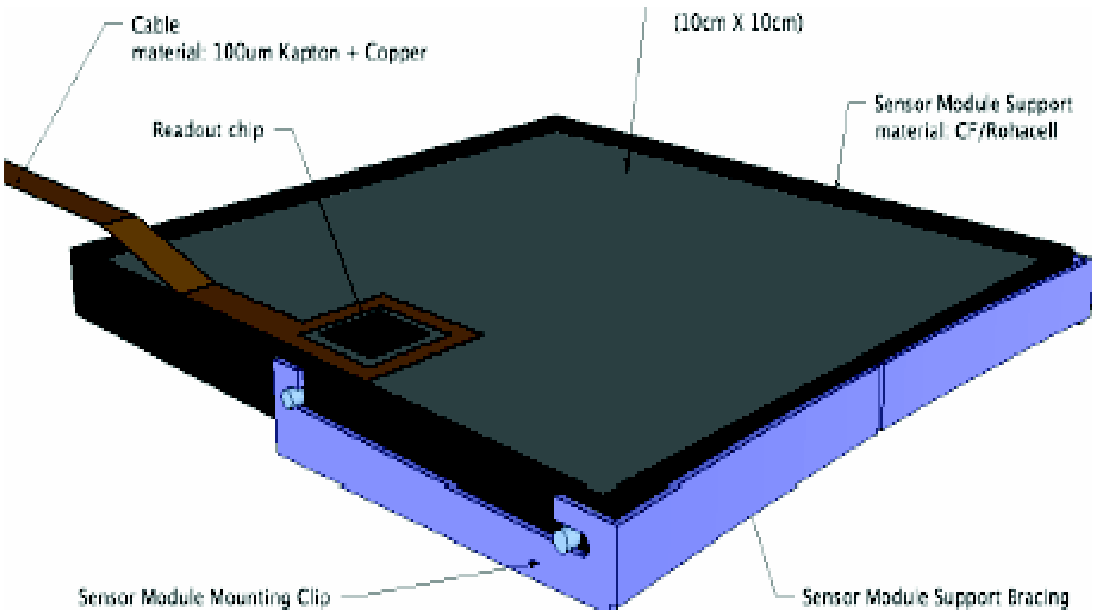
- Outer tracker (micro-strips)
  - 5 barrel layers
  - 5 disks per end
  - OR = 1.25 m
  - IR = 0.2 m
    - May need to adjust inner radius to match beam-line elements
  - Supported from ECAL
- Inner detector (pixels)
  - VXD
    - 5 barrel layers (may increase to 6)
    - 4 disks per end
  - Additional "forward" disks
  - Supported from conical portions of beam pipe



Outer Tracker as Modeled in SiD_{00}

- Closed CF/Rohacell cylinders
- Nested support via annular rings
- Power/readout motherboard mounted on support rings
- Bus cables connect single-sensor modules to motherboards

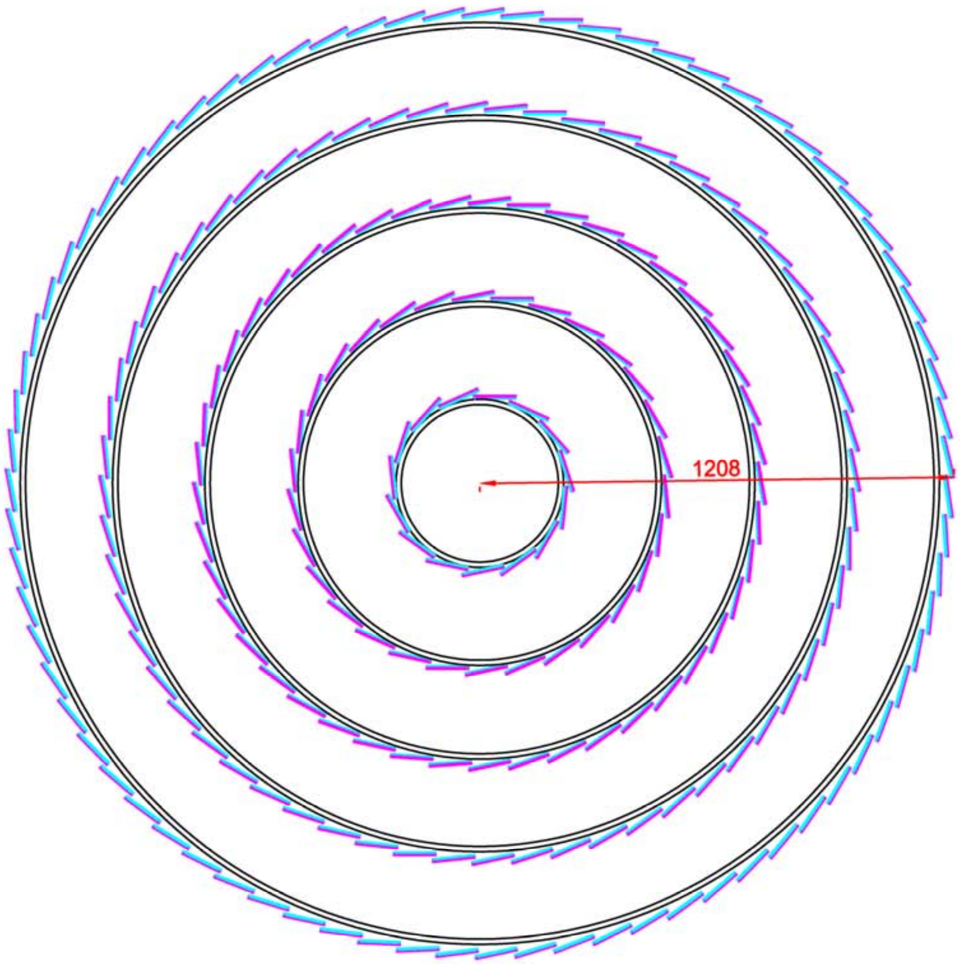




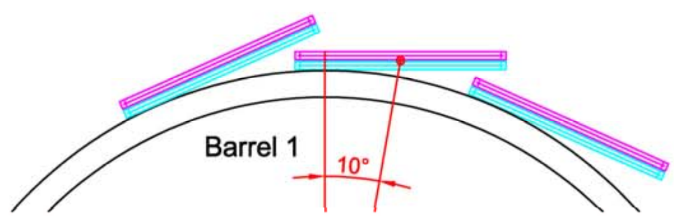
- Cylinders tiled with 10x10cm sensors with readout chip
- Single sided (ϕ) in barrel
- R, ϕ in disks
- Modules mainly silicon with minimal support (0.8% X_0)
- Overlap in ϕ and Z

T. K. Nelson, SLAC

Outer Tracker with a Single Type of Module



Sensors:
Cut dim's: 104.44 W x 84 L
Active dim's: 102.4 W x 81.96 L
Boxes:
Outer dim's: 107.44 W x 87 L x 4 H
Support cylinders:
OR: 213.5, 462.5, 700, 935, 1170
Number of phi: 15, 30, 45, 60, 75
Central tilt angle: 10 degrees
Sensor phi overlap (mm):
Barrel 1: 5.3
Barrel 2: 0.57
Barrel 3: 0.40
Barrel 4: 0.55
Barrel 5: 0.63
Cyan and magenta sensors and boxes are assumed to be at different Z's and to overlap in Z.
Within a given barrel, cyan sensors overlap in phi as do magneta sensors.



0.025 mm strip pitch, 0.050 mm readout pitch

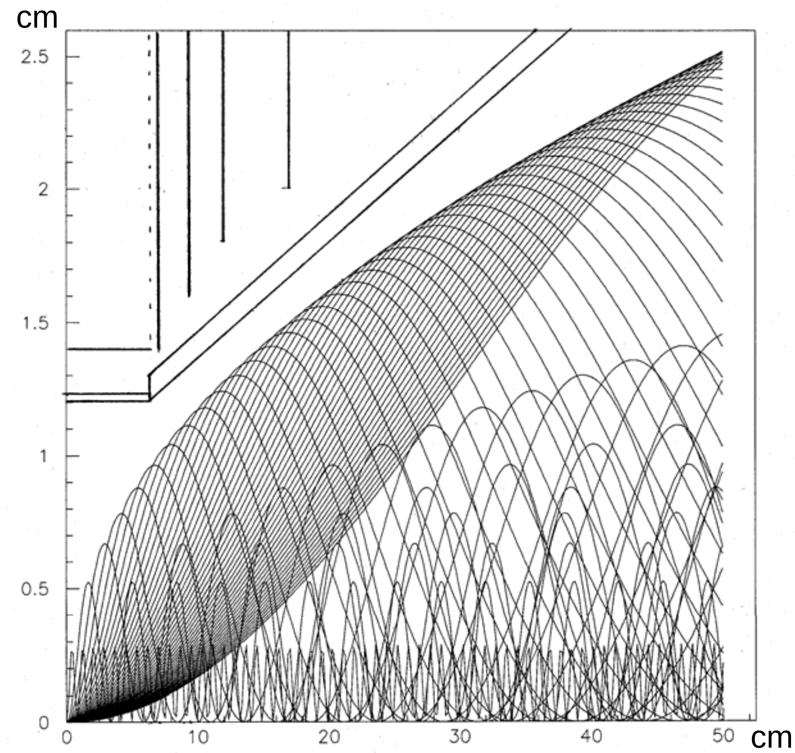
Beam Pipe

- An all-beryllium beam pipe was assumed for design purposes.
  - Portions of cones could be SS.
- Avoidance of pair backgrounds leads to a conical beam pipe shape beyond the central region.
- sidaug05 assumes a beam pipe inner radius of 1.2 cm within the region Z = ±6.251 cm. Beryllium wall thickness = 0.04 cm.
  - Sonja Hillert and Chris Damerell have stressed the importance silicon at a small radius.

  http://nicadd.niu.edu/cdsagenda//askArchive.php?base=agenda&categ=a0562&id=a0562s4t2/moreinfo#262
- Beam pipe liners are under study.
  - sidaug05 assumes a 0.0025 cm titanium shield in the central region and 0.0075 cm titanium shields in the conical regions to absorb low energy (<50 keV) photons and fluorescent x-rays. Tungsten masks were assumed in the conical regions, but consequences of tungsten weight will need to be examined.

Takashi Maruyama

500 GeV Nominal 5 Tesla + 20 mrad xing



Sensor Assumptions

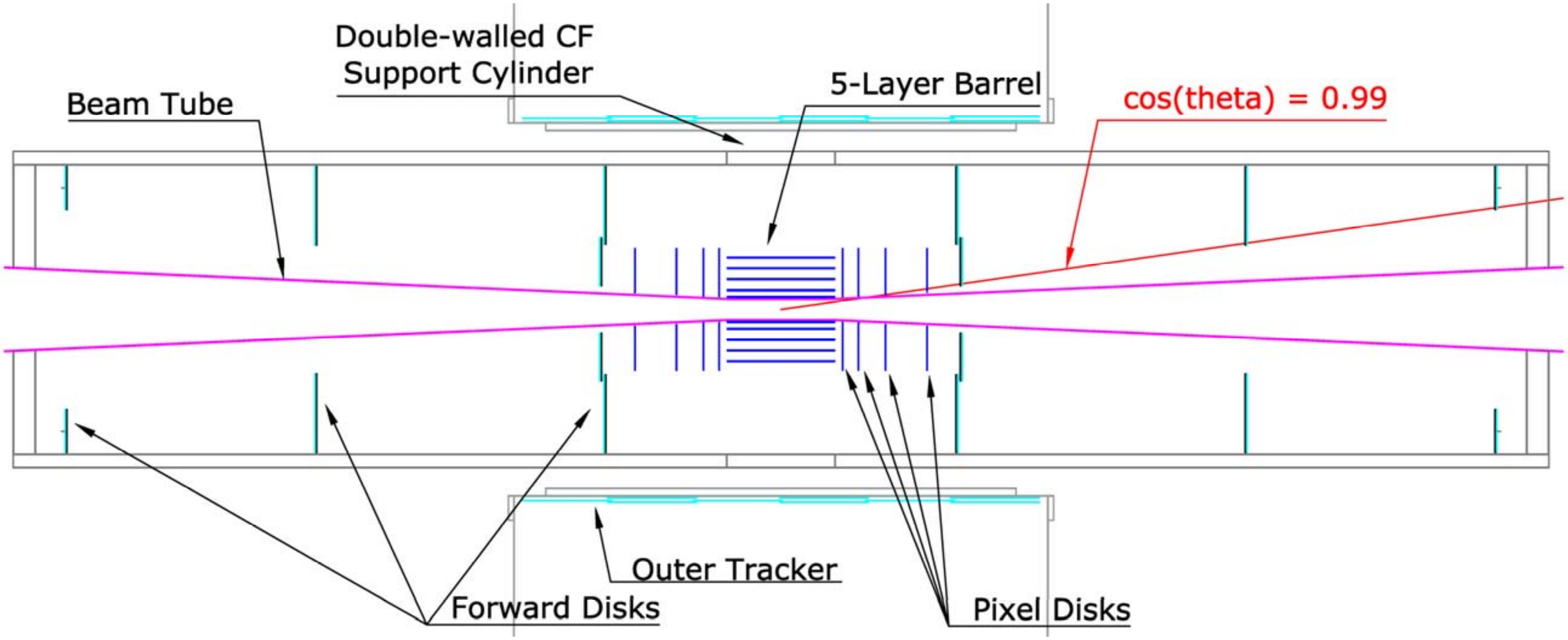
- VXD pixel size = 20 µm x 20 µm x 20 µm (or less) in the central pixel region
  - Provides good resolution and pattern recognition with five layers
  - Forward disks may have a coarser granularity
- Sensors are cooled by forced flow of dry gas.
  - Limits the number of radiation lengths
- To minimize 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.

Sensor Assumptions

- To allow low-mass support with dry air cooling, we assumed a sensor operating temperature > -10^{o} 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 $\mu W/mm^2$ 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 $\mu W/mm^2$.
- We would expect to modify sensor assumptions to match sensor developments.

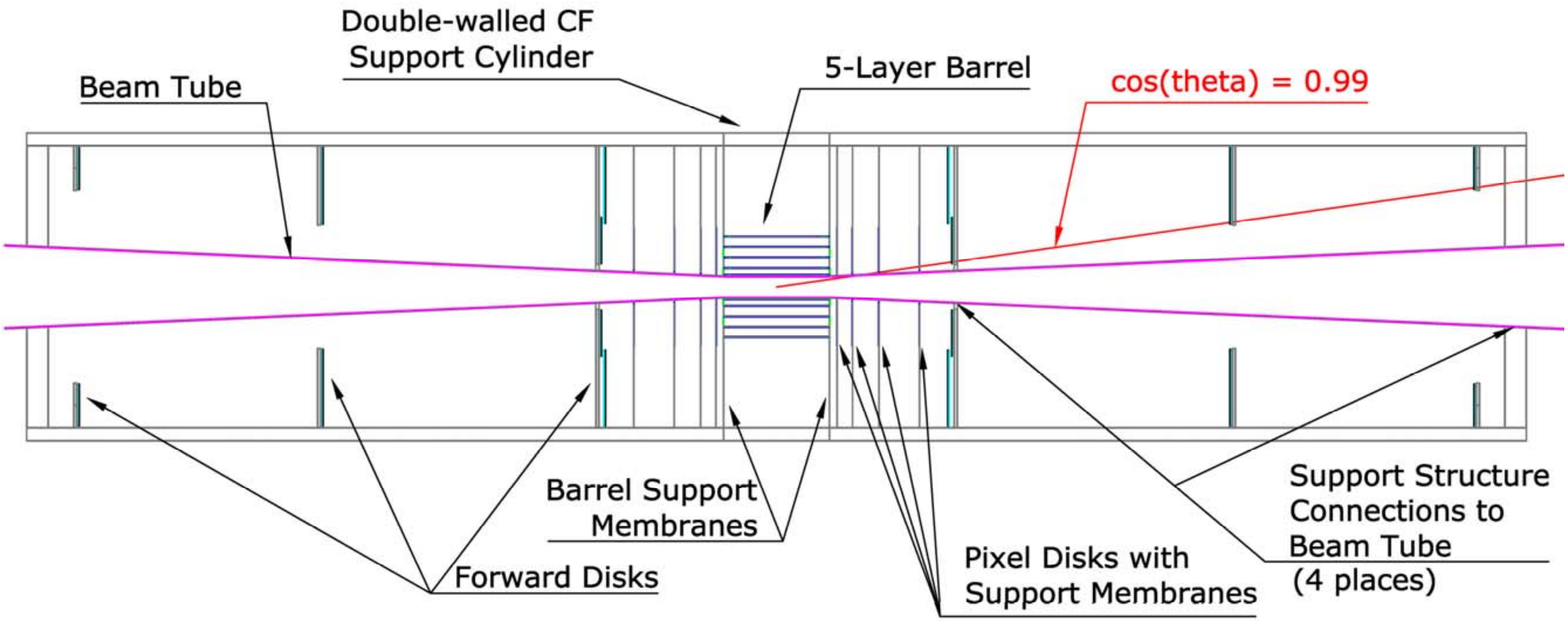
VXD Elevation View

- 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.



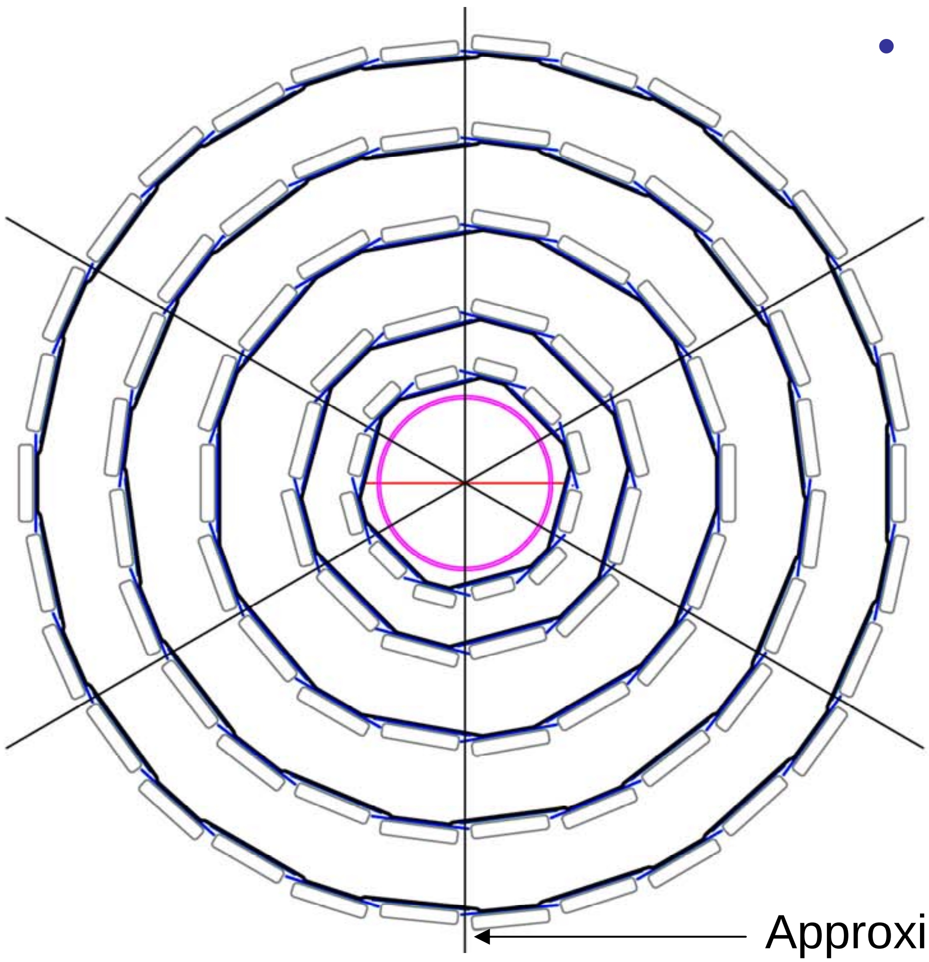
VXD Elevation View

- 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.



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
March 3, 2006

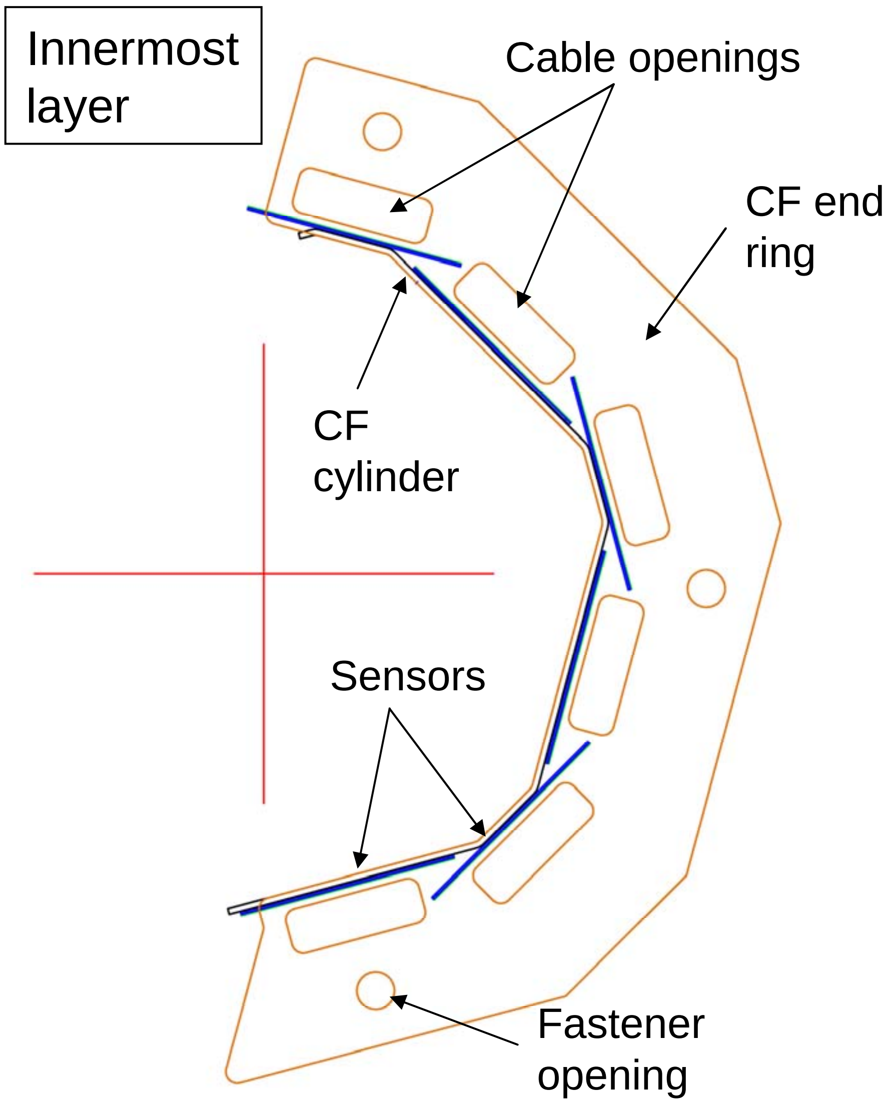
Oblong boxes are openings in end rings and end membranes for cables, optical fibers, and air flow.

Splitting into two halves allows assembly about the beam pipe.

Approximate clam-shell split line

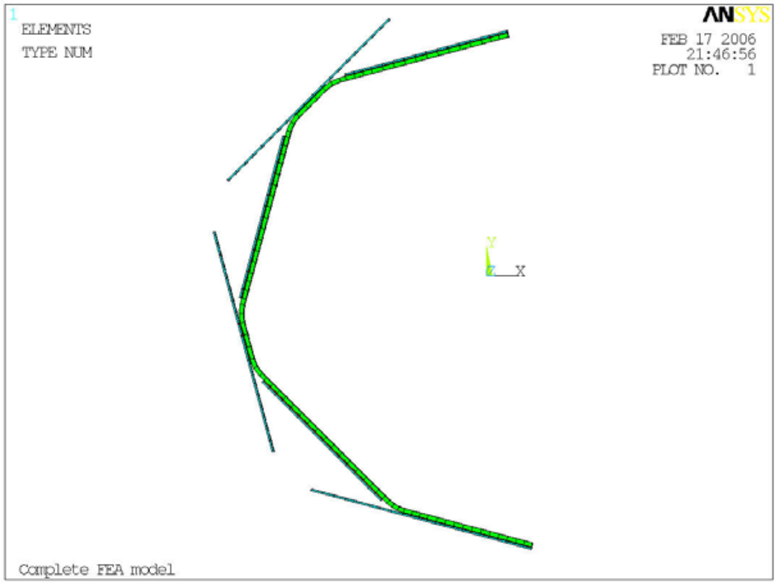
Barrel Layers

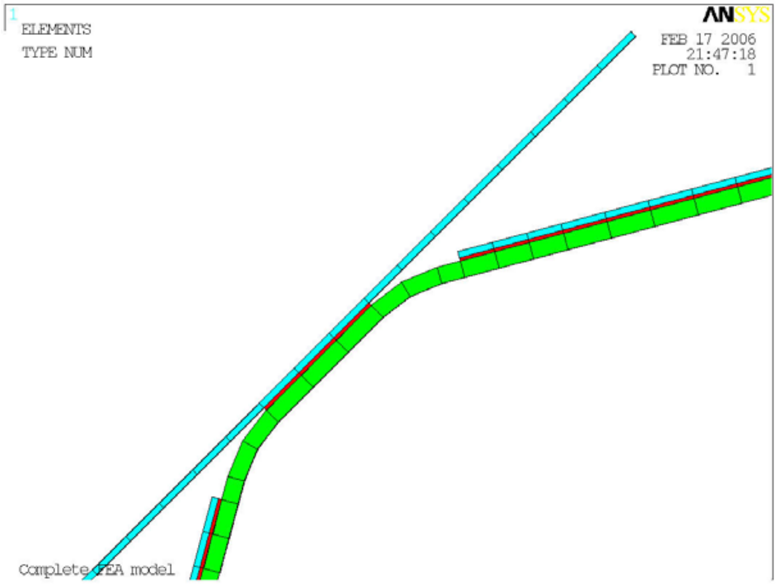
- Sensors are supported from and glued to a carbon fiber (CF) shell.
- Each barrel layer includes a CF end ring, which controls out-of-round distortions.
- Openings provide cable, optical fiber, and dry gas passages.
- Other openings to reduce mass and adjust gas flow would be added.
- End membranes 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)

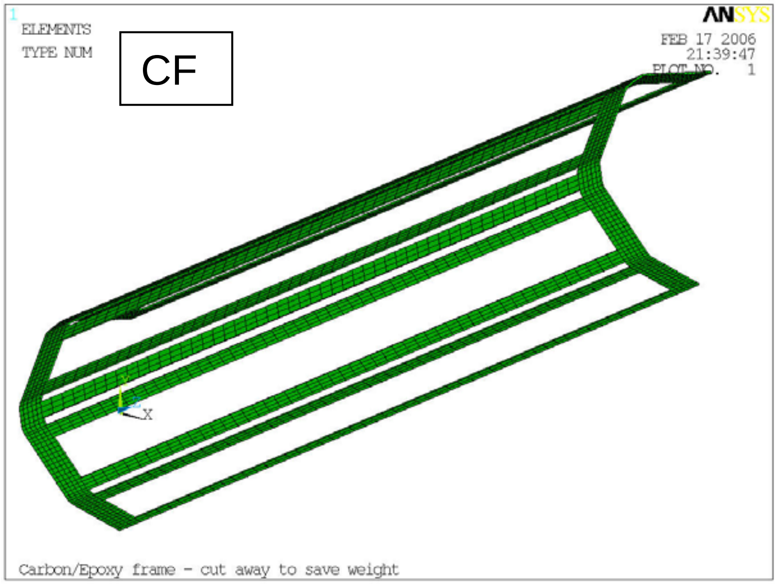
- An initial model was developed by Colin Daly (University of Washington) to represent the barrel 1 carbon fiber (CF) support structure, sensors, and epoxy which holds sensors in place.
- All sensors are on the outer surface of the carbon fiber (CF).
- A & B layers have been placed leaving 0.54 mm from 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.

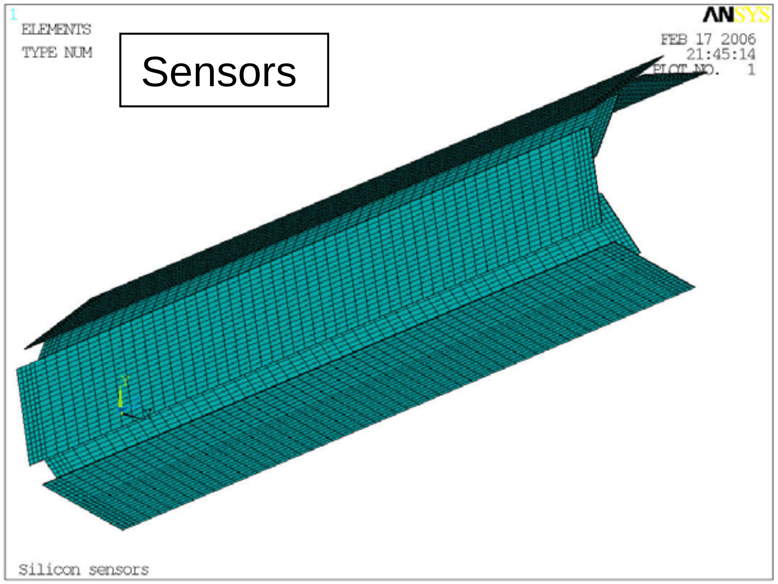




FEA of Innermost Barrel

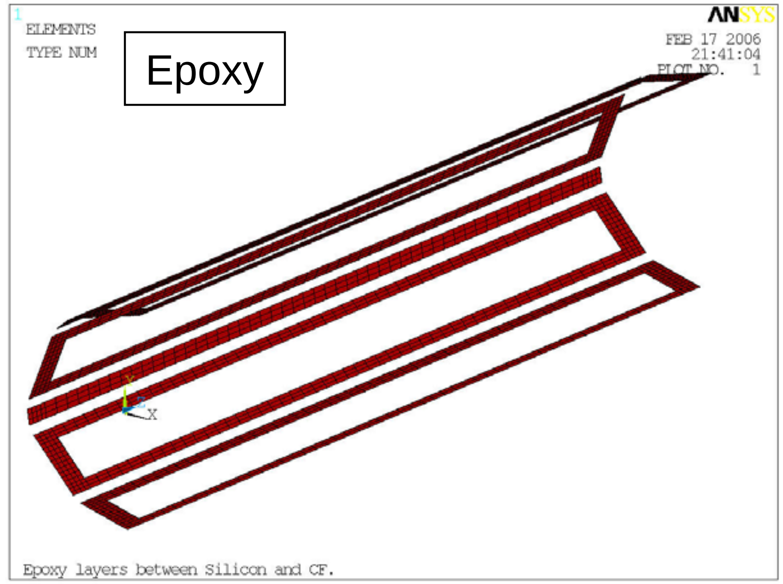
- Thicknesses:
  - CF:
    - 4 layers K13C
    - Each 0.065 mm thick
    - 0^o, 90^o, 90^o, 0^o lay-up
  - Sensors: 0.100 mm
  - Epoxy: 0.050 mm
- Overall length was taken to be 165 mm
  - The present design assumes 125 mm long sensors and 126 mm long CF
- End membranes are not included (yet).

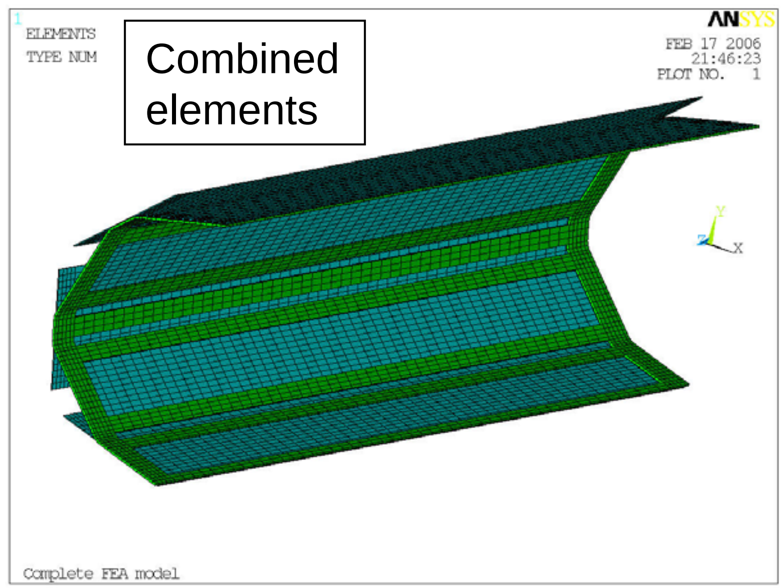




FEA of Innermost Barrel

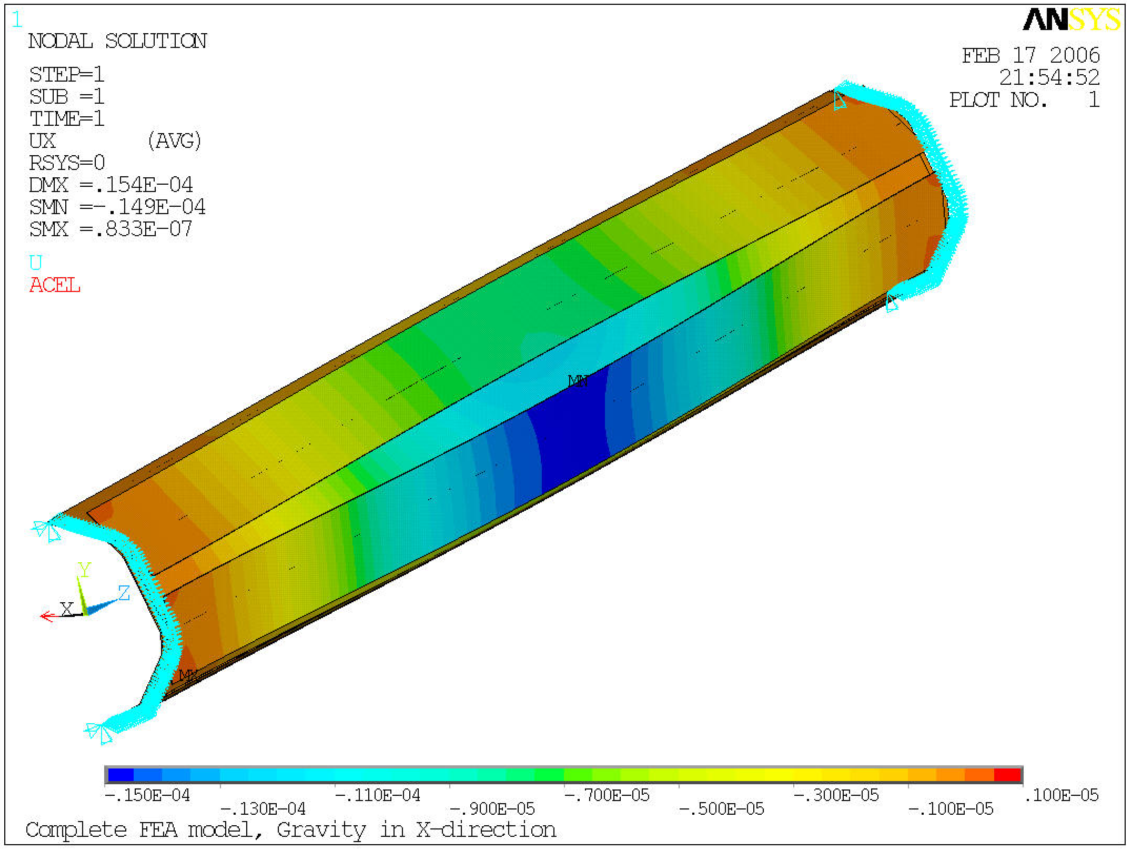
- Our goal is to reduce non-sensor material to ¼ that of continuous structures (structures with no openings).
- We are close to that.
- Each barrel will almost certainly require slightly different structures.
- For full cylinders:
  - Out-of-round deflection increases as radius increases.
  - Beam-like deflection decreases as radius increases.



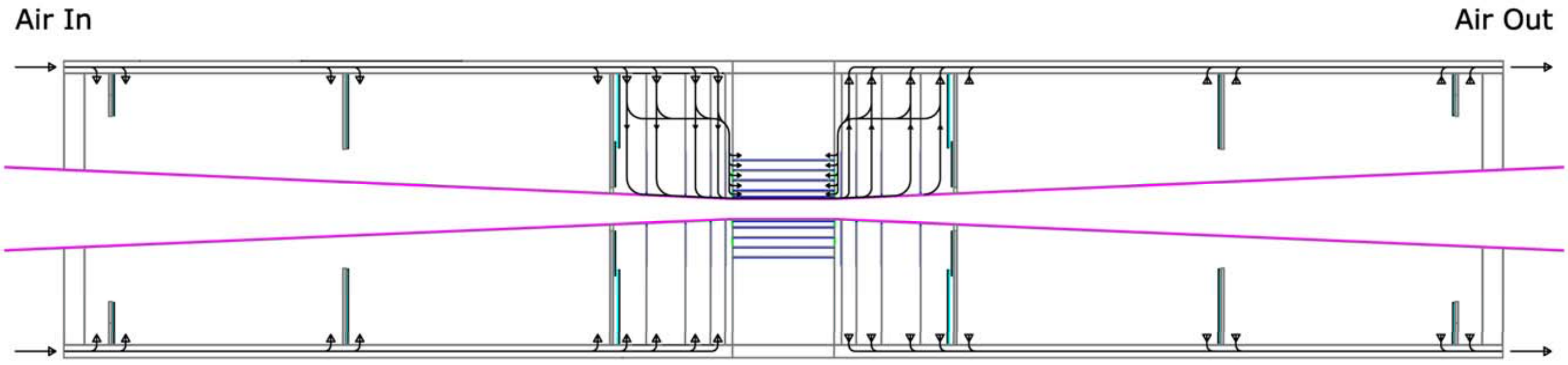


Gravitational Deflections

- Maximum deflection = 15 µm
- The bulk of deflection occurs from bending of CF spars and the silicon itself.
- We expected a pair of CF circumferential ribs placed symmetrically about Z = 0 would be needed.
- Adding end rings should control the ends very well.
- Without the other changes, shortening from 165 mm to 126 mm should reduce deflections by a factor of ~3.



VXD Barrel Cooling



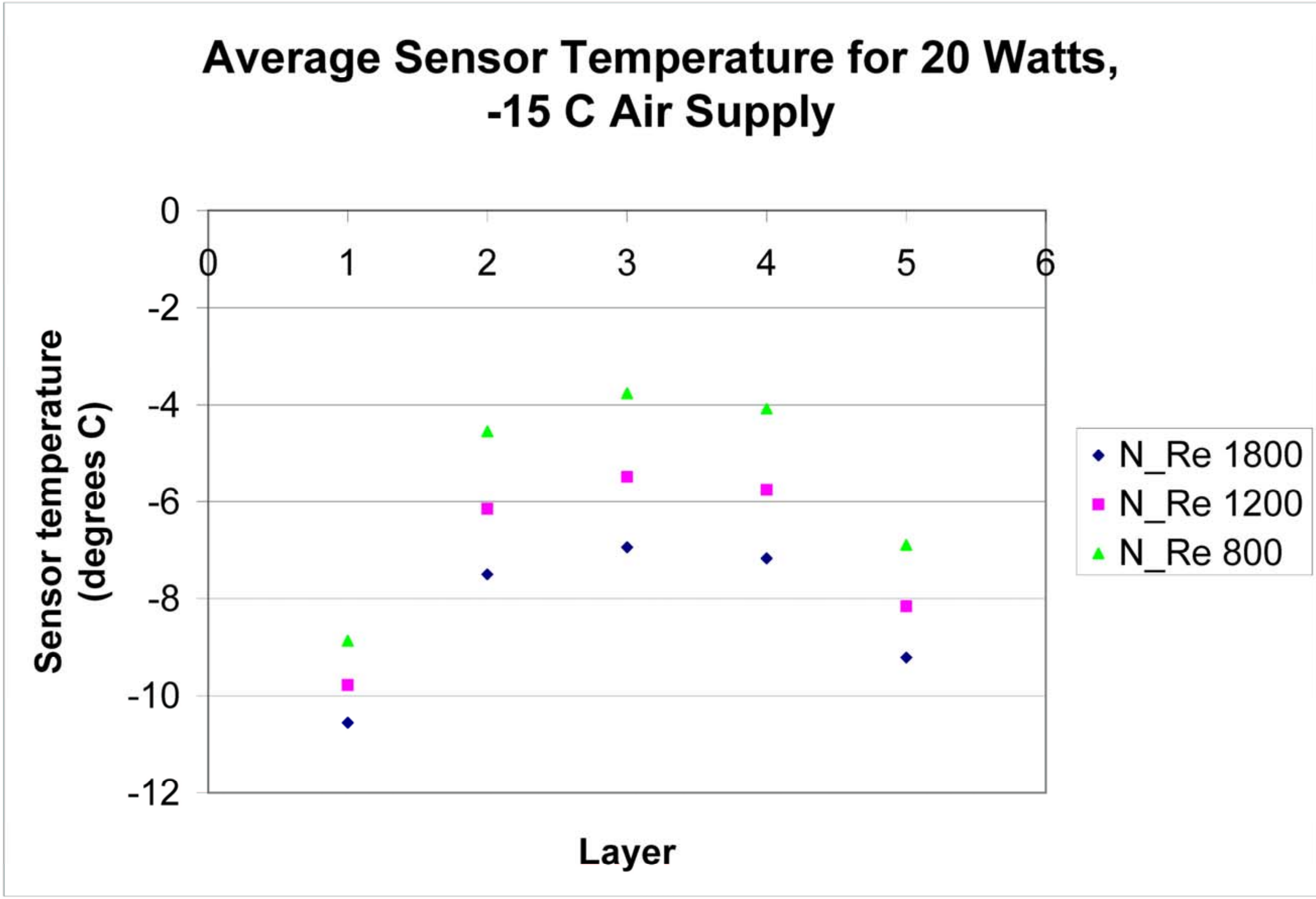
- Dry air was assumed to enter the barrel at a temperature of -15° C.
- We assumed no heat transfer from the beam pipe to the innermost layer, that is, the beam pipe would have thermal intercepts.
- A total power dissipation of 20 watts was assumed for the barrel.
  – Based upon the results, that seems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

Cooling performance as a function of Reynold's number

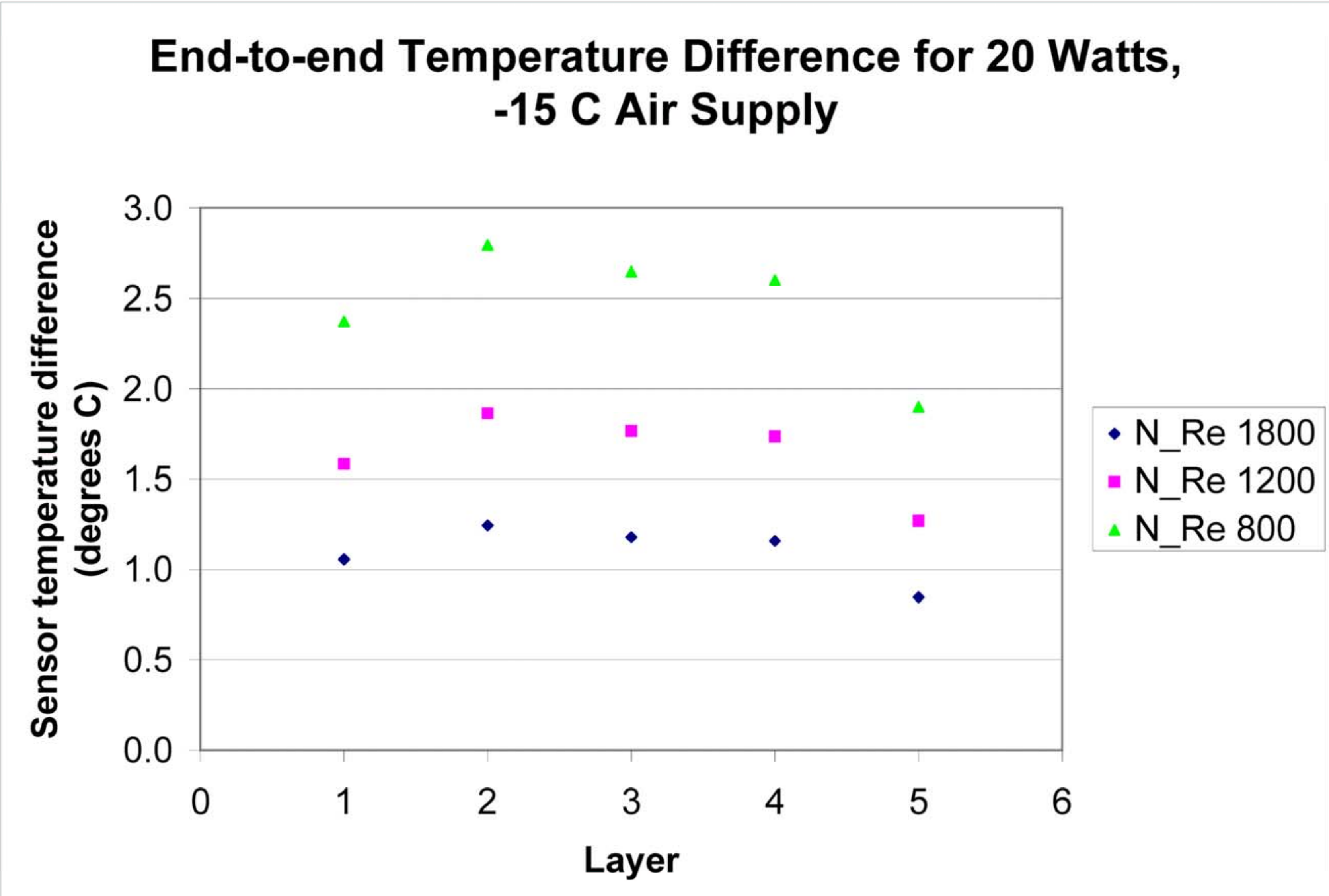
Reynold's number	Total barrel flow (g/s)	Ave. ΔT air (°C)	Max sensor T (°C)
800	9.0	2.21	-2.44
1200	13.5	1.47	-4.61
1800	20.2	0.98	-6.36

- 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 µW/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^o C.

Barrel Radiation Lengths

- The number of radiation lengths at normal incidence has been significantly reduced by aggressive, but realistic, design of support structures. Sensor overlap and thermal insulation have not been taken into account. A simulation remains to be run.

Element	Description	% of a radiation length
Beam pipe	0.05 mm titanium	0.140
	0.4 mm beryllium	0.113
Sub-total		0.253
Each of 5 pixel layers		
Carbon fiber	0.26 mm carbon fiber – epoxy with 3/4 of area cut away	0.027
Epoxy	0.05 mm	0.014
Silicon	0.1 mm	0.107
Readout and cables	0.05 mm silicon equivalent	0.054
Overlap of sensors		???
Sub-total per layer		0.202
Sub-total for 5 layers		1.010
Outer support cylinder	Double-walled carbon fiber support cylinder with 60 ribs, thickness of material = 0.26 mm	0.304
Air		0.065
Total sensors		0.670
Total inactive		0.962
Total		1.632

Radiation Lengths in the Forward Direction

- Contributions from barrel end plates have been reduced enough that other detector elements dominate.
- Contributions from barrel sensors and their support structures remain significant, as do those from the beam tube.
  - Thinning the beam tube would require R&D of discussions with vendors to understand feasibility.
- We plan to examine material seen by tracks through the disks more carefully and see what reductions can be made.

Summary

- Mechanical design features of the outer silicon tracker have been extended to the vertex detector.
- A design based largely upon carbon fiber support structures has been developed.
  - That design is intended to be suitable for sensor operation at > -10^{o} 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 expected to be acceptable.
- 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.
- Barrel material represents slightly more than 1.6% of a radiation length at normal incidence.
- Material seen by tracks through disks will require further study.