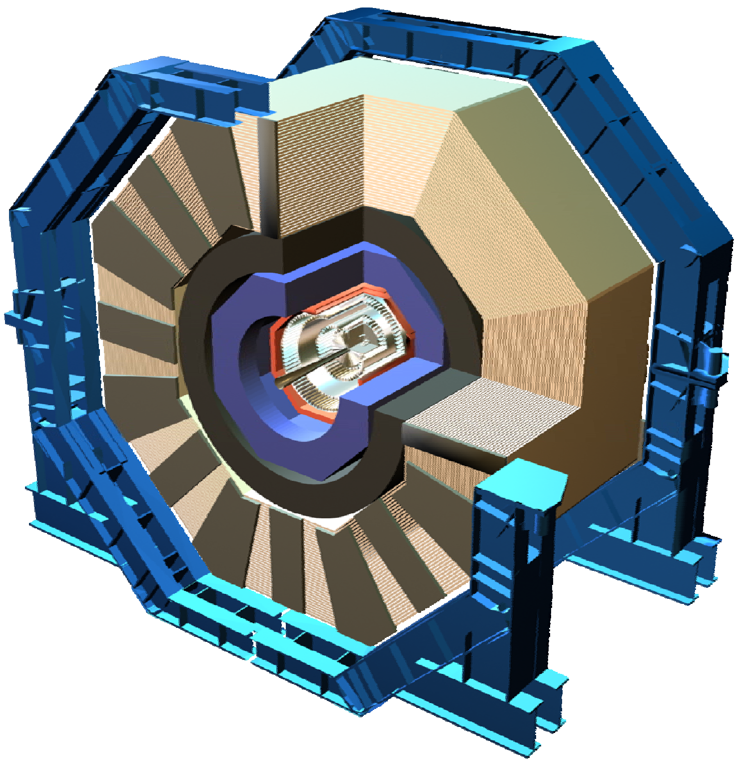
Tracker and Vertex Detector Design



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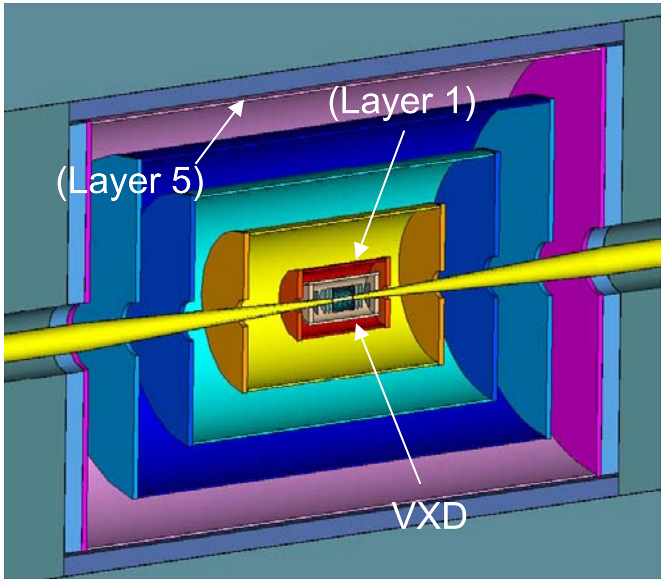


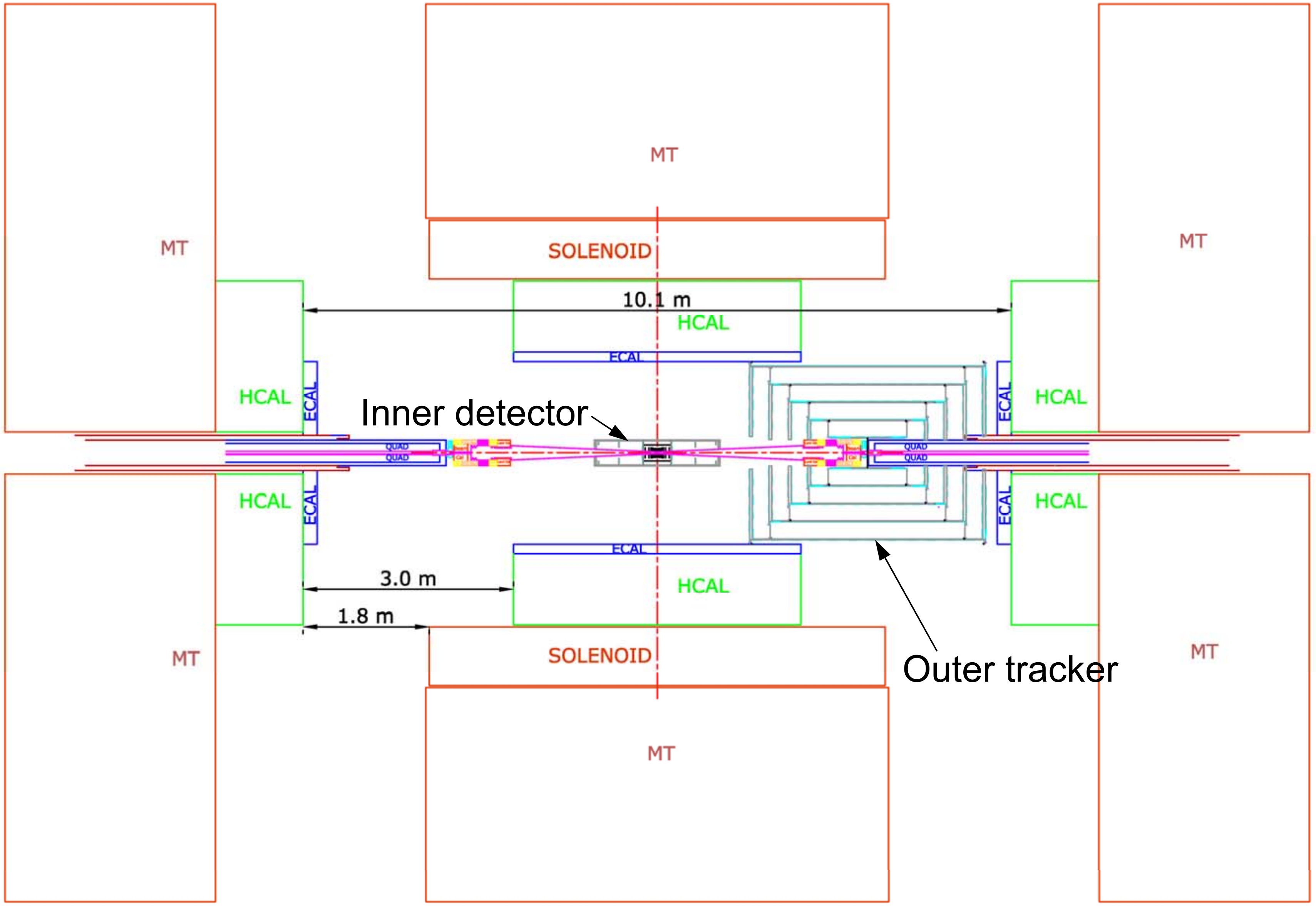
Introduction

- The present tracker and vertex detector layouts will be described.
  - Some of considerations which led to those layouts will be discussed.
- Design considerations in implementing the layouts will be described.
  - Module arrangements with the outer tracker barrels
  - Outer tracker disks
  - Vertex detector barrel support
  - Ideas for vertex detector disks
- Some of the issues remaining to be addressed will be described along the way.
  - Power delivery and removal
  - Assembly

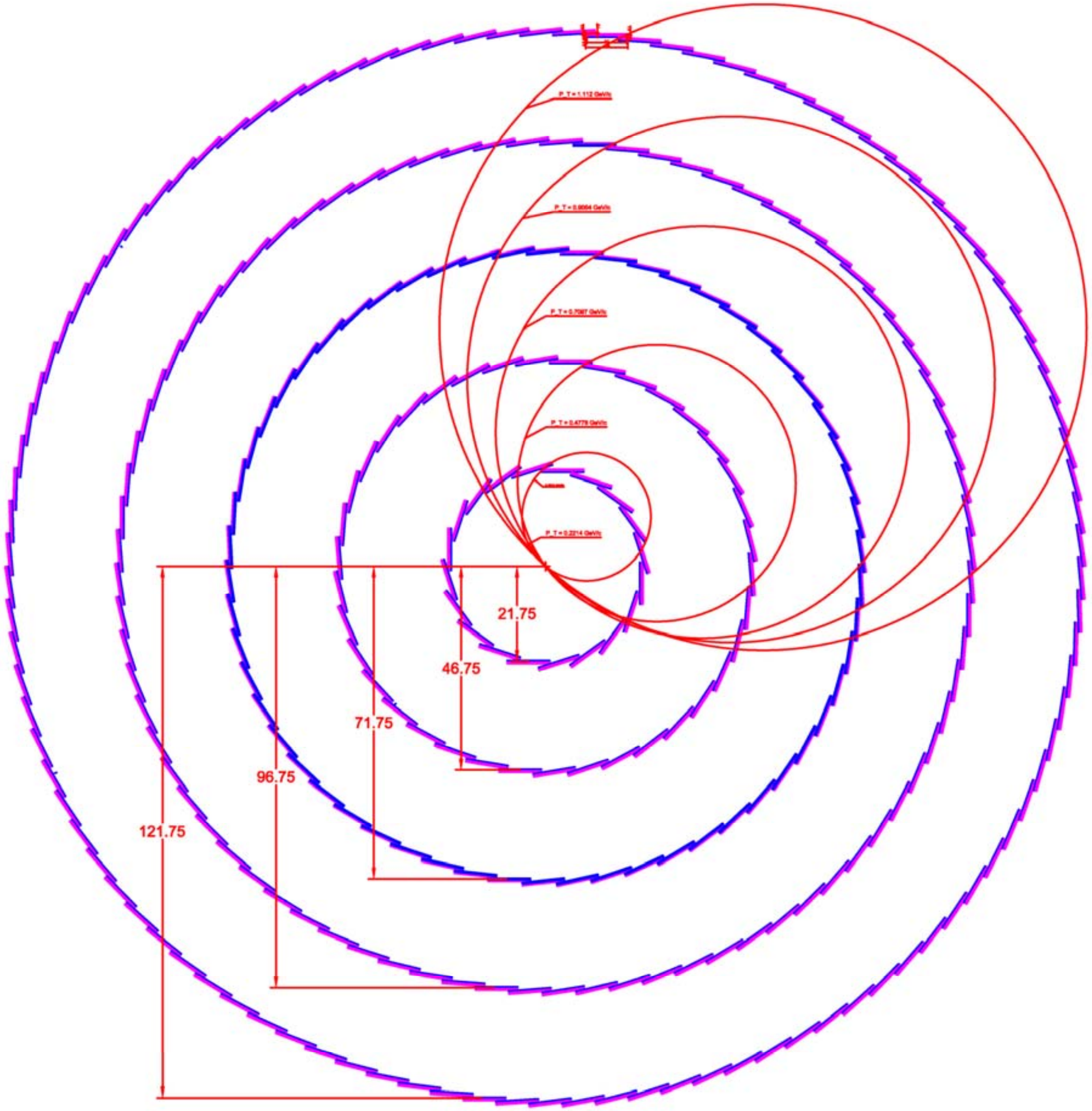
Servicing

- We had considered an arrangement in which the outer support half-cylinders of the vertex detector were lengthened to improve support provided to the beam pipe.
- That geometry does not work well unless the detector is opened a greater distance during servicing.
  - For the moment, the original, shorter length of the VXD support half-cylinders has been retained.
- Stay-clear boundary between the outer tracker and beam-line elements is 20 cm.
  - VXD must also observe that boundary.

Detector Open / Full Access to Inner Detector



Outer Tracker End View



- Sensors positioned mid-way through the thickness of a box
- Closest separation between boxes = 0.1 cm
- Boxes are square
  - Outer dimensions = 0.3 cm x 9.65 cm x 9.65 cm
  - Sensor active dimensions assumed to be 9.2 cm x 9.2 cm

Outer Tracker Barrel Sensor Arrangement

Layer	# Phi	# Z	Rot. Angle	R (cm)	P_T (GeV/c)
1A	20	7	10.12^o	21.75	
1B	20	6	9.94^o	22.15	0.221
2A	38	9	7.03^o	46.75	
2B	38	10	6.97^o	47.15	0.478
3A	58	13	6.60^o	71.75	
3B	58	12	6.57^o	72.15	0.710
4A	80	15	6.60^o	96.75	
4B	80	16	6.58^o	97.15	0.906
5A	102	19	6.58^o	121.75	
5B	102	18	6.56^o	122.15	1.112

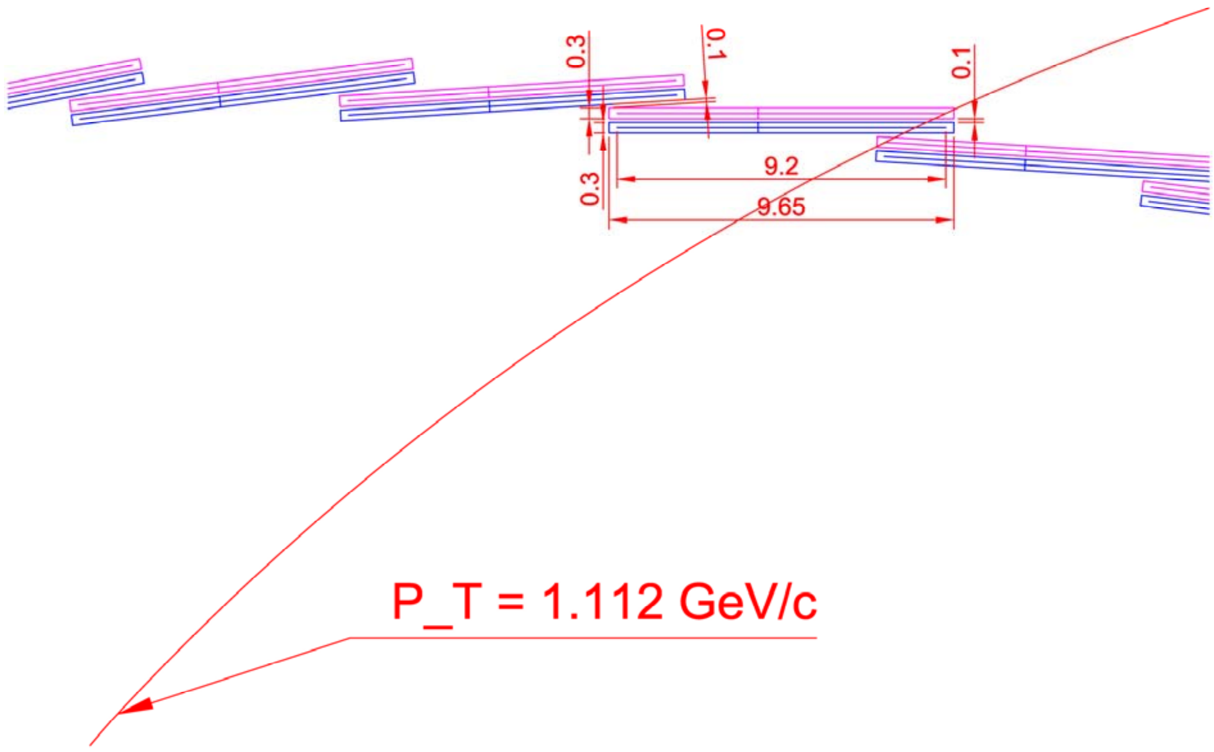
Layout corresponds to 8686 barrel sensors, each with 1840 readout channels

Strip pitch = 25 μm. Readout pitch = 50 μm.

Comments on Sensor Arrangement

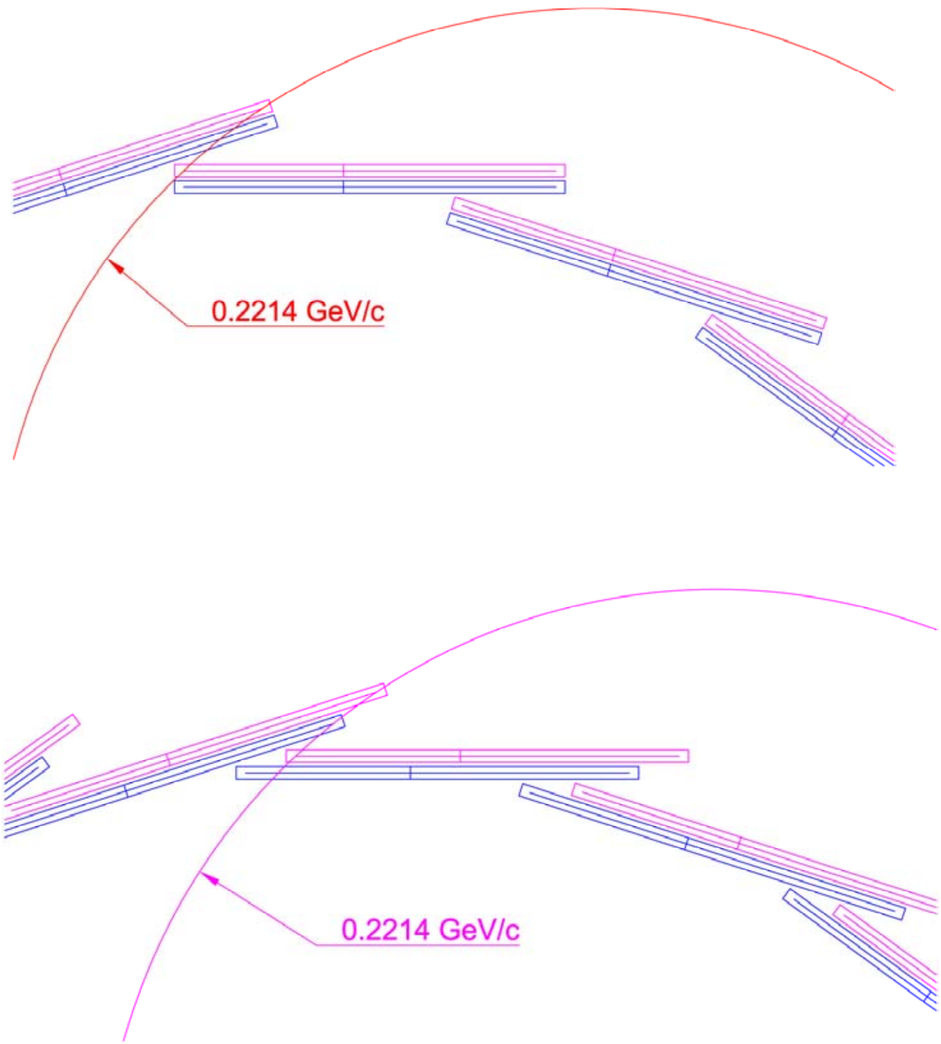
- Sensors alternate in Z between A-layer and B-layer.
- # phi has been chosen to provide reasonable phi overlap while limiting material.
- The rotation angle listed is to sensor center and is the angle that would be applicable to Lorentz drift.
  - It seems difficult to fully compensate for Lorentz drift without opening phi gaps between sensors or adding substantial material.
  - Nevertheless, we should know the ideal angle at 5 T and understand consequences.
- Layer radii are incremented by 25 cm.
- The P_T listed is the momentum below which tracks from the origin can pass through a phi gap between sensors (no multiple scattering or energy loss).
  - B-layer is always slightly worse than A-layer, so only the B-layer has been listed.
- Thicker boxes would increase the gap between sensor active areas.
  - We should keep secondary vertices in mind.

Outer Tracker Barrel 5



- Each sensor is positioned mid-way through the thickness of a box
- Box thickness was chosen to be 0.3 cm to limit the gaps between sensors.
- A- and B-layer boxes have been aligned with the hope that might simplify box mounts.

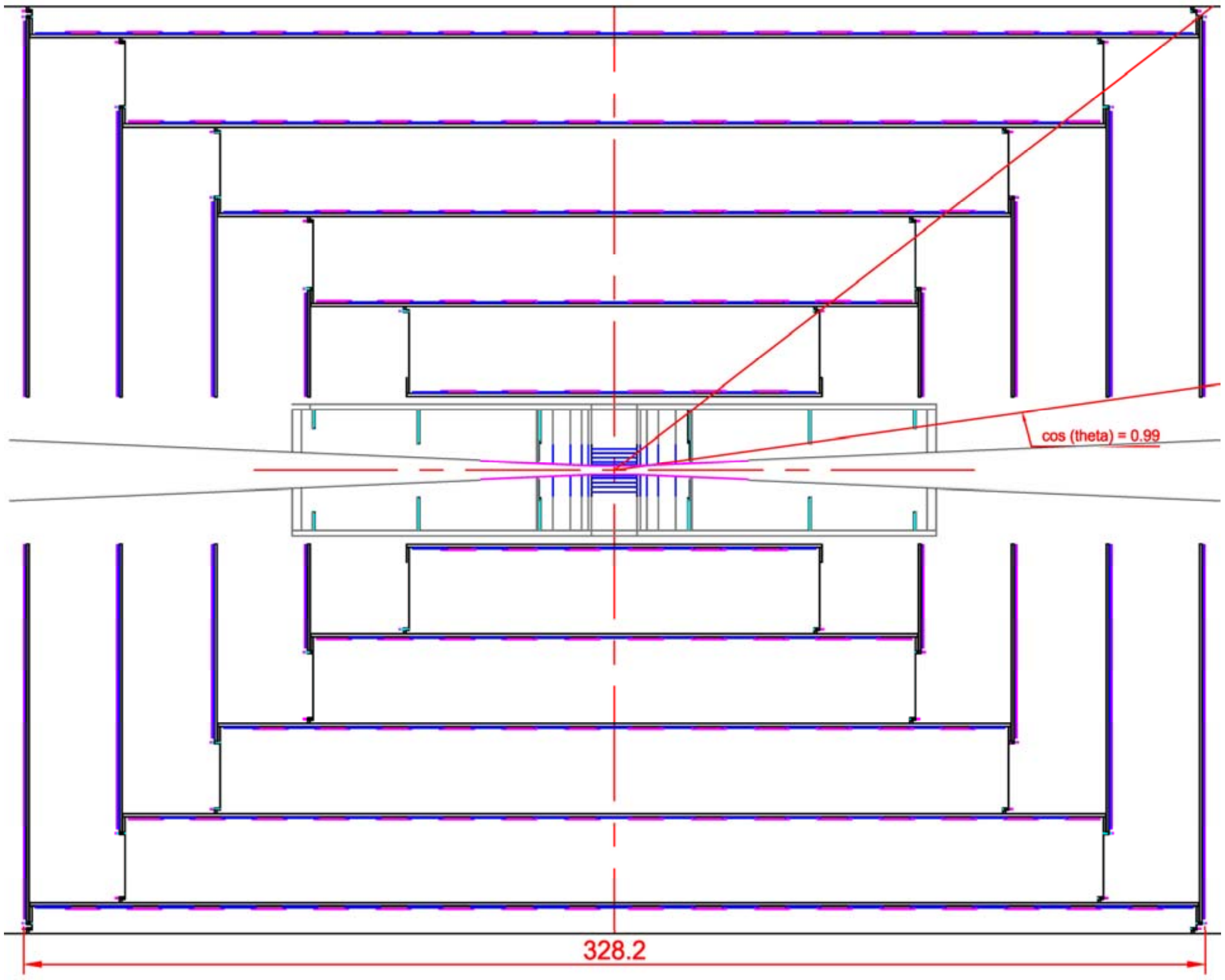
Outer Tracker Barrel 1



- Offsetting the B-layer boxes with respect to A-layer boxes improves the low P_T cut-off for the A-layer, but not the B-layer (the worse of the two).
- Offsetting slightly could make rotation angles of the two sub-layers identical.

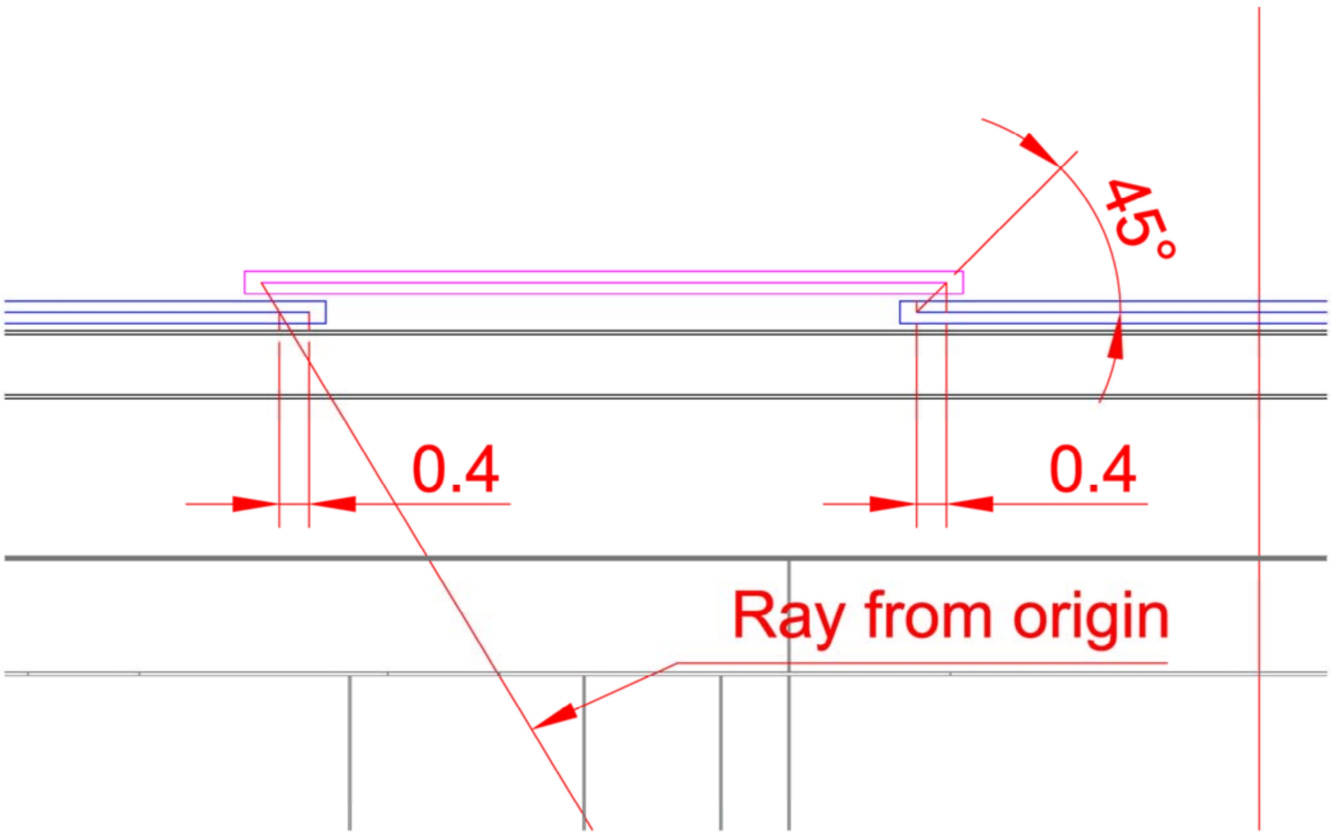
R-Z View

- By lengthening inner barrels of the outer tracker, pointing material has been spread, not eliminated.



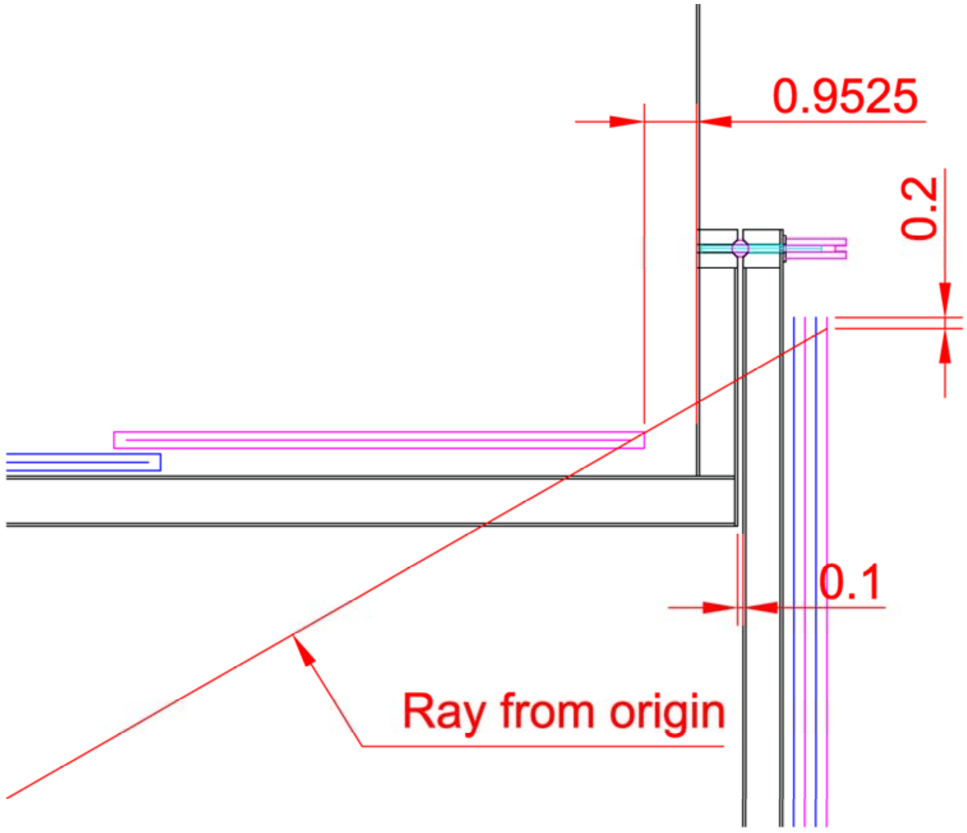
Outer Tracker R-Z View

- Typical A-layer to B-layer overlaps (all layers)
- Depending on how hermetic we want the tracker to be for secondary vertices, we could make other choices.



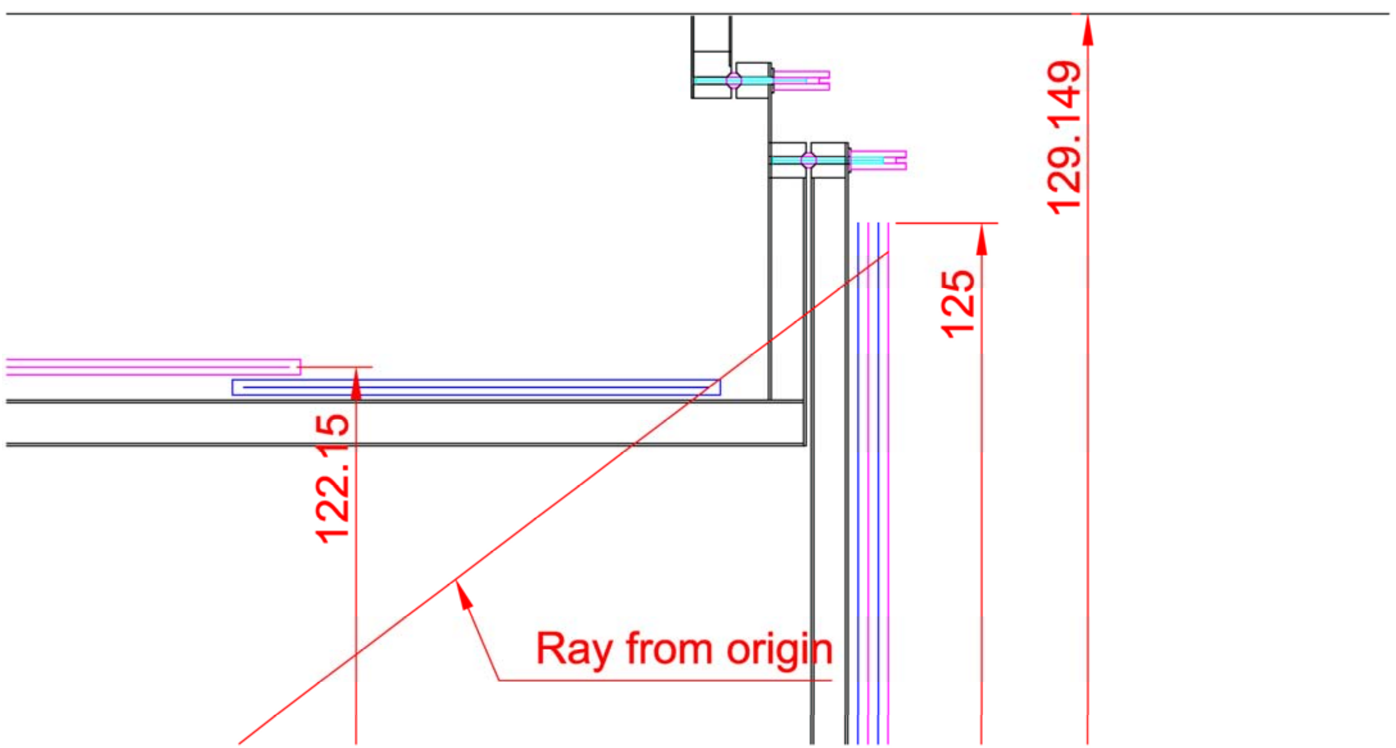
Outer Tracker Disk-Barrel Interface

- Disks have been represented by four planes with a plane-to-plane separation of 0.2 cm.
  - That will need to change once we have developed a tiling concept.
  - Gaps for cabling also need to be understood.



Outer Tracker R-Z View

- A clear difficulty arises at barrel 5 mounts.
  - Maybe mounts can fit within vertices of the calorimeter inner polygon.
    - What is the inner profile of the calorimeter?
  - Give up disk – barrel overlap?
  - Change barrel radii?



Disk Sensor Arrangement

- Tiling for disks is under development.
- To get an idea of some of the design issues, assume that each sensor has the same area and number of readout channels as those in the barrels.
  - Assume that each disk measures two coordinates.
  - Assume that for each of those coordinates, sensors are arrayed at two Z-positions to provide overlap in R.
  - Assume that phi overlap is provided by a spiral geometry.
  - Assume sensor area / area to be populated can be scaled from that in the barrels.
  - Assume that active area of a sensor is $(9.2\ \text{cm})^2 = 84.64\ \text{cm}^2$ (the same as in the barrels).
- Those assumptions lead to about 4738 sensors for the outer tracker disks (sum of both ends).
  - A slightly different number was given in an earlier presentation.

Outer Tracker Power Dissipation

- I'm not sure what the power dissipation of the outer tracker readout chip will be in the end, or what result was obtained for the latest K-PIX prototypes.
- For design purposes, I've assumed the power dissipation suggested in the 2004 Victoria workshop:
  - 0.178 watt per 128 channels with the readout chips fully powered and a factor of 80 reduction for power cycling.
  - That leads to 1.39 milliwatt per readout channel with the chip fully powered and ~ 17.4 µwatt per channel averaged over a power cycle.
  - Average power per module would be 32 milliwatts for a module with 1840 channels and chips which match that channel count.
  - If instead, each module had 2 readout chips and each chip had 1024 channels, the average power per module would be 35.6 milliwatt.
- Power dissipated in cabling within the sensor region, transceivers, and voltage converters adds to the heat to be removed.

Outer Tracker Power Dissipation

- Assume 32 milliwatt per sensor module for the moment.
- Assume that barrel modules are arrayed as described earlier.
- In the disks, assume that power dissipation per unit area is the same the barrel average.
- Assume each disk measures two coordinates.

Total = 429.3 watts

Barrels	P (watts)	Disks	P (watts) 2 ends
Barrel 1	8.3	Disk 1	9.5
Barrel 2	23.1	Disk 2	24.5
Barrel 3	46.4	Disk 3	45.4
Barrel 4	79.3	Disk 4	72.2
Barrel 5	120.7		
Sub-total	277.8	Sub-total	151.5

- Note that, with power ramped up, expected dissipation would be 80(429.3 watts) = 34.3 kilowatts.

Lorentz Forces

- At 2.5 volts, 34.3 kilowatts corresponds to 13.7 kilo-amps.
- Hence the interest in Lorentz forces due to the 5 T field.
  - Granted, the current would likely be distributed over many conductors.
- For a given current delivery path, the Lorentz force depends upon separation of supply and return currents and their orientations in the B-field.
  - Current flux is not necessarily uniform across the conductor cross-section, particularly when the current is being ramped.
    - AC losses may be different from DC losses.
  - One approach is to carry supply and return currents on flat-lines with supply and return parallel to one another and separated by a thin insulator.
  - In general, the force is in a direction which would tend to maximize the distance between supply and return currents.
  - Paths and stiffness of connections within modules may matter.
- The calculations need to be done.
  - I haven't done that yet. Maybe someone else has.

Sizing of Power Traces along Barrel Surface

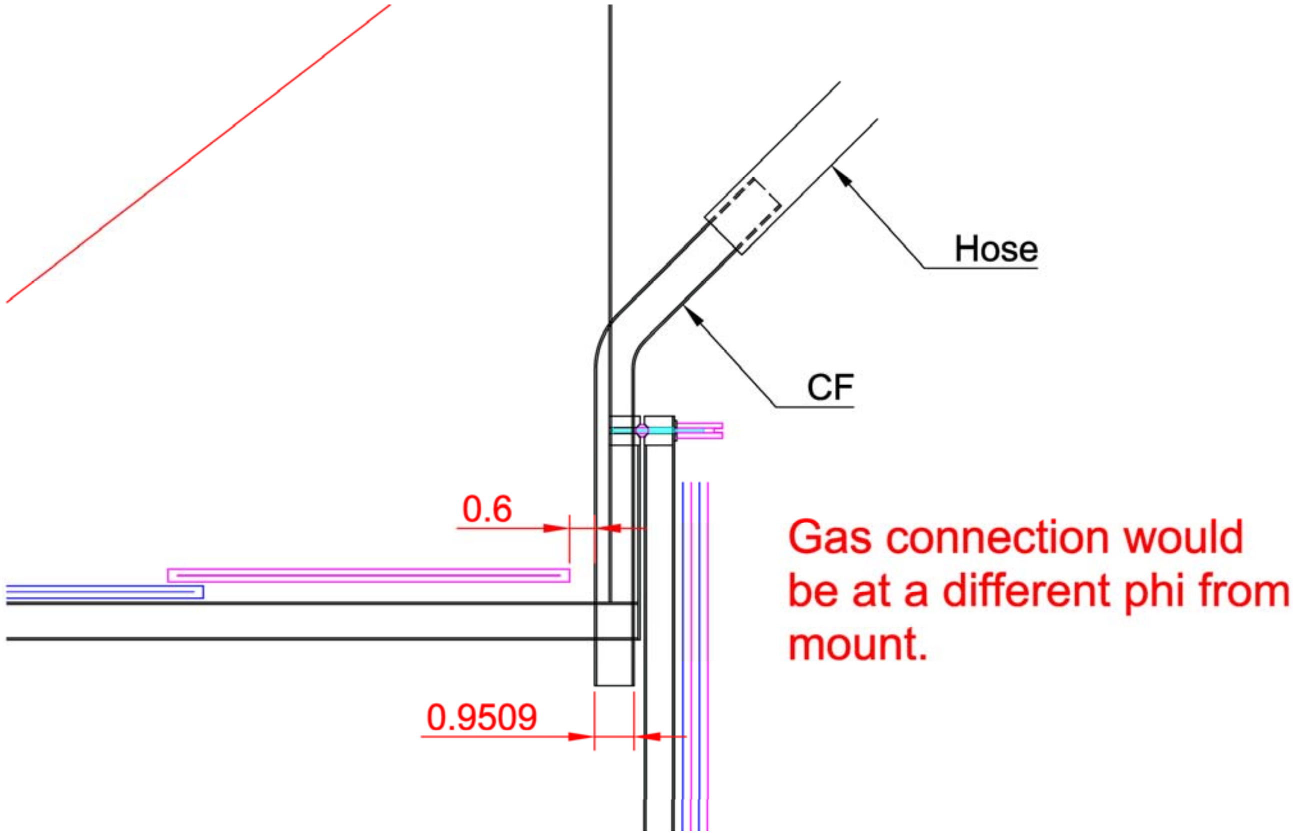
- Preliminary: steady-state
- Assume that 2.5 volts is delivered to sensor module.
  - In other words, sensor modules are individually powered with voltage conversion at the ends of a barrel.
  - Assume power per module = 80 * .032 = 2.56 watts.
  - Allow a voltage drop of 0.1 volts.
  - Then I = 2.56 / 2.5 = 1.024 amp.
  - Power dissipated is 0.1024 watt.
  - Total power / power delivered = 1.04.
- For copper:
  - Variation of resistivity with temperature is not taken into account.
  - Trace width = 3 mm => Thickness = 0.194 mm
  - For an ambient temperature of 20^{o} C, natural convection, and one exposed copper surface 2.5 mm x 3300 mm (to and from module):
    - T_copper = 29.1^{o} C.
    - Actual temperature should be less since we have forced convection.
- This looks OK provided copper cross-sectional area is acceptable, supply and return traces are sufficiently separated and not too close to sensors, and air flow past the copper is not restricted.
  - Stack-up of cables could lead to issues.

Air Flow

- Assume air enters the tracker region at +15^{o} C and that heat removal increases its temperature by $\Delta T = 10^{o}$ C.
  - The required flow rate depends primarily on ΔT and weakly on the assumed entry temperature.
    - 10% decrease in volumetric flow rate with a delivery temperature of -10^{o} C.
  - Density of dry air at 20^{o} C = 1.206 kg/m3
  - Specific heat = 1.0056 kJ/kg-K
- Then the required flow rate to remove 429.3 watts is 0.0354 m^3/s = 75.0 cfm.
  - I suggest planning for 100 cfm, since there are known additional heat sources and some not-so-well known.
  - For those familiar with D0, the purge rate of the D0 silicon enclosure is 50 cfm.
- We will need a reliable air cooling system and extremely reliable cooling interlocks.
  - Back-up tube trailers could address cooling system glitches and allow time for the interlocks to act.

Outer Tracker Disk-Barrel Interface

- Dry gas could be brought in via hoses connected to CF tubes.



Outer Tracker Disk-Barrel Interface

- First thoughts on gas connections
  - Need to work on reducing the number of tubes

Location	Number of tubes	Tube ID (inch)
Barrel 2 – disk 1 gap	4	0.21
Barrel 3 – disk 2 gap	20	0.21
Barrel 4 – disk 3 gap	36	0.335
Barrel 5 – disk 4 gap	72	0.335
Outside barrel 5	72	0.335

Assembly of Outer Tracker Barrels / Disks

- Assembly assumes modules which reproducibly engage mounts.
- Tooling would be provided to hold a barrel from its end rings or inner surface.
- Precision bars would carry mounts and position them on the cylinder outer surface, where they would be glued or otherwise attached.
  - Bar alignment requires a CMM, laser alignment system, or equivalent.
  - A CMM may allow more extensive and automated characterization of barrels or disks.
- Once mounts have been attached to the cylinder surface, modules can be installed by hand.
  - What measurements should be made after module placement?
- Cabling can be added in stages, allowing periodic checks that modules read out.
- Disk assembly would be similar to that of barrels, except that a disk would most likely be oriented horizontally and plates would be used to place module mounts.

Mating of Barrels / Disks

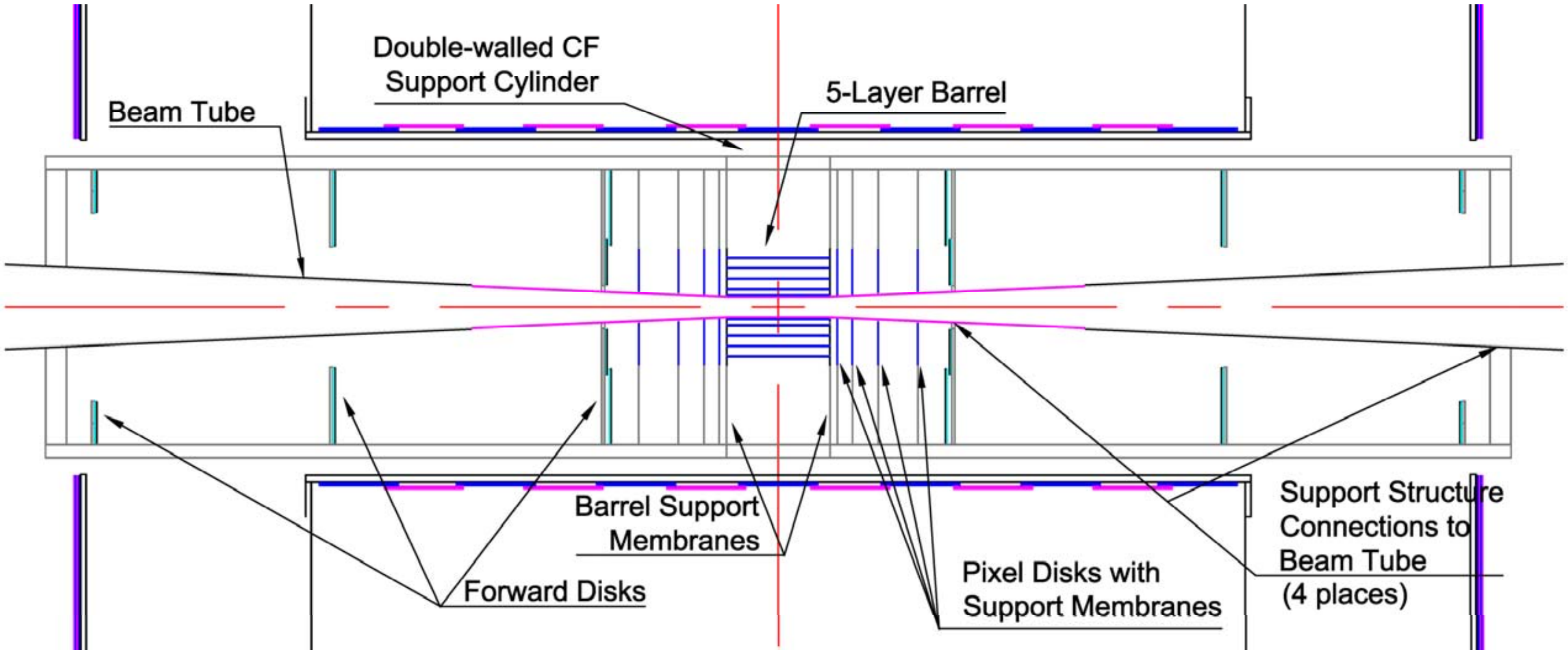
- Barrels and disks would remain on their fabrication tooling until we are ready to mate them.
- I propose mating from the outer barrel inward, so that support of mated assemblies can always be from the outer barrel.
- Two approaches seem reasonable depending on height clearance.
  - If height is sufficient, a C-frame lifting fixture can be used in conjunction with a crane or equivalent.
    - Overall inner length needs to be at least as great as the sum of the lengths of the outer two barrels plus longitudinal clearance.
    - Tooling must allow transverse and rotational adjustments.
  - If height is limited, a carriage system could provide support from below.
    - That was done in mating the D0 fiber tracker barrels.
- Once all barrels have been mated, their cabling should be dressed before disks are added.
- Disks would be added either one at a time or in end-to-end pairs.
  - Cabling needs to be dressed after each disk is installed.

Outer Tracker Issues

- Compensation for Lorentz angle
- Desired hermeticity in R-Z, R-Phi
- Module details
- Disk tiling
- Outer radius and barrel 5 mounts
- Gas and cable flow paths
- Lorentz forces
- Clear paths for laser alignment monitoring

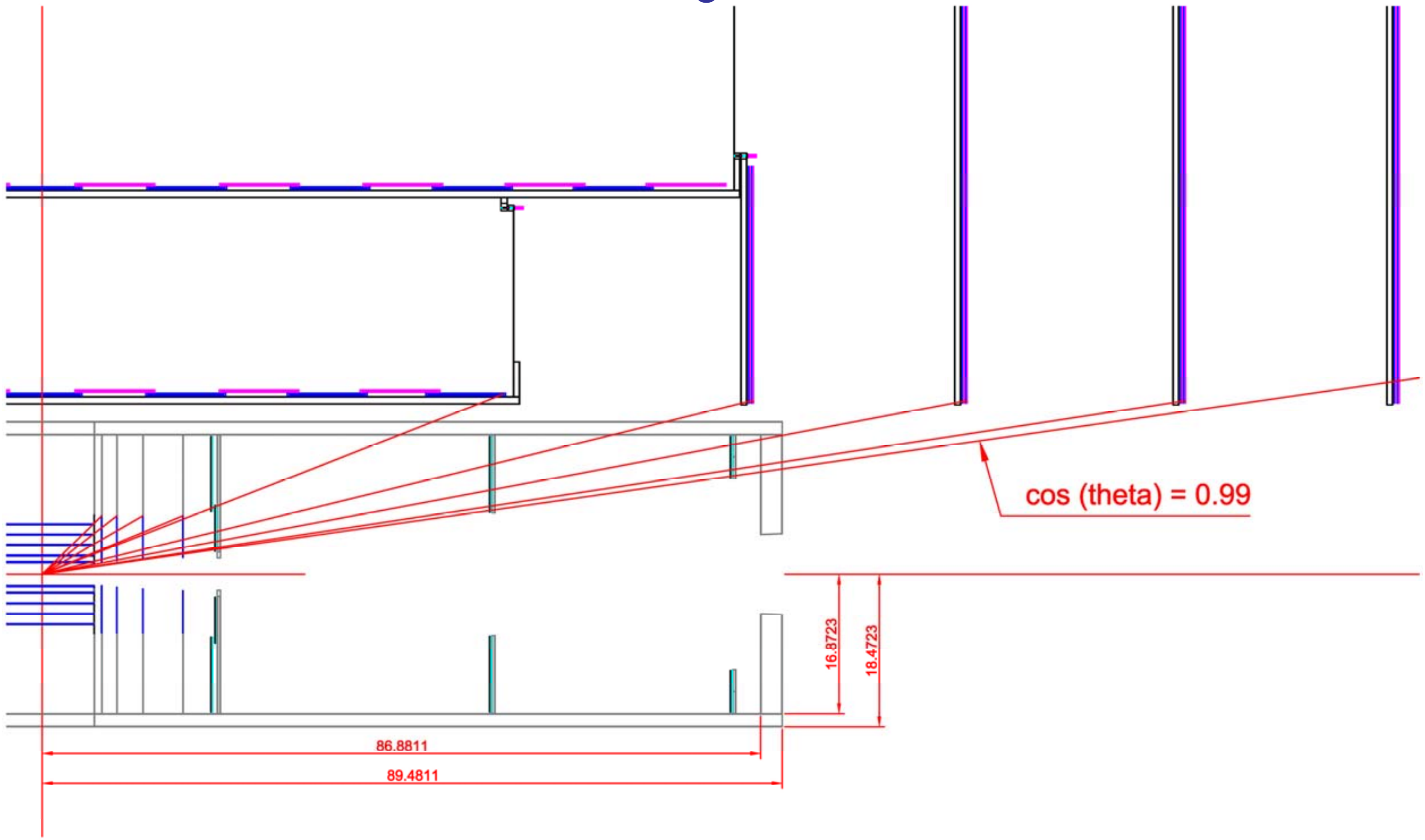
Vertex Detector

- Layout is basically unchanged, but disk active radii and z-positions need to be updated slightly on the drawing to match sidmay06.



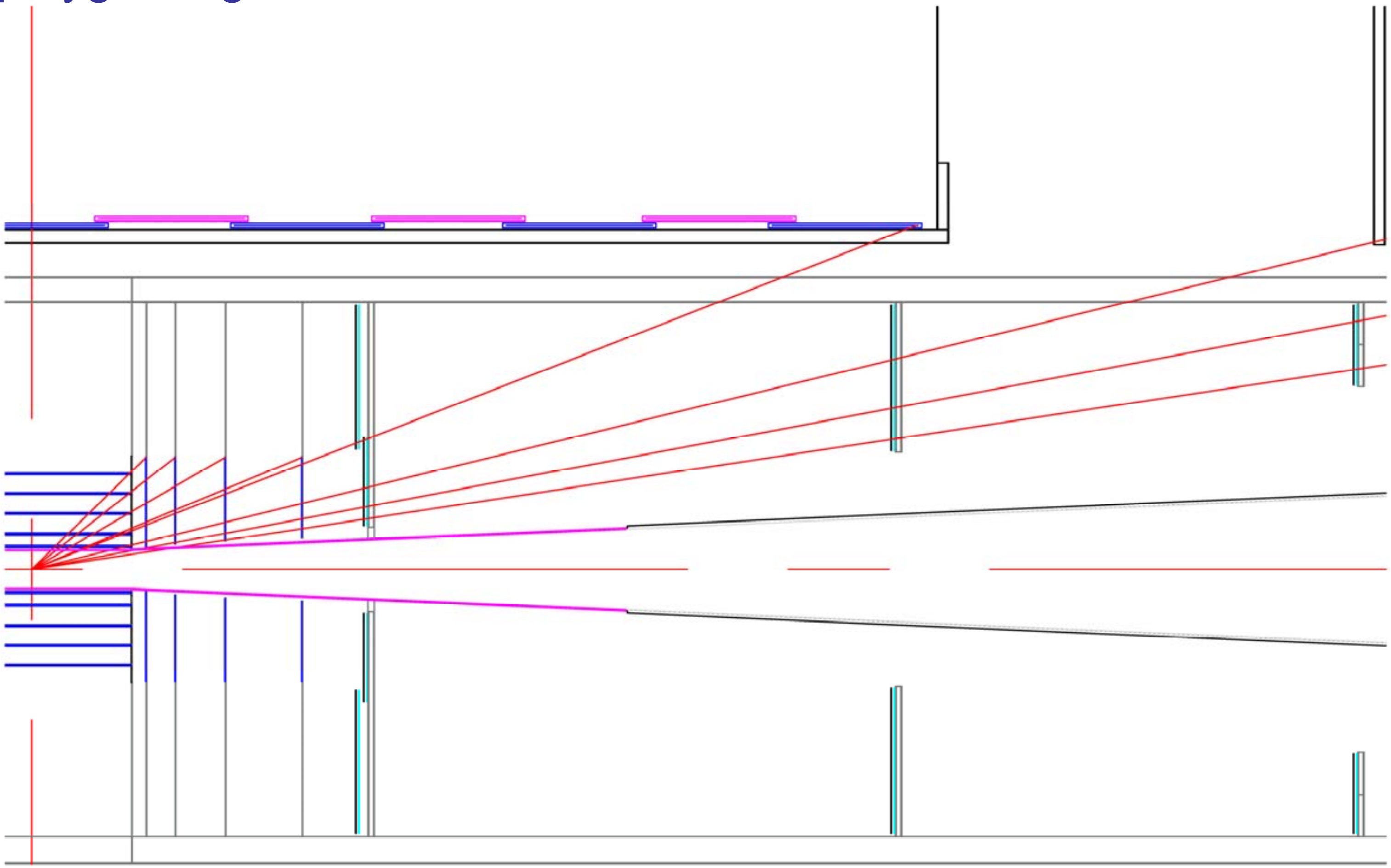
VXD / Outer Tracker Overlaps

- Minimum material radius of the outer tracker is 20.5 cm.
- The first three outer tracker disks do not reach cos (theta) = 0.99, but forward disks in the VXD region do.



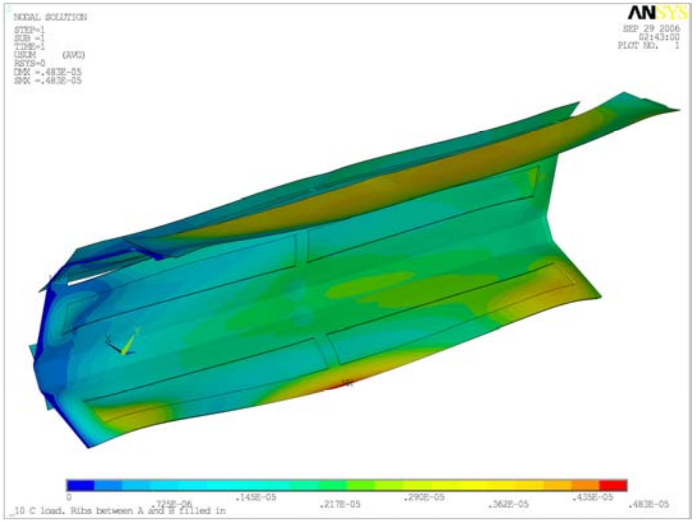
VXD Barrel / Disk Overlaps

- Maximum material radius, as drawn, of the VXD is 18.47 cm.
- Pixel disks overlap ends of associated barrel layers provided polygonal geometries match.



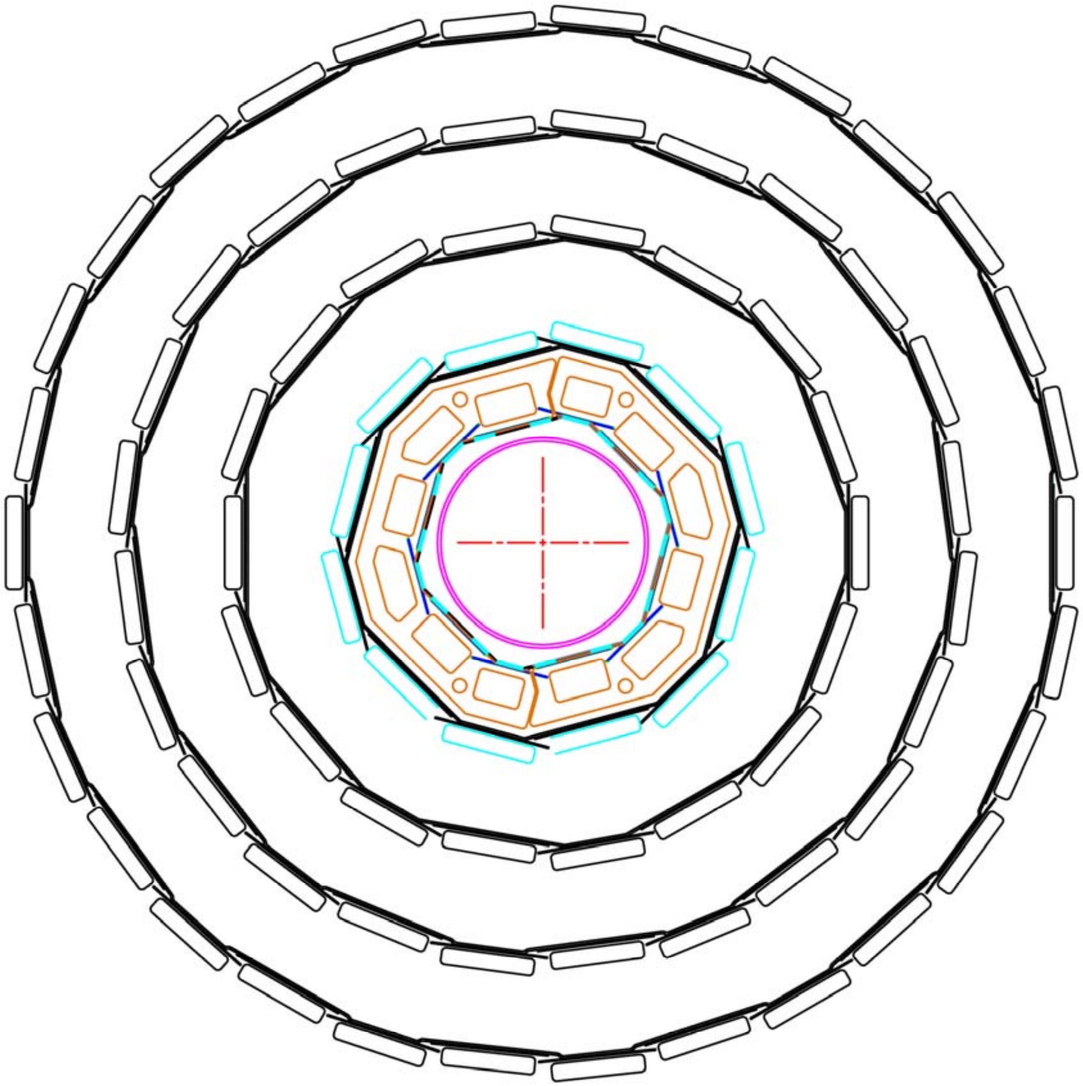
Vertex Detector Barrels

- Five barrel layers
  - Overall sensor length is assumed to be 125 mm.
  - Sensor width is 9.2 mm for the inner layer, 13.8 mm for other layers.
- The baseline design assumes that silicon is glued directly to carbon fiber (CF) support structures.
  - FEA studies of layer 1 by the University of Washington continue.
    - The trade-off between gravitational deflection and thermal distortion needs to be understood better.
    - Some changes in CF geometry will likely be needed.



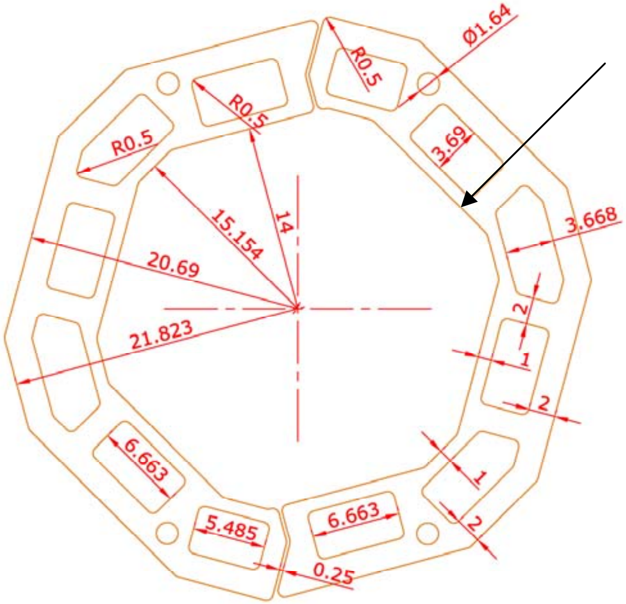
Vertex Detector Barrel End

- Layer 1 end ring has been detailed.
- That remains to be done for the other layers.
- Each layer includes A and B sub-layers at slightly different radii.
- Sensor inner surface radii range from 14 to 60.77 mm.
- The number of sensor phi locations within a layer ranges from 12 to 30.
- 96 r-phi locations



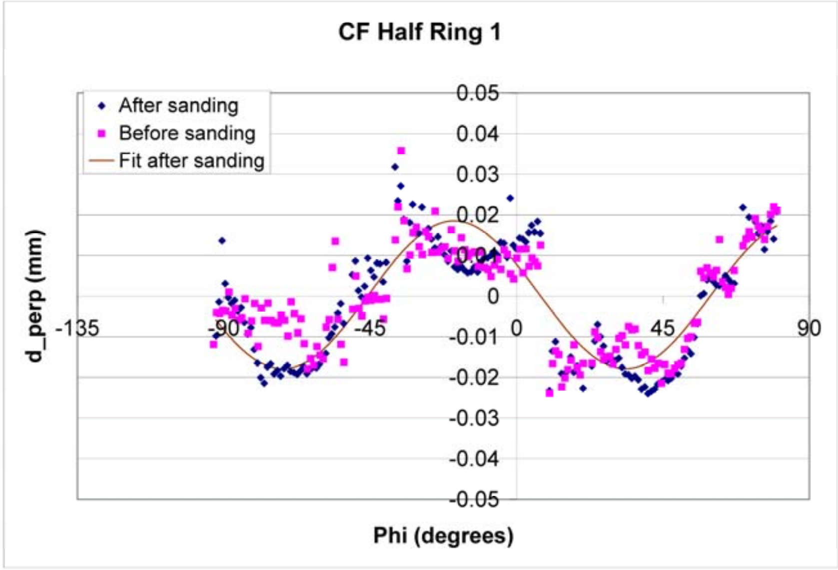
Vertex Detector Barrel 1 Prototype

- Goal is to verify FEA and practice mounting silicon
- Prototype CF end rings have been made for barrel 1 and look OK.
- Distance of inner contour from nominal location is shown at right.
  - Clearance for glue = 0.05 mm.



Half-cylinder fits within this contour

Typical corner radius = 0.5 mm.



- Half-cylinders will be fabricated by the University of Washington.
  - There has been delay associated with budgets and the "continuing resolution" in getting funding set up.

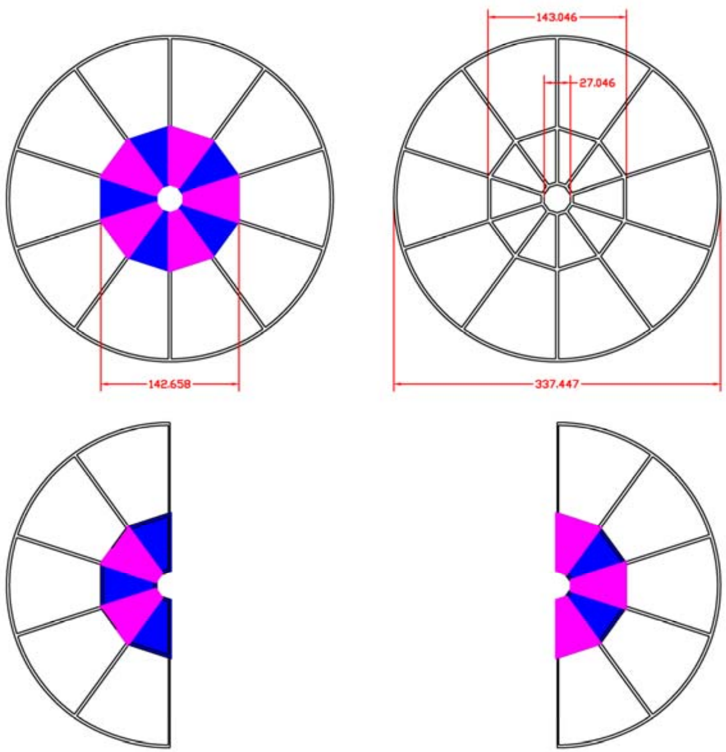
Thinned Silicon

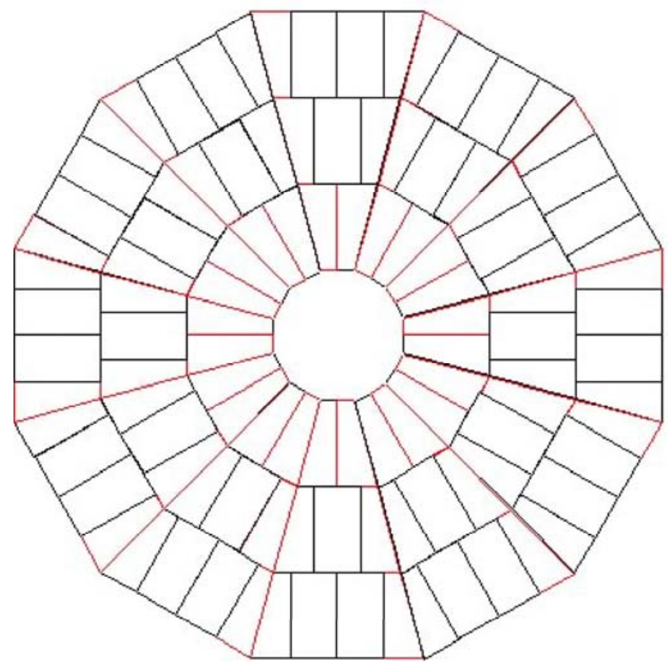
- As a relatively extreme test, Ray Yarema successfully arranged to have a 6” silicon wafer thinned to nominally 20 μm by Disco.
- The wafer includes two sensors (metallization only, no implants) and is held to a dicing frame with UV release dicing tape
- The plan is to dice into 8 rectangles, each 9.2 mm x 125 mm.
  - Some rectangles would be glued to CF for thermal bowing measurements.
  - Others would be mounted on the layer 1 prototype.
- We have a Disco DAD 320 to do the dicing.
- We are waiting for a UV source to release from the dicing tape and a vacuum chuck with proper geometry to remove singulated pieces.
- We would use existing fixtures to place the diced pieces.

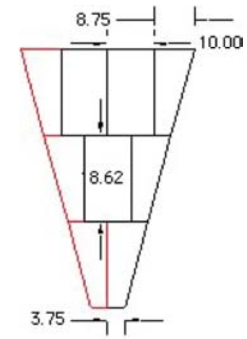
Ideas for Vertex Detector Pixel Disks

- Provide a CF-foam-CF frame on which sensors would be mounted.
- Alternate wedges between the two frame surfaces to provide overlap and stability against thermal distortions.

- Mount sensors directly to a continuous membrane.
- Build up a wedge from pieces which would fit within a ½ reticle, butting them edge to edge.
- Ron Lipton may say more.







Ideas for Vertex Detector Pixel Disks

- Maybe the ideas could be combined.
  - If I understood correctly, Ron considered gluing sensors to CF.
  - An alternative might be to glue sensor pieces to kapton held in a frame to build a wedge, make interconnections, then transfer the kapton to the frame of a disk. Finally, excess kapton could be trimmed.
  - The kapton may help with thermal distortion and handling issues while the disk frame would provide added stiffness.
- We may also want to consider temporary or intermediate support with kapton for the barrels.

Vertex Detector Issues

- Overall geometry
  - Matching with outer tracker
- Sensor geometry and features
- Heat removal
- Thermal distortions
- Handling thin silicon
- Assembly and alignment procedures
- Connections, cabling, and optical fibers
- Paths for cables, optical fibers, and air flow
- Lorentz forces
  - Same general issues as in the outer tracker, but supports to control forces are likely to be less robust