Mechanical Design of Silicon Vertex Detector (Prototype)

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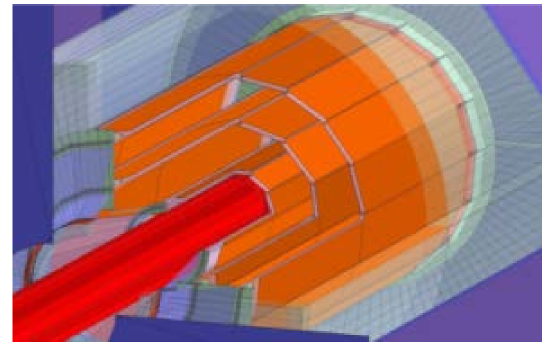
2020/8/29

Vertex Layout in Preliminary Design

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



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

* **Material budget**: 0.15% X/X_0 for each single detector layer.

* **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.

* **Power dissipation:**

Final goal (CEPC): ≤ 50 mW/cm2. (baseline cooling method is air cooling)

Current (estimation of the full size chip): trigger less mode ≤ 150 mW/cm2.

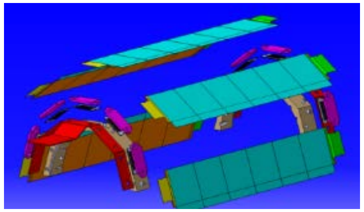
trigger mode ≤ 100 mW/cm2.

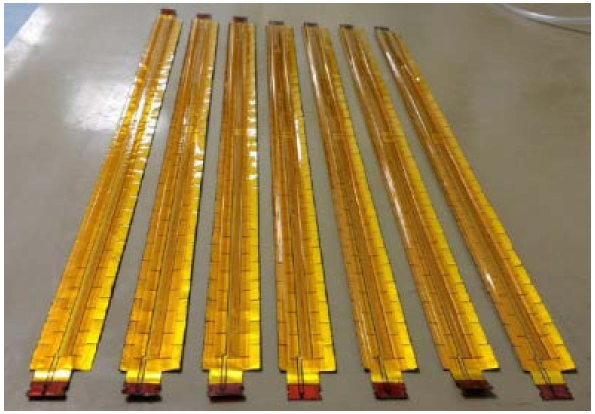
***Working temperature range:** 20-50 ℃ (best performance under 30 ℃)

Challenge

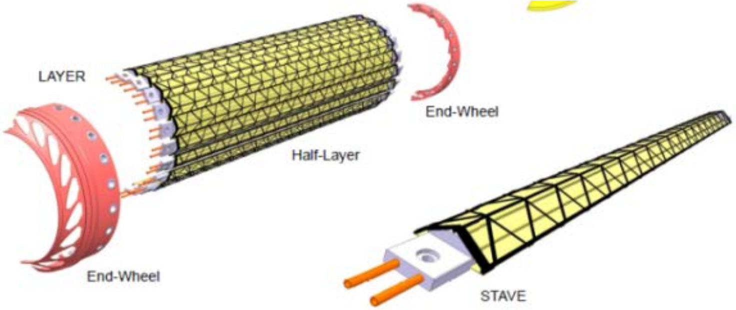
The big challenge: low material & high rigidity

Mu3e
0.1% X/X_0





Alice ITS Upgrade
0.3% X/X_0

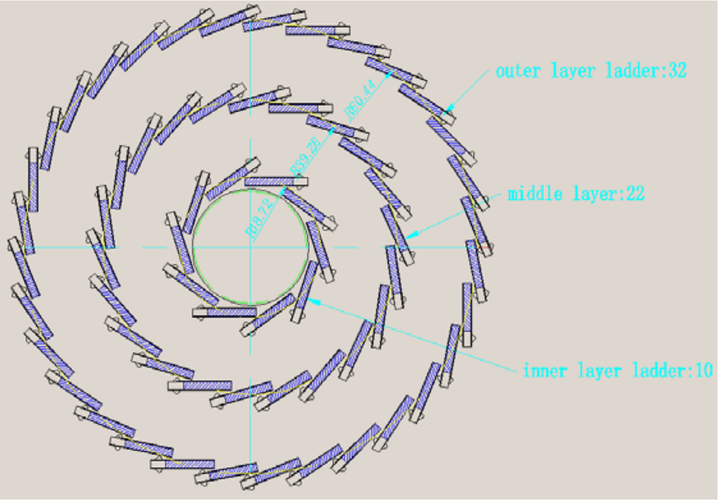


These two experiments both have pixel sensors on one side of the support. Our material budget requirement is 0.15% X/X_0, which is between them and closer to Mu3e, but the positon stability is higher than it.

No such low mass support structure was made in China before.

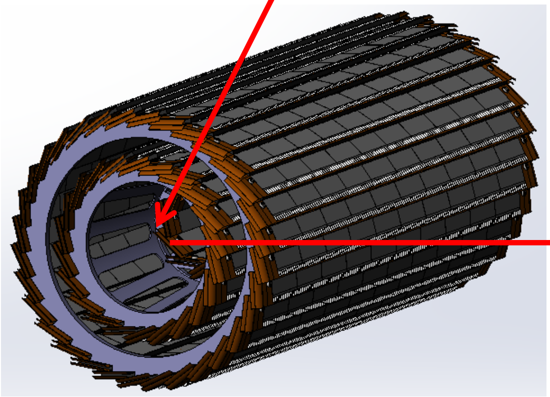
General Structure of the Vertex Detector (VTX)

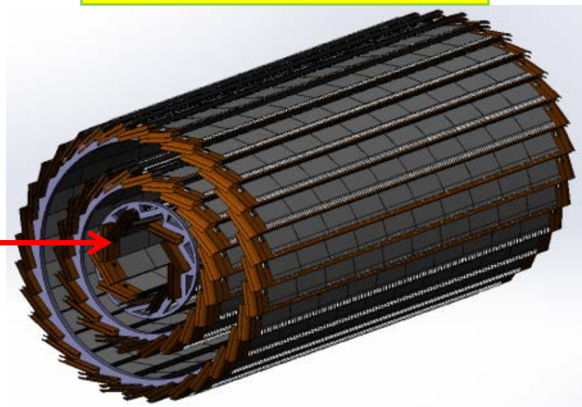
- 3 layers of barrels, diameters close to CDR.
- Each barrel consists of overlapped **ladders**.
- Double sided detectors on ladder.



According to the physical optimization results, the length of the innermost detector will be adjusted to the same as the outer two layers .

Innermost layer extended



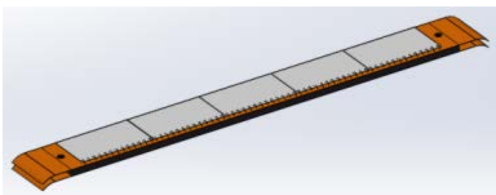


Ladder Structure

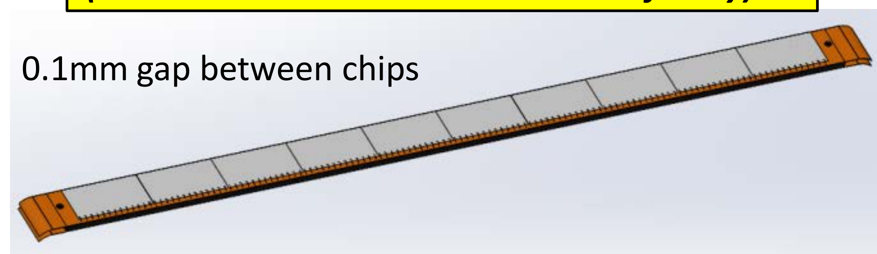
Sensor chip : 14.8 x 25.6 x 0.05 mm (2 mm wide margin at one side for wire bonding)

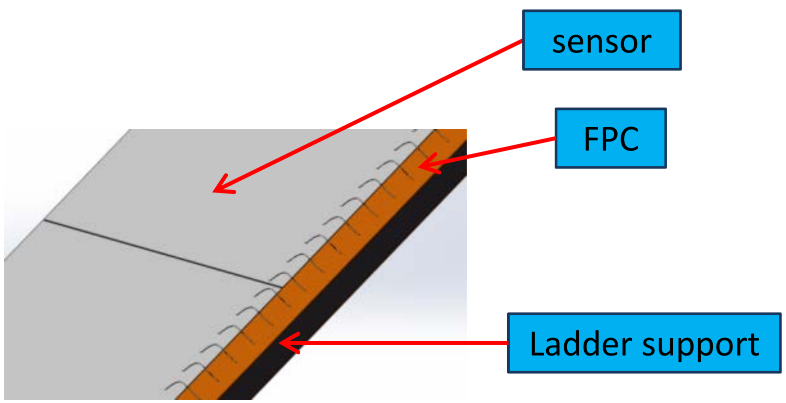
Ladder: support + chips + FPCs

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

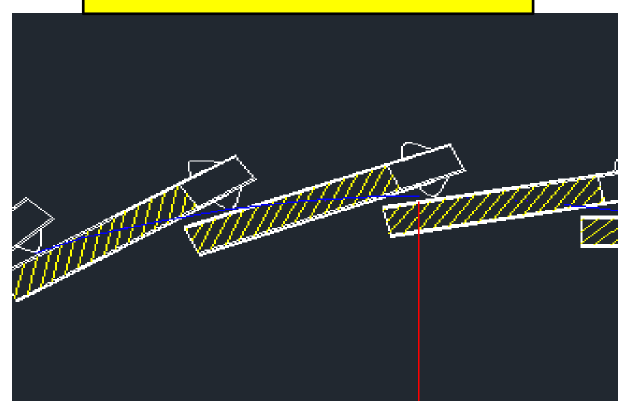


Ladder of outer two layers(16.8 x 266.9 mm)
20 chips total including both sides
(All barrels will use the same ladder finally)





Overlapped and dead area



Ladder Support (ladder-spt)

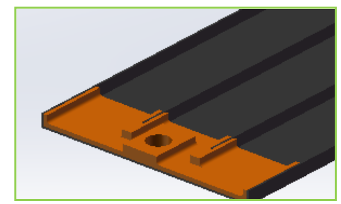
Different ladder support designs have been studied.

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

(*inner barrel 134.4 x 16.8 x 2 mm.)

Material: CFRP, surface thickness is 0.15 mm*, 3 layers , 0-90-0. *(as the result of analysis of the stacking design of the CFRP and optimization).*

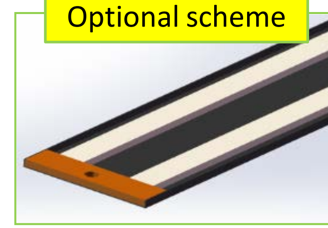
Current preferred design



The optional design:

- The same overall dimensions as the preferred design.
- 2 bars made of PMI foam instead of ribs inside the support.

Optional scheme



Static analysis of these ladder-spts were done for comparison. Results show that given the same mass and same boundary condition and load as the preferred design, the optional design is less rigid.

(preliminary result for comparison)

Design scheme	Mass (g)	Def. Self weight+ given load (μm)
√Preferred design	2.56	4.1
╳ Option	2.55	7.6

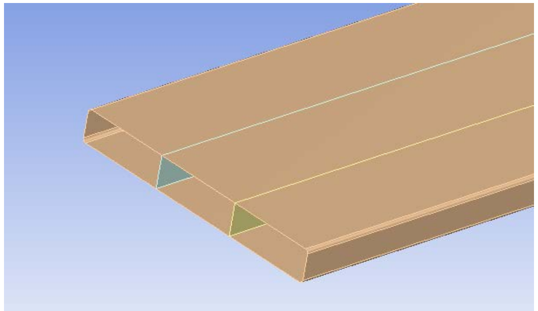
Analysis of the Ladder

The static analysis and cooling analysis of the ladder have been studied.

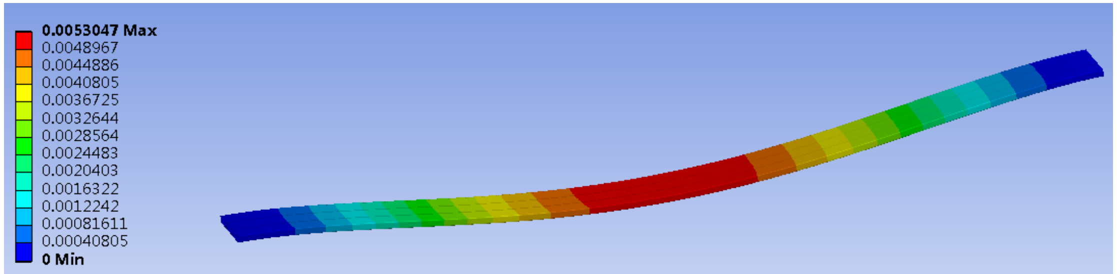
To evaluate the contribution of the sensors and FPCs to the rigidity of the ladder support, two comparative FEA analysis were done based on the current preferred design.

Analysis-1. A bare ladder-spt

- 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.
- Two ends fixed.



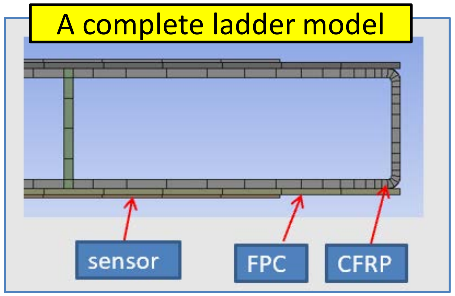
Max def. under full load: 5.3 um



Analysis of the Ladder

Analysis-2. A complete ladder

(include the support and the sensors and FPCs on both sides)



FPC laminates(*)

Mingyi provide

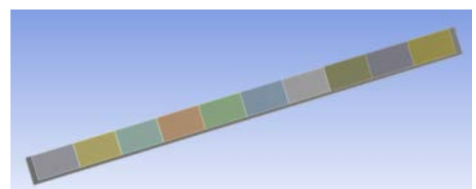
	thickness
Polyimide	25um
Adhesive	28um
Plating copper	17.8um
kapton	50um
Plating copper	17.8um
Adhesive	28um
Polyimide	25um

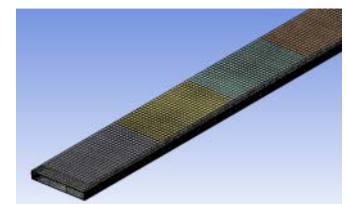
Polyimide 50+25*2 =100 um

Al 18x2 =36 um

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

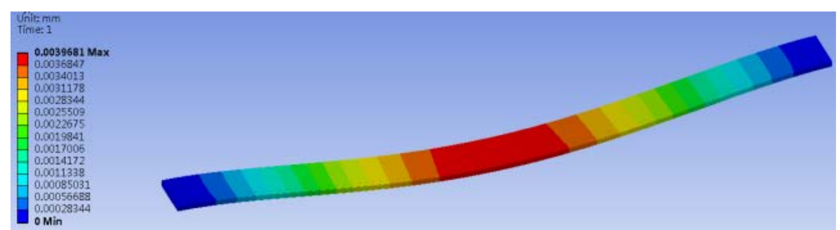
FPC laminate is simplified as single material with total mass.





Max def: 4 um

Once the complete ladder is assembled, the rigidity of it is about 20% increased compare to that of the bare ladder-spt.



Analysis of the Ladder

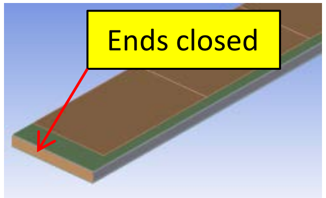
Cooling simulation of a single complete ladder with detailed FPC.

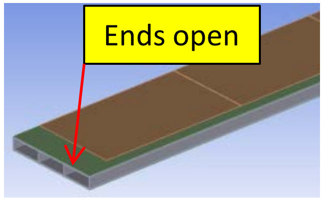
Temperature results

(with different sensor power dissipation and different air speed)

Max temperature of ladder (℃) (air temperature 5 ℃)					
Power Dissipation (mW/cm2) \ Air speed (m/s)	5	4	3	2	1
100	19.6	21.8	25.0	*30.6*	*43.4*
150	26.9	30.1	35	*43.4*	*62.6*
200	34.2	38.6	45.1	*56.2*	*81.8*

Also analyzed that in a speed of 1-5 m/s, the temperature difference between the ladder with ends open and closed is in an negligible level (＜0.5℃) .





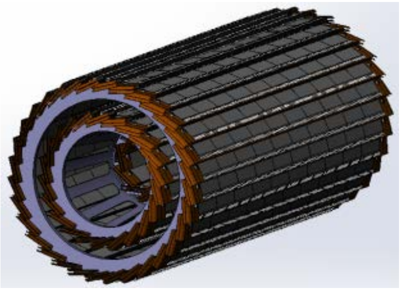
Cooling Analysis of the VTX Assembly

- the innermost layer is still the ***non extended ladders*** which has half length of outer two layers.
- ladders are deployed exactly as the general design.
- the Ladder are simplified as simplified ladder support (*eq. C) + sensors
- the cooling environment is a hollow cylinder with a ID of 150mm and the VTX is located inside.
- beam pipe with OD of 30.7 mm is considered.

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

Preliminary results

Power dissipation (mW/cm²)	T of Inlet (℃)	T of Beam pipe (℃)	Air speed (m/s)	Max T. (℃) Ladders only	Max T. (℃) Ladders + support
100	5	5	2	49.1	51.7
100	5	5	1	72.9	76.4
50	***5***	***5***	***2***		***28.3***
50	***5***	***5***	***1***		***40.6***



Analysis of Cooling Effect of High Thermal Conductivity Material

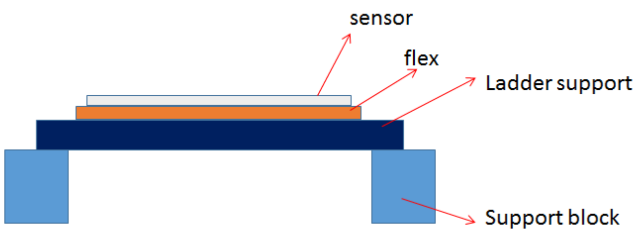
A trial analysis to evaluate the influence of employing material with a high thermal conductivity (Mhc) on ladder cooling.

A given ladder with a sensor (20 x 258 x 2 mm) on one side, dissipation 150 mW/cm^2.

- ladder support (Aluminum)
- support block (Aluminum alloy).
- sensor (silicon with a thickness of 0.05 mm)
- *FLEX*

  a thickness of 0.124mm,

  material: PCB (0.3w/m.K) VS Mhc (1500w/m.K)



FPC materials	T: ℃ (V=3m/s)	T: ℃ (V=3m/s*)	T: ℃ (V=1m/s)	T: ℃ (V=1m/s*)
PCB	36.3	32.6	46.9	36.7
Mhc	35.5	30.7	45.7	33.6
T difference:	0.8	1.9	1.2	3.1

The results show that such a thin material with high conductivity contributes little to enhance cooling effect.

Result of Layout Optimization

-from Hao Zeng

Barrel

Longer first layer

CDR

Layer	1	2	3	4	5	6
r	17.116	19.041	37.667	39.577	58.914	60.842
z_max	64.200	64.200	128.450	128.450	128.450	128.450

Disk	1	2
z	221.000	368.000

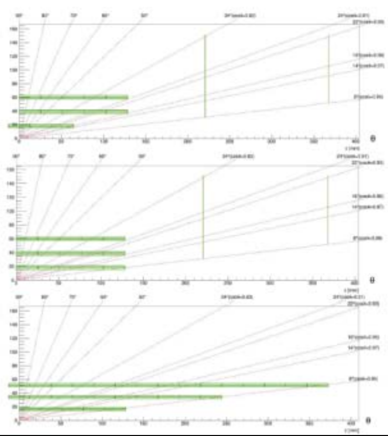
Longer first layer

Layer	1	2	3	4	5	6
r	17.116	19.041	37.667	39.577	58.914	60.842
z_max	128.450	128.450	128.450	128.450	128.450	128.450

Disk	1	2
z	221.000	368.000

long barrel design

Layer	1	2	3	4	5	6
r	15.523	17.479	33.019	34.982	50.522	52.479
z_max	128.450	128.450	244.100	244.100	372.600	372.600



Barrel + disks

Optimal layout

CDR

Layer	1	2	3	4	5	6
r	17.116	19.041	37.667	39.577	58.914	60.842
z_max	64.200	64.200	128.450	128.450	128.450	128.450

Disk	1	2
z	221.000	368.000

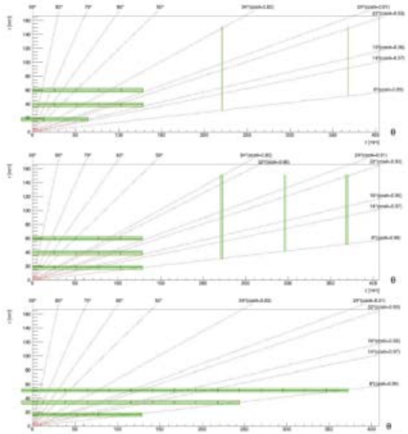
3 double disks(optimal)

Layer	1	2	3	4	5	6
r	17.116	19.041	37.667	39.577	58.914	60.842
z_max	128.450	128.450	128.450	128.450	128.450	128.450

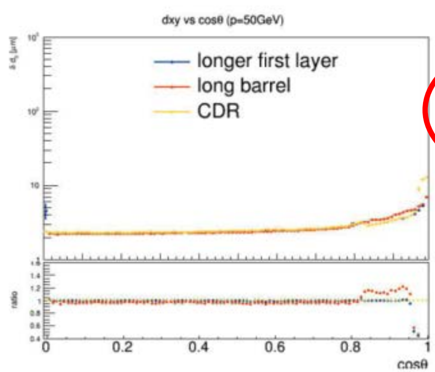
Endcap :	FPIX_1	FPIX_2	FPIX_3	FPIX_4	FPIX_5	FPIX_6
Disk	1	1	1	1	1	1
z	221.000	223.000	295.000	297.000	368.000	370.000

long barrel design

Layer	1	2	3	4	5	6
r	15.523	17.479	33.019	34.982	50.522	52.479
z_max	128.450	128.450	244.100	244.100	372.600	372.600

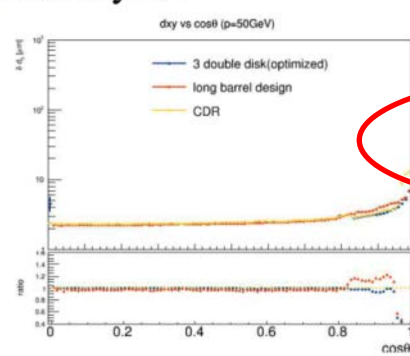


Longer first layer



- longer first layer design has the advantages of long barrel design and disk design
- cosθ: 0.82-0.96, same as CDR
- cosθ> 0.96: similar to long barrel design (even a little better), better than CDR

Optimal layout



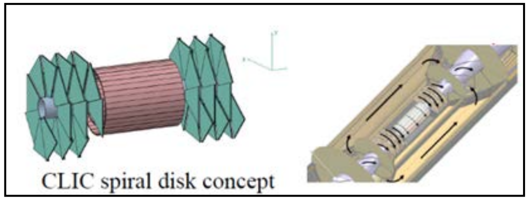
Optimal layout (longer first layer with 3 double disks) has better resolution than full barrel design and CDR design in front region

Conceptual Design of the VTX with Endcap Disks

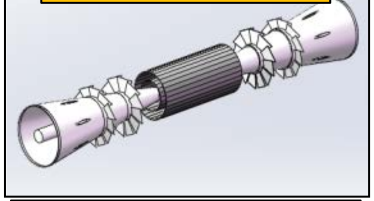
This is a very conceptual design of the VTX with barrels and endcaps combined basically follows the physics layout. And we are just in a early stage of exploring this layout.

As the first step, a tentative analysis of the flow field of this layout combining with the beam pipe has been done:

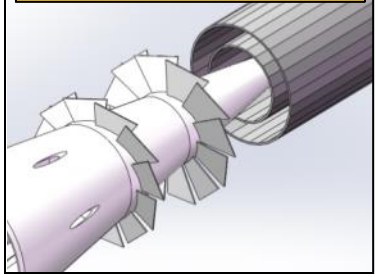
- barrels are simplified to continuous polygon tubes
- the disks are arbitrarily deployed
- no heat generation considered
- no cables considered.



VTX (barrel+disk)



Disk (rotate blades)



Given: Φ150mm gas channel

6 Inlet holes with ID：ϕ12mm，V=15.6m/s，the equivalent flow rate is $0.64 m^3/s$ 。

6 outlet holes with the same size as inlet's。

Very preliminary conclusions

- ✓ The deployment of blades of the disk seems to be good for wind guiding.
- ✓ The results show reasonable air flow field which is consistent with the structures.
- ✓ Not much pressure difference on two sides of the blades.
- ✓ The absolute pressure on each side of the blades and the gas shock pressure need to be further studied.

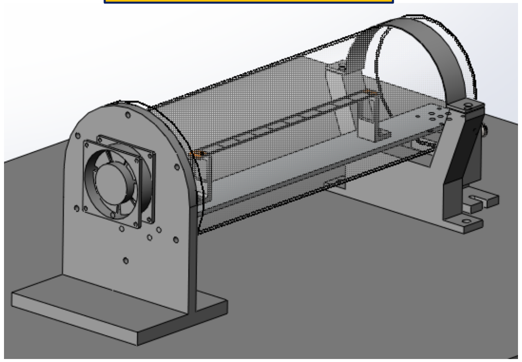
Tests preparation of the Ladder

Ladder related tests have been considered and related designs are being conducted. These tests are very essential to validate our design.

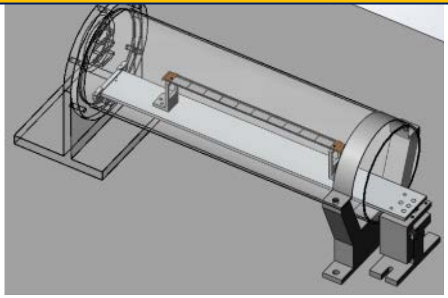
1-Mechanical testing of ladder support.

2- Ladder cooling with fan and piping compressed air are considered.
(to verify the cooling effect and also to test the amplitude of vibration.)

Cooling with fan



Cooling with piped compressed air. (different outside channel boxes are needed to fit detailed study)



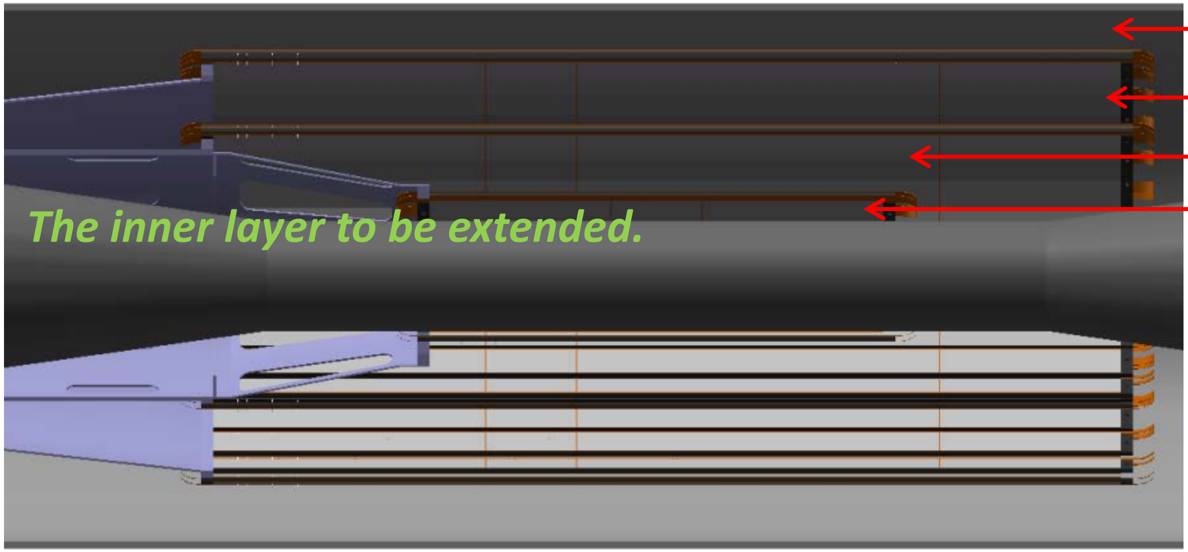
The VTX Prototype Installation and Testing

Heat generation of the VXT

Sensor Power dissipation:

Current (short term) goal: ≤ 150 mW/cm². (air cooling)

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



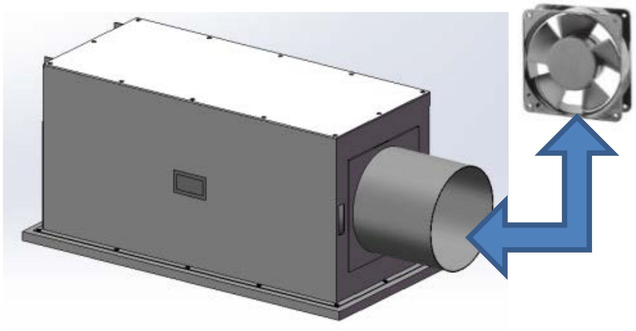
*Refers to the shorter inner layer.

At 150 mW/cm² dissipation, the total heat generation is about 726 (*668) W, for final CEPC level (50 mW/cm²) it will be about **240** W.

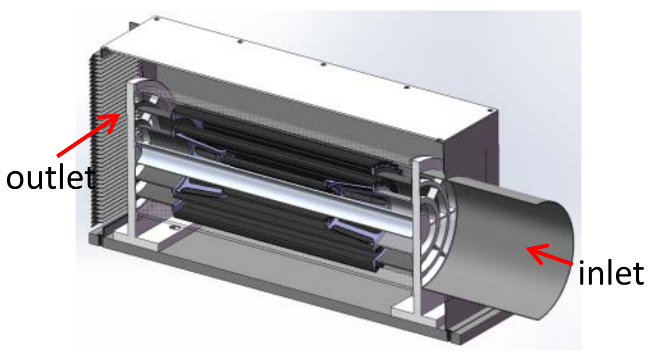
Detector Supporting and Cooling Box

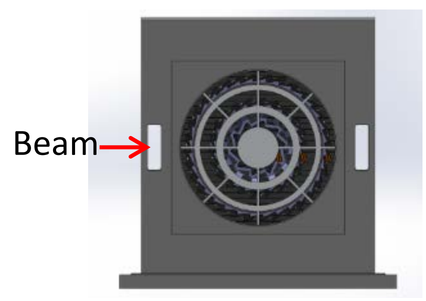
The box is air cooled and light tight.
Application:

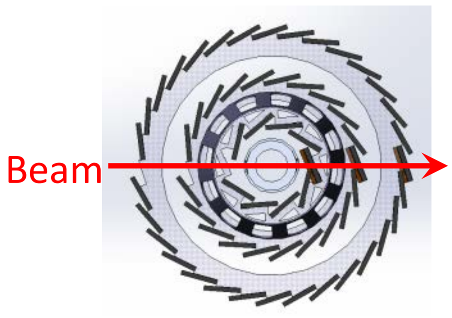
- Assembling of the support structure of the VTX prototype and cooling.
- Final beamline test of the VTX pototype.



Elbow + pipe connection:
-minimize the external vibration
-good for light seal
-cooling source inside the pipe







For final beam testing of the VTX prototype, we plan to mount just **3 - 6 instrumented ladders (one smallest sector)** on 3 barrel layers and make them in a line, also clear any blocking parts on the incident beam direction.

Ladder Support Prototype

- Several venders of CFRP products have been investigated.
- Several manufactures have been investigated on the fabrication of the ladder support prototype.
- One of the manufacture has done the process validation test , basically feasible.
- Specific tests of the CFRP material (mechanical and radiation) have been well planned and the specimens fabrication are ready to start.

Summary and Next (most2)

Summary

- ✓ Preliminary designs of the general VTX support and the ladder-spt are done with necessary simulation analysis.
- ✓ Investigation and preparation for the fabrication of ladder-spt prototype and for related tests are being conducted.

Next

- ➢ *Cooling analysis close to real structure and working condition will be studied further, which would be in a system level by integrating the support structures, endcap disks, inlets and outlets* (fan and griller for VTX prototype cooling of most2).
- ➢ *Further exploration of the support design of the VTX with disks(CEPC)*

- Ladder support prototyping.
- Mechanics and cooling test of the ladder-spt and ladder.
- Final engineering design and fabrication of the support of VTX prototype.

Thanks