Mechanical design of the VTXD prototype

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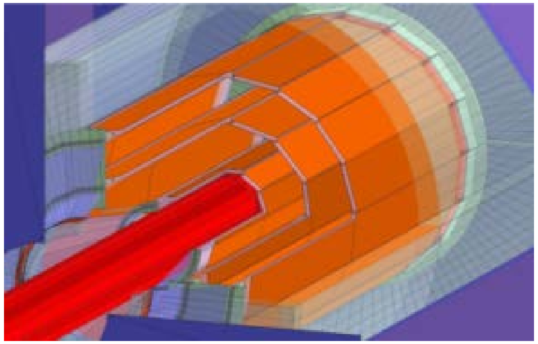
2023-6-8

Vertex Detector Layout in Preliminary Design

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



6 layers of sensors (on 3 layers barrels)

* **Material budget**: 0.15% X/X_0 for a single sensitive 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: ≤ 50 mW/cm2. (air cooling)

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

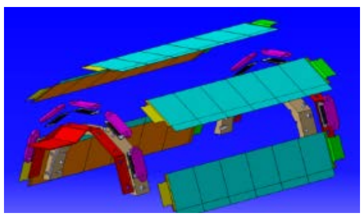
trigger mode ≤ 100 mW/cm2.

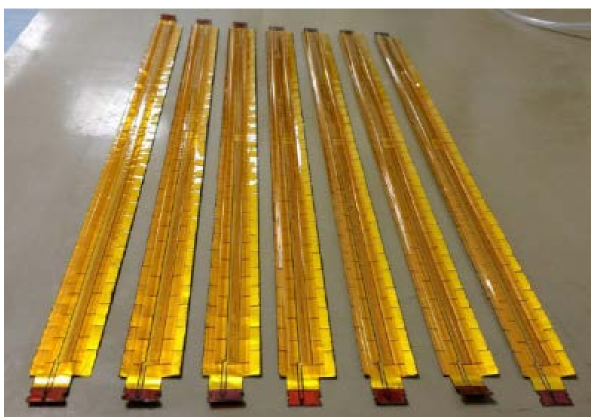
***Working temperature range:** 20-50 ℃ (best performance under 30 ℃)

Challenge

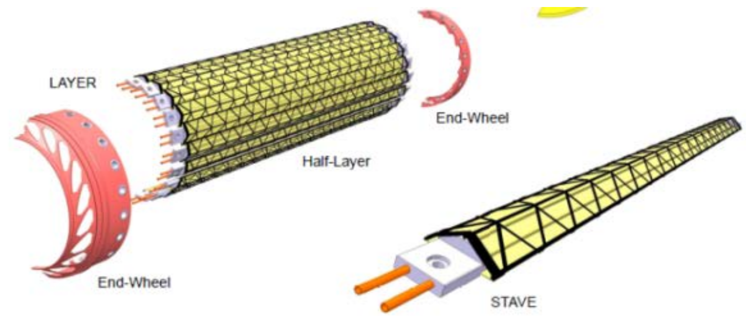
The big challenge: low material & high rigidity

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.

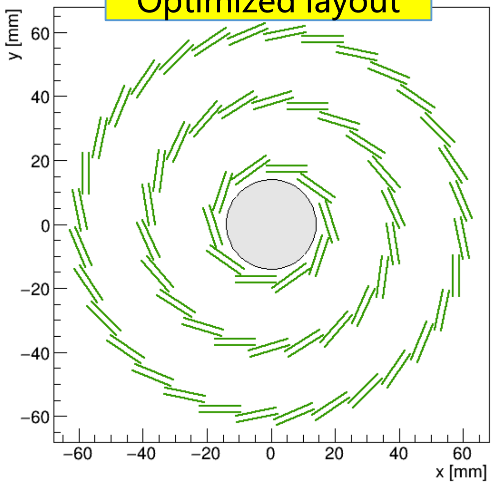
No such low mass support structure was made in China before.

The CEPC VTXD layout

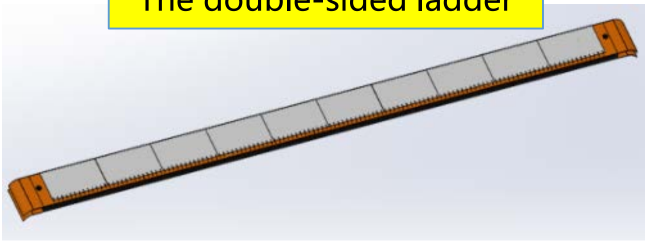
Design parameters of the optimized CEPC vertex detector

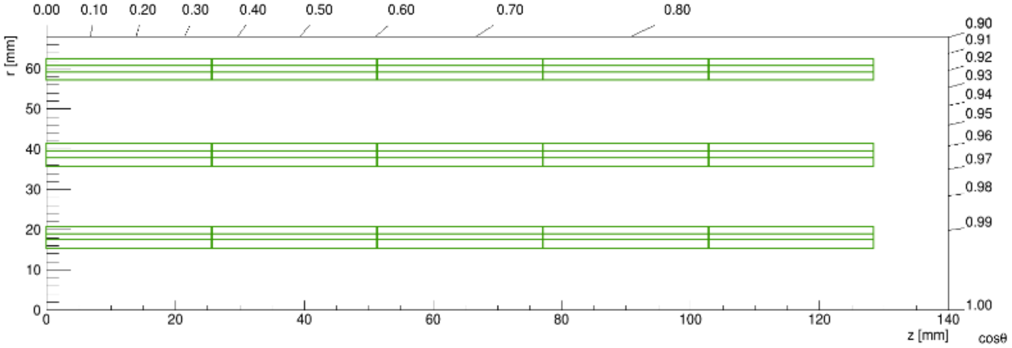
	R (mm)	|z| (mm)	Number of ladders	Number of chips
Layer 1	16	125.0	10	200
Layer 2	18	125.0		
Layer 3	37	125.0	22	440
Layer 4	39	125.0		
Layer 5	58	125.0	32	640
Layer 6	60	125.0		

Optimized layout



The double-sided ladder



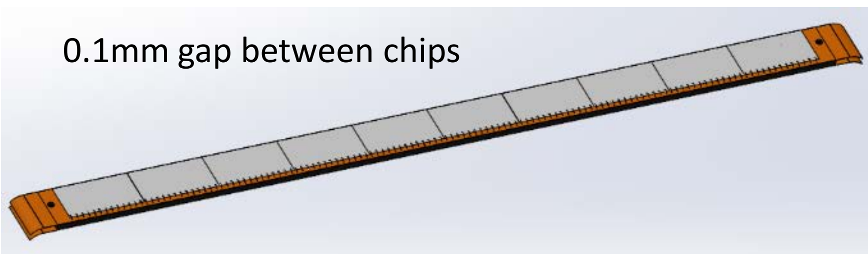


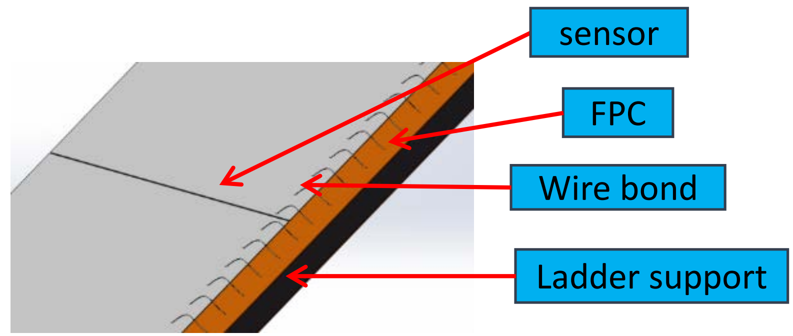
Ladder and Barrels

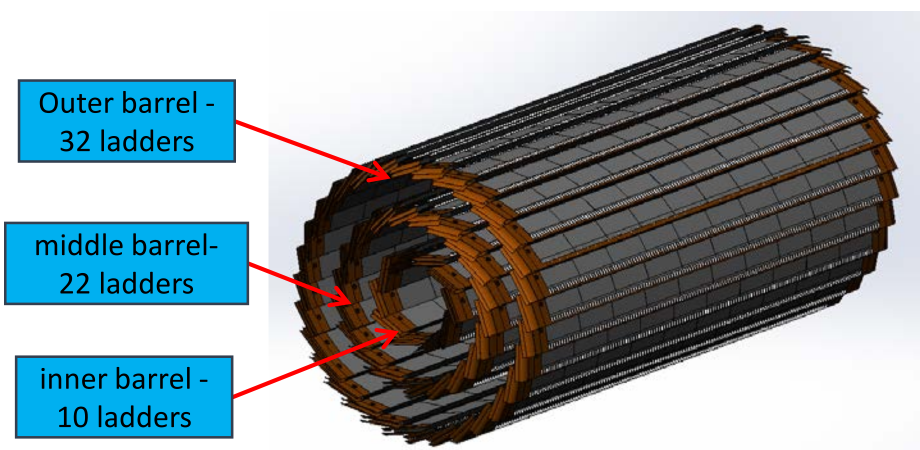
Sensor chip : 16.8* x 25.6 mm (2* mm margin at one side for wire bonding)

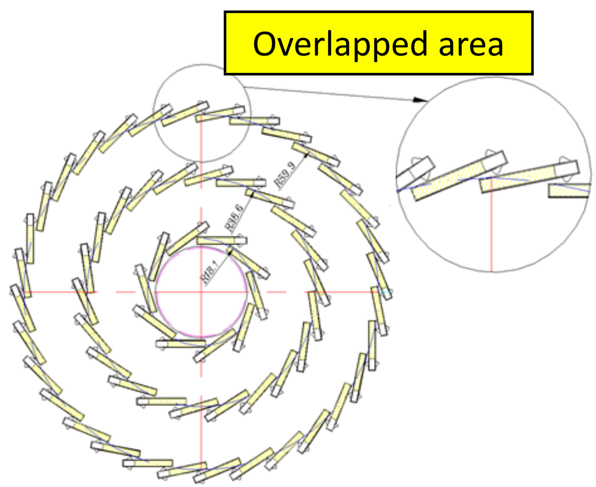
Ladder: support + sensors + FPCs, sensors and FPCs on doubled sides of the ladder.

The double sided Ladder (17.4 *x 272.9 mm)









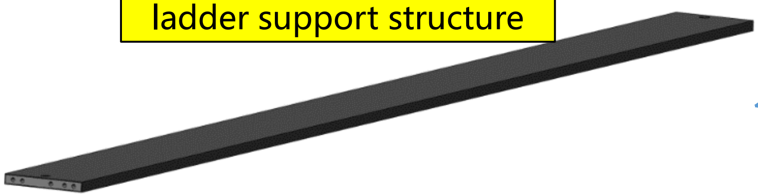
Ladder Support

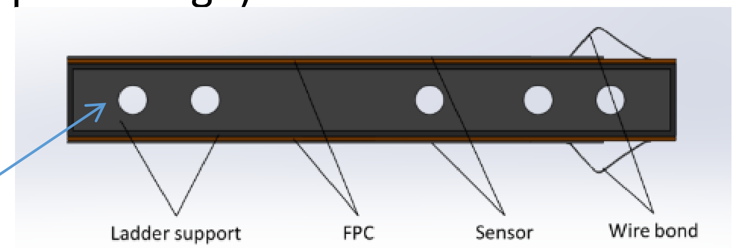
With the FEA assistance, compared different optional design, optimized and finalized the details of the official design (including layers of plies design).

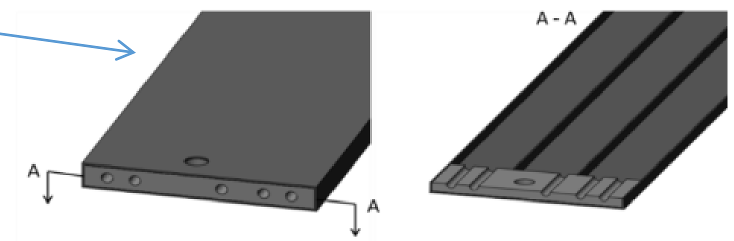
Material: CFRP.

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

ladder support structure







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

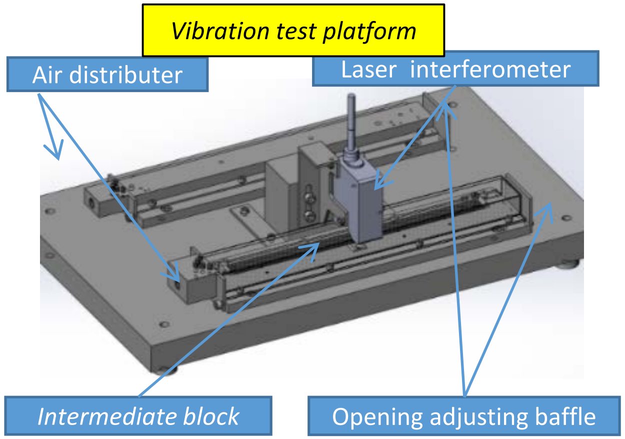
Fabrication process validation

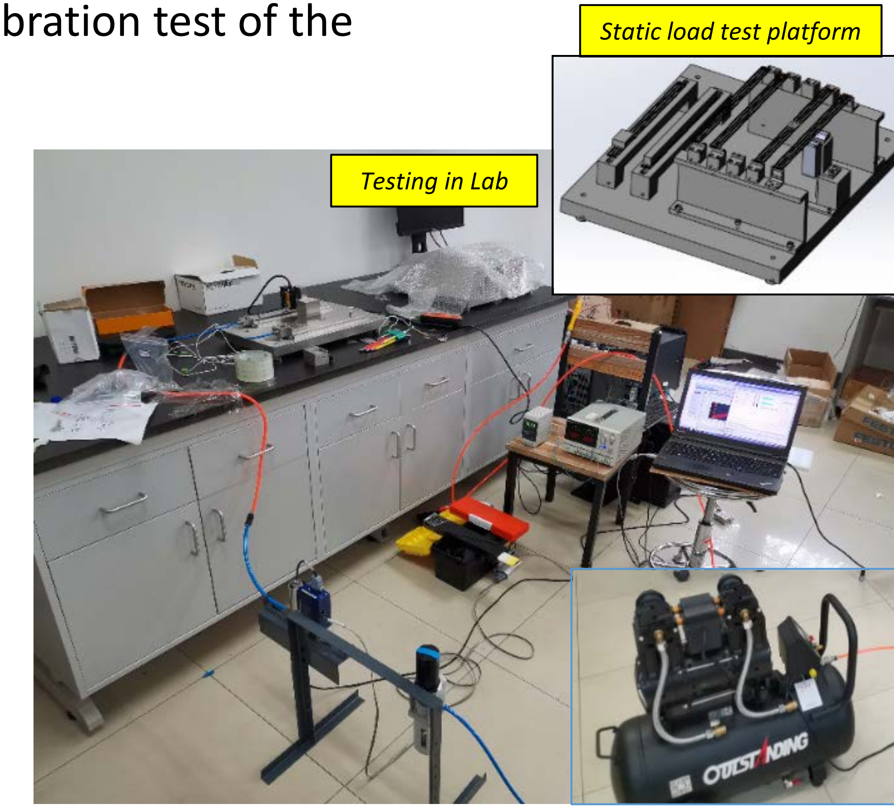
Fabrication is very challenging, after process validation test, the minimum thickness of the CFRP laminate can down to 0.12mm, this significantly reduced material.

Material	Thickness (μm)	Radiation length X_0
CFRP support	*145*	*0.051%*

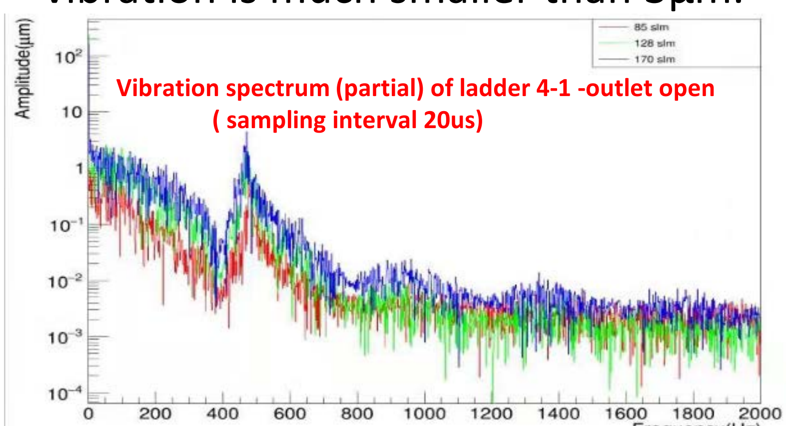
Ladder support test

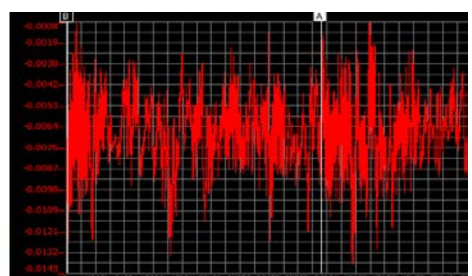
Platforms were designed for static and vibration test of the ladder support.

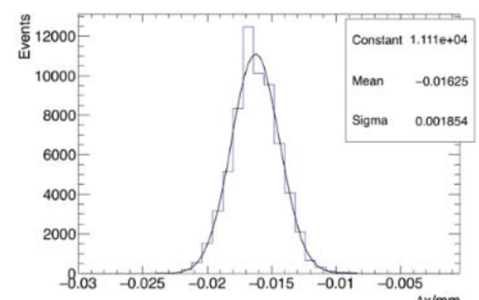




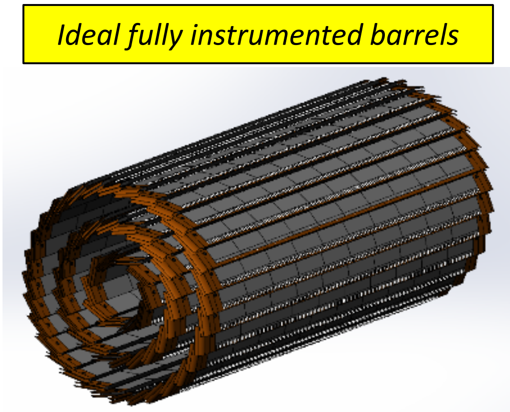
Test result: the max amplitude of vibration is much smaller than 3μm.

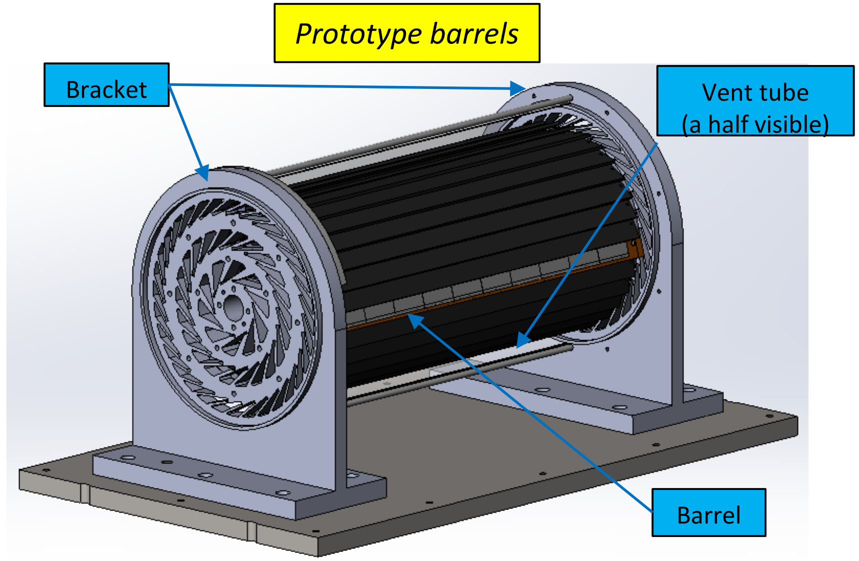




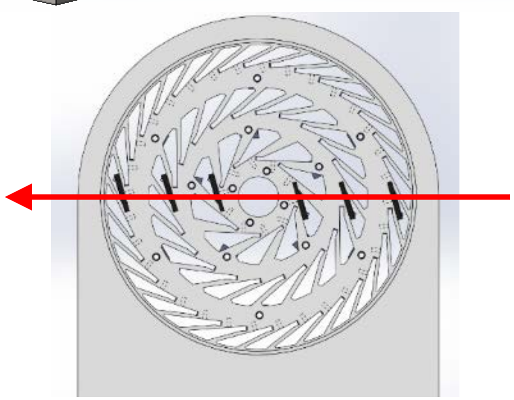


Main structure of the VTXD prototype



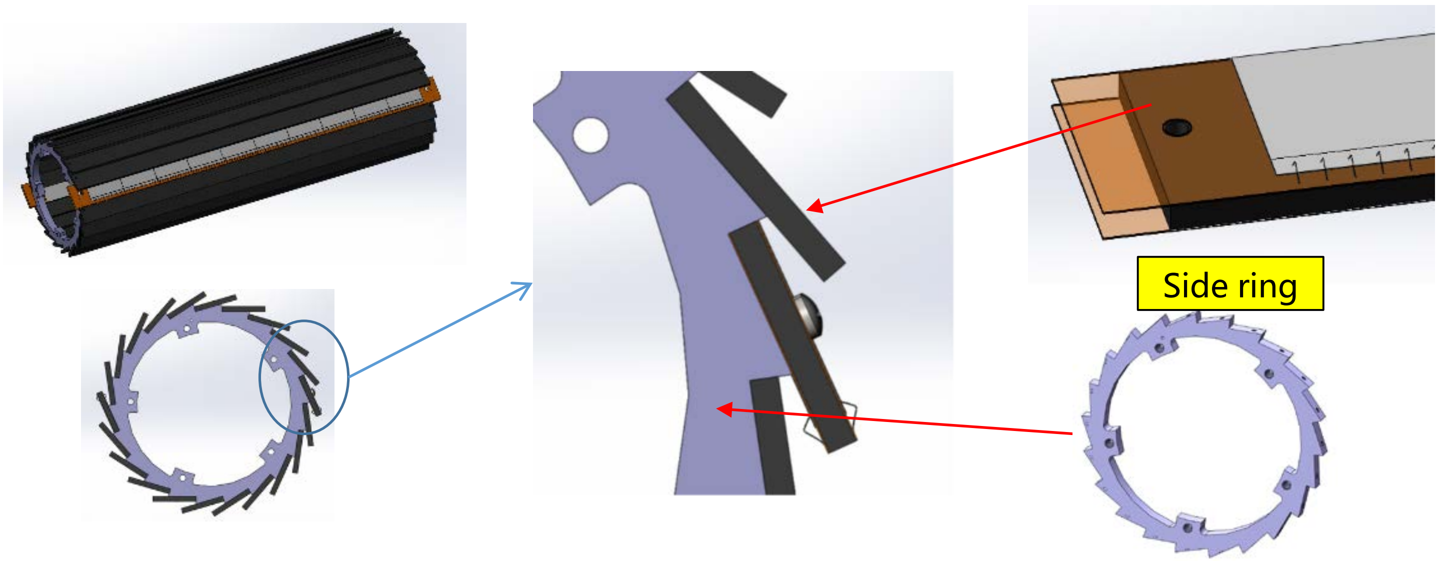


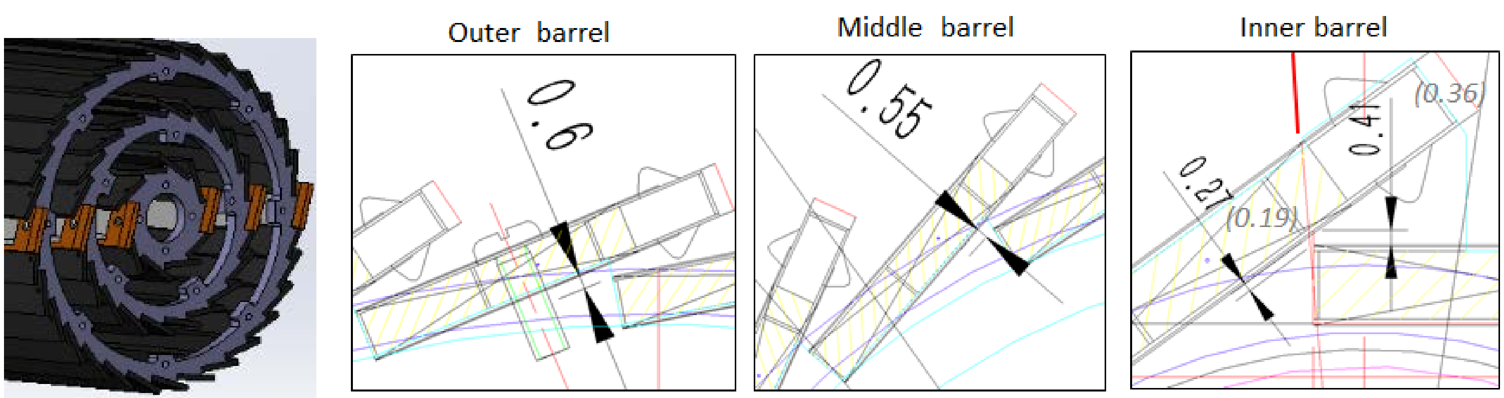
For beam test: 6 ladders are mounted on one line (others are bare ladder support).



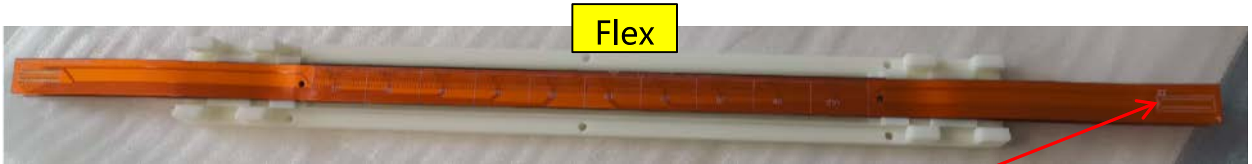
Ladder fixation on barrel

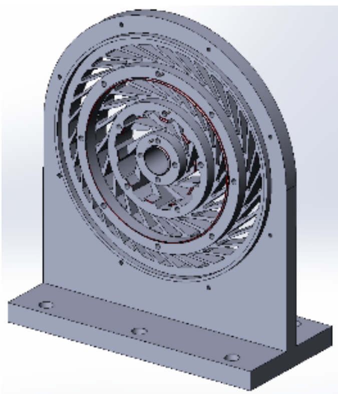
Sides constraint/alignment + screw tighten





Structural details related to ladder





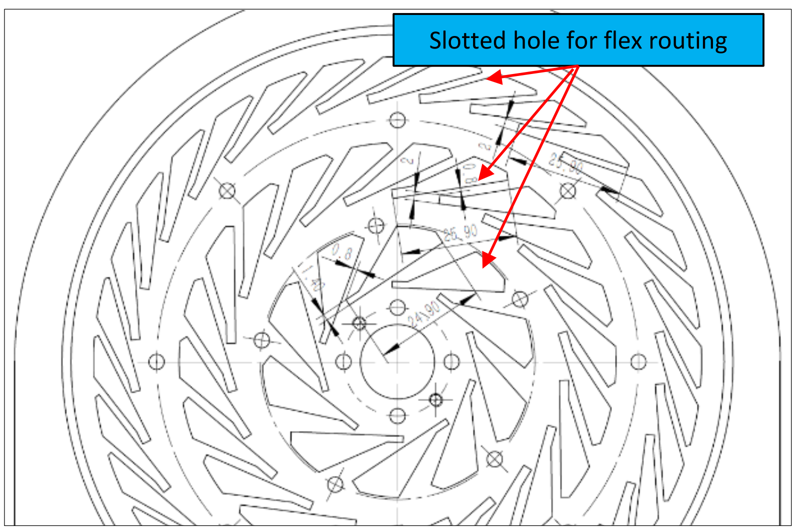
Flex end with socket

Socket: 21.5 mm(L) x 3 mm (w)x 1.5 mm (t)

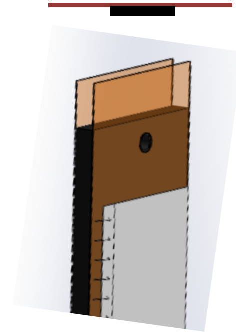
Thickness of the Flex + metal pad under the socket(T):

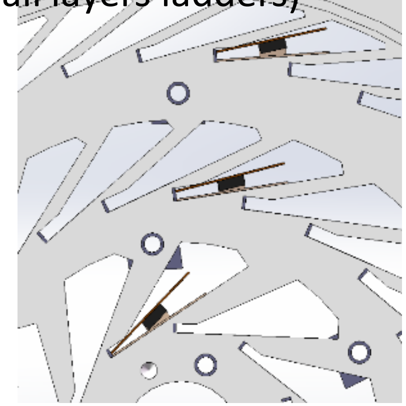
0.2 mm (*Max up to 0.3 is feasible*)

Total length of flex: (~140)+272.9+(~140) = 553 mm

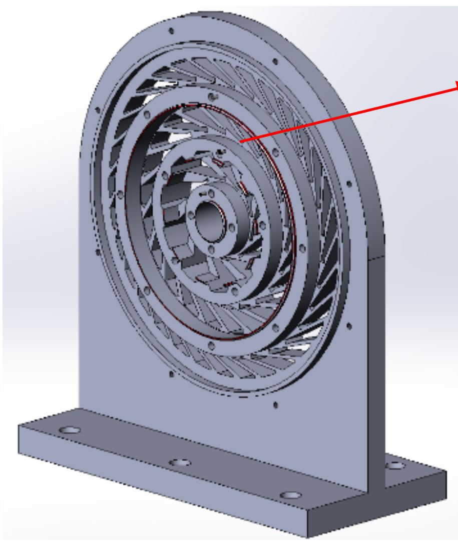


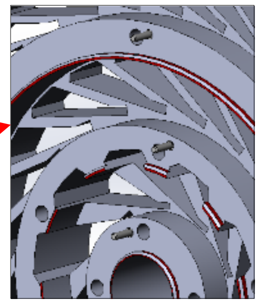
T=0.3, slot height required 2.1 mm (tilt slightly when passing through the holes for all layers ladders)

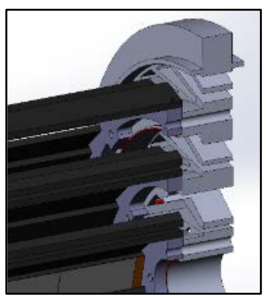




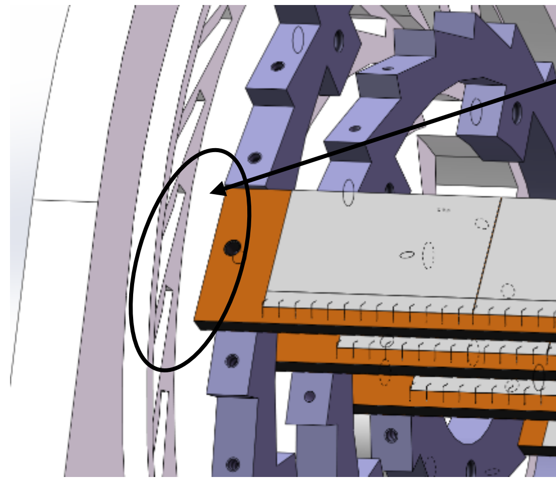
Barrels fixation on the brackets



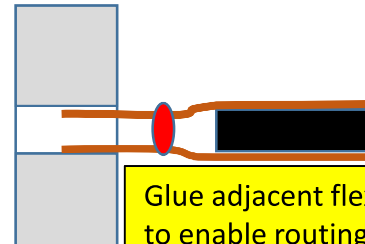




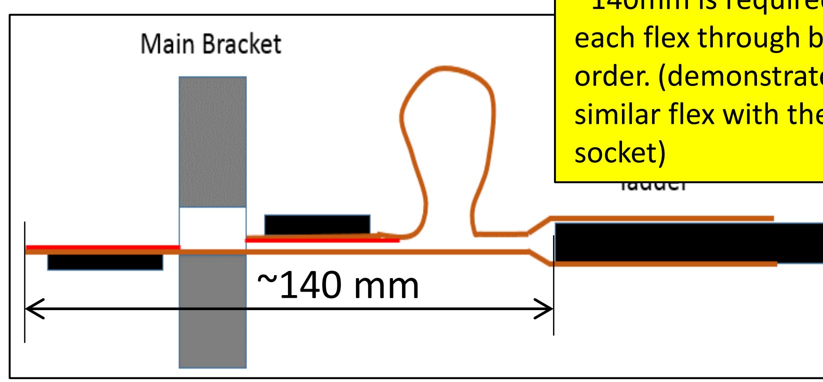
Barrels (side ring) are located on the main bracket by: ring + pin



The convex ring provide a transition region for flex routing.

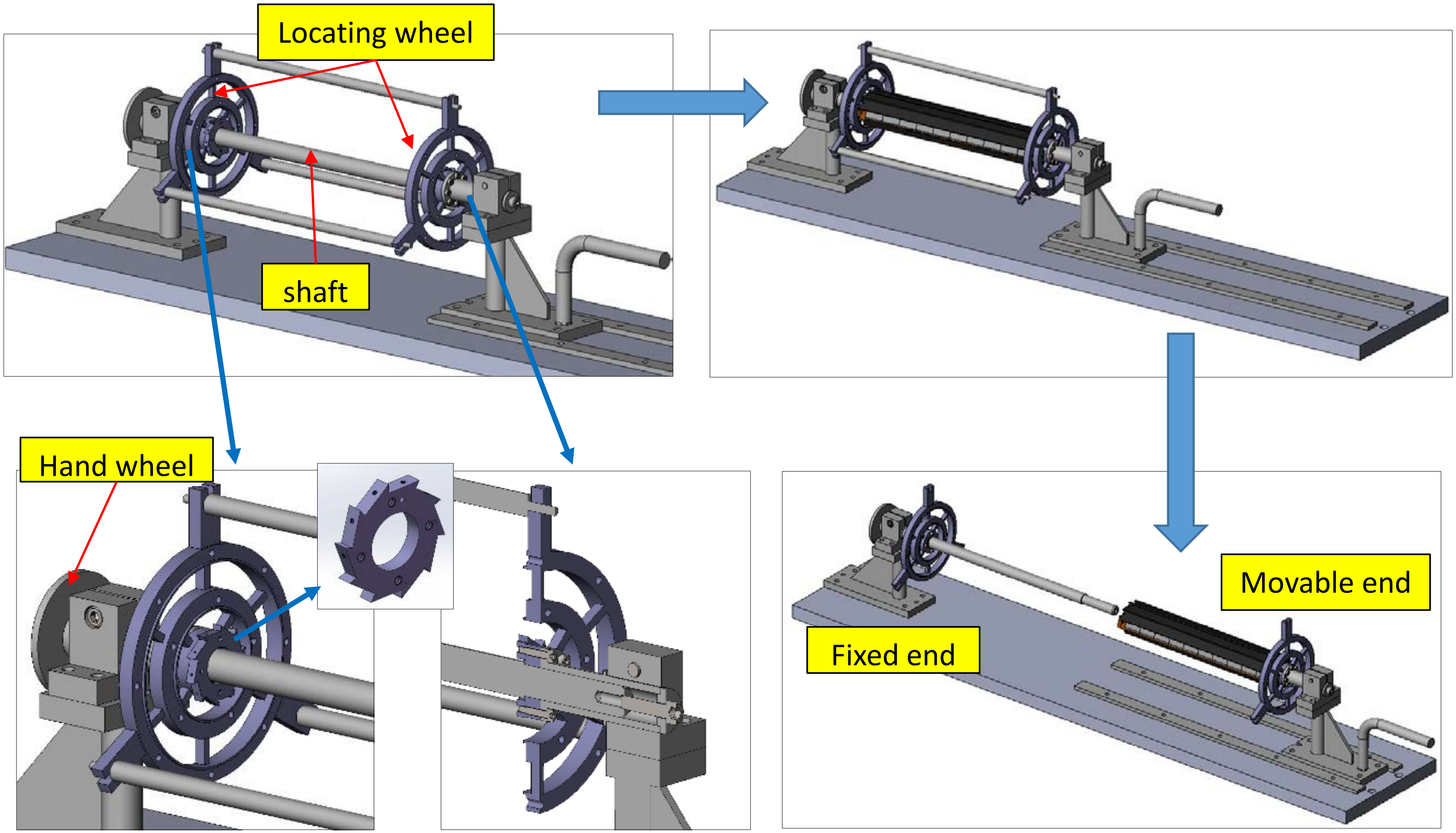


Glue adjacent flex to enable routing and for protection.

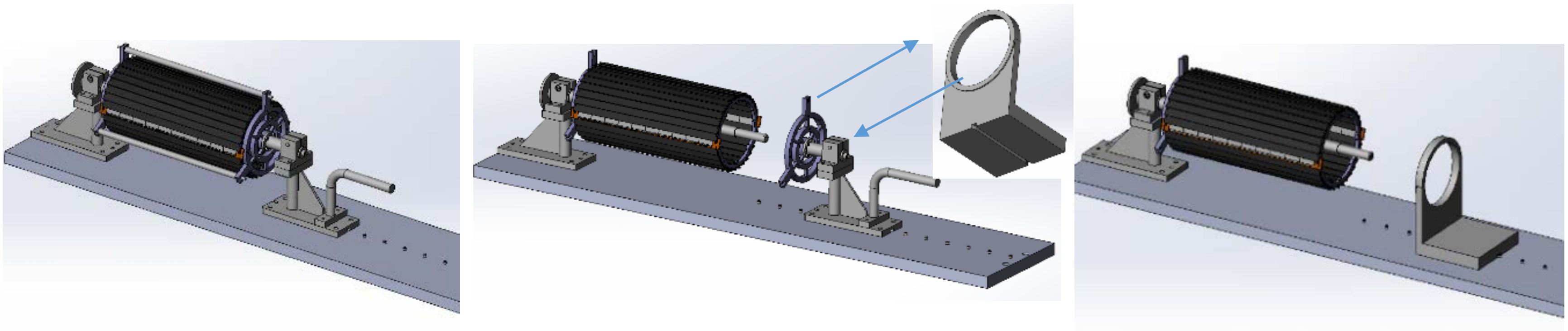


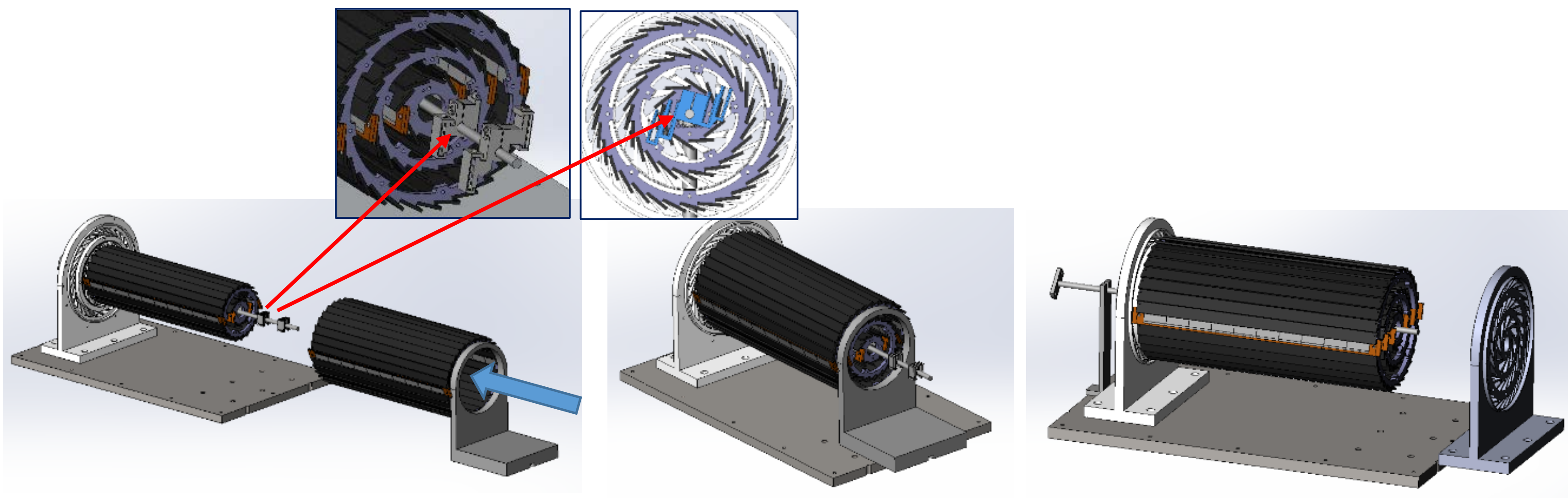
~140mm is required to pass each flex through bracket in order. (demonstrated by a similar flex with the same socket)

Tooling design for VTXD assembly



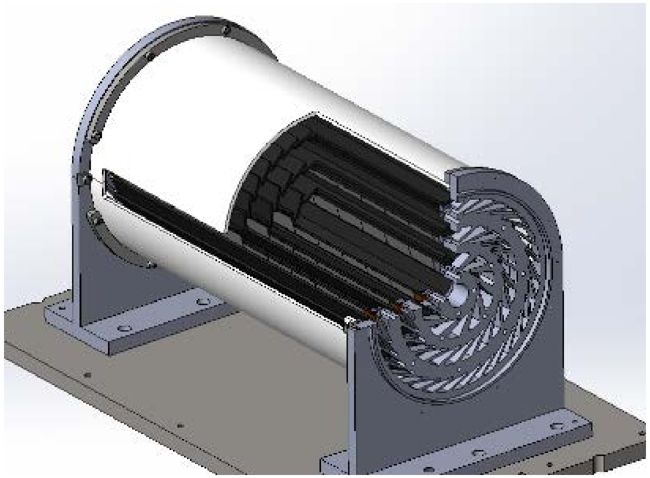
Tooling design for VTXD assembly



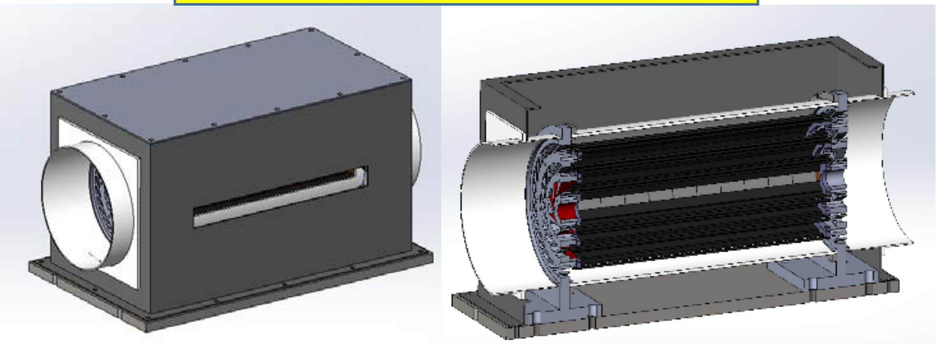


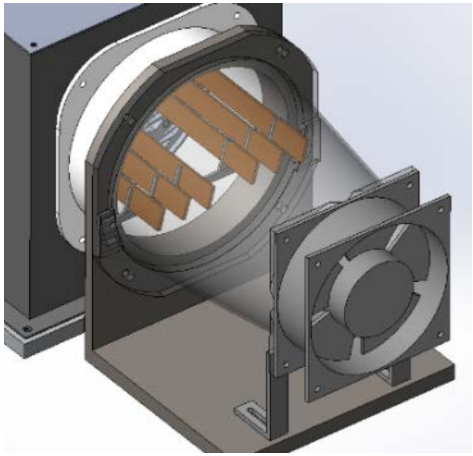
General structure of the VTXD prototype

VTXD assembly



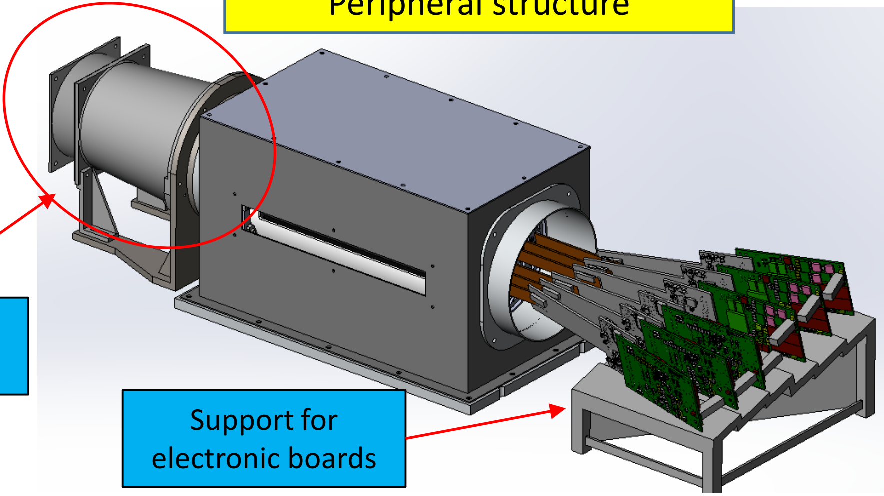
VTXD box (vent, protection, vibration-isolated)





Cooling fan and duct

Peripheral structure



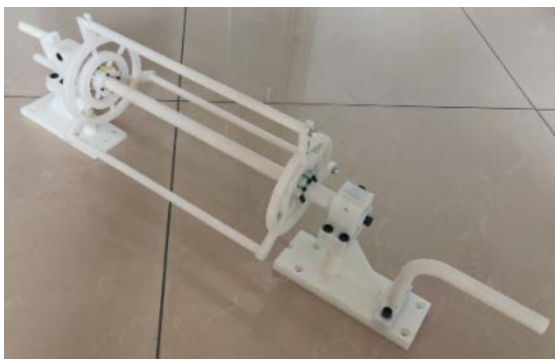
Support for electronic boards

Mockup - barrel assembly

The mockups of the support structure and tooling were made.

Trial assembly and installation verified:

- Operation space of ladder installation on the tooling
- Tooling assembly process
- Barrels assembly process

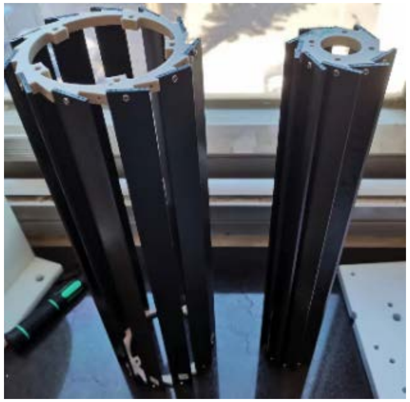


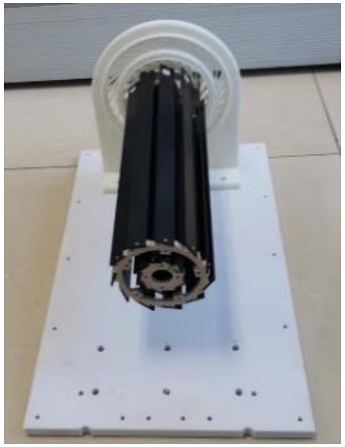
Middle barrel
(Ladder support-half quantity)

Inner barrel

Mockup - Barrels on the main brackets

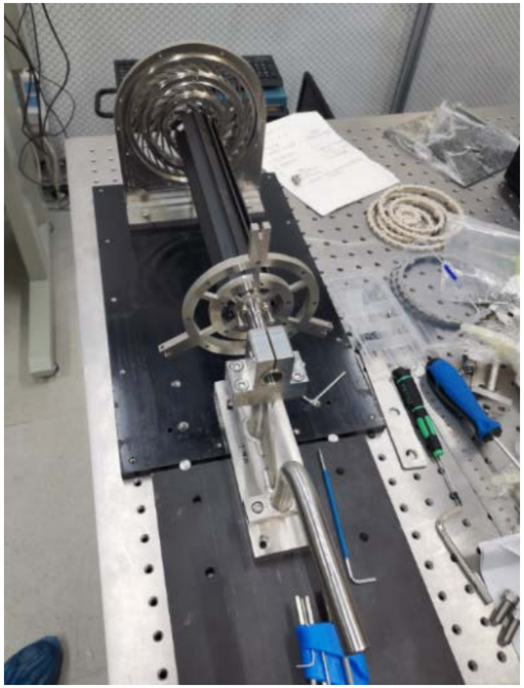
The barrels installation on the main support brackets were demonstrated.

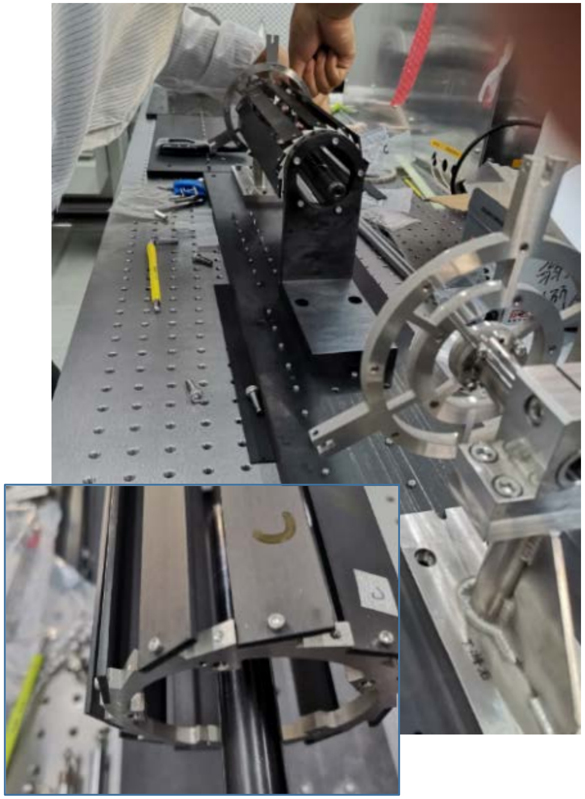




Prototype - barrels assembly

Inner barrel



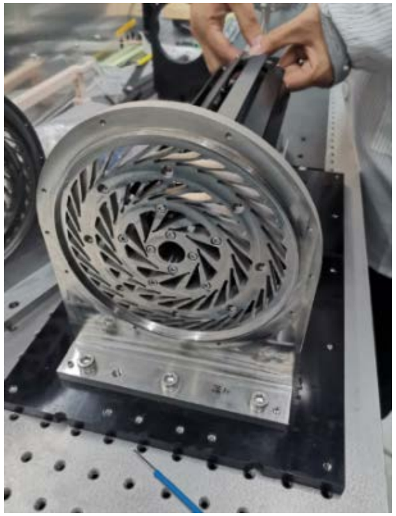
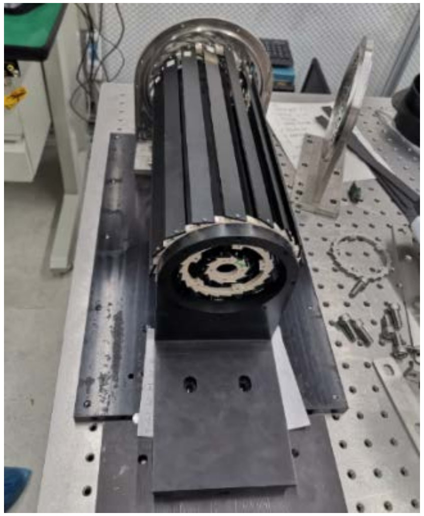
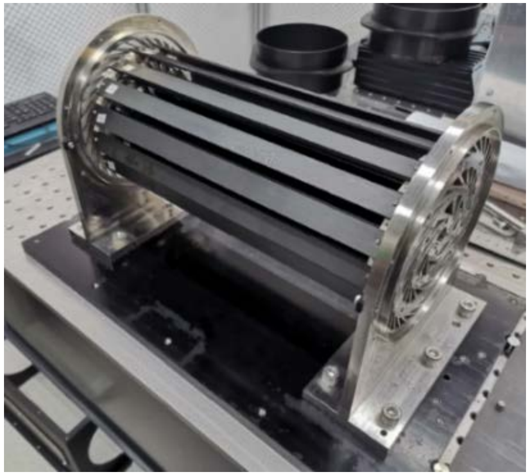
Middle barrel
(half number of ladders)



Outer barrel
(half number of ladders)

Prototype - barrels installation

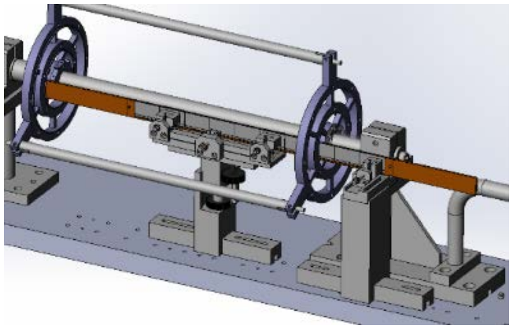
The installation of the real parts was very smooth, all three barrels can fit to the main bracket very well. (Half of the total ladders were mounted)

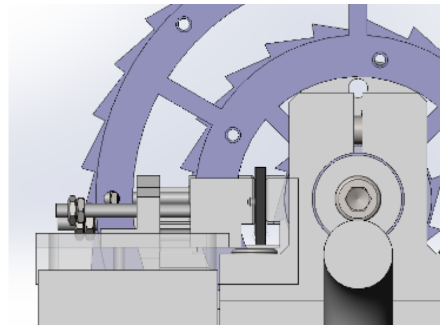




Tooling design for ladder loading

Two assemblies were designed for ladder installation on barrel.

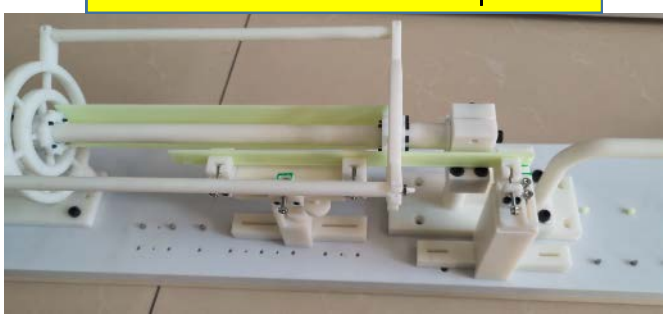
(Allow ladders to move in 3 axial directions and rotate along the longitudinal direction)



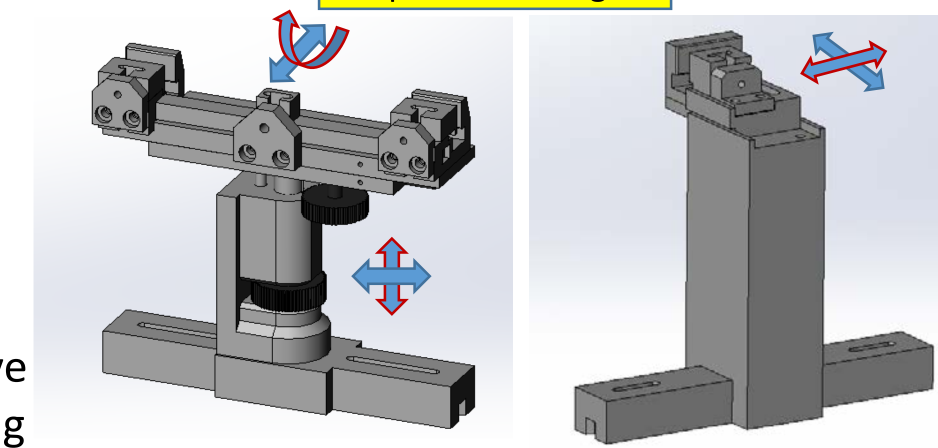


Parts of the mockups V1

Trial use of the mockup V1



Optimized design



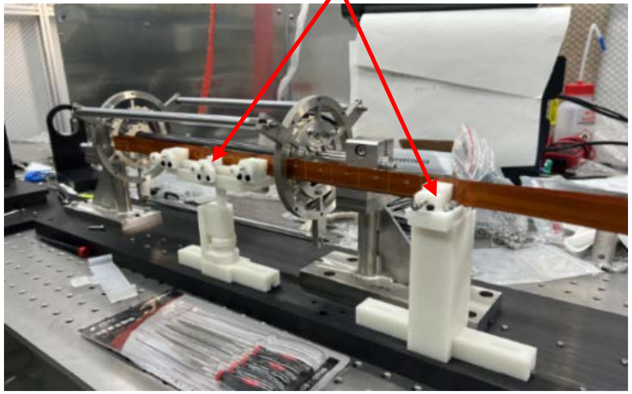
Two version, to make the ladder move more stable also with higher adjusting space, optimized the first version.

Tooling design for ladder loading

The formal jigs have been fabricated and used :

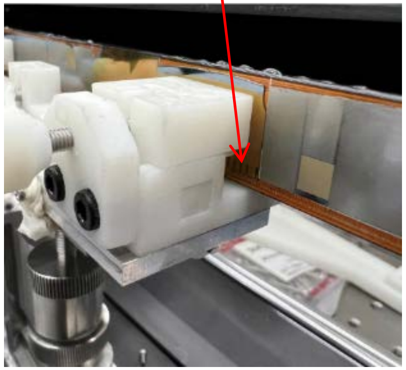
- the fixture and jig work well
- the loading procedure is feasible.
- wire-bond is protected during ladder loading

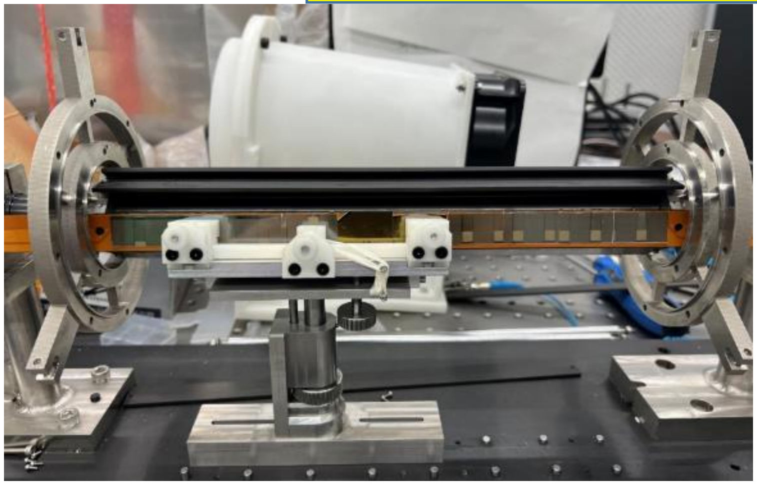
Mockups V2

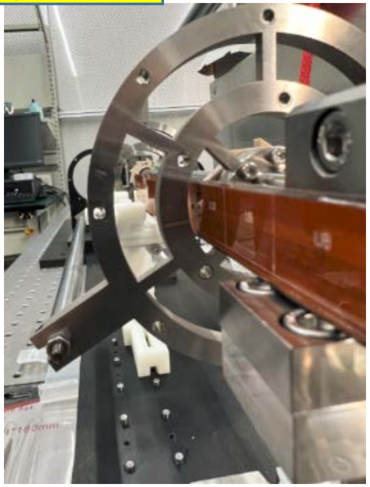


Formal parts - ladder loading test

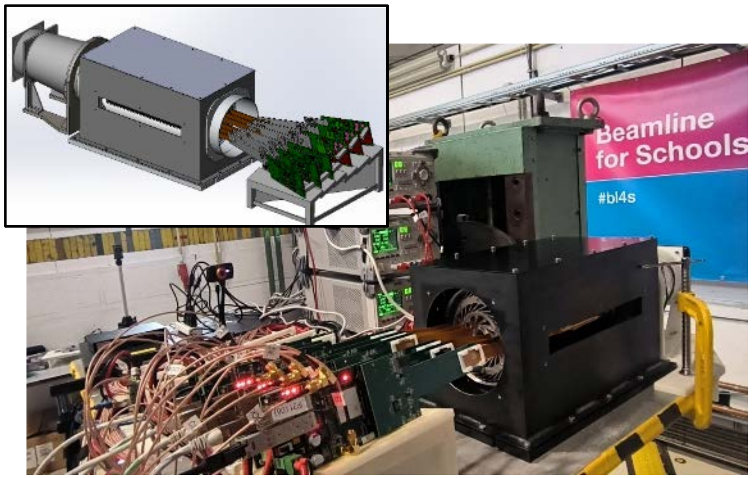
Wire-bonding

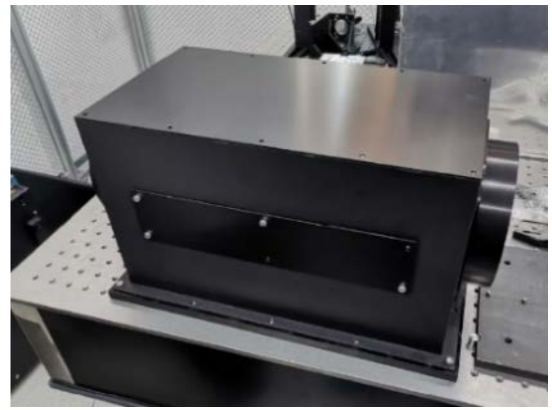
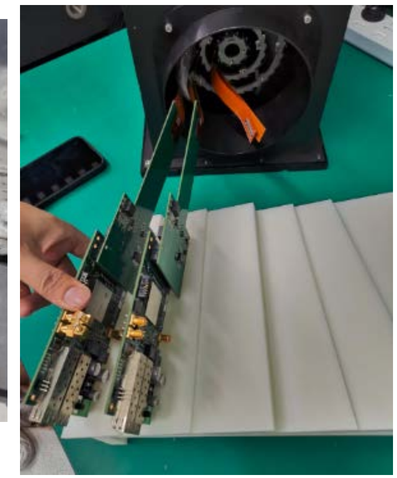


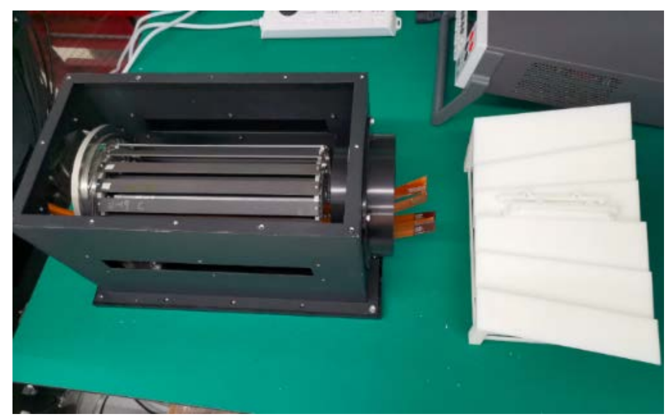




Prototype - general



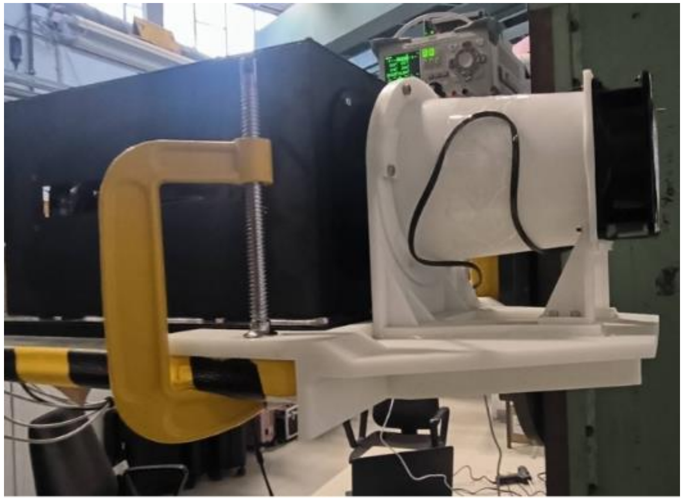



Prototype cooling

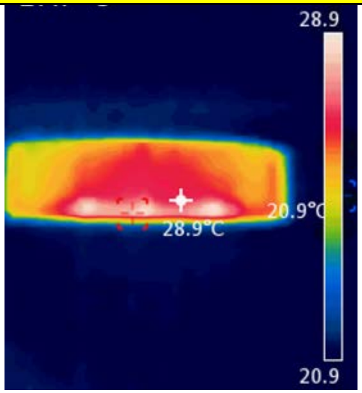
Temperature of the chips was monitored during the beam test. Verified:

- Effective cooling achieved (air cooling and fan selection is suitable).
- Vibration amplitude induced by cooling air does not affect the detector resolution.
- Good vibration isolation due to the non-contact independent assembly.

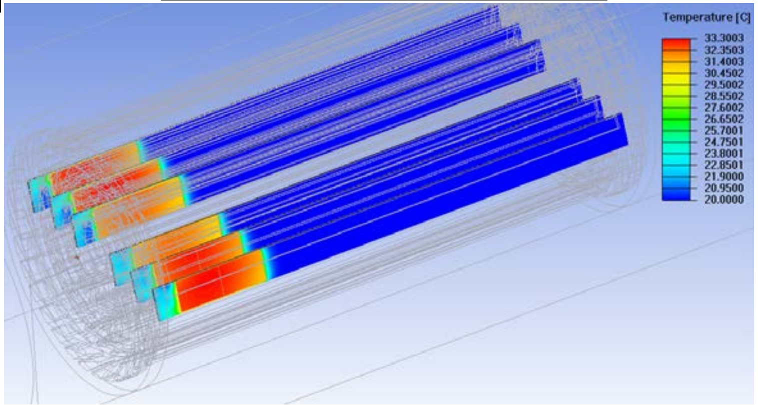


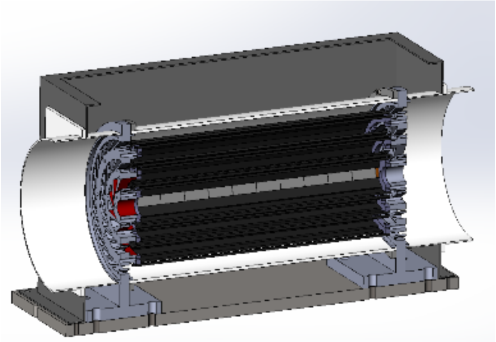
The results of cooling simulation is higher than the measured values most likely due to the simplified structure, but it is useful for a conservative estimation.

Chip temperature with cooling



Prototype cooling simulation





Summary

- The ultralight ladder support was designed and fabricated, which contribute much to lower the material budget of the VTXD.
- The support structure of the VTXD prototype and necessary assembly tooling was designed and mockups were made for some key parts to validate the design and verify related operation procedures
- The general VTXD prototype structure have been fabricated and assembled
- Necessary test and the final beam test proved the mechanical design of the VTX prototype meet the physical requirement(low mass high rigidity, cooling, vibration isolation)

➢ For the mechanical design, two patents authorized, one article published in RDTM.

Back up

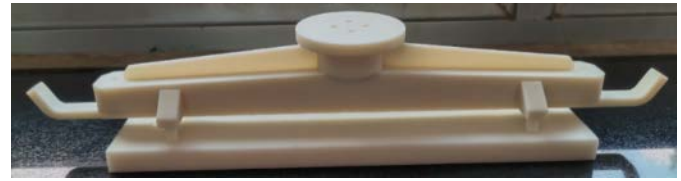
Tooling design for ladder assembly on the gantry

Sensor pickup tool


Vacuum chuck for sensors array

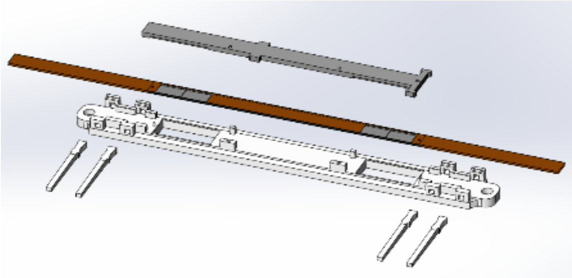
Module fixation and protecti


Module pickup tool and support

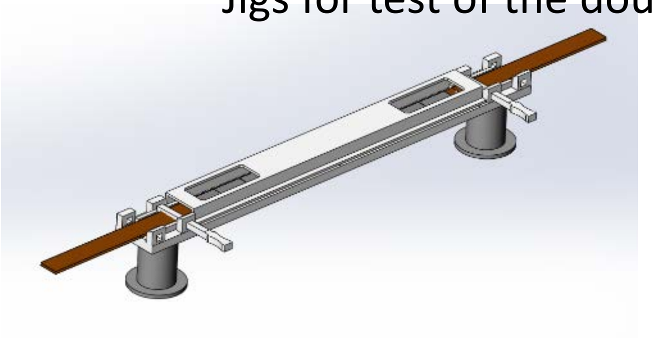




The Jigs and tooling for mounting module on the reverse side of a ladder



Jigs for test of the double-sided ladder



Tooling for the test of ladder with a flex on just one side