Mechanical design of the VTXD prototype

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On behalf of the CEPC VTXD group
2023-6-19

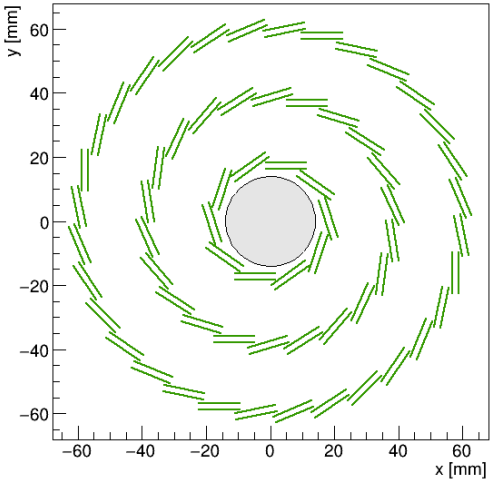
The VTXD layout

The VTXD layout that the prototype design based on is a modified version of the VTXD in CEPC CDR, and it is according to the full-size sensor that needs electronics to be readout.

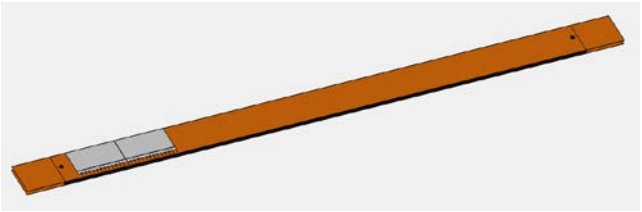
Design parameters of the vertex detector

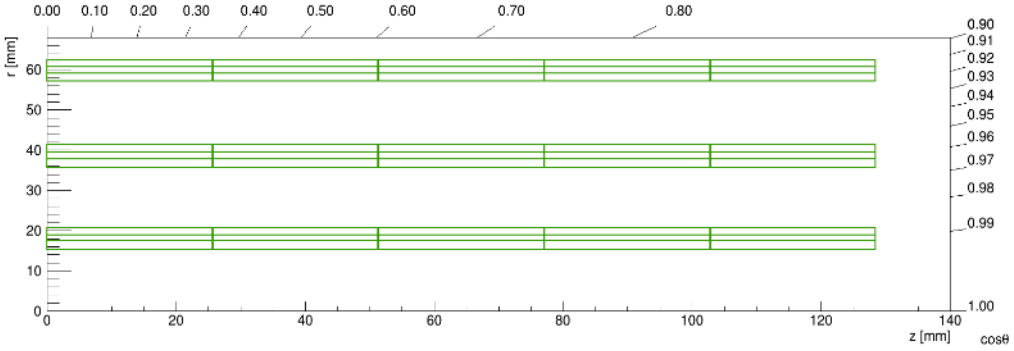
	R (mm)	|z| (mm)	Number of ladders	Number of chips
Layer 1	16	125.0	10	200
Layer 2	18	125.0		
Layer 3	37	125.0	22	440
Layer 4	39	125.0		
Layer 5	58	125.0	32	640
Layer 6	60	125.0		

VTXD layout



The double-sided ladder

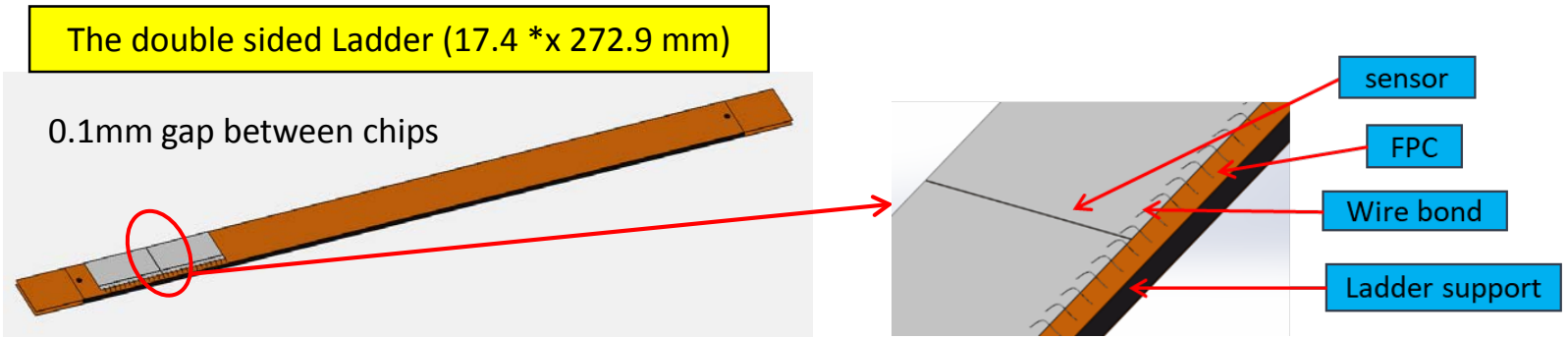


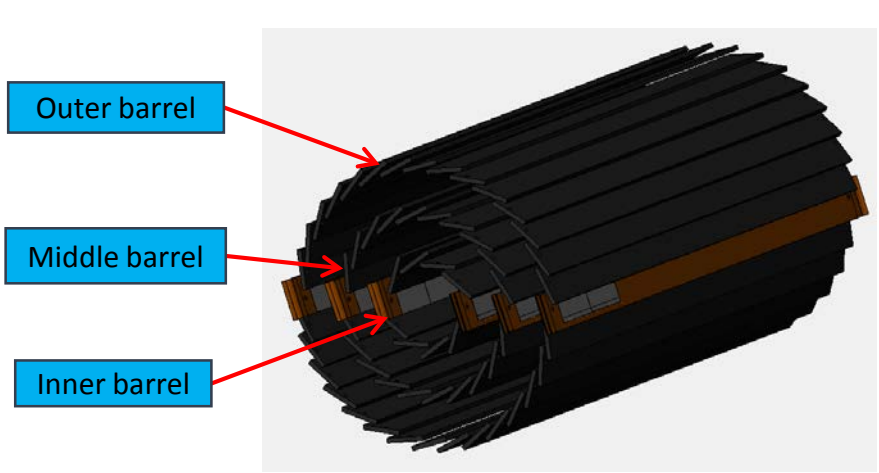


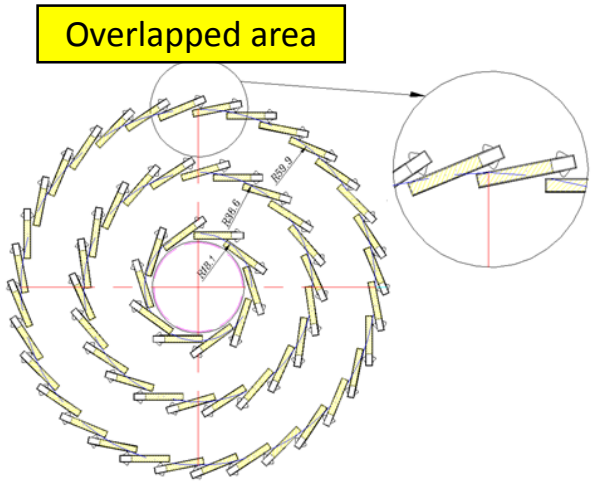
Ladder and Barrels

Sensor chip : 16.8* x 25.6 mm (2* mm margin at one side for wire bonding)

Ladder: support + sensors + FPCs, sensors and FPCs on doubled sides of the ladder.







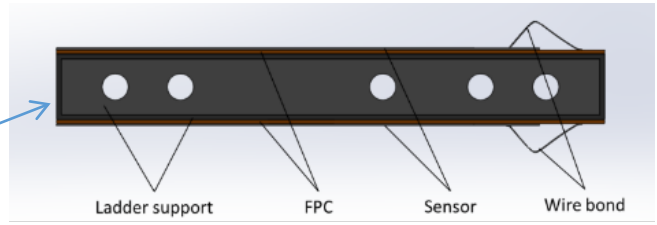
Ladder Support

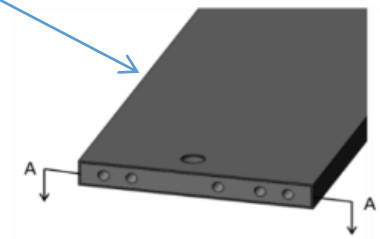
With the FEA assistance, compared different optional designs, optimized and finalized the details of the official design.

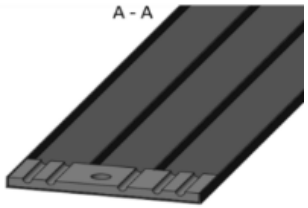
Material: CFRP.

Size: 272.9 x 17.4 x 2 mm (L x W x H).

ladder support structure

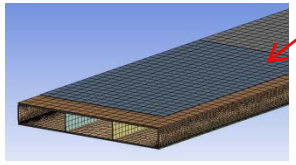


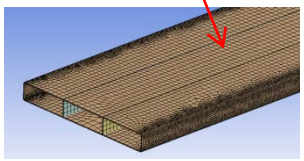




FEA results of static deformation of ladder support

Laminate thickness	Weight of the support tube (gram)	Deformation (μm)	
		Ladder (under self-weight)	*Ladder support* (under full load)
120 μm	2.0	4.9	6.8





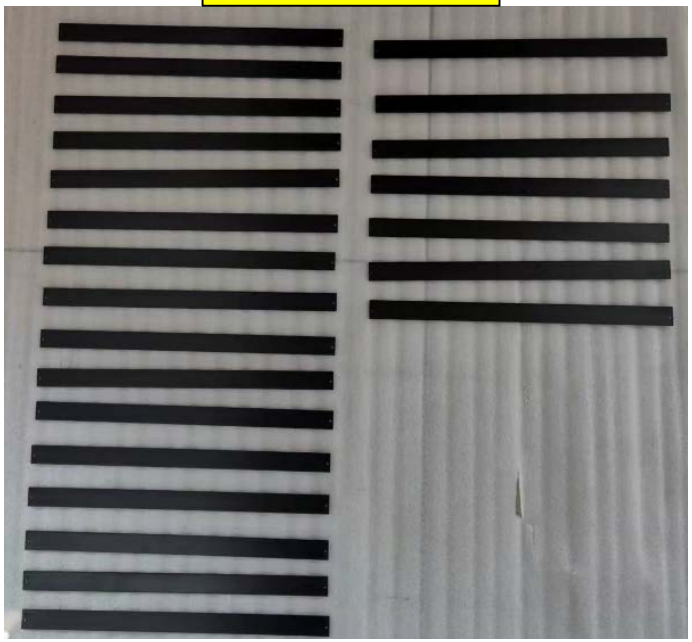
Fabrication process test

Aiming to reduce material, the CFRP laminate need to be very thin, to make the structure with such a length and small section by the thin laminate is challenging.

Ladder support fabrication

Produced a ladder support with CFRP laminate thickness down to 0.12 mm, iterating with a company in their fabrication process.

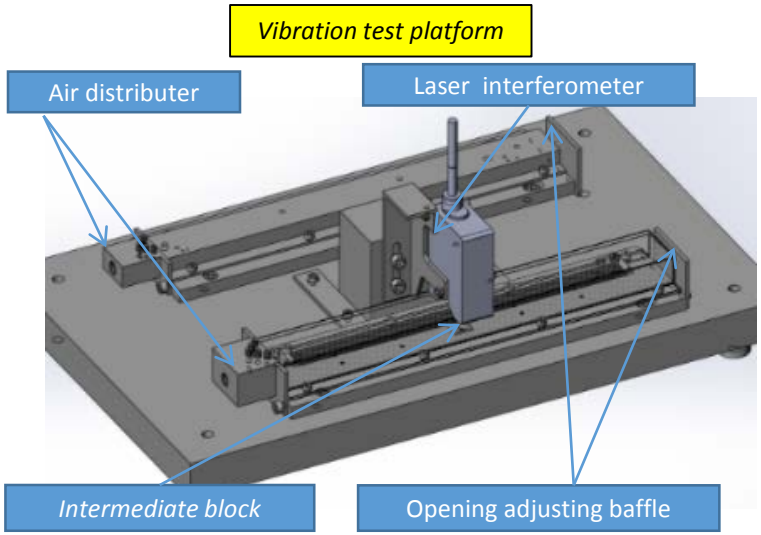
Ladder support



For the prototype, the CFRP laminate is slightly thicker than the previous process test.
(Due to COVID pandemic, a new company that can make it before beam test was chosen to make the ladder support)

Ladder support test

Platforms were designed for static and vibration test of the ladder support.



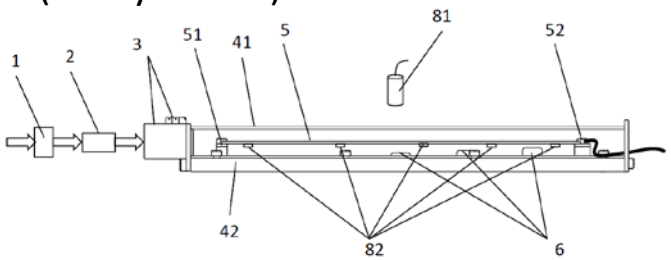
1. **The technical solution for the vibration test platform design** was applied for and got a patent (invention):

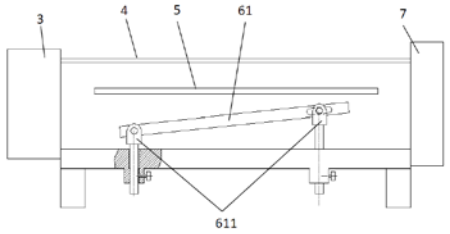
一种超轻梁的振幅测量装置
专利号：ZL202110576983.3
2022年4月授权-发明

该装置可对超轻探测器支撑梁提供流量、导流、扰流、出气口开度等均可进行调节的气流环境，并可对不同环境下产生的振动振幅进行测量。采用非接触式振幅测量仪器，适用于轻质梁，特别是梁的振幅预期非常小(微米级)的情况。

2. **A technical solution** with a structure partly similar to above, but with more components and extended function added, **for detector cooling test and temperature measurement** was also applied for and got a patent (utility model) ：

一种探测器气冷测试装置
专利号：ZL202121144759.9
2022年8月授权-实用新型
发明申请在实审中



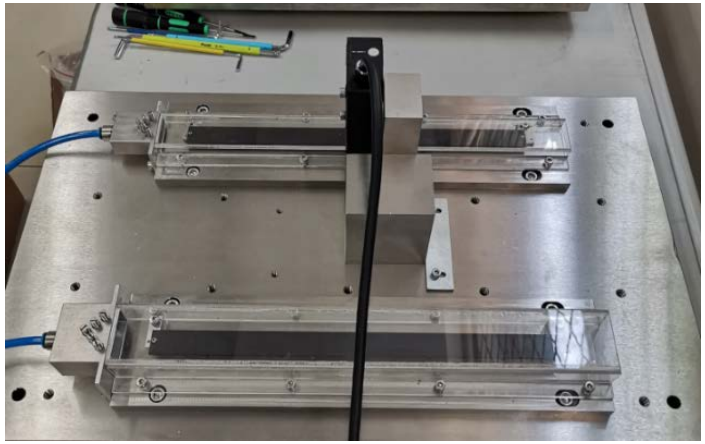


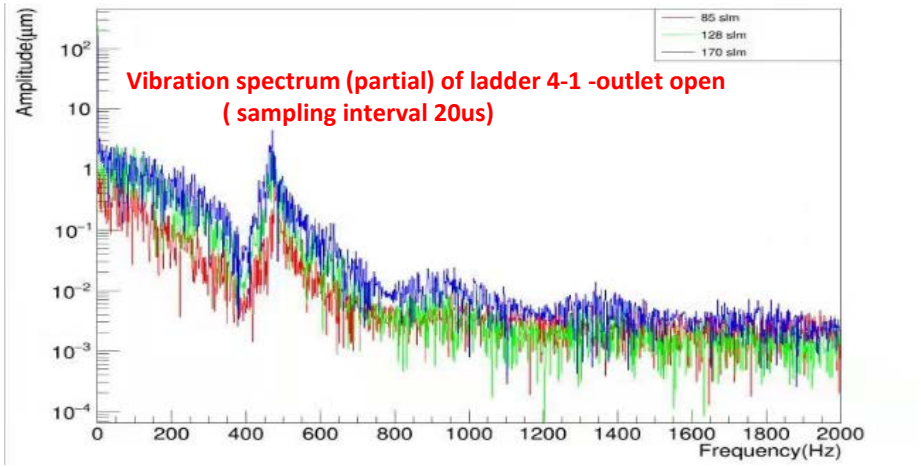
该探测器气冷测试装置，是一个具有对上游气体预冷却，对气体流量、入口导流、气道内扰流、出气口开度等进行调节功能的测试装置，同时可以采用非接触式或接触式方式或者二者结合的方式对探测器进行温度测量.

Test results

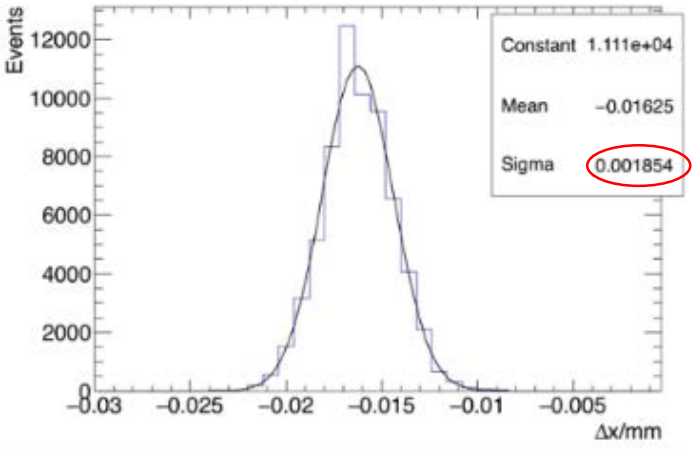
Tested the CFRP ladder support under different estimated air flow rate, and analyzed the result :

- the vibration spectrum *(sample as below)*
- *statistic analysis of the results (Gaussian distribution)*





The max vibration amplitude is 1.9 μm, which is much smaller than the detector resolution. The result shows the ladder support has enough rigidity under estimated air flow.



Tooling design for ladder assembly

To assemble the double-sided ladder is a complex and delicate work.

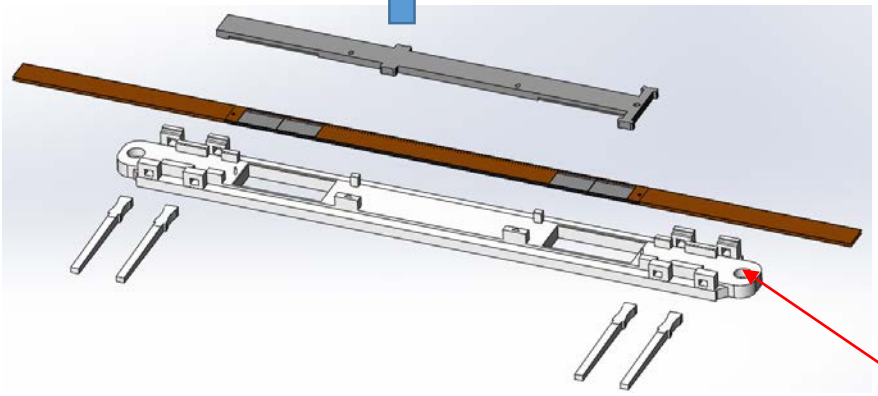
- Assembly scheme and procedures were fully considered.
- Tooling for specific process were designed.

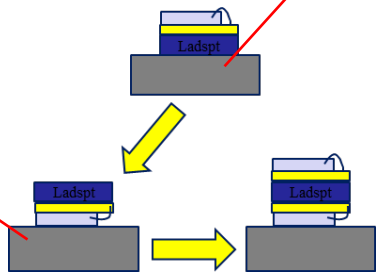
Sensor pickup tool

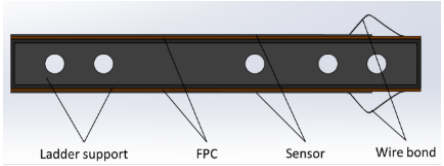
Tooling for mounting module on the reverse side of a ladder

Module fixation and protection components

Vacuum plate for flex and CFRP support fixation

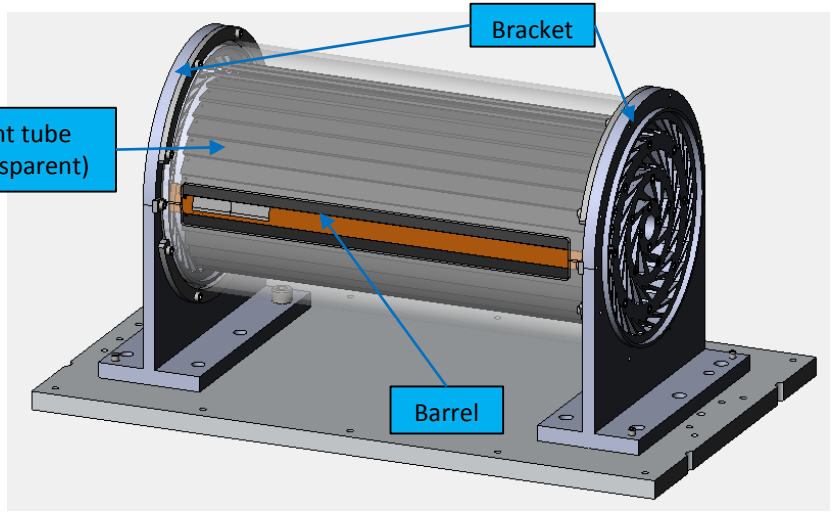


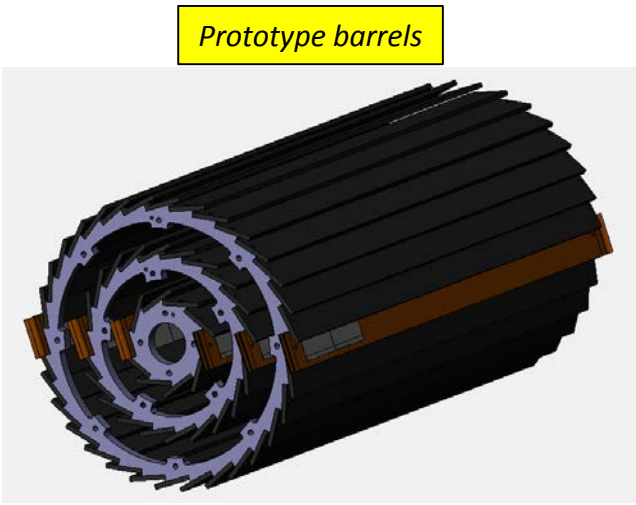




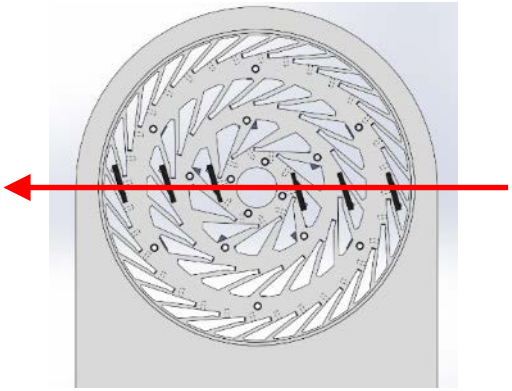
Main structure of the VTXD prototype

Three barrels and two support brackets to locate them as VTXD layout .

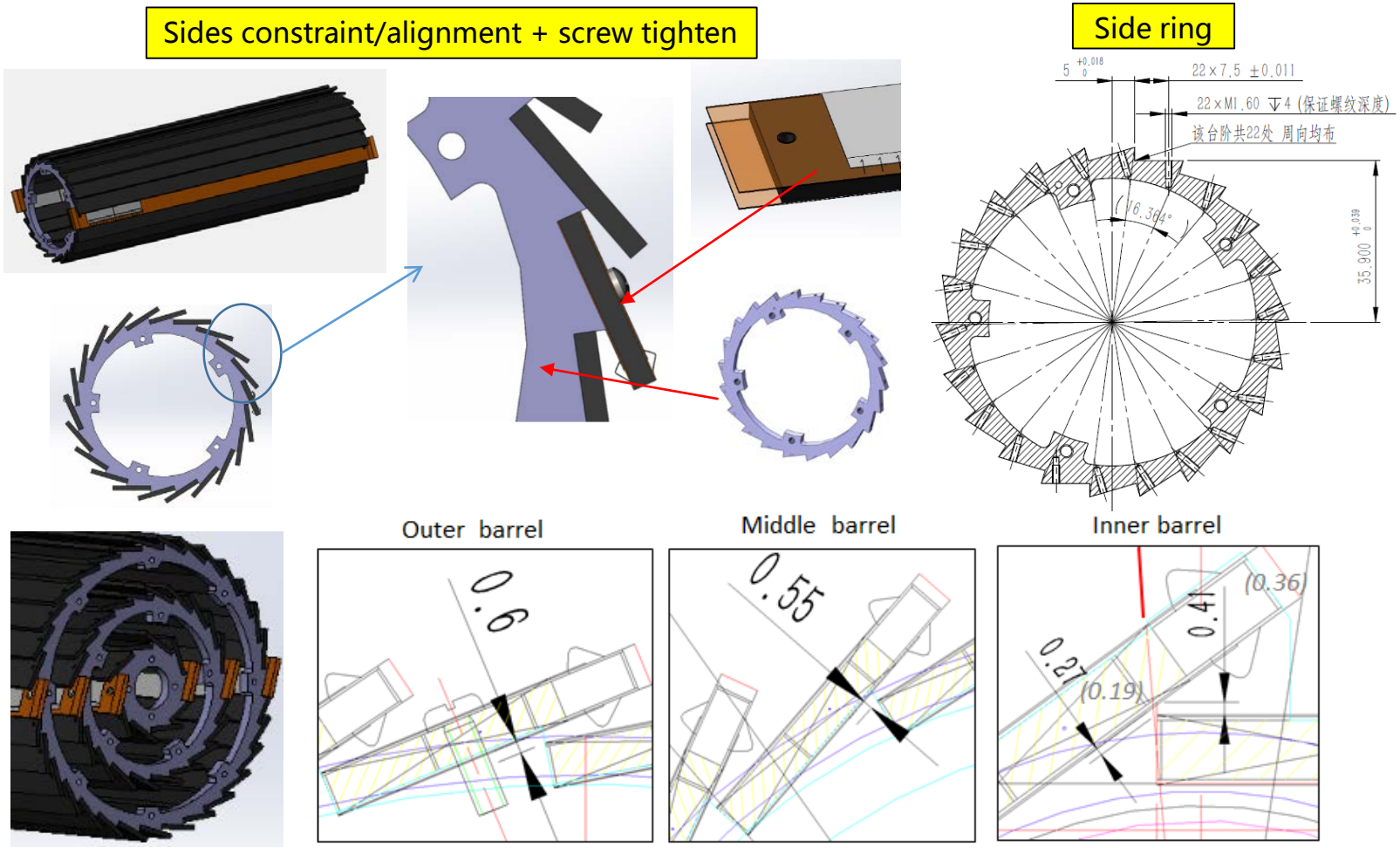




For prototype beam test: 6 ladders are mounted on one line, others are bare CFRP ladder support.



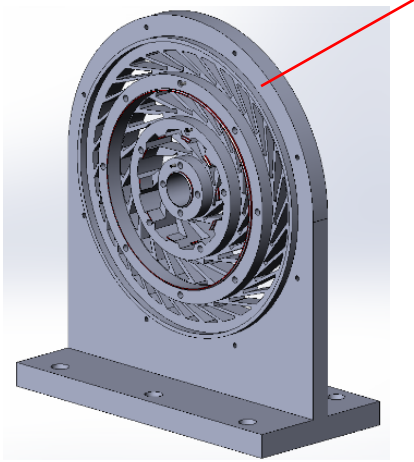
Ladder fixation on barrel

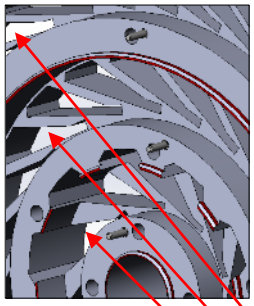


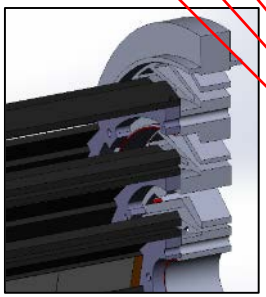
- The barrel is a tight structure with very small gap between ladders, assembly is challenging.
- All support parts need high accuracy to assemble a precise barrel and the VTXD that has three barrels coaxially mounted.

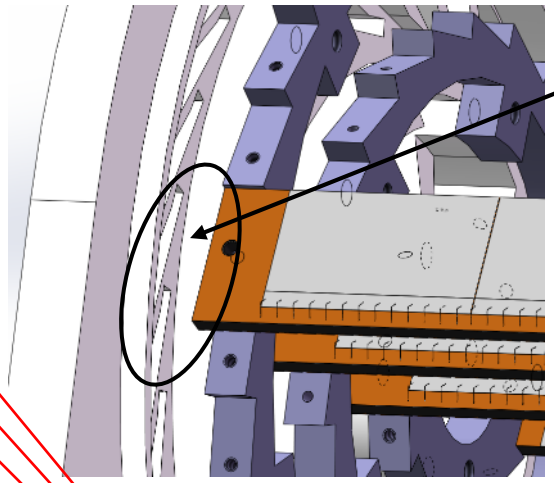
Barrels fixation on the brackets

Barrels (side ring) locating on the main bracket: ring + pin

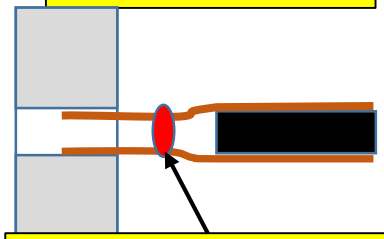






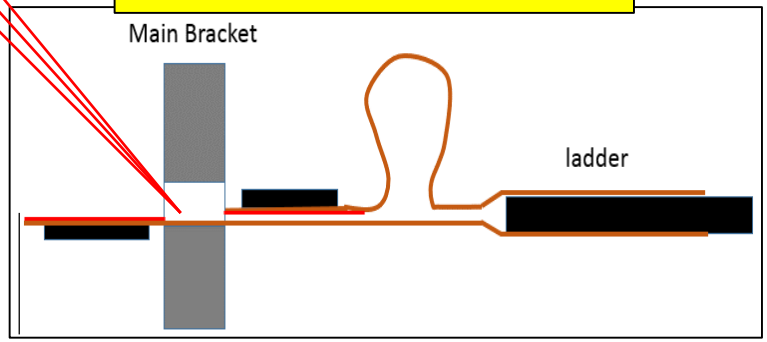


The convex ring provide a transition region for flex routing.

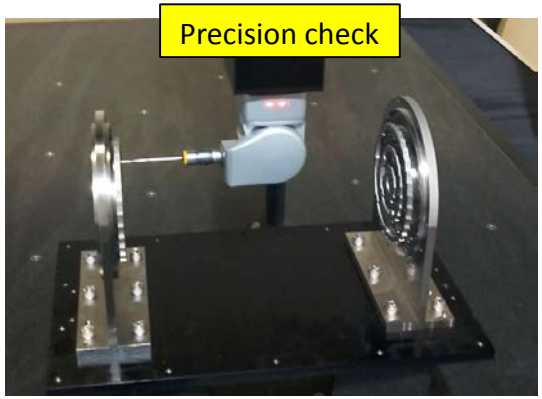


Glue adjacent flex to enable routing and for protection.

Slot holes on the bracket: pass flex through bracket in order, ventilation



Precision check



Flex

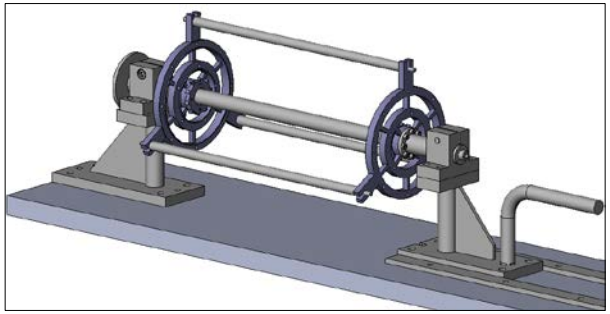
The metal material used for the support brackets and side rings of the prototype is **not necessary for the detector**, it is only for the beam testing and transportation.

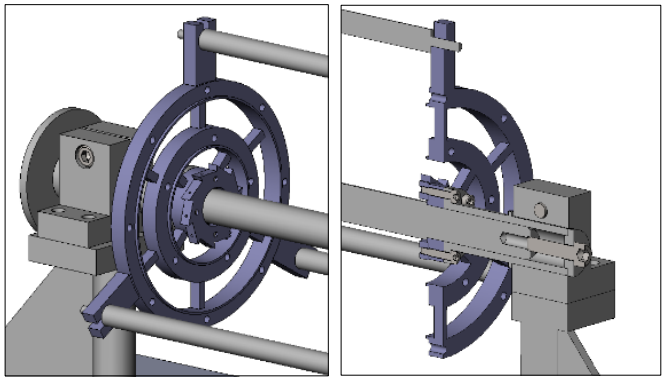
Tooling design for VTXD assembly

To ensure assembly accuracy of the VTXD structure:

- A set of tooling (locating wheels, shaft, constraint rods, etc) was designed.
- Key parts have the same machining accuracy as those support for VTXD.
- The side rings of barrel can be precisely located on the locating wheels with position constraint in three directions (radius, peripheral, axial)

Barrel assembly tooling





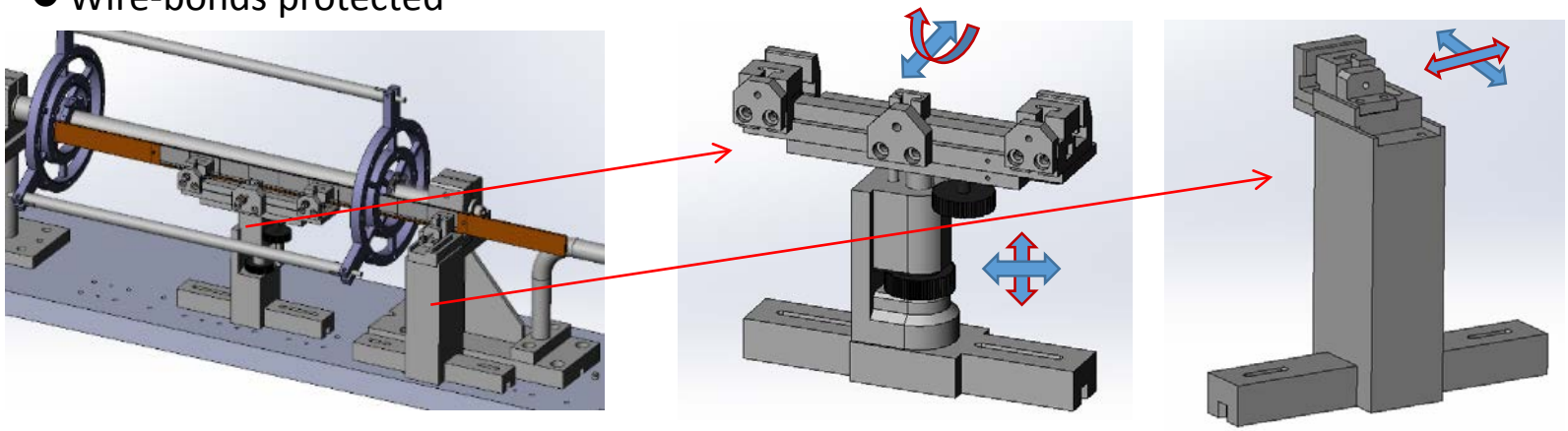
Middle barrel assembling

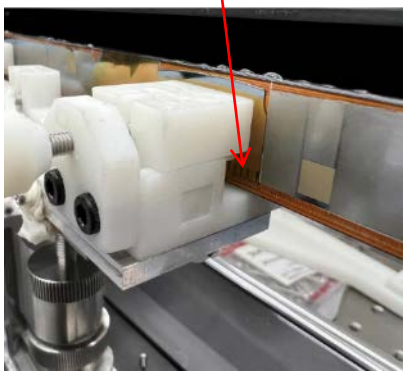
Outer barrel assembling

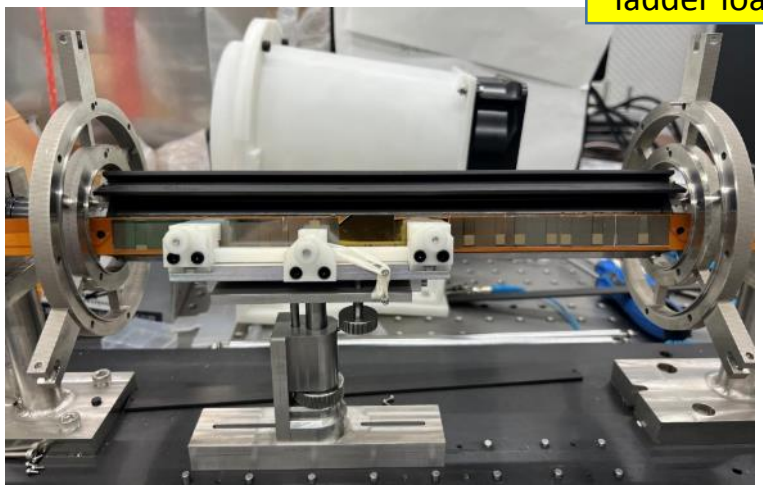
Tooling design for ladder loading

Dedicated jigs were designed and used for ladder installation on barrel.

- Allow ladders to move in 3 axial directions and rotate along the longitudinal direction
- Wire-bonds protected

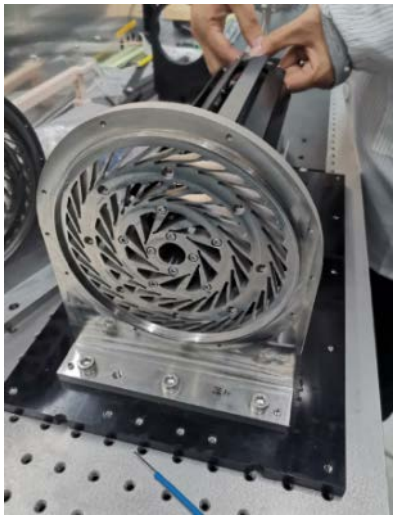


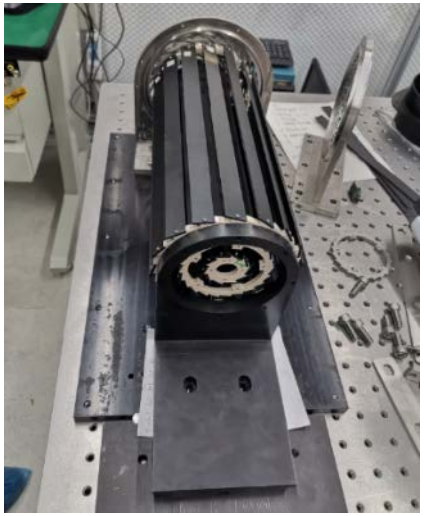


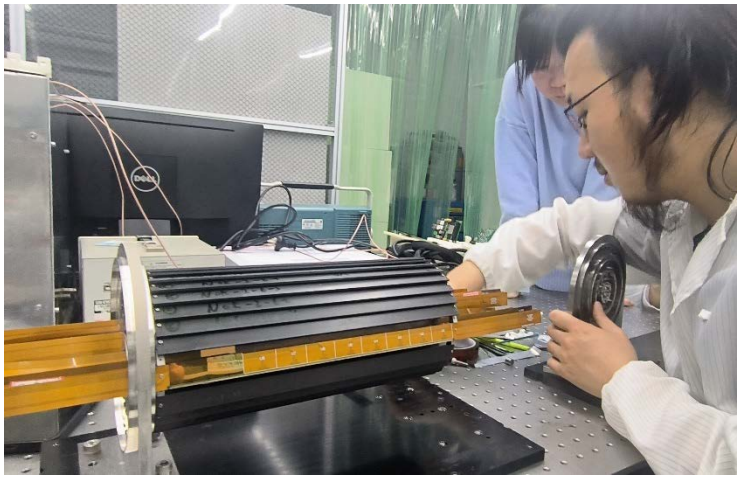


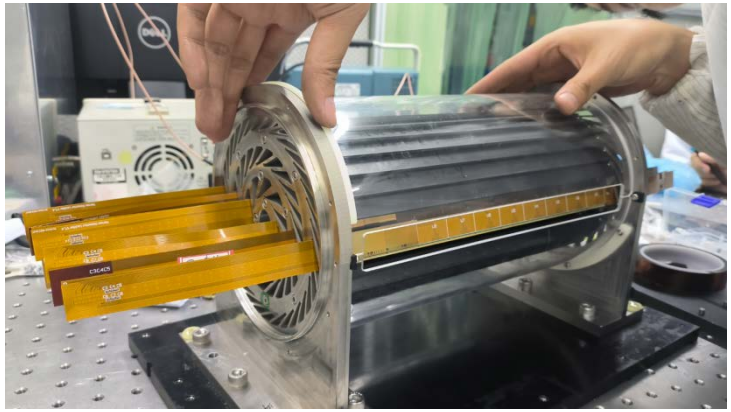
Prototype - barrels installation

The installation proceeded very smooth, all three barrels aligned with and fitted to the main brackets very well.







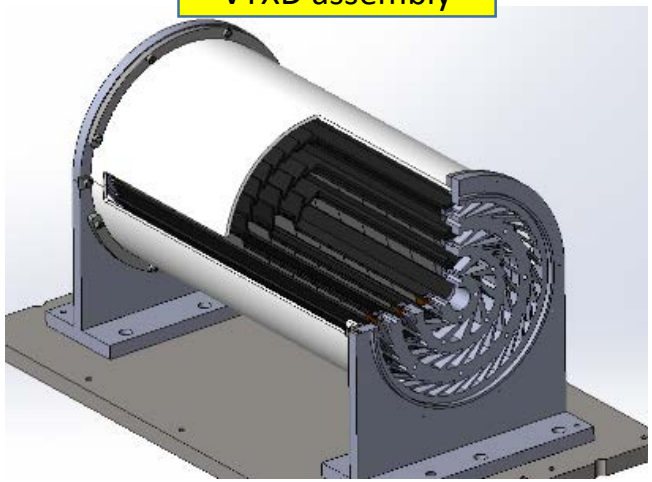


A paper to sum up the VTXD prototype mechanical design was published:

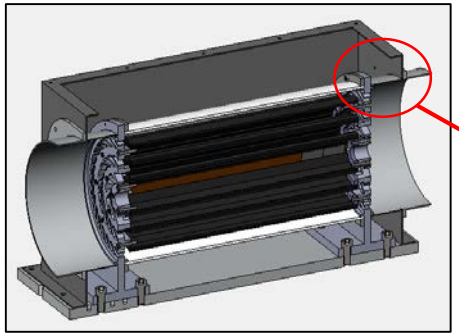
Mechanical design of ultra-light vertex detector prototype for CEPC, Jinyu Fu, Zhijun Liang, et al , Radiation Detection Technology and Methods, 2022, Vol.6 (2), p.159-169

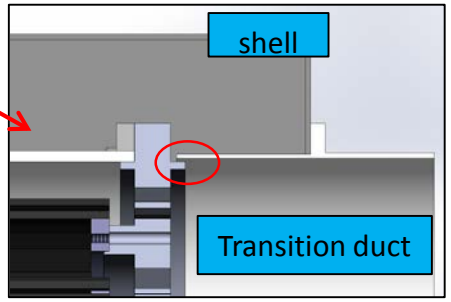
Overall structure design of the VTXD prototype

VTXD assembly

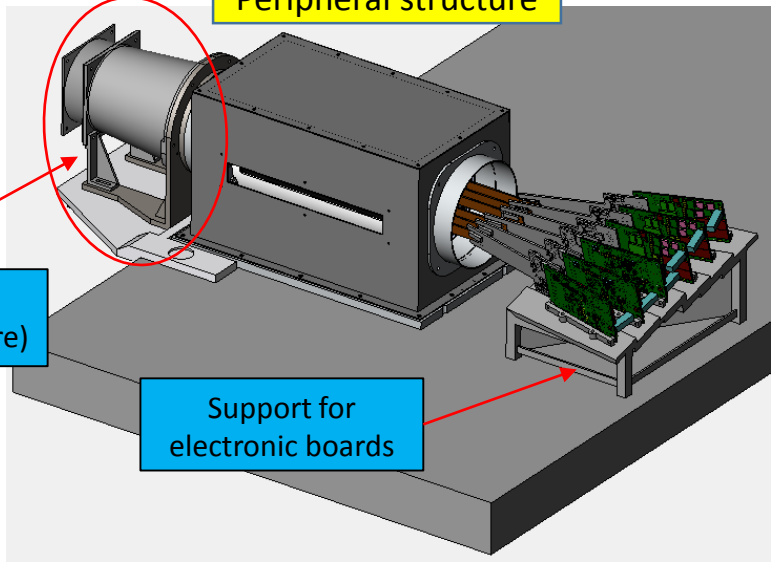


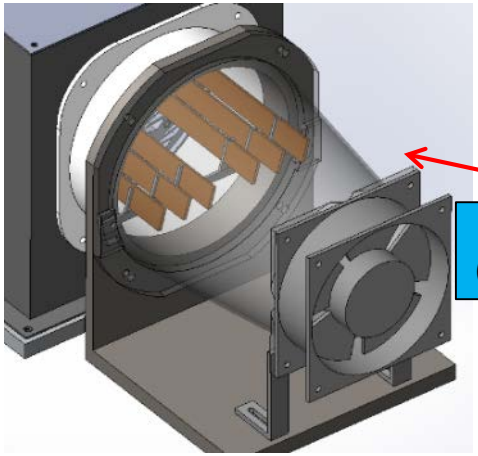
VTXD box (vent, vibration-isolation, protection)





Peripheral structure



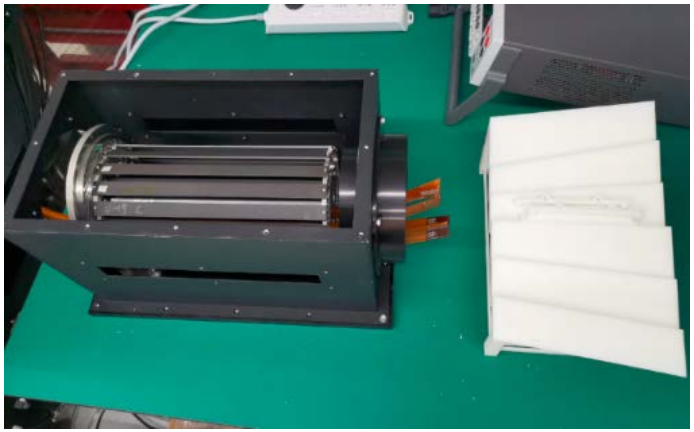


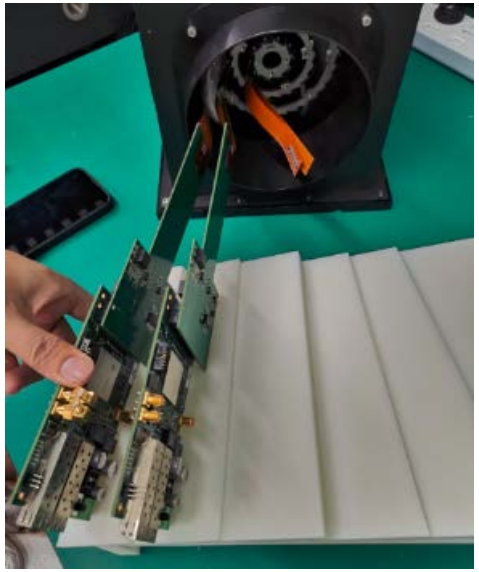
fan and duct
(independent structure)

Support for
electronic boards

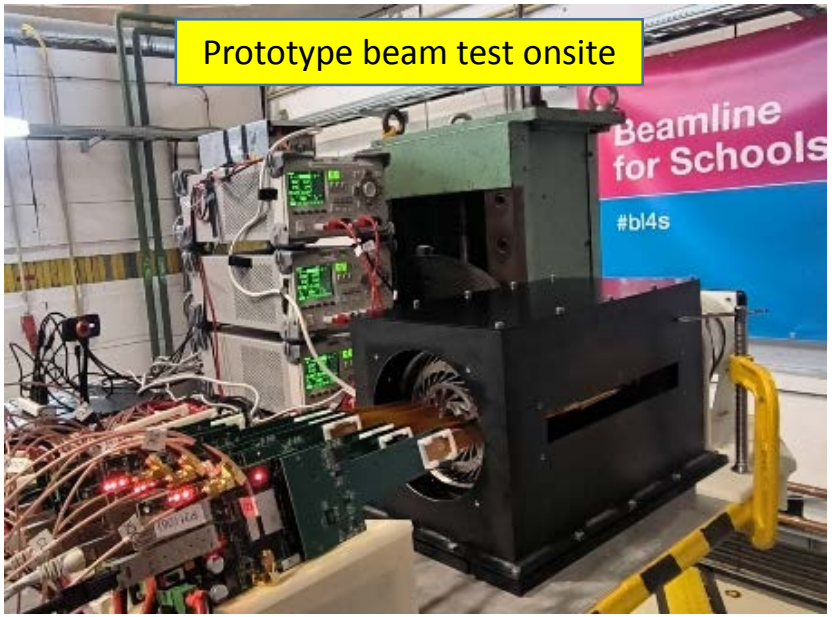
Prototype - general

VTXD box





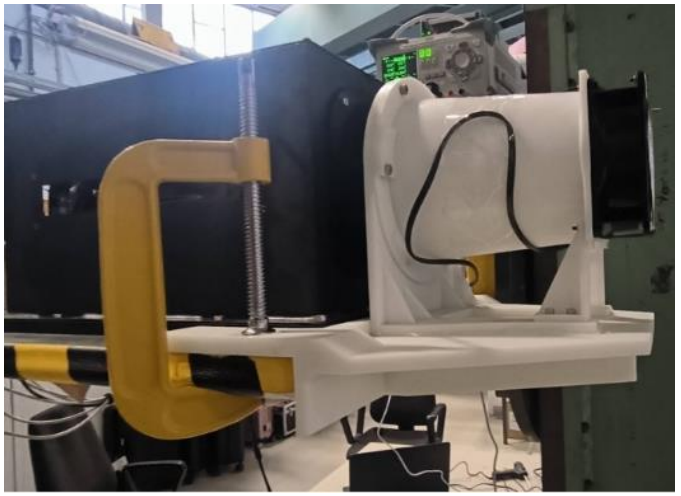
Prototype beam test onsite



Prototype cooling

The cooling for prototype were designed based on the sensor power dissipation:

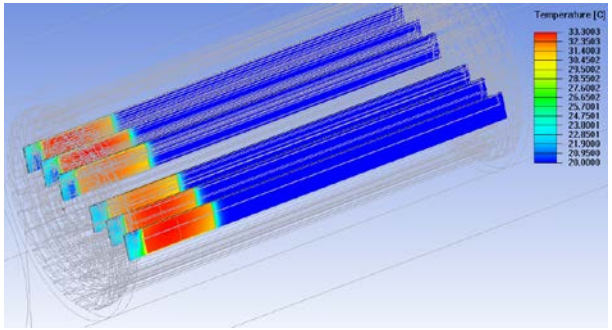
- air cooling (fan selected)
- ventilation and cooling ducts design
- cooling simulation



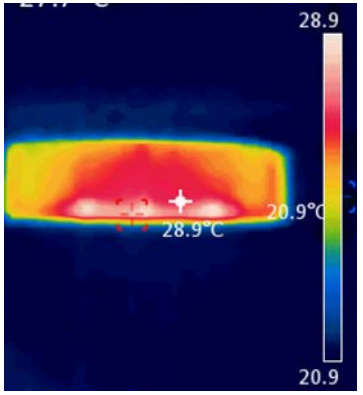
Temperature of the chips was monitored during the beam test. Verified:

- ➢ reasonable cooling design (real temperature is within the simulation)
- ➢ good vibration isolation - Vibration induced by cooling does not affect the detector resolution, benefiting from the non-contact independent assembly design.

Prototype cooling simulation： Max 33.3 ℃



Chip temperature under cooling during beam test: Max 28.9 ℃



Summary

- An ultralight ladder support was designed for the VTXD.
- Dedicate tooling was designed and used for ladder assembly and testing.
- A vertex prototype was designed and assembled with such precision that allow us to achieve 5 micron track resolution, after alignment. As demonstrated in the test beam.
- Achievements:
  - two patents authorized
  - one article published