Vertex Detector Integration and Mechanics

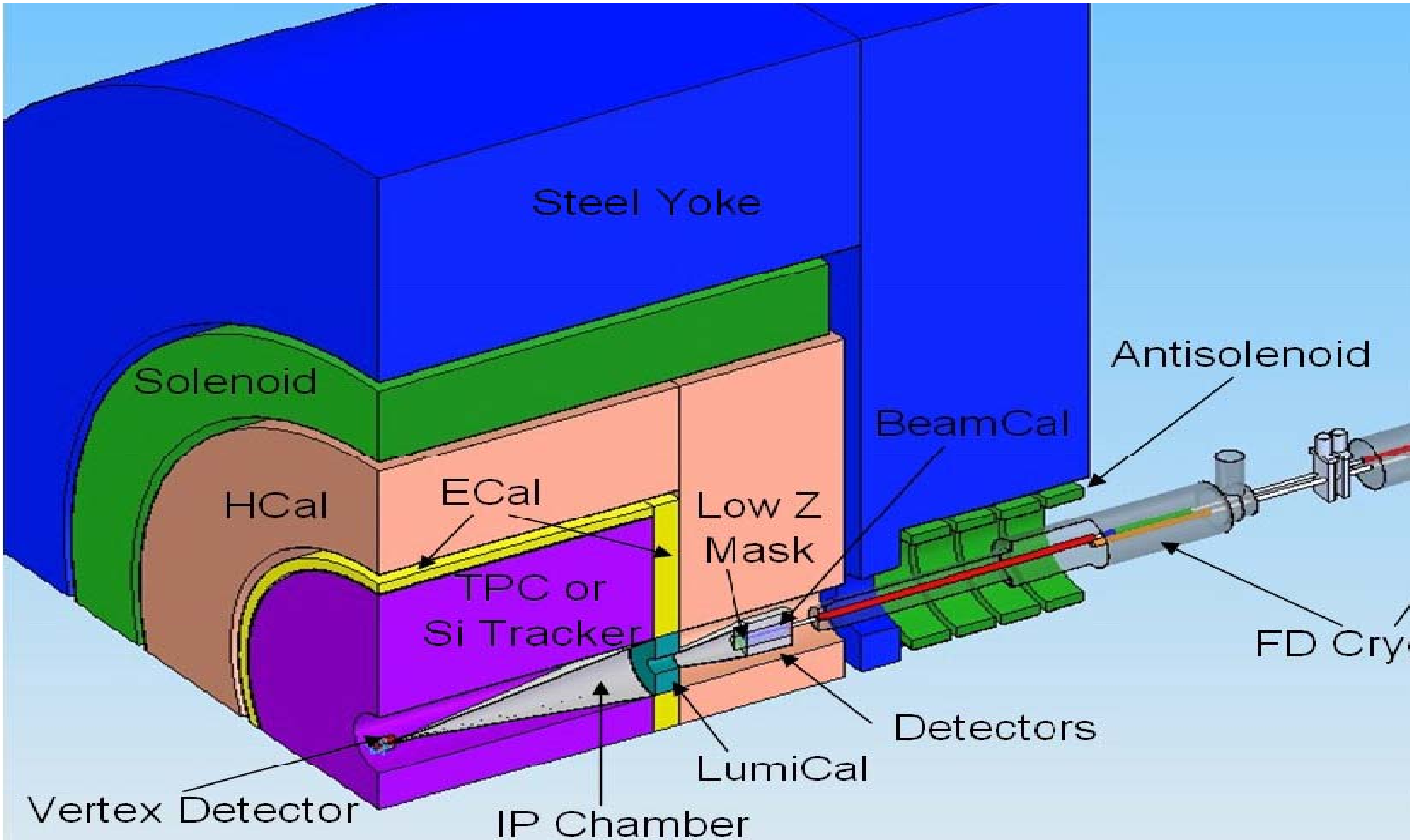
Bill Cooper
Fermilab

Introduction

- Designs should:
  - Be integrated with other detector elements
  - Satisfy requirements related to backgrounds
  - Satisfy radiation length requirements
    - Goal is ~ 0.1% of a radiation length per layer
  - Provide sufficient hermeticity
  - 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 and servicing
  - 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.
- Joel Goldstein has been organizing non-US mechanical work, particularly within LCFI.
  - He and Tim Greenshaw have served as LCFI co-leaders.
  - Regrettably, Joel was unable to come to this conference, so I will try to represent him.

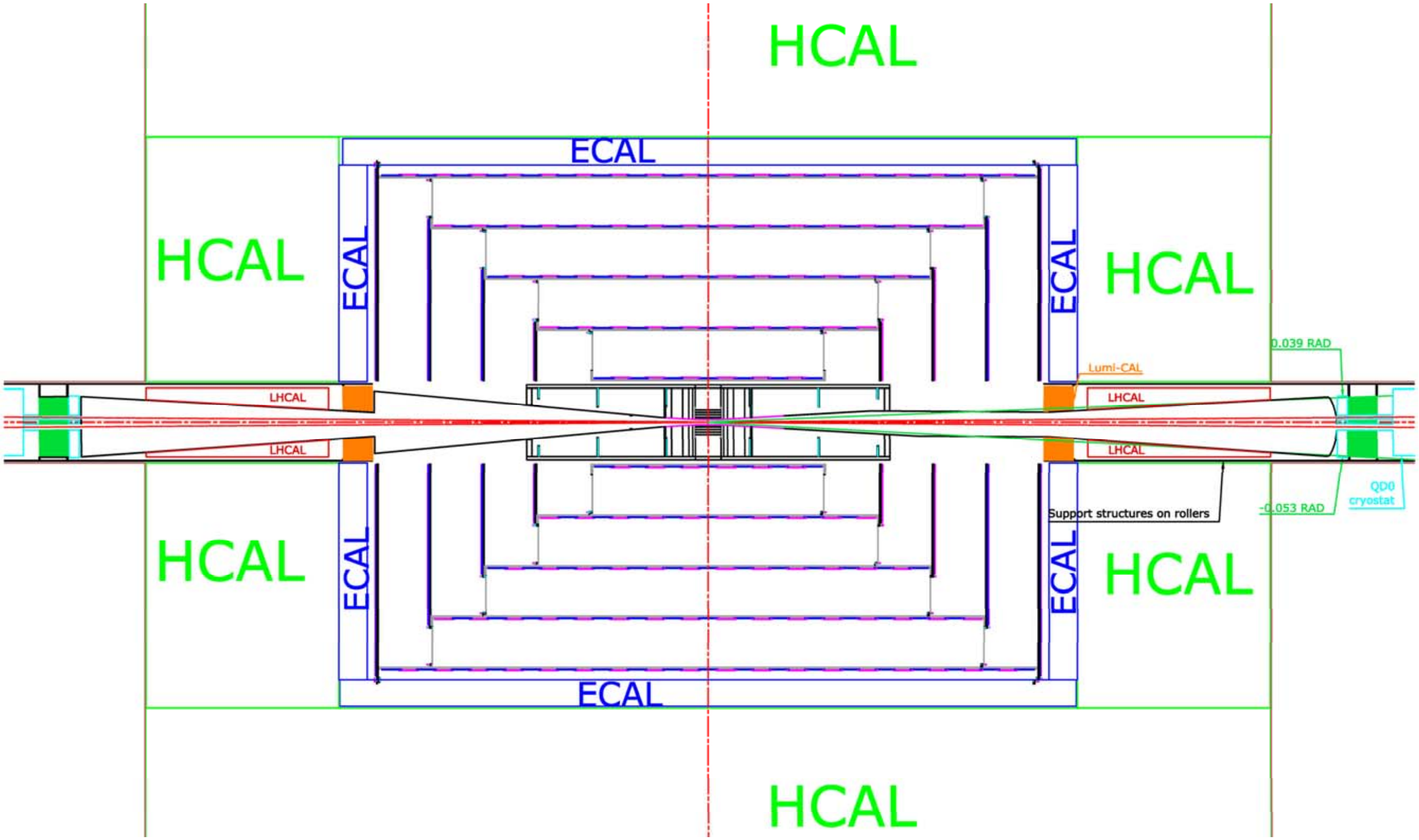
Overall Geometry

- ILD (Sendai, C. Grah):



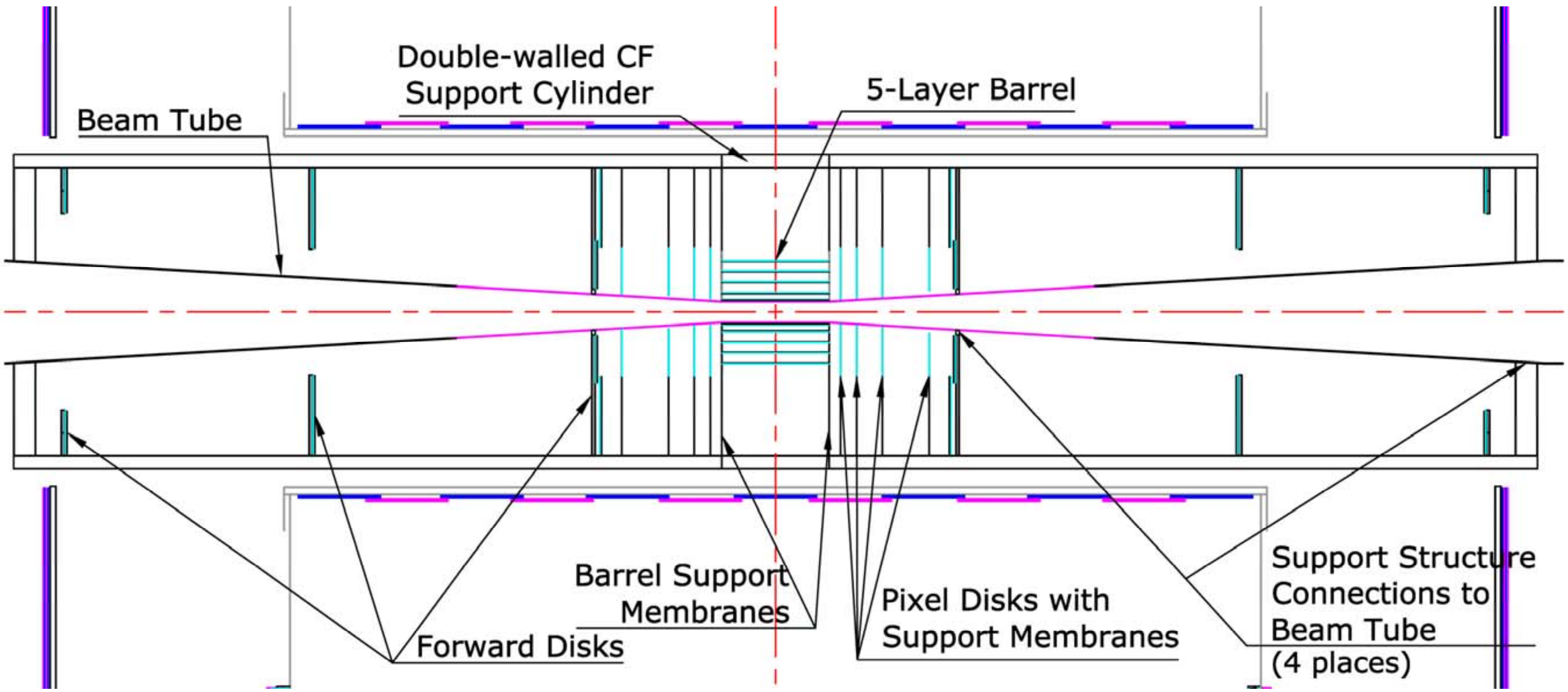
Overall Geometry

- SiD with two alternative beam pipes (neither is the baseline):



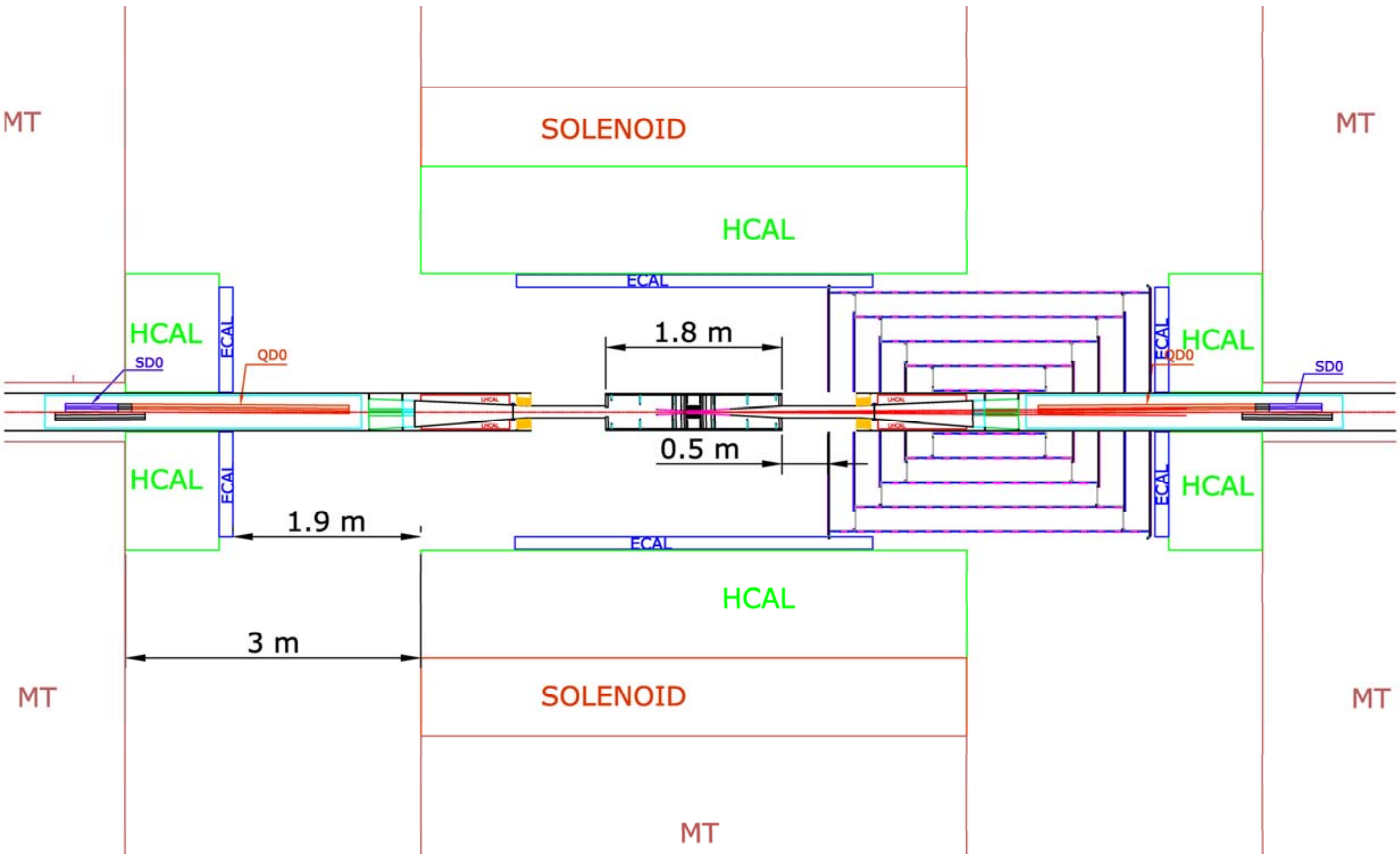
Integration with the Beam Pipe

- If the vertex detector is to be supported from the beam pipe and the beam pipe diameter is small near Z = 0, bending of the beam pipe will need to be addressed.
  - SiD would provide an outer support cylinder which holds the beam pipe straight.
  - Support from the outer tracker is an alternative, but affects servicing.



Servicing Vertex Detector & Tracker (SiD)

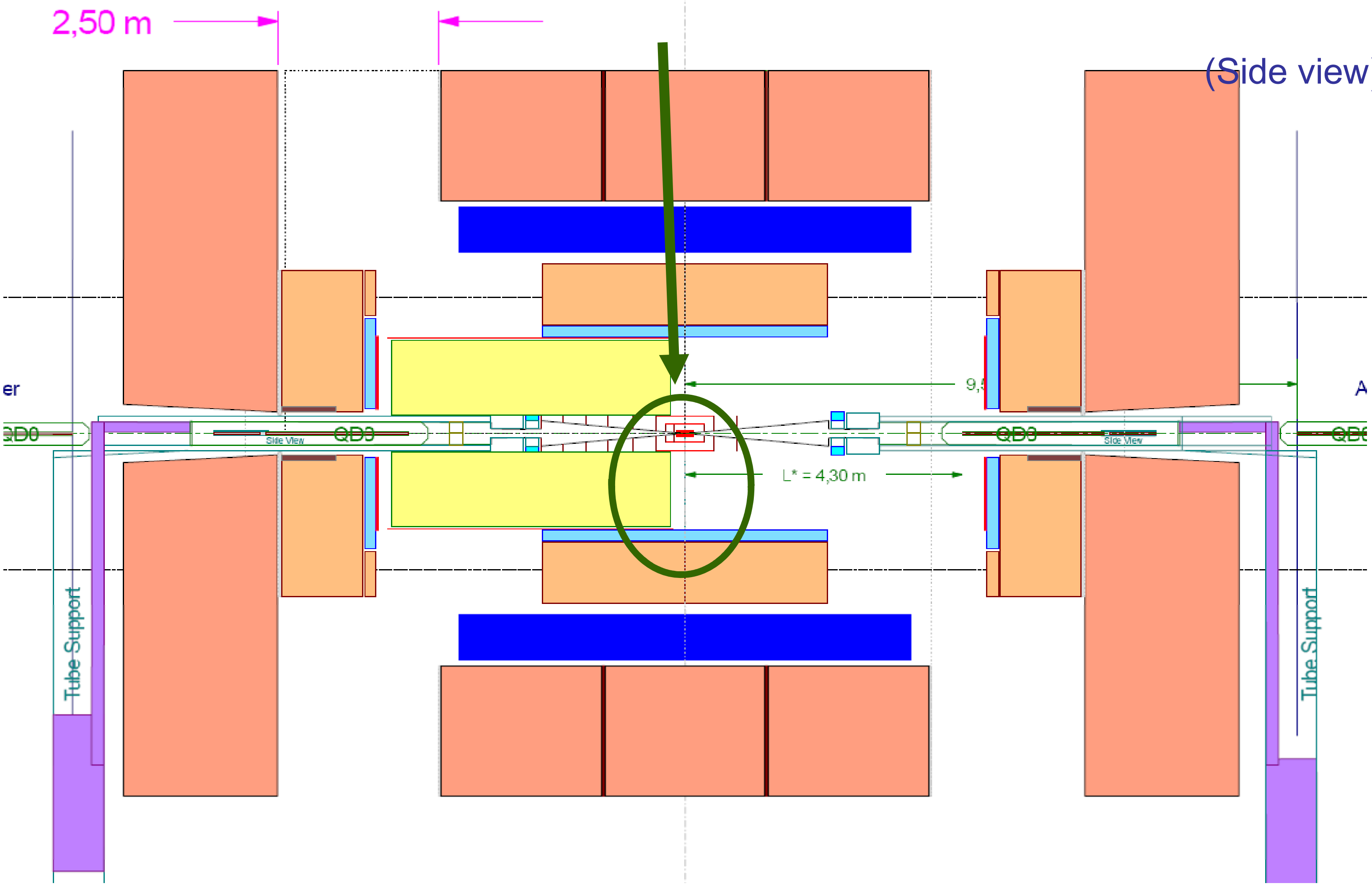
- Detector open 3 m for off-beamline servicing
- Vertex detector can be removed / replaced.



ILD Detector Opening (N. Meyners, IRENG07)

2.5m detector opening would just allow to maintain the vertex detector in the garage position without breaking the vacuum.

(Pumping the central beam pipe is assumed to be very time consuming.)



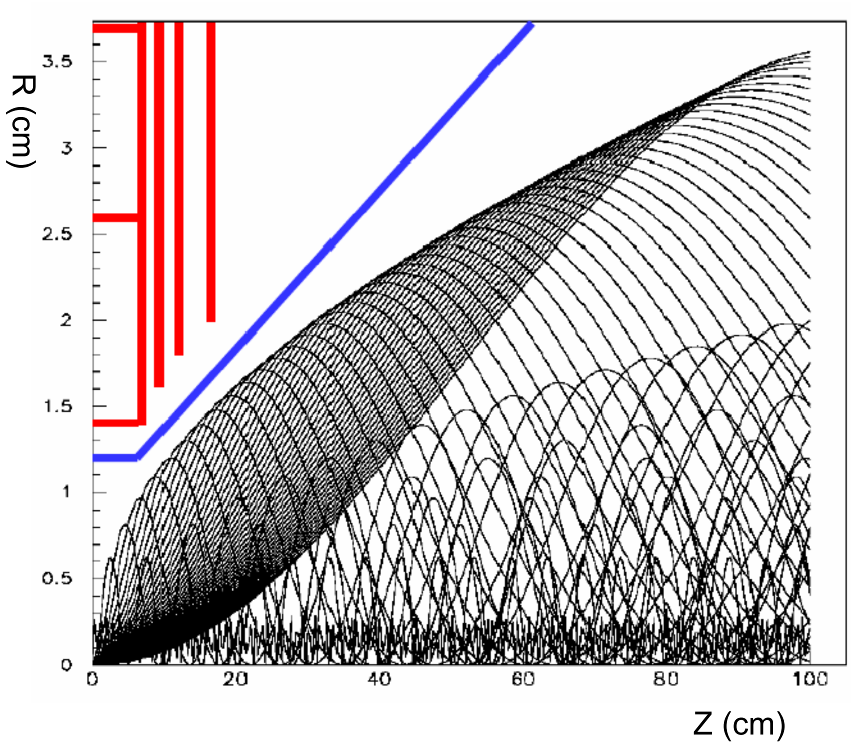
Servicing Vertex Detector & Tracker (SiD)

- People may be interested to know that there has been a proposal within SiD to increase the transition radius for servicing from 20 cm to 30 cm.
  - This would require an updates to the outer tracker and end-cap designs.
  - For the present vertex detector layout, the gap from the outermost sensors of the vertex detector to the start of the tracker volume would increase.
  - Alternatively, the vertex detector could grow in radius.
- The goal is to provide more space for support of final beam line elements.
- To the best of my knowledge, 20 cm is still the SiD baseline.
- I don’t know what ILD assumes.
- Comments?

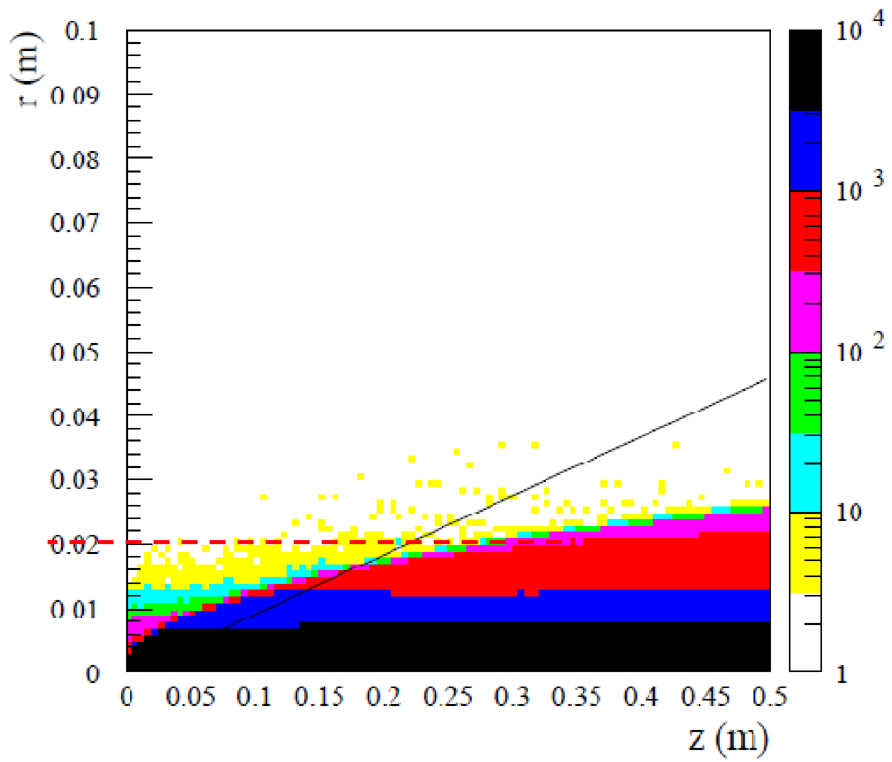
Backgrounds

- T. Maruyama (SLAC)
  - Note that trajectories seem to return to the Z-axis.
  - We need to understand effects of the crossing angle.
- Y. Sugimoto (Sendai meeting)
  - Note the additional background below z = 0.25 m.
  - Yasuhiro suggests a single cone design is not preferable for VTX.

500 GeV Nom., 5 T, 14 mrad, no DID

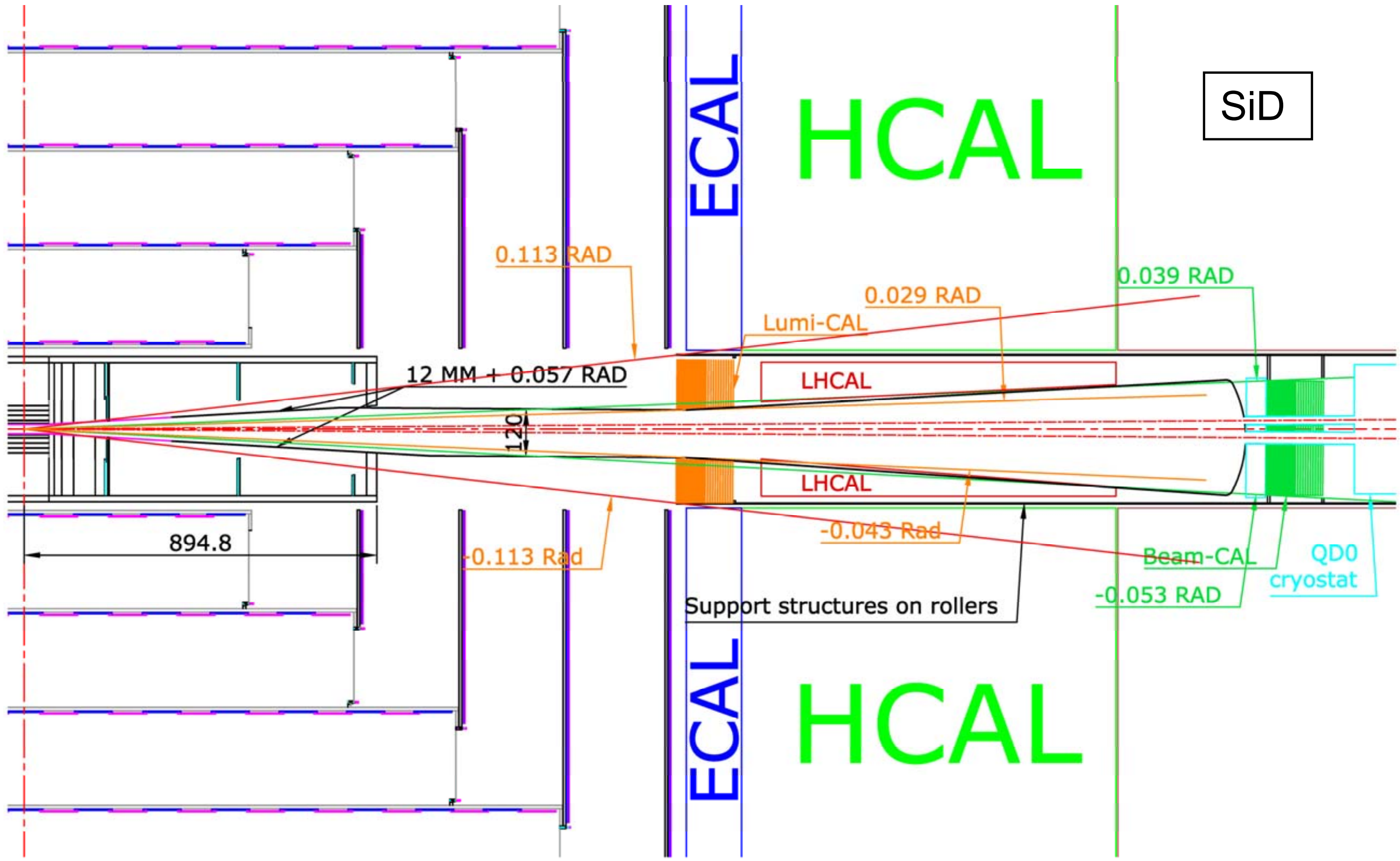


Nominal 500GeV 4T 14mrad



Geometry in the Forward Region

- Which beam pipe portions should be rotated to the outgoing beam line?



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.

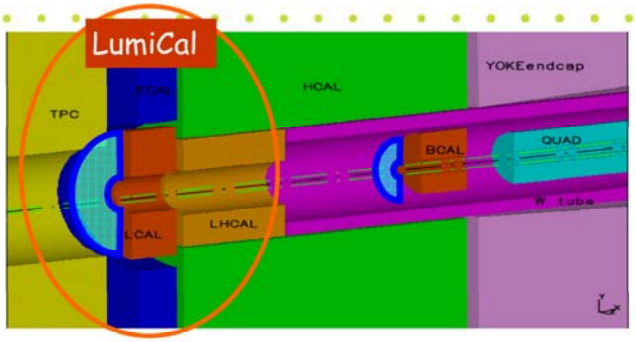
LumiCal inner edge	≈36mrad about outgoing
LumiCal outer edge	≈113mrad about 0mrad
LumiCal fiducial	≈46-86mrad about outgoing
BeamCal outer edge	≈46mrad about outgoing
LumiCal	$30X_0$ Si-W
BeamCal	$30X_0$ rad-hard Si,diamond....

ILD LumiCal Requirements (C. Grah, Sendai Meeting)

Precise Measurement of the Luminosity

- Required precision is:

  $\Delta L/L \sim 10^{-4}$ (GigaZ 10^9/year)
  $\Delta L/L < 10^{-3}$ ($e^+e^- \to W^+W^-$ 10^6/year)
  $\Delta L/L < 10^{-3}$ ($e^+e^- \to q^+q^-$ 10^6/year)



- Bhabha scattering ee->ee(γ) is the gauge process:
  - Count Bhabha event in a well known acceptance region => $L = N/\sigma$
  - High statistics at low angles => $N_{Bhabha} \sim 1/\theta^3$
  - Well known electromagnetic process (LEP: 10^{-3}): the current limit on the theoretical cross section error is at $\sim 5\ 10^{-4}$.

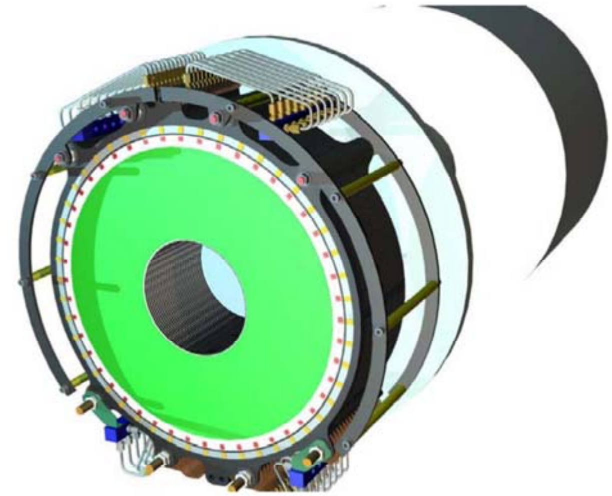
$\sqrt{s} = 500$ GeV, $L = 500$ fb^{-1}, $L = \frac{N}{\sigma_{Bhabha}}$

$R_{min} \to R_{max}$ [mm]	Fiducial volume		σ_{Bhabha} [nb]	Relative Error	
	θ_{min} [mrad]	θ_{max} [mrad]		$\Delta N/N$	$2 \cdot \Delta\theta/\theta_{min}$
80 → 190	41	69	1.23	$4 \cdot 10^{-5}$	$1.7 \cdot 10^{-4}$
90 → 200	50	74	0.86	$4.8 \cdot 10^{-5}$	$1.4 \cdot 10^{-4}$

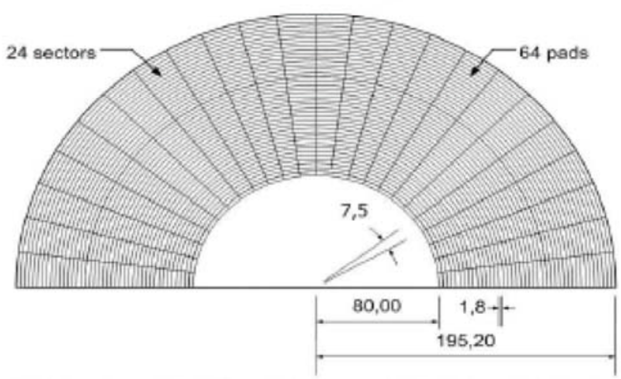
ILD LumiCal Layout (C. Grah, Sendai Meeting)

LumiCal: Design Parameters

- 1. Placement:
  - 2270 mm from the IP.
  - Inner Radius - 80 mm
  - Outer Radius - 190 mm
- 2. Segmentation:
  - 48 sectors & 64 cylinders:
  - Azimuthal Cell Size - 131 mrad
  - Radial Cell Size - 0.8 mrad



Silicon sensor half plane

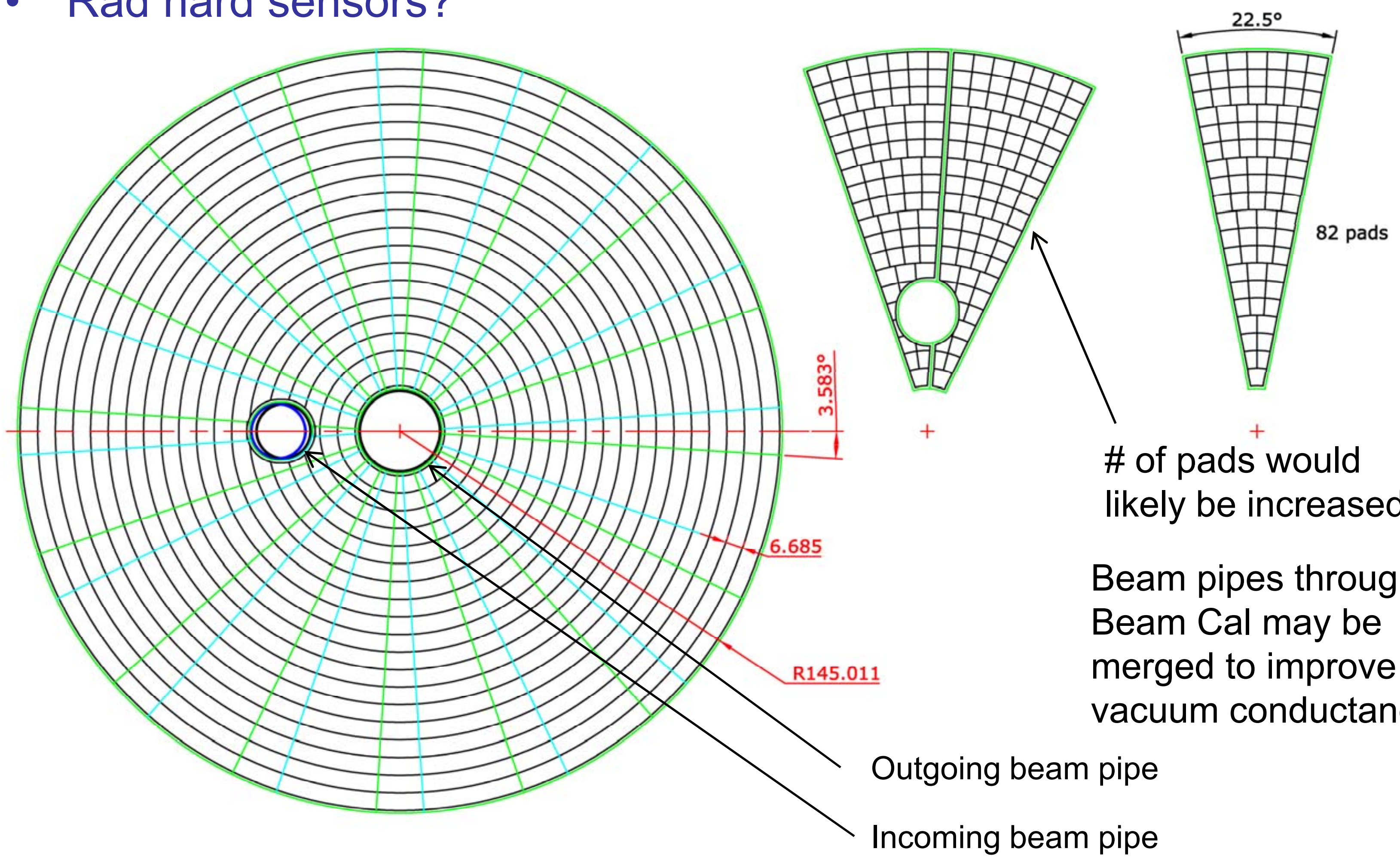


- 3. Layers:
  - Number of layers - 30
  - Tungsten Thickness - 3.5 mm
  - Silicon Thickness - 0.3 mm
  - Elec. Space - 0.1 mm
  - Support Thickness - 0.6 mm

March/2008 C.Grah: Forward Region 5

Preliminary BeamCal Sensor Layout (SiD)

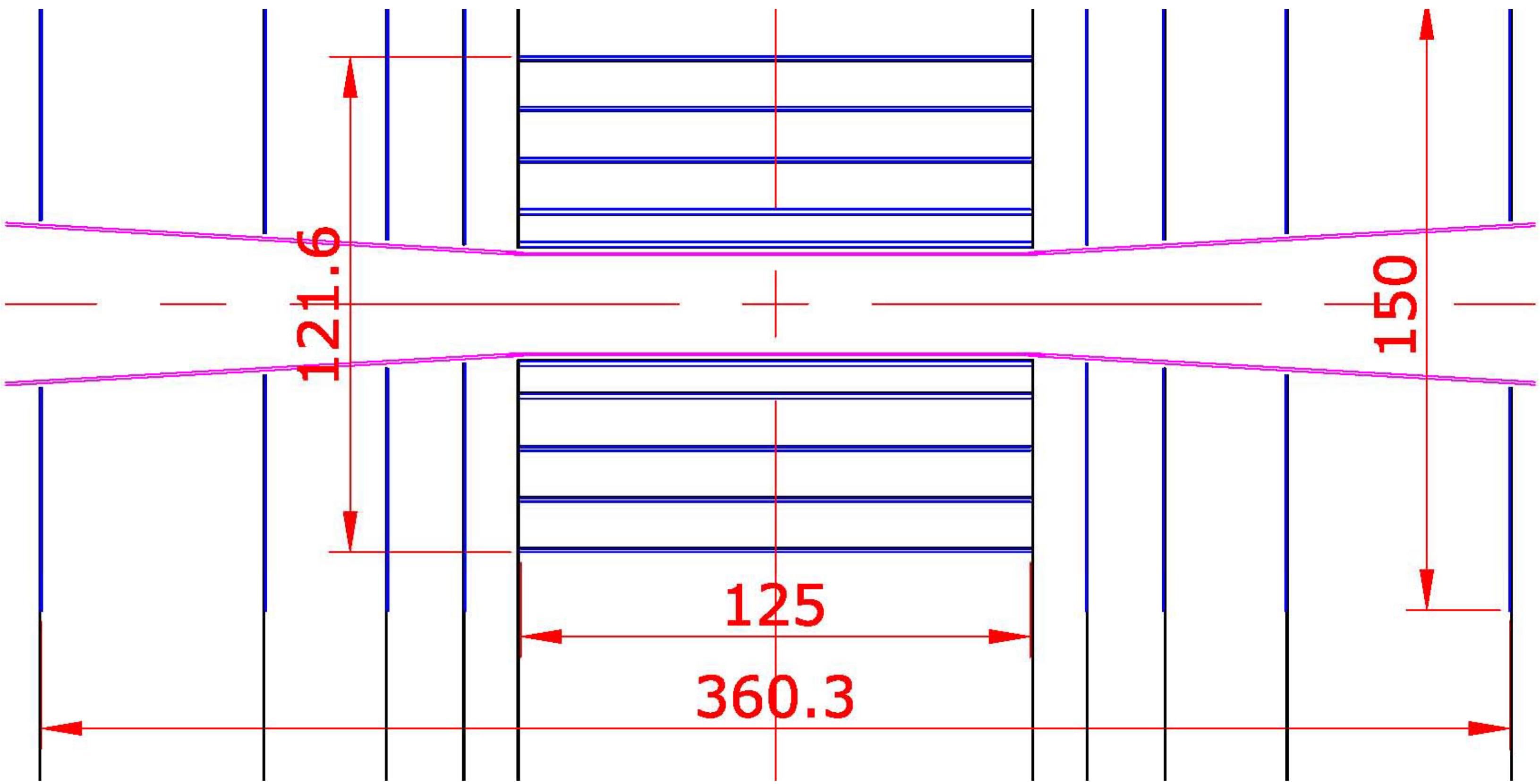
- Assumes 6” silicon sensor technology.
- Wedges rotated in alternate planes for overlap.
- Rad hard sensors?



Beam pipes through Beam Cal may be merged to improve vacuum conductance

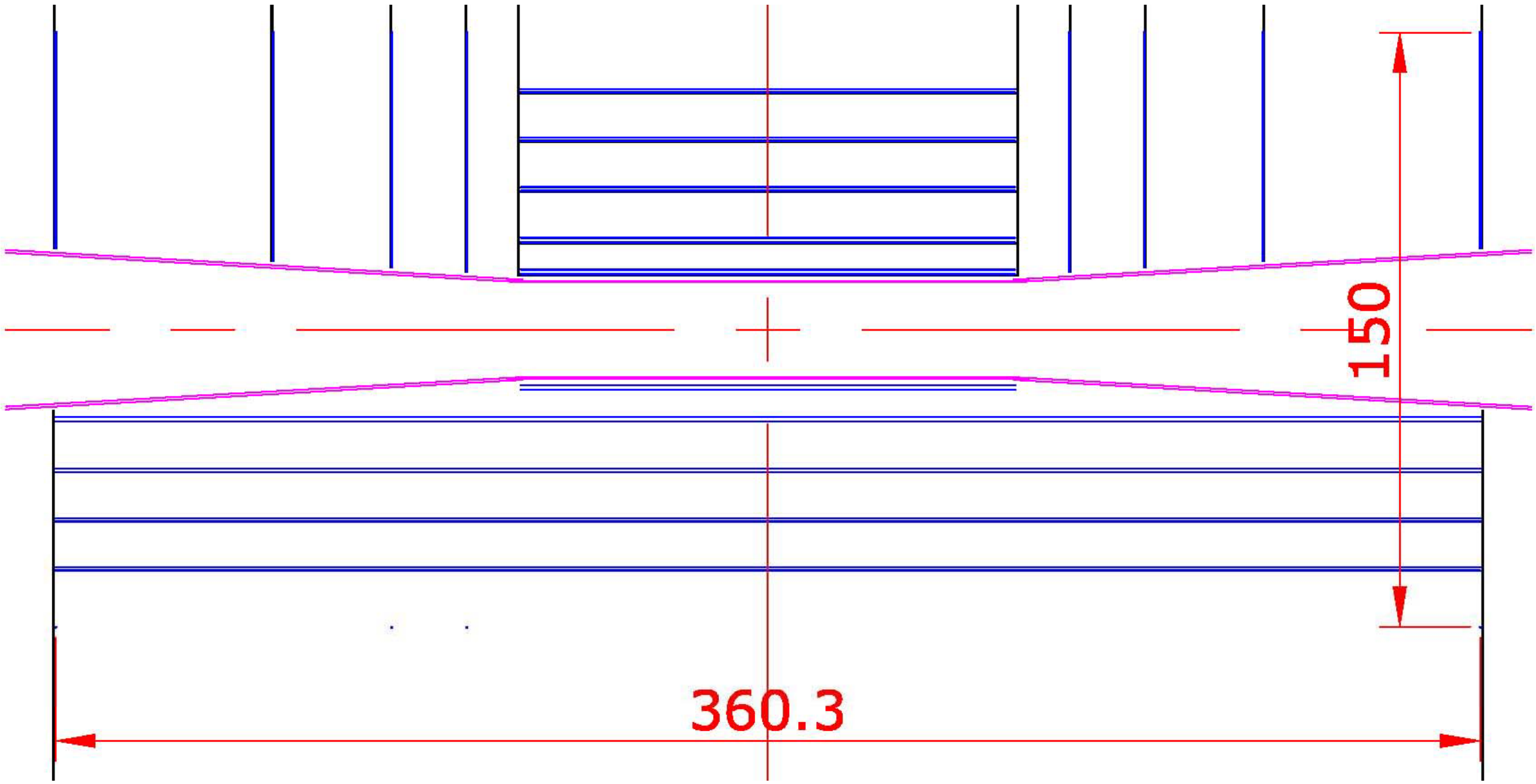
Vertex Detector Pixel Region (SiD)

- Parameters vary as end view and beam pipe shape are iterated.
- To cover this particular region with ladders only, a length of ~360 mm would be needed.



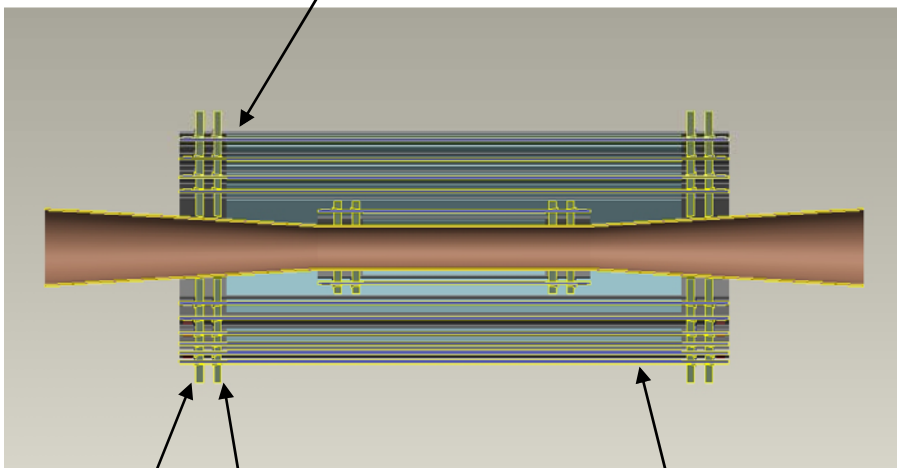
Vertex Detector Pixel Region (Long Ladders)

- Ladders plus disks are in the top half; ladders only, in the bottom.
- Please note that, with ladders only, there are fewer hits for small cone angles.
- Cabling of L2 – L5 is obviously simpler without disks.



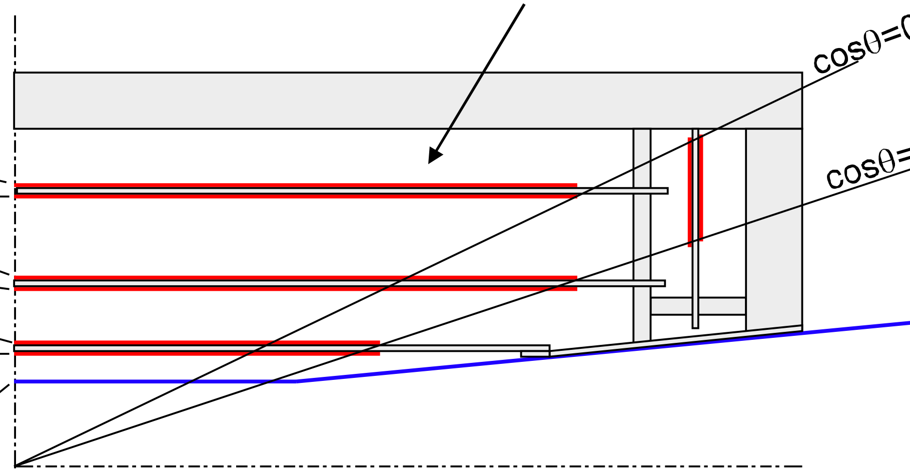
Designs with Longer Ladders

- LCFI



- Both approaches include interesting ladder features and assume foam is used as a structural element.

- KEK



Angular Coverage

- Still under development by concepts; dimensions are approximate.
- Disks are generally included in recent ILD designs.

<table>
<tr><th>Theta coverage</th><th colspan="3">SiD</th><th colspan="3">LCFI/SiD no disks</th><th colspan="3">GLC_0</th></tr>
<tr><td>Element</td><td>R</td><td>Z</td><td>cos(theta)</td><td>R</td><td>Z</td><td>cos(theta)</td><td>R</td><td>Z</td><td>cos(theta)</td></tr>
<tr><td>B1</td><td>14</td><td>62.5</td><td>0.976</td><td>14</td><td>62.5</td><td>0.976</td><td>24.2</td><td>80</td><td>0.957</td></tr>
<tr><td></td><td>14.459</td><td>62.5</td><td>0.974</td><td>14.459</td><td>62.5</td><td>0.974</td><td>26.2</td><td>80</td><td>0.950</td></tr>
<tr><td>B2</td><td>21</td><td>62.5</td><td>0.948 <--------</td><td>21</td><td>125</td><td>0.986</td><td>37.6</td><td>120</td><td>0.954</td></tr>
<tr><td></td><td>21.497</td><td>62.5</td><td>0.946 |</td><td>21.497</td><td>125</td><td>0.986</td><td>39.6</td><td>120</td><td>0.950</td></tr>
<tr><td>B3</td><td>34</td><td>62.5</td><td>0.878 <----- |</td><td>34</td><td>125</td><td>0.965</td><td>58</td><td>120</td><td>0.900</td></tr>
<tr><td></td><td>34.451</td><td>62.5</td><td>0.876 | |</td><td>34.451</td><td>125</td><td>0.964</td><td>60</td><td>120</td><td>0.894</td></tr>
<tr><td>B4</td><td>47</td><td>62.5</td><td>0.799 <--- | |</td><td>47</td><td>125</td><td>0.936</td><td></td><td></td><td></td></tr>
<tr><td></td><td>47.394</td><td>62.5</td><td>0.797 | | |</td><td>47.394</td><td>125</td><td>0.935</td><td></td><td></td><td></td></tr>
<tr><td>B5</td><td>60</td><td>62.5</td><td>0.721 <- | | |</td><td>60</td><td>125</td><td>0.902</td><td></td><td></td><td></td></tr>
<tr><td></td><td>60.355</td><td>62.5</td><td>0.719 | | | |</td><td>60.355</td><td>125</td><td>0.901</td><td></td><td></td><td></td></tr>
<tr><td>B6</td><td></td><td></td><td>| | | |</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>| | | |</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>D1</td><td>14.25</td><td>71.948</td><td>0.981 | | | |</td><td></td><td></td><td></td><td>49.303</td><td>150</td><td>0.95</td></tr>
<tr><td></td><td>70.75</td><td>72.948</td><td>0.718 <- | | |</td><td></td><td></td><td></td><td>76.847</td><td>150</td><td>0.89</td></tr>
<tr><td>D2</td><td>16.25</td><td>90.32</td><td>0.984 | | |</td><td></td><td></td><td></td><td>49.96</td><td>152</td><td>0.95</td></tr>
<tr><td></td><td>70.75</td><td>90.32</td><td>0.787 <--- | |</td><td></td><td></td><td></td><td>77.872</td><td>152</td><td>0.89</td></tr>
<tr><td>D3</td><td>18.25</td><td>121.79</td><td>0.989 | |</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>70.75</td><td>121.79</td><td>0.865 <----- |</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>D4</td><td>20.25</td><td>170.15</td><td>0.993 |</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>70.75</td><td>170.15</td><td>0.923 <--------</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hits</td><td>3</td><td>4</td><td>5</td><td>3</td><td>4</td><td>5</td><td></td><td></td><td>6</td></tr>
<tr><td>min cos(theta)</td><td>0.984</td><td>0.981</td><td>0.974</td><td>0.964</td><td>0.935</td><td>0.901</td><td></td><td></td><td>0.950</td></tr>
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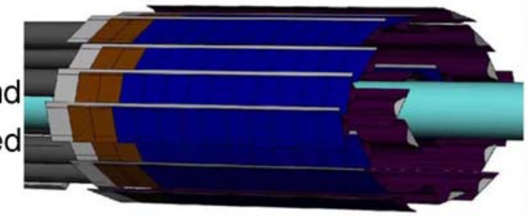
Learning from the STAR experience

- New high-resolution vertex detector inside existing one
- 2 layers at 1.5 cm and 4.5 cm radii, equipped with CMOS pixels

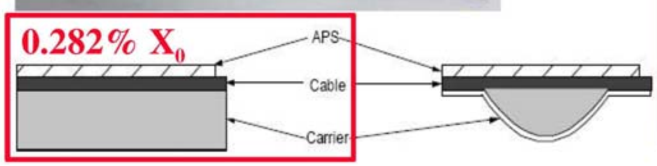
STAR Heavy Flavor Tracker



	STAR	ILC
Performance drivers	Low p_T D	b/c/τ tagging
Position resolution	~10 µm	2-4 µm
Radiation length	0.3% X_0/layer	0.1% X_0/layer
Number of layers	2	5-6
Ladders/layer	6+18	?
Operational T	40ºC	-10ºC ... 20ºC
Cooling	Air flow	?
VTX mount	Side mount	Two sides

- 24 ladders, ~100 Mpixels, 30×30 µm^2, ~0.3% X_0/layer, operation at 40ºC, air cooling

- Developed low-mass ladder prototype with thin CMOS sensors achieving<0.3% X_0/layer



Carrier: 50µm CFC+3.2mm RVC+50µm CFC (=0.11%X_0)

Ladder prototype material budget

Component	% radiation length
MIMOSA detector	0.0534
Adhesive	0.0143
Cable assembly	0.090
Adhesive	0.0143
CF / RVC carrier	0.11
Total	**0.282**

[see L. Greiner's talk]

Berkeley Lab

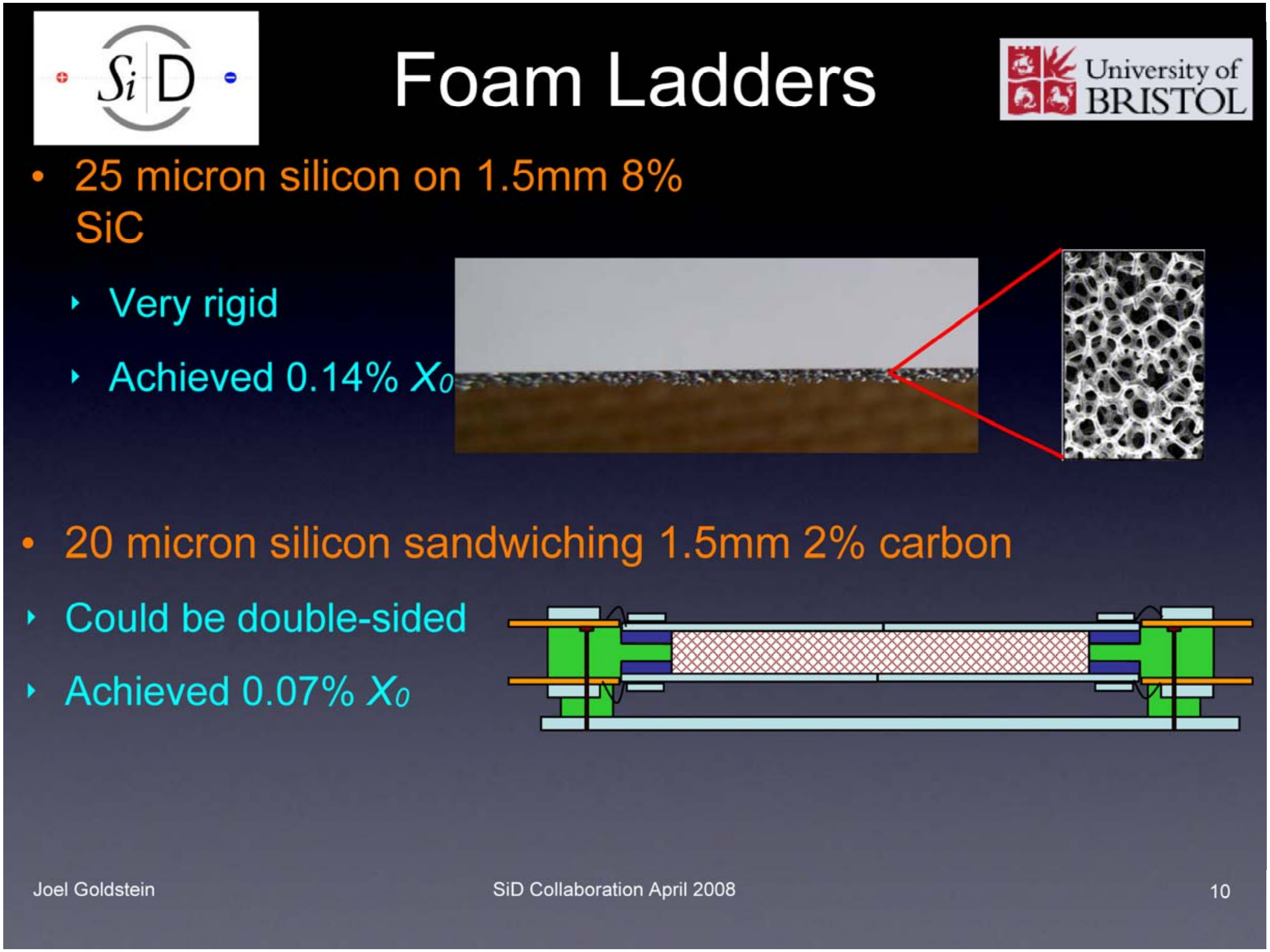
Devis Contarato

Monolithic Pixels Sensors for the ILC

VERTEX 2007

Lake Placid, September 23-28, 2007

LCFI Studies

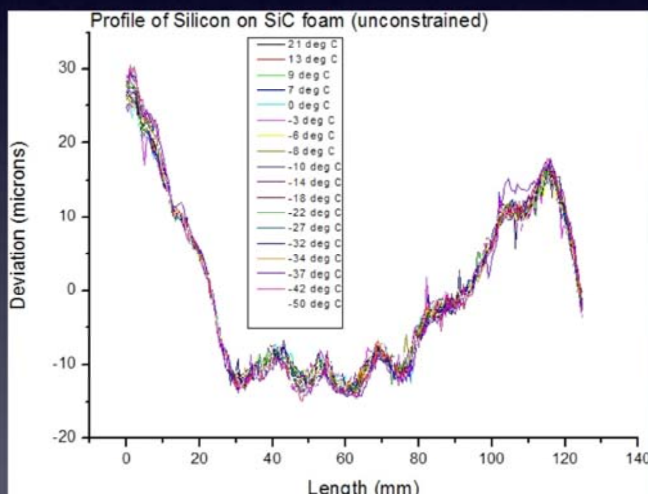


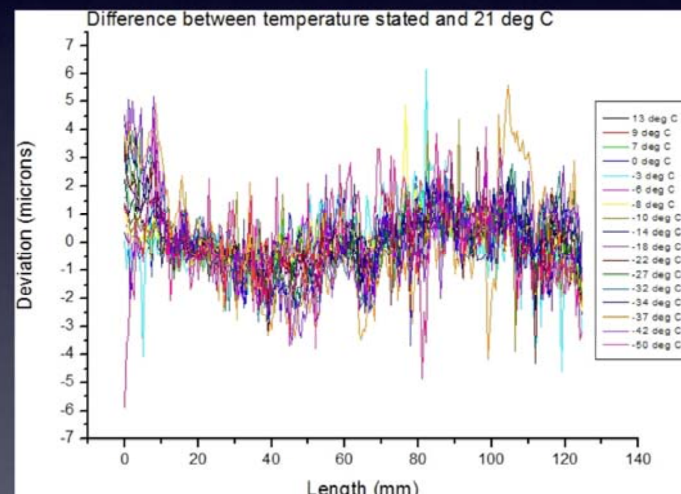
LCFI Studies

SiC Foam Results

University of BRISTOL

- SiC Foam substrate ladder cooled
- Negligible thermal distortion over 70°C

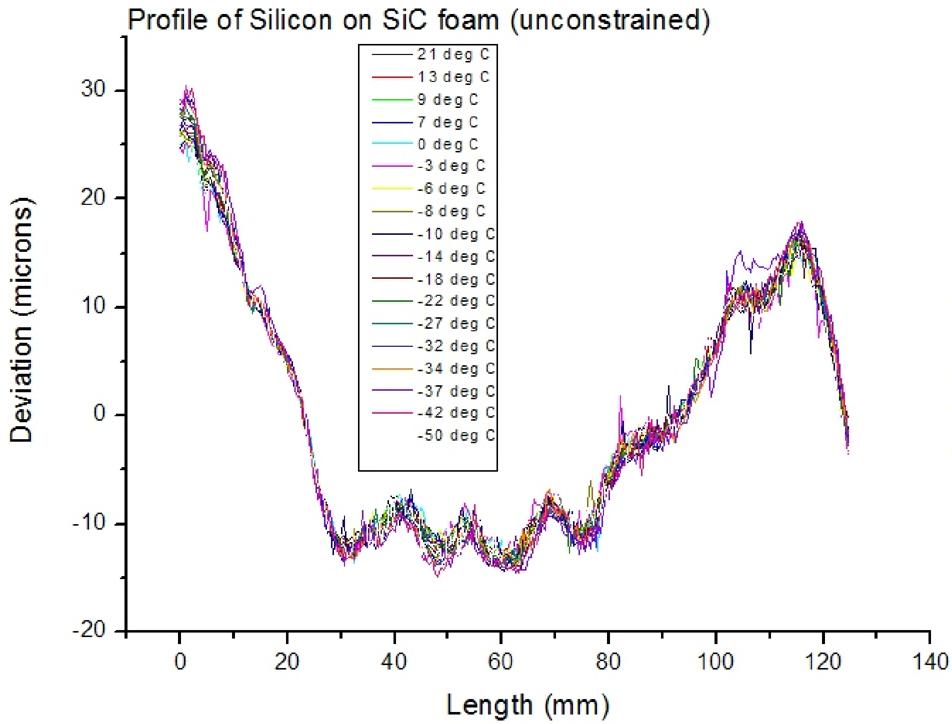


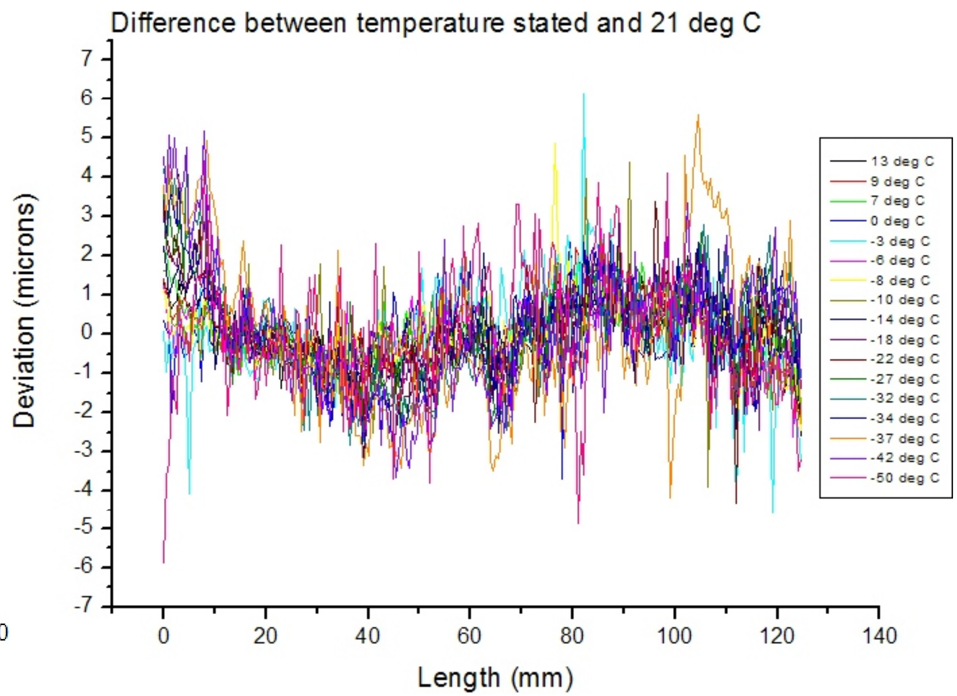


Joel Goldstein SiD Collaboration April 2008 11

Silicon on SiC Foam (LCFI)

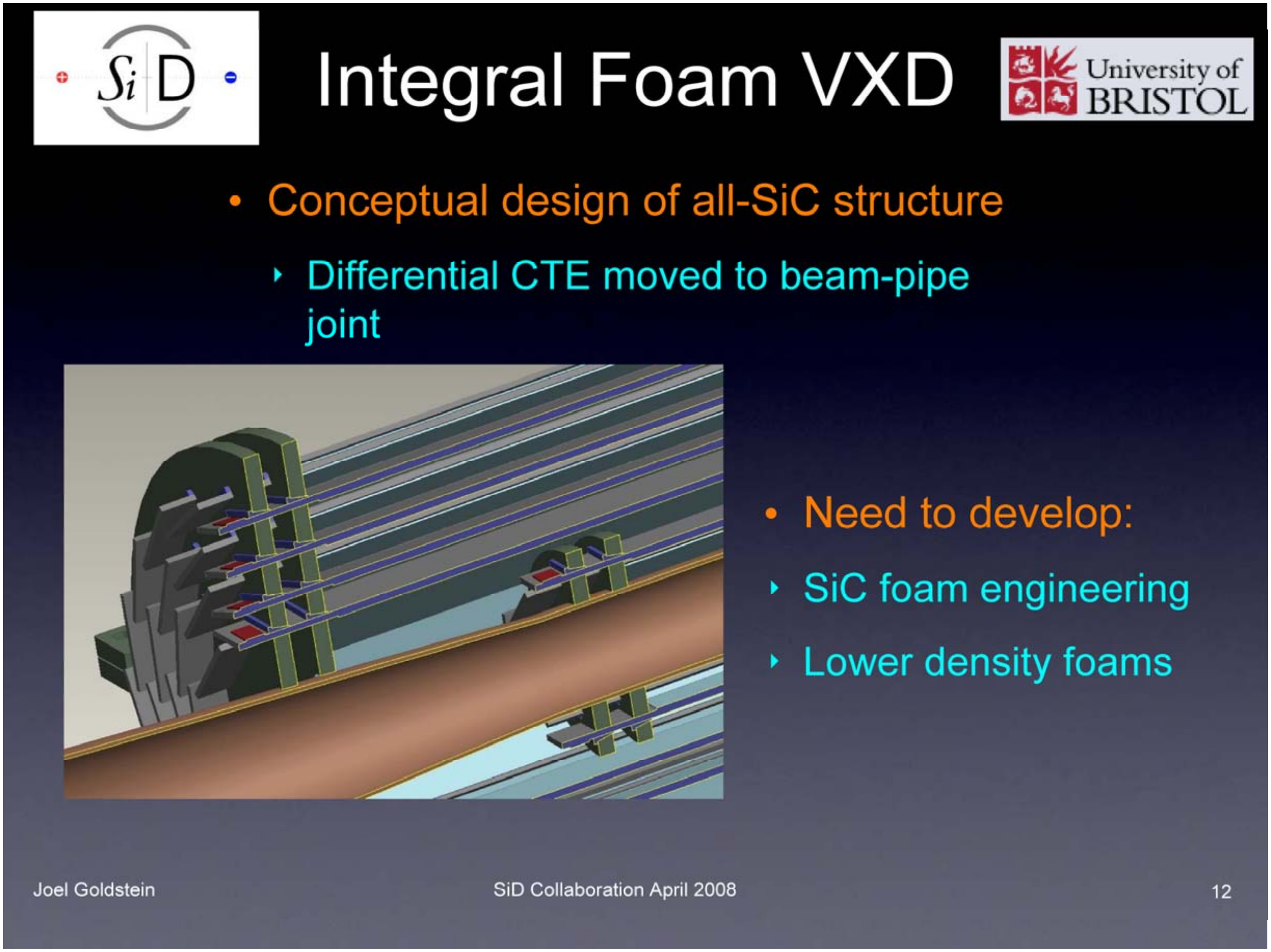
2D results show negligible thermal distortion





- *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*

LCFI Studies



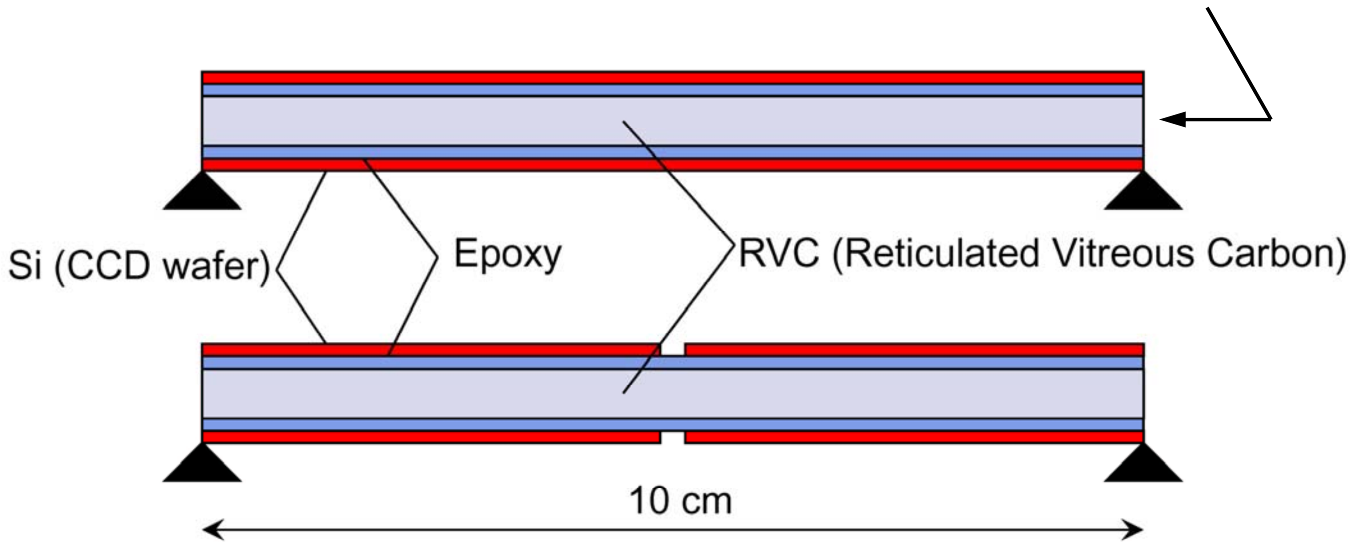
Yasuhiro Sugimoto, 7/24/07

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

9

Symmetric structure reduces thermal distortions

Yasuhiro Sugimoto, 7/24/07

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**

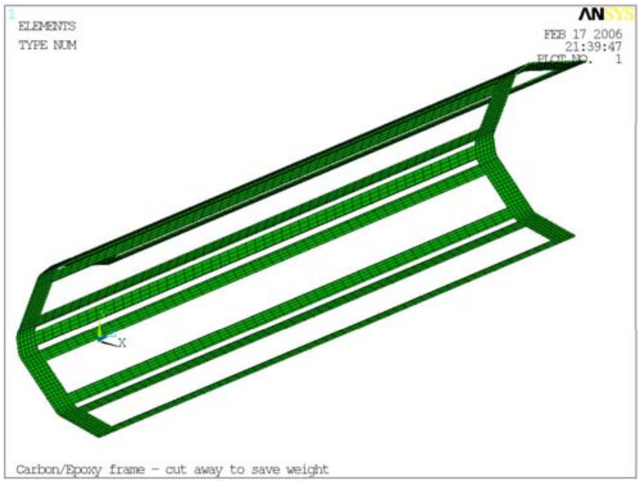
0.08%X_0/layer

10

Thickness allows initial determination of track vector

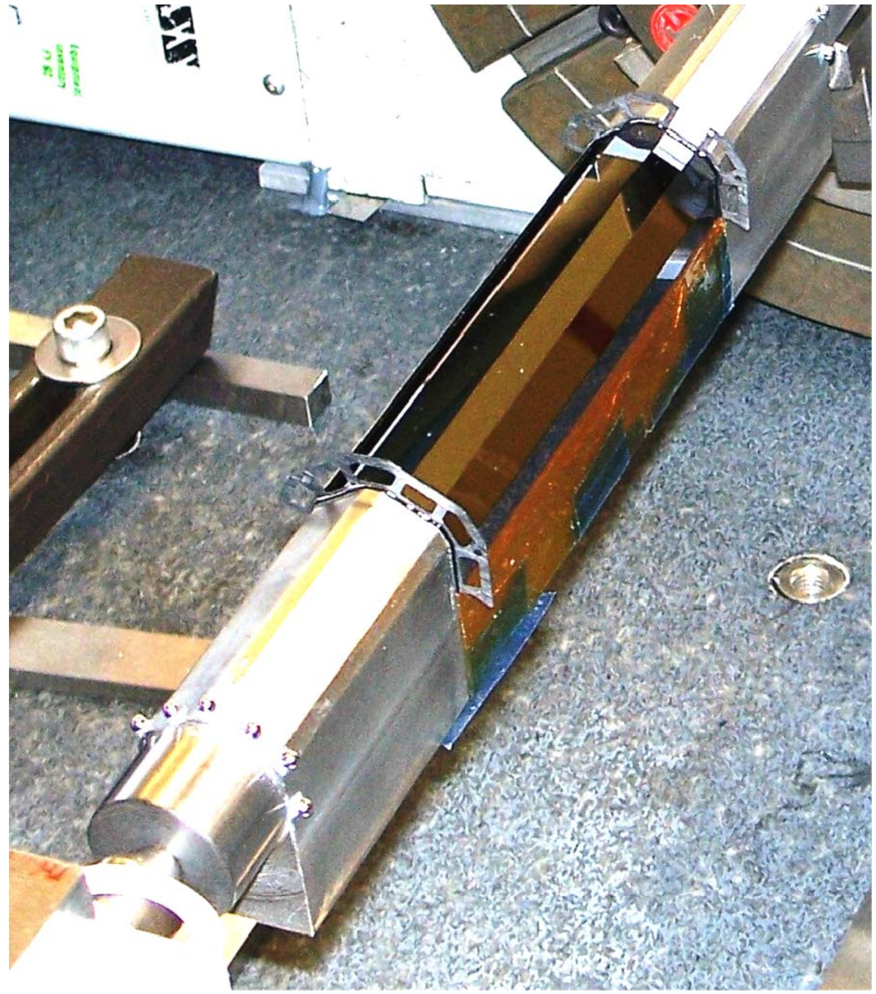
Layer 1 Prototypes

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



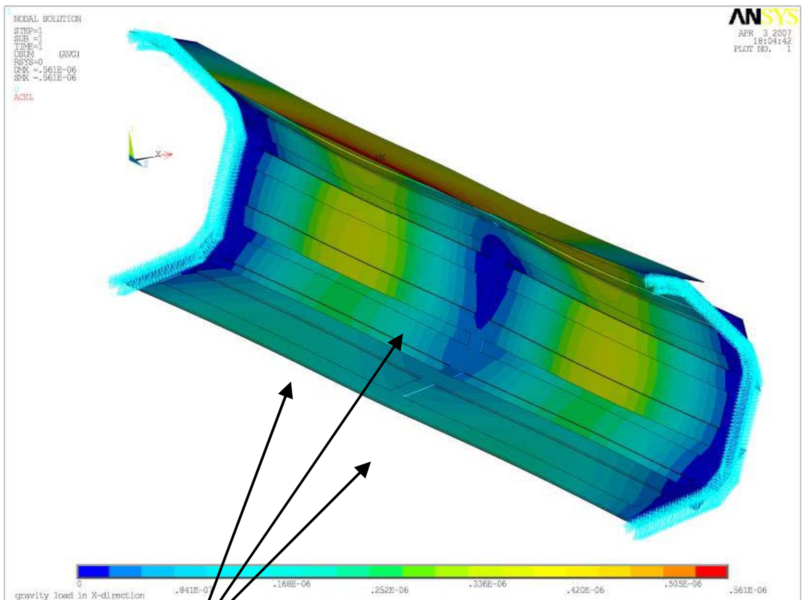
Layer 1 support structure with G-10, rather than carbon fiber, end rings

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

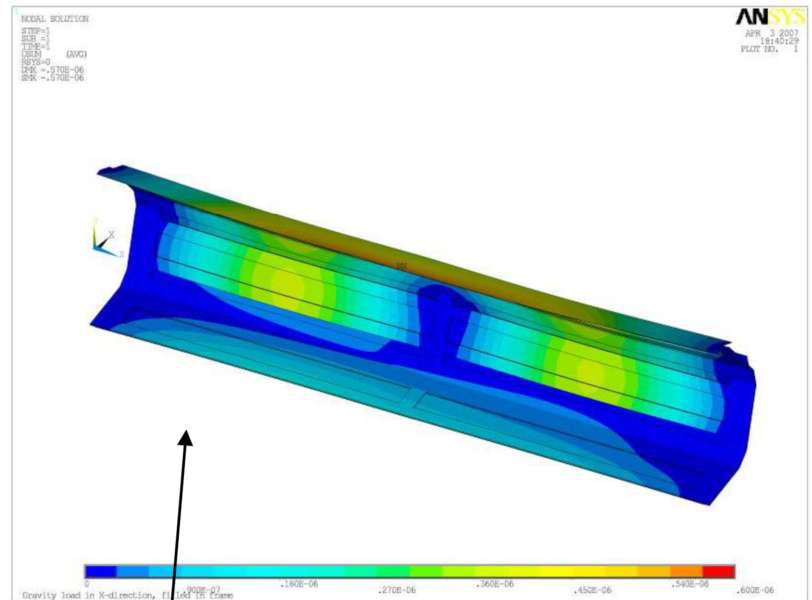


UW FEA Studies, Silicon on CF Structure

- 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

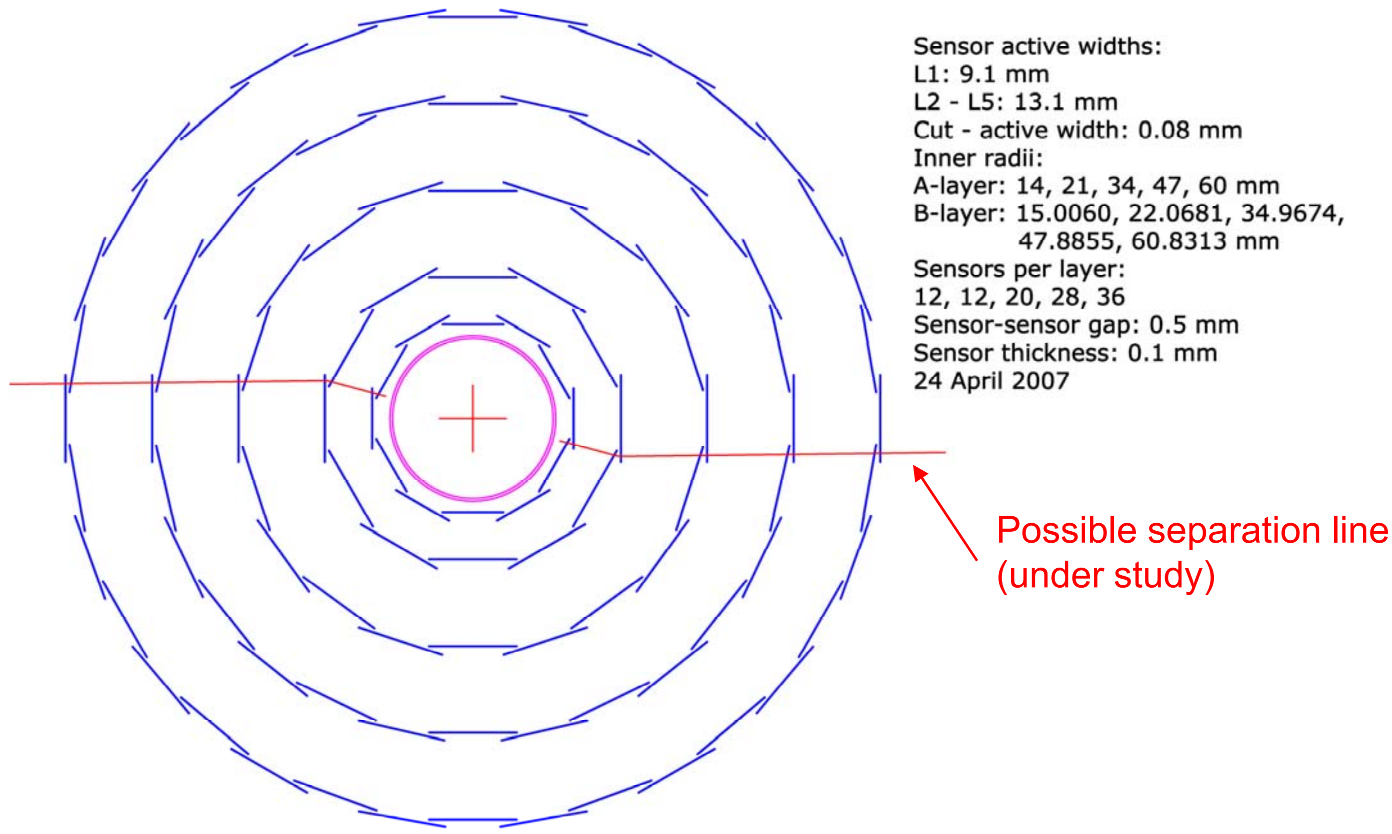


One slot closed to reduce thermal deflection

- 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 ~ 10°C.**

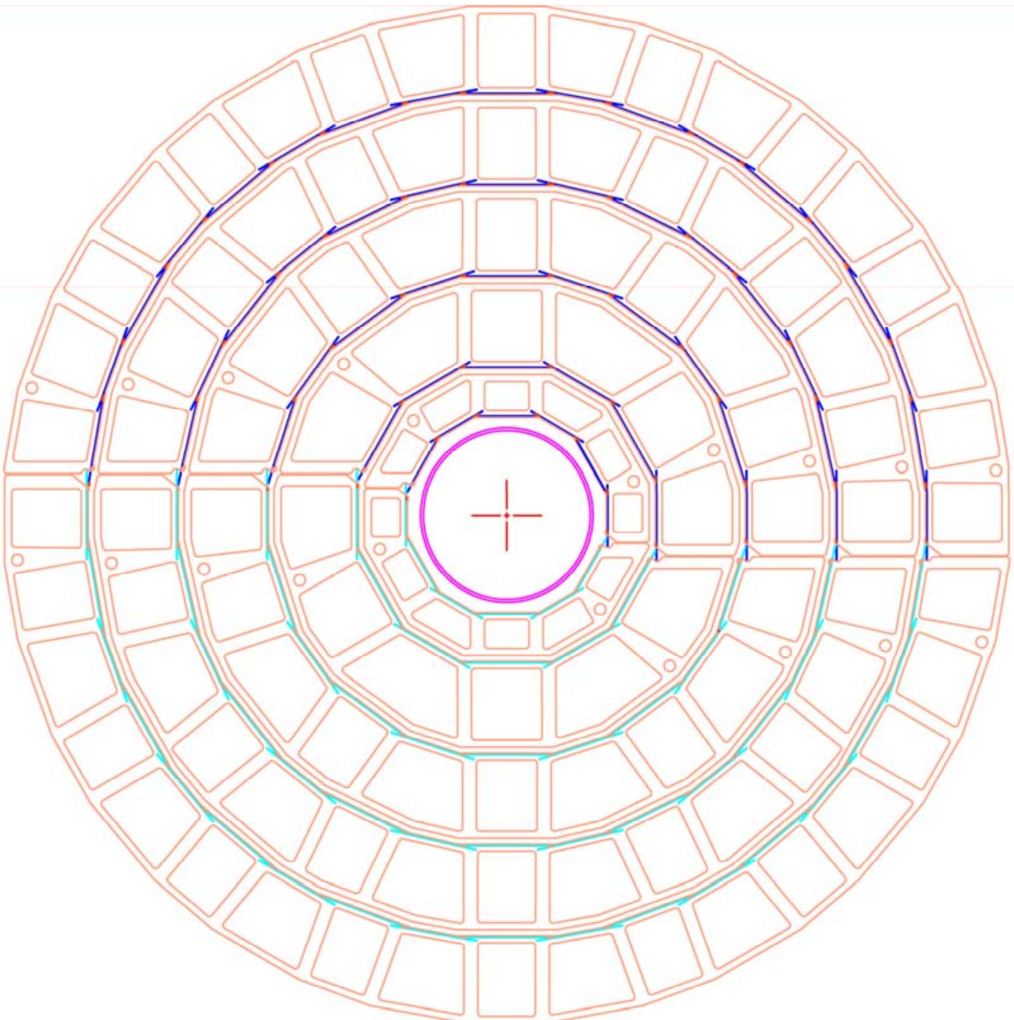
SiD Design Studies and Issues

- 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).



"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**



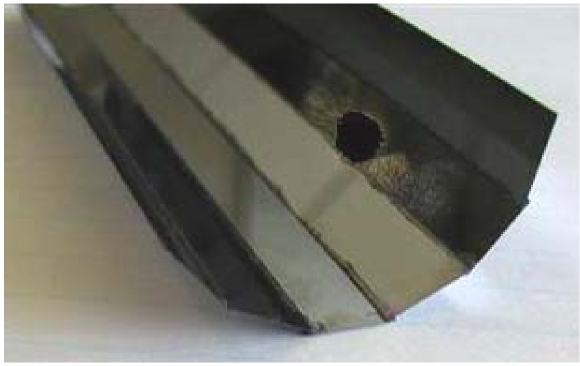
Sensor active widths:
L1: 8.6 mm
L2 - L5: 12.5 mm
Cut - active width: 0.08 mm
Inner radii:
A-layer: 14, 21, 34, 47, 60 mm
B-layer: 14.4593, 21.4965, 34.4510,
47.3944, 60.3546 mm
Sensors per layer:
12, 12, 20, 28, 36
Sensor-sensor gap: 0.1 mm
Sensor thickness: 0.075 mm
7 June 2007, 14 August 2007

- **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

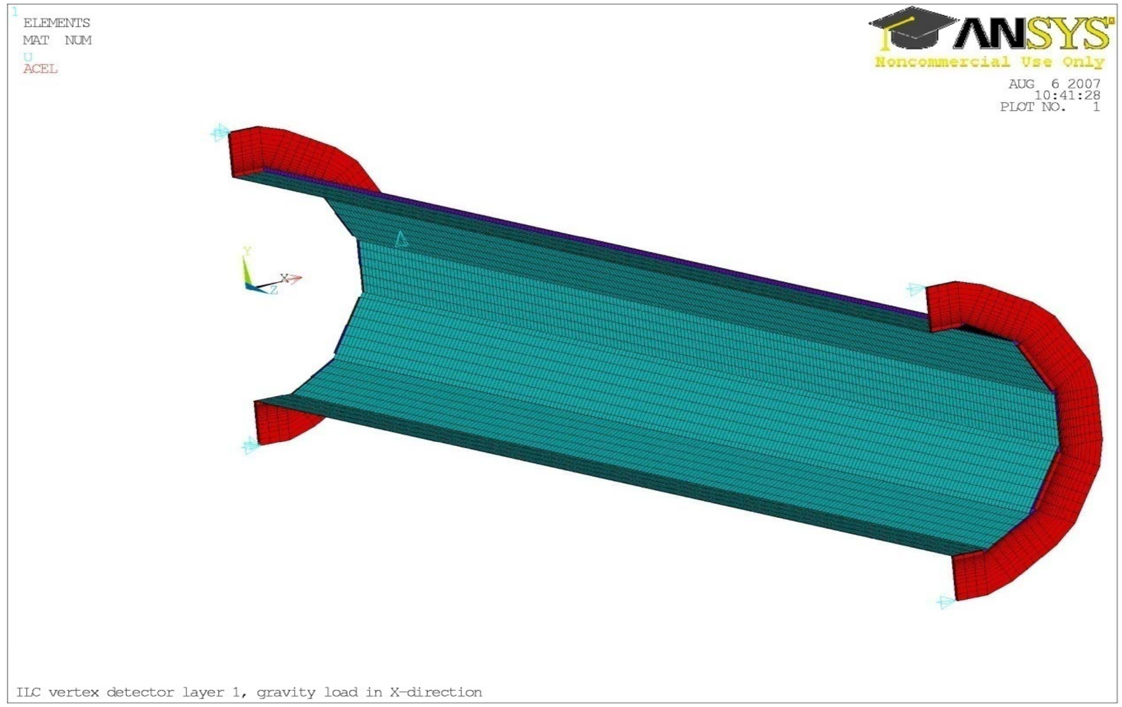
- This version of the vertex detector uses only the silicon sensors in "cylindrical" portions of the structure.
  - They are connected along their long edges by thin beads of epoxy.
  - Thin, flat carbon fiber/epoxy end membranes included in the model.
  - These membranes will be refined as a more detailed 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)

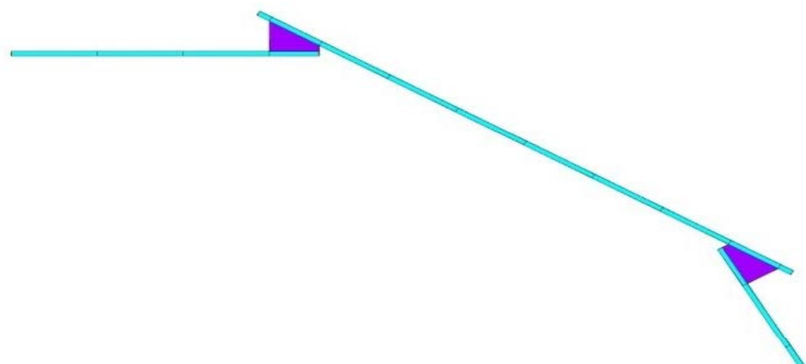


UW All-silicon FEA

Model of layer 1

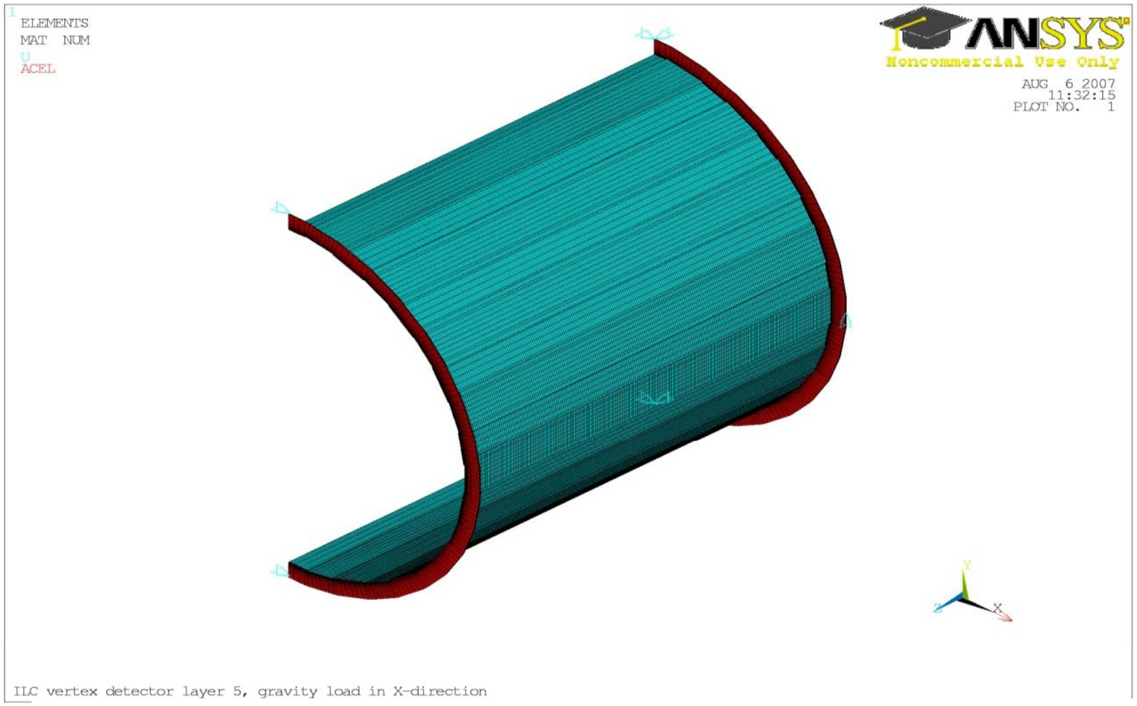


Detail of model of layer 1 showing the 0.7 mm wide epoxy joints.

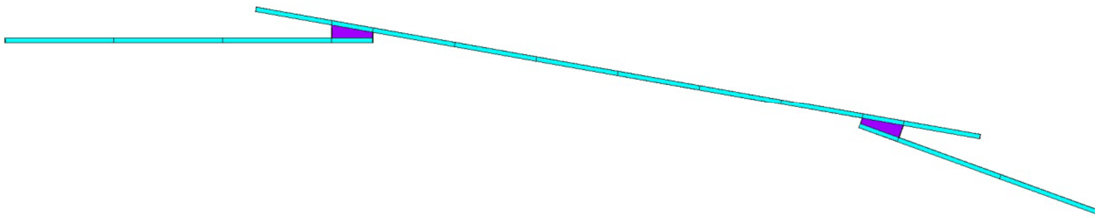


UW All-silicon FEA

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

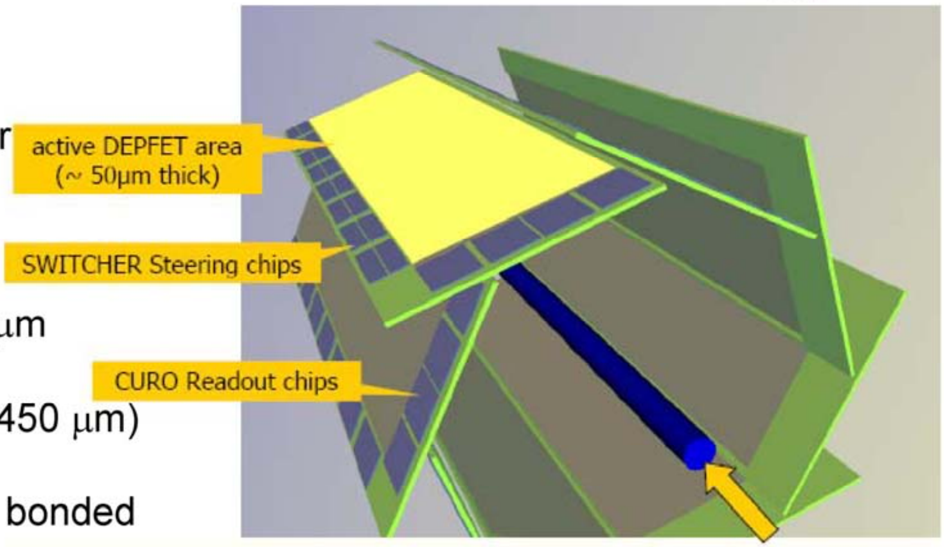
End rings may need to become a sandwich of SiC foam and silicon skins for low temperature operation.

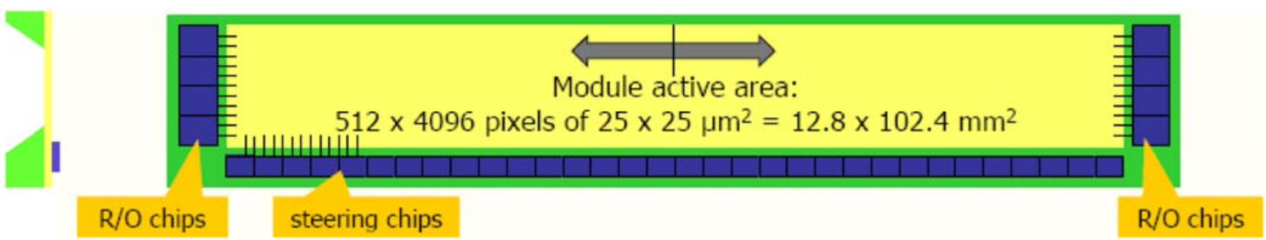
MPI Presentation, Vertex Detector Review

Module Concept & Material Budget

Innermost Layer:

- One self supporting Si-sensor
- Readout at both ends
- Sensitive area thinned to 50 μm
- Support frame not thinned (~450 μm)
- Thinned (50 μm) ASIC bump bonded



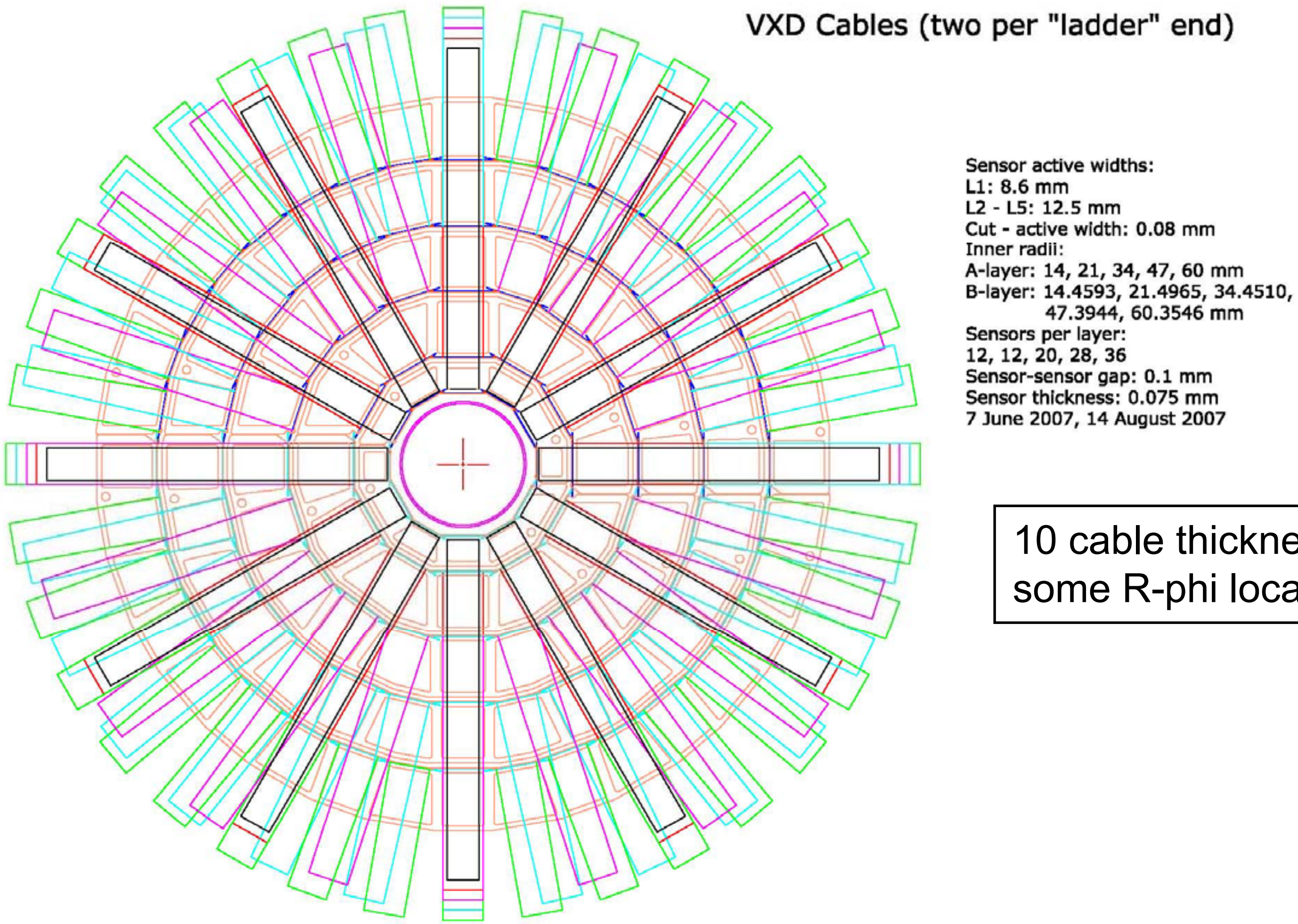


ILC VXD Review, Fermilab, October 23, 2007

Hans-Günther Moser, MPI für Physik

Cables

- **An "all silicon" layout with two cables per "ladder" end (only one of the two is shown)**
- All cables run radially outward to the periphery of the first disk.



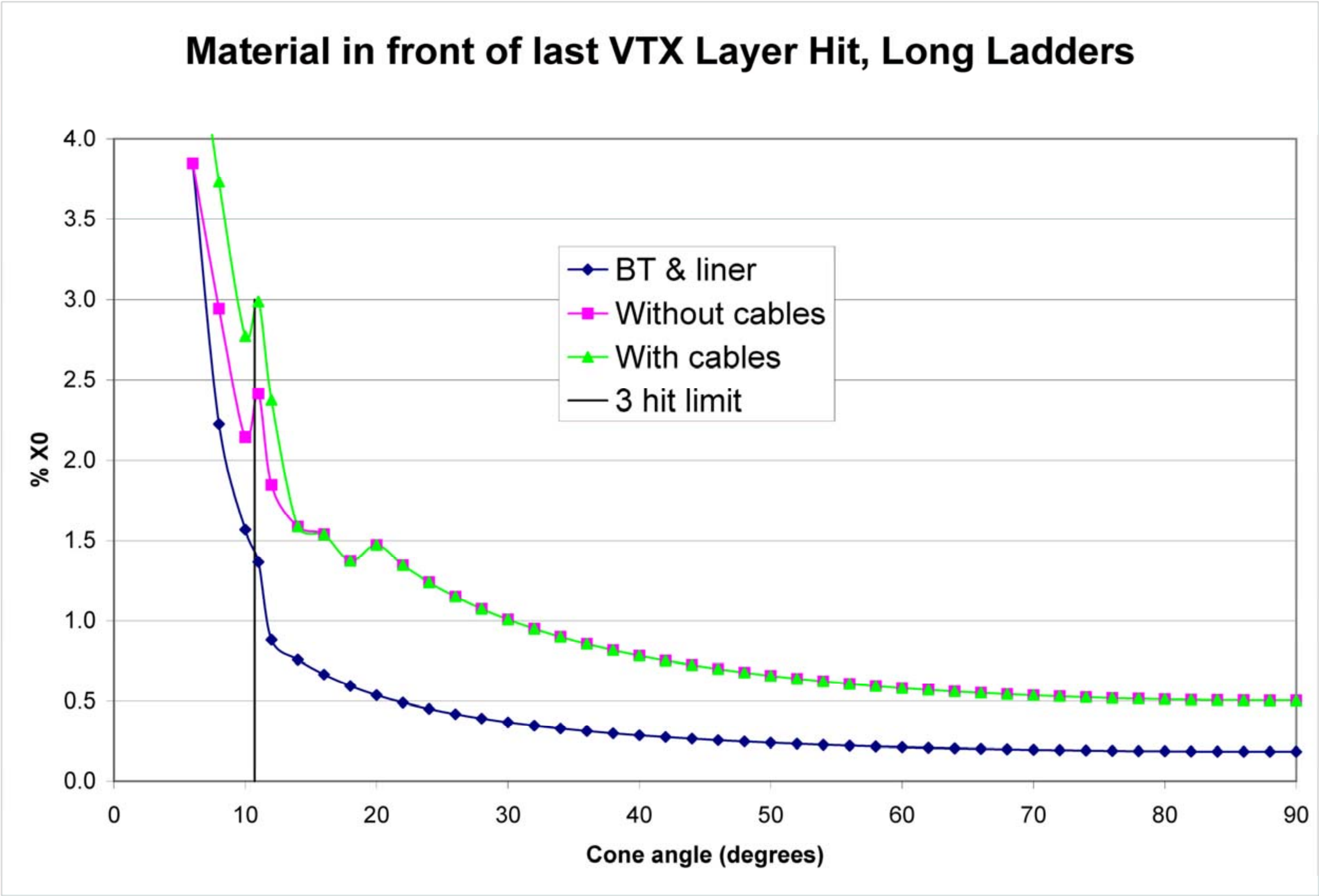
10 cable thicknesses at some R-phi locations

Cable Assumptions

- L1 cables have a total width of 6.4 mm and a conductor width of 5.9 mm.
- L2 – L5 cables have a total width of 8.0 mm and a conductor width of 7.5 mm.
- Andrei Nomerotski and I discussed the following cable stack for initial design purposes (based Upon D0 cables):
  - 18 μm Al, 75 μm kapton, 18 μm Al, 75 μm kapton spacer (14% spacer fill factor)
  - No credit was taken for the reduced conductor fraction in signal cables.
- 0.070% X0 per cable at normal incidence
- Four cables per “ladder” (two per end)
  - Power
  - Clock and control
  - Signal
  - Signal
- Each ladder was taken to represent 0.1% X0 at normal incidence.
- For each R, the number of radiation lengths was averaged over all phi.

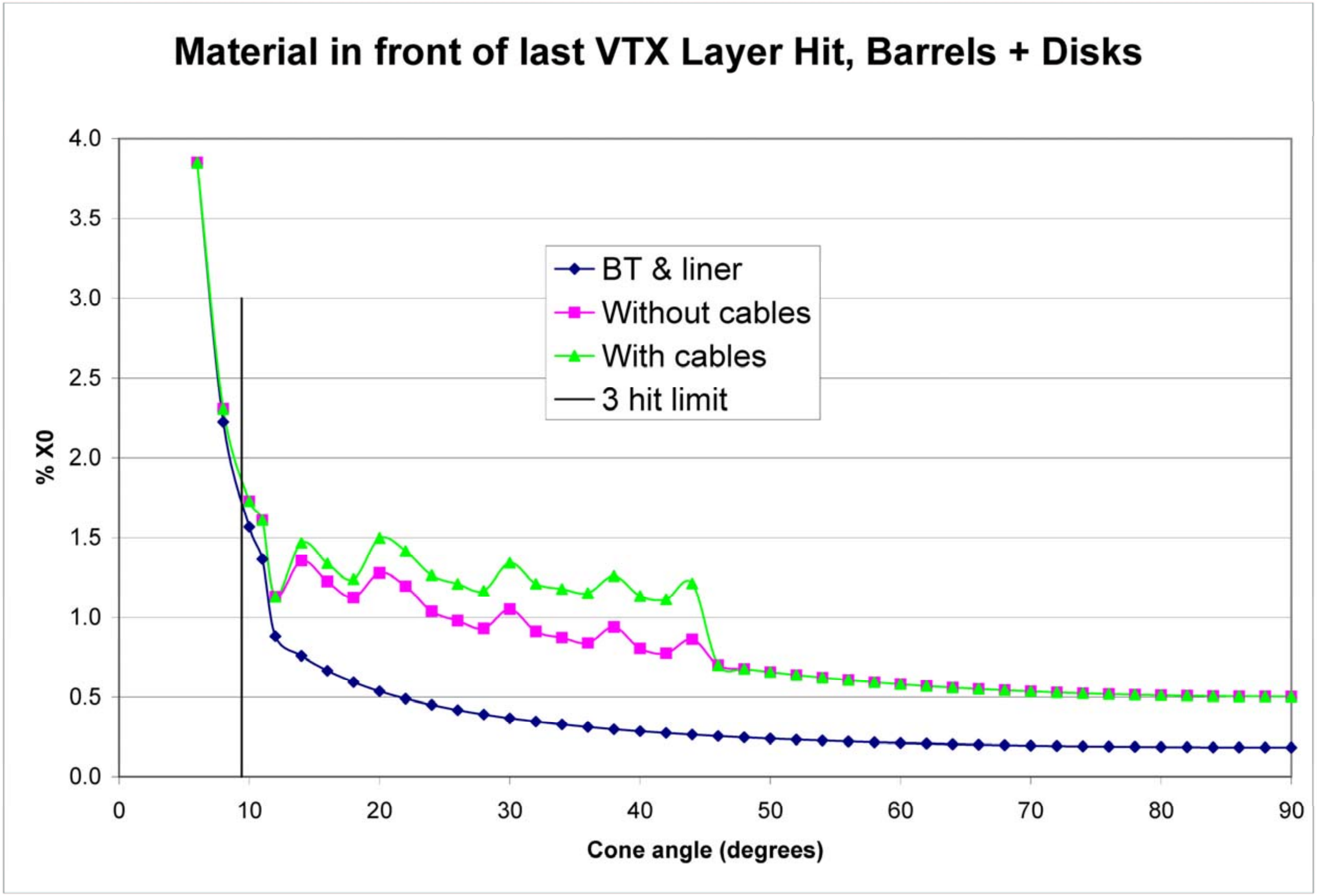
Cables

- SiD “ladder” locations, long ladders, no disks



Cables

- SiD all-silicon layout with disks



Cables

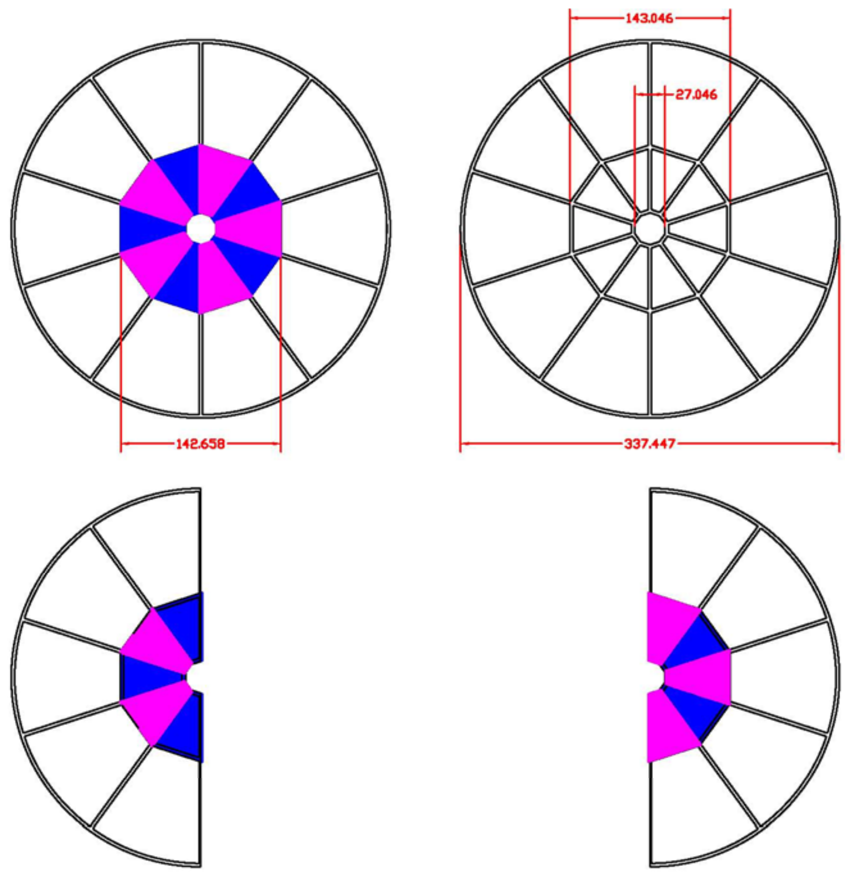
- The barrel / disk design has added material from roughly 20^o to 45^o.
  - Barrel cables plus barrel / disk overlaps
- However, we have yet to learn to make the 360 mm long ladders assumed for L2 – L5.
- In addition, a ladder that long is likely to require cables or equivalent between the ladder end and sensors closer to Z = 0.
  - That material has not been taken into account.
  - I propose to take that material into account by assuming four cables are needed for every 120 mm to 125 mm of ladder length, which is equivalent to the assumptions for the “ladders” of the barrel / disk design.

Cables

- Work on cabling is currently in progress.
- For the barrel / disk geometry, another obvious choice is to run barrel cables to smaller radius and then along the beam pipe.
  - With that geometry, there would be some loss of acceptance at the most forward cone angles.
  - That will be checked.
- Obstruction of cooling gas flow will also be checked for each cable geometry.
- Finally, we realize that a more proper evaluation of cable paths would be based on multiple scattering contributions as a function of momentum, location of the starting point of a trajectory, starting angle, and magnetic field strength.
  - Those calculations will be made.

Disks and Sensors

- For disks, sensor geometry along the inner (low radius) edge may be critical.
- Wedge-shaped sensors may be needed for disk tiling.
  - Such sensors could be more practical with some sensor technologies than others.
  - Please consider and provide advice.



Contour around the beam pipe matters.

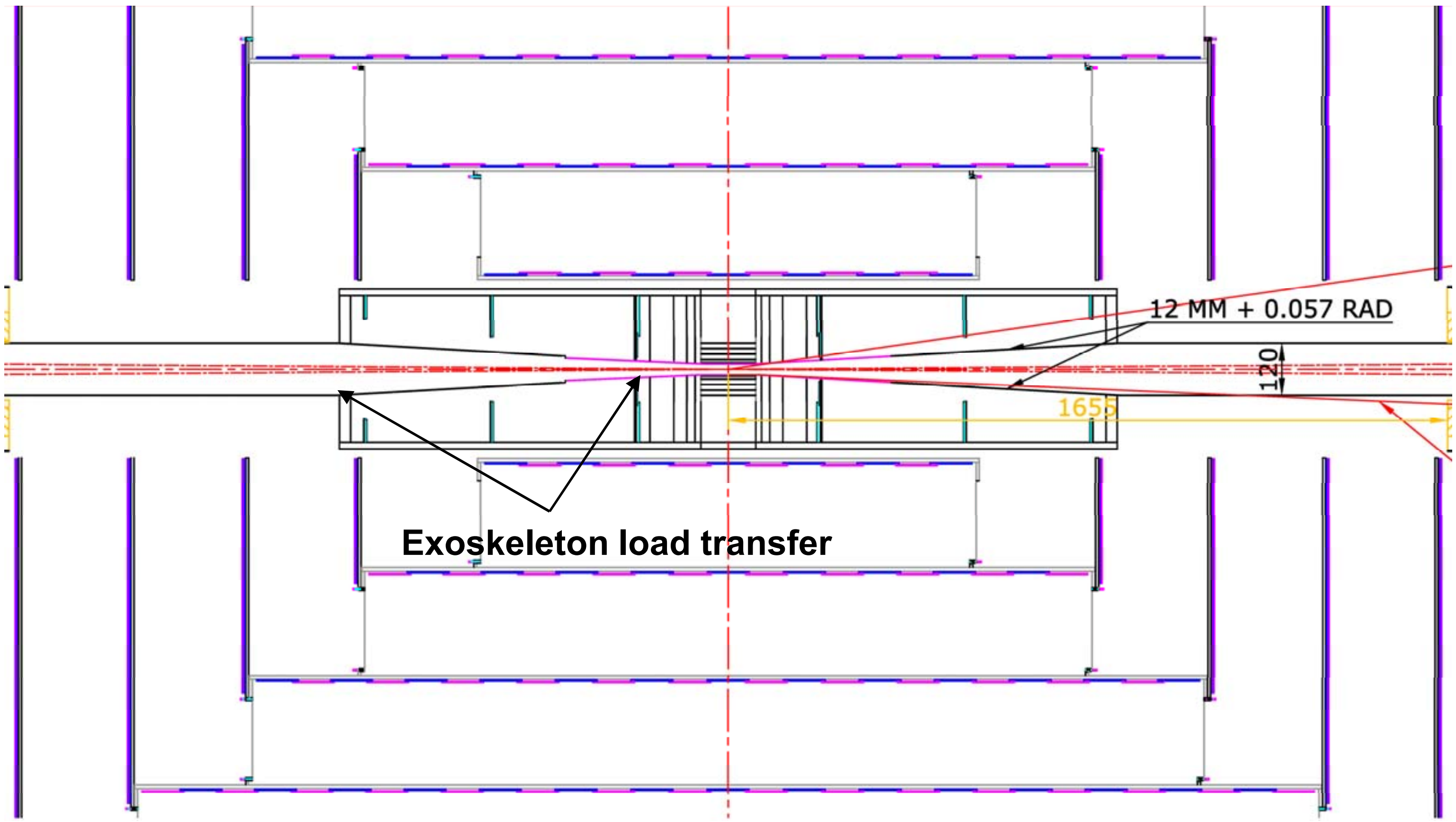
To match the innermost barrel layer, symmetry should probably be 12-fold or higher, not the 10-fold shown.

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.
- Moving power from the sensors to cables is not necessarily wonderful.
- However, heat removal estimates may be quite conservative (factor of 10?) if we do not insist on laminar flow.

SiD Vertex Detector & Beam Pipe Support

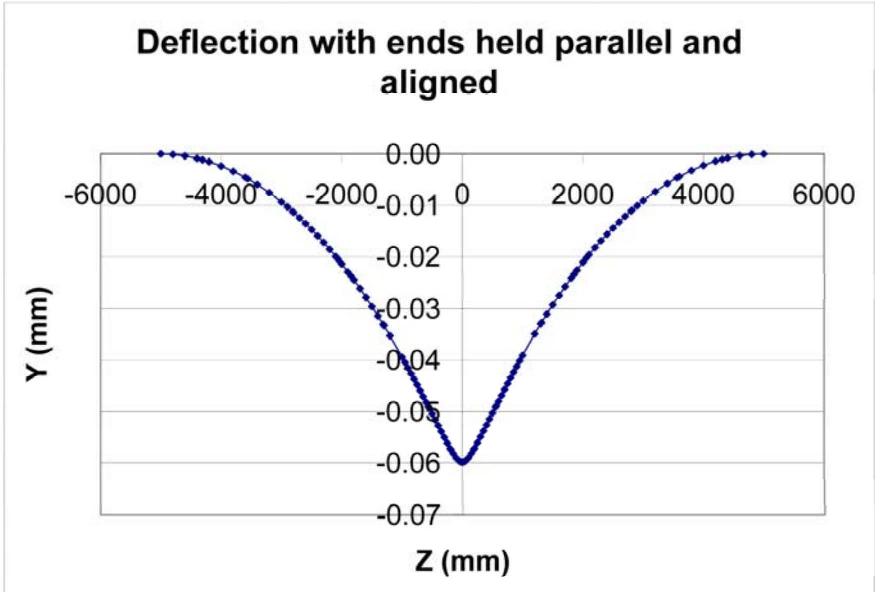
- The CF laminate exoskeleton not only supports the vertex detector from the beam pipe, it also holds the small radius, beryllium portion of the beam pipe straight.
- Both the beam pipe and the exoskeleton bend in the process.



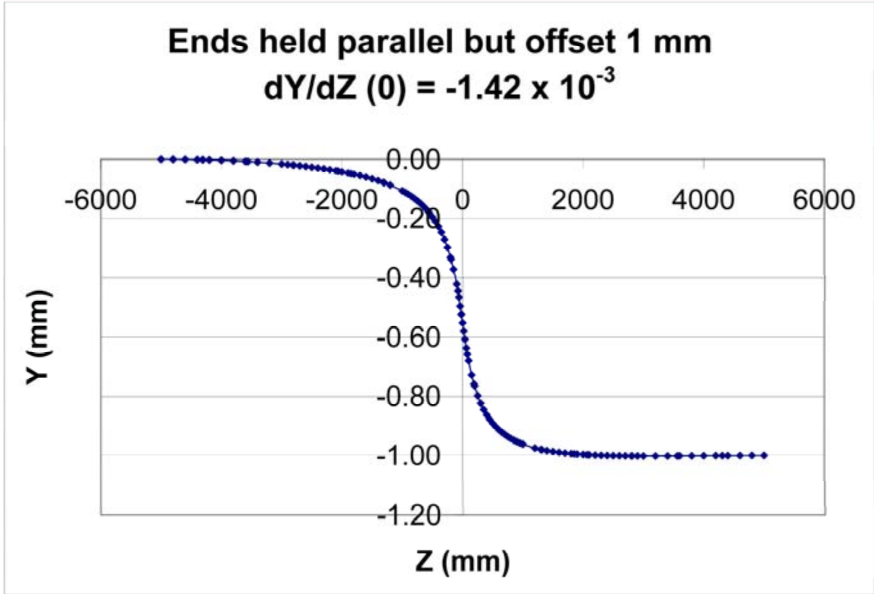
Beam Pipe Deflections

- 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.

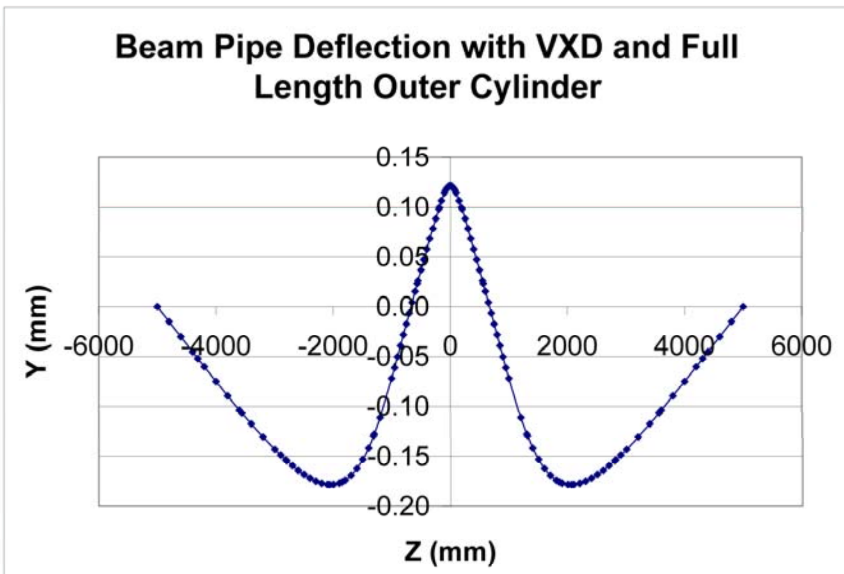


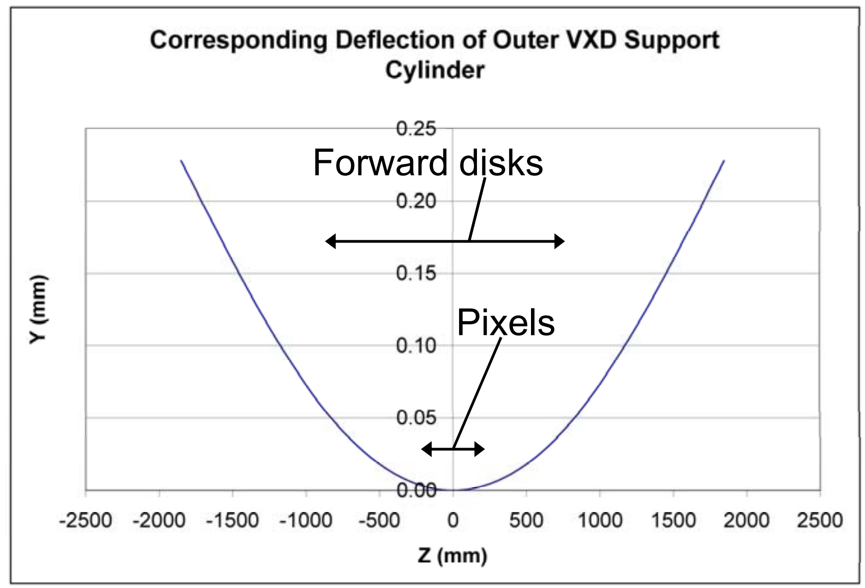
Maximum stress ~ 20 MPa



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.

Beam Pipe Fabrication

- Kurt Krempetz (Fermilab) and Marco Oriunno (SLAC) visited Brush-Wellman Electrofusion (BWE) last January. They were told:
- Any beryllium wall thickness less than 1 mm will require selecting the material for uniformity and lack of porosity.
- BWE would prefer to make the conical sections be rolling sheet material.
  - The motivations are cost and availability of material.
  - A "splitter" joint would run the full cone length at one azimuth.
    - Added strip of beryllium
    - Four aluminum fillets
  - Not a very good solution in my opinion.
- BWE was also not happy about half lap joints between longitudinal sections of tubes.
  - Those joints exist in D0 and CDF beam pipes.
- I am worried that these may reflect personnel changes at BWE.

Comments / Conclusions

- Since the last workshop in Ringberg, we have learned a lot about mechanical design constraints.
  - While some uncertainties remain, we know enough to keep fully occupied.
  - On the other hand, one reason we are able to keep so occupied is that resources are quite limited and have been reduced.
    - Some resources will be very difficult to replace.
- A realistic, accepted schedule would be a great help towards restoration of resources and understanding their scheduling.
- Designs are progressing well and are beginning to show commonality among the various concepts.
- Maybe we will all converge on the same set of solutions.