Silicon Vertex Prototype Mechanics Design

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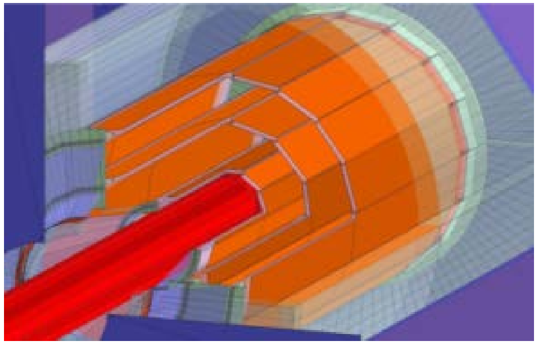
Layout of CEPC Silicon Vertex Detector

	R (mm)	$\|z\|$ (mm)	Current z in total
Layer 1	16	62.5	130.6 mm (Layers 1–2)
Layer 2	18	62.5	
Layer 3	37	125.0	263.1 mm (Layers 3–4)
Layer 4	39	125.0	
Layer 5	58	125.0	263.1 mm (Layers 5–6)
Layer 6	60	125.0	



6 layer of sensors (3 layer barrels, each has sensors mounted double sides)

*** Working temperature range:** 20-50 ℃ *(30 ℃)*

*** Power dissipation:**

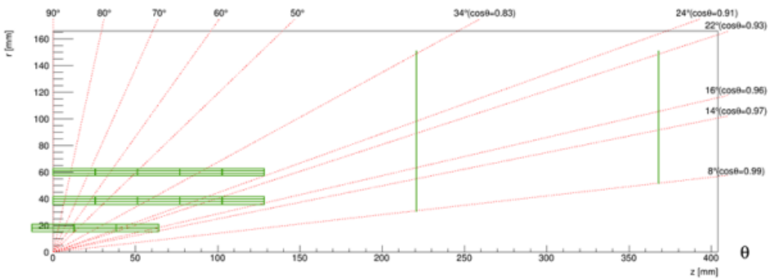
Final goal: ≤ 50 mW/cm2. (air cooling)

Current (short term) goal: ≤ 200 mW/cm2. (air cooling)

*** Single point resolution**: currently in CDR range from 2.8-6 μm, eventually we aim for only one type of pixel sensor with single point resolution of 3-5 μm.

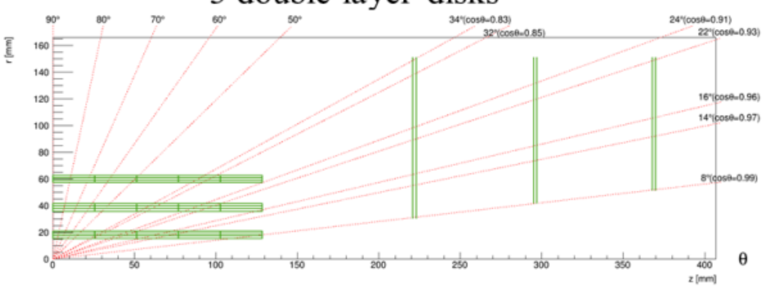
Vertex layout optimization

CDR detector



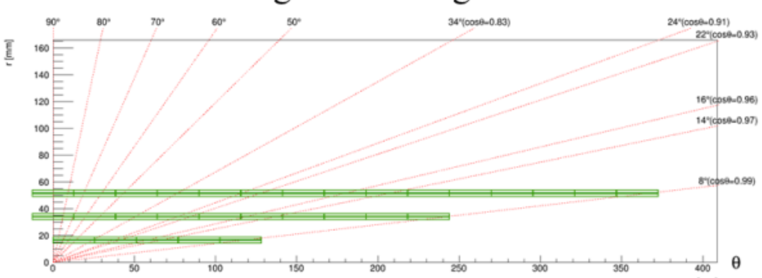
3 double-sided barrel layers with 2 single disks

3 double-layer disks



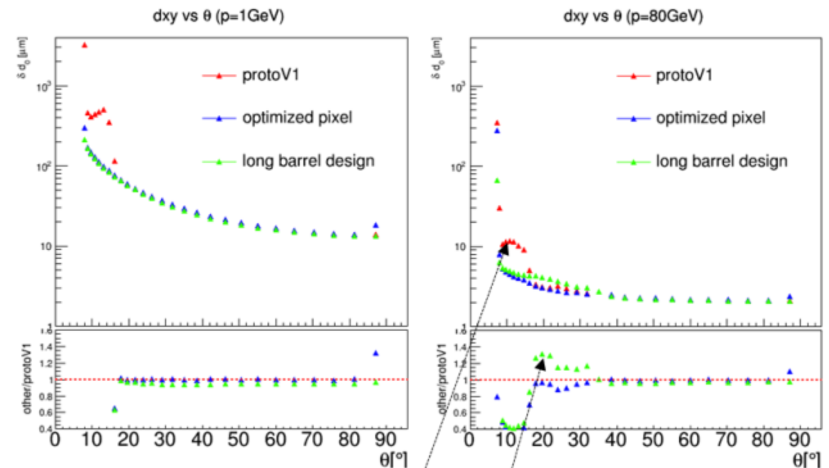
Longer first double layer with 3 double disks

long barrel design



3 very long double-sided layers without disk

Dead material not fully implemented



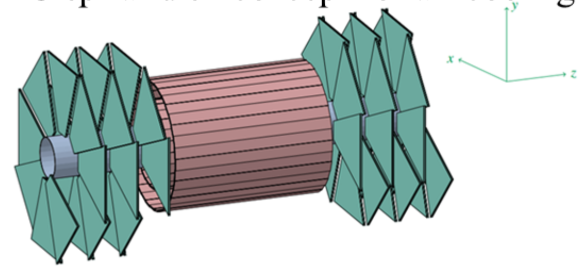
- CDR detector: poor performance in endcap
- Long barrel: large coverage, performance not good in forward region
- Optimized layout (3 double disks): take the advantages of disk and long barrel, excellent performance in front region

All layout tuning results simulated by tkLayout, which was developed by CMS, customized for CEPC tracker fast simulation(on-going).

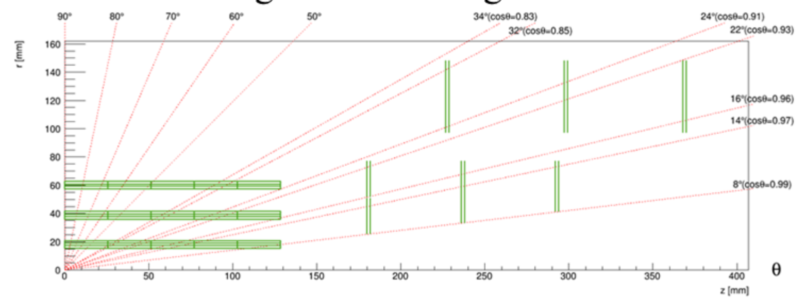
Next step

- Disk is not friendly for vertex air cooling, a layout design including cooling is necessary.
- Possible solution for air cooling:
  - Long barrel without endcap disk (stiffer ladder needed, resolution performance need more study)
  - Short barrel with endcap disk
    - CLIC spiral disk
    - Investigate new arrangements
- Fast simulation tool tkLayout customizing and cross-checking
- Full simulation validation of optimal design
- Investigate performance with smaller beam pipe radius

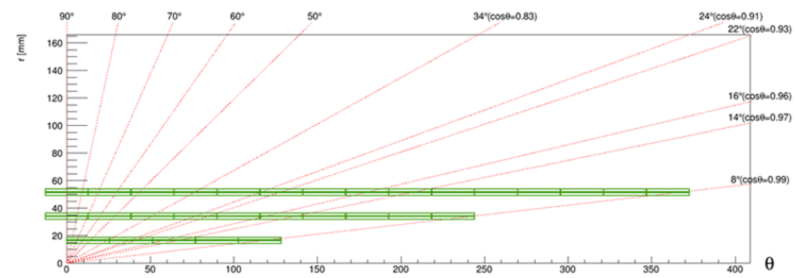
CLIC spiral disk concept for air cooling



Investigate new arrangements



Long barrel without disk



Vertex detector (VTX) model

MOST2 project Goal: build a vertex detector prototype for CEPC

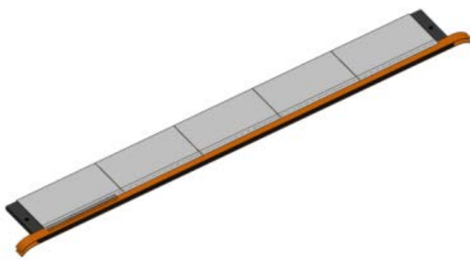
Sensor chip : 14.8 x 25.6 x 0.05 mm (2 mm wide margin at one side for wire bonding)

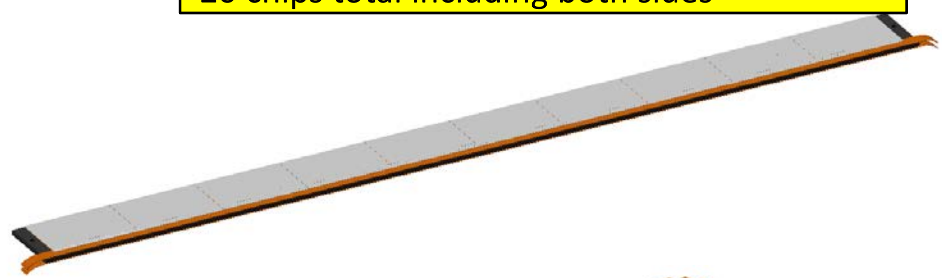
Ladder: support + chips + FPC

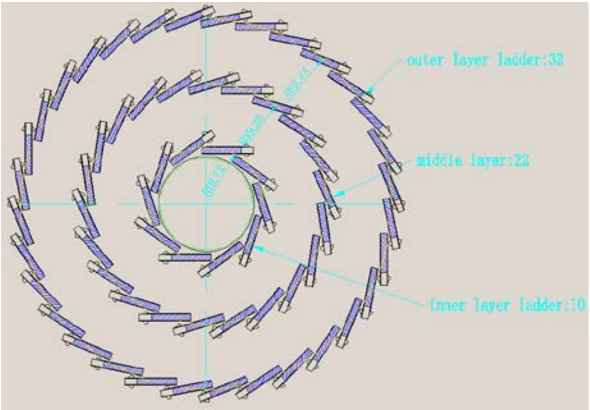
0.1mm gap between chips

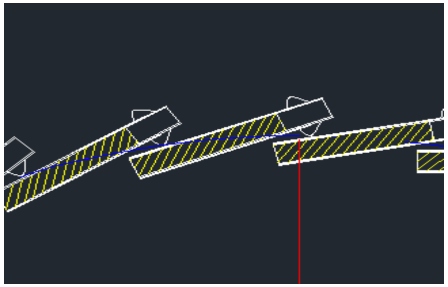
Ladder of inner layer(16.8 x 134.4 mm)
10 chips total including both sides

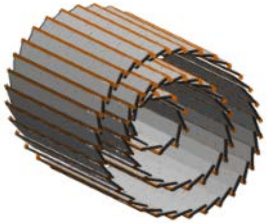
Ladder of outer two layers(16.8 x 266.9 mm)
20 chips total including both sides

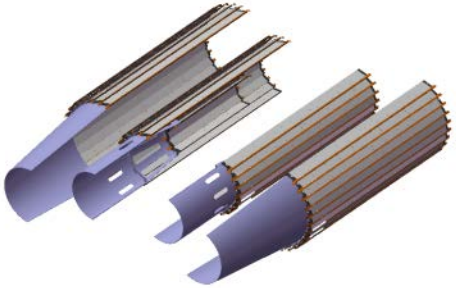












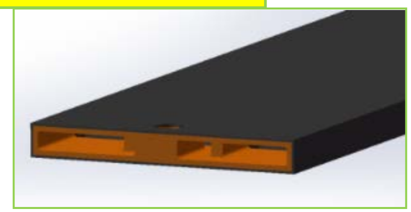
The designs of the ladder support (ladder-spt)

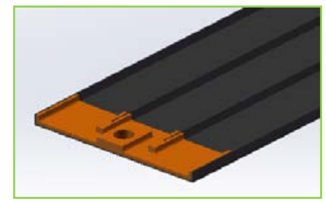
Size: outer and middle barrels 266.9 x 16.8 x 2 mm (L x W x H).

for inner barrel 134.4 x 16.8 x 2 mm.

Material: CFRP, each surface has a total thickness of 0.15 mm*.

Current preferred design





Two other optional designs:

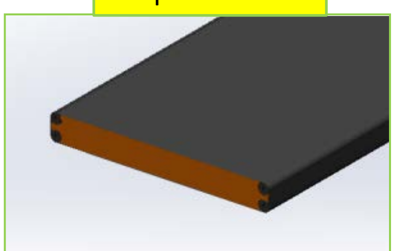
Both have the same overall dimensions as the preferred design.

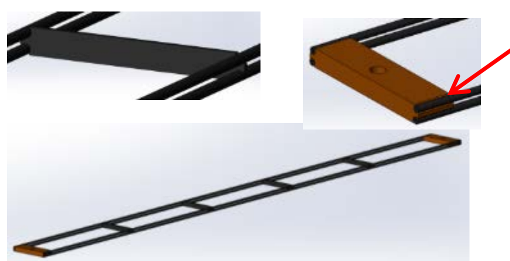
A: 2 bars made of PMI foam inside the support

B: the CFRP pipes (or rod) and surface combination

Option A

Option B-Va





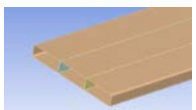
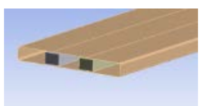
Pipe: OD- 0.8 mm
ID- 0.6 mm

Option B-Vb

Static analysis of the ladder-spt designs

The same boundary condition and the same extra load for each analysis.

The CFRP used in the simulation is less rigid than that we finally will use.

	Design scheme	Mass (g)	Def. Self weight+ load (μm)	Def. under load (μm)
	√Preferred design	2.56	4.1	2.14
	╳ Option A	2.55	7.6	
	*? Option B*	*2.11**	*2.1*	*1.3*

Option A: with the same mass as the preferred design, the stiffness is smaller.

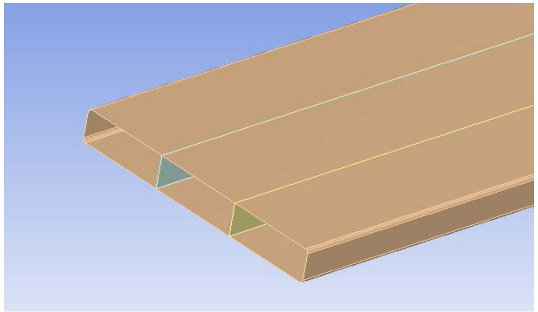
Option B: about 18% material is reduced than the preferred design. Very challenging to make it our size, but still have great potential , fabrication feasibility to be further investigated.

Comparative FEA analysis-1

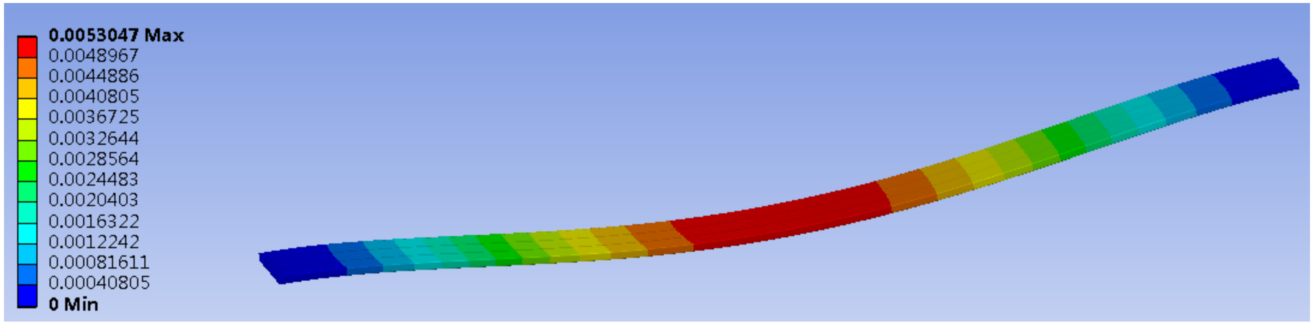
To evaluate the contribution of the sensors and FPCs to the rigidity of the ladder support, two comparative FEA analysis were done based on the current preferred design.

Analysis -1 A bare ladder support with pressure load

- 2.055 g (4.11 g in total) weight of sensors and FPC on either sides of the support, evenly distributed to two side surfaces as pressure load.
- Self weight 2.56 g.



Max def. under full load: 5.3 um



Model of the complete ladder

A complete ladder model with:

- A Ladder support (CFRP)
- FPCs on both sides (kapton + equivalent mass of Aluminum and adhesive)
- Sensors on both sides (50 um silicon)

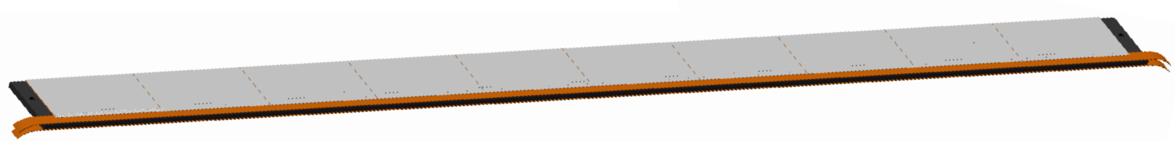
FPC laminates(*)

Mingyi provide

	thickness
Polyimide	25um
Adhesive	28um
Plating copper	17.8um
kapton	50um
Plating copper	17.8um
Adhesive	28um
Polyimide	25um

Polyimide 50+25*2 =100 um

Al 18x2 =36 um

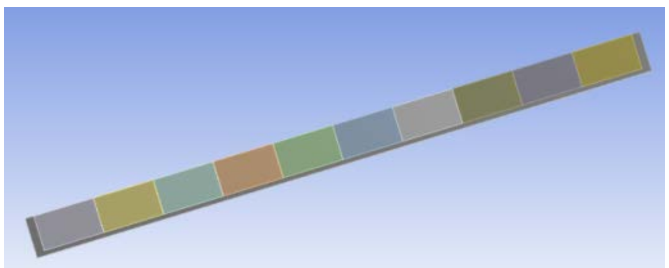


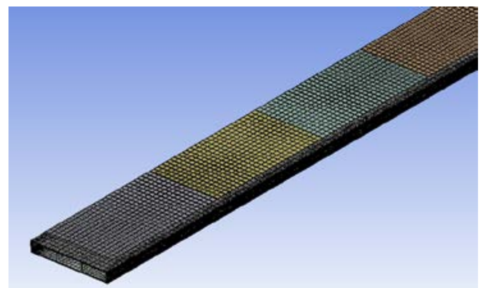
Comparative FEA analysis-2

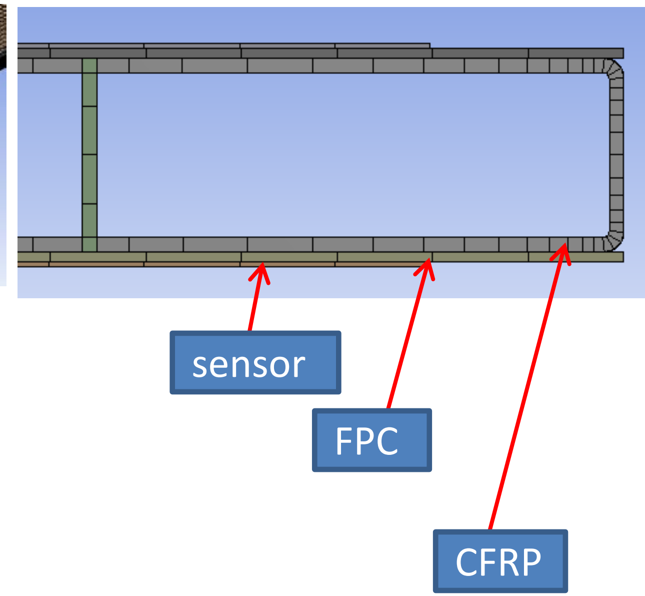
The analysis of a complete ladder model (including the support with sensors and FPCs on both sides):

The total load and the boundary condition are the same as analysis-1.

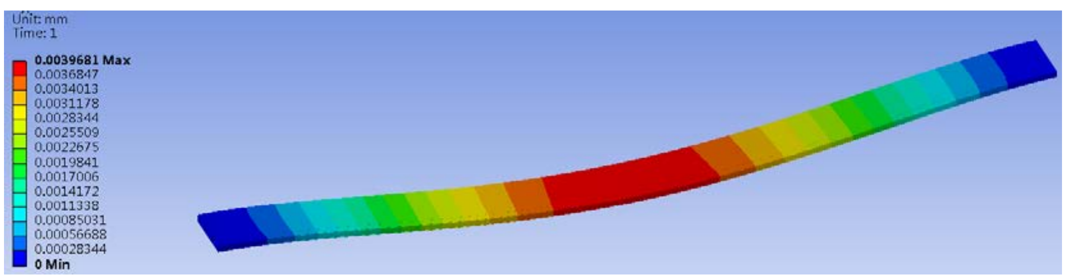
The adhesive layers between the parts and the interlayers of Aluminum trace of the FPC were not modeled, but the mass of these materials was added to the FPC by increasing the density of it.





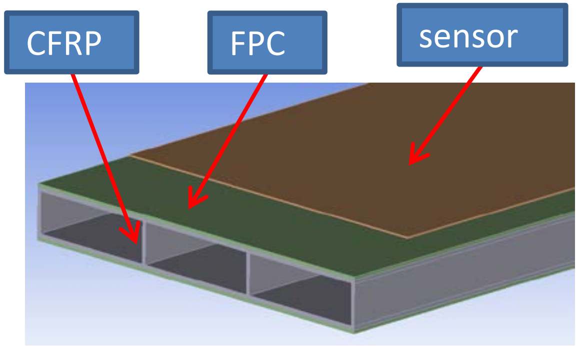


Max def: 4 um



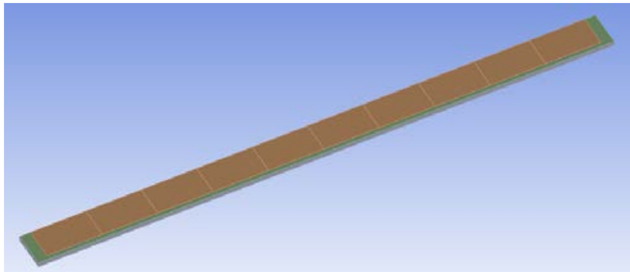
After the FPC with sensors glued on, the rigidity of the full ladder is increased about 20% compare to that of the bare ladder-spt.

Cooling analysis of a complete ladder



A complete ladder model with:

- A Ladder support (CFRP *)
- FPCs on both sides (kapton + Aluminum)
- Sensors on both sides (50 um silicon)
- adhesive not considered
- heat resistance in contact not considered



FPC laminates

Mingyi provide

	thickness
Polyimide	25um
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kapton	50um
Plating copper	17.8um
Adhesive	28um
Polyimide	25um

Polyimide 50+25*2 =100 um

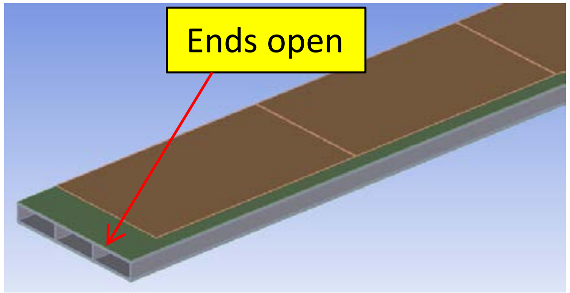
Al 18x2 =36 um

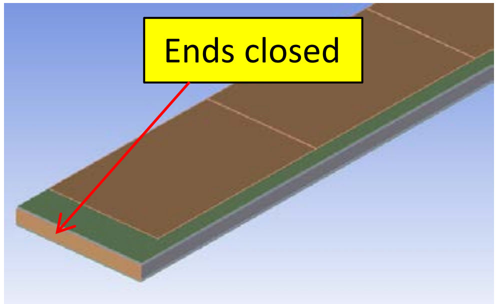
Adhesive is not considered

Results of a complete ladder cooling analysis *ends open VS sealed*

Power dissipation (mW/cm2)	Inlet air temperature (℃)	Inlet air velocity (m/s)	Max temperature (℃) - Ends OPEN	Max temperature (℃) - Ends SEALED
200	20	3	57.1	57.4
200	20	4	50.5	51.3
200	20	5	46.4	47.6

At a speed of 3 m/s, the difference between the ladder with ends open and closed is only 0.3 ℃ (57.4-57.1).



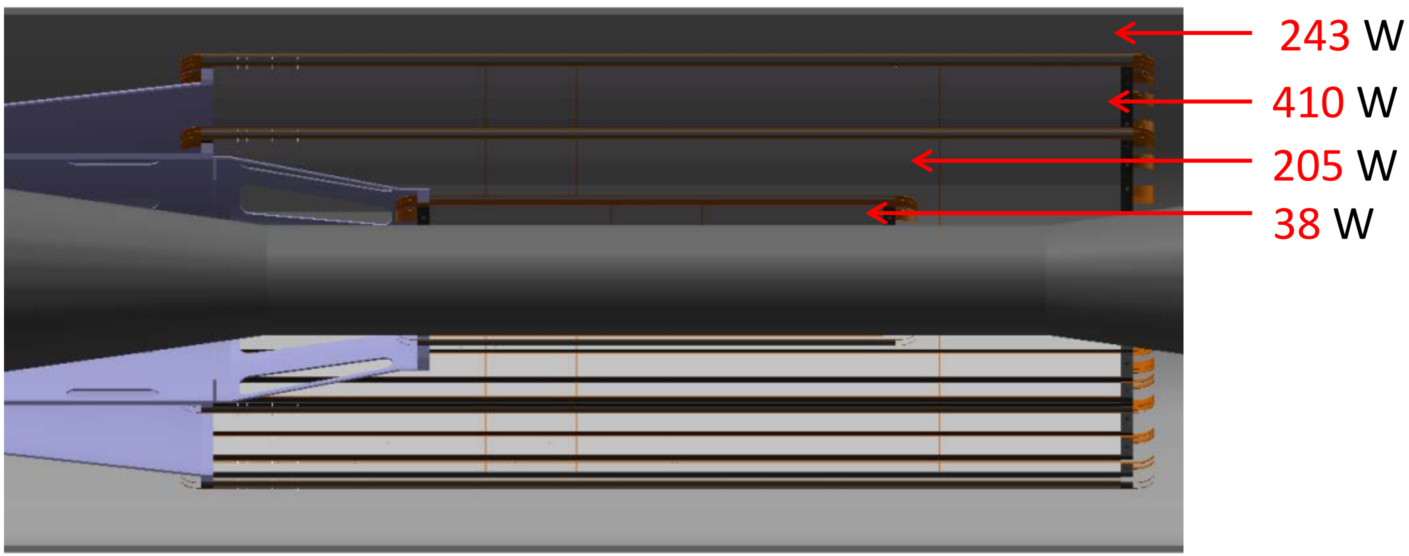


Heat generation of VXT

Sensor Power dissipation:

Current (short term) goal: ≤ 200 mW/cm^2. (air cooling)

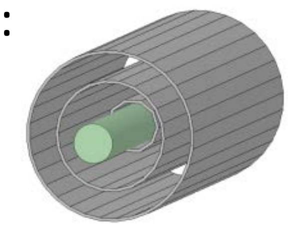
Final goal of CEPC: ≤ 50 mW/cm^2. (air cooling)



At 200 mW/cm^2 dissipation, the total heat generation is about 900 W, for CEPC level it is about 225 W.

Cooling analysis of the simplified VTX

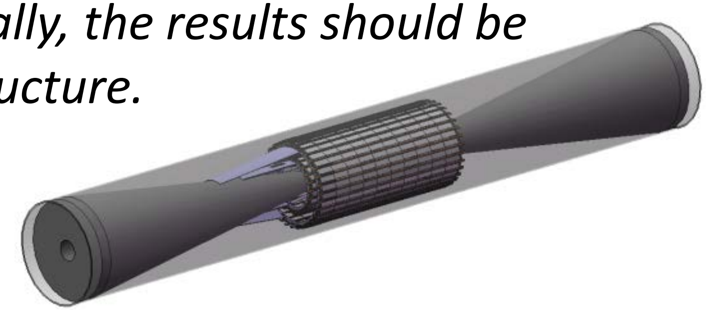
As a first step of the overall cooling simulation, this is a rough simulation to get preliminary estimate of the feasibility of the forced air cooling. Compared with reality, below items are simplified :



- 3 adiabatic barrels* instead of the real support structure with overlapped ladders.
- the total heat generation of each detector layer is evenly smeared on the sides (silicon plate) of the barrel.

i.g. just sensors and forced cooling air in the cooling box (which is a hollow cylinder with a ID of 150mm to mimic the outer tube of beam pipe).

Due to the properties of this model, generally, the results should be conservative compared with the actual structure.



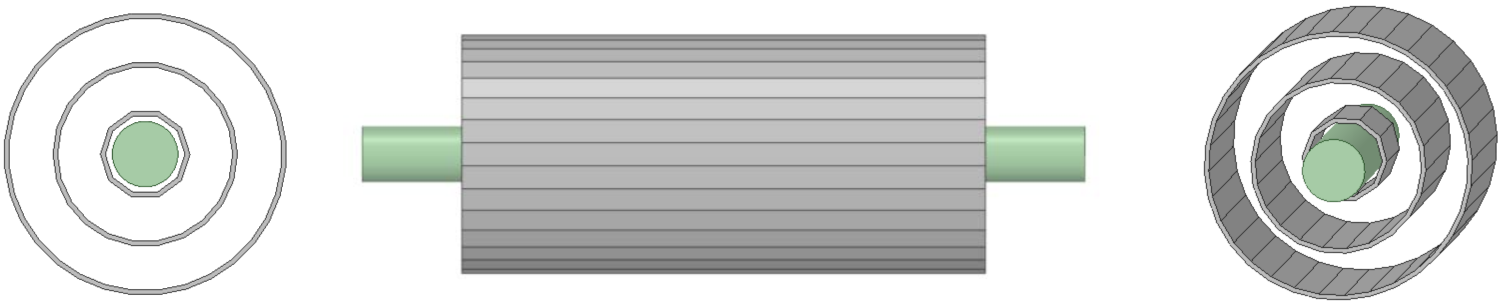
Model of the simplified VTX

Also given:

- 0 degree Celsius inlet air temperature.
- 30 degree Celsius constant temperature of beam pipe's outer surface.

The minimum gap (distance) between the inner barrel and beam pipe is: (D32.4-Φ30.7)/2=0.85 mm in radius direction.

Power dissipation and velocity of the inlet air vary according to different setup.



Result summary

Power dissipation (mW/cm2) `	Temperature of beam pipe's surface (℃)	Inlet air temperature (℃)	Inlet air velocity (m/s)	Max temperature of inner barrel (℃)	Max temperature of middle barrel (℃)	Max temperature of outer barrel (℃)
200	*30*	*0*	*5*	113.1	76.1	73.2
200	*30*	*0*	*6*	106.7	69	66.4
100	*30*	*0*	*3*	79.2	48.5	45.7
100	*30*	*0*	*4*	74.9	42.4	39.8
100	*30*	*0*	*5*	71.2	38	36.6
50	*30*	*0*	*2*	57.1	29.1	26.9
50	*30*	*0*	*3*	54.5	24.3	22.9
50	*30*	*0*	*4*	52.3	21.3	19.9

Note that, the current simplified simulation is **conservative** compare with reality.

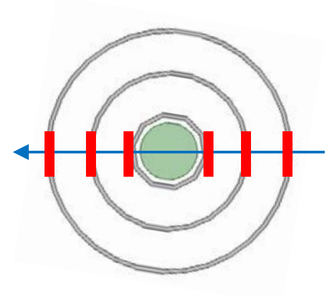
A further comparison

Power dissipation (mW/cm2) `	Temperature of beam pipe's surface (℃)	Inlet air temperature (℃)	Inlet air velocity (m/s)	Max temperature of **inner barrel** (℃)	Max temperature of **middle barrel** (℃)	Max temperature of **outer barrel** (℃)
50	30	0	3	54.5	24.3	22.9
The minimum gap between the inner barrel and beam pipe change to (D32.4-Φ28)/2=**2.2** mm in radius direction.						
50	30	0	3	52.9	24.2	22.8

The temperatures of the innermost barrel are different due to the change of the gap, and the trend of the effect is consistent with the previous analysis of the single ladder.

Cooling of the VTX prototype of MOST2 for beam testing

Based on considerations of the sensors cost and the air cooling feasibility, for MOST2 prototype, it is most likely that only 6 instrumented ladders on three barrels (two on each barrel), and they are deployed in a straight line for beam testing.



incident beam

For the simplified VTX simulation:

- air velocity 5m/s
- Inlet air temperature: 0 ℃.
- Dummy beam pipe: 30 ℃

Due to the model property (conservative) even only 6 ladder instrumented with heat source, the max temperature is almost the same as all ladders activated and can be up to 112 ℃.

In this case, the cooling results of a complete ladder are more valuable for reference before detailed simulation results come out in next step.

Power dissipation (mW/cm2)	Inlet air temperature (Celsius degree)	Inlet air velocity (m/s)	Max temperature (Celsius degree) - Ends OPEN	Max temperature (Celsius degree) - Ends SEALED
200	20	3	57.1	57.4
200	20	4	50.5	51.3
200	20	5	46.4	47.6

Next

- Layout optimization to take into account the realistic material will continue

  Fast and full simulation

  Investigate beam pipe radius

- Cooling analysis close to real structure and working condition will be studied:

  Individual ladders deployed the same as the general structure design.

  System level analysis by integrating the support structures, endcap disks, inlets and outlets (fan and griller for prototype cooling box).