Mechanical Design of Silicon Vertex Detector Prototype

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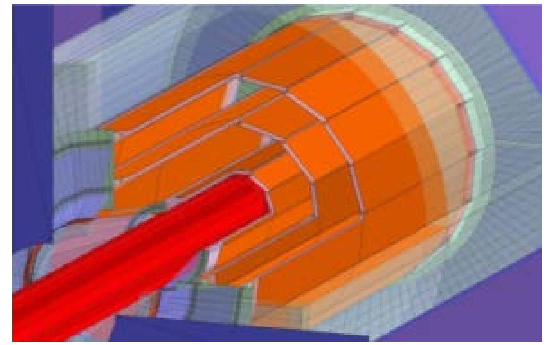
Vertex Layout in Preliminary Design

	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. (air cooling)

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

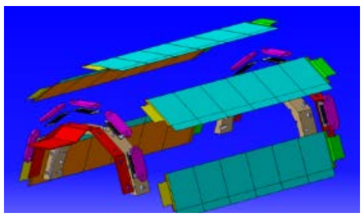
trigger mode ≤ 100 mW/cm2.

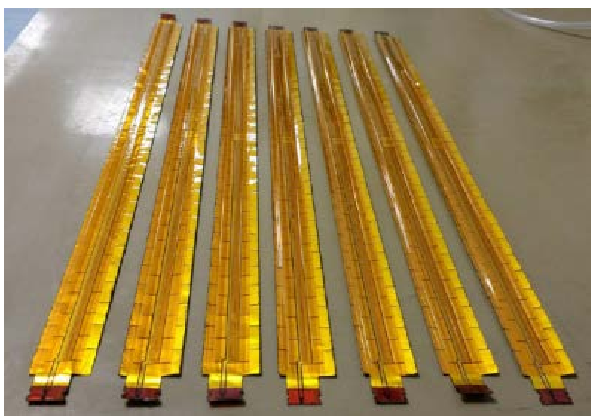
***Working temperature range:** 20-50 ℃ (best performance under 30 ℃)

Challenge

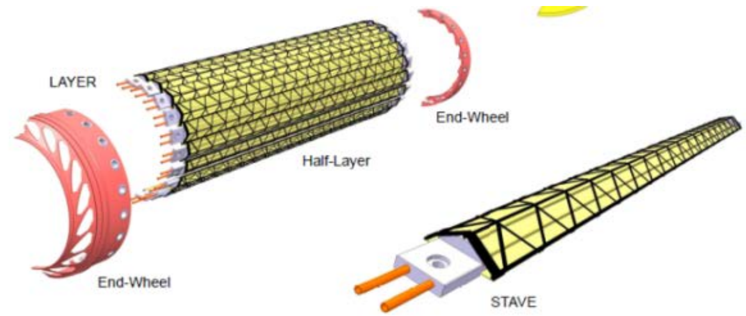
The big challenge: low material & high rigidity

Mu3e
0.1% X/X_0





Alice ITS Upgrade
0.3% X/X_0

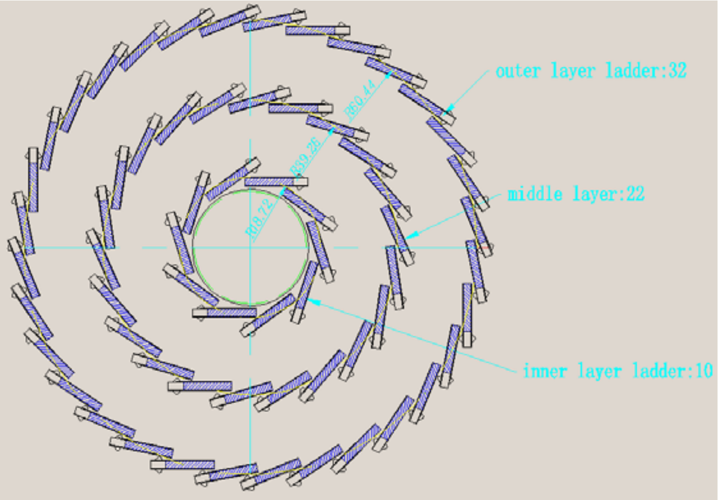


These two experiments both have pixel sensors on one side of the support. Our Material budget requirement is 0.15% X/X_0, which is between them and closer to Mu3e, but the positon stability is higher than it.

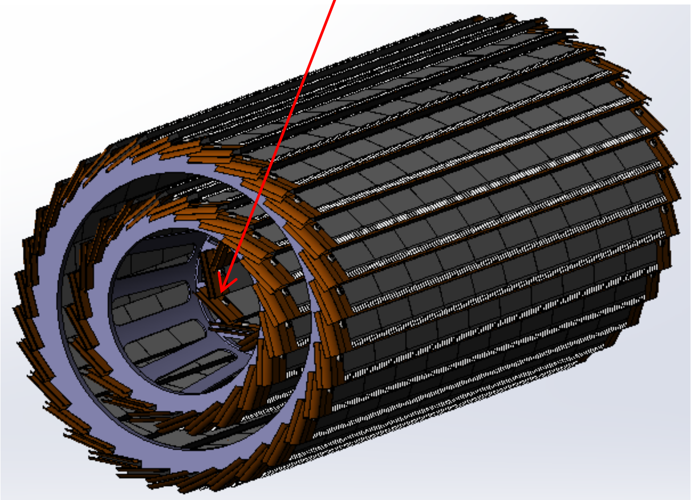
No such low mass support structures was made in China before.

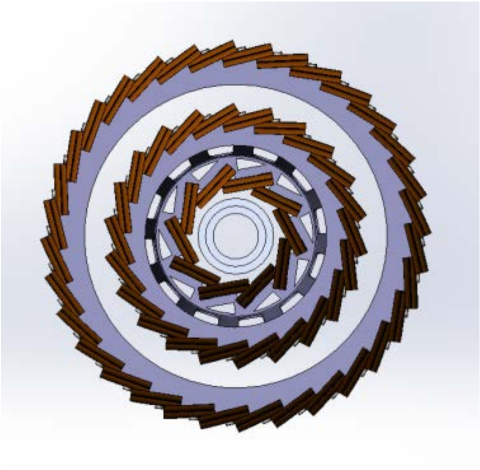
General Structure of the Vertex Detector (VTX)

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



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



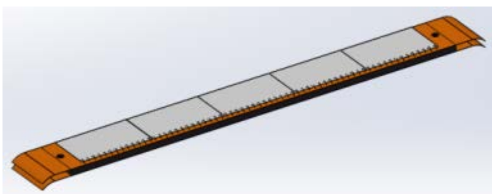


Ladder Structure

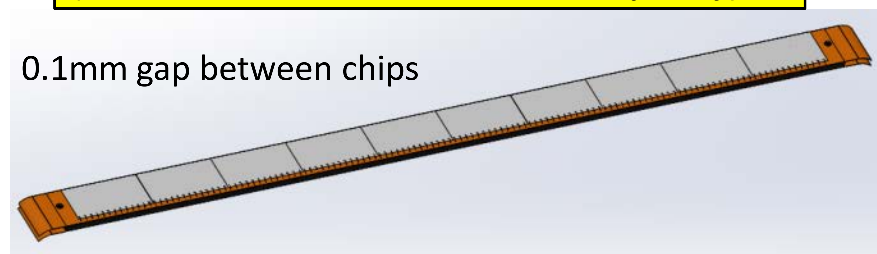
Sensor chip : 14.8 x 25.6 x 0.05 mm (2 mm wide margin at one side for wire bonding)

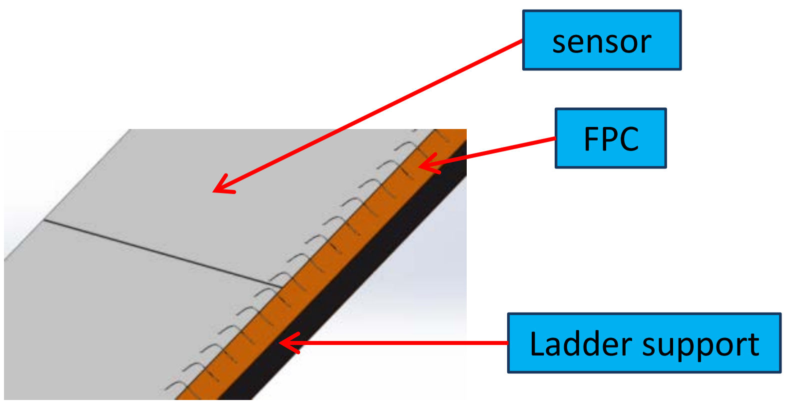
Ladder: support + chips + FPCs

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

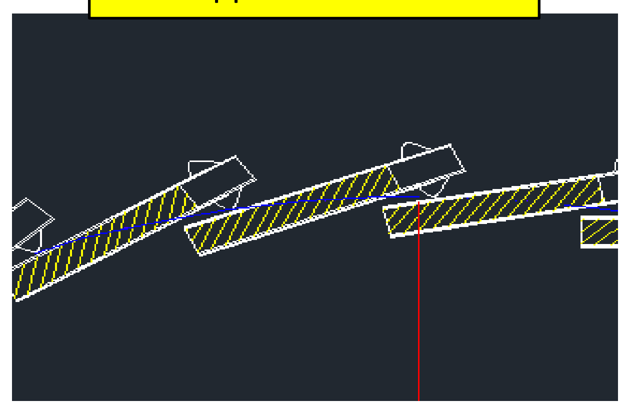


Ladder of outer two layers(16.8 x 266.9 mm)
20 chips total including both sides
(All barrels will use the same ladder finally)





Overlapped and dead area



Ladder Support (ladder-spt)

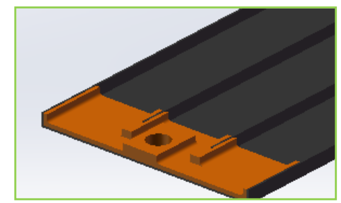
Different ladder support designs have been studied.

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

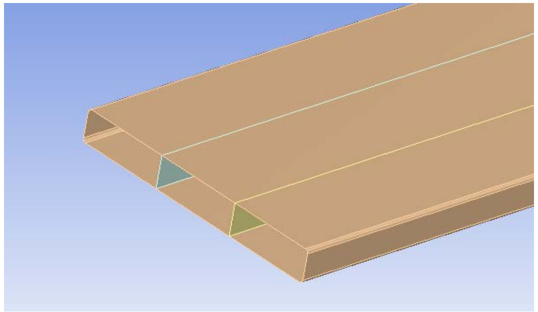
Analysis of the Ladder

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

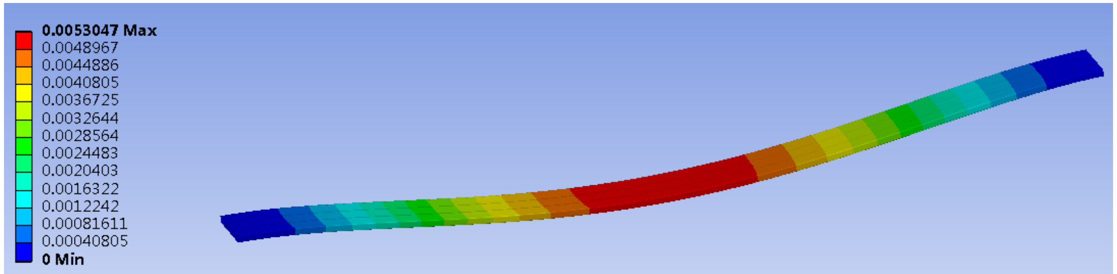
To evaluate the contribution of the sensors and FPCs to the rigidity of the ladder support, two comparative FEA analysis were done based on the current preferred design.

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.



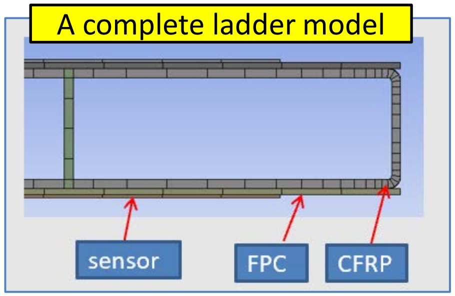
Max def. under full load: 5.3 um

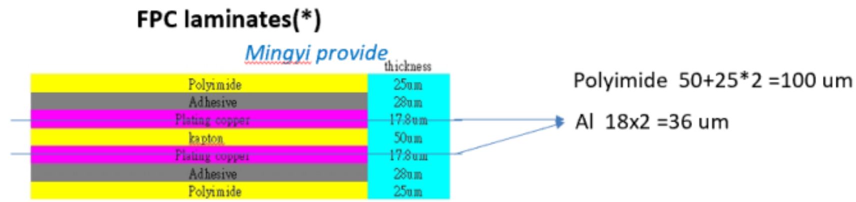


Analysis of the Ladder

Analysis-2. A complete ladder

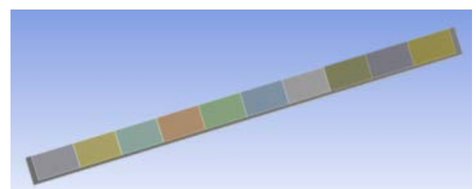
(include the support and the sensors and FPCs on both sides)

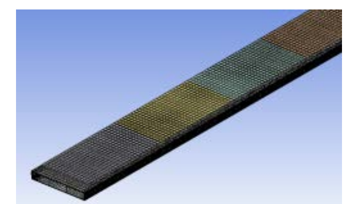




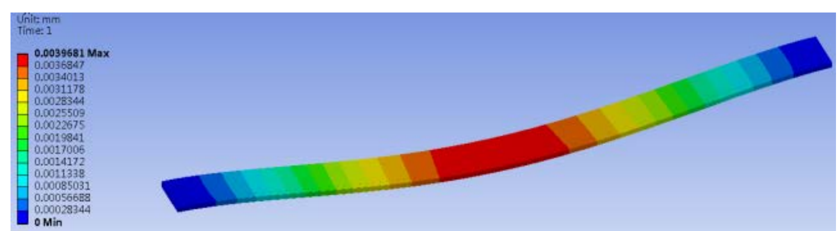
The total load and the boundary condition are the same as analysis-1.

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

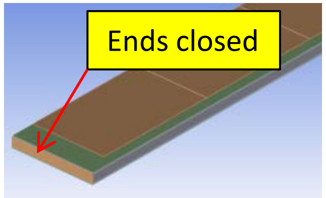
Cooling simulation of a single complete ladder with detailed FPC is also studied.

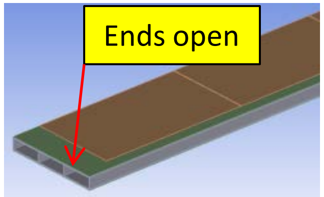
Temperature results

(with different sensor power dissipation and different air speed)

Max temperature of ladder (℃) (air temperature 5 ℃)					
Air speed (m/s) / Power Dissipation (mW/cm2)	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℃) .





The cooling analysis of the overall VTX with a simplified model close to real design which have ladders overlapped will start next.

Tests Plan of the Ladder

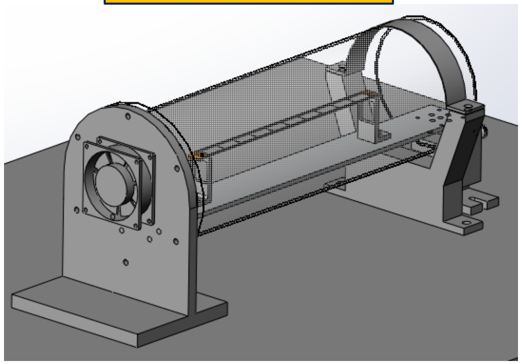
Ladder related tests have been considered and related designs are being conducted. These tests are very essential to validate our design.

1-Mechanical testing of ladder support.

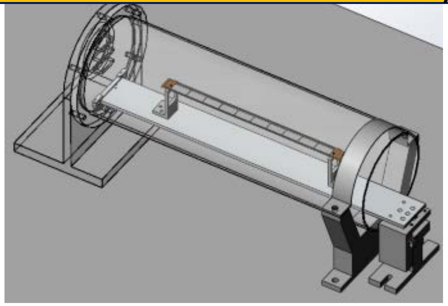
High precision measuring instruments and necessary tools are being procuring.

2- Ladder cooling with fan or 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. (A few different outside channel boxes are needed to fit detailed study)



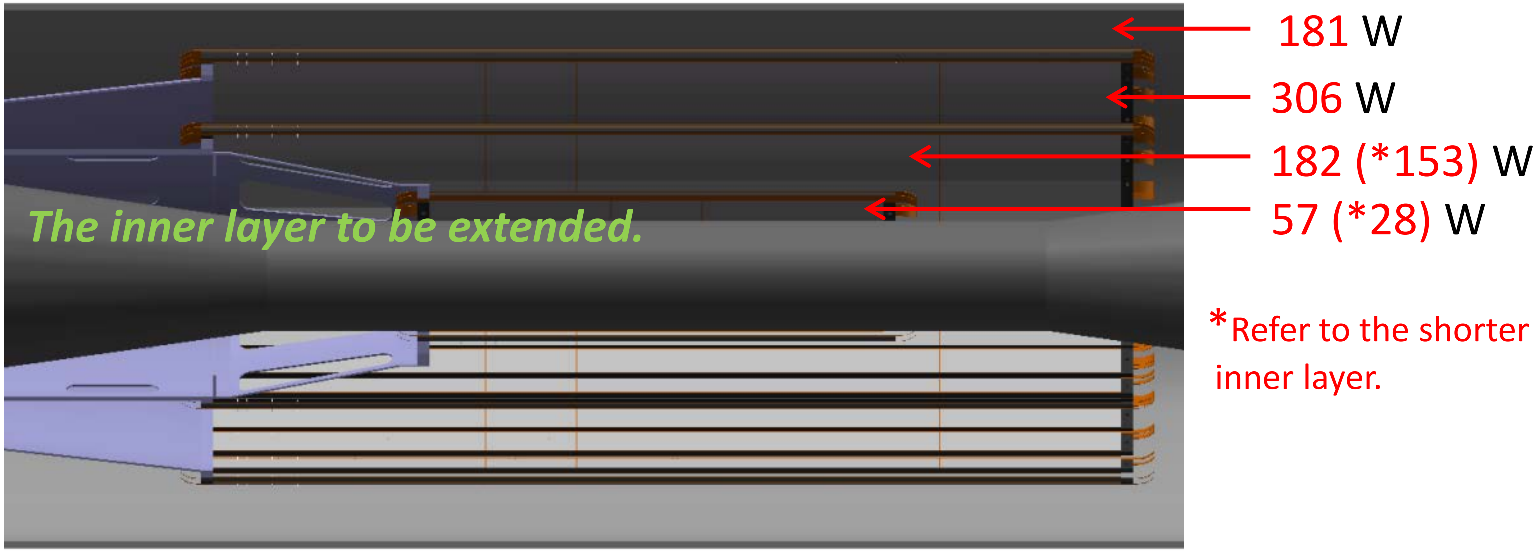
The VTX Prototype Installation and Testing

Heat generation of the VXT

Sensor Power dissipation:

Current (short term) goal: ≤ 150 mW/cm^2. (air cooling)

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

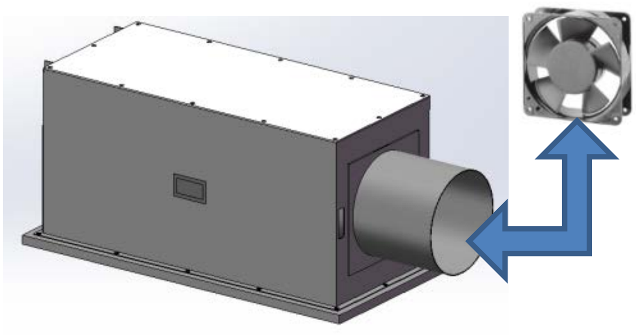


At 150 mW/cm^2 dissipation, the total heat generation is about 726 (*668) W, for final CEPC level (50 mW/cm^2) it will be about 225 W.

Detector supporting and cooling box

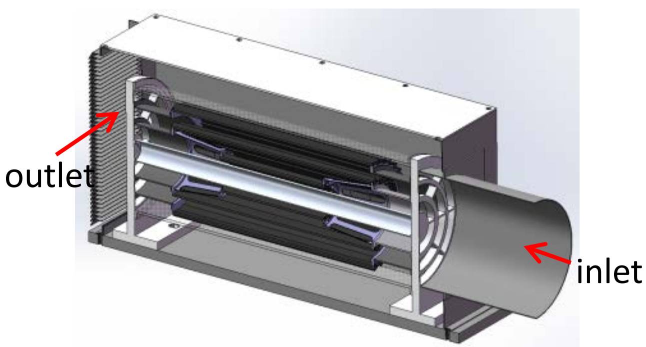
The box is air cooled and light tight.
Application:

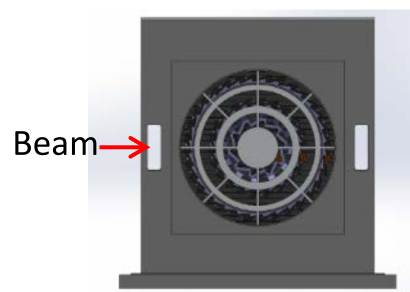
- Assembly of the support structure of VTX prototype and cooling.
- Final beamline test of VTX.

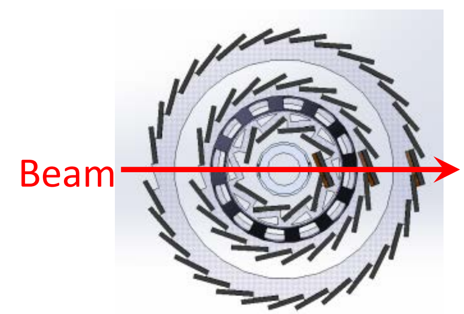


Elbow+ pipe connection:

-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 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 Prototyping

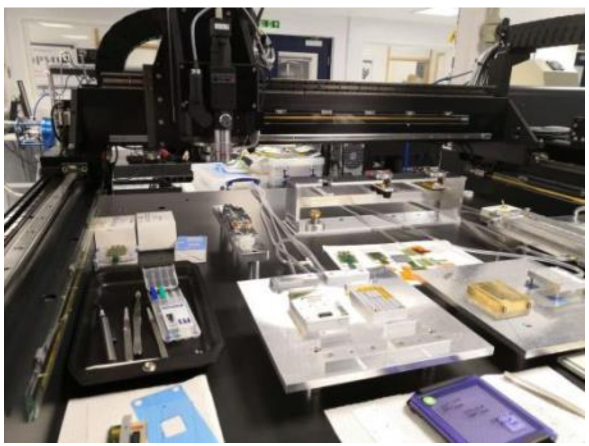
- Several venders of CFRP products have been investigated.
- Several manufactures have been investigated on the fabrication of the ladder support prototype.
- One of the manufacture has done the process validation test , basically feasible.
- Specific tests of the CFRP material (mechanical parameters and radiation) are also planed and specimens fabrication is in communication with manufactures.

International collaboration Activities

- One engineer of our group visited Oxford and Liverpool for 4 weeks last year, learned a lots about silicon.
- Good communication and collaboration with foreign institutes.

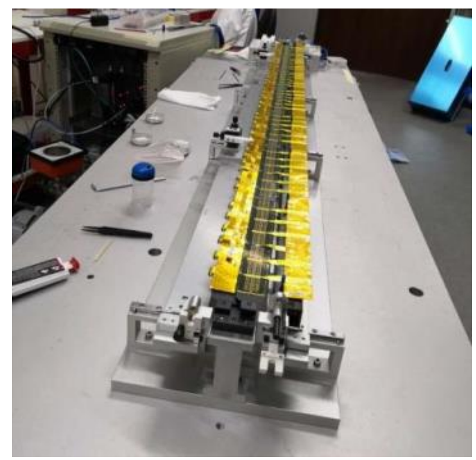
Lab visit in Oxford

Mu3e ladder, Atlas barrel strip stave prototype.



Labs visit in Liverpool

Module of Alice’s OB tracker, Advance material Lab



Summary and Next

Summary

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

Next

- Ladder support prototyping finished by 2021.5.
- Mechanics and cooling test of the ladder-spt and ladder (with dummy sensor) finished by 2021.6.
- Final designs of the ladder support and overall VTX and engineering drawing finished by 2021.7.
- Complete the manufacture of all mechanical support of the VTX by 2021.12.

Thanks